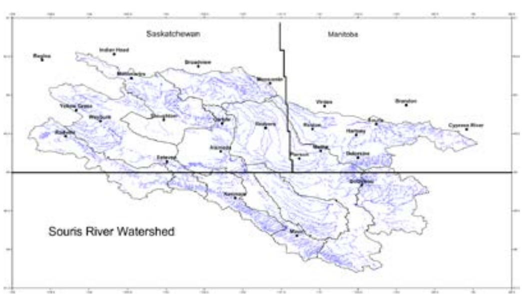
Risks to the Energy Sector from Historic Extreme Climate Events: Case Study of the Souris River Watershed, Canada

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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Cover Photos Captions:

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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LIMITED

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ABSTRACT

Climate extremes are common on the Canadian prairies. Droughts and floods can occur in the same year and can last multiple years. Determining climatic trends of the past provides information to assist with risk management strategies of communities, government, and various industries including the electrical generation and oil and gas sectors. This report illustrates the extreme drought and excessive moisture events in the Souris River watershed for the 20th and early 21st centuries.

The purpose of this report is to examine the historical climate of the Souris River watershed over the last 110 years. The information is designed to assist with improving the planning and preparations for dealing with future extreme climatic events with the focus on the Canadian portion of the Souris River watershed. The objectives are to:

- Develop and analyze temperature and precipitation databases to include the Canadian portion of the Souris River watershed.
- Develop and analyze data using various climatic indices including the Standardized Precipitation and Evapotranspiration Index, Palmer Drought Severity Index and the Standardized Precipitation Index.
- Characterize various temporal events in terms of intensity, duration, frequency and spatial pattern.

The 20th and early part of the 21st centuries have had many periods of extended droughts and excessive moisture. For example, multiple extreme drought years occurred in the 1930s, late 1950s/early 1960s, and 1980s. Excessive moisture events also happened in clusters such as the 1920s, 1950s, 1970s and the 2010s. This is important because single year events may not have as much impact on society as multi-year events and thus requiring different levels and types of adaptation.

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INTRODUCTION

The Canadian Prairies is a land of climate extremes. Extreme events including droughts and excessive moisture conditions, have occurred in the same year and in close proximity with each other. These extremes can last for relatively short periods, but can also be multi-year events. Over the past two centuries, several multi-year droughts have been documented to have occurred across the Canadian Prairies (e.g., Wheaton 2000, Bonsal and Regier 2007) and at least 12 flooding events have occurred in the Assiniboine River basin (Brimelow et al. 2015) which contains the Souris River watershed. These events can be costly and disruptive and can result in built (e.g., infrastructure) and other developments and natural environmental (e.g. soil erosion) hazards.

Climate extremes can result in increasing risks or benefits for oil and gas and electrical generation sectors. The energy sector is an important component of the Saskatchewan and Canadian economies. The Souris River watershed (Figure 1) includes many industries including those associated with the energy sector such as oil and gas production as well as coal-fired electrical generation plants. Each of these industries has varying degrees of susceptibility to extremes, including drought and excessive moisture situations. The potential hazards and negative impacts can increase or change if the extreme events are under-estimated in enterprise risk management procedures and if the limits to adaptation are exceeded.

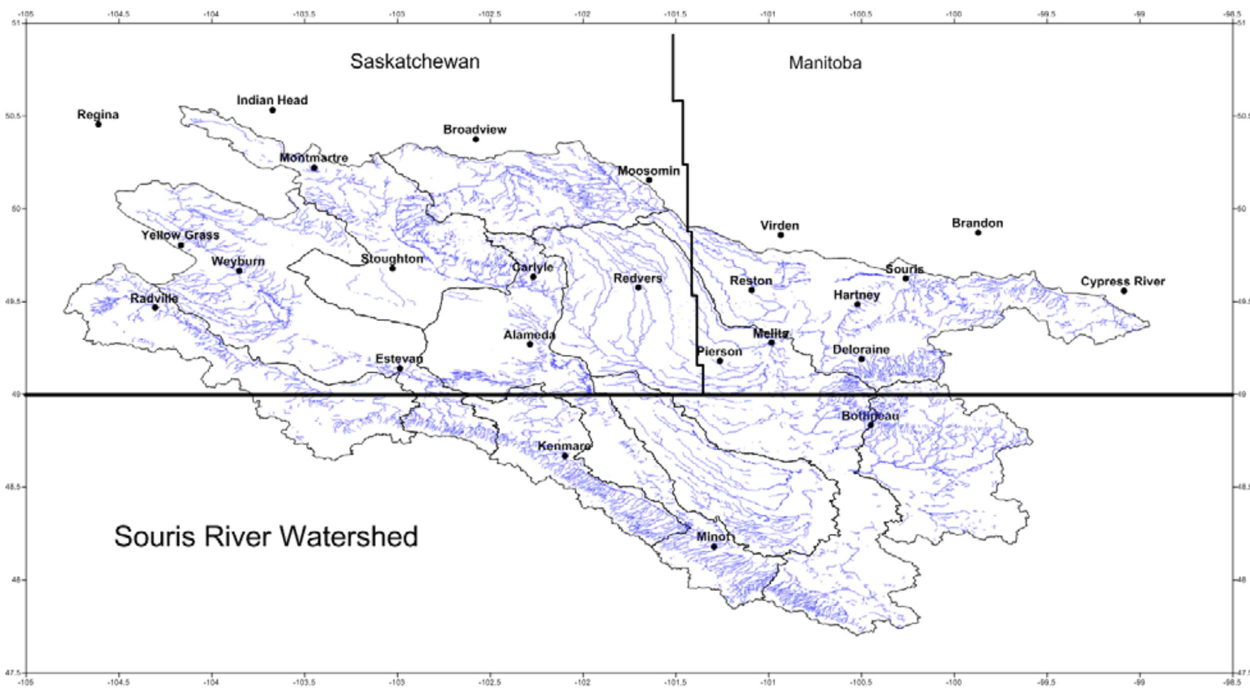

Figure 1 Souris River Watershed (base map and stream flow data provided by Natural Resources Canada (NRCan) and International Joint Commission (IJC) (p. comm. 2015)).

Worldwide natural catastrophes, in particular climate related events, have been increasing. In 2014, 980 loss events were reported, while 2013 had a hundred fewer at 880 loss events. The early 1980s had less than half the number of reported loss events (Munich Re 2015) (Figure 2). Munich Re only documents loss events that result in property damage, economic loss or loss of life (Munich Re 2011).

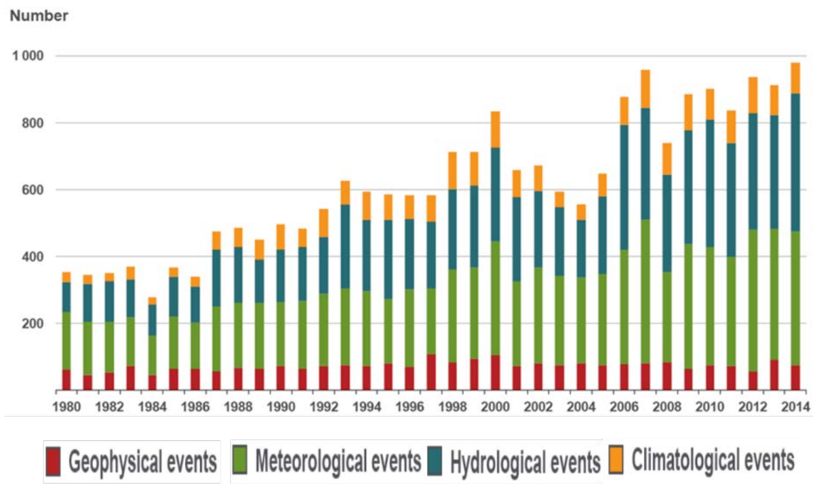

Figure 2 Recorded number of annual natural catastrophes worldwide as defined by Munich Re for the 1980 to 2014 period (Munich Re 2015). Meteorological events include convective storm and local storm, hydrological events include flood and mass movement and climatological events include extreme temperature, drought and fire.

Munich Re (2014) reported both meteorological and hydrological loss events in southern Saskatchewan, southern Manitoba and northern North Dakota (Figure 3) in both 2013 and 2014. Many of these events resulted in infrastructure problems such as roads washed out and communities heavily impacted due to flooding issues with nearly 40 Saskatchewan and almost 45 Manitoba communities declaring states of emergency due to flooding in 2014 (Ellis and McKinnon 2014, Schroeder 2014). Flooding in the Saskatchewan portion of the Souris River watershed resulted in about 100 out of approximately 18,000 oil wells sitting in water between 2011 to 2015 (Graney 2015).

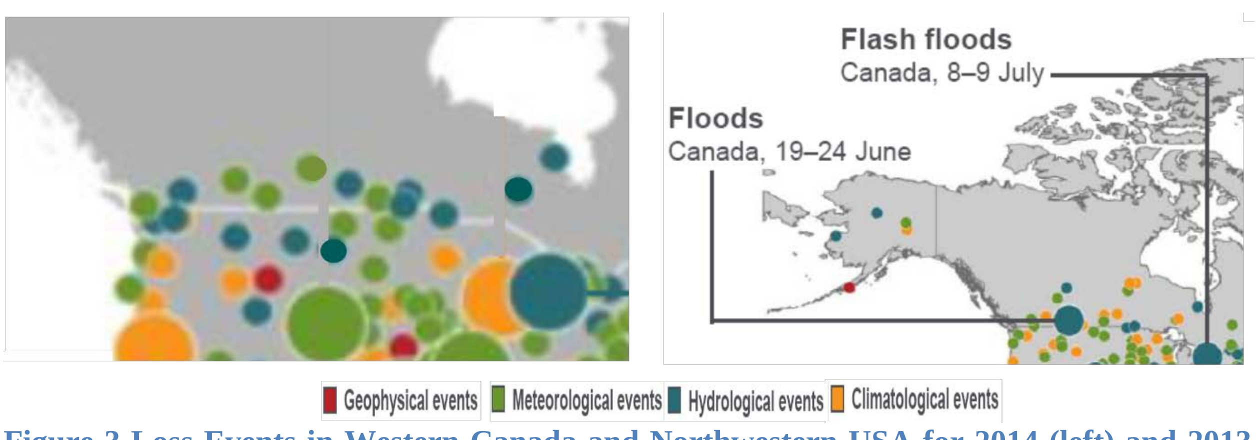

Figure 3 Loss Events in Western Canada and Northwestern USA for 2014 (left) and 2013 (right) (adapted from Munich Re 2015 and 2014).

The future climate will be different from the historical climate due to continued emission of greenhouse gases resulting in warming temperatures and other changes to all components of the climate system (IPCC 2014). An increase in the frequency, intensity and extent of moderate to extreme droughts is projected for Saskatchewan (Wheaton et al 2013). The Intergovernmental Panel on Climate Change (IPCC) estimate that areas affected by drought will likely increase (with a 66% probability of occurrence) (IPCC 2007). The IPCC also estimate, with medium confidence, droughts will intensify in the 21st century due to reduced precipitation and/or increased evapo-transpiration in North America (IPCC 2012). It is also projected the frequency of severe storms and unusually wet periods will increase (Wheaton et al 2013). The IPCC estimate the frequency of extreme precipitation events will increase with a 90 to 99% certainty rating (IPCC 2007) and extreme precipitation events over most mid-latitude land masses will very likely become more intense and frequent in the 21st Century (IPCC 2014).

The Saskatchewan and Canadian economies contain many sectors with energy supply among them. The Souris River watershed (Figure 1) contains many industries associated with the energy sector including oil and gas production (Figure 4), and coal-fired electrical generation plants (Figure 5). Each of these industries has varying degrees of susceptibility to extreme climatic events such as drought and excessive moisture conditions and each has been impacted by both drought and excessive moisture events (Wittrock 2016). For example, the drought of 1988 negatively affected power production through factors such as low water supplies and high temperatures (Wheaton and Arthur 1989). The extended droughts across the prairies of 1988 and 2001 resulted in increased operating costs for SaskPower, because of decreased flows from hydro-generation units (located outside the Souris basin) leading to increased reliance on thermal generation and higher costs at times to obtain cooling water for the major coal generation units in the Souris basin (Nielsen 2003). The extreme rainfall events in recent years have resulted in infrastructure issues such as road systems extensively damaged (Figure 6) (Manitoba Infrastructure and Transportation 2014) and oil wells with surface water on them for extended periods of time (Figure 7). Oil wells that have been under water for extended period of time maintenance of those sites can become a problem (Garney 2015). Other examples of how these energy industries are impacted and their associated adaptation strategies are discussed in associated documents of this project (Wittrock 2016 and Terton and Parry 2016).

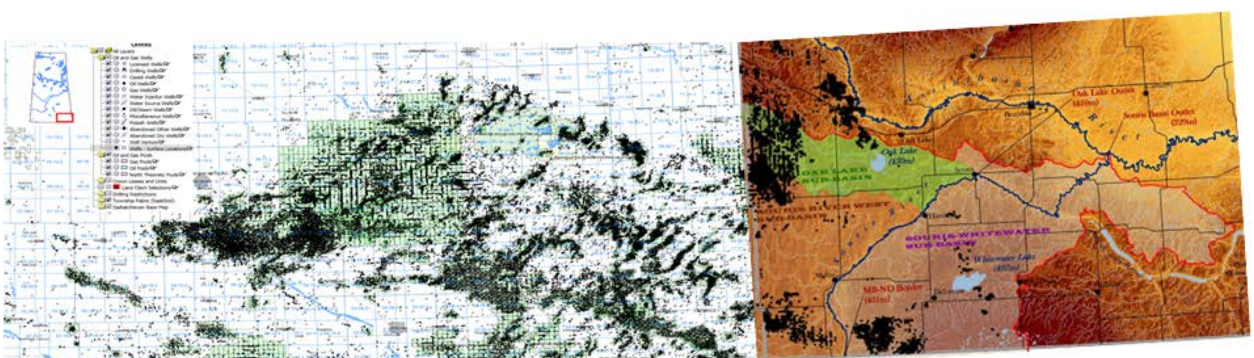

Figure 4 Locations of Oil and Gas wells in the Souris River Watershed (left: adapted from SK Ministry of the Economy 2015; right: MB Mineral Resources 2015)

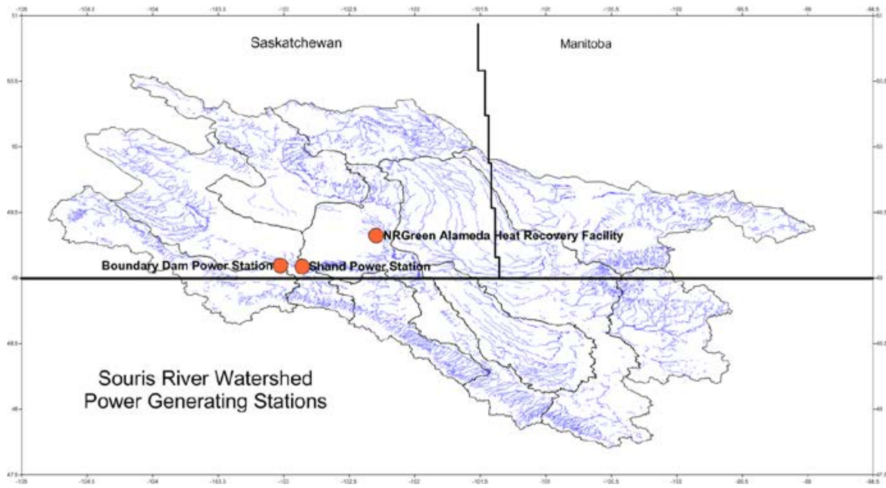

Figure 5 Power Generating Stations located in the Souris River Watershed

Figure 6 Washed-out Road in Southwestern Manitoba from 29 June 2014 Rain Event (Manitoba Infrastructure and Transportation 2014)

Figure 7 Oil Pump Jack and High Surface Water in Southeastern Saskatchewan (28 May 2015) (Photo: Radchenko, SRC)

PURPOSE AND OBJECTIVES

The purpose of this report is to examine the historical climate of the Souris River watershed over the 1901-2014 period, where data are available. This information is designed to assist with improving the planning and preparations for dealing with future extreme excessive moisture and drought events. The objectives are to:

- Develop and analyze temperature and precipitation databases to include both Saskatchewan and Manitoba portions of the Souris River watershed. Analysis will include trends of the Canadian Portion of the watershed.
- Develop and analyze data for the Canadian portion of the Souris River watershed using various climatic indices including the Standardized Precipitation and Evapotranspiration Index, Palmer Drought Severity Index and the Standardized Precipitation Index.
- Characterize the monthly, seasonal and multi-year events in terms of intensity, duration, frequency and spatial pattern.

A companion report (Wittrock 2016) utilizes the information provided in this report to assess the impacts, vulnerability and adaptation actions taken by the oil and gas and thermal power generating stations regarding past, present and future drought and flood risks.

METHODS

Measured Data

Temperature and precipitation variables are utilized in assessing drought and excessive moisture conditions. Some indices do not include temperature, for example the Standardized Precipitation Index, while certain seasons are often not thought of being in drought because of their temperatures, such as winter. Three datasets were used. Environment Canada (Vincent et al. 2012, Mekis and Vincent 2011) developed monthly homogenized temperature and adjusted precipitation datasets for various climate stations throughout Canada. The homogenized temperature dataset is corrected for non-climatic shifts to the dataset including station relocation and changes in observing practices and station automation (Vincent et al. 2012). The adjustments of the precipitation dataset also include corrections for wind undercatch, evaporation and gauge-specific wetting losses (Mekis and Vincent 2011). The stations in the adjusted precipitation dataset having the most complete information available in the watershed and surrounding area are: Estevan, Moosomin, Yellow Grass, Pierson, Indian Head, Regina, Broadview, Cypress River and Brandon. The time periods of this data vary depending on the climate station (Appendix 1) and do not include 2012-2015 data. Therefore, the information was augmented with measured, non-corrected data from the Environment Canada station dataset (Environment Canada 2015a). The 2012-2014 climate station data has not been fully quality assured so the data for this period should be viewed and assessed with caution.

The Souris River watershed is an international watershed so having historical climate information from the United States side of the border is important because the water in the watershed flows from the Saskatchewan side into North Dakota and then back up into Manitoba and eventually joins with the Assiniboine River System. Therefore, the climatic conditions in North Dakota can influence the water levels in Manitoba in the Souris River watershed. The third dataset of monthly temperature and precipitation data were obtained from the National Oceanic and Atmospheric

Administration (NOAA) National Climate Data Center (NOAA 2015) for the Kenmare, Minot and Bottineau, North Dakota stations (Figure 1).

The trend analysis for temperature and precipitation includes seasonal winter (December, January, February), spring (March, April, May), summer (June, July, August), autumn (September, October, November) as well as yearly periods. Homogenized and adjusted datasets were used in the analysis with site data ranging from the start of recording at each particular site (Appendix 1) and ending in December 2011 and were augmented with measured, non-corrected data from the Environment Canada station dataset (Environment Canada 2015a). Pearson Product Moment correlations are performed for the time series analysis utilizing the software available in Excel (Microsoft Office 2010). The correlation coefficient (r) values are discussed in the analysis and the Coefficient of Determination (r^2) values are shown on the graphs (Appendix 2 to 5). Correlation coefficients indicate whether there is a positive, negative or no correlation between temperature or precipitation and time. In other words, has there been upward or downward trend in temperature over time? The correlation, in this case, will tend not to be high because there are large year to year fluctuations in temperature and precipitation. The sign of the correlation coefficient will provide an indication of whether a positive or negative trend exists over time.

Climate Indices

Climate indices datasets are beneficial when examining watershed's climate due in part that they are gridded, thus limiting potential gaps in space and time, a common problem with measured data for stations. Many indices also use multiple variables in their calculations and allow for objective assessments about the severity of droughts or excessive moisture levels based on values calculated (Table 1). Three indices are utilized in this report, the Standardized Precipitation Evapotranspiration Index (SPEI), the Palmer Drought Severity Index (PDSI), and the Standardized Precipitation Index (SPI). These indices were selected based on their accuracy and because they were readily available for use in this report. The gridded data are evaluated based on temporal and spatial patterns and spatial extent to explore the characteristics and patterns of the excessive moisture and drought patterns. The PDSI and SPI indices do not include data from the most recent extreme precipitation period with their periods ending in 2005. The SPEI data ends in 2011, therefore does include part of the most recent extreme moisture period. Unfortunately, none of the three datasets include the most recent period (PDSI and SPI end in 2005 and SPEI ends in 2011), thus do not include the most recent 2012-2014 wet period. To incorporate the most recent years (2010-2014), the Palmer Drought Index (PDI) maps (AAFC 2015a) are used to augment PDSI gridded data. Classifications for drought and excessive moisture levels for SPEI, PDSI and SPI are characterized in Table 1.

Table 1 SPEI, PDSI and SPI Classifications (Wittrock et al. 2013, Palmer 1965 and McKee et al. 1993)

Classification		SPEI	PDSI	SPI
Drought	Exceptional	≤ -2.5	≤ -5	≤ -2.5
	Extreme	> -2.5 to -2.0	> -5.0 to -4.0	> -2.5 to -2.0
	Severe	> -2.0 to -1.5	> -4.0 to -3.0	> -2.0 to -1.5
	Moderate	> -1.5 to -1.0	> -3.0 to -2.0	> -1.5 to -1.0
	Mild	> -1.0 to -0.5	> -2.0 to -1.0	> -1.0 to -0.5
Near Normal		-0.5 to 0.5	-1.0 to 1.0	-0.5 to 0.5
Excessive Moisture	Mild	0.5 to < 1.0	1.0 to < 2.0	0.5 to < 1.0
	Moderate	1.0 to <1.5	2.0 to < 3.0	1.0 to <1.5
	Severe	1.5 to < 2.0	3.0 to < 4.0	1.5 to < 2.0
	Extreme	2.0 to < 2.5	4.0 to < 5.0	2.0 to < 2.5
	Exceptional	≥ 2.5	≥ 5.0	≥ 2.5

The SPEI uses the CANGRD dataset which is a gridded monthly precipitation and temperature dataset covering the 1900-2011 period with a spatial resolution of 50 x 50 km (Zhang et al. 2000). Bonsal (p.comm. 2013) calculated SPEI values for the Vulnerability and Adaptation to Climate Extremes in the Americas (VACEA) project using CANGRD temperature and precipitation and a normalization of a water balance based on methods of Vincente-Serrano et al (2010). The categories of SPEI are the same as those used in the Wittrock et al. (2013) report and are the same categories as used for SPI. SPEI analysis will be emphasized because of its longer time period.

Meinert et al. (2010) compared observed station data with three gridded datasets in order to determine which one would be the most suitable to use for assessing drought. The datasets were the ANUSPLIN, CANGRD and Climate Research Unit Time Series 2.1 (CRU)) and were used for the Canadian Drought Research Initiative (DRI) Project. The ANUSPLIN dataset was found to be the most comparable to observed station data and provided the best spatial coverage. This dataset is on an approximate 10 km grid resolution covering the period 1901 – 2005. The dataset contains monthly total precipitation and average maximum and minimum temperature generated using thin-plate smoothing splines (Hutcheson 2004 and McKenney et al. 2006). The monthly PDSI and SPI used in this report were calculated for each grid by Meinert et al. (2010).

The PDSI is a meteorological drought index utilized to evaluate periods of wet and dry conditions (Palmer 1965). This index has been extensively used for several applications, particularly for agriculture and surficial hydrology (e.g., Bonsal and Regier 2007 and Guttman 1998). PDSI values use information from the current month and from previous months (Guttman 1998), thus giving a longer-term memory of previous moisture conditions. The PDI values used to assess the 2009-2015 period were calculated by Agriculture and Agri-Food Canada (2015a). The time period for these maps July for 2009-2012, July for 2014 and 2015 and June for 2013 because July was not available. PDI is considered a memory index because of its weighting on previous month and is therefore considered a measure of long-term drought or excessive moisture (AAFC 2015b).

The SPI is used to monitor moisture supply conditions and uses only precipitation data (McKee et al. 1993). SPI's main purpose is to have a single value so that regions with limited climatic information can be compared with each other (Meinert et al. 2010). In addition, 12-month SPI values have been found to have strong correlations with PDSI (Guttman 1998).

Six grid points for the PDSI, SPI and SPEI indices were chosen on the Canadian side of the Souris River watershed for temporal analysis (Figure 8) for the hydrologic year (October to September). These sites were chosen because they were scattered throughout the Canadian portion of the watershed and are also relatively close to climate stations. This method enabled a good representation of the watershed and of specific climate stations.

Values from the SPEI, PDSI and SPI datasets were extrapolated for the Canadian portion of the Souris River watershed and imported into a watershed boundary base map. This map was supplied by Natural Resources Canada (NRCan) (p.comm. 2015) and the International Joint Commission (IJC) (p.comm. 2015). The extrapolated data was imported into a Geographical Information System package (SURFER (Golden Software 2015)) for spatial analysis (Appendix 6 to 8). The data analyzed included the hydrologic years (October 1 to September 30) for all three indices. The years with the ten most extreme drought and excessive moisture years were then selected and ranked. The extreme value is a point value within the entire watershed.

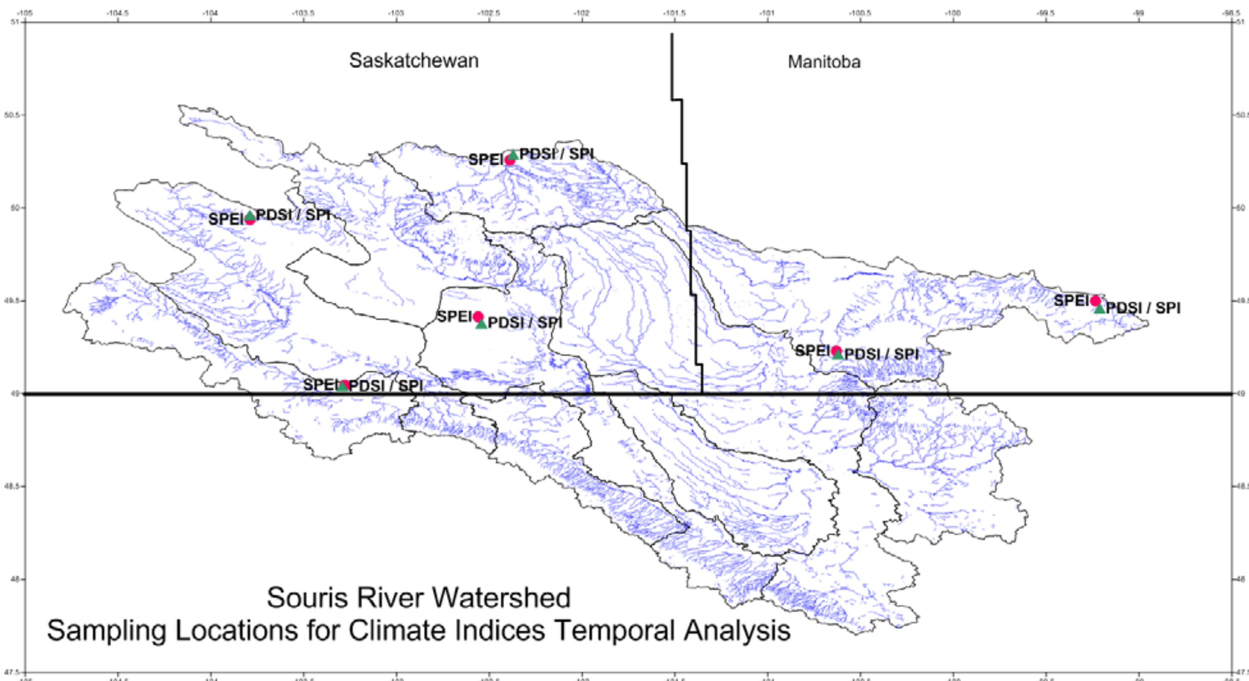

Figure 8 Sampling Locations for the Temporal Analysis of Three Climate Indices for the Canadian Portion of the Souris River Watershed

OVERVIEW OF DROUGHT AND EXCESSIVE MOISTURE HISTORY

It is often thought that the past is a window on the future. Now this statement is considered only partially true, however, past extreme events influence the level of adaptation a sector has developed either in response to that event or in an attempt to diminish severe or negative impacts that will occur in the future. This section gives a brief overview of past extremes of droughts and excessive moisture events that have occurred during the 20th century.

Drought

Droughts are defined as '*a prolonged period of abnormally dry weather that depletes water resources for human and environmental needs*' (Atmospheric Environment Service Drought Study Group 1986). They have major impacts on the environment and the various facets of society including the economy and health. The southern regions of the Canadian Prairies are more susceptible to drought mainly because they experience highly variable precipitation in time and space (Bonsal et al. 2011a). During the 20th and early part of the 21st century, many droughts, including multi-year droughts, have been documented to have occurred on the Canadian Prairies, These include droughts of the 1910s, 1930s, late 1950s to early 1960s, 1980s, 1999 to early 2000s and 2008 to early 2010 (Wheaton 2000, Bonsal and Regier 2007, Wheaton et al. 2008, Wittrock et al. 2010). These droughts affected different portions of the prairies and had different intensities, areas, and durations. For example, the droughts of the 21st century appear not to have impacted the Souris River watershed as intensely as other portions of the prairies (Wheaton et al. 2013).

While the underlying causes of each individual drought event seem to be different (Bonsal and Wheaton 2005), some general characteristics of drought events were found in the 20th and early 21st centuries (Bonsal et al. 2011b) including:

- northward migration of droughts that originated in the US Great Plains.
- some drought events emerged and others sometimes peaked in intensity in the winter months resulting in minimal snowpack and the resultant potential of lower amounts of surface water due to low spring runoff.
- higher temperatures have not yet resulted in greater drought frequency (Bonsal et al. 2011b) and the temporal patterns of droughts appears to follow decadal variations similar to that of precipitation (Wheaton et al. 2013).

As indicated, the amount and duration of snow cover are important for determining the risk of summer drought in the following. Vincent et al. (2015) found snow cover duration in the Souris River watershed has shortened by more than 20 days in the spring over the 1950-2012 period and this decrease is statistically significant at the 5% level. No significant trends duration of snow cover were found for the fall (Vincent et al. 2015). They found the Souris River watershed region has had changes to maximum snow depth over the 60 year period. The Estevan region has had an increase of more than 20cm, as indicated by the blue upwards arrow, in the annual maximum snow depth while just to the north, estimated to be in the Regina region, and eastward, approximately around Winnipeg, snow depth has decreased from 10 cm to more than 20 cm (Figure 9).

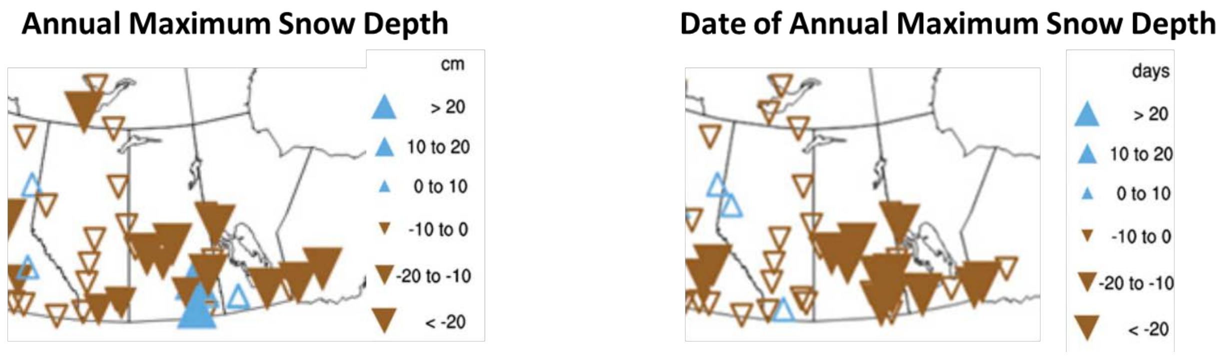

Figure 9 Trends in the Annual Maximum Snow Depth and Date of Annual Maximum Snow Depth. Upward (downward) pointing triangles indicate positive (negative) trends. Solid triangles correspond to trends significance at the 5% level. (Modified from Vincent et al. 2015).

The Souris River watershed, along with the rest of the Canadian Prairies, has had intense drought events. Precipitation, both rainfall and snowfall, is highly variable and therefore droughts can last for months, seasons, years and occasionally decades (Wheaton et al. 2013).

Extreme Precipitation

As witnessed in the spring of 2010, for example, climatic conditions can quickly switch from dry to wet over a short period of time. For example, March 2010 had less than 40% of normal precipitation with a big change to May 2010 with more than 200% of normal precipitation (Figure 10) (Wittrock et al. 2010). This switch from drought to wet conditions has occurred before and will likely occur again.

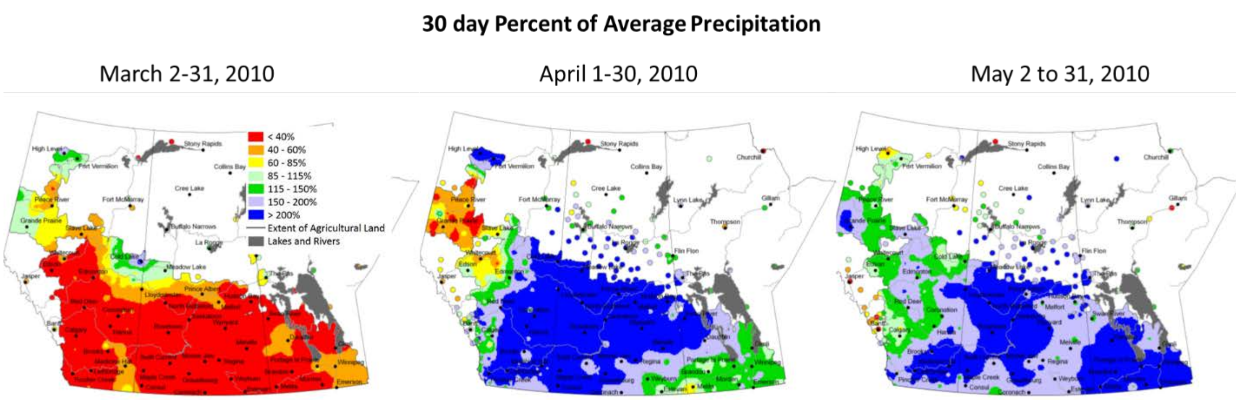

Figure 10 30-day Percent of Average Precipitation (March-May, 2010) (modified from AAFC 2015a).

Peterson et al. (2008) examined heavy precipitation amounts by using the Simple Daily Intensity Index[1] for 1950-2004 and found the average daily precipitation is getting heavier across North America in general. The Canadian Prairie region ranges from -0.35 mm per day per decade to +.35 mm per day per decade. This Index shows the Souris River watershed has a statistically significant

[1] Simple Daily Intensity Index is the total annual precipitation divided by the number of days with precipitation equal to or greater than 1 mm (Peterson et al. 2008).

region of increasing daily precipitation at the Saskatchewan, Manitoba and United States border region (Figure 11) with a larger area of the watershed with no precipitation increase to a 0.35 mm/d/decade decrease (not statistically significant). Shook and Pomeroy (2012) found the Weyburn region had significant negative trends of single-day summer rainfall over the 1951-2000 period but the rest of the watershed did not have any significant change in single-day summer rainfall. The difference between Peterson et al. (2008) and Shook and Pomeroy (2012) may be their methodology. Peterson et al. (2008) used an index and an average whereas Shook and Pomeroy used days with recorded precipitation amounts.

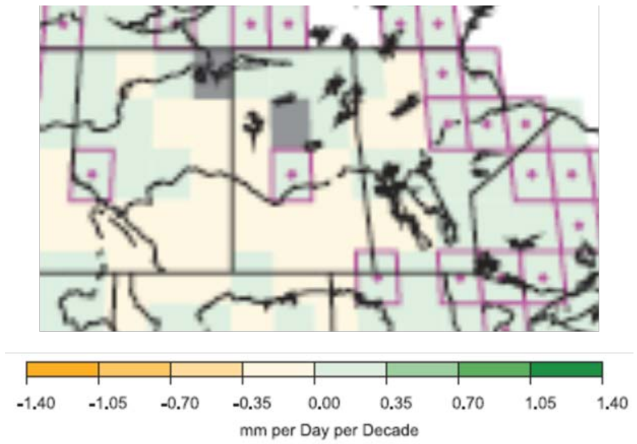

Figure 11 Simple Daily Precipitation Intensity Index (modified from Peterson et al. 2008) Grid boxes with trends that are statistically signficant at the 5% level are outlined in magenta and have a magenta dot in their centers.

Recent years have had numerous extreme precipitation events, particularly rainfall events, across the prairies. In July 2000, the Vanguard area of Saskatchewan had a convective storm event that resulted in 375 mm of rain falling in an eight-hour period (Hunter et al. 2002). The prairies were in a major drought event between 1999 and 2003. A large portion the drought stricken region received a significant rainstorm 8-11 June 2002 running from Pincher Creek Alberta to Winnipeg Manitoba. This rainstorm effectively brought this region out of drought and into excessive moisture conditions (Szeto et al. 2011).

Brimelow et al. (2015) examined many aspects of the hydroclimate conditions of 2011 in the Assiniboine River Basin, including the Souris River watershed. They found that the Assiniboine River Basin typically experiences 10 days with precipitation amounts greater than or equal to 10 mm of precipitation in a 24 hour period during the May through September period with a maximum number of 16 events. On average two events greater than or equal to 25 mm occurred during the 1981-2010 period with a maximum of six events per year. In May-Sept 2010, there were 19 – 10 mm events and five – 25 mm events and May-Sept 2011 had 17 – 10 mm events and four – 25 mm events showing that 2010-2011 was atypical. Using the September 1 to August 31 period, they compared the 2010-2011 period to two previous high precipitation years (1954-1955 and 1975-1976[2]) and the 1971-2000 average at Estevan. The 2010-2011 exceeds the previous extreme wet year of 1954-1955 by about 150 mm (Figure 12).

[2] 1955 and 1976 were years of high river flow discharge in the Assiniboine River watershed (Brimelow et al. 2015)

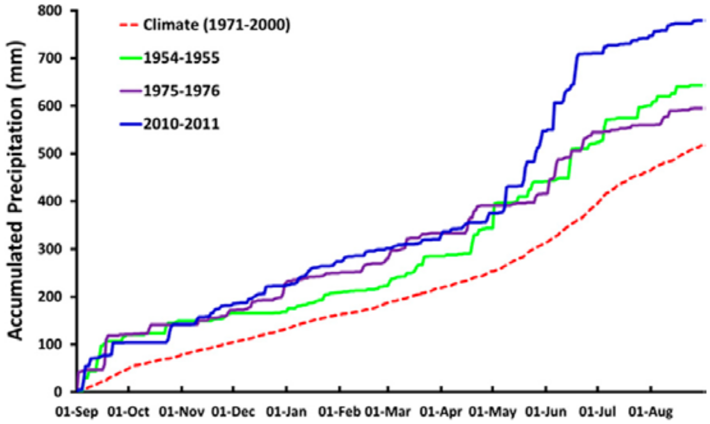

Figure 12 Accumulated Daily Precipitation at Estevan SK for 1954-55, 1975-76, 2010-2011 and Averaging Period (1971-2000) over the September 1 to August 31 Period (Brimelow et al. 2015)

When excessive precipitation events occur, the level of impacts of these events is dependent upon the antecedent conditions (Wheaton et al. 2013, Brimelow et al 2015 and Hopkinson 2011). The level of impacts also depends on precipitation type, intensity, duration, extent and antecedent conditions (e.g., soil moisture content, water storage capacity). Rainstorms have occurred during drought events, and severe droughts have shifted within days to wet conditions (e.g., 2002 (Szeto 2011), spring 2010 (Wittrock et al. 2010)). These situations may become the norm instead of the extraordinary as noted by Francis and Vavrus (2012). They suggest that switches from dry conditions to wet will increase in frequency as the temperature gradient between the poles and equator decreases (Francis and Vavrus 2012).

TEMPERATURE AND PRECIPITATION TRENDS

The Souris River watershed has had numerous excessive moisture and drought episodes. These events impact the energy sector and related services and required infrastructure such as transportation, supplies, and associated manufacturing, to varying degrees. This section examines the temperature and precipitation trends of various locations throughout the watershed. The watershed has seven relatively long-term climate stations located within its boundaries with five more stations located relatively close to the watershed (Figure 13).

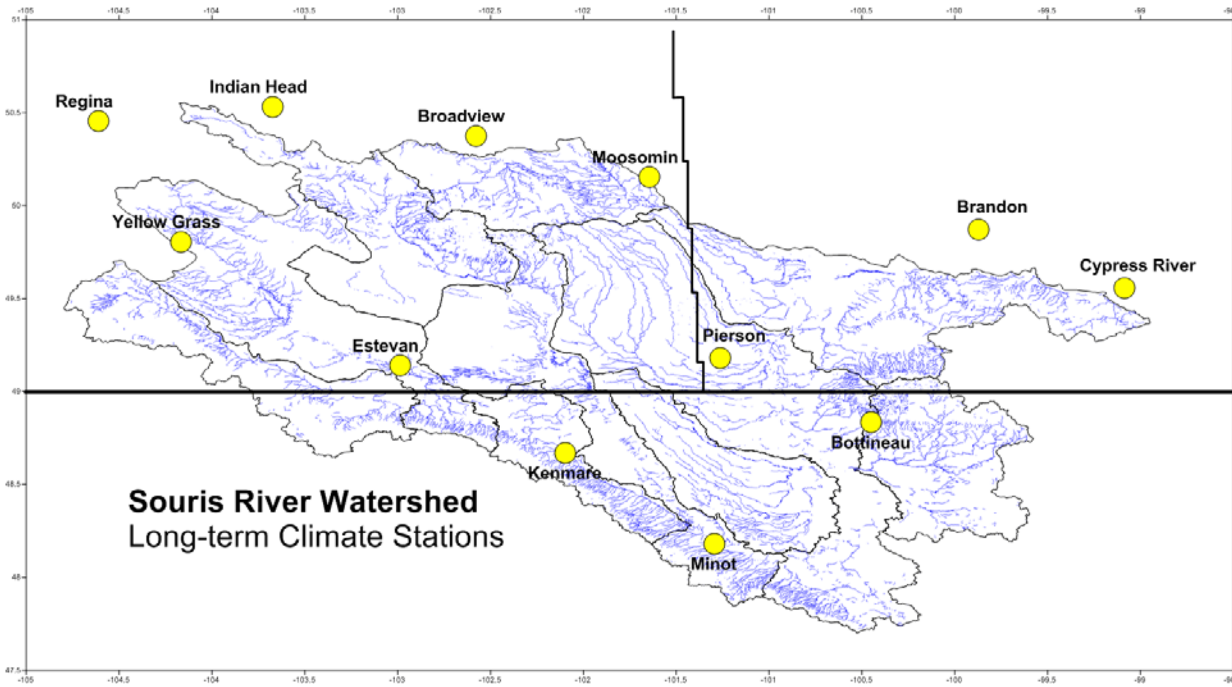

Figure 13 Long-term Climate Stations in the Souris River Watershed and Vicinity

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, then back northwards into Manitoba, eventually joins with the Assiniboine System, and ultimately flows into Lake Winnipeg. This region is relatively flat and is classified as semi-arid prairie (West Souris River Watershed Planning Authority ND). 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 (Table 2). The winter (December, January, February) average minimum temperatures are below -15°C across the watershed. The summer average maximum temperature ranges from 24 to 27°C. Based on the 1981-2010 averaging period, the region gets between 400 and 500 mm of average annual precipitation with spring precipitation (March April May) between 95 and 120 mm and summer (June July August) precipitation from 180 to 230 mm (Table 3) being the major periods of precipitation.

Table 2 The 1981-2010 Average Annual and Seasonal Temperatures for Selected Climate Stations within and around the Souris River Watershed (Data: Environment Canada 2015 and National Climatic Data Center ND)

			Souris River Watershed Selected Climate Stations							Selected Long-term Climate Stations Close to Watershed				
		1981-2010 Averages	Estevan, SK	Moosomin, SK	Yellow Grass, SK	Pierson, MB	Kenmare, ND	Minot Experimental Station, ND	Bottineau, ND	Indian Head, SK	Regina, SK	Broadview, SK	Brandon, MB	Cypress River, MB
Temperature (C)	Annual	Average	3.7	3.0	3.6	3.7	4.5	4.7	4.7	2.7	3.1	2.5	2.2	3.5
		Max	10.1	8.4	10.2	10.0	10.9	10.6	11.1	8.8	9.3	8.6	8.4	9.3
		Min	-2.6	-2.5	-3.1	-2.5	-1.8	-1.1	-1.7	-3.5	-3.2	-3.7	-3.9	-2.3
	Winter	Average	-12.1	-13.1	-12.1	-12.4	-10.7	-10.8	-11.9	-13.1	-12.9	-13.3	-14.7	-13.1
		Max	-6.7	-8.6	-6.5	-7.2	-5.4	-6.0	-6.7	-7.8	-7.6	-7.9	-9.4	-8.1
		Min	-17.5	-17.6	-17.6	-17.5	-16.0	-15.7	-17.1	-18.3	-18.3	-18.6	-20.0	-18.1
	Spring	Average	4.3	3.7	4.1	4.3	4.7	4.8	5.4	3.2	3.8	3.2	2.8	3.9
		Max	10.8	9.4	10.9	10.7	11.2	10.7	12.0	9.5	10.2	9.5	9.1	10.0
		Min	-2.1	-2.1	-2.8	-2.0	-1.8	-1.2	-1.4	-3.1	-2.6	-3.0	-3.5	-2.2
	Summer	Average	18.2	17.8	18.0	18.4	18.7	19.1	19.4	17.1	17.7	16.8	17.4	18.5
		Max	25.2	24.3	25.5	25.6	25.8	25.6	26.8	24.0	24.7	23.7	24.2	25.1
		Min	11.1	11.2	10.4	11.2	11.5	12.5	12.1	10.3	10.7	9.8	10.5	11.8
	Autumn	Average	4.5	3.6	4.3	4.5	5.1	5.6	5.7	3.4	3.6	3.2	3.4	4.6
		Max	11.0	8.7	10.9	10.8	11.6	11.5	12.1	9.5	10.1	9.2	9.6	10.1
		Min	-2.0	-1.5	-2.3	-1.7	-1.3	-0.4	-0.7	-2.7	-2.8	-2.8	-2.7	-0.9

Table 3 The 1981-2010 Average Annual and Seasonal Precipitation for Selected Climate Stations in and around the Souris River Watershed (Data: Environment Canada 2015 and National Climatic Data Center ND)

		Souris River Watershed Selected Climate Stations							Selected Long-term Climate Stations Close to Watershed				
	1981-2010 Averages	Estevan, SK	Moosomin, SK	Yellow Grass, SK	Pierson, MB	Kenmare ND	Minot Experimental Station ND	Bottineau ND	Indian Head, SK	Regina, SK	Broadview, SK	Brandon, MB	Cypress River, MB
Precipitation (mm)	Annual	427.0	515.1	430.6	457.3	464.8	472.2	442.7	428.4	389.7	424.7	474.2	526.8
	Winter	49.6	55.3	58.5	58.7	62.7	48.3	37.8	57.9	40.4	44.3	52.2	66.1
	Spring	102.0	115.8	105.4	105.7	112.0	121.9	108.7	98.6	95.2	100.5	109.5	110.6
	Summer	194.0	232.5	188.3	199.7	197.6	204.2	211.1	192.4	182.6	196.7	220.0	240.2
	Autumn	81.6	111.4	78.4	93.2	92.5	97.8	85.1	79.6	71.5	83.3	92.7	109.9

Temperature Trends

Temperature trends give an indication of the overall tendency of the climate towards warming or cooling. The time series plots also indicate the year-to-year variation and range over the period. This analysis includes the four selected long-term climate stations on the Canadian side plus an additional five Canadian climate stations located relatively close to the watershed (Figure 13). The graphs for this section are located in Appendices 2 to 4 and include annual average temperatures, and seasonal average temperatures, maximum annual temperatures and seasonal average temperatures, and minimum annual temperatures and seasonal average temperature trends. The climate stations have different periods of record, but range between 1889 and 2014 (Appendix 1).

Yearly Trends

The annual average temperature departures from the 1981-2010 average (Appendix 2) for all of the Canadian stations show a general positive slope indicating annual temperatures have been increasing over the last 125 years of measured data. The greatest Pearson Product Moment Correlation coefficient r value is for Estevan with an r value of 0.51 (r^2 value of 0.26) considered to statistically significant at the 95% level. Based on the trend line, the annual average temperature at Estevan has increased over 2°C, with approximately 1.5°C of that increase since 1950. This site also has the longest period of record for the Canadian side of the watershed.

Strong year to year annual temperature variability has also occurred over the period of record with extreme high average annual temperature years being 1988, 1981 and 1931, with extreme low average annual temperatures in the early 1950s. More recently 2009, 2013 and 2014 had between 2 and more than 4°C below average annual temperatures. The annual minimum temperatures have higher r values than the annual maximum temperatures indicating that minimum temperatures have increased more in the last 100-125 years than the annual maximum temperatures (Appendix 3 and 4).

Seasonal Trends

The seasonal trends of average, maximum and minimum temperatures gives a further indication of the nature of temperature increases over the last 100 to 125 years (Appendices 2-4).

Winter Trends

As with the annual minimum temperatures, the winter minimum temperatures trend is towards increasing temperatures at a greater rate than the winter maximum temperatures as indicated by the r values. For example, Estevan’s minimum temperature (departure from average) r value is 0.32, while the winter maximum temperature (departure from average) r value is 0.25. Winter (December, January, February) has the greatest temperature variation of all four seasons ranging from 6°C above the normal temperature calculated from the 1981-2010 averaging period (e.g., 1931) to more than 8°C (e.g., 1936) below the normal winter average temperature. Recent examples of winter seasonal variability are the winters of 2011/2012 and 2013/2014. The 2011/2012 winter had average temperatures ranging from 4 to more than 6°C (Yellow Grass) above normal, while 2013/2014 had temperatures at least 4 to more than 6°C (Cypress River) below normal.

Spring Trends

Spring temperatures in general continue the upward (or warming) trend but the correlations are lower than winter and some are not considered statistically significant. For example the r values for Estevan are statistically significant at the 95% level for maximum, minimum and average spring trend lines (r = 0.238, 0.225 and 0.250). The r values for Yellow Grass are not statistically significant at the 95% level. Spring (March, April, May) temperature variability is less than that of winter. Typically the spring average temperature departures from the 1981-2010 average can range from 8°C below average to less than 4°C above average.

Summer Trends

Summer (June, July, August) average temperatures are increasing across the watershed. However, it is the minimum temperatures that have increased the most with five r values at Estevan, Regina, Indian Head and Brandon being greater than 0.5 and statistically significant at the 95% level.

Autumn Trends

The long-term autumn (September, October, November) trend lines indicate temperature increases. The shorter-term trend lines, depending on the period of record, show decreasing autumn average temperatures, such as at Moosomin. The reason for this decreasing temperature trend may be because Moosomin's autumn time series ends in the mid-1990s and does not include the last 20 years. In addition, Moosomin's early years, the 1940s and 1950s, indicate, in addition to not having continual data, also have their highest temperatures during that period (1953). Again influencing the decreasing trend line. The departure from normal minimum temperatures time series are statistically significant over the last 100 years such as Regina (r=0.356) and Indian Head (r=0.492) but the maximum temperature trend lines are not.

These seasonal temperature trends are similar to the results from Vincent et al. (2015) for the 1948-2012 timeframe. They found every season's mean seasonal temperature increased at a statistically significant level except for the autumn (Figure 14).

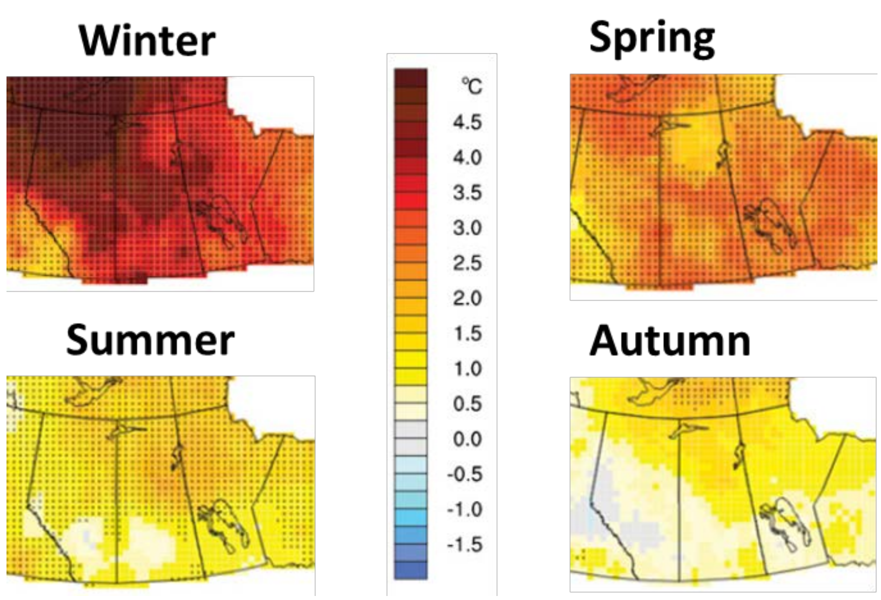

Figure 14 Trends in Canadian Prairie Seasonal Mean Temperatures for 1948-2012 period (modified from Vincent et al. 2015). Grid squares with a dot are statisitically significant at the 5% level. The units are degrees Celcius per 65 years.

Precipitation Trends

Precipitation is highly variable on yearly, seasonal, and daily basis. It also can be extremely localized or it can cover an extensive region. Both the lack of and too much precipitation can impact all facets of society including industry. Trends of precipitation departures from the 1981-2010 average in percentages over the 1890 to 2014 period are plotted for nine Canadian locations located either within or near the Souris River watershed (Appendix 5).

Yearly Trends

Precipitation trends based on the yearly time scale vary with location (Figures 15 to 17 and Appendix 5). Some extended high moisture and dry periods are apparent (Figure 15). Four periods of excessive moisture occurred, including the early 1950s, the 1970s, the 1990s and the 2010s. The year with the highest annual precipitation in the watershed was 2011. Precipitation amounts ranged from 533.5 mm at Kenmare to 770.5 mm at Bottineau. Estevan received over 673 mm of precipitation for the calendar year of 2011. Three major extended drought periods were in the 1930s, late 1950s to early 1960s and the 1980s. The early 2000s also had low precipitation levels. The year with the lowest annual precipitation for many of the sites in the Souris River watershed was 1961 with Minot recording almost 228 mm, while Estevan received almost 280 mm of precipitation throughout the year.

Figures 16 and 17 highlight the differences within and outside (north) of the Souris River watershed, particularly the high precipitation amounts in the 2010 to 2014 period. Climate stations located within the boundaries of the Souris River watershed show almost continuously above average annual precipitation from 2007 to 2014 (Figure 16), whereas climate stations north of the watershed indicated low to very low annual precipitation levels (Figure 17). This contrast may be related to the quality assurance of the data for this time period.

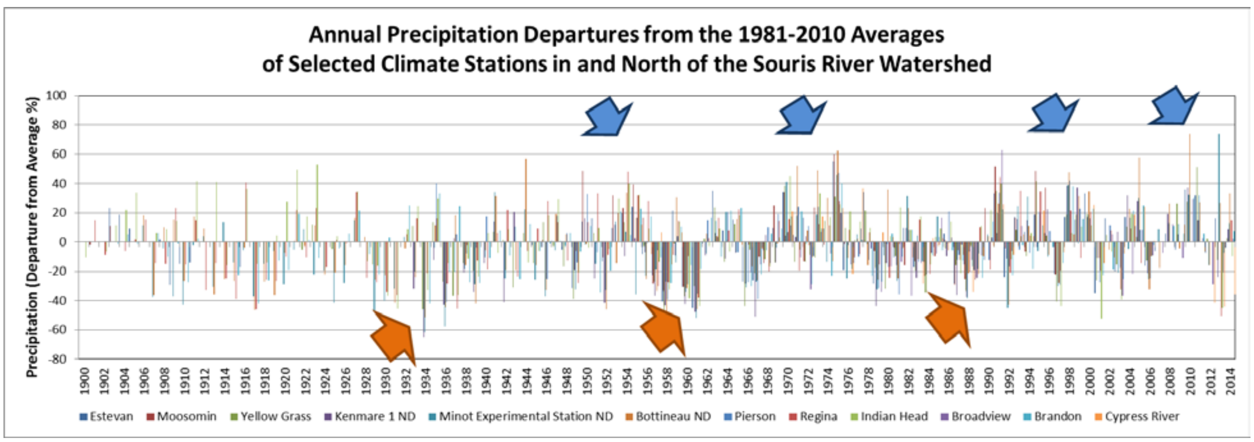

Figure 15 Annual Precipitation Departures from the 1981-2010 Averages of Selected Climate Station in and north of the Souris River Watershed

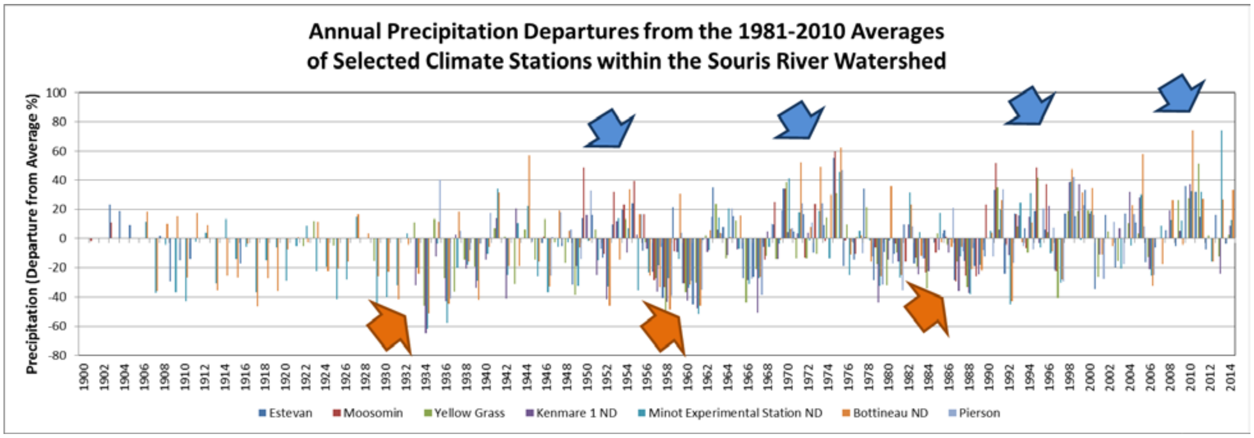

Figure 16 Annual Precipitation Departures from the 1981-2010 Averages of Selected Climate Station in the Souris River Watershed

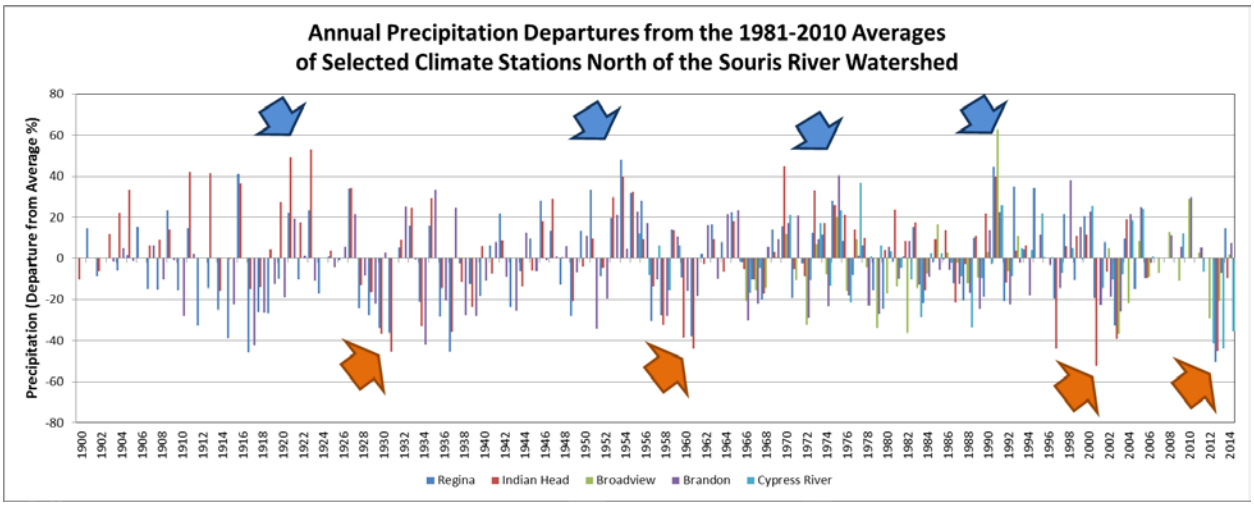

Figure 17 Annual Precipitation Departures from the 1981-2010 Averages of Selected Climate Stations north and outside of the Souris River Watershed

Seasonal trends

Annual precipitation provides only partial information for characterizing drought and excessive moisture occurrences. Seasonal precipitation allows a more complete examination of trends for the shorter periods, for example, addressing questions such as, is winter getting wetter or drier, how much and at what rate? In addition, seasonal examination supplies more detail on extreme precipitation that may be smoothed and thus hidden when analysing yearly variability. Seasonal precipitation graphs are located in Appendix 5 and results are discussed in this section.

Precipitation changes across Canada were documented recently by Vincent et al. (2015). Figure 18 shows the Canadian Prairies and the trends of total seasonal precipitation for the 1948 to 2012 period. They found winter and summer in the Souris River watershed had not changed in total precipitation amounts over the period while spring and autumn had increased amounts. None of these trends are considered to be statistically significant in the Souris River watershed.

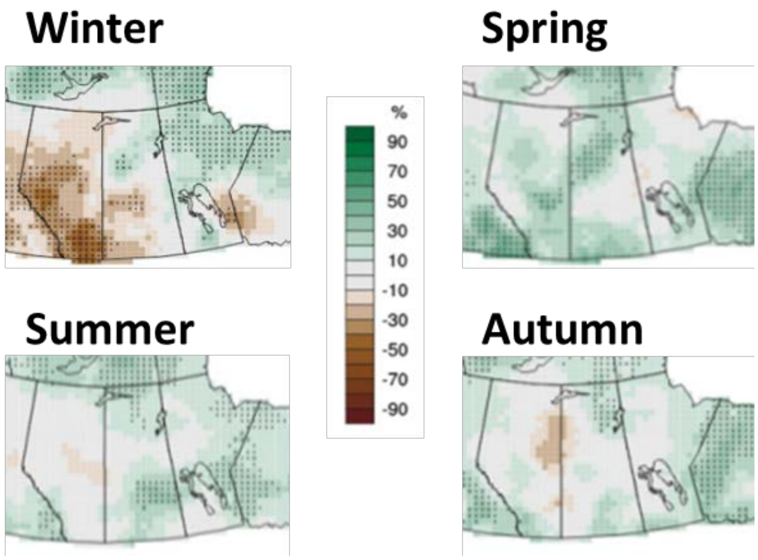

Figure 18 Trends in Total Seasonal Precipitation for the 1948-2012 period on the Canadian Prairies (modified from Vincent at al. 2015). Dots indicate trends are statistically signficant at the 5% level. The units are % per 65 years.

Winter trends

Winter (December, January and February) is usually the season when the precipitation is snow and a useful way to "store" water (Appendix 5). The driest winters in Estevan were in the early 20th century, the mid 1940s and the 1980s when precipitation levels were between 40 and 60% below the 1981-2010 averaging period. Estevan does not have data available for the 1930s period. The climate stations south of the international border follow a similar temporal pattern in the winter as Estevan and Yellow Grass. Winter precipitation amounts for the 2009 to 2011 period were at or above 100% above normal at Minot, North Dakota. The long-term Manitoba climate stations at Brandon and Cypress River have similar temporal patterns with the 1930s and early 1940s having extended dry periods. The late 1940s to 1970s at these two locations fluctuated between extremely high precipitation amounts (greater than 150% above average in 1969 at Cypress River) to dry periods. The late 1950s to early 1960s had winter precipitation amounts that were more than 50% below the 1981-2010 average. The 1980s were all below average while the 1990s and 2000s generally had above normal winter precipitation. The most recent period (2012-2014) had below average winter precipitation amounts. For example Estevan was almost 30% below average in 2012 and more than 40% below average in the winter of 2014.

Spring trends

Spring (March, April, May) precipitation (Appendix 5) either augments spring runoff from the winter snowpack melt or lack of precipitation results in decreased runoff. The selected climate stations in the Souris River watershed were generally consistent indicators of above or below average precipitation for the area. The most recent driest period was in the 1980s when much of the decade, except for 1985 and 1986, had below average precipitation. Yellow Grass reported below more than 50% average precipitation in 1984 and 1989 compared to the 1981-2010 averaging period. The 1990s fluctuated between above average and below average with high precipitation in spring of 1999 of more than 91% above average to more than 50% below average in 1995 at Yellow Grass, for example. 2004 to 2008 had above average precipitation with below average values in the spring of 2008 of more than 40%. For the springs of 2010 to 2014 climate stations generally had above normal precipitation, like Estevan, over 100% above normal in 2011.

The climate stations just north of the Souris River watershed boundary (Appendix 5) illustrate how precipitation can vary from one area to another. The 1980s were also dry north of the watershed during the 1980s with some stations reporting above normal precipitation such as Broadview and Indian Head. The early 1990s had very wet springs but the 1992-1994 period had below average precipitation. Similar to the stations within the Souris River watershed, 1999 had above average precipitation with the 2000 to 2002 having below average amounts. Many of the climate stations stopped reporting precipitation between 2007 and 2011, but the ones with data indicate that spring 2008 had little precipitation, for example, Estevan and Yellow Grass were more than 40% below average. The springs of 2010 to 2013 had above average levels with Estevan being almost 10% above average in 2010 and more than 100% above average in 2011 while Yellow Grass was nearly 60% above average in 2010 and more than 90% above average in 2011. The precipitation of the spring 2013 had some stations reporting below average precipitation such as in Regina and Broadview but within the watershed, Estevan (30%) and Yellow Grass (19%) were both above average. The spring of 2014 had slightly above average precipitation amounts at Yellow Grass (22%) and Estevan was below average by 21%.

Summer trends

Summer (June, July and August) is the time for convective storms where one region can get a deluge while another region, not that far away, can get little to no precipitation. The result is a less consistent temporal and spatial pattern of the climate stations' precipitation amounts, both within and outside the watershed (Appendix 5). The late 1950s and early 1960s had very dry summers as did 1967. In the early 1970s, summer precipitation amounts varied among the climate stations. The late 1970s and 1980s continued the generally dry trend but again, some climate stations did report relatively high summer precipitation amounts. The early 1990s had above average precipitation but the rest of the 1990s fluctuated from year to year. The summer of 2003 was very dry with both Estevan and Yellow Grass being more than 60% below average, as was 2006 with Estevan more than 40% below average and Yellow Grass is 31% below average. The summer of 2005 was quite wet with Yellow Grass and Estevan both reporting between 40% and 50% above average. The precipitation amounts between 2007 and 2014 were highly variable ranging from over 30% below average to 50% below average.

Autumn trends

Autumn (September, October and November) precipitation amounts influence the level of soil moisture and water holding capacity of the soils during spring melt. A wet fall can lead to higher spring runoff due to saturation of the soils and perhaps high groundwater levels. Wet autumns can also have positive or negative impacts, depending on the system affected. The fall of 1959 reported well above average precipitation amounts, but the autumns of the 1960s were generally below average. The 1970s fluctuated between wet fall and dry falls with the early 1980s generally having above average precipitation amounts. The mid 1980s to early 1990s had less precipitation than average, while the mid to late 1990s again fluctuated between above average fall precipitation amounts to below average. The falls were below average between 2000 and 2007 but in general were above average from 2008 to 2013 (Appendix 5). The selected climate stations north of the Souris river watershed had similar fall precipitation patterns except for the most recent years

(Appendix 5). The fall of 2010 had above average precipitation levels but from 2011 to 2014 below average fall precipitation amounts were reported.

CLIMATE INDICES

This section examines the Standardized Precipitation Evapotranspiration Index (SPEI), the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI) both temporally and spatially.

The ten most extreme drought and excessive moisture hydrologic years (October – September) for each of the three indices are shown in Table 4. Four extreme years were common for both excessive moisture and droughts but with different rankings. The year with the highest excessive moisture value for all three indices was 1927 but they also had 1923, 1954 and 1975 in common indicating these were particularly harsh years.

The extreme drought years of 1961 and 1958 were in the top three for all three indices. The other common drought years for all three indices were 1984 and 1988. SPEI had two excessive moisture years (2010 and 2011) and one drought year (2006) that were not determined using the PDSI and SPI datasets.

It is equally important to examine the temporal characteristics of when these extreme events occurred. If the event was part of a multi-year occurrence of either excessive moisture or drought conditions, the severity of the impacts could either be less or more intense.

Table 4 Extreme Maximum and Minimum Values of SPEI (1900-2011), PDSI (1900-2005) and SPI (1900-2005) for the October 1 to September 30 period in the Canadian Portion of the Souris River Watershed

Extreme Maximum Values - Excessive Moisture Conditions						Extreme Minimum Values - Drought Conditions					
SPEI		PDSI		SPI		SPEI		PDSI		SPI	
Year		Year		Year		Year		Year		Year	
1927	2.3	1927	5.3	1927	1.8	1958	-2.3	1958	-5.3	1958	-2.7
1999	2.3	1954	4.1	1975	1.7	1961	-2.3	1988	-4.8	1961	-2.3
2010	2.2	1975	3.9	1954	1.7	1988	-2.2	1961	-4.5	1967	-2.0
1954	2.2	1965	3.8	1991	1.6	1936	-2.1	1989	-3.8	1929	-1.9
1950	2.1	1991	3.5	1963	1.5	1937	-2.0	1984	-3.6	1936	-1.6
1975	2.1	1942	3.4	1995	1.4	1984	-2.0	1931	-3.5	1934	-1.6
2011	1.9	1923	3.0	1923	1.3	1929	-1.8	1915	-3.5	1984	-1.4
1907	1.8	1986	3.0	1999	1.2	1967	-1.8	1934	-3.5	1988	-1.4
1923	1.8	1995	2.9	1965	1.2	1919	-1.6	1937	-3.5	1917	-1.4
1970	1.6	1928	2.9	1985	1.1	2006	-1.5	1919	-3.4	2003	-1.2

Commonalities of extreme years: Yellow (SPEI, PDSI and SPI); Blue (SPEI and SPI); Green (SPEI and PDSI) and Pink (PDSI and SPI).

Standardized Precipitation Evapotranspiration Index

Standardized Precipitation Evapotranspiration Index includes temperature, precipitation and a water balance equation and as such, different temporal and spatial patterns emerge from what was captured in the individual temperature and precipitation analysis. Also of benefit is that there are no data gaps in time or area.

Temporal Patterns

As indicated in Figures 8 and 19, six grid cells, four in Saskatchewan and two in Manitoba, were chosen for characterizing trends and the nature of the extremes including frequency of events and their duration. The start of the 20th century had neutral to moderate excessive moisture conditions until 1907 when the region fluctuated between -0.8 to 0.8 SPEI conditions. The 8th wettest year was in 1907 at the end of a period of generally excessive moisture conditions. In 1910, the two Manitoba grid points had SPEI values near -1.3 indicating moderate drought. Neutral conditions to mild excessive moisture conditions returned in 1911. Drought levels ranged from mild to severe between 1913 and 1919, the 9th driest year, with the exception of 1916 when neutral to mild excessive moisture SPEI values were calculated. Neutral to extreme excessive moisture SPEI values occurred between 1923 and 1928 inclusive resulting in six years having moisture conditions rated as neutral to extreme (1928) followed in 1929 by severe drought conditions, especially for the Manitoba grid cells. Mild to extreme drought conditions lasted until 1940 with two consecutive years, 1936 and 1937 in severe to extreme drought conditions. The 1930s had only one year, 1935, with neutral to severe excessive moisture conditions. The severe excessive moisture values were in the two Manitoba grid cells. The 1940s fluctuated between neutral to moderate excessive moisture and neutral to moderate drought conditions.

The early 1950s, with the exception of 1952, had excessive moisture conditions ranging from near neutral to extreme in 1950 and 1954 both of which are in the top 10 years of excessive moisture. The watershed reverted back to extreme drought conditions in 1958 and again in 1961. 1962 was a rebound year with the Saskatchewan side of the Souris watershed in neutral SPEI conditions and the eastern most grid point in Manitoba had mild excessive moisture conditions in 1962. The latter years of the 1960s and first half of the 1970s had neutral to extreme excessive moisture conditions. The latter part of the 1970s and most of the 1980s were in mild to extreme drought with 1985 and 1986 having positive SPEI values as high as 1.82 (severe excessive moisture) at eastern most Manitoba grid sampling location. The 1990s and the first half of the 2000s fluctuated between moderate drought and moderate excessive moisture conditions with 1999 having the second most extreme excessive moisture conditions in the extreme category (Table 4). A severe drought SPEI value was recorded in middle of the Saskatchewan side of the watershed. Neutral conditions started in 2009 rising to extreme excessive moisture values in 2010 and continuing into 2011.

Extreme or exceptional SPEI values were found 10 times over the 1901 to 2011 period. Six of them were classified in the extreme moisture event category (1927, 1950, 1954, 1975, 1999 and 2010) and six years were classified in the extreme drought category (1936, 1937, 1958, 1961, 1984, and 1988).

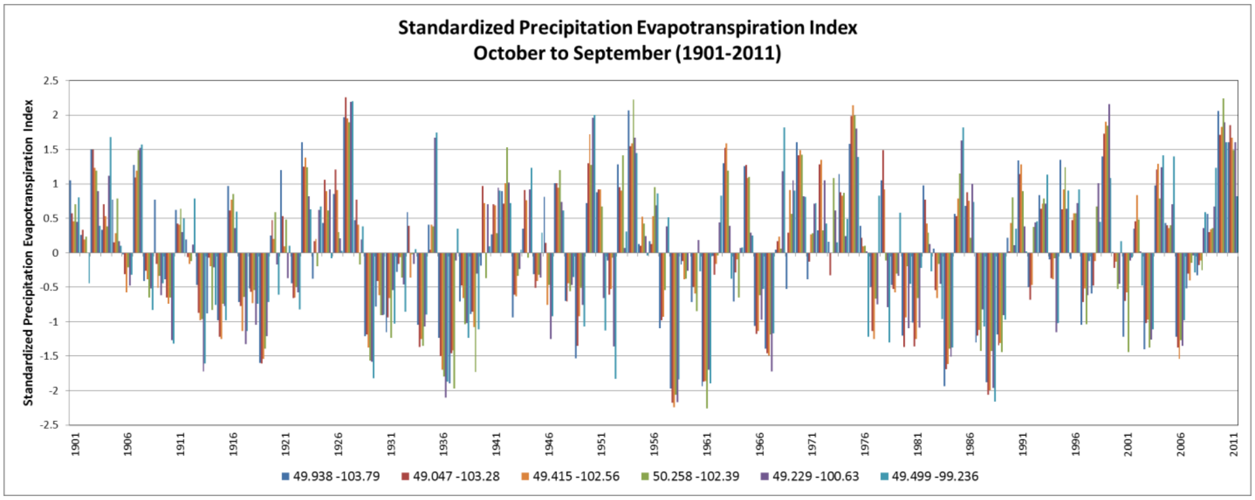

Figure 19 Standardized Precipitation Evapotranspiration Index for selected grid cells (1901-2011)

Spatial Patterns

The ten most extreme SPEI years for both excessive moisture and drought conditions are listed in Table 4 and plotted in Appendix 6. These maps show the variability of SPEI throughout the watershed where one location may be categorized as having exceptional excessive moisture conditions, while another location of the watershed may have neutral or even drought conditions.

Excessive Moisture

During the most extreme excessive moisture year (October 1926 – September 1927) the regions with the highest excessive moisture were on the west and east sides of the Souris River watershed. The second highest excessive moisture year was 1998-1999 had the SPEI extreme values through the central portions of the watershed, along the Saskatchewan / Manitoba border.

2009 – 2010 (Figure 20) had very little variability in the watershed with the northwest portion having SPEI values in the 2.0 to 2.5 range (categorized as extreme), with the rest of the watershed rated as having severe excessive moisture conditions. This was a similar pattern to 1953-1954 with the most eastern portion of the watershed calculated as having moderate excessive moisture conditions.

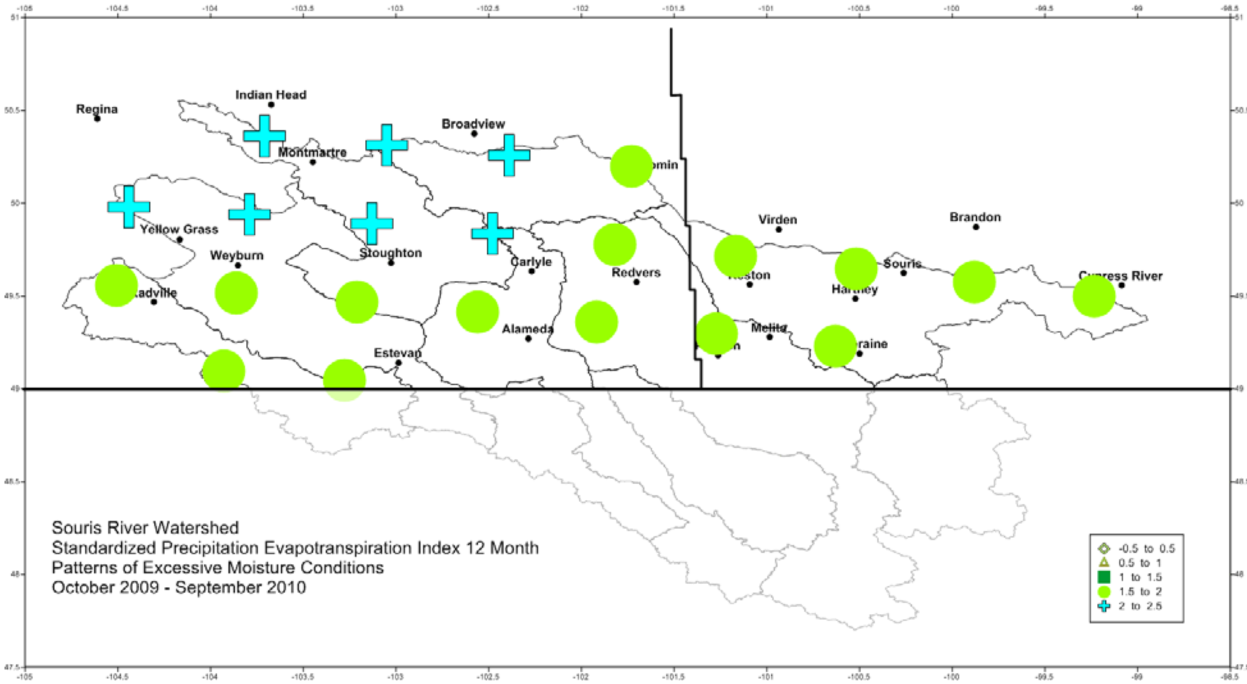

Figure 20 SPEI 12-Month Patterns of Excessive Moisture Conditions (October 2009-September 2010)

The fifth ranked excessive moisture year, 1949-1950, had quite different conditions across the watershed, ranging from near normal in the northwest to extreme excessive moisture on the eastern side. The highest SPEI of 1974-1975 hydrologic years were in the central portion of the watershed decreasing in severity on the western and eastern sides.

The seventh ranked year 2010-2011 (Figure 21) ranked below extreme with severe SPEI values but it was the second year in a row with at least severe excessive moisture conditions throughout most of the watershed. The eighth highest SPEI year was October 1906 – September 1907 when the eastern side of the watershed had values categorized as severe with the western, the entire Saskatchewan side, in the moderate excessive moisture category. As noted in the temporal patterns section, this year was at the end of at least six years of neutral to moderately moist conditions.

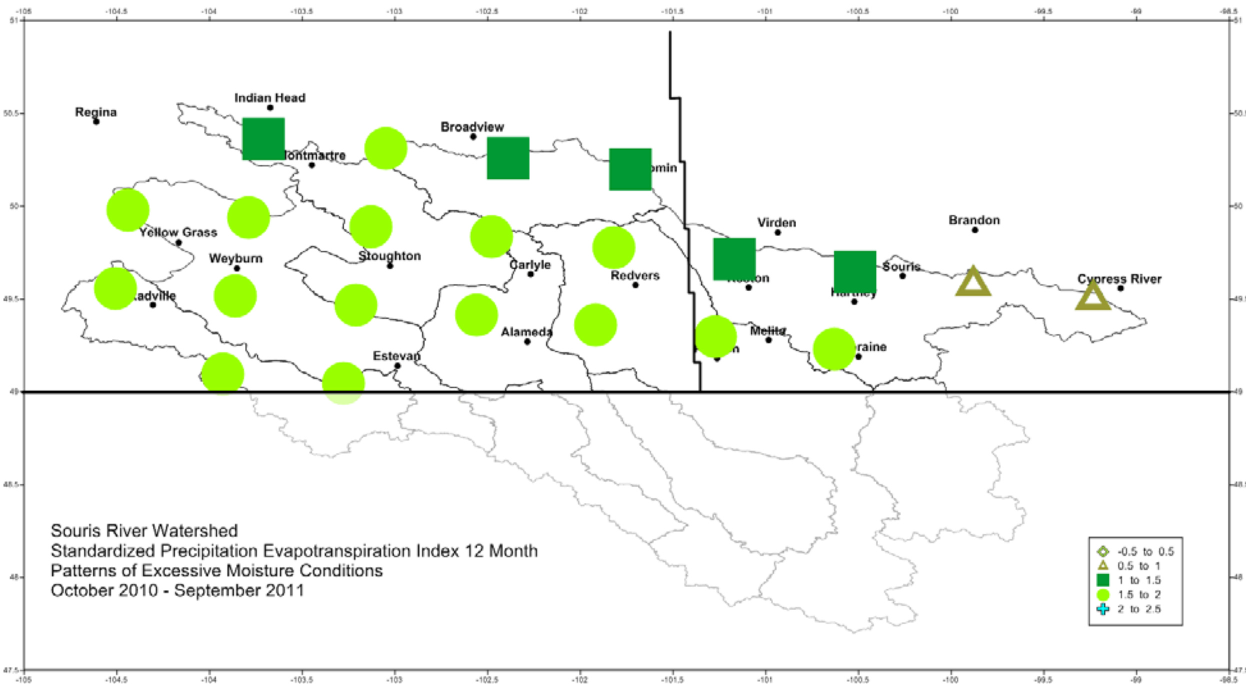

Figure 21 SPEI 12-Month Patterns of Excessive Moisture Conditions (October 2010-September 2011)

1922-1923 hydrologic year had mild excessive moisture conditions in the Manitoba portion of the Souris River watershed with severe excessive moisture conditions in the northwest region. The 1969-1970 excessive moisture pattern again shows Manitoba with mild excessive moisture conditions. The severe excessive moisture slices across the Saskatchewan side in a west/east direction through the middle of the watershed.

Drought

Low SPEI values are classified as drought conditions. The Souris River watershed has had six extreme drought years over the 1901-2011 period (Appendix 6). The most extreme drought year was October 1957-September 1958 when the majority of the watershed was categorized as extreme (Figure 22). This event was followed closely by 1960-1961, the second ranked drought year, when most of the watershed was classified as being in a severe drought (Figure 23).

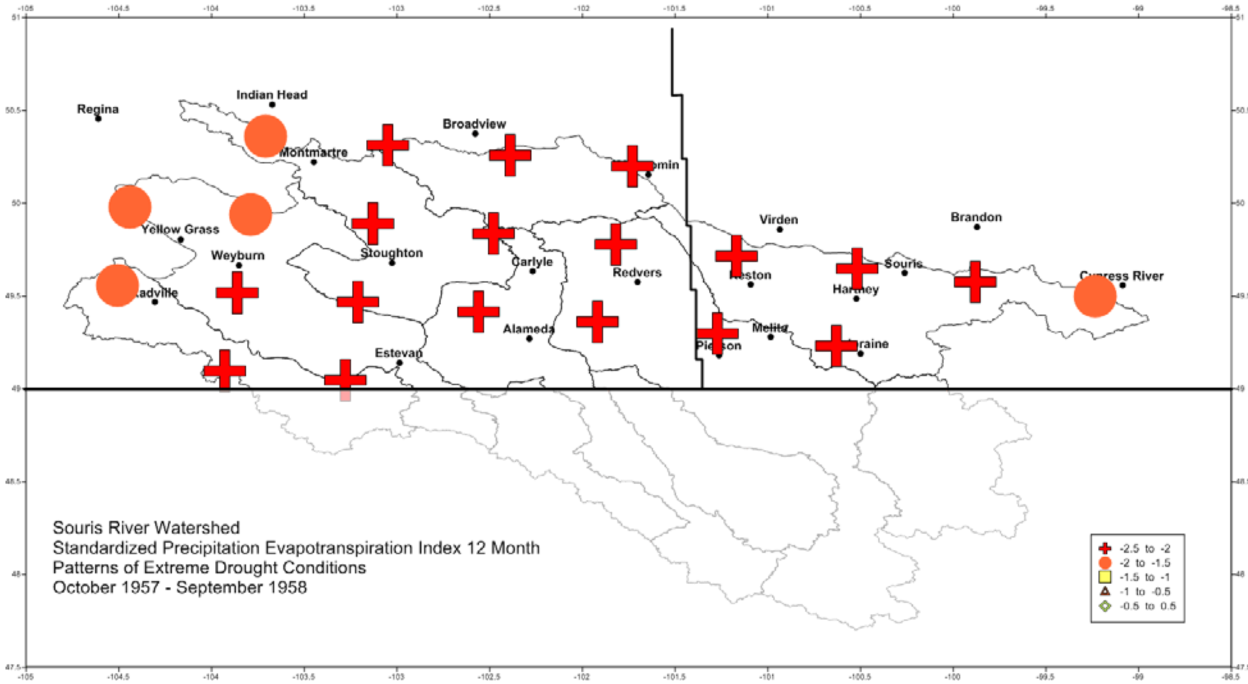

Figure 22 SPEI 12-Month Patterns of Drought Conditions (October 1957-September 1958)

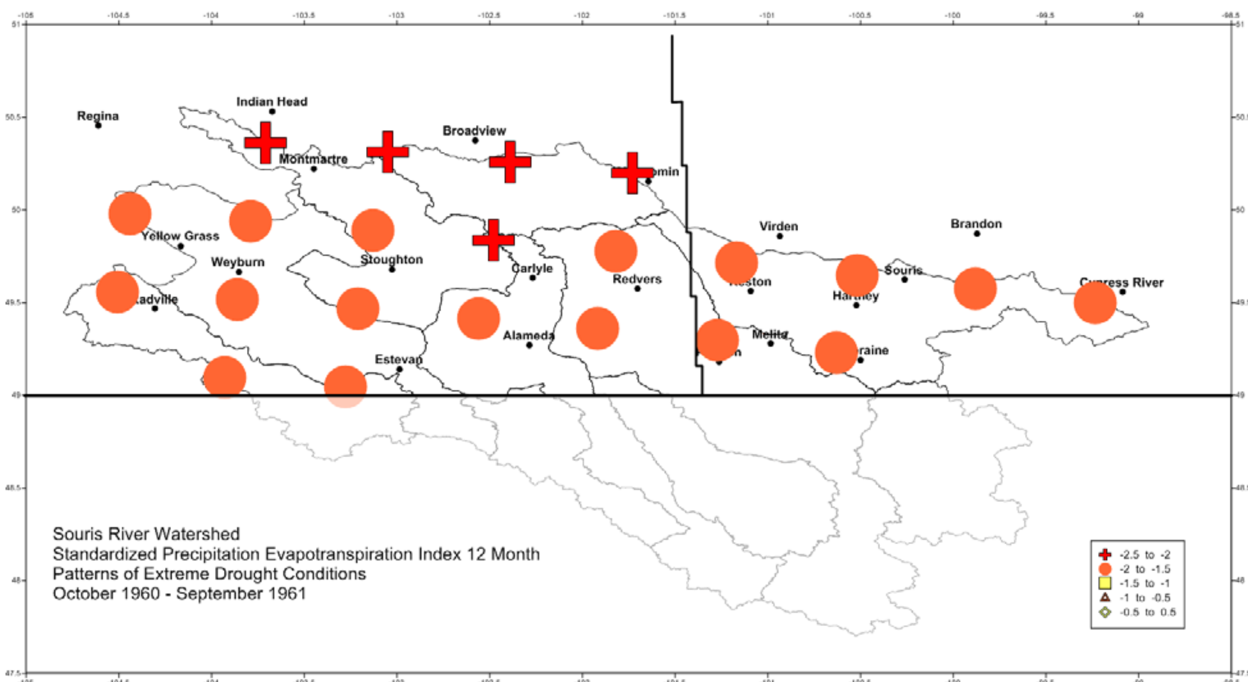

Figure 23 SPEI 12-Month Patterns of Drought Conditions (October 1960-September 1961)

The third and fourth ranked drought years had greater variability across the watershed. 1987-1988 had SPEI values of -2.0 to -2.5 (extreme) on the western and eastern portions but in the central northern portions, the drought conditions were classified as moderate. The 1935-1936 drought year had moderate SPEI values along the western side of the watershed with the eastern portion of SK and most of Manitoba under extreme drought conditions.

The fifth ranked drought year was 1936-1937. The eastern side, encompassing most of Manitoba's portion, was near normal but the majority of Saskatchewan's portion of the Souris River watershed had SPEI values rated as severe to extreme. The sixth ranked year (1983-1984) was the last time in the top ten drought years when a portion of the watershed was categorized as being extreme (northwest corner). The remainder of the watershed was either under severe or moderate drought conditions, based on the SPEI values.

The seventh and eighth ranked drought years of 1928-1929 and 1966-1967 had similar patterns where much of Manitoba's portion of the Souris River watershed was in a severe drought. The Saskatchewan side was in a moderate drought classification. The ninth and tenth ranked drought years (1918-1919 and 2005-2006) were decreasing in severity with larger portions of the watershed being classified as moderate.

Drought and excessive moisture (DEM) conditions using SPEI both spatially and temporally gives an indication of the severity of duration and which region of the watershed was more extreme. The graph (Figure 19) shows the year to year fluctuations over the 1901-2011 hydrologic year. This illustrates that many of the SPEI top ten extreme DEM events (Table 4) occurred in clusters. For example, multiple extreme drought years occurred in the 1930s, late 1950s/early 1960s, and 1980s. Excessive moisture events also happened in clusters such as the 1920s, 1950s, 1970 and the 2010s. This is important because single year events may not have as much impact on society as multi-year events and thus requiring different levels and types of adaptation.

SPEI is emphasized in this document because it has the longest period of record. It also includes important climatic parameters, such as temperature, that other indices do not include e.g., SPI. In order to increase our knowledge of how droughts and excessive moisture events evolve, it is important to keep information current. This knowledge will assist with determining the level of impacts and adaptation required and also track the climate to determine if drought and excessive moisture events are changing in intensity.

Palmer Drought Severity Index

Temporal Patterns

Figure 24 contains the temporal pattern of PDSI for six selected grid locations in the Souris River watershed. The drought and excessive moisture patterns in PDSI are relatively similar to those of the SPEI with a few exceptions.

The selected PDSI grid points demonstrate the differences between the western and eastern regions. For example, while the early 20th century had severe to extreme positive (excessive moisture) PDSI values in the selected grid points in Saskatchewan, mild to extreme negative or drought values occurred for the selected Manitoba grid points. The most exceptionally dry years for the selected Manitoba grid site were in this period with 1910 having a PDSI value of -5.96. In general, a similar pattern exists for PDSI as SPEI with the 1910 generally in drought PDSI conditions, the 1920s in excessive moisture conditions, the 1930s had drought, and the 1940s and most of the 1950s were in excessive moisture conditions.

The latter portion of the 1950s and early 1960s had the lowest PDSI values of the selected grid points with four of the grid points having values less than six. The most exceptional years for the Saskatchewan portion of the watershed were 1958 and 1961 with PDSI values of -6.33 or lower.

The 1970s had in general moderate to severe excessive moisture with the majority of the 1980s being in drought. Both 1988 and 1989 had severe to exceptional droughts throughout the watershed. The 1990s generally had positive PDSI values. Similar to SPEI 2003 had negative PDSI values ranking it in the moderate drought category.

Extreme or exceptional values were found for 25 years in the selected grid points of the Souris River watershed. Extreme or exceptional excessive moisture conditions in one or more grid points were determined for 12 years while extreme to exceptional drought PDSI values occurred in 14 years over the 1901-2004 time span.

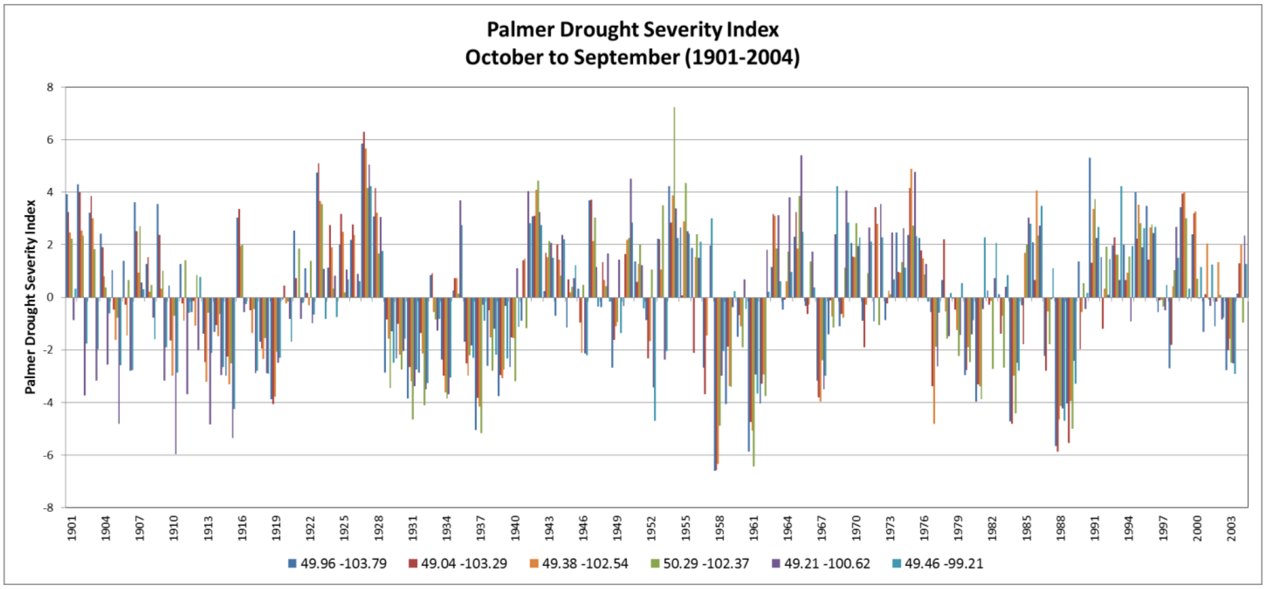

Figure 24 Palmer Drought Severity Index (1901-2004)

Spatial Patterns

This section analyzes the spatial patterns of the most extreme drought and excessive moisture events. As noted previously, in certain years an extreme may occur in one portion of the watershed whereas another part may not have had quite as severe of conditions. The top ten rankings show PDSI values in the Souris River watershed have four hydrologic years of excessive moisture in common with SPEI and five in common with the drought rankings (Table 4 and Appendix 7). Unfortunately, the PDSI dataset ends in 2005 so it does not include the most recent excessive moisture events.

Excessive Moisture

The four excessive moisture years, the PDSI and SPEI have in common are 1923, 1927, 1954 and 1975. 1927 was the most extreme excessive moisture year for both indices. However, they do have slightly different spatial patterns. The PDSI shows levels of extreme exceptional excessive moisture on the western side of the watershed with lower but still classified as exceptional excessive moisture levels on the eastern side. SPEI's most extreme excessive moisture patterns were on the eastern and western sides of the Souris River watershed.

The spatial patterns of the October 1953-September 1954 year between PDSI and SPEI are similar with the northern portion of the watershed having the highest excessive moisture values for both indices. The October 1974-September 1975 also had similar spatial patterns between the PDSI and SPEI with the highest values along the Saskatchewan and Manitoba border and decreasing values along the western and eastern sides of the watershed. The fourth common excessive moisture year was 1922-1923 had a slight variability in spatial patterns between the two indices with PDSI having the highest values in the southwest side of the watershed, whereas the SPEI's highest values were in the northwest portion. Both indices show Manitoba being somewhat less wet in this hydrologic year.

Drought

PDSI and SPEI have five years in common when the ten most extreme drought years are examined (1934, 1958, 1961, 1984, and 1988). The highest ranked drought year of 1957-1958 has some spatial variability in the watershed when the PDSI and SPEI are compared. The Saskatchewan side has higher exceptional drought conditions than the Manitoba (eastern) side. SPEI is more spatially consistent. The remaining common years (1934, 1961, 1984 and 1988) have similar spatial patterns between SPEI and PDSI.

Standardized Precipitation Index

Standardized Precipitation Index (SPI) is a different index compared to SPEI and PDSI because it only utilizes precipitation thus different patterns for SPI exist both spatially and temporally.

Temporal Patterns

SPI illustrates even more variation among the six selected grid cells in the Souris River watershed. The western (Saskatchewan) cells and eastern (Manitoba) portions sometimes showed differences in drought and excessive moisture patterns (Figure 25) as well as more variability in severity among grid cells. Similarities also exist, especially with the anomalous years such as 1958 and 1961 with SPEI values in the exceptional drought range.

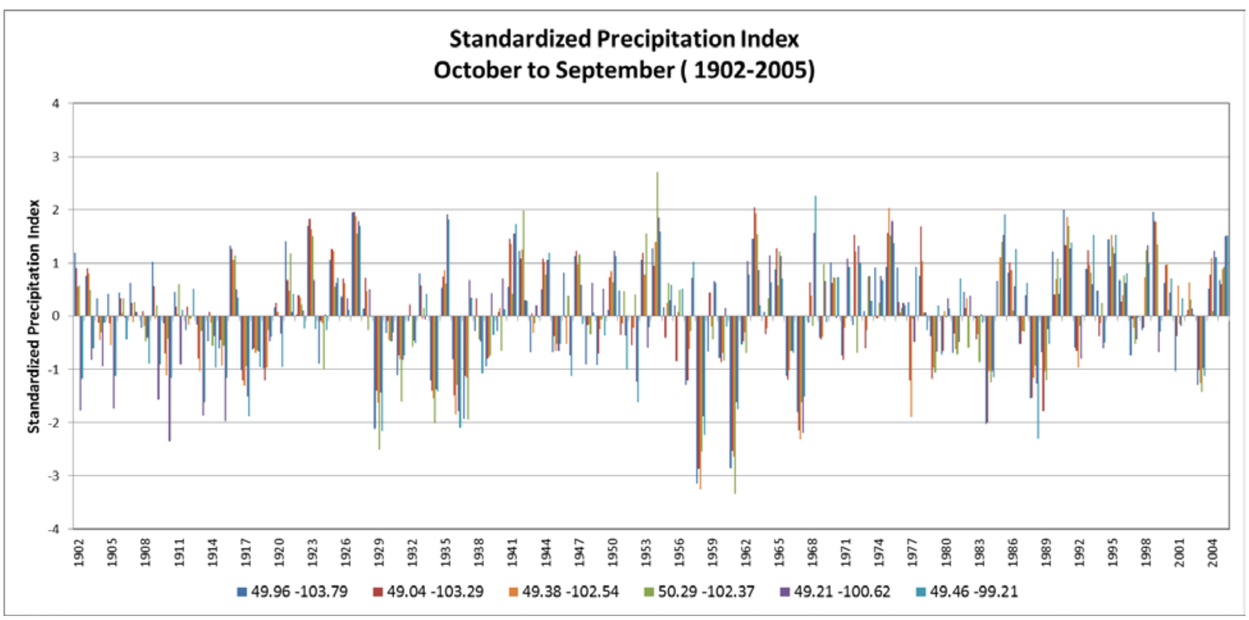

Figure 25 Standardized Precipitation Index (1902-2005)

Spatial Patterns

Excessive Moisture

SPEI utilizes only precipitation data in its calculations. As such, some spatial variability occurs when comparing the three indices. However, SPI does have five excessive moisture years in common with SPEI (1923, 1927, 1954, 1975 and 1999) and six with PDSI (1927, 1954, 1965, 1975, 1991, and 1995) (Table 4; Appendix 8).

The most extreme excessive moisture year of October 1926-September 1927 had a relatively consistent SPI level of excessive moisture throughout the watershed at a "severe" rating. The western and northern sections had higher SPI values resulting in a ranking of "extreme" This hydrologic years was the most extreme excessive moisture year for all three indices (Table 4). The SPEI differed from SPI spatially with the SPEI's western and eastern regions having the higher values. SPI and PDSI have a more similar spatial pattern for this extreme year with the highest values on the west side of the watershed and the lowest excessive moisture values on the east side.

SPI's second most extreme year of 1974-1975 had similar spatial patterns with SPEI and PDSI with the wettest region being in the north central portion. The third year in common with all three indices was 1954. SPI and PDSI had similar spatial patterns with the wettest region being in the north and normal conditions in the southwest, while SPEI was wettest in the northwest and less wet in the east. The fourth common year for all three indices was 1922-1923 with all three having a similar spatial pattern. The western side had the highest values and the eastern side of the watershed the lowest excessive moisture values.

The 1989-1999 hydrologic year was in the top ten most excessive moisture years for SPI and SPEI. They did have spatial differences with the SPI's western side of the watershed having the wettest conditions and the Manitoba portion under near normal conditions. The SPEI's highest excessive moisture values were along the Saskatchewan / Manitoba border.

SPI and PDSI have three years in common. The 1990-1991 hydrologic year had the highest excessive moisture values in the northwest quadrant of the watershed for both indices. The 1994-1995 year had spatial variations. SPI's highest values were in the south central portion along the Saskatchewan / Manitoba border and the eastern side of the watershed with near normal conditions in the southwest, southeast and east central locations. PDSI's highest excessive moisture values were in the west and south central region and the lowest value in Manitoba. The third common year 1964-1965 SPI highest values (1.5-2.0) were in the north central region along the Saskatchewan / Manitoba border and south eastern (Manitoba / USA border). The PDSI had a similar pattern with the highest PDSI values in north central Manitoba.

Drought

SPI has more similar extreme years with SPEI than PDSI when examining the lowest values of the three indices (Table 4; Appendix 8). SPI and SPEI have six common years (1929, 1936, 1958, 1961, 1984 and 1988). SPI and PDSI have five years in common (1934, 1958, 1961, 1984 and 1988).

The most extreme drought year for all three indices was 1958 but there was spatial variability (Appendices 6 to 8). SPI's and PDSI's lowest values were in the south central and northwest portion of Saskatchewan, while SPEI had values that were relatively consistent across the watershed but less severe on the extreme western and eastern sides of the watershed. Three years later, in 1961, the second most extreme SPI event occurred. The SPI and PDSI's lowest values were in the northern Saskatchewan portion of the watershed while the slightly less dry region was in Manitoba. SPEI's driest region was also in the northern Saskatchewan portion but the rest of the watershed was slightly less extreme.

The third drought year all three indices had in common was 1983-1984. SPI's driest area was on the western side of the watershed and normal conditions along the Saskatchewan and Manitoba border. SPEI and PDSI have similar spatial patterns as SPI but unlike SPI, these two indices remained in drought conditions. The fourth common drought year was 1987-1988. SPI's driest regions were on the western and eastern sides of the watershed with normal conditional in the north. SPEI and PDSI had similar patterns as SPI but these two indices remained in drought conditions.

SPI and SPEI had similar spatial patterns in 1967. The driest region was in the south central portion of the watershed and the least dry area ran along the edge of the watershed in moderate drought classifications. SPI and SPEI also had a similar pattern in 1929 when the driest regions of the watershed were in the northern and eastern portions. SPI and SPEI both had the driest portion along the Saskatchewan and Manitoba border in 1936. Slight spatial differences occurred with SPI having normal conditions on the northwest side of the watershed while SPEI had drought categorized along the western side of the watershed.

The only year that PDSI and SPI had a common year without SPEI was 1934. SPI had the driest, or lowest, values in the north central portion of the watershed and normal conditions in the northwestern portion. PDSI was the driest along the Saskatchewan / Manitoba border and less dry but still classified as mild drought on the northwest sid

CASE STUDY – ESTEVAN

The Canadian side of the Souris River watershed has one principal climate station, namely Estevan, that has been in operation continuously from 1945-2014. Estevan was selected for a more detailed examination of the climate, especially the extremes of the region. Estevan's seasonal temperature departures from the 1981-2010 averages indicate a long term increasing temperature trend (Figure 26). Winters have the greatest number of extremes both in being above and below average. Since the mid-1980s, five winters had departures from average greater than 4.0°C (1987, 1992, 1998, 2006 and 2012). Prior to 1980, there were five winters with departures from average below -6.0°C (1949, 1950, 1965, 1978 and 1979) (Figure 26).

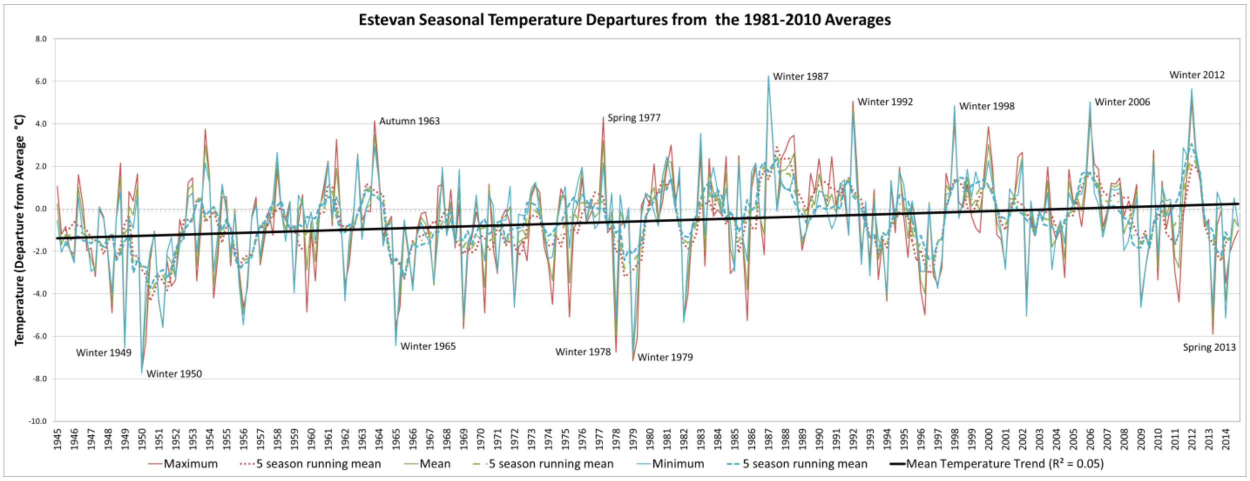

Figure 26 Estevan Seasonal Temperature Departures from Average and 5 Season Running Mean (1945-2014) (Data: Vincent et al. 2012, Environment Canada 2015a)

Estevan averages about 427 mm of precipitation per calendar year based on the 1981-2010 averaging period (Environment Canada 2015b) but this amount is highly variable. For example, in 1961 Estevan received its lowest amount of 279.5 mm while the highest amount recorded was in 1975 with 793 mm. The most recent years with minimal precipitation were 1987 with 365.1 mm and 2001 with 332.7 mm. Recent years have had several near or above average precipitation amounts, with the second highest precipitation year in 2010 (694.1 mm) (Figure 27).

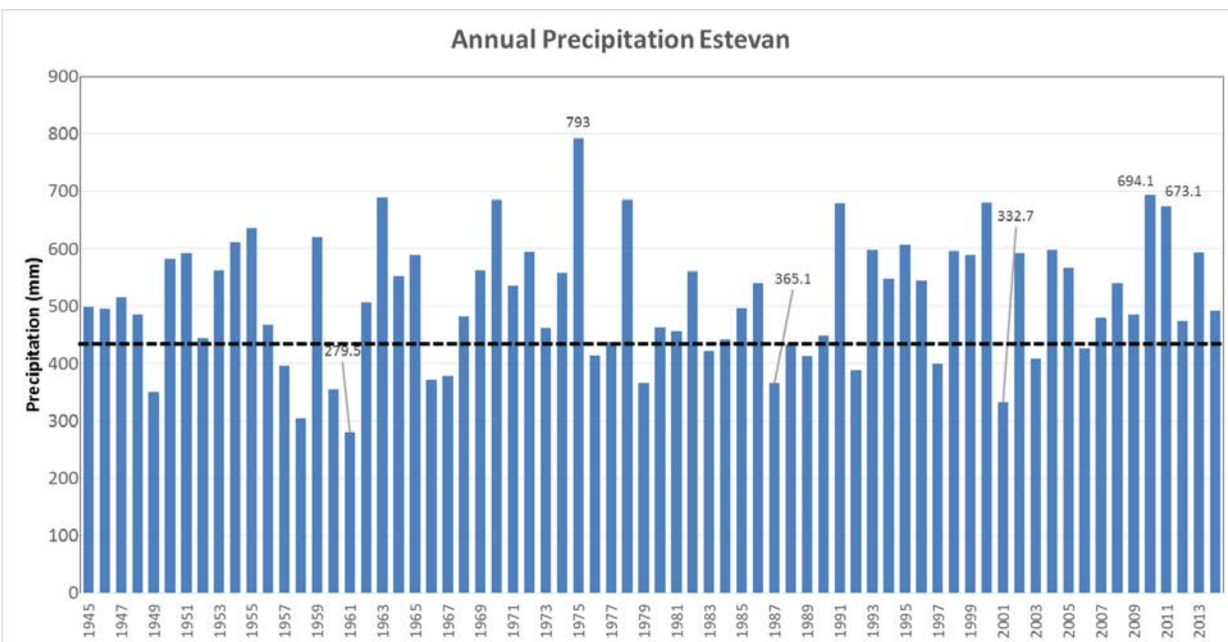

Figure 27 Annual Precipitation at Estevan, SK (1945-2014) (data: Mekis and Vincent 2011 and Environment Canada 2015a&b)

Cumulative high and low precipitation seasons result in extreme water levels. Estevan's climate is an example of the differences in the seasons and of seasons with extended above and below average precipitation amounts (Figure 28). The late 1950s and early 1960s generally had below average precipitation with the fall of 1959 having an extreme exception of above average precipitation.

The rest of the 1960s fluctuated between above and below average precipitation. The early 1970s had a large number of seasons with precipitation amounts greater than 50% above average with a few seasons (e.g., autumn 1974 and autumn 1976) with precipitation amounts more than 75% below average. The 1980s were a relatively dry decade with only the winter of 1989 having precipitation values greater than 50% above average. The 1990s had relatively high amounts of precipitation, particularly the winter of 1994. The next extended dry period occurred in 2001 and 2002 with five consecutive months having below average precipitation. The rest of the 2000s had seasonal fluctuations between precipitation amounts more than 50% above normal to 40 to 50% below normal. Above average precipitation started in the spring of 2010 and continued through to the summer of 2011 with the most recent seasons, from fall of 2011 to fall of 2014, fluctuating between below and above average precipitation levels. The spring of 2011, between May 20 and June 21, had five rain events ranging from one day to multiple days with totals from 49.4 mm to 95.8 mm with an overall total of 322 mm over that 32 day period.

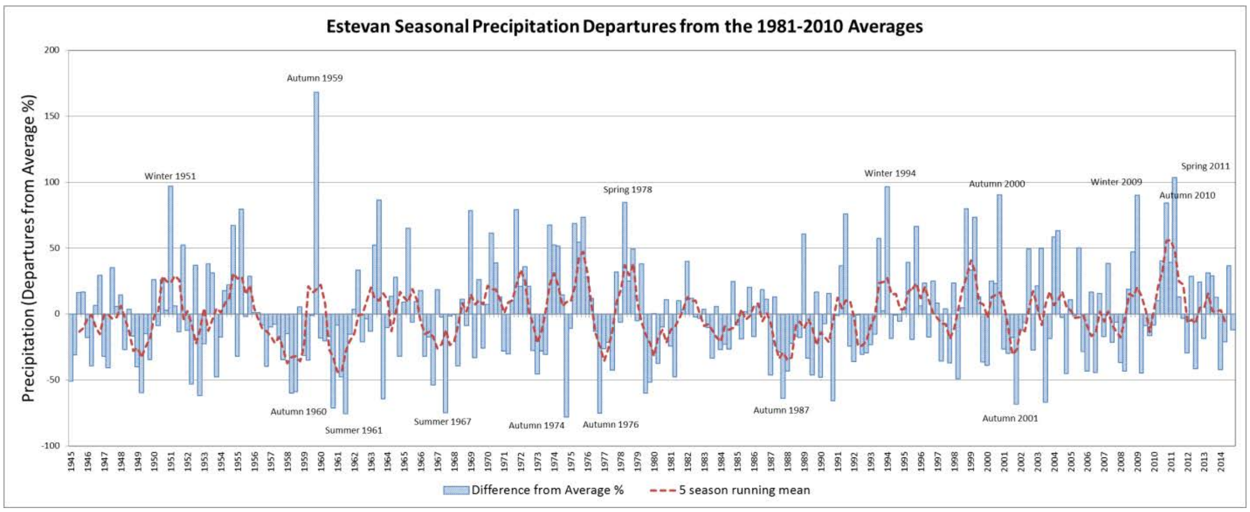

Figure 28 Estevan Seasonal Precipitation Departures from Average and 5 Season Running Mean (1945-2014) (data (Mekis and Vincent 2011 and Environment Canada 2015a)

The seasonal comparison of excessive moisture events shows 2011 has six continuous seasons with above average precipitation. Other high precipitation consecutive seasons of 1954-1955 had three, and 1975-1976 had five consecutive seasons of above normal precipitation (Figure 28).

Annual PDI for July (2009-2015) and June (2013) illustrate how the climatic conditions evolved in the Souris River watershed (Figure 29 and 30). July 2009 had normal PDI conditions in the Estevan region while farther towards the east PDI values ranged from 1 to 2. By July 2010, the PDI values had increased in Estevan area to 1 to 2 but the eastern edge of the watershed in Manitoba was as high as 3.99. July 2011 PDI values were above 5 in most of the watershed corresponding to the seasonal precipitation departures (Figure 17). PDI values had dropped a little by July 2012 in the Estevan region to the 2 to 4 range, while the eastern side of the watershed was back to neutral or mild drought levels. June 2013 PDI values show the Estevan region again in PDI range of at least 5 with the rest of the watershed in the 2 to 3 range. These high PDI values continued into 2014 but the most extreme highs were on the Manitoba side of the watershed. July 2015 PDI values were in the neutral zone for the Estevan region while the Manitoba portion of the watershed was neutral to 2.99.

The spring rainfall events in the Souris River watershed have been investigated by Hopkinson (2011, 2014). He found that in 2011 between the April and June period, many parts of the Souris River watershed were at or above the 200% of normal and were near historic values. In addition, one day total rainfalls were close to 90 mm in some locations (Hopkinson 2011). The June 28-30, 2014 rainstorm resulted in precipitation totals for the month in excess of 200 to over 300% of normal (Hopkinson 2014). The spatial coverage of the rainfall and the April –June period above average precipitation levels resulted in flooding in the region (Hopkinson 2014).

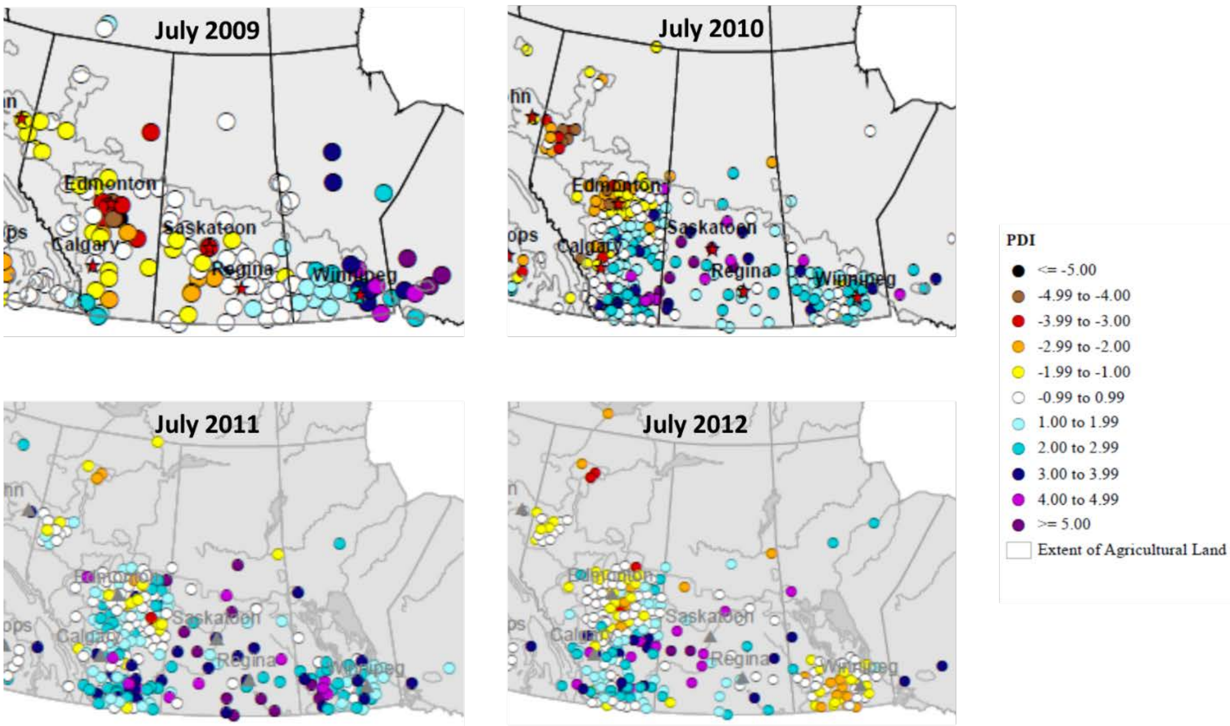

Figure 29 Annual July PDI (2009-2012) for Prairie Provinces (modified from AAFC 2015a)

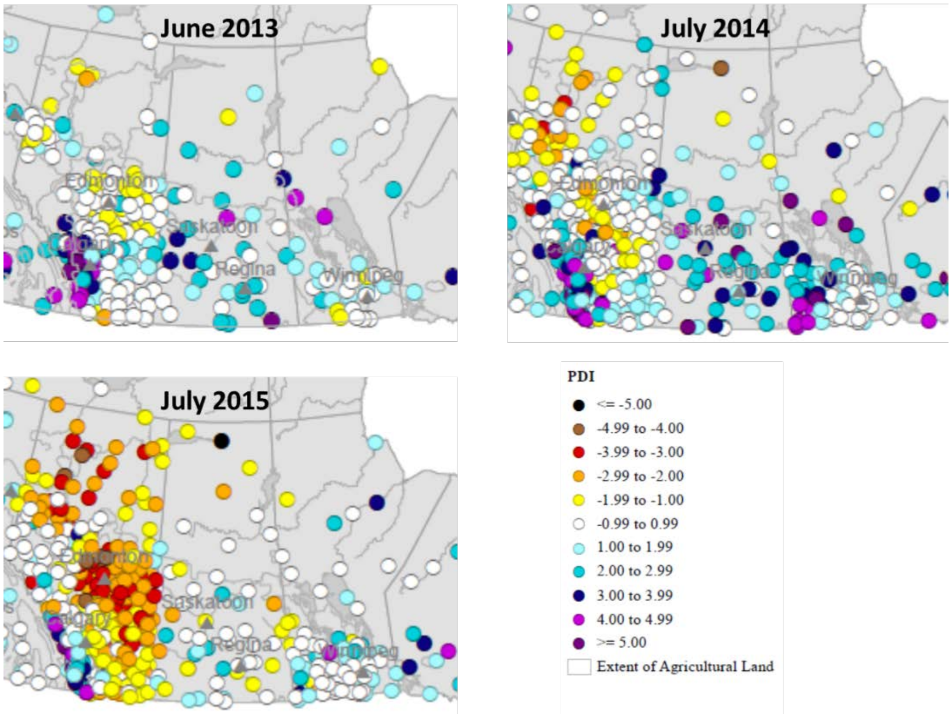

Figure 30 Annual June 2013 and July 2014, 2015 PDI for Prairie Provinces (modified from AAFC 2015a)

CONCLUSIONS AND RECOMMENDATIONS

Determining climatic trends of the past provides information to assist with risk management strategies of communities, government, and various industries including the electrical generation and oil and gas sectors. Understanding the historic climatic variability and extremes will assist with adaptive risk management strategies of many sectors including the electrical generation and oil and gas sectors. This report illustrates the extreme drought and excessive moisture events in the Souris River watershed for the 20th and early 21st centuries.

Temperature and precipitation highlights of the Souris River watershed are:

- Average annual temperatures in the watershed have increased at a statistically significant level (95%). For example, Estevan’s average annual temperature has increased by over 2°C since 1902 and approximately 1.5°C since 1950.
- Winter’s minimum and maximum temperatures are increasing at a statistically significant rate with the minimum temperatures increasing more than the winter maximum temperatures.
- Spring maximum and minimum temperatures are increasing but are not statistically significant.
- Summer average temperatures are increasing with the minimum temperatures increasing at a statistically significant rate.
- Autumn temperatures are increasing with the minimum temperatures increasing at a statistically significant rate.
- Precipitation is highly variable on a yearly, seasonal and daily basis.

- Four periods of high precipitation amounts occurring in the 1950s, 1970s, 1990s and the 2010s
- Three low precipitation periods occurred in the 1930s, late 1950s/early1960s and the 1980s. The early 2000s also had low precipitation levels.
- The highest annual precipitation year was in 2011 with average to higher than average precipitation continuing into 2014.

SPEI is the index emphasized because it has the longest period of record. SPEI shows the year to year fluctuations over the 1901-2011 hydrologic year however many of the DEM events occurred in clusters. For example, multiple extreme drought years occurred in the 1930s, late 1950s/early 1960s, and 1980s. Excessive moisture events also happened in clusters such as the 1920s, 1950s, 1970 and the 2010s. This is important because single year events may not have as much impact on society as multi-year events and thus requiring different levels and types of adaptation.

In order to increase our knowledge of how droughts and excessive moisture events evolve, it is important to keep information current and therefore is a recommendation that the SPEI and the other two indices be updated to include the most recent climatic variables. This knowledge will assist with determining the level of impacts and adaptation required and also track the climate to determine if drought and excessive moisture events are changing in intensity.

The changing climatic conditions have an impact on hydrologic and societal conditions. For example, climatological droughts lead to hydrologic droughts which can influence how society and industry operate, especially if the event lasts for an extended period.

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APPENDICES

APPENDIX 1
PERIODS OF RECORD FOR SELECTED CLIMATE STATIONS

Station	**Temperature**		**Precipitation**	
	Years	Years missing	Year	Missing data years
Estevan	1903-2014	1917-1922, 1925-1944, 1949	1902-2014	1902, 1906, 1907, 1912, 1915, 1917-1944
Moosomin	1942-1994	1945-1947, 1951, 1953, 1957, 1962-1967	1900-2000	1900, 1902, 1903-1945, 1947-1949, 1951, 1961-1967, 1998-2000
Yellow Grass	1914-2014	1916, 1917, 1919, 1920, 1924, 1926, 1927, 1930, 1932, 1935, 1937, 1943, 1947, 1950, 1952, 1955, 1973, 1977, 1978, 1982, 1985-1989, 1992, 2007, 2008	1912-2014	1912, 1921, 1924, 1926, 1928, 1930, 1932, 1950, 1952, 1953, 1955, 1982, 1989, 1990, 1992, 2007, 2008
Pierson	1934-2006	1941-1945, 1951, 1964, 1984	1933-2007	1933, 1934, 1941-1945, 1952-1954, 1974, 1984, 2007
Kenmare	1933-2013	1944-1948, 1976, 1978, 2012	1932-2014	1932, 1944-1948, 1973-1978, 1990, 2002, 2007
Minot Experimental Station	1906-2014	1928, 1984, 2001, 2002	1905-2014	1905, 1927, 1984, 2001, 2002
Bottineau	1906-2014	1943, 1968, 1984	1893-2014	1893-1905, 1968, 1984, 2003
Indian Head	1891-2014	1908, 1995, 1996	1895-2014	1895, 1899, 1901, 1906, 1910, 1912, 1924, 1926, 1943, 1995, 1996, 2007-2012
Regina	1898-2014	1899, 1900	1898-2014	1899-1900, 1903, 2007-2012
Broadview	1966-2014	1995-2001	1965-2014	1965, 1994-2001
Brandon	1890-2014	1894, 1924, 2007-2013	1890-2014	1894, 1900, 1902, 1906, 1912, 1914, 1916, 1924, 1931, 2012
Cypress River	1951-2014	1955, 1960, 1963, 1969	1948-2014	1948-1954,1959-1964, 1968-1969, 1971,2007-2008, 2010

APPENDIX 2
TRENDS OF AVERGE TEMPERATURES OF SELECTED CLIMATE STATIONS

Annual Average Temperature Departures from the 1981-2010 Average

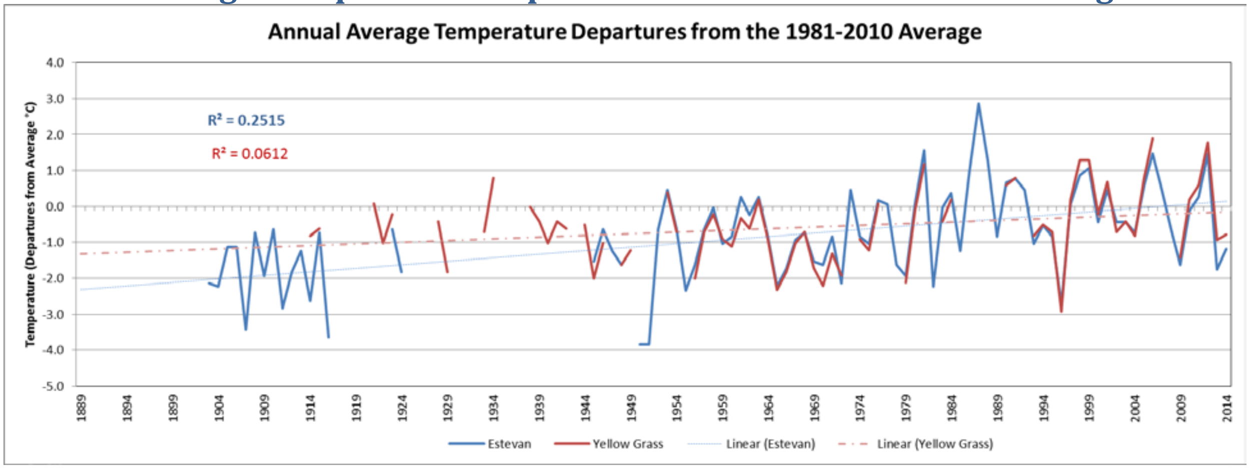


Figure 31 Estevan and Yellow Grass Annual Average Temperature Departures from the 1981-2010 Average

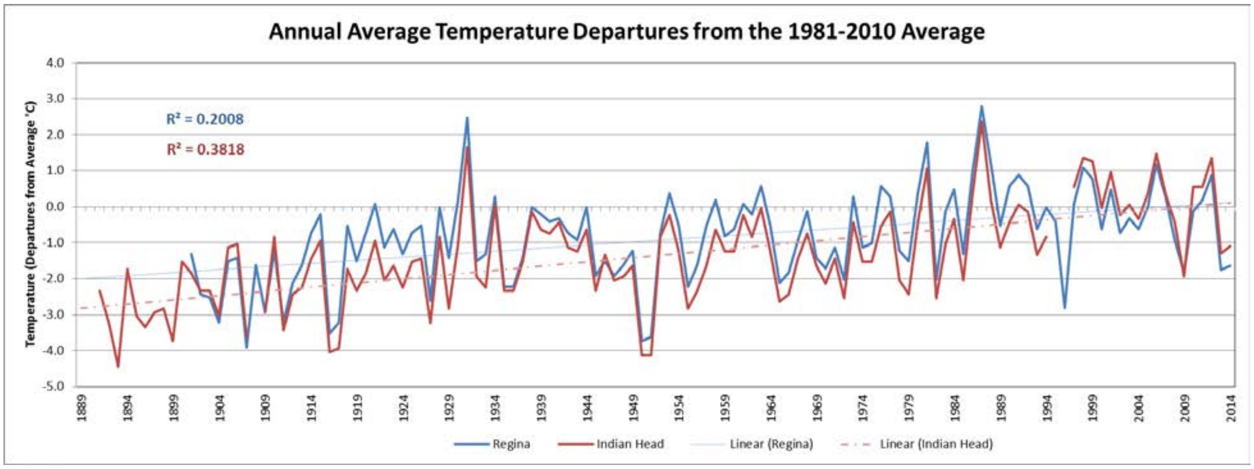


Figure 32 Regina and Indian Head Annual Average Temperature Departures from the 1981-2010 Average

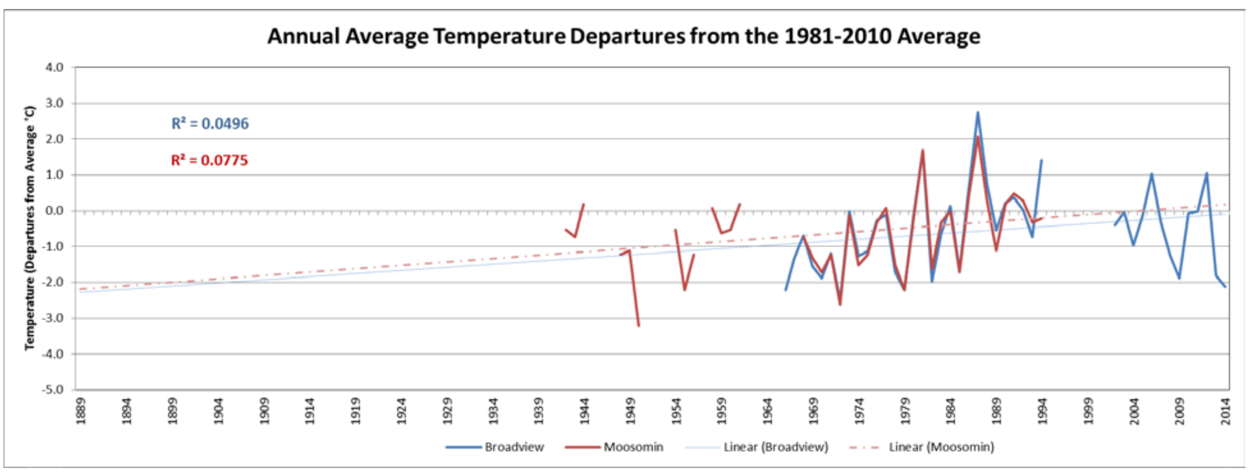


Figure 33 Broadview and Moosomin Annual Average Temperature Departures from the 1981-2010 Average

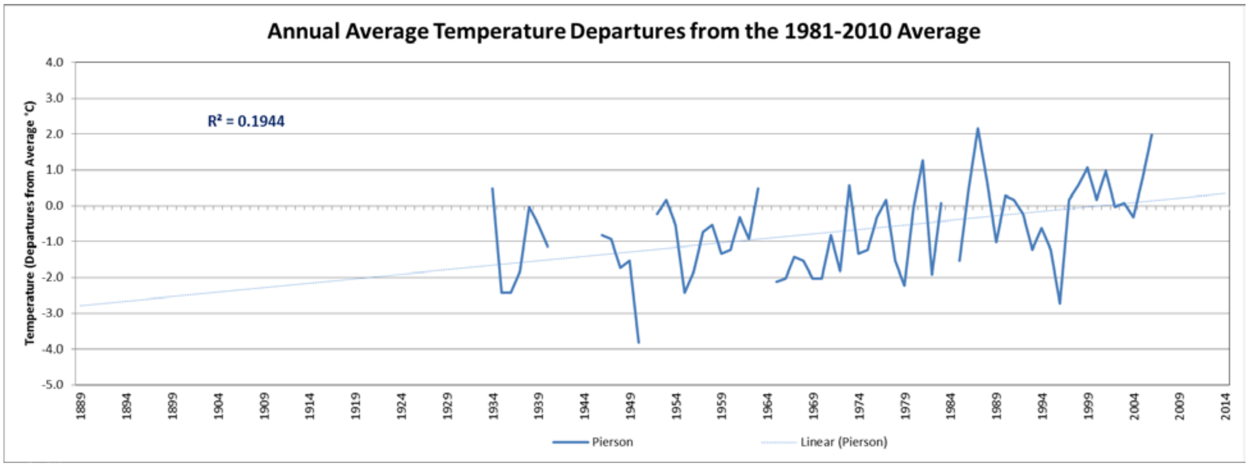


Figure 34 Pierson Annual Average Temperature Departures from the 1981-2010 Average

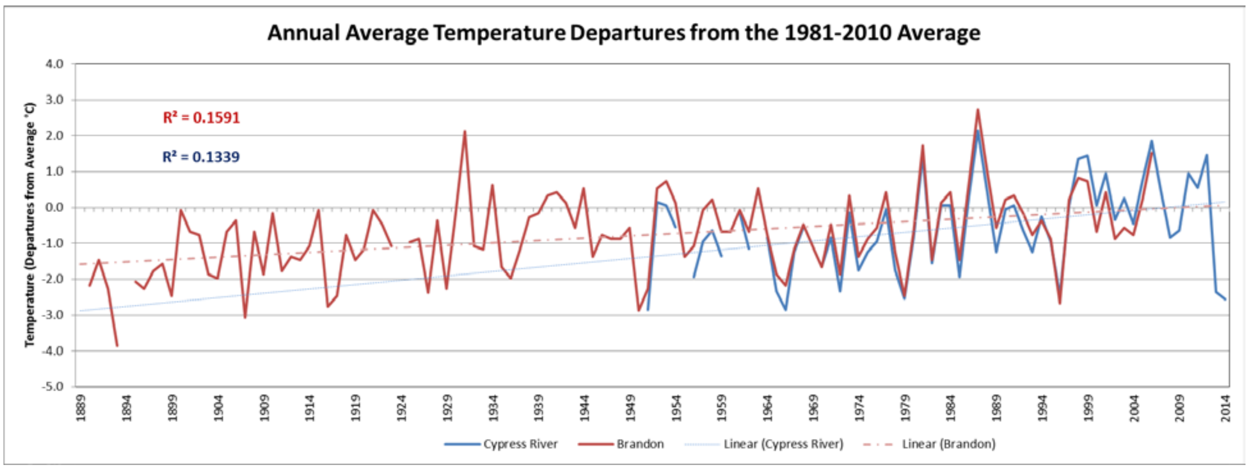


Figure 35 Cypress River and Brandon Annual Average Temperature Departures from the 1981-2010 Average

Winter Average Temperature Departures from the 1981-2010 Average

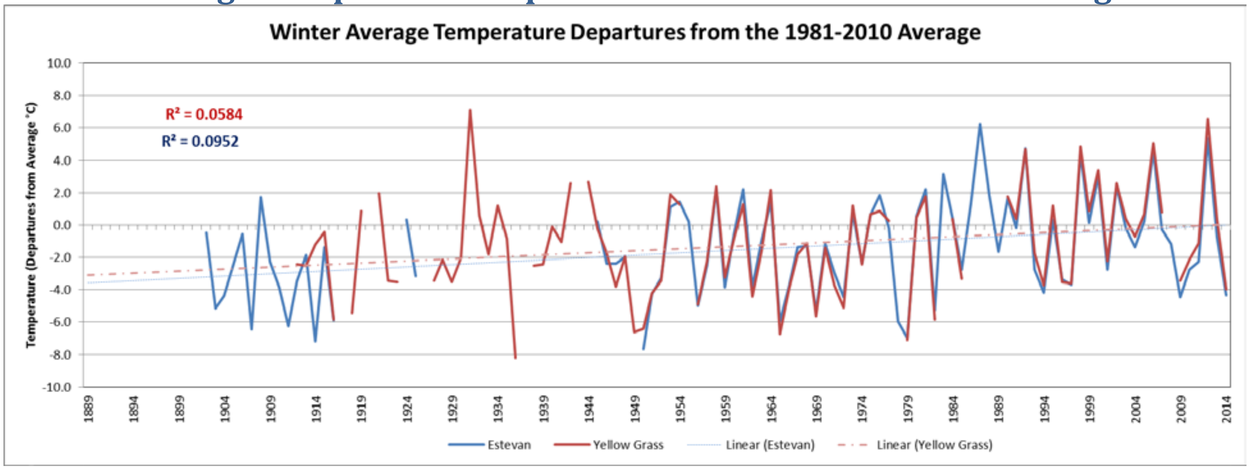


Figure 36 Estevan and Yellow Grass Winter Average Temperature Departures from the 1981-2010 Average

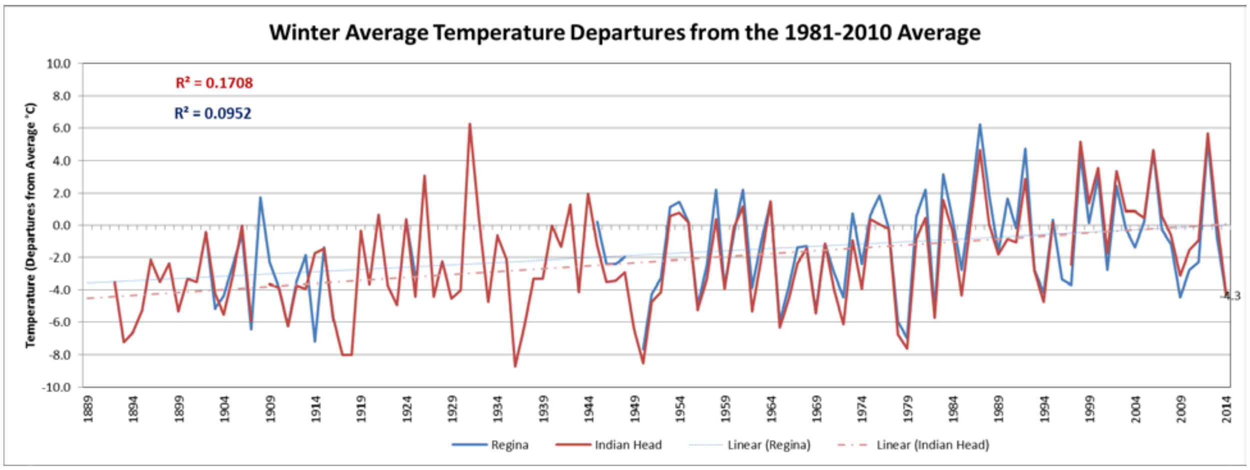


Figure 37 Regina and Indian Head Winter Average Temperature Departures from the 1981-2010 Average

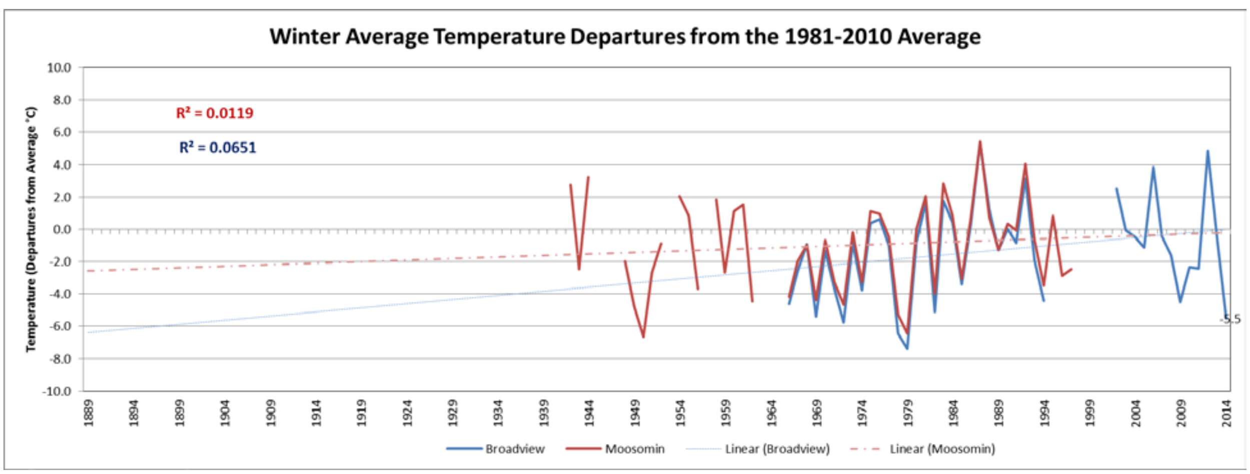


Figure 38 Broadview and Moosomin Winter Average Temperature Departures from the 1981-2010 Average

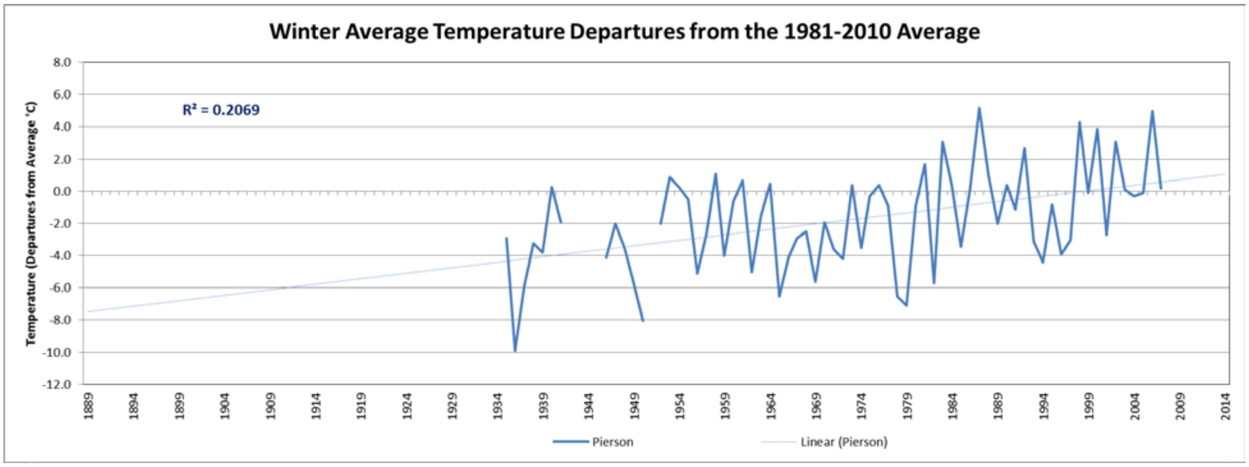


Figure 39 Pierson Winter Average Temperature Departures from the 1981-2010 Average

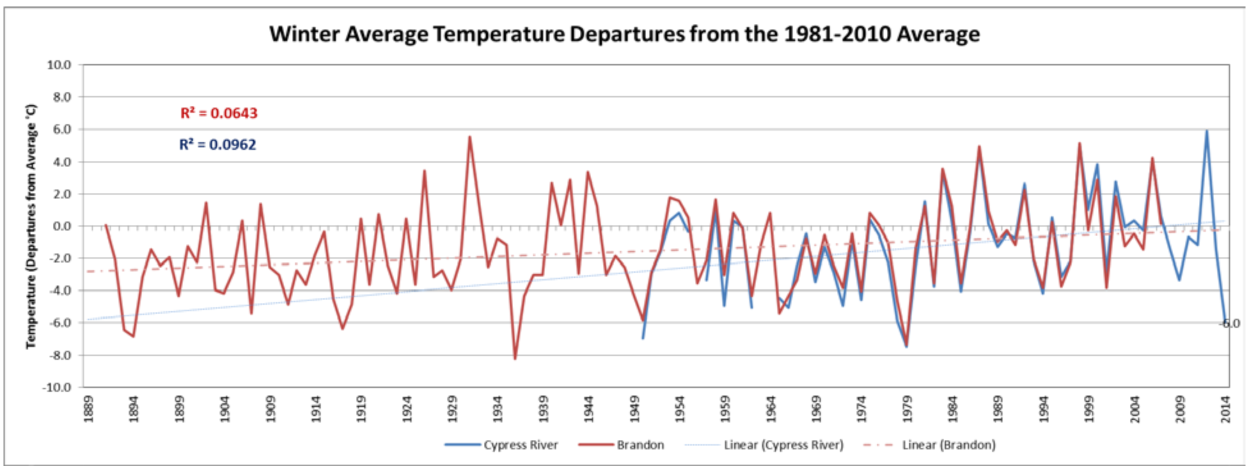


Figure 40 Cypress River and Brandon Winter Average Temperature Departures from the 1981-2010 Average

Spring Average Temperature Departures from the 1981-2010 Average

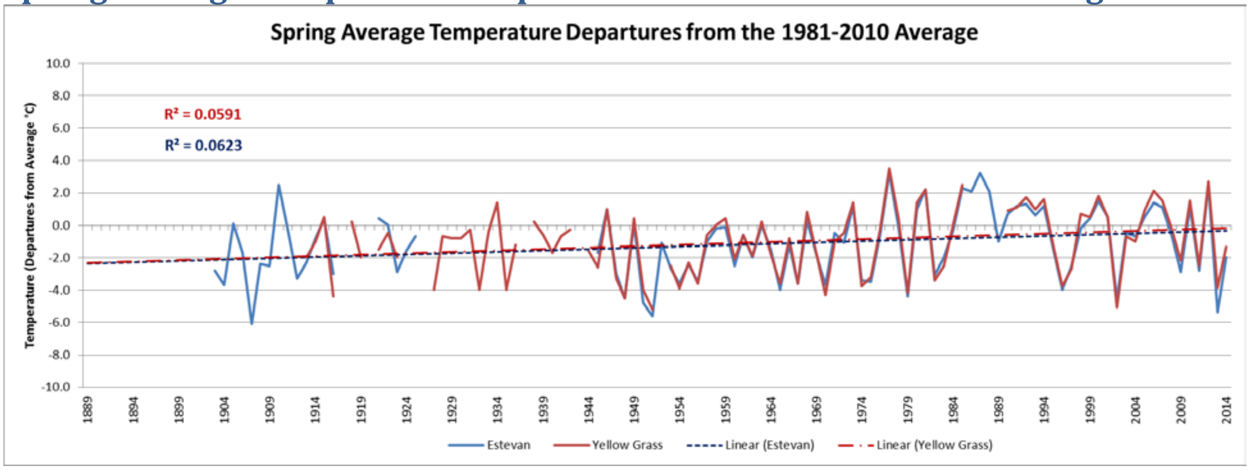


Figure 41 Estevan and Yellow Grass Spring Average Temperature Departures from the 1981-2010 Average

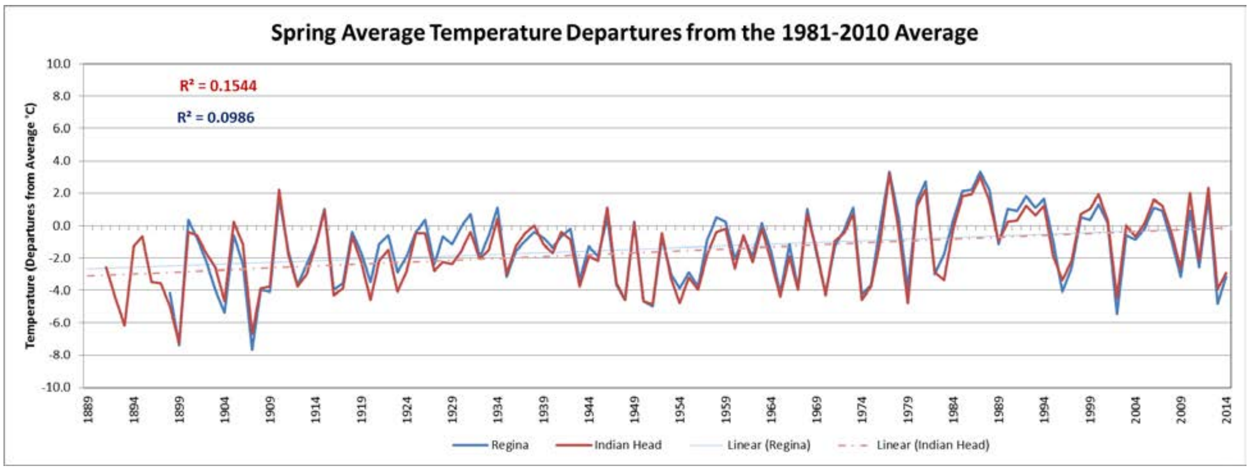


Figure 42 Regina and Indian Head Spring Average Temperature Departures from the 1981-2010 Average

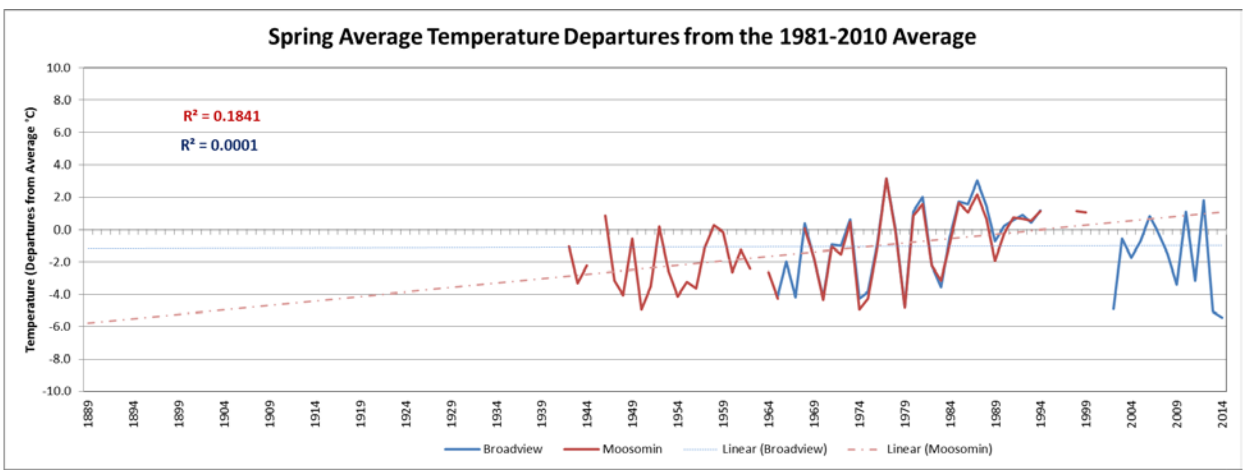


Figure 43 Broadview and Moosomin Spring Average Temperature Departures from the 1981-2010 Average

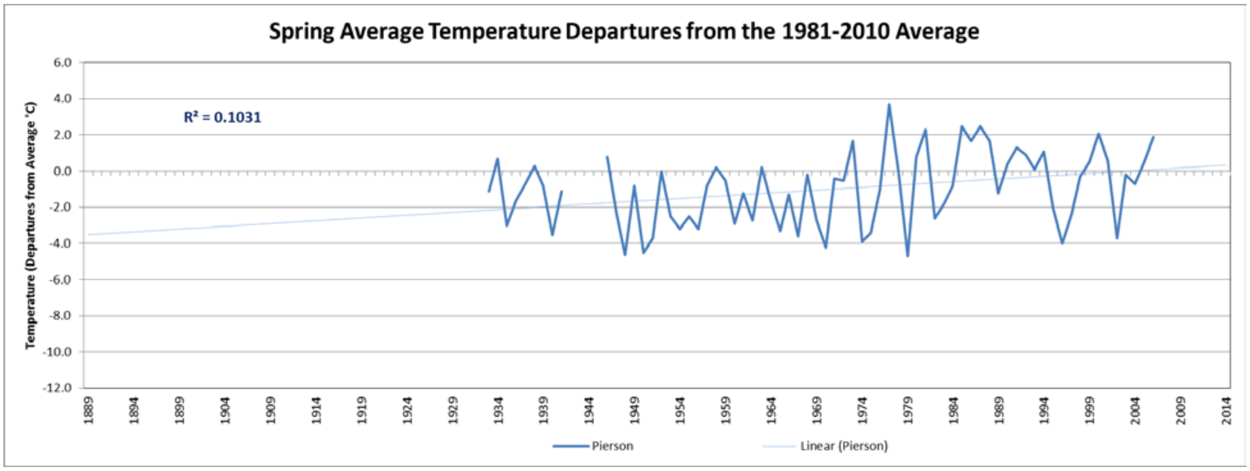


Figure 44 Pierson Spring Average Temperature Departures from the 1981-2010 Average

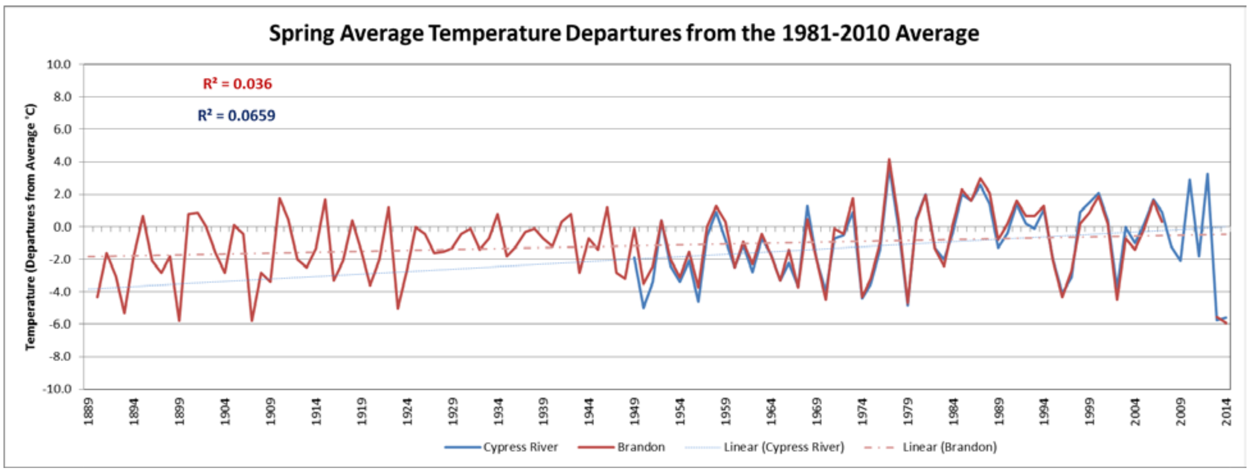


Figure 45 Cypress River and Brandon Spring Average Temperature Departures from the 1981-2010 Average

Summer Average Temperature Departures from the 1981-2010 Average

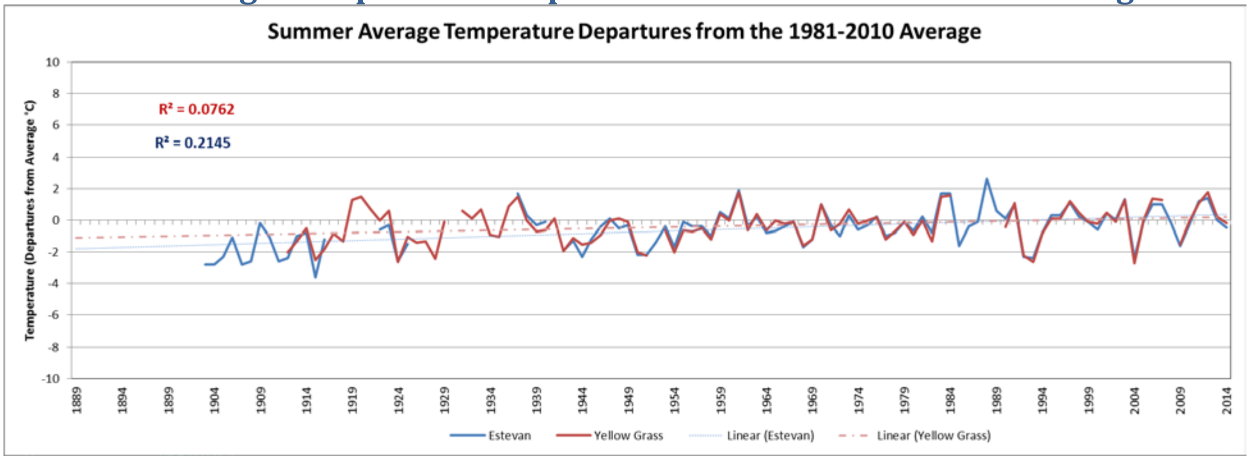


Figure 46 Estevan and Yellow Grass Summer Average Temperature Departures from the 1981-2010 Average

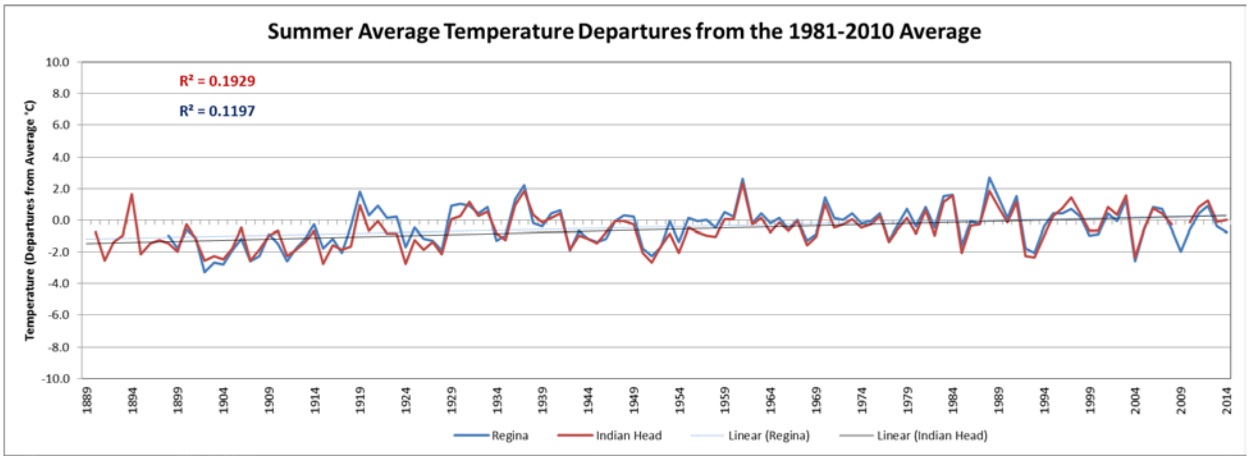


Figure 47 Regina and Indian Head Summer Average Temperature Departures from the 1981-2010 Average

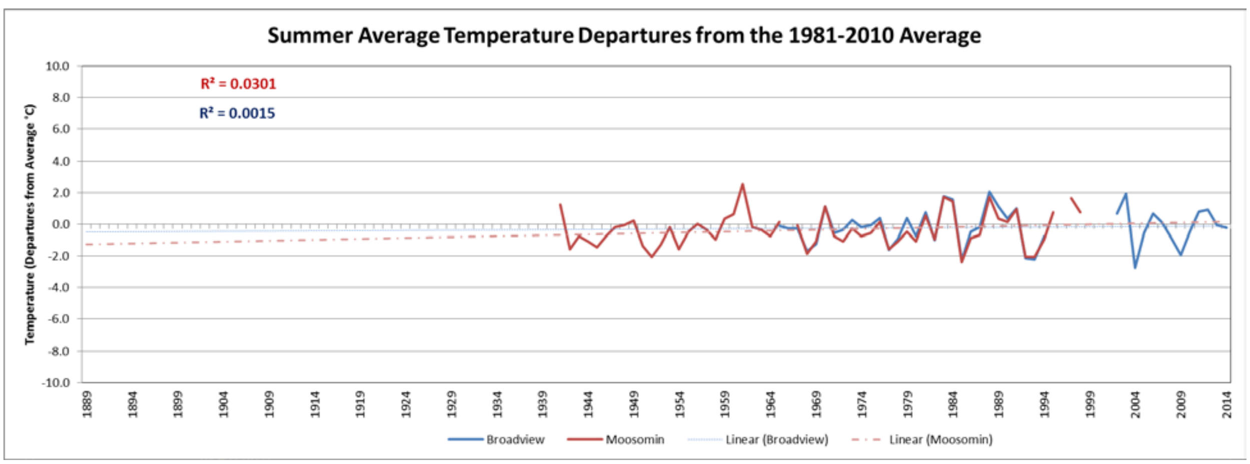


Figure 48 Broadview and Moosomin Summer Average Temperature Departures from the 1981-2010 Average

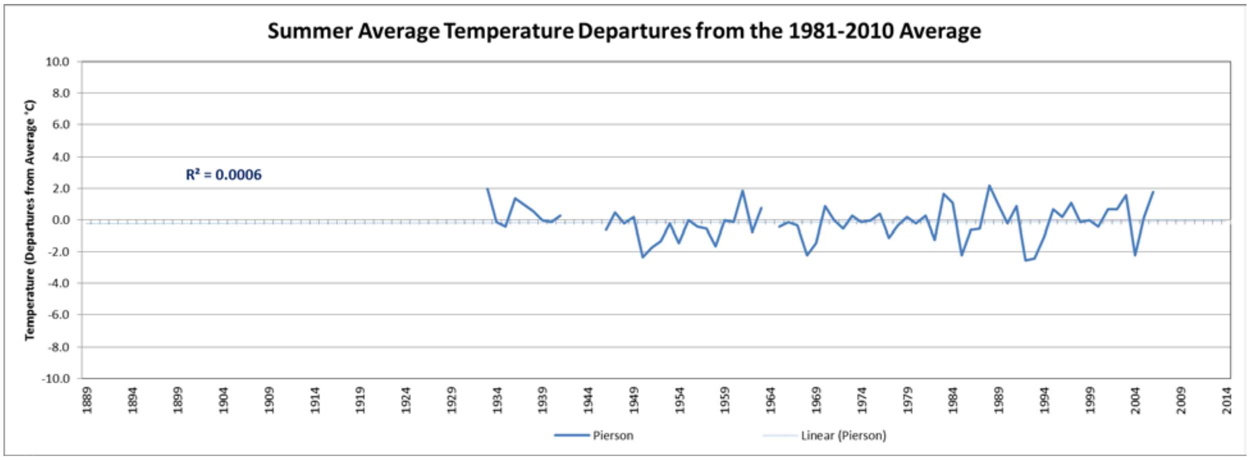


Figure 49 Pierson Summer Average Temperature Departures from the 1981-2010 Average

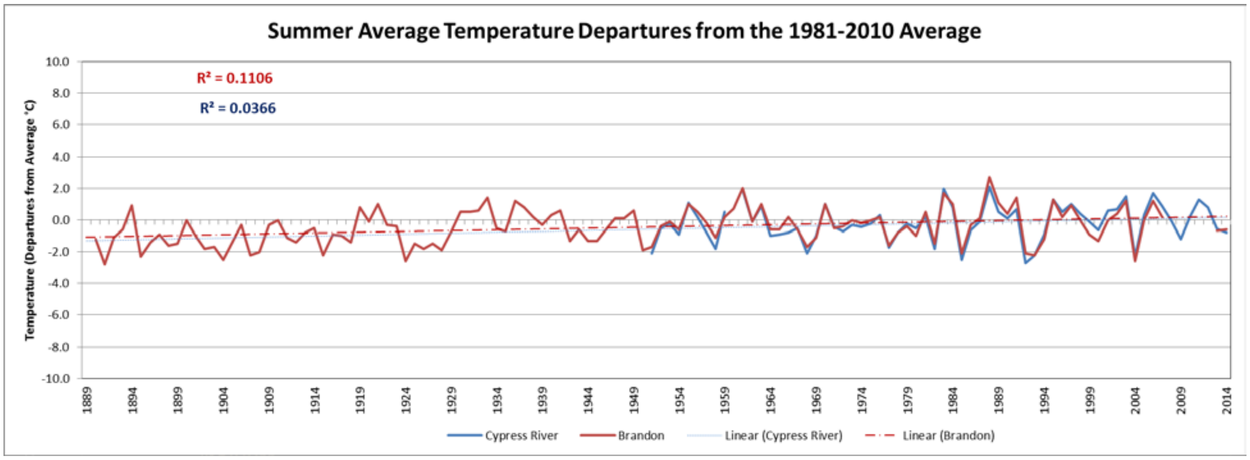


Figure 50 Cypress River and Brandon Summer Average Temperature Departures from the 1981-2010 Average

Autumn Average Temperature Departures from the 1981-2010 Average

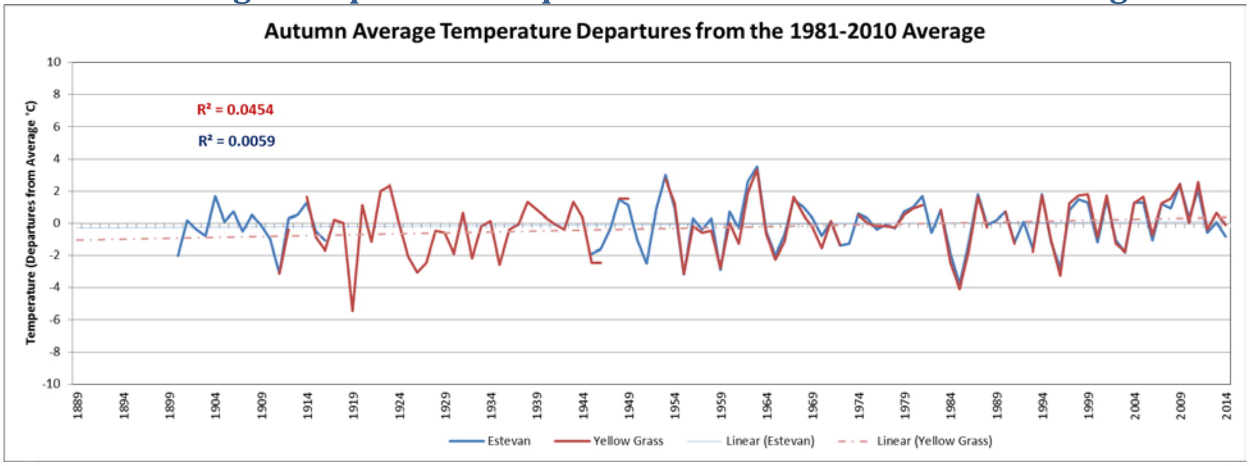


Figure 51 Estevan and Yellow Grass Autumn Average Temperature Departures from the 1981-2010 Average

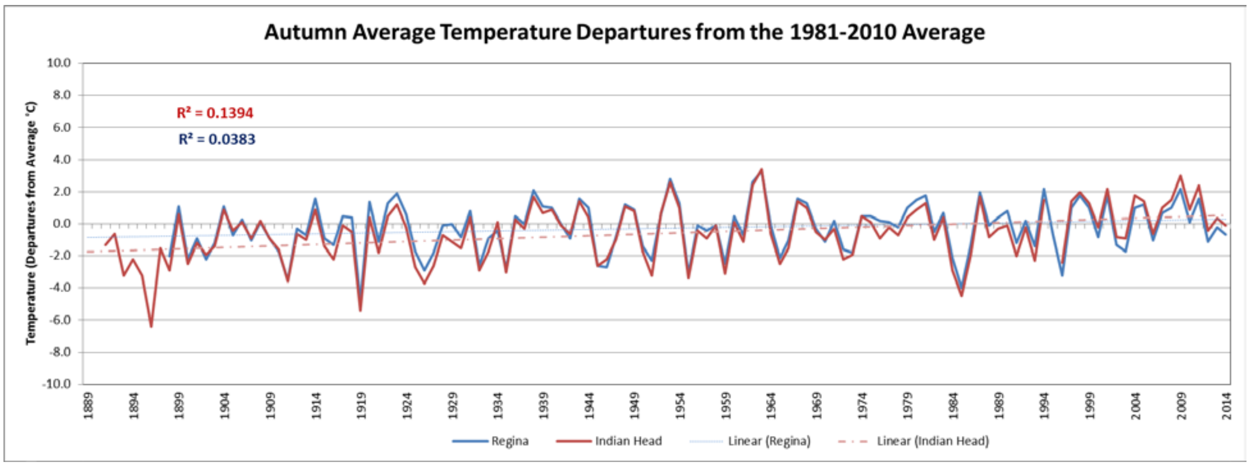


Figure 52 Regina and Indian Head Autumn Average Temperature Departures from the 1981-2010 Average

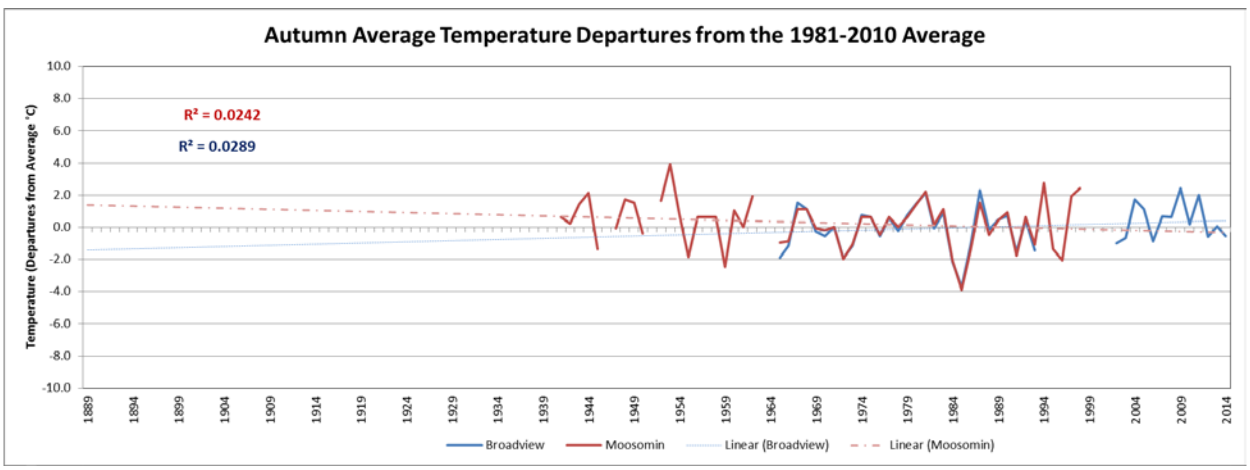


Figure 53 Broadview and Moosomin Autumn Average Temperature Departures from the 1981-2010 Average

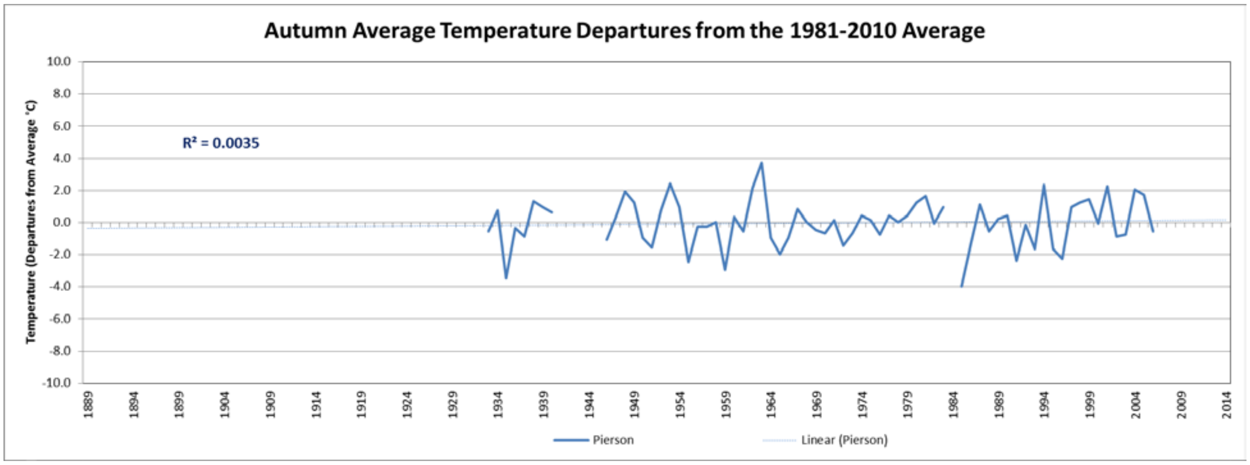


Figure 54 Pierson Autumn Average Temperature Departures from the 1981-2010 Average

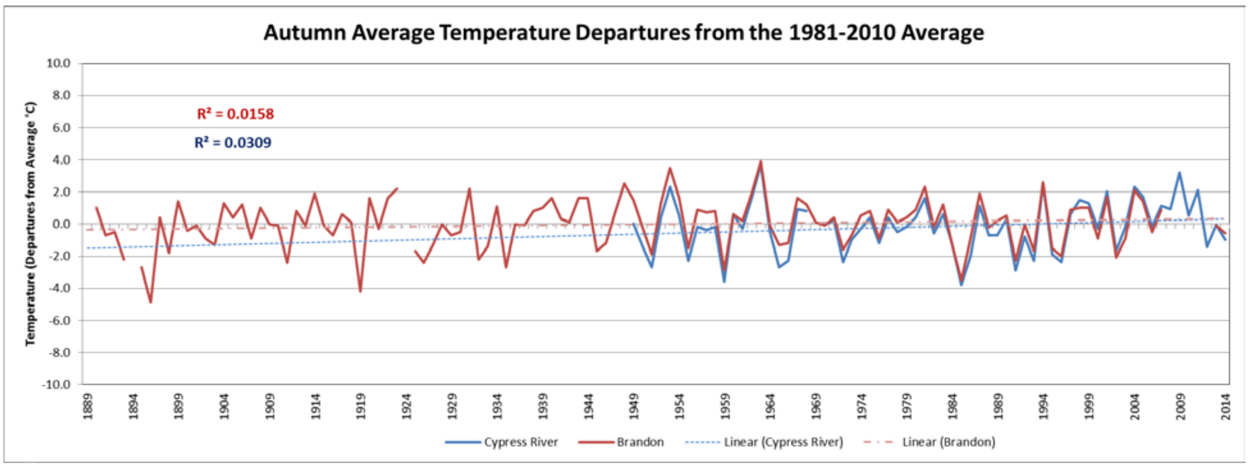


Figure 55 Cypress River and Brandon Autumn Average Temperature Departures from the 1981-2010 Average

APPENDIX 3
TRENDS OF MEAN MAXIMUM TEMPERATURE OF SELECTED CLIMATE STATIONS

Annual Maximum Temperature Departures from the 1981-2010 Average

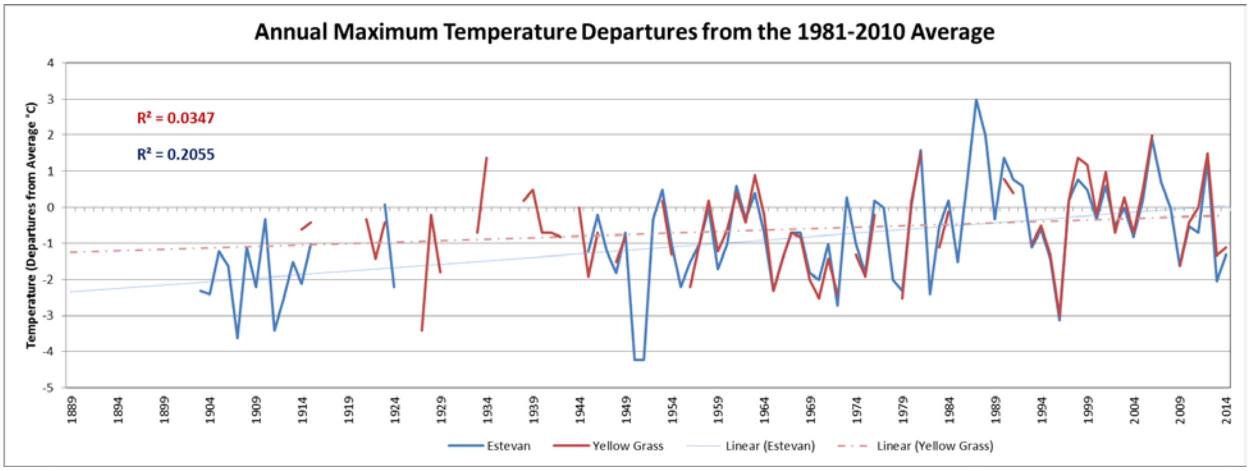


Figure 56 Estevan and Yellow Grass Annual Maximum Temperature Departures from Average

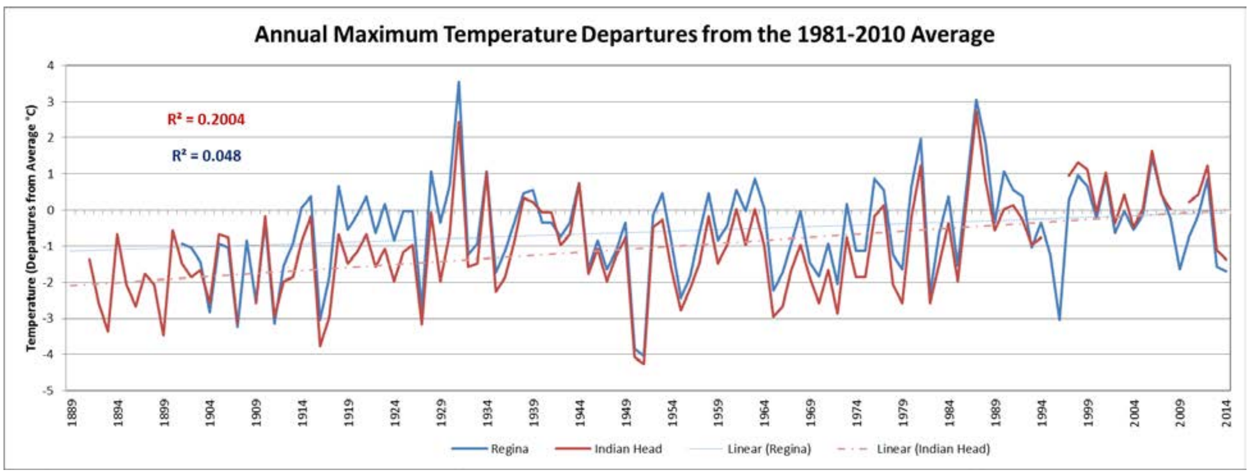


Figure 57 Regina and Indian Head Annual Maximum Temperature Departures from Average

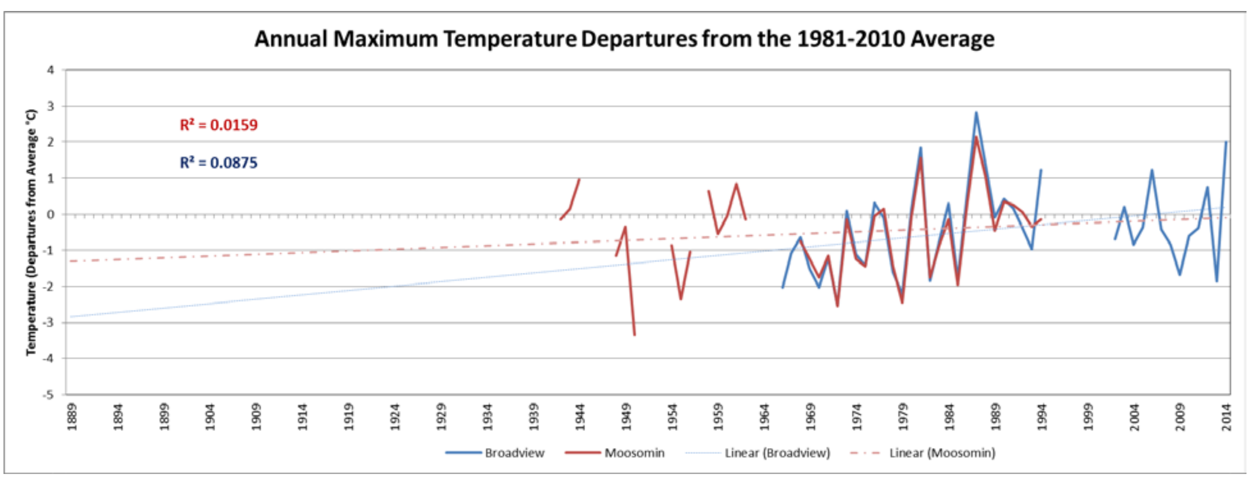


Figure 58 Broadview and Moosomin Annual Maximum Temperature Departures from Average

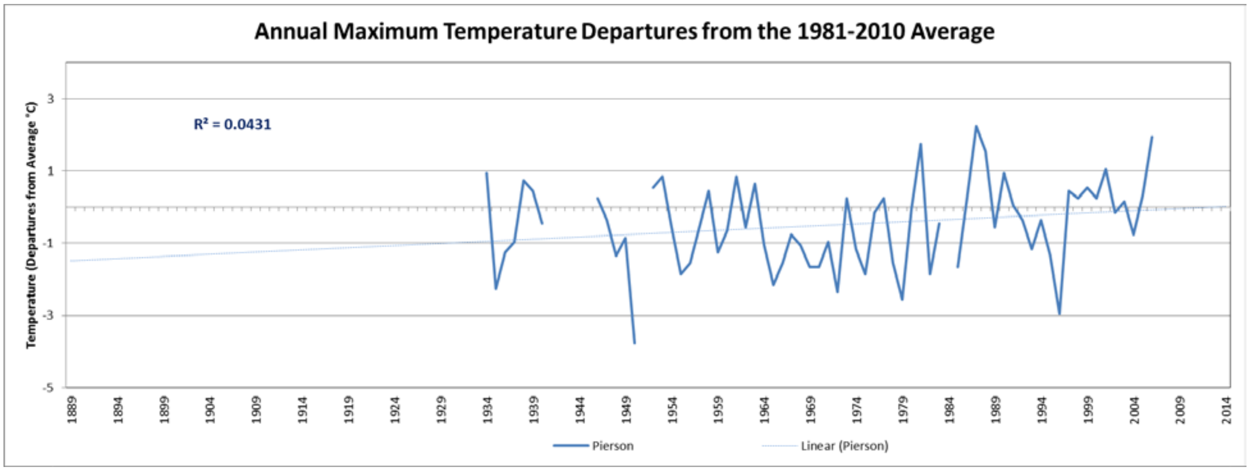


Figure 59 Pierson Annual Maximum Temperature Departures from Average

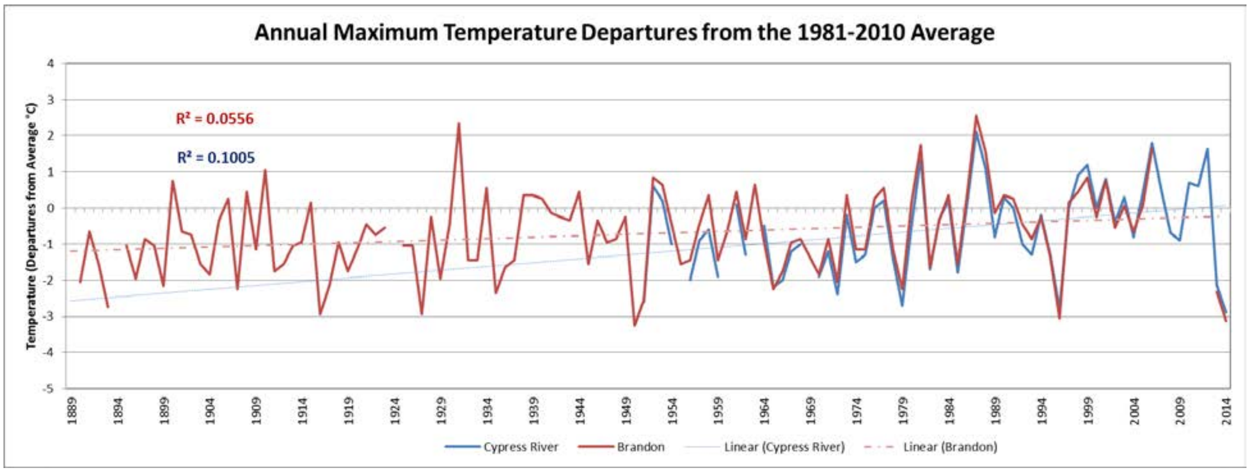


Figure 60 Cypress River and Brandon Annual Maximum Temperature Departures from Average

Winter Maximum Temperature Departures from the 1981-2010 Average

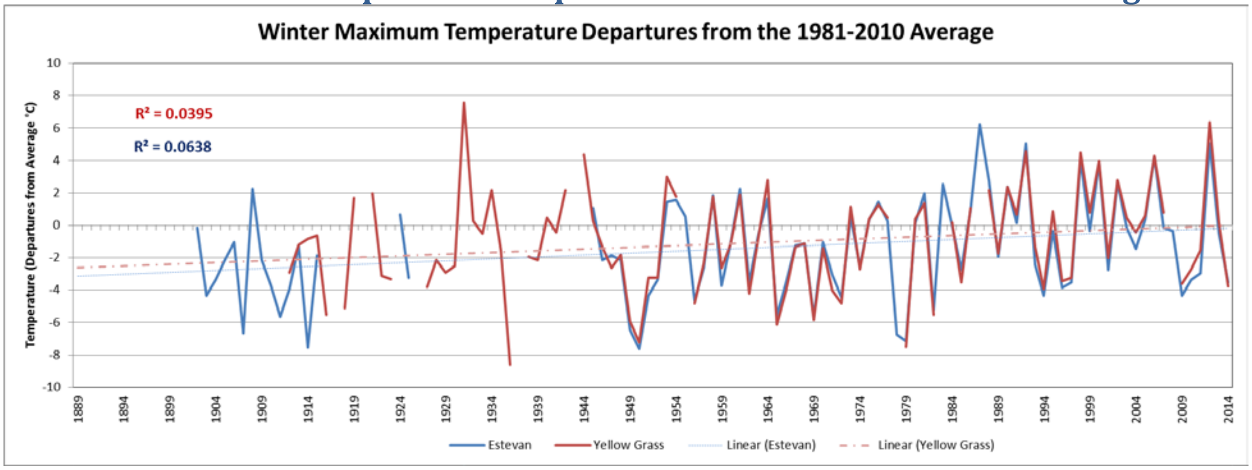


Figure 61 Estevan and Yellow Grass Winter Maximum Temperature Departures from Average

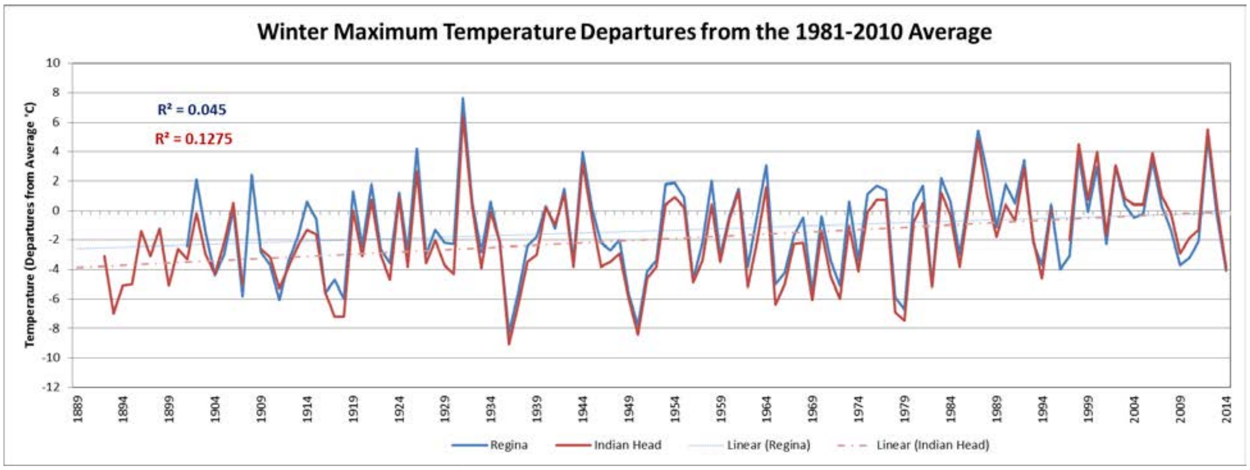


Figure 62 Regina and Indian Head Winter Maximum Temperature Departures from Average

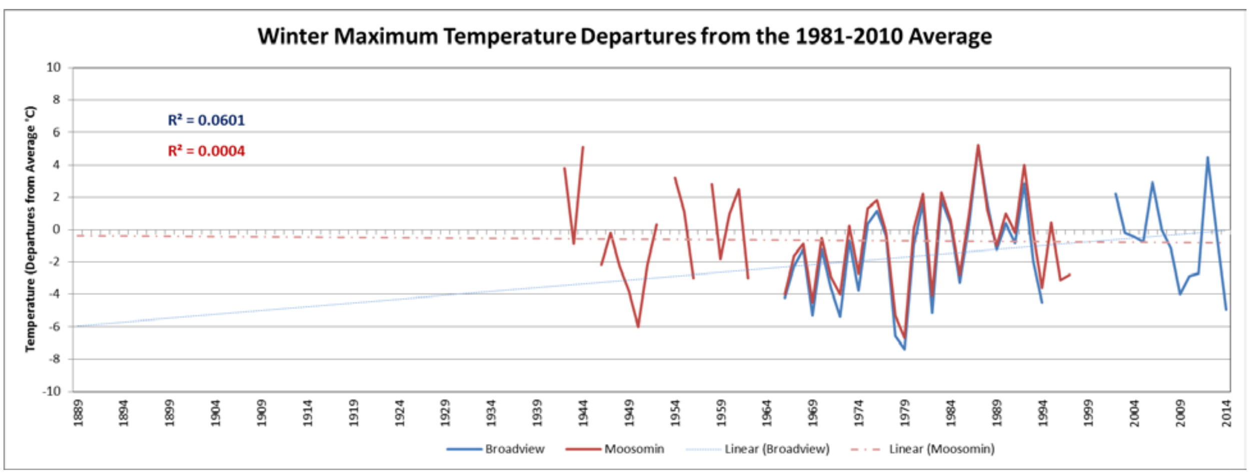


Figure 63 Broadview and Moosomin Winter Maximum Temperature Departures from Average

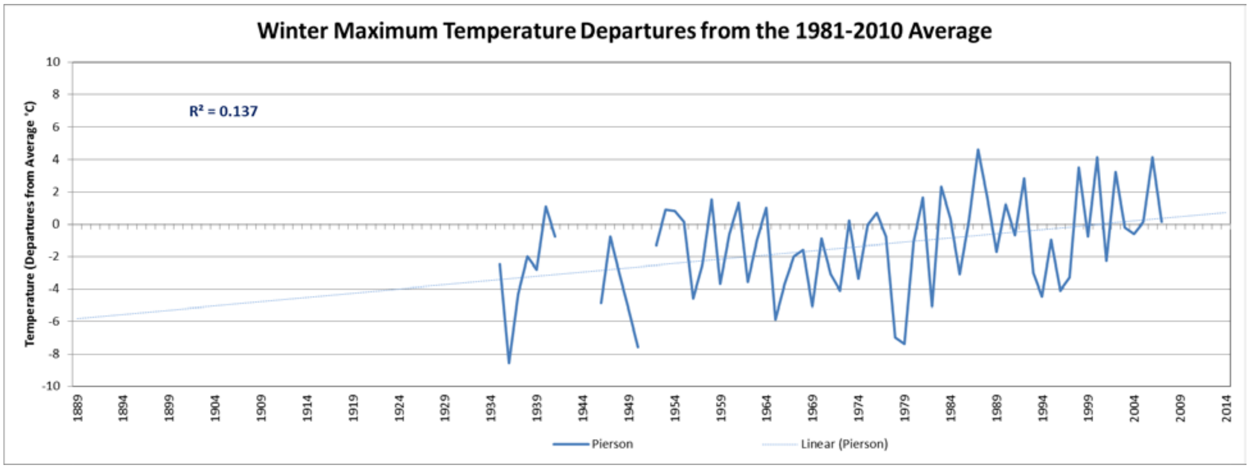


Figure 64 Pierson Winter Maximum Temperature Departures from Average

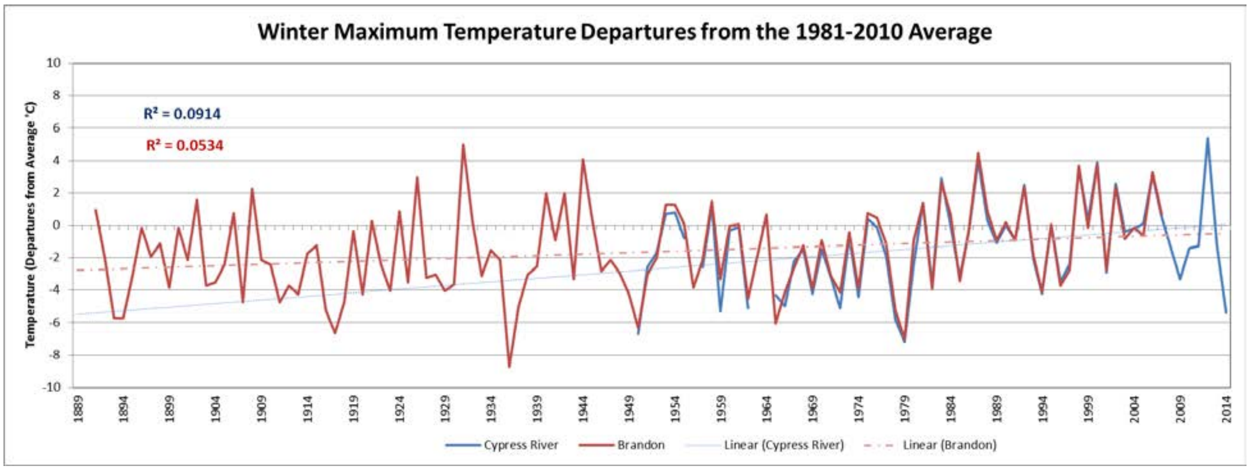


Figure 65 Cypress River and Brandon Winter Maximum Temperature Departures from Average

Spring Maximum Temperature Departures from the 1981-2010 Average

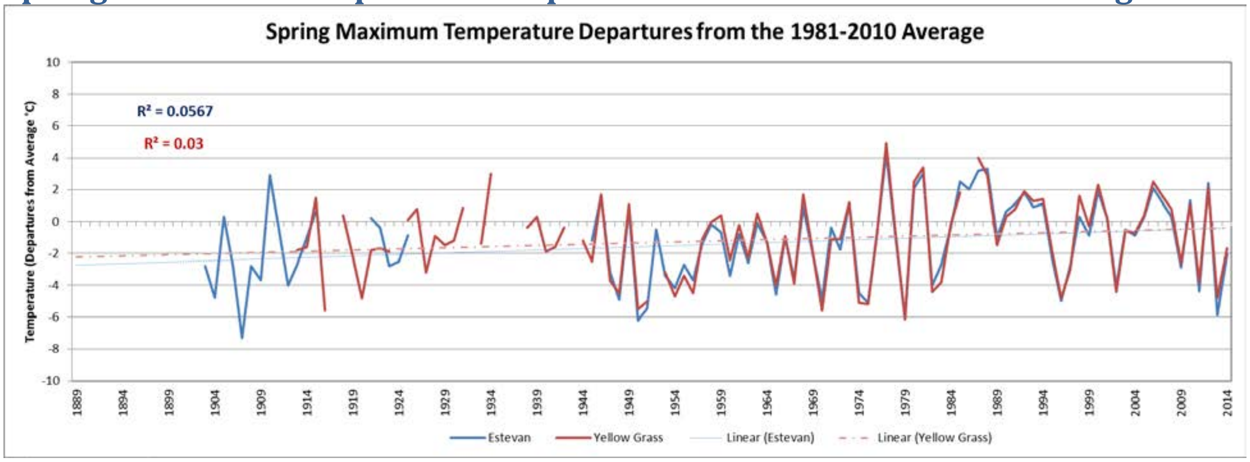


Figure 66Estevan and Yellow Grass Spring Maximum Temperature Departures from the 1981-2010 Average

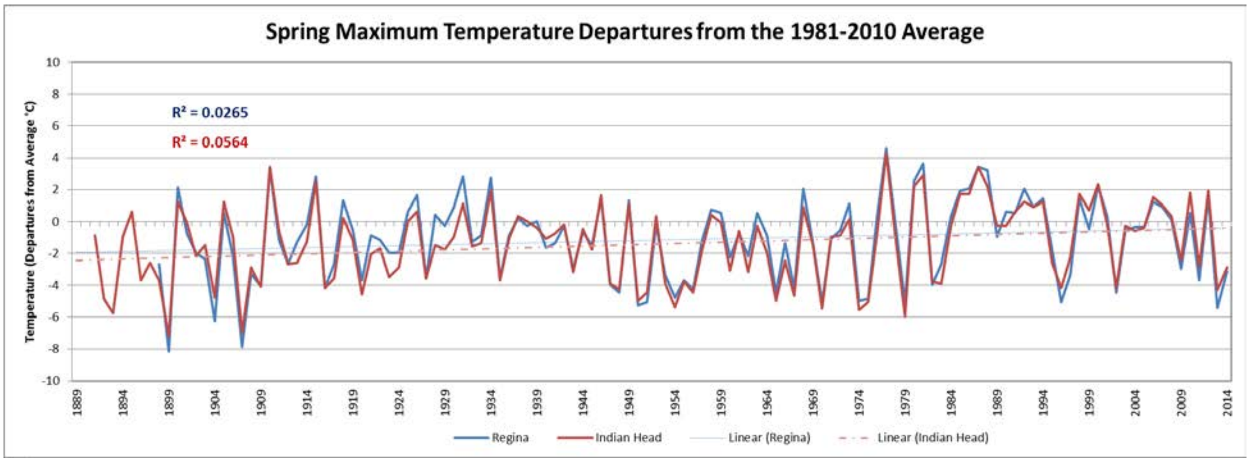


Figure 67 Regina and Indian Head Maximum Temperature Departures from the 1981-2010 Average

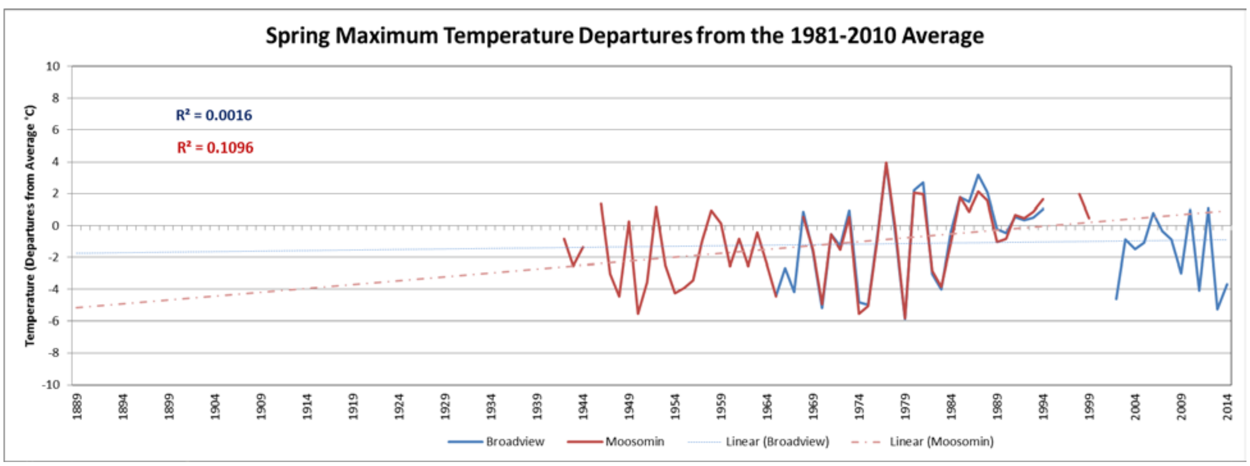


Figure 68 Broadview and Moosomin Maximum Temperature Departures from the 1981-2010 Average

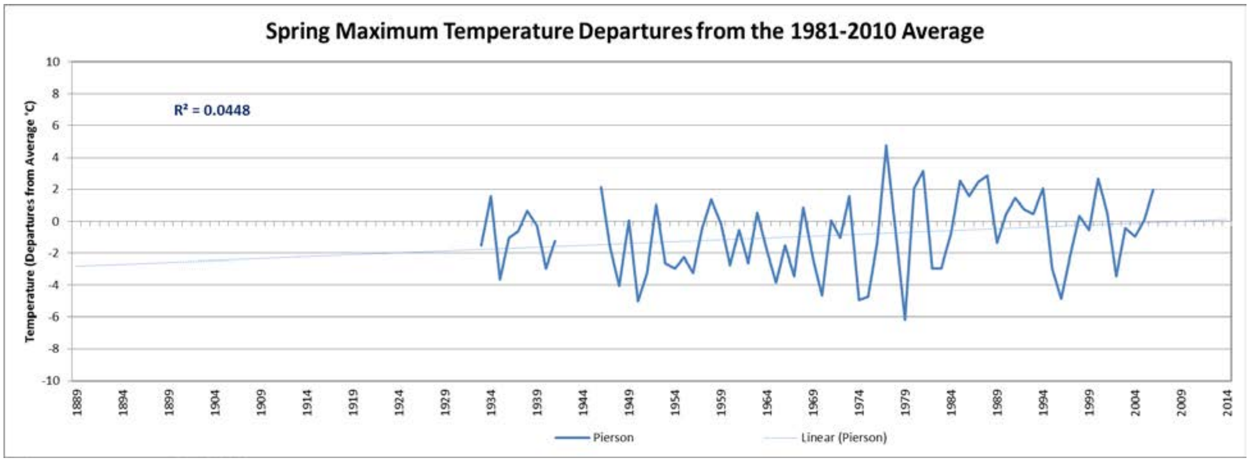


Figure 69 Pierson Maximum Temperature Departures from the 1981-2010 Average

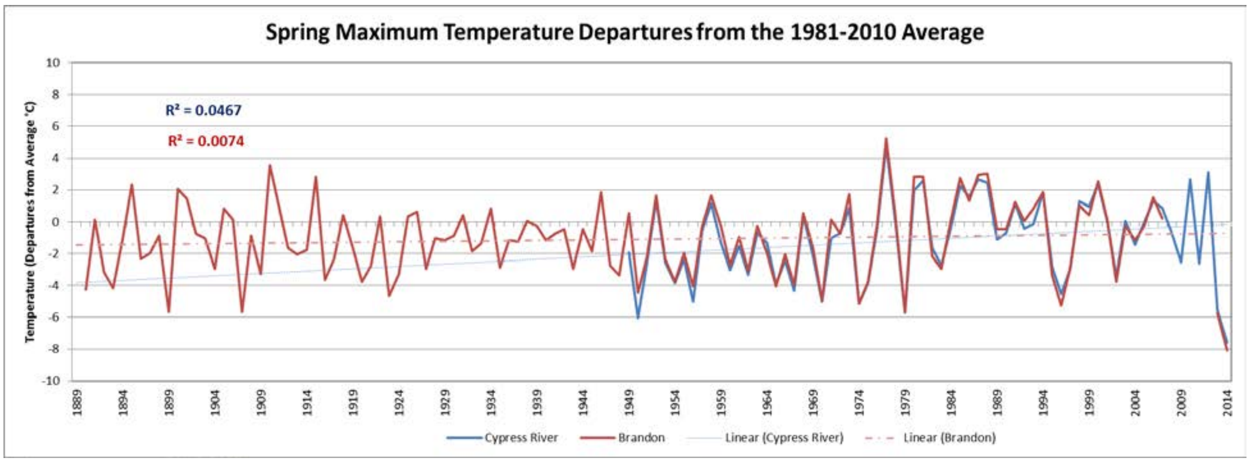


Figure 70 Cypress River and Brandon Maximum Temperature Departures from the 1981-2010 Average

Summer Maximum Temperature Departures from the 1981-2010 Average

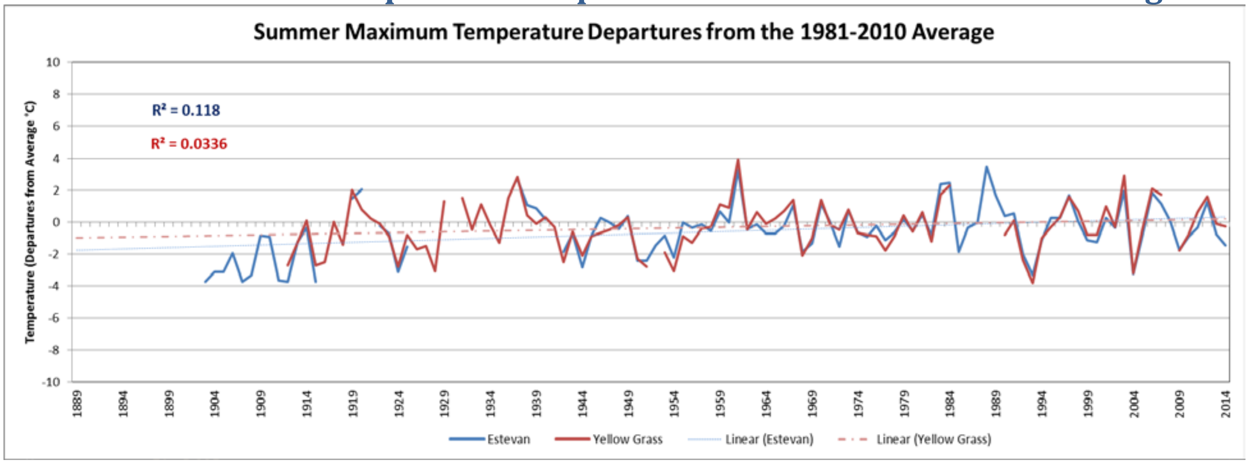


Figure 71 Estevan and Yellow Grass Summer Maximum Temperature Departures from the 1981-2010 Average

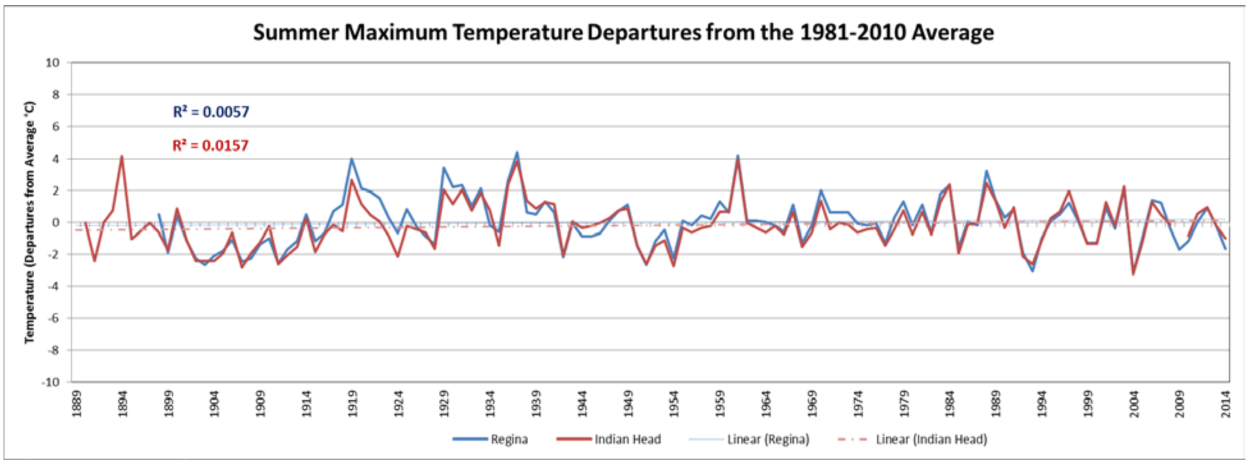


Figure 72 Regina and Indian Head Summer Maximum Temperature Departures from the 1981-2010 Average

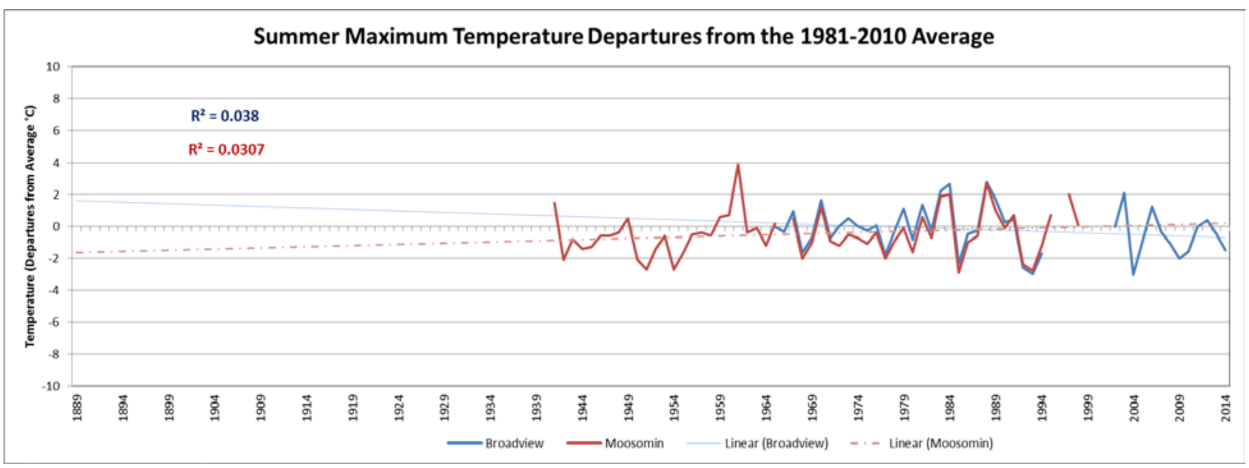


Figure 73 Broadview and Moosomin Summer Maximum Temperature Departures from the 1981-2010 Average

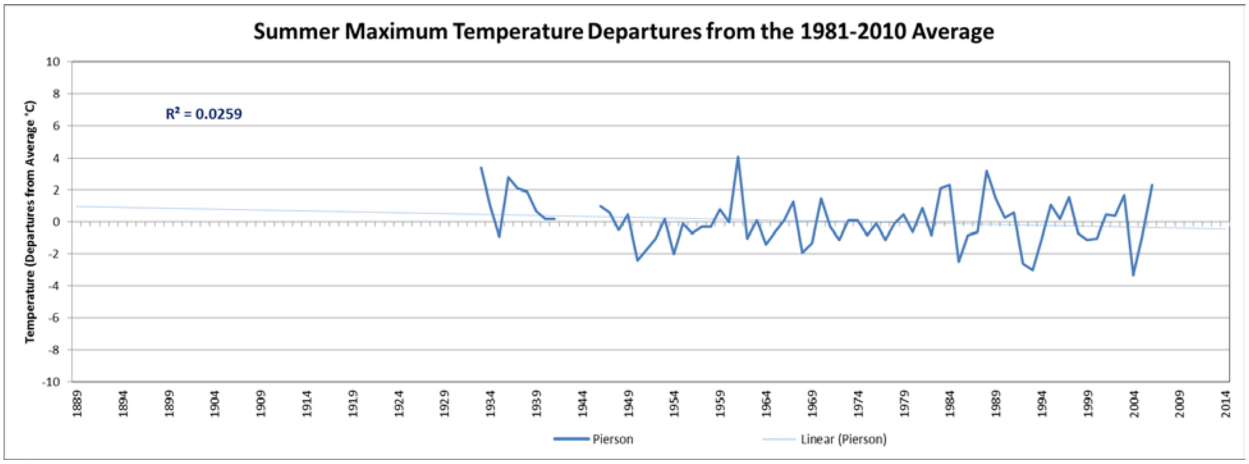


Figure 74 Pierson Summer Maximum Temperature Departures from the 1981-2010 Average

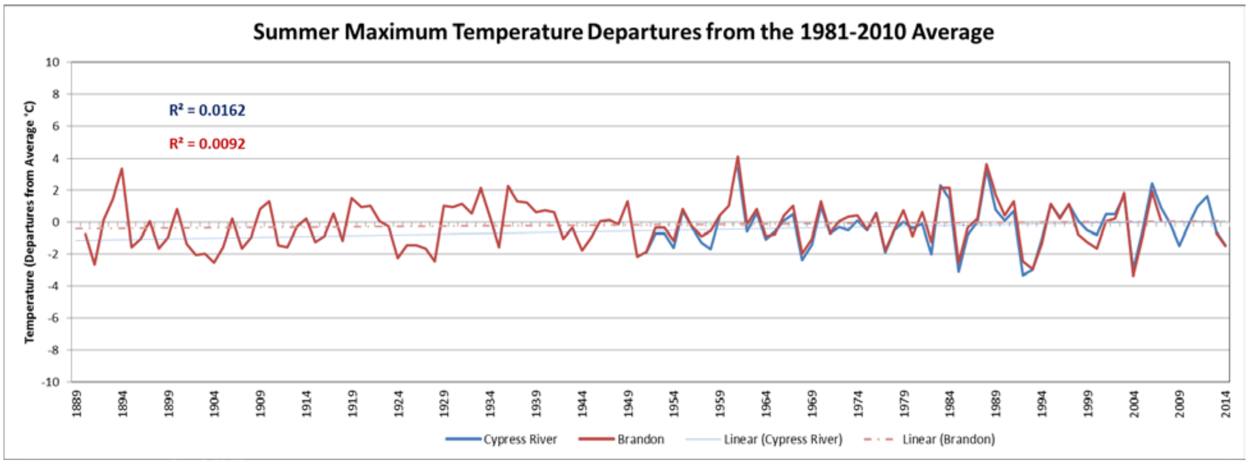


Figure 75 Cypress River and Brandon Summer Maximum Temperature Departures from the 1981-2010 Average

Autumn Maximum Temperature Departures from the 1981-2010 Average

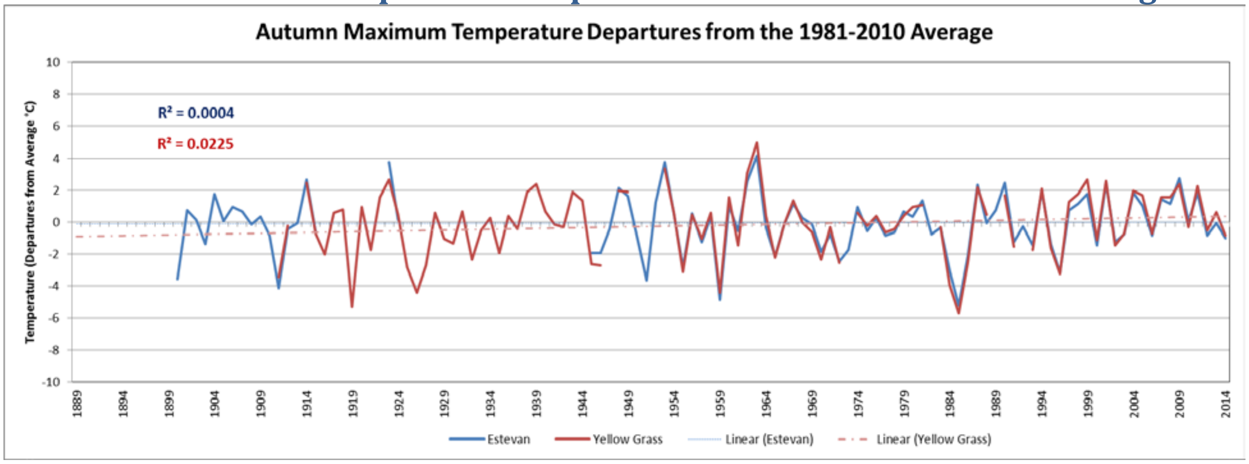


Figure 76 Estevan and Yellow Grass Autumn Maximum Temperature Departures from the 1981-2010 Average

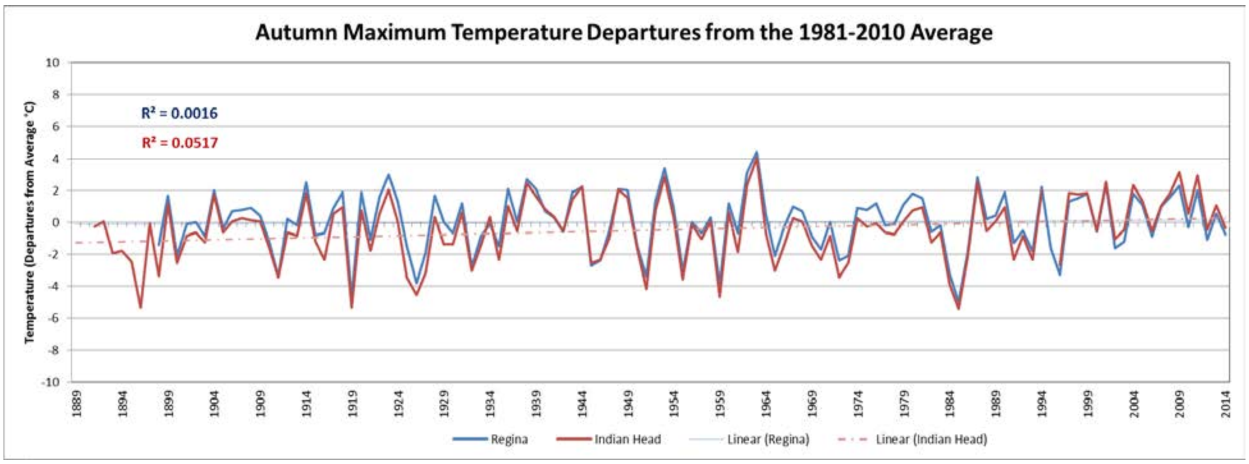


Figure 77 Regina and Indian Head Autumn Maximum Temperature Departures from the 1981-2010 Average

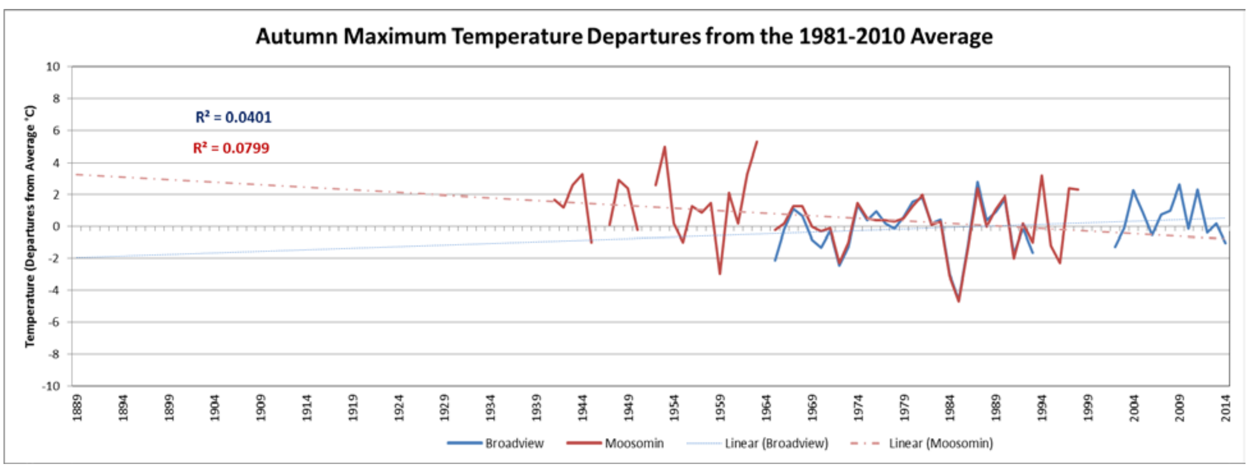


Figure 78 Broadview and Moosomin Autumn Maximum Temperature Departures from the 1981-2010 Average

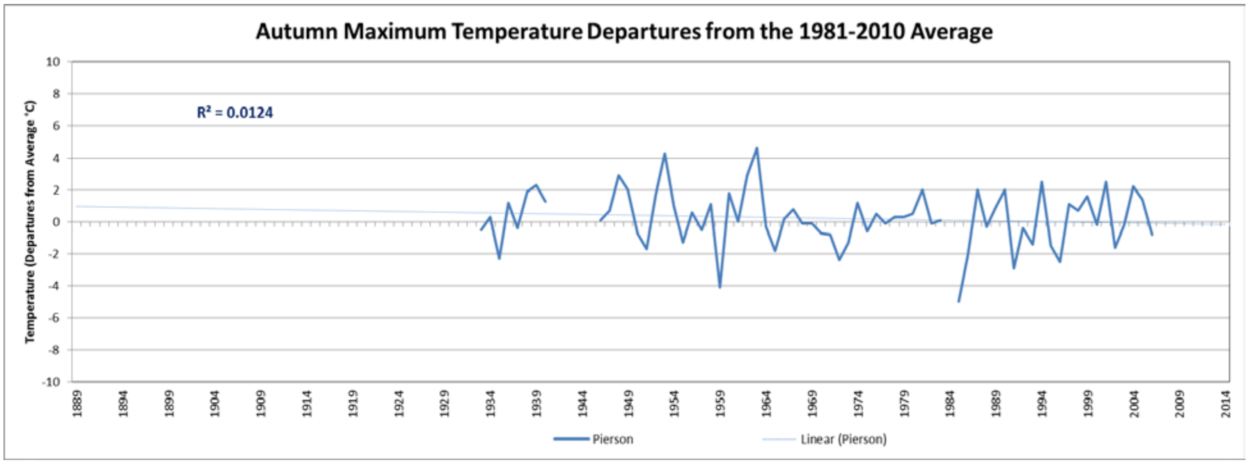


Figure 79 Pierson Autumn Maximum Temperature Departures from the 1981-2010 Average

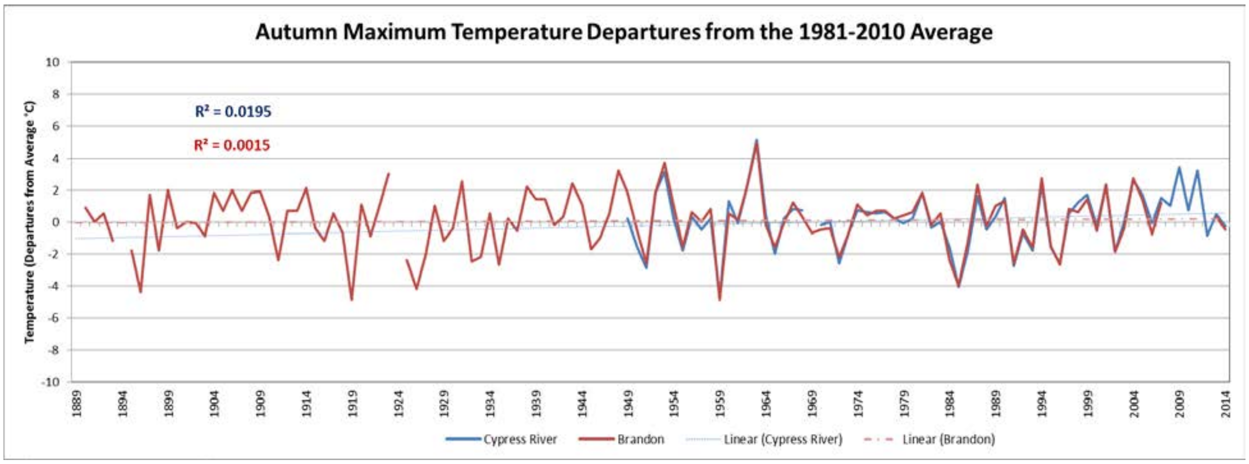


Figure 80 Cypress River and Brandon Autumn Maximum Temperature Departures from the 1981-2010 Average

APPENDIX 4
TRENDS OF MEAN MINIMUM TEMPERATURE OF SELECTED CLIMATE STATIONS

Annual Minimum Temperature Departures from the 1981-2010 Average

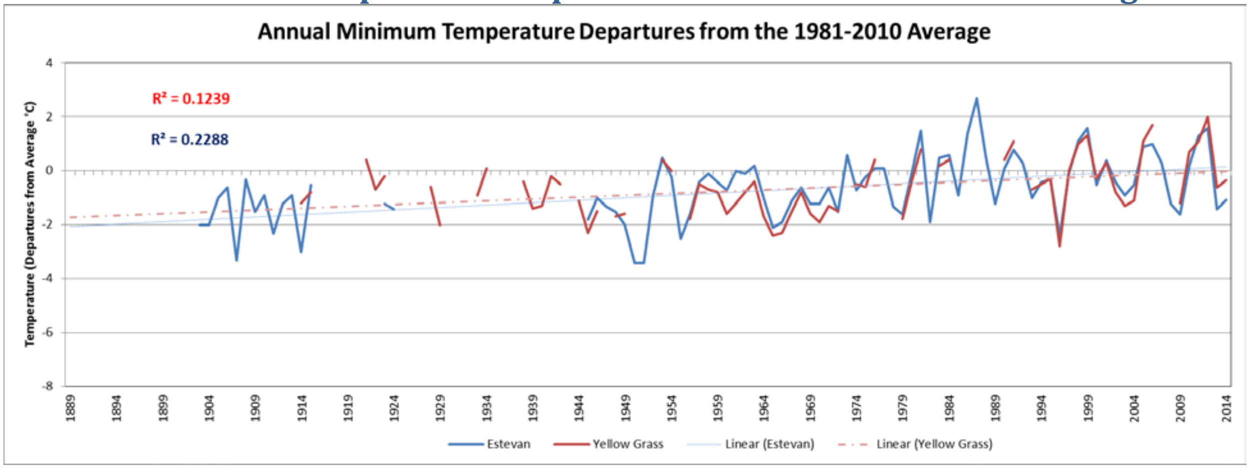


Figure 81 Estevan and Yellow Grass Annual Minimum Temperature Departures from the 1981-2010 Average

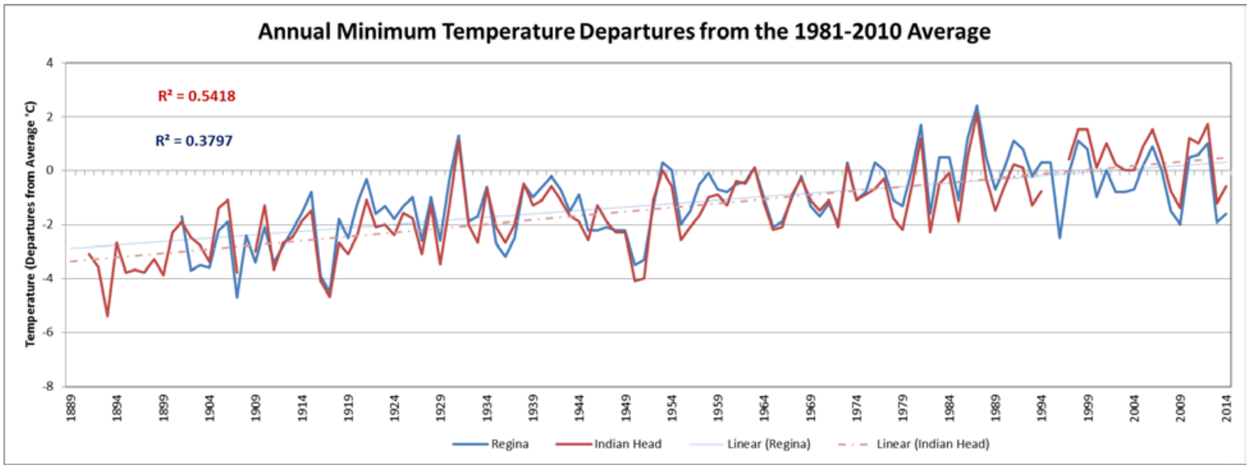


Figure 82 Regina and Indian Head Annual Minimum Temperature Departures from the 1981-2010 Average

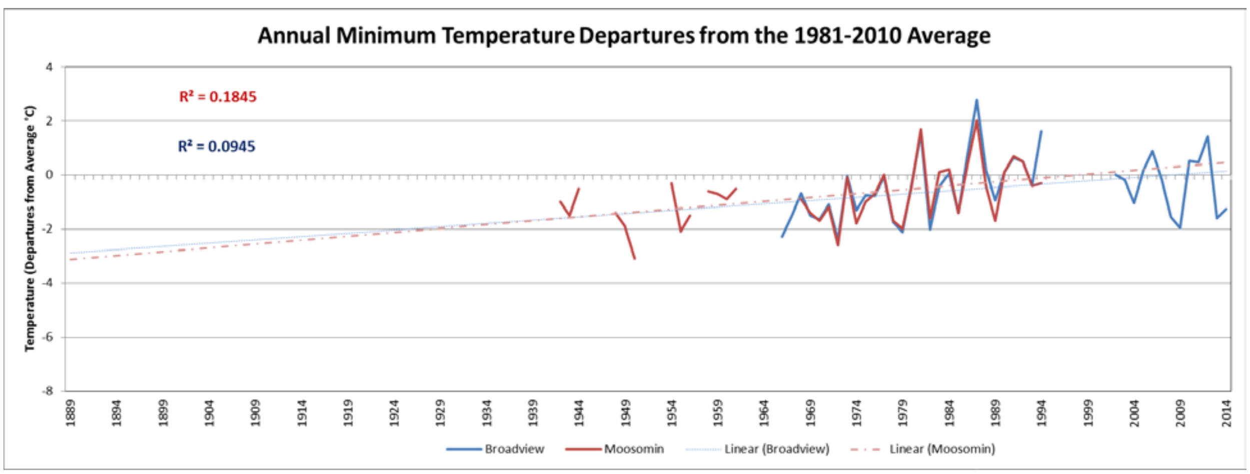


Figure 83 Broadview and Moosomin Annual Minimum Temperature Departures from the 1981-2010 Average

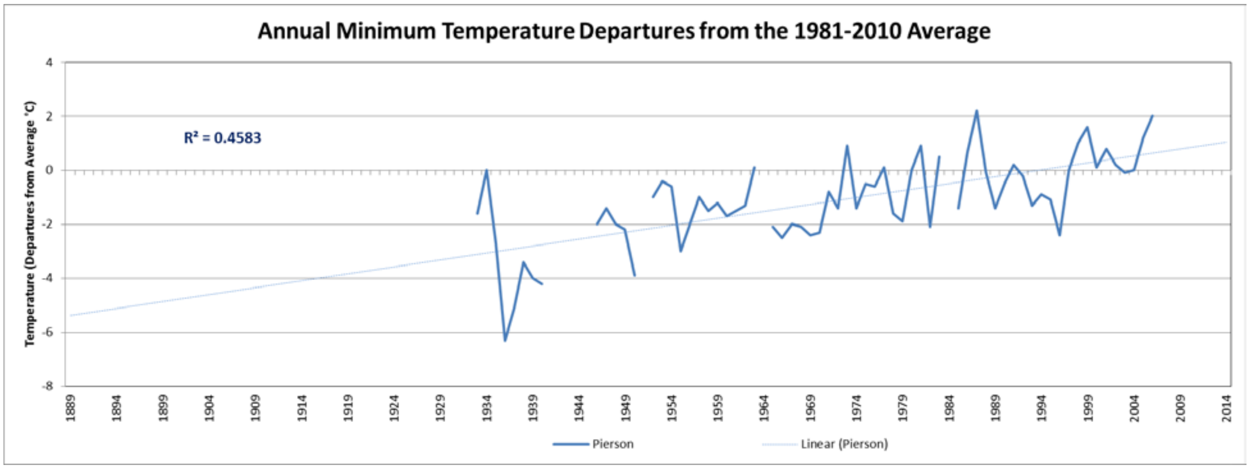


Figure 84 Pierson Annual Minimum Temperature Departures from the 1981-2010 Average

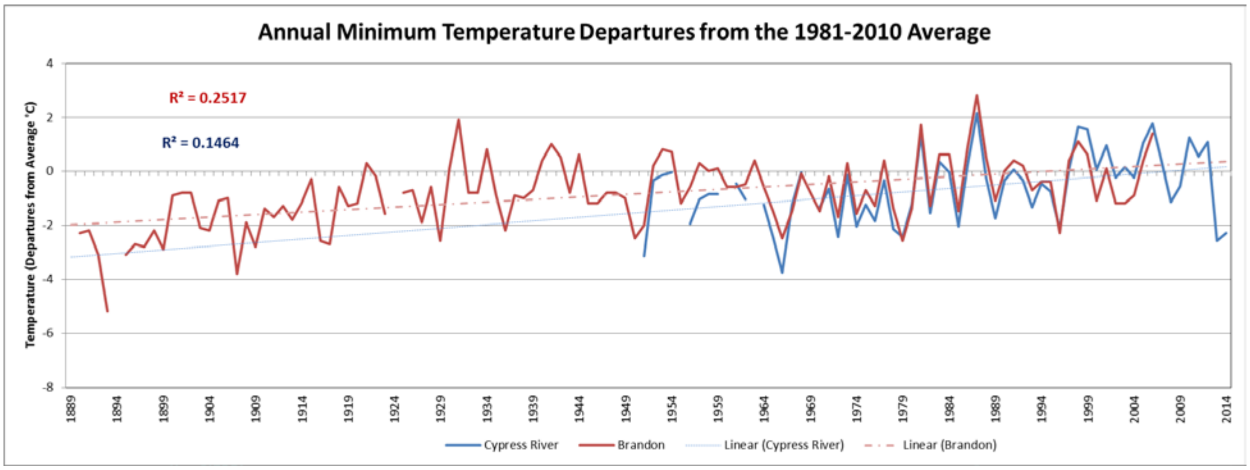


Figure 85 Cypress River and Brandon

Winter Minimum Temperature Departures from the 1981-2010 Average

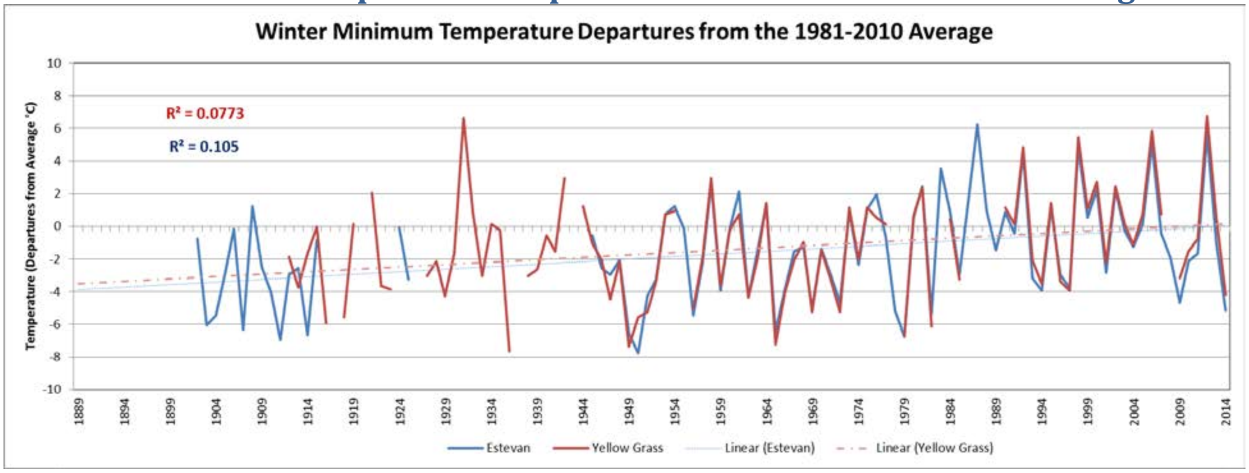


Figure 86 Estevan and Yellow Grass Winter Minimum Temperature Departures from the 1981-2010 Average

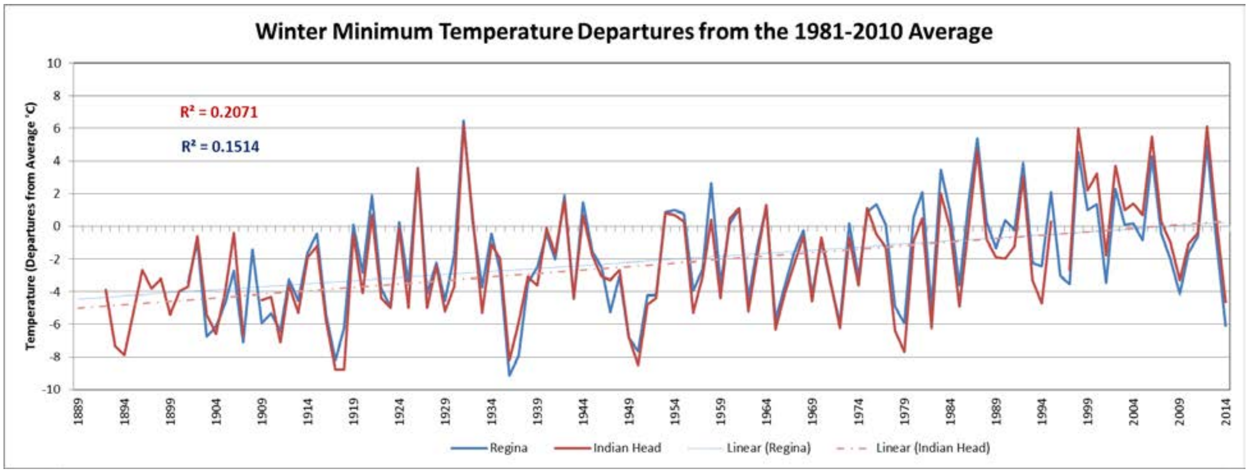


Figure 87 Regina and Indian Head Winter Minimum Temperature Departures from the 1981-2010 Average

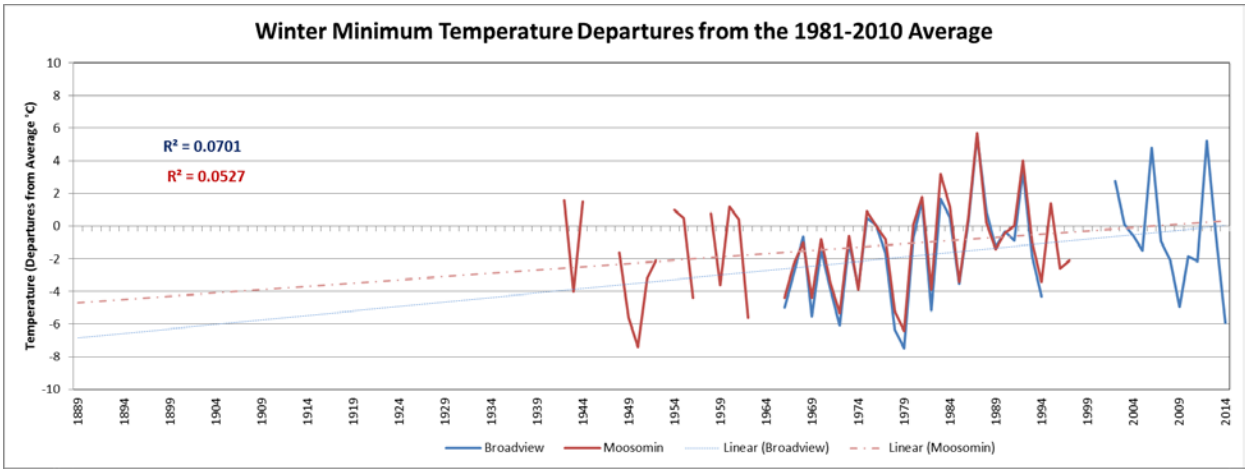


Figure 88 Broadview and Moosomin Winter Minimum Temperature Departures from the 1981-2010 Average

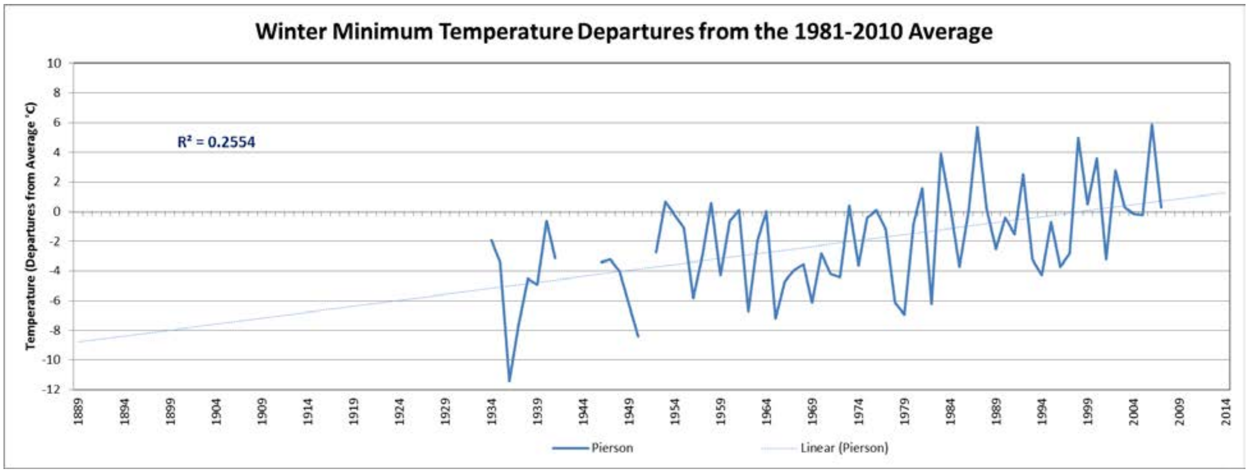


Figure 89 Pierson Winter Minimum Temperature Departures from the 1981-2010 Average

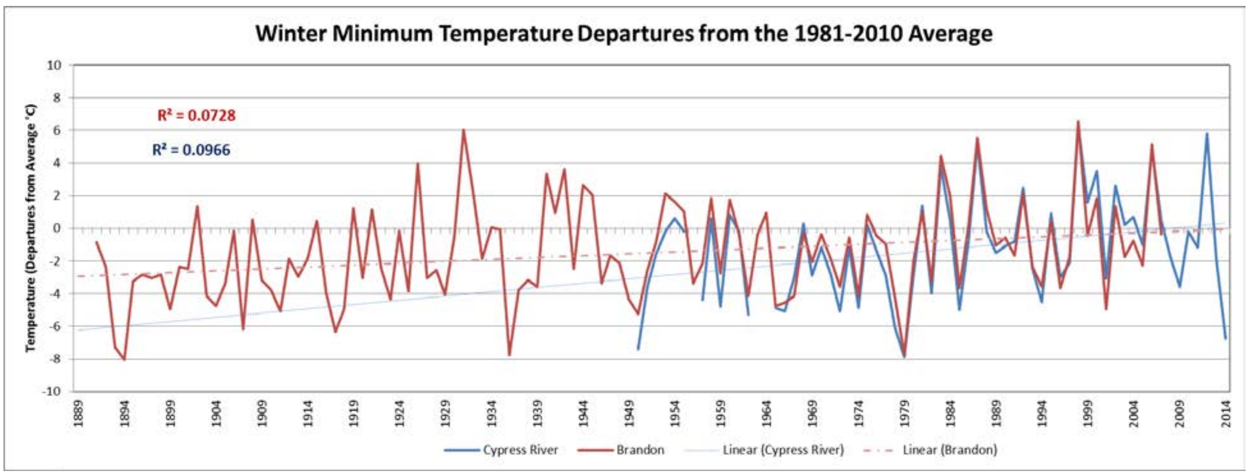


Figure 90 Cypress River and Brandon Winter Minimum Temperature Departures from the 1981-2010 Average

Spring Minimum Temperature Departures from the 1981-2010 Average

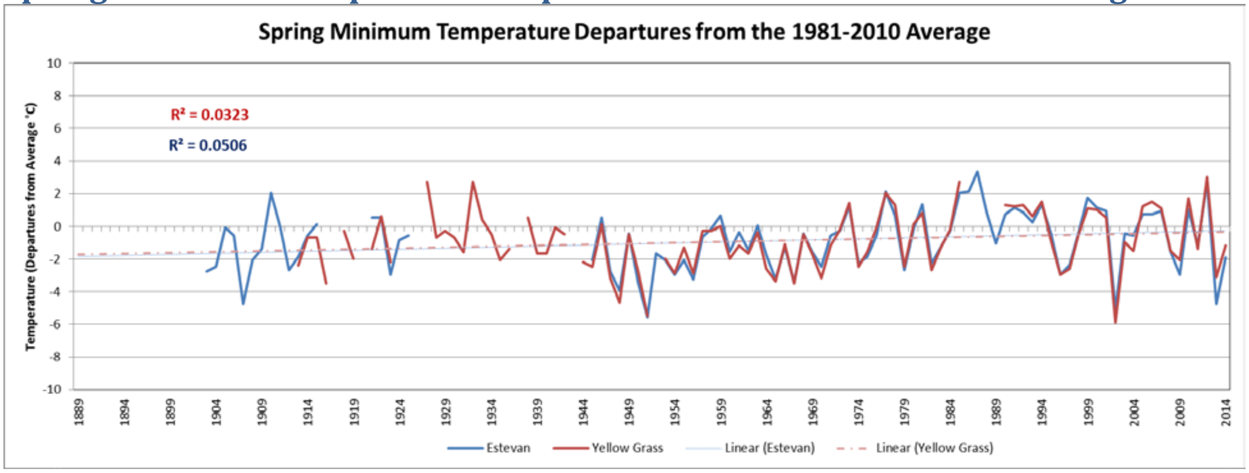


Figure 91 Estevan and Yellow Grass Spring Minimum Temperature Departures from the 1981-2010 Average

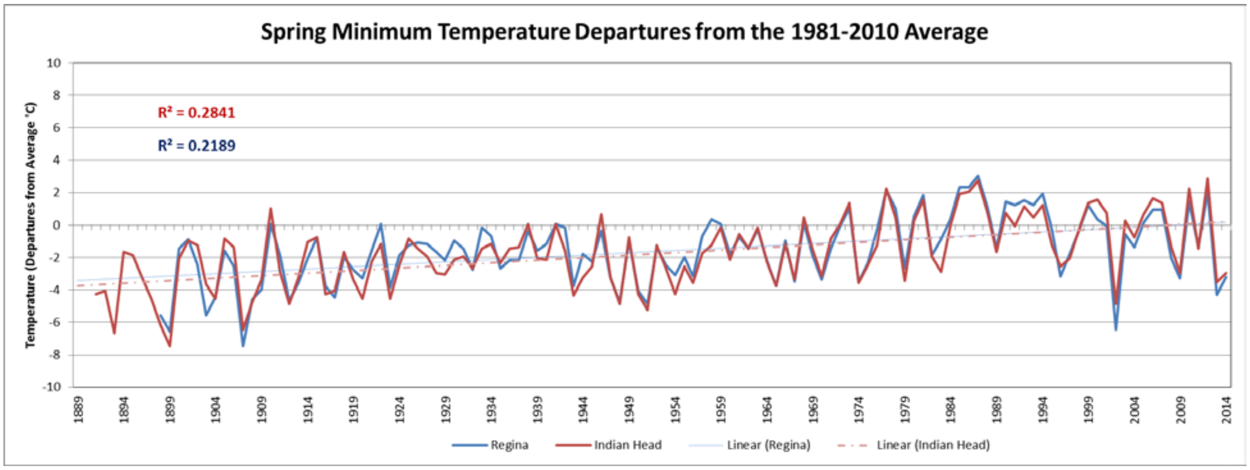


Figure 92 Regina and Indian Head Spring Minimum Temperature Departures from the 1981-2010 Average

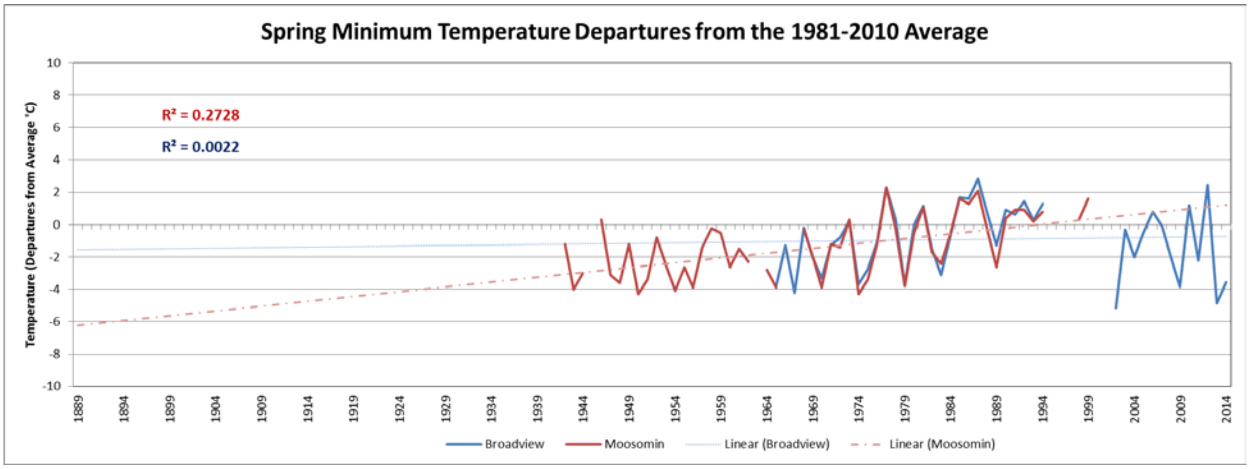


Figure 93 Broadview and Moosomin Spring Minimum Temperature Departures from the 1981-2010 Average

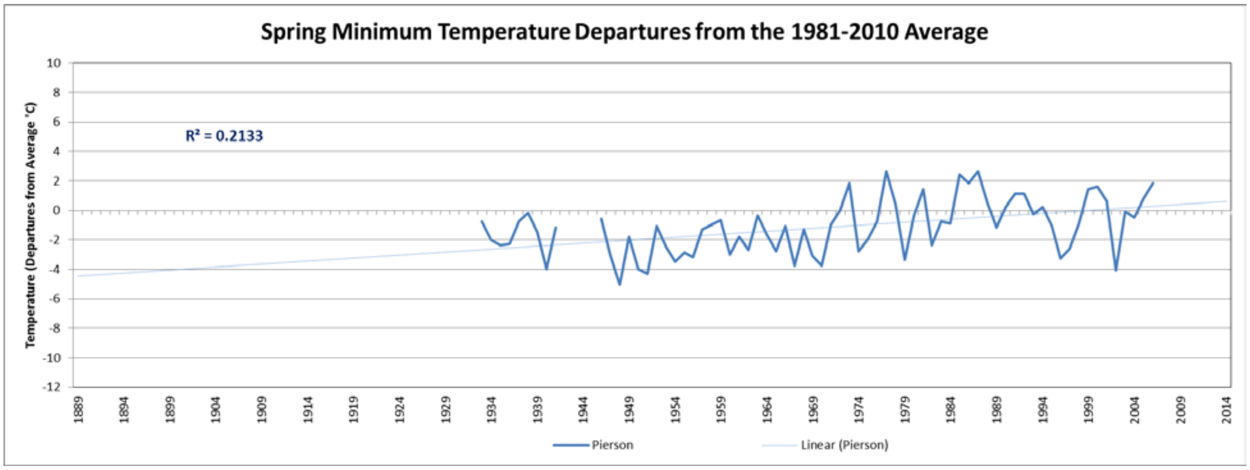


Figure 94 Pierson Spring Minimum Temperature Departures from the 1981-2010 Average

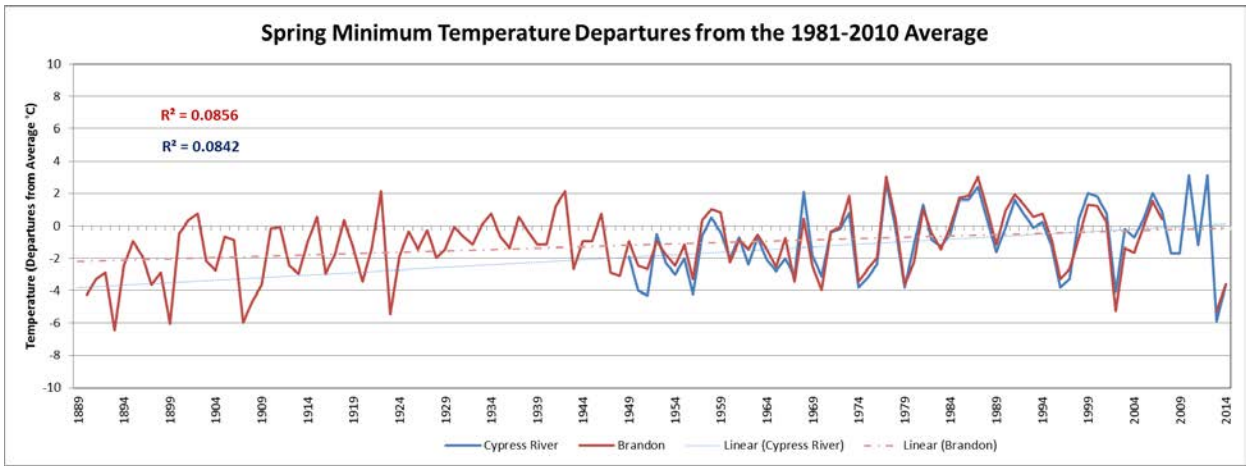


Figure 95 Cypress River and Brandon Spring Minimum Temperature Departures from the 1981-2010 Average

Summer Minimum Temperature Departures from the 1981-2010 Average

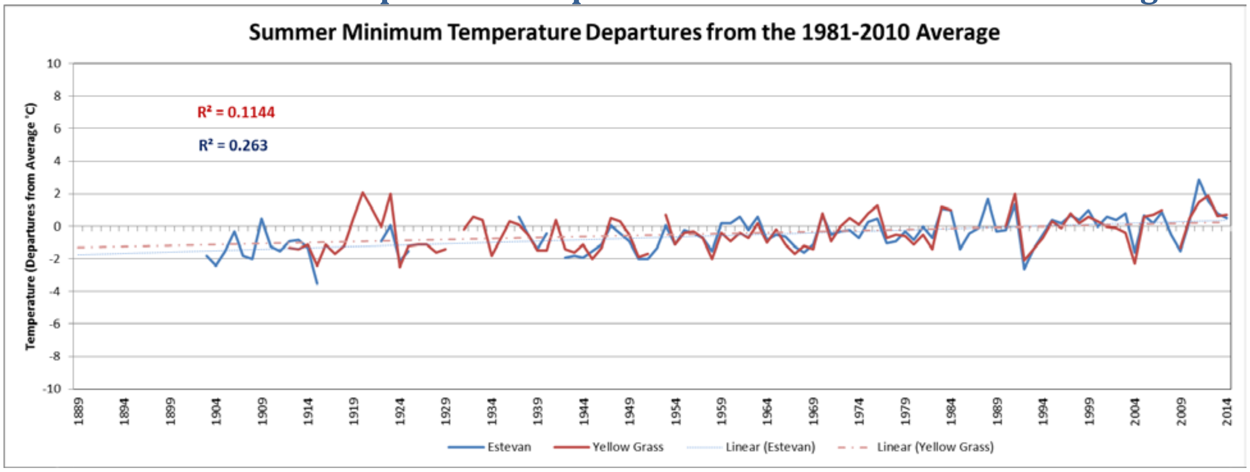


Figure 96 Estevan and Yellow Grass Summer Minimum Temperature Departures from the 1981-2010 Average

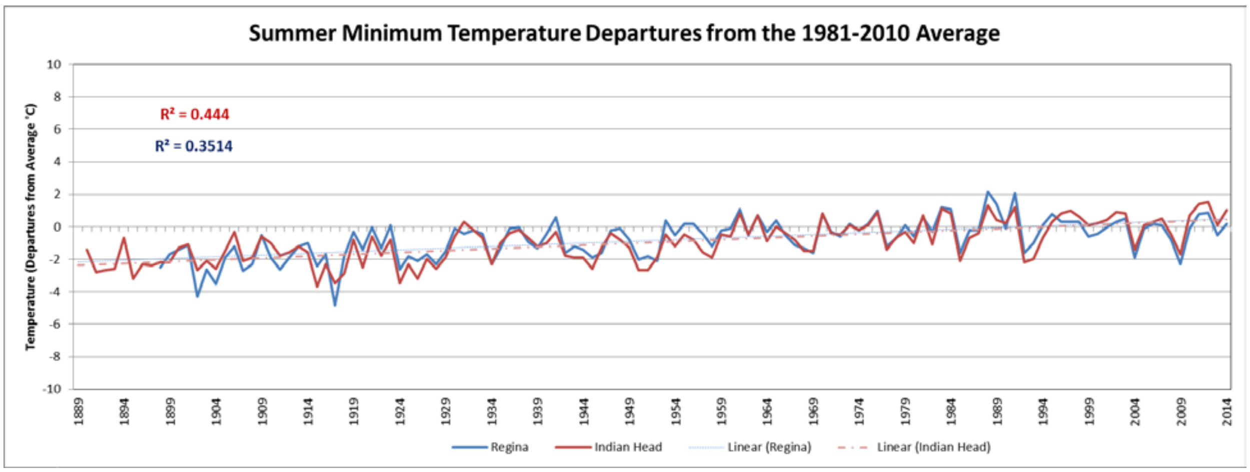


Figure 97 Regina and Indian Head Summer Minimum Temperature Departures from the 1981-2010 Average

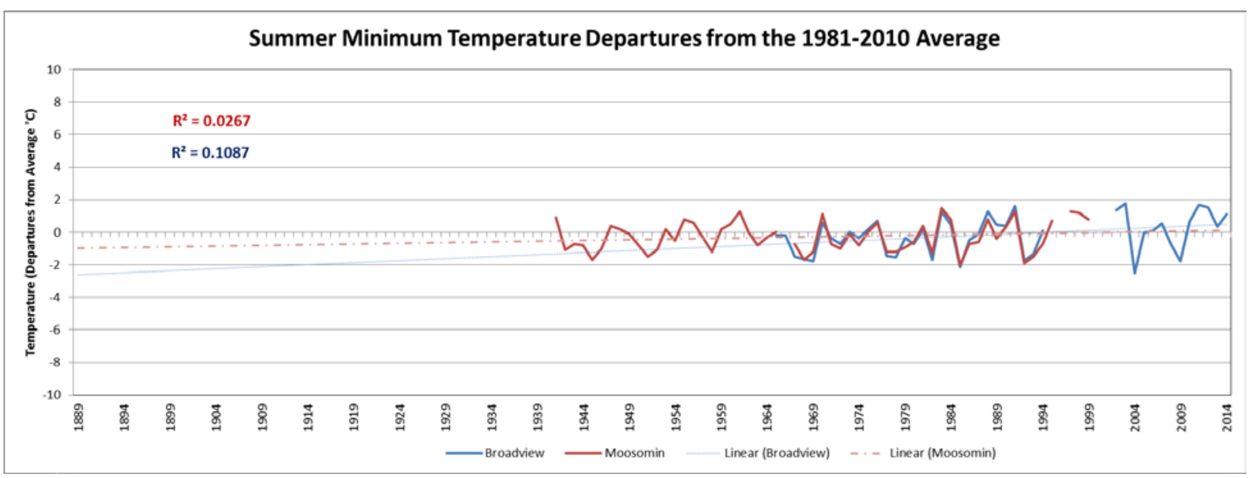


Figure 98 Broadview and Moosomin Summer Minimum Temperature Departures from the 1981-2010 Average

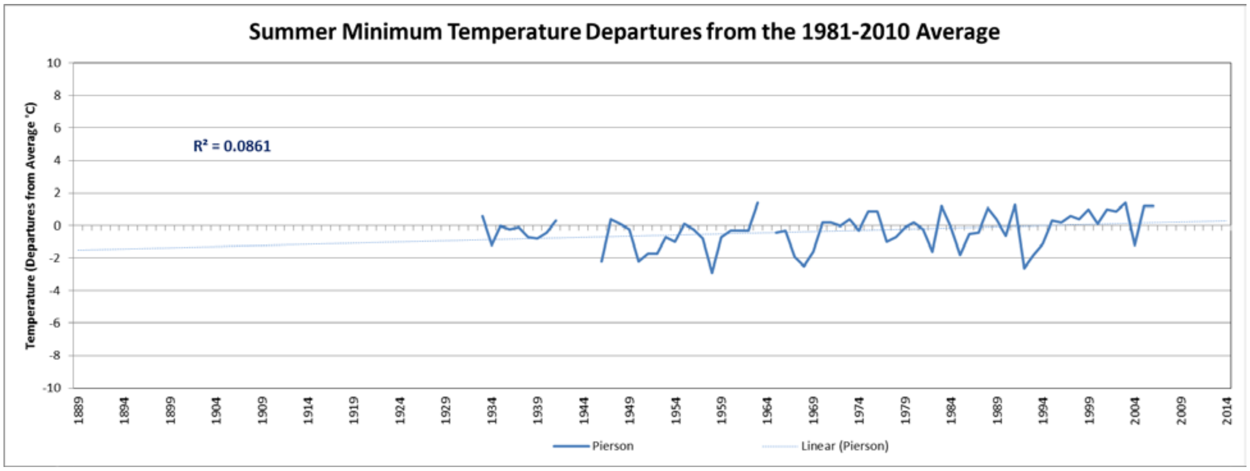


Figure 99 Pierson Summer Minimum Temperature Departures from the 1981-2010 Average

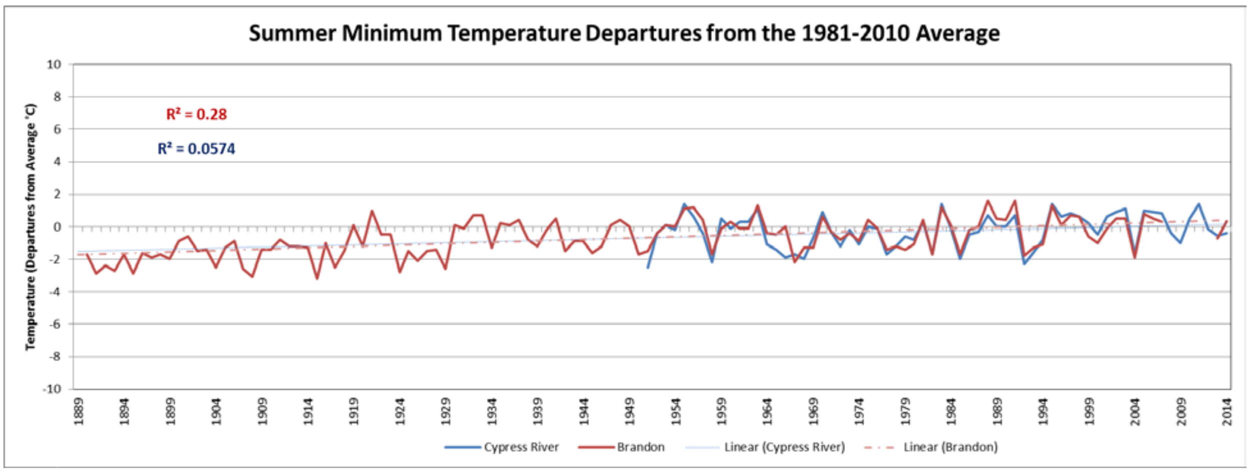


Figure 100 Cypress River and Brandon Summer Minimum Temperature Departures from the 1981-2010 Average

Autumn Minimum Temperature Departures from the 1981-2010 Average

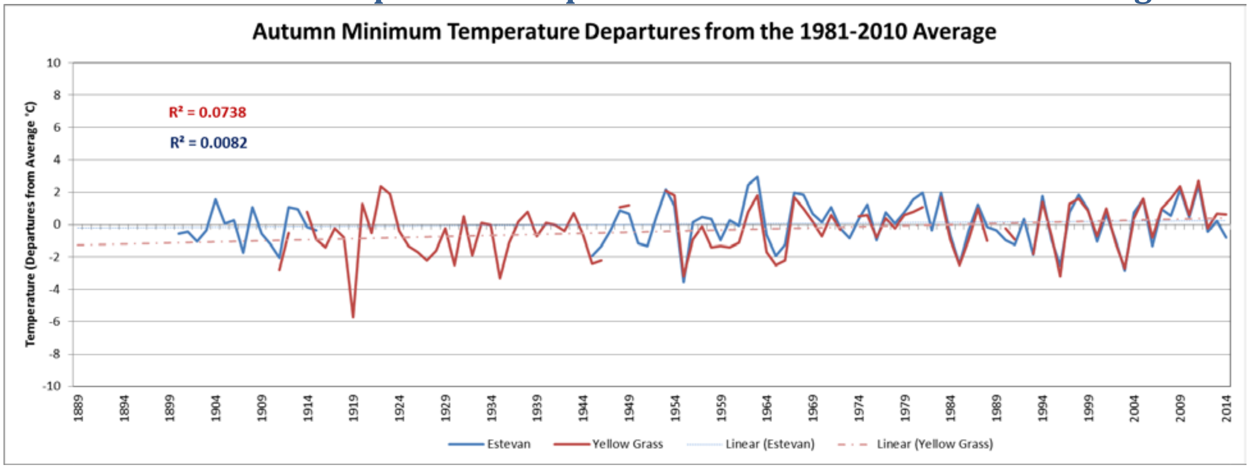


Figure 101 Estevan and Yellow Grass Autumn Minimum Temperature Departures from the 1981-2010 Average

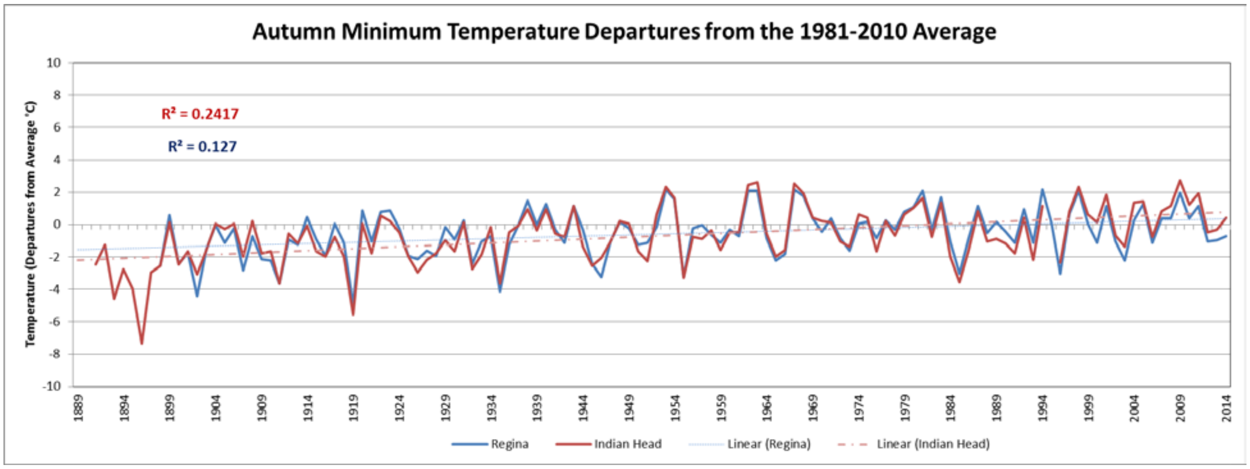


Figure 102 Regina and Indian Head Autumn Minimum Temperature Departures from the 1981-2010 Average

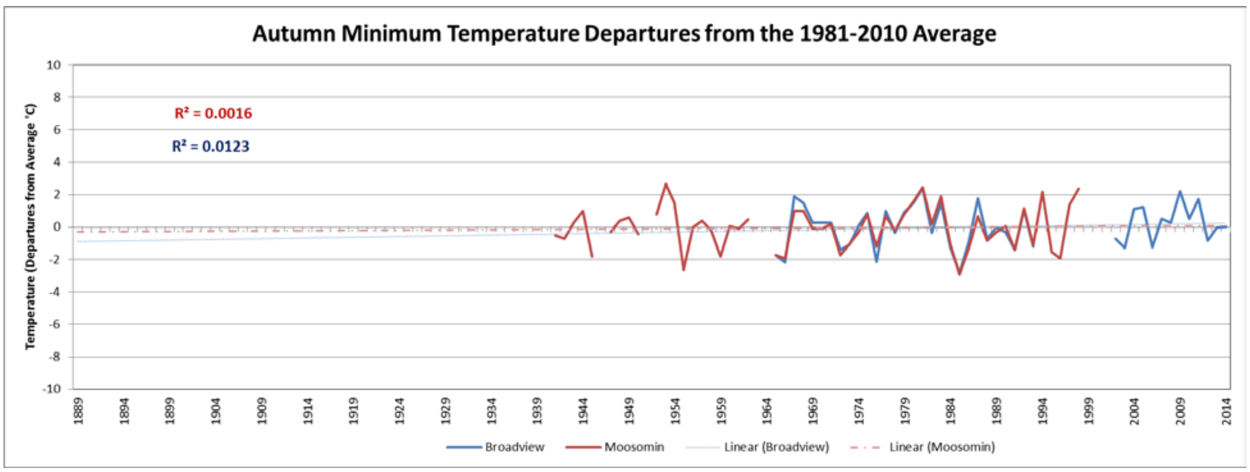


Figure 103 Broadview and Moosomin Autumn Minimum Temperature Departures from the 1981-2010 Average

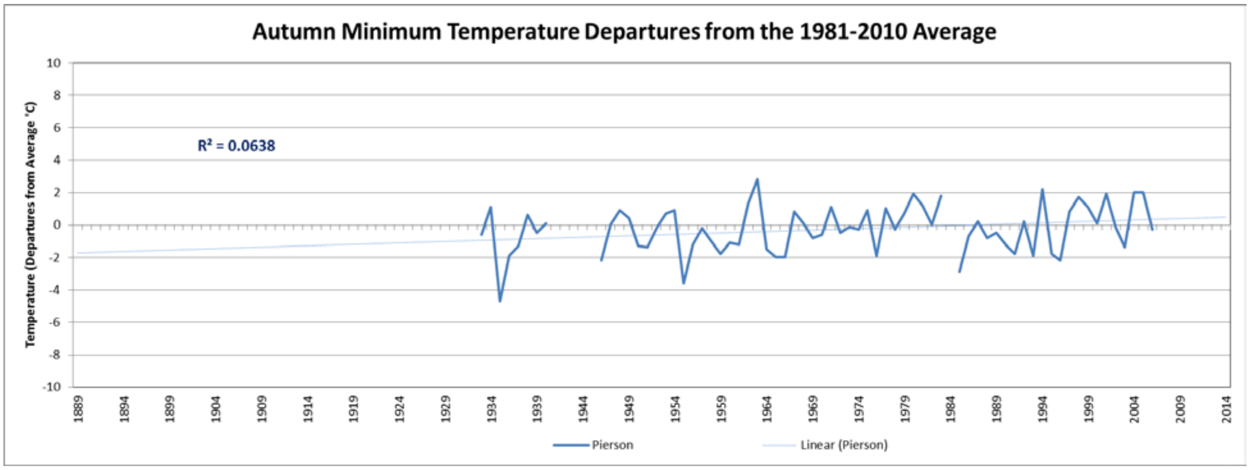


Figure 104 Pierson Autumn Minimum Temperature Departures from the 1981-2010 Average

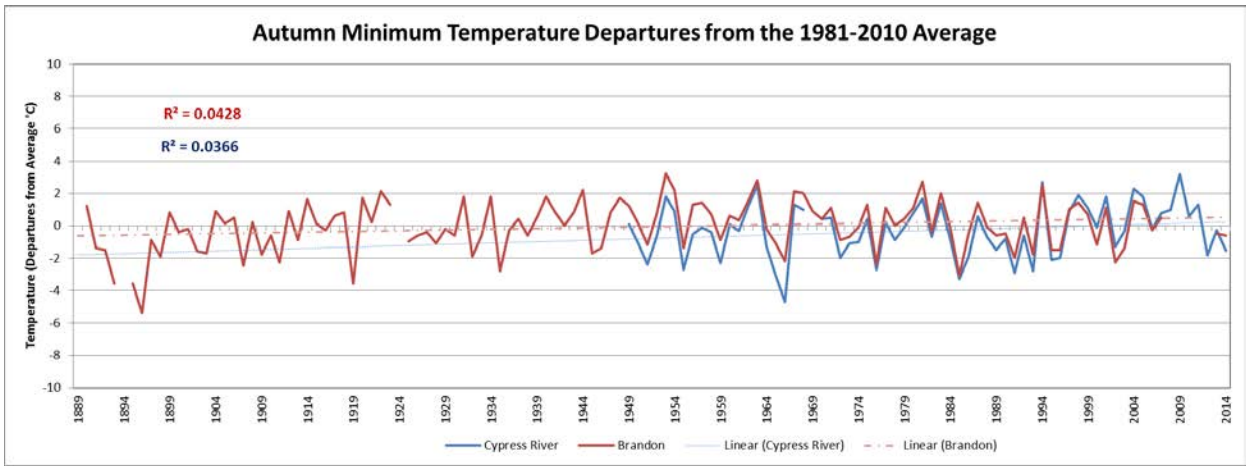


Figure 105 Cypress River and Brandon Autumn Minimum Temperature Departures from the 1981-2010 Average

APPENDIX 5 TRENDS OF SEASONAL PRECIPITATION OF SELECTED CLIMATE STATIONS

Winter Precipitation Departures from the 1981-2010 Average

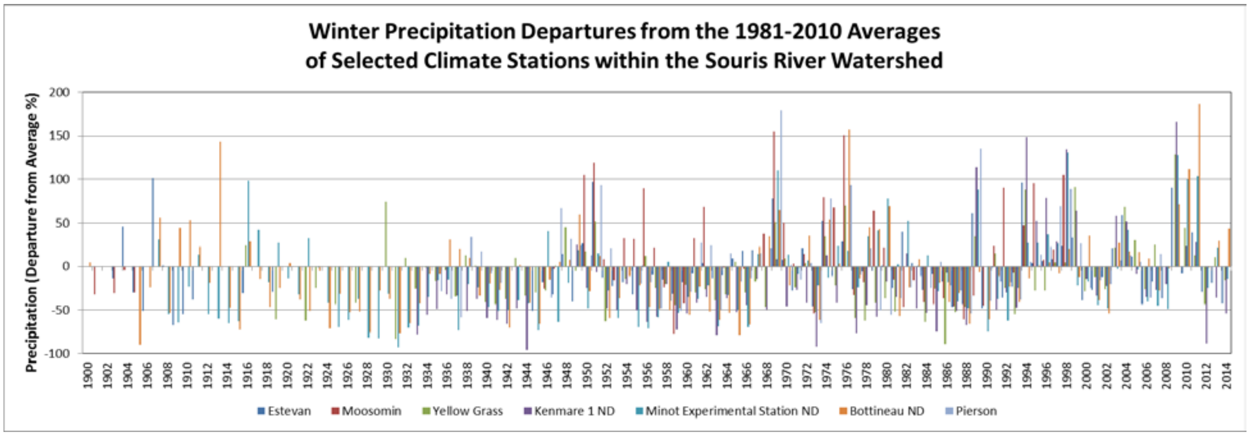


Figure 106 Winter Precipitation Departures from the 1981-2010 Averages of Selected Climate Station in the Souris River Watershed

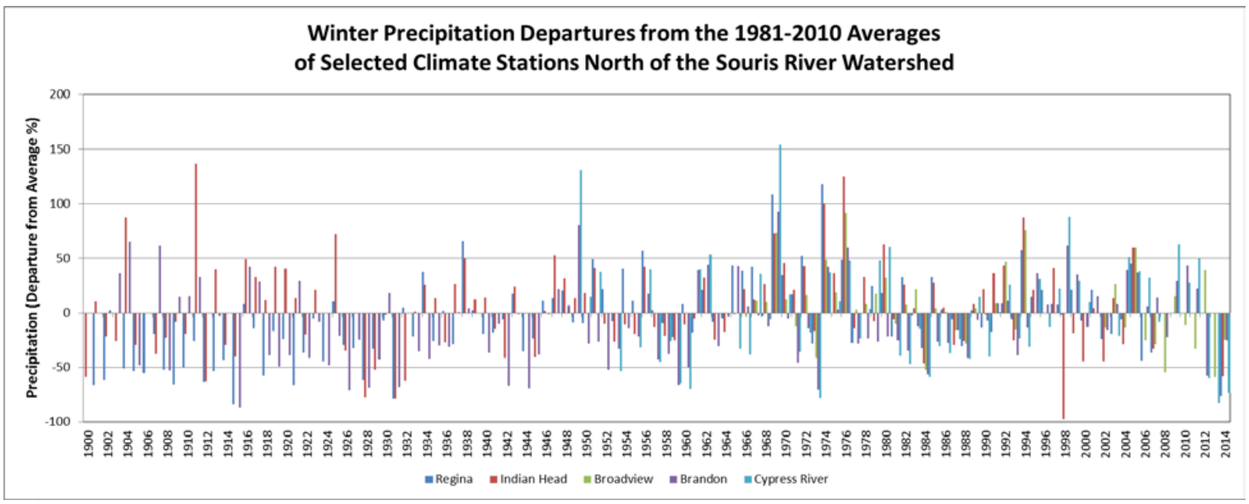


Figure 107 Winter Precipitation Departures from the 1981-2010 Averages of Selected Climate Station north of the Souris River Watershed

Spring Precipitation Departures from the 1981-2010 Average

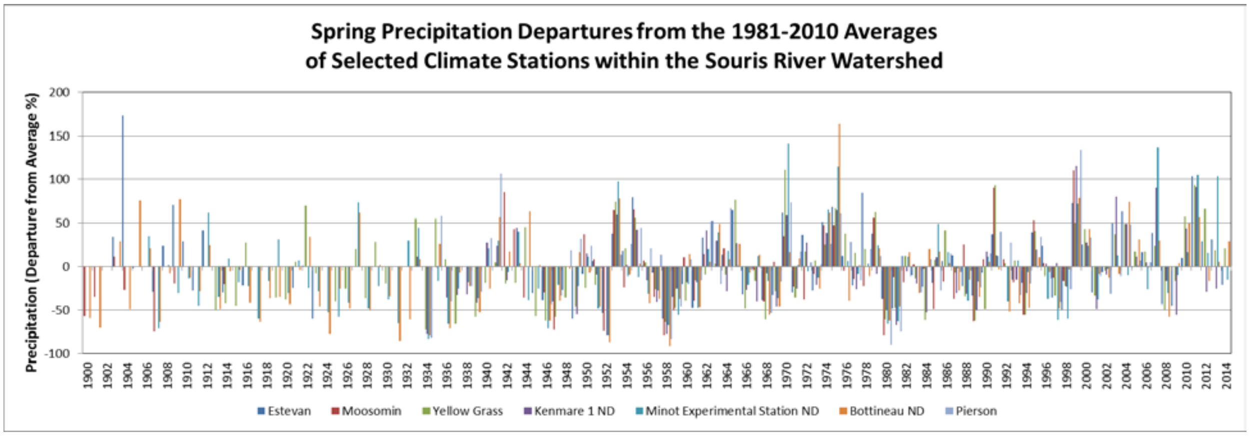


Figure 108 Spring Precipitation Departures from the 1981-2010 Averages of Selected Climate Station in the Souris River Watershed

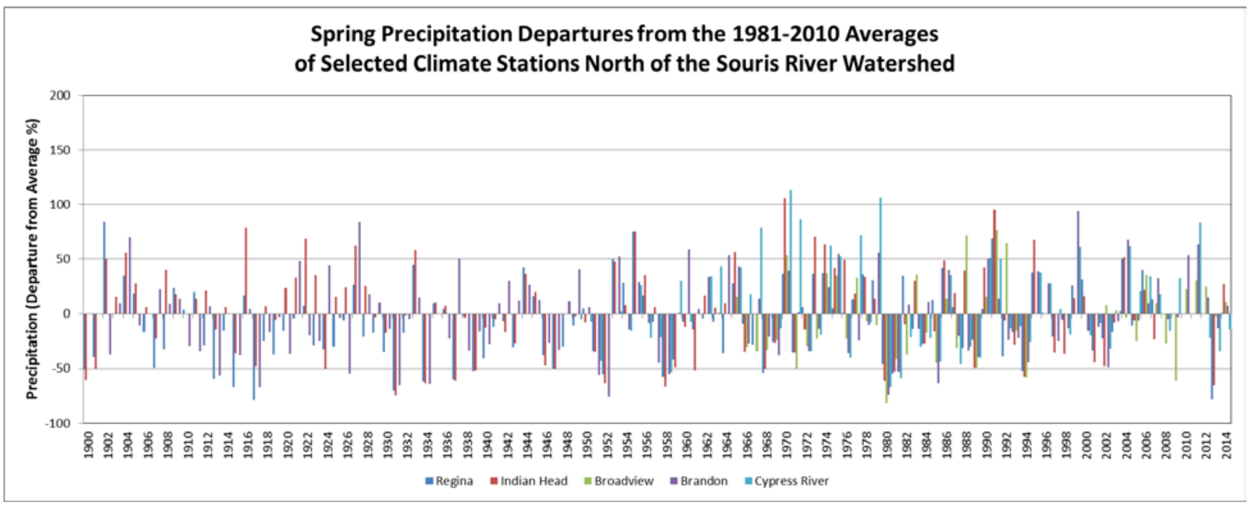


Figure 109 Spring Precipitation Departures from the 1981-2010 Averages of Selected Climate Station north of the Souris River Watershed

Summer Precipitation Departures from the 1981-2010 Average

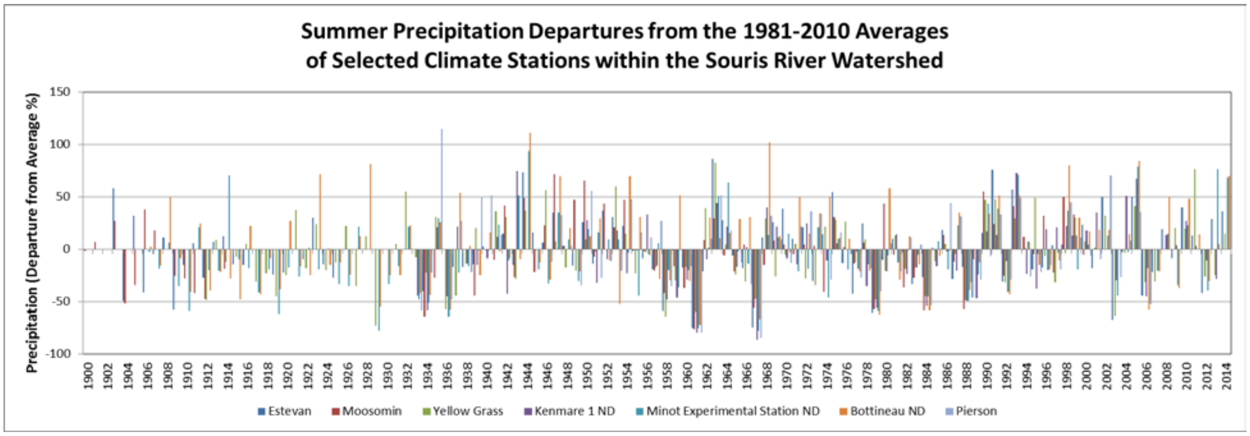


Figure 110 Summer Precipitation Departures from the 1981-2010 Averages of Selected Climate Station in the Souris River Watershed

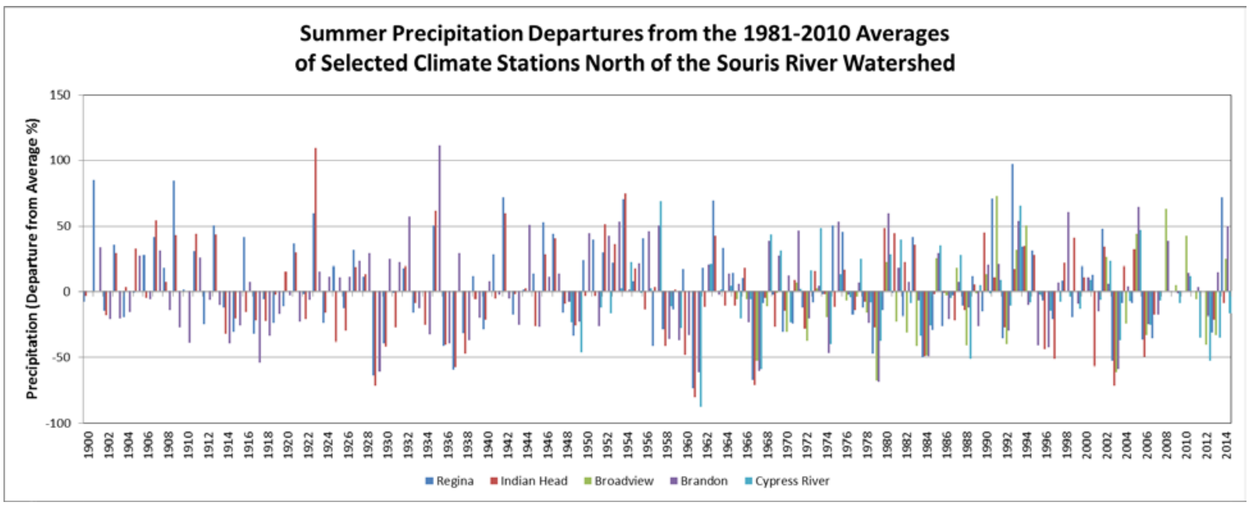


Figure 111 Summer Precipitation Departures from the 1981-2010 Averages of Selected Climate Station north of the Souris River Watershed

Autumn Precipitation Departures from the 1981-2010 Average

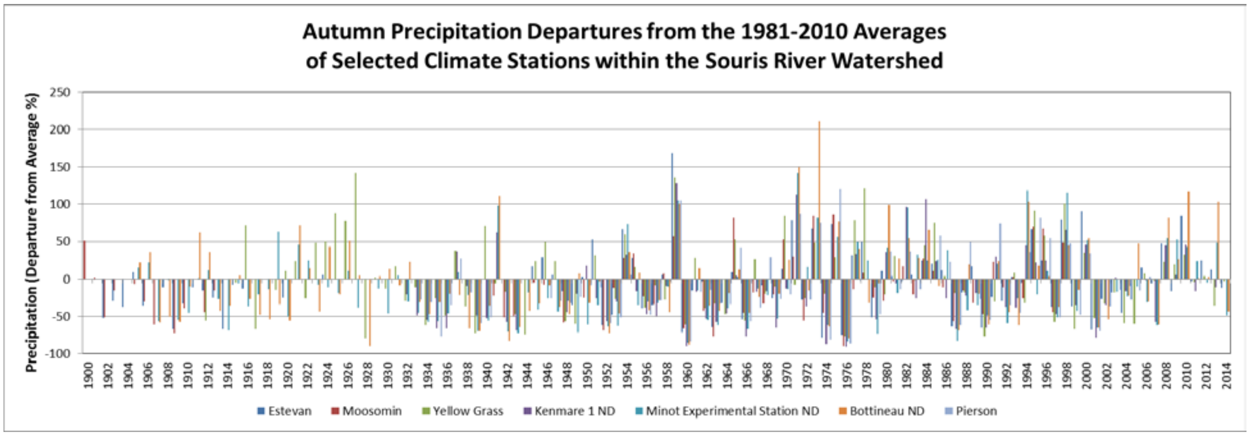


Figure 112 Autumn Precipitation Departures from the 1981-2010 Averages of Selected Climate Station in the Souris River Watershed

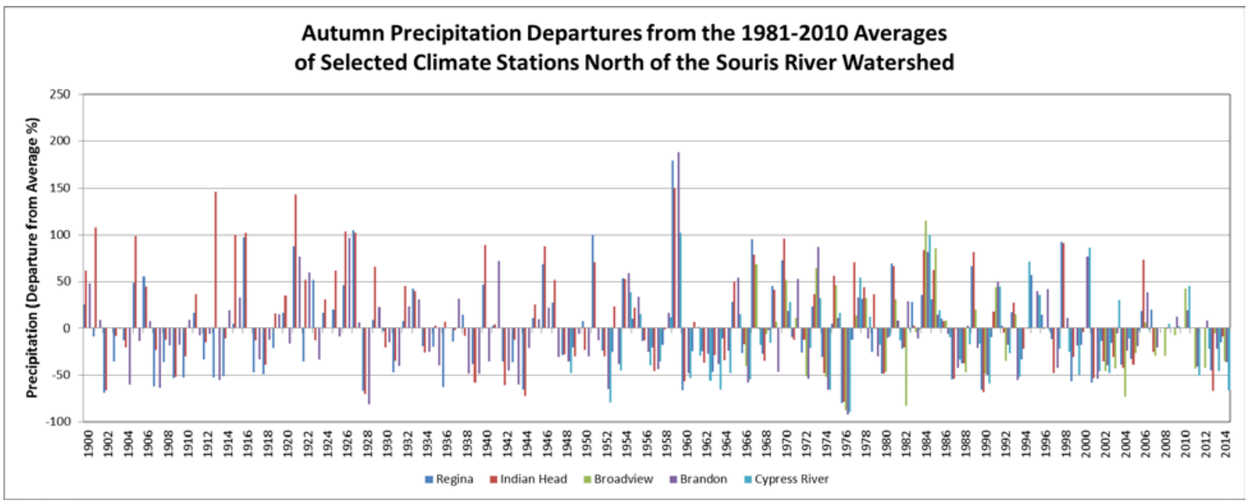
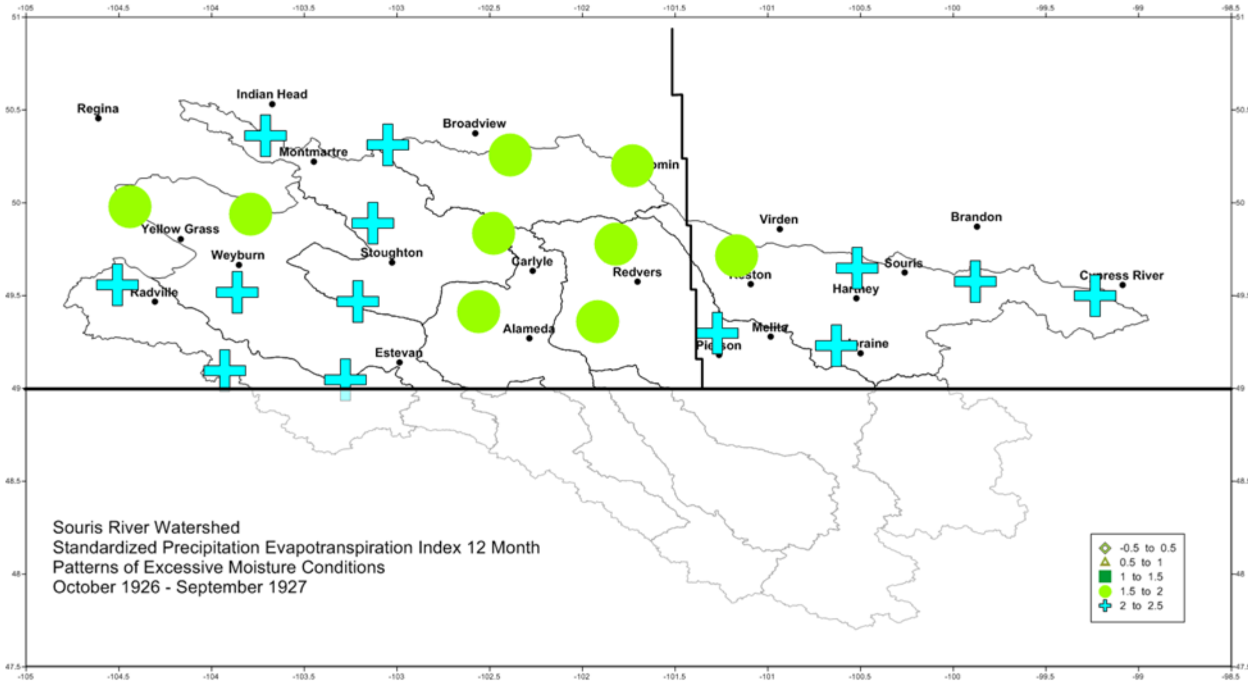
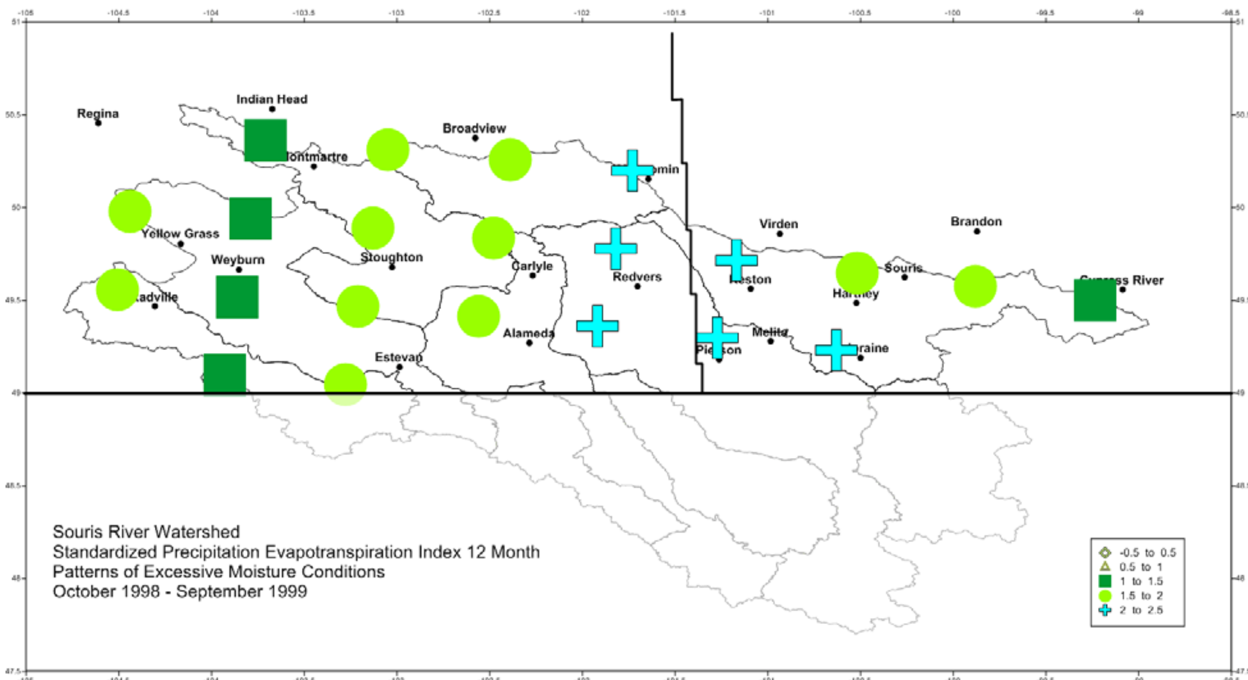
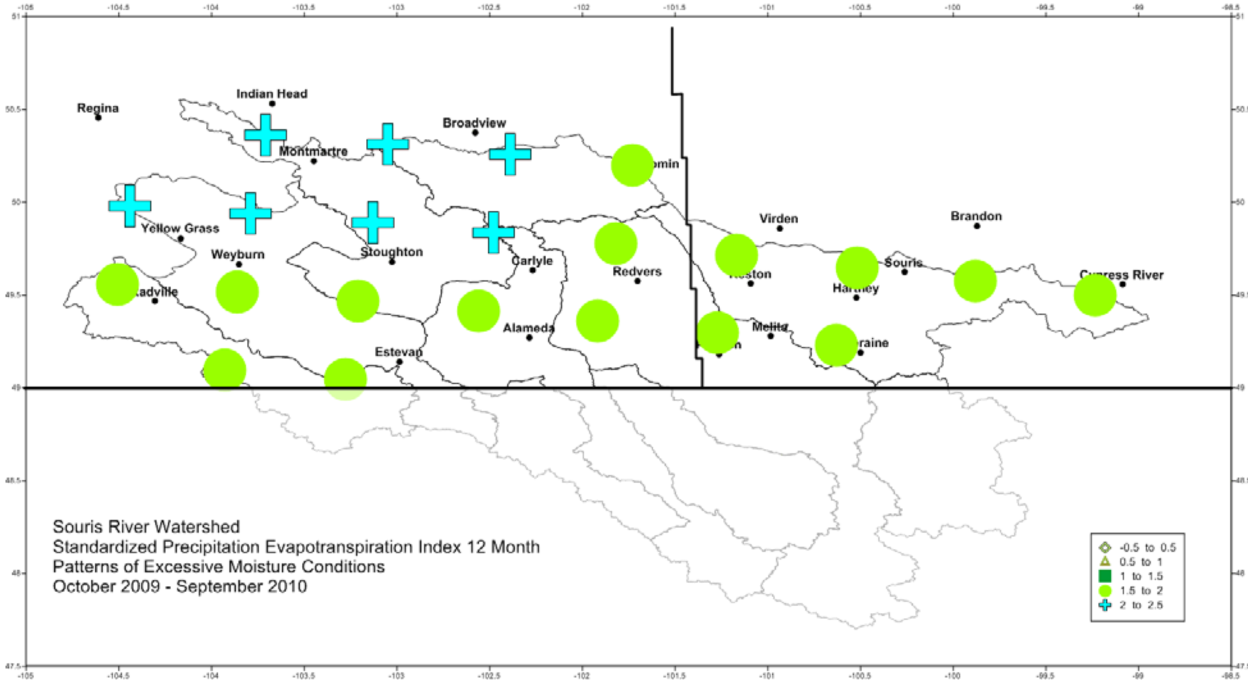


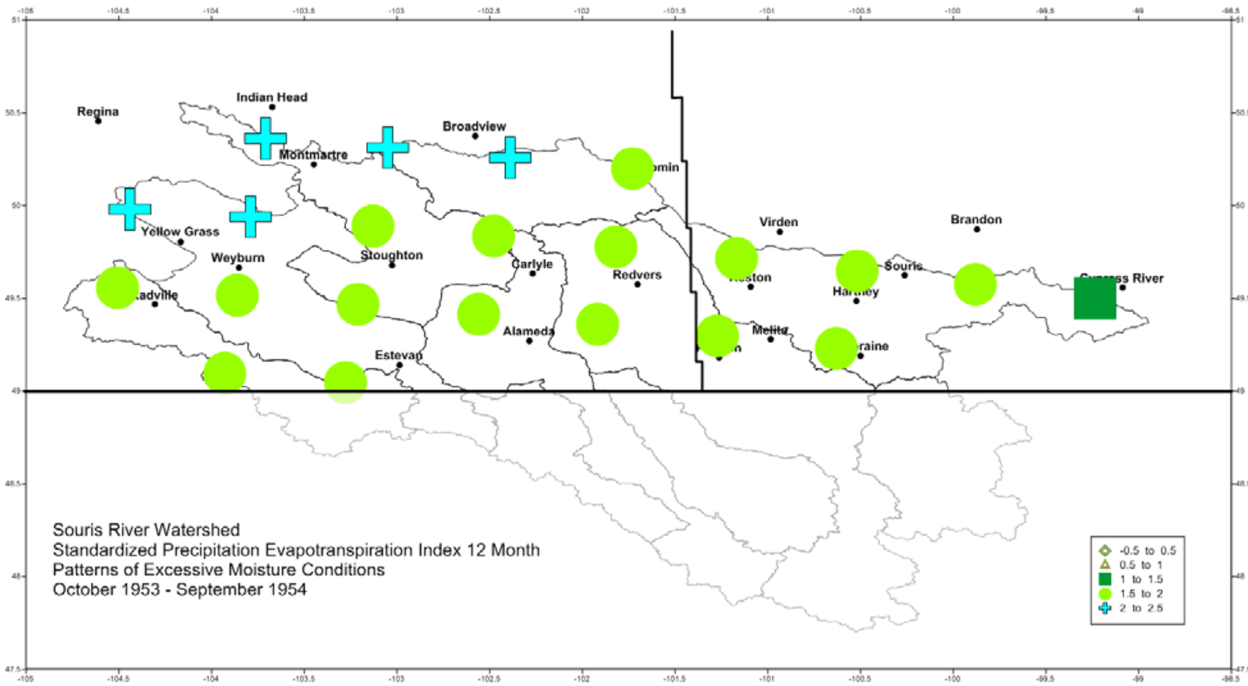
Figure 113 Autumn Precipitation Departures from the 1981-2010 Averages of Selected Climate Station north of the Souris River Watershed

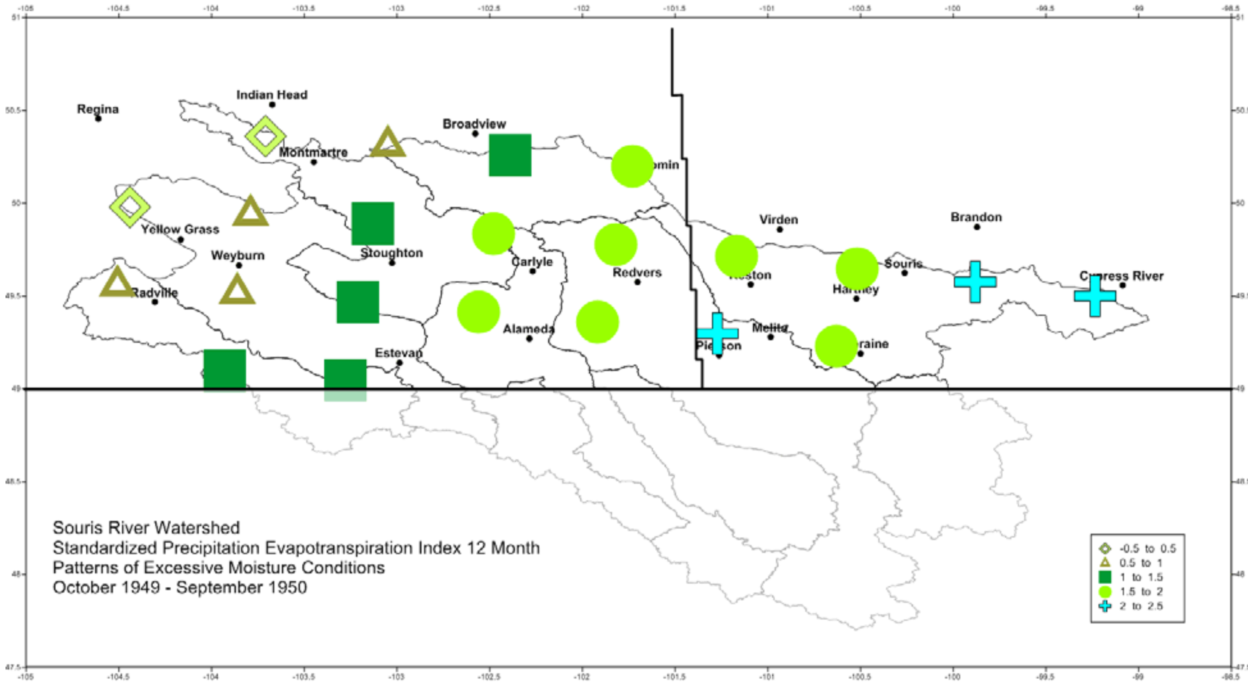
APPENDIX 6 STANDARDIZED PRECIPITATION EVAPOTRANSPIRATION INDEX SPATIAL VARIABILITY – HYDROLOGIC YEAR (OCTOBER TO SEPTEMBER) 10 MOST EXTREME EXCESSIVE MOISTURE AND DROUGHT YEARS FOR THE 1901-2011 PERIOD

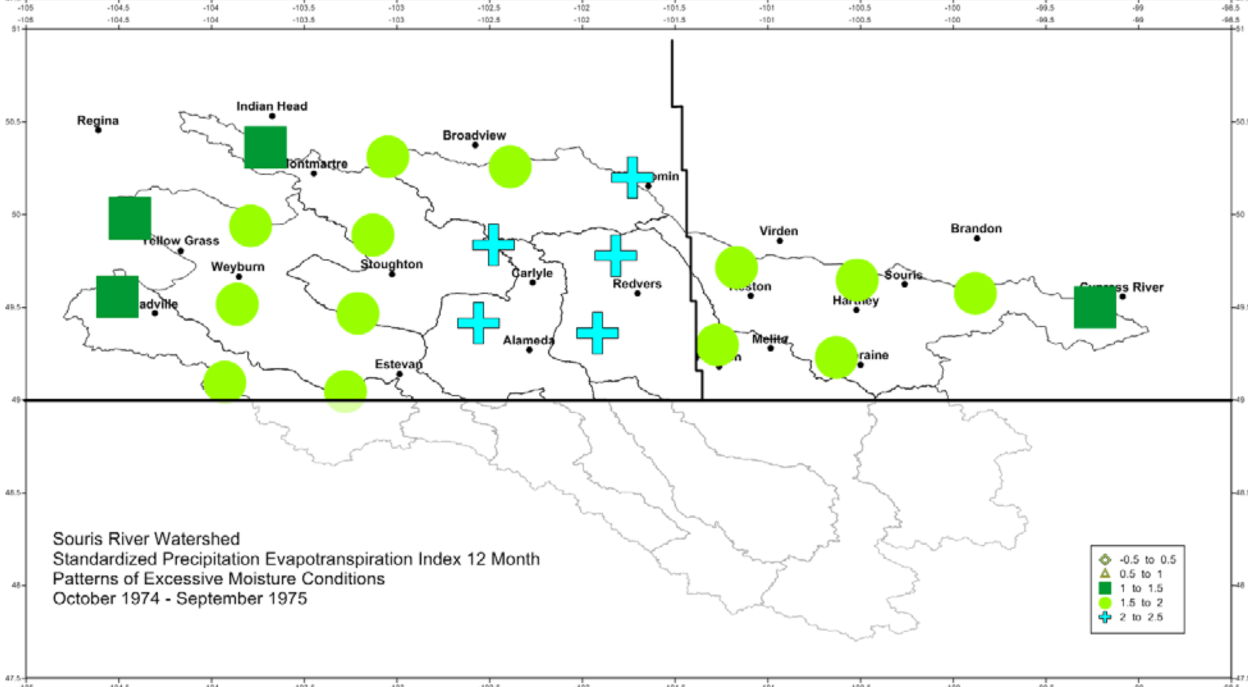

Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1926 - September 1927
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
Regina
Indian Head
Broadview
Montmartre
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Radville
Alameda
Estevan
Virden
Brandon
Souris
Cypress River

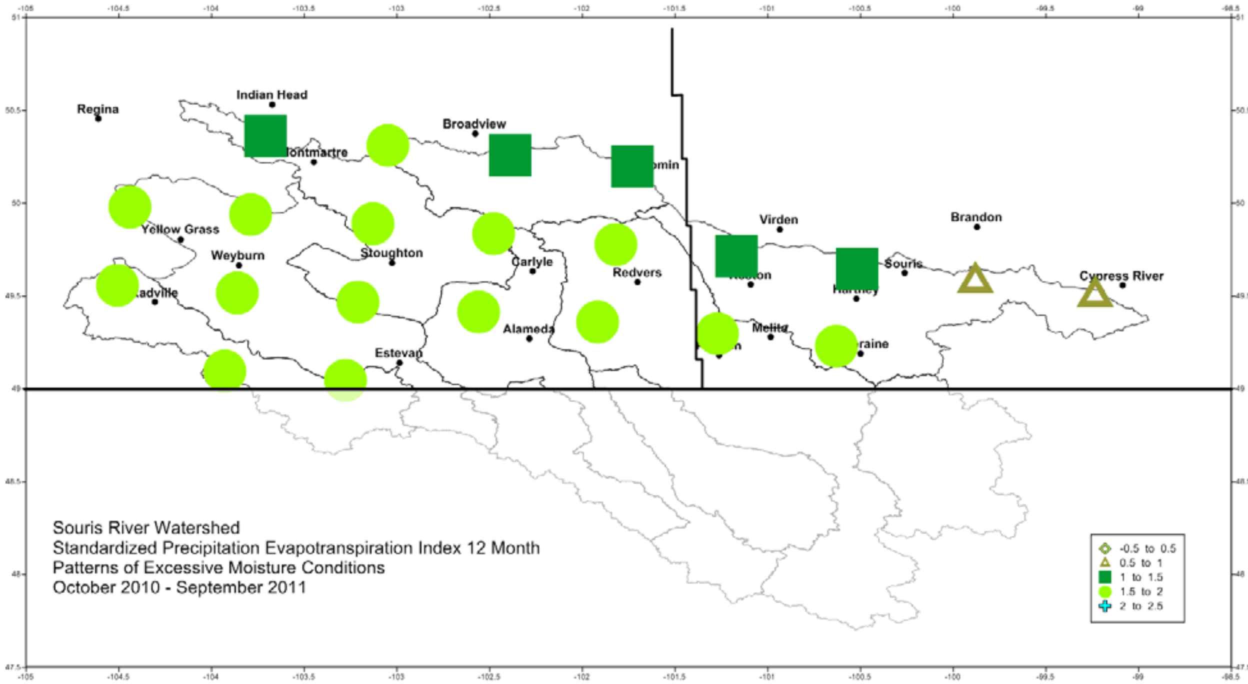

Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1998 - September 1999
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
Regina
Indian Head
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Alameda
Estevan
Virden
Brandon
Souris

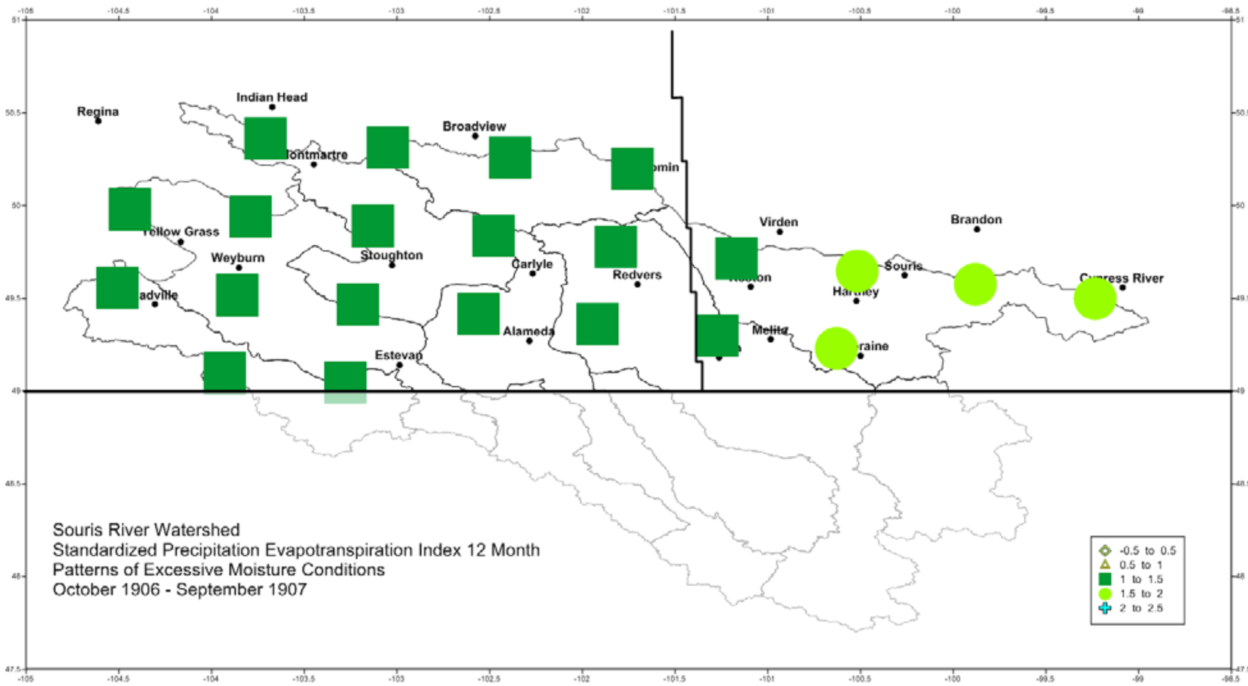

Regina
Indian Head
Broadview
Montmartre
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Souris
Alameda
Estevan
Melita
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 2009 - September 2010
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5

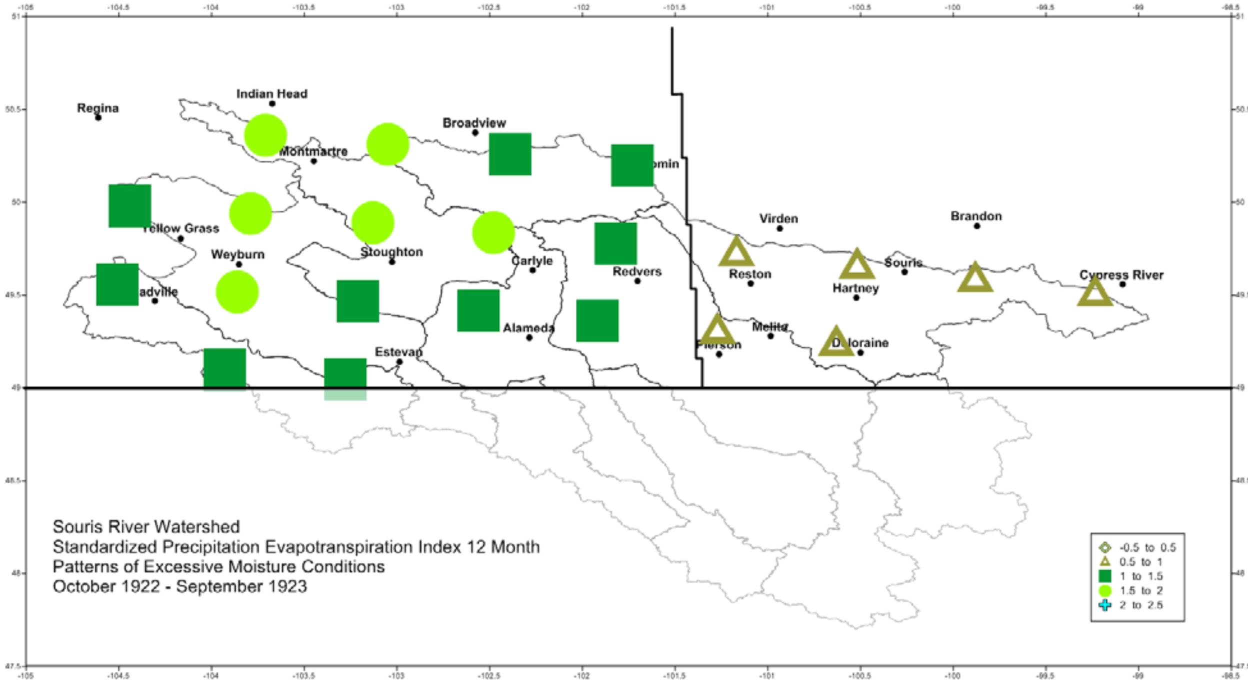

Regina
Indian Head
Broadview
Montmartre
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Souris
Alameda
Estevan
Melita
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1953 - September 1954
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5


Regina
Indian Head
Montmartre
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Radville
Alameda
Estevan
Melita
Souris
Cypress River
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1949 - September 1950
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5


Regina
Indian Head
Broadview
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Alameda
Estevan
Melita
Souris
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1974 - September 1975
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5


Regina
Indian Head
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Alameda
Estevan
Virden
Brandon
Souris
Cypress River
Melita
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 2010 - September 2011
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5


Regina
Indian Head
Broadview
Weyburn
Stoughton
Carlyle
Redvers
Alameda
Estevan
Virden
Brandon
Souris
Melita
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1906 - September 1907
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5


Regina
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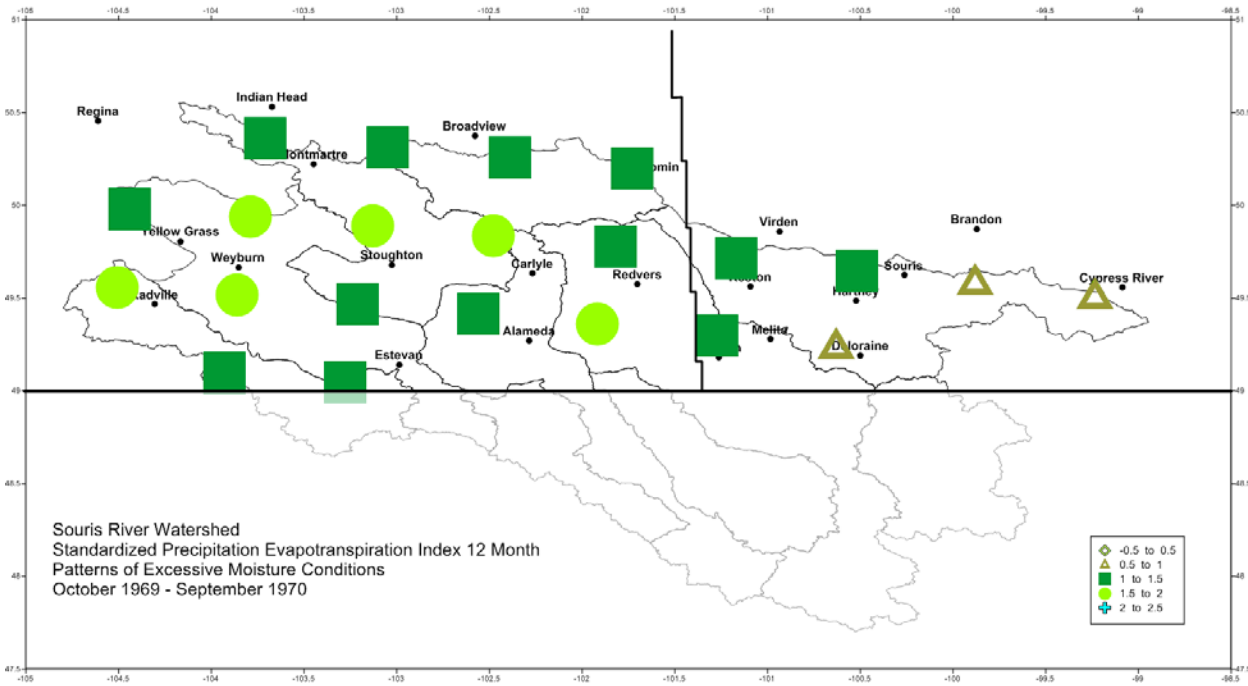
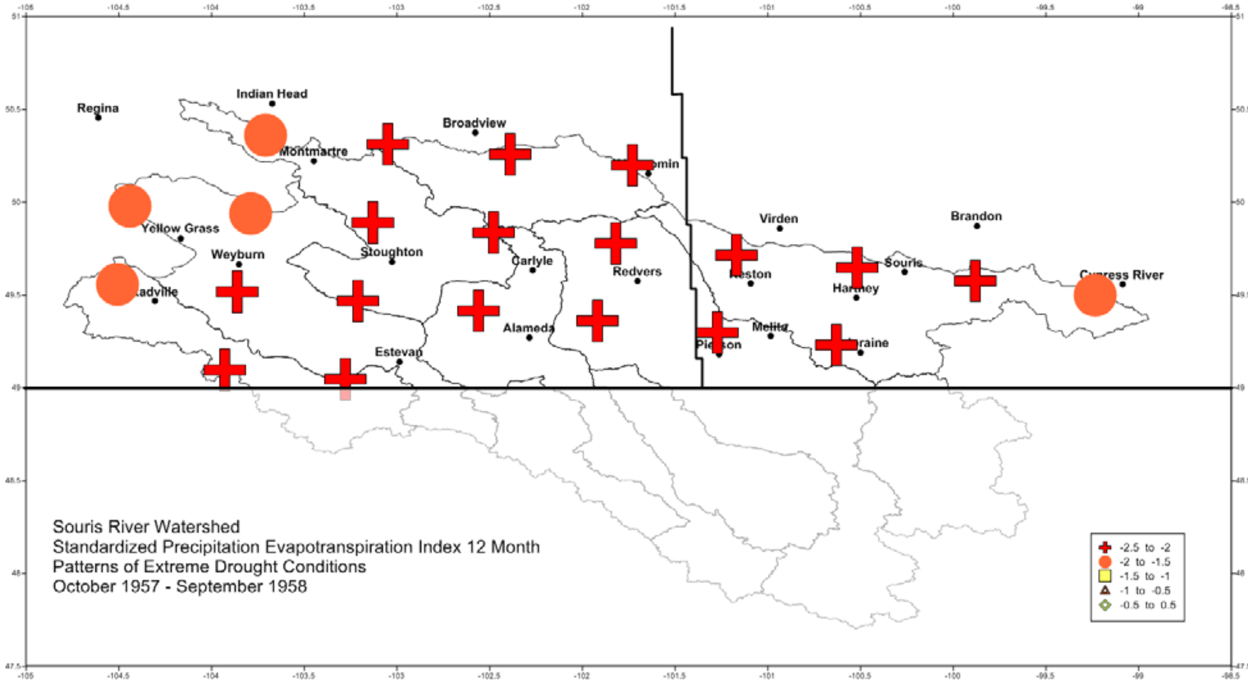
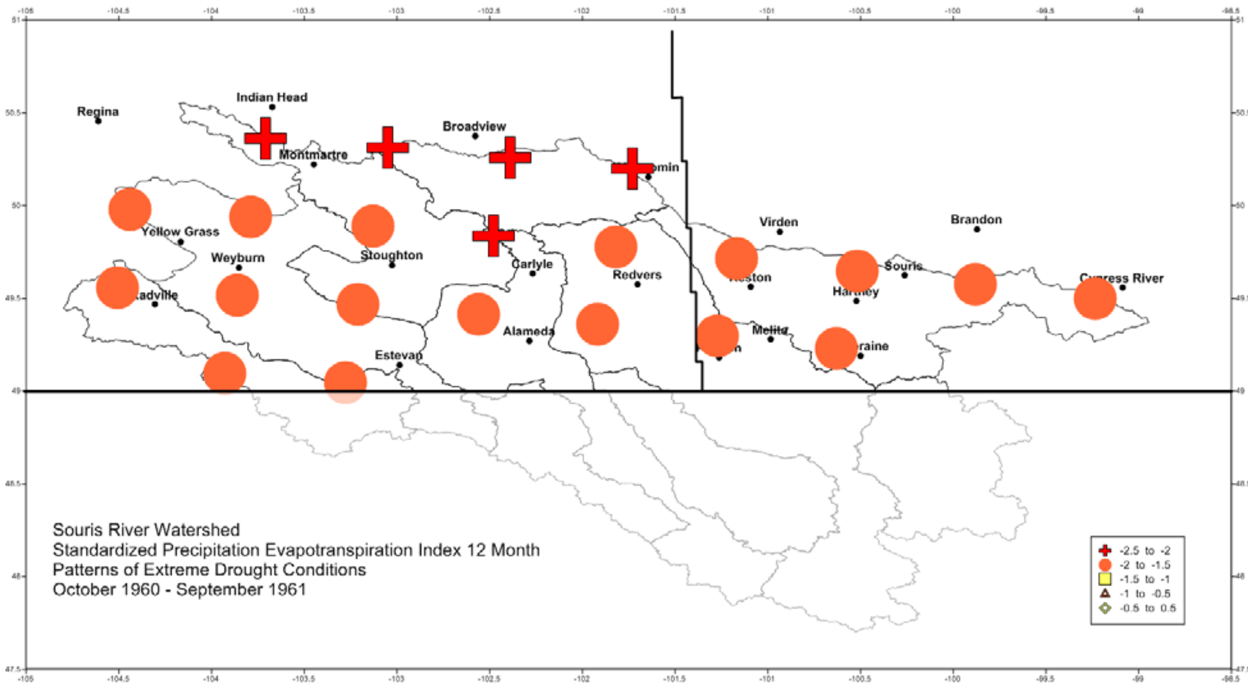
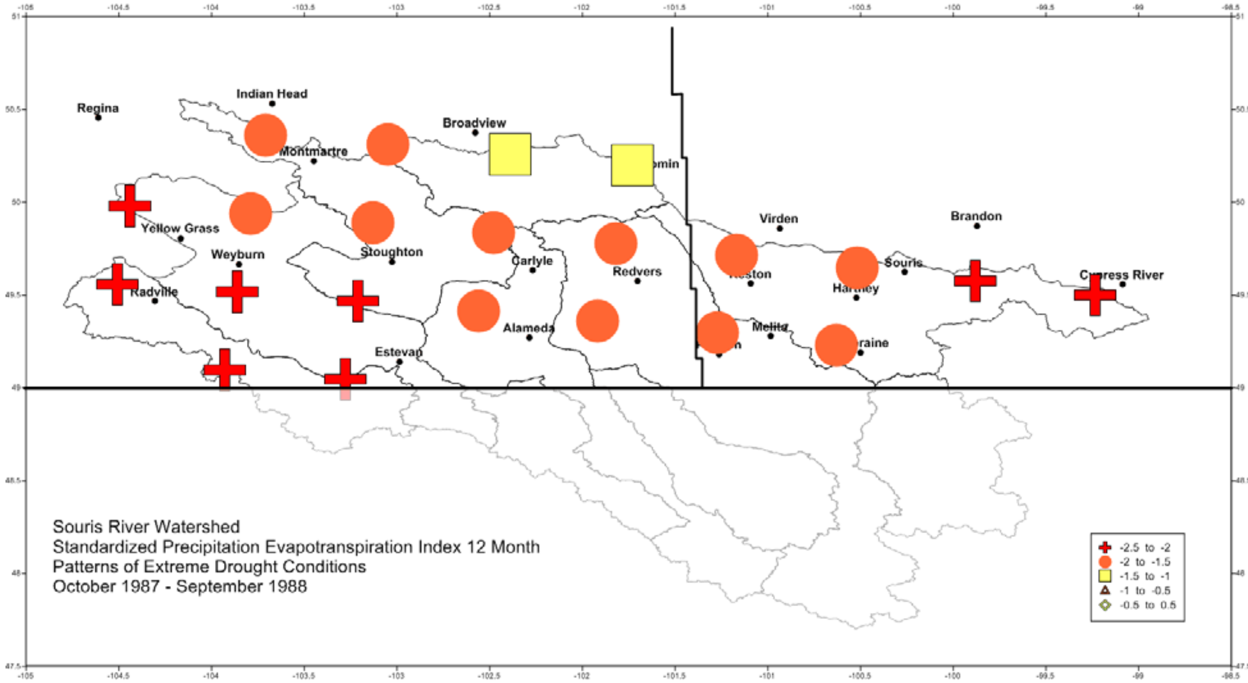
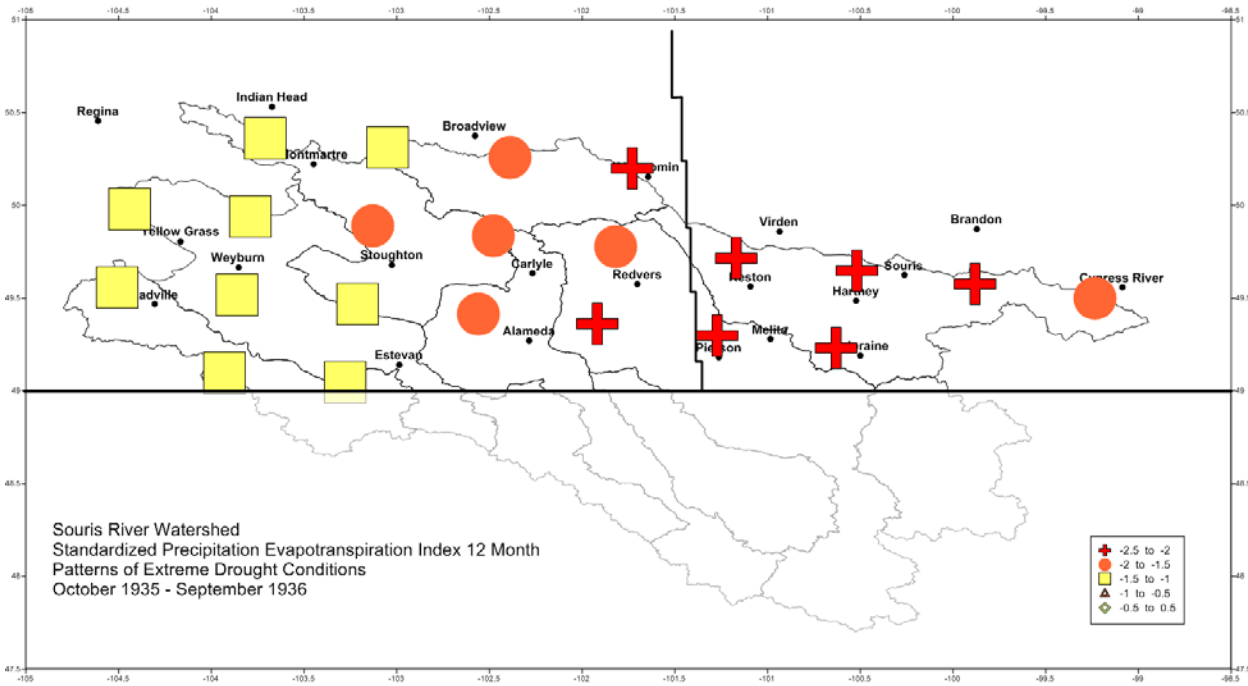
Broadview
Montmartre
Virden
Brandon
Weyburn
Stoughton
Carlyle
Redvers
Reston
Souris
Hartney
Cypress River
Alameda
Melita
Deloraine
Estevan
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1922 - September 1923
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5

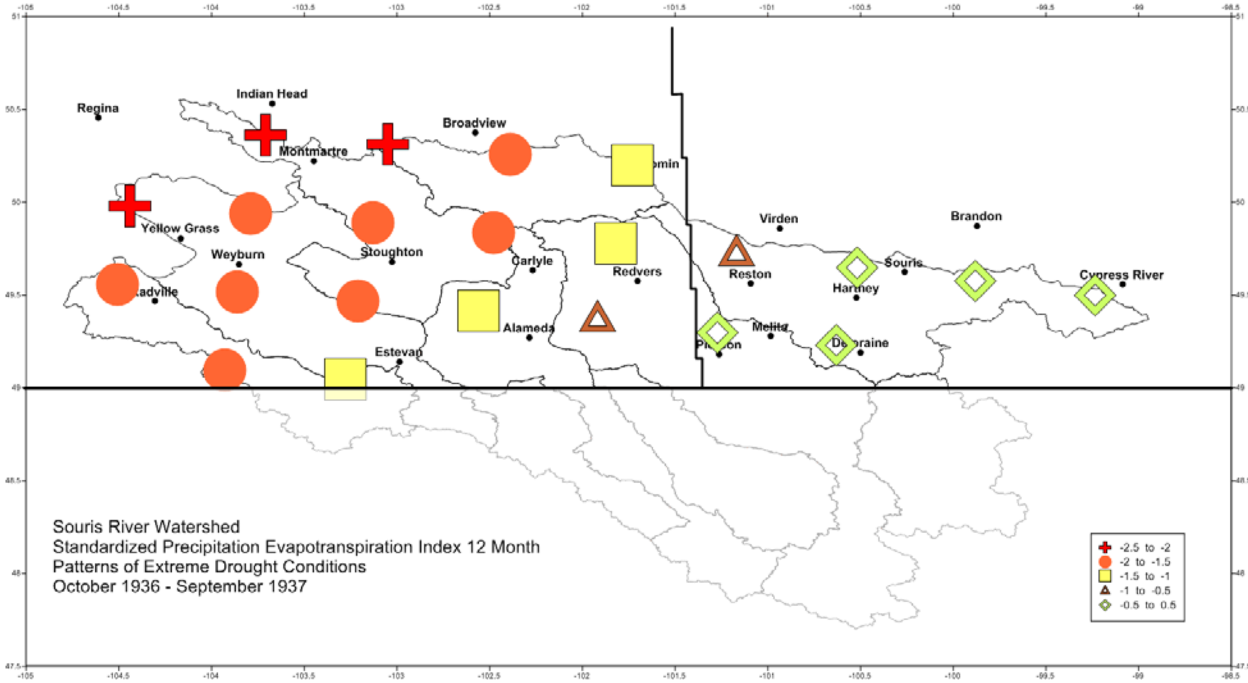

Regina
Indian Head
Broadview
Virden
Brandon
Weyburn
Stoughton
Carlyle
Redvers
Souris
Cypress River
Alameda
Melita
Deloraine
Estevan
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Excessive Moisture Conditions
October 1969 - September 1970
-0.5 to 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5

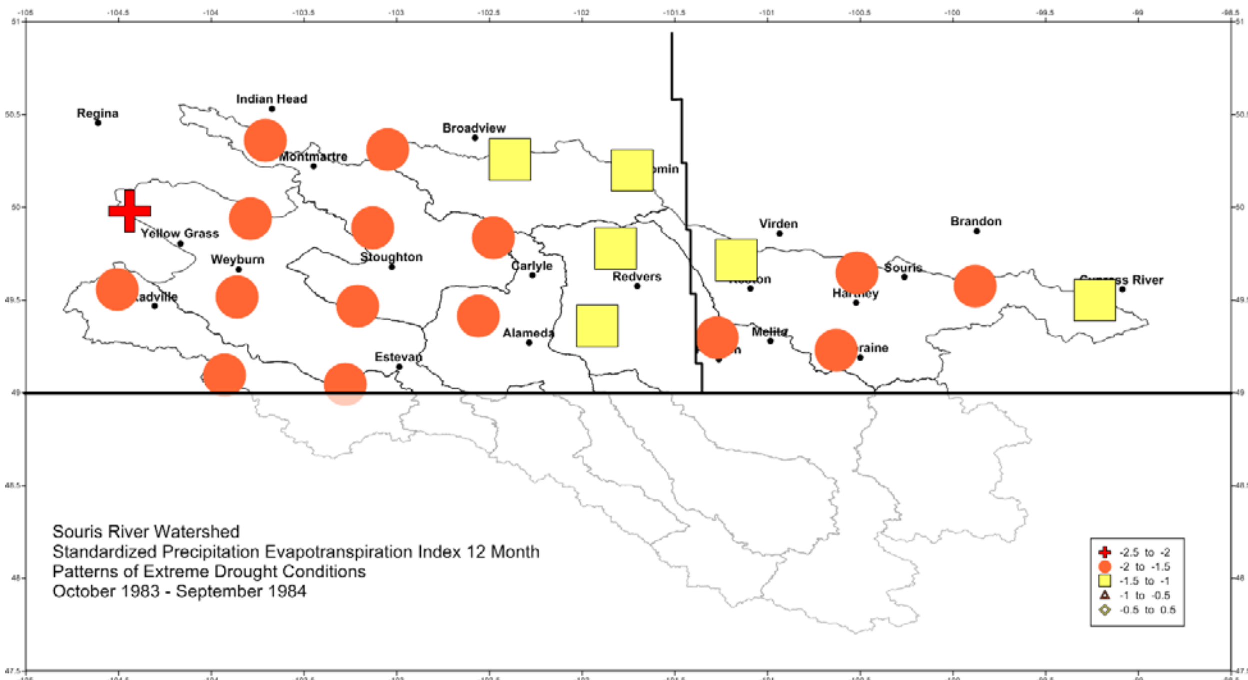

Regina
Indian Head
Montmartre
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Souris
Alameda
Estevan
Melita
Cypress River
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1957 - September 1958
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5

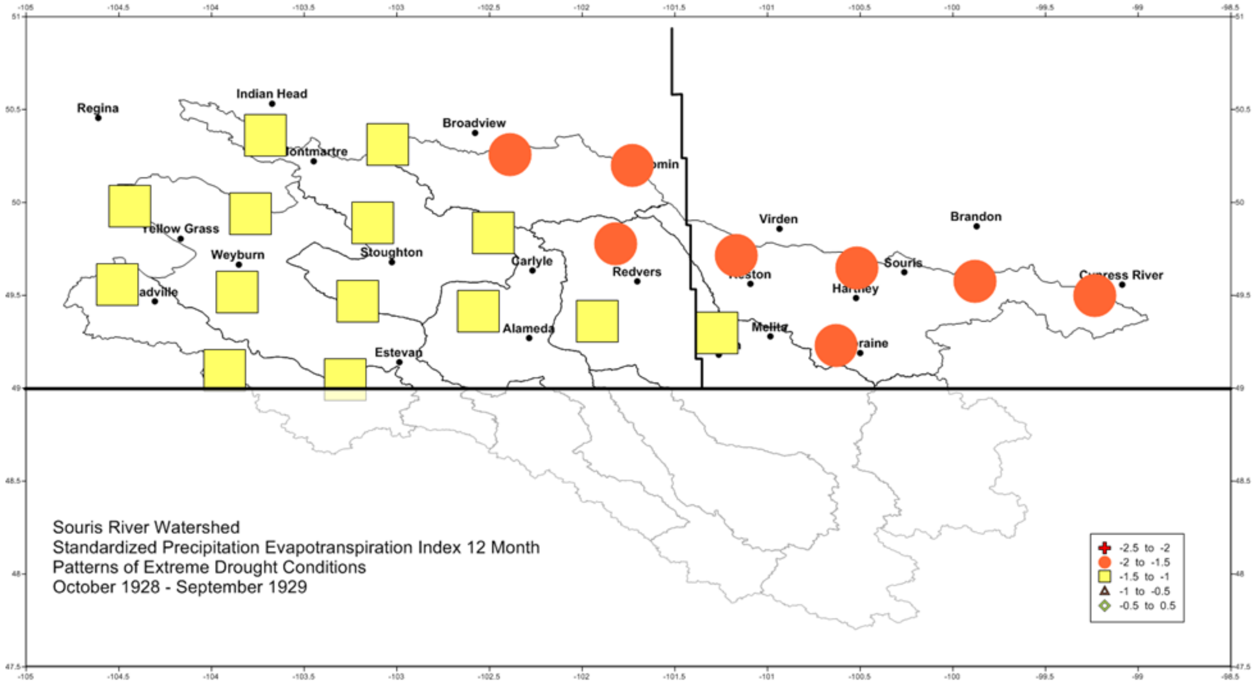

Regina
Indian Head
Montmartre
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Souris
Alameda
Estevan
Melita
Cypress River
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1960 - September 1961
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5

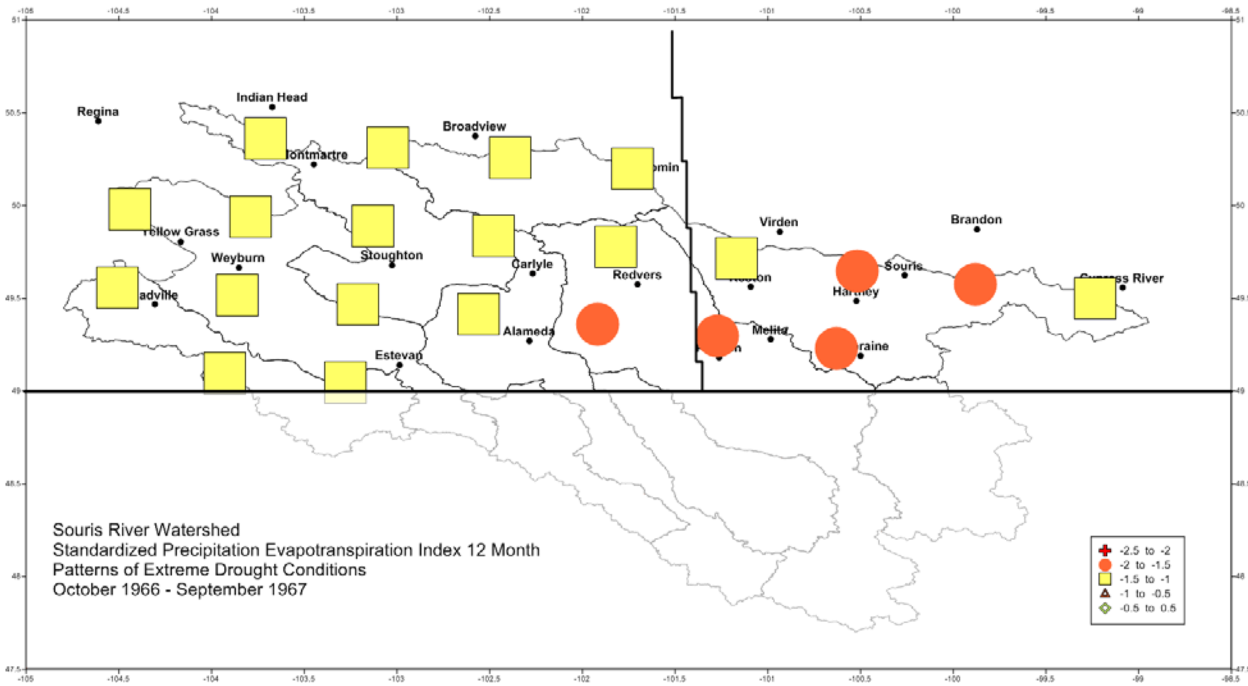

Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1987 - September 1988
Regina
Indian Head
Montmartre
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Souris
Radville
Alameda
Estevan
Melita
Cypress River
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5

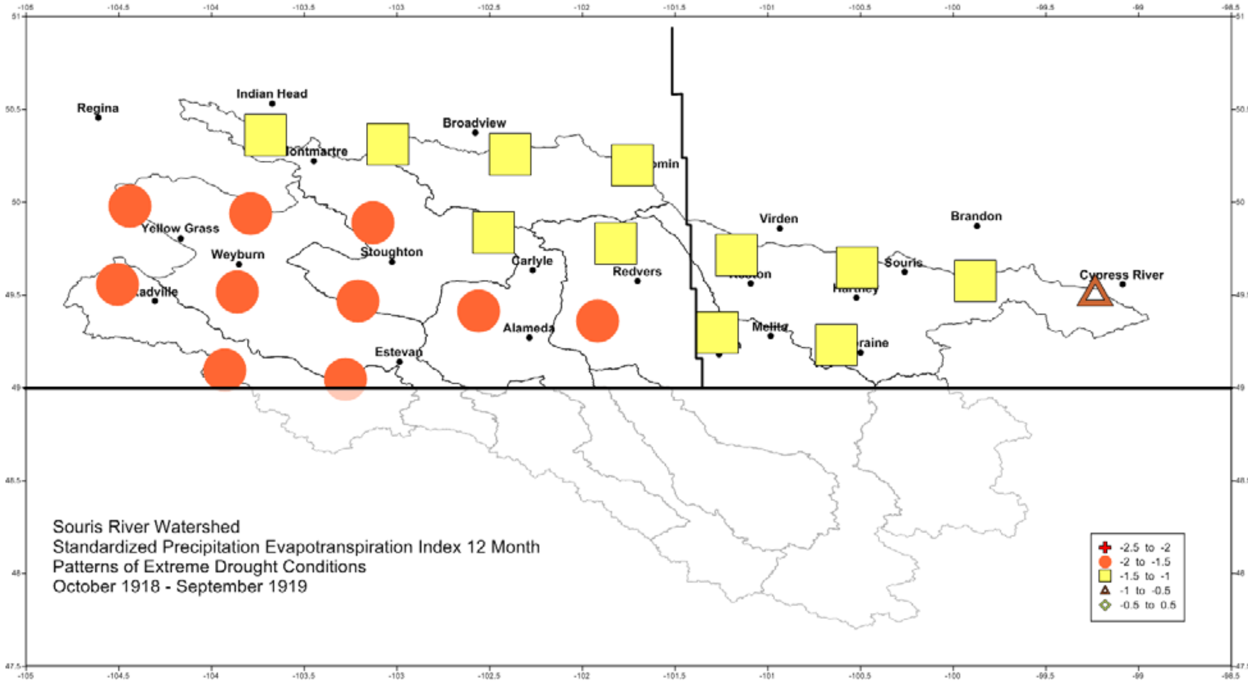

Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1935 - September 1936
Regina
Indian Head
Broadview
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Souris
Alameda
Estevan
Melita
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5

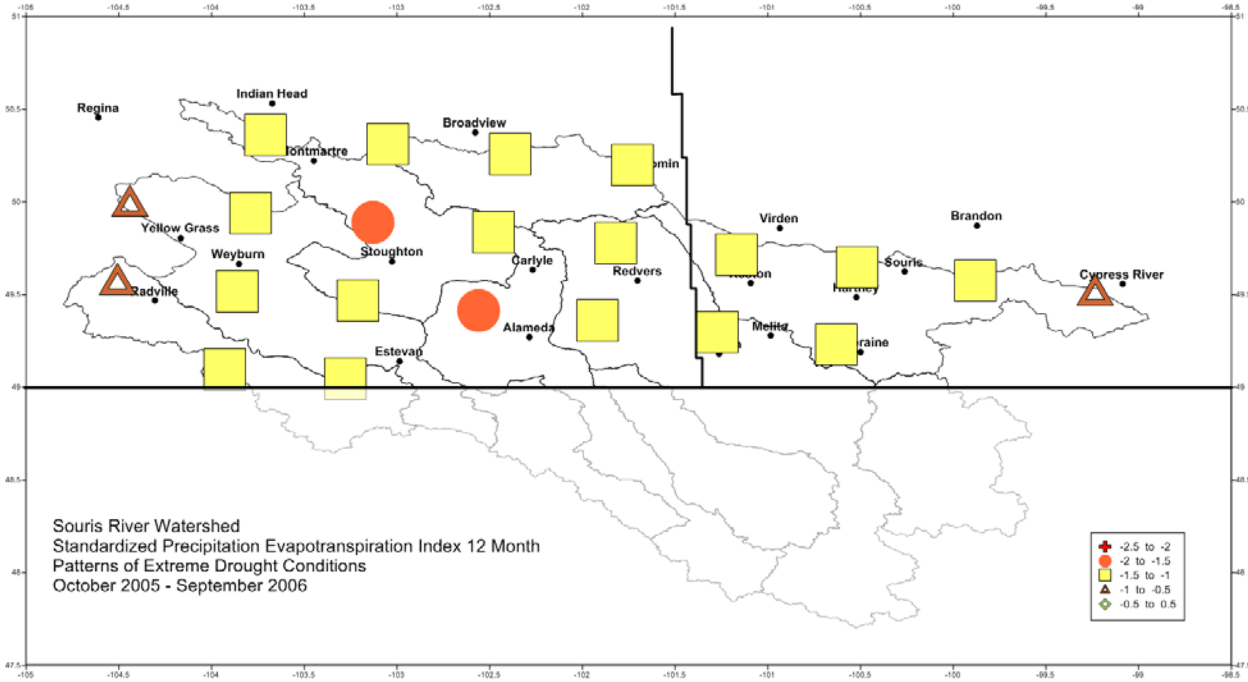

Regina
Indian Head
Montmartre
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Reston
Souris
Hartney
Cypress River
Alameda
Estevan
Melita
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1936 - September 1937
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5


Regina
Indian Head
Montmartre
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Virden
Brandon
Souris
Alameda
Estevan
Melita
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1983 - September 1984
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5

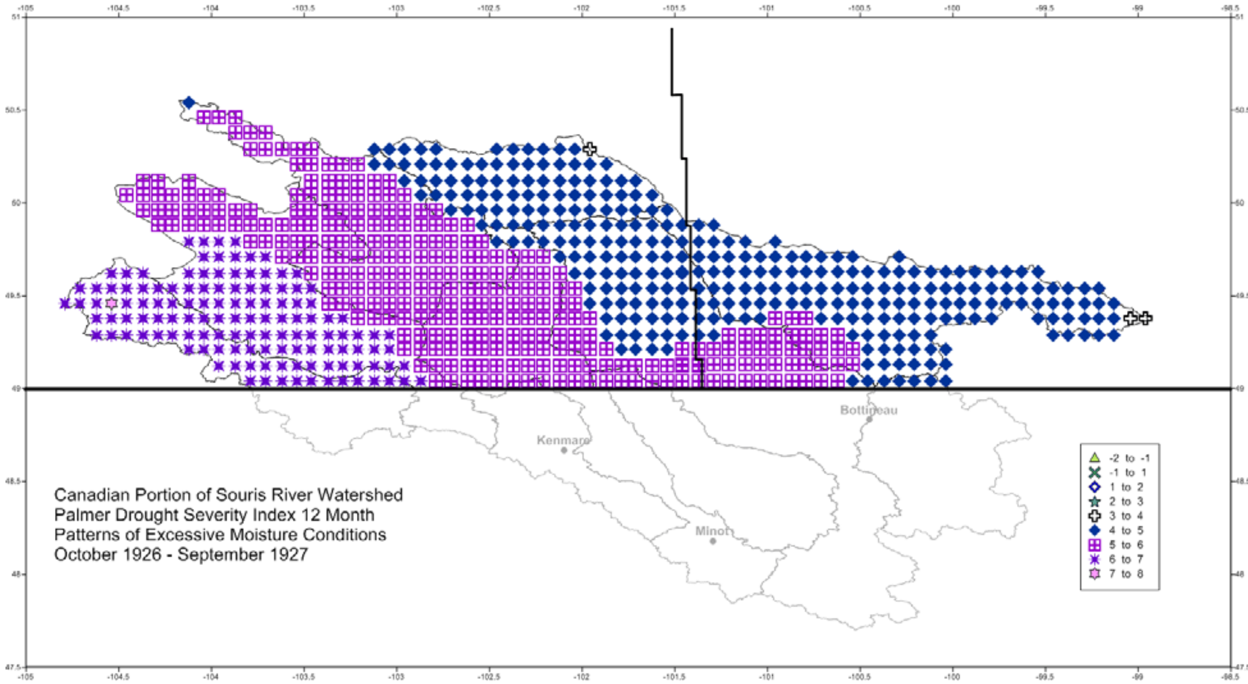

Regina
Indian Head
Broadview
Virden
Brandon
Weyburn
Stoughton
Carlyle
Redvers
Alameda
Estevan
Melita
Souris
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1928 - September 1929
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5


Regina
Indian Head
Broadview
Virden
Brandon
Weyburn
Stoughton
Carlyle
Redvers
Alameda
Estevan
Melita
Souris
Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1966 - September 1967
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5

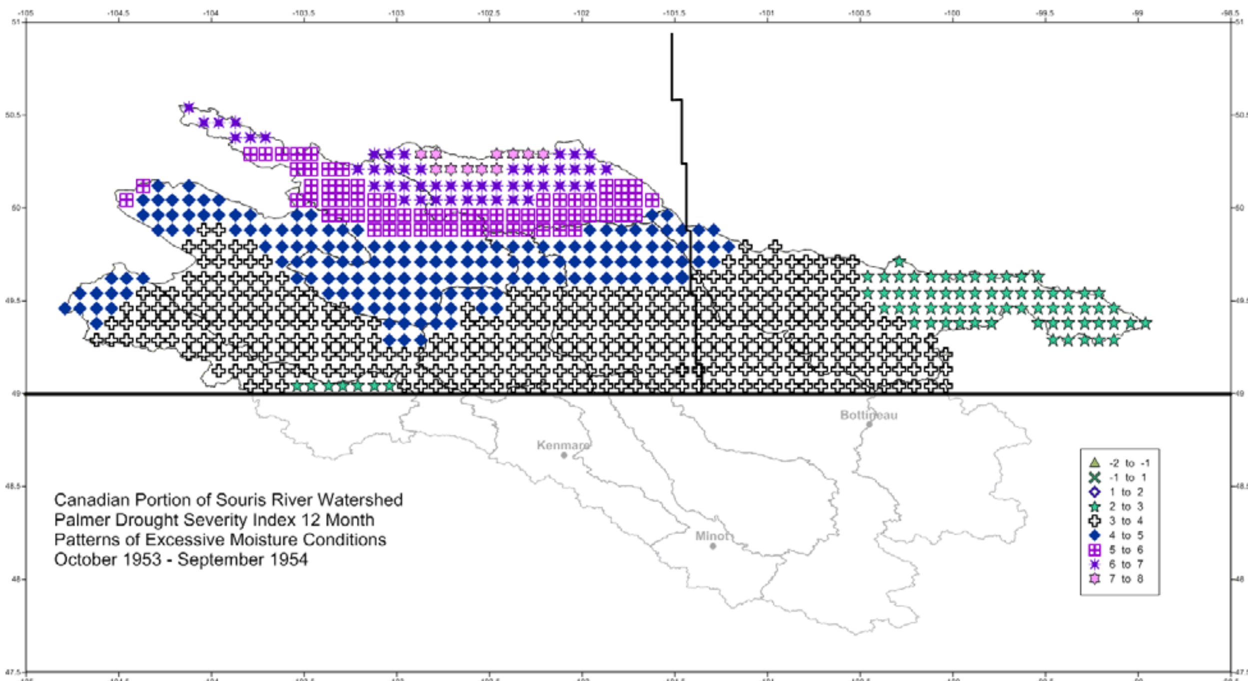

Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 1918 - September 1919
Regina
Indian Head
Broadview
Yellow Grass
Weyburn
Stoughton
Carlyle
Redvers
Alameda
Estevan
Virden
Brandon
Souris
Cypress River
Melita
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5


Souris River Watershed
Standardized Precipitation Evapotranspiration Index 12 Month
Patterns of Extreme Drought Conditions
October 2005 - September 2006
Regina
Indian Head
Broadview
Yellow Grass
Weyburn
Radville
Stoughton
Carlyle
Redvers
Alameda
Estevan
Virden
Brandon
Souris
Cypress River
Melita
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0.5

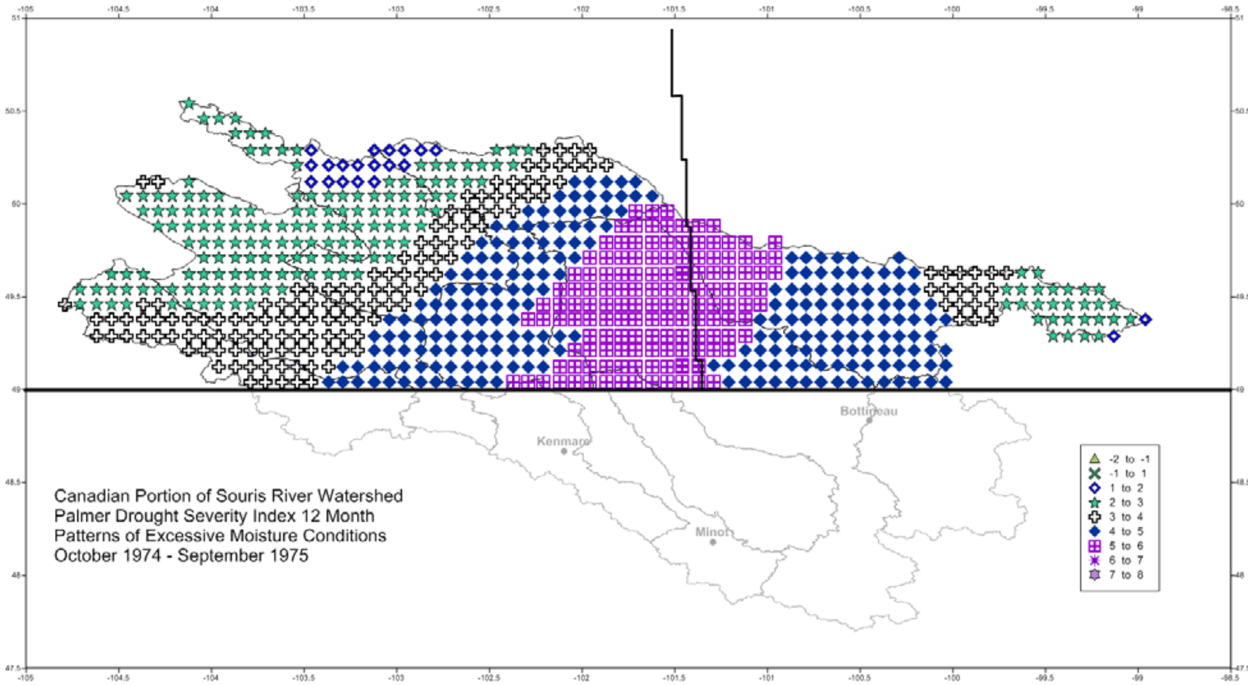
APPENDIX 7 PALMER DROUGHT SEVERITY INDEX - HYDROLOGIC YEAR (OCTOBER TO SEPTEMBER) 10 MOST EXTREME EXCESSIVE MOISTURE AND DROUGHT YEARS FOR THE 1901-2005 PERIOD

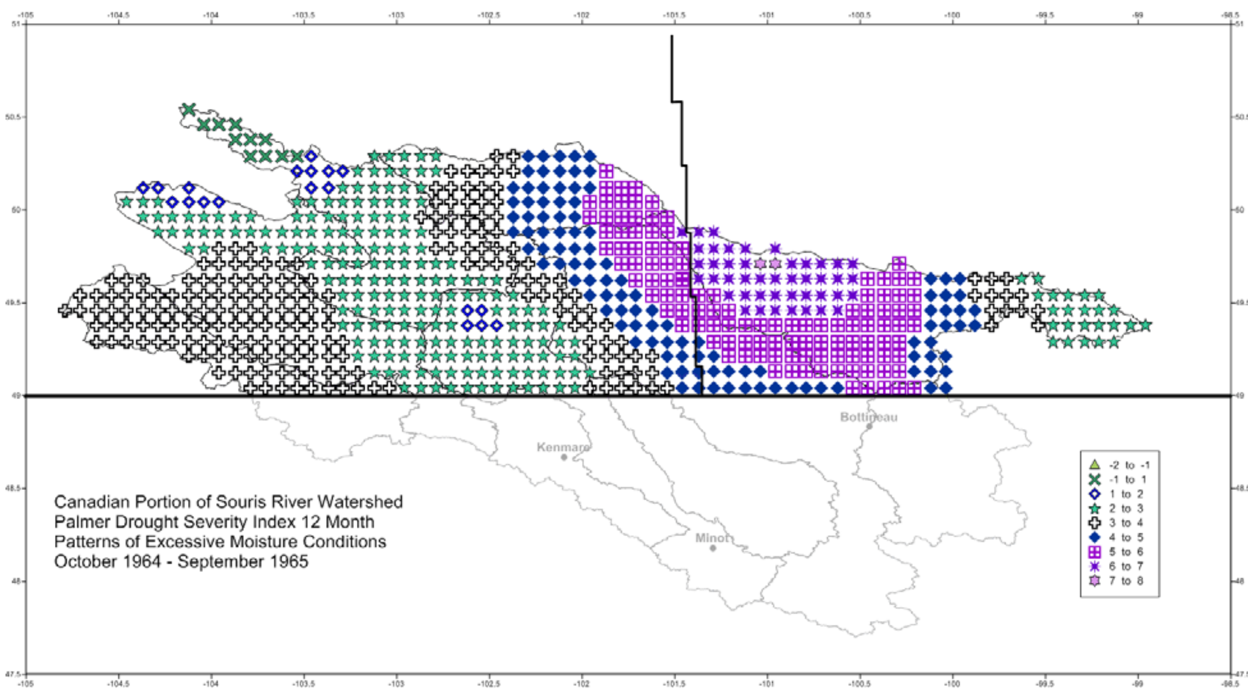


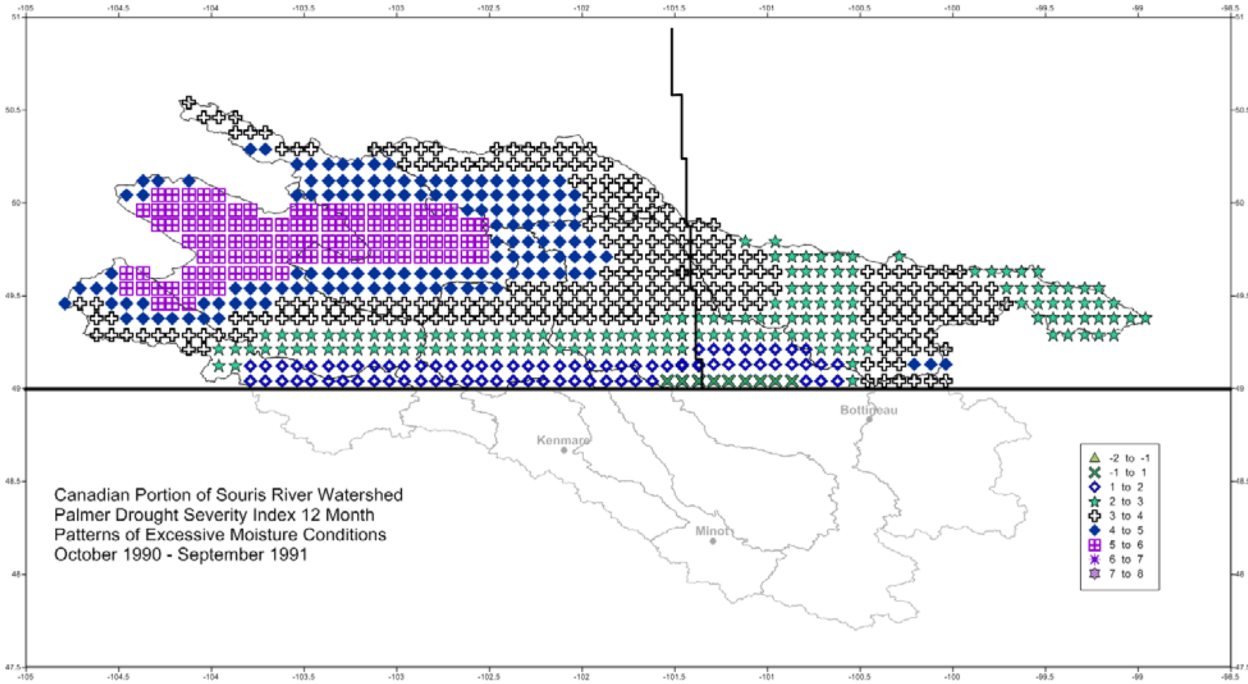
Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1926 - September 1927
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

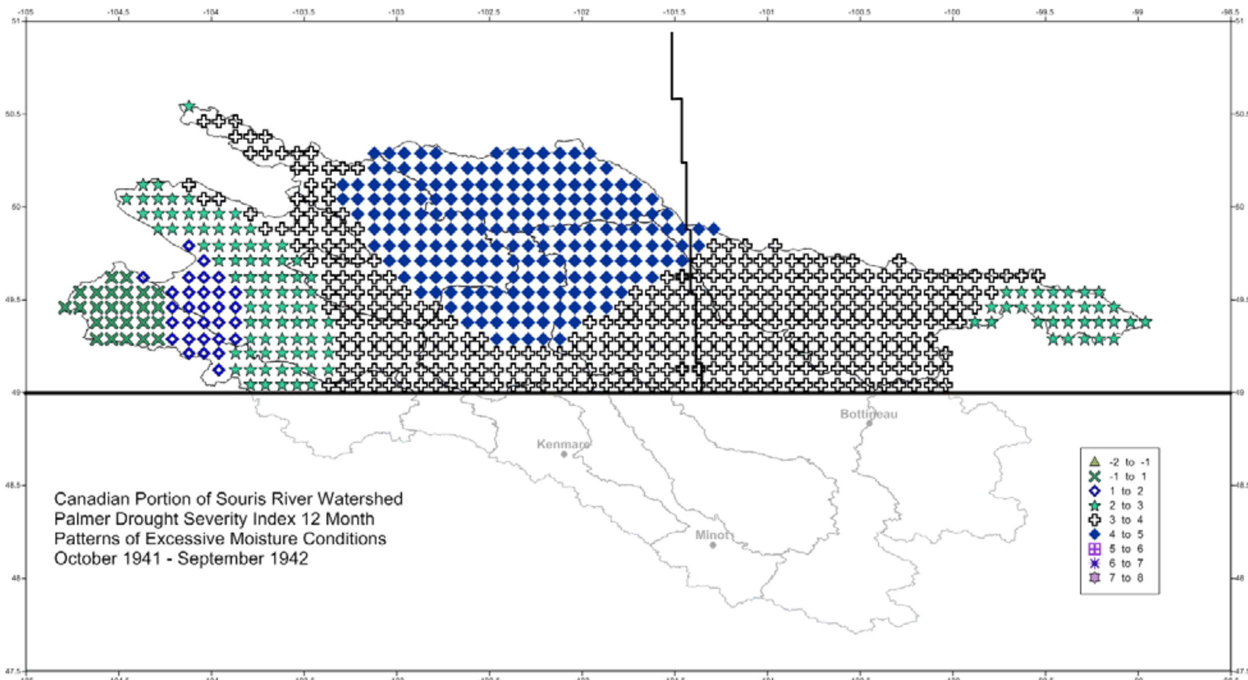


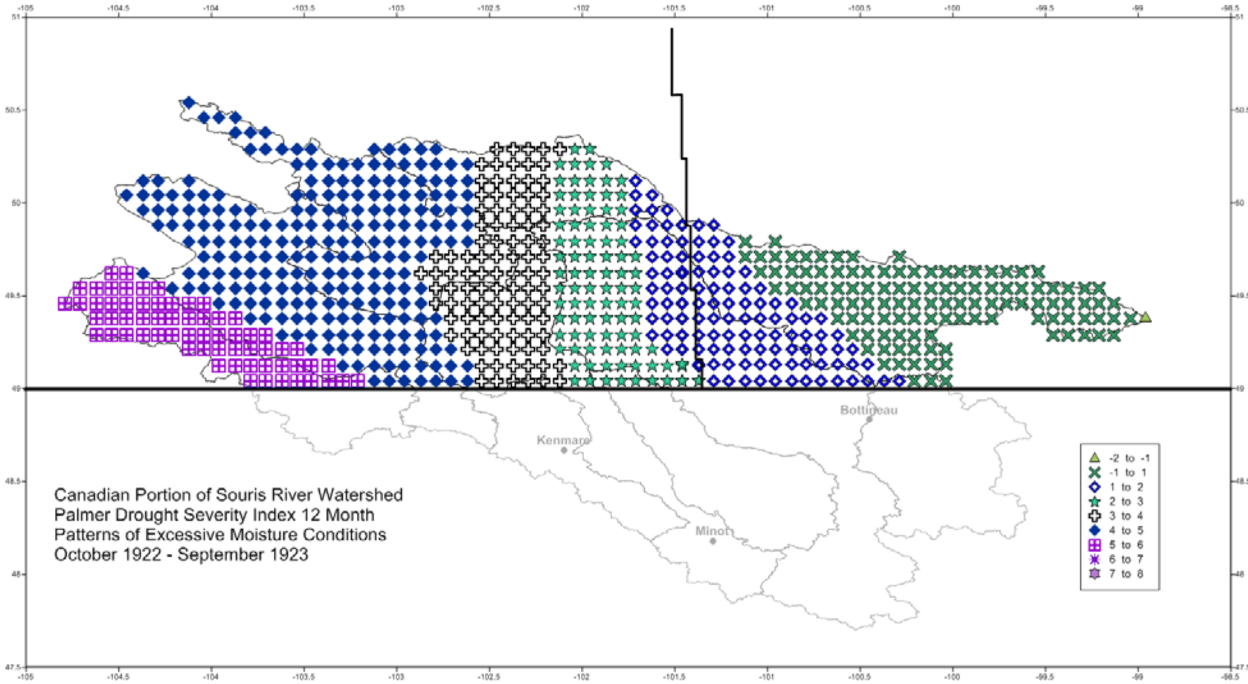
Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1953 - September 1954
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

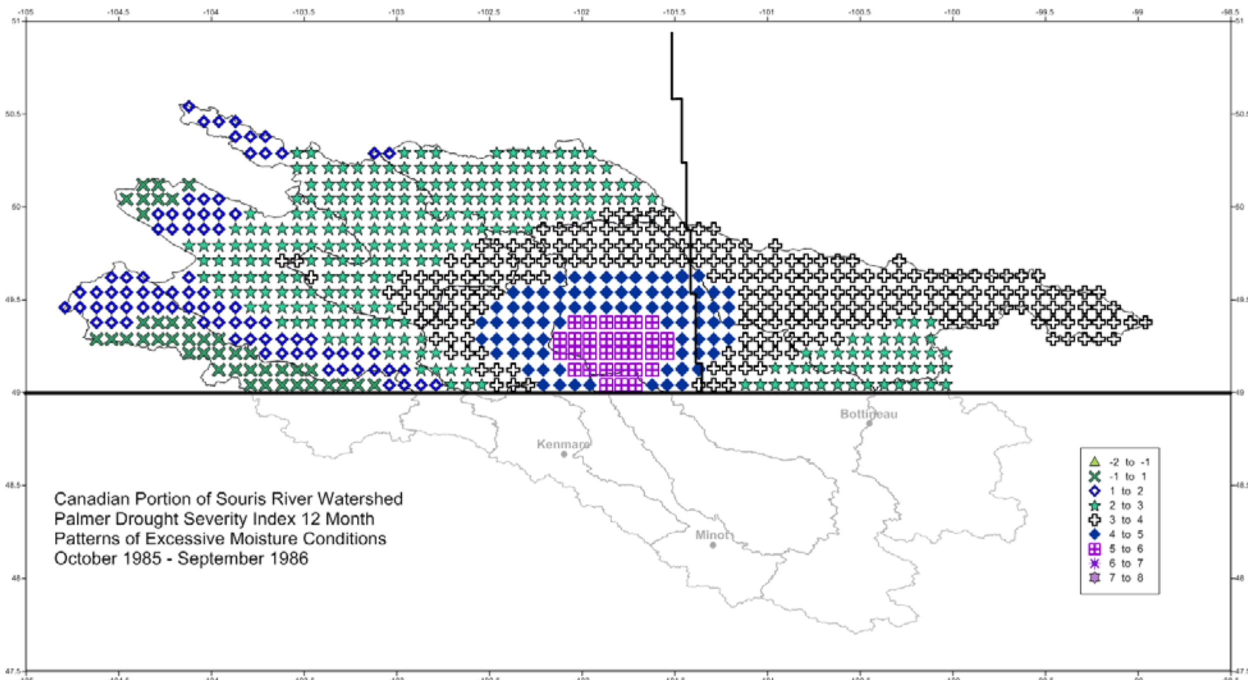

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1974 - September 1975
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

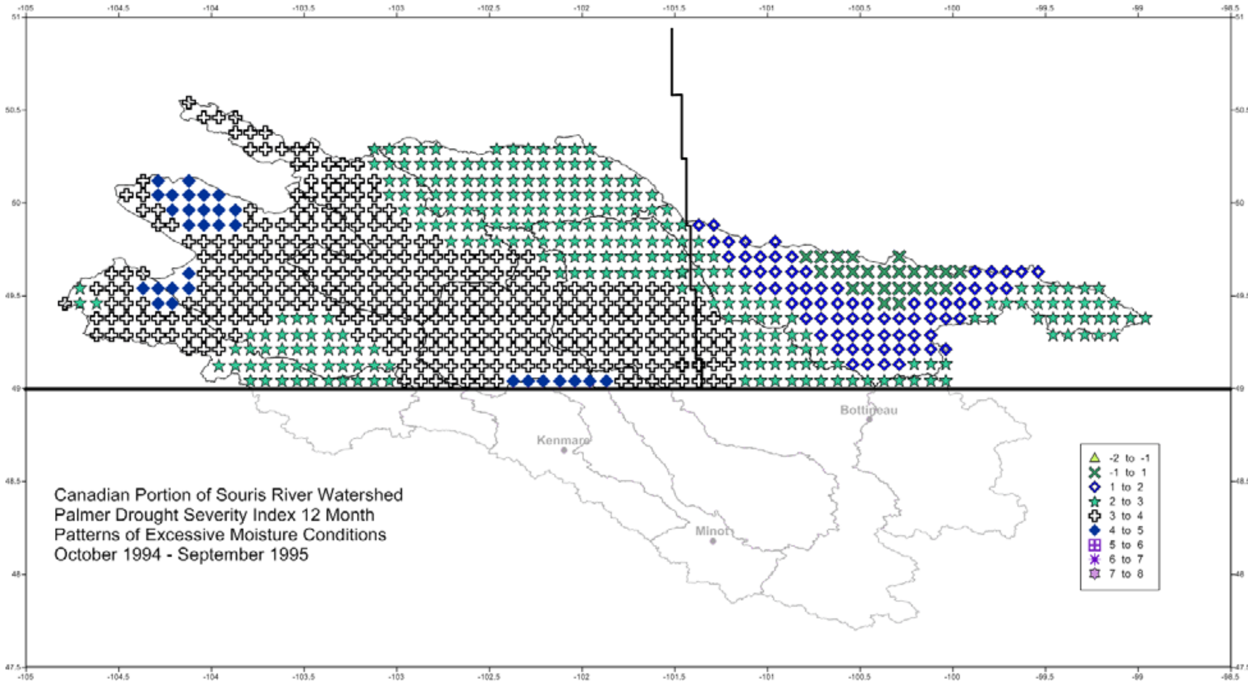

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1964 - September 1965
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

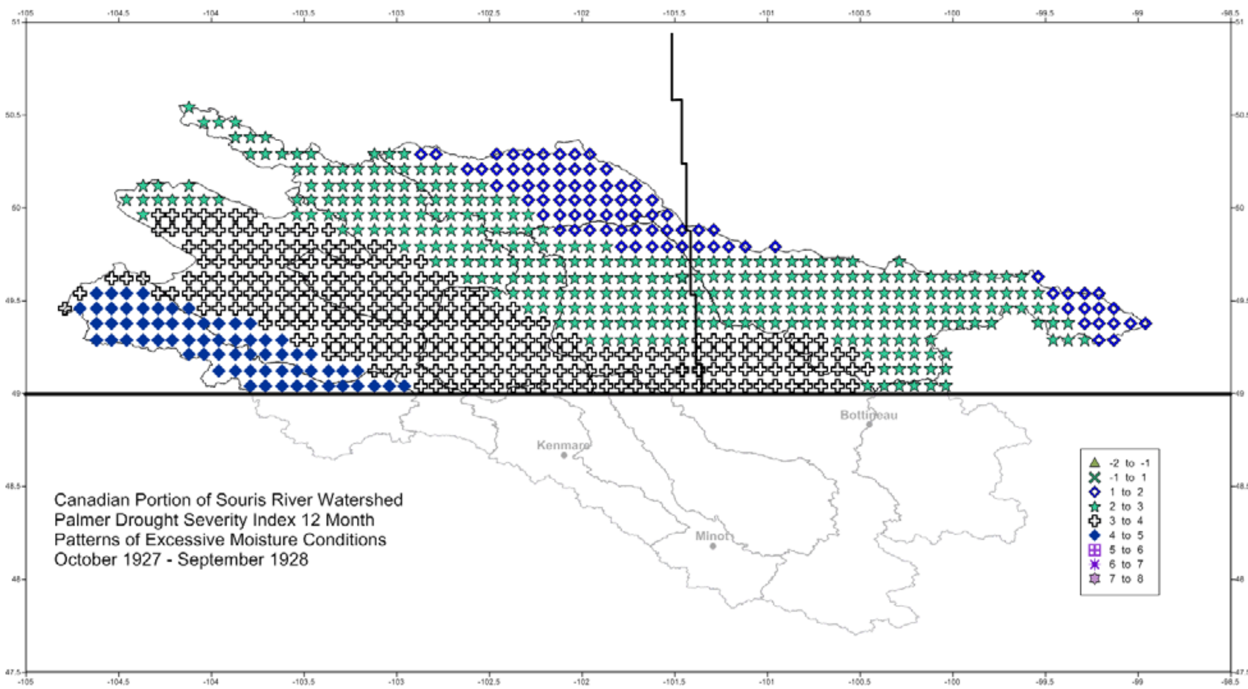

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1990 - September 1991
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8
Bottineau
Kenmare
Minot

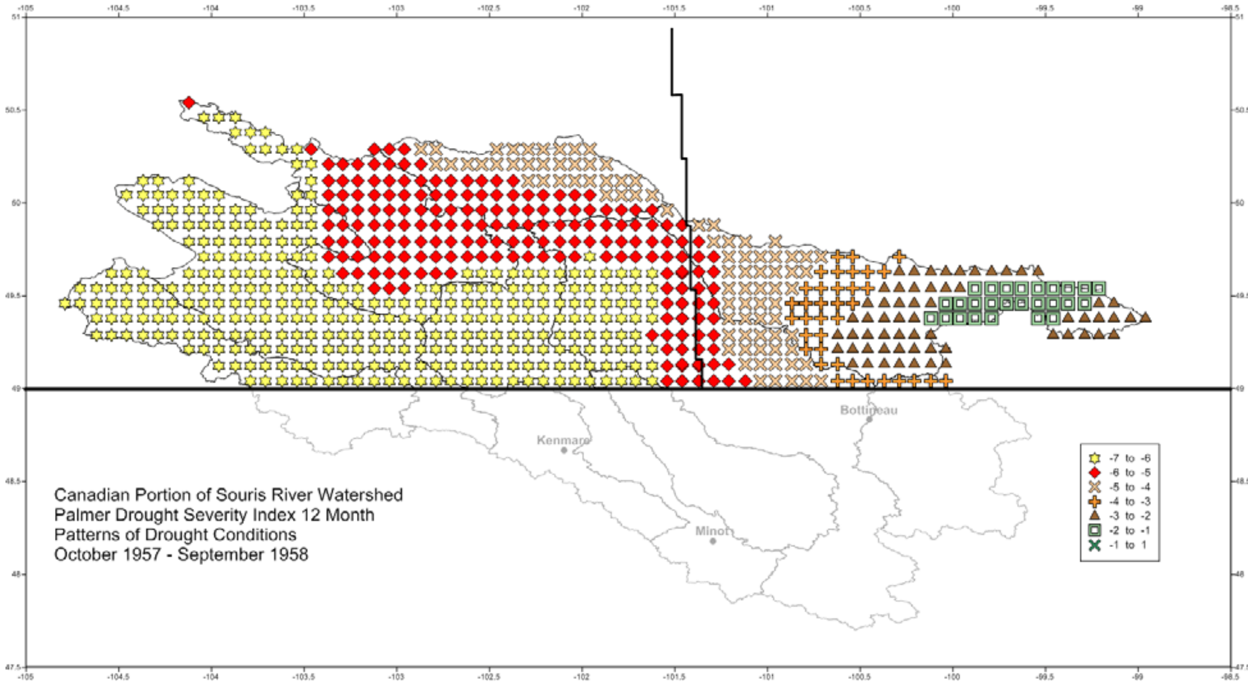

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1941 - September 1942
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8
Bottineau
Kenmare
Minot

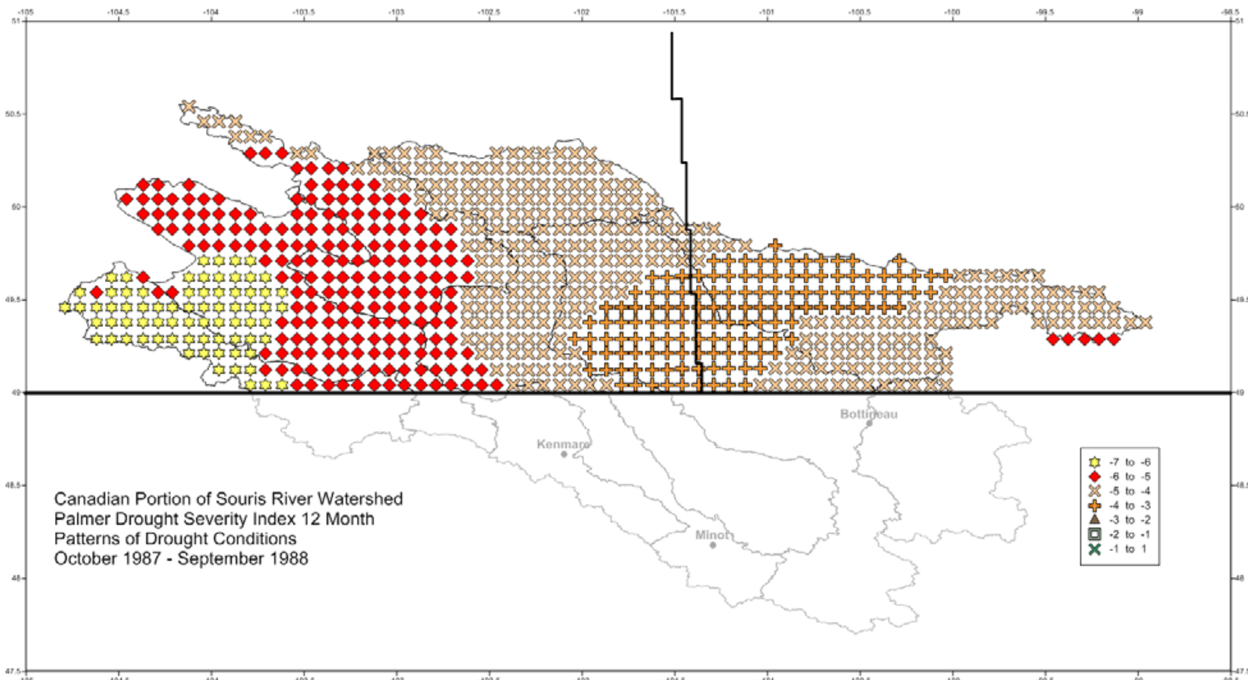

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1922 - September 1923
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

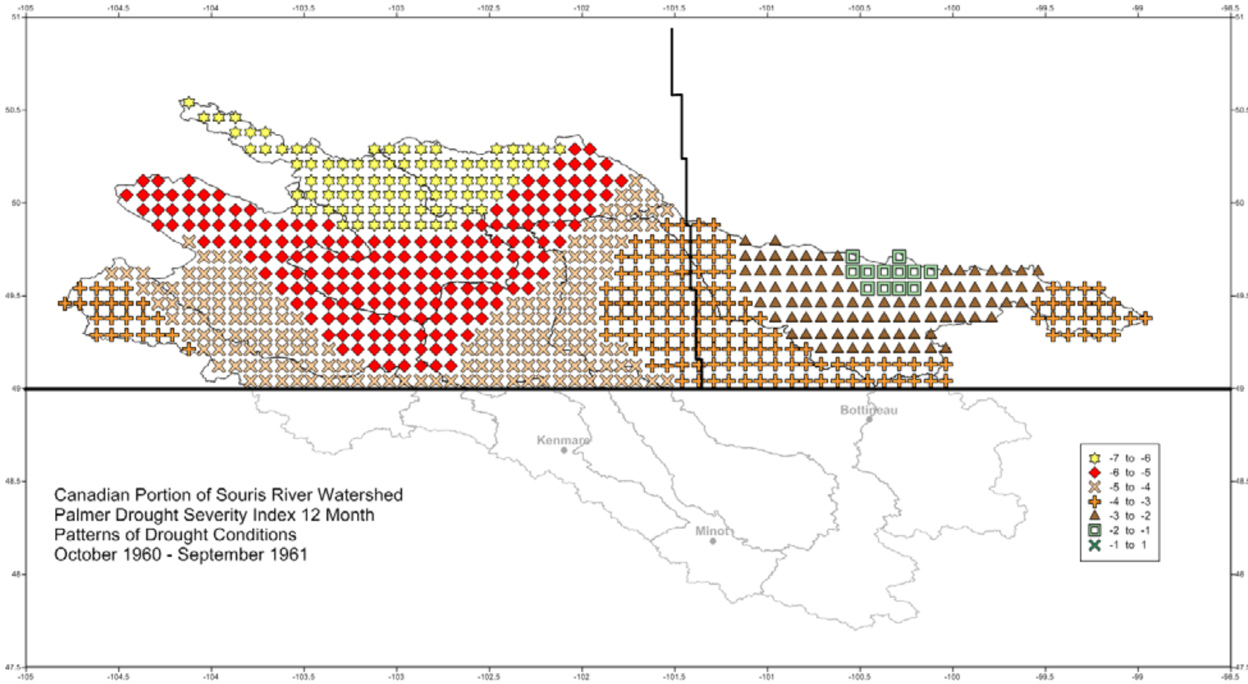

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1985 - September 1986
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

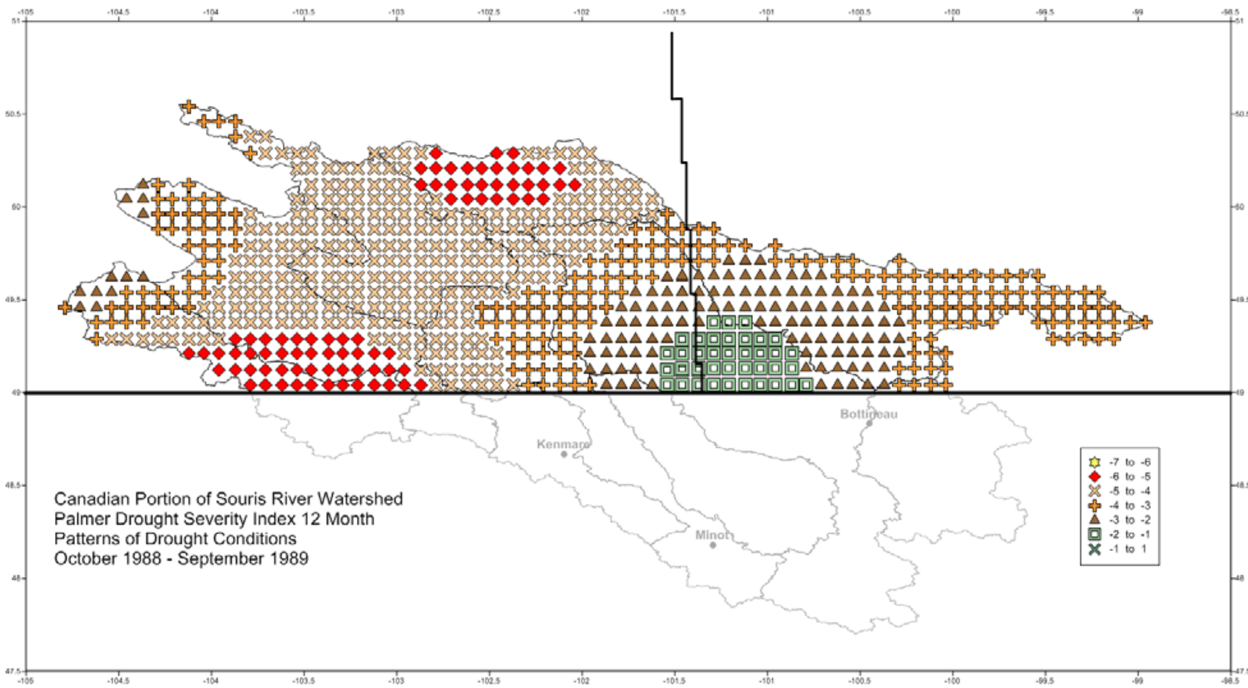

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1994 - September 1995
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

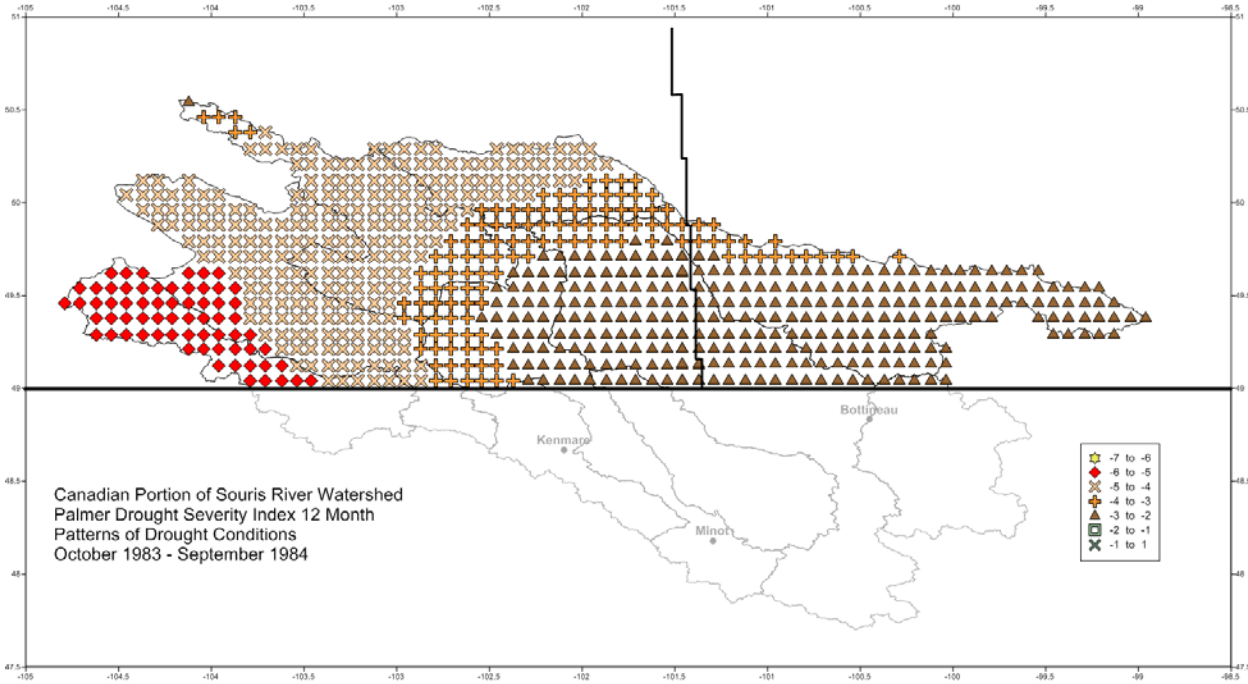

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Excessive Moisture Conditions
October 1927 - September 1928
Bottineau
Kenmare
Minot
-2 to -1
-1 to 1
1 to 2
2 to 3
3 to 4
4 to 5
5 to 6
6 to 7
7 to 8

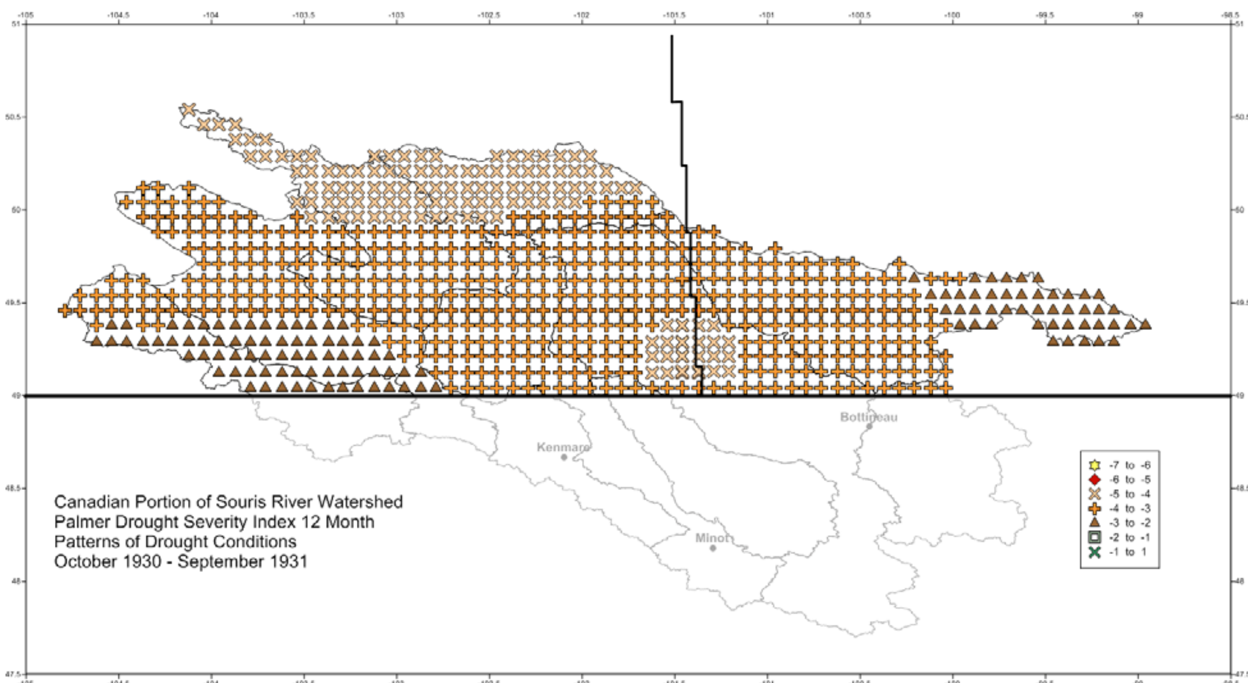

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1957 - September 1958
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1

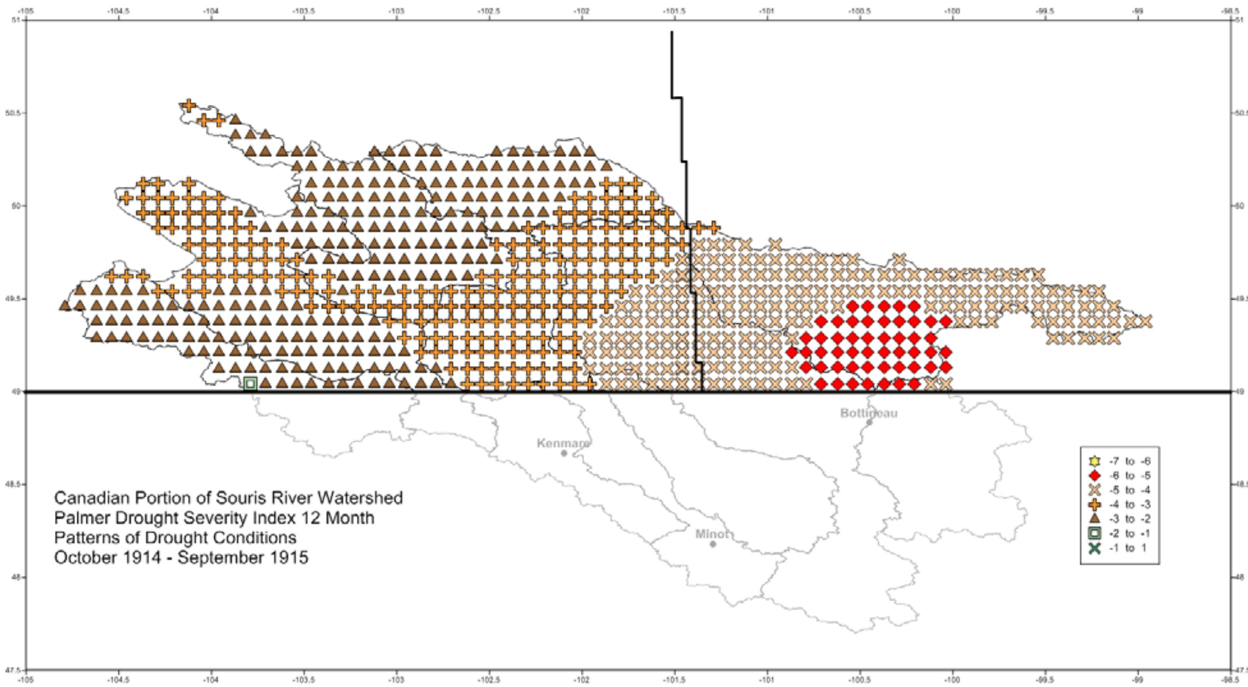

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1987 - September 1988
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1

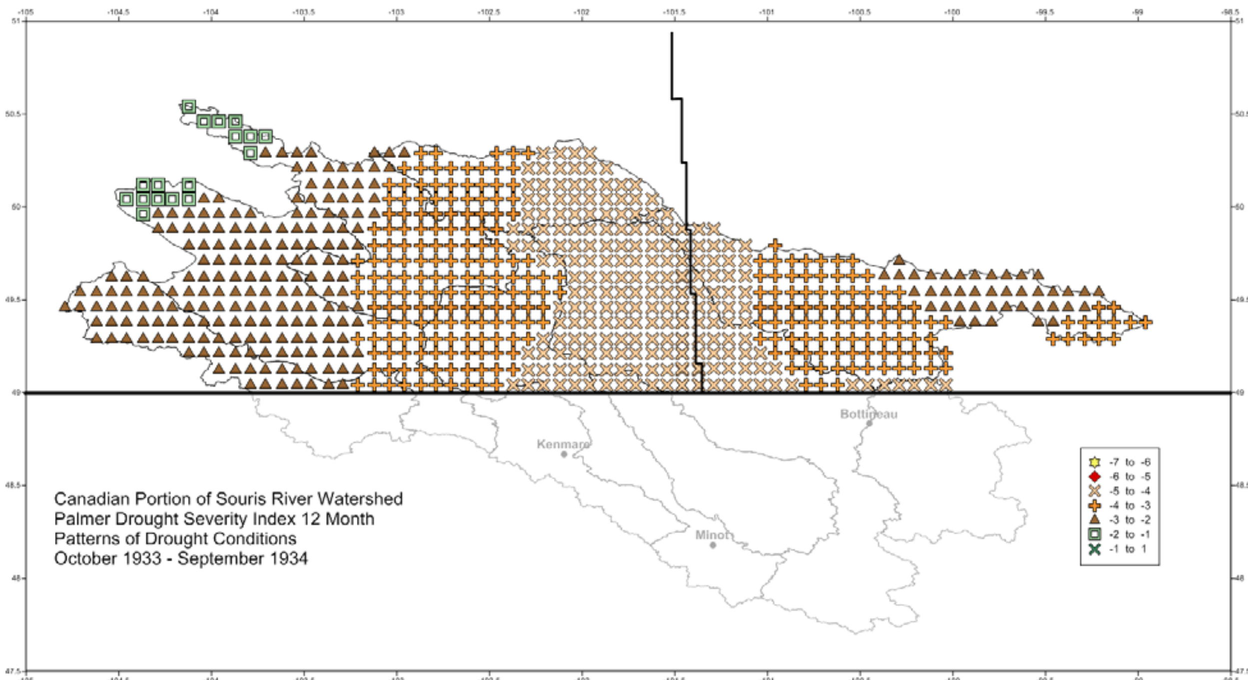

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1960 - September 1961
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1

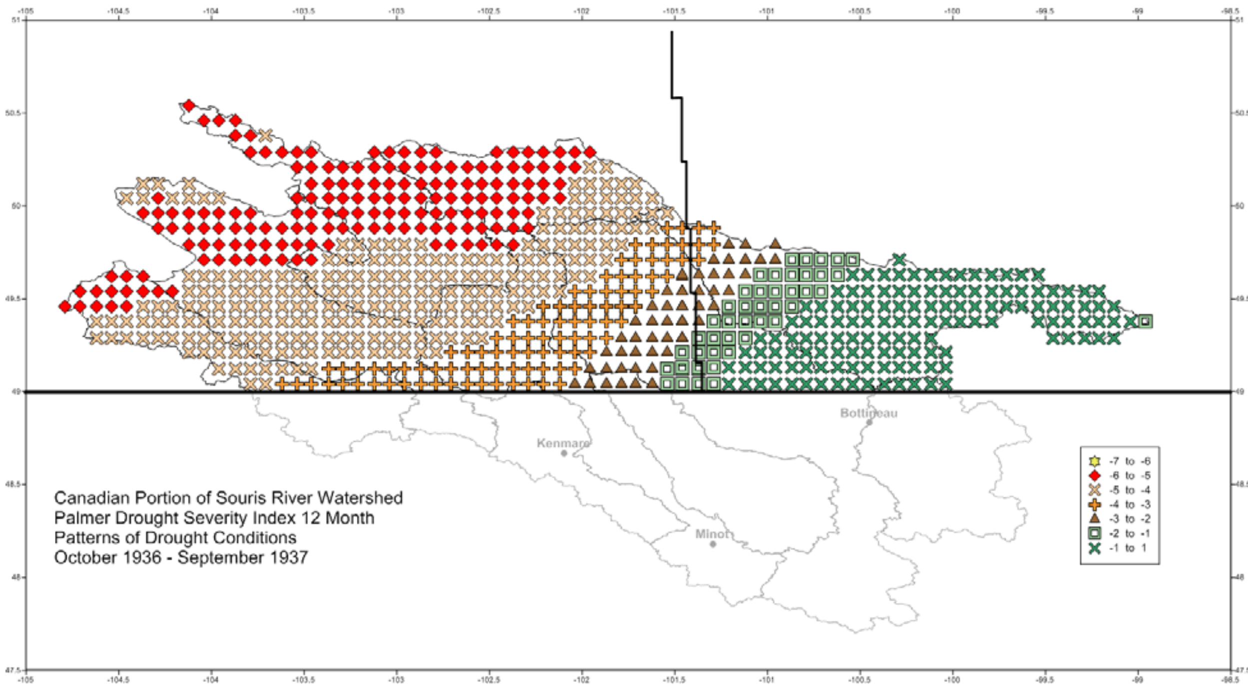

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1988 - September 1989
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1

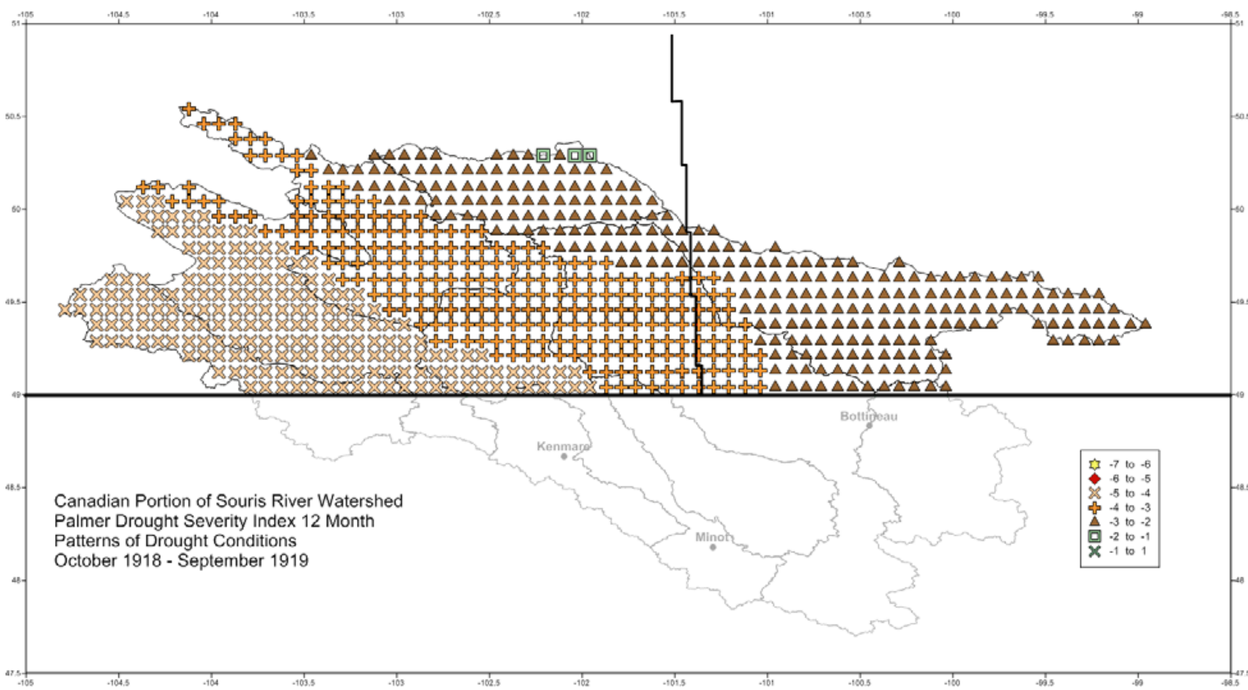

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1983 - September 1984
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1


Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1930 - September 1931
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1

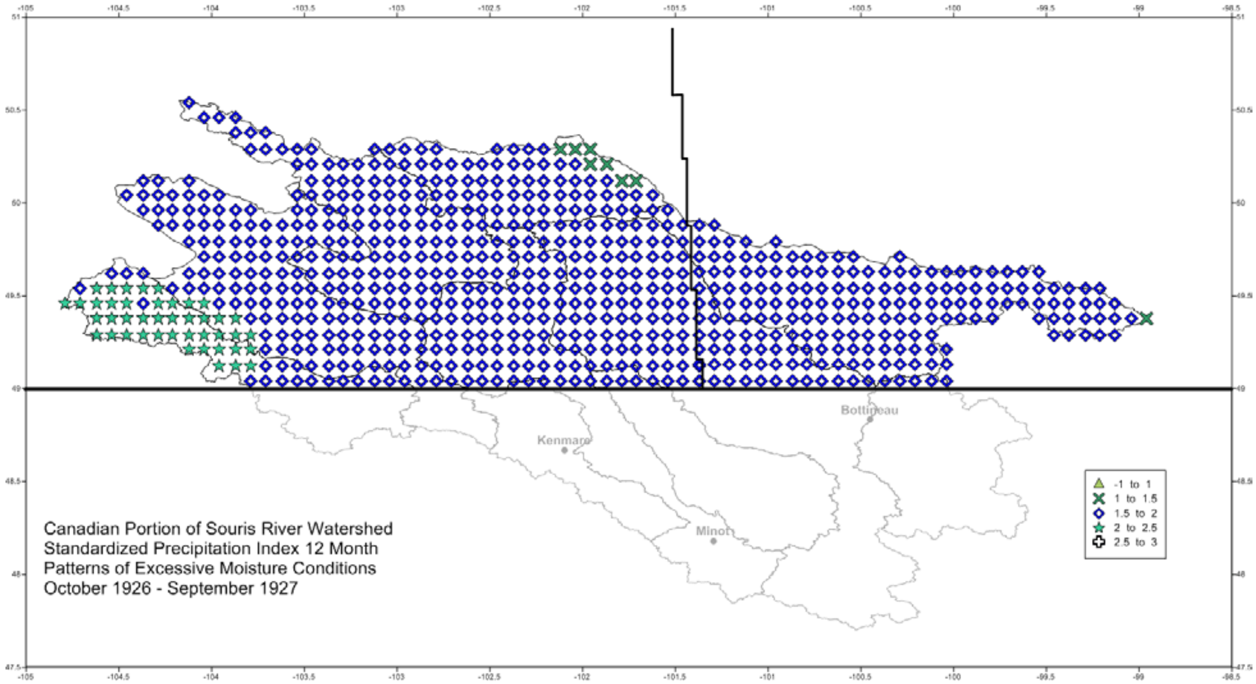

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1914 - September 1915
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1

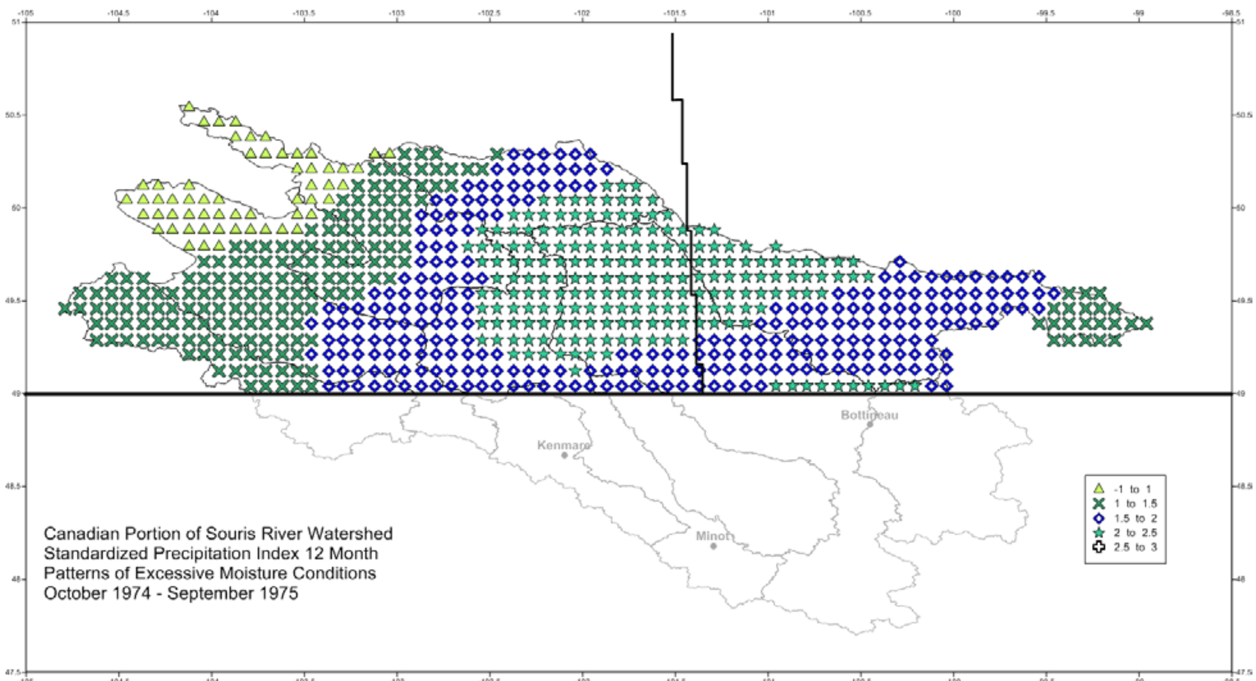

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1933 - September 1934
Bottineau
Kenmare
Minot
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1

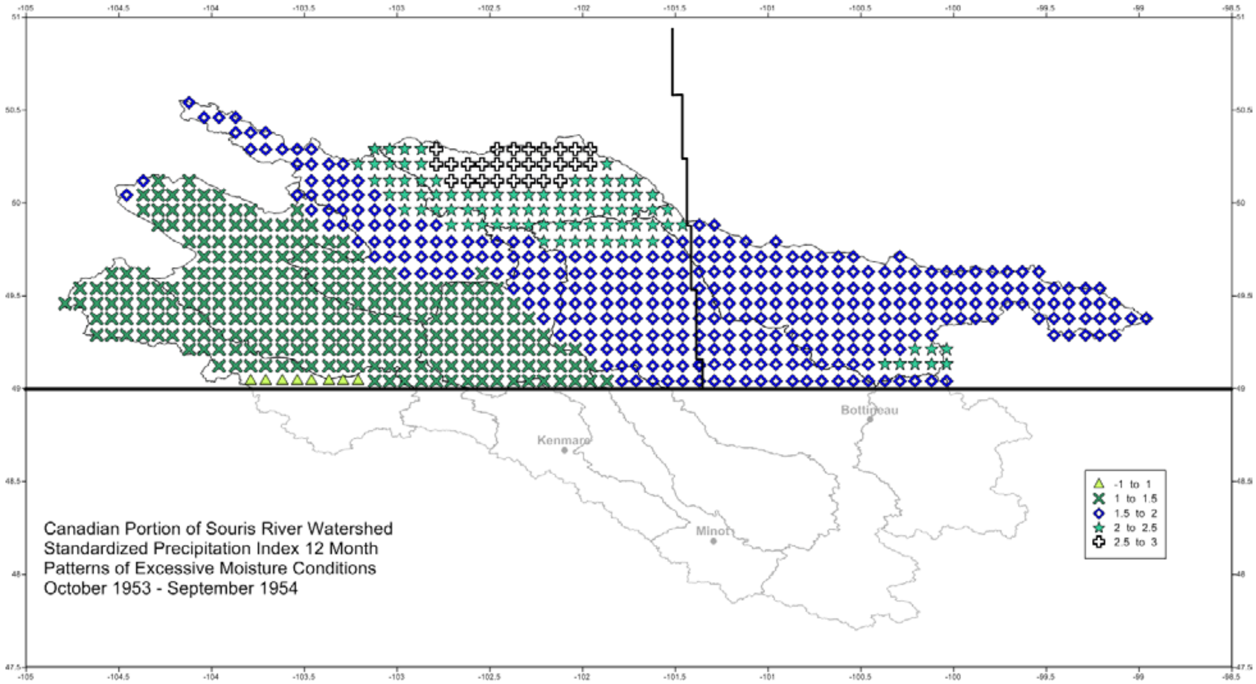

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1936 - September 1937
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1
Bottineau
Kenmare
Minot

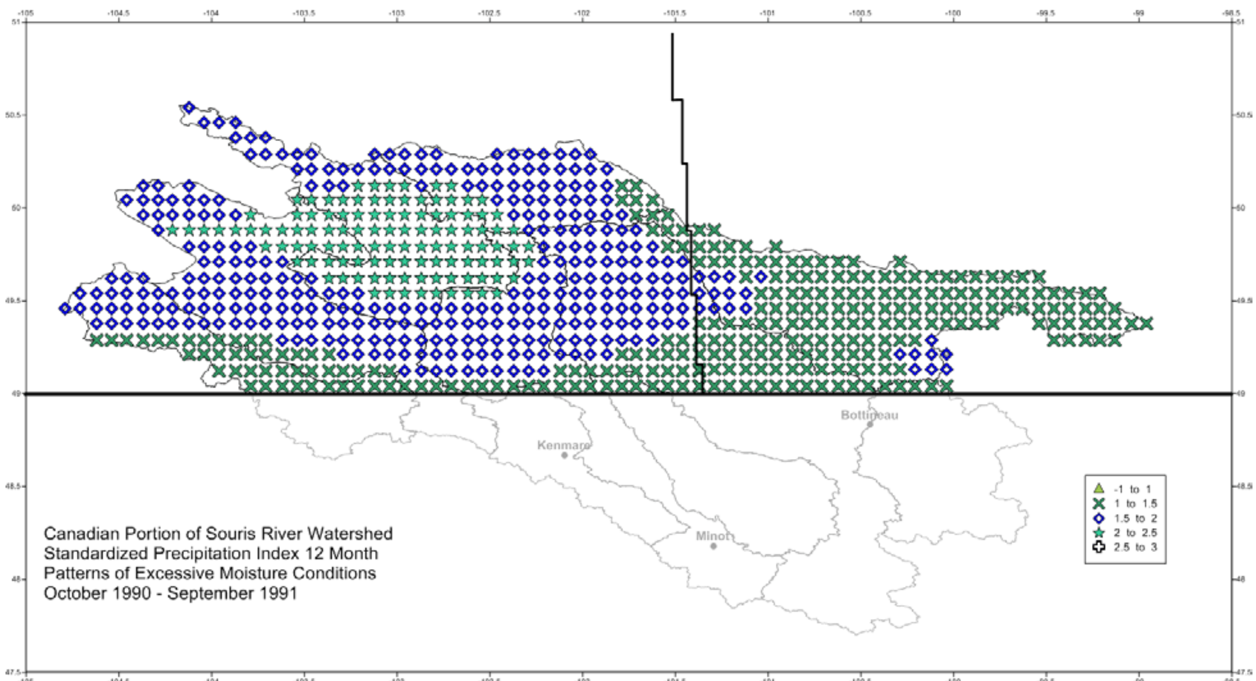

Canadian Portion of Souris River Watershed
Palmer Drought Severity Index 12 Month
Patterns of Drought Conditions
October 1918 - September 1919
-7 to -6
-6 to -5
-5 to -4
-4 to -3
-3 to -2
-2 to -1
-1 to 1
Bottineau
Kenmare
Minot

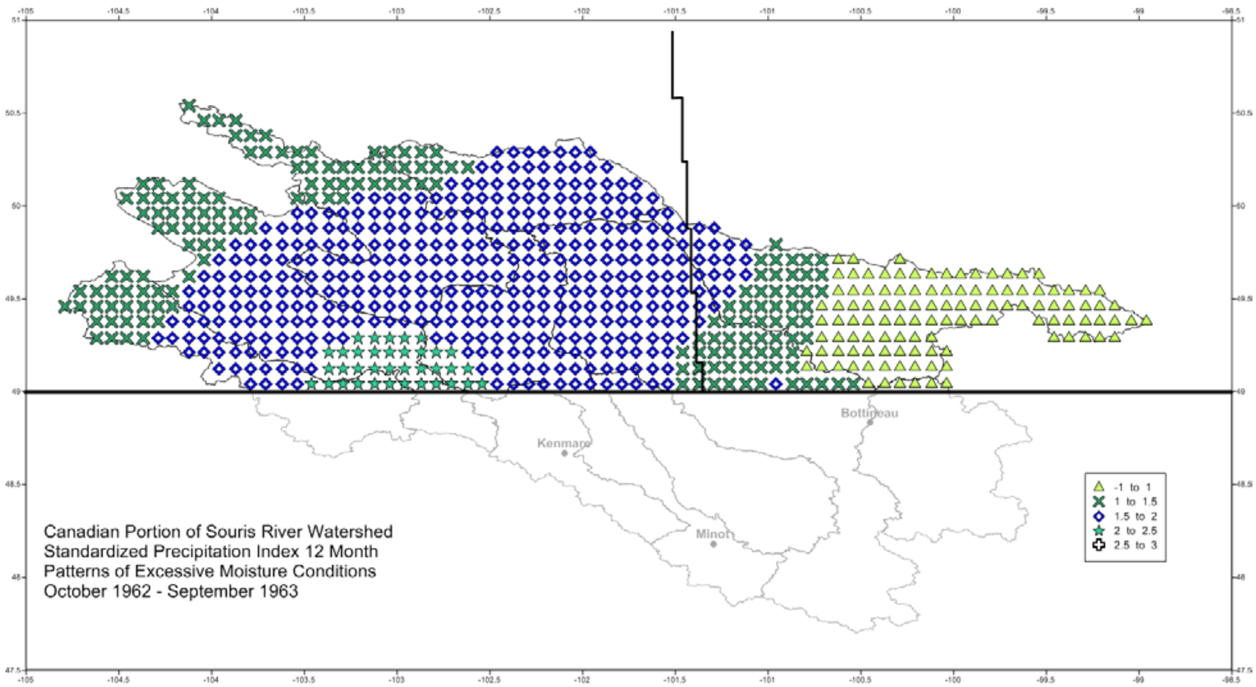
APPENDIX 8 STANDARDIZED PRECIPITATION INDEX - HYDROLOGIC YEAR (OCTOBER TO SEPTEMBER) 10 MOST EXTREME EXCESSIVE MOISTURE AND DROUGHT YEARS FOR THE 1901-2005 PERIOD

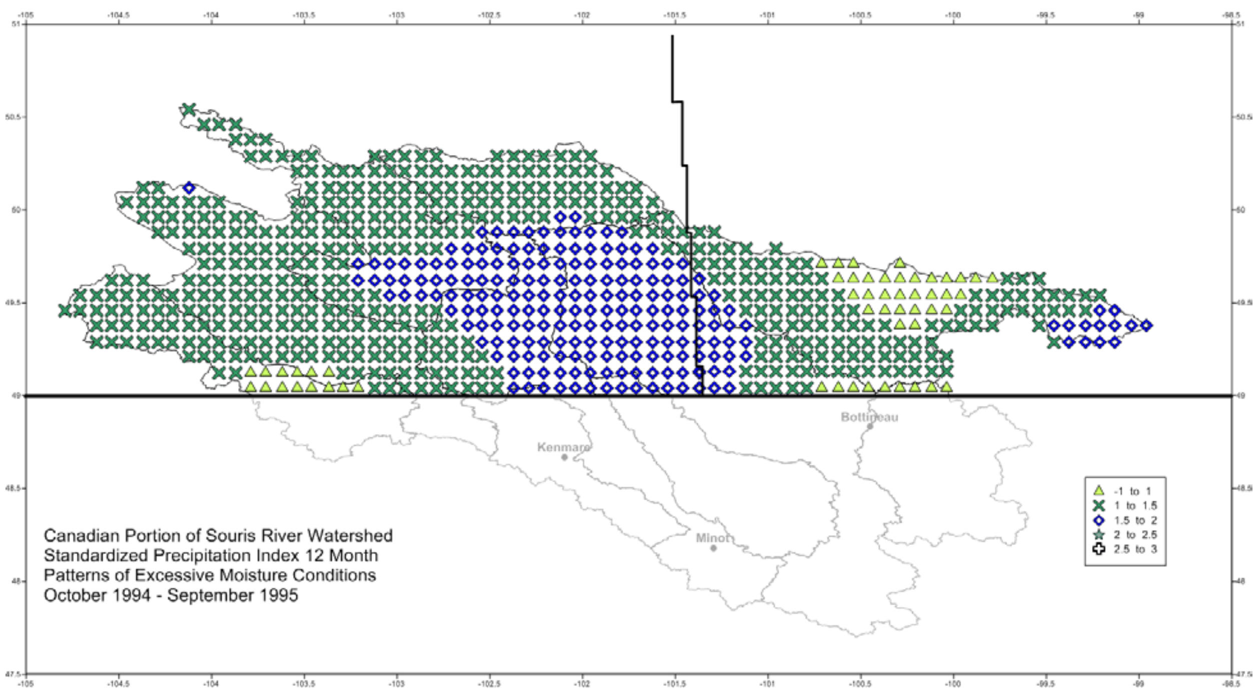

Bottineau
Kenmare
Minot
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1926 - September 1927

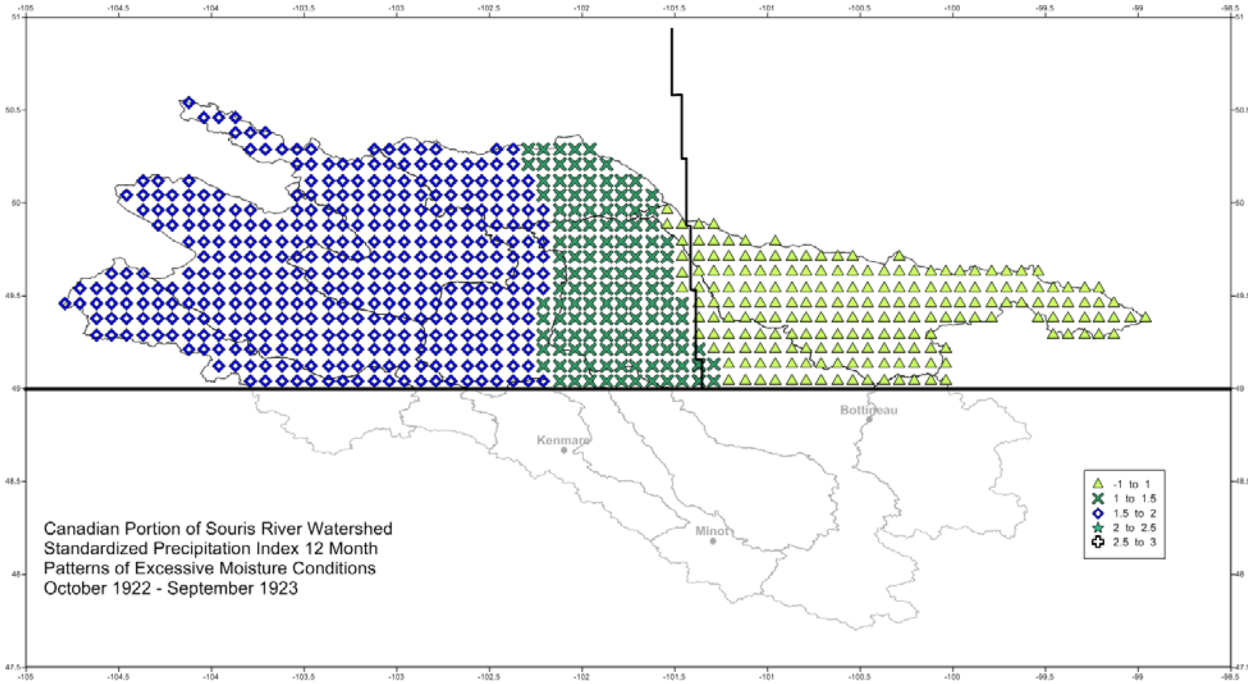

Bottineau
Kenmare
Minot
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1974 - September 1975

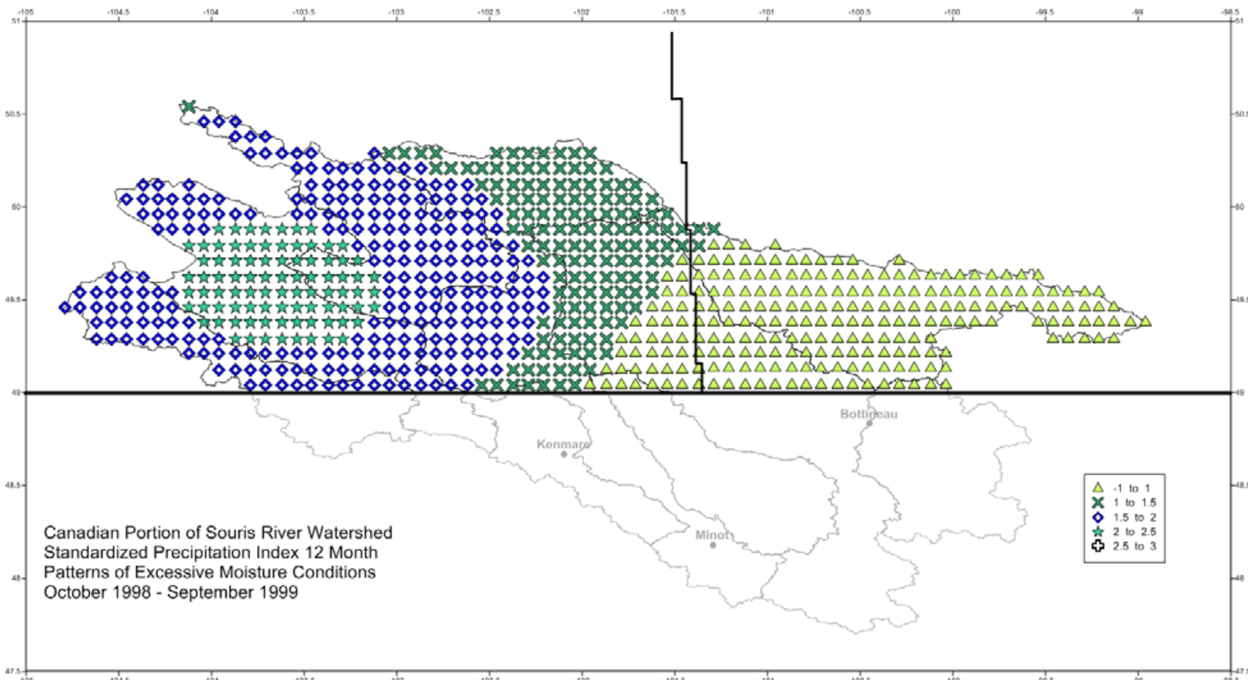

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1953 - September 1954
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Bottineau
Kenmare
Minot

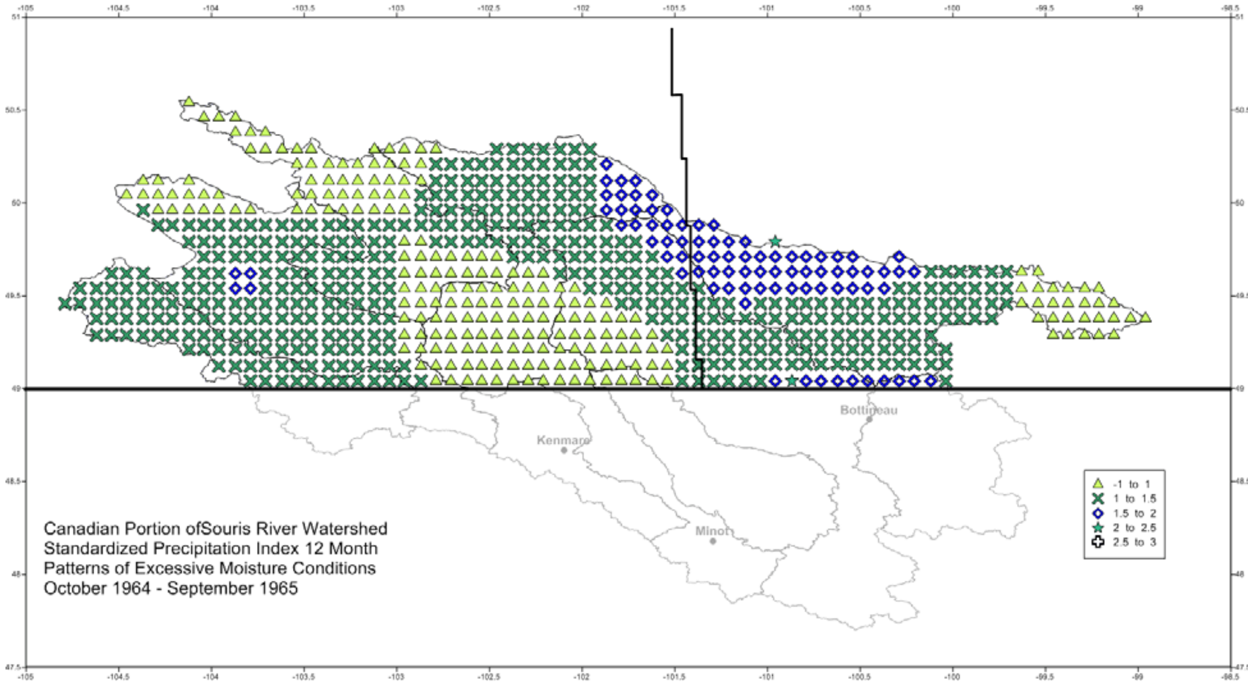

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1990 - September 1991
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Bottineau
Kenmare
Minot

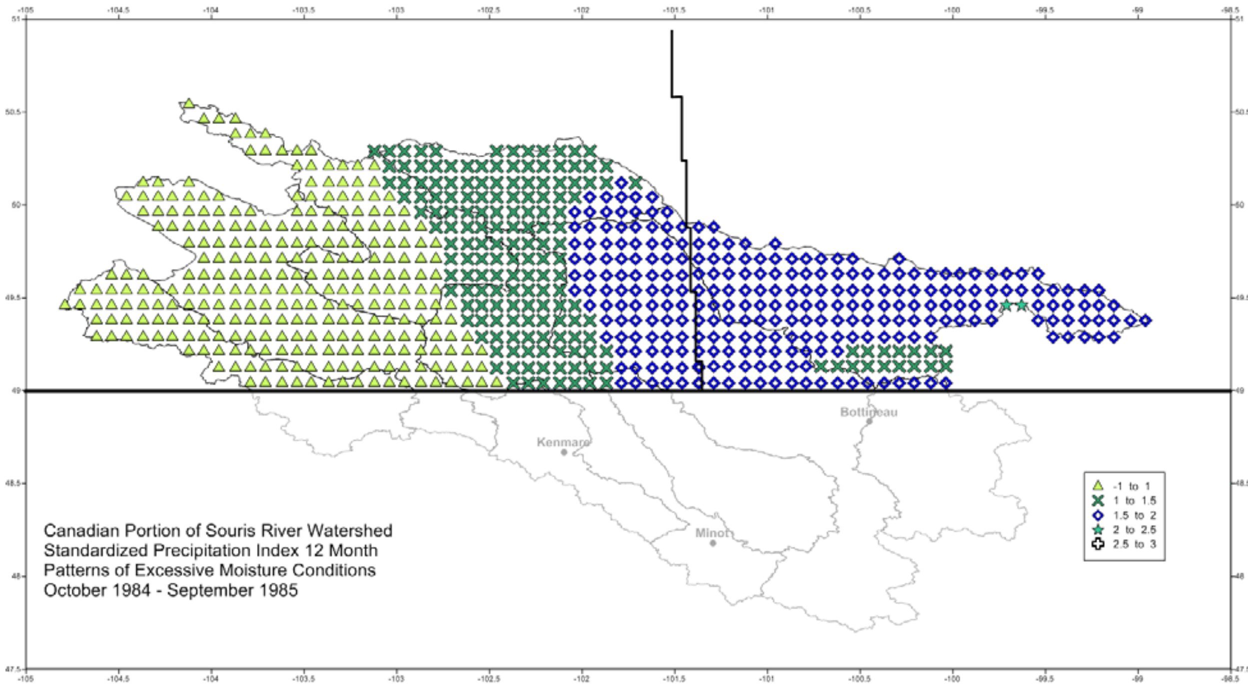

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1962 - September 1963
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Bottineau
Kenmare
Minot

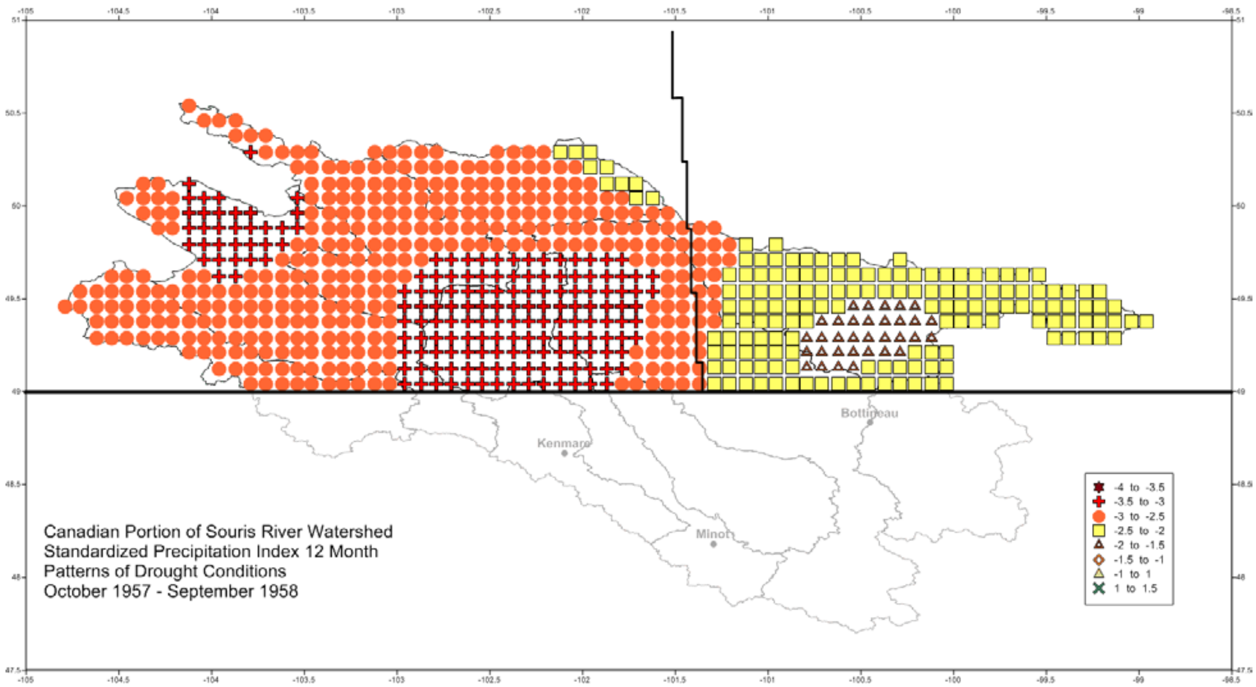

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1994 - September 1995
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Bottineau
Kenmare
Minot

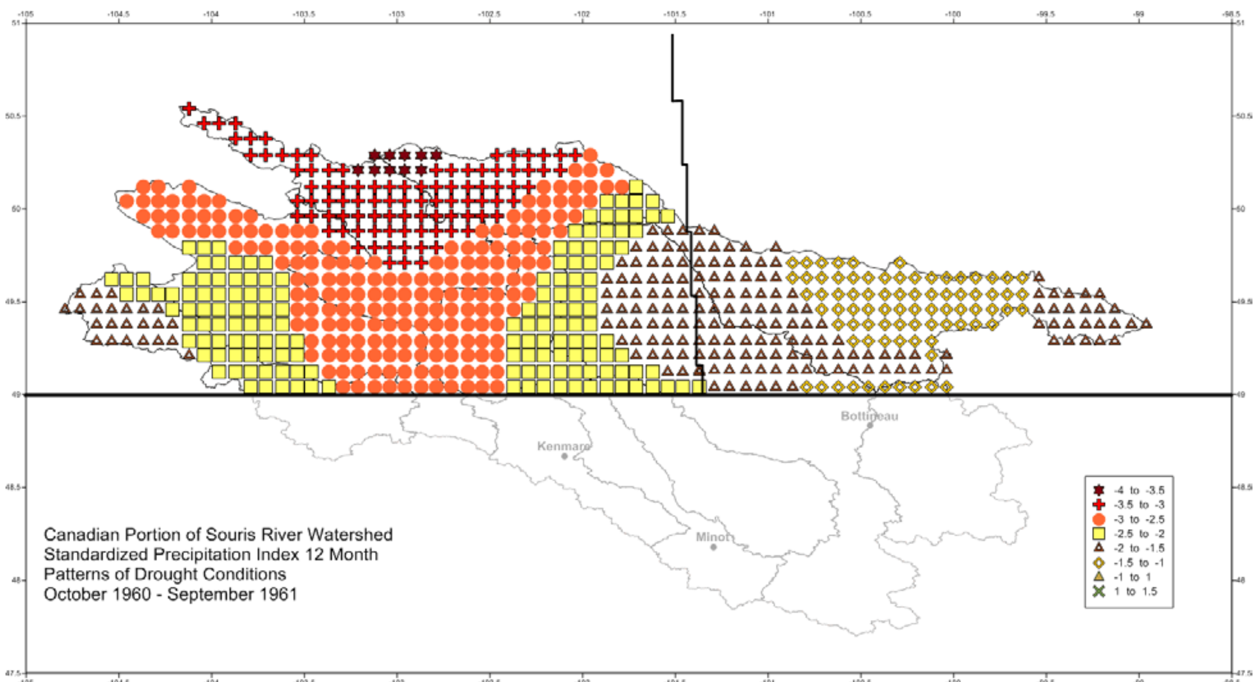

Bottineau
Kenmare
Minot
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1922 - September 1923

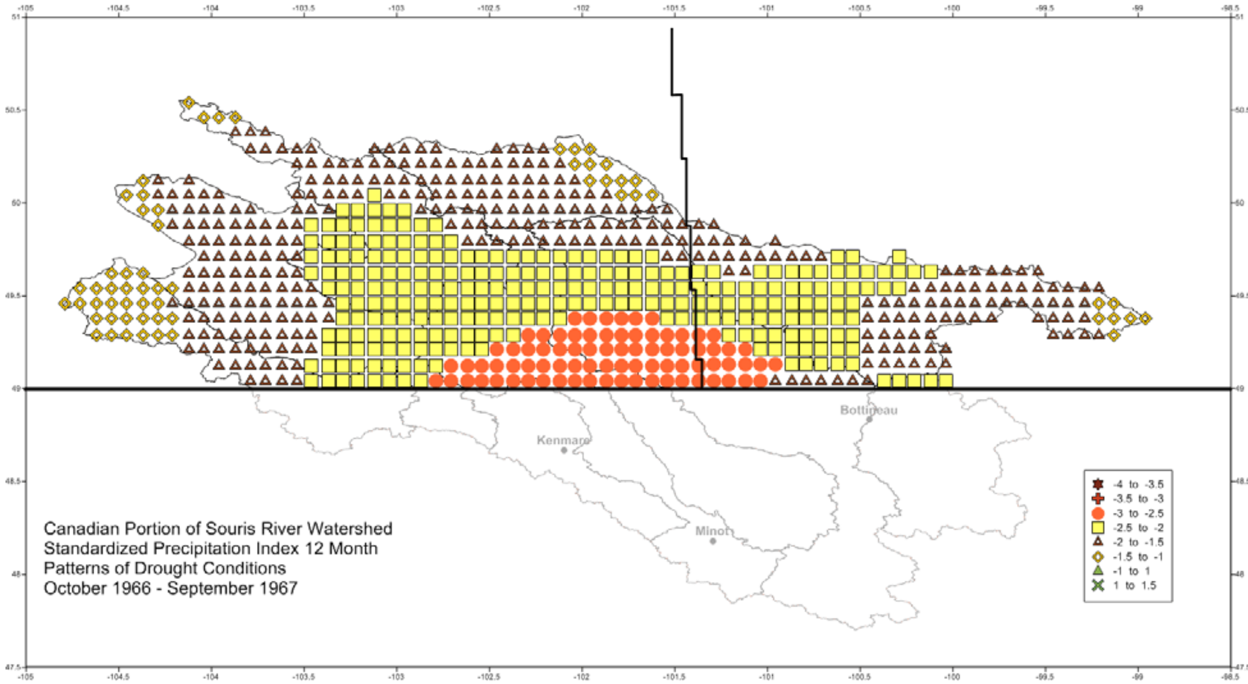

Bottineau
Kenmare
Minot
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1998 - September 1999

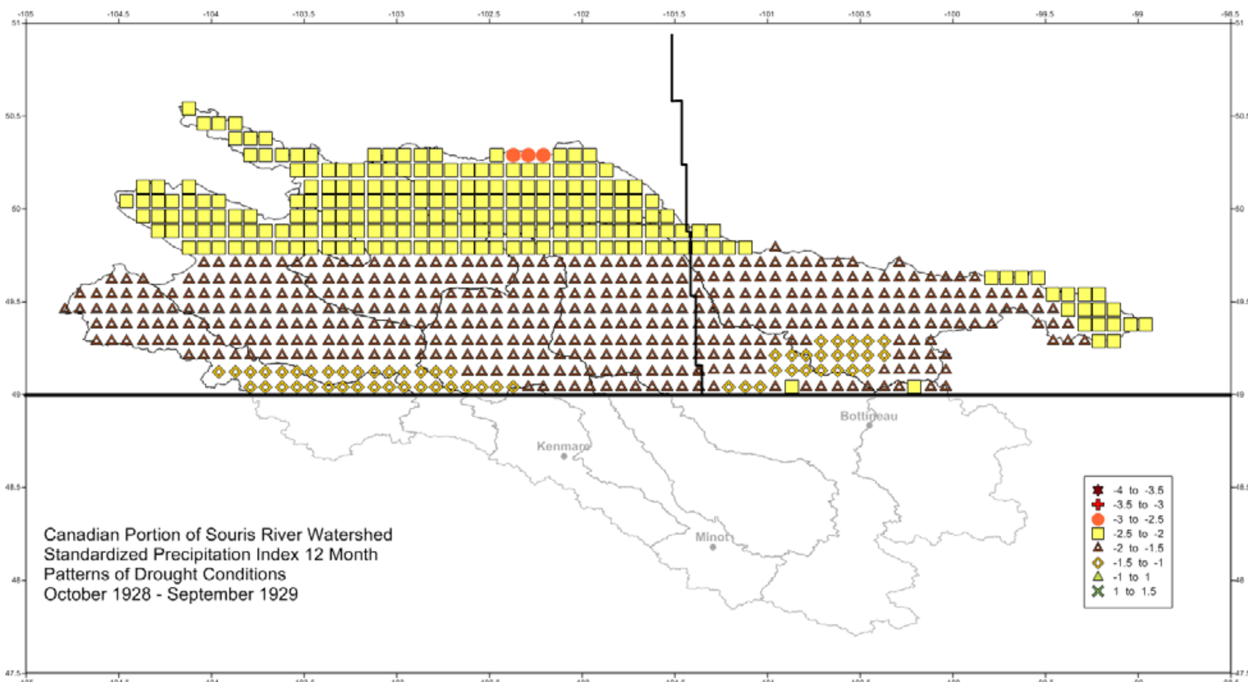

Bottineau
Kenmare
Minot
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Canadian Portion ofSouris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1964 - September 1965

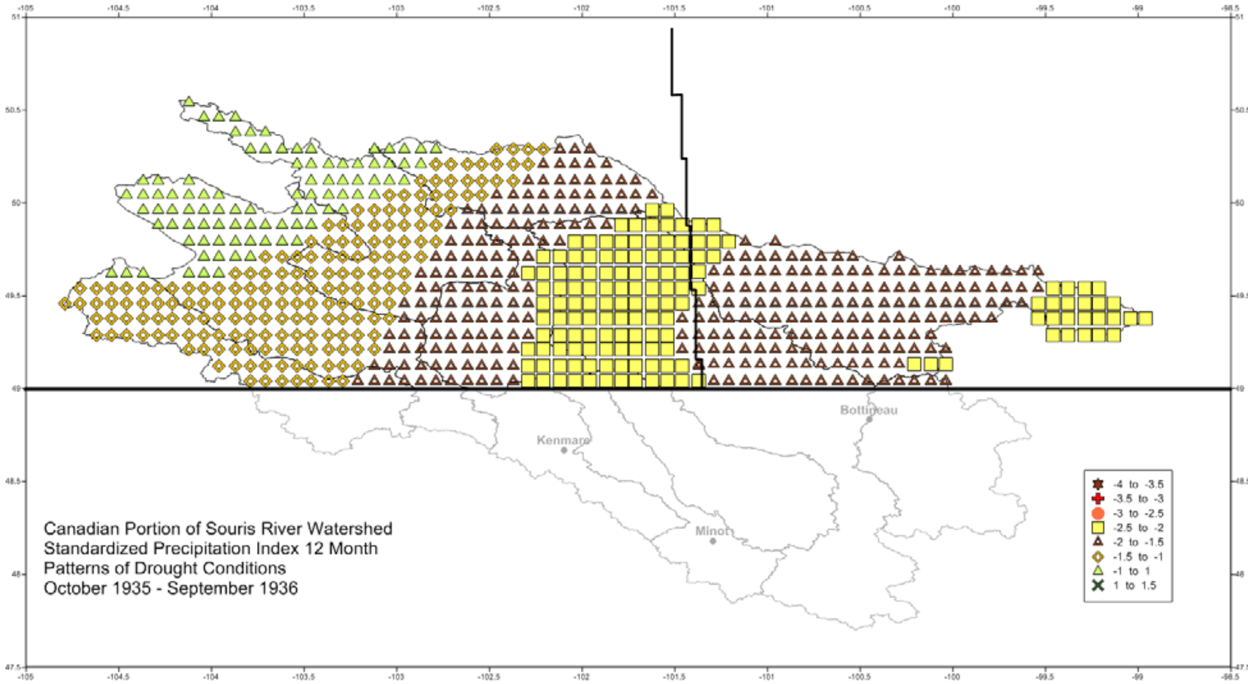

Bottineau
Kenmare
Minot
-1 to 1
1 to 1.5
1.5 to 2
2 to 2.5
2.5 to 3
Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Excessive Moisture Conditions
October 1984 - September 1985

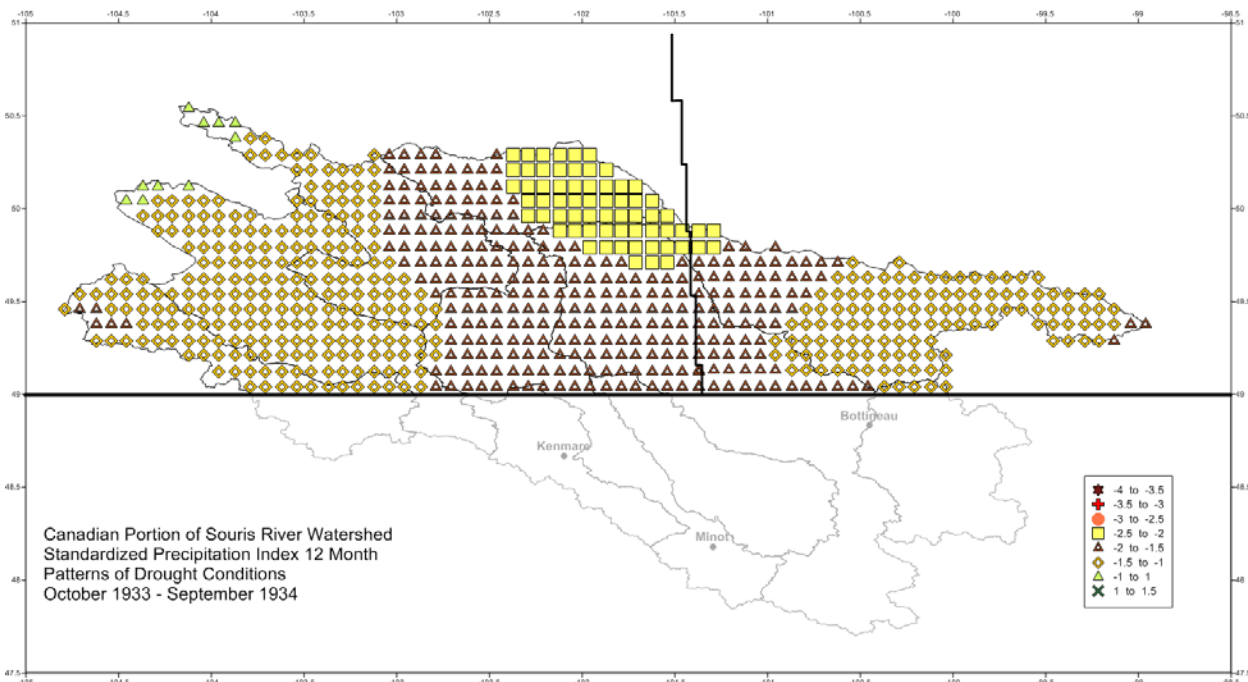

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1957 - September 1958
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5

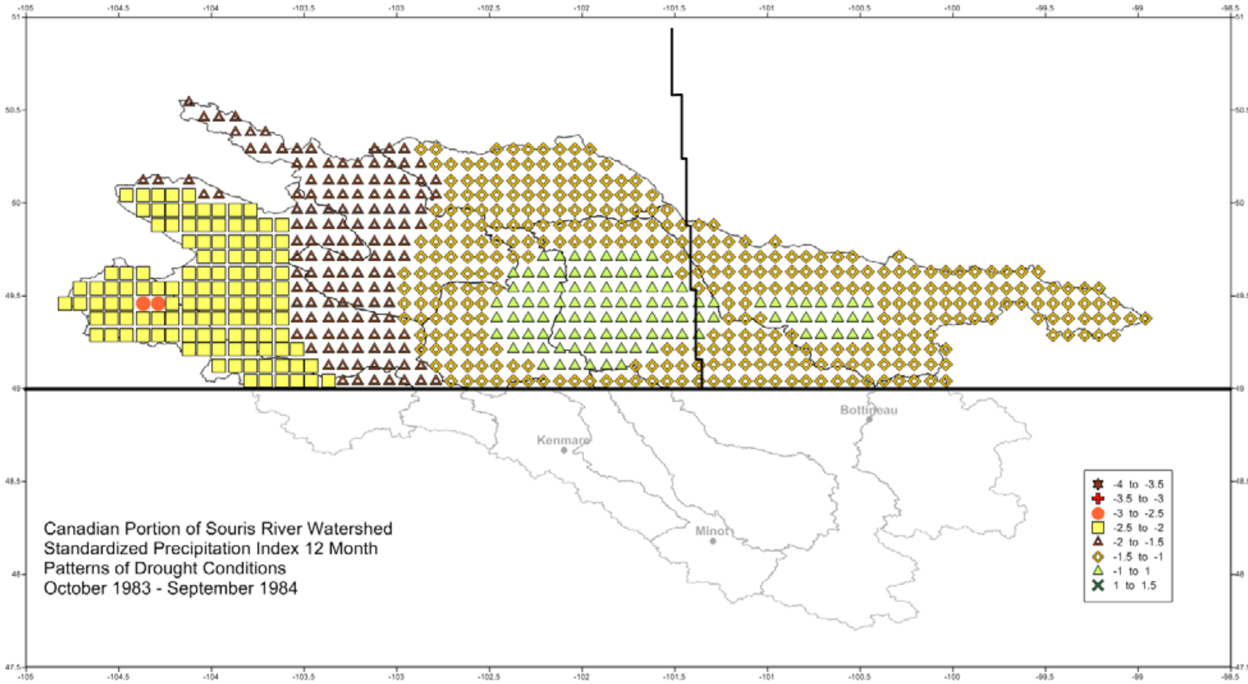

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1960 - September 1961
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5

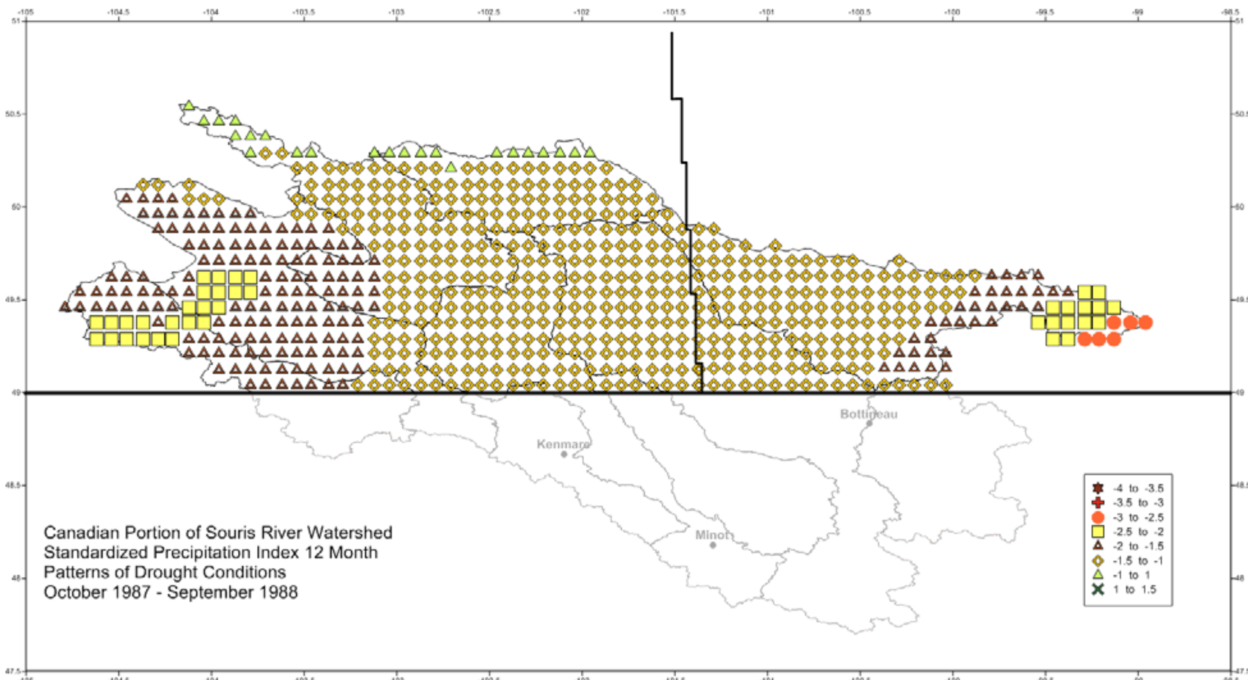

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1966 - September 1967
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5

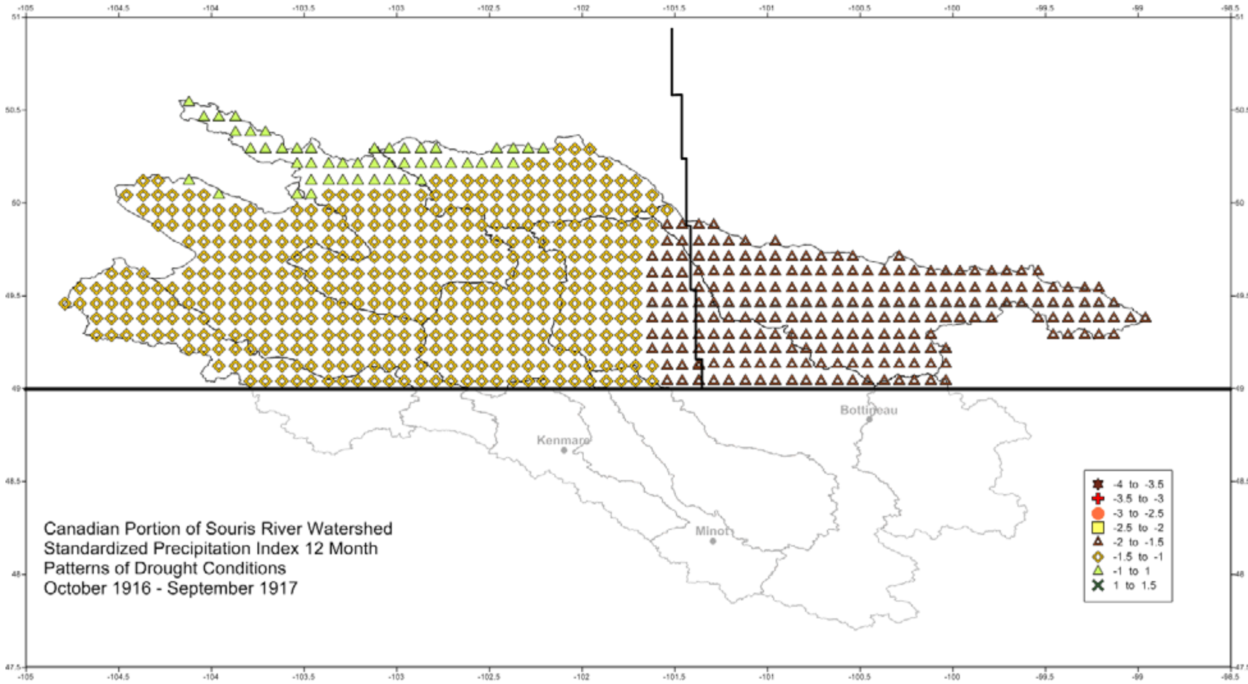

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1928 - September 1929
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5

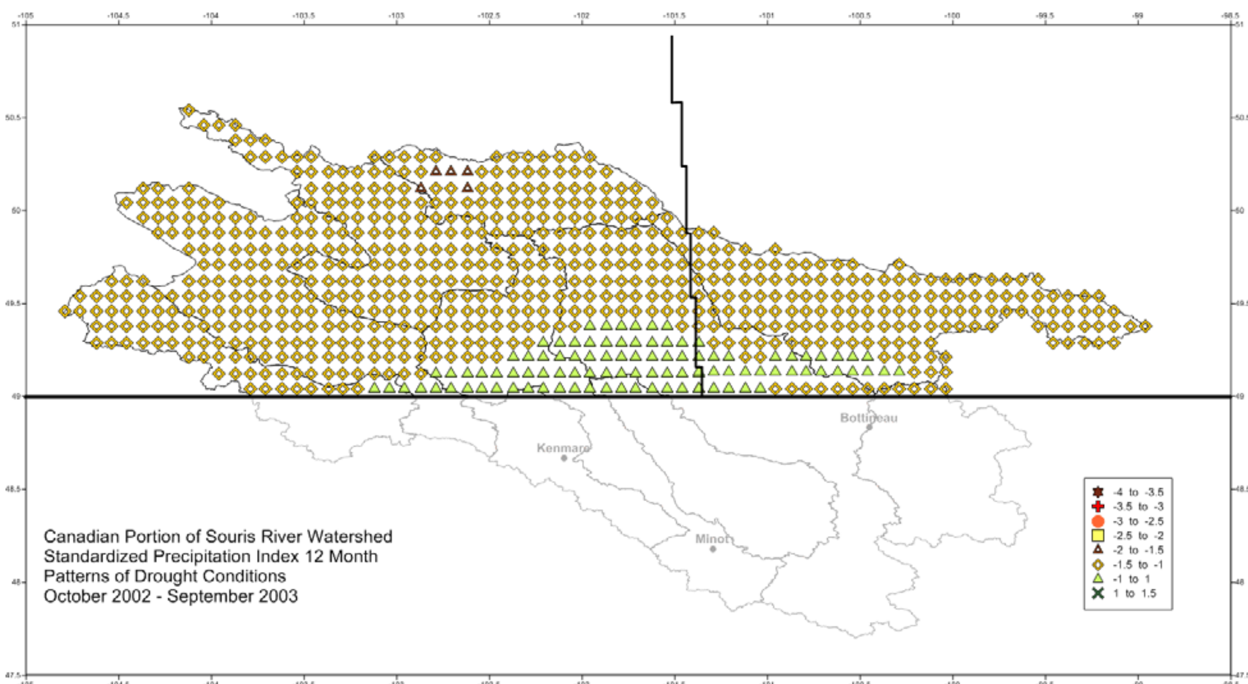

Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1935 - September 1936
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5
Bottineau
Kenmare
Minot


Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1933 - September 1934
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5
Bottineau
Kenmare
Minot


Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1983 - September 1984
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5


Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1987 - September 1988
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5


Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 1916 - September 1917
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5


Canadian Portion of Souris River Watershed
Standardized Precipitation Index 12 Month
Patterns of Drought Conditions
October 2002 - September 2003
Bottineau
Kenmare
Minot
-4 to -3.5
-3.5 to -3
-3 to -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to 1
1 to 1.5