



## **CLIMATE TRENDS AND PROJECTIONS FOR THE SOUTH SASKATCHEWAN RIVER BASIN**

### **SEAWA Watershed Report 2010-13 SEAWA Web-based State of the Watershed Report**

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# Climate Trends and Projections for the South Saskatchewan River Basin

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## Executive Summary

This report is brief overview of the trends and variability in climate and streamflow in the South Saskatchewan River Basin (SSRB) with a focus on southeastern Alberta. Recent trends in instrumental records are compared to longer-term trends and cycles evident in tree-ring records for the past 600 years. This report also compares these two sets of climate observations to climate changes projected for the next 50 years as derived from global climate models (GCMs). Also included is a discussion of the modes and causes of the internal variability of the regional climate. The objective of this report is to provide the SEAWA with a scientific perspective on the variability of surface water in southeastern Alberta and how it relates to observations and projections of the regional climate.

Annual temperatures recorded at Medicine Hat since 1895 show a warming trend of about one degree. Most of the warming has been in winter and since the 1970s. Precipitation recorded at Medicine Hat clearly shows large inter-annual variability and longer wet and dry cycles in winter. The flow of the South Saskatchewan River has similar variability. No place else in Canada, and few places on earth, have this much variability in the annual water balance. Short trends of a few decades can be artefacts of the decadal-scale variability. The only certain trend in precipitation or water levels is the reduction in flow resulting from the increased consumption and diversion of surface water, mostly for irrigation.

The records from weather and water gauges are relatively short compared to the longer climate cycles, lasting 50-70 years. The longest instrumental records, such as those from Medicine Hat, capture only one full cycle and part of another. Proxy records of the climate and hydrology of the past 600 years capture many more of these longer cycles and a greater range of extreme annual conditions. Trees growing at dry sites in the Cypress Hills and on the eastern slopes of the Rocky Mountains record year to year variations in the availability of water, since this is the factor that most limits tree growth. The tree-ring reconstruction of annual streamflow indicates that the instrumental period of the past 100 years may represent fairly well the frequency of one- to two-year droughts, but it does not capture the full range of intensity and duration. The tree rings suggest that the climate of the 20th century was relatively favourable for the settlement of the prairies. The initial phase of homesteading during 1880 through the 1910s coincided with the longest sustained wet period of the past 600 years. Furthermore, the droughts of greatest severity and duration occurred before the prairies were settled. These include the intense drought years of the 1790s, when sand dune fields in the SSRB became active, and the sustained drought of the 1850-60s, when the southern prairies were deemed unsuitable for agriculture.

The observed temperature changes can be directly related to global and external factors such as earth's energy balance which currently is being altered by a change in the chemistry of the atmosphere and specifically the concentration of greenhouse gases. Regional precipitation and the surface water balance, on the other hand, are the outcome of various global and regional processes and feedbacks. In particular, precipitation and streamflow from western North America have strong inter-annual to multi-decadal variability; wet and dry cycles of a few years are superimposed on cycles lasting a few decades. This short-term variability has been linked to teleconnections in climate and specifically oscillations in sea surface temperature in the Pacific Ocean. Two climate oscillations, the El-Niño Southern Oscillation and the Pacific Decadal

Oscillation have an especially strong influence on winter precipitation in western Canada at inter-annual and inter-decadal time scales, respectively.

The natural climate variability, recorded by water gauges and the tree rings, underlies changes to regional water cycle that are caused by a warming global climate. Global climate models (GCMs) are the best source of climate projections for the next 50 years. This report presents a range of climate scenarios for the SSRB based on output from various GCMs. All of these scenarios include increased temperature for the SSRB in all seasons, but especially in winter, conforming to the recent temperature observations. All of the climate change scenarios suggest an increase in precipitation in winter and spring; some show less in summer. Increased temperatures will result in an increased number of days with net positive evaporation from soil, dugouts, rivers, lakes and reservoirs. As a result there is no increase in effective precipitation (the climate moisture index:  $P - PET$ ) under the median climate change scenario, despite the increased precipitation ( $P$ ) in winter and spring, because it is offset or exceeded by a rise in evapotranspiration ( $PET$ ). One of the scenarios for the SSRB is a shift in water supplies from summer to winter and spring.

These scenarios of the future climate of the SSRB provide information about the shift in average conditions that can be expected. This is critical information in anticipation of the impacts of climate change, but not necessarily the most relevant information for southern Alberta, where the major climate risks are departures from average conditions and extreme climate events. Therefore as important or more relevant than the expected trends are the internal cycles that likely will continue to dominate the observed variations in climate and hydrology. In fact, probably the major impact of global warming in this region will be the tendency for a warmer climate to amplify the already large natural variability. Thus knowledge of the existing natural cycles in the weather and climate is required before the impacts of warming global climate can be understood. The decadal-scale variability, evident in the tree-ring records for the past 600 years, will be a significant component of the future hydroclimate. Adaptation strategies (e.g. insurance, water storage) have evolved for coping with short (1-2 year) relatively frequent droughts. The prolonged infrequent drought is the most challenging aspect of climate variability.

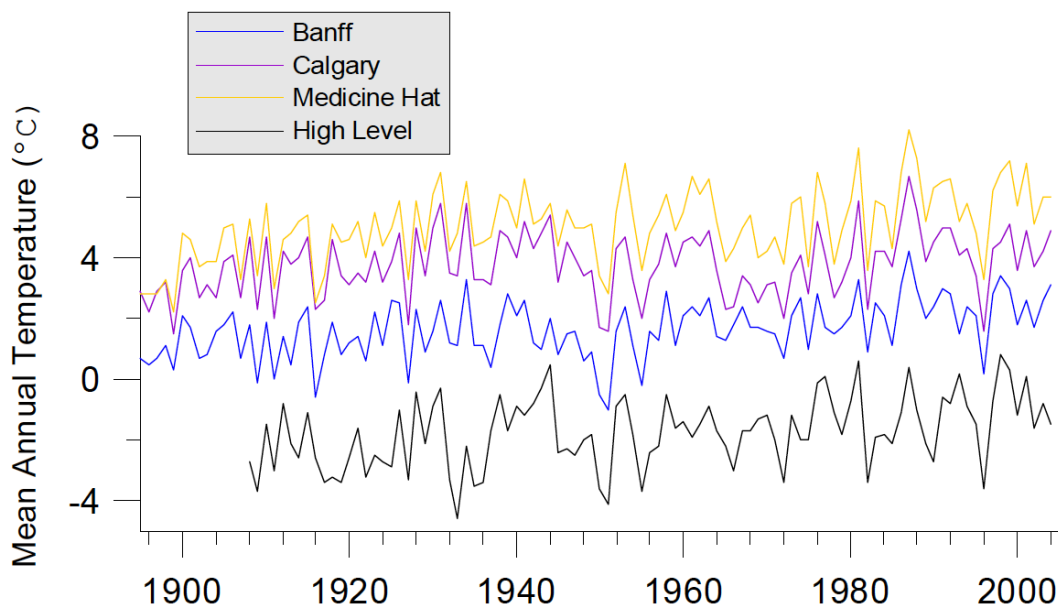
## **Introduction**

This report is brief overview of the trends and variability in climate and streamflow in the South Saskatchewan River Basin (SSRB) with a focus on southeastern Alberta. Recent trends in instrumental records are compared to longer-term trends and cycles evident in tree-ring records for the past 600 years. This report also compares these two sets of climate observations to climate changes projected for the next 50 years as derived from global climate models (GCMs). Also included is a discussion of the modes and causes of the internal variability of the regional climate. The objective of this report is to provide the SEAWA with a scientific perspective on the variability of surface water in southeastern Alberta and how it relates to observations and projections of the regional climate.

## Recent Trends in the Instrumental Record

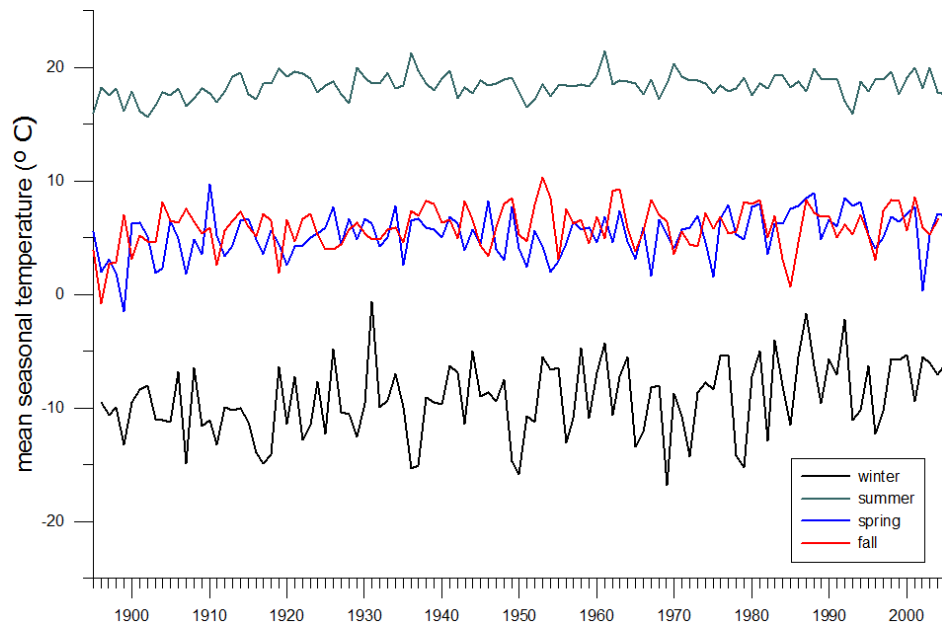
### *Temperature and Precipitation*

Precipitation and temperature have been measured at Medicine Hat for nearly 120 years, ever since the construction of the trans-continental railway across southern Canada. Rachel Brown and Katie van der Sloot (2010) extricated these weather data from the Environment Canada's National Climate Data and Information Archive. They examined trends and fluctuations, noting the recent increase in annual temperature. If Figure 1, the mean annual temperature for Medicine Hat is plotted for the period 1895-2006. Two other temperature records from the SSRB, for Calgary and Banff, also are plotted, and to have a provincial perspective, the temperature record for High Level, Alberta's most northerly community, also is shown. At all other these locations, there has been rising temperature throughout the instrumental record. There is also considerable year-to-year variability that is consistent across the SSRB, and in most years across the province. Therefore even though there is clear trend of increasing annual temperature, there still are cold years like 1951 and 1996. At Medicine Hat the mean annual temperature has risen by approximately one degree from about 4° C to about 5° C.



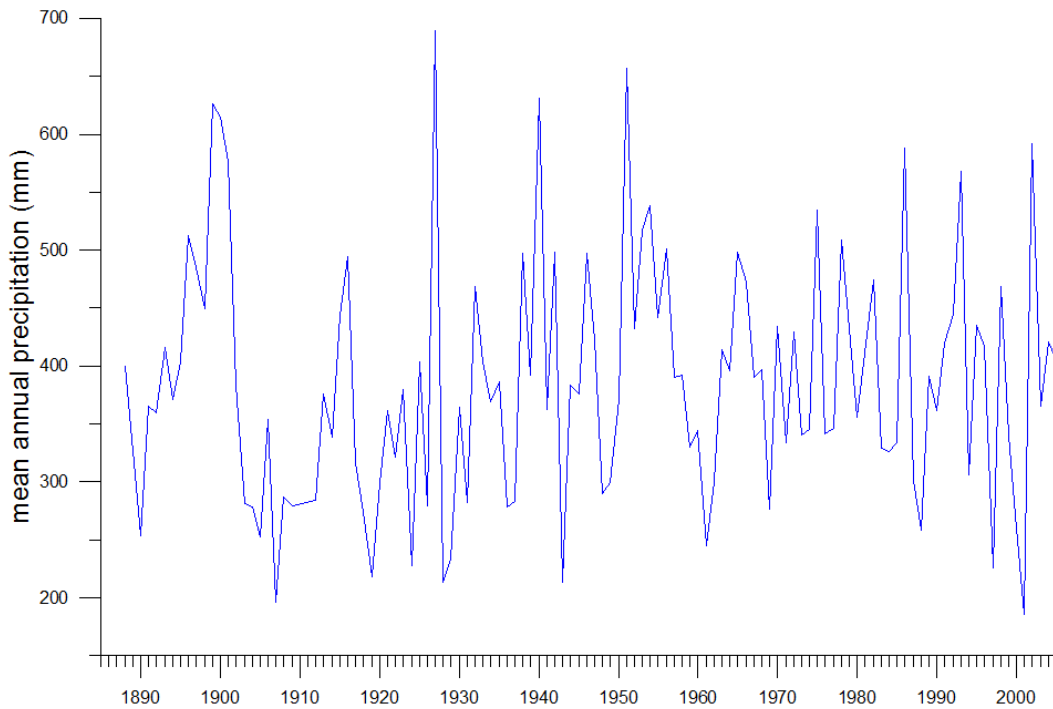
**Figure 1.** Mean annual temperature for Banff, Calgary and Medicine Hat from 1895 to 2006. This trend in increasing temperature is seen across Alberta including the northernmost community of High Level.

A graph of temperatures each year according to the season (Figure 2) shows that most of warming at Medicine Hat is in one season, winter. The rise in winter temperature is especially dramatic since the 1970s. Given the large inter-annual variability, about 30 years of data are required to reveal a trend. A shorter period of 10 years can show near trend (1970-80), declining temperature (1988-1997) or a rapid rise (1979-1988). These short-term fluctuations are embedded in a longer-term trend of rising winter temperatures.



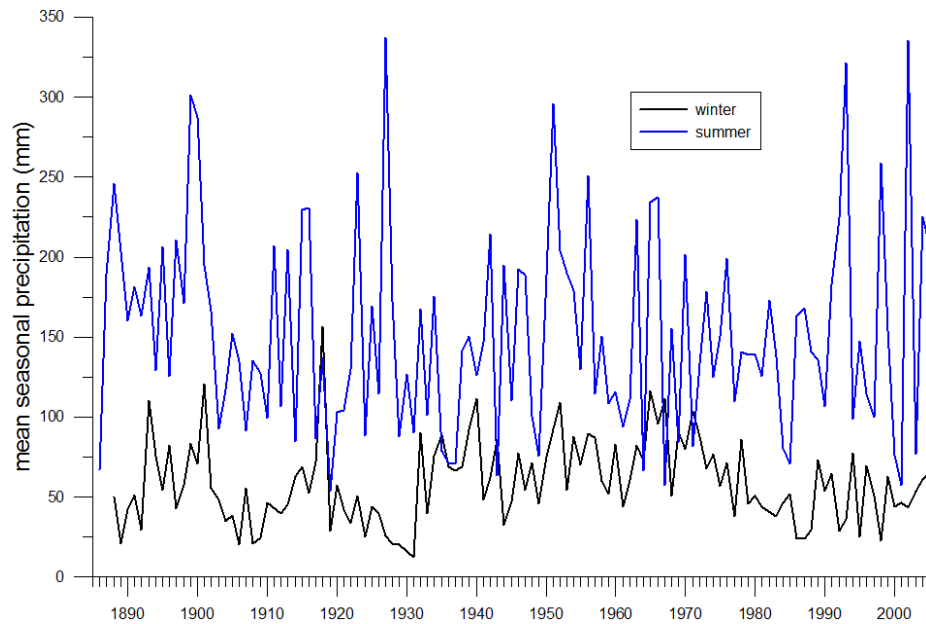
**Figure 2.** Mean seasonal temperatures (deg C) for Medicine Hat from 1895-2005. Over the past 40 years the warming trend has been in winter.

The mean annual precipitation record for Medicine Hat, from 1885 to 2006, is plotted in Figure 3. There is no overall trend; however there is considerable interannual and lower-frequency (interdecadal) variability. As a result annual precipitation has ranged from 689 mm in 1927 to 186 mm in 2001, the driest year on record. At an interdecadal scale, there are periods of one to several decades that are predominately wet (1885-1915, 1940s-60s) and mostly dry (1920s-30s, mid 1980s to mid 2000s), although large departures from these dominant conditions have occurred, such as the extreme wet year of 1927 and the extreme dry year of 1961, that occur during periods of generally below and about average precipitation, respectively.



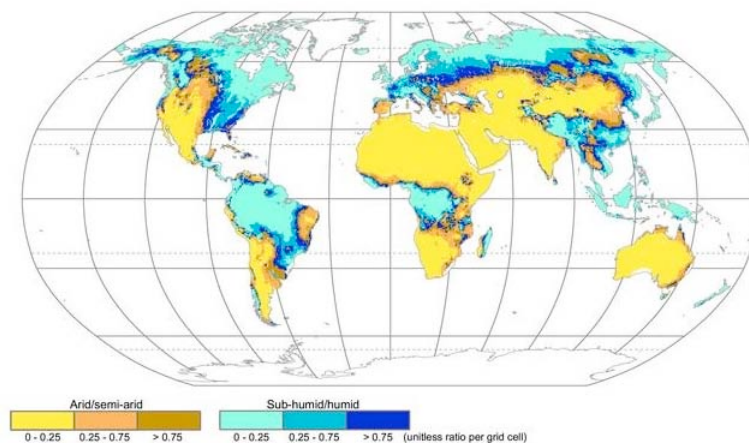
**Figure 3.** Mean annual precipitation (mm) at Medicine Hat, 1885-2006. The two driest years have been in the past decade. There is no overall trend but considerable interannual and interdecadal variability.

As with temperature, there is a contrast between seasons, and especially between winter and summer as illustrated in Figure 4. This graph shows that at Medicine Hat, more precipitation falls as rain in the warm season than snow in cold season. It also shows that there is much more interannual variability in summer precipitation and the inter-decadal variability is most apparent in the winter precipitation record. This low frequency variability includes a significant decline in snowfall since about 1970, whereas there seems to be no trend in summer precipitation.



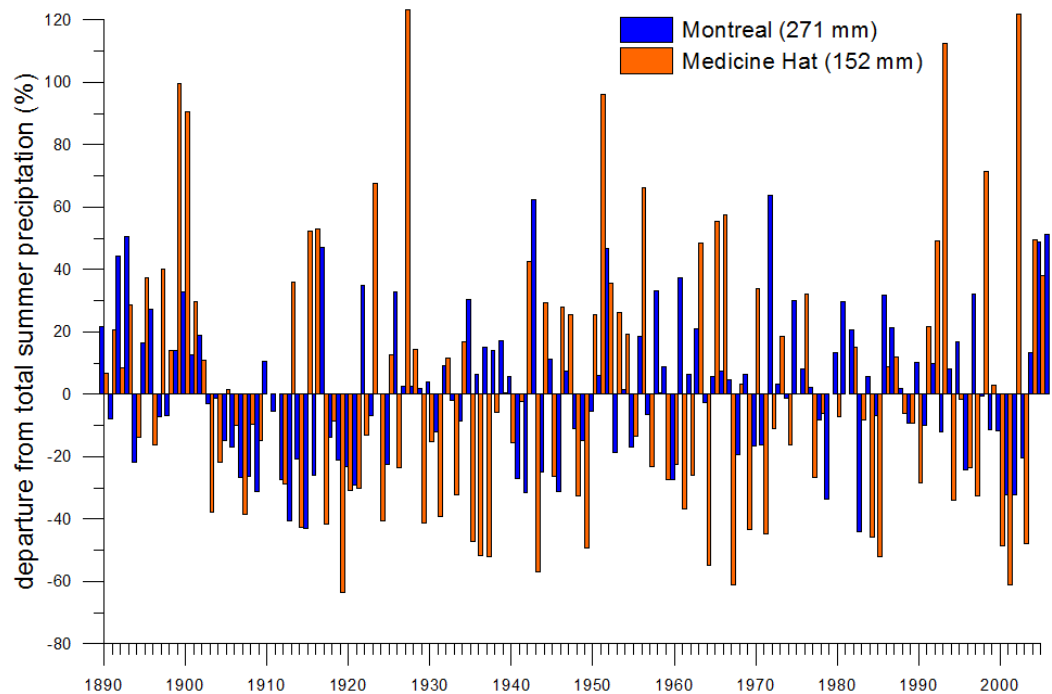
**Figure 4.** Mean annual summer and winter precipitation for Medicine Hat from 1885-2006.

Detecting trends in the climate of southern Alberta is made difficult by the extreme variability between years and decades. Few places on earth have a more variable climate, especially in terms of precipitation and the hydroclimate in general. Figure 5 is a map of the world showing the coefficient of variability in the annual value of the climate moisture index, which is the difference between precipitation and plant water demand (potential evapotranspiration). The regions of maximum interannual variability are mapped in brown for dry climates and blue for humid climates. The map clearly shows that the highest moisture variability, and greatest uncertainty from year to year, is in the transition from grassland (dry) to forest (humid), such as across Asia and Eastern Europe and in central Africa. However, one of the largest regions of with a variable hydroclimate is the margins of the North America plains, and in particular the Canadian prairies.



**Figure 5.** The global distribution of the interannual variability in the climate moisture index (source: World Water Development Report II; <http://wwdrii.sr.unh.edu>).

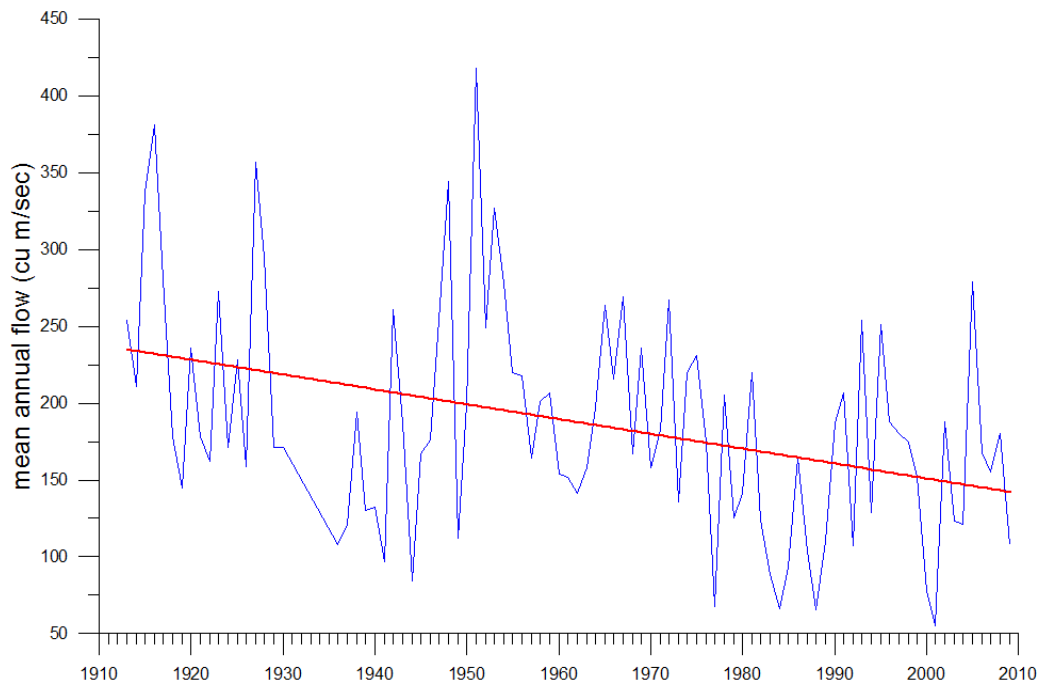
This inter-annual variability is illustrated for Medicine Hat in Figure 6, which shows annual departures from total summer precipitation, from 1890 to 2009, as a percentage of the mean value of 152 mm. For comparison the same data are plotted for Montreal, which receives roughly twice as much rainfall in summer, 271 mm. Whereas at Montreal few years had departures of exceeding 30%, at Medicine Hat summer rainfall has been double the average (departure of > 100%) several times and rainfall deficits of more than 30% have been frequent.



**Figure 6.** Annual departures from total summer precipitation, from 1890 to 2009, for Medicine Hat and Montreal. The departure are plotted as a percentage of the mean summer precipitation for the period of record: 152 mm for Medicine Hat and 271 mm for Montreal.

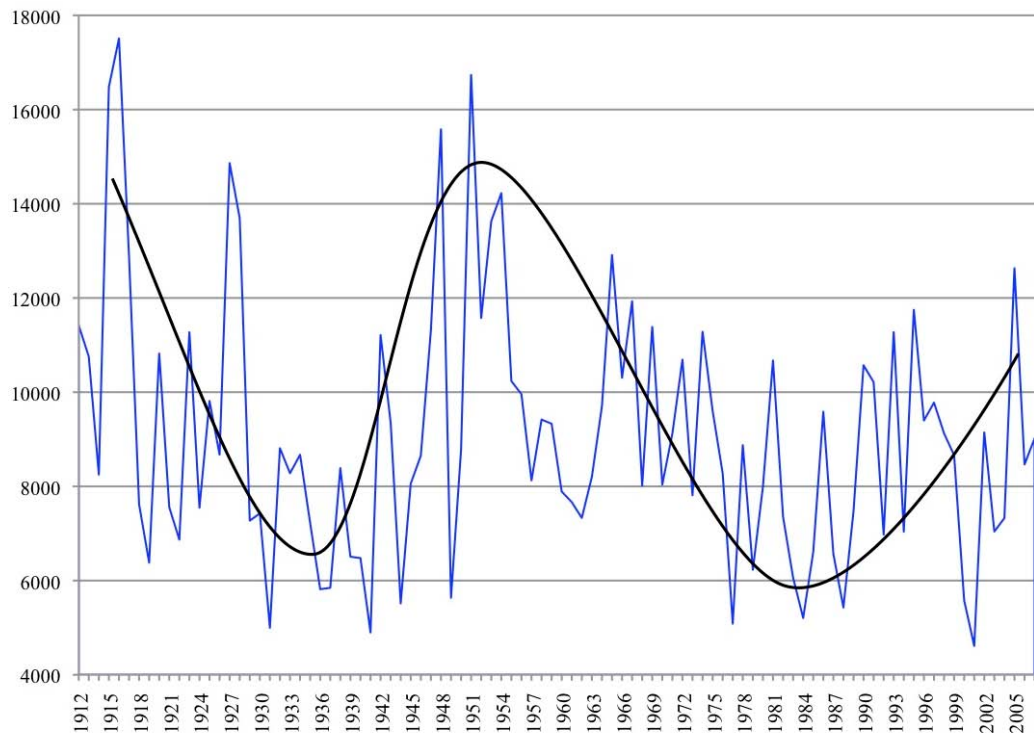
### *Streamflow*

The level and volume of water in a river channel reflects the climate and hydrology of the entire basin upstream of the recording gauge. Streamflow data also integrate the climate over time, from weeks to months, since the water flowing in a large river could have precipitated in the headwaters as rain several weeks ago or even months ago in the case of snowfall or water which enters the channel as groundwater. As a result, streamflow data are a good indicator of climate and hydrology throughout the watershed. We would therefore expect to see the same annual to inter-decadal variability in the streamflow records that we saw above (Figures 2-5) in precipitation and effective moisture. The mean annual flow of the South Saskatchewan River has been measured at Medicine Hat since 1913. This record is plotted in Figure 7. While there is considerable inter-annual variability, the most obvious feature is the significant downward trend. This decline in recorded flow can be attributed almost entirely to the increasing consumption and diversion of river water, mostly for irrigation upstream.



**Figure 7.** The mean annual flow of the South Saskatchewan River recorded at Medicine Hat, 1913-2009. The significant decline in recorded flow can be attributed primarily the increasing diversion and consumption of the river water, mostly for irrigation upstream.

This direct impact of land and water use on the flow of the South Saskatchewan River complicates our analysis of the effect of climate change and variability. Fortunately Alberta Environment estimated the amount of water that has been withdrawn and consumed each year and added these volumes to the recorded flow to produce a record of the naturalised flow of the South Saskatchewan River at Medicine Hat. This time series (Figure 8) displays strong inter-decadal variability highlighted using a solid black line. From peaks and trough in this curve there are short 30-year trends in river flow with large departures from these trends from year to year. For example, there is a declining trend from high flows in the late 40s and early 50s to low flows in the 80s, but with some very dry years in the late 50s/early 60s and some wet years in the 70s. Similarly, there has been generally higher flows since the 1980s, but 2001 recorded the lowest river levels in the entire record.



**Figure 8.** The naturalized flow record of the South Saskatchewan River at Medicine Hat. This flow reconstruction restores the river water that each year if consumed or diverted, mainly for irrigation (source: Alberta Environment). The strong inter-decadal variability in this record is represented by the solid black curve.

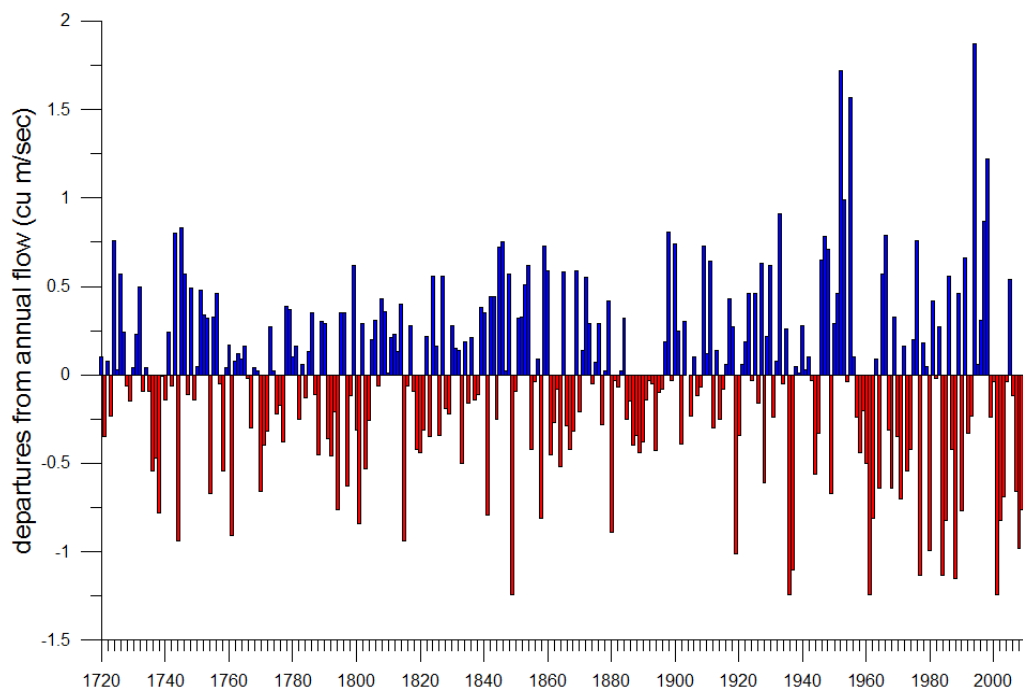
## The Hydrology of the Past 600 Years

The inter-decadal cycles in river flow and winter precipitation at Medicine Hat are long relative to length of most instrumental records. A full inter-decadal cycle, consisting of a high phase plus a low phase, spans about 50-70 years. The water and weather records used in this report from Medicine Hat are unusually long. Even these records, however, capture only one full inter-decadal cycle plus part of another. Longer proxy records are required to better understand this scale of variability in the regional hydroclimate and to capture a greater range of climate extremes (St. George and Sauchyn, 2006). Tree rings are the preferred climate proxy for recording inter-annual to multi-decadal variability extending over many centuries. They are the source of both climate information and an absolute annual chronology; each tree ring corresponds to a calendar year. The amount of growth each year (i.e., the width of the annual ring) is determined by the environmental factor that is most growth limiting. Typically this limiting factor is heat at cold locations (e.g., at arctic and alpine treeline) or soil moisture at dry sites.

Researchers from the Tree-Ring Lab at the University of Regina's Prairie Adaptation Research Collaborative have collected tree rings from 148 sites that are scattered across the boreal forest of Saskatchewan, Alberta and the Northwest Territories, the montane forest of the Rocky

Mountains, and island forests of the northern Great Plains. Because the Canada's western interior has a dry climate and the tree-rings are from dry sites (south- and west-facing slopes, sandy soils, ridge crests), there is a strong statistical relationship between the moisture-sensitive tree-ring chronologies and hydroclimatic variables, including precipitation and streamflow, and indices of drought and climate moisture. Of the 148 tree-ring sites, The very first site in this network of tree-ring sites was the Cypress Hills of southeastern Alberta and southwestern Saskatchewan. A reconstruction of precipitation was derived from this tree-ring chronology and published in 1998 (Sauchyn and Beaudoin, 1998). This chronology was recently updated to 2009 using samples collected this past summer.

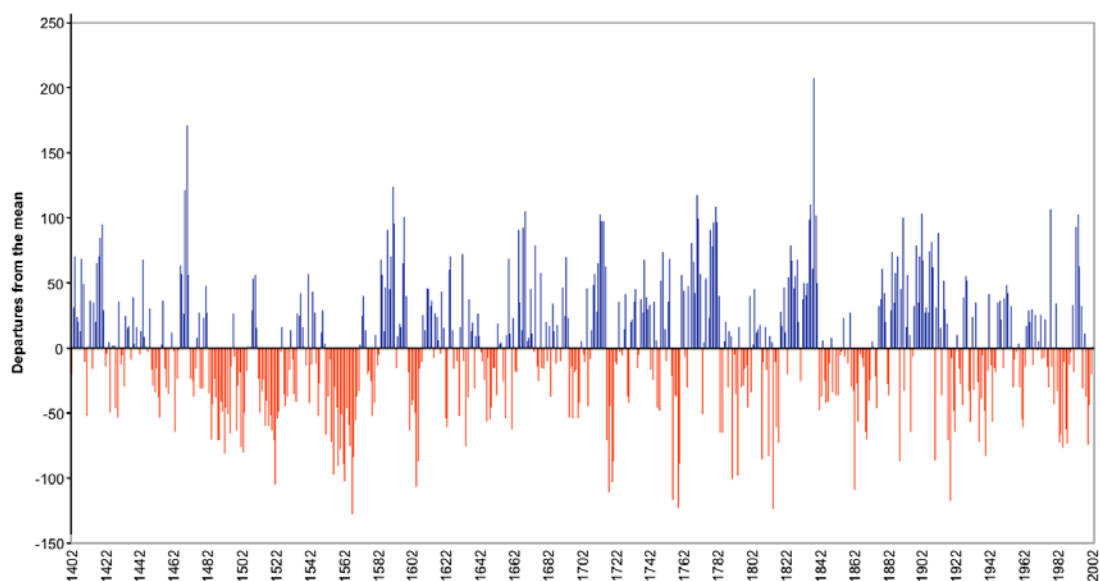
The coniferous forest of the Cypress Hills is surrounded by the dry sub-humid grasslands of the northern plains. With higher precipitation and lower temperatures than at lower elevations, there is just enough soil moisture in the Cypress Hills to support white spruce and lodgepole pine, but available soil moisture is the limiting growth factor; there is plenty of nutrients, carbon dioxide and heat in summer. Therefore, there are significant statistical relationships between our tree-ring data from the Cypress Hills and hydroclimatic data from the surrounding area. For the purpose of this report, a tree-ring chronology from the white spruce was calibrated using the spring-summer (April to July) flow of Lodge Creek recorded near the provincial boundary southeast of Medicine Hat. The streamflow and tree-ring data are significantly correlated ( $r = 0.48$ ;  $p < 0.05$ ). In Figure 9, the annual flow of Lodge Creek from 1720-2009 is plotted as positive (blue) and negative (red) departures from the mean annual flow.



**Figure 9.** Reconstruction of the flow of Lodge Creek, 1720-2009, from white spruce tree rings from the Cypress Hills. The flow is plotted as positive (blue) and negative (red) departures from the mean annual flow.

The tree rings replicate the instrumental record; for example, the wet years of the 1950s and 1990s and the severe droughts of 1936-37, 1961, 1984, 1988, and much of the past decade. The much longer tree-ring record reveals that these recent years of excess moisture are the wettest of the past 290 years. The recent droughts represent the driest years in the tree ring record, along with 1849. However, the most prolonged drought of the past 290 years, during 1885-1896, pre-dates the streamflow record. In February, 1891, the editorial *Our True Immigration Policy* in the first edition of the Medicine Hat Times stated: “It would be almost criminal to bring settlers here to try to make a living out of straight farming” (Sauchyn et al., 1993).

This reconstruction of the flow of Lodge Creek back to 1720 gives an indication of the variability of the hydroclimate of southeastern Alberta over the past three centuries. This variability, and especially the drought years, have had a profound affect on dryland farming in the region. However, the water supply for most of the population of the SSRB and the dominant industry, irrigated agriculture, is the rivers that flow from the Rocky Mountains. Axelson, Sauchyn and Barichivich (2009) reconstructed the annual flow of the South Saskatchewan River at Medicine Hat using tree-rings collected throughout the runoff generating upper reaches of the SSRB. This proxy streamflow record, shown in Figure 10, extends from 1402 to 2004.

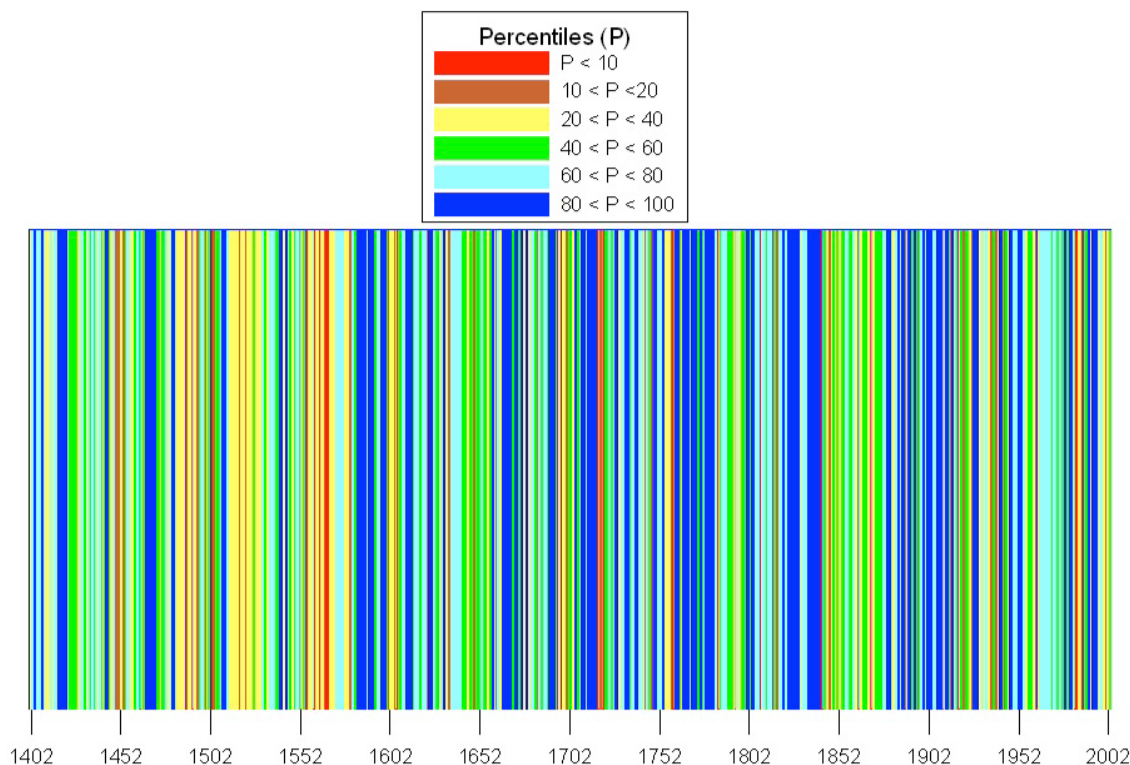


**Figure 10.** The tree-ring reconstruction of the annual flow of the South Saskatchewan River at Medicine Hat. The reconstructed flow is plotted as positive (blue) and negative (red) departures from the mean flow for the period of reconstruction. (Source: Axelson, Sauchyn and Barichivich, 2009)

The most prolonged wet period in this 603-year record extends from the 1880s to the mid 1910s. It is represented by many consecutive blue bars and relatively few red ones. This was the period of homesteading, when the SSRB basin was settled and agriculture became established. The long periods of sustained low flow, represented by consecutive red bars, mostly predate European settlement of southern Alberta. During 1840 to 1870, just before the western prairies were surveyed and settled, there were consistently low levels in the South Saskatchewan River with

only five years of barely above average flow. Midway through this period, the Palliser expedition was sent to the Canadian plains to explore and assess the suitability of this region for agriculture and settlement by immigrants from Western Europe. He advised the British government that a large area (known today as Palliser's triangle) would be "forever comparatively useless". Other pre-settlement periods of extreme (early 1720s and 1760s) and sustained (1780-1820 and 1470-1580 – 100 years!) low flow indicate that the most devastating post-settlement droughts of the 1920-30s, 1980s and early 2000s are not the worst case scenario. The tree-ring record suggests the recent occupants of the SSRB could in the future be exposed to droughts of greater severity and/or duration than those that we have experienced over the past 120 years.

The proxy flow record for the South Saskatchewan River suggests that wet and dry spells reoccur at quasi-regular intervals. This is perhaps more visually apparent when the flows are classified by percentile and plotted as a bar code in Figure 11. Because drought is a greater concern in the watershed than excess water, the lowest two classes represent the least 10% of flows and those in the 10 to 20% range. They are coded in red and brown, respectively. The other classes represent 20% of the distribution of stream flows, with the highest flows coded in blue. A scan of the bar code reveals some variability at a roughly decadal scale.



**Figure 11.** The flow of the South Saskatchewan River from 1602-2004 plotted as a bar code. The lowest two classes represent the least 10% of flows and those in the 10 to 20% range. The other classes represent 20% of the distribution of stream flows.

## Future Climate and Water Supplies

The foregoing analysis of the instrumental and proxy records of hydroclimate of the SSRB give an indication of trends and natural modes of variability. The climate and water supplies of the new future are difficult to anticipate because in recent decades the earth's climate has undergone unprecedented rates of warming that are well documented (IPCC 2007). The future climate will combine the natural variability and changes imposed by a warming climate. Global Climate Models (GCMs) "are the only credible tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations" (IPCC-TGCI, 2007). GCMs are mathematical representations of the complex physical laws and interactions between ocean/atmosphere/sea-ice/land-surface. A high level of confidence is placed in these models because they are (1) based on established physical laws, such as conservation of mass, energy and momentum, along with numerous observations; (2) able to simulate important aspects of the current climate; and (3) able to reproduce features of past climates and climate changes. GCM experiments simulate future climate conditions based on estimated warming effects of carbon dioxide (CO<sub>2</sub>), other greenhouse gases (GHGs), and the regional cooling effects of increasing sulphate aerosols. The Intergovernmental Panel on Climate Change (IPCC) developed 40 SRES (Special Report on Emission Scenarios) socio-economic storylines as the basis for projecting and classifying (e.g. A1B, A2 and B1) the range of potential concentrations of GHGs (Nakicenovic et al 2001).

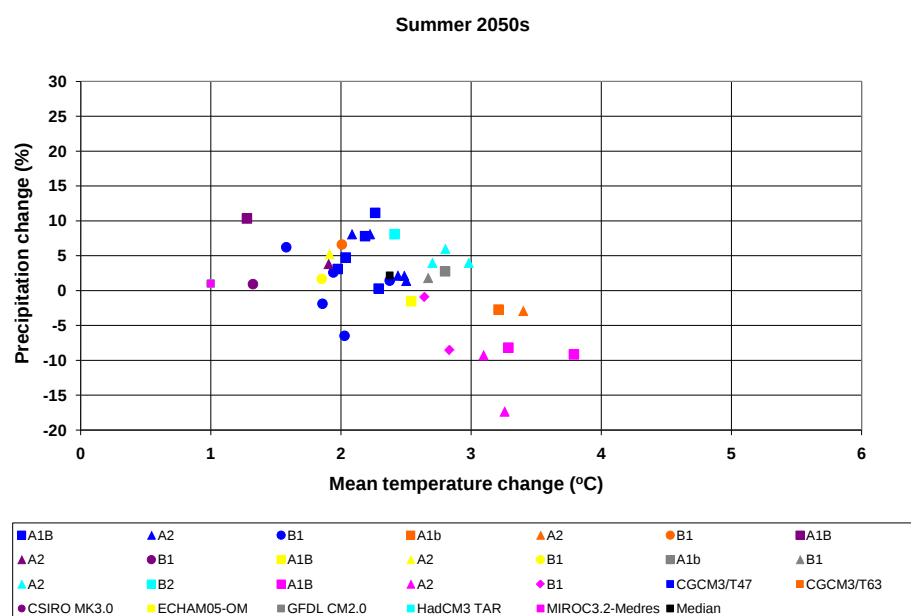
Because future climate cannot be predicted, the best approach to exploring possible future conditions is to examine a range of plausible climate scenarios based on outputs from seven Global Climate Model (GCM) experiments, and one to four greenhouse gas emission scenarios. A climate change scenario is typically expressed as a difference in temperature, or percentage change in precipitation, between a mean baseline of 1961-1990 and a future 30-year time period, generally the 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099). Using an array of GCMs and emission scenarios captures a broad range of future climates and much of the uncertainty in the modeling of the response of the climate system to changes in natural and anthropogenic forcing. To map the climate changes for SSRB the GCM output was interpolated to a 0.5 degree grid. Observed historical (1901-2000) climate data have been gridded (0.5°) for North America from by the Canadian Forest Service (McKenney et al., 2006). Lapp et al. (2009) provide further details about the methods used to develop climate change scenarios for the SSRB.

### *Temperature and Precipitation*

Figure 12 is scatter plot of the projected changes in mean summer temperature (°C) and summer precipitation (%) for the SSRB from 1961-1990 to the 2050s (2040-69). There are 38 scenarios derived from the selected GCM experiments and emission scenarios. We plotted summer scenarios because they show the largest range of uncertainty: temperature changes of +1 to almost +4 degrees and precipitation changes of -10 to +10% (with one outlier at -17%). In theory all scenarios are equally probable, but to reduce them to a smaller representative sample for further analysis we identified in Figure 12 the scenario that plots nearest to the center (median) of the scatter (+2.2°C/+2.2%), CGCM3.1/T47 B1(2), and the four that capture the extreme combinations of temperature and precipitation:

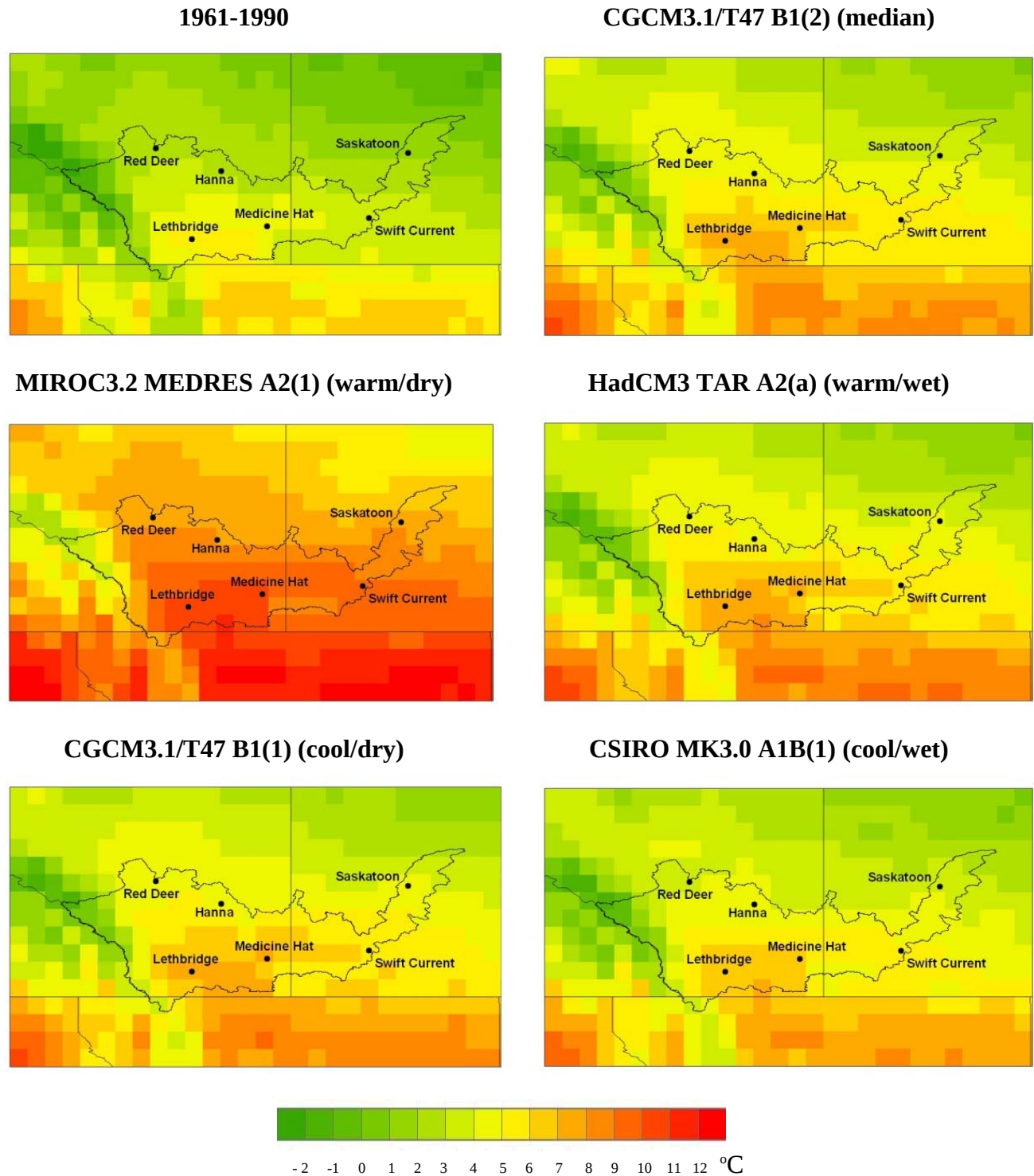
- warm/dry (+3.3°C/-17.3%), MIROC3.2 MEDRES A2(1)
- warm/wet (+2.9°C/+4%), HadCM3 A2(1)
- cool/dry (+2.1°C/-6.5%), CGCM3.1/T47 B1(1)
- cool/wet (+1.3°C/+10.3%), CSIRO MK3.0 A1B(1)

Note that the labelling of the extremes refers to relative change from baseline conditions and thus “cool/dry” does not refer to a cooler and drier future climate but rather to the scenario that projects the least increase in temperature and precipitation.

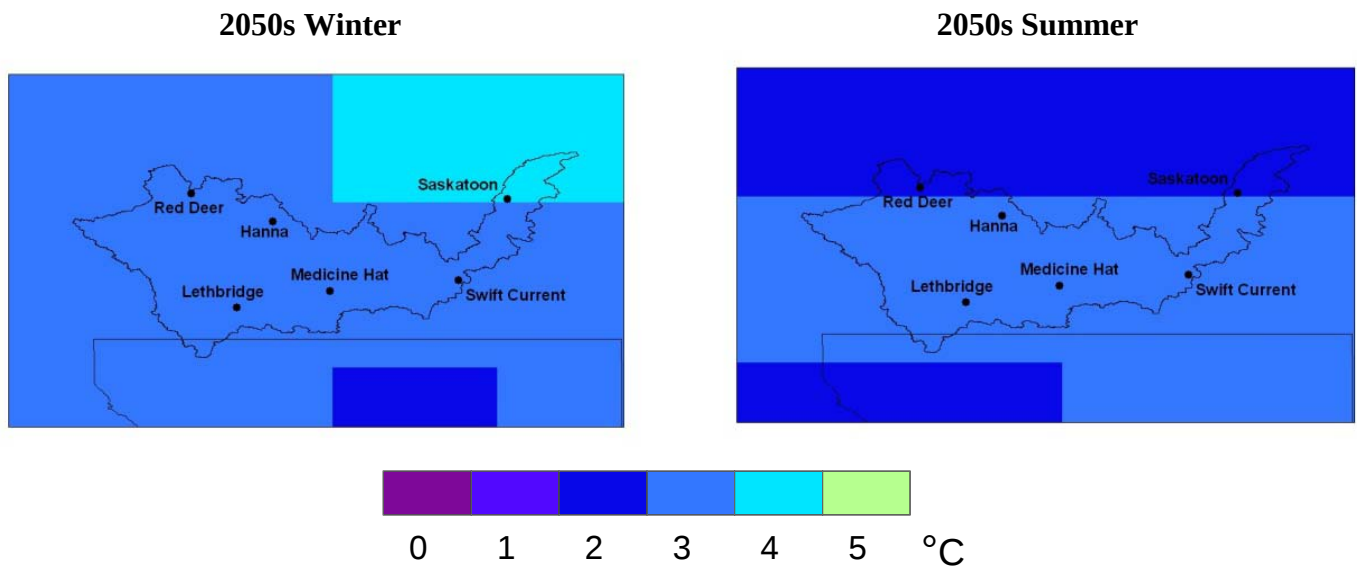


**Figure 12.** A scatter plot of changes in mean temperature (°C) and precipitation (%) for the SSRB for the 2050s (2040-69) summer. The colours refer to the global climate model (GCM) and the symbols identify the greenhouse gas emission scenario.

We applied the climate changes projected by these five GCMs experiments to baseline temperature and precipitation data and interpolated the results to the 0.5° grid to produce maps showing the future climate against the outline of the SSRB and a few communities. The maps in Figure 13 show 1961-1990 mean annual temperature and the projected temperatures for the 2050s from the five climate model experiments. These maps display warming throughout the basin with mean temperatures rising from below zero in 1961 to well above zero by the 2050s. These annual conditions mask, however, the seasonal contrast in climate changes shown in Figure 14; temperature changes of 4-5°C in winter versus 3-4°C in summer.



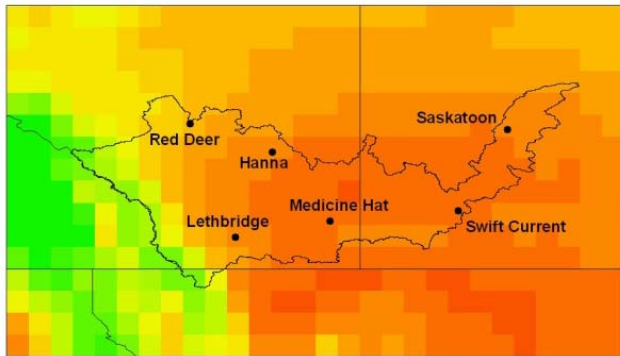
**Figure 13.** Annual mean temperature (°C) for the 1961-1990 and a range of scenarios for the 2050s.



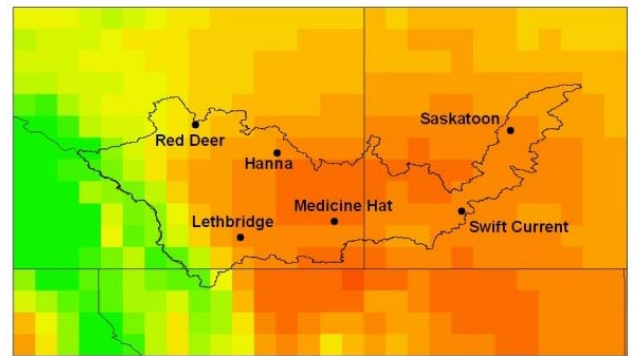
**Figure 14.** Winter (left) and summer (right) temperature changes from 1961-90 to the 2050s (2040-69). These are the median projections from the model CGCM3.1/T47 B1(2).

The precipitation scenarios for the 2050s are mapped in Figures 15 and 16. The median projection for annual precipitation indicates a shift up the precipitation scale by one class (50 mm or about 10%) for most of the grid cells. Again the critical information is the contrast (Figure 16) between winter, with increases of 10-20%, versus summer, when most of basin will have decreased precipitation or only a slight increase. These projections of increased annual temperatures, amplified during winter, and decreased summer and increased winter/spring precipitation, extend over most of southwestern Canada.

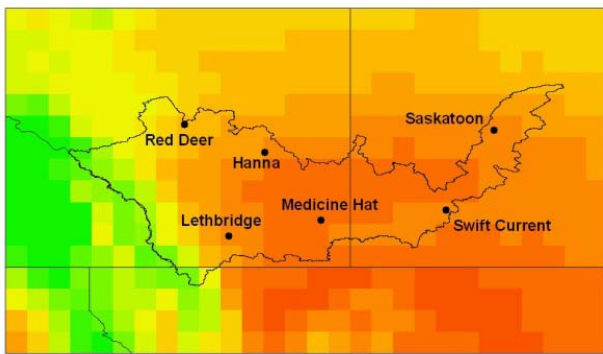
1961-1990



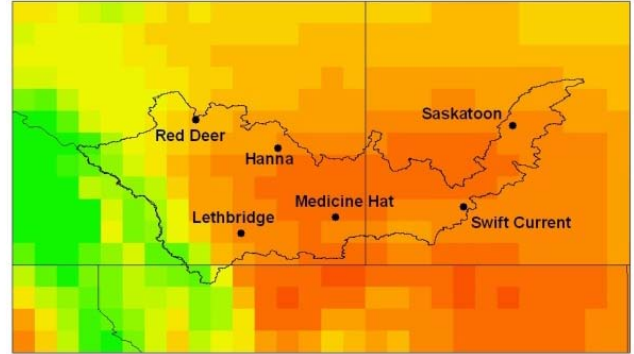
CGCM3.1/T47 B1(2) (median)



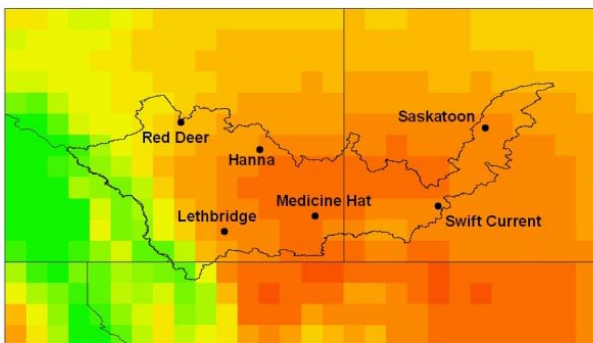
MIROC3.2 MEDRES A2(1) (warm/dry)



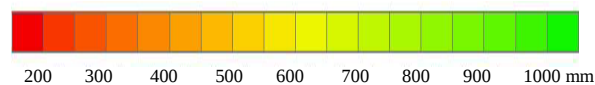
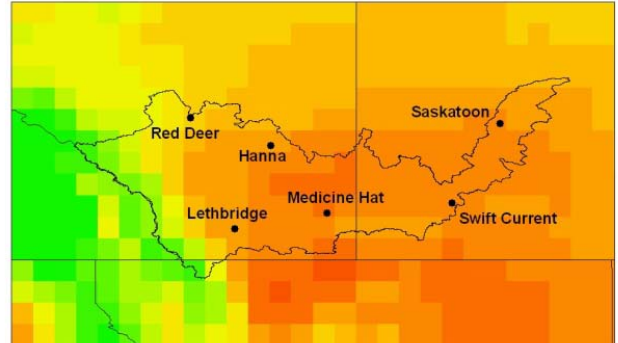
HadCM3 TAR A2(a) (warm/wet)



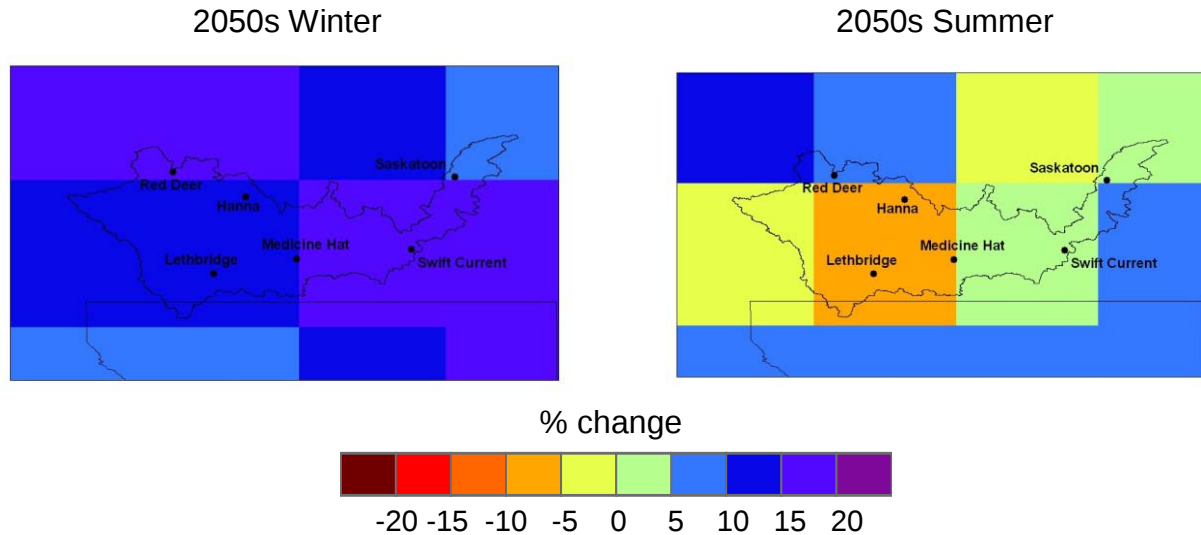
CGCM3.1/T47 B1(1) (cool/dry)



CSIRO MK3.0 A1B(1) (cool/wet)



**Figure 15.** Annual total precipitation (mm) for 1961-1990 and a range of scenarios for the 2050s.

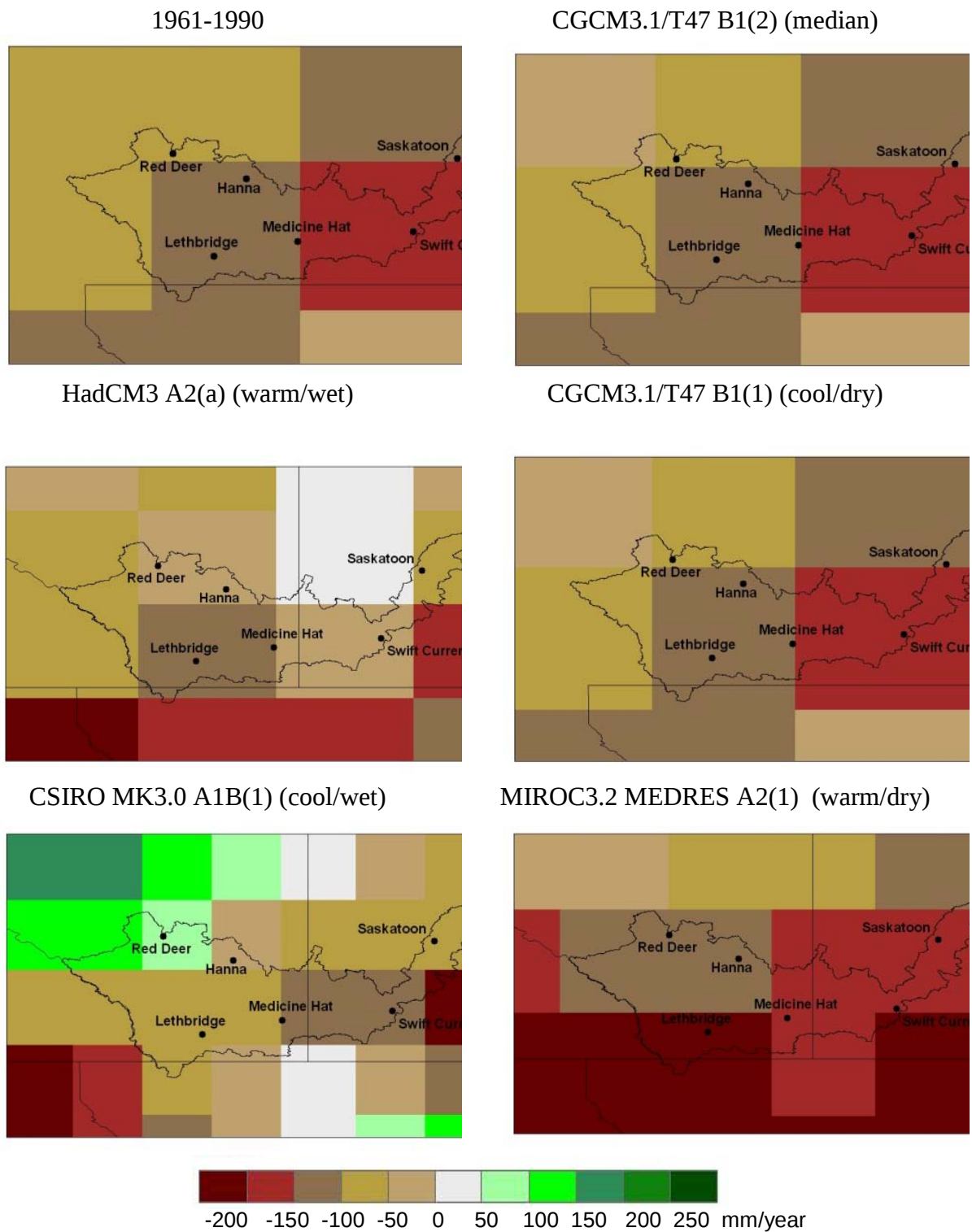


**Figure 16.** Projected changes in winter (left) and summer (right) precipitation from 1961-90 to the 2050s (2040-69). These are median projections from the model CGCM3.1/T47 B1(2).

### *Moisture Index*

The SSRB coincides with Canada’s largest dryland region where moisture deficits typically exceed 100 mm per year and are offset by using surplus water from the headwaters of the basin. Furthermore, this region has Canada’s most variable hydroclimate as shown earlier in this report. Therefore most of the climate risk in the basin is related to extremes of water availability. A fairly simple indicator of the annual water balance is the Climate Moisture Index (CMI), the difference between precipitation (P) and potential evapotranspiration (PET) (Hogg, 1997). Annual PET was calculated using the Thornthwaite equation because it is relatively simple, requiring only mean monthly temperature and day length, data that are readily available from the GCMs.

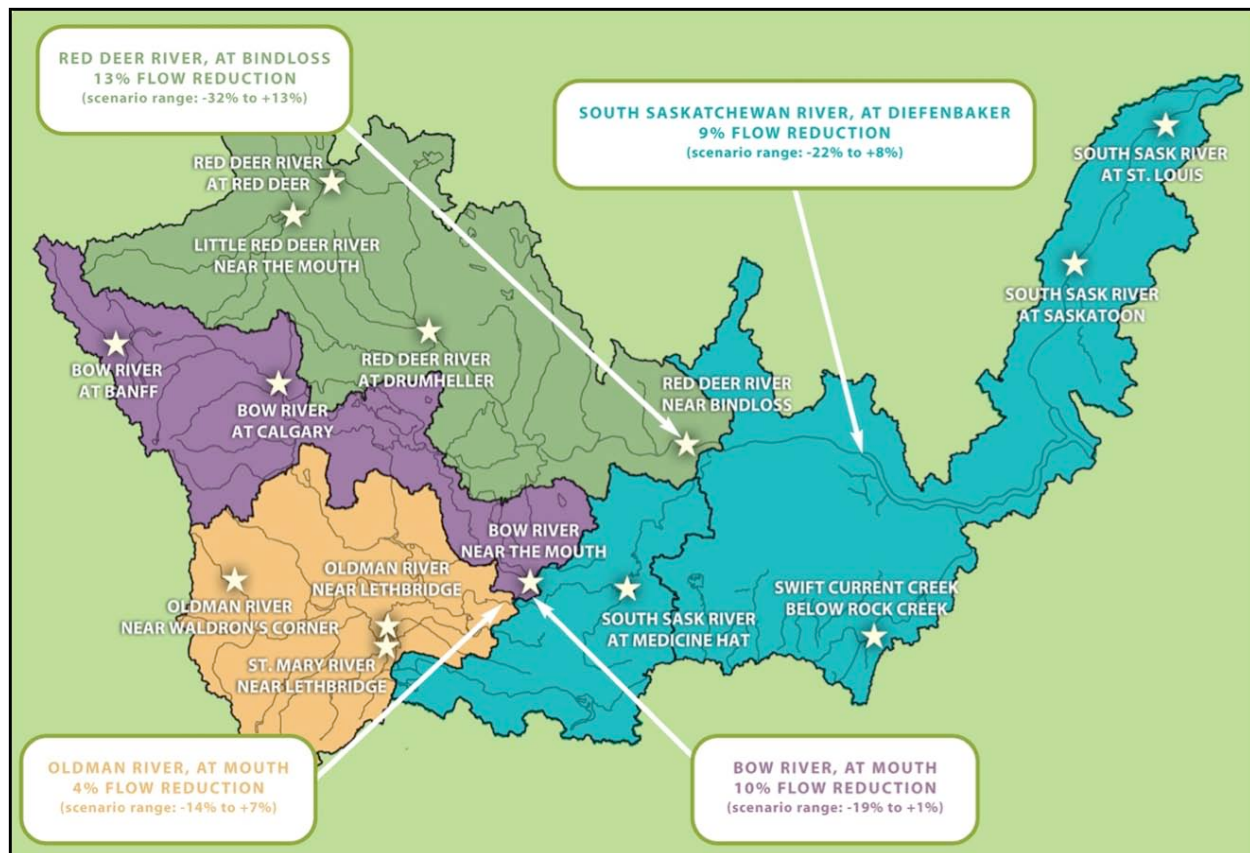
In Figure 17 the May-June-July CMI is mapped for 1961-1990 and for the 2050s for the range of climate scenarios. These maps indicate that, despite the projected increases in winter precipitation, the median scenario shows little or no improvement in the water balance. The extreme scenarios range from a shift to a lesser moisture deficit under with a “cool/wet” climate (least global warming and largest increase in precipitation) to a much larger moisture deficit throughout the basin under a “warm/dry” regime. These results of increased moisture deficits, under the median to worst case scenarios, is consistent with climate change studies at broader scales that project summertime drying of the continental interiors as increased evapotranspiration offsets any additional inputs of water or is combined with reduced summer precipitation. The western margin of the basin is mountainous; this analysis using a simple moisture index and coarse GCM data does not properly model the change in water balance of the alpine watersheds.



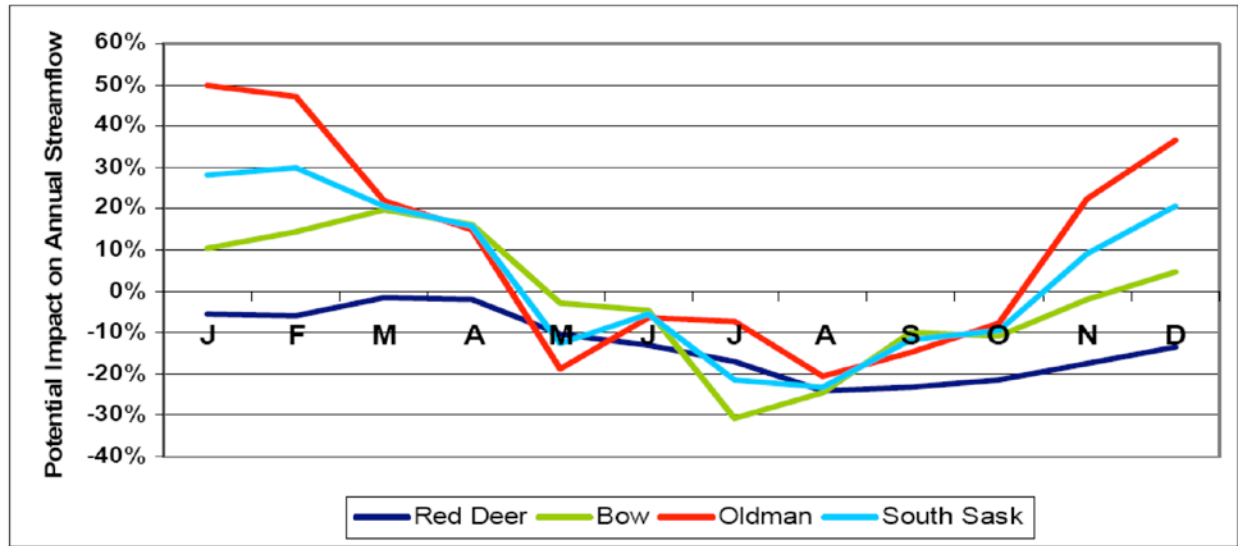
**Figure 17.** The May-June-July, Climate Moisture Index for 1961-1990 and the 2050s for a range of scenarios.

## Streamflow

Potential changes in annual water yield and mean monthly flow have been projected for the SSRB for each major sub-basin (Martz et al 2009; Lapp et al 2009). A group of scientists, led by Dr. Alain Pietrinero and Dr. Brenda Toth from Environment Canada, linked climate change scenarios like those given above with a model of watershed hydrology. Because there is a relatively large range of plausible future climate conditions, there is an equally large range of possibilities for the future flow of the SSR and its tributaries. Figure 18 shows the range of scenarios for each sub-basin. For the SSR where it leaves AB and enters Lake Diefenbaker in western SK, the projected changes ranges from decline of 22% to a increase of 8%. For all four sub-basins, however, the declines are much larger than the increases, such that the median projections are for flow reductions of between 13% for the Red Deer River to 4% for the Oldman River. The median decline for the main stem is 9%. These are values are the middle projection for a range scenarios and represent the change from one 30 year period (1961-90) to another (2040-69). They give no indication of when the declines are expected within or between years. The seasonal variation is shown in Figure 19.



**Figure 18.** Projected changes in sub-basin water yield for the SSRB between 1961-90 and 2040-69 (source: Lapp et al. 2009; map drawn by CPRC)



**Figure 19.** Projected changes in mean mostly flow for the SSR and its major tributaries between 1961-90 and 2040-69 (source: AMEC 2009, Martz et al 2009; Lapp et al. 2009)

This plot of projected changes in mean mostly flow for the SSR and its major tributaries shows much increased flows in winter and reduced flow during May to October (The Red Deer is anomalous but it does not have the large high elevation catchment area of the Bow and Oldman Rivers). This shift in water supplied from summer to winter is one of the most certain and challenging impacts of a warmer climate. It implies adaptation strategies such as corresponding shift in water consumption and use and increased storage of winter precipitation in reservoirs but also in protected and restored headwater ecosystems.

## Discussion

Temperature records for Medicine Hat show a warming trend, mostly in winter and especially since the 1970s. This rise in annual temperatures, with the largest increase in winter, is the climate trend projected by global climate models (GCMs) for the South Saskatchewan River Basin (SSRB). Annual temperatures rose by about one degree from 1895 to 2006. Another 2-3 degrees of warming is projected by the GCMs. Regional temperature changes can be directly related to global and external factors such as earth's energy balance which currently is being altered by the change in the chemistry of the atmosphere and specifically the concentration of greenhouse gases. Whereas temperature trends and projections are relatively consistent, precipitation and streamflow are much more variable. Regional precipitation and the surface water balance are the outcome of various global and regional processes and feedbacks. In particular, precipitation and streamflow records from western North America have strong inter-annual to multi-decadal variability; wet and dry cycles of a few years are superimposed on cycles lasting a few decades. This short-term variability has been linked to teleconnections in climate and specifically oscillations in sea surface temperature in the Pacific Ocean. Two climate oscillations, the El-Niño Southern Oscillation and the Pacific Decadal Oscillation have an especially strong influence on winter precipitation in western Canada at inter-annual and inter-decadal time scales, respectively (Bonsal et al., 1993; Mantua et al., 1997; Shabbar et al., 1997).

Precipitation measured at Medicine Hat, and the flow of the South Saskatchewan River, clearly show large inter-annual variability and the longer wet and dry cycles. No place else in Canada, and few places on earth, have this much variability in the annual water balance. This complicates the detection of trends in regional hydroclimatic records. The records from weather and water gauges are relatively short compared to the longer climate cycles lasting 50-70 years. The longest instrumental records, such as those from Medicine Hat, capture only one full cycle and part of another. Proxy records of the climate and hydrology of the past 600 years capture many more of these longer cycles and a larger range of extreme annual conditions. Trees growing at dry sites in the Cypress Hills and on the eastern slopes of the Rocky Mountains record annual variation in the availability of water, since this is the factor that most limits the annual growth of these trees. The tree-ring reconstruction of annual streamflow indicates that the instrumental period of the past 100 years may represent fairly well the frequency of one- to two-year droughts, but it does not capture the full range of intensity and duration. The tree rings suggest that the climate of the 20th century was relatively favourable for the settlement of the prairies. The initial phase of homesteading during 1880 through the 1910s coincided with the longest sustained wet period of the past 600 years. Furthermore, the dry periods of greatest severity and duration occurred before the prairies were settled. These include the intense drought years of the 1790s, when sand dune fields in the SSRB became active (Wolfe et al., 2001), and the sustained drought of the 1850-60s, when the southern prairies were deemed unsuitable for agriculture (Sauchyn et al., 2003).

The instrumental and tree-ring data record the natural climate variability that underlies changes to the regional water cycle that are caused by a warming global climate. The warming that can be expected for the next 50 years is simulated by various global climate models (GCMs). This report presents a range of climate scenarios for the SSRB based on output from GCMs. All these GCMs project increased temperature for the SSRB in all seasons, but especially in winter, conforming to recent observations. The projected changes in temperature will influence snow accumulation in the mountains likely causing a shift in the dominant flow season from summer to spring and lower flows in summer and fall. All of the climate change scenarios suggest increased precipitation in winter and spring; some show less in summer. Increased temperatures will result in an increased number of days with net positive evaporation from soil, dugouts, rivers, lakes and reservoirs. As a result there is no increase in the climate moisture index (P-PET) under the a median climate change scenarios, despite the increased precipitation (P) in winter and spring; it is offset or exceeded by a rise in evapotranspiration (PET).

These scenarios of the future climate of the SSRB provide information about the shift in average conditions which can be expected. This is critical information in anticipation of the impacts of climate change, but not necessarily the most relevant information for southern Alberta. The major climate risks are departures from average conditions and extreme climate events. Therefore as important or more relevant than the expected trends are the internal cycles that likely will continue to dominate the observed variations in climate and hydrology. In fact, probably the major impact of global warming in this region will be to amplify the already large natural variability (Kharin and Zwiers, 2000). Thus knowledge of the existing natural cycles in the weather and climate is required before the impacts of warming global climate can be understood. The decadal-scale variability, evident in the tree-ring records for the past 600 years,

will be a significant aspect of the future hydroclimate. Adaptation strategies (e.g. insurance, water storage) have evolved for coping with the short (1-2 year) relatively frequent droughts. The prolonged dry spells that occur infrequently, but are possibly more often with global warming, will be the most challenging aspect of future climate variability.

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The **South East Alberta Watershed Alliance (SEAWA)** was formed in 2007, incorporated as a non-profit society in 2008, and designated as the WPAC (Watershed Policy and Advisory Council) for the South Saskatchewan River sub-basin.

*SEAWA Vision: A healthy watershed that provides balance between social, environmental and economic benefits.*

*SEAWA Mission: South East Alberta Watershed Alliance brings together diverse partners to plan and facilitate the sustainable use of the South Saskatchewan River Watershed for present and future needs.*

SEAWA Members include interested individuals throughout the watershed along with our communities, ranchers, farmers, industries, companies, governments, conservation groups and educational institutions. We are proud to include the following among our founding members:

*Government Sector:* Alberta Government, City of Medicine Hat, Government of Canada, Cypress County, Palliser Health Region, Town of Redcliff, Town of Bow Island, and Special Areas Board.

*Land Resource - Industry and Agriculture Sectors:* St Mary River Irrigation District, Murray Lake Ranching, GG Bruins Farms, Short Grass Ranches, Canadian Fertilizers Limited, Redcliff Technology Enterprise Centre, Box Springs Business Park, and Canadian Centre for Unmanned Vehicles.

*Academic, Research and Non-Governmental Organizations Sectors:* Medicine Hat College, Alberta Research Institute, Red Deer River Watershed Alliance, and Hyperion Research.

*Tourism and Conservation Sectors:* Grasslands Naturalists, Canadian Badlands, and Medicine Hat Interpretive Program.

**SEAWA Web-based State of the Watershed Report** is managed by the *SEAWA State of the Watershed Committee (members - 2010):*

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**Gary Bierback**, SEAWA Vice-Chair, *St Mary River Irrigation District*  
**Grayson Mauch**, *City of Medicine Hat Water and Wastewater*  
**Herb Scott**, *Cypress County*  
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**Audrey Goodwin**, *Alberta Environment*  
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**Gerard Klotz**, *Medicine Hat College*  
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*SEAWA Watershed Reports are part of our Web-based State of the Watershed Report.*

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