A climate change adaptation study for the South Saskatchewan River Basin

Sylvia Lac
University of Regina
April, 2004

IACC Project Working Paper No. 12

Please contact Sylvia Lac at sauchyn@uregina.ca.

TABLE OF CONTENTS:

APPENDICES:

LIST OF FIGURES:

1 INTRODUCTION

With the Kyoto Protocol ratification, the government of Canada made climate change a national priority. Climate change in Canada is co-managed by the Ministry of Environment and the Ministry of Natural Resources. They are active in a number of areas, including climate change impacts and adaptation research, general circulation modeling to simulate likely effects of greenhouse gases, measuring and modeling sources, sinks and reservoirs of greenhouse gases in Canada, and energy efficiency technology. Reducing the impact of climate change has been pursued in agriculture, forestry, transportation, renewable energy and energy efficiency.

Nevertheless, regional differences and provincial legislation often require a different approach by the federal government as well as a high level of integration. Unlike other countries (with centralized federal governments), Canada's federal government is a young institution in itself that continuously needs to negotiate with the provinces to include matters of national interest. Simply put, the decentralized power is sometimes a constraining factor to enable a single large-scale climate change approach by the Canadian federal government.

In the heart of the Canadian Great Plains (including parts of Alberta and Saskatchewan) and within the Palliser Triangle, the South Saskatchewan River Basin (SSRB) area is historically subject to droughts. Its location (east of the Canadian Rocky Mountains) includes natural barriers blocking the flow of moisture from the Pacific Ocean, creating "Chinook" conditions (i.e. warm dry winds from air masses that crossed the mountains after losing moisture to orographic precipitation).

The SSRB rivers are heavily influenced by snow-melt and are considered to be some of the most sensitive (i.e. prone to changes in hydrology and fluvial processes) and most vulnerable watersheds to climate change in Canada (Natural Resources Canada, 2004). They are vulnerable in that changes to fluvial processes are likely to increase fluvial hazards, to hamper human activity and to damage structures.

Climate change is likely to increase the drought frequency and severity in the SSRB area. Planning for adaptation is therefore essential, as even the best mitigation efforts cannot halt the effects of climate change in the region. However, planning for adaptation can decrease the vulnerability of this area by providing options to strengthen the economic and environmental systems to better cope with droughts and other climate change impacts. An adaptation strategy can potentially ensure water availability to various levels of operational uses (e.g. agriculture, domestic, wildlife, etc). Although some autonomous adaptation can be expected, planning can reduce costs and residual damages. Without adaptation plans, disputes over water use in this area can be expected to become frequent.

This document is intended to provide background information about the SSRB in five parts: introduction (part 1); a description of the study area (part 2); a review on the climate change prediction tools and impacts for the study area (part 3); the climate change vulnerabilities and adaptation options in natural and human systems with relevance to the study area (part 4); conclusions and discussions (part 5); and references (part 6). Among the human systems vulnerabilities to climate change, further analysis has been done on the water resources sector.

2 STUDY AREA

2.1 The Saskatchewan River Basin History

The following historical information on the Saskatchewan River Basin was extracted from the Partners FOR the Saskatchewan River Basin website (Partners FOR the Saskatchewan River Basin, 2004).

The Saskatchewan River Basin's ecological diversity, and its importance in Canadian history are almost as broad as the basin itself. The Basin, one of the most diverse in North America, covers 420,000 square kilometres (168,000 square miles), encompasses three provinces and one state, and includes some of the longest rivers in Canada. The Saskatchewan River itself is Canada's fourth longest.

The North Saskatchewan River begins as an icy waterfall at the foot of the Saskatchewan Glacier in western Alberta. Smaller streams join its flow, including the Brazeau and Clearwater Rivers, near Rocky Mountain House. Gathering momentum, it curves past Edmonton, the Battlefords, through the forest and parkland, then to Prince Albert where it meets the South Saskatchewan at the confluence known as The Forks.

The South Saskatchewan is a prairie river, arising from seven small rivers flowing from the Great Divide in Montana and southern Alberta. These rivers merge, and between the cities of Lethbridge and Medicine Hat, the South Saskatchewan first appears at the junction of the Oldman and Bow Rivers. After cutting its way through prairie grasslands, it widens into Lake Diefenbaker, then angles north past Saskatoon, into the parkland and on to The Forks.

Just west of the Manitoba-Saskatchewan border, the Saskatchewan River divides into a delta, forming the Cumberland Marshes. The main branch continues its eastward journey through The Pas and broadens into Cedar Lake before rushing past Grand Rapids into Lake Winnipeg. It continues on to the Hudson Bay.

The history of the Saskatchewan River Basin is as dynamic as its geography. Aboriginal peoples long ago followed its curves and raced its rapids to hunting and fishing grounds. The Saskatchewan River carried fur traders, missionaries and settlers to the heart of the continent.

With the development of the railroad, the importance of the river as a transportation route declined, but its waters were put to many other uses, by the new farmers and communities growing along its banks.

Humankind has flourished in the Saskatchewan River Basin for almost as long as the river has existed, weathering several major changes in climate and ecology.

Archeologists have found more than 650 sites throughout the Basin showing the presence of humans 10,500 years ago, and 1,000 years before that in southern Saskatchewan, literally on the heels of the last glacial age. These early residents probably relied on hunting large Pleistocene animals such as mammoth, camel and caribou.

Around 11,000 years ago, mammoths and other species began to disappear and hunters pursued large game such as bison, which were becoming more abundant as the grasslands expanded and competing species disappeared. Bison continued to adapt and thrive, and remained the mainstay of the Plains Indian until the 19th century.

About 7,700 years ago, the plains environment became much warmer and drier. The population of large bison began to dwindle under the severe drought conditions.

About 5,000 years ago, the environment became cooler and wetter. The smaller plains bison (buffalo) had become more abundant, and humans living near the river had begun to trade extensively with other cultures. That trade, improved hunting techniques, and the more productive climatic conditions all combined to help humans flourish along the river. Approximately 2,000 years ago, as the Roman Empire flourished and Christianity began, two technological innovations influenced the cultures of the Plains Indian: pottery; and the bow and arrow.

Pottery provided a better means for processing, storing, transporting and preparing foods and other provisions. The bow and arrow, which replaced spears and darts, made for more efficient bison hunting.

Contact with European traders, explorers and settlers changed the lifestyle of the First Nations rapidly - and irrevocably. The arrival of horses and guns let them move farther and faster, and hunt more efficiently. Contact also meant the successive introduction in the 1700s of epidemic diseases such as smallpox and measles, against which the Indians had no resistance.

The virtual demise of the bison by the late 1870s spelled the end of the traditional Plains Indian lifestyle. The impact of human activity became stamped on the landscape.

While the influx of settlers, the virtual eradication of the buffalo and the presence of whisky traders took their toll on the First Nations. The arrival of the North West Mounted Police in the 1880s proved a legal system of order. The Mounties - forerunners of the Royal Canadian Mounted Police - restricted the flow of whisky from Montana, and imposed the laws and justice of the British Empire with some sense of respect and courtesy for natives. Chief Crowfoot spoke of the Mounties protecting the tribes as the feathers of a bird protect it from winter.

When Sitting Bull, chief of the Sioux Nations, fled to Canada after the battle at Little Big Horn, he was told to follow the law of the land - and, for the most part, he did. In fact, when first approached by the U.S. government to return to the States, he refused - praising the Mounties for speaking the truth with him.

But despite the lack of bloodshed, the impact of change was no less inevitable. As the buffalo disappeared, the 1870s also saw the signing of treaties between the First Nations and the Crown. Soon after, reserves were set aside for the First Nations.

The Métis (children of white fur traders and their Indian wives) culture traces its ancestry back to the fur trade. They were known as metifs or bois brules if their fathers were of French origin; or mixed-bloods and half-breeds if they were of English or Scottish descent.

In 1821, with the merger of the Hudson's Bay Company and Northwest Company, came a layoff of approximately two-thirds of the workers - predominantly Metis who settled in Manitoba's Red River Colony. They had developed a profitable role in the fur trade supplying provisions such as pemmican (a mix of dried meat, grain and berries), transporting furs and supplies, and working for the trading companies.

Hunting expeditions took them farther and the Metis spent their winters in hivernements - wintering villages, derived from hiver, the French word for winter. The sites were abandoned in the spring and summer when the Metis were hunting.

While hivernement settlements sprang up throughout the Saskatchewan River Basin, focus was brought to one in particular when, in 1863, Gabriel Dumont was elected Chief of the South Saskatchewan River hivernement. Dumont would later emerge as a masterful military leader during the Riel Rebellion.

In the 1870s, unable to sustain themselves through buffalo-hunting, the Metis adopted a more agrarian lifestyle by cultivating "river lots" and raising cattle, supplementing this with freighting and trading. Discontent grew as government surveys imposed a square township system over their land. Many Metis had difficulty obtaining legal title to the homes they had built, and efforts to get greater representation in territorial and federal politics were stymied. Discontent also grew within the First Nations people, watching the buffalo disappear. They demanded the food, equipment and farming assistance that had been promised by the treaties.

The federal government's failure to respond to numerous petitions brought events to a head in the spring of 1885 with the Riel Rebellion. Several skirmishes and battles occurred along the South Saskatchewan River, which played a major tactical role in the transportation of troops. The confrontation escalated, involving settlers, the North West Mounted Police and some of the First Nations, but the uprising could not be sustained. The final shots were fired at Batoche, Saskatchewan, in June 1885.

While Metis resistance failed on the battlefield, the Metis community was not destroyed and significant events and individuals associated with Metis heritage have been commemorated at a number of locations along the river. Work continues on other historical and cultural initiatives in this region of Saskatchewan.

2.2 Study Area General Description

The study area (Figure 1) includes six major cities in the South Saskatchewan River Basin (SSRB): Saskatoon, Swift Current, Red Deer, Calgary, Medicine Hat, and Lethbridge. The South Saskatchewan River Basin (SSRB) has approximately 225 rural communities, although most population in this area is concentrated in major urban centers (i.e. Calgary, Lethbridge, Medicine Hat, Swift Current, and Saskatoon) (Sobool and Kulshreshtha, 2003).

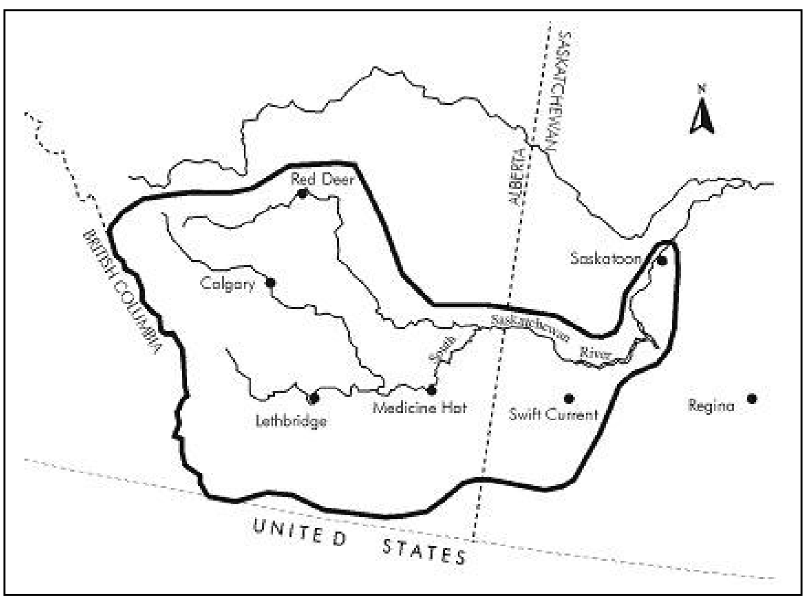

Figure 1: South Saskatchewan River Basin, Canada (Source: SSHRC MCRI).

From data compiled from Sobool and Kulshreshtha (2003) for 2001, the population size of communities (i.e. towns, cities, hamlets and villages) living in the South Saskatchewan River Basin within Alberta boundaries (1,491,039) exceeds by more than 5 times the population living in communities within Saskatchewan boundaries (285,199).

Within Saskatchewan boundaries in the SSRB, there are 90 communities, and the great majority of communities (73%) have each a population size of less than 500 people, 12% have a population size between 500 and 1,000, and 15% have a population size exceeding 1,000 people. Within the Alberta provincial boundaries in the SSRB, there are 143 communities, and the slight majority of communities (37%) each have a population size of less than 500 people, 14% have a population size between 500 and 1,000, 20% have a population size between 1,000 and 3,000, 10% have a population size between 3,000 and 5,000, and 19% have a population size exceeding 5,000 people (Sobool and Kulshreshtha, 2003).

However, when the total population of the basin (1,776,237) is distributed among urban, rural, and farm population, the vast majority of the SSRB population appears concentrated in urban areas (85%) and lower population size appears concentrated in rural areas (12%) and farms (3%). Among the sub-basins, the Bow River Basin has the highest population (56.3%) as it includes Calgary, followed by the South Saskatchewan River Basin (20.3%), the Red Deer River Basin (13%), and the Oldman River Basin (10.4%). More details on this data are provided in Sobool and Kulshreshtha (2003).

The following description of the study area was compiled from the Terrestrial Ecozones and Ecoregions of Canada (Environment Canada, 2004; Acton et al., 1998), and the Atlas of Canada (Natural Resources Canada, 2004; Stanford, 1998).

The study area is mostly within the Prairie Ecozone but also includes (in its western boundary) small portions of the Boreal Plain and the Montane Cordillera Ecozones. Within the Prairie Ecozone, the study area is mostly within the Mixed Grassland Ecoregion, but also includes part of the Cypress Upland Ecoregion and parts of the Aspen Parkland, Moist Mixed Grassland, and Fescue Grassland. The Aspen Parkland constitutes the northern edge of the study area, a transition zone to the boreal forest, but has expanded southward considerably since the prairie fires were effectively stopped by settlement.

The study area comprises the northern extension of open grasslands in the Great Plains of North America, meeting with the boreal forest on its northern boundary and desciduous forests on its eastern boundary. This area is mostly characterized by relatively little topographic relief (elevation increasing from east to west from roughly 500m to 800m above sea level).

The climate is determined by its location. The Rocky Mountains to the west impede easy access of moisture-bearing winds from the Pacific. The result is a continental climate, subhumid to semiarid with short hot summers (with mean temperatures from 14°C to 16°C), long cold winters (with mean temperatures from -12.5°C to -8°C), low levels of precipitation (with mean annual precipitation extremely variable but generally increasing northwards from less than 330 mm to 600 mm per year, and also increasing eastwards), and high evaporation. Mean annual temperatures in this area range from 1.5°C to 3.5°C. A water deficit is a characteristic of this area, with the the presence of high winds accelerating the evaporation of water.

The surface of this nearly level to rolling plain area consists largely of hummocky and undulatins glacial moraine and level to gently undulating lacustrine deposits. The relatively high natural fertility and good moisture-holding capacity of the area's Chernozemic soils make them highly productive for agriculture. The most productive soils are found on the Black, Dark Gray and Dark Brown Chernozems of its north boundary. Relatively flat topography is particularly conducive to highly mechanized farming. Depending on rainfall, there are millions of small depressional wetland areas in the form of sloughs, ponds and marshes. The greatest concentration occurs in the subhumid northern grasslands. Most of the major rivers originate in the Rocky Mountains and flow in an easterly direction across the ecozone. They are dominated by rainfall as well as snowmelt and glacial runoff at their headwaters. Many of the smaller rivers and streams have pronounced variability in streamflow and are often dry for extended periods.

The wetlands in the study area provide major breeding, staging, and nesting habitat for migratory waterfowl using the North American Flyway. The transformation of this area by agricultural activities has resulted in dramatic reduction in habitat for many species. It has resulted in a significant number of extirpated, threatened and endangered wildlife species relative to its area and population. Sobool and Kulshreshtha (2003) reported a total of 84,930 wetlands (most not exceeding 1 acre in size) in the SSRB, from which most (60%) are within the South Saskatchewan River Basin (i.e. sub-basin).

Large and mid-scale agriculture is the dominant land use in this area, producing commercial crops such as wheat and canola. The other major activities contributing to the economy are mining (coal, potash, mineral, and aggregates) and oil and gas production.

2.3 Economic activities

The study area depends economically on agriculture, food processing industry, petrochemical industry, hydropower generation (especially Alberta), mining (i.e. potash and oil and gas), and also includes some cattle (beef) production (Natural Resources Canada, 2004; Dough Ohrn- Alberta Environment, personal communication). This area has a high percentage of farms (51 to 80% of their area) cultivated with wheat (Natural Resources Canada, 2004) and is cropped mostly with only 15 field crops (grain, oilseeds and pulses) and a few forage crops (Canadian Council of Ecological Areas, 2004).

Economic activities in the study area can be divided according to their water use in two broad categories (as suggested by the Bow River Basin Council, 2002)**:** *consumptive water use activities* (i.e. those which withdraw water from the river resulting in a net decrease in downstream river flow) and *non-consumptive water use activities* (i.e. activities that do not reduce downstream river flow). As the same author describes, *consumptive water use activities* include domestic/municipal water supplies, irrigation, agriculture other than irrigation (e.g. livestock), industrial (e.g. fertilizer manufacturers, oilfield injections), and other uses (e.g. golf courses). *Non-consumptive water use activities* include recreation and aesthetic enjoyment (e.g. fishing and canoeing, as well as for waterside parks, cottage development and campground operations), and hydropower generation (although they affect downstream water use and the aquatic and riparian ecosystems, the water loss from its activity is negligible). Even though *non-consumptive* water use activities may not deplete water, they do require a minimum water level to maintain operational.

From data provided by Sobbol and Kulshreshtha (2003), the livestock operation with highest water use coefficient in the SSRB is the dairy cows (56.21 m^3/year/animal), followed by bulls (35.41 m^3/year/animal), horses (24.82 m^3/year/animal), and beef cows (23.36 m^3/year/animal). Irrigated grain production can be also identified as a major water consumptive activity in the study area since it takes 1,000 tons of water to produce 1 ton of grain (Postel, 2000).

Furthermore, worldwide, grain production has been linked to the increasing depletion of water reservoirs, as the vast majority of over-pumped groundwater by many food-producing regions is used to irrigate grain production (Postel, 2000). Postel (2000) concluded that roughly 10% of the global grain harvest is being produced by depleting water supplies.

3 CLIMATE CHANGE PREDICTION TOOLS AND IMPACTS

Much of the research on climate change impacts to some sectors is based on output of earlier generation models. The better understanding of current climate change predictions then requires an understanding of how models have evolved over time. Basically, models were first developed for isolated climatic processes, which later have been increasingly integrated. Further improvement in these models is made possible with paleoclimate records. One example of paleoclimate study is Laird et al. (1996), which suggests (from diatom-inferred salinity) that the North American Great Plains have experienced more droughts in the past (A.D. 1,200) than in the last 800 years.

From the mid 70s to the present, General Circulation Models (GCMs) first evolved from simple atmospheric models to coupled models (Atmosphere-Ocean General Circulation Models-AOGCM) (in the early 90's), and then from coupled models to the more complex models (e.g. atmosphere-land surface-ocean-sulphate aerosol-non-sulphate aerosol-carbon cycle GCMs) of today (IPCC, 2001[1]). The AOGCMs development and improvements are of particular importance for climate change predictions for the study area, as it enables the representation of the ENSO phenomena (El Niño-South Oscillation) which in turn can produce large interannual variations in weather and climate (e.g. droughts, floods, heat waves, etc) with impacts to agriculture, fisheries, environment, health, energy demand, etc (IPCC, 2001[1]).

To predict climate change impacts, various AOGCMs are available from the IPCC DDC (IPCC Data Distribution Centre, 2004) and the Canadian Climate Impacts Scenarios website (Canadian Climate Impacts Scenarios, 2004). Some of the most recent models include HadCM3 from the UK Hadley Centre for Climate Prediction and Research, GFDLR30 from the US Geophysical Fluid Dynamics Laboratory, CGCM2 from the Canadian Centre for Climate Modeling and Analysis, ECHAM4 from the Germany Max Planck Institute for Meteorology, CSIROMK2 from Australia Commonwealth Scientific and Industrial Research Organization, NRCAR-PCM from the US National Centre for Atmospheric Research, and CCSRNIES from Japan Centre for Climate Research Studies/National Institute for Environmental Studies. These models provide output for SRES (Special Report on Emission Scenarios), which include high emission (e.g. A1FI), mid-range emission (e.g. A2, B2), and low emission (e.g. B1) scenarios. SRES scenarios are more recent than the previous scenarios (i.e. IS92 scenarios, double carbon dioxide concentration scenarios, etc) and therefore should give more realistic results (Ruosteenoja et al., 2003).

For the southern Prairies (2050), the CGCM2 mid range emissions scenario A21 predicts temperature increase in the spring from 5 to 7°C higher than 1961-1990 normal, with decreased soil moisture throughout all seasons as much as 20% lower soil moisture from 1961-1990 normal, despite the increased precipitation (Canadian Climate Impacts Scenarios, 2004). See appendix A (Figures 1A, 2A, and 3A) for seasonal climate change maps for Canada (2050).

From scatter plots (temperature versus precipitation) for Medicine Hat to which monthly multiscenario analysis was applied (meaning that 1 mid-range and 4 extreme scenarios in reference to the subdivision of each monthly scatter plot into four parts- cooler wetter, cooler drier, warmer wetter, and warmer drier) and assuming the climate change models' grid (200 km by 300 km) representative for the study area, A2 scenarios can be considered the most representative for climate change impacts assessments for the study area. Monthly scatter plots were used from the Canadian Climate Impacts Scenarios website (Canadian Climate Impacts Scenarios, 2004) and can be visualized in Appendix B (Figures 1B, 2B, and 3B).

Even though there is no single climate change model that can be considered best, a model is considered promising when it can reproduce present climate from past records with the minimum flux adjustment (i.e. non-flux adjusted) and can also produce similar results to other models. To reduce errors to the models' results, a common strategy is to fix the increased level of carbon dioxide in the atmosphere (IPCC, 2001[1]), which is normally done through doubling the carbon dioxide concentration from its initial value and analyzing "equilibrium" results (i.e. CO_2 stabilization scenarios).

However, even though climate change models have been greatly enhanced, to date, they continue to have limited ability to produce estimates for regional or more local scales (IPCC, 2001[1]). Downscaling methods are most often done through the individual selection of a few coarse-scale GCM grid boxes. And the adjustments involved in the downscaling process for regionally-detailed scenarios (e.g. interpolation, statistical methods, parameterization, etc) do not necessarily maintain internal consistency to the GCM used. The lack of knowledge in transferring information across scales, proper field data collection, and in the basic understanding of certain climatic processes (e.g. precipitation) remain limiting to application of climate change models to more local scale assessments (Waring & Running, 1998, IPCC, 2001[2]).

To produce meaningful results for impacts assessment, climate change predictions have been normally used analogous to historical records (i.e. past climatic events with similar characteristics are considered a good approximation to the climate change impacts) (Herrington *et al*., 1997; International Institute for Applied Systems Analysis, 2000). Nevertheless, these predictions can be considered at best approximations of climate change effects, since past climatic events were clearly not exposed to the same levels of greenhouse gases concentration, which may impose a new set of conditions and restrictions to various systems (International Institute for Applied Systems Analysis, 2000).

Nevertheless, although climate change predictions have improved quantitatively with the evolution of climate change models, qualitative prediction trends have been maintained (IPCC, 2001[2]). Climate change models indicate for Canada that temperature will increase, and increase more in the winter than in the summer, but not all places will experience a steady increase in temperature and minimum and maximum temperature anomalies will change with time; an increase in temperature will lead to an increase in precipitation, but the increase in precipitation would not compensate for the increased evaporation and evapotranspiration and droughts will occur (Herrington *et al*., 1997; International Institute for Applied Systems Analysis, 2000; Stewart *et al.*, 1997; Singh & Wheaton, 1991).

More recent climate change predictions indicate that glaciers and ice caps will continue to retreat, and places with decreased soil moisture will experience increased heat waves, reducing human and animal (livestock) health (IPCC, 2001[1]). Snow-melt dominated watersheds in western North America will experience a change in the timing of streamflow through the year, with a smaller proportion of precipitation during winter falling as snow (with proportionally more run off in winter) and, as there’s less snow to melt, less runoff during spring (i.e. spring peak flows will happen earlier) (IPCC, 2001[1]; IPCC, 2001[2]). Increasing temperature therefore will reduce the size of the natural reservoir in winter, thus reducing water quality (IPCC, 2001[2]).

Analysis of drought risks for southern Saskatchewan indicates that the frequency of drought and severe drought could increase dramatically and the southern prairies could experience serious summer deficiencies in soil moisture by the end of this century (Natural Resources Canada, 2002). So far, the Prairies have experienced a decrease in amount of precipitation falling as snow and earlier spring runoff compared to past years, warmer average air temperature 1.2°C over the last 50 years (3°C in the winter and 0.2°C in the summer), and increased length of growing seasons by 10 to15 days compared to the 1940s and early 1950s (Natural Resources Canada, 2002).

Even though glacial contributions to downstream flow regimes could be expected to first increase from initial retreat of glaciers (IPCC, 2001), this phase appears to have already passed for the North Saskatchewan River Basin due to the rapid decrease in the Canadian Rocky Mountains glacial cover (Demuth and Pietroniro, 2003), suggesting the SSRB may also have potentially entered a long-term trend of declining flow. Zhang et al. (1999) concluded from hydrometric data for 1947-1996, that the annual mean streamflow for almost all of southern Canada has shown a downward trend, increasingly so since 1967.

Ecosystems can be expected to migrate northwards, assuming soil physical and moisture conditions are favorable. However, biophysical response is likely to happen at a slower rate than other environmental changes, and that can cause reduction of ecosystems' size and changes in species composition and distribution (Stewart *et al*., 1997; Institute for Applied Systems Analysis, 2000). Zonation changes will likely encourage changes in land use such as from forestry to agriculture (Singh & Wheaton, 1991). Pest and pathogen outbreaks are also likely to increase as climate warms (Natural Resources Canada, 2002[1]). North American forests are particularly vulnerable to invasions by Asian and European insects (Canadian Forest Service, 1999). Niemelä and Mattson (1996) concluded that over 300 species of tree feeding insects from Europe have successfully invaded North America, compared to only 34 that have made the reverse journey. When the pest does not damage the host tree species in its country of origin, scientists have little information with which to begin their search for controls (Canadian Forest Service, 1999).

For the Great Plains, Rosenzweig & Hillel (1993) coupled GCMs (Goddard Institute for Space Studies and Geophysical Fluid Dynamic Laboratory) with the CERES crop model, and predicted (with double the concentration of carbon dioxide in the atmosphere) droughts worse than those in the 1930s for all stations, with lower yields for wheat. They also predicted that climate change would be more detrimental to typical summer crops than to those crops whose main growing season is in the spring. The 1930's drought resulted in 32% wheat yields decline, 200,000 farms failure, and in the migration of 300,000 people elsewhere (Herrington *et al*. (1997).

The study by Herrington *et al*. (1997) compared the climate change effects to the 1988 drought in Saskatchewan. From that, they estimated that Saskatchewan's thermal generation of energy would increase as well as its volume of electrical energy imports, since thermal power stations would face problems with reservoirs as temperature increases. In the 1988 drought, purchased electricity costs increased by 28.9% and thermal power stations faced operational problems. Herrington *et al.* (1997) predicted that insurance companies and policyholders would be negatively affected, as premiums would rise, to accompany higher risks. Warmer temperatures would reduce and could even compromise snow ski resorts activities; would encourage algae and plant growth that could lead to fish kills, reduce recreational fishing, and also decrease the quality of water to water-based activities (e.g. swimming and water skiing) (Herrington *et al*., 1997). Herrington *et al*. (1997) also concluded that the scarcity of water would, in turn, increase the demand for good quality water for human and animal consumption.

Historically, within the Palliser Triangle, three major prolonged agricultural droughts (i.e. based on wheat production) have caused great losses to the agricultural industry and subsequent mass emigration of farmers from this area: the Dry Beat Droughts 1917-1926 resulted in the emigration of approximately 73% of farmers (1,741 farmers); the “Dry Thirties” Droughts 1929-1937 resulted in the migration of 66,000 people; and the Droughts of the 1980’s (1983-1988) drove farmers to adopt irrigation systems from the newly expanded irrigation districts by the Prairie Farm Rehabilitation Administration (PFRA) (Nemanishen, 1988). More recently, the 2001-2002 drought in this area is considered similar or worse than the 1988 drought (Elaine Wheaton-Saskatchewan Research Council, personal communication). For the most important past droughts in North America, see Appendix C (Figure 1C).

Caution is needed when comparing drought studies as different drought definitions lead to distinct conclusions regarding drought events (drought spells) and drought periods. Different disciplines perceive droughts in different magnitude and severity as to reflect their operational capacity. Agriculture defines drought in the context of soil moisture deficiency to support crops; meteorology views drought in the context of a period below normal precipitation; hydrology is concerned with drought in the context of a length of time period with bellow mean monthly or annual stremflows; and economics and sociology are concerned with the impact of drought on society’s productivity and consumptive activities (Dracup and Kendall, 1990).

4 CLIMATE CHANGE VULNERABILITIES AND ADAPTATION

4.1 Definitions

Vulnerability is defined by the IPCC (2001) as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." The vulnerability of human societies and natural systems to climate extremes is demonstrated by the damage, hardship and death caused by extreme climatic events such as drought (IPCC, 2001). Sensitivity, in turn, is "the degree which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate change stimuli encompass all elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes" (IPCC, 2001).

Vulnerability is not a static concept, it can be increased through increased exposure to stress, increased consequences severity, inadequate capacity to resist and/or recover from damage (resilience), reduced adaptive capacity (capacity to change in the face of adversity), and for sensitive systems with decreased capacity to be positively affected by adversity (e.g. some crops may increase yields due to longer warm seasons while others may not meet their moisture needs). Vulnerability also constantly changes because of changes in technology (i.e. improved technology reduces vulnerability through increased number of available adaptation options), population (i.e. increased population growth increases vulnerability as the available resources are faster depleted), practices and policies.

A highly vulnerable system would be a system that is very sensitive to modest changes in climate, where the sensitivity includes the potential for substantial harmful effects, and for which the ability to adapt is severely constrained (IPCC, 2001[2]). The flip side of it is resilience.

The federal government (through Natural Resources Canada) has created programs to address adaptation strategies. The Government of Canada's Climate Change Impacts and Adaptation Program provides funding for research and activities to improve the knowledge of Canada's vulnerability to climate change, to better assess the risks and benefits posed by climate change and to build the foundation upon which appropriate decisions on adaptation can be made, and to facilitate interaction between stakeholders and researchers (i.e. Canadian Climate Impacts and Adaptation Research Network- C-CIARN) (Government of Canada, 2002; Standing Senate

Committee on Agriculture and Forestry, 2003). The C-CIARN network is composed of six regions (i.e. British Columbia, Prairies, Ontario, Quebec, Atlantic, and North) and seven sectors (i.e. health, water resources, coastal zone, forest, agriculture, landscape hazards, and fisheries) (Canadian Climate Impacts and Adaptation Research Network, 2004). The regional C-CIARN office for the Prairies is the Prairie Adaptation Research Collaborative (PARC) (Canadian Climate Impacts and Adaptation Research Network, 2004).

The further development of a framework to define determinants for vulnerability and adaptive capacity across sectors has been a difficult task, especially because often they cannot be reproduced across scales (Yohe and Tol, 2002). Results have been more qualitative than quantitative (IPCC, 2001[2]). Nevertheless, various frameworks proposing a wide range of different adaptation indicators are available, such as IPCC (2001), Wheaton and Maciver (1999), Loë et al. (2001), Handmer et al. (1999), and Smit and Pilifosova (2001).

Adaptation can be differentiated according to system type (e.g. natural or human systems, public or private interests), purposefulness (autonomous or planned, passive or active), timing (anticipatory or responsive, proactive or reactive), temporal scope (short term or long term, tactical or strategic), spatial scope (localized or widespread), function/effects (retreat, accommodate or protect; prevent, tolerate, spread, change or restore), form (structural, legal or institutional; regulatory, financial and technological), and performance (cost-effectiveness, efficiency; implementability, equity) (Smit and Pilifosova, 2001).

Generally, adaptation strategies can be composed of 3 (ideally simultaneous) stages: system monitoring (e.g. observed conditions over representative systems), system prediction (e.g. modeling future response to climatic, defining systems' coping ranges, etc), and system management (e.g. policy change, management plans, etc) (IPCC, 2001[2]). Simultaneously used, these give a wide range of potential actions to be taken under various circumstances. For example, conservation strategies can be implemented for a particular species when this species enters a declining trend beyond its limiting thresholds (e.g. decreased genetic variability, decline in habitat availability, etc) that is identified through monitoring.

To overcome difficulties in the quantification of vulnerability and adaptive capacity, extreme climatic events are of particular importance, as past interannual climate variability is often within most systems coping range (Smit and Pilifosova, 2001, Yohe and Tol, 2002). Past experience can serve as an indicator of a system or sector vulnerability and adaptive capacity.

From that, assuming past economic losses can serve as an indicator of lack of adaptive capacity, then Canada is most vulnerable to droughts in the prairies, as droughts were the most expensive natural disasters in Canadian history (CAN$ 2.5 billion in 1989) (Mayer and Avis, 1998).

To address climate change vulnerabilities, a framework approach is used which identifies two major systems (which in turn should include all other systems): the *natural* and *human* systems (IPCC, 2001). The vulnerabilities and adaptive capacity within these systems relevant for the study area are further explained in 4.1.1 and 4.2.2.

4.1.1 Natural systems

Natural systems most vulnerable to climate change (due to limited adaptive capacity and perhaps susceptibility to irreversible damage), as identified by the IPCC (2001), include: glaciers, coral reefs and atolls, mangroves, boreal and tropical forests, polar and alpine ecosystems, prairie wetlands, and native grassland. The IPCC (2001) also identified snowmelt-dominated watersheds and cold-water ecosystems to be highly vulnerable to climate change. Raymond Stemp (Alberta Environment, personal communication) added the existing concern for the SSRB area with the increased fire frequency and disease (especially the mountain pine beetle) in forested ecosystems (although trees are scarcely distributed in the SSRB area) and in trees in urban areas.

From these, the most important natural systems identified at risk in the study area are the prairie wetlands, the native grassland, and the snowmelt-dominated watersheds. Currently, most attention has been concentrated in human systems, with a tendency of natural systems to be included in later stages within plans for the human sectors (IPCC, 2001). For example, in Alberta, the application for water allocation plans involves no significant adverse effect on the aquatic environment from the transfer, but the development of a specific strategy for the protection of aquatic environment is predicted for future phases within the water management plan (Alberta Environment, 2002).

Adaptation strategies may include creating more conservation areas, protecting wildlife corridors, monitoring wildlife and wildlife habitat, restoring degraded areas and habitats (especially wetlands, peatlands, and riparian areas), preventing land from being brought into production, and increasing protection from disturbances (fire, insects, and diseases) through decreasing the response time and increase suppressing capacity while increasing the participation in international research and monitoring efforts (Lac, 2003). Conservation of natural systems must allow natural ecosystem processes to continue unimpeded within all natural areas, with continuity and size to permit sustainable genetic flow and maintain ecological variety (Epp, 1991).

Adaptive strategies suggested for lost ecosystem services (especially wildlife services) include captivity breeding and translocation (for reintroduction of species at risk), replacement of lost ecological services (e.g. replacement of natural pest control with other natural controls and/or artificial control, replacement of natural pollination with introduced, replacement of hunting with in store products, etc) (IPCC[2], 2001).

At the international level, Canada signed the United Nations Convention on Biological Diversity in 1992. Since then, Canada federal, provincial, and territorial governments cooperatively began to develop the a Canadian Biodiversity Strategy, and within 2 years, the Federal-Provincial-Territorial Biodiversity Working Group was established including industry, scientific community, conservation groups, academia, and indigenous organization in various focus groups. These support Canadian initiatives such as the Committee on the Status of Endangered Wildlife (COSEWIC), the Recovery of Nationally Endangered Wildlife (RENEW), and the Endangered Plants and Invertebrates of Canada (EPIC) (Environment Canada, 2004). These initiatives increase participation in planning feedback, while active monitoring (i.e. wildlife, flora and fauna population and species trends, water and air quality, climate, diseases outbreak, fire, and other natural resources) has involved mostly the World Conservation Monitoring Centre, and government and non-government organizations. Other policies and programs for the management of biological resources include the Canada Forest Accord, the Wildlife policy for Canada, the federal policy on Wetland Conservation, and the provincial and territorial conservation and protected area strategy (Environment Canada, 2004).

At the federal government level, Environment Canada and the Department of Fisheries and Oceans and Parks Canada have the mandates for the establishment and management of various types of protected areas. Parks Canada is responsible for the establishment and management of National Parks (created under the Canada National Parks Act, a legislative framework for protecting representative samples of Canada's 39 terrestrial natural regions), National Marine Conservation Areas (created under the National Marine Conservation Areas Act, a legislative framework for protecting representative samples of Canada's 29 marine regions), and over 140 National Historic Sites (Parks Canada, 2004). Even though Environment Canada (i.e. joint effort from Canada's federal, provincial and territorial ministers of the environment, parks, wildlife and forestry) is expanding the allocation of conservation areas through the development of the system of protected areas (protected area strategy)- “Alberta Special Places” (Alberta Environment, 2004), and Saskatchewan “Representative Area Network” (Saskatchewan Environment, 2004) and is also encouraging management in parks and reserves, a few parks (provincial or federal) have management plans and climate change effects is rarely taken into account (IPCC, 2001[2]). These parks and protected areas could be further encouraged to monitor ecosystems and model responses to climatic change impacts, and use such information in their management plans (IPCC, 2001[2]).

Environment’s Canada Canadian Wildlife Service is responsible for Migratory Bird Sanctuaries- created under the Migratory Bird Convention Act, and National Wildlife Areas- created under the Canada Wildlife Act (Convention on Biological Diversity, 2004). The areas under the Canadian Wildlife Service protect critical wildlife habitat, and unique and productive ecosystems for wildlife conservation and protection (Canadian Wildlife Service, 2004). International partnerships created with the wildlife services include the North American Waterfowl Management Plan (NAWMP); the North American Bird Conservation Initiative (NABCI); the Water bird conservation for the America's program; Partners in Flight; international shorebird initiatives; and the ongoing continental management of waterfowl populations (Convention on Biological Diversity, 2004). According to Malcolm Conley (Canadian wildlife Service, personal communication), all conservation strategies undertaken by the Canadian wildlife Service consider general climate change impacts predictions. Malcolm Conley is currently monitoring and modeling wetland water levels within the SSRB area (Swift Current).

Environment Canada’s regional office for the study area is the Prairie and Northern Prairie Region's Canadian Wildlife Service office which has the mandate to deliver an integrated program through its seven branches (Meteorological Service of Canada- MSC, Environmental Conservation Branch- ECB, Environmental Protection Branch- EPB, Northern Corporate Affairs Branch- NCAB, Human Resources-HR, Finance and Administration- F&A, and Departmental Affairs Branch- DAB) (Environment Canada, 2004). Nevertheless, this office has limited conservation initiatives to its habitat stewardship program, which most often do not consider climate change impacts (although it is more extensively involved in water monitoring programs through its Climate Change Action Fund Projects) (Carol McKinley- Environment Canada Prairie and Northern Region, personal communication).

Environment Canada Provincial offices are further stratified to administrative areas (field operations). Alberta Environment is divided in 3 administrative regional offices (with most of the study area represented by its Southern Region, except Red Deer) (Alberta Environment, 2004), while Saskatchewan Environment is divided in 5 regional offices (with most study area represented by the Grassland Ecoregion office, except Saskatoon) (Saskatchewan Environment, 2004).

In Saskatchewan, the Saskatchewan Watershed Authority (under the Saskatchewan Watershed Authority Act) coordinates the NAWMP; delivers the Prairie Shores Program (in Saskatchewan); and contributes to the Large Wetlands and Nest Structures program (delivered by Ducks Unlimited), to the Waterfowl Crop Damage Prevention Program (delivered by Saskatchewan Environment), and to the Crop Damage Compensation Program (delivered by Saskatchewan Crop Insurance Corporation) (Saskatchewan Watershed Authority, 2004). However, current initiatives do not take climate change into consideration (Jennifer Lohmeyer-Saskatchewan Watershed Authority, personal communication).

The Conservation Easements Acts within both federal and provincial legislation- voluntary legal agreement between a landowner and a qualified conservation agency where the landowner takes steps to preserve the property's conservation values, retain use of the land, and at the same time receive income tax benefits; and the stewardship programs (i.e. verbal agreement with land owners) have also been valuable tools in promoting protection in private lands (Environment Canada, 2004). In the study area, conservation easement agreements have been undertaken mostly by Nature Conservancy of Canada, while stewardship programs have been mostly undertaken by Nature Saskatchewan (i.e. Operation Burrowing Owl), the Alberta Fish and Game Association (Operation Grassland Community) (Carol McKilkley- Environment Canada Prairie and Northern Region, personal communication). Also various other groups and NGOs are involved in stewardship programs, education, and in advocating policy change (e.g. Red Deer River Naturalists, Nature Saskatchewan, Partners FOR the Saskatchewan River Basin, etc.), although these initiatives often do not consider the climate change impacts directly (Carol McKilkley-Environment Canada Prairie and Northern Region, personal communication).

Conservation Action Plans have also been under development by each of the governments of Alberta (Alberta Prairie Conservation Forum) and Saskatchewan (Saskatchewan Prairie Conservation Action Plan) involving industry, federal and provincial government agencies, non-government organizations, and universities (Environment Canada, 2004). Other legislation important for environment conservation in Saskatchewan include the Ecological Reserves Act, the Environmental Management and Protection Act, the Fisheries Act, the Natural Resources Act, the Wildlife Act, the Wildlife Habitat Protection Act, the Provincial Lands Act, the Clean Air Act, the Environmental Assessment Act, and the Parks Act (Saskatchewan Environment, 2004). In Alberta, the most important acts are the Water Act and the Environmental Protection and Enhancement Act (EPEA). The Environmental Protection and Enhancement Act (EPEA) created a new framework in a single act that takes an integrated approach to the protection of air, land and water, and consolidates various other acts (e.g. Clean Air Act, Clean Water Act, Ground Water Development Act, Land Surface Conservation and Reclamation Act, and some sections of the Department of the Environment Act) (Alberta Environment, 2004).

Despite all conservation efforts, the Prairie Ecozone has a high number of threatened and endangered species (Canadian Council of Ecological Areas, 2004) and few efforts to directly consider climate change impacts (i.e. monitoring linked to forecasting and management planning). Agriculture has probably had the greatest impact on this area, with crops replacing wetlands, with the drainage of wetlands reducing the wildlife habitat (including the aquatic wildlife ecosystem), and with native species competing with introduced species (Canadian Council of Ecological Areas, 2004).

4.1.2 Human Systems

The indicators of adaptive capacity of human systems across regions and countries are economic resources (i.e. greater economic resources increase adaptive capacity, while lack of financial resources limits adaptation options); technology (i.e. lack of technology limits the range of potential adaptation options); information and skills (i.e. lack of informed, skilled and trained personnel reduces adaptive capacity); infrastructure (i.e. characteristics and variety of infrastructure can enhance adaptive capacity); institutions (i.e. well developed social institutions increase adaptive capacity); and equity (i.e. equitable distribution of resources increase adaptive capacity) (IPCC, 2001[2]).

For North America and also worldwide, adaptive capacity to climate change is directly correlated with wealth, i.e., wealthy countries, communities, and institutions are more likely to adapt as they can afford the resources to do so (IPCC, 2001). Poor communities are less likely to adapt as they have limited access to the necessary resources to adjust. Thus, poor communities are more sensitive and vulnerable to climate change as the lives and livelihoods are more exposed and their coping range is reduced (e.g. poor farmers may not be able to afford irrigation systems to adapt and may need to relocate to greater risk areas from the expanding pressure from irrigation farmers, poor households may not be able to afford drinking water, etc).

Thus, although adaptive capacity of human systems is generally high and vulnerability low in North America, these are not equally distributed (IPCC, 2001). Some communities are clearly more vulnerable than others (e.g. indigenous communities, poor communities, and communities highly dependent on climate-sensitive resources) (IPCC, 2001). And despite the overall low vulnerability in North America, concerns are high regarding uses of snowmelt-dominated watershed and aquatic ecosystems, crops in the Canada's prairies (i.e. even though some crops may benefit in the short term, benefits would decline and possibly becoming a net loss with further warming), weather-related insurance losses and public sector disaster relief, and decreased human health (i.e. increased vector born diseases and heat stress morbidly and mortality) (IPCC, 2001).

Human systems especially vulnerable to climate change (and that will most urgently need adaptation strategies), as identified by the IPCC (2001), include: water resources; agriculture (especially food security) and forestry; coastal zones and marine systems (fisheries); human settlements, energy, and industry; insurances and other financial services; and human health. The vulnerability of these systems varies with geographic location, time, and social, economic, technological, and environmental conditions (IPCC, 2001).

For the study area, the most important sectors at risk (as identified from IPCC, 2001 and IPCC, 2001[2]) include the water resources, agriculture, the human settlements where population is growing (e.g. Calgary) and where communities have little resources (e.g. with growing poverty) and/or little economic diversification (e.g. energy-reliant communities), insurances and other financial services (specially to agricultural insurance costs, which will raise with the increased risk with this activity), and human health. Among these sectors, the water resources sector is the single most sensitive sector to climate change in the study area due to the high risk of this area to drought and streamflow permanent decline (Zhang et al., 1999; Demuth and Petroniro, 2003) and the high risk of this sector to increase the sensibility and vulnerability of all other sectors (i.e. impose new limitations) in a chain reaction. Therefore the water resources sector will be further analyzed in this study, although the remaining identified sectors at risk in the study area should be included in further studies.

Changes in water availability can further reshape society as we now know, with economic sectors with low priority to water use being replaced by other sectors with higher priority to water use. And where management plans and legislation are not in place to coordinate the water distribution, the power will probably concentrate on the hands of a few that can afford it. In India, for example, the ongoing decrease in groundwater reservoirs require larger pumps to be installed for irrigation purposes. While wealthier farmers have been able to afford the new pump costs, poor farmers (small scale operations) that cannot afford new pump systems are renting out their land and becoming laborers on these larger farms (Postel, 2000).

To address communities' distinct understanding and adaptation options to climate change as well as to engage community members in the climate change adaptation process (i.e. rise awareness and promote inclusion), the next part of the *SSHRC MCRI- Institutional Adaptation to Climate Change project* includes the gathering of secondary data sources relevant to water use and access (e.g. indicators such as levels and geographic distribution of poverty, regional income distribution, the existence of public and private water systems, amount of water available per household, level of contaminants, educational levels, etc), and the creation of a program of community engagement (e.g. focus groups and stakeholder meetings oriented to understanding ways in which stakeholders and people in the communities perceive and define vulnerabilities to water scarcities). Research methods that will be used include the analysis of statistical data (e.g. population, labor and agricultural censuses); literature reviews (including research reports, scholarly publications, public speeches, government documents, materials prepared by public and private organizations); and interviews and the creation of focus groups among stockholders (including private organizations, NGOs, community organizations, and public agencies). Results from a previous questionnaire to the SSRB residents (see appendix D) reveal that reducing pollution in rivers and lakes is the most important environmental action perceived in this community.

4.1.2.1 Water Resources

Originating in the Rocky Mountains glaciers, the Southern Saskatchewan River is a combination of three mountain streams, the Red Deer, Bow and Oldman Rivers. After supplying water to the southern communities in Alberta, the Bow and Oldman Rivers join to form the South Saskatchewan River. A few kilometers east (in the Alberta-Saskatchewan boundary), the Red Deer River adds to its water (Prince Albert). Continuing eastwards, the South Saskatchewan River is joined by the North Saskatchewan River to form the Saskatchewan River. The Saskatchewan River, after some lakes (e.g. Cedar Lake) continues eastwards to Hudson Bay. And while most of the study area contributes water to the Hudson Bay (i.e. is part of the Nelson-Hudson Bay Basin), part of it drains internally.

The management of the SSRB water resources is a challenging task as it involves integrated planning from three provinces: Alberta, Saskatchewan, and Manitoba. In 1948, these three provinces and Canada formed the Prairie Provinces Water Board (PPWB) to recommend water allocations between the provinces (Environment Canada, 2004). When that was no longer adequate to allow long-term water planning by the provinces, a sharing system was created in 1969- the Master Agreement on Apportionment- that continues to guide board activities to this day (Environment Canada, 2004).

Under the Master Agreement on Apportionment, Environment Canada (with the Prairie Farm Rehabilitation Administration) must monitor and report information from long-term water quantity monitoring stations, meteorological stations, and water quality monitoring sites (Environment Canada, 2004). The data from 14 water quantity and 12 water quality stations along Alberta-Saskatchewan and Saskatchewan-Manitoba borders inform the PPWB if the requirements of the Agreement are being met (Environment Canada, 2004). Under the same agreement, Alberta and Saskatchewan should not exceed each the use of 50% (net depletion) of the natural flow within its boundary, and should also not exceed the use of 50% (net depletion) of the flow entering the province (Environment Canada, 2004).

The PPWB is made up of one representative from each the three provinces, two representatives from the federal government, and three permanent committees involving provincial and federal government personnel: the Committee on Hydrology (studies water quantity in streams crossing provincial borders), the Committee on Water Quality (coordinates the water quality monitoring program, and is responsible for the Water Quality Contingency Plan which keeps downstream users informed of unusual water quality conditions), and the Committee on Groundwater (deals with the use and quality of the groundwater shared by the provinces) (Environment Canada, 2004).

The provincial governments are responsible for the management of their water resources to meet their commitment to the Master Agreement on Apportionment and also to ensure water availability to all water users (including domestic, municipal, agricultural, industrial, fisheries, wildlife, and recreation and aesthetic users) (Government of Alberta, 2004). The provincial governments (through the Saskatchewan Watershed Authority and Alberta Environment for the study area) are also responsible for the monitoring of water level and streamflow, as well as for undertaking climate change forecasting (Ross Herrington, Environment Canada, personal communication). Nevertheless, although monitoring data have been compiled, no climate change forecasting have yet been practiced or implemented in management plans (Ross Herrington-Environment Canada, personal communication).

For water management, both Alberta (Alberta Environment, 2004) and Saskatchewan (Saskatchewan Environment, 2004) have developed water management strategy frameworks (i.e. water for life in Alberta, and Saskatchewan water framework). Alberta is also developing a multiphase water management plan for the water use in the SSRB, which involves input from four multi-sector stakeholder Basin Advisory Committees (on for each of its four sub-basins, see Figure 2) and the general public (Government of Alberta, 2004).

Figure 2: The South Saskatchewan River Basin as stratified in four sub-basins for Alberta (Source: Bow River Basin Council, 2002).

Phase one was approved in 2002 and authorizes water allocation transfers within the SSRB, subject to Alberta Environment Approval (Alberta Environment, 2004). Phase two, according to the Government of Alberta (2004), seeks to find the balance between water consumption and environmental protection (i.e. to define conservation objectives after consideration of economic and social values and ecological requirements) and is scheduled to be completed by 2004.

The legislation that guided the SSRB water management plan includes the Water Act; the Environmental Protection and Enhancement Act; the Federal Fisheries Act; the framework for

Water Management Planning; the 1990 Water Management Policy for South Saskatchewan River Basin; the 1991 South Saskatchewan River Basin Water Allocation Regulation; the Master Agreement on Apportionment; the 1909 Canada-US Boundary Waters Treaty and the International Boundary Water Treaty Act; the Irrigation Districts Act; Alberta's Commitment to Sustainable Resource and Environmental Management; the 1982 Policy for Resource Management of the Eastern Slopes, Fish & Wildlife Policy of Alberta; the 2000-2005 Fish Conservation Strategy for Alberta; and the Public Lands Act (Alberta Environment, 2001).

Other initiatives related to the water management in the SSRB (i.e. watershed protection) include the Southern Alberta Regional Strategy, the Integrated Resource Plans and Regionally Integrated Decisions, the Municipal development plans (for rural and urban municipalities), the Management Plans for parks and protected areas (national and provincial initiative- Parks Canada/Alberta Community Development), and local watershed initiatives (e.g. Little Red Deer River Watershed Initiative, Crowford Creek, Elbow River Watershed Partnership, Mosquito Creek/Little Bow Watershed Group, Nose Creek Watershed Partnership) (Alberta Environment, 2001). There are also management initiatives for the SSRB sub-basins: Bow River Basin (Bow Basin Plan, phase two of the SSRB water management plan will provide instream objectives for the Bow River downstream of Bearspaw Dam, Highwood management plan, implementation of instream objectives for the upper Elbow River, and the work of the Fisheries and Recreation Enhancement Working Group), Red Deer River Basin (Red Deer River Corridor Integrated Management Plan, Glennifer Lake Reservoir Shorelands Areas Structure Plan, and the Feasibility of the Special Areas Water Supply Project), and Oldman River Basin (Oldman River Basin Water Quality, C5 Forest Management Operational Land Use Management Plan, and the Castle River Access Management Plan) (Alberta Environment, 2001).

Saskatchewan has not developed a specific water management plan for the SSRB. Nevertheless, the majority of Saskatchewan irrigation occurs in the Lake Diefenbaker area and is currently less than what the infrastructure, land and water resources can support (Hoppe, 2004). Saskatchewan has 4 irrigation development areas and 26 irrigation districts, although just a few districts are irrigated (Hoppe, 2004). For more information on the Saskatchewan water management related legislation, see Appendix E.

From the 14 irrigation districts in the SSRB within Saskatchewan boundaries, most water diversion (to irrigation, in 1996) is recorded from the South Saskatchewan River Irrigation District

(38,638 dam^3), followed by the Luck Lake Water Users District (7,607 dam^3) and the Riverhurst Water Users District (6,756 dam^3) (Sobool and Kulshreshtha, 2003). From the 13 irrigation districts in the SSRB within Alberta boundaries, most water diversion (to irrigation, in 1996) is recorded for the Eastern Irrigation District (844,605 dam3), followed by the St. Mary River Irrigation District (568,660 dam^3) and the Bow River Irrigation District (510,191 dam^3) (Sobool and Kulshreshtha, 2003).

Adaptation strategies for the water resources include structural and institutional changes (Natural Resources Canada, 2002; Standing Senate Committee on Agriculture and Forestry, 2003). Natural Resources Canada (2002) concluded that most existing water management plans, water-supply and water-drainage systems are based upon historic climatic and hydrological records and assume that future will resemble the past. Therefore, these systems should be able to handle variations in the mean conditions over the next couple of decades but are very likely to have difficulties in coping with extreme events (Natural Resources Canada, 2002). Natural Resources Canada (2002) also concluded that the water regulations and legislation presently do not consider climate change (e.g. transboundary agreements, water transfers, etc).

The IPCC (2001) concluded that climate change could substantially affect irrigation withdrawals. As irrigation in Alberta is a major water user, and streamflows are variable and may be even more reduced as climate change is reducing the Rocky Mountain glaciers, most concern and adaptation strategies have focused on irrigation (supply-side, as demand-side alter exposure to stress) (Loë et al., 2001).

Loë et al. (2001) further investigated adaptation options for southern Alberta. They identified 3 types of adaptation actions: *accepting losses*, *preventing effects*, and *changes uses and/or locations*. *Accepting losses* include options for irrigation farmers (to supplement income by seeking off-farm employment, and to purchase additional crop insurance); for irrigation districts (contingency planning for water shortages); for the provincial (Alberta) and federal governments (to enhance crop insurance, stabilization, and relief programs) (Loë et al., 2001). *Preventing effects* include options for irrigation farmers (acquire additional rights to water, and construct farm ponds and dugouts to store water and/or increasing pumping capacity and relocate intakes-especially private irrigators); for irrigation districts (upgrade canals and storage infrastructure to increase capacity and to reduce losses during transportation and storage; and to relocate water intakes to accommodate changes in river channels); for the provincial government- Alberta (construct additional on-stream reservoirs to increase storage capacity and control river flows, and interbasin transfer-from northern river systems to southern); and for the federal government (subsidize irrigation district infrastructure improvements, relocate diversion structures to accommodate changes in river channels, promote construction of farm ponds and dugouts, and subsidize infrastructure improvements-individuals and district/provincial) (Loë et al., 2001). *Changing uses and/or location* include options for irrigation farmers (switch from low to high efficiency irrigation systems, and switch to crops that require less water); for irrigation districts (improved irrigation water use to reduce wastage- e.g. scheduling, and adjust operation of district water control structures and water distribution systems- e.g. automation and system optimization); for the provincial government- Alberta (promote efficiency and proper water use practices among water users, encourage transfer of water rights from less efficient to more efficient water users, and promote efficiency and proper water use among all license holders); and for the federal government (adjust operation of provincial water control structures- e.g. automation and system optimization, encourage shift from marginal lands to more productive lands, promote research into new cultivars, new practices, and new technologies) (Loë et al., 2001).

Nevertheless, because climate change predictions bear uncertainties, Loë et al. (2001) proposed also a set of criteria for selecting adaptation options: no regrets, reversibility, minimize environmental impacts, cost effectiveness, equity, reduce vulnerability or at least do not increase it, ease of implementation (feasibility), and effectiveness.

From, that, Loë et al. (2001) concluded the best adaptation option for irrigation farmers (district or private) is to improve irrigation water use to reduce wasting (e.g. scheduling); for irrigation districts is to promote efficiency and proper water practices among all users; for the provincial government (Alberta) is to encourage shift from marginal land to more productive lands; and for the federal government is to promote research into new cultivars, new practices, and new technologies. The same authors also concluded adaptation options that can further stress water resources to be inappropriate (e.g. increasing pumping capacity, relocate intakes, upgrade canals and storage infrastructure to increase capacity, subsidize infrastructure improvements).

Other adaptation options include land zoning (i.e. to avoid exposure to extreme events, contamination of water supplies, and development of areas with inadequate water supply), the incorporation of projections of climate change in the planning and implementation of all management decisions relating to water, improving forecasting and warning systems to extreme climatic events (e.g. drought, flood, etc), establishing and enforcing building codes, evacuation planning, alternate production systems (Global Change Strategies international Inc and the Meteorological Service of Canada, 2000), desalinization, and increased use of groundwater (IPCC, 2001[2]). Drought plans could be implemented (at the provincial level) that would make possible to develop criteria or triggers for drought-related actions such as to issue emergency permits for water use (Wilhite, 1997; National Drought Monitoring Center, 2004; International Strategy for Disaster Reduction, 2004).

Currently, Alberta has a strategic plan to develop its drought risk management plan, which includes shared responsibility among its 3 major partner agencies (i.e. Alberta Agriculture, Food and Rural Development; Alberta Environment; and the Prairie Farm Rehabilitation Administration) involved in the development of 3 basic strategies: *Drought Preparedness, Drought Reporting, Drought Response* (Agriculture, Food and Rural Development, 2004). *Drought Preparedness* include identifying approaches to drought preparedness and risk management, packaging and delivering information on drought preparedness for producers, completing municipal level assessments of water demands and resources, and developing and maintaining inventories of water resources; D*rought Reporting* includes data collection and analysis, information distribution, forecasting impacts, evaluating damage, and assessing options for drought response; and *Drought Response* includes response options such as providing AAFRD Water Pumping Program, implementing water rationing, providing information to affected farmers on financial and personal counseling, assessing available feed supplies, implementing a water hauling program, implementing a feed/livestock freight assistance program, offering the Dugout Water Pumping Program at reduced rates, recommending tax deferral, implementing drought disaster loan program, implementing direct acreage payments to farmers, and providing support to municipalities for a grasshopper control program (Agriculture, Food and Rural Development, 2004). Currently, the Prairie Farm Rehabilitation Administration (PFRA) is the federal agency involved in monitoring, forecasting (i.e. seasonal climate, with Environment Canada/Meteorological Service), and also in recommending adaptation strategies for droughts (i.e. for the agriculture sector) in the Prairies (Agriculture and Agri-Food Canada, 2004; Phil Atkins-PFRA, personal communication).

5 CONCLUSION AND DISCUSSIONS

Various climate change models (AOGCMs) and scenarios (SRES) available for the study area were mentioned in this study. Because most in depth impacts studies precede more recent models development, earlier predictions are limited to the model used. Nevertheless, qualitative predictions remained the same across models improvements. Models continue to improve, but yet they still lose reliability in downscaling (i.e. in more local assessments). Climate change analogies to past climatic events continues to be a valuable tool to expose the vulnerabilities within a given area, even though these cannot be expected to fully reproduce climate changes and are at best estimated.

Climate change impacts to the SSRB area include increased temperature (more so in spring) and increased precipitation not compensating for increased evaporation (i.e. decreased soil moisture) with increased droughts, and continuous water quantity and quality decrease (due to continued glacier retreat). Ecosystems can be expected to migrate north at a slower rate than climatic changes, further increasing exposure to disturbances (e.g. pathogens, diseases, and fire).

Most attention has been given to human sectors adaptive capacity, with natural sectors often being considered in a secondary plan. Frameworks to identify vulnerabilities and adaptive capacity are yet mostly qualitative. Therefore, the vulnerabilities in this study were identified from IPCC assessments and within the IPCC framework when common to the study area.

The natural systems most vulnerable to climate change in the SSRB area include:

- Prairie wetlands;
- Native grassland;
- Snowmelt watershed (addressed in the water sector).

Generally, adaptation strategies should link monitoring to forecasting (climate change impacts) and management plans (i.e. establish what and where actions will be taken under future scenarios). Most conservation efforts are at best in the monitoring and forecasting stage and these are most often linked to Canada's response to its international commitment (i.e. initiatives proceed mostly from Canada's federal government level and its partnerships). Current conservation strategies such as the protected areas systems, conservation easements, and stewardships do not include climate change impacts. With the exception of the Wildlife Service, and some specific programs and policies that integrate federal (Environment Canada) and provincial government levels (i.e. Saskatchewan Environment and Alberta Environment), there is clear lack of "climate change every day thinking" in decision taking among the agencies and especially on regional offices. In various occasions, the agencies contacted had little idea as to how climate change can be considered and even less on adaptation strategies. The climate change awareness appears to increase when the agency has in its staff someone with climate change background or a specific "climate change" position within the institution.

Because natural systems are intrinsically sensitive to climate change, most often the only possible strategy may be the increased conservation efforts. Nevertheless, climate change monitoring and forecasting are important tools in defining where and what conservation strategies can be used and intensified. For example, if a migration route of a particular fish species is altered as a result of climate change, the need of conservation efforts will shift accordingly.

Adaptive strategies for the SSRB natural systems include creating more conservation areas, protecting wildlife corridors, monitoring wildlife and wildlife habitat, restoring degraded areas and habitats (especially wetlands, peatlands, and riparian areas), preventing new areas from being brought into production, increasing protection from disturbances (by decreasing the response time and increase suppressing capacity to fire, insects, and diseases; while increasing the participation in international research and monitoring efforts), captivity breeding and translocation (for reintroduction of species at risk), replacement of lost ecological services (e.g. replacement of natural pest control with other natural controls and/or artificial control, replacement of natural pollination with introduced, and replacement of hunting with in store products.

The identified human systems most vulnerable to climate change in the SSRB area include:

- Water resources;
- Agriculture;
- Human settlements with growing population (e.g. Calgary);
- Human settlements with little economic diversification and/or poor communities;
- Insurances and other financial services (specially to agriculture);
- Human health.

This study, due to time constrain, only analyzed further the water sector among the identified vulnerabilities within human systems. Nevertheless, future studies should include the remaining identified vulnerabilities.

Water is monitored for long-term changes and to ensure provinces meet their requirements (i.e. in the Master Agreement on Apportionment) by Environment Canada. The provincial governments (i.e. Alberta Environment and the Saskatchewan Watershed Authority) are responsible for the management of water resources to ensure water availability for all water users. Monitoring streamflow and forecasting climate change is also done at the provincial level. Nevertheless, both federal and provincial initiatives are presently limited to monitoring and data compilation, missing the next steps to adaptation plans (i.e. linking monitoring to forecasting and management plans). Future studies should also include a high level of community involvement, so that its outcome is inclusive to all community members who will ultimately be the agents for change towards adaptation; and so that the envisioned changes by the research community are grounded with local knowledge.

Climate change modeling is not yet done by the water sector and is not incorporated in water management plans, water regulation, and water legislation; instead most of these are based in past historic records and assume that the future will resemble the past. The implication of such approach is that these institutions are at best prepared for the next 20 years, but are not ready to cope with increased climate extremes.

Nevertheless, various water management initiatives are available to which climate change adaptation could be applied such as Alberta's and Saskatchewan's water management frameworks, Alberta's multiphase water management plan for the SSRB, Alberta's sub-basin management initiatives (e.g. Bow Basin plan), and local watershed initiatives (e.g. Little Red Deer River Watershed Initiative).

Adaptive strategies for the SSRB water sector focus mostly in the irrigation sector, which is its major water user. Farmers (district or private) can improve water use efficiency as to reduce waste (e.g. scheduling); irrigation districts can promote increased use efficiency and proper water practices among users; provincial governments can encourage shifts in land use from marginal to more productive areas and use land use zoning to avoid developments in high risk areas (e.g. drought prone); the federal government can promote research into new cultivars, new practices and new technologies; and governments (most likely provincial) can incorporate climate change considerations in water regulation and legislation and develop drought plans. Alberta has already started its drought planning.

Furthermore, from contacting various agencies involved in water management, climate change awareness appears to be increased when agencies do have a climate change related position or background. Despite that, such staff does not seem to reach the ongoing water management initiatives. These people could be an instrumental tool in implementing climate change adaptation concepts in their organization (e.g. educating staff on climate change impacts considerations).

6 REFERENCES

Acton, D.F.; Padbury, G.A. & Stushnoff, C.T., 1998. The Ecoregions of Saskatchewan. Saskatchewan Environment and Resource Management, Canadian Plains Research Centre, University of Regina. Regina, Saskatchewan. 205pp.

Agriculture and Agri-Food Canada, 2004. Drought Watch website (http://www.agr.gc.ca/pfra/drought/index_e.htm).

Agriculture, Food and Rural Development, 2004. Agriculture Drought Risk Management Plan for Alberta Strategic Plan (http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/cl3883/$file/plan.pdf?OpenElement).

Alberta Environment, 2004. Alberta Environment website (http://www3.gov.ab.ca/env/index.html)

Alberta Environment, 2002. South Saskatchewan River Basin Water Management Plan Phase One, Water Allocation Transfers (http://www3.gov.ab.ca/env/water/regions/ssrb/PDF_documents/Appendices_Phase_1_Plan_22_April%202002.pdf).

Alberta Environment, 2001. South Saskatchewan River Basin Water Management Plan Phase One, Water Allocation Transfers (http://www3.gov.ab.ca/env/water/regions/ssrb/PDF_documents/Appendices_Phase_1_Plan_22_April%202002.pdf).

Bow River Basin Council, 2002. Bow River Basin Council, Alberta, Canada (http://www.brbc.ab.ca/aboutbas.asp).

Canadian Climate Impacts and Adaptation Research Network, 2004. Canadian Climate Impacts and Adaptation Research Network website (http://www.c-ciarn.ca/index_e.asp).

Canadian Climate Impacts Scenarios, 2004. Canadian Climate Impacts Scenarios website (http://www.cics.uvic.ca/scenarios/).

Canadian Council of Ecological Areas, 2004. Ecozones of Canada. Canadian Council of Ecological Areas, Environment Canada (http://www.ccea.org/ecozones/index.html).

Canadian Forest Service, 1999. Alien Forest Pests, Context for the Canadian Forest Service's Science Program. Science Program Context Paper. Ottawa, Ontario. 16pp.

Canadian Wildlife Service, 2004. Canadian Wildlife service website, Environment Canada (http://www.cws-scf.ec.gc.ca).

Convention on Biological Diversity, 2004. Thematic Report on Protected Areas, Canada National Report (http://www.biodiv.org/doc/world/ca/ca-nr-pa-en.pdf).

Demuth, M.N. and Pietroniro, A., 2003. The impact of climate change on the glaciers of the Canadian Rocky Mountain eastern slopes and implications for water resource-related adaptation in the Canadian prairies. Phase I- Headwaters of the Northern Saskatchewan River Basin. PARC Prokect P55 (http://www.albertawestcountry.com/Ram%20Glacier/Summary_PARC_P55_master.pdf).

Dracup, J.A. and Kendall, D.R., 1990. Floods and Droughts. In Waggoner, P.E. (ed.), Climate Change and U.S. Water Resources. Wiley Publishers, New York, NY, pp. 243-267.

Environment Canada, 2004. Environment Canada website (http://www.ec.gc.ca).

Epp, H.T., 1991. Ecological process management for mantaining biological diversity on the Canadian Prairies. In: Jonker, P., 1992. Saskatchewan Endangered Spaces, an Introduction.Extensin Division, University of Saskatchewan, Saskatoon, Saskatchewan, 146pp.

Global Change Strategies international Inc and the Meteorological Service of Canada, 2000. Water Sector: Vulnerability and Adaptation to Climate Change, Final Report (http://www.gcsi.ca/downloads/ccafwaterf.pdf).

Government of Alberta, 2004. SSRB Management Plan, Government of Alberta (http://www3.gov.ab.ca/env/water/regions/ssrb/index.asp).

Government of Canada, 2002. Climate Change Plan for Canada (http://www.climatechangeconnection.org/pdfs_ccc/nov21_fedplan.pdf).

Handmer, J.W., Dovers, S., and Downing, T.E., 1999. Societal vulnerability to climate change and variability. *Mitigation and Adaptation Strategies for Global Change* 4:276-281.

Herrington, R.; Johnson, B. & Hunter, B., 1997. Responding to Global Climate Change in the Prairies. Volume III of the Canada Country Study: Climate Change Impacts and Adaptation. Adaptation and Impacts section, Atmospheric and Hydrologic Sciences Division, Environment Canada. http://www.parc.ca/pdf/ccs%201997/ccs%20index.html

Hoppe, T., 2004. Report on The Potential for Irrigation Expansion in Western Canada. Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration. (http://agr.gc.ca/pfra/pub/irrexpan.htm)

International Institute for Applied Systems Analysis, 2000. Future climate change and carbon budgets. http://www.iiasa.ac.at/Research/FOR/papers/medea/10_future_climate_change.htm

International Strategy for Disaster Reduction, 2004. International Strategy for Disaster Reduction website (http://www.unisdr.org/eng/task%20force/tf-disc-group1-eng.htm).

IPCC, 2001. Summary for Policymakers Climate Change 2001: Impacts, Adaptation, and Vulnerabilities. A Report of Working Group II of the Governmental Panel on Climate Change (http://www.ipcc.ch/pub/wg2SPMfinal.pdf).

IPCC, 2001[1]. Technical Summary, A report accepted by Working Group I of the IPCC but not approved in detail. IPCC (1http://www.grida.no/climate/ipcc_tar/wg1/010.htm).

IPCC, 2001[2]. Climate Change: Impacts, Adaptation, and Vulnerability (http://www.ipcc-wg2.org/index.html).

IPCC Data Distribution Centre, 2004. IPCC Data Distribution Centre website (http://ipcc-ddc.cru.uea.ac.uk/asres/scatter_plots/scatterplots_home.html)

Lac, S., 2003. Climate change: implications for SK forestry and agriculture. Paper prepared for the Standing Senate Committee on Agriculture and forestry, Hearings in Western Canada. Regina, Saskatchewan.

Laird, K.R., S.C. Fritz, E.C. Grimm, and P.G. Mueller. 1996. Century-scale paleoclimatic reconstructions from Moon Lake, a closed-basin lake in the northern Great Plains. *Limnology and Oceanography* 41(5): 890-902.

Loë, R. de; Kreutzwiser, R., and Moraru, L., 2001. Adaptation options for the near term: climate change and the Canadian water sector. *Global Environmental Change* 11: 231-245.

Mayer, N. and W. Avis, 1998. Canada country study: Climate impacts and adaptation. Volume VIII National Cross-Cutting Issues. Environment Canada (http://dsp-psd.communication.gc.ca/Collection/En56-119-7-1998E.pdf).

National Drought Monitoring Center, 2004. National Drought Monitoring Center website, University of Nebraska (http://www.drought.uncl.edu/).

Natural Resources Canada, 2004. Atlas of Canada, Natural Resources Canada (http://atlas.gc.ca/site/english/).

Natural Resources Canada, 2002. How are climates changing in the Prairies? http://adaptation.nrcan.gc.ca/posters/articles/pr_03_en.asp?Region=pr&Language=en

Natural Resources Canada, 2002[1]. Climate Change Impacts and Adaptation: A Canadian perspective. Agriculture Chapter, prepared for the Climate Change Impacts and Adaptation Directorate (http://adaptation.nrcan.gc.ca/app/filerepository/53228D320F4147B6B8A6DF3EEF94CB93.pdf).

Nemanishen, W., 1998. Drought in the Palliser Triangle; a Provisional primer. Prairie Farm Rehabilitation Administration Agriculture Drought Committee, Agri-Food Canada, Calgary, Alberta, 58 pp.

Niemelä, P. and Mattson, W.J., 1996. Invasion of North American forests by European phytophagus insects: legacy of the European crucible. *Bioscience* 46(10):741-753.

Parks Canada, 2004. Parks Canada website (http://parkscanada.pch.gc.ca/index_e.asp).

Partners FOR the Saskatchewan River Basin, 2004. Partners FOR the Saskatchewan River Basin website (http://www.saskriverbasin.ca/).

Postel, S., 2000. Redesigning irrigated agriculture. In: *State of the World 2000*. A Worldwatch Institute Report on Progress Toward a Sustainable Society, New York, pp. 39-58.

Rosenzweig, C. & Hillel, D., 1993. Plant and environment interactions, the dust bowl of the 1930's: analog greenhouse effect in the Great Plains? *Journal of Environmental Quality* 22:9-22.

Ruosteenoja, K.; Carter, T.R., Jylhä, K. and Tuomenvirta, H., 2003. Future climate in world regions: an intercomparision of model-based projections for the new IPCC emission scenarios. *The Finnish Environment* 644, Finish Environmental Institute, 83 pp.

Saskatchewan Environment, 2004. Saskatchewan Environment website (http://www.se.gov.sk.ca/).

Saskatchewan Watershed Authority, 2004. Saskatchewan Watershed Authority website (http://www.swa.ca/).

Singh, T. & Wheaton, E.E., 1991. Boreal forest sensitivity to global warming: implications for forest management in Western Interior Canada. *The Forestry Chronicle* 67:342-348.

Smit, B. and Pilifosova, O., 2001. From adaptation to adaptive capacity and vulnerability reduction (http://www.c-ciarn.ca/app/filerepository/F54181687CEE431092EBAC2DA92A3761.pdf).

Sobool, D. and Kulshreshtha, S., 2003. Socio-Economic Database: South Saskatchewan River Basin (Saskatchewan and Alberta). A Report Prepared for Prairie Adaptation Research

Collaborative under a contract from Agriculture and Agri-Food Canada-Prairie Farm Rehabilitation Administration (P.F.R.A.), 56pp.

Standing Senate Committee on Agriculture and Forestry, 2003. Climate Change: We are at Risk. Final report for the Standing Senate Committee on Agriculture and Forestry, Government of Canada, Ottawa, Ontario, 111pp.

Stanford, Q.H., 1998. Canadian Oxford World Atlas. Oxford University Press, Toronto, Ontario. 220pp.

Stewart, R.B.; Wheaton, E. & Spittlehouse, D., 1997. Climate change: implications for the boreal forest. Pp. 22-24 in: Proceedings of "Air and Water Waste Management Association Symposium. Implications of Climate Change: What Do We Know?". Calgary, Alberta, 23pp.

Waring, R.H. & Running, S.W., 1998. Forest Ecosystems Analysis at Multiple Scales. Second Edition. Academic Press, San Diego, California. 370pp.

Wheaton, E.E. and Macifer, D.C. (1999). A framework and key questions for adapting to climate variability and change. *Mitigation and Adaptation Strategies for Global Change* 4: 215-225.

Wilhite, D.A. (1997). State actions to mitigate drought: lessons learned. *American Water Resources Association* 33(5): 961-968.

Yohe, G. and Tol, R.S.J., 2002. Indicators for social and economic coping capacity- moving toward a working definition of adaptive capacity. *Global Environmental Change* 12: 25-40.

Zhang, X., Harvey, K.D., Hogg, W.D., Yuzuk, T.R., 1999. Trends in Canadian Streamflow, M.Sc., Environment Canada, 38pp In: Global Change Strategies international Inc and the Meteorological Service of Canada, 2000. Water Sector: Vulnerability and Adaptation to Climate Change, Final Report (http://www.gcsi.ca/downloads/ccafwaterf.pdf).

Appendix A: Seasonal climate change maps for Canada (2050) from CGCM2 A21
(Source: Canadian Climate Impacts Scenarios, 2004).

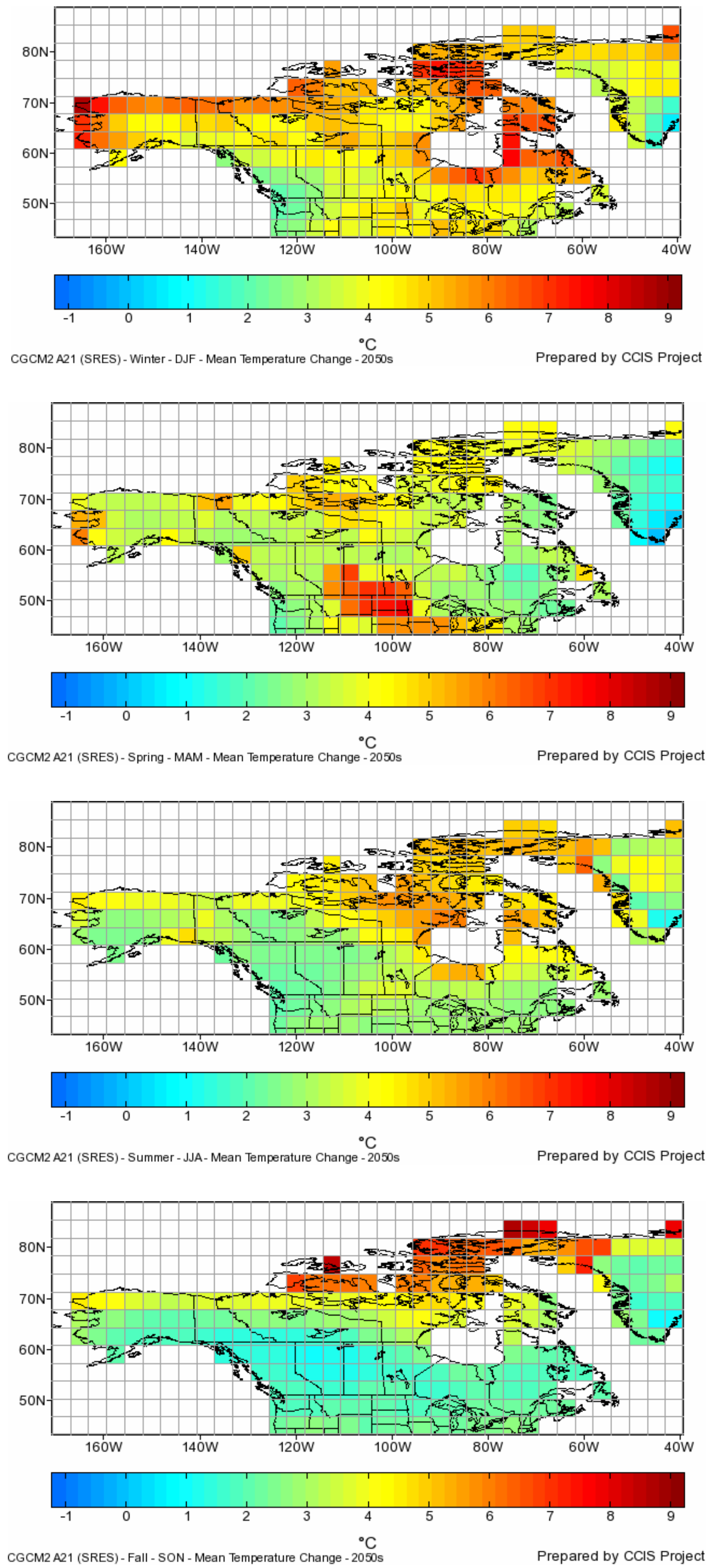

Figure 1A: Mean temperature change from 1961-1990 normal to 2050 (absolute difference in degrees Celsius temperature values) for all seasons.

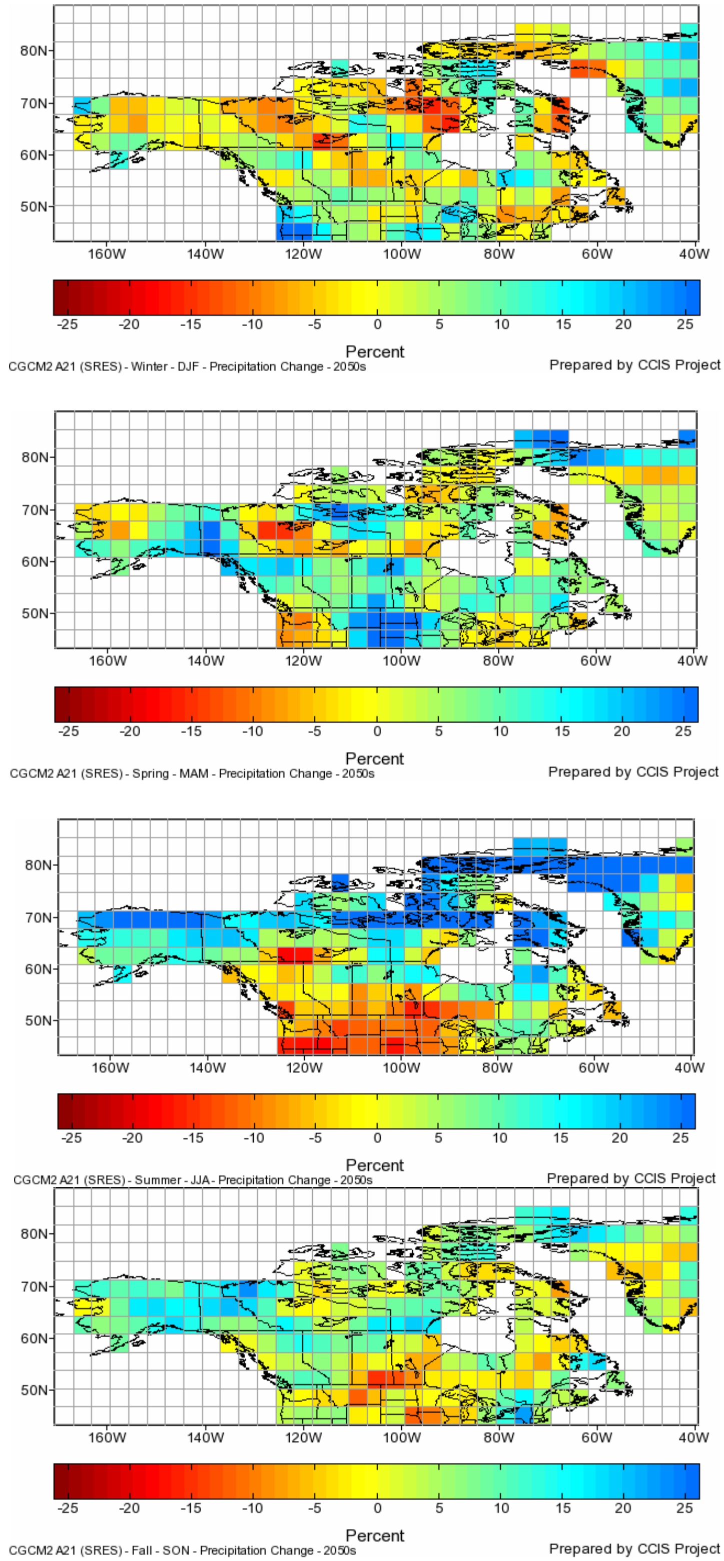

Figure 2A: Precipitation change (%) from 1961-1990 normal to 2050 for all seasons (original baseline and 2050 data in mm/day).

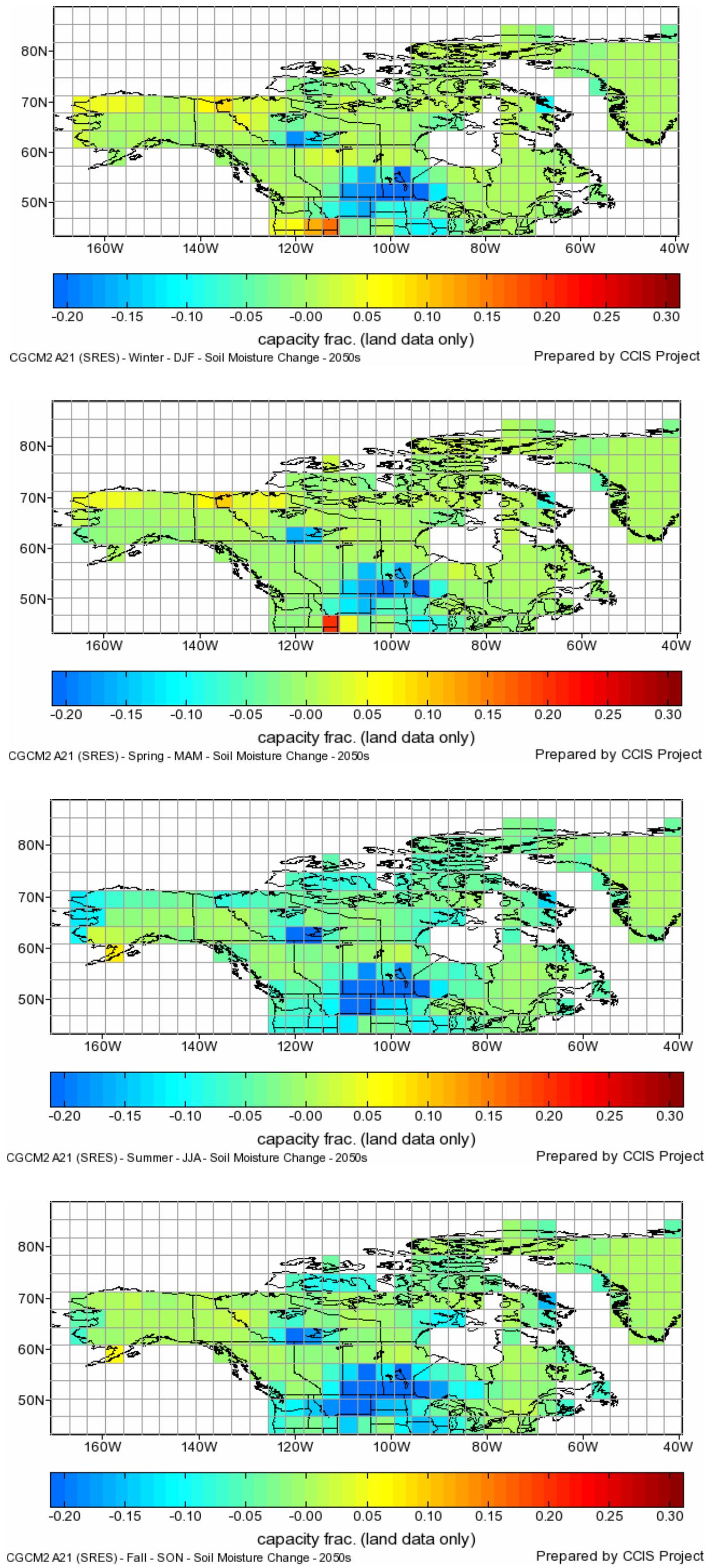

Figure 3A: Soil moisture change from 1961-1990 normal to 2050 (absolute difference in capacity fraction values) for all seasons.

Appendix B: Monthly scatter plots for Medicine Hat (50.1°N, 110.43°W) used for multiscenario analysis. All scatter plots (Figures 1B, 2B, and 3B) present temperature versus precipitation changes for 2050 from the 1961-1990 baseline (Source: Canadian Climate Impacts Scenarios, 2004).

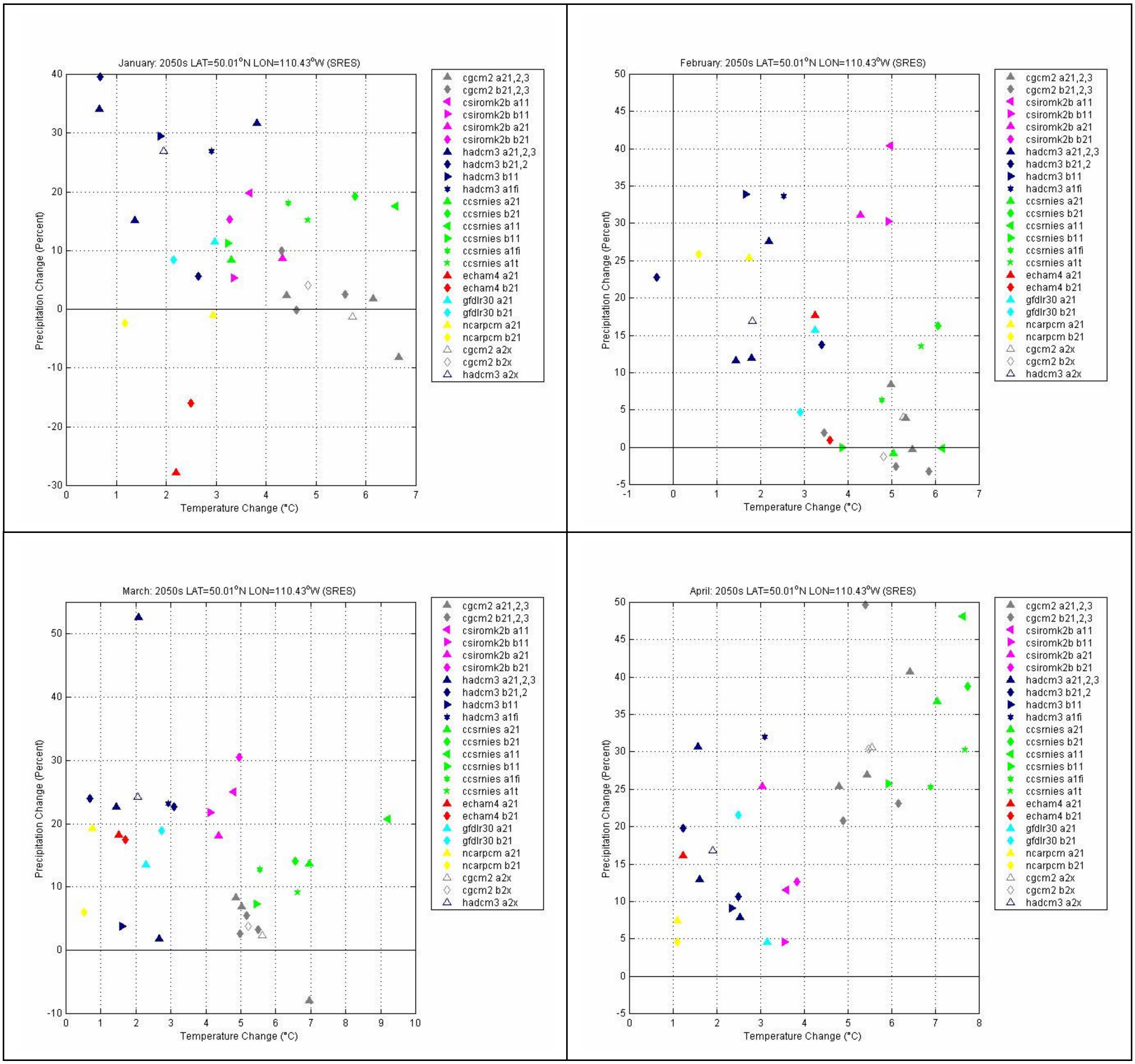

Figure 1B: Medicine Hat monthly scatter plots including the months of January, February, March, and April.

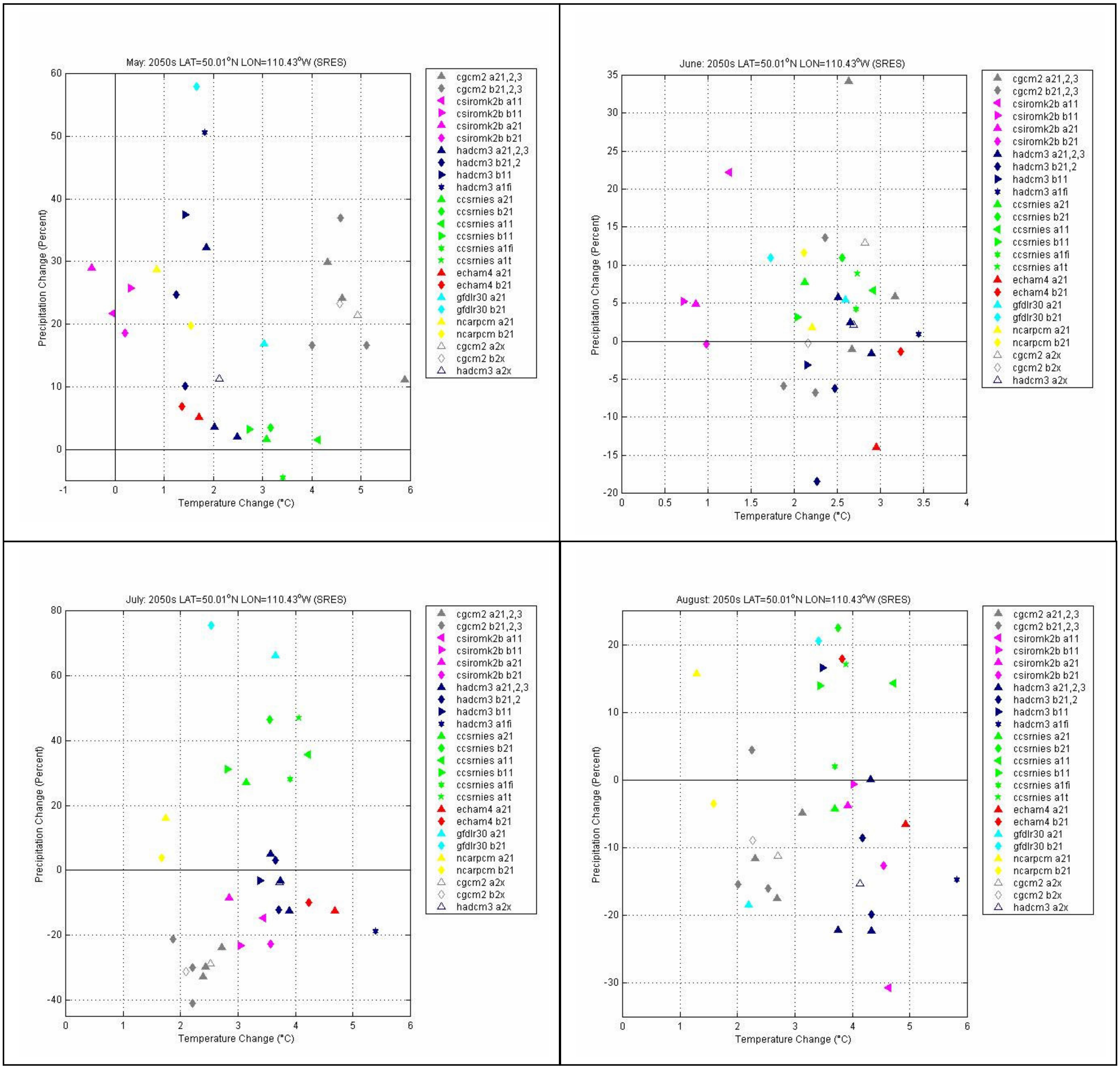

Figure 2B: Medicine Hat monthly scatter plots including the months of May, June, July, and August.

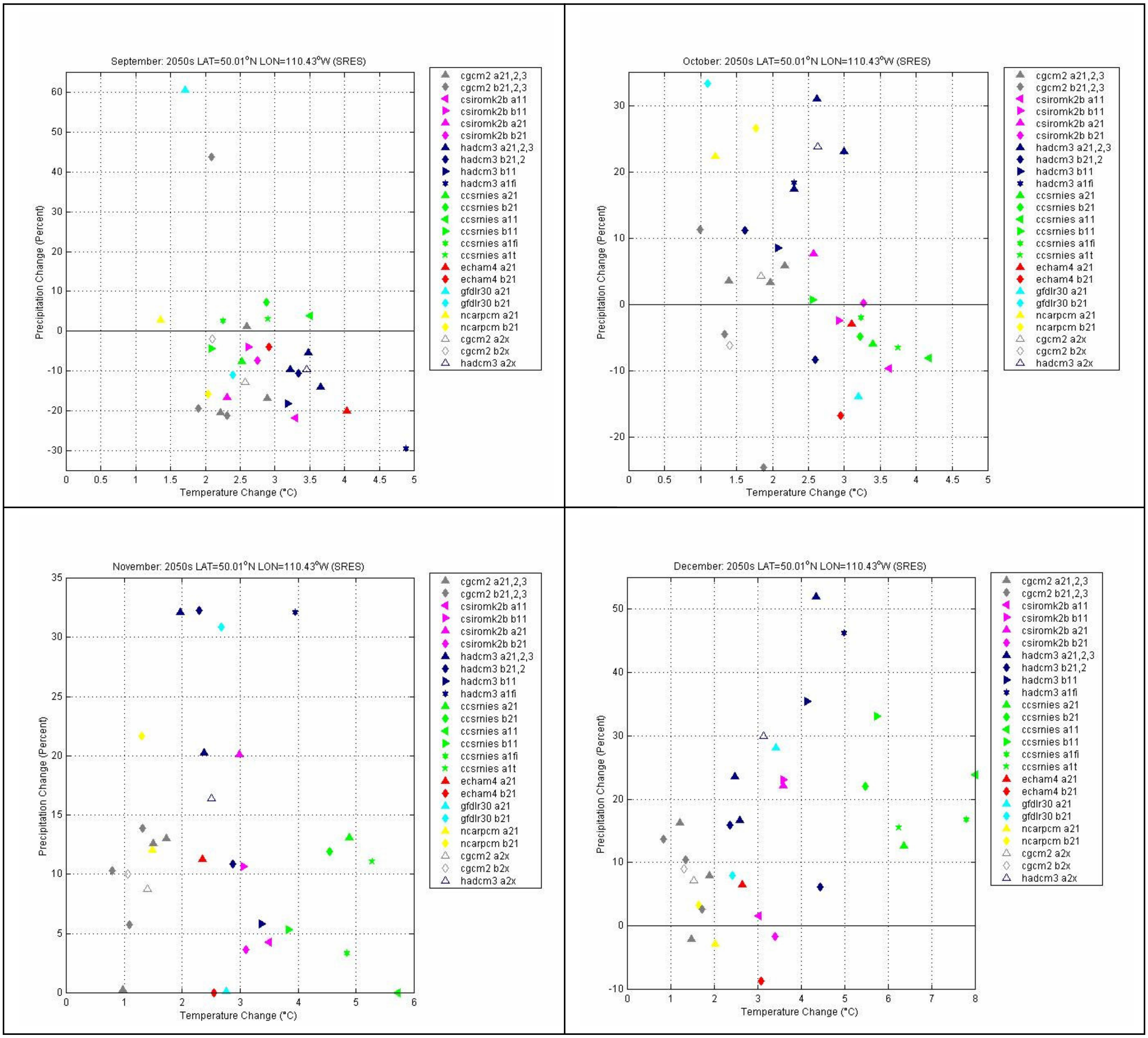

Figure 3B: Medicine Hat monthly scatter plots including the months of September, October, November, and December.

Appendix C: Major droughts in North America (see Figure 1C); drought is defined with the Palmer Drought Severity Index of -3 and less for summer months- June, July and August) (Source: Elaine Wheaton- Saskatchewan Research Council, personal communication).

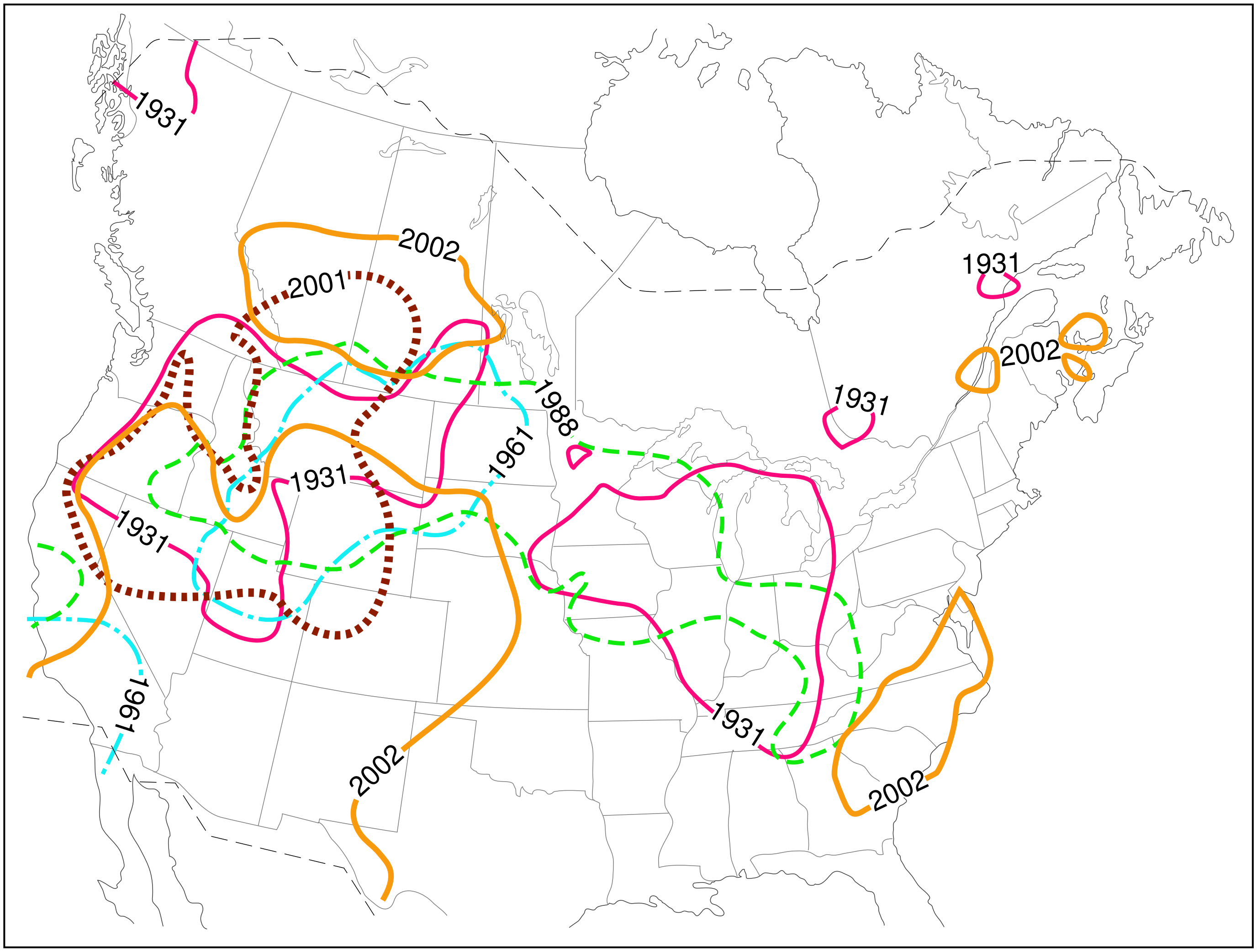

Figure 1C: Major (summer) droughts in North America.

Appendix D: Saskatchewan River Basin survey of residents and key informant interviews (1994).
(Source: Partners FOR the Saskatchewan River Basin, 2004).

EXECUTIVE SUMMARY

SURVEY OF RESIDENTS

A survey was conducted of a random sample of 550 residents of the Saskatchewan River Basin in late February and early March 1994. The survey involved 250 residents in Alberta, and 150 each in the Saskatchewan and Manitoba portions of the Basin. Thus Saskatchewan and Manitoba respondents are over-represented in proportion to their share of the Basin population. This stratification was designed to allow for comparisons among the three provinces. When the results below refer to the basin as a whole, the sample has been weighted so that each province is represented in correct proportion to its population.

Environmental Actions

• Respondents were asked to rate the importance of a number of environmental actions. Of the 10 actions offered two were seen as very important by almost all respondents (parenthetically after each is the average rating out of 10)

- *reducing pollution in rivers and lakes (9.3);*
- *reducing pollution of the atmosphere (9.0);*

Three others were rated highly by respondents:

- *reforestation (8.8);*
- *protecting wildlife habitats (8.7);*
- *protecting fish habitats (8.4);*

Protecting fish habitats was rated much higher among Manitoba respondents than in the other provinces reflecting the importance of fishing in that portion of the Basin.

• Less important among respondents were these environmental actions:

- *wetland preservation (7.7);*
- *preserving old growth forests (7.7);*
- *creating more protected areas (7.5);*
- *creating water-related tourism development (5.8);*

Water Management Issues

• Overall, only about one-quarter were highly satisfied (a rating of 8 out of 10 or higher, and an average rating of 6 out of 10) with the management of water resources in their area. Alberta respondents tended to be the least satisfied on average, while Manitoba respondents were the most satisfied.

• When asked what changes if any they would like to see in the way water resources are managed in their area, about 20 percent stated that no changes were necessary. The most common (38%) change suggested was reducing pollution in rivers and lakes in their area.

• However, about 30 percent of respondents stated that they do not know who is responsible for managing water in their area. Provincial or municipal governments (each cited by 28% of respondents) were the most often seen as responsible for water management.

• The vast majority of respondents feel it is very important that people in all areas of the Basin have more of a say in the overall management of all water resources within the Saskatchewan River Basin. Manitobans were the most likely to feel this way, while Albertans were the least likely.

• The respondents' average rating of the quality of water in the rivers and lakes in their area is 5.8 (on a 0 to 10 scale, where 0 is terrible and 10 is excellent). Manitoba respondents gave the highest rating, with over 40 percent rating the quality as very good (that is, 8 or higher out of 10). Alberta respondents gave the lowest quality rating with 25 percent rating the water quality very good. The higher the perceived quality of water, the more satisfied respondents tend to be with the management of water in their area.

Water Management Concerns

• Respondents were read a list of water management issues and were asked to rate their concern with each. On average, the greatest concern was for:

- *pollution from industry* (average rating of 9.0 out of 10, where 10 meant a great concern);
- *protecting the quality and quantity of ground water* (8.6);
- *pollution from cities and towns* (8.5);
- *loss of fish habitat* (8.2); and
- *forestry practices* (8.0);

• Of less concern to respondents were:

- *loss of wetland and riverbank habitats* (7.8);
- *agricultural practices* (7.5);
- *amount of water used in homes* (6.7);
- *loss of heritage resources such as archaeological sites due to riverbank development* (6.7);
- *use of water from lakes and river water for irrigation* (6.6); and
- *recreational developments such as golf courses along lakes and rivers* (5.8).

Information on Water Management

• Saskatchewan River Basin residents do not consider themselves to be very well informed about water management issues. The overall average rating was 5.5 out of 10 about midway between "not al all informed" and "very well informed". About one-quarter classified themselves as well informed.

• The most common sources mentioned by respondents when asked where they would go first to get answers or information about local water issues were a branch or department of their municipal (34%) or provincial (25%) governments. This is not surprising since nearly as many residents had said such government bodies were responsible for water management in their area.

• When asked to rate their personal interest in obtaining additional information on issues of local water management, most respondents showed that they were at least somewhat interested and over 40 percent indicated they were very interested.

• Those who identified themselves as being well informed about local water management issues are also the most likely to express interest in obtaining more information.

• The ways these respondens thought it best to receive additional information were: newspaper, TV, through schools, and mail pamphlets.

• These methods of receiving information are reflected in how these respondents had obtained information on the environment in the last year. Over 80 percent of respondents had received such information from TV or radio news, newspapers, or magazines, or TV/radio programs on the environment.

• Respondents rate their likelihood of becoming involved in a public process for managing water resources, if given an opportunity to do so. The average overall rating of 5 out of 10 (where 10 meant they definitely would) indicated some apathy on the part of residents. However, a fifth of these respondents though they would be very likely to get involved (that is, a rating of 8 or higher out of 10).

Current Water Use

• Although nearly two-thirds (63%) of homes in the Basin have water meters, there are regional differences. Only one-quarter of the Manitoba respondents have meters in their homes. Just over half the Saskatchewan residents (55%) and two-thirds of these in Alberta (66%) have water meters.

• The most common conservation device in use within homes in the Saskatchewan River Basin is a flow-regulating shower head. About half the respondents claim to have such a device, and over 40 percent use some method to reduce the volume of water used by their toilets. Under a third use flow-regulated taps on their faucets. Whether or not a respondent’s home is metered makes no difference in their use of these devices.

• The most popular water-related activity overall Is walking or cycling along rivers and lake shores, mentioned by over 80 percent of Basin residents. Three quarters also camp along a river or lake during a typical summer, or have a cottage in such an area. Swimming and wading was cited by 70 percent of respondents. All the other activities are undertaken by less than half the respondents during the summer. Hunting, jet-skiing, and commercial fishing are activities for under 10 percent of the Basin population.

KEY INFORMANT INTERVIEWS

• 20 representatives of organizations with an interest in water management issues representing industry, government, and nongovernmental organizations were interviewed.

• All respondents supported the concept of sustainable development, although there were some differences in the definition, approach and implementation.

• The misconceptions about water cited by these respondents as being commonly held by the public were numerous and include:

- there is an unlimited abundance of water, both in quantity and quality;
- rivers and lakes are more polluted than they actually are;
- industry causes most of the water pollution and other negative impacts on rivers and lakes;
- water delivered to urban residents in contaminated, or in some way a health concern.

• The survey of residents appears to support the view that many of these "misconceptions" are held by the public. For example. The public appears to believe that rivers and lakes are quite polluted and that industry and cities are the main causes of this pollution.

• The major water management issues cited by these respondents revolved around:

- educating the public about water management issues;
- maintaining the quantity and quality of water;
- allocation of a scarce resource among competing interests;
- having more input into the management of water resources.

• Several methods of encouraging sustainable water use were mentioned, including:

- education;
- greater public involvement in water management;
- pricing;
- better government regulation.

• Most respondents acknowledged that there was a need for greater cooperation and coordination among various public, private and nonprofit stakeholders in the management of water resources in the Saskatchewan River Basin. The benefits of such cooperation and coordination include:

- conserving resources;
- sharing information; and
- building understanding.

- Respondents gave the following advice to the Partners FOR the Saskatchewan River Basin:
  - It should try to involve all groups that utilize the Basin, including industry, agriculture, NGOs and government.
  - The Partners should try to act as a clearinghouse of water management information to encourage a sharing of knowledge.
  - The Partners should develop a plan for educating the public on: the nature of the Basin (its size, the various users, etc.), water management issues and techniques, and the sustainable use of water.
  - It should focus on problems on which it has a realistic chance to make a positive impact.
  - It should consider methods used by other successful water resource organizations.
  - The Partners must be non-partisan in the educational and organizational activities.
  - There is the need for better definitions of the Partners' goals. Some of the goals are seen as "*too general*".

- Respondents identified several priorities for the Partners FOR the Saskatchewan River Basin:
  - Gather and disseminate information of water management issues;
  - Educate the public;
  - Facilitate among stakeholders.

Appendix E: Water management roles and responsibilities (Saskatchewan)
(Source: Saskatchewan Environment, 2004).

Assignment of responsibilities between agencies for water is complex and often shared. Under the Natural Resources Transfer Agreement, 1930, and the subsequent 1938 Amendment, Canada transferred control over water to the Government of Saskatchewan.

Saskatchewan water management agencies are responsible for:

- *Legislation of areas of water supply, pollution control, thermal and hydroelectric power development;*
- *Authorization of water use and development; and*
- *Flow regulation.*

Federal responsibilities are in areas that have the potential for significant national economic impact such as:

- *Navigation;*
- *Fish habitat;*
- *Water on federal lands (e.g., Prince Albert National Park) and Indian Reserves; and Boundary and Transboundary waters.*

Shared federal-provincial responsibilities:

- *National water issues;*
- *Interprovincial water issues;*
- *Agriculture; and Health.*

Provincial agencies with direct water management responsibilities:

- **Saskatchewan Environment** - The department's mandate is to manage, enhance and protect Saskatchewan's natural and environmental resources - fish, wildlife, lands, forests, parks and protected areas, air, water and soil - for conservation, recreation, social and economic purposes and to ensure they are sustained for future generations.
- **Sask Water** - Sask Water's mandate is to manage, protect and develop the province's water and land related resources for the economic and social benefit of the province. The Corporation invests in or operates environmentally sustainable water based initiatives which provide economic and social benefits to the province and provides water and waste water utilities which can service current and future provincial needs.
- **Saskatchewan Health** - The department and those Health Districts designated as local authorities are involved in water and wastewater management. They monitor and provide advice on water quality and treatment to owners and operators of private water supplies. Permits and inspections are made for the installation of private sewage works. The Department's Provincial Lab provides analytical services on water samples submitted by owners or operators of water systems/supplies.

- **Saskatchewan Wetland Conservation Corporation** - SWCC is a wildlife habitat conservation organization that encourages integrated land use by linking agriculture, wildlife and industry interests. SWCC's programs provide technical advice on wetland, range and riparian management.
- **Saskatchewan Agriculture and Food** - The department's mandate is to provide leadership in developing and supporting competitive agriculture and food industries. The department's role in water management centres around the relationship between agricultural activities and water resources.
- **Saskatchewan Municipal Government** - The department's mandate is to strengthen communities by providing the legal framework, organization support, financial assistance and other services to meet their needs; and, to work in partnership to encourage co-operation, understanding and self-reliance. Community Planning provides assistance to rural, urban and northern municipalities and provides advice to municipalities on infrastructure development options.
- **Saskatchewan Research Council** - SRC applies science and technology to help provincial industries be globally competitive. Core activities are in the areas of Resources, Environment, Agricultural Biotechnology and Small Industry Services. SRC's Water Section is recognized as a center of excellence on technology issues regarding surface water treatment and supply. SRC Analytical Service Lab provides water analysis for a service fee. In resource development, SRC helps the province and industry define and develop ground water resources for agriculture, processing and industrial development. In rural areas SRC helps to sustain ground water resources.

Provincial agencies with indirect water management responsibilities:

- Saskatchewan Economic and Cooperative Development - The department's mandate is to expand the Saskatchewan economy by promoting, coordinating and implementing policies, strategies and programs that encourage economic growth.
- Saskatchewan Intergovernmental and Aboriginal Affairs - The mandate of the department is to promote and facilitate partnerships between Aboriginal and non-Aboriginal peoples and organizations in achieving common goals and enhancing quality of life. The department periodically facilitates discussions between Aboriginal peoples and government agencies dealing with water management decisions.

Provincial Government Legislation

Saskatchewan Health

- The Public Health Act, 1994

Saskatchewan Agriculture and Food

- The Pest Control Products
- (Saskatchewan) Act
- The AgriFood Innovation Fund Act
- The Provincial Lands Act

- The Agricultural Operations Act

Saskatchewan Intergovernmental and Aboriginal Affairs

- The Treaty Land Entitlement
- Implementation Act

Saskatchewan Environment and Resource Management

- The Environmental Assessment Act
- The Environmental Management and Protection Act
- The Provincial Lands Act
- The Fisheries Act (Saskatchewan), 1994
- The Natural Resources Act
- The Water Appeal Board Act

Sask Water

- The Water Corporation Act
- Water Right Regulations
- Drainage Control Regulations
- Reservoir Development Area Regulations
- The Ground Water Conservation Act
- The Watershed Associations Act
- The Conservation and Development Act
- The Water Power Act
- The Irrigation Act, 1996

Saskatchewan Municipal Government

- The Department of Rural Development Act
- The Department of Urban Affairs Act
- The Meewasin Valley Authority Act
- The Rural Municipality Act, 1989
- The Urban Municipality Act, 1984
- The Wakamow Valley Authority Act
- The Wascana Centre Act