South Saskatchewan River Basin Biogeography

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TABLE OF CONTENTS

1 INTRODUCTION ……………………………………………………………………..4

2 SOUTH SASKATCHEWAN RIVER BASIN BIOGEOGRAPHY DESCRIPTION…………………………………………………………………….5

2.1 The Prairie Ecozone…………………………………………………………...10

2.1.1 The Aspen Parkland ecoregion……………………………………………11

2.1.2 The Moist Mixed Grassland ecoregion……………………………………12

2.1.3 The Mixed Grassland ecoregion…………………………………………..13

2.1.4 The Cypress Upland ecoregion……………………………………………14

2.1.5 The Fescue Grassland ecoregion…………………………………………15

2.2 The Boreal Plains Ecozone………………………………..……………………..16

2.2.1 The Boreal Transition ecoregion……………………………………………17

2.2.2 The Western Alberta Uplands ecoregion…………………………………18

2.3 The Montane Cordillera Ecozone…………………………………………………18

2.3.1 The Eastern Continental Ranges ecoregion………………………………19

2.3.2 The Northern Continental Divide ecoregion………………………………20

3 NATURAL HAZARDS……………………………………………………………21

3.1 Drought…………………………………………………………………………...21

3.1.1 Definition and causing factors……………………………………………21

3.1.2 Past droughts- will the future mirror the past?..26

4 SENSITIVE AREAS IN THE SOUTH SASKATCHEWAN RIVER BASIN……………………………………………………………………………… 31

5 CONCLUSIONS…………………………………………………………..……...35

6 REFERENCES…………………………..…………………………………………..39

FIGURES:

Figure 2.1: Study Area: The South Saskatchewan River Basin…………………………...5

Figure 2.2: South Saskatchewan River Basin sub-basins…………………………………5

Figure 2.3: South Saskatchewan River Basin watersheds………………………………...7

Figure 2.4: South Saskatchewan River Basin mean annual temperature………………….7

Figure 2.5: South Saskatchewan River Basin total annual precipitation………………….8

Figure 2.6: South Saskatchewan River Basin maximum elevation……………………….8

Figure 2.7: South Saskatchewan River Basin annual potential evapotranspiration……….8

Figure 2.8: South Saskatchewan River Basin ecozones…………………………………..9

Figure 2.9: South Saskatchewan River Basin ecoregions………………………………...9

Figure 3.1: Relationships between types of droughts……………………………………22

Figure 4.1: Sensitive aridity classes in the South Saskatchewan River Basin…………...32

Figure 4.2: South Saskatchewan River Basin annual wind speed……………………….33

Figure 4.3: Sensitive available water capacity in the South Saskatchewan River Basin...33

Figure 4.4: Sensitive soil textures in the South Saskatchewan River Basin……………...33

Figure 4.5: Agricultural land-use in the South Saskatchewan River Basin………………34

Figure 4.6: Sensitive areas in the South Saskatchewan River Basin, with sensitive soil textures and sub-basins represented……………………………………34

TABLES:

Table 3.1: Paleoclimate recorder (evidences), proxy recorder, and property measured…27

Table 3.2: Past Droughts in the Canadian Prairies……………………………………......28

1 INTRODUCTION

In 2004, the Institutional Adaptations to Climate Change project was started, with the objective to improve the understanding of vulnerability and adaptation options in the South Saskatchewan River Basin (SSRB) in Canada and El Coquimbo basin in Chile. These two basins have in common rural communities whose livelihood is naturally highly exposed to climate, and face common threats under a changing climate (e.g. increased drought, decreased soil and water quality).

This document is part of the Institutional Adaptations to Climate Change project, and is intended to provide a description of the SSRB biogeography and the identification of areas within the SSRB which are more exposed to permanent degradation, from which the rural communities can be assumed to be at greater risk to climate change impacts.

This report is divided in 6 parts: introduction, (part 1); biogeography description of the SSRB which includes a general overview of the SSRB and a description of its ecozones and ecoregions (part 2); the natural hazards (part 3) which includes a review on drought definition, its causing factors and past (long-term) records; the sensitive areas selected in the SSRB as an indicator of vulnerable communities (part 4); the conclusions (part 5); and references (part 6). This paper is a result of a joint effort of the authors. Camilla Conlan contributed with the description of the ecozones and ecoregions, and Silvia Lac contributed with the remaining sections of this document.

2 SOUTH SASKATCHEWAN RIVER BASIN BIOGEOGRAPHY DESCRIPTION

The South Saskatchewan River Basin (SSRB) is located in the southern part of Alberta and Saskatchewan and includes 5 major urban centers: Saskatoon, Swift Current, Red Deer, Calgary, Lethbridge and Medicine Hat (see Figure 2.1). The SSRB boundaries include the Big Stick Lake, Bow River, Oldman River, Red Deer River, Seven Persons Creek, South Saskatchewan River, and the Swift Current Creek sub-basins (Richard J. Rickwood- Prairie Farm Rehabilitation Administration); see figure 2.2.

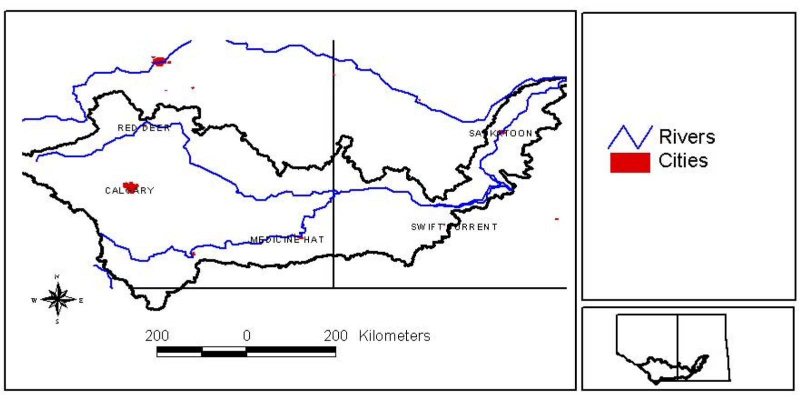

Figure 2.1: Study area: the South Saskatchewan River Basin

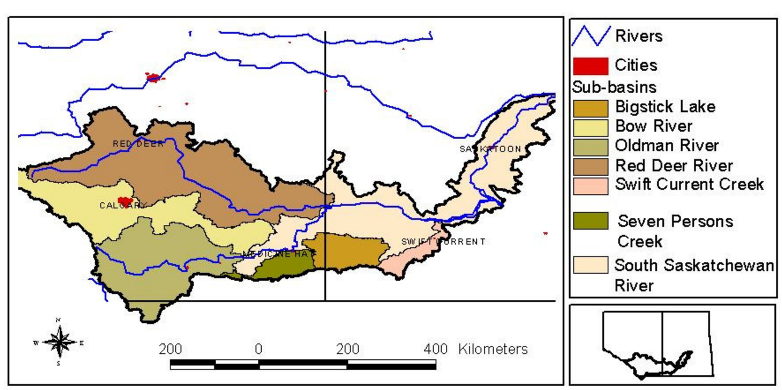

Figure 2.2: South Saskatchewan River Basin Sub-basins

The South Saskatchewan River Basin (SSRB) has approximately 225 rural communities, although most population in this area is concentrated in major urban centers (Sobool and Kulshreshtha, 2003). 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) (Sobool and Kulshreshtha, 2003). 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 SSRB is part of the Saskatchewan River Basin which, in turn, is part of the Nelson-Hudson Bay Basin. 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 SSRB area contributes water to the Hudson Bay (i.e. is part of the Nelson-Hudson Bay Basin), part of it drains internally. The SSRB includes four watersheds: Bow, Red Deer, Upper South Saskatchewan, and Lower South Saskatchewan (see figure 2.3).

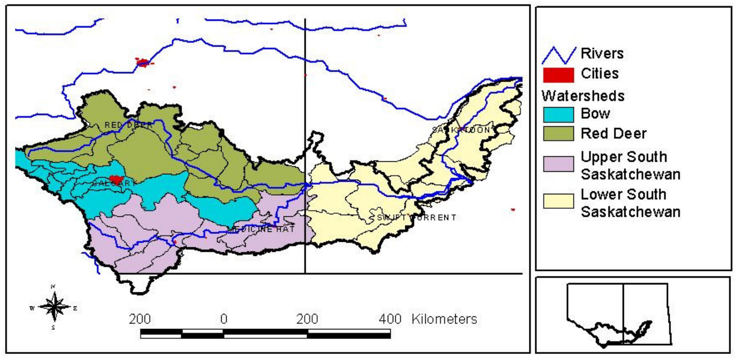

Figure 2.3: South Saskatchewan River Basin watersheds

The temperature in the SSRB increases southwards, with mean annual temperature ranging from approximately 2ºC to 6ºC (see figure 2.4). Precipitation increases mostly to west in the SSRB but also northwards, with total annual precipitation ranging from approximately 282 mm to over 800 mm in the Rocky Mountains, see figure 2.5. The elevation in the SSRB increases westwards, with maximum elevation ranging from approximately 333 m to over 3,000 m in the Rocky Mountains, see figure 2.6. The potential evapotranspiration increases to the south and, to a lesser extent, to the east of the SSRB with annual potential evapotranspiration (Penman method) ranging from approximately 450 mm to over 800 mm.

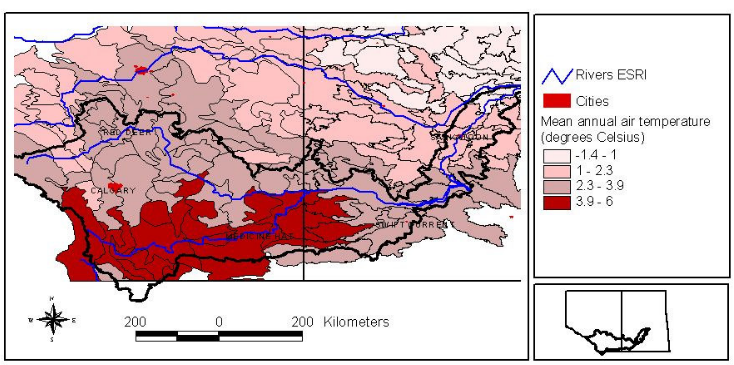

Figure 2.4: South Saskatchewan River Basin mean annual air temperature (degrees Celsius)

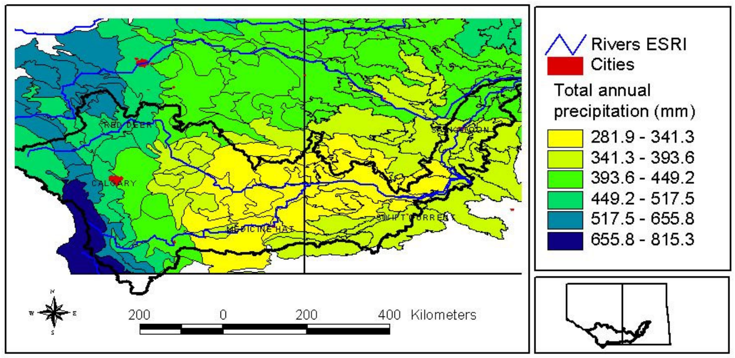

Figure 2.5: South Saskatchewan River Basin total annual precipitation

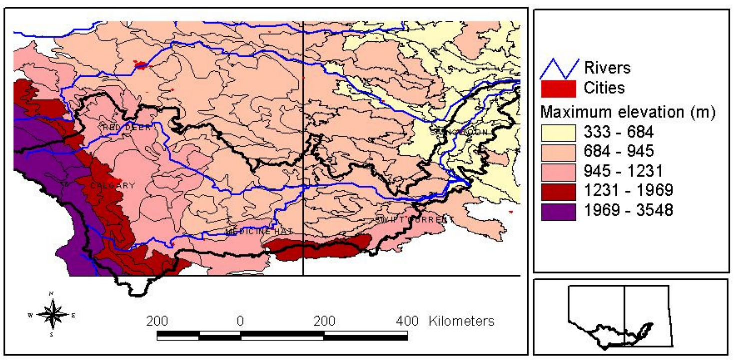

Figure 2.6: South Saskatchewan River Basin maximum elevation

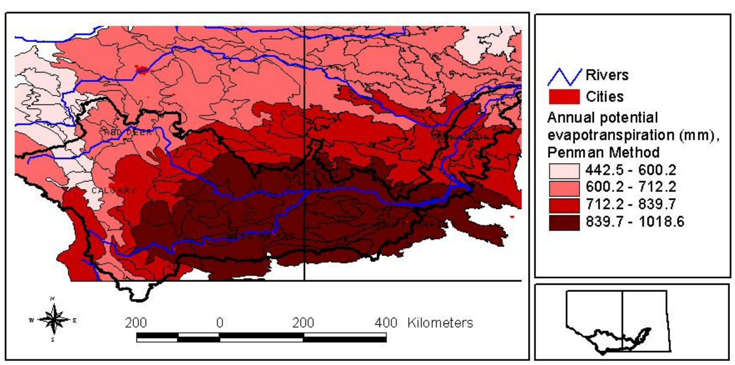

Figure 2.7: South Saskatchewan River Basin annual potential evapotranspiration (Penman Method)

The SSRB area includes three ecozones (Canadian Council of Ecological Areas, 2004): the Prairies which extends to approximately 80% of the area, and the Boreal Plains and the Montane Cordillera which together occupy roughly 20% of the area (see figures 2.8).

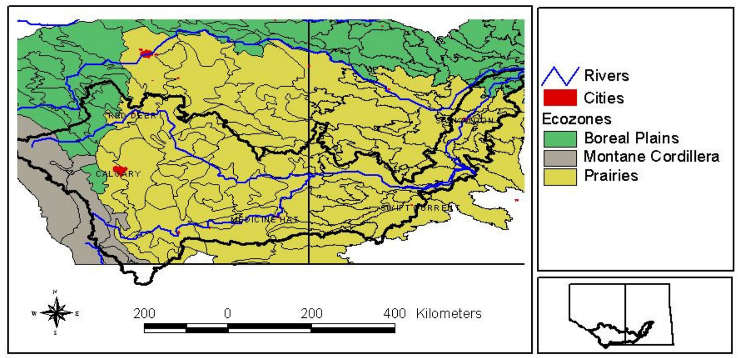

Figure 2.8: South Saskatchewan River Basin ecozones

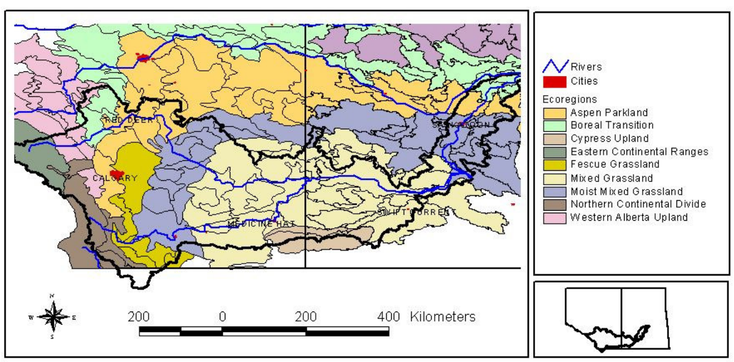

Figure 2.9: South Saskatchewan River Basin ecoregions

Figures 2.1 to 2.9 include basemaps downloaded for Saskatchewan and Alberta from Geogratis (2004) (1:1,000,000); rivers from ESRI; and SSRB sub-basins and watersheds obtained from the Prairie Farm Rehabilitation Administration (2004). Mean annual air temperature, total annual precipitation, maximum elevation, annual potential evapotranspiration, ecozones, and ecoregions were obtained from the ECOATLAS series available from Geogratis (2004) (1:2,000,000). ArcView 3.2 was used to compile and process the maps.

What will follow now is a brief description of the ecozones and the ecoregions found within each ecozone in the SSRB area. Unless otherwise stated, for sections 2.1 to 2.1.4 and sections 2.2 and 2.2.1 properties such as soils, geology, climate, and ecology will be discussed by summarizing information from Acton et al. (1998).

2.1 The Prairie ecozone

The Prairie Ecozone is located in the southern part of Saskatchewan and Alberta and is characterized by the presence of grassland. In Saskatchewan alone the prairies take up approximately 24 million hectares of land. As one would expect on the prairies, it is dominated by flat land, or gently rolling hills. From a geological perspective, the prairies are littered with glacial deposits remaining from the last glacial retreat about 10,000 years ago. The composition of this glacial deposit it influenced strongly by the underlying topography or bedrock. The soils that form in this ecoregion are Chernozemic soils and reflect the vegetation that it supports- grasslands. Grasslands prevail and include species such as wheatgrass, June grass, and blue grama.

The climate of the prairies ranges from semiarid to humid continental. It is typified by long cold winters and short warm summers with very little precipitation. The average winter temperature ranges from anywhere between -12.5ºC and -8ºC and average summer temperatures are between 14ºC and 16ºC (Saskatchewan Environment and Resource Management, 1997). As for precipitation, this ecozone receives annual amounts ranging from as little as 250 millimetres in the arid grass lands in the southern part of the ecozone upwards to 500 millimetres in the northern Aspen Parkland ecoregion. Water deficit has been a reoccurring characteristic of this ecozone (Saskatchewan Environment and Resource Management, 1997). The wildlife is diverse and includes bison, antelope, elk, wolves, mice and voles. Bison used to be the dominant species on the prairies. Human activity has caused many species to be on the edge of extinction in this ecozone. 80% of Saskatchewan’s economic activity is produced in this ecozone with agriculture being the dominant land use. Other activities in this ecozone include mining, oil and gas production.

There are five ecoregions located in the prairies: Aspen Parkland (to the north), Moist Mixed Grassland (in the central part of the prairies), Mixed Grassland (in the southern part), the Cypress Upland (south), and the Fescue Grassland (western part of the prairies in Alberta). Each of these ecoregions has different properties that will be discussed.

2.1.1 The Aspen Parkland ecoregion

This ecoregion serves as a transition between the grasslands on the south to the forests of the north. In the SSRB area, aspen parkland can be found in northeast Saskatchewan and western Alberta. Various rivers and valleys run through this broad plain. The elevation increases to north and east, as a mirror of the underlying bedrock, ranging from 425m to 700m above average sea level. The geology of the aspen parkland is marine sedimentary rock which consists primarily of gray-green silty clay and shale. In some places of the SSRB, there is the presence of local bentonite. Deposits of potash, other salts and petroleum can be found in the subsurface of the SSRB.

The climate of this ecoregion is humid continental, with mean annual daily temperature of 1.8ºC and annual precipitation ranging from 262 mm to 420 mm. The soils of this ecoregion are primarily Black Chernozemic soils, which have a thick A-horizon and are dark in color due to the accumulation of organic matter, and develop in areas that have well to imperfectly drained soils (Soil Classification Working Group, 1998). Other soil types that are found include the Dark Brown soils (found on south facing slopes), Dark Gray Chernozemic, Dark Gray, and Gray Luvisolic soils (which occur on north facing slopes and at elevations). Soils of the Luvisolic order have a lighter color and also develop in areas that have well to imperfectly drained soils, but have illuvial B-horizon where silicate clay has accumulated (Soil Classification Working Group, 1998).

The vegetation of the Aspen Parkland ecoregion alternates between woodlands in the lower areas and grasslands on the upper slopes. Aspen groves are found in areas with more moisture and grasslands are found in drier areas, usually on hill tops and south facing slopes. Human settlement has suppressed fires and caused trembling aspen to move into the grasslands. In the woodland areas, the main stands consist of trembling aspen with an understory of shrubs, herbs and grasses.

Wildlife in this ecoregion is diverse due to the presence of grassland, woodland and various wetlands. White tailed deer is the dominant species of this ecoregion. This ecoregion includes 55 mammal species, 320 bird species (i.e. savannah sparrow, horned lark, clay-coloured sparrow, American crow), 47 fish species (i.e. walleye, northern pike, yellow perch) and 11 reptile species (i.e. painted turtle, snapping turtle, various snakes, tiger salamander).

Human settlement has changed this ecoregion. Today, approximately 20% of Saskatchewan's population inhabit this ecoregions in communities like North Battleford, Yorkton and Melville. Agriculture prevails in this ecoregion since here are some of the most productive lands. Crops include spring wheat, cereals, and oilseeds (Saskatchewan Environment and Resource Management, 1997). Dams and water reservoirs have been built on this and also in the other ecoregions within the Prairie ecozone.

2.1.2 The Moist Mixed Grassland Ecoregion

This ecoregion is a broad band that extends right across Saskatchewan into Alberta. It makes up for 11% of Saskatchewan's land with approximately 6,789,000 ha claimed (Fung, 1999). In the SSRB, moist mixed grassland can be found in the eastern part of Saskatchewan and central Alberta. It is the northern most extension of the open grasslands. The slope of this area is downward to the north and east once again mirroring the bedrock surface. There are many valleys in this ecoregion. From a geological perspective, this area has bedrock of marine sedimentary rocks from the Bearpaw formation which consist mainly of gray-green silty mudstones and shale. The subsurface composition is important for the Saskatchewan economy since it consist of salts, oil fields and gas fields.

The climate of the moist mixed grassland is slightly different than that of the aspen parkland to the north and the mixed grasslands to the south. It has a subhumid continental climate. The mean daily temperature is 2.4ºC with a mean annual precipitation amount of 383mm. It is cooler and wetter than the mixed grassland and warmer and drier that the aspen parkland.

The Moist Mixed Grasslands consist of mainly Dark Brown Chernozemic soils. Soils are thicker on the slopes bottom due to the increased amount of soil moisture and organic matter that is accumulated in lower slope positions. The types of vegetation that are found in the moist mixed grasslands are reflected by the soil types found here. Dark Brown Chernozems have woodland and a mixture of grasslands, although woodlands are few and most often confined to areas where there are sloughs (increasing thus to the north). The mid grasses are prevalent in this ecoregion. Species include wheatgrass, speargrass, June grass, and sedges. Shrubland is also found here with the most abundant species being pasture sage. Woodlands are most commonly composed by trembling aspen with an understory of shrubs, herbs and grasses.

The wildlife in the ecoregion is diverse, with 51 mammals species reportedly found in this ecoregion. Species of mammals that prevail are porcupine, white-tailed jack rabbit and meadow vole to name a few. This ecoregion is home to a few grassland biome sites of the international Biological Program that provides a large area of grassland for the study of fauna. 198 species of birds were counted in only 1500 Km^2, although only 10 species are considered permanent residents. Species living in this area include the burrowing owl, sharp-tailed grouse, and savannah sparrow. There are 41 species of fish found in this ecoregion including walleye, northern pike and yellow perch. As for the reptiles, there are five snake species, six frog/toad species, one turtle and one salamander (tiger salamander) species.

The human population in this ecoregion accounts for approximately 55% of Saskatchewan's population with major communities such as Saskatoon, Regina (capitol), Moose Jaw, and Weyburn. Amongst these, Saskatoon is the only community included within the SSRB area. The main economic activity is agriculture with at least if not more than 80% of this ecoregion being cultivated at some point in the past. Main crops are cereal crops. This area is also home to some of the heavy industry that the province holds. Industries such as potash, salts, oil, and gas to name a few with the majority of these industries located in the Weyburn-Estavan area.

2.1.3 The Mixed Grassland ecoregion

The mixed grassland ecoregion in the SSRB can be found in the southwest corner of Saskatchewan and south-western Alberta. The landscapes in this ecoregion are the most diverse in all of the Prairie Ecozone. The general slope of this ecoregion is downward to the north and east. Elevation difference in this ecoregion ranges from as low as 50m to as high as 800m above average sea level. The geology of this ecoregion is similar to the moist mixed grassland ecoregion. It is mainly marine sedimentary rocks left from the bearpaw formation that consist of gray-green silty clays and shales.

The mixed grassland ecoregion has a semiarid climate that is conducive with having short warm summers and long cool winters. The average annual daily temperature is 4ºC with a mean annual precipitation amount of 352 mm. Most of this precipitation falls in between the months of May and September. Temperatures in this ecoregion tend to be warmer in areas with lower elevation and cooler in areas with higher elevation (mainly on the northern part of this ecoregion).

Soil types in this ecoregion are of the chernozemic order, more specifically, brown chernozemic soils. This ecoregion has relatively little addition of organic matter into the soils as compared to the soils to the north. The little organic matter that does enter the soil decomposes at a faster rate that that of the soils to the north. This is due to the relatively warmer temperatures. Soils are thinner on the upper slopes and thicker on the lower portion of the slopes.

The vegetation in this ecoregion is dominated by grasses. The dominant grass species are wheatgrass, speargrass and blue grama grasses. These grasses are associated with loamy soils. Shrublands appear in areas of sandy soils. Pasture sage is the most common shrub in this ecoregion.

The wildlife in this ecoregion is basically the same as it is in the moist mixed grassland ecoregion. The only difference would lie in the fish species diversity, which is lower in this ecoregion than in the moist mixed grasslands, but higher than in the cypress hills uplands ecoregion.

The human influence in this ecoregion evident because about 62% of the land being used for agricultural purposes. About half of this land is devoted to pasture land or rangeland with much of Saskatchewan's cattle production occurring here. The semiarid climate in this ecoregion greatly limits the crop choices. This ecoregion is where the majority of Saskatchewan's irrigation occurs.

2.1.4 The Cypress Upland ecoregion

In contrast to its surrounding land, the cypress upland raises abruptly 400 to 500m above the surrounding plains (Fung, 1999). In the SSRB, it occupies a small area (see figure 2.9). The cypress uplands are a plateau that was formed 50 million years ago (Fung, 1999). They have steep slopes and numerous valleys and coulees. The abrupt change in elevation is reflected in the soils and vegetation found throughout this ecoregion. Unlike other ecoregions in the Prairies, this ecoregion has only been slightly affected by agriculture. The general direction of drainage in this ecoregion is southward as part of the Missouri River basin and to the east as part of the Saskatchewan basin.

The climate of the cypress uplands is a subhumid to humid continental one. This means that it is cooler and moister than the surrounding plains. Summers here are short and warm, with a mean July temperature of 16ºC. The mean annual precipitation is 450 mm (244 mm falling as rain in between May and September).

Soils in this ecoregion vary according to slope positions. South facing slopes tend to be dominated by Dark Brown soils under grasslands, while north facing slopes tend to be dominated by Dark Gray and Gray Luvisolic soils under white spruce and aspen forests. Black and Dark Gray soils are found on the plateau area. The soils in this ecoregion support the Lodgepole pine community, which is unique in Saskatchewan and quite similar to that in the foothills along the

Rocky Mountains. Aspen Woodlands occur below the lodgepole pine woodland on the north side of the plateau. There is also fescue prairie grassland found on top of the western plateau and a mixedgrass prairie on the eastern part of the plateau. Wetlands are found in this ecoregion. Along the river valleys, distinctive flora such as willow and white birch prosper can be found.

The wildlife in this ecoregion is as diverse as the flora. There is a large variety of mammals inhabiting this region. The Pronghorn are the dominate ungulate. Mule, white tailed deer, moose and elk are all found in this ecoregion. In the woodlands areas, porcupines and chipmunks are common. Red squirrels are found on pine and spruce woodlands. Wetland areas are favourable to cottontail and snowshoe hare. As much as 246 bird species have been recorded in this area at some time. Some birds are permanent habitants of this area, but most are spring dwellers, summer dwellers, use this area for breeding ground, or simply fly through. Fish species are unique to Saskatchewan and depend on the river system in which they occur. Some species that are found include black bullhead, chestnut lamprey, mountain sucker, and brassy minnow.

The human influence in this ecoregion is not as great as it is on other ecoregions of the Prairies. The population is approximately 2,000 with the major community being Eastend. This ecoregion has potential to become a tourist town because of the recent archaeological find of a Tyrannosaurus Rex. Approximately 21% of this region has been cultivated but the physical conditions are much more suited for free range livestock grazing.

2.1.5 The Fescue Grassland ecoregion

This ecoregion can only be found in Alberta. With in the SSRB boundary, the fescue grassland ecoregion is found in central Alberta. This ecoregion covers about a 12.3 Km^2 in Alberta. The description that follows is summarized from Strong and Leggat (1992) unless otherwise stated. The information is not as extensive for this ecoregion as it was for other ecoregions.

The fescue grassland ecoregion is underlain by sandstone and shale with a surface of loamy glacial till and clayey lacustrine deposits. The soils that are found here are Black Chernozemic, Brown Chernozemic, and Gleysolic soils. The fescue grassland boundary is determined by the Black to Dark Brown Chernozem soil boundary and the eastern extent of aspen.

This ecoregion does not have the typical grassland climate discussed in the previous ecoregions, because of its proximity to the Rocky Mountains and the increased elevation. This region has relatively cool summers and warmer winters as compared to other regions, due to the fact that it lies in the Chinook belt of southwestern Alberta. The mean summer temperature is 14ºC and precipitation amounts can range from 400 to 450 mm annually. As a result, the type of vegetation that is dominant here is rough fescue followed closely by parry oat grass. The wildlife in the ecoregion is similar to those found in the mixed grass ecoregion. Common species are prairie falcon, marbled godwit, horned lark, coyote, and white-tailed deer. Endangered or threatened species in this region include the burrowing owl, piping plover, and Baird's sparrow.

2.2 The Boreal Plains ecozone

This ecozone is found in eastern Saskatchewan and western Alberta within the SSRB boundaries (see figure 2.8). The majority of this ecozone is covered by boreal forest (Saskatchewan Environment and Resource Management, 1995). This ecozone is influenced by continental climate conditions and as a result exhibits a subhumid to cold climate with cold winters and warm summers. The average annual precipitation is approximately 450 mm with mean July temperatures of about 16ºC and mean January temperatures being a cold -20ºC. The bedrock of this ecozone is a composition of sandstones, siltstones and shale. The glacial sediments are 100 to 250 m thick and are less sandy than those of the Boreal Shield ecozone to the north. On the surface, the boreal plains are flat to hummocky and are dominated by moraine deposits. There are a number of lakes in this ecozone that reflect the moraine deposits.

Soils that prevail in this ecozone are generally Luvisols (occurs in areas with loamy and clayey textured sediments), Brunisols (found in areas with sandy deposits), and Organic (confined to low lying areas). Vegetation in this ecozone is species rich, dominated by closed-crown mixedwood and coniferous forests. The main coniferous species are white and black spruce, jack pine and tamarack. In this region, there are 50 mammals (i.e. moose, bear, red squirrel), 300 birds (i.e. common loon, Canada goose, raven), 40 fish (northern pike, walleye, yellow perch), and 6 amphibian and reptile species, this ecozone is very species rich. There are approximately 151,000 humans living in this ecozone.

The main industries in this ecozone include forestry and agriculture. There are four ecoregions that occur in the Boreal Plains ecozone, of which only two occur within the SSRB boundaries. They are the boreal transition, mid-boreal uplands, mid boreal lowlands, and the western Alberta uplands. The boreal transition ecoregion and the western Alberta uplands are the only two that occur in the SSRB boundary and will now be discussed.

2.2.1 The Boreal Transition ecoregion

As the name implies, this region serves as a transition between the forest lands of the north and the grasslands of the south. It takes up approximately 5.3 million hectares of the provinces land. It does extend into both Alberta and Manitoba. The SSRB touches this ecoregion only slightly in eastern Saskatchewan and western Alberta.

The underlying bedrock in this ecoregion is of silt and clay left from the Cretaceous age. There is a gentle slope in this region. Hummocky moraines are common in this region especially in areas of higher elevations and areas that have glaciolacustrine, glaciaofluvial, and glacial till deposits.

The boreal transition ecoregion is warmer and drier than the mid-boreal lowland and mid-boreal upland but cooler than the aspen parkland. It has a more humid continental climate with mean annual precipitation of 452 mm, a mean July temperature of 17.4ºC and a mean January temperature of -20ºC. The mean annual daily temperature is 0.4ºC.

The soils of this region are diverse since this ecoregion serves as a transition between grasslands and forests and also between two ecoregions. In the area that borders the aspen parkland, Black and Dark Gray Chernozemic soils are found, where was once dominated grasslands. Gray Luvisolic soils occur where forests have prevailed. Some Gleysolic soils can be found in this area, especially in areas with imperfectly drained to poorly drained soils. The soils in this ecoregion tend to be some of the most fertile soils in the province.

The vegetation found in this ecoregion is just as diverse as the soil but, generally speaking, this ecoregion is dominated by a deciduous boreal forest and has a mix of forestland and farmland. There are seven major vegetation classes in this ecoregion: agriculture land, aspen forest (found in areas with rapidly or well drained slopes and escarpments and contain mainly trembling aspen but does include balsam poplar and white spruce), mixedwood forest (found in areas with well-drained soils and has white spruce mixed in with trembling aspen and balsam poplar), jack pine forest (which characterize fire prone, nutrient deficient sandy soils), grasslands, peatlands, and boreal wetlands.

This ecoregion is very high in species richness. There are many species of mammals (e.g. white tailed deer, moose, and elk), birds (e.g. boreal chickadee and gray jay), fishes (e.g. northern pike, walleye, and fathead minnow), and amphibians and reptiles (e.g. red-sided garter snake, Canadian toad, and tiger salamander).

There are a few major communities in this ecoregion and they account for approximately 12% of Saskatchewan population. They are Prince Albert, Meadow Lake, Nipawin and Melfort. The approximate number of people who live in this ecoregion is 124,000. The major land uses in this region are forestry, agriculture, hunting and fishing, and recreation. It is estimated that about 50% of this ecoregion is farmland that produces cereal crops, oilseeds and hay.

2.2.2 The Western Alberta Uplands ecoregion

This ecoregion is found in Alberta south of the boreal transition ecoregion and west of the Aspen Parkland ecoregion. EcoAtlas of Canada refers to this ecoregion as the Western Albert Upland but Strong and Leggat (1992) (i.e. authors of the Ecoregions of Alberta) call this ecoregion the Lower Boreal-Cordilleran Ecoregion. Information from Strong and Leggat (1992) was used to summarise the characteristics of this ecoregion unless otherwise stated.

The climate in this ecoregion is a continental one with a large temperature range between summer and winter. The total annual precipitation is approximately 464 mm. There can be as little as 258 mm or as much as 756 mm. The average temperature in this ecoregion is 15.1ºC for the summer and -7.8ºC for the winter. Winter extremes can occur with temperatures falling to -37ºC to -39ºC. In the summer, temperatures rarely exceed 22ºC.

The types of vegetation and wildlife that are found in this ecoregion are greatly affected by their site location. Deciduous components are more frequent at lower elevations. Lodgepole pine can be found in well drained areas such as on south facing slopes. Well drained sites generally have Brunisolic soils, and imperfectly drained sites normally have Gleyed Luvisols and Gleysols. Well drained sites support lodgepole pine with black and white spruce; while poorly drained depressions support most commonly black spruce.

This ecoregion is important for wintering animals. Common ungulates that exist in the winter time are the elk and mule deer just to name a few. This ecoregion is not as high in species diversity as other ecoregions are, due to the lesser amount of wetlands. Some other species that are found in this ecoregion are ruffed grouse, common snipe, and moose.

2.3 The Montane Cordillera ecozone

This ecozone is found only in Alberta. This ecoregion comprises 473,000 Km^2 and stretches from north British Columbia to the south western corner of Alberta. With in the SSRB boundary, the Montane Cordillera ecozone is found in western Alberta. There are two ecoregions that are found in this ecozone: the eastern continental ranges and the northern continental divide ecoregions. This ecozone is rugged and mountainous. The geology of this ecozone is very complicated but consists mainly of folded and faulted sedimentary bedrock. Annual precipitation in this ecozone ranges from 1,200 to 2,000 mm at higher elevations, while some lower areas in this ecozone may receive less than 500 mm. The temperature varies with changes in altitude. The vegetation reflects such changes. At high elevations, white spruce dominates. Douglas fir and Lodgepole Pine occur at mid elevations (~400–1500m). The lower elevations are dominated by Ponderosa Pine. Natural grasslands do not do well in this area, perhaps because of the fire suppression, introduced species, and cattle grazing. Wetlands are few in this ecozone and are in general restricted to non-forest bogs, marshes and skunk cabbage swamps. Wildlife is just as diverse as the vegetation cover. In the middle to upper elevations, one can find mountain goats, moose, caribou and mule deer as the common ungulate species. Grizzly Bear and Black Bear are the most common mammals.

2.3.1 The Eastern Continental Ranges ecoregion

This ecoregion is found with in the northwest corner of the SSRB. It includes Banff and Jasper National Parks and the Willmore Wilderness Provincial Park. The human population in this ecoregion is approximately 10,100, and are found in the major communities of Banff, Jasper, and Lake Louise. This ecoregion is primarily used for recreation and tourism within the provincial and national park boundaries. Outside these boundaries, the main land use is hunting and forestry.

The mean annual temperature is 2.5ºC with a mean summer temperature of 12ºC and a mean winter temperature of -7.5ºC. The mean annual precipitation ranges from 600 mm to 800 mm and increase with elevation. As a result, this ecoregion has relatively warm, dry summers and mild snowy winters. The ecosystems that prevail in this region are primarily subalpine and alpine. This is evident in the presence of mixed forests of lodgepole pine, Engelmann spruce, and alpine fir. Since this ecoregion is located on areas of steep slopes with colluvial, morainal, and fluvioglacial deposits, soils of the Regosolic order (soils that are weakly developed and a rapidly to imperfectly drained) (Soil Classification Working Group, 1998) and Eutric Brunisolic (soils that have a high degree of base saturation and lack a well developed mineral-organic surface horizon) (Soil Classification Working Group, 1998) prevail. In areas of alpine and subalpine environments, Dystric Brunisolic soils (acidic soils that lack a well-developed mineral-organic surface horizon) (Soil Classification Working Group, 1998) can be found. Because this ecoregion is found on a mountain, there are patches of permafrost that can be found at higher elevations. A number of wildlife species can be found in this ecoregion and include elk, sheep, deer, caribou, and grizzly and black bear.

2.3.2 The Northern Continental Divide ecoregion

This ecoregion can be found along the Alberta British Columbia border. In the SSRB boundary, it is found in the southwest. Small portions of the Banff and Waterton Lakes national parks fall within this ecoregion. Population in this ecoregion is approximately 35,200. The majority of this ecoregion can be found at elevations ranging from 1200 to 2000m above sea level and, as a result, the winters are affected by Chinooks. In general, the mean annual temperature is 3.5ºC with a mean summer temperature of 12.5ºC and mean winter temperature of -6.5ºC. Annual precipitation in this ecoregion can vary from anywhere between 600 mm and 700 mm per year. The vegetation is stratified according to the elevation. In areas that have been affected by forest fires, closed canopied forests of lodgepole pine are common. At high elevations, Engelmann spruce and alpine fir make up the old growth forest. The wildlife species found in this area include the lynx, bobcat, cougar, elk, and bears. Soils that are found in this ecoregion are Humo-Ferric Podzols and Dystric Brunisols.

3 NATURAL HAZARDS

3.1 Drought

Droughts affecting the prairies are the most expensive natural disasters in Canadian history (e.g. CAN$ 2.5 billion in 1989) (Mayer and Avis, 1998). The prairies are particularly susceptible to increased droughts (Herrington *et al*., 1997) and decreased streamflow (Zhang et al., 1999) due to climatic changes. In the heart of the Canadian Great Plains (including parts of Alberta and Saskatchewan) and within the Palliser Triangle, the 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).

3.1.1 Definition and causing factors

Defining drought is an evolving challenge. Droughts have received over 150 definitions over time and, in most cases, thresholds for declaring drought are arbitrary (Wilhite, 2000).

Every component of the biosphere (e.g. agriculture, wildlife, native vegetation, etc) has a different sensitivity to water shortage (Ripley, 1999). Thus, each component of the biosphere may receive a specific drought definition that addresses its particular operational limits (Ripley, 1999), i.e. specific thresholds of drought intensity (degree of precipitation shortfall and/or severity of impacts associated), duration (usually from a minimum of three months for a drought to become established to years with extended adverse effects), and spatial coverage (which greatly affects response capability) (Wilhite, 2003).

Different disciplines perceive droughts in different magnitude and severity as to reflect their operational capacity. While most *meteorological drought* definitions relate actual precipitation departure to average amounts on monthly, seasonal, water year, or annual time scales; *agricultural drought* focus on precipitation shortages, differences between actual and potential evapotranspiration, and soil water deficits (for specific crop activities); *hydrological drought* focus on the effects of periods of precipitation shortfall on surface or subsurface water supply (i.e. streamflow, reservoir and lake levels, groundwater) rather than with precipitation shortfalls; and *socioeconomic drought* associates the supply and demand of some economic good or service (e.g. water, hydroelectric power) affected by precipitation shortages (Wilhite, 2003). The difficulty in attempting to define drought is reflected in the literature, whereas different authors have somewhat distinct drought definitions (e.g. Blumenstock, 1942; Yevjevich et al., 1978; Dey 1982; Dracup and Kendall, 1990; Ripley, 1999; Wilhite, 2003; Palmer, 1965), from simple instrumental measurements to drought indexes more recently. According to Wilhite (2003), drought definitions should be not only impact- or application-specific, but also region-specific.

Drought definitions can be further understood in terms of time (i.e. duration, cumulative effect); see figure 3.1. This conceptualization shows a strong symbiosis between drought and its impacts in human activities, whereas the incidence of drought could increase because of a change in the frequency of meteorological drought, a change in societal vulnerability to water shortages, or both (Wilhite, 2003).

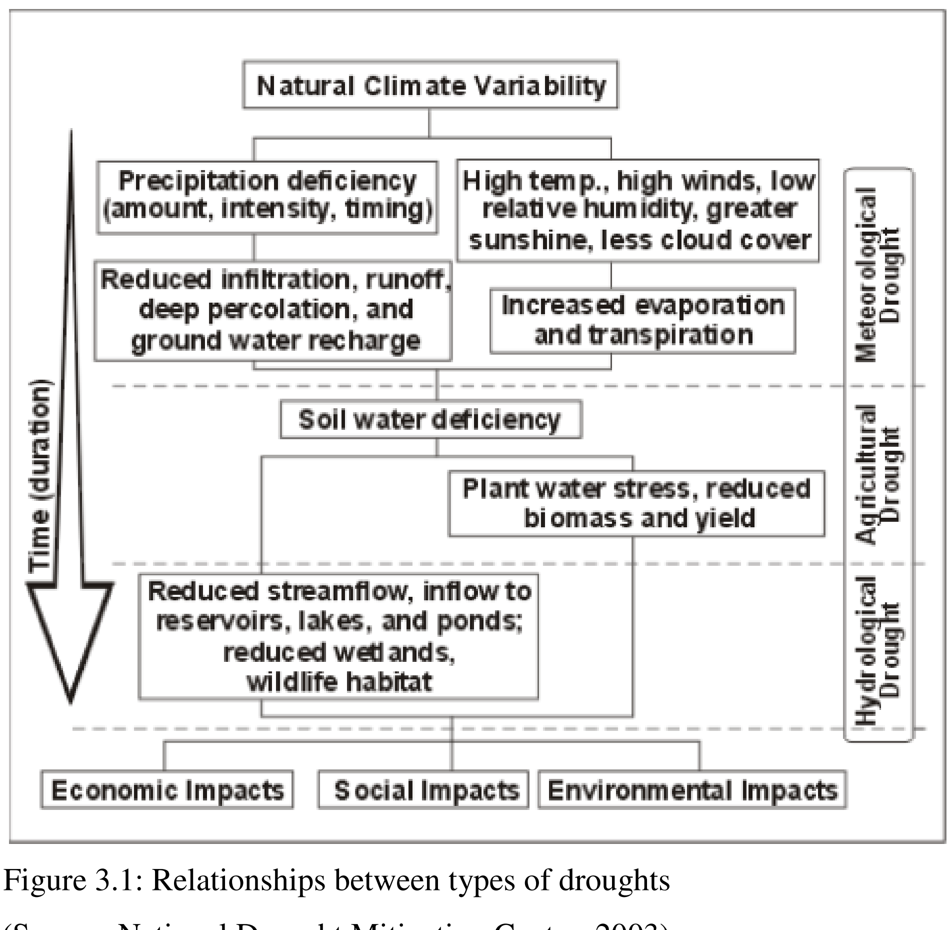

Figure 3.1: Relationships between types of droughts
(Source: National Drought Mitigation Center, 2003).

Wilhite (2000) further differentiated drought from aridity, defining the first as a temporary reoccurring feature of climate not limited to low precipitation areas, and the later as a permanent feature of climate limited to low rainfall areas (Wilhite, 2000).

Although each drought can have distinct characteristics, some broad definitions exist that summarize most approaches. The National Drought Mitigation Center (2004) defines drought as "a deficiency of precipitation over an extended period of time resulting in a water shortage for some activity, group, or environmental sector". Environment Canada (2004) further defined drought as a result of disruptions to an expected precipitation pattern and can be intensified by anomalously high temperatures that increase evaporation.

Causing factors of drought have been extensively debated, although yet little understood (e.g. National Drought Mitigation Center, 2003; Nemanishen, 1998; Bonan, 2002; National Weather Service Climate Prediction Center, 2004; Hoerling and Kumar, 2003). The immediate cause of drought is the predominant sinking motion of air that results in compressional warming or high pressure which inhibits cloud formation and results in lower relative humidity and less precipitation (National Drought Mitigation Center, 2003). Most climatic regions in the world experience varying degrees of high pressure, often depending on the season (National Drought Mitigation Center, 2003). Prolonged droughts occurs when large scale anomalies in the atmospheric circulation patterns persist for months, seasons, or longer (National Drought Mitigation Center, 2003).

The solar radiation is identified as the main extra-terrestrial (drought) driver and *El Niño* is the heat sink which stores the solar energy and slowly releases it to reinforce the sun's energy in powering the climate system (Nemanishen, 1998). Some extra-terrestrial energy can also come from volcanoes (Nemanishen, 1998). The veil dust from volcanoes and also from atmospheric nuclear tests, however, can decrease the incoming solar radiation causing some places to be cooler and wetter and thus disguise what could otherwise be dry periods (e.g. the wet period from 1911 to 1915 in the Dry Belt has been attributed to a four decade long decrease in solar radiation- from about 1875 to 1915 and to 2 huge volcanic eruptions- Santa Maria- Guatemala in 1902 and Mount Katmai's Novarupta- Alaska in June, 1912; the cool period of 1953-1954 has been associated with the dust veil created by atmospheric nuclear tests- hydrogen bomb tests, from 1952 to 1954) (Nemanishen, 1998).

The primary terrestrial (drought) driving forces in North America are the *El Niño* and the *Southern Oscillation*, which when acting in tandem, are denoted *ENSO* (Nemanishen, 1998; Laird and Cumming, 1998; Bonan, 2002; National Drought Mitigation Center, 2003). The *El Niño* is the oceanic property of *ENSO* and refers to abnormally warm sea surface temperatures (SST's), and the *Southern Oscillation* is the atmospheric component of *ENSO* and refers to changes to the Walker Circulation as a consequence to abnormally warm SST's (i.e. Walker Circulation comprehends to the low level easterly winds and upper level westerly winds across the Pacific) (National Drought Mitigation Center, 2003; Bonan, 2002).

ENSO can cause abnormally warm conditions especially in winter for Canada, most likely indirectly (i.e. in teleconnection), through anomalies to the Pacific-North American (PNA, a high pressure ridge over northwestern North America and a low pressure in the Southern US) and shifts to jet streams (i.e. jet streams are south to north temperature gradient creating high altitude differences, with the wind normally flowing north, with its trough allowing cold air to move south and its ridge allowing warm air to flow north) (National Drought Mitigation Center, 2003; Bonan, 2002; National Weather Service Climate Prediction Center, 2004).

During a an *ENSO* (warm phase- El Niño), Canada can experience an abnormally high pressure system with temperatures above normal over most of its area, which acts as a barrier blocking the incoming moisture from the Pacific jet stream and the cold air from the polar jet stream (National Weather Service Climate Prediction Center, 2004; Bonan, 2002, Bonsal et al. 2004). Also during an *ENSO*, mid-latitude low pressure systems tend to be more vigorous than normal in the region of the eastern North Pacific, and this can cause abnormally warm air to be pumped in western Canada (National Weather Service Climate Prediction Center, 2004). The wavelike pattern to the jet stream over North America during an *ENSO* (most likely in its cold phase-La Niña) can be amplified, which can further favor warm dry weather conditions in the Canadian Prairies, especially in southern Alberta (i.e. south from the Alberta high pressure ridge) (Nemanishen, 1998; Bonan, 2002; Dey, 1982). These anomalies can persist for several months or seasons (National Weather Service Climate Prediction Center, 2004; Nemanishen, 1998).

Nemanishen (1998) suggested that, for the Palliser Triangle and the Canadian Great Plains, droughts are caused by the Pacific North American SST's and sustained by a positive 4-Pt PNA pattern, an *ENSO* derivate which show amplified wavelike pattern to the jet stream over North America. A positive 4-Pt PNA pattern dominant features comprise to the extensive low pressure in the Gulf of Alaska (i.e. the Aleutian Gyre), the Alberta high pressure ridge, and the low pressure system over the US southeast (Nemanishen, 1998). Bonsal and Lawford (1999) suggest that more extended dry spells in the summer in the Canadian Prairies tend to occur during the second summer following the mature stage of El Niño.

Although most relationships between the Canadian temperature and precipitation to large scale circulation patters (e.g. ENSO, Pacific Decadal Oscillation- PDO, North Atlantic Oscillation-NAO, etc) are found stronger in winter (National Drought Mitigation Center, 2003; Nemanishen, 1998; Bonan, 2002; Environment Canada, 2004), droughts can start and persist through both warm and cold seasons. Drought can be perpetuated in the cold season when the lack of precipitation results in lower than normal spring runoff (and thus in reduced streamflow and reservoir and soil moisture replenishment) with a subsequent warm and dry spring which can lead to a warm and dry summer; and a warm and dry summer, in turn, which can favor a subsequent warm and dry summer in what appears to be a feedback process where drought (or low soil moisture) contributes to drought persistence (Environment Canada, 2004; Bonan, 2002; Nemanishen, 1998; Bonsal et al., 2004).

Other feedbacks that can further contribute to extended droughts include the regional topography (e.g. topography relief causing loss of moisture from air masses such as the Rocky Mountains) and the land surface covers (e.g. land cover promoting higher absorption of solar radiation can further increase temperature and evapotranspiration, contributing to drought perpetuation) (Bonan, 2002). According to Laird and Cumming (1998), persistent anomalies in the atmospheric circulation and the feedback process produce droughts in western North America and in the Great Plains that tend to persist longer than in any other regions.

Understanding drought thus is clearly an evolving process further limited by an overall lack of long term climate data, which in turn limits the understanding of its drivers and their distinct cycles and patterns. Nevertheless, current drought monitoring efforts in Canada (i.e. real time reports of lakes and reservoir lakes, streamflows, snowpack accumulations, water supply volume forecasts, dougout water levels, and precipitation anomalies- Environment Canada, 2004) might provide answers to fill some of the current knowledge gaps in this science.

3.1.2 Past droughts- will the future mirror the past?

The western Canadian Interior is a water short region, with moisture from summer precipitation normally lost through evaporation, whereas contributions from rainfall to streamflow or groundwater recharge are unusual. When fall precipitation does not come and winter snowfall is lacking the prairies are in a very precarious position with water resources (Lang and Jones, N.D.).

Historically, the first drought records for the Great Plains and especially for the "dry belt" and the Palliser Triangle areas are visual descriptions from the first expeditions to these areas (Jones, 1987). The first long term climatological station was not established until 1883 at Winnipeg (Nemanishen, 1998). And routine weather observations have only been collected in western Canada for scarcely a century (Ripley, 1986). Within the instrumental records period, for the Palliser Triangle, three major prolonged agricultural droughts (i.e. based on wheat production), which have caused great losses to the agricultural industry, were recorded: the 1920's drought (1917-1926); the 1930's drought (1929-1937); and the 1980's drought (1983-1988) (Nemanishen, 1998). More recently, the 2001-2002 drought is considered similar or worse than the 1988 drought (Elaine Wheaton- Saskatchewan Research Council, personal communication). Little can be learned about long-term patterns and causing factors of drought within such a short time window; limiting the ability to predict and prepare.

To extend the instrumental records of climate to the past, paleoclimate proxy records are used. Normally, the paleoclimate proxies show a relationship to the instrumental records that is assumed constant to the past, and thus can be used to infer about past climate (Alley et al., 2002); i.e. proxies are first calibrated to the instrumental records period and then this relationship is used to infer about past droughts before instrumental records. Existing paleoclimate evidences, proxy recorder, and property measured are listed in table 3.1.

Table 3.1: Paleoclimate recorder (evidences), proxy recorder, and property measured (adapted from Alley et al., 2002).		
Ice	Atmospheric composition	Trapped bubbles
	Windiness	Dust grain sizes
	Source strength of wind-blown materials	Abundance of pollen, dust, sea salt
	Temperature	Ice isotopic ratios; borehole temperatures; gas isotopes; melt layers
	Snow accumulation rate	Thickness of annual layers; in-situ radiocarbon
Ocean sediments and corals	Temperature	Species assemblages; shell geochemistry; Alkenone thermometry
	Salinity	Shell isotopes after correction for temperature and ice volume
	Ice volume	Isotopic composition of pore waters; shell isotopes after correction for temperature and salinity
	pH	Boron isotopes in shells
	Ocean circulation	Cd/Ca in shells; carbon isotopic data
	Corrosiveness/chemistry of ambient waters	Shell dissolution
Lake and bog sediments	Temperature	Species assemblages; shell geochemistry
	Atmospheric temperature and soil moisture	Washed- or blown-in materials including pollen and spores; macrofossils such as leaves, needles, beetles, midge flies, etc
	Water balance (precipitation minus evaporation)	Species assemblage; shell geochemistry
Tree rings	Temperature and/or moisture availability	Ring width or density of trees stressed by cold or drought
	Variations in isotopic ratio of water related to temperature	Cellulose isotopic ratio
Speleothems/cave formations	Moisture availability	Growth rate formations
	Isotopic ratios of water related to temperature or precipitation rate	Oxygen isotopic composition
	Overlaying vegetation	Carbon-isotopic composition
Terrestrial sediment types/ nature of erosion	Temperature	Glaciers; permafrost
	Snowfall/rainfall	Lakes; sand dunes; glaciers; loess
	Windiness	Loess; sand dunes
	Soil formation rate/moisture availability	Soil profile; loess
Boreholes	Temperature	Direct measurements
Old groundwater	Temperature	Isotopic and noble gas composition of water
Desert varnish	Moisture availability	Growth rate; chemistry

A list of recorded and reconstructed droughts for the Canadian Prairies can be visualized in table 3.2.

Table 3.2: Past droughts in the Canadian Prairies.			
Year(s)	Record type	Observation	Source
1999-2002	Muti-year drought[a]; low precipitation records[b]	Severe drought with vast spatial extent in the 2001-2002 period including most southern Canada[a]; 1999-2001 drought period (low precipitation) in Medicine Hat[b]	Bonsal et al. (2004)[a] Sauchyn et al.(2003)[b]
1980s	Wheat drought[a]; Muti-year drought[b]; Water Balance Estimated Wheat Yields (WBEWY) and Palmer Drought Index (PDI)[c]	Severe drought in the Palliser triangle (1983-1988)[a]; Muti-year drought (1980s) in southern regions of Alberta, Manitoba, and Saskatchewan[b]; extensive hydrological drought in the Prairies recorded for 1980-1981, 1984, 1988-1989[c]	Nemanishen (1988)[a] Bonsal et al. (2004)[b] Jones (1991)[c]
1977-1980	Wheat drought[a]; spring snowmelt runoff[b]; WBEWY and PDI[c]	Severe drought in the Palliser Triangle (1977-1980)[a]; steady decline in spring snowmeld runoff time since ~1977 in west-central Canada[b]; extensive hydrological drought recorded in the Prairies for 1977-1978[c]	Nemanishen (1988)[a] Burn (1994)[b] Jones (1991)[c]
Late 1940s-early 1970s	Precipitation decrease[a]; WBEWY and PDI[b]; tree rings[c,d]	Decrease in precipitation from the first half to the second from the 1945-1970 period for Alberta, Saskatchewan and Manitoba[a]; most extensive agricultural drought in area in 1961, agricultural drought period extensive in area from 1967 to 1968, and extensive hydrological drought recorded in 1961-1962 and 1964 in the Prairies)[b]; prolonged drought interval in the southern Canadian Cordillera, Alberta (1968-1979)[c]; major period of low flow of the South Saskatchewan River centered in the mid 19th Century[d]	Thomas (1975)[a] Jones (1991)[b] Watson and Luckman (2003)[c] Case and MacDonald (2003)[d]
1920s- early 1940s	Wheat drought[a]; tree rings[b,g] Muti-year drought[c]; salinity, inflow[d]; climatological data[e]; WBEWY and PDI[f]; low precipitation[h]	Severe drought in the Palliser Triangle (1929-1937)[a]; prolonged drought interval in the southern Canadian Cordillera, Alberta (1917-1941)[b]; multi-year drought (1930s) in southern regions of Alberta, Manitoba, and Saskatchewan[c]; Palliser Triangle drought (1920s and 1930s) from steady decline in lake levels (Big Quill Lake, Saskatchewan)[d]; severe drought in the Prairies with "no general recovery"[e]; agricultural drought extensive in area in the Prairies (1936-1938)[f]; severe drought in the southwestern Canadian Plains in 1937 (from July PDSI reconstruction in the Cypress Hills)[g]; drought period (low precipitation) in Medicine Hat (1918-1920)[h]	Nemanishen (1988)[a] Watson and Luckman (2003)[b] Bonsal et al. (2004)[c] Vance and Wolfe (1996)[d] Currie (1953)[e] Jones (1991)[f] Sauchyn and Skinner, (2001)[g] Sauchyn et al. (2003)[h]
1910s	Wheat drought[a]; low precipitation records[b]	Severe drought, in the Dry Belt south of the Red Deer River, average rainfall (Medicine Hat station) from the 6 years (April-June) <100 mm (1917-1926)[a]; 1918-1920 drought periods (low precipitation) in Medicine Hat[b]	Nemanishen (1988) [a] Sauchyn et al. (2003)[b]
1905-1909	Low precipitation records	1905-1907 and 1707-1709 drought periods (low precipitation) in Medicine Hat	Sauchyn et al. (2003)
1880s- 1890s	Low precipitation	Muti-year drought (1890s) in southern regions of Alberta, Manitoba, and Saskatchewan[a]; severe drought in the Prairies (late 1880s and	Bonsal et al. (2004)[a] Currie (1953)[b]

		early 1890s)[b]	
1850s-1860s	Visual observation[a]; tree rings[b]	Severe drought, from Capitain John Palliser exploration (1857-1859) and other expeditions[a]; clusters of drought in the southwestern Canadian Plains in the 1850s-1860s (from July PDSI reconstruction)[b]	Nemanishen (1988)[a] Sauchyn and Skinner (2001)[b]
1840s-1850s	Tree rings	Prolonged drought interval in the southern Canadian Cordillera, Alberta (1839-1859)	Watson and Luckman (2003)
1820s	Tree-rings	Clusters of drought in the southwestern Canadian Plains in the1820s (from July PDSI reconstruction)	Sauchyn and Skinner (2001)
1700s-1800	Tree-rings[a,b,c]	Major periods of low flow of the South Saskatchewan River centered in the first 2 decades of the 1700s[a]; clusters of drought in the southwestern Canadian Plains in the 1690s, 1720s, 1750s, 1760s, and 1790-1800s (from July PDSI reconstruction)[b]; prolonged drought interval in the southern Canadian Cordillera, Alberta (1717-1732)[c]	Case and MacDonald (2003)[a] Sauchyn and Skinner (2001)[b] Watson and Luckman (2003)[c]
1560s-1570s	Tree rings	Major period of low flow of the South Saskatchewan River centered in the 1560s and 1570s	Case and MacDonald (2003)
~210 BP (1790 AD)	Multiple proxy	Peak aridity interval in the Palliser Triangle and southern Canadian Prairies	Lemmen and Vance (1998)
~300-230 BP (~1700-1770 AD)	Tree rings[a]; multiple proxy (lake sediments)[b]	Most prolonged extreme drought (1670-1775 AD, i.e., ~350-230 BP) in the Red River Basin-Manitoba since AD 1409[a]; LIA[2] drought peak in centered at ~300 BP[b]	St. George and Nielsen (2002)[a] Yu et al. (2002)[b]
~600-900 BP	Multiple proxy (lake sediments)	Peak MCA[1] drought (~600-700 BP) and peak MCA[1] drought (~800-900 BP) in the north Great Plains (Rice Lake, Coldwater Lake, and Elk Lake)	Yu et al. (2002)
~800-1,100 BP (1200-900 AD)	Multiple proxy[a]; Lake sediments[b,c]	Arid conditions in the Palliser Triangle and southern Canadian Prairies (1200-900 AD-medieval warm period)[a]; high frequency of extreme droughts in the northern Great Plains (~800-1000 BP) (from Moon Lake, North Dakota)[b,c]	Lemmen and Vance (1998)[a] Laird et al. (1998)[b] Laird et al. (1996)[c]
~700-1500 BP (1300-500 AD)	Lake sediments[a,b,c]	High frequency of extreme droughts in the northern Great Plains (from Moon Lake, North Dakota) (1150-1300 BP)[a,b]; major shift from wet to dry in the northern prairies- ~1200-1300 BP in 2 sites from western Canada, ~1200-1500 BP in 3 Canadian sites, and ~700-1000 BP in US sites[c]	Laird et al. (1998)[a] Laird et al. (1996)[b] Laird et al. (2003)[c]
~1630-1800 BP (370-200 AD)	Lake sediments[a,b]; Multiple proxy (lake sediments)[c]	High frequency of extreme droughts in the northern Great Plains (from Moon Lake, North Dakota)[a,b]; Centered ~300 BP, a single broad LIA[2] drought in the north Great Plains (Rice Lake, Moon Lake, Coldwater Lake, and Elk Lake)[c]	Laird et al. (1998)[a] Laird et al. (1996)[b] Yu et al. (2002)[c]
Prior to 6000 BP	Lake sediment and pollen (lake water levels)	Very dry period of frequent and severe droughts in the Canadian Great Plains (from Chappice Lake, Alberta)	Vance et al. (1992)

1- Medieval Climatic Anomaly 2- Little Ice Age.

Despite differences in the methods and timeframe considered, the available climate reconstructions in the Northern Great Plains agree that the last 100 years of instrumental records have not experienced a full range of possible conditions and that the prior climate was more variable and persistent, with longer and more frequent droughts (Sauchyn and Beaudoin, 1998; Sauchyn and Skinner, 2001, Sauchyn et al., 2003; St.George and Nielsen, 2002; Case and MacDonald, 1995; Case and MacDonald, 2003). These climate reconstructions from tree rings extend the records to the past as far as ~500 years. Studies by Sauchyn et al. (2003) and Case and MacDonald (2003) further suggest from tree ring reconstructions that more severe droughts (i.e. longer or more persistent) have occurred preceding the last 3 or 4 centuries in the Canadian Prairies. Studies by Laird et al. (1996), Laird et al. (2003) and Vance et al. (1992) suggest, from lake sediments, a higher frequency of droughts prior to ~1,000 BP for the Southern Canadian Prairies. And Vance et al. (1992) suggest, also from lake sediments, that dry spells in the Canadian Great Plains were more frequent in the Mid-Holocene (~5,000 BP).

Thus, if the future mirrors the past, it is clear that worse droughts can be expected than what has been experienced before, and that the coping capacity based on past experience will be most likely not enough to avoid greater losses in increasingly challenging droughts.

4 SENSITIVE AREAS IN THE SOUTH SASKATCHEWAN RIVER BASIN

Current and future changes to climate in the Prairies can increase exposure to aridity (Sauchyn et al., 2002). Sauchyn et al. (2002) reported that approximately a 50% increase in the area of subhumid and semiarid climate by 2050. Increased aridity means greater risks to permanent soil degradation, which in turn means increasingly lower chances of success to agriculture. The people that rely on agriculture in areas more naturally exposed to aridity are in clear disadvantage. They are less likely to adapt to any change despite their best efforts. Instead, they are likely to be trapped between recovering costs, surviving, and increasingly lower chances to afford adaptation costs (e.g. wells, irrigation, new machinery for a crop switch, etc) or relocation.

Locating areas with high sensitivity to permanent degradation is an important tool for management decisions. In power of such information, communities and policy makers can make choices today to avoid future economic, health, and environmental losses. Locating sensitive areas in the Prairies has been an ongoing field of research at PARC (Prairie Adaptation Research Collaborative) (e.g. Kennedy, 2004; Sauchyn et al., 2002). Kennedy (2004) suggested 6 criteria to be used in identifying increased sensitivity to aridity and permanent degradation in Southern Saskatchewan:

1) Aridity index (i.e., P/PET) between 0.05 and 0.65 which are classified as susceptible to desertification from the United Nations Convention to Combat Desertification (1994). This includes the following aridity zones: hyper arid (P/PET<=0.05), arid (P/PET from 0.05 to 0.2); semi arid (P/PET from 0.2 to 0.5), and dry subhumid (P/PET from 0.5 to 0.65).

2) Wind speed. The greater the wind speed, the greater is the exposure to wind erosion.

3) Coarser soil textures such as sand and sandy-loam are more prone to degradation. Coarser texture soils have lower water holding capacity which decreases crop choices and increase the need for irrigation. Soil structure is easily lost in these soil textures, thus they require increased conservation practices to remain productive (e.g. no till, rotation choice, best crop selection-McRae et al., 2000).

4) Available water capacity less or equal to 150 mm per year. Lower available water is indicative of higher sensitivity through limited water for plant growth and thus reduced crop choices.

5) Slope gradient and slope aspect. Steep slopes increase exposure to soil erosion from water, while aspect can increase solar radiation and thus evapotranspiration and also increase the exposure to wind erosion.

6) Agricultural land-use. Agriculture activity can increase the exposure to environmental degradation which in turn can compromise the way of living of the people that rely on it.

The following maps were compiled:

1) Basemaps downloaded for Saskatchewan and Alberta from Geogratis (2004) (1:1,000,000). The rivers are a simplified layer from ESRI. The SSRB boundaries were downloaded from the Prairie Farm Rehabilitation Administration (2004) and included the sub-basins of Big Stick Lake, Bow River, Oldman River, Red Deer River, Seven Persons Creek, South Saskatchewan River, and Swift Current Creek (Richard Rickward, the Prairie Farm Rehabilitation Administration , personal communication) (1:50,000).

2) Aridity Index (P/PET) including PET calculated from the Penman Method, annual wind speed (in km/hr), and soil texture, were obtained from the ECOATLAS series available free of charge from Geogratis (2004) in 1:2,000,000 scale.

3) Agricultural land-use (for Alberta and Saskatchewan) from the vmap_zero_r4 series from Geogratis (2004) (1:1,000,000).

4) Available water capacity less or equal to 150 mm in the upper soil (upper 120 cm, in the dominant soil landscape) was obtained from the Soil Landscapes of Canada from the Canadian Soil Information System (2004) in 1:1,000,0000.

See figures 4.1 to 4.5 for the maps of aridity, wind speed, available water capacity, soil texture, and agricultural land-use.

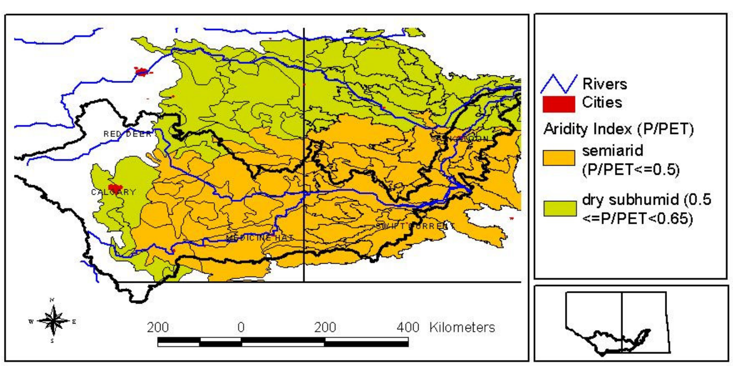

Figure 4.1: Sensitive aridity classes in the South Saskatchewan River Basin

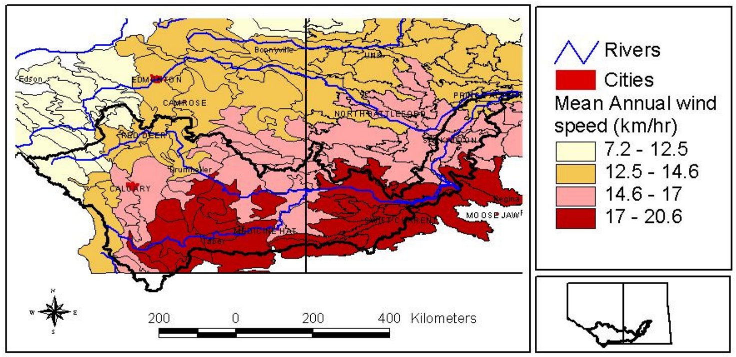

Figure 4.2: South Saskatchewan River Basin annual wind speed

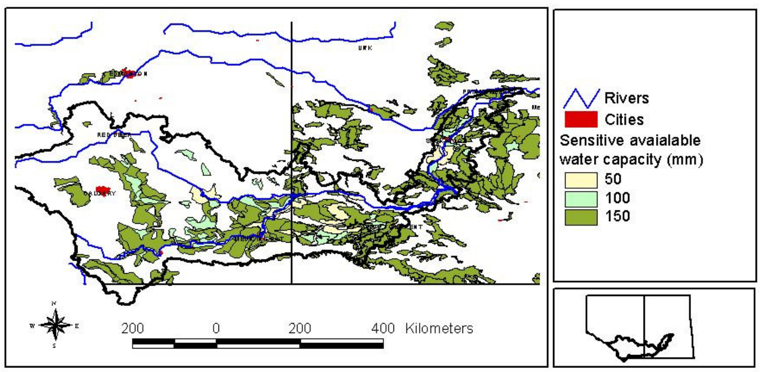

Figure 4.3: Sensitive available water capacity in the South Saskatchewan River Basin

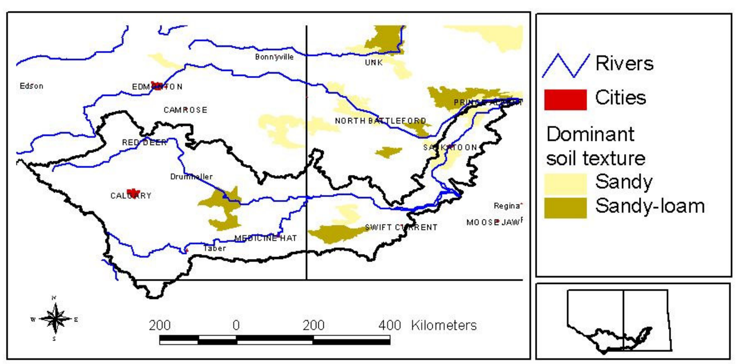

Figure 4.4: South Saskatchewan River Basin sensitive soil textures

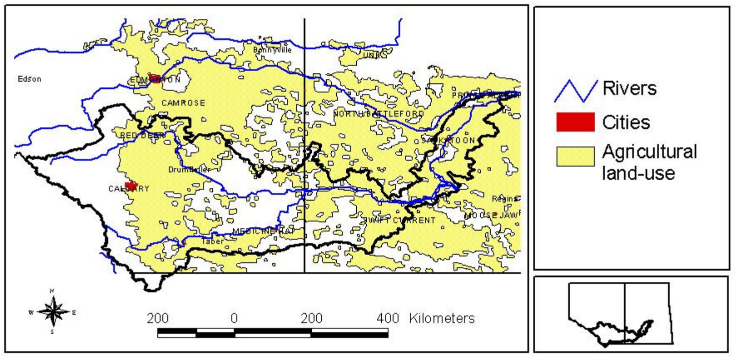

Figure 4.5: Agricultural land-use in the South Saskatchewan River Basin

Three areas were identified as having higher exposure to erosion, aridity: northwest from Medicine Hat (i.e. district number 812), west Swift Current (district number 819 and 827), and south from Saskatoon (district number 776). The selected areas scored highest in sensitivity, which means they included simultaneously semiarid or dry subhumid aridity classes, sandy or sandy-loam soil textures, lowest water available capacity, and highest wind speeds (i.e. upper 2 classes). In the climate change context, these are the areas that are most vulnerable despite the best management efforts. See figure 4.6, which has the 3 sensitive areas represented in red circles. Due to graphic limitations, a complete query could not be represented in a single map. Thus, the selected sensitive areas are shown with sensitive soils and sub-basins only. District numbers were obtained from the ECOATLAS series at Geogratis.

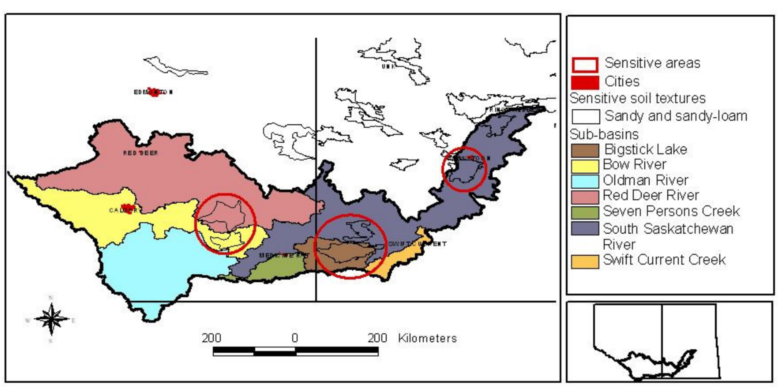

Figure 4.6: Sensitive areas in the South Saskatchewan River Basin to climate change and aridity (district numbers 776, 812, 819, and 827), with sensitive soils and sub-basins represented.

5 CONCLUSIONS

The South Saskatchewan River Basin (SSRB) boundaries have been defined according to PFRA (Richard J. Rickwood, personal communication) in terms of its 7 sub-basins boundaries. The sub-basins included in the SSRB are the following:

1) Big Stick Lake,
2) Bow River,
3) Oldman River,
4) Red Deer River,
5) Seven Persons Creek,
6) South Saskatchewan River,
7) Swift Current Creek.

The SSRB has been shown to be composed by 4 major watersheds, namely:

1) Bow,
2) Red Deer,
3) Upper South Saskatchewan,
4) Lower South Saskatchewan.

General trends in the landscape and climate of the SSRB were identified through map compilation and ecological frameworks:

1) Temperature tends to increase southwards with mean annual temperature ranging from ~ 2°C to 6°C;
2) Precipitation tends to increase to west and to north with total annual precipitation ranging from ~282mm to 80mm;
3) Elevation tends to increase to west with maximum elevation ranging from ~333m to more than 3,000m in the Rocky mountains;
4) Potential evapotranspiration tends to increase to southeast with annual values ranging from ~450mm to more than 800mm.

Ecological frameworks were further used to carefully describe the SSRB biogeography, which included various aspects of the landscape such as its geology, geography, vegetation, wildlife, soils, climate, as well as the reshaping of it by the human influence to the reshaping of the landscape. Because much of this area has been almost completely reshaped by human influence, ecological frameworks are very valuable tools (and sometimes the only resource) to describe the natural landscape. The ecological frameworks used included ecozones and ecoregions. The following ecozones are included within the SSRB boundaries:

1) Prairies (covering ~90% of the SSRB area),
2) Boreal Plains (covering ~5% of the SSRB area),
3) Montane Cordillera (covering ~5% of the SSRB area).

Each ecozone, in turn, was shown to include the following ecoregions:

1) Five ecoregions within the Prairie ecozone: the Aspen Parkland, the Moist Mixed Grassland, the Mixed Grassland, the Cypress Upland, and the Fescue Grassland ecoregions;
2) Two ecoregions within Boreal Plains ecozone: the Boreal Transition and the Western Alberta Uplands ecoregions; 3
3) Two ecoregions within the Montane Cordillera ecozone: the Eastern Continental Ranges and the Northern Continental Ranges ecoregions.

The single most important natural hazard for the SSRB was identified, and that is drought. Definitions of drought were further explored, and although drought was shown to be often quantitatively defined according to the demands of water users, 4 definitions are most commonly accepted within the literature, which greatly reflect the perception of the respective disciplines which describes them:

1) Meteorological Drought (most commonly defined in terms of actual precipitation departure to average amounts on monthly, seasonal, water year, or annual time scales),
2) Agricultural Drought (commonly described in terms of precipitation shortages, differences between actual and potential evapotranspiration, and soil water deficits for specific crop activities),

3) Hydrological Drought (most commonly defined in terms of the effects of periods of precipitation shortfall on surface or subsurface water supply rather than with precipitation shortfalls, i.e., streamflow, reservoir and lake levels, groundwater),
4) Socioeconomic Drought (most commonly defined in terms of the supply and demand of some economic good or service affected by precipitation shortages such as drinking water or hydroelectric power).

The causes of drought in the SSRB have been shown to be yet still poorly understood, although extensively studied. *ENSO* (El Nino-Southern Oscillation) has been identified as the primary terrestrial driving force of drought in North America. *ENSO* can cause abnormally warmer conditions through anomalies to the Pacific-North American (PNA) and is also associated with shifts to the jet stream. The mechanisms that in turn trigger changes and the teleconnections involved are subject of ongoing investigations. Such investigations are in turn difficult due to the limited availability of climate records.

The most extensive records of climatic records in the Prairies are available in the form of climate proxies. A range of proxy records are available for the prairies and northern plains. The reconstructed climate records from proxy records show a frightening picture for the prairies, with longer and more frequent droughts to what has been previously experienced. If the future mirrors the past, the coping capacity based on previous experience might not be sufficient to prevent greater losses.

Future changes that can be expected to the prairie climate include areas of increased aridity. Areas that are prone to increased aridity are likely to become inhospitable despite the best adaptation efforts. Thus, locating these biophysically sensitive areas is of great importance to any decision making regarding adaptation strategies and planning. Biophysically sensitive areas were identified through analysis to maps in the SSRB that included the following criteria:

1) Aridity index between 0.05 and 0.65,
2) High wind speeds,
3) Coarse soil texture (i.e. sandy and sandy-loam),
4) Available water capacity less or equal to 150mm/year,
5) Agricultural land-use.

These criteria applied simultaneously resulted in the following districts with increased biophysical exposure to climate change: 776, 812, 819, and 827. People living in these areas are less likely to adapt to climatic changes despite their best efforts.

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.

Alley, R.B.; Marotzke, J.; Nordhaus, W.D.; Overpeck, J.T.; Peteet, D.M.; Pielke Jr., R.A.; Pierrehumbert, R.T.; Rhines, P.B.; Stocker, T.F.; Talley, L.D. and Wallace, J.M. (2002). Abrupt Climate Change: Inevitable Surprises. National Research Council, National Academy Press, Washington, DC, 230pp.

Bonan, G. (2002). Ecological Climatology, Concepts and Applications. National Center for Atmospheric Research. Cambridge University Press, Cambridge, United Kingdom.678pp.

Bonsal, B.; Koshida, G.; O'Brien, E.G. and Wheaton, E. (2004). Droughts. National Water Research Institute, Environment Canada (http://www.nwri.ca/threats2full/ch3-1-e.html).

Bonsal, B.R. and Lawford, R.G. (1999). Teleconnections between El Niño and La Niña events and summer extended dry spells on the Canadian Prairies. Int. J. Climatol. 19: 1445-1458.

Blumenstock, G. (1942). Drought in the United States Analyzed by Means of the Theory of Probability. US Department of Agriculture, Technology Bulletin 819, Washington, D.C.

Burn, D.H. (1994). Hydrologic effects of climate change in west-central Canada. *Journal of Hydrology* 160: 53-70.

Canadian Soil Information System (2004). Soil Landscapes of Canada 2.2. Canadian Soil Information System, Agriculture and Agri-Food Canada (http://sis.agr.gc.ca/cansis/nsdb/slc/v2.2/intro.html).

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

Case, R.A. and MacDonald, G.M. (1995). A dendroclimatic reconstruction of annual precipitation on the western Canadian prairies since A.D. 1505 from *Pinus flexilis* James. Quaternary Research 44:267-275.

Case, R.A. and MacDonald, G.M. (2003). Tree ring reconstructions of streamflow for three Canadian prairie rivers. *Journal of the American Water Resources Association* 39(3): 703-715.

Currie, B.W. (1953). Prairie Provinces and Northwest Territories Precipitation. Physics Department, University of Saskatchewan, 38pp. In: Ripley, E.A. (1986). Is the Prairie becoming drier? Canadian Hydrology Symposium, Associate Committee on Hydrology, National Research Council of Canada, Regina, Saskatchewan. 49-61pp.

Dey, B (1982). Nature and possible causes of droughts on the Canadian Prairies. *Journal of Climatology* 2:233-249.

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). Threats to water availability in Canada. National Water Research Institute, Burlington. Ontario. NWRI Scientific Assessment Report Series No.3 and ACSD Science Assessment Series No. 1. 128pp.

Fung, K. (ed) (1999). Atlas of Saskatchewan. University of Saskatchewan, Saskatoon, Saskatchewan. 336pp.

Geogratis (2004). Geogratis index of download (http://geogratis.cgdi.gc.ca/download/).

Hoerling, M. and Kumar, A.(2003). The perfect ocean for drought. *Science (Reports)* 299:691-694.

Jones, D.C. (1987). Empire of Dust: Settling and Abandoning the Prairie Dry Belt Edmonton: University of Alberta Press.

Jones, K.H. (1991). Drought on the Prairies. 125-130pp. In: Wall, G. (Ed) (1991). Symposium on the impacts of climatic change and variability on the Great Plains. Proceedings. University of Waterloo, Deptartment of Geography.

Kennedy, S.D. (2004). Landscape Sensitivity and Climate Change in Southern Saskatchewan. Master of Science Thesis, Department of Geography, University of Regina. Regina, Saskatchewan. 138pp.

Lang, T. and Jones, K. (N.D.). A Comparison of the Meteorological Conditions During the Drought of the 1930's and the 1980's for the Prairie Provinces. Scientific Services Regina. Regina. Saskatchewan.

Laird, K.R.; Cumming, B.F. (1998). Tracing droughts in the past, two millennia of North American Drought events recorded in lake bottom cores. *Science Spectra* 11:50-57.

Laird, K.R.; Cumming, B.F.; Wunsam, S.; Rusak, J.A.; Oglesby, R.J. and Fritz, S.C. (2003). Lake sediments record large-scale shifts in moisture regimes across the northern prairies of North America during the past 2 Millennia. *Proceedings of the National Academy of Sciences of the United States of America* 100(5):2483-2488.

Laird, K.R.; Fritz, S.C. and Cumming, B.F. (1998). A diatom-based reconstruction of drought intensity, duration and frequency from Moon Lake, North Dakota: a sub-decadal record of the last 2300 years. *Journal of Paleolimnology* 19:161-179.

Laird, K. R., Fritz, S.C.; Maash, K.A. and Cumming, B.F. (1996). Greater drought intensity and frequency before AD 1200 in the northern Great Plains, USA. *Nature* 384:551-554.

Lemmen, D.S. and Vance, R.E. (1998). Climate variability on the southern Canadian prairies during the last 1000 years based on multiple proxy indicators. 45-49pp. In: Maclver, D. C. and Meyer, R.E. (1998). Proceedings of the workshop on Decoding Canada's Environmental Past: Climate Variations and Biodiversity Change During the Last Millennium.

Mayer, N. and Avis, W (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).

McRae, T.; Smith, C.A.S.; Gregorich, L.J. (2000). Environmental Sustainability of Canadian Agriculture. Report of the Agri-Environmental Indicator Project. Agriculture and Agri-Food Canada, 224pp.

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/).

National Drought Mitigation Center (2003). What's drought? Understanding and defining drought. (http://www.drought.unl.edu/whatis/concept.htm).

National Weather Service Climate Prediction Center (2004). Warm (El Niño/Southern Oscillation- ENSO) Episodes in the Tropical Pacific (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/impacts/warm_impacts.html)

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.

Palmer, W.C. (1965). Meteorological drought. *Research Paper No. 45*. U.S. Weather Bureau, Washington, D.C., 58pp.

Prairie Farm Rehabilitation Administration (2004). Mapping applications and data. Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada (http://www.agr.gc.ca/pfra/gis/gwshed_e.htm).

Ripley, E.A. (N.D.). Drought Prediction on the Canadian Prairies. A report to the Hydrometeorological Research Division of the Canadian Climate Centre. A publication of the Canadian Climate Program. Saskatoon, Saskatchewan. 137pp.

Saskatchewan Environment and Resource Management (1997). State of the Environment Report 1997. The Prairie Ecozone: Our Agricultural Heartland. Environment and Resource Management. Regina, Saskatchewan. 93pp.

Saskatchewan Environment and Resource Management (1995). State of the Environment Report 1995. The Boreal Plain Ecozone: A Forest Community. Saskatchewan Environment and Resource Management. Regina, Saskatchewan. 123pp.

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

Sauchyn, D.J. and Beaudoin, A.B. (1998). Recent environmental change in the southwestern Canadian Plains. *The Canadian Geographer* 42: 337-353.

Sauchyn, D.; Barrow, E.; Hopkinson, R. and Leavitt, P. (2002). Aridity on the Canadian Plains: future trends and past variability. The pre-settlement record of the prairie drought and a forecast of future aridity and what they mean for the management of soil and water resources. Summary document No. 03-01, PARC (Prairie Adaptation Research Collaborative).

Sauchyn, D. J. and Skinner, W.R. (2001). A proxy record of drought severity for the Southwestern Canadian Plains. *Canadian Water Resources Journal* 26 (2):253-272.

Sauchyn, D.J.; Stroich, J. and Beriault, A. (2003). A paleoclimate context for the drought of 1999-2001 in the northern Great Plains of North America. *The Geographical Journal* 169(2):158-167.

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. 56pp.

Soil Classification Working Group (1998). The Canadian System of Soil Classification. Agriculture and Agri-Food Canada, Publication 1646. 187pp.

St.George, S. and Nielsen, E. (2002). Hydroclimatic change in Southern Manitoba since A.D. 1409 inferred from tree rings. *Quaternary Research* 58:103-111.

Strong, W.L. and Leggat, K.R. (1992). Ecoregions of Alberta. Alberta Forestry, Lands and Wildlife, Land Information Services Division, Resource Information Branch, Edmonton, Alberta. 59pp.

Thomas, M.K. (1965). Climatic Trends in the Canadian Prairies. Report No. 2, Water Research Institute In: Ripley, E.A. (1986). Is the Prairie becoming drier? Canadian Hydrology Symposium, Associate Committee on Hydrology, National Research Council of Canada, Regina, Saskatchewan. 49-61pp.

United Nations Convention to Combat Desertification (1994). United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly in Africa. United Nations (http://www.unccd.int/convention/text/convention.php).

Vance, R.E. and Wolfe, S.A. (1996). Geological indicators of water resources in semi- arid environments: Southwestern interior of Canada. 237-250pp. In Berger, A.R. and Iams, W.J. (eds). Geoindicators: Assessing rapid environmental changes in earth systems. A.A. Balkema, Rotterdam.

Vance, R.E.; Mathewes, R.W. and Clague, J.J. (1992). 7000 year record of lake-level change on the northern Great Plains: a high resolution proxy of past climate. *Geology* 20:879-882.

Yevjevich, V., Hall, W.A., and Salas, J.D. (1978). Proc. Conference on Drought Research Needs. Water Resources Publications, Fort Collins. 276p.

Yu, Z.C.; Ito, E.; Engstrom, D.R. and Fritz, S.C. (2002). A 2100-year trace-element and stable-isotope record at decadal resolution from Rice Lake in the northern Great Plains, USA. *The Holocene* 12: 605-617.

Watson, E. and Luckman, B. (2003). Tree-ring based reconstructions of precipitation for the southern Canadian Cordillera. *Climatic Change* 65(1-2): 209-241.

Wilhite, D.A. (2003). Drought. 650-658pp In J.R. Holton, J.A. Pyle, and J.A. Curry (eds.). *Encyclopedia of Atmospheric Sciences*, Elsevier Science Ltd., New York.

Wilhite, D.A. (2000). Drought, Volume 1: Global Assessment. Hazards and Disasters Series. Taylor and Francis Group. Routledge, New York. 396pp.

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).