GEOGRAPHY OF THE SOUTH SASKATCHEWAN RIVER BASIN

SEAWA Watershed Report 2009-1

SEAWA Web-based State of the Watershed Report

South East Alberta Watershed Alliance
721 97 Carry Drive SE
Medicine Hat, Alberta, Canada T1B 3M6

www.seawa.ca 403.488.8110

GEOGRAPHY OF THE SOUTH SASKATCHEWAN RIVER BASIN

Introduction

This report describes the topography, geology and climate of the South Saskatchewan River Basin (SSRB). A drainage basin or watershed is the area drained by a single river or stream.[25] The whole SSRB has an area of about 121,000 square kilometers.[108] The Red Deer, Bow and Oldman rivers are the three main tributaries of the South Saskatchewan River. The Bow and Oldman rivers come together approximately 60 kilometers west of Medicine Hat to form the South Saskatchewan River; this point is known as the Grand Forks. The Red Deer River joins the South Saskatchewan River farther north and east, near the Alberta-Saskatchewan border.[75]

The Red Deer, Bow and Oldman sub-basins have areas of about 49,000 square kilometers, 25,000 square kilometers and 27,000 square kilometres respectively.[107, 102, 105] The land which drains directly into the South Saskatchewan River, not including the three main tributaries, is called the South Saskatchewan River Sub-basin. About 14,000 square kilometers of this sub-basin is in Alberta.[108] Minor streams in the sub-basin include Seven Persons Creek, Ross Creek, Bullshead Creek and Gros Ventre Creek.[92, 75]

The western side of the South Saskatchewan River Basin runs along the eastern side of the Rockies. This side of the basin extends north to about 52°N latitude, at the beginning of the Bow River. This is also its westernmost point. Its northernmost point is at almost 53°N latitude, near the beginning of the Medicine River.[26, 75]

Farther east, the South Saskatchewan joins with the North Saskatchewan River. From there the Saskatchewan River flows into Lake Winnipeg, which drains into Hudson Bay via the Nelson River.[76]

Flow Rates and Water Levels

The flow rates of rivers can vary greatly over the year. The Alberta Ministry of Environment provides readings for flow rates for April through October. On average, the South Saskatchewan River, measured at Medicine Hat, has its highest flow rate in June. The average peak flow rate is about 700 cubic meters per second . This drops down to a minimum of about 80 cubic meters per second in September or October. Flow rates have been below average for most of the current year (2009). The highest reading was slightly less than 300 cubic meters per second in early June. In July

there was also a local maximum reading of nearly 300 cubic meters per second. Despite the low readings, the flow rate has risen above average in August and remains high. The minimum flow rate measured this year was less than 60 cubic meters per second, in early July.[26]

On average, the Bow River measured at the mouth of the river ranges from about 200 cubic meters per second in June to about 30 cubic meters per second in early to mid-October.[26] The Oldman River measured near Lethbridge ranges from more than 300 cubic meters per second in June to about 20 m^3/s in August. The Oldman River measured near the mouth of the river ranges from about 200 cubic meters per second in late May to about 30 cubic meters per second in August.[26] The Red Deer River measured at Red Deer ranges from more than 100 cubic meters per second in June to less than 20 cubic meters per second in April. The same river measured near Bindloss, farther downstream, ranges from more than 100 cubic meters per second in June to less than 30 cubic meters per second in October.[26]

General Description and Topography

The South East Alberta Watershed Alliance (SEAWA) watershed is roughly centered around Medicine Hat. In Alberta, it covers parts of Cardston County, Warner County, Forty Mile County, Lethbridge County, Taber Municipal District, Cypress County, Newell County, Special Area no. 2, Special Area no. 3 and Acadia Municipal District. In Saskatchewan, it covers parts of the rural municipalities of Maple Creek, Big Stick, Piapot, Gull Lake, Enterprise, Fox Valley, Pittville, Deer Forks, Happyland, Clinworth, Chesterfield, Newcombe, Milton, Kindersley, Antelope Park, Prairiedale and Heart's Hill. The area extends west to Milk River Ridge, south to Pakowki Lake, east to the rural municipality of Pittville, and north to the rural municipality of Heart's Hill.[92, 75] The southern boundary of the SEAWA area lies on the boundary of two major river basins. The basin to the south is the Milk River Basin, which is part of the Mississippi-Missouri River system.[104]

Meandering paths are typical of Prairie rivers. Meanders form when a river changes shape due to differences in flow speed of the water. Examples of this can be seen in the Belly River, Willow Creek, St. Mary River and Little Bow River. As the land in between two bends narrows, it is possible for a river to cut its banks. This leads to the formation of an oxbow lake.[93] One oxbow lake is located by the Bow River near the point where the Crowfoot River joins the Bow River.[75]

Notable bodies of water in the SEAWA area include Pakowki Lake, Milk River Ridge Reservoir and Many Islands Lake.[92, 75] Pakowki Lake is located about 100 km south of Medicine Hat and 30 km north of the U.S. border.[75] It is an intermittent lake, and it has undergone cycles in water level which have lasted several years. In a 1996 study, its area was about 109 km^2.[91] Its only inflow stream is

Etzikom Coulee, a long glacial spillway channel.[32] Marsh habitat and sand dunes are located near the lake.[23]

Several other notable bodies of water are in the vicinity of the SEAWA area. Chappice Lake is a small saline lake located about 20 km northeast of Medicine Hat.[34] It is less than one meter in depth. The lake used to be fed by a stream from the northeast, but in 1978 a weir was constructed in this location, preventing surface water from flowing in. However, underground water still flows into the lake and partially maintains the water level. Water levels in Chappice Lake have decreased in the last few decades.[60]

Elkwater Lake is located in Cypress Hills Provincial Park and has an area of about 2 square kilometres. Its outlet has been artificially deepened to increase water flow to the nearby reservoir.[98] Travers Reservoir is a man-made reservoir built on the Little Bow River, about 35 kilometers southeast of the town of Vulcan, with an area of 22.5 square kilometers. It was constructed in 1954 to store water from the Bow River.[99] White Horse Lake, Dishpan Lake and Easy Lake are located in Canadian Forces Base Suffield, in the Middle Sand Hills area.[75]

The St. Mary River Irrigation District is a large system of canals and pipelines covering over 150,000 hectares (1500 square kilometers).[87] A large part of this is in the SEAWA management area.[92] The entire irrigation area is south of the Oldman and South Saskatchewan rivers, extending from Medicine Hat in the east to Lethbridge in the west.[88]

The Cypress Hills rise 600 meters above the surrounding land and cover about 2600 square kilometers, stretching across the Alberta-Saskatchewan border.[89] Their highest point, Head of the Mountain, is 1466 meters above sea level. It is the highest point of land between the Rocky Mountains and Labrador. The western part of the Cypress Hills lies within the SEAWA area.[28, 92]

The prairies of Alberta contain numerous wetland areas. Wetlands are places where the land has been saturated with water long enough to have poorly drained soils. Unlike lakes, some wetlands do not have well-defined boundaries, and some are not permanent. Most wetlands in southern Alberta are temporary, with water accumulating in the spring.[71] Over 60% of the wetlands in southern Alberta have been drained.[106]

The main types of wetlands located in central and southern Alberta are marshes and ponds. These types of wetlands differ by their structure and the wildlife which live there. Marshes (sloughs) form as water drains into depressions to create pools of still water which contain high levels of nutrients.[110, 109] Ponds are still-water basins which are wide and generally shallow. Water in ponds is accumulated from precipitation or groundwater sources. Ponds can undergo dry periods in the late summer.[109]

Prairie marshes, also known as prairie potholes or sloughs, are depressions of about 30 to 80 meters in diameter which formed during recent ice ages. These potholes were later partially filled with sediments.[111] The SEAWA area is part of the Prairie Pothole Region, a large area that covers much of southern and eastern Alberta, southern Saskatchewan, North Dakota and South Dakota.[61]

Many of these depressions resulted from melting glaciers.[70] Prairie wetlands often act as groundwater recharge or discharge sites. Because the prairies experience wet and dry periods, some of the wetlands can dry up for several years. When this happens, different types of plants may begin to grow.[110] Most depressional wetlands do not have inflows or outflows on the surface. Depressional wetlands that provide groundwater recharge tend to have lower salt content, and those that receive groundwater discharge tend to have higher salt content.[73]

The Middle Sand Hills are one of many sand dune fields on the prairies. They are located on the Suffield Military Reserve and cover about 400 square kilometers.[69]

Climate and Weather

Present Climate and Weather Events

The Canadian Prairies generally have a continental climate, characterized by warm or hot summers, cold winters, and usually low precipitation. Air and the associated weather patterns commonly travel from west to east across southern Canada. Apart from the Rocky Mountains, several large mountain ranges are located farther west in British Columbia. The westerly winds must pass over these ranges, forcing the air to drop a large amount of precipitation (orographic precipitation). The lack of large water bodies causes temperatures to vary greatly between summer and winter.[17]

Occasionally, in the past, the Prairies have experienced longer periods of moisture or drought. Excess moisture tends to promote more precipitation, and a lack of moisture promotes a lack of precipitation. This is because when a large amount of rain falls, the soil gains more water. After plants draw up this water, they release water vapour into the air, leading to more cloud formation. During a dry period, the soil loses its moisture and not as much water can transpire into the air.[90] On the Prairies, it is not easy to predict weather weeks or months in advance.

The SSRB is located within the Palliser Triangle, a large area of the Prairies characterized by dry conditions. The Triangle is the Canadian portion of an area with fairly uniform climate. The west boundary and the north/east boundary of the Triangle are defined based on climate.[74] The west side runs along the edge of the Rocky Mountains. The north/east side runs along the edge of parkland fringe in Alberta, Saskatchewan and Manitoba, toward the southeast. A similar climate extends south into the U.S., although the Palliser Triangle only includes Canadian land. [30]

The Palliser Triangle area experiences the greatest temperature ranges in Canada. Precipitation is even lower in the winter than the summer; snow only makes up about 30% of annual precipitation.[74] The record high temperature for Medicine Hat was 42°C, recorded on July 12, 1886. The record low temperature was -46°C, recorded on January 22, 1886.[66]

Most of the Canadian Prairies receive little precipitation. The land loses more water through evaporation (from lakes, ground, plants, etc.) than it receives in rain or snow; this is known as a moisture deficit.[33] Precipitation is especially low in southeast Alberta. Among Canadian cities, Medicine Hat has the most days per year without measurable precipitation (271 on average).[94] Figure 5 shows that southeast Alberta, including much of the SEAWA area, has low precipitation levels. However, convective storms can drop a large amount of rain in a short time. In Medicine Hat, the record rainfall for one day occurred on August 14, 1927, when 122 mm of rain was dropped.[66]

Floods occur occasionally in southern Alberta: recent examples of this occurred at Medicine Hat in 1995 and 2005.[36] In the June 2005 flood, several other communities in southern Alberta were affected. The flooding was most severe in High River, south of Calgary, where 700 people were evacuated. The Highwood River, a tributary of the Bow River, runs through the town. The flooding did not occur immediately after the heavy rains in early June. Later that month, saturated soil and increased water runoff led to greater river flows.[56]

The Cypress Hills region is generally a few degrees cooler than the surrounding land and also tends to receive more clouds and thunderstorms.[59]

An air mass is a huge volume of air which has nearly uniform temperature and humidity at any given altitude. Continental air masses form over continents and maritime air masses form over the ocean.[62] Two main air masses typically affect Alberta: a continental polar air mass coming from the interior of Canada and a maritime polar air mass coming from the north Pacific. In the summer, a maritime tropical air mass occasionally enters Alberta from the Gulf of Mexico or the Pacific. This sometimes results in frontal precipitation due to the added moisture. Air from the Arctic is dominant in the winter. [19]

A significant amount of the summer rainfall is convective precipitation. Convection is the transport of heat in the air through vertical motion.[19] First the Sun heats the ground, which heats the air immediately above it. The resulting movement of air upward causes clouds to form. Convection is associated with storms, which can produce short, intense rainfalls.[19] Dry soil has less moisture to hold earth together, so a sudden heavy rainfall can cause significant erosion.[80]

Figure 3 shows the risk of water erosion on bare, unprotected mineral soil. Southeast Alberta has some areas of severe risk, although the level of risk varies greatly. Dry soil also increases the risk

of wind erosion. As shown in Figure 4, wind erosion risk tends to be higher in southeast Alberta. A lack of vegetation also contributes to erosion from water and wind.[80]

Southern Alberta sometimes experiences a Chinook wind – a warm, dry wind that descends from the Rockies as it travels from west to east. This air has dropped much of its moisture after travelling over several mountain ranges in British Columbia. The Chinook can warm temperatures by more than 20˚C in several hours. The farther from the Rockies the land is located, the smaller effect the Chinook has on temperature.[19]

Air temperatures above 5°C are considered "growing temperature". One measure for temperature over a period of time is growing degree-days (GDDs); this statistic can be useful for agricultural purposes. Growing degree-days are the number of days with temperatures higher than 5°C multiplied by the number of degrees above 5°C that occur over a period of time.[79] For example, if the temperature stays at 7°C for three days, this counts as six GDDs. Relative to 5°C, most locations around Medicine Hat have values of about 1500 to 1900 GDDs annually. In some parts of the Cypress Hills the average value is as low as 1000 GDDs annually.[23]

Degree-days are also sometimes calculated for temperatures above 0°C. The number of frost-free days in a year also determines how agriculture fares because crops can be damaged by frost. In a year, southeast Alberta can have more than 125 days above 0°C – more than other parts of Alberta but less than many of the maritime regions of Canada. Most of the South Saskatchewan River Basin experiences more than 115 days annually above 0°C (see Figure 6).[14]

An ecological region, or ecoregion, is an area that has fairly uniform climate, vegetation, soil, topography, animals, water patterns, and land use throughout.[18] Most of the South Saskatchewan River Sub-Basin is in the "Mixed Grassland" ecoregion (see Figure 7). In this ecoregion, precipitation averages about 250 to 350 millimeters/year and average temperatures are higher than in other parts of Alberta.[20] The Mixed Grassland ecoregion has Chernozem soils – a dark soil which is high in organic matter.[18]

The Cypress Hills region is called either the "Cypress Upland" ecoregion or a "Fescue Grassland" ecoregion similar to the Foothills area of Alberta.[18] Fescue prairie is wetter than mixed prairie and has a greater abundance and variety of wildlife.[67]

According to the Weather Network of Canada, Medicine Hat receives 322 millimeters of precipitation annually (also see Figure 5).[95] By most definitions, Medicine Hat's climate is dry but not that of a true desert. According to the Meigs classification system, places with 250 to 500 millimeters of precipitation annually are semi-arid lands.[101] In contrast, Toronto receives about 800 millimeters of precipitation while Phoenix, Arizona only receives about 190 millimeters.[97, 96]

Prehistoric climate

In the last 12,000 years or so, the climate of the Palliser Triangle has ranged from warm to cold and from moist to dry. More than 13,000 years ago, the climate of the Triangle began to warm up, and by 10,000 years ago, the temperatures were similar to what we experience today. A warm and moist climate led to an increase in plant cover and soil formation. As warming continued, the effective precipitation decreased, and plant cover decreased as well. This long period of drought lasted from about 9000 to 5000 years ago. At this time, rivers were shallower and warmer than they are today. The climate began to cool about 5000 years ago, and the modern plant communities started to form. About 3000 years ago, warming began again and continued until modern times.[30]

Climate Change and Its Effects

Climate change may have serious implications for the SSRB. The Palliser Triangle is believed to be more vulnerable to its effects than other regions in Canada. Some possible changes associated with climate change are increasing temperatures, melting glaciers (which affect water levels and flow rates), faster evaporation, a more active precipitation cycle, a change in timing of stream flow, and effects on groundwater.[103]

A report by Martz et al. (2007) predicts that temperatures in the SSRB will increase by 1.5 to 2.8˚C by 2050. A study by Barrow and Yu (2005) suggests that by the 2050s, Calgary's annual mean temperature will be similar to that of Medicine Hat and Lethbridge. The annual mean temperature for Medicine Hat from 1961 to 1990 was 5.1˚C. This is predicted to increase to 8.1˚C in 2050 (Barrow and Yu, 2005).[103]

The study also predicts that overall precipitation will increase in Alberta, but less of this will fall as snow. Stream flow during the winter will increase, and by the time summer arrives, the snowpack will be depleted. If snow melts earlier in the year and winter weather tends to produce rain instead of snow, ecosystems could be negatively affected (e.g., species extinct, habitat loss, increased water contamination).[103]

Simulations are useful in predicting the likely changes in climate and this process is known as climate modelling. The Intergovernmental Panel on Climate Change (IPCC) commissioned a Special Report on Emissions Scenarios (SRES) in 2001. Different simulations were conducted by scientific organizations, including the Canadian Centre for Climate Modelling and Analysis (Canada), the National Center for Atmospheric Research (USA) and the Hadley Centre for Climate Prediction and Research (UK).[31]

Climate predictions were made for the 2020s, the 2050s and the 2080s. Changes were calculated relative to the period of 1961-1990. For temperature predictions, five different scenarios were used: cooler and wetter, cooler and drier, warmer and wetter, warmer and drier, and a median scenario.[31]

Climate warming may have a few positive effects, namely a longer growing season and increased precipitation for crops. However, water will also evaporate faster, and water supplies for agriculture will decrease. Therefore, agricultural demand for water will also rise. Hydroelectric power generation will also be affected by receding glaciers and their stream flows.[103]

General Circulation Model simulations have predicted that increased greenhouse gases in the atmosphere will be associated with increased temperature and less precipitation in the summer.[103] Additionally, some glaciers are receding due to warmer temperatures. The total glacial cover of the Rocky Mountains is almost at a minimum for the last 10,000 years.[68]

Geology

Rock formations

In geological terms, a "formation" is a unit of sedimentary rock which is mostly uniform throughout. "Distribution" refers to the geographical area in which the layer is spread out. The vertical thickness of a layer is typically measured in meters. See Table 5 for the names of geologic time periods. Although a rock layer may be present in southeast Alberta, the thickness of the layer will vary across its geographic area.

Most of the upper layers of rock in the Canadian Prairies are sedimentary (formed from grains of sand or clay which were deposited and cemented together). Very old Precambrian "basement" rock exists across Canada.[6] In much of eastern Canada, this rock is exposed at the surface in a region called the Canadian Shield. In western Canada, the Precambrian rock is covered by many layers of newer rock from the Cambrian Period and later. The thickness of this cover decreases from the Rocky Mountains east. In southeast Alberta and southwest Saskatchewan, its thickness is roughly 2000 to 2400 meters.[9] The basement rock is igneous (formed from solidified magma) or metamorphic (formed from another rock type which has been changed by heating and compression).

Paleozoic Layers

The following rock layers (from the Cambrian Period and later) are listed from oldest to newest. The Earlie Formation was deposited in the Middle Cambrian Period. It is composed of siltstone, sandstone and shale. It has a maximum thickness of 172 meters near Lloydminster.[7, 44]

The Deadwood Formation was deposited in the Late Cambrian Period to Early Ordovician Period. It consists of conglomerate and buff sandstone at the bottom, grey-green shale in the middle, and red-brown quartz sandstone on top. At the Alberta-Saskatchewan border the Deadwood Formation has a thickness of over 300 meters.[7, 43]

The Yeoman Formation dates from the Late Ordovician Period. It is mostly composed of biomicrites (a type of limestone with fossils) and has a maximum thickness of about 180 meters in North Dakota.[8, 55, 112]

The Interlake Group was deposited in the Silurian and mostly consists of yellowish grey to yellowish brown dolomite. It has a maximum thickness of over 300 meters in North Dakota.[8, 48]

Cretaceous, Tertiary and Quaternary Layers

The Mannville Group was deposited in the Early Cretaceous. It is distributed across part of Alberta and Saskatchewan. Its lower part consists of interbedded sandstone and shale. Above this is a thin calcareous layer, and further above this are marine shales and various types of sand.[5, 49]

The Colorado Group is a large rock unit distributed over Alberta, Saskatchewan, and several U.S. states. It was deposited in the Cretaceous and has a maximum thickness of more than 1000 meters in southern Alberta.[41] This group consists of several layers, including the Basal Colorado Sandstone, Joli Fou Formation, Spinney Hill Sandstone, Viking Formation, St. Walburg Sandstone, Barons Sandstone, Dunvegan Formation, part of the Kaskapau Formation, part of the Second White Speckled Shale, Cardium Formation, Medicine Hat Sandstone and part of the Lea Park Formation. The Medicine Hat Sandstone contains the largest gas pool in Canada.[4]

The Milk River Formation is composed of sandstone and has a maximum thickness of 113 meters. It can be divided into three units: a lower layer of interbedded sandstone and shale, a middle layer of sandstone, and an upper layer of interbedded shale, sandy shale, sandstone and low-quality coal.[4, 50]

Above this is the Pakowki Formation, composed of dark grey mudstone as well as siltstone. It has a maximum thickness of 200 meters in west-central Saskatchewan but is thinner to the west.[4, 52]

The Belly River Group is distributed over the Rocky Mountain Foothills and Southern Alberta. It is composed of clastic wedge sediments.[4, 40]

The Foremost Formation consists of beds of sandstone and shale as well as coal seams. It has a maximum thickness of 168 meters near Lethbridge and thins out toward the east. Near Medicine Hat its thickness has been measured at 107 meters.[4, 46]

The Oldman Formation consists of sandstone, shale and siltstone. It has a thickness of 328 meters at Lethbridge and thins out to 122 meters in eastern Alberta.[4, 51]

The Bearpaw Formation, named after the Bearpaw Mountains in Montana, stretches across large areas of southern Alberta and south-western Saskatchewan. It consists of dark grey clay, claystone, shale, silt and siltstone.[10, 39] It also has beds of concretions – rocks which are cemented together by a mineral material.

Three thin layers are located above the Bearpaw Formation, deposited near the end of the Cretaceous: the Eastend, Whitemud and Battle formations. The Eastend Formation consists of fine-grained sand with siltstone and sandstone ledges. It has beds which alternate with the Bearpaw Formation over a height of several meters.[10, 45]

The Whitemud Formation has a lower layer of medium to fine-grained sand; a middle layer of shale, silt and clay; and an upper layer of clay with some silt. It has a maximum thickness of 23 meters but in the Cypress Hills it is only 8 meters thick.[10, 54]

The Battle Formation has a maximum thickness of 14 meters. It consists of silty shale with a porous weathered crust. In many places (e.g., parts of the Bow River Valley), this unit has been removed by erosion.[10, 38]

The Frenchman Formation consists of sand, ranging from coarse to fine-grained, interbedded with clay. It was formerly known as the Lower Ravenscrag Formation. It has a maximum thickness of 113 meters, at a location south of Elkwater.[10, 47]

The Ravenscrag formation was deposited at the end of the Cretaceous Period to the Tertiary Period. It consists of sandy clays along with sandstones, shales and coal. It can be divided into an upper unit which ranges from 162 meters to about 244 meters and a lower unit which ranges from 6 to 58 meters.[10, 53] Above these formations is a layer of glacial drift from the Laurentide glaciation, deposited in the Quaternary period (about 2.6 million years ago to present).[10]

Glacial Action

Glaciers have had a major effect on the SEAWA area and the Canadian prairies in general. The last major advance of glaciers over North America is known as the Wisconsin glaciation.[33] This glacial period lasted from about 100,000 years ago to 10,000 years ago. When the glaciers were at their maximum extent about 18,000 years ago, almost all of Canada was covered.[33] The Laurentide Ice Sheet was the huge continental ice sheet which covered part of North America. Two small areas in Alberta known as refugia were not covered: part of the Cypress Hills and a strip of land near the Rocky Mountain Foothills. The Wood Mountain upland in southern Saskatchewan was also free from

glaciation. Some examples of glacier-formed lakes are Bow Lake, Lake Agnes, Lake Louise and Moraine Lake.

A wide variety of lakes are located in the Palliser Triangle. In the early Holocene (about 10,000 to 7,000 years ago), freshwater was prevalent and lake levels were generally high, but this was interspersed with short periods of low water and higher salt content.[74] Several lakes show evidence of rapid changes from low salinity to high salinity, including Oro Lake in Saskatchewan. Groundwater had a large effect on the hydrology of the region.[74]

In the mid-Holocene (7,000 to 5,000 years ago), lake levels were low and some bodies of water dried up completely. The absence of sediment deposits for most lakes formed in this period provides evidence that some of these lakes dried up. Clearwater Lake in southwest Saskatchewan is 9.5 meters deep today, but was probably dry during the mid-Holocene epoch.[74]

At the start of the late Holocene (5,000 years ago to present), water levels began to rise. This happened at about the same time as the start of a glacial period. The greatest water levels and freshwater conditions occurred at about 3000 to 2000 years ago.[74]

Several different post-glacial processes occurred in the Palliser Triangle after the glaciers retreated but before vegetation was established. Steep valley walls underwent landslides or slumps caused by stream incision. They were also cut by river tributaries. Erosion of hills produced sediments that settled in the bottom of depressions. These processes occurred at later times as well. Because of these processes, a variety of soils of different ages exists in this region.[30] The Laurentide glacier reached southern Alberta about 22,000 years ago, and the glacier receded from the area about 18,000 years ago.

Places of Geological Interest near the SEAWA Area

Southern Alberta and Saskatchewan contain a variety of interesting geological features. Known as an erosional plateau, the Cypress Hills were not glaciated as the surrounding areas were. Some rock layers exist in the Cypress Hills where in other places they have been eroded away.[28] From about 44 to 35 million years ago, some coarse gravels were deposited by rivers, forming a protective layer over the existing sediments.[89] The Cypress Hills are a drainage divide – a landform around which rivers flow.

The Bearpaw Formation exists at the base of the Cypress Hills. The Eastend, Whitemud, Battle, Frenchman and Ravenscrag formations lie on top of this. For a period of time around 66 million years ago, deposition stopped and some rock was eroded. The top layer of coarse gravel called the Cypress Hills formation. The gravel came from rivers which eroded rock from the newly formed Rocky Mountains.[28]

Red Rock Coulee is a small area about 40 kilometers south of Medicine Hat. It is notable for its sandstone concretions – rounded boulders that formed from sand, calcite and iron oxide which can be up to 2.5 meters in diameter. The minerals were deposited in layers on a nucleus of shells, leaves or bones.[72]

The Foremost – Cypress Hills area has some notable glacial features, including moraines and drumlins. Some major glacial features exist along Frenchman Valley near the Alberta-Saskatchewan border. Known as moraine plateaus, they are elevated patches of land with flat tops which may be circular or irregular in shape. They are composed mostly of glacial till. Most of the plateaus are 400 to 800 meters in diameter.[30]

Two different ideas have been proposed to explain the formation of moraine plateaus. One explanation is that till is squeezed up and into cavities of stagnant ice. Another explanation is that ablation material falls away into cavities in the ice as it melts.[30]

Studies suggest that moraine plateaus form on land that was poorly drained and had unmoving glacier ice. The currently accepted idea is that moraine plateaus formed in openings in stagnant ice, and this was caused by blocked meltwater drainage as well as a large supply of debris.[30]

A megablock is a large mass of material that has been fixed in place by a glacier. Most of the megablocks discovered in the world are made of bedrock, but some are made of glacial till. A megablock exists about 9 kilometers from Bow Island, on the east bank of the South Saskatchewan River.[30]

A moraine at Green Lake, near the Cypress Hills, marks the furthest extent of glaciers. Silts from glacial lakes were deposited in a basin known as Glacial Lake Downie. The uppermost layer of these sediments has been radiometrically dated at about 13,500 years. The Elk Valley was deglaciated more than 12,200 years ago. After glaciation, alluvium formed surfaces along the main valleys, between 11,000 and 10,000 years ago.[30]

Mineral Resources

Coal is distributed in Alberta approximately as far north as Grande Prairie. Coal exists in several grades: lignite is the lowest quality, followed by sub-bituminous coal, bituminous coal and anthracite. The Prairie region (including the SEAWA area) contains only sub-bituminous coal and lignite. Higher grades of coal are found near the Rocky Mountains.[3] Coal is usually found in coal "zones" or "seams". These occur in rock ranging from the Late Jurassic Period to the Tertiary Period (about 145 to 65 million years ago).

Three major coal zones are located in or around the Belly River rock group: The McKay Coal Zone below it, the Taber Coal Zone in the middle, and the Lethbridge Coal Zone above the rock group.

The Taber Coal Zone is located above the Foremost formation and below the Oldman formation.[1] The part of the Taber Coal Zone in southeast Alberta contains only sub-bituminous coal. The Lethbridge coal zone is between the Oldman formation and the Bearpaw formation. Some of this coal has the potential to be mined for coal-bed methane.[1]

Coal bed methane contains small amounts of carbon dioxide and nitrogen and can be extracted as an energy source.[21] The Drumheller Coal Zone has been a target for coal bed methane exploration.[2]

Some regions of the prairies contain uranium deposits. Although the largest deposits are found in the Athabasca Basin much farther north, southern Alberta contains some uranium deposits in sandstone.[11]

Extra-terrestrial Rocks

Meteorites are geological items of interest which have brought many visitors to the Prairies. When a piece of rock falls from space at high speed, it enters the atmosphere, and friction with the air causes it to burn up. This burning rock is called a meteor and can produce a bright flash of light which is visible from the ground.[78]

Most meteors disintegrate before they reach the ground, but sometimes a rock is large enough to fall all the way to the Earth's surface. Once on the surface, the rock is known as a meteorite. If a rock is large, it may explode into smaller pieces before it hits the ground. Some meteorites are called stony meteorites, containing minerals with silicon and oxygen. Others have larger amounts of iron and nickel, giving them a high density.[78]

Although it is rare to find a meteorite, Alberta is a good environment for locating them because of its expanse of flat ground. In fact, of 50 meteorites recovered in Canada since records have been kept, 14 have originated from Alberta. Meteorites from Alberta have provided valuable information about some of the oldest rocks of the solar system, particularly to university researchers.[35] A plateau created by a past meteorite impact is known to exist south of Elkwater Lake, at Eagle Butte.

On November 20, 2008, a meteor created a very bright flash over the Prairies. Astronomers believe that its original mass may have been 10 tonnes – much larger than most meteors that pass through the sky. The meteor was large enough to produce fragments which may have fallen near the Alberta-Saskatchewan border.[37]

Air Quality

Good air quality is important to human health and to ecosystems. While a certain amount of impurities are unavoidable, steps can be taken by residents and businesses to limit the amount emitted. Major pollutants include carbon monoxide, ammonia, volatile organic compounds, ozone, the sulphur dioxides, the nitrogen oxides and particulate matter.[58] Concentrations of gases are often measured in parts per million (ppm) or parts per billion (ppb).

Particulate matter consists of smoke, dust or soot. Some natural sources of particulate matter are forest fires, dust from fields, pollen and sea spray. Some anthropogenic sources are fuel combustion, wood burning, residential heating, pesticide use and smoking. Particulates are classified into coarse and fine particles. A coarse particle has a diameter of less than 10 micrometers; while a fine particle has a diameter has a diameter of less than 2.5 micrometers.[85]

Sulphur dioxide (SO_2) is a colorless gas with a strong odour. Much of the sulphur dioxide emitted in Alberta comes from natural gas processing plants. It is produced from the burning of fuels such as coal, pulp and paper mills, petroleum refineries, the smelting of metals, and volcanic eruptions.[86]

Nitrogen dioxide (NO_2) is a poisonous reddish-brown gas. It is released as a by-product when fossil fuels (oil, gas and coal) are burned. The main sources of nitrogen dioxide are motor vehicles and industry. Small amounts are also produced naturally.[84]

Carbon monoxide (CO) is a poisonous, colorless gas. The main source of carbon monoxide is motor vehicles; gas appliances and charcoal grills also produce it.[82]

Ozone (O_3) is a colorless gas which exists naturally several kilometres above the Earth's surface. The Ozone Layer protects the Earth from the Sun's ultraviolet rays. However, motor vehicles and industries can produce ground-level ozone which can potentially cause breathing problems, nausea and lung damage. It can also damage the leaves of plants.[83]

Environment Alberta has air quality monitoring stations in Medicine Hat, Lethbridge and Calgary. The Air Quality Index is a system for reporting air quality hourly. This scale uses number ratings as follows: 0-25, good air quality; 26-50, fair; 51-100, poor; over 100, very poor. In general for Calgary and Edmonton, air quality ratings are "good" more than 90% of the time.[24]

In the southeast corner of Alberta, air quality is monitored by the Palliser Airshed Society (PAS). The Palliser Airshed area reaches as far north as Esther, as far west as Bassano, south to the U.S. border, and east to the Saskatchewan border.[81]

Figure 8 shows air quality risk with respect to agricultural use. The risk values were based on several factors, including the number of livestock in an area and cultivation intensity.[12]

Crescent Heights Monitoring Station

The monitoring station in Crescent Heights, Medicine Hat, provides data for several contaminants as well as air temperature, relative humidity and wind direction.

The following data are from the Clean Air Strategic Alliance and deals with annual average levels of contaminants from 2004 to 2008. The Air Quality Index increased from 12.96 in 2005 to 15.20 in 2007 (this represents an increase in contaminants). Carbon monoxide levels were fairly stable at about 0.17 ppm from 2005 to 2008. Nitrogen dioxide remained around 0.008 ppm from 2004-2006, and then decreased to 0.006 ppm in 2007 before rising slightly in 2008. Ozone reached a minimum of 0.0247 ppm in 2005 and a maximum of 0.0281 ppm in 2007. The total for hydrocarbons has remained approximately stable at 2.1 ppm. Fine particulate concentrations were higher in 2006-2008 than they were in 2004-2005.

The following information is based on monthly data from 2004 to January 2009. The Air Quality Index tends to be highest from March or April to August and lowest form September to January. Carbon monoxide concentrations tend to be highest from December to June and lowest from July to November. Nitrogen dioxide levels tend to be higher in the winter months, but they vary considerably. Ozone levels are consistently higher in the summer months than in the winter. Total hydrocarbon levels do not change greatly over the year, but they tend to be the highest in January or February. Fine particulate levels tend to be highest in July or August and lower from September to June.[58]

Air Quality in Alberta has improved in a number of ways, particularly in the major urban centers. In downtown Calgary, carbon monoxide concentrations decreased by 65% from 1982 to 2000; nitrogen dioxide concentrations decreased by 38% from 1982 to 2000; inhalable particulate values decreased by 46% from 1986 to 1999. Lead concentrations decreased by 98% from 1980 to 1992, and monitoring for lead is no longer needed for Calgary or Edmonton.[58]

Greenhouse gases (GHGs) are gases that prevent heat from escaping the Earth as it radiates away from the ground. This insulating effect may contribute to global warming. In Calgary, the main sources of GHG emissions are the production of electricity used in homes and in industrial operations, vehicles, and natural gas for heating homes and hot water. A small amount of GHG emissions comes from the decomposition of organic waste.

The City of Calgary has a plan to reduce GHG emissions to 50% below the 1990 levels. The city plans to increase its use of “green” power, decrease its reliance on fossil fuels for transport, capture methane from landfills to use in energy production, and improve the energy efficiency of buildings, among other things.[57]

Sightseeing Locations in the South Saskatchewan River Basin

Southern Alberta contains many interesting landforms which can be visited by photographers, natural historians, documentarians and rock collectors. **Dinosaur Provincial Park** is located along the Red Deer River about 35 kilometers northeast of Brooks.[75] It is listed as a World Heritage Site by UNESCO.[27] The land is characteristic of the badlands, a dry region where soft sedimentary rock was deposited by rivers. The Red Deer River Valley was carved out by water from melting glaciers at the end of the last ice age. Erosion by wind and water has produced some unusual shapes in the rock. This park has fossil beds where more than thirty species of dinosaurs from the Cretaceous Period have been found.

Echo Dale Regional Park is located near Medicine Hat. It provides visitors with a panoramic view and guided audio recording of the geological formations in the cliffs along the South Saskatchewan River. It also provides visitors with a tour of the Ajax Coal Mine which was used in the early 20th century.

3-D Topographical Display: Viewers who wish to get a general idea of the topography of the basin in relation to the entire province can view a 3-D model of Alberta located west of Brooks beside the Trans-Canada Highway.

Conclusion

The landscape of the South Saskatchewan River Basin has been influenced by changes in climate, geologic processes and human activity. Millions of years ago sediments were deposited on the Prairies by rivers and seas. Changes in temperature and precipitation led to the development of different kinds of animal and plant life. In the last several thousand years, glaciers carved out river valleys and deposited rocks and gravel.

In future years, the issues of weather, water supply, land use and air quality may become more prominent as human activity is putting the environment under stress.

Recommendations

Below is a list of recommendations for the further study of the river basin and the general environment.

- Conduct more climate simulations for Alberta to help determine if human activity is affecting the climate, and whether air emissions controls are satisfactory.
- Study the effects of erosion in high-risk areas, and determine the risk of property damage.
- Ensure that flood warning systems are effective and improve weather forecasts to predict floods better.
- Conduct long-term studies on the effects of air pollution on humans, relating to respiratory disease, life expectancy.
- Study fluvial processes with respect to the South Saskatchewan River, to predict long-term changes in the river.

Glossary

alluvium
Material deposited by rivers. May consist of sand, silt, clay and organic matter.[63]

convection
The transport of heat through vertical motion, occurring in the lowest few kilometers of the atmosphere. One of the causes of storms.

drumlin
An elongated hill which forms when glacial ice moves across rock debris in a streamlined fashion.[64]

fluvial
Of or relating to a river or stream.

frontal precipitation
Precipitation that occurs when one air mass overtakes another or two air masses converge.

moraine
A mound of unsorted rock debris, deposited by a glacier. Rocks range in size from boulders to sand and clay.[65]

orographic precipitation
Precipitation that occurs when air encounters mountains and is forced to rise.

radiometric dating
Determining the age of rocks by measuring radioactive elements that have a specific rate of decay.

sediment
Small fragments of rock generated by erosion of rock. Grains of sediment can be fine (clay or silt), medium size (sand) or large (gravel). When cemented together, the grains form layers of sedimentary rock.

till
Unsorted glacial drift, ranging in size from clay to large rocks.[77]

Table 1. Notable Bodies of Water in the South Saskatchewan River Basin
Note: The top three lakes are in the South Saskatchewan River Sub-basin.

Body of Water	**Location (Lat/Long)**	**Area (km^2)**	**Max. Depth (m)**	**Mean Depth (m)**	**Drainage Basin Area**
Elkwater Lake	49°39' N, 110°18' W	2.31	8.4	3.5	25.7
Milk River Ridge Reservoir	49°22' N, 112°35' W	15.3	16.5		168
Tyrell Lake	49°23' N, 112°16' W	3.99	6.1		122
St. Mary Reservoir	49°18' N, 113°11' W	37.5	56.4	10.4	2250
Travers Reservoir	50°13' N, 112'51' W	22.5	39.6	18.3	4230
Lake Newell Reservoir	50°25' N, 111°57' W	66.4	19.8	4.8	84.6
McGregor Lake	50°24' N, 112°50' W	51.4	9.7		993
Spray Lakes Reservoir	50°54' N, 115°20' W	19.9	65.4	13.5	493
Ghost Reservoir	51°12' N, 114°45' W	11.0	34	14.5	6460
Buffalo Lake	52°28' N, 112°54' W	93.5	6.5	2.8	1440
Gull Lake	52°34' N, 114°00' W	80.6	8	5.4	206
Crawling Valley Reservoir	50°56' N, 112°21' W	25.1	16	5.2	802
Gleniffer Lake	52°03' N, 114°10' W	17.6	33	11.6	5610
Sylvan Lake	52°18' N, 114°06' W	42.8	18.3	9.6	102

Source: Atlas of Alberta Lakes: http://sunsite.ualberta.ca/Projects/Alberta-Lakes/view/

Table 2. Air quality monitoring stations (active and proposed) in the Palliser Airshed Locations for Jun. 19, 2009

Site number	Location	Coordinates
1	Schuler	50°24’ N, 110°07’ W
2	Burstall	50°42’ N, 110°04’ W
3	Oyen	51°14’ N, 110°31’ W
4	Esther	51°36’ N, 110°13’ W
5	Youngstown	51°36’ N, 111°05’ W
6	Finnegan	51°13’ N, 111°58’ W
7	Bassano	50°44’ N, 112°24’ W
8	Jenner	50°45’ N, 111°01’ W
9	CFB Suffield	50°29’ N, 111°10’ W
10	Iddesleigh	50°40’ N, 111°18’ W
11	Brooks	50°35’ N, 111°51’ W
12	Tilley	50°26’ N, 111°42’ W
13	Hays / Bow Island	50°06’ N, 111°30’ W
14	Whitla	49°51’ N, 111°06’ W
15	Foremost	49°31’ N, 111°28’ W
16	Pendant d’Oreille	49°11’ N, 110°57’ W
17	Onefour	49°13’ N, 110°12’ W
18	Medicine Hat – Taylor	50°00‘ N, 110°38’ W
19	Medicine Hat – Crescent Heights	50°03’ N, 110°41’ W
20	Redcliff	50°04’ N, 110°45’ W
Rover Site 01	(Brooks)	50°35’ N, 111°51’ W
Rover Site 02	(Jenner)	50°45’ N, 111°01’ W
Rover Site 03	(Burstall)	50°42’ N, 110°04’ W
Rover Site 04	(Onefour)	49°14’ N, 110°14’ W

Source: Palliser Airshed Society and Google Earth. http://www.palliserairshed.com/data/data.php

Table 3. Maximum Allowable Concentrations of Various Pollutants in Alberta

Pollutant	**Max. 1-hour average**	**Max. 8-hour average**	**Max. 24-hour average**	**Max. annual average**
ozone	82 ppb or 160 µg per m^3			
sulfur dioxide	172 ppb or 450 µg per m^3		57 ppb or 150 µg per m^3	11 ppb or 30 µg per m^3
hydrogen sulfide	10 ppb or 14 µg per m^3		3 ppb or 4 µg per m^3	
carbon monoxide	15,000 µg per m^3 or 13,000 ppb	6000 µg per m^3 or 5000 ppb		
ammonia	1400 µg per m^3 or 2000 ppb			
nitrogen dioxide	400 µg per m^3 or 212 ppb		200 µg per m^3 or 106 ppb	60 µg per m^3 or 32 ppb
lead	1.5 µg per m^3			
methanol	2000 ppb or 2600 µg per m^3			
chlorine	5.0 ppb or 15 µg per m^3			
$PM_{2.5}$	80 µg per m^3 (guideline only)		30 µg per m^3	
total suspended PM			100 µg per m^3	60 µg per m^3

Source: Alberta Environment. http://environment.gov.ab.ca/info/library/5726.pdf

Table 4. Average Concentrations of Pollutants in Calgary in the Period of 1998 to 2003

Pollutant	**Concentration**
carbon monoxide	600 ppb
nitrogen dioxide	23 ppb
sulfur dioxide	3 ppb
$PM_{2.5}$	7.0 µg per m^3
lead $PM_{2.5}$	0.0003 µg per m^3

Source: CASAdata and Alberta Environment. http://environment.gov.ab.ca/info/library/5726.pdf

Table 5. Geologic Time Scale

(mya = million years ago)

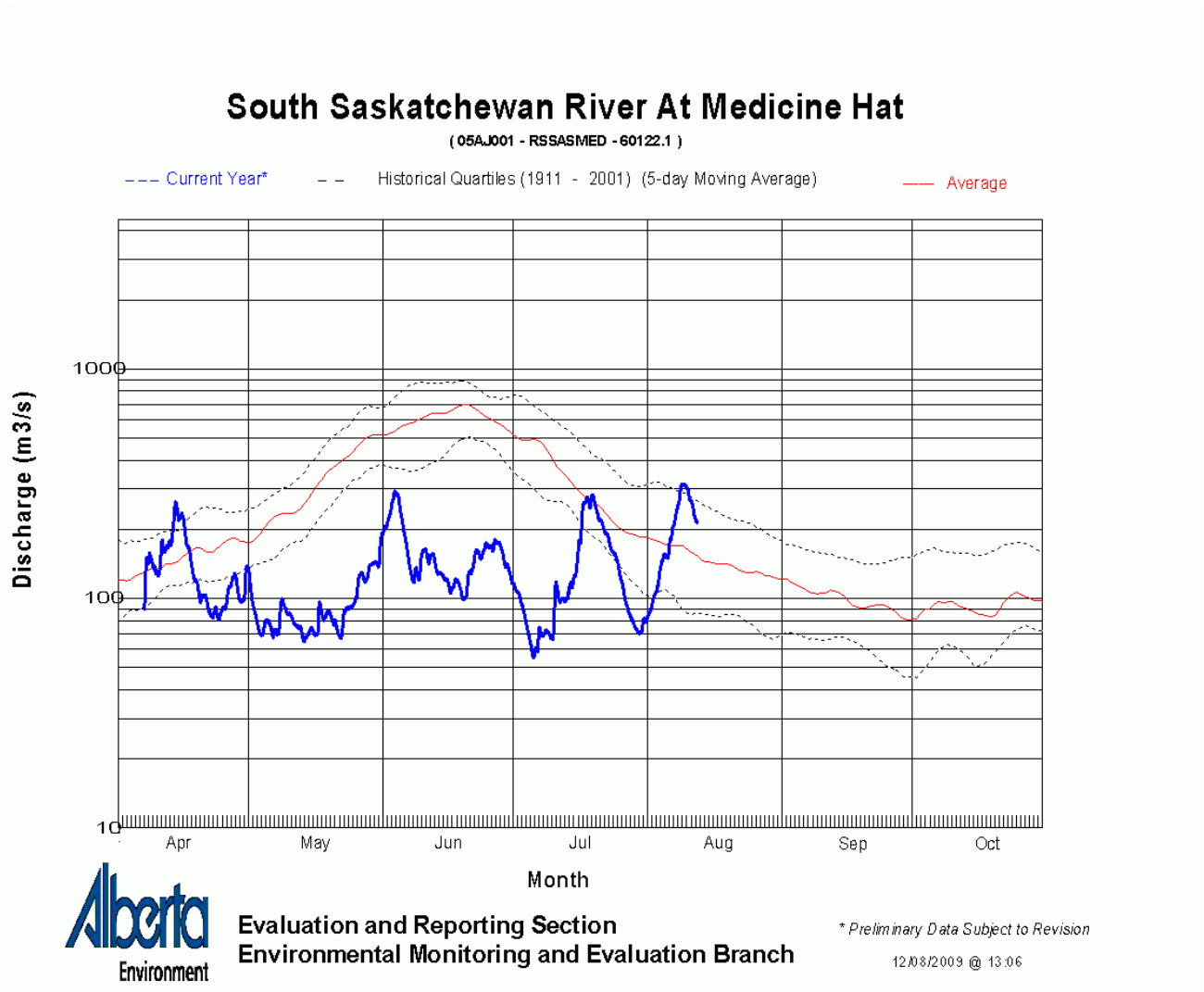
Phanerozoic Eon (543 mya to present)	Cenozoic Era (65 mya to today)	Quaternary (1.8 mya to today) Holocene (10,000 years to today) Pleistocene (1.8 mya to 10,000 yrs) Tertiary (65 to 1.8 mya) Pliocene (5.3 to 1.8 mya) Miocene (23.8 to 5.3 mya) Oligocene (33.7 to 23.8 mya) Eocene (54.8 to 33.7 mya) Paleocene (65 to 54.8 mya)
	Mesozoic Era (248 to 65 mya)	Cretaceous (144 to 65 mya) Jurassic (206 to 144 mya) Triassic (248 to 206 mya)
	Paleozoic Era (543 to 248 mya)	Permian (290 to 248 mya) Carboniferous (354 to 290 mya) Pennsylvanian (323 to 290 mya) Mississippian (354 to 323 mya) Devonian (417 to 354 mya) Silurian (443 to 417 mya) Ordovician (490 to 443 mya) Cambrian (543 to 490 mya) Tommotian (530 to 527 mya)
Precambrian Time (4,500 to 543 mya)	Proterozoic Era (2500 to 543 mya)	Neoproterozoic (900 to 543 mya) Vendian (650 to 543 mya) Mesoproterozoic (1600 to 900 mya) Paleoproterozoic (2500 to 1600 mya)
	Archaean (3800 to 2500 mya)	
	Hadean (4500 to 3800 mya)	

Source: University of California Museum of Paleontology.
http://www.ucmp.berkeley.edu/help/timeform.html

Figure 1. Selected Rivers and Streams in the South Saskatchewan River Basin **NEED MAP**

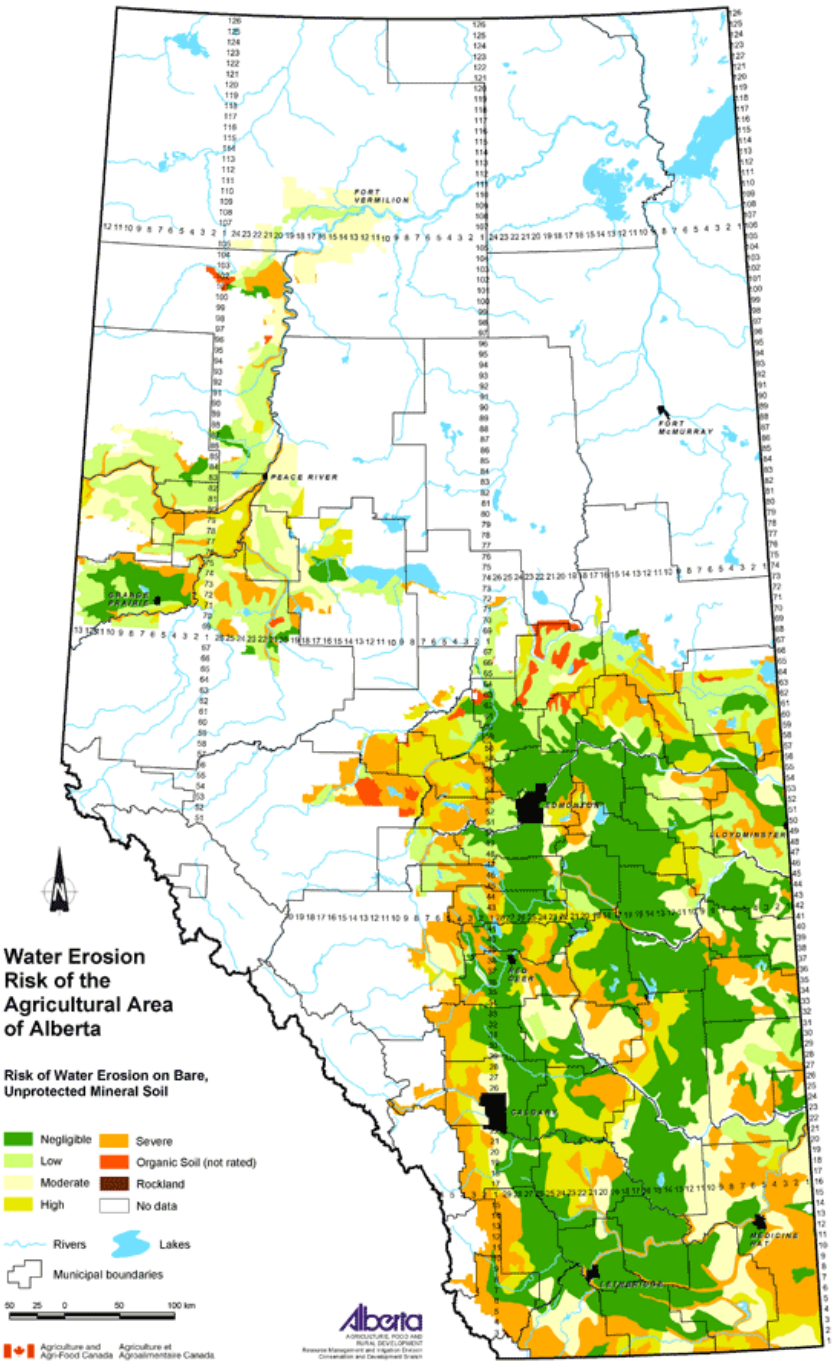
South Saskatchewan River
- Bow River
  - Cascade River
  - Crowfoot River
  - Elbow River
  - Ghost River
  - Highwood River
  - Kananaskis River
  - Spray River
- Bullshead Creek
- Oldman River
  - Belly River
  - Castle River
  - Crowsnest River
  - Little Bow River
  - St. Mary River
  - Willow Creek
- Red Deer River
  - Alkali Creek
  - Berry Creek
  - Blood Indian Creek
  - Bullpond Creek
  - Kneehills Creek
  - Medicine River
  - Rosebud River
  - Threehills Creek
- Ross Creek
- Seven Persons Creek

Figure 2. Flow Rate for the South Saskatchewan River at Medicine Hat.



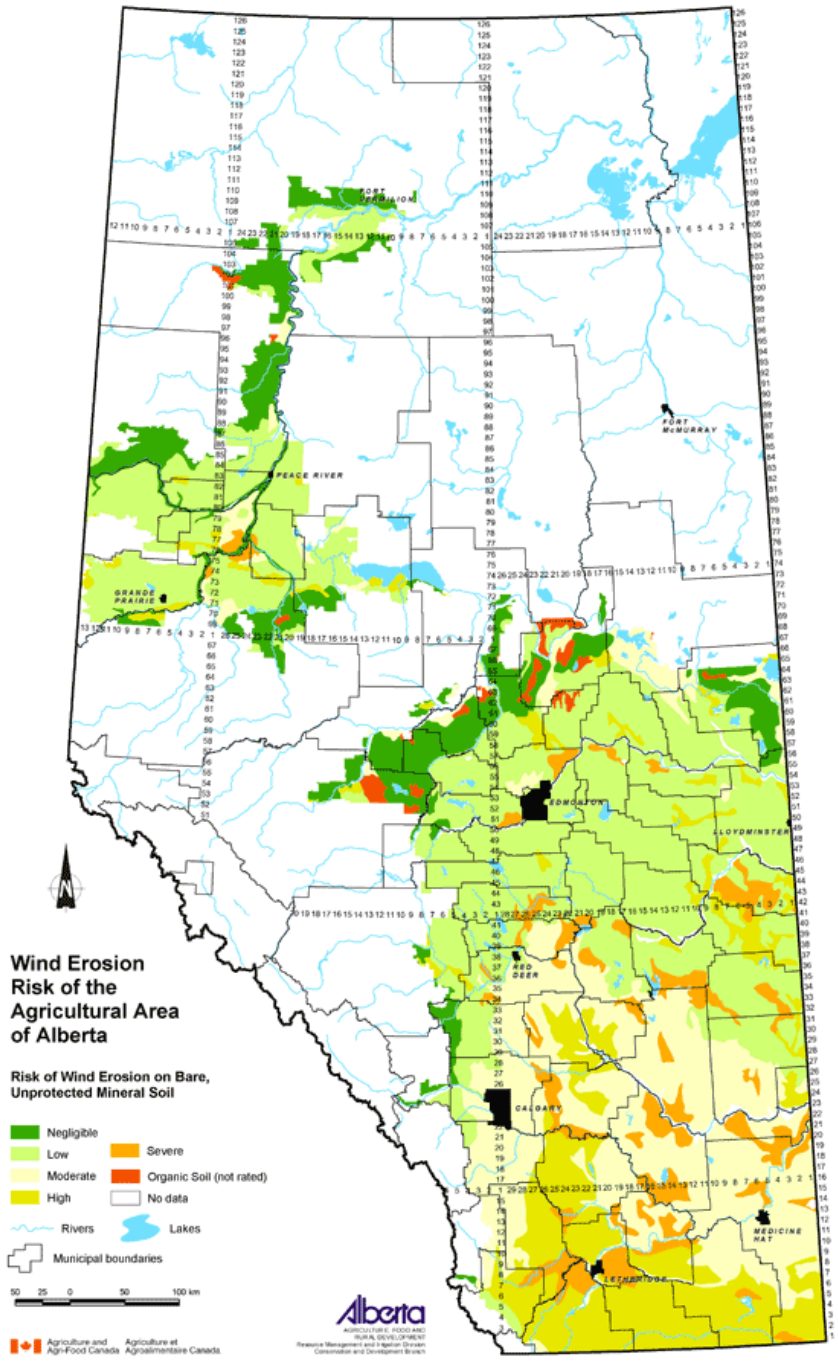
Source: Alberta Environment.
http://www.environment.alberta.ca/apps/basins/DisplayData.aspx?Type=Figure&BasinID=9&DataType=1&StationID=RSSASMED

Figure 3. Water Erosion Risk of the Agricultural Area of Alberta

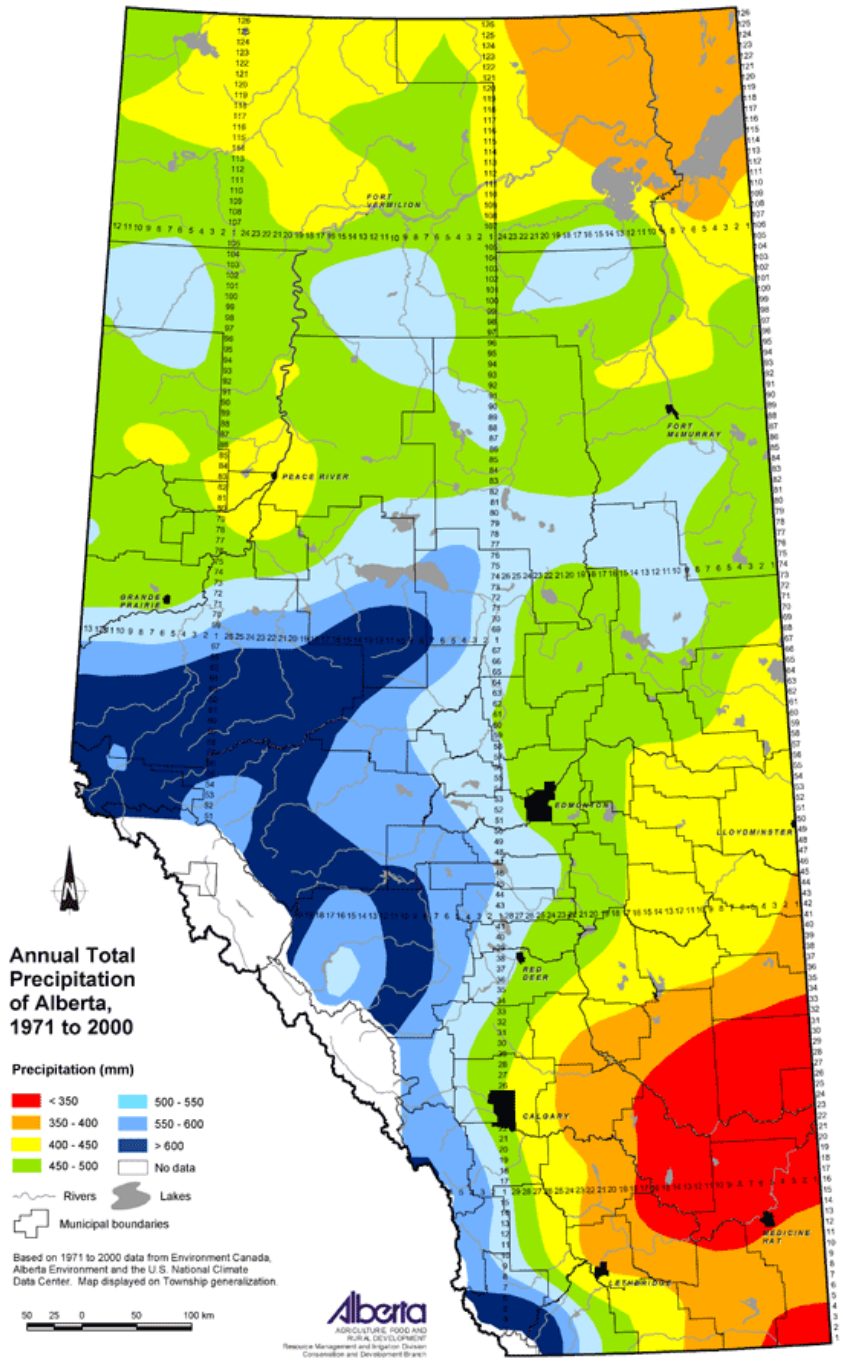


Source: Alberta Ministry of Agriculture and Rural Development.
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10314

Figure 4. Wind Erosion Risk of the Agricultural Area of Alberta

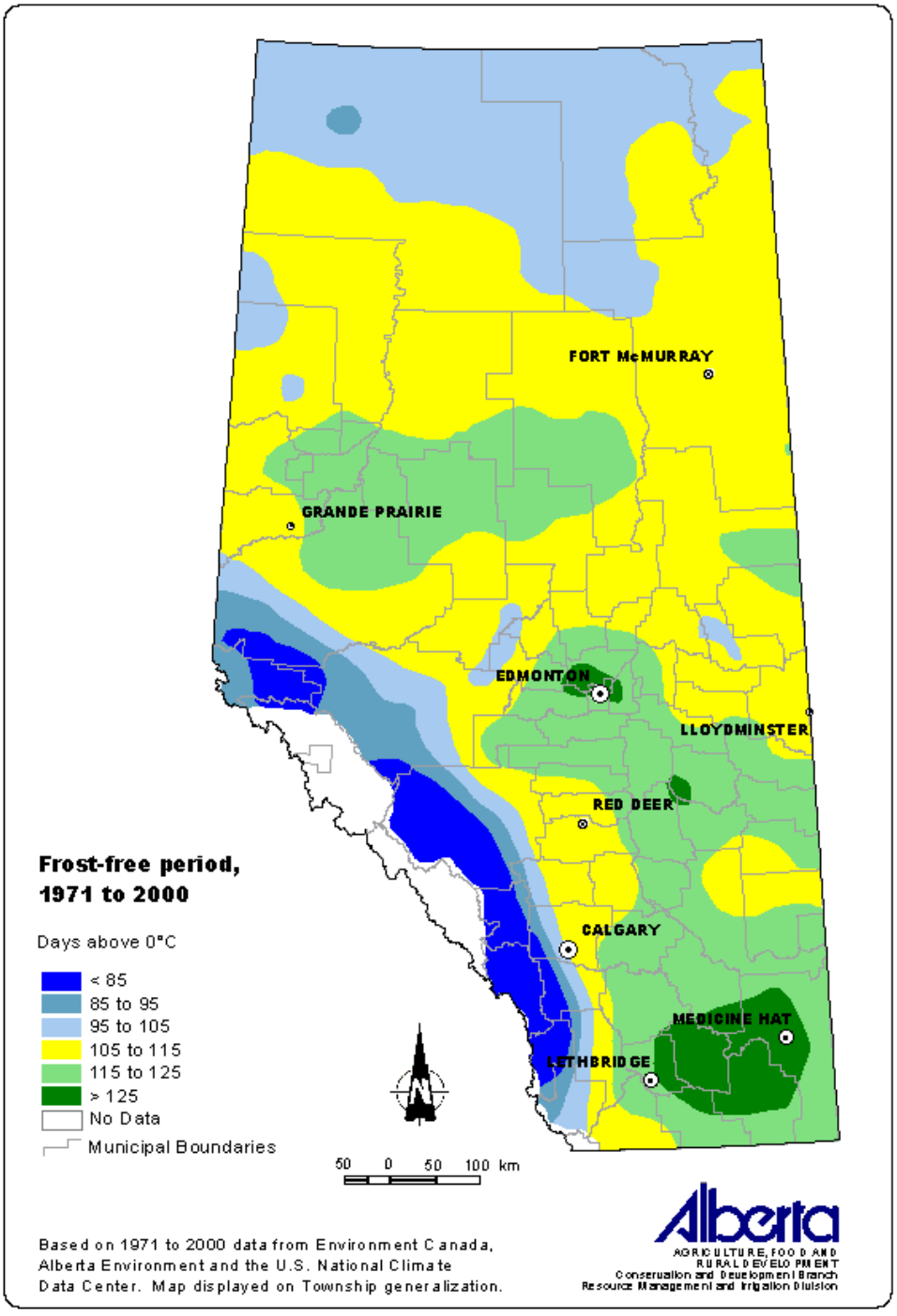


Source: Alberta Ministry of Agriculture and Rural Development.
Figure 5. Annual Total Precipitation of Alberta, 1971 to 2000.



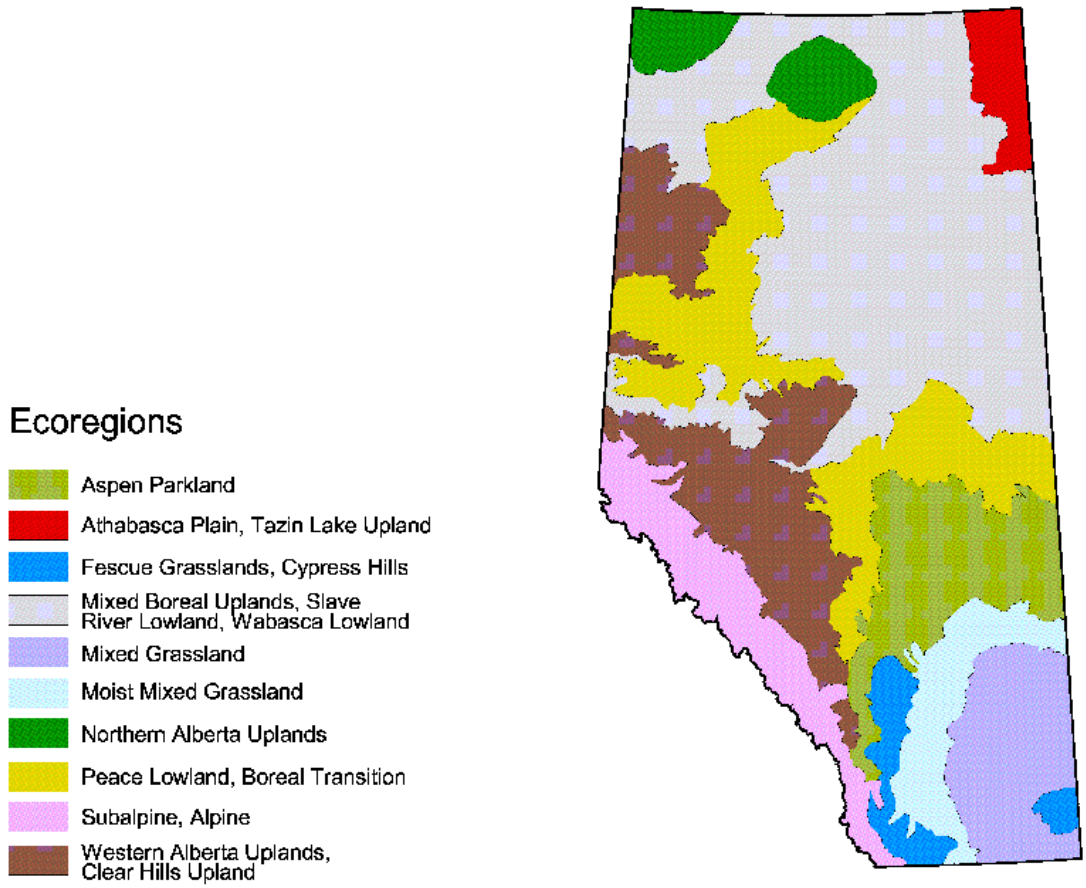
Source: Alberta Ministry of Agriculture and Rural Development.
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10303

Figure 6. Frost-free Days in Alberta during the Period of 1971 to 2000



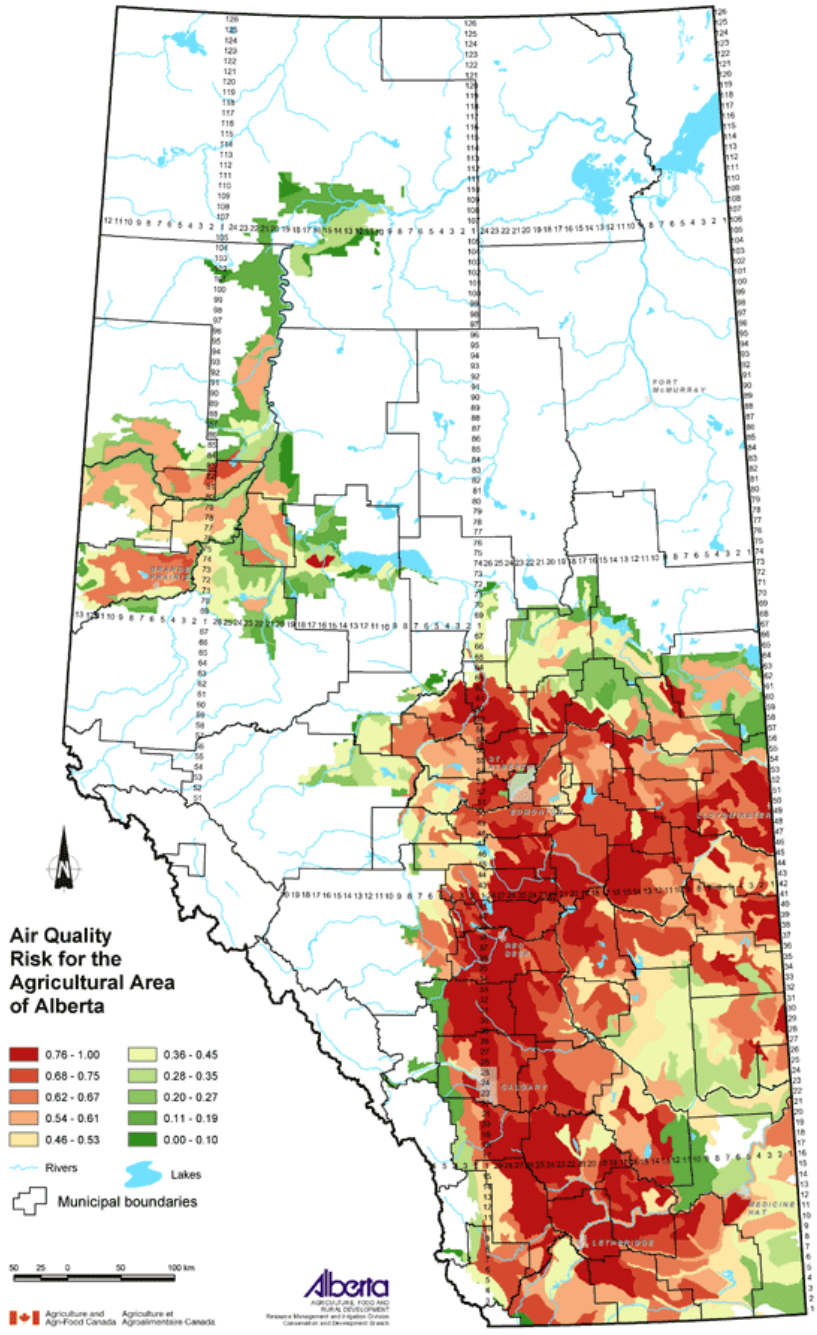
Source: Alberta Ministry of Agriculture and Rural Development.
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10304

Figure 7. Ecoregions of Alberta



Source: Alberta Ministry of Agriculture and Rural Development.
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6299

Figure 8. Air Quality Risk for the Agricultural Area of Alberta.



source: Alberta Ministry of Agriculture and Rural Development.
http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10341

References

1. Alberta Geological Survey. Alberta Coal Occurrences and Potential Coalbed Methane (CBM) Exploration Areas. N.d. <http://www.ags.gov.ab.ca/energy/cbm/coal_and_cbm_intro.html>. 21 July 2009.

2. Alberta Geological Survey. CBM Potential of the Drumheller Coal Zone in the Alix Area. N.d. <http://www.ags.gov.ab.ca/energy/cbm/cbm_potential_drumheller_Coal_Zone.html>. 11 August 2009

3. Alberta Geological Survey. Coal Maturation and Coalbed Methane (CBM) Generation. 21 July 2009. <http://www.ags.gov.ab.ca/energy/cbm/coal_and_cbm_intro2.html> 7 August 2009.

4. Alberta Geological Survey. Cretaceous Colorado / Alberta Group. *Atlas of the Western Canada Sedimentary Basin*. 15 August 2008. <http://www.ags.gov.ab.ca/publications/wcsb_atlas/A_CH20/CH_20.html >

5. Alberta Geological Survey. Cretaceous Mannville Group. *Atlas of the Western Canada Sedimentary Basin*. 15 August 2008. <http://www.ags.gov.ab.ca/publications/wcsb_atlas/A_CH19/CH_19.html>. 11 August 2009.

6. Alberta Geological Survey. Introduction. *Atlas of the Western Canada Sedimentary Basin*. 31 July 2008. <http://www.ags.gov.ab.ca/publications/wcsb_atlas/A_CH01/CH_01_F.html>. 21 August 2009.

7. Alberta Geological Survey. Middle Cambrian to Lower Ordovician Strata. *Atlas of the Western Canada Sedimentary Basin.* 7 August 2008. <http://www.ags.gov.ab.ca/publications/wcsb_atlas/A_CH08/CH_08.html>. 20 August 2009.

8. Alberta Geological Survey. Middle Ordovician to Lower Devonian Strata. *Atlas of the Western Canada Sedimentary Basin*. 8 August 2008. <http://www.ags.gov.ab.ca/publications/wcsb_atlas/A_CH09/CH_09.html>. 20 August 2009.

9. Alberta Geological Survey. Structure and Architecture. *Atlas of the Western Canada Sedimentary Basin*. 6 August 2008. <http://www.ags.gov.ab.ca/publications/wcsb_atlas/A_CH03/FG03_02.GIF>. 20 August 2008.

10. Alberta Geological Survey. Uppermost Cretaceous and Tertiary Strata. *Atlas of the Western Canada Sedimentary Basin*. 20 August 2008. <http://www.ags.gov.ab.ca/publications/wcsb_atlas/A_CH24/CH_24.html>. 11 August 2009.

11. Alberta Geological Survey. Uranium in Alberta. 24 November 2008. <http://www.ags.gov.ab.ca/minerals/uranium/uranium.html>. 21 August 2009.

12. Alberta Ministry of Agriculture and Rural Development. Agricultural Land Resource Atlas of Alberta – Air Quality Risk for the Agricultural Area of Alberta. 1 September 2005. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10341. 14 August 2009.

13. Alberta Ministry of Agriculture and Rural Development. Agricultural Land Resource Atlas of Alberta – Annual Total Precipitation of Alberta, 1971 to 2000. 1 September 2005. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10303>. 14 August 2009.

14. Alberta Ministry of Agriculture and Rural Development. Agricultural Land Resource Atlas of Alberta – Frost-free Period of Alberta, 1971 to 2000. 1 September 2005. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10304>. 12 August 2009.

15. Alberta Ministry of Agriculture and Rural Development. Agricultural Land Resource Atlas of Alberta – Soil Groups of Alberta. 1 September 2005. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10307>. 11 August 2009.

16. Alberta Ministry of Agriculture and Rural Development. Agricultural Land Resource Atlas of Alberta – Water Erosion Risk of the Agricultural Area of Alberta. 1 September 2005. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10314>. 14 August 2009.

17. Alberta Ministry of Agriculture and Rural Development. Agroclimatic Atlas of Alberta: Climate Basics. 7 September 2007. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6294>. 18 August 2009.

18. Alberta Ministry of Agriculture and Rural Development. Agroclimatic Atlas of Alberta: Climate of Alberta. 9 September 2003. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6299> 14 August 2009.

19. Alberta Ministry of Agriculture and Rural Development. Agroclimatic Atlas of Alberta: Weather in Alberta. 9 September 2003. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6295>. 22 July 2009.

20. Alberta Ministry of Agriculture and Rural Development. The Mixed Grassland Ecoregion. 1 August 2001. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag1499>. 22 July 2009.

21. Alberta Ministry of Energy. About Coalbed Methane. 9 January 2008. <http://www.energy.gov.ab.ca/NaturalGas/754.asp>. 11 August 2009.

22. Alberta Ministry of Environment. Alberta Ambient Air Quality Objectives. June 2009. <http://environment.gov.ab.ca/info/library/5726.pdf>. 14 August 2009.

23. Alberta Ministry of Environment. Alberta Climate Model to Provide Climate Estimates (1961-1990) for Any Location in Alberta from its Geographic Coordinates. Alberta Environment. 2005. <http://environment.gov.ab.ca/info/library/6151.pdf>. 11 August 2009.

24. Alberta Ministry of Environment. Alberta's Air Quality Index. N.d. <http://environment.gov.ab.ca/info/library/5729.pdf>. 21 August 2009.

25. Alberta Ministry of Environment. Frequently Asked Questions – Definitions/Terminology. N.d. <http://environment.alberta.ca/forecasting/FAQ/definitions.html>. 3 July 2009.

26. Alberta Ministry of Environment. South Saskatchewan River Basin Water Information Portal. N.d. <http://ssrb.environment.alberta.ca>. 7 August 2009.

27. Alberta Tourism, Parks and Recreation. Dinosaur Provincial Park: Location. 11 May 2009. <http://tpr.alberta.ca/parks/dinosaur/location.asp.> 21 August 2009.

28. Alberta Tourism, Parks and Recreation. Geology: Cypress Hills Interprovincial Park. N.d. <http://www.tpr.alberta.ca/parks/cypresshills/Download/Geology.pdf>. 10 August 2009.

29. Alberta Wilderness Association. Pakowki Lake. 2000. <http://issues.albertawilderness.ca/PAKOWKI/Pakowki_Lake.htm>. 7 August 2009.

30. Barendregt, R. W., M. C. Wilson and F. J. Jankunis. *The Palliser Triangle*. 1993.

31. Barrow, Elaine, and Ge Yu. Climate Scenarios for Alberta. May 2005. <http://www.parc.ca/pdf/Alberta_Scenarios/main_report.pdf>. 11 August 2009.

32. Bird Studies Canada. Pakowki Lake; Foremost, Alberta. N.d. <http://www.bsc-eoc.org/iba/site.jsp?siteID=AB064>. 25 May 2009.
33. Bone, Robert M. *The Regional Geography of Canada*, 3rd edition. Oxford University Press: 2005.

34. Bowman, Jeff, and Julian Sachs. Chemical and physical properties of some saline lakes in Alberta and Saskatchewan. *Saline Systems* 4:3. 2008. <http://www.redberrylake.ca/images/Adobe%20documents/Chemical%20and%20physical%20properties%20of%20some%20saline%20lakes%20in%20Alberta%20and%20Saskatchewan.pdf>. 20 July 2009.

35. Canadian Broadcasting Corporation. “Fall of fireball in Alberta caught on tape.” *CBC.ca*. 2 December 2002. <http://www.cbc.ca/health/story/2002/11/28/meteorite021128.html>. 14 August 2009.

36. Canadian Broadcasting Corporation. “River still rising in Medicine Hat.” 11 June 2005. <http://www.cbc.ca/canada/story/2005/06/10/medicine-hat-flood050610.html>. 10 August 2009.

37. Canadian Broadcasting Corporation. “Western Canadian meteor had mass of 10 tonnes: scientists.” *CBC.ca*. 25 November 2008. <http://www.cbc.ca/canada/edmonton/story/2008/11/25/meteor.html?ref=rss&loomia_si=t0:a16:g2:r2:c0.0473133:b19806909>. 14 August 2009.

38. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Battle Formation). 18 March 2009. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:000893>. 11 August 2009.

39. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Bearpaw Formation). 19 March 2009. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:000966>. 11 August 2009.

40. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Belly River Group). 24 March 2009. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:001145>. 20 August 2009.

41. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Colorado Group). 28 May 2008. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:003233>. 11 August 2009.

42. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Crowfoot Formation). 29 April 2003. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:003592>. 11 August 2009.

43. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Deadwood Formation). 16 May 2004. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:003832>. 20 August 2009.

44. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Earlie Formation). 16 May 2004. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:004396>. 20 August 2009.

45. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Eastend Formation). 29 April 2003. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:004444>. 20 August 2009.

46. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Foremost Formation). 29 April 2003. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:005119>. 13 August 2009.

47. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Frenchman Formation). 28 May 2008. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:005334>. 11 August 2009.

48. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Interlake Group). 20 May 2004. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:006978>. 20 August 2009.

49. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Mannville Group). 28 May 2008. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:009141>. 11 August 2009.

50. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Milk River Formation). 28 May 2008. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:009784>. 11 August 2009.

51. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Oldman Formation). 28 May 2008. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:011229>. 11 August 2009.

52. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Pakowki Formation). 8 April 2008. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:011476>. 11 August 2009.

53. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Ravenscrag Formation). 28 May 2008. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:012524>.11 August 2009.
54. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Whitemud Formation). 26 January 2009. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:016419>. 13 August 2009.

55. Canadian Geoscience Knowledge Network. Lexicon of Canadian Geologic Units (Yeoman Formation). 29 January 2009. <http://cgkn1.cgkn.net/weblex/weblex_litho_detail_e.pl?00053:016769>. 20 August 2009.

56. The City of Calgary. 2005 Flood Report. N.d. <http://www.calgary.ca/docgallery/bu/water_services/emergency_planning/2005_flood/full_report_on_flooding.pdf>. 11 August 2009.

57. City of Calgary. Climate Change. 21 July 2009. <http://content.calgary.ca/CCA/City+Hall/Business+Units/Environmental+Management/Climate+Change/Climate+Change.htm>. 21 August 2009.

58. Clean Air Strategic Alliance. Substances Monitored. 2006. <http://www.casadata.org/pollutants/index.asp>. 11 August 2009.

59. Cypress Hills Interprovincial Park. About Cypress Hills Interprovincial Park: Weather and Climate. N.d. <http://www.cypresshills.com/index.php?id=142>. 10 August 2009.

60. Dickinson, Dawn. Chappice Lake: Important Bird Area Conservation Plan. N.d. <http://www.ibacanada.com/pdf/ChappiceLake.pdf>. 20 July 2009.

61. Ducks Unlimited. Prairie Pothole Region. N.d. <http://www.ducks.org/conservation/initiative45.aspx>. 10 August 2009.

62. Encyclopaedia Britannica. Air mass. *Encyclopaedia Britannica Online*. 2009. <http://www.britannica.com/EBchecked/topic/10749/air-mass>. 10 August 2009.

63. Encyclopaedia Britannica. Alluvium. *Encyclopaedia Britannica Online*. 2009. <http://www.britannica.com/EBchecked/topic/16665/alluvium>. 21 August 2009.

64. Encyclopaedia Britannica. Drumlin (geology). *Encyclopaedia Britannica Online*. 2009. <http://www.britannica.com/EBchecked/topic/172086/drumlin>. 14 August 2009.

65. Encyclopaedia Britannica. Moraine (geology). *Encyclopaedia Britannica Online.* 2009. <http://www.britannica.com/EBchecked/topic/391696/moraine>. 14 August 2009.

66. Environment Canada. Canadian Climate Normals or Averages 1971-2000. 1 November 2008. <http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html>. 10 August 2009.

67. Environment Canada. Fescue Prairie. 24 August 2004. <http://www.mb.ec.gc.ca/nature/whp/prgrass/df03s34.en.html>. 22 July 2009.

68. Erickson, Jim. “Glaciers melting at fastest rate in 10,000 years.” *BNET*. 25 November 2004. <http://findarticles.com/p/articles/mi_qn4188/is_20041125/ai_n11490937/>. 22 July 2009.

69. Geological Survey of Canada. Sand Dune & Climate Change Studies in the Prairie Provinces. 2001. <http://gsc.nrcan.gc.ca/climate/sanddune/pdf/sanddune.pdf> 10 August 2009.

70. Gusman, Jake A., Richard L. Voigt and Selena M. Forman. Delineation and Classification of Prairie Pothole Wetlands Using GIS and Aerial Photos. *ASCE Publications*, section 34, ch. 1. 2001. <http://cedb.asce.org/cgi/WWWdisplay.cgi?0106390>. 21 July 2009.

71. Heritage Community Foundation. Alberta’s Wetlands. 1994. <http://www.abheritage.ca/abnature/environmental/wetlands_alberta.htm>. 10 August 2009.

72. Heritage Community Foundation. Red Rock Coulee. N.d. <http://www.abheritage.ca/abnature/grasslands/featured_red_rock_coulee.htm>. 11 August 2009.

73. LaBaugh, James W., Thomas C. Winter and Donald O. Rosenberry. Hydrologic Functions of Prairie Wetlands. *Great Plains Research* 8: 17-37. 1998. <http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1361&context=greatplainsresearch>. August 10, 2009.

74. Lemmen, D. S. and R. E. Vance (ed.). *Holocene Climate and Environmental Change in the Palliser Triangle: A Geoscientific Context for Evaluating the Impacts of Climate Change on the Southern Canadian Prairies*. Geological Survey of Canada: 1999.

75. MapArt Publishing. *Alberta Road Atlas*. 2004.

76. Marsh, James. Saskatchewan River. *The Canadian Encyclopedia*. N.d. <http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1ARTA0007158> 20 July 2009.

77. Merriam-Webster Online Dictionary. Till. 2009. <http://www.merriam-webster.com/dictionary/till>. 21 August 2009.

78. NASA. World Book at NASA: Meteor. 29 November 2007. <http://www.nasa.gov/worldbook/meteor_worldbook.html>. 21 August 2009.

79. Ontario Ministry of Agriculture, Food and Rural Affairs. Growing Degree Days in Ontario – A Description. 12 June 2009. <http://www.omafra.gov.on.ca/english/crops/facts/GDDOntario.htm>. 20 August 2009.

80. Ontario Ministry of Agriculture, Food and Rural Affairs. Soil Erosion – Causes and Effects. 17 August 2009. <http://www.omafra.gov.on.ca/english/engineer/facts/87-040.htm>. 20 August 2009.

81. Palliser Airshed Society. Air Quality Data. N.d. <http://www.palliserairshed.com/data/data.php>.

82. Palliser Airshed Society. Carbon Monoxide. N.d. <http://www.palliserairshed.com/health/CO.php>. 20 August 2009.

83. Palliser Airshed Society. Ground Level Ozone (O_3). N.d. <http://www.palliserairshed.com/health/O3.php>. 20 August 2009.

84. Palliser Airshed Society. Nitrogen Dioxide (NO_2). <http://www.palliserairshed.com/health/NO2.php>. 20 August 2009.

85. Palliser Airshed Society. Particulate Matter ($PM_{2.5}$ and PM_{10}). N.d. <http://www.palliserairshed.com/health/PM.php>. 11 August 2009.
86. Palliser Airshed Society. Sulphur Dioxide (SO_2). N.d. <http://www.palliserairshed.com/health/SO2.php>. 20 August 2009.

87. St. Mary River Irrigation District. General. N.d. <http://www.smrid.ab.ca/smrid/Default.htm>. 20 July 2009.

88. St. Mary River Irrigation District. St. Mary River Irrigation District (map). N.d. <http://www.smrid.ab.ca/smrid/smrid.pdf>. 20 July 2009.

89. Saskatchewan Ministry of Energy and Resources. Cypress Hills. 2008. <http://www.er.gov.sk.ca/Default.aspx?DN=3719,3580,3569,3539,3538,3385,2936,Documents>. 11 August 2009.

90. Savage, Candice. *Prairie: A Natural History*. Greystone Books: 2004.

91. Sosiak, Al. Pakowki Lake Water Quality Study. July 1997. <http://environment.gov.ab.ca/info/library/5813.pdf>. 9 June 2009.

92. South East Alberta Watershed Alliance. Welcome to SEAWA. 2008. <http://www.seawa.ca>. 20 July 2009.

93. South West Grid for Learning Trust. Journey Along a River. 2004. <http://content.swgfl.org.uk/rivers/WaterWheel.htm>. 20 July 2009.

94. The Atlas of Canada. Weather. 12 December 2006. <http://atlas.nrcan.gc.ca/site/english/learningresources/facts/superweather.html>. 10 August 2009.

95. The Weather Network. Statistics: Medicine Hat, AB, Canada. 2009. <http://www.theweathernetwork.com/statistics/C02079/caab0211>. 22 July 2009.

96. The Weather Network. Statistics: Phoenix/Int'l, AZ, United States of America. 2009. <http://www.theweathernetwork.com/statistics/C02742/usaz0166>. 22 July 2009.

97. The Weather Network. Statistics: Toronto Island Airport, ON, Canada. 2009. <http://www.theweathernetwork.com/statistics/C01997/caon0696> 22 July 2009.

98. University of Alberta Dept. of Biological Sciences. Lakes of the Atlas: Elkwater Lake. *Atlas of Alberta Lakes*. N.d. <http://sunsite.ualberta.ca/Projects/Alberta-Lakes/view/?region=South%20Saskatchewan%20Region&basin=South%20Saskatchewan%20River%20Basin&lake=Elkwater%20Lake&number=124&page=Introduction>. 20 July 2009.

99. University of Alberta Dept. of Biological Sciences. Lakes of the Atlas: Travers Reservoir. *Atlas of Alberta Lakes*. N.d. <http://sunsite.ualberta.ca/Projects/Alberta-Lakes/view/?region=South%20Saskatchewan%20Region&basin=Oldman%20River%20Basin&lake=Travers%20Reservoir&number=123&page=Introduction>. 20 July 2009.

100. University of California Museum of Paleontology. Web Geological Time Machine. November 2002. <http://www.ucmp.berkeley.edu/help/timeform.html>. 14 August 2009.

101. U.S. Geological Survey. What Is a Desert? 18 December 2001. <http://pubs.usgs.gov/gip/deserts/what/>. 22 July 2009.

102. Water Matters Society of Alberta. Bow River Sub-basin. N.d. <http://www.water-matters.org/watershed/bow-river-sub-basin>. 21 August 2009.

103. Water Matters Society of Alberta. Climate Change: How will it affect the Bow River? 24 April 2008. <http://www.water-matters.org/node/136>. 22 July 2009.

104. Water Matters Society of Alberta. Milk River Basin. N.d. <http://www.water-matters.org/watershed/milk-river-basin>. 20 July 2009.

105. Water Matters Society of Alberta. Oldman River Basin. N.d. <http://www.water-matters.org/watershed/oldman-river-sub-basin>. 21 August 2009.

106. Water Matters Society of Alberta. Protecting birds of prey with better stormwater management. 11 December 2008. <http://www.water-matters.org/node/252>. 21 August 2009.

107. Water Matters Society of Alberta. Red Deer River Sub-basin. N.d. <http://www.water-matters.org/watershed/red-deer-river-sub-basin>. 21 August 2009.

108. Water Matters Society of Alberta. South Saskatchewan River Sub-basin. N.d. <http://www.water-matters.org/watershed/south-saskatchewan-river-sub-basin>. 9 June 2009.

109. Wetlands Alberta. What is a Wetland? 2009. <http://www.wetlandsalberta.ca/what-is-a-wetland/>. 18 August 2009.

110. Whyte Museum of the Canadian Rockies. Alberta's Aquatic Ecosystems. N.d. <http://www.whyte.org/time/riveroflife/SOEAqua3.pdf>. 10 August 2009.

111. Yansa, Catherine H. Holocene paleovegetation and paleohydrology of a prairie pothole in southern Saskatchewan, Canada. *Journal of Paleolimnology* 19: 429-441. 1998. <https://www.msu.edu/~yansa/Yansa%201998.pdf>.10 August 2009.

112. The University of Texas at Austin, The Water Geology Library, Glossary. http://www.lib.utexas.edu/geo/ggtc/gloss.html

South East Alberta Watershed Alliance
721 97 Carry Drive SE
Medicine Hat, Alberta, Canada T1B 3M6

www.seawa.ca **403.488.8110**

The **South East Alberta Watershed Alliance (SEAWA)** was formed in 2007 and incorporated as a non-profit society in 2008. SEAWA is the designated WPAC (Watershed Policy and Advisory Council) for South East Alberta. SEAWA Members include interested individuals throughout the watershed along with our communities, ranchers, farmers, industries, companies, governments, conservation groups and educational institutions.

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

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

SEAWA has over two hundred members and encourages new individual and community sector members. We are proud to include the following among our founding members:

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

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

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

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

SEAWA Watershed Reports are part of the SEAWA Web-based State of the Watershed Report. Funding for this series of SEAWA Watershed Reports was provided by:

Government of Alberta

AACTI Alberta Association of Colleges & Technical Institutes