A Case Study of the Saskatchewan River System

For: Rosenberg Conference on Managing Upland Watersheds in an Era of Global Change

Banff, Alberta

6-11 Sept 2005

D. W. Schindler

Department of Biological Sciences

University of Alberta

Edmonton AB Canada

T6G 2E9

W. F. Donahue

Freshwater Research Limited

Edmonton, Alberta

T6C 0R6

ABSTRACT

Despite having relatively low average population density in most of its catchment, the Saskatchewan River has developing problems for management.

Much of the river runs through semi-arid parts of the western prairies that contribute little water to the river. The river's headwaters in the Rocky Mountains provide most of the runoff that has allowed agriculture and large cities to develop along the river. Waters in parts of the South Saskatchewan watershed have already been overallocated, largely for irrigated agriculture, threatening the instream flow needs of valuable fisheries and the availability of water for downstream users.

The 20th century was wetter than average, and it is likely that prolonged droughts will occur in the future. Climate change is warming the basin rapidly, exacerbating water scarcity by causing glaciers to dwindle, less precipitation to fall as snow, snowpacks to melt earlier, and evaporation to increase. The result will be decreased water supplies, and higher concentrations of nutrients and other contaminants in the rivers.

Modifications to the river's channel and catchment are also significant. Numerous dams and reservoirs have caused modifications to flow patterns and increased evaporation. While the impoundments are highly beneficial to residents near the reservoirs, they allow less water to pass downstream, particularly in the summer months when water is in high demand for human activity, and fishes are stressed by high temperature or low oxygen. The catchments of most mountain headwaters are well protected, but most of the prairie parts of the basin have been converted to agriculture. Over 50% of wetlands have been drained or filled, limiting the capacity of the basin to accommodate drought. Pollutant loads have increased, of both nutrients and

pathogens. Again, effects are most severe in the South Saskatchewan basin, particularly in the Oldman and Bow River drainages.

A number of recent water management initiatives show some promise for mitigating some of the river’s problems, but they will have to be intensified to accommodate both human activity and healthy biota. Coordination between all levels of government will be essential.

INTRODUCTION

GENERAL FEATURES OF THE SASKATCHEWAN RIVER SYSTEM

The Saskatchewan River system drains 334,100km^2 of the southern parts of the western prairie provinces of Canada, and 1800 km^2 of the adjacent USA (Figure 1). It is a major part of the Nelson River system, which drains waters of western Canada and the northern USA to Hudson's Bay (Rosenberg et al. 2005).

The river consists of two main branches, which cross seven terrestrial ecoregions. The North Saskatchewan begins at high elevation in the Rocky Mountains of western Alberta, at the foot of the Saskatchewan Glacier (Figure 1). The South Saskatchewan has three main tributaries, the Red Deer, the Bow and the Oldman rivers (Figure 1). The Red Deer and Oldman rivers originates in the snows of the Rocky Mountains, and the Bow River originates at the Bow and Peyto glaciers in Banff National Park (Figure 2). The two branches of the Saskatchewan join in east- central Saskatchewan to form the mainstem river (Figure 1). At its mouth, the North Saskatchewan has a mean annual flow of 241 m^3/s (Rosenberg et al. 2005). Where the river enters Lake Winnipeg, its average flow is 567 m^3/s (Rosenberg et al. 2005). During the period 1913-1989, average annual flow at the Pas, upstream of Lake Winnipeg, ranged from 307 m^3/s in 1941 to 1170 m^3/s in 1916 (Cohen 1991).

Seasonality of Flows and Water Yields

The highest flows of the year in the lower reaches of the North Saskatchewan usually occur in July, when the water from melting mountain snowpacks reaches the area. Lowest average flows are in February. In the South Saskatchewan, highest flows occur during spring snowmelt, which typically occurs in late March and April in lower parts of the basin, and in May-June at the higher altitudes of the Rockies. Once snowmelt has dwindled, glacial melt contributes to summer flow. In a dry year, glacial inputs can be as high as 50 % in the Bow and North Saskatchewan rivers, though the annual contribution is <5 % (BRBC 2005). Autumn flows can be quite variable, depending on temperature and precipitation. Winter flows are typically low, because much of the catchment of the river is below freezing in December through February. Groundwater is an important winter water source in many areas (BRBC 2005). Both branches of the river are ice covered for about 4 months.

With the exception of the mountainous regions of western Alberta, the Saskatchewan River drains rather flat areas of prairie. Gradients of various tributaries in the mountains are generally 3-7 m/km, whereas in the rest of the catchment, they are only 0.15-0.5 m/km. Much of the prairie part of the catchment is semi-arid, particularly in the south. Most of the flow of the river system is generated by higher precipitation in the Rocky Mountains and foothills. Average water yields are over 500 mm per year in the mountains, but in semi-arid areas of the southern prairies, it can be very near to zero. Similarly, runoff/precipitation ratios can vary from over 90% in mountainous areas to near zero for more arid areas of the prairies. For example, the Battle River, which has no mountain headwaters, drains 40% of the North Saskatchewan Basin, but supplies only 3% of the water reaching the North Saskatchewan from its tributaries (NSWA 2005). There is also a wide range of spatial and interannual variability in runoff (Gan 2000).

Recent studies using proxy indicators of drought indicate that periods of prolonged droughts, some lasting for decades, were very common before the 20th century (Sauchyn, this conference; Case and MacDonald 2003; Cumming et al. 2002; Watson and Luckman 2005). The Canadian Senate's Standing Committee on Energy, the Environment and Natural Resources (2005) expressed concern about the effects of climate warming and water scarcity on human activities and environment in the western prairies.

Until recently, most attention has been focussed on annual or natural flows in the rivers. In most cases, the total effect of climate warming and human withdrawals on annual river flow have so far been slight or negligible (Rood et al. 2005) although the South Saskatchewan at Saskatoon has decreased by about 30% in the past century, and the average annual flow in the North Saskatchewan at Edmonton has declined by 15% between 1911 and 2003 (NSWA 2005). There have, however, been rather severe disruptions to the seasonality of flow. Summer (May-August) flows in most rivers have declined severely, with the North Saskatchewan at North Battleford now averaging 40% lower than in the early years of record, and the South Saskatchewan at Saskatoon averaging 85% lower (Schindler and Donahue 2006). The summer period is very critical for the Saskatchewan River. The fisheries of the system are generally coldwater species, with preferred temperatures in the teens (degrees C), and lethal temperatures in the low to mid-20s. They are also very sensitive to low oxygen, with some species intolerant of concentrations less than 6.5 mg/L for prolonged periods.

The summer is also critical for human residents. Irrigation and municipal use are high during the May-August period. Also, reservoirs are usually drawn down in fall and winter, and are re-filling during the May-August period.

Biota

Headwater parts of both branches of the Saskatchewan contain coldwater fishes. Downstream parts on the prairies contain a combination of cold and warm water species. Overall, the North Saskatchewan has an assemblage of 36 species of fishes. This increases to 44 species in the Cumberland Marshes, on the mainstem Saskatchewan near the Manitoba-Saskatchewan Border (Rosenberg et al. 2005).

Introduced species In headwater and upstream areas, deliberate introductions of alien species have displaced native species. In particular, non-native eastern brook trout *Salvelinus fontinalis*, rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* have displaced native bull trout *Salvelinus confluentus* and cutthroat trout *Oncorhynchus clarki* in the headwaters of the South Saskatchewan. These introductions have combined with overfishing and habitat destruction to make the bull trout a threatened species through much of its range.

Crayfish have also been introduced to the North Saskatchewan River in recent years. They are now commonly found in the river near Edmonton. They are believed to be the result of transport in bait buckets by fishermen. They will undoubtedly slowly work their way downstream. The current extent of their invasion is unknown, but their range will undoubtedly increase. They are resident to the nearby Beaver-Churchill River.

At the lower end of the Saskatchewan, Lake Winnipeg has been invaded by common carp *Cyprinus carpio*, rainbow smelt *Osmerus mordax*, and the cladoceran *Bosmina coregoni*. Other invasive species including zebra mussels and the spiny waterflea *Bythotrephes* are approaching the Nelson River system, and have the potential to work their way up the Saskatchewan, where humans will probably assist them in surmounting dams, as has happened in other rivers of the world.

Climate Warming in the Catchment and its Effects on the Hydrological Cycle

The longest temperature records in the Saskatchewan River catchment generally begin in the 1880s. During the 20th century, most stations that are relatively free of urban "heat islands" in Alberta and Saskatchewan have recorded a warming trend of 1-4 degrees C, mostly after 1970. Regional climate models indicate that average temperatures by 2100 will increase by another 4.8

to 8.4 degrees (Schindler and Donahue 2006), well outside the range where human society is prepared to adapt. Winter temperatures in most areas have increased more than summer.

Warming has already affected several aspects of the hydrologic cycle, including increased glacial melt (Demuth et al. 2002), earlier spring melt, smaller snowpacks and a lower proportion of precipitation as snow (Schindler and Donahue 2006). Potential evaporation is expected to increase (Sauchyn, this conference; Schindler and Donahue 2006), although effects on actual evaporation and transpiration are less clear, because they depend somewhat on soil moisture, wind and the response of plants to higher concentrations of atmospheric CO_2 (Gan 2000). Glaciers and snowpacks are predicted to continue to decline as climate continues to warm (Demuth et al. 2002; Lapp et al. 2005). The role of snow and ice as "free storage" of water for summer use in the prairies has been underappreciated.

Humans in the Saskatchewan River Catchment

Humans have occupied the catchment of the Saskatchewan since the river was formed by the last glaciation. It is believed that they originally subsisted on large Pleistocene mammals such as mammoths, camels, and caribou, switching to bison as these species approached extinction. Bison remained the mainstay for aboriginal people until late in the 19^{th} century, when Europeans began to significantly affect their lifestyles, eradicating bison, introducing alcohol, guns, trade, and new diseases. Lac (2004) gives more details.

In mountainous areas, the catchments of the rivers have been modified very little, except by small communities (Banff, Jasper and Lake Louise are the largest at 8300, 5000 and 1500 people, respectively, although all three grow by several-fold during the summer tourist season). Highways through the national parks are few, although they and two railroads through the parks carry much of the traffic between eastern and western Canada. There are also a few reservoirs, as described below. The Saskatchewan's montane headwaters are largely protected as national or provincial parks, world heritage sites, and other designations that restrict development. Nevertheless, detailed examination shows that some features of the river systems have been compromised in these areas, as discussed later.

With European settlement came the first tillage of the land. It is estimated that 67% of the catchment is now farmed (Rosenberg et al. 2005). With the expansion of agriculture came significant modifications to the catchment and the river, including clearing of forests, construction of dams, canals and diversions for irrigation, draining and filling of wetlands, increasing populations, oil and gas exploration, and other industrial and municipal activities.

While the average human population of the Saskatchewan's catchment is still low (about 3.5 million, or an average of <10 people per km^2, much of the population is concentrated in Alberta, where it is estimated that 80% of the human population live in the Saskatchewan basin, which constitutes only 20% of the province's water supply (AIA 2005). Calgary on the Bow River and Edmonton on the North Saskatchewan have populations of about a million people each. Densities in these urban areas can exceed 1000 people/km^2. Approximately another half million humans occupy the area between Edmonton and Calgary, and about the same number in the Oldman-South Saskatchewan drainage, near Lethbridge and Medicine Hat. In Saskatchewan, Saskatoon, Swift Current, and Prince Albert add about a half million more humans. Through the rest of the basin, few settlements of over 10000 occur, and most are <1000. BRBC (2005) and Lac (2004) give more detailed information on human history and distribution.

Dams and Reservoirs

Gan (2000) estimates that there are 770 dams in the western prairie provinces. While there is no data base showing the locations of all of them, most of these would be in the Saskatchewan River basin. Here we shall describe some of the largest ones.

North Saskatchewan The North Saskatchewan has two large reservoirs, both constructed largely for the generation of hydroelectric power. Abraham Lake is where the river leaves the mountains, just below the boundary of Jasper National Park. The Brazeau Reservoir, in the lower foothills, is on a tributary, the Brazeau River.

The South Saskatchewan and its tributaries The South Saskatchewan and its tributaries have a number of large dams, in addition to hundreds of small ones.

The Red Deer River (Figure 1) is still relatively free-flowing. Only Dickson Dam just upstream of Red Deer is a major regulator of river flows. It regulates downstream water supplies, primarily in winter. It also provides some hydroelectric power, recreation, and flood reductions (Alberta Environment 2004).

On the Bow River (Figures 1 and 2), hydroelectric generation plants rely on several reservoirs, most of them on tributaries in mountainous areas. They generate less than 5 percent of Transalta Utilities' power, but are regarded as important because of the rapidity with which they can respond to fluctuating power demand. Farther downstream, several reservoirs and weirs impound water for irrigation and municipal supplies. They, and major reservoirs on the Oldman River, will be discussed in more detail later. Overall, reservoirs in the South Saskatchewan basin within Alberta are capable of storing nearly 40% of annual flows (AIA 2005).

Below where the Red Deer, Bow and Oldman rivers join, Gardiner Dam forms Lake Diefenbaker, the largest impoundment on the South Saskatchewan River system. The reservoir is 43000 ha in area and contains 9.4 billion m^3 of water when full. It supplies drinking water for

40% of Saskatchewan's population, recreation, water for irrigation and for industry (including 10 potash mines), and flood control (Saskatchewan Watershed Authority www.swa.ca). On the mainstem Saskatchewan River, the Tobin Lake and Codette Lake reservoirs near Nipawan, Sask., and the Cedar Lake reservoir, formed by the damming of the Grand Rapids near Lake Winnipeg, are for hydroelectric power. Little information is available on the impacts of these dams, although Tobin and Codette Lakes have become world-renowned sport fisheries for walleye and pike.

Displacement of two native communities by the formation of the Cedar Lake reservoir caused considerable loss of livelihood for aboriginal people in that area (Loney 1987). Similar fates have met aboriginal communities in other Canadian hydroelectric developments (Rosenberg et al. 1997).

The Effects of Impoundment on Channel Morphology and other Riparian Features Reservoirs also have well-known negative effects, (reviewed by Hecky et al. 1984 and Rosenberg et al. 1997). It is widely recognized that the form of stream channels is a function of high flows (Hecky et al. 1984; Newbury and Gaboury 1993), and that elimination of high flow periods by damming or diversion results in gradual changes to stream channels. High sediment loads are also deposited behind dams, causing degradation of downstream riverbeds due to starvation for sediments. Concentration of rivers' energy below dams can adversely affect channels. For example, Galay et al. (1985) found that Gardiner Dam had caused degradation of the riverbed for 8 km downstream from Lake Diefenbaker. The river bed has eroded by 2 m, and has started to "armor" (become coarser). High flood releases are predicted to accelerate the degradation. On the other hand, the broader energy distribution from normal high flows in undammed river reaches scours streambeds of organic matter and vegetation that accumulated during previously low flow periods, helping to minimize the oxygen depletion that occurs during stagnant periods in summer, or under winter ice (Clipperton et al. 2003).

Periodic flooding also helps to rejuvenate and sustain riparian forests, especially species of *Populus*, which are very common in the flood plains of the Saskatchewan River. Often, these forests decline below dams on the river system (Rood and Mahoney 1990; BRBC 2005).

Impoundments that fluctuate widely annually often cause decreased production of stream macroinvertebrates, including Trichoptera, Ephemeroptera, Mollusca and Plecoptera, many species of which require a full year to complete their life cycles in cold waters. In many cases, these are replaced by smaller, shorter-lived species of less value for supporting fish stocks, generally Chironomidae species (Rawson 1958). Fluctuating water levels also prevent the formation of stable riparian zones.

Downstream of reservoirs, many species of macroinvertebrates become less abundant or are extirpated as a result of disrupted thermal regimes. Typically, discharges from reservoirs are cooler in summer and warmer during winter than natural rivers, hindering hatching of many species. The effect was evident for 110 km below reservoirs on the Saskatchewan River (Lehmkuhl 1972).

Impoundment has been shown to cause increased mercury concentrations in fishes in many areas (Jackson 1998; James Bay Mercury Committee 1995). The increases appear to be the result of increased methylation and mobilization of mercury from flooded vegetation and soils (Kelly et al. 1997). While hydroelectric power has been widely touted by politicians as "good clean power," reservoirs release both CO_2 and methane to the atmosphere (Kelly et al. 1997; St. Louis et al. 2000). In short, while dams and reservoirs confer many benefits to humans, they negatively affect many features of the ecological integrity of streams and riparian areas.

Human Use and its Effects on the Rivers

North Saskatchewan In the North Saskatchewan basin, permanent water withdrawals are small, and effluents from communities rather widely spaced. However, much of the area outside of the mountains has been converted to agriculture, resulting in a slow degradation of water quality downstream. In applying nine indicators of "health" to the 18 main tributaries of the North Saskatchewan, NSWA (2005) rated four as good, nine as fair and five as poor.

South Saskatchewan In the South Saskatchewan basin, where most of Canada's irrigated agriculture and human population is concentrated, water is already scarce, and water quality has been compromised. Both human and animal populations are growing rapidly. In order of importance, human withdrawals are for agriculture, power generation and municipal use.

Referring to the entire South Saskatchewan system, Alberta Environment (2003) stated: "We have difficult decisions to make about the use of water, retaining water in the rivers, and maintaining a sustainable aquatic ecosystem. It is not possible to have, in any given river reach, both a high degree of consumptive water use and a near-natural aquatic ecosystem over the long-term." They divide the South Saskatchewan and its tributaries into 33 distinct river reaches. Of these, only a single reach is rated as unchanged or recovered. Thirty one reaches are listed as from moderately to heavily impacted, or degraded (Figure 3).

Prairie Agriculture Unlike the Great Plains of the USA, which rely heavily on groundwater (chiefly the oversubscribed Ogallala Aquifer), most of the agriculture in the Saskatchewan River basin relies on surface waters. As mentioned above, 67% of the total area of the catchment is used for agriculture. Typically, the prairie provinces supply about 2/3 of Canada's $15 billion in agricultural exports (1994 figures; Gan 2000). The amount can be highly variable, and in drought years, farm relief can be very high. The worst case was the "dirty thirties," when several consecutive years of drought forced 250,000 farmers to leave the prairies and 7.3 million hectares of land were affected (Godwin 1986 in Gan 2000). In the 1980s and 1990s, several annual droughts caused export losses of 1 to 4 billion dollars (Gan 2000). Due to extreme spatial and interannual variability of rain and snow, many reservoirs have been constructed for agricultural use. Several of the larger reservoirs and their effects on water resources were described above.

Irrigation is by far the most consumptive use of prairie water. Almost all of the irrigated land in the prairies is in the South Saskatchewan basin, particularly in the basins of two of its major tributaries, the Bow and Oldman rivers of Alberta. Irrigation has a long history, with the Canadian Pacific Railway promoting it as early as the 1890s. The Northwest Irrigation Act of 1894 established regulations for the first irrigation districts. Today, thirteen irrigation districts and privately-irrigated land apply about 2.5 km^3 of water per year to about 1.63 million acres (0.65 million ha) of land. Typically, about 20 percent of this is returned to the rivers, although it can be quite heavily polluted with pathogens, nutrients, pesticides and herbicides. It is estimated that the five percent of arable lands that are irrigated in Alberta provide 20 percent of the province's gross agricultural production (AIA 2005).

Livestock culture is also increasing rapidly in the Saskatchewan basin. Alberta is the province most affected, with over 6 million cattle, and over 2 million hogs. The province of Alberta has a goal of doubling livestock numbers (Toma and Bouma 1997).

<u>Power generation</u> The second largest user of water in the Saskatchewan basin is power generation. Hydroelectric generation is a relatively small part of the power supply. While it causes problems described earlier, it consumes very little water. Thermal power generation is

more common, as the result of abundant coal deposits, most notably in central Alberta. Much of the thermal generation is in the basin of the North Saskatchewan, where several thermal power plants near Lake Wabamun use nearby coal to generate 4000 MW of power, roughly 48% of the province's need in 2003 (Schindler et al. 2004). The plants rely on water from the lake or the nearby Saskatchewan River for cooling. It is estimated that 98 percent of the water used for thermal power is returned to surface waters, with little pollution (AIA 2005).

Municipal Use Municipal water use is still a relatively small proportion of allocated water. There are some concerns with respect to population is the rapid growth in southern and central Alberta, where rapid population increases in the Calgary area is expected, and also in the Battle River basin, which receives no "subsidy" from glaciers or mountain snowpacks. A number of conservation measures will be necessary to protect water supplies and instream flow needs. A recent study by Watrecon (2005) outlines the problems and discusses likely future water needs in the Battle River Basin.

Per capita water use in most urban areas of the Saskatchewan basin is very close to Canadian averages. From 80 to over 90 percent of water withdrawn for municipal use is eventually returned to the rivers. Sewage treatment at large municipal plants in the basin is excellent, with many cities removing nutrients as well as pathogens. However, storm runoff can still be highly polluted with pathogens, nutrients, pesticides and herbicides. Antibiotics, hormones, and personal care products have also recently emerged as issues. Many of these are not efficiently removed by sewage treatment, and their breakdown in rivers is limited by cold temperatures and ice during part of the year. Most smaller communities have less effective sewage treatment. In many cases, effluents are simply pumped into lagoons, where they are left for several months before discharging directly to nearby rivers.

Use by the Petrochemical Extraction Industry Although the petrochemical industry is not a large user of water, several features of its use have been the subject of public outrage. For example, an annual amount roughly equal to municipal use is pumped down wells to facilitate oil and gas extraction. This is permanently removed from the water cycle. Other alleged insults include the pollution or re-routing of aquifers during the drilling of oil and gas wells, and the discharge of polluted or saline water to surface or ground waters. A current plan to extract methane from coal beds promises up to 64 gas wells per square mile. The initial proposal is for development in the area of Pincher Creek, a tributary to the Oldman River. The plan has evoked outrage and opposition among ranchers and farmers who hold only surface rights to the area, and are fearful that their water supplies will be compromised. Alberta Environment has just announced that it will require increased study of the aquifers in an area before drilling, but details are not yet available.

Pathogens in the River Systems

In areas of extensive agriculture and below the sewage outfalls of some cities, pathogens pose a problem with water supplies. For example, significant proportions of >1400 water samples from the Oldman River and its tributaries over two years were found to contain *E. coli* 0157:H7 (0.9%) and/or *Salmonella spp.* (6.2%) (Johnson et al. 2003). There have also been problems in the North Saskatchewan basin. Outbreaks of gastrointestinal disease caused by the protozoan *Cryptosporidium* have occurred in Edmonton Alberta (1982) and North Battleford, Saskatchewan (2001) (Hrudey and Hrudey 2004). Both communities draw water from the N. Saskatchewan River. The protozoan *Giardia* is also a concern. Livestock (chiefly beef cattle) have been identified as the most important sources of these parasites, especially during periods of high runoff, although wildlife, other livestock and human sewage are other sources of the parasites (Heitman et al. 2002; AFFRD 2006). As the result of the high potential for contamination and the resistance of these protozoans to chlorination, water treatment plants in Edmonton now treat intake water with UV radiation.

Actinomycetes have also caused taste and odor problems in the North Saskatchewan River, particularly during spring runoff. Some strains are resistant to disinfection at water treatment plants (Jensen et al. 1994).

Toxic Substances in the River Mercury in fish is the primary toxin of concern in the Saskatchewan River. It is believed that natural sources to the river are high. Long range transport in the atmosphere appears to have roughly doubled atmospheric loading. Coal-fired power plants have contributed still more via emissions to the atmosphere to some areas (Donahue et al. 2006). Mercury was also used in the North Saskatchewan by gold prospectors early in the 20th century. It is still possible to separate elemental mercury from sediments with a simple gold pan in the region around Edmonton.

Alberta Sustainable Resource Development (2006) recommends that women of child-bearing age and children under 15 should not eat fish from either the North or South Saskatchewan. Others should not eat more than one meal of fish from these rivers per week. The Bow, Red Deer and Oldman rivers also carry consumption advisories for some species. High mercury has been recorded at many sites in the Saskatchewan River system throughout its length (Wobeser et al. 1970). At least one case of mercury intoxication in a fish-eating mammal (mink) eating fish from the river has been recorded (Wobeser and Swift 1976).

Increased forest fire in the mountains has been shown to increase the supplies of mercury and nutrients to lakes and streams (Kelly et al. in review and unpublished). Forest fire has been shown to cause increased mercury concentrations in fish in downstream waters. Both nutrient inputs, via their effects on food web relations, and mercury input are responsible. Forest fires are predicted to increase under climate warming (Flannigan et al. 2005). In addition, Parks Canada is undertaking an aggressive policy of controlled burning, to rejuvenate early successional stages that are vital for maintaining food supplies for large mammals. A conflict between forest and water management may result.

The Cumulative Effects of Climate Warming, Human Withdrawals and Channel Modifications: Some Worst Cases

The most threatened parts of the Saskatchewan River basin are the Oldman and Bow systems. On average, each supplies roughly 40 % of the flow to the South Saskatchewan River, with the Red Deer River supplying the remaining 20 percent. Most water for irrigation is drawn from the Bow and Oldman rivers, and they are areas of rapidly increasing human and livestock populations. Under the Master Agreement on Water Apportionment, signed in 1969 Alberta must allow 50 percent of the flow of the South Saskatchewan River to pass into Saskatchewan. In recent dry years, most of the water necessary to meet this commitment has come from the Red Deer River, because of high water withdrawal from the Bow and Oldman. The combination of climate warming, via its effects on glaciers, evaporation and spring melt, plus higher water temperatures, increasing human populations, agricultural use and industrial development have put the Bow and Oldman rivers in precarious positions. At present, over-allocation of water in the rivers has not been a problem, because water withdrawal and consumption are much lower than allocated limits. However, the proportion used of allocated water is expected to increase as human activity intensifies (AIA 2005).

The Bow and Oldman rivers have world-renowned fisheries for brown and rainbow trout, which generate a considerable income. Most of the fishes in these rivers, as well as the Red Deer and South Saskatchewan, have lethal temperatures of 22 to 29 C, and 7-day chronic lethality values of 18 to 24 C (Clipperton et al 2003). Water allocations in much of the South Saskatchewan basin exceed instream flow needs (IFN) for maintaining the morphology of channels and the integrity of biota. A recent analysis recommended that maintaining IFN in the South Saskatchewan system would require 85% of natural flows, which is impossible with allocations already made, in either the Oldman or Bow systems (Alberta Environment 2003). They state that "the aquatic environment is believed to be in a state of long-term declining health." As a result, a moratorium on further allocations was imposed in 2003 in the St. Mary's, Belly and Waterton rivers, tributaries to the Oldman (AIA 2005).

Below, we discuss in detail the features of the two most heavily impacted tributaries to the South Saskatchewan:

The Bow River The Bow River (Figure 4) originates in the glaciers above Bow and Hector Lakes in the alpine regions of Banff National Park. At its headwaters, nutrients and coliform counts are very low (Schindler and Pacas 1996), although melting glaciers and contaminated high-elevation snowpacks contribute significant amounts of organochlorine pesticides and PCBs to the river (Blais et al. 1998; Donald et al. 1999). There is little modification to land use within the national park, although there have been some effects on the river's flow patterns and chemistry. Schindler and Pacas (1996) and Schindler (2000) reviewed the status of the Bow River in Banff National Park. They found that 41.5% of the river's flow within the national park was regulated, all of it toward the Park's eastern boundary. The following describes the two largest reservoirs that affect waters of the national park:

Lake Minnewanka in Banff National Park, had early low-level dams constructed before 1912. The current structure, built in 1939-1941 under authorization by Order in Council under the War Measures Act, raised the original lake level by 25 m. The reservoir is drawn down in winter and re-filled in summer, with an annual operating range of 6-7 meters. Water is released via the Cascade generating station, and can fluctuate from zero to 1400 cfs several times a day. The annual drawdown exposes much of the littoral zone, and comparison with pre-dam studies by D.S. Rawson shows that the bottom fauna changed from about 50 % macroinvertebrates (molluscs, Trichoptera, Ephemeroptera, Plecoptera and other large species to over 90% chironomids (Schindler and Pacas 1996).

The Lake Minnewanka reservoir was stocked with several alien species of fishes and invertebrates. It also destroyed most of the Cascade River and surrounding riparian habitat by diverting water around the original river channel. The original Cascade River was about 15% the size of the Bow River at Banff.

The Spray Reservoir, constructed in 1947-1951, lies outside the Park boundary, but the Spray River drains the reservoir into the Bow within Banff. The level of the original Spray Lakes was raised by more than 60m. The raised water level in the lakes and the decreased summer flows destroyed major cutthroat trout *Oncchorhynchus clarki* fisheries in both the Spray Lakes and the Spray River. The latter was termed by Rawson (1958) “the best stream angling in Banff Park.”

The communities of Lake Louise and Banff once discharged sewage into the Bow River within the Park, causing eutrophication and contamination with fecal coliforms for some distance below their outfalls. These problems have largely been solved by phosphorus removal and UV treatment of wastewater before discharge to the Bow (Schindler and Pacas 1996). The river reaches have now largely recovered, with much reduced growth of attached algae and return of original benthic communities (Bowman et al. 2005). Salting of Trans-Canada highway in winter has caused elevated concentrations of sodium and chloride in the river within the parks (Schindler and Pacas 1996).

Below the Banff Park boundary, little of the Bow River Basin remains in its natural state (BRBC 2005). Logging, agriculture, and oil and gas development are the main activities. Rapid urbanization is occurring between Canmore, at the Park Boundary, and Calgary. Sixty eight percent of the river's flow has been allocated by the time it reaches its confluence with the Oldman River in eastern Alberta. Of the allocated water, 76% is for irrigation (BRBC 2005), although with the exception of irrigation, much of the allocated water is returned to the river. Several dams and weirs impede fish passage. Rapid human population growth in the basin poses additional demands on water supplies, and climate change and glacial retreat are future threats. Water quality declines along the length of the river, as the result of coliform bacteria, nutrients, pesticides, and salts.

Reservoirs outside of Banff Park include the Interlakes (1955), Pocaterra (1955) and Barrier (1947) dams on the Kananaskis River, a major tributary. The Ghost Reservoir (1929) on the Bow just below the entry of the tributary Ghost River, and Bearspaw Dam (1954), which regulates flow without storage, complete the list of major dams. Overall, eleven hydroelectric facilities rely on the dams. The flows in the reach of the river between the Cascade River and the Bearspaw Dam fluctuate rapidly, sometimes several times a day, to facilitate adjustments in electricity supply to changing demands. This makes the reach fairly inhospitable as habitat for riparian animals and fish. The Bearspaw Dam smooths these flows. The Bow River Basin Council (BRBC 2005) gives more detailed information.

Overall, the reservoirs have had a devastating effect on cutthroat and bull trout populations in the upper reaches of the Bow. With respect to the impact of reservoirs on the fisheries of the mountain parks, Rawson, the most eminent fisheries biologist of his day, remarked (1958): "…we would be inclined to think that reservoirs are fundamentally poor in productivity, the fluctuating water levels are especially unfavourable for our best game trout which tend to feed in shallow water, and that fish plantings are usually ineffective as a management procedure in such bodies of water." Rawson's various publications from the 1930s document the disappearance of many native invertebrates and fishes from lakes and streams after reservoir construction. Stocked lake trout *Salvelinus namaycush* have, however done well in the reservoirs, largely replacing native fishes. Altogether, of twenty fish species found in the Bow within the Banff boundary, ten are non-native. The Banff Bow Valley Task Force (1996) made several recommendations to reduce the impact of impoundments in Banff National Park, but few of these have been implemented to date. In the rivers of the Bow basin, native bull and cutthroat trout have largely been replaced by non-native eastern brook trout, rainbow trout, and European brown trout. BRBC (2005) give more detailed information.

The reach from the Bearspaw Dam to the intake of the Western Irrigation District has the highest population density in the entire Saskatchewan basin, because of the city of Calgary and surrounding bedroom communities. Statistics Canada shows that the Census region including the city grew 16% between 1996 and 2001, and this growth rate appears to be continuing or even increasing. The population of the Calgary area is forecast to increase by about 50% by 2030 (BRBC 2005).

Calgary draws roughly half its drinking water directly from the Bow, the other half from Glenmore Reservoir on the tributary Elbow River (Figure 2). Until recently, Calgary has not metered water use in most of its area. In 2002, meters were required on new dwellings. Unmetered homes use 50% more water on average than metered ones (BRBC 2005). The city has also undertaken a program to reduce water leaks in its distribution system, and undertaken a major campaign to reduce water consumption. As a result, peak summer water demand in 2002 was 7 percent less than in 1987, despite a 39% increase in population (BRBC 2005). The city has also treated its sewage to the highest standard of any waste treatment plant in Canada, and undertaken a program of constructing and protecting wetlands to reduce the pollutants in storm drainage before they enter the river.

The first major irrigation withdrawals are just downstream of Calgary. Water quality also declines, and there are periodic fish kills as the result of high temperatures and low oxygen (Clipperton et al. 2003). The Bassano Dam below Calgary is owned and operated by the Eastern Irrigation District. Its main purpose is to impound and divert the Bow's water for irrigation.

Near its mouth, the summer flows of the Bow River are less than 50 percent of values in the late 1960s, when record keeping began.

The Oldman River The Oldman River and its tributaries also have several significant dams. All are primarily to supply water for irrigation, although flood control, municipal supply, erosion control and recreation are other objectives. The largest are the Waterton-St. Mary's Headworks System and the Oldman River Dam (built in 2001, Alberta Environment 2004).

The Oldman River covers 3 million ha in southern Alberta (Figure 4). The river originates at a small lake in the Rocky Mountains. There are no glacial inflows. The river and its tributaries extend through generally forested catchments in the west at higher elevations, through savanna-type rangelands of the foothills to semi-arid grasslands of the western prairies to the east. Much of the eastern part of the basin receives only 300-450 mm of precipitation per year on average, and is classified as semi-arid.

The basin is currently home to about 160,000 people, half in or near the city of Lethbridge. About 266,000 ha of land is irrigated, 40% of the total in Alberta. It also has the greatest density of intensive livestock operations in the province (Figure 5), making it one of the most intensively managed agricultural regions in western Canada (OWC 2005). In addition, the catchment is the site of high densities of oil and gas extraction. This is expected to intensify even more as coal-bed methane is extracted in the coming decade.

In the late 1990s, many of the subbasins of the Oldman had poor water quality, with waters nearly always exceeding fecal coliform guidelines for drinking, and often exceeding coliform guidelines for irrigation and recreation. The protozoans *Cryptosporidium* and *Giardia* were also common (CAESA 1998). Many waters contained high concentrations of herbicides and pesticides. In response to the concerns of residents, the Oldman River Watershed Council was formed to investigate poor water quality and remediate its causes.

A large step in cleaning up the Oldman was the improvement of sewage treatment at Lethbridge, which had been responsible for 59% of the point-source inputs nitrogen, 87 % of the phosphorus and 82% of bacterial inputs to the river. Overall, the city's effluent was reduced to 11% of the nitrogen, 24% of the phosphorus and 0.1% of the fecal coliform input from point sources (OWC 2005). Other measures were taken to curb inputs from agriculture, including off-stream water sources for cattle, restoration of riparian areas and construction of confined, low-impact cattle crossings on streams, and improved incorporation of manure in soil immediately after application. Measures were also taken to reduce street runoff of pollutants, including effective lawn watering practices, use of lawn fertilizers and pesticides, and "poop and scoop" pet management. Much of the rapid success of the program OWC initiative was the result of public education in rural and urban areas, earning its Water Quality Initiative an Emerald Award for Environmental Excellence in 2001.

Summer flows at the mouth of the Oldman River are currently about 40% of values in the early 20th century (Schindler and Donahue 2006).

Lake Winnipeg

As mentioned in the introduction, the Saskatchewan River drains into Lake Winnipeg. At the turn of the 20th century, it was the major source of water to the north basin of that lake. Due to flow reductions, the importance of the Saskatchewan River in renewing the waters of the lake are greatly decreased. Nutrient inputs to the lake have increased, largely the result of increased livestock production, fertilizer use and human populations in the southern part of the lake's catchment. The result has been rapid increase in the eutrophication of the lake (A. Salki, Freshwater Institute, pers. comm.).

Summary

Extensive and increasing human population and land-use are causing increasing demand for water. At the same time, climate warming is providing further strain on the meagre water supplies of the Saskatchewan basin. There is increasing evidence that the 20th century, regarded by most people as "normal," was unusually wet in the western prairies.

The cumulative effects of climate warming, drought and human activity have seldom, if ever been considered by land managers and policy makers. There is little integrated catchment planning in the WPP, and science is poorly represented in the planning process. Decisions to expand cities, clear forested land, fill in wetlands, place and construct feedlots, approve major industrial projects and expansions, apply fertilizer, apportion water supplies, and expand cottage developments are made on a project-specific basis by different government departments, communities, committees, or even by individuals. Ecological instream flow needs and lake levels have been ignored until recently. This has resulted in the allocation of more than 100% of at least one river's water, leading to potential conflict between licensed users. When communities resist development because of concerns over environmental impacts, decision-making powers are often removed to provincial political levels. In addition, governmental agencies charged with environmental monitoring and applying and enforcing laws protecting freshwater resources have suffered extreme funding cuts, primarily for short-sighted budgetary reasons. As a consequence, historical weather, snowpack, and water quality and quantity data are often incomplete or non-existent. As problems arise, reactionary solutions are derived piecemeal, usually by different departments and levels of government, and too late for easy, inexpensive, or timely remediation. Catchment-scale planning for management and conservation of freshwaters in the WPP and other rapidly developing dryland areas is urgently needed in order to maximize efficient use of increasingly scarce freshwaters in a time of warming climate and rapidly increasing human activity.

In response to increasing evidence for water shortages and the need for integrated watershed management, several new programs are attempting to provide direction. The Alberta Water for Life program www.waterforlife.gov.ab.ca has formed committees to study sustainable water strategies for the major river watersheds of Alberta, to summarize problems and provide public information. This process is in its early stages, and reports have just begun to appear in the past year. So far, there is no sign of comprehensive policies to manage water problems.

While little can be done to halt the disappearance of snowpacks and icefields, much can be done to protect the integrity of the watersheds of the WPP, by retaining or restoring wetlands and riparian zones. Agricultural developments and industries can be chosen that do not require extensive water supplies, at least during the water-scarce summer months. Controlling greenhouse gas emissions soon can reduce the amount of warming, and hence evaporation and glacial wastage, expected in the latter years of this century. Finally, it may prove wise to keep human populations in the drier parts of the Saskatchewan basin relatively low, to avoid the water scarcity that has already become a major problem in the southwestern USA and many other populous dryland areas of the world, as described in the recent Millenium Assessment http://www.MAweb.org.

References

AAFRD (Alberta Agriculture, Food and Rural Development). 2006. Relationship between beef production and waterborne parasites (Cryptosporidium spp. and Giardia spp.) in the North Saskatchewan River Basin. www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/wat6400?opendocument.

Alberta Environment. 2003. South Saskatchewan river basin water management plan. Phase two: background studies. www3.gov.ab.ca/env/water/regions/ssrb/index.asp

Alberta Environment. 2004. Major dams in the South Saskatchewan River Basin.

AIA (Alberta Institute of Agrologists). 2005. Environment for Growth: People to Water, Water to People. www.aia.ab.ca.

Alberta Sustainable Resource Development. 2006. Alberta Guide to Sportfishing Regulations. ISBN 0-9732626-5-6

Banff-Bow Valley Study. 1996. Banff-Bow Valley: At the Crossroads. Technical Report of the Banff-Bow Valley Task Force (Robert Page, Suzanne Bayley, J. Douglas Cook, Jeffrey

E. Green, and J.R. Brent Ritchie). Prepared for the Honourable Sheila Copps, Minister of Canadian Heritage, Ottawa, ON.

Blais, J.M., Schindler, D.W., Muir, D.C.G., Donald, D.B. and Rosenberg, B. 1998. Accumulation of persistent organochlorine compounds in mountains of western Canada. Nature 395: 585-588.

Bowman, M., Chambers, P. and Schindler, D.W. 2005. Epilithic algal abundance in relation to anthropogenic changes in phosphorus bioavailability and limitation in mountain rivers. Can. J. Fish. Aquatic. Sci. 62: 174-184.

BRBC (Bow River Basin Council) 2005. The 2005 report on the State of the Bow River. www.brbc.ab.ca/report

CAESA (Canadian-Alberta Environmentally Sustainable Agriculture Water Quality Committee). 1998. Agricultural Impacts on Water Quality in Alberta: An Initial Assessment. CAESA Agreement. Lethbridge, Alberta: Canadian-Alberta Environmentally Sustainable Agriculture Water Quality Committee.

Case, R.A. and MacDonald, G.M. 2003. Tree ring reconstructions of streamflow for three Canadian prairie rivers. J. Amer. Water Resources Assn. 39: 703-716.

Clipperton, G.C., Koning, C.W., Locke, A.G.H., Mahoney, J.M. and Quasi, B. 2003. Instream flow needs determinations for the South Saskatchewan River Basin, Alberta, Canada. ISBN 0-7785-3044-2. Alberta Environment, Edmonton.

Cohen, S.J. 1991. Possible impacts of climatic warming scenarios on water resources in the Saskatchewan River sub-basin, Canada. Climatic Change 19: 291-317.

Cumming, B.F., Laird, K.R., Bennett, J.R., Smol, J.P. and Salomon, A.K. 2002. Persistent millennial-scale shifts in moisture regimes in western Canada during the past six millennia. Proc. Natl. Assoc. Sci. USA 99: 16117-16121.

Demuth, M.N., Pietroniro, A., Ouarda, T. and Yetter, J. 2002. The impact of climate change on the glaciers of the Canadian Rocky Mountain eastern slopes and implications for water resource adaptation in the Canadian prairies. Geological Survey of Canada Open File 4322.

Donahue, W.F., Allen, E.W. and Schindler, D.W. 2006. Impacts of coal-fired power plants on trace metals and polycyclic aromatic hydrocarbons (PAHs) in lake sediments in central Alberta, Canada. J. Paleolimnology 35: 111-128.

Donald, D.B., Syrgiannis, J., Crosley, R.W., Holdsworth, G., Muir, D.C.G., Rosenberg, B., Sole, A. and Schindler, D.W. 1999. Delayed deposition of organochlorine pesticides at a temperate glacier. Environ. Sci. Technol. 33: 1794-1798.

Flannigan, M.D., Logan, K.A., Amiro, B.D., Skinner, W.R. and Stocks, B.J. 2005. Future area burned in Canada. Climatic Change 72: 1-16.

Galay, VJ, Pentland, RS, and Halliday, RA. 1985 Degradation of the South Saskatchewan River below Gardiner Dam. Can. J. Civil Engineering 12: 849-862.

Gan, T.Y. 2000. Reducing vulnerability of water resources of Canadian prairies to potential droughts and possible climatic warming. Water Resources Management. 14: 111-135.

Hecky, R.E., Newbury, R.W., Bodaly, R.A. Patalas, K. and Rosenberg, D.M. 1984. Environmental-impact prediction and assessment – the Southern Indian Lake experience. Can. J. Fish. Aquat. Sci. 41: 720-732.

Heitman, T.L., Frederick, L.M., Viste, J.R., Guselle, N.J., Morgan, U.M., Thompson, R.C.A. and Olson, M.E. 2002. Prevalence of *Giardia* and *Cryptosporidium* and characterization of *Cryptosporidium* spp. isolated form wildlife, human and agricultural sources in the North Saskatchewan River Basin in Alberta, Canada. Can. J. Microbiol. 48: 530-541.

Hrudey, S.E. and Hrudey, E.J. 2004. Safe Drinking Water: Lessons from the Recent Outbreaks in Affluent Nations. IWA Publishing, London, UK.

Jackson, T.A. 1998. Mercury in aquatic ecosystems. In: Langston, W.J. and Bebianno, M.J.(eds), Metal Metabolism in Aquatic Environments., p 77-158. London, Chapman & Hall.

James Bay Mercury Committee. 1995. Report of activities 1993-1994. James Bay Mercury Committee, Montreal Quebec.

Jensen, S.E., Anders, C.L., Goatcher, L.J., Perley, T., Kenefick, S. and Hrudey S.E. 1994. Actinomycetes as a factor in odour problems affecting drinking water from the Saskatchewan River. Water Res. 28: 1393-1401.

Johnson, J.Y.M, Thomas, J.E., Graham, T.A., Townshend, I., Byrne, J., Selinger, L.B. and Gannon, V.P.J. 2003. Prevalence of *Escherichia coli* 0157:H7 and *Salmonella spp*. in surface waters of southern Alberta and its relation to manure sources. Can. J. Microbiol. 49: 326-335.

Kelly, C.A., Rudd, J.W.M., Bodaly, R.A., Roulet, N.T., StLouis, V.L., Heyes, A., Moore, T.R., Schiff, S., Aravena, R., Scott, K.J., Dyck, B., Harris, R., Warner, B. and Edwards, G. 1997. Increases in fluxes of greenhouse gases and methyl mercury following flooding of an experimental reservoir. Environ. Sci. Technol. 31: 1334-1344.

Lac, S. 2004. A climate change adaptation study for the South Saskatchewan River Basin. IACC Working Paper no 12.

Lapp, S., Byrne, J., Townshend, I. and Kienzle, S. 2005. Climate warming impacts on snowpack accumulation in an alpine watershed. Int. J. Climatol. 25: 521-536.

Lehmkuhl, D.M. 1972. Change in thermal regime as a cause of reduction of benthic fauna downstream of a reservoir. J. Fish. Res. Board Can. 29: 1329-1332.

Loney, M. 1987. The construction of dependency: the case of the Grand Rapids Hydro Project. Can. J. Native Studies 7: 57-78.

Newbury, R. and Gaboury, M. 1993. Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour. Freshwater Biol. 29: 195-210.

NSWA (North Saskatchewan Watershed Alliance) 2005. State of the North Saskatchewan Watershed Report 2005. ISBN 0-9737599-0-9.

OWC (Oldman Watershed Council) 2005. Oldman River Basin Water Quality Initiative. Five Year Summary Report. www.oldmanbasin.org/pdfs/orbwqi_5year.pdf

Rawson, D.S. 1958. Indices to lake productivity and their significance in predicting conditions in reservoirs and lakes with disturbed water levels. In: Larkin, P.A. (ed), H.R. MacMillan Lectures in Fisheries: The Investigation of Fish - Power Problems p. 27-42. University of British Columbia, Vancouver.

Rood, S.B. and Mahoney, J.M. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. Environmental Management 14: 451-464.

Rood, S.B., Samuelson, G.M., Weber, J.K. and Wywrot, K.A. 2005. Twentieth-century decline in streamflows from the hydrographic apex of North America. J. Hydrol. 306, 215-233.

Rosenberg, D.M., Berkes, F., Bodaly, R.A., Hecky, R.E., Kelly, C.A., and Rudd, J.W.M. 1997. Large-scale impacts of hydroelectric development. Environ. Rev. 5: 27-54.

Rosenberg, D.M., Chambers, P.A., Culp, J.M., Franzin, G., Nelson, P.A, Salkim, A.G., Stainton, P., Bodaly, A. and Newbury, R.W. 2005. Nelson and Churchill river basins. In: Benke, A. and Cushing, C., Rivers of North America, p. 852-901. Elsevier.

Schindler, D.W. 2000. Aquatic problems caused by human activities in Banff National Park. Ambio 29: 401-407.

Schindler, D.W. and Pacas, C. 1996. Cumulative effects of human activity on aquatic ecosystems in the Bow Valley of Banff national Park. Chapter 5 in: Green, J., Pacas, C., Bayley S. and Cornwell, L. (eds.). Ecological Outlooks Project. A Cumulative Effects Assessment and Futures Outlook of the Banff Bow Valley. Prepared for the Banff-Bow Valley Study. Department of Canadian Heritage, Ottawa, Ontario. 74 pp.

Schindler, D.W., Anderson, A.-M., Brzustowski, J., Donahue, W.F., Goss, G., Nelson, J., St.Louis, V., Sullivan, M. and Swanson, S. 2004. Lake Wabamun: A review of scientific studies and environmental impacts. Publication No. T769 prepared for the Minister of Alberta Environment.

Schindler, D.W. and W.F. Donahue. 2006. An impending water crisis in Canada's western prairie provinces. Proc. Natl. Acad. Sci. USA 103: 7210-7216.

Senate Standing Committee on Energy, the Environment and Natural Resources. 2005. Water in the West: Under Pressure. 4th Interim Report.

St.Louis, V.L., Kelly, C.A., Duchemin, E., Rudd, J.W.M. and Rosenberg, D.M. 2000. Reservoir surfaces as sources of greenhouse gases to the atmosphere: a global estimate. BioScience 50: 766-775.

Toma & Bouma Management Consultants. "The pursuit of quality!". A sustainable growth strategy for the Alberta agri-food sector. Edmonton, AB; 1997.

Watrecon Consulting (2005). Battle River Basin: Water Use Assessment and Projections. Submitted to Alberta Environment.

Watson, E. and Luckman, B.H. 2005. Spatial patterns of preinstrumental moisture variability in the southern Canadian cordillera. J. Climate 18: 2847-2863.

Wobeser , Nielsen NO, and Dunlop RH. 1970. Mercury concentrations in tissues of fish from the Saskatchewan River. J. Fish. Res. Board Can. 27: 830-834.

Wobeser, G. and Swift, M. 1976. Mercury poisoning in a wild mink. J. Wildlife Diseases 12: 335-340.

Captions for Figures

Figure 1. A map of the Saskatchewan River Basin. Physiographic provinces are separated by yellow lines. The river drains into Lake Winnipeg at the eastern end of the basin. The position of the basin within the Nelson River basin is shown in the inset. Seasonal average temperatures, precipitation patterns, evapotranspiration and runoff, and other information about the basin are shown are shown in the lower panel. From Rosenberg et al. (2005).

Figure 2. The Bow River Basin, showing major features. BRBC (2005).

Figure 3. The rating of 33 reaches of the South Saskatchewan and its tributaries. Data from Alberta Environment (2003).

Figure 4. The Oldman River Basin, showing vegetation types and other major features. From OWC (2005).

Figure 5. Livestock density in the Oldman River Basin. Figure supplied by Brad Stelfox.

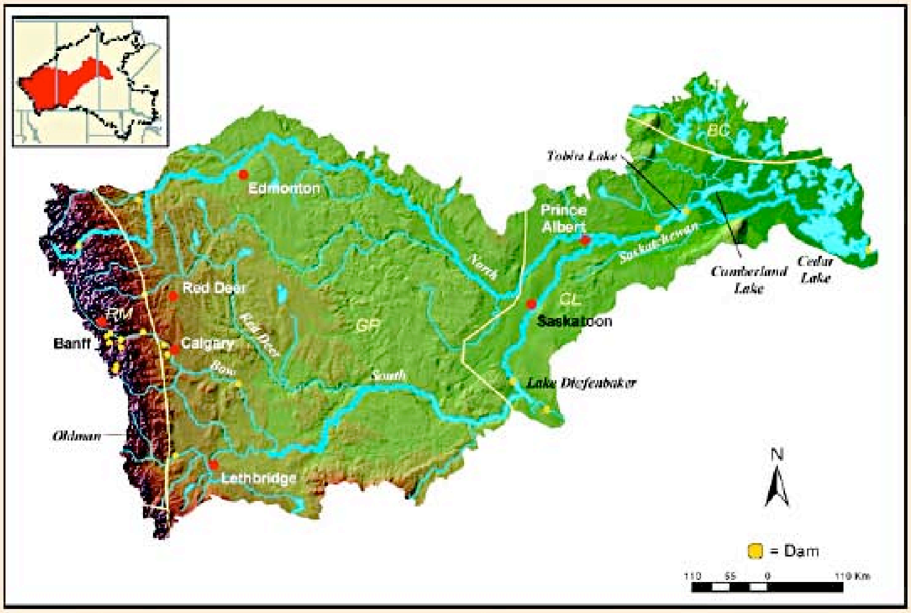


FIGURE 19.11 Map of the Saskatchewan River basin. Physiographic provinces are separated by yellow lines.

SASKATCHEWAN RIVER

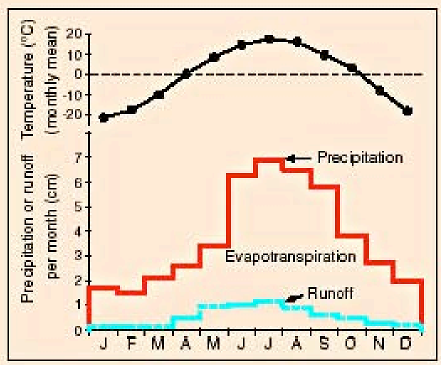
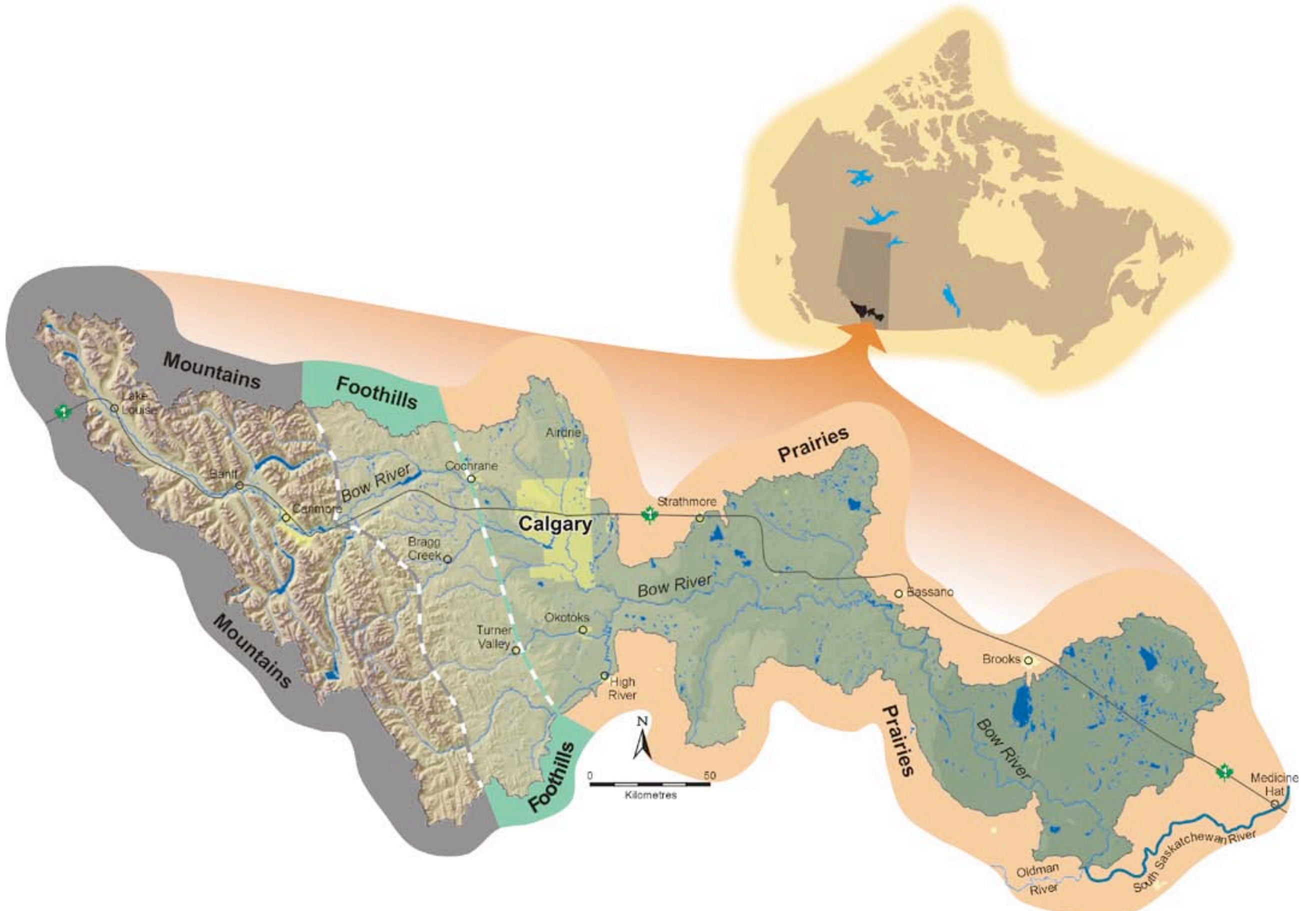


FIGURE 19.12 Mean monthly air temperature, precipitation, and runoff for the Saskatchewan River basin.

Relief: 3307 m
Basin area: 335,900 km^2
Mean discharge: 567 m^3/s (postregulation)
River order: 8
Mean annual precipitation: 45.2 cm
Mean air temperature: −0.3°C
Mean water temperature: 9.7°C
Physiographic provinces: Rocky Mountains in Canada (RM), Great Plains (GP), Central Lowland (CL), Bear–Slave–Churchill Uplands (BC)
Biomes: Temperate Mountain Forest, Temperate Grasslands, Boreal Forest
Freshwater ecoregions: Canadian Rockies, Upper Saskatchewan, Lower Saskatchewan
Terrestrial ecoregions: Alberta Mountain Forests, Alberta/British Columbia Foothills Forests, Canadian Aspen Forest and Parklands, Montana Valley and Foothill Grasslands, Northern Mixed Grasslands, Northwestern Mixed Grasslands, Mid-continental Canadian Forests
24 **Number of fish species:** ≥44
Number of endangered species: none
Major fishes: cutthroat trout, rainbow trout, bull trout, brook trout, brown trout, mountain whitefish, longnose sucker, longnose dace, northern pike, walleye, goldeye, yellow perch, quillback, shorthead redhorse, lake sturgeon
Major other aquatic vertebrates: beaver, mink, white pelican, river otter, muskrat, tundra swan, ring-necked duck
Major benthic invertebrates: mayflies (*Baetisca*, *Baetis*, *Ephemera*, *Ephemerella*, *Ephoron*, *Heptagenia*, *Tricorythodes*), stoneflies (*Isoperla*, *Choroterpes*), caddisflies (*Brachycercus*, *Cheumatopsyche*, *Helicopsyche*, *Symphitopsyche*, *Traverella*), true flies (*Chironominae*, *Tanypodinae*, *Orthocladiinae*), crustaceans (*Orconectes*)
Nonnative species: brown trout, rainbow trout, brook trout, purple loosestrife, curly pondweed
Major riparian plants: red-osier dogwood, sandbar willows, poplar, water birch
Special features: originates in glaciers and snowfields of Rocky Mountains in Alberta, a World Heritage Site; headwaters of North Saskatchewan River in Banff National Park designated Canadian Heritage Rivers; designated globally important bird areas in portions of prairies and boreal forests
Fragmentation: dams throughout for hydropower and irrigation
Water quality: pH = 8.0, alkalinity = 131 mg/L as $CaCO_3$; relatively free of pollutants in mountains (NO_3-N = 0.075 mg/L, PO_4-P = 0.009 mg/L); higher nutrient concentrations below major cities and in agricultural areas
Land use: 67% cropland, 3% shrub, 7% grassland, 22% forest
Population density: 9.6 people/km^2
Major information sources: Donald and Mutch 1980, Culp and Davies 1982, Charlton et al. 1986, Cross et al. 1986, Hamilton and North 1986, Sosiak 1990, Culp et al. 1992, Chambers and Prepas 1994, Carr and Chambers 1998, Environment Canada 2001, 2002

Figure 1



Mountains
Foothills
Prairies
Lake Louise
Banff
Canmore
Bow River
Cochrane
Airdrie
Calgary
Strathmore
Bragg Creek
Bow River
Bassano
Okotoks
Turner Valley
High River
Brooks
Mountains
Foothills
Prairies
Bow River
Kilometres
Medicine Hat
South Saskatchewan River
Oldman River

Figure 2

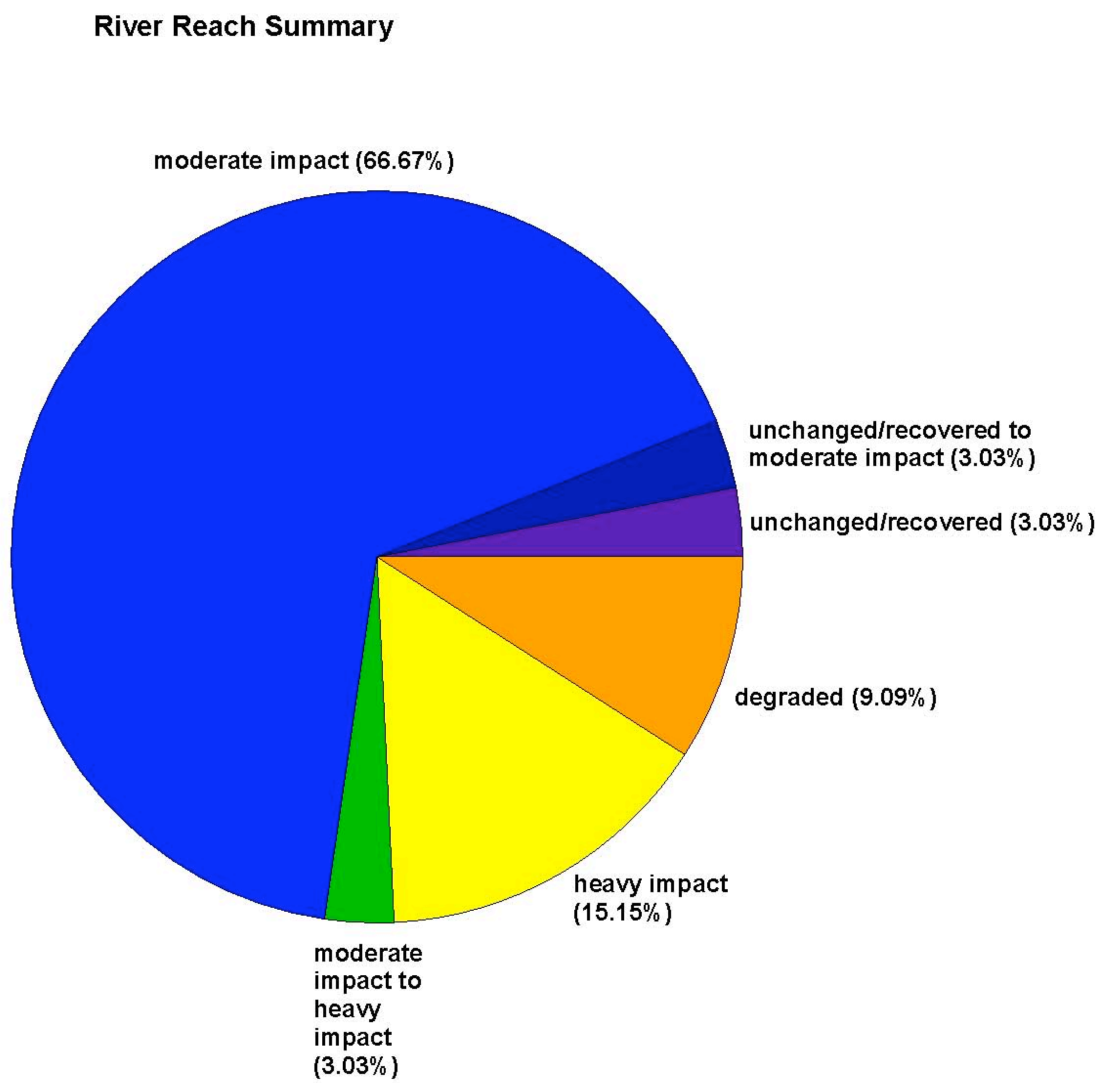

River Reach Summary
moderate impact (66.67%)
unchanged/recovered to moderate impact (3.03%)
unchanged/recovered (3.03%)
degraded (9.09%)
heavy impact (15.15%)
moderate impact to heavy impact (3.03%)

Figure 3

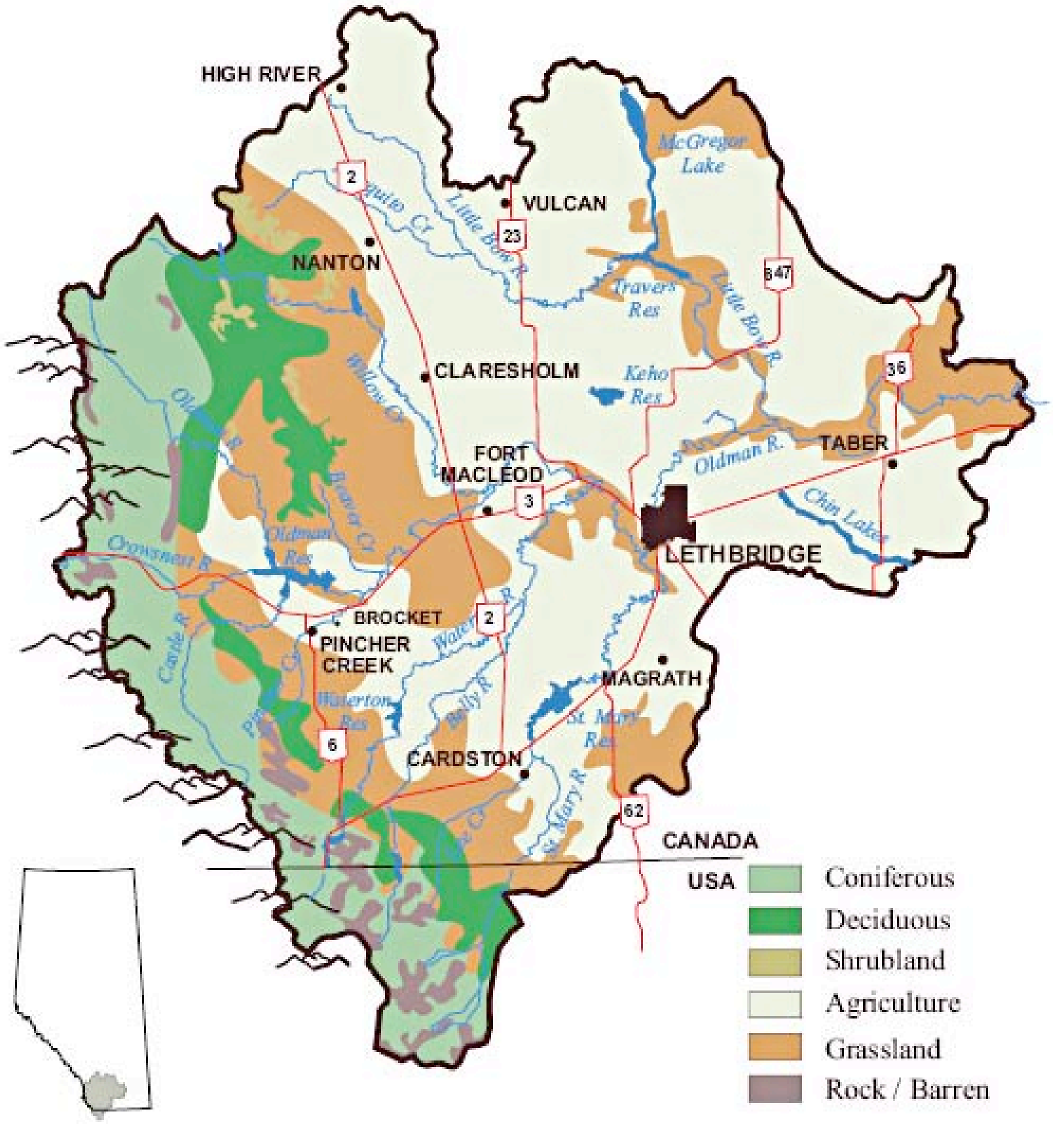

HIGH RIVER
VULCAN
NANTON
McGregor Lake
Travers Res
Little Bow R.
CLARESHOLM
Keho Res
TABER
FORT MACLEOD
Oldman R.
Chin Lakes
LETHBRIDGE
Oldman Res
Crowsnest R.
BROCKET
PINCHER CREEK
Waterton Res
MAGRATH
St. Mary Res
CARDSTON
CANADA
USA
Coniferous
Deciduous
Shrubland
Agriculture
Grassland
Rock / Barren

Figure 4

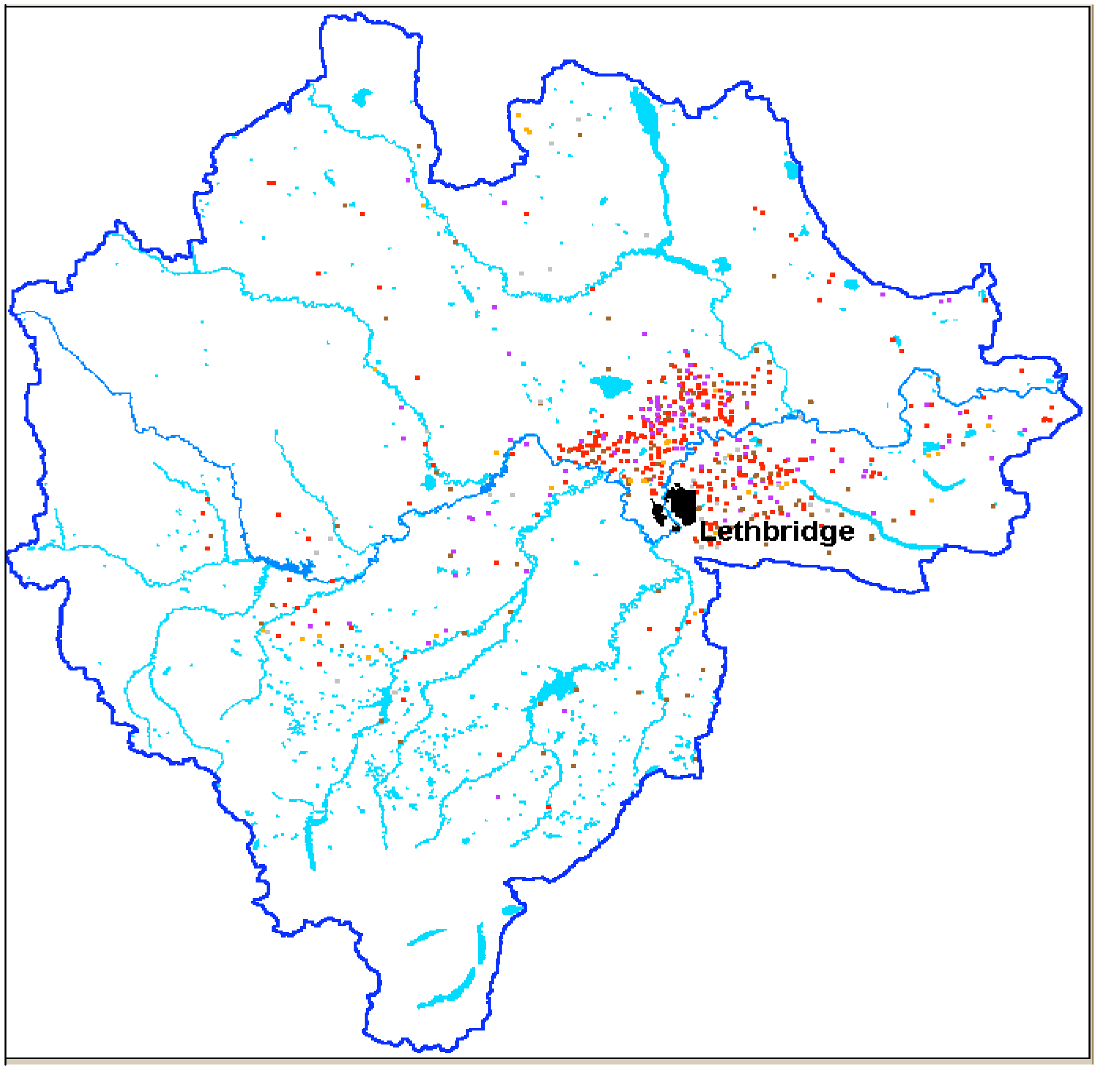


Figure 5