Prepared for

ALBERTA WATER COUNCIL

Current State of Non-Point Source Pollution: Data, Knowledge, and Tools

October 6, 2011

Prepared by

CPP
CHARETTE PELL POSCENTE ENVIRONMENTAL CORP

ACKNOWLEDGEMENTS

We would like to thank the numerous individuals that have contributed material and personal knowledge that was included in this report. We are very grateful to Alberta Environment who has shared with us documents in draft form. These documents have been critical in ensuring that reported knowledge was most recent.

We would like to particularly acknowledge the project technical team, composed of Yin Deong, Alesha Hill, Andrea Kalischuk, Steph Neufeld, Meredith Walker and Jay White. The individuals on this team provided substantial comment and many hours of review time that ensured progression of this document to its current state. Their passion and dedication to the project is greatly appreciated.

Last, but not least, Alberta Water Council Project Team were instrumental in providing comment and expectations for the project.

The following people contributed material, experience, and comments that contributed to the production of this report:

Alberta Environment: Curtis Brock, Roderick Hazewinkel, Brian Hills, Wendell Koning, Natalie Kromrey, Darcy McDonald, Leigh Noton, Dinesh Pokhrel, Joe Prusak, Chris Teichreb, Mike Wang

Alberta Agriculture: Andrea Kalischuk and Joanne Little

City of Calgary: Yin Deong

EPCOR: Steph Neufeld

Oldman Watershed Council: Natalie Kromrey

Other: Jay White, Aquality Environmental Consulting

Authors of this report include Théo Charette, from CPP Environmental Corp., and Marsha Trites.

This report should be cited as: CPP Environmental Corp. 2011. Current state of non-point source pollution: Knowledge, data, and tools. Report prepared by T. Charette and M. Trites for the Alberta Water Council. 153 pp.

Document layout and formatting by

Jessica Coles

EXECUTIVE SUMMARY

Alberta's streams, rivers, and lakes have many human uses, including drinking water, irrigation, livestock, fishing, and recreation, that depend on suitable water quality. Surface water quality is also important to support healthy aquatic ecosystems and wildlife. The health of aquatic ecosystems can be degraded by both point and non-point sources (NPS) of pollution. Much is known about the effects of point sources of pollution on the quantity and quality of waterbodies, largely because they are easier to measure and manage. Managing NPS pollution is difficult because the sources of pollution are difficult to pinpoint since contaminants enter aquatic ecosystems by diffuse means. The contributions of NPS pollution and the policies and tools that minimize their impacts need to be understood. The purpose of this report is to support this objective by assessing the current state of knowledge of surface water NPS pollution in Alberta, to provide a scientific foundation for management and policy recommendations.

The main paths by which NPS pollutants may reach water bodies are surface runoff, atmospheric deposition and groundwater, which have all been documented in Alberta. Factors that affect the movement of water through the landscape and soil erodibility are highly important in the expression of NPS pollution. These factors include the land surface form (shape, size, slopes of the earth's surface), the soil texture, and climatic setting, with climate (and thus natural region) as the overriding factor.

At the mainstem scale, the Alberta Provincial River Water Quality index generally rates water quality as good in the major river basins of Alberta. Although NPS loading to mainstem rivers is occurring, its expression in mainstem rivers is somewhat elusive. The impact of NPS pollution to mainstem rivers has been proven explicitly in only a few cases. Due to relatively low dilutive capacity, streams and tributaries are most affected by, and are at most risk from, NPS pollution. At this scale, NPS pollution has been documented for many human activities occurring in Alberta: agriculture, forestry, mining, recreational use and urban development. Due to expanding industrial and urban development, the impact of mining, *In Situ* oil and gas, recreational use and urban development are expected to increase in the province whereas agriculture has largely reached its spatial limit.

Provincially, where agriculture occurs, NPS movement of agriculture-related constituents to aquatic ecosystems can generally be expected. Nutrients (especially dissolved nutrients), pesticides and pathogens are the constituents that are mostly involved in agricultural NPS pollution. Basins that are the most influenced by NPS agricultural pollution are generally those that have the greatest proportion of their basin as agricultural land and those that have, proportionately, greater expanses of high-intensity agricultural development. In consequence, basins where agricultural NPS contributions appear to be highest would include the Oldman, Battle and Red Deer River basins. Basins that are relatively least affected are the Athabasca River Basin followed by the Peace River Basin, which both contain vast expanses of forested areas. All other basins fall somewhere in the middle.

Out of all human activities, large urban developments in the Bow and North Saskatchewan River basins seem to have the most direct effect on mainstem water quality, primarily because urban centers typically cluster around mainstems and many stormwater outfalls directly discharge to them. Urban development, through stormwater runoff, is also affecting the water quality and ecosystem health of streams. This runoff exports relatively important NPS pollutant loads of TSS, metals, nutrients, salts, pesticides, and fecal coliforms. Chloride salt is perhaps one of the best signatures of urban loading to aquatic ecosystems since its concentration is naturally low in the environment and it is highly associated with road salt application and runoff.

The impacts of forest clearing activities have been and are being well studied in northern Alberta, particularly in the Athabasce River Basin. Logging practices are extremely important in the response magnitude, particularly given that road construction and use pose the largest risk associated with logging. In general, in watersheds that have high logging density (e.g., greater than 50% of watershed logged has been proposed, Prepas et al. 2008), water yield and NPS pollution is likely to respond. Also, NPS response generally increases with logging intensity (as % of watershed area logged). An important finding from logging-related studies that is extremely important for NPS pollution management in Alberta is that wetlands often reduce the expression of NPS pollution.

The impact of recreational use has been receiving increasing attention with increased access to public lands. From the few studies that exist, it is clear that a lack of recreational oversight or over-use in certain sensitive areas (e.g., stream crossings) can be quite damaging in terms of TSS loads to streams. These streams are often critical habitat for highly valued fish species in Alberta.

The impact of active mining is well understood in the case of coal mines in the eastern slopes. The impact of a much younger industry, active oil sands mining, is cause for great debate. What is not well understood, and something that is of great concern is the NPS pollutant legacy of reclaimed sites and the length of time it will take for reclaimed areas to reach background levels.

Historically, NPS studies in Alberta focus on agriculture (largest land base) and municipal development. There is relatively good data on these human activities. One of the most important gaps identified in this report is that very little knowledge exists on NPS cumulative contributions from logging, oil & gas and recreational use in most headwaters, where these disturbances occur concomitantly. Documentation of the extent and severity of these disturbances is lacking as well. Also, important data gaps exist for most tributaries, which also constitutes the greatest challenge for watershed models used for decision-making.

A synthesis of NPS pollution knowledge by Basin is included in the report.

TABLE OF CONTENTS

ACRONYMS & ABBREVIATIONS

NPS	Non-Point Source
TSS	Total Suspended Solids
TDS	Total Dissolved Solids

1.0 INTRODUCTION

The Alberta Water Council is a multi-stakeholder partnership with members from governments, industry, and non-government organizations, all of whom have a vested interest in water. The Council was created in 2004 under Ministerial Order by Alberta's Minister of Environment, and it transitioned to a not-for-profit organization in 2007. The Council and its teams and committees operate by consensus. More information on the Council is available at www.awchome.ca. The council's report *Recommended Projects to Advance the Goal of Healthy Aquatic Ecosystems (March 2009)* identified a number of priority areas for work, including two recommendations around improving the understanding and management of non-point source (NPS) pollution. At the Council's 2010 Business Planning workshop, the board decided to undertake a project that would make recommendations to advance efforts in managing the impacts of NPS pollution in Alberta.

Alberta's streams, rivers, and lakes have many human uses, including drinking water, irrigation, livestock, fishing, and recreation, that depend on suitable water quality. Surface water quality is also important to support healthy aquatic ecosystems and wildlife. The health of aquatic ecosystems can be degraded by point and non-point sources of pollution, and the contributions of both sources of pollution and the policies and tools that minimize their impacts need to be understood. Much is known about the effects of point sources of pollution on the quantity and quality of waterbodies, largely because they are easier to manage. Managing NPS pollution is difficult because the sources of pollution are difficult to pinpoint since contaminants enter aquatic ecosystems by diffuse means.

The intent of this report is to assess the current state of knowledge of surface water NPS pollution in Alberta. Although the report is not intended to provide policy recommendations, it will provide a scientific foundation for management and policy recommendations in future documents (phase II and beyond).

This report will:

1) Identify major NPS pollutants in Alberta surface water,
2) Evaluate links between land practices, NPS pollutants, and water quality in Alberta or neighbouring jurisdictions,
3) Describe the availability and utility of NPS pollution data sources in Alberta, and
4) Describe tools for assessing NPS pollution in Alberta.

1.1 What is Non-Point Source Pollution?

According to AWC (2011), NPS pollution is contamination that enters a water body from diffuse points of discharge and has no single point of origin. Supporting characteristics include:

- Origins and diffuse points of discharge that are not easily identifiable and can be sporadic
- Difficult to prevent, measure, control, quantify, and manage
- Associated with particular land uses, as opposed to individual points of origin or discharge

- Can originate from activities related to agriculture, forestry, urban, mining, construction, roads/streets, recreation, hydraulic modification (i.e., dams, channels), hydro modification
- Transported by rain water, snowmelt, runoff, air deposition and groundwater
- Discharges to surface water that are often not regulated or covered by an approval or code of practice.

Land-based NPS pollution can be examined from a plot / field-scale, that is, pollutant runoff from patches of land. What has been particularly useful is the assessment of NPS pollution from a watershed-scale. A watershed is the area of land where all of the water that is under it or drains off of it goes into the same place. A watershed would include runoff from smaller patches such as plots and fields. Land-based non-point source pollution occurs as a result of two processes: increased water yield (particularly peak yields) as a result in changes in hydrology, and increased availability of pollutants that are carried by runoff.

1.2 Human Activities Associated with NPS Pollution

A number of human activities have the potential to contribute to NPS pollution. Main activities in Alberta include:

- Agriculture: Environmental risks to the aquatic environment are associated with land disturbance, animal and plant wastes, and substances applied to enhance production, including fertilizers (e.g., manure or chemical fertilizers) and pesticides. Agricultural activities that particularly cause NPS pollution include poorly located or managed animal feeding operations; overgrazing; plowing too often or at the wrong time; and improper, excessive, or poorly timed application of pesticides, irrigation water, and fertilizer. Pollutants that result from agriculture include sediment, nutrients, pathogens, pesticides, metals and salts.
- Forestry: NPS pollution associated with forestry activities include increased run-off as a result of land disturbance, increased sedimentation as a result of road construction and use and the mechanical preparation for the planting of trees, and substances applied to enhance production (pesticides).
- Mining: Environmental concerns related to mining are most often focused on land disturbance and run-off from mine sites. The mines intermittently release water from settling ponds containing groundwater, precipitation, and surface runoff that have passed through mined land and overburden. The water quality parameters of concern can be quite specific to the mine itself, depending on geology, tailings, etc. These can include pH (from acid mine drainage), total suspended solids and associated metals, total dissolved solids from coal preparation and treatment facilities, nitrogen (from explosives), and selenium. Mines of concern in Alberta include aggregate, coal and oil sands.
- Urban runoff (Figure 1): Urban runoff occurs when precipitation from rain or snowmelt flows over the ground. Impervious surfaces like driveways, sidewalks, and streets prevent urban runoff from naturally soaking into the ground (Figure 2). Urban runoff can pick up debris, chemicals, soil, and other pollutants and flow into a storm sewer system or directly to a lake, stream, river or wetland. Furthermore, urban stormwater tends to gather speed

and erosional power as it travels through conduits. At the point of discharge, stream banks can be highly eroded because of the highly energetic force of the water. Anything that enters a storm sewer system is discharged untreated into the waterbodies we use for swimming, fishing and providing drinking water. Constituents typically associated with stormwater include sediment, nutrients, pathogens and hazardous wastes such as pesticides, solvents, motor oil, and also higher water temperatures.

- Oil and Gas: Oil and gas exploration disturbs large areas of land in Alberta. The amount of forest cleared for seismic lines in Alberta is reported to be roughly equivalent to that of the forest industry (Alberta Environment and Environment Canada 2004a, for more detail, see Section 3.1). Potential contributions from the oil and gas industry to NPS pollution could result from soil erosion; spills from roads, well sites, and exploration corridors; and contamination of groundwater from saltwater injection wells or disposal wells. A by-product of oil and gas exploration is typically an increase in recreational use (see below).
- Recreation: Recreational use is growing in Alberta as unregulated access to wilderness areas increases with new infrastructure development. With this increase, trail damage can be severe (Figure 3) and quite common, which leads to erosion of exposed soil. Also, where trails encounter streams and no crossing structures are present, increased bank erosion and sedimentation of stream beds can occur, which can in turn affect fish populations.

Erosion caused by exposure of soil in construction projects

Stream erosion caused by stormwater swiftly carried to waterways during rain events. When stormwater is routed through pipes to nearby streams and rivers, it picks up speed and scours streambeds and erodes stream banks

Figure 1: Human activities in urban areas that can cause NPS pollution. Photos from the USEPA at http://water.epa.gov/action/weatherchannel/stormwater.cfm

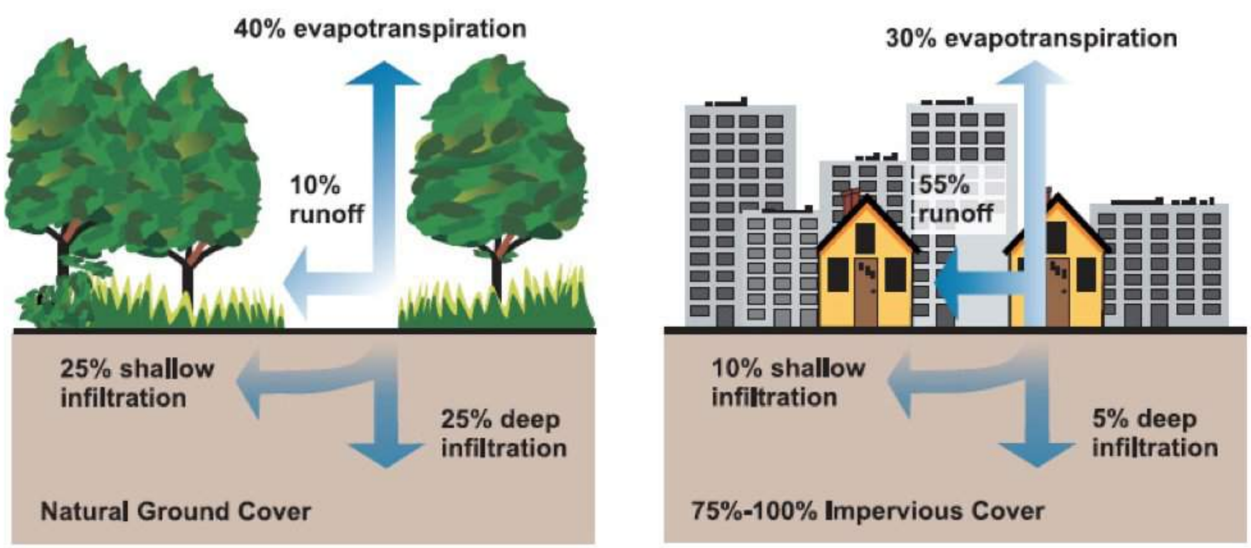

Figure 2: Relationship between impervious cover and surface runoff. NPS pollution related to urban development is a product of this increased surface runoff, which causes increased erosion and sedimentation and which also moves pollutants (such as nutrients, pathogens and pesticides) to watercourses. From USEPA (2003). Protecting water quality from urban runoff. Publication number 841-F-03-003.

1.3 Environmental Factors affecting NPS Pollution

NPS pollution is carried by the movement of water over and through the earth. In the natural environment, the movement of water through the landscape is controlled by common physical principles: the land surface form (shape, size, slopes of the earth's surface), the hydraulic properties of the geology, and climatic setting. These three factors combine to determine the potential for surface water flow (i.e., runoff) and erosion in a particular region. Out of these three factors, climate is the overriding factor and must be considered first. Precipitation and evapotranspiration affect the distribution, timing, and magnitude of surface runoff and groundwater recharge, and by association, NPS pollution. The natural regions of Alberta (Figure 4) are a provincial-level classification of geology, climate, and vegetation. Differences in climate among the subregions will dictate runoff, and thus, NPS pollution movement potential. As an example, results from the Alberta Environmentally Sustainable Agriculture (AESA) provincial program show that subregion plays an overriding role in that sites from more humid subregions export greater loads of agricultural-related constituents. Geology and landform are also important factors in determining NPS pollution movement potential. The quantity and rate that water flows over the surface (runoff) versus water that infiltrates into the soil depends on soil texture. Generally, finer textured soils (e.g., clays) are more likely to become saturated and generate runoff than coarse textured soils (e.g., sand and gravel). In addition, increased topography of the landscape also corresponds to a higher potential to generate runoff and higher soil erodibility.

Figure 3: Trail degradation due to a combination of poor water drainage and excessive motorized traffic in the Bighorn Wildland, North Saskatchewan River Basin. From AWA 2007.

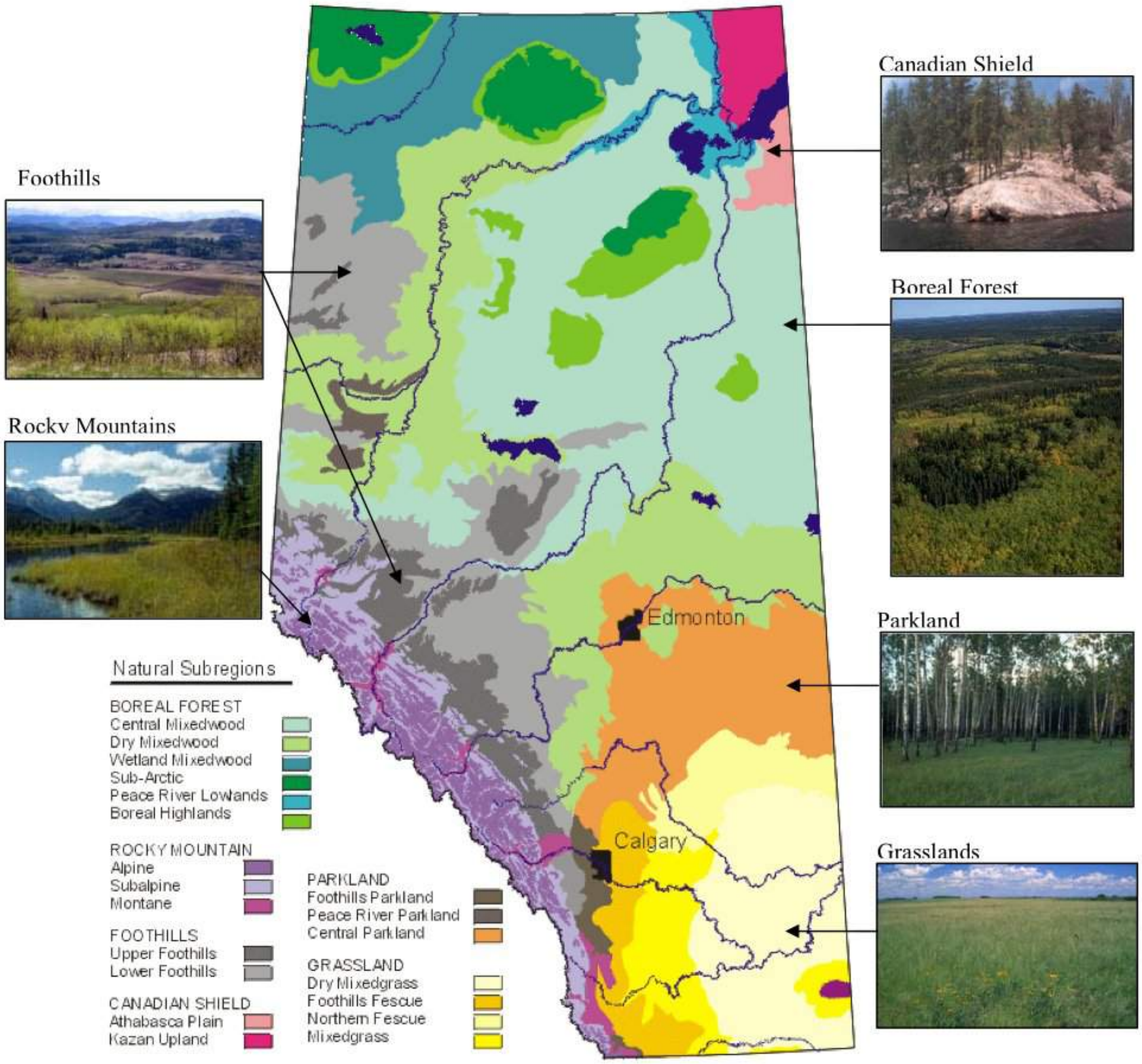

Figure 4: Natural Regions and Subregions of Alberta. From Braun and Hanus 2005.

Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Texture is the principal factor affecting erodibility, but structure, organic matter, and permeability also contribute. Sand, sandy loam, and loam-textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils. For example, sediments increase along the Peace River, largely as a result of a change in substrate material from coarse materials to silts and clays (see Section 3.9).

Certain areas are natural sinks for pollutants. Riparian areas and wetlands can act as filters for pollutants prior to runoff reaching larger water bodies. Buffer strips of vegetation, including riparian areas, are areas of land maintained in permanent vegetation that provide a physical set-back between human activities and a water body. Buffer strips tend to be particularly effective at intercepting sediments and associated pollutants before they are delivered to an aquatic ecosystem. In addition, wetlands play an important role in determining surface water quality in Alberta. Section 3.9 describes the importance of the amount and type of wetlands in relation to logging disturbances. Section 3.1 describes the importance of beaver ponds in the retention of pollutants. Generally, the importance of wetland-mediated responses to NPS pollution is expected to be greater in northern basins. However, even in northern basins, the amount and type of wetlands can be highly variable from one watershed to the next.

Because hydrological regimes differ from one subregion to the next, and arguably from one watershed to the next, the effect of human disturbance on NPS pollution can be quite different, depending on watershed-specific characteristics. As mentioned above, the transport of NPS constituents to aquatic ecosystems is partly dictated by geology. Alberta's hydrologeological framework is one of the most complex in the world. Deep glacial tills that underlie most of the province are highly variable in soil texture. Thus, as is mentioned throughout Section 3, natural variability can be quite high and mask the expression and detection of NPS pollution.

2.0 OVERVIEW OF KNOWLEDGE

2.1 Total Suspended Solids

Sediment is a very important component of and largely defines riverine ecosystems in Alberta. Through its energetic forces, water carries sediment and deposits it along watercourse beds and banks, in bars, and on the floodplain. As water flows downstream, it typically loses energy and its ability to carry larger sediment sizes usually decreases and larger-sized material (gravel, sand) drops out. It is common to find that bed material sediment size decreases with distance downstream (for example, see Section 3.9). Total suspended solids (TSS) is a measure of the sediment and particles that are suspended in water, which can include silt, clay, organic matter, and other particles.

Water quality patterns in Alberta rivers reflect flow patterns. This is particularly true of TSS, which typically increases exponentially with increasing river flow (Donahue 2010). As a result, TSS concentrations in Alberta's major rivers are high during spring flows. This relationship generally exists for tributaries and smaller streams; however, beaver ponds or wetlands in the local watershed can act similarly to settling ponds and mask the flow-TSS relationship (see Section 3.1).

Movement of sediments and solids into water bodies is a natural process, but human activities can increase the load of suspended solids exported into water bodies. This is a concern because TSS can harm aquatic systems by directly reducing fish feeding capacity and egg survival and causing gill abrasion, and also by carrying contaminants, such as nutrients, pathogens, pesticides, and metals. These contaminants are typically associated with the small sediment particles (especially clay sizes), which tend to be carried into a watercourse by bank erosion, soil erosion, and runoff. Human-related mechanisms that can affect TSS loads include direct sediment loading to an aquatic system (for example, through municipal discharge), an increase in runoff/discharge, disturbance/exposure of soil (for example, through channelization or construction), or a combination of these.

Any human activity that removes vegetation, decreases the permeability of soils, and disturbs and exposes soil to erosional forces has the highest potential for soil loss and increasing downstream TSS loads. Urbanization, construction, tillage, and riparian degradation are good examples of such activities.

Direct modifications to stream channels are perhaps the most invasive and highest impact human activities that result in high TSS loads. Perhaps one of the best examples of engineering project effects on aquatic ecosystems is the channelization of Lesser Slave Lake tributaries (Section 3.5). Not only has this channelization irreparably affected the tributaries themselves, but TSS loading has caused significant environmental impact to downstream Lesser Slave Lake that is likely to last decades.

One of the greatest NPS threats to aquatic ecosystems from urbanization is erosion, measurable as TSS. In Alberta, a few key studies have demonstrated the impacts of urbanization on aquatic ecosystems. Due to urbanization, West Nose Creek in Calgary has experienced excessive erosion, channel widening, undermining of storm sewer outfalls, and exposure of bridge abutments (Section 3.4). Similarly, Hardisty Creek in Hinton has experienced sedimentation, which has been traced back to erosion of recently developed land. These developed areas have bare soil or extensive gravel areas, both of which increase sediment loads to stormwater systems (McCleary 2009). At a larger scale, TSS has increased slightly over the last 100 years in the North Saskatchewan River mainstem as a result of urbanization in Edmonton (Section 3.7). Aquatic ecosystems that are most at risk are those that have relatively lower peak flows as compared to total stormwater peak discharge. Thus, smaller streams and tributaries are at highest risk. Small urban streams, such as West Nose Creek (Calgary), Whitemud and Goldbar creeks (Edmonton) are highly affected. The North Saskatchewan and the Bow rivers, although less impacted by urbanization, have been exposed to impacts from stormwater. Smaller rivers, such as the Wapiti River (in which the rapidly growing City of Grande Prairie discharges) and the Oldman River (in which the City of Lethbridge discharges) could also be at risk.

The impacts of forestry activities on water quality have been studied extensively in northern basins (Sections 3.1 and 3.9). Forestry companies are required to maintain riparian buffer areas around permanent and intermittent watercourses and are not permitted to operate within ephemeral waterbodies (Alberta Sustainable Resource Development 2008). Furthermore logging companies have to develop and follow forest management plans that address the full range of forestry activities that can cause NPS pollution. These clearly identify areas to be harvested, locate areas of protection, plan for proper timing of forestry activities and describe management measures for road layout, design, construction, and maintenance. However, suspended sediment loading to water courses have been measured as being related to forestry roads, especially when good forestry practices from the plans are not followed (Sherburne and McCleary 2002, Nip 1991).

Across North America, agricultural practices have been shown to increase TSS loads to water courses. In the Alberta setting, TSS movement to streams seems to be associated primarily in relation to cattle grounds in floodplains or direct access of cattle to water courses. An Alberta example is presented in Section 3.11 (Milk River Basin), which describes a study conducted in the Cypress Hills where authors detected significantly higher TSS loads in small streams where cattle were allowed unrestricted access (Scrimgeour and Kendall 2002). Another example, from the Red

Deer River Basin (Section 3.10), describes increased TSS loading from cattle wintering sites in the Haynes Creek watershed (Anderson et al. 1998). In addition, in irrigated areas, the concentration of TSS was significantly greater in return flows in five out of seven districts, as compared to source waters, indicating a degradation of water quality as water flows through the irrigation distribution system (Little et al. 2010). Although agricultural practices can increase TSS loads, as compared to native cover, agricultural intensity seems to have less of an impact. In a province-wide study of streams draining areas with varying agricultural intensity, Anderson et al. (1998) found that TSS was more related to runoff potential and stream discharge patterns than agricultural intensity. These studies combined indicate that site-specific conditions are very important in determining the potential risk to aquatic ecosystems.

Recreational activity is common in Alberta and tends to be concentrated in the green zones where public land, and thus public access, is common. Sections 3.7 and 3.8 describe recreational activity and its impact in headwaters of the North Saskatchewan and Oldman basins. In general, recreational activity along trails and other linear features increase TSS loads to streams. Along these access trails, there is largely no stream crossing infrastructure and the mode of impact is primarily from vehicular movement directly across streams. What is perhaps more important is the fact that recreational use, and thus impact, is largely undocumented for most of the green zone in Alberta, even though access is increasing at a fast pace (for more on increasing access, see Sections 3.1 and 3.3).

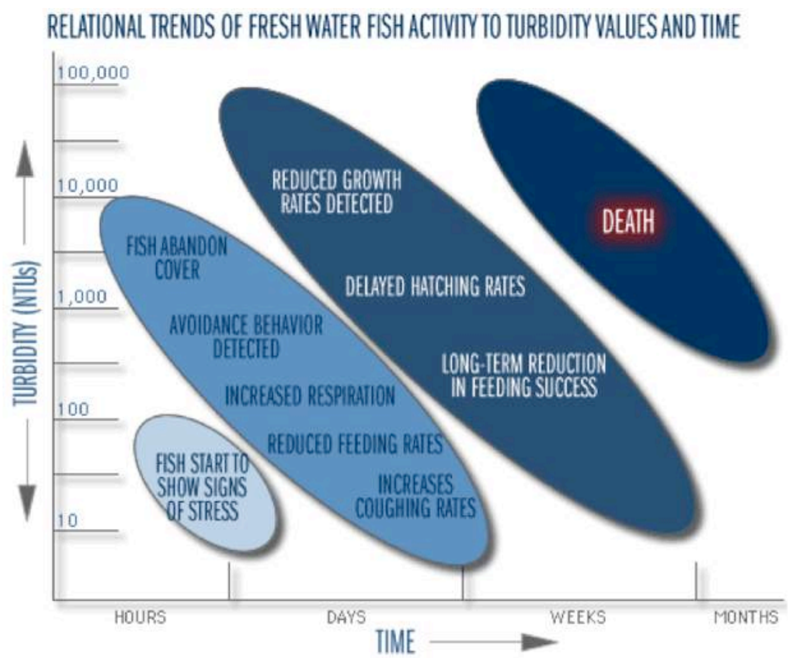

Figure 5: This figure below shows how aquatic organisms are generally affected. Very high levels of turbidity for a short period of time may not be significant and may even be less of a problem than a lower level that persists longer. From www.lakesuperiorstreams.org. Schematic adapted from "Turbidity: A Water Quality Measure", Water Action Volunteers, Monitoring Factsheet Series, UW-Extension, Environmental Resources Center. It is a generic, un-calibrated impact assessment model based on Newcombe, C. P., and J. O. T. Jensen. (1996).

In summary, the effects of NPS pollution are impacting small streams and tributaries and, in the case of large urban centers, the mainstem of main rivers. Small streams are extremely important for fish habitat and reproduction and TSS loads can have both acute and chronic effects on fish populations (Figure 5). At this scale, impacts have been documented for stream channelization projects, urbanization, forestry, agriculture and recreational use. The impact at the large tributary and mainstem scale has been shown in the case of urbanization; however, it generally remains elusive for most other human activities. Very large TSS loads in Alberta rivers, especially unregulated rivers (see Section 3.1 – Athabasca River), can effectively mask the relatively subtle expression of NPS TSS pollution in mainstem systems.

2.2 Nutrients

Nutrients are an essential component of any aquatic ecosystem; they feed the bottom of the food chain, allowing ecosystems to function. However, a state of excessive nutrient concentrations, termed "eutrophication", can be problematic. Excess phosphorus (and to a lesser extent nitrogen) in water bodies leads to excess growth of algae or aquatic plants, which can directly impair recreational activities and the movement of water for irrigation. In many cases in Alberta, algal blooms have cyanotoxin-producing species that can harm both wildlife and livestock. Furthermore, decomposition of dead algae and plants can lead to anoxic conditions in surface water, which can lead to fish kills, particularly under ice (Tonn et al. 2003). Excessive nutrients also reduce the diversity of aquatic plant and animal species. In addition to potential eutrophication effects, nitrate (NO3), nitrite (NO2) and ammonia (NH3) become toxic at high concentrations. Nitrate concentrations greater than 10 mg/L in drinking water can cause health effects for humans and livestock, while ammonia can be toxic to fish or other aquatic organisms (Alberta Agriculture and Rural Development 2004).

In a detailed review of factors that influence nutrient export from land to water, Beaulac and Reckhow (1982) identify geology, land use, management practices, and climate as the most important. Many aquatic ecosystems in Alberta are naturally productive due to the deep, phosphorous rich glacial till that underlies them (Garner Lee Limited 2007). For example, lakes in Alberta's Boreal Plain contain naturally higher nutrient concentrations than lakes that sit on the thin soils of the Boreal Shield. On average, they have six times more total phosphorus, five times more total nitrogen, and three times more dissolved carbon (Prepas et al. 2003b). Forest fire, a natural disturbance, can release nutrients that were locked into organic material and contribute significantly more particulate phosphorus to watersheds than unburned forests (Burke et al. 2005, Prepas et al. 2003a). In Alberta, nitrogen and phosphorus concentrations in surface waters can naturally exceed the guidelines for the protection of aquatic life when these nutrients are associated with high-flow TSS.

Because Alberta surface waters are naturally nutrient-rich, they are more prone to the negative effects of eutrophication. Land use has a well documented influence on nutrient export and eutrophication. Forested drainage basins or native prairie watersheds export nutrients, but they tend to do so at much lower rate than watersheds that have been disturbed by human activities such as logging, urban development or agriculture. These activities all increase TSS (see Section 2.1), which carries nutrients, in particular phosphorus. These sediment-bound nutrients are generally in particulate form. Dissolved nutrients, which are easily transportable in water, tend to be found in runoff from soils that contain nutrients in excess of what is required by vegetation.

Diffuse losses from agriculture have been identified as the largest non-point source of phosphorus to water bodies in the United States (USEPA 2002). In Alberta, it is also clear that agricultural activities contribute NPS nutrient pollution to aquatic ecosystems. The primary concern about agricultural NPS pollution, from a provincial perspective, is related to the build-up of nutrients in soil when manure and other fertilizers are applied at rates faster than can be used by crops (Soil Phosphorus Limits Committee and Landwise, Inc. 2006, Olson et al. 2010a). Organic (manure) fertilizer rates are often calculated in Alberta based on nitrogen requirements of crops, and this frequently leads to an excess of soil phosphorus (Miller et al. 2011). A strong positive relationship between soil and stream phosphorus indicates loss of phosphorus in small agricultural watersheds (Little et al. 2007). Section 3.1 (Athabasca River Basin) describes numerous examples of stream studies that have documented increased nutrient loads from agricultural, as compared to forested, watersheds. Section 3.3 (Beaver River Basin) describes a strong relationship between lake total phosphorus and land disturbance in the catchment of about 20 lakes, with agriculture being the main disturbance. In the Oldman Basin (Section 3.8), total nitrogen in tributaries of the Little Bow River increases in relation to percent land cover irrigated, and strongly decreases with percent native prairie on the landscape (Little et al. 2003). In addition to these studies that have shown impact of agriculture in general, agricultural intensity has been shown to play a very important role in determining NPS loads to watersheds. In a province-wide study of small watersheds, the Canada-Alberta Environmentally Sustainable Agriculture (CAESA; Anderson et al. 1998) and Alberta Environmentally Sustainable Agriculture (AESA; Lorenz et al. 2008) programs found that as agricultural intensity (chemical and fertilizer expenses and manure production percentiles) increases:

- Concentrations of phosphorus and nitrogen (mainly the dissolved fraction) in streams increase; dissolved nitrogen and phosporus fractions were positively correlated with agricultural intensity metrics; and
- Compliance with provincial and national surface water quality guidelines for the protection of aquatic life decrease.

These studies combined demonstrate the importance of agricultural NPS pollution in general, but also the importance of agricultural intensity on aquatic ecosystems in Alberta. That being said, agriculture has, by far, been the most intensively studied land use disturbance. Numerous other land uses contribute to, or could contribute to, NPS pollution in Alberta. Stormwater sewers in Edmonton contribute nutrients to the North Saskatchewan River, but the contribution to the total nutrient load to the North Saskatchewan River is relatively minor (i.e., 10% of total nutrient load; McDonald and Muricken 2009). In the Bow River, nutrient enrichment coming from urban stormwater increases oxygen demand (Golder Associates Ltd. 2007). Fertilizer from lawns of recreational properties may be a source of nutrients to Alberta lakes, but loads are not well documented (Association of Summer Villages of Alberta n.d.).

The impact of land clearing on aquatic ecosystems is described in Sections 3.1 (Athabasca River Basin) and 3.9 (Peace River Basin). In general, land-clearing effects depend on many factors, such as the density of disturbance, slope, the presence of wetlands in the watershed, and differences in forest management practices. In general, land clearing tends to exhibit a local effect that is less disruptive than natural disturbance (wildfire). The magnitude of response of aquatic ecosystems is related to the intensity of clearing in the watershed, with 50% of watershed disturbance being suggested as a threshold that is likely solicit a nutrient response (Prepas et al. 2008). Below this value, effects can occur, but they are likely to be relatively minor. Despite substantial changes in hydrology, studies may not be able to tease apart changes resulting from logging from that of naturally large inter-annual variation. The movement of water through wetlands and especially peatlands is difficult to predict and highly variable, thereby muddying the watershed disturbance-aquatic response relationship.

When a watershed has little development, nutrient loading is typically not a problem. For example, the less developed Milk River has dissolved phosphorus through its entire reach that is comparable to the upper reaches of other southern rivers (Younge 1988). In lakes, however, atmospheric deposition can play a greater role. Approximately 39% of the nutrient load into Pigeon Lake is through precipitation and dustfall (Logan and White 2007). In Narrow Lake, atmospheric deposition contributes 20 $mg/m^2/year$ of phosphorus whereas surface runoff contributes only 8 mg (Shaw et al. 1988). In these cases, it may be difficult to separate natural and anthropogenic sources of nutrients.

In summary, similar to our knowledge of NPS TSS pollution, NPS nutrient pollution is impacting streams and small tributaries, and large rivers in the case of large urban centres. Thus, these systems are subject to eutrophication and are at risk of exhibiting eutrophication-related effects described at the beginning of this section. At the small-watershed scale, impacts occur in relation to urbanization, agriculture and, to a lesser extent, forestry. The impact at the large tributary and mainstem scale has been shown in the case of urbanization associated with large urban centers. The impact at the large tributary and mainstem scale associated with other human activities generally remains elusive. This is largely a reflection of the main focus of human impact studies being on point-source pollution, hydrogeological complexity and a general lack of data on tributaries. Also, very large nutrient loads in Alberta rivers can effectively mask the relatively subtle expression of NPS pollution.

2.3 Salts

Natural waters contain cations and anions that combine to form salts. The major cations in surface waters are calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) and the major anions are bicarbonate (HCO^{3-}), carbonate (CO_3^{-2}), chloride (Cl^-), and sulphate (SO_4^{-2}). Springs, seeps, and groundwater are natural sources of ions to river systems in Alberta (Hillman et al. 1997). Dissolved salt concentrations are naturally high in many areas of Alberta because of the underlying marine-derived geology. As a result, many of the saline water bodies in Canada are located within the Interior Plains, which cover the southern portions of the Prairie provinces (EC & HC 2001). Climate plays a very important role in salt runoff and the salt balance of aquatic ecosystems. Salt concentrations are related to water levels in the Beaver River watershed, which have decreased substantially over the past two decades (Alberta Environment 2006a).

NPS pollution is a concern because salts in general cause osmotic stress for plants, which inhibits water absorption and reduces root growth. Salt also disrupts the uptake of plant nutrients and inhibits long-term growth. EC (2000) cites numerous studies attributing tree injury and decline to road-salt application, concluding that NaCl can cause severe injury to the flowering, seed germination, roots, and stems of roadside plant species. Damage to vegetation can occur up to 200 m from roadways that are treated with de-icing salts. Up to 50.8% of woody plant species are sensitive to NaCl, and many of these have disappeared from Canadian roadsides. As a result of salt concentrations in roadside soils, salt-tolerant halophytic plant species, formerly endemic to coastal wetlands, now colonize inland roadsides (EC & HC 2001). These species include cattails and *Phragmites*, both of which can be indicators of degraded wetlands subject to excessive nutrient loading or salt contamination. In general, sodium and chloride are the ions of most concern in Alberta. Chloride is one of the most damaging ions for crops because it can accumulate in plant leaves (Little et al. 2007, 2010). Sodium can also be toxic to sensitive species, but there is no surface water quality guideline in Alberta for sodium (Alberta Environment 1999). In addition, over the long term, excess sodium in soils can replace more stabilizing ions (Ca^{2+}, Mg^{2+}, CO^{-2}, and HCO^{3-}) in cation-exchange sites thereby degrading soil stability. Salts are also toxic to most downstream aquatic organisms, including fish, crustaceans, amphibians, invertebrates, and microbes.

Although salts naturally occur in soils, they can be enhanced by human activities such as urban development, agriculture, and mining. In agricultural watersheds, irrigation is of greatest concern with respect to salinization and salt export to aquatic ecosystems. In arid areas, evaporation of irrigation water can concentrate salts. Many irrigation districts have significantly greater salt concentrations in return flows than in source waters (Little et al. 2010). However, salt concentrations in these returns were generally below guidelines and are not considered to be problematic.

The use of road salt as a de-icer on roads is common practice in Alberta, although less so than most other provinces. The cheapest and most commonly used de-icing salt is sodium chloride (NaCl). Sodium chloride dissociates in aquatic systems into chloride ions (Cl^{-}) and sodium cations (Na^{+}). While sodium may bond to negatively charged soil particles or be taken up in biological processes, chloride ions are less reactive and can be transported to surface water through soil and groundwater. Mayer et al. (1999) completed a mass balance model to estimate chloride

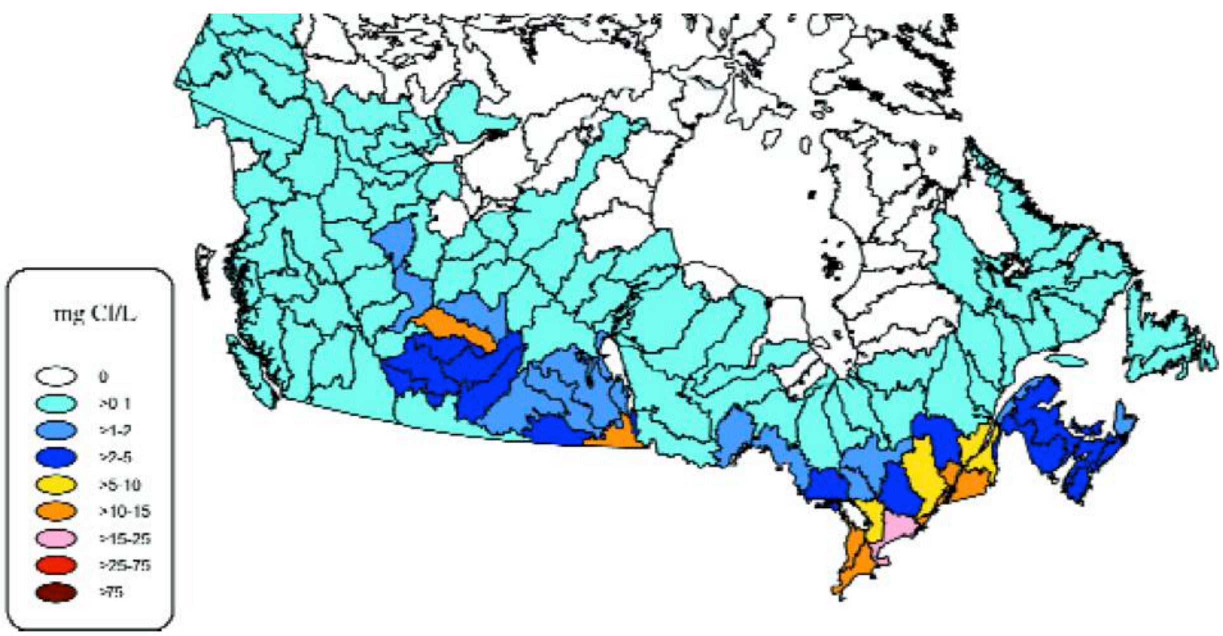

Figure 6: Estimated road salt chloride concentrations by watershed, calculated from average annual road salt loadings and average annual runoff (from Mayer et al. 1999).

concentrations in Canadian watersheds from the use of road salts. While the model is inherently simplified, it provides a reasonable estimate of the potential chloride concentrations resulting from road salt use. That said, the concentrations do not indicate actual exposure concentrations for specific watercourses or water bodies. Through modelling using road salt application rates and annual runoff rates, most of the province is estimated to have low loads of road salt. However, central Alberta is estimated to have relatively high loads of road salts, as compared to other areas in Canada, which may indicate a relatively high potential for NPS pollution (Figure 6). Section 3.7 (North Saskatchewan Basin) describes important increases in chloride downstream of the City of Edmonton that are linked to urban stormwater. Furthermore, small urban creeks in the City of Edmonton exhibit particularly high chloride concentrations, as compared to other creeks in the Basin. In Calgary, Nose Creek frequently exceeded total dissolved solids concentrations of 500 mg/L and excess chloride at the mouth has been related to road salt application. Fish Creek, also in Calgary, has also exhibited chloride concentrations in exceedence of guidelines to protect aquatic life (see Section 3.4).

Mining is another land use that typically leads to an overall increase in salts in affected surface water in Alberta. Typically, mines in Alberta disturb and expose wide swath of sediments that can oxidize and release ions into surface water runoff. Coal mining in the rocky mountain catchments causes overall ion concentration, and increases the relative importance of sulphate in contributing to total salinity (Hackbarth 1979). Salts associated with surface oil sands mining in the lower Athabasca basin disturb vast amounts of marine and estuarine deposited sediments which can oxidize and release ions. Reclaimed oil sands mines have saline soils (Purdy et al. 2005); therefore surface runoff from reclaimed oil sands mines will have elevated ions. As a result, the greatest uncertainty related to aquatic reclamation of oil sands mines is related to salinity. Much effort is currently being invested on reclamation research, planning and mitigative strategies to contend with predicted elevated salt concentrations.

In summary, NPS salt pollution is of greatest immediate concern related to road salt de-icing. De-icer assuredly has immediate impacts to roadside ditches. It also impacts aquatic ecosystems in Alberta, including mainstem rivers. This stresses the great importance of salt management, which should continue to be a high priority. In addition, reclamation is, relatively speaking, in its early stages in Alberta, particularly related to oil sands mining. In this context, there is great uncertainty related to salt runoff to reclaimed aquatic ecosystems, however, tremendous effort is currently being expended on the matter.

2.4 Metals

The concentration of certain metals is naturally high in Alberta geology. As a result, many rivers in Alberta exceed guidelines for some or all of aluminum, copper, manganese, lead, zinc and iron during periods of high flows (see sections 3.1, 3.9 and 3.10). As described in Section 3.0, most of these exceedances are associated with high TSS carried during periods of high flows that erode the local geology. Aluminum is perhaps the metal that generally most often exceeds guidelines. For example, on a local scale, the Muskeg River exhibits higher than expected aluminum concentrations, from unknown origins (Alberta Environment 2009). Also, aluminum water quality guidelines were usually exceeded in Alberta's irrigation districts (Little et al. 2010). In some parts of Alberta, namely the Peace River and Cold Lake regions, arsenic is known to be particularly high in the local geology. Arsenic guidelines are exceeded in several lakes in the Beaver River basin, again, presumed to be from natural sources of geologic materials (AENV 2006a).

Although certain metals are naturally high in Alberta soils, human activities may exacerbate their release. Activities such as logging, urban development, recreation and agriculture (including irrigation) all increase TSS (see Section 2.1), which carries metals. The activities described in Section 2.1 which increase TSS also generally increase metal concentrations in aquatic ecosystems.

Mining has been linked to increased metal mobilization. In the oil sands region, thirteen metals of concern to surface water (Bb, As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Tl, and Zn) were detected with elevated concentrations in snow within 50 km of oil sands mining operations. Mechanisms for transport into the snow and water could have been from upgrading activities, land clearing, mining, road dust, or other emissions (Kelly et al. 2010). Although it is unclear what impact these emissions have on the Athabasca River and its tributaries, NPS pollution is nonetheless occurring from atmospheric sources. In addition, coal mines in the Peace and Athabasca Basin headwaters are contributing NPS pollution of selenium to small streams. In surveys conducted in 1999 determined that selenium concentrations were about an order of magnitude greater than CCME chronic guidelines immediately downstream of three mines (Casey and Siwik 2000).

In summary, metal NPS pollution is of greatest concern with respect to urban development across the province and mining, and perhaps to a lesser extent, agriculture. Coal mining in headwater streams of the Athabasca and Peace River Basins and oil sands mining are of particular concern. Although NPS pollution may be occurring at a local (small watershed) scale, the large variability in metal concentration in Alberta rivers, especially unregulated rivers (see Section 3.1), can effectively mask the relatively subtle expression of NPS pollution. It can therefore be difficult to track metals in surface water back to their source. Luckily, metals in rivers are often associated with suspended sediments, which often does not make them biologically available.

2.5 Pesticides

Pesticides are synthetic substances introduced into the environment to control pests that interfere with crop production, forestry, or the cosmetic appearance of landscaped areas. There are no natural sources of pesticides in surface water. The most common categories of pesticides are herbicides, insecticides, and fungicides.

Pesticides tend to be water-soluble, volatile, and persistent, which means they can be transported to surface water bodies via groundwater, surface water runoff, or the atmosphere (Government of Alberta 2010). Factors affecting transport of any particular pesticide into surface waters are the solubility of the pesticide, rate of chemical degradation, and the degree to which the pesticide binds to soil particles. Sandy soils bind less tightly to pesticides, steep slopes are erosion prone and promote pesticide movement into surface water, and areas with shallow water tables are more vulnerable to pesticide movement into groundwater. Finally, factors relating to application timing also influence pesticide movement into surface water. Pesticides applied in the fall or early spring may be moved into water bodies by snowmelt, extreme rainfall events within the first few days after application move pesticides into surface water, and applying pesticides on windy days can increase risk of water body contamination (Alberta Agriculture and Rural Development 2004).

Pesticide detections are common and widespread in Alberta surface waters (see Section 3.0), being detected in 65% of all samples from Alberta environment's pesticide monitoring program since 1995 (Anderson 2005). More than 50 pesticides are routinely analyzed in Alberta surface water (Government of Alberta 2010). Seventeen of the most commonly applied pesticides in Alberta are 2,4-D, MCPA, Diazinon, Lindane, Picloram, Dicamba, Triallate, Atrazine, Bromoyuxynil, Cyanazine, Malathion, Methoxychlor, Chlorpynfos, Imazamethabenz, Diuron, Dichloroprop (Government of Alberta 2008). Generally, pesticides with the greatest sale records in Alberta are also the most frequently detected. However, in a few cases, characteristics related to pesticide mobility and persistence can result in selected pesticide types being more or less frequently detected in surfaces waters than their sale records alone would suggest (Anderson 2005). 2,4-D is the most commonly detected pesticide in Alberta surface water, found in more than 53% of samples.

Pesticides have been detected in a broad range of Alberta water bodies, from rivers, creeks, and urban streams, to lakes and wetlands, and irrigation canals and returns (Anderson 2005). Non-point sources are generally attributed to agricultural, domestic, and municipal uses (Lorenz et al. 2008). The Smoky, Wapiti, Peace, and Athabasca rivers have the lowest pesticide levels in the province, reflecting less development and overall lower pesticide use in this region. Localized areas of the Red Deer River, the Bow River, and the Battle River have the province's highest levels of pesticides (Government of Alberta 2010), due to a combination of both relatively high intensity urban development and agriculture. Pesticide concentration in water is correlated with agricultural intensity (Anderson 2005) and pesticides are routinely detected in irrigation return channels and in streams passing through high intensity agriculture (Little et al. 2010). In urban settings, detections can be as common or more common as compared to agricultural watersheds, primarily due to stormwater runoff (for example, see Section 3.7 – North Saskatchewan River). There are patterns of increased detections and diversity of pesticides downstream from major urban centres in the province, notably Lethbridge, Edmonton, Calgary, and Red Deer (Anderson 2005). Also, pesticides are routinely applied by the forestry industry in Alberta. They are most commonly used to control growth of non-commercial species in clearcuts, thereby encouraging regeneration of target tree species (Strong and Gates 2006). Roughly 30,000 ha of clearcut forests are sprayed with herbicides in Alberta each year (Government of Canada 2010). At this time, we are unsure how much forestry related pesticides reach Alberta's surface water, but they are likely to be a source.

Pesticides do occur in surface waters that are long distances from application sites. They have been detected in the Rocky Mountains of Alberta. Organochloride pesticides originating in warmer climates were deposited on glaciers via precipitation from 1950-1970 but more recently have reached surface waters via glacial meltwater (Blais et al. 2001). Pesticides are also detected in snow and snowmelt water in the mountains (Lafrenière et al. 2006). Wind eroded soil and dust is another potential transport mechanism for pesticides. Increased glyphosate contamination has been detected in aspen parkland wetlands during dry spells, and it is speculated that dust clouds were the cause (Anderson et al. 2002).

Provincially, pesticide detections occur most frequently from March to September and in June and July. This is related to patterns of ice and snowmelt in March and April, and peak rainfall in June and July. Pesticides detected during spring melts are from the previous season's application. Highest concentrations of pesticides can be measured when rainfall events occur shortly after main application periods (Anderson 2005).

Alberta does not have guidelines for aquatic life, recreation, irrigation, and livestock for all pesticides used in Alberta. Only 30 out of 68 pesticides detected in Alberta surface waters have associated water quality guidelines. Surface water quality guidelines for pesticides are exceeded in some locations. For example, MCPA and Dicamba are commonly exceeded for irrigation and may be a concern for crop production.

In summary, urban development and agriculture are the two most predominant sources of pesticides in the province. Pesticide detection and diversity increase with both agricultural intensity in small streams and in small urban streams and in mainstem rivers downstream of large population centers. Both of these sources are likely to increase as commodity prices and population continue to rise in Alberta. Although individual guidelines are not commonly exceeded, multiple pesticides are often detected simultaneously and pesticides are particularly persistent in the environment, the impacts of which are not clearly resolved (Government of Alberta 2010).

2.6 Pharmaceuticals, Hormones, and Other Endocrine Disruptors

Pharmaceuticals, hormones, and other endocrine disruptors are emerging contaminants. In Alberta, the history of monitoring for these compounds in surface water has been relatively short. Many of these contaminants would be from point sources (wastewater treatment plants). However, low concentrations of commonly used livestock pharmaceuticals, such as antimicrobials, are detectable in streams in Alberta's agricultural areas (Forrest et al. 2011). Concentrations in streams correlate to other constituents associated with agricultural activities, and tend to peak in concentration during the spring. It is not clear at this point what effects these pharmaceuticals may have on aquatic life or the implications to water users.

2.7 Organics

Organic carbon is a natural compound found in aquatic ecosystems in Alberta. The amount of wetland cover in a catchment largely determines how much dissolved organic carbon is exported to aquatic ecosystems. As a result, rivers that drain significant amounts of wetlands, in particular peatlands, will usually have a deep brown colour. Rivers like this include the Muskeg River in the Athabasca basin and the Wabasca River in the Peace basin.

The addition of excess organic carbon in water bodies, due to human influence, leads to increased oxygen demand, which can impact oxygen concentrations that fish and other organisms depend on. In northern basins, pulp mill and municipal wastewater are important point sources that have been well-documented. On the Bow River in Calgary, although industrial and municipal outfalls are point sources of organics, water downstream of Calgary is still within water quality guidelines (Telang 1990). In the North Saskatchewan River, storm sewers are considered to have minimal impact since they contribute less than 10% of the total organic loads (McDonald and Muricken 2009). In the Milk River Basin, cattle grazing has been reported as being a potentially important source of organic carbon (Mapfumo et al. 2002). That said, Milk River water quality is generally good.

Certain organic compounds can also be directly toxic to aquatic life. Log yards servicing the logging industry in Alberta are sources of a variety of organic compounds to surface waters. Phenolic compounds, resins and fatty acids, and tannins are common in runoff water from log yards, all of which can be toxic to aquatic life. Measured levels of total organic carbon in log yard leachate can range from 20 to 2,230 mg/L. Log yards are located throughout Alberta's forested natural subregions – many within 500 m of surface water bodies (McDougall 1996).

Naphthenic acids are a complex and large class of cyclic organic compounds that tend to occur as mixtures. They are released from bitumen, and in Alberta, they are primarily associated with the oil sands mining region of the lower Athabasca River. There are no established water quality guidelines associated with naphthenic acids at present. However, native fish species do show sensitivity to naphthenic acids at concentrations as low as 1.12 mg/L (Peters et al. 2007). Waste waters from oil sands extraction, stored in large tailings ponds, can have naphthenic acid concentrations that exceed 80 mg/L (Peters et al. 2007). It is uncertain whether oil sands mining is a source of naphthenic acids to the Athabasca River and its tributaries. Concentrations of naphthenic acids in the mainstem and tributaries are less than 0.2 mg/L at most sampling stations (Hatfield Consultants et al. 2011). There are gradual increases in concentration moving downstream, particularly downstream of the mouth of the Muskeg River (Hatfield Consultants et al. 2011). Some natural sources of naphthenic acids likely occur where the Athabasca River and its tributaries cut through naturally exposed bitumen deposits. However, present technologies for measuring naphthenic acids are not able to routinely differentiate between naturally sourced naphthenic acids and those derived from oil sands oil sands extraction. Environment Canada research programs are progressing on this front (Wrona and di Cenzo 2011). The toxicity associated with naphthenic acids is one of the primary concerns with respect to aquatic ecosystems near oil sands development and those that are planned for reclamation.

Polycyclic aromatic compounds (PACs) are a large group of chemicals with fused aromatic carbon rings that typically exist as mixtures rather than pure compounds (Timoney and Lee 2011). They are common contaminants in many ecosystems and enter the environment from natural pathways, such as forest fires or seepage from natural hydrocarbon deposits, and through industrial and other anthropogenic sources. Due to harmful effects of PACs on humans and animals, many individual PACs are addressed by Alberta's surface water quality guidelines (Alberta Environment 1999). PACs are harmful in very low concentrations; environmentally relevant effects occur with PAC concentrations in the μg/L range. There is significant controversy surrounding PACs in the Athabasca River. It is likely that flow of the mainstem river and its tributaries through exposed bitumen deposits leads to PAC movement into surface water. Because of this, there is much debate regarding whether oil sands development is causing release of PACs.

Similarly to PACs and naphthenic acids, hydrocarbons have been detected at higher than normal levels in rivers in the oil sands mining area. It is unresolved at present if these are due to natural erosion of natural hydrocarbon deposits, or if this is due to oil sands mining activity. The hydrocarbons, carried in the suspended sediment, are typically observed in the tributaries and concentrations decline rapidly (values less than 0.01 μg/g) within the mainstem of the Athabasca River (Alberta Environment 2009).

In summary, NPS organic pollution is primarily an issue associated with industrial activities, which are largely concentrated in the northern portion of the province. A great amount of debate is occurring surrounding the source, impact, and possible legacy of oil sands development on organic pollution of aquatic ecosystems in the Athabasca River Basin.

2.8 Pathogens

Fecal pollution of water from a health point of view is the contamination of water with disease-causing organisms (pathogens) that may inhabit the gastrointestinal tract of mammals. Pathogens associated with mammals are carried in water and can move through the environment via stormwater runoff, groundwater and surface waters. Sources of pathogens are leaky septic tanks and runoff of pet wastes from urban areas. Also, wildlife species that concentrate in herds or flocks can contaminate waterbodies in localized areas (Palliser Environmental Services Ltd. 2009). In agricultural areas, pathogens may be transported from runoff from grazing areas, fields treated with manure, animal housing areas, manure storage facilities and animals defecating directly into waterways (Figure 7). However, this depends on what type of manure is used and how manure is treated and handled before being spread on crops.

The detection of bacteria in surface water tends to be localized, and does not always correspond to particular land use activities (Little et al. 2003). *E. coli* and fecal coliforms suggest contamination from fecal matter (either human or animal). Fecal coliforms are relatively short-lived; hence, their presence indicates local sources of contamination (Palliser Environmental Services Ltd. 2009). For example, local tributaries, rather than the mainstem of the Oldman River, are more frequently close to or above water quality guidelines for bacteria (Koning et al. 2006). This pattern is evident throughout Alberta.

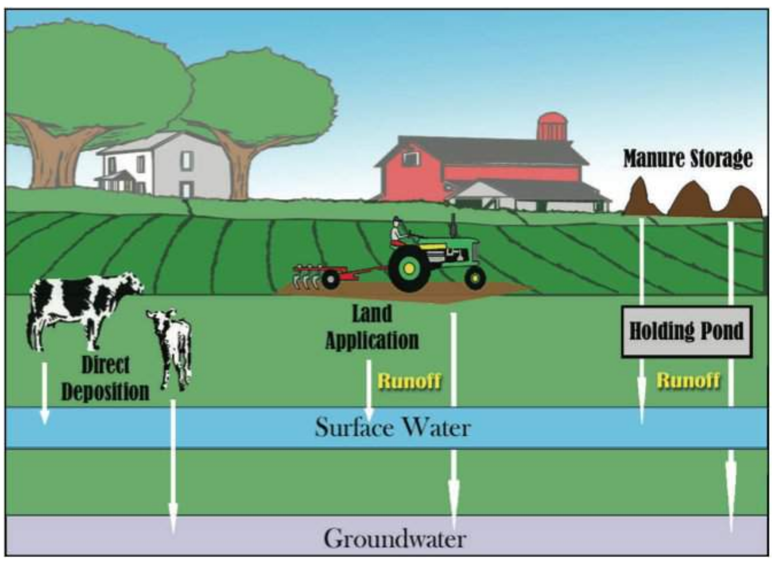

Figure 7: Pathways that pathogens may be transported from agricultural areas. Figure from J. Thurston-Enriquez.

Non-point sources are known to be important sources of pathogens to aquatic ecosystems in Alberta. In the North Saskatchewan River, urban runoff is an important source of fecal coliforms (see Section 3.7). In the same river, *Cryptosporidium* and *Giardia* in the NSR Basin have been primarily linked to agriculture. Both parasites increase with total livestock density in agricultural streams (Mitchel 2002). Giardia detections occur in the Oldman River (Koning et al. 2006) and in runoff from grazing activities in the Milk River basin (Mapfumo et al. 2002). In short, other than natural sources such as wildlife, pathogen NPS pollution is largely an issue related to urbanization and agricultural activities.

3.0 KNOWLEDGE BY BASIN

3.1 Athabasca

3.1.1 Introduction

The Athabasca River Basin drains 138,000 km^2 and passes through the Rocky Mountains, Foothills, Boreal Plains, and Boreal Shield. The Athabasca River's headwater source is the melting snow and glaciers of the Columbia icefield. Finely ground rock adds a silty grey colour to the water. The river flows through Jasper National Park and into the foothills where it passes through coal mining areas. The river encounters major point sources of pollutants from pulp mills in Hinton and Whitecourt. In Whitecourt, the Athabasca joins with one of the major tributaries to the Athabasca River, the McCloud River. The McLeod River passes through coal mining areas and limestone quarries. Past Whitecourt, the Athabasca River joins with another major tributary, the Pembina River, which drains agricultural lands to the south. The Athabasca River continues through the town of Athabasca, and soon after passes another pulp mill. The river then joins with another major tributary, the Lesser Slave River, which flows into and out of Lesser Slave Lake (the second largest lake in Alberta) before its confluence with the Athabasca River. As the Athabasca River moves north, it encounters a series of turbulent rapids that increase dissolved oxygen in the river (NRBS 2002). The Athabasca River joins with the Clearwater River at Fort McMurray. After this, the river is joined by several smaller tributaries and passes through oil sands mine development before reaching Lake Athabasca, the fourth largest lake in Canada.

Hydrometric monitoring stations are located at the headwaters (Jasper), mid-river (Athabasca) and lower river (Fort McMurray), where mean annual discharge is 2,790,000 dam^3, 13,600,000 dam^3, and 20,860,000 dam^3, respectively (Alberta Environment 2011).

The Athabasca River basin is sparsely populated. Major centers include Fort McMurray (pop. >65,000), Hinton and Whitecourt (pop. <10,000), and Athabasca and Jasper (pop. <5,000). Point source inputs include continuous discharge from four pulp mills and five waste water treatment plants.

Water quality is regularly monitored by Alberta Environment (AENV) at four long-term river network (LTR)N sites from upstream of Hinton to the mouth of the Athabasca River. Alberta's Water Quality Index has consistently rated water quality in the Athabasca River as excellent (headwaters) to good (middle and lower reaches). Water samples collected from the Athabasca sub-basin occasionally exceed guidelines for nutrients and metals. These elevated concentrations were associated with increases in suspended solids.

A number of human activities potentially contribute to non-point source (NPS) pollution in the Athabasca River Basin. Main activities include:

- Forestry: Large-scale forestry is very active throughout the basin and feeds four pulp mills in Alberta. The risks to the aquatic environment are mainly associated with increased run-off as a result of land disturbance. Pesticides are also used in the forestry industry.
- Agriculture: Most of the agricultural land is located in the Pembina and Central Athabasca sub-basins. Environmental risks to the aquatic environment are associated with land

disturbance, animal and plant wastes, and substances applied to enhance production, including fertilizers (e.g., manure or chemical fertilizers) and pesticides.

- Oil and Gas (conventional and in-situ): The oil and gas and in-situ oil sands industry is very active within the basin (Figure 9). A large network of pipelines, access roads and cutlines crisscross the Basin (Figure 10) to serve these operations. The oil and gas industry may contribute to NPS pollution through soil erosion; spills from roads, well sites, and exploration corridors; and contamination of groundwater from saltwater injection wells or disposal wells. These activities and processes could lead to changes in Total Suspended Solids (TSS), certain metals, ion concentrations, pesticides, and trace organics (North/South Consultants et al. 2007).
- Coal Mining: Six coal mines operate in the upper portion of the Basin, located in the McLeod, Pembina, and Berland river sub-basins. Environmental concerns related to mining are most often focused on land disturbance and run-off from mine sites. The mines intermittently release water from settling ponds which contain groundwater, precipitation, and surface runoff that have passed through mined land and overburden. The water quality

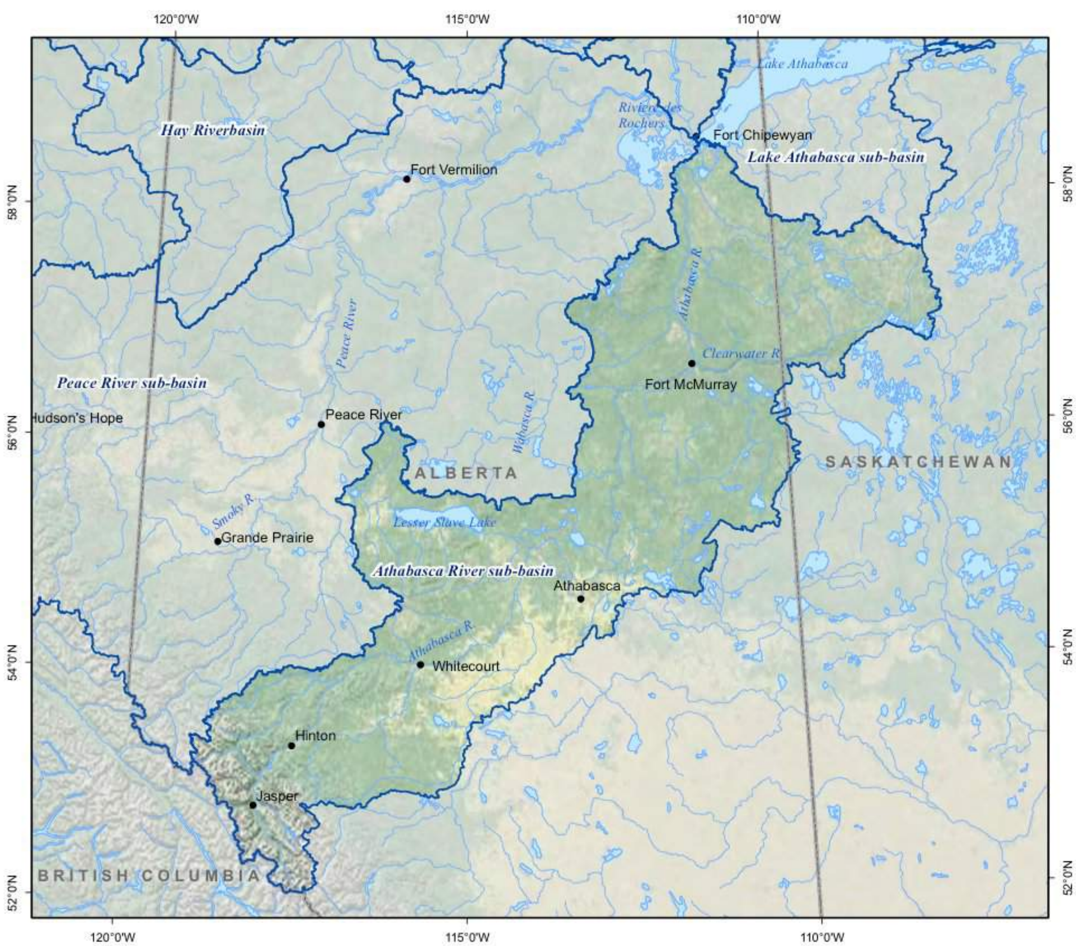

Figure 8: Athabasca River Basin. Yellow and green areas correspond to cleared and forested land cover, respectively. From Hatfield 2009.

parameters of concern can be quite specific to the mine itself, depending on geology, tailings, etc. These can include pH (from acid mine drainage), TSS and associated metals, total dissolved solids from coal preparation and treatment facilities, nitrogen (from explosives), and selenium.

- Oil Sands Mining: Environmental concerns related to oil sands mining, similarly to coal mining, are related to land disturbance and run-off from mine sites. Due to the high density of oil sands mines (Figure 9), aerial deposition of constituents is also a concern.
- Sand and gravel: A number of sand and gravel pits are operating throughout the Athabasca River Basin. These pits tend to operate next to watercourses, which increases the risk for NPS pollution. Sand and gravel operations currently follow a code of practice that stipulates runoff water from the pit must meet certain water quality criteria before it is discharged to the natural environment.
- Urban: Five main municipalities contribute urban runoff to the Athabasca River, including the City of Fort McMurray and the towns of Athabasca, Hinton, Whitecourt, and Jasper.

Point sources of pollution in Alberta include wastewater from the four pulp mills and from municipalities.

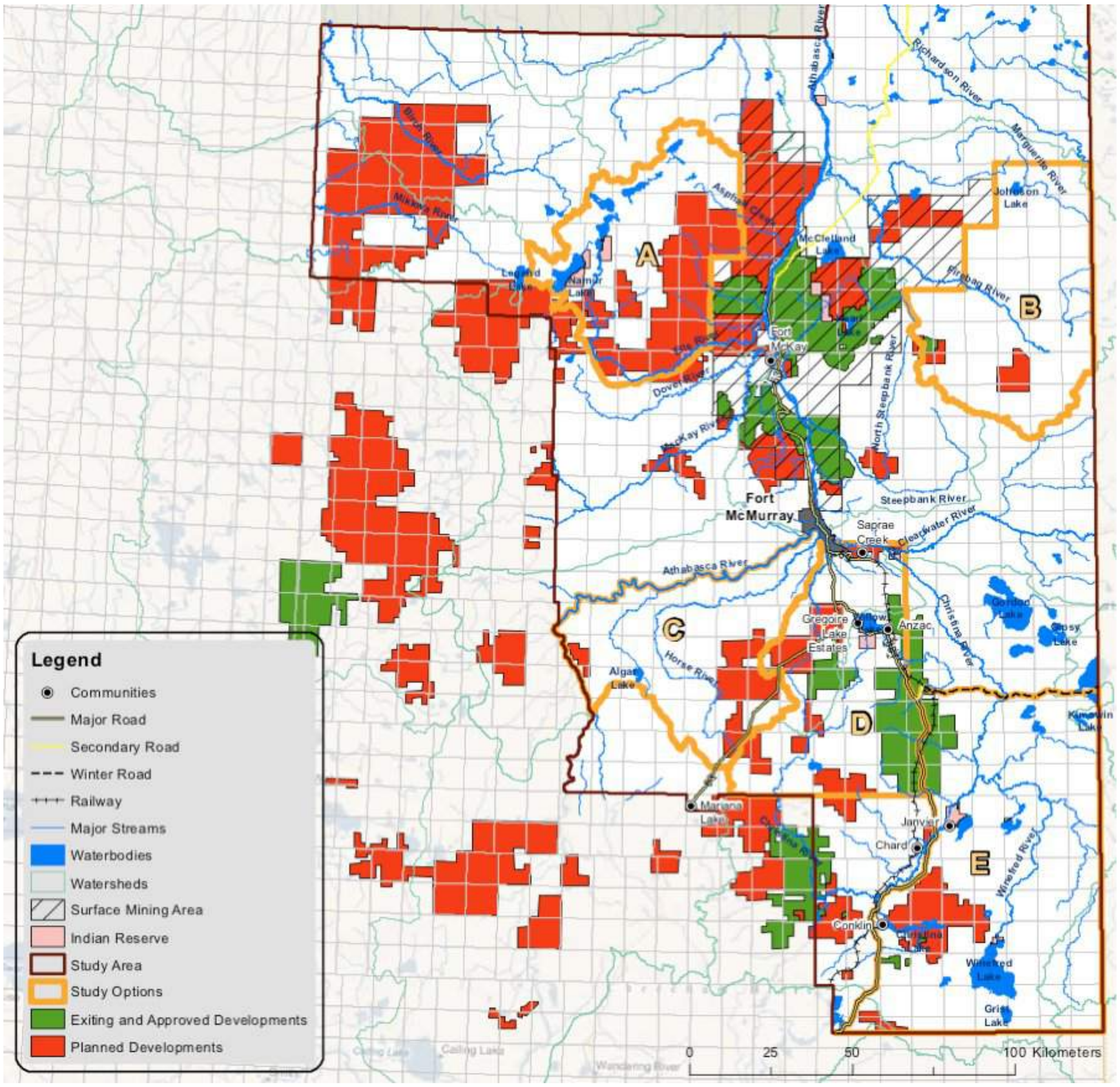

Figure 9: Existing and planned oil sands developments in the Regional Municipality of Wood Buffalo. From Compass Resource Management Ltd. (2010).

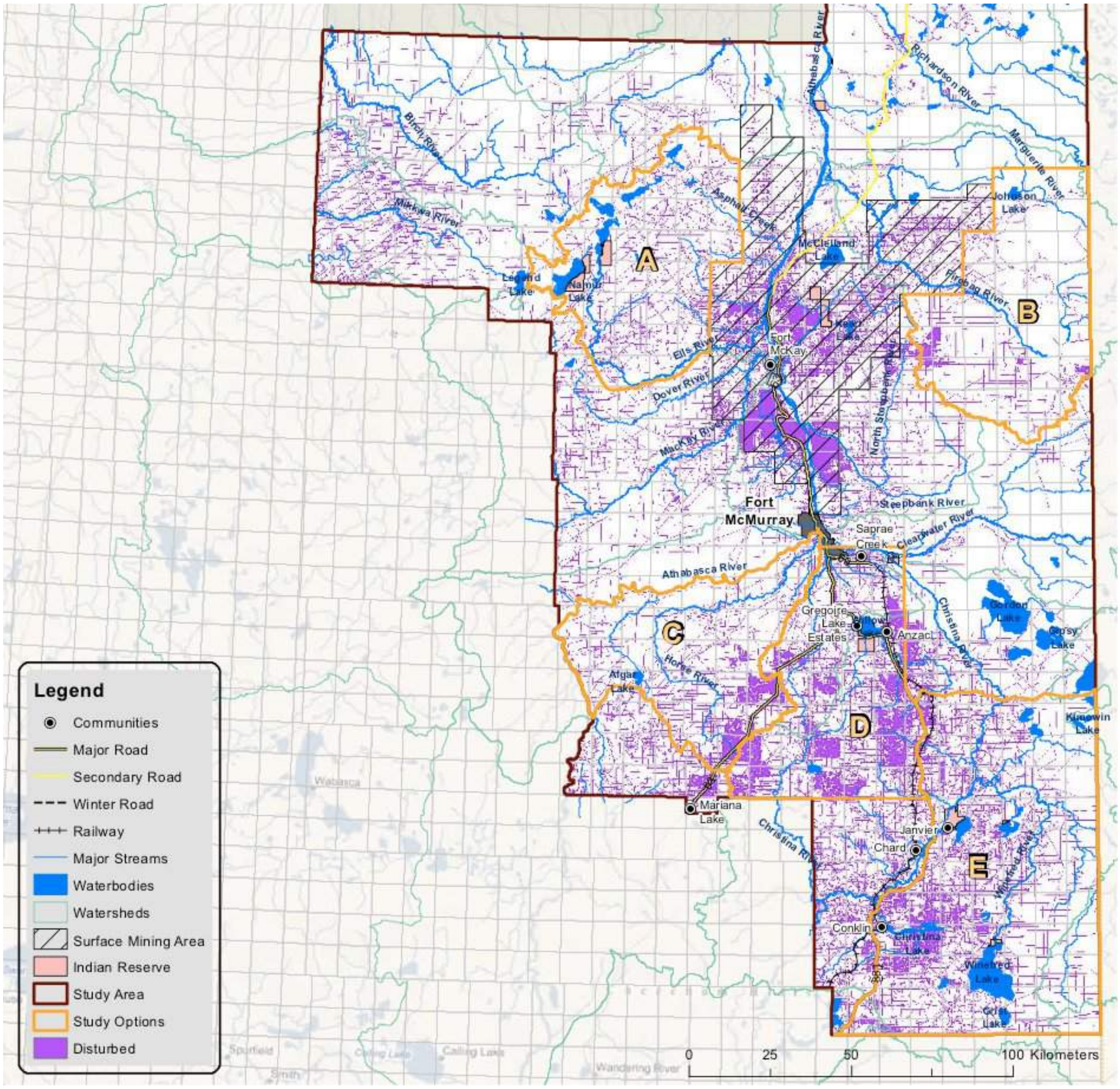

Figure 10: Disturbances (mines, pads, cutlines, trails, pipelines and roads) in the Regional Municipality of Wood Buffalo. From Compass Resource Management Ltd. (2010).

3.1.2 Knowledge

Suspended Solids and Metals

Basin-scale (mainstem)

As a river with unregulated flows, Athabasca River flows can vary by orders of magnitude, depending on the season. Because of this, suspended sediment and the constituents associated with it are highly important for the hydrogeochemistry of the river. Flows typically peak in early summer (June), due to summer rains and glacial melt in the mountains. During these high flows, TSS can become very high and along with it, particulate phosphorus and certain total metals. Aluminum (Al), copper (Cu), iron (Fe), and lead (Pb) typically exceed CCME water quality guidelines in the river at Fort McMurray.

TSS generally increases with distance downstream from the headwaters from a combination of point-sources (pulp mill effluents) and non-point sources (tributaries). The largest input of TSS is from non-point sources, although TSS loads from natural vs. human-related effects have not be separated (North/South Consultants et al. 2007).

Local-scale (tributaries & watersheds)

Headwater streams that flow in the McLeod River receive drainage inputs from reclaimed lands and sedimentation ponds from a number of coal mines (Gregg River mine, Cardinal River Coals mine, Luscar mine). Casey (2005) reported slightly elevated concentrations of selenium in surface water at the mouth of the McLeod River, although these were below CCME selenium WQGs. Given that selenium in these streams is typically undetectable, the detections were attributed to the cumulative increase in selenium loads to the McLeod River from its headwater streams that drain mined lands. Localized effects were observed in Luscar Creek where selenium concentrations exceeded the CCME WQGs on separate occasions. This local source contributed to the detections in the McLeod River.

In agricultural streams, TSS movement to streams seems to be associated primarily in relation to cattle grounds in floodplains or direct access of cattle to water courses. Although agricultural practices can increase TSS loads, as compared to native cover, agricultural intensity seems to have less of an impact. In a province-wide study of streams draining areas with varying agricultural intensity, Anderson et al. (1998) found that TSS was more related to runoff potential and stream discharge patterns than agricultural intensity. These studies combined indicate that site-specific conditions are very important in determining the potential risk to aquatic ecosystems.

NUTRIENTS

Basin-scale (mainstem)

Nutrients (total phosphorus, total nitrogen, and ammonia), and consequently dissolved oxygen (DO) concentrations, in the Athabasca River increase from the headwaters to Fort McMurray (Figure 11). Compliance with Alberta Surface Water Quality Guidelines and DO concentrations generally follow this pattern. In the lower reaches, TP concentrations often exceed ASWQGs during spring and summer high flow periods (North/South Consultants et al. 2007). These nutrients generally increase and then decrease to background levels within 100 km downstream from pulp mills and wastewater treatment plants, indicating largely point-source influences (Dube et al. 2006, Chambers and Guy 2004).

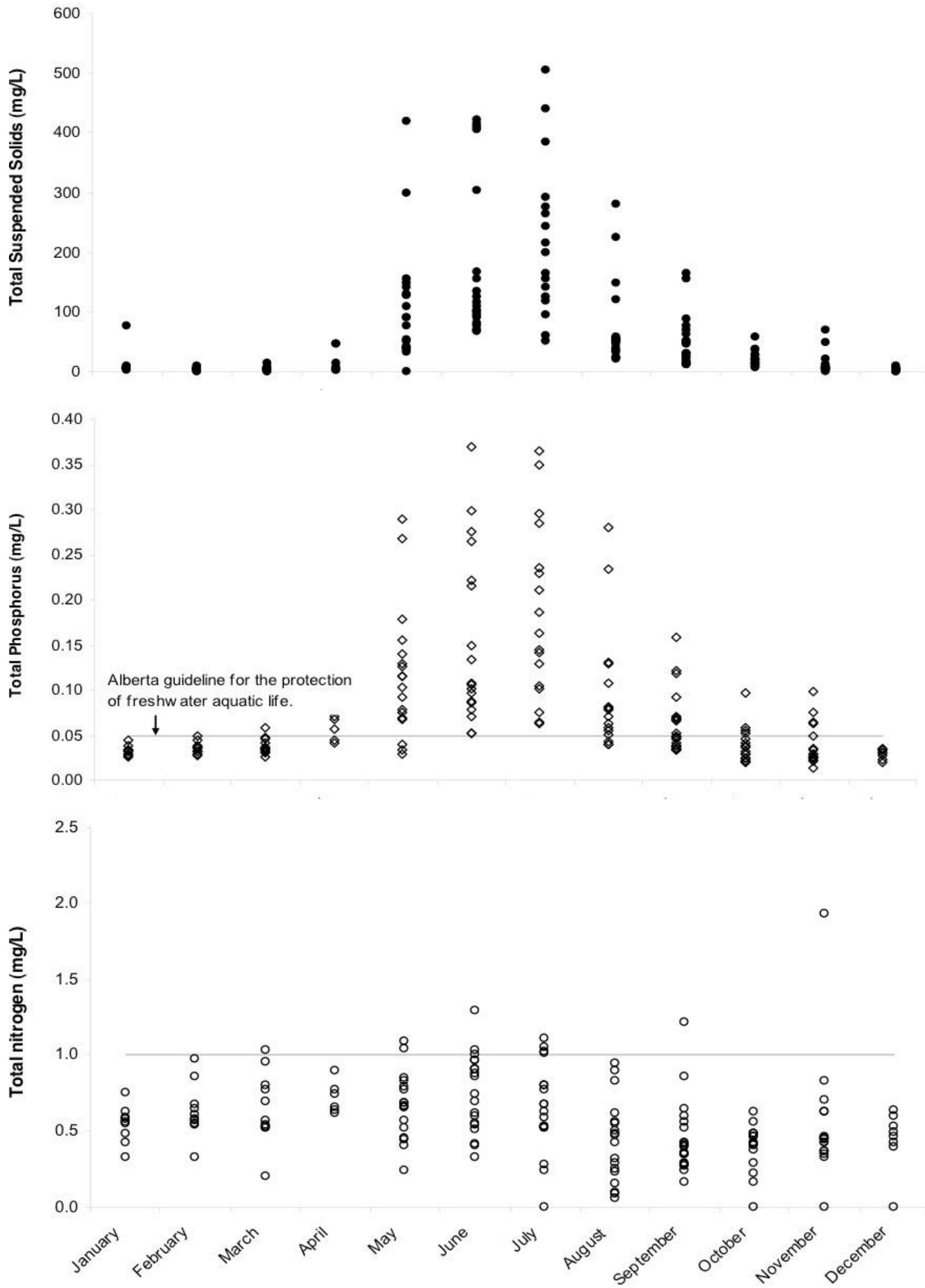

Figure 11: Total suspended solids, total phosphorus and total nitrogen concentrations at old Fort, 1987 to 2006, demonstrating peak constituent concentrations during high June flows. From Hatfield 2009.

Local-scale (tributaries)

In a study of two agricultural and four forested streams in the Lac LaBiche area, Neufeld (2005) found that agricultural watersheds exported over 2.5 and 4.5 times more phosphorus and inorganic nitrogen than forested watersheds, respectively. Near Baptiste Lake, Cooke and Prepas (1998) similarly found over 2 and 50 times greater export of phosphorus and inorganic nitrogen in two agricultural watersheds, respectively, as compared to two forested watersheds. In both studies, dissolved nutrient fractions were particularly affected in agricultural watersheds. Similarly, Trew et al. (1987) found much higher concentrations of total phosphorus in small agricultural streams flowing into Baptiste Lake (Figure 4). These studies support the argument that NPS pollution occurs at the stream/small watershed scale in agricultural (>40% of watershed) watersheds in the Athabasca River Basin.

The Alberta Environmentally Sustainable Agriculture (AESA) program has monitored the water quality in the Paddle River and Wabash Creek. The Paddle River flows into the Pembina River (a major Athabasca River tributary), while Wabash Creek is located further west. The Paddle River is a low intensity dryland agricultural watershed while Wabash Creek is a high intensity dryland watershed. Relationships established through the AESA program can be applied to agricultural areas in the Peace River Basin. In general, as agricultural intensity increases:

- Concentrations of phosphorus and nitrogen (mainly the dissolved fraction) in streams increase; dissolved nitrogen and phosphorus fractions were positively correlated with agricultural intensity metrics (chemical and fertilizer expenses and manure production percentiles); and
- Compliance with provincial and national surface water quality guidelines for the protection of aquatic life decrease.

The agricultural streams from the Pembina and Central Athabasca sub-basins are likely affected by NPS constituents, with an increase in effect with agricultural intensity. It is not currently clear to what degree NPS loads from the Pembina and Central Athabasca sub-basins are affecting the water quality of the mainstem; however, the impact appears to be minimal since intensity is likely fairly low.

The effects of logging on the hydrology and water quality of Boreal Plain lakes and streams were studied as part of two large-scale programs in the Athabasca River Basin: the TROLS and FORWARD programs:

- The FORWARD program (near Whitecourt) examined the effects of harvesting 52% to 84% of four stream watersheds, as compared to five reference streams. Overall, runoff was greater in the test watersheds by 68%, as compared to reference streams. TP and TDP concentrations were greater in streams draining harvested watersheds than reference watersheds, but only during storm events (not during base flows).
- The TROLS program (near Athabasca) examined nutrient concentrations in 11 headwater lakes two years before and two years after the harvest (mean 15%, range 0-35%) of the watersheds. A slight increase in total phosphorus concentrations was noted post-harvest. In a related study on streams, no impact was detected to nutrients in small streams with small scale logging (<3% of watersheds logged) (Veliz 1999).

Important findings from the two studies include:

- Both the TROLS and FORWARD programs found that riparian buffer strips did not appear to reduce the magnitude of nutrient response.
- The magnitude of response of aquatic ecosystems to logging is related to the intensity of logging activities in the watersheds. Prepas et al. (2008) suggest that a threshold of about 50% of watershed disturbance will solicit a nutrient response in catchments. However, the TROLS program indicates that weak effects can be detected below this threshold.
- Logging appears to affect certain parts of the hydrograph (periods of high flow) more than others.
- As part of the FORWARD study, a comparison between reference lakes in the Boreal Foothills and mixedwood sub-regions showed that total phosphorus and some major ion concentrations were several times higher in the Mixedwood lakes. The author recommends that considering the ecoregion is important for evaluating watershed disturbance (Allen et al. 2003).

Other constituents

Basin-scale (mainstem)

A few pesticides were detected in the Athabasca River near the Town of Athabasca (triclopyr and 2,4-D) and near the mouth (2,4-D, MCPA and MCPP), but none were detected in the headwaters upstream of Hinton (Anderson 2005). Given that pesticides are almost exclusively a NPS issue, these detections indicate that human-related NPS pollution is making its way to the Athabasca River where human activities are greatest. However, these concentrations were below water quality guidelines.

Local-scale (tributaries)

At the small watershed-scale, in agricultural watersheds part of the AESA program pesticide detection frequency, total pesticide concentration, and the total number of compounds detected increased significantly as agricultural intensity increased from low to high. Similar to nutrients, the agricultural streams from the Pembina and Central Athabasca sub-basins are likely affected by pesticide use, with an increase in effect with agricultural intensity. It is not currently clear to what degree pesticide loads from the Pembina and Central Athabasca sub-basins affect the water quality of the mainstem; however, the impact appears to be minimal.

Oil sands development in general has become a great concern for the health of the Athabasca River and northern communities that depend on the river. The importance of the oil sands industry as a non-point source of contaminant loading is the subject of ongoing scientific and political debate. The fundamental issue is the relative importance of natural and anthropogenic loads of oil sands related contaminants including hydrocarbons, organic acids, and heavy metals.

Streams near operating mines (e.g., Steepbank, Tar, and Muskeg rivers) have been monitored as part of the Regional Aquatics Monitoring Program (RAMP). The water quality of these sites was reported to be unaffected by oil sands development. However, some watersheds in which oil sands development has occurred (i.e., lower Steepbank and Tar watersheds) have shown changes in benthic community composition over time, including reductions in the proportion of sensitive taxa.

Two main critical pathways for loading of oil sands related contaminants have been identified: atmospheric deposition and seepage of contaminated groundwater. Atmospheric deposition of anthropogenic contaminants on a local scale (i.e., near the mineable area) has been demonstrated unequivocally (Kelly et al. 2009). However, the extent to which these contaminants are exported to the Athabasca River is not known. Oil sands extraction process affected fluids are seeping from containment structures, and the seepage will contribute oil sands related contaminants to the Athabasca River. In the case of the Tar Island Dyke, the rate of seepage has been quantified by direct measurement and modelling. Seepage from other facilities has been quantified using numerical models validated by groundwater monitoring. In all cases, the loading of extraction process related contaminants is low relative to natural seepage. However, quantification of natural and anthropogenic loading remains controversial (R. Hazewinkel, pers. comm.).

The cumulative land disturbances, mostly related to oil and gas exploration and extraction, are substantial in the Athabasca River Basin (Figure 10). Most (~80%) of these disturbances are caused by cutlines, which are created during the exploration phase. The effect this cumulative land clearing has on tributaries and the mainstem of the Athabasca River is currently unknown, but due to the magnitude of the disturbance, the risk of impact exists.

3.1.3 Data

Several long-term water quality monitoring sites exist on the Athabasca River (Table 1), from the headwaters to the lower reaches. In addition, AENV and RAMP have sampled many other locations on the mainstem and tributaries. Regular sampling at Alberta Environment LTRN and Environment Canada stations includes inorganics, nutrients, biological variables, metals, and organic compounds.

Table 1: Long-term water quality monitoring stations in the Athabasca River. From Hatfield 2009.

Location	Organization	Period of Record	Water quality variables		
			Inorganics	**Metals**	**Organics**
Upper AR (headwaters to Whitecourt)					
Below Snaring River, JNP	EC	1973 to present	Yes	Yes	Yes
U/s Hinton	AENV	1993 to 2003	Yes	Yes	Yes
At old entrance town site	AENV	2003 to present	Yes	Yes	Yes
Middle AR (Whitecourt to McMurray)					
At Town of Athabasca	AENV	1987 to present	Yes	Yes	Yes
Lower AR (McMurray to L. Athabasca)					
U/s Fort McMurray	AENV	1985 to present	Yes	Yes	Yes
At Old Fort	AENV	1987 to present	Yes	Yes	Yes

3.1.4 Synthesis

Water quality in the Athabasca River mainstem largely reflects seasonal patterns in flow, which affects TSS and the constituents associate with them (nutrients, metals). Human activities affecting mainstem water quality are primarily point sources from municipal and pulp mill discharge.

Streams are affected by NPS pollution in the Athabasca River Basin in the following ways:

- Pesticides are detected in the Athabasca River, indicating that NPS pollution is making its way to the river.
- The McLeod River and its tributaries are experiencing NPS selenium loading from active and reclaimed coal mine drainage.
- Another mining industry, oil sands mining, is contributing to NPS pollution from atmospheric deposition and seepage of contaminated groundwater.
- Logging has been shown to solicit a relatively minor and short-lived response in peak flow water yield and nutrients.
- NPS pollution occurs at the stream/small watershed scale in agricultural watersheds in the Athabasca River Basin. The concentrations of nutrients and pesticides can be expected to increase with agricultural intensity in these streams. The Pembina and Central Athabasca sub-basins are most likely to be affected by agricultural NPS pollution since this is where agriculture is most concentrated.

An important finding from small watershed studies in the Athabasca River Basin is the high importance of wetlands in mediating NPS pollution responses. Wetlands typically delay or reduce NPS pollution by acting as pollutant sinks.

In terms of gaps, the magnitude of impact that human NPS contributions have on the Athabasca River mainstem is not well understood. Most assessments have focused on point-source pollution (pulp mill and municipal wastewater) and its mitigation. There is relatively little data on tributaries to support NPS pollution assessments, which could be enhanced through an updated synoptic survey. In addition, very little information exists on recreational use in the Athabasca River Basin and its impact on constituent loads. Given the high density of linear disturbances, the potential for recreation-related impacts exist at a stream scale. Lastly, information on urban runoff constituent contributions and impact is also lacking.

3.1.5 References

Alberta Environment. 2011. Alberta River Basins. Retrieved from http://environment.alberta.ca/apps/basins/default.aspx.

Allen, E.W., E.E. Prepas, S. Gabos, W. Strachan and W. Chen. 2003. Surface water chemistry of burned and undisturbed watersheds on the Boreal Plain: An ecoregion approach. Journal of Environmental Engineering and Science 2: 73-86.

Anderson, A.-M. 2005. Overview of pesticide data in Alberta surface waters since 1995. Alberta Environment, Edmonton, AB. 210 pp.

Casey, R. J. 2005. Results of aquatic studies in the McLeod and upper Smoky river systems. Alberta Environment, Edmonton, AB. 62 pp.

Chambers, P.A. and M. Guy. 2004. Setting nutrient guidelines for the northern rivers of Alberta. In: Environment Canada, Northern Rivers Ecosystem Initiative: Collective Findings (CD-ROM). Compiled by F.M. Conly, Saskatoon, SK. 2004.

Compass Resource Management Ltd. 2010. Identification of a linear footprint project area within the RMWB. Report prepared for the Sustainable Ecosystems Working Group of the Cumulative Environmental Management Association. Fort McMurray, AB. 66 pp.

Cooke, S.E. and E.E. Prepas. 1998. Stream phosphorus and nitrogen export from agricultural and forested watersheds on the Boreal Plain. Canadian Journal of Fisheries and Aquatic Sciences 55: 2292-2299.

Dubé, M., B. Johnson, G. Dunn, J. Culp, K. Cash, K. Munkittrick, I. Wong, K. Hedley, W. Booty, D. Lam, O. Resler and A. Storey. 2006. Development of a new approach to cumulative effects assessment: A Northern River Ecosystem example. Journal of Environmental Monitoring and Assessment 113: 87-115.

Hatfield Consultants. 2009. Current state of surface water quality and aquatic ecosystem health in Alberta-Northwest Territories Transboundary Waters. Report prepared for Alberta Environment.

Kelly, E. N., J. W. Short, D. W. Schindler, P. V. Hodson, M. Ma, A. K. Kwan, and B. L. Fortin. 2009. Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. Proceedings of the National Academy of Sciences 106:22346 -22351. doi: 10.1073/pnas.0912050106.

Little, J., A. Kalischuk, and C. Sheedy. 2010. Assessment of water quality in Alberta's irrigation districts. Second edition. Page 181 pp. Alberta Agriculture and Rural Development, Edmonton, Alberta. Retrieved from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13000/$FILE/wqreportfull_nov2010.pdf.

Lorenz, K., S. Depoe, and C. Phelan. 2008. Assessment of environmental sustainability in Alberta's agricultural watersheds project: Volume 3: AESA water quality monitoring project. Page 543 pp. Alberta Agriculture and Rural Development.

Mitchell, P., and D. Trew. 1992. Agricultural Runoff and Lake Water Quality. *in* Agricultural Impacts on Surface and Ground Water Quality, Lethbridge Lodge Hotel, Lethbridge, Alberta.

Neufeld, S. 2005. The effects of catchment land use on nutrient export, stream water chemistry, and macroinvertebrate assemblages in boreal Alberta. A thesis submitted to the University of Alberta. University of Alberta, Edmonton, AB. 103 pp.

North/South Consultants Inc., Clearwater Environmental Consultants Inc. and Patricia Mitchell Environmental Consulting. 2007. Information synthesis and initial assessment of the status and health of aquatic ecosystems in Alberta. Report prepared for Alberta Environment, Edmonton, AB. 522 pp.

NRBS (Northern River Basins Study). 2002. Northern River Basins Study final report. Northern River Basins Study.

Prepas, E.E., J.M. Burke, G. Putz and D.W. Smith. 2008. Dissolved and particulate phosphorus concentration and export patterns in headwater streams draining Boreal Plain watersheds one year after experimental forest harvest and post-harvest silvicultural activities. Journal of Environmental Engineering and Science 7: S63-S77.

Trew, D.O., D.J. Beliveau, and E.I. Yonge. 1987. The Baptiste Lake Study Technical Report. Alberta Environment, Edmonton, AB. 380 pp.

Veliz, M.A. 1999. Relationship of nutrients, and mayfly (Ephemeroptera) abundance and diet to periphyton biomass in boreal streams. Master of Science thesis, Department of Biological Sciences, University of Alberta. 95 pp.

3.2 Battle

3.2.1 Introduction

The Battle River is a prairie-fed river with a total length of 1,035 km. Mean annual precipitation in the headwaters is 480 mm (Partners for the Saskatchewan River Basin n.d.). It originates in Battle and Pigeon lakes, and flows eastward roughly 800 km through Alberta's prairie-parkland ecozone into Saskatchewan. Mean annual discharge at the Saskatchewan border is 275 000 dam^3 (Alberta Environment 2001). The Battle River joins the North Saskatchewan River in Battleford, Saskatchewan. The average elevation gradient is 0.4 m/km. Although the Battle River drains 40% of the area of the North Saskatchewan basin, it contributes only 3% of the flow (Anderson 1999). The Battle River sub-basin drains a total area of 45,654 km^2, and more than half of this area is within Alberta. However, due to internal drainage basins, the effective drainage area of the basin is just 12,498 km^2 (Partners for the Saskatchewan River Basin n.d.). Key tributaries are Pipestone, Iron, Paintearth, Ribstone, and Pigeon Lake creeks. Once the local spring snowmelt is gone, this river is largely fed by groundwater springs. Flow can be reduced to a trickle in hot summers with little rain or cold winters with little snowmelt.

Roughly 125,000 people live within the Battle River sub-basin. Municipal wastewater inputs are the Alberta Hospital, Alliance, Camrose, Fabyan, Hardisty, Lacombe, Millet, Mullhust Bay, Ponoka, Wainwright, and Wetaskiwin. Each municipality typically discharges twice per year. Some may be far enough upstream that little effluent reaches the mainstem of the Battle River.

Non-point inputs include runoff from agriculture, coal mining, and urban runoff. Most of the agricultural cover in the basin is cropland, but there is also livestock grazing. The Battle River is unique in that most of its population and land use activities occur near the river's headwaters. The primary land use is agriculture. The upper sub-basins tend to be dominated by livestock while the lower sub-basins have more cultivated cropland (Stevens et al. 2010).

Water quality and effluent loadings tend to improve downstream. During much of the year, municipalities may have little to no effluent loading impact to the Battle River. Agriculture, being a non-point source of nutrients and other water quality parameters, tends to have a more consistent loading pressure on the river. Non-point influences would have more effect during spring runoff and rainstorm events, eventually declining to zero during winter.

3.2.2 Knowledge

TOTAL SUSPENDED SOLIDS

Basin-scale (mainstem)

TSS has been relatively consistent across years and among sites in the Battle River mainstem (Chris Teichreb , personal communication). Data from Saskatchewan indicate a slight increase in TSS concentration since 1974, although the cause in not known. TSS concentrations increase with increased flow rates and reach their highest concentrations in April or May in the Battle River, when runoff from the surrounding land is highest (Anderson 1999).

There is limited information on water quality of tributaries to the Battle River. AENV sampled Camrose Creek in the fall of 2007. From their unpublished report, TSS concentration ranged from 600 mg/L to nearly 1400 mg/L (Chris Teichreb, personal communication). The Camrose Creek sampling location was just downstream of the Camrose wastewater discharge point. At the same time, TSS in the mainstem ranged from 300 to 700 mg/L.

NUTRIENTS

Basin-scale (mainstem)

Nutrients are the most important water quality problem in the Battle River. Both long-term river monitoring sites, near Highway 53 and upstream of Driedmeat Lake, received water quality ratings of poor with respect to nutrients for 2009-10 (Alberta Environment 2011a), and they have consistently been rated either poor or marginal since 2003 (Chris Teichreb, personal communication). Since the Battle River is a slow moving river with a silt bottom, nutrients tend to become trapped in the soft river bottom and can be released back into the water column. The Battle River, like other prairie rivers and tributaries, has likely always had high nutrient levels due to high nutrient content in soils.

Nutrient levels are highest between Samson Lake and the Forestburg Reservoir and tend to decline or stabilize further downstream (Anderson 1999). Development is highest in the headwaters, and the upstream point and non-point sources tend to be diluted further downstream with groundwater.

Total phosphorus concentrations in the Battle River are often as high as 1 mg/L, even in upstream locations. (Chris Teichreb, personal communication). Dissolved phosphorus follows similar patter to total phosphorus. An AENV loading study from 2007 (Chris Teichreb, personal communication) found that 4.62% of total phosphorus loads can be attributed to point sources (municipal wastewater discharges). The remainder would come from non-point natural sources and non-point pollution, although the available data do not allow separation of these. The same loading study attributed 10% of total nitrogen loading to municipal wastewater discharges.

Local-scale (tributaries)

Total nitrogen concentrations were similar to mainstem sites and above 1 mg/L on all sampling dates in Camrose Creek. Total phosphorus concentrations tended to be lower in Camrose Creek than mainstem sites, but all samples were above water quality guidelines of 0.5 mg/L (Chris Teichreb, personal communication).

Buffalo Creek was included in the AESA stream study as a high intensity dryland agriculture stream. Its catchment area was 62% cropland. It was in compliance with TP water quality guidelines only 6% of the time (Lorenz et al. 2008). Total phosphorus and total dissolved phosphorus concentrations increased with time in Buffalo Creek despite agricultural intensity ratings decreasing over the same time period. Most of the phosphorus was in dissolved form. Buffalo Creek was in compliance with total nitrogen guidelines 30% of the time, but met nitrate guidelines 100% of the time and NH3 guidelines 85% of the time. Most of the nitrogen in this creek was organic or particulate. Nitrogen concentrations were stable through the AESA study duration. Overall, nutrient exports to Buffalo Creek were low compared to other agricultural streams in the province, but a large portion of the Buffalo Creek basin does not actually drain in to the creek (Lorenz et al. 2008). Low precipitation rates also contribute to lower loading rates than wetter regions of the province.

Salt

Basin-scale (mainstem)

Total dissolved solids (TDS) in the mainstem range from 400 to 800 mg/L during the fall of 2007 (Chris Teichreb, personal communication). An estimated 11% of the load of salts comes from municipal wastewaters. The remaining amount would come from natural weathering and erosion, groundwater, and non-point sources such as fertilizers or road salts. The data do not allow separation of natural non-point from sources from anthropogenic sources.

Local-scale (tributaries)

Camrose Creek has higher TDS concentrations than the mainstem. All major ions increase in concentration from upstream to downstream in Camrose Creek and reflect input from municipal wastewater. TDS concentration increased from 800 to 1200 mg/L following fall municipal wastewater discharge (Chris Teichreb, personal communication).

Pesticides

Basin-scale (mainstem)

Pesticides have been measured along the mainstem of the Battle River since the mid 1990s. About 3% of more than 9,600 water samples from the mainstem have had pesticides detected (Chris Teichreb, personal communication). Some of the most commonly detected pesticides (2,4-D, MCPA, and clopyralid) are primarily associated with agriculture. MCPA was the only herbicide that exceeded water quality guidelines. However, clopyralid and MCPP were also commonly detected, and these are more often associated with urban weed control (Chris Teichreb, personal communication). The persistence of some pesticides in aquatic environments was reflected with pesticides often being detected below ice in winter months. The Alberta River Water Quality Index for pesticides (2009-10) in the Battle River ranked water quality as good at the upstream Highway 53 long-term monitoring site, but as marginal further downstream near Driedmeat Lake (Alberta Environment 2011b).

Local-scale (tributaries)

Pesticides were detected in 3.5% of the 10,964 samples analyzed since 1995 in tributaries of the Battle River (Chris Teichreb, personal communication), which is a very low detection rate. Concentrations did not change through time, and concentrations do not tend to increase with distance downstream. MCPP and picloram tend to be higher in tributaries than in mainstem sites (Chris Teichreb, personal communication). It is unclear if this is due to higher intensity of use along tributary streams or if this reflects lower flow and hence less dilution. Buffalo Creek, from the AESA stream studies, exceeded pesticide water quality guidelines less than 5% of the time. Buffalo Creek pesticide concentrations were much lower than in other high intensity AESA streams, likely reflecting low precipitation rates in this basin.

PATHOGENS

Basin-scale (mainstem)

Bacteria levels have typically been lower near Driedmeat Lake than at the upstream Highway 53 long-term river network (LTRN) site (Chris Teichreb, personal communication). The Alberta River Water Quality Index for bacteria (2009-10) in the Battle River ranked water quality as excellent at both the upstream Highway 53 long-term monitoring site and further downstream near Driedmeat Lake (Alberta Environment 2011b). In previous years, however, good or fair ratings were common for the Highway 53 monitoring site. Peaks in fecal coliform bacteria concentration are strongly affected by rainstorm events. Density ranged from 0 to 200 cfu/100 mL (Chris Teichreb, personal communication).

Local-scale (tributaries)

Fecal coliform concentrations are often higher in tributary sites than the mainstem of the Battle River. The typical fecal coliform density range in the tributaries is 0 to 600 cfu/100 mL (Chris Teichreb, personal communication). Buffalo Creek, included in the AESA stream study, was in compliance with fecal coliform and *E. coli* guidelines 80% and 88% of the time, respectively (Lorenz et al. 2008), which is fairly high compliance.

3.2.3 Data

There are two AENV long-term river monitoring network stations in the Battle River sub-basin: Highway 53 upstream of Ponoka, and just upstream of Driedmeat Lake. Monitoring started in 1989 at Highway 53 site. Data collection started in 1989 at both stations and lasted for two years, Sampling started again in 2003 with monthly sampling. The Highway 53 station captures the major point source discharges to the Battle River, as well as urban runoff, from Ponoka, Lacombe, Wetaskiwin, Pipestone sub-watershed drainage, and Camrose. The Driedmeat Lake location represents non-point source input from Battle Lake to that point, and the difference between the two stations could represent municipal inputs plus some additional non-point sources. AENV did some additional water quality sampling near the mouth of Camrose Creek, and at Highway 21 upstream of Camrose Creek in 2007. Buffalo Creek was included in the AESA stream study and has limited water quality data from 1995 to 1998, and continuous data from 1999 until 2006. ATCO has undertaken additional monitoring in the Battle River Basin at the Forestburg Reservoir as part of their approval, but water quality parameters collected are different from those measured at the

LTRN stations. The Prairie Provinces Water Board has a monitoring station near Unwin, Saskatchewan, as part of Alberta's apportionment agreement with Saskatchewan. At this station, all point and non-point sources for the Alberta side of the Battle Watershed would be captured.

3.2.4 Synthesis

The Battle River is unique in Alberta in that it receives no mountain snowmelt. It also has low precipitation volumes, leading to smaller flows than other rivers basins. Nutrients are the pollutant of most concern in this basin. Nutrient rich soils export nitrogen and phosphorus, and concentrations in the Battle River are not diluted due to low flow volumes. Because municipal wastewater inputs are low in this basin, it is apparent that non-point sources dominate water quality. The types of detections suggest that pesticides are coming from both urban and agricultural sources.

3.2.5 References

Alberta Environment. 2001. Mean Annual Natural River Discharges (from 1994 State of the Environment Comprehensive Report). Retrieved from http://www3.gov.ab.ca/env/water/images/mardmap.pdf.

Alberta Environment. 2011a. 2009-10 River Water Quality Index ratings for Nutrients. Retrieved from http://environment.alberta.ca/01282.html.

Alberta Environment. 2011b. 2009-10 River Water Quality Index ratings for pesticides. Retrieved from http://environment.alberta.ca/01278.html.

Anderson, A.-M. 1999. Water quality of the Battle River. Page 30. Alberta Environment, Edmonton, AB. Retrieved from http://environment.gov.ab.ca/info/library/5807.pdf.

Lorenz, K., S. Depoe, and C. Phelan. 2008. Assessment of environmental sustainability in Alberta's agricultural watersheds project: Volume 3: AESA water quality monitoring project. Page 543 pp. Alberta Agriculture and Rural Development.

Partners for the Saskatchewan River Basin. (n.d.). The state of the Saskatchewan River Basin. Retrieved from http://www.saskriverbasin.ca/page.php?page_id=70&PHPSESSID=mcjnq63jg36k1ctsv8hj241171.

Stevens, C. E., T. Council, and M. G. Sullivan. 2010. Influences of human stressors on fish-based metrics for assessing river condition in Central Alberta. Water Quality Research Journal of Canada 45:35-46.

3.3 Beaver

3.3.1 Introduction

The Cold Lake–Beaver River Basin is located approximately 300 km northeast of Edmonton and covers about 2% of Alberta's surface area which represents an area of 22,000 km^2. The basin is within the Boreal Forest Natural Region of Alberta, with undulating to moderately rolling topography and elevations ranging from about 500 m to 750 m above sea level. The Beaver River is a relatively small river with a mean annual discharge of about 650 million m^3 per year. From the north, the Beaver River drains the Sand and Amisk rivers as well as Manotokan, Jackfish and Marie creeks. Tributaries from the south include Moose Lake River and Muriel and Reita creeks.

Disturbed land is mostly concentrated along the southern part of the basin near population centers (Figure 12). In 1998, disturbed land area covered about a quarter of the basin. The basin's land cover only changed by 5% between 1986 and 1998, which is not a great change. The greatest change occurred in the Beaver River sub-basin, where 12% of the sub-basin changed to disturbed lands (AENV 2006).

Water quality in the Beaver River is rated by the Prairie Provinces Water Board (PPWB), using site-specific objectives for the Beaver River near the Alberta-Saskatchewan border. Levels of nutrients, dissolved minerals, metals, bacteria, and herbicides in the Beaver River water (1966-2003) were compared to PPWB objectives for the river. The objectives were exceeded for total copper (Cu), total iron (Fe) and dissolved manganese (Mn) concentrations, and to a lesser degree for fecal coliform, dissolved iron (Fe), total cadmium (Cd), total chromium (Cr), dissolved oxygen, and total zinc (Zn) concentrations.

Similar to other rivers in Alberta, iron, manganese, and copper occur at naturally high concentrations in the Beaver River, and exceedances occurred throughout the 1966-2003 period without any apparent pattern. Fecal coliform, dissolved iron, total cadmium, total chromium, dissolved oxygen and total zinc exceedances were few (i.e., under 10 times over a 40-year span) and scattered through time; thus, they are not considered a problem. Overall, water quality in the Beaver River is generally good and exceedances of PPWB objectives for the river have been few over the past four decades. Most of the water quality concerns with the Beaver River occur under ice when very low flows cause oxygen concentrations to fall bellow water quality objectives. This is considered to be a natural phenomenon since it occurs in the relatively undeveloped Sand River as well.

Table 2: Change in sub-basin land area to disturbed lands (agriculture, urban, clearing) in 1998. Unpublished data from DU land cover classification.

Sub-basin	Percentage of Sub-basin Area as Disturbed Lands
Amisk	23
Beaver	49
Jackfish	30
Manatokan	46
Marie	16
Medley	1.4
Moose	63
Muriel	51
Reita	26
Sand	3.1

Very little information exists for the tributaries of the Beaver River. Rather, the focus of water quality monitoring has been on lakes.

Lake water quality values (2003 data) were compared to provincial and federal Surface Water Quality Guidelines for the Protection of Aquatic Life for 15 lakes in the Basin. Guidelines were exceeded in only a few of the lakes.

- Total phosphorus guidelines were exceeded in the most fertile lakes.
- pH guidelines were exceeded in most of the lakes sampled.
- Arsenic guidelines were slightly exceeded in two lakes. Concentrations in these lakes varied from 6 to 7.5 μg/L, slightly higher than the guideline value for arsenic (5 μg/L).

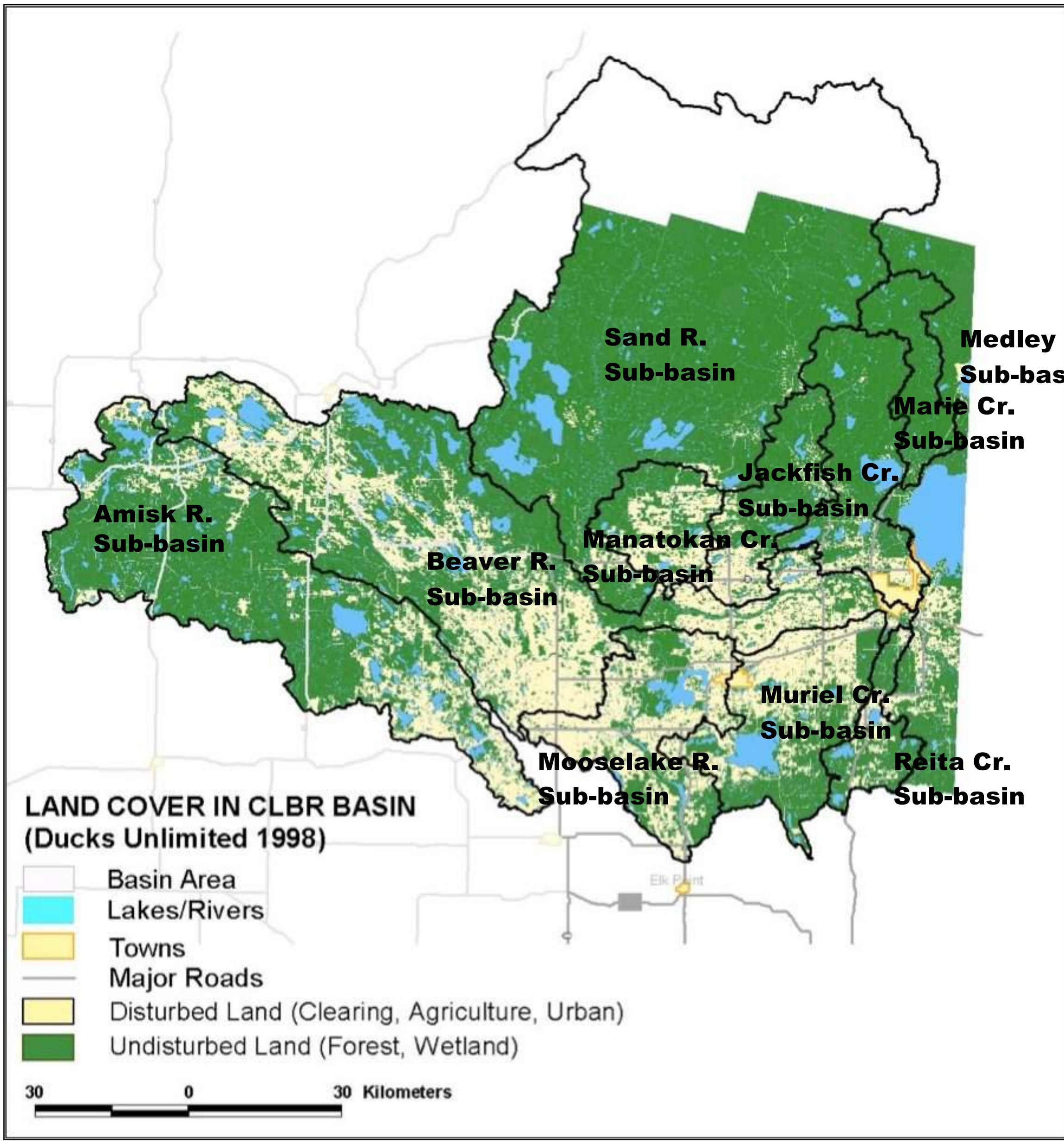

Figure 12: Land cover in the Cold Lake-Beaver River Basin (from AENV 2006).

Exceeding phosphorus and pH guidelines levels is common in Alberta because surface waters are naturally productive and buffered. However, human activities can enhance phosphorus concentrations. The below-average precipitation over the past two decades has increased pH in many lakes. Arsenic exceedances of guidelines are attributed to naturally occurring arsenic in the geology.

A number of human activities have the potential to contribute to NPS pollution in the Beaver River Basin. Main activities include:

- Agriculture: Agricultural land accounts for 85% of land disturbances within the Beaver River Basin and is concentrated in the southern portion of the basin, where soil conditions are suitable. Environmental risks to the aquatic environment are associated with land disturbance, animal and plant wastes, and substances applied to enhance production, including fertilizers (e.g., manure or chemical fertilizers) and pesticides. Commercial fertilizer application in the Beaver River Basin has tripled since the 1970s. However, the amount of commercial fertilizer applied in the Beaver River Basin is less than most basins in the province (AENV 2006).
- Oil and Gas: Conventional oil and gas is found throughout the basin, thus the oil and gas industry is very active in this region. In-situ operations are highly concentrated north of the Beaver River, which is underlain by a large area of oil sands deposit. Potential contributions from the oil and gas industry to NPS pollution could result from soil erosion, spills from roads, well sites, and exploration corridors, and contamination of groundwater from saltwater injection wells or disposal wells. These activities and processes could lead to changes in TSS, certain metals, ion concentrations, pesticides, and trace organics (North/South Consultants et al. 2007).
- Sand and gravel: A few sand and gravel pits are operating in the upper portion of the Beaver River Basin. Although this activity is no widespread throughout the basin, these pits tend to operate immediately adjacent to the river, which increases the risk for NPS pollution. Sand and gravel operations currently follow a code of practice that stipulates runoff water from the pit must meet certain water quality criteria before it is discharged to the natural environment.
- Urban: The two main urban areas include the city of Cold Lake and the town of Bonnyville. Cold Lake discharges stormwater to the Beaver River and near the discharge point of one of its tributaries, Marie Creek. Bonnyville largely discharges its stormwater to Jessie Lake, which also receives treated wastewater. Jessie Lake is a closed basin, for the most part. Due to its proximity to Bonnyville, Moose Lake receives runoff from the western portion of the Bonnyville.

3.3.2 Knowledge

Over half the total annual flow of the Beaver River near the Saskatchewan border is attributed to the Sand River. The Sand River drains a highly forested and largely undisturbed watershed, which keeps the Beaver River relatively clean. Essentially, management of the Sand River sub-basin is key to protect the Beaver River from the negative influences of NPS pollution.

Although water quality in the mainstem is relatively good, localized issues have come to light. There is some information on the upper Beaver sub-basin, upstream of the Sand River, which could be classified as a stream, based on flows. This site was sampled quarterly in 2003 and revealed relatively high dissolved nutrients. The 3.5-fold higher total phosphorus concentrations in 2003, as compared to 1983/1984 is mostly due to a 4-fold increase in the dissolved fraction of phosphorus. No data exists to pinpoint the cause of these observations, but they may be related to a general increase in land disturbance (12%) and fertilizer application.

Not much is known on the water quality of Beaver River tributaries. Watershed-scale studies have provided some insight in the influence of NPS pollution in the basin:

- The percentage of watershed as cleared land was calculated for 14 lake watersheds in the basin and was compared to lake water quality measures. The differences in fertility (total nitrogen and phosphorus) among lakes in the Cold Lake-Beaver River Basin can largely be attributed to the amount of disturbance in their watersheds. The greater the disturbance in a watershed, the more fertile its lakes generally becomes. Similarly, lake water clarity decreases with the amount of watershed disturbance, mostly for the first 40% disturbance of the lake's watershed area.
- A number of small streams were sampled during spring melt in the Moose Lake watershed. In general, the concentration of nutrients increased with the amount of agricultural and urban development in the watersheds. The one high intensity agricultural watershed (Yelling Creek with a watershed that is over 90% converted) had at least double the concentrations of phosphorus and nitrogen compared to other streams. Loads were not calculated for this study (AENV, unpublished data).

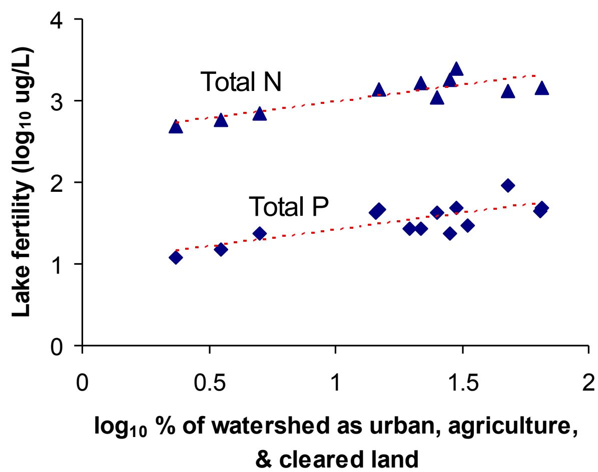

Figure 13: Relationship between % of watershed disturbance and lake fertility. From AENV (2006).

Linear disturbances, mostly related to oil and gas exploration and extraction, are substantial in the Beaver River Basin. To our knowledge, no comprehensive linear disturbance maps exist for the Beaver River Basin. However, linear disturbances are likely similar to the southern portions of the Regional Municipality of Wood Buffalo (see Section 3.1). About 80% of these disturbances are caused by cutlines, which are created during the exploration phase. These linear features can provide access points for recreation which, under heavy use, can become sources of suspended solids and associated constituents (Figure 14). Increased access in the basin has also led to poaching of pine trees for firewood, which leaves small-scale clearcuts near access points. The effect this cumulative land clearing has on tributaries and the mainstem of the Beaver River is currently unknown. Given our knowledge on logging-related effects (see Section 3.1), impacts are likely very localized. However, due to the magnitude of the disturbance, the risk of impact exists.

The effect of sand and gravel on aquatic ecosystems has not been examined closely in the Beaver River Basin.

Figure 14: Linear disturbances in the Beaver River Basin, indicating heavy recreational use. Photo: J. Prusak.

3.3.3 Data

Water quality monitoring data is sampled monthly at the Alberta-Saskatchewan border by the federal government to support PPWB water quality objective assessments. Parameters include total and dissolved nutrients, inorganics, total and dissolved metals and pesticides. The most recent synoptic on the Beaver River was completed in 1983.

3.3.4 Synthesis

One main feature - the Sand River - provide the tapestry for water quality in the Beaver River. The high-quality Sand River drains a relatively pristine watershed and provides about 50% of the flows to the Beaver River. Thus, the water quality of the Beaver River is generally good and exceedances of Prairie Provinces Water Board objectives for the river have been few over the past four decades. This buffers the Beaver River to any potential human-related constituent loads.

Human activity has been demonstrated to affect water quality in small watersheds. A strong relationship between watershed disturbance and nutrient concentrations in 14 lakes in the Basin demonstrates a lake nutrient NPS pollution effect that increases with disturbance. Also, recent sampling of streams in the Moose Lake watershed demonstrated agricultural and urban NPS nutrient pollution. Lastly, an important increase in dissolved phosphorus since the mid-1980s in the Upper Beaver River was suggested to be caused by an increase in land disturbance and fertilizer application. Thus, similar to other basins, NPS pollution is being detected at the stream-scale.

In terms of gaps, there is a very poor understanding of the significance of urban runoff on NPS pollution in the Beaver River Basin. To increase our knowledge, collection and synthesis of stormwater water quality information is required. In addition, there are no comprehensive datasets on tributaries in the Beaver River Basin. Perhaps the most useful dataset was collected in 1983-1984. Significant changes have occurred in the Basin since then. Thus quantitative data on non-point loadings, relative to point-source loadings, are an unknown at present time. Much of these data gaps could be filled using a synoptic monitoring approach.

Other gaps include a lack of information on linear disturbance and recreational use in the basin, other than anecdotal information. Information from other basins (Section 3.7) clearly indicates increased sedimentation as a result of stream crossing where no infrastructure exists. In addition, little information exists on cumulative environmental impacts of recreation, In Situ and conventional oil sands development.

3.3.5 References

Alberta Environment (AENV). 2006. Cold Lake - Beaver River Surface Water Quality State of the Basin report. Edmonton, AB. 65 pp.

North/South Consultants Inc., Clearwater Environmental Consultants Inc. and Patricia Mitchell Environmental Consulting. 2007. Information synthesis and initial assessment of the status and health of aquatic ecosystems in Alberta. Report prepared for Alberta Environment, Edmonton, AB. 522 pp.

3.4 Bow

3.4.1 Introduction

The Bow River sub-basin drains an area of 25,430 km^2 (Alberta Environment 2011a). The Bow River begins in Bow Lake (elevation 1,920 m) in the Rocky Mountains and flows through a steep valley corridor in Banff National Park. The river moves east through the foothills and into the prairie, widening and decreasing in gradient until it joins the Oldman River to form the South Saskatchewan River (elevation 740 m). The gradient of the Bow River in the mountains averages 7 m/km while in the prairies averages 0.5 m/km (Bow River Basin Council 2010). Total length of the Bow River is 645 km.

Average annual discharge at the confluence with the Oldman River to form the South Saskatchewan River is 4,085,000 dam^3 (Bow River Basin Council 2010). Major mountain tributaries of the Bow River include the Spray, Cascade, Kananaskis, Elbow, Sheep, and Highwood rivers, which contribute the most of the total flow to the Bow River (Bow River Basin Council 2005). Much of this flow is from melting snow, with peak discharges occurring in June. Glacial melt contributes 2.5% of flow during the late summer and early fall, and flows during winter are heavily influenced by groundwater. Stable isotope analyses suggest that most snowmelt and rainfall must pass through the ground before being discharged into the river (Grasby 1997). There are fewer tributaries in the plains, the most important ones being Nose, Fish, West Arrowhead, Arrowhead, and Crowfoot creeks. They have lower flow than the mountain tributaries. Mean annual precipitation ranges from 700 mm in the upper regions of the Bow River to 412 mm per year in Calgary (Bow River Basin Council 2010). Half of that precipitation in the headwaters falls as snow, while 78% of the precipitation in the plains falls as rain (Bow River Basin Council 2010). The hydrology of the Bow River is heavily regulated by 13 dams, 4 weirs, and 8 reservoirs. Three irrigation districts divert water from the Bow River. Some of these flows are returned to the Bow River, while others are diverted to the Oldman River or the Red Deer River (Bow River Basin Council 2010).

Home to the City of Calgary, the Bow River Basin is the most highly populated river basin in Alberta with a population of roughly 1.2 million, 95% of which lives in urban centres. Generally, water quality is excellent in the mountain and foothills, where there are fewer potential inputs. Pressures facing these areas include forestry, oil and gas developments, recreation, low intensity agriculture, and small urban centres (wastewater and stormwater). Water quality decreases when it passes through the City of Calgary, going form excellent to good water quality according to the Alberta River Water Quality Index (Alberta Environment 2011), largely due to a reduction in nutrient and pesticide sub-indices. On the plains, the Bow River passes through larger urban centres (receiving stormwater runoff and waste water inputs) and intensive agricultural lands. There are three irrigation districts within the basin: the Western, Bow River, and Eastern Irrigation Districts (WID, BRID, and EID, respectively). The city of Calgary has started using screens, wet ponds, and wetlands to improve their stormwater quality; however, 90% of the urban lands in the basin receive little to no stormwater treatment (Bow River Basin Council 2005).

The upper/western region of the Bow basin is dominated by forests and rock. Cropland and forage become increasingly dominant in central and eastern areas of the basin, along with grassland. Overall, rock covers 9.4% of the basin, forests cover 21.5%, and clear cut forests cover 0.2%. The dominant land use on an area basis is agriculture. Crops cover 21.9% and forage covers 3.9%. Grasslands cover 32.4% and urban infrastructure covers 1.4% of the basin (Bow River Basin Council 2005).

3.4.2 Knowledge

TOTAL SUSPENDED SOLIDS

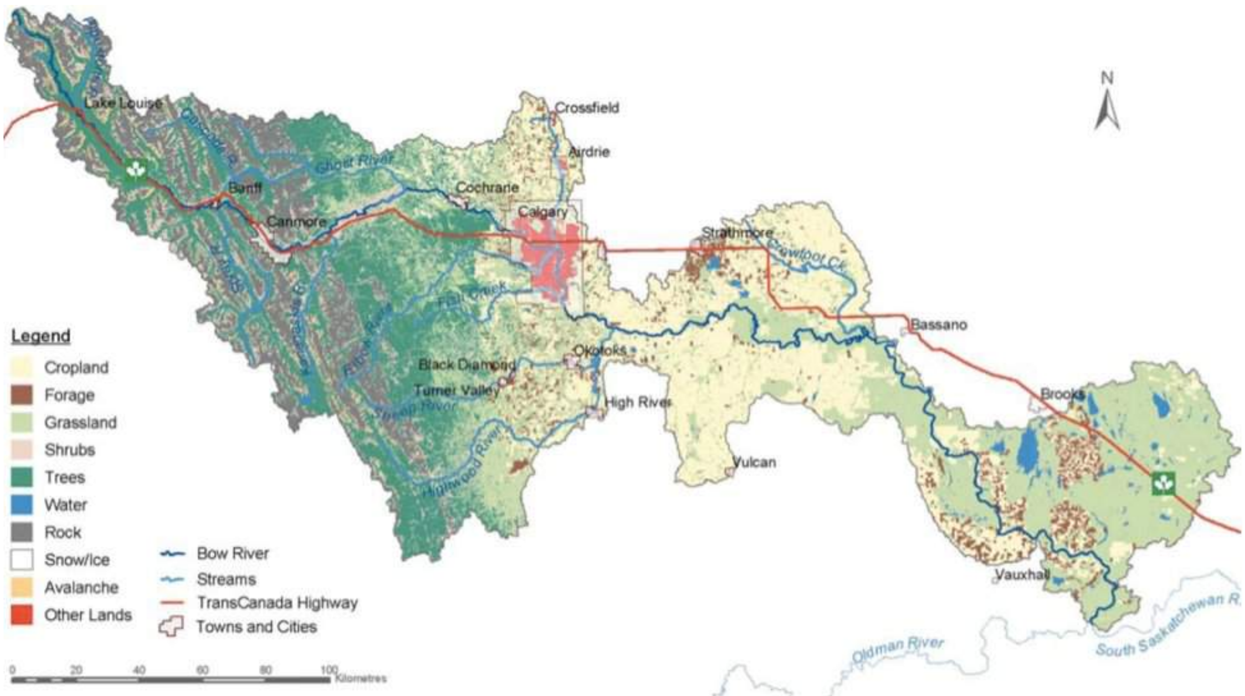

Figure 15: General land cover of the Bow River Basin (Bow River Basin Council 2010)

Basin-scale (mainstem)

Like most rivers, TSS concentration and loading in the Bow Basin is highly dependent on flow rates. In portions of the Bow River (from Banff to the Bearspaw Dam), dams act as sinks for TSS (Bow River Basin Council 2005).

From Bow Lake to Lake Louise, the Bow River passes through protected land in Banff National Park. There are no major point source inputs to the river or other major contaminant sources for suspended solids, and the water is generally clear or coloured by glacial silts (Bow River Basin Council 2005). Most of the glacial silts settle in the mountain lakes resulting in very low sediment levels in the river, even during spring runoff. From Lake Louise to the boundary of Banff National Park, wastewater treatment plants from the communities of Banff and Lake Louise do contribute some TSS. Potential non-point sources include runoff from roadways, urban developments, and old mines; however, no specific data are available to determine their impacts. Generally, the water contains very low TSS concentrations in this part of the mainstem (Bow River Basin Council 2010).

From the Banff National Park border to Bearspaw Dam, TSS concentrations are generally in a natural condition in the mainstem of the Bow River (Bow River Basin Council 2010). TSS concentrations rarely exceed water quality objectives.

TSS concentrations tend to be below water quality objectives along the Bow mainstem until Calgary. Stormwater outfalls within the city of Calgary contribute TSS to the mainstem. Of the total TSS load generated by the city of Calgary, 90% was delivered via stormwater sewers prior to initiation of retrofits and 10% via WWTPs (Letourneau et al. 2008). Despite these loadings, however, TSS concentrations have consistently been low in the mainstem throughout and just beyond the City of Calgary from 2004 to 2009 (Bow River Basin Council 2010). Total loading objectives for the city have been set to 52,920 kg/day (Kobryn 2008).

Beyond the City of Calgary to the Carseland Wier, the Bow River is heavily influenced by the Highwood River and Sheep River, and by the City of Calgary. TSS concentrations in this section of the mainstem are highly variable from year to year. Mainstem TSS concentrations are also highly variable from beyond the Carseland Wier to the Bassano Dam (Bow River Basin Council 2010). Here the main tributaries are Crowfoot Creek and West Arrowwood Creek. Beyond the Bassano Dam, TSS concentrations vastly improve in the mainstem (Bow River Basin Council 2010). This may be related to the Bassano Dam regulating flows.

Local-scale (tributaries)

In Ghost River, one of the most pressing water quality issues is potential impact from erosion and sedimentation related to trail use by motorized vehicles. The Ghost River basin is located just 60 km from Calgary. Although it only has 500 residents, summer long weekends often bring >10,000 people to the basin for recreation. Off-highway recreational vehicles, using more than 2,000 km of trails, contribute more sediment to runoff in the Ghost River basin than agriculture or forestry (Yarmoloy and Stelfox 2011). Roads, over 250 km, also contribute high sediment loads in this tributary.

We did not locate TSS concentration data for the Kananaskis River. Although recreational use is also high in this sub-basin, a large portion of the land is protected parkland (Bow River Basin Council 2005). We expect off-highway recreational vehicle use is likely lower than in the Ghost sub-basin, and therefore, TSS concentrations are probably of less concern than in the Ghost River.

TSS concentration data has been collected sporadically at various locations along the mainstem of the Elbow River and its tributaries since 1974. Most of the sampling stations show no significant trend across years (Sosiak and Dixon 2004), and the River is considered to essentially be in a natural state with respect to TSS (Bow River Basin Council 2010). The Elbow River consistently has increasing TSS concentrations with increasing distance downstream sites (Sosiak and Dixon 2004). TSS concentration reflects flow rates, with higher TSS during high flow years. Along the mainstem of the Elbow, median TSS concentrations ranged from 0.1 to 10 mg/L during lower flow years (1999, 2000, and 2001). During a higher flow year (2002) however, median concentrations were often over 10 mg/L (Sosiak and Dixon 2004). Annual peak concentrations are associated with spring runoff events in June and July. Timing of peak concentrations within tributaries of the Elbow

River are more variable, and depend on whether their peak flow comes from mountain snowmelt or local snowmelt in the foothills or parkland (Sosiak and Dixon 2004). Generally, median concentrations of TSS are similar among tributaries of the Elbow River, from 1.2 to 5.2 mg/L (Sosiak and Dixon 2004).

The Elbow River can have high TSS coming from re-suspension of bed material, bank erosion, and storm sewers releasing urban runoff. Aerial surveys suggested that bank erosion was particularly important in 2002 (Sosiak and Dixon 2004). Sosiak and Dixon (2004) estimated that, during 2002, only 0.3% of the total mass flux of TSS came from tributaries to the Elbow River. The rest of the flux was from a mix of natural non-point sources and NPS pollution along the mainstem.

Nutrients

Basin-scale (mainstem)

The most recent synoptic survey of the Bow River was completed in August 1995 (Sosiak 1996). At that time, nutrient loadings from WWTPs were much higher than present-day, and had the greatest impact on concentration and mass of nutrients in the Bow River. The synoptic survey showed that, during low flow, most tributaries individually contributed small mass loads of phosphorus and nitrogen and had little influence on mainstem concentrations (Sosiak 1996). Concentrations of phosphorus and nitrogen were often high in irrigation return flows, but individual loadings were low (5 and 50 kg/day, respectively, or less). Thus, irrigation return flows are not likely to impact the Bow River (Sosiak 1996).

Stable isotope analysis has been used to trace sources of nitrate to the Bow River (Chao 2011). Riverine nitrate in the Bow is mainly derived from nitrification in forest soil and from wastewater effluents. Wastewater accounts for less than 50% of nitrate in the Bow River upstream of Calgary, but accounts for 84% to 92% of the nitrate load downstream of Calgary. Overall, total nitrate loads in the Bow can be partitioned as follows: 14% from mountain tributaries, <10% from prairie tributaries, and 77% from the Bonnybrook WWTP in Calgary (Chao 2011). We therefore can say that most nitrate in the mainstem is coming from either point sources, or natural non-point sources.

The mountain headwaters of the Bow River have naturally low concentrations of nutrients. Within Banff National Park, most nutrients in the Bow River are in particulate form from natural weathering of rocks (Bow River Basin Council 2005). While there may be small phosphorus loadings from camping facilities, phosphorus concentrations are often below detection limits (Bow River Basin Council 2005). WWTPs within the park historically discharged significant loads of phosphorus, more than half in dissolved form. Loading has decreased since upgrades were made to the WWTPs, but water quality effects may be long lasting due to the ability of phosphorus to bind to soil particles. Nitrogen and ammonia both increase in concentration beyond WWTPs from Banff and Lake Louise town sites (Bow River Basin Council 2010). Any additional phosphorus loadings to naturally oligotrophic systems such as these can have major ecosystem effects.

From the Banff National Park border to Bearspaw Dam, nutrient concentrations are generally in a natural oligotrophic condition in the Bow River. Nutrients rarely exceed water quality guidelines for this reach of the Bow River (Bow River Basin Council 2010). For total phosphorus, water quality objectives were exceeded in more than 10% of samples in 2007, but other years since 2000 have had very few exceedances. The WWTP in Canmore is the largest human source of nutrients to this section of the Bow River. The Ghost and Kananaskis rivers and the Spray Diversion Canal are major tributary sources of nutrients. Potential non-point sources of nutrients from these tributaries include recreational access and logging, although no data are available to quantify those loads.

Most of nutrient loads entering the Bow River from the City of Calgary come from the city's WWTPs. Out of total loads from the City of Calgary, stormwater runoff in Calgary contributes about 18% of TP loads, 15% of TKN loads, 6% of nitrate+nitrite loads, and 5% of ammonia loads to the Bow River; WWTPs largely contribute the remaining loads (Kobryn 2008). Major upgrades to the city stormwater management system are in progress. The total loading objective for the city is 340 kg/day of total phosphorus (Kobryn 2008). From 2003 to 2009, total phosphorus and total dissolved phosphorus concentrations upstream of Calgary's WWTPs and stormwater outfalls have nearly always met water quality objectives. Downstream of these loading sources, TP and TDP concentrations have exceeded water quality objectives at least 10% of the time from 2004 to 2009. From 2005 to 2007, exceedances occurred more than 50% of the time (Bow River Basin Council 2010). Major flood or storm events during this period likely account for decreases in water quality those years. For most years between 2003 and 2009, nitrate+nitrite nitrogen concentrations near the City of Calgary have been similar to a natural state both upstream and downstream of WWTPs and stormwater outfalls. As the City of Calgary has undertaken steps to reduce wastewater effluent impacts on receiving water, the impacts of stormwater runoff have become more evident.

The tributaries Nose Creek and Elbow River are also inputs of nutrients to the mainstem near Calgary. Nose Creek carries the largest load of nutrients (Bow River Basin Council 2005) and is influenced mainly by non-point sources (i.e., it has no WWTPs). Runoff into Nose Creek comes from a mix of agricultural and urban land uses, but partitioning how much load comes from each source is not possible with current data.

Beyond the City of Calgary to the Carseland Wier, the Bow River is influenced by the Highwood River and Sheep River, which drain agricultural areas, and still by the City of Calgary. Total phosphorus and total dissolved phosphorus concentrations in this section of the mainstem have been rated as fair or poor for all years from 1995 through 2008, with the exception of 2006 (Bow River Basin Council 2010). Water quality gradually improves with respect to dissolved phosphorus concentrations as the mainstem continues towards its confluence with the Oldman River. Nitrogen concentrations are generally excellent along the remainder of the mainstem (Bow River Basin Council 2010).

Local-scale (tributaries)

Although we generally lack water quality data from the Kananaskis sub-basin, we can infer that potential non-point sources of nutrients to the sub-basin are forest harvesting (Sawmills FMA), recreation, and small amounts of grazing. However, we would expect overall NPS pollution loads to be low because 93.6% of land in the Kananaskis sub-basin is protected as parkland (Bow River Basin Council 2005). Point sources of nutrients to the Kananaskis are wastewater discharges from Kananaskis Village, Fortress Mountain, Nakiska Ski Lodge, and the Kananaskis Golf Course.

The Ghost River sub-basin is used for ranching, grazing, logging (Sawmills FMA), and oil and gas extraction, and it is under increasing pressure from recreational use. There are no forestry specific water quality data within this sub-basin, but other basins generally show increased nutrient loading following logging. We would expect logging effects to be localized and temporary, decreasing with forest regeneration. Total phosphorus and total dissolved phosphorus concentrations tend to be below water quality guidelines for the protection of aquatic life (0.05 mg/L) in the Ghost River. Median total nitrogen concentration was 0.25 mg/L, but maximum concentrations reached 1.48 mg/L during high flows. These concentrations may be related to high recreational use by motorized vehicles.

Total phosphorus concentrations increase with distance along the Elbow River; however, median concentrations are generally below water quality guidelines (Sosiak and Dixon 2004). Peak total phosphorus concentrations are associated with spring snowmelt, and water quality guidelines are often exceeded at that time. In the Elbow River, we cannot individually assess non-point sources of phosphorus in tributaries at present using available data, but major non-point sources could include urban runoff, agricultural activities, groundwater, and direct atmospheric deposition (Sosiak and Dixon 2004). Some tributary streams of the Elbow River have phosphorus and nitrogen concentrations above guidelines at concentrations high enough to potentially cause nuisance periphyton growth. Future increases in nutrients will likely be related to increasing urban presence in the lower sub-basin.

From 2007 to 2009, the concentrations of all nutrients were low in Jumpingpound Creek, meeting the protection of aquatic life more than 90% of the time (City of Calgary Water Resources 2009, Jumpingpound Creek Watershed Partnership 2009). When exceedances occur in this tributary, they do so during high spring runoff. The Jumpingpound Creek sub-basin is dominated by grazing in native pasture (Jumpingpound Creek Watershed Partnership 2009). Relative to other sub-basins further east, fertilizer use by farmers is very low in the Jumpingpound Creek sub-basin. Future increases in total phosphorus in the sub-basin will likely be related to increasing urban developments in the lower sub-basin.

Total phosphorus and total dissolved phosphorus meet protection of aquatic life water quality guidelines most of the time in Fish Creek (City of Calgary Water Resources 2009). However, total nitrogen exceedences occur often. Exceedences are more likely to occur during high flow periods (Friends of Fish Creek Provincial Park Society 2009). Eleven stormwater outfalls discharge into Fish Creek, three of these are untreated, and upstream land use tends to be dominated by cattle grazing and grain farming.

Total phosphorus and nitrogen at sites in Nose Creek within Calgary often exceed surface water quality guidelines (Appleby et al. 2009). Exceedance rates range from 70% in West Nose Creek at Mountain View Road, to 100% in Nose Creek at 15th Street (City of Calgary Water Resources 2009). Total dissolved phosphorus exceeded guidelines less frequently. Nutrient loads likely originate from surface runoff because there are no WWTPs along Nose Creek. Crossfield is the only municipality to discharge wastewater to the tributary. Nose Creek flows through the plains and the majority of its natural vegetation communities have been replaced by pasture, cropland, and urban landscapes (Bow River Basin Council 2005). Upper reaches of Nose Creek are primarily influenced by agricultural lands while lower reaches receive urban runoff.

There is a general lack of water quality data for the Sheep River. The river drains a large number of small mountain tributaries. Because of this, water quality tends to be poor during spring due to considerable contributions from mountain runoff and snowmelt (Bow River Basin Council 2010).

The Sheep River sub-basin is under increasing pressure from residential developments. Urban stormwater runoff and wastewater will likely be important sources of phosphorus to the river in the future.

Water quality data from the Highwood River are scarce. The biggest influence on water quality is diversion of water from the Highwood River into the little Bow sub-basin of the Oldman River Basin. This can lead to low flow rates in summer, and we could speculate higher concentrations of nutrients.

Many tributaries in the plains regions, such as Crowfoot, West Arrowwood, and 12 Mile creeks, have total phosphorus well above water quality guidelines (Sosiak 1996). Irrigation return flows in the Bow Basin generally had higher concentrations of TP and TDP than streams (Sosiak 1996). During the AESA study, Crowfoot Creek was only in compliance with TP guidelines in 5% of samples and with TN in 49% of samples (Lorenz et al. 2008). We can consider agriculture to be an important source of nutrients in these tributaries because it is the predominant land use, although the Crowfoot Creek watershed contains some urban development.

Salts

Basin-scale (mainstem)

From Bow Lake to Lake Louise, the Bow River passes through protected land in Banff National Park. From 1983 through 2002, there have been increases in the concentrations of several major ions. Sodium and chloride have increased, likely due to non-point loading from septic tanks and road salts (Bow River Basin Council 2010). Downstream of Lake Louise water quality is still excellent with respect to salts, although concentrations are slightly higher than upstream. WWTPs at the towns of Lake Louise and Banff are likely contributing sodium and chloride. Salting of the highways and roads within the park likely also contribute to increasing concentrations, although available data do not allow partitioning of the loads at present (Bow River Basin Council 2010).

The concentrations of major ions sodium, potassium, and chloride increase with river distance in the mainstem (Sosiak 1996). Concentration of each was much higher downstream from Calgary WWTP effluents, which were the largest point sources in the basin. Loadings from individual tributaries and irrigation return flows were small in 1995.

Local-scale (tributaries)

Total dissolved solids range from 151 to 376 mg/L in Jumpingpound Creek and concentrations peak during low flow-periods and are lowest during spring run-off. It is likely that much of the TDS load is coming from natural groundwater sources (Jumpingpound Creek Watershed Partnership 2009).

Total dissolved solids in Nose Creek frequently exceed concentrations of 500 mg/L (Appleby et al. 2009). Excess chloride has been detected at the mouth of Nose Creek, which is suspected to be due to road salts and animal waste. Higher concentrations of chloride in the winter and spring support road salt as a source (Appleby et al. 2009). Depending on temperature, the City of Calgary applies between 6,700 and 67,000 kg of salt per application to streets that have storm sewers draining into Nose Creek.

Occasionally Fish Creek in Calgary has had chloride concentrations above guidelines for continuous concentration to support freshwater aquatic life (Leung 2009). Although exceedances are rare, chloride has increased in Fish Creek during time span of 1975 to 2008 (Leung 2009). Because there is not a very dense network of roads draining into Fish Creek, the increase in chloride is likely related to increased development upstream.

METALS

Basin-scale (mainstem)

There are no major NPS pollution sources for metals to the Bow River within Banff National Park. Total aluminum, copper, and lead occasionally exceed water quality guidelines for protection of aquatic life, but these exceedances likely have natural sources (Bow River Basin Council 2010). Also, metals were usually in non-bio-available form. From the Banff National Park border to Bearspaw Dam, metal concentrations have been consistently low. Transient elevated concentrations have occurred for cobalt, nickel, silver, and zinc. The source of these metals to the mainstem is largely from natural tributary sources, especially the Kananaskis River, but also from the Canmore WWTP (Bow River Basin Council 2005).

Generally, metal concentration data are scarce in the Bow River. Iron is the only metal that exceeded water quality guidelines in the mainstem during a synoptic survey in 1995 (Sosiak 1996). There was little evidence that metals cause adverse aquatic impacts in the Bow River. The Alberta River Water Quality Index for metals for 2009-10 was rated as excellent for all sampling stations along the Bow River (Alberta Environment 2010).

Local-scale (tributaries)

Jumpingpound Creek typically meets water quality guidelines for freshwater aquatic life. Exceedances for chromium, lead, iron, and mercury were associated with single events (Jumpingpound Creek Watershed Partnership 2009).

PATHOGENS

Basin-scale (mainstem)

Bacterial concentrations are low in the Bow River between Bow Lake and Lake Louise. There are occasional detections of fecal coliforms, indicating contamination by wildlife or human wastes (Bow River Basin Council 2005). WWTPs do not have an impact on bacteria concentrations downstream of Lake Louise, thus occasional detections of fecal coliforms on this section of the river is likely due to wildlife contamination or human waste from recreational users. From the Banff National Park border to Bearspaw Dam, bacteria concentrations are generally in a natural condition in the mainstem of the Bow River (Bow River Basin Council 2010).

Fecal coliforms concentrations increase downstream of Calgary's WWTPs, but generally remain below guidelines for recreational use (200 cfu/100 mL) (Bathory et al. 2005).

Local-scale (tributaries)

An emerging concern in the Ghost River sub-basin is human manure from recreational visitation where outhouses are unavailable. It is estimated that within the next 50 years, up to 270 t/year of human manure may be contributed to the watershed (Yarmoloy and Stelfox 2011). This could lead to contamination by bacteria and other pathogens.

Within the City of Calgary, the sub-index for bacteria in Nose Creek is rated as “marginal”, due to frequent exceedences of *E. coli* (City of Calgary Water Resources 2009). Other tributary sites within the City and Fish Creek, are more often in compliance with *E. Coli* objectives (City of Calgary Water Resources 2009). Fecal coliforms recreation guidelines are frequently exceeded in Jumpingpound Creek, but data are limited and there is no pattern to the exceedances (Jumpingpound Creek Watershed Partnership 2009).

Pesticides

Basin-scale (mainstem)

Pesticides are not routinely monitored in Banff National Park due to lack of agricultural activity in the area (Bow River Basin Council 2005). There is potential for contamination, however, from municipal and residential use in the town sites. Melting glaciers currently supply organochlorine pesticides to Bow Lake (Blais et al. 2001).

Pesticide detections have been consistently low from Banff to the Bearspaw Dam. 2,4-D has been detected in the highest concentrations. Commercial use, lawns, parks, and golf courses are all likely sources of pesticides along this portion of the Bow River mainstem (Bow River Basin Council 2005). There is also logging in this portion of the basin, which could contribute herbicides to the river, although data are not available at present.

Stormwater from the city of Calgary is an important source of pesticides to the Bow River. Residential use of pesticides is four times that of city parks, and accounts for 70% of pesticide use in the city (Bow River Basin Council 2005). However, pesticide loading appears to have minimal impact to the river. Downstream of Calgary, the mainstem Alberta River Quality Index for pesticides was rated as good at Carseland Weir, Cluny, and Ronalane (Alberta Environment 2011b). Guidelines were occasionally exceeded, but usually by small amounts, and the overall threat to water quality is minimal.

Local-scale (tributaries)

No water quality data are available with respect to pesticides in Jumpingpound Creek; however, it is known that farms in the sub-basin use small amounts of herbicides and fungicides compared to farming operations in more eastern sub-basins (Jumpingpound Creek Watershed Partnership 2009).

Analyses of water samples taken from five sites along Fish Creek in August 2009 did not detect any pesticides (Friends of Fish Creek Provincial Park Society 2009). Pesticides have been detected in Nose Creek (Bow River Basin Council 2010).

Crowfoot Creek was monitored as an AESA stream, and three pesticides were detected in high concentrations; dicamba, 2,4-D, and MCPA (Lorenz et al. 2008). Concentrations were in exceedance of water quality guidelines more than 70% of the time. MCPP was also detected in Crowfoot Creek. Detection of this pesticide shows that this tributary is also under the influence of urban runoff (Lorenz et al. 2008).

3.4.3 Data

Alberta Environment's water quality monitoring on the Bow River has included five LTRN stations; at Cochrane, Elbow River at 9th Bridge, Carseland Weir, Cluny, and at Ronalane. These stations have been monitored monthly since the late 1980s. Typically, samples have been analyzed for chlorophyll, temperature, DO, turbidity, color, DOC, specific conductance, nutrients, and major ions. Most samples have also been analyzed for bacteria and some have been analyzed for metals.

AENV has collected water quality data from a multitude of sampling stations in the Bow River Basin starting in the 1970s. The largest sampling efforts were made in the 1990s. Parameters measured reflect those from the LTRN stations. Metals and pesticides have been infrequently measured compared to nutrients and major ions.

Some other major water quality sampling efforts within the Bow Basin could also be used in assessing NPS pollution. Synoptic surveys were completed by AENV in the Bow River in 1994-1995. The City of Calgary and AENV conducted extensive water quality monitoring in the Elbow River and its tributaries from 1999 to 2003. The City of Calgary has 34 monitoring stations located both upstream and downstream of the city that are sampled monthly (all year long for some stations, only during open water for others). Crowfoot Creek was selected for monitoring by the CAESA and AESA stream surveys (from 1995 to 2006) and was also included in the Alberta Soil Phosphorus Limits project (2002 to 2006). Under conditions stipulated in their newest detailed forest management plans, Spray Lakes Sawmills are required to do water quality monitoring within their forestry management area and report on the findings every five years.

3.4.4 Synthesis

The City of Calgary has the greatest impact on the water quality of the Bow River. According to the Alberta River Water Quality Index, water quality in the Bow River is excellent in the mountains and foothills and then decreases to "good" after passing through the City of Calgary, largely due to a reduction in nutrient and pesticide sub-indices. The WWTP is largely responsible for the decrease in the nutrient sub-index, contributing about 85% of nutrient loads from the City of Calgary. Urban runoff contributes relatively low loads, at about 15% of total City of Calgary loads to the Bow River. The pattern is the reverse for TSS; that is, stormwater contributes 90% of total TSS loads from the City of Calgary. In addition, stormwater is an important source of pesticides to the Bow River, which may account for the reduction in this sub-index from "Excellent" to "good" downstream of the City of Calgary. Although improvements are underway in the city of Calgary's stormwater management system, a growing population and city footprint will also bring increasing demands to the stormwater systems.

Streams in the Bow Basin are impacted by NPS pollution from both urban development and agriculture. Streams that pass through the City of Calgary (particularly Nose Creek, and to a much lesser extent Fish Creek) exhibit high exceedance rates for nutrients. In addition, high concentrations of salts (chloride in particular) are measured in winter and spring in Nose and Fish Creeks as a result of road salt use. Pesticides were also detected in Nose Creek. In the lower reaches of the Bow Basin (plains region), agricultural watersheds (Crowfoot, West Arrowwood and 12 Mile creeks) have very high concentrations of nutrients and certain pesticides, which are in exceedance of water quality guidelines over half the time, depending on the constituent.

Increasing recreational use is of great concern in the mountain and foothill tributaries, particularly in the Ghost River watershed. Potential impacts include human waste from random campsites and erosion due to off-highway motor vehicle. The extent of this disturbance remains a gap that needs to be closely examined.

Urban sprawl and recreation will likely lead to overall increased constituent contamination, while agricultural inputs will likely remain stable.

3.4.5 References

Alberta Environment. 2010. Alberta River Water Quality Index-Metals (2009-2010). Retrieved from http://environment.gov.ab.ca/info/library/7718.pdf.

Alberta Environment. 2011a. Alberta River Basins. Retrieved from http://environment.alberta.ca/apps/basins/default.aspx.

Alberta Environment. 2011b. 2009-10 River Water Quality Index ratings for pesticides. Retrieved from http://environment.alberta.ca/01278.html.

Appleby, A., A. Nielsen, Z. Noel, and V. Tran. 2009. Trends in the historical water quality: Nose Creek, Alberta. University of Calgary, Calgary, Alberta. Retrieved from http://www.ucalgary.ca/ensc/files/ensc/Historical Water Quality (ENSC502).pdf.

Bathory, S., K. Campbell, M. Dankers, R. Foote, K. Gray, F. Guirgis, T. Johnson, D. Lawson, A. Lubyk, M. Lupart, O. Madjidi, R. Magliocco, E. Motz, K. Murray, A. Nechka, T. Nyuishhi, A. Pawlak, J. Schnell, J. Shorrocks, C. Spavor, S. Sterling, J. Watson, and A. Yousef. 2005. Fate of Calgary's effluent in the Bow River. University of Calgary. Retrieved from http://wsow.brbc.ab.ca/reports/ENSC502-04-05-FinalReport-FateCalgaryEffluent.pdf.

Blais, J. M., D. W. Schindler, D. C. Muir, M. Sharp, D. Donald, M. Lafrenière, E. Braekevelt, and W. M. Strachan. 2001. Melting glaciers: a major source of persistent organochlorines to subalpine Bow Lake in Banff National Park, Canada. Ambio 30:410-415. Retrieved July 24, 2011, .

Bow River Basin Council. 2005. Nurture, renew, protect: a report on the state of the Bow River Basin. Calgary, Alberta. Retrieved from http://wsow.brbc.ab.ca/index.php?option=com_content&view=article&id=93&Itemid=179.

Bow River Basin Council. 2010. Web-based state of the watershed tool. Retrieved from http://wsow.brbc.ab.ca/.

Chao, Y.-J. J. 2011. Major ion and stable isotope geochemistry of the bow River, Alberta, Canada. MSc, University of Calgary, Calgary, Alberta.

City of Calgary Water Resources. 2009. Calgary watershed report, 2007-2009: A summary of surface water quality in the Bow and Elbow River watersheds. Calgary, Alberta.

Friends of Fish Creek Provincial Park Society. 2009. Water quality monitoring report 2009. Page 96. Calgary, Alberta. Retrieved from http://wsow.brbc.ab.ca/reports/FishCreekStudy2.pdf.

Grasby, S. E. 1997. Controls on the chemistry of the Bow River, southern Alberta, Canada. PhD, University of Calgary, Calgary, Alberta.

Jumpingpound Creek Watershed Partnership. 2009. Jumpingpound Creek state of the watershed report 2009. Page 91. Retrieved from http://wsow.brbc.ab.ca/reports/JCWP-StateWatershed2009.pdf.

Kobryn, B. 2008. 2008 Calgary total loading management plan. Page 48. City of Calgary, Calgary, Alberta.

Letourneau, R., B. Amell, Y. Deong, and R. Wouts. 2008. City of Calgary stormwater quality retrofit program. Edinburgh, Scotland, UK. Retrieved from http://web.sbe.hw.ac.uk/staffprofiles/bdgsa/11th_International_Conference_on_Urban_Drainage_CD/ICUD08/pdfs/759.pdf.

Leung, C. 2009. Water quality and invertebrate study of Fish Creek in Calgary, Alberta, Canada. ENSC505 Project, University of Calgary, Calgary, Alberta. Retrieved from http://wsow.brbc.ab.ca/reports/FishCreekStudy.pdf.

Lorenz, K., S. Depoe, and C. Phelan. 2008. Assessment of environmental sustainability in Alberta's agricultural watersheds project: Volume 3: AESA water quality monitoring project. 543 pp. Alberta Agriculture and Rural Development.

Silins, U., K. D. Bladon, M. D. Stone, M. B. Emelko, S. Boon, C. Williams, M. Wagner, and J. Howery. 2009. Southern Rockies watershed report: impact of natural disturbance by wildfire on hydrology, water quality, and aquatic ecology of Rocky Mountain watersheds: Phase 1 (2004-2008). Page 92.

Sosiak, A. 1996. Bow River synoptic surveys 1994-1995: preliminary evaluation of results. Page 117. Prepared for the Bow River Water Quality Council. Retrieved from http://environment.gov.ab.ca/info/library/7902.pdf.

Sosiak, A., and J. Dixon. 2004. Impacts on water quality in the Upper Elbow River. Page 95 pp. Alberta Environment and the City of Calgary Waterworks and Wastewater. Retrieved from http://wsow.brbc.ab.ca/reports/ImpactsOnWaterQuality-UpperElbowRiver.pdf.

Yarmoloy, C., and B. Stelfox. 2011. An assessment of the cumulative effects of land uses within the Ghost River Watershed, Alberta, Canada. Page 79. Ghost Watershed Alliance, Cochrane, AB. Retrieved from http://www.ghostwatershed.ca/GWAS/Research_%26_Data.html.

3.5 Lesser Slave

3.5.1 Introduction

The Lesser Slave River Basin covers an area of 20,100 km^2 and comprises five sub-basins. The westernmost sub-basin drains via the South Heart River into Buffalo Bay. The East and West Prairie, Driftpile, and Swan Rivers drain land to the south of Lesser Slave Lake, in the Swan Hills area, and a few smaller tributaries drain land to the north of the lake. Water flows out of the lake to the east via the Lesser Slave River, which joins the Athabasca River approximately 75 km downstream. Lesser Slave Lake, at 1,150 km^2, is the third largest lake in the province. It is a very important area for tourism and recreation in the province and, as the home of Canada's northernmost bird migration monitoring station, it is recognized internationally as a significant area for bird life.

Tributary discharge to Lesser Slave Lake is greatest in areas that drain the Swan Hills, where precipitation, snow accumulation, and topography are greatest in the basin (Jamison 2009). The South Heart River, to the west of the lake, drains a relatively large but flat area and thus produces relatively less surface runoff. Two of the rivers that drain the Swan Hills area, the Driftpile and Swan Rivers, contribute almost twice as much runoff to the lake system than the relative size of their drainage area (Seneka 2002). These tributaries are highly seasonal in their discharge, having very low flows in winter.

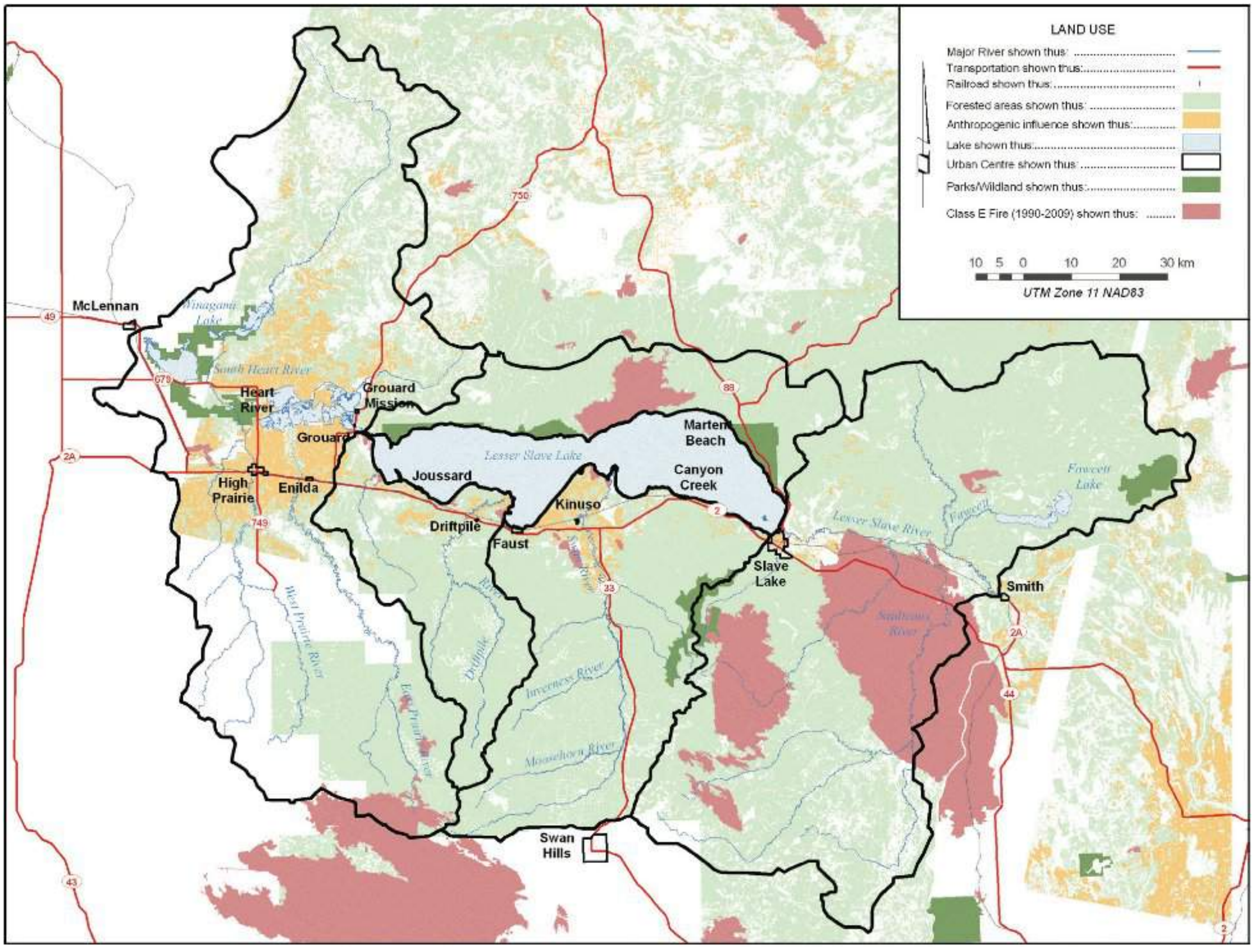

Figure 16: Land cover in the Slave Lake River Basin. From Jamison 2009.

The Basin is sparsely populated and urban development is relatively minor. However, most communities are located near watercourses, thereby increasing the risk to aquatic ecosystems. The largest community in the Basin is the town of Slave Lake (pop. 7,031 in 2007), followed by High Prairie (pop. 2,836 in 2007). Several smaller communities are located in the Basin, mostly near the shore of the lake, including the village of Kinuso; the hamlets of Grouard, Joussard, Faust, and Canyon Creek; and the First Nation communities of Kapawe'no, Sucker Creek, Driftpile, Swan River, and Sawridge.

Agricultural areas within the basin are concentrated within the western sub-basins (South Heart/East and West Prairie River sub-basin) and along the south shore of Lesser Slave Lake (Figure 16). Agricultural lands in the region are used for a variety of activities including forage, seed crops, cultivation and livestock grazing. Crops grown within the watershed include wheat, barley, oats, canola, seed, and forage crops (LSLCDC 2003).

Linear disturbances affect about 2.5% of the Lesser Slave River Basin. About 85% of these disturbances are from cutlines that crisscross the landscape. These cutlines were created mainly to support the oil and gas industry, which is the most active industry within the basin. The Swan River

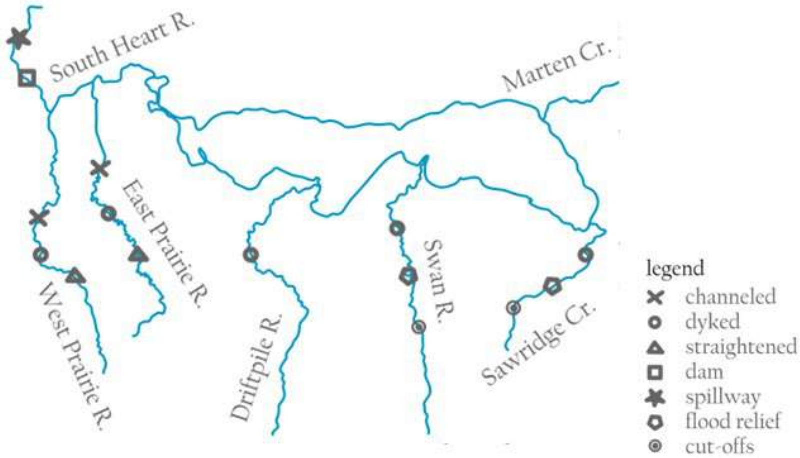

Figure 17: Engineering projects conducted in the Lesser Slave River Basin. From LSLWC 2008a.

sub-basin, for example, contains the third largest oilfield deposit in Canada (LSLCDC 2003). Other active industries include logging and sand and gravel. Forestry operates throughout the forested areas of the basin. Sand and gravel is most active in the Swan Hills sub-basin near the shore of Lesser Slave Lake and in the upper reaches near the town of Swan Hills. This industry is also very active to the north of the lake, in the Lesser Slave Lake North sub-basin. These are located along Highway 754 near aquatic ecosystems (Cabin and Marten creeks). Impacts from industry are thought to be greatest through activities that disturb and displace soils, such as road construction, particularly near watercourses, where a combination of slopes, runoff, and exposed soils provide ideal conditions for erosion and siltation (Jamison 2009).

Riparian health assessments, using aerial videography (Johns and Hallett 2009), were completed for the lower portions of the South Heart (90 km) and West Prairie rivers (16 km), as well as the shore of Lesser Slave Lake. According to Johns and Hallett (2009), the highest scores on the two rivers coincided with the Winagami Lake Provincial Park and the lowest scores were observed along channelized sections of the river, urban areas (Town of High Prairie), and areas of agricultural cultivation. About 12% and 9% of the shores of Lesser Slave Lake are moderately and highly impaired, respectively (Osokin and Hallett, 2007). The north shore, an area of little shoreline development, is healthy. Most of the impaired locations occurred on the southern shore where urban development, recreational use and agricultural activity are occurring.

In an effort to reduce flooding, numerous river modification projects were undertaken, beginning in the 1950s (Figure 17). The West and East Prairie rivers were channelized (straightened and widened) along a stretch of about 8.5 km and 13.5 km, respectively, each upstream of the confluence with the South Heart River. In reaches of the South Heart River, channelization and the construction of two dams and a spillway were also completed. Dykes were installed along the Driftpile River ,and dykes, flood relief channels, cutoffs, and erosion control measures were installed in the Swan River and Sawridge Creek.

In the lake, most water quality variables including pesticides, trace metals, and other elements complied with the Alberta Surface Water Quality Guidelines for protection of aquatic life except for higher than guideline concentrations of total phosphorus and total nitrogen (Wolanski 2006). High nitrogen and phosphorus concentrations were seen fairly consistently throughout the watershed (Noton 1998). Point-sources of pollutants (Town of Slave Lake and Slave Lake Pulp effluents) have been the greatest concern for the water quality of the Lesser Slave River. Using data from 1998 to 2002, water quality was rated as "excellent" at the outflow from Lesser Slave Lake and "good" further downstream at two sites, located upstream and at the confluence with the AR (North/South Consulting et al. 2007). At the lake outflow parameters were compliant with Water Quality Guidelines, but further downstream measurements of some total metals (Cd, Cu, Pb) or total phosphorus exceeded Water Quality Guidelines. Pulp mill effluent is responsible for a substantial increase in total and dissolved phosphorus, which decreases with distance downstream from the mill (Golder 2004). Total nitrogen concentrations can also rise under low flow conditions in winter, mainly due to municipal and pulp mill effluent loading (Noton and Seneka 2000). Dissolved oxygen sags can occur in the river near the mouth under these low flow conditions. Certain metals (B, Cd, Cu, Mn, U and V) and total dissolved solids also increase downstream from the pulp mill effluent discharge.

3.5.2 Knowledge

Suspended solids and metals

Tributaries in of the Lesser Slave River naturally export high loads of suspended solids. Streams that drain the Swan Hills have high carrying capacity for total suspended solids due to steep slopes, greater runoff potential, and high flow velocities. Because of this, many of the tributaries (Driftpile River, South Heart River, Swan River) have formed deltas at the discharge points in Buffalo Bay and Lesser Slave Lake. Based on an analysis of historical aerial photos, these deltas have grown by up to 800 m in the last 50 years (AMEC 2005). As in other areas of Alberta, metals such as iron, copper lead, nickel, vanadium and zinc are typically related to suspended solids in tributaries (Noton 1998).

The tributary engineering projects from the 1950s to 1970s have locally increased the amount of channel erosion and downcutting, thereby increasing sediment transport within these rivers (AMEC 2005). Also, the potential for sediment loading to aquatic ecosystems is likely related to the number of road crossings. In a study that monitored three small streams in the foothills near Hinton for several years, forest harvesting increased sediment production by 130% to 210%. Poor forestry management practices (poorly constructed and maintained stream crossings) were attributed to this increased loading (Jablonski 1986). Tchir et al. (2004) found that 19% of culvert crossings and 36% of bridge crossings in the Lesser Slave River Basin had a high potential to contribute sedimentation to the watercourse that they crossed. Sediment loading may have also increased as a result of littoral transport from degraded riparian areas.

These activities, particularly the engineering works in the western tributaries, have affected sedimentation in Lesser Slave Lake. Sediment cores taken from the east and west basins show that sediment deposition rates have increased substantially since 1950 in the west basin (Hazewinkel, unpublished data, Figure 18).

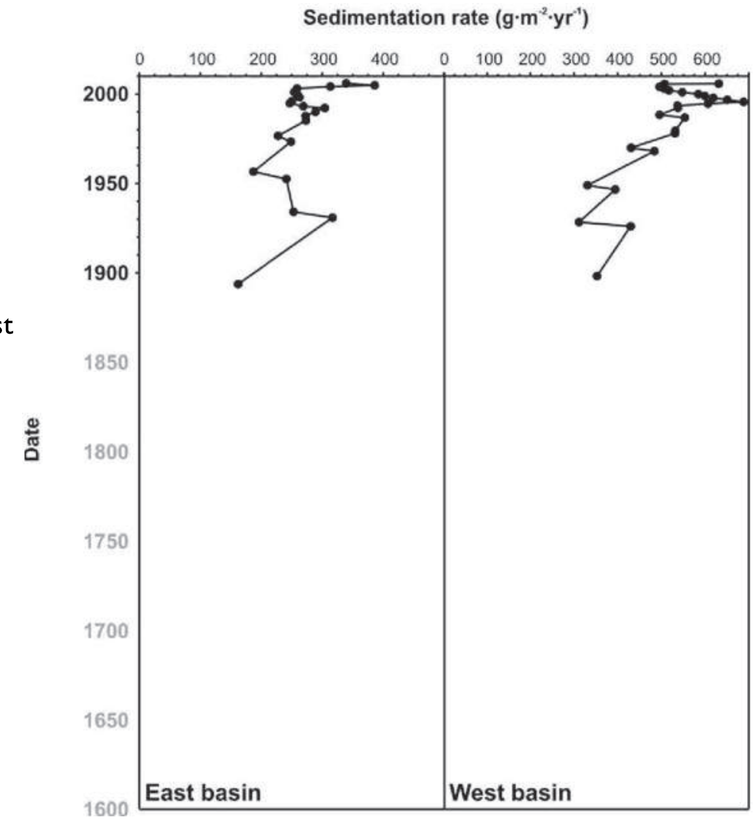

Figure 18: Sedimentation rates in the east and west basins of Lesser Slave Lake. From Jamison 2009.

Nutrients

The majority of phosphorus inputs to the water column of Lesser Slave Lake is from internal loading from the sediment-water interface and exceeds tributary inputs by over 2 to 1 (Figure 19). However, it is important to realize that nutrient loading from tributaries contributes to sedimentary nutrient concentrations, which in turn can be re-distributed to the water column. Sediment cores taken from the lake indicate that lake productivity began a slight increase when the region was settled in the late 1700s and then rapidly increased in the 1960s and 1970s (Figure 20). This is consistent with an increase in sedimentation rate at about this time (Figure 18). Sediments carry nutrients, which likely caused the increase in productivity. Today, the lake (especially the western basin) is one of the most productive lakes in Alberta and on some occasions, boil water advisories have been issued.

Total phosphorus and nitrogen concentrations are high in the tributaries, with the South Heart River being highest and most often exceeding guidelines. Total phosphorus generally follows total suspended solids concentrations, and is higher during the spring season. The South Heart River is an exception, where total phosphorus concentrations changed relatively little throughout the open-water season. This likely reflects the slow nature of this river, which may produce internal phosphorus loads later in the year when oxygen concentrations dip. The cause of the relatively higher concentrations of nitrogen and phosphorus in the South Heart River is unclear. It may reflect the naturally productive soils or extensive agriculture in this sub-basin.

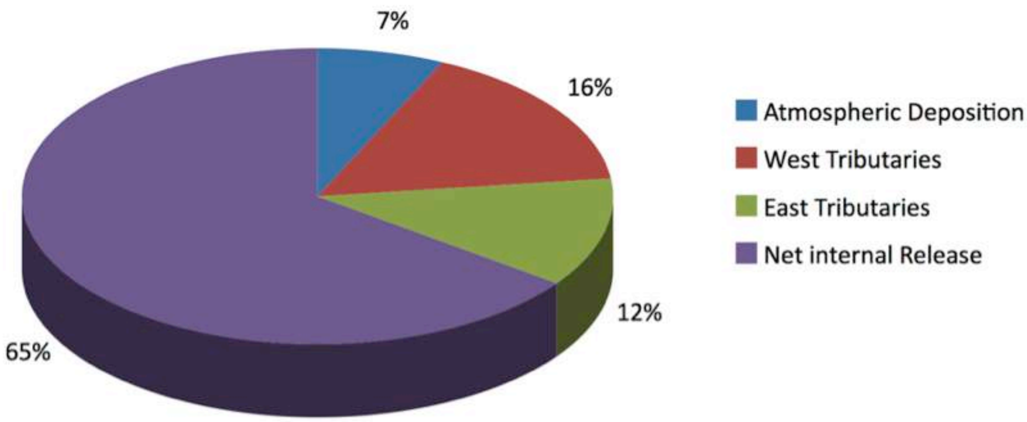

Figure 19: Phosphorus budget of Lesser Slave Lake. From Noton (1998).

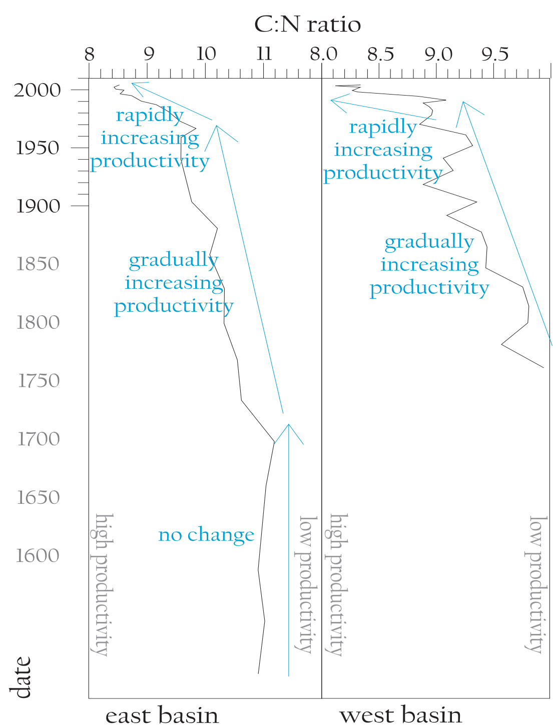

Figure 20: Productivity rates, as estimated from carbon to nitrogen ratio in sediment cores from the east and west basins of Lesser Slave Lake. From LSLWC (2008b).

Other constituents

No pesticides or trace organic "priority pollutants" were detected in the four rivers sampled for these contaminants – the South Heart, Driftpile, Swan, and Lesser Slave rivers (Noton 1998). Also, total and fecal coliform bacterial densities did not appear to differ among these tributaries.

The Swan Hills Treatment Centre is a waste management facility located in the upper reaches of the Lesser Slave River sub-basin that disposes of hazardous wastes such as PCBs and dioxins. There is considerable concern that emissions from this facility are causing adverse effects to downwind aquatic ecosystems. Sediment cores from nearby Christina Lake indicate deposition of PCBs in the lake. The impacts of this centre appear to cause mainly local effects.

3.5.3 Data

Lesser Slave River

AENV water quality monitoring on the Lesser Slave River has included two 'Medium Term River Network' (MTRN) sites: at the outflow of Lesser Slave Lake and near the confluence with the Athabasca River. At these sites, sampling has been conducted approximately six times per year, for routine inorganics, nutrients, pesticides, metals and trace organics. In addition, 'synoptic' surveys were conducted during the winters of 1990-96, and dissolved oxygen was recorded near the Athabasca River confluence during the winters of 1989-97. During the winter of 1999-2000, two synoptic surveys were carried out, including dissolved oxygen recording.

In addition to AENV monitoring, Slave Lake Pulp has conducted baseline and operational monitoring, which focused on dissolved oxygen and parameters associated with pulp mill discharge. Monitoring was also conducted as part of the federal Environmental Effects Monitoring (EEM) program.

Lesser Slave Lake

During the spring of 1991 to the fall of 1993, the two basins of lesser slave lake, as well as five of its tributaries (South Heart, Driftpile, Swan, Assineau, and Marten Creek) were sampled for nutrients, metals, pesticides, bacteria, and trace organics. From 2000 to 2001, four sampling events were conducted in both lake basins.

3.5.4 Synthesis

Water quality in the Lesser Slave River is typically rated as "excellent" at the outflow of Lesser Slave Lake and diminishes to "good" further downstream near the confluence with the Athabasca River. Municipal and pulp mill point sources are largely responsible for this degradation.

Many streams in the Lesser Slave River Basin naturally export high loads of suspended solids (and associated constituents), due to steep slopes, high runoff potential and high flow velocities. In addition to this background influence on water quality, human activity has been demonstrated to affect stream water quality. In particular, engineering works in western tributaries that drain into Lesser Slave Lake have increased the amount of channel erosion and downcutting, thereby increasing sediment transport. As a result, sedimentation and nutrient enrichment have rapidly increased in the early 1960s, which has resulted in eutrophication in the lake that endures to this day. In addition, there is limited evidence that the Heart River, may be contributing NPS pollution from agricultural lands it drains. As a result of these impacts, particularly the engineering works, the western basin of Lesser Slave Lake has become one of the most eutrophic lakes in Alberta.

Forestry, oil & gas, and aggregate mining are very active in the Lesser Slave Lake. From other basins (Sections 3.1 and 3.10), we know that logging can increase peak water yields, nutrients and sedimentation. The latter is largely related to road construction and use. There is good documentation of linear disturbances in the Basin, which affect about 2.5% of the land base. However, there is no information on recreational use of these linear features. Recreational use has been linked to sedimentation of streams in other basins (see Section 3.7) and thus remains a risk to streams in the LSR. Studies in the basin indicate that over 20% of culvert and bridge crossings have high potential to contribute sedimentation to the watercourses they cross. Although oil and gas well densities and linear disturbance have been reported and can be very high in this basin, little information exists on cumulative environmental impacts of logging, oil & gas, aggregate and recreation.

Other gaps include a poor understanding of the significance of urban runoff on NPS pollution to Lesser Slave Lake. This may be important since pollution to lakes can last decades through the internal recycling of certain pollutants.

3.5.5 References

AECOM. 2009. Swan Hills Treatment Centre, EarthTech, AECOM Canada. Online Resource: http://www.shtc.ca/. Accessed January 4, 2010.

AMEC. 2005. Lesser Slave Lake sedimentation study. Prepared for Alberta Environment, Edmonton, Alberta.

Golder Associates Ltd. 2004. Lesser Slave River instream flow needs assessment scoping study. Prepared for Alberta Environment, Peace River, AB.

Jablonski, P. 1986. Tri-Creeks: Documentation of Timber Harvesting Operation From a Watershed Management Perspective. Alberta Energy and Natural Resources, Lands and Forests Branch.

Jamison, T. 2009. State of the Lesser Slave Watershed 2009. Carson Forestry Services Inc. Prepared for Lesser Slave Watershed Council. High Prairie, AB. 116 pp.

John, T. and J. Hallett. 2009. Aerial Videography Assessment for Selected Reaches of the South Heart and West Prairie Rivers, Alberta. Alberta Conservation Association. Peace River, Alberta.

Lesser Slave Watershed Council (LSLWC). 2008a. LSWC fact sheet: Sedimentation in Lesser Slave Lake. High Prairie, AB.

Lesser Slave Watershed Council (LSLWC). 2008b. LSWC fact sheet: Paleolimnology in Lesser Slave Lake. High Prairie, AB.

North/South Consultants Inc., Clearwater Environmental Consultants Inc. and Patricia Mitchell Environmental Consulting. 2007. Information synthesis and initial assessment of the status and health of aquatic ecosystems in Alberta. Report prepared for Alberta Environment, Edmonton, AB. 522 pp.

Noton, L. 1998. Water quality of Lesser Slave Lake and its tributaries, 1991-93. Alberta Environment, Water Sciences Branch, Water Management Division, Natural Resources Service.

Noton, L and M. Seneka. 2000. Low flow conditions in the Lesser Slave River, 1999-2000. Water Science Branch. Alberta Environment.

Osokin, L. and J. Hallett. 2007. Aerial video assessment of Lesser Slave Lake, Alberta. Alberta Conservation Association. Slave Lake, Alberta.

Tchir, J. P., P. J. Hvenegaard and G. J. Scrimgeour. 2004. Stream crossing inventories in the Swan and Notikewin river basins of northwest Alberta: resolution at the watershed scale. Pages 53-62 in G. J. Scrimgeour, G. Eisler, B. McCulloch, U. Silins and M. Monita. Editors. Forest Land – Fish Conference II – Ecosystem Stewardship through collaboration. Proc. Forest-Land-Fish Conf. II, April 26-28, 2004. Edmonton, AB.

Seneka, M. 2002. Hydrology of the Lesser Slave Lake Watershed. Alberta Environment, Evaluation and Reporting Section, Water Assessment. Edmonton, Alberta.

Wolanski, A., 2006. Lesser Slave Lake results of water quality survey conducted by Alberta Environment in 2000-2002. Alberta Environment, Environmental Management, Northern Region.

3.6 Milk

3.6.1 Introduction

The Milk River Basin is the smallest of Alberta's major river basins, covering 6,664 km^2 in Alberta, although the total watershed area is 61,642 km^2 (Milk River Watershed Council Canada 2008). The river enters Alberta from Montana and flows east through the province before heading south back into Montana. Mean annual precipitation in the basin ranges from 316 to 450 mm, over half of which falls as rainfall during the growing season. Basin-wide, the highest amounts of precipitation fall in the Cypress Hills.

Flows in the Milk River range from about 0.7 m^3/s in winter to 20 m^3/s in June. The St. Mary River diversion in Montana diverts a relatively significant amount of water from the St. Mary River into the North Milk River; 61% of observed stream flow in the Milk River in Alberta is from water diverted from the St. Mary River during the irrigation season. The St. Mary River diversion maintains flows in the Milk River between 12 to 20 m^3/s between June and August, when flows would naturally have ranged from about 2 to 12 m^3/s (McLean and Beckstead 1985, Milk River Watershed Council Canada 2008). Other flow contribution to the Milk River in Alberta is 22% from the mainstem Milk River watershed in Montana, 8% from the North Milk River watershed in Montana, and 10% from runoff within Canada. In some years, there have been periods with no flow recorded in the river at the eastern crossing. The variation in flow volume has major impacts water quality in the river and its tributaries.

Tributaries flowing into the Milk River are generally intermittent. Southern tributaries of the Milk

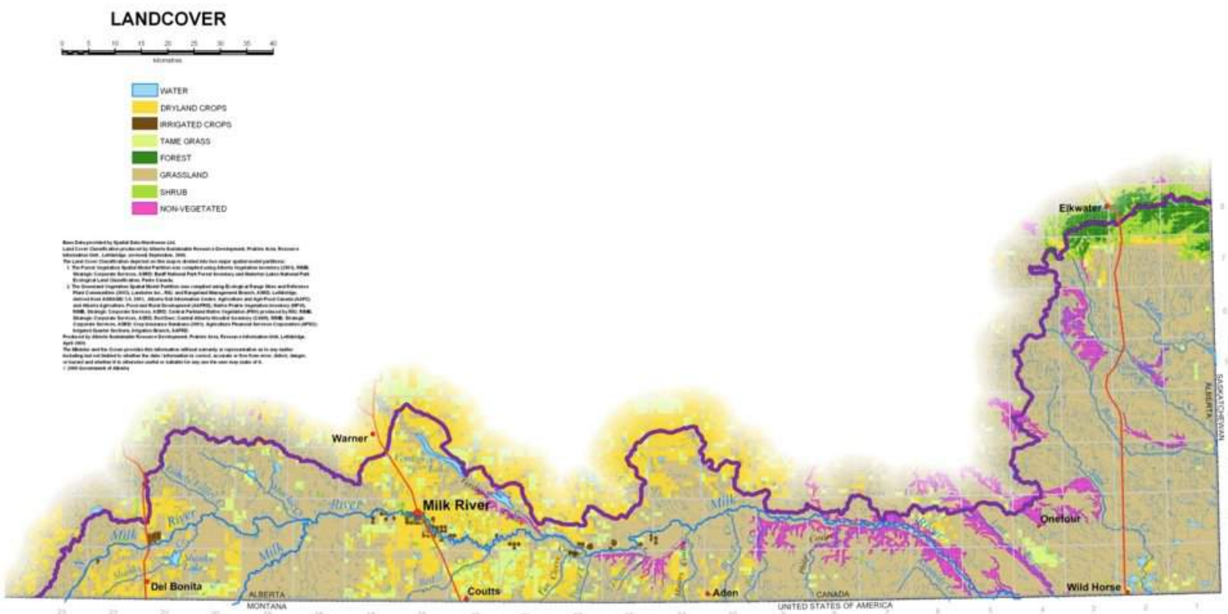

Figure 21: Land cover of the Milk River Basin (Milk River Watershed Council Canada 2008)

River include Bear Creek and Breed Creek, both of which are intermittent streams flowing from the Sweetgrass Hills of northern Montana. Northern tributaries in Alberta are the intermittent Sage Creek and Lost River. The eastern tributaries, Battle, Middle, and Lodge creeks, originate in the Cypress Hills and flow east into Saskatchewan before joining the mainstem Milk River in Montana.

The Milk River Basin has a small population of 2,403; 52% are rural and 48% live in towns. The town of Milk River is the largest town in the basin (pop. 846), followed by the village of Coutts (pop. 305). The town of Milk River has a wastewater treatment plant and a storm water system that route water into the river. Ranching and grazing are dominant economic drivers in the basin. Fertilizer, pesticide, and manure use are used with less intensity than other basins in Alberta. Oil and gas development is also prevalent and could contribute to NPS pollution in the basin via of roads, which can contribute sediments or salts. Native grassland covers 71% of the watershed area. Cropland covers 13% and tame grass covers 6% of the area. The cropland area includes privately irrigated agriculture. Shrubs or forest covers only 3% of the basin, and nearly 5% is non-vegetated (badlands). Less than 3% is covered by lakes or wetlands due to the area's semi-arid climate (Milk River Watershed Council Canada 2008).

3.6.2 Knowledge

TOTAL SUSPENDED SOLIDS

Mainstem

Both natural processes and human activities affect TSS concentrations in the Milk River. Flow volume, and thus TSS concentrations, can be incredibly variable along the mainstem of the Milk River. Sediment concentrations in the mainstem have ranged from 3 mg/L during low flow conditions to 12,200 mg/L during floods (McLean and Beckstead 1985). Upstream sections of the

North Milk River and the Milk River, before their confluence, have median TSS concentrations of 5.3 and 4 mg/L, respectively (AMEC Earth & Environmental 2008), which increases along the mainstem of the river. By just downstream of the town of Milk River, median TSS concentration is 21 mg/L (AMEC Earth & Environmental 2008). At the eastern border crossing, concentrations of 1,000 to 2,000 mg/L are not unusual (McLean and Beckstead 1985, AMEC Earth & Environmental 2008). TSS concentrations in the lower reaches of the Milk River are strongly affected by the St. Mary River diversion. This reflects the river banks sediment type and likelihood for erosion or re-suspension. Upstream bottoms and banks are largely gravel, while downstream sediments are finer and sandy and more prone to erosion. Furthermore, the downstream badlands are highly erodible and contribute significant sediment loads during rainfall events (AMEC Earth & Environmental 2008).

Tributaries

Little to no data are available on TSS in the tributaries. Pakowki Lake has a high median TSS concentration of 2,110 mg/L (Sosiak 1997), which is very high for Alberta lakes. Concentrations increase through the year due to evaporation. Although this lake occurs in the Milk River basin, it is part of an endoheric drainage basin and does not contribute flow to the river.

Nutrients

Mainstem

Total phosphorus concentration in the Milk River is largely a function of flow volume and is strongly correlated with TSS concentration (AMEC Earth & Environmental 2008). Similarly to TSS, total phosphorus, mostly in the form of particulate phosphorus bound to sediment particles, increases with distance downstream. The Alberta River Water Quality Index ranking for nutrients in Milk River was good at the Highway 880 long-term monitoring station in 2009-10 (Alberta Environment 2011b). However, exceedances of total phosphorus concentration at this location are historically quite common, whereas upstream of this point, total phosphorus concentrations nearly always meet guidelines for aquatic life. The total phosphorus concentrations in the lower reaches of the Milk River are strongly affected by the St. Mary River Diversion. In October, when flows from the diversion cease, total phosphorus concentrations generally decrease to below water quality guidelines (Milk River Watershed Council Canada 2008).

Total nitrogen concentrations along the mainstem and in major tributaries tend to always meet water quality guidelines (Milk River Watershed Council Canada 2008). Unlike phosphorus, nitrogen concentrations increase when flows from the St. Mary River diversion stop in October due to loss of dilution (Milk River Watershed Council Canada 2008).

Tributaries

Tributaries of the Milk River usually have higher concentrations of phosphorus than the mainstem, and contain more dissolved phosphorus than particulate phosphorus (Milk River Watershed Council Canada 2008). Quality varies across tributaries. Red Creek typically has low phosphorus concentrations, less than 0.01 mg/L, while Miner's Coulee usually has TP concentrations over 0.2 mg/L. Many tributaries tend to be intermittent and concentrations of nutrients can become exceedingly high late in the summer just before they become dry.

At the stream-scale, grazing in the Cypress Hills has been shown to significantly increase non-point source phosphorus loading. Concentrations of soluble reactive phosphorus were significantly higher in grazed than ungrazed treatments in the Cypress Hills (Battle and Graburn creeks, but not in Nine Mile Creek). In these grazing treatments, livestock, which were allowed access to the stream banks, reduced riparian vegetation. Mechanisms of increasing phosphorus loads through grazing on these tributaries includes: increasing the overland flow during precipitation events, reducing phosphorus uptake by riparian grasses, voided livestock wastes, and mobilizing stream bank sediments (Scrimgeour and Kendall 2002).

Pakowki Lake is an important water body in the Milk River Basin. However, as a closed basin, it does not contribute nutrients to the Milk River. Pakowki Lake has extremely high concentrations of phosphorus, with a median total phosphorus concentration of 0.793 mg/L, and median total dissolved phosphorus of 0.503 mg/L. Internally released phosphorus was responsible for 89.5% of the phosphorus load in the lake from May to October in 1996, 8.6% came from tributary streams and diffuse runoff, and 1.9% came from precipitation. Etzikom Coulee was the most important tributary for loadings (5% of total loading). Loadings of phosphorus to Etzikom Coulee could come from agricultural sites (no estimated load), municipal wastewater (maximum 9%), or other sources. Nitrogen concentrations within Pakowki Lake are relatively small (Sosiak 1997).

Metals

The Alberta River Water Quality Monitoring Index rating for metals at the Highway 880 long-term river monitoring station is excellent (Alberta Environment 2010).

Pakowki Lake does not have any external drains, but it is an important lake in the region. Aluminum and iron levels occasionally exceed water quality guidelines for the protection of aquatic life, but these metals are likely associated with the high loads of TSS in the lake and therefore are biologically unavailable (Sosiak 1997).

Salts

Salt concentrations in the Milk River seem to largely reflect natural processes in a semi-arid climate. The Milk River itself meets drinking water quality guidelines for salts (Saffran 1998). However, many of the water bodies within the Milk River Basin are naturally saline. Although they do not all naturally drain into the Milk River, some of the coulees are important sources of salt to the Milk River. Verdigris Lake has a constructed diversion to the Milk River to improve lake water quality via flushing. The water quality in the drain does not meet irrigation or livestock water quality guidelines, but does not significantly impair water quality of the Milk River. The Verdigris Lake drain can contribute nearly 25% of salt loads measured immediately downstream in the Milk River (Saffran 1998). Other natural tributaries and groundwater flow are other likely contributors to salt loading in the Milk River. Water from the St. Mary River dilutes salt concentrations in the Milk River. Salt concentrations increase each year once the St. Mary River diversion stops (Milk River Watershed Council Canada 2008).

Pathogens

The Alberta River Water Quality Monitoring Index for Pathogens ranking is fair at the long-term monitoring station at Highway 880 (Alberta Environment 2011c). Fecal coliforms often exceed recreation guidelines of 200 per mL. Exceedances are common in the tributaries, at the western boundary, at Highway 501, and at Highway 880 (Milk River Watershed Council Canada 2008). High concentrations are more common in the early summer months, when flows and temperatures are higher than the fall. Bacteria are likely coming from wildlife and livestock contact with streams.

PESTICIDES

There have been few detections of pesticides in the Milk River basin, indicating low potential for NPS pollution. However, there has also been much lower sampling effort than in most river basins in the province (Anderson 2005). The Alberta River Water Quality Monitoring Index rating for pesticides at the Highway 880 long-term river monitoring station is excellent (Alberta Environment 2011d). Pesticides most commonly detected at low concentrations are 2,4-D, MCPA, and dicamba (Milk River Watershed Council Canada 2008).

In Pakawki Lake, low concentrations of 2,4-D (0.096 μg/L) were detected in the lake, even though areas nearby have high pesticide sales of 2,4-D, carbofuran, and dicamba. Perhaps low flow in tributaries at times when pesticides usage is high prevents transport (Sosiak 1997).

3.6.3 Data

AENV maintains one long-term water quality monitoring station near Highway 880. Water quality was sampled at this location from 1986 to 1988, and from 2003 to present. AENV has shorter periods of water quality for the North Milk River near the eastern boundary, the North Milk River upstream of the confluence to the Milk River, the Milk River near the western boundary, the Milk River upstream of the confluence to the North Milk River, upstream of the town of Milk River, downstream of the town of Milk River, at Coffin Bridge, at Highway 878, at Writing-on-Stone Provincial Park, downstream of the provincial park, and near the eastern boundary at the Pinhorn Grazing Reserve. Most of these sites were sampled in the mid-1980s. Environment Canada started monitoring the eastern and western boundary crossings in 1960. The monitoring stopped in 1995 but resumed in 2006. The United States Geological Survey has monitored water quality at the western and eastern international border crossings since 1960. There have been fewer water quality studies within this watershed compared to others in the province. The Milk River Watershed Council, in collaboration with municipalities, Writing-On-Stone Provincial Park, and AENV, began a water quality monitoring program in 2006 (Milk River Watershed Council Canada 2008).

3.6.4 Synthesis

Hydrologic modification of the river, via the St. Mary Diversion, is the most important controller of NPS pollution in the Milk River mainstem. During the diversion season, modified flows are substantially higher than natural conditions and lead to re-suspension of large loads of erodible sediments in lower reaches. Particulate phosphorus concentrations often exceed guidelines in lower reaches, and are associated with local suspended sediment loads.

The St. Mary Diversion leads to improvements in other NPS pollutants via dilution. Nitrogen concentrations are generally not a problem in the Milk River mainstem, and hydrologic modification actually improves nitrogen concentrations via dilution. The same can be said for salts.

Agriculture is a source of nutrients to tributaries and small streams in the Milk River Basin. A local-scale study showed increased phosphorus loading to a stream with grazing via several mechanisms, especially when livestock were allowed access to streams. At the tributary and small stream scale, nutrients concentrations are often well above guidelines for the protection of aquatic life. Given the small contribution of total flow provided to the mainstem and the relatively low intensity of agriculture, however, agriculture activities along tributaries do not appear to be significantly impacting the mainstem. However, water quality of tributaries and small-scale streams is a concern.

The information about pesticides, metals, and pathogens within the basin is scarce enough that we cannot draw many conclusions. Although the concentration of pathogens is a concern at certain locations, we cannot say whether they are naturally sourced or associated with land use activities. Pesticides and metals are presently at low enough concentrations in the mainstem that NPS pollution concern for these constituents is low.

Synoptic surveys along the mainstem would help confirm how much pollutant loading reaches the mainstem via each of the tributaries.

3.6.5 References

Alberta Environment. 2010. Alberta River Water Quality Index-Metals (2009-2010). Retrieved from http://environment.gov.ab.ca/info/library/7718.pdf.

Alberta Environment. 2011a. Alberta River Basins. Retrieved from http://environment.alberta.ca/apps/basins/default.aspx.

Alberta Environment. 2011b. 2009-10 River Water Quality Index ratings for Nutrients. Retrieved from http://environment.alberta.ca/01282.html.

Alberta Environment. 2011c. 2009-10 River Water Quality Index ratings for Bacteria. Retrieved from http://environment.alberta.ca/01280.html.

Alberta Environment. 2011d. 2009-10 River Water Quality Index ratings for pesticides. Retrieved from http://environment.alberta.ca/01278.html.

AMEC Earth & Environmental. 2008. Study of erosion and sedimentation on the Milk River. Page 57. Submitted to Milk River Watershed Council Canada, Calgary, Alberta.

Anderson, A.-M. 2005. Overview of pesticide data in Alberta surface waters since 1995. Page 190 pp. Alberta Environment, Environmental Monitoring and Evaluation Branch, Edmonton, Alberta. Retrieved from http://environment.gov.ab.ca/info/library/7614.pdf.

McLean, D. G., and G. R. Beckstead. 1985. Long term effects of a river diversion on the regime of the Milk River. Page 21. Alberta Research Council and Alberta Department of Environment.

Milk River Watershed Council Canada. 2008. Milk River State of the Watershed Report. Page 155 pp. Milk River, AB. Retrieved from www.milkriverwatershedcouncil.ca.

Saffran, K. A. 1998. Impact of Verdigris Lake on the Milk River, 1997. Page 12. Alberta Environment, Edmonton, Alberta.

Scrimgeour, G. J., and S. Kendall. 2002. Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. Environmental Management 29:824-844.

Sosiak, A. 1997. Pakowki Lake water quality study. Page 61. Alberta Environment, Edmonton, AB.

3.7 North Saskatchewan

3.7.1 Introduction

The North Saskatchewan River (NSR) is one of Alberta's major river systems. It is a large river, originating in Banff National Park's Columbia Icefields where it receives meltwater from the Saskatchewan Glacier. The river flows east from the Rocky Mountains to Saskatchewan, and passes through the city of Edmonton, the only major city along the mainstem. From there it flows through primarily agricultural land to the Alberta/Saskatchewan border. The NSR in Alberta has a total length of about 1,000 km. Its basin area of about 55,000 km^2 is approximately 9% of the total area of the province.

About one-third of Albertans live in the NSR basin, and most of the population is concentrated in Edmonton and the adjacent Capital Region. Approximately 76,000 people live in the NSR basin upstream of Edmonton. There are 18 hamlets, 8 summer villages, 4 villages and 5 towns (including Devon, Drayton Valley, and Rocky Mountain House) scattered throughout the region. Most of the population is located within the Drayton Valley to Edmonton corridor, which is also similar to the distribution of livestock production in the basin. The NSR, which generates 5.5% of Alberta's water supply, is the main source of water in the basin, and treated municipal wastewater.

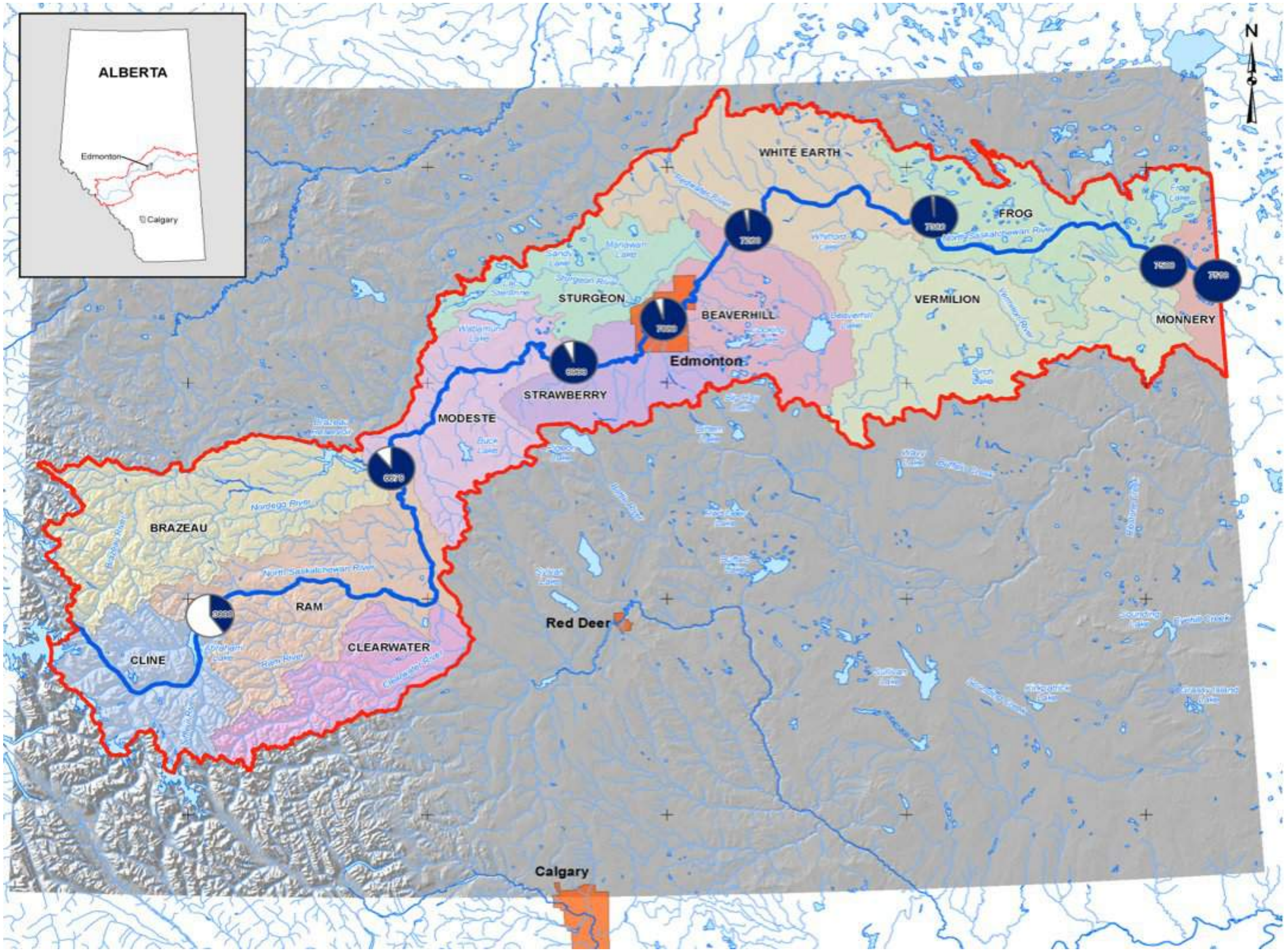

Figure 22: North Saskatchewan River Basin cumulative mean annual flow (million m³) from hydrologic regions. From Golder 2008.

Flows in the NSR largely reflect headwater hydrologic conditions and dam regulation. Within Alberta, six major tributaries flow into the NSR mainstem: the Brazeau, Nordegg, Ram, Clearwater, Sturgeon and Vermillion rivers. The headwaters (i.e., Brazeau, Ram, and Clearwater rivers) contribute 90% of the flow in the NSR. The low water yields in downstream areas reflect relatively low precipitation, higher temperature and evapotranspiration, and a very large land area that does not contribute flow to the NSR. Flows are regulated by two dams, both located in the upper reaches of the river. Flow regulation began in 1961 with the construction of the Brazeau Dam on the Brazeau River near its confluence with the NSR. The Bighorn Dam was constructed in 1972 on the mainstem of the NSR where it forms Abraham Lake. Typically, flows in the NSR are low during the winter and peak in June and July. They also increase in spring as a result of local runoff. Flows decline by late summer and autumn and remain stable during winter. Flow regulation and storage have altered seasonal patterns and resulted in somewhat lower summer flows and higher winter flows.

Water quality is rated as “good” by the Alberta River Water Quality Index. However, a number of human activities have the potential to contribute to NPS pollution in the North Saskatchewan Basin. The headwaters of the North Saskatchewan River remain sparsely populated and largely forested (Figure 23); resource extraction, recreation, and timber harvesting are prominent land uses in the region. As the river flows past the towns of Rocky Mountain House and Drayton Valley, agricultural land use increases and, by the time the river reaches Devon, the surrounding land use is predominantly agriculture. Oil and gas activity in the Drayton Valley area is notably high, and the density of pipelines is one of the highest in Alberta, with several intersecting the North Saskatchewan River. As the river makes its way towards Edmonton, human use and point and non-point influences increase. The towns of Rocky Mountain House, Drayton Valley, Devon, and other villages and towns have wastewater treatment plants and wastewater lagoons that either discharge their treated effluent directly into the NSR, or into its tributaries. The largest footprint is from the greater Edmonton area, where most of the population in the watershed is concentrated and where treated wastewater and stormwater enters the NSR. Industrial development occurs throughout the major basin (e.g., coal mining, oil and gas extraction).

Currently, 36 industrial facilities located in the Greater Capital Region discharge treated wastewater to the NSR. Of these, 12 discharge treated process wastewaters to the NSR regularly. Most of these industries produce and process oil, gas, and petrochemicals, or they are involved in advanced manufacturing. Industrial discharges make up about 6% of the estimated annual discharge volume to NSR.

3.7.2 Knowledge

Total suspended solids

Basin-scale (mainstem)

Flows typically peak in early summer (June), due to summer rains and glacial melt in the mountains. During these high flows, TSS can become very high and along with it, particulate phosphorus and certain total metals. Loadings to the river from tributaries account for just over half of the loads to the NRS at Lloydminster. The remainder is assumed to be primarily from bed and bank erosion (Shaw et al. 1994). Loadings to the NSR from tributaries, at any time of the year, is primarily from its headwaters (i.e., Brazeau, Ram, and Clearwater rivers), which mirrors the large (90%) flow contributions from this region. TSS concentrations follow this general trend; however,

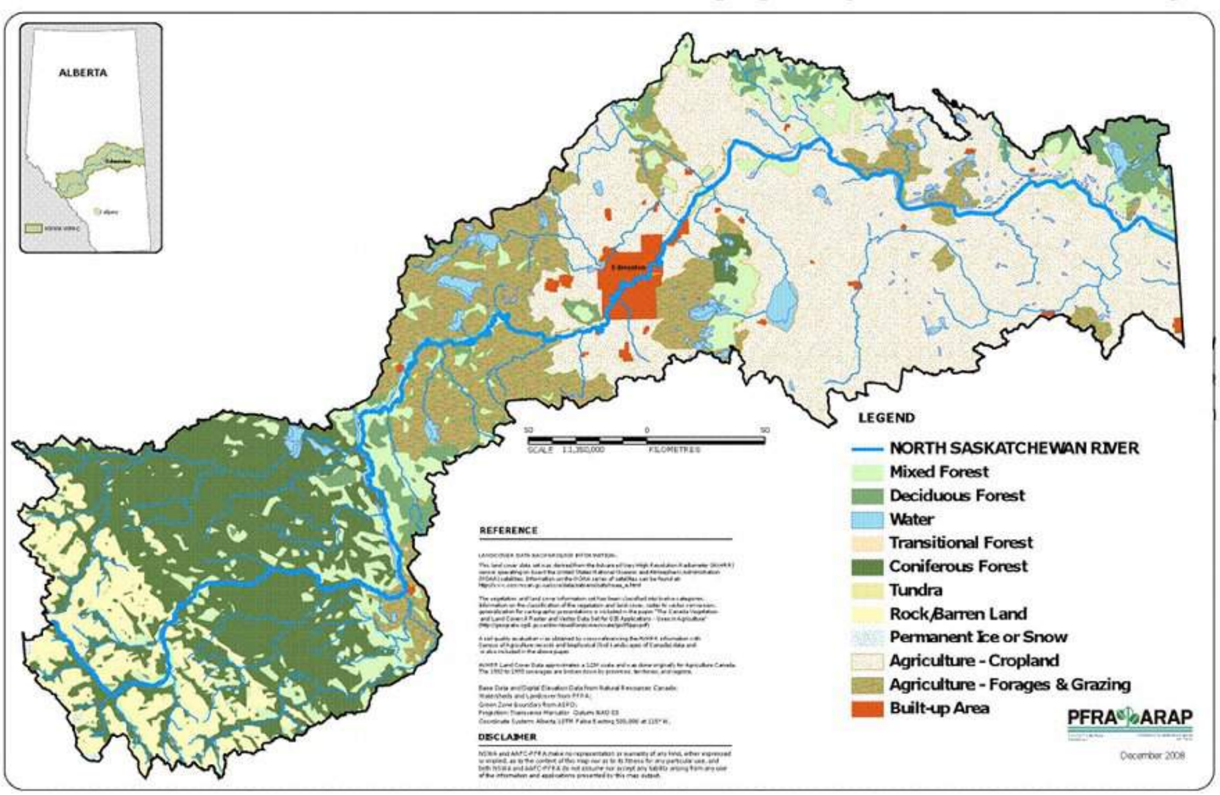

Figure 23: Land cover in the North Saskatchewan River.

a substantial increase is observed in downstream reaches (Figure 25). Causes for this increase are currently unknown, but a shift to more erodible material (e.g., clay-silt) may be responsible (Shaw et al. 1994).

In short, headwaters areas are clearly an important source of sediment to downstream reaches. What is not clear is what proportion of these loadings is the result of NPS pollution in these headwaters. Conversely, land use in the lower reaches of the NSR are highly unlikely to significantly affect the NSR mainstem simply because the NPS-portion of these contributions would be dwarfed by headwater loads (Figure 24).

Local-scale (tributaries and/or watersheds)

TSS in the tributaries of the NSR is closely linked to high flow events (Figure 26). During these events TSS can be orders of magnitude higher than during baseflow and upwards of 3,000 mg/L, depending on the tributary. As previously mentioned, headwater streams contribute most of the TSS to the NSR. The contribution of NPS pollution to streams and tributaries in the NSR headwaters is not well understood. The main human activities in the headwaters of the NSR that could contribute NPS pollution include resource extraction, forestry, and recreation.

The Alberta Wilderness Association (AWA 2007) monitored the impacts of recreational use from 2004 to 2006 in the Bighorn Wildland area, which is in the headwaters of the NSR just upstream of Nordegg. Their study found that current levels of recreational activity were causing severe environmental degradation. In summary, approximately 20% of total trail length was damaged along all trails. Furthermore, users tended increased trail density by breaking new trails; authors found more than one non-designated trail junction for every kilometre of designated trail. Perhaps most importantly, out of all water crossings, 93% had no formal crossing structures and 72% of crossings went through permanent water bodies. These types of studies are relatively rare in Alberta, but they consistently demonstrate the very high and increasing use of green spaces that are not designated as protected areas, largely by off-highway vehicles. These types of activities and impacts are highly likely occurring throughout the headwaters of the NSR, which as mentioned above, are critical to the water quality of the river. This use is contributing to TSS loads in streams where crossings occur. The impact of these loads on streams and tributaries is currently unknown but certainly merits further investigation.

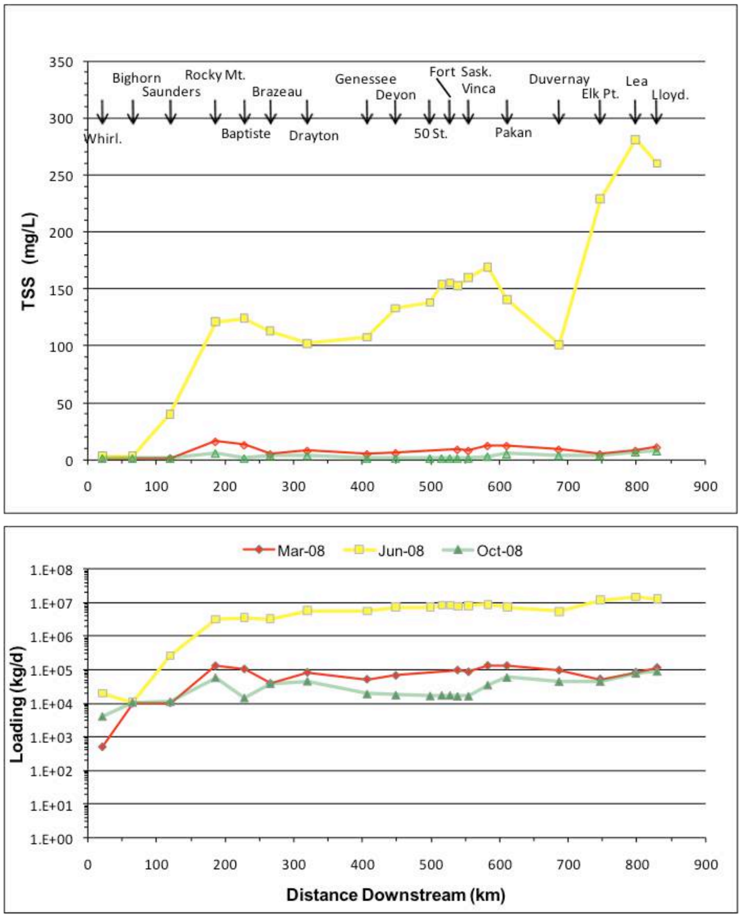

Figure 25: TSS concentrations and loadings in the mainstem NST during a 2008 synoptic survey. From Clearwater (2011).

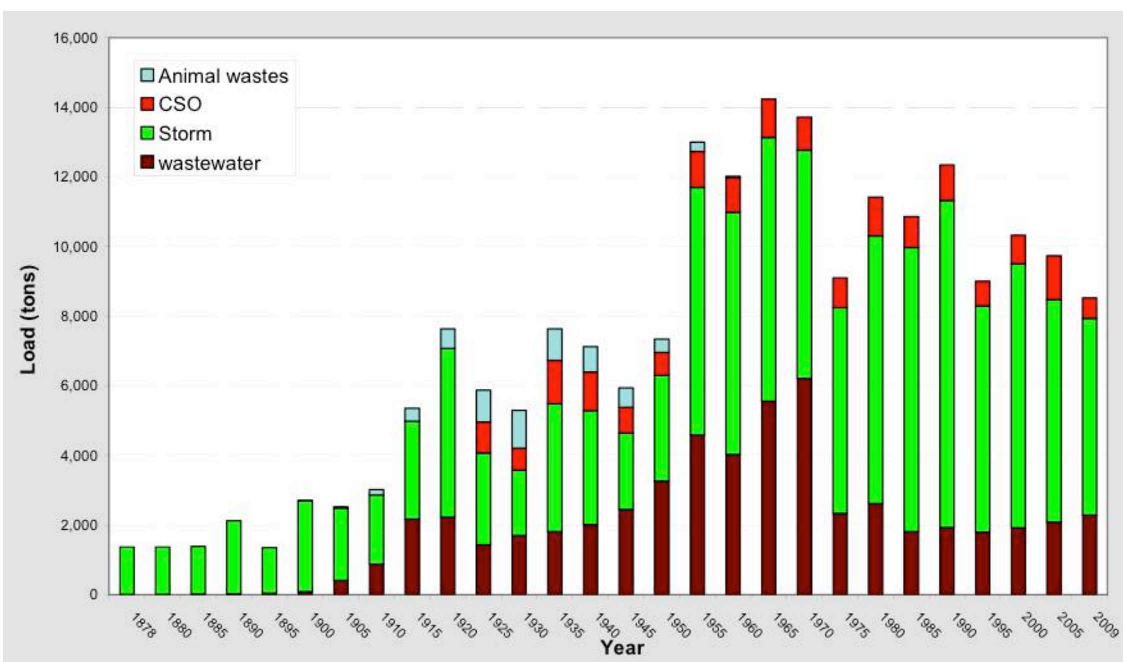

Figure 24: TSS load to the NSR from different sources in the City of Edmonton. From City of Edmonton (2010).

Very little knowledge exists on non-point source effects of logging in the NRS Basin. However, the effects of forestry activities on small streams have been studied in other basins, which are described at length in Sections 3.1 (Athabasca River Basin) and 3.9 (Peace River Basin). Much can be learned from these studies, which can be applied, albeit cautiously, to other regions in Alberta. In the NSR Basin, most logging activities occur in the foothills. Sites studied in the same natural region in the adjacent Athabasca River Basin (Tri-Creeks, Swan Hills) indicate that in watersheds with high logging density (e.g., greater than 50% of watershed logged has been proposed, Prepas et al. 2008), water yield and NPS pollution is likely to correspond. TSS loading, specifically, associated with road construction and use, in particular, when roads are poorly built and maintained (Jablonski 1986). A general trend of increasing impact to aquatic ecosystems with logging intensity indicates that the cumulative impacts of oil and gas development, recreation, and logging could be important, particularly at the small stream and tributary scale. These potential impacts require further study in the NSR headwaters.

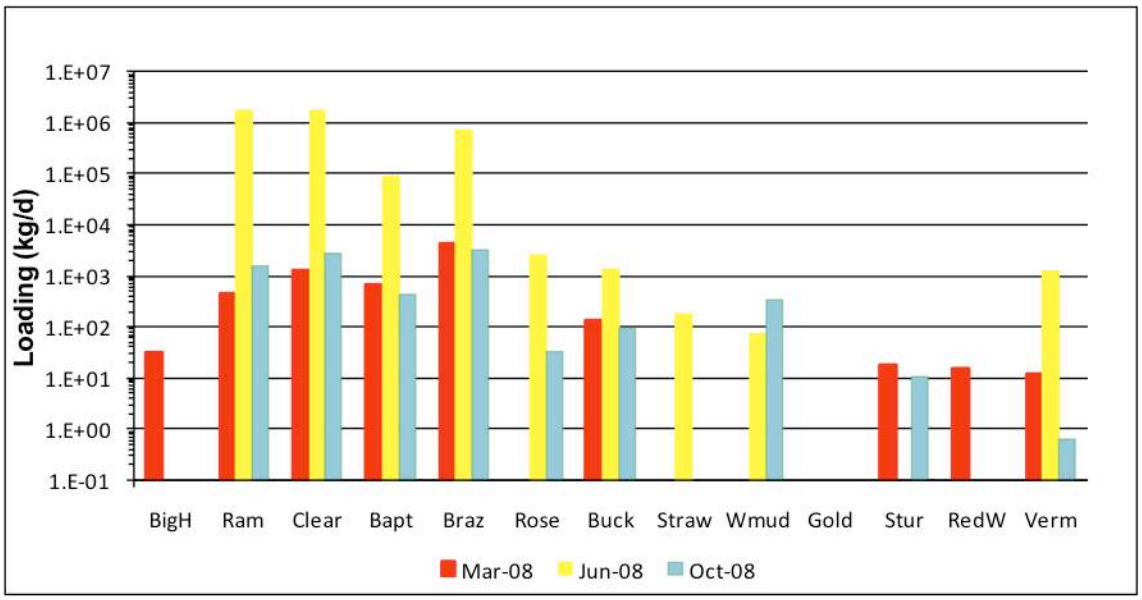

Figure 26: TSS loadings in the NSR tributaries. From Clearwater (2011).

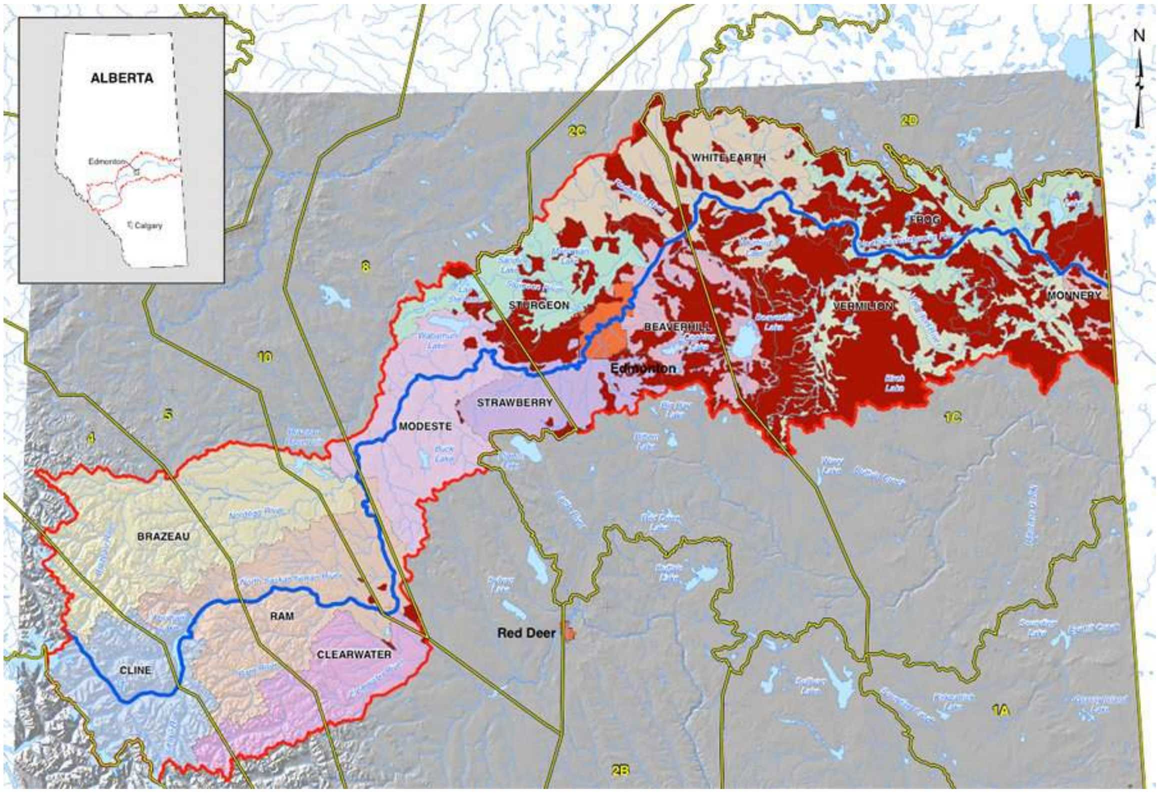

Figure 27: Non-contributing areas (red areas) in the North Saskatchewan River Basin. From Golder (2008)

The impact of various municipal and industrial discharges in the Heartland-Capital Region of Alberta is currently being extensively studied to support cumulative water planning for the planned increase in industrial development in the region. These studies show that stormwater contributes less than 1% of total TSS loads to the NSR, which is dwarfed by headwater contributions. However, stormwater loading is important because it is the largest human source of TSS in the region (Figure 26). Stormwater loading does appear to have a direct affect on the NSR mainstem, as evidenced by reductions in benthic invertebrate densities downstream from the Quesnell stormwater outfall (RL&L 2000). Smaller streams that receive stormwater (e.g., Whitemud Creek) are more likely to be affected by this disturbance. Data examining the effects of stormwater discharge on small streams appears to be lacking. However, it is generally well known that streams that receive stormwater runoff are typically the most vulnerable, typically exhibiting higher peak flows, evidence of scouring, and as a result, high concentrations of TSS (see Section 3.4). Whitemud Creek, which winds through south-central Edmonton, has greater low-flow loads of TSS, as compared to high-flow loads, than other tributaries (Figure 27), perhaps indicating the greater efficiency of water movement from impermeable surfaces to the creek during periods of low rainfall. Although speculative, urban stream studies, similar to the West Nose Creek study in Calgary, would shed light on the local effects of urban runoff on streams. As the city grows, it can be expected that the relative TSS loads from stormwater will increase, which has been documented over the past decades (City of Edmonton 2010). That] said, the City of Edmonton has adopted a progressive Stormwater Quality Control Strategy and is actively addressing the issue of stormwater constituent loads to the NSR.

As mentioned earlier, although agricultural activity likely does not significantly affect mainstem TSS concentrations in the NSR, some small streams are likely affected. In a provincial-scale study, TSS was found to be less affected by general agricultural activities and intensity than runoff potential and stream discharge patterns (Anderson et al. 1998b). However, TSS may be moving to streams in the NSR basin in certain sites, particularly at cattle wintering sites and where cattle have access to streams (Anderson 1998a, Scrimgeour and Kendall 2002). The extent of this potential impact on streams, basin-wide, is currently unknown.

NUTRIENTS

Basin-scale (mainstem)

Nutrient concentrations in the NSR largely reflect TSS loads from the headwaters and point-source contributions from the city of Edmonton. During low flow conditions, point sources account for the majority (>88%) of the loading of nutrients (total and dissolved phosphorus and nitrogen). During high-flow conditions in June, the headwaters contribute the greatest amount (>95%) of phosphorus to the NSR, due to its close relationship with TSS. Unlike TSS, the headwaters are not a major contributor of inorganic nitrogen (ammonia, nitrite and nitrate) to the river. However, all effluent load estimates agree that the major sources of ammonia and nitrate nitrogen are the municipal WWTPs.

Local-scale (tributaries)

Total phosphorus concentration in upper tributaries of the NSR (Baptiste, Clearwater, Ram, Nordegg, Brazeau) is low with periodic runoff events that elevate levels an order of magnitude above surface water quality guidelines. In tributaries in the central and lower portions of the NSR Basin, TP concentrations are typically consistently high (approximately six times greater than ASWQ guideline value of 0.05 mg/L). The dominant land use in these regions is agriculture. Province-wide, numerous studies have shown a positive relationship between nutrient export and agriculture and agricultural intensity in small streams (see Section 2.2). Thus, water quality in central and lower tributaries of the NSR likely reflect the influence of agriculture. The impact of agriculture in these tributaries has little, if any, impact on the NSR mainstem as these tributaries contribute little flow to the NSR and vast expanses of land in these central and lower sub-watersheds are non-contributing regions (Figure 27).

Urban influence on nutrient loads to tributaries that pass through the city of Edmonton is apparent, particularly in the winter. A 2008 synoptic study conducted by AENV determined that the highest concentration of TP observed in any of the NSR tributaries in winter (March) was in urban tributaries (0.571 mg/L in Goldbar Creek, 0.125 in Whitemud Creek). As a result of high concentrations, Goldbar Creek was one of the three tributaries in the NSR basin (along with the Clearwater and Brazeau rivers) that contributed most to TP loading to the NSR. It is clear that urban streams are affected by NPS nutrient contributions.

SALTS

Sodium chloride is the most commonly used road salt in Alberta. Stormwater contributes substantial loads of chloride to the NSR, particularly during spring runoff when road salt applied to the road network is washed away (Figure 28). As a result, stormwater contributes to elevating the concentration of chloride in the NSR by over two times (AECOM & Anderson 2011). Also, chloride concentrations are almost two orders of magnitude higher in spring and summer in streams that receive urban runoff (Whitemud and Goldbar creeks), compared to headwater streams (Clearwater 2011), reflecting the important impact of urbanization on aquatic ecosystems.

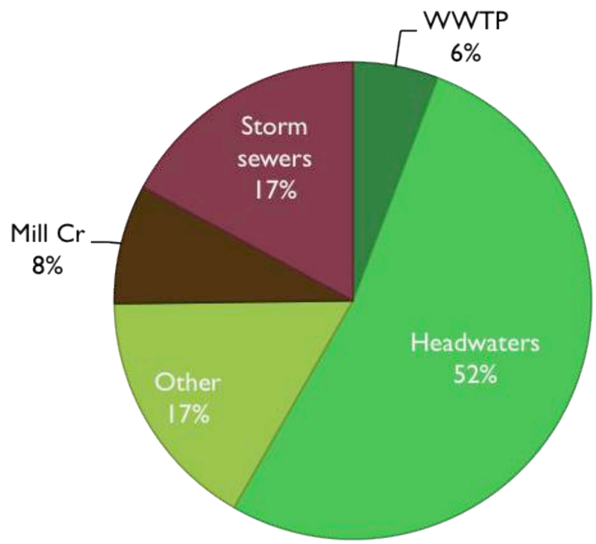

Figure 28: Spring 2007 dissolved chloride load to the Industrial Heartland – Capital Region water management reach of the NSR. Adapted from AECOM & Anderson (2011).

METALS

Metal concentrations in the NSR are generally highly related to TSS. Shaw et al. (1994) found that 10 common trace metals were significantly correlated with suspended solids. These included aluminum, arsenic, barium, chromium, copper, iron, manganese, nickel, vanadium and zinc. Highly turbid urban creeks (Goldbar and Whitemud) generally contained high concentrations of metals. Distinct increases in metal concentrations, such as aluminum, were evident downstream of Edmonton, corresponding to discharges from water treatment plants, waste water treatment plants, stormwater and turbid streams such as Goldbar Creek (8700 mg/L in March) and Whitemud Creek (1520 mg/L March) (Clearwater 2011). Similarly to TSS, urban runoff is affecting metal concentrations in small urban streams, and, to a lesser extent, the NSR itself.

PESTICIDES

Urban runoff is one of the most important sources of pesticides in the NSR Basin, impacting both the mainstem and smaller urban streams. Pesticide detections, non-compliance and diversity was more numerous downstream of Edmonton (AECOM & Anderson 2011, Figure 29). In the NSR Basin, two urban streams (Whitemud and Goldbar creeks) had the greatest number and concentration of detectable herbicides (Figure 9). In addition, three exceedances of the CCME guidelines also occurred in these creeks for Dicamba, indicating possible toxic risk in small urban streams.

At the small watershed-scale, in agricultural watersheds part of the AESA program pesticide detection frequency, total pesticide concentration, and the total number of compounds detected increased significantly as agricultural intensity increased from low to high. Detections of pesticides in central and lower tributaries of the NSR likely reflect the influence of agriculture. Agriculture is likely contributing to the detection of pesticides in the NSR mainstem downstream of Edmonton.

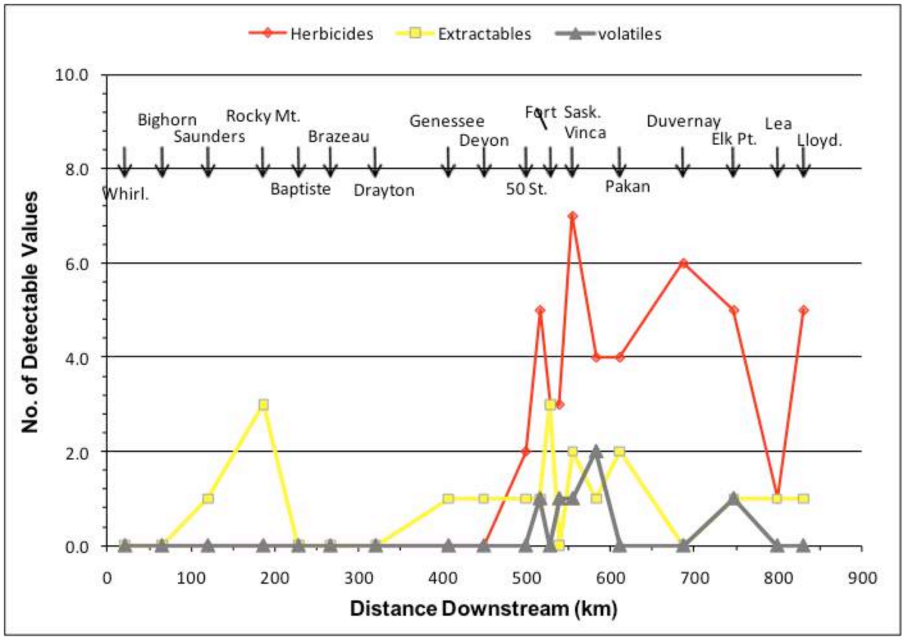

Figure 29: Number of detectable volatiles, extractables and pesticides in the NSR during the 2008 synoptic survey. From Clearwater 2011.

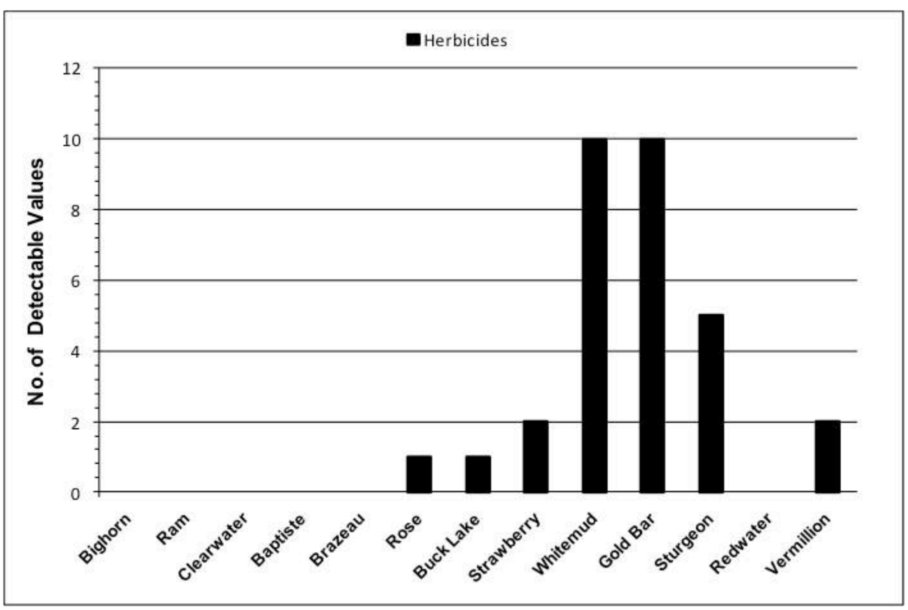

Figure 30: Number of detectable herbicides in the NSR tributaries. From Clearwater 2011.

PATHOGENS

Fecal coliform bacteria counts in the NSR largely reflect TSS loads from the headwaters and contributions from the City of Edmonton. Since recent wastewater treatment plant upgrades, stormwater and combined stormwater contribute about half of the total annual load of fecal coliforms from the Industrial Heartland – Capital Region area (Figure 31). This stormwater load is partly responsible for a dramatic increase in fecal coliforms in the NSR at Edmonton.

Cryptosporidium and *Giardia* in the NSR Basin have been primarily linked to agriculture. Both parasites increase with total livestock density in agricultural streams. Largely because of high concentrations (as opposed to high water yields), streams draining agricultural lands contribute the highest loads of parasites to the NSR (Mitchel 2002).

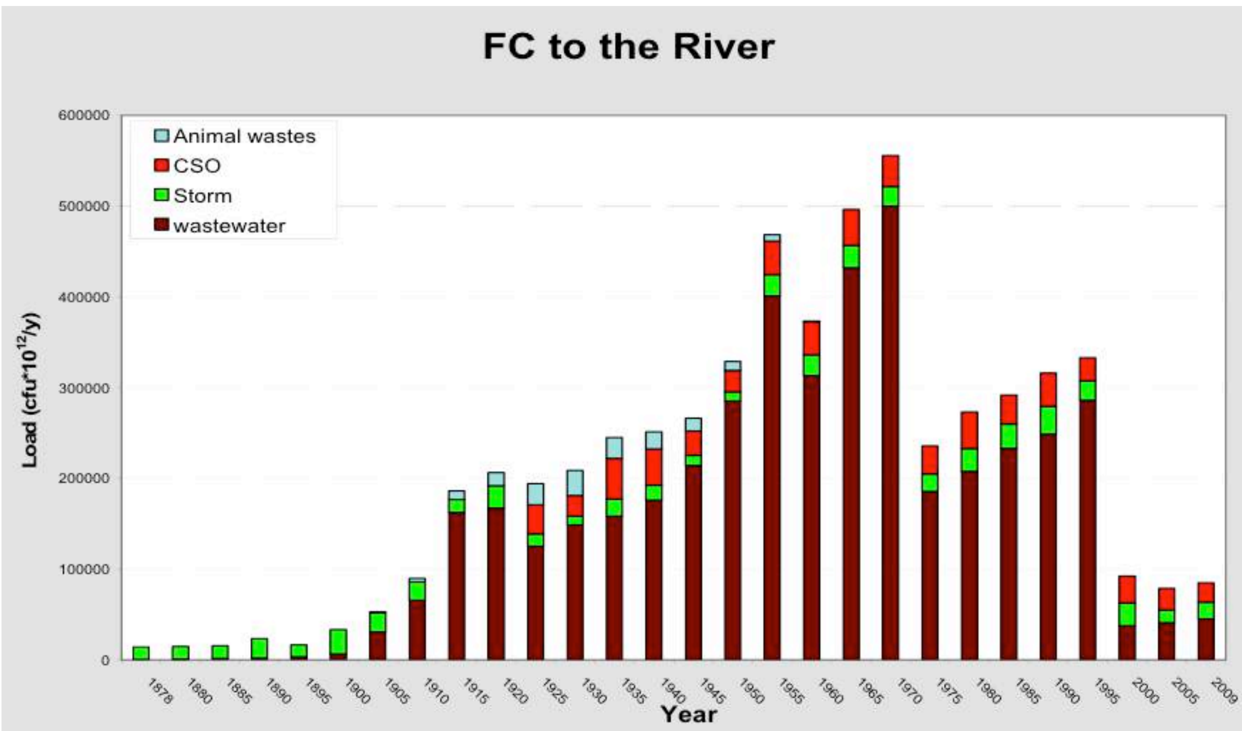

Figure 31: Loading of fecal coliforms to the NSR from the City of Edmonton. From City of Edmonton (2010).

3.7.3 Data

LONG-TERM RIVER NETWORK MONITORING PROGRAM

AENV's mainstem sampling on the NSR is limited to LTRN sites at Rocky Mountain House, Devon, and Pakan. Sampling is done monthly (approximately 12 samples per year) and does not depend on flow conditions. Data are available from 1988 to present, except at Rocky Mountain House where data are only available from 2004 on. In 2008, the LTRN sites underwent enhanced sampling for the same suite of water quality parameters as the synoptic study with *Giardia* and *Crypto* as well. This data collection is to support water quality modelling at different flow regimes; samples are collected twice per week during high flow periods and less frequently during lower flow periods.

Synoptic Surveys

In 2008, AENV conducted three synoptic surveys on the NSR: in March representing winter conditions, in June (spring conditions) and in October (fall conditions). The three synoptic surveys were conducted at 67 locations along the NSR, and included mainstem, tributaries, municipal, and industrial effluent locations. A broad suite of water quality variables was monitored including organic, inorganic and pathogenic parameters. Synoptic surveys were also conducted in the 1980s.

Alberta Environmentally Sustainable Agriculture (AESA)

As part of the AESA Water Quality Monitoring Project, the most extensive monitoring and study of the tributaries flowing into the NSR mainstem, focusing primarily on streams upstream of Edmonton, to date was completed. The AESA Soil and Water Quality Monitoring Projects were developed to address recommendations from the Canada-Alberta Environmentally Sustainable Agriculture (CAESA) Agreement. Under the CAESA Agreement, scientific and producer-led studies were undertaken to broadly assess the impact of agriculture on the environment. It included the first comprehensive assessment of the industry's impact on water quality in Alberta. There are up to 12 years of continuous water quality data for streams sampled under the CAESA and AESA Stream Surveys (1995 to 2006) and eight years of data for the streams sampled under the AESA Stream Survey alone (1999 to 2006). Within the NSRB, Rose, Tomahawk, Stretton, and Strawberry creeks were all sampled as part of the CAESA and AESA program and therefore there is 12 years of continuous data for these streams. Stream water samples were analyzed for the following parameters: nutrients (total and dissolved forms of nitrogen and phosphorus); fecal bacteria (fecal coliforms and *E. coli*); pesticides (herbicides, insecticides, and fungicides); and pH, temperature, non-filterable residue (NFR), total dissolved solids, and conductivity.

City of Edmonton Monitoring Program

Since 1991, the City of Edmonton has completed an annual Environmental Monitoring Program. The water quality surveys have evolved to transect sampling and now to intake sampling of the NSR as it flows through Edmonton and past Fort Saskatchewan. The program has also expanded to include sampling of NSR tributaries that flow through the city. The tributaries are sampled twice a year at their confluence with the NSR, once during spring runoff and once during a summer precipitation event. In addition to the daily regulatory sampling requirements of the Gold Bar and Capital Region Wastewater Treatment Plants, extended sampling is completed on their effluents on the same days the tributaries are sampled. The City of Edmonton also maintains continuous monitoring stations located at the four largest storm sewer outfalls (30th Avenue, Groat Road, Quesnell and Kennedale) and the two largest combined sewer outfalls (i.e., Rat Creek and Capilano). In addition, stormwater management facilities (wetlands and wet ponds) have been monitored for their water quality, and are now monitored on an inlet/outlet basis in an attempt to quantify treatment efficiency. Parameters monitored most frequently include biochemical oxygen demand, TSS, chloride, total Kjeldahl nitrogen, ammonia, nitrate+nitrite, total phosphorus, and *E. coli*. Other less frequently monitored parameters include metals and hardness, pesticides, pathogens, and volatile organic compounds.

Environment Canada

Environment Canada operates two water quality monitoring stations on the NSR: one at Whirlpool Point in the headwaters and a site at the Alberta-Saskatchewan Border (PPWB site). Data are available from the early 1980s on. A similar suite of parameters is sampled with a similar frequency of sampling (monthly) as at the LTRN sites.

3.7.4 Synthesis

The water quality of the NSR mainstem is largely influenced by the headwaters and urban and industrial activities in the Greater Capital Region. There is currently little documentation of the cumulative land uses and pressures in the headwaters, although recreation, oil and gas, and forestry are known to be important. What is also lacking is an understanding of the effect of these land uses and relative partitioning of NPS pollution loads in the headwater regions of the basin. This is due to poor water quality data in these areas.

There is a good understanding of the effects of agricultural NPS pollution on streams in the NSR, relative point and non-point contributions for major contaminants to the mainstem, and good mainstem water quality data and synthesis. Small watersheds in the NSR basin are being impacted by agricultural and urban NPS pollution. Watersheds affected by urbanization, relative to other small watersheds in the Basin, export relatively important NPS pollutant loads for TSS, metals, salts, pesticides, and fecal coliforms. At this time, it appears that urbanization is the greatest contributor of NPS pollution to the NSR mainstem. NPS pollution is occurring at the tributary/stream scale, which is highly important for the overall health of the NSR Basin.

3.7.5 References

AECOM and A.M. Anderson. 2011 (draft). Synthesis of recent knowledge on water quality, sediment quality and non-fish biota in the North Saskatchewan River, with special emphasis on the Industrial Heartland – Capital Region Water Management Framework reach. Draft report submitted to Alberta Environment. 88 pp.

Alberta Wilderness Association (AWA). 2007. The Bighorn Wildland recreational trail monitoring project: An interim research summary from 2004-2006. 76 pp.

Anderson, A.-M., D.O. Trew, R.D. Neilson, N.S. MacAlpine and R. Borg. 1998a. Impacts of agriculture on surface water quality in Alberta Part 1: Haynes Creek Study. 198 pp.

Anderson, A.-M., D. O. Trew, R. D. Neilson, N. D. MacAlpine, and R. Borg. 1998. Impacts of agriculture on surface water quality in Alberta. Part II: Provincial stream surveys. Page 152 pp. Alberta Environmental Protection and Alberta Agriculture, Food and Rural Development. Retrieved from http://www.environment.gov.ab.ca/info/library/8099.pdf.

City of Edmonton. 2010. Historical loading to the North Saskatchewan River from Edmonton (1878-2009). Edmonton, AB. 79 pp.

Clearwater Environmental Consultants. 2011 (draft). Overview of ambient and effluent water quality in the North Saskatchewan River based on 2008 data. Report prepared for Alberta Environment. Edmonton, AB. 602 pp.

Golder. 2008. Water supply assessment for the North Saskatchewan River Basin. Report submitted to the North Saskatchewan Watershed Alliance. Edmonton, AB. 37 pp.

Jablonski, P. 1986. Tri-Creeks: Documentation of Timber Harvesting Operation From a Watershed Management Perspective. Alberta Energy and Natural Resources, Lands and Forests Branch.

Mitchell, P. 2002. Overview: Relationship between Beef Production and Waterborne Parasites (*Crytopsporidium* and *Giardia spp*.) in the North Saskatchewan River Basin Alberta, Canada. Conservation and Development Branch, Alberta Agriculture, Food and Rural Development, Summary Report, 24 pages.

Prepas, E.E., J.M. Burke, G. Putz and D.W. Smith. 2008. Dissolved and particulate phosphorus concentration and export patterns in headwater streams draining Boreal Plain watersheds one year after experimental forest harvest and post-harvest silvicultural activities. Journal of Environmental Engineering and Science 7: S63-S77.

RL&L (RL&L Environmental Services Ltd.) 2000 Influence of discharges from the Quesnell storm sewer on the distribution of benthic macroinvertebrates in the North Saskatchewan River. Edmonton, AB. 43 pp.

Scrimgeour, G. J., and S. Kendall. 2002. Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. Environmental Management 29:824-844.

Shaw, R.D., P.A. Mitchell and A.M. Anderson. 1994. Water quality of the North Saskatchewan River in Alberta. Prepared by Shaw Environmental Consulting and Alberta Environmental Protection.

3.8 Oldman

3.8.1 Introduction

The Oldman River basin covers 23,000 km^2 in Alberta and 2,100 km^2 in Montana (State of the Watershed Team 2010). The Oldman River originates from an unnamed alpine lake (elevation 1791 m) on the eastern slopes of the Rocky Mountains in southern Alberta. From the forested slopes of the mountains, the Oldman River flows through the foothills to the plains and prairie grasslands. Headwaters come from the Oldman River, Castle River, and Crowsnest River, which merge at the Oldman Reservoir. Other main tributaries include Beaver Creek, Pincher Creek, Willow Creek, Belly River, St Mary's River, and the Little Bow River. The Oldman River eventually joins the Bow River to become the South Saskatchewan River (elevation 700 m).

Precipitation varies across the Oldman Basin. Headwater areas in the Rocky Mountains can get over 1000 mm/year (Silins et al. 2009b). The foothills portion of the basin receives roughly 600 mm/year, while the eastern plains portion of the basin receives 350 mm/year (Hebben 2007). Flows in the Oldman River reflect headwater snowmelt and summer precipitation throughout the basin, which combine to cause peak flows in June. Roughly 60% of annual natural flows occur between mid-May and mid-July, with lower flows from late July to October (Hebben 2007). Flows in the River vary greatly from one year to the next, depending on snow pack, but particularly summer storm events. For example, summer flows at Lethbridge ranged from a high of 1554 m^3/sec (in 2002) to more typical summer flows of 50-200 m^3/sec. Mountain sub-basin headwaters (Crowsnest, Oldman, and Castle Rivers) contribute 36% of the flow into the Oldman River mainstem , the Belly and Waterton Rivers provide 32%, the St. Mary River contributes 25%, and other tributaries, such as Pincher Creek, Willow Creek, and the little Bow River contribute 7% (State of the Watershed Team 2010).

The Oldman River Basin has a population of 160,000, roughly half of whom live in Lethbridge (Saffran 2005). Major land uses (in addition to urban) in the river basin include forestry, recreation and oil and gas extraction in the headwaters, and agriculture in the mid to lower parts of the basin. In this region of the basin, irrigated crop land and high densities of livestock operations make this basin one of the most intensive agricultural areas in Canada.

Agriculture covers 57.4% of the land in the Oldman basin. Most of this is cereal or canola crops. 20% of the cultivated land is irrigated. 30% of the watershed has soil erosion risk of moderate or more. Grasslands cover 9.4%, coniferous forests cover 10.5%, deciduous forests cover 5.88%, and native prairie covers 16.79% (State of the Watershed Team 2010).

In the mountains sub-basins, the dominant land cover is forest, with about 25% of the land altered by humans. Most of the modified landscape (22% of total land cover) is agriculture (State of the Watershed Team 2010). Soil erosion risk is negligible over most of these sub-basins. Forest harvesting, grazing, fire, and pine beetle potentially have the largest effect on the sub-basins. Removing trees from the landscape increases the amount of surface runoff entering streams and the load of sediments and nutrients. There is also high recreational camping usage, but it is difficult to quantify the effects on watershed. There was extensive coal mining from 1900-1960 in the Crowsnest sub-basin. The Crowsnest River runs through five small communities (Coleman, Blairmore, Frank, Bellevue, Hillcrest) that include extensive low density acreage development and one golf course. The Oldman and Castle sub-basins have middle and lower reaches dominated by extensive grazing, cow/calf operations, and a limited amount of cropland.

The foothills sub-basins have 60% cover of forests and native grasslands. There are negligible soil erosion risks over most of the foothills sub-basins. Agriculture, urban, infrastructure, and recreation cover 40% of the land area. The southern tributary sub-basins have the highest levels of development: land use affects 69% of the land, with agriculture covering 66% of the land. Soil erosion risk is low to moderate throughout these sub-basins. In the prairie sub-basins, land use activities cover 73% of the basin. Agriculture is dominant, 12% of which is irrigated agriculture, which tends to be more intensive than dryland agriculture (State of the Watershed Team 2010).

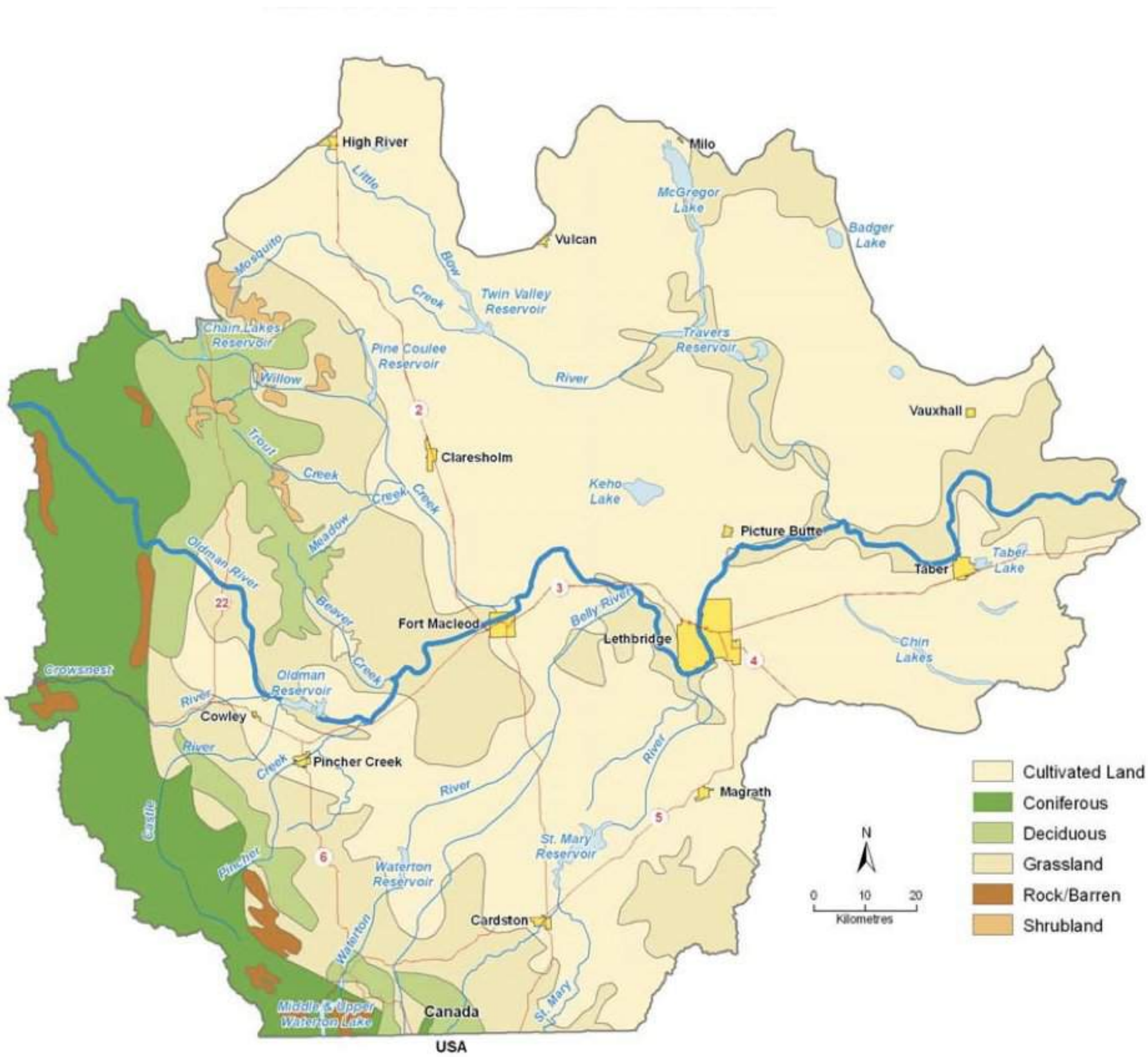

Figure 32: Land cover in the Oldman River Basin (State of the Watershed Team 2010)

3.8.2 Knowledge

The water quality of the Oldman River is very good in the headwaters, which are mostly forested, and progressively degrades downstream (Table 3). Water quality in tributaries and agricultural drains (return flows) is poorer than in the mainstem. The streams listed in Table 3 drain agricultural and urban land.

Table 3: Water quality index results, Oldman River and tributaries, 1998-2002. Adapted from Koning et al. 2006.

Location	Period of Record		Pesticide Index	
	Average	Rating	Average	Rating
Mainstem (us to ds sites)				
Near Brocket	94	Good	95	Excellent
Highway 3 bridge	94	Good	84	Good
SW of Diamond City	79	Fair	70	Fair
At Hwy 845	79	Fair	64	Marginal
At Hwy 36 bridge	86	Good	74	Fair
Tributaries & Drains				
Beaver Cr. At Hwy 785	73	Fair	89	Good
Six Mile Coulee spillway	59	Marginal	39	Poor
Piyami Drain	56	Marginal	58	Marginal
Battersea Drain	62	Marginal	47	Marginal
Little Bow River nr mouth	78	Fair	50	Marginal

Total suspended solids

Basin-scale (mainstem)

Total suspended solids have been measured in the mainstem of the Oldman River since 1971. Generally, TSS concentrations increase from upstream to downstream in the watershed, and increase during periods of high flow. Water control structures along the mainstem help keep concentrations low by allowing settling of TSS. Long-term concentrations of TSS through most of the mainstem are low but, similarly to flow, can vary significantly from year to year. TSS concentrations more than double median values occur 10% to 15% of the time, typically during flood events. 2005 was an especially high flow year, and TSS concentrations in the mainstem frequently exceeded 100% of median concentration throughout the mainstem (State of the Watershed Team 2010). In general, TSS is not a major concern to the mainstem Oldman River.

Local-scale (tributaries)

TSS measurements have been sporadic in the major tributaries of the Oldman. The 2010 State of the Watershed Report notes stable TSS concentrations in most major tributaries with data.

Mountain Tributaries

Fast-moving mountain tributaries have a naturally high capacity to carry suspended solids. Loadings from the Castle and Crowsnest rivers were more than 1000 t/year in the early 1990s, but were substantially lower in 1998 and 2001 (State of the Watershed Team 2010). Median concentrations of TSS are similar among the Castle, Crowsnest, and Oldman Rivers just upstream of the Oldman Reservoir, ranging from 0.4 to 19 mg/L from 1991 to 1996 (Mitchell 2001). About 97% of the TSS load of these rivers is deposited and retained in the Oldman Reservoir as bottom sediment, and therefore median TSS concentration at the outflow of the Oldman Reservoir is low (Mitchell 2001).

Commercial logging has been active in the mountain sub-basins since the 1960s. The C5 Management Plan calls for an important amount of clear-cutting in these areas over the next 15 years (Government of Alberta 2010). Very little knowledge exists on non-point source effects of logging in the Basin. However, the effects of forestry activities on small streams have been studied in other basins, which are described at length in Sections 3.1 (Athabasca R. Basin) and 3.9 (Peace R. Basin). Sites studied in the same natural region in the adjacent Athabasca River Basin (Tri-Creeks, Swan Hills) indicate that in watersheds that have high logging density (e.g., greater than 50% of watershed logged has been proposed, Prepas et al. 2008), water yield and NPS pollution is likely to respond. TSS loading, specifically, associated with road construction and use, in particular, when roads are poorly built and maintained (Nip 1991). We expect that logging may have localized effects in streams in clearcut catchments lasting several years until forest regeneration begins.

Forest fires are natural sources of suspended sediments to small tributary creeks of the Castle and Crowsnest rivers (Silins et al. 2009b). Sediment yields to tributaries, typically 0.3 kg/ha/day, increased dramatically to roughly 2.1 kg/ha/day for at least four years following burns (Silins et al. 2009b). The increases occurred in both salvage logged and non-salvage logged sites (Silins et al. 2009b). Therefore, we think that salvage logging itself is not a major non-point source of TSS pollution in these tributaries.

Recreation has the potential to affect TSS in streams, primarily through un-structured crossings (see Section 3.7 – North Saskatchewan River Basin). Recreational use has been monitored in the headwaters of the Oldman River using remote cameras (Duke and Quinn 2009). This study shows that motor vehicles, by far, are the largest use of trails. These vehicles are typically associated with high-impact use.

A general trend of increasing impact to aquatic ecosystems with use intensity indicates that the cumulative impacts of oil and gas development, recreation and logging could be significant, particularly at the small stream and tributary scale. These potential impacts require further study in the Oldman headwaters. Luckily, because of the Oldman Reservoir, sediment loads are unlikely to reach or impact the mainstem of the Oldman River.

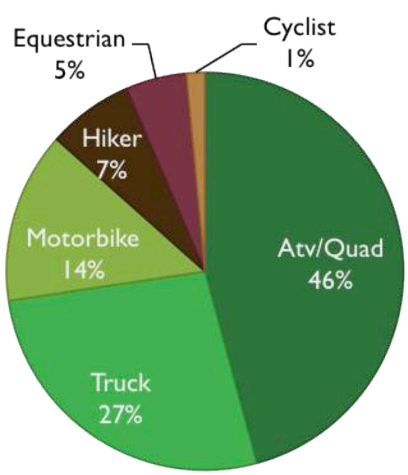

Figure 33: Breakdown of human uses in the Livingstone Range. Adapted from Duke and Quinn (2009).

Foothills Tributaries

TSS loading information is available for two sites on Willow Creek, one site on Beaver Creek, and one site on Pincher Creek. Willow Creek had higher loadings and concentrations of TSS than elsewhere in the foothills sub-basins. Overall, loading rates in 1991, 2000, and 2004 ranged from negligible to over 8000 t/year (State of the Watershed Team 2010). The soil erodibility risk rises from low or negligible up to moderate in areas suitable for agriculture, most of which are found in the Willow Creek sub-basin. Available information does not allow separation into natural vs. non-point source TSS loads for these areas, although we suspect human activities, such as agriculture, do exacerbate soil erosion.

Southern Tributaries

In the Southern Tributary sub-basins, the Belly River and St. Mary River regularly had loading rates over 6000 t/year in the 1990s. In 2005 the St Mary River loading was roughly 8000 t/year, while the Belly River had negligible loading of TSS (State of the Watershed Team 2010). Generally all of the above mentioned tributaries meet TSS concentration objectives for TSS. Urban runoff at Cardston contributed significant TSS loads to Lee Creek when it was measured after large storm events of 2005 (State of the Watershed Team 2010). Again, however, concentrations did not exceed guidelines. Generally, then, NPS pollution from TSS concerns are minimal in these tributaries.

Prairies Tributaries

Control structures within the sub-basin generally dampen the impact of large flood on TSS concentrations in surface waters. Loading data exist for one site on Mosquito Creek and two sites on the Little Bow River. TSS loading was over 3000 t/year at all three sites during a high flow year, 1998, and was negligible in 2001 (State of the Watershed Team 2010). There have been trends of increasing TSS concentrations along the Little Bow River. This tributary has higher than natural flows due to diversion from the Highwood River and higher flow rates cause sediments to remain suspended for longer. Large portions of the sub-basin have highly or severely erodible soils and are dominated by cultivated land. Despite the soil conservation practices that have been implemented by agriculture, land use activities are likely to exacerbate natural erosion rates.

Phosphorus

Basin-scale (mainstem)

The mainstem of the Oldman River commonly exceeded total phosphorus water quality guidelines from 1970 through 1990, but water quality has improved greatly since then (State of the Watershed Team 2010). The Alberta River Water Quality Index for nutrients ranked both long-term monitoring stations on the Oldman River as good in 2009 and 2010 (Alberta Environment 2011). Improvements can be related to the improvements to the Lethbridge and Fort Macleod waste water treatment plants (WWTPs), as well as completion of the Oldman Dam, which permits greater water flow during late summer and fall thereby diluting phosphorus concentrations. During a June 2005 flood event, a four-day high flow synoptic survey showed water quality problems (exceeded guidelines) along most of the mainstem for total phosphorus (Kromrey et al. in press), likely associated with suspended sediment.

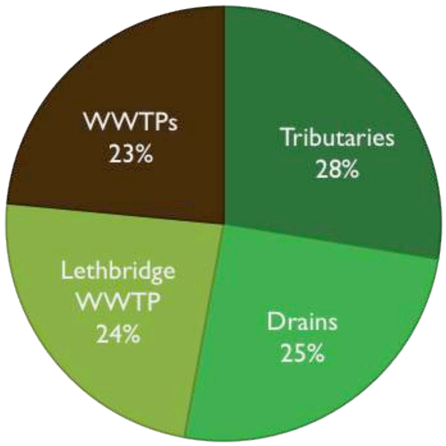

Figure 34: Total phosphorus loading to the Oldman River in September 2000 (Oldman Watershed Council 2005). Note that the Fort Macleod WWTP has been upgraded since 2000, thus the WWTP contribution is likely smaller at present.

At the time of writing this report, the best available loading data comes from a synoptic loading study completed by the Oldman River Water Quality Initiative project in September 2000. This September 2000 survey determined that the total phosphorus loading rate to the Oldman River was 63 kg/day (Saffran 2005). Wastewater treatment plants contributed 47% of the loads (Figure 34); since the Fort Macleod WWTP has been improved since then, point source loading has likely decreased. Tributaries were the dominant contributor of total phosphorus to the Oldman River. The Belly River (which also drains the Waterton River) and St. Mary River contributed the most, 13% and 8%, respectively (Saffran 2005). The Belly, Waterton, and St. Mary rivers regularly contribute roughly half of the water flow to the mainstem (State of the Watershed Team 2010). The catchments of these three rivers comprise the Southern Tributaries sub-basin, an area where 66% of the land area is used for agricultural activities (State of the Watershed Team 2010). Most (48%) is cropland or summer fallowed and 18% is pasture. Some of the cropland is intensive, irrigated cropland. We can speculate that, of the total non-point loads, much of the phosphorus loading into these tributaries is likely from agricultural lands. Less than 1% of the land is disturbed by recreational activities, while infrastructure, roads and cutlines cover just 1.7% (State of the Watershed Team 2010).

The 25% of the total phosphorus load coming from drains (Figure 34) likely also has some non-point agricultural influence. 10% of the total phosphorus load into the Oldman River was attributed to the Piyami Drain, which drains agricultural areas in the Picture Butte area (Saffran 2005). Within the Oldman Basin, irrigation return flows typically have higher concentrations of phosphorus than their source water (Little et al. 2010), indicating agricultural influence. Particulate phosphorus is notably higher in return flows of the St. Mary and Taber irrigation districts, while dissolved reactive phosphorus is higher in return flows of the Lethbridge Northern and United irrigation districts (Little et al. 2010). Dissolved forms are most likely related to fertilizers. One drain, Six Mile Coulee, receives agricultural runoff as well as urban runoff from Lethbridge.

Stormwater runoff from urban centres is also a source of total phosphorus to the Oldman River. Flow and concentration data collected by the ORWQI in 2001 and 2002 show that total phosphorus is loaded into the Oldman River mainstem from Lethbridge stormwater drains at a rate of 0.94 t/year, and more than half of this is inorganic phosphorus (Pokhrel et al. 2011). Urban use of fertilizers on lawns and park areas is the most likely explanation for the inorganic phosphorus loading in stormwater.

A second synoptic survey was conducted in the Oldman River during a four-day flood event in June 2005 (Knapp et al., in preparation). This survey showed that flow and pollutant loadings from the Foothills tributaries became proportionally much more important than they were during the low flow synoptic survey in 2000. Willow Creek especially was contributing roughly half of the flow and total phosphorus load during the flood event. Potential explanations will be discussed below.

Local-scale (tributaries)

Recent TP exceedances have been noted in some very small tributaries in the Foothills sub-basins, rarely in the Southern Tributaries sub-basins (although there is less data available in those areas), and most often in the Prairie sub-basins (State of the Watershed Team 2010). The Alberta surface water quality guideline for TP is 0.05 mg/L.

Mountain sub-basins

Nutrient concentrations in the headwater tributaries (Oldman River, Castle River, and Crowsnest River,) are low and indicative of low-productivity systems (Howery 2010). The median total phosphorus concentrations for these three streams were very low (between 10 and 15.0 μg/L). Nutrient concentration was relatively similar between headwater and downstream sampling sites in all three sub-basins; however, total nitrogen and phosphorus production (yields) increased linearly with distance downstream in the Oldman and the Castle River sub-basins. The lower sites in the Oldman and Castle sub-basin yielded approximately six times more nutrients than headwater sites (Howery 2010). The author attributed increased nutrient production to a shift from primarily forested to mixed agricultural use. Although eutrophication is not occurring in these headwater streams, this study provides evidence that nutrient contamination from NPS sources is occurring as upstream as the headwaters in the Oldman River Basin.

In parallel with TSS, the potential effects of increased logging in the mountain sub-basins are likely short-lived at localized locations. However, any additional loading of nutrients, especially phosphorus, is of particular importance to normally nutrient-poor streams in the Rocky Mountains; it can have dramatic effects on local algal productivity, aquatic invertebrate community composition, and fish growth rates (Silins et al. 2009a).

Forest fires are an important natural source of phosphorus to small tributary streams of the Castle and Crowsnest Rivers (Silins et al. 2009a). Mean annual total phosphorus concentrations increased 3- to 12-fold in streams of burned and salvaged logged watersheds compared to reference streams (Silins et al. 2009a). Streams in salvaged logged watersheds had mean annual TP concentrations 1.3 to 3.8 times higher than those in burned watersheds (Silins et al. 2009a), indicating a synergistic effect due to logging.

Foothills sub-basins

Phosphorus loadings and concentrations in Willow Creek, Pincher Creek and Beaver Creek closely follow TSS loads, indicating that phosphorus is primarily associated with erosional processes. There are overall trends of increasing phosphorus concentrations in reaches of Willow Creek and downstream of the Pine Coulee Reservoir; however, sufficient data are not available to link these increases to changes in land use practices (State of the Watershed Team 2010).

Southern Tributaries sub-basins

In general, Prairie Blood Coulee, Lee Creek, Belly River, Waterton River, and St. Mary River have been in compliance with annual median total phosphorus concentration water quality guidelines (State of the Watershed Team 2010). In addition, small AESA study streams in these sub-basins are also generally in compliance with phosphorus guidelines (Lorenz et al. 2008). However, occasionally elevated total phosphorus concentrations in Prairie Blood Coulee and Lee Creek have been speculated to be due to runoff from irrigated and dryland agriculture (State of the Watershed Team 2010).

Prairies sub-basins

The Little Bow River and Mosquito Creek exceeded total phosphorus concentration guidelines for many years between 1990 and 2006, but Women's Coulee generally met total phosphorus guidelines (State of the Watershed Team 2010). The Little Bow River is subject to intense agriculture. The two largest irrigation return flows into the Little Bow River contribute significant concentrations of total phosphorus and dissolved phosphorus (Little et al. 2003). Positive relationships exist between the portion of land cover as cereal crop, irrigated land, confined feeding operation density and maximum concentrations of total phosphorus during wet years (Little et al. 2003). This is consistent with findings from the AESA program that show a relationship between agricultural intensity and nutrient concentrations in streams (Lorenz et al. 2008).

NITROGEN

Basin-scale (mainstem)

From 1970 to 2008, with few exceptions, the Oldman River mainstem remained below guidelines for total nitrogen (State of the Watershed Team 2010). At the time of writing this report, the best available loading data comes from a synoptic loading study that was completed by the Oldman River Water Quality Initiative in September 2000. During the survey, most of the nitrogen (47%) was loaded from tributaries. The most important contributing tributaries were the Belly River (22%), the Little Bow River (10%) and the St. Mary River (9%) (Saffran 2005). These river catchments, in the Southern Tributary sub-basins and the Prairies sub-basins, have high coverage of agricultural land, including dryland and irrigated cropland. Drains were also a significant contributor to total nitrogen loading. Most of these drains carry water from agriculturally dominated lands; however, urban storm runoff from Lethbridge also drains into Six Mile Coulee. Flow and concentration data collected by the ORWQI in 2001 and 2002 showed Lethbridge storm water loads 40 t/year of total nitrogen to the Oldman River mainstem, more than half of this in the form of nitrate (Southern Loading Inventory Tool 2011), indicating fertilizer and/or fecal sources.

From 2000 to 2003, Rock and Mayer (2006) studied nitrate concentration, loadings, and isotopic signatures in the Oldman River mainstem and some of its major tributaries. Overall, concentrations were highest during low-flow conditions (October). At this time, the concentrations of nitrate in the western portions of the Oldman River were usually less than 0.5 mg/L, while downstream concentrations could exceed 5 mg/L (Rock and Mayer 2006). In the mainstem of the Oldman River, daily nitrate fluxes rose in the eastern portion by almost 4-fold. Isotopic signatures indicate that most of the nitrate loads in western portions of the watershed are derived from soil processes, while at least 50% of loads in eastern portions of the watershed are derived from manure (Rock and Mayer 2006). It is difficult to say how much of the soil derived NO_3-N is natural and how much may be due to anthropogenic activities (i.e. forestry or other land clearing). Manure derived loads are likely a NPS pollution issue related to land application of manure or grazing, but could also be related to confined feeding operations which are generally considered to be point sources of pollution.

A high flow synoptic survey was completed during a June 2005 flood event (Knapp et al., in preparation). This four-day synoptic survey showed that flow and pollutant loadings from the Foothills tributaries became proportionally much more important than they were during the low flow synoptic survey in 2000. Willow Creek especially was contributing roughly half of the flow and total nitrogen load during the flood event, and Pincher and Beaver creeks were also very important.

Local scale (tributaries)

Mountain Tributaries

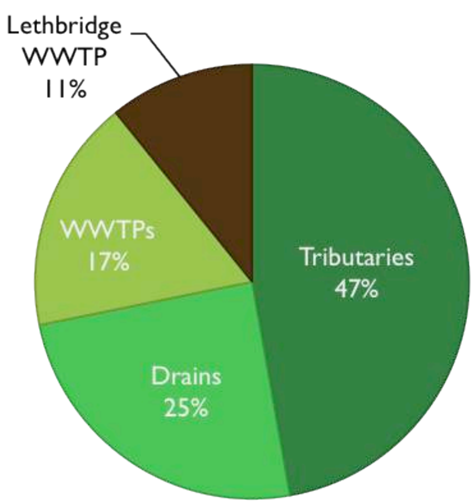

Figure 35: Total nitrogen loading of the Oldman River in September 2000 (Oldman Watershed Council 2005)

The headwater tributaries (Oldman River, Castle River, and Crowsnest River) were studied by Howery (2010) between 2005 and 2008. The median total nitrogen concentrations for these three streams were 134 µg/L, 166 µg/L, and 251 µg/L (Howery 2010). Within each sub-basin, there were weak patterns of increasing total nitrogen concentration with distance downstream, and there were marked increased in total nitrogen yield with distance downstream. In the Oldman sub-basin, yields increased from 11.0 x 10^{-4} kg/ha/day at the most upstream sampling sites to 88.0 kg x 10^{-4} kg/ha/day closer to the Oldman Reservoir. The Castle sub-basin had five times greater total nitrogen yield downstream compared to upstream, and the Crowsnest River had a non-significant increase in total nitrogen yield, with mid and downstream sites yielding 61 to 68 x 10^{-4} kg/ha/year. In all three sub-basins, the upstream portions are heavily forested. The increasing nitrogen-yield with distance downstream for the Oldman and Castle Rivers corresponds with low density grazing, cow/calf operations, and cropland. These land uses would be mainly associated with non-point sources of nitrogen. The middle and lower reaches of the Crowsnest basin experience an urban disturbance gradient, passing through five small towns before reaching the Oldman Reservoir. Although some of the urban influenced nitrogen enrichment may be related to stormwater runoff, some is also likely coming from wastewater treatment facilities.

Forest fires are an important natural source of nitrogen to small tributary creeks of the Castle and Crowsnest rivers (Silins et al. 2009a). In the first year following a major fire, total nitrogen concentration was 5.3-fold higher in streams draining burned watersheds than those in reference watersheds. Differences were less pronounced, but still evident five years after the fire. Salvage logging after fire appears to increase inorganic nitrogen concentration in streams to a greater extent than fire alone, perhaps because the associated network of trails and roads move runoff more efficiently.

Foothills Tributaries

Nitrogen loadings in Pincher Creek and Beaver Creek closely follow TSS loads, implying that nitrogen is related to sediment loadings coming from the land. Total nitrogen levels have exceeded water quality guidelines in both Beaver and Pincher creeks, most notably during flood conditions in 2005. Cropland and grasslands are the dominant landcovers in these areas, so agricultural activities have likely contributes to nitrogen loads. Nitrogen concentrations are increasing in upper Willow Creek and downstream of the Pine Coulee Reservoir, but it is unclear what land use activities are currently contributing to this water quality change (State of the Watershed Team 2010). Most development (oil and gas, urban, and agriculture) occurs in the lower reaches of Willow Creek.

Southern Tributaries

Median annual total nitrogen concentrations in Belly River, Lee Creek, Waterton River, and St. Mary River did not exceed water quality guidelines in years they were monitored between 1984 and 2006. Prairie Blood Coulee has had exceedances, more frequently since 2002 (State of the Watershed Team 2010). Some of these exceedances may be related to increasing agricultural land use intensity. Chemical fertilizer sales increased in this sub-watershed from 1996 to 2006 (Lorenz et al. 2008).

Prairies Tributaries

The two largest irrigation return flows into the Little Bow River do contribute significant concentrations of TN, TP and dissolved P (Little et al. 2003). There are inverse relationships between the amount of native prairie and total nitrogen, and nitrogen concentrations also increases with increase with proportion of irrigated lands (Little et al. 2003). However, the Little Bow River, Women's Coulee, and Mosquito Creek have met TN concentration guidelines most years from 1990 to 2006 (State of the Watershed Team 2010).

SALTS

Basin-scale (mainstem)

Dissolved sodium in the mainstem increases with distance downstream and usually does not exceed 30 mg/L. The best available loading data for salts in the Oldman Basin is for sodium during the synoptic loading study that was completed by the Oldman River Water Quality Initiative project in September 2000. The estimated loading rate of sodium in that study was 34,097 kg/day. The largest portions could be attributed to tributaries and drains in the Southern Tributaries and Prairie Tributaries sub-basins. Also, the concentration of salts tends to be high within city of Lethbridge storm drains compared to other Oldman River Basin sites (Saffran 2005). Non-point sources of salts appear to be important in the Oldman River Basin.

Rock and Mayer (2006) used isotopic fingerprinting to trace sources of sulphate into the Oldman River mainstem and its tributaries between 2000 and 2003. They found that concentrations in the mainstem ranged from 10 to 91 mg/L, while tributaries ranged from 6 to 2110 mg/L. The concentrations generally increased as the river moved eastward. Sulphate daily fluxes also increased downstream. The low fluxes in the western portion of the river were traced back primarily to soil evaporate dissolution, while 74% of the eastern fluxes were traced back to pyrite oxidation in glacial tills, a result of soil exposure. Human disturbances often increase soil weathering and export.

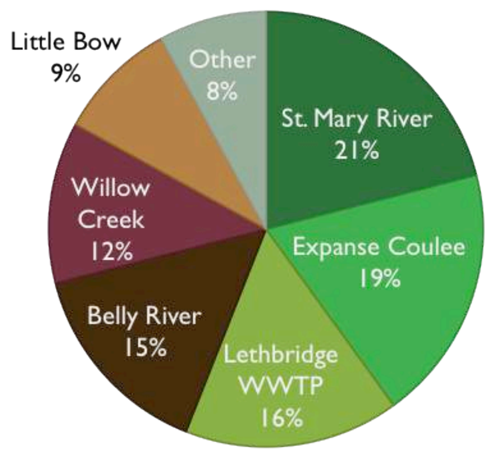

Figure 36: Sources of sodium in the Oldman River in September 2000 (Saffran 2005).

Local-scale (tributaries)

Sodium concentration tends to be higher in tributaries than in the mainstem. Six Mile Coulee had by far the highest peak concentrations in sodium, at 610 mg/L, which is likely related to urban development. Six Mile Coulee is the only tributary that receives urban stormwater from the City of Lethbridge. Expanse Coulee had the second highest peak concentration of sodium at 145 mg/L (Saffran 2005).

METALS

Basin-scale (mainstem)

From 2009 to 2010, the Alberta River Water Quality Index for metals was excellent to good along the mainstem (Alberta Environment 2010). There are fewer data on metals than most other contaminants within the Oldman Basin. Some of this may be related to problems with detection limits in past years. The ORBWQI five-year report regularly measured iron, manganese, mercury, selenium, and arsenic, and measured a suite of other metals during the 2000 city storm drain study and synoptic surveys (Saffran 2005). Generally, most of these were below detection limits. Concentrations were higher in effluents and tributaries than in the mainstem. But, even in tributaries, there were no mercury detections, and arsenic and selenium were below water quality guidelines. There were exceedances for total aluminum at the Piyami Drain, and for dissolved aluminum in the Crowsnest River upstream of Coleman. It is not clear if these have natural or anthropogenic sources.

Local-scale (tributaries)

Forest fires can be a natural source of metals to surface waters in the Rocky Mountain headwaters of the Castle and Crowsnest rivers. Total mercury concentrations and exports in burned catchments were 4.5 to 9 times higher than unburned reference catchments (Silins et al. 2009a). Aluminum, cobalt, lead, manganese, and molybdenum concentrations also increased dramatically after forest fires (Silins et al. 2009a).

PESTICIDES

Basin-scale (mainstem)

Pesticide detections are more common and diverse in the Oldman Basin than any other basin in Alberta. This reflects heavy pesticide use in the basin, and lower water flow in the Oldman than other basins to dilute the pesticides. The sampling intensity is also highest in this basin, which also leads to more detections (Anderson 2005). Fourteen pesticides (11 herbicides and 3 insecticides) were detected in the Oldman River from 1998 to 2003 (Saffran 2005). The herbicide 2,4,-D was the most frequently detected, and was detected at the highest concentrations (0.46 µg/L near Purple Springs). MCPA, dicamba, and mecoprop were the other dominant pesticides and they occasionally exceeded irrigation water quality guidelines, most often downstream of Lethbridge. Pesticide concentrations were higher in Lethbridge storm drains than elsewhere in the Oldman Basin (Oldman Watershed Council 2005). The herbicides 2,4-D, mecoprop, and dicambra were detected together in high concentrations, which are commonly used in lawn and garden care products. The total load of pesticides reaching the Oldman River through urban stormwater is potentially significant.

Sales for glyphosate, the active ingredient in Roundup, are higher in Alberta than for any other pesticide (Anderson 2005). Standard water quality pesticide analyses do not routinely screen for this pesticide, so we have little information on its actual distribution and concentration in surface waters. It has been detected downstream of Lethbridge (Anderson 2005). However, it is difficult to pinpoint the source since glyphosate is registered and commonly used for agricultural, municipal, industrial, and domestic uses.

Local-scale (tributaries)

Agricultural tributaries

There were 31 pesticides (25 herbicides and 6 insecticides) detected in tributaries of the Oldman River (Saffran 2005). The herbicide 2,4-D was detected in more than 80% of samples. This herbicide exceeded guidelines for the protection of aquatic life in Six Mile Coulee and in the Battersea Drain. MCPA and dicamba were the next most commonly detected, and concentrations of both exceeded water quality guidelines in the Belly and St. Mary Rivers in 1998 (State of the Watershed Team 2010). Lindance, chlorpyrifos, and MCPA occasionally exceeded aquatic life guidelines, and MCPA, bromoxynil and dicambra exceeded irrigation guidelines (Saffran 2005). Exceedances occur more frequently in areas east of Lethbridge than in the western half of the Oldman Basin. Five small-scale AESA study streams are located within the Oldman Basin. Two of these, Prairie Blood Coulee and the Battersea Drain, had noncompliance with water quality guidelines for pesticides in 30% to 31% of samples (Lorenz et al. 2008). Both of these streams have high intensity agriculture in their catchments. Willow Creek and Meadow Creek, in lower intensity catchments, rarely exceeded water quality guidelines (Lorenz et al. 2008). The AESA study found that increasing pesticide detections and concentrations occurred with increasing agricultural activity (Lorenz et al. 2008). Diversity of pesticides also increases with intensity of agriculture. A number of specialty crops are grown in irrigated portions of the Oldman Basin, and these require the use of specialized pesticides. Atrazine is used on sweet corn and field corn in the Oldman Basin, and it has been detected at levels above guidelines for aquatic life at one site in the basin (Anderson 2005).

Urban and forestry tributaries

As mentioned previously, during storm events, urban streams can have pesticide concentrations higher than those in agricultural streams (Anderson 2005). Since glyphosate is not routinely monitored, the impact of urban pesticide use on water quality in tributaries is potentially underestimated at present. Glyphosate is also the most commonly used herbicide by the Canadian forest industry (Thompson and Pitt 2011), but due to lack of relevant water quality data, we cannot estimate the effect forestry has on pesticide concentrations in the Oldman River and its tributaries at present.

PATHOGENS

Overall, the Oldman River has seen long-term improvements with respect to fecal coliforms counts (State of the Watershed Team 2010). This is most likely due to improvements in wastewater treatment plants. Exceedances along the mainstem are common but generally localized. In 2009 and 2010, the Alberta River Water Quality Index ranking for bacteria was excellent near Brocket and fair just upstream of Lethbridge. At the time of writing this report, the best available loading data for fecal coliforms comes from a synoptic loading study that was completed by the Oldman River Water Quality Initiative project in September 2000. The total calculated fecal coliforms load for all measured inputs was 22.8 x 10^{10} cfu/day. This survey was done after the Lethbridge WWTP upgrades, but before the Fort Macleod WWTP upgrade, thus the point source contribution may have been significantly reduced since 2000. Tributaries were an important source to the mainstem. The Belly River contributed 25% of fecal coliforms, the St. Mary River contributed 16%, and the Little Bow River contributed 5% (Saffran 2005). The drains that contributed bacterial loads are primarily associated with agricultural land uses. However, high bacteria counts have been noted in many storm drains of Lethbridge. The constant nature of flow from the storm drains in the summer mean that the total load of bacteria entering the mainstem is potentially important (Oldman Watershed Council 2005).

Another synoptic survey was completed on the Oldman River during a June 2005 flood event (Knapp et al. in preparation). This four-day synoptic survey showed that flow and pollutant

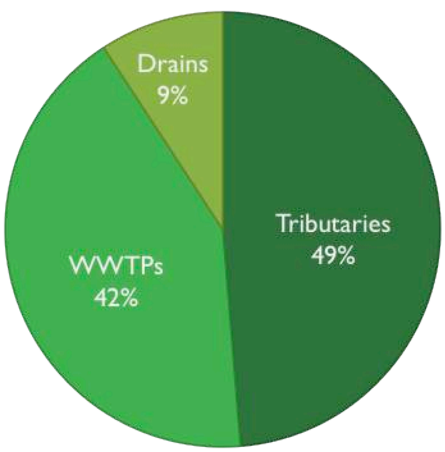

Figure 37: Sources of fecal coliform bacteria to the Oldman River in September 2000. WWTPs include Lethbridge (Oldman Watershed Council 2005).

loadings from the Foothills tributaries became proportionally much more important than they were during the low flow synoptic survey from 2000. Willow Creek especially was contributing roughly half of the flow and fecal coliform load during the flood event, and Pincher and Beaver creeks were also very important.

Headwaters of the Oldman River generally have excellent water quality with respect to bacteria counts. Exceedances of water quality guidelines are more likely to occur in the Prairie, Southern Tributary, and Foothills sub-basins. These basins have higher densities of livestock and people. Peak exceedances were observed across the entire Oldman Basin in 2005, which corresponded to a higher than usual flow (State of the Watershed Team 2010).

The protozoan pathogens *Giardia* and *Cryptosporidium* have also been detected in the mainstem of the Oldman River and resulted in boil water orders for selected communities. *Giardia* detections are more frequent than *Cryptosporidium*. Neither pathogen correlates well with livestock concentrations. Detections are likely related to where animals, both livestock and wildlife, have access to surface water bodies (Saffran 2005).

3.8.3 Data

The Long-Term River Monitoring Network (LTRMN) has two sites on the Oldman River that were established by Environment Canada in 1966. AENV became responsible for these monitoring sites in 1987. The first site is located upstream of Lethbridge (the Highway 3 site), and the second site is located downstream of Lethbridge near Taber (Highway 36 site). The first site could be useful for evaluating water quality effects of the following NPS sources: dam construction, forestry, agriculture, and mineral resource extraction. The second site would capture the following NPS sources: urban sources and agriculture. AENV added a third LTRMN site upstream of Lethbridge near Brocket in 1998. This station is upstream of Pincher Creek (Hebben 2007).

Water quality sampling within the Mountains Tributaries has been sporadic. Intensive data collection occurred in 1979 and 1980, and from 1991 until 2005 in the Crowsnest and Castle Rivers, and in the West Castle River from 2007 until 2009 (State of the Watershed Team 2010).

Foothills tributary water quality data collection began in 1982 and increased in intensity around 1998 for nitrogen, phosphorus, total suspended solids, and fecal coliforms. The increased number of sites and sampling frequency was related to construction of the Pine Coulee reservoir and its potential impacts on Willow Creek. Sampling sites are also located in Pincher Creek and Beaver Creek (State of the Watershed Team 2010).

Within the Southern Tributaries sub-basin, water quality measurements have been sporadic from 1976 onwards. The three sampling stations with the most data are located near the confluence of tributaries with the mainstem. Upstream in the tributaries, and smaller tributaries have only occasionally been sampled (State of the Watershed Team 2010).

Water quality data has been collected sporadically in the Prairie sub-basins. In the Little Bow sub-basin, water quality data was collected in 1987, 1990, 1997, 1999, 2001, and 2003 to 2006. The most frequently sampled sites represent the middle and lower reaches of the basin (State of the Watershed Team 2010).

Trends in water quality cannot be determined for many areas of the Oldman watershed because water quality data has not been collected regularly. The absence of simultaneous flow and concentration data also limit the ability to perform mass balance calculations.

3.8.4 Synthesis

Water quality is good to excellent for TSS, phosphorus, nitrogen, salt, and metal concentrations in the mainstem of the Oldman River. Most of the water quality guideline exceedences occur in tributaries of the Oldman rather than in the mainstem. Given major improvements to most WWTPs in the basin, we can generally attribute most pollutant loadings to non-point rather than point sources. The most important non-point sources of pollution to the Oldman River and its tributaries are agriculture and urban runoff.

Agricultural areas are the dominant land cover in the basin, and they export their largest loadings of pollutants with heavy rainfall events. These areas often have erodible soils that get carried into streams. TSS loadings increase, and nutrients and pathogens tend to be associated with TSS particles in streams. Overall, separating effects of natural sediment erosion from agriculturally exacerbated soil erosion is difficult. Stable isotope analysis can help separate some of these effects by tracing nutrients back to soil processes vs. manure.

Urban runoff and loading of pollutants also increase with storms; however, urban stormwater flows are also supplemented by lawn watering during dry periods. Hence, they are likely to be relatively consistent sources of TSS, nutrients, and pathogens to the Oldman River. Impervious surfaces also mean that runoff is generated more easily in urban areas than in agricultural ones.

Logging is expected to increase in the mountain tributaries sub-basins. Clear-cutting does increase TSS and nutrient loads to streams, although effects will be localized and of shorter duration compared to other land uses due to forest regeneration.

Pesticide use is heavy in the Oldman River Basin, and relatively low flows to dilute the pesticides lead to frequent detections in the mainstem and common exceedances of water quality guidelines in tributaries. Pesticide detections are associated mainly with agricultural and urban use in the Oldman basin at the present time. It is difficult at present to estimate the effect forestry practices may have on pesticide detections because the most frequently used pesticide by the forestry industry, glyphosate, is not routinely included in water quality analyses. This pesticide is also used in agricultural and urban settings, so overall pesticide impacts may currently be underestimated in the basin.

3.8.5 References

Alberta Environment. 2010. Alberta River Water Quality Index-Metals (2009-2010). Retrieved from http://environment.gov.ab.ca/info/library/7718.pdf.

Alberta Environment. 2011. 2009-10 River Water Quality Index ratings for Nutrients. Retrieved from http://environment.alberta.ca/01282.html.

Anderson, A.-M. 2005. Overview of pesticide data in Alberta surface waters since 1995. Page 190 pp. Alberta Environment, Environmental Monitoring and Evaluation Branch, Edmonton, Alberta. Retrieved from http://environment.gov.ab.ca/info/library/7614.pdf.

Government of Alberta. 2010. C5 Forest Management Plan 2006-2026. Page 221. Retrieved from http://www.srd.alberta.ca/LandsForests/ForestManagement/ForestManagementPlans/documents/ForestManagementUnitC5/FMU-C5-FMP.pdf.

Hebben, T. 2007. Analysis of water quality conditions and trends for the long-term river network Oldman River, 1966-2005. Page 178. Alberta Environment. Retrieved from http://environment.gov.ab.ca/info/posting.asp?assetid=7806&categoryid=5.

Howery, J. 2010. An assessment of the effects of land use on water quality: A case study in the Oldman River Basin, Alberta. MSc, University of Alberta, Edmonton, Alberta.

Little, J. L., K. A. Saffran, and L. Fent. 2003. Land Use and Water Quality Relationship in the Lower Little Bow River Watershed, Alberta, Canada. Water Quality Research Journal of Canada 38:563-584.

Little, J., A. Kalischuk, and C. Sheedy. 2010. Assessment of water quality in Alberta's irrigation districts. Second edition. Page 181 pp. Alberta Agriculture and Rural Development, Edmonton, Alberta. Retrieved from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13000/$FILE/wqreportfull_nov2010.pdf.

Lorenz, K., S. Depoe, and C. Phelan. 2008. Assessment of environmental sustainability in Alberta's agricultural watersheds project: Volume 3: AESA water quality monitoring project. Page 543 pp. Alberta Agriculture and Rural Development.

Mitchell, P. M. 2001. Limnological assessment of the Oldman River Reservoir. Page 66. Prepared for Alberta Environment, Edmonton, AB. Retrieved from http://www.environment.gov.ab.ca/info/library/5840.pdf.

Oldman Watershed Council. 2005. Oldman River Basin water quality initiative: five year summary report. Lethbridge, Alberta, Canada.

Pokhrel, D., M. Wang, and A. Berlando. 2011. Southern Alberta Loading Inventory Tool. Alberta Environment.

Prepas, E. E., B. Pinel-Alloul, D. Planas, G. Methot, S. Paquet, and S. Reedyk. 2001. Forest harvest impacts on water quality and aquatic biota on the Boreal Plain: introduction to the TROLS lake program. Canadian Journal of Fisheries and Aquatic Science 58:421-436.

Rock, L., and B. Mayer. 2006. Tracing nitrates and sulphates in river basins using isotope techniques. Water Science & Technology 53:209-217.

Saffran, K. A. 2005. Oldman River Basin water quality initiative surface water quality summary report - 1998-2003. Page 395. Oldman River Basin Water Quality Initiative. Retrieved from http://oldmanbasin.org/index.php/publications/.

Silins, U., K. D. Bladon, M. D. Stone, M. B. Emelko, S. Boon, C. Williams, M. Wagner, and J. Howery. 2009a. Southern Rockies watershed report: impact of natural disturbance by wildfire on hydrology, water quality, and aquatic ecology of Rocky Mountain watersheds: Pase 1(2004-2008). Page 92.

Silins, U., M. D. Stone, M. B. Emelko, and K. D. Bladon. 2009b. Sediment production following severe wildfire and post-fire salvage logging in Rocky Mountain headwaters of the Oldman River Basin, Alberta. Catena 79:189-197.

State of the Watershed Team. 2010. Oldman River state of the watershed report. Retrieved from oldmanbasin.org.

Thompson, D. G., and D. G. Pitt. 2011. Frequently asked questions (FAQs) on the use of herbicides in Canadian Forestry. Page 7. Canadian Forest Service, Sault Ste. Marie, Ontario. Retrieved from http://publications.gc.ca/collections/collection_2011/rncan-nrcan/Fo123-1-112-eng.pdf.

3.9 Peace River

3.9.1 Introduction

The Peace River Basin spans British Columbia and Alberta, and is the largest watershed in Alberta. The total drainage area covers 302,500 km^2, with 118,000 km^2 of this area occurring in British Columbia. The Peace River begins as streams in the Rocky Mountains of British Columbia. The Finlay River (elevation 1,140 m) and Parsnip River (elevation 5,630 m) discharge into Williston Lake (elevation 748 m), which feeds the WAC Bennett Dam. From the Williston Lake reservoir, the Peace River travels through the boreal plains ecozone, discharging into the Slave River Basin at Lake Athabasca (213 m).

Most of the flow (76%) of the Peace River originates in British Columbia (Alberta Environment and Environment Canada 2004). The mean annual discharge of the Peace River at Peace Point, in Wood Buffalo National Park, is 68,200,000 dam^3 (Alberta Environment 2011). The W.A.C. Bennett Dam has altered the flow patterns of the Peace River. Although annual flow has not changed significantly since dam construction, at Peace Point, there has been a 25% to 50% reduction in mean monthly summer flows and an increase of 175% to 250% in mean monthly winter flows (Alberta Environment and Environment Canada 2004). The Peace Canyon Dam, located 23 km downstream of the W.A.C. Bennett Dam, does not regulate flow, but it can still influence water quality.

The Smoky River, also with headwaters in the Rocky Mountains, is a major tributary of the Peace River, contributing 11,000,000 dam^3 annually. It drains the Wapiti River, Little Smoky River, and a number of smaller rivers. The headwaters of the Wapiti also originate in the Rocky Mountains, and it has mean annual flow of 3,100,000 dam^3 when it joins the Smoky River (Alberta Environment and Environment Canada 2004).

Fort St. John (pop. 22,000), Dawson Creek (pop. 11,529), and Grande Prairie (pop. 55,227) are the major cities on the Peace River and its tributaries. Towns and villages in the drainage basin include MacKenzie, Hudson's Hope, Chetwynd, Spirit River, Grande Cache, Beaverlodge, Sexsmith, Fairview, Grimshaw, Valleyview, Fox Creek, Peace River, Manning, Paddle Prairie, High Level, and Fort Vermillion.

Water quality in shared watercourses is rated with two water quality indices:

- the Canadian Water Quality Index for the Peace River site near Taylor, BC, and
- the Alberta Water Quality Index at the mouth of the Smoky River and on the Peace River, near Fort Vermillion, AB.

Figure 38: Peace River Basin. Yellow and green areas correspond to cleared and forested land cover, respectively. From Hatfield 2009.

Because water quality parameters and the methods used to calculate the Canadian Index and the Alberta Index differ, the water quality of these sites should not be directly compared by using these two indices. The Canadian Index is based on measurements of bacteria, nutrients, metals, major ions, total suspended solids, and colour. The Alberta Index is based on measurements of metals, nutrients, bacteria, and pesticides. The main difference between the two is the Canadian Index uses total suspended solids and colour and may or may not use pesticides, depending on the site. In addition, the period of reporting differs: BC applies the Canadian Index for each decade, whereas Alberta applies its index for each year.

In BC, the Canadian Water Quality Index has been calculated for each decade since the 1980s. The Canadian Water Quality Index fluctuated from “fair” to “poor” to “fair” between the 1980s and the current decade (MRBB 2004). Colour and total suspended solids were the most important water quality parameters that affected the rating. The quality of water in the Peace River in British Columbia closely matches river flows and increased amounts of suspended sediment that occur during the spring freshet. Suspended sediment carries elevated levels of dissolved organic carbon.

The large quantities of dissolved organic carbon produce high measurements of colour, a water quality parameter that is used in the calculation of the Canadian Water Quality Index.

The Alberta Water Quality Index has consistently rated water quality in the Peace River as good. However, water samples collected from the Peace sub-basin occasionally exceed guidelines for nutrients and metals (AENV 2006). These elevated concentrations were associated with increases in suspended solids. Similarly to sites in BC, Shaw et al. (1990) found that concentrations of suspended solids and nutrients were significantly related to discharge, and followed a strong seasonal pattern of high concentrations in spring and summer and low concentrations in fall and winter. Several metals, including aluminum, arsenic, barium, copper, iron, manganese, nickel, and zinc, were highly correlated with suspended solids and also followed this seasonal pattern.

A number of human activities could contribute to NPS pollution in the Peace River Basin. Main activities include:

- Agriculture: Agricultural land accounts for 23% of all land within the Peace River Basin (MRBB 2004). Most of the agricultural land follows the banks of the Peace River mainstem and extends as far north as Fort Vermillion. Environmental risks to the aquatic environment are associated with land disturbance, animal and plant wastes, and substances applied to enhance production, including fertilizers (e.g. manure or chemical fertilizers) and pesticides. Grain, vegetable, and hay crops are the main activity, and are accompanied by heavy use of fertilizers and herbicides (primarily the phenoxy group). Agriculture has likely reached its spatial limit in the basin because the remaining undeveloped lands are found on marginal soils and require significant modification, such as draining or clearing, to support agricultural production. The area under cultivation in the basin is expected to remain relatively constant.
- Forestry: Large-scale forestry is predominant throughout the basin and feeds two pulp mills in Alberta: DMI in Peace River and Weyerhauser in Grande Prairie. The risks to the aquatic environment are mainly associated with increased run-off as a result of land disturbance. Pesticides are also used in the forestry industry.
- Oil and Gas: The oil and gas industry is also active within the basin, within both BC and Alberta. There is also in-situ oil sands mining occurring near the Cadotte River, which drains into the Peace River near the town of Peace River. The Cadotte River drains an area underlain by a relatively large oil sands deposit. Potential contributions from the oil and gas industry to NPS pollution could result from soil erosion, spills from roads, well sites, and exploration corridors, and contamination of groundwater from saltwater injection wells or disposal wells. These activities and processes could lead to changes in TSS, certain metals, ion concentrations, pesticides, and trace organics (North/South Consultants et al. 2007).
- Mining: Mining activity in the Peace River Basin is focused on coal extraction. This industry has been operating in the watershed since the late 1800s, but activities have increased in the past five years. Extensive coal exploration is ongoing in the basin. Demand for coal is expected to increase in the future. In fact, several coal mining projects are currently under review for approval in BC. Most of these proposals are located in the Pine River sub-basin, a major tributary to the Peace River. One proposed mine is located in the Wapiti River sub-basin. Environmental concerns related to mining are most often focused on land

disturbance and run-off from mine sites. The mines intermittently release water from settling ponds which contain groundwater, precipitation, and surface runoff that have passed through mined land and overburden. The water quality parameters of concern can be quite specific to the mine itself, depending on geology, tailings, etc. These can include pH (from acid mine drainage), total suspended solids and associated metals, total dissolved solids from coal preparation and treatment facilities, nitrogen (from explosives), and selenium.

- Urban: Stormwater from the older sections of the City of Grande Prairie are combined with sewage and managed as wastewater according to the terms of the EPEA approval issued to the local utilities company. The newer areas of the City are serviced by a separate stormwater system, consisting of collection, dry or wet ponds, and outfalls primarily and ultimately to Bear Creek. This stormwater is managed under the terms and conditions of the EPEA stormwater registration issued to the City.

Point sources of pollution in Alberta include wastewater from the two pulp mills and from municipalities. Six municipalities discharge wastewater continuously to the Peace River basin: Grande Cache, Grande Prairie, Peace River, Manning, Wabasca, and the Peace River Correctional Center. Grande Prairie's wastewater plant uses a tertiary treatment system, while all the other major municipalities use secondary treatment. Numerous other smaller municipalities intermittently discharge relatively minor levels of treated effluent into the two basins, typically o annually or semi-annually.

3.9.2 Knowledge

The magnitude of impact that human NPS contributions have on the Peace River mainstem is not well understood. Most assessments up until now have focused on point-source pollution (pulp mill and municipal wastewater) and its mitigation. However, NPS pollution in the Peace River Basin, particularly from coal, agriculture and forestry, remains a concern.

SUSPENDED SOLIDS & METALS

Basin-scale (mainstem)

Based on data collected between 1984 and 2002, at the federal site in BC, Peace River water quality was closely aligned with flow patterns, with elevated TSS levels during the high-flow spring freshet period (BC MOE 1996, BWP 2003). Elevated TSS loads were transported to the mainstem by tributaries with highly erodible soils. It is not known to what degree the TSS load is caused by human disturbances. However, logging, which is primarily conducted to the north of the Peace River, likely affects the nutrient and sediment regimes of the larger tributaries, such as the Beatton River and Halfway River (Les Swain, BC MOE, pers. comm.). During these high spring flows, total forms of several trace metals (i.e., Al, Cr, Co, Cu, Fe, Mn, Pb, Zn) were frequently noncompliant with BC water quality guidelines. However, these metals most likely occurred in particulate forms that for the most part were considered non-bioavailable to biota. During the rest of the year, particularly under low flow conditions, TSS levels and associated trace metals were generally present at low concentrations, primarily because a large proportion of the river flow came from Williston Reservoir via release from the WAC Bennett dam.

Water quality conditions observed close to the provincial border in BC largely resembled that of the upper Alberta reach, upstream of the Smoky River confluence (Shaw et al. 1990). For most of the year, the mainstem in Alberta was characterized by low levels of many water quality parameters (e.g., TDS, nutrients, trace metals, TSS). As described at the upstream BC site, historical TSS levels in Alberta were elevated during high flows, as were some total metals. The mainstem PR exhibited comparatively low seasonal and spatial variability in dissolved constituents, which Shaw et al. (1990) attributed to the Cordilleran origin of the river (i.e., water from hundreds of mountain streams), the disproportionately large size of the river compared to its tributaries and point sources, and the release of fairly homogenous water from the WAC Bennett dam. Dissolved oxygen levels in this stretch of the river are typically high and compliant with the ASWQG during all seasons.

It is unclear whether NPS pollution is contributing to seasonally high TSS. NPS pollution contributions (urban, forestry, agriculture, mining and oil & gas) to the Peace River mainstem have not been assessed. However, we do know that the water quality of the Peace River mirrors closely the natural geology and vegetation of the basin. Glacial deposits of fine-grained sediments, such as silt and clay, cover large portions of the region and are susceptible to erosion. Because of this, total suspended solid concentrations are typically higher than other large rivers in Alberta (Shaw et al. 1990). Shaw et al. (1990) found a pattern of lower concentrations of dissolved oxygen and higher concentrations of most other water quality variables, especially suspended solids and associated substances, from the BC border to downstream near Fort Vermillion. These higher concentrations of suspended and dissolved materials result, in part, from changes in the composition of the riverbed and banks from gravel to sand and silt. There is debate regarding how much effect the cumulative influence of tributary and effluent loadings have on the Peace River mainstem. Further north, tributaries such as the Wabasca River, are highly affected by extensive peatland areas, which export highly coloured water.

Local-scale (tributaries and/or watersheds)

Much of the focus on tributaries in Alberta has been on examining the effects of the City of Grande Prairie and Weyerhauser pulp mill effluents on the Wapiti and Smoky rivers. In general, the impact of these point sources has been limited to the Wapiti River and is not detected downstream in the Smoky and Peace rivers. The Smoky River contributes about 20% of the flows in the Peace River. Thus, it affects the water quality of the Peace River, and some of its loading is likely from non-point sources.

A number of watershed-scale studies have been completed in the Basin that examine the influence of agriculture, forestry, and oil and gas extraction on the water quality of small watersheds. Results from these studies are summarized along with a discussion on the potential impact to NPS pollution in the Peace River Basin.

Oil & gas extraction

Through a collaborative monitoring program agreement between NAL Resources and AENV, water quality indicators were measured at six sampling sites in the Bridlebit Creek sub-basin near Valleyview, AB, from 2000 to 2003. This allowed potential water quality effects from oil and gas activities (Cygna Environmental 2007) to be assessed. Development in the Bridlebit watershed has produced surface disturbance footprints for well pads, pipelines and access roads through the 2001 to 2003 period. This is in addition to existing disturbance limited primarily to seismic lines. Total disturbance area was 4.61% of the 19.7 km^2 watershed area with well pads accounting for 47% and linear features for 53% of the total disturbed area. The study was conceived as a before/after comparative design, wherein previous available studies plus monitoring in the year 2000 were to establish pretreatment conditions in Bridlebit Creek, and monitoring data from 2001 to 2003 characterizes post-treatment changes.

There was no indication that NAL activities increased the sediment concentration or hydrocarbons in Bridlebit Creek. NAL applied limited herbicide treatments in the Bridlebit watershed using best-practices that ensured they were not mobilized to surface runoff. No herbicides were detected in samples from Bridlebit Creek. In summary, NAL activities in the Bridlebit Creek watershed did not have any detectable impacts on water quality. This is not surprising since such a small proportion of the watershed was disturbed (5% of watershed). According to the authors, a general consensus is that with the application of current best practices common to forestry (riparian buffer strips, proper road and ditch design), surface disturbance of vegetation must exceed 10% before changes in hydrology and solute export become pronounced in watershed impact studies with a similar design as the Bridlebit Creek study.

Coal

Grande Cash Coal is operating a mine within the upper Smoky River sub-basin. Two creeks, Sheep and Beaverdam, flow through mine-affected areas. NPS pollution from the mine affects both these creeks. Sediment selenium concentrations were elevated in both creeks downstream of mining activity. In the fall of 1999, selenium levels in Beaverdam Creek downstream from mine activities were 15 times the CCME water quality guidelines. Beaverdam Creek has been directly and recently influenced by mine activities. It is downstream of recent mine pits, a rock drain, and a settling pond (Casey 2005).

Agriculture

In the AESA program, total suspended solids concentrations between 1999 and 2002 were not related to agricultural intensity. Although the three AESA streams located in the Peace Basin were located in high run-off watersheds, TSS concentrations were relatively low. Anderson et al. (1998) found that TSS was more related to runoff potential and stream discharge patterns than agricultural intensity.

Other

There are currently no known studies of other human activity impacts (forestry, urban runoff) to total suspended solids in the Peace River Basin.

Nutrients and related substances

Basin-scale (mainstem)

The Peace River upstream of the Smoky River confluence was classified as oligotrophic according to total phosphorus and total nitrogen. Although TP and TN concentrations were generally low at this site, they peaked at higher levels during the May-June high flow period, reducing overall water quality guideline compliance rates to 62% (TP) and 85% (TN). Conditions downstream do not get much better; the nutrient sub-index rating rated "fair" for nutrients at the Fort Vermillion site, largely due to 42% compliance rates (1998 to 2004, North/South Consultants et al. 2007) in TP. Concentrations of nutrients (i.e., all nitrogen species and total phosphorus) are correlated with suspended solids concentrations. Similarly to suspended solids, TP and TN peak from April to June. Nutrient-related effects on the Wapiti River downstream of the Grande Prairie WWTP and pulp mill discharges have been documented. The impacts of nutrient enrichment were documented downstream to the Smoky River (Golder 2000).

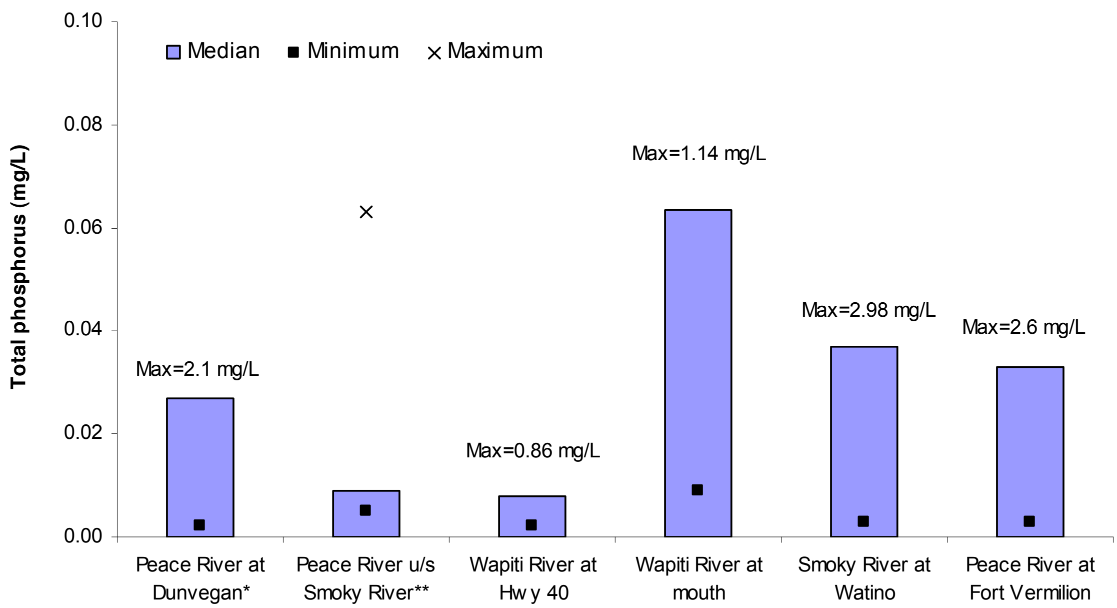

Figure 39: Total phosphorus concentration at different sites in the Peace River as well as at sites in its main tributary in Alberta (Smoky River and associated Wapiti River). Wapiti River at mouth is downstream of Grande Prairie WWTP and Weyerhauser pulpmill loading. Smoky River at Watino represents Smoky River water quality prior to discharge to the Peace River. From Hatfield 2009. * Data from 1969 to 1997. ** Data from 2006 and 2007.

In 2005, unseasonably warm temperatures early in March caused early spring runoff in tributaries of the Peace River Basin. As a result of this unprecedented event, dissolved oxygen concentrations declined to the Alberta Surface Water Quality Guideline for the Protection of Aquatic Life (5 mg/L). Widespread dissolved oxygen sags in the Peace River have never been observed, indicating an unusual event. Because unapproved wastewater discharges to the Peace River were not reported during March 2005, non-point sources (i.e., biochemical oxygen demand loading from surface runoff) were attributed to this decline. The authors speculated that a large tributary load from the Smoky River under ice in the Peace River played a part in the event (Charette and Friesenhan 2009).

Local-scale (tributaries)

The effects of logging and agriculture on nutrient NPS pollution have both been examined at the watershed-scale in the Peace River Basin.

Logging

On a local scale, some knowledge exists on non-point source effects of logging. The impacts of logging on aquatic ecosystems have been studied in parallel with wildfire in the Boreal Plain and the Peace River Basin. Forest fire is an extremely important natural process that plays a large role in shaping the boreal forest. Recent forest management strategies have examined the approach of emulating fire in forest harvesting practices.

Catchment disturbance can affect the quality and quantity of receiving waters. Since trees take up water, their removal results in excess soil water. Soil saturation can cause greater export of water and nutrients (through both subsurface and overland flow) from the catchment after snowmelt and rainstorms. Potential hydrologic impacts from timber harvesting include reduced infiltration, increased surface runoff and increased export of major nutrients such as nitrogen, phosphorus and base cations. Snowmelt usually occurs sooner and more moisture is lost to snow/ice melt following clear-cut harvesting (Verry et al. 1983). The result can be small peaks in stream discharge over an extended melt period (Buttle and Metcalfe 2000). Mechanical compaction, increased soil saturation, reduced evapotranspiration, and changes in biotic activity in soils are some of the causes for increased water and solute flux following harvesting. Wildfire, in particular, can increase the availability of water-soluble nutrients, because fire mineralizes organic nutrients contained in vegetation. Severe fires can burn off the surface organic layer of soils, exposing the underlying mineral soil (Bayley et al. 1992). Such an increase in soil nutrient availability can further increase nutrient export from catchments (Lamontagne et al. 2000). Nutrients can even be directly deposited into aquatic systems through smoke and ash (Spencer and Hauer 1991).

The effect of fire on water quality tends to be fire- and region-specific because each fire will have a different level of intensity and the hydrological regime differs from one catchment to the next. For instance, catchment features such as vegetation and slope are important determinants of surface water quality. Surface waters on the Boreal Plain are highly affected by the amount and type of peatlands in their catchment (Prepas et al. 2001). The movement of water through peatlands is difficult to predict and highly variable, thereby muddying the watershed disturbance-aquatic response relationship. In these peatland-dominated systems, runoff typically occurs in the spring when snowmelt flows over frozen peat. Later in the year, hydrology can switch to the groundwater flow system, which is largely governed by the hydraulic conductivities of the glacial till (C. Mendoza, pers. comm.). The geology of glacial till on the Boreal Plain is highly variable with materials ranging in hydraulic conductivities from clays (10^{-10} cm/s) to sand and gravel (10^{-1} cm/s) (Evans et al. 2000). Because of this complexity, determining change in surface water chemistry due to disturbance can be difficult and may require long time series of data.

In spite of this complexity, some patterns have emerged from watershed studies. Studies from the Caribou Mountains and the Buffalo Head Hills in the Peace River Basin show eutrophication in lakes and streams with burned catchments (Charette et al. 2003, McEachern et al. 2000). These effects can last decades, depending on the severity of the fire. Surface waters in small catchments were particularly vulnerable since pathways for runoff and groundwater were shorter and more related to shallow soil pathways. In general, surface waters that had a strong hydrologic connection to their watersheds were sensitive to watershed disturbance.

The physical characteristics of slope, percent peatland cover, percent disturbance and differences in timber harvesting practices play a role in how logging affects aquatic ecosystems. In general, logging impact studies show relatively minor impacts to short-lived (~3 years) aquatic ecosystems. Despite substantial changes in hydrology, studies may not be able to tease changes resulting from logging apart from those of naturally large inter-annual variation. Typically, water yield, suspended solids, and nutrient concentrations (especially phosphorus) increase following harvest. However, in a study of streams in the peatland-dominated Caribou Mountains, logging effects were minimal.

In general, logging may be contributing NPS pollution on a local scale in the Peace River Basin in Alberta. However, current studies on relatively flat landscapes (Boreal Plain) tend to indicate minimal impact. It is possible that steep-sloped watersheds (e.g., foothills) with greater runoff potential are more responsive. However, Nip's (1991) paired watershed experiments on the Tri Creeks Experimental Watershed in the Eastern Slopes near Hinton indicated slight increases in total phosphorus. The difference in effect for fire vs. logging may reflect the selective nature of logging. The magnitude of harvest is typically determined by the distribution of merchantable trees and the logistics of harvesting them. Severe wildfire removes vegetation and surface organic layers, whereas experimental harvesting leaves organic soil layers, undergrowth and slash on site, which impedes erosion. Further, fire suppression is very active in northern Alberta where the logging and oil and gas footprint has, to a certain extent, replaced the fire footprint. Given that fire typically exhibits a larger response, the net effect of logging on a regional basis may be negligible.

Agriculture

Agricultural activities that could contribute contaminants to surface water include, but are not limited to, manure or fertilizer application, intensive livestock operations (e.g., feedlots, dairies), non-intensive livestock operations (e.g., pasture, cow-calf, watering sites), some tillage methods, pesticide application, and irrigation. The impact of agricultural activities on water quality in specific watersheds in the Peace River Basin will depend on the amount and distribution of land under cultivation, the farming practices employed, soil type, topography, weather, and climate patterns (Lorenz et al. 2008).

Three watersheds in the Peace River Basin were part of a provincial program named Alberta Environmentally Sustainable Agriculture program (AESA): Hines Creek (low agricultural intensity), Grande Prairie Creek (moderate agricultural intensity) and Kleskun Drain (moderate agricultural intensity). Relationships established through the AESA program can be applied to agricultural areas in the Peace River Basin. In general, as agricultural intensity increases:

- Dissolved nutrient export increase;
- Concentrations of phosphorus and nitrogen (mainly the dissolved fraction) in streams increase; Dissolved nitrogen and phosphorus fractions were positively correlated with agricultural intensity metrics (chemical and fertilizer expenses and manure production percentiles); and
- Compliance with provincial and national surface water quality guidelines for the protection of aquatic life decrease.

One field-scale study was conducted in the Peace River Basin (Grande Prairie Creek), as part of the Phosphorus Limits Project (Little et al. 2006). In general, this study showed that field-scale concentrations of total phosphorus from non-manured sites exceeded the Alberta water quality guideline for the protection of aquatic life by 3 to 16 times in all three years of the study. The concentrations of total phosphorus from non-manured sites were similar to watershed-scale values of total phosophorus measured in first-order streams that drain high intensity agricultural watersheds in Alberta. Given that most surface runoff in Alberta's agricultural areas occurs during spring snowmelt, phosphorus export is primarily expected in spring or during unusually pronounced summer rainstorm events. During these events, substantial amounts of phosphorus are found in runoff water. Further, as the amount of phosphorus in the upper soil profile increases, so does the concentration of phosphorus in runoff water.

In general, it is recognized that agriculture contributes to NPS pollution in the Peace River Basin. However, the extent of this contribution is currently unknown. In general, current studies demonstrate that NPS pollution increases as agricultural intensity increases and that the potential for NPS pollution from agricultural land is greatest in spring.

Other constituents

Basin-scale (mainstem)

Eight pesticides, including alpha-BHC, lindane, 2,4-D, 2,4,5-T, bromoxynil, picloram, MCPA and MCPP were detected in varying numbers of samples collected at Dunvegan. Alpha-BHC was detected in 34 of 40 samples. However, concentrations of this compound, an impurity in the pesticide lindane, showed a significant decrease from 1977 to 1989, suggesting a decrease in the use of lindane in the Peace River basin during this period. Concentrations of PCBs and hydrocarbons were below detection limits in all samples (Hatfield 2009).

Since pesticides are almost exclusively a NPS issue, these detections indicate that human-related NPS pollution is making its way to the Peace River. That said, historical concentrations of 2.4-D and 2,4,5-T are within guidelines for the protection of aquatic life (Anderson 2005), indicating low risk to aquatic ecosystems. Sub-index ratings of the ARWQI for pesticides is consistently "excellent".

Local-scale (tributaries)

Agriculture

Agricultural activities that could contribute bacteria to surface waters include manure spreading, allowing direct cattle access to streams, and improper storage and handling of manure. In AESA streams, *E. coli* and fecal coliforms were commonly found. Sixty-nine percent of all samples collected (1999 to 2006) had detectable levels of *E. coli,* and 79% had detectable levels of fecal coliforms. Fecal bacterial counts are variable and rarely strongly related to environmental metrics. Unlike nutrient concentrations, fecal bacteria counts did not show an increasing pattern with increasing agricultural intensity.

In agricultural watersheds from the AESA program, one or more of the 68 pesticide compounds monitored were detected in 64% of samples from 1999 to 2006. Pesticide detection frequency, total pesticide concentration, and the total number of compounds detected increased significantly as agricultural intensity increased from low to high. There is also a strong correlation between agricultural intensity (as cropland and fertilizer and chemical expense percentages) and total pesticide detection frequency. Irrigated watersheds had a higher toxicity risk than high intensity dryland watersheds; irrigated watersheds exceeded guidelines more frequently than other dryland watersheds. Total pesticide concentrations appeared to be influenced by the type of water management used (irrigated vs. dryland) as well as by the intensity of chemical use.

Similarly to nutrients, agriculture is generally recognized to contribute to bacterial and pesticide NPS pollution in the Peace River Basin. However, the extent of this contribution is currently unknown and is likely scale-dependent. Agriculture is also widely recognized as a source of bacterial contributions, but no generalizations can be made with respect to agricultural intensity. For pesticides, current studies demonstrate that NPS pollution increases as agricultural intensity increases.

3.9.3 Data

Table 4 lists historical monitoring in Alberta-British Columbia shared watercourses. Currently, one long-term monitoring site exists near the Alberta-British Columba border: Peace River upstream of the Alces River. Historically, the Peace River near Dunvegan was monitored extensively. Monitoring at this site was discontinued in 1994 after a synoptic survey showed no substantial difference from other sites on the Peace River. The Peace River site, upstream of the confluence with the Smoky River was added in 2006, in response to a low oxygen event in the Peace River, during spring 2005 runoff (Charette and Friesenhan 2009).

Table 4: Historical monitoring of the Peace River and its tributaries.

Watercourse	Sampling regime	Most recent sample	Parameters
Chinchaga R @ Hwy 28	Single grab	1987	Inorganics, metals
Peace R			
Above Alces R	Bi-weekly	2011	Inorganics, metals
@ Dunvegan	Monthly	1997	Inorganics, metals, organics
U/s Smoky R	Monthly	2011	Inorganics, metals, organics
Fort Vermillion	Monthly	2011	Inorganics, metals, organics
Various locations	Synoptic	1991	Inorganics, metals, organics
Pouce Coupé R			
@ border	Weekly, open water	2001	Inorganics
nr mouth (AB)	Monthly, open water	1989	Inorganics, metals
Sheep Ck			
u/s Smoky R Coal	Synoptic	2000	Inorganics, metals
Nr Smoky R	Synoptic	2000	Inorganics, metals
Wapiti R Basin			
Beaverlodge R u/s Horse Lake	Flow-based	2006	Inorganics, pesticides
Beavertail R nr mouth	Flow-based	2006	Inorganics, pesticides
Redwillow R nr mouth	Seasonal	1995	Inorganics, pesticides
Steeprock R nr mouth	Flow-based	2006	Inorganics, pesticides
Wapiti R @ Hwy 40	Monthly	2011	Inorganics, metals, organics
Wapiti R u/s Smoky R	Monthly	2011	Inorganics, metals, organics
Wapiti R various locations	Synoptic	1998	

3.9.4 Synthesis

Water quality in the Peace River mainstem largely reflects seasonal patterns in flow, which affects TSS and the constituents associate with them (nutrients, metals). Human activities affecting mainstem and tributary water quality include primarily point sources from municipal and pulp mill discharge, particularly in the Wapiti River.

Streams are affected by NPS pollution in the Peace River Basin in the following ways:

- Pesticides are detected in the Peace River, indicating that NPS pollution is making its way to the river.
- Beaverdam Creek is experiencing NPS selenium loading from active and reclaimed coal mine drainage.
- Logging has been shown to solicit a relatively minor and short-lived response in peak flow water yield and nutrients.
- NPS pollution occurs at the stream/small watershed scale in agricultural watersheds in the Peace River Basin. The concentrations of nutrients and pesticides can be expected to increase with agricultural intensity in these streams.

In terms of gaps, the magnitude of impact that human NPS contributions have on the Peace River mainstem is not well understood. Most assessments have focused on point-source pollution (pulp mill and municipal wastewater) and its mitigation. There is relatively little data on tributaries to support NPS pollution assessments, which could be enhanced through an updated synoptic survey. This is particularly important in light of an important event that occurred in the Peace River in 2005, that is, abnormally low dissolved oxygen concentrations were detected under ice. NPS sources were blamed for the event, although it is not clear what role was played by the human-related NPS pollution from the tributaries.

In addition, very little information exists on recreational use in the Peace River Basin and its impact on constituent loads. Given the high density of linear disturbances, the potential for recreation-related impacts exist at a stream scale. Lastly, information on urban runoff constituent contributions and impact is also lacking.

3.9.5 References

Alberta Environment. 2011. Alberta River Basins. Retrieved from http://environment.alberta.ca/apps/basins/default.aspx.

Alberta Environment (AENV). 2006. Alberta Environment Annual Report 2005-2006. 84 pp.

Alberta Environment, and Environment Canada. 2004a. Northern rivers ecosystem initiative: synthesis report.146 pp. Retrieved from http://www.assembly.ab.ca/lao/library/egovdocs/alen/2004/149827.pdf.

Anderson, A.-M. 1998. Water Quality Monitoring Program of Agricultural Streams and Lakes. Prepared for Alberta Environmentally Sustainable Agriculture (AESA) Resource Monitoring, Water Quality Component.27 pp.

Bayley, S.E., Schindler, D.W., Beaty, K.G., Parker, B.R., and Stainton, M.P. 1992. Effects of multiple fires on nutrient yields from streams draining boreal forest and fen catchments: nitrogen and phosphorus. Can. J. Fish. Aquat. Sci. **49**: 584-596.

BC MOE (British Columbia Ministry of the Environment). 1996. State of Water Quality of Peace River above Alces River 1984-1995. British Columbia Ministry of the Environment, 32 pp.

Buttle, J. M. and R. A. Metcalfe (2000). Boreal forest disturbance and streamflow response, northeastern Ontario. Can. J. Fish. Aquat. Sci. **57**(Supp. 2): 5-18.

BWP Consulting (2003). Water quality assessment of the Peace River above Alces River (1984-2002). Report prepared for Environment Canada and the BC Ministry of Water, Land, and Air. 42 pp.

Casey, R. J. 2005. Results of aquatic studies in the McLeod and upper Smoky river systems. Alberta Environment, Edmonton, AB. 62 pp.

Charette, T. and E. Friesenhan. 2009. Report on a low dissolved oxygen concentration event in the Peace River, Spring 2005. Alberta Environment, Edmonton, AB. 32 pp.

Charette, T. and E.E. Prepas. 2003. Wildfire impacts on phytoplankton communities of three small lakes on the Boreal Plain, AB, Canada: a paleolimnological study. Canadian Journal of Fisheries and Aquatic Sciences 60: 584-593.

Cigna Environmental Ltd. 2007. The water quality impacts of hydrocarbon resource development in the Bridlebit Creek basin. Report prepared for Alberta Environment. 35 pp.

Evans, J. E., E. E. Prepas, K. J. Devito and B. G. Kotak (2000). Phosphorus dynamics in shallow subsurface waters in an uncut and cut subcatchment of a lake on the Boreal Plain. Can. J. Fish. Aquat. Sci. **57**(Supp. 2): 60-72.

Golder (Golder Associates Ltd.) 2000. Weyerhaeuser Canada Ltd., Grand Prairie Environmental Effects Monitoring Cycle 2. Prepared for Environment Canada.

Hatfield Consultants. 2009. Current state of surface water quality and aquatic ecosystem health in Alberta-Northwest Territories Transboundary Waters. Report prepared for Alberta Environment.

Lamontagne, S., Carignan, R., and D'Arcy, P. 2000. Element export in runoff from eastern Canadian Boreal Shield catchments following forest harvesting and wildfires. Can. J. Fish. Aquat. Sci. **57** (Suppl. 2): 118-128.

Little, J.L., Nolan, S.C., and Casson, J.P. 2006. Relationships between soil-test phosphorus and runoff phosphorus in small Alberta watersheds. 150 pp. In Alberta Soil Phosphorus Limits Project. Volume 2: Field-scale losses and soil limits. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

Lorenz, K.N., Depoe, S.L., and Phelan, C.A. 2008. Assessment of Environmental Sustainability in Alberta's Agricultural Watersheds Project. Volume 3: AESA Water Quality Monitoring Project. Alberta Agriculture and Rural Development, Edmonton, Alberta, Canada. 487 pp.

Mackenzie River Basin Board (MRBB). 2004. Mackenzie River Basin state of the aquatic ecosystem report 2003. 213 pp.

McEachern, P., E.E. Prepas, J.J. Gibson and W.P. Dinsmore. 2000. Forest fire induced impacts on phosphorus, nitrogen, and chlorophyll a concentrations in boreal subarctic lakes of northern Alberta. Canadian Journal of Fisheries and Aquatic Sciences 57: 73-81.

Nip, A. M.-K. 1991. The Tri-Creeks Experimental Watershed: Changes in hydrology and water quality following harvesting and their impact on salmonid fishes in the Tri-Creeks Basin. Alberta Forestry, Lands and Wildlife, Edmonton, AB.66 pp.

North/South Consultants Inc., Clearwater Environmental Consultants Inc. and Patricia Mitchell Environmental Consulting. 2007. Information synthesis and initial assessment of the status and health of aquatic ecosystems in Alberta. Report prepared for Alberta Environment, Edmonton, AB. 522 pp.

Prepas, E.E., W.P. Dinsmore, D. Planas, S. Paquet, J.J. Prowse, J.J. Gibson, L.A. Halsey, D.H. Vitt, P.M. McEachern, G.J. Scrimgeour, W.M. Tonn, C.C. Paszkowski and K. Wolfstein. 2001. Landscape variables influencing nutrients and phytoplankton communities in Boreal Plain lakes of northern Alberta: a comparison of wetland- and upland-dominated catchments. Canadian Journal of Fisheries and Aquatic Sciences 58: 1286-1299.

Shaw, R.D., L.R. Noton, A.M. Anderson and G.W. Guenther. 1990. Water quality of the Peace River in Alberta. Alberta Environment, Edmonton, AB. 247 pp.

Spencer, C.N., and Hauer, F.R. 1991. Phosphorus and nitrogen dynamics in streams during a wildfire. J. N. Am. Benthol. Soc. **10**: 24-30.

Verry, E. S., J. R. Lewis and K. N. Brooks (1983). Aspen clear-cutting increases snowmelt and storm flow peaks in north central Minnesota. Water Resour. Bull. **19**: 59.

3.10 Red Deer

3.10.1 Introduction

The total area contained within the Red Deer River Basin is 57, 426 km^2; however, due to the prevalence of endoheric drainage basins the Red Deer River drains an area of 49,650 km^2 (Red Deer River Watershed Alliance 2009). Red Deer River originates in Banff National Park in the Rocky Mountains, and flows through mountains, foothills, rangeland, residential land, industrial land, coal deposits, urban areas, forests, parks, and croplands across southern Alberta. It joins the South Saskatchewan River 8 km after crossing the border into Saskatchewan. Mean annual flow is 1,840,000 dam^3 (Alberta Environment 2001). The river is primarily fed by precipitation and snowmelt (minimal by glaciers). In the headwaters, where there is high relief of landscape, spring snowmelt can lead to stream discharge rates more than 100 m^3/s (Red Deer River Watershed Alliance 2009). Red Deer River has one dam, Dixon Dam, which regulates flow. Since dam construction, flows have decreased in summer months and increased in winter months. The mountains and foothills section of the basin above Sundre contribute about 6% of the total area, but contribute nearly 50% of the mean annual discharge while the Bindloss catchment covers 40% of the land area, but only contributes 13% of the mean annual discharge (Campbell 1977). These differences reflect differences in precipitation from the Rocky Mountains through the prairies.

In 2006, the population of the basin was 267,863; 69% of the population was urban. Major centres include cities of Red Deer and Brooks, and towns of Strathmore and Sylvan Lake. The watershed contains 55 urban centres (cities, towns, villages, and summer villages). The watershed is forecast to experience a 40% increase in population over the next 25 years (Red Deer River Watershed Alliance 2009). Urban centres discharge both point source pollution (wastewater) and NPS pollution (stormwater) to the Red Deer River.

The land cover of the Red Deer Basin is heavily dominated by agriculture. Annual cropland covers 36% of the land, and this land cover class is most prominent in central area of the basin. Perennial cropland or pasture covers 20%, and grasslands cover 23%. These land types are dominant in the eastern portions of the watershed. Forests cover 10% of the watershed, and they decrease along a west-east gradient across the watershed. Exposed and developed lands cover 2% and 0.75% of the land surface, respectively.

Non-point contributions to the basin have both natural and anthropogenic origins. High natural erodibility of the badlands in the Red Deer Basin has been noted (Campbell 1977). These areas have high probability of contributing high total suspended solids loads to the river. Other pollutants, such as nutrients, are often bound to suspended solids. Human activities that could be contributing NPS pollutants are recreation use, oil and gas, roads, grazing, and cropland. The Red Deer River receives return irrigation flows from the Eastern Irrigation District (although source water for the EID comes from the Bow Basin).

3.10.2 Knowledge

Total suspended solids

TSS responds rapidly to changing geology along the length of the mainstem, and to changing flow rates. Highest concentrations are associated with spring and summer runoff (can reach over 1517 mg/L upstream of Gleniffer Lake Reservoir), but median TSS concentration for the mainstem is 6.6 mg/L (Shaw and Anderson 1994). Peak sediment values are measured in spring along the entire river, and during the summer storm season (June/July) in the lower reach of the river. Thus, headwaters largely respond to spring melt whereas summer rainstorms, and to a lesser extent spring melt, affect TSS concentrations past Drumheller (Cross 1991).

In essence, TSS concentrations in the Red Deer River largely reflect two main features; the Gleniffer Lake Reservoir and changing geology and soil erodibility. The Gleniffer Lake Reservoir is a sink for TSS thereby reducing TSS loads from the headwaters, particularly during peak flows. TSS progressively increases downstream of the Dam, particularly in the lower reaches (between Drumheller and the Saskatchewan border) due to erodible soils as the river passes through the badlands. High natural erodibility of the badlands in the Red Deer Basin has been noted (Campbell 1977). Although badlands cover a very small portion of the basin, they contribute massive amounts of sediment to the river, due to their high erodibility. Mean annual sediment yields of 1.4 kg/m^2

were calculated for badland surfaces, but during high precipitation years the annual yield could be as high as 8.23 kg/m^2 (Campbell 1977).

In the tributaries, much lower sediment concentrations (measured as turbidity) were measured in streams from the upper reaches than those in the lower reaches, which seems to reflect a shift in geology (Cross 1991). In addition, Anderson et al. (1998a) determined that runoff from cattle wintering grounds during spring melt contributes TSS in sufficient amounts to cause increases in concentrations and mass loads in Haynes Creek. When it was flooded in April 1996, the cattle wintering ground located in the flood plain contributed substantial TSS to the stream, demonstrating the influence of this type of disturbance to small streams in the Red Deer River Basin.

NUTRIENTS

Basin-scale (mainstem)

Water quality degrades progressively along the Red Deer River, particularly downstream of the Dickson Dam. Upstream of the Dam, in the headwaters, total phosphorus concentrations are low and indicative of oligotrophic conditions. Upstream of Red Deer, the Alberta River Water Quantity Index ranking for nutrients was excellent in 2009 and 2010, and was ranked as good for most years in the preceding decade (Alberta Environment 2011a). Downstream from Red Deer, at Nevis Bridge, quality degrades to good. Further downstream, at Morrin Bridge and at Jenner, water quality is ranked fair with respect to nutrients (Alberta Environment 2011a). In general, total nutrient concentrations follow patterns in TSS, with low concentrations in the headwaters and a jump in concentration in the badlands, from the erosion and resuspension of highly erodible materials.

Nutrient concentrations are being affected by human activities in the Red Deer River Basin. The City of Lethbridge is a well-known contributor of dissolved nutrients to the Red Deer River, although upgrades to the municipal wastewater treatment facility have resulted in water quality improvements. A longitudinal survey of the Red Deer River in spring 1997 found that nutrient loading from tributaries is highly important during high spring flows. On such occasions, high tributary loads can have a large impact on the river. At this time, most of the phosphorus and nitrogen in the Red Deer River at Innisfail was loaded from the Little Red Deer River (TP = 1,704 kg/day, TN = 7,313 kg/day) and the Medicine River (TP = 3,444 kg/day, TN = 18,191 kg/day) rather than from further up the mainstem of the Red Deer River near the Dickson Dam (TP = 41 kg/day) (Anderson 1999). Loads are higher in the Medicine than the Little Red Deer because of higher flow rates at the former. Substantial loadings from the Blindman River have also been noted (Cross 1991). Over 30% of all three of these watersheds are covered by disturbed land (Red Deer River Watershed Alliance 2009), almost entirely as agriculture. Given the well-established relationship between agriculture and nutrient loading, it is likely that agricultural activities contribute nutrients to these watersheds and the Red Deer River. Due to relatively low water yields, other tributaries contribute smaller phosphorus loadings (Cross 1991). This is not surprising, given that vast areas in other portions of the basin do not contribute flow to the Red Deer River (Figure 42).

Source water for the EID comes from the Bow River Basin, and it has higher total and inorganic nitrogen concentrations that other irrigation district source water (Little et al. 2010). There are actually improvements in nitrogen concentrations as water flows through the EID (Little et al. 2010). Also, water quality does not degrade with respect to phosphorus as it passes through the Eastern Irrigation District (Little et al. 2010). Thus it is unlikely that irrigated lands are significantly affecting water quality of the Red Deer River.

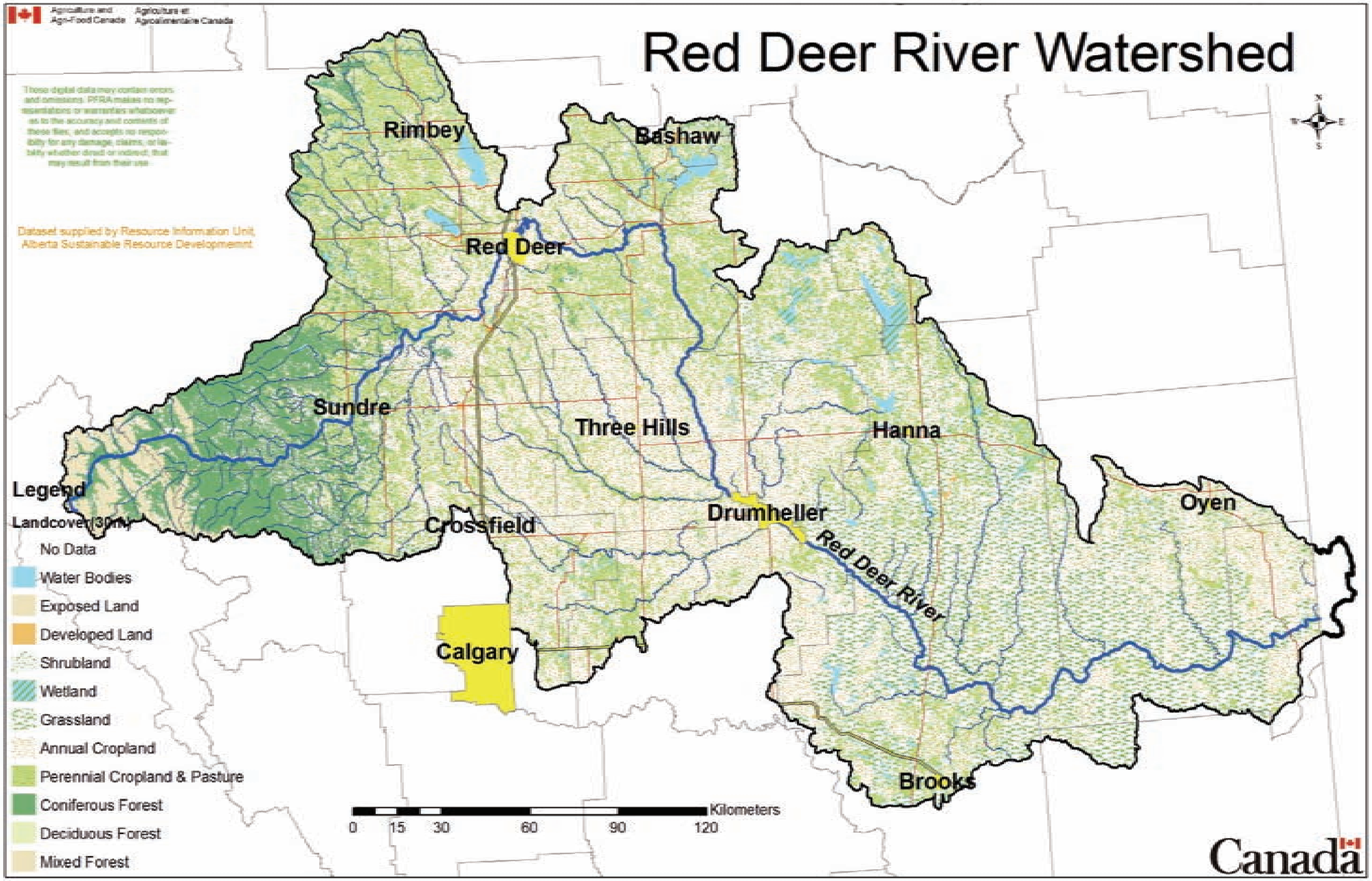

Figure 40: Land cover in the Red Deer River Watershed. From Red Deer Watershed Alliance 2009.

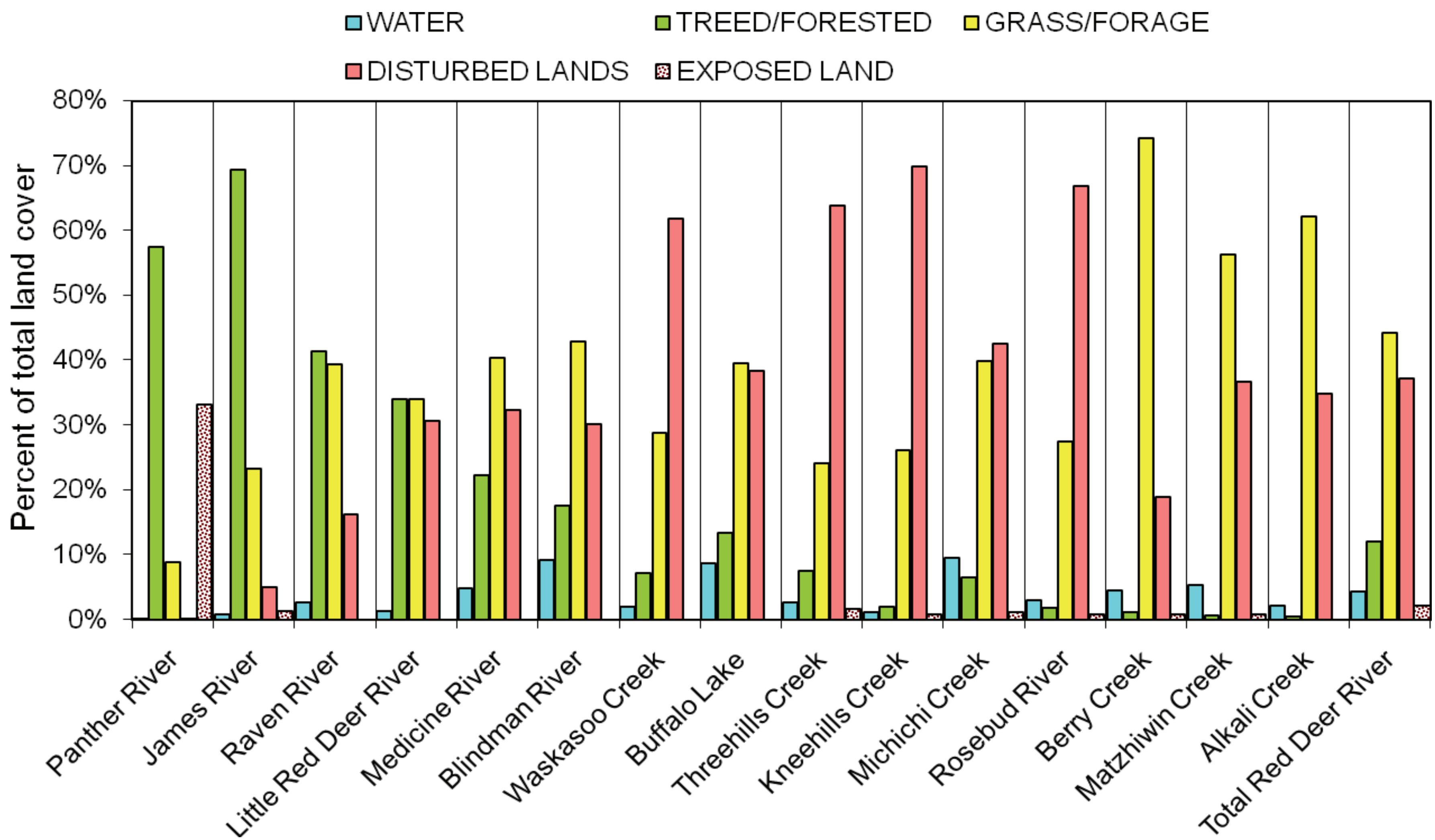

Figure 41: Land cover in sub-watersheds of the Red Deer River Basin. From Red Deer Watershed Alliance 2009.

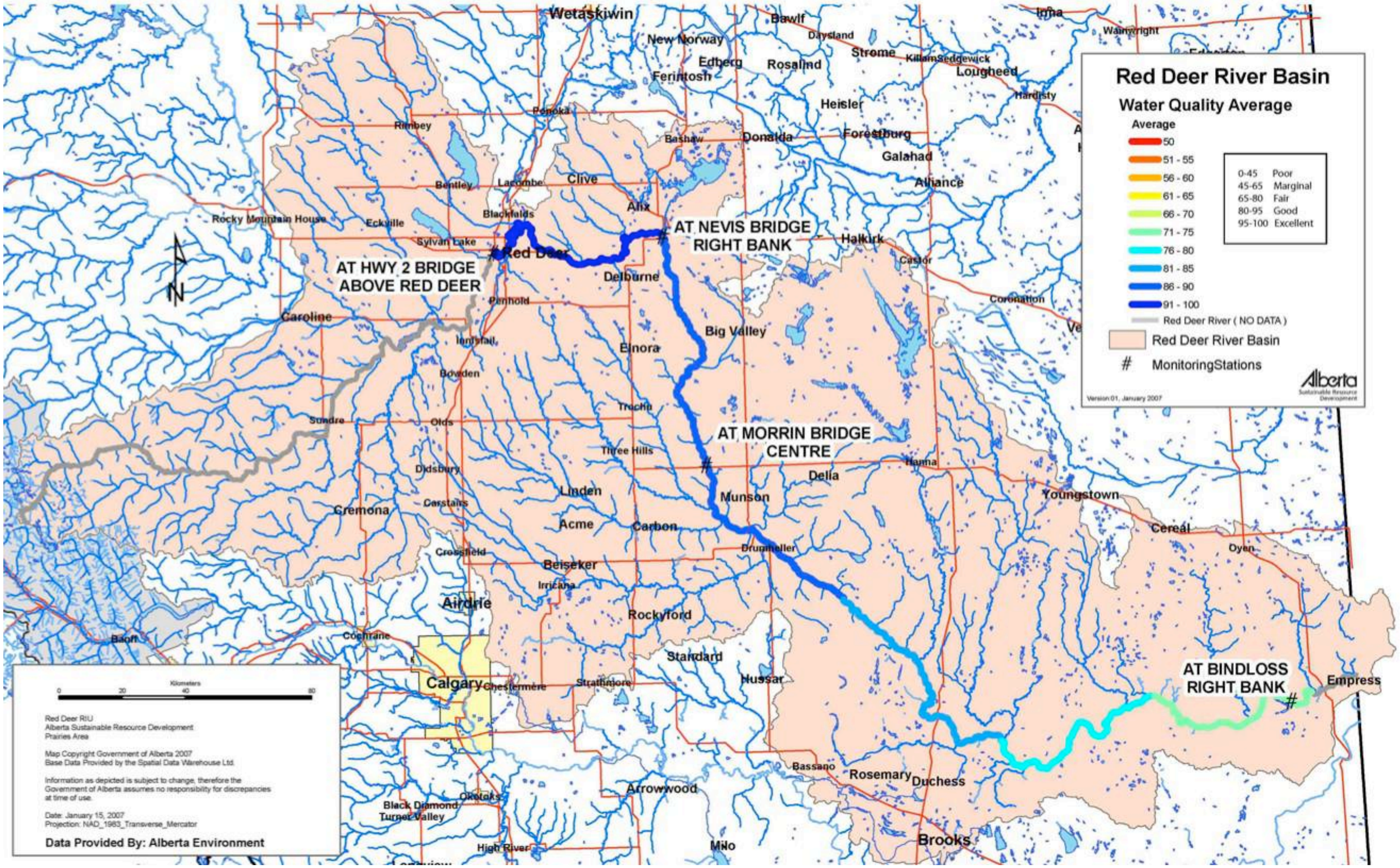

Figure 42: Alberta River Water Quality Index ratings along the Red Deer River. Retrieved on October 4 from www.rdrwa.ca.

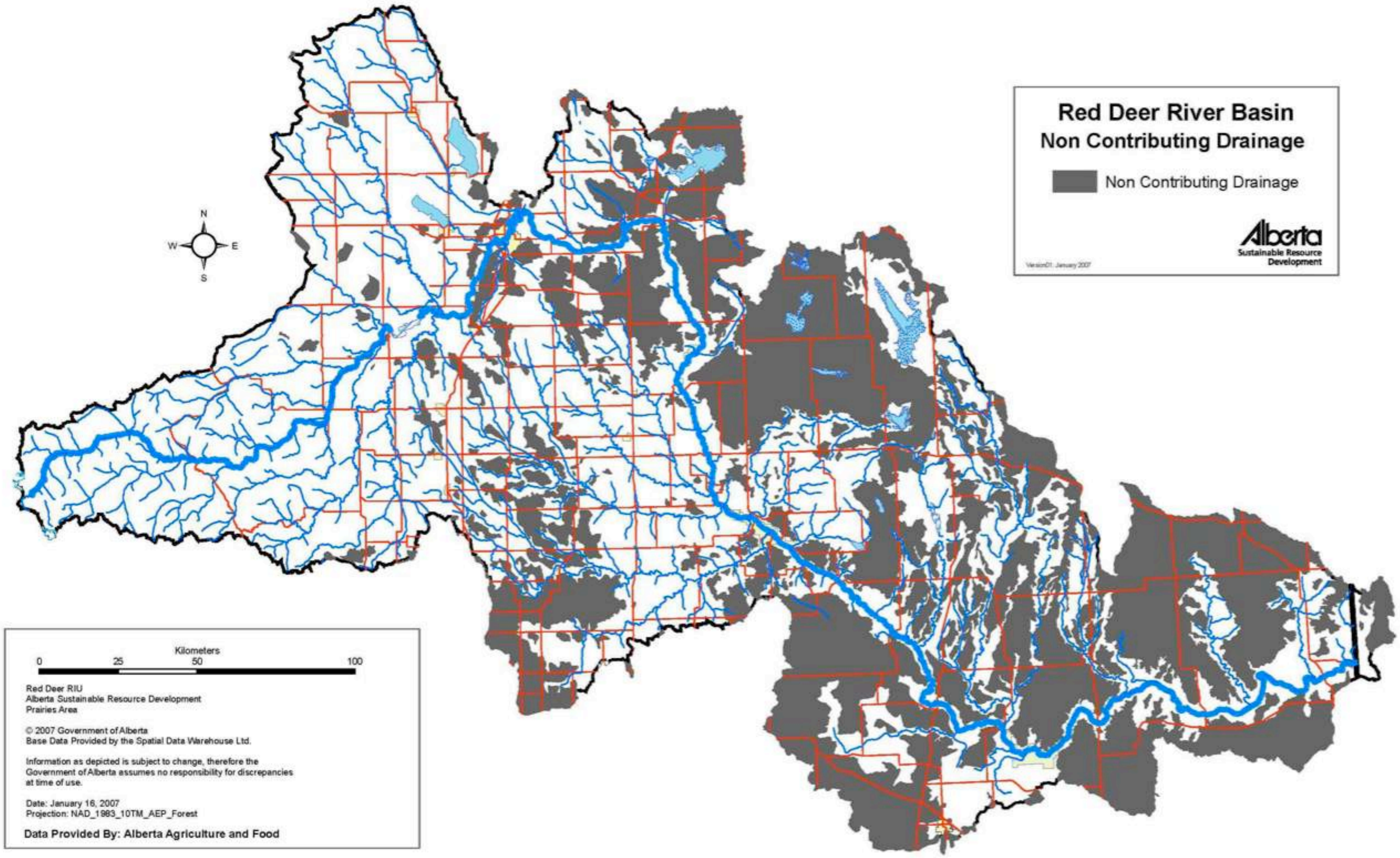

Figure 43: Non contributing drainage areas in the Red Deer River Basin. Retrieved on October 4 from www.rdrwa.ca.

Local-scale (tributaries)

Headwaters

Water quality data are very limited in the Panther River sub-basin. One sample taken in Douglas Creek (August 1991) exceeded ASWQ guidelines for total phosphorus and total nitrogen (Red Deer River Watershed Alliance 2009). In the James River watershed, water quality samples were most recently collected from 1994 through 1997. There were occasional exceedances of total phosphorus concentration guidelines, but the phosphorus loading cannot be attributed to a specific source. Possible anthropogenic sources include urban or agricultural runoff, but natural sources are also likely. Data are also scarce in the Raven River sub-basin. Sampling was only done at one location in 1991, and it did not exceed total phosphorus concentration guidelines.

Foothills

The Little Red Deer River sub-basin has the most water quality data from Fallentimber Creek, with small amounts from three other tributaries. Mean total phosphorus and total dissolved phosphorus have been above water quality guidelines for the tributaries that are close to cropland and livestock operations. In the Little Red Deer River sub-basin, there were no recorded exceedances of TN or inorganic N.

The Medicine River sub-basin has had two creeks sampled for nutrients: Black Creek through the mid to late 1990s, and Horseguard Creek through the early to mid 2000s. Both exceeded water quality guidelines for total phosphorous and nitrogen. Horseguard Creek receives runoff from cropland and pasture that are likely contributing phosphorus. Medicine River itself exceeded guidelines for total phosphorus and nitrogen during years of high precipitation (Anderson 1999).

The Blindman River sub-basin contains Gull Lake and Sylvan Lake, which frequently exceeded TP and TN guidelines in the 1970s and 80s. Both lakes' water quality has improved since that time, and the lakes usually have TP below guidelines. In the 60s and 70s, inorganic forms of nitrogen made up a substantial fraction of TN. In more recent years, it appears much of the N is bound in organic matter; therefore, soil erosion or manure is likely a larger contributor than chemical fertilizers. Tributary inflow accounts for 74% and 55% of the TP and TN load in Sylvan Lake; 9% and 33% of the load is atmospheric, and 16% and 12% is from groundwater or septic inflow (AXYS Environmental Consulting Ltd. 2005). Blindman River itself has consistently had high TP, TN and TDP since the 1960s. Also, nearly every stream monitored within the basin has had TP and TN above water quality guidelines (Red Deer River Watershed Alliance 2009). Agriculture covers large portions of this sub-basin, hence some agricultural contributions to nutrient loadings are likely. The city of Red Deer is also in this sub-basin. Urban and suburban fertilizer use then may also be a contributing factor to high nutrient concentrations in the river. With the city of Red Deer expected to grow in size and population over the next few decades, urban loadings of nutrients will also likely increase. Unless agricultural intensity increases, agricultural inputs are likely to remain stable.

Parkland

Waskasoo sub-basin does not have surface water nutrient data.

Within the Buffalo watershed, usually Buffalo Lake and occasionally Alix Lake exceed TP, TN and TDP water quality guidelines (Red Deer River Watershed Alliance 2009). Little Buffalo Creek and Haynes Creek also have elevated TP and TN. Anderson et al. (1998a) determined that runoff from cattle wintering grounds during spring melt contributes nutrients in sufficient amounts to cause increases in concentrations and mass loads in Haynes Creek, and to induce declines in compliance with surface water quality guidelines. During spring melt, runoff from specific agricultural activities can have an impact on stream water quality. During a high runoff year (1996), authors also measured high losses of nitrogen (39%) and phosphorus (16%) that had been applied in fields in the previous growing season, which are deemed to be environmentally and economically significant.

Within the Three Hills Creek sub-basin, Ghostpine Creek and Pine Lake have frequently exceeded guidelines for TP and TN. Cropland and pasture cover 80% of this sub-basin and are suspected to be sources of nutrients to surface waters.

Within the Kneehills Creek sub-basin, Kneehills Creek and Lonepine Creek have had sporadic water quality assessments from the mid 1980s through mid 1990s. TP and TN frequently exceeded guidelines. Although a definite source is not known, cropland and grazing are both predominant land cover classes in the sub-basin and may contribute to nutrient loading (Red Deer River Watershed Alliance 2009). Naturally nutrient rich soils in the area are also a likely contributing source.

Prairie

Water quality was assessed once in the mid 1980s within the Michichi Creek sub-basin at Wolf Creek. At that time, TP and TN concentrations were above water quality guidelines (Red Deer River Watershed Alliance 2009). Nutrient loading may be related to the high cover of cropland and grazing in the area.

Water quality has not been assessed in the Rosebud River sub-basin since the mid 1980s. At that time, TP and TN concentrations in Serviceberry Creek were above water quality guidelines (Red Deer River Watershed Alliance 2009). There is a high portion of cropland and grazing in the region, which likely contribute to nutrient loads.

TP and TN concentrations in the Berry Creek sub-basin exceed water quality guidelines in Berry Creek and Bullpound Creek. Nutrient loading may partially be coming from the cropland and livestock operations near both creeks. Naturally nutrient rich soils in the area are also a likely contributing source.

Water quality data are scare within the Matzhiwin Creek sub-basin. The most current data, from 2005, show that TP and TDP concentrations are below water quality guidelines in the Crawling Valley Reservoir (Red Deer River Watershed Alliance 2009). Water quality sampling has only been completed sporadically in the Alkali Creek sub-basin from the mid 1980s through 2000. TP did not exceed water quality guidelines. TN exceeded water quality guidelines in Indian Blood Creek, although a source could not be determined as agricultural intensity is low in that portion of the sub-basin (Red Deer River Watershed Alliance 2009).

PESTICIDES

Basin-scale (mainstem)

The Alberta River Water Quality Pesticide index is excellent to good for the mainstem of the Red Deer River (Alberta Environment 2011b). Pesticides have been detected in 40% of samples collected on the mainstem, with total concentrations ranging from 0 to 10.6 µg/L. The maximum number of pesticides detected in any one sample is 8 (Anderson 2005). Pesticide concentrations and diversity increase beyond the City of Red Deer. 2,4-D, MCPP, picloram, dicamba, and imazamethabenz all show non-significant increases in detection downstream of Red Deer, reflecting their use in the city. Agricultural sources upstream of Red Deer are also important. The relative loading of pesticides by urban use in Red deer is considerably smaller than those of larger cities in other river basins. This is due to both considerable agricultural influence upstream of Red Deer and the smaller size of Red Deer compared to Edmonton or Calgary (Anderson 2005).

Local-scale (tributaries)

Headwaters

There are no data related to pesticide concentrations for any water body within the Panther River sub-basin, James River, or Raven River.

Foothills-Parkland

Eleven different pesticides have been detected in surface waters of the Little Red Deer River sub-basin, although no samples exceeded water quality guidelines where they exist. 2,4-D and MCPA were the most widely detected. Fourteen pesticides were detected in surface waters of the Medicine River sub-basin but none exceeded existing water quality guidelines. MCPA and 2,4-D were the most widely detected. There have been 14 pesticides detected in 15 water bodies within the Blindman River sub-basin. Most commonly detected were 2,4-D and MCPA, but none of the pesticides exceeded water quality guidelines (Red Deer River Watershed Alliance 2009). These are likely from agricultural sources since urban development is minimal in this sub-basin.

Parkland

Waskasoo Creek sub-basin does not have surface water pesticide concentration data. Three water bodies in Buffalo sub-watershed have been tested for pesticides, and six pesticides were detected at low concentrations. 2,4,-D, MCPA, and triallate were the most frequently detected (Red Deer River Watershed Alliance 2009). Twenty different pesticides have been detected in six water bodies in the Three Hills Creek sub-basin although none have exceeded water quality guidelines. Most frequently detected were 2,4-D, dicamba, and MCPA (Red Deer River Watershed Alliance 2009). There are no surface water pesticide concentration data for the Kneehills Creek sub-basin. Buffalo Creek was sampled intensively during the AESA stream study. Pesticides were detected in all samples and concentrations occasionally exceeded water quality guidelines for MCPA (Lorenz et al. 2008).

In a study of Haynes Creek during a very wet time-period (1995-1996), most pesticide detections were made at Haynes Creek sites, little detection was made in the Red Deer River upstream of Haynes Creek, and there were no detections at a control site. Eight of the 13 compounds analysed were detected. Fifty percent of the trifluralin and 38% of the triallate detections exceeded guidelines for the protection of aquatic life; 43% of the MCPA and 66% of the bromoxynil detections exceeded irrigation guidelines (Anderson et al. 1998a). These results indicate environmental impacts related to pesticides in small intensive agricultural watersheds in the Red Deer Basin.

Prairie

Michichi Creek sub-basin has only had pesticide concentrations measured in Foxall Lake. 2,4-D and MCPA were both detected at levels below water quality guidelines (Red Deer River Watershed Alliance 2009). Twelve pesticides have been detected in the Rosebud River, none of which exceeded water quality guidelines. Pesticides with the highest concentrations were 2,4-D, MCPA, and dicamba. There are no surface water pesticide concentration data available in the Berry Creek sub-basin, the Matzhiwin sub-basin, or the Alkali sub-basin.

PATHOGENS

Basin-scale (mainstem)

The Alberta River Water Quality Index for bacteria was recently ranked excellent for 3 out of 4 long-term monitoring stations along the Red Deer River. Historically, the ranking was good, indicating occasional exceedances of water quality guidelines. Downstream, the ranking is fair for the station at Jenner (Alberta Environment 2011c). There is no long-term temporal trend to *E. coli* exceedances in the mainstem. Most of the exceedances tend to occur in June, when temperature and flow are relatively high (Red Deer River Watershed Alliance 2009). Potential non-point sources of bacteria in the Red Deer River include spreading of manure and seepage from septic fields. Point sources are also likely where smaller wastewater treatments plants do not have tertiary treatment.

Local-scale (tributaries)

Headwaters

No pathogen data was found for any water body within the Panther River sub-basin or the Raven sub-basin. In the James River sub-basin, only one water sample was analyzed for bacteria, and it was within water quality guidelines. No parasite data are available.

Foothills

No data is available for the Little Red Deer River sub-basin.

Horseguard Creek in the Medicine River sub-basin, and Medicine River, exceeded guidelines for fecal coliforms in the mid 2000s. Manure production and livestock density are low in the areas, and bacteria seemed to be associated with storm events. *Cryptosporidium* and *Giardia* were also detected near moderate intensity grazing sites and feedlots.

In the Blindman River sub-basin, nearly every stream that has been sampled has had fecal coliform bacteria levels in excess of agriculture, irrigation, and recreation water quality guidelines, although total coliform concentrations have been more moderate (Red Deer River Watershed Alliance 2009). This has been attributed to high manure production rates throughout most of the sub-basin, but could also be related to urban runoff, wildlife, or faulty septic systems (Red Deer River Watershed Alliance 2009). There are no parasite data for the Blindman sub-basin.

In the Little Red Deer River sub-basin, fecal coliform concentrations in Fallentimber Creek have occasionally exceeded water quality guidelines for irrigation, but the source of contamination was not determined. The Little Red Deer River and Beaverdam Creek have also exceeded guidelines, and it was speculated in these cases that agricultural runoff could be the source.

Parkland

Waskasoo sub-basin does not have surface water pathogen data.

Buffalo sub-basin has limited surface water bacteria data. Alix Lake, Buffalo Lake, and Little Buffalo Creek have been under guidelines although have been sampled very infrequently (Red Deer River Watershed Alliance 2009). There are no parasite data for the Buffalo sub-basin.

Within the Three Hills sub-basin, bacteria have only been measured for a short period in Pine Lake. In that time, fecal and coliform bacteria concentrations were generally low (Red Deer River Watershed Alliance 2009). No data are available for parasites in this sub-basin.

Total coliform and fecal coliform bacterial concentrations have exceeded guidelines in Kneehills Creek by a considerable margin, which may be related to a high density of livestock in the area. Lonepine Creek had bacterial concentrations well below water quality guidelines (Red Deer River Watershed Alliance 2009). Parasite data are not available for Kneehills Creek sub-basin.

Prairie

No surface water pathogen data are available for the Michichi Creek sub-basin.

Within the Rosebud River sub-watershed, total and fecal coliforms were measured in Serviceberry Creek during the mid 1980s. Both concentrations were below water quality guidelines (Red Deer River Watershed Alliance 2009).

Berry Creek and Bullpound Creek in the Berry Creek sub-basin both have fecal coliform concentrations below water quality guidelines (Red Deer River Watershed Alliance 2009). No parasite data are available for the Berry Creek sub-basin.

Bacterial concentrations have been assessed in several streams within the Matzhiwin Creek sub-basin. In many cases, fecal coliform and total coliform concentrations exceed water quality guidelines and have been attributed to cropland and livestock throughout the sub-basin (Red Deer River Watershed Alliance 2009). There are no parasite data for these streams.

Only five water samples have been analyzed for bacterial concentration in the Alkali Creek sub-basin. Fecal coliform concentrations exceeded guidelines in Blood Indian Creek but not Alkali Creek (Red Deer River Watershed Alliance 2009). No parasite data are available for the Alkali sub-basin.

METALS

Metals are correlated to stream flow and TSS in the Red Deer River. Thus, metals closely follow patterns in TSS along the river. The Alberta River Water Quality Index for metals rates the mainstem water quality as good to excellent. However, aluminum and iron water quality guidelines have frequently been exceeded in the lower river at Bindloss during high flow events. In parallel to TSS, this has been related to the highly erodible soils of the badlands between Drumheller and Saskatchewan (Red Deer River Watershed Alliance 2009).

3.10.3 Data

There are four long-term river monitoring stations on the Red Deer River: one just upsteam of Red Deer at Highway 2 and the other three downstream of Red Deer at Nevis Bridge, Morrin Bridge, and Jenner. The PPWB also monitors the Red Deer River at Bindloss. More intensive water quality sampling occurred in the years immediately preceding and following construction of the Dickson Dam in 1983 (Shaw and Anderson 1994, Cross 1991).

3.10.4 Synthesis

Two features - the Gleniffer Lake Reservoir and the badlands - provide the tapestry for water quality in the Red Deer River. The Gleniffer Lake Reservoir is a sink for TSS, and constituents associated with it (mainly total nutrients, pathogens, and certain metals), thereby reducing constituent loads from the headwaters, particularly during peak flows. Downstream, TSS and related constituents particularly increases in the lower reaches (between Drumheller and the Saskatchewan border) due to high natural erodibility of soils as the river passes through the badlands.

Tributaries that drain foothills-boreal-parkland subregions (Little Red Deer, Blindman, and Medicine Rivers) contribute important flows to the Red Deer River. Other downstream tributaries produce relatively low yields, which reflect vast areas in those portions of the basin that do not contribute flow to the Red Deer River. Nutrient loadings mirror these differences in water yield.

In addition to this background influence on water quality in the Red Deer River mainstem, human activity has been demonstrated to affect tributary water quality. Pesticide concentrations and diversity increases beyond the City of Red Deer, reflecting NPS pollution from their use in the city. Nearly 40% of the Red Deer Basin is covered by disturbed lands, most of which is concentrated in the central portion of the Basin. In this area, nearly every stream monitored had TP and TN concentrations above water quality guidelines and pesticide detections. Also, fecal coliforms were frequently detected above surface water quality guidelines in sub-basins with high densities of livestock (Kneehills and Blindman sub-basins). Extensive study of Haynes Creek, a small high-intensity agricultural stream, showed that streams that drain intensively farmed land in this Basin have higher nutrient levels and more frequent pesticide detections than streams that drain land farmed at moderate or low intensity. There was high (often 100%) frequency of non-compliance with surface water quality guidelines in Haynes Creek for total phosphorus and nitrogen, nitrite, fecal coliforms and fecal enterococci. Of particular concern is relatively high (>38%) proportion of samples that exceeded guidelines for the protection of aquatic life for certain pesticides, indicating environmental degradation. This study also showed that cattle wintering grounds located in the floodplain significantly increased sediment, nutrients and pathogen concentrations in Haynes Creek, indicating the importance of such sensitive areas during flooding.

In terms of gaps, there is a very poor understanding of the significance of urban runoff on NPS pollution in the Red Deer River Basin. To increase our knowledge, collection and synthesis of stormwater water quality information is required. In addition, there are no comprehensive datasets on tributaries in the Red Deer Basin. Perhaps the most useful dataset was collected in 1983-1984 and summarized by Cross (1991). Important changes in wastewater treatment, in particular, have occurred since then. Thus quantitative data on non-point loadings, relative to point-source loadings, are an unknown at present time. Much of these data gaps could be filled using a synoptic monitoring approach.

Other gaps include a complete lack of information on recreational use in the basin. In addition, although oil and gas well densities have been reported and can be very high in this sub-basin, little information exists on cumulative environmental impacts.

3.10.5 References

Alberta Environment. 2001. Mean Annual Natural River Discharges (from 1994 State of the Environment Comprehensive Report). Retrieved from http://www3.gov.ab.ca/env/water/images/mardmap.pdf.

Alberta Environment. 2011a. 2009-10 River Water Quality Index ratings for Nutrients. Retrieved from http://environment.alberta.ca/01282.html.

Alberta Environment. 2011b. 2009-10 River Water Quality Index ratings for pesticides. Retrieved from http://environment.alberta.ca/01278.html.

Alberta Environment. 2011c. 2009-10 River Water Quality Index ratings for Bacteria. Retrieved from http://environment.alberta.ca/01280.html.

Anderson, A.-M. 1999. Water quality of the Battle River. Page 30. Alberta Environment, Edmonton, AB. Retrieved from http://environment.gov.ab.ca/info/library/5807.pdf.

Anderson, A.-M. 2005. Overview of pesticide data in Alberta surface waters since 1995. Page 190 pp. Alberta Environment, Environmental Monitoring and Evaluation Branch, Edmonton, Alberta. Retrieved from http://environment.gov.ab.ca/info/library/7614.pdf.

AXYS Environmental Consulting Ltd. 2005. Sylvan Lake water quality assessment and watershed management considerations. Page 441. Calgary, Alberta. Retrieved from http://www.lacombecounty.com/index.php?option=com_docman&task=doc_download&gid=296&Itemid=15.

Campbell, I. A. 1977. Stream discharge, suspended sediment and erosion rates in the Red Deer River basin, Alberta, Canada. Pages 244-259 Erosion and solid matter transport in inland waters Symposium. Paris. Retrieved from http://itia.ntua.gr/hsj/redbooks/122/iahs_122_0244.pdf.

Cross, P. M. 1991. An overview of water quality in the Red Deer Basin (1983-1984). Alberta Environment.

Little, J., A. Kalischuk, and C. Sheedy. 2010. Assessment of water quality in Alberta's irrigation districts. Second edition. Page 181 pp. Alberta Agriculture and Rural Development, Edmonton, Alberta. Retrieved from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13000/$FILE/wqreportfull_nov2010.pdf.

Lorenz, K., S. Depoe, and C. Phelan. 2008. Assessment of environmental sustainability in Alberta's agricultural watersheds project: Volume 3: AESA water quality monitoring project. Page 543 pp. Alberta Agriculture and Rural Development.

Red Deer River Watershed Alliance. 2009. Red Deer River state of the watershed. Red Deer, AB. Retrieved from http://www.rdrwa.ca/sow.php.

Shaw, R. D., and A. M. Anderson. 1994. The effect of the Dickson Dam on water quality and zonnbenthos of the Red Deer River. Page 151. Alberta Environmental Protection. Retrieved from http://environment.gov.ab.ca/info/library/7982.pdf.

3.11 Southeast Alberta

3.11.1 Introduction

The entire South Saskatchewan River Basin drains an area of 121,000 km^2 and its three main tributaries are the Red Deer, Bow, and Oldman rivers. The South Saskatchewan River begins at the confluence of the Bow River and the Oldman River at Grand Forks, about 60 km east of the Saskatchewan border. The land that drains directly into the South Saskatchewan River is called the South Saskatchewan River Sub-basin and 14,000 km^2 of this catchment area is in Alberta (South East Alberta Watershed Alliance 2009). The sub-basin receives minimal precipitation; mean annual precipitation at Medicine Hat is 322 mm (South East Alberta Watershed Alliance 2009). Most of this falls as rain.

Mean annual discharge at the Saskatchewan border is 7,440,000 dam^3 (Alberta Environment 2001). Most of this flow originates in the Bow (4,085,000 dam^3) and Oldman (3,191,000 dam^3) rivers (Bow River Basin Council 2010, State of the Watershed Team 2010). Because most of the flow of the South Saskatchewan River in Alberta comes from the Bow and Oldman rivers, flows peak in June due to mountain snowmelt and lowest flows occur in winter. Water quality in the mainstem also reflects water quality in the Bow and Oldman Rivers. The largest tributaries within the South Saskatchewan sub-basin are Seven Persons Creek, Ross Creek, Bullshead Creek and Gros Venture Creek. Annual runoff from these local tributaries is highly variable and varies with precipitation.

The population of the South Saskatchewan River sub-basin in 2001 was 65,451. Urban municipalities contain 88% of the population. Medicine Hat is the largest city (population 60,426 in 2006) (South East Alberta Watershed Alliance 2009).

Agriculture is the dominant land use in the South Saskatchewan River Sub-basin; farms cover 11,000 km^2 or roughly 80% of the sub-basin. One-quarter of the agricultural land is used to grow crops while 63% of the agricultural land is used for pasture (South East Alberta Watershed Alliance 2009). The St. Mary Irrigation District is located within the sub-basin.

3.11.2 Knowledge

Nutrients

At the long-term river monitoring network station upstream of Medicine Hat, the mainstem of the South Sasktachewan River has an Alberta River Quality Index Ranking for nutrients of fair (Alberta Environment 2011a). Total phosphorus concentration have decreased since 2000 at that station. For five of the years from 2000 to 2008, total phosphorus exceeded water quality guidelines in less than 10% of recorded measurements (South East Alberta Watershed Alliance 2011). Some of this reduction in phosphorus concentrations may be related to improvements at wastewater treatment plants (far upstream at Calgary and Lethbridge). Urban contributions (both wastewater and stormwater) are considered to be the biggest non-natural sources of phosphorus to the SSR sub-basin (South East Alberta Watershed Alliance 2011). Other sources are sedimentation, erosion, and agriculture. From 2003 to 2008, TP concentrations consistently exceeded water quality guidelines at least 10% of the time at the Alberta-Saskatchewan border (South East Alberta Watershed Alliance 2011). Total nitrogen concentrations in the mainstem from 1995 to 2008 have exceeded water quality guidelines in at least 10% of recorded measurements in all years except for 2006 and 2007, when guidelines were exceeded in more than half of recorded measurements (South East Alberta Watershed Alliance 2011).

There are little to no data for the tributaries of the SSR sub-basin. Drain S6 is part of the St. Mary Irrigation District, and was included in the AESA stream survey. Water was in compliance with TP guidelines in 69% of samples, with TN guidelines in 83% of samples, with NO2-NO3 guidelines in 100% of samples, and with NH_3-N guidelines in 93% of samples (Lorenz et al. 2008). The St. Mary Irrigation District has significantly more particulate phosphorus and organic nitrogen in its return flows than in its source water (Little et al. 2010). It suggests, then, that soil erosion causes higher loading that use of chemical fertilizers.

Salts

Water quality has met guidelines for total dissolved solids in nearly all recorded samples from 1995 to 2008 across the mainstem of the South Saskatchewan River (South East Alberta Watershed Alliance 2011). There are no data available for tributaries within the South Saskatchewan River sub-basin.

Metals

At the long term river monitoring network station upstream of Medicine Hat, the mainstem of the South Sasktachewan River has an Alberta River Quality Index Ranking for metals of excellent

(Alberta Environment 2010). There are no data available for tributaries within the South Saskatchewan River sub-basin.

Pesticides

At the long term river monitoring network station upstream of Medicine Hat, the mainstem of the South Sasktachewan River has an Alberta River Quality Index Ranking for pesticides of good (Alberta Environment 2011b).

There is little to no data available for tributaries within the South Saskatchewan River sub-basin,;however, Drain S6 from the St. Mary Irrigation District was included in the AESA stream survey. Pesticides were detected in about 70% of samples from Drain S6, and about 35% of samples showed non-compliance with water quality guidelines (Lorenz et al. 2008). Dicamba, MCPA, and 2,4-D were the three pesticides with non-compliance. More than 15 pesticides were detected within Drain S6 with a median of 6 pesticides per sample (Lorenz et al. 2008).

Pathogens

At the long-term river monitoring network station upstream of Medicine Hat, the mainstem of the South Sasktachewan River has an Alberta River Quality Index Ranking for bacteria of excellent (Alberta Environment 2011c). *E. coli* concentrations were highly variable from 1995 to 2008 throughout the mainstem of the SSR (South East Alberta Watershed Alliance 2011).

There are little to no data available for tributaries within the South Saskatchewan River sub-basin. Drain S6 was included in the AESA stream survey and was in compliance with fecal coliforms irrigation water quality guidelines in 62% of samples. Drain D6 met recreation water quality guidelines for *E. Coli* in 76% of samples (Lorenz et al. 2008).

3.11.3 Data

AENV maintains one long-term river monitoring network site above Medicine Hat. Environment Canada maintains a monitoring station on the Alberta-Saskatchewan border near Highway 41. There are little to no water quality data available for the tributaries within the South Saskatchewan River sub-basin.

3.11.4 Synthesis

Overwhelmingly, quality in the mainstem of the South Saskatchewan River reflects the quality of the Bow and the Oldman rivers. Agricultural and urban land uses are the dominant sources of NPS pollution in this basin, with pollutants of most concern being nutrients and pesticides.

3.11.5 References

Alberta Environment. 2001. Mean Annual Natural River Discharges (from 1994 State of the Environment Comprehensive Report). Retrieved from http://www3.gov.ab.ca/env/water/images/mardmap.pdf.

Alberta Environment. 2010. Alberta River Water Quality Index-Metals (2009-2010). Retrieved from http://environment.gov.ab.ca/info/library/7718.pdf.

Alberta Environment. 2011a. 2009-10 River Water Quality Index ratings for Nutrients. Retrieved from http://environment.alberta.ca/01282.html.

Alberta Environment. 2011b. 2009-10 River Water Quality Index ratings for pesticides. Retrieved from http://environment.alberta.ca/01278.html.

Alberta Environment. 2011c. 2009-10 River Water Quality Index ratings for Bacteria. Retrieved from http://environment.alberta.ca/01280.html.

Bow River Basin Council. 2010. Web-based state of the watershed tool. Retrieved from http://wsow.brbc.ab.ca/.

Little, J., A. Kalischuk, and C. Sheedy. 2010. Assessment of water quality in Alberta's irrigation districts. Second edition. Page 181 pp. Alberta Agriculture and Rural Development, Edmonton, Alberta. Retrieved from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13000/$FILE/wqreportfull_nov2010.pdf.

Lorenz, K., S. Depoe, and C. Phelan. 2008. Assessment of environmental sustainability in Alberta's agricultural watersheds project: Volume 3: AESA water quality monitoring project. Page 543 pp. Alberta Agriculture and Rural Development.

South East Alberta Watershed Alliance. 2009. Geography of the South Saskatchewan River Basin: SEAWA watershed report 2009-1. Medicine Hat, AB. Retrieved from http://www.albertawater.com/seawa/reports/SEAWA%20Watershed%20Report%202009-1%20Geography.pdf.

South East Alberta Watershed Alliance. 2009. Land use planning and water licensing/allocation in the South Saskatchewan River Sub-basin. Page 34. Medicine Hat, AB.

South East Alberta Watershed Alliance. 2011. State of the Watershed-SEAWA. Retrieved from http://www.seawa.ca/index.php?option=com_content&view=article&id=116&Itemid=113.

State of the Watershed Team. 2010. Oldman River state of the watershed report. Retrieved from oldmanbasin.org.

4.0 DATA

Here we describe data that is available at a provincial scale. Water quality data that is available for each basin is described under each sub-section of Section 3.0.

4.1 Water Quality Data

Alberta government agencies monitor water quality in rivers, stream, lakes, and wetlands across the province. All data are available through the Water Database System, and measured parameters include metals, pathogens, pesticides, organic compounds, and inorganic parameters (Alberta Environment 2011a).

Up until recently, the AESA program monitored 23 streams in agricultural areas during both high and low flows every year. NPS pollutants measured in this program included pesticides, nutrients, and pathogens in addition to many standard water quality parameters (Lorenz et al. 2008). The historical database associated with these streams span 8 to 13 years (Anderson et al. 1998). There has also been considerable water quality data collected from irrigation systems in southern Alberta, available in Appendix 3 of Little et al.'s (2010) assessment of water quality in Alberta's irrigation districts.

As part of the PPWB Master Agreement on Apportionment, Environment Canada has long-term water quality monitoring sites located on major rivers along the Alberta-Saskatchewan border. Water samples are collected and analyzed for a range of parameters and compared with the PPWB water quality objectives in Schedule E of the Master Agreement.

Urban centres are also required to monitor water quality as part of their approval conditions for operating storm water systems. This data is reported to Alberta Environment annually. Urban centres also frequently operate expanded monitoring programs, such as that described in Section 3.7 for the City of Edmonton.

4.2 Soils, Geology and Topography

Physical properties of soil influence surface water runoff and chemical properties of soils influence nutrient export rates, making soil data important components of NPS pollution assessments. Soils and landform data for the white zone in Alberta are available from the Agricultural Regions of Alberta Soils Inventory Database (AGRASID) 3.0 database (Alberta Agriculture and Rural Development 2011).

The Alberta Geological Survey has a variety of data sources that may be useful in assessing NPS pollution. Some examples of their data include lake bathymetry and mineral resource information. Knowing where resource extraction and exploration may occur in the future could be useful in predicting future non-point pollution sources. Surficial sediment data are also available for some basins in Alberta that are not covered by AGRASID (Alberta Geological Survey 2011).

The Alberta Digital Elevation (DEM) data contains three dimensional spatial ground elevation values representing grid points, break lines, and spot heights that have been compiled using 1:60 000 aerial photography. This data is available from Alberta Sustainable Resource Development.

4.3 Land Use

Examples of land uses are agricultural, residential, commercial, recreational, industrial, transportation, utilities, resource extraction, or natural areas. Uses influence the physical conditions of a watershed (runoff vs. recharge). Also, they each may be associated with particular NPS pollutants. Land use data can be good surrogates for nutrients when modelling water quality outcomes, such as chlorophyll a (Carr et al. 2005).

Agricultural

Statistics Canada conducts agricultural surveys every five years (Statistics Canada 2011). Examples of NPS pollution relevant data available from these surveys include pesticide use, amount of actively farmed land in watersheds, and fertilizer use. The most recently available data is from 2006.

Forestry

The National Forestry Database contains forest industry land use data, summarized annually by province (Government of Canada 2011). Although this level of resolution may not be useful for assessing NPS pollution for individual watersheds, it is useful for looking at overall provincial trends in pesticide use and harvest rates.

Land Cover

Land cover refers to vegetation, structures, and other features that cover the landscape. This information should be considered when assessing NPS pollution because it can have profound effects on factors such as timing and delivery of pollutants. Impervious surfaces, for example, will direct stormwater and the pollutants it carries into waterbodies with greater magnitude and speed than vegetated areas.

A wide variety of land cover data layers are available in Alberta. A few examples are as follows:

- Alberta Vegetation Inventory (AVI) covers portions of Alberta's forested areas and identifies type, location, and extent of vegetation. Potential users of AVI data need to make data sharing agreements with forest management companies who maintain the databases in order to access the data (Alberta Sustainable Resource Development 2011).
- Central Parkland Native Vegetation Inventory covers the aspen parkland region of Alberta and was last updated in 2003. The data is available from ASRD (Alberta Sustainable Resource Development 2011).
- Native Prairie Vegetation Inventory was originally designed as a complete inventory of the non–forested crown land and was last updated in 2004. It is available through ASRD (Alberta Sustainable Resource Development 2011).
- Provincial Wetland Inventory is being completed as a joint effort between Alberta Environment and Ducks Unlimited. The spatial database includes wetland class, extent, and status (Ducks Unlimited Canada 2011). Once completed, this initiative should be useful for assessing NPS pollution given the extent to which wetlands can act as sinks and as sources for various NPS pollutants.
- Prairie Farm Rehabilitation Administration (PFRA) generalized landcover data is available for agricultural areas in Canada. This landcover imagery is available for 1995 and 2000 and has a 30 m resolution.

4.4 Meteorological Data

Daily precipitation and temperature data are available for many regions of Alberta through Environment Canada's National Climate Data and Information Archive. This data is available free of charge online (Environment Canada 2010).

5.0 TOOLS

In the broadest sense, tools for assessing water quality fall into two types: 1) empirical methods, which involve assessing field measurements to form interpretations about current or historic water quality, and 2) simulation models, from which predictions about future water quality can be made.

Some useful empirical tools for assessing NPS pollution impacts to water quality in Alberta are as follows.

5.1 Surface Quality Guidelines and Site-Specific Objectives

Surface Water quality guidelines can be used in conjunction with monitoring programs to assess which nonpoint source pollutants are in concentrations above recommended maxima, and therefore likely causing problems for freshwater aquatic life, agriculture uses (livestock and irrigation), and recreation or aesthetics. Where water quality data do not exceed values outlined in these guidelines, than problems associated with NPS pollutants are unlikely. When values are exceeded, however, further investigations will be required with respect to potential sources, extent, and potential consequences of the exceedance.

This is a straight-forward way to evaluate the environmental significance of surface water contamination in Alberta. However, these guidelines do not discuss all contaminants that could have environmental effects. Naphthenic acids, certain pesticides and PACs, and pharmaceuticals are some examples of NPS pollutants that cannot currently be assessed using surface water quality guidelines in Alberta.

Water quality objectives establish the conditions necessary to support and protect the most sensitive designated use of water at a specified site. Objectives are typically based on generic water quality guidelines, which may be modified to account for local environmental conditions. Examples of site-specific objectives include:

- The Prairie Provinces Water Board (PPWB) water quality objectives developed and applied at the AB-SK border specifically for each of the Beaver River, NSR, Battle River, Red Deer River and SSR.
- The Muskeg River Interim Management Framework for Water Quantity and Quality, which contains water quality targets and limits.
- Proposed site-specific water quality objectives for the mainstem of the NSR

5.2 Mass loads, Export Coefficients, and Flow Weighted Concentrations (Cooke et al. 2005)

A mass load is a calculation of the total mass of a pollutant carried within a stream or river, and can be used to assess the magnitude of impact on downstream water bodies. To calculate a mass load, one needs to know sample concentrations, instantaneous stream flow rates, and the length of time that each sample represents. Calculating accurate mass loads for NPS pollutants requires samples collected during periods of high flow. This is because most NPS pollutants are delivered during periods of high flow, such as spring snowmelt or extreme summer precipitation events.

Mass export coefficients describe mass loads per unit area of a watershed. The primary purpose would be determining amount of pollutant leaving a particular area, but these calculations also permit general comparisons of non-point pollutant loads among watersheds of different sizes.

Flow weighted mean concentrations are mass loads per total stream flow volume for a given period of time. This will allow comparisons to be made among years or seasons for a particular river reach, or can permit comparisons among streams with different flow volumes.

5.3 Indexes

AENV uses a variety of water quality indexes when reporting yearly water quality information to the public (Alberta Environment 2011b). The Alberta River Water Quality Index mathematically combines chemical, biological, and physical data into simple composite descriptors and allows for easy comparison of overall water quality among river basins and among years. The indexes consider how many water quality parameters fail to meet water quality objective, how often they fail, and the magnitude by which they fail. Sub-indexes may be most useful when considering non-point sources. The River Nutrient Index integrates total phosphorus, total nitrogen, dissolved nitrite, total ammonia, DO, and pH. The River Pesticide Index integrates 17 commonly applied pesticides in Alberta.

5.4 Models

Models can be useful tools for assessing NPS pollution because they often allow users to make predictions about future water quality using projected future scenarios. They are useful for developing beneficial management practices for NPS pollutants. Modelling approaches will vary depending on objectives. Therefore, there is not a consistent modelling approach that is used across the province. Approaches can be broadly classified as **conceptual/mechanistic models** and **data-driven** models (Li et al. 2008). Some of the modelling based tools and projects being used to asses NPS pollution in Alberta are briefly described below.

Comprehensive Economic and Environmental Optimization Tool (Olson and Kalischik 2011)

Comprehensive Economic and Environmental Optimization Tool (CEEOT) based modelling is being applied in the agricultural area of Alberta to identify beneficial management practices for nutrients (Olson and Kalischik 2011). CEEOT is a computer program that interfaces the Soil and Water Assessment Tool (SWAT), the Agricultural Policy/Environmental eXtender (APEX) and Farm-level Economic (FEM) programs. SWAT and APEX are the portions that model environmental quality and they are linked by the SWAPP interface. SWAT is a public domain conceptual watershed scale model that operates on a daily timestep (Li et al. 2008). It predicts the impact of watershed management on water, sediment, nutrient, and agricultural yields in basins, which can be subdivided based on topography. SWAT simulates surface runoff, percolation, shallow subsurface flow, groundwater flow, snowmelt, water storage, and nutrient cycling. APEX is a management practice simulator.

North Saskatchewan River Water Quality Model (McDonald and Muricken 2009)

A number of models have been developed as part of the Industrial Heartland project (Table 1). The North Saskatchewan River Water Quality Model uses the Environmental Fluid Dynamic Code (EFDC, US EPA 2011) to model hydrodynamics and water quality. EFDC is non-proprietary modelling tool that can operate in one, two, or three dimensions. The hydrodynamics portion of the model predicts depth, velocities, and temperature, which are used by the water quality portion the model. A sediment transport section uses the hydrodynamic model to calculate settling of TSS and resuspension. The model has been used in the NSR to evaluate contaminant loadings and their effect on river water quality under various industrial heartland area management options (McDonald and Muricken 2009). The model can handle NPS pollutants, such as nutrients, metals, and bacteria, transport and fate of toxic substances, biogeochemical processes.

A limitation of the models in general is very high computing times and limited datasets for tributaries, which means that interpolations can be very broad. Lack of available data from tributaries can be worked around by incorporating SWAT to account for NPS loadings in tributaries. Ultimately empirical monitoring data will be required for reliable calibration.

FORWARD program model (Li et al. 2008)

The FORWARD research program uses modelling tools to simulate streamflow, suspended solids, and nutrients in streams on the Boreal Plain. This project has employed both the SWAT model and artificial neural network (ANN) models. ANN models are data driven and can often find and simulate data patterns without understanding their underlying mechanisms. They usually require fewer input variables and may be especially useful is areas where detailed spatial land cover data are unavailable or when large areas are being modelled.

Bow River Water Quality Model

The Bow River Water Quality Model (BRWQM) model was commissioned by city of Calgary for use as a planning tool for water quality effects of wastewater treatment plant effluents (Robinson et al. 2009) The BRWQM can accurately simulate water temperature, TSS levels, nutrient concentration, benthic algae, macrophyte biomass, and DO concentration in the Bow River within and downstream of Calgary (Golder 2007). The model is uses a one dimensional HEC-RAS hydraulic model and interfaces it with the multi-dimensional Water Quality Analysis Simulation Program (WASP). WASP models the sediment and water quality components of the BRWQM. The model is not only used to assess wastewater treatment plant effects on river quality, but also the effects of storm sewage.

6.0 CONCLUSIONS AND GAPS

The main paths by which NPS pollutants may reach water bodies are groundwater, atmospheric deposition, or surface runoff, which have all been documented in Alberta. Individual contaminant loads may travel via more than one transport mechanism. Groundwater delivery becomes increasingly important for delivery pollutants compared to surface runoff as soils become more porous, depth of glacial till increases, and terrain becomes more flat. Groundwater can be an important NPS delivery mechanism and has been shown to be important, particularly on the Boreal Plain, where groundwater-fed peatlands can dominate the landscape.

Province-wide, streams and tributaries are being most affected by and are at most risk from NPS pollution. These systems are extremely important for the general health of aquatic ecosystems, both from a basin and provincial perspective. Current tools (e.g., water quality guidelines and objectives, models) and data are highly focused on mainstem water quality, reflecting priorities established by provincial auditing requirements and inter-jurisdictional bilateral agreements, as well as budgetary constraints. Data gaps exist for most tributaries in Alberta's river basins. These gaps also constitute the greatest challenge for watershed models to support decision-making related to NPS pollution. Modelling tools used in Alberta have a track record of being very useful in the support of environmental management decision-making and policy development. In the case of modelling useful with respect to NPS pollution, strong relational databases that quantify relationships between land use and water quality are required. To be useful, this type of information exists at the stream and tributary scale. No model is right, but some models are useful. What useful models have in common are good input data, good calibration datasets, and validation using data that is independent of the input data that was used to build the model.

In general, in between the small watershed and the large mainstem river scale, there is a gap in knowledge. Rarely is there enough information to determine conclusively what effect, if any, NPS pollution at the small watershed scale is having at the tributary and mainstem scale. In addition, an important learning from this report is that the natural variability in both hydrology and constituent loading and concentration in aquatic ecosystems is very high at multiple spatial (local, regional, provincial) and temporal (seasons, years) scales. Given this great amount of variability, a substantial amount of data would be required at the sub-watershed level to distinguish effects from natural variability. Although modelling can be a very powerful tool in determining what effect NPS pollution is having on aquatic ecosystems at the tributary and basin-scale, the models are only as good as the input data and data is rarely available for primary input variables at scales appropriate for modelling (McEachern 2008, D. McDonald, pers. comm.). Although a sector-based approach has been very useful at a watershed-scale, a cumulative approach is perhaps more appropriate at the sub-basin or tributary scale.

At the mainstem scale, the Alberta Provincial Water Quality indexes generally rate water quality as good for mainstem rivers in the major river basins of Alberta. The focus of water quality assessments for the mainstem of the major rivers in Alberta has been on point-source pollution. This may reflect the relative ease of these assessments, which are based on fairly straightforward loading calculations from points of impact that are readily identifiable and measurable. Numerous studies have targeted small watersheds to assess the potential impacts of NPS pollution. Often these studies have selected watershed sites, or have grouped them in categories, to minimize natural variability among sites and maximize the data's ability to show a response. For example, most if not all forestry studies have adopted paired watershed experiments, or study only headwater lakes and streams. As another example, agricultural studies have selected watersheds based on agricultural intensity. These approaches have been paramount in being able to detect activity-specific NPS impacts. What such studies demonstrate is a definite and measurable impact from the well-studied main human activities outlined in this report (urbanization, forestry and agriculture) on a local scale, that is, at the small watershed level.

At the small watershed scale, having been the focus of NPS studies, much is known on agricultural impacts to aquatic ecosystems. Provincially, where agriculture occurs, NPS movement of agriculture-related constituents to aquatic ecosystems can generally be expected. Nutrients (especially dissolved nutrients), pesticides and pathogens appear to be the constituents that are mostly involved in agricultural NPS pollution. Furthermore, as agricultural intensity increases:

- N, P and total pesticide concentrations in streams increase,
- Compliance with provincial and national surface water quality guidelines for the protection of aquatic life decrease, and
- Pesticide detection frequency and the total number of compounds increase.

To varying degrees, agricultural NPS constituent loading to streams and tributaries have been noted in all basins. At this scale, basins that are the most influenced by NPS agricultural pollution are generally those that have the greatest proportion of their basin as agricultural land and those that have, proportionately, greater expanses of high-intensity agricultural development. In consequence, basins where agricultural NPS contributions appear to be highest would include the Oldman, Red Deer and Battle River basins. Basins that are relatively least affected are the Athabasca River Basin followed by the Peace River Basin, which both contain vast expanses of forested areas. All other basins fall somewhere in the middle. In general, the impact to mainstem rivers, although intuitive, has been proven explicitly in very few cases. Many reports (including this one) use speculative logic and make general statements that “agriculture likely contributes” NPS pollution to rivers in areas where land cover is predominantly agricultural. Determining the full extent of impact of agriculture on mainstem rivers in Alberta remains a gap.

Our of all human activities, urban development seems to have the most direct effect on mainstem water quality, primarily because urban centers typically cluster around mainstems and many stormwater outfalls directly discharge to them. Urban development, through stormwater runoff, is also significantly affecting the water quality and ecosystem health of streams. This runoff exports relatively high NPS pollutant loads of TSS, metals, nutrients, salts, pesticides, and fecal coliforms. Chloride salt is perhaps one of the best signatures of urban loading to aquatic ecosystems since its concentration is naturally low in the environment and it is highly associated with road salt application and runoff.

The impacts of forest clearing activities have been and are being well studied in northern Alberta. Although generalizations can be made, there is much more variability in the expression of water quality and hydrology responses to logging than there is for agriculture or urban development. This reflects the very high complexity associated with the Alberta hydrogeological framework, particularly in boreal systems where wetlands can effectively mask or delay the expression of effects. Research programs, such as the HEAD program in the Utikuma area is currently attempting to reduce the uncertainty associated with logging response. In general, however, logging does contribute NPS pollution to small streams and headwater lakes in Alberta. The magnitude of this response is variable and depends on hydrogeology, which in turn depends on regional climate, topography, geology and soil characteristics (permeability and placement). In addition, logging practices are extremely important in the response magnitude, particularly given that road construction and use pose the largest risk associated with logging. In general, in watersheds that have high logging density (e.g., greater than 50% of watershed logged has been proposed, Prepas et al. 2008), water yield and NPS pollution is likely to respond. Also, NPS response generally increases with logging intensity (as % of watershed area logged).

The impact of recreational use has been receiving increasing attention. Province-wide, recreational use data is greatly lacking. Less information yet documents the relationship between recreational use and water quality. From these studies, however, it appears that lack of recreational oversight or over-use in certain sensitive areas (e.g., stream crossings) can be quite damaging at a local level and could perhaps be akin to the effects of poor forest harvesting practices. The cumulative effect of this type of disturbance is unknown.

One of the most noticeable gaps identified in this report is that very little knowledge exists on NPS contributions from logging, oil & gas and recreational use in most headwaters. Documentation of the extent and severity of these disturbances is lacking as well. Existing information has demonstrated increase TSS associated with these disturbances. The headwaters of most mainstem rivers in Alberta produce substantial amounts of TSS. This TSS is largely attributed to natural origins, however some of the TSS loads could be generated from NPS pollution related to human activity in the headwaters. A general trend of increasing impact to aquatic ecosystems with disturbance intensity indicates that the cumulative impacts of oil & gas development, recreation and logging could be important, particularly at the small stream and tributary scale. Since these activities occur concomitantly, a cumulative approach must be adopted.

The impact of active mining is well understood in the case of coal mines in the eastern slopes. The impact of a much younger industry, active oil sands mining, is cause for great debate. In general, water bodies and tributaries draining oil sand impacted areas have been intensively and extensively monitored. These monitoring programs have detected little change over time and between "impacted" and "non-impacted" sites. Hypothesis-based study of oil sand mining related impacts is lagging behind monitoring. The few peer-reviewed studies that have taken place unquestionably demonstrate NPS loading. However, there is considerable debate surrounding the magnitude and implications of the impacts related to these loads. What is not well understood, and something that is of great concern, particularly to aboriginal groups who inherently view the landscape from a long-term (generational) perspective, is the NPS pollutant legacy of reclaimed sites and how long it will take for reclaimed areas to reach background levels.

7.0 REFERENCES

Alberta Environment. 2011a. Surface water quality data. Retrieved from http://environment.alberta.ca/01288.html.

Alberta Environment. 2011b. Alberta river water quality index. Retrieved from http://environment.alberta.ca/01275.html.

Alberta Environment. 1999. Surface Water Quality Guidelines for use in Alberta. Edmonton, Alberta. Retrieved from http://environment.gov.ab.ca/info/library/5713.pdf.

Alberta Agriculture and Rural Development. 2011. Alberta soil information centre. Retrieved from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag6903?opendocument.

Alberta Agriculture and Rural Development. 2004. Beneficial Management Practices: Environmental Manual for Crop Producers in Alberta - Water Quality Guide, . Retrieved July 26, 2011, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex9317.

Alberta Environment. 2006a. Cold Lake-Beaver River: surface water quality state of the basin report. Page 65 pp. T/845, Edmonton, Alberta. Retrieved from http://beaverriverwatershed.ca/uploads/Publications/SW%20Quality%20Mar%2010_06-s.pdf.

Alberta Geological Survey. 2011. Alberta's geology. Retrieved from http://www.ags.gov.ab.ca/alberta_geology.html.

Alberta Sustainable Resource Development. 2011. Forest and vegetation inventories. Retrieved from http://www.srd.alberta.ca/MapsPhotosPublications/Maps/ResourceDataProductCatalogue/ForestVegetationInventories.aspx.

Alberta Water Council (AWC). 2011. NPS project team Terms of Reference.

Alberta Wilderness Association (AWA). 2007. The Bighorn Wildland recreational trail monitoring project: An interim research summary from 2004-2006. 76 pp.

Anderson, A.-M., D.O. Trew, R.D. Neilson, N.S. MacAlpine and R. Borg. 1998. Impacts of agriculture on surface water quality in Alberta Part 1: Haynes Creek Study. 198 pp.

Anderson, A.-M., D. O. Trew, R. D. Neilson, N. D. MacAlpine, and R. Borg. 1998. Impacts of agriculture on surface water quality in Alberta. Part II: Provincial stream surveys. Page 152 pp. Alberta Environmental Protection and Alberta Agriculture, Food and Rural Development. Retrieved from http://www.environment.gov.ab.ca/info/library/8099.pdf.

Anderson, A.-M. 2005. Overview of pesticide data in Alberta surface waters since 1995. Page 190 pp. Alberta Environment, Environmental Monitoring and Evaluation Branch, Edmonton, Alberta. Retrieved from http://environment.gov.ab.ca/info/library/7614.pdf.

Anderson, A.-M., G. Byrtus, J. Thompson, D. Humphries, B. Hill, and M. Bilyk. 2002. Baseline pesticide data for semi-permanent wetland in the aspen parkland of alberta. Page 104 pp. Alberta Environment, Science and Standards Branch, Edmonton. Retrieved from http://environment.alberta.ca/02496.html.

Association of Summer Villages of Alberta. (n.d.). Stormwater management. Retrieved from http://www.albertasummervillages.org/media/76679/stormwater.pdf.

Beaulac, M.N. and K.H. Reckhow. 1982. An examination of land use – nutrient export relationships. Water Resources Bulletin 10: 1013-1024.

Blais, J. M., D. W. Schindler, D. C. Muir, M. Sharp, D. Donald, M. Lafrenière, E. Braekevelt, and W. M. Strachan. 2001. Melting glaciers: a major source of persistent organochlorines to subalpine Bow Lake in Banff National Park, Canada. Ambio 30: 410-415. Retrieved July 24, 2011, .

Braun, T. and S. Hanus. 2005. Forest fragmentation – Effects of oil and gas activities on Alberta forests. 21 pp.

Burke, J. M., E.E. Prepas, and S. Pinder. 2005. Runoff and phosphorus export patterns in large forested watersheds on a western Canadian Boreal Plain before and for 4 years after wildfire. Journal of Environmental Engineering and Science 4:319-325.

Carr, G. M., P. A. Chambers, and A. Morin. 2005. Periphyton, water quality, and land use at multiple spatial scales in Alberta rivers. Canadian Journal of Fisheries and Aquatic Sciences 62:1309-1319. doi: 10.1139/f05-044.

Casey, R. and P. Siwik. 2000. Overview of selenium in surface waters, sediment and biota in river basins of west-central Alberta. Proceedings of the 24th Annual British Columbia Mine Reclamation Symposium in Williams Lake, BC, 2000. 10 pp.

Donahue, W. F. 2010. An assessment of water quality, sediment quality, benthic invertebrates, and hydrology of the Joslyn North Mine project. Page 33. Retrieved from http://www.ceaa.gc.ca/050/documents_staticpost/cearref_37519/44851/nn.pdf.

Ducks Unlimited Canada. 2011. Provincial wetland inventory. Retrieved from http://www.ducks.ca/province/ab/how/research/inventory/index.html.

Environment Canada. 2010. National climate data and information archive. Retrieved from http://climate.weatheroffice.gc.ca/Welcome_e.html.

Environment Canada. 2000. Priority Substances Assessment Report: Road Salts. www.ec.gc.ca/cceb1/eng/public/road_salts.html.

Environment Canada, and Health Canada (EC & HC). 2001. Priority substances list assessment report: road salts. Retrieved from http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/ contaminants/psl2-lsp2/road_salt_sels_voirie/road_salt_sels_voirie-eng.pdf.

Forrest, F., K. Lorenz, T. Thompson, J. Keenliside, J. Kendall, and J. Charest. 2011. A Scoping Study of Livestock Antimicrobials in Agricultural Streams of Alberta. Canadian Water Resources Journal 36:1-16. doi: 10.4296/cwrj3601001.

Golder Associates Ltd. 2007. Bow River impact study - Phase 2: Development of total loading management targets for the City of Calgary. Page 126. Calgary, Alberta.

Government of Canada. 2011. National forestry database. Retrieved from http://nfdp.ccfm.org/index_e.php

Government of Alberta. 2010, April 26. Pesticide Index. Text, . Retrieved July 24, 2011, from http://environment.alberta.ca/02877.html.

Government of Alberta. 2008. Handbook for State of the Watershed Reporting: A Guide for Developing State of the Watrershed Reports in Alberta. Page 98 pp. Water for Life.

Government of Canada. 2010. National Forestry Database: Pest control product use - jurisdictional tables. Retrieved from http://nfdp.ccfm.org/pest/jurisdictional_e.php.

Hackbarth, D. A. 1979. The effects of surface mining of coal on water quality near Grande Cache, Alberta. Canadian Journal of Earth Sciences 16:1242-1253.

Hatfield Consultants, Kilgour and Associates Ltd., and Western Resource Solutions. 2011. Regional aquatics monitoring program 2010 technical report. Page 792 pp. Retrieved from http://www.ramp-alberta.org/UserFiles/File/AnnualReports/2010/RAMP_2010_Technical%20Report_Final.pdf.

Hillman, G. R., J. C. Feng, and C. C. Feng. 1997. Effects of watershed characteristics and disturbances on the water quality of two boreal streams. Page 75 pp. Canadian Forest Service, Edmonton, Alberta. Retrieved from http://cfs.nrcan.gc.ca/bookstore_pdfs/18866.pdf.

Kelly, E. N., D. W. Schindler, P. V. Hodson, J. W. Short, R. Radmanovich, and C. C. Nielsen. 2010. Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. Proceedings of the National Academy of Sciences 107:16178 -16183. doi: 10.1073/pnas.1008754107.

Koning, C. W., K. A. Saffran, J. L. Little, and L. Fent. 2006. Water quality monitoring: the basis for watershed management in the Oldman River Basin, Canada. Water Science & Technology 53:153-161.

Garner Lee Limited. 2007. A summary of paleolimnological studies conducted in Alberta. Report prepared for Alberta Environment. 54 pp.

Lafrenière, M. J., J. M. Blais, M. M. Sharp, and D. W. Schindler. 2006. Organochlorine pesticide and polychlorinated buphenyl concentration in snow, snowmelt, and runoff at Bow Lake, Alberta. Environmental Science and Technology 40: 4909-4915.

Li, X., M. H. Nour, D. W. Smith, E. E. Prepas, G. Putz, and B. M. Watson. 2008. Incorporating water quantity and quality modelling into forest management. The Forestry Chronicle 84:338-348.

Little, J., A. Kalischuk, and C. Sheedy. 2010. Assessment of water quality in Alberta's irrigation districts. Second edition. Page 181 pp. Alberta Agriculture and Rural Development, Edmonton, Alberta. Retrieved from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/irr13000/$FILE/wqreportfull_nov2010.pdf.

Little, J. L., S. C. Nolan, J. P. Casson, and B. M. Olson. 2007. Relationships between soil and runoff phosphorus in small Alberta watersheds. Journal of Environmental Quality 36:1289-1300.

Little, J. L., K. A. Saffran, and L. Fent. 2003. Land Use and Water Quality Relationship in the Lower Little Bow River Watershed, Alberta, Canada. Water Quality Research Journal of Canada 38:563-584.

Logan, M., and J. S. White. 2007. Pigeon Lake Water Quality Report 2007. Page 12 pp. Aquality Environmental Consulting. Retrieved from http://www.pigeonlakewatershedassociation.com/document/show/421.

Lorenz, K., S. Depoe, and C. Phelan. 2008. Assessment of environmental sustainability in Alberta's agricultural watersheds project: Volume 3: AESA water quality monitoring project. Page 543 pp. Alberta Agriculture and Rural Development.

Mapfumo, E., W. D. Willms, and D. S. Chanasyk. 2002. Water quality of surface runoff from grazed fescue grassland watersheds in Alberta. Water quality of surface runoff from grazed fescue grassland watersheds in Alberta 37:543-562.

Mayer, T., W.J. Snodgrass and D. Morin. 1999. Spatial characterization of the occurrence of road salts and their environmental concentrations as chlorides in Canadian surface waters and benthic sediments. Water Qual. Res. J. Can. 34(4): 545-574.

McCleary, R. 2009. Fish population and water quality monitoring: Hardisty Creek restoration project. Page 58. Foothills Research Institute. Retrieved from http://foothillsresearchinstitute.ca/Content_Files/Files/FW/FW_hc_ASN_report1.pdf.USEPA. 2003. Protecting water quality from urban runoff. Publication number 841-F-03-003.

McDonald, D., and D. Muricken. 2009. North Sasktachewan River Water Quality Model: Alberta Environment Technical Report. Alberta Environment. Retrieved from http://www.environment.gov.ab.ca/info/library/8252.pdf.

McDougall, S. 1996. Assessment of log yard runoff in Alberta. Page 60 pp. Alberta Environment. Retrieved from http://environment.gov.ab.ca/info/library/7260.pdf.

McEachern, P. 2008. Cumulative effects management and the role of predictive models in the new policy for regulating land disturbance in Alberta. Journal of Environmental Engineering and Science 7: 13-22.

Miller, J. J., D. S. Chanasyk, T. W. Curtis, and B. M. Olson. 2011. Phosphorus and nitrogen in runoff after phosphorus- or nitrogen-based manure applications. Journal of Environmental Quality 40:949-958. doi: 10.2134/jeq2010.0279.

Mitchell, P. 2002. Overview: Relationship between Beef Production and Waterborne Parasites (*Crytopsporidium* and *Giardia spp*.) in the North Saskatchewan River Basin Alberta, Canada. Conservation and Development Branch, Alberta Agriculture, Food and Rural Development, Summary Report, 24 pages.

Newcombe, C.P. and J.O.T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16: 693-727.

Nip, A. 1991. Tri-Creeks experimental watershed: Changes in hydrology and water quality following forest harvesting and their impact on salmonid fishes in the Tri-Creeks basin. Alberta Forest Service, Edmonton, AB. 66 pp.

Olson, B. M., E. Bremer, R. H. McKenzie, and D. R. Bennett. 2010a. Phosphorus accumulation and leaching in two irrigated soils with incremental rates of cattle manure. Canadian Journal of Soil Science 90:355-362. doi: 10.4141/CJSS09025.

Olson, B. M., and A. R. Kalischik (Eds.). 2011. Section 6. Appliaction of the CEEOT model to Alberta watersheds. Page 370 Nutrient Beneficial Management Practices Evaluation Project 2007-2012 - 2010 Progress Report. Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. Retrieved from http://www1.agric.gov.ab.ca/$Department/deptdocs.nsf/all/epw11955/$FILE/2010report_section6_modelling.pdf.

Palliser Environmental Services Ltd., and Alberta Agriculture and Rural Development. 2008. Sustainability in Alberta's agricultural waters. Volume 1: Summary and recommendations. Page 81 pp. Mossleigh, Alberta. Retrieved from Sustainability in Alberta's agricultural waters. Volume 1: Summary and recommendations.

Peters, L. E., M. MacKinnon, T. Van Meer, M. R. van den Heuvel, and G. D. Dixon. 2007. Effects of oil sands proccess-affected waters and naphthenic acids on yellow perch (Perca flavescens) and Japanese medaka (Orizias latipes) embryonic development. Chemosphere 67: 2177-2183.

Prepas, E.E., J.M. Burke, G. Putz and D.W. Smith. 2008. Dissolved and particulate phosphorus concentration and export patterns in headwater streams draining Boreal Plain watersheds one year after experimental forest harvest and post-harvest silvicultural activities. Journal of Environmental Engineering and Science 7: S63-S77.

Prepas, E. E., J. M. Burke, D. S. Chanasyk, D. W. Smith, G. Putz, S. Gabos, W. Chen, D. Millions, and M. Serediak. 2003a. Impact of wildfire on discharge and phosphorus export from the Sakatamau watershed in the Swan Hills, Alberta, during the first two years. Journal of Environmental Engineering and Science 2: S63-S72.

Prepas, E. E., B. Pinel-Alloul, R. J. Steedman, D. Planas, T. Charette, D. W. Smith, and W. L. Adamoeicz. 2003b. Impacts of forest disturbance on boreal surface waters in Canada. Pages 369-393 *in* P. J. Burton and C. Messier, editors. Towards sustainable management of the boreal forest. NRC Research Press, Ottawa, Ontario.

Purdy, B. G., S. E. Macdonald, and V. J. Lieffers. 2005. naturally saline boreal communities as models for reclamation of saline oil sands tailings. Restoration Ecology 13:667-677.

Robinson, K. L., C. Valeo, M. C. Ryan, A. Chu, and M. Iwanyshyn. 2009. Modelling aquatic vegetation and dissolved oxygen after a flood event in the Bow River, Alberta, Canada. Canadian Journal of Civil Engineering 36: 492-503. doi: 10.1139/L08-126.

Scrimgeour, G. J., and S. Kendall. 2002. Consequences of livestock grazing on water quality and benthic algal biomass in a Canadian natural grassland plateau. Environmental Management 29:824-844.

Shaw, R. D., A. M. Trimbee, A. Minty, H. Fricker, and E. E. Prepas. 1988. Atmospheric deposition of phosphorus and nitrogen in Central Alberta eith emphasis on Narrow Lake. Water, Air, & Soil Pollution 43: 119-134.

Sherburne, C., and R. McCleary. 2002. Overview assessment of historic and current land-ise activities in selected Foothills Model Forest watersheds. Page 48. Fish and Watershed

Research Program, Foothills Model Forest. Retrieved from http://foothillsresearchinstitute.ca/Content_Files/Files/FW/FW_Fm14.pdf.

Soil Phosphorus Limits Committee, and Landwise, Inc. 2006. Phosphorus standards in Alberta: potential impacts on the agriculture industry. Page 57 pp. Alberta Agriculture, Food and Rural Development, Lethbridge, Alberta, Canada.

Statistics Canada. 2011. 2006 Census of Agriculture. Retrieved July 28, 2011, from http://www.statcan.gc.ca/ca-ra2006/index-eng.htm.

Strong, W. L., and C. C. Gates. 2006. Herbicide-induced changes to ungulate forage habitat in western Alberta, Canada. Forest Ecology and Management 222:469-475.

Telang, S. A. 1990. Effects of reservoir-dam, urban, industrial, and sewage treatment run-off on the presence of oxygen and organic compounds in the Bow River. Water, Air, and Soil Pollution 50. doi: 10.1007/BF00284785.

Timoney, K. P., and P. Lee. 2011. Polycyclic aromatic hydrocarbons increase in Athabasca River delta sediment: temporal trends and environmental correlates. Environmental Science and Technology 45:4278-4284.

Tonn, W., C. Paszkowski, G. Scrimgeour, P. Aku, M. Lange, E. Prepas, and K. Westcott. 2003. Effects of Forest Harvesting and Fire on Fish Assemblages in Boreal Plains Lakes: A Reference Condition Approach. Transactions of the American Fisheries Society 132:514-523. doi: 10.1577/1548-8659(2003)132<0514:EOFHAF>2.0.CO;2.

US EPA, O. 2011. Environmental Fluid Dynamics Code (EFDC) Page. Data & Tools. Retrieved July 31, 2011, from http://www.epa.gov/ATHENS/wwqtsc/html/efdc.html.

USEPA. 2002. National Water Quality Inventory: 2000 report. Rep. no. 841R02001. USEPA, Washington, DC. 468 pp.

Wrona, F. J., and P. di Cenzo. 2011. lower Athabasca water quality monitoring program: phase 1, Alberta River mainstem and major tributaries. Page 90 pp. Environment Canada. Retrieved from http://www.ec.gc.ca/Content/8/A/1/8A1AB11A-1AA6-4E12-9373-60CF8CF98C76/WQMP_ENG.pdf.

Younge, E. I. 1988. A review of epilithic algal biomass, nutrient, and nonfilterable residue data for major Alberta River basins. Page 55. Alberta Environment, Edmonton, Alberta. Retrieved from http://www.environment.gov.ab.ca/info/library/8228.pdf.