

Prepared for



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

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Prepared by



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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 Athabasca 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.

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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>

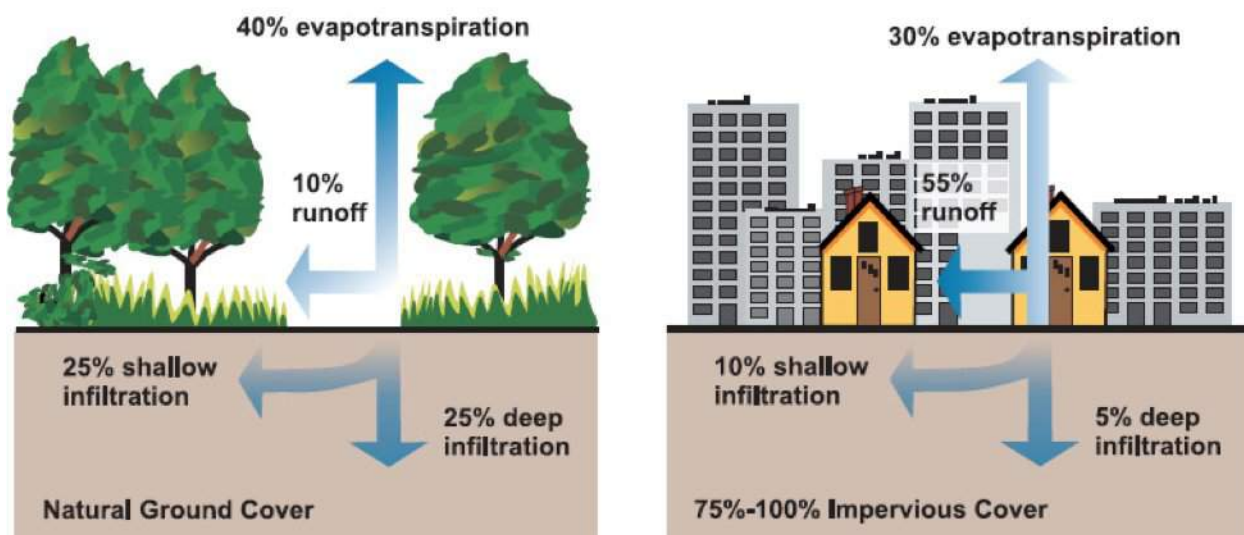


Figure 2: Relationship between impervious cover and surface runoff. NPS pollution related to urban development is a product of this increased surface runoff, which causes increased erosion and sedimentation and which also moves pollutants (such as nutrients, pathogens and pesticides) to watercourses.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

I.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 (AESAs) 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.

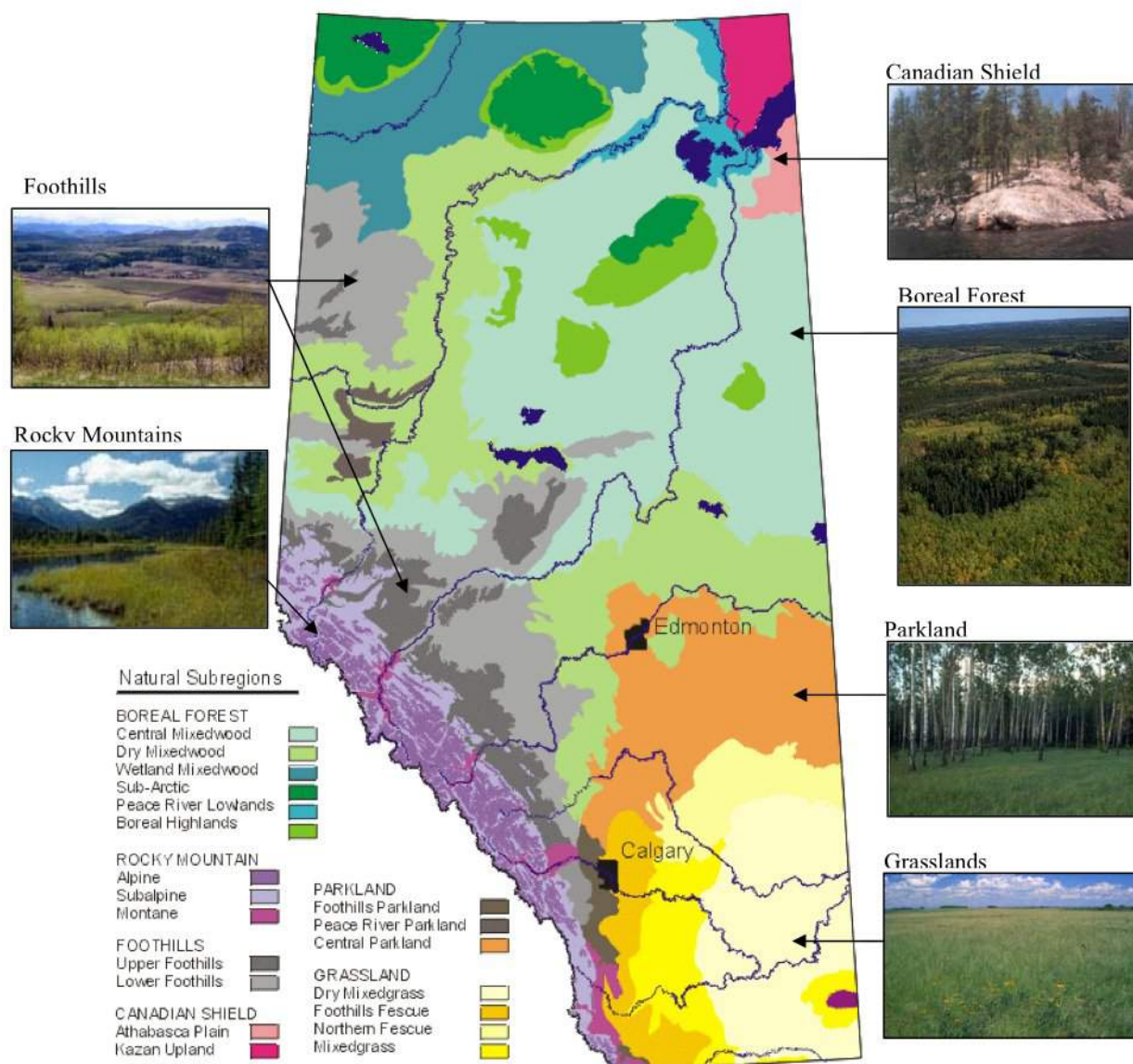


Figure 4: Natural Regions and Subregions of Alberta. From Braun and Hanus 2005.

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 hydrogeological 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).

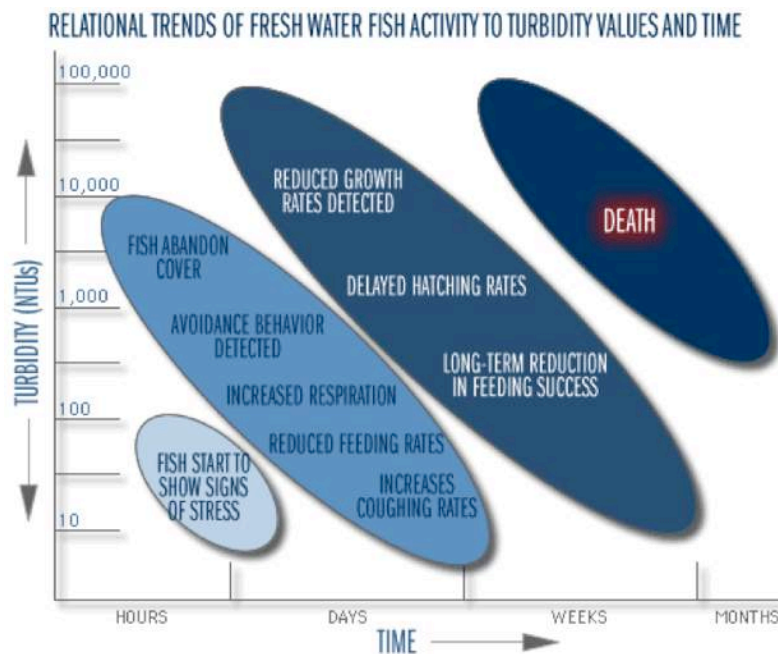


Figure 5: This figure below shows how aquatic organisms are generally affected. Very high levels of turbidity for a short period of time may not be significant and may even be less of a problem than a lower level that persists longer. From www.lakesuperiorstreams.org. Schematic adapted from "Turbidity: 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 phosphorus 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 to 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/m²/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 (Ca²⁺), magnesium (Mg²⁺), and potassium (K⁺) and the major anions are bicarbonate (HCO₃⁻), carbonate (CO₃⁻²), chloride (Cl⁻), and sulphate (SO₄⁻²). 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_3^{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

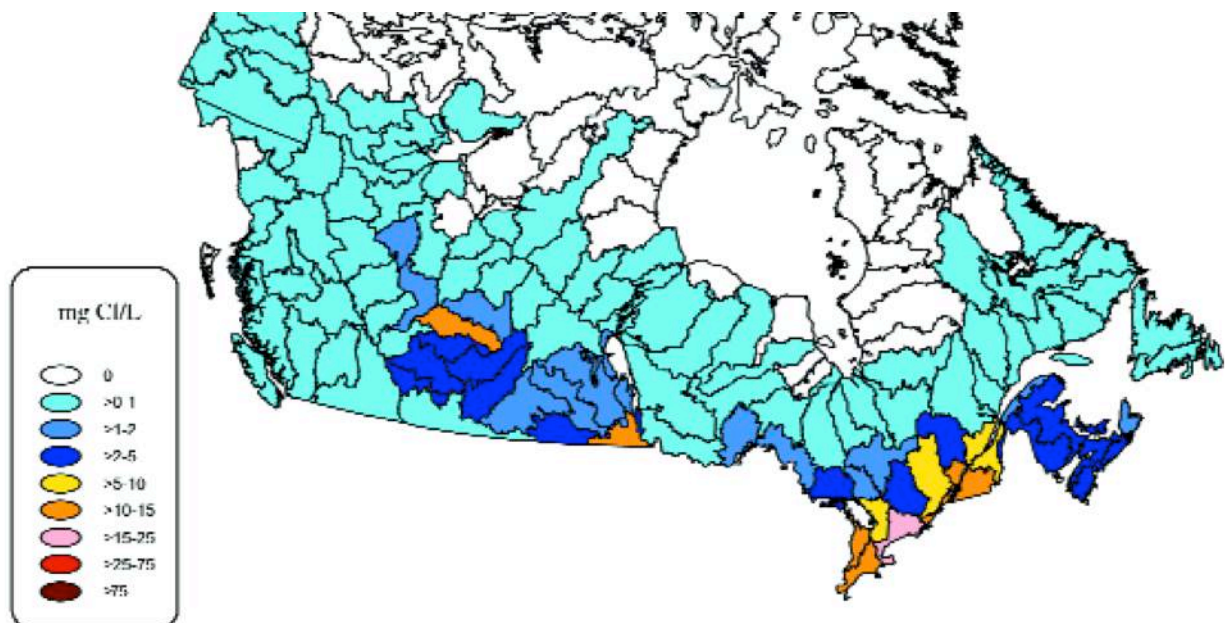


Figure 6: Estimated road salt chloride concentrations by watershed, calculated from average annual road salt loadings and average annual runoff (from Mayer et al. 1999).

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, Bromoxynil, Cyanazine, Malathion, Methoxychlor, Chlorpyrifos, 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 surface 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 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.

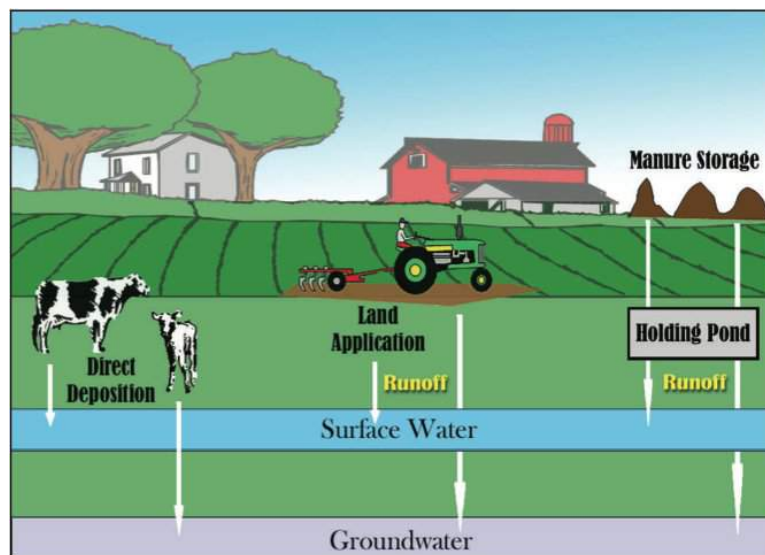


Figure 7: Pathways that pathogens may be transported from agricultural areas. Figure from J. Thurston-Enriquez.

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.

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 assess 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.

