Monitoring data for these 22 parameters were obtained from the provincial and federal databases for the 16 sampling locations through two methods:

1. By downloading data from the Ministry of Environment in Alberta, through their online website (for all provincial monitoring stations in Alberta).

2. By direct request in writing to the Ministry of Environment in Saskatchewan, and Environment Canada, for all provincial monitoring stations in Saskatchewan and all federal monitoring stations across the basin (in both Alberta and Saskatchewan).

III UNDERSTANDING WATER QUALITY

> **Water is the one substance from which the earth can conceal nothing; it sucks out its innermost secrets and brings them to our very lips.**
>
> ***-Jean Giraudoux, The Madwomen of Chaillot, 1946***

III.1 Chemical Constituents of Surface Water

The chemical composition of natural water is derived from a mixture of naturally occurring and human-introduced solutes and solids. Sources of these constituents include atmospheric gases and aerosols, weathering and erosion of rocks and soil, chemical reactions in the ground, and the impacts of human activities above and below the earth's surface (Hem, 1985). Solutes contained in natural water represent the physical, chemical, and biological processes operating within the water system. Adhering to the concept of the watershed, chemical constituents in water represent the culmination of water's journey across the land: percolating through soils and bedrock as groundwater, flowing across fields and pavements as surface runoff, collecting in wetlands, cutting through hills, and constantly in flux with the objects, activities, processes, and elements it encounters along the way. Natural water is a dynamic thing: responding to the environment as the lifeblood of the aquatic ecosystem. There are over 200 chemical and physical properties of water measured by municipal, provincial, and federal monitoring programs in Canada. These include physical parameters such as odor, taste, temperature, and turbidity; biological indicators like algal growth, chlorophyll concentration, and coliform counts; naturally occurring elements and compounds such as salts, ions, metals, and organic nutrients; and a plethora of human-made chemicals, including innumerable pharmaceuticals, pesticides, industrial chemicals, aromatic hydrocarbons, residues, and many others. 'Water quality' is in the eye of the beholder: what constitutes 'good' water quality versus 'bad' water quality depends partially on the natural state of water as it operates within the undisturbed environment, but also partly on the purpose of defining the quality of water in the first place. Water that is 'good' for fishing may not be 'good' for watering crops. Water that is ideal for drinking may be essentially useless for supporting aquatic ecosystems because it lacks the essential nutrients that a health ecosystem needs. It is very important, then, to understand that water quality is a relative term, and to define the meaning of water quality as far as it will be used in this report.

III.2 Determining "Water Quality"

According to the Canada-wide Framework for Water Quality Monitoring (CCME Water Quality Task Group, 2006), "water quality" is a term used to describe the physical, chemical, and biological characteristics and conditions of water and aquatic ecosystems. It is a term used to describe both the relative state of the aquatic environment, and is used to assess the presence and abundance of specific parameters. Water quality is therefore measured with a variety of physical, chemical, and biological variables which may be qualitative (indices or ratings of environmental risk and health), or quantitative (measurements or amounts of specific indicators or parameters). However the term is used, water quality is in a constant state of flux, changing from season to season, year to year, or even throughout a single day. As a result, water quality measurements typically represent only a "snapshot in time" or single moment of water quality conditions at the time of measurement. It is from these single-moment measurements that a holistic understanding of the overall conditions of water quality must be reconstructed using any number of intuitive or mathematical approaches, such as statistical analysis, risk assessment, visual observation, or modeling.

Water quality may be measured in a state of use, as the water in pipes, canals, or wells, or it may be measured in the environment. The 'state' of water quality in the natural environment is most often assessed in two general ways: 1) as a measurement of the health of the aquatic environment (often reported as a qualitative health rating, such as stressed/unstressed or high/medium/low risk), and 2) the degree to which the water is suitable for specific purposes: namely, agricultural use (crop irrigation and watering livestock), recreational use (swimming, boating, fishing), drinking use (as treated or untreated water), or its use in aquatic ecosystems. When assessing the suitability of water for use in aquatic ecosystems, this can be considered a measurement of how the current water state may impact or change the aquatic ecosystem that resides within it, or connected to it.

III.2.i Water Quality Variability

The composition or quality of surface and groundwater in the natural environment is largely dependent on the characteristics of the drainage basin in which it resides (UNEP and WHO, 1996). Geological, hydrological, biological, meteorological, and climatological processes determine the natural state of water in the environment by affecting the quantity of water available through various portions of the hydrological cycle, and the chemical constituents water encounters as it travels through land and air. These chemical constituents may include the material of bedrock and surficial soils or other unconsolidated materials, and the gases in the atmosphere. Acting on this baseline of physical processes are the biological organisms and ecosystems that further influence water quality through biological processes such as photosynthesis and biological decomposition. As a result, water quality in surface waters naturally goes through daily, weekly, and seasonal changes each year that fluctuate within a range of natural conditions to which the aquatic ecosystem will adapt (CCME, 1999).

Human activities such as land development and the release of effluent directly into surface waters impacts water quality in a variety of ways, both direct and indirect, and over different time scales. Effluent release may impact water quality in the short term, such as during the time of release for lagoons and water treatment systems, or during precipitation events due to stormflow discharges from the landscape and urban storm water outfalls (Bolstad and Swank, 1997). Alternatively, vegetation changes due to land development can have a significant impact on fluvial processes (Basnyat et al., 1999) and can also contribute water contaminants, but these changes occur at much larger time scales via the slow process of vegetation conversion. Therefore to understand the natural and anthropogenically-driven temporal variability in water quality, it is necessary to examine water quality at multiple time scales, ideally at the smallest available time scale, but at the least, from a seasonal perspective (Ouyang et al., 2006).

III.2.ii Water Quality Monitoring and Assessment

When measured in the context of determining ecosystem health, surface water quality is related to an expected or 'normal' condition (Karr, 1999), which often represents undisturbed or pre-human development conditions. In contrast, when measured in the context of specific water uses, water quality is related to conditions or thresholds which are determined based on the type of use. For example, agricultural water users are not likely to be concerned with water taste or odour if they are using the water for irrigation purposes, but drinking water users will, and the thresholds for these parameters will reflect this difference. However, for the purposes of monitoring water quality, a suite of multiple quality indicators may be measured which are relevant to several purposes and then it is the desirable level or condition of those parameters to which the measurements are compared.

The collection of water quality data may occur at different frequencies, depending on the purpose of the monitoring program, which may include short term (several months to one or two years) but intensive sampling for environmental compliance purposes, in which case sampling may be weekly, daily, or even hourly; or longer term (multiple year) sampling which is more likely to be monthly, quarterly, or even less frequent.

III.3 Threats to Water Quality

Aquatic ecosystems and the quality of their lifeblood -water- can be impacted and influenced in a variety of ways and by a variety of sources. The broadest categories of impact are those which arise from anthropogenic activities, and those impacts which occur due to natural processes. The pathways that connect human activities and natural processes to water quality are complex and interacting, and there are indirect links between cause and effect. For example, a controversial environmental issue in the United States involves timber harvest in old growth forests. Unsustainable harvesting practices have led to increased surface runoff and soil erosion, increasing sediment loading in local streams and river channels. This increased sediment load has affected the health and viability of many aquatic species and decreased the overall water quality (McCold and Saulsbury, 1996). Simultaneously there are several indirect impacts that may arise from these physical environmental changes, for example by reducing riparian vegetative cover which increases light penetration into the water column and raises overall water temperature, or the increase in overall nutrient loading due to the influx of eroded soil material. These secondary impacts have a synergistic effect on overall ecosystem function, in this example by increasing phytoplankton productivity which requires nutrients and sunlight for photosynthesis. Algae blooms and exponential phytoplankton growth could result, which are a common cause of eutrophication processes that lead to destabilized diurnal dissolved oxygen cycling, and elevated nutrient loadings for certain times of the year.

Natural processes may also impact water quality seasonally, and over the long term. Across any given year, water quality may be strongly driven by weather and therefore vary with the seasons, while in the very long term, climate change may slowly alter the normal water quality conditions. The naturally occurring material through which water travels prior to and upon reaching a waterbody also influence the resulting water quality: water as the universal solvent will naturally dissolve elements occurring in surficial and bedrock materials as it travels through them, and as a result, the chemical constituents of the surface and groundwater inputs to a river or lake system may differ considerably. For example, arsenic is a naturally occurring element in bedrock and a common contaminant in groundwater, while various forms of nitrogen, phosphorus, and carbon can be dissolved from surface soils as water flows overland.

Differentiating between natural and anthropogenic sources of water quality contamination is challenging enough, but even for the same type of contaminant source, there are additive upstream to downstream impacts that must be considered as well. These are the impacts that result in cumulative effects or changes in overall water quality due to specific individual activities that combine with other past, present, or future activities across space (Piper, 2001) (MacDonald, 2000). As water in river systems flows from upstream to downstream, the impact of upstream activities on downstream water quality correspondingly accumulates. The natural manifestation of cumulative change shows in the gradual progression of water quality contaminant concentrations from upstream to downstream in any river system. This is illustrated by a change in trophic status from oligotrophic or nutrient-poor conditions to mesotrophic and eventually eutrophic (nutrient-rich) conditions for most of the prairie systems in Canada, particularly those which originate in areas with shallow surficial material and therefore little sediment or nutrient input, such as mountainous areas. This progression is to be expected; however, it can also be enhanced or driven by anthropogenic activities which bring further contaminants into the water source, such as land clearing, urban wastewater effluent release, or the use of fertilizers in agricultural production.

Identifying the complex interactions between human activities on the landscape of a watershed and the impacts they have on water quality within a river channel can be simplified by examining the macro-scale activities which are known to negatively impact water quality each in turn before attempting to look at the upstream to downstream changes that may be a result of those activities. In this manner, nine major anthropogenic activities that may influence water quality will be discussed individually: urban development, population density, municipal wastewater effluent, agricultural activity (livestock production and cropland), wetland drainage, mining and petroleum production, industrial manufacturing and processing, energy production, and landfills.

III.3.i Urban Development and Wastewater Effluent

Urban developments such as towns and cities may impact river water quality in both direct and indirect ways. Urbanization, or the process of land conversion from farming or native vegetative landcover to residential or other forms of urban landcover, has been linked to changes in river hydrology, increases in pollutant runoff, and decreases in river baseflow (Fu, Butler, and Khu, 2009) (Wilson and Weng, 2010).

The most direct and perhaps well-studied impact is the release of wastewater effluent, however, while the contamination potential of wastewater is partially dependent on the size of the population within the urban area (and therefore amount of waste generated), that potential is also greatly influenced by the type of wastewater treatment available. For example, the cities of Calgary and Saskatoon use secondary treatment for wastewater, including tertiary treatment for advanced phosphorus removal. A secondary direct impact from urbanization includes the discharge of storm water effluent. This is the water that is released from direct-discharge sewers and includes water which runs off of the roofs of buildings, parking lots, sidewalks, and streets. Stormwater effluent therefore may include snowmelt and stormwater, but may also include untreated sewage, as in many cases outdated sewer systems include so called “combined” sewers which discharge a combination of both (Yetunde Jeje, Alberta Environment, 2006). The potential for contamination from stormwater effluent also depends on a variety of factors, including the presence of settling ponds or wetlands that intercept stormwater drainage before discharge, whether there is some other mechanical or biological treatment before discharge, and the types of land use within the urban environment which may act as contaminant sources or sinks.

For example, green spaces such as parks and golf courses may in fact operate as nutrient sinks for overland runoff if they are well vegetated with minimal maintenance. If they are highly maintained with routine fertilizer and chemical pesticide applications, and frequent grooming activities such as mowing and clipping, they may in fact be a contaminant source. Impervious areas such as roads, cemented pathways, and buildings may intercept rainfall and siphon it directly to the stormwater system, simultaneously increasing the amount of flow generated from the urban land base, and increasing the amount of contaminants discharged to the water source without the benefit of filtration systems or biological digestion/uptake. Highly industrial areas usually also include a large portion of impervious surfaces, and may contribute contaminants to stormwater runoff from improperly stored chemicals, or vehicle hydrocarbon residues.

Indirect impacts to water quality from urban areas arise from overland flow not captured by stormwater management systems (which is more common for smaller towns with no underground stormwater management infrastructure), or by influencing river hydrology. As discussed previously, water quality is highly related to flow and channel morphology, both of which may be highly altered in urban environments (Fu, Butler, and Khu, 2009) (Wilson and Weng, 2010). For example, the implementation of spurs, dikes, or weirs to artificially raise, lower, or redirect river flow can have major impacts on river sediment by creating areas of channel erosion or channel deposition. Increased river turbidity has been observed from structures such as weirs which create artificial water falls, or by structures such as intake spurs and reinforced or constructed channel banks that narrow channel width and increase the rate of flow. Most of these physical changes to the river bed or channel flow have direct impacts on river sediment load, and therefore secondarily, on other physical characteristics of water quality such as temperature, light penetration, oxygen saturation levels, the potential for biochemical oxygen uptake (oxidation) in exposed sediments, or the amount of dissolved solids, all of which may have consequences for contaminant concentrations.

Wastewater effluent from urban centers may contain a variety of contaminants, depending on the type of treatment that is applied prior to release. It is possible, in cases of highly treated wastewater being discharged into waterbodies with naturally poor water quality, for wastewater effluent to input relatively lower concentrations of water quality contaminants than are present in the receiving body, although this is very rare. Instead, wastewater effluent is usually considered a source of contamination. The primary contaminants that come from wastewater effluent are water and nutrients such as nitrates, phosphorus, and organic forms of carbon (Fu, Butler, and Khu,

2009) (Zeilhofer et al., 2010), but additional contaminants are often present, including pharmaceuticals, antibiotics, and synthetic hormones which are passed in human excrement, household chemicals, and fluoride from treated drinking water that is passed back into wastewater after use (Ritter et al., 2002). Wastewater effluent is also a very significant source of fecal coliform bacteria, particularly human-borne pathogens like Escherichia coli, and has been correlated with changes in water temperature, dissolved oxygen concentrations, sediments, and overall conductivity (Fu, Butler, and Khu, 2009) (Wang and Yin, 1997) (Zeilhofer et al., 2010). Wastewater effluent may also alter river pH, and contribute trace amounts of toxic metals and metalloids, although many heavy metals are removed with wastewater treatment (Makaya, 2010).

Runoff from stormwater sewers often includes many of the same contaminants as wastewater effluent, particularly for combined sewer systems, however stormwater in particular is known to contribute significant levels of sediment, pathogens, hydrocarbons (polycyclic aromatic hydrocarbons, or PAHs) and metals (Ritter et al., 2002). In fact, in many cases, urban stormwater effluent has a greater impact on water quality in receiving waterbodies because it is largely untreated (Zeilhofer et al., 2010).

III.3.ii Population Density

Population density does impact water quality in catchments, and many studies have correlated increased population density with declining water quality. However, while there is a definitive relationship between population density and overall water quality, the particular contaminants that may be contributed by changes in population density depend on the mechanisms of impact. Population density does not directly affect water quality, but rather, drives the activities that contribute to water quality problems more directly. For example, increases in overall population result in increased pressure for goods and services, including food production (agriculture) and manufacturing (industrial activities). The impact of increased population ***density*** (the number of people present in relation to the total land base) is manifested in the overall production and subsequent discharge of waste products, which are discharged to receiving waterbodies through industrial and municipal waste waters. In fact, the estimation of nutrient inputs to riverine and lake systems is often based, at least partially, on the total number of people living in the given area, for example the total number of people living in an urban area (along with some knowledge of water treatment methods) may be used to estimate nitrogen inputs from wastewater discharge (Bourne, Armstrong, and Jones, 2002) (Johnes, 1996).

III.3.iii Agricultural Activity

Agriculture impacts water quality via two main types of activity: crop production, and livestock production, with each type of production responsible for a different pathway of impact. Crop production has an effect on water quality by the removal of permanent, perennial vegetative landcover; impacting soils and soil quality; and leaching of the chemicals applied to cropland to enhance production (such as pesticides and fertilizers). Livestock production primarily impacts water quality by providing a source of nutrients and pathogens from livestock feces, although secondary impacts have been observed regarding gradual landcover change in heavily grazed pastures. Including both types of production, agriculture is associated with four classes of pollution to surface waters: bacterial, fungal, and viral pathogens, nutrients (particularly nitrogen and phosphorus), sediment, and synthetic chemicals from applied pesticides to waterways either from direct runoff into stream and river channels, or through irrigation return flows (Ritter et al., 2002). Perhaps the most significant direct impact of agriculture on water systems stems from sediment contributions in surface runoff (Ritter et al., 2002). Any activity which disturbs surface soil can lead to soil erosion and sedimentation issues from surface runoff, and agriculture not only impacts the largest land base in the prairies, but most agricultural activities contribute to soil erosion to some degree.

III.3.iii-A Crop Production

The amount of nutrients such as nitrogen and phosphorus actually lost from the soil and contributed to runoff due to agricultural activity is dependent on several factors, including the methods of cropland production (tillage and cultivation practices and fertilizer application rates), soil type, natural processes of nitrogen and phosphorus production and fixation, the pathways of water flow, and the amount of available soil moisture and precipitation (Bechmann et al., 2008) (Fealy et al., 2010). In dry periods, nutrient transport decreases dramatically, even if nutrients are applied excessively in the form of fertilizer inputs, simply because there is no mechanism of transport (Bechmann et al., 2008). During droughts, for example, the amount of nitrogen present in soils may gradually increase and concentrate, assuming there are no losses from soil due to aeolian (wind) erosion or other processes, simply to due natural nitrogen fixation from the atmosphere and the decomposition of organic matter in the soil. However, applied fertilizers are highly soluble, and plant nutrient uptake is relatively slow. As a result, under wet conditions and during precipitation events, there is the potential for very significant soil nutrient losses to surface runoff from both artificially applied nutrient inputs and natural soil nutrient sources, and it is not uncommon to see a spike in nitrogen and phosphorus inputs to river systems (and irrigation canals) during or shortly after major precipitation events.

Soil type influences nutrient losses and subsequent nutrient transport to waterbodies by influencing the *availability* of nutrients to transportation. Particle size, mineral composition, and amount of organic matter all impact the movement of nutrients through the soil and into surface runoff and groundwater. For example, smaller particle size results in a greater affinity for water and nutrient binding, with sandy soils presenting a greater vulnerability to nutrient loss compared to silty or clay soils. Mineral composition changes the nutrient binding characteristics of the soil as well, depending on whether elements present in the soil are positively or negatively charged, and if they readily form compounds with phosphorus, nitrogen, or carbon, or are prone to oxidation and chemical breakdown. The elements present in the soil (silicates, metals, salts, etc.) also provide an opportunity for dissolving into runoff as it moves across the landscape, or down through the soil into groundwater. Organic matter represents either a source or a sink for nutrients, depending on the time of year and biological processes present. For example, the breakdown of organic matter through aerobic and anaerobic decomposition converts bound nutrients into bioavailable compounds which can be taken up by plants or consumed by invertebrates and microorganisms. If these organisms are present and biologically productive, organic matter will convert into forms of nutrients which are then taken up into plant and animal tissues. If, however, there is not vegetative cover and within-soil productivity is low, organic matter may instead leach these bioavailable nutrients down into groundwater and surface waters instead.

Crop production practices can either reduce nutrient losses or increase them, depending on the type of practice and the method of crop production. The removal of permanent and perennial vegetation for the production of crops, particularly the removal of riparian vegetation along waterways, primarily affects soil erosion rates, nutrient capture, and runoff infiltration (Friedmann, 2007) (Peterjohn and Correll, 1984). Therefore production strategies which maximize perennial vegetative cover by leaving crop stubble, and avoiding soil disturbance through direct seeding and no-tillage practices can reduce the losses of applied and naturally occurring nutrients to surface runoff and infiltration (Bechmann et al., 2008). Other methods such as crop rotation also increase overall nutrient retention in surface soils. Primarily this retention occurs as a result of reducing overall soil erosion and by increasing nutrient fixation through the utilization of different crop types (such as nitrogen-fixing legumes). Practices which remove or reduce vegetative cover, or disturb the soil surface (particularly during spring when there is snowmelt, or in the summer and fall when there is greater precipitation) will ultimately provide greater opportunities for nutrient loss.

Contamination of waterways by agricultural pesticides can occur by a variety of mechanisms, including intentional dumping and accidental spills, overspray, or improper use. Indirect routes include the transport and deposition of airborne pesticides from aerial applications, or the leaching of soluble pesticides through soils into groundwater, or into runoff during precipitation events. The toxicity of pesticides (and therefore the risk they present once in surface waters) depends on a number of factors, including the type of pesticide, concentration in the water column, amount of time in the environment, and pathways and rates of biodegradation, which are all influenced by application amounts, methods, and rates, and physical factors such as soil type, topography, or land management practices (Hunt et al., 2006). While most pesticides pose a relatively low risk to human health at low doses, long-term exposure to pesticides in drinking water has been linked to cancer, reproductive impairment, and methemoglobinaemia (abnormal hemoglobin production) (Nikolaidis, Mandalos, and Vantarakis, 2008). Even in very small concentrations many pesticides can cause serious harm to aquatic organisms such as amphibians and fish species with sensitive metabolic systems, and numerous studies have implicated pesticide runoff as a cause of aquatic ecosystem health degradation (Hunt et al., 2006). For example, Atrazine, a highly water-soluble pesticide in common use today, has been suspected to cause endocrine disruption and reproduction impairment in Daphnia (water fleas), a common indicator of ecological health (Ritter et al., 2002).

III.3.iii-B Livestock Production

Livestock production also contributes to soil erosion and consequently, some of the same issues as cropland production. The risk for soil erosion is largely dependent on livestock management practices and stocking rates. Perhaps the most concerning input from livestock production to surface waters is fecal coliform contamination from feces because of the risk it poses to human health, particularly in rural populations which rely on untreated or minimally treated groundwater for their water supply (Ritter et al., 2002). Some livestock pathogens are species-specific, and therefore pose little or no risk to human health, however there are other fecal pathogens that can cause disease in multiple species, such as the enterohemorrhagic H7:0157 variant of Escherichia coli which was responsible for the deaths and widespread illness in the contamination crisis of Walkerton Ontario. While relatively rare compared to less virulent strains, EHEC (enterohemorrhagic Escherichia coli) is particularly difficult to detect due to a combination of two factors: cattle, a common carrier of EHEC, are essentially immune to the toxin that causes illness from the bacterium, and therefore cattle can be asymptomatic carriers, and secondly, relatively small concentrations of this strain can cause serious illness at 10 to 100 units or CFUs (colony-forming units), and cannot be quickly or easily differentiated from other strains of fecal coliforms using the commonly accepted methods of water quality sample analysis. Livestock also contribute nutrients to surface runoff from digested plant matter in feces, and may alter permanent vegetative cover, particularly in sensitive riparian areas where they access water.

III.3.iii-C Wetlands

> **Wetlands are one of the earth's most precious land resources. …Wetlands buffer the effects of floods, storms, and droughts, purify the water of entire watersheds, provide habitat for thousands of plant and animal species, and use energy with an efficiency that rivals the most productive croplands.**
> **- Environment Council of Alberta, 1990 (Alberta's Wetlands: Water in the Bank!)**

There is another indirect effect on water quality from agriculture which arises from the draining of wetlands to increase the arable land base. While interim wetland protection policies have been enacted or are currently in development for in Alberta, Saskatchewan, and Manitoba, historically the practice of wetland drainage has been widespread in the arable regions of the prairies to increase the farming land base. Approximately 85% of wetland loss in Canada has been due to drainage for agricultural purposes, resulting in a total estimated loss of over 100 0000 hectares of wetlands in Manitoba (Ducks Unlimited Canada, 2012), over 600 000 hectares in Saskatchewan (Huel, 2000), and approximately 2 200 000 hectares of non-peat wetlands in Alberta (Wilson, Griffiths, and Anielski, 2001).

Before and after pictures of farmland near Smith Creek Saskatchewan over 30+ years of canal development and wetland drainage (provided by Ducks Unlimited Canada).

Wetlands are integral to the health and maintenance of surface water systems, particularly in the prairies where they comprise up to 65% of the total land base in some areas (Alberta Water Council, 2008). By intercepting surface runoff, wetlands provide an important hydrological retention and storage function, thereby reducing the intensity of flooding events and serving as a recharge point for groundwater. Wetlands also play a very important role in maintaining water quality by reducing and storing sedimentation from surface runoff, storing nutrients and other potential contaminants, and moderating soil moisture and soil salinity (Alberta Water Council, 2008). Saline wetlands store salts from surround soils by acting as a closed-system endpoint for surface runoff, which evaporates into the atmosphere or infiltrates into the groundwater, leaving the majority of its salts behind. In highly cultivated landscapes, wetlands may also provide the only available permanent vegetative cover because they are largely undeveloped (Huel, 2000). Another extremely important function of wetlands is the sequestration and storage of carbon from organic matter and the atmosphere (. Wetlands are hot spots of biological productivity, where atmospheric carbon is incorporated into plant tissues through photosynthesis. While productive wetlands eventually reach an equilibrium between carbon storage through plant growth and carbon release through respiration and organic matter decomposition, they represent a large portion of long-term carbon storage on the prairie landscape, which is largely release back into the environment when wetlands are drained for other uses. It is not surprising then to see that a steady decline in sequestered carbon has been correlated with an exponential increase in the number of drained peatlands, a type of wetland dominants in northern regions (Wilson, Griffiths, and Anielski, 2001).

A research project by the University of Saskatchewan's Centre for Hydrology examined the impact of wetland drainage on downstream water quality in streams in prairie regions. Measurements in water quality in one permanent wetland over a 20 week period indicated that wetlands act as important interceptors for nutrients (nitrogen and phosphorus), salts, sediment, and bacteria in runoff. Furthermore it was demonstrated that the export of water quality contaminants from uplands to local waterways such as streams was significantly higher in sub basins with a greater amount of wetland drainage, and effect that scaled upwards with sub basin size (Westbrook et al., 2011).

III.3.iv Mining and Petroleum Production

The extraction of natural resources from the environment presents a risk for surface water contamination because of two primary pathways of impact: 1) the process the extraction often exposes naturally occurring materials to dissolution in surface runoff and groundwater and 2) extraction and processing creates by-product and industrial wastes which may be injected directly into the ground, discharged to surface waterways, or held in surface or underground storage which present a risk for leaching into groundwater or spillage into surface runoff.

Smaller scale industrial operations such as processing plants and manufacturing factories, while producing significant amounts of by-product waste for disposal, often use local municipal waste treatment plants or settling lagoons to reduce the impact of waste discharge into waterways or landfills, which offers some protection from environmental contamination, depending on the type and capacity of the waste treatment system. In contrast, large scale resource extraction operations such as mines are usually independently responsible for the management of their waste (Jeje, 2006). This can result in an increased risk to for surface water contamination due to the scale of operations (larger operations will produce more waste) and because provincial regulations may impose adequate requirements for waste management but oversight of those regulations on a day to day basis falls to the private industry. For environmentally-conscience companies, this may result in stricter waste-management procedures compared to public entities like municipalities, however, in some cases this means less oversight, resulting in significant environmental risk.

Two main resource extraction activities occur within the South Saskatchewan River Basin: mining (mostly coal, gravel, and potash) and oil and gas extraction. Other types of natural resource extraction such as forestry and uranium mining mostly occur in other parts of the provinces. Uranium sources are mostly in the Canadian Shield and therefore more northern portions of the prairie provinces (mostly northern Saskatchewan), while forestry occurs only in the headwater regions of the South Saskatchewan River, where there are also several national and provincial parks protecting the waterways, particularly for the Bow River (Banff National Park, Jasper National Park, etc.).

III.3.iv-A Mining

Perhaps the most concerning type of contamination from mining occurs as a result of exposing ground materials (as talus, open pit walls, or tailings) containing potentially toxic substances such as heavy metals to dissolution in surface runoff, or leaching into groundwater (USEPA, 1997). This can occur during the mining process, or as a waste product of post-mining processing, where large piles of 'slag' or ground surficial and bedrock material are left exposed to the elements. Often more than 90% of the excavated material at a mine site is left in situ and largely unmanaged (Ptacek et al., 2012). Exposed bedrock material undergoes oxidation from the atmosphere and in runoff. When occurring due to exposure to the atmosphere, oxidation results in the potential production and release of sulphide materials. When occurring in runoff, this contributes to the biochemical oxygen demand of surface waterbodies once the runoff reaches receiving waters, which ultimately results in the de-oxygenation of those waters. Some mines also discharge wastewater directly into surface waterways either as by-product from mine site dewatering, or as post-processing effluent. Most (78% of mines in Canada) of this water undergoes little or no treatment before discharge (Ptacek et al., 2012), however mining site discharge during operation (and for the first few years after mining cessation) is subject to federal and provincial water quality regulations. It is important to note that while current operations are subject to wastewater monitoring at significant cost, there are many mining sites which were established prior to provincial and federal monitoring regulations, which continue to leach contaminants to surface waters and require significant remediation efforts. In addition, peak concentrations of contaminants discharged from mining activity may occur several years after mining activity has ceased, and therefore may not be detected through monitoring efforts (Natural Resources Canada, 2010). The primary contaminants in this type of wastewater are trace metals and natural occurring salts.

Metals are one of the most commonly occurring yet toxicologically significant contaminants found in surface water. Unlike organic contaminants, most metals are persistent and accumulative in the environment, and while they provide essential macro and micro nutrients for the growth and reproduction of aquatic organisms, at concentrations higher than optimal conditions, most metals actually impair biological function or cause acute toxicity and death. Examples of commonly occurring trace metals and their significance as surface water contaminants can be found in table 1.

Table 1: Classification of Trace Elements in Water Supplies According to Water Quality Significance (from Ritter et al., 2002, Table 4, page 16).

Significance	Trace element
Aesthetic significance—taste and discoloration problems	Cu, Fe, Mn, Zn
Toxic at levels found in some water	As, Ba, Cd, Cr, Hg, Pb
Toxic but present levels in water are probably unimportant	Ag, Al, Be, Bi, Ni, Sb, U
Probably not toxic up to ppm levels, current levels are ppb or less	Ga, Ge, Sn, Sr, Ti, V, Zr
Nutrient metals (at ppb levels), some may be toxic at higher levels	B, Co, Cu, Fe, Mn, Mo, Se, Zn

At optimal concentrations, trace metals may provide essential nutrients to aquatic organisms. However, past a threshold concentration, the same element may limit biological productivity, or incur lethal toxicity (figure 6, taken from Ritter et al., figure 5, page 26). The tolerable or optimal concentration range varies among trace metals.

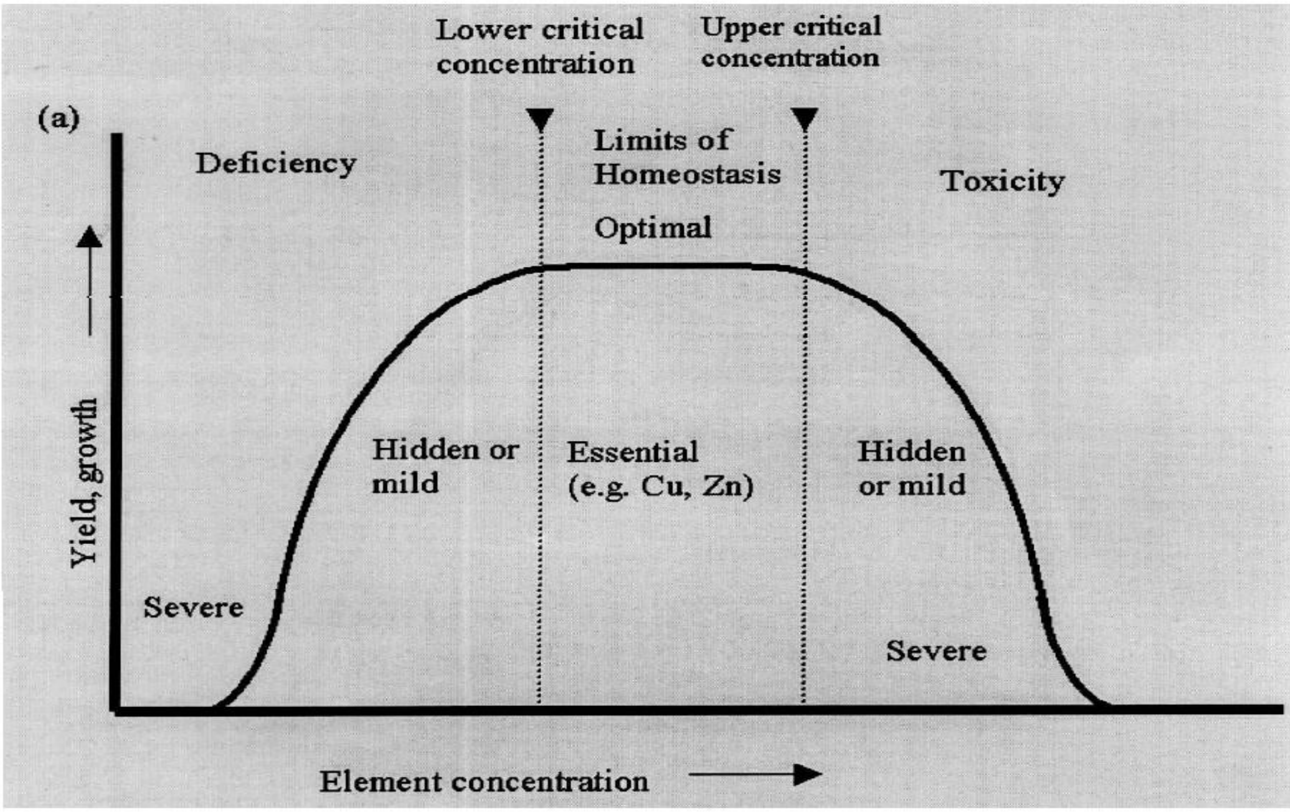

Figure 6: Diagram of concentration-toxicity relationship for some trace metals.

The toxicity of metals in the environment depend on several factors, including the interactions between organic and inorganic species already present in the receiving waterbody, the speciation of the metal (which impacts bioavailability, or the uptake of metals into biological tissues), and the physical/chemical characteristics of the water body in which the metals are present, such as temperature and pH. The storage of material from mining operations in regions with naturally high concentrations of sulphur in the bedrock or surficial material can lead to a highly acidic and toxic form of leachate called acid rock drainage. Sulfuric acid or metallic sulfide (most of which is iron sulfide, but may also include lead sulfide, zinc sulfide, or iron copper sulfide) a by-product of this leachate (USEPA, 1997), can solubilize metals from waste and bedrock materials and increase the risk of groundwater or surface water contamination (Ritter et al., 2002), including the solution and uptake of elements such as aluminum, arsenic, cadmium, cobalt, copper, iron, mercury, manganese, nickel, lead, selenium, and zinc (Ptacek et al., 2012).

Coal and potash mining have some of the same risks as metal mining in terms of exposing surficial material to the surface environment resulting in metal and metalloid leaching. However, wastewaters from these types of production may contain other contaminants as well, such as high concentrations of naturally occurring salts (potash) and traces of hydrocarbon (coal), particularly where the waste material includes oil-bearing sands and shales.

Acid mine drainage from Sherridon mine, northern Manitoba (Ptacek et al., 2012).

III.3.iii-B Petroleum Extraction

Large volumes of water are used for the extraction of oil and gas, primarily for heavy crude extraction in oil sands production, coal bed methane extraction, tertiary recovery, and to maintain fluid pressures in the below-ground extraction of light crude (Ptacek, 2012). The extraction of light crude involves the injection of water into bored wells to maintain hydrostatic pressure as oil is extracted from underground. Similarly, tertiary oil recovery methods involves the injection of fluid at very high pressures, either as steam, chemical solutions, or surfactants. Oil extraction from oil sands includes the use of steam, at a rate of three barrels of water per barrel of oil. Coal bed methane production relies on the dewatering of large volumes of rock, similar to some methods of metal mining, which produces large volumes of wastewater. Natural gas extraction may use injected stream or other fluids as well for hydraulic fracturing.

The extraction of petroleum products through the use of pipelines and boreholes can lead to groundwater contamination through leaks in casings and pipes. Obviously the number of wells, materials used, and methods of extraction all contribute to the risk of contamination, however most of this contamination occurs in groundwater which may or may not make its way into surface waters. Greater contamination risk comes from the production of waste water used in extraction or the injection of chemical fluids to precipitate hydrocarbon from the bedrock or to artificially raise or maintain interstitial pressure if these waste fluids are not managed properly. In hydraulic fracturing or “fracking” methods, after the initial well is drilled the casings are perforated, usually with explosives, and then high-pressure fluid (often saline water) is injected into the well to fracture the bedrock. A slurry of fraccing fluids and proppants (sand or fine particulate ceramic) is then injected into the well to keep the fractures open but permeable to allow the underground gasses to escape up the well hole. Fraccing fluids may include water, sand, and lubricating chemicals, although regulations stipulate that the chemicals used must be non-toxic to human health (although not specifically environmentally inert). These fluids are injected hundreds or thousands of feet below the water table, minimizing the risk of the upward migration of natural oils and gases or fraccing fluids into water sources or surface water. However, there have been a few North American cases of suspected shallow groundwater contamination by fraccing despite the industry’s efforts to reduce the risk by ensuring cement capping and other protection measures are situated well below the deepest groundwater source. Unfortunately since many of the potential fraccing contaminants are naturally occurring substances (such as sand, natural hydrocarbon compounds, saline groundwater and natural gases), without considerable pre-operation sampling, it is difficult to accurately determine if contamination from fraccing has actually occurred, or would have occurred without fraccing due to the nature of the overlying bedrock materials. Improper drilling techniques are most likely to blame for most documented occurrences of fraccing fluid contamination (Getches-Wilkinson Centre for Natural Resources, Energy, and the Environment, 2012). Most onshore operations in North America require some degree of fraccing or “stimulation” to ensure productive flow (CSUG, 2012).

“Produced water” is the groundwater that accompanies oil and gas extraction from pressurized underground formations that are brought to the surface as an extraction by-product. By volume, it is the biggest waste product generated from in-situ extraction (Veil et al., 2004). Most oil and gas reservoirs contain both petroleum hydrocarbons, and water, which are combined with injected extraction fluids and then brought to the surface as an oil/gas-water-sediment-chemical mixture which must be separated post-extraction. In the case of coal bed methane production, production water is the formation water extracted from the reservoir to facilitate the movement of naturally occurring gases to collection wells ("dewatering"). Since it is a combination of naturally occurring fluids and extraction fluids, the composition of production water varies considerably, however its main constituents include oil, water, natural salts, and other organic and inorganic compounds. Trace constituents may include metals, hydrocarbon residues, and any chemicals used in extraction, such as corrosion inhibitors, scale inhibitors, biocides, emulsion breakers and clarifiers, coagulants, flocculants, and solvents (Veil et al., 2004). Production waters from gas extraction may be more toxic than oil because of the presence of aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylene which are highly toxic. Chemicals used in gas extraction include dehydration chemicals, hydrogen-sulfide removing chemicals, and well stimulation chemicals such as mineral acids, brines, and other additives (Veil et al., 2004). Produced water from methane extraction originates from the reservoir rather than being injected into it, and therefore usually does not contain additional chemicals, but may vary significantly in terms of the volume of water produced.

Hydrocarbons present in production waters include organic acids, polycyclic aromatic hydrocarbons, phenols, and volatiles, and in addition to the chemical and heavy metal components of production water (zinc, lead, iron, barium, manganese, among others), they contribute to the high toxicity of these waste waters. Most of the soluble organics (carboxylic acids, ketones, and alcohols) in production waters are not easily or efficiently removed, and neither are partially soluble components such as metals and higher-weight hydrocarbons (polycyclic aromatic hydrocarbons or PAHs) (Veil et al., 2004). Therefore waste water produced from in-situ well extraction is often re-injected once operations are complete, rather than discharge into surface waters. Often disposal sites are located in deep, highly saline aquifers because provincial and federal regulations prohibit the direct discharge of extraction wastewater to surface waterbodies. These disposal sites are relatively safe in terms of surface water contamination, as waters from these types of aquifers are rarely connected to surface water systems except for deep groundwater cycling that occurs over thousands of years. However, in some cases additional protection measures are necessary such as well capping with cement mixtures, or the use of specialized casing materials. Even with these additional measures, leaks have been known to occur, which is particularly problematic when leakages occur at the shallow groundwater level and contaminate the water table.

Unlike in-situ well extraction, oil sands production waters are not usually disposed of in deep wells, but rather in tailings ponds. Regulations prohibit the release of untreated tailings water to the environment, however, secondary contamination arises from leaching and exposed waste material, much like metal mining where the bedrock, or in this case loose surficial material, is exposed to precipitation and runoff. Oil sands developments in Canada are located primarily in the province of Alberta, as part of the Cretaceous fluvial-estuarine deposits of the north-eastern portion of the province. The locations for these developments are shown in figure 7. There are currently no oils sands operations in the South Saskatchewan River Basin, although there is substantial in-situ well extraction for both oil and gas across the basin, particularly for oil in the tributary basins in Alberta, and for natural gas in the western portion of the South Saskatchewan River Basin in Saskatchewan.

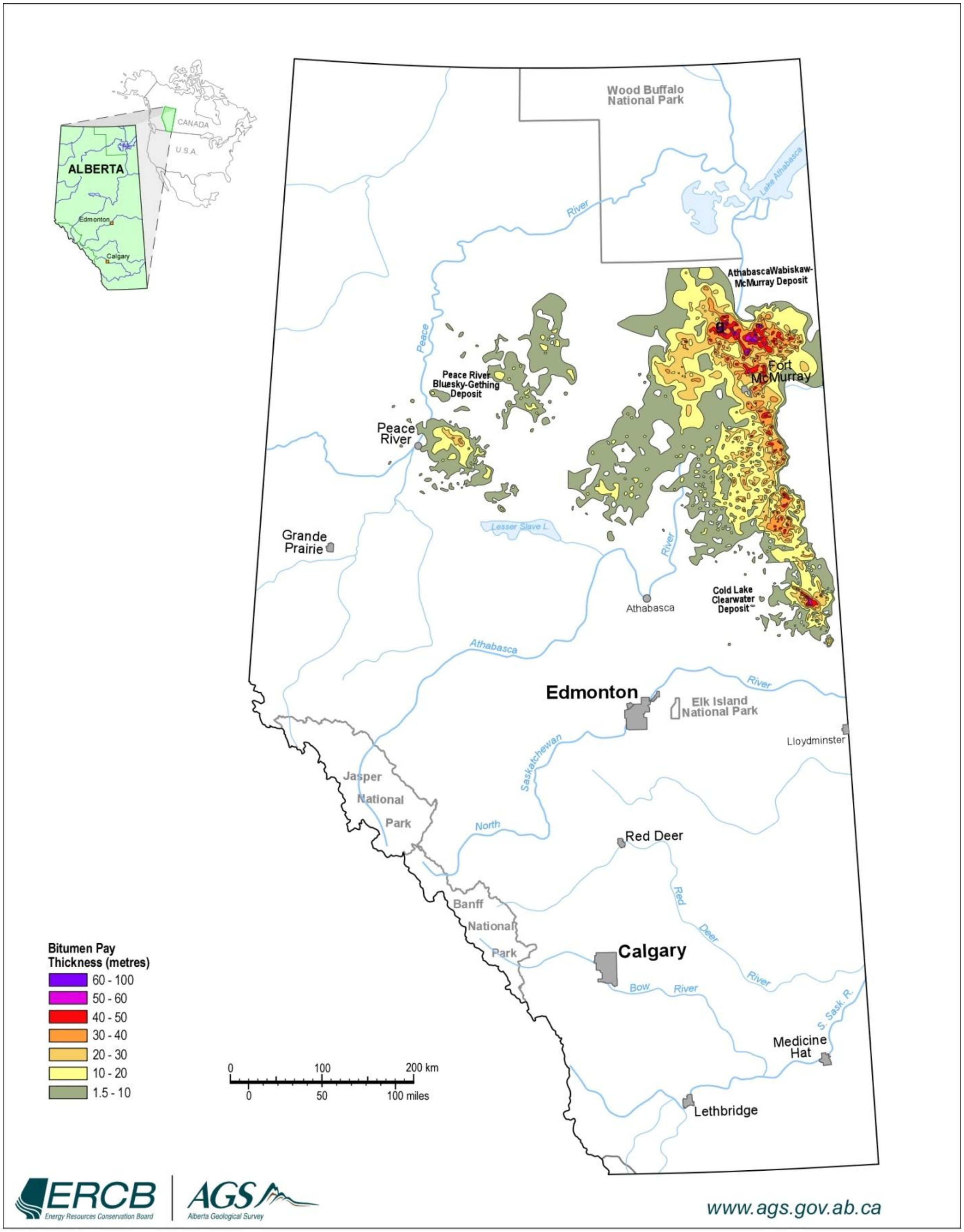

Figure 7: Athabasca, Cold Lake, and Peace River Oil Sands Developments in Alberta

III.3.v Energy Production

Water contamination from energy production primarily occurs in one of two ways: 1) atmospheric deposition from the burning of fossil fuels, as with coal-fired production and 2) the discharge of cooling waters from additional types of energy production (such as nuclear). A third pathway of impact would be the discharge of water from hydropower production, which does not directly contribute contaminants to surface waters, but may have other significant impacts on water quality because of changes to natural river hydrology. While power plants used to discharge waste waters from production directly into surface waters, for the most part this practice has been eliminated in Canada. Instead, any waste products produced through power generation (such as coal-fired plant ash) are now de-watered and disposed of in toxic waste landfills, stored in containment ponds, or directed to municipal waste treatment systems. Solar and wind energy production do not impact surface water quality except occasionally during construction, if constructed near waterways, or if wetlands are drained for their construction.

Atmospheric deposition from fossil fuel combustion in energy production plants impacts surface waters primarily by contributing to the acidity of precipitation. Fossil fuel combustion produces sulfur dioxide and nitrogen oxides which are precursors of acid rain. This type of rain has a large-scale, large area effect that is difficult to quantify or directly relate to downstream changes in water quality, except over the very long term. In addition, trace mercury emissions are also known to result from coal-fired power plants, which can pose a threat to human health in extreme cases (Krantz and Bassermann, 2010). The use of scrubbers (passing emissions through a mixture of limestone and water) can reduce or eliminate these particulates from plant emissions, but results in the production of sludge waste which must be disposed of, and represents a contamination risk when disposed of improperly, such as disposal in unlined landfills, over areas of shallow groundwater, or near waterways.

The discharge of cooling waters from energy production (whether its nuclear, fossil-fuel, or hydro power generation) may have a significant impact on the temperature of receiving bodies. A 500-megawatt power plant uses about 8.3 million cubic meters of water a year, while nuclear power plants require 225 litres of water for every kilowatt hour of electricity produced (Krantz and Bassermann, 2010). Some types of energy production from fossil fuels or nuclear production use less water, such as dry-cooled coal-powered plants, but these represent a very small fraction of plants in North America (less than 1% as of 2012, according to the Union of Concerned Scientists, http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/water-energy-electricity-coal.html). Most power plants have massive water requirements for daily energy production. While cooling waters do not typically contain contaminants (with the exception of nuclear power generation which may include trace amounts of radiation), the amount of water required and the speed at which this water is used and discharged back into receiving water bodies means water is discharged at a greater temperature than ambient condition. An increase in ambient or background temperatures in natural water bodies affects the behavior of aquatic organisms, but may also present more acute and lethal impacts such as deoxygenation and the acceleration of biological production, further impacting oxygen cycling and nutrient concentrations.

Where power plants require the alteration of a natural waterway to accommodate water withdrawals or discharge, this may impact water quality directly by creating sedimentation issues, or by restricting flow and thereby changing water turbidity, sediment load, or temperature (Ritter et al., 2002).

III.3.vi Industrial Manufacturing and Processing

The impact of industrial activity on surface water depends on the type of industry or activity, whether it discharges effluent, and if that effluent is treated in any manner before discharge. As a result, whether or not a particularly industrial activity poses a risk to water quality depends on the specific activity being examined. However, some types of effluents have common constituents, such as pulp and paper mills, which discharge dyes and organochlorines, chemicals typical to the industry (Ritter et al., 2002). Steel and other metal product manufacturers usually produce metal by-products, although they are not often discharged directly to waterways but are rather recycled for other uses or disposed of in chemical dumps. Other constituents that may be produced as a manufacturing or production by-product include compounds with high oxidative potential, and therefore contribute to the biochemical oxygen demand of sediments in waterways when discharged. Industrial wastes can contaminate surface water through three pathways: direct discharge into waterways and emissions through combustion of wastes in stacks (which are later deposited in precipitation or fallout); leaching into groundwater from storage and disposal sites such as landfills; and from overland runoff during precipitation events or from snowmelt.

Manufacturing and processing activities, with the exception of pulp and paper mills, often do not discharge directly into waterways, but may contribute chemicals and metallic by-products to chemical landfills, including hazardous or toxic wastes. Present-day regulations ensure that industrial waste is disposed into landfills with strict construction and management protocols that help to ensure these landfills do not leach waste into groundwater or surface runoff, however, not all landfills currently in operation follow these protocols, and certainly not all old and outdated landfills were regulated when implemented, or properly decommissioned following abandonment. As a result, many of these landfills have contributed trace amounts of toxic contaminants to groundwater and have therefore shown up in drinking water supplies even in North America (Ritter et al., 2002). Industrial-borne contaminants have broad impacts on aquatic ecosystem health and water quality, and may even pose direct risks to human health (Ritter et al., 2002). Keith (1979) reviewed the occurrence of contaminants in industrial waste from a study conducted by the U.S. EPA, which reviewed 129 chemicals including several contaminants with a high risk rating known as "priority pollutants" (pollutants with a need for strict risk assessment and management).

Since the primary pathways of impact for most industrial contaminants are through disposal in municipal wastewater or landfills, industrial waste contaminants will not be explored further here. Pulp and paper mills typically discharge directly into waterways, however while there are mills in operation on the North Saskatchewan River and Saskatchewan River, there are currently no pulp and paper mills operating within the South Saskatchewan River Basin (as of 2008).

III.3.vii Landfills

Landfills impact water quality through mostly indirect means: either via leachate which contaminates groundwater, or by contaminating surface runoff when landfills are improperly designed without effective runoff management, and are located close to waterways. The content of landfill leachate depends on the stored materials: hazardous waste disposal sites will have different leachate compared to regulated municipal landfills. In addition, the age of the landfill will affect the risk it poses for surface or groundwater contamination, as older landfills will have been subject to different regulations when established and may be unlined (Kjeldsen et al., 2002), and contain toxic materials which would otherwise be recycled and disposed of in strictly managed storage facilities under current legislation (Ehrig, 1983). Landfills may leach contaminants for decades after decommissioning, particularly for older landfills with no discharge management features put in place (Barnes et al., 2004).

Whether a landfill poses a risk to surface water depends primarily on its location in relation to waterways: water bodies located down-gradient or in close proximity to unlined landfills are at the highest risk for contamination, with contamination risks generally decreases the further the landfills is away from the water source. Some contaminants travel very well through groundwater, such as insect repellants like DEET and phosphates, and may pose a contamination risk hundreds of meters down-hill (Barnes et al., 2004).

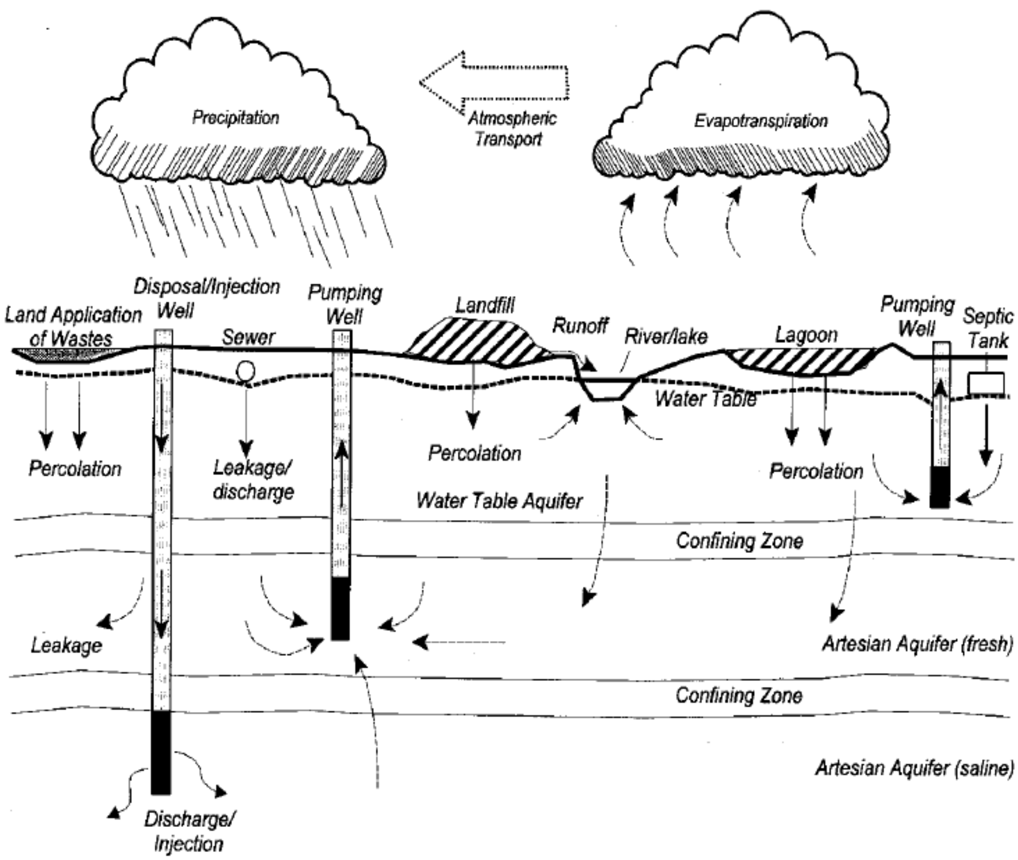

Figure 8: Sources of water contamination from landfill and disposal wells. Ritter et al., 2002, figure 7, page 48.

While specific constituents may vary, landfill leachate contaminants can be broadly grouped into several categories: pathogens, nitrates, chlorinate organics, trace metals, and hazardous chemicals. Landfill types include industrial waste impoundments; underground storage disposal sites including tanks and disposal wells; landfills and dumps; hazardous waste disposal sites; agricultural waste disposal sites (including livestock manure sites); and septic tanks and cesspools. Industrial wastewater impoundments are facilities designed to store liquid-solid wastes either temporarily (prior to treatment), or for permanent long-term storage, usually as waste generated from municipal wastewater treatment (treatment sludge), animal feedlots, dewatered oil and gas extraction waste, mining waste, pulp and paper mill solids, or chemical operations. Once treated, industrial wastewater may be discharged into surface waters. Underground storage tanks are often used to store toxic chemicals that pose a hazard for human exposure, such as petroleum products and pesticides. Leaking storage tanks pose a significant risk for groundwater contamination: a single litre of gasoline can contaminate up to 1 million litres of groundwater (Ritter et al., 2002). Among petroleum products, perhaps the most hazardous are BTEX compounds (benzene, toluene, ethylbenzene, and xylenes). Benzene is particularly toxic, and is a known carcinogen.

Landfills and dumps are used to dispose of household or municipal waste. When buried in a municipal landfill, refuse will undergo several stages of decomposition: 1) an initial aerobic phase 2) anaerobic acid phase 3) in initial unstable methanogenic phase and 4) a stable methanogenic phase (Kjeldsen et al., 2002), each with their own potential by-products. Sanitary landfills may or may not be lined, or have any leachate containment measures, while secured landfills are lined and may have runoff control measures implemented. Landfill leachates are usually highly mineralized, and may contain heavy metals (cyanide, cadmium, lead) and chlorinate organics (chlorinated hydrocarbons, polychlorinated biphenyls) (Ritter et al., 2002) which often contribute to the biochemical oxygen demand in waterways where they are eventually discharged. Pharmaceuticals and household chemicals may also be found in landfill leachate, such as flame retardants, disinfectants, antibiotics, insect repellant, and even prescription medications (Barnes et al., 2004). In some cases, landfill waste may be treated to reduce toxicity of leachates, for example by transfer to another, more secure location, through biodegradation, chemical and physical treatment methods, or membrane filtration processes (Renou et al, 2008). However, the efficacy of such treatments versus the cost of treatment is widely debated, with some studies suggesting that only advanced treatment methods such as tertiary treatment in a waste treatment plant can reduce or eliminate leachate toxicity in some cases (Marttinen et al., 2002) (Lema, Mendez, and Blazquez, 1988).

Septic tanks and cesspools that store human and animal excrement and household waste are typically located in rural areas. The primary contaminant of concern from septic tanks is pathogens such as fecal coliform bacteria, but they may also be a localized source of excess nutrients. Disposal wells are drilled into the ground for the purpose of disposing industrial waste, contaminated stormwater, agricultural drainage, or natural resource extraction production water. Animal feedlot wastes are often stored in poorly managed excrement mounds which are often a source of contamination for local wetlands which may contribute runoff to major waterways under extremely wet conditions.

III.3.viii Summary of Contaminant Sources

A summary of primary water quality contaminant sources can be found in table 2.

Table 2: A Summary of Primary Water Quality Contaminant Sources

	Water Quality Parameter	Principal Sources of Water Quality Contaminants							
		Urban Stormwater	Municipal Wastewater	Industrial Wastewater	Mining	Petroleum Extraction	Energy Production	Agriculture	Landfills
Nutrients	Carbon	x	x	x			x	x	x
	Nitrogen	x	x	x			x	x	x
	Phosphorus	x	x	x				x	x
Physical	Turbidity	x	x		x	x	x	x	x
	Temperature	x	x				x		x
	pH	x	x	x	x	x	x		x
	Sediments	x	x	x	x	x	x	x	x
	Conductivity	x	x	x	x	x		x	x
	Total Dissolved Solids	x	x	x	x	x		x	x
Biological	Oxygen	x	x	x	x	x	x	x	x
	Biological Productivity	x	x	x	x	x	x	x	x
	Fecal Coliforms	x	x	x				x	x
Salts / Ions	Sodium	x	x	x	x	x			x
	Chloride	x	x	x	x	x			x
	Sulphate	x	x	x	x	x	x		x
	Magnesium	x	x	x	x	x			x
	Fluoride		x	x	x				x
Metals	Arsenic	x	x	x	x	x			x
	Copper	x	x	x	x	x			x
	Zinc	x	x	x	x	x			x
	Lead	x	x	x	x	x			x
Other	Hydrology / Flow	x	x	x	x	x	x	x	x
	OTHER	pesticides	pharmaceuticals, household and automotive chemicals	dyes, organochlorines, industrial processing chemicals, pesticides	sulphides, hydro-carbons	toxic hydro-carbons, proppants, chemicals	acid rain (sulfur dioxide, nitrogen oxide), mercury	pesticides	industrial and household chemicals