Hutchinson
Environmental Sciences Ltd.

Battle River Synoptic Survey

Phase II

Prepared for: Alberta Environment and Sustainable Resource Development
Job #: J130037
Contract: 140176
June, 2014

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June 4, 2014 HESL Job #: J130037

Chris Teichreb
Alberta Environment and Sustainable Resource Development
#304, 4920-51 St
Red Deer, AB T4N 6K8

Dear Mr Teichreb:

Re: Contract 140176 – Battle River Synoptic Survey Phase II – Draft Report

Please find enclosed the final report describing the methods and results of the Phase II Battle River Synoptic Survey. We present the results in the context of Phase I Synoptic Survey results. We also provided an in-depth interpretation of temporal and spatial water quality trends in the Battle River using the collected lagoon and tributary data as well as land use information derived from GIS products. We also addressed your comments on the draft report and a detailed response is provided under separate cover by email.

We thank you for the opportunity to assist AESRD with this project. Please do not hesitate to contact us if you have any questions.

Sincerely,
Hutchinson Environmental Sciences Ltd.

Dörte Köster, Ph.D., Senior Aquatic Scientist
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Signatures

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Executive Summary

A set of draft WQOs for Battle River were developed for variables of concern in support of the North Saskatchewan Regional Plan (NSRP). As the objectives apply to the entire length of the reach for which they were established, there is a need for a better understanding and delineation of point and non-point sources along the entire length of the Battle River prior to implementation of objectives. Phase I synoptic survey conducted in 2011 described water quality patterns during summer, fall and winter in the Battle River mainstem. The purpose of this Phase II study was to augment existing datasets for the Battle River mainstem and to address the data gap of point and non-point sources by monitoring tributaries and major point discharges to the Battle River.

The 2013 sampling program was based on the Phase I survey, with minor modifications. It included 23 sites in total, 12 along the main stem of the Battle River, six at the confluence with major tributary inflows, and five at selected point sources. Sites were sampled during summer (late August), fall (October), and winter (January), with mainstem and tributary sites visited in each season and lagoon discharges sampled once during the fall discharge. The same suite of water quality indicators was monitored at all sites and included standard field parameters, nutrients, fecal bacteria, major ions and related parameters, and suspended solids. Flow was measured where possible to allow load calculations. Results were compared to 2011 monitoring results and interpreted in the context of observed point discharges and mapped land use.

Flow

Flows were highest in summer and lowest in winter. Flows increased with downstream direction, as expected, but also decreased at some locations during summer. This indicates that water is lost from the river at some times, either due to water withdrawals, evaporation in stagnant areas or loss to groundwater. Tributary flows were often negligible, in particular in the downstream reaches.

Provincial and Federal Guidelines

Provincial and federal guidelines for the protection of aquatic life and for irrigation were exceeded for five parameters, as detailed below:

- Fluoride exceeded the CCME guideline for the protection of aquatic life (PAL) in all samples and therefore appeared to be naturally elevated in the system. It did, however, increase downstream of lagoon discharges.
- Low oxygen levels under ice in January were among the most severe cases of non-compliance, as it dropped locally below acute levels (< 5 mg/L). Decomposition of large amounts of biomass produced during the open-water season is likely the reason for oxygen depletion.
- Elevated un-ionized ammonia concentrations at the north end of Driedmeat Lake exceeded Provincial PAL water quality guidelines. The high un-ionized ammonia levels were due to a combination of ammonia loads from the City of Camrose lagoon discharge, elevated pH in the Battle River and poor mixing conditions in the local river reach (stagnant waters upstream of Driedmeat Lake) to attenuate the discharge effect.
- pH exceeded the PAL guideline in reach 2, likely related to high aquatic productivity.

- Bacteria levels above the irrigation guideline of 100/mL were observed upstream of point discharges in reaches 1, 2 and 4, indicating a non-point source for bacteria.

Reach-Specific Water Quality Objectives

The proportion of measurements that exceeded 50th percentile WQOs ranged from 17% for Reach 1 winter data to 44% for Reach 2 summer data. While improving trends since the period from which the WQOs were derived (2000-2010) cannot be ruled out, it is likely that the low-flow seasons sampled by the synoptic surveys were not representative for the entire open-water period that was used for objective setting. It can be expected that many parameters, in particular the parameters associated with particles, e.g., TP and TSS, be more elevated in spring samples, resulting in open-water WQOs that are naturally higher than low-flow water quality levels. Spring synoptic surveys would be required to balance the representation of the open water season in the monitoring record.

A considerable number of measurements exceeded the 90th percentile WQO in 2011 and 2013. These values can be of concern as they are at the highest end of the historical data distribution. A recurring pattern of high values is apparent for nitrate and nitrite values in all reaches. Nitrate and nitrite can originate from fertilizers, point sources and decomposition of organic matter, all of which possibly may play a role in the Battle River.

Reach 2 had generally the largest number of values exceeding the 50th and 90th percentile WQOs, which is likely reflective of the cumulative effect of point- and non-point sources in this reach. Reach 1 had the second-largest number of values exceeding the 90th percentile WQO, which compared to reach 4 may be explained by high-intensity agriculture combined with larger runoff from the larger contributing areas.

Spatial Patterns

The general spatial patterns were relatively low values of most substances in reach 1, increases in reaches 2 and 3 and then decreases in substance concentrations in reach 4, consistent with previous studies. The largest increase in nutrients and major ions occurred between the sites upstream and downstream of Ponoka, reflecting the cumulative impact of loadings from the most important (in terms of flow) tributary, Wolf Creek and two lagoon discharges, Lacombe and Ponoka. A second large increase often occurred between downstream of Ponoka and upstream of Pipestone Creek, part of which (TOC, turbidity) can be explained by the Samson Lake wetland complex, but part of which (bacteria, nitrate) is unknown. The largest decreases occurred downstream of Driedmeat Lake, indicating that the lake acts as a sink for nutrient loads from upper reaches. Only occasionally the lake recycles some of the loads and becomes as source of nitrate and nitrite, dissolved phosphorus and sulphate, likely due to decomposition of accumulated organic matter and/or anoxic conditions.

An exception to these general patterns were bacteria levels, which peaked upstream of Ponoka and upstream of Pipestone Creek, confirming non-point sources of bacteria loads. Another exception were conductivity, major ions and related parameters, which increased in reach 1, decreased to lower levels within reach 2 and 3 and then increased again in reach 4. These patterns may be due to ion uptake in the Samson Lake wetland downstream of Ponoka and the influence of ion-rich tributaries entering reach 4 of the Battle River. The natural occurrence of saline soils and high evaporative loss in this dry area are possible reasons for this increase in conductivity in reach 4.

The newly added site at the Battle Lake outflow showed elevated levels of ammonia and dissolved phosphorus, but these levels were not sustained in the other reach 1 sites. This indicates that the outflow may not contribute enough volumes to influence downstream water quality or that these levels were assimilated in the river.

Gaps and Conclusion

This study identified some knowledge gaps that we recommend addressing in the future:

- Spring sampling would be required to complete a year-round description of the Battle River ecosystem. This will help to better represent the open water season with respect to WQO and will provide insight into the season when most runoff from the watershed can be expected and some seasonal lagoon discharges occur.
- The reach between downstream of Ponoka and upstream of Pipestone Creek requires further investigation, as there was an unidentified large source for a variety of substances, including fecal bacteria, TSS, turbidity, organic carbon, and nitrogen, only parts of which (TOC, possibly turbidity) can be explained by the Samson Lake wetland complex in this reach.
- Continuous dissolved oxygen data collected at hourly or sub-hourly intervals are needed to adequately assess diurnal oxygen conditions in the Battle River in the summer months, in particular in reach 2, where abundant macrophyte beds and high day-time oxygen levels were observed.
- The impact of the Camrose lagoon discharge on ammonia levels in the Battle River above Driedmeat Lake warrants ongoing monitoring to assess if planned upgrades to the wastewater facility address this issue.

In conclusion, the Battle River shows the characteristics of a prairie river, with low flows in summer, fall and winter, high nutrient concentrations and aquatic productivity and hard, alkaline waters. The high aquatic productivity and some of the major ion content are further enhanced through point- and non-point source discharges to a point where aquatic habitat is impaired in fall and winter, in particular in reach 2. Elevated bacteria levels, likely from livestock operations, also impair water quality in all reaches. Given the naturally low flow volumes, Battle River is more sensitive to the cumulative impact of human activities in the watershed than other Alberta rivers that benefit from the enhanced flow from mountain snow melt and precipitation. It therefore deserves particular attention to mitigating the current impacts on the Battle River ecosystem.

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1. Introduction

A set of draft WQOs for Battle River were developed for variables of concern in support of the North Saskatchewan Regional Plan (NSRP) (Golder 2011). For the purpose of objective setting, the Battle River in Alberta was subdivided into four reaches (Figure 5). As the objectives apply to the entire length of the reach for which they were established, there is a need for a better understanding and delineation of point and non-point sources along the entire length of the Battle River prior to implementation of objectives.

In 2011, Golder Associates (Golder 2012) completed the Phase I synoptic survey of water quality in the Battle River. Discharge was measured and water quality samples were taken from the Battle River over a range of seasons and flow regimes to provide water quality and loading estimates for comparison with the draft WQOs and to further characterize the river. The sampling program did not include tributaries or point source discharges.

Results of the Phase I surveys showed that, for most parameters, concentrations in the Battle River were lowest in Reach 1, increased substantially in response to point and non-point sources in Reach 2 (most notably discharges from the Ponoka and Camrose lagoons), and were stable or decreased downstream. River loads increased substantially in Reach 2 and increased slightly in Reach 3. Loads were highest in the late summer (early September), consistent with point source loadings during low flow conditions. The sampling program did not include tributaries or point source discharges and therefore all interpretation in terms of the source of loads in the river were hypothetical.

The purpose of this study is to address the data gap of point and non-point sources along the entire length of the Battle River and to augment existing datasets for the Battle River mainstem. The project required the selection of strategic locations for monitoring—including major tributaries and lagoon discharges—and sampling of those during summer 2013 (August), when little point discharges occur, in autumn 2013 during lagoon discharges (October), as well as in winter 2014 (January) under ice conditions.

The specific objectives of this study were to

1) Understand and delineate the sources of any significant water quality pressures along the Battle River, i.e.,
    a. Non-point source pollution (runoff from urban and agricultural areas), as identified by tributary data and water quality changes in the main river in absence of municipal discharges,

    b. Point source pollution (wastewater discharges), by sampling municipal discharges, where no operational effluent quality is available for the full suite of indicators,

2) Augment the existing detailed spatial water quality data with another year of data,
3) Increase the data coverage for Reach 3, where data were insufficient to develop objectives, and
4) Provide recommendations for further work necessary to support the implementation of water quality objectives.

In this report, we present spatial patterns along the Battle River mainstem for each measured parameter, and put them into context by discussing concentrations and loads in the tributaries and effluents and by comparing them to historical data. We also conducted a reach-based loading analysis, in order to compare the sum of loads from tributaries to those from point sources in the context of reach-specific water quality objectives. In addition, some mapping was completed to aid interpretation of the spatial patterns in water chemistry and flow.

2. Study Area

The Battle River watershed is part of the North Saskatchewan River Basin in central Alberta. Unlike most of Alberta's major rivers, which are continuously fed by melting mountain snowpack and glaciers, the Battle River watershed is entirely prairie fed. Their modest water supply is derived solely from local surface water runoff (from rain storms and spring melt), groundwater flow, and supply from tributaries, lakes and reservoirs (Battle River Watershed Alliance (BRWA) 2011).

The Battle River is about 1100 km in length. It flows across Alberta for about 800 km before reaching the Saskatchewan border. Covering over 25,000 square kilometres, the Alberta portion of the Battle River watershed is entirely within the province's settled "White Zone" and is characterized by productive agricultural communities that span the Parkland, Grassland, Boreal and Foothills Natural Regions (BRWA 2011), with the Parkland covering the majority of the watershed (Figure 5).

There are three inline lakes on the Battle River; Samson Lake (between d/s Ponoka and u/s Pipestone Creek), Driedmeat Lake (downstream of Camrose), and Forestburg Reservoir (between u/s Meeting Creek and Hwy 872), which is used by ATCO for cooling water of a coal-fired power plant). In addition, there are three lakes that feed into the Battle River; Battle Lake and Pigeon Lake in the headwaters and Coal Lake via Pipestone Creek.

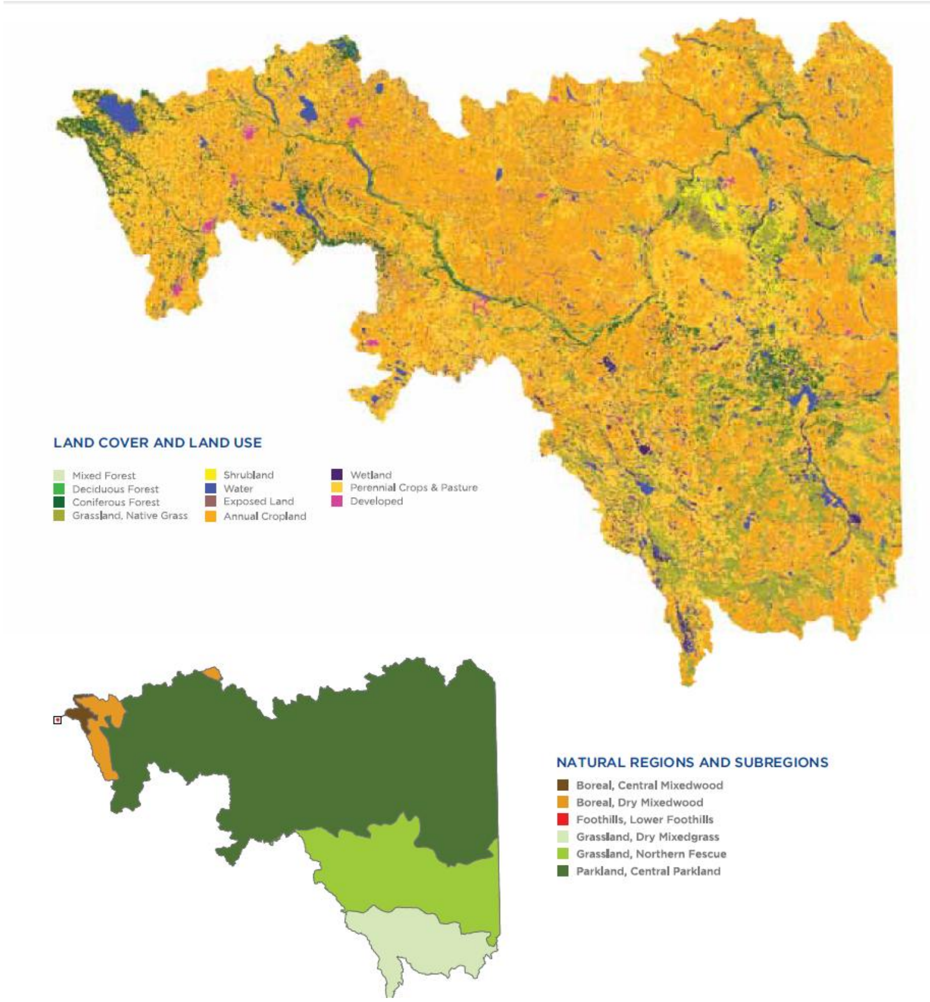


Figure 1. Land Use and Natural Regions in the Battle River and Sounding Creek Watersheds (from BRWA 2011)

The Battle River is an important water source for a number of stakeholders and types of uses, including municipal and residential drinking water, stock watering, irrigation, industry (power plant and oil injection), aesthetics and recreation. Interestingly, the City of Camrose takes its drinking water downstream from the point of discharge from its own sewage lagoons. With several communities located within the watershed and along the river, in particular in reach 2, water is repeatedly re-used for drinking water purposes. In combination with non-point sources from intensive agricultural practices in the watershed and the relatively low dilution capacity of the Battle River due to limited runoff, the Battle River is potentially at high risk for water quality deterioration. This highlights the importance of adequate treatment and management of cumulative loads of point-and non-point sources in the watershed to minimize the effects on aquatic health of the Battle River.

The Battle River is home to 19 fish species. A detailed assessment of fish populations and land use patterns found that the Index of Biological Integrity was poor, with lower numbers of fish species associated with larger percentage of cropland and higher road densities in the watershed (Stevens and Council 2008).

The risk to surface water quality from agricultural activities is high in large portions of the watershed, low in the headwaters around Battle and Pigeon Lake and medium in the south-eastern parts of the watershed (Alberta Agriculture and AgriFood 2001, based on census data; Figure 2). Factors considered in the assessment were application of fertilizer and manure and the intensity of crop and livestock operations, indicating that the risk to surface water is likely expressed in terms of nutrient and bacterial loads.

Risk to groundwater quality from agricultural activities is high in the headwaters, in particular in the Wolf Creek and Pipestone Creek watersheds, as well as along some of the tributaries, e.g., Meeting and Iron Creeks. The risk is medium along the mainstem and generally low in the remainder of the central and eastern watershed (Figure 3).

A large portion of these high risk areas, in particular in the central and eastern portions of the watershed, are non-contributing areas during most of the year, where water evaporates or infiltrates (Figure 2). These areas produce limited runoff and therefore low contaminant loads to surface waters. The small contributing river and creek watershed areas still are at high risk and therefore may have high nutrient and bacteria concentrations, but they would likely produce lower loads to the Battle River. In contrast, precipitation and runoff are higher in the headwaters, where most areas do contribute to surface waters (Figure 4). Therefore most land-use related loads from high-risk areas in the western portion of the watershed would reach the surface waters, contributing relative high loadings compared to the eastern tributaries. Incidentally, the western portion of the watershed is also the most developed one in terms of urban development, so stormwater runoff from municipalities, is another potential influence on surface water quality in the upper reaches.

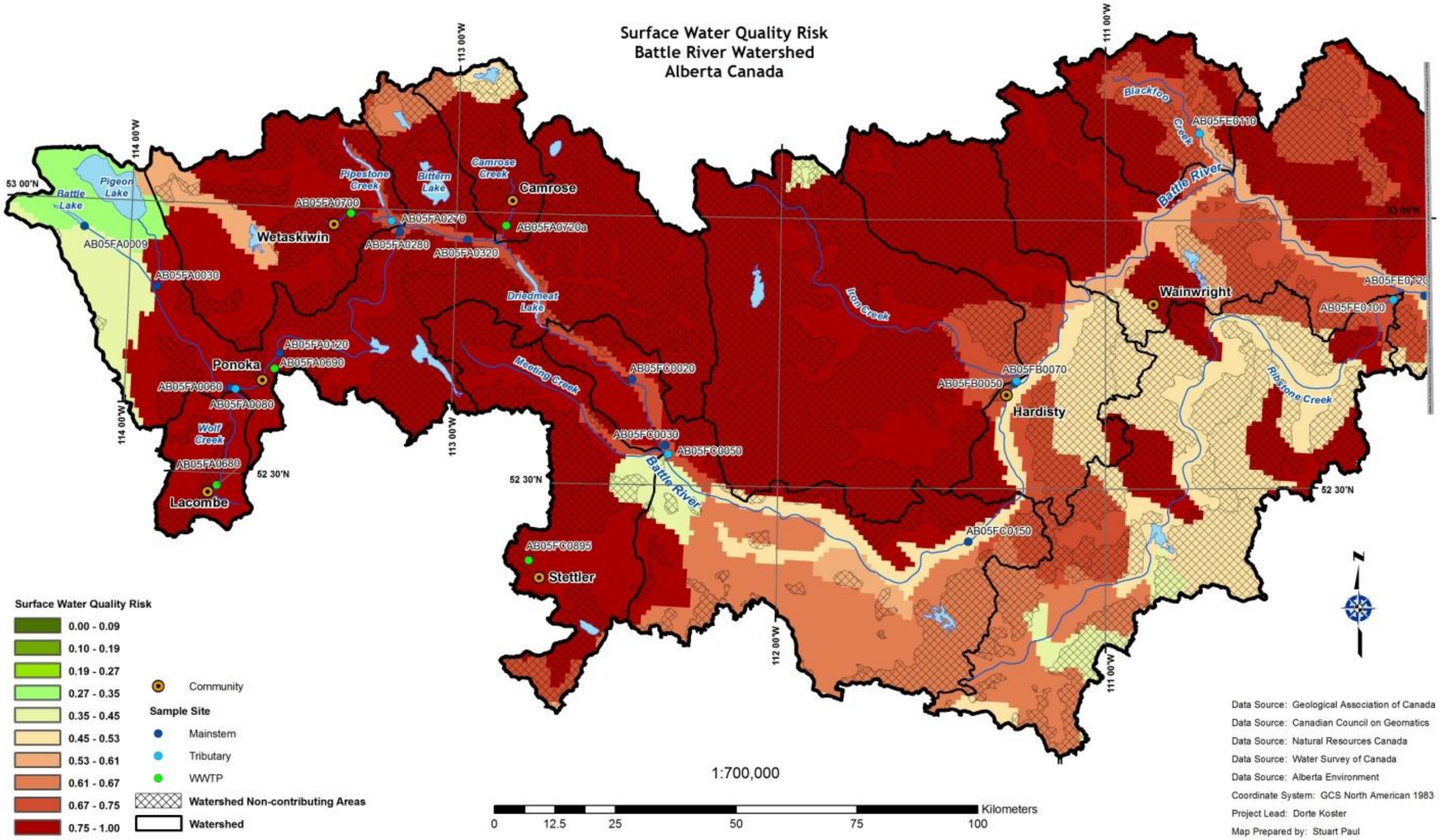


Figure 2. Surface Water Quality Risk in the Battle River Watershed

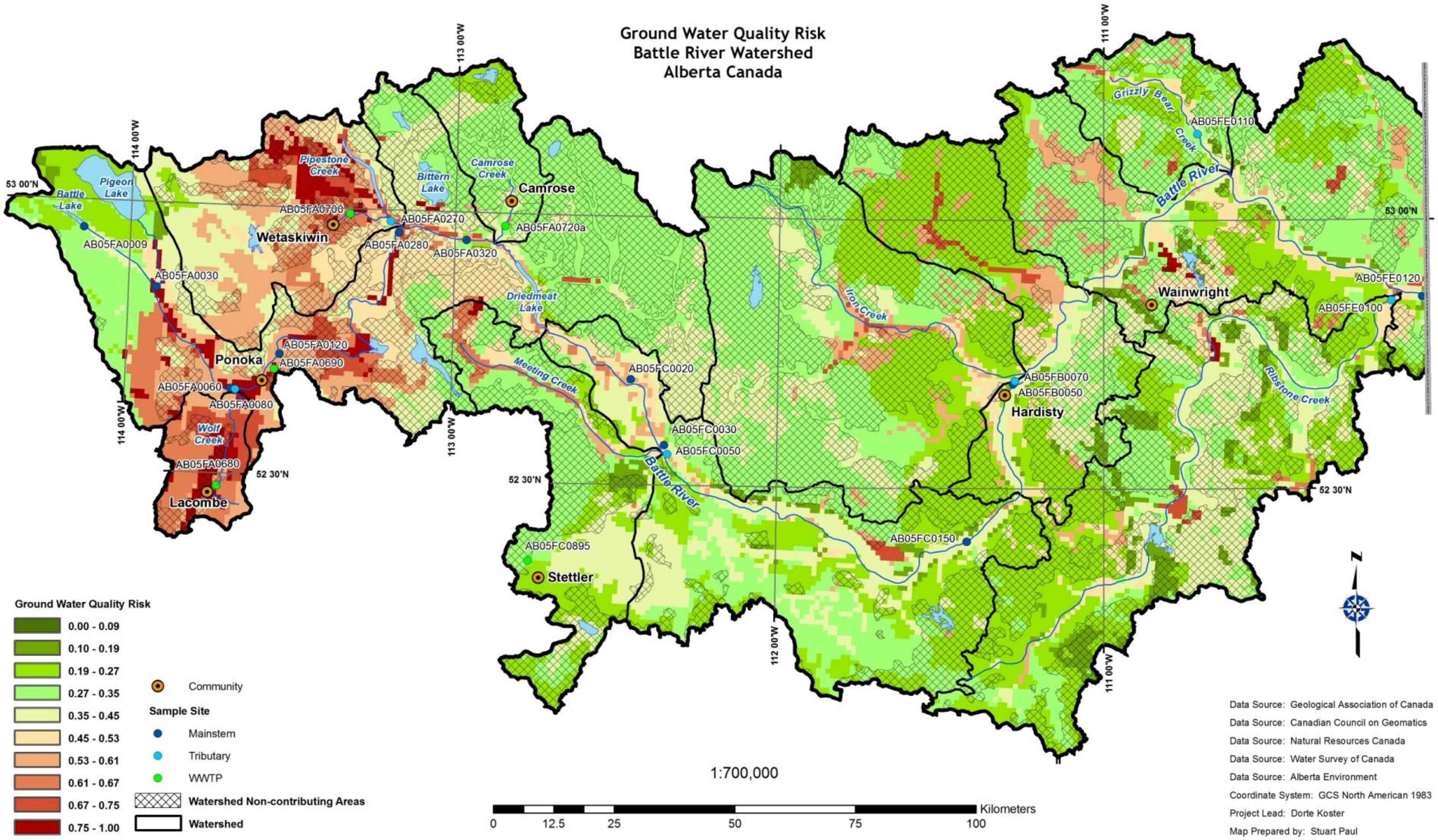


Figure 3. Ground Water Quality Risk in the Battle River Watershed

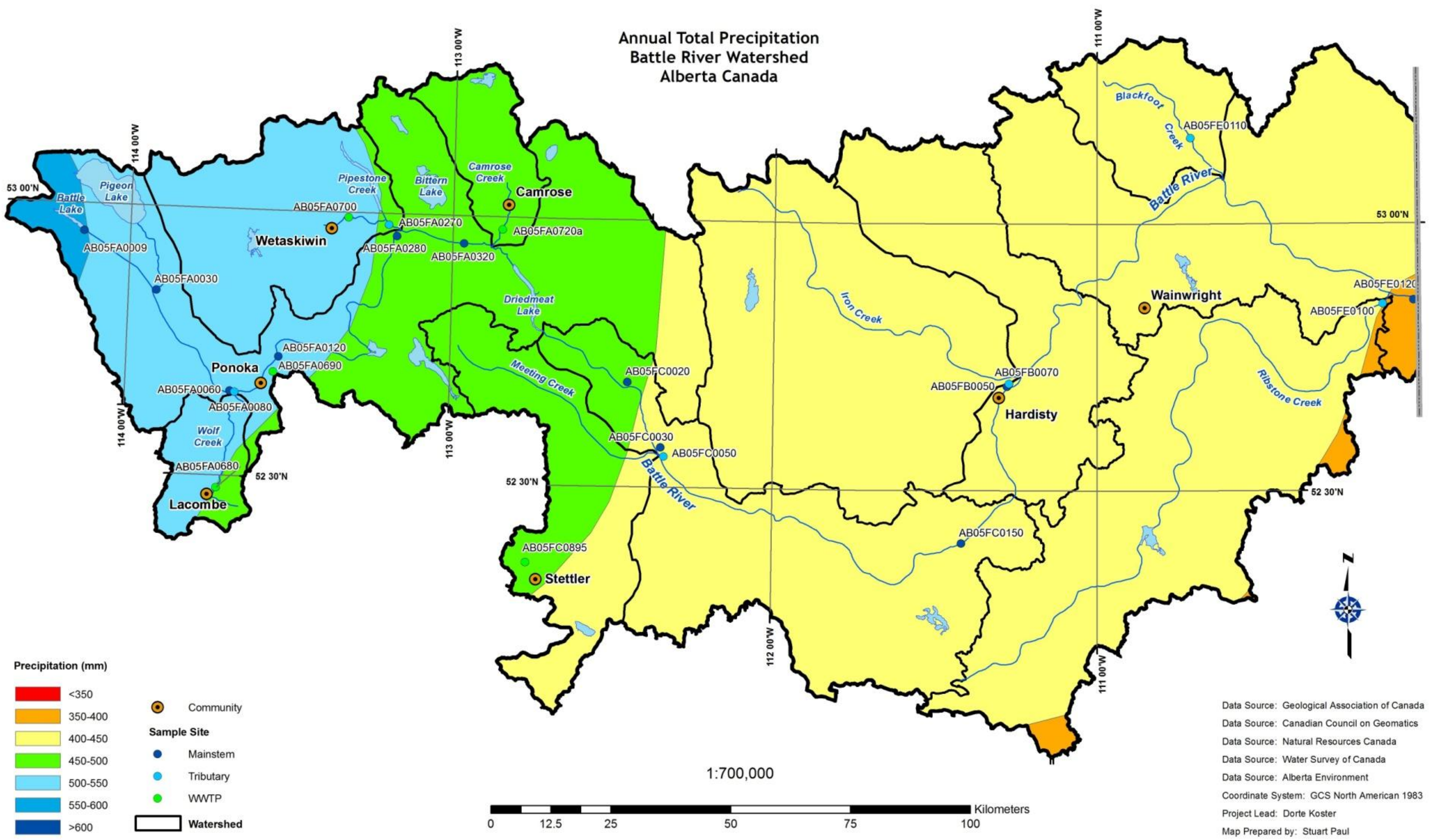


Figure 4. Mean Annual Precipitation, Sample Sites and WSC Flow Stations in the Battle River Watershed

3. Regulatory Context

3.1 Provincial and Federal Guidelines

River and creek water chemistry was compared to the revised Alberta water quality guidelines (ESRD 2014), the Canadian Council of the Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQGs) for the protection of aquatic life (CCME, 2012), as well as the draft water quality objectives developed for the Battle River (Table 1). For the purpose of developing site-specific water quality objectives, the Battle River was subdivided into four reaches taking into account knowledge of the river, the surrounding watershed, as well as locations of major inputs and long-term monitoring stations (Golder 2011, Figure 5). Draft site-specific water quality objectives were developed for reaches 1, 2, and 4. For reach 3, data were insufficient to develop site-specific water quality objectives, and therefore we compared water chemistry to provincial guidelines as well as upstream concentrations for the purpose of this report.

The CWQGs are numerical limits or narrative statements based on the most current, scientifically defensible toxicological data available for the parameter of interest, and are meant to protect all forms of aquatic life and all aspects of the aquatic life cycles, including the most sensitive life stage of the most sensitive species over the long term. Ambient water quality guidelines developed for the protection of aquatic life provide the science-based benchmark for a nationally consistent level of protection for aquatic life in Canada (CCME 2012).

Table 1. Draft Site Specific Water Quality Objectives (from Golder 2011)

Guideline		Site Specific																		Alberta		
		Reach 1						Reach 2						Reach 4								
Season		Ice Cover			Open Water			Ice Cover			Open Water			Ice Cover			Open Water					Irrigation/
Percentile		10	50	90	10	50	90	10	50	90	10	50	90	10	50	90	10	50	90	Aquatic Life	Recreation	Livestock
Parameter	Units																					
Total suspended solids	mg/L		7	22		7	39		19	40		23	81		6	22		27	288	Narrative[1]		
Turbidity	NTU		6	55		7	15		26	42		16	60		5	13		17	140	Narrative[2]	Narrative[3]	
pH	-	6.9	7.4	7.9	7.9	8.2	8.9	7.2	7.5	8.3	7.9	8.4	9.1	7.4	7.8	8.5	8.1	8.5	8.8	6.5 - 9.0	5 to 9	
Total phosphorus	mg/L		0.09	0.98		0.16	0.41		0.27	0.92		0.26	0.59		0.04	0.09		0.09	0.33	Narrative[4]		
Dissolved phosphorus	mg/L		0.03	0.11		0.09	0.33		0.07	0.31		0.09	0.3		0.02	0.04		0.03	0.05			
Chloride	mg/L		7	12		5	9		61	160		26	48		26	37		17	38	120		100 to 700
Calcium	mg/L		69	102		42	52		78	143		42	59		81	100		45	61			1000
Fluoride	mg/L		0.22	0.34		0.15	0.21		0.37	0.73		0.22	0.37		0.25	0.32		0.23	0.28			1/ 1 to 2
Water Temperature	˚C		0	1		13	21		1	2		14	21		0	1		15	21	Narrative[5]		
Dissolved Oxygen	mg/L	0.2	3.3		7.8	9.4		0.4	3.3		6.7	9.4		0.4	3.6		7.2	9.1		6.5/8.3/9.5		
Total dissolved solids	mg/L		498	818		322	381		834	1460		418	589		702	750		536	616			500 to 3500/ 3000
Nitrite-N	mg/L		0	0.006		0.003	0.007		0.008	0.032		0.001	0.038							Varies[6]		10
Nitrate-N	mg/L		0.019	0.158		0.003	0.046		0.22	0.561		0.005	0.483							3		
Nitrate + nitrite-N	mg/L		0.022	0.213		0.004	0.066		0.253	0.55		0.007	0.511		0.06	0.48		<0.01	0.33			100
Total nitrogen	mg/L		1.1	3.4		1	1.6		3.8	10.1		1.8	5		1	1.3		1	2.4	Narrative[4]		
Total ammonia	mg/L		0.28	1.26		0.04	0.12		1.81	9.19		0.1	1.99		0.15	0.4		<0.01	0.06	Equation[7]		
Sulphate	mg/L		25	38		19	28		186	403		75	136		164	214		118	179	Varies[8]		1000
Total organic carbon	mg/L		18	28		15	23		26	32		19	23		12	18		16	26			
Total coliforms	No/100 ml		86	104		254	2070		110	200		169	2730		8	40		71	460			
Fecal coliforms	No/100 ml		10	50		42	198		10	50		22	70		4	22		32	199			100
E. coli	No/100 ml		8	30		31	150		8	20		12	50		6	21		41	236		200	100
Hardness	mg/L		280	409		170	213		360	610		190	236		349	434		213	267			
Specific conductivity	µS/cm		819	1251		515	619		1264	2229		663	943		1190	1477		816	1130			
Sodium adsorption ration (SAR)	-		2	3.2		1.3	2.6		4	5.1		2.4	3.6		3.5	4.2		5	5.5			

[1]During clear flows or for clear waters: maximum increase of 25 mg/L from background for any short-term exposure (e.g. 24-h period). Maximum average increases of 5 mg/L from background levels for expsoures greater than 24-h. During high flow or for turbid waters: Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is ≥250 mg/L.

[2]For clear waters: Maximum increase of 8 NTU from background for any short-term exposure (e.g. 24-h period). Maximum average increase of 2 NTU from background levels for expsures greater than 24-h. For high flow or turbid waters: maximum increase of 8 NTU from background levels at any time when background levels are between 8 and 80 NTU. Should not increase more than 10% of background levels when background is >80 NTU.

[3]Turbidity should not exceed 50 NTU to satisfy most recreational users.

[4]For major rivers, nitrogen (total) and phosphorus concentrations should be maintained so as to prevent detrimental changes to algaland aquatic plant communities, aquatic

[5]Thermal additions should not alter thermal stratification or turnover dates, exceed maximum weekly average temperatures, nor exceed maximum short-term temperatures.

[6]Nitrite guideline varies with chloride concentration.

[7]Varies with pH and temperature.

[8]Sulphate guideline varies with hardness.

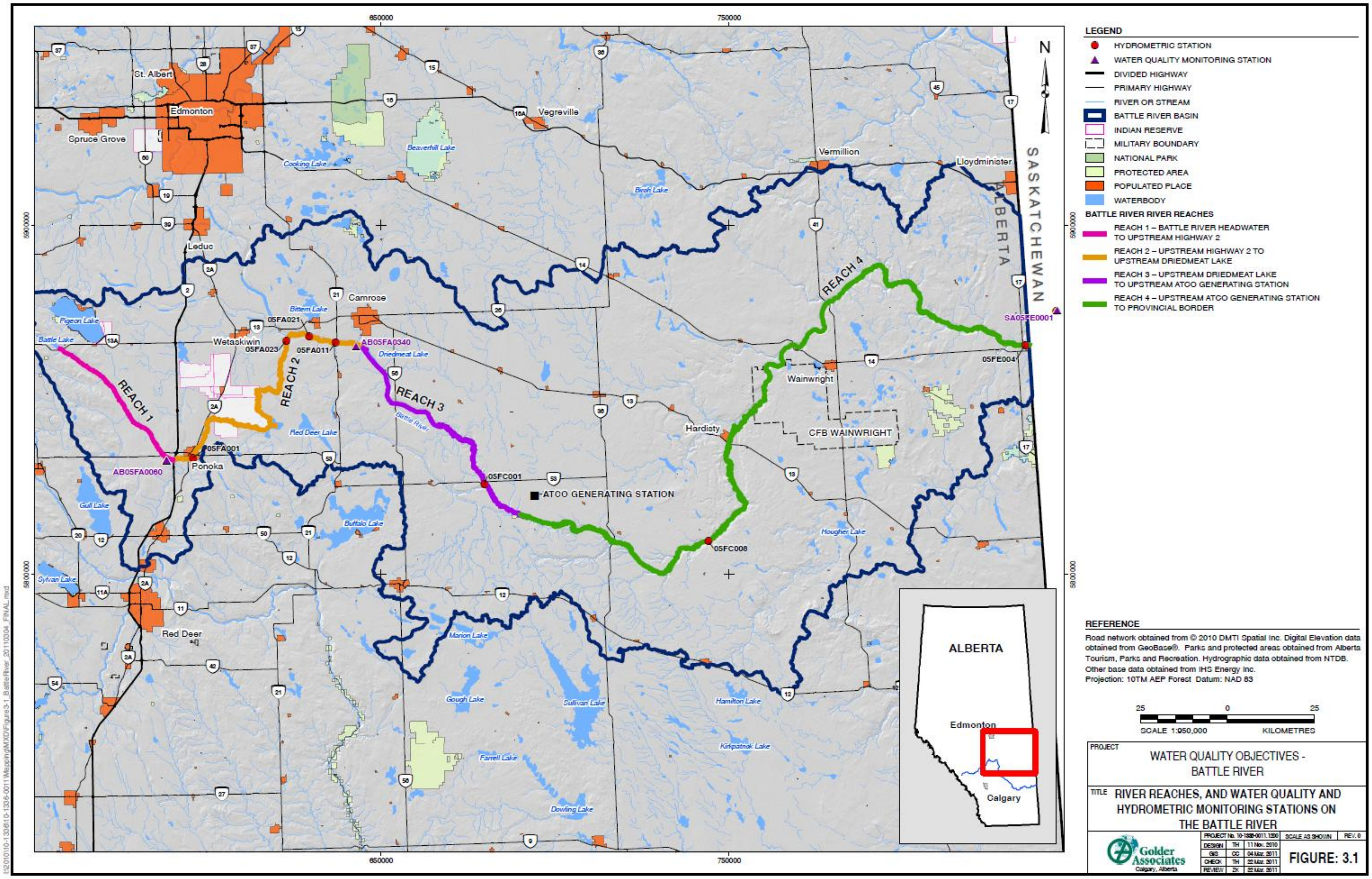


Figure 5. Four Reaches Defined for the Development of Site-Specific Water Quality Objectives (from Golder 2011)

4. Methodology

4.1 Sampling Program

The 2013 sampling program included sites within each of the four reaches of the Battle River. There were 23 sites in total, 12 along the main stem of the Battle River, six at the confluence with major tributary inflows, and five at selected point sources (Figure 4). Sites were sampled during the end of summer (August), fall (October), and winter (January) (Table 2).

The sampling design was based on the Phase I study program (Golder 2012), although four initial modifications were made to the sampling design of the Golder (2012) sampling program.

1. A new site was added at the outflow of Battle Lake to establish the difference in water quality from the headwaters to the initial monitoring site (AB05FA009).

2. The first site of Reach 3 (AB05FC0020) was moved further upstream to the outlet of Driedmeat Lake (AB05FA0370) to understand the effects of the lake on river water quality.

3. The furthest downstream site in Reach 4 (AB05FE0050) was moved further downstream, to the provincial border (AB05FE0120) in order to measure the impact that the largest Alberta tributary of the Battle River, Ribstone Creek, has on the main stem of the river.

4. The addition of a site between the end of Reach 3 and the upper end of Reach 4 (HWY 872, AB05FC0150) was made to better understand how the contributions of several tributaries draining agricultural land affect the Battle River in this area.

Sample sites were further modified during the study. Difficulties with flow measurements due to a wide and deep channel with very slow water movement caused the site at the outlet of Driedmeat Lake (AB05FA0370) to be moved further downstream. Difficulties continued at this site and in October the site was moved further downstream, ultimately returning to the initial sampling site AB05FC0020 visited during the Phase I survey.

Table 2. Location of Sampling Sites and Dates of Field Visits

AESRD Site ID	Water Course	Site/Location	Reach	Latitude °N	Longitude °W	Sampling Dates		
						Summer	Fall	Winter
AB05FA0009	Battle River	0.2 Km d/s of Battle Lake (Battle Lake outflow)	1	52.94891	114.14359	Aug 26/13	Oct 15/13	Jan 17/14
AB05FA0030	Battle River	At Hwy 611 u/s of Muskeg Creek	1	52.84326	113.91332	Aug 26/13	Oct 15/13	Jan 17/14
AB05FA0060	Battle River	Approximately 2 Km d/s Hwy 53	1	52.65918	113.67537	Aug 26/13	Oct 15/13	Jan 17/14
AB05FA0080	Wolf Creek	Near Hwy 2 at Twp Rd. 425		52.65747	113.66069	Aug 26/13	Oct 15/13	Jan 16/14
AB05FA0120	Battle River	At Diamond 5 Rd. (Twp Rd 434) d/s of Ponoka	2	52.72673	113.52897	Aug 26/13	Oct 22/13	Jan 16/14
AB05FA0270	Pipestone Creek	At sec Hwy 822 near Gwynne		52.97988	113.19881	Aug 29/13	Oct 22/13	Jan 16/14
AB05FA0280	Battle River	5.5 Km u/s of confluence with Pipestone Creek	2	52.95920	113.17319	Aug 29/13	Oct 22/13	Jan 16/14
AB05FA0320	Battle River	At Hwy 21 bridge	2	52.94874	112.96424	Aug 29/13	Oct 22/13	Jan 15/14
AB05FA0390	Battle River	At sec Hwy 850, north of Donalda	3			Aug 29/13	-	-
AB05FC0020	Battle River	U/s Hwy 854	3	52.69696	112.44996	-	Oct 22/13	Jan 15/14
AB05FB0050	Battle River	D/s of Hardisty 5 Km north of Hwy 13 on Hwy 881	4	52.69616	111.27778	Aug 27/13	Oct 16/13	Jan 14/14
AB05FB0070	Iron Creek	At sec Hwy 881 near Hardisty		52.70181	111.27193	Aug 27/13	Oct 16/13	-
AB05FC0030	Battle River	Above Meeting Creek – at Hwy 53 bridge	3	52.57528	112.34407	Aug 27/13	Oct 16/13	Jan 15/14
AB05FC0050	Meeting Creek	U/s of confluence with Battle River		52.55870	112.33371	Aug 27/13	Oct 16/13	-
AB05FC0150	Battle River	At Hwy 872 bridge		52.40212	111.41706	Aug 27/13	Oct 16/13	Jan 14/14
AB05FE0100	Ribstone Creek	At Hwy 14		52.84991	110.11533	Aug 30/13	Oct 17/13	Jan 13/14
AB05FE0120	Battle River	At Hwy 17 bridge near WSC gauging station	4	52.85671	110.01971	Aug 30/13	Oct 17/13	Jan 13/14
AB05FE0110	Blackfoot Creek	At Unwin Rd (TWP 462)		53.16191	110.70870	Aug 30/13	Oct 17/13	-
AB00QC0001	Battle River	Field Blank		-	-	Aug 30/13	Oct 24/13	Jan 17/14
AB05FA0680	WW	Lacombe sewage final effluent		52.47740	113.70718	-	Oct 24/13	-
AB05FA0690	WW	Ponoka sewage final effluent		52.69830	113.54359	-	Oct 22/13	-
AB05FA0700	WW	Wetaskiwin sewage final effluent		52.99125	113.32462	-	Oct 24/13	-
AB05FA0720[a]	WW	Camore sewage final lagoon		52.97707	112.84595	-	Oct 24/13	-
AB05FC0895	WW	Outflow from Stettler Wastewater Treatment Pond		52.355571	112.752225	-	Oct 29/13	-

Lagoon discharges from five of the larger communities in the watershed were sampled during their fall discharge period. All of these lagoons discharge only seasonally, but for different durations. Most discharge only during the fall, while some discharge during spring and fall or during a longer period from summer through fall (Table 3)

Table 3. 2013 Discharge Periods of Five Lagoons in the Battle River Watershed.

Lagoon	2013 Discharge Periods	
	Spring	Fall
Lacombe	June 20th to October 23rd	
Ponoka		October 18th to 29th
Wetaskiwin	April 10th to May 8th	September 28th to October 19th
Camrose		October 15th to November 14th
Stettler	May 3rd to October 31st	

4.2 Field Methods

4.2.1 Water Quality

Water quality samples were taken as sub-surface grabs (ca. 20 cm depth) at each of the sampling sites (Photo 1). Field parameters were measured at the time of sampling, using a YSI multi-parameter meter and included: conductivity, temperature, total dissolved solids, pH and dissolved oxygen (DO). All samples were field preserved and placed into coolers chilled with ice packs. Samples were submitted to Maxxam Analytics in Edmonton, AB, the same day as they were collected and analyzed for a suite of water quality parameters, including nutrients, fecal bacteria and major ions. (Table 4).

Photo 1. Water Sample Collection in Ribstone Creek

Table 4. Water Quality Parameters Monitored in Phase II Battle River Synoptic Survey

Parameter	Field/Lab	Equipment
river discharge	Field	Flow meter
turbidity	field	Turbidity meter
pH	Field+lab	multimeter
temperature	Field	multimeter
dissolved oxygen	Field	multimeter
conductivity	Field+lab	multimeter
total dissolved solids	Field+lab	multimeter
Total suspended solids	Lab	-
total phosphorus	lab	-
dissolved phosphorus	lab	-
total nitrogen (measured as Total Kjeldahl nitrogen + nitrate and nitrite)	lab	-
chloride	lab	-
calcium	lab	-
fluoride	lab	-
nitrate	lab	-
nitrite	lab	-
nitrate + nitrite	lab	-
total nitrogen	lab	-
total ammonia	lab	-
sulphate	lab	-
total organic carbon	lab	-
fecal coliforms	lab	-
E. coli	lab	-
hardness	lab	-
sodium	lab	-
magnesium	lab	-

4.2.2 Discharge

Flow measurements were conducted according to the standard procedures of Alberta Environment Environment and Sustainable Resource Development (Chris Ware, personal communication, Photo 2). The river width was measured and subdivided into a number of equally spaces segments. Velocity measurements were taken at 60% of total water depth if the water body was less than 1 m deep or at 20% and 80% of total water depth if the water body was more than 1 m deep.

In winter, the ice was probed with an ice chisel, then sample holes were drilled into the ice to ensure the ice thickness was safe. Five locations along the watercourse cross section were measured for stream discharge.

The cross sectional area was chosen where the channel was relatively narrow. A tape was stretched along the cross section and velocity and depth were measured at through holes drilled in the ice over the length of the cross section. Each measurement location represents a partial cross section. The measurements and discharge calculations were based on the following assumptions:

- The width for each partial section is one half the distance from the preceding sample hole plus one half the distance to the following sample hole.
- The observed depth at each sample hole is considered to be the mean depth for each partial section.
- The mean velocity measured at each sample hole is considered to be the mean velocity for each partial section.

The area-velocity method was used to calculate flow at each location.

Photo 2. Flow Measurement in Battle River

4.3 Quality Assurance and Quality Control

Quality Assurance/Quality Control (QA/QC) samples were collected during each sampling event. At each sampling event, one duplicate sample and one field blank sample was collected. Field blanks were prepared in the field using laboratory grade de-ionized water. These QA/QC procedures are in addition to the internal QA/QC requirements and programs of the analytical laboratory.

Field blanks were deemed contaminated when they were equal to or larger than five times the reported detection limit (U.S. EPA 1985). This (≥5 times reported detection limit) value takes into account the possible lack of accuracy when concentrations are near or below the reported detection limits. None of the field blanks showed an indication of sample contamination.

The difference in concentration between duplicates was measured by calculating the relative percent difference for each parameter. For measurements below detection, the detection limit was used for the calculation. The average relative percent difference for all parameters for each sampling survey was calculated. The difference between duplicates appeared not significant.

4.4 Data Analysis

The Phase II study only collected samples in 2013. In the results section, the 2013 data are presented together with the 2011 data produced during Phase I (Golder 2012), to asses if the observed spatial trends in both surveys are recurring or were unique to the study year.

4.4.1 Data Preparation

Data were organized from upstream to downstream. Measurements below detection were replaced with the Reportable Detection Limit (RDL) and graphed with an open symbol. Differences between seasons were identified based on colour and differences in survey years were identified with symbols and stylized lines.

4.4.2 Load Calculations

Loads were calculated for total organic carbon, total suspended solids, hardness, nutrients, major ions and bacteria. Daily loads were calculated by multiplying instantaneous flow by concentration measurements to obtain kilograms per day. Concentrations below RDL were replaced with RDL values, consistent with a conservative approach.

Flow and water quality data from lagoons were used to calculate lagoon loads. On occasions when it was not feasible to obtain river or creek flow data for specific sites, flow measurements were obtained from the Water Survey of Canada (WSC) (Table 5). Fall loads for Pipestone Creek and Iron Creek, for example, were calculated using mean 2002-2011 October flow measurements from the most closely located WSC gauges. We did not verify if 2013 was a wet or dry year compared to the mean, but we assumed that mean flows would be most representative of average conditions and therefore general patterns. There is no flow station in Grizzly Bear Creek, so loads were assumed to be zero for dates when flow as not detectable in the field.

Table 5. Water Survey of Canada Sites Used to Complement Flow Data Set

Discharge Summary 2013									
AESRD Site ID	Station Name	WSC Station	Distance between sites (km)	Sample Date	Discharge August (m^3/s)	WSC Discharge (m^3/s)	Sample Date	Discharge October (m^3/s)	WSC Discharge (m^3/s)
AB05FA0060	U/S Ponoka	05FA001	6.7	Aug 26/13	0.000	**0.368**	Oct 15/13	[b]0.0850392	0.283
AB05FA0270[1]	Pipestone Cr.	05FA012	11.5	Aug 29/13	0.023	0.467	Oct 22/13	0.000	**0.044**
AB05FB0050	D/S Hardisty	05FC008	40	Aug 27/13	0.797	1.870	Oct 16/13	0.797	0.337
AB05FB0070[1]	Iron Cr.	05FB002	2.7	Aug 27/13	0.013	0.098	Oct 16/13	0.000	**0.062**
AB05FC0030	U/S Meeting Cr.	05FC001	0.2	Aug 27/13	3.346	0.719	Oct 16/13	0.395	0.528
AB05FE0100[1]	Ribstone Cr.	05FD001	40.2	Aug 30/13	0.060	0.129	Oct 17/13	0.018	0.079
AB05FE0120	D/S Ribstone Cr.	05FE004	0.1	Aug 30/13	4.456	3.330	Oct 17/13	4.022	1.600

[1]Water survey of Canada data is the average for the month over a ten year period (2002 to 2011)

[2]Water survey of Canada data is a monthly average from 1980 to 1983

Bold font indicates occassions when water survey of Canada data was used instead of measured flow data.

Reach specific load calculations were made with the following equation:

Unknown Load = DL – UL – TL – LL

Where

DL is the load of the most downstream site in that reach,

UL is the load of the most upstream site in that specific reach,

TL is the total tributary load for that reach, and

LL is the total lagoon load for that reach.

All reach specific loads were only calculated for the fall survey when effluent from lagoons was being discharged.

5. Results

In this section we first present results of flow measurements and then water quality. The water quality data are presented by parameter group and individual parameters, including a synoptic – upstream to downstream – figure, tributary data and lagoon effluent data. For selected parameters, we present a reach-based loading analysis where the loads from the most downstream location in a reach are subdivided into individual loads of point sources (i.e., lagoon discharges) and tributary loads in the reach.

5.1 Flow

During both 2011 and 2013, flow was greatest during the late summer survey campaigns. Flow was generally higher in 2011 than in 2013. In 2013, flow increased between upstream of Pipestone Creek and Hwy 872; decreased at downstream of Hardisty; and then increased downstream of Ribstone Creek. The small decrease between Meeting Creek and HWY 872 may be explained by evaporation in the Forrestburg Reservoir, where water residence time is higher than in the remainder of the river.

In 2011, flow also increased upstream of Pipestone Creek, but then continued to increase to the Hwy 41 bridge (Figure 6).

The most downstream location was moved from Highway 41 to a location downstream of Ribstone Creek and therefore no direct comparison for the most downstream sites is available between both years.

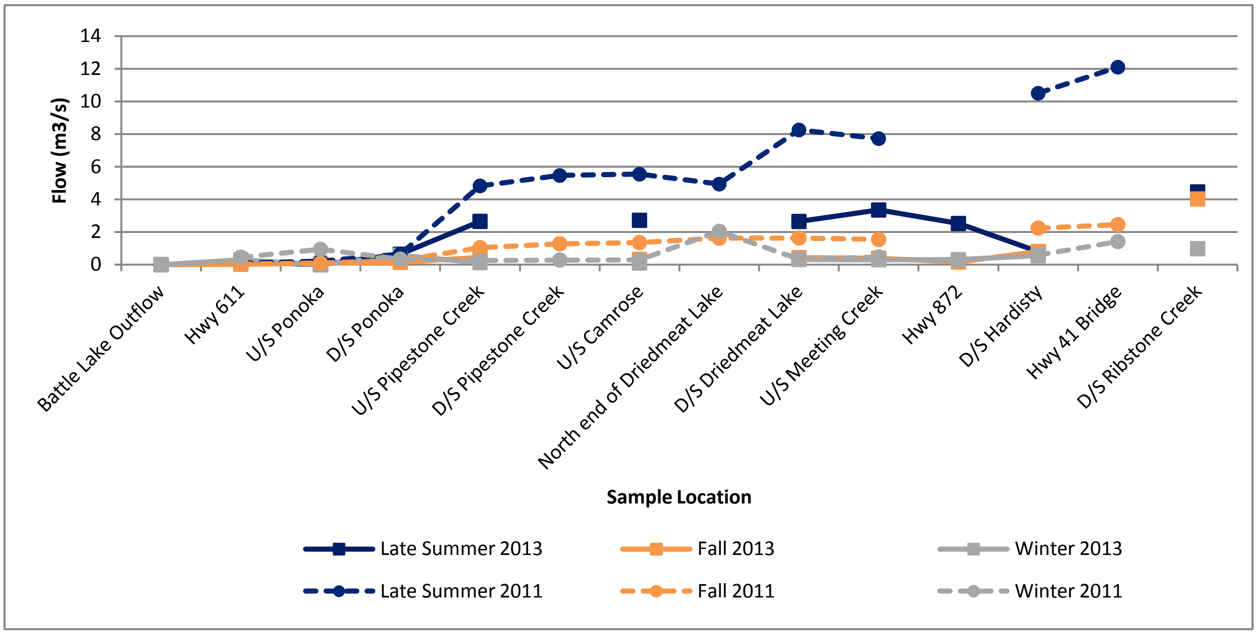


Figure 6 Battle River Flow Data for Eat of the Six Survey Campaigns in 2011 and 2013.

Interestingly, flows did decreased downstream on two occasions, once in summer 2011 from Camrose to the inflow of Driedmeat Lake and once in summer 2013 from Meeting Creek to Hardisty. This indicates that water is lost from the river at some times, either due to water withdrawals, evaporation in stagnant areas or loss to groundwater. The City of Camrose, for example, takes drinking water out of Driedmeat Lake, but no flow difference was detected between upstream and downstream Driedmeat Lake.

Tributary flows were only measured during the 2013 field campaign, as tributaries were not part of the 2011 survey. Similar to Battle River, creek flows were also greatest during the summer monitoring event. Wolf Creek had the largest measured flows in all seasons, followed by Ribstone Creek, Pipestone Creek, Iron Creek, then Meeting Creek (Figure 7). Meeting Creek, Iron Creek and Grizzly Bear Creek were not visited during the winter sampling event, as flows were assumed to be negligible. Flows were too low to be measured in Pipestone and Ribstone Creek during winter, in Iron Creek and Pipestone Creek during the fall, and in Grizzly Bear Creek during summer and fall.

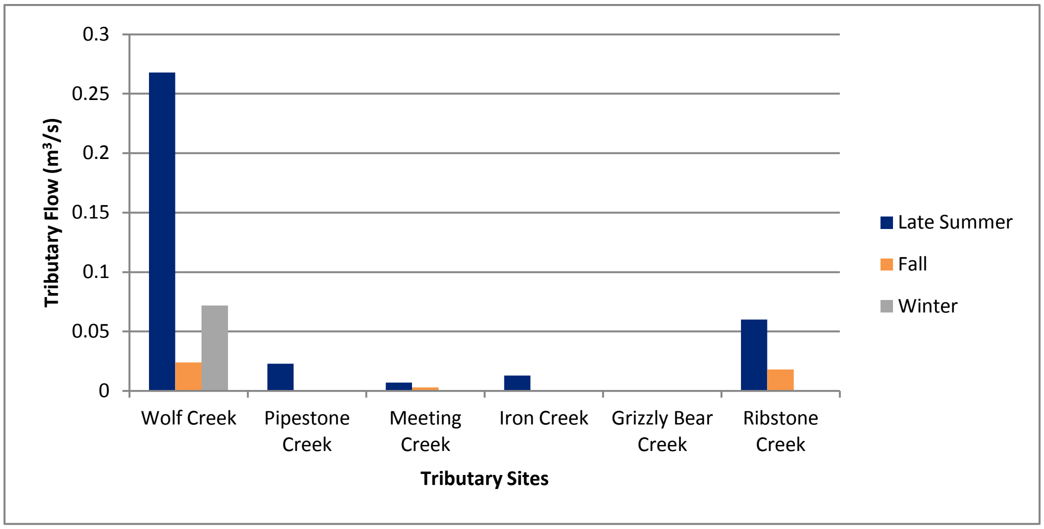


Figure 7. Tributary Flows in Summer, Fall and Winter of 2013.

5.2 Field Parameters

5.2.1 Dissolved Oxygen

5.2.1.1 Mainstem Patterns

In August, all DO concentrations in Reach 1 were below provincial and federal WQG; they were also below the 10^{th} (8 mg/L) percentile reach specific objective. All but one site in Reach 2 was below provincial (9.5 mg/L) and CCME (9.5 mg/L) guidelines for larval fish development.

Dissolved oxygen concentrations were mostly higher during the fall sampling campaigns compared to summer, as expected due to higher solubility of oxygen in water at lower temperatures. Two sites in Reach 1 and one site in Reach 2 were below the provincial and federal (9.5 mg/L) guidelines. The outflow of Battle Lake was below the 10^{th} percentile WQO (8 mg/L) in fall as well.

In January, oxygen levels upstream of Pipestone Creek and downstream of Ribstone Creek were below the provincial guidelines. Most samples in Reach 2 and 3 in winter also remained below the acute DO guideline for short term exposure of 5 mg/L, indicating that fish habitat is severely limited in these reaches in winter.

During the fall 2013 sampling campaign, DO gradually increased from upstream to downstream, with small declines downstream of Ponoka and downstream of Driedmeat Lake. During the winter 2013 sampling survey, Reaches 2 and 3 had lower DO concentrations than Reaches 1 and 4. The large increase in winter DO between Meeting Creek and Highway 872 is possibly related to the thermal power discharge from the ATCO Power plant into the Forrestburg Reservoir, which is located between these two locations and likely results in some open water in that reach. Low DO levels were observed in summer and fall at the Battle Lake outflow, possibly due to oxygen consumption by respiring aquatic plants during the morning hours when this site was sampled. No other longitudinal trend could be observed for the late summer 2013 program (Figure 8).

Dissolved oxygen concentrations were for the most part higher in the late summer and fall of 2011 than during the same period in 2013, possibly related to lower flow conditions in 2013, creating less turbulence and hence aeration of the water.

Diurnal concentrations of dissolved oxygen can be highly variable, in particular during summer and fall, when oxygen levels are high during the day due to high photosynthetic activity of aquatic plants and low during the night due to respiration. Some of the variations in the data may therefore be due to diurnal variations and oxygen concentrations during summer may be significantly lower at night-time than the day-time monitoring data presented here suggest. Continuous dissolved oxygen data collected at hourly or sub-hourly intervals are needed to adequately assess between site oxygen conditions in the Battle River in the summer months, in particular in reach 2, where abundant macrophyte beds and high day-time oxygen levels were observed.

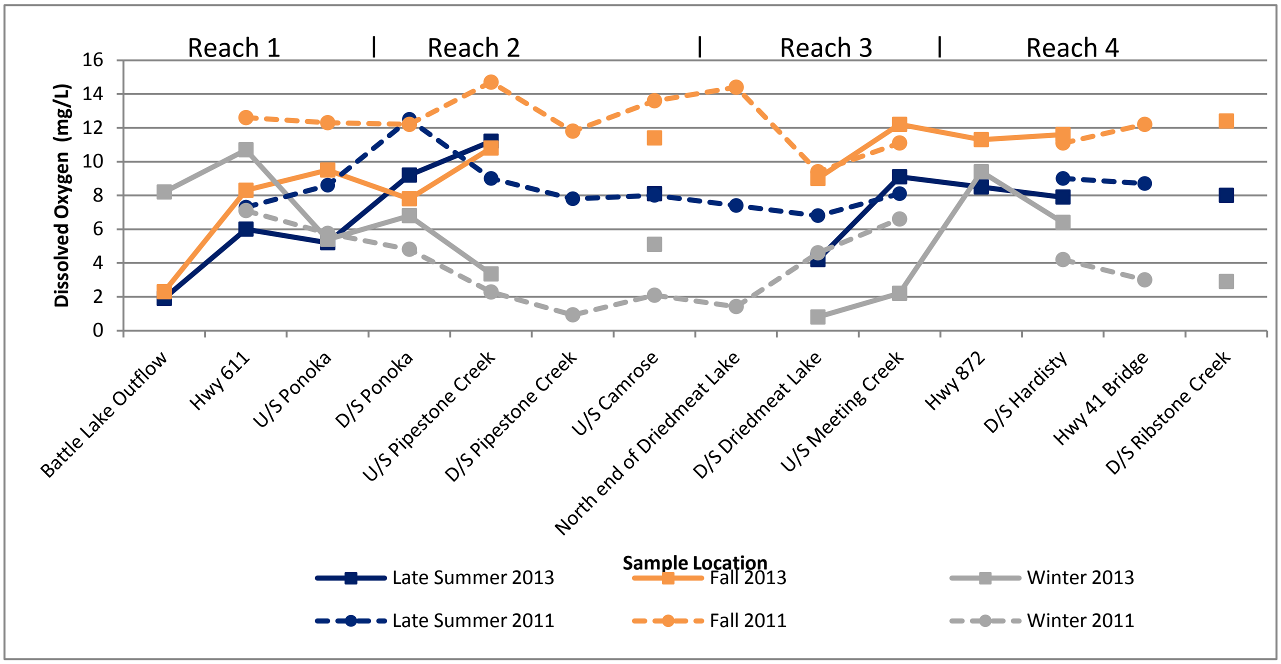


Figure 8 Dissolved Oxygen Concentrations Along the Battle River.

5.2.1.2 Tributaries

Dissolved oxygen concentrations in the tributaries were similar to those in Battle River. Similar to the mainstem, the fall sampling survey had the highest DO concentrations of 2013, ranging between 9.1 mg/L at Iron Creek to 13 mg/L at Wolf Creek (Figure 9). During the fall campaign, all sites except Iron Creek were above provincial and federal WQG of 9.5 mg/L for early life stages of cold water biota. During both the late summer and winter surveys, all sites were below federal and provincial WQG (9.5 mg/L) for early life cold water biota, with the exception of Grizzly Bear Creek (11.3 mg/L). Iron Creek (5.4 mg/L) in

August and Pipestone Creek (0.4 mg/L) in winter were below federal WQG (6.5 mg/L) for late life stages of cold biota.

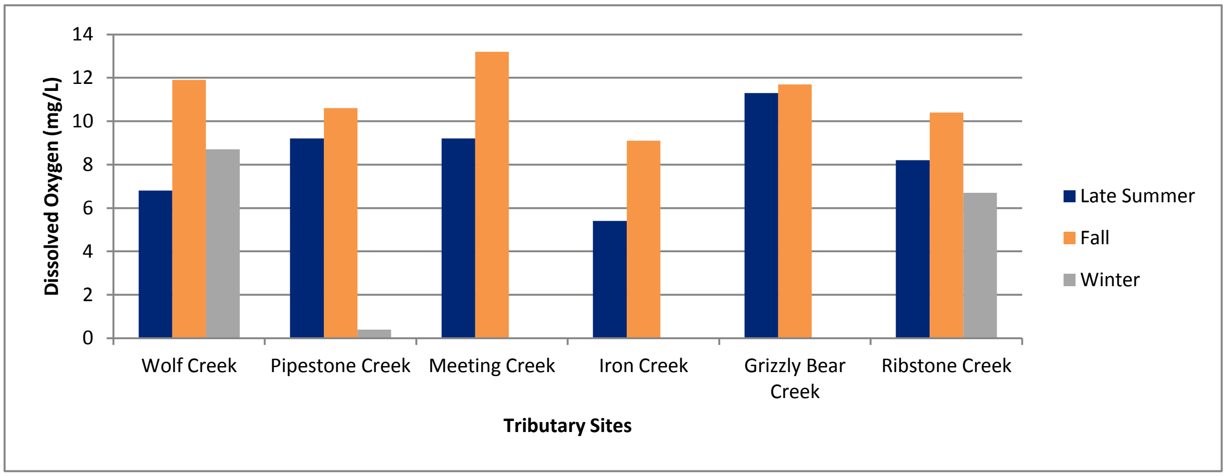


Figure 9. Dissolved Oxygen Concentrations for Major Tributaries of the Battle River in 2013.

5.2.1.3 Lagoon Discharges

Dissolved oxygen concentrations in lagoon effluent were fairly high, ranging from 8.0 mg/L at Lacombe to 11.8 mg/L at the Wetaskiwin lagoon (Figure 10). .

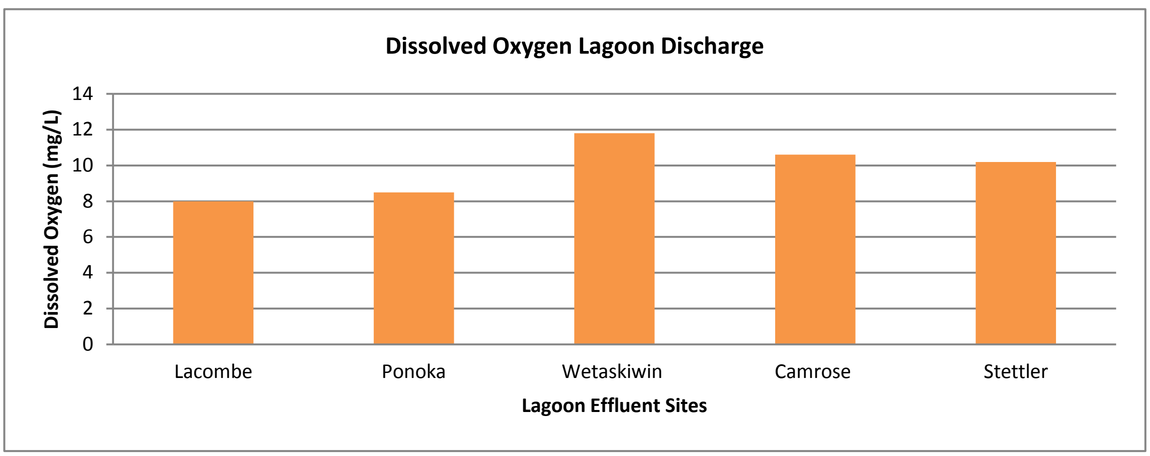


Figure 10. Dissolved Oxygen Concentrations in Lagoon Discharges in 2013.

5.2.2 pH

5.2.2.1 Mainstem Patterns

At the sites upstream of Pipestone creek and upstream of Camrose, pH exceeded the 90th percentile of the WQO (9.1) and federal and provincial guidelines (9). In Reach 4 pH exceeded the federal and provincial guidelines at the site downstream of Ribstone (9.34). The pH at the Battle Lake outflow during the August 2013 survey was recorded as 2.82; this is believed to be a recording error, therefore the lab pH was used for this data point.

The pH of the Battle River appears to slowly increase until reaching a maximum upstream of Pipestone Creek. Dense macrophyte stands were observed at the site downstream of Ponoka, which may have increased pH through photosynthetic activity. This peak is followed by a slow decrease, reaching a minimum downstream of Driedmeat Lake, followed by another gradual increase to Hwy 872 and another decrease within Reach 4 of the river (Figure 11).

In 2013, the most basic waters were found during the late summer sampling survey. This differs from the 2011 campaign, which found the most basic waters in the fall. During both the 2011 and 2013 campaigns, the winter surveys had the lowest recorded pH values (Figure 11), possibly due to the lack of photosynthetic activity under ice.

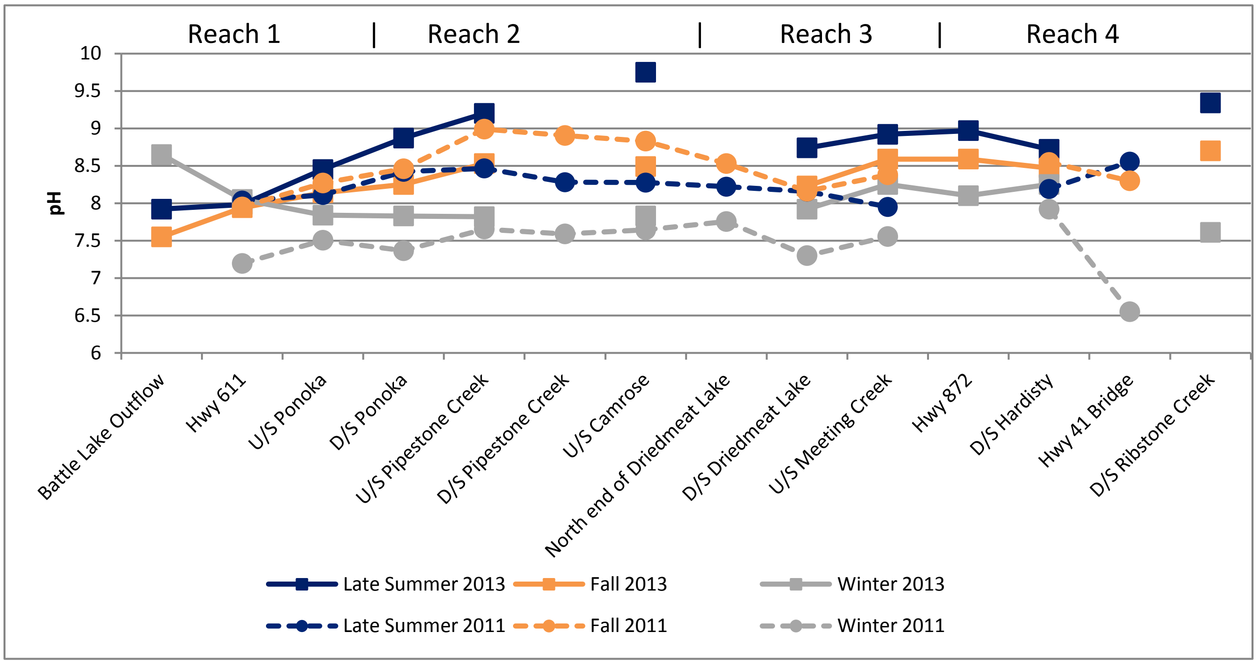


Figure 11. pH along the Battle River in 2011 and 2013.

5.2.2.2 Tributaries

Most tributaries were slightly basic, similar to the mainstem. Tributary pH exceeded provincial and federal guidelines at all sites but Wolf Creek during the 2013 late summer survey, with a pH range between 8.4 and 9.54. The winter 2013 sampling survey sampled the most neutral waters, with a pH range between 7.85 to 7.94 (Figure 12).

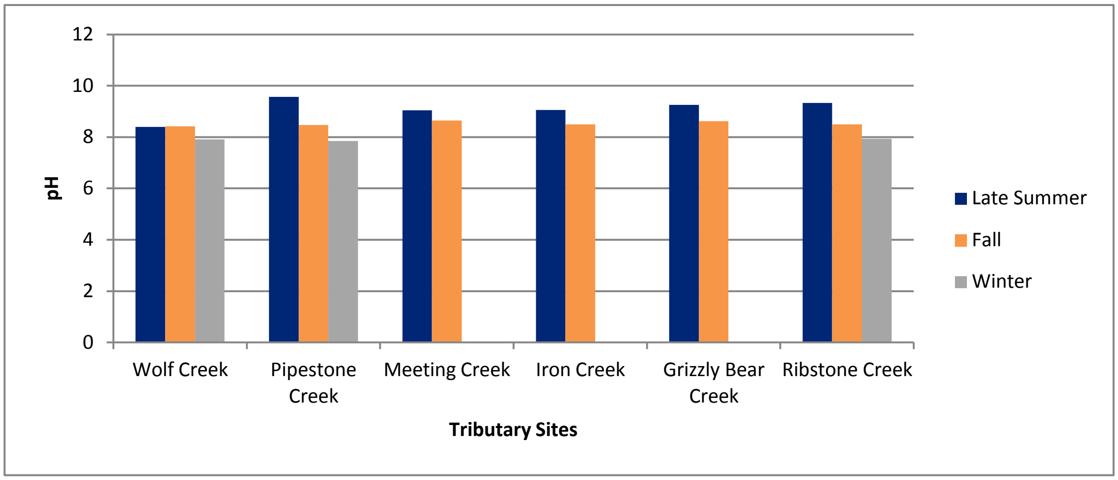


Figure 12. pH of Major Tributaries along the Battle River in 2013.

5.2.2.3 Lagoon Discharges

None of the lagoon effluents exceeded the federal or provincial pH WQGs. The pH ranged from 8.29 at the Lacombe lagoon to 8.7 at the Wetaskiwin lagoon (Figure 13).

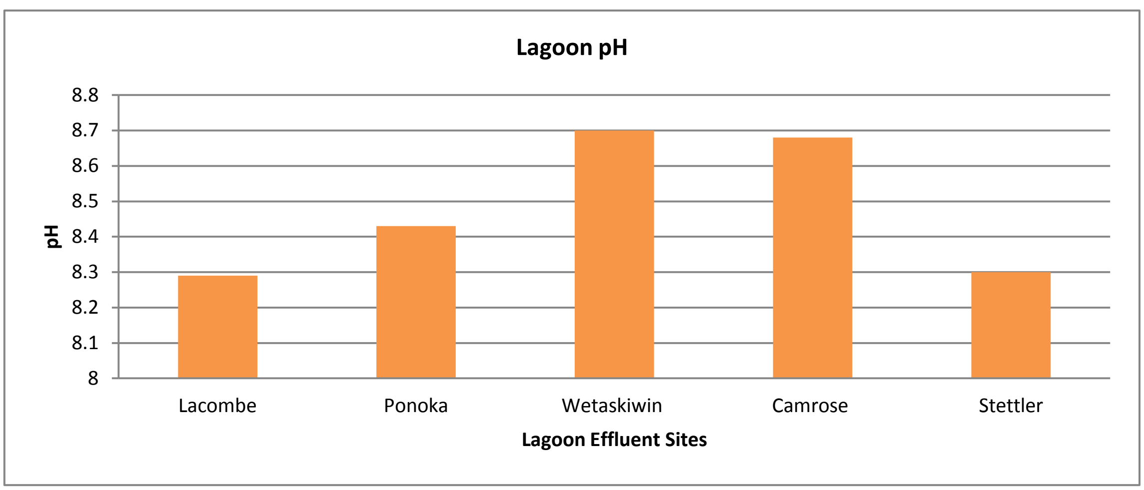


Figure 13 pH of Sewage Effluent from Lagoons along the Battle River in October of 2013

5.2.3 Temperature

5.2.3.1 Mainstem Patterns

Temperatures upstream of Pipestone Creek (21.7˚C) exceeded the 90th percentile reach specific open-water WQO (21˚C) for Reach 2. The outflow of Battle Lake was above the 90th percentile WQO in winter (1˚C), with a temperature of 2.1˚C, which can be expected from a lake environment that differs from the river environment. Temperature is closely related to climatic patterns of a given year, so any levels above or below the WQO may not necessarily indicate a concern for the Battle River. To assess trends in river temperature that may affect aquatic habitat, continuous temperature loggers would need to be installed throughout the river for an extended period.

During the late summer and fall surveys, temperature increased gradually from Hwy 611 to upstream of Pipestone Creek. In summer temperatures appeared to stabilize at this point and in fall they started to decline from downstream of Driedmeat Lake. A small increase in temperatures was observed between Meeting Creek and HWY 872 in summer and fall, which may be related to the power plant, but the degree of change was minimal and smaller than some other changes throughout the Battle River and not observed in winter, indicating no consistent or significant effect of the power plant on river temperatures. Seasonal temperatures between 2011 and 2013 appeared similar (Figure 14).

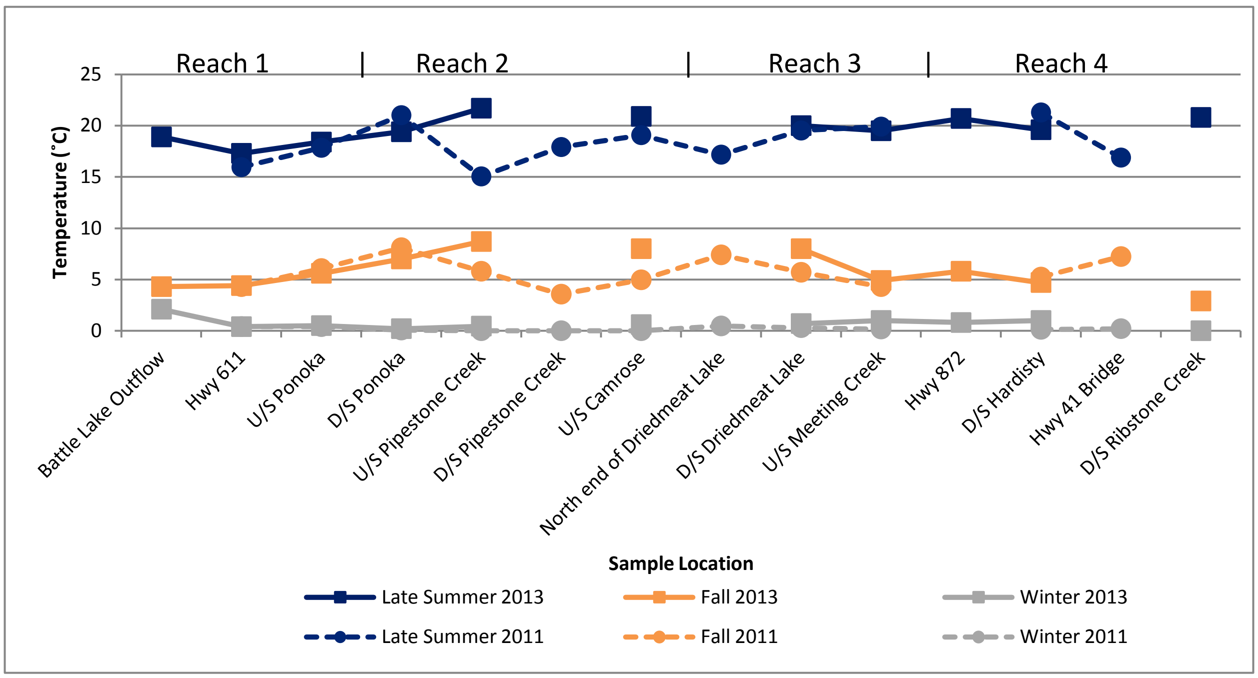


Figure 14 Temperature along the Battle River in 2011 and 2013.

5.2.3.2 Tributaries

Water temperature in the tributaries ranged from 16.6˚C at Wolf Creek to 26.3˚C at Grizzly Bear Creek during the late summery 2013 survey. During the fall survey, water temperature ranged from 3.9˚C at Ribstone Creek to 8.3˚C at Pipestone Creek. During the winter 2013 survey, water temperature ranged from 0˚C at Pipestone Creek to 1˚C at Ribstone Creek (Figure 15).

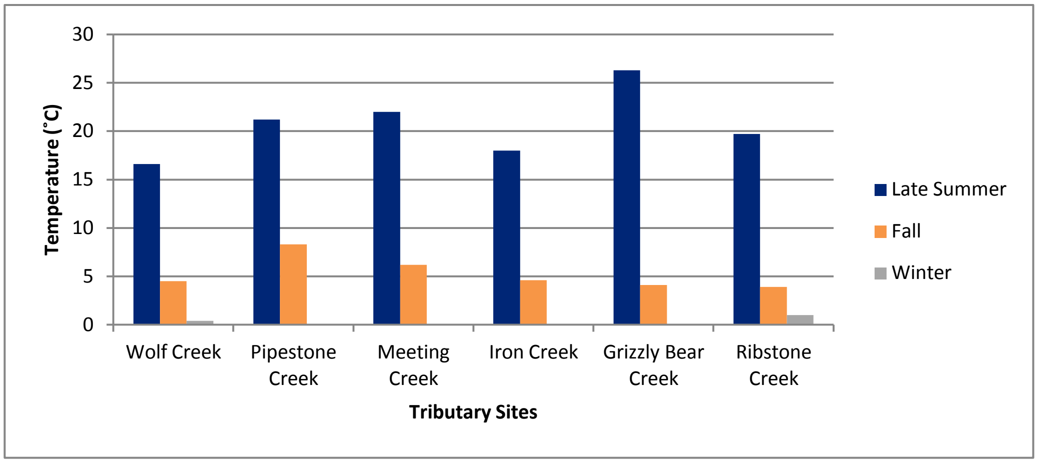


Figure 15. Temperature of Six Major Tributaries of the Battle River in 2013.

5.2.3.3 Lagoon Discharges

During the fall survey of lagoons, temperatures ranged from 2.6˚C at the Stettler to 8.2˚C at the Ponoka (Figure 16).

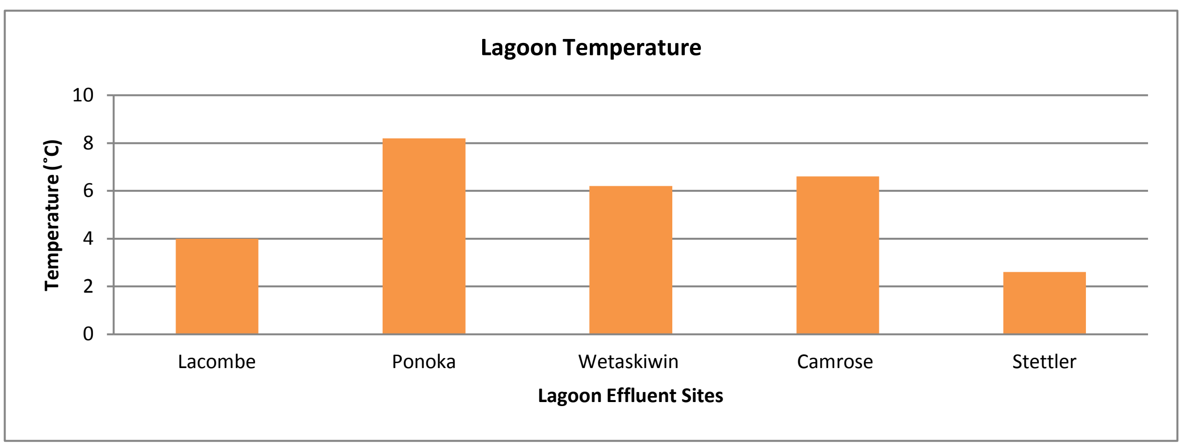


Figure 16. Temperature of Sewage Effluent from Lagoons Along the Battle River in October of 2013.

5.2.4 Conductivity

5.2.4.1 Mainstem Patterns

The conductivity during the 2013 late summer survey ranged from 300 µS/cm at the Battle Lake outflow to 863 µS/cm downstream of Ribstone Creek and from 370 µS/cm at the Battle Lake outflow to 886 µS/cm downstream of Ponoka during the fall 2013 survey. There are no federal or provincial guidelines for conductivity and conductivity did not show notable trends in comparison to WQOs. The two sites in Reach 3, downstream of Driedmeat Lake and upstream of Meeting Creek, had conductivity values of 652 and 662 µS/cm respectively.

During the 2013 campaign, conductivity gradually increased with distance downstream with the exception of a large peak downstream of Ponoka in the late summer and fall, likely due to lagoon discharges, and a large peak upstream of Camrose in the winter, possibly due to road salt influence (Figure 17). The Ponoka peak is consistently assimilated during the open-water season in the reach upstream of Pipestone Creek, possibly due to the effect of the wetland complex of Samson Lake. A consistent increase in conductivity was observed between Meeting Creek and HWY 872, possibly due to the large amount of saline soils in the subwatershed of that reach (Figure 19), which is also reflected in high conductivity in reach 4 tributaries (Figure 18).

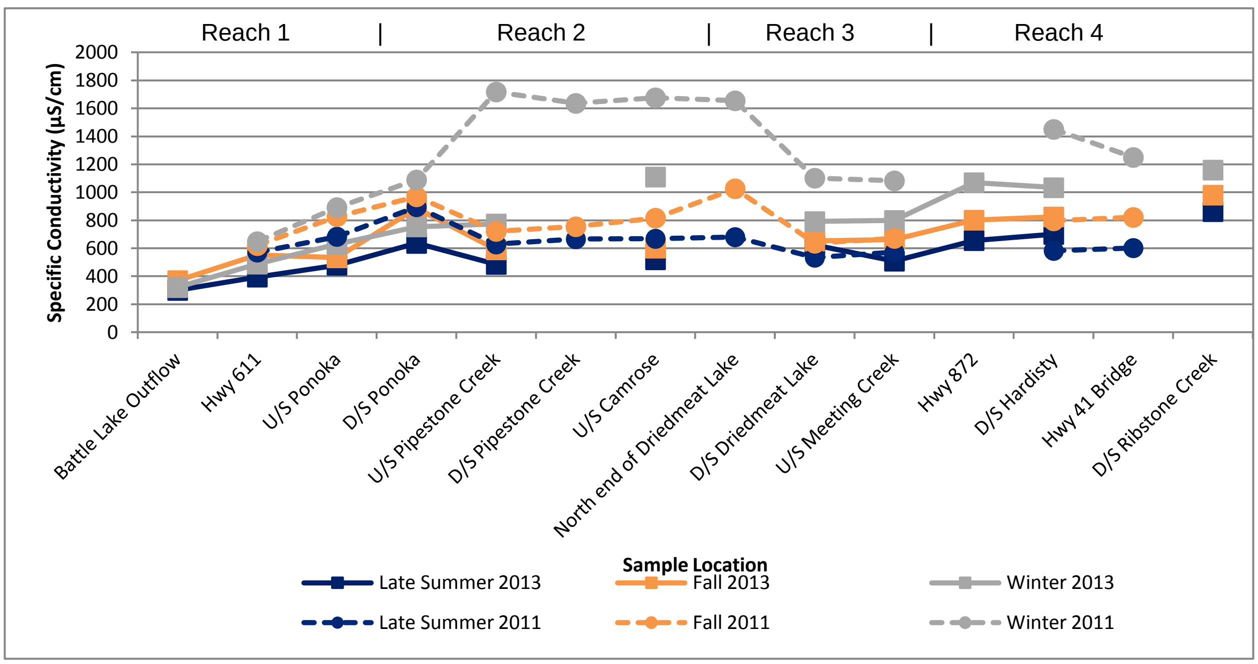


Figure 17. Specific Conductivity Along the Battle River in 2011 and 2013.

For the most part, the winter of 2013 had higher conductivity values than fall or late summer, possibly due to larger groundwater influence or road salt inputs in winter and fall conductivity was slightly higher than late summer, possibly for the same reason. This is similar to the seasonal patterns demonstrated in 2011, however, 2011 values were generally greater than 2013 values.

5.2.4.2 Tributaries

During the late summer survey in 2013, tributary values ranged from 532 µS/cm at Pipestone Creek to 2025 µS/cm at Grizzly Bear Creek. Grizzly Bear Creek and Iron Creek flow through areas of saline soils (Figure 19), which is likely the reason for such high conductivity values, which are atypical of freshwater. During the fall, survey values ranged from 662 to 2540 µS/cm, with the lowest and highest values occurring in the same creeks as the late summer survey. The winter conductivity values ranged from 869 µS/cm at Wolf Creek to 1750 µS/cm in Ribstone Creek (Figure 18). Meeting, Iron and Grizzly Bear Creeks were not sampled during the winter survey.

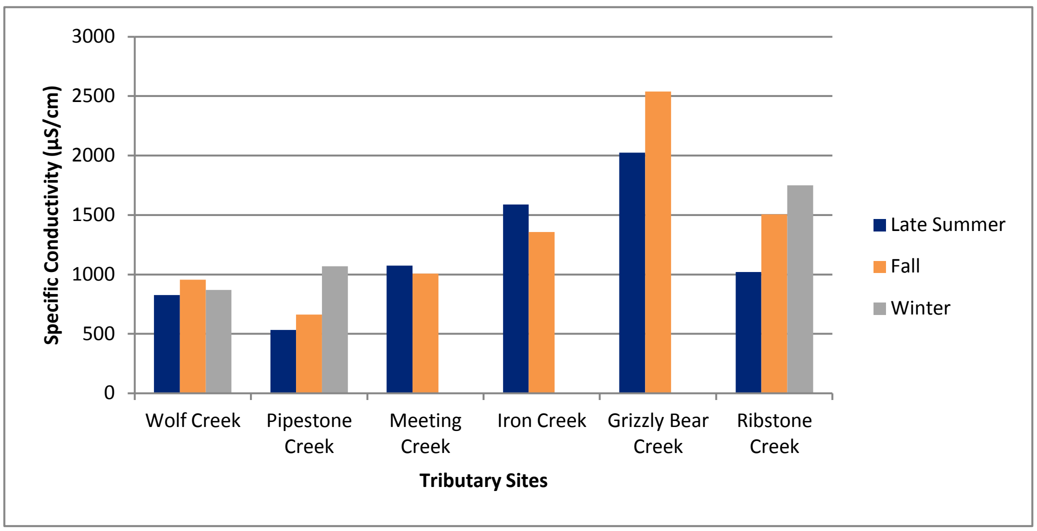


Figure 18. Specific Conductivity in Major Tributaries Along the Battle River in 2013.

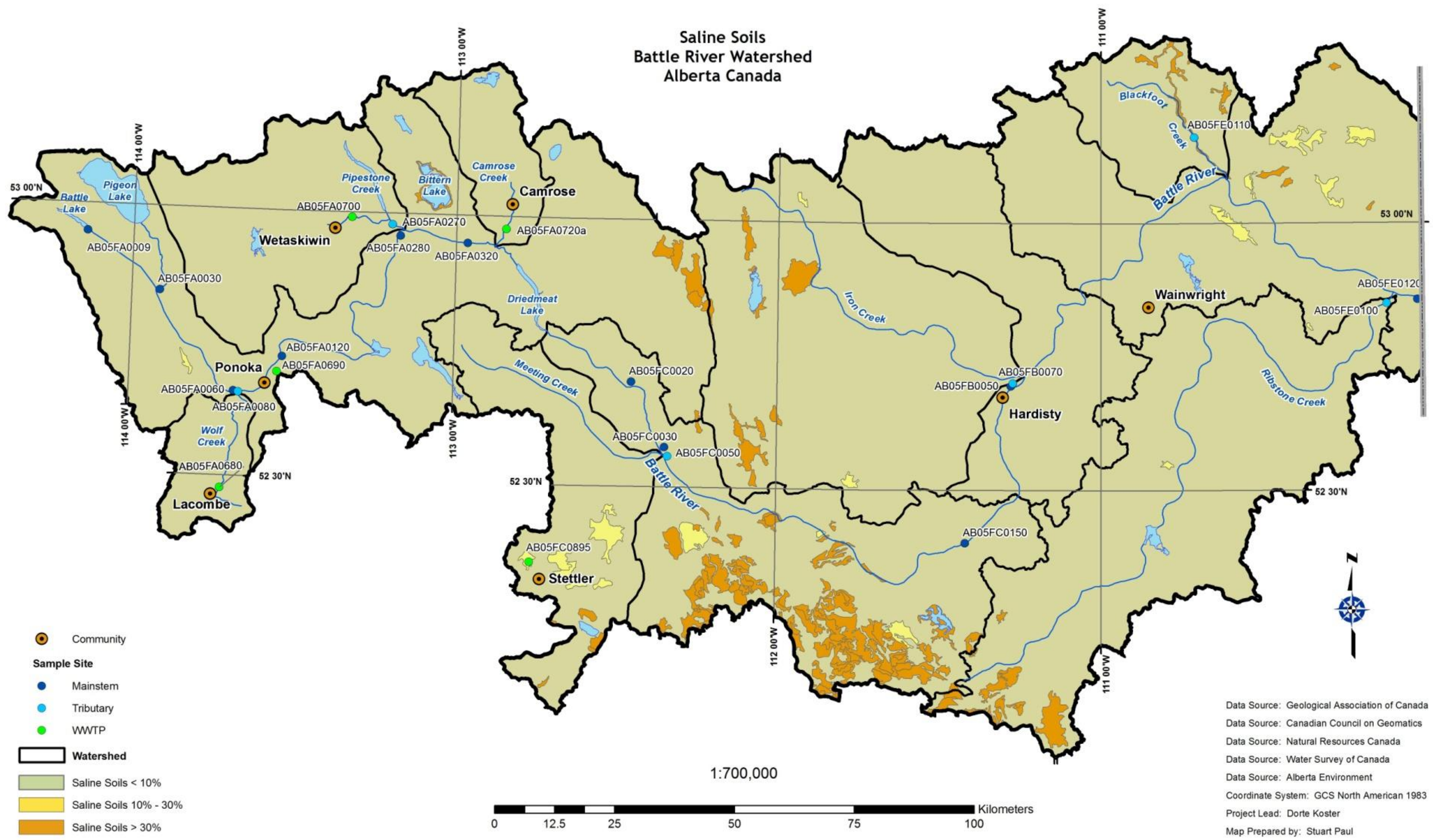


Figure 19. Map of Saline Soils in the Battle River Watershed

5.2.4.3 Lagoon Discharges

Specific conductivity ranged from 1059 µS/cm in the Ponoka lagoon effluent to 1709 µS/cm in the Wetaskiwin lagoon effluent (Figure 20). It is not clear why lagoon conductivity showed this range, but the type of institutions or industries served by the lagoons beside residential households or the type of source water may play a role.

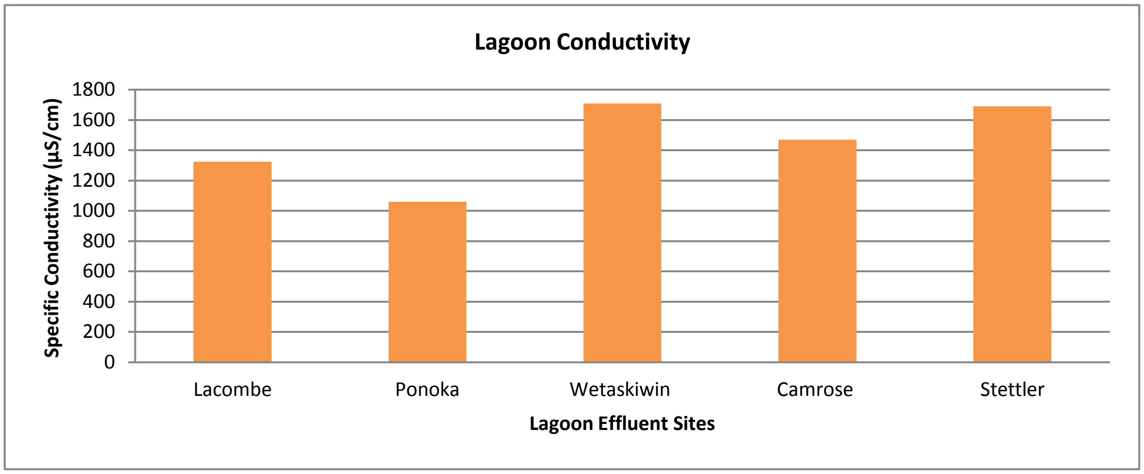


Figure 20 Specific Conductivity in Lagoon Effluent along the Battle River.

5.2.5 Turbidity

5.2.5.1 Mainstem Patterns

Turbidity ranged from 0.1 to 18.6 NTU during late summer 2013, from 0 to 50.1 NTU during the fall and from 0 to 20 NTU in winter.

There was a relatively consistent longitudinal pattern of low turbidity in the headwaters, increases downstream of Ponoka and lower turbidity towards the Saskatchewan border. Peaks in turbidity occurred during every season of 2013 upstream of Camrose. There was also an increase in turbidity downstream of Hardisty during the 2013 late summer survey. During the 2011 campaign, peaks in turbidity occurred downstream of Pipestone Creek, a pattern that is consistent with the peaks upstream of Camrose in 2013 (Figure 21). Peaks downstream of Driedmeat Lake and some of the patterns downstream of Ponoka may be related to planktonic algae growth in the stagnant, warm waters of Samson and Driedmeat Lakes. Planktonic chlorophyll was not measured as part of the synoptic surveys, but Long-term River Network (LTRN data from the site upstream of Camrose showed elevated planktonic chlorophyll a concentrations, in particular in September (135 mg/m^3) and October (114 mg/m^3). Another explanation for increased turbidity downstream of Driedmeat Lake can be the channelized morphometry and virtual absence of riparian zones in this river reach, providing no barrier to any sediment inputs from the local watershed.

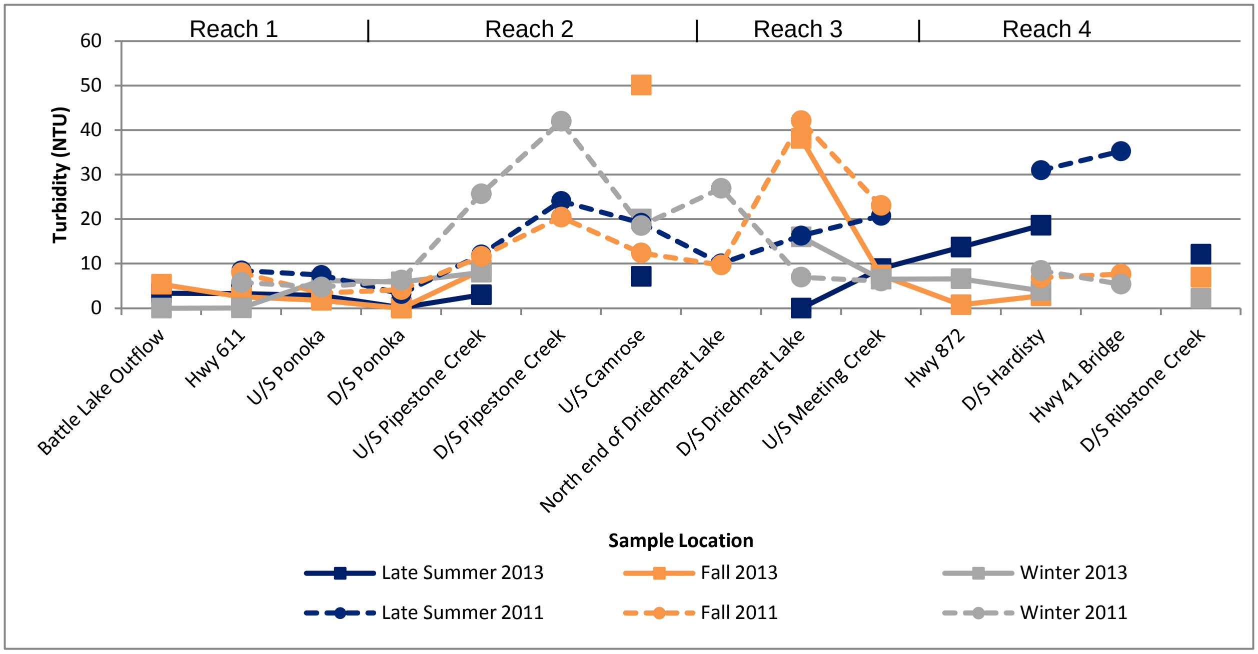


Figure 21 Turbidity Along the Battle River in 2011 and 2013.

5.2.5.2 Tributaries

In late summer, turbidity ranged from 0 NTU at Meeting Creek to 31.6 NTU at Grizzly Bear Creek. In fall, turbidity ranged from 4.2 NTU at Meeting Creek to 19.3 NTU at Ribstone Creek (Figure 22). Winter turbidity values were lower, ranging from 2.1 to 5.9 NTU, likely due to the lack of overland runoff that would entrain suspended sediments, and limited planktonic algae growth.

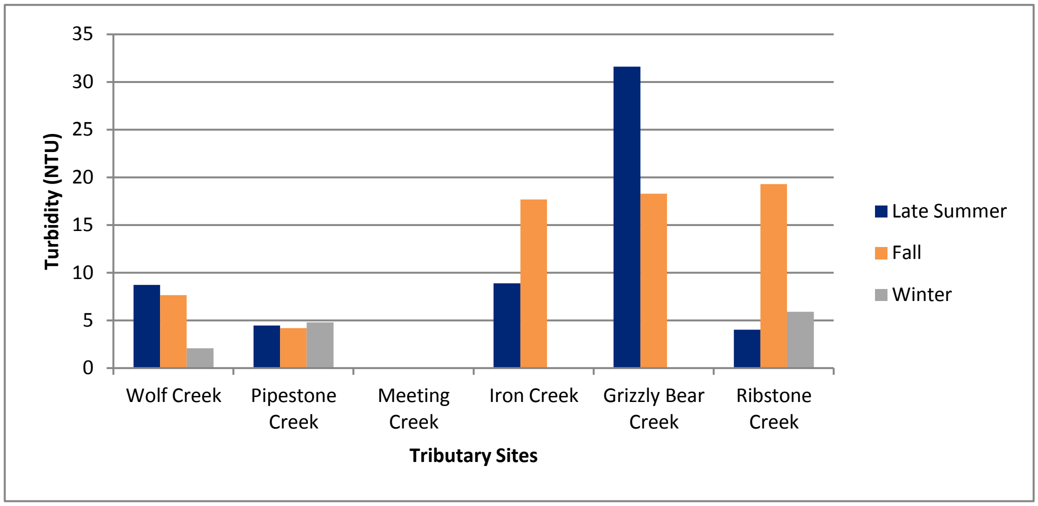


Figure 22. Turbidity of Major Tributaries Along the Battle River in 2013.

5.2.5.3 Lagoon Discharges

Turbidity in Lacombe lagoon effluent was 450 NTU, while turbidity was 0 NTU in Ponoka, Wetaskiwin and Stettler effluent. Turbidity data was not available at the other effluent discharges.

5.2.6 Summary Field Parameters

The most notable information derived from field parameters were the low oxygen levels in reach 2 and 3 during winter under ice, which were on occasion below acute levels for aquatic life. Oxygen is likely consumed by decomposition of organic matter that resulted from high productivity in this reach during the open water season, as discussed in the following section. The Battle River was naturally elevated in pH and showed increased pH beyond water quality guidelines in reach 2, again likely due to the elevated productivity in this reach. Conductivity patterns were influenced by point-source discharges in reach 2 and possibly by naturally saline soils in reach 4. Elevated turbidity levels in reaches 2 and 3 were observed compared to low levels in reaches 1 and 4, possibly related to high planktonic algae mass, but elevated winter turbidity in 2011 indicates another source of turbidity.

5.3 Nutrients

5.3.1 Total Phosphorus

5.3.1.1 Mainstem Patterns

Total phosphorus levels were high in Battle River, consistent with the only water source being from a local prairie watershed.

In the fall of 2013, the outflow of Battle Lake had a very high TP concentration (0.32 mg/L), possibly due to internal phosphorus loading in the lake, as indicated by the large dissolved portion of this measurement (Figure 24). Aside from this occurrence, TP concentrations increased throughout reach 1, were highest in Reach 2 for all seasons and then decreased in reach 4. At most sites, late summer TP concentrations were greater than other seasons. Total phosphorus concentrations peaked downstream of Ponoka in summer and fall, and downstream of Driedmeat Lake in summer and winter. The 2011 campaign also found an increase in TP in Reach 2, with a large peak in TP concentrations downstream of Ponoka in late summer, associated with lagoon discharge (Figure 23).

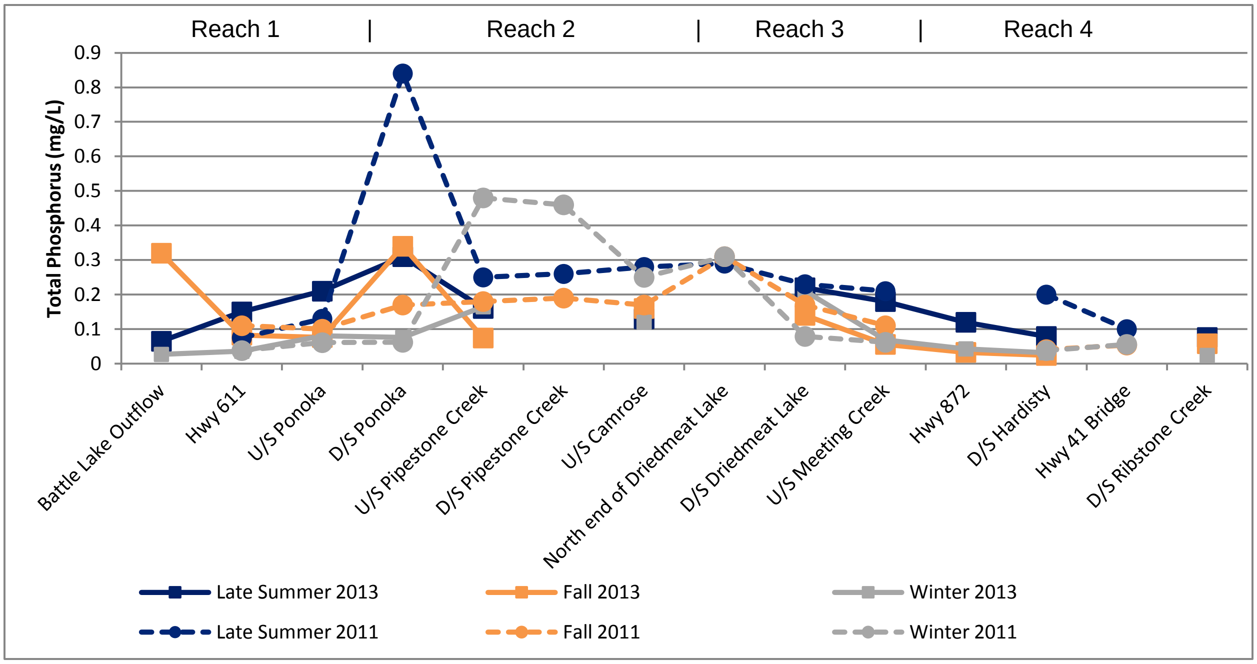


Figure 23 Total Phosphorus Concentrations along the Battle River in 2011 and 2013.

Battle River has elevated phosphorus concentrations, as expected from naturally nutrient-rich prairie rivers. The spatial patterns on increased phosphorus concentrations in reach 2 and 3, however, indicate that loads from human point- and non-point sources are affecting the nutrient status of Battle River in these reaches.

5.3.1.2 Tributary Loadings

During the 2013 late summer survey, TP concentrations ranged from 0.027 mg/L at Meeting Creek to 0.77 mg/L at Grizzly Bear Creek. In the fall, concentrations ranged from 0.015 mg/L at Meeting Creek to 0.26 mg/L at both Iron Creek and Grizzly Bear Creek. Total phosphorus concentrations were lower during the winter survey, ranging between 0.058 at Wolf Creek and 0.083 mg/L at Ribstone Creek (Figure 24).

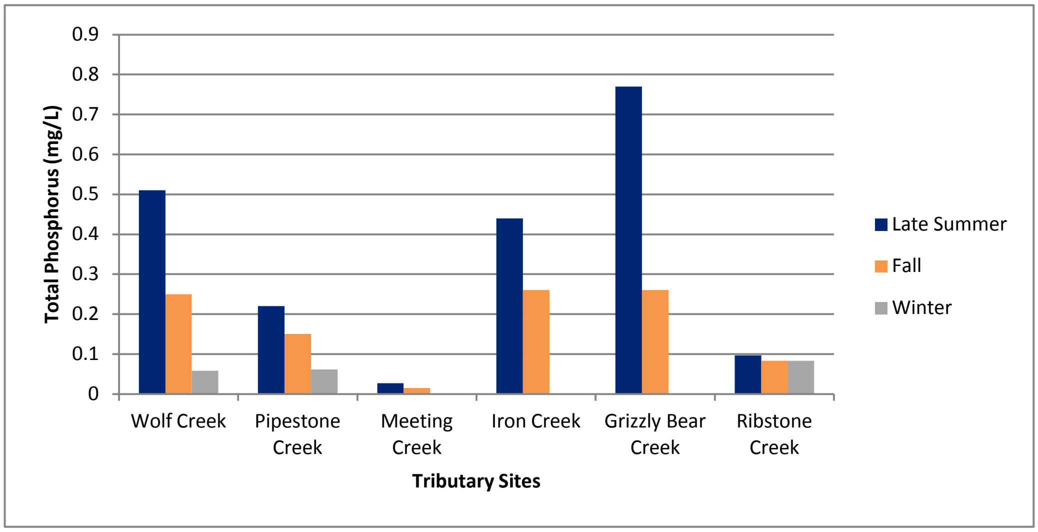


Figure 24. Tributary TP Concentrations in 2013.

Similarly to TDP, flow had a large influence on tributary loads. Wolf Creek had the largest TP load during the late summer of 2013, with 11.8 kg/day of TP. In the fall, Iron Creek had the largest load (1.4 kg/day) due to its high concentration and flow. During both the summer and fall, Grizzly Bear Creek had high concentrations of TP, however, the low flows resulted in small loads during both seasons (Figure 25). While the influence of Wolf Creek is recorded in the Battle River by a sharp increase of TP concentrations between upstream and downstream of Ponoka, the Iron Creek loads did not have a detectable influence on Battle River water quality (Figure 23).

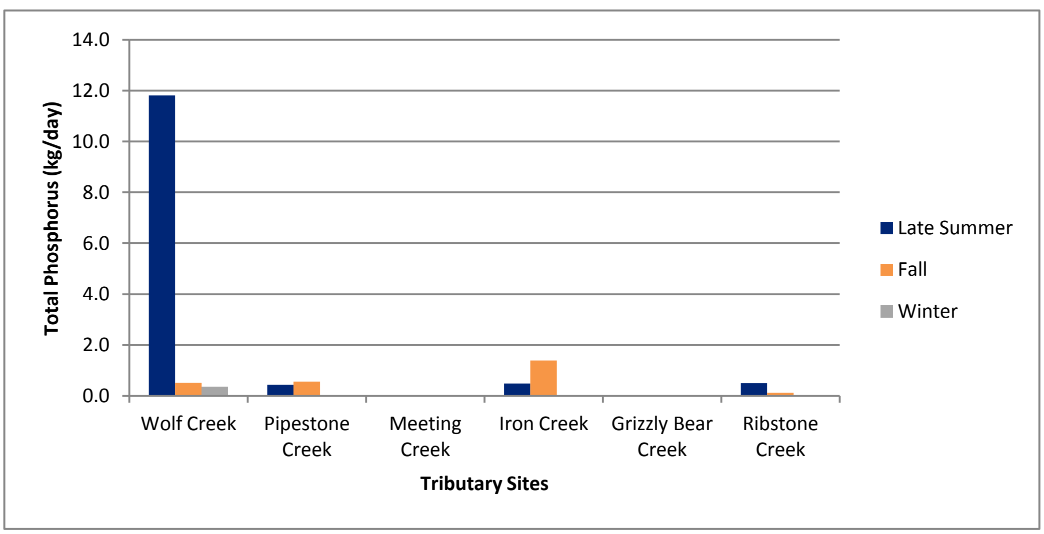


Figure 25. Tributary TP Loads in 2013.

5.3.1.3 Lagoon Discharges

Lacombe lagoon effluent had the highest TP concentration in October of 2013 (3 mg/L). Camrose sewage lagoon had the lowest TP concentration (0.47 mgL) (Figure 26). Total phosphorus loads were very similar to TDP loads, with the exception of Lacombe effluent, due to higher TP concentrations 3 mg/L versus 0.81 mg/L of TDP. Total phosphorus loads ranged from 1 kg/day at the Ponoka lagoon to 14 kg/day at the Stettler lagoon, with the second largest load discharged by the Lacombe lagoon (11 kg/d) (Figure 27).

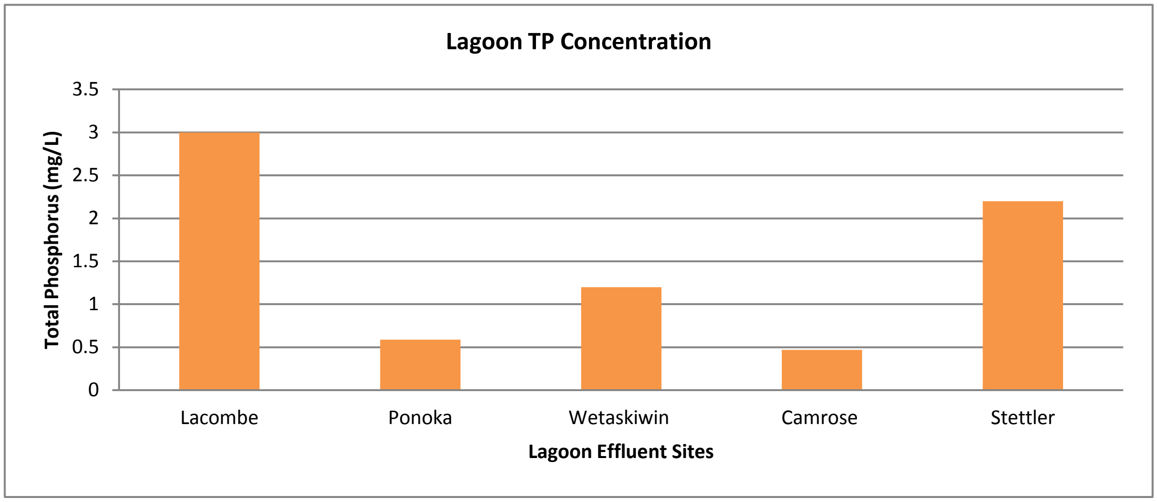


Figure 26. Lagoon TP Concentrations for the Fall 2013.

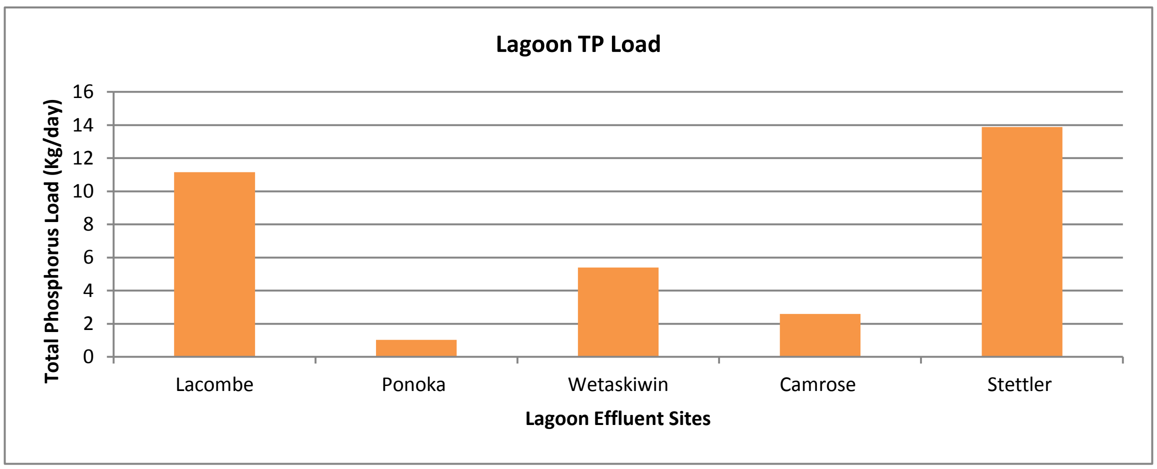
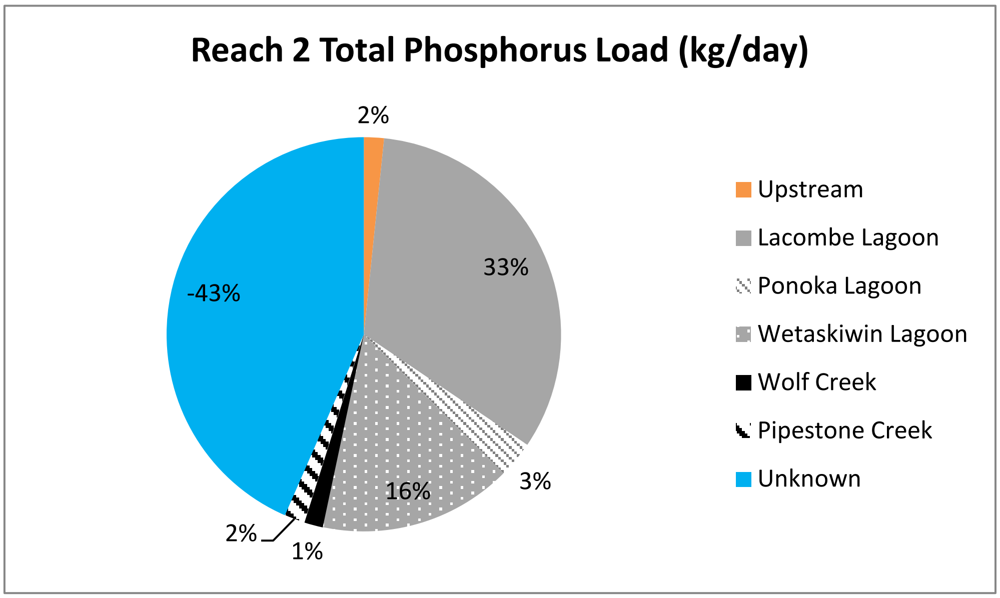
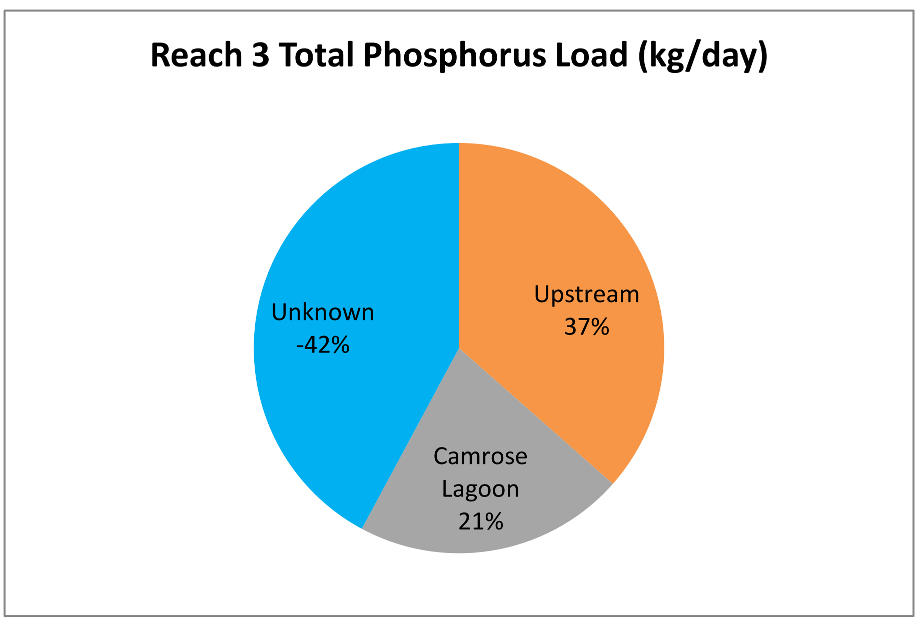


Figure 27. Lagoon TP Load for the Fall of 2013.

5.3.1.4 Total Phosphorus Loads by Reach

Total phosphorus loads in Reaches 2 and 4 were primarily attributable to lagoon discharge representing 52 and 69% of reach total load. Tributaries in both of these reaches contributed less than 10% of the total load for each reach. Reaches 2 and 3 had large TP sinks removing 43 and 42% of TP loads respectively, again, likely due to water use or water loss to groundwater. Upstream TP loads explained 37% of TP loads in Reach 3 (Figure 28). Stettler lagoon loads are likely an overestimate.





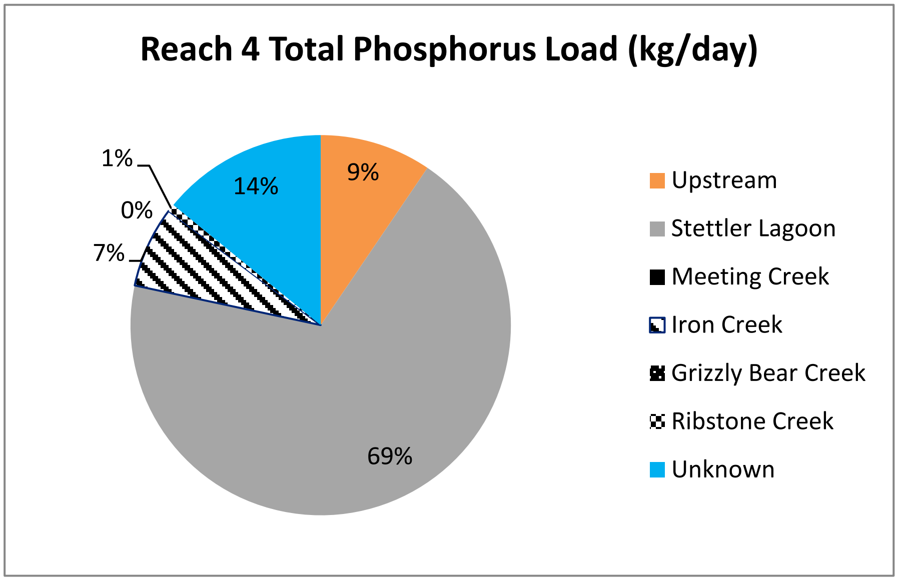


Figure 28. TP Loads for Reaches 2, 3 and 4.

5.3.2 Total Dissolved Phosphorus

5.3.2.1 Mainstem Patterns

Total dissolved phosphorus (TDP) concentration of the Battle River at Hwy 872 (0.076 mg/L) was greater than the 90th percentile WQO (0.05 mg/L) for reach 4.

In the late summer 2011 and 2013 and fall of 2013, TDP concentrations peaked downstream of Ponoka, with the 2011 concentrations being appreciably higher (Figure 29). Wolf Creek showed high TDP concentrations (Figure 30), possibly from the Lacombe lagoon discharge, in 2013. In 2011, Ponoka lagoon discharge occurred in late summer (Aug. 17 to Sep. 8), indicating that the large TDP peak in late summer 2011 was cause by Ponoka lagoon discharge. Lacombe did not discharge during the 2011 sampling program, so none of the 2011 patterns were influenced by that discharge (before mid-August and after December 2).

During the fall survey, the Battle Lake outflow dissolved phosphorus concentration (0.12 mg/L) was greater than in the remainder of reach 1, possibly due to internal loading from lake sediments. There was also a large peak in late summer downstream of Driedmeat Lake and consistently higher TDP concentrations upstream and downstream of Driedmeat Lake compared to the site upstream of Camrose. One possible explanation for the TDP peak downstream of Ponoka could be cumulative lagoon discharges from Lacombe (effluent concentration 0.8 mg/L) and Ponoka (effluent concentration of 0.5 mg/L, Figure 32). Sampling in summer 2013 was conducted during Lacombe's lagoon discharge to Wolf Creek, indicated by high TDP concentrations in Wolf Creek. Fall sampling was conducted at a time when both lagoons were discharging, although the effect on Wolf Creek was minor, pointing to the Ponoka lagoon for the fall peak. While the same late summer peak was observed in 2011, the fall concentrations were low, demonstrating the difference when sampling is conducted outside the lagoon discharge period.

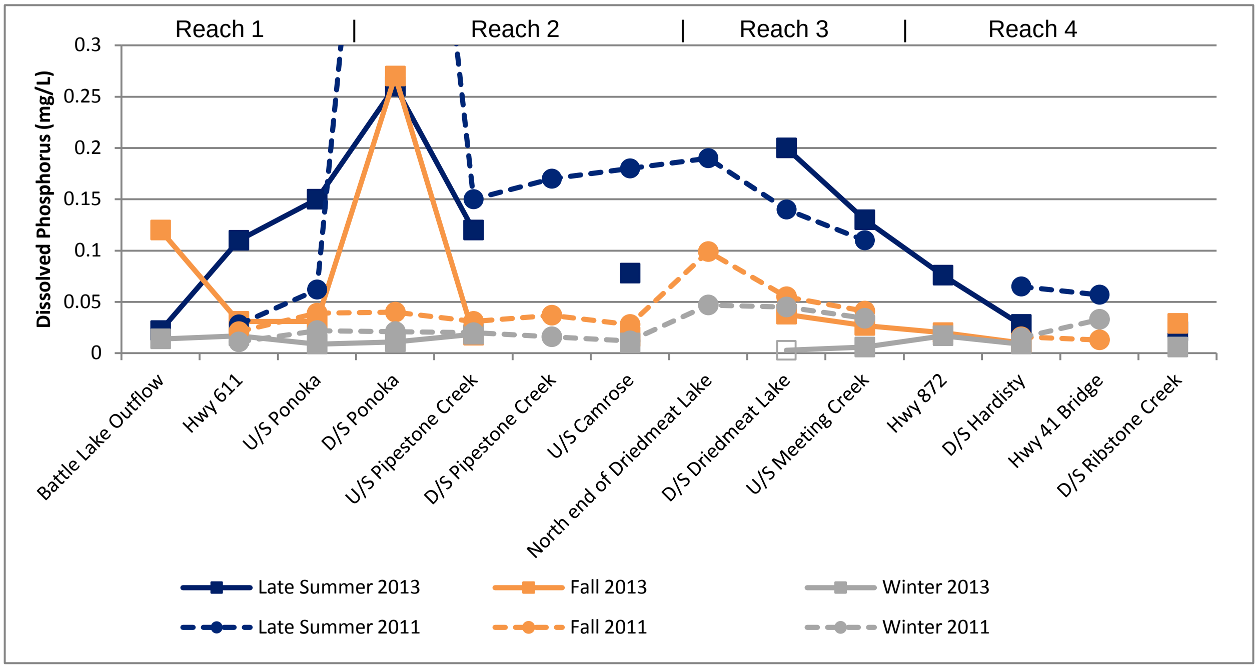


Figure 29. TDP Along the Battle River in 2011 and 2013.

For the most part, late summer TDP concentrations were the greatest. During that season, TDP also showed the most distinct spatial patterns, increasing from Battle Lake outflow, peaking downstream of Ponoka, then decreasing, and continuously declining from downstream of Driedmeat Lake to downstream of Ribstone Creek. In 2011, TDP concentrations were also greatest in the late summer and in Reach 2.

Summer total phosphorus concentrations were largely made up of TDP (63% in 2013 and 58% in 2011) indicating that a large portion of the total phosphorus is in the dissolved form, potentially available for uptake by algae. These are relatively high proportions and indicate that there are either important outside sources of TDP to the river, for example from lagoon discharges that typically contain high proportions of TDP, or that in stagnant areas and reservoirs dissolved phosphorus is released from bottom sediments during low oxygen periods or through remineralisation of organic matter. In fall and winter, TDP made up lower proportions, between 22 and 41% of total phosphorus, with no continuous pattern between 2011 and 2013.

5.3.2.2 Tributaries

In later summer of 2013, TDP concentrations ranged from 0.013 mg/L at Meeting Creek to 0.69 mg/L at Grizzly Bear Creek. In fall, TDP concentrations were below summer concentrations and ranged from 0.0074 to 0.18 mg/L, occurring at the same tributaries as in the summer. Winter concentrations were the lowest, ranging from 0.003 at Pipestone Creek to 0.025 at Ribstone Creek (Figure 30).

TDP loading from the tributaries was largely influenced by flow. The summer 2013 load from Wolf Creek (11.1 kg/day) was approximately an order of magnitude greater than the loads from the other tributary inflows to Battle Creek, due to high flow measured during the summer 2013 event. 2013 loads from Pipestone Creek, Iron Creek, Ribstone Creek and fall and winter loads from Wolf Creek remained below 1 kg/d. Many creeks had low to no loading of TDP due to low flow conditions (Figure 31).

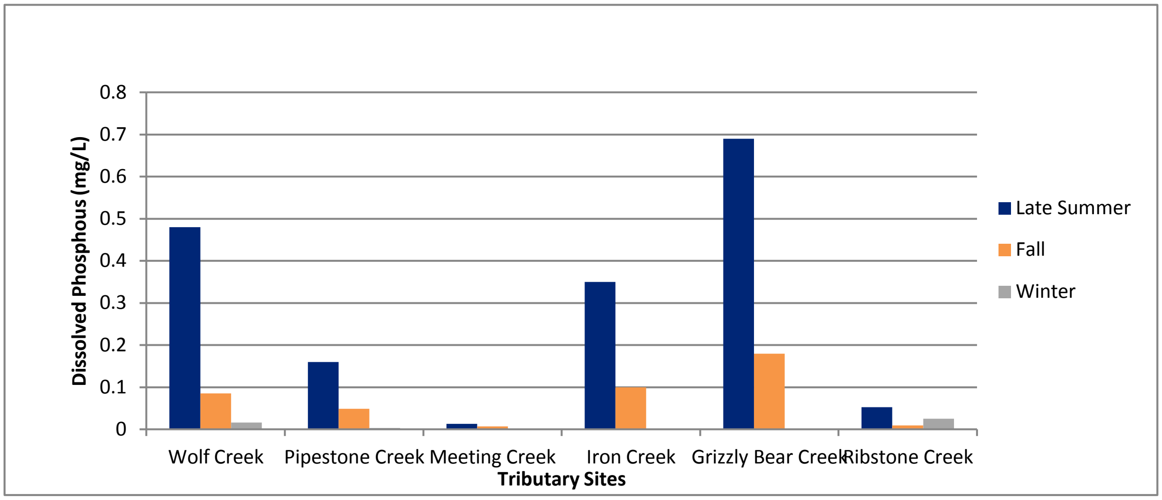


Figure 30. TDP Concentrations in Major Tributaries Along the Battle River.

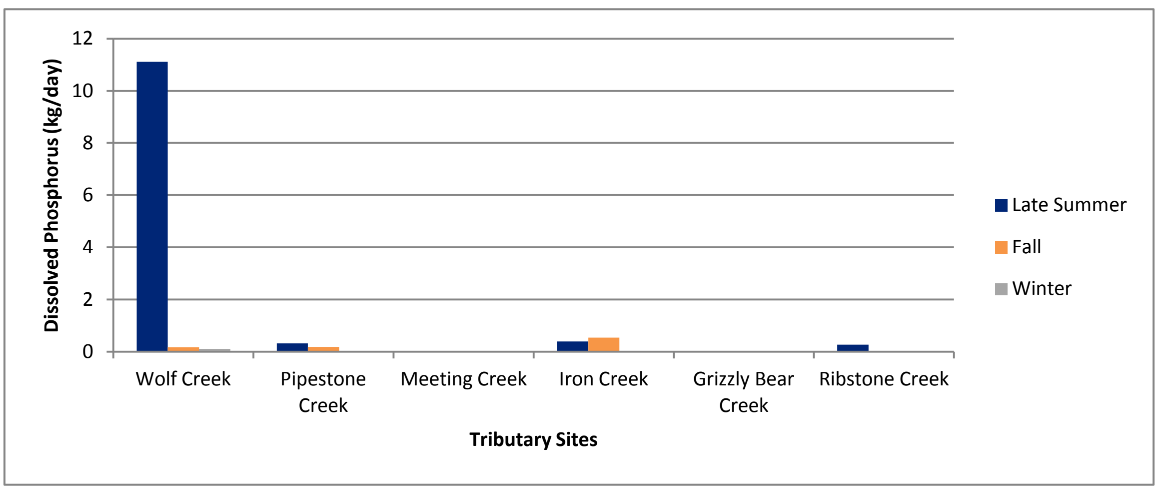


Figure 31. TDP Loads in Major Tributaries Along the Battle River.

5.3.2.3 Lagoon Discharges

Dissolved phosphorus concentrations in effluent from lagoons ranged from 0.42 mg/L at Camrose sewage lagoon to 1.2 mg/L at Wetaskiwin (Figure 32).

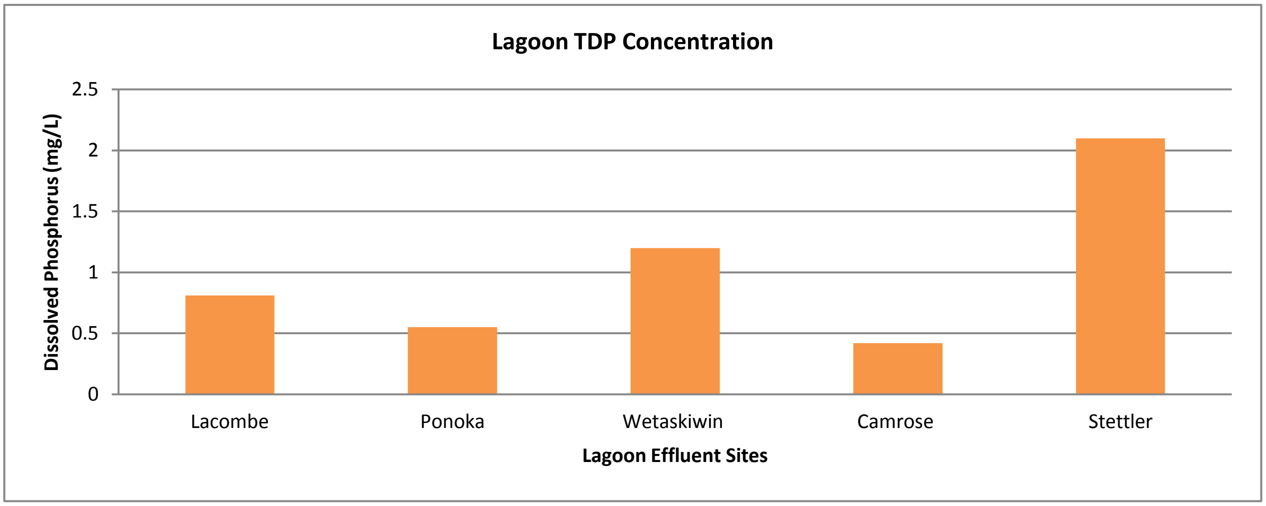


Figure 32. TDP Concentrations in Sewage Effluent from Lagoons.

Daily TDP loads from effluents ranged from 1 kg/day at the Ponoka lagoon to 13 kg/day at the Stettler lagoon. The higher loadings from the Stettler Lagoon are a combination of higher flows (0.073 m^3/s) and higher TDP concentrations of the effluent (Figure 33).

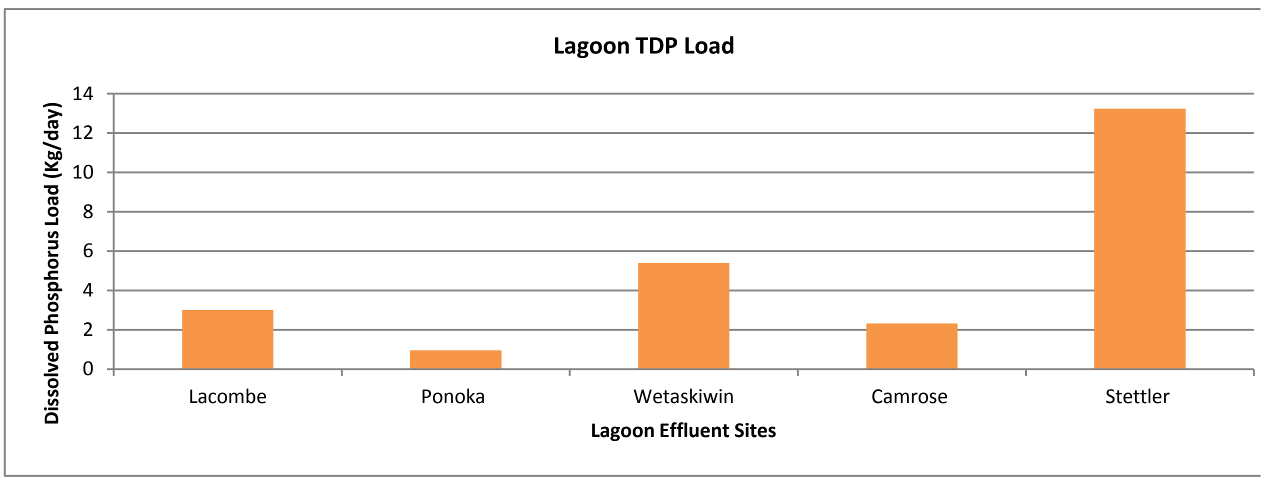
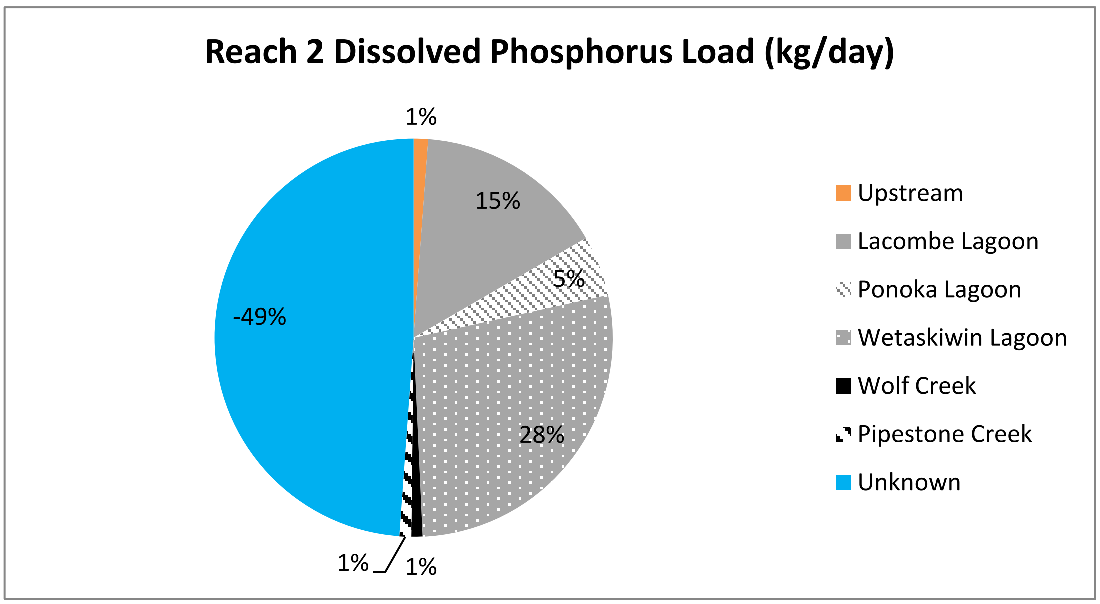


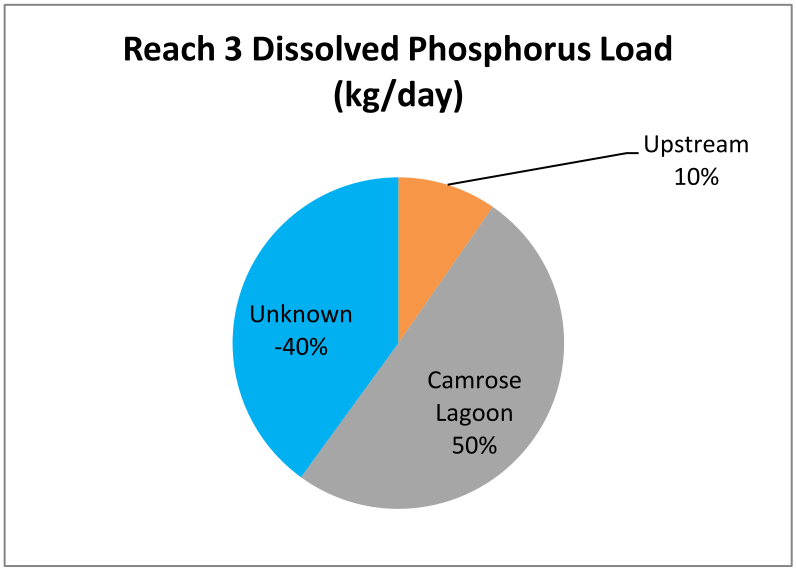
Figure 33. TDP Loads in Sewage Effluent from Lagoons Along the Battle River.

5.3.2.4 TDP Loads by Reach

Mainstem TDP loads were most influenced by point source loads from lagoon discharges, representing 48, 50 and 68% of total reach load for Reaches 2, 3 and 4 respectively (Figure 34). What is also important to note is that there were large phosphorus sinks in each reach with 49, 40 and 24% of TDP loads in Reaches 2, 3 and 4 not making it to downstream sites (Figure 34). Dissolved phosphorus is readily available for biological uptake and therefore could have been assimilated into algal biomass, but one reason is likely also loss of water from water withdrawals.

There is some uncertainty associated with lagoon discharge loads, as these were based on average lagoon discharge volumes and a one-time measurement of concentrations, and some of them discharge into creeks, where assimilation of TDP can occur. There is also the possibility of loss of river water to groundwater, as indicated by decreasing flows between Meeting Creek and Hardisty in summer 2013 (Figure 6).





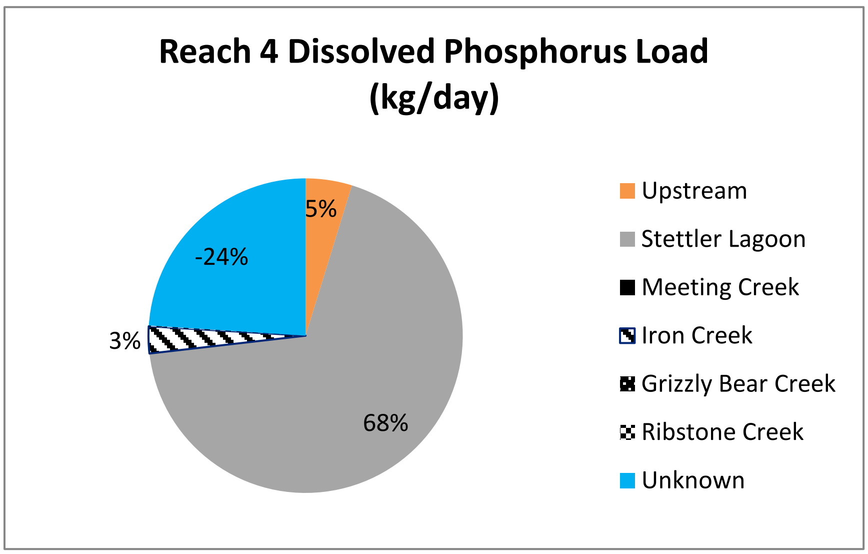


Figure 34. TDP Loads for Reaches 2, 3 and 4.

The Stettler Lagoon represents two thirds of the TDP load in reach four, which is likely an overestimation. The discharge is located in the headwaters of the Meeting creek watershed and there was usually little flow in Meeting Creek at the mouth, indicating that a large portion of that load may not reach the Battle River.

5.3.3 Nitrate and Nitrite

5.3.3.1 Mainstem Patterns

Nitrate plus Nitrite – N concentrations, rang from below detection (<0.003 mg/L) in Reach 4 to 0.94 mg/L in Reach 2 during the 2013 late summer survey. Nitrate and nitrate concentrations at the site upstream of Pipestone Creek were higher than the 90th percentile WQO for Reach 2 (0.511 mg/L).

In October, nitrate plus nitrite – N concentrations ranged from below detection in Reach 4 to 1.4 mg/L in Reach 2. All sites in Reach 2 and upstream of Ponoka in Reach 1 exceeded the 90th percentile WQOs.

In winter, nitrate plus nitrite – N concentrations ranged from 0.014 to 1.1 mg/L, with many samples exceeding the 50th percentile WQOs for their respective reaches. The samples collected upstream of Pipestone Creek (0.91 mg/L) and upstream of Camrose (1.1 mg/L) had concentrations greater than the 90th percentile WQO for Reach 2.

Nitrate plus Nitrite – N concentrations were elevated above headwater concentrations upstream of Ponoka, but were highest in Reach 2 during all seasons. Highest concentrations occurred during fall, with the exception of Reach 4, which had higher Nitrate plus Nitrite – N concentrations in winter. In late summer and fall of 2013, concentrations peaked upstream of Pipestone Creek. In winter, concentrations peaked upstream of Camrose. During the 2011 campaign, Nitrate plus Nitrite – N concentrations peaked downstream of Ponoka. This cannot be explained by transformation of lagoon discharge ammonia ammonia to nitrate and nitrite, as total nitrogen showed similar patterns. Therefore there appears to be a source of nitrogen in this reach and given the absence of large communities, it is likely non-point source contributions from agricultural lands in the area.

During both campaign years, Reach 4 had the highest concentrations in winter. Winter patterns differed drastically between 2011 and 2013, with non-detectable levels between upstream of Pipestone Creek and Driedmeat Lake in 2011 and peak concentrations in the same reach in 2013. A source of nitrate and nitrite in winter is the decomposition of aquatic plants and mineralization of organic sediments. This aerobic processes may have been inhibited in 2011 due to lower oxygen levels than in 2013 (Figure 8), making nitrites and nitrates the preferred oxygen source.

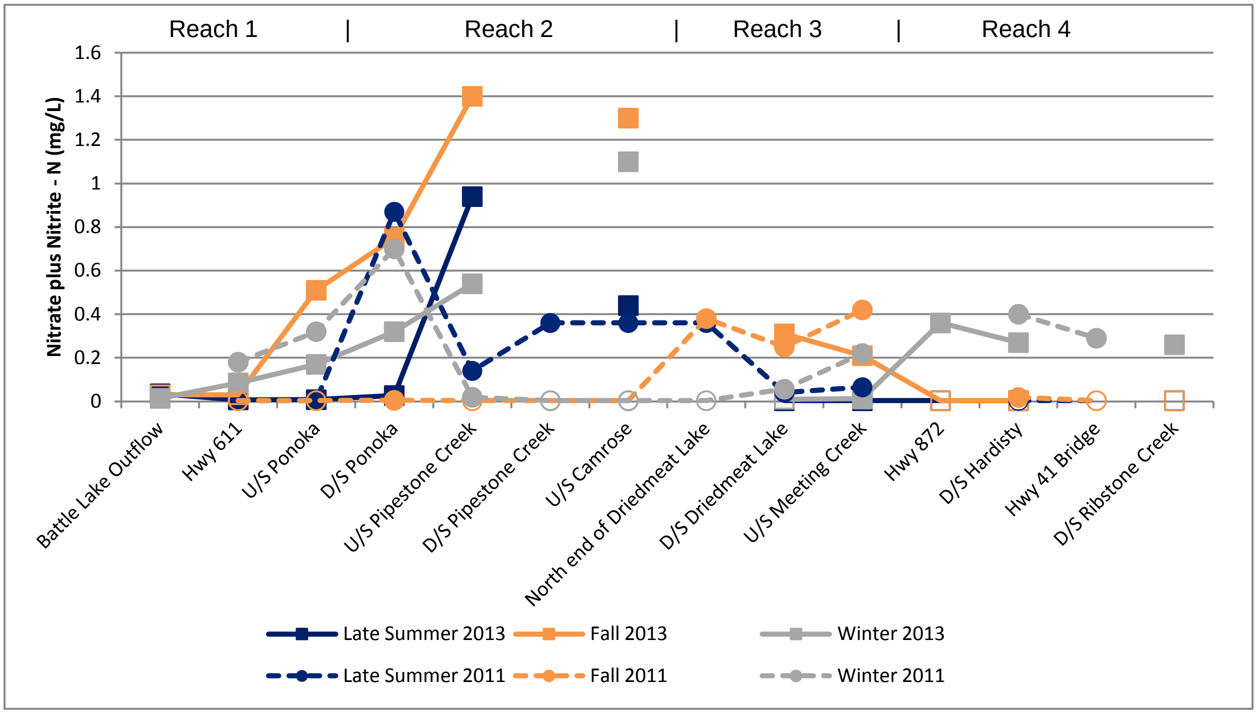


Figure 35 Battle River Mainstem Nitrate and Nitrite – N Concentrations

5.3.3.2 Tributaries

On the two occasions Iron Creek was sampled, concentrations of nitrate plus nitrite – N were below detection and concentrations were also below detection at Ribstone Creek on two out of the three occasions it was sampled. During the late summer survey, only Wolf and Pipestone Creeks had measureable concentrations of nitrate plus nitrite – N. During the fall survey, concentrations ranged from below detection to 0.43 mg/L. The three creeks sampled in the winter all had measureable concentrations of nitrate plus nitrite – N, ranging from 0.18 mg/L at Ribstone Creek to 0.77 mg/L at Wolf Creek (Figure 36), possibly from macrophyte decay or nitrate-rich groundwater influence in these larger creeks. Groundwater quality risk from agriculture is highest in the Wolf Creek and Pipestone Creek watersheds (Figure 2. Surface Water Quality Risk in the Battle River Watershed), and low in most of the Ribstone Creek watershed. This interpretation is unsubstantiated, without further analysis of groundwater chemistry data.

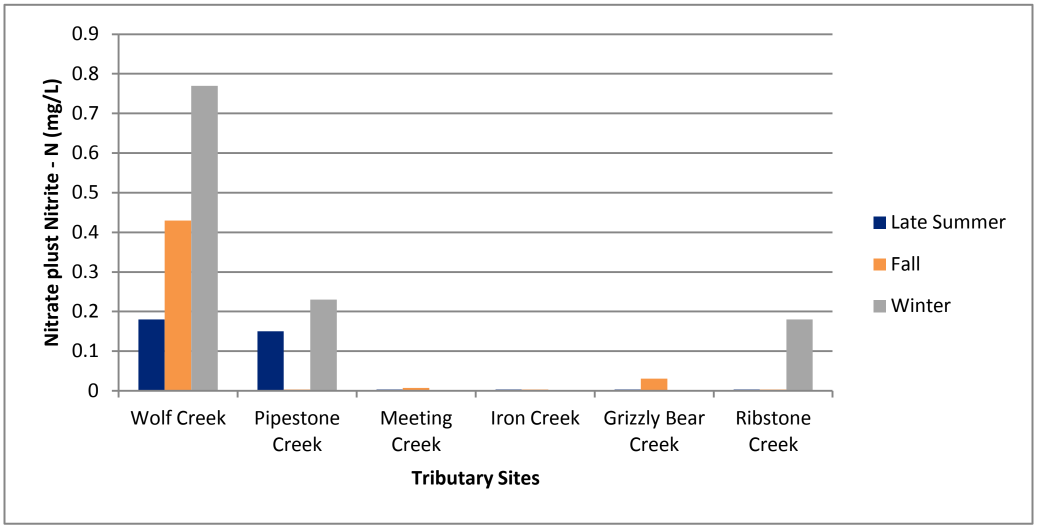


Figure 36. Tributary Concentrations of Nitrate and Nitrite – N in 2013.

Wolf Creek was the only tributary in which nitrate plus nitrite – N loads were measureable in all seasons, ranging from 0.9 kg/day in fall to 4.8 kg/day in winter. Loads in Pipestone Creek were in summer (Figure 37). Due to low concentrations and or flow conditions, loads were not calculated for the other tributaries.

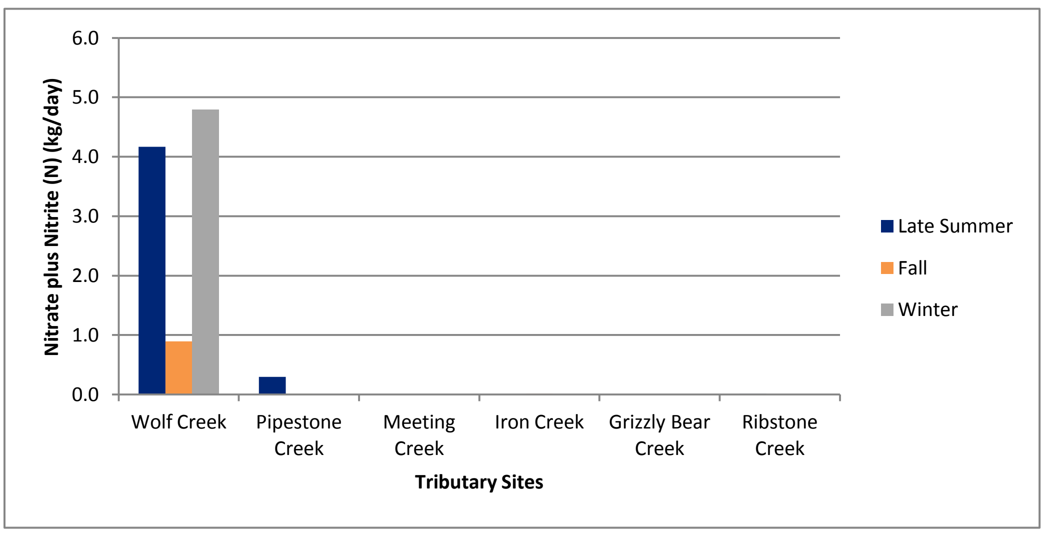


Figure 37 Tributary Daily Nitrate and Nitrite – N Loads in 2013

5.3.3.3 Lagoon Discharges

Effluent Nitrate and Nitrite – N concentrations ranged from 0.54 mg/L in the Camrose sewage lagoon effluent to 3.1 mg/L in the Stettler lagoon effluent (Figure 38).

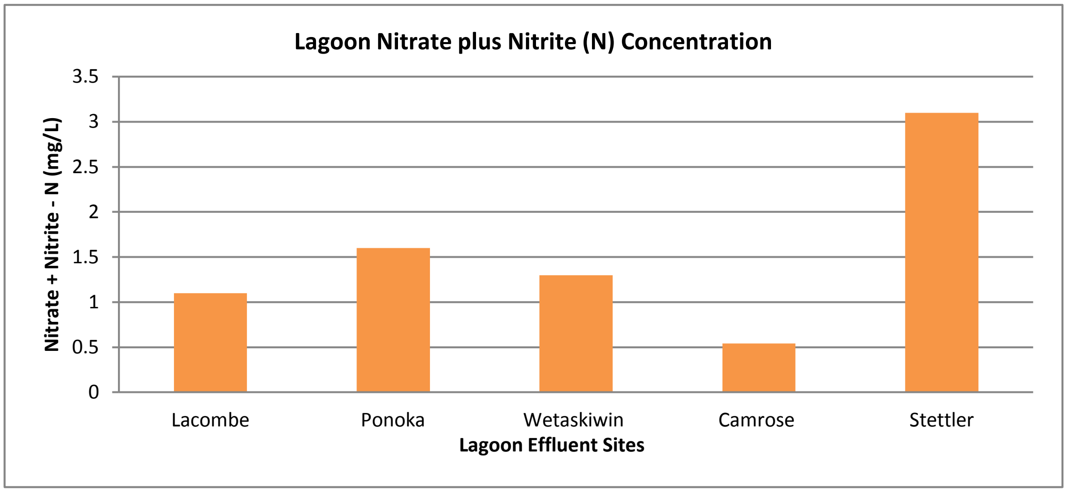


Figure 38 Lagoon Nitrate and Nitrite – N Concentrations in October of 2013

Stettler sewage effluent Nitrate and Nitrite – N load was the highest at 20 kg/day, while Ponoka and Camrose had the smallest daily Nitrate and Nitrite – N load at 3 kg/day (Figure 39). While Ponoka effluent had higher concentrations of Nitrate and Nitrite – N, Camrose lagoon flow was greater (0.064 m^3/s). The cumulative influence of these discharges certainly contributed to the elevated nitrate and nitrite concentrations in reach 2, while the Stettler discharge influence was not detectable downstream of the Meeting Creek confluence.

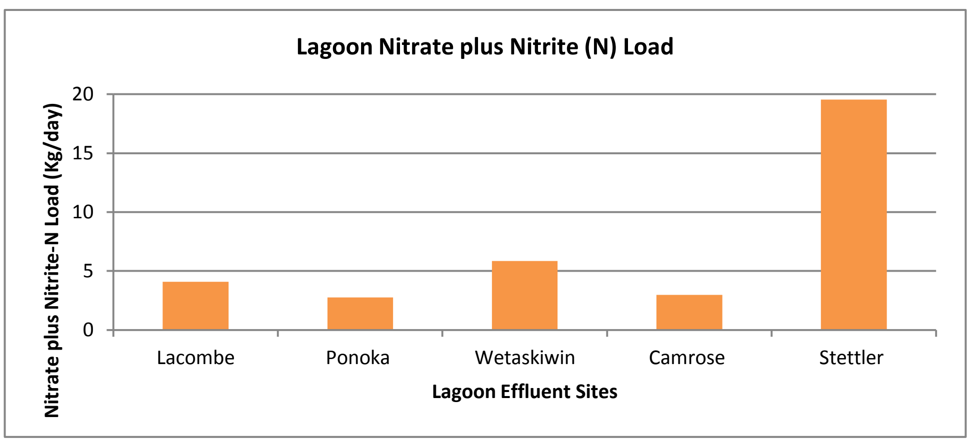


Figure 39. Lagoon Daily Nitrate and Nitrite – N Loads along the Battle River in October of 2013.

5.3.4 Dissolved Nitrite (N)

5.3.4.1 Mainstem Patterns

During the late summer 2013 survey, dissolved nitrite (N) concentrations exceeded the 90th percentile WQO (0.038 mg/L) upstream of Pipestone Creek (0.15 mg/L) and upstream of Camrose (0.052 mg/L). Reach 3 and 4 had concentrations below detection.

Dissolved nitrite concentrations were highest in Reach 2 and not detected in the headwaters and downstream of Meeting Creek in every survey during 2013 campaign. During the 2011 survey, dissolved nitrite (N) concentrations were highest in Reach 2 only during the summer survey (Figure 40).

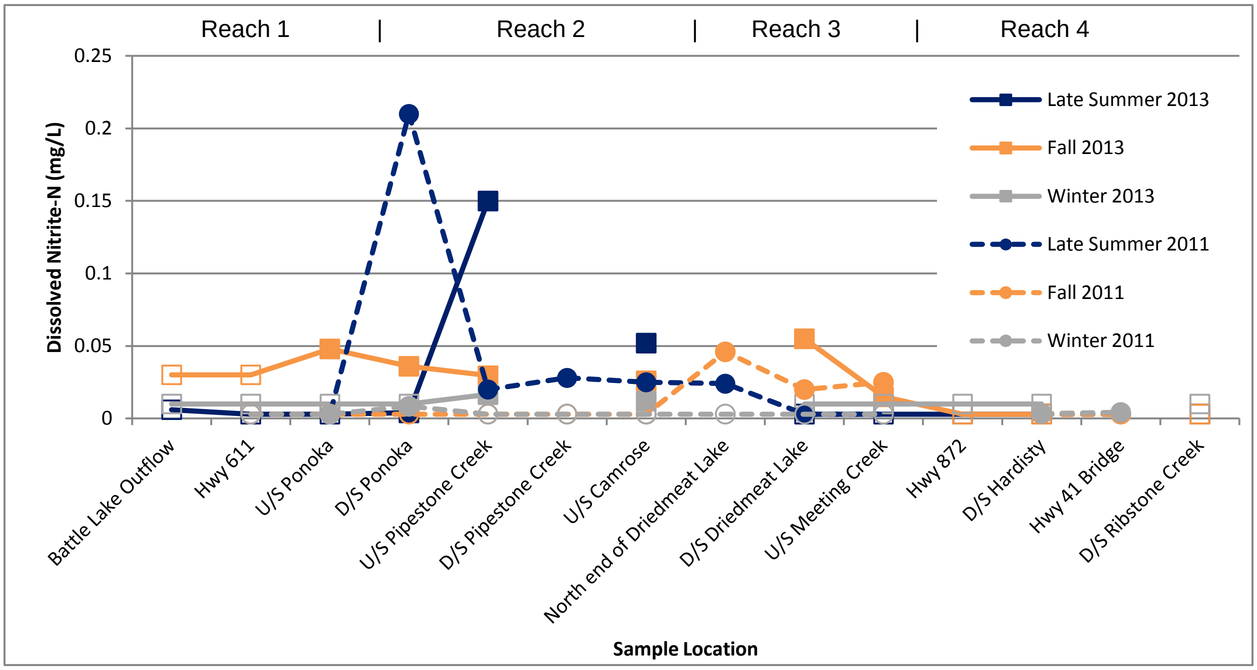


Figure 40 Mainstem Nitrite (N) Concentrations in 2013 and 2011.

5.3.4.2 Tributaries

Neither Meeting Creek nor Iron Creek had measureable dissolved nitrite (N) concentrations. Pipestone Creek had the highest dissolved nitrite (N) concentration (0.016 mg/L) in late summer and winter (0.023 mg/L), while Wolf Creek had the highest concentration (0.049 mg/L) in fall (Figure 41). Daily loads were low in all Creeks, except Wolf Creek (Figure 42) which had the largest load in all seasons, due to the combination of higher flow and concentrations.

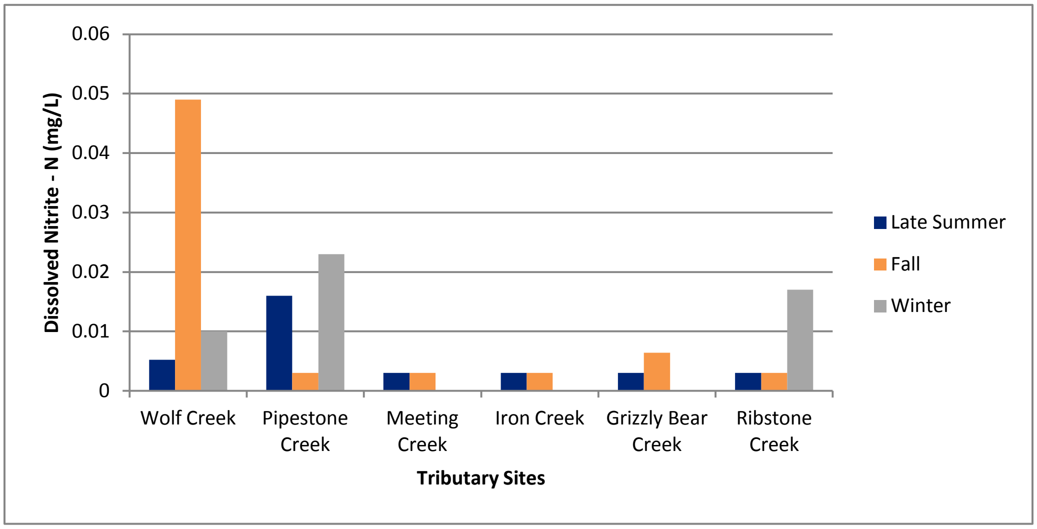


Figure 41 Tributary Dissolved Nitrite (N) Concentrations in 2013.

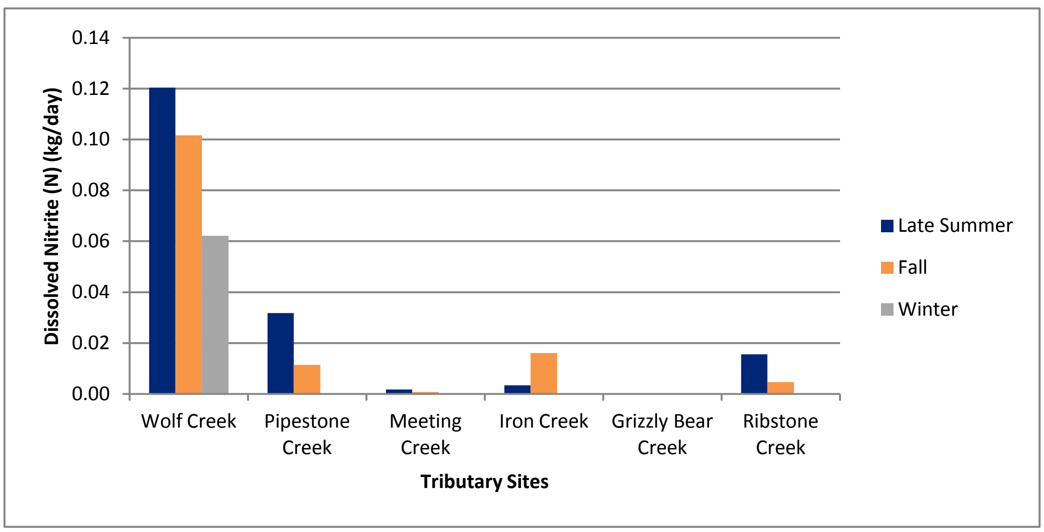


Figure 42 Tributary Dissolved Nitrite (N) Daily Loads in 2013.

5.3.4.3 Lagoon Discharges

Effluent from the Stettler lagoon had the highest dissolved nitrite concentrations (0.18 mg/L) and effluent from Wetaskiwin lagoon had the lowest dissolved nitrite concentrations (0.027 mg/L) (Figure 43). Nitrite loads ranged from 0.1 to 1.14 kg/day (Figure 44).

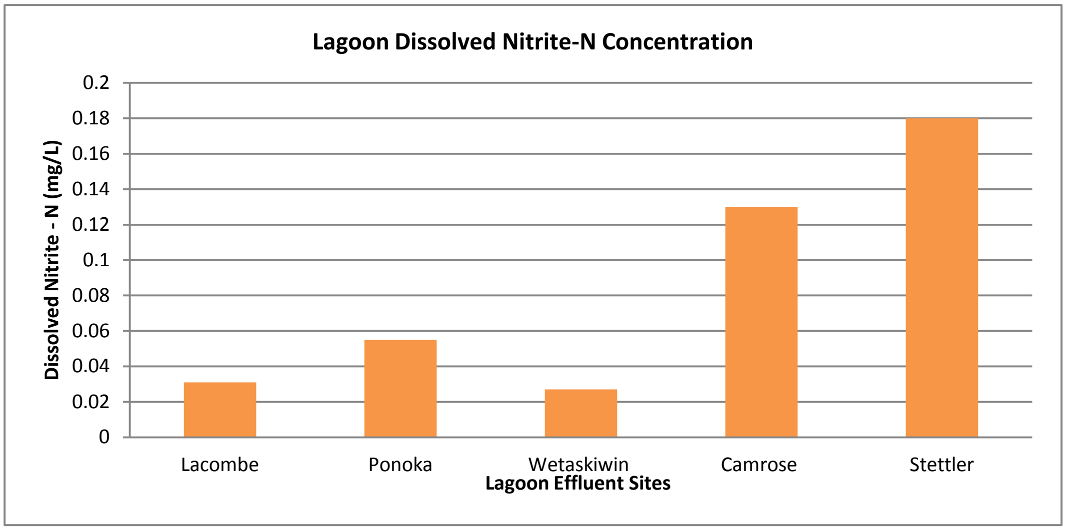


Figure 43 Dissolved Nitrite (N) Effluent Concentrations in October 2013.

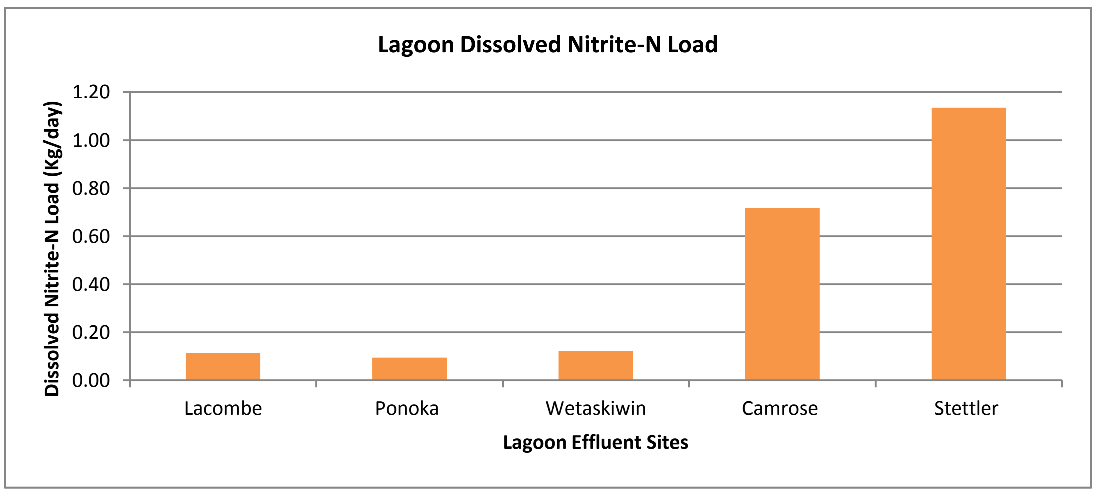


Figure 44 Daily Dissolved Nitrite (N) Effluent Loads.

5.3.5 Nitrate

5.3.5.1 Mainstem Patterns

During the August 2013 sampling survey, dissolved nitrate concentrations were below detection in Reaches 3 and 4. Reach 4 also had below detection concentrations in October. In Reach 2 the sample from upstream of Pipestone Creek exceeded the 90th percentile WQO. During the fall 2013 survey, samples from upstream of Ponoka and all sites located in Reach 2 exceeded the 90th percentile WQOs.

Nitrate formed the majority of the previously discusses parameter nitrate and nitrite – n, and therefore spatial patterns of nitrate were quite similar to that of nitrate and nitrite – N. During all surveyed seasons in 2013 and in summer 2011, there was an increase in dissolved nitrate (N) concentrations in Reach 2. During summer and fall, the highest dissolved nitrate concentrations occurred upstream of Pipestone Creek, indicating a source in this reach. In winter 2013, the largest concentrations occurred upstream of Camrose, while in winter 2011, nitrate was not detected. Dissolved nitrate (N) concentrations increased in Reach 4 during the winter of both campaigns (Figure 45), suggesting the influence of nitrate-rich groundwater or decaying organic matter in this reach. The only tributary in reach 4 sampled in winter 2013 was Ribstone Creek, which showed lower nitrate concentrations (0.15 mg/L) than the Battle River (>0.2 mg/L). Also, risk to groundwater quality in this area is low (Figure 3), which would suggest a low probability of nitrate contamination from land use activities.

Fall concentrations were high at most sites, likely due to the larges influence of lagoon discharges during that time. An exception to that are Hwy 611 and Reach 4, where concentrations were highest in winter. The elevated nitrate concentrations upstream of Ponoka in fall 2013 are unusual as well, as there are no known point sources upstream of that site. This area has the highest amount of contributing area and therefore surface runoff combined with high-risk to water quality (Figure 2) therefore these impacts may stem from non-point-source impacts of agriculture.

Dissolved nitrate (N) concentrations were greater than dissolved nitrite concentrations during both campaigns. Therefore, nitrite plus nitrate (N) patterns reflect dissolved nitrate concentrations.

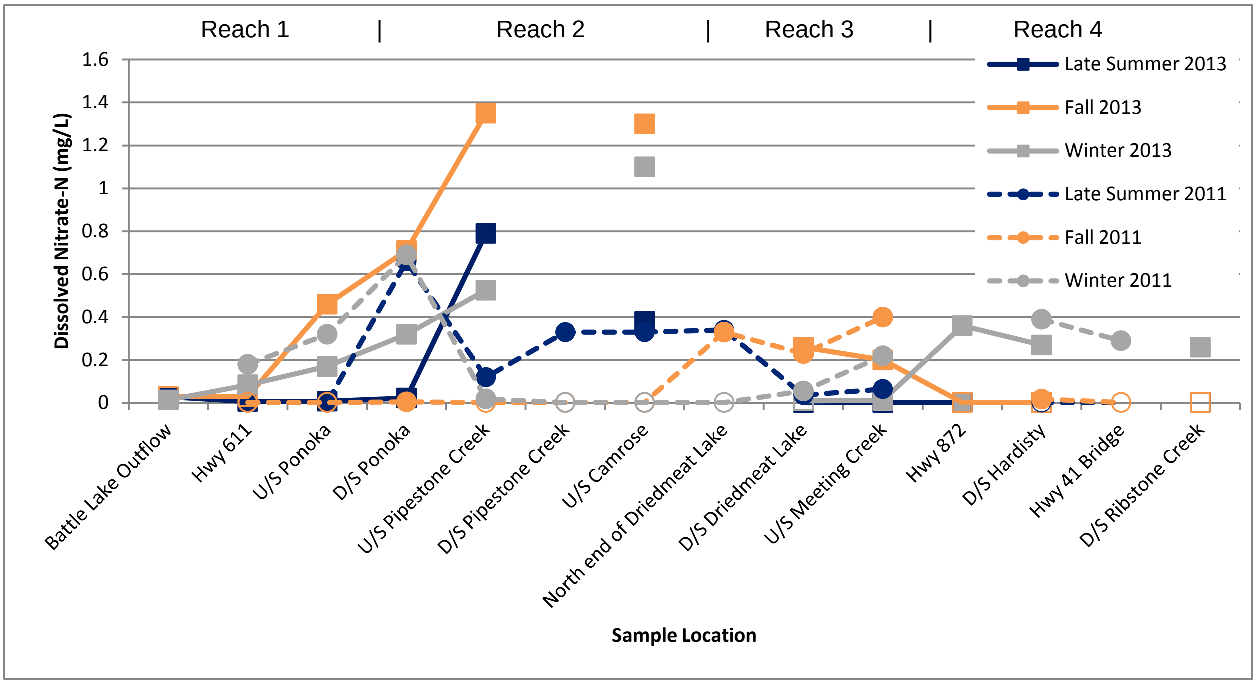


Figure 45. Nitrate Concentrations in the Battle River 2011 and 2013.

5.3.5.2 Tributaries

Iron Creek had non-detectable concentrations of dissolved nitrate (N). The highest dissolved nitrate (N) concentrations occurred in the tributaries during the winter survey, ranging from 0.16 mg/L in Ribstone Creek to 0.77 mg/L in Wolf Creek (Figure 46), which may indicate aquatic plant decay or nitrate-rich groundwater influence. Wolf Creek had the largest daily dissolved nitrate (N) loads during every season surveyed in 2013 (Figure 47), because it was the only tributary which had measureable concentrations and flows every season. It therefore likely contributed to the increase of nitrate in the Battle River downstream of Ponoka.

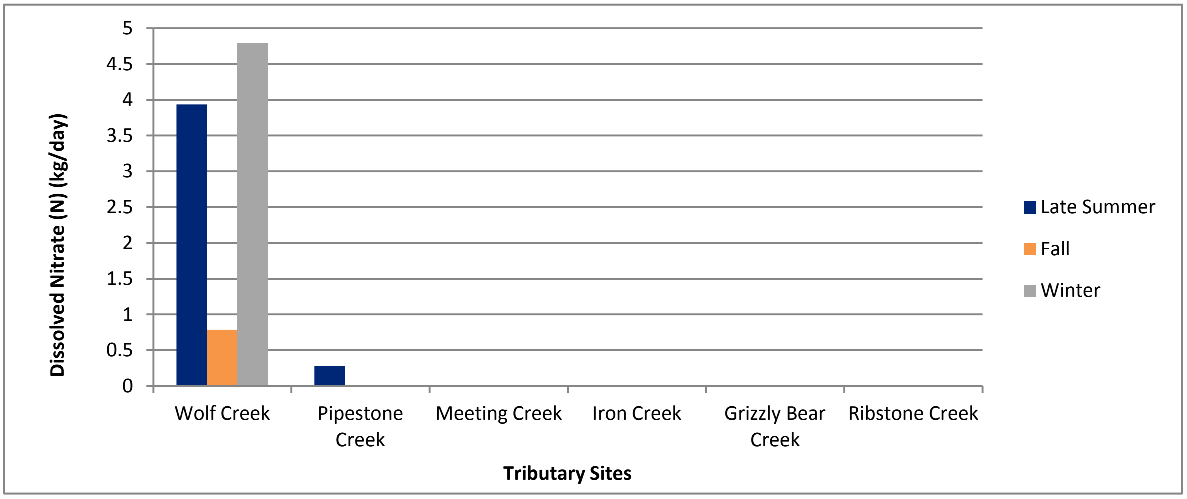


Figure 46. Dissolved Nitrate (N) Concentrations in Major Tributaries Along the Battle River.

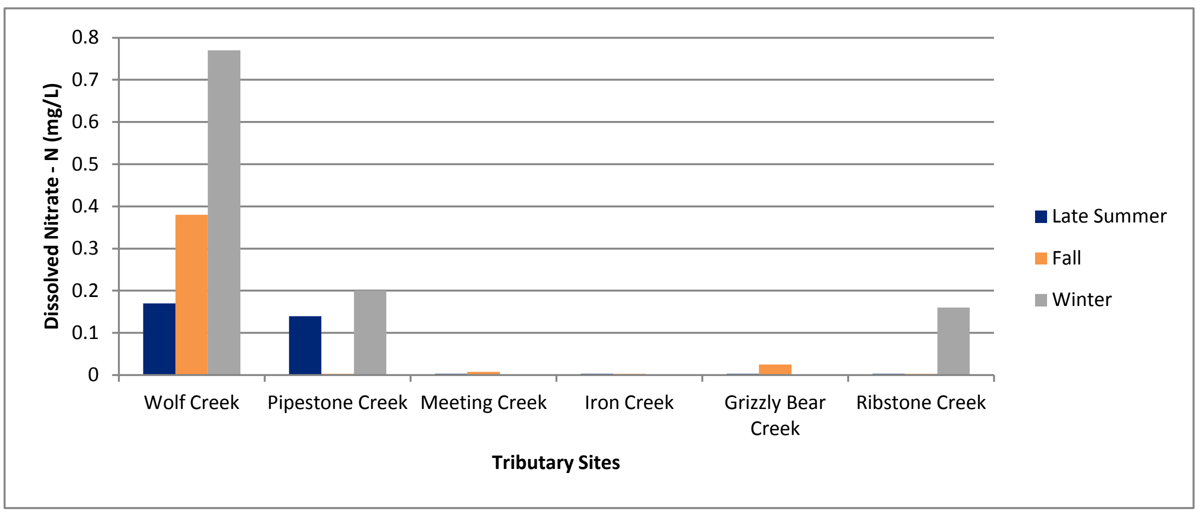


Figure 47. Daily Dissolved Nitrate (N) Loads for Tributaries Along the Battle River in 2013.

5.3.5.3 Lagoon Discharges

Dissolved nitrate (N) concentrations in lagoon effluents ranged from 0.42 at the Camrose lagoon to 3.0 at the Stettler lagoon (Figure 48).

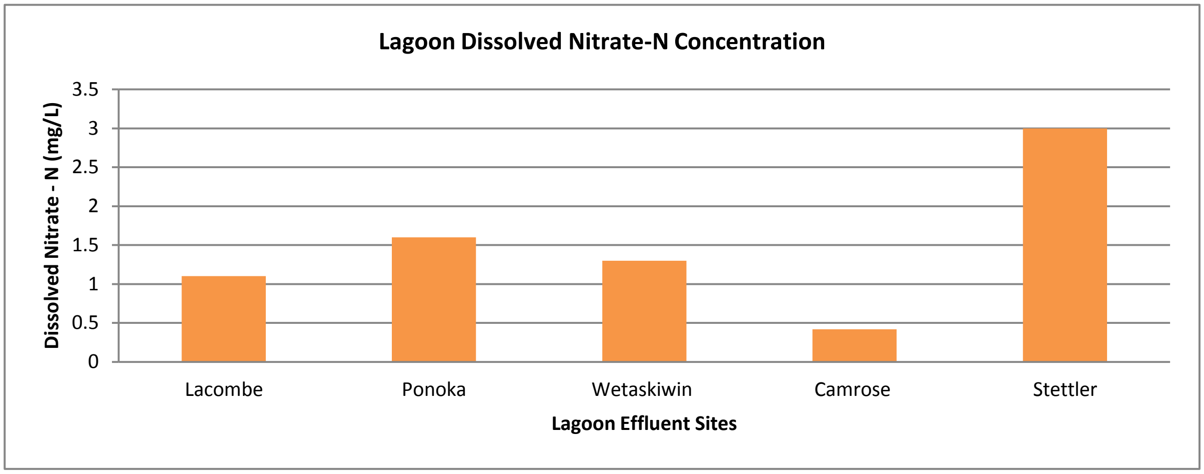


Figure 48 Dissolved Nitrate (N) Concentrations in Lagoons along the Battle River in 2013.

Dissolved nitrate (N) loads ranged from 3 kg/day in Ponoka sewage effluent to 19 kg/day in Stettler sewage effluent (Figure 49). While Ponoka effluent contained the second highest concentration of nitrate, the flow of the lagoon was the lowest (0.02 m^3/s), thus reducing the load. The Wetaskiwin lagoon contributed the largest measured load to reach 2, but no change in nitrate concentrations were found between the site upstream of Pipestone Creek (which carries Wetaskiwin effluent) and upstream of Camrose.

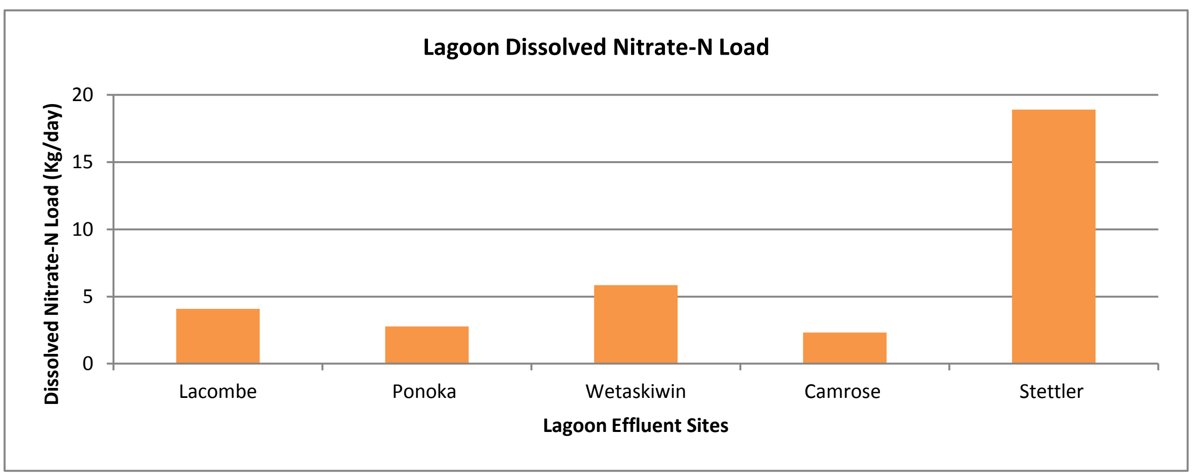


Figure 49 Dissolved Nitrate (N) Loads in Lagoon Effluent along the Battle River in 2013.

5.3.6 Ammonia

5.3.6.1 Mainstem Patterns

Total ammonia concentrations were low in the Battle River in 2013. Concentrations were below detection in August and October 2013 at two of the sites in reach 1, occasionally in reach 2 and reach 3 and all sites in reach 4. Ammonia concentrations below detection are expected for natural waters that are usually low in ammonia. The outflow of Battle Lake was the only site on the Battle River sampled that was above the 50th percentile WQO (0.28 mg/L) in August and October.

Total ammonia concentrations were higher in the winter, ranging from 0.11 mg/L at the outflow of Battle Lake to 1.7 mg/L upstream of Pipestone Creek.

In both years surveyed, total ammonia was greatest in the winter in Reach 2, with a consistent increasing pattern from the headwaters to reach 2 and declines only starting in reach 3 (2011) and reach 4 (2013). Decomposition of organic matter, including plants and sediments, is probably the major source of ammonia in winter.

In 2013, both summer and fall had spikes in total ammonia concentrations at the outflow of Battle Lake (Figure 50), which is likely related to ammonia release from sediments under anoxic conditions (Wetzel 2001). This hypothesis is supported by elevated TDP concentrations in fall 2013 as well. Interestingly, these concentrations drop significantly towards the HWY 611 site, indicating that Battle Lake is not a major source of these substances to the Battle River.

During the fall of 2011 and 2013, there was a spike in total ammonia concentrations at the north and downstream end of Driedmeat Lake, likely due to the relatively large ammonia load form the Camrose lagoon discharge (Figure 54). The values measured here exceeded the Provincial surface water quality guideline for chronic effects of 0.63 mg/L total ammonia-N at the measured pH (8.2) and temperature (8°C) in both years.

The summer 2011 peak downstream of Ponoka can be explained by the Ponoka lagoon discharge, which occurred from August 17 to September 8 2011.

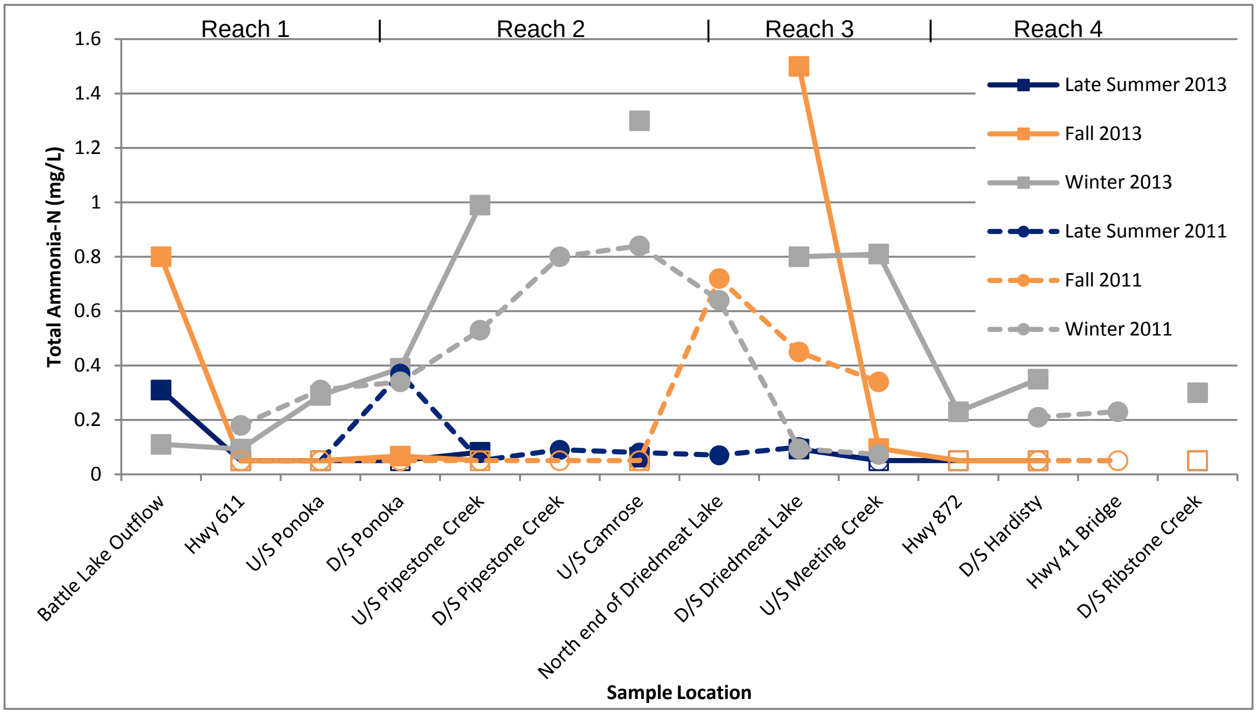


Figure 50 Total Ammonia Concentrations along the Battle River in 2011 and 2013.

5.3.6.2 Tributaries

In summer, total ammonia concentrations were low, ranging from below detection to 0.066 mg/L. During the fall of 2013, only Meeting Creek had a measureable concentration of total ammonia (0.069 mg/L). Total ammonia concentrations were highest in the winter, ranging from 0.28 mg/L in Wolf Creek to 1.4 mg/L at Pipestone Creek (Figure 51), indicating decomposition of organic matter. Wolf Creek again had the largest daily loads of all tributaries, with the greatest occurring in the winter of 2013, with a total ammonia load of 1.7 kg/day (Figure 52).

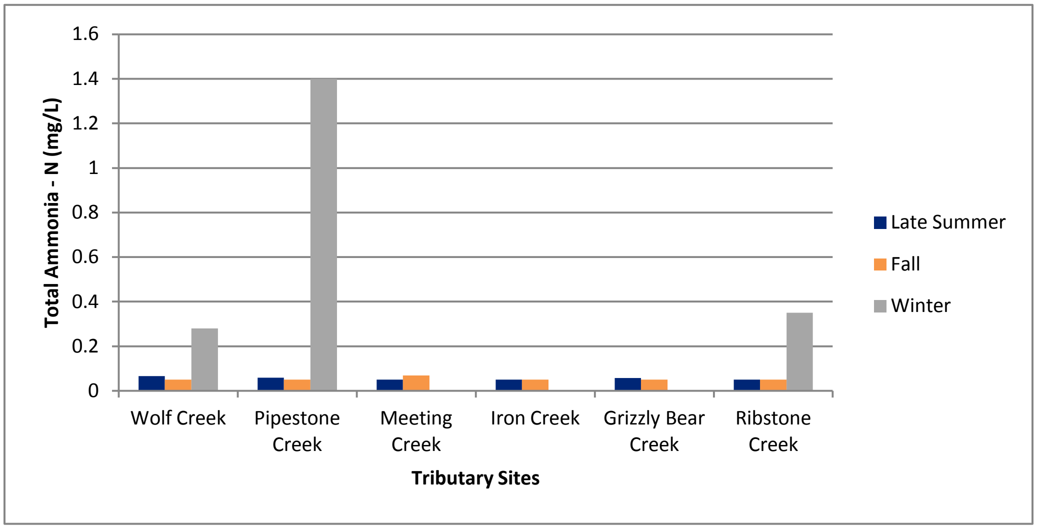


Figure 51 Concentrations of Total Ammonia in Battle River Tributaries in 2013.

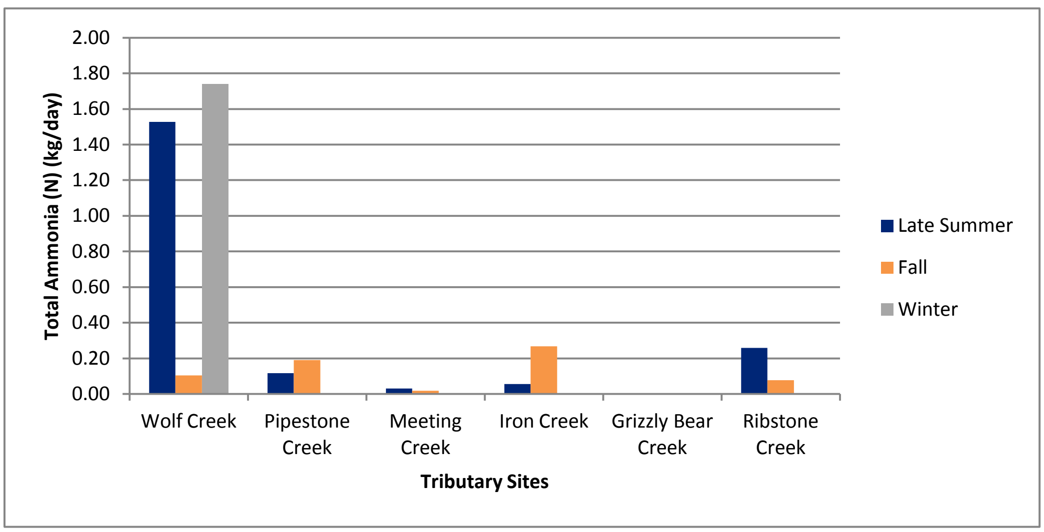


Figure 52 Tributary Daily Loads of Total Ammonia along the Battle River in 2013.

5.3.6.3 Lagoon Discharges

Effluent total ammonia-N concentrations ranged from 0.15 mg/L to 15 mg/L (Figure 53). Daily ammonia loads varied between the various lagoons, ranging from 0.26 kg/day at Ponoka to 22.71 kg/day at 60.8 kg/day at the Camrose lagoon (Figure 54). Although Lacombe effluent had higher concentrations of total ammonia-N (15 mg/L), the higher flow at Camrose (0.0064 m^3/s) resulted in a slightly larger load.

Ammonia from the Lacombe lagoon discharge was probably assimilated by plants and algae in Wolf Creek, given the low ammonia concentrations at the creek mouth. The Camrose ammonia load, on the other hand, coincided with a large increase in ammonia at the site downstream of Driedmeat Lake, possibly indicating an influence on Battle River from that discharge. This conclusion is confirmed by data collected by the City of Camrose in the Battle River downstream of the mouth of Camrose Creek that conveys Camrose lagoon discharge. Total ammonia levels of 3.5 mg/L and 2.7 mg/L were measured on October 23 and 30th, 2013, respectively, and further increased to 6 and 8 mg/L in November (City of Camrose, 2013). These values exceeded the Provincial surface water quality guideline for chronic effects at the measured pH (8.2), despite the relatively low temperatures. The City of Camrose is currently upgrading their wastewater treatment facilities in preparation for continuous open-water discharge, with anticipated improved effluent quality (5 mg/L in summer, 10 mg/L in winter), which will help reduce ammonia levels in the Battle River.

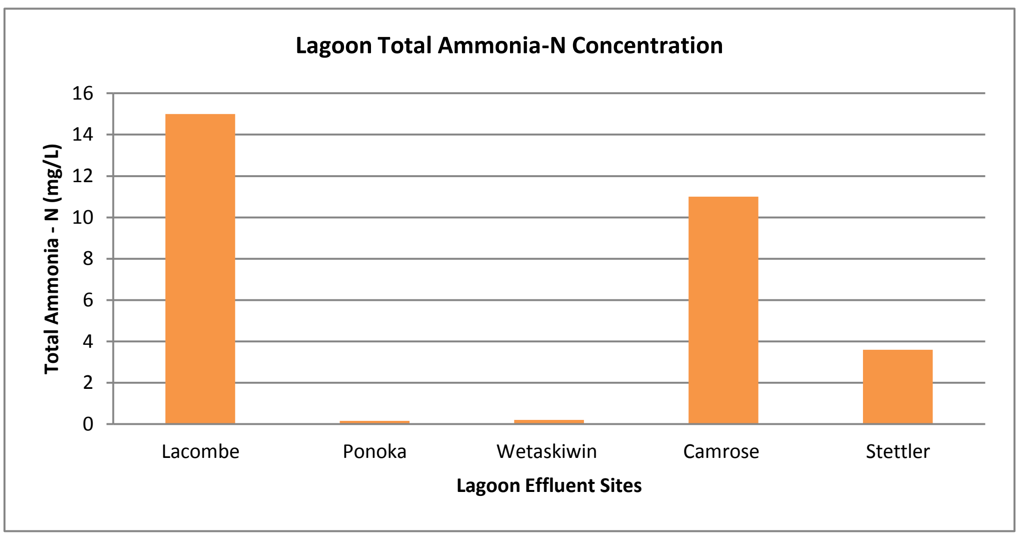


Figure 53. Total Ammonia Concentrations in Lagoon Effluent.

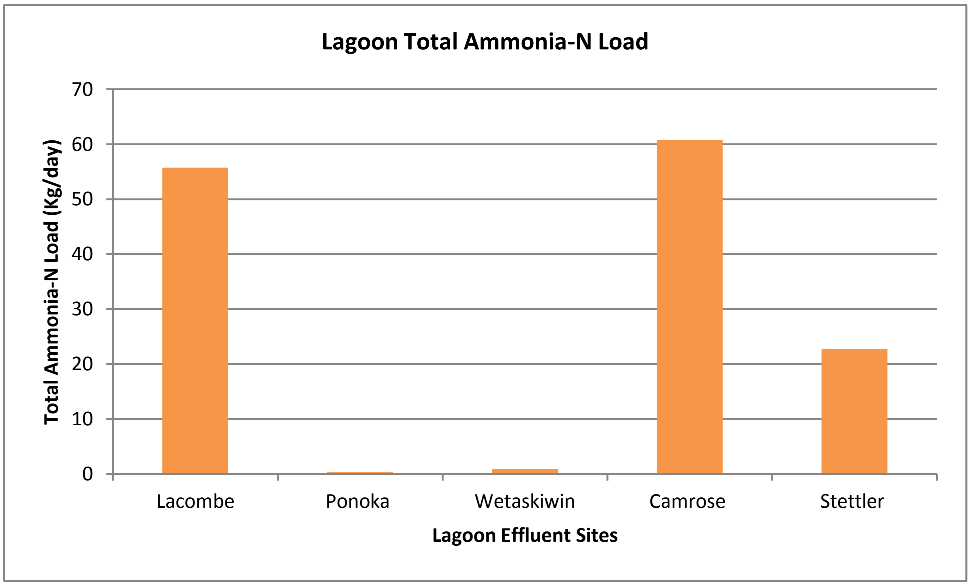


Figure 54. Daily Total Ammonia Loads of Lagoons Along the Battle River in 2013.

5.3.7 Total Kjeldahl Nitrogen

5.3.7.1 Mainstem Patterns

During all 2011 and 2013 campaigns, TKN concentrations increased in Reach 2 followed by a gradual decrease in reaches 3 and 4 (Figure 55). Concentrations found at the downstream end of reach 4 were similar to those found in the headwaters in most seasons, indicating that the river has the capacity to assimilate the increased nitrogen loads received in reach 2. Some of that nitrogen may be incorporated into plant biomass and ultimately into sediment, which in turn will be washed downstream during spring high flows. A spring synoptic survey would be necessary to explore this hypothesis.

In the fall of 2011 and 2013, the greatest TKN concentrations were observed at the north end or downstream Driedmeat Lake, likely due to the large ammonia contributions from the Camrose lagoon during fall discharge (Figure 54).

Another peak occurred in summer 2013 at the outflow of Battle Lake, again related to large ammonia concentrations at the ouflow, but was not translated into large concentrations at the next Battle River headwater site (HWY 611), similar to ammonia and TDP. The HWY 611 site is downstream of the tributary that drains Pigeon Lake, indicating that water draining from that direction may have different water quality than Battle Lake water.

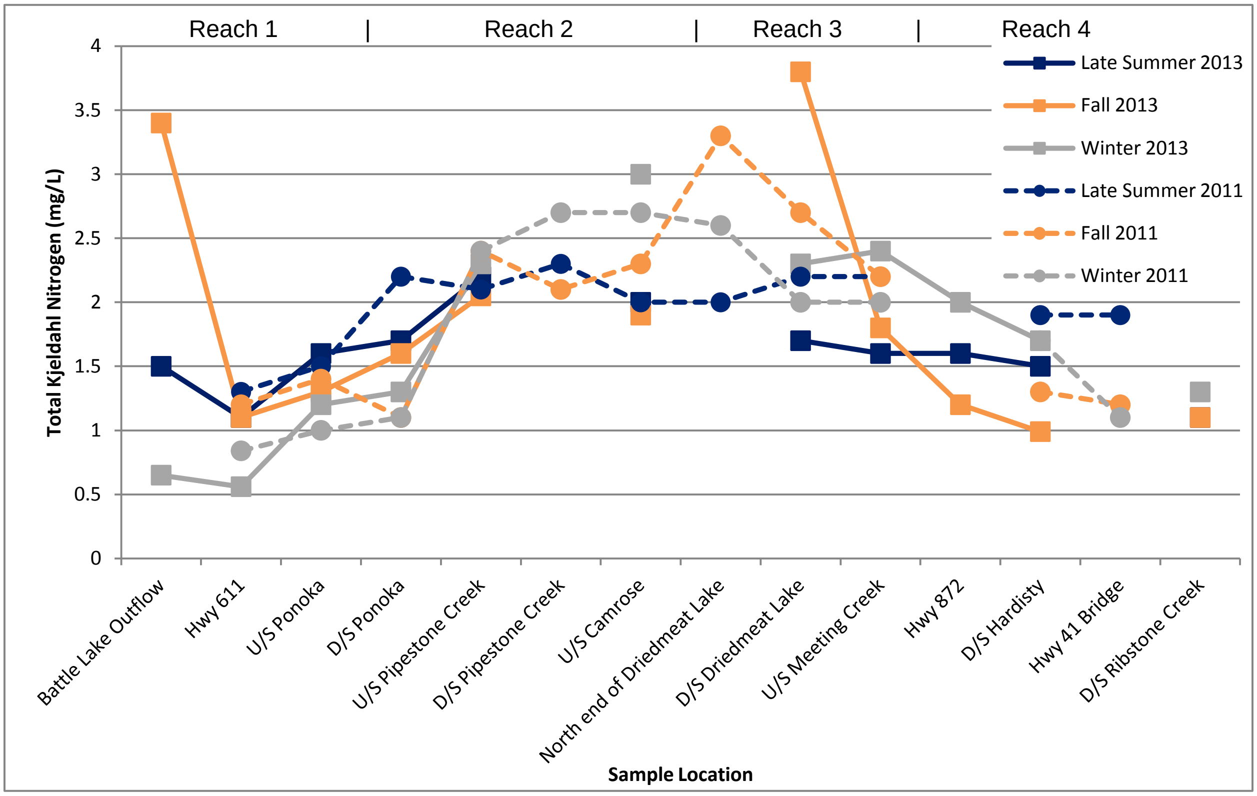


Figure 55 Total Kjeldahl Nitrogen Concentrations along the Battle River in 2011 and 2013.

5.3.7.2 Tributaries

In the summer and fall of 2013, Iron Creek had the highest TKN concentrations (3.5 and 2.2 mg/l respectively (Figure 55). The second-highest TKN concentrations were observed in Grizzly Bear Creek in summer and Wolf Creek in fall. In winter 2013, Pipestone Creek had the highest TKN concentration (2.3 mg/L). The lowest TKN concentrations for the summer, fall and winter of 2013 were in Pipestone Creek (0.98 mg/L), Meeting Creek (0.99 mg/L) and Wolf Creek (0.89 mg/L) respectively (Figure 57Figure 56).

The high summer TKN concentrations in the reach 4 tributaries Iron Creek, Grizzly Bear Creek and Ribstone Creek were closely related to concurrently high total organic carbon concentrations (Figure 117).

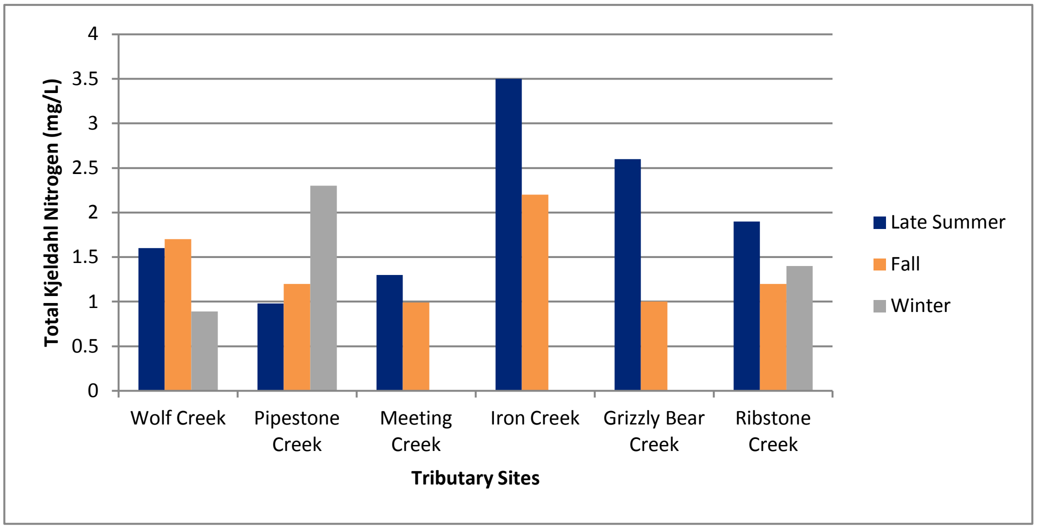


Figure 56. Battle River Tributary TKN Concentrations in 2013.

In the summer and winter of the 2013 campaign, Wolf Creek had the largest daily loads with 37, and 5.5 kg/day respectively. In the fall, Iron Creek had the largest TKN load of 11.8 kg/day (Figure 57).

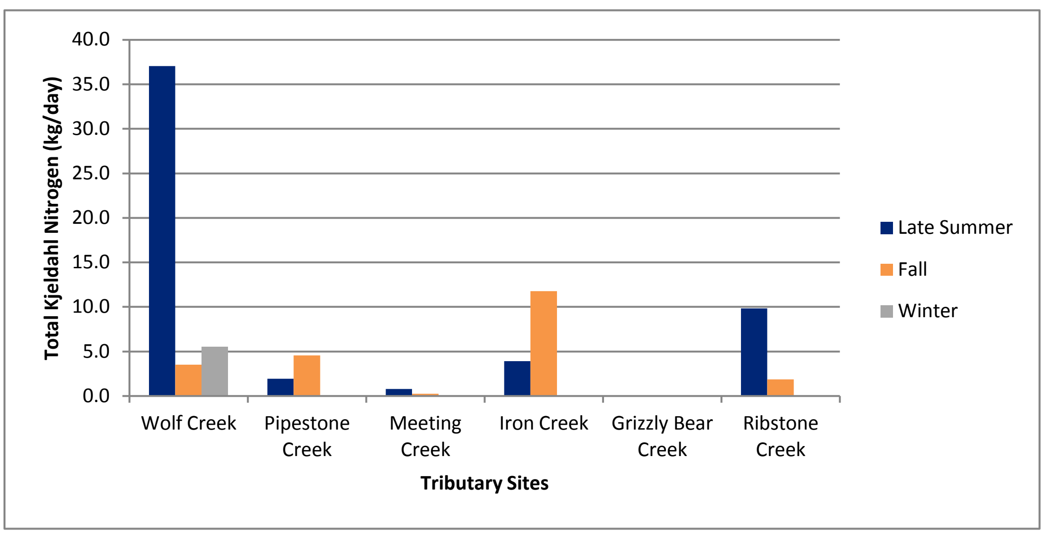


Figure 57 Battle River Tributary TKN Loads in 2013.

5.3.7.3 Lagoon Discharges

Total Kjeldahl nitrogen concentrations in effluent from lagoons along the Battle River ranged from 1.8 mg/L in Ponoka effluent to 23 mg/L in Lacombe effluent (Figure 58). Concentrations had the greatest influence on loads. The high concentration of TKN in the Lamcombe effluent (23 mg/L) resulted in the largest load (85 kg/day) (Figure 59).

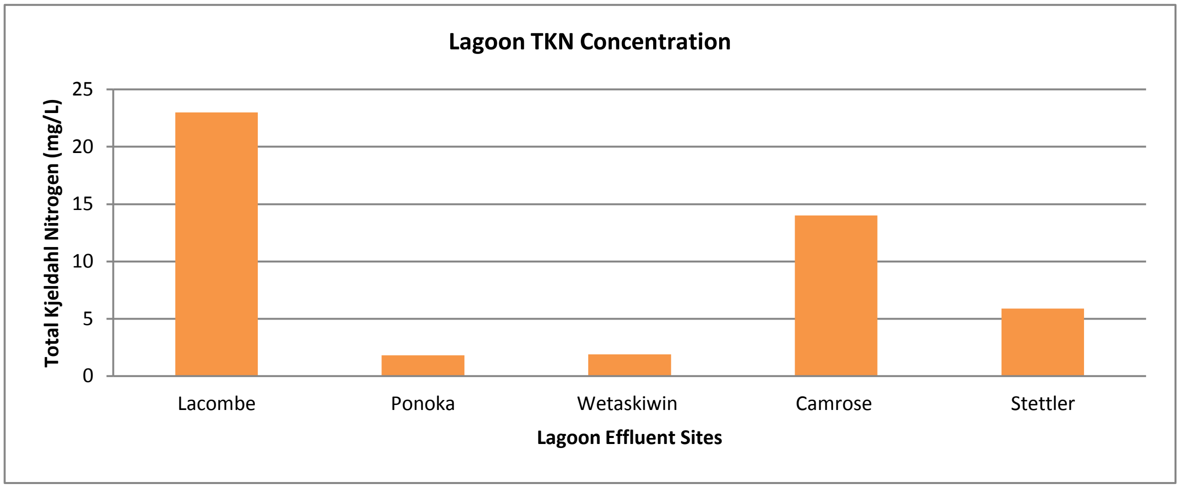


Figure 58 Concentration of TKN in Lagoon Effluents along the Battle River in October 2013.

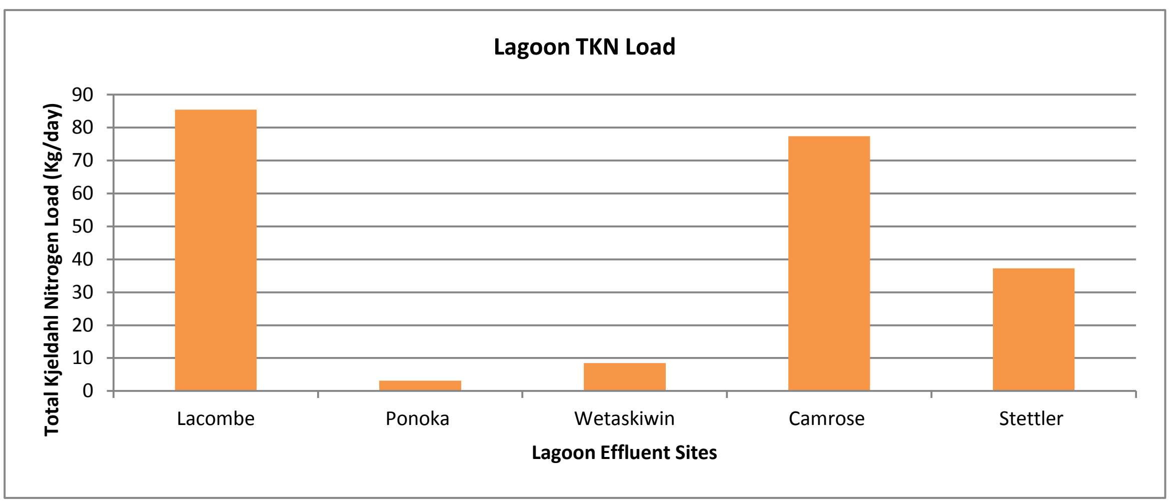


Figure 59 Lagoon TKN Loads in October 2013.

5.3.8 Total Nitrogen

5.3.8.1 Mainstem Patterns

Total nitrogen was calculated as the sum of TKN, NO_2 and NO_3.

Concentrations upstream of Ponoka in Reach 1 were above the 90th percentile WQO in August 2013. The outflow of Battle Lake and the concentrations upstream of Ponoka in Reach 1 exceeded the 90th percentile WQO for this reach. The concentrations measured in Reach 4 were also above the 90th percentile WQO.

In both recent synoptic surveys (2011 and 2013), TN increased across Reaches 2 and 3, and decreased in Reach 4 in all seasons (Figure 60). The extra site sampled in Reach 1 in 2013 (the outflow of Battle Creek) had high TN concentrations in late summer and fall; this reflects high TKN concentrations. While upstream concentrations were highest in the open-water season, mid-reach and downstream concentrations were highest in winter. This indicates that open-water nitrogen sources, in particular those in reach 2, are effectively assimilated during the open-water season, but returned, at least partially, into the river during winter. Another reason for larger downstream concentrations in winter can be nitrogen-rich groundwater, which needs to be confirmed using groundwater quality data.

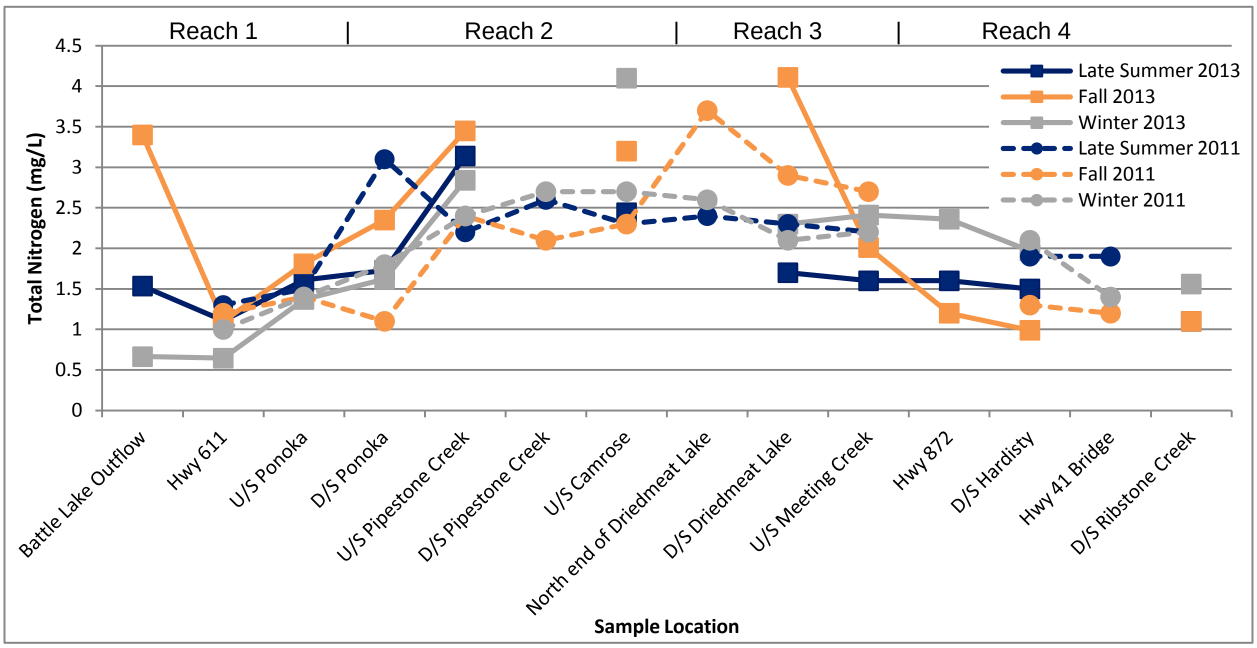


Figure 60 Total Nitrogen Concentrations along the Battle River in 2011 and 2013.

5.3.8.2 Tributaries

In the tributaries, TN concentrations ranged from 1.13 to 3.5 mg/L in summer, from 1.0 to 22.2 mg/L in fall and from 1.58 to 2.53 mg/L in winter (Figure 61).

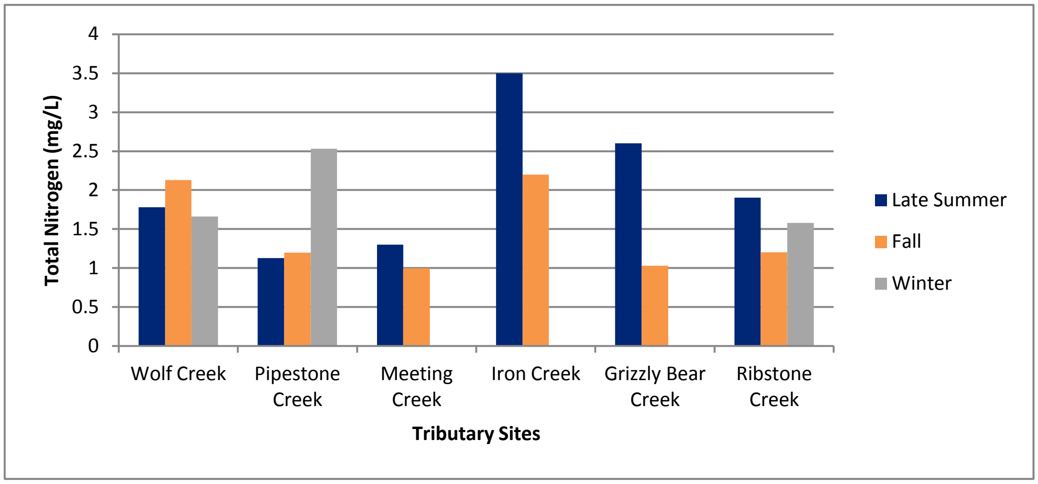


Figure 61 Total Nitrogen Concentrations in Major Tributaries along the Battle River in October 2013.

In the summer and winter, Wolf Creek had the largest TN loads (41.2 and 10.3 kg/day, respectively) (Figure 62). The high loads in Wolf Creek were due to high flow and not high TN concentrations. In the fall, Iron Creek had the highest TN concentrations (2.2 mg/L) and largest flow (0.062 m^3/s), resulting in the largest load.

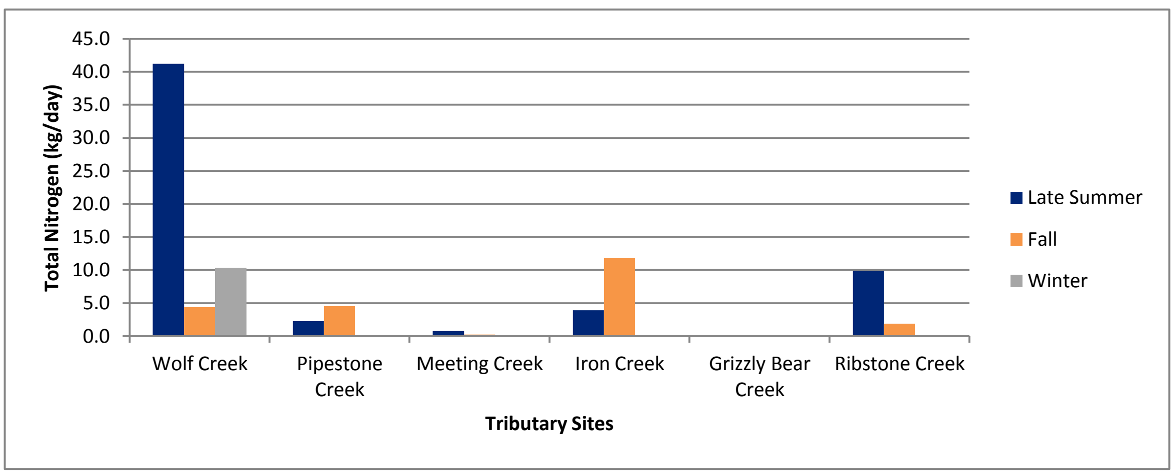


Figure 62 Total Nitrogen Loads in Major Tributaries along the Battle River in October 2013.

5.3.8.3 Lagoon Discharges

Total Nitrogen concentrations in lagoon effluents ranged from 3.2 (Ponoka) to 24.1 mg/L (Lacombe) (Figure 63). Lagoon loads, influenced primarily by concentration, ranged from 5 kg/day at Ponoka to 90 kg/day at Lacombe (Figure 64).

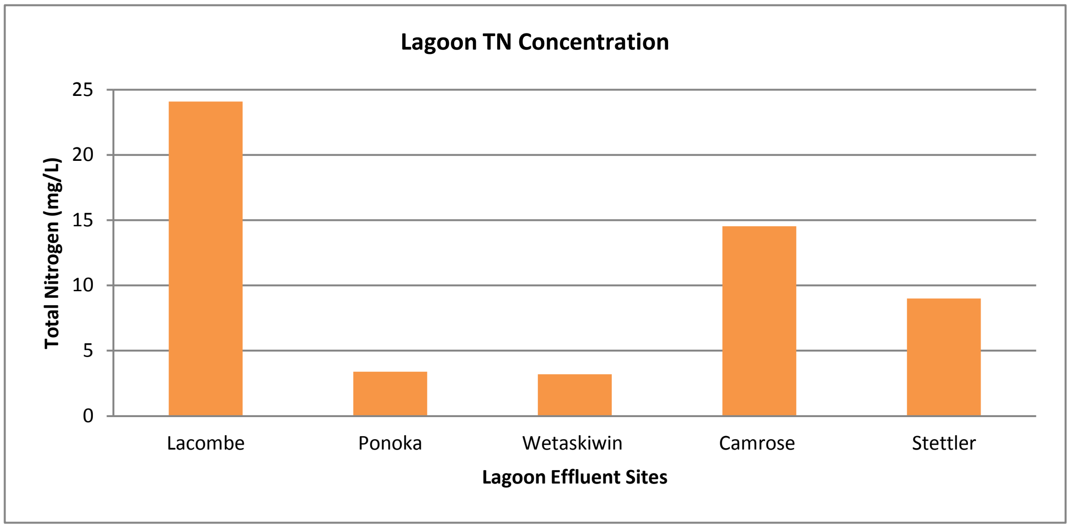


Figure 63 Total Nitrogen Concentrations in Lagoon Effluent of along the Battle River in October 2013.

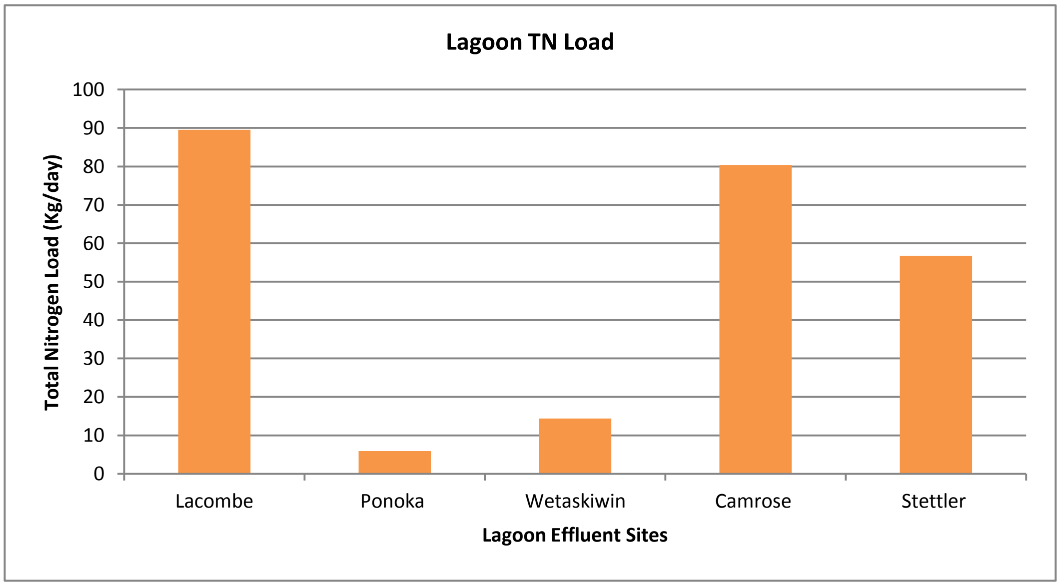
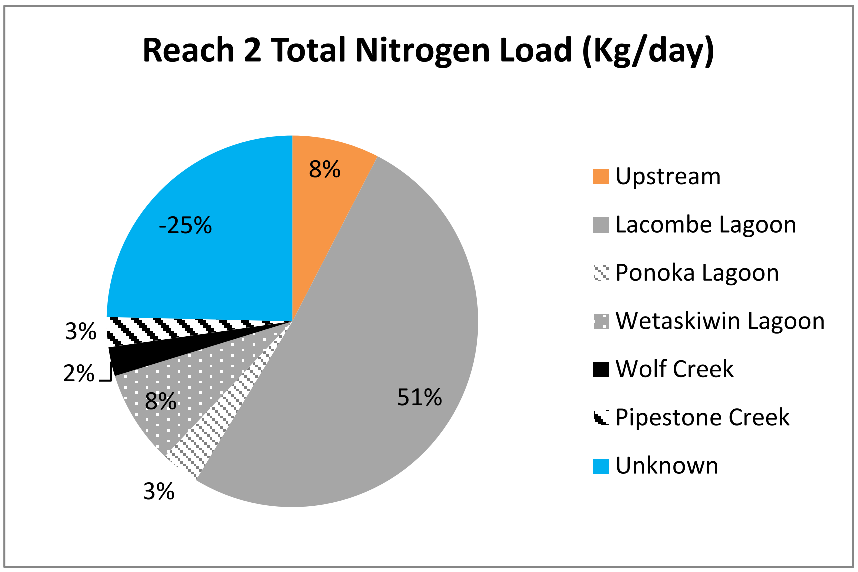
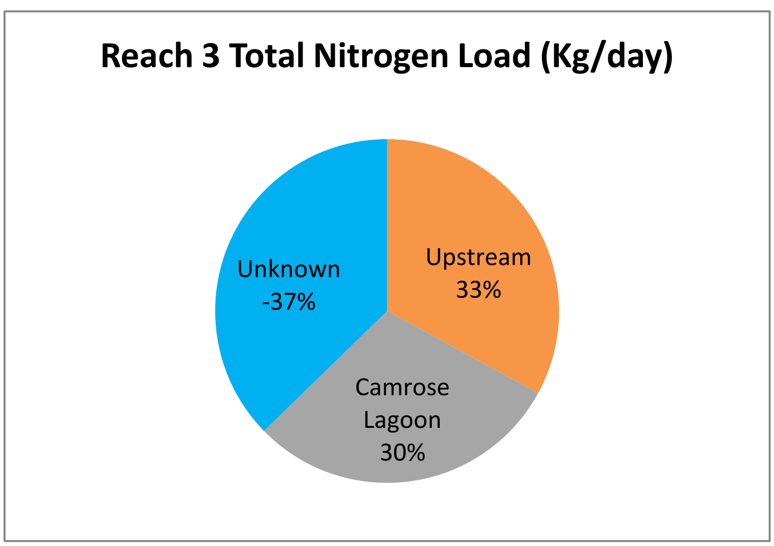


Figure 64 Total Nitrogen Loads for Lagoon Effluent along the Battle River in October 2013.

5.3.8.4 Total Nitrogen Loads by Reach

In Reach 2, the majority of the TN load originated from the three lagoons while only a small portion was from upstream loads (8%) and tributaries (5%). Reach 2 and 3 had nitrogen sinks as 25 and 37% of the nitrogen load from upstream, lagoons and tributaries was not accounted for at the most downstream station in each of these reaches. In reach 4, more than half of the nitrogen is of unknown source (Figure 65), after accounting for the measured tributaries and the likely over-estimated Stettler load. The cumulative effect of other tributaries and possibly other fall lagoon discharges in this reach is the only explanation for this result.





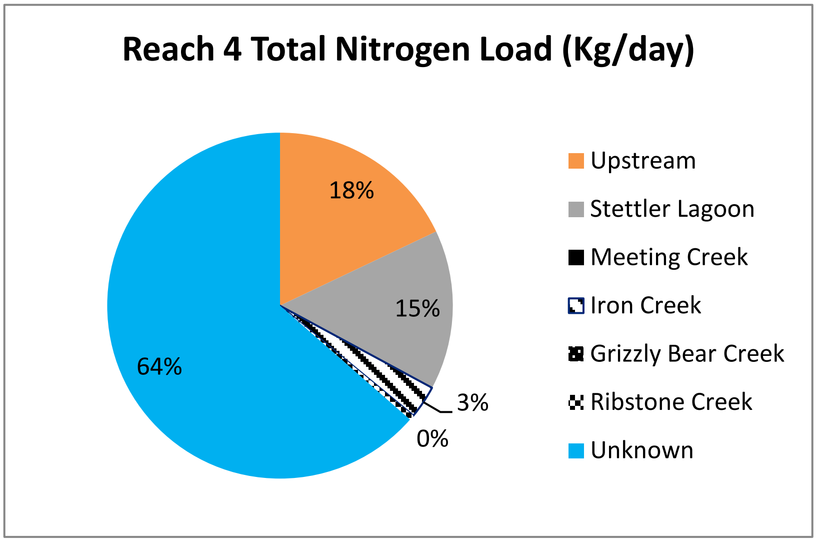


Figure 65. TN Loads for Reaches 2, 3 and 4 in Fall 2013.

5.3.9 Summary of Nutrient Parameters

Batter River and its tributaries were generally rich in nutrients, as expected from prairie-fed water bodies. Total and dissolved phosphorus as well as nitrate, nitrite and total nitrogen increased in reach 1, reached highest levels in reach 2 and declined throughout reaches 3 and 4 during the open water season. During winter, nitrates were elevated in reaches 2 and 4, consistent with organic matter breakdown in reach 2 and possibly nitrate-rich groundwater influence in reach 4. Wolf Creek was overall the largest source of nutrients, both in terms of concentrations and loads, although Iron Creek and Grizzly Bear Creek also had high phosphorus concentrations.

Ammonia was mostly non-detected during the open-water season, as expected from the rapid biological uptake during the warm seasons. An exception to that were sites immediately downstream of lagoon discharges and lake outflows; where elevated ammonia levels were observed. The levels immediately downstream of the Camrose lagoon discharge were above chronic and acute guidelines for the protection of aquatic life.

5.4 Major Ions

5.4.1 Magnesium

5.4.1.1 Mainstem Patterns

In the mainstem of the Battle River, Mg concentrations gradually increased from Reach 1 to Reach 2. In the summer and fall, concentrations peaked downstream of Ponoka, then decreased at the site upstream of Pipestone Creek and remained either stable (summer) or increased in downstream direction. During all seasons, Mg concentrations rose in Reach 4. During the fall of 2013, Mg concentrations were the greatest downstream of Ribstone Creek when compared to any other site on the river. This gradual, undulating pattern was also observed in 2011. In 2011, however, winter concentrations were greatest at all sites except at Hwy 611 (Figure 66).

In winter, concentrations continued to increase in reach 2 before they decreased downstream of Driedmeat Lake. There may be increased influence of groundwater in this reach in winter, which would be diluted by older water, possibly stemming from the open water period, downstream of Driedmeat Lake. Further increases in reach 4 in winter indicate additional groundwater sources.

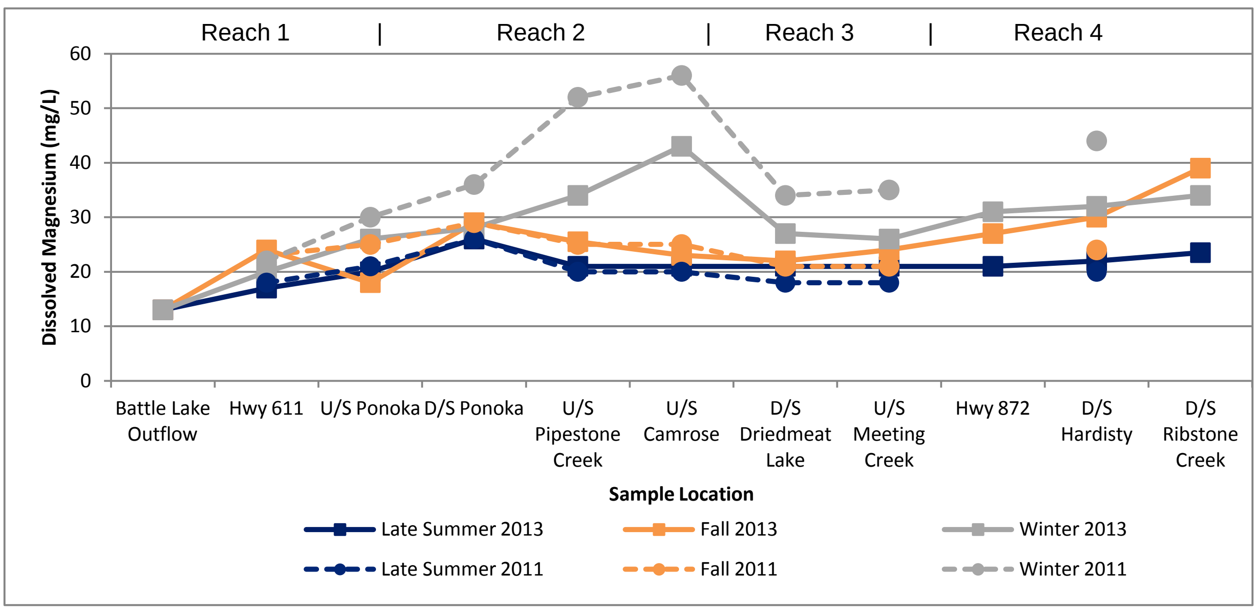


Figure 66 Magnesium Concentrations along the Battle River 2011 and 2013.

5.4.1.2 Tributaries

Dissolved magnesium concentrations in tributaries ranged from 15 to 60 mg/L in the summer of 2013, with higher concentrations found in the reach 4 tributaries, indicating their relative enrichment from groundwater sources. In the fall, concentrations were similar, ranging from 19 to 61 mg/L. In Pipestone and Ribstone Creeks, Mg concentrations were slightly higher in the winter (31 and 36 mg/L respectively) (Figure 67).

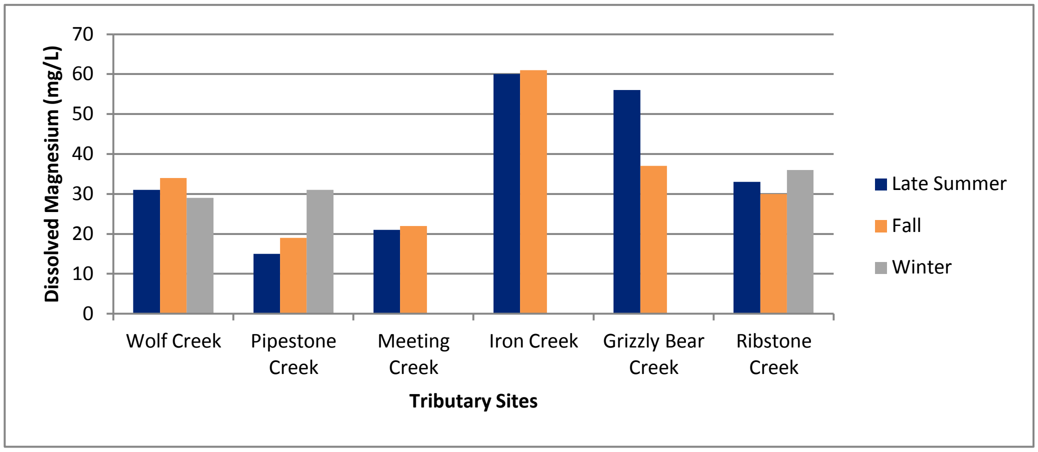


Figure 67 Concentrations of Mg in Major Tributaries along the Battle River.

Summer Mg loads ranged from 0 kg/day at Grizzly Bear Creek to 718 kg/day at Wolf Creek (Figure 68). In fall, the largest load was calculated for Iron Creek. This was due to both a high Mg concentration (61 mg/L) and a relatively high flow.

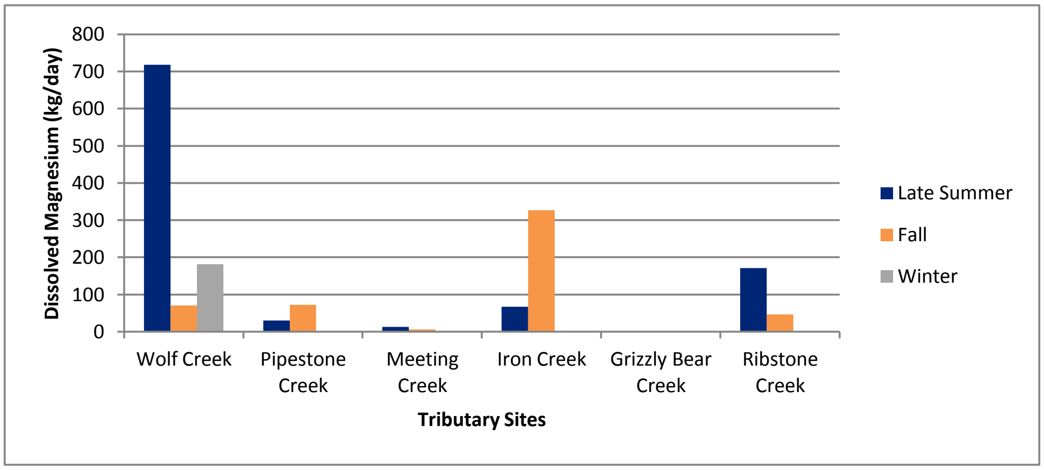


Figure 68 Daily Magnesium Loads in Major Tributaries along the Battle River in 2013.

5.4.1.3 Lagoon Discharges

Magnesium concentrations were fairly consistent across the five lagoons, ranging from 41 to 44 mg/L, with the exception of Ponoka sewage effluent, which had a magnesium concentration of 28 mg/L (Figure 69).

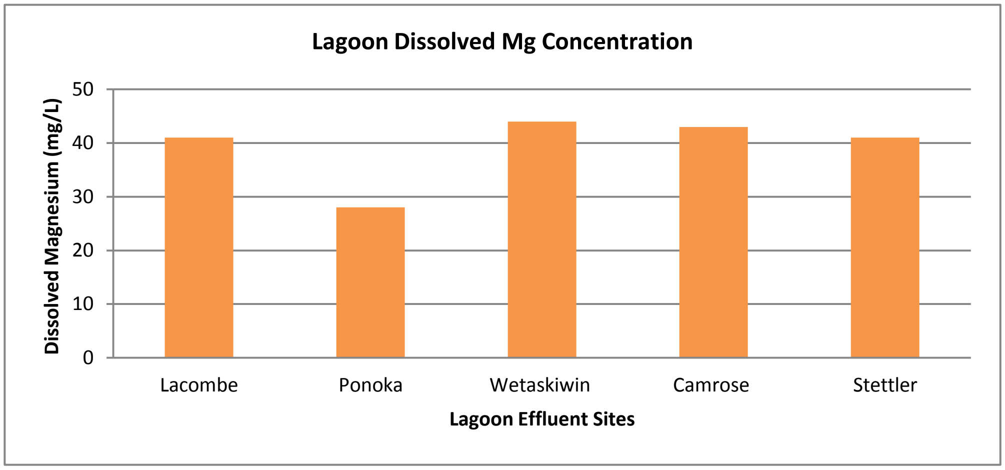


Figure 69 Magnesium Concentrations in Lagoon Effluents along the Battle River.

Due to a small range in Mg concentration, flow had the greatest influence on lagoon Mg loads. Loads ranged from 48 kg/day at Ponoka to 259 kg/day at the Stettler lagoon (Figure 70).

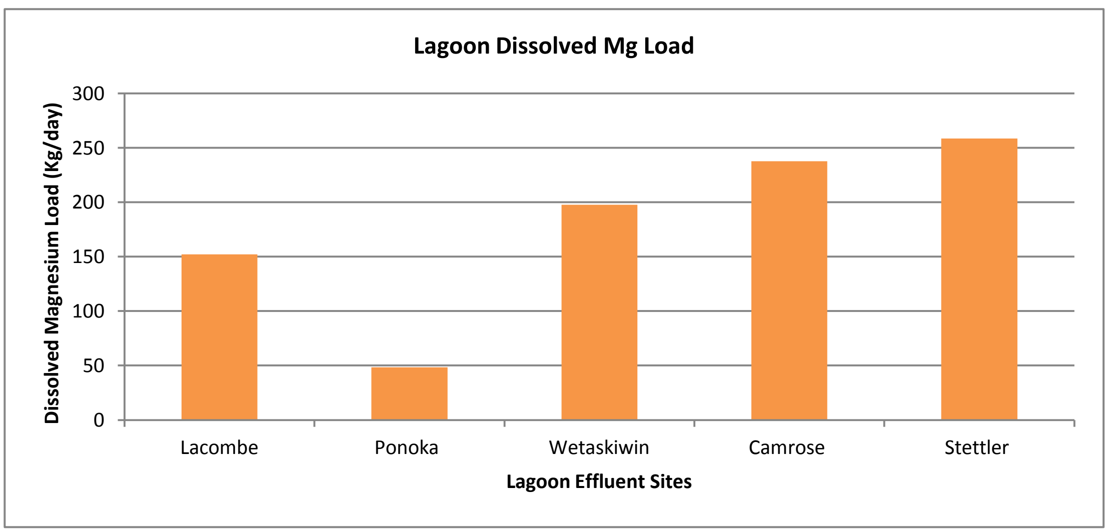
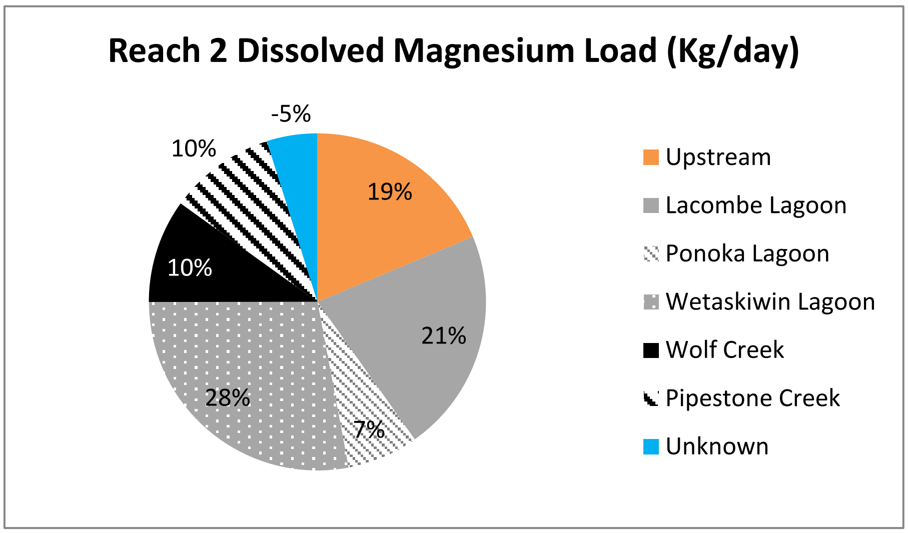
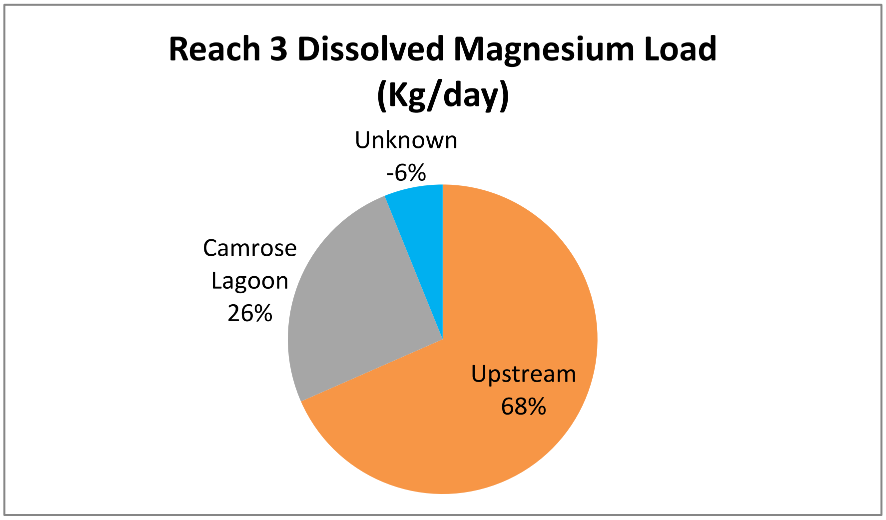


Figure 70 Magnesium Loads from Lagoons along the Battle River.

5.4.1.4 Magnesium Loads by Reach

Over half of the Mg load in Reach 2 originated from lagoon effluent; upstream loads (19%) and Mg loads from tributaries (20%) contributed almost equal amounts to Reach 2's total load. In Reach 3, the majority of Mg originated upstream, with Camrose lagoon contributing only 26% of the reach total load. In Reach 4, the majority of the Mg load came from unknown sources (Figure 71). The large increase in Mg load came from the high flows downstream of Ribstone Creek. This was most likely due to ground water infiltration. Anderson (1999) noted that ion concentrations increased downstream of the Battle River and suggested it was due to changes in groundwater quality. The magnesium losses in reach 2 and 3 are either due to the loss of water volume within these reaches in fall 2013 or due to the uncertainty of some of the lagoon flows.





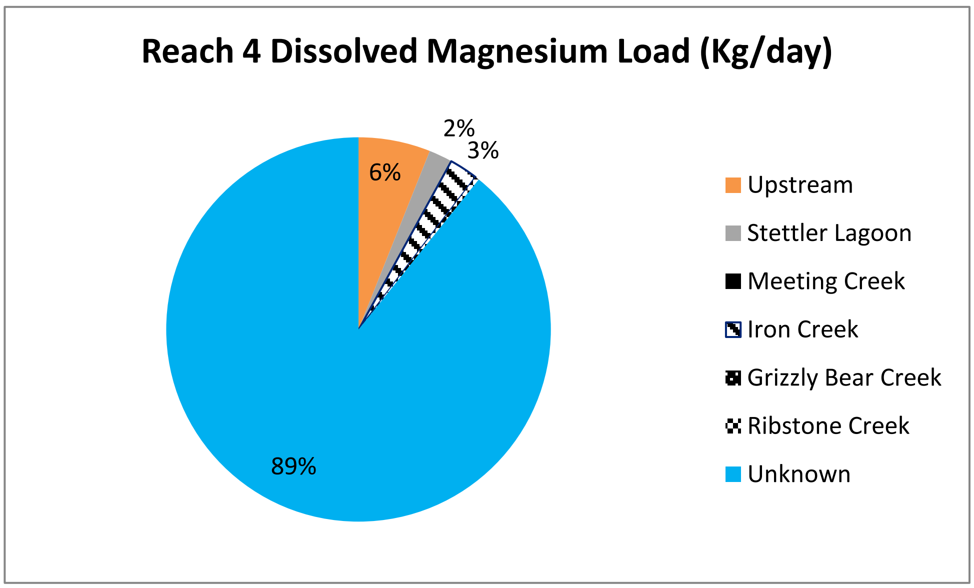


Figure 71. Dissolved Mg Loads for Reaches 2, 3 and 4

5.4.2 Calcium

5.4.2.1 Mainstem Patterns

Calcium concentrations downstream of Ponoka were above the 90th percentile WQO for Reach 2 in August 2013. Concentrations in Reach 2 downstream of Ponoka and in Reach 4 downstream of Hardisty exceeded the ice-cover 90th WQO for their respective reaches.

Calcium displayed a very similar longitudinal pattern as magnesium along the Battle River in the summer and fall, likely due to similar sources of both elements. Both in 2011 and 2013, Ca concentrations increased gradually in Reach 1, reaching an apex downstream of Ponoka in Reach 2. Upstream of Pipestone Creek, Ca concentrations decreased, possibly indicating ion uptake by plants in the wetland complex of Samson Lake. This interpretation is supported by winter increases, where plant decomposition appears to leach calcium back into the water column. Alternatively, there may be a low-ion water source in this reach during the open-water season. Calcium levels then continued to gradually increase throughout reaches 3 and 4. In winter, Ca concentrations continued to increase in Reach 2, peaking upstream of Pipestone Creek and upstream of Camrose (Figure 72).

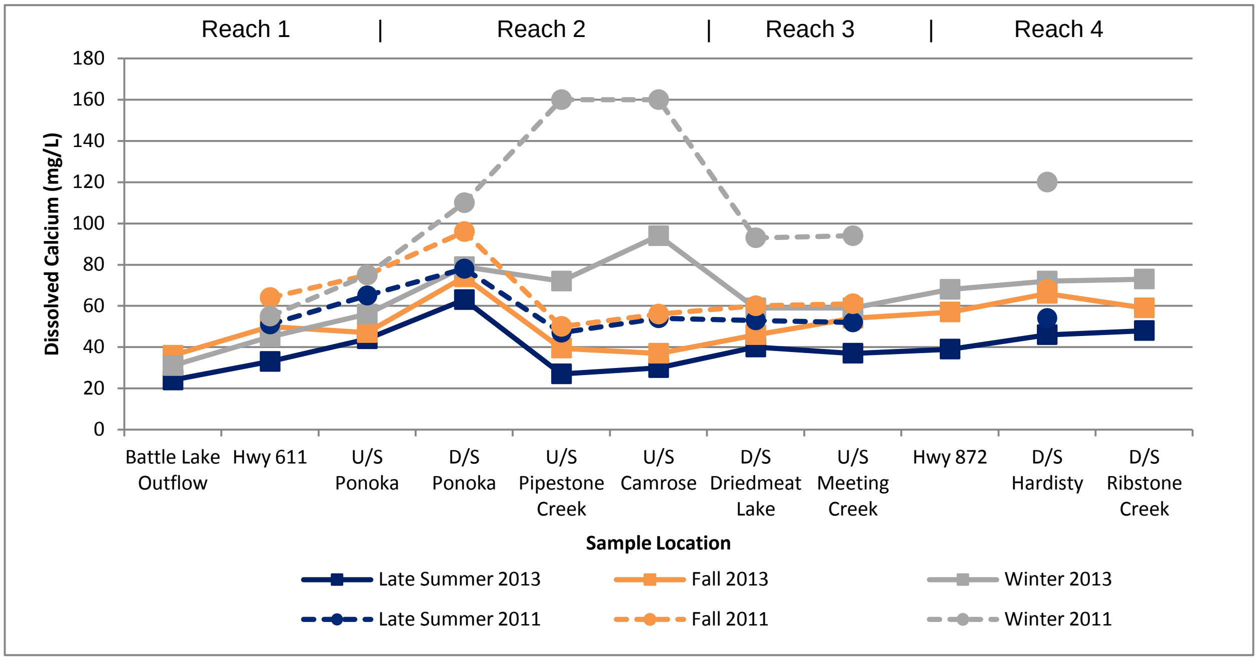


Figure 72 Calcium Concentrations along the Battle River in 2011 and 2013.

5.4.2.2 *Tributaries*

During the summer 2013 survey, tributary calcium concentrations ranged from 33 mg/L at Grizzly Bear Creek to 80 mg/L at Wolf Creek. During the fall survey again, Grizzly Bear Creek had the lowest Ca concentrations (35 mg/L) and Wolf Creek had the highest (110 mg/L). In winter, Ca concentrations ranged from 60 to 110 mg/L (Figure 73). These spatial patterns were different from those in Mg in tributaries, indicating a different source of calcium than magnesium, in particular in Wolf Creek.

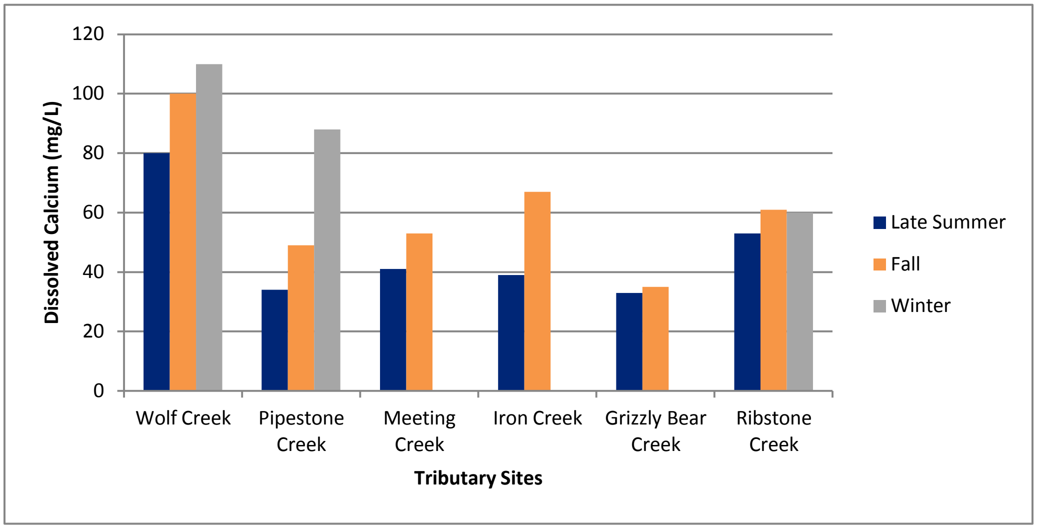


Figure 73 Calcium Concentrations in Major Tributaries along the Battle River.

With the highest flows and concentrations, Wolf Creek had the largest loads in summer and winter (Figure 74). In the fall, load was influenced more by flow than concentration. Even though Wolf Creek had a higher Ca concentration (100 mg/L) than Iron Creek (67 mg/L), the higher flows of Iron Creek resulted in a larger calculated load (359 kg/day) than Wolf Creek (207 kg/day).

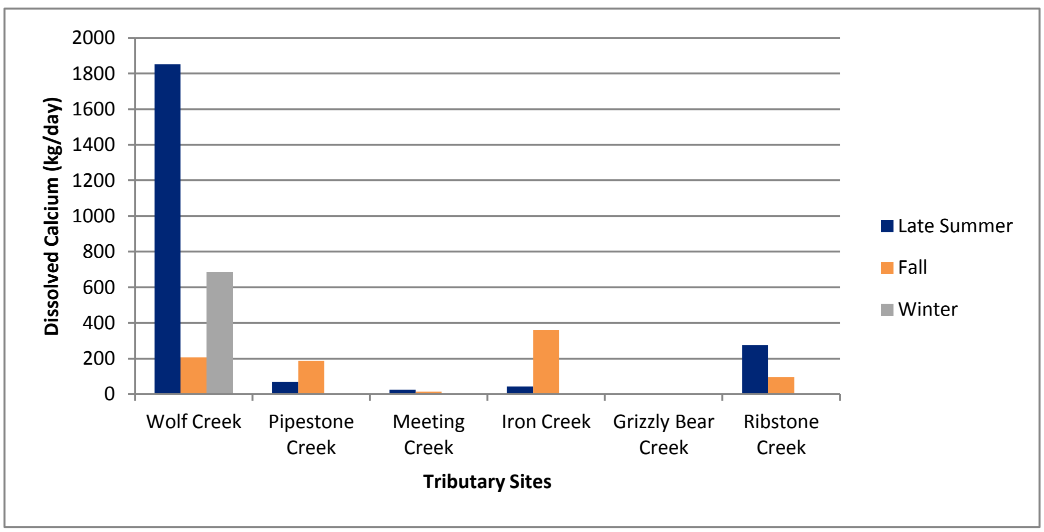


Figure 74 Calcium Loads in Major Tributaries along the Battle River.

5.4.2.3 Lagoon Discharges

Calcium concentrations ranged from 69 to 110 mg/L in sewage effluent from lagoons along the Battle River in October of 2013 (Figure 75).

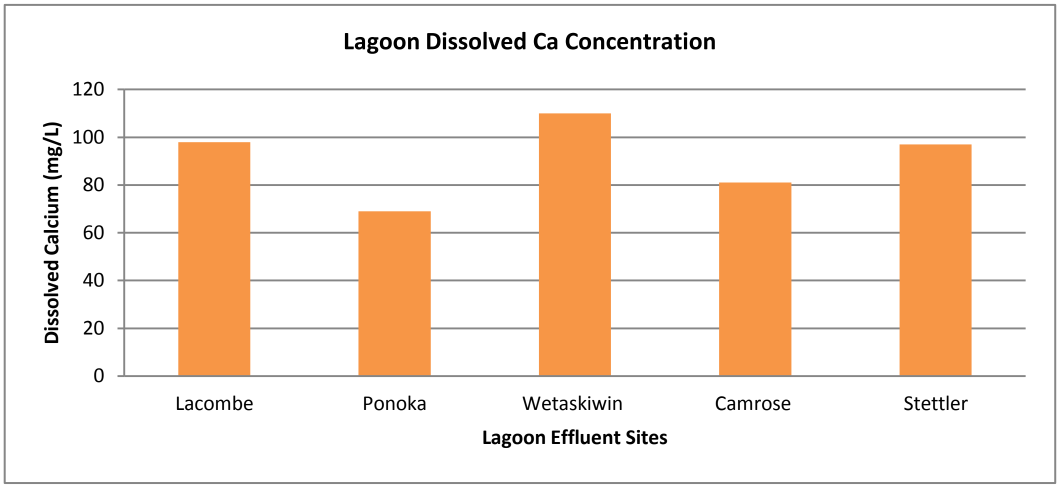


Figure 75 Calcium Concentrations in Lagoons along the Battle River.

Calcium loads in sewage effluent ranged from 119 kg/day to 612 kg/day during the sampling survey in October of 2013 (Figure 76).

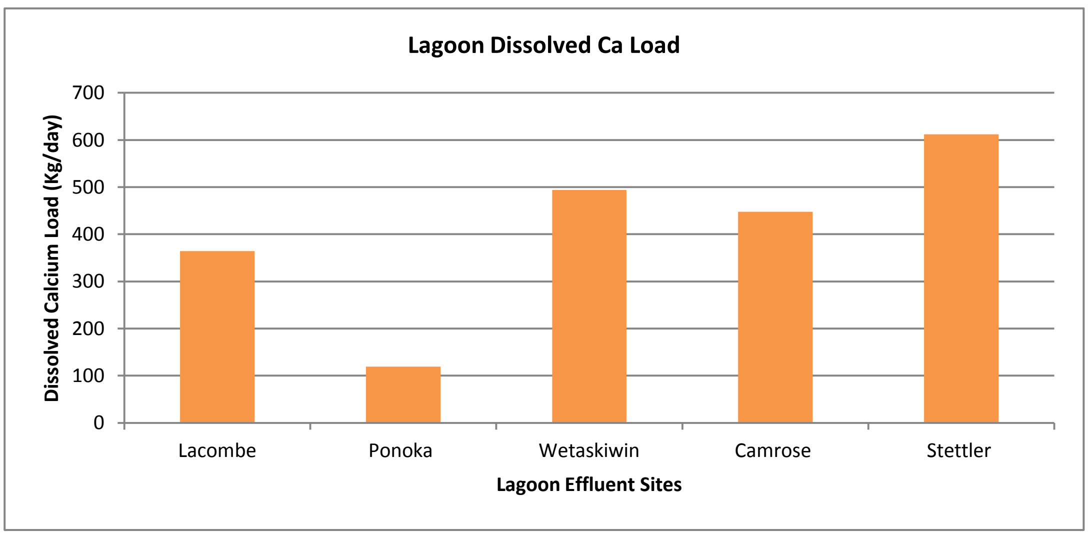
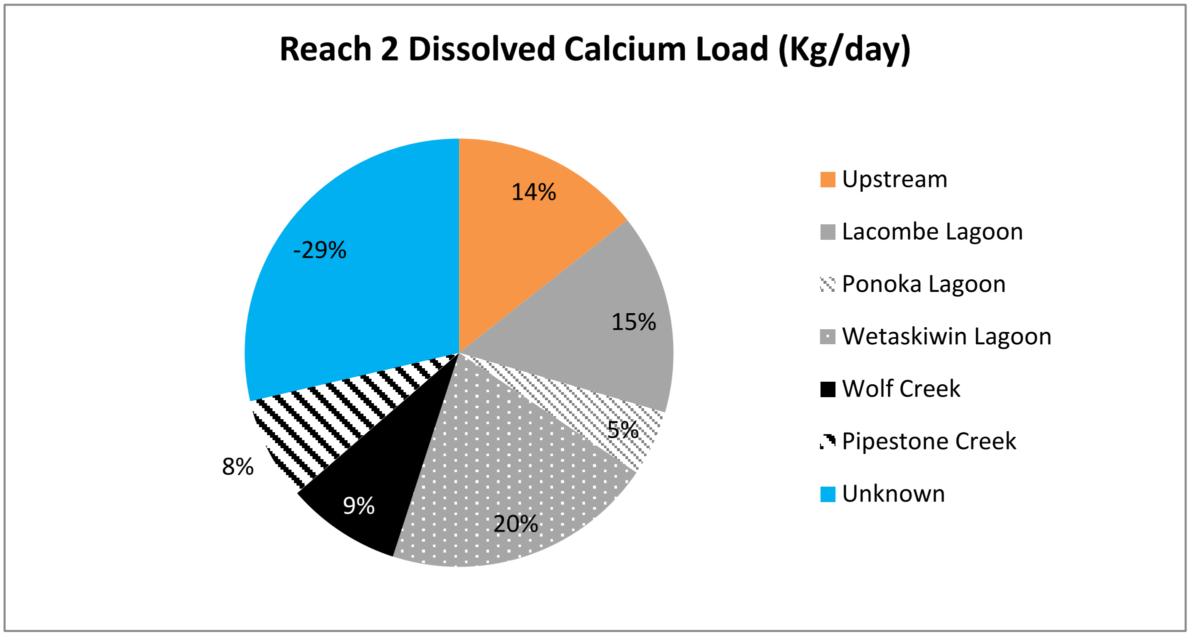
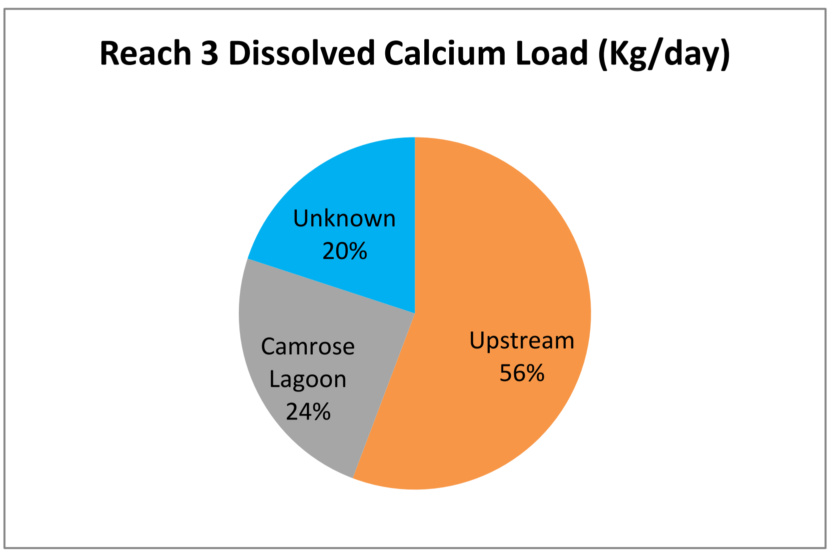


Figure 76 Calcium Loads in Sewage Effluent from Lagoons along the Battle River.

5.4.2.4 Calcium Loads by Reach

In Reach 2, the primary contributor to the Ca load was lagoon effluent; tributaries and upstream loads contributed similar quantities. Similarly to Mg, there appeared to be a Ca sink, as 29% of Ca load was removed by the time it reached the last station in Reach 2. The Ca load in Reach 3 was mainly attributable to upstream loads. Similarly to Mg, Ca loads in Reach 4 came from unknown sources (Figure 77) again associated with the large increase of flow downstream of Ribstone Creek.





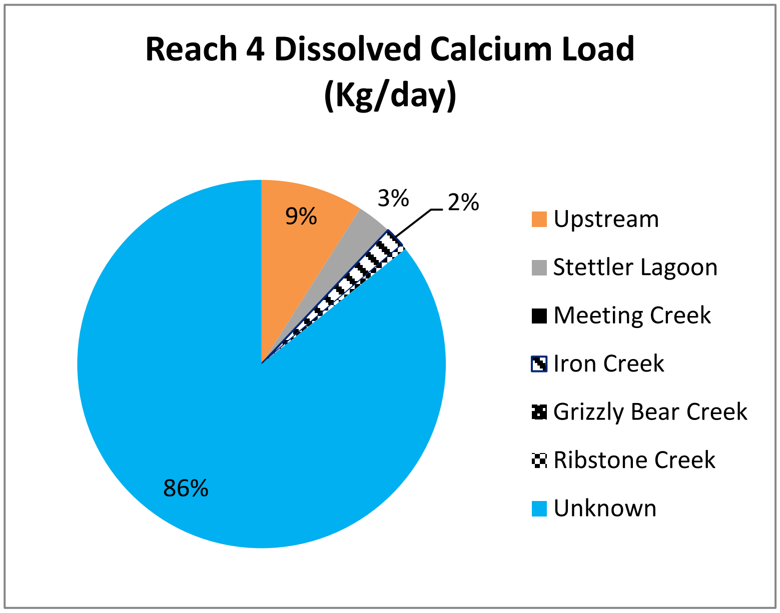


Figure 77. Dissolved Ca Loads for Reaches 2, 3 and 4.

5.4.3 Chloride

5.4.3.1 Mainstem Patterns

Chloride concentrations ranged from 4.1 to 33 mg/L during the summer and from 4.6 to 88 mg/L during the fall 2013 survey, with many concentrations exceeding the 50th percentile WQOs. Concentrations upstream and downstream of Ponoka were above the 90th percentile WQO for chloride for Reaches 1 and 2 respectively. In winter, concentrations at two of the three sites were at or above the 90th percentile WQO for chloride in Reach 4.

In 2011 and 2013, chloride concentrations increased gradually in Reach 1. In summer and fall of both years, chloride concentrations peaked downstream of Ponoka and in summer 2011 at the north end of Driedmeat Lake (Figure 78). These peaks can be related to lagoon discharges, given that lagoon effluent contained about 10 times the chloride concentrations of the Battle River upstream of Ponoka (Figure 81) and that Lacombe and Ponoka lagoons were discharging in fall 2013, Ponoka was discharging in late summer 2011 and Camrose discharged in fall 2011.

In winter of both years, chloride concentrations gradually rose in Reach 1 and in reach 2 until the site upstream of Pipestone Creek, and then remained fairly consistent along the river. The reason of this pattern is unclear, but it may be related to spatial patterns in groundwater quality.

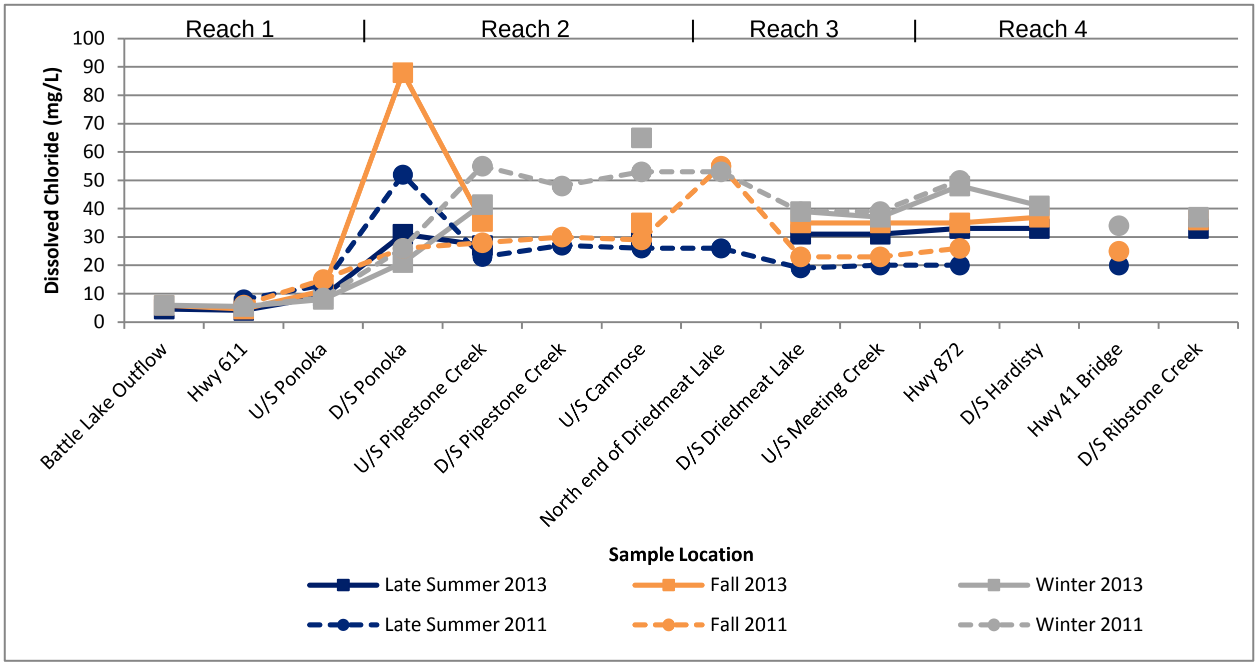


Figure 78 Chloride Concentrations along the Battle River in 2011 and 2013.

5.4.3.2 Tributaries

In the summer, chloride concentrations ranged from 32 mg/L at Pipestone Creek to 56 mg/L at Wolf Creek. In the fall, chloride concentrations ranged from 25 mg/L at Iron Creek to 100 mg/L at Grizzly Bear Creek. In the winter, chloride concentrations ranged from 37 to 60 mg/L (Figure 79).

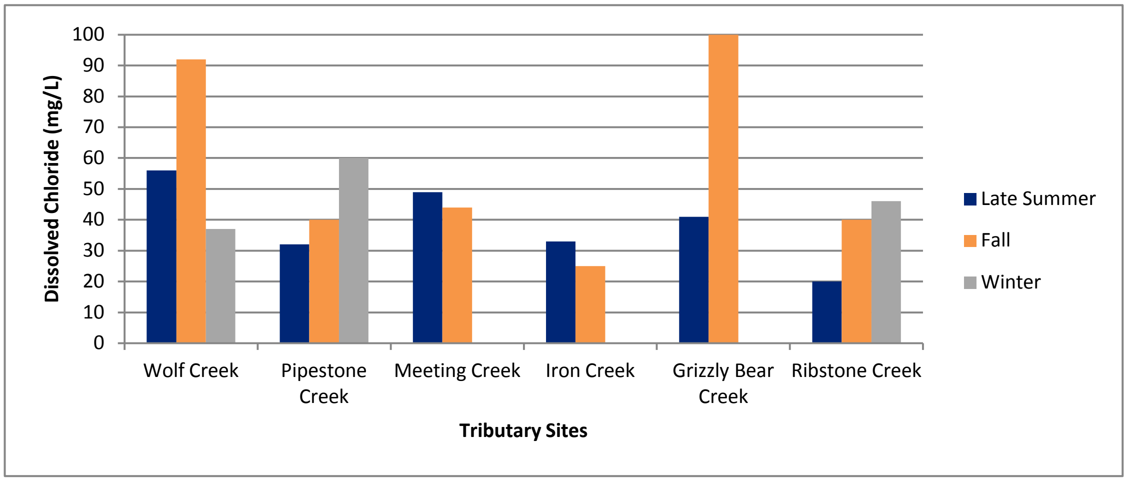


Figure 79. Chloride Concentrations in Major Tributaries Along the Battle River.

Chloride loads in major tributaries along the Battle River were greatly influenced by flow in the summer. In the summer, when the highest flows were measured, dissolved chloride loads ranged from 4 to 1294 kg/day. In the fall, chloride loads ranged from 11 to 191.4 kg/day. In the winter, the majority of tributaries were either not sampled or had a flow of 0, with the exception of Wolf Creek. Wolf Creek had a daily chloride load of 230.2 kg/day (Figure 80).

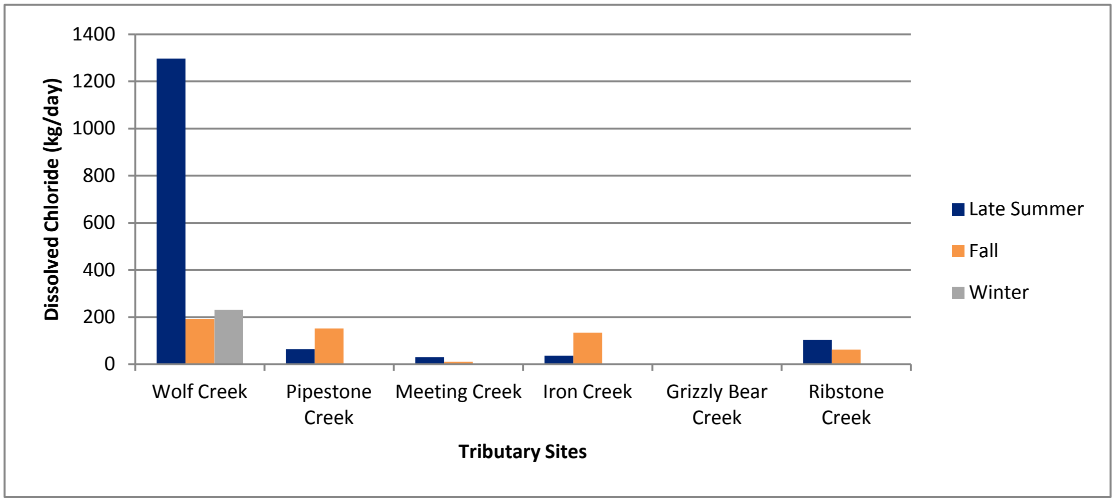


Figure 80. Daily Chloride Loads in Major Tributaries Along the Battle River in 2013.

5.4.3.3 Lagoon Discharges

Chloride concentrations did not vary greatly between lagoons, ranging from 110 to 140 mg/L (Figure 81). They were almost ten times the concentrations in Battle River reach 1, indicating that lagoon discharges likely had an effect on Battle River chloride concentrations. Elevated chloride concentrations in lagoons can result from the residential use of water softeners and may have been exacerbated by evaporation in the lagoons. The minor variation in chloride concentrations across the five lagoons resulted in flow having a major influence on chloride loads. Lacombe had the same concentration of chloride as Stettler, but there was more than a 300 kg/day difference between the two loads.

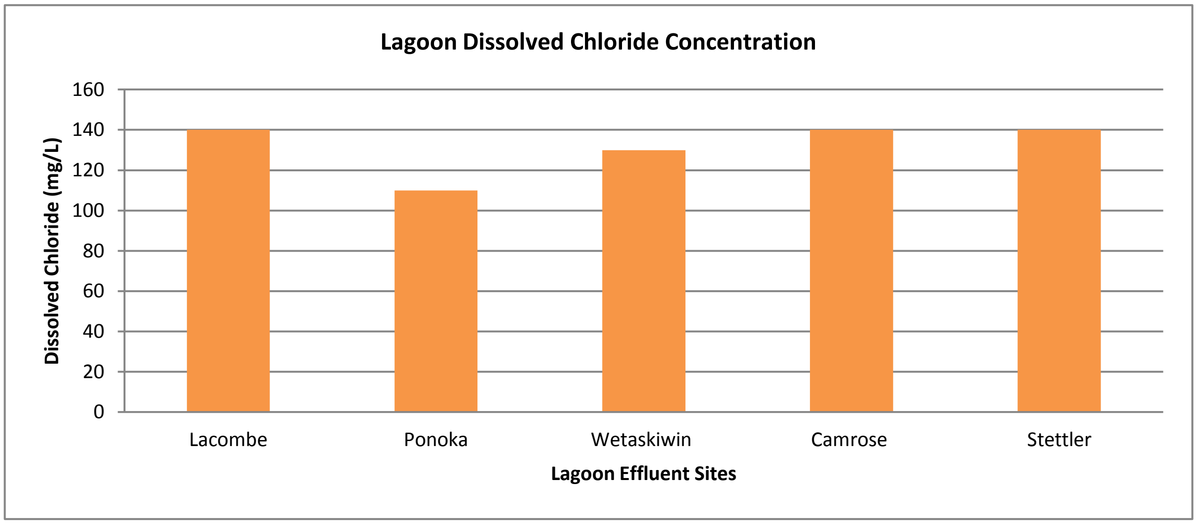


Figure 81. Chloride Concentrations in Sewage Effluent from Lagoons Along the Battle River in October 2013.

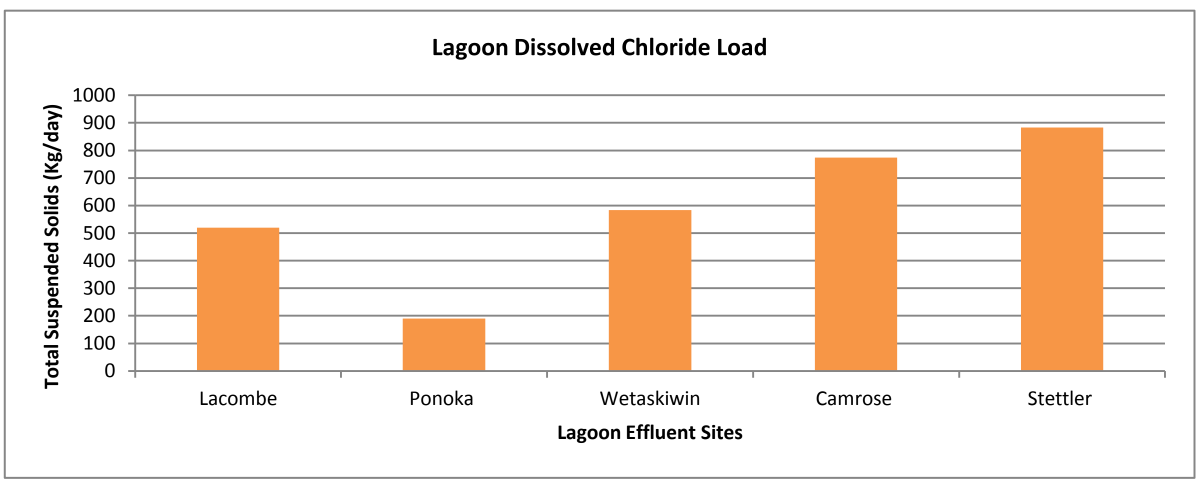


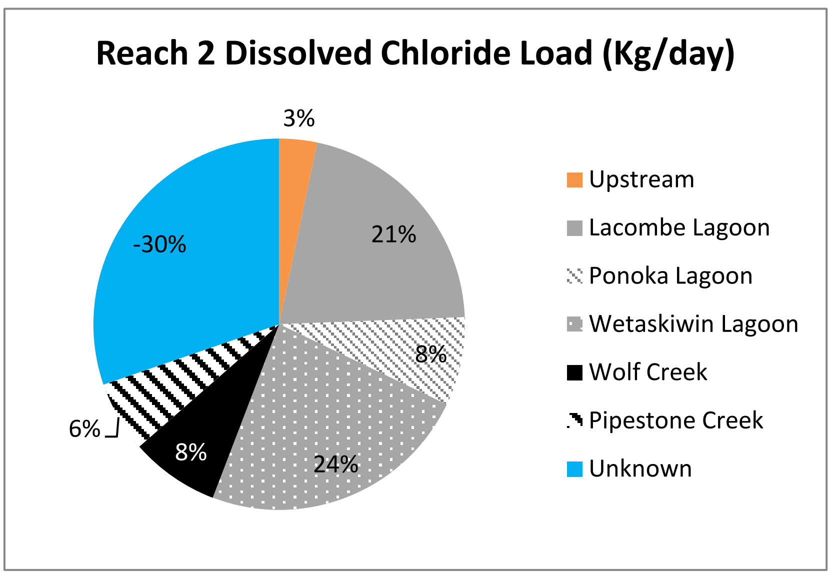
Figure 82 Daily Dissolved Chloride Loads in Lagoons along the Battle River in October 2013.

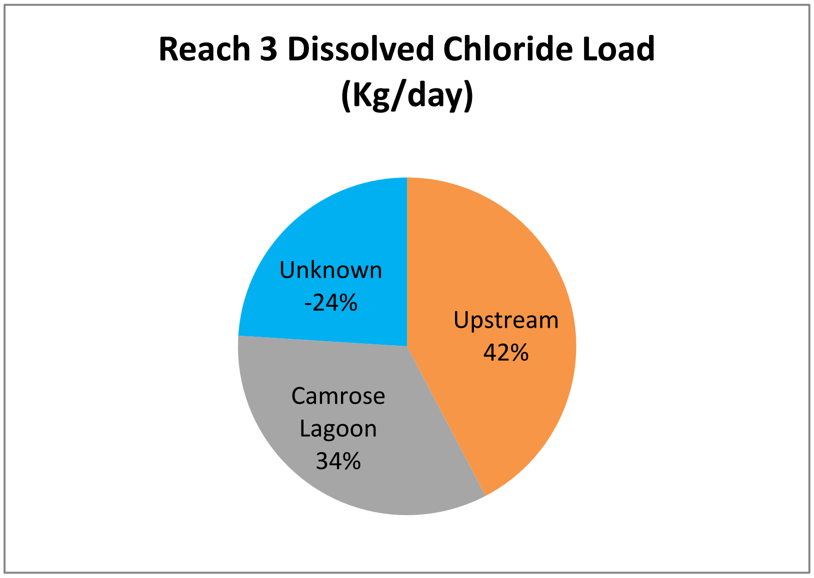
5.4.3.4 Chloride Loads by Reach

In Reach 2, lagoons were responsible for over half of the chloride load (53%), with Lacombe and Wetaskiwin lagoons contributing almost similar amounts to the total reach load. Interestingly, the Lacombe and Ponoka loads were expressed as a chloride peak in the Battle River, while the Wetaskiwin load did not seem to affect the Battle River downstream of the creek confluence, possibly due to limited creek flows. Upstream chloride loads contributed the least (3%), and the two tributaries contributed 14% of the chloride load.

In Reach 3 a large part of the chloride load originated upstream (42%). Camrose effluent added a large fraction of chloride to the total chloride load for Reach 3. In reaches 2 and 3, the downstream load was lower than the sum of the contributing loads, either indicating loss due to water withdrawals or overestimation of some of the sources, such as the lagoon flow volumes.

In Reach 4, 81% of the load came from an unknown source (Figure 83). However, upstream concentrations were similar to those downstream of Ribstone Creek. The greatest difference between downstream and upstream was flow, which was 10 times greater downstream. The increase in flow resulted in a larger downstream chloride load. Increased flow was most likely due to groundwater influence on tributaries and the Battle River itself. The relatively low flows of the four tributaries and Stettler lagoon resulted in their contributions to chloride load in Reach 4 being minimal.





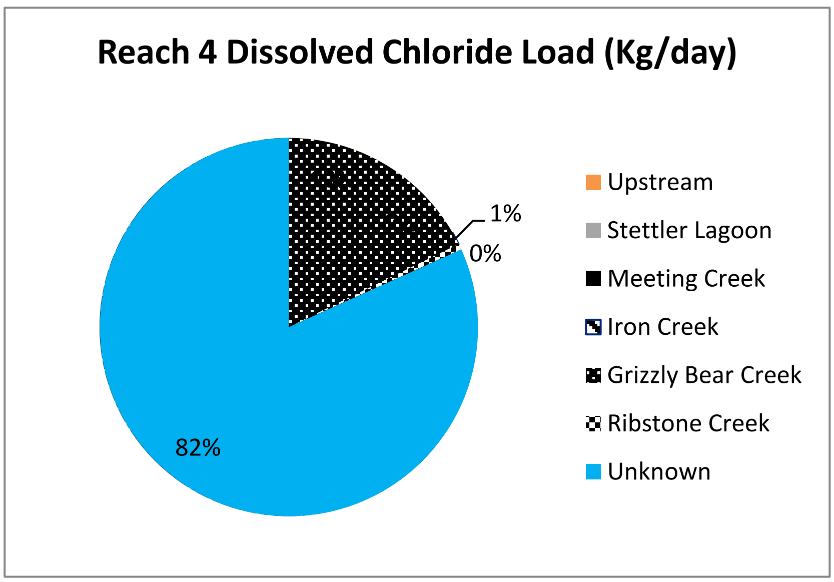


Figure 83. Dissolved Chloride Loads for Reaches 2, 3 and 4.

5.4.4 Fluoride

5.4.4.1 Mainstem Patterns

All sites with the exception of the outflow of Battle Lake had fluoride concentrations above the CCME guideline for the protection of aquatic life of 0.12 mg/L in all three seasons. The consistency of these high values suggests naturally high fluoride concentrations in the Battle River. This confirms a general pattern for Alberta rivers, which mostly exceed the CCME guidelines at the border to Saskatchewan, thereby indicating that Alberta waters have naturally elevated fluoride levels (C. Teichreb, AESRD, pers. comm.). All three sites in Reach 4 had concentrations greater than the reach-specific 90th percentile WQO. In summer, fluoride concentrations downstream of Hardisty (0.30 mg/L) were greater than the 90th percentile WQO for this reach (0.28 mg/L).

There was a fairly consistent longitudinal pattern in fluoride concentrations. In every season there was a gradual increase in fluoride along the Battle River. There was a large spike downstream of Ponoka in fall of 2013 and summer of 2011, likely associated with lagoon discharges. In 2013, fluoride concentrations were greater in the winter than the summer, with the exception of downstream of Ponoka, downstream of Hardisty and at the Saskatchewan border. In 2011, winter fluoride concentrations were greater than fall and summer concentrations with the exception of upstream and downstream of Ponoka (Figure 84).

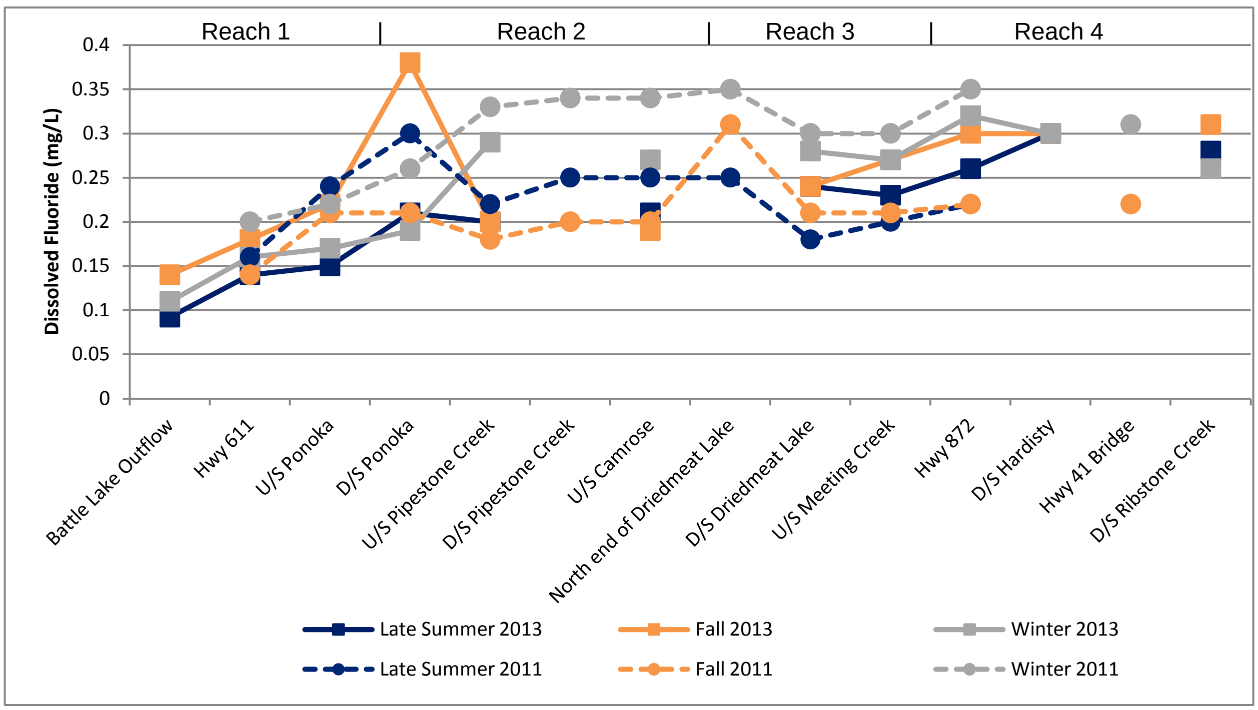


Figure 84 Dissolved Fluoride Concentrations along the Battle River in 2011 and 2013.

5.4.4.2 Tributary Loadings

In late summer of 2013 fluoride concentrations ranged from 0.19 to 0.38 mg/L in the major tributaries of the Battle River. In October and January, fluoride concentration range remained similar 0.2 to .4 mg/L and 0.23 to 0.32 mg/L respectively (Figure 85). All concentrations were greater than the CCME guidelines.

Due to higher flows in the summer, daily summer loads were greatest in the tributaries, ranging from 0.02 to 6.48 kg/day. In the fall, loads ranged from 0.10 to 1.07 kg/day (Figure 86). In the winter, the only flow measured above zero was in Wolf Creek, which equated to a daily fluoride load of 1.4 kg/day.

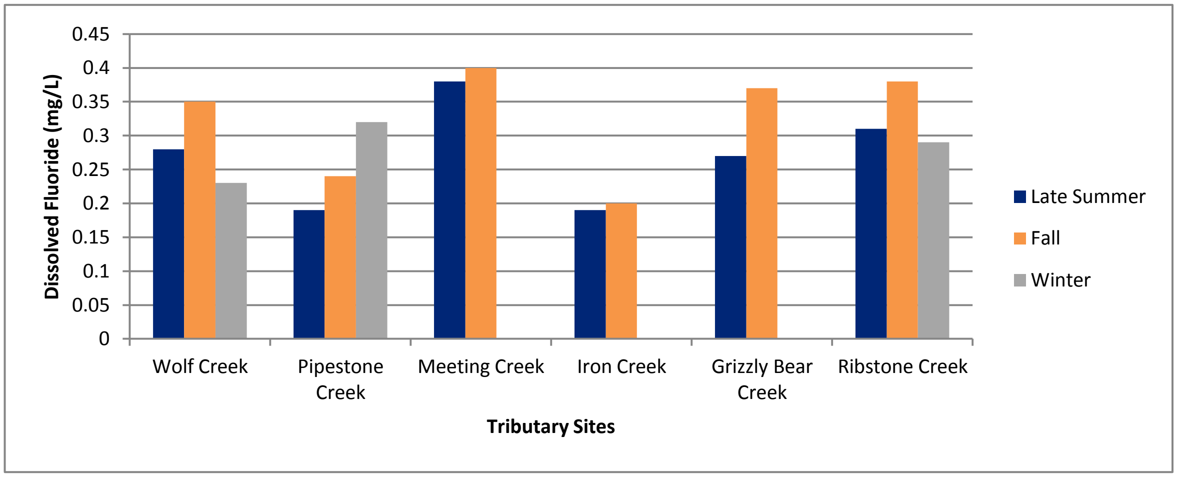


Figure 85 Dissolved Fluoride Concentrations in Major Tributaries along the Battle River.

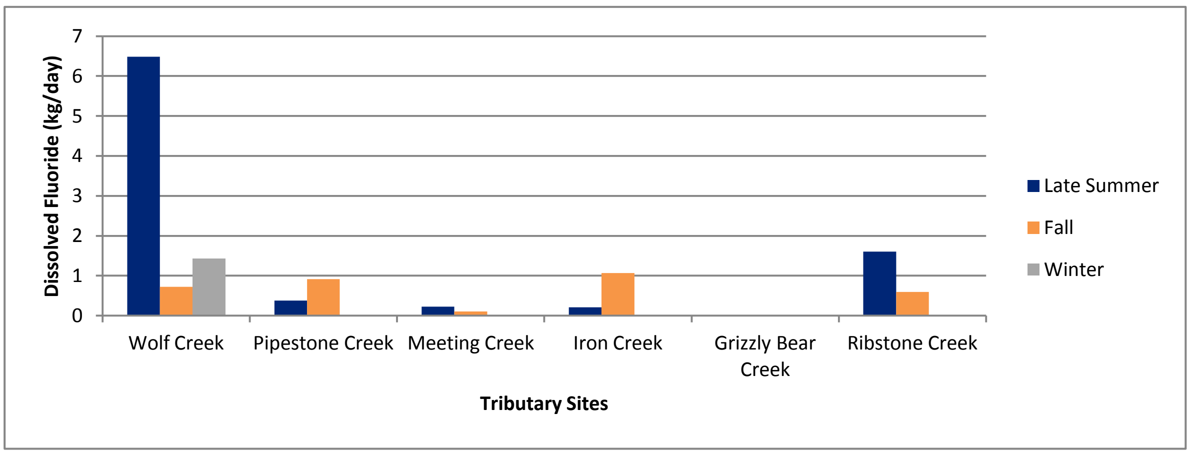


Figure 86 Daily Fluoride Loads in Major Tributaries along the Battle River in 2013.

5.4.4.3 Lagoon Discharges

In the five lagoons, surveyed fluoride concentrations ranged from 0.51 to 0.9 mg/L (Figure 87), about three to five times higher than the Battle River concentrations. Fluoride loads ranged from 1 to 6 kg/day in the five lagoons in October 2013 (Figure 88).

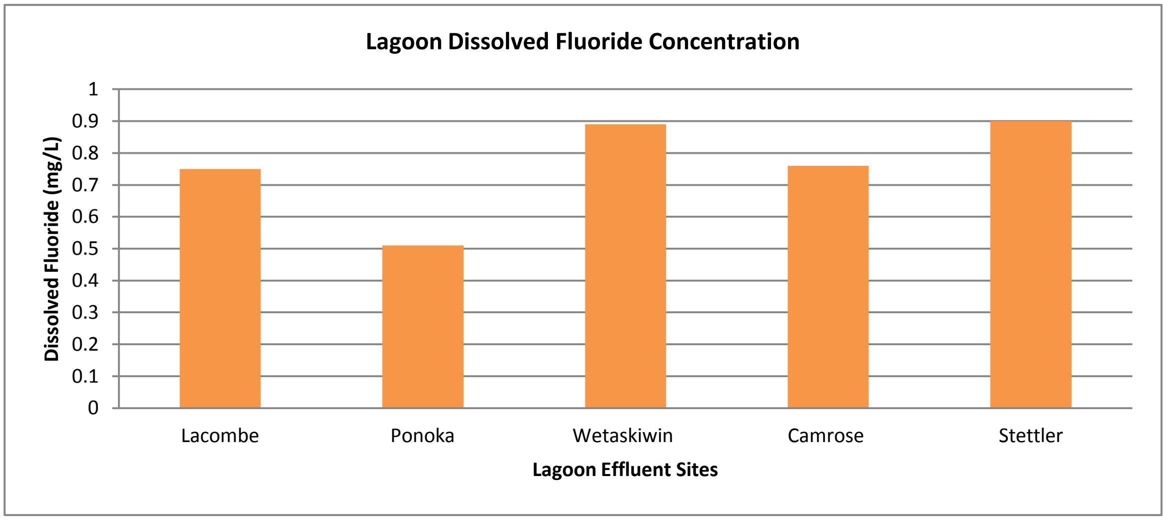


Figure 87 Dissolved Fluoride Concentrations in Lagoon Effluent along the Battle River in 2013.

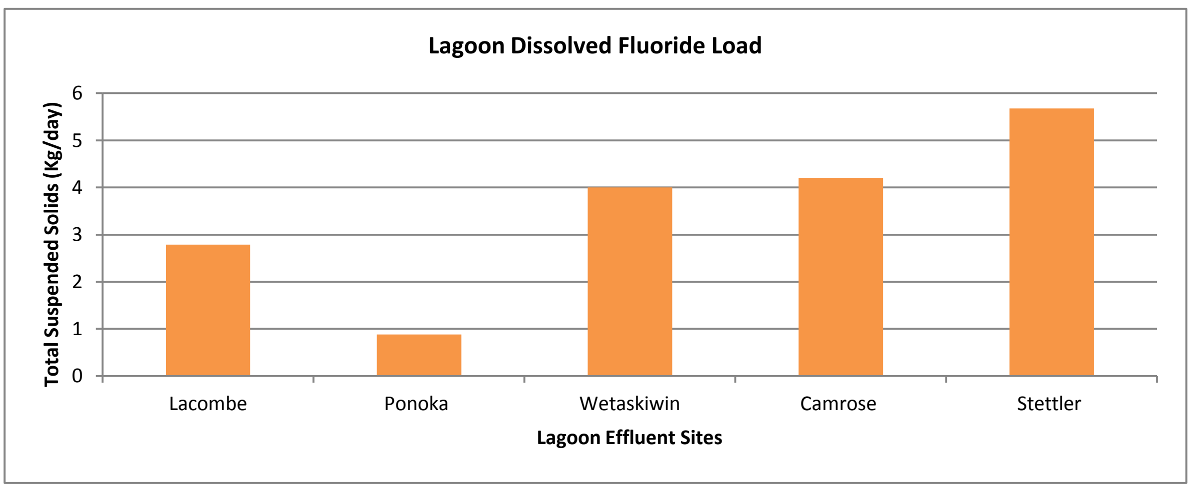
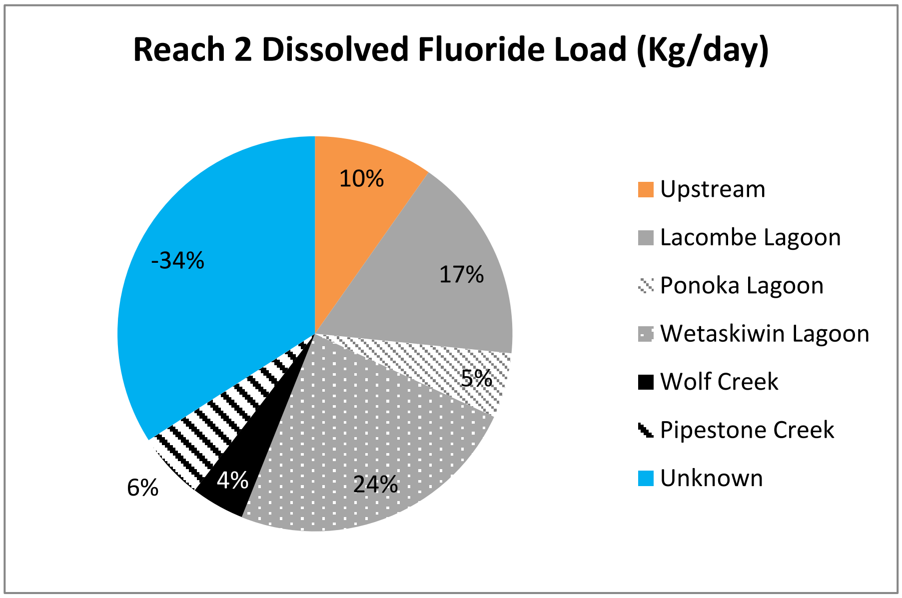
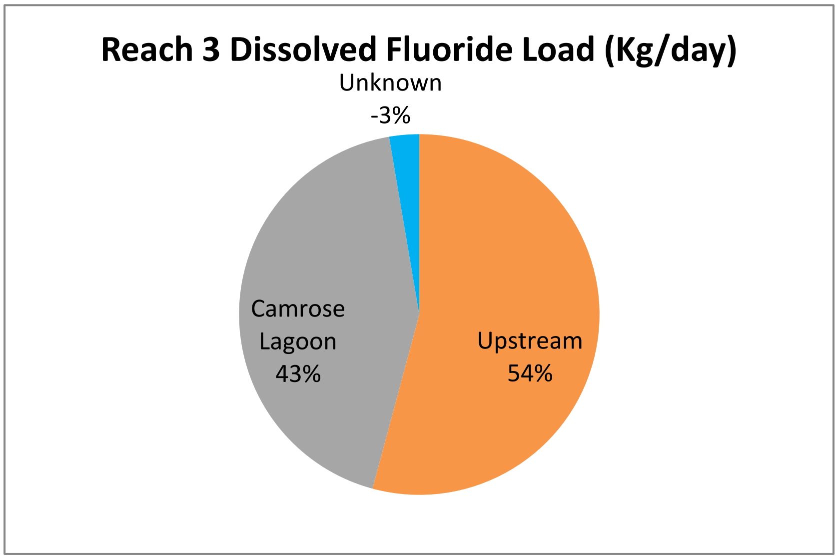


Figure 88 Daily Dissolved Fluoride Load for Lagoons along the Battle River in October 2013.

5.4.4.4 Fluoride Loads by Reach

Similar to other ions the fluoride load in Reach 1 came from lagoon effluent with upstream and tributary loads contributing equally and minimally (Figure 89). A large fluoride sink also existed in Reach 2. Upstream and effluent loads contributed greater amounts to the fluoride load than other major ions. While there was a fluoride sink in Reach 3, far less fluoride was removed from the system than Mg, Ca or chloride. A similar breakdown of fluoride load occurred in Reach 4 as was seen for other major ions.





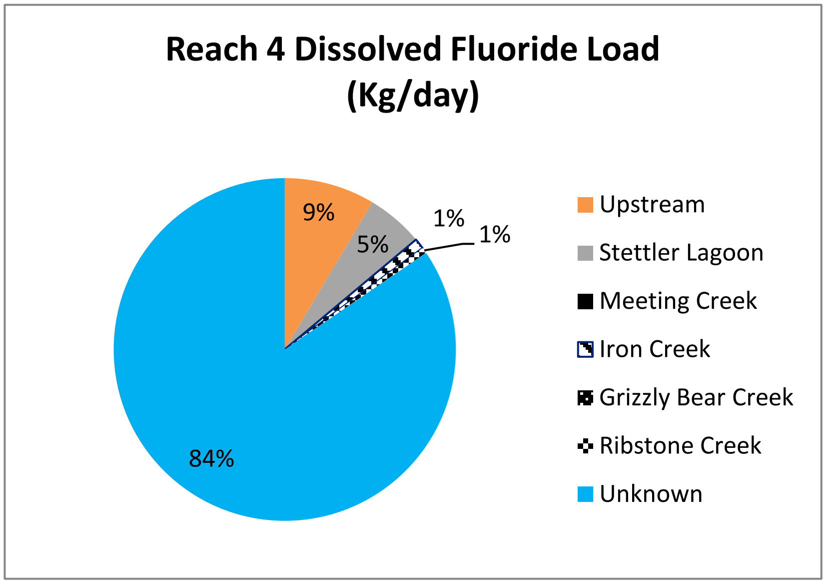


Figure 89 Fluoride Load Break Down for Reaches 2, 3 and 4.

5.4.5 Sulphate

5.4.5.1 Mainstem Patterns

Based on hardness, sulphate concentrations never exceeded the provincial WQGs. In August, sulphate concentrations downstream of Ribstone Creek (130 mg/L) exceeded the 50th percentile WQO for Reach 4 (118 mg/L). In October, sulphate concentrations upstream and downstream of Ponoka (27 and 94 mg/L respectively) exceeded the WQO for Reach 1 (19 mg/L) and Reach 2 (75 mg/L) respectively. All sites in Reach 4 had concentrations which exceeded the 50th percentile WQO for this reach in fall and winter of 2013. Upstream of Ponoka in winter had sulphate concentrations greater than the WQO for Reach 1 during the ice-cover season (25 mg/L).

In 2013, sulphate concentrations along the Battle River increased steeply (Figure 90). Peaks downstream of Ponoka and Camrose in fall and late summer indicate lagoon discharge influence. Winter concentrations were greater than either summer or fall concentrations, with the exception of downstream of Ponoka. Sulphate is one by-product of organic matter decomposition, which seems to be important in reach 2 in winter, based on other water quality indicators (oxygen, nitrate). Fall concentrations were greater than summer concentrations, with the exception of the outflow of Battle Lake, downstream of Driedmeat Lake and upstream of Meeting Creek. These results are very different than those found in the open-water seasons of the 2011 campaign, when sulphate concentrations varied more with season than longitudinally (Figure 90).

One main difference between 2011 and 2013 was that Driedmeat Lake was a source of sulphate in summer and fall 2013 while in 2011 it was not. Sulphate is released from sediments due to organic matter decomposition and in response to low oxygen conditions. Possibly, climatic conditions in 2013 were more favorable for sulphate releases to occur in Driedmeat Lake. Interestingly, sulphate concentrations also increased downstream of the ATCO powerplant reservoir (HWY 872) in fall 2011 and 2013 and in winter 2013, indicating another sulphate source in this river reach, possibly the reservoir.

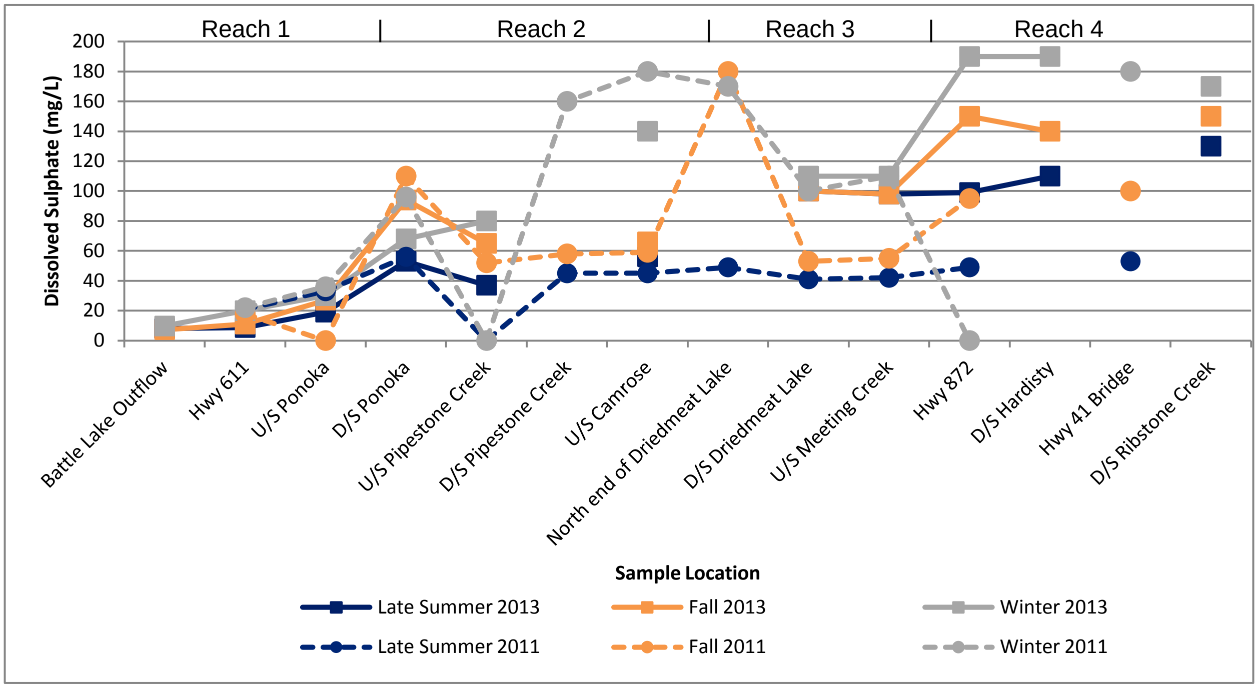


Figure 90 Dissolved Sulphate Concentrations along the Battle River in 2011 and 2013.

5.4.5.2 Tributaries

In summer of 2013, sulphate concentrations in major tributaries along the Battle River ranged from 89 mg/L in Wolf Creek to 430 mg/L in Grizzly Bear Creek, with a distinct difference between the headwater tributaries Wolf, Pipestone and Meeting Creek and the eastern tributaries Iron, Grizzly Bear and Ribstone Creek. In fall, concentrations ranged from 78 mg/L in Pipestone Creek to 560 in Grizzly Bear Creek. In winter, concentrations ranged from 120 to 300 mg/L (Figure 91). Although Grizzly Bear Creek had the highest sulphate concentrations in summer and fall, the flow in this creek was not detectable, resulting in a daily sulphate load of zero. Even though Wolf Creek had the lowest sulphate concentrations in the summer and winter, it had the largest sulphate daily loads in both seasons due to high flows. In the fall, Iron Creek had the largest calculated daily load (1499 kg/day) (Figure 92); this was due to a combination of high sulphate concentrations (280 mg/L) and high flow.

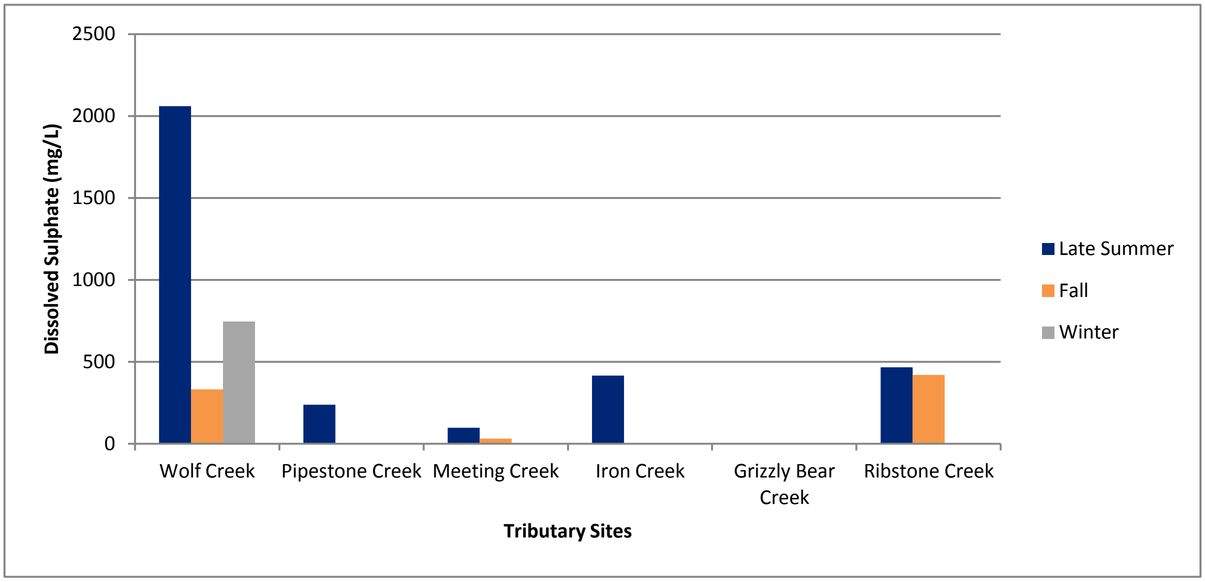


Figure 91 Sulphate Concentrations in Major Tributaries along the Battle River 2013.

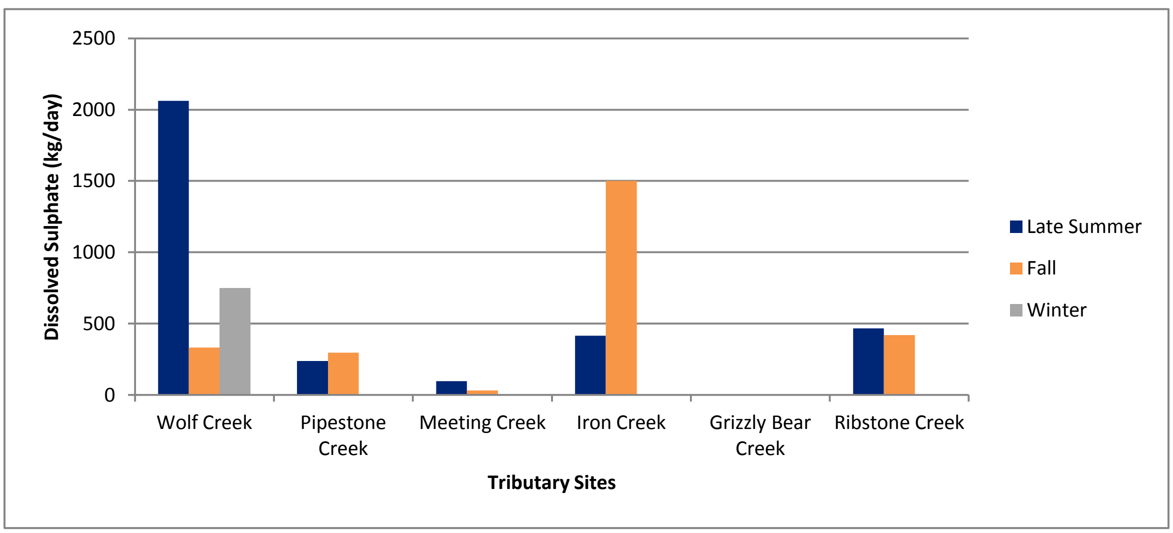


Figure 92 Daily Sulphate Loads in Major Tributaries along the Battle River in 2013.

5.4.5.3 Lagoon Discharges

In October of 2013, sulphate concentrations in five lagoons along the Battle River ranged from 83 to 380 mg/L (Figure 93).

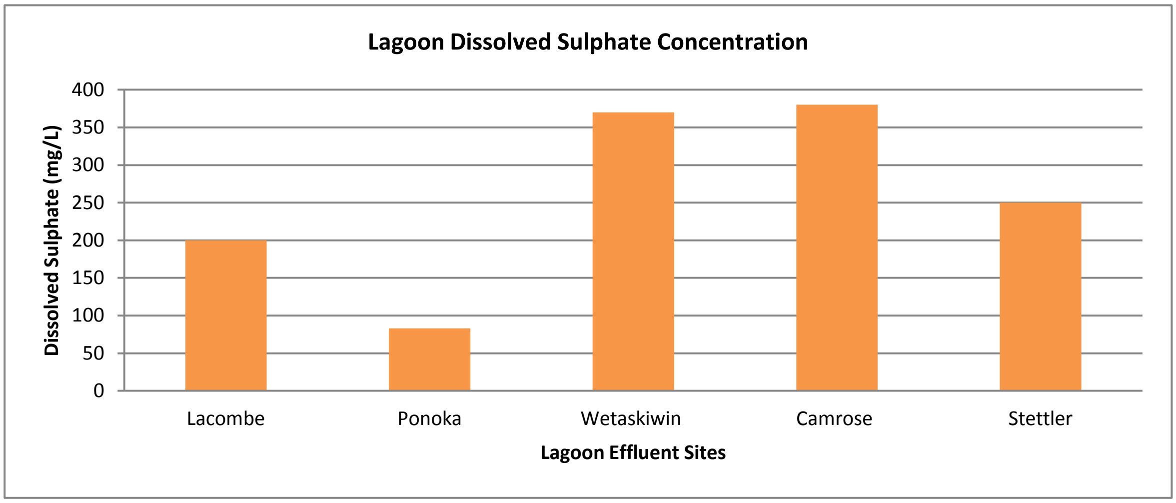


Figure 93. Sulphate Concentrations in Five Lagoons along the Battle River in October 2013.

The high sulphate concentrations in the sewage effluent from the Wetaskiwin (370 mg/L) and Camrose (380 mg/L) lagoons resulted in the two largest sulphate loads (1662 and 2101 kg/day, respectively) (Figure 94).

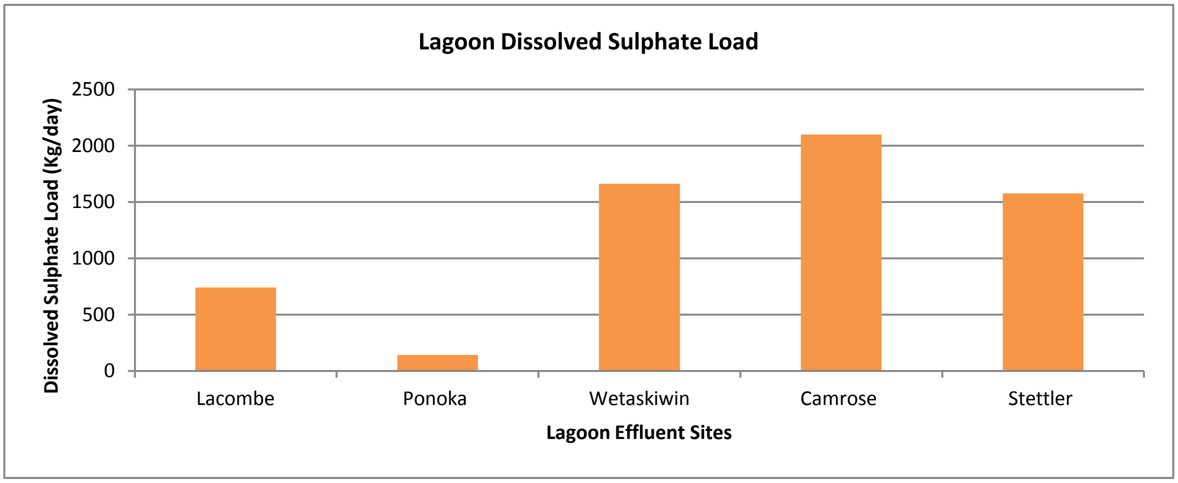
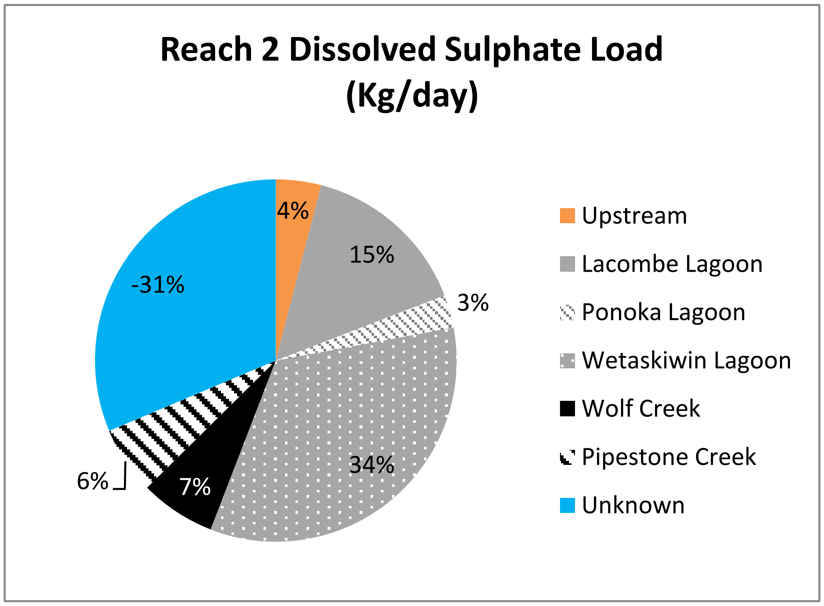
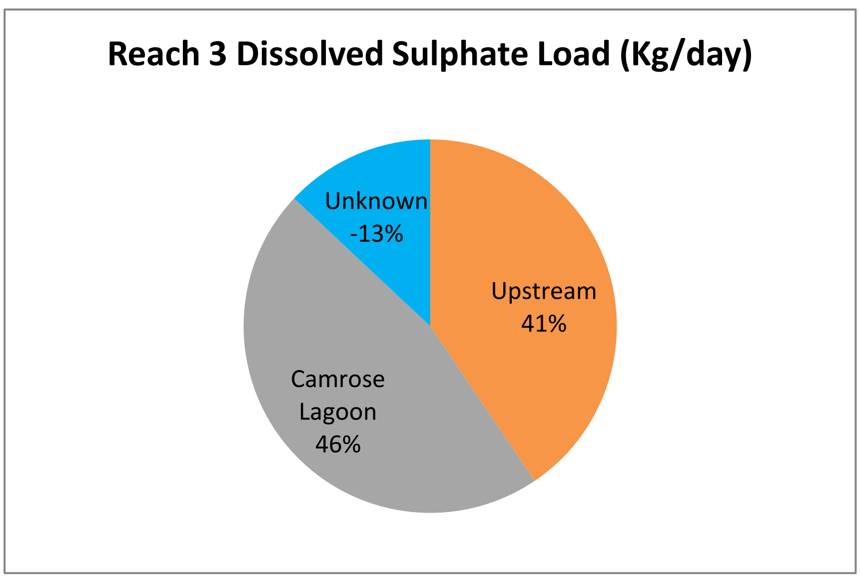


Figure 94. Daily Sulphate Loads in Sewage Effluent of Five Lagoons along the Battle River in 2013.

5.4.5.4 Sulphate Loads by Reach

A large portion of the sulphate load in Reach 2 came from lagoons, mainly from Wetaskiwin. Only a minor portion of the load came from Reach 1 (4%). In both Reach 2 and 3, a sulphate sink existed, but less sulphate was retained in the river in Reach 3 than 2. In Reach 3, both upstream and lagoon sulphate loads contributed over 40% of the total reach load (Figure 95). The origin of the sulphate load in Reach 4 was very similar to other major ions.





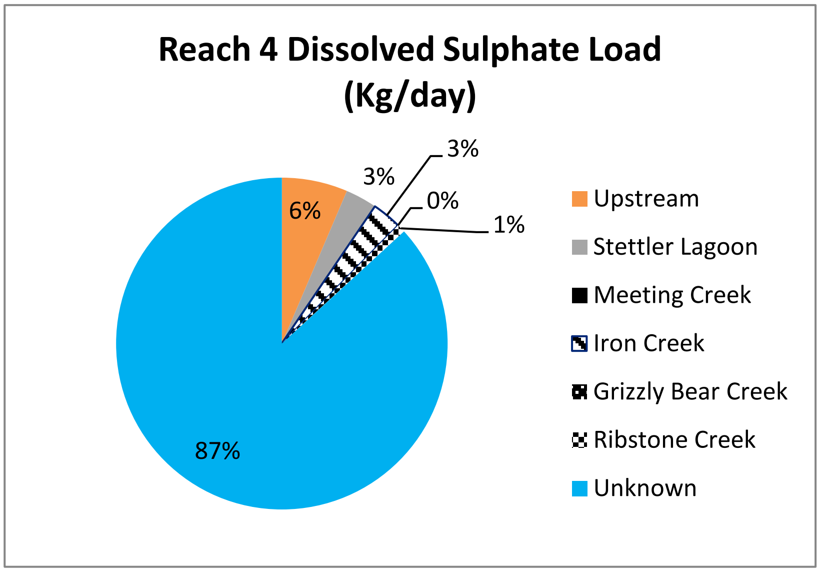


Figure 95. Dissolved Sulphate Loads for Reaches 2, 3 and 4.

5.4.6 Sodium

5.4.6.1 Mainstem Patterns

There are no reach-specific WQOs, provincial or federal guidelines for sodium.

In 2013, sodium concentrations increased very gradually along the Battle River in all seasons, with winter concentrations often exceeding summer and fall concentrations. An exception to that were the sites downstream of Ponoka, likely due to lagoon discharge, and downstream of Ribstone Creek, where sodium concentrations more than tripled from downstream of Hardisty to downstream of Ribstone Creek, possibly due to larger sodium concentrations in local groundwater around reach 4, as indicated by high sodium concentrations in Grizzly Bear Creek and Iron Creek. Similar to the 2013 campaign, in 2011 winter concentrations exceeded summer and fall sodium concentrations (Figure 96).

The longitudinal patterns showed similarities and differences between the two campaign years. In both years the winter concentrations increased along the river, with highest values in reach 2, possibly due to highest groundwater influence in this reach. In both years, sodium increased downstream of the ATCO reservoir, at HWY 827. There was a dip in concentration downstream of Driedmeat Lake in 2011, whereas in 2013, concentrations increased slightly at this location, a difference that is similar to sulphate patterns.

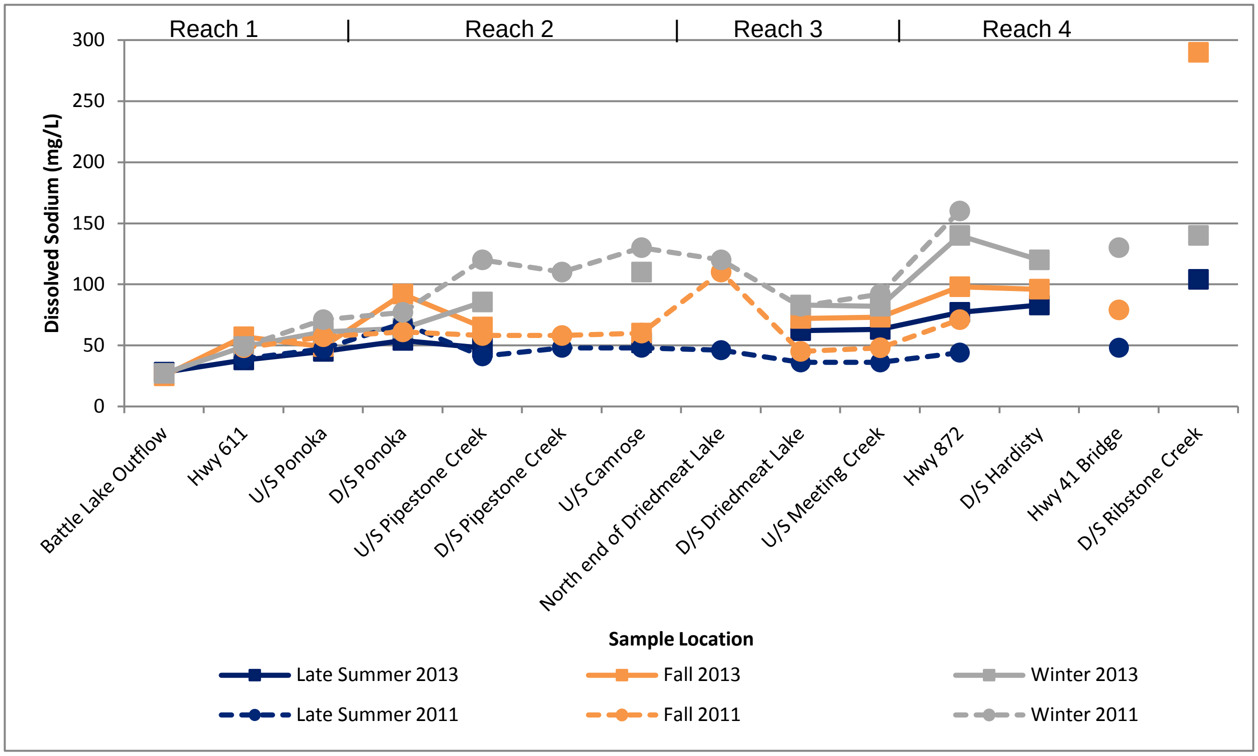


Figure 96 Sodium Concentrations along the Battle River in 2011 and 2013.

5.4.6.2 *Tributaries*

In the summer of 2013, sodium concentrations ranged from 54 mg/L at Pipestone Creek to 370 mg/L at Grizzly Bear Creek. In the fall, Pipestone Creek and Grizzly Bear Creek again had the smallest and largest concentrations of sodium, again ranging from 80 to 590 mg/L. In the winter, Wolf Creek had the lowest concentration of sodium at 52 mg/L and Ribstone Creek had the highest concentration at 330 mg/L (Figure 97). In most tributaries, flows were greatest in the summer, resulting in relatively large sodium loads. Exceptions to this included Iron Creek, which had a summer load of 303 kg/day and a fall load of 1071 kg/day (Figure 98). The discrepancy between the two seasons for Iron Creek was due to a higher fall flow.

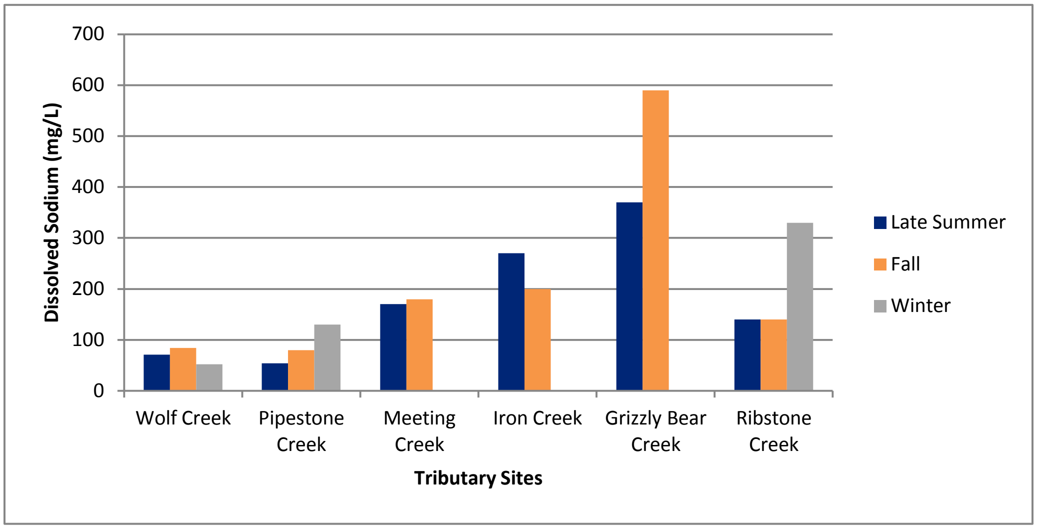


Figure 97 Sodium Concentrations of Major Tributaries along the Battle River.

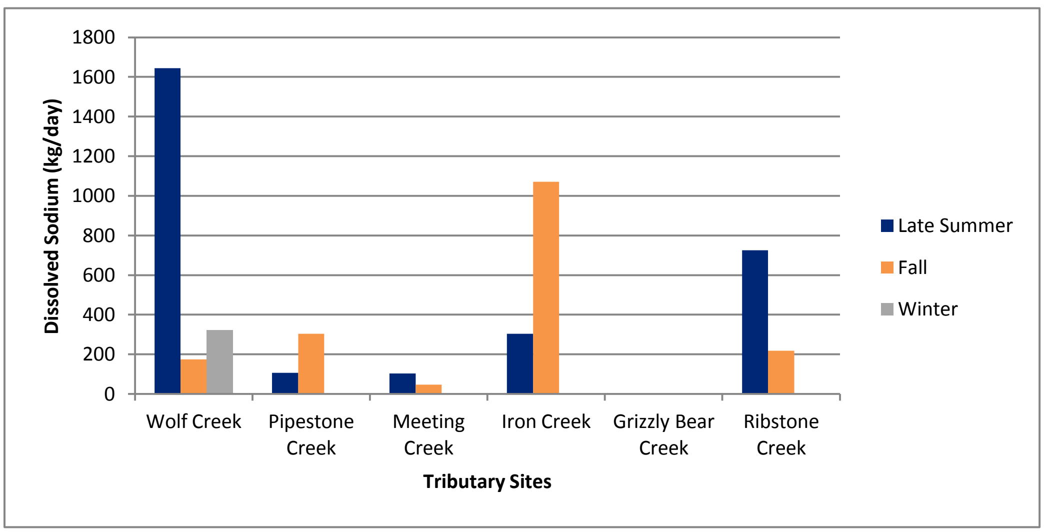


Figure 98 Dissolved Sodium Loads for Major Tributaries along the Battle River in 2013.

5.4.6.3 Lagoon Discharges

In sewage effluent from five lagoons along the Battle River, sodium concentrations ranged from 95 mg/L to 250 mg/L (Figure 99). The low concentration of sodium (95 mg/L) and low flow (0.02 m^3/s) resulted in low sodium loads in the sewage effluent of the Ponoka lagoon. High concentrations of sodium in sewage effluent from Camrose (220 mg/L) and Stettler (250 mg/L) as well as their relatively high flows (0.052 and 0.073 m^3/s) resulted in two of the largest loads (1216 and 1577, respectively) (Figure 100).

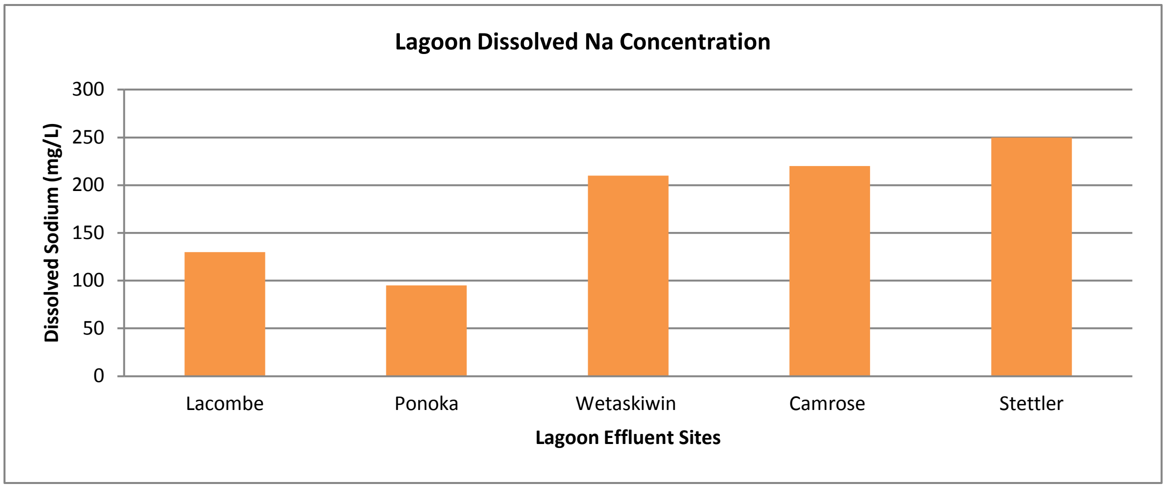


Figure 99 Sodium Concentrations of Lagoon Effluent along the Battle River.

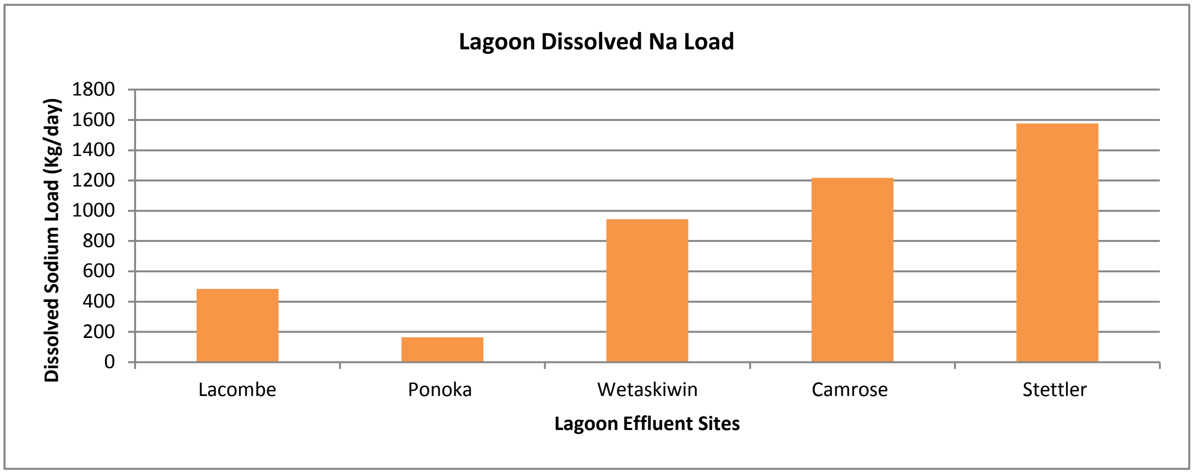
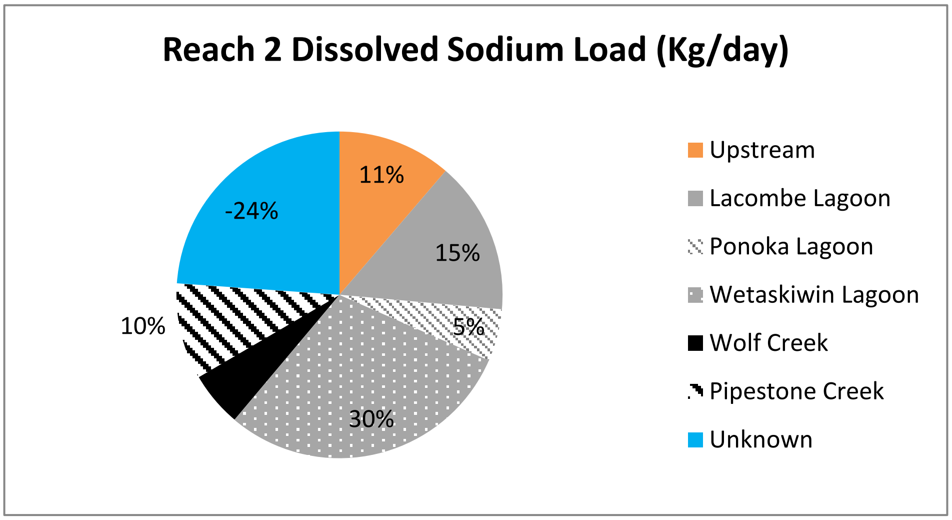
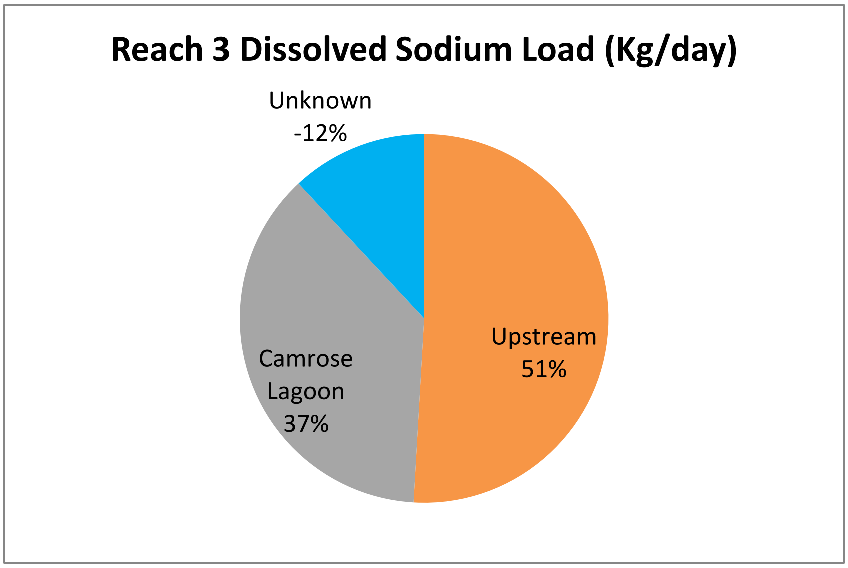


Figure 100 Daily Sodium Loads for Five Lagoons along the Battle River in October of 2013.

5.4.6.4 Sodium Loads by Reach

Sodium Load in Reach 2 originates primarily from lagoons. Wetaskiwin lagoon was the largest contributor of the lagoons. Tributaries' contributions were slightly greater than upstream sodium loads. Pipestone Creek contributed twice as much to the sodium load as Wolf Creek. There was a sodium sink in both Reach 2 and 3, as 24 and 12% of the sodium load from upstream, lagoons and tributaries were not accounted for in the downstream stations of these reaches (Figure 101). In Reach 4, a larger portion of the sodium load came from unknown sources than other major ions. In the case of sodium, both concentration and flow increased downstream of Ribstone Creek.





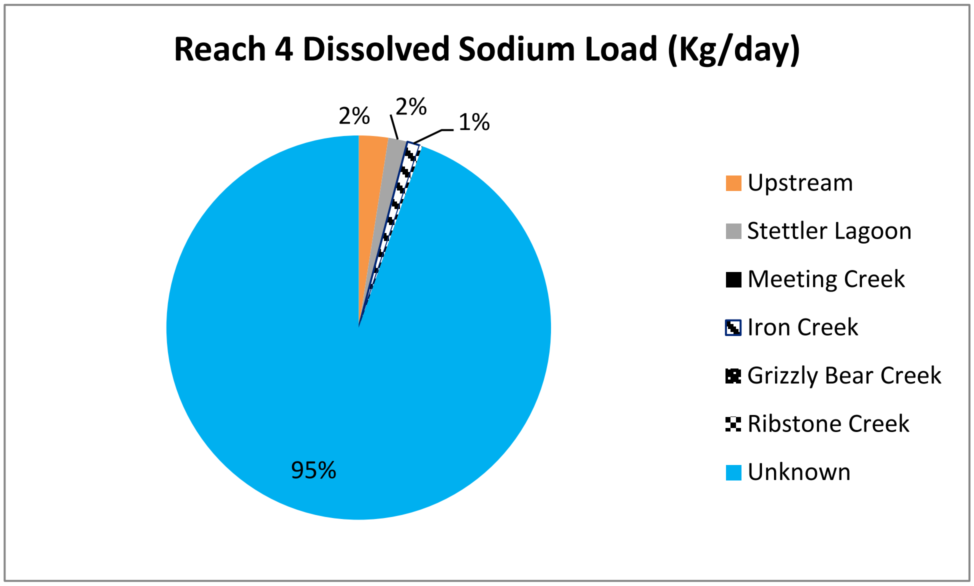


Figure 101. Dissolved Sodium Load Break Down for Reach 2, 3 and 4.

5.4.7 Sodium Adsorption Ratio

Sodium adsorption ratio (SAR) is a calculation used to determine water's suitability for usage in irrigation. High sodium concentrations can cause soils to swell and disperse; leading to hardened soils with decreased rates of permeability at and below the surface (Hanson et al., 1993). SAR is a measure of the ratio of sodium ions to calcium and magnesium ions (measured as milliequivalents); as SAR increases, so too does water's potential to cause harm to soils (Hanson et al. 1993) (Clark & Mason, 2006). Very little irrigation in fact occurs in the watershed. This is particularly of note in the eastern regions, where farmers know that the saline soils and high SAR in the river make it unsuitable for use in irrigation. SAR is thus of importance as it ultimately prevents irrigation from being used in the region.

5.4.7.1 Mainstem Patterns

Compliance with water quality objectives varied with reach and season. In summer 2013 SAR the sample upstream of Ponoka (1.4) was greater than the 50th percentile WQO for Reach 1 (1.3). In fall 2013, SAR in the Battle River samples collected at Hwy 611 (1.7) and upstream of Ponoka (1.7) were above the 50th percentile WQO for Reach 1. Scores downstream of Ribstone Creek (7.2) were greater than the 50th (5) and 90th (5.5) percentile WQO for Reach 4. None of the samples collected along the Battle River exceeded reach specific WQOs during the winter 2013 survey.

There were no seasonal patterns in sodium adsorption ratio in 2013, with the exception of the Battle River at Hwy 872, where SAR varied with season. There is a gradual increase in SAR along the Battle River, with the largest SAR occurring primarily downstream of Ribstone Creek. The fall SAR, downstream of Ribstone Creek, was the largest due to high sodium concentrations (290 mg/L) (Figure 102).

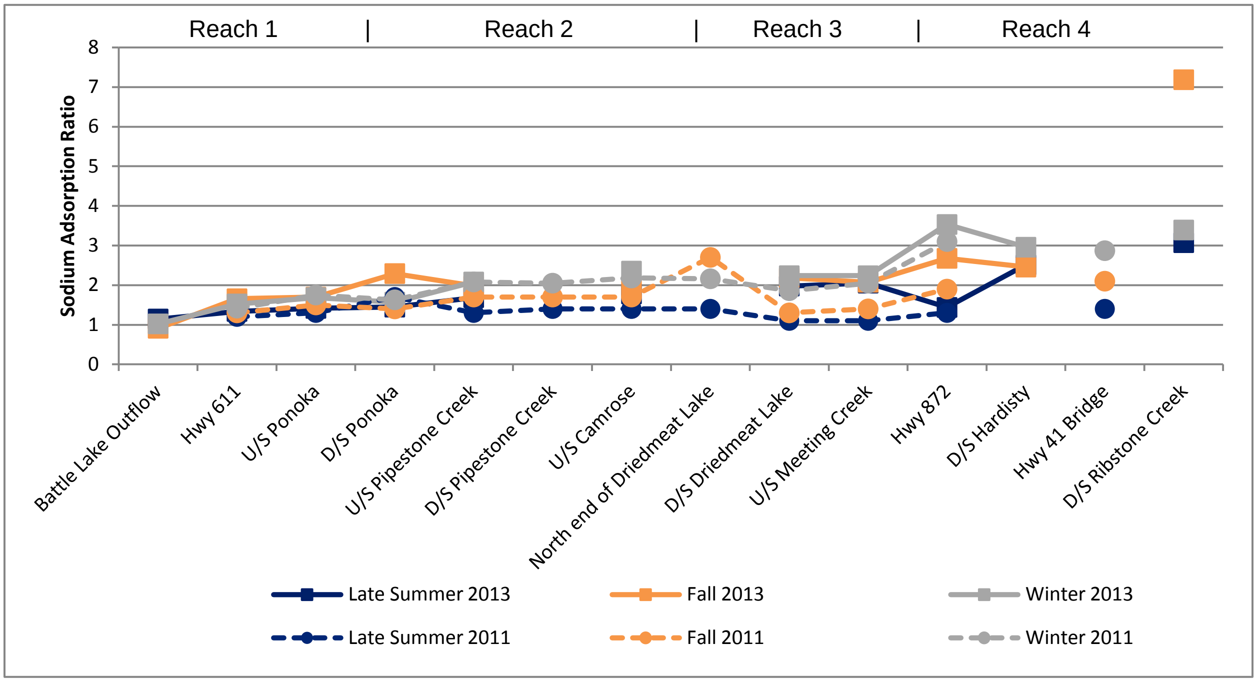


Figure 102 Sodium Adsorption Ratio along the Battle River in 2011 and 2013.

5.4.7.2 Tributaries

Sodium adsorption ratios ranged from 1.8 at Wolf Creek to 9.1 at Grizzly Bear Creek in the summer of 2013. In the fall, SAR ranged from 1.0 at Pipestone Creek to 16.6 at Grizzly Bear Creek. During the winter survey, SAR ranged from 1.1 to 8.3 (Figure 103). High SARs were related to high sodium concentrations, as calcium and magnesium concentrations remained similar. Iron, Grizzly Bear and Ribstone Creeks drained watersheds with highly saline soils, which may be one of the reasons why these creeks carried higher sodium levels relative to other ions.

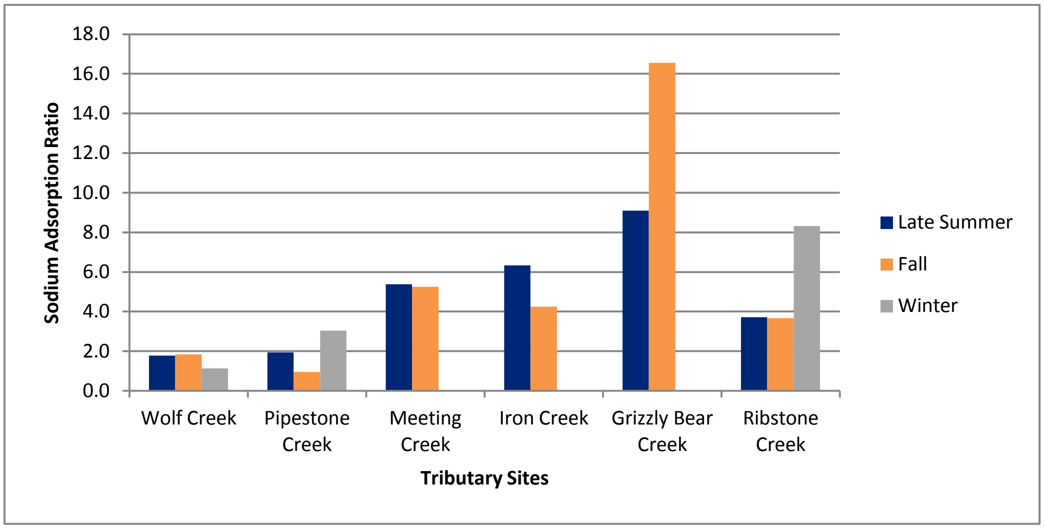


Figure 103 Sodium Adsorption Ratio of Major Tributaries along the Battle River in 2013.

5.4.7.3 Lagoon Discharges

The sodium adsorption ratio ranged from 7.7 to 17 in the sewage effluent from the five lagoons investigated (Figure 104). .

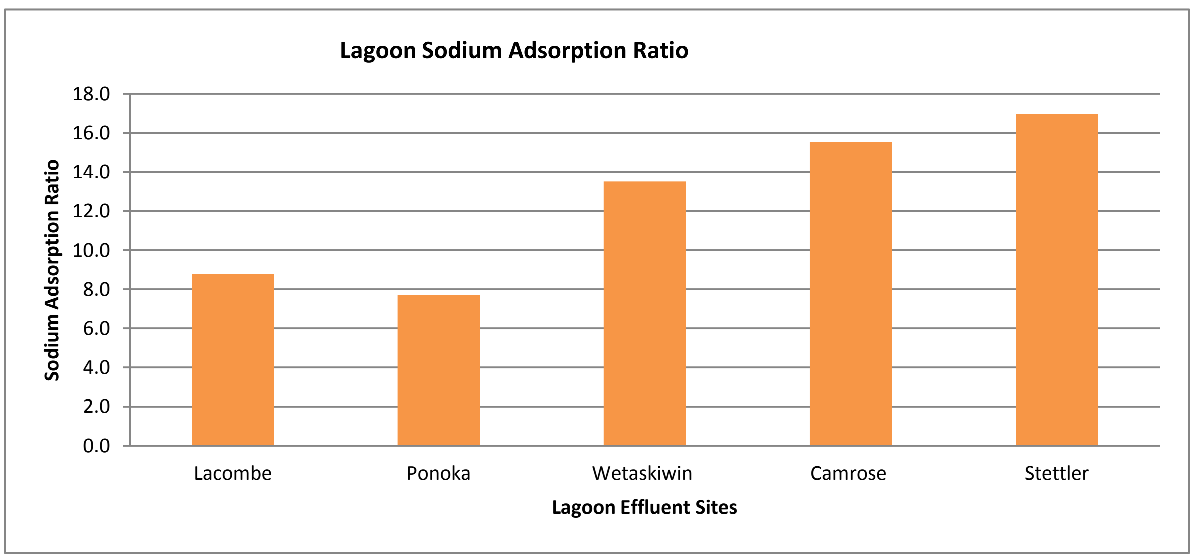


Figure 104 Sodium Adsorption Ratio of Five Lagoons along the Battle River in October of 2013.

5.4.8 Summary of Major Ions

Major ions showed a general increasing pattern from the headwaters to the Saskatchewan border, except chloride that only increased in reach 2 and then remained stable. Superposed on this general increasing trend were marked increases in chloride and fluoride downstream of Ponoka during the open-water season, possibly related to lagoon discharges. Sulphate also increased downstream of Ponoka, but this increase was consistent across seasons, indicating a non-point or internal source, possibly from decomposition of organic matter.

The majority of ions showed a notable decline between the site downstream of Ponoka and upstream of Pipestone Creek during the open-water season. This change suggests the dilution of Battle River water with a foreign water source of different geological origin. This change coincided with large increases in nutrients, fecal bacteria and carbon, pointing to a discharge of municipal or agricultural wastewater.

5.5 Bacteria

5.5.1 Escherichia coli

5.5.1.1 Mainstem Patterns

E. coli concentrations could not be compared to reach specific objectives because the analytical methods used to measure *E. coli* were not consistent with the methods used to establish the reach specific WQOs. The method used to measure *E. coli* in this study, the most probable number (mpn) method, usually results in higher quantities than the methods used to determine colony forming units (CFU) or No./100 mL (used to create objectives), because nonviable cells are counted as well. We therefore focus our discussion on spatial patterns evident within datasets of consistent analysis methods.

The highest concentrations of *E. coli* were observed during the summer 2013 survey along the Battle River. In both open-water surveys, *E. coli* counts peaked upstream of Pipestone Creek, decreased downstream of Pipestone Creek, and peaked again downstream of Driedmeat Lake. We have no information on a specific source between the site downstream of Ponoka and upstream of Pipestone Creek, but many water quality parameters beside *E. coli* changed significantly in this reach, indicating a significant input. Given the high bacteria counts, this source is likely livestock-related or human waste. The source of *E. coli* downstream of Driedmeat Lake is unknown as well. In summer, there was an additional peak upstream of Ponoka.

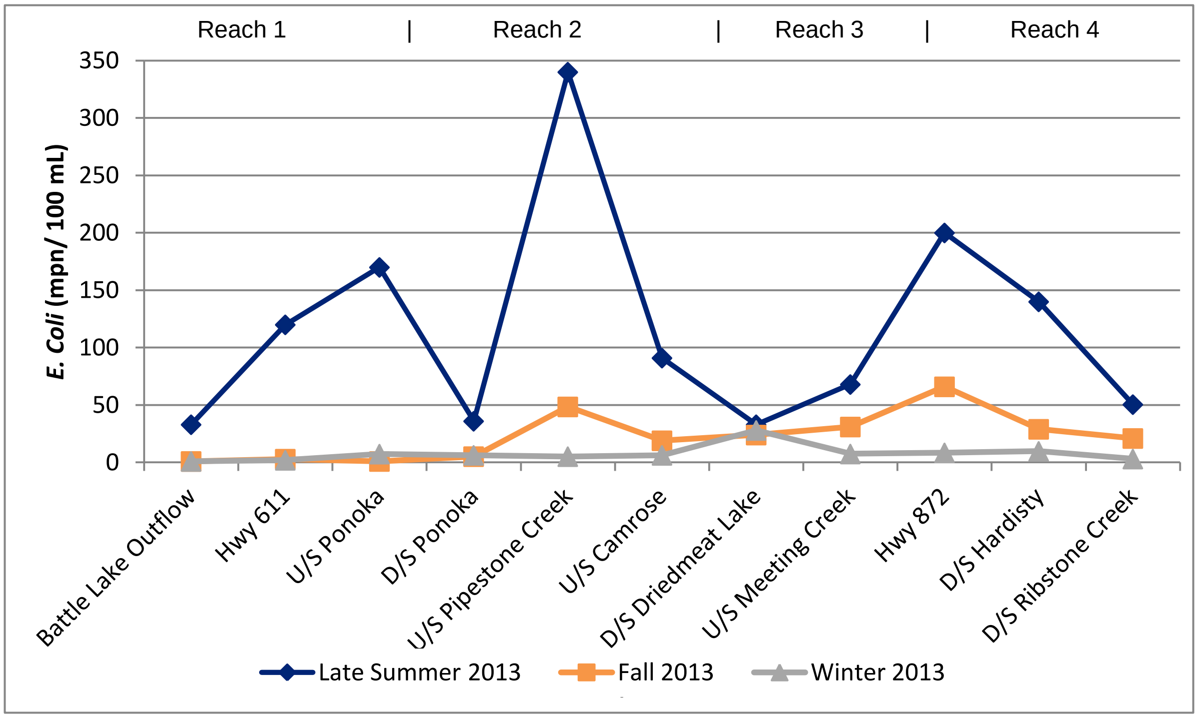


Figure 105. *E. coli* Concentrations in the Battle River in 2013.

5.5.1.2 Tributaries

The summer 2013 survey had the highest concentrations of *E. coli* in tributaries along the Battle River, ranging from 61 mpn/ 100 mL in Grizzly Bear Creek to 1400 mpn/ 100 mL in Meeting Creek (Figure 106). Concentrations of *E. coli* in Wolf Creek, Meeting Creek, Iron Creek and Ribstone Creek exceeded provincial and federal WQG for irrigation in summer of 2013. Manure spread on fields and runoff from manure storage sites can potentially be a source of the elevated bacteria counts in tributaries. The largest amount of manure per unit area is being produced in the watersheds of Wolf Creek and Pipestone Creek (Bigstone subwatershed), followed by intermediate amounts in Meeting (part of Paintearth), Ribstone and Iron Creek watersheds (). Lowest bacteria counts were recorded in the Blackfoot subwatershed, part of which is Grizzly Bear Creek, which had the lowest manure application rates.

In Wolf Creek, elevated concentrations in summer may have been associated with Lacombe lagoon discharge, which carried large counts (1200 mpn/100mL) of *E. coli* (Figure 109). Still, these numbers were expressed as mpn/100 mL, which indicates that a different method was used to enumerate bacteria than that for the WQO. Bacteria numbers in mpn units are usually higher than bacteria numbers in CFU and therefore the results for *E. coli* presented here cannot be directly compared to the WQOs or WQGs.

In fall 2013 *E. coli* concentrations ranged from 9.8 to 310 mpn/100 ML. Meeting Creek (310 mpn/100 mL) and Iron Creek (110 mpn/100 mL) (Figure 106). Winter concentrations were lower, ranging from 6.3 to 8.5 mpn/100 mL.

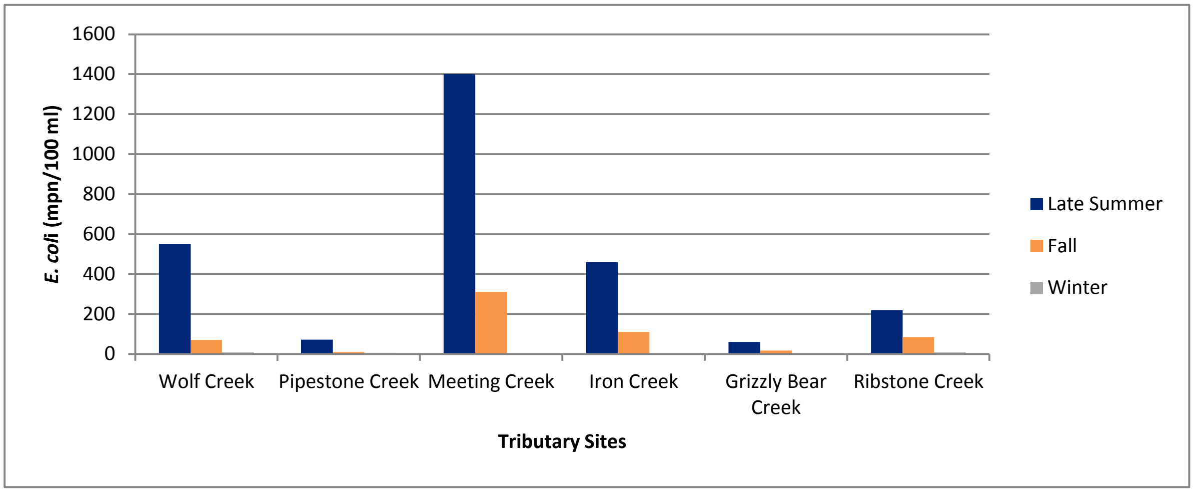


Figure 106 *E. coli* Concentrations in Major Tributaries along the Battle River in 2013.

E. coli loads were greatest in the summer of 2013, ranging from 0 mpn/day at Grizzly Bear Creek to 12735 mpn/day at Wolf Creek (Figure 107). In the fall, daily loads were less, with the exception of Iron Creek bearing a load of 589 mpn/day due to its higher flow in fall than summer.

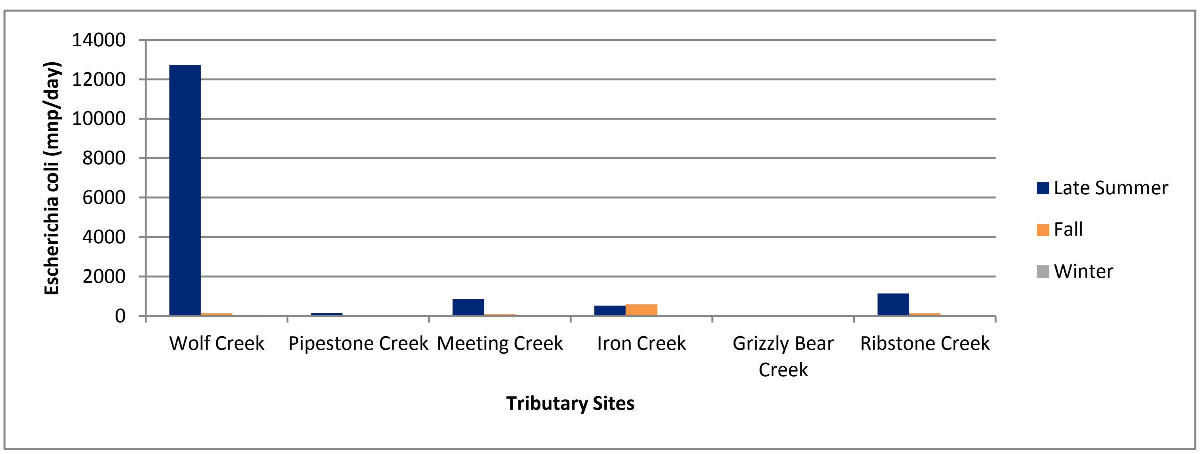


Figure 107. Daily Loads of *E. coli* in Five Major Tributaries along the Battle River in 2013.

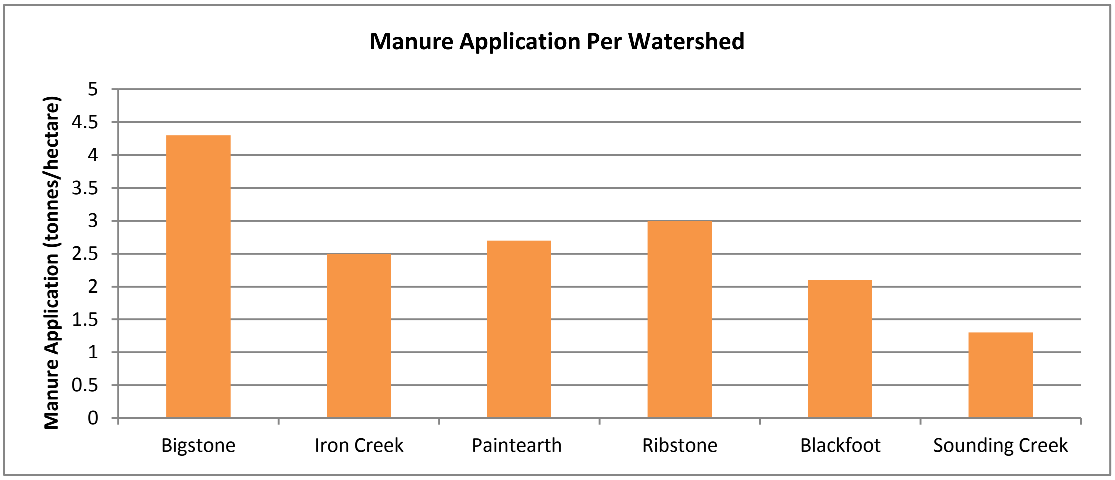


Figure 108. Manure Application in Six Watersheds within the Battle River Watershed.

Note: Data from State of the Watershed Report (BRWA 2011)

5.5.1.3 Lagoon Discharges

In four out of the five lagoon, *E. coli* concentrations were low, ranging from 1 to 41 mpn/100 mL (Figure 109). *E. coli* concentrations in Lacombe sewage effluent, however, were very high, measuring 1,200 mpn/100 mL. These high concentrations resulted in a high daily load (4458 mpn/day, data not shown).

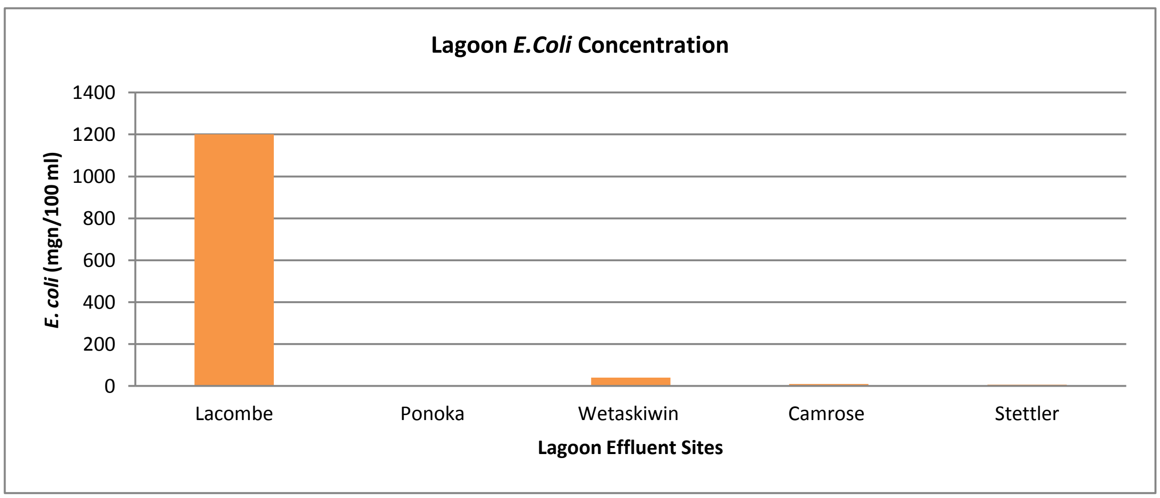


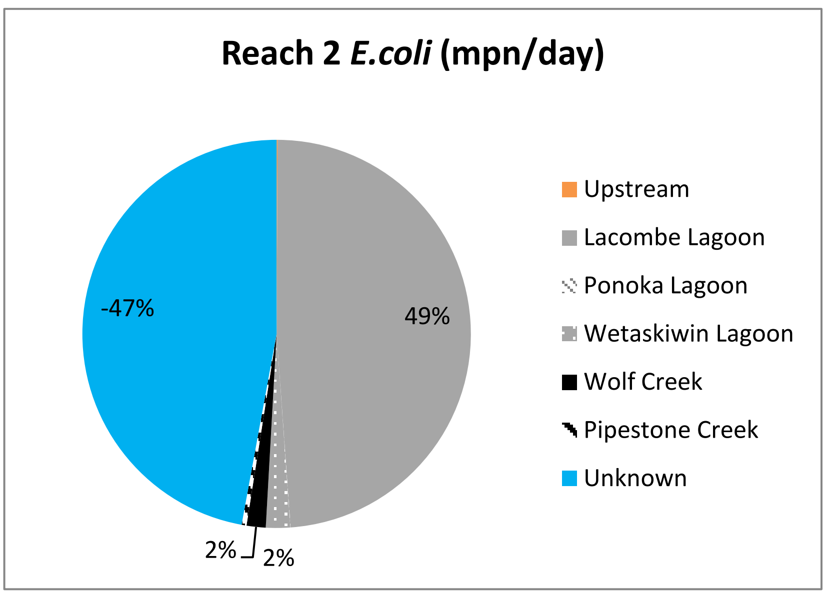
Figure 109. *E. coli* Concentrations in the Sewage Effluent of Five Lagoons along the Battle River in 2013.

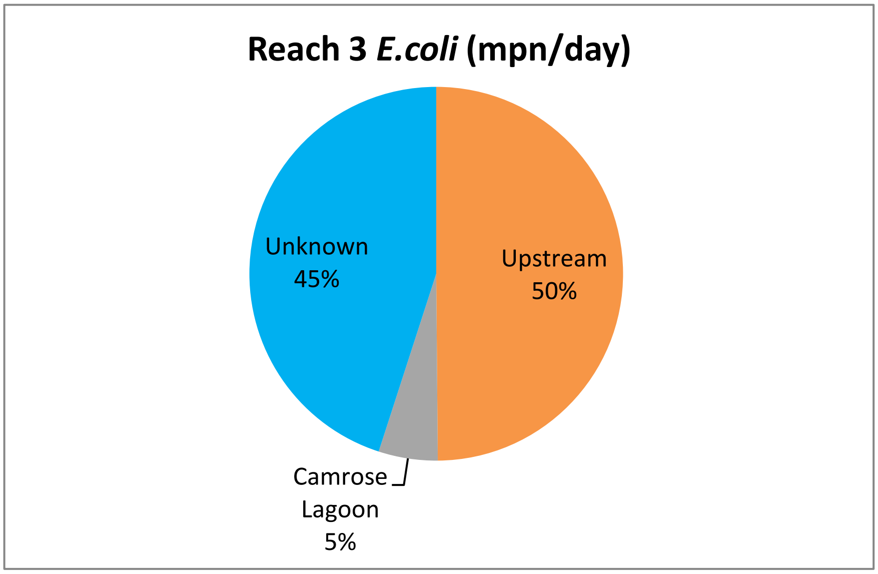
5.5.1.4 Escherichia coli Loads by Reach

Escherichia coli loads in Reach 2 originated primarily from lagoons (51%), most of which stemmed from the Lacombe effluent (49%). A small portion of the load originated from creeks and nothing was attributable to upstream loads. There was a large sink for *E. coli* in Reach 2, as 47% of the load was retained in the reach (Figure 110). Sand and sediment are known to act as temporal sources and sinks of human-derived *E. coli* (Ishii, Hansen, Hicks, & Sadowsky., 2007) and *E. coli* decline quickly in counts in natural, warm aquatic environments, presumably due to predation (Flint 1987, Wcisło and Chróst 2000).

In Reach 3 a large fraction of the *E. coli* load came from upstream (50%); another large portion is unknown. The unknown fraction of the *E. coli* load was a combination of an increase in concentration, as well as flow, at the downstream site.

In Reach 4, tributaries contributed a larger amount (10%) of the *E. coli* load than the Stettler lagoon. However, there was a large portion of the load originating from unknown sources. Discharge was not measured from either the Hardisty or Wainwright lagoons; however, the main difference between upstream and downstream sites was flow, suggesting neither of these sites were contributing large concentrations of *E. coli* to the Reach.





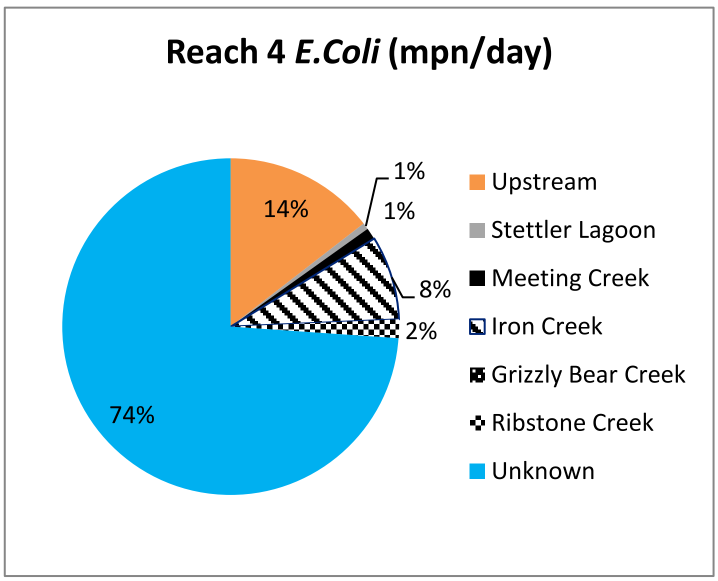


Figure 110. *E. coli* Load Break Down for Reaches 2, 3 and 4.

5.5.2 Fecal Coliforms

5.5.2.1 Mainstem Patterns

Fecal coliform concentrations at all sites in Reaches 1, 2 and 4 were above the 50th percentile WQO for their respective reaches in August with the exception of concentrations found at the outfall of Battle Creek. In Reach 2, fecal coliform concentrations upstream of Pipestone Creek (240 CFU/100 mL) and Camrose (86 CFU/100 mL) were above the 90th percentile WQO (70 CFU/100 ML). Upstream of Ponoka, Pipestone Creek and downstream of Hardisty fecal coliform concentrations exceeded the federal and province WQG for irrigation. No sample concentrations along the Battle River in the fall of 2013 exceeded reach specific WQOs, provincial or federal guidelines. In winter, samples collected upstream of Camrose (12 CFU/100 mL) in Reach 2, and downstream of Hardisty in Reach 4, exceeded the 50th percentile WQOs for their respective reaches.

The longitudinal patterns in fecal coliforms were similar to those of *E. coli,* with peaks upstream of Ponoka, upstream of Pipestone Creek and downstream of Driedmeat Lake. Summer concentrations were the greatest, ranging from 23 to 240 CFU/100 mL. In the fall and winter, fecal coliform concentrations ranged from below detection to 19 and 13 CFU/100 mL, respectively (Figure 111).

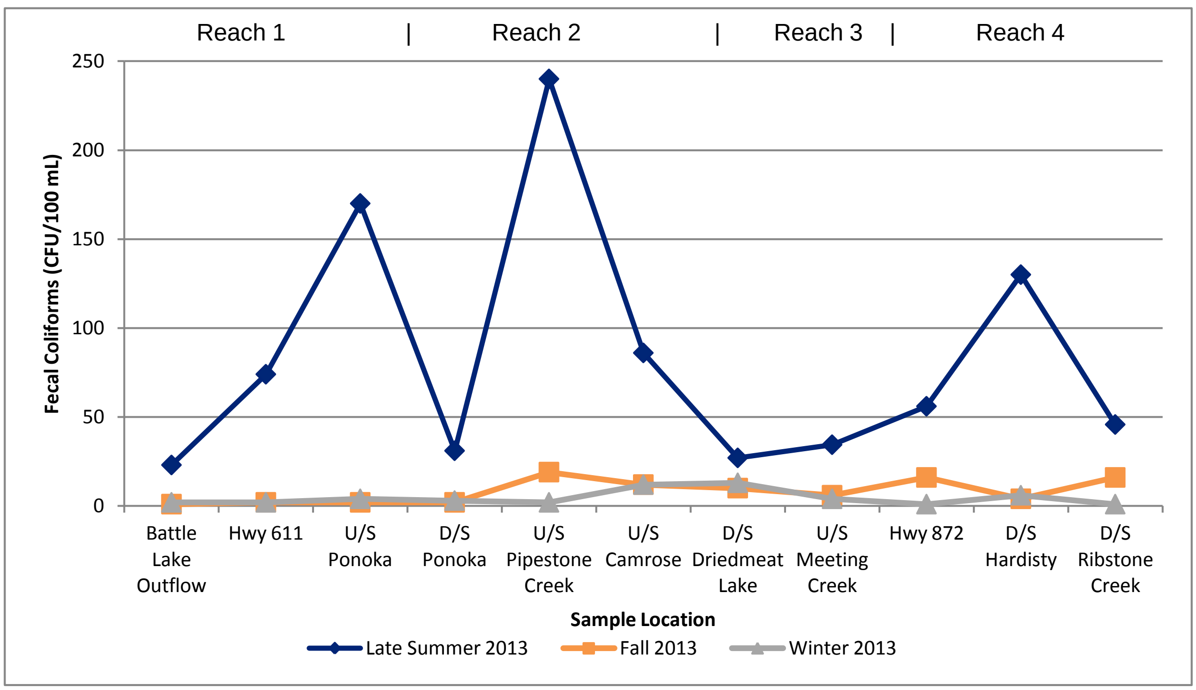


Figure 111. Fecal Coliform Concentrations along the Battle River in 2013.

5.5.2.2 Tributaries

Fecal coliform concentrations in tributaries along the Battle River were greatest during the summer survey, ranging from 46 to 260 CFU/100 mL. Concentrations in the fall of 2013 ranged from 2 to 68 CFU/100 mL. The lowest concentrations occurred in the winter and ranged from 2 to 14 CFU/100 mL (Figure 112).

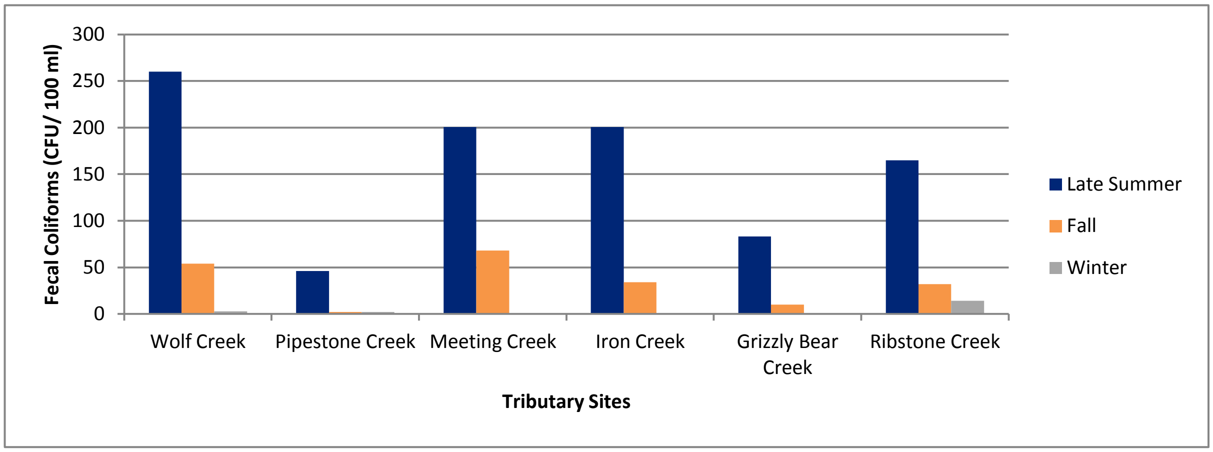


Figure 112 Fecal coliform Concentrations in Major Tributaries along the Battle River in 2013.

High fecal coliform concentrations in the summer reflected large summer daily loads, ranging from 7 to 6,011 CFU/day. Fall loads were lower, ranging from 5 to 182 CFU/day. Winter had the lowest loads, ranging from 0 (due to flow measurements of 0) to 19 CFU/day (Figure 113).

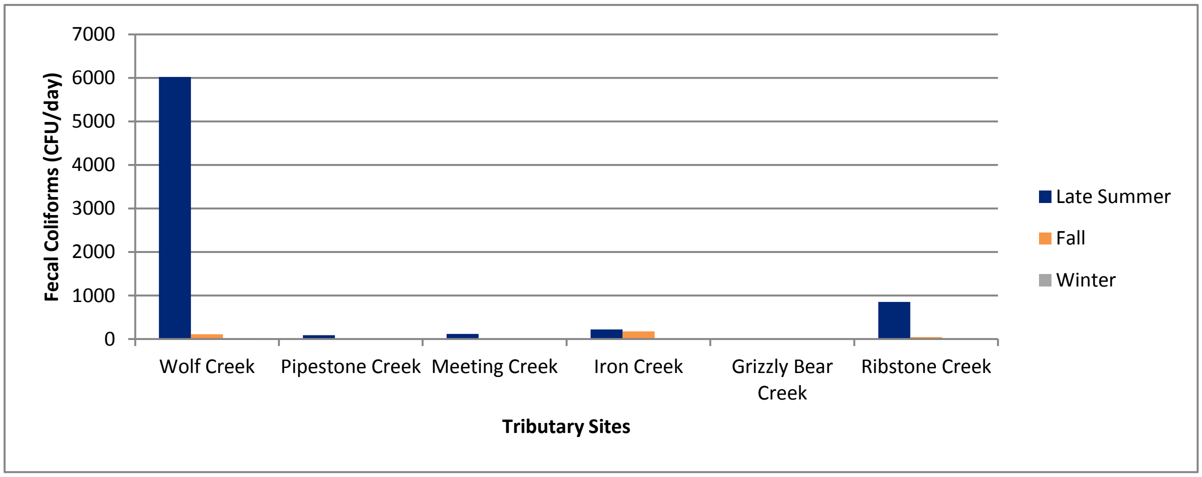


Figure 113 Fecal coliform Daily Loads in Six Major Tributaries along the Battle River in 2013.

5.5.2.3 Lagoon Discharges

Fecal coliform concentrations in the sewage effluent from five lagoons along the Battle River ranged from below detection to 650 mpn/100 mL (Figure 114). The largest fecal coliform daily load was measured from the Lacombe lagoon (2,976 mpn/day, data not shown) due to high concentrations.

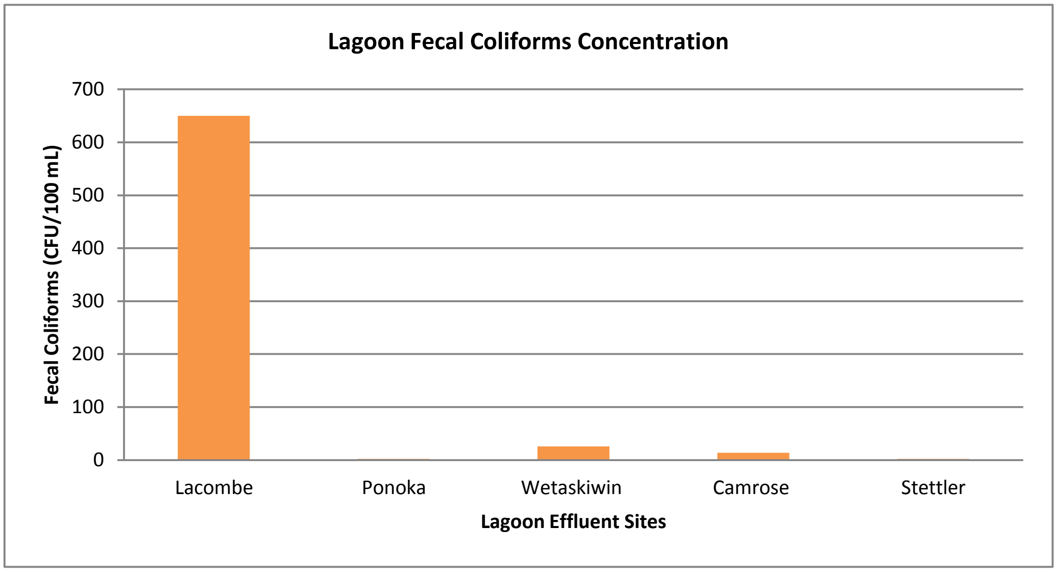
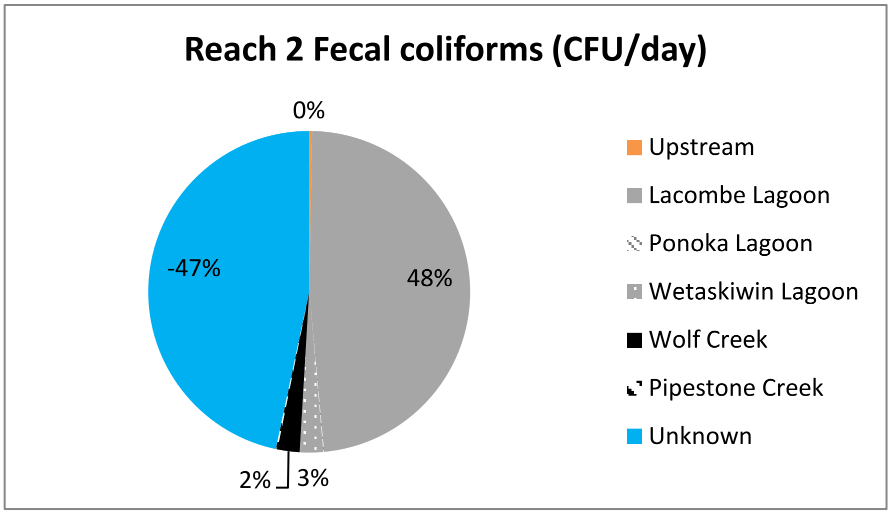
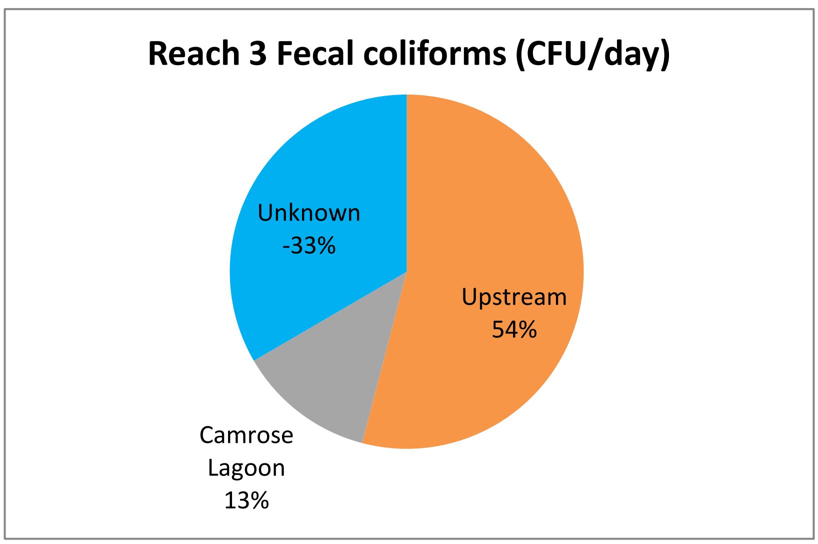


Figure 114. Fecal Coliform Concentrations for Five Lagoons along the Battle River in 2013.

5.5.2.4 Fecal coliform Loads by Reach

Fecal coliform load breakdown in Reach 2 was similar to that of *E. coli,* with the lagoons contributing the greatest fraction of the load and a large fraction remaining within the reach. Reach 3 was also similar to the *E. coli* break down, with a larger fraction originating from the Camrose lagoon (Figure 115). In Reach 4, a larger fraction of the fecal coliform load originated from unknown sources. In this instance, there was an increase in concentration downstream compared to upstream, as well as an increase in flow.





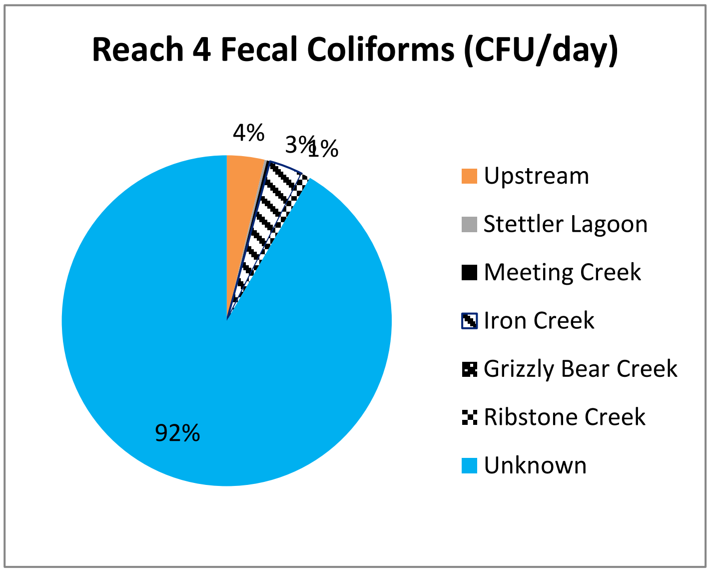


Figure 115. Fecal Coliform Load from Reaches 2, 3 and 4.

5.5.3 Summary of Bacteria

Bacterial counts were low in winter and fall and elevated in summer, occasionally exceeding the guideline for irrigation. Bacteria peaks were observed in areas lacking the influence of point-discharges; e.g., upstream of Ponoka, upstream of Pipestone Creek and downstream of Hardisty, suggesting that non-point sources contribute the main bacteria loads to Battle River.

5.6 Other Parameters

5.6.1 Total Organic Carbon

5.6.1.1 Mainstem Patterns

During the summery 2013 survey, TOC concentrations exceeded the 90th percentile WQO (23 mg/L) upstream of Pipestone Creek. There are no provincial or federal guidelines for TOC.

There were seasonal differences in TOC concentrations in Reaches 1, 2 and 3, however in Reach 4, TOC concentrations remained similar. In Reaches 1 through 3, winter concentrations were below those of summer or fall in 2013, while in 2011, winter concentrations were higher than summer or fall concentrations in Reaches 2 and 3 (Figure 116). With the exception of the outflow of Battle Lake and Hwy 611, summer concentrations were greater than those in fall. Summer concentrations rose in Reach 1, peaked in Reach 2 upstream of Pipestone Creek in all seasons and years, and declined from upstream of Camrose to the end of Reach 4. The peak upstream of Pipestone Creek may be due to the Samson Lake wetland complex, which may leach dissolved organic carbon into the water.

Fall TOC concentrations ranged from 11 to 19 mg/L, peaking in Reach 2. These results were different from those of the 2011 campaign. .

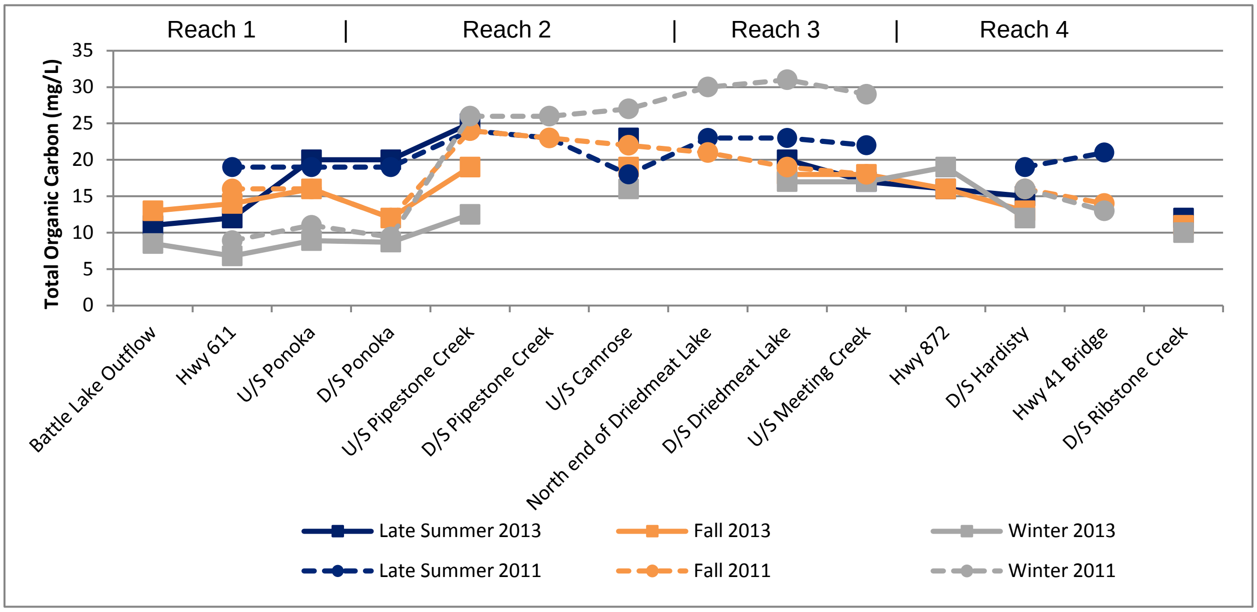


Figure 116 Total Organic Carbon Concentrations along the Battle River 2011 and 2013.

5.6.1.2 Tributaries

Total organic carbon concentrations in summer 2013 ranged from 11 mg/L in Pipestone Creek to 32 mg/L in Iron Creek, with clearly higher TOC levels in the reach 4 tributaries compared to the tributaries located further upstream. In the fall, TOC concentrations ranged from 10 to 22 mg/L and in winter, TOC concentrations ranged from 6.4 to 12 mg/L. Similar to the mainstem, summer TOC concentrations were greater than fall or winter in four of the six creeks (Figure 117).

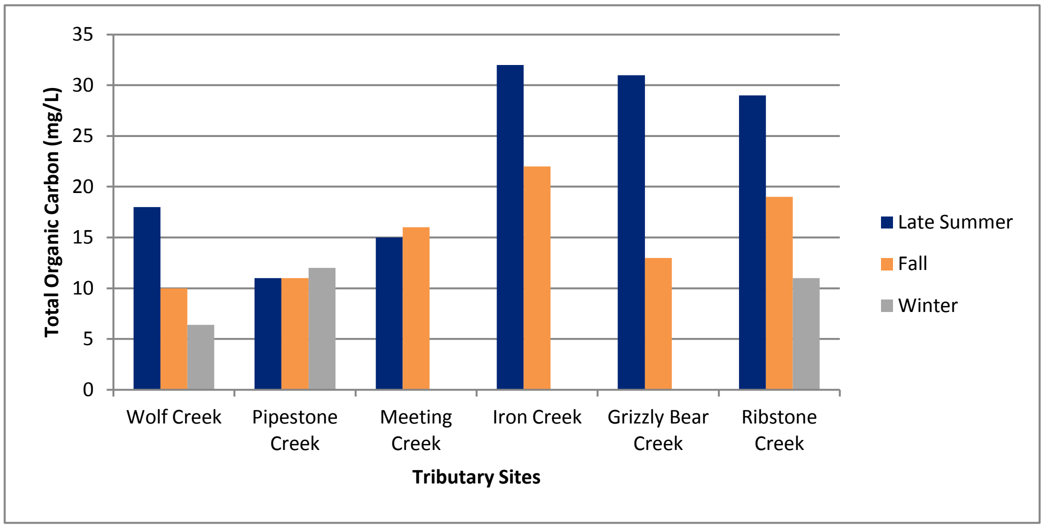


Figure 117. TOC Concentrations in Six Tributaries along the Battl eRiver in 2013.

Total organic carbon loads were greatest in the summer due to higher flows and concentrations than the other two seasons. Daily loads were greatest in Wolf Creek in the summer (416.2 kg/day) and winter (39.8 kd/day) when compared to the other creeks. In the fall, Iron Creek had the largest daily load (118 kg/day) (Figure 118).

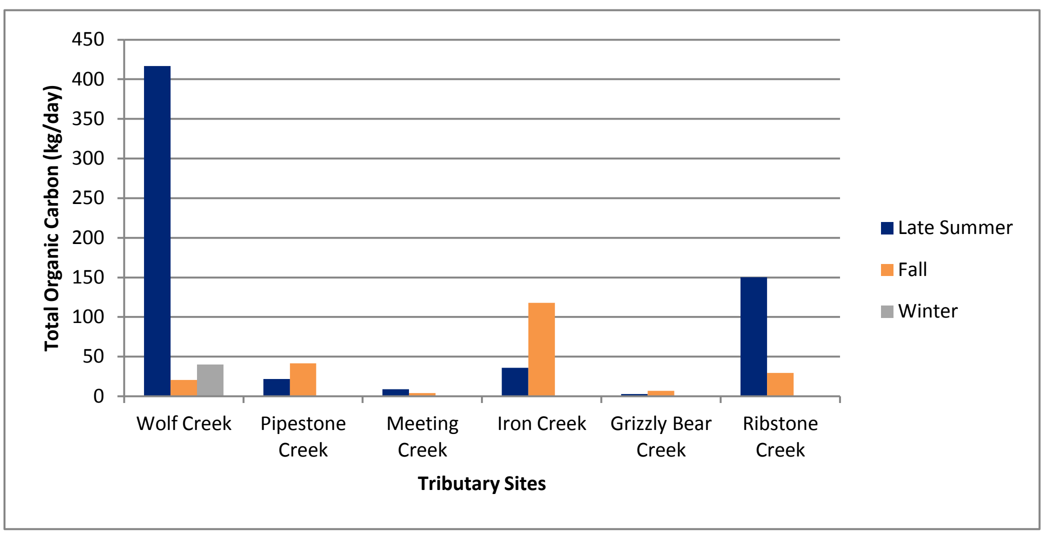


Figure 118. Daily TOC Loads for Six Tributaries along the Battle River in 2013.

5.6.1.3 Lagoon Discharges

Total organic carbon concentrations ranged from 11 to 17 mg/L in five lagoons along the Battle River in October of 2013, showing similar concentrations as mainstem and tributary samples. Camrose and Stettler concentrations were greatest (Figure 119). High TOC concentrations and flows measured at Camrose and Stettler lagoons resulted in these two lagoons having the largest daily TOC loads (Figure 120).

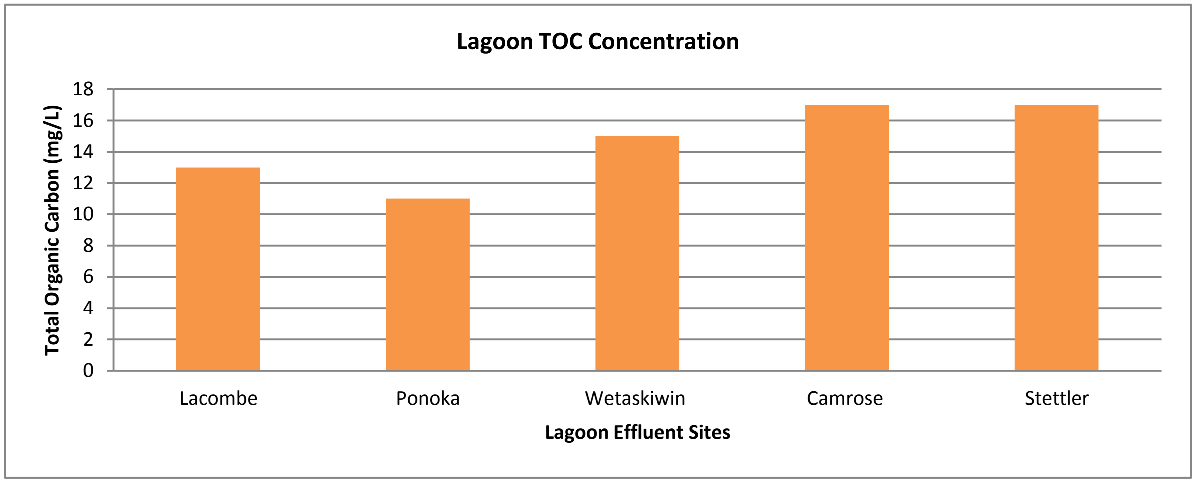


Figure 119 Total Organic Carbon Concentrations in Five Lagoons along the Battle River in 2013.

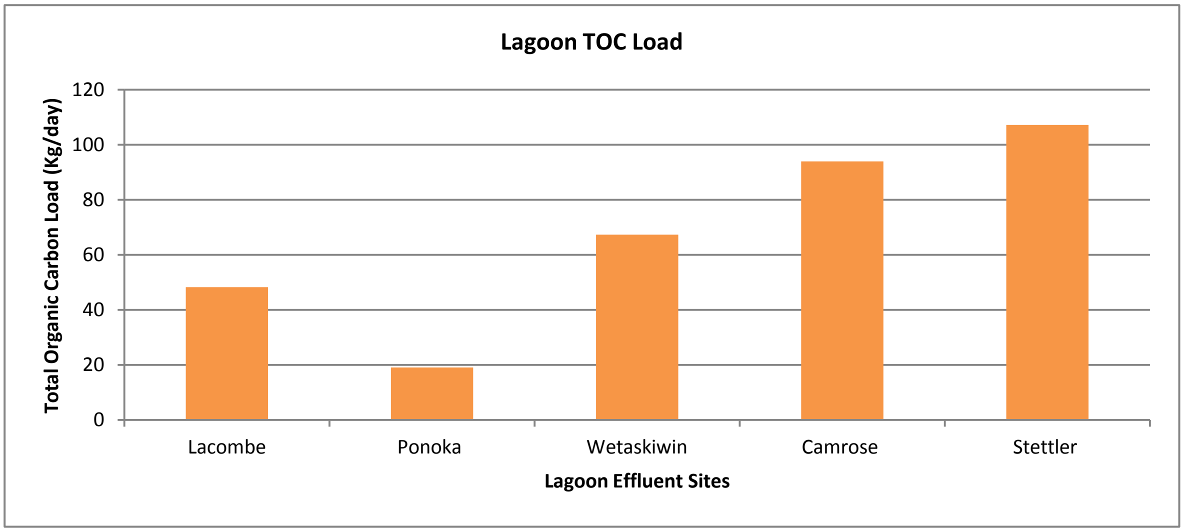
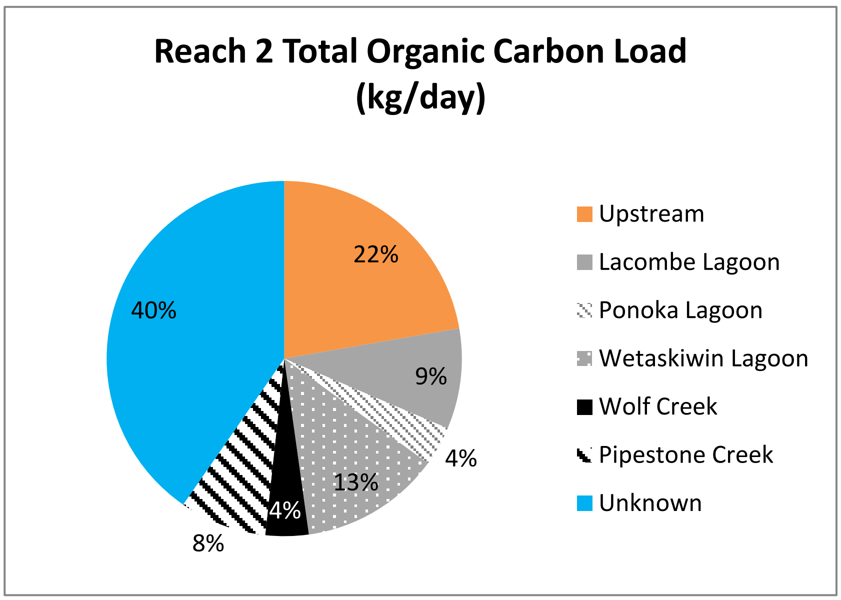
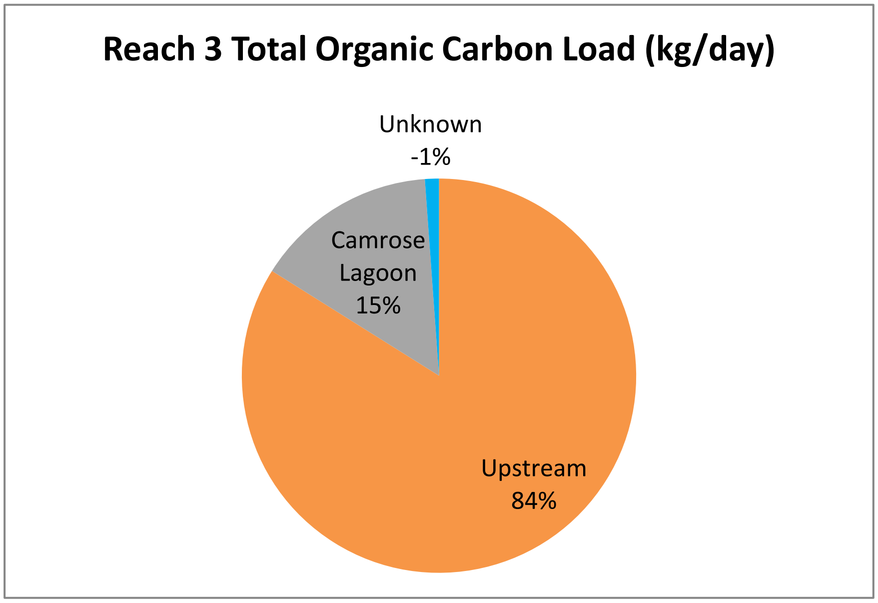


Figure 120. Daily TOC Loads from Five Lagoons along the Battle River in 2013.

5.6.1.4 Total Organic Carbon Loads by Reach

The TOC load in Reach 2 originated primarily from unknown sources (40%). Given the large increase in TOC from downstream of Ponoka to upstream of Pipestone Creek, this unknown load may in part be attributed to the unknown source that was identified through several water quality parameters in this region. Upstream loads (22%) and lagoon loads (26%) contributed similar amounts to the total reach load. Creeks contributed the least to the total creek load, and Pipestone Creek contributed double the amount Wolf Creek did to the total creek TOC load. In Reach 3, the TOC load came chiefly from upstream (84%). The lagoon contributed a small portion to the total load and a very small fraction of TOC (1%) was retained in Reach 3. In Reach 4, the majority of TOC came from an unknown source and tributaries had little influence on TOC in this reach, likely due to the low flows and despite more elevated concentrations compared upstream tributaries (Figure 121). Concentrations in reach 4 decreased downstream; therefore, the large difference in load upstream to downstream was attributable to increased flow.





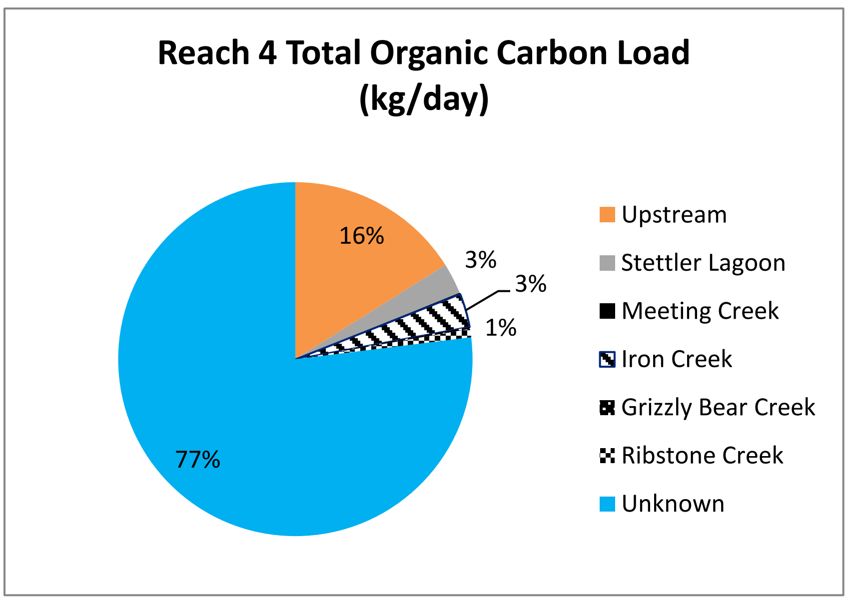


Figure 121. TOC Loads for Reaches 2, 3 and 4.

5.6.2 Total Suspended Solids

5.6.2.1 Mainstem Patterns

There was a longitudinal pattern in TSS concentrations in 2011 and 2013. There were minimal concentrations of TSS in Reach 1. There was a peak in Reach 2 downstream from Pipestone Creek in all seasons in 2011. This site was not visited in 2013, but given the comparatively slight increases in TSS at the next downstream site upstream of Camrose, this pattern may have been unique to 2011. There was a peak in 2011 downstream of Driedmeat Lake, which was not confirmed in 2013. In winter 2011 and 2013 winter concentrations increased in Reach 4.

TSS concentrations were higher in 2011 than 2013 at most sites along the Battle River (Figure 122). There was also higher flow, indicating that this might be due to greater precipitation increasing flow and TSS from surface runoff. TSS data for fall 2013 were not available due to a lab communication error and therefore no direct comparisons can be made for fall data. Turbidity data, which are usually strongly correlated with TSS, suggest that fall 2013 TSS followed similar patterns as in 2011, with generally low values and a peak downstream of Driedmeat Lake, possibly due to local sediment inputs through the limited riparian buffers in this channelized river reach.

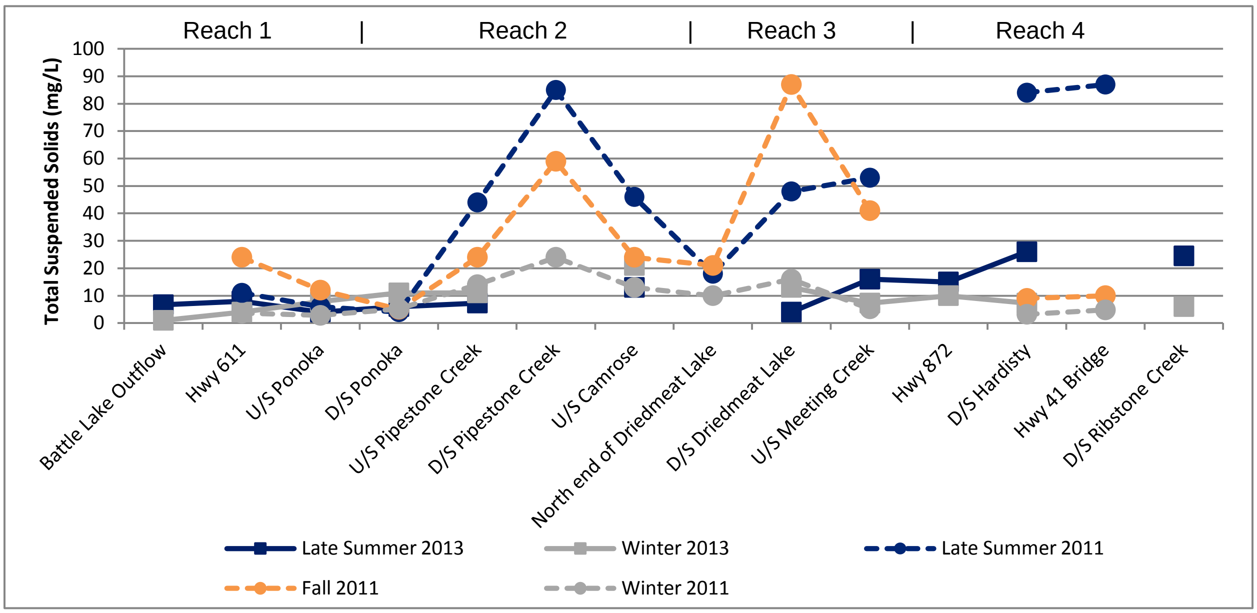


Figure 122 Total Suspended Solids Concentrations along the Battle River in 2011 and 2013.

5.6.2.2 Tributaries

In 2013, summer concentrations of TSS in tributaries were low, ranging from 2 to 13 mg/L. For fall, no data were available. In winter, concentrations declined overall and ranged from 5.3 to 11 mg/L (Figure 123). In the summer, flow greatly influenced loads, as Wolf Creek had the largest daily TSS load in summer (Figure 124).

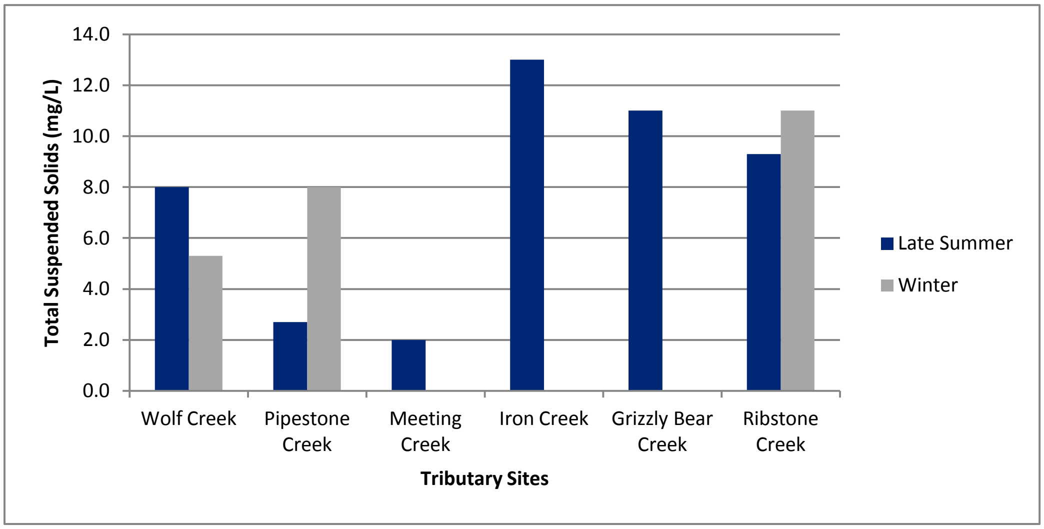


Figure 123 Total Suspended Solid Concentrations in Major Tributaries along the Battle River in 2013.

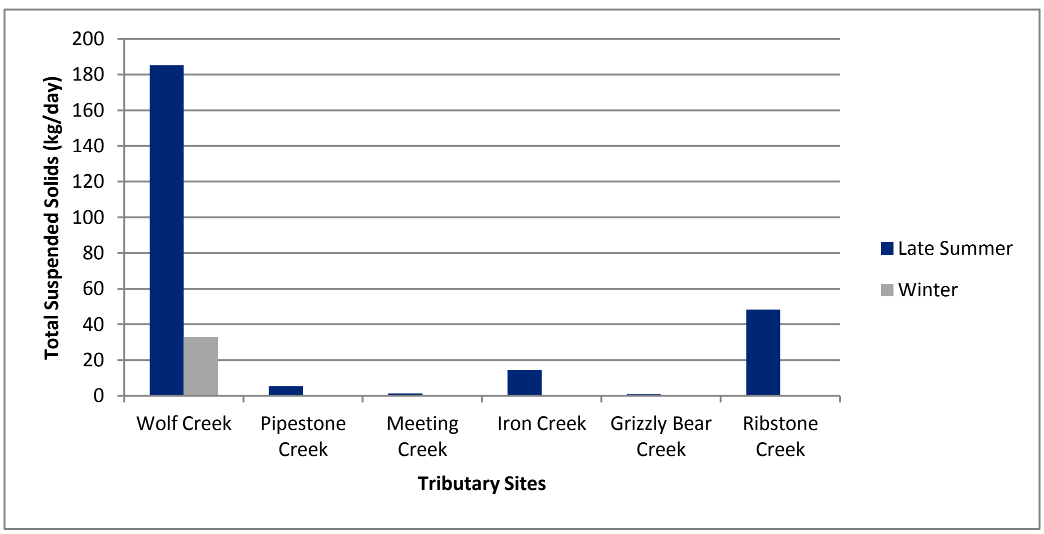


Figure 124 Daily TSS Loads in Six Major Tributaries along the Battle River in 2013.

5.6.3 Total Dissolved Solids

5.6.3.1 Mainstem Patterns

During the 2013 campaign, the sample downstream of Ribstone Creek had concentrations greater than the 90th percentile WQO (616 mg/L) for reach 4, but no other notable trends were observed with regards to the WQOs.

Total dissolved solid concentrations increased along the Battle River in 2011 and 2013 and, as expected, mirror spatial patterns in conductivity. In fall and summer there were peaks in TDS downstream of Ponoka, likely due to lagoon discharge influence. In winter, TDS concentrations peaked upstream of Camrose. Fall concentrations were greater than summer concentrations and winter concentrations were greater than fall concentrations—with the exception of Battle River at Hwy 611, downstream of Ponoka and downstream of Ribstone Creek where fall concentrations were higher. Winter concentrations in 2011 were also greater than fall or summer concentrations, similarly to 2013, however, winter 2011 concentrations were higher than winter 2013 concentrations (Figure 125).

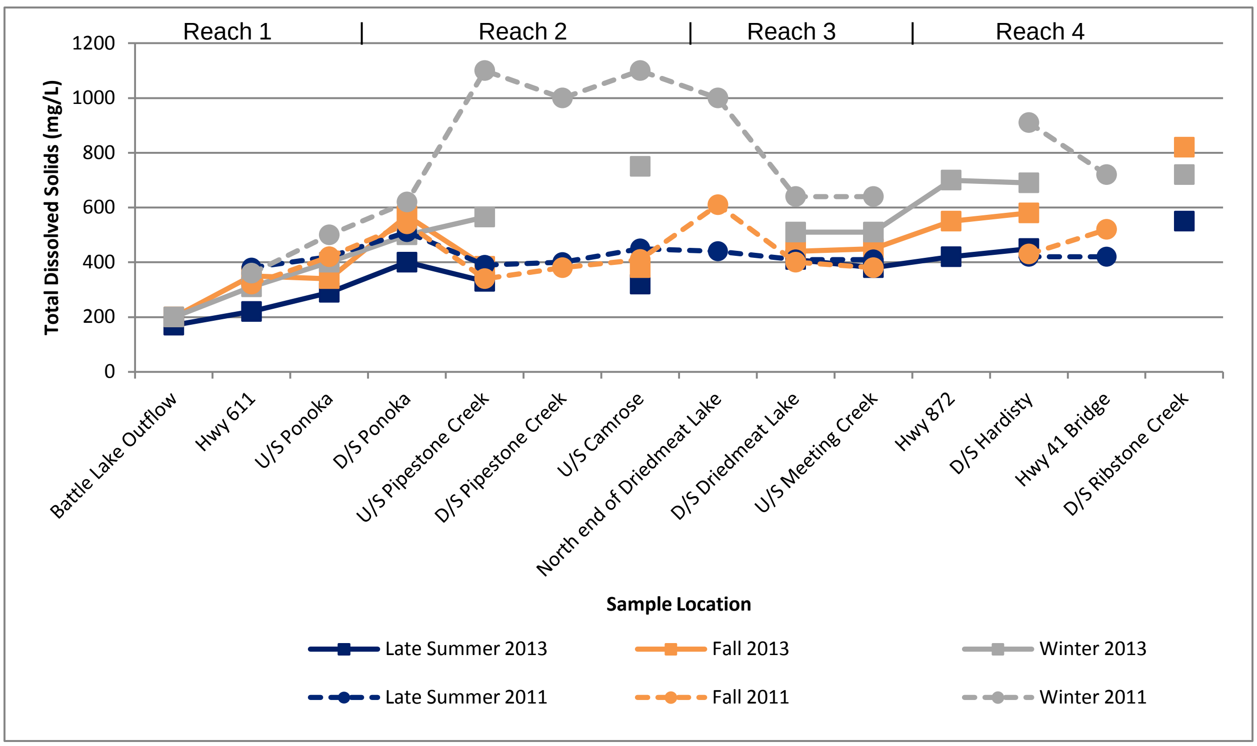


Figure 125 Total Dissolved Solid Concentrations along the Battle River in 2011 and 2013.

5.6.3.2 Tributaries

Total dissolved concentrations ranged from 266 mg/L at Pipestone Creek to 1010 mg/L in Grizzly Bear Creek during the summer 2013 survey. TDS was generally higher in the eastern tributaries than in the headwater tributaries, in expected accordance with conductivity and major ion concentrations. In the fall, TDS concentrations were slightly higher in tributaries, ranging from 330 mg/L to 1276 mg/L. Winter concentrations were not consistently higher in the three creeks measured (Figure 126). Due to high flows, summer TDS loads were higher than other seasons in most creeks, with the exception of Pipestone Creek and Iron Creek (Figure 127). Pipestone Creek had a higher TDS concentration in fall, as well as greater flow. Iron Creek had a lower TDS concentration in the fall, but higher flow.

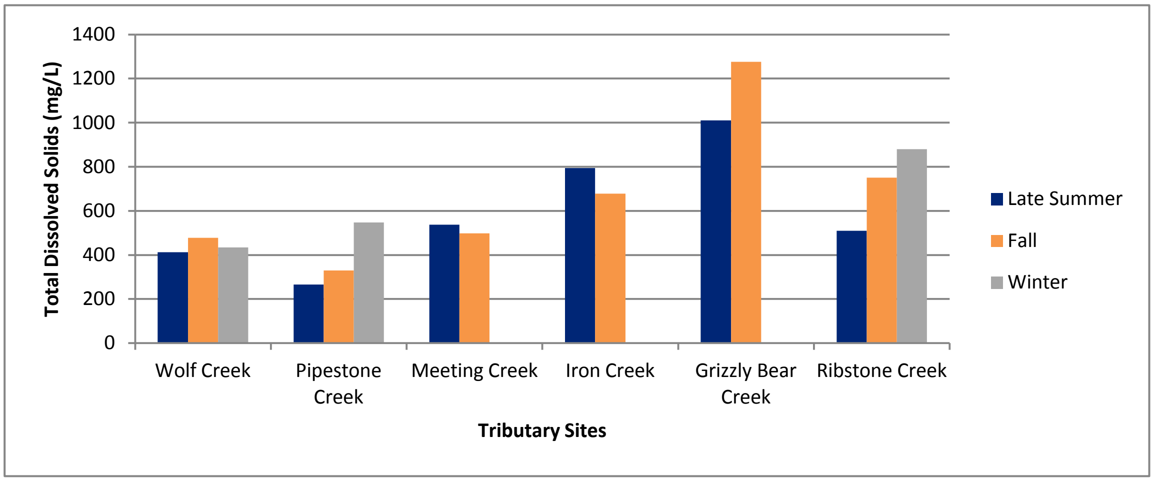


Figure 126 Total Dissolved Solid Concentrations in Major Tributaries along the Battle River.

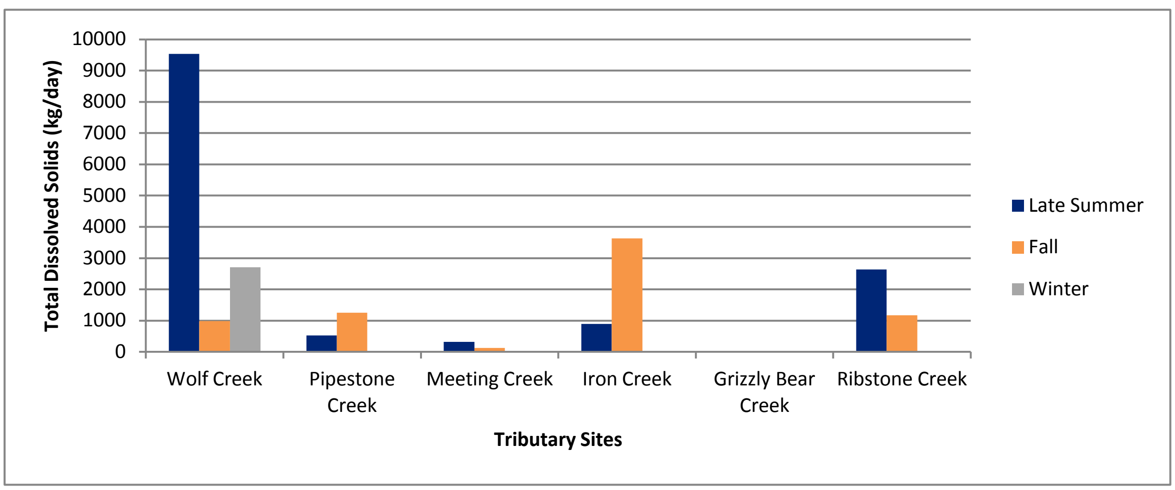


Figure 127 Total Dissolved Solid Loads in Major Tributaries along the Battle River in 2013.

5.6.3.3 Lagoon Discharges

Total dissolved solid concentrations in the lagoons along the Battle River ranged from 590 mg/L in Ponoka sewage effluent to 1100 mg/L in the sewage effluent of Wetaskiwin, Camrose and Stettler (Figure 128). The high concentration of TDS in Camrose and Stettler effluent, along with their high flows, resulted in large daily loads (Figure 129).

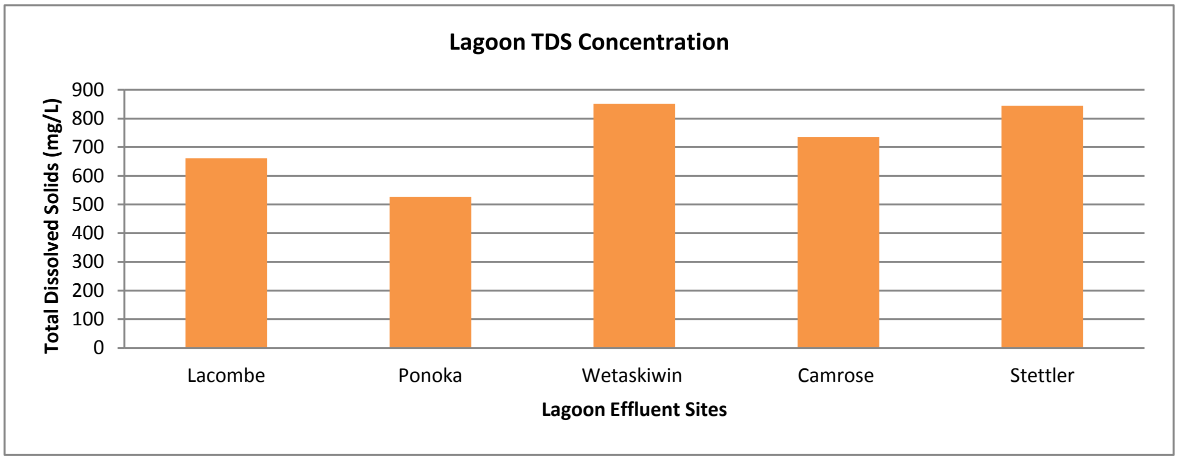


Figure 128 Total Dissolved Solid Concentrations in Sewage Effluent of Five Lagoons along the Battle River.

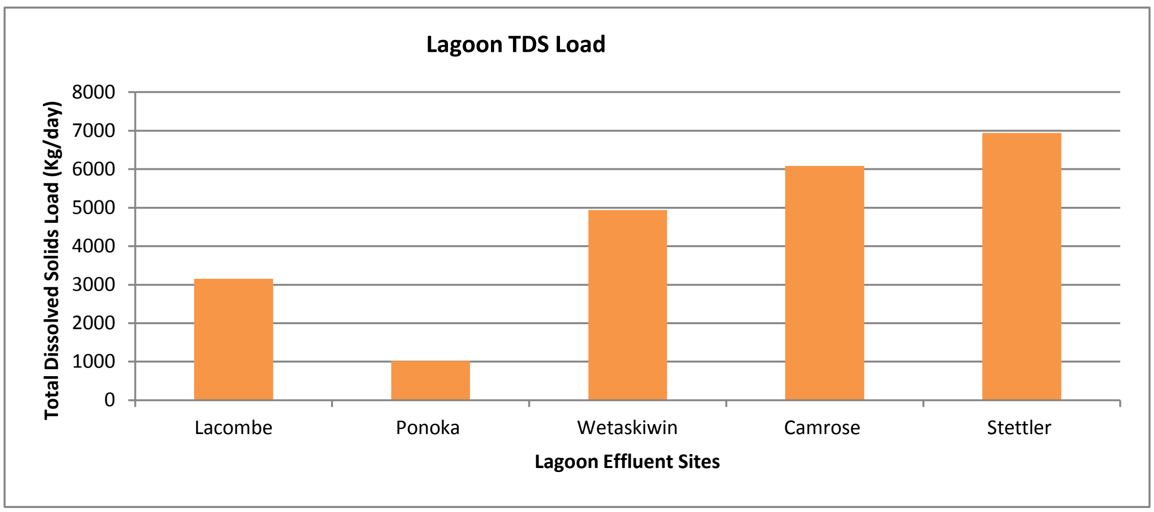
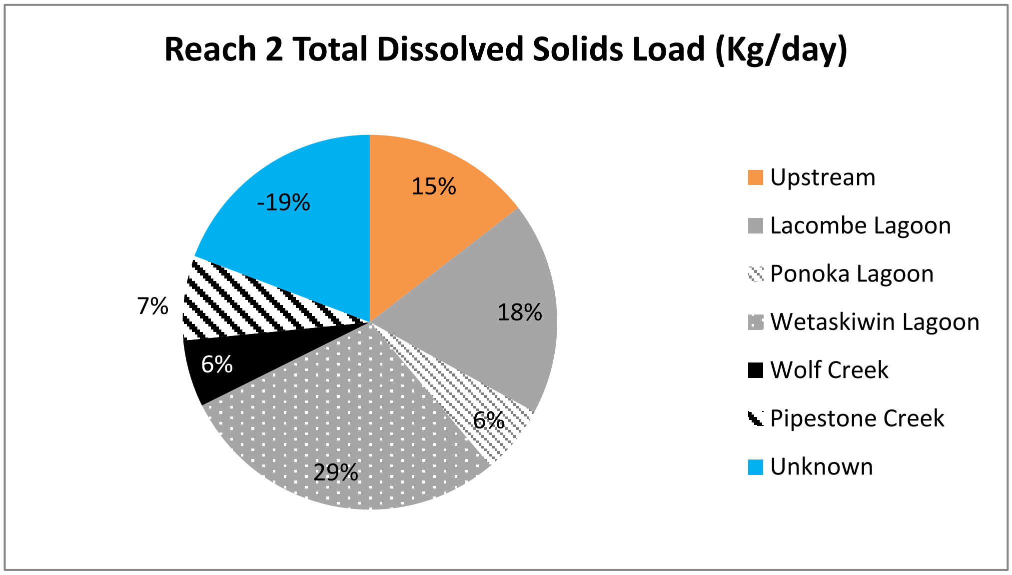
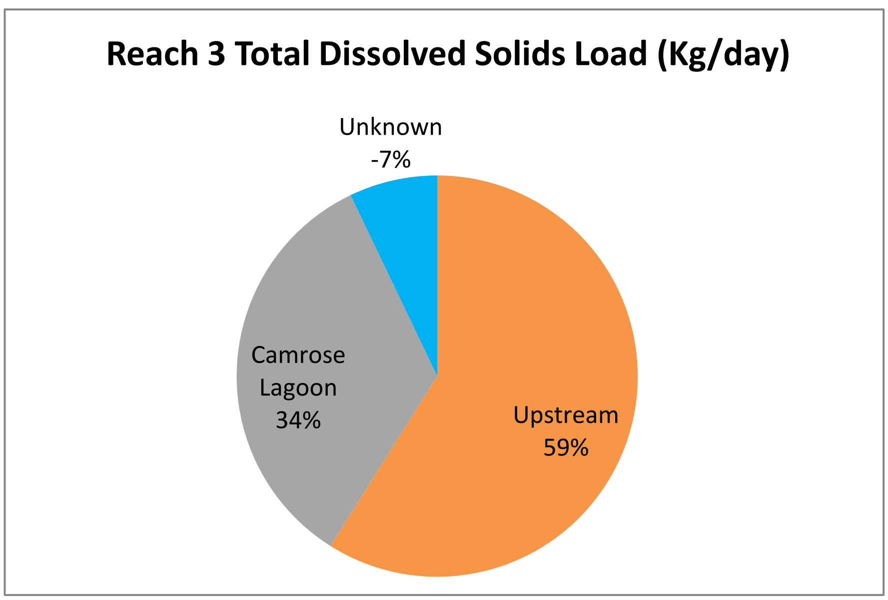


Figure 129 Total Dissolved Solid Loads of Five Lagoons along the Battle River.

5.6.3.4 Total Dissolved Solids Loads by Reach

The TDS load in Reach 2 was principally from lagoons, with Wetaskiwin being the main contributor. There was a TDS sink in Reach 2, as 19% of the expected load was not measured at the downstream station. Given the usually conservative nature of TDS, this is likely due to losses in flow or overestimation of lagoon discharge flow. In Reach 3, the TDS load came chiefly from upstream. There was also a TDS sink in Reach 3 (Figure 130). In reach 4, the majority of TDS originated from unknown sources, likely local tributaries and groundwater, with both TDS concentration and flow increasing at the downstream site of Reach 4.





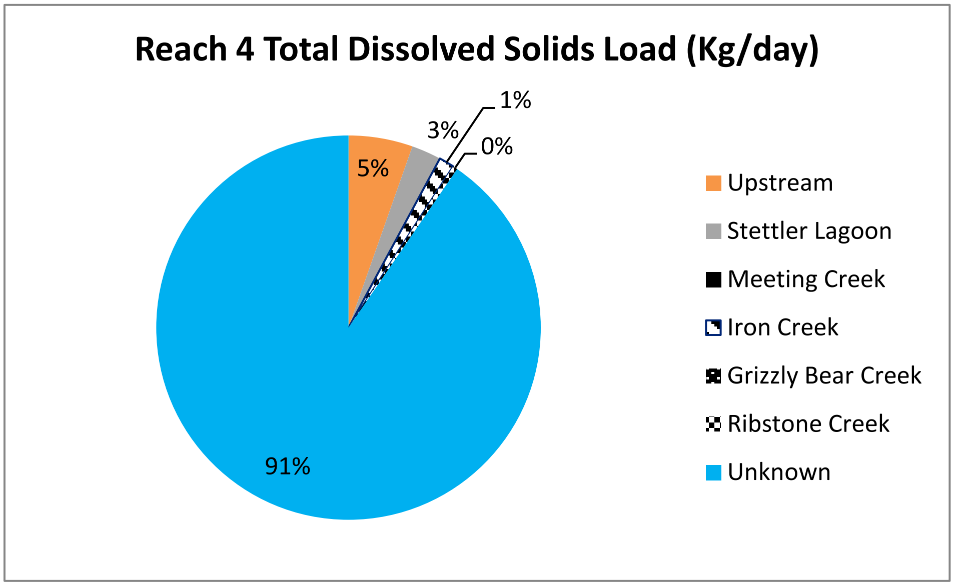


Figure 130. TDS Loads for Reach 2, 3 and 4.

5.6.4 Hardness

5.6.4.1 Mainstem Patterns

There are no provincial or federal WQG for hardness, as the parameter itself has no direct effect on aquatic biota; the importance of hardness is in regulating toxicity of other substances to aquatic biota. Hardness did not show any particular patterns in relation to reach-specific WQOs.

Seasonal and spatial patterns in hardness were similar to patterns in major ions that form part of hardness, such as calcium and magnesium. In Reach 1, hardness increased during all three seasons—with the exception of fall, upstream of Ponoka. In the summer and fall of 2013, hardness peaked downstream of Ponoka, fell at the site upstream of Pipestone Creek and remained stable throughout the remainder of Reach 2. Along Reaches 3 and 4, hardness gradually increased. Winter concentrations were greater than fall concentrations, followed by summer concentrations, with the exception of the outflow of Battle Lake and at Hwy 611. Winter concentrations peaked upstream of Camrose, fell upstream of Driedmeat Lake, and slowly increased along Reach 4. These results were similar to those obtained in 2011—with the exceptions of 2011 concentrations being higher seasonally; and of Reach 4 in the summer, where 2013 concentrations were higher (Figure 131).

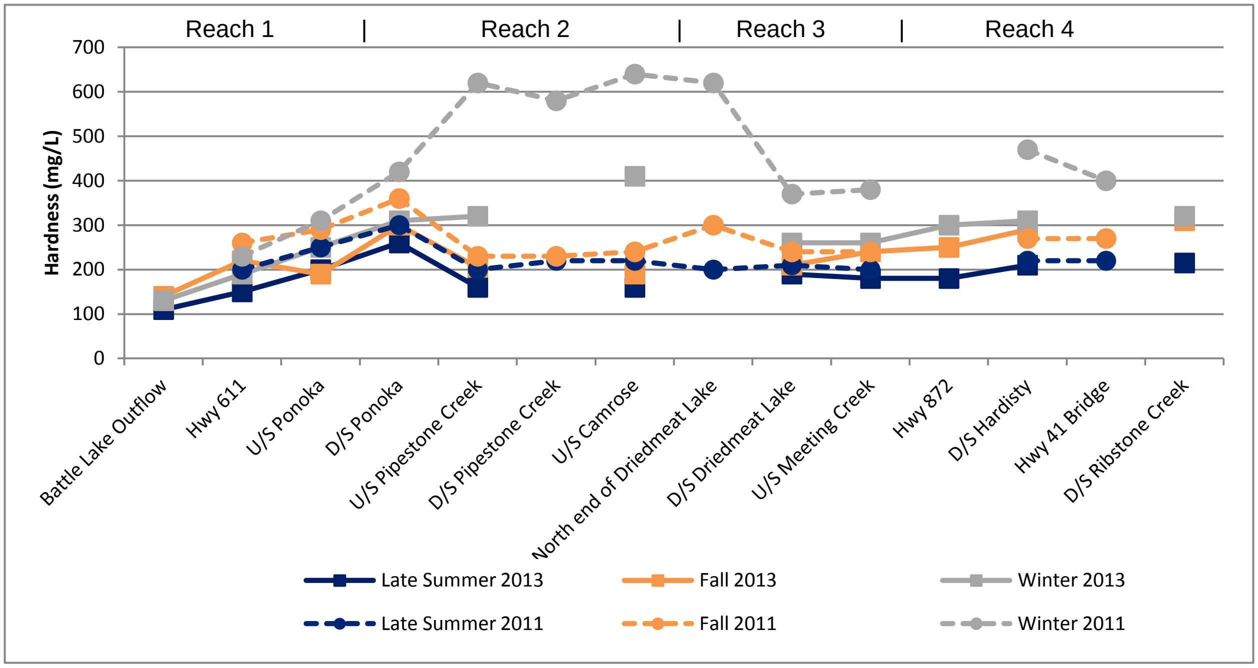


Figure 131 Hardness along the Battle River in 2011 and 2013.

5.6.4.2 Tributaries

In the summer, hardness concentrations ranged from 150 mg/L to 350 mg/L in the major tributaries along the Battle River. In the fall, hardness concentrations ranged from 200 mg/L in Pipestone Creek to 420 mg/L in Iron Creek. In the three creeks where measurements were taken in the winter, winter hardness concentrations were greatest, ranging from 300 mg/L in Ribstone Creek to 400 in Wolf Creek (Figure 132). In summer and winter, Wolf Creek had the largest daily Hardness loads (Figure 133). This was due to a combination of high $CaCO_3$ concentrations and high flows in Wolf Creek. In the summer, Ribstone had the second largest load (1400 kg/day), again, due to a combination of flow (0.06 m^3/s) and concentration (270 mg/L). In the fall, Iron Creek had the largest concentration (420 mg/L), flow (0.062 m^3/s) and therefore load (2250 kg/day).

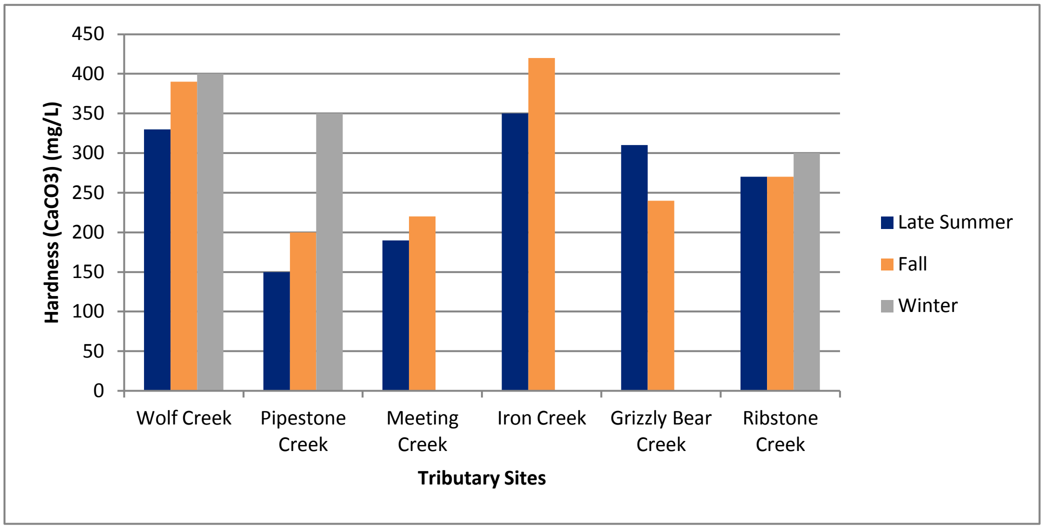


Figure 132 Hardness in Six Major Tributaries along the Battle River in 2013.

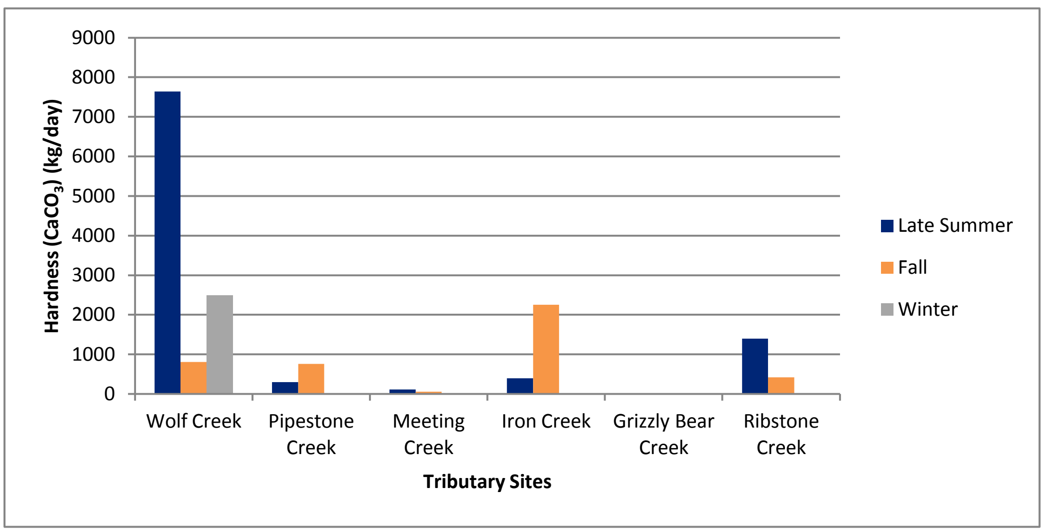


Figure 133 Hardness Loads in Six Major Tributaries along the Battle River in 2013.

5.6.4.3 Lagoon Discharges

Hardness concentrations ranged from 290 mg/L in Ponoka effluent to 450 mg/L in Wetaskiwin sewage effluent (Figure 134). Hardness loads ranged from 501 kg/day in Ponoka due to the low concentrations and low flow to 2586 kg/day in Stettler effluent due to high concentrations and high flows (Figure 135).

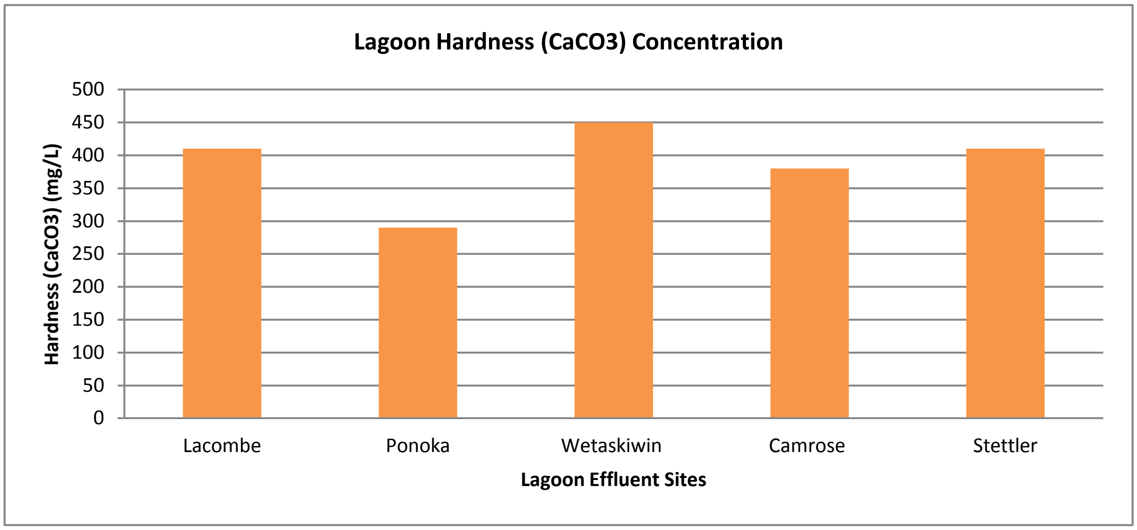


Figure 134 Hardness of Sewage Effluent from Five Lagoons along the Battle River in October 2013.

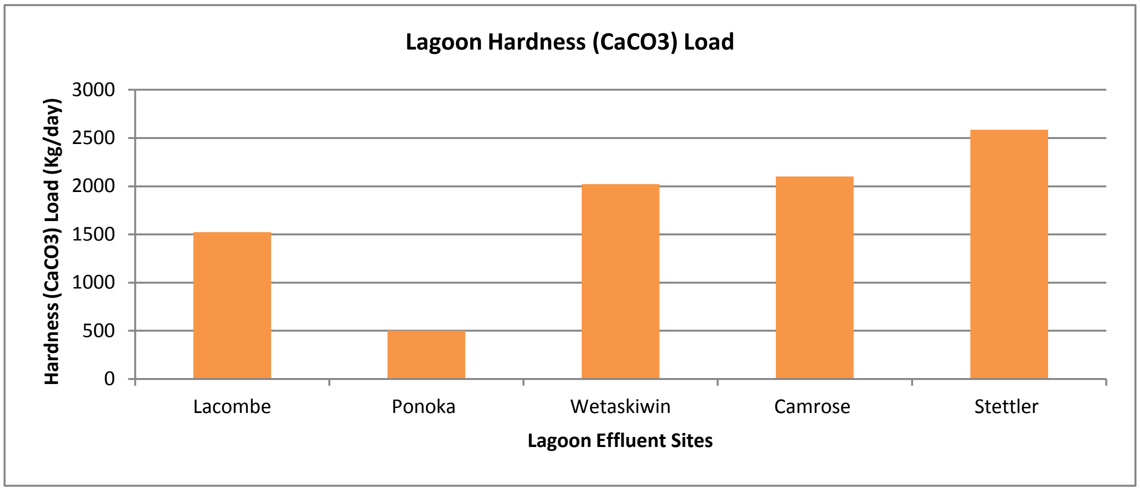
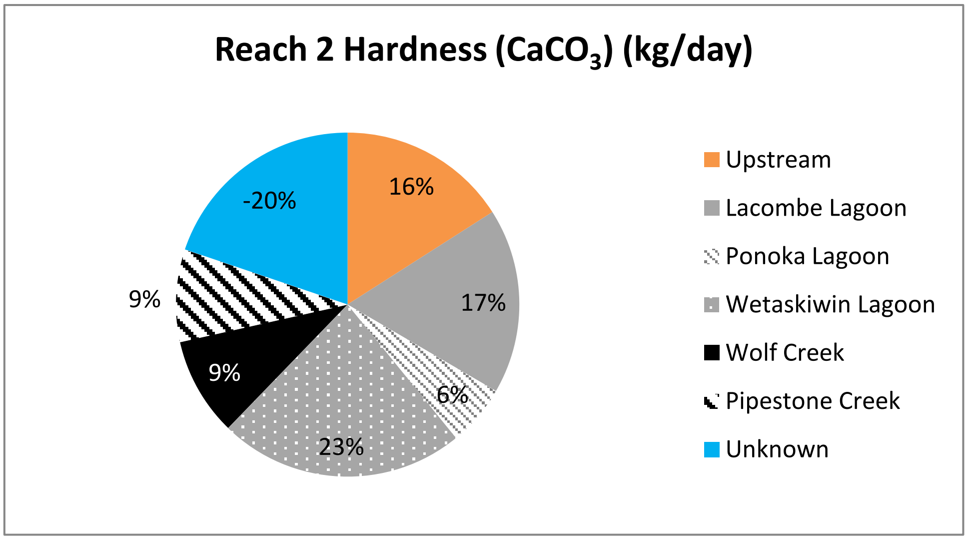
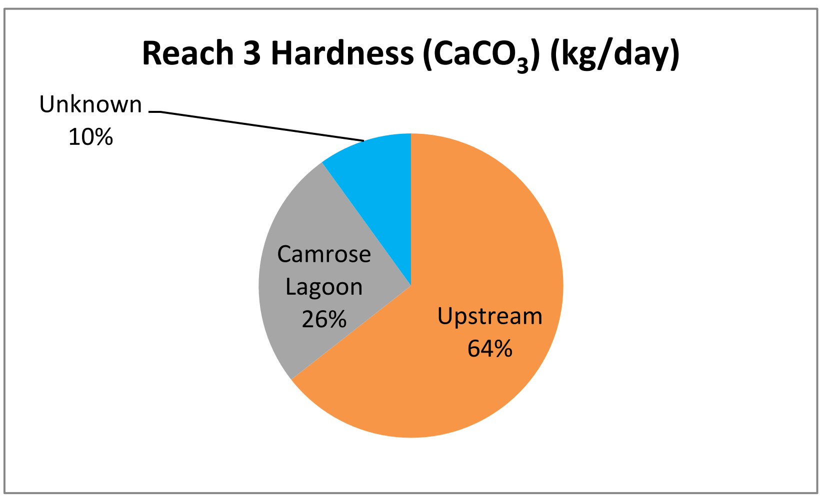


Figure 135 Hardness Loads for Five Lagoons along the Battle River in October 2013.

5.6.4.4 Hardness Loads by Reach

The hardness load in Reach 2 was principally established by lagoons, contributing 46% of the load. Wolf and Pipestone Creeks contributed equally for a total of 18%. Similar contributions came from upstream. There was a CaCO3 sink, as 20% of the possible load was not measured at the downstream site in Reach 2. There was also a sink in Reach 3. In Reach 4, the majority of $CaCO_3$ came from an unknown source, reflecting increased flow downstream of Ribstone Creek. Contributions from Stettler lagoon were almost equal to that of tributaries, in which only Iron Creek contributed to the hardness load of Reach 4 (Figure 136).





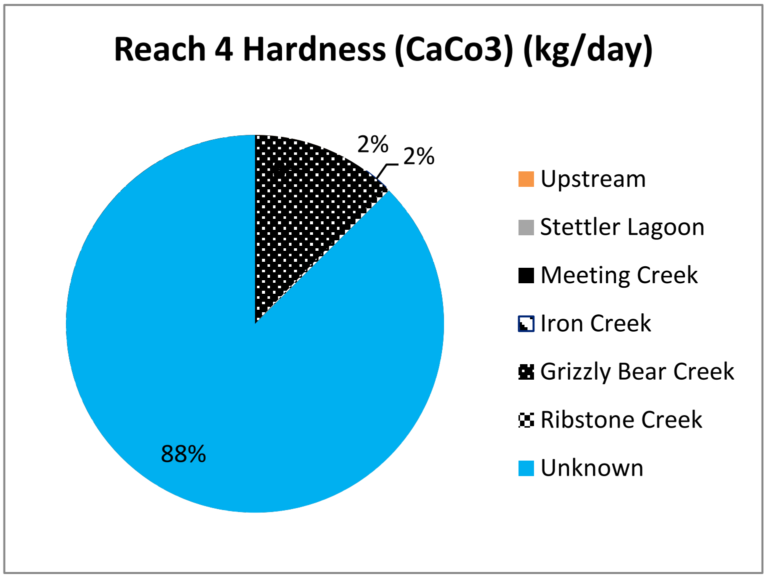


Figure 136. Hardness Loads for Reaches 2, 3 and 4.

5.6.5 Summary of Other Parameters

Total organic carbon followed similar patterns as nitrogen and phosphorus species, increasing throughout reaches 1 and 2 and decreasing in reaches 3 and 4. This close relationship between all nutrients is likely reflective of the naturally productive character of Battle River and may have been enhanced by nutrient-stimulated increased productivity in reaches 2 and 3.

Total suspended solids differed strongly between 2011 and 2013, indicating year-specific influences, such as weather and flow, in this parameter.

Total dissolved solids and hardness followed very similar patterns as conductivity and the major ions, as expected, with a generally increasing trend throughout the watershed, but a sharp drop between Ponoka and Pipestone Creek, supporting the hypothesis of a foreign water source in this reach.

6. Summary

6.1 Status Compared to Federal and Provincial Guidelines

Four parameters did not meet provincial or federal guidelines for the protection of aquatic life on occasions; dissolved oxygen, pH, ammonia and fluoride. Bacteria levels were occasionally above the guideline for irrigation use, but the geometric mean of high-frequency data would be required to confirm this.

Fluoride exceeded the federal guideline at all sites at all times, except the Battle River outflow, indicating naturally elevated fluoride levels in the watershed.

The lowest dissolved oxygen levels occurred during winter under ice in reaches 2 and 3, when both the chronic and acute levels were not met. This may be due to high rates of matter decomposition from the large aquatic macrophyte beds observed in these reaches. The abundant macrophyte growth may be a natural occurrence due to the slow moving river in these flat reaches that encourages plant growth, but influence from nutrient-rich point-and non-point source discharges that enhance these patterns cannot be disregarded. Low oxygen levels also occurred in summer downstream of the lakes, indicating that periodic anoxia occurs in these lakes. High oxygen levels were observed during daytime in summer and fall in reaches 2 and 3, which is likely due to high photosynthetic activity of plants and algae and therefore may indicate that oxygen is depleted during night, when respiration processes dominate.

Levels of pH were occasionally above the federal and provincial guideline of 9 and many tributaries exceeded it in summer. While the tributary levels may be due to elevated alkalinity and hardness from natural watershed characteristics, the high levels in reach 2 were likely caused by high primary productivity. Beside the observed dense macrophyte beds, chlorophyll-a levels measured at the LTRN site upstream of Camrose confirm elevated planktonic productivity in reach 2, confirming this hypothesis.

Ammonia levels exceeded chronic guidelines downstream of Ponoka in summer 2011 and upstream of Driedmeat Lake in fall 2011 and 2013 due to lagoon discharges. These levels are a combination of elevated ammonia levels in the lagoon discharges, elevated pH in the Battle River and poor mixing conditions in the river to attenuate the discharge effect. The location upstream of Driedmeat Lake is particularly unsuitable for a discharge, given the stagnant and highly productive waters in that area. In order to avoid impairment to aquatic life in this area it appears that either the discharge location or the discharge quality or timing needs to be revised. Upgrades to the City of Camrose wastewater treatment facility are currently under way, which will likely reduce the impacts of this discharge on the Battle River.

In summary, the guideline exceedences observed in Battle River are mainly related to high aquatic productivity in reaches 2 and 3, which is affected by seasonal lagoon discharges and possibly enhanced by non-point sources of nutrients from high-intensity agriculture in the reach 1 and reach 2 watersheds.

6.2 Status Compared to Draft Battle River WQOs

A large number of measurements exceeded the reach-specific 50th percentile WQOs. If the collected water quality data collected were representative for the open-water and ice-covered seasons and no trends occurred, then it would be expected that about half of the measurements exceed 50th percentile WQO and half would meet them. The proportion of measurements that exceeded 50th percentile WQOs ranged from 17% for Reach 1 winter data to 44% for Reach 2 summer data (Table 6). This result suggests that overall, water quality has either improved since the period used for WQO setting, that data collected further upstream in a reach may be less representative of the downstream end of the reach and thus bias the results for any given reach, or that the seasons sampled are not representative for the seasons used for objective setting.

Table 6. Percentage of Measurements that Exceeded 50th Percentile WQOs in 2013

	Summer	Fall	Winter
Reach 1	40%	36%	17%
Reach 2	44%	40%	28%
Reach 4	38%	35%	41%

A statistically sound trend analysis with corrections for flow, seasonality and considerations for non-detectable values would be required to test the hypothesis of temporal trend in available data. The assessment of long-term trends was beyond the scope of this study but is recommended to inform the continued process of WQO refinement.

Water quality objectives were developed for sites at the downstream end of each reach and therefore the applicability of WQOs to sites further upstream in each reach may be limited given spatial differences in water quality within reaches. A number of substances increase within reach 1, explaining the low number of measurements exceeding the 50th percentile WQO. Many substances increase and then decrease in reach 2, so it would be expected that more than or approximately 50% of the measurements exceed the WQOs in this reach. In reach 4, many substances decline from upstream towards downstream, again not supporting the hypothesis of within-reach bias for the majority of measurements meeting the WQO.

One probable cause of measurements remaining below the historical 50th percentile is that the seasons included in the Synoptic Surveys did not reliably represent the open-water (April-October) and ice-covered (November-March) seasons as defined for the WQO setting. For the winter season this argument is difficult to make given stable conditions under ice, but at the beginning and end of the ice-covered season some of the samples may occasionally represent open water conditions, thereby bias winter objectives towards higher levels.

For the open-water season (April to October), the synoptic surveys were clearly biased towards the summer and fall low flow season, excluding the high spring runoff season. It can be expected that many parameters, in particular the parameters associated with particles, e.g., TP and TSS, be more elevated in spring samples, resulting in open-water WQOs that are naturally higher than low-flow water quality levels.

The parameters exceeding 50th percentile WQOs almost exclusively included dissolved substances (Table 7), strongly suggesting that the higher than expected proportion of measurements meeting objectives is due to seasonal water quality differences. Fecal bacteria commonly exceeded 50th and 90th percentile WQOs in summer, outside most lagoon discharge periods and in all reaches, suggesting loadings from non-point sources.

Table 7. Summary of Parameters that Exceeded 50th Percentile WQOs in 2013

	Summer	Fall	Winter
Reach 1	$NO_3 + NO_2$ - N	TN	Temp
	TN		
	E. coli		
	NO_3		
	DO		
	Temp		
Reach 2	$NO_3 + NO_2$ - N	$NO_3 + NO_2$ - N	$NO_3 + NO_2$ - N
	TOC	TN	NO_3
	Cl	Cl	pH
	E. coli	NO_3	
	Fecal coliforms	NO_2	
	NO_2	pH	
	NO_3		
	pH		
	Temp		
Reach 4	TN	Hardness	$NO_3 + NO_2$ - N
	F	TDS	TN
	Cl	F	F
	E. coli	SO4	SO4
	Fecal coliforms	Cl	Cl
	pH	Ca	NH3
	DO		
	Temp		

A considerable number of measurements also exceeded the 90th percentile in 2011 and 2013. These values can be of concern as they are at the highest end of the historical data distribution. A recurring pattern of high values is apparent for nitrate and nitrite values in all reaches, with values exceeding the

90th percentiles in all seasons at a minimum of one site in reach 2 and in both fall and winter. Nitrate and nitrite can originate from fertilizers, point sources and decomposition of organic matter, all of which possibly may play a role in the Battle River. Dissolved and total phosphorus also occasionally exceeded the WQOs in summer, with the dissolved fraction representing the majority of phosphorus. Spring high flows would offer a larger dilution capacity for these parameters. Open-water WQOs that include all three seasons of sampling (spring, summer and fall) would therefore be lower than the open-water WQO observed here for summer and fall values only.

Reach 2 had generally the largest number of values exceeding the 50th and 90th percentile WQOs, which is likely reflective of the cumulative effect of point- and non-point sources in this reach. Reach 1 had the second-largest number of values exceeding the 90th percentile WQO, which compared to reach 4 may be explained by high-intensity agriculture combined with larger runoff from the larger contributing areas.

Table 8. Summary of Measurements that Exceeded 90th Percentile WQOs in 2013

	Summer	**Fall**	**Winter**
Reach 1	Ca Cl Cond (11) *E.Coli* F (11) Hardness pH (13) SO_4 (11) TDS (11) TN TSS	Ca Cl Cond Hardness NO_3 - N (13) $NO_3 + NO_2$ - N (13) TN	NO_3 - N $NO_3 + NO_2$ - N Temp
Reach 2	Ca Cl *E.Coli* Fecal coliforms Hardness NO_2 - N NO_3 - N $NO_3 + NO_2$ - N pH TDP Temp TN TOC TP TSS (11)	Ca Cl Cond Hardness NO_2 - N NO_3 - N $NO_3 + NO_2$ - N TDS TOC	Ca Hardness NO_3 - N $NO_3 + NO_2$ - N SO_4 (11)
Reach 4	F (13) TDP	Ca F (13) Hardness SAR (13)	Ca (11) Cl *E.Coli* F (11) Hardness (11) TDS Temp TN

Number in brackets indicates year exceedance occurred.
If no there is no number in brackets indicates excedance occurred both years.

6.3 Spatial Patterns

The general spatial patterns described in previous studies (Golder 2011, Anderson 1999) were also observed in 2013: there were relatively low values of most substances in reach 1, increases in reaches 2 and 3 and then decreases in substance concentrations in reach 4. Some of the most prevalent patterns are as follows:

- The largest increases in nutrients and major ions occurred between the sites upstream and downstream of Ponoka, reflecting the cumulative impact of loadings from the most important (in terms of flow) tributary, Wolf Creek and two lagoon discharges, Lacombe and Ponoka.
- A second large increase often occurred between downstream of Ponoka and upstream of Pipestone Creek, the source of which is unknown given the absence of any monitored point discharge in this river stretch. In this reach, some major ions decrease drastically and TOC increases, possibly indicating the influence of the Samson Lake wetland complex, but increases in bacteria and nitrogen remain unexplained and point to agricultural non-point sources.
- The largest decreases occurred mainly downstream of Driedmeat Lake, indicating that the lake acts as a sink for many of the nutrient loads that the Battle River receives in the upper reaches. Only occasionally the lake recycles some of the loads and becomes as source of nitrate and nitrite, dissolved phosphorus and sulphate, likely due to decomposition of accumulated organic matter and/or anoxic conditions.

An exception to these general patterns were bacteria levels, which peaked upstream of Ponoka and upstream of Pipestone Creek, strongly suggesting non-point sources of bacteria loads. These results confirm earlier work conducted in the river (Anderson 1999). Tributaries were occasionally rich in bacteria as well (>1000 no./mL); so these numbers may have had an influence on the Battle River, despite the minimal tributary flows during the low flow season.

Another exception was conductivity, which increased in reach 1, decreased to lower levels within reach 2 and 3 and then increased again in reach 4. This pattern can be explained by tributaries entering reach 4 of the Battle River, which were elevated in conductivity and many major ions. The natural occurrence of saline soils and high evaporative loss in this dry area are likely reasons for this increase in conductivity in reach 4.

The newly added site at the Battle Lake outflow showed elevated levels of ammonia and dissolved phosphorus, but these levels were not sustained in the other reach 1 sites. This indicates that the outflow may not contribute enough volumes to influence downstream water quality or that these levels were assimilated in the river.

7. Recommendations

The work completed so far has provided a thorough understanding on the temporal and spatial water quality patterns in the Battle River and the factors influencing them. There are some gaps in our knowledge, however, that should be address in future sampling campaigns:

1) Spring sampling would be required to complete a year-round description of the Battle River ecosystem. This will help to better represent the open water season with respect to WQO and will provide insight into the season when most runoff from the watershed can be expected and some seasonal lagoon discharges occur.

2) The reach between downstream of Ponoka and upstream of Pipestone Creek requires further investigation, as there was an unidentified large source for a variety of substances, including fecal bacteria, TSS, turbidity, organic carbon, and nitrogen, only parts of which (TOC, possibly turbidity) can be explained by the Samson Lake wetland complex in this reach.

3) Continuous dissolved oxygen data collected at hourly or sub-hourly intervals are needed to adequately assess diurnal oxygen conditions in the Battle River in the summer months, in particular in reach 2, where abundant macrophyte beds and high day-time oxygen levels were observed.

Last but not least, the impact of the Camrose lagoon discharge on the Battle River above Driedmeat Lake is of concern, but the current upgrades of the Camrose wastewater facility in preparation for continuous discharge will likely address this issue. Ongoing monitoring of the area upstream of Driedmeat Lake is required to describe the changes induced by the modified discharge quality and duration.

8. Conclusion

In conclusion, the Battle River shows the characteristics of a prairie river, with low flows in summer, fall and winter, high nutrient concentrations and aquatic productivity and hard, alkaline waters. The high aquatic productivity and some of the major ion content are further enhanced through point- and non-point source discharges to a point where aquatic habitat is impaired in fall and winter, in particular in reach 2. Elevated bacteria levels, likely from livestock operations, also impair water quality in all reaches. Given the naturally low flow volumes, Battle River is more sensitive to the cumulative impact of human activities in the watershed than other Alberta rivers that benefit from the enhanced flow from mountain snow melt and precipitation. It therefore deserves particular attention to mitigating the current impacts on the Battle River ecosystem.

9. References

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Appendix A. Water Quality Data

Mainstem

RESULTS OF CHEMICAL ANALYSES OF WATER			Reach 1			Reach 2			Reach 3		Reach 4			
Maxxam ID			**HI0604**	**HI0605**	**HI0606**	**HI0608**	**HJ5530**	**HJ5531**	**HJ5532**	**HI4390**	**HI4392**	**HI4282**	**HJ0492**	**HJ0495**
AESRD Site ID			**AB05FA0009**	**AB05FA0030**	**AB05FA0060**	**AB05FA0120**	**AB05FA0280**	**AB05FA0320**	**AB05FA0390**	**AB05FC0030**	**AB05FC0150**	**AB05FB0050**	**AB05FE120**	**AB05FE0120**
Sample Number			**13SWE11000**	**13SWE11001**	**13SWE11002**	**13SWE11004**	**13SWE11006**	**13SWE11007**	**13SWE11009**	**13 SWE11012**	**13 SWE11014**	**13 SWE11010**	**13SWE11016**	**13SWE11019**
Site Name			**Battle Lake Outflow**	**Hwy 611**	**U/S Ponoka**	**D/S Ponoka**	**U/S Pipestone Creek**	**U/S Camrose**		**U/S Meeting Creek**	**Hwy 872**	**D/S Hardisty**	**D/S Ribstone Creek**	**Field Duplicate**
Date Sampled			**26-Aug-13**	**26-Aug-13**	**26-Aug-13**	**26-Aug-13**	**29-Aug-13**	**29-Aug-13**	**29-Aug-13**	**27-Aug-13**	**27-Aug-13**	**27-Aug-13**	**30-Aug-13**	**30-Aug-13**
	UNITS	**RDL**												
Calculated Parameters														
Anion Sum	meq/L	N/A	3.2	4.2	5.4	7.4				7.1	7.8	8.4		
Cation Sum	meq/L	N/A	3.6	4.8	6.1	7.8				6.7	7.3	8.1		
Hardness (CaCO3)	mg/L	0.50	110	150	200	260	160	160	190	180	180	210	200	230
Ion Balance	N/A	0.010	1.1	1.1	1.1	1.1				0.94	0.94	0.97		
Dissolved Nitrate (NO3)	mg/L	0.013	0.13	0.031	0.037	0.10	3.5	1.7	<0.013	<0.013	<0.013	<0.013	<0.013	<0.013
Nitrate plus Nitrite (N)	mg/L	0.0030	0.035	0.0070	0.0080	0.027	0.94	0.44	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030
Dissolved Nitrite (NO2)	mg/L	0.0099	0.020	<0.0099	<0.0099	0.013	0.50	0.17	<0.0099	<0.0099	<0.0099	<0.0099	<0.0099	<0.0099
Total Nitrogen	mg/L		1.54	1.11	1.61	1.73	3.14	2.44	1.70	1.60	1.60	1.50	1.10	
Sodium Adsorption Ratio			1.1	1.3	1.4	1.4	1.7	1.8	1.98	2.05	1.44	2.51	3.07	
Misc. Inorganics														
Conductivity	uS/cm	1.0	320	420	520	700	520	560	670	680	730	780	920	920
pH	N/A	N/A	7.92	8.06	8.17	8.39	8.69	8.53	8.15	8.45	8.54	8.50	8.53	8.51
Total Organic Carbon (C)	mg/L	0.50	11	12	20	20	25	23	20	17	16	15	12	12
Total Dissolved Solids	mg/L	10	170	220	290	400	330	320	410	380	420	450	560	540
Total Suspended Solids	mg/L	1.0	6.7	8.0	4.0	6.0	7.3	13	4.0	16	15	26	23	26
Anions														
Alkalinity (PP as CaCO3)	mg/L	0.50	<0.50	<0.50	<0.50	3.8				4.1	7.7	7.0		
Alkalinity (Total as CaCO3)	mg/L	0.50	140	200	240	270				210	240	260		
Bicarbonate (HCO3)	mg/L	0.50	170	240	290	320				250	270	300		
Carbonate (CO3)	mg/L	0.50	<0.50	<0.50	<0.50	4.6				5.0	9.2	8.4		
Dissolved Fluoride (F)	mg/L	0.050	0.092	0.14	0.15	0.21	0.20	0.21	0.24	0.23	0.26	0.30	0.28	0.28
Hydroxide (OH)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50				<0.50	<0.50	<0.50		
Dissolved Sulphate (SO4)	mg/L	1.0	8.1	8.7	19	53	37	56	100	98	99	110	130	130
Dissolved Chloride (Cl)	mg/L	1.0	4.6	4.1	9.0	31	27	29	31	31	33	33	33	33
Microbiological Param.														
E.Coli DST	mpn/100mL	1.0	33	120	170	36	340	91	33	68	200	140	57	44
Fecal Coliforms	CFU/100mL	1.0	23	74	170	31	240	86	27 (4)	34.4	56	130	59.1	32.4
Total Coliforms DST	mpn/100mL	1.0	2000	>2400	>2400	>2400	>2400	>2400	>2400	>2400	>2400	2400	2400	>2400
Nutrients														
Total Ammonia (N)	mg/L	0.050	0.31	<0.050	<0.050	<0.050	0.081	0.063	0.093	<0.050	<0.050	<0.050	<0.050	<0.050
Dissolved Phosphorus (P)	mg/L	0.0030	0.022	0.11	0.15	0.26	0.12	0.078	0.20	0.13	0.076	0.028	0.022	0.021
Total Phosphorus (P)	mg/L	0.0030	0.065	0.15	0.21	0.31	0.16	0.13	0.22	0.18	0.12	0.079	0.076	0.076
Total Total Kjeldahl Nitrogen	mg/L	0.050	1.5	1.1	1.6	1.7	2.2	2.0	1.7	1.6	1.6	1.5	1.1	1.1
Dissolved Nitrite (N)	mg/L	0.0030	0.0060	<0.0030	<0.0030	0.0039	0.15	0.052	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030
Dissolved Nitrate (N)	mg/L	0.0030	0.029	0.0071	0.0084	0.023	0.79	0.38	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030	<0.0030
Elements														
Dissolved Calcium (Ca)	mg/L	0.30	24	33	44	63	27	30	40	37	39	46	45	51
Dissolved Iron (Fe)	mg/L	0.060	<0.060	0.13	0.076	0.062				<0.060	<0.060	<0.060		
Dissolved Magnesium (Mg)	mg/L	0.20	13	17	20	26	21	21	21	21	21	22	22	25
Dissolved Manganese (Mn)	mg/L	0.0040	0.029	0.050	0.060	0.014				<0.0040	<0.0040	<0.0040		
Dissolved Potassium (K)	mg/L	0.30	4.3	6.1	7.5	8.7				14	13	13	9.1	10
Dissolved Sodium (Na)	mg/L	0.50	28	38	45	54	48	52	62	63	77	83	98	110
Physical Properties														
Turbidity	NTU	0.10	4.6	4.3	3.9	3.2								
Field Parameters														
Turbidity	NTU		3.35	3.3	2.85	0.1	3	7.11	0	8.87	13.7	18.6	12.1	
pH			2.82	7.98	8.45	8.87	**9.2**	**9.75**	8.74	8.92	8.97	8.72	**9.34**	
Conductivity	µS/cm		300	395	480	636	486	519	624	509	656	700	863	
Totoal Dissolved Solids	mg/L		151	194	242	317	242	59	311	304	327	349	431	
Dissolved Oxygen	mg/L		**1.9**	**6**	**5.2**	**9.2**	11.2	**8.1**	**4.2**	**9.1**	**8.5**	**7.9**	**8**	
Dissolved Oxygen	%		23	69	61	118	140	100	50	109	105	95	99	
Temperature	˚C		18.9	17.3	18.4	19.4	21.7	20.9	20	19.5	20.7	19.6	20.8	

RDL = Reportable Detection Limit — Above reach specific guideline
EDL = Estimated Detection Limit — **Above Alberta PAL guideline**

Detection limits raised due to dilution to bring analyte within the calibrated range.

Detection limits raised due to matrix interference.

Sample analyzed 28 hours after sample collection. Sample analysis is recommended within 24 hours of sample collection.

(4) Sample analyzed 28 hours after sample collection. Sample analysis is recommended within 24 hours of sampling.

For sample 13SWE11004 RDL TOC = 2.5

For sample 13SWE11006 RDL TOC = 1.0, SO4 = 2.0, TKN = 0.25

For samples 13SWE11007 and 13SWE11009 RDL TOC = 1.0

RESULTS OF CHEMICAL ANALYSES OF WATER			Reach 1			Reach 2				Reach 3		Reach 4			
Maxxam ID			HV2992	HV3020	HV3021	HX0115	HX0119	HX0120	HX0117	HX0116	HV7055	HV7054	HV7053	HW0535	HX6328
AESRD Site ID			AB05FA0009	AB05FA0030	AB05FA0060	AB05FA0120	AB05FA0280	AB05FA0280	AB05FA0320	AB05FC0020	AB05FC0030	AB05FC0150	AB05FB0050	AB05FE0120	AB00QC0001
Sample Number			13SWE11020	13SWE11021	13SWE11022	13SWE11033	13SWE11037	13SWE11038	13SWE11035	13SWE11034	13SWE11027	13SWE11026	13SWE11025	13SWE11029	13SWE11042
Site Name			Battle Lake Outflow	Hwy 611	U/S Ponoka	D/S Ponoka	U/S Pipestone Creek	Duplicate	U/S Camrose	D/S Driedmeat Lake	U/S Meeting Creek	Hwy 872	D/S Hardisty	D/S Ribstone Creek	Field Blank
Date Sampled			15-Oct-13	15-Oct-13	15-Oct-13	22-Oct-13	22-Oct-13	22-Oct-13	22-Oct-13	22-Oct-13	16-Oct-13	16-Oct-13	16-Oct-13	17-Oct-13	24-Oct-13
	UNITS	RDL													
Calculated Parameters															
Anion Sum	meq/L	N/A	4.0	7.0	6.8	11	7.2	7.0	7.3	7.8	8.2	9.8	10	12	0.00050
Cation Sum	meq/L	N/A	4.1	7.1	6.1	10	7.3	7.0	6.5	7.7	8.3	9.7	10	19	0.0010
Hardness (CaCO3)	mg/L	0.50	140	220	190	300	210	200	190	210	240	250	290	310	<0.50
Ion Balance	N/A	0.010	1.0	1.0	0.90	0.98	1.0	1.0	0.90	0.98	1.0	0.99	0.98	1.5	2.0
Dissolved Nitrate (NO3)	mg/L	0.013	<0.13	<0.13	2.0	3.2	6.0	5.9	5.5	1.1	0.89	<0.013	<0.013	<0.013	0.030
Nitrate plus Nitrite (N)	mg/L	0.0030	<0.030	<0.030	0.51	0.75	1.4	1.4	1.3	0.31	0.21	<0.0030	<0.0030	<0.0030	0.0068
Dissolved Nitrite (NO2)	mg/L	0.0099	<0.099	<0.099	0.16	0.12	0.083	0.11	0.085	0.18	0.048	<0.0099	<0.0099	<0.0099	<0.0099
Total Nitrogen	mg/L		3.40	1.10	1.81	2.35	3.5	3.4	3.20	4.11	2.01	1.20	0.99	1.10	
Total Dissolved Solids	mg/L	10	200	350	340	570	390	380	380	440	450	550	580	820	<10
Sodium Adsorption Ratio			0.9	1.7	1.7	2.3	2.0		1.9	2.2	2.1	2.7	2.5	7.2	
Misc. Inorganics															
Conductivity	uS/cm	1.0	380	620	600	1000	690	700	710	770	760	930	950	1100	2.2
pH	N/A	N/A	7.45	8.02	8.11	8.19	8.31	8.32	8.27	8.13	8.29	8.32	8.28	8.41	5.83
Total Organic Carbon (C)	mg/L	0.50	13	14	16	12	20	18	19	18	18	16	13	11	<0.50
Anions															
Alkalinity (PP as CaCO3)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	0.66	0.77	<0.50	<0.50	<0.50	1.0	<0.50	5.0	<0.50
Alkalinity (Total as CaCO3)	mg/L	0.50	180	330	290	300	240	230	240	230	260	280	320	400	<0.50
Bicarbonate (HCO3)	mg/L	0.50	220	400	360	370	290	280	290	290	310	340	390	470	<0.50
Carbonate (CO3)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	0.80	0.93	<0.50	<0.50	<0.50	1.3	<0.50	6.1	<0.50
Dissolved Fluoride (F)	mg/L	0.050	0.14	0.18	0.22	0.38	0.20	0.20	0.19	0.24	0.27	0.30	0.30	0.31	<0.050
Hydroxide (OH)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Dissolved Sulphate (SO4)	mg/L	1.0	7.3	11	27	94	66	64	66	100	98	150	140	150	<1.0
Dissolved Chloride (Cl)	mg/L	1.0	5.9	4.6	11	88	36	35	35	35	35	35	37	36	<1.0
Microbiological Param.															
E.Coli DST	mpn/100mL	1.0	<1.0	3.0	1.0	5.2 (8)	50	47	19	24	31	66	29	21	<1.0
Fecal Coliforms	CFU/100mL	1.0	<1.0 (4)	2	<2.0	<2.0 (10)	22 (6)	16 (6)	12 (6)	10 (6)	6.0 (5)	16 (5)	4.0 (5)	16 (6)	<2.0 (6)
Total Coliforms DST	mpn/100mL	1.0	370	1400	230	1700 (8)	>2400	2400	>2400	2000	1400	220	1500	180	<1.0
Nutrients															
Total Ammonia (N)	mg/L	0.050	0.80	<0.050	<0.050	0.067	<0.050	<0.050	<0.050	1.5	0.095	<0.050	<0.050	<0.050	<0.050
Dissolved Phosphorus (P)	mg/L	0.0030	0.12	0.031	0.031	0.27	0.018	0.017	0.016	0.038	0.027	0.020	0.010	0.029	0.0030
Total Phosphorus (P)	mg/L	0.0030	0.32	0.083	0.076	0.34	0.074	0.075	0.16	0.14	0.056	0.033	0.024	0.058	<0.0030
Total Total Kjeldahl Nitrogen	mg/L	0.050	3.4	1.1	1.3	1.6	2.1	2	1.9	3.8	1.8	1.2	0.99	1.1	<0.050
Dissolved Nitrite (N)	mg/L	0.0030	<0.030	<0.030	0.048	0.036	0.025	0.034	0.026	0.055	0.015	<0.0030	<0.0030	<0.0030	<0.0030
Dissolved Nitrate (N)	mg/L	0.0030	<0.030	<0.030	0.46	0.71	1.4	1.3	1.3	0.26	0.20	<0.0030	<0.0030	<0.0030	0.0068
Elements															
Dissolved Calcium (Ca)	mg/L	0.30	36	50	47	74	40	39	37	46	54	57	66	59	<0.30
Dissolved Iron (Fe)	mg/L	0.060	<0.060	0.089	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060
Dissolved Magnesium (Mg)	mg/L	0.20	13	24	18	29	26	25	23	22	24	27	30	39	<0.20
Dissolved Manganese (Mn)	mg/L	0.0040	<0.0040	0.021	0.014	0.013	0.0052	0.0080	0.035	0.19	0.026	0.056	0.084	0.012	<0.0040
Dissolved Potassium (K)	mg/L	0.30	4.4	4.6	6.0	12	9.9	9.4	7.9	14	14	14	12	6.8	<0.30
Dissolved Sodium (Na)	mg/L	0.50	25	57	49	92	66	64	60	72	73	98	96	290	<0.50
Field Parameters															
Turbidity	NTU		5.36	2.58	1.76	0	8.56	8.56	50.1	38.1	7.46	0.75	2.76	6.94	0
pH			7.55	7.94	8.14	8.25	8.53	8.53	8.49	8.23	8.59	8.59	8.47	8.7	9.2
Conductivity	µS/cm		370	553	533	886	590	590	602	652	662	802	825	981	2
Totoal Dissolved Solids	mg/L		172	276	264	441	295	295	300	325	331	399	411	488	1
Dissolved Oxygen	mg/L		**2.3**	**8.3**	9.5	**7.8**	10.8	10.8	11.4	**9**	12.2	11.3	11.6	12.4	9.6
Dissolved Oxygen	%		20	73	85	71	103	103	107	84	108	100	99	103	97
Temperature	˚C		4.3	4.4	5.6	7	8.7	8.7	8	8	4.9	5.8	4.7	2.9	11.4

RDL = Reportable Detection Limit
EDL = Estimated Detection Limit
Detection limits raised due to dilution to bring analyte within the calibrated range.
Detection limits raised due to matrix interference.
Sample analyzed 24.5 hours after sample collection. Sample analysis is recommended within 24 hours of sampling.
(4) Sample analyzed 25 hours after sample collection. Sample analysis is recommended within 24 hours of sampling.
(5) Sample was originally processed within hold time. Data quality required investigation. Re-analysis was completed past recommended hold time.
(6) Detection limit raised based on sample volume used for analysis
(7) Sample analyzed 26.33 hours after sample collection. Sample analysis recommended within 24 hours of sampling.
(8) Sample analyzed 25.5 hours after sample collection. Sample analysis recommended within 24 hours of sampling.
(9) Sample analyzed 26.5 hours after sample collection. Sample analysis is recommended within 24 hours of sampling. Detection limit raised based on sample volume used for analysis.
(10) Sample analyzed 25.75 hours after sample collection. Sample analysis is recommended within 24 hours of sampling. Detection limit raised based on sample volume used for analysis.
(11) Sample was past hold time when received, set up 25.2 hours after sample collection.
(12) Detection limit raised based on sample volume used for analysis. Sample was past hold time when received, set up 26.33 hours after sample collection.
(13) Analysis requested past recommended holding time
(14) Analysis requested past recommended holding time. Detection limit raised based on sample volume used for analysis.

For sample 13SWE11020 RDL E. coli = 1.0, Fecal coliforms = 1.0, Total coliforms = 1.0
For sample 13SWE11021 RDL Fecal coliforms = 2.0, dissolved nitrite (N) = 0.03, dissolved nitrate (N) = 0.03
For sample 13SWE11022 RDL Fecal coliforms = 2.0, dissolved nitrite (N) = 0.03, dissolved nitrate (N) = 0.03
For sample 13SWE11026 RDL dissolved CL = 2.0
For sample 13SWE11029 RDL dissolved Cl = 2.0 and Fecal coliforms = 2.0
For sample 13SWE11033 RDL fecal coliforms = 2.0
For sample 13SWE11034 RDL fecal coliforms = 2.0 and TKN = 0.25
For samples 13SWE11035 RDL fecal coliforms = 2.0
For samples 13SWE11037 and 13SWE11038 RDL fecal coliforms = 2.0 and TKN = 0.25
For sample 13SWE11042 RDL fecal coliforms = 2.0

ROUTINE WATER - FILTERED (WATER)			Reach 1			Reach 2				Reach 3		Reach 4			
Maxxam ID			IL9921	IL9922	IL9923	A179162	A179162	IL9924	IL5160	IL5159	IL5158	IL3303	IL3302	IL3281	IL9943
Sampling Date			AB05FA0009	AB05FA0030	AB05FA0060	AB05FA0120	AB05FA0280	AB05FA0280	AB05FA0320	AB05FC0020	AB05FC0030	AB05FC0150	AB05FB0050	AB05FE0120	AB00QC0001
COC Number			**13SWE11055**	**13SWE11056**	**13SWE11057**	**13SWE11053**	**13SWE11052**	**13SWE11058**	**13SWE11050**	**13SWE11049**	**13SWE11048**	**13SWE11047**	**13SWE11046**	**13SWE11044**	**13SWE11059**
Site Name			**Battle Lake Outflow**	**Hwy 611**	**U/S Ponoka**	**D/S Ponoka**	**U/S Pipestone Creek**	**Replicate**	**U/S Camrose**	**D/S Driedmeat Lake**	**U/S Meeting Creek**	**Hwy 872**	**D/S Hardisty**	**D/S Ribstone Creek**	**Field Blank**
Sample Date			**17-Jan-14**	**17-Jan-14**	**17-Jan-14**	**16-Jan-14**	**16-Jan-14**	**17-Jan-14**	**15-Jan-14**	**15-Jan-14**	**15-Jan-14**	**14-Jan-14**	**14-Jan-14**	**13-Jan-14**	**17-Jan-14**
	UNITS	**RDL**													
Calculated Parameters															
Anion Sum	meq/L	N/A	3.9	6.2	7.9	9.6	14	7.9	14	9.2	9.2	12	12	13	0
Cation Sum	meq/L	N/A	3.9	6.1	7.7	9.2	13	7.7	14	9.2	9.1	12	12	13	0.0040
Hardness (CaCO3)	mg/L	0.50	130	190	250	310	390	250	410	260	260	300	310	320	<0.50
Ion Balance	N/A	0.010	0.99	0.98	0.97	0.95	0.94	0.98	0.98	1.0	0.99	1.0	0.96	0.96	NC
Dissolved Nitrate (NO3)	mg/L	0.044	0.063	0.37	0.77	1.4	3.9	0.77	4.9	<0.044	0.052	1.6	1.2	1.2	<0.044
Nitrate plus Nitrite (N)	mg/L	0.010	0.014	0.085	0.17	0.32	0.91	0.17	1.1	<0.010	0.012	0.36	0.27	0.26	<0.010
Dissolved Nitrite (NO2)	mg/L	0.033	<0.033	<0.033	<0.033	<0.033	0.093	<0.033	0.039	<0.033	<0.033	<0.033	<0.033	<0.033	<0.033
Total Nitrogen	mg/L		0.66	0.65	1.37	1.62	4.41	1.27	4.10	2.30	2.41	2.36	1.97	1.56	
Total Dissolved Solids	mg/L	10	200	310	400	500	730	400	750	510	510	700	690	720	<10
Sodium Adsportion Ratio			1.0	1.5	1.7	1.6	2.1		2.4	2.2	2.2	3.5	3.0	3.4	
Misc. Inorganics															
Conductivity	uS/cm	1.0	340	550	690	840	1200	690	1200	850	850	1200	1100	1200	1.5
pH	pH	N/A	8.10	7.80	7.81	7.76	7.88	7.81	7.79	7.72	7.76	7.83	7.73	7.68	5.43
Total Organic Carbon (C)	mg/L	0.50	8.5	6.8	8.9	8.7	15	10	16	17	17	19	12	10	<0.50
Total Suspended Solids	mg/L	1.0	<1.0	4.0 (6)	7.8 (6)	11	8.0	14 (6)	21	13	7.3	10	7.3	6.0	<1.0
Anions															
Alkalinity (PP as CaCO3)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Alkalinity (Total as CaCO3)	mg/L	0.50	180	280	350	380	450	350	450	290	290	350	360	430	<0.50
Bicarbonate (HCO3)	mg/L	0.50	220	340	430	460	550	430	550	350	350	420	440	520	<0.50
Carbonate (CO3)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Dissolved Fluoride (F)	mg/L	0.050	0.11	0.16	0.17	0.19	0.29		0.27	0.28	0.27	0.32	0.30	0.26	<0.050
Hydroxide (OH)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Dissolved Sulphate (SO4)	mg/L	1.0	9.7	20	30	68	130	30	140	110	110	190	190	170	<1.0
Dissolved Chloride (Cl)	mg/L	1.0	5.9	5.5	8.0	21	75	7.9	65	39	37	48	41	37	<1.0
Microbiological Param.															
E.Coli DST	mpn/100m	1.0	1.0 (7)	2.0 (8)	7.4 (9)	6.3	4.1	6.3 (9)	6.3	28	7.5	8.5	9.8 (5)	3.1	<1.0 (9)
Fecal Coliforms	CFU/100m	1.0	<2.0 (10)	<2.0 (11)	4.0 (12)	3.0	3.0	<2.0 (12)	12	13	4	1.0	6.0	1.0	<2.0 (12)
Total Coliforms DST	mpn/100m	1.0	78 (7)	220 (8)	550 (9)	410	410	730 (9)	210	2000	250	130	120 (5)	44	<1.0 (9)
Nutrients															
Total Ammonia (N)	mg/L	0.050	0.11	0.093	0.29	0.39	1.7	0.28	1.3	0.80	0.81	0.23	0.35	0.30	<0.050
Dissolved Phosphorus (P)	mg/L	0.0030	0.014	0.017	0.0090	0.011	0.025	0.012	0.010	<0.0030	0.0060	0.017	0.0090	0.0060	<0.0030
Total Phosphorus (P)	mg/L	0.0030	0.027	0.036	0.081	0.076	0.21	0.12	0.12	0.21	0.069	0.043	0.032	0.024	<0.0030
Total Total Kjeldahl Nitrogen	mg/L	0.050	0.65	0.56	1.2	1.3	3.5	1.1	3	2.3	2.4	2	1.7	1.3	<0.050
Dissolved Nitrite (N)	mg/L	0.010	<0.010	<0.010	<0.010	<0.010	0.028	<0.010	0.012	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dissolved Nitrate (N)	mg/L	0.010	0.014	0.085	0.17	0.32	0.88	0.17	1.1	<0.010	0.012	0.36	0.27	0.26	<0.010
Elements															
Dissolved Calcium (Ca)	mg/L	0.30	31	45	56	79	88	56	94	59	59	68	72	73	<0.30
Dissolved Iron (Fe)	mg/L	0.060	<0.060	0.067	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060
Dissolved Magnesium (Mg)	mg/L	0.20	13	20	26	28	42	26	43	27	26	31	32	34	<0.20
Dissolved Manganese (Mn)	mg/L	0.0040	0.0043	0.079	0.16	0.28	0.61	0.16	0.40	1.0	1.4	0.069	0.12	0.085	<0.0040
Dissolved Potassium (K)	mg/L	0.30	4.2	3.8	5.1	5.7	14	5.1	14	14	13	16	13	9.0	<0.30
Dissolved Sodium (Na)	mg/L	0.50	27	49	61	64	110	61	110	83	82	140	120	140	<0.50
Field Parameters															
Turbidity	NTU		0	0.05	6.2	5.9	9.9	6.2	20	16	6.5	6.6	3.9	2.2	0
pH			8.65	8.05	7.84	7.83	7.8	7.84	7.83	7.92	8.25	8.1	8.25	7.61	9.21
Conductivity	µS/cm		320	488	630	754	920	630	1110	792	800	1070	1034	1160	0
Totoal Dissolved Solids	mg/L		159	244	307	374	455	307	553	391	385	533	517	580	2
Dissolved Oxygen	mg/L		**8.2**	10.7	**5.4**	**6.8**	**1.3**	**5.4**	**5.1**	**0.8**	**2.2**	**9.4**	**6.4**	**2.9**	9.2
Dissolved Oxygen	%		65	82	42	51	9	42	39	6	17	71	48	22	83
Temperature	˚C		2.1	0.4	0.5	0.2	0.4	0.5	0.6	0.7	1	0.8	1	0	9.5
							4.41								

RDL = Reportable Detection Limit
EDL = Estimated Detection Limit
Detection limits raised due to dilution to bring analyte within the calibrated range.
Detection limits raised due to matrix interference.
Sample was past hold time when received, set up 46.5 hours after sample collection.
(4) Sample was past hold time when received, set up 44.75 hours after sample collection.
(5) Sample analyzed 24.5 hours after sample collection. Sample analysis is recommended within 24 hours of sampling.
(6) Detection limit raised based on sample volume used for analysis
(7) Sample was past hold time when received, set up 76.5 hours after sample collection.
(8) Sample was past hold time when received, set up 75.5 hours after sample collection.
(9) Sample was past hold time when received, set up 74.25 hours after sample collection.
(10) Detection limit raised based on sample volume used for analysis. Sample was past hold time when received, set up 77 hours after sample collection.
(11) Detection limit raised based on sample volume used for analysis. Sample was past hold time when received, set up 76 hours after sample collection.
(12) Detection limit raised based on sample volume used for analysis. Sample was past hold time when received, set up 74.75 hours after sample collection.
(13) Sample analyzed 24.75 hours after sample collection. Sample analysis is recommended within 24 hours of sampling.

For sample 13SWE11045 RDL SO4 = 5.0
For sample 13SWE11047 RDL SO4 = 2.0 and TKN = 0.25
For sample 13SWE11055 RDL Fecal coliforms = 2.0.
For sample 13SWE11056 RDL TSS = 3 and fecal coliforms = 2.
For samples 13SWE11057 and 13SWE11057 RDL TSS = 1.7 and fecal coliforms = 2
For sample 13SWE11059 RDL fecal coliforms = 2.0.
For sample 13SWE11051 and 13SWE11052 RDL for TKN = 0.25
For sample 13SWE11054 RDL for Cl = 2.0

Tributaries

Maxxam ID		HI0607	HJ5515	HI4391	HI4388	HJ0493	HJ0465
AESRD Site ID		AB05FA0080	AB05FA0270	AB05FC0050	AB05FB0070	AB05FE110	AB05FE100
Sample Number		13SWE11003	13SWE11005	13 SWE11013	13 SWE11011	13SWE11017	13SWE11015
Site Name		Wolf Creek	Pipestone Creek	Meeting Creek	Iron Creek	Grizzly Bear Cre	Ribstone Creek
Date Sampled		26-Aug-13	29-Aug-13	27-Aug-13	27-Aug-13	30-Aug-13	30-Aug-13
	UNITS						
Calculated Parameters							
Anion Sum	meq/L	9.3		13	20		
Cation Sum	meq/L	9.9		11	19		
Hardness (CaCO3)	mg/L	330	150	190	350	310	270
Ion Balance	N/A	1.1		0.90	0.92		
Dissolved Nitrate (NO3)	mg/L	0.75	0.60	0.013	0.013	0.013	0.013
Nitrate plus Nitrite (N)	mg/L	0.18	0.15	0.003	0.003	0.003	0.003
Dissolved Nitrite (NO2)	mg/L	0.017	0.053	0.0099	0.0099	0.0099	0.0099
Misc. Inorganics							
Conductivity	uS/cm	900	560	1200	1800	2100	1100
pH	N/A	8.22	8.54	8.65	8.68	8.65	8.54
Total Organic Carbon (C)	mg/L	18	11	15	32	31	29
Total Dissolved Solids	mg/L	510	340	700	1100	1500	710
Total Suspended Solids	mg/L	8.0	2.7	2.0	13	11	9.3
Anions							
Alkalinity (PP as CaCO3)	mg/L	0.5		20	34		
Alkalinity (Total as CaCO3)	mg/L	290		410	590		
Bicarbonate (HCO3)	mg/L	350		450	630		
Carbonate (CO3)	mg/L	0.5		24	41		
Dissolved Fluoride (F)	mg/L	0.28	0.19	0.38	0.19	0.27	0.31
Hydroxide (OH)	mg/L	0.5		0.5	0.5		
Dissolved Sulphate (SO4)	mg/L	89	120	160	370	430	90
Dissolved Chloride (Cl)	mg/L	56	32	49	33	41	20
Microbiological Param.							
E.Coli DST	mpn/100mL	550	72	1400	460	61	220
Fecal Coliforms	CFU/100mL	260	46	200.5	200.5	83.1	165
Total Coliforms DST	mpn/100mL	2400	1600	2400	2400	2400	2400
Nutrients							
Total Ammonia (N)	mg/L	0.066	0.059	0.05	0.05	0.058	0.05
Dissolved Phosphorus (P)	mg/L	0.48	0.16	0.013	0.35	0.69	0.053
Total Phosphorus (P)	mg/L	0.51	0.22	0.027	0.44	0.77	0.097
Total Total Kjeldahl Nitrogen	mg/L	1.6	0.98	1.3	3.5	2.6	1.9
Dissolved Nitrite (N)	mg/L	0.0052	0.016	0.003	0.003	0.003	0.003
Dissolved Nitrate (N)	mg/L	0.17	0.14	0.003	0.003	0.003	0.003
Elements							
Dissolved Calcium (Ca)	mg/L	80	34	41	39	33	53
Dissolved Iron (Fe)	mg/L	0.077		0.06	0.062		
Dissolved Magnesium (Mg)	mg/L	31	15	21	60	56	33
Dissolved Manganese (Mn)	mg/L	0.027		0.017	0.0063		
Dissolved Potassium (K)	mg/L	11		12	18	11	7.9
Dissolved Sodium (Na)	mg/L	71	54	170	270	370	140
Field Parameters							
Turbidity	NTU	8.72	4.48	0	8.9	31.6	4.04
pH		8.4	9.57	9.04	9.06	9.25	9.33
Conductivity	µS/cm	826	532	1075	1588	2025	1020
Totoal Dissolved Solids	mg/L	412	266	537	794	1010	509
Dissolved Oxygen	mg/L	6.8	9.2	9.2	5.4	11.3	8.2
Dissolved Oxygen	%	79	111	116	62	148	98
Temperature	˚C	16.6	21.2	22	18	26.3	19.7

Maxxam ID		HV3022	HX0118	HV7075	HV7052	HW0534	HW0533
AESRD Site ID		AB05FA0080	AB05FA0270	AB05FC0050	AB05FB0070	AB05FE0110	AB05FE0100
Sample Number		13SWE11023	13SWE11036	13SWE11028	13SWE11024	13SWE11031	13SWE11030
Site Name		Wolf Creek	Pipestone Creek	Meeting Creek	Iron Creek	Grizzly Bear Cre	Ribstone Creek
Date Sampled		15-Oct-13	22-Oct-13	16-Oct-13	16-Oct-13	17-Oct-13	17-Oct-13
	UNITS						
Calculated Parameters							
Anion Sum	meq/L	12	8.0	13	18	32	19
Cation Sum	meq/L	12	7.7	12	17	31	12
Hardness (CaCO3)	mg/L	390	200	220	420	240	270
Ion Balance	N/A	0.99	0.96	0.98	0.99	0.96	0.60
Dissolved Nitrate (NO3)	mg/L	1.7	0.013	0.034	0.013	0.11	0.013
Nitrate plus Nitrite (N)	mg/L	0.43	0.003	0.0076	0.003	0.031	0.003
Dissolved Nitrite (NO2)	mg/L	0.16	0.0099	0.0099	0.0099	0.021	0.0099
Total Dissolved Solids	mg/L	660	430	690	970	1900	920
Misc. Inorganics							
Conductivity	uS/cm	1100	780	1100	1500	2900	1700
pH	N/A	8.19	8.27	8.39	8.20	8.37	8.29
Total Organic Carbon (C)	mg/L	10	11	16	22	13	19
Anions							
Alkalinity (PP as CaCO3)	mg/L	0.5	0.5	5.0	0.5	7.0	0.5
Alkalinity (Total as CaCO3)	mg/L	290	260	450	560	870	630
Bicarbonate (HCO3)	mg/L	350	320	530	680	1000	760
Carbonate (CO3)	mg/L	0.5	0.5	6.0	0.5	8.4	0.5
Dissolved Fluoride (F)	mg/L	0.35	0.24	0.40	0.20	0.37	0.38
Hydroxide (OH)	mg/L	0.5	0.5	0.5	0.5	0.5	0.5
Dissolved Sulphate (SO4)	mg/L	160	78	120	280	560	270
Dissolved Chloride (Cl)	mg/L	92	40	44	25	100	40
Microbiological Param.							
E.Coli DST	mpn/100mL	70	9.8	310	110	18	84
Fecal Coliforms	CFU/100mL	54	2	68	34	10	32
Total Coliforms DST	mpn/100mL	1700	580	870	2400	730	2400
Nutrients							
Total Ammonia (N)	mg/L	0.05	0.05	0.069	0.05	0.05	0.05
Dissolved Phosphorus (P)	mg/L	0.085	0.049	0.0074	0.10	0.18	0.0090
Total Phosphorus (P)	mg/L	0.25	0.15	0.015	0.26	0.26	0.083
Total Total Kjeldahl Nitrogen	mg/L	1.7	1.2	0.99	2.2	1.0	1.2
Dissolved Nitrite (N)	mg/L	0.049	0.003	0.003	0.003	0.0064	0.003
Dissolved Nitrate (N)	mg/L	0.38	0.003	0.0076	0.003	0.025	0.003
Elements							
Dissolved Calcium (Ca)	mg/L	100	49	53	67	35	61
Dissolved Iron (Fe)	mg/L	0.06	0.06	0.06	0.06	0.06	0.06
Dissolved Magnesium (Mg)	mg/L	34	19	22	61	37	30
Dissolved Manganese (Mn)	mg/L	0.046	0.010	0.088	0.0082	0.082	0.0047
Dissolved Potassium (K)	mg/L	11	8.2	10	14	5.0	8.8
Dissolved Sodium (Na)	mg/L	84	80	180	200	590	140
Field Parameters							
Turbidity	NTU	7.65	4.2	N/A	17.7	18.3	19.3
pH		8.42	8.47	8.64	8.5	8.62	8.5
Conductivity	µS/cm	955	662	1007	1356	2540	1505
Totoal Dissolved Solids	mg/L	478	330	498	678	1276	751
Dissolved Oxygen	mg/L	11.9	106	13.2	9.1	11.7	10.4
Dissolved Oxygen	%	106	100	117	80	100	87
Temperature	˚C	4.5	8.3	6.2	4.6	4.1	3.9

Maxxam ID		A179162	A179162				IL3301
Sampling Date		AB05FA0080	AB05FA0270				AB05FE0100
COC Number		**13SWE11054**	**13SWE11051**				**13SWE11045**
Site Name		**Wolf Creek**	**Pipestone Creek**				**Ribstone Creek**
Sample Date		**16-Jan-14**	**16-Jan-14**				**13-Jan-14**
	UNITS						
Calculated Parameters							
Anion Sum	meq/L	11	14				21
Cation Sum	meq/L	10	13				20
Hardness (CaCO3)	mg/L	400	350				300
Ion Balance	N/A	0.95	0.91				0.96
Dissolved Nitrate (NO3)	mg/L	3.4	0.90				0.70
Nitrate plus Nitrite (N)	mg/L	0.77	0.23				0.18
Dissolved Nitrite (NO2)	mg/L	0.033	0.074				0.057
Total Dissolved Solids	mg/L	580	760				1200
Misc. Inorganics							
Conductivity	uS/cm	970	1300				1900
pH	pH	7.86	7.65				7.90
Total Organic Carbon (C)	mg/L	6.4	12				11
Total Suspended Solids	mg/L	5.3	8.0				11
Anions							
Alkalinity (PP as CaCO3)	mg/L	0.5	0.5				0.5
Alkalinity (Total as CaCO3)	mg/L	370	470				670
Bicarbonate (HCO3)	mg/L	450	580				820
Carbonate (CO3)	mg/L	0.5	0.5				0.5
Dissolved Fluoride (F)	mg/L	0.23	0.32				0.29
Hydroxide (OH)	mg/L	0.5	0.5				0.5
Dissolved Sulphate (SO4)	mg/L	120	150				300
Dissolved Chloride (Cl)	mg/L	37	60				46
Microbiological Param.							
E.Coli DST	mpn/100mL	8.5	6.3				7.5
Fecal Coliforms	CFU/100mL	3.0	2				14
Total Coliforms DST	mpn/100mL	440	1600				550
Nutrients							
Total Ammonia (N)	mg/L	0.28	1.4				0.35
Dissolved Phosphorus (P)	mg/L	0.016	0.0030				0.025
Total Phosphorus (P)	mg/L	0.058	0.061				0.083
Total Total Kjeldahl Nitrogen	mg/L	0.89	2.3				1.4
Dissolved Nitrite (N)	mg/L	0.01	0.023				0.017
Dissolved Nitrate (N)	mg/L	0.77	0.20				0.16
Elements							
Dissolved Calcium (Ca)	mg/L	110	88				60
Dissolved Iron (Fe)	mg/L	0.06	0.06				0.06
Dissolved Magnesium (Mg)	mg/L	29	31				36
Dissolved Manganese (Mn)	mg/L	0.19	2.1				0.13
Dissolved Potassium (K)	mg/L	5.6	8.7				5.2
Dissolved Sodium (Na)	mg/L	52	130				330
Field Parameters							
Turbidity	NTU	2.1	4.8				5.9
pH		7.91	7.85				7.94
Conductivity	µS/cm	869	1070				1750
Totoal Dissolved Solids	mg/L	434	548				880
Dissolved Oxygen	mg/L	8.7	0.4				6.7
Dissolved Oxygen	%	67	3				51
Temperature	˚C	0.4	0				1

Lagoons

RESULTS OF CHEMICAL ANALYSES OF WATER							
Maxxam ID			**HX6329**	**HX0114**	**HX6327**	**HX6319**	**HZ0125**
AESRD Site ID			**AB05FA0680**	**AB05FA0690**	**AB05FA0700**	**AB05FA0720**	**AB05FC0895**
Sample Number			**13SWE11039**	**13SWE11032**	**13SWE11041**	**13SWE11040**	**13SE11043**
Site Name			**Lacombe Sewage Effluent**	**Ponoka Sewagte Effluent**	**Wetaskiwin Sewage Effluent**	**Camrose Sewage Lagoon**	**Stettler WW**
Date Sampled			**24-Oct-13**	**22-Oct-13**	**24-Oct-13**	**24-Oct-13**	**29-Oct-13**
	UNITS	**RDL**					
Calculated Parameters							
Anion Sum	meq/L	N/A	15	11	18	17	19
Cation Sum	meq/L	N/A	15	10	19	18	20
Hardness (CaCO3)	mg/L	0.50	410	290	450	380	410
Ion Balance	N/A	0.010	1.0	0.92	1.0	1.1	1.1
Dissolved Nitrate (NO3)	mg/L	0.013	4.8	7.0	5.6	1.9	13
Nitrate plus Nitrite (N)	mg/L	0.0030	1.1	1.6	1.3	0.54	3.1
Dissolved Nitrite (NO2)	mg/L	0.0099	0.10	0.18	0.088	0.41	0.60
Total Dissolved Solids	mg/L	10	850	590	1100	1100	1100
Misc. Inorganics							
Conductivity	uS/cm	1.0	1400	1100	1700	1700	1700
pH	N/A	N/A	8.09	8.22	8.52	8.30	8.06
Total Organic Carbon (C)	mg/L	0.50	13	11	15	17 (2)	17
Total Suspended Solids	mg/L	1.00	420 (14)	140 (14)	6.0 (13)	9.0 (14)	
Anions							
Alkalinity (PP as CaCO3)	mg/L	0.50	<0.50	<0.50	13	<0.50	<0.50
Alkalinity (Total as CaCO3)	mg/L	0.50	330	300	330	270	460
Bicarbonate (HCO3)	mg/L	0.50	400	370	370	330	570
Carbonate (CO3)	mg/L	0.50	<0.50	<0.50	16	<0.50	<0.50
Dissolved Fluoride (F)	mg/L	0.050	0.75	0.51	0.89	0.76	0.90
Hydroxide (OH)	mg/L	0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Dissolved Sulphate (SO4)	mg/L	1.0	200 (1)	83	370 (1)	380 (1)	250 (1)
Dissolved Chloride (Cl)	mg/L	1.0	140	110	130	140	140
Microbiological Param.							
E.Coli DST	mpn/100mL	1.0	1200 (11)	1.0 (7)	41	9.8	7.3
Fecal Coliforms	CFU/100mL	1.0	650 (12)	<2.0 (9)	26 (6)	14 (6)	2.0
Total Coliforms DST	mpn/100mL	1.0	>2400 (11)	61 (7)	1700	770	120
Nutrients							
Total Ammonia (N)	mg/L	0.050	15 (1)	0.15	0.20	11 (1)	3.6 (1)
Dissolved Phosphorus (P)	mg/L	0.0030	0.81 (1)	0.55 (1)	1.2 (1)	0.42	2.1 (1)
Total Phosphorus (P)	mg/L	0.0030	3.0 (1)	0.59 (1)	1.2 (1)	0.47	2.2 (13)
Total Total Kjeldahl Nitrogen	mg/L	0.050	23 (1)	1.8	1.9 (2)	14 (1)	5.9 (1)
Dissolved Nitrite (N)	mg/L	0.0030	0.031	0.055	0.027	0.13	0.18
Dissolved Nitrate (N)	mg/L	0.0030	1.1	1.6	1.3	0.42	3.0
Elements							
Dissolved Calcium (Ca)	mg/L	0.30	98	69	110	81	97
Dissolved Iron (Fe)	mg/L	0.060	<0.060	<0.060	<0.060	<0.060	<0.060
Dissolved Magnesium (Mg)	mg/L	0.20	41	28	44	43	41
Dissolved Manganese (Mn)	mg/L	0.0040	0.16	0.062	0.016	0.28	0.080
Dissolved Potassium (K)	mg/L	0.30	18	13	28	26	20
Dissolved Sodium (Na)	mg/L	0.50	130	95	210	220	250
Field Parameters							
Turbidity	NTU		450	0	0	3.9	0
pH			8.29	8.43	8.7	8.68	8.3
Conductivity	µS/cm		1325	1059	1709	1471	1690
Totoal Dissolved Solids	mg/L		661	527	851	735	845
Dissolved Oxygen	mg/L		8	8.5	11.8	106	10.2
Dissolved Oxygen	%		68	81	104	93	86
Temperature	°C		4	8.2	6.2	6.6	2.6

RDL = Reportable Detection Limit

EDL = Estimated Detection Limit

(1) Detection limits raised due to dilution to bring analyte within the calibrated range.

(2) Detection limits raised due to matrix interference.

(3) Sample analyzed 24.5 hours after sample collection. Sample analysis is recommended within 24 hours of sampling.

(4) Sample analyzed 25 hours after sample collection. Sample analysis is recommended within 24 hours of sampling.

(5) Sample was originally processed within hold time. Data quality required investigation. Re-analysis was completed past recommended hold time.

(6) Detection limit raised based on sample volume used for analysis

(7) Sample analyzed 26.33 hours after sample collection. Sample analysis recommended within 24 hours of sampling.

(8) Sample analyzed 25.5 hours after sample collection. Sample analysis recommended within 24 hours of sampling.

(9) Sample analyzed 26.5 hours after sample collection. Sample analysis is recommended within 24 hours of sampling. Detection limit raised based on sample volume used for analysis.

(10) Sample analyzed 25.75 hours after sample collection. Sample analysis is recommended within 24 hours of sampling. Detection limit raised based on sample volume used for analysis.

(11) Sample was past hold time when received, set up 25.2 hours after sample collection.

(12) Detection limit raised based on sample volume used for analysis. Sample was past hold time when received, set up 26.33 hours after sample collection.

(13) Analysis requested past recommended holding time

(14) Analysis requested past recommended holding time. Detection limit raised based on sample volume used for analysis.

For sample 13SWE11032 RDL TSS = 1.5, Fecal coliforms = 2.0, DP = 0.015 and TP = 0.015

For sample 13SWE11039 RDL TSS = 6.0, SO4 = 5.0, fecal coliforms = 10, total ammonia = 0.50, DP = 0.015, TP = 0.03, and TKN = 1.3

For sample 13SWE11040 RDL TOC = 1.0, SO4 = 5.0, fecal coliforms = 2.0, total ammonia (N) = 0.5, and TKN = 0.50

For sample 13SWE11041 RDL SO4 = 5.0, fecal coliforms = 2.0, DP = 0.015, TP = 0.015, and TKN = 0.1

For sample 13SWE11043 RDL SO4 = 5.0, total ammonia (N) = 0.25, DP = 0.015, TP = 0.015, and TKN = 0.25

Appendix B. Flow Data

Measured Flow Data and Comparison with Water of Canada Survey Data

Discharge Summary 2013			
AESRD Site ID	Discharge August (m^3/s)	Discharge October (m^3/s)	Discharge January (m^3/s)
AB05FA0009	0.000	0.000	0.000
AB05FA0030	0.167	0.020	0.294
AB05FA0060	0.000	[b]0.0850392	0.000
AB05FA0080	0.268	0.024	0.072
AB05FA0120	0.634	0.136	0.572
AB05FA0270	0.023	0.000	0.000
AB05FA0280	2.650	0.438	0.122
AB05FA0320	2.715	0.322	0.096
AB05FC0020	2.644	0.430	0.313
AB05FB0050	0.797	0.797	0.547
AB05FB0070	0.013	0.000	-
AB05FC0030	3.346	0.395	0.299
AB05FC0050	0.007	0.003	-
AB05FC0150	2.517	0.162	0.300
AB05FE0100	0.060	0.018	0.000
AB05FE0120	4.456	4.022	0.975
AB05FE0110	0.000	0.000	-
AB00QC0001	-	-	-
AB05FA0680	-	0.053	-
AB05FA0690	-	0.039	-
AB05FA0700	-	0.375	-
AB05FA0720[a]	-	0.217	-
AB05FC0895	-	0.055	-

*Note: Discharge = 0.000 indicates discharge not measurable due to insufficient flow. - indicates site not measured.

[a] Discharge calculated from an estimated velocity.

[b]this discharge is underestimated due to the culvert under the low level crossing that was not seen until the January sampling

Discharge Summary 2013									
AESRD Site ID	Station Name	Water Survey of Canada Station	Distance between sites (km)	Sample Date	Discharge August (m^3/s)	Water Survey of Canada Discharge (m^3/s)	Sample Date	Discharge October (m^3/s)	Water Survey of Canada Discharge (m^3/s)
AB05FA0060	U/S Ponoka	05FA001	7.7	Aug 26/13	0.000	0.368	Oct 15/13	[b]0.0850392	0.283
AB05FA0270[1]	Pipestone Cr.	05FA012		Aug 29/13	0.023	0.467	Oct 22/13	0.000	**0.044**
AB05FB0050	D/S Hardisty	05FC008	50	Aug 27/13	0.797	1.870	Oct 16/13	0.797	0.337
AB05FB0070[1]	Iron Cr.	05FB002		Aug 27/13	0.013	0.098	Oct 16/13	0.000	**0.062**
AB05FC0030	U/S Meeting Cr.	05FC001	0	Aug 27/13	3.346	0.719	Oct 16/13	0.395	0.528
AB05FE0110[2]	Blackfoot Cr.	05FE005		Aug 30/13	0.000	**0.001**	Oct 17/13	0.000	**0.006**
AB05FE0100[1]	Ribstone Cr.	05FD001		Aug 30/13	0.060	0.129	Oct 17/13	0.018	0.079
AB05FE0120	D/S Ribstone Cr.	05FE004		Aug 30/13	4.456	3.330	Oct 17/13	4.022	1.600

[1]Water survey of Canada data is the average for the month over a ten year period (2002 to 2011)

[2]Water survey of Canada data is a monthly average from 1980 to 1983

Bold font indicates occassions was water survey of Canada data was used instead of measured flow data.

Appendix C. Field Data Sheets