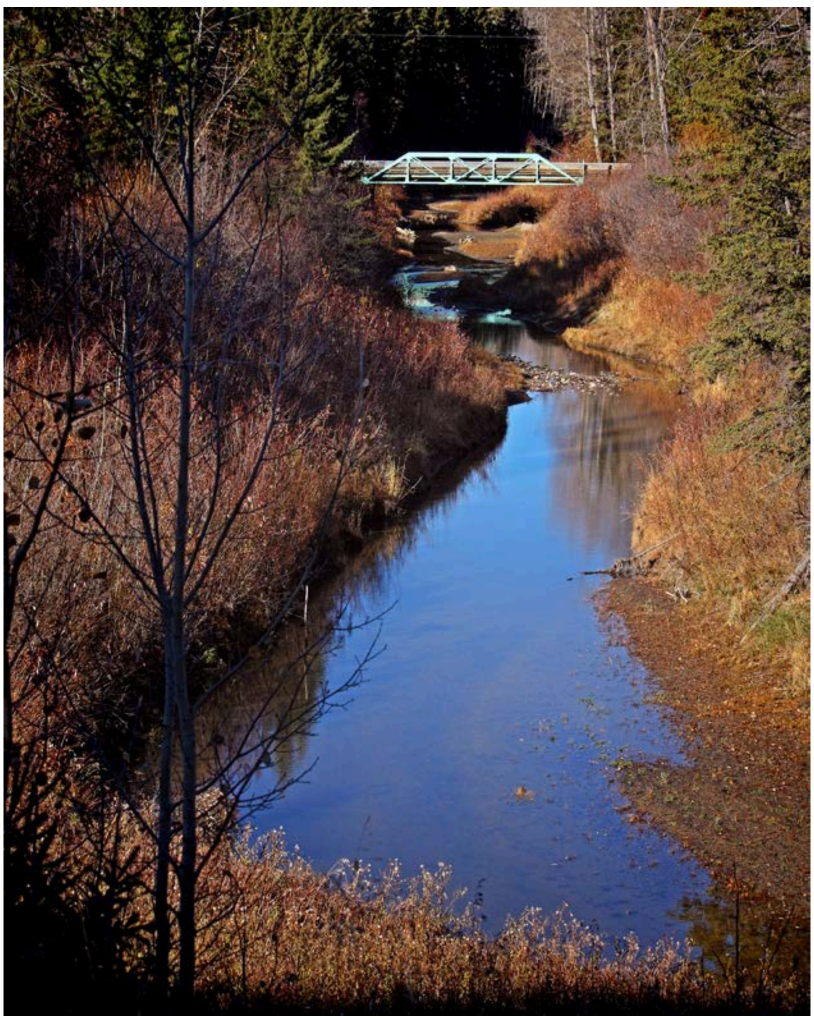
North Saskatchewan Watershed Alliance

A Compilation of Stream Nutrient Data for Alberta



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The North Saskatchewan Watershed Alliance (NSWA) is a non-profit society whose purpose is to protect and improve water quality and ecosystem functioning in the North Saskatchewan River watershed in Alberta. The organization is guided by a Board of Directors composed of member organizations from within the watershed. It is the designated Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River under the Government of Alberta's *Water for Life Strategy.*

Alberta Government

This report was prepared by Ms. Jennifer Regier, B.Sc. and Mr. David O. Trew, P. Biol. of the North Saskatchewan Watershed Alliance.

Cover photo courtesy of Images Alberta Camera Club
Strawberry Creek in the midst of Telfordville Village.
The image was captured from Township Road 495A looking northwest. The bridge in the image is Range Road 21. Photographer: Robert Burkholder

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Executive Summary

This report provides a descriptive compilation of stream nutrient data collected in Alberta between 1977 and 2013. The purpose was to consolidate information from many diverse sources into one document and to provide a useful reference point for future studies of lake and watershed management in this province.

Stream nutrient data from eleven watershed studies are presented for ten lake watersheds. These include streams draining into Baptiste Lake, Wabamun Lake, Lac La Nonne, Pine Lake, Lesser Slave Lake, Lac Ste. Anne, Lake Isle, Gull Lake, Lac la Biche and Pigeon Lake. Most of these studies were conducted by Alberta Environment (AENV); some were conducted by faculty and graduate students at the University of Alberta.

This document also includes data from detailed studies conducted on a large selection of streams draining agricultural watersheds with varying degrees of agricultural intensity and runoff. These longer-term studies were conducted jointly by Alberta Environment and Alberta Agriculture & Rural Development. These included the *Canada-Alberta Environmentally Sustainable Agriculture* (CAESA 1998) and *Alberta Environmentally Sustainable Agriculture* (AESA 2008) projects. A smaller stream study from the Swan Hills is also included (Munn and Prepas 1986).

Data were compiled for 108 streams; several streams were sampled for more than one year providing a total of 190 years of stream data. The compiled data are presented in graphical and tabular formats as Annual Flow-Weighted Mean Concentrations (AFWMCs) and Annual Export Coefficients (AECs). Twenty nutrient fractions and ratios are presented.

Acknowledgements

The authors thank Ms. Marilou Montemayor (NSWA), Mr. Gord Thompson (NSWA), Dr. Les Gammie (NSWA) and Ms. Alyssa Tuininga (AESRD) for reviewing this document. Ms. Candace Vanin (Agriculture Canada) and Ms. Mary Ellen Shain (NSWA) assisted with mapping. Ms. Melissa Logan (NSWA) formatted the final document.

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1.0 Introduction

Many Alberta lakes display advanced symptoms of eutrophication as a result of high nutrient concentrations. Over the years a number of watershed-scale studies have been conducted on Alberta lakes to develop nutrient budgets and to measure phosphorus and nitrogen loadings via tributary streams. The study streams drained both forested and agricultural watersheds. These variations in land cover are thought to have a major influence on runoff water quality.

Phosphorus is considered to be the most common limiting chemical factor for algal growth in freshwater lakes (Trimbee and Prepas 1987; Schindler et al. 2008). The nitrogen content of freshwater lakes can also be an important factor and may influence the patterns of algal succession that occur during the open-water growing season (Prepas and Trimbee 1988). Other factors such as salinity, turbidity and physical mixing patterns are important determinants of the quantity and types of algae that develop (Bierhuizen and Prepas 1985). Algal blooms are a major feature of summer water quality in Alberta lakes, affecting water transparency and aesthetics and influencing other lake features such as oxygen concentrations and cyanotoxicity. The control of excessive summer algal blooms is therefore an important goal of lake management in this province.

The development of phosphorus budgets has become commonplace in the lake research and management literature, and they are used as diagnostic tools to quantify pollution sources and evaluate long-term management options for lakes (Dillon and Rigler 1974; Rast and Lee 1978; Teichreb 2014). The development of phosphorus budgets and models has been an ongoing field of limnological research since the first watershed/lake nutrient relationships were developed in the 1960s (Vollenweider 1968). Stream surveys are one component of phosphorus budgets.

Although many studies have shown increases in stream phosphorus and nitrogen in agricultural areas, it is important to acknowledge natural variations. Soils are particularly relevant since agricultural lands are often found in nutrient rich regions. This makes it difficult to determine the proportions of anthropogenic and natural influences on phosphorus in streams, especially when there are few reference sites available for comparison. Additional geologic and hydrologic controls can affect phosphorus levels and should also be considered when assessing stream nutrient data (Dillon and Kirchner 1975; Gburek and Sharpley 1998; Donahue 2013).

This report provides a basic compilation of the nutrient data collected between 1977 and 2013 during these various Alberta stream studies. The purpose is to consolidate information into one document and provide an additional reference point for future studies of lake and watershed management. Data from a total of 108 individual streams are presented in graphical and tabular formats as Annual Flow-Weighted Mean Concentrations (AFWMCs) and Annual Export Coefficients (AECs). Twenty nutrient fractions and ratios are presented. Interpretation of the compiled data is limited in scope; the authors recommend further evaluation.

2.0 Background Information

2.1 Eutrophication of Alberta Lakes

Eutrophication is a process in which lakes may become increasingly more productive - a process that occurs naturally, but can be accelerated by human activities. It is driven by enhanced nutrient inputs, particularly phosphorus. The eutrophication process is also influenced by the physical and chemical characteristics of the individual lake (e.g., depth, flushing, salinity) as well as the size of the watershed, land cover, local climate, etc.

The trophic state of a lake refers to its level of biological productivity and is usually defined in terms of its phosphorus and chlorophyll a concentrations. Lakes are categorized along a trophic spectrum: oligotrophic (low productivity), mesotrophic (moderate productivity), eutrophic (high productivity) and hypertrophic (very high productivity).

Both internal and external sources of phosphorus contribute to lake eutrophication. In shallow Alberta lakes, phosphorus concentrations increase rapidly in mid to late summer as phosphorus is released from lake bottom sediments in a process referred to as "internal loading" (Figure 1). The response of the phytoplankton community is equally rapid and algal blooms quickly develop during these ideal conditions of fertility, warm weather and ample sunlight. Phosphorus and other nutrients also enter lakes through a variety of external loading pathways including tributaries, groundwater, atmospheric inputs and shoreline sources (Figure 2).

Many Alberta lakes are naturally eutrophic due to the presence of fertile watershed soils (Mitchell and Trew 1992). However, natural lake productivity is being amplified by human disturbance. Paleolimnological evidence suggests that changes occurred during the 1950s to 1970s due the combined effects of converted land cover, agricultural intensification, increased cottage development and related hydrologic impacts (AESRD 2007).

2.2 Hydrologic Influences on Nutrient Loading

Runoff in streams on the Alberta plains is largely driven by snowmelt. An example of a plains stream hydrograph (Strawberry Creek) is presented in Figure 3. Discharges are typically highest during spring runoff and gradually decrease, with the exception of a few summer storm events that can briefly raise flow rates. Snowmelt was observed to contribute over 90% of annual runoff in eight Alberta watersheds in a study conducted by Little et al. (2007). The shape of the hydrograph greatly influences the timing of nutrient loading. The high volume of water accompanied by the release of nutrients from frozen snow, soils and plant residue generally results in the greatest nutrient flux occurring during the spring snowmelt period. Snowmelt runoff also contributes to overall water quality issues related to total organic carbon (TOC), colour, bacteria, protozoans, taste and odour. An example of the seasonal pattern in phosphorus concentrations for a small forested stream at Baptiste Lake is presented in Figure 4.

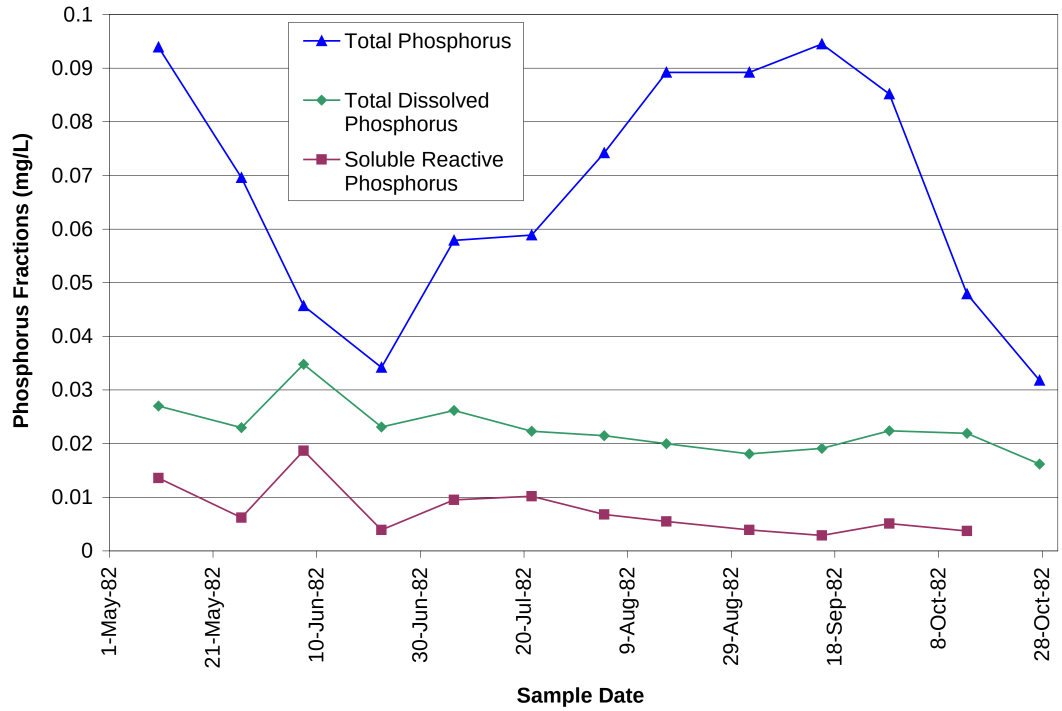

Figure 1. Seasonal fluctuations in phosphorus fractions in Tucker Lake, 1982 (Source: Chow-Fraser and Trew 1990)

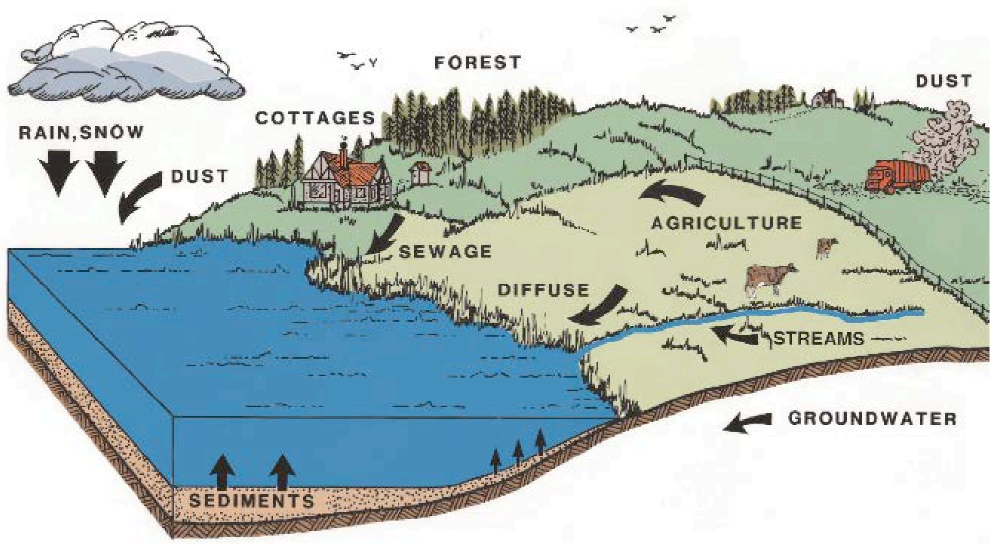

Figure 2. Typical phosphorus sources to lakes (Source: AESRD 2014)

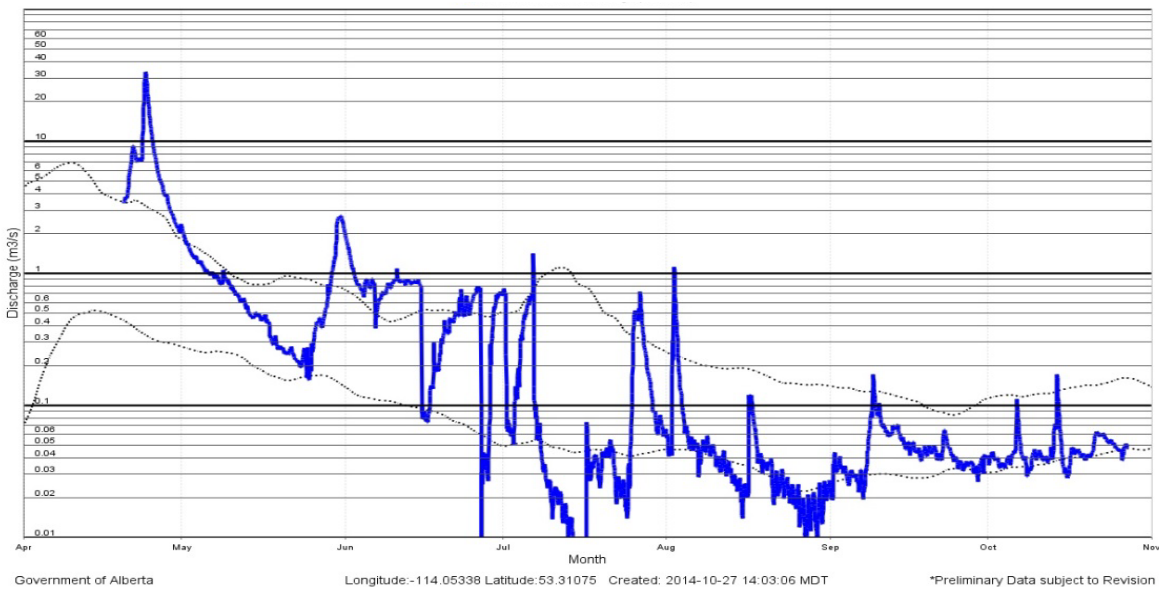

Figure 3. Hydrograph for Strawberry Creek near the Mouth (Station 05DF004) for April to November; current year (2014) shown in blue; normal range (quartiles) shown in grey (Source: AESRD 2014)

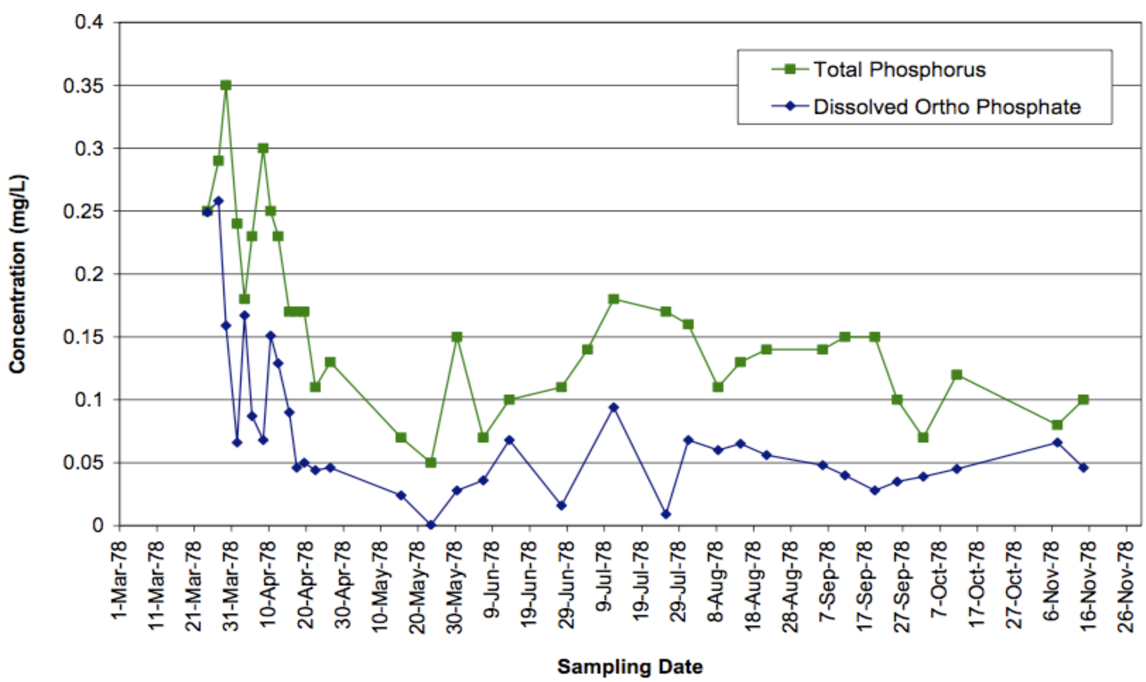

Figure 4. Seasonal fluctuations in total phosphorus concentrations in Stream E, Baptiste Lake (Source: Trew et al. 1987)

Thus, stream nutrients are often concentrated in the earlier part of the open-water season. Streams that only flow during this time often have a much higher concentrations and loads relative to their total volume of flow. Not all streams follow this truncated ephemeral pattern, but it is important to consider this attribute when comparing AFWMCs within and among watersheds. Flow effects should also be understood when evaluating AECs, which can exhibit great variations from year to year for individual streams, depending on inter-annual runoff and loading variations. AFWMCs are useful in describing and modeling nutrient load patterns because they minimize the variability within and among stream types over time (Anderson 2006).

2.3 Natural Regions and Land Cover Influences

Stream loading patterns are influenced by the characteristics of the soil and the vegetation that are encountered and transported during runoff events. Eco-regions are the natural indicators of base soil and vegetation characteristics. Strong relationships between soil phosphorus levels and concentrations of phosphorus in runoff have been documented in southern and central Alberta (Little 2007).

Soil nutrients are naturally lower in the mountain headwater regions and higher in Parkland and Boreal Forest eco-regions (AESRD 2014). Land cover changes within an eco-region cause variations in the quantity and quality of runoff from base conditions. Nutrient runoff data are therefore best aggregated and compared for streams within similar eco-regions (Anderson 2006).

Not all land cover types have the same effect on nutrient loading. A number of agricultural land cover types have been loosely ranked according to their nutrient contribution. A summary of total phosphorus (TP) export coefficients for southern Alberta agricultural areas concluded that export coefficients from feedlots were generally much higher than other types, followed by corn/soybeans, row, non-row, grazed, fallow, dairy, and alfalfa crops (Jeje 2003). These ranges are not always consistent due to variations in soil management, runoff and crops planted. While clearing of vegetation generally results in greater sediment and particulate nutrient flux in runoff, the presence of live groundcover over winter can increase the contribution of dissolved phosphorus and nitrogen fractions (Elliott 2013). The numerous freeze-thaw cycles common to prairie spring melts are thought to increase cell rupturing and release water soluble phosphorus. This process is more dependent on moisture content than nutrient content and may produce high runoff concentrations when green plants are actively growing at first frost, including recently seeded clover, winter wheat, and alfalfa (White 1973; Robertson 2007; Elliott 2013).

In light of these various findings, beneficial management practices (BMPs) are being promoted throughout Alberta (CAESA 1998; Paterson et al. 2006; Olson et al. 2011). These include applying nutrients only as needed, keeping livestock away from streams and lakes, managing manure storage and spreading to avoid groundwater contamination, and preventing soil nutrients from getting to the water by reducing tillage and increasing vegetation cover in areas susceptible to erosion. More research and monitoring of BMPs are required to further understand their effectiveness and implications in different regions of Alberta.

2.4 Water Quality Guidelines

Guidelines for water quality are science-based recommendations that provide “the best estimate of no-effect thresholds or safe levels for the particular use and substance in question” (AESRD 2014). Concentrations of 0.05 mg/L for Total Phosphorus and 1.0 mg/L for Total Nitrogen were used previously as the Alberta Surface Water Quality Guidelines (ASWQG) for the Protection of Aquatic Wildlife (PAL) (AESRD 2014). Over the past few years, a case has been made for site-specific guidelines. Unlike PAL guidelines, these attempt to account for biogeochemical differences unique to individual ecoregions and water bodies, requiring extensive understanding of the local limnology, hydrogeology, point and non-point sources (Anderson 2006). Interim regional guidelines can be put in place while site-specific ones are being developed. For the present, AESRD has replaced the former PAL guidelines with narrative guidelines (Table 1).

Other guidelines for phosphorus were suggested via the Soil Phosphorus Limits Project developed by Alberta Agriculture and Rural Development (Paterson et al. 2006). The project was based on the conclusion of Little et al. (2007) that soil test phosphorus (STP) relates directly to runoff concentrations and was concerned with the implications of limits for both agriculture and water quality. Using hypothetical guidelines of 1.0 mg/L (Alberta Environment’s limit for point source discharge from waste-water treatment plants) and 0.5 mg/L, the level of STP required to meet these guidelines was calculated. The project determined that soil test phosphorus levels should be kept below 60 ppm over very large areas of agricultural land. Although this level is also considered to be the agricultural threshold over which plant response to phosphorus increase is minimal, it was concluded that setting such limits was not reasonable from a management and policy perspective.

The greatest perceived hurdle for implementing these limits was transportation costs to properly spread manure beyond concentrated livestock regions. It was also suggested by Patterson et al. (2006) that the high runoff concentrations were not significantly impacting the main stem of major river systems. Beneficial Management Practices (BMPs) were strongly encouraged with a focus on riparian areas and tributaries.

Table 1. Surface water quality guidelines for nutrients
(Source: AESRD 2014)

Water Body Type	Guideline
Lakes	No increase in nitrogen (total) or phosphorus over existing conditions. Where nitrogen and/or phosphorus have increased due to human activity, develop lake-specific nutrient objectives and management plans where warranted.
Major River (Interim*)	For major rivers, nitrogen (total) and phosphorus concentrations should be maintained so as to prevent detrimental changes to algal and aquatic plant communities, aquatic biodiversity, oxygen levels and recreational quality. Where priorities warrant, develop site-specific nutrient objectives and management plans.
Other Water Bodies	For surface waters not covered by specific guidelines, nitrogen (total) and phosphorus concentrations should be maintained so as to prevent detrimental changes to algal and aquatic plant communities, aquatic biodiversity, oxygen levels, and recreational quality. Where priorities warrant, develop site-specific nutrient objectives and management plans.

**Work to develop science-based numeric guidelines for major Alberta rivers is ongoing*

3.0 Study Area

Most streams included in this report are located in central Alberta; however the north-south extent ranges from Hines Creek (approximately 130 km north of Grande Prairie, AB) to Prairie Blood Coulee (approximately 20 km southwest of Lethbridge, AB). The region is generally characterized by rich soils and high agricultural activity in the form of various livestock and grain operations. A number of undisturbed forested streams, located in the Boreal Ecoregion, are also included in this compilation. Stream locations are presented on the Alberta Ecoregion map (Figure 5).

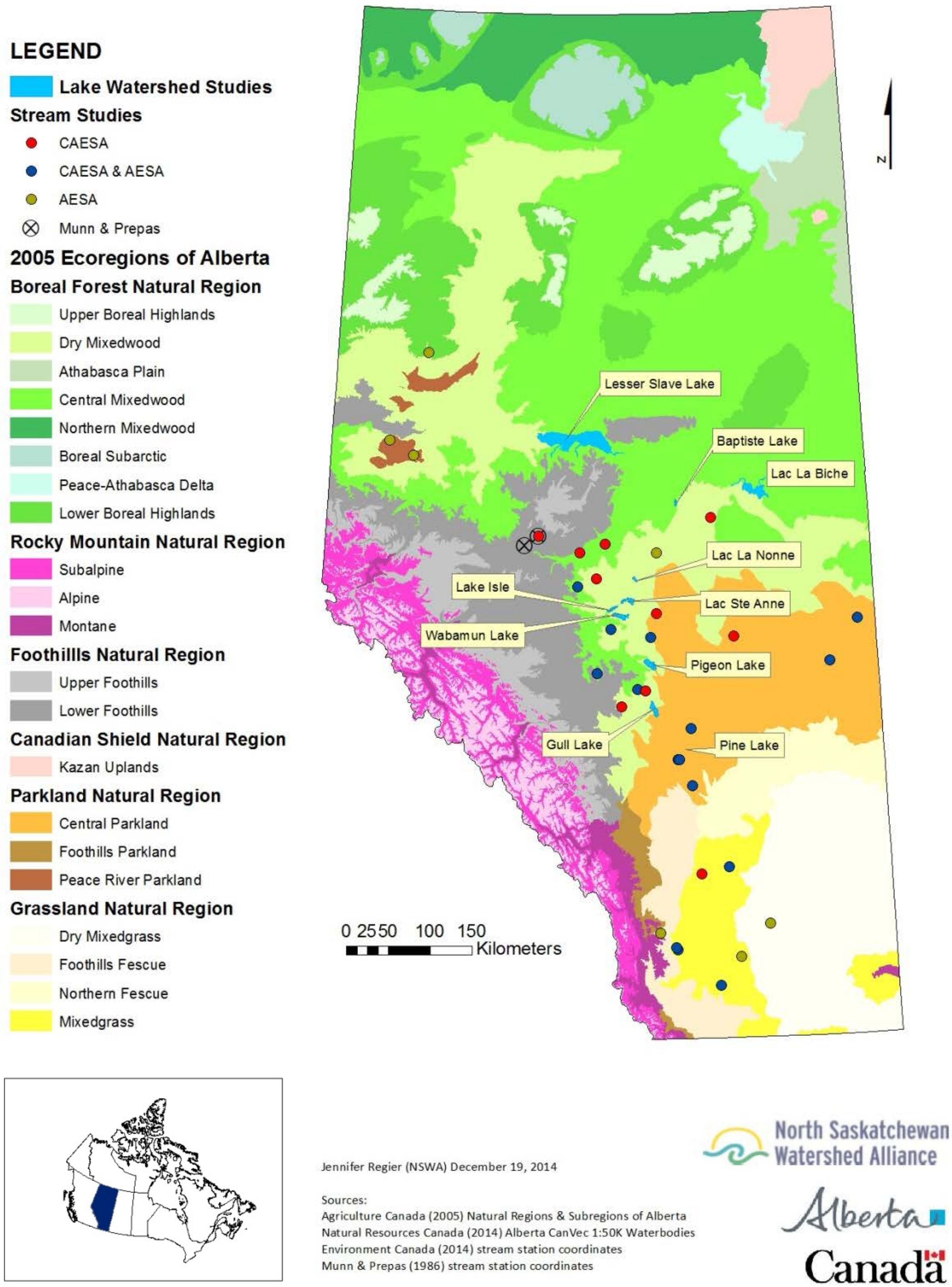

Figure 5. Alberta Natural Regions map with stream locations.

4.0 Compilation Methods

4.1 Data Collection

The individual studies included in this compilation are listed in Table 2 along with their year(s) of study, number of streams sampled and numbers of samples (sampling days). Note that some streams were resampled during later studies. Nutrient fractions collected are listed in Table 3. This is not a comprehensive list of all stream nutrient data for Alberta, but rather a compilation of studies known to report annual loads and/or concentrations. Data were obtained directly from databases, grey literature and scientific publications. Most studies were sourced from Alberta Environment and Alberta Agriculture & Rural Development.

4.2 Data Analysis

Calculated values

Annual Flow Weighted Mean Concentrations (AFWMCs) and Annual Export Coefficients (AECs) are the metrics presented in this report. In cases where the desired metric was not reported directly these values were derived from data presented in the original studies. AFWMCs (mg/L) were calculated by dividing the reported annual load by the reported annual discharge. AECs (kg/ha/yr) were determined by dividing the reported annual load by the stream basin area. A summary of the metrics compiled is presented in Table 4.

Box plots

Box plots were created to illustrate the range of AFWMCs and AECs compiled for each nutrient fraction. Plots for both metrics were also compiled for TP and TN by study and by ecoregion. Each AFWMC and AEC value is from a single stream year and "n" is indicated for each category. The error bars indicate the maximum and minimum values. The box shows the values ranging from the first to the third quartile (the middle 50% of the data). The line dividing the box horizontally indicates the median. Thus, each section represents one quarter of the data for each category.

Histograms

Summary histograms were created to show the provincial range of AFWMCs and AECs for TP and TN according to land cover type. The median of AFWMC and AEC values was calculated for each stream and plotted as the single data point for that stream. For many streams, no calculation was required as there was only one metric presented (either from a single year or a pre-calculated median, as in the AESA study).

Table 2. Summary of data sources compiled for this report listed chronologically by study type (lake watershed or stream). Each time a new stream was compiled, it was added to the "Stream Tally". Some streams were studied more than once so the number of "Streams per Study" is also listed. "Stream Years" consist of multiple streams sampled in the same year and/or multiple years of the same stream. Multi-year averages presented in the original studies were treated as single stream years where indicated (^{o}). "Sample Days" are as reported in the original studies or estimated (*) using raw data or sampling descriptions.

Study	Year(s) sampled	Stream Tally	Streams per Study	Stream Years	No. Sample Days
Lake Watershed Studies					
Baptiste Lake (Trew et al. 1987)	1977-1978	6	6	12	400*
Wabamun Lake (Mitchell 1985)	1980-1981	14	14	28	1030
Lac La Nonne (Mitchell & Hamilton 1982)	1981	1	1	1	16
Pine Lake (Sosiak & Trew 1996)	1989 & 1992	8	8	15	134
Lesser Slave Lake (Noton 1998)	1991-1993	7	7	7^{o}	67
Baptiste Lake (Cooke & Prepas 1998)	1994-1995	0	4	8	1400*
Lac Ste. Anne & Lake Isle (Mitchell 1999)	1997	12	12	12	100*
Gull Lake (Mitchell & LeClair 2003)	1999	12	12	12	109
Lac La Biche (Neufeld 2005)	2003-2004	6	6	6^{o}	126
Wabamun Lake (Emmerton 2008)	2008	2	7	7	61
Pigeon Lake (Teichreb 2014)	2013	7	7	7	54
Stream Studies					
Sakwatamau Two Creek (Munn & Prepas 1986)	1983	2	2	2	600*
CAESA (Anderson et al. 1998)	1995-1996	24	25	51	840*
AESA (Lorenz et al. 2008)	1999-2006	7	22	22^{o}	3040
TOTAL		**108**	**133**	**190**	**8000***

Table 3. Nutrient fractions compiled from studies listed in Table 2.

	Phosphorus Fractions		Nitrogen Fractions
TP	Total phosphorus	TN	Total nitrogen
TDP	Total dissolved phosphorus	TDN	Total dissolved nitrogen
PP	Particulate phosphorus	PN	Particulate nitrogen
FPP	Fine particulate phosphorus	TON	Total organic nitrogen
CPP	Course particulate phosphorus	TKN	Total Kjehldahl nitrogen
SRP	Ortho-phosphate	NO2/NO3	Nitrite & nitrate
BAP	Biologically available phosphorus	NO2	Nitrite
DRP	Dissolved reactive phosphorus	NO3	Nitrate
TDP:TP	Ratio dissolved to total phosphorus	NH3	Ammonia
		NH4	Ammonium
		DIN:TN	Ratio inorganic to total nitrogen

Many studies designated streams as draining a particular land cover. The criteria for assigning these land cover types varied from study to study. Information on land cover types and percent coverage during the study year(s) was also varied, making it difficult to create universal categories without manipulating the data beyond the intent of this compilation. The original designations were kept and are explained for each study in Table 5. Some streams not originally designated as a particular land cover type were later assigned designations during the CAESA study. Undesignated streams were given a broad designation (Forested or Agriculture) for the Natural Region boxplots (Figures 10, 11, 14 and 15). These are indicated in brackets.

Hydrology & Climate

A selection of long-term precipitation data was compiled to illustrate the climate context of the various study years. Precipitation values were collected from Environment Canada's Historic Weather website for the lake watershed study locations and Sakwatamau River. Annual precipitation for the study year and the 1981-2010 Climate Normals were collected from the nearest station possible.

Flow data were obtained from the studies themselves. The majority of flows reported were presented as annual discharges for individual streams and are included in the results section for information. Flows from the other studies may be found in the original documents in various other formats, such as instantaneous flows and graphs, but not always as annual flow volumes.

Table 4. Summary of nutrient metrics presented in this report as Annual Flow-Weighted Mean Concentrations (AFWMC) and Annual Export Coefficients (AEC). Studies area listed chronologically by type (lake watershed or stream). Most metrics were directly presented in the original study (√). Others were calculated using reported annual loads, discharges and stream basin areas where available (●).

Study		TP	TDP	PP	FPP	CPP	SRP	BAP	DRP	TDP:TP	TN	TDN	PN	TON	DON	TKN	NO2 / NO3	NO2	NO3	NH3	NH4	DIN:TN
Lake Watershed Studies																						
Baptiste	AFWMC	√					√				√			√			√			√		
(1978-1979)	AEC	√					√				√			√			√			√		
Wabamun	AFWMC	√									√											
(1980-1981)	AEC	√									√											
La Nonne	AFWMC	√									√											
(1981)	AEC	√									√											
Pine Lake	AFWMC	√	√	√			√	√			√					√	√			√		
(1989 & 1992)	AEC	●	●	●			●				●					●	●		●		●	
Lesser Slave	AFWMC	√	√																			
(1991-1993)	AEC	√																				
Baptiste	AFWMC	√	√	√					√										√		√	
(1994-1995)	AEC	√	√	√					√										√		√	
Ste.Anne &	AFWMC	√																				
Isle (1997)	AEC	●	●																			
Gull	AFWMC	●									●									●		
(1999)	AEC	●									●									●		
La Biche	AFWMC	√	√								√											
(2003-2004)	AEC	√	√	√							√	√	√		√				√		√	
Wabamun	AFWMC	√	√								√					√	√	√	√	√		
(2008)	AEC																					
Pigeon	AFWMC	●	●				●				●					●	●	●	●	●		
(2013)	AEC	●	●				●				●					●	●	●	●	●		
Stream Studies																						
Sakwatamau	AFWMC	√	√		√																	
Two Creek	AEC	√	√		√	√																
CAESA	AFWMC	√	√								√					√	√			√		
	AEC	√	√								√					√	√			√		
AESA	AFWMC	√	√	√						√	√			√			√			√		√
	AEC	√	√	√							√			√			√			√		

Table 5. Land cover designation and criteria as specified in original stream reports or the CAESA summary. Broad designations (Forested/Agriculture) for undesignated streams are in brackets.

Study	Criteria	Designation
Lake Watershed Studies		
Baptiste Lake (Trew et al. 1987)	>85% cultivated land >85% forested land	**Agriculture** **Forested**
Wabamun Lake (Mitchell 1985)	<75% forested >85% forested	**Mixed Agriculture** **Forested**
Majeau Creek Lac La Nonne (Mitchell & Hamilton 1982)	cattle dominated averaging 15 animal units per square kilometer where 1 animal unit = 1 cow = 180 poultry	**Agriculture** (assigned by CAESA)
Pine Lake (Sosiak & Trew 1996)	50% cleared land with intensive shoreline development and livestock access to streams 1, 3, 4, and 6	**Agriculture** (assigned by CAESA)
Lesser Slave Lake (Noton 1998)		**Undesignated (Forested)** (majority forested with some agricultural activity in each stream watershed; important recreational lake)
Baptiste Lake (Cooke & Prepas 1998)	>85% cultivated land >85% forested land	**Agriculture** **Forested**
Lac Ste. Anne & Lake Isle (Mitchell 1999)		**Undesignated (Agriculture)** (important recreational lakes with strong agricultural presence – no land cover percentages available)
Gull Lake (Mitchell & LeClair 2003)		**Undesignated (Agriculture)** (important recreational lake with strong agricultural presence – no land cover percentages available)
Lac La Biche (Neufeld 2005)	~ 70% forest ~ 40% agriculture	**Reference** (hence forth ‘Forested’) **Agriculture** (for details see Table A2-1)
Wabamun Lake (Emmerton 2008)		**Undesignated (Forested/Agriculture)** (for details see Table A2-2)
Pigeon Lake (Teichreb 2014)		**Undesignated (Agriculture)** (for details see Table A2-3)
Stream Studies		
Sakwatamau Two Creek (Munn & Prepas 1986)	mixed boreal forest	**Forested** (assigned by CAESA)
CAESA (Anderson et al. 1998)	Agricultural intensity rankings based on fertilizer expense, chemical expense, and animal unit density: *0 to 25th percentile* *25th to 75th percentile* *75th to 100th percentile*	 **Low Intensity Agriculture** **Moderate Intensity Agriculture** **High Intensity Agriculture**
AESA (Lorenz et al. 2008)	Agricultural intensity rankings based on fertilizer expense, chemical expense, and manure production: *0 to 40th percentile* *40th to 75th percentile* *75th to 100th percentile*	 **Low Intensity Agriculture** **Moderate Intensity Agriculture** **High Intensity Agriculture**

5.0 Results

5.1 Calculated Values

See Appendix 3. Values in bold font were calculated by NSWA. The remaining values are as reported in the original studies.

5.2 Data Range Box Plots

All nutrient fractions

AFWMCs and AECs are presented for each nutrient fraction in Figures 6 and 7.

Total phosphorus

AFWMCs and AECs for TP are presented by study in Figures 8 and 9 and by Natural Region/Sub-Regions in Figures 10 and 11. Data for the two Baptiste and Wabamun studies are combined.

Total nitrogen

AFWMCs and AECs for TN are presented by study in Figures 12 and 13 and by Natural Regions/Sub-Regions in Figure 14 and 15. Data for the two Baptiste and Wabamun studies are combined.

5.3 Individual Stream Value Histograms

Total phosphorus

Median TP AFWMCs for individual streams are presented as histograms colour-coded by land cover type in Figure 16. Median TP AECs are presented in the same manner in Figure 17.

Total nitrogen

Median TN AFWMCs for individual streams are presented as histograms colour-coded by land cover type in Figure 18. Median TP AECs are presented in the same manner in Figure 19.

5.4 Hydrology

Annual precipitation data for selected study years compared with Climate Normals are presented in Figure 20. Available annual stream discharge data are presented in Figure 21.

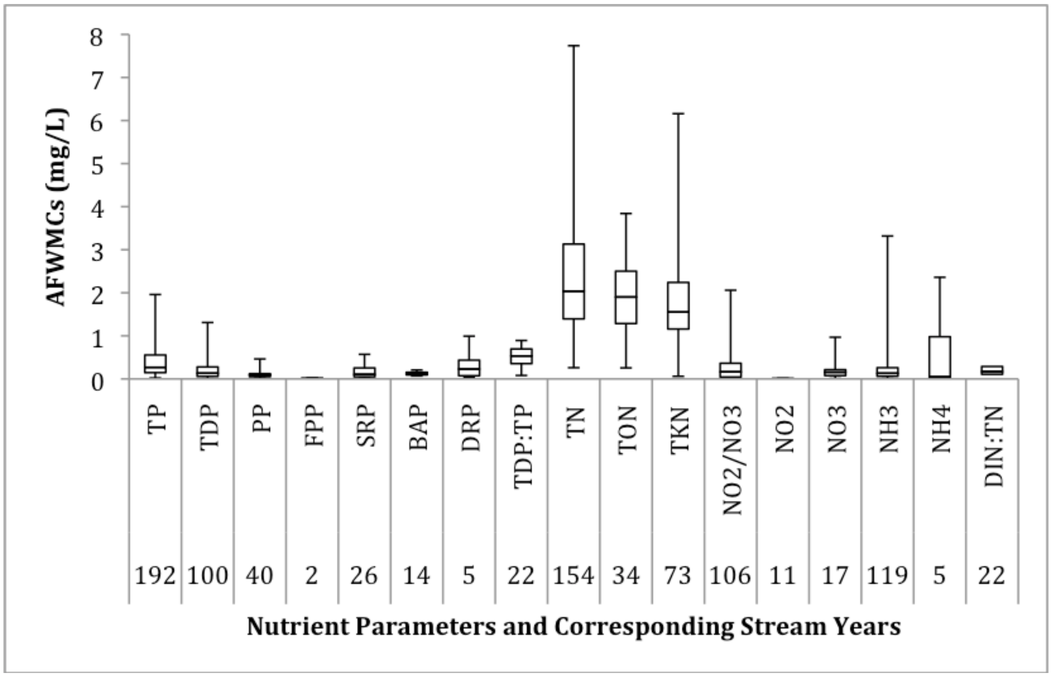

Figure 6. AFWMCs (all stream years) for each nutrient fraction

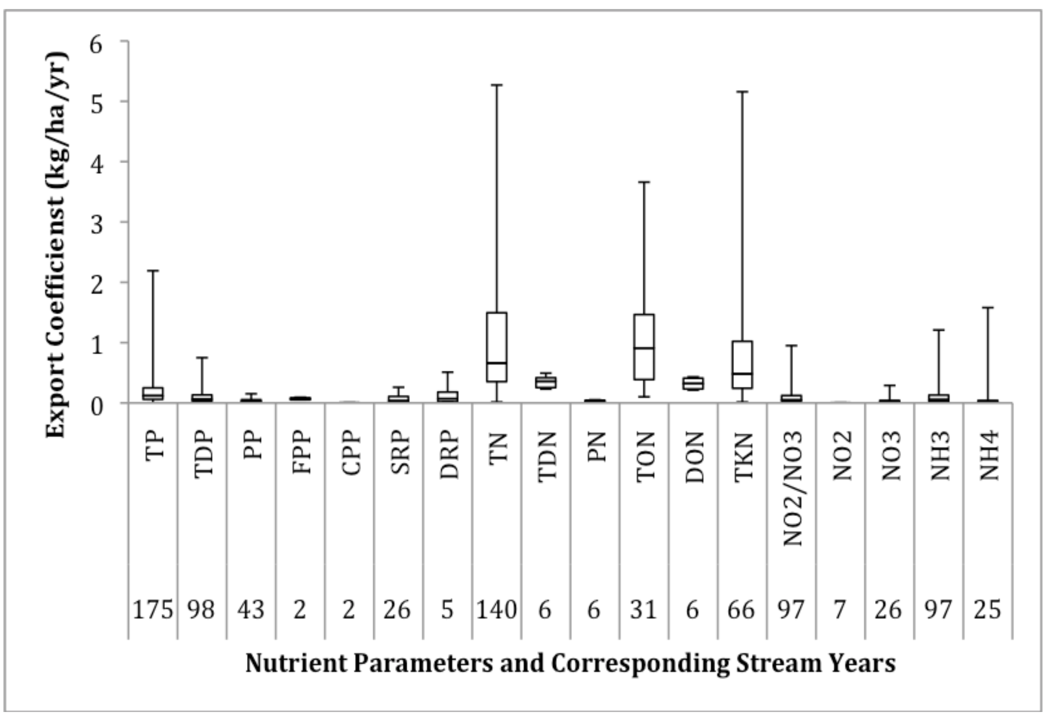

Figure 7. AECs (all streams years) for each nutrient fraction

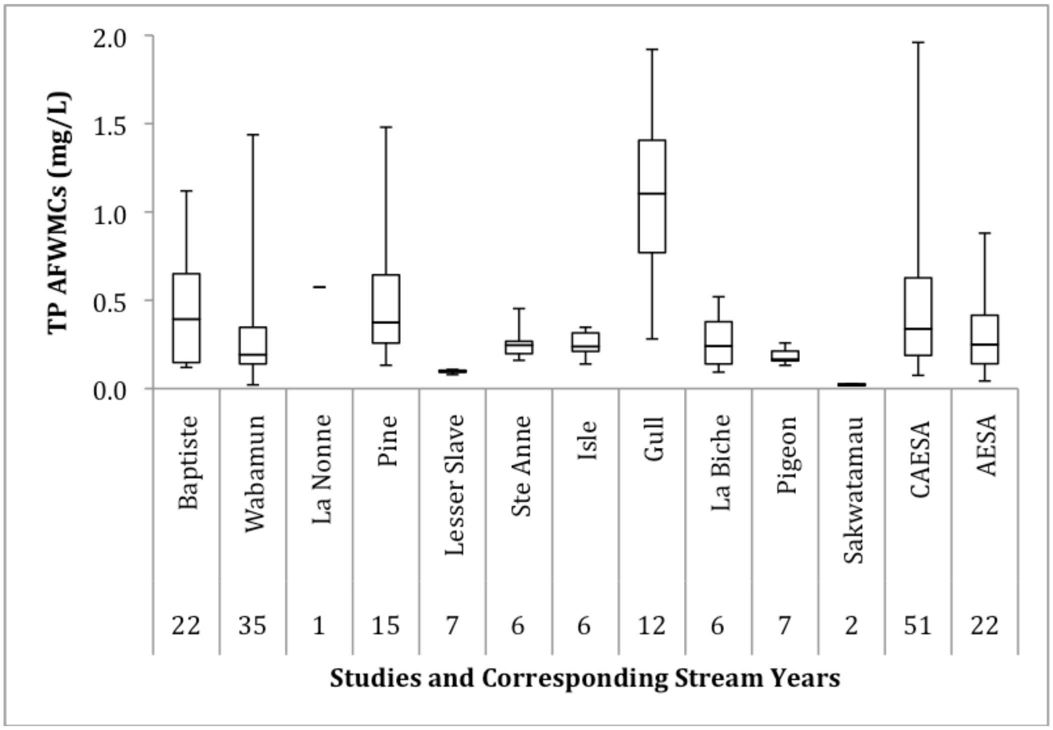

Figure 8. Total phosphorus AFWMCs (all stream years) for each study

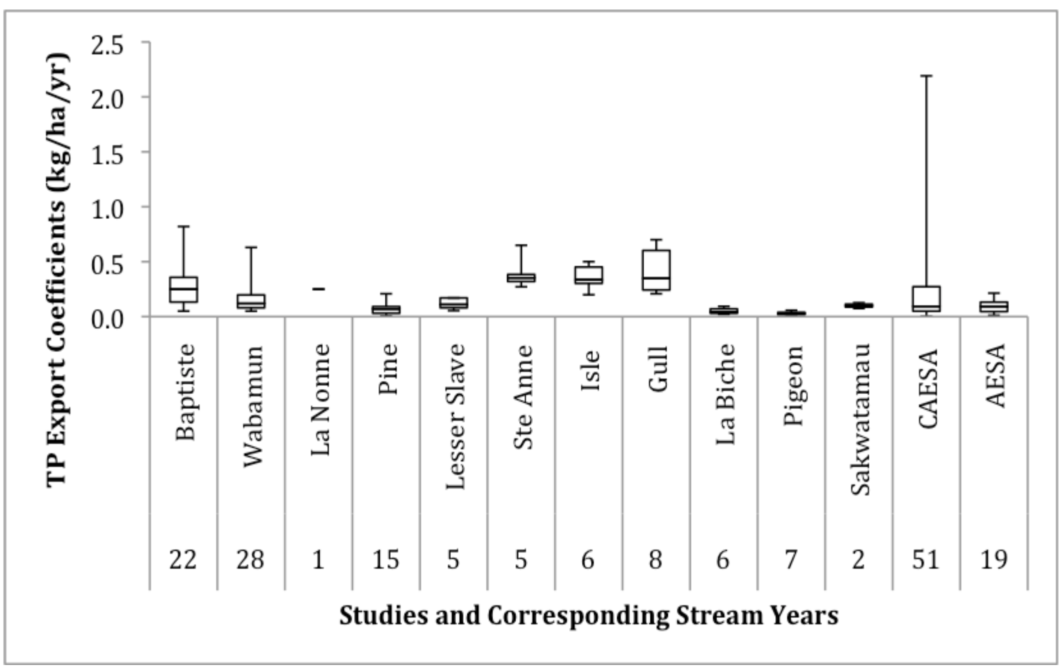

Figure 9. Total phosphorus AECs (all stream years) for each study

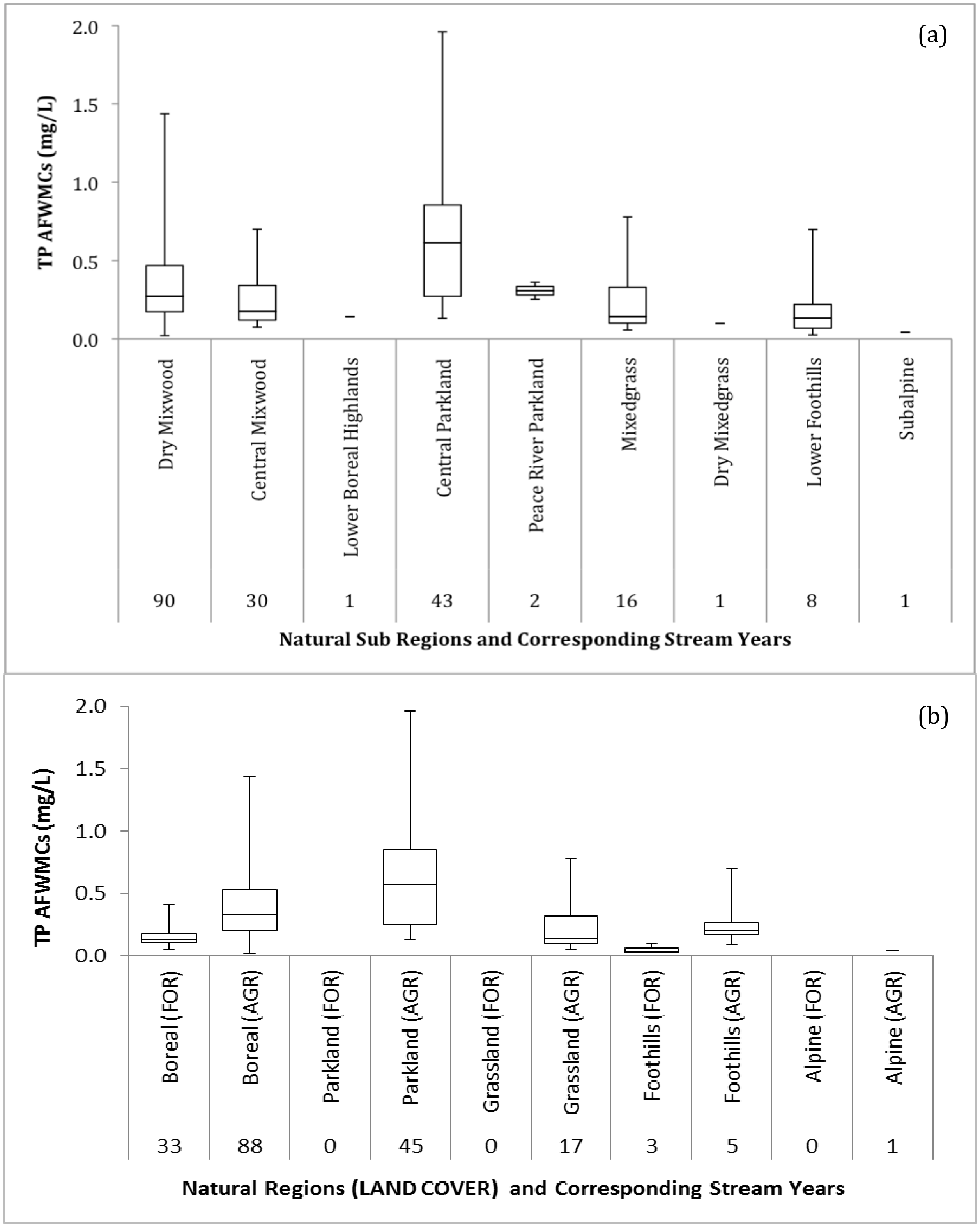

Figure 10. Total phosphorus AFWMCs (all stream years) for (a) Natural Sub Regions and (b) Forested (FOR) and Agricultural (AGR) streams in each Natural Region

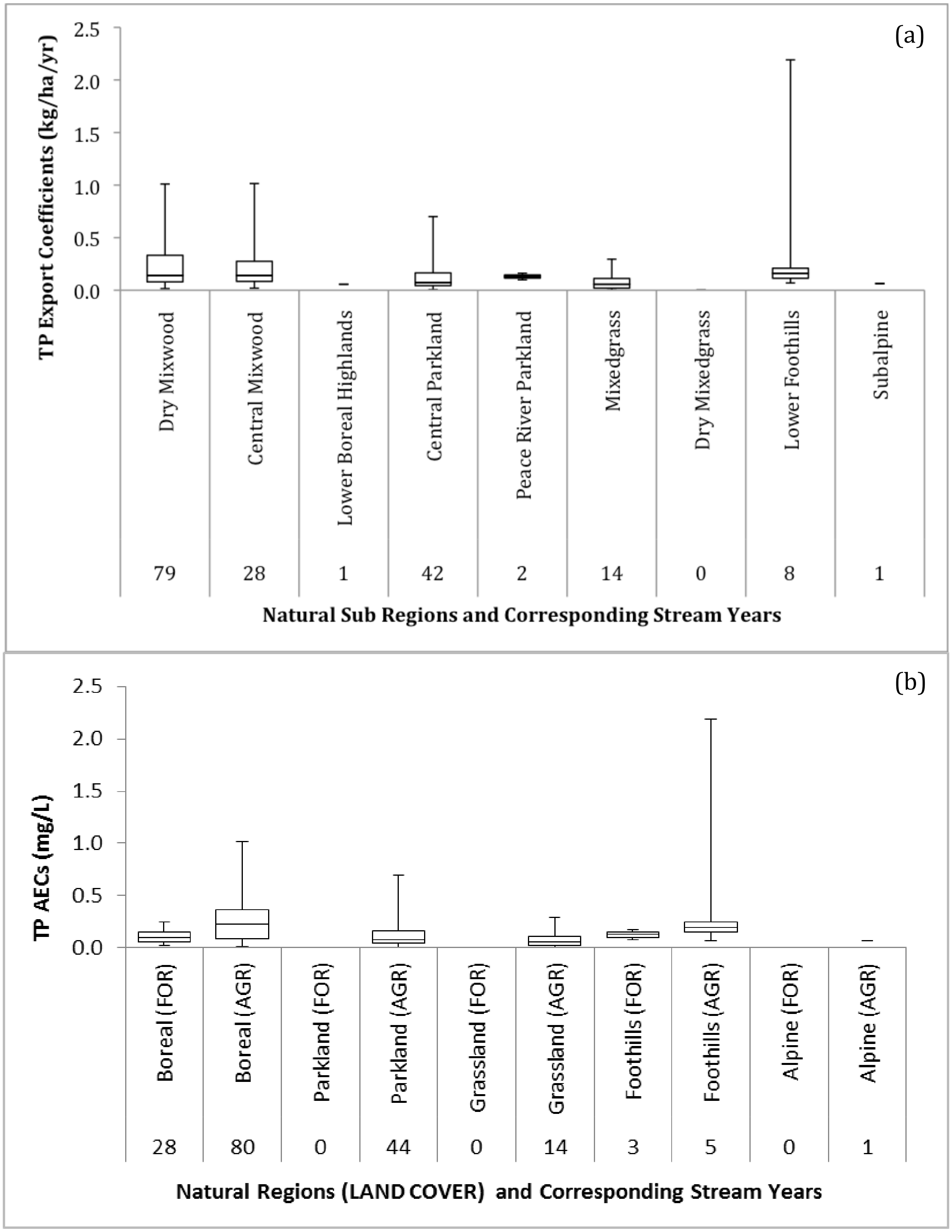

Figure 11. Total phosphorus AECs (all stream years) for (a) Natural Sub Regions and (b) Forested (FOR) and Agricultural (AGR) streams in each Natural Region

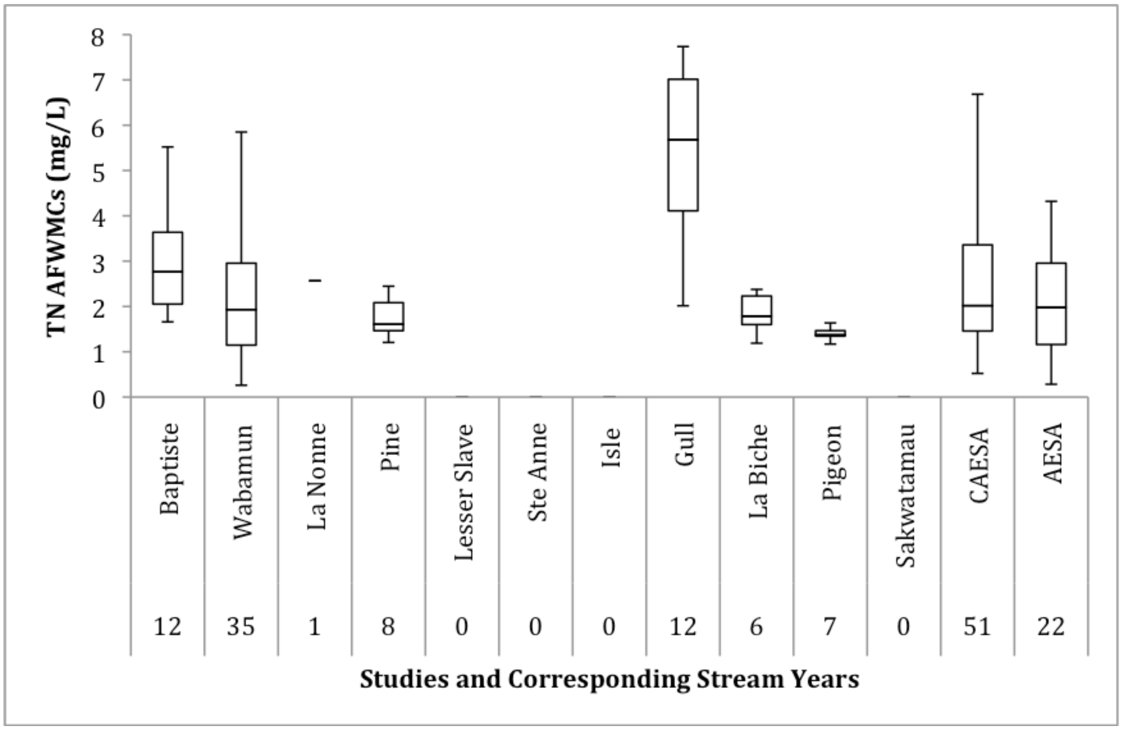

Figure 12. Total nitrogen AFWMCs (all stream years) for each study

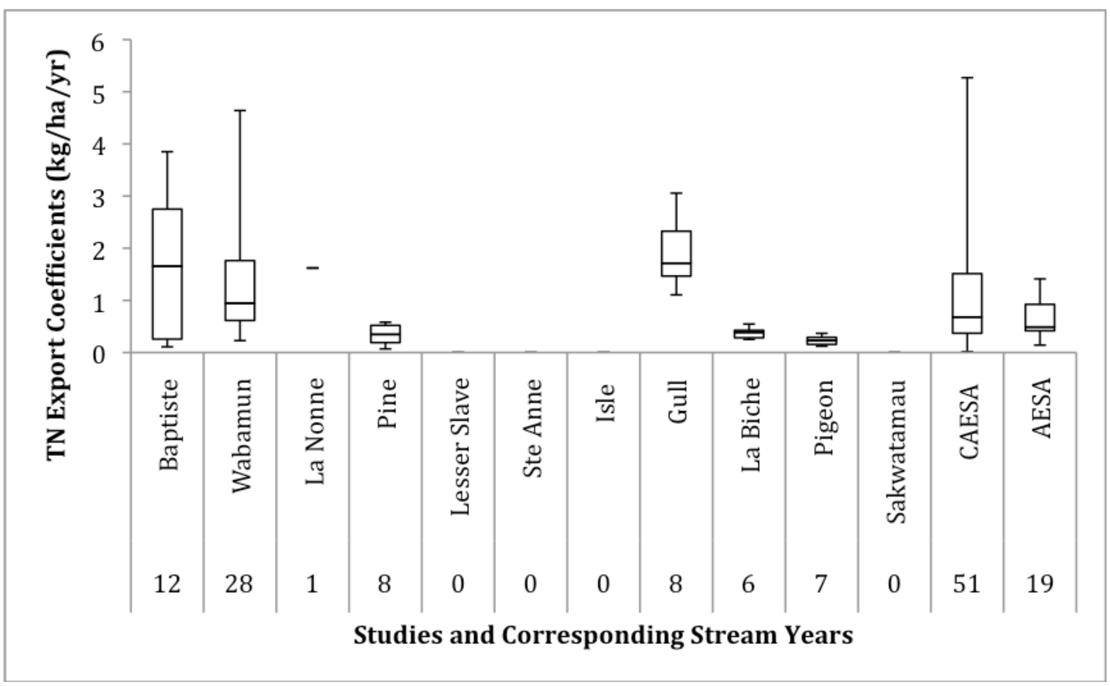

Figure 13. Total nitrogen AECs (all stream years) for each study

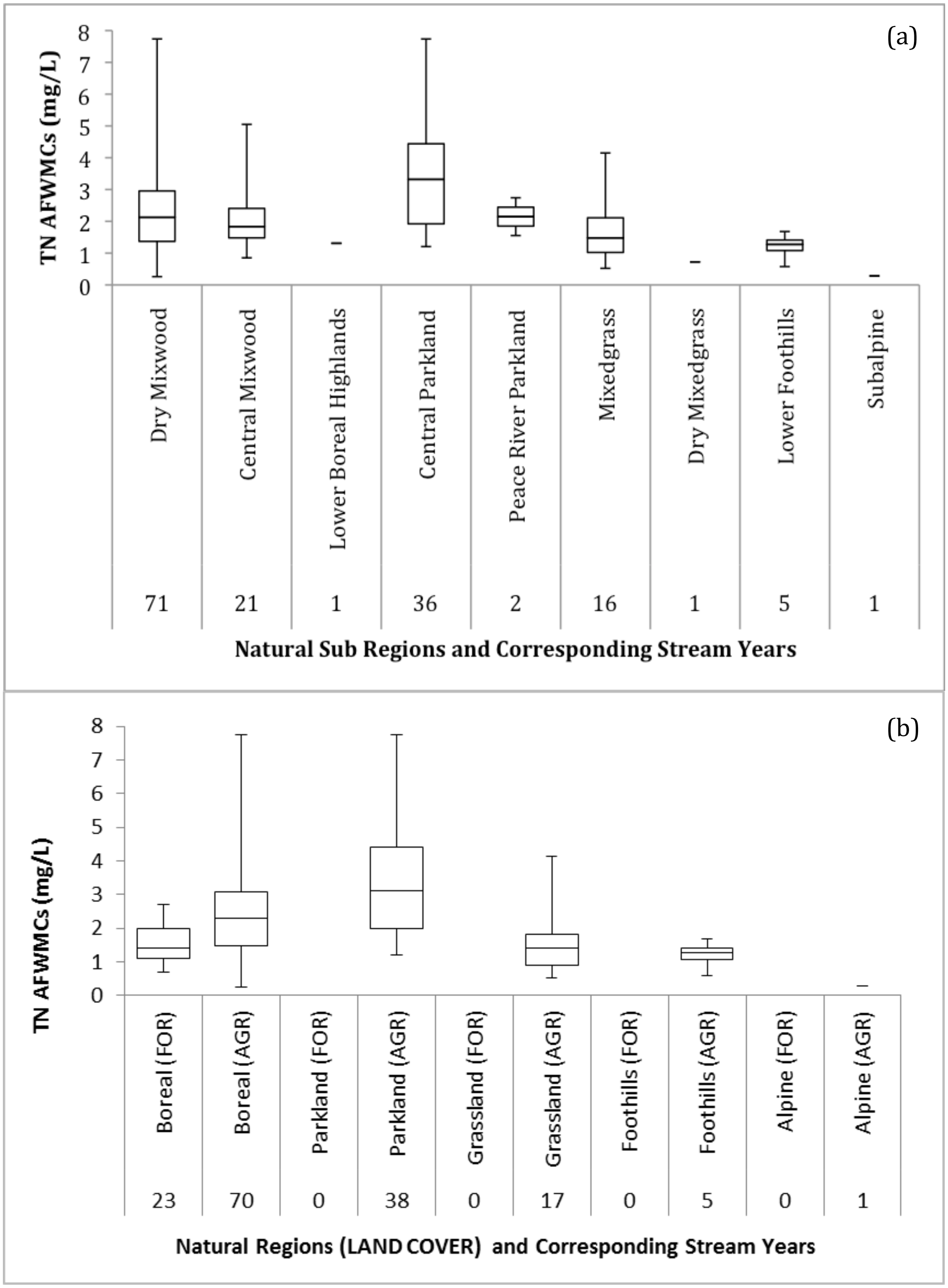

Figure 14. Total nitrogen AFWMCs (all stream years) for (a) Natural Sub Regions and (b) Forested (FOR) and Agricultural (AGR) streams in each Natural Region

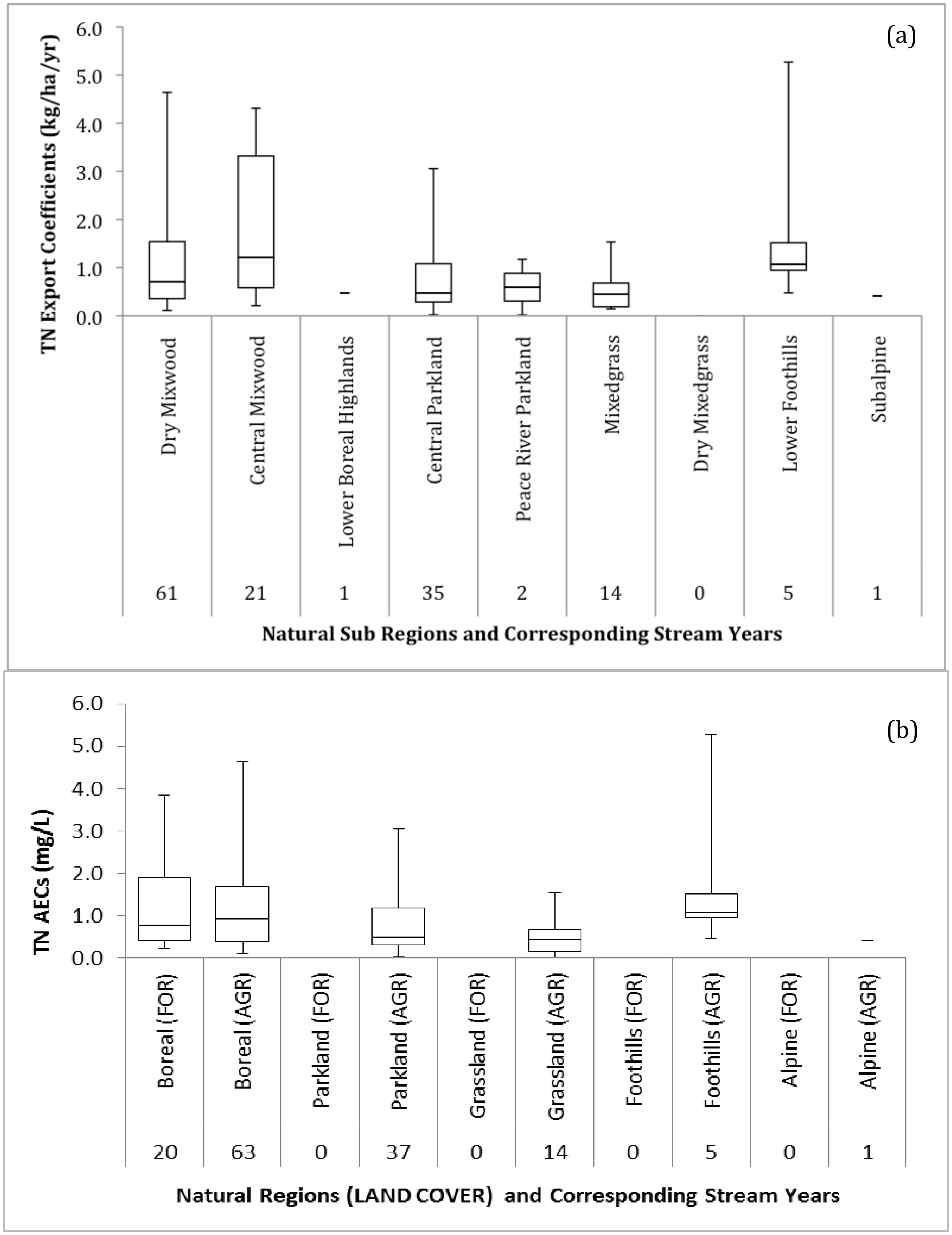

Figure 15. Total nitrogen AECs (all stream years) for (a) Natural Sub Regions and (b) Forested and Agricultural streams in each Natural Region

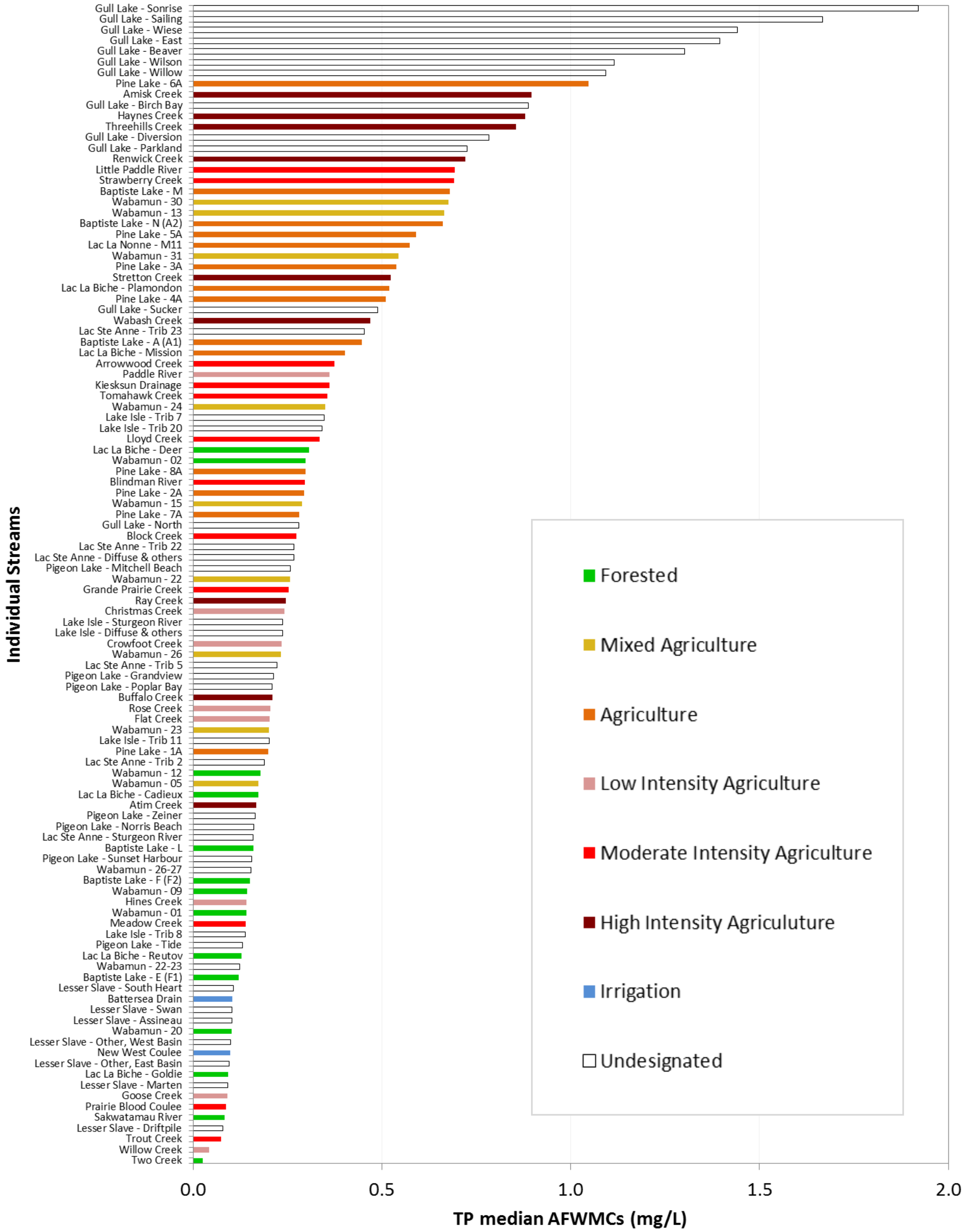

Figure 16. Median data for total phosphorus AFWMCs and land cover designations for 108 Alberta streams. See Table A3-1 for details.

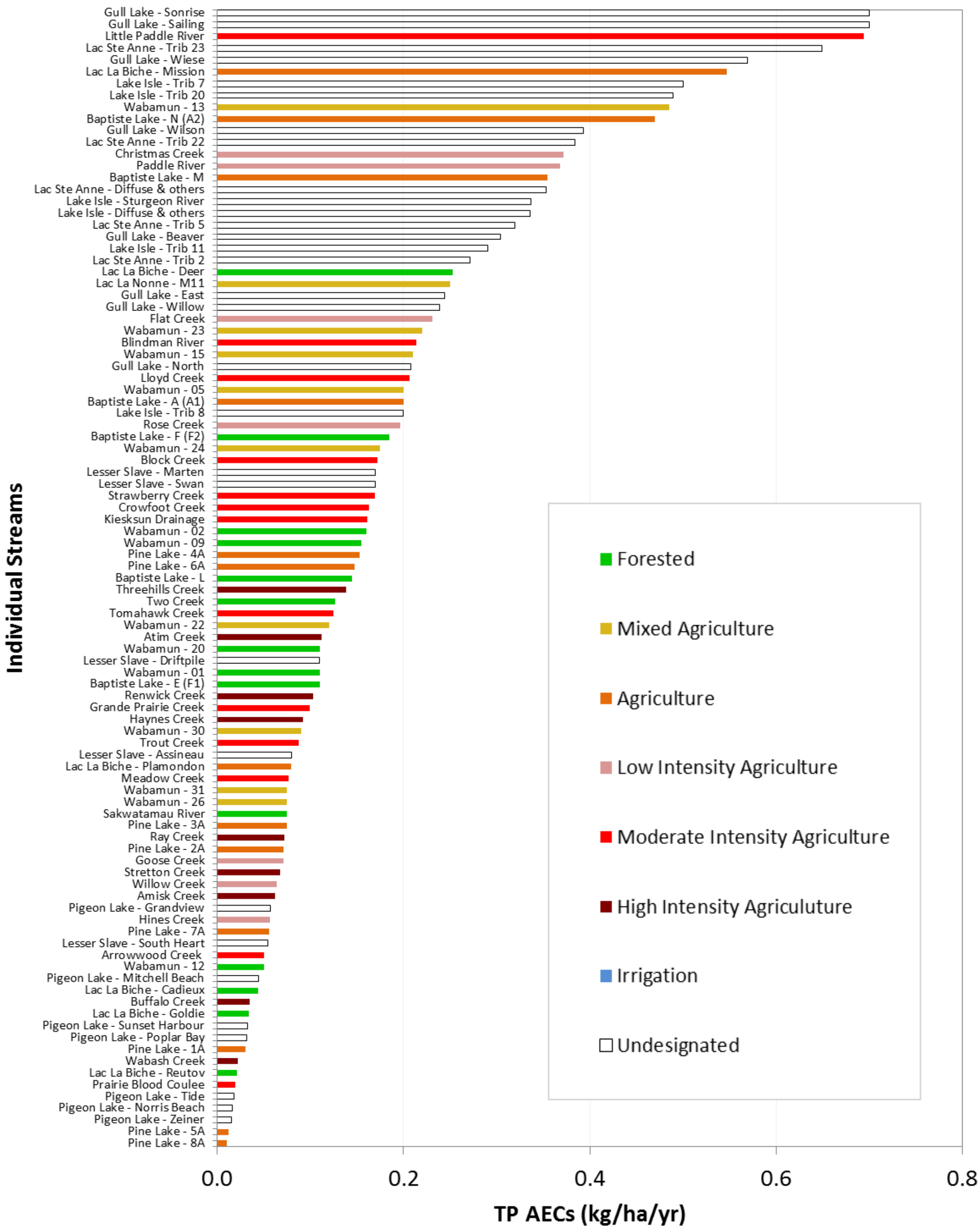

Figure 17. Median data for total phosphorus AECs and land cover designations for 97 of 108 Alberta streams. See Table A3-2 for details.

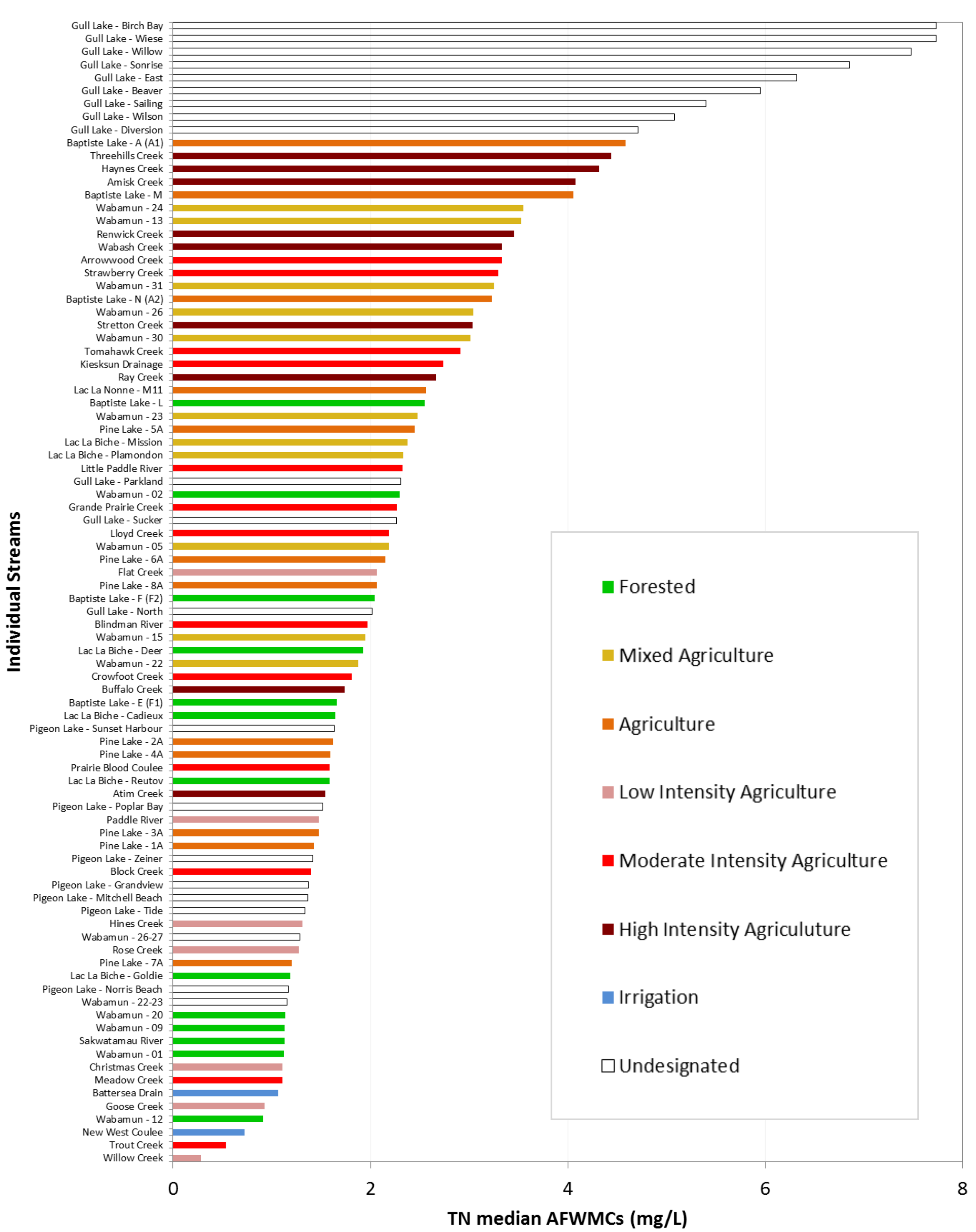

Figure 18. Median data for total nitrogen AFWMCs and land cover designations for 88 of 108 Alberta streams. See Table A3-3 for details.

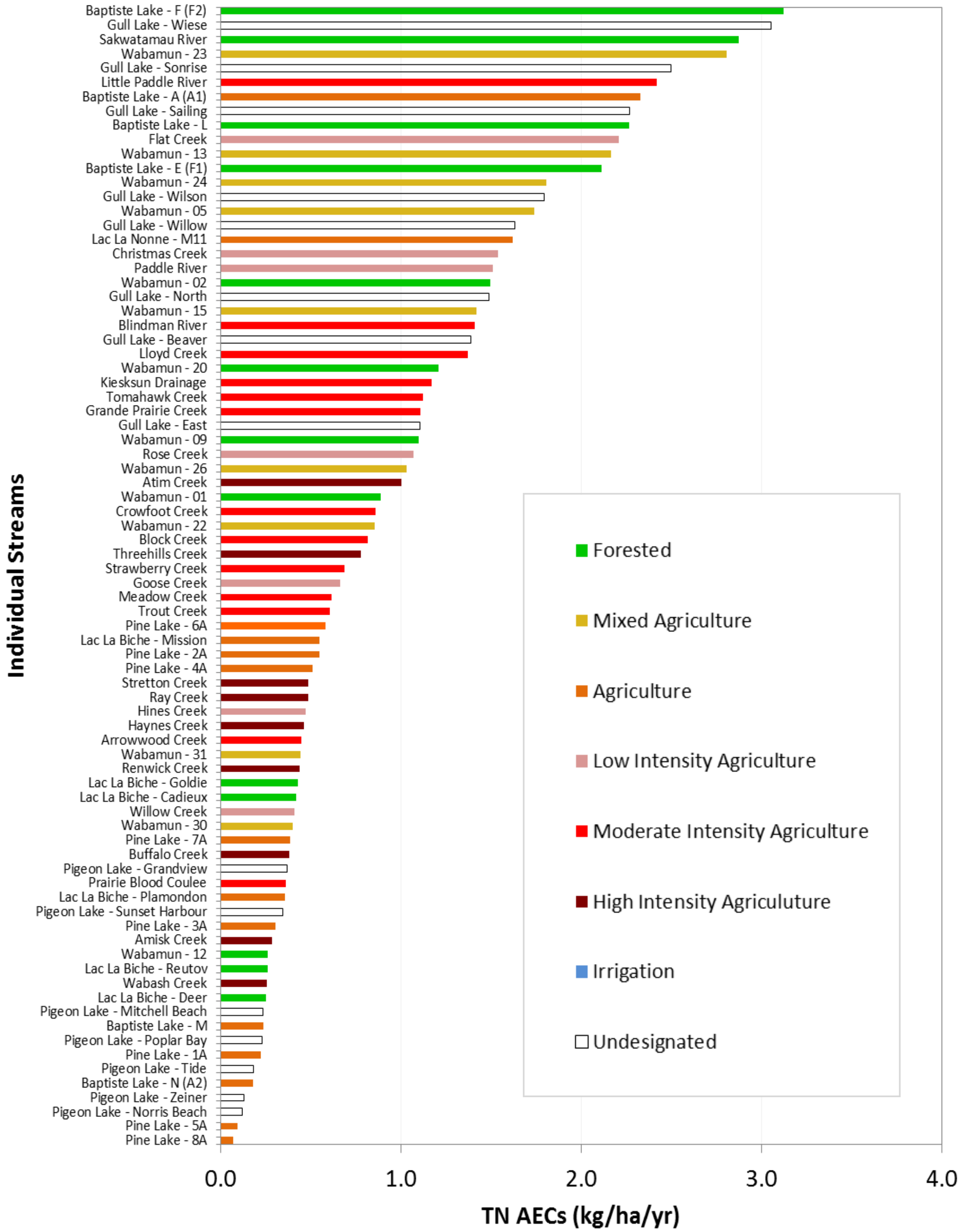

Figure 19. Median data for total nitrogen AECs and land cover designations for 80 of 108 Alberta streams. See Table A3-4 for details.

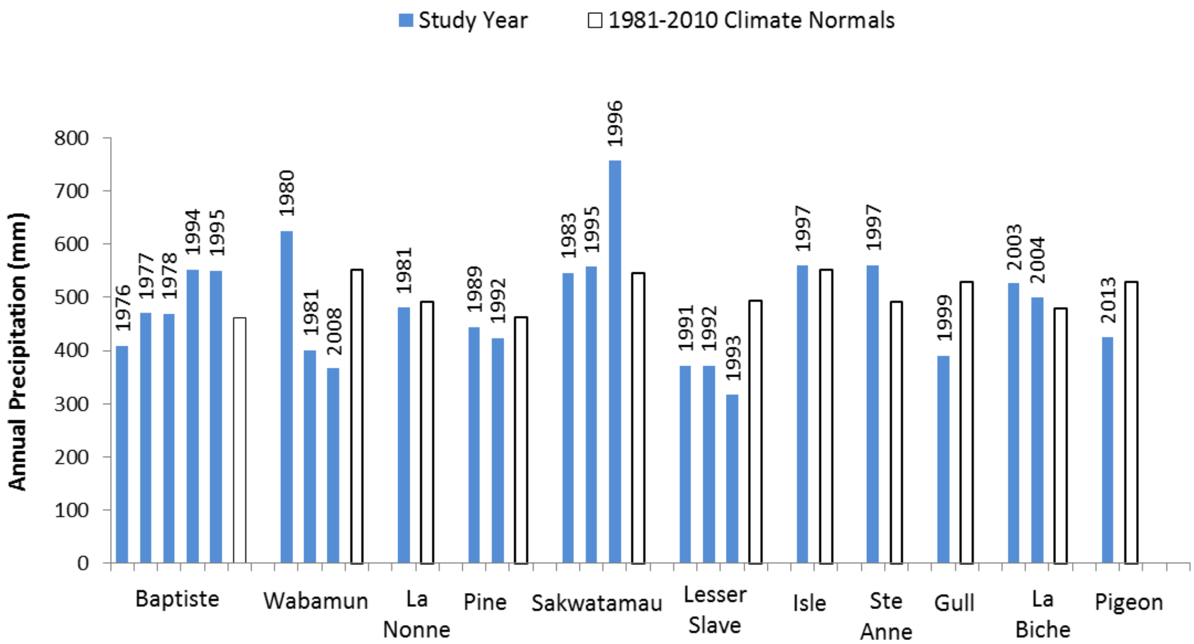

Figure 20. Annual precipitation values for selected lakes/rivers during study years compared with 1981-2010 Climate Normals at nearby meteorological stations as reported by Environment Canada.

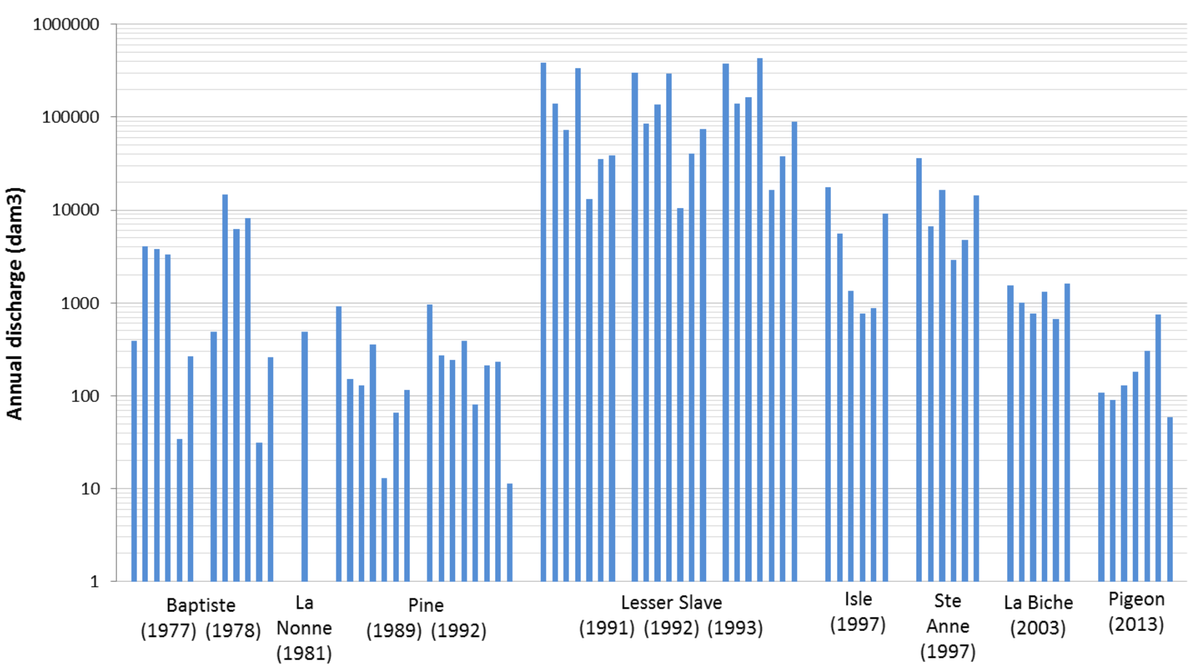

Figure 21. Annual stream discharges from selected lake watershed studies.

6.0 Discussion

6.1 Data Range Box Plots

All nutrient parameters

A wide range of AFWMCs and AECs are evident in the various box plots presented in Figures 6 to 15. The variation is a reflection of the number of fractions reported by each study, the number of stream years available for each fraction and the variable nature of the sampling regime employed for each study.

Variations among study data also arise from the biogeochemical characteristics of the various ecoregions in Alberta, human influences and temporal factors. There are differences in soils, land cover and management practices, some of which may change over time. Weather and hydrology can vary greatly from year to year; dry years tend to generate lower flows, which often correspond to lower loadings. Many of these factors likely contribute to the variation within studies.

Total phosphorus

AFWMC and AEC values for TP display high variability in the top 25% of their data ranges. This may reflect the wider range of TP data available compared to other fractions. High values for other fractions may not have been consistently captured across the range of studies conducted.

TP variations by study

Most median AFWMC values are less than 0.5 mg/L with the exception of Gull Lake streams. These data were collected from ephemeral, short-lived streams. A similar pattern is evident in the AEC values, with the median value at Gull Lake being the highest in the data set. Sources of phosphorus were not identified in the original study, but the authors noted that the values fell within the range of streams draining high intensity agricultural lands as reported in the CAESA project (Mitchell and LeClair 2003; Anderson et al. 1998).

The streams sampled in the CAESA and AESA projects incorporated numerous ecoregions (Figure 5), agricultural intensities and flows, yet the CAESA data display a higher range of AFWMCS and AECs than the AESA data. One reason for this change could be the gradual implementation of BMPs during the more recent period of the AESA study, which may have contributed to lower nutrient losses resulting in lower loads in streams. Another possible explanation is the higher sampling frequency of the original CAESA study, in which more extreme flow events may have been captured than in the AESA sampling regime. In addition, the highest values for AECs in the CAESA study come from 1996 when Sakwatamau River was resampled during a particularly wet year, while AFWMCs at Sakwatamau River that same year were closer to the median.

Pigeon Lake data are the newest in this compilation and record lower values than expected for a nutrient-rich agricultural area. This might be attributed to the lower precipitation in 2013 (Figure 20) or perhaps the success of improved land management practices in the watershed. In addition, samples were only taken an average of every two weeks and may have missed peak flows from spring melt or summer storms.

The remaining studies produce varying medians and ranges of AFWMCs and AECs. Values at Baptiste and Wabamun Lakes span larger ranges. This could be a result of the contrasting land cover types or perhaps the slightly larger datasets derived in this analysis by combining two studies from different decades for each lake. Smaller ranges exist at Pine Lake and Lac La Biche and even smaller ranges are apparent at Lac Ste Anne, Isle Lake, Lesser Slave Lake, and Lac La Nonne. The Pine Lake study spanned multiple years. Lac La Biche has varied land cover and geology. The remaining studies presented only one season's data or a single median from multiple years (Lesser Slave) and covered areas of more uniform land cover.

In general, studies with agricultural watersheds have higher median AFWMCs than studies with mostly forested watersheds, though it is unclear to what degree antecedent natural conditions affect these concentrations. AECs are strongly affected by flow patterns in the different study regions.

TP variations by Natural Region and Subregions

Total Phosphorus AFWMCs are plotted by Natural Regions and Natural Subregions in Figure 10. These plots provide a clear and interesting summary of the provincial nutrient patterns. Overall, the Parkland Natural Region (Central and Peace River Sub-Regions) displays the highest median and upper quartile values in stream TP concentrations. The Boreal Natural Region (Dry Mixedwood, Central Mixedwood and Lower Boreal Highlands) displays the second highest AFWMC values, followed by the Grasslands, Foothills and Alpine natural regions respectively.

The Parkland Natural Region and Dry Mixwood Natural Regions include many of the high agricultural intensity CAESA and AESA streams, as well as the Gull Lake streams previously discussed. These are naturally nutrient-rich areas, attracting much of the high intensity agriculture (AESRD 2014).

Lower TP AFWMCs in the Grasslands Ecoregion and Foothills Natural regions may be related to the lower intensity of agricultural land cover combined with natural biogeochemical conditions.

The highest median values for TP AECs are in the Boreal and Foothills Natural Regions, and may reflect the influence of higher runoff from these zones as AFWMCs are lower. The highest value for the Foothills Natural Region is for Sakwatamau River during high flows in 1996.

Total nitrogen

AFWMCs and AECs for TN, TON and TKN span a much wider range and their median values are typically an order of magnitude higher than median AFWMC values for the other nutrient fractions (Figure 6). These same nitrogen fractions also display the highest AECs (Figure 7). Ammonia and ammonium also display high variability.

TN variations by study

Ranges of AFWMCs and AECs for Total Nitrogen (Figures 12 and 13) reveal a similar pattern to TP ranges (Figures 8 and 9), with large ranges for Baptiste, Wabamun, and CAESA; a smaller range for AESA; high values at Gull Lake; and lower values at Pine, Pigeon and La Biche. The variables discussed above for TP AFWMCs and AECs are likely influential on TN data patterns as well.

TN variations by Natural Region and Subregions

Ranges of Total Nitrogen AFWMCs relative to Natural Regions (Figure 14) are again very similar to the patterns for Total Phosphorus, but with one exception. The main difference is the Dry Mixedwood maximum is slightly higher than Central Parkland. The reason for this is unclear, though many of the forested streams were found to contribute more nitrogen than phosphorus relative to other land cover types.

The box plot for TN AECs (Figure 15) is almost identical in appearance to the box plot for TP AECs (Figure 11). Higher annual flow rates (basin yields) are again perceived to have the greatest effect on the upper values in the Central Mixedwood and Lower Foothills Natural Regions.

6.2 Individual Stream Value Histograms

Figures 16 and 18 suggest that AFWMCs increase as land becomes less forested and more intensely developed, but the degree depends greatly on other variables such as ecoregion biogeochemistry, hydrology and land management. In addition, agriculture or any variation of the agricultural classification categories used here are extremely broad categories, encompassing a wide variety of practices, each with varying effects. Thus watersheds with agricultural designations create a wide range of AFWMC data.

The graphs for AECs show a similar pattern for TP, but the AECs for TN reveal a different pattern. Stream TN loadings from certain northern forested watershed s are high, and the corresponding AECs are at the higher end of the data set. This could be a reflection of the natural soil chemistry, vegetation and hydrology of this region.

7.0 Conclusion

This report provides a descriptive compilation of stream data collected in Alberta over the past four decades. The data are primarily drawn from historic agricultural and lake management studies.

Current work on stream nutrients is being conducted by various groups. Alberta Agriculture & Forestry's *Alberta Phosphorus Watershed Project* is examining the effectiveness of BMPs. EPCOR is undertaking a similar agricultural assessment project in the Strawberry Creek Watershed.

Various studies on the effects of forest management and forest fires have also been conducted in Alberta, but are not included in this compilation (Smith et al. 2003; Burke et al. 2005; Bladon et al. 2008; Howery 2010; Silins et al. 2014; Bladon et al. 2015).

It is hoped that this report will provide a useful reference point for the next phases of work to support lake eutrophication management in the province.

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Appendices

A1 Definitions

Annual Flow-Weighted Mean Concentration (AFWMC): a calculation of the total mass load of a nutrient divided by the total flow volume. This is most often done for a single year, or in colder climates, during the open water season.

Annual Export Coefficient (AEC): a calculation of the total mass load of a nutrient divided by the watershed area for a single year.

Stream year: a single year of measurement for a single stream. Multiple stream years could include multiple years of the same stream and/or multiple streams of the same year.

A2 Land cover details

Table A2-1: Lac La Biche land cover (Adapted from Neufeld 2005)

Landcover type (%)	Plamondon (A)	Mission (A)	Reutov (R)	Deer (R)	Cadieux (R)	Goldie (R)
Urban	7.9	10.1	4.9	6.5	5.8	3.6
Agricultural	42.9	38.9	10.4	4.3	3.4	0.0
Forest	34.1	42.5	70.5	77.7	79.5	82.0
Wetland	4.4	2.4	9.0	2.2	2.5	7.5
Subwatershed Area (ha)	**111.4**	**46.1**	**48.0**	**109.0**	**28.4**	**46.6**
% Watershed Area	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**

Table A2-2: Wabamun Lake land cover (Adapted from Emmerton 2008)

Landcover type (%)	Ascot _09	Coal_12	Fallis_13	Freeman_05	Rosewood_26-27	Seba_20	Seba_22-23
Forested	47.5	37.0	16.8	40.4	38.5	47.6	27.0
Agriculture/Exposed Soil	13.9	35.7	44.2	33.0	27.5	19.6	45.4
Urban	4.6	2.1	5.2	2.0	0.2	6.2	1.3
Wetlands	15.3	10.1	7.3	7.0	20.4	11.9	11.9
Grasslands/Shrubs	18.7	15.2	26.5	17.7	13.3	14.6	14.4
Subwatershed Area (ha)	**250**	**1190**	**540**	**330**	**3960**	**810**	**5400**
% Watershed Area	**0.9**	**4.4**	**2.0**	**1.2**	**14.5**	**3.0**	**19.8**

Table A2-3: Pigeon Lake land cover (Adapted from Teichreb 2014)

Landcover type (%)	Grandview (05FA-PL11)	Mitchell Beach (05FA-PL3)	Norris Beach (05FA-PL10)	Poplar Bay (05FA-PL13)	Sunset Harbour (05FA-PL15)	Tide (05FA-PL1)	Zeiner (05FA-PL2)
Ecological lands	**49.3**	**54.0**	**30.9**	**31.6**	**36.1**	**34.1**	**58.4**
Water	1.8	1.1	0.8	0.4	0.7	8.1	0.6
Shrubland	1.3	0.7	0.3	0.0	0.6	0.5	0.8
Wetland	1.4	0.0	1.0	0.1	0.5	2.6	0.6
Coniferous	0.0	0.1	0.0	0.0	0.6	5.3	4.7
Deciduous	44.8	52.0	28.8	30.5	32.2	23.5	49.6
Mixed Forest	0.0	0.2	0.0	0.5	1.5	1.6	2.1
Built-Up/Urban lands	**50.7**	**46.0**	**69.1**	**68.4**	**63.9**	**65.9**	**41.6**
Exposed Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Developed	5.0	2.1	2.0	1.6	0.3	0.1	0.9
Annual Crops	1.9	3.3	5.7	3.9	7.4	11.1	12.3
Perrenial Crops/Pasture	43.9	40.7	61.3	62.9	56.2	54.7	28.4
Subwatershed Area (ha)	**402.8**	**526.4**	**1254.2**	**1194.9**	**1451.8**	**5528.0**	**624.4**
% Watershed Area	2.3	3.0	7.1	6.7	8.2	31.1	3.5

Table A2-4: Land cover designations, natural regions and natural sub regions for individual streams. If streams were included in multiple studies, the land cover designation of the first study was used for Figures 17-20. Land cover abbreviations are as follows: AGR – Agriculture, FOR – Forested, MIX – Mixed Agriculture, HIA – High Intensity Agriculture, MIA – Moderate Intensity Agriculture, LIA – Low Intensity Agriculture. Undesignated streams are left blank. Natural regions include: B – Boreal, F – Foothills, G – Grasslands, P – Parkland and A – Alpine (Rocky Mountain).

STREAM	Land Cover	Natural Region	Natural Sub Region
BAPTISTE LAKE STUDIES (Trew et al. 1987; Cooke & Prepas 1998)			
Baptiste Lake - A (A1)	AGR	B	Dry Mixedwood
Baptiste Lake - M	AGR	B	Central Mixwood
Baptiste Lake - N ()	AGR	B	Dry Mixedwood
Baptiste Lake - E (F1)	FOR	B	Central Mixwood
Baptiste Lake - F (F2)	FOR	B	Central Mixwood
Baptiste Lake - L	FOR	B	Central Mixwood
WABAMUN LAKE STUDIES (Mitchell 1985; Emmerton 2008)			
Wabamun - 01	FOR	B	Dry Mixedwood
Wabamun - 02	FOR	B	Dry Mixedwood
Wabamun - 09	FOR	B	Dry Mixedwood
Wabamun - 12	FOR	B	Dry Mixedwood
Wabamun - 20	FOR	B	Dry Mixedwood
Wabamun - 05	MIX	B	Dry Mixedwood
Wabamun - 13	MIX	B	Dry Mixedwood
Wabamun - 15	MIX	B	Dry Mixedwood
Wabamun - 22	MIX	B	Dry Mixedwood
Wabamun - 22-23		B	Dry Mixedwood
Wabamun - 23	MIX	B	Dry Mixedwood
Wabamun - 24	MIX	B	Dry Mixedwood
Wabamun - 26	MIX	B	Dry Mixedwood
Wabamun - 26-27		B	Dry Mixedwood
Wabamun - 30	MIX	B	Dry Mixedwood
Wabamun - 31	MIX	B	Dry Mixedwood
LAC LA NONNE STUDY (Mitchell & Hamilton 1982)			
Lac La Nonne - M11	AGR	B	Dry Mixedwood
PINE LAKE STUDY (Sosiak & Trew 1996)			
Pine Lake - 1A	AGR	P	Central Parkland
Pine Lake - 2A	AGR	P	Central Parkland
Pine Lake - 3A	AGR	P	Central Parkland
Pine Lake - 4A	AGR	P	Central Parkland
Pine Lake - 5A	AGR	P	Central Parkland
Pine Lake - 6A	AGR	P	Central Parkland
Pine Lake - 7A	AGR	P	Central Parkland
Pine Lake - 8A	AGR	P	Central Parkland
LESSER SLAVE LAKE STUDY (Noton 1998)			
Lesser Slave - South Heart		B	Dry Mixedwood
Lesser Slave - Driftpile		B	Central Mixwood
Lesser Slave - Other, West Basin		B	Central Mixwood
Lesser Slave - Swan		B	Central Mixwood
Lesser Slave - Assineau		B	Central Mixwood
Lesser Slave - Marten		F	Lower Foothills
Lesser Slave - Other, East Basin		B	Central Mixwood
LAC STE. ANNE & LAKE ISLE STUDY (Mitchell 1999)			
Lac Ste Anne - Diffuse & others		B	Dry Mixedwood

STREAM	Land Cover	Natural Region	Natural Sub Region
Lac Ste Anne - Sturgeon River		B	Dry Mixedwood
Lac Ste Anne - Trib 2		B	Dry Mixedwood
Lac Ste Anne - Trib 22		B	Dry Mixedwood
Lac Ste Anne - Trib 23		B	Dry Mixedwood
Lac Ste Anne - Trib 5		B	Dry Mixedwood
Lake Isle - Diffuse & others		B	Dry Mixedwood
Lake Isle - Sturgeon River		B	Dry Mixedwood
Lake Isle - Trib 11		B	Dry Mixedwood
Lake Isle - Trib 20		B	Dry Mixedwood
Lake Isle - Trib 7		B	Dry Mixedwood
Lake Isle - Trib 8		B	Dry Mixedwood
GULL LAKE STUDY (Mitchell & LeClair 2003)			
Gull Lake - Beaver		B	Dry Mixedwood
Gull Lake - Birch Bay		B	Dry Mixedwood
Gull Lake - Diversion		P	Central Parkland
Gull Lake - East		B	Dry Mixedwood
Gull Lake - North		B	Dry Mixedwood
Gull Lake - Parkland		B	Dry Mixedwood
Gull Lake - Sailing		P	Central Parkland
Gull Lake - Sonrise		P	Central Parkland
Gull Lake - Sucker		B	Dry Mixedwood
Gull Lake - Wiese		P	Central Parkland
Gull Lake - Willow		P	Central Parkland
Gull Lake - Wilson		P	Central Parkland
LAC LA BICHE STUDY (Neufeld 2003-2004)			
Lac La Biche - Plamondon	AGR	B	Dry Mixwood
Lac La Biche - Mission	AGR	B	Dry Mixwood
Lac La Biche - Reutov	FOR	B	Dry Mixwood
Lac La Biche - Deer	FOR	B	Dry Mixwood
Lac La Biche - Cadieux	FOR	B	Dry Mixwood
Lac La Biche - Goldie	FOR	B	Dry Mixwood
PIGEON LAKE STUDY (Teichreb 2014)			
Pigeon Lake - Grandview		B	Dry Mixedwood
Pigeon Lake - Mitchell Beach		B	Dry Mixedwood
Pigeon Lake - Norris Beach		B	Dry Mixedwood
Pigeon Lake - Poplar Bay		B	Dry Mixedwood
Pigeon Lake - Sunset Harbour		B	Dry Mixedwood
Pigeon Lake - Tide		B	Dry Mixedwood
Pigeon Lake - Zeiner		B	Dry Mixedwood
SAKWATAMAU TWO CREEK STUDY (Munn & Prepas 1986)			
Sakwatamau River	FOR	F	Lower Foothils
Two Creek	FOR	F	Lower Foothils
CAESA & AESA STREAM STUDIES (Anderson et al. 1998; Lorenz et al. 2008)			
Amisk Creek	HIA	P	Central Parkland
Arrowwood Creek	MIA	G	Mixedgrass
Atim Creek	HIA	P	Central Parkland
Battersea Drain	IRR	G	Mixedgrass
Blindman River	MIA	B	Central Mixwood
Block Creek	MIA	B	Dry Mixedwood
Buffalo Creek	HIA	P	Central Parkland
Christmas Creek	LIA	B	Central Mixwood
Crowfoot Creek	MIA (CAESA) IRR (AESA)	G	Mixedgrass
Flat Creek	LIA	B	Dry Mixedwood
Goose Creek	LIA	B	Central Mixwood
Grande Prairie Creek	MIA	P	Peace River Parkland

STREAM	Land Cover	Natural Region	Natural Sub Region
Haynes Creek	HIA	P	Central Parkland
Hines Creek	LIA	B	Lower Boreal Highlands
Kiesksun Drainage	MIA	P	Peace River Parkland
Little Paddle River	MIA	B	Dry Mixedwood
Lloyd Creek	MIA	B	Dry Mixedwood
Meadow Creek	MIA	G	Mixedgrass
New West Coulee	IRR	G	Dry Mixgrass
Paddle River	LIA	B	Central Mixwood
Prairie Blood Coulee	MIA (CAESA) LIA (AESA)	G	Mixedgrass
Ray Creek	HIA	P	Central Parkland
Renwick Creek	HIA	P	Central Parkland
Rose Creek	LIA	F	Lower Foothills
Sakwatamau River	LIA	F	Lower Foothills
Strawberry Creek	MIA (CAESA) HIA (AESA)	B	Dry Mixedwood
Stretton Creek	HIA	P	Central Parkland
Threehills Creek	HIA	P	Central Parkland
Tomahawk Creek	MIA	B	Central Mixwood
Trout Creek	MIA	G	Mixedgrass
Wabash Creek	HIA	B	Dry Mixedwood
Willow Creek	LIA	A	Subalpine

A3 Stream nutrient data

Table A3-1: Annual flow weighted mean concentrations (AFWMCs) of phosphorus fractions for individual streams. Alternate names for streams in subsequent studies are listed in brackets. Bolded values were derived by NSWA from other reported measurements (annual loads/annual flows). All values are in mg/L.

STREAM	YEAR	TP	TDP	PP	FPP	SRP	BAP	DRP	TDP:TP
BAPTISTE LAKE STUDIES (Trew et al. 1987; Cooke & Prepas 1998)									
Baptiste Lake - A	1977	0.78				0.25			
	1978	0.46				0.32			
(A1)	1994	0.434	0.351	0.083					
	1995	0.396	0.275	0.121				0.229	
Baptiste Lake - M	1977	0.66				0.48			
	1978	0.70				0.42			
Baptiste Lake - N	1977	0.39				0.18			
	1978	0.62				0.42			
(A2 upstream)	1994	0.464	0.389	0.045					
	1995	0.839	0.737	0.102				0.436	
(A2 downstream)	1994	0.702	0.637	0.065					
	1995	1.119	0.994	0.125				0.993	
Baptiste Lake - E	1977	0.12				0.03			
	1978	0.12				0.04			
(F1)	1994	0.123	0.062	0.061					
	1995	0.187	0.050	0.137				0.038	
Baptiste Lake - F	1977	0.13				0.02			
	1978	0.13				0.04			
(F2)	1994	0.170	0.081	0.089					
	1995	0.198	0.093	0.105				0.074	
Baptiste Lake - L	1977	0.14				0.05			
	1978	0.18				0.07			
WABAMUN LAKE STUDIES (Mitchell 1985; Emmerton 2008)									
Wabamun - 01	1980	0.139							
	1981	0.143							
Wabamun - 02	1980	0.407							
	1981	0.191							
Wabamun - 09	1980	0.144							
	1981	0.192							
	2008	0.101	0.042						

STREAM	YEAR	TP	TDP	PP	FPP	SRP	BAP	DRP	TDP:TP
Wabamun - 12	1980	0.186							
	1981	0.179							
	2008	0.094	0.042						
Wabamun - 20	1980	0.053							
	1981	0.133							
	2008	0.102	0.056						
Wabamun - 05	1980	0.275							
	1981	0.174							
	2008	0.052	0.042						
Wabamun - 13	1980	1.437							
	1981	0.666							
	2008	0.021	0.011						
Wabamun - 15	1980	0.216							
	1981	0.363							
Wabamun - 22	1980	0.227							
	1981	0.288							
Wabamun - 22-23	2008	0.124	0.060						
Wabamun - 23	1980	0.192							
	1981	0.212							
Wabamun - 24	1980	0.330							
	1981	0.370							
Wabamun - 26	1980	0.140							
	1981	0.324							
Wabamun - 26-27	2008	0.153	0.069						
Wabamun - 30	1980	0.684							
	1981	0.670							
Wabamun - 31	1980	0.472							
	1981	0.615							
LAC LA NONNE STUDY (Mitchell & Hamilton 1982)									
Lac La Nonne - M11	1981	0.574							
PINE LAKE STUDY (Sosiak & Trew 1996)									
Pine Lake - 1A	1989	0.180	0.138				0.087		
	1992	0.217	0.102	0.097		0.079	0.072		
Pine Lake - 2A	1989	0.374	0.190				0.104		
	1992	0.214	0.151	0.103		0.132	0.092		
Pine Lake - 3A	1989	0.764	0.647				0.168		
	1992	0.314	0.259	0.031		0.190	0.120		
Pine Lake - 4A	1989	0.716	0.535				0.158		
	1992	0.306	0.261	0.032		0.257	0.121		

STREAM	YEAR	TP	TDP	PP	FPP	SRP	BAP	DRP	TDP:TP
Pine Lake - 5A	1989	0.673	0.490				0.154		
	1992	0.509	0.278	0.186		0.383	0.124		
Pine Lake - 6A	1989	1.480	1.310				0.205		
	1992	0.614	0.466	0.144		0.571	0.151		
Pine Lake - 7A	1989	0.432	0.313				0.130		
	1992	0.132	0.098	0.016		0.098	0.070		
Pine Lake - 8A	1992	0.298	0.208	0.085					
LESSER SLAVE LAKE STUDY (Noton 1998)									
Lesser Slave - South Heart	1991-1992	0.108	0.0286						
Lesser Slave - Driftpile	1991-1992	0.079	0.0225						
Lesser Slave - Other, West Basin	1991-1992	0.1							
Lesser Slave - Swan	1991-1992	0.104	0.0192						
Lesser Slave - Assineau	1991-1992	0.103	0.0215						
Lesser Slave - Marten	1991-1992	0.092	0.0164						
Lesser Slave - Other, East Basin	1991-1992	0.095							
LAC STE. ANNE & LAKE ISLE STUDY (Mitchell 1999)									
Lac Ste Anne - Diffuse & others	1997	0.268							
Lac Ste Anne - Sturgeon River	1997	0.160							
Lac Ste Anne - Trib 2	1997	0.189							
Lac Ste Anne - Trib 22	1997	0.268							
Lac Ste Anne - Trib 23	1997	0.453							
Lac Ste Anne - Trib 5	1997	0.223							
Lake Isle - Diffuse & others	1997	0.238							
Lake Isle - Sturgeon River	1997	0.238							
Lake Isle - Trib 11	1997	0.202							
Lake Isle - Trib 20	1997	0.341							
Lake Isle - Trib 7	1997	0.347							
Lake Isle - Trib 8	1997	0.139							
GULL LAKE STUDY (Mitchell & LeClair 2003)									
Gull Lake - Beaver	1999	**1.30**							
Gull Lake - Birch Bay	1999	**0.89**							
Gull Lake - Diversion	1999	**0.78**							
Gull Lake - East	1999	**1.39**							
Gull Lake - North	1999	**0.28**							
Gull Lake - Parkland	1999	**0.73**							
Gull Lake - Sailing	1999	**1.67**							
Gull Lake - Sonrise	1999	**1.92**							
Gull Lake - Sucker	1999	**0.49**							
Gull Lake - Wiese	1999	**1.44**							
Gull Lake - Willow	1999	**1.09**							

STREAM	YEAR	TP	TDP	PP	FPP	SRP	BAP	DRP	TDP:TP
Gull Lake - Wilson	1999	**1.11**							
LAC LA BICHE STUDY (Neufeld 2003-2004)									
Lac La Biche - Plamondon	2003-2004	0.520	0.382						
Lac La Biche - Mission	2003-2004	0.402	0.302						
Lac La Biche - Reutov	2003-2004	0.128	0.080						
Lac La Biche - Deer	2003-2004	0.308	0.250						
Lac La Biche - Cadieux	2003-2004	0.173	0.133						
Lac La Biche - Goldie	2003-2004	0.093	0.070						
PIGEON LAKE STUDY (Teichreb 2014)									
Pigeon Lake - Grandview	2013	**0.214**	**0.171**			**0.113**			
Pigeon Lake - Mitchell Beach	2013	**0.258**	**0.208**			**0.174**			
Pigeon Lake - Norris Beach	2013	**0.160**	**0.111**			**0.076**			
Pigeon Lake - Poplar Bay	2013	**0.210**	**0.076**			**0.049**			
Pigeon Lake - Sunset Harbour	2013	**0.156**	**0.068**			**0.040**			
Pigeon Lake - Tide	2013	**0.132**	**0.082**			**0.045**			
Pigeon Lake - Zeiner	2013	**0.165**	**0.135**			**0.100**			
SAKWATAMAU TWO CREEK STUDY (Munn & Prepas 1986)									
Sakwatamau River	1983	0.0258	0.0131		0.0131				
Two Creek	1983	0.0255	0.0117		0.0140				
CAESA & AESA STREAM STUDIES (Anderson et al. 1998; Lorenz et al. 2008)									
Amisk Creek	1995	0.940							
	1996	0.853	0.531						
Arrowwood Creek nr. Arrowwood	1995	0.145							
- nr. Arrowwood	1996	0.779	0.414						
- nr. Ensign	1996	0.374	0.278						
Atim Creek	1995	0.144							
	1996	0.190	0.057						
Battersea Drain	1999-2006 median	0.105	0.024	0.049					0.338
Blindman River	1995	0.269							
	1996	0.471	0.210						
	1999-2006 median	0.297	0.142	0.150					0.590
Block Creek	1995	0.250							
	1996	0.299	0.106						
Buffalo Creek	1995	0.210							
	1996	0.214	0.143						
	1999-2006 median	0.157	0.089	0.048					0.639
Christmas Creek	1995	0.124							
	1996	0.361	0.036						

STREAM	YEAR	TP	TDP	PP	FPP	SRP	BAP	DRP	TDP:TP
Crowfoot Creek	1995	0.136							
	1996	0.578	0.132						
	1999-2006 median	0.234	0.154	0.094					0.551
Flat Creek	1995	0.186							
	1996	0.221	0.139						
Goose Creek	1995	0.075							
	1996	0.109	0.058						
Grande Prairie Creek	1999-2006 median	0.253	0.092	0.127					0.528
Haynes Creek	1995	1.960							
	1996	0.765	0.584						
	1999-2006 median	0.880	0.808	0.089					0.892
Hines Creek	1999-2006 median	0.142	0.059	0.063					0.500
Kiesksun Drainage	1999-2006 median	0.362	0.237	0.101					0.715
Little Paddle River	1995	0.735							
	1996	0.650	0.080						
Lloyd Creek	1995	0.338							
	1996	0.333	0.264						
Meadow Creek	1995	0.112							
	1996	0.315	0.038						
	1999-2006 median	0.140	0.018	0.105					0.129
New West Coulee	1999-2006 median	0.098	0.044	0.052					0.536
Paddle River	1995	0.362							
	1996	0.394	0.072						
	1999-2006 median	0.201	0.093	0.095					0.456
Prairie Blood Coulee	1995	0.086							
	1996	0.544	0.224						
	1999-2006 median	0.087	0.054	0.026					0.611
Ray Creek	1995	0.204							
	1996	0.572	0.478						
	1999-2006 median	0.245	0.214	0.042					0.808
Renwick Creek	1995	0.619							
	1996	0.721	0.595						
	1999-2006 median	0.787	0.692	0.098					0.872
Rose Creek	1995	0.205							
	1996	0.175	0.037						
	1999-2006 median	0.268	0.028	0.248					0.116
Sakwatamau River	1995	0.083							
	1996	0.698	0.020						
Strawberry Creek	1995	0.420							
	1996	1.070	0.149						
	1999-2006 median	0.692	0.123	0.463					0.250

STREAM	YEAR	TP	TDP	PP	FPP	SRP	BAP	DRP	TDP:TP
Stretton Creek	1995	0.618							
	1996	0.523	0.375						
	1999-2006 median	0.433	0.362	0.071					0.836
Threehills Creek	1995	1.131							
	1996	0.856	0.650						
	1999-2006 median	0.550	0.439	0.104					0.807
Tomahawk Creek	1995	0.184							
	1996	0.635	0.149						
	1999-2006 median	0.356	0.120	0.204					0.402
Trout Creek	1995	0.075							
	1996	0.287	0.046						
	1999-2006 median	0.057	0.008	0.050					0.135
Wabash Creek	1999-2006 median	0.470	0.223	0.189					0.501
Willow Creek	1999-2006 median	0.043	0.004	0.039					0.080

Table A3-2: Export coefficients of phosphorus fractions for individual streams. Alternate names for streams in subsequent studies are listed in brackets. Bolded values were derived by NSWA from other reported measurements (annual loads/watershed areas). All values are in kg/ha/yr.

STREAM	YEAR	TP	TDP	PP	FPP	CPP	SRP	DRP
BAPTISTE LAKE STUDIES (Trew et al. 1987; Cooke & Prepas 1998)								
Baptiste Lake - A	1977	0.36					0.12	
	1978	0.26					0.18	
(A1)	1994	0.14	0.11	0.03				
	1995	0.12	0.08	0.04				0.07
Baptiste Lake - M	1977	0.36					0.26	
	1978	0.35					0.21	
Baptiste Lake - N	1977	0.25					0.11	
	1978	0.37					0.25	
(A2 upstream)	1994	0.57	0.49	0.06				
	1995	0.34	0.30	0.04				0.18
(A2 downstream)	1994	0.82	0.75	0.07				
	1995	0.57	0.51	0.06				0.51

STREAM	YEAR	TP	TDP	PP	FPP	CPP	SRP	DRP
Baptiste Lake - E	1977	0.07					0.02	
	1978	0.25					0.09	
(F1)	1994	0.13	0.065	0.065				
	1995	0.09	0.03	0.06				0.02
Baptiste Lake - F	1977	0.15					0.03	
	1978	0.25					0.08	
(F2)	1994	0.22	0.11	0.11				
	1995	0.05	0.02	0.03				0.02
Baptiste Lake - L	1977	0.07					0.03	
	1978	0.22					0.10	
WABAMUN LAKE STUDIES (Mitchell 1985; Emmerton 2008)								
Wabamun - 01	1980	0.13						
	1981	0.09						
Wabamun - 02	1980	0.10						
	1981	0.22						
Wabamun - 09	1980	0.19						
	1981	0.12						
	2008							
Wabamun - 12	1980	0.05						
	1981	0.05						
	2008							
Wabamun - 20	1980	0.14						
	1981	0.08						
	2008							
Wabamun - 05	1980	0.32						
	1981	0.08						
	2008							
Wabamun - 13	1980	0.63						
	1981	0.34						
	2008							
Wabamun - 15	1980	0.15						
	1981	0.27						
Wabamun - 22	1980	0.12						
	1981	0.12						
Wabamun - 22-23	2008							
Wabamun - 23	1980	0.36						
	1981	0.08						
Wabamun - 24	1980	0.24						
Wabamun - 26	1980	0.06						
	1981	0.09						

STREAM	YEAR	TP	TDP	PP	FPP	CPP	SRP	DRP
Wabamun - 26-27	2008							
Wabamun - 30	1980	0.06						
	1981	0.12						
Wabamun - 31	1980	0.06						
	1981	0.09						
LAC LA NONNE STUDY (Mitchell & Hamilton 1982)								
Lac La Nonne - M11	1981	0.25						
PINE LAKE STUDY (Sosiak & Trew 1996)								
Pine Lake - 1A	1989	**0.026**	**0.020**					
	1992	**0.034**	**0.016**	**0.015**			**0.012**	
Pine Lake - 2A	1989	**0.070**	**0.036**					
	1992	**0.072**	**0.051**	**0.035**			**0.045**	
Pine Lake - 3A	1989	**0.084**	**0.071**					
	1992	**0.065**	**0.054**	**0.006**			**0.039**	
Pine Lake - 4A	1989	**0.208**	**0.156**					
	1992	**0.098**	**0.084**	**0.010**			**0.083**	
Pine Lake - 5A	1989	**0.004**	**0.003**					
	1992	**0.020**	**0.011**	**0.007**			**0.015**	
Pine Lake - 6A	1989	**0.129**	**0.114**					
	1992	**0.166**	**0.126**	**0.039**			**0.155**	
Pine Lake - 7A	1989	**0.069**	**0.050**					
	1992	**0.042**	**0.032**	**0.005**			**0.031**	
Pine Lake - 8A	1992	**0.010**	**0.007**	**0.003**				
LESSER SLAVE LAKE STUDY (Noton 1998)								
Lesser Slave - South Heart	1991-1992	0.054						
Lesser Slave - Driftpile	1991-1992	0.110						
Lesser Slave - Other, West Basin	1991-1992							
Lesser Slave - Swan	1991-1992	0.170						
Lesser Slave - Assineau	1991-1992	0.08						
Lesser Slave - Marten	1991-1992	0.170						
Lesser Slave - Other, East Basin	1991-1992							
LAC STE. ANNE & LAKE ISLE STUDY (Mitchell 1999)								
Lac Ste Anne - Diffuse & others	1997	**0.353**	**0.265**					
Lac Ste Anne - Sturgeon River	1997							
Lac Ste Anne - Trib 2	1997	**0.272**	**0.195**					
Lac Ste Anne - Trib 22	1997	**0.384**	**0.288**					
Lac Ste Anne - Trib 23	1997	**0.649**	**0.568**					
Lac Ste Anne - Trib 5	1997	**0.320**	**0.243**					
Lake Isle - Diffuse & others	1997	**0.336**	**0.197**					

STREAM	YEAR	TP	TDP	PP	FPP	CPP	SRP	DRP
Lake Isle - Sturgeon River	1997	**0.336**	**0.205**					
Lake Isle - Trib 11	1997	**0.291**	**0.181**					
Lake Isle - Trib 20	1997	**0.489**	**0.466**					
Lake Isle - Trib 7	1997	**0.500**	**0.423**					
Lake Isle - Trib 8	1997	**0.199**	**0.115**					
GULL LAKE STUDY (Mitchell & LeClair 2003)								
Gull Lake - Beaver	1999	**0.30**						
Gull Lake - Birch Bay	1999							
Gull Lake - Diversion	1999							
Gull Lake - East	1999	**0.24**						
Gull Lake - North	1999	**0.21**						
Gull Lake - Parkland	1999							
Gull Lake - Sailing	1999	**0.70**						
Gull Lake - Sonrise	1999	**0.70**						
Gull Lake - Sucker	1999							
Gull Lake - Wiese	1999	**0.57**						
Gull Lake - Willow	1999	**0.24**						
Gull Lake - Wilson	1999	**0.39**						
LAC LA BICHE STUDY (Neufeld 2003-2004)								
Lac La Biche - Plamondon	2003-2004	0.079	0.058	0.021				
Lac La Biche - Mission	2003-2004	0.093	0.069	0.023				
Lac La Biche - Reutov	2003-2004	0.021	0.013	0.008				
Lac La Biche - Deer	2003-2004	0.041	0.033	0.008				
Lac La Biche - Cadieux	2003-2004	0.044	0.034	0.010				
Lac La Biche - Goldie	2003-2004	0.034	0.025	0.009				
PIGEON LAKE STUDY (Teichreb 2014)								
Pigeon Lake - Grandview	2013	**0.057**	**0.046**				**0.030**	
Pigeon Lake - Mitchell Beach	2013	**0.045**	**0.036**				**0.030**	
Pigeon Lake - Norris Beach	2013	**0.017**	**0.011**				**0.008**	
Pigeon Lake - Poplar Bay	2013	**0.032**	**0.012**				**0.007**	
Pigeon Lake - Sunset Harbour	2013	**0.033**	**0.014**				**0.008**	
Pigeon Lake - Tide	2013	**0.018**	**0.011**				**0.006**	
Pigeon Lake - Zeiner	2013	**0.015**	**0.013**				**0.009**	
SAKWATAMAU TWO CREEK STUDY (Munn & Prepas 1986)								
Sakwatamau River	1983	0.0747	0.0187		0.0558	0.0002		
Two Creek	1983	0.1264	0.0321		0.0943	0.0040		
CAESA & AESA STREAM STUDIES (Anderson et al. 1998; Lorenz et al. 2008)								
Amisk Creek	1995	0.0522						
	1996	0.0726	0.0452					

STREAM	YEAR	TP	TDP	PP	FPP	CPP	SRP	DRP
Arrowwood Creek nr. Arrowwood	1995	0.0014						
- nr. Arrowwood	1996	0.2505	0.1330					
- nr. Ensign	1996	0.0501	0.0372					
Atim Creek	1995	0.0473						
	1996	0.1764	0.0530					
Battersea Drain	1999-2006 median							
Blindman River	1995	0.0929						
	1996	0.8445	0.3776					
	1999-2006 median	0.2136	0.13015	0.08345				
Block Creek	1995	0.1092						
	1996	0.2346	0.0830					
Buffalo Creek	1995	0.0318						
	1996	0.0494	0.0330					
	1999-2006 median	0.0345	0.02295	0.00925				
Christmas Creek	1995	0.0849						
	1996	0.6594	0.0663					
Crowfoot Creek	1995	0.0315						
	1996	0.2950	0.0674					
	1999-2006 median							
Flat Creek	1995	0.0813						
	1996	0.3817	0.2409					
Goose Creek	1995	0.0193	0.0103					
	1996	0.1228	0.0655					
Grande Prairie Creek	1999-2006 median	0.0994	0.0429	0.05135				
Haynes Creek	1995	0.0379	0.0335					
	1996	0.2410	0.1842					
	1999-2006 median	0.092	0.0882	0.01065				
Hines Creek	1999-2006 median	0.05695	0.02555	0.02585				
Kiesksun Drainage	1999-2006 median	0.1612	0.11985	0.0413				
Little Paddle River	1995	0.3787						
	1996	1.0100	0.1243					
Lloyd Creek	1995	0.0839						
	1996	0.3285	0.2606					
Meadow Creek	1995	0.0768						
	1996	0.1202	0.0145					
	1999-2006 median	0.0173	0.0034	0.01515				
New West Coulee	1999-2006 median							
Paddle River	1995	0.3684						
	1996	1.0149	0.1840					
	1999-2006 median	0.0665	0.03205	0.0293				

STREAM	YEAR	TP	TDP	PP	FPP	CPP	SRP	DRP
Prairie Blood Coulee	1995	0.0194						
	1996	0.0638	0.0262					
	1999-2006 median	0.01175	0.0073	0.00155				
Ray Creek	1995	0.0187						
	1996	0.2029	0.1700					
	1999-2006 median	0.0717	0.06185	0.00985				
Renwick Creek	1995	0.0643						
	1996	0.1610	0.1329					
	1999-2006 median	0.1032	0.08585	0.01				
Rose Creek	1995	0.1517						
	1996	0.2460	0.0525					
	1999-2006 median	0.19685	0.02635	0.1519				
Sakwatamau River	1995	0.0690						
	1996	2.1911	0.0635					
Strawberry Creek	1995	0.0460						
	1996	0.7098	0.0988					
	1999-2006 median	0.16935	0.03035	0.1519				
Stretton Creek	1995	0.0679						
	1996	0.0265	0.0188					
	1999-2006 median	0.10425	0.09255	0.01415				
Threehills Creek	1995	0.0484						
	1996	0.3165	0.2402					
	1999-2006 median	0.13855	0.1057	0.0209				
Tomahawk Creek	1995	0.0469						
	1996	0.6520	0.1533					
	1999-2006 median	0.12465	0.0361	0.08985				
Trout Creek	1995	0.0873						
	1996	0.1477	0.0238					
	1999-2006 median	0.0201	0.0025	0.01745				
Wabash Creek	1999-2006 median	0.0218	0.00995	0.0073				
Willow Creek	1999-2006 median	0.06355	0.00605	0.05745				

Table A3-3: Annual flow weighted mean concentrations (AFWMCs) of nitrogen fractions for individual streams. Alternate names for streams in subsequent studies are listed in brackets. Bolded values were derived by NSWA from other reported measurements (annual loads/annual flows). All values are in mg/L.

STREAM	YEAR	TN	TON	TKN	NO2/NO3	NO2	NO3	NH3	NH4	DIN:TN
BAPTISTE LAKE STUDIES (Trew et al. 1987; Cooke & Prepas 1998)										
Baptiste Lake - A	1977	5.52	3.10		2.06			0.13		
	1978	3.66	2.61		0.78			0.27		
(A1)	1994									
	1995						0.968		0.049	
Baptiste Lake - M	1977	3.07	2.02		0.37			0.79		
	1978	5.05	3.84		1.09			0.11		
Baptiste Lake - N	1977	2.83	2.59		0.25			0.21		
	1978	3.63	3.35		0.05			0.24		
(A2 upstream)	1994									
	1995						0.196		0.979	
(A2 downstream)	1994									
	1995						0.151		2.359	
Baptiste Lake - E	1977	1.66	1.35		0.09			0.15		
	1978	1.66	1.52		0.08			0.06		
(F1)	1994									
	1995						0.065		0.030	
Baptiste Lake - F	1977	2.06	1.83		0.04			0.16		
	1978	2.03	1.94		0.04			0.06		
(F2)	1994									
	1995						0.034		0.039	
Baptiste Lake - L	1977	2.40	1.94		0.02			0.15		
	1978	2.70	2.56		0.04			0.11		
WABAMUN LAKE STUDIES (Mitchell 1985; Emmerton 2008)										
Wabamun - 01	1980	1.39								
	1981	0.86								
Wabamun - 02	1980	2.55								
	1981	2.04								
Wabamun - 09	1980	1.19								
	1981	1.10								
	2008	1.131		1.119	0.011	0.003	0.009	0.071		
Wabamun - 12	1980	1.09								
	1981	0.86								
	2008	0.911		0.828	0.082	0.006	0.077	0.135		

STREAM	YEAR	TN	TON	TKN	NO2/NO3	NO2	NO3	NH3	NH4	DIN:TN
Wabamun - 20	1980	0.68								
	1981	1.14								
	2008	1.298		1.078	0.220	0.006	0.214	0.122		
Wabamun - 05	1980	2.45								
	1981	1.44								
	2008	2.185		1.498	0.687	0.006	0.680	0.020		
Wabamun - 13	1980	5.85								
	1981	3.53								
	2008	0.260		0.221	0.039	L0.002	0.038	0.026		
Wabamun - 15	1980	1.46								
	1981	2.44								
Wabamun - 22	1980	1.82								
	1981	1.93								
Wabamun - 22-23	2008	1.153		1.146	0.007	L0.002	L0.006	0.029		
Wabamun - 23	1980	2.48								
	1981	2.48								
Wabamun - 24	1980	3.56								
	1981	3.54								
Wabamun - 26	1980	3.06								
	1981	3.03								
Wabamun - 26-27	2008	1.283		1.275	L0.006	L0.002	L0.006	0.016		
Wabamun - 30	1980	2.88								
	1981	3.15								
Wabamun - 31	1980	3.45								
	1981	3.06								
LAC LA NONNE STUDY (Mitchell & Hamilton 1982)										
Lac La Nonne - M11	1981	2.566								
PINE LAKE STUDY (Sosiak & Trew 1996)										
Pine Lake - 1A	1989									
	1992	1.425		1.408	0.017			0.068		
Pine Lake - 2A	1989									
	1992	1.621		1.553	0.068			0.378		
Pine Lake - 3A	1989									
	1992	1.479		1.444	0.035			0.086		
Pine Lake - 4A	1989									
	1992	1.594		1.585	0.009			0.095		
Pine Lake - 5A	1989									
	1992	2.447		2.419	0.028			0.116		
Pine Lake - 6A	1989									
	1992	2.149		1.911	0.238			0.156		

STREAM	YEAR	TN	TON	TKN	NO2/NO3	NO2	NO3	NH3	NH4	DIN:TN
Pine Lake - 7A	1989									
	1992	1.206		1.074	0.132			0.036		
Pine Lake - 8A	1992	2.062		1.831	0.231			0.131		
LESSER SLAVE LAKE STUDY (Noton 1998)										
Lesser Slave - South Heart	1991-1992									
Lesser Slave - Driftpile	1991-1992									
Lesser Slave - Other, West Basin	1991-1992									
Lesser Slave - Swan	1991-1992									
Lesser Slave - Assineau	1991-1992									
Lesser Slave - Marten	1991-1992									
Lesser Slave - Other, East Basin	1991-1992									
LAC STE. ANNE & LAKE ISLE STUDY (Mitchell 1999)										
Lac Ste Anne - Diffuse & others	1997									
Lac Ste Anne - Sturgeon River	1997									
Lac Ste Anne - Trib 2	1997									
Lac Ste Anne - Trib 22	1997									
Lac Ste Anne - Trib 23	1997									
Lac Ste Anne - Trib 5	1997									
Lake Isle - Diffuse & others	1997									
Lake Isle - Sturgeon River	1997									
Lake Isle - Trib 11	1997									
Lake Isle - Trib 20	1997									
Lake Isle - Trib 7	1997									
Lake Isle - Trib 8	1997									
GULL LAKE STUDY (Mitchell & LeClair 2003)										
Gull Lake - Beaver	1999	**5.95**						**1.29**		
Gull Lake - Birch Bay	1999	**7.74**						**0.30**		
Gull Lake - Diversion	1999	**4.71**						**0.21**		
Gull Lake - East	1999	**6.32**						**0.93**		
Gull Lake - North	1999	**2.02**						**0.18**		
Gull Lake - Parkland	1999	**2.30**						**0.33**		
Gull Lake - Sailing	1999	**5.40**						**0.34**		
Gull Lake - Sonrise	1999	**6.86**						**3.32**		
Gull Lake - Sucker	1999	**2.26**						**0.19**		
Gull Lake - Wiese	1999	**7.74**						**0.66**		
Gull Lake - Willow	1999	**7.48**						**0.22**		
Gull Lake - Wilson	1999	**5.08**						**0.77**		
LAC LA BICHE STUDY (Neufeld 2003-2004)										
Lac La Biche - Plamondon	2003-2004	2.333								

STREAM	YEAR	TN	TON	TKN	NO2/NO3	NO2	NO3	NH3	NH4	DIN:TN
Lac La Biche - Mission	2003-2004	2.376								
Lac La Biche - Reutov	2003-2004	1.587								
Lac La Biche - Deer	2003-2004	1.924								
Lac La Biche - Cadieux	2003-2004	1.643								
Lac La Biche - Goldie	2003-2004	1.189								
PIGEON LAKE STUDY (Teichreb 2014)										
Pigeon Lake - Grandview	2013	**1.374**		**1.270**	**0.104**	**0.010**	**0.094**	**0.059**		
Pigeon Lake - Mitchell Beach	2013	**1.363**		**1.201**	**0.162**	**0.007**	**0.155**	**0.229**		
Pigeon Lake - Norris Beach	2013	**1.169**		**1.072**	**0.096**	**0.011**	**0.086**	**0.048**		
Pigeon Lake - Poplar Bay	2013	**1.518**		**1.197**	**0.321**	**0.007**	**0.314**	**0.082**		
Pigeon Lake - Sunset Harbour	2013	**1.637**		**1.158**	**0.478**	**0.011**	**0.467**	**0.089**		
Pigeon Lake - Tide	2013	**1.339**		**1.170**	**0.169**	**0.007**	**0.162**	**0.071**		
Pigeon Lake - Zeiner	2013	**1.415**		**1.207**	**0.208**	**0.006**	**0.202**	**0.052**		
SAKWATAMAU TWO CREEK STUDY (Munn & Prepas 1986)										
Sakwatamau River	1983									
Two Creek	1983									
CAESA & AESA STREAM STUDIES (Anderson et al. 1998; Lorenz et al. 2008)										
Amisk Creek	1995	4.247		3.390	0.857			0.819		
	1996	3.905		3.568	0.338			0.547		
Arrowwood Creek nr. Arrowwood	1995	1.553		1.550	0.003			0.028		
- nr. Arrowwood	1996	4.15		0.060	0.964			0.359		
- nr. Ensign	1996	3.334		1.869	1.465			0.037		
Atim Creek	1995	1.437		1.093	0.344			0.230		
	1996	1.647		1.310	0.334			0.128		
Battersea Drain	1999-2006 median	1.062	0.680		0.272			0.066		0.355
Blindman River	1995	1.74		1.653	0.088			0.172		
	1996	2.406		2.252	0.154			0.310		
	1999-2006 median	1.973	1.732		0.130			0.224		0.171
Block Creek	1995	1.618		1.543	0.076			0.176		
	1996	1.178		1.141	0.038			0.069		
Buffalo Creek	1995	1.74		1.593	0.147			0.124		
	1996	1.65		1.590	0.061			0.124		
	1999-2006 median	1.982	1.630		0.048			0.255		0.184
Christmas Creek	1995	0.853		0.827	0.026			0.028		
	1996	1.364		1.346	0.018			0.061		
Crowfoot Creek	1995	0.806		0.789	0.018			0.029		
	1996	3.004		2.252	0.752			0.243		
	1999-2006 median	1.814	1.265		0.446			0.127		0.273
Flat Creek	1995	2.114		1.946	0.168			0.127		
	1996	2.018		1.941	0.077			0.225		

STREAM	YEAR	TN	TON	TKN	NO2/NO3	NO2	NO3	NH3	NH4	DIN:TN
Goose Creek	1995	0.873		0.861	0.012			0.034		
	1996	0.978		0.963	0.015			0.050		
Grande Prairie Creek	1999-2006 median	2.268	1.863		0.308			0.063		0.171
Haynes Creek	1995	6.685		6.160	0.492			1.370		
	1996	4.11		3.214	0.897			0.696		
	1999-2006 median	4.321	3.098		0.788			0.518		0.399
Hines Creek	1999-2006 median	1.310	1.236		0.011			0.054		0.054
Kiesksun Drainage	1999-2006 median	2.741	2.287		0.265			0.115		0.157
Little Paddle River	1995	2.3		2.132	0.168			0.220		
	1996	2.349		2.240	0.109			0.143		
Lloyd Creek	1995	2.128		1.960	0.176			0.263		
	1996	2.245		1.859	0.386			0.197		
Meadow Creek	1995	0.901		0.697	0.204			0.016		
	1996	1.779		1.596	0.184			0.114		
	1999-2006 median	1.108	0.973		0.071			0.030		0.099
New West Coulee	1999-2006 median	0.724	0.573		0.057			0.021		0.135
Paddle River	1995	1.482		1.427	0.055			0.083		
	1996	1.479		1.434	0.046			0.096		
	1999-2006 median	1.347	1.145		0.052			0.068		0.100
Prairie Blood Coulee	1995	1.589		1.582	0.008			0.029		
	1996	3.507		2.770	0.737			0.164		
	1999-2006 median	1.110	1.000		0.105			0.028		0.133
Ray Creek	1995	2.668		2.334	0.324			0.093		
	1996	3.435		2.234	1.201			0.337		
	1999-2006 median	1.995	1.760		0.201			0.094		0.128
Renwick Creek	1995	3.203		2.960	0.243			0.207		
	1996	4.221		2.791	1.431			0.217		
	1999-2006 median	3.453	2.543		0.626			0.257		0.290
Rose Creek	1995	1.274		1.258	0.017			0.045		
	1996	1.08		1.054	0.026			0.049		
	1999-2006 median	1.411	1.350		0.016			0.055		0.046
Sakwatamau River	1995	0.576		0.570	0.006			0.010		
	1996	1.68		1.644	0.035			0.042		
Strawberry Creek	1995	2.607		2.294	0.312			0.499		
	1996	4.274		3.485	0.788			0.304		
	1999-2006 median	3.296	2.516		0.321			0.313		0.284
Stretton Creek	1995	4.439		2.432	2.007			0.314		
	1996	3.035		2.608	0.428			0.394		
	1999-2006 median	2.969	1.986		0.952			0.145		0.387
Threehills Creek	1995	5.003		4.410	0.593			0.855		
	1996	4.445		2.914	1.531			0.628		

STREAM	YEAR	TN	TON	TKN	NO2/NO3	NO2	NO3	NH3	NH4	DIN:TN
	1999-2006 median	3.571	2.461		0.580			0.494		0.304
Tomahawk Creek	1995	1.836		1.635	0.201			0.142		
	1996	3.386		3.097	0.289			0.367		
	1999-2006 median	2.916	2.387		0.289			0.230		0.191
Trout Creek	1995	0.522		0.451	0.070			0.007		
	1996	1.404		1.292	0.117			0.045		
	1999-2006 median	0.538	0.479		0.042			0.014		0.101
Wabash Creek	1999-2006 median	3.336	2.095		0.646			0.464		0.348
Willow Creek	1999-2006 median	0.283	0.256		0.020			0.010		0.093

Table A3-4: Export coefficients of nitrogen fractions for individual streams. Alternate names for streams in subsequent studies are listed in brackets. Bolded values were derived by NSWA from other reported measurements (annual loads/watershed areas). All values are in kg/ha/yr.

STREAM	YEAR	TN	TDN	PN	TON	DON	TKN	NO2/NO3	NO2	NO3	NH3	NH4
BAPTISTE LAKE STUDIES (Trew et al. 1987; Cooke & Prepas 1998)												
Baptiste Lake - A	1977	2.56			1.43			0.95			0.06	
	1978	2.10			1.50			0.45			0.16	
(A1)	1994											
	1995									0.29		0.02
Baptiste Lake - M	1977	0.26			1.1			0.20			0.43	
	1978	0.21			1.9			0.54			0.06	
Baptiste Lake - N	1977	0.11			1.62			0.16			0.13	
	1978	0.25			2.02			0.03			0.14	
(A2 upstream)	1994											
	1995									0.08		0.40
(A2 downstream)	1994											
	1995									0.04		1.58
Baptiste Lake - E	1977	0.91			0.73			0.05			0.08	
	1978	3.32			3.04			0.16			0.13	
(F1)	1994											
	1995									0.03		0.01
Baptiste Lake - F	1977	2.40			2.13			0.04			0.19	
	1978	3.85			3.66			0.08			0.11	

STREAM	YEAR	TN	TDN	PN	TON	DON	TKN	NO2/NO3	NO2	NO3	NH3	NH4
(F2)	1994											
	1995									0.01		0.01
Baptiste Lake - L	1977	1.21			0.98			0.01			0.08	
	1978	3.32			3.14			0.05			0.13	
WABAMUN LAKE STUDIES (Mitchell 1985; Emmerton 2008)												
Wabamun - 01	1980	1.26										
	1981	0.52										
Wabamun - 02	1980	0.64										
	1981	2.35										
Wabamun - 09	1980	1.54										
	1981	0.66										
	2008											
Wabamun - 12	1980	0.29										
	1981	0.23										
	2008											
Wabamun - 20	1980	1.76										
	1981	0.66										
	2008											
Wabamun - 05	1980	2.82										
	1981	0.66										
	2008											
Wabamun - 13	1980	2.56										
	1981	1.77										
	2008											
Wabamun - 15	1980	1.02										
	1981	1.82										
Wabamun - 22	1980	0.92										
	1981	0.79										
Wabamun - 22-23	2008											
Wabamun - 23	1980	4.64										
	1981	0.97										
Wabamun - 24	1980	2.57										
	1981	1.04										
Wabamun - 26	1980	1.21										
	1981	0.85										
Wabamun - 26-27	2008											
Wabamun - 30	1980	0.26										
	1981	0.54										
Wabamun - 31	1980	0.43										
	1981	0.46										

STREAM	YEAR	TN	TDN	PN	TON	DON	TKN	NO2/NO3	NO2	NO3	NH3	NH4
LAC LA NONNE STUDY (Mitchell & Hamilton 1982)												
Lac La Nonne - M11	1981	1.62										
PINE LAKE STUDY (Sosiak & Trew 1996)												
Pine Lake - 1A	1989											**0.014**
	1992	**0.222**					**0.219**	**0.003**		**0.011**		**0.011**
Pine Lake - 2A	1989											**0.035**
	1992	**0.547**					**0.524**	**0.023**		**0.127**		**0.031**
Pine Lake - 3A	1989											**0.035**
	1992	**0.306**					**0.299**	**0.007**		**0.018**		**0.025**
Pine Lake - 4A	1989											**0.051**
	1992	**0.512**					**0.509**	**0.003**		**0.030**		**0.039**
Pine Lake - 5A	1989											**0.006**
	1992	**0.096**					**0.095**	**0.001**		**0.005**		**0.005**
Pine Lake - 6A	1989											**0.056**
	1992	**0.582**					**0.517**	**0.064**		**0.042**		**0.041**
Pine Lake - 7A	1989											**0.042**
	1992	**0.388**					**0.345**	**0.042**		**0.012**		**0.022**
Pine Lake - 8A	1992	**0.070**					**0.062**	**0.008**		**0.004**		
LESSER SLAVE LAKE STUDY (Noton 1998)												
Lesser Slave - South Heart	1991-1992											
Lesser Slave - Driftpile	1991-1992											
Lesser Slave - Other, West Basin	1991-1992											
Lesser Slave - Swan	1991-1992											
Lesser Slave - Assineau	1991-1992											
Lesser Slave - Marten	1991-1992											
Lesser Slave - Other, East Basin	1991-1992											
LAC STE. ANNE & LAKE ISLE STUDY (Mitchell 1999)												
Lac Ste Anne - Diffuse & others	1997											
Lac Ste Anne - Sturgeon River	1997											
Lac Ste Anne - Trib 2	1997											
Lac Ste Anne - Trib 22	1997											
Lac Ste Anne - Trib 23	1997											
Lac Ste Anne - Trib 5	1997											
Lake Isle - Diffuse & others	1997											
Lake Isle - Sturgeon River	1997											
Lake Isle - Trib 11	1997											
Lake Isle - Trib 20	1997											
Lake Isle - Trib 7	1997											
Lake Isle - Trib 8	1997											

STREAM	YEAR	TN	TDN	PN	TON	DON	TKN	NO2/NO3	NO2	NO3	NH3	NH4
GULL LAKE STUDY (Mitchell & LeClair 2003)												
Gull Lake - Beaver	1999	**1.39**									**0.30**	
Gull Lake - Birch Bay	1999											
Gull Lake - Diversion	1999											
Gull Lake - East	1999	**1.11**									**0.16**	
Gull Lake - North	1999	**1.49**									**0.13**	
Gull Lake - Parkland	1999											
Gull Lake - Sailing	1999	**2.27**									**0.14**	
Gull Lake - Sonrise	1999	**2.50**									**1.21**	
Gull Lake - Sucker	1999											
Gull Lake - Wiese	1999	**3.06**									**0.26**	
Gull Lake - Willow	1999	**1.63**									**0.05**	
Gull Lake - Wilson	1999	**1.79**									**0.27**	
LAC LA BICHE STUDY (Neufeld 2003-2004)												
Lac La Biche - Plamondon	2003-2004	0.355	0.304	0.051		0.232				0.015		0.057
Lac La Biche - Mission	2003-2004	0.547	0.494	0.052		0.432				0.042		0.021
Lac La Biche - Reutov	2003-2004	0.259	0.239	0.020		0.232				0.002		0.005
Lac La Biche - Deer	2003-2004	0.253	0.231	0.023		0.214				0.003		0.013
Lac La Biche - Cadieux	2003-2004	0.418	0.414	0.003		0.410				0.001		0.003
Lac La Biche - Goldie	2003-2004	0.429	0.419	0.011		0.412				0.002		0.005
PIGEON LAKE STUDY (Teichreb 2014)												
Pigeon Lake - Grandview	2013	**0.369**					**0.341**	**0.028**	**0.003**	**0.025**	**0.016**	
Pigeon Lake - Mitchell Beach	2013	**0.236**					**0.208**	**0.028**	**0.001**	**0.027**	**0.040**	
Pigeon Lake - Norris Beach	2013	**0.122**					**0.112**	**0.010**	**0.001**	**0.009**	**0.005**	
Pigeon Lake - Poplar Bay	2013	**0.232**					**0.183**	**0.049**	**0.001**	**0.048**	**0.013**	
Pigeon Lake - Sunset Harbour	2013	**0.347**					**0.245**	**0.101**	**0.002**	**0.099**	**0.019**	
Pigeon Lake - Tide	2013	**0.181**					**0.158**	**0.023**	**0.001**	**0.022**	**0.010**	
Pigeon Lake - Zeiner	2013	**0.132**					**0.113**	**0.019**	**0.001**	**0.019**	**0.005**	
SAKWATAMAU TWO CREEK STUDY (Munn & Prepas 1986)												
Sakwatamau River	1983											
Two Creek	1983											
CAESA & AESA STREAM STUDIES (Anderson et al. 1998; Lorenz et al. 2008)												
Amisk Creek	1995	0.2360					0.1884	0.0476			0.0455	
	1996	0.3323					0.3035	0.0287			0.0466	
Arrowwood Creek nr. Arrowwood	1995	0.0151					0.0151	0.0000			0.0003	
- nr. Arrowwood	1996	1.3336					1.0237	0.3099			0.1154	
- nr. Ensign	1996	0.4465					0.2503	0.1929			0.0050	
Atim Creek	1995	0.4746					0.3610	0.1136			0.0761	
	1996	1.5325					1.2188	0.3107			0.1189	

STREAM	YEAR	TN	TDN	PN	TON	DON	TKN	NO2/NO3	NO2	NO3	NH3	NH4
Battersea Drain	1999-2006 median											
Blindman River	1995	0.6001					0.5759	0.0304			0.0595	
	1996	4.3115					4.0353	0.2762			0.5549	
	1999-2006 median	1.41205			1.072			0.09565			0.1437	
Block Creek	1995	0.7068					0.6740	0.0334			0.0767	
	1996	0.9256					0.8961	0.0295			0.0541	
Buffalo Creek	1995	0.2637					0.2414	0.0223			0.0187	
	1996	0.3812					0.3672	0.0140			0.0287	
	1999-2006 median	0.42315			0.351			0.0081			0.05905	
Christmas Creek	1995	0.5821					0.5642	0.0180			0.0188	
	1996	2.4921					2.4594	0.0327			0.1121	
Crowfoot Creek	1995	0.1862					0.1821	0.0040			0.0067	
	1996	1.5331					1.1495	0.3836			0.1240	
	1999-2006 median											
Flat Creek	1995	0.9229					0.8496	0.0733			0.0554	
	1996	3.4914					3.3585	0.1329			0.3891	
Goose Creek	1995	0.2248					0.2217	0.0031			0.0089	
	1996	1.0972					1.0804	0.0168			0.0561	
Grande Prairie Creek	1999-2006 median	1.11025			1.004			0.07615			0.029	
Haynes Creek	1995	0.1292					0.1191	0.0095			0.0265	
	1996	1.2958					1.0132	0.2826			0.2193	
	1999-2006 median	0.4607			0.276			0.0798			0.0494	
Hines Creek	1999-2006 median	0.4739			0.455			0.0034			0.01875	
Kiesksun Drainage	1999-2006 median	1.17195			0.954			0.06885			0.04065	
Little Paddle River	1995	1.1849					1.0983	0.0866			0.1133	
	1996	3.6516					3.4825	0.1692			0.2225	
Lloyd Creek	1995	0.5278					0.4862	0.0436			0.0653	
	1996	2.2124					1.8315	0.3809			0.1938	
Meadow Creek	1995	0.6173					0.4777	0.1396			0.0112	
	1996	0.6796					0.6095	0.0701			0.0435	
	1999-2006 median	0.14175			0.131			0.0068			0.00545	
New West Coulee	1999-2006 median											
Paddle River	1995	1.5080					1.4524	0.0557			0.0845	
	1996	3.8064					3.6891	0.1173			0.2463	
	1999-2006 median	0.5579			0.47			0.02985			0.03215	
Prairie Blood Coulee	1995	0.3595					0.3578	0.0018			0.0065	
	1996	0.4113					0.3249	0.0864			0.0192	
	1999-2006 median	0.15465			0.102			0.0074			0.0054	
Ray Creek	1995	0.2444					0.2147	0.0297			0.0085	
	1996	1.2195					0.7932	0.4262			0.1196	
	1999-2006 median	0.48765			0.403			0.0608			0.01435	

STREAM	YEAR	TN	TDN	PN	TON	DON	TKN	NO2/NO3	NO2	NO3	NH3	NH4
Renwick Creek	1995	0.3327					0.3075	0.0252			0.0215	
	1996	0.9430					0.6234	0.3196			0.0486	
	1999-2006 median	0.44065			0.326			0.06435			0.01825	
Rose Creek	1995	0.9448					0.9325	0.0126			0.0335	
	1996	1.5160					1.4797	0.0364			0.0688	
	1999-2006 median	1.06905			1.016			0.0173			0.04095	
Sakwatamau River	1995	0.4763					0.4714	0.0050			0.0081	
	1996	5.2692					5.1581	0.1111			0.1307	
Strawberry Creek	1995	0.2852					0.2510	0.0342			0.0546	
	1996	2.8358					2.3127	0.5231			0.2018	
	1999-2006 median	0.68625			0.559			0.1101			0.05925	
Stretton Creek	1995	0.4882					0.2675	0.2207			0.0346	
	1996	0.0188					0.1307	0.0214			0.0197	
	1999-2006 median	0.7353			0.509			0.21165			0.03035	
Threehills Creek	1995	0.2141					0.1888	0.0254			0.0366	
	1996	1.6433					1.0773	0.5660			0.2323	
	1999-2006 median	0.7768			0.516			0.1237			0.1103	
Tomahawk Creek	1995	0.4683					0.4171	0.0512			0.0362	
	1996	3.4764					3.1798	0.2966			0.3769	
	1999-2006 median	1.12315			0.909			0.127			0.07195	
Trout Creek	1995	0.6055					0.5243	0.0812			0.0085	
	1996	0.7222					0.6648	0.0575			0.0230	
	1999-2006 median	0.158			0.142			0.01065			0.00555	
Wabash Creek	1999-2006 median	0.25625			0.145			0.06905			0.0278	
Willow Creek	1999-2006 median	0.41125			0.373			0.02735			0.00975	