Hutchinson

Environmental Sciences Ltd.

North Saskatchewan River: Water Quality and Related Studies (2007 – 2012)

Final Report

Prepared for: Alberta Environment and Sustainable Resource Development

In collaboration with: Limnologic Solutions Ltd. and
O2 Planning & Design Inc.

Job #: J130062
AESRD Contract: 140125

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August 13, 2014 HESL Job #: J130062

Eleanor Kneffel
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Environment and Sustainable Resource Development
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Edmonton, AB, T6B 2X3

Dear Ms. Kneffel:

Re: North Saskatchewan River: Water Quality and Related Studies (2007 – 2012) - Final Report

We are pleased to submit this report to you that contains the Review and Synthesis of Water Quality and Related Studies in the North Saskatchewan River from 2007 to 2012. This report first presents an overview and evaluation of the different programs and studies provided by Alberta Environment and Sustainable Resource Development. It then presents our assessment methods, followed by a synthesis section where the status of the aquatic ecosystem is discussed by ecosystem component. The report closes with a summary section where new contributions to water resource management in the NSR are discussed and recommendations are provided to align monitoring programs with ongoing management initiatives and evolving priorities.

This report was a collaborative effort under the lead of Hutchinson Environmental Sciences (project management, technical lead, report preparation), but with contributions by Stoneleigh Data Ltd. (database development), Limnologic Solutions Ltd. (management input and reporting) and O2 Planning and Design Inc. (mapping).

In this final version of the report, we have addressed comments provided by ESRD and subjected the report to another round of internal review for quality assurance purposes. We hope that this document will be useful for informing ongoing water management initiatives in the NSR.

Sincerely,

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

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Executive Summary

Purpose and Scope of Report

Considerable effort has been invested into monitoring, modelling and reporting on the conditions in the NSR over the last 5 years, particularly in the Industrial Heartland and Capital Region Reach (IH-CR Reach). Alberta Environment and Sustainable Resource Development retained the team of Hutchinson Environmental Sciences, Limnologic Solutions Ltd. and O2 Planning and Design Ltd. to compile, review and synthesize this information.

The purpose of this report was to provide a synoptic evaluation of the North Saskatchewan River and anthropogenic impacts on that system. The report summarizes data collected from 2007 to 2012 and builds on findings from technical study reports produced during this time period, including information on water quality, sediment quality and biota. This document provides a summary of the studies conducted, their purpose, methods, information gained and relevance to local and basin-wide water management. The report also evaluates the present state of the aquatic environment in the NSR and assesses effects on the in-stream water quality and aquatic ecosystem health resulting from current human activities in the watershed. The synthesized information and document supports the ongoing watershed planning initiatives for the North Saskatchewan River, including the North Saskatchewan Regional Plan and the Industrial Heartland - Capital Region Water Management Framework (IH-CR WMF).

Methodology

The approach to this synthesis report included five main components, as listed below:

1) Report review: 15 reports produced by AESRD, the City of Edmonton and their collaborators (section 3),

2) Data compilation: data from six synoptic surveys, six years of LTRN data (2007-2012), and six years of Datasonde data were compiled into two databases (Appendices A and B),

3) Data Analysis: New data sets were analyzed and the results were integrated into the status assessment, with detailed technical reports produced for the datasonde, diurnal, and fish tissue datasets (Appendix C)

4) Status assessment: All analyzed and reviewed data were used to assess the status of water quality, sediment quality, non-fish biota and fish tissue in the NSR. This included comparison to Site-Specific Water Quality Objectives (SSWQOs) and guidelines, assessing spatial and temporal patterns and integration of results for the reviewed reports.

5) Synthesis and Evaluation: The contributions of the conducted studies to water and watershed management in the North Saskatchewan Region were discussed, priority issues and knowledge gaps were identified and recommendations were developed for ongoing management.

Review of Studies

A large number of studies were conducted on the NSR from 2007 to 2012 involving monitoring and assessment of water quality and biota, quantifying inputs to the river from tributaries and point sources, modeling contaminant transport, developing new tools and synthesizing existing information. These studies varied in temporal, spatial scales and pollution type focus, depending on the specific objectives of the individual studies. Together findings from these studies contributed diverse and useful pieces of information to water and watershed managers (Table a).

Table A. Summary of Programs and Their Main Contributions to NSR Water Quality Management

Reference	Pollution Type		Main Contribution
	Point	Non-Point	
WATER QUALITY			
AESRD (LTRN)			• Continuous, consistent, long-term record of water quality, that allows for trend analysis and regular status assessments.
AESRD (Datasonde)			• Describes daily fluctuations that aquatic life is exposed to. • Allows for more reliable summary statistics and description of extremes for variables that vary on a daily basis.
AESRD (Diurnal)			• Determines if routine daily collections of water quality are representative of water chemistry in the North Saskatchewan River.
AESRD (Synoptic)	x		• Provides spatial patterns related to natural watershed changes as well as point-and non-point source inputs. • Provides information to assess longitudinal changes. • Distinguishes local impacts from watershed impacts. • Assesses sensitivity of the NSR to impacts during different seasons and flow levels. • Only program that collects systematic information on tributary water quality across the watershed, which provides immense value for future watershed planning initiatives under the NSR Regional Plan.
City of Edmonton EPM (Golder 2013 a,b,c)	x		• Quantifies the contaminant loading from approved facilities (combined and storm sewers, WTP, WWTP) to the NSR on an annual basis. • High-frequency, within-City sampling of NSR water quality. • Limited information on urban tributaries at mouth and upstream of City.
SEDIMENT & NON-FISH BIOTA			
Benthic Study (Clearwater & Kilgour 2010)			• Establishes an important link between water quality and aquatic ecosystem health in the NSR. • Solid baseline to which compare future changes in NSR non-fish biota.

Reference	Pollution Type		Main Contribution
	Point	Non-Point	
Sediment Provenance (Stone and Collins 2012)		x	• Provides information on sediment contaminant levels and relative source proportions.
FISH CONTAMINANTS			
Fish Tissue (AESRD)			• New information on contaminant levels in a variety of fish species for a range of metals and organic compounds. • Provides baseline to which future programs can be compared
MODELS & MIXING			
Watershed Model (TetraTech 2012)		x	• Provides representation of watershed-derived sources and transport of temperature, sediment, nutrients, metals and bacteria, mainly from non-point sources. • Complements a suite of previous models that were developed for the IH-CR and intended for evaluating point source management scenarios. • Allows simulating land use management scenarios. • Deeper understanding of hydrological processes in the watershed in their influence on water quality.
Dye Study (Pilechi et al. 2012)	x		• Describes individual plume mixing patterns of three major effluents (i.e., Goldbar WWTP, Captial Region WWTP and Agrium Redwater Fertilizer plant)
DATA ANALYSIS, SYNTHESIS AND TOOLS			
Synthesis (AECOM & Anderson 2011)	x		• Provides a succinct overview of technical studies (2006-2009) conducted in the NSR IH-CR, and how they support the Water Management Framework, and identified gaps and research needs. • Focused on the IH-CR reach and provided detailed reviews of effluent loading.
Trend Analysis (Anderson 2012)			• Trends in the LTRN data set, for ice-cover and open water periods. • Percentiles, which can serve as a foundation to derive site-specific objectives.
WQOs and MALs (McDonald 2013)			• Criteria and Process to establish Variables of Concern (VoCs). • Pilot Site-Specific Water Quality Objectives for Devon & Pakan. • Maximum Allowable Loads for VoCs for different flow seasons.
Loading Tool (Kessler 2010)	x		• Selects the best and most appropriate tool for estimating in-stream loads and point-source loadings - annually and seasonally. • Useful tool for evaluating the relative importance of different discharges on the NSR and therefore supports the management of cumulative effects from multiple discharges for variables of concern.

North Saskatchewan River Status 2007-2012

Water Quality

Natural characteristics of the North Saskatchewan River and its watershed create a number of water quality patterns, including the following main patterns:

- The transition from mountains to prairies results in the natural enrichment of NSR water with ions, some metals, turbidity, solids and nutrients and changes to the aquatic habitat, affecting biotic communities.
- Seasonally varying river flows have a dominant effect on river water quality, where periods of high river discharge coincide with the transport of large amounts of total suspended solids and associated contaminants such as nutrients, metals, bacteria and pathogens.

Anthropogenic effects from point and non-point source discharges have measurable impacts on the water quality in the NSR:

- Loading from WWTP effluent increased total nutrient concentrations and the proportion of dissolved nutrients downstream of Edmonton. The magnitude of this effect has declined considerably since the 1980s, in response to improvements in the WWTPs;
- During periods of runoff, TSS was higher downstream than upstream of Edmonton, possibly related to stormwater influences, although the TSS contributions within the IH-CR are partially masked by the large, mostly natural contributions from the upper watershed;
- Chloride concentrations increase in the IH-CR Reach during local spring runoff, and are possibly related to the application of road salt, which reached the river mainly via stormwater outfalls and urban tributaries. During summer, stormwater baseflow concentrations were still high and tributary chloride concentrations at locations upstream of the City were similar to or higher than concentrations measured at the mouths within the City, suggesting an upstream watershed source during this time;
- Increases in coliform bacteria occurred mainly during runoff events when CSOs in Edmonton and bypasses from the GBWWTP contributed large loads of bacteria to the river. This represents a considerable improvement over historical conditions when WWTPs were a large continuous source of bacteria;
- Increases in dissolved aluminium, total and dissolved molybdenum and total nickel, total zinc, total cadmium and total cobalt downstream of the IH-CR Reach, associated with urban point- and non-point sources; and
- The only organic compound detected consistently as part of the LTRN water monitoring program was 2,4-D (herbicide), with most detections at Pakan. It is a highly persistent compound and has been observed at low levels in both agricultural and urban watersheds. During the synoptic surveys, six detections of PAHs and 16 detections of phthalates were recorded. Values were measured near the method detection limits and therefore do not indicate a serious problem, but there may be a potential for accumulation in the ecosystem and other environmental components.

Sediment

Sediment chemistry data were collected throughout the basin and indicated:

- Little accumulation of nutrients and metals.
- The presence of PAHs throughout the river, with some PAH compounds exceeding sediment quality guidelines,
- The presence of pharmaceutical and personal care products mainly occurring downstream of WWTPs,
- Organochlorine pesticides (i.e., DDT congeners) detections at some locations and at concentrations that exceeded the sediment quality guidelines,
- Generally there were higher contaminant levels in sediments downstream of Edmonton, but decreasing particle size likely played a direct role in these patterns, and
- Concentrations of arsenic and chromium exceeding the ISQG at several sites throughout the basin, indicating natural sources.

The presence, distribution and possible sources of sediment contaminants, however, remain uncharacterized due in part to the difficulty in consistently obtaining representative samples from mobile, relatively coarse-grained sediments in the river.

Non-Fish Biota

Algae, benthic invertebrate and aquatic macrophyte communities were indicative of high quality, low-nutrient environments in the headwaters and exhibited clear responses to nutrient enrichment within and downstream of the IH-CR. These changes were mostly indicative of increased aquatic productivity, as communities were still healthy with a high diversity and large abundance of sensitive species.

- *Planktonic algae* biomass was very low at the Clearwater and Devon sites, and increased significantly between Devon and Pakan. Median values at Pakan, however, remained in the oligotrophic to mesotrophic range for running waters. Declining trends in planktonic chlorophyll-*a* at Devon and Pakan Hwy 17 from 1987 to 2009 likely represent a biological response to declining nutrient levels as a result of WWTP upgrades.
- *Epilithic algae* biomass was low upstream of Edmonton and increased downstream of the GBWWTP effluent outfall. Epilithic algae biomass remained higher on the right bank, in the slow mixing effluent plume, for about 80 km downstream of the outfall. Relative abundance of major epilithic algae groups did not change significantly along the river, but significant spatial differences were observed at the species level.
- *Benthic invertebrate* abundance also increased in response to nutrient enrichment, and communities contained more individuals from pollution-tolerant groups. In contrast with historical data, sensitive groups of mayflies and caddis flies were still fairly abundant downstream of treated sewage discharges. These results were in stark contrast with earlier studies conducted in 1982,

when EPT were virtually absent in the IH-CR demonstrating the large positive effect of WWTP upgrades on the benthic communities in the NSR. Downstream distance, embeddedness (a habitat indicator) and alkalinity exerted the strongest influence on benthic community composition, indicating that impacts from the IH-CR were superimposed on effects of natural gradients in river and watershed characteristics from upstream to downstream.

- *Macrophyte* biomass increased steadily between Rocky Mountain House and Devon and steadily decreased downstream of Devon, with the lowest biomass observed downstream of Edmonton. This pattern likely reflected changes in turbidity and resultant effects on light transmission.

These recently acquired data on aquatic non-fish biota, in conjunction with sediment quality and water quality data, provide an improved foundation for the assessment of aquatic ecosystem health, and for the inclusion of biotic indicators as site-specific water quality objectives.

Fish Tissue

Fish tissue samples showed that:

- Three different sources of organics were being taken up; specifically, industrial and consumer products, PAHs and historic use pesticides;
- PAHs were the only compounds that were detected in both sediment and fish;
- Napthalene, phenanthrene, anthracene, fluoranthene and pyrene were more concentrated in the fish relative to the sediments by factors ranging from 2 to 95; and
- Metals data showed accumulation of some metals but none stand out as suggesting a concern at this point.

Priority Issues

Based on the status assessment and the impact of human activities on the status, three priority issues have emerged that may require more attention in ongoing monitoring, assessment and management activities. These include non-point sources, acute effects, and emerging contaminants, as detailed below.

- With large improvements in place for point-source loads of conventional wastewater substances, focus of water quality management is now shifting to emerging substances and non-point source loadings. The continuing growth of the City of Edmonton, combined with the improvements to waste water treatment, has resulted in a proportional increase in the effects observed on the quality of the NSR downstream that are derived from non-point sources and this trend is likely to continue. Storm water and rural non-point source management should therefore become an increasing focus for the management of water quality in the NSR.
- Emerging contaminants, such as pharmaceuticals and personal care products, are mainly a concern due to the large uncertainties associated with their fate and effects on the aquatic ecosystem. Assessing trends and human impacts is difficult for organic compounds, including emerging contaminants (e.g. pesticides, industrial compounds, pharmaceuticals and personal care products), due to the difficulty in obtaining representative samples (e.g. fish and sediment),

due to the fact the time series data for these compounds is quite limited and that levels are often lower than detection limits.

Gaps and Recommendations

A number of knowledge gaps have been identified and recommendations were developed to address these, as detailed in the table below.

Table B. Summary of Data Gaps and Issues and Recommendations to Address Them.

Gap/Issue	Recommendation
Relative role of urban road salt compared to watershed sources of chloride	• Broader accounting of identified and potential additional sources
Sources and fate of trace organic contaminants in the NSR	• Coordinated water/suspended sediment/and young forage fish sampling from expected source areas to the NSR to quantify water/sediment/fish accumulation factors
Appropriate limits and targets for water quality management	• Use Site-specific Water Quality Objectives and implement through loading management, accommodating different river flow seasons
Standardized approach for rating the status of sediment and biota	• Jurisdictional review to locate sediment quality guidelines for contaminants, in particular organics • Develop site-specific objectives for biological indicators (e.g., epilithic algae, benthic invertebrates) that integrate and reflect cumulative effects over extended periods of time • Use diatom indices as a sensitive indicator of algae community response to nutrient enrichment
Understanding of relationships between aquatic plants, nutrients and other factors to confirm the value of this indicator for status assessments	• Aerial and satellite-based surveys as alternative ways to estimate macrophyte abundance on a large scale • Sampling approach throughout the growing season, including the months before attainment of maximum biomass • Refine desired outcomes for both nutrients and aquatic plants
No data on oxygen saturation	• Add elevation as a site characteristic to the AERSD water quality database • Derive oxygen saturation levels for past and future oxygen concentration measurement
Refine the accuracy and precision of water quality model predictions	• Increase the utility of EFDC in simulating biologic response (e.g., plant growth), sediments (e.g., sediment/water interactions; sediment transport), and metal dynamics (e.g., sorption processes, speciation) • Assess and address monitoring and research needs for testing and calibrating the model

Gap/Issue	Recommendation
Aquatic health in the tributaries	• increased monitoring focus in tributaries, including headwater sites and biological indicators
Document the progress and success of the IH-CR Water Management Framework	• Integrate aquatic health status into evaluation and reporting framework
Limited detection of organic contaminants in water and sediment	• Deploy passive integrated samplers over long periods to target the pesticides, PAHs, industrial contaminants and the PPCPs
Stormwater impacts: acute effects and future trends	• Continue comprehensive stormwater sampling • model future development scenarios, including flows, TSS and nutrients and other contaminants, their effect on tributary geomorphology (assess potential for erosion under increased storm flows) • conduct acute toxicity tests on SO and CSO outfalls during storm events

Conclusion

Information on the current status of the NSR has been updated with recent data acquired for the entire river with emphasis on the IH-CR water management reach. Comprehensive spatial and temporal water quality datasets and individual studies on sediments and biota have been completed and allow an up-to-date assessment of aquatic ecosystem status and the natural and anthropogenic factors that influence it. This synthesis and the resulting recommendations will help guide future efforts in implementing watershed management plans under the NSR Regional Plan and the Industrial Heartland and Capital Region Water Management Framework (IH-CR WMF).

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1. Introduction

1.1 Project Background

The North Saskatchewan River (NSR) flows from the Rocky Mountains to the Saskatchewan border within Alberta and ultimately joins with the South Saskatchewan River in Saskatchewan and discharges to Lake Winnipeg in Manitoba. It supports a number of landuse activities within its watershed. Natural and anthropogenic activities influence the receiving water quality in the North Saskatchewan River. There is particularly high urban and industrial growth in the Industrial Heartland and Capital Region river reach, which includes the Alberta capital, Edmonton and this growth is expected to continue. Cumulative impacts on the river from point and non-point sources will need to be properly monitored and managed.

In the last 5 years, considerable effort has been invested into monitoring, modelling and reporting on the conditions in the NSR, particularly in the Capital Region and Industrial Heartland reach. Information has been collected on effluent discharge, water withdrawals, ambient biotic and abiotic conditions in the NSR and on inputs from some tributaries. Based on the information gathered, in-stream water quality objectives and maximum allowable loads have been proposed at key locations along the NSR to assist with reporting and cumulative effects management within the river. Modelling studies have also been completed for cumulative management scenario predictions. The overall intent of these monitoring, modelling and reporting efforts has been to update and improve our understanding of the drivers and stressors in the NSR and ultimately assist with successful water management decisions for the river.

1.2 Purpose of Report

The purpose of this report was to provide a synoptic evaluation of the North Saskatchewan River and anthropogenic impacts on this system. The report summarizes findings from ambient river and tributary data collected from 2007 to 2012 and builds on findings from technical study reports produced during this time period. This document also builds on information summarized from the last 5-year synthesis report (AECOM and Anderson 2011). Information on water quality, sediment quality and biota for the North Saskatchewan River has been reviewed and compiled. This document provides a short summary of the studies conducted, their purpose, methods, information gained and relevance to local and basin-wide water management. The report also evaluates the present state of the aquatic environment in the NSR and assesses effects on the in-stream water quality and ecosystem health resulting from current human activities in the watershed. The synthesized information and document supports the ongoing watershed planning initiatives for the North Saskatchewan River.

1.3 Report Overview

This report is structured into six main chapters. Chapter 1 provides an introduction to the context and scope of work. The background geographic and watershed planning context is provided in Chapter 2. A short summary of the completed studies, data and watershed tools reviewed is provided in Chapter 3. Chapter 4 describes the methodology adopted to synthesize the information. Chapter 5 describes the current status of the North Saskatchewan River, by variable group. Chapter 6 highlights the contributions of the main findings in the context of water and watershed management. Chapter 7 summarizes the main findings and concludes the report.

Several appendices complement the main report. The database manual is described in Appendix A. The data preparation methodology is described in Appendix B. The detailed technical reports for the Synoptic, Long-term monitoring network, datasonde, diurnal and fish tissue data are presented in Appendix C. Appendices D through J provide complete data summaries, graphs and station locations for all reviewed new datasets.

2. Geographic and Planning Context

2.1 Geographic Area

In Alberta, the North Saskatchewan River (NSR) flows approximately 1,000 km and has a total drainage area of about 57,000 km^2 (NSWA 2014). Currently, the mean annual discharge from the basin in Alberta into Saskatchewan is over seven billion m^3 (AENV 2014). The main tributaries that contribute flow to the NSR include the Brazeau, Ram and Clearwater rivers in the headwaters, where about 90% of the total annual flow is generated. The Sturgeon and Vermillion rivers contribute important flow additions downstream of Edmonton. Two large dams regulate flow in the river and are located in the upper basin. The Big Horn Dam on the North Saskatchewan River creates Lake Abraham. The Brazeau Reservoir is created by the Brazeau Dam, located on the Brazeau River.

The NSR river basin is divided into twelve tributary sub-watersheds (NSWA 2014). The watersheds are located within a variety of natural regions including: the Rocky Mountains, Foothills, Boreal Forest, Central Parkland and Grassland regions. These natural regions differ in climate, geology, soils, landscape and vegetation and these components naturally influence the river system. River bottom substrate tends to change from coarse cobble gravel in the headwaters to sandy or silty sediment in the lower reaches reflective of initial high flow velocities and then progressively lower flow velocities as the river widens across the flatter central parkland and grassland regions.

The diversity of landforms in the NSR watershed supports a wide range of human land uses. Major urban centres within the basin include Rocky Mountain House, Drayton Valley, Edmonton, Fort Saskatchewan and the Saddle Lake Indian Reserve (Figure 1). Approximately 1.2 million people reside in the watershed, most of whom live in the Capital Region (City of Edmonton and area) (NSWA 2014). The Capital Region is also home to the Industrial Heartland, situated northeast and downstream of the City of Edmonton. The Industrial Heartland supports a large portion of Alberta's oil and gas refining, chemical, and petrochemical facilities. Along with industrial growth, it is expected that urban and suburban populations will continue to grow such that the population of the Capital Region is expected to grow to over 1.7 million people in the next 35 years (AESRD 2014). Unless growth is managed carefully, cumulative impacts on the river from the point and non-point source loading of contaminants could lead to deterioration of water quality and aquatic ecosystem health.

Historically, point sources in the Edmonton area have had a significant impact on the water quality of the NSR. Contaminant loads from Edmonton's municipal discharges have, however, declined considerably over the last 30 years as a result of ongoing upgrading of municipal wastewater treatment. The Goldbar Wastewater Treatment Plant (GBWWTP) became operational in 1956 and initially provided secondary treatment. Over the years, it has undergone several upgrades, including the implementation of Biological

Nutrient Removal (BNR) in the 1990's, the construction of a UV disinfection process in 1998, and membrane filtration (for a portion of the flow) in 2005 (City of Edmonton 2010). Capital Region Wastewater Treatment Plant (CRWWTP) was opened in 1984. It treats sewage from various towns in the Capital Region and also has a history of upgrades of which the most important ones (BNR and UV treatment) were implemented in 2005 (City of Edmonton 2010).

Beneficial management practices have also been implemented to storm and combined sewers which drain the Edmonton urban area. These upgrades continue and have resulted in some improvements in river water quality (AECOM and Anderson 2011).

2.2 Planning Context

Land and water management of the North Saskatchewan River and its watershed are guided by Alberta's Land Use Framework and the Water For Life Strategy. The Land Use Framework (LUF) is an approach to manage cumulative effects to the Province's land and natural resources to achieve long-term economic, environmental and social goals (GOA 2013). The North Saskatchewan River watershed roughly corresponds to the North Saskatchewan Planning Region under this initiative (GOA 2013).

The North Saskatchewan Watershed Alliance (NSWA) is designated as the Watershed Planning and Advisory Council (WPAC) for the North Saskatchewan River watershed in Alberta under the Water for Life Strategy (GOA, 2003; GOA 2008). The NSWA has a mandate to prepare an Integrated Watershed Management Plan (IWMP). An IWMP was developed in 2012 and is designed to meet the three goals of the Water for Life strategy: safe, secure drinking water; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy and to integrate cumulative effects management in support of the goals for the Land Use Framework (LUF) (NSWA 2012).

Water-related goals of the latest NSWA watershed management plan (2012) include:

- Water quality in the North Saskatchewan River watershed is maintained or improved,
- In-stream flow needs of the NSR watershed are met, and
- Aquatic ecosystem health in the NSR watershed is maintained or improved.

The Industrial Heartland - Capital Region Water Management Framework (IH-CR WMF) complements the above IWMP but focuses on the cumulative effects management of current and future municipal and industrial impacts within the central reach of the NSR, Devon to Pakan (AENV 2007; AESRD 2012).

The vision of the IH-CR WMF is to be a "world-class integrated water management system within the North Saskatchewan River to sustainably support the environment, and social and economic development". The intent is to provide a framework to:

- improve the quality of the North Saskatchewan River in this reach and meet targets described by existing policy related to pollution prevention and water quality limits;
- manage water quantity to ensure that sufficient water remains in the river to maintain aquatic life and support current and proposed industrial development; and

- attain water quantity and quality targets.

Framework outcomes include 'maintain or improve the current water quality in the Devon to Pakan reach of the river' and 'minimize the loading discharges for return flows to the North Saskatchewan River' (AENV 2008; AESRD 2013).

3. Review of 2007-2012 Studies

A large number of studies were conducted on the NSR from 2007 to 2012 involving monitoring and assessment of water quality and biota, quantifying inputs to the river from tributaries and point sources, modeling contaminant transport, developing new tools and synthesizing existing information. These varied in time frame and spatial focus, depending on the specific objectives of the individual studies (Table 1, Figures 1 and 2). These studies also varied in their stages of reporting and analysis as of 2013, ranging from raw datasets and data with preliminary reporting to completed study reports and peer-reviewed publications. In this section, only completed final and draft study reports were reviewed and main conclusions summarized. The reviews of reports presenting sediment quality and non-fish biota were conducted in most detail, given that no other data on these indicators were available for the status assessment. Raw datasets and data that were the source of preliminary data reports are discussed further in the methodology section and the applicable appendices (Appendices C.1 – C.3).

Table 1. Temporal and Spatial Focus of Studies and Sampling Programs Conducted on the NSR (Updated from AECOM and Anderson 2011)

Reference	Time Frame		Spatial Focus						
	Years	Seasons, frequency	NSR	NSR LTRN	NSR IH-CR	NSR-City	Tributaries	CSO/ SO	Effluents
WATER QUALITY									
AESRD (LTRN)	2008-2012	All, monthly		X					
AESRD (Datasonde)	2007-2012	All, hourly		X	X				
AESRD (Diurnal)	2011-2012	Fall		X					
Clearwater 2010	2008	Winter, Summer, Fall	X	X	X	X	X		X
AESRD (Synoptic)	2012	Spring, Summer, Fall	X	X	X	X	X		X
Golder (2013 a,b,c)	2012	Wet and dry weather				X	X	X	X
SEDIMENT & NON-FISH BIOTA									
Clearwater & Kilgour 2010	2007-2008	Fall	X	X	X	X			
Stone and Collins 2012	2010-2011	Fall	X	X	X	X	X		

Golder 2011	2010	Fall	X						
FISH CONTAMINANTS									
AESRD	2011-2012	Summer, Fall	X						
MODELS & MIXING									
TetraTech 2012	1998-2009	All	X				X		
Pilechi et al. 2012	2011	Fall	X		X	X			
DATA ANALYSIS, SYNTHESIS AND TOOLS									
AECOM & Anderson 2011	2006-2009	All	X	X	X	X	X	X	X
Anderson (2012)	1987-2011	Ice-cover, open-water		X					
McDonald (2013)	2000-2011	Ice-cover, open-water		X					
Kessler (2010)	2000-2008	All							X

Notes: *NSR: Headwaters to provincial border*

NSR-LTRN: Only LTRN sites on river mainstem

NSR-IH-CR: River mainstem within the IH-CR reach

NSR-City: River mainstem within City of Edmonton (COE)

Tributaries: Tributaries flow to the NSR

CSO/SO: Combined Sewer Overflow/Sewer Overflows and Storm Outfalls that discharge directly to NSR

Effluents: treated municipal and industrial effluent that discharge directly to the NSR (note: Golder did not monitor ACRWWTP or industrial effluents)

Figure 1. Map of Water Quality Sampling Programs in the North Saskatchewan River 2008-2012

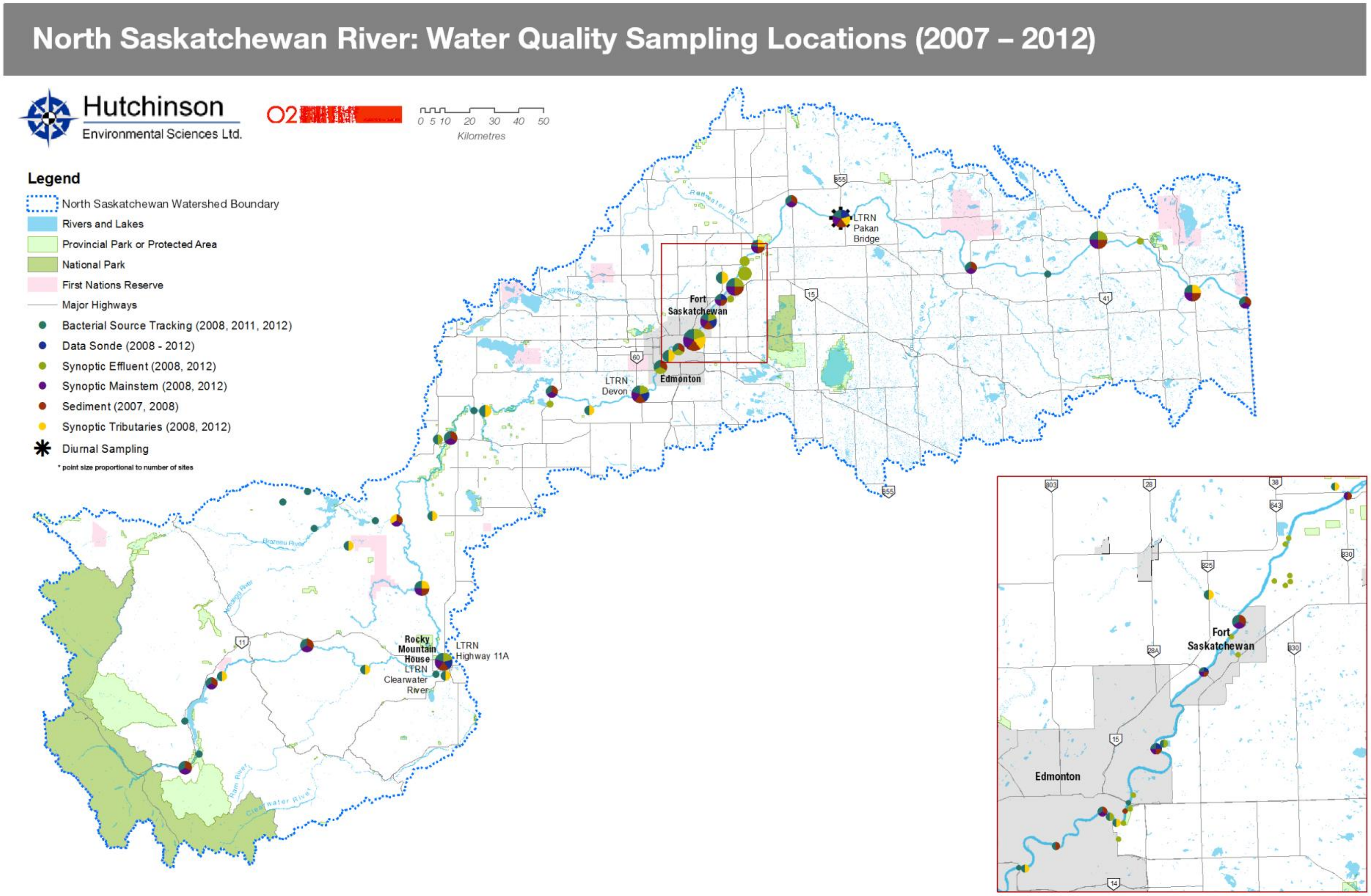
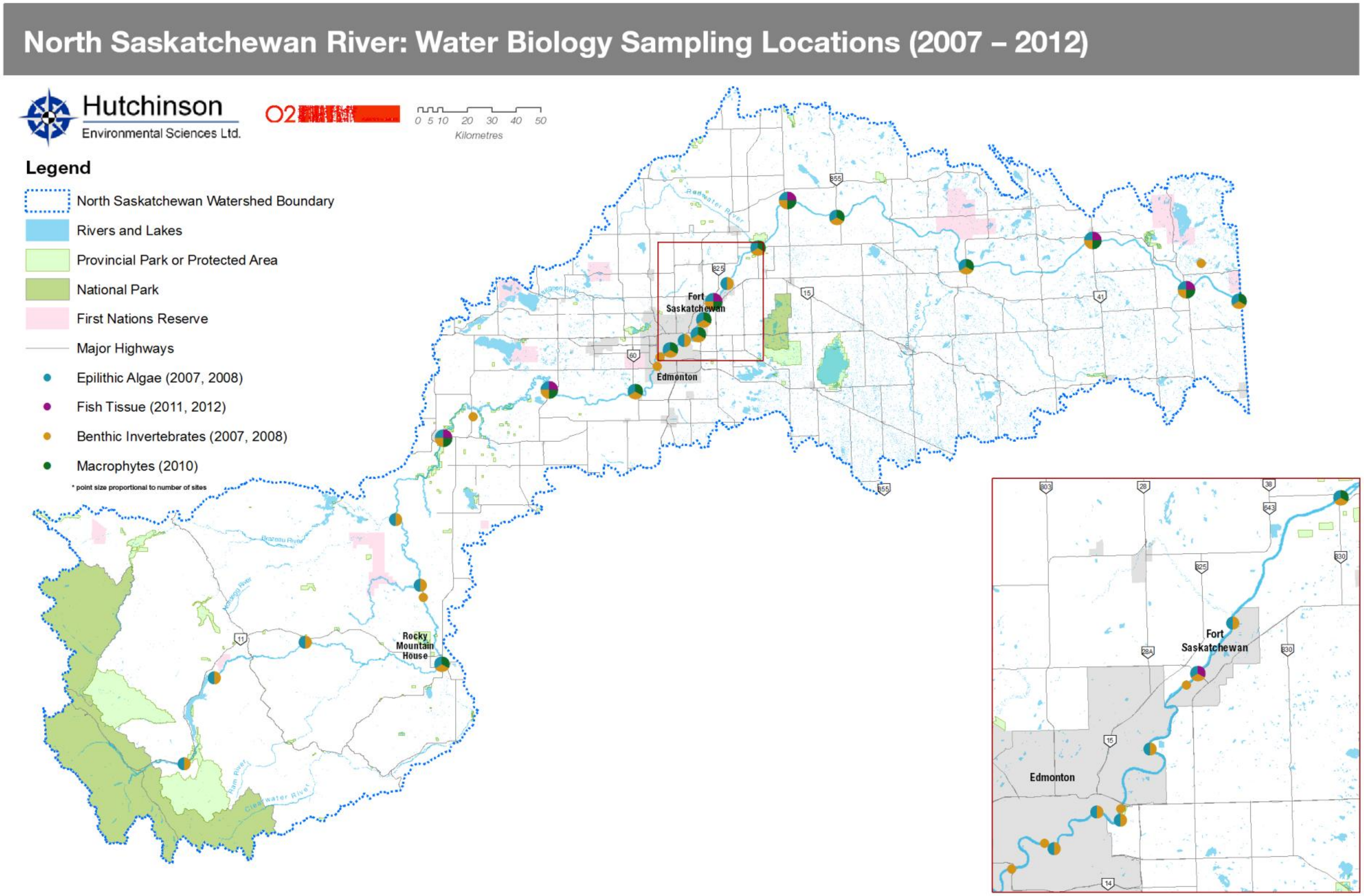


Figure 2. Map of Biological Sampling Programs in the North Saskatchewan River 2008-2012



3.1 Water Quality

The review of water quality studies in this section mostly introduces the purpose, scope, methodology and value of the programs. The data results of the programs as they pertain to status and trends in the NSR are presented and discussed in section 5, the status assessment, and in technical reports (Appendix C).

3.1.1 Long-Term River Network

AESRD maintains a long-term water quality monitoring network on the NSR. The Long-Term River Network (LTRN) consists of three sites on the NSR: at approximately 1 km upstream of the confluence with the Clearwater River, at Devon upstream of the City of Edmonton and at Pakan Bridge downstream of the City of Edmonton. These locations are illustrated in Figure 1. Data analyzed from these sites for this report ranged from 2007 through 2012 for Devon and Pakan and from 2009 through 2012 for the site upstream of the Clearwater River.

The number of samples and sample dates for each site are summarized in Table 7. One of the strengths of this dataset is that the field methods and analytical list have remained consistent over the years and that there is a continuous, long-term record of water quality, allowing for trend analysis. The distribution of sample events over the flow seasons is displayed in Figure 4. The monthly LTRN sampling is biased towards low-flow conditions, given that these occupy about three quarters of the year. Additional sampling focussed on the high flow season has been conducted in the years when synoptic surveys were conducted (2008, 2012), in order to allow better represent the high flow season in the water quality record. These flow weighted data also allow more precise loading calculations given that the NSR carries a large portion of annual substance loadings during the short high-flow period.

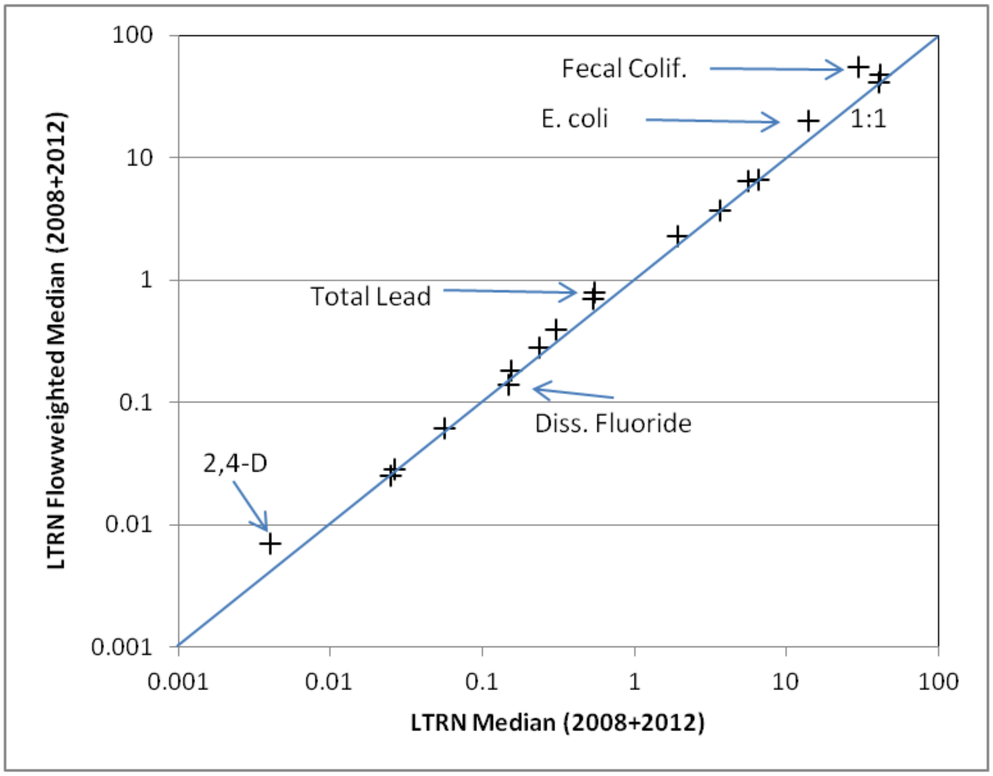
Table 2 Summary information for LTRN water quality monitoring sites from 2007-2012

Sampling Location	NSR 1 km Upstream of Clearwater River	Devon	Pakan
Total Number of Samples 2007-2012, Ice Cover (IC)	20	30	30
Sample Dates – 2007 IC		15-Jan-07, 12-Feb-07 05-Mar-07, 05-Nov-07 10-Dec-07	22-Jan-07, 20-Feb-07 08-Mar-07, 08-Nov-07 13-Dec-07,
Sample Dates – 2008 IC		07-Jan-08, 11-Feb-08 10-Mar-08, 12-Nov-08 16-Dec-08	10-Jan-08, 14-Feb-08 12-Mar-08, 13-Nov-08 18-Dec-08
Sample Dates – 2009 IC	08-Jan-09, 05-Feb-09 12-Mar-09, 05-Nov-09 03-Dec-09	12-Jan-09, 09-Feb-09 16-Mar-09, 09-Nov-09 07-Dec-09	14-Jan-09, 12-Feb-09 19-Mar-09, 12-Nov-09 10-Dec-09
Samples Dates – 2010 IC	07-Jan-10, 04-Feb-10 04-Mar-10, 03-Nov-10 02-Dec-10	11-Jan-10, 08-Feb-10 08-Mar-10, 03-Nov-10 06-Dec-10	14-Jan-10, 11-Feb-10 11-Mar-10, 08-Nov-10 08-Dec-10

Sampling Location	NSR 1 km Upstream of Clearwater River	Devon	Pakan
Sample Dates – 2011 IC	06-Jan-11, 02-Feb-11 03-Mar-11, 03-Nov-11 01-Dec-11	10-Jan-11, 10-Feb-11 07-Mar-11, 07-Nov-11 05-Dec-11	11-Jan-11, 10-Feb-11 10-Mar-11, 09-Nov-11 08-Dec-11
Sample Dates – 2012 IC	05-Jan-12, 01-Feb-12 01-Mar-12, 01-Nov-12 05-Dec-12,	09-Jan-12, 06-Feb-12 05-Mar-12, 05-Nov-12 10-Dec-12	12-Jan-12, 09-Feb-12 08-Mar-12, 14-Nov-12 13-Dec-12
Total Number of Samples 2009-2012, Open Water (OW)	28	43	44
Sample Dates – 2007 OW		10-Apr-07, 07-May-07 11-Jun-07, 09-Jul-07 07-Aug-07, 10-Sep-07 09-Oct-07	12-Apr-07, 10-May-07 14-Jun-07, 12-Jul-07 12-Jul-07, 12-Jul-07 09-Aug-07, 13-Sep-07 11-Oct-07
Sample Dates – 2008 OW		07-Apr-08, 05-May-08 09-Jun-08, 07-Jul-08 11-Aug-08, 08-Sep-08 06-Oct-08	10-Apr-08, 07-May-08 12-Jun-08, 09-Jul-08 14-Aug-08, 10-Sep-08 08-Oct-08
Sample Dates – 2009 OW	02-Apr-09, 07-May-09 04-Jun-09, 09-Jul-09 06-Aug-09, 03-Sep-09 01-Oct-09	06-Apr-09, 11-May-09 08-Jun-09, 13-Jul-09 10-Aug-09, 08-Sep-09 05-Oct-09	08-Apr-09, 13-May-09 11-Jun-09, 15-Jul-09 12-Aug-09, 10-Sep-09 07-Oct-09
Samples Dates – 2010 OW	08-Apr-10, 06-May-10 03-Jun-10, 06-Jul-10 05-Aug-10, 02-Sep-10 04-Oct-10	12-Apr-10, 10-May-10 07-Jun-10, 05-Jul-10 09-Aug-10, 07-Sep-10 04-Oct-10	15-Apr-10, 13-May-10 10-Jun-10, 08-Jul-10 12-Aug-10, 09-Sep-10 07-Oct-10
Sample Dates – 2011 OW	07-Apr-11, 05-May-11 02-Jun-11, 07-Jul-11 04-Aug-11, 31-Aug-11, 06-Oct-11	11-Apr-11, 09-May-11 06-Jun-11, 11-Jul-11 08-Aug-11, 06-Sep-11 11-Oct-11	13-Apr-11, 11-May-11 09-Jun-11, 14-Jul-11 11-Aug-11, 08-Sep-11 13-Oct-11
Sample Dates – 2012 OW	04-Apr-12, 03-May-12 07-Jun-12, 05-Jul-12 02-Aug-12, 06-Sep-12 03-Oct-12	10-Apr-12, 07-May-12 11-Jun-12, 08-Jul-12 08-Jul-12, 07-Aug-12 10-Sep-12, 09-Oct-12	12-Apr-12, 10-May-12 14-Jun-12, 10-Jul-12 09-Aug-12, 13-Sep-12 11-Oct-12

Median concentrations of variables of concern at the Pakan site (as identified by McDonald 2013, and including nitrate, nitrite and other dissolved variables) as derived from the flow-weighed sampling programs in 2008 and 2012 were either higher (most cases) or the same (TOC, NH_4, SO_4) as those from the regular LTRN program for the same years (Figure 3). The exception to this was dissolved fluoride, which was 7% lower in the flow-weighted dataset. The largest deviations were observed in bacteria indicators (*E. coli*: 43% difference, fecal coliforms: 83%), total suspended solids (TSS, 13%), total metals (As: 31%, Co: 29%, Pb: 46%) and 2,4-D (75%), reflective of high flow conditions with associated natural sediment transport and possibly urban and rural non-point sources during wet periods. These results demonstrate the significant effect of flow on water quality and show that the regular LTRN data are more representative of the lower values encountered for many variables under low flow due to its temporal bias to low flow seasons.

Figure 3. Median Water Quality Concentrations at Pakan from LTRN and Flow-weighted LTRN datasets



3.1.2 Synoptic Studies

Synoptic studies were conducted along the NSR in 2008 and 2012. Monitored sites were consistent among all surveys and included the mainstem (Figure 1), tributary mouths (Figure 1) and effluent discharges (Appendix J). The only exception to that was the site at Rocky Mountain House that was moved upstream of the Clearwater River for the 2012 survey, to align with the LTRN site move. In 2008, the sampled seasons included winter (March), summer (June) and fall (October), while in 2012, they included spring (May), summer (July) and fall (October). The fall sampling events were conducted under similar flow conditions and are therefore comparable. The summer sampling in June 2008 occurred during much higher flows (~600 m^3/s) than in July 2012 (~400 m^3/s, Figure 4), potentially affecting water quality patterns. Samples collected under ice in March 2008 represented a unique seasonal sampling event, as did the spring synoptic survey in May 2012. The list of analyzed variables was overall consistent among synoptic surveys, except that organic contaminant parameters were not analyzed in spring and summer of 2012. Most of the sites upstream of Edmonton were only sampled at one location in the river, while for most sites between Edmonton and Pakan, several samples along cross-sectional transects were collected (Table 3).

Table 3. Synoptic Mainstem Sample Locations 2008 and 2012

Station Name (NSR)	Distance Downstream (km)	Station Number	Latitude	Longitude	2008 Survey			2012 Survey		
					Location Across River			Location Across River		
					Mar	**Jun**	**Oct**	**May**	**Jul**	**Oct**
at Whirlpool Point	21	AB05DA0010	52.00167	116.4731	L	L	L	L	L	T
Below Bighorn Reservoir (Abraham Lake)	65	AB05DC0010	52.31861	116.3025	L	L	L	L	L	T
at Saunders Campground	120	AB05DC0025	52.45381	115.7595	L	L	L	L	L	T
1 km upstream of Clearwater River		**AB05DC0050**						**L**	**L**	**T**
u/s Rocky Mountain House / Highway 11A	**186**	**AB05DC0051**	**52.37656**	**114.9403**	**L**	**M**	**M**			
1 km above Baptiste River	228	AB05DC0060	52.66486	115.0691	L	L	R	M	M	T
1 km above Brazeau River	266	AB05DC0080	52.9075	115.2178	M	R	R	M	M	T
at Drayton Valley Bridge	320	AB05DE0020	53.20583	114.9297	M	R	L	M	M	T
at Genesee Bridge / Highway 70	407	AB05DE0095	53.38083	114.2778	M	T	T	T	T	T
at Devon Bridge	**449**	**AB05DF0155**	**53.37056**	**113.7514**	**R**	**M**	**M**	**T**	**T**	**T**
at 50th St. Bridge	499	AB05EB0215	53.56333	113.4192		T	T	T	T	T
0.5 km u/s Horsehills	516	AB05EB0495	53.62831	113.3225		T	T	M	M	T
at Fort Saskatchewan Highway 15 Bridge	528	AB05EB0595	53.70667	113.2347		T	T	T	T	T
1 km u/s Sturgeon River	539	AB05EB0671	53.75861	113.1703	T	T	T	M	M	T
at Vinca Bridge	555	AB05EB0835	53.88722	112.9728	T	T	T	T	T	T
at Waskatenau Bridge	583	AB05EC0095	54.05944	112.7794	T	T	T	M	M	T
at Pakan Bridge	**611**	**AB05EC0215**	**53.99111**	**112.4764**	**T**	**T**	**T**	**T**	**T**	**T**
at Duvernay Bridge	687	AB05ED0025	53.78944	111.6886	M	M	M	M	M	T
at Elkpoint	747	AB05ED0115	53.86139	110.8978	T	M	M	M	M	T
at Lea Park Bridge	799	AB05EF0075	53.66028	110.3373	M	M	M	M	M	T
at Lloydminster Ferry	830	AB05EF0115	53.60389	110.0106	M	M	M	M	M	T

Notes: L = Left bank; R = Right bank; M = Midstream; T = Transect; Bold Face Type = LTRN Sites.

The synoptic surveys provided a seasonal snapshot of water quality along the entire length of the NSR within Alberta and offered the unique opportunity to observe spatial patterns related to natural watershed changes as well as point-and non-point source inputs. Local impacts can be distinguished from watershed impacts on NSR water quality, and the sensitivity of the NSR to such impacts during different seasons and flow levels can be assessed. It is currently the only program that collects systematic information on tributary water quality across the watershed, which provides immense value for future watershed planning initiatives under the NSR Regional Plan. Additional value would be added if sites in tributary headwaters were also sampled so that comparison with samples taken near tributary confluences with the NSR would allow assessment of changes within each tributary.

3.1.3 Microbial Source Tracking

Microbial Source Tracking (MST) is a methodology used to identify sources of fecal pollution in water bodies. Certain U.S. states require MST for the development of total maximum daily loads (Malakoff, 2002). In 2008, 2011 and 2012, AESRD used polymerase chain reaction (PCR) MST methods to identify sources of fecal pollution in the NSR mainstem and tributaries (Clearwater 2010). In 2008, during the open water season, MST methods were used to link fecal coliforms and *E. coli* samples collected from 51 stations (i.e., LTRN sites, NSR tributary sites and WWTP effluent sources) to human, dog, generic mammalian, horse, bovine and pig sources. In 2011, the source tracking was conducted in the fall and was focussed on ruminant and human sources at 62 locations. Some general statements about the relative importance of human versus ruminant sources could be made, providing important information to distinguish human sanitary sewage sources from livestock sources (see section 5.2.5.4).

The objectives of this program have varied over the years. The program would provide more information if the sampling was conducted over a focused period of time to better link information on land-use activities (for example, cropland with manure spreading and cow-calf pasture) to runoff from spring melt or summer storms (see Cooke et al 2002). Alternatively, the program could focus on a smaller area of the NSR or specific NSR tributaries with high fecal coliform contamination and unknown sources. The cost of this monitoring, however, should be evaluated against the cost of targeted educational programs or financial incentive programs for best management practices in watersheds with known fecal contamination sources.

3.1.4 Datasondes

Datasondes provide continuous records of water chemistry. The resultant data describe daily fluctuations that aquatic life is exposed to and allows calculation of more reliable summary statistics for variables that vary on a daily basis. This is important in particular for variables that have consistent differences between day and night (e.g., oxygen in summer) and for which day-time sampling points used in conventional monitoring programs may not generate representative datasets.

From 2007 to 2012, datasonde data were collected from seven sites along the NSR mainstem, including the LTRN sites and two additional sites downstream of Edmonton, but with varying length of data record. Measurements of temperature, conductivity, pH, turbidity and dissolved oxygen were taken every 15 minutes. These datasets provided comprehensive data coverage for the monitored variables, showed spatial and seasonal differences in diurnal ranges of variables and provided insight into extreme events, such as low oxygen levels under ice. This monitoring program is therefore an important component of the AESRD surface water quality monitoring in the NSR.

Detailed results and interpretation of the datasonde monitoring program are presented in the datasonde technical report (Appendix C.1) and the main results were included in the status section of this synthesis report (Section 5).

3.1.5 Diurnal Sampling

Diurnal patterns in all water quality variables can potentially affect aquatic life and add great interpretive value to monitoring programs. Datasondes can only record a limited number of water quality variables, while the majority of variables need to be analyzed in a laboratory environment. The goals of the diurnal sampling program were to:

- determine the degree by which different variables vary over the course of a day and
- establish if routine daily collections of water quality are representative of water chemistry in the North Saskatchewan River.

Water samples were collected in 2-h intervals over two days in October of 2011 and 2012. The data were inspected for recurring diurnal trends within the 48-h periods and similar patterns within both years and groups of variables were identified by Principal Components Analysis (PCA). The results showed that the diurnal ranges of most variations were smaller than annual variations but on occasion, diurnal variations exceeded seasonal variation observed in LTRN data during the sampled low-flow period. Most diurnal patterns were not recurring and were therefore attributed to random factors and, overall, the results showed that there was no particular bias in LTRN data due to diurnal patterns in water chemistry other than those recorded by the datasondes (e.g., DO, pH).

Detailed results and interpretation of the diurnal monitoring program are presented in the diurnal technical report (Appendix C.2) and the main results were included in the status section of this synthesis report (Section 5).

3.1.6 Environmental Monitoring Program (EMP)

Reference: Golder Associates 2013c

Organization: City of Edmonton

The EMP was established in response to conditions of the Approval to operate storm water, combined sewer, and municipal wastewater treatment systems which was issued to the City of Edmonton by Alberta Environment (AENV, now Alberta Environment and Sustainable Resource Development, AESRD). The overall purpose of the EMP was to quantify the contaminant loading from approved facilities to the NSR on an annual basis. Point sources were monitored during periods of dry weather and rain-or snow melt-induced runoff. Golder Associates Ltd. has managed and implemented the EMP since 2006.

All of the components related to drainage performance (i.e., portions of the 2012 EMP that involved sampling from the SSOs [storm sewer outfalls], CSOs [combined sanitary and storm sewer overflows] and other associated features of the stormwater runoff system, including the collection of water and sediment samples from selected stormwater management [SWM] lakes and constructed wetlands) are described in the EMP report. The EMP report also includes a description of the quality of the effluents discharged from the Gold Bar and Capital Region WWTPs and the variable loading rates from these facilities to the NSR.

An additional WWTP, the Alberta Capital Region WWTP CRWWTP is not managed by the City of Edmonton, but by a consortium of surrounding communities, the Alberta Capital Region Wastewater Commission. Quantifying contaminant loadings from this facility is therefore not part of the EMP, neither are industrial point sources, hence any information on this monitoring excludes ACRWWTP and industrial discharges. The information for the ACRWWTP is included, however, in the “North Saskatchewan River 2012 Water Quality Sampling Program” (Golder 2013b).

3.1.7 Intensive River Intake Monitoring Program

Reference: Golder Associates 2013a

Organization: City of Edmonton

The long-term goal of this program is to measure the performance of the CSO improvements, Goldbar WWTP improvements and stormwater management improvements within the City in terms of their impact on the NSR. The approach taken is to derive and compare annual intake Water Quality Index (WQI) values and sub-index values over time. Water quality monitoring is conducted at select municipal, and industrial water intakes and data are used as surrogate for nearby river water quality in Edmontons Environmental Monitoring Program.

The intensive river intake sampling started in 2008 and was introduced to supplement the existing river intake sampling program that had started in 2005 as part of the EMP (section 3.1.6). Objectives of the intensive intake sampling program are to:

- quantify and evaluate how water quality changes as the river flows through Edmonton under wet and dry conditions,
- generate intake Water Quality Index (WQI) values for E.L. Smith and Dow chemical intakes (using the AESRD River Water Quality Index (RWQI) tool); and
- generate subindex values for each of the 4 water quality groups (ie. metals, nutrients, bacteria and pesticides).

3.1.8 North Saskatchewan River Water Quality Sampling Program

Reference: Golder Associates 2013b

Organization: City of Edmonton

The purpose of this study is to produce an annual documentation of effects of contaminant loading from approved facilities and urban tributaries on NSR water quality. Changes in river water quality are documented during periods of dry weather and during periods of runoff resulting from snowmelt or rain.

Objectives of this program are to:

- quantify and evaluate how water quality in the NSR has changed as it flows through Edmonton past Fort Saskatchewan under both wet and dry conditions, taking travel time into account,
- characterize water quality in tributaries at their entrance into City limits and at their confluence with the NSR,

- evaluate how spring runoff from urban areas within Edmonton influenced water quality in selected tributaries,
- monitor *E. coli* levels within and downstream of Edmonton during dry conditions when flows in the NSR are high, and
- monitor *E.coli* levels in the NSR during the Klondike Days Sourdough Raft Race July 15.

This program provides valuable information on local-scale water quality changes in the NSR as it flows through the City of Edmonton and on tributary water quality. It allows tracing the source of specific pollutants, such as pesticides, to specific tributary watersheds. The "coordinated wet sampling events" involve sample collection in tributaries and CSOs, SOs and the WWTP outfalls (EMP) at the same time, which allows a comparison of different In-City source loadings during storm events.

The limitation of the program is that it does not include dry weather sampling in the tributaries and that the number of wet event samples in tributaries per year (2) is low, limiting the thorough assessment of longitudinal patterns (Golder 2013b). The program could also be expanded to estimate annual or seasonal loads contributed by the tributaries and to allocate them to the upstream watershed versus the in-City watershed.

3.2 Sediments and Non-Fish Biota

3.2.1 An Assessment of Sediment Quality, Benthic Invertebrates and Epilithic Algae in the NSR

Reference: Clearwater & Kilgour (2010)

Organization: Alberta Environment

Alberta Environment (AENV) collected sediment, benthic invertebrate and epilithic algal samples from all synoptic survey sites on the NSR in the fall of 2007 and 2008 (Clearwater 2010). In 2007, seven sites on the mainstem of the NSR were sampled between Rocky Mountain House and Lea Park near the Alberta/Saskatchewan Border. In 2008, the number of sample sites was increased to 20 and again, focused on the mainstem of the river. An additional two sites were sampled for sediment quality only in 2008 and analyses limited to polycyclic aromatic hydrocarbons (PAH) at locations upstream and downstream of the Anthony Henday Bridge in Edmonton.

Four of these sampling sites are situated at long-term monitoring stations, specifically, the Rocky Mountain House, Devon and Pakan sites are part of AENV's Long Term River Network (LTRN) while the Lea Park site is maintained by Environment Canada (EC) and the Prairie Provinces Water Board (PPWB).

Sites from Devon to Pakan were sampled on both the left and right banks of the sampling location. Both the left and right banks were sampled in order to elucidate point source impacts and to demonstrate where incomplete mixing occurs along the NSR. Left and right bank sample data were analyzed separately.

Sediments, which were assumed to be from depositional areas, were analyzed for a wide range of contaminants, including nutrients, metals and trace organic contaminants (e.g., extractable priority pollutants, PAHs, PCBs, pesticides, pharmaceuticals, personal care products and flame retardants). In addition to the sediment and biological sampling, flow velocity, depth, and a visual assessment of substrate type were recorded at each sampling location (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010). The details regarding the sampling including sample dates and locations are provided in Table 4.

3.2.1.1 Benthic Invertebrates

Sampling was conducted for benthic organisms at the same time as sediment samples were collected as per Table 4, along the NSR and including left and right-bank sampling downstream of Edmonton. Benthic invertebrates were sampled from both erosional and depositional areas, using different sampling techniques, and sent for taxonomic analysis and enumeration. Common community indices were calculated and interpreted with regards to water and habitat quality. Multivariate analyses were carried out to describe community differences between sites and to assess what environmental variables best explained these differences.

An aquatic health index was calculated based on benthic invertebrate metrics and following the principle of reference conditions, which were represented by the benthic communities found upstream of Edmonton. This allowed classification into poor-marginal-fair-good-excellent aquatic health classes. This classification allowed comparison of aquatic health among river locations, banks and habitat types. It showed that aquatic health based on benthic invertebrates deteriorated between locations upstream and downstream of Edmonton, although there were some inconsistencies between results from two different habitats and sampling methods.

3.2.1.1 Epilithic Algae

Epilithic algal communities were sampled from erosional areas, on left and right banks upstream and downstream of Edmonton, and were analyzed for chlorophyll-*a*, its break-down product phaeophytin-a and algal community composition. Multivariate analysis of community composition data was conducted to describe differences between sites in terms of algal assemblages and to assess what environmental variables best explained these differences. Aquatic health ratings including the same classes as used for the benthic invertebrates were developed using trophic status classification for rivers based on benthic algal biomass (chl-*a*).

This study derived spatially detailed information on benthic primary producers and a thorough analysis on the influence of environmental factors, including water quality, on benthic algae communities.

Table 4. Summary of sediment sampling, benthic organism sampling and epilithic algae sampling in the North Saskatchewan River in 2007 and 2008 (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010)

Station Name	Distance Along River (km)	Station	Latitude	Longitude	Parameters and Years					
					Sediment		Epilithic		Benthic	
					2007	2008	2007	2008	2007	2008
NSR at Whirlpool Point	21	AB05DA0010	52 00 06	116 28 23		X		X		X
NSR Below Bighorn Reservoir (Abraham Lake)	65	AB05DC0010	52 19 07	116 18 09		X		X		X
NSR at Saunders Campground	120	AB05DC0025	52 27 13.7	115 45 34.1		X		X		X
NSR u/s Rocky Mountain House / Highway 11A (RB)	186	AB05DC0051	52 22 35.6	114 56 24.9	X	X	X	X [c]	X	X
NSR 1 km above Baptiste River	228	AB05DC0060	52 39 53.5	115 04 8.9		X		X		X
NSR 1 km above Brazeau River	266	AB05DC0080	52 54 27	115 13 04		X		X		X
NSR at Drayton Valley Bridge	320	AB05DE0020	53 12 21	114 55 47		X		X		X
NSR at Genesee Bridge / Highway 70	407	AB05DE0095	53 22 51	114 16 40		X		X		X
NSR at Devon Bridge (RB&LB)	449	AB05DF0155	53 22 14.02	113 45 05	X	X	X	X [c]	X	X
NSR 0.2 km u/s Anthony Henday Bridge (RB&LB)	470	AB05DF0180	53 27 26.4	113 37 01.8		X [b]				
NSR 0.2 km d/s Anthony Henday Bridge (RB&LB)	470.5	AB05DF0190	53 27 41.4	113 36 50.7		X [b]				
NSR at Walterdale (105 St.) Bridge (RB&LB)	490	AB05EB0075	53 31 43	113 30 08	X	X [b]	X		X	
NSR at 50 St. Bridge (u/s Goldbar) (RB&LB)	499	AB05EB0215	53 33 48	113 25 09		X		X		X
NSR at Rundle Bridge (RB&LB)	503	AB05EB0345	53 33 47	113 22 44	X		X		X	
NSR 0.5 km u/s Horsehills	516	AB05EB0495	53 37 41.9	113 19 21		X		X		X
NSR at Fort Saskatchewan Highway 15 Bridge (RB&LB)	528	AB05EB0595	53 42 13.5	113 14 12.6		X		X		X
NSR 1 km u/s Sturgeon River (RB&LB)[a]	539	AB05EB0671	53 45 31	113 10 13		X		X		X
NSR at Vinca Bridge (RB&LB)	550	AB05EB0835	53 53 14	112 58 22	X	X	X	X	X	X
NSR at Waskatenau Bridge (RB&LB)	583	AB05EC0095	54 03 34	112 46 46		X		X		X
NSR at Pakan Bridge(RB&LB)	611	AB05EC0215	53 59 28	112 28 35	X	X	X	X [c]	X	X
NSR at Duvernay Bridge	687	AB05ED0025	53 47 22	111 41 19		X		X		X
NSR at Elkpoint	747	AB05ED0115	53 51 41	110 53 52		X		X		X
NSR at Lea Park Bridge	799	AB05EF0075	53 39 37	110 20 14.4	X	X	X	X	X	X
NSR at Highway 17 Bridge	830	AB05EF0110	53 36 24.3	110 01 24.6		X		X		X

The solid sampling design and interpretation need to be maintained for future studies. The authors recommended that a larger amount of replicate samples per site may be necessary to better control for the large within-site variability in periphyton biomass and to allow for robust statistical analyses. Our review concluded that the algal community analysis may also benefit from a focus on diatom taxonomy and possibly, the application of diatom-based water quality indices, as this group represents the majority of epilithic biomass in the NSR and such methods have been successfully applied in other rivers in Canada (Lavoie et al. 2006, 2010) and internationally (e.g., Kelly and Whitton 1995, Potapova and Charles 2007, Stevenson et al. 2008).

Overall, the benthic study established an important link between water quality and aquatic ecosystem health in the NSR. Given that this study was conducted after major upgrades to WWTPs, this biological assessment can be used as a baseline to which compare future changes in NSR aquatic health. The development of site-specific objectives based on biota or, alternatively, ecological thresholds that can serve as trigger limits in water resource management, is recommended in order to include aquatic ecosystem health in the water management frameworks of the NSR. This would represent a more complete approach to river protection, which is currently based only on individual water quality performance measures, which may not sufficiently represent the cumulative effect that different pollutants can have on biota when acting together.

3.2.2 Assessment of Sediment Quality and Sources in the North Saskatchewan River and its Tributaries

Reference: Stone and Collins 2012

Organization: Alberta Environment and Water

Stone and Collins (2012) investigated the source, transport and fate of sediment-associated contaminants in the NSR to gain a better understanding of the possible management of anthropogenic impacts on water quality and related ecosystem services. The specific questions addressed by these authors were:

- What are the physical (grain size distribution), geochemical (mineralogy, major element composition) and contaminant (trace metals, PAH) characteristics of sediment in the North Saskatchewan River and its tributaries; and,
- What are the key spatial sources of sediment in the NSR?

Grab samples of fine grained river bed/bank sediment deposits were collected by an Alberta Environment and Water team at 20 monitoring sites along the NSR from Rocky Mountain House to Lloydminister in 2010 and 2011. An additional 10 samples (fine-grained river bed/bank sediment) were collected at the confluence of 10 tributaries with the NSR to evaluate the source apportionment of sediment from key spatial source units. A list of all sample locations and their distance downstream on the NSR is provided in Table 5.

Table 5. Sediment sampling locations on the NSR and its tributaries

Site	Type	Latitude	Longitude	Distance (km)
Cline River u/s of Abraham Lake	Tributary	521016	1162849	30
Siffleur River u/s confluence with NSR	Tributary	520306	1162335	46
Bighorn River u/s confluence with NSR	Tributary	522040	1161700	67
Ram River u/s confluence with NSR	Tributary	522205	1152430	142
NSR at Rocky Mtn House	Mainstem	522712	1145911	186
Clearwater River @ Rocky Mtn House	Tributary	522040	1145610	191
NSR 1 km above Bapiste River	Mainstem	533746	1150246	228
Baptiste River near the mouth	Tributary	523952	1150434	229
Brazeau River at Brazeau Dam	Tributary	530058	1154557	266
NSR at Drayton Valley	Mainstem	531233	1145611	320
NSR at Tomahawk	Mainstem	531911	1144434	346
NSR at Genesee Bridge	Mainstem	532240	1141642	407
NSR at Genesee Bridge	Mainstem	532238	1141651	407
NSR at Devon	Mainstem	532221	1134422	449
NSR at Devon	Mainstem	532215	1134422	449
NSR at Anthony Henday	Mainstem	532743	1133649	471
NSR u/s of Quesnell Br	Mainstem	533020	1133402	482
NSR at Walterdale Br.	Mainstem	533154	1133044	491
NSR at Beverly Bridge	Mainstem	533404	1132242	505
NSR at Beverly Bridge	Mainstem	533403	1132230	505
NSR 0.5 km u/s Horsehills Ck	Mainstem	533741	1131915	516
NSR u/s Fort Sask at Hwy 15 Br	Mainstem	534143	1131515	528
Sturgeon River at Hwy 825	Tributary	534714	1131324	539
NSR at Vinca Bridge	Mainstem	535243	1130002	555
NSR at Vinca Bridge	Mainstem	535209	1130228	555
NSR at Waskatenau Br.	Mainstem	540331	1124631	583
NSR at Pakan	Mainstem	535933	1122705	611
NSR at Pakan	Mainstem	535927	1122711	611
NSR at Duvernay	Mainstem	534723	1114204	687
NSR at Myrnam	Mainstem	534514	1111360	722
NSR at Elk Point	Mainstem	535136	1105319	747
Vermilion River confluence with NSR	Tributary	533920	1102020	799
NSR at Lea Park	Mainstem	533934	1102014	799
NSR at Lloydminister Ferry LB & RB	Mainstem	533603	1095948	830

Previous sediment sampling (2007 and 2008) showed that sediment grain size and composition were key variables which had a direct influence on the interpretation of environmental contaminant information. Sediment that was transient and dominated by silt and sand size particles with low concentrations of organic matter, made source tracking of sediment-adsorbed contaminants from anthropogenic sources difficult and potentially misleading. The high seasonal flows in the NSR meant that transient sediments represented deposition zones at the end of the freshet and consequently did not characterize the true contaminant chemistry of the NSR during the low flow open water and ice cover periods. For example, the duration of exposure of samples collected Sep. 8-18, 2010 and Sep. 20 – Oct. 25, 2011, is limited to approximately 1 to 2 months after the high flow season which generally extends from June to July.

The percentage of clay and silt in each sample was highly variable and several samples consisted mainly of sand fractions, despite the fact the sampling was directed at cohesive sediment deposits (bed and bank). For example, tributary sediments all consisted of > 75% sand and samples from the Duvernay Bridge and Anthony Henday Bridge were comprised of > 85% sand.

Recognizing the limitations of the samples, this study provided information on contaminant levels and relative source proportions.

- Overall, relative spatial sediment source contributions by tributary were estimated to be 11% (Vermilion River), 19% (Sturgeon River), 6% (Brazeau River), 12% (Baptiste River), 11% (Nordegg River), 14% (Clearwater River), 15% (Ram River), 4% (Bighorn River), 4% (Cline River) and 4% (Siffleur River). These contributions were expressed as frequency-weighted average median values derived from a complex statistical simulation procedure using a mixing model and the observed NSR and tributary sediment fingerprints[1].

Results on contaminant levels and spatial patterns are presented in the synthesis section on sediments (5.3).

Stone and Collins (2012) proposed alternative approaches to using sediment to monitor anthropogenic contaminant concentrations and potential source signatures in the future. Given that the bed sediments are generally coarse grained and likely transient, an emphasis should be placed on sampling fine grained suspended sediments in the water column synoptically and across a range of flow events. Continuous flow centrifuge samplers or less expensive time-integrating samplers (Phillips et al. 2000) could be deployed in a longitudinal gradient along the river to passively collect composite samples of suspended solids. Further consideration of an alternate approach to sediment sampling is recommended.

[1] *Frequency-weighted average median values were derived from a statistical simulation process (Monte-Carlo), where a mixing model was applied to the sediment composition fingerprints of the NSR bed to estimate relative contributions of sources (tributaries), resulting in a large amount of different possibilities. From these individual results, a weighted average (weighted by frequency) of median tributary contributions was calculated to obtain the most likely source distribution.*

3.2.3 Literature Review of Aquatic Macrophytes and the NSR

Reference: Golder Associates 2011a

Organization: Alberta Environment

The purpose of this report was to present a review of primary producers in the NSR and in large rivers similar to NSR and address factors that influence their relative importance, growth and distribution, with a focus on macrophytes. The report provided recommendations on how the available information could be applied to the NSR to determine anticipated responses to further nutrient load reduction from point sources. In addition, experimental approaches to investigate responses of algae and macrophytes to further nutrient limitations and alterations of N/P ratios were reviewed.

The only literature source found that was specific to the NSR was a study of macrophyte distribution between Edmonton and the Saskatchewan border as well as a periphyton and phytoplankton study presented by Shaw (1994). The small amount of information on macrophytes in the NSR is likely the result of low macrophyte abundance and cover in the NSR in general. Shaw (1994) found a sharp increase in periphyton and phytoplankton biomass in areas downstream of the City of Edmonton, interpreted as a result of nutrient loading from municipal point source discharges. The qualitative assessment of macrophytes showed moderate abundances downstream of the City and low abundances near the Alberta/Saskatchewan border.

The macrophyte conceptual model that was part of the Bow River water quality model developed for the City of Calgary (Golder 2004) was presented, and a modified version for the NSR discussed (Golder 2005). Factors influencing macrophytes include light, nutrients, and flow. It was hypothesized that light played a larger role for NSR macrophytes than in other rivers, due to elevated turbidity levels in the river. Given the dominance of light control on macrophytes in the NSR, the report predicted no reduction in macrophyte biomass in response to decreased nutrient loadings from point sources. On the other hand, results from Shaw (1994) were cited that did indicate a nutrient influence and therefore a potential to revert. Between the Shaw (1994) study (field work in 1988) and the Golder assessment in 2011 major upgrades to Edmonton wastewater treatment plants had been completed (1995-2001). With decreased nutrient levels in the NSR downstream of Edmonton, the importance of nutrients in controlling macrophyte growth in the NSR may have decreased and may have been replaced by turbidity. This hypothesis was confirmed by the macrophyte monitoring study reviewed below (Golder 2011b).

3.2.4 Evaluation of Aquatic Plants and Controlling Factors in the NSR

Reference: Golder Associates 2011a

Organization: Alberta Environment

The purpose of this work was to establish baseline data for macrophyte communities in the NSR, along with information on key variables known to influence macrophyte growth and distribution. The intent was to use that information in water quality modelling to help enhance the understanding of the nutrient-plant relationships.

The study included:

- a visual survey of macrophyte density between Devon and Pakan;
- a sampling program in 2010 which assessed spatial differences in macrophytes and other biotic and abiotic variables between Rocky Mountain House and the Alberta/Saskatchewan border, including
  - water quality,
  - sediment quality,
  - macrophyte biomass, community compositions and tissue nutrient concentrations,
  - epilithic and phytoplankton chlorophyll *a*; and
- a seasonal sampling program that assessed the temporal variability of macrophytes and other biotic and abiotic variables, but only included sites between Fort Saskatchewan and Pakan.

The main results of this study are presented in the status section (5.4.3). This study provided an update to a much older macrophyte survey conducted in the 1980s (Shaw 1994) and established a baseline understanding of macrophyte occurrence, biomass and relation to environmental factors for current conditions in the NSR, after completion of major WWTP upgrades and following significant population growth in the IH-CR. Given the main result that turbidity appears to control macrophyte growth more than nutrient availability, macrophytes may not be a suitable biological indicator for nutrient enrichment in the river, but may show localized effects of stormwater discharges on aquatic plants within the City of Edmonton. Understanding the role of macrophytes in the NSR ecosystem and their spatial and temporal variability is also beneficial for river water quality models. The authors of the study recommended considering aerial surveys to better understand spatial coverage of macrophytes along the entire river stretch, which could be possible through air photo and/or satellite imagery interpretation during periods of clear water flow.

3.3 Modeling and Mixing

3.3.1 North Saskatchewan Integrated Water Quality Model Enhancement for Scenarios Analysis

Reference: TetraTech 2012

Organization: Alberta Environment

This report presented a fully functional watershed model for the North Saskatchewan watershed in Alberta, with a number of improvements over previous versions of watershed models and the first integrated water quality model developed by TetraTech (2011). These watershed modeling efforts focussed on the representation of watershed-derived sources, mainly non-point sources of sediment, nutrients, bacteria and metals, and complemented a suite of previous models that were developed for the IH-CR and intended for evaluating point source management scenarios, including an in-stream EFDC[2] water quality model, CORMIX mixing zone models and a wastewater mass balance model, (AECOM and

[2] *Environmental Fluid Dynamics Code*

Anderson 2011). The additional modeling presented by TetraTech (2011, 2012) mainly focused on improving the instream-sediment transport modules as well as a better representation of specific hydrological processes in the watershed, such as snow and non-contributing areas.

The ultimate goal of this modeling report was to deliver a fully functional watershed model that was ready for performing scenario analyses. Specific objectives to attain that goal were:

- Development of an approach for representing the unique hydrology associated with non-contributing areas (NCAs) in the watershed model,
- Extension of the hydrology calibration to include subwatersheds with NCAs in the prairie region,
- Configuring the model for sediment loading and transport to represent suspended solids, and
- Extension of the water quality calibration to the prairie regions and revising the previous calibrations as necessary to consider sediment-associated influences.

The outcome of this modeling exercise was a fully functional watershed model that can model temperature, sediment, nutrients, metals and bacteria and is capable of simulating land use management scenarios. In addition, a deeper understanding of hydrological processes in the watershed and their influence on water quality was gained throughout the model calibration and the associated data analyses, as summarized below.

For non-contributing areas (NCAs):

- Non-contributing areas are likely important deep-aquifer recharge areas during summer, and
- During spring, snow melt from NCAs is transported to rivers and creeks, as the frozen ground effectively functions as an impervious area.

In terms of hydrology, two main phenomena were important for calibrating the water quality model:

- The 1:2-year flood events were driven mostly by snowmelt events that occur in March through May in the eastern Prairie region of the watershed, and
- The May through July peak flows that occur in the Rocky Mountain regions are caused by the compounded effect of a later snowmelt and the highest annual precipitation levels.

Systematic water quality patterns that were closely related to flow patterns were identified and included in model calibration as follows:

- In the prairie watersheds, pollutant loads for nitrogen and phosphorus were highest during March, April, and May and were also correlated with the highest flows.
- For dissolved nitrogen species, instream concentrations were shown to generally decrease whenever runoff occurred, suggesting that surface flow has a diluting effect on the relatively higher dissolved nitrogen concentrations, which would have to be associated with baseflow or point source discharges for this behaviour to occur.

- Bacteria concentrations were shown to be highest during the periods of warmer weather and higher rainfall-driven runoff. Snowmelt-driven runoff generally had lower bacteria levels because those organisms are not as viable during colder weather.

Sediment source loadings depending on land use type and in-stream sediment transport were calibrated for selected subwatersheds and validated using 2008 synoptic data. The model was shown to replicate expected system-wide trends in sediment loading and transport.

Future work for model improvement recommended by TetraTech (2012) included increasing the spatial coverage of meteorological data, representing summer irrigation activity in the model, enhancing the frozen ground representation in the watershed model, improving point source representation, and extending the watershed model calibration effort to the mainstem NSR. Another suggested step was to dynamically link the watershed and mainstem NSR river models together to create a platform for evaluating cumulative mainstem impacts.

3.3.2 Physical Mixing Patterns of Water and Contaminants in the NSR

Reference: Pilechi et al. 2012

Organization: Alberta Environment

The objectives of this study were to:

- Describe plume mixing patterns of three major effluents (Goldbar WWTP, Captial Region WWTP and Agrium Redwater Fertilizer plant),
- Determine the downstream distance required to achieve full mixing, and
- Measure spatially distributed tracer concentration and water velocity in the mixing zone, such that dispersion patterns could be determined.

One tracer study was conducted for each effluent, for the duration of 3 days for the WWTPs and 1 day for the Agrium plant. Rhodamine WT dye was injected into the effluents and concentrations of the dye were tracked using a boat-mounted fluorometer and verified by water samples submitted to the laboratory for analysis of rhodamine. In addition, an Acoustic Doppler-Coupled Profiler (ADCP) was mounted to the survey vessel to track water depths and velocities.

The plume was observed to disperse to the opposite bank by 6.3 km (Capital Region WWTP), 11.6 km (Goldbar WWTP), and 12 km (Agrium) downstream from the outfalls. The results showed that despite the massive survey effort over many (92) river kilometers, full mixing to the point of uniform concentration across the section was not observed. It was estimated that it would take approximately 123 km to achieve full mixing of the Goldbar effluent within the river water.

Dilution rates were not discussed in the report, but the presented data indicate that at 92 km downstream, the Goldbar effluent was diluted approximately 60 times (from 13.7 to 0.23 ppb of dye), that at 83 km downstream the Capital Region WWTP was diluted 133 times (from 100 to 0.75 ppb) and that the Agrium effluent was diluted 400 times (from 279 to 0.7 ppb) at 11.5 km from the outfall. As expected, the river had the lowest dilution capacity for the largest effluent volumes (3.2 m^3/s) from the Goldbar plant and the highest dilution capacity for the smallest effluent volumes (0.07 m^3/s) from the Agrium plant. Under such high dilution rates, cross-sectional differences for some water quality variables of concern may not be detectable by standard laboratory methods and therefore not relevant for water quality assessments. For the flow conditions encountered this can be easily verified by applying the calculated dilution rates to measured effluent and river concentration data.

The ecological significance of lateral water quality differences downstream of the City of Edmonton due to incomplete mixing of point source discharges has been well documented. Periphyton biomass was elevated at the right bank, where the plume is more concentrated, for about 80 km downstream of the Goldbar WWTP (Clearwater & Kilgour 2010, see section 5.4.2). Benthic invertebrates showed inconsistent lateral differences between sites, years and sampling techniques (Clearwater & Kilgour 2010, see section 5.4.4).

The LTRN site at Pakan is located ca. 110 km downstream of the Goldbar plant, where there may still be small differences in water chemistry under low flow conditions, although no differences in biological response were detected. This site therefore still represents a suitable location to assess effects from the IH-CR Reach without major interpretation issues if samples are collected from one or the other bank.

The results and interpretation of the mixing study were based on individual plume tracer studies and did not take into account the cumulative effect of overlapping plumes. Given that both the Goldbar and CR WWTP outfall are located at the right bank of the river within 18 km distance, the CR WWTP effluent is mixed with the Goldbar plume, increasing wastewater substances beyond what would be expected in a single plume. The cumulative effect of these discharges will therefore likely result in spatial differences in wastewater variables across the river that are larger than the predictions of the plume study.

The main implication of this study for the assessment of NSR water quality and aquatic biota remains that water close to the right (or south) bank of NSR has higher WWTP-related pollutant concentrations than water close to the left (or north) bank for a very long distance downstream of Edmonton, at least during the low flow season when the study was conducted. Samples taken at any one location across the river may not be representative of the entire river width. As mixing studies have not been undertaken during high flow conditions or under ice, it is impossible to predict what occurs under these conditions. A dye tracer study under high flow, and under ice if at all feasible, would be required to assess this further.

3.4 Data Analysis, Synthesis and Tools

3.4.1 NSR Industrial Heartland Substance Loading Calculation 2000-2008

Reference: Kessler 2010 (unreleased)

Organization: Alberta Environment

The purpose of this study was to:

- compare different loading calculation tools and select the best and most appropriate for estimating in-stream loads and point-source loadings - annually and seasonally;

- use the selected tool to determine in-stream North Saskatchewan River loads and contributing point source loads;
- provide the information necessary for load inventories and management; and,
- provide additional constraints for simulation model calibration.

This report provided information on all known loading sources, including TSS, selected nutrients, metals, and bacteria. The error range for load estimates was variable and sometimes large, and depicted uncertainty in capturing temporal variability. The results also highlighted the overwhelming influence of flows on loads.

The authors prepared an ACCESS database (= “LOADS TOOL”) to complete loading calculations, using in-stream data, licensed discharger data and City of Edmonton outfall data. This tool should be useful for evaluating the relative importance of different discharges in impacting the NSR and therefore support the management of cumulative effects from multiple dischargers for the variables of concern.

3.4.2 Synthesis of recent knowledge on water quality, sediment quality, and non-fish biota in the North Saskatchewan River, with emphasis on the IH-CR WMF Reach

Reference: AECOM and A-M. Anderson 2011

Organization: Alberta Environment

The objective of this report was to provide a succinct overview of recent technical studies (2006-2009) conducted in the NSR, with a focus on the IH-CR. The synthesis included the process of data and information acquisition, the resulting knowledge gain, how the studies fit together and supported the Water Management Framework, and the outstanding needs with respect to research, development or refinement of management tools, and monitoring. This synthesis report provided a valuable basis upon which the current report is built. The report was focused more on the IH-CR Reach and provided detailed reviews of effluent loading, while the focus in this report is the entirety of the NSR, with a focus on most recent collected water quality data.

3.4.3 Investigations of Trends in Select Water Quality Variables at Long-Term Monitoring Sites on the North Saskatchewan River

Reference: A.-M. Anderson 2012

Organization: Alberta Environment

This report updates the analysis of trends for select variables of concern with recent data (1987 to 2011) for the four long-term monitoring sites. In addition to examining trends in the entire data set, trends for the ice-cover and open water periods were assessed separately. Percentiles, which can serve as a foundation to derive site-specific objectives, were provided for each site. Although the resulting databases reflected natural changes over time, they also reflected the influence of man's activities in the drainage basin. Trends in water quality variables can be indicative of the effectiveness of watershed management. Hence long-term data sets can be particularly valuable in guiding watershed management efforts. Trend analysis on regular, multi-year intervals is useful to track ongoing changes in NSR water quality.

The results of trend assessment in the NSR were incorporated into the synthesis of the State of the North Saskatchewan River in section 5.2.

3.4.4 Pilot Water Quality Objectives and Allowable Contaminant Loads for the North Saskatchewan River

Reference: McDonald, D. 2013

Organization: Alberta Environment and Sustainable Resource Development

Understanding factors that influence water quality over time is important when developing meaningful Water Quality Objectives (WQO's). Trend analysis and the use of percentiles that capture the long-term variability in water quality variables are recommended tools in the development of WQO's (AEW, 2012). In this report, WQOs for a selected number of variables of concern were developed for Devon and Pakan, for open water (Apr-Oct) and ice-covered (Nov-Mar) seasons. Water quality objectives were based on 50^{th} and 90^{th} percentiles of LTRN data collected from 2000-2008 for most datasets, except for bacteria, nutrients at Pakan, where the period of 2006-2008 was used to focus on the period following significant major wastewater treatment plant upgrades in the Capital Region. Where ambient concentrations exceeded federal/provincial surface water quality guidelines (SWQG), the default WQO was the SWQG.

The selection of the variables of concern (VoC) was based on the following considerations:

- instream or effluent exceedence of Federal-Provincial Guidelines (AENV, 1999; CCME, 2012);
- instream exceedence of NSWA Draft Water Quality Objectives (NSWA, 2010);
- identification as VoC in previous scenario modelling, based on mixing zone analysis (AENV, 2010);
- substantial increase in water quality pollutant values at Pakan, relative to Devon (e.g., > 20% in median and/or 90^{th} percentile);
- increased detection of trace contaminants downstream relative to upstream; and,
- elevated overall point-source loads relative to overall tributary loads (ratio of effluent to tributary load increased substantially at low flows; e.g., > 1.5 times).

Selection, as per the individual criteria above, resulted in a large number of variables (> 100) identified as VoCs. This included, for example, nutrients, physical variables, metals, organic compounds, and "emerging" contaminants such as pharmaceuticals and perfluorinated compounds. To enable the practical development of objectives for a pilot suite of variables, the VoC list was refined based on combining criteria above, and on professional judgement. This refined list used by AESRD (2013) and in this report includes those that were predicted to be altered, or which were already elevated in the environment (Table 6). Their derivation builds on the approach that was used by the North Saskatchewan Watershed Alliance (NSWA) and works towards the same goal to ensure non-degradation from current conditions (NSWA, 2010).

Table 6. Water quality variables of concern for which Pilot Water Quality Objectives were set by AESRD (McDonald 2013)

Metals (µg/L)	Nutrients and Total Suspended Solids (TSS)	Ions	Trace Organics and Bacteria
Arsenic – Total Recoverable (As)	Ammonia – Dissolved (NH_4 + NH_3)	Chloride – Dissolved (Cl)	Dichlorophenoxyacetic Acid (2,4-D)
Cadmium – Total Recoverable (Cd)	Carbon – Total Organic (TOC)	Sodium – Dissolved/Filtered (Na)	Escherichia Coli (E. coli.)
Cobalt Total Recoverable (Co)	Nitrate + Nitrite – Nitrogen Dissolved (NO_3 + NO_2)	Sulphate – Dissolved/Filtered (SO_4)	Fecal coliform (Fecal-coli)
Copper – Total Recoverable (Cu)	Phosphorus – Total Dissolved (TDP)	Fluoride – Dissolved (F)	
Mercury – Total* (Hg)	Phosphorus – Total (TP)		
Lead – Total Recoverable (Pb)	Total Suspended Solids (also referred to as Residue – Non-filterable (TSS)		
Selenium – Total Recoverable (Se)			
Zinc – Total Recoverable (Zn)			

Note: Hg was reported in ng/L and this was changed to µg/L to correspond to the other metals

Maximum allowable daily loads (MAL) for the range of observed daily flows were estimated using load duration curves (LDCs). An underlying premise of the LDC approach is the correlation of water quality impairments to flow conditions, which is of high importance for the NSR where flows fluctuate by orders of magnitude throughout the year. The higher the flow, the larger the assimilative capacity of the river. The loadings can be higher during high river flows than during low river flows in order to maintain water quality in the river below the WQO for that substance, assuming that upstream concentrations of that substance are similar. The observed flow range was subdivided into five hydrological categories with similar flows (low, dry, mid, moist, high flow) to provide required load reduction numbers for a manageable number of flows.

Maximum allowable loads can be a powerful tool in a water management framework, as demonstrated by the TMDL system used in the U.S.A. They provide the opportunity to manage cumulative effects of multiple dischargers, as they provide flexibility to allocate loads among sources. In addition, seasonally varying MALs, as proposed by McDonald (2013), allow for the adaptation of point discharge strategies to seasonal sensitivities of the receiving aquatic ecosystem. This adds another level of flexibility in terms of point discharge management whilst protecting the river when it is most vulnerable to human impacts.

More consideration may need to be given to the definition of flow seasons in the development and application of MALs. If seasonal MALs are to be considered in point source load management, the WQOs which these are based on have to fully represent the season for which a seasonal MAL is developed. The current subdivision of WQOs into open-water and ice-covered seasons does not take into account the large differences in river water quality between the open water high and low flow seasons, as recognized by the five flow classes proposed for the MALs. For example, if the TP open-water objective is based on data from April through October and the MAL is calculated for low flows, that WQO may not be protective enough for the low flow conditions. The relationships between WQOs, MALs, and flow seasons and averaging periods for performance monitoring need to be carefully considered to warrant a successful implementation of MALs within a water management framework.

3.4.5 Seasonal Water Quality Index Calculator

Reference: Alberta Environment and Sustainable Resource Development, unreleased

The ESRD Water Quality Index Tool (WQI) provides consistent procedures for reporting complex watter quality information in a simple format. The computational methods are based on a set of pre-defined equations and methods that compare analytical results with WQ standards and guidelines. The WQI is an enhanced version of the Canadian Council of Ministers of the Environment (CCME 2001) WQI tool, and is presently undergoing significant upgrades to enable greater user interactions, flexibility in calculation (e.g., to address seasonality), selection of variables, data manipulation, and results visualization.

4. Methodology for Status Assessment

4.1 New Data

A number of new datasets collected by AESRD were available for the synthesis of NSR status. These were either not previously analyzed, or they were analyzed, but reporting had not been completed. Detailed descriptions of some of these datasets (Diurnal, Datasonde and Fish Tissue) and results of data analysis were produced in the form of individual technical reports, which are provided in Appendices C1-3. Datasonde, synoptic and LTRN data were compiled into databases specific to this project, as discussed in Section 4.2.

Table 7. Summary of Datasets Analyzed for State of NSR Synthesis

Study	Sites	Indicators	Period of Record	Frequency	Data (D) or Report (R)
Synoptic Survey 2008	NSR Mainstem, Tributaries, Effluents	WQ, Bacterial source tracking	2008	March, July, October	D+R
Synoptic Survey 2012	NSR Mainstem, Tributaries, Effluents	WQ, Bacterial source tracking	2012	May, July, October	D
LTRN	Upstream of Clearwater River, Rocky Mtn. House, Devon, Pakan	WQ	2008-2012	Monthly	D
Datasonde	LTRN sites plus 2 sites in Industrial Heartland	pH, DO, temp, conductivity, turbidity	2008-2012	15 min	D
Diurnal	Pakan	WQ	Oct. 2011, 2012	2 h	D+R
Fish Tissue	NSR Mainstem	Metals and Organics	2011, 2012		D

4.2 Database Overview

The database contains environmental data collected for the North Saskatchewan River in Alberta, from Alberta Environment, EPCOR and the City of Edmonton. The database manages data from several projects, including: diurnal, effluent, LTRN, sediment, synoptic, and tributary surveys. Due to the large amount of data from Datasondes, this information is stored in a separate database. The database allows for easy calculation of station-based summary statistics, which can be further segregated based on season. Data can also be compared to guidelines, including Environmental Quality Guidelines for Alberta Surface Waters Protection of Aquatic Life (PAL), Irrigation (PAL-IR) and Livestock and Water (PAL-IW), as well as site-specific water quality objectives for Pakan. The database allows for easy retrieval and analysis of large amounts of data.

4.3 Variable and Data Combining Rules

The initial review of the dataset provided by AESRD for this project showed that there are a large number of replicate variable names within the dataset that must be reconciled in order to proceed with populating the project database. These replicates were replete with differences in units, detection limits and other factors which questioned how best to work with these data. Simply accepting all data that had a similar variable name and consolidating it within the database was not acceptable as the methods may be different and the results not comparable, detection limits may be different or the data not comparable for other reasons. Alternatively, leaving all variables as standalone entities creates difficulties in interpreting the data and preparing temporal plots or summary statistics. For example, it would not be appropriate to produce four sets of summary statistics for Dissolved Aluminum analysed by four different methods with sample sizes of 31, 6, 261 and 520. The data had to be reviewed to develop a rational approach to the creation of data rules for the database in order for us to proceed.

A review of other reports for guidance generally found these reports silent on this issue or at least lacked the specifics that could be used as a guide for proceeding. Advice was also requested from AESRD and guidance was provided for a limited set of water quality variables in the form of variable acceptance rules (dated October, 2010). These included the following variables:

- Secchi disk transparency
- chlorophyll *a*
- temperature water
- oxygen dissolved (field meter)
- oxygen dissolved (winkler)
- specific conductance (field)
- specific conductance (lab)
- pH (field)
- pH (lab)
- turbidity
- colour true
- phosphorus total (p)
- phosphorus total dissolved
- ammonia dissolved
- ammonia total
- nitrogen NO_3 & NO_2
- nitrogen dissolved NO_3 & NO_2
- bacteria variables

These rules were informative but incomplete and consequently the task of developing data combining, integration and acceptance/exclusion guides commenced with a detailed and comprehensive evaluation of all of the water data received. As part of this exercise, each water quality variable and its method detection limit, reported units, frequency and time period of use as well as the general description of the field and/or analytical method used in the analysis (data method dictionary) as provided by AESRD was considered. The guiding principle in the decision to combine variables was that they should be combined unless there was a clear justification for not doing so. Thus if information was lacking, the default was to combine.

The guides that were created for moving data into the database are detailed in Appendix A and the full description of variable combining rules is provided in Appendix B.

The guides for specifically excluding variables from the database were built on the following:

- Variables with a very limited number of results;
- Variables with a different method but with very few samples relative to other methods;
- Variables with different units or detection limits or both and relatively small number of samples compared to other variable methods.

An example of this situation is illustrated in Table 8 below.

Table 8. Example of variables that were excluded from the database

<table>
<tr><th>VARIABLE_ NAME</th><th>UNIT_ CODE</th><th>Comment</th><th>Parameter ID</th><th>Parameter Group</th><th>N result Values</th></tr>
<tr><td>ALUMINUM DISSOLVED (AL)</td><td>mg/L</td><td rowspan="2">exclude these from analysis, methods identical but weak acid so may be different from majority, only 37 samples out of 780, also high detection limit</td><td>1292</td><td>ALUMINUM DISSOLVED (AL) mg/L</td><td>31</td></tr>
<tr><td>ALUMINUM DISSOLVED (AL)</td><td>mg/L</td><td>1304</td><td>ALUMINUM DISSOLVED (AL) mg/L</td><td>6</td></tr>
</table>

Variables that were separated in the raw data set with unique variable codes and which had similar methods but detection limits, field procedures or laboratory procedures varied slightly were combined. Similarly, variables that lacked any method description and detection limits but which were apparently paired with other methods that had this information were integrated with like variables. In these cases the original detection limits were retained in the database to avoid the problem of creating false real values by standardizing detection limits. If the detection limit was not reported, the highest detection limit was incorporated as a conservative assumption. An example of this situation is provided in Table 9.

Table 9. Example of like variables with similar methods and results that were combined

VARIABLE_NAME	UNIT_CODE	Comment	Parameter ID	Parameter Group	N result Values
ZINC TOTAL RECOVERABLE	ug/L	combine these results, no reason to assume one method differs from the other, check for duplicate date and times when combined and exclude one of the duplicates; if DL not specified, use highest DL, keep specific DLs as reference	1249	ZINC TOTAL RECOVERABLE ug/L	261
ZINC TOTAL RECOVERABLE	ug/L		1251	ZINC TOTAL RECOVERABLE ug/L	556
ZINC_66 TOTAL RECOVERABLE - ZN	ug/L		1194	ZINC_66 TOTAL RECOVERABLE - ZN ug/L	40

There were variations on each of these main themes that were assessed. Specific examples of some of these included:

- Potassium Dissolved/Filtered (5 different methods were consolidated – one has no information and another has different reporting units);
- Sodium Dissolved/Filtered (same as above); and,
- Descriptions such as river width, cloud cover, distance from bank etc. (all of which were combined).

A basic description as to how each group of variables were addressed is provided below and details are provided in Appendix B.

4.3.1 Physical and Other Variables

This group included microbiological variables, chlorophyll *a*, oxygen demand, specific conductance, total dissolved solids (TDS), non-filterable residue (NFR), field descriptors and field analysed variables. In general, microbiological variables were combined for like measurements (e.g. *E. coli* and Fecal coli) with infrequently used methods being excluded from the database. TDS and laboratory specific conductance were combined for all methods, respectively. Field and laboratory variables for measurements such as pH and conductivity were kept separate but multiple methods within the field or laboratory measurements were combined. Dissolved oxygen by the Winkler method were excluded as there were no data while all field meter dissolved oxygen data were accepted and integrated. A number of methods for various measurements were excluded due to the infrequency of the measurement.

4.3.2 Ions

Most of the methods for ions were combined if they were reported in the same units. However, these different measurements may have had different detection limits. In such cases the real data were combined but the detection limit associated with each method was retained so that false positive values (above the lowest detection limit) were not created. In some cases (e.g. potassium and sodium), there were specific methods that were reported in different units, or with a unique detection limit of for very few samples and these were excluded from the database.

4.3.3 Nutrients

The management of the nutrient data was quite complex due to varied and unclear method naming nomenclature. Here we received considerable guidance from AESRD. For example “ammonia” and “ammonia total” were treated as different methods in the raw data but based on direction from AESRD both results were from filtered samples and thus both were dissolved and comparable. Consequently in the database these data were combined. A check for duplicates was performed to confirm that a single sample was not analysed by two different methods and duplicates, if any were set aside from the database. This approach was similarly applied to other nitrogen compounds, carbon and total phosphorus. This was not a problem with dissolved ortho-phosphorus. A number of infrequently used nitrogen and phosphorus methods were excluded from the database. These were generally excluded because of the method used (e.g. ICP-MS for total phosphorus) and/or because of a high detection limit.

4.3.4 Metals – Total and Dissolved

The results for dissolved metals tended to be consistent. There were two methods that were derived from ICP-MS analysis with a high detection limit and reported concentrations in mg/L with a very limited sample size. These were excluded for all dissolved metals. Other metals analyses were accepted and combined with units in µg/L and some variation in method detection limits which were retained. The same approach was used for total metals.

4.3.5 Organic Compounds

In most cases, organic compounds were accepted as received from the AESRD. A limited set had 2 or 3 method results and in all cases these were combined. There were no exclusions from the database for these compounds.

4.4 Dataset Preparation for Analysis

4.4.1 Internal QA/QC Protocols

Data provided by AESRD were assumed to have passed a first level of QA/QC check that is standard before being approved for release.

Data were assessed by inspecting the results of trip and field blank samples to assess the quality of field collection and laboratory methods. Blanks were deemed contaminated when they were equal to or larger than five times the reported detection limit (U.S. EPA 1985). Several metal concentrations were greater than five times the detection limit. These samples were flagged as problematic and all samples from these dates were inspected for unusually high values. None of the metals on these dates were found to be extraordinarily high and therefore were not excluded from analysis and reporting.

Outliers were not excluded from data analysis and presentation, given that interpretation focused on percentile statistics, which are relatively insensitive to outliers.

More data quality checks and revisions arose from work with the database and during data analyses, where issues were detected and resolved (see section 4.4.5).

4.4.2 Replicates

Averages were calculated for any replicate measurements encountered in the datasets. Measurements below detection were replaced with the detection limit to align with the graphing approach of displaying values at detection limit. An evaluation of replicates was conducted for the synoptic dataset, as this was a stand-alone monitoring program conducted by contractors, while all other datasets were collected by AESRD staff and assumed to be evaluated internally by AESRD.

Replicates in the synoptic dataset were exclusively duplicates. The relative percent difference (RPD) for each parameter group was calculated to evaluate the variation in replicates, and an overall average produced. We were not aware of any official method quality objectives for AESRD data that would identify the desired RPD for each variable, but the “Guidelines for Quality Assurance and Quality Control in Surface Water Quality Programs in Alberta” state that at RPD above 25%, data should be viewed with caution (Mitchell 2006).

The largest variation between replicates was encountered in biological parameters, such as epilithic and sestonic chlorophyll-a (35%), followed by bacteria (28%) and dissolved metals (20%) (Table 10). The latter can likely be explained by values close to the detection limit, where relative differences are large, but are mostly related to lower method precision at low levels. Epilithic chlorophyll is naturally variable due to variable habitat at different replicate sites, so these samples do not represent true replicates in the same way as replicates in water quality sampling. Bacteria were slightly above the 25% threshold, indicating some caution may be warranted, bacteria are often found in clumps associated with particulate matter and so are naturally variable. All other parameter groups were at 11% or less RPD, which is an acceptable degree of precision.

Table 10. Relative Percent Difference in Duplicate Measurements

Variable Group	RPD
Bacteria	27.9
Biological	34.9
Dissolved Metals	19.6
Hydrocarbons	0
Nutrients	6.3
Other parameters	2.4
PAHs	0.4
Physical	9.4
Total Metals	11.2
Overall Average	8.8

4.4.3 Transects

During synoptic surveys, a large number of sites downstream of Edmonton were sampled as transects, with three to five samples taken across the river (Appendix J). This sampling approach addresses lateral water quality differences due to limited lateral mixing of WWTP discharge plumes (See Section 3.3.2 above). Selecting any subset of these samples would have resulted in a bias for one area in the river and may have missed or exaggerated important discharges for point sources or tributaries. In consultation with the project leads, we therefore took the approach of calculating a mean concentration based on all available transect data per site. This approach approximates a mass balance approach where any inputs are assumed to be fully mixed with river water at the point of discharge. We caution that this approach results in overestimated concentrations for the left bank and underestimated concentrations for the right bank, where the plume centreline is located.

4.4.4 Field versus Laboratory Results

Direct comparison of field and laboratory measurements for variables such as TDS and pH were outside the scope of the current synthesis. In general, we preferentially used field measurements in order to characterize river water quality. Laboratory measurements were used for calculating dependent variables relative to guidelines.

4.4.5 Data Gaps and Deficiencies

A few data deficiencies were identified throughout the project, including:

- date format inconsistence (e.g., mmddyyyy versus ddmmyyyy, occurring in datasonde data),
- missing sample codes, and
- unmarked replicate data.

These issues were corrected in the database itself and data were analyzed based on the corrected version. This will assure that any future work based on the database will not be affected.

The water quality datasets provided by AESRD originated from the AESRD database and therefore were comprehensive and well organized. The only data gap identified was the lack of oxygen saturation as a primary field measurement or the lack of supporting elevation data to calculate it. We considered implementing a tool in the database to calculate oxygen saturation based on oxygen and temperature measurements, but the lack of elevation data for site locations prevented development of an exact formula. We recommend adding elevation as a site characteristic to the AERSD water quality database in order to allow for the derivation of oxygen saturation levels for any past and future oxygen concentration measurement.

4.5 Benchmarks for Status Assessment

The data sets for variables with SSWQOs were segregated into two seasonal sets for the purpose of comparing LTRN data to SSWQOs. These corresponded to the ice covered period (November through March) and the open-water period (April to October), as defined by McDonald (2013, see section 3.4.4). The pilot site-specific water quality objectives (SSWQO) were used as benchmarks to assess the general status of the water quality in the NSR based upon the LTRN data. A six year period (2007 to 2012) is too short to observe any real water quality trends in the data themselves unless there had been a major change in an activity that affected the river. Trend analysis usually requires at least ten years of data. The SSWQO were based on data ranging from 2000 – 2008, except for nutrients and bacteria, which were based on 2006-2008 data to avoid the period before WWTP upgrades (see section 3.4.4). There was little overlap between the data used for establishing the SSWQO (2 years - 2007 and 2008) and the summary statistics for 2007 through 2012 of the LTRN dataset and so any differences between the SSWQO and the six year summary statistics may have indicated a trend.

The Devon LTRN site was upstream of any impacts from the City of Edmonton, and so it was assumed that that SSWQO for Devon could also be applied to the site 1 km upstream of the confluence with the Clearwater River near Rocky Mountain House. The rationale for this approach was that the water quality at the Clearwater site was representative of background conditions as the human impacts upstream of Rocky Mountain House are relatively small compared to the downstream sites. Therefore, if the Devon site objectives were exceeded at Rocky Mountain House, then water quality was influenced by background conditions indicating that the objective was not appropriate for the upstream portion of the NSR.

For variables without SSWQOs, the applicable provincial and federal guidelines were used to assess water quality status in the NSR.

5. Current Status of the North Saskatchewan River

The water-quality related studies conducted between 2007 and 2012 as listed in section 3, all provided important individual pieces of information on the current status of the NSR. Each of them either focused on one or several ecosystem components (e.g., water quality, sediments, benthic organisms, macrophytes) or on water quality in a certain temporal (e.g., diurnal) or spatial (e.g., synoptic) context. The purpose of this section is to summarize and synthesize all results of those studies to paint a comprehensive picture of NSR water quality and the factors that influence it.

The status of the NSR is discussed by ecosystem component for increased clarity, but cross-connections between water quality and biota responses are drawn where possible. Water quality discussions are mainly based on the synoptic studies as well as LTRN data, but supported by datasonde and diurnal datasets. Non-fish biota status was mostly based on completed reports. Contaminant levels in fish tissue were discussed based on data that were collected by AESRD. The data sources were summarized in Section 3, Table 1.

5.1 Flow

Flow regime has a major influence on river water quality. The annual regime of snowmelt, runoff, recession of flows and under ice flow produces varying levels of major ions and TSS. Variable flows result in variable volume of water available for dilution and assimilation of point- and non-point source loads. This is particularly true for large Alberta rivers, such as the NSR, in which flow can vary by orders of magnitude within one year. Flows therefore need to be considered when studying water quality and biota in the NSR.

Flow in the NSR is partially regulated by two headwater dams, the Bighorn on the main stem near the mouth of the Bighorn River (forming Abraham Lake), and the Brazeau on the Brazeau River. The net effect of these impoundments is to redistribute flow to a higher average flow in the winter and lower average flow in the summer (NSWA 2011). There are still large seasonal variations in flows, which can be subdivided into four main flow seasons in the North Saskatchewan River:

1) Spring flow season of medium flows from prairie river freshet (a few weeks in April or May),

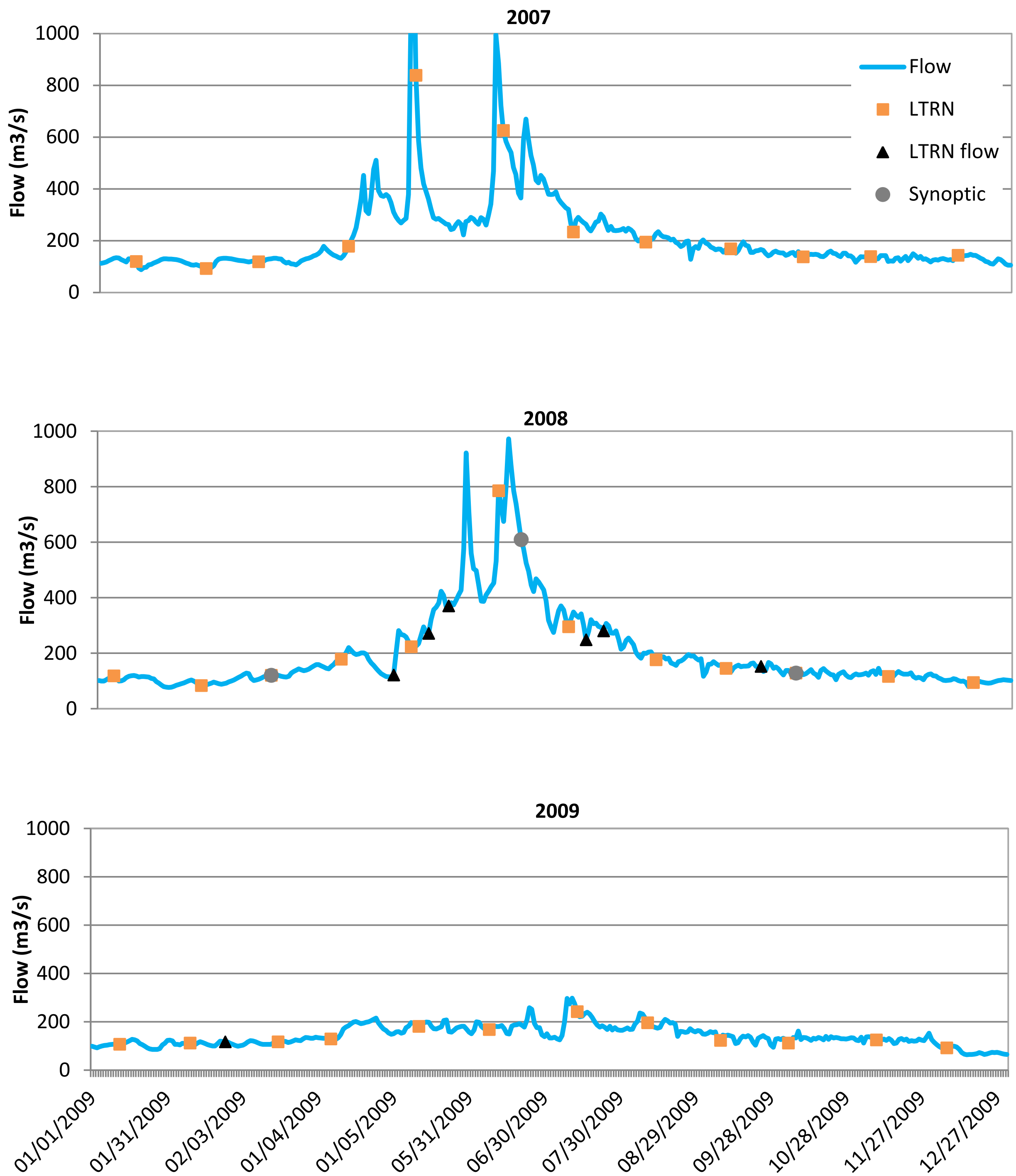
2) Summer high flow season due to snow melt in the mountain headwaters (June and July, sometimes early August),

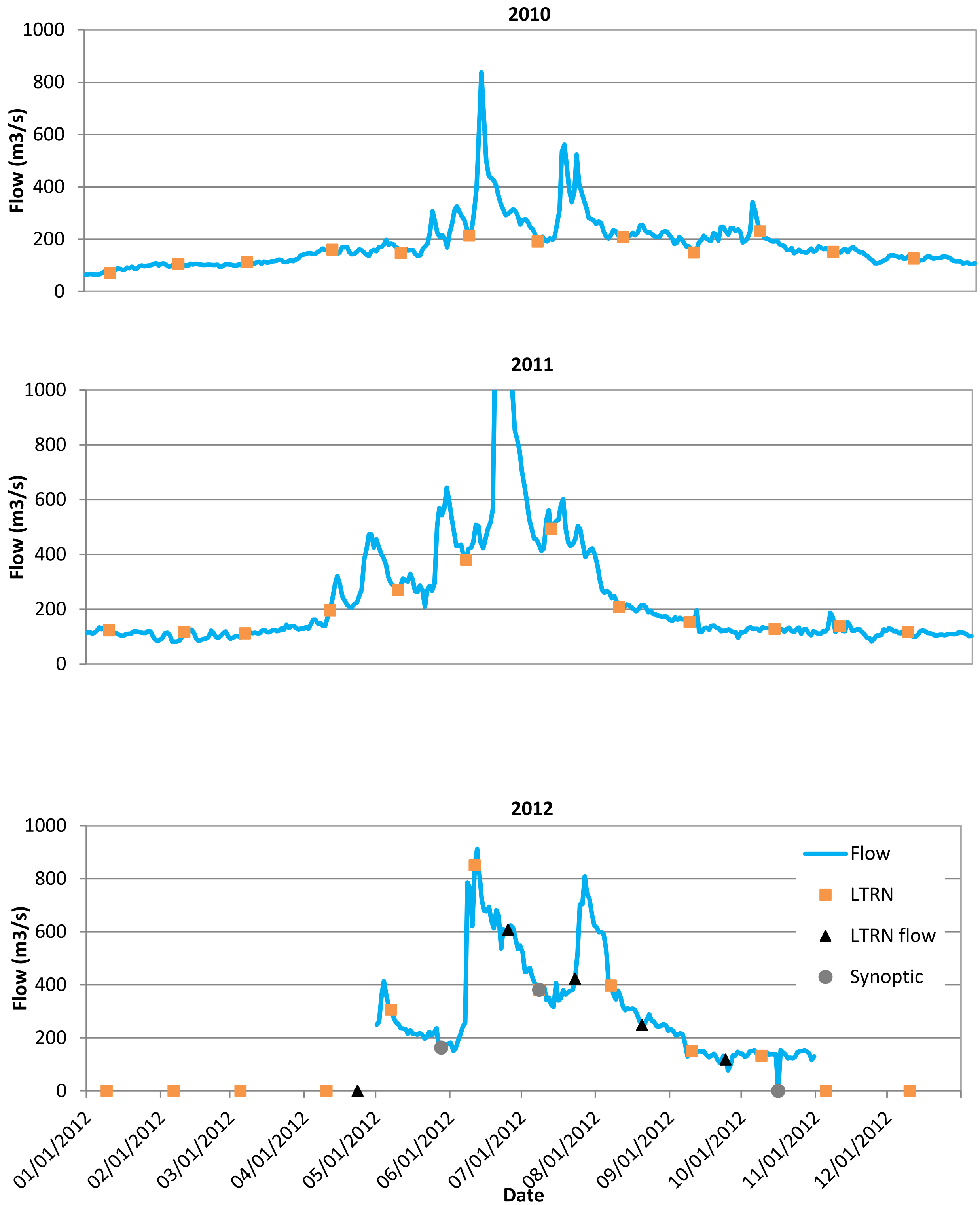
3) Mid-to late summer declining flow, similar in flow to the spring season, and

4) fall and winter low flow from about September to March, with lowest flows occurring in winter.

Flow patterns vary from year to year based on weather patterns. During the 2007-2012 period that was the subject of this report, spring flow peaks were only clearly expressed in 2007, 2011 and 2012 hydrographs for flows measured at the Water Survey of Canada gauge in Edmonton. Summer high flows were observed in five out of six years, with highest maximum flows in 2011, and unusually low summer flows in 2009 (Figure 4).

Figure 4. Hydrographs for the Six Study Years for the NSR at Edmonton and Timing of LTRN and Synoptic Sample Collection.





Note: Validated flow data for winter 2012 were not yet available at time of reporting.

5.2 Water Quality

The timing of water quality surveys undertaken from 2007-2012 captured all flow regimes in the NSR and the peak freshet was only missed in 2010 and 2011. The data set therefore provides a solid representation of seasonality.

In the following sections, the status of major groups of water quality variables is discussed, starting with field parameters, major ions and sediment parameters, followed by nutrients and metals, and concluding with organic contaminants.

5.2.1 Dissolved Oxygen and pH

5.2.1.1 Dissolved Oxygen

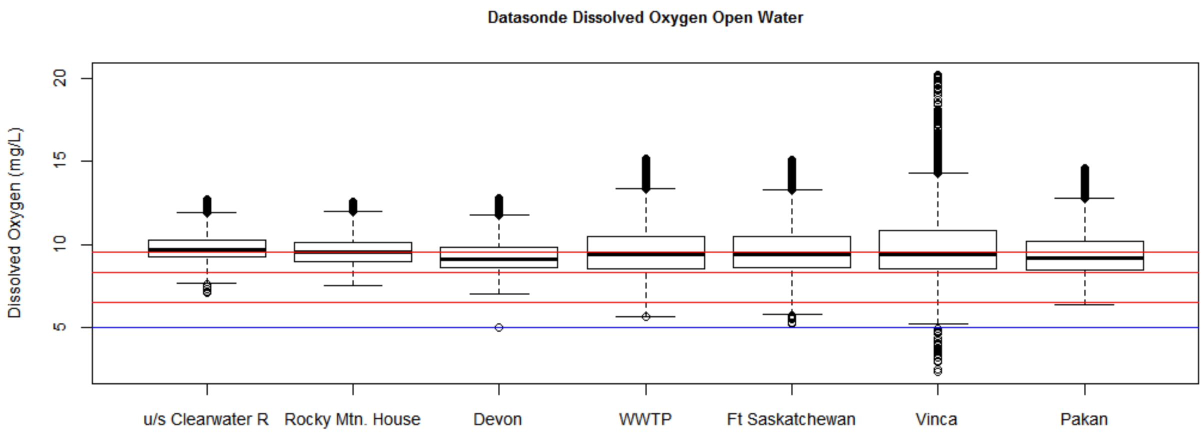
Dissolved oxygen concentrations measured on 15-minute intervals by datasondes along the mainstem remained, on average, above all applicable water quality guidelines for dissolved oxygen at all sites. An exception to that was the Pakan right bank site, which had average open-water DO concentrations of 0.3 mg/L lower than the guideline of 9.5 mg/L for larval fish development in gravel beds. Median concentrations at all sites during the open-water season were at or slightly below the guideline for larval fish development, the 25th percentile was above the 8.3 mg/L guideline for mayfly emergence at all sites, and most values were above the 6.5 mg/L guideline for adult cold water biota (Figure 5). This indicates that oxygen conditions in the river were appropriate for adult aquatic life, but that young stages of cold water biota only have the required amount of oxygen about half of the time.

Oxygen conditions in the river were appropriate for adult fish at the vast majority of time, but for larval fish only about half of the time.

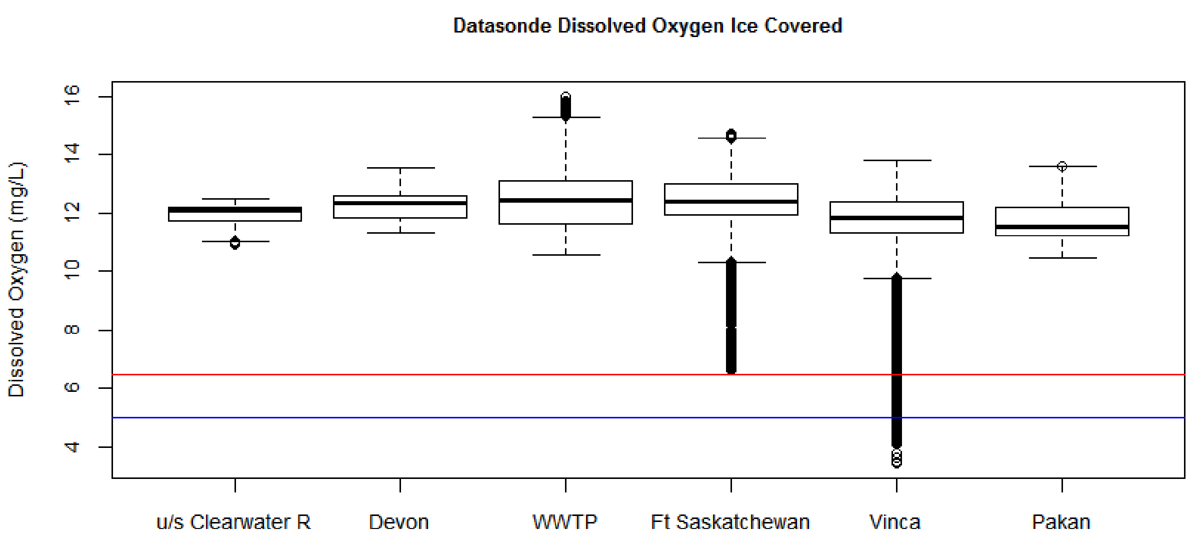
Open-water DO concentrations at all sites downstream of Edmonton showed some measurements below the 6.5 mg/L guideline. This was probably due to the larger night-time oxygen consumption from increased algae and plant respiration due to increased aquatic productivity, compared to the nutrient-poorer reaches upstream of Edmonton (Figure 42). This is supported by the concurrent increase in maximum day-time oxygen concentrations resulting from increased photosynthesis. This pattern of increased variance was established at all sites downstream of Devon and the magnitude of the variance increased with distance downstream, with the widest range reported at Vinca (Figure 5).

Dissolved oxygen levels were generally higher in winter, as expected from the higher solubility of oxygen in colder water. During the ice-covered season, the chronic coldwater biota guideline of 6.5 mg/L was always met at most sites at all times, except at Vinca, where a number of values were below 6.5 mg/L and numerous values were below the guideline of 5 mg/L for acute exposure. (Figure 12). A number of lower values just above the guideline were also observed at Ft. Saskatchewan. These patterns were not accompanied by increased oxygen maxima and happened under ice, excluding aquatic productivity as a causal factor. The increasing frequency of low oxygen occurrences and wider range of D.O. concentration from Edmonton to Vinca suggests the cumulative effect of effluents high in oxygen demand along this river reach. The City of Edmonton storm sewer system has typically been the largest source of BOD within the CR-IH reach under dry and wet weather conditions (Golder 2013b). The Edmonton WWTPs also discharge BOD, but treatment process improvements have largely reduced BOD discharges to the river and as a result, oxygen conditions in the river have greatly improved since the 1980s (AECOM and Anderson 2011).

Figure 5. Boxplot of Open-Water and Ice Cover Periods Dissolved Oxygen Datasonde Data 2007-2012



Notes: The black solid horizontal line represents the median, box limits indicate the 25th and 75th percentiles (interquartile range), whiskers indicate values at 1.5x the interquartile range, and open dots represent extreme values outside 1.5 x the interquartile range. The three red lines indicate chronic DO guidelines in mg/L for juvenile cold water biota (9.5), mayfly emergence (8.3), and adult cold water biota (6.5). The blue line indicates the acute DO guideline (5).

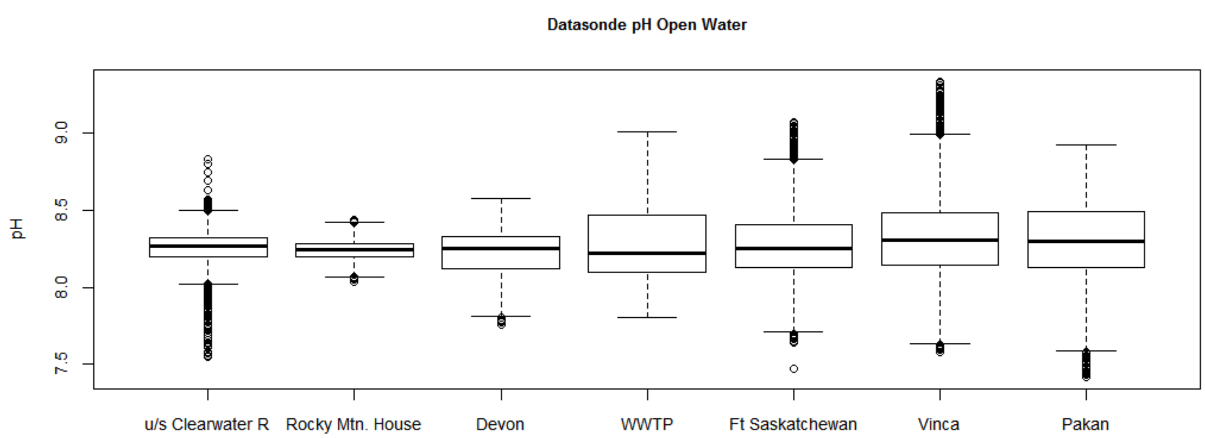


5.2.1.2 pH

The NSR water is naturally alkaline, with median pH levels around 8.3. The pH measured by the mainstem datasondes remained within the guideline range of 5-9 mg/L at most times and locations. Some individual values occasionally exceeded the Alberta guideline of 9.0 at the WWTP, Fort. Saskatchewan and Vinca locations in August and September, but the short-time nature of these measurements (15-min intervals) and the low number of such values (<10 for each site) indicate that chronic effects on aquatic life would not occur (see Datasonde Technical Report, Appendix C.1 for more details).

Increased daily fluctuations in pH at these three sites downstream of Edmonton compared to upstream sites were most likely due to stimulated algal growth resulting from nutrient inputs from the City of Edmonton WWTPs and, to a lesser degree, the storm sewer system. Increased rates of algal photosynthesis during the day and respiration during the night result in diurnal changes of the carbonate balance in water, which in turn increase the pH during the day and reduce pH during the night. This hypothesis is confirmed by elevated periphyton biomass (see Figure 42) and by increased daily oxygen fluctuations (Figure 5) downstream of the City of Edmonton compared to sites upstream of the City. Interestingly, there were larger pH variations at the site upstream of Clearwater Ricer compared to the site at Rocky Mountain House, which may either represent seasonality of melt water and precipitation in the headwaters, effects of Abraham Lake or the municipal discharge of Nordegg, which reaches the NSR through a tributary about 80 km upstream of the Clearwater site.

Figure 6. Boxplot of Open-Water Datasonde pH



5.2.1.3 Temporal Variation

Datasonde data showed that dissolved oxygen and pH undergo diurnal (on a daily cycle) changes in the NSR, in particular downstream of Edmonton, where increased aquatic productivity is observed, as discussed above. Datasonde data provided the high-resolution data necessary to calculate representative summary statistics for these variables, including day and night-time data, and to assess the daily range of values aquatic biota are exposed to. This overcomes the systematic bias in LTRN and synoptic sampling programs, which occur during day time and thereby would result in higher average values than datasonde data that include day and night data.

Anderson (2012) detected increasing long-term trends in day-time DO concentrations at Devon, Pakan, and Hwy 17 between 1987 and 2011. Increasing trends, particularly those observed at Pakan and Hwy 17, are likely related to the reduction in nutrient levels and oxygen consuming material, especially after the major upgrades at GBWWTP in the late 1990s. Gradual and step trends measured a greater change in DO under ice than during the open water period, indicating that the reduction of effluent BOD had a more obvious positive effect on NSR oxygen conditions than nutrient reductions and resultant changes in productivity although reduced productivity due to nutrient reductions should result in lower oxygen levels during the day and higher levels during the night.

Anderson (2012) also found an indication that pH was declining at Devon (only under ice cover), but increasing at Pakan (open water) and Hwy 17 (under ice). The cause of these pH trends remains to be further understood.

5.2.2 Total Suspended Solids and Turbidity

Total suspended solids (TSS, also called filterable residuals) and turbidity are indicators of the amount of particles suspended in the water column, with TSS representing a direct measurement of sediments while turbidity is a measure of light scattering. High concentrations, of suspended sediments may have direct physiological effects on fish that can lead to lethality, may reduce light penetration into the river, thereby affecting photosynthesis of algae and plants, and impair fish and benthic invertebrate habitat by siltation of gravel beds.

The large seasonal change in sediment load in the NSR as it passes from low-flow clear water to high-flow turbid water is one of the most significant natural water quality patterns in the NSR (Figure 7). Many other water quality patterns, such as particulate nutrients and metals, are related to this visually striking change and it is quite difficult to distinguish natural sources of sediment-related substances from sources of anthropogenic origin. The large amount of data that has been collected in the NSR to clarify the role of different sediment sources is the subject of this section.

5.2.2.1 Status with Respect to Guidelines and Objectives

Median open-water TSS concentrations at Pakan were at the SSWQO of 19 mg/L (McDonald 2013, Figure 8) and median ice-covered TSS concentrations were just below the ice-cover SSWQO of 4 mg/L (see Appendix D, Table 1). This indicates no recent change in TSS concentrations in comparison to values for the period of 2000-2008 from which the SSWQO was calculated.

Figure 7. Average Open-Water Monthly Total Suspended Solids Concentrations and Flow in the NSR 2007-2012

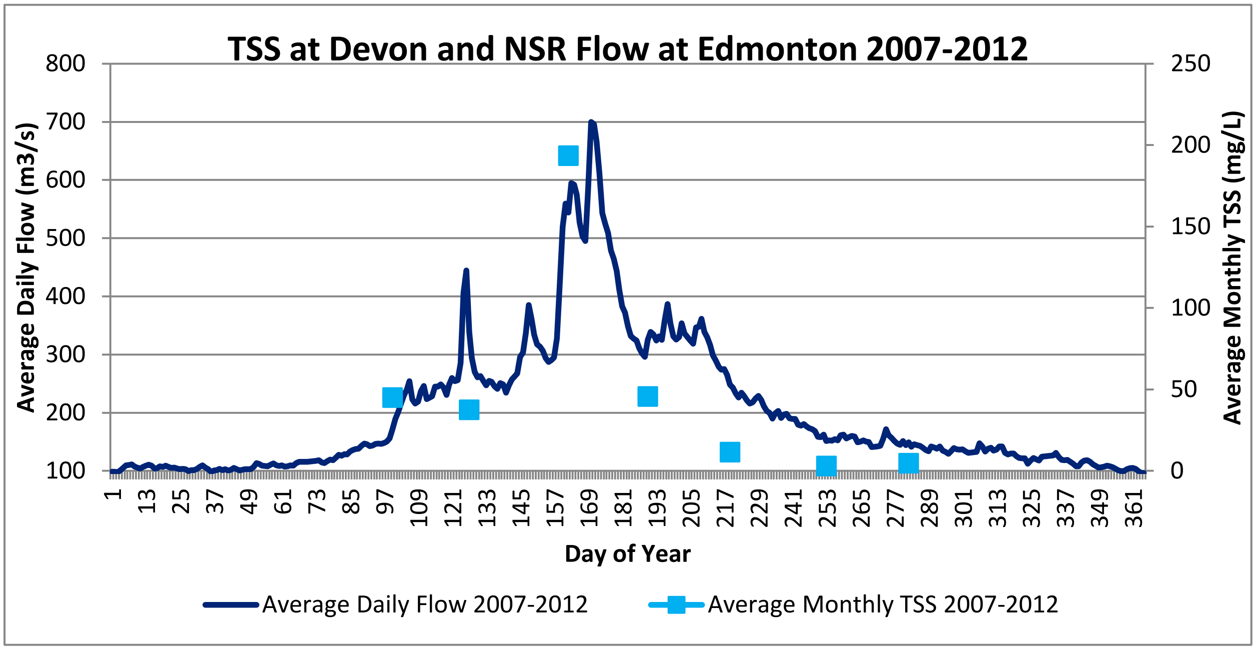
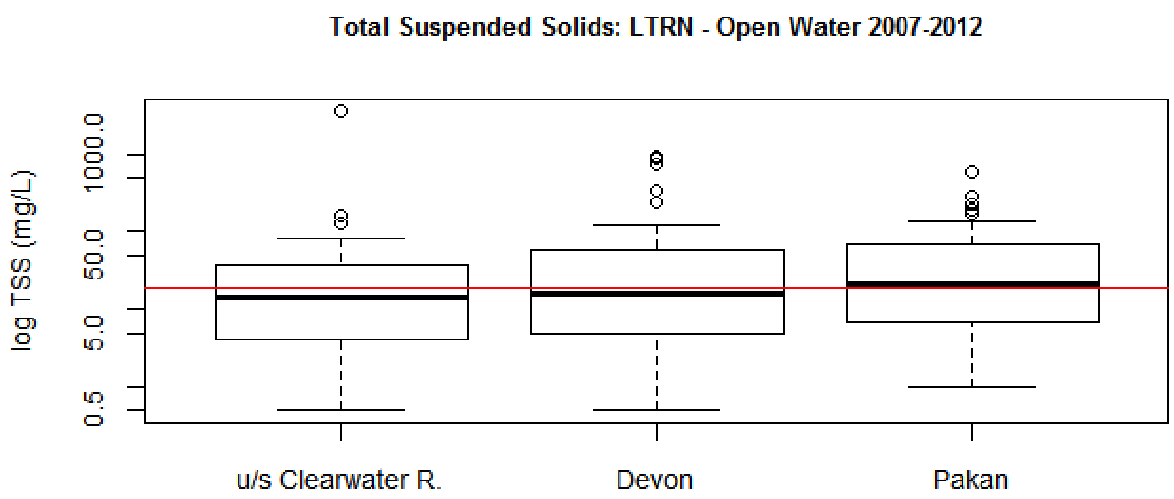


Figure 8. Boxplot of Open-Water TSS at LTRN Sites



5.2.2.1 Spatial Variation

Total suspended solids and turbidity remained relatively stable throughout the mainstem during low flow synoptic surveys, but increased gradually from upstream to downstream during the high flow summer synoptic surveys (Figure 9). This slight increase throughout the mainstem was also visible in the LTRN TSS data (Figure 8), which include many low flow samples (Figure 4). This increase may represent sediment inputs from the watershed in response to increased disturbance or changing surficial geology, scouring of river banks and bed and sediment resuspension from depositional areas. Tributaries were generally much more elevated in TSS concentrations than the mainstem, in particular during NSR low flow. While tributary flows are low in summer, these inputs would still result in a cumulative downstream increase in TSS concentrations in the mainstem at large concentration differentials.

The City of Edmonton storm sewer system has typically been the largest source of TSS to the IH-CR under dry and wet weather conditions, with the largest loadings during storm events (Golder 2013b). Total TSS loadings to the NSR from the City of Edmonton increased by two orders of magnitude from dry to wet conditions (5,389 kg/day to 141,242 kg/day, respectively) (Golder 2013a). The largest TSS concentrations in all seasons were recorded in the urban tributaries Goldbar Creek, Whitemud Creek and Sturgeon River. These creeks are naturally turbid (“Whitemud Creek”) but also receive a large amount of urban storm runoff and are the focus of urban construction which is a significant source of TSS from land disturbance.

TSS is the only variable that has consistently increased with distance downstream during the spring City of Edmonton NSR monitoring program (2006-2012; Golder 2013b). Spring is a sensitive time for the NSR, as the NSR flows remain low prior to mountain snowpack melt, while lowland streams and rivers reach peak flows and loads from spring runoff. The 2008 and 2012 synoptic surveys did not capture this season, so it would be informative to schedule a synoptic survey during early spring.

Figure 9. Synoptic Graph of Total Suspended Solids

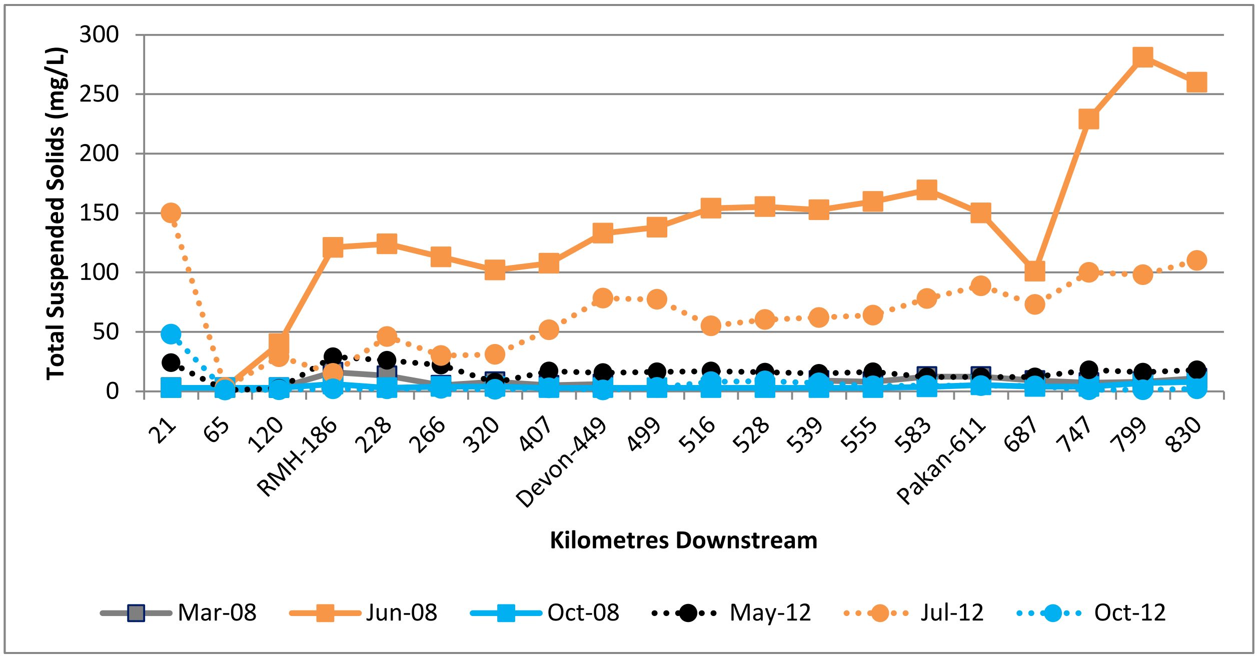
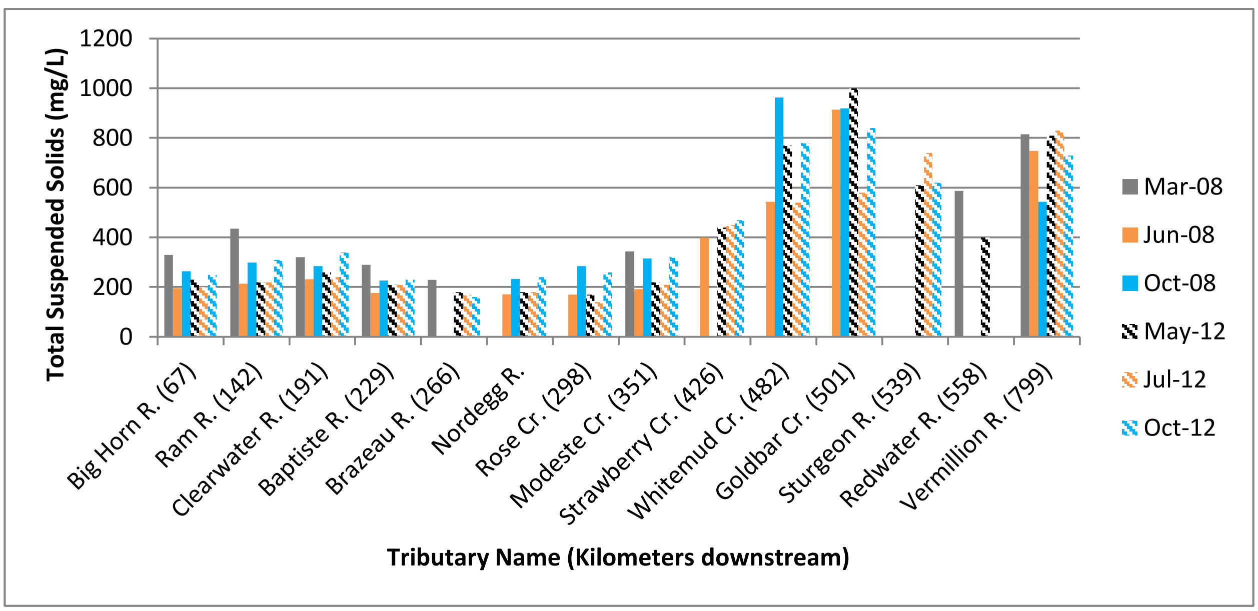


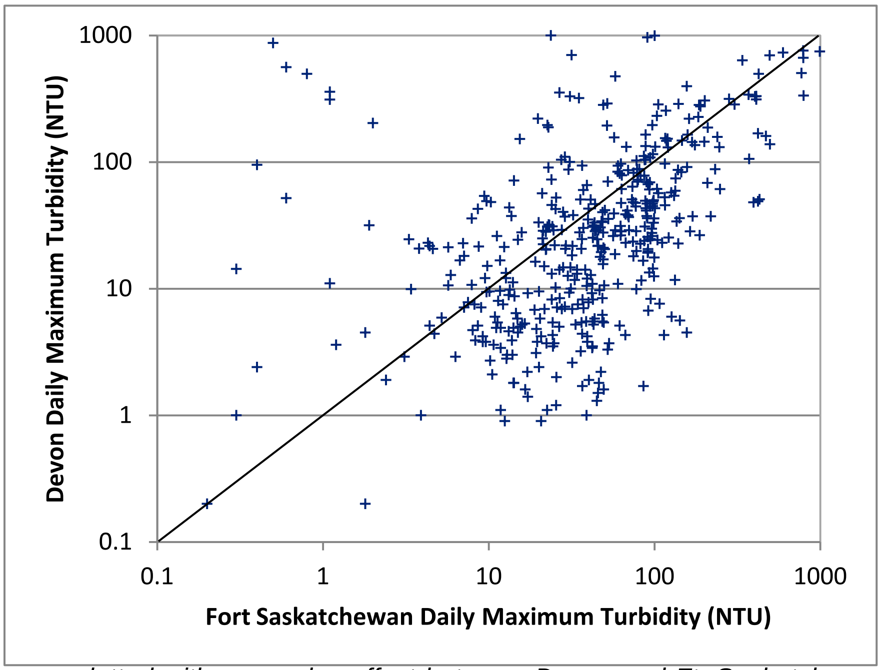
Figure 10. Synoptic Tributary TSS Concentrations



Mean turbidity calculated from datasonde data for all sampling periods did not differ between Devon and Fort Saskatchewan, suggesting that the City of Edmonton, on average, was not adding turbidity to the

NSR in a consistent manner. Maximum turbidity values, however, showed a tendency to higher values downstream of the City, with Ft. Saskatchewan levels exceeding Devon levels during the majority of the time (Figure 11), indicating an influence from urban sources on turbidity. Potential sources include suspended solids loads from the Edmonton storm and combined sewer system, any Goldbar WWTP bypasses, or elevated phytoplankton biomass downstream of Edmonton. These spatial differences have been observed between Devon and Pakan (Table 15) and were attributed to nutrient enrichment. Reasons for turbidity changes cannot be determined with certainty based on the currently available datasonde data.

Figure 11. Maximum Daily Datasonde Turbidity Data collected at Devon and Ft. Saskatchewan (2010-2012)



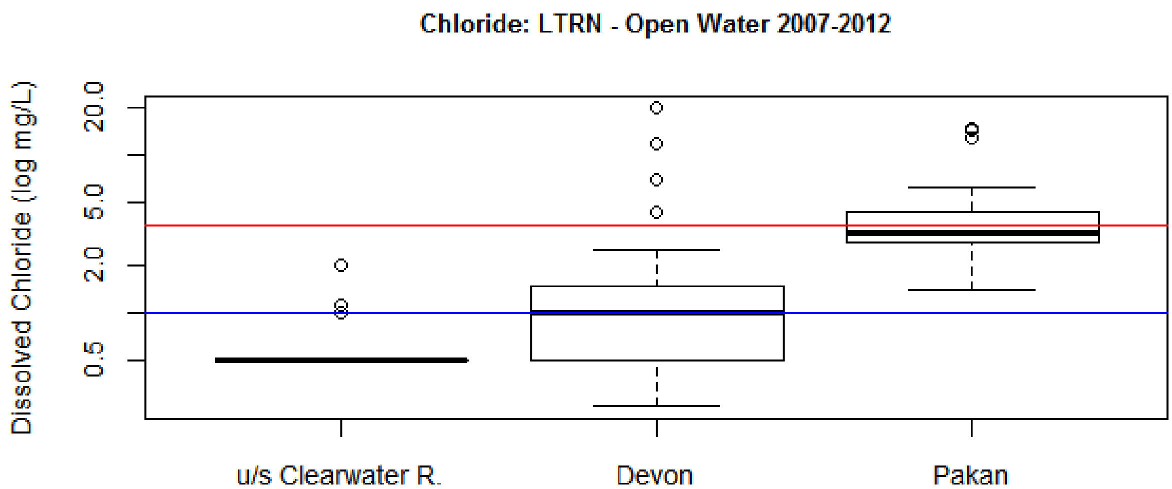
Note: The data were plotted with a one-day offset between Devon and Ft. Saskatchewan, as during the dominant low flows, travel time would be about 28 hours, based on extrapolated NSR travel times that were estimated by Golder (2013c) for the distance between the E.L. Smith WTP and the Dow Chemical Plant Intakes. For details on the dataset, see the datasonde technical report in Appendix C.1.

5.2.3 Ions and Conductance

5.2.3.1 Status with Respect to Guidelines and Objectives

The median open-water chloride concentrations (3.2 mg/L) and median ice-covered values (4 mg/L) at Pakan were below their SSWQOs (open-water 3.6 mg/L, ice-cover: 4.2, Figure 12). This may indicate a slight recent decreasing trend in chloride concentrations in the reach from Devon to Pakan compared to the period on which the SSWQO was based (2000-2008), given that no change was observed at Devon. The highest observed chloride levels were one order of magnitude lower than the Alberta guidelines for irrigation that are 100 mg/L – 700 mg/L, depending on the type of crop (AESRD 2013). The highest observed TDS was about half that of the lowest Alberta irrigation guideline for TDS of 500 mg/L.

Figure 12. Boxplot of Open-water Chloride Concentrations at LTRN sites 2007-2012

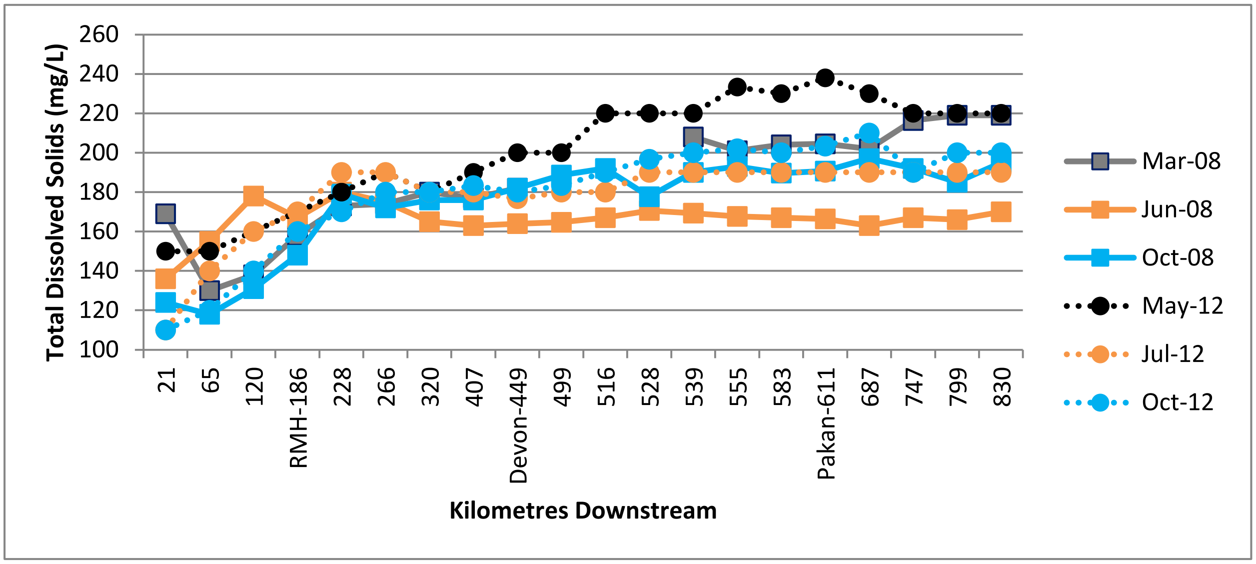


Note: The red horizontal line represents the open-water SSWQO for Pakan; the blue line is for Devon (McDonald 2013).

5.2.3.2 Spatial Variation

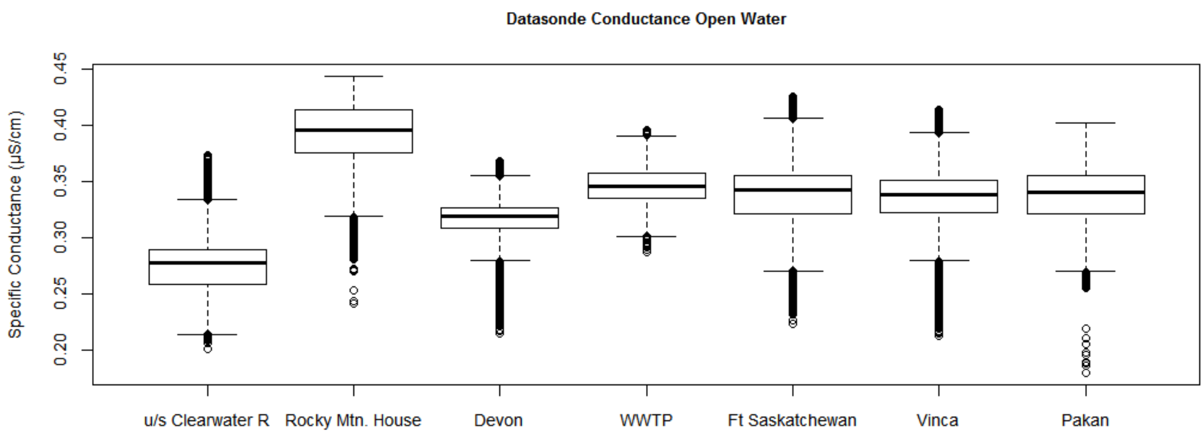
There was a general trend to increasing concentrations of total ion content, as indicated by TDS and conductivity, from upstream to downstream in the NSR (Figure 13) and in the tributaries (Appendix E.2). The first large increase occurred in the headwaters at km 228 (downstream of the Clearwater River), indicating a chloride source in the Clearwater River watershed, and another large increase occurred within the IH-CR reach (kms 449-555), indicating the influence of point sources and tributaries, for example from road salt or water softener brines at WWTPs. Sodium chloride (road salt) and other chloride-containing de-icing agents (calcium chloride, magnesium chloride) are used on Alberta highways (Alberta Roadbuilders and Heavy Construction Association 2014) and the City of Edmonton Snow and Ice Control Policy states that a mixture of sand and salt be used (City of Edmonton 2011). The increase downstream of the Clearwater confluence was consistent across seasons, indicating a constant natural source of ions, while the downstream increases were less pronounced in summer and more pronounced during winter, spring and fall, likely due to higher dilution capacity in the river for point loads and tributary loads under high flow summer conditions,. Not surprisingly, sodium and potassium showed similar patterns to TDS as they represent the majority of dissolved ions, while magnesium and calcium were constant across the basin, except with a small increase in the headwaters (Appendix E.1). Fluoride was high in the headwaters and remained relatively stable, except for one step increase downstream of Edmonton, indicating an urban source (Appendix E.1).

Figure 13. TDS Synoptic Graph 2008 and 2012



Conductivity data collected in 15 minute intervals by datasondes confirmed the spatial patterns in TDS (Figure 14). The large difference between the site upstream of Clearwater River and downstream of the Clearwater River confluence (Rocky Mtn. House) indicates that Clearwater River is a major contributor of dissolved substances in this reach. The large decrease from Rocky Mtn House to Devon is unexpected, however, and may be due to complete mixing of Clearwater River waters and additional influences of other tributaries. The datasonde at the RMH site may also have been installed near the right bank, under predominant influence of the Clearwater River water, which is not fully mixed with NSR waters at this location (Google Earth).

Figure 14. Datasonde Data for Conductivity during the Open-Water Season



Chloride showed a different spatial pattern than all other ions, with mostly non-detectable levels upstream of Devon, only a few low detections at Devon and large increases within and downstream of the City of Edmonton (Figure 15). The City of Edmonton storm sewer system has typically been the largest source of chloride to the NSR in the IH-CR reach under dry and wet weather conditions (Golder 2013c). Stormwater outfall chloride concentrations were highest in the spring and early winter, assumedly as a result of road salt application. During summer, baseflow concentrations were still high (medians of individual outfalls ranging from 143 mg/L to 218 mg/L), due to groundwater influence (Golder 2013c) or discharge of WWTP effluent. Surface aquifer maps produced by the Alberta Geological Survey, however, indicate groundwater chloride concentrations of 20 mg/L or lower in the Edmonton area (Barker et al. 2013), making groundwater influence an unlikely reason for elevated stormwater chloride. Urban chloride sources to the storm sewer system, including WWTP outfalls and cross-connections from sanitary sewers may be an alternate explanation of elevated stormwater chloride under dry weather.

Elevated chloride concentrations in the urban tributaries Whitemud Creek, Goldbar Creek and Sturgeon River (Figure 16) compared to lower concentrations in rural tributaries, would suggest the importance of urban sources of chloride. The tributary sampling program conducted by the City of Edmonton, however, showed that chloride concentrations at locations upstream of the City were similar or higher than concentrations measured at the mouths (Golder 2013b). Evaporative concentration of ions including chloride during the summer season and flushing of chloride from soils in spring runoff could be reasons of elevated chloride levels in tributaries upstream of the City of Edmonton. The relative role of urban road salt compared to watershed sources of chloride warrants more investigation.

Further increases in the NSR and elevated chloride levels in tributaries were observed in rural western Alberta, possibly due to pockets of saline soils that are present in that area, and rural road salt and dust suppressant (calcium chloride) application.

Figure 15. Chloride Synoptic Graph 2008 and 2012

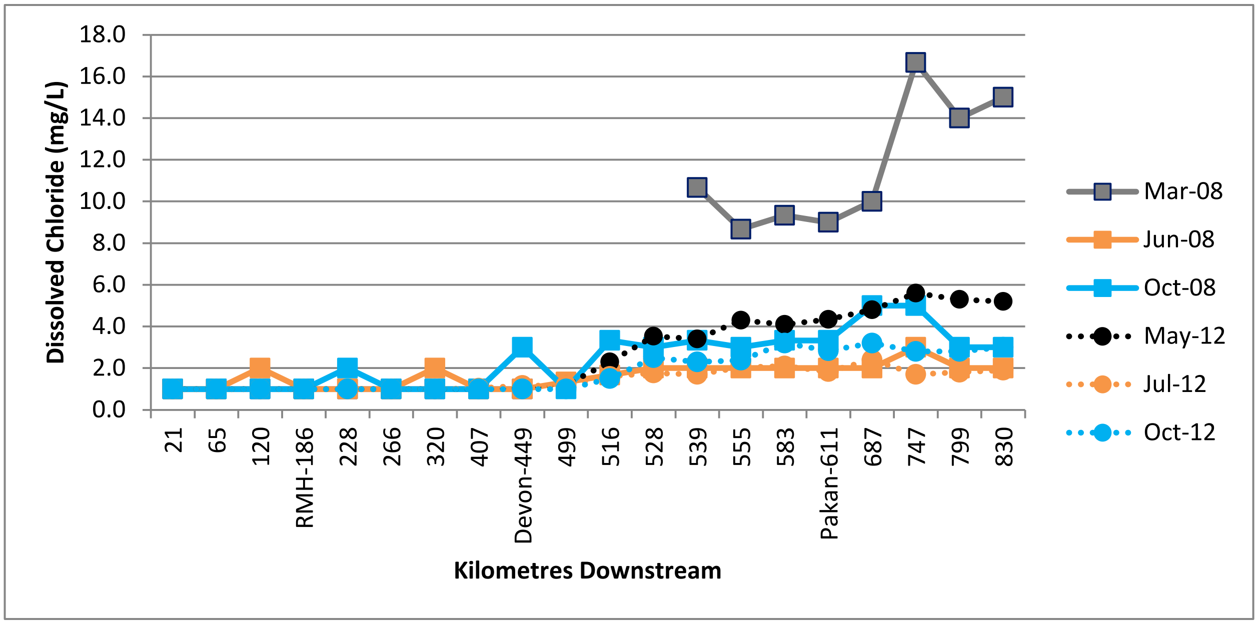
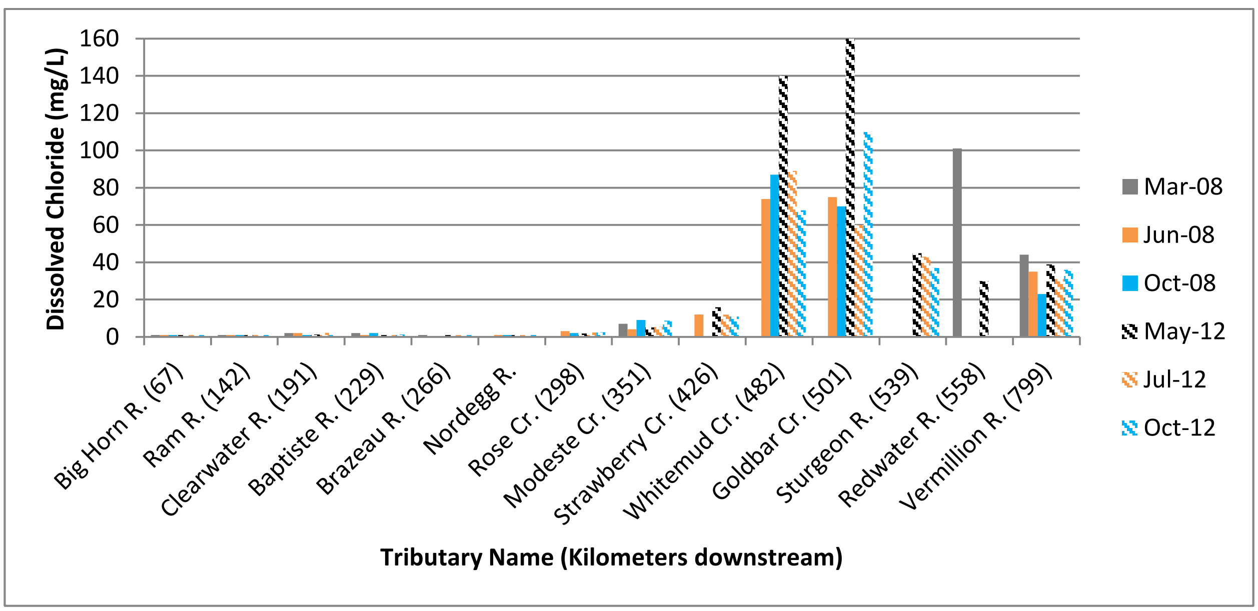


Figure 16. Chloride Concentrations in Synoptic Tributary Samples 2008 and 2012



5.2.3.1 Temporal Variation

Anderson (2012) detected increasing trends in total dissolved solids and sulphate over the period from 1987 to 2011 both upstream and downstream of Edmonton. An increase in chloride levels was also observed after 1998 at Pakan and Hwy 17. The most recent median LTRN concentrations (2007-2012) were lower than the SSWQOs based on the 2000-2008 period, however, suggesting a recent decrease.

5.2.4 Nutrients

Nutrients are essential elements for plant and algae growth that naturally occur in surface waters. There is a large range in natural nutrient levels in rivers due to differences in bedrock and soil chemistry, ranging from very low levels (oligotrophic) to high levels (eutrophic). Human-derived nutrient inputs, such as fertilizers from cropland or treated wastewater, can raise nutrient levels, and as a result, enhance plant and algae growth, which, in excess, can result in nuisance algae levels and large diurnal oxygen fluctuations, as discussed above. Rivers in the North Saskatchewan watershed range from oligotrophic in the headwaters to naturally eutrophic in the prairies, which can confound patterns due to human inputs.

The nutrients that comprise the majority of biomass and are therefore of interest in freshwaters are usually phosphorus (P), nitrogen (N) and carbon (C). Either phosphorus or nitrogen or both are of particular importance, as their supply determines the plant growth, e.g., can be the limiting nutrients. For the purpose of monitoring and assessment in the NSR, a few variables of concern were chosen for setting SSWQOs, including total organic carbon (TOC), total phosphorus (TP, the total amount of phosphorus, including dissolved and particulate P), total dissolved phosphorus (TDP, one of the more bio-available forms of P and a good wastewater indicator), and nitrite and nitrate (NO_3 + NO_2), which are usually low in naturally waters due to quick uptake by plants, but are elevated in treated wastewater and fertilizer runoff.

5.2.4.1 Status with Respect to Guidelines and Objectives

LTRN nutrient data for 2007 to 2012 (with the exception of data from upstream of Clearwater River, 2009-2012 only) are summarized for ice cover and open water periods in Figure 17. Under ice cover, TDP exceeded the SSWQO at Devon and TP upstream of Clearwater exceeded the Devon SSWQO. During the open water season, several nutrient medians exceeded SSWQO, including:

- TOC at both Devon and Pakan,
- NO_3 + NO_2 at Pakan
- TDP at Devon, and
- TP at all sites.

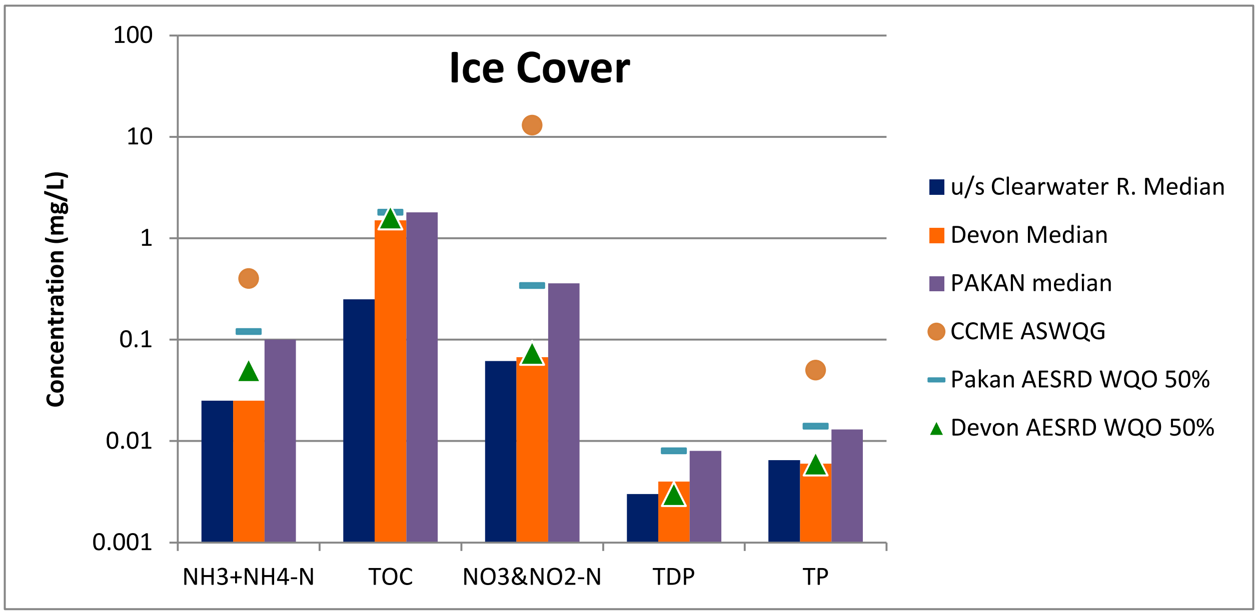
NO_3 + NO_2 upstream of Clearwater River exceeded the Devon objective. The Nordegg WWTP discharge into the NSR tributary Shunda Creek may be one possible explanation for this, although Nordegg is located about 80 km upstream from the Clearwater site, reducing the likelihood of a significant influence.

Ammonia, TOC, NO_3 + NO_2 were at or below the under-ice 50th percentile SSWQO upstream of Clearwater R. and Devon. All site medians were below the CCME guidelines.

Both TDP and TP exceeded the median open-water objective at Clearwater and Devon, and this may be a result of high sediment loads. TOC and TP exceedances occurred both upstream and downstream of the IH-CR reach, which indicates a watershed source rather than an urban source. Overall, most median SSWQOs were exceeded at Devon and the greatest number of variables that exceeded the 90th percentile SSWQO was observed at Devon, including ammonia, TOC, $NO_3 + NO_2$, TDP, and TP (see Appendix D.1.), possibly due to recent increased watershed inputs or more frequent high flows in the recent period; which requires more investigation.

At Pakan, only TOC exceeded the 90th percentile SSWQO. At Pakan, medians mainly met SSWQOs, which is expected since the SSWQO was based on 2006-2008 data, which are in part included in our summary statistics. More post-WWTP upgrade nutrient data are required to reliably evaluate nutrient status against SSWQOs.

Figure 17 Nutrient concentrations under ice and in open water along the NSR relative to SSWQOs for LTRN data (2007-2102)



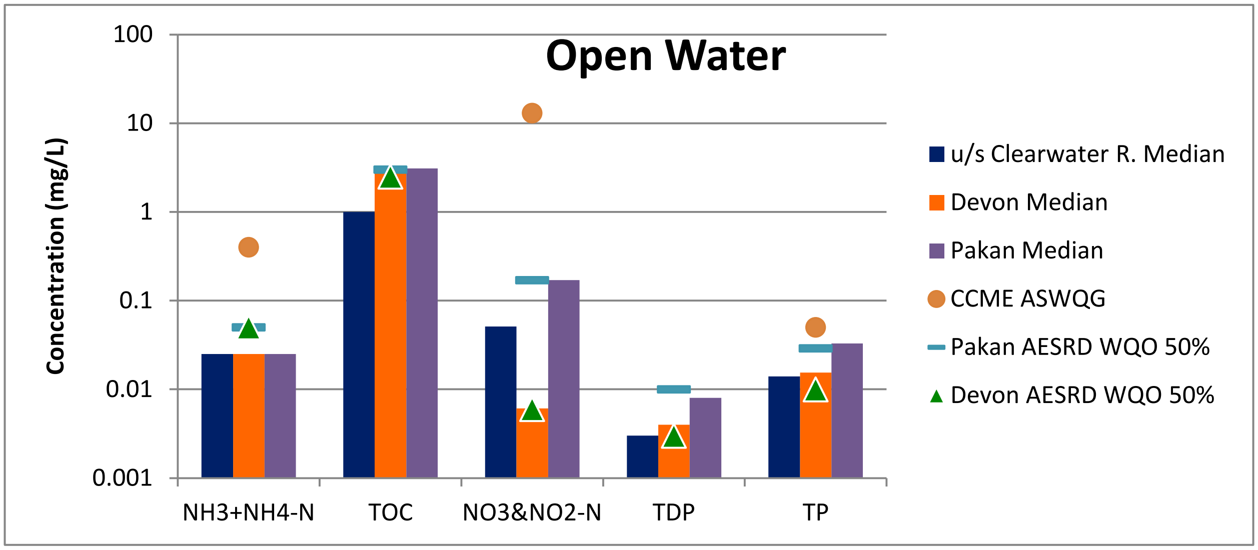
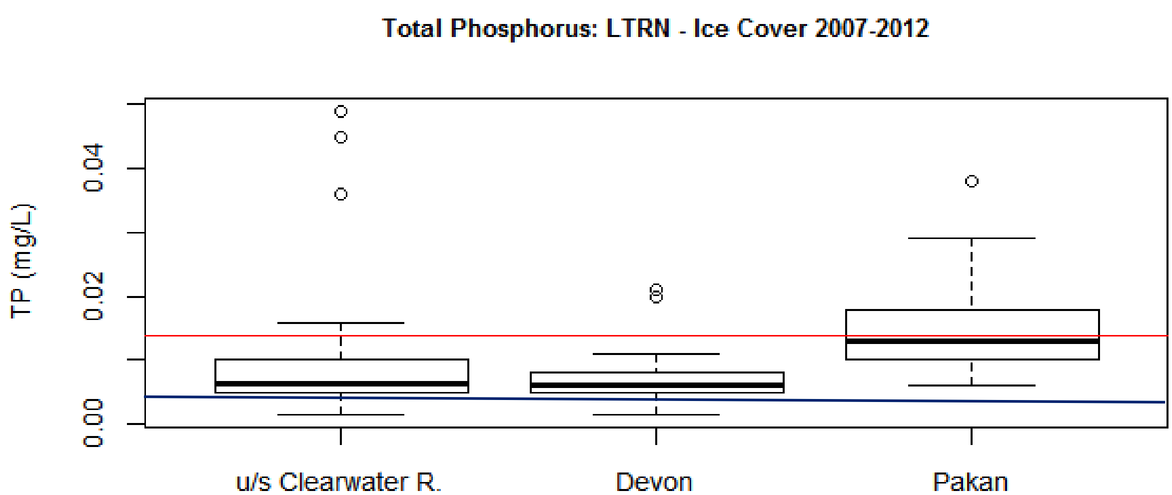
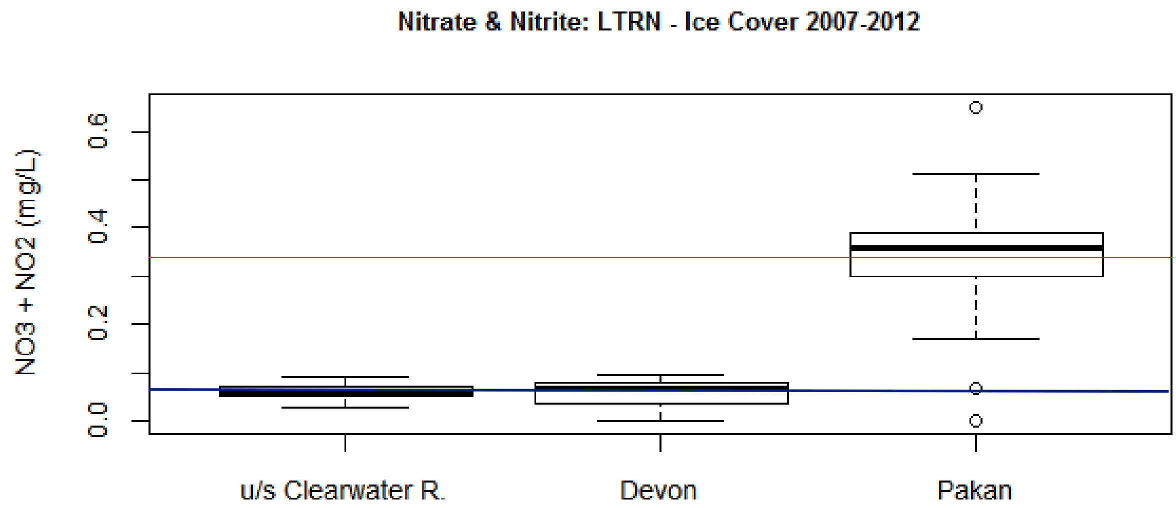


Figure 18. Boxplot of Ice-Cover Total Phosphorus at LTRN Sites 2007-2012



Note: the red horizontal line represents the ice-cover SSWQO for Pakan, the blue line that for Devon (McDonald 2013).

Figure 19. Boxplot of Ice-Cover Nitrate and Nitrite at LTRN Sites 2007-2012



Note: the red horizontal line represents the ice-cover SSWQO for Pakan, the blue line that for Devon (McDonald 2013).

5.2.4.2 Spatial Variation

Three different spatial patterns in nutrients from upstream to downstream locations in the NSR were observed in synoptic studies;

1) a gradual increase from upstream to downstream, with largest increases in the prairies (TKN (Figure 20), TOC),

2) low values in the upstream reaches and an abrupt increase downstream of the City of Edmonton (e.g., NO_2 + NO_3, ammonia, Figure 22) and

3) a combination of both where increases occured throughout the NSR, but were most pronounced downstream of the IH-CR (TP, TDP, Figure 23).

The gradual increase in nitrogen and carbon concentrations throughout the prairies is likely the result of cumulative inputs from nutrient-rich prairie tributaries (Figure 21) and in addition, human impacts from agricultural and urban land use. Abrupt increases in dissolved nitrogen forms downstream of the CR-IH reach (Figure 22) are indicative of loads from large point sources, such as WWTPs. Continuous increases of TP (Figure 23) and TDP (Appendix E) along the NSR, with the largest increase occurring downstream of the CR-IH, indicates cumulative effects of watershed and point sources of phosphorus. During the low flow-synoptic survey in October, TDP declined downstream of Pakan, possibly indicating algal uptake.

The City of Edmonton NSR river monitoring program is conducted on a regular basis and confirmed these patterns (Golder 2013c), with concentrations of ammonia and TP significantly higher at the downstream river intake site (Dow Chemical, located in Fort Saskatchewan, downstream of both Goldbar and Capital Region WWTPs) than the upstream site (E.L. Smith WTP) for the past 5 years (2008 to 2012) (Golder 2013c).

Figure 20. TKN Synoptic Graph 2008 and 2012

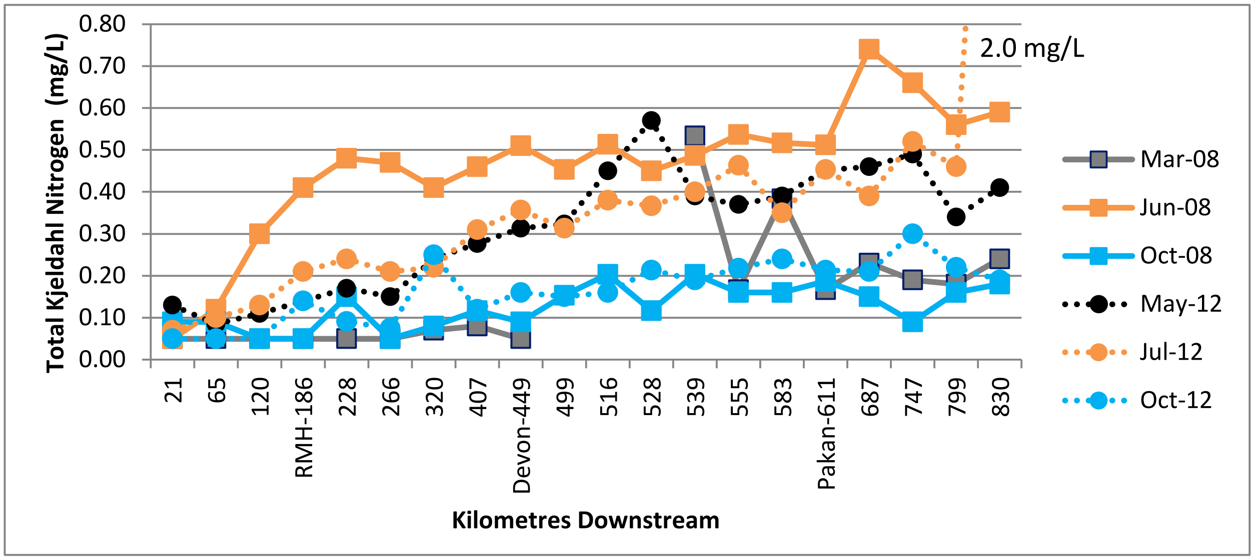


Figure 21. TKN Concentrations in Synoptic Tributary Samples 2008 and 2012

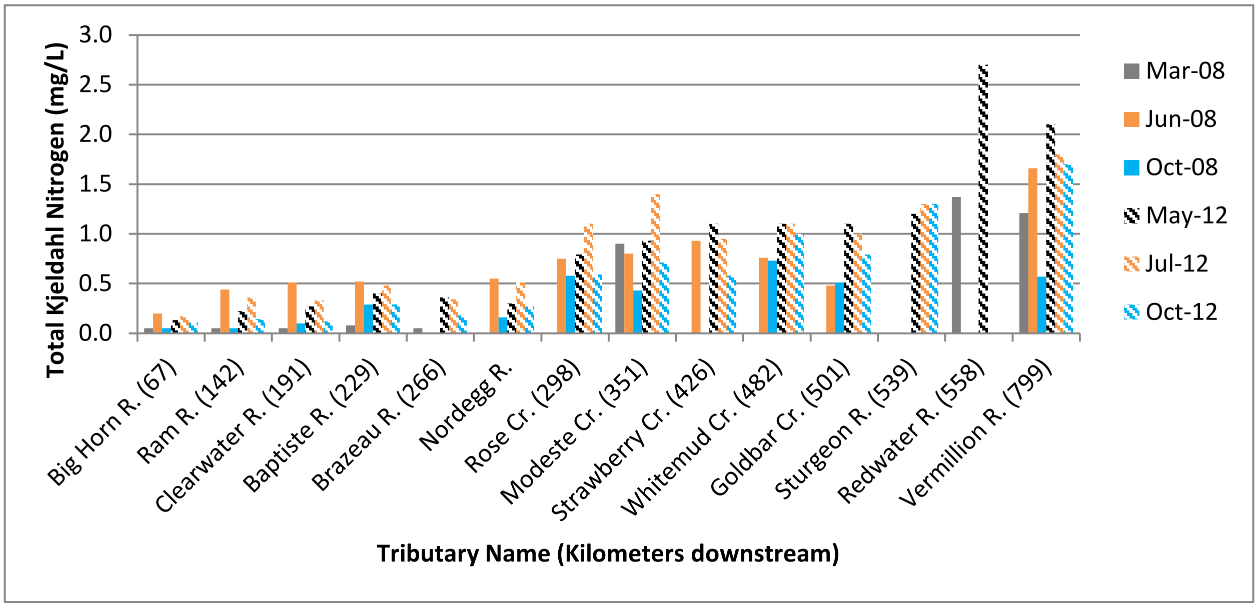


Figure 22. Nitrate and Nitrite Synoptic Graph 2008 and 2012

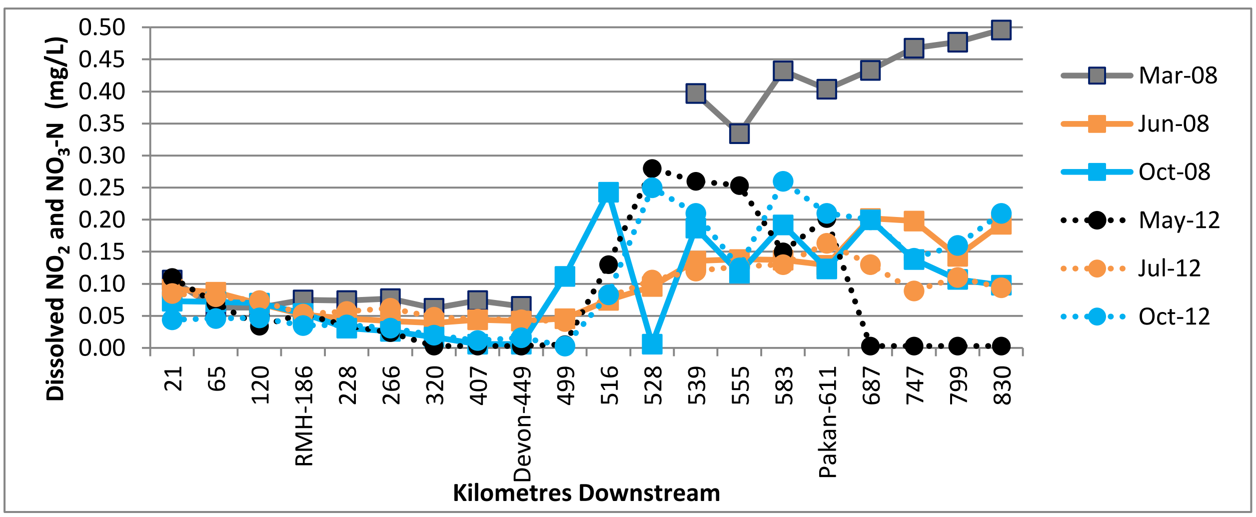
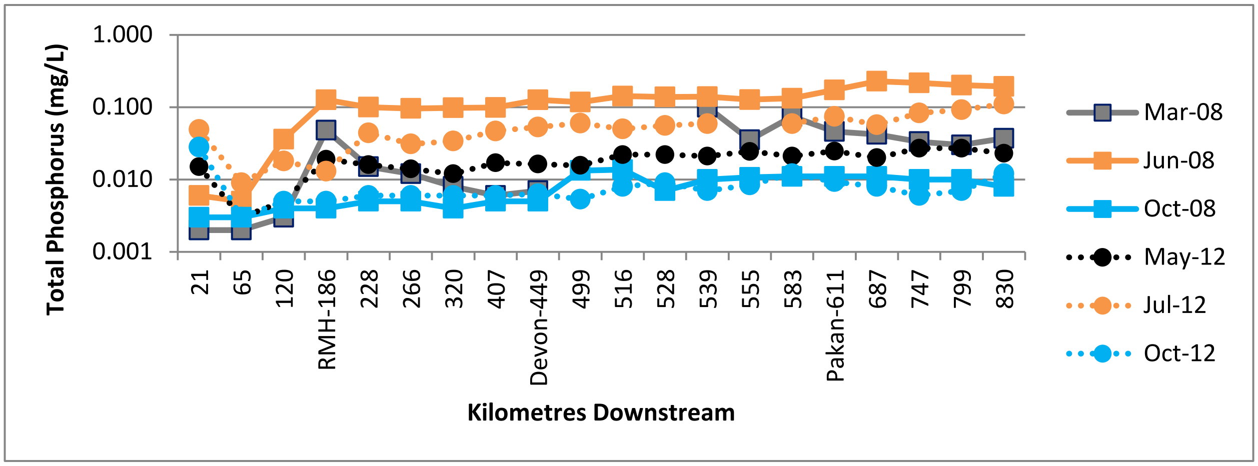


Figure 23. TP Synoptic Graph 2008 and 2012



Note: The TP value of 2.47 mg/L at 555 km(NSR at Vinca bridge) in July 2012 was removed from this graph, as it appeared to be an outlier.

Results from the past six years of the City of Edmonton's loading analysis (Golder 2013a) indicate that the Gold Bar WWTP is the predominant source of TP, TKN, ammonia and NO_3+NO_2 to the NSR in the reach through Edmonton under dry conditions. Under wet weather conditions, the Gold Bar WWTP continues to be the main source of these nutrients to the NSR within the City, with the bypass flows that circumvent the facility having a large influence.

5.2.4.3 Temporal Variation

Anderson (2012) measured significant declining trends (monotonic and step trends) at Pakan from 1987 to 2009. Declines in ammonia, nitrite+nitrate-N, total nitrogen, total phosphorus and total dissolved phosphorus coincided with major upgrades at the GBWWTP and ASRWWTP in 1998 and 2005, respectively. Some nutrients (i.e., nitrate+nitrite-N, total phosphorus and total dissolved phosphorus) showed the declining trend for the same period downstream to Hwy 17.

5.2.5 Pathogens

Two bacterial variables (fecal coliforms and E. coli) and two protozoan parasites (*Cryptosporidium* and *Giardia lamblia*) are monitored in the NSR as indicators of fecal contamination. Fecal coliforms and *E. coli* are used as water quality indicators because large numbers of these bacteria are always present in the feces of humans and other warm-blooded animals, but are not naturally found in surface water. *E. coli* typically accounts for a large proportion of fecal coliforms in a water sample and therefore results of these two variables are often similar. Fecal coliforms and *E. coli* were measured in the LTRN and synoptic surveys.

Giardia and *Cryptosporidium* are microscopic parasites that can be found in water. Both parasites cause intestinal illnesses and produce resting stage cysts that are very resistant to harsh environmental conditions. Cysts are counted as an indication of the number of protozoans in the water. The cysts can remain dormant for weeks to months and are resistant to conventional water treatment methods (e.g. chlorination). *Giardia* and *Cryptosporidium* were measured in the NSR and tributaries in May of the 2012 synoptic survey.

The main sources of these pathogens are discharges from municipal sewage or runoff from livestock operations and manured cropland following rain events or snowmelt (e.g. Cooke et al 2002). The direct access of wildlife and domestic animals to water bodies also contributes contaminant loads to watercourses.

5.2.5.1 Status with Respect to Guidelines and Objectives

Guidelines for fecal coliforms and *E. coli* for the protection of recreational and irrigation water uses apply to Alberta surface waters (Health Canada 2010; CCREM 1987). There are currently no guidelines for *Giardia* and *Cryptosporidium*. The irrigation guideline for fecal coliforms and *E. coli* is 100 CFU per 100 mL (CCREM 1987). The recreational guideline for *E. coli* is 200 counts per 100 mL (Health Canada 2012; as a geometric mean of at least five samples within a 30 day period). Due to insufficient temporal data to calculate geometric means, individual samples were compared directly to the irrigation and recreational guidelines for general inferences.

Water quality guidelines for bacterial pathogens for irrigation and recreational uses were typically met during the open water and ice-covered seasons at the upstream LTRN stations on the NSR (Figure 24). Incidences of non-compliance occasionally occurred at Pakan during both seasons. The City of Edmonton has previously reported incidences of non-compliance of guidelines for *E. coli* in samples taken from the downstream Dow chemical river intake in April, July and August, which reflect bacterial loading sources within the city (Golder 2013). The City of Edmonton 2012 compliance monitoring program reported *E. coli* concentrations above the recreational contact and agricultural water use guidelines in approximately half of the samples at locations downstream of the E.L. Smith WTP (Golder 2012b). The Rat Creek combined sewer outfall and the Goldbar WWTP bypass are two known predominant bacterial loading sources (Golder 2013c).

Median fecal coliform and *E. coli* counts were below the SSWQOs (McDonald 2013) at Pakan for the open water season (Figure 24; Table 11). In the ice-covered season, median fecal coliform counts were just above the median SSWQOs (Table 11; Appendix D.1) and median *E. coli* counts were below the SSWQO (Figure 25). These differences were substantial (14 vs. 29 and 10 vs. 15), suggesting reduced bacteria levels downstream of the IH-CR.

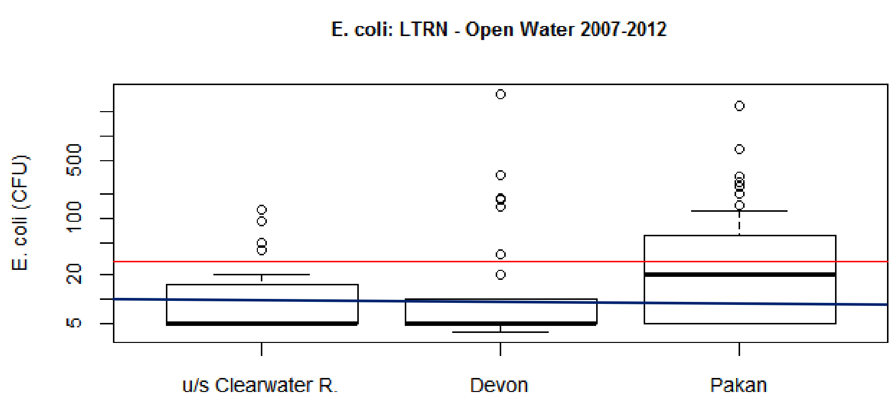
The 90th percentile SSWQOs were met in 73 % and 76 % of the samples during the open water period for fecal coliforms and and *E. coli,* respectively (Appendix D.1). The SSWQOs (90th) were met in 87% and 90% of the samples during the ice-covered period for fecal coliforms and *E. coli*, respectively (Appendix D.1), indicating no change in bacteria concentration extremes.

Table 11. Seasonal pathogen summary statistics at Pakan

	Fecal coliforms					*E. coli*				
	50th SSWQO	90th SSWQO	50th	90th	%> 90th	50th SSWQO	90th SSWQO	50th	90th	%> 90th
Open Water	41	100	30 (55)	294 (1076)	29 (44)	29	100	14 (20)	184 (680)	21 (32)
Ice Cover	22	100	25	112	13	15	93	10	96	10

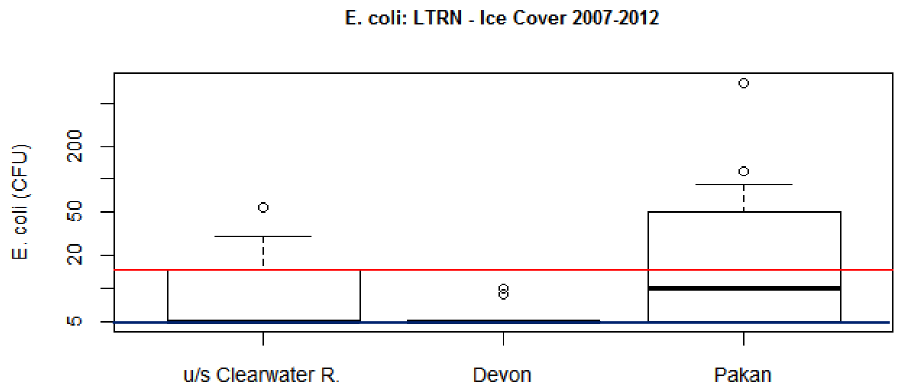
Note: Parentheses include samples during high flow

Figure 24. Boxplot of E.coli in open-water season at LTRN Sites Compared to Pakan SSWQO



Note: the red horizontal line represents the open water median SSWQO for Pakan and blue for Devon (McDonald 2013).

Figure 25. Boxplot of E.coli in ice-covered season at LTRN Sites Compared to Pakan SSWQO



Note: the red horizontal line represents the ice cover SSWQO for Pakan and blue for Devon (McDonald 2013).

5.2.5.2 Spatial Variation

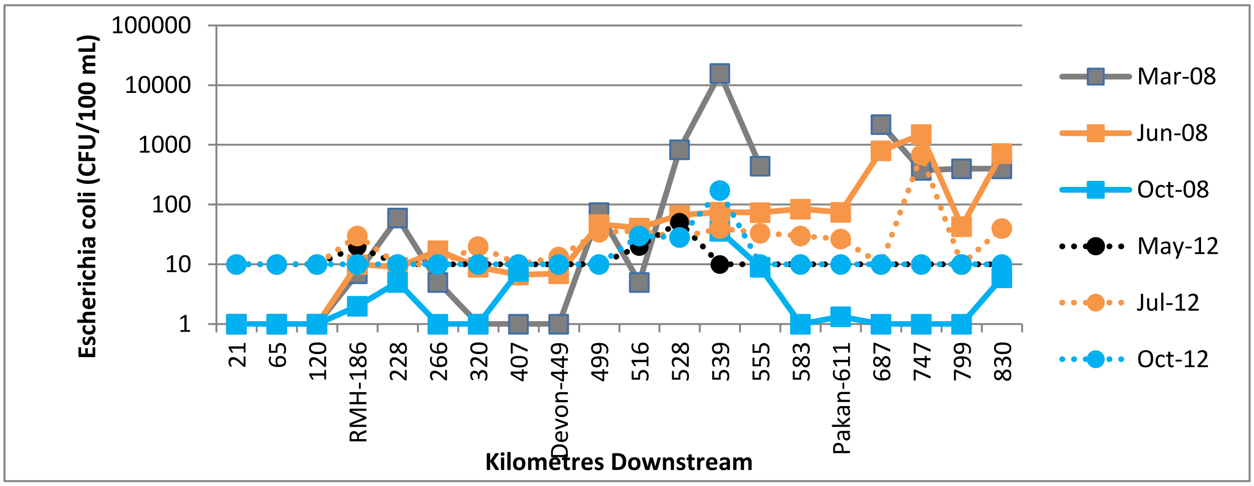
Bacterial pathogens

In the 2008 and 2012 synoptic studies, the bacterial counts in the NSR were very low in the headwaters (≤10 MDL /100 mL) in all three seasons. Counts of *E. coli* generally increased at Rocky Mountain House and downstream of Devon and remained relatively high until Pakan (Figure 26). Bacterial counts were also low (<10 MDL/100 mL) in the headwater tributaries, with the exception of results from May 2012 at the Big Horn River (Figure 27).

Along the mainstem, bacterial counts increased by an order of magnitude during the month of July in 2012 at Elk Point, which is downstream of the Vermillion River confluence. Higher bacterial counts were measured in summer during high flow associated with mountain snow melt (June 2008) and during warmer temperatures and following a series of precipitation events (July of 2012, data not shown). In the NSR tributaries, *E. coli* counts were higher in June in samples from Rose, Modeste, Strawberry and Vermillion rivers and may reflect runoff from agricultural activities occurring in these watersheds (Cooke et al 2002).

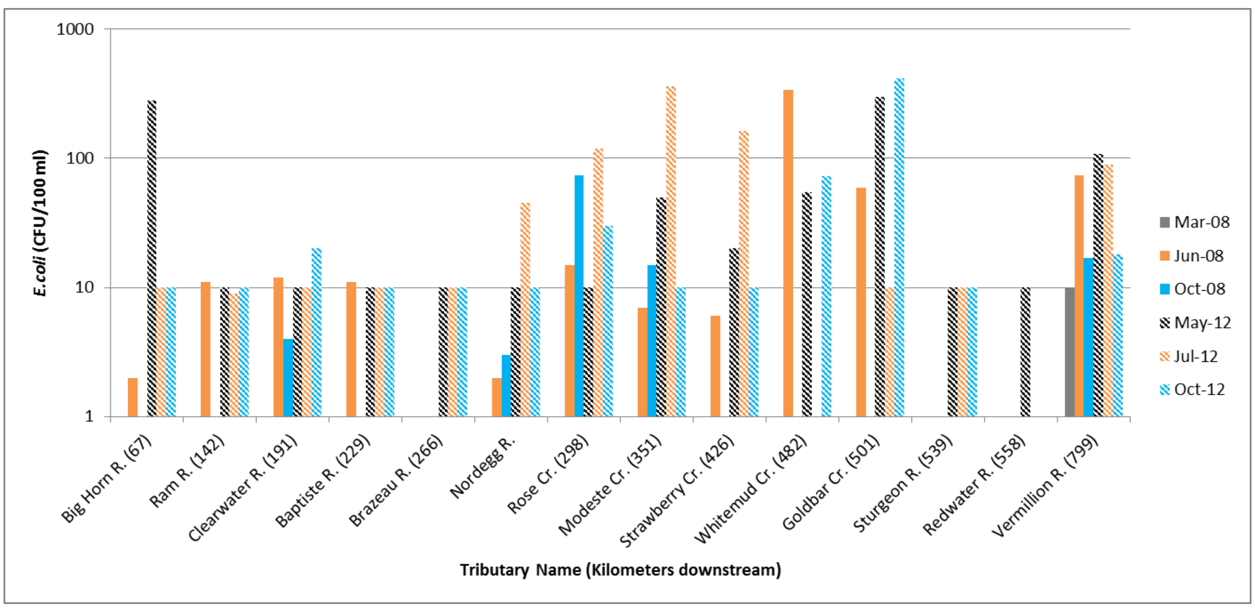
In October, during low flow, counts were typically lower (below the MDLs) in the NSR and tributaries with the exception of those samples from the Edmonton watersheds of Whitemud and Goldbar creeks, which had relatively high coliform counts. Within of the City of Edmonton along the NSR mainstem, *E. coli* concentrations were higher in downstream locations and significantly higher under wet compared to dry conditions (Golder 2013). The City of Edmonton storm sewer system and the Gold Bar WWTP bypass have typically been the largest source of E. coli loading under wet conditions (Golder 2013c). The Gold Bar WWTP bypass typically only flows during wet events and for an additional day following a number of rain events (Golder 2013c).

Figure 26. E. coli counts in the NSR during synoptic surveys



Note: MDL = 10 CFU/ 100mL

Figure 27. E. coli counts in the NSR tributaries during synoptic surveys



<u>*Cryptosporidium*</u>

Cryptosporidium oocysts were measured in June and October 2008 synoptic surveys and in the May 2012 synoptic study. In May 2012 program, oocyst counts were relatively constant and less than 20 counts/100L at all NSR mainstem stations (Figure 28). *Cryptosporidium* cyst counts were also low in the upstream NSR tributaries (Figure 29) but higher spring concentrations were measured at downstream NSR tributaries including Whitemud and Goldbar Creeks and Redwater and Vermillion Rivers. Higher concentrations of *Cryptosporidium* (> 100 cysts/100L) have occasionally been measured in the NSR within the City of Edmonton during summer storm events (Golder 2013). Concentrations of *Cryptosporidium* spp. were measured below the detection limit in each of the urban Edmonton tributaries, with the exception of Horsehills Creek during the spring monitoring program (Golder 2013b).

In June and October of 2008, concentrations along the NSR mainstem ranged from non-detected levels to 130 counts/100L, with no recurring spatial patterns. In NSR tributaries, *Cryptosporidium* counts were generally higher in the headwater watercourses in the June sampling event and may have reflected contributions from spring melt. In October of 2008, concentrations were relatively low in NSR tributaries with the exception of those from Rose and Modeste Creeks which were potentially related to agricultural sources given their rural catchments.

Figure 28. Cryptosporidium counts in the NSR during synoptic surveys

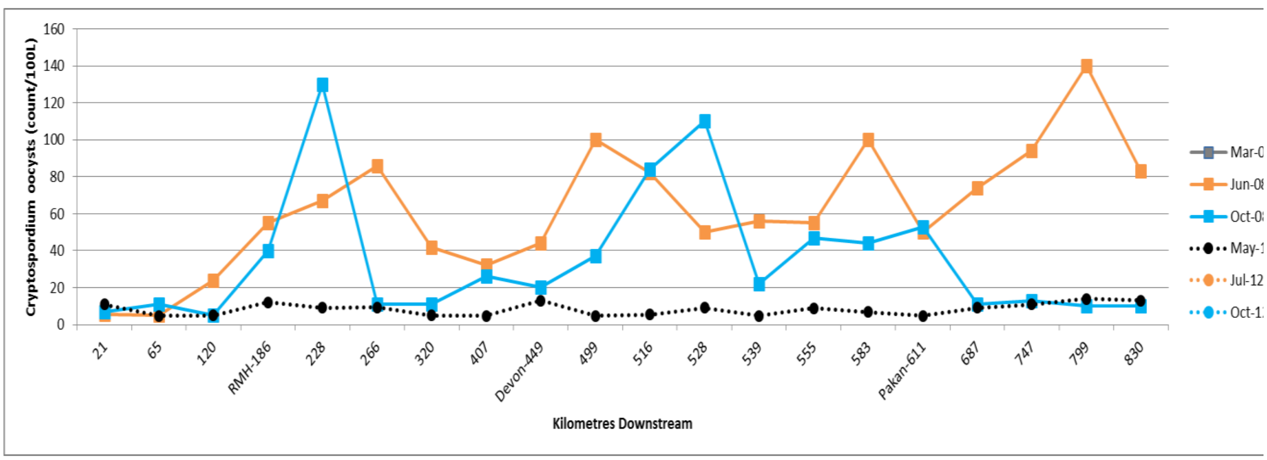
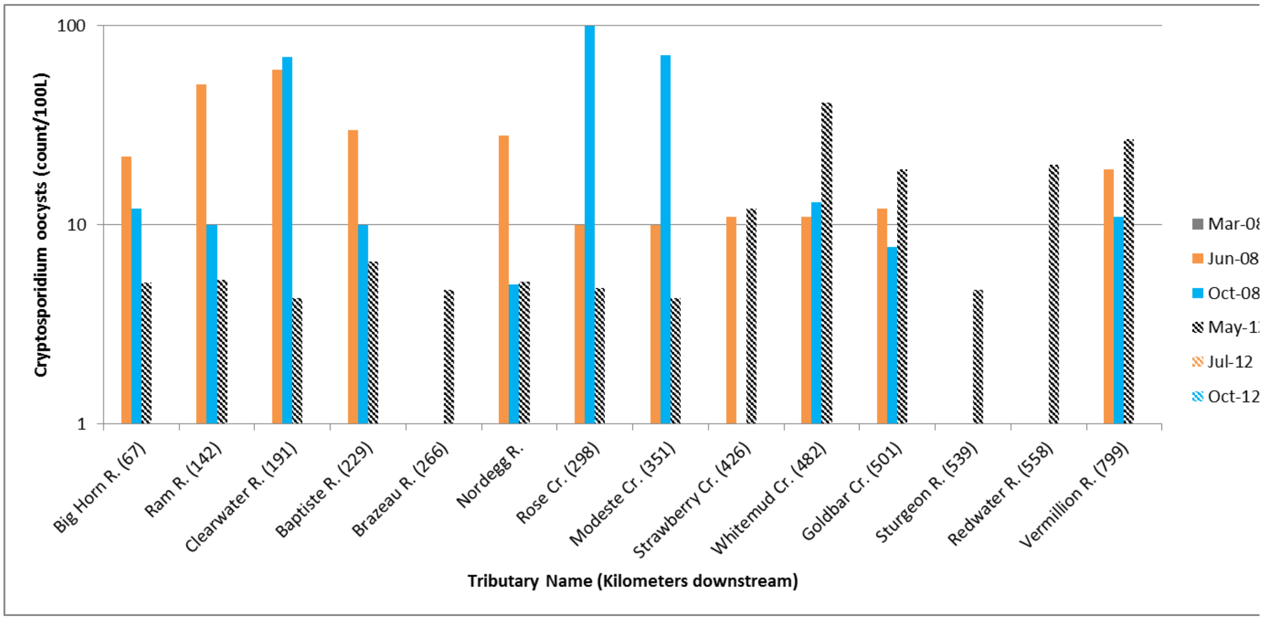


Figure 29. Cryptosporidium counts in the NSR tributaries during synoptic surveys



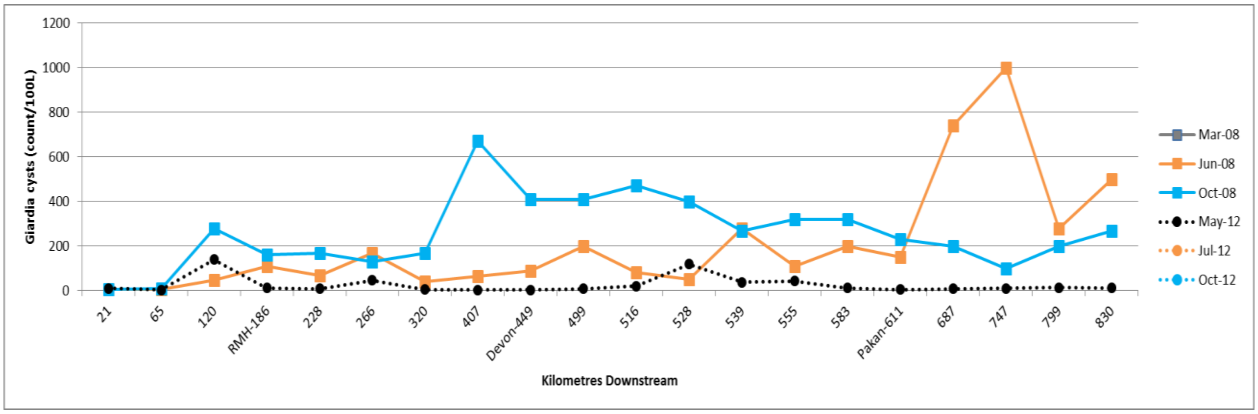
Note: MDL 4 count/100L

Giardia

Giardia cyst counts were also low in the May 2012 synoptic survey (generally < 100 /100L) compared to counts from June and October 2008 (Figure 30). In May 2012, *Giardia* counts were highest (140 and 120 counts/100L respectively) at a site upstream of Saunders campground (120 km) and at the Fort Saskatchewan Hwy 15 bridge (528 km) likely reflecting local point sources. The large peaks in *Giardia* at Genesee Bridge (407 km) 670/100L in May of 2012 and 1.69E+12 counts/100L in October 2008 was attributed to the Drayton Valley WWTP (Clearwater 2010). Elevated *Giardi*a counts (>300 cysts/100L) were previously reported in the NSR within the City of Edmonton during wet conditions from 2008-2012 (Golder 2013, 2013b). Concentrations were higher in downstream locations compared to upstream locations, with higher concentrations measured during wet conditions (Golder 2013).

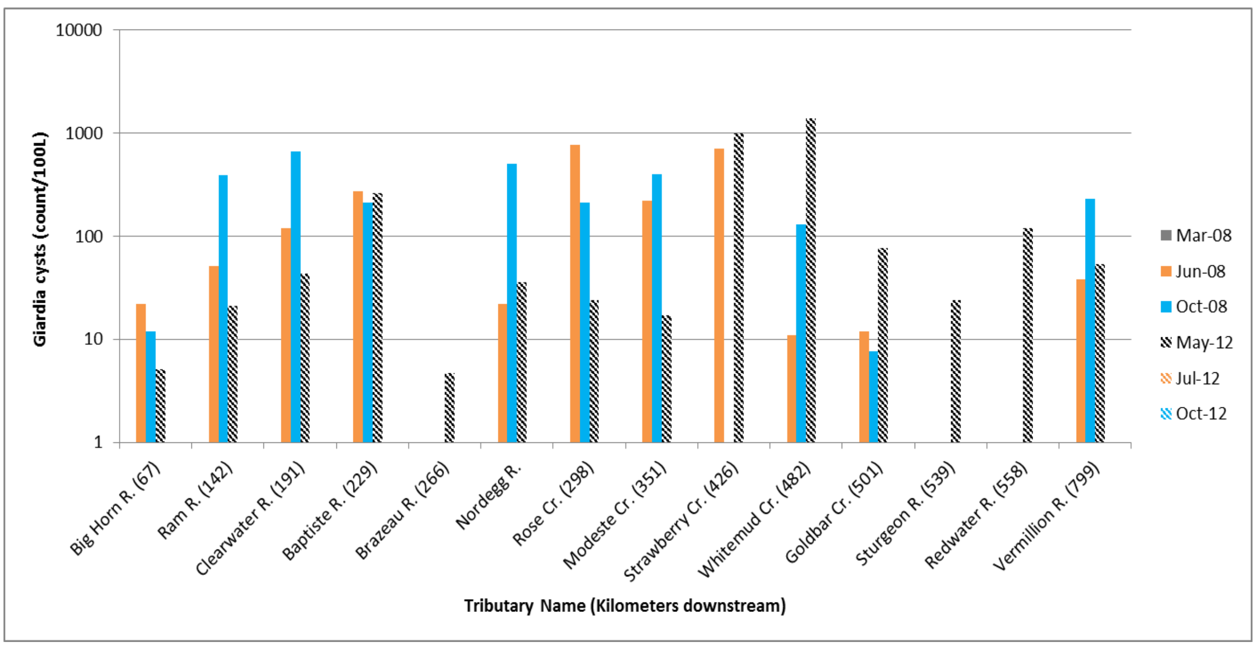
Giardia counts were low in upstream NSR tributaries with the exception of Baptiste River (>100/100L, Figure 31). In May 2012 counts were high in Strawberry and Whitemud Creeks and may have reflected local runoff from urban sources. There were no obvious patterns between the 2012 and 2008 synoptic survey data. Concentrations of *Giardia spp*. were also detected at Gold Bar Creek and Sturgeon River during the 2012 spring and summer high flow sampling program for the City of Edmonton and in the treated effluent from the Gold Bar and Capital Region WWTPs (Golder 2013b) during the 2012 spring and summer high flow sampling program (Golder 2013b).

Figure 30. *Giardia* Counts in the NSR during Synoptic Surveys



Note: MDL 5 count/100L

Figure 31. *Giardia* Counts in the NSR tributaries during Synoptic Surveys



5.2.5.3 Temporal Variation

A trend analysis of LTRN sites found a slight increasing trend in fecal coliform bacteria during the open water season for flow-adjusted data[3] for Devon (1987 to 2011), but between 30 and 50% of the data were below the detection limit and the slope was zero, so the results have to be viewed with caution (Anderson 2012). Declining trends in fecal coliforms and *E. coli* were reported at Pakan for ice-cover and open-water seasons for the 1987 to 2011 period. Declines in bacteria at Pakan were associated with major upgrades at GBWWTP and ACRWWTP and resultant reductions loadings (Anderson 2012), as indicated by a significant step trend in the post-upgrade year 1998. The GBWWTP and ACRWWTP apply UV treatment to their final effluent and their bacterial load is now considered too small to affect river water quality as the effluent limit of 200/100 mL is routinely met. Increasing trends in *E. coli* were measured at HWY 17 for the ice cover season, however, some data quality issues (multiple MDLs) were reported for this sites' data set and were thought to potentially bias this trend. Multiple detection limits were dealt with by using ½ of the highest detection limit, such that for the period with lower detection limit, the analysis may have used artificially higher values in this period, if there were non-detects.

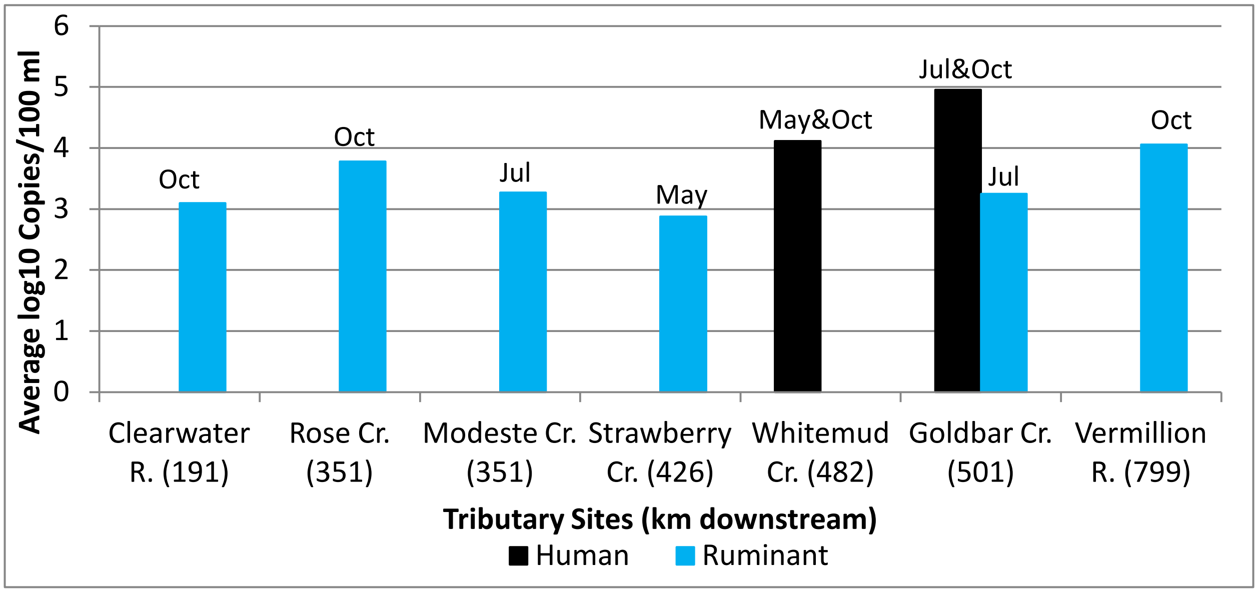
5.2.5.4 Bacterial Source Tracking

Microbial source tracking (MST) was conducted in 2008, 2011 and 2012. In 2008, MST methods were used over the open water season, to source fecal coliforms and *E.coli* collected from LTRN sites, NSR tributary sites and WWTP effluent samples to human, dog, generic mammalian, horse, bovine (cattle) and pig sources. In 2011, the source tracking was conducted in the fall and was focussed on ruminant (cattle, sheep, goat) and human sources. Seventy-three percent (45/62) of the samples with bacterial contamination at the NSR sites were identified as coming from human sources and only one 2008 sample taken from the Vermillion River u/s of the confluence with NSR was identified as from a ruminant source.

In 2012, samples were taken at 13 mainstem NSR stations and six tributaries during the open water season (April to October), mostly in concurrence with the synoptic surveys. Fecal contamination during this sampling program was sourced to human and ruminant sources. Human sources of fecal contamination were identified for samples from Whitemud, and Goldbar tributary samples, consistent with urban sources for the latter two creeks (Figure 32). Ruminant sources were identified in samples from Clearwater, Rose, Modeste, Strawberry, and Vermillion Rivers, consistent with non-point source loadings from livestock operations in these rural watersheds. Ruminant markers were also found in Goldbar Creek in July, suggesting a source upstream from the City. Results indicated the predominant bacterial contaminant sources (e.g. urban or agricultural) in the watersheds at the time of sampling, but the time of source identification varied among sites (Figure 31). Sampling of all tributaries within short time intervals is required to confirm these patterns. Data for other dates and sites were not available, so it is not clear if samples were submitted but did not contain human or ruminant markers or if these results represent the only samples that were submitted for analysis.

[3] *Flow adjustment is a procedure to remove the effect of changes in flow on trend analyses in parameters that are significantly related to flow. If regression analysis identifies a significant relationship between the variable and flow, the trend analysis was repeated on residuals of the regression.*

Figure 32. Bacteria Sources in NSR Tributaries (2012) identified by Microbial Source Tracking.



Note: Samples were collected at different times throughout the open-water season and therefore do not represent concurrent patterns. Sampling of all tributaries within short time intervals is required to confirm these patterns.

5.2.6 Metals

Metals are constituents of the earth crust and soils and they enter surface waters through weathering of superficial geological layers, erosion and groundwater discharge. High loads of total metals tend to coincide with high TSS loads at high river flows (see Section 5.2.8.1, this report, AECOM and Anderson 2011).

5.2.6.1 Status with Respect to Guidelines and Objectives

Several metals exceeded the Alberta Surface Water Quality Guidelines for the protection of aquatic life (PAL) in LTRN samples (Table 12). Most of these patterns were confirmed by the City of Edmonton river intake program in 2012 where concentrations were higher than chronic quality guidelines for total aluminum, chromium, copper, iron and zinc, with aluminum concentrations in a majority of samples measured above acute water quality guidelines (Golder 2013b). Many of these variables showed high levels exceeding guidelines in upstream reaches as well or showed a continued increase throughout the study area (see Section 5.2.6.2 below), indicating natural sources. Total cadmium and dissolved aluminum, however, showed an increase between Devon and Pakan,

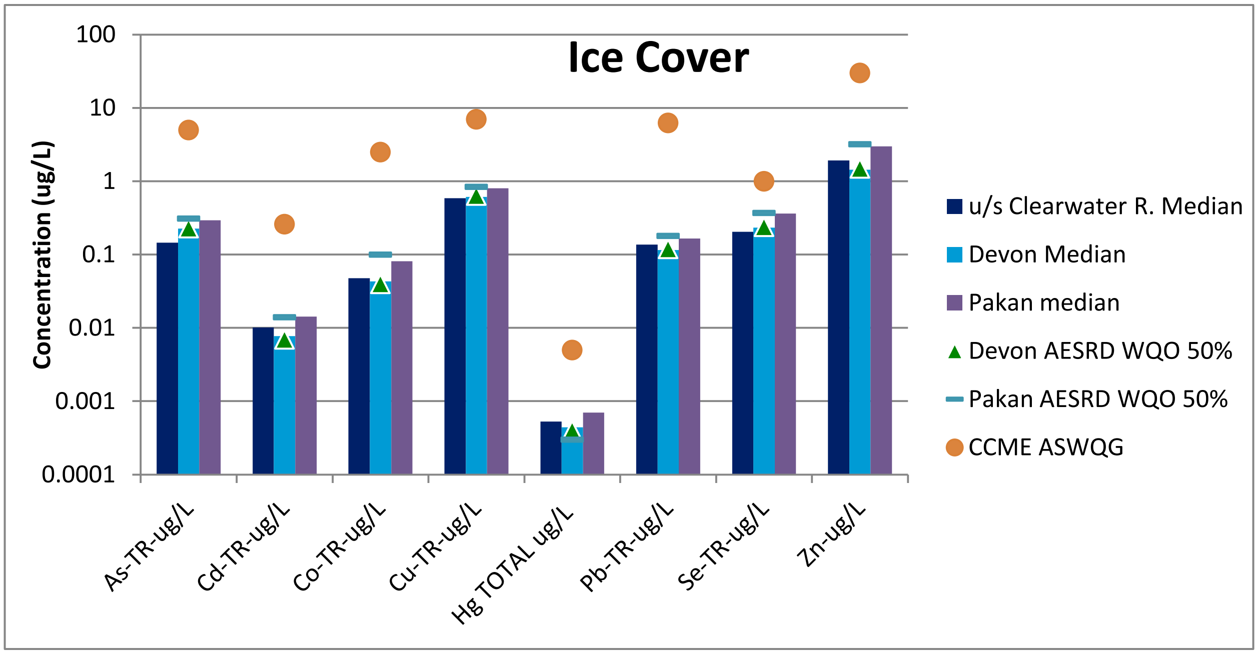
Table 12. Number of Metal Samples that Exceeded Alberta Water Quality Guidelines

Metal		u/s Clearwater R.	Devon	Pakan
Al - T µg/L	n	18	42	44
	%	100	100	100
Al - D µg/L	n	0	0	10
	%	0	0	32
B - T µg/L	n	18	42	44
	%	100	100	100
Cd - T µg/L	n	1	6	9
	%	6	14	21
Co - T µg/L	n	0	3	1
	%	0	7	2
Cu - T µg/L	n	0	3	1
	%	0	7	2
Fe - T µg/L	n	7	15	20
	%	39	38	46
Pb - T µg/L	n	0	2	0
	%	0	5	0
Ag - T µg/L	n	0	2	0
	%	0	5	0
Zn - T µg/L	n	0	2	0
	%	0	5	0

The numbers of samples exceeding chromium guidelines that were documented in the Edmonton intake program were not observed in the LTRN data; in fact, hexavalent chromium, one of the two chromium forms (along with trivalent Chromium) for which guidelines exist, was not detectable in most LTRN samples (> 80%). This discrepancy was likely due to the fact that Golder (2013b) compared total chromium results to the guideline for hexavalent chromium, while the LTRN dataset contained measurements of total and hexavalent chromium, the latter of which could be compared directly. Hexavalent chromium (Cr (VI)) made up a very low proportion (average 0.2%) of the total in the LTRN data set. Hexavalent chromium therefore does not exceed applicable guidelines in the NSR, while the status of trivalent chromium is unknown.

Metals for which SSWQOs were determined are summarized in Figure 29. Under ice cover exceedances occurred for Cd and Co at Devon and concentrations above the Devon SSWQO were noted at the site upstream of Clearwater River indicating high background concentrations. High background concentrations were also noted for Pb and Zn. During the open water season only Co showed a high background concentration upstream of Clearwater. Median total mercury was above the SSWQO for both seasons at Pakan, but the same was true for LTRN data collected from Clearwater River and Devon sites. However, both were well below the CCME ASWQG value suggesting that the pilot site-specific Hg water quality objective (McDonald 2013) may be low relative to background conditions or that there is a new source of mercury in the headwaters (Figure 35). No long-term trends were found, however, by Anderson (2012). The SSWQO Hg objective should be reassessed.

Figure 33. Median LTRN Metals Concentrations (2007-2102) Under Ice and in Open Water Relative to SSWQOs and ASWQGs.



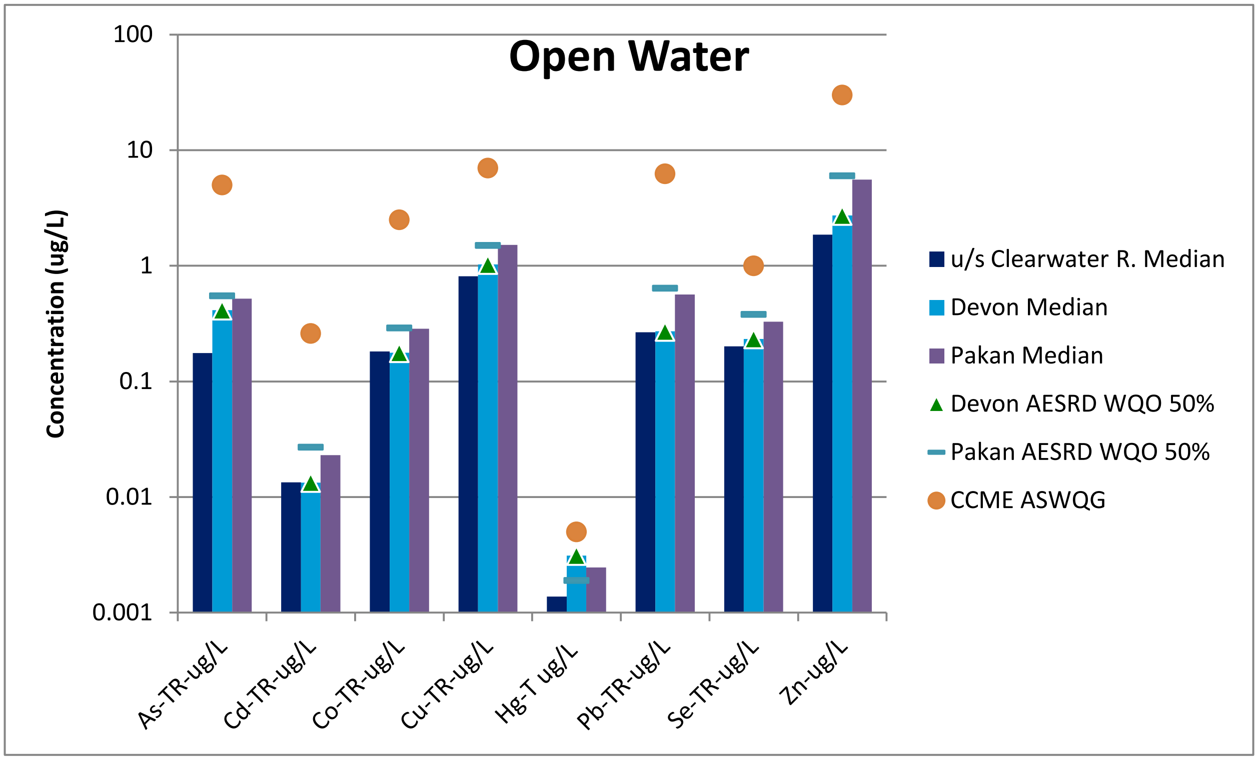
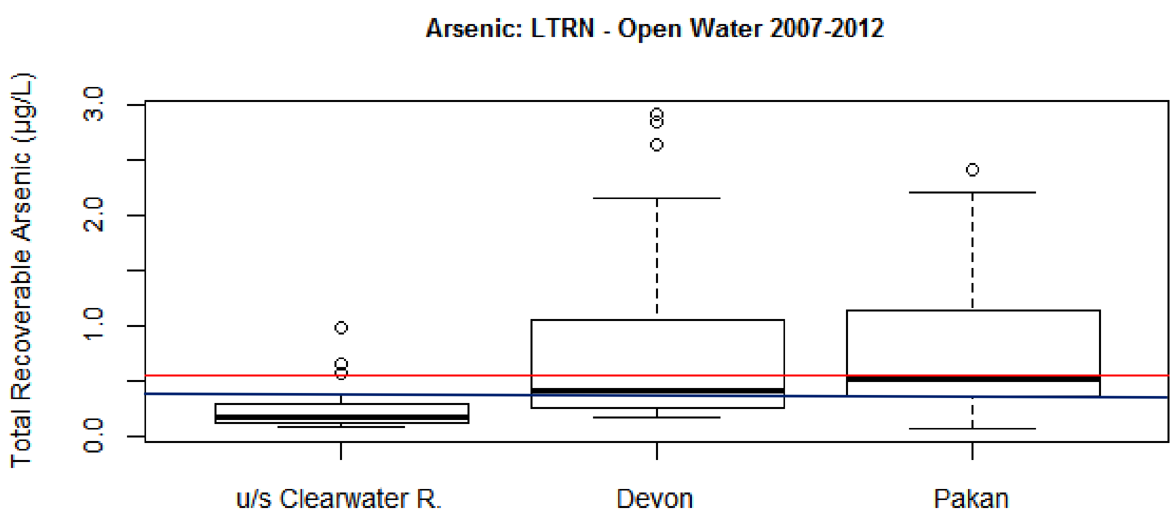
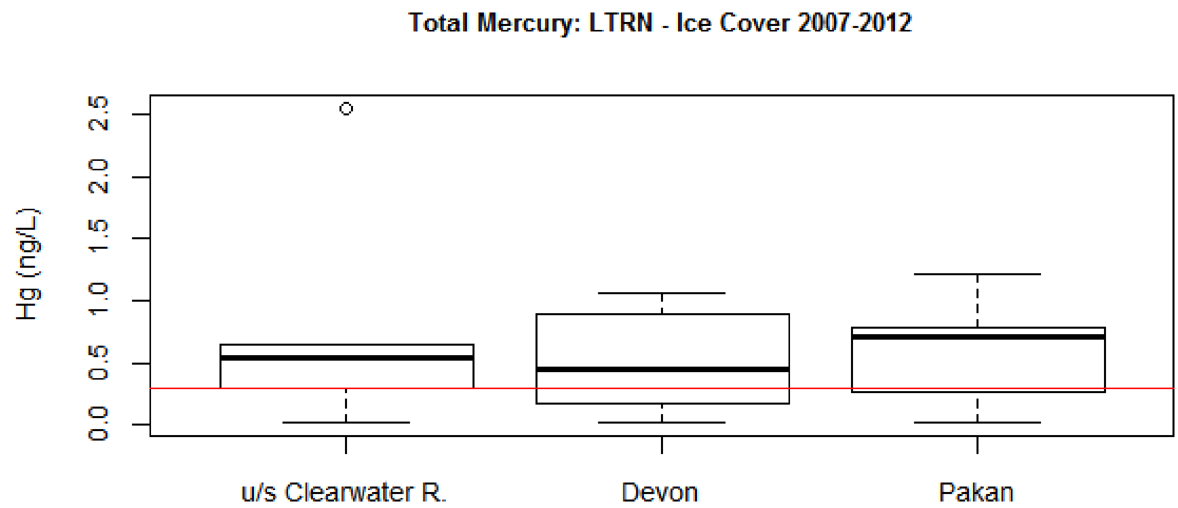


Figure 34. Boxplot of Total Arsenic at LTRN Sites During Open-Water Season 2007-2012



Note: The red horizontal line indicates the Open-Water SSWQO for Arsenic at Pakan and the blue line indicates the SSWQO for Devon.

Figure 35. Boxplot of Total Mercury at LTRN Sites for Ice-Covered Season 2007-2012



5.2.6.2 Spatial Variation

Metals are often found in naturally elevated levels in surface waters and so guideline exceedances should be interpreted in this context. Only if spatial patterns point to an anthropogenic source can elevated levels be of concern and be targeted and potentially reduced by management strategies.

Metals displayed four different spatial trends in the 2008 and 2012 synoptic surveys (Table 13): no trend, increase in the headwaters followed by stable levels (Figure 36), continuously increasing trend (Figure 37), or a significant increase downstream of the CR-IH reach (Figure 38). The first three patterns can be related to natural factors, as no change or a steady increase was observed and because increases started in the relatively undisturbed mountain regions. Metals in the fourth category would indicate an anthropogenic source, given the concentrated urban non-point and municipal and industrial point sources in the reach where the change occurred. The LTRN total metals data supported the total metals pattern observed in the synoptic survey.

Table 13. Spatial Patterns Displayed by Dissolved and Total Metals in 2008 and 2012 Synoptic Surveys.

Spatial Pattern	Stable/ No trend	Increase in Headwaters, then stable	Increasing Continuously	Main Increase d/s of CR-IH
Dissolved Metals	Be, Fe, (Mn), Se, Ag, Th, Sn,	Ba,	Sb, As, B, Cu, Pb, Li, Tl, U, V,	Al, (Bi), Cd, Co, (Mn), Mo, Ni, Zn,
Total Metals	Cr, Se, Sn,	Al, As, Ba, Be, Co, Fe, (Pb), Ag, Th, Ti, V, Zn	Sb, B, Cd, Cu, (Pb), Li, Mn, Hg, Ni, Tl, U,	(Bi), (Cd), Mo,

Note: Parentheses indicate metals that showed the pattern in some synoptic surveys, but not all. Seasonal differences in spatial patterns are displayed in synoptic graphs for all variables in Appendix E.

Concentrations of total aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, molybdenum, selenium, silver and zinc were higher than the PAL or agricultural use guidelines in at least one sample from tributaries in the 2012 sampling program (Golder 2013b). The increases of metals in the CR-IH reach of the NSR may therefore also in part be attributed to tributary influences. Metal concentrations were frequently higher in Whitemud, Mill, and Gold Bar creeks compared to Horse Hills Creek and Sturgeon River, likely because the latter two have fewer urban impacts and lower TSS concentrations (Golder 2013b).

Figure 36. Synoptic Graph for Total Recoverable Iron 2008 and 2012

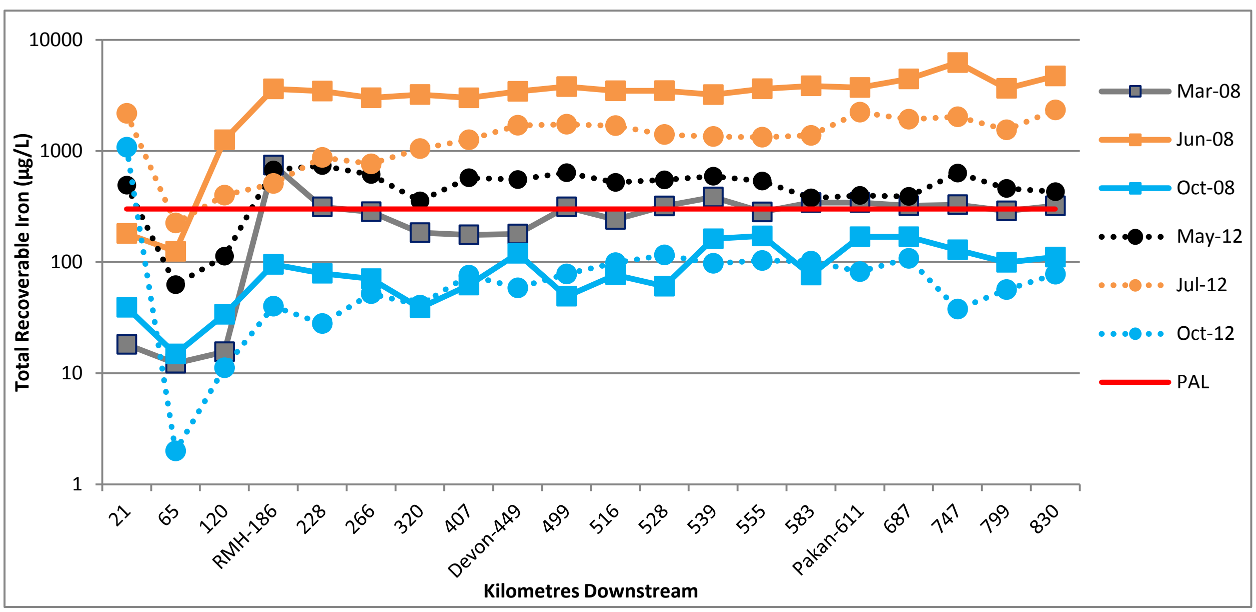


Figure 37. Synoptic Graph for Total Recoverable Cadmium 2008 and 2012

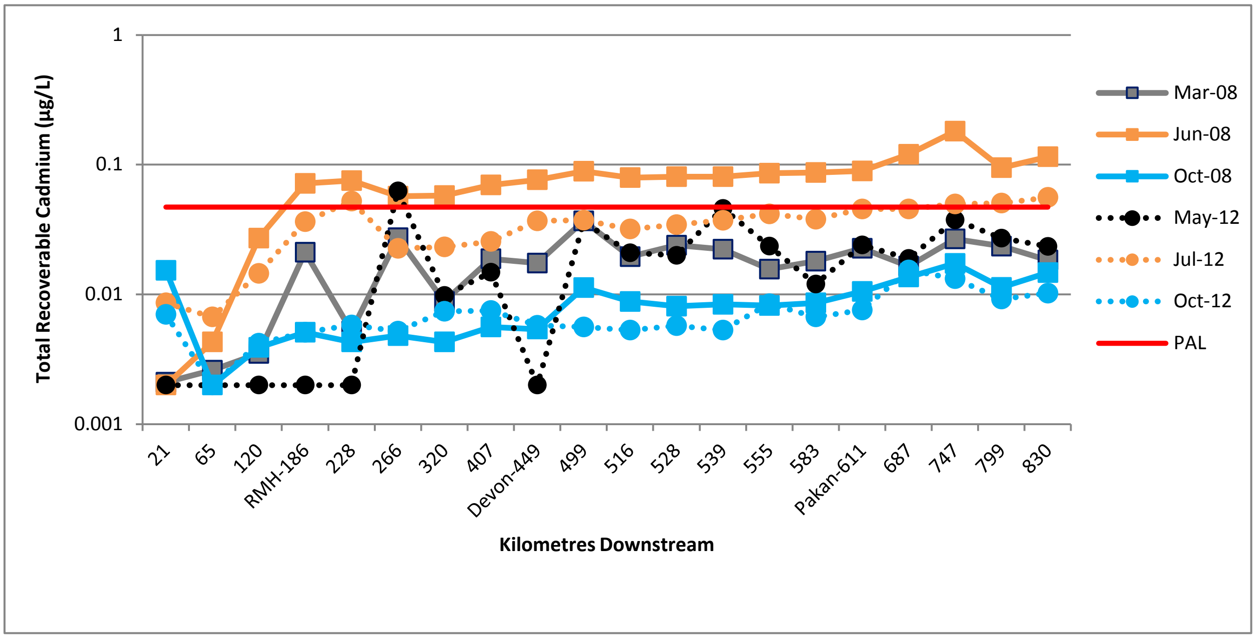
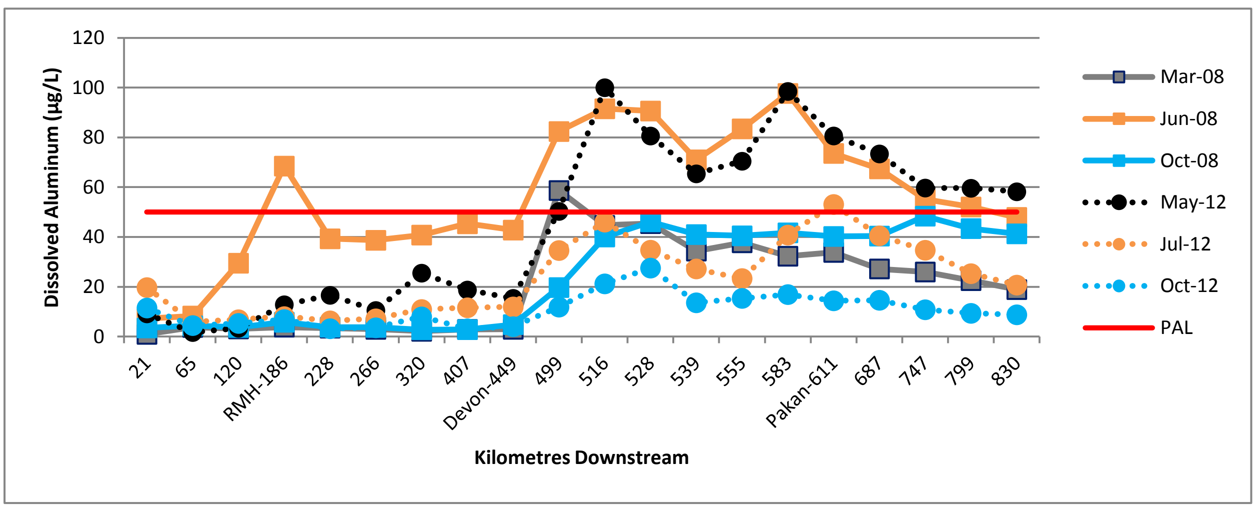


Figure 38. Synoptic Graph for Dissolved Aluminum 2008 and 2012



The metals indicative of a human source are mainly dissolved, including dissolved aluminum, bismuth, cadmium, cobalt, manganese, molybdenum, nickel and zinc. Only total bismuth (in March 2008, May 2012 and July 2012), total cadmium (in October 2008) and total molybdenum and total zinc followed the same pattern. The dissolved phase indicates that these metals were not associated with sediment inputs, therefore pointing to municipal or industrial wastewaters as a source. Total aluminum, molybdenum, and zinc concentrations in treated effluent from Gold Bar and Capital region WWTPs were higher than the PAL or agricultural guidelines in at least one of the WWTPs during the 2012 spring sampling program

(Golder 2013b), confirming that municipal effluent is one cause of the observed enrichment of these metals in the NSR CR-IH reach. Metals in the WWTP effluents occur mainly in dissolved form, which can be more toxic than particulate forms (AECOM and Anderson 2011).

Notably, most metals occurred in predominantly particulate form in tributaries and storm outfalls of the City, while metals in WWTP effluent occurred in dissolved form (Golder 2013 NSR). Concentrations of dissolved metals in tributaries, however, were similar to those found in WWTP effluent (Golder 2013b).

Some individual metals showed other patterns than those listed in Table 13: Dissolved chromium, for example, was stable or high in the headwaters and then decreased with major increases downstream of Pakan, possibly due to geological sources that are poorer in the prairie tributary watersheds compared to the headwaters or due to adhesion to sediments. Dissolved and total strontium were stable, but decreased within Edmonton for unknown reasons. Lastly, dissolved silica was stable in most synoptic surveys, but declined downstream between Edmonton and the Saskatchewan boundary in October 2008, possibly indicating enhanced uptake by elevated planktonic and/or benthic siliceous algal growth. Dissolved titanium showed the same decreasing pattern. This could be related to diatom uptake as well, as diatoms have been found to bio-accumulate trace levels of titanium and nano-biotechnology experiments successfully incorporated Ti into diatom frustules under silica starvation (Jeffryes 2006).

5.2.6.3 Temporal Variation

Anderson (2012) found a declining trend in total arsenic, zinc and selenium concentrations in monthly metals data at Hwy 17 since 1998. A step trend in selenium which occurred after spring 2009 at Pakan and at Hwy 17 was also detected in the 2007-2012 LTRN data (Appendix LTRN boxplots). Declining trends in these metals were suggested to coincide with the implementation of changes in industrial waste discharges (Anderson 2012).

5.2.7 Organics

LTRN samples were commonly analyzed for pesticides in current use, with only some samples submitted for broad spectrum analysis of pesticides, VOCs, PAHs and hydrocarbons. In total, one sample from upstream of Clearwater River and six samples each from Devon and Pakan were submitted for this broader analytical suite in the 2007-2012 period.

The only organic compound detected consistently and in all seasons by the LTRN water monitoring was 2,4-D, a pattern observed previously in Alberta waterways (Anderson 2005). The locations Upstream of Clearwater River and at Devon had only one and two samples, respectively, exceeding the MDL. In contrast, more than 50% of the samples at Pakan exceed the MDL with the maximum concentration at 0.104 µg/L. The median concentration[4] at Pakan was 0.007 µg/L (equal to the AESRD open water objective) while the 90th percentile was 0.030 µg/L (slightly below the AESRD 90th percentile WQO of 0.038 µg/L). Other compounds that were occasionally detected at or slightly above the method detection limit are summarized in Table 1.

[4] *Statistics were calculated if more than 50% of the samples exceed the MDL. For statistics with some samples less than the MDL, the concentration of samples at less than MDL was assumed to be one half of the MDL (i.e., 0.0025 µg/L).*

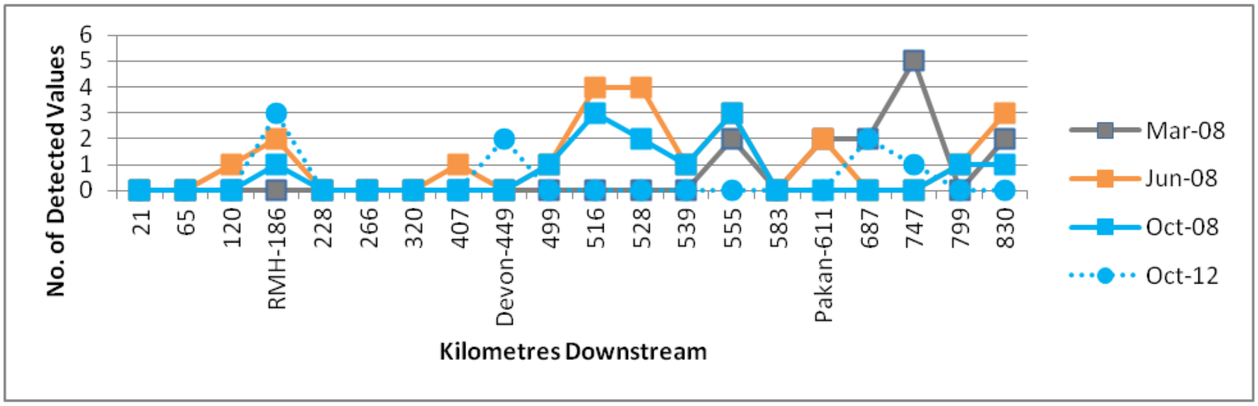
Table 14. Summary of Detections for Trace Organic Contaminants in NSR for LTRN Data from Upstream of Rocky Mountain House, Devon and Pakan (Jan. 22, 2007 to Aug. 9, 2012)

Analyte Group	Upstream of Clearwater River (# of detections)	Devon (# of detect ions)	Pakan (# of detections)
PAHs			
			RETENE (7-ISOPROPYL-1-METHYLPHENANTHRENE) (2)
Volatile Organic compounds (VOCs)			
	2-CHLOROETHYLVINYLETHER (1)	BUTYLBENZYL PHTHALATE (2)	2-CHLOROETHYLVINYLETHER (6)
	BUTYLBENZYL PHTHALATE (1)	DIETHYL PHTHALATE (2)	DIETHYL PHTHALATE (1)
		DI-N-BUTYL PHTHALATE (2)	DI-N-BUTYL PHTHALATE (1)
Pesticides			
		MCPA (1)	ATRAZINE (1)
		PICLORAM (TORDON) (2)	BENTAZON (1)
		TRICLOPYR (1)	BROMOXYNIL (1)
			CHLORPYRIFOS-ETHYL (DURSBAN) (1)
			CLOFIBRIC ACID (1)
			CLOPYRALID (LONTREL) (1)
			DICAMBA (BANVEL) (5)
			IMAZAMETHABENZ-METHYL (1)
			IMAZETHAPYR (1)
			IPRODIONE (1)
			MCPA (4)
			MCPP (MECOPROP) (11)
			PICLORAM (TORDON) (4)
			SIMAZINE (1)
			TRIALLATE (AVADEX BW) (1)
			TRICLOPYR (1)
Tri-halomethanes			
			CHLOROFORM (1)
			TRIHALOMETHANES (1)

5.2.7.1 Spatial and Temporal Variation

The mainstem NSR synoptic survey water samples from March, June and October 2008 and October 2012 were analysed for trace organic contaminants including Polycyclic Aromatic Hydrocarbons (PAHs), Volatile Organic Compounds (VOCs), Herbicides and Pesticides, including chlorinated pesticides, and trihalomethanes, a by-product of chlorination when organic and inorganic matter is present. The trihalomethanes consist of chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The count of detections above the MDL for all compounds by station for each synoptic event shows that there were detections at Rocky Mountain House, but that the majority of detections occurred downstream of Devon: within and downstream of the IF-CR reach (Figure 39).

Figure 39. Count of Detections Above the MDL for all Organic Compounds in NSR synoptic surveys 2008 and 2012



A total of 6 samples contained PAHs at or above the MDL, all exclusively in June 2008. These included anthracene and phenanthrene at Rocky Mountain House, benzene and fluoranthene downstream of Edmonton and perylene and retene at Pakan. A total of 16 detections for VOCs were reported, including various phthalates (15 detections) and a single detection of phenol, spread across the river length. The synoptic surveys did not detect any consistent spatial or temporal patterns for PAHs and VOCs, although the June 2008 sampling event had more detections than any other sampling event.

Pesticides, especially 2,4-D (herbicide) and MCPP (herbicide), were never detected upstream of Devon and regularly detected downstream at concentrations near the MDL. 2,4-D was detected a total of 17 times across all seasons. MCPP was detected 7 times at concentrations at or greater than the detection limit and was reported at concentrations less than the MDL 5 times. The herbicide Dicamba was detected 3 times above the MDL and the guideline in October 2008, while MCPA, another herbicide, was confirmed once at concentrations below the MDL. The trihalomethane chloroform was detected at 0.151 µg/L[5] at Elkpoint once in March 2008.

The pattern of increased numbers of detections in the synoptic surveys within and downstream of the IH-CR reach is mainly caused by pesticides. This pattern was also observed by the City of Edmonton River

[5] *Well below the CCME Guideline for the Protection of Aquatic Life of 1.8 µg/L.*

intake program (2013c), where pesticides were more frequently detected at the downstream Dow Chemical location compared to the upstream E.L. Smith WRP location, with concentrations typically higher at the Dow chemical location compared to the E.L smith WTP location. In general, a larger number of pesticides were detected by the Intake Program than in synoptic surveys, including 2,4-D, Bromoxynil, Dicamba, Diuron, MCPA, MCPP, and Triclopyr, likely due to a greater sampling frequency.

The organic contaminants in NSR water generally occurred near the MDL concentration and while likely of low ecological significance, may warrant further intensive investigation to identify sources and remedial options.

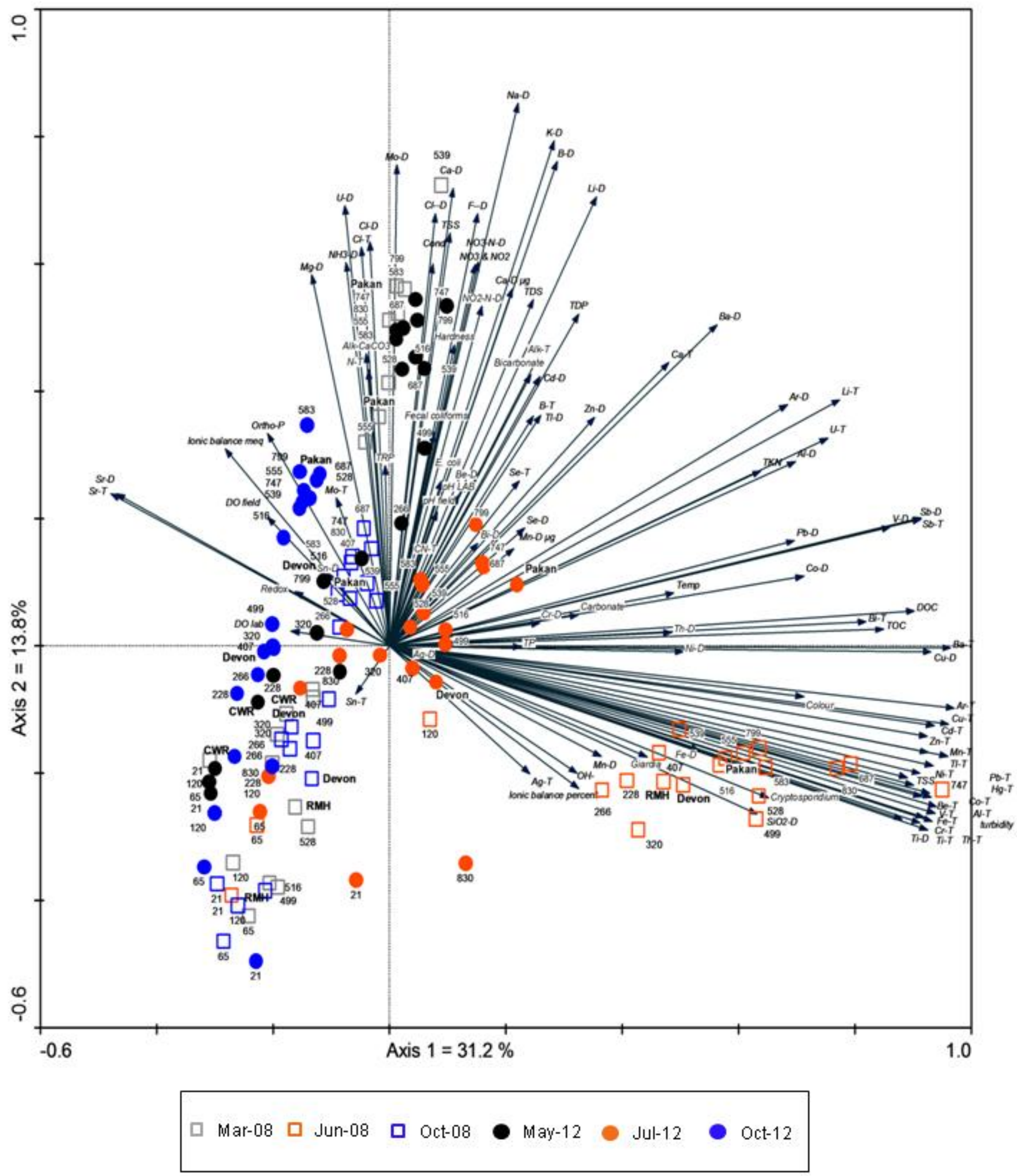
5.2.8 Synoptic Water Quality Summaries

Principal components analyses (PCA) were conducted to summarize patterns in synoptic surface water chemistry data, including general variables, nutrients, pathogens and total and dissolved metals. Organic compounds were excluded due to the large number of non-detects. Separate analyses were conducted on the synoptic mainstem data for 2008 and 2012 (Figure 40) and the synoptic tributary data for 2008 and 2012 (Figure 41). Variables that were associated with the first PCA Axis (i.e. arrows near the axis) played the largest role in differentiating water chemistry between the samples. Variables associated with the second axis showed the second-most important patterns in water chemistry, which were unrelated to the patterns of the first axis. Samples at the tip of the arrows had higher concentrations of the variables that these arrows represent, while samples plotting at the “tail” end of the arrow had lower concentrations.

5.2.8.1 Mainstem Synoptic

The first principal component (Axis 1) of the mainstem synoptic PCA corresponded to seasonal variation with a major influence of the high flow June-2008 samples, as indicated by the June 2008 samples scoring high on Axis 1. The second axis corresponded to a spatial pattern in water quality, with upstream sites (including sites at 21 to 499 km downstream to just past Devon) clustering together at the bottom of the second axis, with lower concentrations of variables related to Axis 2 and sites further downstream at the top of the axis, with higher concentrations of Axis 2 variables. The exception was the furthest downstream site (at 830 km), which also appears at the bottom of the x-axis in June 2012. This suggest that assimilation processes downstream of the IH-CR WWTP and industrial inputs may have improved water quality.

Figure 40. Principal Components Analysis of Mainstem Synoptic Water Quality 2008 & 2012



Nutrients:

Total nutrients, such as TP and TKN, scored high on the first axis, likely due to large peaks in the June 2008 samples (see also Figure 20 and Figure 23). TP is associated with suspended sediments and given the large influence of the June 2008 sample in the mainstem PCA, variation in TP is governed by the seasonal patterns in suspended sediments as well. Dissolved nutrients increased along the second axis, corresponding to the spatial up-stream to down-stream pattern, consistent with loads from WWTP effluent inputs and from prairie tributaries.

Metals:

Most total metals scored high on the first axis, along with June 2008 samples, and to a lesser degree, the July 2012 sampled, indicating that high concentrations of total metals corresponded to the sediment-rich high flow samples. Most dissolved metals and some total metals scored highest on the second axis, along with sites located downstream of Edmonton, likely indicating point-source influence.

Bacteria:

Giardia and *Cryptosporidium* were strongly associated with the first axis, indicating an upstream watershed source during high flow, while *E. coli* and fecal coliforms were associated with the second axis, indicating a consistent increase from upstream to downstream in all seasons.

General Parameters:

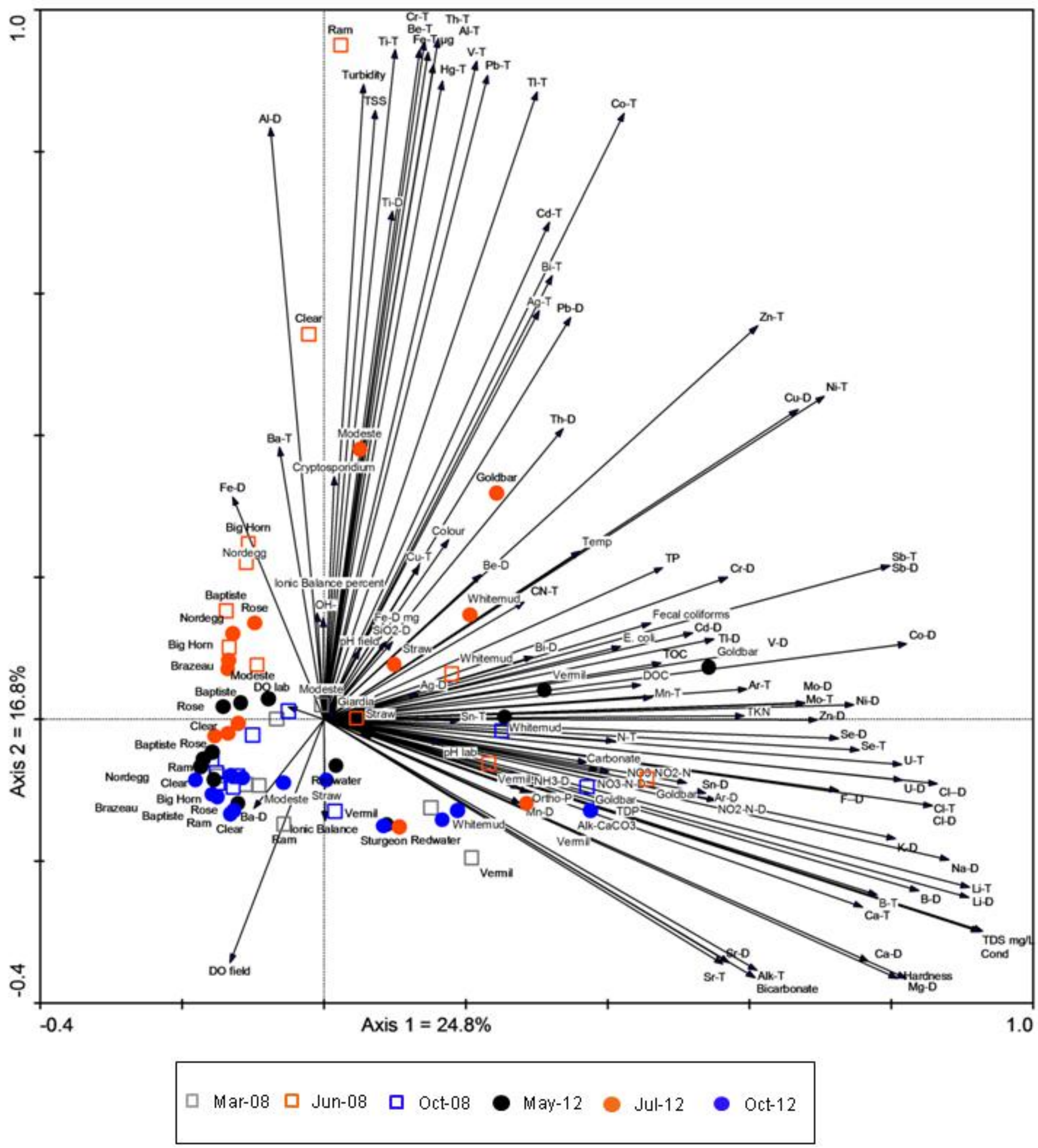
TDS, conductivity, pH and alkalinity were associated with the second axis, perhaps reflecting the increased influence of ion-rich tributaries and point sources in the downstream direction. Colour, DOC, TOC, turbidity and TSS were all associated with the first axis with turbidity, TSS and TOC in particular associated with the sediment-rich June 2008 sample.

TDS appeared twice in the figure, with “TDS mg/L” referring to non-filterable residue, while “TDS” was measured by a different method, but representing the same variable.

5.2.8.2 Tributary Synoptic

The first axis of the tributary PCA was driven by the geographical variation in streams with mountain and foot hill streams on the left and urban and agricultural streams (prairie streams) on the right (Figure 41). The second axis was driven by seasonal variation, with the June 2008 sample having the greatest influence, similar to the patterns seen in the mainstem PCA. Including sites from the headwaters of tributaries in the synoptic survey would help distinguish the influence of human from naturally occurring sources on the spatial pattern of water quality.

Figure 41. Principal Components Analysis of Tributary Synoptic Water Quality 2008 & 2012



Nutrients:

Most nutrients were associated with the first axis for urban tributaries such as Goldbar, Whitemud and the rural Vermilion River. Redwater and Sturgeon River scored intermediate along this axis, showing lower nutrient concentrations than Goldbar, Whitemud and Vermillion, but higher levels than foothill tributaries, such as Clearwater and Nordegg Rivers. This likely reflected the general pattern in naturally more nutrient-rich prairie streams but also increased nutrient loads from urban and agricultural land uses in the prairie streams.

The distinction between dissolved and total nutrient patterns found in the mainstem differed from that in the tributaries. All nutrient species, regardless of their form, showed the largest differences spatially, from upstream to downstream tributaries, whereas seasonal differences were more pronounced in the mainstem. These patterns demonstrate that geographical factors, including location and land use, play a larger role in tributary nutrient patterns than the influence of seasons.

Metals:

Total Cr, Be, Fe, Th, Al, V, Hg, Pb were associated with the second axis, indicating that these metals were controlled by the seasonal suspended sediment patterns through the June 2008 sample and, to a lesser degree, the July 2012 sample.

A large number of dissolved metals, such as Ni, Zn, Se, U, and Co and some total metals such as Ar, Mo, Se, and U, were represented by the first axis which was associated with tributaries in urban areas.

Bacteria:

Fecal coliforms and *E.coli* were associated with the first axis, corresponding to urban and agricultural sources. *Cryptosporidium* was associated with the second axis, corresponding to seasonally-dominating watershed sources, similar to the mainstem PCA.

5.2.8.3 Overall Discussion

The mainstem and tributary PCA showed the same two main patterns in water quality, but their order of importance differed. The spatial differences in water quality from the headwaters to the prairies dominated variation in the tributaries (PCA axis 1) and were secondary (PCA axis 2) in the mainstem. In contrast, the seasonally sediment-rich high flow samples in June 2008 and in July 2012 (although to a lesser degree) drove the main variation in the mainstem, but was secondary in the tributaries. One simple explanation for this pattern is that the summer high flow/high sediment load pattern observed in all mainstem sites was caused by a few mountain and foothill rivers only, so would not appear in any of the prairie tributaries and therefore not dominate overall variation in tributary data. In addition, the volumes supplied by these upstream tributaries in summer are much larger than those in the prairie tributaries, resulting in an overwhelming influence of this relatively local upstream phenomenon on the entire mainstem of the NSR, with little influence of tributary water quality on summer mainstem conditions. The summer high flows and associated sediment transport also caused extreme values in certain variables, such as TSS and turbidity, which dominated the PCA patterns despite standardization of the variables prior to analysis.

The main conclusions from the PCAs was that the two main water quality patterns in the surface waters of the NSR watershed, seasonal and spatial, were consistent across years and sites. The PCA summarized and confirmed patterns observed in individual variables of tributaries and the mainstem as discussed in previous sections. The PCA is a powerful visualization tool where variables that are associated with those seasonal and spatial patterns can be easily identified and subtle differences in water quality between sites and sampling dates discerned.

5.3 Sediment Quality

Sediment quality studies were initiated in 2006 in which the top 2 – 4 cm of sediment were scooped into appropriate storage containers for analysis of metals and trace organics (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010). Seven sites were collected on the mainstem of the NSR in 2007 and this was increased to 20 sites in 2008. Sampling in 2008 included an additional two sites for PAH upstream and downstream of the Anthony Henday Bridge in Edmonton.

Sediments were sampled at 20 locations along the NSR from Rocky Mountain House to Lloydminister again in 2010 and 2011. An additional 10 samples (fine grained river bed/bank sediment were collected at the confluence of 10 tributaries of the NSR. Specific sampling techniques were not described (Stone and Collins, 2012). The information presented below has been synthesized from these two reports.

5.3.1 Particle Size

The sampling sites along the NSR were dominated by sand and silt material, with a smaller component of clay. In 2007, sand proportions ranged from 38% at the right bank of the Vinca site to 70% at both the right bank of Rundle and the left bank of Vinca. Silt content varied from a low of 24% at both the right bank of Rundle and the left bank of Vinca, to a high of 55% at the Lea Park site. There was relatively little difference in the proportion of clay at each site, which ranged from 6 to 14%. The particle size proportions were similar for the 2008 data. Again, sand and silt were dominant, ranging from 19% at Brazeau to 78% at Rocky Mountain House and from 17% at Rocky Mountain House to 72% at Brazeau, respectively. Clay proportions varied little, ranging from 5% to 14% (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010).

This information demonstrates that most of the sediment samples were not from true depositional zones that would be representative of what is accumulating in the river bottom. Rather, the majority of locations should be considered transient accumulations sites and thus the grain size and the contaminant chemistry of the samples will vary depending upon preceding conditions (e.g. high or low flow). Unfortunately this introduces a bias into interpretation of the results which limits the ability of these samples to represent contaminant conditions in the NSR. Alternative methods to collecting suspended sediments in the water column that will better characterize the contaminant chemistry of the NSR should be considered for future investigations (Stone and Collins 2012). For the characterization of habitat quality for benthic organisms and bottom-feeders, on the other hand, bottom sediment mapping should be undertaken to characterize grain size and identify the most apparent depositional zones for future sediment and benthic organism sampling.

For both the 2007 and 2008 data, the proportion of sand tended to decline longitudinally from upstream to downstream with a corresponding increase in silt and clay content. Particle size influences the concentrations of contaminants within sediments, with the smaller silt and clay particles having a larger surface area relative to their mass and thus a greater likelihood of adsorbing pollutants, particularly phosphorus, metals and hydrophobic organic compounds. As a result, the trend toward decreasing particle size likely played a direct role in the higher contaminant levels observed downstream of Edmonton (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010). Drawing conclusions from a longitudinal comparison of sediment samples with variable grain size composition must be approached carefully. Grain size variability effects were exacerbated by the low to non-detectable levels of organic carbon in the samples. Overall, total carbon content decreased slightly downstream (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010).

5.3.2 Sediment Chemistry

5.3.2.1 Nutrients

There was a clear increasing trend in TKN content along the NSR for both the 2007 and 2008 datasets. An increasing longitudinal trend in TP over both 2007 and 2008 was less distinct, but still present. The transect data indicated, however, that nutrient levels in sediments did not show longitudinal trends that could be linked directly to point source discharges from the wastewater treatment plant discharges (Gold Bar and Capital Region Wastewater Treatment Plants-WWTP) that are located in Edmonton, suggesting confounding effects of the sampling locations .

5.3.2.2 Metals

Nearly all total and extractable metals were detected in NSR sediment samples. The metals content of sediments is determined primarily by the geology of the drainage basin, however, human activities can contribute metals to aquatic systems, where they can be adsorbed to, or otherwise incorporated in the sediments. Longitudinal trends in sediment metal concentrations were complex, and generally rather subtle. A slight increasing downstream trend in concentration was found for many metals in 2007. With more samples in 2008, increasing concentrations downstream were found for the majority of metals. Elevated concentrations (but not always peak levels) of chromium, lead, manganese and nickel were found at the right and left banks of the Fort Saskatchewan site, supporting this area as a potential source. However, at the spatial resolution of the sampling program, clear links between point sources and metal concentrations in sediments could not be established (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010). This is at least in part due to the fact that the sediment sampling locations were not clearly defined long-term depositional zones of fine grained material, a definition that should be possible using geomorphological surveys.

Sediment concentrations of cadmium, copper, mercury and zinc were well below the ISQG and PEL guidelines established by CCME (CCME 1999, 2001) in both 2007 and 2008. However, in both years, arsenic and chromium concentrations exceeded the ISQG at several sites throughout the NSR. The arsenic guideline was also exceeded by the concentration of extractable As at nine sites in 2008, but not in 2007. Arsenic and chromium guideline exceedances occurred throughout the basin, however, from headwaters to the Saskatchewan border and so natural sources are probable, and non-compliance with ISQG does not necessarily mean that aquatic organisms were experiencing toxic effects (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010).

Stone and Collins (2012) found that chromium and nickel exceeded the consensus based threshold effect concentration (TEC) by 28% and 20%, respectively of the NSR and tributary samples analyzed, respectively. In contrast to previous studies which reported that metal concentrations in the NSR increased downstream, no downstream increases in metal levels were observed in the Stone and Collins (2012) study. Metal speciation data indicated that the majority of Chromium (Cr) was bound to the largely non-bioavailable silicate phase and represented a natural geological source.

5.3.2.3 Trace Organic Compounds

The majority of the trace organic compounds analysed in the NSR sediments were non-detectable in the 2007 and 2008 samples. Detectable priority pollutants included benzo(a)anthracene, chrysene, di-n-butylphthalate fluoranthene, fluorene, naphthalene, phenanthrene, phenol and pyrene in 2007 and chrysene, di-n-butylphthalate, fluoranthene, fluorene, hexachlorocyclopentadiene, n-nitroso-diphenylamine, naphthalene, phenanthrene, phenol and pyrene. None of the detectable extractable priority pollutant (EPP) variables had associated ISQG or PEL values and PAHs were also analysed as a PAH scan with lower detection limits, and so the results may not provide an accurate resolution of patterns.

Clearwater Environmental Consultants and Kilgour & Associates Ltd., (2010), reported that the longitudinal pattern was fairly consistent for all PAHs in that:

- Concentrations upstream of Edmonton were generally lower than concentrations recorded within and downstream of Edmonton;
- The number of detectable compounds was lowest at Devon (5) and highest at the left bank of Walterdale (20);
- The highest concentrations for individual PAH compounds were often found at sites within Edmonton;
- The highest concentration for 13 of the 22 detectable PAHs was recorded at the left bank at Walterdale;
- Four other compounds were highest at the left bank of Rundle; and,
- Together, the right and left banks of the Walterdale and Rundle sites had the highest concentration records for 19 of the 22 compounds detected in the NSR in 2007.

In 2008, many more sites were sampled upstream of Devon and, in addition to these, sites upstream and downstream of the Anthony Henday Bridge (between Devon and the Walterdale Bridge) were also sampled specifically for PAHs in an attempt to improve the identification of possible urban sources. The Anthony Henday Bridge delineated the upper boundary of the most developed Edmonton urban area along the NSR. The 2008 data indicated that PAH detections were common in NSR sediments, but that urban contributions were not nearly as apparent as were inferred from the smaller 2007 data set and that concentrations were highly variable (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010). This lack of apparent trend and source signature was likely a result of a coarse sample grain size and very low concentrations of organic carbon. Thus, even though ISQG guidelines were exceeded for several PAHs within or downstream of Edmonton in 2007, all ISQG exceedances in 2008 were found upstream of Edmonton. This inconsistency points to the difficulty in sampling transient fluvial bed sediments for environmental chemistry purposes and the need to standardize sample characteristics among all samples.

Stone and Collins (2012) found PAHs in the NSR sediment at concentrations well below the consensus based threshold effect condition for the congeners evaluated in that study. There was no downstream increase in PAH levels. The majority of PAHs in NSR sediments were of pyrolytic origin (likely due to mining and combustion of fossil fuels and some industrial discharges). Two exceptions in the data set were Drayton Valley Bridge and Baptiste River near the mouth, where PAHs were likely of petrogenic origin from sources such as petroleum, crude oil and its refined products.

Total polychlorinated biphenyls (PCBs) were not detected at any site in either 2007 or 2008. Flame retardants such as polybrominated diphenyl ethers (PBDEs) were only detected in 2008 - BDE-17 was found on the left bank of 50 St., within Edmonton and BDE-47 was found at several sites along the NSR, from Drayton Valley, within Edmonton and at the left bank of Waskatenau (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010).

Nonylphenol Ethoxylates (NPEs) are solely anthropogenic in origin and are used in many industrial applications as surfactants and cleaning products. Of the seven NPEs analysed, five were identified in the NSR in both 2007 and 2008. Nonylphenol, and nonylphenol -di, -penta, -tri and –tetra ethoxylate were detected at several sites within and downstream of Edmonton but no NPEs were detected at any of the sites upstream of Edmonton (Whirlpool to Devon). All individual detections as well as well as the sum of NPE detected per sample were below the provisional ISQG of 1.4 µg/g . A PEL for NPE is currently not available (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010).

5.3.2.4 Pesticides

Organochlorine pesticides were not detected in 2007. In 2008, phorate, o,p-DDD and p,p-DDT were detected. Phorate and o,p-DDE were detected in the upper basin of the NSR, at the Rocky Mountain House and Bighorn sites, respectively. p,p-DDT was recorded in the lower basin, at the Duvernay, Elk Point and Highway 17 sites. All three detectable p,p-DDT values exceeded the ISQG for this compound, with two also exceeding the PEL (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010). These concentrations have to be interpreted carefully or even disregarded as the MDL was an order of magnitude higher than the PEL concentrations. Phorate (Thimet) is an organophosphate insecticide which is mostly used in Southern Alberta and there are no known users in the NSR basin.

5.3.2.5 Pharmaceuticals and Personal Care Products

Pharmaceuticals include medications made for human use or veterinary or agribusiness purposes, including, but not limited to antibiotics, pain relief and birth-control. Personal care products may include cosmetics, fragrances (including musks), lotions, shampoos, soaps, toothpastes, sunscreen and insectifuges. These products typically enter the environment when passed through or washed off the body and into the ground or sewer lines, or when disposed of in the trash, septic tank, or sewage system.

Only two of the 11 musks analysed were detected in 2007. Galaxolide and tonalide are synthetic fragrances that are used in many personal care products. Galaxolide was detected in sediments from all sites, except Rocky Mountain House. Galaxolide and tonalide were detected in 2008, but only at sites downstream of Edmonton. (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010).

Only two pharmaceuticals fluoxetine (Prozac, antidepressant) and pipemidic acid (quinolone antibiotic) were detected in the 2007 sediment samples. The addition of more sampling sites in 2008 corresponded with an increasing number of detectable pharmaceuticals. Acetaminophen (Tylenol, pain relief), cotinine (metabolite of nicotine, found in tobacco products), fluoxetine, norfloxacin (Noroxin, antibiotic), sulfamethazine (antibiotic) and trimethoprim (antibiotic) were neutral drug residues detected in the 2008 sediment samples. Acid drug residues detected in 2008 included methyl triclosan, n,n-diethyl-m-toluamide (DEET, pesticide) and salicylic acid (Aspirin, pain relief). Several of these residues were found within or downstream of Edmonton (e.g., acetaminophen, cotinine, salicylic acid). The residues were not found solely downstream of the Gold Bar and Capital Region WWTPs, but most were found in the upper watershed as well, at sites downstream of municipal effluent discharges s (i.e., Rocky Mountain House) (e.g., fluoxetine, norfloxacin, sulfamethazine, and thrimethoprim). Notable exceptions were methyl triclosan and DEET, which were detected in the mountain headwaters, upstream of Whirlpool and Saunders, respectively (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010).

5.3.2.6 Sediment Quality Index

Although a Sediment Quality Index (SeQI) was applied to the data (Clearwater Environmental Consultants and Kilgour & Associates Ltd., 2010) it's utility was limited by the low numbers of samples with detectable concentrations, the lack of associated sediment quality guidelines, the effect that small differences in concentrations can have on index values and the inherent issues with the sediment samples (standard characteristics of grain size and TOC content) . Based on ISQG compliance, the 2007 rankings ranged from 'Good' (97%) to 'Excellent' (100%). The 'Good' rankings all occurred within and downstream of Edmonton (left banks of Walterdale and Fort Saskatchewan and at Lea Park). The 2008 rankings were more variable, and ranged from 'Fair' (81%) to 'Excellent' (100%). 'Fair' rankings occurred throughout the NSR basin, including Saunders, Brazeau, right bank of Fort Saskatchewan, Duvernay, Elkpoint and at Highway 17. Decreasing trends in SeQI rankings were weak along the NSR sites.

5.3.2.7 Sediment Summary

The sediment data, even with the difficulties in finding appropriate sedimentation zones, indicate a much greater presence of trace organic contaminants in the NSR than the water samples. There was no consistent pattern along the watercourse between years for contaminant concentrations in sediment likely due to the difficulty in sampling apparently transient sediments in the NSR. Concentrations of individual compounds did exceed the ISQG for some PAHs and for p,p-DDT upon occasion. There were no exceedances of the PEL where these have been established for detected compounds.

5.4 Non-Fish Biota

5.4.1 Planktonic Algae

Planktonic algae are floating algae that live in the water column. Their growth is mainly controlled by the availability of nutrients and light, but also by grazing from planktonic invertebrates, such as zooplankton. Planktonic chlorophyll-a was monitored routinely at the LTRN sites as a measure of planktonic algae biomass.

Planktonic algae biomass was very low at the Clearwater and Devon sites, and increased significantly between Devon and Pakan (Table 15) in response to elevated nutrient concentrations from large point-source discharges, in particular WWTPs, in the IH-CR reach. Despite this increase, median values at Pakan remained in the oligotrophic to mesotrophic range for running waters, as defined by planktonic chlorophyll-a, TN and TP (Dodds 2006).

Table 15. Open-Water Summary Statistics of Planktonic Chlorophyll-a at LTRN sites, 2007-2012

Planktonic Chl-a (mg/m^3)	u/s Clearwater R.	Devon	Pakan
Mean	0.7	1.2	4.7
Median	0.6	0.8	3.6
Standard Deviation	0.5	1.1	3.7
n	28	42	44

Anderson (2012) measured declining trends in planktonic chlorophyll-*a* at Devon and Pakan Hwy 17 between 1987 and 2009, which may represent a biological response to declining nutrient levels along the river, as WWTPs were upgraded.

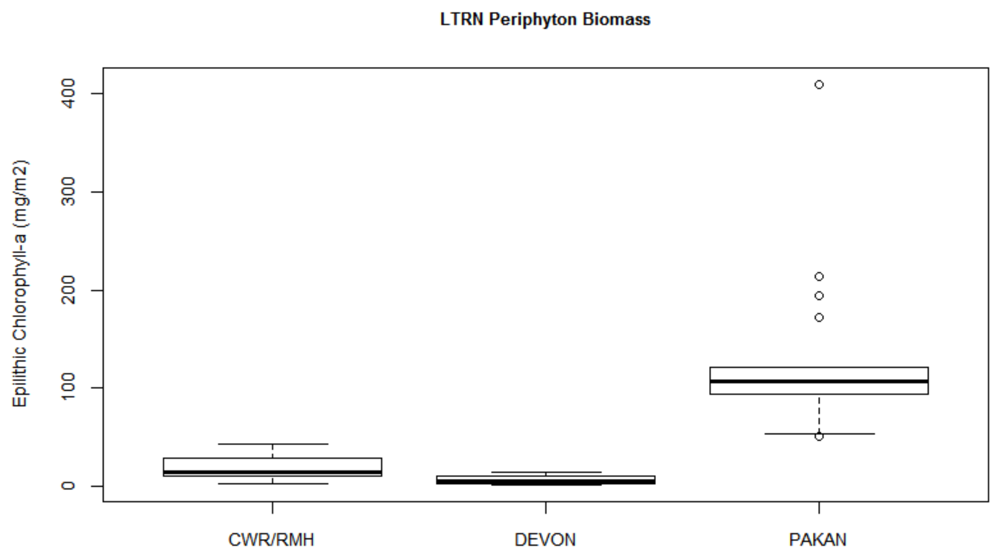
5.4.2 Benthic Algae

Benthic algae are algae that live attached to the substrate in the river bed, and epilithic algae are those benthic algae that are attached to rocks. Benthic algae form part of the periphyton community, which also includes bacteria and fungi. Benthic algae growth is generally controlled by the availability of nutrients and light. In addition, the overall benthic algae biomass is affected by benthic invertebrate grazing and shearing stress from flow. Epilithic algae chlorophyll a and ash-free dry mass (AFDM) were routinely measured at LTRN sites during the open-water season as measures of benthic algae biomass and overall periphyton biomass, respectively. In addition, detailed periphyton surveys were conducted from the headwaters to the Saskatchewan border, in conjunction with the 2008 synoptic survey, including left and right banks (Clearwater and Kilgour, 2010).

5.4.2.1 Biomass

Periphyton biomass at LTRN sites was low in the headwaters, even lower at Devon, and an order of magnitude higher than upstream sites at Pakan (Figure 42). The reason for the decrease in benthic algae biomass from Clearwater to Devon is unknown, but may be related to habitat, such as light regime, depth or velocity. The increase in benthic algae biomass at Pakan can be explained by elevated nutrient concentrations due to large point-source discharges, in particular WWTPs, in the IH-CR reach. This is obvious from the significantly larger chlorophyll-a levels on the right bank compared to the left bank, within the plumes of the Goldbar and Capital Region WWTPs (Clearwater and Kilgour, 2010).

Figure 42. Boxplot of Epilithic Periphyton Biomass collected at LTRN Sites.



The biomass levels in the upstream reaches were indicative of oligotrophic conditions (low productivity), while the levels at Pakan were indicative of eutrophic conditions (high productivity), as defined by benthic algae biomass in running waters (Dodds 2006). The threshold for nuisance benthic algal biomass of 150 mg/m^2, which was adopted as the site-specific water quality objective for epilithic algae in the Bow River below Calgary (BRBC 2008), was only exceeded on four occasions at the Pakan site.

5.4.2.2 Community Composition

The epilithic algae communities in the NSR were dominated by diatoms, which represent about 80-90% of the taxa count (Figure 43) and biomass at all sites (Clearwater and Kilgour 2010). Blue-green algae (Cyanobacteria) and green algae (Chlorophyceae) taxa occurred in low numbers across the study region. There were no significant changes in the relative importance of major algae groups (diatoms, green algae, blue-green algae) along the river, as their biomass increased about ten times. Diversity indices also remained relatively stable along the river. Community changes occurred on the species level within major algae groups, in particular diatoms, as was demonstrated by correspondence analysis, which showed distinct differences between algae communities collected from upstream and downstream reaches.

Figure 43. Number of Epilithic Algae Taxa for main Phyla in the NSR (2008)

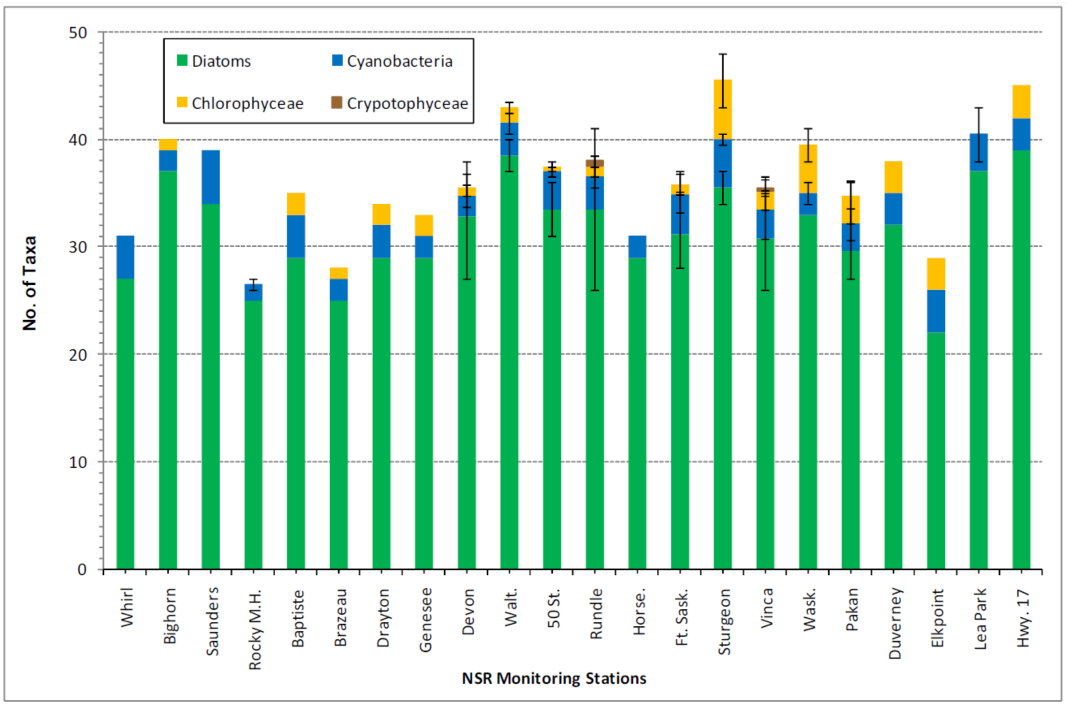


Figure C16 Longitudinal Trends in the No. of Taxa (by Phylum) for the NSR (2007-2008)

5.4.3 Macrophytes

A comprehensive macrophyte survey was conducted in 2010. This study showed that

- Macrophyte biomass increased steadily between Rocky Mountain House and Devon,
- Macrophyte biomass decreased steadily downstream of Devon, with the lowest biomass being observed downstream of Edmonton. These unexpected results were explained by patterns in turbidity, which reduces light penetration and may be a major controlling factor of macrophyte biomass in the NSR. Increased turbidity results from stormwater runoff from urban areas. Stormwater runoff is also higher in nutrients; however, macrophyte biomass declined in areas exposed to stormwater runoff. These results suggest that turbidity is a more important factor in controlling macrophyte biomass than nutrients in the Edmonton reach of the NSR.
- No consistent seasonal patterns in macrophyte biomass were observed between mid-August and early October at the sites between Fort Saskatchewan and Pakan, with macrophyte biomass remaining similar throughout the sampling program.

The authors noted a high variability of macrophyte density throughout the NSR, which may limit the representativeness of samples that were collected in macrophyte beds selected for sampling. Aerial and satellite-based surveys were recommended as more appropriate approaches to estimate macrophyte abundance throughout the NSR.

Another shortcoming of the study may have been the temporal focus on periods of maximum biomass, while not considering the conditions during which this biomass was accrued. Relevance of turbidity and light limitations could potentially be better assessed by a repeated sampling approach throughout the growing season, which would include the months before attainment of maximum biomass, e.g., late July and August.

5.4.4 Benthic Invertebrates

A comprehensive study of benthic invertebrate communities was conducted in 2007 and 2008 by Clearwater Environmental Consultants and Kilgour & Associates (2010) and the results presented in this section exclusively stem from that study.

Total benthic abundance was generally low upstream of the City of Edmonton, increased within the Edmonton area and then declined with distance from the IH-CR. The strongest positive correlation of total abundance was observed with periphyton chl-a, which can be expected, given that periphyton is a major food source for benthic invertebrates.

Figure 44. Total Benthic Invertebrate Abundance in the NSR in fall 2007 and 2008

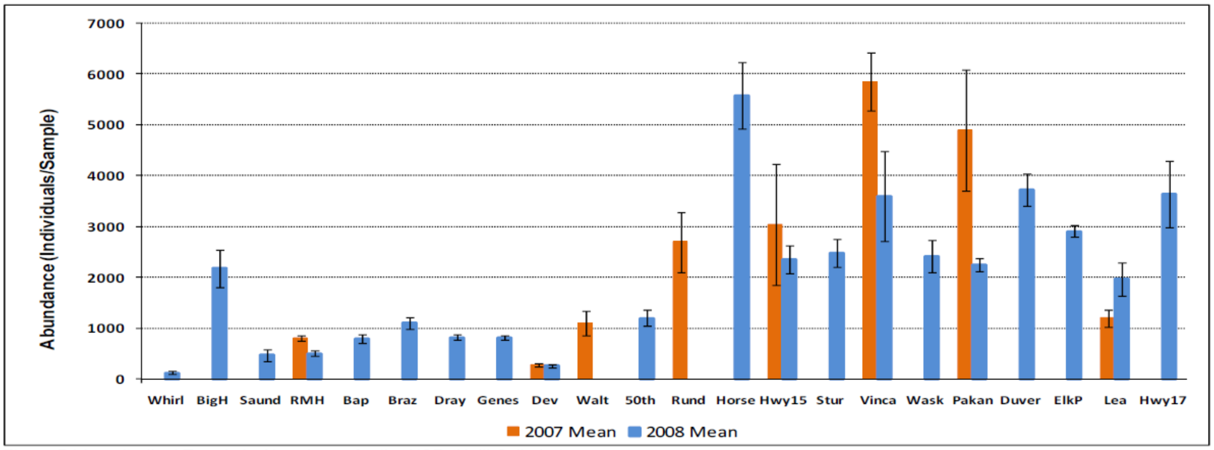


Figure B1 Longitudinal Trends in Abundance for the NSR (Neill Cylinder)

Note: Figure taken from Clearwater and Kilgour (2010).

Diversity index values were consistently above the threshold for degraded conditions (1), indicating reasonably good diversity. Diversity also remained relatively stable throughout the NSR, with some slightly lower values downstream of Edmonton. Diversity did not correlate with any of the analyzed water quality variables.

Figure 45. Benthic Invertebrate Shannon-Wiener Diversity in the NSR in fall 2007 and 2008

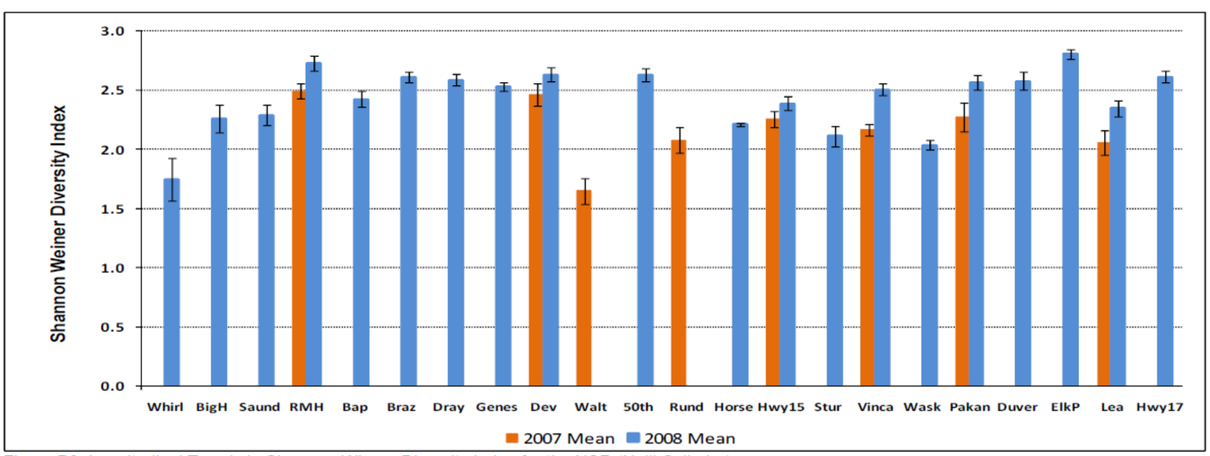


Figure B3 Longitudinal Trends in Shannon-Wiener Diversity Index for the NSR (Neill Cylinder)

Note: Figure taken from Clearwater and Kilgour (2010).

Total and percent abundance of EPT (mayflies, stoneflies, caddisflies), indicators of good water quality, were low in the headwaters, increased with distance downstream, were low at the Walterdale Bridge in central Edmonton and then increased with distance downstream. The only consistent indicators of water quality deterioration downstream of large point-discharges in the IH-CR were the increased percent Chironomidae, which are tolerant to pollutant loadings and lower oxygen levels, and lower evenness in the communities. These results were in stark contrast with earlier studies conducted in 1982, when EPT were virtually absent in the in the IH-CR (AECOM and Anderson 2011), demonstrating the large positive effect of WWTP upgrades on the benthic communities in the NSR.

Benthic communities from sites upstream of Edmonton were generally different from those within and downstream of the City. This difference was more obvious in Neill Cylinder samples (erosional habitat), which clearly separated in the analysis (Figure 46, top) whereas the Kick samples (depositional habitat) showed a more gradual transition in communities (Figure 46, bottom). Samples collected at the Walterdale Bridge, which is located upstream of all WWTP and industrial outfalls of the IH-CR, were similar to samples collected downstream of Edmonton, indicating that stormwater discharges or other local urban influences may have a strong but localized influence on benthic invertebrate communities. This location was not sampled in 2008, however, so another year of sampling would be required to confirm this pattern.

Figure 46. Correspondence Analyses of Benthic Invertebrate Samples from Neill Cylinder and Kick Samples, 2008.

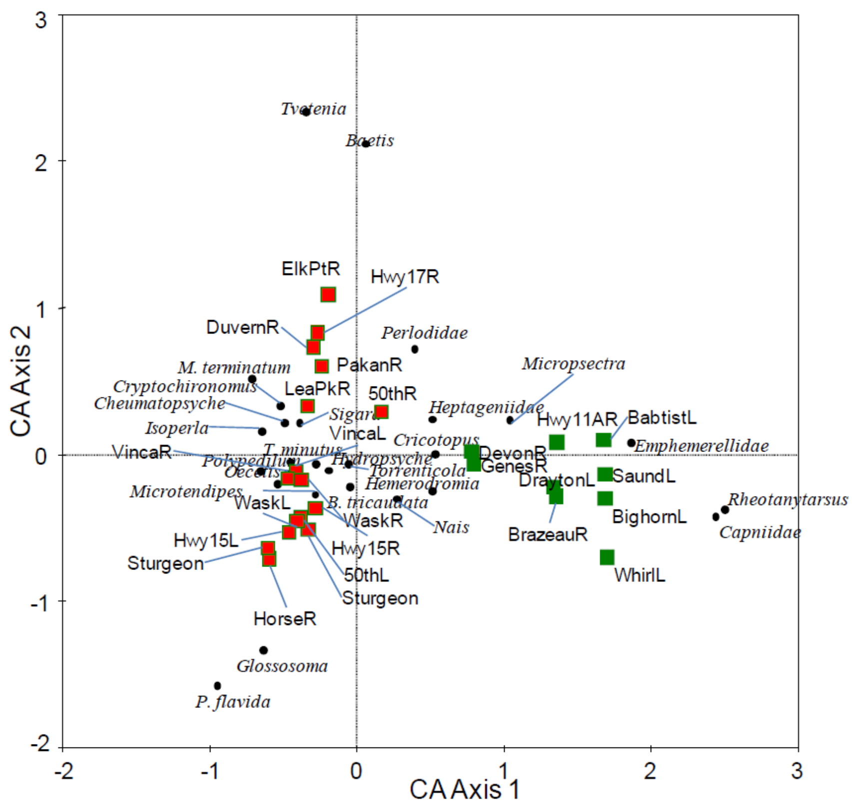


Figure B12. Correspondence Analysis (CA) biplot of 2008 Neill Cylinder benthic community taxa abundances.

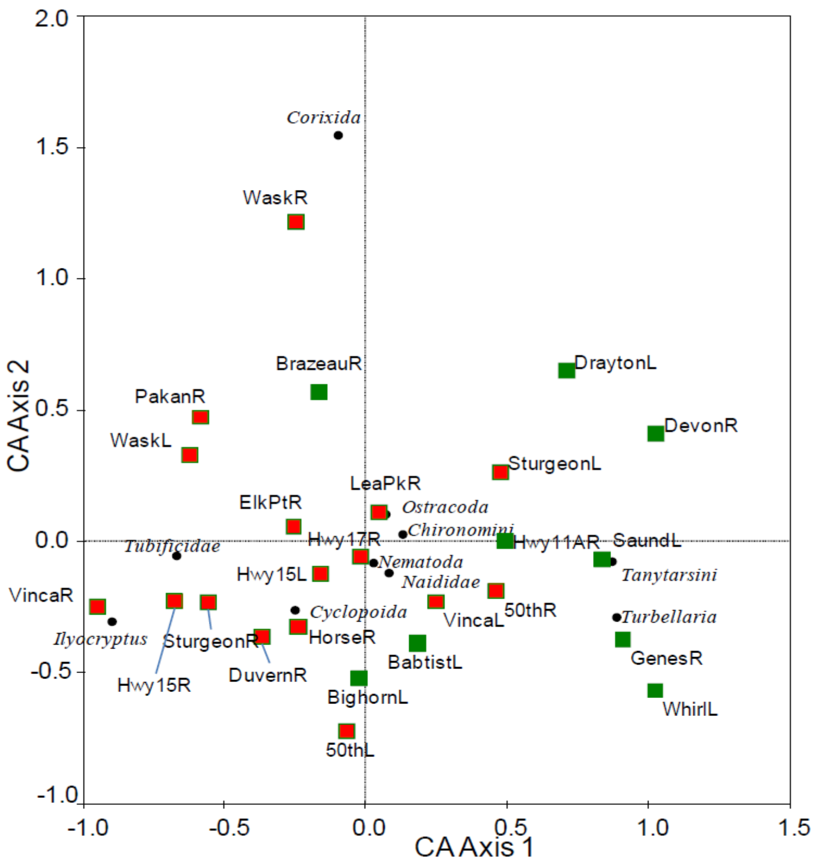


Figure B45. Correspondence Analysis (CA) biplot of 2008 kick sample benthic community taxa abundances

Notes: Figure taken from Clearwater and Kilgour (2010). Red symbols indicate sites within and downstream of the IH-CR, green symbols indicate sites upstream of the IH-CR.

Benthic community indices showed some differences between left and right banks, but these differences were not consistent and were far less important than upstream-downstream differences. They also did not confirm the expectation that the right bank should be more impacted from a series of point-source discharges; in fact, the right bank showed indications of better aquatic health, such as higher diversity and %EPT.

Multivariate analysis indicated that downstream distance, embeddedness (a habitat indicator) and alkalinity exerted the strongest influence on benthic community composition. Downstream distance was correlated to nutrients, which are reflective of both watershed and IH-CR point-sources, and alkalinity and embeddedness, which are naturally changing from upstream to downstream. This strong spatial component in both natural and human sources makes it difficult to determine the relative importance of human versus natural factors on community composition. As Clearwater and Kilgour (2010) noted, all these factors are related to the natural increase in nutrient and ion levels and habitat changes from headwaters to low-land reaches of a river, as described by the river continuum concept (Vannote et al.

1980). Benthic invertebrate communities in the NSR were therefore responding to the impacts from the IH-CR on the NSR with abrupt increases in abundance and some community changes, but these effects were superimposed on the effects of natural gradients in river and watershed characteristics from upstream to downstream.

5.5 Fish Tissue

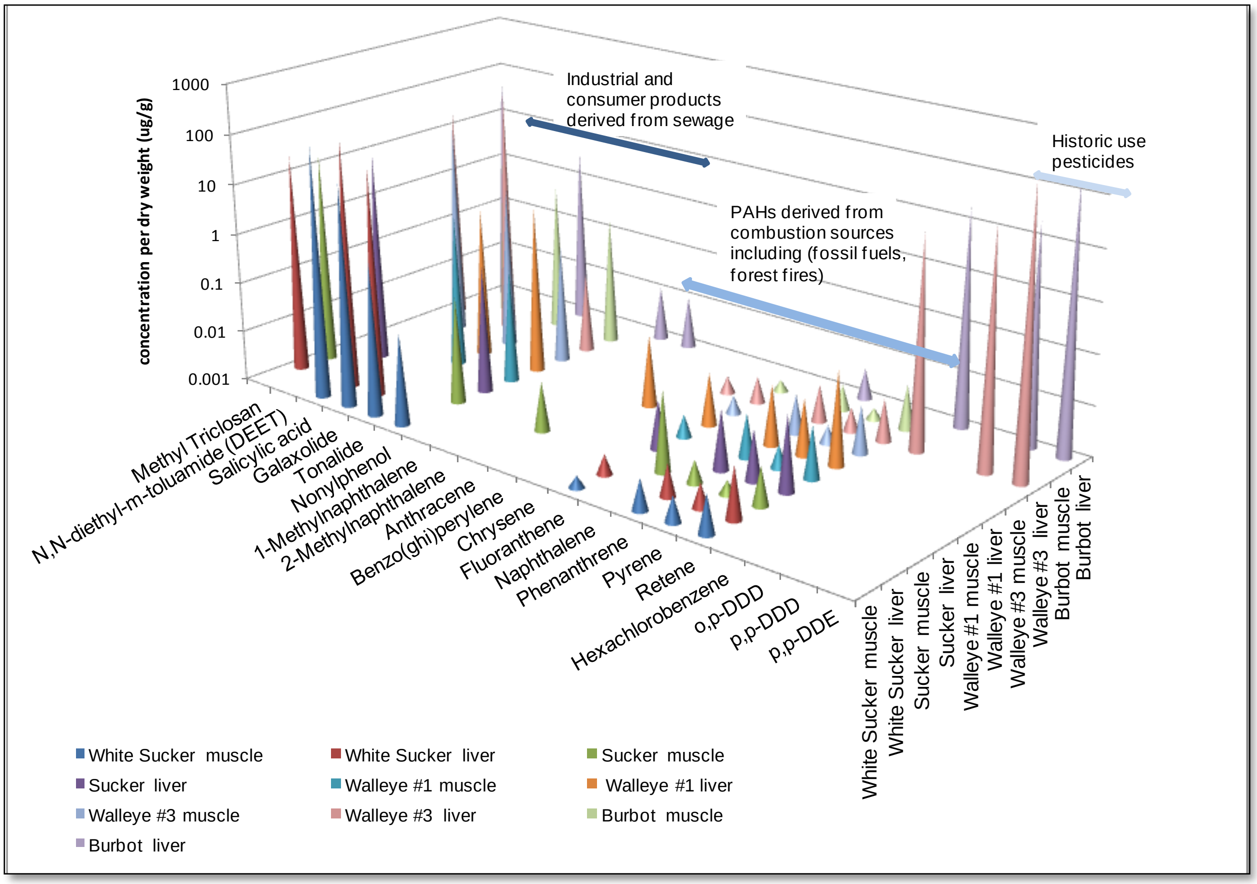
Fish tissue samples were collected at various locations from the NSR in 2011 and 2012. Muscle residue concentrations of metals were assessed in 2011 using a non-lethal dermal plug sample. In 2012 the fish were sacrificed and both dorsal muscle samples for all fish and liver samples for selected fish were sampled and analyzed for metals and trace organics. Species included in the sampling program were Goldeye, Sturgeon, Sauger, Mooneye, White and Long-nosed Sucker, Burbot, Walleye, and Rocky Mountain Whitefish. An assessment of the results for metals in muscle indicated that the results between 2011 and 2012 were not comparable and this is believed to be due to the different sampling techniques (i.e. dermal plug versus dorsal muscle).

Most of the analyzed metals were detected in most fish samples (see Appendic C3). The general pattern of concentrations of metals in 2012 was similar to 2011 (i.e. high concentrations are evident for calcium, chlorine, magnesium, potassium, sodium and sulfur) and the concentrations were generally in the same range. The variability between species was reduced largely because the high and low concentrations found in sturgeon in 2011 were not present in 2012. Metals that were preferentially concentrated in the liver tissue relative to the muscle samples by an order of magnitude in the 2012 samples included bismuth, chromium, cobalt, manganese, selenium and uranium. There are no Alberta guidelines for the analyzed metals in fish tissue, so the metal levels in NSR fish cannot be evaluated in quantitative terms.

A biota/sediment accumulation factor (BSAF) was used to characterize the bioaccumulation in fish from sediment. Interpretation of the BSAF was confounded by the different sources of data, use of migratory fish species with large home ranges, and the use of sediment data from 2010 and 2011 and 2012 fish data given that the latter were judged of better quality. Cd and Ni were the only metals that were significantly bio-concentrating in all fish, while most other metals except Cu were diluted in the fish muscle samples compared to sediment.

Only a limited set of trace organic contaminants were detected consisting of low level PAHs and industrial and consumer products believed to be derived from sewage effluents (Figure 47). These were observed in muscle and liver tissues for most samples. Hexachlorobenzene and metabolites of DDT were in one each walleye and burbot liver samples. These compounds were not found in any muscle samples indicating the preferential accumulation of these compounds in livers. The Catostomidae species (suckers) were the only species in which salycilic acid was detected and this same family of fish had the highest concentrations of DEET at 110 µg/g. Catostomidae members also had the highest lipid concentrations perhaps explaining in part the preferential accumulation of these compounds in these fish. The PAHs, napthalene, phenanthrene, anthracene, fluoranthene and pyrene were concentrated in the fish relative to the sediments by factors ranging from 2 to 95. Anthracene was the most concentrated PAH. There was no discernible distinction among the various species of fish.

Figure 47. Trace Organic Contaminant Residues in Fish with both Liver and Muscle Tissue Analysed in 2012



The amount of lipids or fat content of the samples can influence the residual concentration of these organic compounds. Lipid percentages ranged from a low of 0.44% (median) for the seven Percidae to a median of 1.25% for four Catostomidae. Normalizing the residues for lipid (as if all fish had a lipid concentration of 1%) levelled the concentrations, most notably for DEET, suggesting the widespread presence, persistence and uptake of this compound in the NSR or at least the waters frequented by these fish. Lipid normalized median DEET concentrations were 50, 35, 37 and 36 µg/g for Percidae, Lotae, Hiodon and Catostomidae, respectively, indicating highest theoretical DEET levels in Percidae but the observed values would be influenced by a variety of factors including feeding habits, home range and resultant exposure as well as metabolism of individual species. This illustrates some of the cautions that have to be considered when comparing fish tissue residues.

Detailed recommendations to improve the fish sampling program for contaminant analysis are provided in the fish tissue Technical report (Appendix C3).

6. Summary

The report has summarized findings from ambient river and effluent data collected from 2007 to 2012 and has built on findings from technical study reports produced during this time period. This document also complements information summarized from the last 5-year synthesis report (AECOM and Anderson 2011). Short summaries of the studies outlining their purpose, methods, information gained and relevance to local and basin-wide water management have been presented. Information on water quality, sediment quality and biota for the North Saskatchewan River has been reviewed and compiled. This report has evaluated the present state of the aquatic environment in the NSR and assesses effects on the in-stream water quality and ecosystem health resulting from current human activities in the watershed. In this section, we provide a brief synopsis of the knowledge as gained from the studies conducted between 2007 and 2012 on the North Saskatchewan River, as detailed in Section 5. The focus of this summary is newly found information in the studies and data we reviewed, but comparisons with pre-2007 data were used to illustrate any changes in the importance of issues and, accordingly, in management focus. The 6-year period of study considered in this report was too short to detect trends in water quality reliably, so this was a minor focus of the report.

6.1 Water Quality

Natural features in the watershed induce longitudinal changes in river water quality and these are modified by the seasonality of river flow. The transition from mountains to prairies results in natural enrichment of the water with ions, some metals, turbidity, solids and nutrients and in changes to aquatic habitat, affecting biotic communities. Seasonally varying river flows have a dominant effect on river water quality, where periods of high river discharge coincide with the transport of large amounts of total suspended solids and associated contaminants such as nutrients, metals, bacteria and pathogens. Seasonal changes in water temperature influence dissolved oxygen levels, particularly in winter. Temperature effects on biochemical processes are also reflected in higher levels of nitrate and nitrite during the open water season and higher total ammonia-N levels under ice.

Anthropogenic effects from point and non-point source discharges have measurable impacts on the water quality in the NSR, including:

- Nutrient loading from WWTP induced the most measurable change in river water quality. Total nutrient concentrations increased measurably downstream of the GBWWTP and the proportion of dissolved nutrients was higher than the proportion upstream. River nutrient levels in general, and particularly phosphorus, have declined considerably compared to historical data from the 1980s, in response to improvements in the Edmonton WWTPs;
- During periods of runoff, TSS was higher downstream than upstream of Edmonton, possibly related to stormwater influences. The influence of point source contributions of TSS within the IH-CR is partially masked by the large, mostly natural contributions from the upper watershed;
- Chloride concentrations increase in the IH-CR Reach during local spring runoff, possibly related to road salt application that reach the river mainly via stormwater outfalls and urban tributaries. During summer, stormwater baseflow concentrations were still high and tributary chloride concentrations at locations upstream of the City were similar to or higher than concentrations

measured at the mouths within the City, suggesting an upstream watershed source in this season;

- Increases in coliform bacteria occurred mainly during runoff events when CSOs in Edmonton and bypasses from the GBWWTP contributed large loads of bacteria to the river. This represents a considerable improvement over historical conditions when WWTPs also contributed a large continuous source of bacteria; and
- Increases in dissolved aluminium, total and dissolved molybdenum and total nickel, total zinc, total cadmium and total cobalt downstream of the IH-CR reach, associated with urban point- and non-point sources.

Multivariate analysis (PCA) of the mainstem and tributary synoptic data showed two main patterns in water quality, but their order of importance differed. The spatial differences in water quality from the headwaters to the prairies dominated variation in the tributaries, as they were most affected by their local watersheds, while the seasonally sediment-rich high flow samples in June 2008 and July 2012 drove the main variation in the mainstem, which is hydrologically driven by seasonality in the headwaters.

6.2 Sediment Quality

Sediment chemistry data showed little accumulation of nutrients and metals but did show the presence of PAHs throughout the river. Sediments also contained pesticides and pharmaceutical and personal care products, with the latter mainly occurring downstream of WWTPs. The presence, distribution and possible sources, however, remain uncharacterized due in part to the difficulty in consistently obtaining representative samples from mobile, relatively coarse grained sediments in the river. Particle size influences the concentrations of contaminants within sediments and the trend toward decreasing particle size likely played a direct role in the higher contaminant levels observed downstream of Edmonton. Future studies should consider improved characterisation of sediment depositional zones and particle sizes to allow spatial comparisons based on standard characteristics.

Sediment concentrations of arsenic and chromium exceeded the ISQG at several sites along the NSR. Given the fact that higher levels occur throughout the basin, a natural source is probable and non-compliance with ISQG does not necessarily mean that aquatic organisms are experiencing toxic effects.

6.3 Biological Communities

Algae, benthic invertebrate and aquatic macrophyte communities were indicative of high quality, low-nutrient environments upstream of the City of Edmonton, and exhibited clear responses to nutrient enrichment within and downstream of the IH-CR. These changes were mostly indicative of increased aquatic productivity, as communities were still healthy with a high diversity and large abundance of sensitive species.

Planktonic algae biomass was very low at the Clearwater and Devon sites, and increased significantly between Devon and Pakan. The increase in planktonic algae biomass at Pakan can be explained by elevated nutrient concentrations due to large point-source discharges in the IH-CR reach. Median values at Pakan, however, remained in the oligotrophic to mesotrophic range for running waters, in spite of the observed nutrient enrichment. Declining trends in planktonic chlorophyll-*a* at Devon and Pakan Hwy 17 from 1987 to 2009 may represent a biological response to declining nutrient levels along the river.

Epilithic algae biomass was low upstream of Edmonton and increased downstream of the GBWWTP effluent outfall. Epilithic algae biomass remained higher on the right bank, in the slow mixing effluent plume, for about 80 km downstream of the outfall. Relative abundance of major epilithic algae groups did not change significantly along the river, with consistent dominance by diatoms.

Benthic invertebrate abundance also increased in response to nutrient enrichment, and communities contained more individuals from pollution-tolerant groups, but in contrast with historical data, sensitive groups of mayflies and caddis flies were still fairly abundant downstream of treated sewage discharges. These results were in stark contrast with earlier studies conducted in 1982, when EPT were virtually absent in the IH-CR demonstrating the large positive effect of WWTP upgrades on the benthic communities in the NSR. Downstream distance, embeddedness (a habitat indicator) and alkalinity exerted the strongest influence on benthic community composition, indicating that impacts from the IH-CR were superimposed on effects of natural gradients in river and watershed characteristics from upstream to downstream.

Macrophyte biomass increased steadily between Rocky Mountain House and Devon and steadily decreased downstream of Devon, with the lowest biomass observed downstream of Edmonton and the pattern likely reflected changes in turbidity and resultant effects on light transmission.

These recently acquired data on aquatic non-fish biota algae, in conjunction with sediment quality and water quality data, provide an improved foundation for the assessment of aquatic ecosystem health, and for the inclusion of biotic indicators as site-specific water quality objectives.

6.4 Trace Organic Contaminant Synthesis

6.4.1 Water

LTRN water samples were submitted for current use pesticide analysis with a limited number of samples submitted for broad spectrum analysis of pesticides, VOCs, PAHs and hydrocarbons. The only organic compound detected consistently as part of the LTRN water monitoring was 2,4-D, a persistent pesticide that is frequently found in Alberta waterways (Anderson 2005). The locations upstream of Clearwater River (UCR) and at Devon had only one and two samples, respectively, exceeding the MDL. In contrast, more than 50% of the samples at Pakan exceed the MDL with the median concentration[6] at Pakan at 0.007 µg/L (equal to the AESRD open water objective) while the 90th percentile was 0.030 µg/L (slightly

[6] *Statistics were calculated if more than 50% of the samples exceeded the MDL. For statistics with some samples less than the MDL, the concentration of samples at less than MDL was assumed to be one half of the MDL (i.e. 0.0025 µg/L).*

below the AESRD 90th percentile WQO of 0.038 µg/L). Other compounds were occasionally detected in water at or slightly above the method detection limit.

The mainstem NSR water synoptic surveys from March, June and October 2008 and October 2012 included analysis for a broad suite of trace organic contaminants in a total of 63 samples in 2008 and 24 samples in 2012. Trace organics were detected occasionally as follows:

- 6 samples contained PAHs at or above the MDL;
- A total of 16 detections for VOCs were reported for various phthalates;
- Pesticides, especially 2,4-D (herbicide) and MCPP (herbicide) were regularly detected downstream of Devon at concentrations near the MDL;
- The trihalomethane chloroform was detected at 0.151 µg/L[7] at Elkpoint once in March 2008.

Phthalates are ubiquitous in industrial areas just as herbicides are in agricultural areas. The occurrence of these near the MDL concentration do not indicate a serious problem but potential accumulation in the ecosystem and other environmental compartments suggest the need for continued investigation to identify sources and assess management options.

6.4.2 Sediment

AECOM and Anderson (2011) and surveys reviewed for this study confirmed that only a few trace organic contaminants were detected in sediment:

- PAHs were detected at all sites, and some PAH compounds exceeded sediment quality guidelines;
- Common pharmaceuticals, metabolites of nicotine and musks occurred below municipal wastewater discharges in the lower reaches of the NSR while methyl triclosan and DEET were detected upstream of Whirlpool and Saunders; and,
- Organochlorine pesticides (i.e., DDT congeners) were detected at some locations and at concentrations that exceeded the sediment quality guidelines.

At the spatial resolution of the recent sampling programs, the influence of specific point sources on sediment quality is unclear, except for pharmaceuticals and personal care products which are in WWTP discharges. Some PAHs may be associated with urban sources. To improve the understanding and management of contaminants typically associated with sediments (e.g., PAH), there is a need for a better understanding of the source and fate of settled sediments and associated contaminants.

The sediment data, even with the difficulties in finding appropriate sedimentation zones, indicate low levels of nutrients and metals in the NSR. Sediments showed the presence of trace organic

[7] *Well below the CCME Guideline for the Protection of Aquatic Life of 1.8 µg/L.*

contaminants in the NSR to a greater degree than did water samples. Concentrations of individual compounds did exceed the ISQG for some PAHs and for p,p-DDT on occasion but there were no exceedances of PELs where these have been established. There was no consistent pattern along the watercourse between years for contaminant concentrations in sediment likely due to the difficulty in sampling apparently transient sediments in the NSR. Given that there is consistently a large number of non-detections of organics in the water samples and that many organics have a tendency to associate with particles, it may be more cost-effective to put emphasis on effective sediment sampling for trace organic contaminants over water sampling for the same compounds in future surveys.

It is premature to speculate on trends of trace organic contaminants in any medium at this stage, in part due to evolving sampling programs. Nevertheless, the water data for trace organics showed that PAHs, VOCs (commonly phthalates and phenols), pesticides (2,4-D and MCPP, Dicamba {herbicides}) were most frequently detected. At the present time there is insufficient information to indicate a longitudinal pattern, to implicate sources or to assess ecological significance, but their presence warrants further intensive investigation to identify sources and potential remedial options. Sediment and fish tissue data were not particularly instructive with respect to identifying sources and the potential for ecological impacts; nevertheless, the data discussed in this report points to a requirement for more, better integrated efforts for sampling these media for these contaminants.

6.4.3 Fish

Fish tissue samples showed that three different sources of organics were being taken up; specifically, industrial and consumer products, PAHs and historic use pesticides. PAHs were the only compounds that were detected in both sediment and fish. Napthalene, phenanthrene, anthracene, fluoranthene and pyrene were concentrated in the fish relative to the sediments by factors ranging from 2 to 95. Metals data showed accumulation of some metals but none stand out as suggesting a concern at this point.

7. Contributions to Informed Water and Watershed Management

The intent of this section is to discuss contributions that the reviewed studies made to advance water and watershed management in the NSR basin. We provide a preliminary status and trend assessment for key indicators of aquatic health, summarize recurring patterns in the importance of sources affecting NSR water quality, evaluate evolving priority issues and key indicators and discuss how the data reviewed addressed these. Based on these discussions, we will identify data and information gaps and provide recommendations on how to fill them.

7.1 Key Indicators - Status and Trends

Indicators of system health or quality should serve several purposes including simplifying the available scientific information to provide the status of the aquatic system for scientific purposes as well as for managers and general information users. Further, indicators should not only show the current status, but associated trends used to identify progress and priorities. A preliminary overview of indicator status and temporal and spatial trends is presented here.

This section is, however, not intended to be a detailed development of system health indicators for the NSR but to present existing information on indicators and other key information that has been reviewed in a scientifically valid approach. These indicators should be further assessed relative to their utility, success and effectiveness in reporting and influencing decision makers at a future time.

7.1.1 Definition of Indicator Status and Trends

In this assessment, the status of each indicator was been assessed qualitatively on the basis of following ranking:

- Good: The indicator demonstrated that the ecosystem objective(s) were being met or otherwise were in an acceptable condition;
- Fair: The indicator demonstrates that the ecosystem objective(s) were currently exhibiting minimally acceptable conditions but not meeting established ecosystem objectives, criteria, or other characteristics of fully acceptable conditions;
- Poor: The indicator demonstrated that the ecosystem objective(s) were severely negatively impacted and did not display even minimally acceptable conditions;
- Mixed: The indicator demonstrated that the ecosystem objective(s) displayed both good and degraded features; and,
- Undetermined: Data were not available to assess the ecosystem component(s), so no trend could be identified.

In addition, each indicator, if feasible, was described with respect to an ecosystem trajectory or trend (mainly qualitative, only in some cases quantitative by, e.g., Anderson 2012) with time as follows:

- Improving: Information provided by the report showed the ecosystem component(s) to be changing toward more acceptable conditions;
- Unchanging: Information provided by the report showed the ecosystem component(s) were neither getting better nor worse;
- Deteriorating: Information provided by the report showed the ecosystem component(s) to be changing away from acceptable conditions; and,
- Undetermined: Data were not available to assess the ecosystem component(s) over time, so no trend was identified.

This approach followed that developed for the Great Lakes as part of the State of the Lakes Ecosystem Conferences (SOLEC)[8], but was tailored to meet the available information and priorities for the NSR. The primary indicators used fell into the following categories: water quality, sediments, fish, and other non-fish organisms. Each is discussed further below.

Finally, a primary objective of this analysis was to assess the effect of the Industrial Heartland-Capital Region (IH-CR) on the quality of the river system. This was referred to as the longitudinal trend. It was evaluated simply as:

- Stable: there was no evidence of degradation of the indicator from inputs from IH-CR;
- Deteriorating: there was evidence of degradation of the indicator from inputs from city and industrial heartland; and,
- Undetermined: there was insufficient information or the data were equivocal with respect to the longitudinal effect on the NSR.

7.1.2 Water Quality

The nature of indicators (variables) used to support evaluations depends on a variety of factors, including: program objectives, resource constraints, current and proposed human activities, and basin characteristics. In identifying variables of concern for the NSR, a key goal should be to determine those that are likely to be the most representative and practical indicators of potential change or trends based on available monitoring information (McDonald, 2013). Selection of indicators by McDonald (2013) considered the following:

- In-stream or effluent exceedance of Federal-Provincial Guidelines (AENV, 1999; CCME, 2012);
- in-stream exceedance of NSWA Draft Water Quality Objectives (NSWA, 2010);
- identification as Variable of Concern (VoC) in previous scenario modelling based on mixing zone analysis (AENV, 2010);
- substantial increase in water quality pollutant values at Pakan relative to Devon (e.g., >20% in median and/or 90th percentile);
- increased detection of trace contaminants downstream relative to upstream; and
- elevated overall point-source loads relative to overall tributary loads (ratio of effluent to tributary load increased substantially at low flows; e.g., > 1.5 times).

One approach used by AESRD has been the establishment of site and seasonally specific water quality objectives (SSWQO) for substances that do not have toxic properties. The SSWQO is determined from probable concentrations in surface waters derived from an analysis of existing in-stream data (e.g., phosphorus). The SSWQO variables considered in McDonald (2013) were discussed in Section 3.4.4.

[8] *There is extensive information available on SOLEC at the joint Canada/USA site: http://binational.net/solec/pub_e.html*

As not all variables were responding the same way, we treated each as an indicator. Due to the high degree of flow variability in the NSR and thus the predominant source water (i.e. mountain melt during the high flow period of the summer versus prairie melt and runoff and baseflow during the fall, winter and spring seasons), it was necessary to further refine SSWQOs and thus water quality indicators based on seasons. The long-term median concentrations for open water and under ice conditions as established by McDonald (2013) provided these preliminary indicators (Table 16).

Table 16. Water Quality Indicator Assessment

Indicator	Indicator Assessment		Ecosystem Trajectory or Trend over Time		Longitudinal Trend (Upstream to downstream)	
	Open Water	Ice Cover	Open Water	Ice Cover	Open Water	Ice Cover
Ammonia – N	good	good	Improving	Improving	Deteriorating	Deteriorating
$NO_2 + NO_3$ – N	fair	fair	Improving	Improving	Deteriorating	Deteriorating
Dissolved Phosphorus	Fair (background effect)	Fair (background effect)	Improving	Improving	Deteriorating	Deteriorating
Total Phosphorus	Fair (background effect)	Fair (background effect)	Improving	Improving	Deteriorating	Deteriorating
Total Organic Carbon	Fair (background effect)	Fair (background effect)	Unchanging	Unchanging	Stable	Stable
Total Suspended Solids	Good (background effect)	good	Unchanging	Unchanging	Deteriorating	Stable
Chloride	good	good	Improving	Improving	Deteriorating	Deteriorating
Fluoride	good	good	Unchanging	Unchanging	Stable	Stable
Sodium	good	good	Undetermined	Undetermined	deteriorating	deteriorating
Sulphate	fair	fair	Deteriorating	Deteriorating	Stable	Stable
Fecal coliforms	Fair	fair	Unchanging	Unchanging	Deteriorating	Deteriorating
E. coli	Fair	fair	Unchanging	Unchanging	Deteriorating	Deteriorating
Arsenic – total	Fair (background effect)	Fair (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)
Cadmium – total	Fair (background effect)	Fair (background effect)	Unchanging	Unchanging	Undetermined	Undetermined
Copper – total	Fair (background effect)	Fair (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)

Indicator	Indicator Assessment		Ecosystem Trajectory or Trend over Time		Longitudinal Trend (Upstream to downstream)	
Lead – total	Fair (background effect)	Fair (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)
Mercury – total	Fair (background effect)	Fair (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)
Selenium – total	Fair (background effect)	Fair (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)
Zinc – total	Fair (background effect)	Fair (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)	Unchanging (background effect)
2,4 – D	Mixed	Good	Unchanging	Unchanging	Deteriorating	Deteriorating

7.1.3 Sediments

Sediment indicators are normally based upon a comparison of contaminant concentrations in sediments to the Sediment Quality Guidelines (SQGs). SQGs were developed to describe contaminant concentration levels that are associated with the absence of occurrence of adverse biological impacts (i.e. toxicity to benthic organisms). Sediment quality guidelines are provided by CCME (1999). As noted previously in this report, there was difficulty in obtaining appropriate "deposition zone" sediment samples for the NSR and the samples that were analysed may not be truly reflective of the burden of contaminants associated with the sediments or the trends may be undetermined. With this caveat, the following indicators summary is provided for sediment:

Table 17 Sediment Indicator Assessment

Indicator	Indicator Assessment	Ecosystem Trajectory or Temporal Trend	Longitudinal Trend
Nutrients	Undetermined	Undetermined	Undetermined
Metals	Undetermined	Undetermined	Undetermined
Polycyclic Aromatic Hydrocarbons (PAHs)	Good	Stable	Stable
Pesticides	Undetermined	Undetermined	Undetermined
P&PCP*	mixed	Undetermined	Deteriorating

**P&PCP = Pharmaceuticals and Personal Care Products*

7.1.4 Fish

Indicators for fish are generally based upon a number of indicators including tissue and organ residues of selected contaminants with respect to potential impacts on the fish and impacts on people consuming the fish relative to the consumption of sport fish and the maximum recommended consumption of contaminants from the fish. Both of these indicators have relatively little data at this point in time and are summarized in Table 18.

Table 18 Fish Tissue Indicator Assessments

Indicator	Qualitative Assessment	Ecosystem Trajectory or Temporal Trend	Longitudinal Trend
Metals	Undetermined	Undetermined	Undetermined
Polycyclic Aromatic Hydrocarbons (PAHs)	Undetermined	Undetermined	Deteriorating
Pesticides	Undetermined	Undetermined	Deteriorating
P&PCP*	Undetermined	Undetermined	Deteriorating

**P&PCP = Pharmaceuticals and Personal Care Products*

Complete surveys of contaminants and metals in a variety of fish species, including forage fish (such as Slimy Sculpin, for which there is a good database across the country and which has a limited home range and so takes up contaminants that are local to where they are caught, sentinel fish (such as suckers which are widely distributed and top predator fish, therefore accumulating the highest levels of contaminants). Sturgeon recovery and walleye recruitment are success stories in the NSR but are largely independent of contaminants in the river (at the levels we found), and more dependent on physical habitat, including the degree of siltation and harvest pressure. Fish consumption advisories may be another useful indicator if they are supported by good data, but are developed for human consumers, not ecological criteria, and include a limited suite of parameters (Hg, PCBs).

7.1.5 Non-Fish Biota

Table 19 summarizes the findings for other biological indicators for the NSR, as assessed by Clearwater and Kilgour (2010, epilithon and benthic invertebrates) and based on the data reviewed for this assessment (planktonic algae).

Table 19. Non-Fish Biologic Indicator Assessment

Indicator	Qualitative Assessment for Devon to Pakan Reach	Ecosystem Trajectory or Temporal Trend	Longitudinal Trend
Planktonic algae biomass	Good (oligo-mesotrophic)	Improving	Deteriorating
Benthic algal biomass	Fair-marginal	Improving	Deteriorating
Epilithic community composition	Good	Improving	Stable
Macrophyte populations	Good (turbidity controlled)	Stable	Deteriorating
Benthic invertebrate abundance	Fair	Improving	Deteriorating
Benthic invertebrate communities	Excellent-fair	Improving	Deteriorating

7.2 Types of Pollution Sources and their Impact on the NSR

Extensive upgrading of the GBWWTP and ACRWWTP have resulted in significant contaminant load reductions and accompanying improvements in water quality. Nevertheless, the two plants remain the largest point sources of TDS, nitrate, nitrite, ammonia, and phosphorus (especially dissolved phosphorus), and other contaminants including pharmaceuticals and personal care products in the NSR Some of the industrial compounds (phthalates and phenols) may be sourced through the WWTPs as well as storm water systems. The source distribution for these trace compounds has not been fully assessed.

The reduction of point sources, on the other hand, has allowed loadings of anthropogenic compounds from prairie watersheds, storm water and combined sewer overflows to assume a more significant relative role in observed impacts on the river. Sampling programs and loading evaluations have made it possible to compare WWTP loadings to those from other sources for a number of pollutants, showing that

- WWTPs remain the largest source of nutrients, including dissolved phosphorus and nitrogen compounds;
- Watersheds and urban stormwater drainage are large contributors of TSS and chloride, but their discharge is episodic and coincides with runoff events and the distribution of the relative contribution between urban and upstream rural watershed sources requires further assessment;
- CSOs and the GBWWTP bypass are the largest point sources of bacteria during runoff events but their episodic nature reduces their long term impact. Short-term effects of bacteria and other substances that are elevated in these discharges, such as TSS and chloride, may require further

definition if there are uses or possible impairments to the river as a result of episodically high contaminant levels; and,

- Industrial loadings have not been considered directly in this report but evidence from the 2008 synoptic study showed that some effluents contain high concentrations of many metals (e.g., Alta Steel) while some effluents contained high concentrations of single metals (e.g., selenium in Scotford Upgrader) suggesting that the larger effect, if any, of these industrial sources should be fully integrated into the assessment of the NSR.

Pollutant sources by category are summarized in Table 20.

Table 20. Contaminant Occurrence by Source

Source	Nutrients		Metals		Pathogens	Pesticides	Other Organics	Chloride
	Total	Dissolved	Total	Dissolved				
WWTP		X		X	X	X	X	X
WTP			X					
CSO	X		X		X	X		X
SSO	X		X		X	X		X
Industrial			X				X	
Urban watersheds			X		X	X		X
Rural Watersheds	X	X			X	X		X

Future monitoring needs to be combined with a greater emphasis on targeting and quantifying specific sources of known pollutants to identify management options for these rather than trying to quantifying the impact of the sources within the NSR itself. In other words, move the monitoring "upstream". It is not practical to assume that all problems will be identified and resolved by looking at receiving waters. More emphasis needs to be directed at documenting sources, monitoring the smaller prairie watersheds upstream of City to understand rural tributary headwaters in the context of urban non-point source impacts and total loadings and peak concentrations to the NSR from these systems. If loads from each source are known, then the most cost -effective means to improve the river can be targeted. One step into this direction could be the fuller integration of existing data from City of Edmonton reports to address important issues and data gaps relevant to water quality in the NSR.

7.3 Priority Issues

7.3.1 Non-Point Sources

The data discussed in this report were collected after the implementation of major upgrades to WWTPs in the IH-CR and the implementation of upstream flow regulation and therefore represents a new, higher level of environmental performance. River regulation has increased the flow available in summer and fall, better satisfying in-stream flow needs for water quality and biota. WWTP upgrades have reduced the amount of oxygen consuming substances (CBOD), bacteria and nutrients in the effluents, resulting in improved oxygen conditions, lower bacteria counts, decreased nutrient levels, decreased aquatic productivity, and improved aquatic health in terms of benthic invertebrate and fish communities. With improvements in place for conventional wastewater substances, focus of water quality management is now shifting to emerging substances and non-point source loadings.

The continuing growth of the City of Edmonton, combined with the improvements to waste water treatment, has resulted in a proportional increase in the effects observed on the quality of the NSR downstream that are derived from non-point sources and this trend is likely to continue. Storm water management should therefore become an increasing focus to the management of the quality of the NSR. For bacterial loadings, for example, the use of ultraviolet sterilization of WWTP effluents virtually eradicated contamination from treated wastewater. Bacterial contributions that reach the NSR during storm event runoff from tributaries, storm sewers and combined sewer overflows have since increased in relative importance for river impacts. This is especially true as the footprint of the city expands.

Point source management in the IH-CR is well established and an effective regulatory process in place through the issuance of approvals to operate. Ongoing improvements are made as the City of Edmonton updates storm and sanitary sewer systems and urban non-point source impact is partially quantified through the monitoring and modeling of storm sewer outfalls. It would be beneficial to determine what proportion of the City is covered by this program and what proportion drains to tributaries and unmonitored stormwater catchments, if any. The City of Edmonton Environmental Monitoring Program provides detailed loading information, but collaboration with upstream jurisdictions may be required to assess tributary loadings from upstream watersheds.

7.3.2 Emerging Contaminants

Assessing trends and human impacts is difficult other than for conventional variables that are responding to improvements in the treatment of the waste water (e.g. dissolved oxygen, nutrients, algae responses) as these have a substantial history of data and the large scale improvements are measurable. Measuring trends for organic compounds, for example, (e.g. pesticides, industrial compounds, pharmaceuticals and personal care products) is more difficult due to the difficulty in obtaining representative samples (e.g. fish and sediment) and due to the fact the time series data for these compounds is quite limited. Further, while the data for these compounds is more expansive in the water samples, the concentrations are commonly so low that they do not exceed the analytical detection limit. This makes trend analysis difficult and in some cases impossible at this stage. Sampling for emerging contaminants and aquatic toxicity endpoints at WWTP and Storm outfalls where concentrations are likely highest is one way to tackle this challenge.

7.4 Contributions of Existing Programs to Achieving Water Management Goals

The NSR is a complex river system requiring a complex monitoring program that can address local meltwater effects from prairie watersheds, urban non-point and point sources, the effect of mountain meltwater and the influence of industrial effluent. An effective water quality monitoring program has been implemented that has provided managers with information on many conditions within the NSR and has permitted the historic determination of the large influence of treated wastewater discharge on the receiving water and the benefits from the improvements to the treatment plants and the reductions in loadings. In addition, a number of focused studies helped to evaluate the status of biological components, to describe physical mixing of plumes and transport of sediments, and tools have been developed to support ongoing assessments of contaminant loads and their fate in the NSR. A summary of programs and contributions is provided in Table 21.

Table 21. Summary of Programs and Their Main Contributions to NSR Water Quality Management

Reference	Pollution Type		Main Contribution
	Point	Non-Point	
WATER QUALITY			
AESRD (LTRN)			• Continuous, consistent, long-term record of water quality, that allows for trend analysis and regular status assessments.
AESRD (Datasonde)			• Describes daily fluctuations that aquatic life is exposed to. • Allows for more reliable summary statistics and description of extremes for variables that vary on a daily basis.
AESRD (Diurnal)			• Determines if routine daily collections of water quality are representative of water chemistry in the North Saskatchewan River.
AESRD (Synoptic)	x		• Provides spatial patterns related to natural watershed changes as well as point-and non-point source inputs. • Provides information to assess longitudinal changes. • Distinguishes local impacts from watershed impacts. • Assesses sensitivity of the NSR to impacts during different seasons and flow levels. • Only program that collects systematic information on tributary water quality across the watershed, which provides immense value for future watershed planning initiatives under the NSR Regional Plan.
City of Edmonton EPM (Golder 2013 a,b,c)	x		• Quantifies the contaminant loading from approved facilities (combined and storm sewers, WTP, WWTP) to the NSR on an annual basis. • High-frequency, within-City sampling of NSR water quality. • Limited information on urban tributaries at mouth and upstream of City.
SEDIMENT & NON-FISH BIOTA			
Benthic Study (Clearwater & Kilgour 2010)			• Establishes an important link between water quality and aquatic ecosystem health in the NSR. • Solid baseline to which compare future changes in NSR non-fish biota.

Reference	Pollution Type		Main Contribution
	Point	Non-Point	
Sediment Provenance (Stone and Collins 2012)		x	• Provides information on sediment contaminant levels and relative source proportions.
FISH CONTAMINANTS			
Fish Tissue (AESRD)			• New information on contaminant levels in a variety of fish species for a range of metals and organic compounds. • Provides baseline to which future programs can be compared
MODELS & MIXING			
Watershed Model (TetraTech 2012)		x	• Provides representation of watershed-derived sources and transport of temperature, sediment, nutrients, metals and bacteria, mainly from non-point sources. • Complements a suite of previous models that were developed for the IH-CR and intended for evaluating point source management scenarios. • Allows simulating land use management scenarios. • Deeper understanding of hydrological processes in the watershed in their influence on water quality.
Dye Study (Pilechi et al. 2012)	x		• Describes individual plume mixing patterns of three major effluents (i.e., Goldbar WWTP, Captial Region WWTP and Agrium Redwater Fertilizer plant)
DATA ANALYSIS, SYNTHESIS AND TOOLS			
Synthesis (AECOM & Anderson 2011)	x		• Provides a succinct overview of technical studies (2006-2009) conducted in the NSR IH-CR, and how they support the Water Management Framework, and identified gaps and research needs. • Focused on the IH-CR reach and provided detailed reviews of effluent loading.
Trend Analysis (Anderson 2012)			• Trends in the LTRN data set, for ice-cover and open water periods. • Percentiles, which can serve as a foundation to derive site-specific objectives.
WQOs and MALs (McDonald 2013)			• Criteria and Process to establish Variables of Concern (VoCs). • Pilot Site-Specific Water Quality Objectives for Devon & Pakan. • Maximum Allowable Loads for VoCs for different flow seasons.
Loading Tool (Kessler 2010)	x		• Selects the best and most appropriate tool for estimating in-stream loads and point-source loadings - annually and seasonally. • Useful tool for evaluating the relative importance of different discharges on the NSR and therefore supports the management of cumulative effects from multiple discharges for variables of concern.

7.5 Advances in Cumulative Effects Management

The main purpose of the local and regional watershed planning, IH-CR Water Management Framework and the North Saskatchewan Regional Plan under the Land Use Framework and Water For Life Policy is to allow for the management of cumulative effects on aquatic ecosystems. For the purpose of these watershed management initiatives, cumulative effects are implied to be the combined effect of multiple human activities in a watershed on the water resources, which in turn are shared among diverse users. In the scientific literature, a cumulative effect (CE) is defined as an effect on the environment that results from the incremental, accumulating and interacting impacts of an action when added to other past, present, and reasonably foreseeable future actions (Hegmann et al., 1999). There are three broad categories of cumulative effects:

1) Incremental impacts include the combined effect of successive stressor events, each with similar but small effects, but whose combined effect exceeds a critical ecological threshold thereby compromising ecosystem integrity;

2) Multiple source impacts occur when sources of stressors and their effects overlap spatially (e.g., multiple WWTPs); and

3) Multiple stressor impacts include scenarios where different classes of stressors interact in an additive, synergistic or antagonistic fashion preventing a priori prediction of biotic responses (Culp et al. 2000).

The current approach taken in the NSR management initiatives is to address multiple sources, for example through the total loadings management plan for the City of Edmonton. Tools to assess the effect of current and future multiple sources on water quality and biota include water quality and watershed models. This approach has the advantage that it is relatively straight-forward to calculate and manage, as individual sources can be identified and managed. Incremental and multiple stressor impacts, on the other hand, are not well understood in the NSR and cannot therefore be addressed explicitly at the present time, as discussed further below.

Incremental effects over long time periods may exist in long-lived organisms, such as predatory fish (as shown by occurrence of historical pesticides in fish tissue), but are generally limited in a river environment due to the constant water renewal. Bio-magnification in fish tissue would be one indicator for incremental effects of contaminants on fish, but such assessments are not feasible with the data at hand (see Appendix C.3, Fish Tissue Technical Report). Incremental effects over short periods of time, such as the effects of multiple storm event discharges within one open-water season on benthic invertebrate communities, are a real possibility in the NSR, but the individual and incremental short-term effects of these discharges on river biota are largely unknown. Focussed biotic assessments within the City of Edmonton would be required to provide more insight into such effects.

Multiple stressor impacts are an ongoing subject of research, with the state of knowledge ranging from well-established interactions between certain water quality stressors to large uncertainties in others. It would be useful to conduct a literature review of known interactive effects of variables of concern in the NSR to determine the potential for such effects. The objective of such a review should be to assess if current objectives for individual parameters or for environmental indicators are sufficient to protect from such interactions or if interdependent objectives or indicators would be beneficial.

Biotic communities that integrate the effect of multiple stressors over time and across pollutants are excellent indicators for the cumulative effects of anthropogenic stressors, but are less useful for identifying causation. For example, the recovery of benthic invertebrate communities downstream of Edmonton within the past decade and of the sturgeon population within the system are good demonstrations on how the improvement in multiple environmental stressors, e.g., dissolved oxygen levels, nutrients, and flow has had a significant positive effect on the benthic communities and endangered species populations. The regular assessment of biota in the NSR will be key to tracking the cumulative effect of human impacts at the ecosystem response level, while research should be ongoing to identify current and predict future potential cumulative effects based on known contaminant combinations at the source.

7.6 Information and Data Gaps and Strategies to Address Them

Based on this analysis and previous studies we identified information and data gaps and deficiencies, broadly ranked them in terms of importance and recommended strategies to address them. The recommendations were made to provide direction to resource managers to streamline monitoring and assessments while achieving goals and objectives. They were ranked into either important or desirable categories but were not ranked within these broader categories. Some of these data gaps were previously identified by AECOM and Anderson (2011), while others were derived from additional review and analysis conducted for this report.

7.6.1 Important

1. The relative role of urban road salt and other chloride-based de-icing agents compared to watershed sources of chloride warrants more investigation. This could be done through a complete or at least broader accounting of identified and potential additional sources, both historical and ongoing, in order to improve the understanding of the relative importance of the contributions from different sources for the targetting of remedial measures;
2. A better understanding of the sources and fate of trace organic contaminants in the NSR through coordinated water/suspended sediment/and young forage fish sampling from expected source areas to the NSR to quantify water/sediment/fish accumulation factors. This includes the distribution of compounds such as pharmaceuticals, personal care products and nonylphenol ethoxylates. Sources and bio-concentration factors should be documented and related to external research on aquatic toxicity and health; human health implications in treated drinking water and technological and social control measures;
3. In order to maintain or improve the health of the NSR, it is necessary to set appropriate limits. Site-specific Water Quality Objectives for water quality indicators are critical in water quality management plans as they are the quantitative measure of desired outcomes and therefore the target at which to aim management actions. Site-specific objectives have been proposed for

Devon and Pakan and remain to be created for the other LTRN sites. Proposed objectives will require refinement with flow categories as modelling and loading management tools are refined. The relationships between WQOs, MALs, and flow seasons and averaging periods for performance monitoring need to be carefully considered to warrant a successful implementation of MALs within a water management framework.

4. The current assessments are exclusively considering chronic effects on aquatic biota. It is currently unknown if peak stormwater discharges have acute effects or not, which should require further investigation, in particular given the increased size of urban footprint and therefore the increased volumes of stormwater that can lead to combined short-term effects in the river. Screening of targeted stormwater or CSO outfalls using conventional acute toxicity tests (i.e. 96 hr rainbow trout or 48 hr Daphnia magna tests) would a) determine if there was a problem and b) indicate the most problematic source areas.

7.6.2 Desirable

5. There is a need to develop a standardized approach for rating the status of sediment and biota once an effective sampling program is put into place. The interpretation of sediment quality data is greatly hampered by the lack of Alberta sediment quality guidelines for key contaminants of concern; hence, objectives describing desirable conditions would be particularly useful for the NSR. One way to improve sediment quality assessment would be to conduct a jurisdictional review to locate sediment quality guidelines for contaminants, in particular organics (e.g. British Columbia: MacDonald Environmental Sciences Ltd. 2003). Similarly, the development of objectives for biological indicators (e.g., epilithic algae, benthic invertebrates) that integrate and reflect cumulative effects over extended periods of time and from additive effects of multiple sources would facilitate the standardization of aquatic ecosystem health assessment, although it has to be recognized that the development of objectives for biological indicators is challenging and requires a thorough understanding of stressor-indicator relationships in the NSR. This would require selecting media and species, indicators and indicator thresholds to develop integrated quantitative assessments. These objectives are not as high a priority as appropriate concentration data is generally absent for the key indicators but the metrics should be developed together with survey designs incorporating the necessary sampling strategies and detection limits.
6. A better understanding of relationships between plants, nutrients and other influencing factors (e.g., flow velocity, TSS, turbidity) is needed for the NSR to confirm the value of this indicator for status assessments and to refine desired outcomes for both nutrients and aquatic plants.
7. Data on oxygen saturation are missing, but data on oxygen concentrations are comprehensive. We recommend adding elevation as a site characteristic to the AERSD water quality database in order to allow for the derivation of oxygen saturation levels for any past and future oxygen concentration measurement.
8. The role of some pollutants within the ecosystem and the processes of transfer from one component to another are less well understood than their total levels in the system. This information is key to correctly model and understand pollutant substance fate in the river.

Although the predictive capabilities of the EFDC model have been demonstrated for the NSR, refinements and further development are essential to refine the accuracy and precision of model predictions. Further refinements include increasing the utility of EFDC in simulating biologic response (e.g., plant growth), sediments (e.g., sediment/water interactions; sediment transport), and metal dynamics (e.g., sorption processes, speciation). Model development is continuing and consequently it is shown here as desirable. Many of the development needs require additional monitoring information first for testing and calibrating the model.

9. The monitoring at selected tributaries and the watershed model have provided important insight into non-point source loads from rural watersheds, but this information requires validation, spatial refinement, and expansion to biological indicators. Aquatic health in the tributaries in particular is much less well known than that of the NSR and so, increased monitoring focus in tributaries is warranted.

10. In addition to monitoring, this NSR water quality and aquatic health status reporting information needs to communicated to document the progress and success of the IH-CR Water Management Framework at predetermined times. This would involve the evaluation and reporting of:

    - Ambient water quality conditions,
    - Point and non-point source loading ;
    - Progress in implementing management measures;
    - Success of management actions at eliciting the desired degree of change (e.g., load reductions, improvements in the aquatic environment).

7.7 Recommendations

Technical Workshop

A TECHNICAL WORKSHOP WITH EXTERNAL EXPERTS AND SPECIALISTS TO REVIEW ALL RECENT INFORMATION AND RATIONALIZE THE EXISTING MONITORING PROGRAM SO THAT IT IS MORE EFFECTIVE AND COMPREHENSIVE.

The available water quality, sediment quality, fish residue data and ecological information and source monitoring data available for the NSR are wide ranging and comprehensive in many respects. The main ecosystem components and relevant indicators have been investigated at a comprehensive set of sites. Nonetheless, gaps remain and this leads to the proposition of more study needs and possible research needs. While these are of value and will be discussed further below, the first priority should be a rationalization of the monitoring program itself. In addition, the relative importance and therefore priority of types of sources have shifted, with increasing importance of non-point sources. This shift needs to be recognized in a monitoring program that is adapted to the evolving and emerging water quality priorities.

A rationalization of the monitoring program should take the elements that currently exist and rather than introducing new elements, better integrate the current ones and refine them to optimize the information generated. Further, this optimization should consider the cost-effectiveness of refining the monitoring to allow enhancements and expansions where required. One way to explore options to achieve optimization would be to convene a technical workshop for all parties involved in monitoring activities in the NSR. This technical workshop should specifically address how to go about setting or establishing limits or indicators (Gaps 3, 4 and 8) and then recommend the necessary changes in the monitoring programs.

The monitoring program rationalization and evolution should consider:

1. Continued emphasis on the LTRN sites for water quality, supplementing the trace organic sampling part of the water sampling with the use of passive integrated samplers deployed over long periods to target the pesticides, PAHs, industrial contaminants and the PPCPs (addresses Gaps 2 and 7), instead of the past reliance on grab samples;

2. Refocus of the synoptic surveys with reduced emphasis on spatial NSR coverage and greater emphasis on better monitoring of key prairie watersheds both at the confluence with the NSR and upstream of main watershed sources (addresses Gaps 1 and 9) to determine the contributions of the tributaries to water quality in the main stem;

3. Greater emphasis on stormwater, including comprehensive sampling and modeling future development scenarios, including flows, TSS and nutrients and other contaminants, their effect on tributary geomorphology (assess potential for erosion under increased storm flows) and consideration of the potential for acute toxicity during storm events , as these may have a growing impact with continued urban expansion (addresses Gaps 8 and 9);

4. Continuing biological indicator programs using benthic organisms and macrophytes at a limited number of representative sites once every few years (3 or 4 years), using suitable replication and representative accompanying water quality sampling (addresses Gaps 5 and 6);

5. Cessation of the existing sediment and fish sampling programs (sediments are too dynamic and the sports fish are generally too mobile) and replace this with an integrated water/sediment/tissue monitoring component using a method of sampling sediments consistently and accounting for their characteristics and fish tissue collection using small bodied fish with a limited home range and sampling muscle and organs. This should include:

    a. preferably sacrificing the fish and sampling muscle and organs (addresses Gaps 2 and 9).

    b. sampling fine grained suspended sediments in the water column synoptically and across a range of flow events. Continuous flow centrifuge samplers or less expensive time-integrating samplers (Phillips et al. 2000) could be deployed in a longitudinal gradient along the river to passively collect composite samples of suspended solids (gaps 5, 7)

    c. For the characterization of sedimentary habitat quality for benthic organisms and bottom-feeders, bottom sediment mapping should be undertaken to characterize grain size and identify the most apparent depositional zones for future sediment and benthic organism sampling.

6. There was a high variability of macrophyte density throughout the NSR, which may limit the representativeness of samples that were collected in macrophyte beds selected for sampling. Aerial and satellite-based surveys were mentioned as more appropriate approaches to estimate macrophyte abundance throughout the NSR. Another shortcoming of the study may have been the temporal focus on periods of maximum biomass. Relevance of turbidity and light limitations could potentially be better assessed by a repeated sampling approach throughout the growing season, which would include the months before attainment of maximum biomass, e.g., late July and August (Gap 6).

7. Epilithic algae community assessments were only sensitive to nutrient gradients observed in the river at the species-level. In addition to ordination techniques applied to all species, diatom indices that are based on diatom species-level evaluation of nutrient status could be used as a sensitive indicator of algae community response to nutrient enrichment in the NSR, given that diatoms represent 80-90% of epilithic algae biomass in all river reaches. Methods for diatom-based water quality assessment are well developed, and quantitative health assessment approaches and thresholds have been developed elsewhere (Gap 5).

8. Incremental effects over short periods of time, such as the effects of multiple storm event discharges within one open-water season on benthic invertebrate communities, are a real possibility in the NSR, but the individual and incremental short-term effects of these discharges on river biota are largely unknown. Focussed biotic assessments within the City of Edmonton would be required to provide more insight into such effects.

8. Conclusions

Information on the current status of the NSR has been updated with recent data acquired for the entire river with emphasis on the IH-CR water management reach. Comprehensive spatial and temporal water quality datasets and individual studies on sediments and biota have been completed and allow an up-to-date assessment of aquatic ecosystem status and the natural and anthropogenic factors that influence it.

The general state of the NSR downstream of the IH-CR reach was assessed as fair to good with clear improvements with respect to nutrients and biological responses. These will require continuous attention so that the improvements are not reversed due to continued population growth. Some new issues are emerging that need to be understood and addressed in the near term. Specifically, urban non-point source issues are becoming a larger concern because of the management of point sources and the continued expansion of the urban footprint. Other issues are becoming evident as a result of continued enhancements to the monitoring program, including pesticides, industrial compounds and pharmaceuticals and personal care products. Fully assessing the presence, fate and effects of these contaminants may require significant adjustments to the monitoring program in order to determine the need for future management actions. For example, pharmaceuticals and other micro-constituents have been identified as concerns in municipal effluents but there is insufficient information to assess the threat they pose to the aquatic system, the degree of treatment required or effective means to manage sources and treat effluents.

With the focus shifting from point- to non-point source load management, the complexity of water quality management increases significantly due to a much larger spatial extent of sources and hence, potential mitigation measures, and the associated jurisdictional and implementation challenges.

Recommendations provided build on the continuation of successful base programs, to tailor and refocus some programs to meet specific objectives and better integrate different media to address sources and study questions, such as nutrient enrichment, sediment load or organic contaminants.

This synthesis of all relevant information on NSR water quality in one report will help guide watershed management planning under the NSR Regional Plan and the Industrial Heartland Capital Region Water Management Framework (IH-CR WMF).

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