The WaterSHED monitoring program

(Water: Saskatchewan headwaters Edmonton and downstream) – technical progress report 2018-2019

Air

Land

Water

Biodiversity

The WaterSHED monitoring program: technical progress report 2018-2019

Cristina Buendia-Fores, Craig A. Emmerton

Cover photo: Elynne Murray

This publication can be found at: https://open.alberta.ca/publications/watershed-monitoring-program-technical-progress-report

Comments, questions, or suggestions regarding the content of this document may be directed to:
Airshed and Watershed Stewardship Branch, Alberta Environment and Parks
10th Floor, 9888 Jasper Avenue NW, Edmonton, Alberta, T5J 5C6
Email: AEP-RSD-AWSWatershedSciences@gov.ab.ca
Website: environmentalmonitoring.alberta.ca

For media inquiries please visit: alberta.ca/news-spokesperson-contacts.aspx

Recommended citation:
Buendia-Fores, C; Emmerton, C.A. 2021. Government of Alberta, Ministry of Environment and Parks. ISBN 978-1-4601-4971-3.
Available at: https://open.alberta.ca/publications/watershed-monitoring-program-technical-progress-report

Date of publication: January 2021

ISBN 978-1-4601-4971-3

Acknowledgements

We would like thank the tireless efforts of our technical field staff and supervisors in Edmonton for careful collection and processing of water samples and field data. Several commercial laboratories analyzed numerous water samples in a timely manner with prudent quality control procedures; we appreciate their efforts. We thank several key people at EPCOR Water Canada, Alberta Environment and Parks, the North Saskatchewan Watershed Alliance, and the City of Edmonton for helping to conceptualize, design, implement and manage this program, including its financial operation. We are grateful that permission for implementation of water monitoring stations across the North Saskatchewan River basin came from both public and private interests, including Indigenous communities. The authors would also like to thank all reviewers who provided helpful feedback on this annual report, particularly Dr. John Orwin.

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

AEH	Aquatic Ecosystem Health
AEP	Alberta Environment and Parks
CABIN	Canadian Aquatic Biomonitoring Network
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
fDOM	Fluorescence Dissolved Organic Matter
LTRN	Long Term River Network
MER	Monitoring Evaluation and Reporting
NSR	North Saskatchewan River
NSRB	North Saskatchewan River Basin
TMN	Tributary Monitoring Network
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
WTP	Water Treatment Plant

The WaterSHED Monitoring Program

The North Saskatchewan River Basin (NSRB) is one of Alberta's key river basins as it supplies drinking water to over one million residents, provides important natural resources for industry, accommodates a rich terrestrial and aquatic biodiversity, and offers citizens quality recreational opportunities. To help guide sustainable management of the NSRB, multiple land and water management initiatives have been developed recently including the Integrated Watershed Management Plan (NSWA, 2012), the River For Life strategy (City of Edmonton), EPCOR's Source Water Protection Plan (EPCOR, 2017), the Water Management Framework for the Industrial Heartland and Capital Region (AEP, 2008; McDonald, 2013), and the North Saskatchewan Regional Plan (currently under development; AEP, 2014).

These management initiatives need to be supported by a solid scientific understanding of the nature and scale of inputs into freshwater ecosystems. The recently implemented WaterSHED (Water: Saskatchewan Headwaters Edmonton and Downstream) monitoring program is a unique collaboration between Alberta Environment and Parks (AEP), EPCOR, the North Saskatchewan Watershed Alliance (NSWA) and the City of Edmonton. This monitoring program aims at filling critical gaps in our understanding of the links between watershed processes and changes in water quality, quantity and overall ecosystem functioning. Consequently, expertise within the collaborative WaterSHED program, with support of $1 million per year from EPCOR Water Canada for four years (2018-2021) from City of Edmonton water rate payers, have conceptualized and implemented a multi-disciplinary river water monitoring program across the NSRB.

AEP's participation within the WaterSHED program aligns with its 2020-2023 Business Plan outcomes, including the key objective to monitor, evaluate and report on the ambient condition of Alberta's environment (Environment and Parks Business Plan, 2020-2023). Section 15 of Alberta's Environmental Protection and Enhancement Act further mandates the development and implementation of an environmental science program to monitor, evaluate and report on the condition of the environment in Alberta.

The WaterSHED monitoring program is also integrated into AEP's core river water quality monitoring programs. These core programs, the Long Term River Network (LTRN) and Tributary Monitoring Network (TMN) are defined by regular collection of flow, water quality and biological data from Alberta rivers for comprehensive assessments of watershed and riverine conditions and how they respond to natural and anthropogenic factors. The design of the core water quality program is driven by AEP's 5-year Monitoring, Evaluation and Reporting (MER) plan (Kerr and Cooke, 2019) and supported by targeted focused studies, which are shorter-term investigations designed to address specific knowledge gaps.

Using the MER plan and other regional strategies (e.g., Alberta's *Water for Life* strategy), the WaterSHED program was designed and implemented as an enhanced TMN program to align closely with AEP's standards for monitoring river ecosystems, and address key environmental issues particular to the NSRB using integrated and interdisciplinary methods. More specifically, this program utilizes new deployments of enhanced water monitoring stations across the diverse landscapes of the NSRB to assess near continuous changes in river water quality and quantity, and also employs targeted focused studies to address problem-based environmental issues across the basin.

WaterSHED's collaborative approach to aquatic ecosystem monitoring at the large river basin scale is unique to Alberta and is positioned to produce critical data on the condition of the environment in the NSRB to support participating stakeholder initiatives. This report provides a technical overview of the WaterSHED monitoring program design and implementation, as well as preliminary findings after the first year of data collection (2019). This document is divided in four main sections: Section 1 '*The monitoring network*' that introduces the geographic setting of the NSRB and provides an overview of the design and implementation of the core monitoring program. Preliminary results from the first year of the program implementation are included in section 2 '*Core Program: Preliminary findings*'. Section 3 '*Focused studies*' outlines the short-term studies initiated during the first year. Last, section 4 '*On-going work*' identifies on-going monitoring activities and highlights new monitoring approaches and focused studies that will be undertaken in the following years of the program.

The monitoring network

Geographic setting

The North Saskatchewan River (NSR) is one of Alberta's major river systems. It originates in Banff National Park's Columbia Icefields, where it receives melt water from the Saskatchewan Glacier. The river flows east across Alberta and towards Saskatchewan, where it joins with the South Saskatchewan River, forming the Saskatchewan River, which eventually flows into Lake Winnipeg.

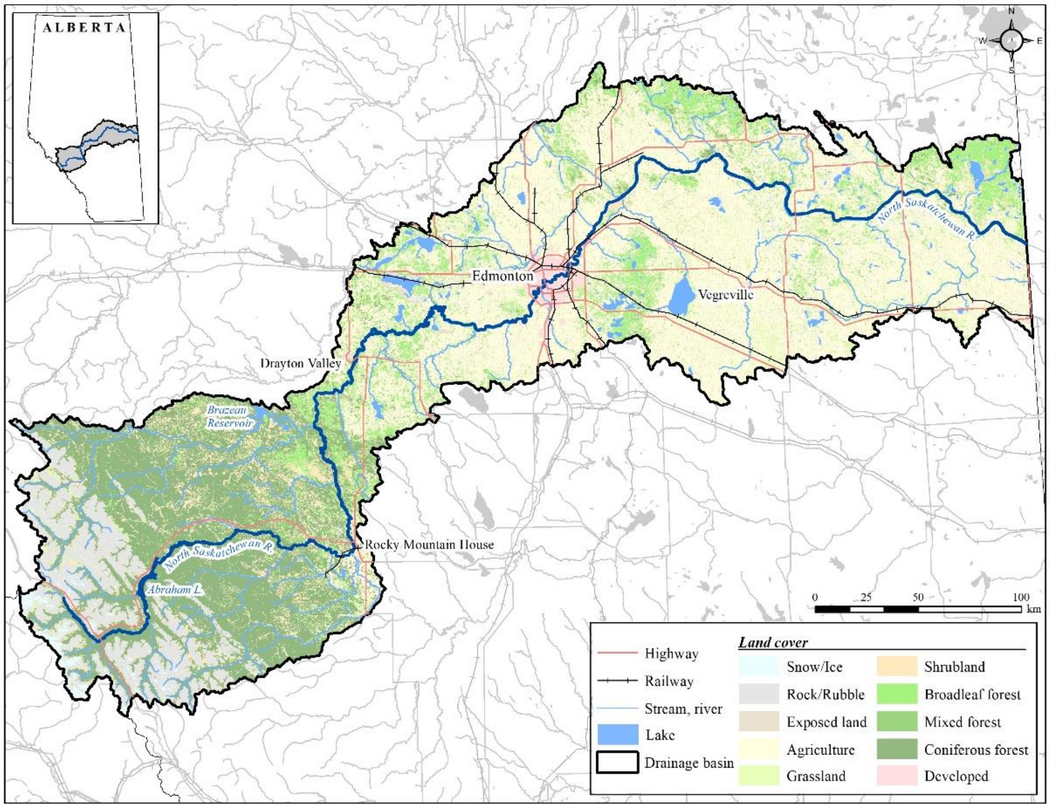

Figure 1. Location of the North Saskatchewan River watershed within Alberta and land cover types (Source: ABMI Provincial Land Cover, 2010).

The NSR has a basin area up to the Alberta-Saskatchewan border of about 57,000 km^2 (approximately 9% of the total area of Alberta, Figure 1). Mean annual flow at the Alberta-Saskatchewan border is 221 m^3/s (from 1980-2019). The main sub-watersheds that contribute flow to the NSR main stem are located in the headwaters: Brazeau (57 m^3/s), Ram (20 m^3/s), and Clearwater (37 m^3/s) rivers. While they contribute less water, the Sturgeon and the Vermilion rivers are the most important additions of flow downstream of Edmonton (3.2 m^3/s and 1.8 m^3/s respectively). Flow contribution from the main sub-watersheds is shown in Tables 1, 2 and Figures 2, 3.

Seasonal and inter-annual differences in climate conditions influence the magnitude and timing of river hydrology throughout the NSRB, as conditioned by watershed structure (e.g. topography, land cover). For example, steep and cold headwater rivers experience prolonged frozen conditions in winter before a rapid runoff period in spring that delivers water quickly and intensively downstream. Low-flow conditions may persist thereafter until the next freezing period, save for summer storm events. Inter-annual differences in spring snowpack depth and storm intensities can have major impacts on hydrological conditions each year. Lower-relief prairie rivers experience longer open-water conditions, less rainfall, and are prone to beaver activity and seasonal drying. The geography of convective summer storms within a river subwatershed can have important influences on annual water budgets in these typically small rivers on the prairies. Flows in the NSR are regulated by two dams located in the upper reaches of the river: the Brazeau dam on the Brazeau River (built in 1961) and the Bighorn Dam on the mainstem of the NSR (constructed in 1972) which forms Abraham Lake. Flow regulation has altered seasonal patterns and resulted in lower summer flows and higher winter flows than would naturally occur. In addition, the operation of the reservoirs for hydropower production results in diurnal fluctuations in water levels.

The NSR traverses a variety of natural regions, from high-relief mountainous areas (Rocky Mountains region), through rolling forested foothills landscapes, to agriculturalized low-relief boreal and parkland regions towards the Alberta border. These regions have different climate, geology, soils, land cover and land use characteristics, which impact the morphology of the NSR, as well as its water quantity and quality. For instance, the steeper and wetter landscapes of the Rocky Mountains and Foothills regions efficiently delivery water downstream and supply most of NSR’s water measured downstream at the border. Alternatively, the drier and flatter landscapes in the prairies more effectively store water in soils and groundwater resulting in fewer water contributions to the NSR from local tributaries.

Urban development and resource exploitation also vary throughout the basin. Forestry is the most spatially relevant land use activity in the NSRB upstream of Drayton Valley, while most agricultural activity occurs in the central and eastern portion of the basin (Figure 1). Industrial development, as well as coal mining and oil and gas extraction, also occur throughout the basin, but the most intensively developed area is the Industrial Heartland area near Fort Saskatchewan. About one third of Albertans live in the NSRB, with most of the population concentrated in Edmonton (ca. 1,000,000 people) and the adjacent Capital Region. The NSR generates ~ 5% of Alberta’s water supply, and is Edmonton’s only source of drinking water.

Network design

Well-designed long-term monitoring networks provide the basis for understanding hydrologic processes, pathways and trends. The acquisition, evaluation and reporting of high-quality data from representative monitoring networks, is paramount for understanding how watersheds respond to natural variability and identifying the influence of anthropogenic pressures. This information ultimately determines the adequacy and effectiveness of existing and new watershed management initiatives, including the role of modeling for future management decisions.

The proposed monitoring network design for the NSRB was based on previous provincial monitoring programs and the original NSR Water Quality and Aquatic Health Monitoring Program developed in 2015 (EPCOR, 2015). These program designs were modified based on the mass balance approach outlined in the MER plan for lotic systems in Alberta (Kerr and Cooke, 2017). Site selection requires consideration of five basic criteria:

- The volume of flow contribution;
- Land-use and other anthropogenic stressors within the sub-watershed;
- Co-location with existing flow gauging stations;
- The extent that an existing station is representative of the broader river system;
- Accessibility.

One key constraint to implementing a sustainable and targeted monitoring program is the number of monitoring sites sampled. In most monitoring programs the full suite of desired watersheds and sub-watersheds are not able to be monitored, typically due to budget and logistical constraints. As a result, site selection needs to be optimized in a defensible manner that minimizes the impact of network reduction on the data being produced and maximizes the value of collected data.

Achieving monitoring program optimization is best done by applying sound scientific principles in identifying which locations to monitor. An added benefit of program optimization in terms of site numbers and technology application is the ability to introduce flexibility into future monitoring. For example, reducing the number of primary monitoring sites may free up budget that can be used for more targeted focused studies.

AEP has applied a geospatial and statistical approach to identify, characterize, and classify sub-watersheds within the NSRB based on their structure. Characterizing this structure was based on the physical characteristics of watersheds that typically modulate climatic inputs and, in large part, determine variation in water quantity and quality. These characteristics include slope, surficial geology, land use and land cover. Following characterization using published spatial datasets, statistical clustering of sub-watersheds into similar groups provided a mechanism to identify groupings of sub-watersheds. The underlying principle of this approach is that the sub-watersheds within each cluster will likely show a similar hydrological response to different drivers that determine their hydrological regime and, therefore, a similar range of variability in flow and water quality. This classification process also serves as a quantitative way to determine if the range of sub-watersheds selected for monitoring were representative of the NSRB as a whole.

A total of 18 tributaries representative of the watershed structures found within the NSRB were selected to form the WaterSHED monitoring network. Where logistically feasible, monitoring stations were located as close as possible to the confluence with the NSR. Monitoring requirements at each site include continuous measurement of river flow (hydrometric station), high-frequency general water quality (multiprobe data sondes), as well as sampling and analysis of a greater suite of chemicals through discrete sampling. Eleven of these representative tributary stations had an existing hydrometric station maintained by either AEP or Water Survey of Canada. The remaining seven tributaries required the installation of a new hydrometric station. All hydrometric sites record data at 15 minute intervals, which is sent via telemetry to AEP servers. All sites required deployment of a continuously recording water quality data sonde and implementation of discrete sampling programs. In addition to these 18 tributary sites, two stations were added on the mainstem of the NSR. These two sites were part of other provincial and federal water quality monitoring programs, but lacked continuous water quality monitoring and an expanded water sampling plan, which were both implemented by the WaterSHED program. Most stations are also equipped with fixed cameras that are updated daily, with imagery available from the Alberta River Basins website (https://rivers.alberta.ca/). More detailed information about each station and their location within the NSR watershed is provided in Table 1 and Figure 2.

The design of this network will improve our ability to:

- Quantify mass fluxes within major sub-watersheds (tributaries),
- Quantify major tributary inputs to the NSR mainstem, and,
- Characterize spatial and temporal patterns in water quantity and quality within each watershed.

Currently, the WaterSHED monitoring network covers a total drainage area of 33,444 km^2 (this value excludes the drainage area at Pakan), which corresponds to approximately 60% of the NSRB (i.e. ~57,000 km^2) and 71% of Edmonton's source water area. In terms of flow contribution, the network monitors an average of approximately 4,921,700 dam^3/year (calculated using flow data from existing stations from 1980 onward, and not including new stations). This volume corresponds to ~80% of the average annual volume of the NSR at Edmonton (i.e., 6,082,235 dam^3/year), and ~70% of the annual volume at the Alberta-Saskatchewan border (i.e. 6,682,367 dam^3/year).

Table 1. List of tributary and mainstem sites monitored under the WaterSHED program (only those sites in Figure 2 with paired flow and water quality data are included in the table). Installation of a hydrometric station at Pakan was completed in late 2020.

Sub-watershed		ID	Area (km^2)	Lat	Lon	Flow station	Sonde
Tributary Monitoring Network (TMN)	Siffleur River	05DA002	512	52.044	-116.38	New	New
	Bighorn River	05DC005	330	52.369	-116.30	New	New
	Ram River	05DC006	1,881	52.368	-115.42	Existing	Upgrade
	Clearwater River	05DB006	3,221	52.252	-114.85	Existing	Upgrade
	Baptiste River	05DC012	1,358	52.664	-115.07	Existing	Upgrade
	Nordegg River	05DD009	865	52.819	-115.51	Existing	Upgrade
	Brazeau River below plant	05DD005	5,658	59.912	-115.36	Existing	Upgrade
	Rose Creek	05DE953	654	53.051	-115.05	New	New
	Modeste Creek	05DE911	1,178	53.247	-114.70	Existing	Upgrade
	Tomahawk Creek	05DE930	186	53.351	-114.65	New	New
	Strawberry Creek	05DF004	589	53.311	-114.05	Existing	Upgrade
	Weed Creek	05DF911	300	53.300	-113.98	New	New
	Conjuring Creek	05DF913	308	53.337	-113.81	New	New
	Whitemud Creek	05DF009	1,086	53.483	-113.55	Existing	Upgrade
	Sturgeon River	05EA001	3,330	53.832	-113.28	Existing	Upgrade
	Redwater River	05EC005	1,602	53.896	-112.99	Existing	Upgrade
	Atimoswe Creek	05ED002	363	53.866	-110.91	Existing	Upgrade
	Vermilion River	05EE002	7,904	53.651	-110.34	New	New
NSR	NSR at Whirlpool point	05DA009	1,920	52.001	-116.47	Existing	Upgrade
	NSR at Pakan	05EC919	39,333	53.991	-112.46	New	Existing

Figure 3 and Figure 4 show the flow contribution of each (active) mainstem and tributary monitoring station to the total annual volume of the NSR at the Alberta-Saskatchewan border.

These figures evidence the significant contribution from the headwater tributaries to the mainstem flows. For example, the Brazeau River (including flows from the Nordegg River and the Brazeau dam) contributes on average 27% of the NSR annual volume (i.e., 1,798,244 dam^3/year). This contribution is significantly reduced in the downstream tributaries (e.g. the annual contribution from Strawberry Creek is 0.4%; 27,010 dam^3/year).

Table 2. Mean annual water yields and daily flow statistics (Mean, Median, Minimum, Maximum, Standard Deviation and Coefficient of Variation) for each sub-watershed with existing flow data (Table 1). Flow data obtained from: https://rivers.alberta.ca/

		Water Yield		Daily flows (m^3/s)					
Sub-watershed	**Years**	**dam^3/y**	**mm/y**	**Mean**	**Median**	**Min**	**Max**	**SD**	**CV**
Ram River	1980-2019	470,609	250	20.5	13.2	1.4	805	25.8	1.3
Clearwater River[1]	2005-2019	565,853	183	37	27	4	774	35	0.9
Baptiste River	1980-2019	195,388	144	6.45	2.7	0.1	224	11.1	1.7
Brazeau River [2]	1980-2019	1,798,244	275	57.9	44.1	1.3	1,586	56.1	0.9
Rose Creek[3]	1980-2019	55,937	86	2.6	0.8	0.04	228	7.0	2.7
Modeste Creek	1996-2019	87,973	75	4.4	1.1	0.03	416	12.4	2.8
Tomahawk Creek	2004-2019	4,321	23	0.3	0.03	0.0	27.3	0.9	3.3
Strawberry Creek	1980-2019	27,010	46	1.4	0.18	0.01	229	6.1	4.4
Weed Creek[4]	2005-2019	3,349	17	0.23	0.03	0.0	73.9	1.7	7.6
Whitemud Creek	2013-2019	27,703	26	1.6	0.4	0.0	41.1	3.6	2.3
Sturgeon River	1980-2018	67,014	20	3.2	1.1	0.0	44.0	5.4	1.7
Redwater River	1980-2019	19,436	12	0.9	0.1	0.0	64.8	3.1	3.4
Atimoswe Creek	1980-2019	3,789	10	0.2	0.01	0.0	20.8	0.8	4.7
Vermilion River	1980-2018	33,971	4	1.8	0.3	0.0	48.6	4.3	2.4

[1] Combined flow values from Clearwater at Dovercourt (05DB006) and Prairie Creek near Rocky Mountain House (05DB002). [2] Combined flow values from Nordegg River at Sunchild Road (05DD009) and Brazeau River below Brazeau plant (05DD005). [3]Flow data from Rose Creek near Alder flats (05DE007), upstream of the newly installed station. [4]Flow data from Weed Creek at Thorsby (05DF008), upstream of the newly installed station.

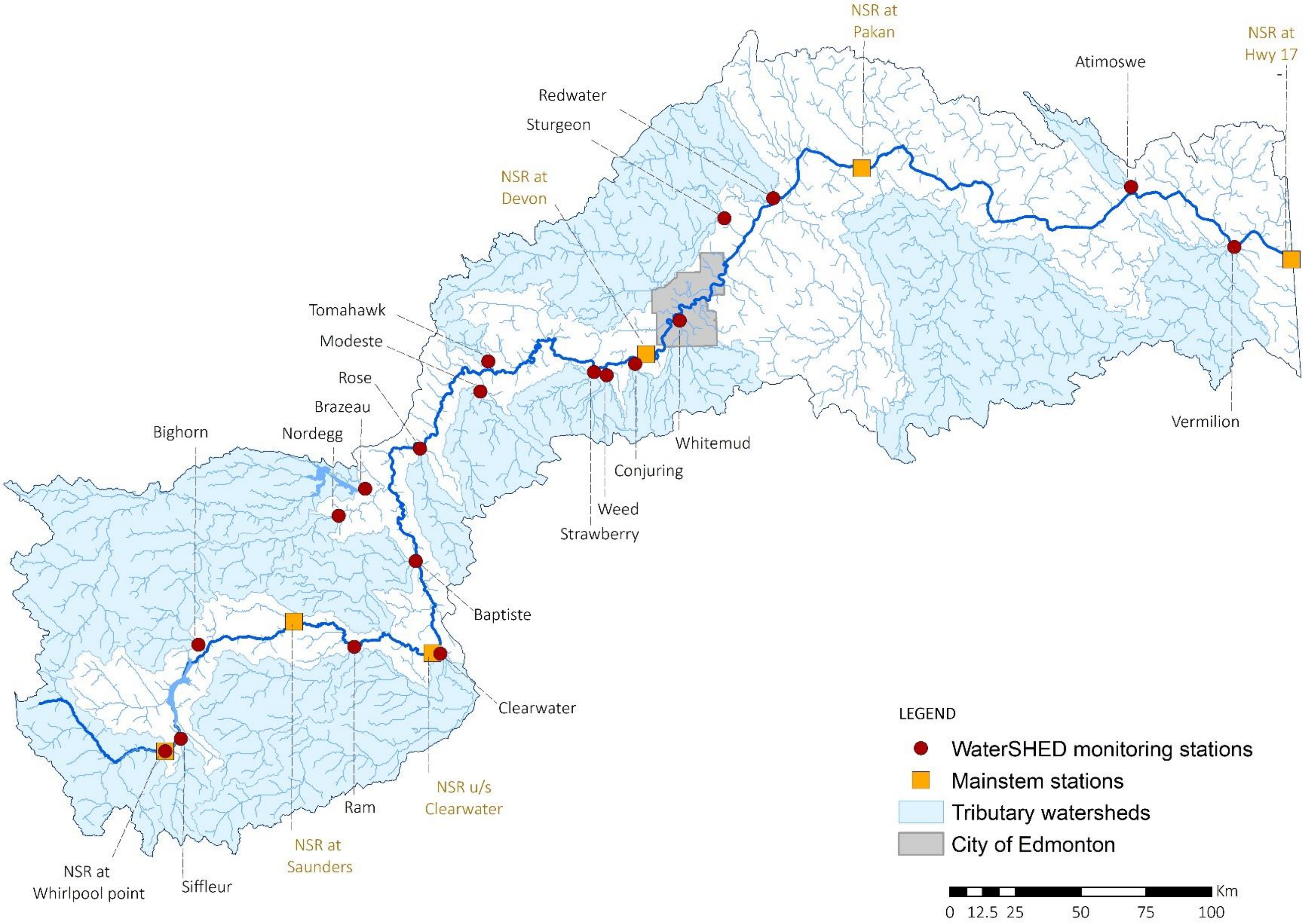

Figure 2. Location of the WaterSHED monitoring stations (red circles). Yellow squares show the monitoring stations in the mainstem of the NSR that are included in AEP's Long Term River Network (LTRN; Saunders, Clearwater, Devon, Pakan) or long term monitoring by Environment and Climate Change Canada (Whirlpool Point and Hwy 17).

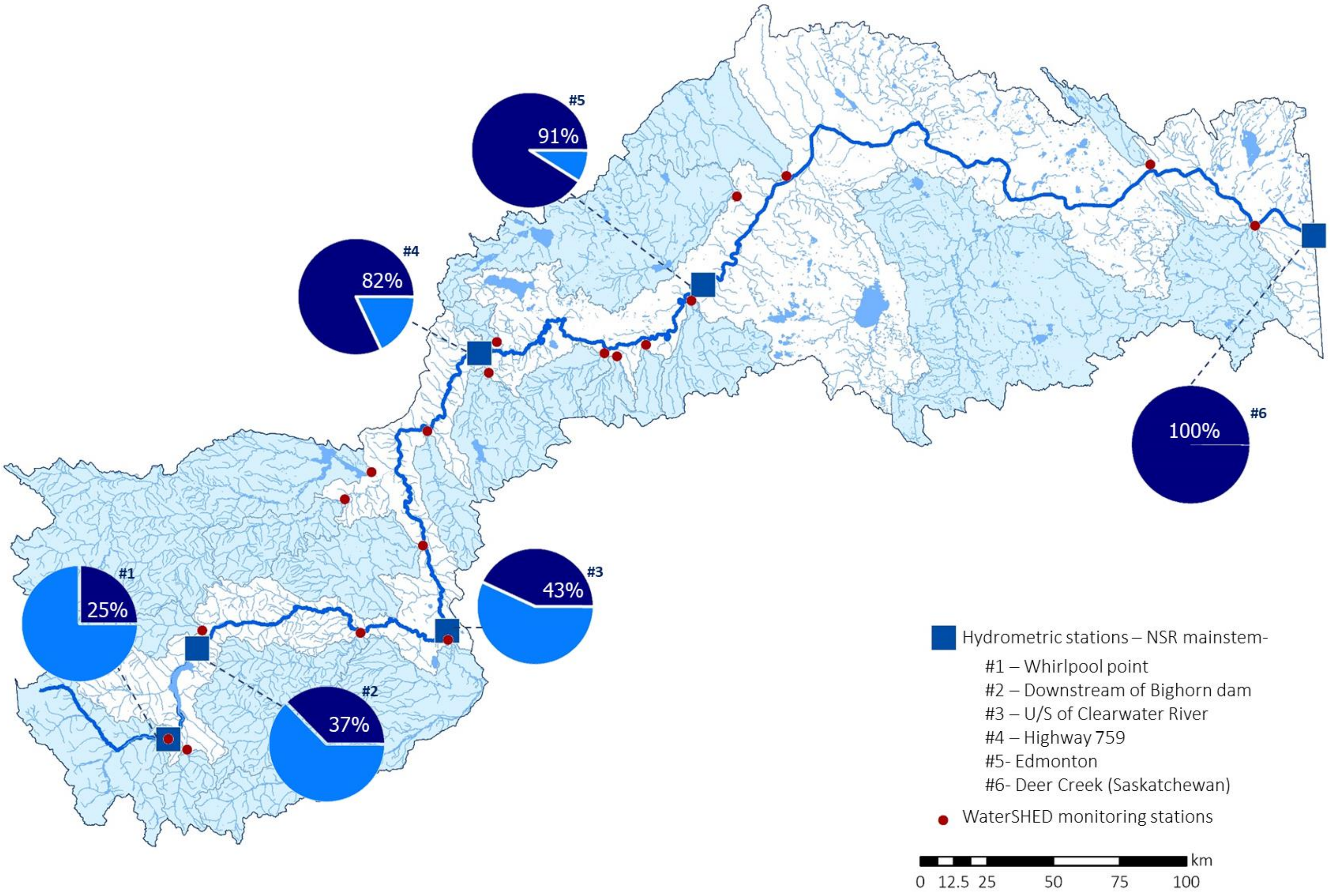

Figure 3. Proportion of annual flow contribution of each NSR mainstem station relative to the annual contribution at the Alberta-Saskatchewan border. Values have been calculated using flow data for the period 1980-2019.

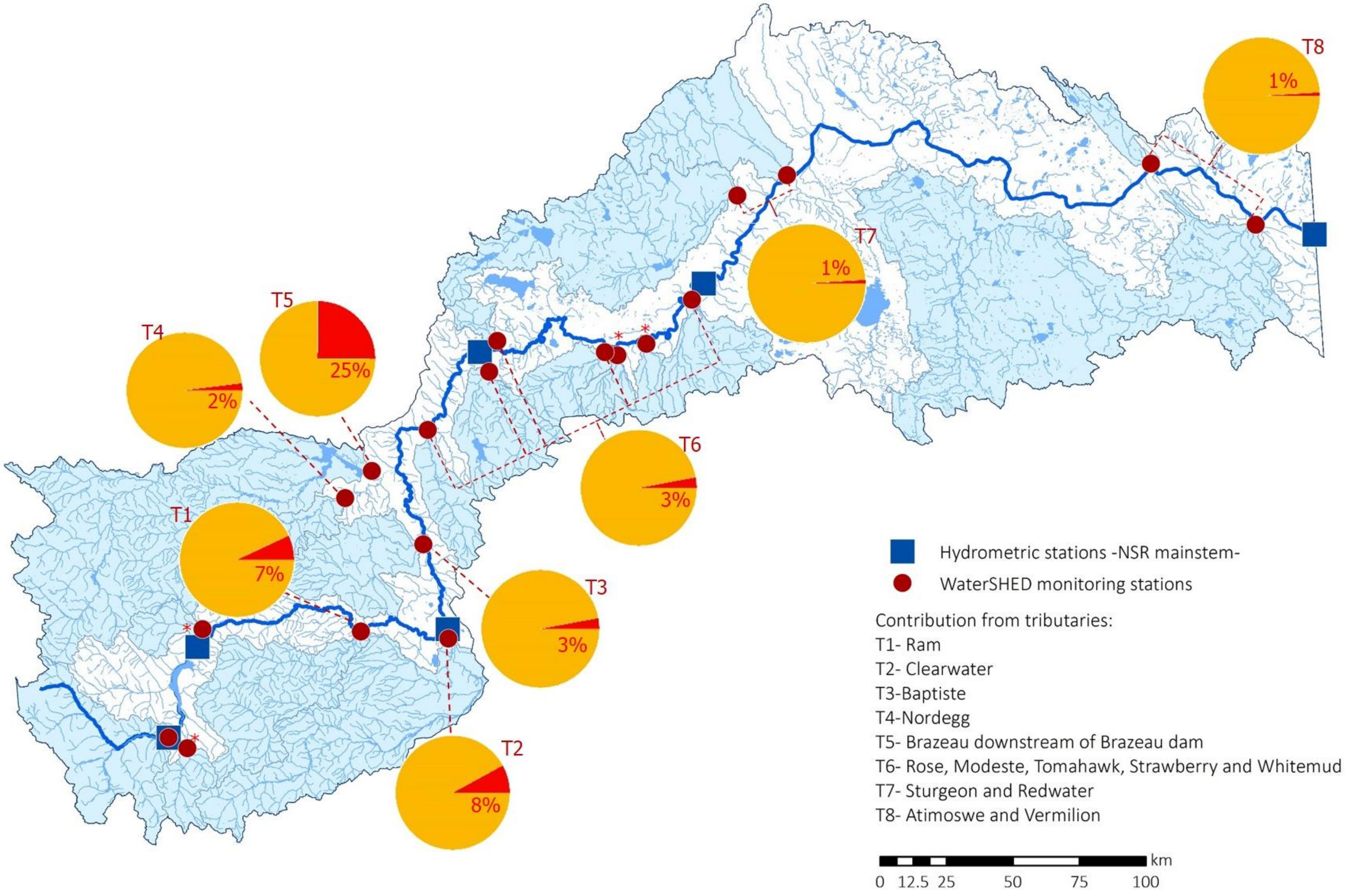

Figure 4. Mean flow contribution from the tributaries to the annual flows of the NSR at the Alberta-Saskatchewan border. Values have been calculated using flow data starting in 1980 for existing stations. The new stations installed under the WaterSHED monitoring program (marked with a red asterisk*) could not be included in the calculations since rating curves are still being developed. The exceptions were Tomahawk, Rose and Vermilion, for which flow data from established upstream stations were used as an approximation. These values will consequently change once flow data from the new stations are available.

Water quantity and quality monitoring

The water quantity delivered by a stream or river is monitored in a near real-time frequency using a hydrometric station (Figure 5). Hydrometric stations automatically measure river water levels using a forced-air pressure system. Near real-time water quantity is calculated as a river flow (volume per time) using a station rating curve (i.e., water level - flow relationship) established from periodic manual measurements of flow in the river by technicians and concurrently measured water level. However, due to hydromorphological processes (e.g., riverbed scouring or sediment deposition), this curve may change over time, particularly after extreme flow events. The provisional nature of these curves may increase the error associated with flux/load estimates, and consequently its stability and reliability must be continuously assessed by performing frequent manual flow measurements.

Figure 5. Photos of hydrometric stations deployed nearby Strawberry Creek (left) and the Siffleur River (right).

To date, most hydrometric stations have been equipped with cameras for remote environmental monitoring. These cameras provide daily images of the sites via (GOES) satellite connection, which are crucial to help correct flow measurements, monitor flow increases during rainfall events and determine ice breakup dates. This information is also used to help alert water treatment plant operators regarding potential changes in water quality conditions. Figure 6 shows some examples of camera photos from selected tributaries.

Water quality may be measured in several ways depending on available equipment, laboratory analyses and funding. Important general water quality parameters can be measured in near real-time or as a spot measurement using continuously recording water quality data sondes. These sondes measure general but important water quality parameters including water temperature, specific conductivity (proxy for total dissolved material), pH, turbidity, dissolved oxygen and oxidation-reduction potential. When deployed directly into a stream or river over a period of time, sondes can measure and record near real-time data. In contrast, discrete water sampling, or periodic collection of surface water, allows for measurement of a larger suite of water quality parameters when samples are sent to an accredited water quality laboratory. Site observations and water quality parameters manually collected in this program at each station include measurements of general chemistry (e.g., water temperature, pH, specific conductivity), nutrients (e.g., carbon, nitrogen, phosphorus), metals (e.g., arsenic, copper, lead), proxy measurements of algae biomass (e.g., Chlorophyll-*a*) and water isotopes (^{18}O and ^{2}H). A full list of parameters analyzed using this sampling approach is included in Appendix I.

Water quality samples are collected at a monthly frequency. However, sampling frequency increases during the spring freshet (starting in March) to capture changes in water quality during the dynamic, higher-flow snowmelt period.

Figure 6. Camera photos from selected monitoring stations in the WaterSHED program. See Figure 2 for site location. Current site photos are available at: https://rivers.alberta.ca.

Water quantity and quality measurements of the ambient conditions in these monitoring sites will provide valuable information on how tributary inputs infuence the water quality and habitat conditions in the mainstem of the NSR. Consequently, these data will be key to fully understand the condition of biological communities and the overall health of the aquatic ecosystem in the NSRB.

Aquatic Ecosystem Health assessment

Historical background

Aquatic Ecosystem Health (AEH) is a concept that integrates environmental conditions with the impacts of anthropogenic activities in order to give information for a sustainable use and management of natural resources. Therefore, indicators used to evaluate AEH must be responsive to anthropogenic impacts and be able to provide insights into the complex cause-effect relationship (Burkhard et al, 2008). Although biological communities respond to human stressors (changes in river habitat, water chemistry and flow regime alterations), they also are affected by natural longitudinal gradients in freshwater ecosystems (e.g. changes in substrate type, riparian vegetation, channel morphology and flow velocity).

A range of factors contributes to the ability of aquatic ecosystems to support and maintain its ecological structure and function over time and space, such as water and sediment quality, channel processes, hydrological regime and riparian condition. However, while water quality has been largely monitored in the mainstem of the North Saskatchewan River (NSR), biological monitoring has been mostly sporadic. The first assessments of biological condition ("Biological Pollution Surveys") date back to 1970 (Paetkau, 1970). This study highlighted the increasing attention that stream pollution investigations had been receiving and the need for greater conservation of aquatic resources. Subsequent studies in the 1970s included greater focus on biological condition in their assessments (e.g. the "River Bottom Fauna Surveys" by Reynoldson, 1973 and Reynoldson and Exner, 1978). Later in the 1980s, additional studies were conducted at various stations in the mainstem of the NSR: in 1982 (Anderson, 1986) and 1985 (Shaw et al. 1994). The most recent AEH assessments with reported data were conducted in 2007 and 2008 (Clearwater and Kilgour 2010). Water quality, sediment quality and biological community data in the NSR were reported on in a synthesis document by AECOM and Anderson (2011). In 2015, Alberta Environment and Parks conducted another basin-wide biological condition assessment, and the data collected is currently under evaluation and review.

Historical AEH studies in the NSR have mostly focused on the study of non-fish biota, including benthic invertebrates and epilithic algae. Benthic invertebrates are aquatic animals without backbones that live on or in the river substrate. They have been traditionally used as indicators of AEH because they are relatively sedentary, have relatively long life cycles, and many species have documented habitat preferences or tolerances to river chemical and/or physical degradation. As an example, Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) taxa are considered sensitive to habitat and chemical degradation. These groups are referred to as EPT taxa, and their abundance and species composition can provide an indication of river condition. Conversely, other groups such as Chironomidae (midge) and Oligochaeta (worms) species, are tolerant to nutrient-rich waters and low oxygen concentrations. Epilithic algae are algae that grow on submersed rocks. The abundance, community composition and diversity of these primary producers respond to increased ambient levels of nutrients, and consequently, they can be used as indicators of nutrient loading to the system. While most of the historical studies used benthic invertebrate fauna and Chlorophyll-*a* (a photosynthetic pigment used as a surrogate for epilithic algal biomass) as indicators of AEH, the composition and abundance of epilithic algae was not included in the surveys until 2007 and 2008.

2019 AEH assessment

Biomonitoring, with the exception of Chlorophyll-*a* measurements in water and the collection of epilithic algae, is not incorporated in the monitoring designs at LTRN stations. In 2019, a basin-wide assessment of AEH was conducted along the mainstem of the NSR to: (i) assess the current status of biological communities in the mainstem of the NSR; and (ii) complement the historical dataset to evaluate the spatio-temporal changes in biological communities (both benthic invertebrates and epilithic algae).

Eighteen sites were selected to include a range of hydro-climatological and morphological conditions found in the watershed, from the Rocky Mountains to the Grassland region (Figure 7). Most of these sites have been sampled historically by AEP as part of synoptic studies and previous AEH assessments (e.g. Clearwater, 2010). These sites incorporate the natural longitudinal variability and the effects of major tributary inputs, as well as changes resulting from point and non-point sources. Four of these sites were situated at existing long-term monitoring stations: the Rocky Mountain House, Devon and Pakan sites are part of the AEP’s LTRN, while the Whirlpool Point and AB-SK border (Hwy. 17) sites are monitored by Environment and Climate Change Canada (ECCC).

Field surveys were conducted in the spring (early June) and fall (late September) of 2019. Sampling is typically done in the fall or late summer when flow conditions are optimal for sampling and the largest proportion of the taxa are likely to be present in an aquatic life stage. While all the sites were sampled in the fall of 2019, a subset of sites (LTRN stations) were also sampled in the spring. At each of the studied sites, sampling included the collection of benthic invertebrates and epilithic algae, as well as sediment and water quality samples. Field data collected is currently under analysis and review by AEP.

Ultimately, data collected from these two surveys will allow for a basin-wide assessment of AEH and also an evaluation of inter-annual changes in biological communities. The integration of biomonitoring with the regular monitoring of physical and chemical parameters will be valuable for the provincial program to transition to a more holistic understanding of environmental conditions and the response of aquatic ecosystems to natural and anthropogenic stressors.

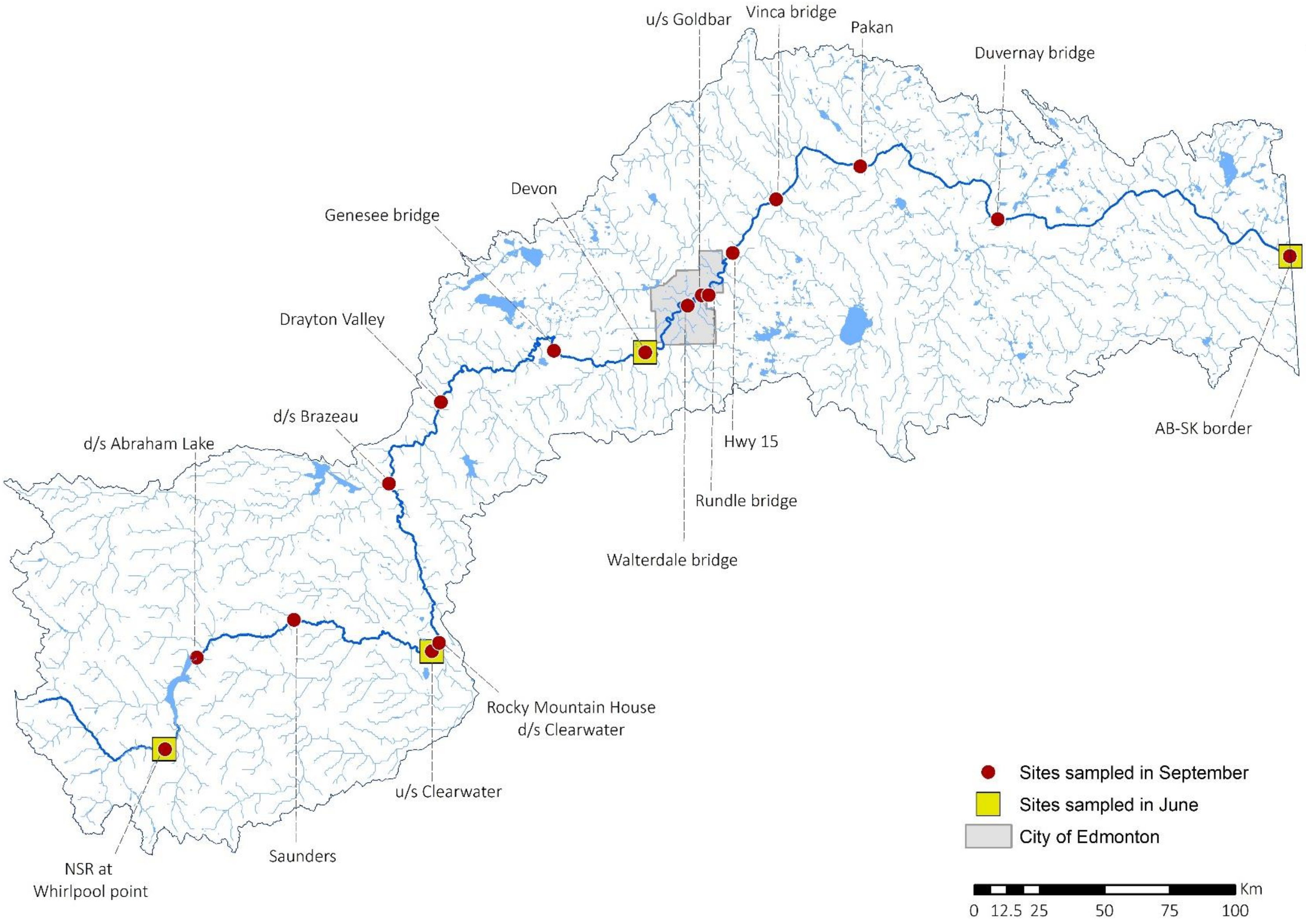

Figure 7. Sampling locations (June and September, 2019 surveys) for the Aquatic Ecosystem Health Assessment in the mainstem of the NSR. d/s: downstream; u/s: upstream. Note that Pakan could not be sampled in June due to high flows in the NSR.

Core monitoring: Preliminary results

During the first year of the program (2018), work focused primarily on the design of the monitoring network and the installation of the new hydrometric stations (Table 1). Flow and water quality monitoring was initiated in 2019 following the corresponding installations and development of appropriate flow conditions (i.e. some smaller tributaries appear completely frozen during the winter, thus hampering sonde deployment and sampling). This section summarizes flow conditions and preliminary water quality results from tributary monitoring sites in 2019.

Hydrological and climate conditions

During 2019, several manual flow measurements were conducted to start the development of the rating curve (i.e. stage-flow relationship) at the seven new stations (listed in Table 1). However, manual measurements could not be performed across all ranges of flow conditions, and consequently more flow data will be collected on an ongoing basis to further develop the rating curves and account for shifts in hydraulic geometry over time due to high flow events (Figure 8).

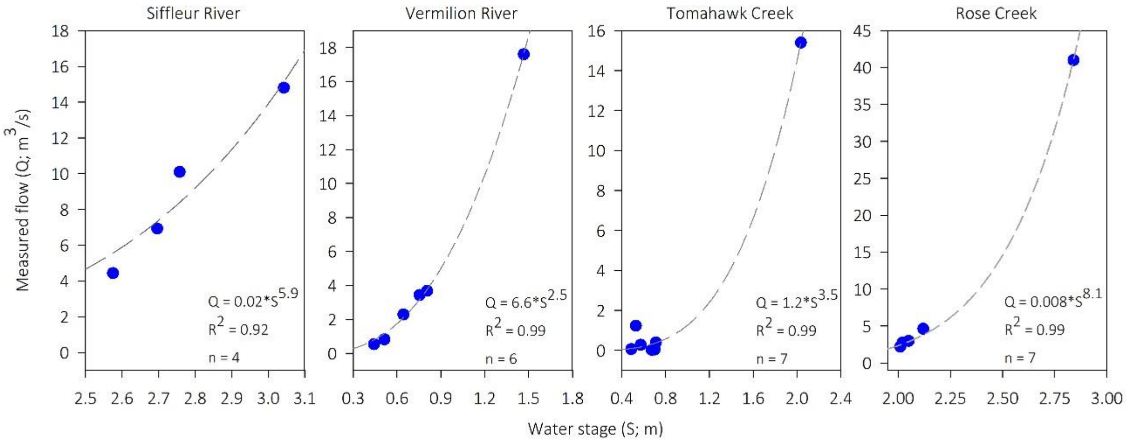

Figure 8. Example of stage-flow relationships at 4 new stations. Additional flow measurements are needed to derive a reliable rating curve (as evidenced by the lack of observations at intermediate flow ranges). Regression fit lines are preliminary and are shown for visual purposes only. *n* indicates the number of flow measurements at each station.

Figure 9 shows monthly precipitation and air temperature for three existing stations in the NSRB with available historical data (e.g. NSR at Whirlpool point in the Alpine region, Ram River in the Foothills, and Strawberry Creek in the Boreal/Parkland region). This figure shows that mean temperature through September 2019 was overall lower than the average temperature for the last

~15 years, notably in February. Precipitation in 2019 showed a marked monthly variability: while some months were drier (e.g., May, August and September in the headwaters and Strawberry Creek and May in the Ram River), other months were wetter (e.g. June and July in all stations).

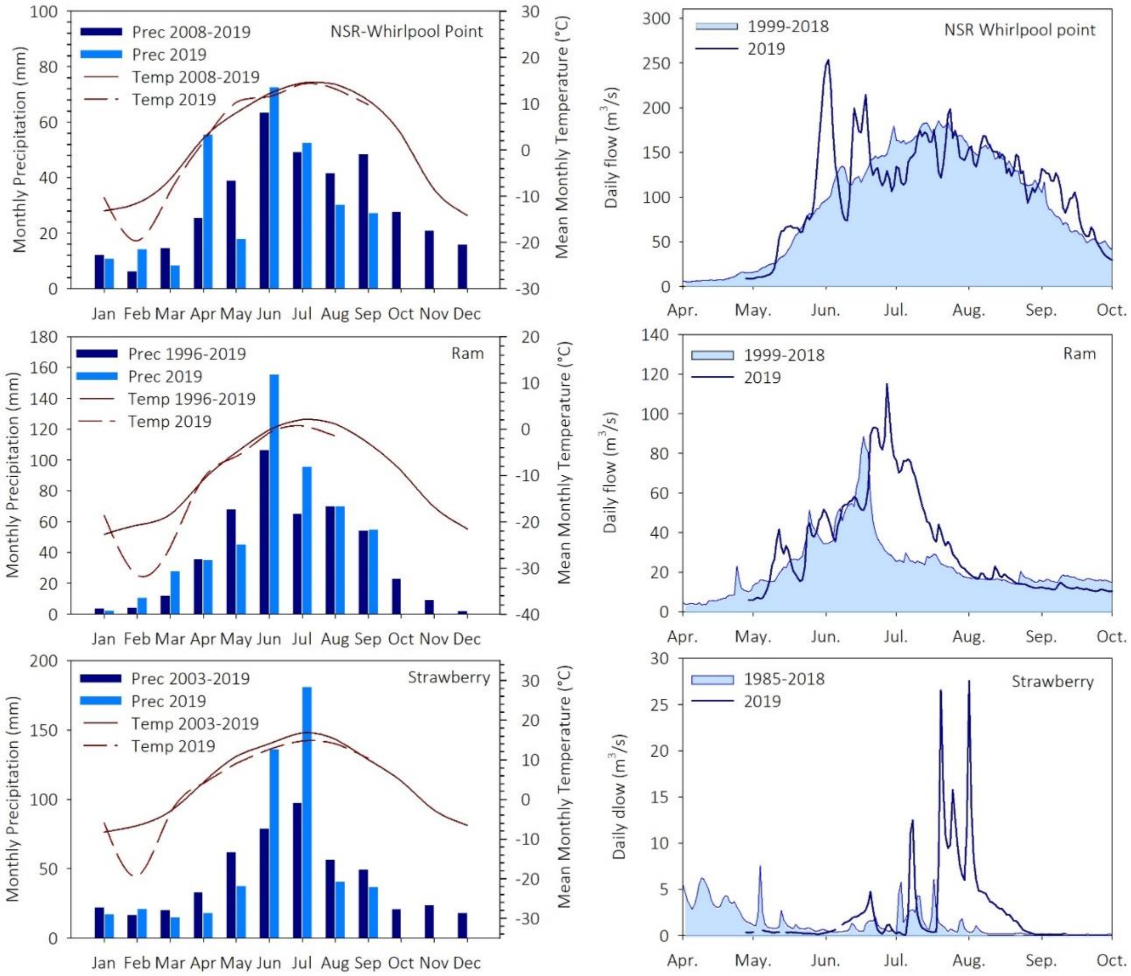

Figure 9. Historical and 2019 climate (left panels) and flow (right panels) data from selected stations of the WaterSHED monitoring program (source: Alberta River Basins; https://rivers.alberta.ca/). Meteorological stations have been selected based on their proximity to the headwaters of the corresponding monitoring station. The meteorological stations used to create this figure are: Saskatchewan River Crossing (MSC-037) for the NSR at Whirlpool point; Ram headwaters (AB FIRES-R2 PR-01) for the Ram River and Breton Plots (05DE802) for Strawberry Creek. Note the different time periods between the stations. Flow data prior to May are currently not available.

Climate conditions were reflected in the hydrological regime though September 2019 (Figure 9). For example, the NSR at Whirlpool point showed a peak at the end of May clearly above the average flow conditions, likely caused by above normal temperatures and subsequent glacial and snow melt during this month. Flows during July and August were also above average conditions, particularly in Strawberry Creek, where summer storm events resulted in notably high flows during these months (maximum daily flow of 27 m^3/s).

Water Quality

Sonde data

Sondes were deployed at each WaterSHED monitoring station at the same time discrete sampling commenced. Figure 10 shows the operational period of sondes at monitoring stations in 2019.

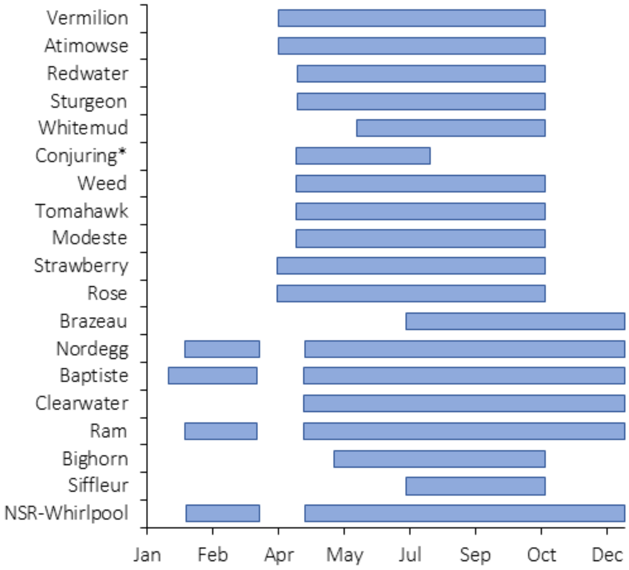

Figure 10. Data sonde deployment during 2019 at each station. Note that sondes were retrieved in April during the ice break-up to avoid damages to the monitoring equipment. *The station at Conjuring Creek was subject to vandalism in July 2019 and was inoperative the rest of the year.

Some examples of continuous water quality parameters monitored using sondes are shown in Figure 11: (i) temperature, which drives biological activity and influences other water quality indicators; (ii) specific conductivity, an index of dissolved ionic solids in water used as a general measured of water quality; and (iii) turbidity, an optical indicator of suspended sediment concentration (which can also harbor other pollutants such as heavy metals and pathogens, nutrients and organic matter). This figure shows water quality changes in response to high flow events in monitored streams. For example, a marked decrease in specific conductivity was observed in Strawberry and Tomahawk creeks following a high flow event in early-July, while marked increases in turbidity occurred following intense rainfall events (e.g. end of June in the Ram River and also Strawberry and Tomahawk creeks).

The range of turbidity values observed at each site also differs likely due to different watershed-scale characteristics (e.g. geology, land use and land cover) and differences in sediment mobilization thresholds. NSR at Whirlpool Point and the Ram River showed a maximum (mean daily value) of ~500 and 970 NTUs respectively, while turbidity values at Strawberry and Tomahawk Creek reached values above 2,000 NTU.

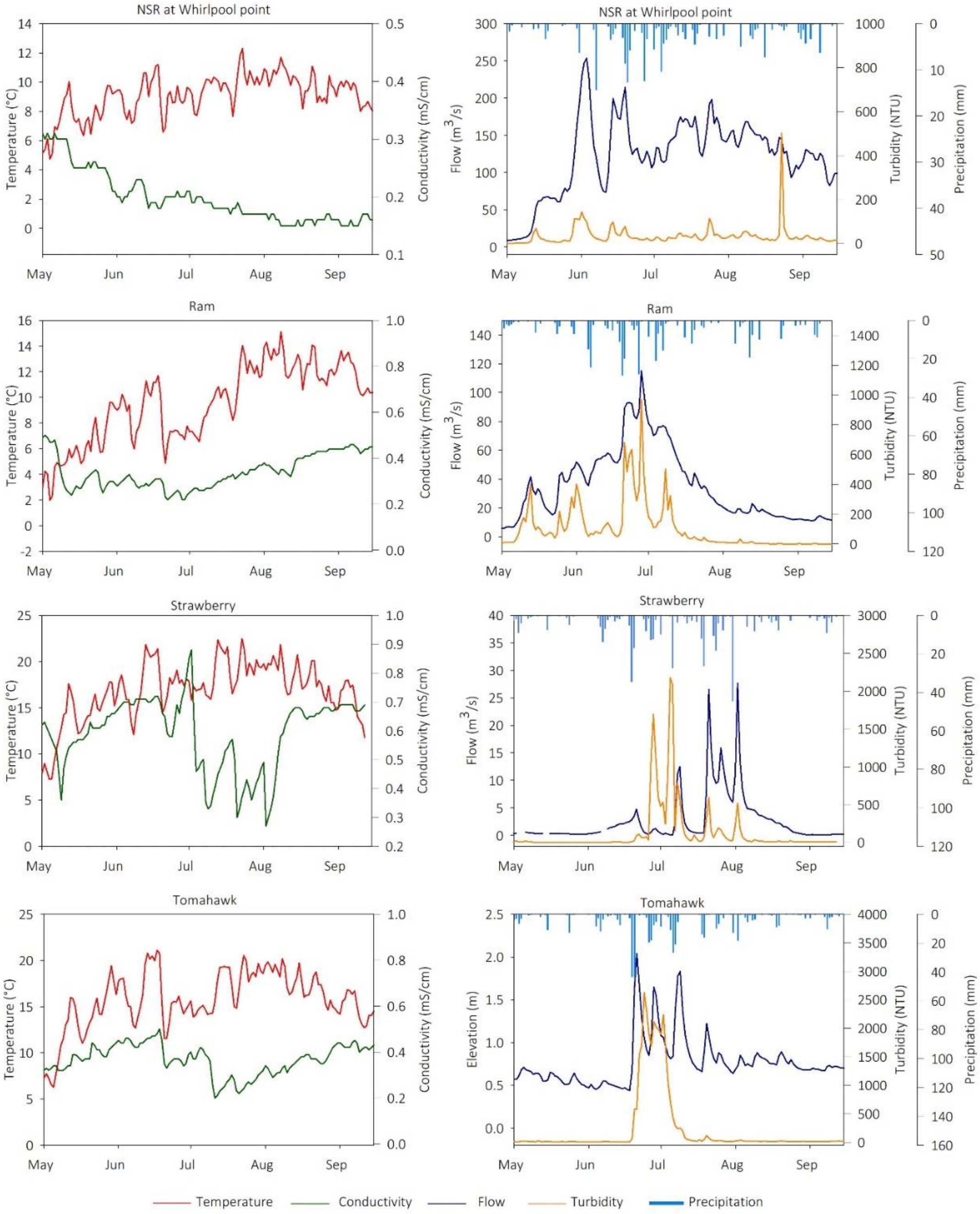

Figure 11. Continuous water quality data from sondes deployed at selected monitoring stations. Precipitation data from nearby meteorological stations have been included to show flow responses to rainfall events. Data prior to May has not been included as flow data for earlier months were not available yet.

Discrete sampling

Water quality samples were mostly collected at a monthly frequency from WaterSHED stations in 2019. However, sampling frequency was increased during the spring freshet to capture changes in water quality during the snowmelt period. For example, sampling frequency was increased during April-May in those sites showing an early spring runoff (e.g. Strawberry Creek and Vermilion River in Figure 12), whereas the frequency was increased in June-July in those sites with a later snowmelt (e.g. NSR at Whirlpool point and Ram River).

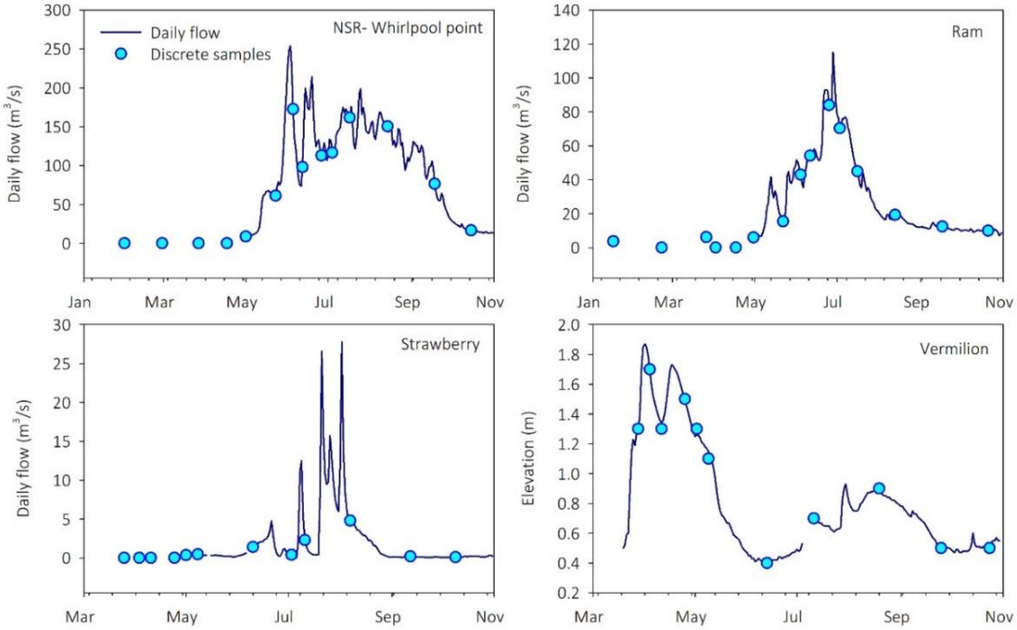

Figure 12. Timing of discrete water quality sampling upon hydrographs at 4 monitoring stations (Water level - flow relationships for the new stations and flow data prior to May are currently being calculated).

The total number of water quality samples collected at each station by month are shown in Figure 13. Sampling at existing stations with under-ice flow started in January 2019, while sampling at the tributaries further downstream commenced following the onset of the spring runoff. Sampling at new stations began following installation. The total number of samples at each sites ranges between 15 (existing sites in the headwaters with good under-ice flow conditions; e.g. Nordegg, Baptiste, Ram Rivers) to 7 (e.g. Siffleur, where sampling started later in June).

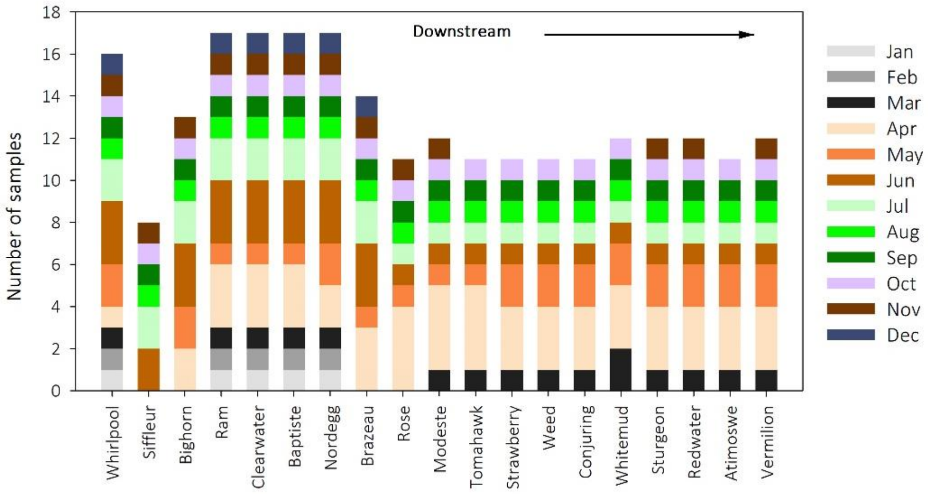

Figure 13. Number of water quality samples collected per month at each WaterSHED station during 2019.

Although the water quality data collected to date does not yet allow for an accurate and reliable calculation of trends and loads from the tributaries, it is possible to observe some apparent spatial patterns in concentrations across the sub-watersheds in 2019.

Some of the measured variables that showed clear spatial patterns across the NSRB included Dissolved Organic Carbon (DOC) and nutrient concentrations (Total Nitrogen –TN and Total Phosphorus –TP). There is a pattern of increasing DOC and nutrient concentrations in the downstream direction, following the land cover gradient in the NSRB (Figure 14). Similar downstream trends were observed for both TP and TN. However, a relatively high value for TP (0.45 mg/L) was captured on the Ram River on June 25th during a high flow event, likely related to high total suspended solids (TSS) concentrations, which are often associated with erosion of soil material during storm events.

TSS concentrations were highly variable across the basin but were on average higher in downstream tributaries (e.g., Rose, Strawberry and Whitemud) relative to those upstream. The maximum concentration (i.e., 523 mg/L) was observed in the Ram River (coinciding with the high TP concentration as mentioned above). TSS is highly variable and depends on a number of interacting factors at the basin scale (e.g. surficial geology, rainfall intensity, hydrological connectivity of sediment sources, antecedent moisture conditions in the watershed, and flows).

To obtain a representative characterization of TSS dynamics across the NSRB and determine main sources of sediment to the mainstem, it is necessary to collect data under a wide range of flow conditions in all tributaries. Data collected in 2019 do not include all the range of flow conditions at all the sites (for example, Figure 12 shows that peak flows in Strawberry Creek were not captured). Consequently, it is not possible to reach definitive conclusions on basin-wide TSS dynamics based on the data collected to date. Additional data collected over the coming years under a range of hydrological conditions will provide better insights into tributary water quality across the basin.

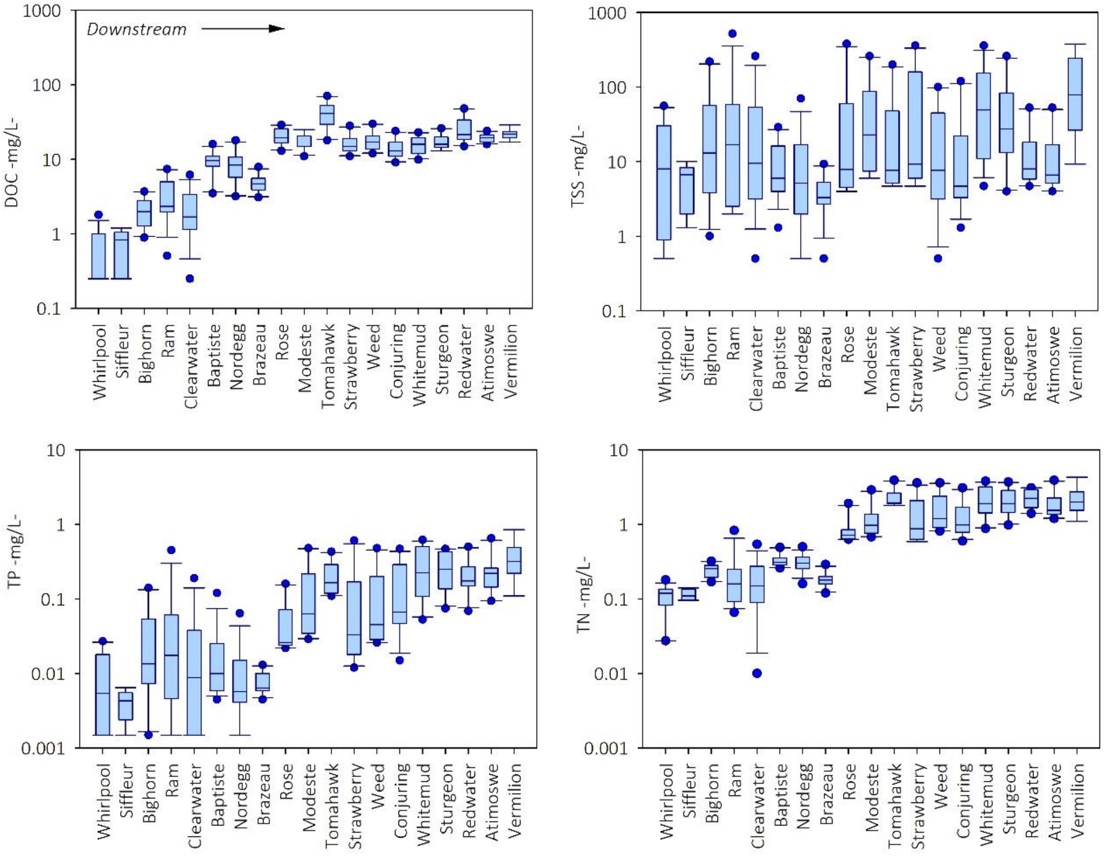

Figure 14. Boxplots of Dissolved Organic Carbon (DOC), Total Suspended Solids (TSS), Total Phosphorus (TP) and Total Nitrogen (TN); y-axis is shown in log-scale.

In summary, the paired sampling approach, using discrete and continuous water quality data, will allow for examination of relationships for selected parameters and develop continuous water quality proxies. For example, if a relationship between turbidity (continuous) and TSS (discrete) is determined, it may be possible to develop site specific regression models for TSS using turbidity as a predictor variable. These relationships between continuous and discrete water quality data is fundamental for a reliable calculation of substance loads.

Focused studies

Two focused studies were initiated in 2019: (i) Comparison of traditionally-used benthic invertebrate sampling methods, and (ii) evaluation of sources and dynamics of Dissolved Organic Matter (DOM) in the NSR. More details for these two studies are provided below.

Sampling method comparison

Historically, AEP has sampled benthic invertebrates in the NSR from erosional (riffle) locations using the Neil cylinder sampler (Figure 15). This method is considered quantitative since the sampler covers a known area (0.1 m^2), which allows estimates of invertebrate abundances per unit area. The cylinder is inserted in the substrate to create a real seal and avoid the loss of fauna. Rocks within the cylinder are cleaned by hand and the substrate agitated with a shovel. Benthic invertebrates and debris is then washed into a net (210 μm mesh size) attached to the downstream portion of the cylinder and then poured into a collection bottled and preserved with either buffered formaldehyde or 95% ethanol.

Figure 15. Neil cylinder (left) and kick-net used in CABIN sampling protocol (right).

However, the CABIN method (Canadian Aquatic Biomonitoring Network) has been introduced as the standard sampling protocol across Canada and provides a consistent and standardized approach to biological assessments. The CABIN method uses a kick-net sampling method standardized by sampling effort (i.e. time). The kick net is a triangular metal frame holding a mesh bag of 400 μm with a collection cup at the end (Figure 15). The kick net is placed downstream of the collector, and the sampler walks in the upstream direction for a timed period of 3 minutes, kicking the substrate to disturb it to a depth of ~5-10cm (Figure 16). Once sampling is completed, the cup is removed and the sampled preserved with 95% ethanol.

Figure 16. Example of CABIN sampling using a kick net. Photo courtesy of: Justin Hanisch and Kristin Hynes.

While reaching consistency in sampling methods across the province is meaningful for inter-basin comparison, changing sampling methods would hinder the calculation of some indicators as well as the ability to combine contemporary and historical data. Recent studies in the Athabasca Oil Sands using the CABIN approach have shown this method to adequately represent benthic invertebrate communities' composition (Culp et al., 2018). For consistency with other basins across the province, mainstem sites in the NSR were sampled following the CABIN protocol. However, Neil cylinder samples were also collected at the LTRN sites in the spring and fall surveys (Figure 7). Data collected in these two surveys will allow the comparison of sampling methods as well as determine appropriate data collection techniques for the WaterSHED monitoring program.

Dissolved Organic Matter (DOM) dynamics

Background and objective

Dissolved organic matter (DOM) is a common constituent in surface waters and is primarily sourced from runoff passing through organic soils and wetlands. High concentrations of DOM present considerable challenges to drinking water treatment plants (WTP) because it may: (i) produce taste and odour problems; (ii) interfere with ultraviolet disinfection; and (iii) produce potentially carcinogenic by-products during the treatment process. A key unknown in the NSRB is which land cover types, hydrometeorological conditions and tributaries most effectively mobilize DOM to the NSR, which is used by WTPs to deliver treated drinking water to Edmonton and surrounding communities. The objective of this focused study, therefore, is to quantify the nature, concentration and export of DOM in tributaries draining contrasting land covers and link these events to DOM concentrations observed at WTPs in Edmonton.

In surface waters, DOM is a key energy source for microbial communities and affects nutrient cycling, ecosystem productivity, UV light penetration and heavy metal transport. Climate variability and land use changes can impact when and where DOM is mobilized within a watershed, and is therefore critical information for predicting and managing downstream water quality (Saraceno et al. 2009). For example, significant pulses of DOM can be rapidly mobilized and transported through a river network during storm events (Hinton et al. 1997), and rainfall intensity has been identified as a key control on the transport of DOM (Jeong et al. 2012). Climate change is further predicted to modify the delivery of DOM to river networks due to, for example, increased precipitation intensity and runoff, longer growing seasons, increased frequency of freeze-thaw cycles and more widespread wildfire activity throughout river basins. These drivers of DOM concentrations in rivers are difficult to predict and often result in WTP operators having to add additional chemicals to effectively remove DOM from raw water, though at an increased cost.

Considering the challenges of treating raw water with higher concentrations of organic material, a proxy for DOM concentration is closely monitored at EPCOR's WTPs. High concentrations of certain types of DOM linked to organic soils (called chromophoric DOM) can result in coloured (i.e., stained) water that can be quickly monitored in a laboratory by measuring the optical properties of water, or water colour. Operators at EPCOR WTPs continuously monitor NSR water colour and have observed that colour is typically low during the winter months, but can quickly increase during spring runoff and summer in response to snowmelt or precipitation events. However a more proactive understanding of the driving factors associated with periods of high water colour (high-colour events) in the NSR is of importance for effective operation of WTPs and provides the foundation for this focused study.

Study sites and Methods

Two contrasting tributaries (Rose Creek, Strawberry Creek) were selected to study how land cover influences the character, concentrations and export of DOM to the NSR. The watersheds of these tributaries are similar in surface area (Rose: 650 km^2; Strawberry: 590 km^2), but have contrasting land covers as Rose Creek is mostly forested, while Strawberry Creek is mostly agricultural (Figure 17). Runoff is typically higher in Rose Creek (mean: 86 mm yr^{-1}), relative to Strawberry Creek (mean: 45 mm yr^{-1}).

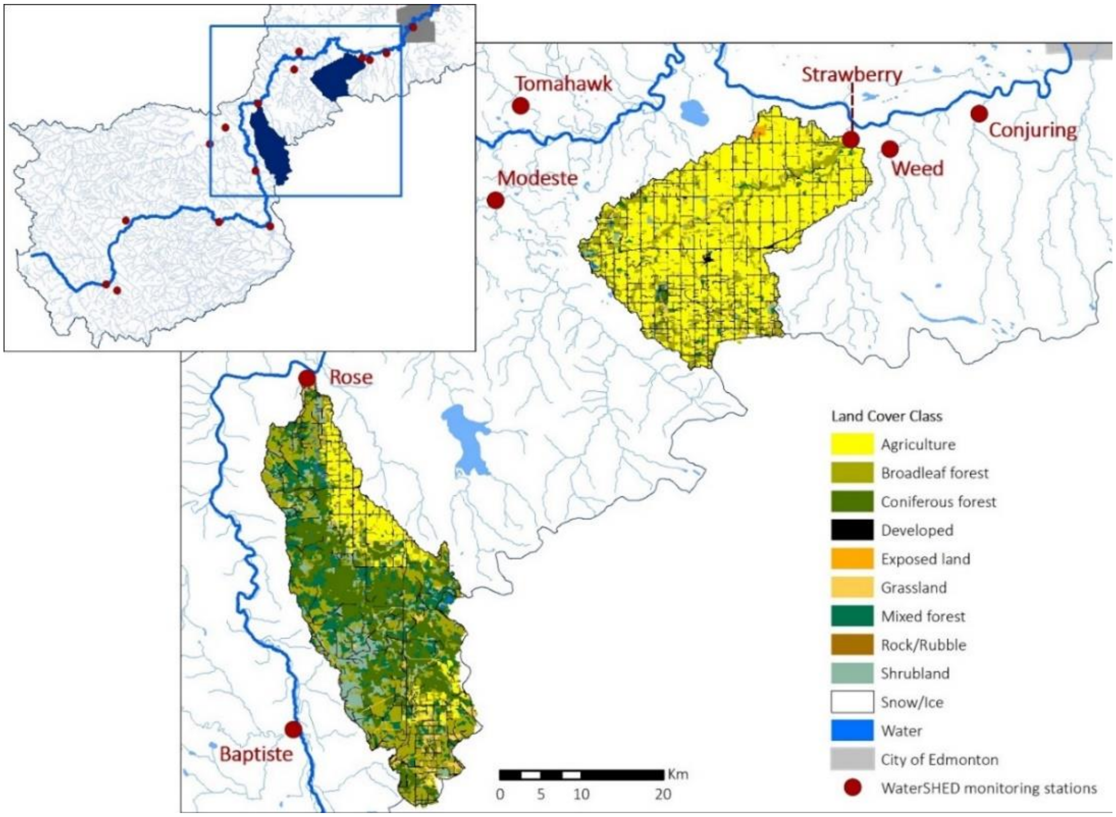

Figure 17. Landsat land cover classes in Rose and Strawberry creeks, the two focus tributaries selected for the dissolved organic carbon focused study.

At the mouths of each creek, continuous water quantity and quality are monitored while a broader suite of chemicals are sampled semi-monthly, including DOM concentration (see River quantity and water quality section above). However, to better understand short-term changes in DOM concentrations (e.g., in response to rainfalls), we will deploy fluorescent Dissolved Organic Matter (fDOM) sensors in each creek, which continuously monitor an effective proxy of DOM concentrations (Mülller et al., 2014; Lee et al., 2015). We will also deploy autosamplers at each site that will intensively monitor DOM concentrations as these creeks respond to individual precipitation events. In addition to general water quality analyses, all collected samples will be preserved and measured for high-resolution characterization of DOM using size-exclusion mass spectrometry. Together, continuous monitoring, semi-monthly and storm-related sampling, and specialized laboratory analysis will allow for quantification of the timing, composition and concentration of DOM exported from the tributaries. In 2019, fDOM sensors and autosamplers were deployed in each tributary to test the effectiveness of each sensor and sampler given the different environmental conditions at each site. We were able to optimize the deployments of the fDOM sensors and autosamplers at each site in anticipation of full deployment in 2020.

In addition to this intensive tributary monitoring in 2020 and 2021, we will also use fDOM sensors and water quality monitoring of the NSR in Edmonton (Rossdale Water Treatment Plant- raw water intake) to assess similar changes in DOM quality and quantity as at tributary sites. This monitoring and sampling approach will allow for a link between chemical conditions in tributaries relative to those in the NSR at WTP water intakes.

Data collected over the two-year period will provide insights into the timing and magnitude of changes in DOM during storm events as well as into DOM fluxes from agricultural and forested watersheds. Results will also be used to evaluate the usefulness of fDOM sensors as early-warning systems of high colour events at EPCOR’s WTPs.

Case study – Colour event in July 2019

Recent events in the NSR have demonstrated the impact of DOM on EPCOR WTP operations. In 2016, a summer precipitation event resulted in a record intense and prolonged water colour event in the NSR that challenged the operations at EPCOR’s WTPs to produce drinking water at low cost. Similarly, an early melt event in February 2017 increased colour in the NSR and forced WTP operators to add chemicals to reduce organic matter concentrations much earlier in the season than normal. Implementation of the WaterSHED monitoring program has already improved our understanding of the sources of high colour events in NSR water in Edmonton. For example, a precipitation event in the summer of 2019 induced another colour record in the NSR (26-27th July). The preceding precipitation event occurred in July 23-25, and resulted in between 15-35 mm of rain falling between Drayton Valley and Edmonton (Figure 18).

Preliminary tributary flow data indicated that these precipitation events and the subsequent runoff in the streams near Drayton Valley were likely most responsible for the high colour event in Edmonton (Figure 19a).Rose and Modeste creeks, in particular, showed a strong precipitation-driven runoff event just days before the high colour was measured in Edmonton. Flow increases were less pronounced in upstream regions during this event (e.g., Baptiste, Nordegg; Figure 19b), or those just west of Edmonton (e.g., Strawberry; Figure 19c).

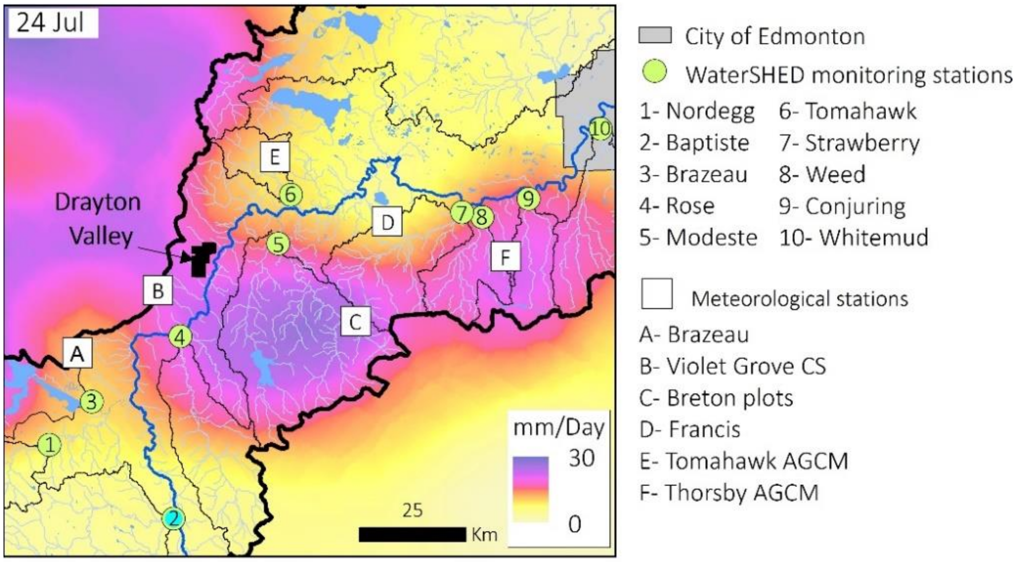

Figure 18. Daily precipitation accumulation upstream of the City of Edmonton on July 24, 2019. This rainfall event resulted in increased runoff in some tributaries and the NSR mainstem as well as a record water colour event in the NSR. This map was generated using the interpolated datasets developed by Alberta Agriculture and Forestry (data available at: http://agriculture.alberta.ca/acis/township-data-viewer.jsp).

The drivers and sources of colour in the NSR are not yet fully understood. During spring runoff, high colour originates from small creeks located between Edmonton and Drayton Valley (i.e. Conjuring, Weed, Strawberry, Modeste, etc.). While the relationship has not been determined, the intensity and duration of the increased colour in the spring appears to be due to the depth of snowpack, and the intensity and duration of the spring melt.

As observed in Figure 19, heavy precipitation events in the headwaters of the NSR typically result in increased colour at WTPs in Edmonton, however, until more sample and continuous data are available, as well as accurate estimate of water travel times between tributary mouths and Edmonton, it is not known how summer precipitation events across the NSRB ultimately influence colour measured at the Edmonton WTPs in Edmonton.

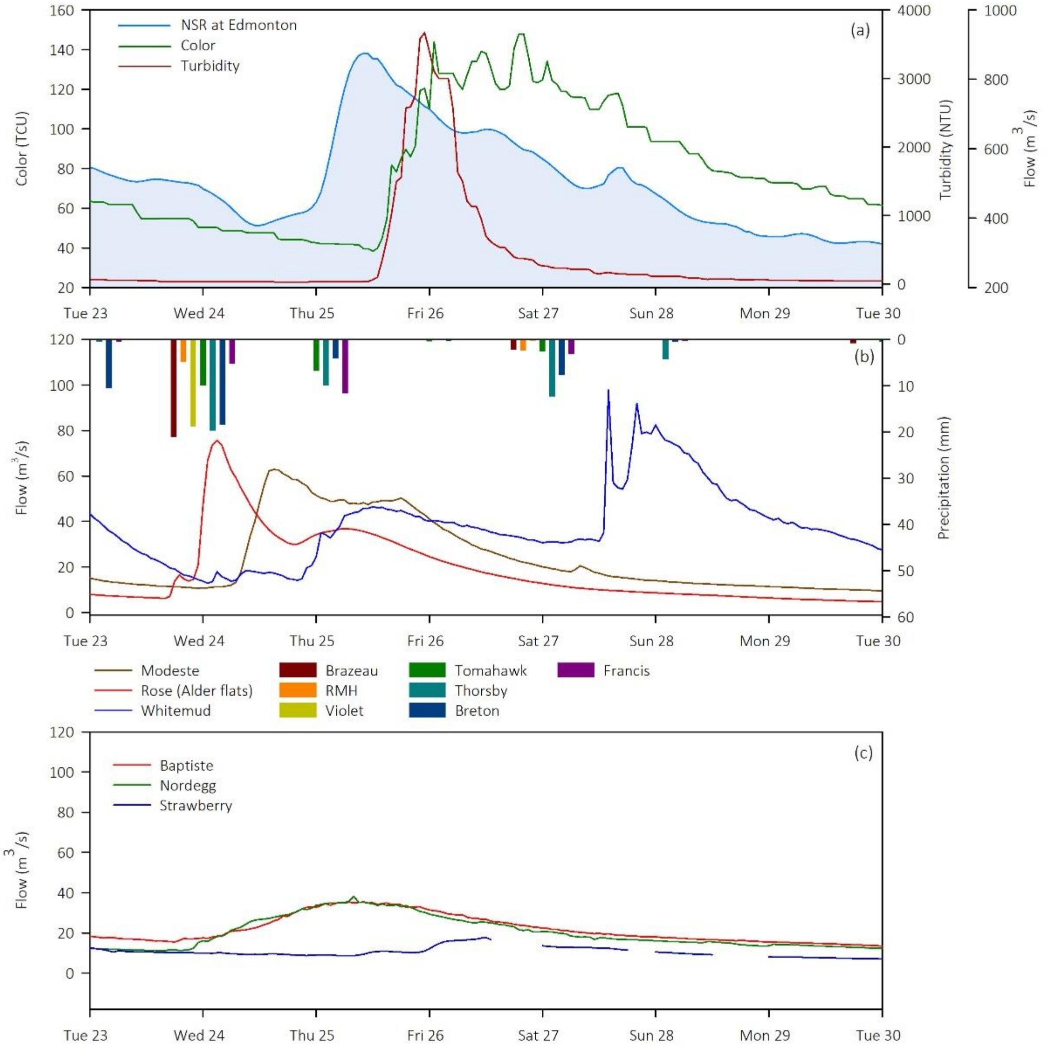

Figure 19. Top panel: Flow measurements from the North Saskatchewan River in Edmonton and colour and turbidity measurements from the Rossdale WTP (top panel); Middle and bottom panels: precipitation (bars) and river flow from several monitored tributaries (lines) upstream of Edmonton during a high water colour event period in July 2019.

On-going work

Main objectives of the WaterSHED monitoring program for subsequent years are:

- Continue to collect continuous measurements and discrete water quality samples at all core monitoring stations and perform manual flow measurements for the development of rating curves at the new tributary sites.
- Enhance the monitoring network to address gaps identified:
    - Recent analyses of climate models indicate rapid changes in meteorological conditions at high elevations in the NSRB. However, few meteorological stations exist anywhere in Alberta at elevations above 1,500 m. As such, a fully-equipped meteorological station (e.g., air temperature, relative humidity, precipitation, wind speed and direction, solar radiation, ground temperature, snow depth, snow water equivalent) will be installed in the headwaters of the NSR (location to be determined) and will enhance our ability to understand the often extreme meteorological conditions that occur in the upper headwaters of the NSR basin.
    - Following the initial geospatial selection of subwatersheds to monitor in the NSRB, monitoring gaps remained in the foothills and alpine regions of the basin. As such, a new station in these upper regions of the basin will be installed to strengthen the understanding of the hydrology and biogeochemistry of these under-monitored regions in the basin.
- Analyze benthic invertebrate and epilithic algae data to evaluate the current status and longitudinal changes of biological communities in the NSR mainstem. The recently collected data, in conjunction with historical data, will allow us to evaluate temporal conditions and trends in AEH, as well as to identify appropriate biological indicators to be used in regional frameworks.
- Full operation of the Dissolved Organic Matter focused study in Rose and Strawberry creeks, as well as the Rossdale WTP. This implementation includes deployment of continuous sensors and autosamplers at tributary sites, as well as enhanced chemical analysis of dissolved organic matter character in all collected samples, in particular during storm events. These data will support the development of predictive scenarios of high colour events at Edmonton WTP based on the location of rainfall events and continuous measurements of river flow and water quality.
- Initiate a flow-weighted sampling program on the mainstem of the NSR to support the development of Maximum Allowable Loads of chemicals of concern in the NSR. Maximum

Allowable Loads define the maximum amount (or mass) of a particular substance that a body of water can receive while still meeting water quality objectives (McDonald, 2013). Use of Maximum Allowable Loads is a cornerstone of AEP’s Water Management Framework for the Industrial Heartland and Capital Region (2008), which manages NSR water quality through the Edmonton region. This focused study involves targeted water quality sampling upstream and downstream of Edmonton across the range of hydrologic conditions, including extreme high and low flows. This monitoring will provide important data for the development of Maximum Allowable Loads, which may change substantially across a full range of flow conditions in the river.

References

AECOM, Anderson, A.M. 2011. Synthesis of recent knowledge on water quality, sediment quality and non-fish biota in the North Saskatchewan River, with Special Emphasis on the Industrial Heartland-Capital Region Water Management Framework Reach. Prepared for Alberta Environment. 92pp. Available at: https://open.alberta.ca/publications/w1206

AEP- Alberta Environment and Parks. 2008. The Water Management Framework for the Industrial Heartland and Capital Region. Government of Alberta. Alberta Environment. ISBN 978-0-7785-6807-0. Available at: https://open.alberta.ca/publications/9780778568070

AEP- Alberta Environment and Parks. 2014. Terms of Reference for Developing the North Saskatchewan Regional Plan. Government of Alberta. ISBN: 978-1-4601-1717-0 (online version) and 978-1-4601-1716-3 (Printed version). Available at: https://open.alberta.ca/publications/9781460117170

Anderson, A.M. 1986. North Saskatcehwan River. Characterization of Water Quality in the vicinity of Edmonton (1982-1983). Part II. Zoobenthic surveys of spring, summer and fall 1982. Water Quality Control Branch, Alberta Environment, Edmonton, AB.

Burkhard, B., Muller, A., Lill, A. 2008. Ecosystem Health Indicators. Encyclopedia of Ecology, Volume 1, 407-414.

Clearwater Environmental Consultants. 2010. Prepared for Alberta Environment. An Assessment of Sediment Quality, Benthic Invertebrates and Epilithic Algae in the North Saskatchewan River Based on 2007 and 2008 data. Available at: https://open.alberta.ca/publications/w1004

Culp, J. C., Glozier, N. E., Baird D. J., Baird, Wrona, F. J., Brua, R. B., Ritcey A. L., Peters D. L., Casey. R., Choung, C. B., Curry, C. J., Halliwell, D., Keet, E., Kilgour, B., Kirk, J., Lento, J., Luiker, E. & C. Suzanne. 2018. Assessing ecosystem health in benthic macroinvertebrate assemblages of the Athabasca River main stem tributaries, and Peace-Athabasca delta. Oil Sands Monitoring Technical Report Series No. 1.7. 82 p.

Environment and Parks Business Plan 2020-23. https://open.alberta.ca/dataset/503f5c97-1fc9-4d72-b1ab-f32eafd9dd7f/resource/a907a4ac-0a80-476b-998f-7886d1643f44/download/environment-and-parks-business-plan-2020-23.pdf

EPCOR, 2015. Water quality and aquatic health monitoring program for the North Saskatchewan River watershed. 14 pp

EPCOR, 2017. 2017 Source Water Protection Plan. Edmonton’s Drinking Water System. Available at: https://www.epcor.com/products-services/water/Documents/source-water-protection-plan.pdf

Government of Alberta, Ministry of Environment and Parks. 2019. Knowledge for a Changing Environment: 2019-2024 Science Strategy. ISBN 978-1-4601-4237-0. Available at: https://open.alberta.ca/publications/9781460142370

Hinton, M., Schiff, S., English, M., 1997. The significance of storms for the concentration and export of dissolved organic carbon from two Precambiran Shield catchments. Biogeochemistry, 36: 67-88.

Jeong, J.J., Bartsch, S., et al., 2012. Differential storm responses of dissolved and particulate organic carbon in a mountainous headwater stream, investigated by high-frequency, in-situ optical measurements. J. Geophys. Res.Biogeosci. 117 (G3)

Kerr, J.G., Cooke, C.A. 2019. A five-year provincial water quality monitoring, evaluation and reporting (MER) plan for lotic systems. Government of Alberta, Ministry of Environment and Parks. ISBN 978-1-4601-4136-6. Available at: https://open.alberta.ca/publications/9781460141366

Lee, E, J., Yoo, G.Y., Jeong, Y., Kim, K.U., Park, J.H., Oh, N.H. 2015. Comparison of UV-VIS and FDOM sensors for in situ monitoring of stream DOC concentrations. Biogeosciences, 12, 3109-3118.

McDonald, D. 2013. Pilot Water Quality Objectives and Allowable Contaminant Loads for the North Saskatchewan River. Government of Alberta, Alberta Environment and Sustainable Resource Development – Red Deer/North Saskatchewan Region. ISBN 978-1-4601-1277-9. Available at: https://open.alberta.ca/publications/pilot-water-quality-objectives-and-allowable-contaminant-loads

Müller, R. A., Kothawala, D.N., Podgrajsek, E., Sahlée, E., Koehler, B., Tranvik, L.J., Weyhenmeyer, G.A. 2014. Hourly, daily, and seasonal variability in the absorption spectra of chromophoric dissolved organic matter in a eutrophic, humic lake, J. Geophys. Res. Biogeosci., 119, 1985–1998.

North Saskatchewan Watershed Alliance (NSWA). 2012. Integrated Watershed Management Plan for the North Saskatchewan River in Alberta. The North Saskatchewan Watershed Alliance Society, Edmonton, Alberta. Available at: https://www.nswa.ab.ca/resource/nsr-integrated-watershed-management-plan-iwmp/

Paetkau, P. Interim Summary report. Biological Pollution Surveys: Oldman River, Bow River, Red Deer River and North Saskatchewan River. 1969-1970. Alberta Fish and Wildlife Division. Department of Lands and Forests. Government of the Province of Alberta.

Reynoldson, T.B. 1973. Macrobenthic Fauna Surveys. Alberta Environment, Pollution Control Division. Water Quality Control Branch. Government of Alberta.

Reynoldson, T.B., Exner, K.K. Macrobenthic Fauna Surveys 1973-1977. Alberta Envionment, Pollution Control Division. Water Quality Control Branch. Government of Alberta.

Saraceno, J.F., Pellerin, B.A., et al. 2009. High-frequency in situ optical measurements during a storm event: assessing relationships between dissolved organic matter, sediment concentrations, and hydrologic processes. Journal of Geophysical Research, Vol 114, G00F09.

Shaw, R.D., Mitchell, P.A., Anderson, A.M. 1994. Water quality of the North Saskatchewan River in Alberta. Surface Water Assessment Branch. Technical Services and Monitoring Division. Alberta Environment Protection.

Appendix 1

A1. Table 1. Variables measured and sampling frequencies in the WaterSHED program.

Chemicals monitored		Unit	Sampling method	Frequency
Observational	Ice/snow cover, thickness	%, m	Visual assessment	Per visit
	Cloud cover	%		
	Water turbidity	0-1-2-3		
	Foam on water			
	Water colour			
	Classification of stream flow			
	Odour in water sample			
General chemistry	Water temperature	°C	Sonde	15-minute
	Specific conductivity	µS cm^{-1}		
	pH	Unitless		
	Turbidity	NTU		
	Dissolved oxygen	mg L^{-1}		
	Oxidation-Reduction potential	mV		
	Total suspended/dissolved solids	mg L^{-1}	Grab sample	Per visit
	Water colour	relative		
	Alkalinity/Hardness	mg L^{-1}		
	Major cations (Na^+,K^+,Ca^{2+} Mg^{2+})	mg L^{-1}		
	Major anions (Cl^-, HCO_3^{1-},SO_4^{2-},CO_3^{2-})	mg L^{-1}		
	Chlorophyll-*a*	mg m^{-3}		

Chemicals monitored			Unit	Sampling method	Frequency
Nutrients	Total/dissolved organic carbon		mg L^{-1}	Grab sample	Per visit
	Total/dissolved nitrogen				
	Total/dissolved Kjeldahl nitrogen				
	Nitrate-Nitrite-Ammonia				
	Total/dissolved phosphorus				
	Dissolved orthophosphate				
Total recoverable / Dissolved metals	Aluminum	Lithium	µg L^{-1}	Grab sample	Per visit
	Antimony	Manganese			
	Arsenic	Mercury			
	Barium	Molybdenum			
	Beryllium	Nickel			
	Bismuth	Selenium			
	Boron	Silver			
	Cadmium	Strontium			
	Calcium	Thallium			
	Chlorine	Thorium			
	Chromium	Tin			
	Cobalt	Titanium			
	Copper	Uranium			
	Iron	Vanadium			
	Lead	Zinc			