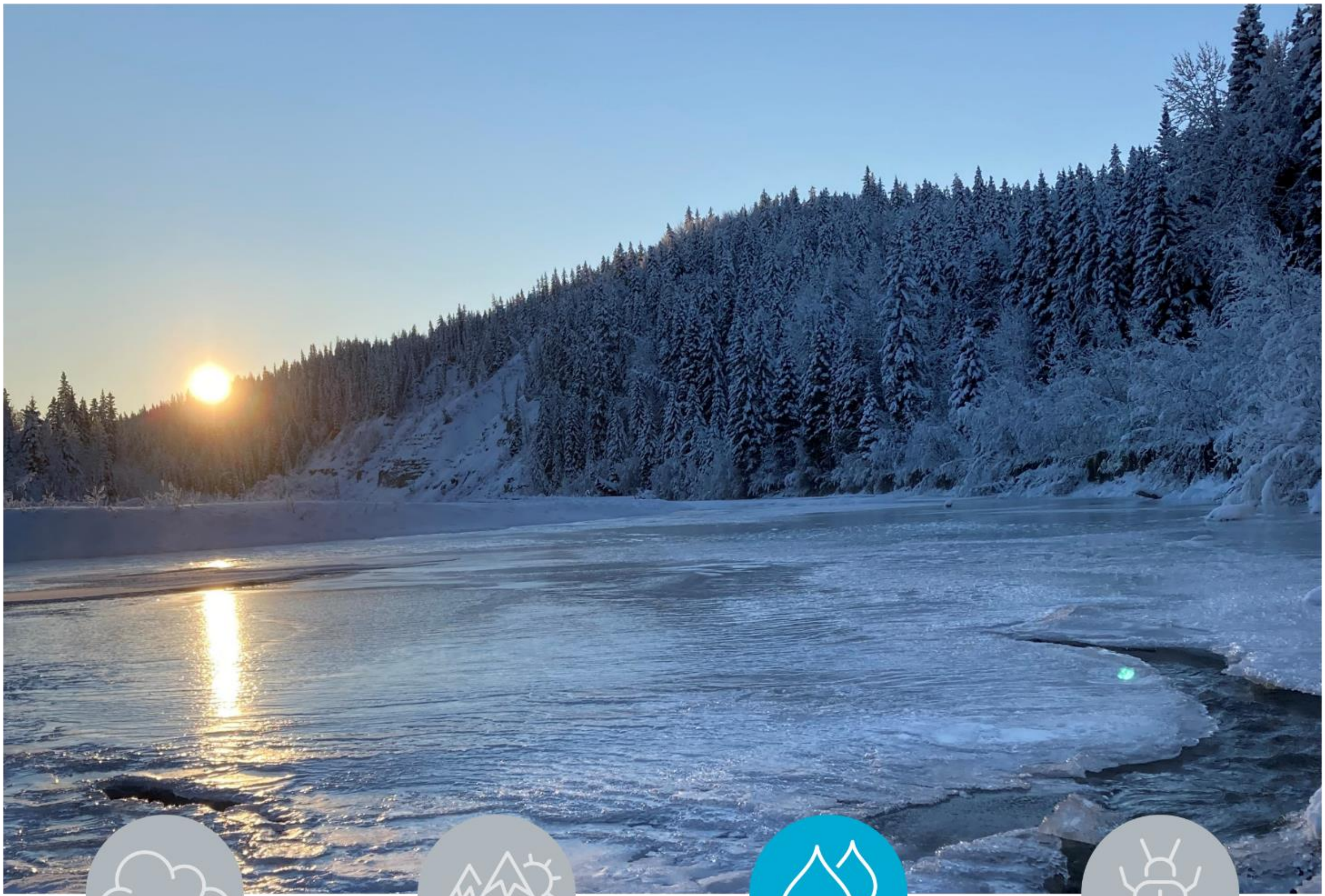
The WaterSHED monitoring program

(Water: Saskatchewan Headwaters Edmonton and Downstream) - technical progress report 2018–2021



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The WaterSHED monitoring program: technical progress report 2018-2021

Craig Emmerton, Nadine Taube, J. Patrick Laceby, Cristina Buendia-Fores, John Orwin, John Willis, Brian Jackson, Chris Ware, Elynne Murray, Rick Pickering, Ryan Ozipko

Cover photo: Elynne Murray

Comments or questions regarding the content of this document may be directed to:

Airshed and Watershed Stewardship Branch, Resource Stewardship Division, Environment and Protected Areas

9th Floor, 9888 Jasper Avenue NW, Edmonton, Alberta, T5J 5C6

Email: aep.info-centre@gov.ab.ca

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Introduction

The North Saskatchewan River Basin (NSRB) is a significant drainage area within Alberta as it supplies drinking water to over one million residents via the North Saskatchewan River (NSR), provides natural resources for industry, accommodates a rich terrestrial and aquatic biodiversity, and offers people cultural and recreational opportunities. Multiple management initiatives have been developed over time in the NSRB and are reviewed in, The WaterSHED monitoring program (Water: Saskatchewan headwaters Edmonton and downstream): technical progress report 2018-2019 (Buendia-Fores and Emmerton, 2021). These initiatives, and those developed in the future, need to be supported by a solid scientific understanding of natural processes and human activities throughout the NSRB and how they affect freshwater environments.

The WaterSHED (Water: Saskatchewan Headwaters Edmonton and Downstream) monitoring program is a unique collaboration between the Government of Alberta, EPCOR, the North Saskatchewan Watershed Alliance (NSWA), and the City of Edmonton. This monitoring program was developed to broaden our understanding of the links between catchment (i.e., stream or river drainage area) processes and changes in river water quality, quantity, and overall ecosystem function. Design, implementation, and early operation of the WaterSHED program was supported by up to $1 million per year from EPCOR for four years (2018-2021) from City of Edmonton water rate payers. This funding was supplemented by approximately $0.4 million of in-kind monitoring and scientific work provided by the Government of Alberta. Recently, the WaterSHED program was renewed for five additional years (2022–2026) under the same funding structure at a level of up to $0.5 million per year. This new funding level reflects the completion of the implementation phase of the project that included substantial capital investments to construct and equip monitoring stations across the NSRB. In-kind scientific, technical, and communications support from the Government of Alberta, EPCOR, NSWA, and the City of Edmonton will continue during this renewed five-year period to ensure sustained success of the program. As an acknowledgement of the first four years of successful development and operation of WaterSHED, this program was a finalist for a 2020 Emerald Award under the Project-Water category (https://emeraldfoundation.ca/30th-annual-emerald-awards/).

The Government of Alberta's participation within the WaterSHED program aligns with its business plans (Alberta Environment and Protected Areas, 2022) and section 15 of Alberta's Environmental Protection and Enhancement Act (Government of Alberta, 2022), which both outline key objectives to monitor, evaluate, and report on the ambient condition of Alberta's environment. The WaterSHED monitoring program is also integrated into the Government of Alberta's core river water quality monitoring programs, as outlined in its 5-year river monitoring, evaluation and reporting plan (Kerr and Cooke, 2019). These core programs, the Long Term River Network (LTRN) and Tributary Monitoring Network (TMN), are networks of fixed stations across Alberta rivers where regular monitoring of river flow, water quality, and biological conditions occurs for comprehensive assessments of catchment and riverine conditions. A key goal of the Government of Alberta's core river programs is to understand the impact that human-caused and natural processes have on river water quality. This can be achieved using a mass-based assessment approach that takes the product of river flow and water quality parameter concentration to quantify mass export at each monitoring station. When calculating mass export of a water quality parameter throughout a monitoring network (see Methods section), we can determine which tributaries (i.e., TMN stations) are most important contributors of a particular water quality parameter to major rivers (i.e., LTRN stations). By standardizing mass export to upstream drainage areas (i.e., catchment yields), we can directly compare how different tributary catchments produce and mobilize chemicals to better understand the role that natural and anthropogenic processes have on water quality. For example, by knowing catchment yields, we may predict particular water quality changes in the NSR if a heavy rainfall is situated over an urbanized catchment versus a heavily forested catchment. After several years of data collection, WaterSHED is now well-positioned to report on concentrations, mass export, and catchment yields of key water quality parameters across its network to provide a more in-depth, basin-wide understanding of river water quality in the NSRB.

WaterSHED's collaborative approach to aquatic ecosystem monitoring at the large river basin scale is unique within Alberta and is positioned to produce critical data on the condition of the environment in the NSRB to support participating stakeholder initiatives. This second effort within WaterSHED's technical report series provides an updated technical overview of the WaterSHED monitoring program and presents program findings to date from data collected between 2018 and 2021. This document is divided in four main sections: Section 1 'WaterSHED monitoring program' introduces the geographic setting of the NSRB, provides an overview of the design and implementation of the program, and reports on the current status of the program. Methodologies used to assess data produced by the WaterSHED program are outlined in section 2 'Data reporting: Methods'. Section 3 'Data reporting: Results and discussion' presents data assessments of the WaterSHED program including water quality results relative to surface water quality guidelines, quantification of spatial and seasonal changes of water quality across the network, and mass export and catchment yields of water quality parameters at river stations. Lastly, section 4 'Program learnings and ongoing work' recaps our learnings during the first phase of the WaterSHED program and highlights on-going and future monitoring activities that will be undertaken in the following years of the program.

WaterSHED monitoring program

Geographic setting

The NSR is one of Alberta's great river systems and the NSRB has an area up to the Alberta-Saskatchewan border of about 57,000 km^2 (Figure 1). Mean annual flow in the NSR at the Alberta-Saskatchewan border is ~221 m^3/s (from 1980-2019). The main catchments that contribute flow to the NSR mainstem are located in the headwaters and include the 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 in the NSR is regulated by two dams located in the upper reaches of the river: the Brazeau Dam on the Brazeau River (built in 1962) and the Bighorn Dam on the mainstem of the NSR (constructed in 1972) that forms Abraham Lake. Flow regulation has altered the NSR's seasonal patterns and resulted in lower summer flows and higher winter flows than would naturally occur (NSWA, 2007).

The NSR traverses a variety of natural regions, from mountainous areas (i.e., Rocky Mountains), through rolling forested foothills landscapes, to agriculturalized lower-elevation boreal and parkland regions towards the Alberta-Saskatchewan border (Figure 1). Urban development and resource utilization also vary throughout the basin. About one third of Albertans live in the NSRB, with most of the population concentrated in Edmonton Census Metropolitan Area (CMA; pop. 1.4M; Statistics Canada, 2022), which primarily depends on the NSR for drinking water. Forestry is the most spatially relevant land use activity in the NSRB upstream of Drayton Valley, while most agriculture occurs in the central and eastern portion of the basin (Figure 1). Industrial development, including oil and gas extraction, also occurs throughout the basin, with the most intensively industrialized area being the Industrial Heartland area northeast of Edmonton.

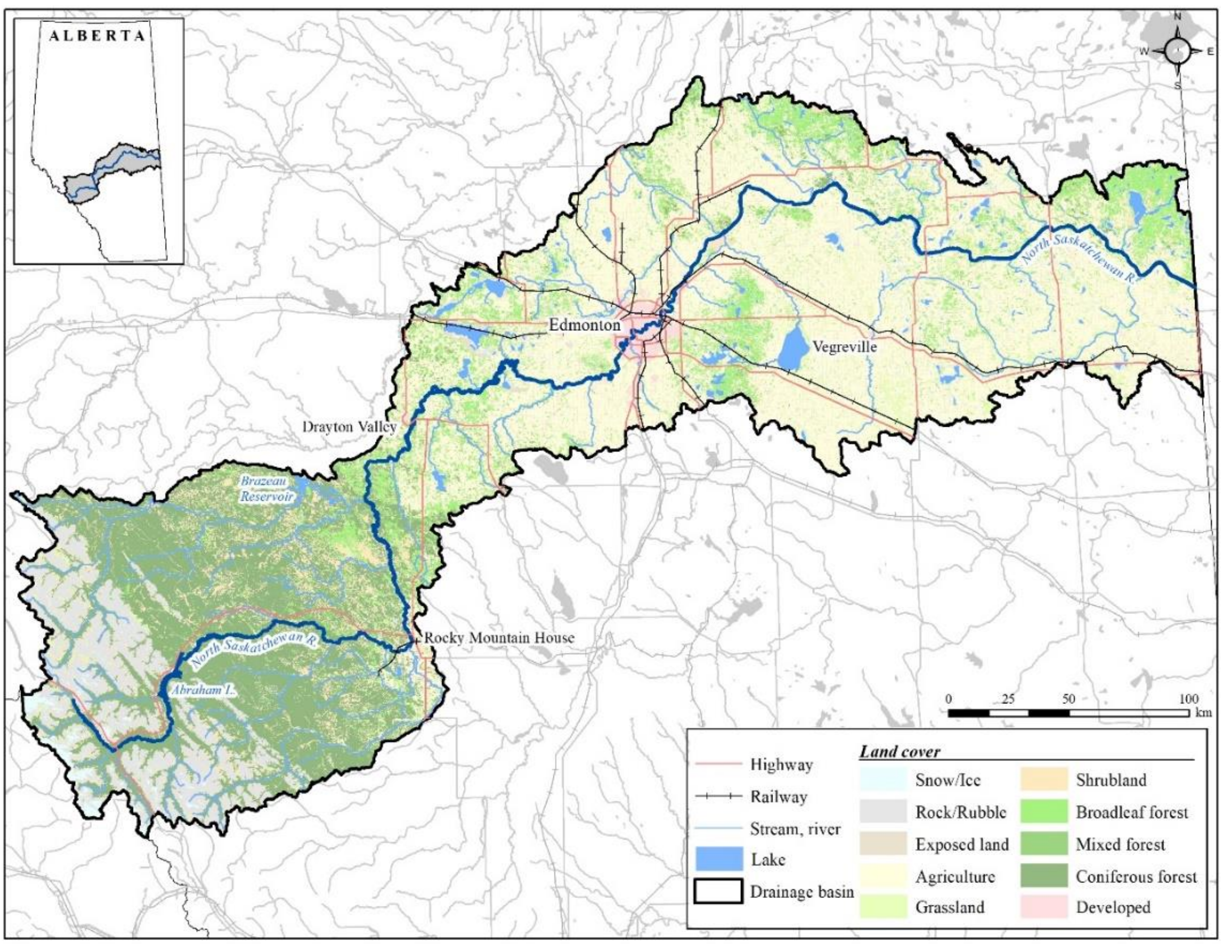

Figure 1. Location of the North Saskatchewan River Basin within Alberta and land cover types (Source: ABMI Provincial Land Cover, 2010).

Network design, station landscape classifications

Full details of the WaterSHED network of monitoring stations is outlined in Buendia-Fores and Emmerton (2021). Briefly, site selection of a monitoring station on an NSRB tributary considered several factors including the tributary's volume of flow contribution to the NSR, accessibility, locations of existing flow stations, and representativeness of the tributary drainage area relative to the broader NSRB. Representativeness of chosen monitoring locations was addressed through a geospatial and statistical approach to identify, characterize, and classify catchments within the NSRB based on their physical characteristics, land cover, and human activities (Catchment Structural Units; CSU; Orwin et al., 2022). As such, each chosen catchment was assigned a CSU classification (i.e., cordillera, foothills, plains-mixed, plains-coarse; see Table 1 for definitions).

A total of 19 tributaries representative of basin characteristics, and one mainstem station, across the NSRB were selected to form the WaterSHED monitoring network (Table 1, Figure 2). Tributary monitoring stations were located as close as possible to the confluence with the NSR. The lone mainstem site (North Saskatchewan River at Whirlpool Point) was included as a large de-facto tributary from protected national parks regions. Monitoring at each site includes measurement of river flow, water quality, and other parameters (see next section). Together, the WaterSHED monitoring network of 20 river stations covers a total drainage area of 33,723 km^2, which corresponds to nearly 60% of the Alberta portion of the NSRB (i.e. ~57,000 km^2). This network monitors >80% of the average annual volume of the NSR at Edmonton and >70% of the annual volume at the Alberta-Saskatchewan border (Water Survey of Canada, 2022).

WaterSHED also funded additional hydroclimatological monitoring in the NSRB by constructing a river flow station at the NSR at Pakan LTRN station, as well as a high-elevation meteorological station in the headwaters above Lake Abraham in the far west of the NSRB (Table 1, Figure 1). Both stations will support future data assessments and improve overall water monitoring capacity in the NSRB.

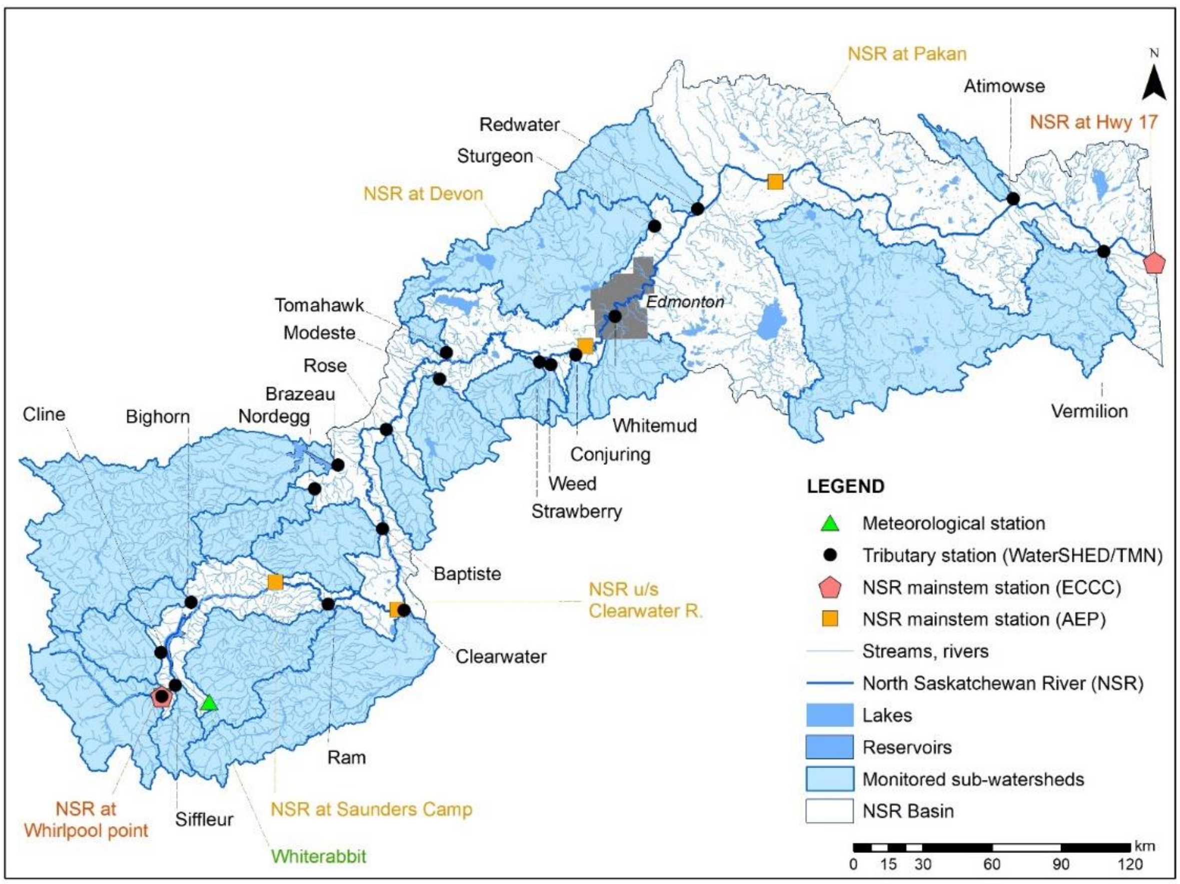

Figure 2. Locations of the WaterSHED monitoring stations, mainstem stations of the NSR monitored under the Government of Alberta's Long Term River Network (LTRN; Saunders, Clearwater, Devon, Pakan), and long term monitoring stations of the NSR monitored by Environment and Climate Change Canada (Whirlpool Point and Hwy 17).

Table 1. List of tributary and hydroclimatology monitoring stations operational under the WaterSHED program including identification, location, and other metrics. *indicates new flow station was installed at location at the start of the program.

Catchment	Flow Station ID	Water Quality Station ID	Flow/WQ Monitoring Schedule	Start Year	Drainage Area (km^2)	Lat.	Long.	CSU class
Tributary Monitoring Network								
NSR at Whirlpool Point	05DA009	05DA0010	Continuous	2019	1,920	52.001	-116.471	cordillera
Siffleur River*	05DA002	05DA0025	Mar. – Oct.	2019	512	52.044	-116.385	cordillera
Cline River*	05DA004	05DA0015	Mar. – Oct.	2021	822	52.171	-116.482	cordillera
Bighorn River*	05DC005	05DC0021	Mar. – Oct.	2019	330	52.370	-116.303	cordillera
Ram River	05DC006	05DC0040	Continuous	2019	1,881	52.368	-115.420	cordillera
Clearwater River	05DB006	05DB0010	Continuous	2019	3,221	52.253	-114.856	foothills
Baptiste River	05DC012	05DC0070	Continuous	2019	1,358	52.664	-115.076	foothills
Nordegg River	05DD009	05DD0200	Continuous	2019	865	52.820	-115.513	foothills
Brazeau River	05DD005	05DD0030	Continuous	2019	5,658	52.913	-115.364	foothills
Rose Creek*	05DE953	05DE0015	Mar. – Oct.	2019	654	53.052	-115.052	plains-M
Modeste Creek	05DE911	05DE0155	Mar. – Oct.	2019	1,178	53.248	-114.706	plains-M
Tomahawk Creek*	05DE930	05DE2000	Mar. – Oct.	2019	186	53.352	-114.660	plains-M
Strawberry Creek	05DF004	05DF0020	Mar. – Oct.	2019	589	53.311	-114.052	plains-M
Weed Creek*	05DF911	05DF0840	Mar. – Oct.	2019	300	53.300	-113.981	plains-M
Conjuring Creek*	05DF913	05DF0030	Mar. – Oct.	2019	308	53.337	-113.816	plains-M
Whitemud Creek	05DF009	05DF0260	Mar. – Oct.	2019	1,086	53.484	-113.555	plains-C
Sturgeon River	05EA001	05EA0025	Mar. – Oct.	2019	3,330	53.833	-113.283	plains-M
Redwater River	05EC005	05EC0065	Mar. – Oct.	2019	1,602	53.897	-113.000	plains-M
Atimoswe Creek	05ED002	05ED0100	Mar. – Oct.	2019	363	53.867	-110.912	plains-C
Vermilion River*	05EE002	05EE0530	Mar. – Oct.	2019	7,904	53.652	-110.345	plains-C
Hydroclimatology								
NSR at Pakan* flow station	05EC919	05EC0010	Continuous	2020	39,333	53.991	-112.476	-
Whiterabbit met. station	05DA807	-	Continuous	2021	-	51.981	-116.169	-

CSU notes: cordillera: primarily mountainous landscapes with mixed exposed bedrock and forest cover with little human land-use. foothills: rolling forests with shrublands and wetlands with forestry and oil and gas development. plains-mixed (M): low-elevation plains with fine and coarse surficial geology with agriculture being the primary land-use. plains-coarse (C): low-elevation plains with primarily coarse surficial geology with agriculture and urbanized land-uses.

Monitoring approach and status

Water quantity and quality are monitored at WaterSHED stations using automated equipment (e.g., flow stage measurements and telemetry, in-stream multiprobe water quality), manual measurements and water collections on-site by Government of Alberta field technicians, and daily photographs of selected rivers using cameras affixed to hydrometric stations (Figure 3).

Figure 3. Monitoring approaches used in the WaterSHED program for monitoring river flow (left), in-river continuous water quality via data sondes (left centre), water quality grab sampling (right centre), and daily camera imagery of rivers (right).

Water quantity

The water quantity delivered by a stream or river is monitored in a near real-time frequency using a hydrometric station (Figure 3). Hydrometric stations automatically measure river water levels using a forced-air pressure line system. Near real-time water quantity is calculated as a river flow (volume per time) using a station rating curve (i.e., water level vs. flow relationship) established from periodic manual measurements of flow in the river by technicians and concurrently measured water level. Twelve WaterSHED monitoring locations had an existing hydrometric station maintained by either the Government of Alberta or the Water Survey of Canada and have historical flow data available for data assessments. The remaining eight locations required the installation of a new hydrometric station and are not currently suitable for data assessments until more manual flow measurements are completed. The final hydrometric station to begin operation within the network was at the Cline River, which began operation in June 2021. Flow stations may operate either continuously (January to December) or seasonally (~March to ~November) depending on the nature of the river's channel, ice, winter flow, and other considerations (Table 1). All hydrometric sites record data at subhourly intervals, which is sent via telemetry to Government of Alberta servers and can be downloaded from Alberta River Basins (https://rivers.alberta.ca/) or from the Water Survey of Canada for certain stations (https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/monitoring/survey.html). Operational history of flow stations for the entire network is shown in Figure 4.

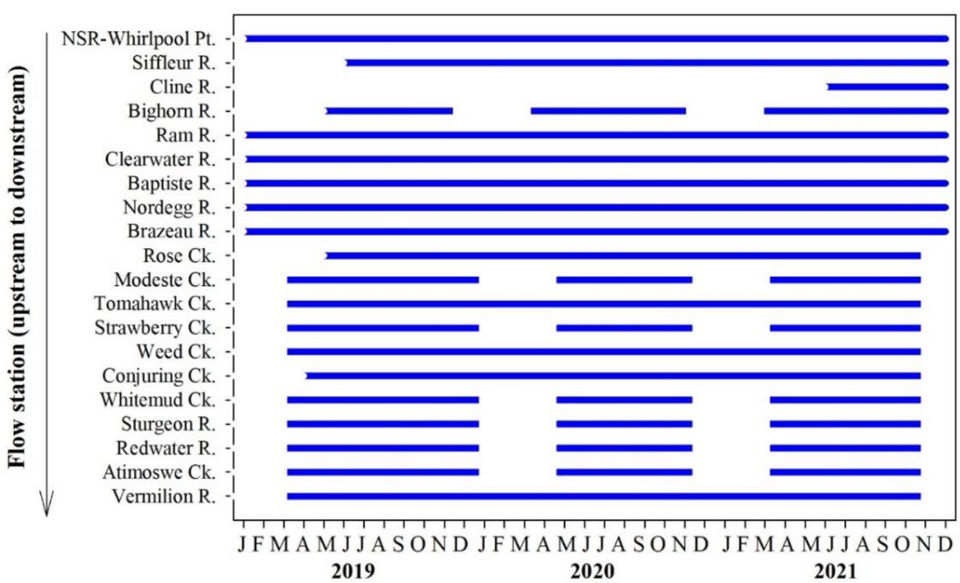

Figure 4. Operational history of all seasonal (i.e. winter shutdown) and continuous (full-year operation) flow stations as part of the WaterSHED program.

Water quality

Water quality may be measured in several ways depending on available equipment, staffing, 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 (Figure 3). 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 nearly continuous data. Sondes are deployed at each tributary monitoring station soon after ice cover releases and clears on a river in spring and remain in continuous operation throughout the open water season. Before ice-cover forms in mid-autumn, all sondes are removed from the rivers and those in plains streams are not deployed again until the spring. At larger river stations in the upper NSRB, once safe ice cover is established, sondes are redeployed under ice and measure continuously until spring. All sonde data (Figure 5) are available upon request from https://www.alberta.ca/surface-water-quality-data.aspx using swq.requests@gov.ab.ca.

In contrast, discrete water sampling, or periodic manual (grab) collection of surface water, allows for measurement of a larger suite of water quality parameters when samples are sent to accredited water quality laboratories (Figure 3). 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., forms of carbon, nitrogen, phosphorus), metals (e.g., arsenic, copper, lead), proxy measurements of algae biomass (e.g., chlorophyll-a), and water isotopes (18O and 2H). A full list of parameters analyzed using this sampling approach is shown in Table A1.1. Water quality samples are collected at a monthly frequency, except during spring freshet (starting in March) when frequency increases to capture changes in water quality during the dynamic, higher-flow snowmelt period. During winter, only larger upper basin rivers are sampled for water quality while plains stations are discontinued until the spring. Three years of grab sampling counts are shown in Figure 6, including distributions across calendar years, months, and sampling sites. COVID-19 restrictions contributed to the lower sampling counts in 2020. All discrete water collection data are available via download from https://www.alberta.ca/surface-water-quality-data.aspx or by using swq.requests@gov.ab.ca.

Fixed cameras

Most hydrometric stations (16 of 20) have been equipped with cameras for qualitative and quantitative remote environmental monitoring (Figure 7, Figure 8). These cameras provide daily images of the sites via satellite connection, which are crucial to correct flow measurements, monitor flow increases during rainfall events, determine ice breakup dates, identify beaver activities, and provide insight into seasonal changes across landscapes. Daily imagery from the 16 WaterSHED stations is available from the Alberta River Basins website (https://rivers.alberta.ca/).

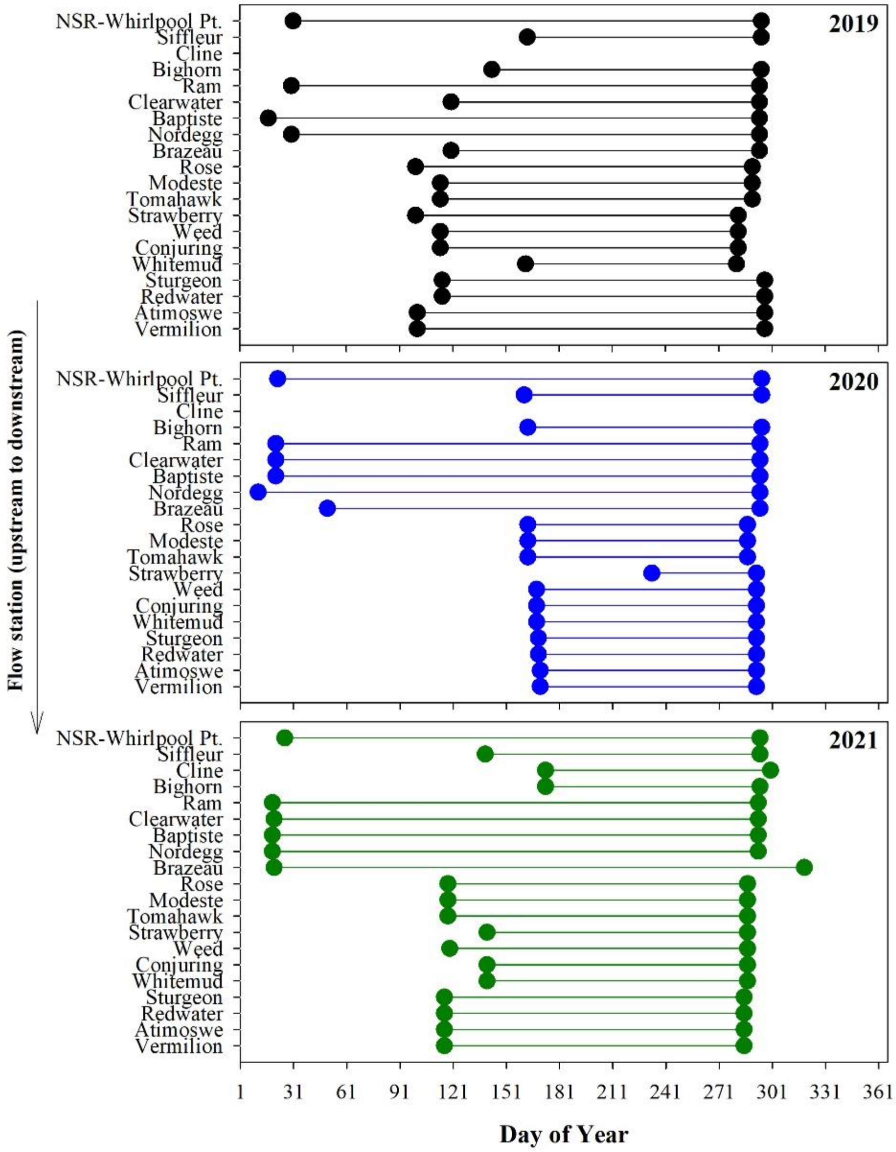

Figure 5. Operational history of seasonal (i.e., winter shutdown) and continuous (nearly full-year operation; removed during dynamic ice cover conditions) data sonde deployments at monitoring stations as part of the WaterSHED program; organized upstream to downstream locations.

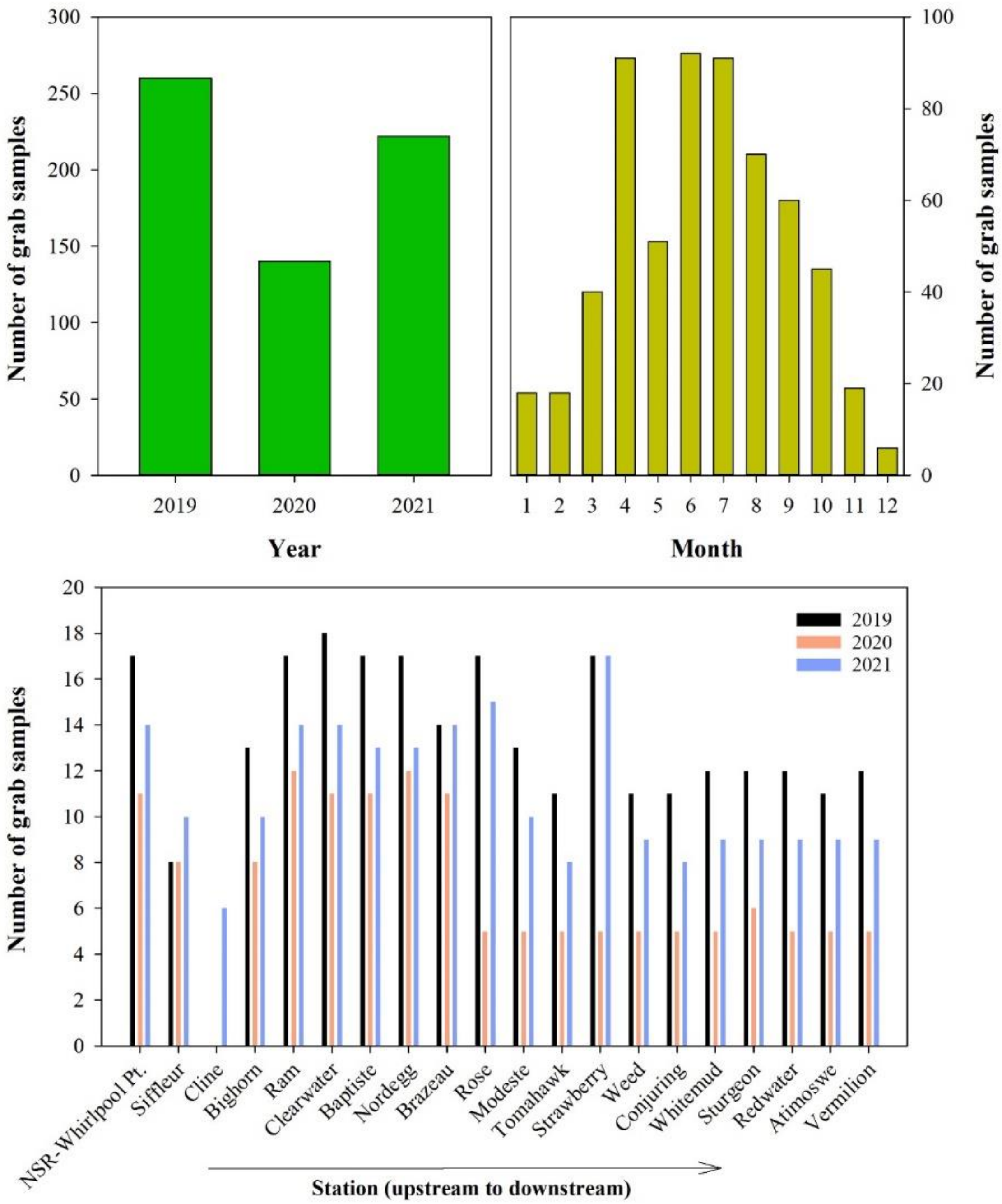

Figure 6. Grab sampling history between calendar years, months, and by station by year for the 2019 to 2021 period as part of the WaterSHED program.

Figure 7. Daily camera photo examples from selected monitoring stations in the WaterSHED program. Current site photos are available at: https://rivers.alberta.ca.

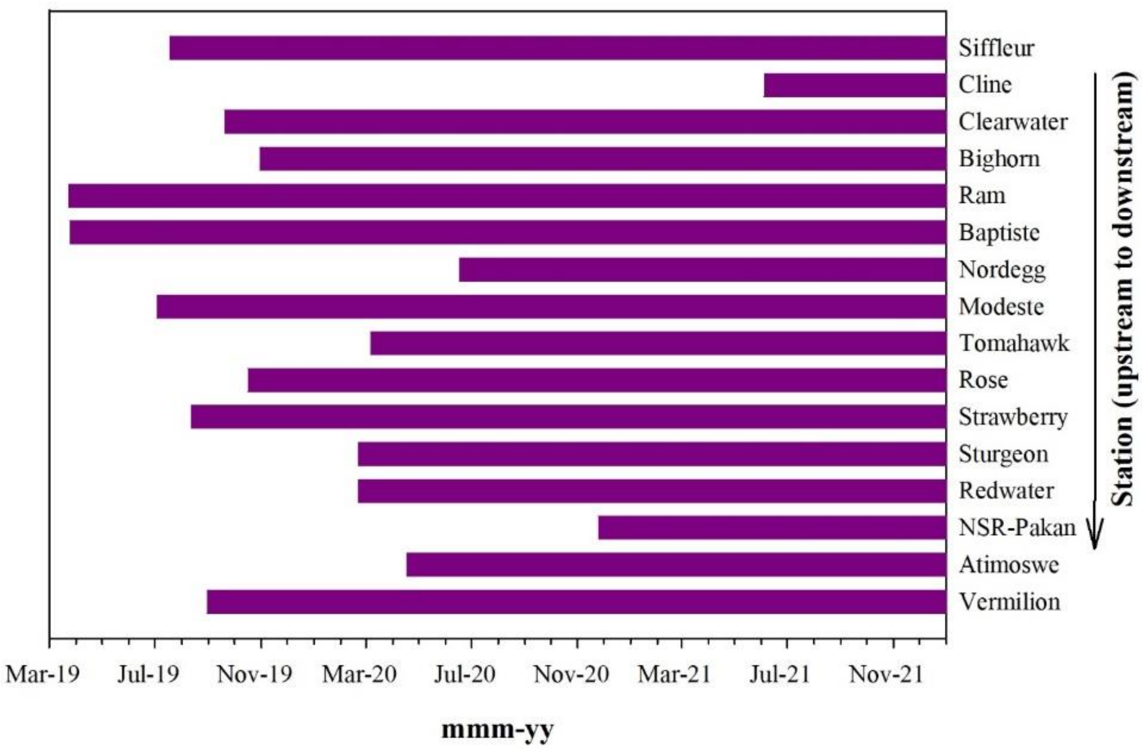

Figure 8. Operational periods of fixed cameras reporting daily images from monitoring stations in the WaterSHED program. Current-day site photos are available at: https://rivers.alberta.ca.

Data reporting: Methods

Water quality guidelines

All individual discrete water quality grab samples from the water years (i.e., November-October) of 2018-19 through to 2020-21 from all stations were compared to Alberta surface water quality guidelines for protection of aquatic health and protection of agricultural water uses (Alberta Environment and Protected Areas, 2018). Water quality data were compared to both chronic and acute exposure guidelines and the number of exceedances (if present) are reported for all parameters with applicable guidelines.

Water quality parameter grouping

The WaterSHED program collects data of over 100 water quality parameters, either via data sondes or discrete water sampling. Some parameters consistently report data below laboratory reporting limits (i.e., censored data), which is problematic for many data analyses, particularly when the percentage of censored data increases towards 100% in a particular data set. Within scientific literature, there is debate over which level of censoring poses difficulties when computing statistical analyses (Helsel, 2006; Antweiler, 2015; George et al., 2021). As comparisons between station data are a focus in WaterSHED, we removed parameters (n=11) reporting >40% censored data from further analysis due to loss of statistical confidence beyond that value (Antweiler, 2015). Seven parameters reporting >40% censored data were kept for analysis based on most censored data occurring at a handful of stations, rather than across the network. In total, 80 parameters were used for further analysis and censored data were substituted with one-half of the laboratory reporting limit for descriptive statistic calculations and group comparisons (Antweiler and Taylor, 2008; Antweiler, 2015; George et al., 2021). Station data from water years 2018-19 to 2020-21 were used in these analyses.

Analyzing all of these parameters individually is impractical and does not account for the similar biogeochemical behavior that is shared amongst many parameters. We therefore used hierarchical clustering implementing Ward's method and Euclidean distance on the 80 standardized (z-scores) water quality parameters across all sites to cluster parameters that exhibit similar patterns of water quality concentrations (IBM SPSS, v28). The number of clusters for water quality parameter grouping was chosen post-hoc to balance replication and number of clusters. Post-clustering, we chose representative (proxy) parameters of each grouping for further analysis.

Parameter concentrations and mass export

Using selected proxy parameters from water years 2018-19 to 2020-21 (see above), descriptive statistics of each station's concentration record were reported. We then used linear mixed models to compare tributary concentration data between different landscapes classed under the original CSU exercise used to design the WaterSHED network (see above, Table 1). Differences in proxy parameter concentrations between NSR mainstem stations were assessed separately from tributaries using descriptive statistics and autocorrelation assessments between stations (i.e., Durbin-Watson statistical test).

Quantification of water flow (volume per time) and mass export (mass per time) of chemicals by streams or rivers is a robust approach for understanding sources and losses of water and chemicals throughout a river basin, particularly when concurrently comparing export from tributaries and mainstem stations. For example, using mass export approaches in a river monitoring network allows for the quantification of: mass export of a parameter (x) at a major river station (MR); at upstream monitored tributaries (TR); and by difference, from upstream ungauged inputs to the system from unmonitored streams, effluents, major river beds and channels, or non-point source additions (UG; e.g., groundwater, diffuse runoff):

$$\text{Mass}_{(x)}\ \text{MR} = \text{Mass}_{(x)}\ \text{TR} + \text{Mass}_{(x)}\ \text{UG}. \qquad (1)$$

Flow and chemical mass export between water years also provides additional context of different hydrometeorological conditions and subsequent impacts on stream and river transport of water quantity and quality parameters. To quantify the relative mass contributions of selected water quality parameters of WaterSHED and NSR mainstem (LTRN) stations, mass export was calculated using water quality sample data (water years 2018-19 to 2020-21) paired with daily flow measured at the same selected stations. Selected stations were used as some newly installed flow stations did not yet have enough appropriate flow measurements to ensure accuracy of flow data. After assembling paired water quality-flow data at the selected WaterSHED and LTRN stations, we used the R package *loadflex* (Appling et al., 2015) to calculate several annual mass export and variability data sets and report on the mass contributions of monitored tributaries and mainstem stations. This report includes results from four different approaches, namely rectangular interpolation (period-weighted averaging), a custom log(concentration)~log(flow) regression, the rloadest program (Runkel and De Ciico, 2017), and the composite method (Aulenbach, 2006). Annual means or ranges (minimum, maximum) of estimated export from the four different approaches in the *loadflex* package for each station are reported. Water (runoff) and catchment chemical yields (volume or mass by area) were also quantified using flow or mass export values from each station and standardizing by the upstream catchment areas at the monitoring stations.

Data reporting: Results and Discussion

Water quality guidelines

Guideline exceedances for the protection of aquatic life and agricultural water uses were less frequent in rivers and streams of the upper forested NSRB, compared to those in the agriculturalized and developed plains areas of the lower NSRB (Table 2, Table 3). This transition occurred most consistently at the Rose Creek station where rich organic soils and agricultural land uses comprise substantial areas within its catchments compared to upstream landscapes. This pattern was similar to the mainstem NSR stations, which reported increasing frequency of guideline exceedances downstream. In particular, parameters that typically associate with suspended particulate matter (e.g., several trace metals, bacteria) reported more consistent guideline exceedances in the lower NSRB compared to dissolved parameters (e.g., dissolved aluminum, dissolved chloride [d-Cl], nitrate). Total mercury reported the most frequent exceedances of protection of aquatic life guidelines of all parameters, in part due to its affinity to bind to suspended material and in part to the more conservative Government of Alberta guideline concentrations (5 ng L^{-1}) compared to other jurisdictions (e.g., Canada, British Columbia). Of note, the urbanized Whitemud Creek, and Conjuring Creek, reported the only chloride guideline exceedances. Higher concentrations of trace metals, dissolved material, and bacteria are typical in streams and rivers draining cleared, agriculturalized landscapes prone to soil erosion and those draining more developed and urbanized creeks (McGrane, 2016; Evans et al., 2019). Dissolved oxygen concentrations below guidelines only occurred in tributaries from Rose Creek downstream, reflecting warm, slow moving waters prone to stagnation due to flat topography and beaver activities, and ongoing ecological consumption of oxygen.

Water quality parameter grouping

Cluster analysis of 80 water quality parameters from WaterSHED reported four distinct groups of parameters at a distance of 7.5 using Ward's method (Table 4). We named each grouping based on types of parameters included in the group and locational information of the highest parameter concentrations in the data set. Groupings identified were: 1. urban; 2. organics-nutrients; 3. dissolved materials; and 4. inorganic particles. The urban grouping was identified based on the high concentrations of urban related chemicals (e.g., nitrates, chloride, selenium) typically occurring within the most developed streams in the WaterSHED monitoring program (e.g., Whitemud). The organics-nutrients group included parameters commonly associated with rich organic soils including dissolved organic carbon (DOC), water colour, total nutrients (nitrogen [TN], phosphorus [TP]), dissolved iron, and mercury. The dissolved materials grouping included alkalinity, pH, total dissolved solids (TDS), major ions (e.g., potassium, sodium), and various metals (e.g., boron, calcium, strontium). Chlorophyll-a concentrations are included in this category likely due to its associations with pH changes in productive surface waters (Verspagen et al., 2014). Finally, the inorganic particles grouping represents parameters measuring or typically bound to inorganic particles including total suspended solids (TSS), turbidity, and several total recoverable metals (e.g., aluminum, cadmium, lead). To reduce analysis and reporting, we chose six common water quality parameters (urban: d-Cl; organics-nutrients: DOC, TN, TP; dissolved materials: TDS; inorganic particles: TSS) from the four categories for further statistical analysis with a caveat that the measurement was mass-based for export-related assessments (e.g., used DOC [mg L-1] instead of related water colour parameter [light-based measure]). Consequently, patterns of these proxy parameters are expected to be similar to those parameters from the same group that were not selected for further analysis (Table 4).

Downstream concentrations changes across the NSRB

Boxplots and descriptive statistical summaries of concentrations of the six proxy parameters for each WaterSHED and NSR mainstem station are shown in Figure 9–Figure 11 and Table A2.1–Table A2.6, respectively. Boxplots of each WaterSHED station were further coded by CSU landscape classification and mixed model results (Table A3.1) of concentration comparisons between classes were reported. Urban and organics-nutrients proxy parameters were of relatively low concentration in the cordillera and foothills rivers compared to downstream systems (Figure 9, Figure 10). Dilute nutrient and organic matter chemistries in these high-elevation rivers is attributed to a lack of mature soils and subsequent fast-moving snowmelt and rain-related runoff that reduces water contact with surface soil materials (Slaymaker and Kovanen, 2017; Chen et al., 2021). Sharp increases in the concentrations of urban and nutrients-organics proxy parameters in river water near the Rose Creek region corresponded closely in space with the increased frequency of surface water quality guideline exceedances relative to upstream regions (Table 2, Table 3). Rose Creek lies within an important topographical, climate, and soil transition zone of the NSRB where elevation decreases, climate transitions towards less rainfall and more intense evapotranspiration, and luvisolic soils change to more agriculturally-fertile chernozemic soils (CSSS, 2020, ACIS, 2022). Landscapes where evapotranspiration generally exceeds rainfall promote salinization of soils (Eilers et al., 1997), while chernozemic soils are generally organic- and nutrient-rich relative to many other soil classes.

Table 2. Percent surface water quality guideline exceedances for protection of aquatic life of all WaterSHED samples collected and analyzed for various parameters. Only stations with water quality exceedances in their records are shown and stations are organized down the table upstream to downstream. Showing exceedances of chronic guidelines (i.e., long-term exposures) unless within parentheses, which indicates exceedances of acute guidelines (i.e., short-term exposures). Full parameters names can be found in Table A1.1.

Parameter	**d-O**	**d-Al**	**d-Cl**	**d-Fe**	**Nitrate**	**Nitrite**	**t-Hg**	**t-As**	**t-Cd**	**t-Co**	**t-Cu**	**t-Pb**	**t-Zn**
Guideline	**VR**	**EQ**	**120**	**300**	**3**	**EQ**	**5(13)**	**5**	**EQ**	**EQ**	**EQ**	**EQ**	**30**
Guideline unit	**-**	**-**	**mg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**	**-**	**ng L^{-1}**	**µg L^{-1}**	**-**	**-**	**-**	**-**	**µg L^{-1}**
Tributaries													
NSR Whirlpool										3			
Siffleur						4							
Ram R.		3		3			3			8			
Clearwater R.							11						
Baptiste R.							3						
Nordegg R.							6						
Rose Ck.	3						21	3	3	12	6	6	3
Modeste Ck.							14 (4)	4	11	15	7(4)	11	7
Tomahawk Ck.	12	8		54			25(4)	25		25	8	12	
Strawberry Ck.	5						37(9)	9	6	31	23(3)	9	6
Weed Ck.	12(4)			8	8		28			20	8		
Conjuring Ck.				4			17			8			
Whitemud Ck.			16		4		32			32	12	4	
Sturgeon R.	8			4			16			8	4	4	
Redwater R.	16(4)			32			8						
Atimoswe Ck.	38(17)			12			4	4					
Vermilion R.				4			24	24		12	4		
NSR Mainstem													
NSR-u/s Clear.		3								3			
NSR-Devon							7			7	7		
NSR-Pakan		21					7			10	7		

Notes: VR-guideline varies depending on season (6.5 mg L-1 all year; 8.3 mg L-1 mid-May to end-June to protect mayfly emergence); EQ-guideline calculated using equation; d-Al: 50 **µ**g L^{-1} or if pH<6.5, see Alberta Environment and Protected Areas, 2018 Table 1.1.; Nitrite: varies with Cl concentrations; see Alberta Environment and Protected Areas, 2018 Table 1.4; t-Cd, t-Co, t-Cu, t-Pb vary with hardness' see Alberta Environment and Protected Areas, 2018 Table 1.3.

Due to lower elevations in the plains and richer soils, agricultural activities abound eastward in the NSRB from Rose Creek. This essential activity can expose lands to greater flushing and erosion of soils and thus mobilize salts, nutrient-rich organic soils, and fertilizers downstream through river networks, particularly during hydrological events (Evans et al., 2019). In addition, NSRB plains regions are more urbanized, which can increase delivery of certain trace metals (e.g., nickel) and road salts (e.g., sodium chloride) to local creeks, particularly in areas where road de-icing agents are used (Tiefenthaler et al., 2008; Laceby et al., 2019). Consequently, plains-mixed and plains-coarse landscape classes showed statistically higher concentrations in mixed-model results (alpha=0.05) than cordillera and foothills classes for DOC, TN, and TP, while plains-coarse stations had significantly higher d-Cl concentrations than stations in the forested foothills and cordillera (Figure 9, Figure 10). TP concentrations of plains-mixed stations were statistically lower than plains-coarse stations, but not for TN concentrations, indicating a sharp decrease in TN:TP ratios, particularly in the far eastern Atimoswe and Vermilion systems. Decreases in mass-based TN:TP ratios may be due in part to the predominance of productive lake and reservoir features in the Atimoswe and Vermilion catchments. Productive lake environments can both promote release of excess phosphorus from bottom sediments into the water column and also support increased losses of nitrogen to the atmosphere by microbial activity (Zhang et al., 2018). Concentration transitions between upstream forested regions and downstream plains regions were less sharp for TDS and TSS compared to other proxy parameters. For example, plains stations were not statistically higher in TDS concentrations than stations draining foothills and cordillera catchments (Figure 11). This lack of differentiation between plains and forested upstream areas was driven by relatively high TDS concentrations from rivers draining cordillera and foothills regions, likely due to weathering of exposed bedrock material in those regions (Emberson et al., 2016) and subsequent additions of dissolved material downstream. Plains-coarse stations had higher TDS concentrations than other land classes due to higher concentrations of major ions, likely due to urban influences (i.e., road salts) and lake influences that tend to concentrate ions particularly in high evaporation areas of the eastern prairies (Evans and Prepas, 1996).

Table 3. Percent surface water quality guideline exceedances for protection of agricultural water uses of all WaterSHED samples collected and analyzed for various parameters. Only stations with water quality exceedances in their records are shown and stations are organized down the table upstream to downstream. Showing chronic guideline unless within parentheses, which indicates acute guideline. Full parameters names can be found in Table A1.1.

Parameter	**d-Cl**	**E. Coli**	**TDS**	**t-Al**	**t-Fe**	**t-Mo**	**t-Mn**
Guideline	**100-700**	**100**	**500-3,500**	**5**	**5**	**10-500**	**200**
Guideline unit	**mg L^{-1}**	**CFU# 100mL^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**μg L^{-1}**
Tributaries							
Ram R.				3	3		
Rose Ck.		5		6	9		6
Modeste Ck.		13		4	7		18
Tomahawk Ck.		55	21	4	8	17	17
Strawberry Ck.		10	6	9	11		26
Weed Ck.		15	16		8		20
Conjuring Ck.	4	8	33				17
Whitemud Ck.	32	15	56		8		28
Sturgeon R.		8	28		4		16
Redwater R.			12				40
Atimoswe Ck.							38
Vermilion R.		33	80		8		12
NSR Mainstem							
NSR-Devon		7		3	7		3
NSR-Pakan		24			7		3

Notes: CFU: colony forming units

Table 4. Water quality parameters from all WaterSHED data grouped using hierarchical cluster analysis. Bold and underlined parameters denote those used for further analysis (i.e., proxy parameters), including chemical export calculations. Percentage of all data below the laboratory reporting limit are indicated in parentheses. Full parameters names can be found in Table A1.1.

Urban	**Organics-nutrients**	**Dissolved materials**	**Inorganic particles**
NO3(19), NO3+NO2(23), NH3(58)	DOC(10), TOC(10)	Conductivity(0)	TSS(7), Turbidity(1)
d-Cd(15)	Colour(12)	TDS(0), Filtered Residue(0)	t-Ag(20)
d-Cl(26)	TP(16), TDP(45), PO4(50)	Alkalinity(0)	t-Al(0)
d-Cu(3)	DKN(13), TKN(12), TN(2)	Hardness(0)	t-Be(20)
d-Mn(0), t-Mn(0)	K^{+}(2)	pH(0)	t-Bi(56)
d-Mo(0), t-Mo(0)	d-Al(1)	Chlorophyll-a(20)	t-Cd(46)
d-Ni(2)	d-As(0), t-As(0)	HCO3^{-}(0)	t-Co(2)
d-Sb(66), t-Sb(0)	d-Co(10)	Na^{+}(1)	t-Cr(21)
d-Se(26), t-Se(19)	d-Fe(21)	Mg^{2+}(0)	t-Cu(2)
d-Tl(25)	d-Hg(3), t-Hg(0)	SO4^{2-} (0)	t-Fe(0)
d-U(0), t-U(0)	d-Th(31)	d-B(0), t-B(0)	t-Ni(1)
d-Zn(32)	d-Ti(0), t-Ti(0)	d-Ba(0), t-Ba(0)	t-Pb(1)
	d-V(3)	d-Ca(0), t-Ca(0)	t-Th(8)
		d-Li(0), t-Li(0)	t-Tl(16)
		d-Sr(0), t-Sr(0)	t-V(1)
			t-Zn(2)

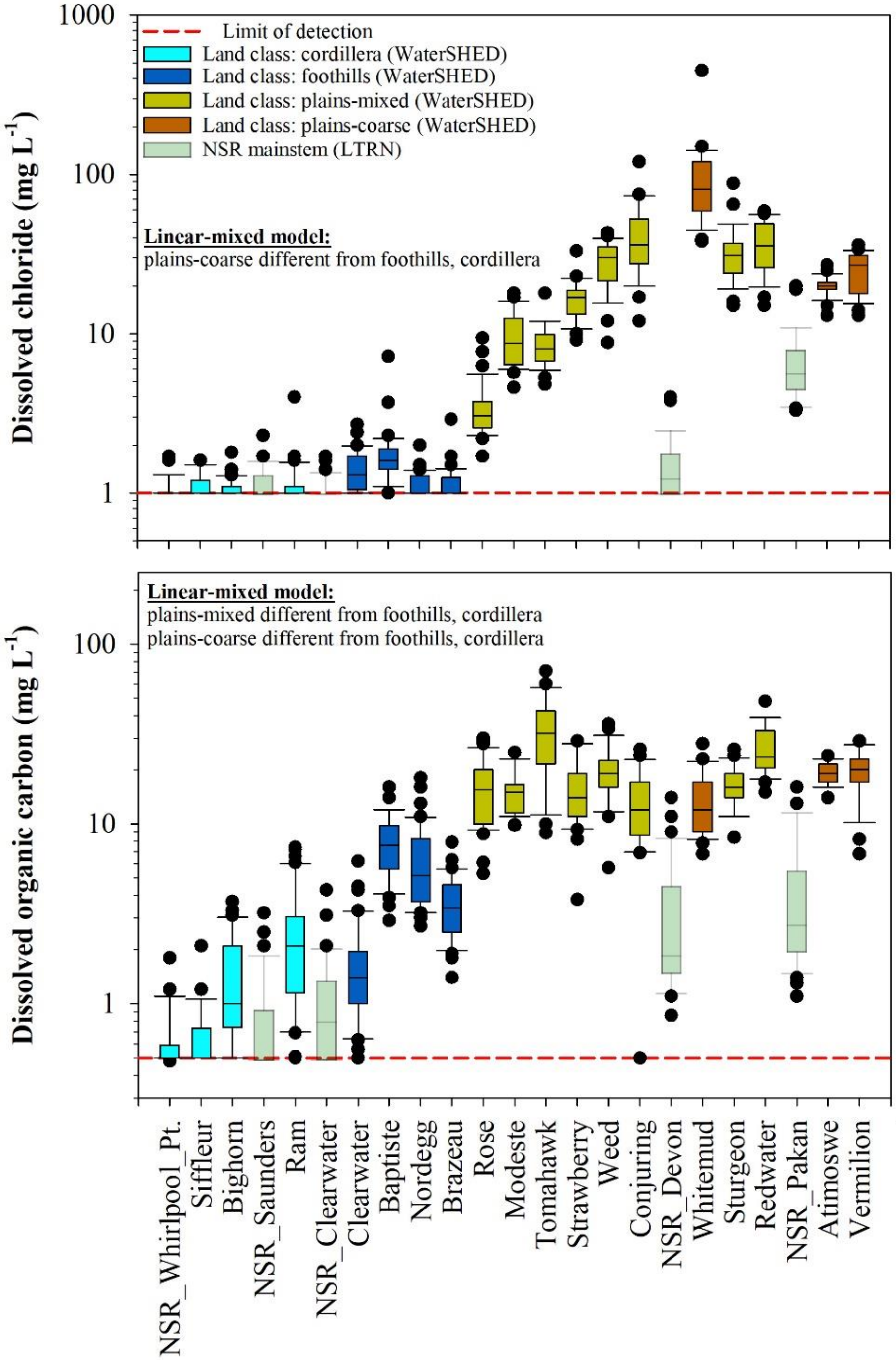

Figure 9. Concentration boxplots of dissolved chloride (upper) and dissolved organic carbon (lower) of all WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream. The dashed red line indicates the reported analytical detection limit for each chemical. Linear mixed model results between landscape classes are also shown.

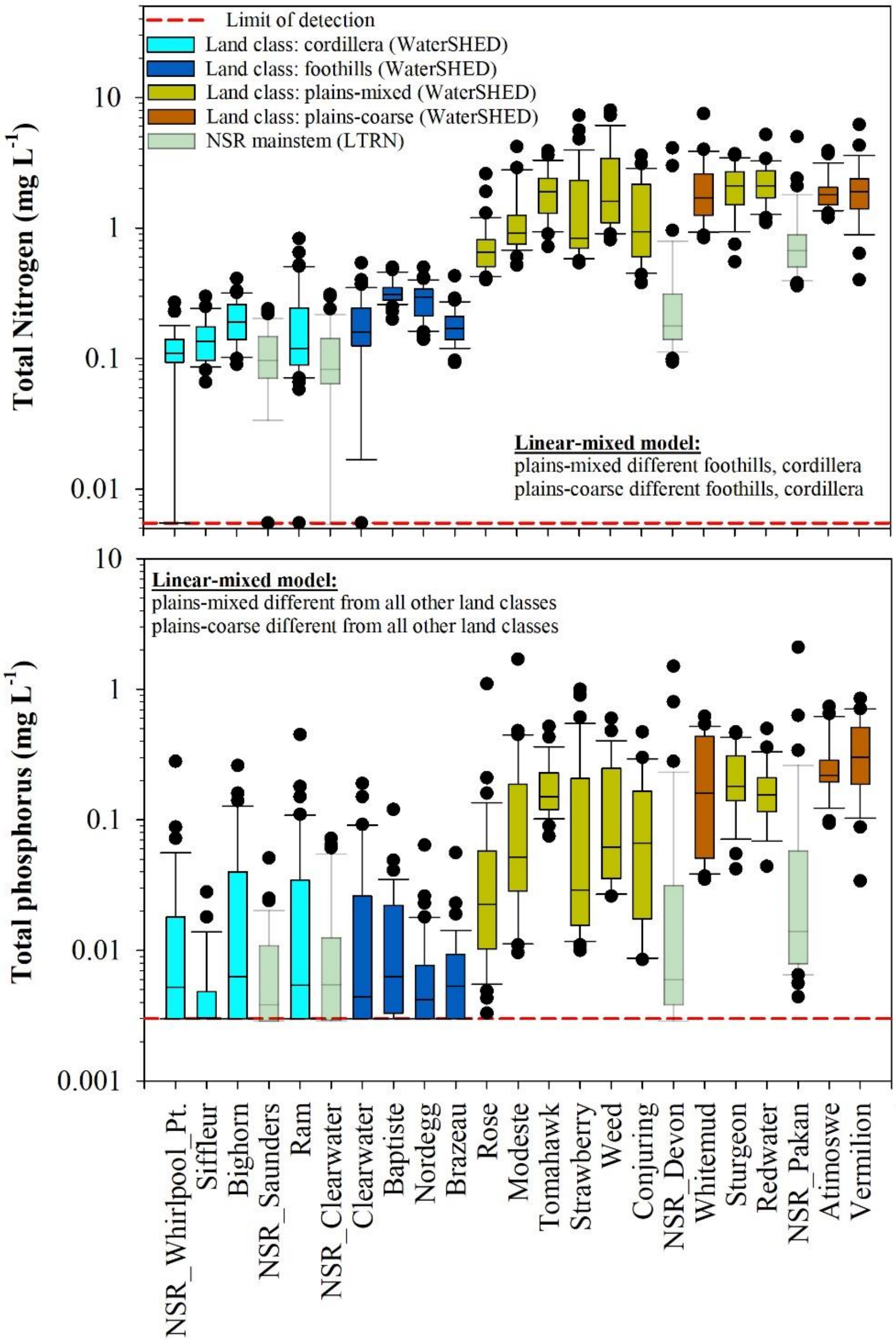

Figure 10. Concentration boxplots of total nitrogen (upper) and total phosphorus (lower) of all WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream. The dashed red line indicates the reported analytical detection limit for each chemical. Linear mixed model results between landscape classes are also shown.

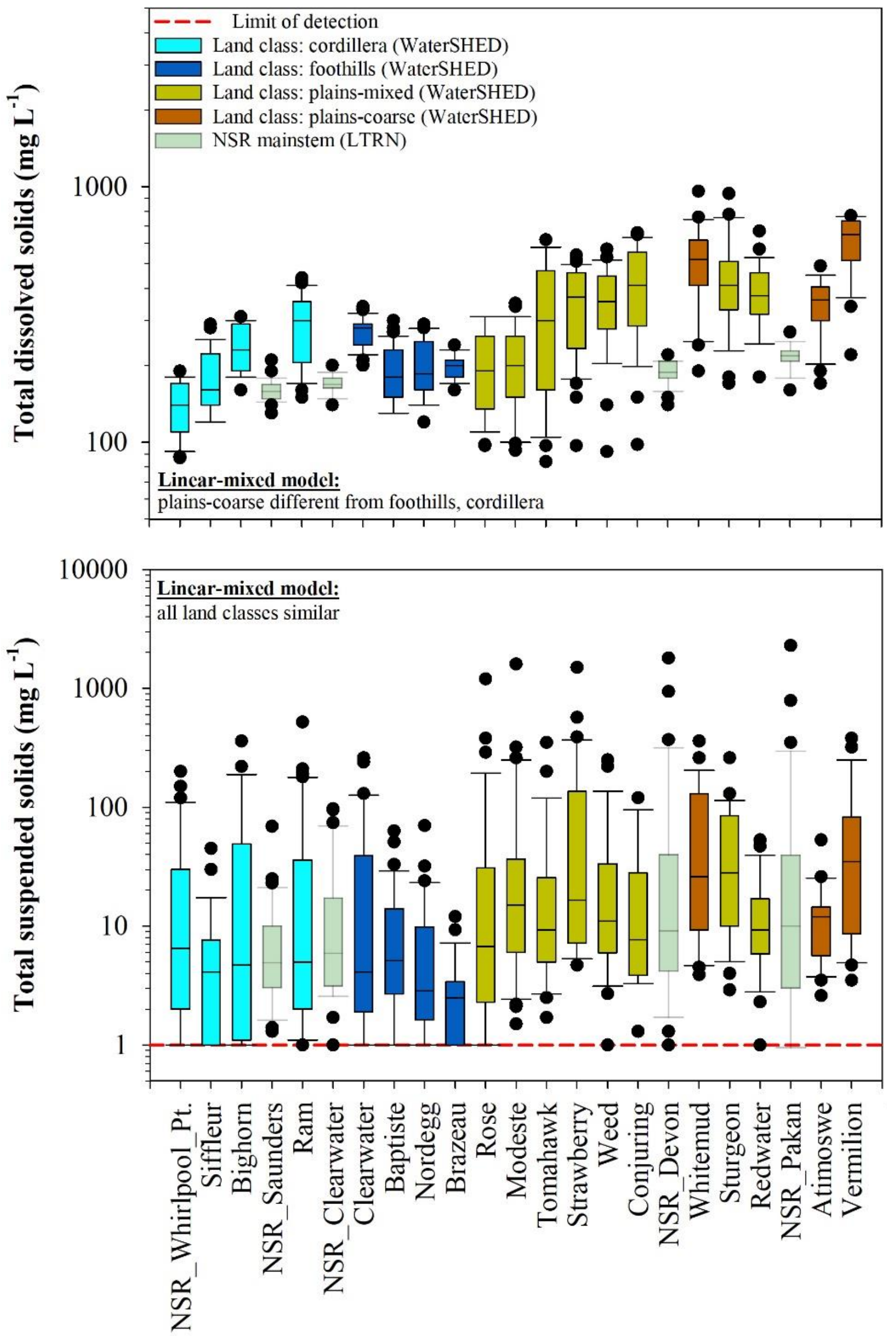

Figure 11. Concentration boxplots of total dissolved solids (upper) and total suspended solids (lower) of all WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream. The dashed red line indicates the reported analytical detection limit for each chemical. Linear mixed model results between landscape classes are also shown.

For TSS, concentrations were highly variable within and between stations and there were no statistical differences between land classes, though median and maximum concentrations were generally higher in plains regions than upstream forested regions (Table A2.6). Sediment transport is often dependent on various factors within a given catchment including sediment supply, topography, soil structure, in-channel storage and release of sediment, and the influence of human activities (Vercruysse et al., 2017). For example, large flood-control and hydroelectric reservoirs on the North Saskatchewan and Brazeau rivers have induced sedimentation and clarifying of rivers downstream from these structures (i.e., NSR-Saunders, Brazeau; Figure 11). Alternatively, rivers draining agricultural areas often show increases in suspended sediment concentrations due to soil erosion upstream, particularly those draining croplands, rather than pastures (Kort et al., 1998).

Overall, landscape classifications that guided site selection of the WaterSHED program were successful in differentiating headwater and plains regions water quality, as well as urbanized and lake-influenced streams of the plains-coarse land class with the plains-mixed class, particularly for TP. More robust statistical separation between the plains landscape classes may have occurred with additional monitoring stations in the plain-coarse class. Ultimately, the water quality of upstream and relatively intact foothills and cordillera regions were dilute compared to cleared, worked, and settled plains landscapes, similar to other Alberta river basins (Emmerton et al., 2022).

Downstream patterns of proxy parameter concentrations in mainstem NSR stations generally followed downstream changes in tributaries (Figure 9–Figure 11; Table A2.1–Table A2.6). In particular, step changes in concentrations at mainstem stations occurred between the NSR upstream of the Clearwater River and at the NSR at Devon stations, between which substantial changes in topography, climate, and soil take place (i.e., in proximity to the Rose Creek tributary station). As a result, lower NSRB mainstem stations (i.e., NSR-Devon, NSR-Pakan) within the plains classifications reported concentrations of d-Cl, DOC, TN, TP, and TSS typically several times higher than the upper NSRB mainstem stations (i.e., NSR-Whirlpool, NSR-Saunders, NSR-Clearwater; Table A2.1–Table A2.6). TDS concentrations were only slightly higher in lower NSRB mainstem stations relative to those upstream, suggesting a disconnection between concentrations of d-Cl and TDS in the NSR through Edmonton. Based on Durbin-Watson autocorrelation test results, upper NSRB mainstem stations were most similar to one another, while in-river chemistries were commonly different between lower and upper mainstem sites. DOC concentrations, however, reported autocorrelation (i.e., similarities) between the lower NSR at Devon site and several upper NSRB sites, suggesting a common, sustained source of DOC to these stations. The NSR at Pakan site showed no autocorrelation with other sites, suggesting differing sources of DOC through the Edmonton corridor. These findings suggest that concentrations of proxy parameters in mainstem stations are influenced by concentrations in adjacent tributaries draining into the NSR. However, only mass-based assessments can address true contributions of chemicals in tributaries on the chemistry of mainstem rivers downstream.

River flow and chemical export across the NSRB

River flow and chemical export from a stream or river is inherently connected to the intensity of runoff in the upstream catchment. Between the water years of 2018-19 and 2020-21, inter-annual river flow and runoff across the NSRB changed substantially between relatively wet periods (2018-19, 2019-20) and extremely dry periods (2020-21; Figure 12). During the early 2021 summer, a high pressure system stalled over western Canada and resulted in record high temperatures through much of the NSRB and runoff was consequently much lower compared to other years at nearly all monitoring stations. An exception to this was at the North Saskatchewan River at Whirlpool Point station that is primarily glacial-fed from the Saskatchewan and Peyto glaciers. In 2021, flow at this station increased substantially relative to previous years as glacial melt accelerated. Though 2019-20 was generally wetter than 2018-19 in the NSRB, this condition was not ubiquitous in space and demonstrated the often concentrated nature of convective storms across large areas of prairie ecosystems. Flow and runoff between years at mainstem NSR stations were generally resistant to large changes compared to tributaries due to the modifying effects of reservoir management and groundwater additions. Between stations, the upper NSRB rivers delivered larger flows than those downstream as cordillera and foothills regions of Alberta receive much higher precipitation rates, on higher-grade landscapes with less landscape water storage than downstream plains stations (ACIS, 2022). Thus, these western NSRB regions produce higher water yields resulting in larger catchments, denser river networks, and greater river flows compared to the east (Figure 12).

At any given station and time, riverine chemical mass export associated closely with changes in river flow, so inter-annual differences were apparent for most proxy chemicals (Table A4.1–Table A4.6), with drought-impacted 2020-21 export usually lower than other years. However, between stations, chemical export did not necessarily associate closely with the size of river or its flow (Figure 13 – Figure 15). For example, d-Cl mass export from tributaries across the NSRB was usually greatest from the relatively small Whitemud Creek station in Edmonton, compared to larger rivers upstream and thus reported the highest catchment yields of d-Cl in the NSRB (Figure 16). These additions are likely related to urban-specific inputs (i.e., road salts), and this was supported by large increases in export of d-Cl in the NSR mainstem upstream to downstream of Edmonton (Figure 13).

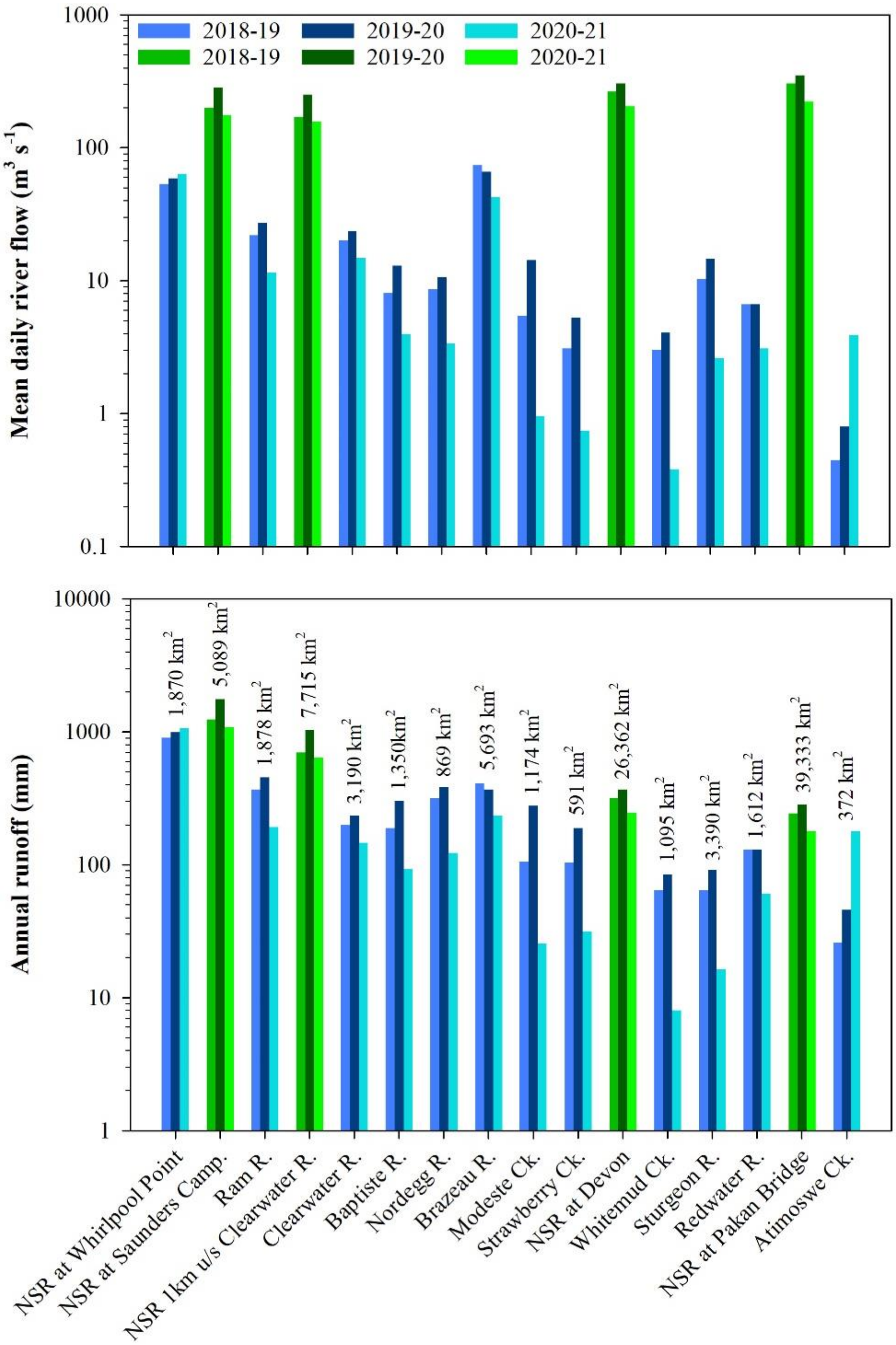

Figure 12. Grouped bar graphs of mean daily river flow (above) and annual runoff (below) from selected WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream. Blue bars indicate WaterSHED tributary stations and green indicate NSR mainstem LTRN stations.

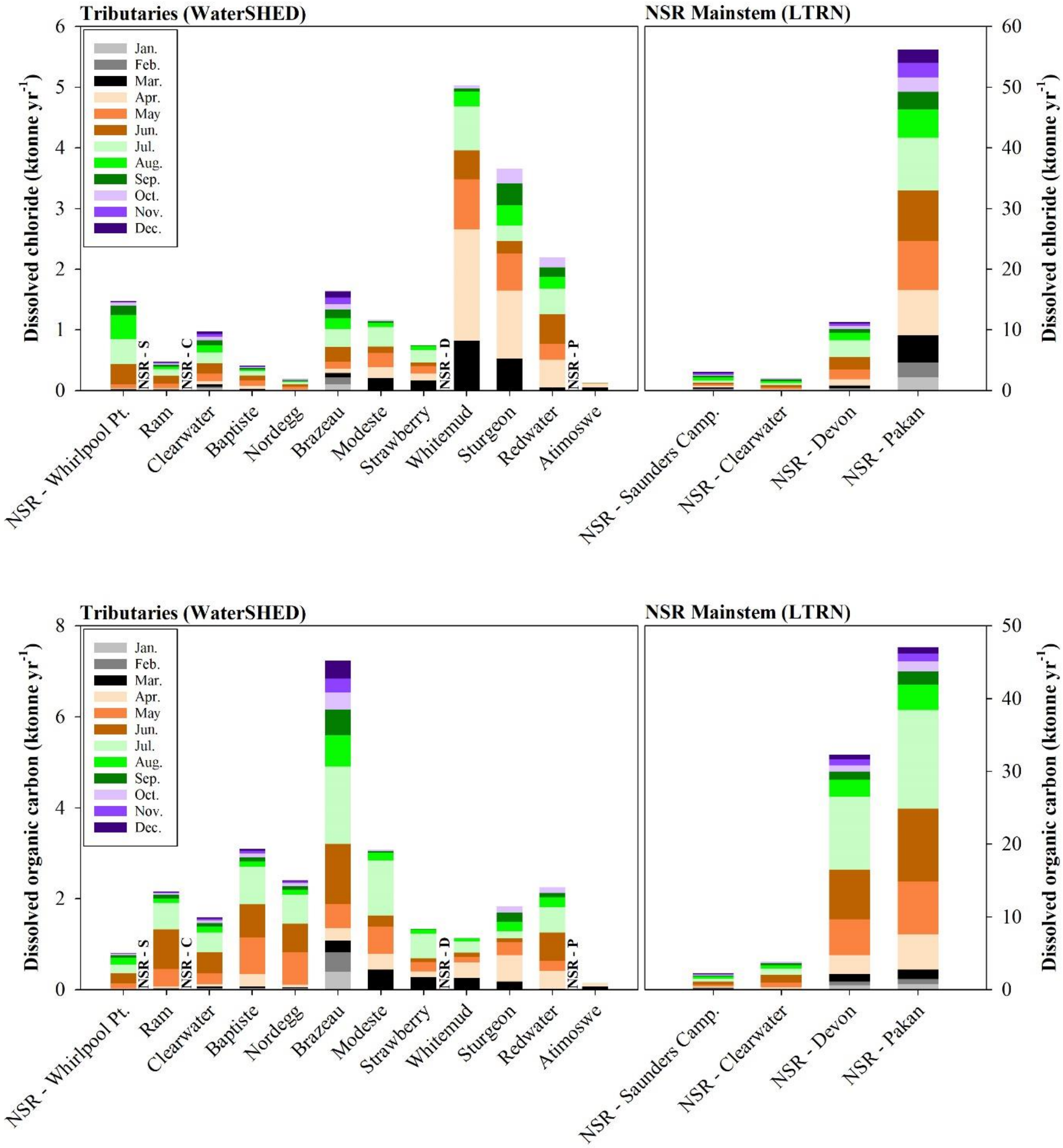

Figure 13. Stacked bar graphs of monthly dissolved chloride (above) and dissolved organic carbon (below) export from selected WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream and relative location of LTRN stations are shown in the left panels.

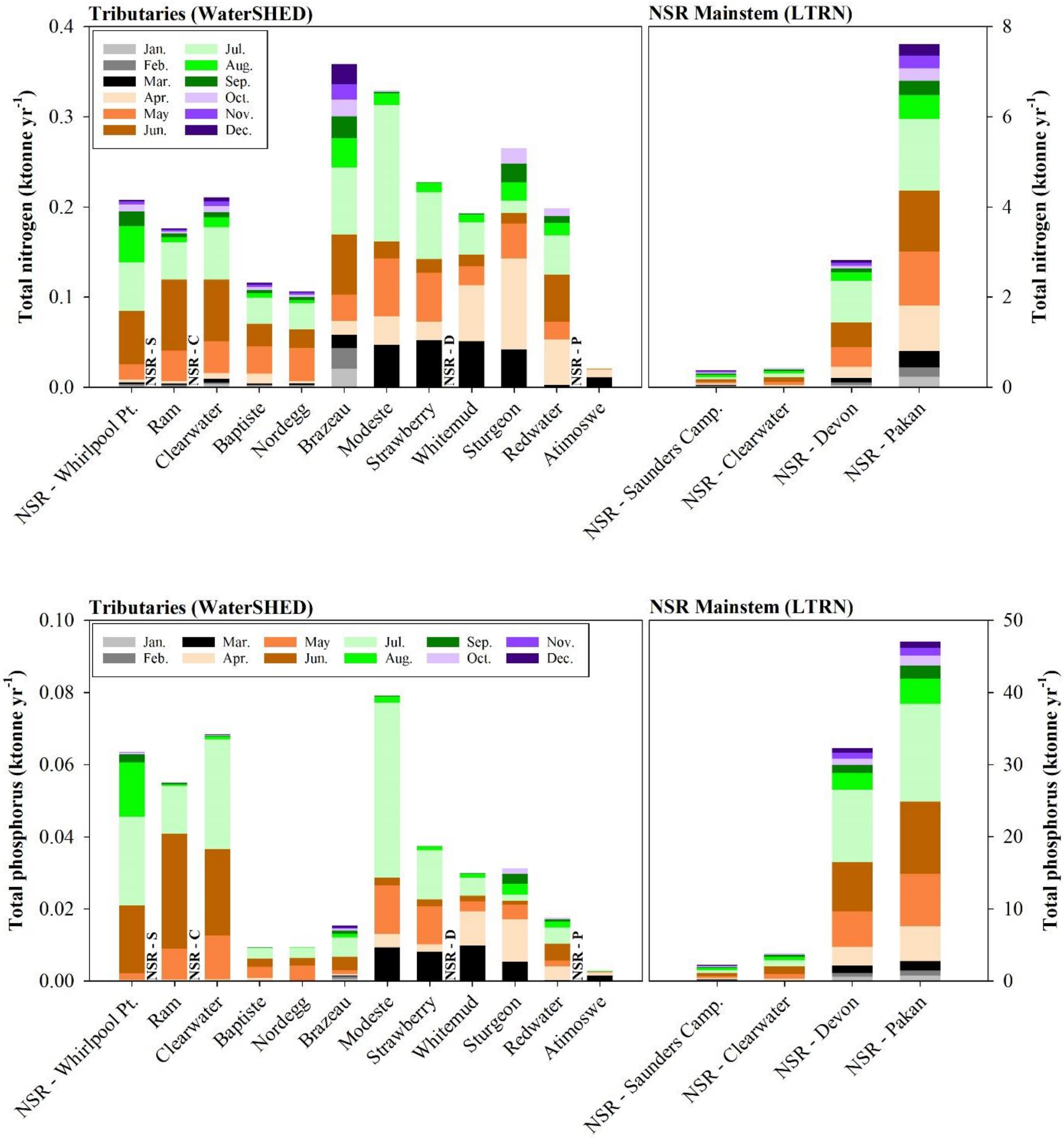

Figure 14. Stacked bar graphs of monthly total nitrogen (above) and total phosphorus (below) export from selected WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream and relative location of LTRN stations are shown in the left panels.

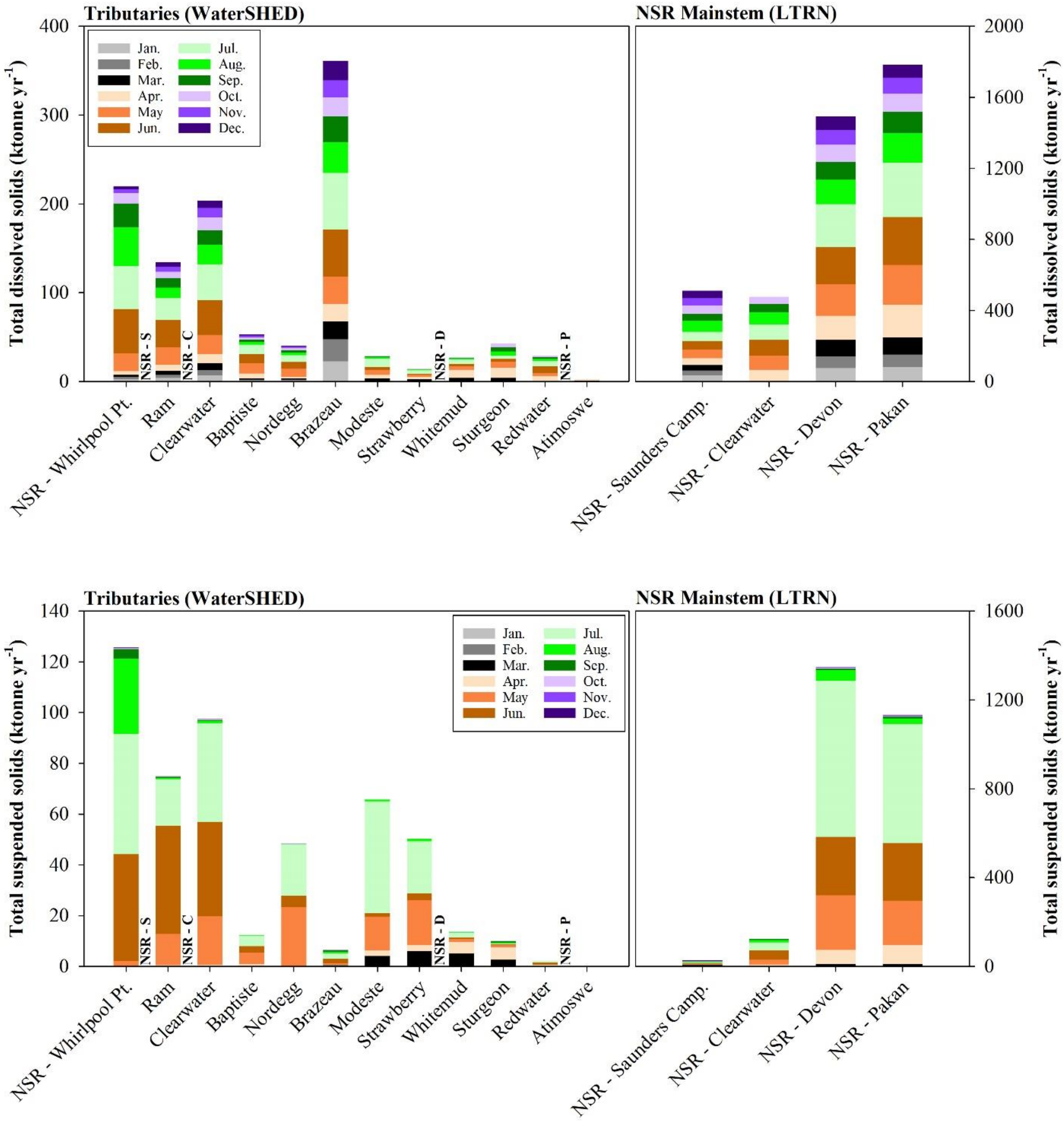

Figure 15. Stacked bar graphs of monthly total dissolved solids (above) and total suspended solids (below) export from selected WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream and relative location of LTRN stations are shown in the left panels.

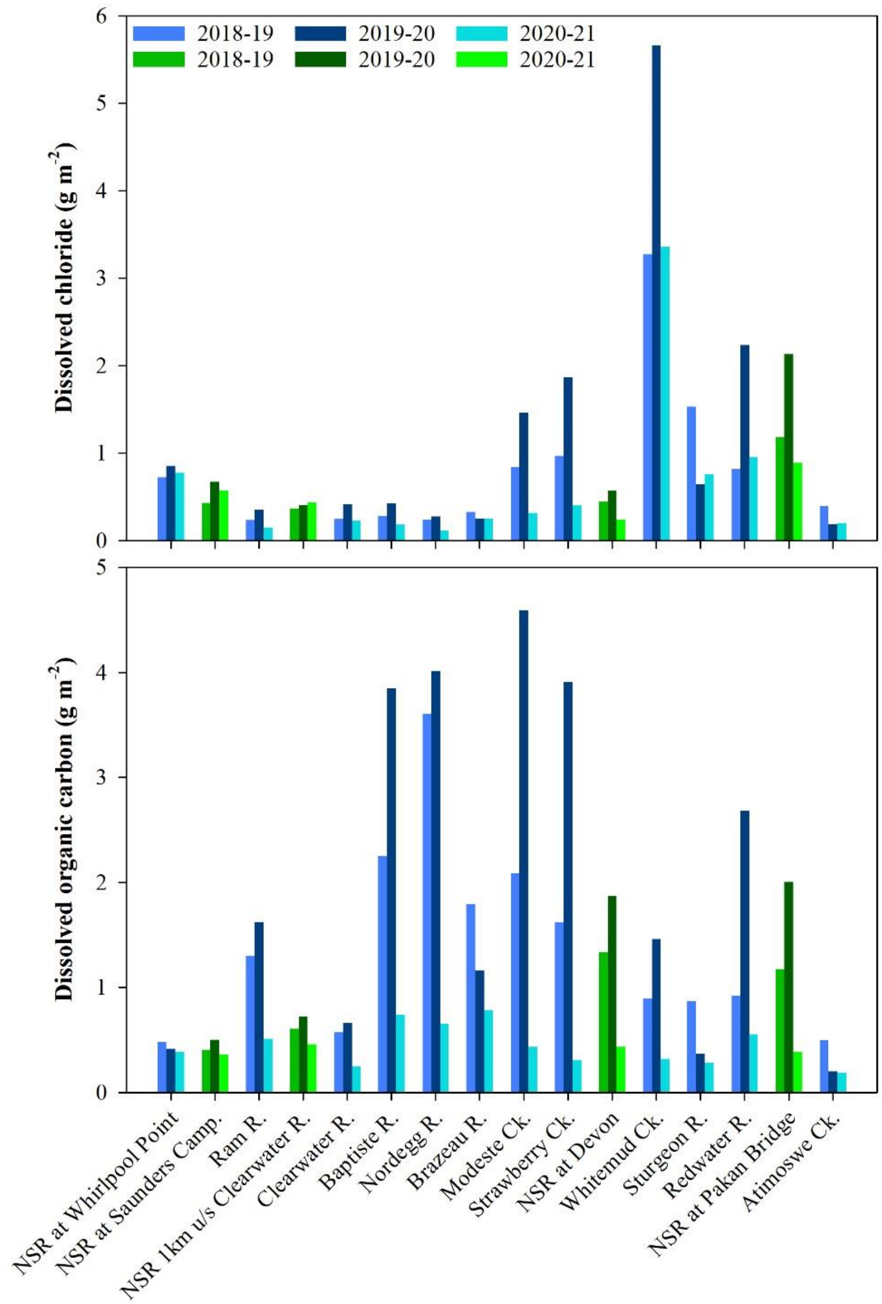

Figure 16. Grouped bar graphs of annual yields of dissolved chloride (above) and dissolved organic carbon (below) from selected WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream. Blue bars indicate WaterSHED tributary stations and green indicate NSR mainstem LTRN stations.

Using a mass balance approach at mainstem stations (see Equation 1), we found that ungauged additions of d-Cl between NSR at Devon and NSR at Pakan (i.e., through Edmonton) were exceptionally high relative to the rest of the NSRB (Table A4.1), suggesting a further influence of urban additions, likely from stormwater, ungauged urban creeks, and domestic and industrial wastewater (EPCOR, 2020).

Tributary export of DOC, TN, and TP across the NSRB showed substantial differences in space, despite clear concentration changes from west to east across the basin. The heavily forested and mostly intact catchment of the Brazeau River exported the most DOC of any monitored tributary, due mostly to its large drainage area with moderate DOC yields (Figure 13, Figure 16). The Brazeau, in particular, is a dominant DOC source to the NSR during winter. Higher DOC catchment yields than the Brazeau occurred in the smaller forested foothills rivers (e.g., Baptiste, Nordegg) and agriculturalized prairie creeks and contributed notable exports of DOC to the NSR. These catchments are heavily influenced by peatlands, wetlands, and rich chernozemic soils that deliver DOC downstream when flushed. Interestingly, ungauged sources of DOC (Table A4.2) were extremely important contributors to masses measured in the lower NSR stations and suggested a possible over-weighted contribution of DOC from small, ungauged streams and urban runoff and effluents. For example, DOC concentrations from Tomahawk Creek were the highest of all WaterSHED stations, though export was not quantified at that station due to lack of flow data currently. Forested upper NSRB tributaries and agriculturalized lower tributaries reported relatively high export of both TN and TP (Table A4.3, Table A4.4) despite their large size differences. In most cases, TN and TP catchment yields were elevated at lower NSRB tributary stations draining rich, worked, and developed soils prone to erosion. River sizes controlled export more in upper NSRB rivers as TN and TP yields were relatively low and consistent between sites (Figure 17). TP yields showed more variability between sites than TN, suggesting a non-agricultural, geological source of TP to some river systems (e.g., Ram River). Of note was the relatively low TN and TP export and catchment yields from the Brazeau R., which was likely related to burial of particle-bound nutrients or biological uptake in the low-energy lacustrine conditions in the Brazeau Reservoir. At the NSR at Devon station, tributaries and ungauged sources delivered similar supplies of TN and TP. This pattern continued through Edmonton to the NSR at Pakan station for TP, but TN reported large, ungauged additions of TN, likely pointing to substantial wastewater additions of nitrogen to the NSR (HESL, 2014).

Though concentrations of TDS generally increased downstream across the NSRB, river sizes and flow dictated TDS export as the large upper sites had higher exports and yields of TDS compared to downstream stations (Table A4.5, Figure 15, Figure 18). This may reflect the greater groundwater contributions to flow in larger rivers, which often has greater major ion concentrations than surface water (Boulton and Hancock, 2006). Greater precipitation and hydrological connection with exposed parent bedrock also induces greater weathering rates in the upper NSRB compared to downstream areas with more arid climates with parent bedrock buried deep beneath glacial till and productive soils. This may also explain the more blunted changes in TDS export between hydrologically different years at each site compared to other, surface-related chemicals such as DOC, TN, and TP (Table A4.5). Consequently, TDS export from the largest upper NSRB rivers comprised most of the TDS at all NSR mainstem stations. This downstream pattern occurred in contrast to d-Cl, highlighting that chloride contributed little to overall TDS across the NSRB compared to calcium, sodium, and magnesium, for example (Table 4).

Most TSS exported by tributaries across the NSRB originated from upper basin rivers, in particular the NSR at Whirlpool Point, the Ram River, and the Clearwater River; three of the largest tributaries in the WaterSHED program. The largest tributary, the Brazeau River, was a weak contributor of sediments to the NSR due to burial effects of the reservoir upstream of the station. Smaller agriculturalized stations showed relatively high yields of suspended sediment (Figure 18), most prominently during wetter years. High yields during these periods showed that erosion-prone agriculturalized regions of the NSRB efficiently mobilize soils and nutrients downstream enough to become important mass contributors of these chemicals on a basin-scale, similar to larger rivers upstream. However, tributary additions of sediment were only moderately important at NSR mainstem stations (Figure 15), suggesting an alternative source of sediments. Using the bass balance approach (Equation 1; Table A4.6), ungauged contributions were considered the most important contributors of sediment to the lower NSR mainstem stations, particularly during wet years. For example, during the wetter 2018-19 and 2019-20 water years, ungauged contributions were substantially higher compared to the very dry 2021 season, suggesting that in-river mobilization of sediment and other particle-bound chemicals was considerable during wet years relative to drier conditions. In fact, in-channel mobilization of sediments outpaced changes in tributary export between years and thus controlled much of the mainstem TSS export and concentrations. This pattern would also extend to other particle-bound sediment measurements. Interestingly, sediment mobilization was particularly high in the reach between the NSR u/s Clearwater River and NSR at Devon LTRN stations, whereas sediment deposition was more common through the Edmonton CMA (Figure 15). This is likely related to a lowering of river gradient of the NSR just upstream of the Edmonton CMA. In contrast to other tributaries, TSS export from the NSR at Whirlpool Point station was greatest during the dry 2021 season, relative to the other years; reflecting intensive glacial melt and sediment mobilization that occurred in the cordilleran headwaters of the NSR during the intensive heat of June and July. However, downstream export of TSS from the upper NSR was stored in the Abraham Lake reservoir resulting in much lower exports of TSS downstream from the Bighorn Dam (i.e., NSR-Saunders).

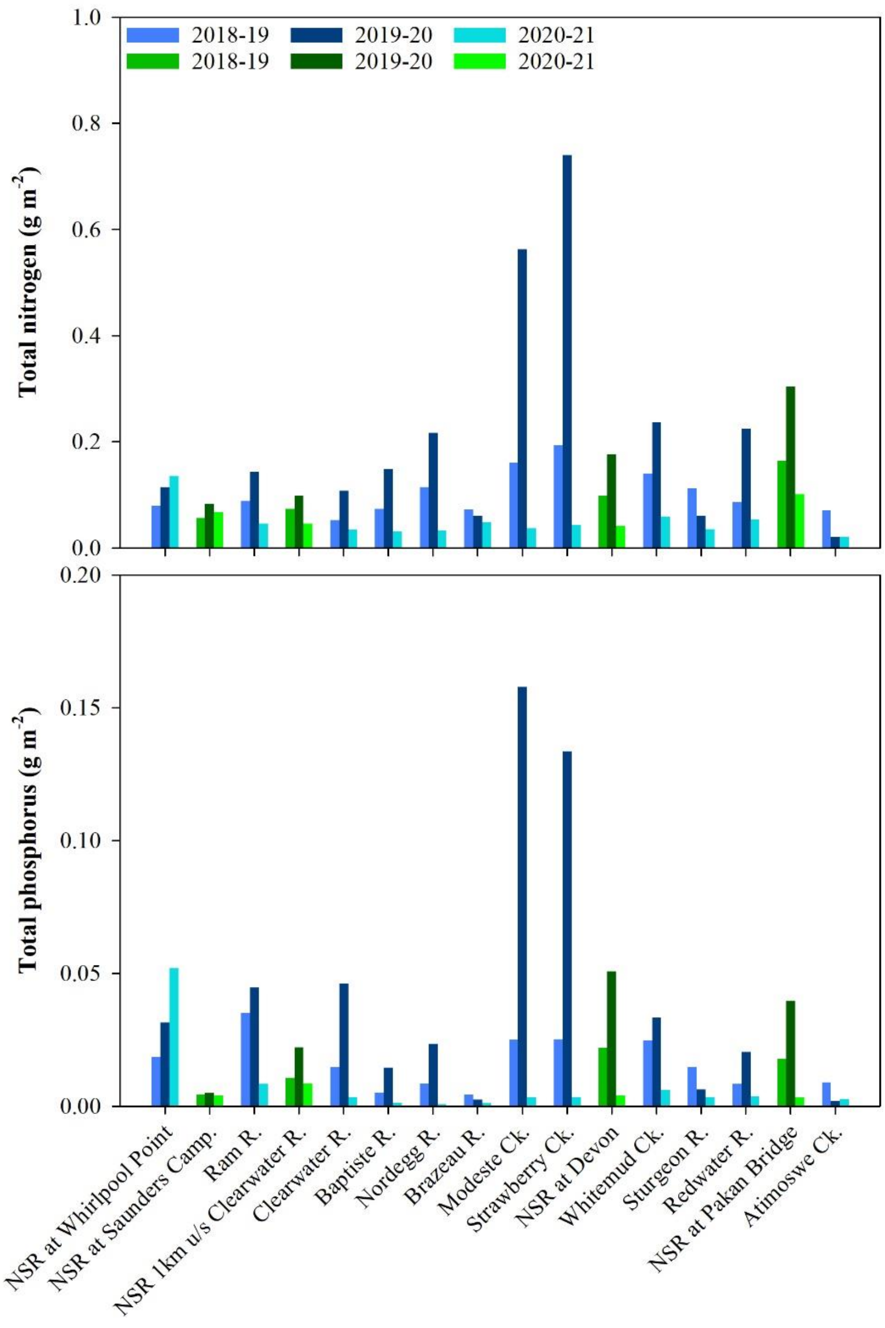

Figure 17. Grouped bar graphs of annual yields of total nitrogen (above) and total phosphorus (below) from selected WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream. Blue bars indicate WaterSHED tributary stations and green indicate NSR mainstem LTRN stations.

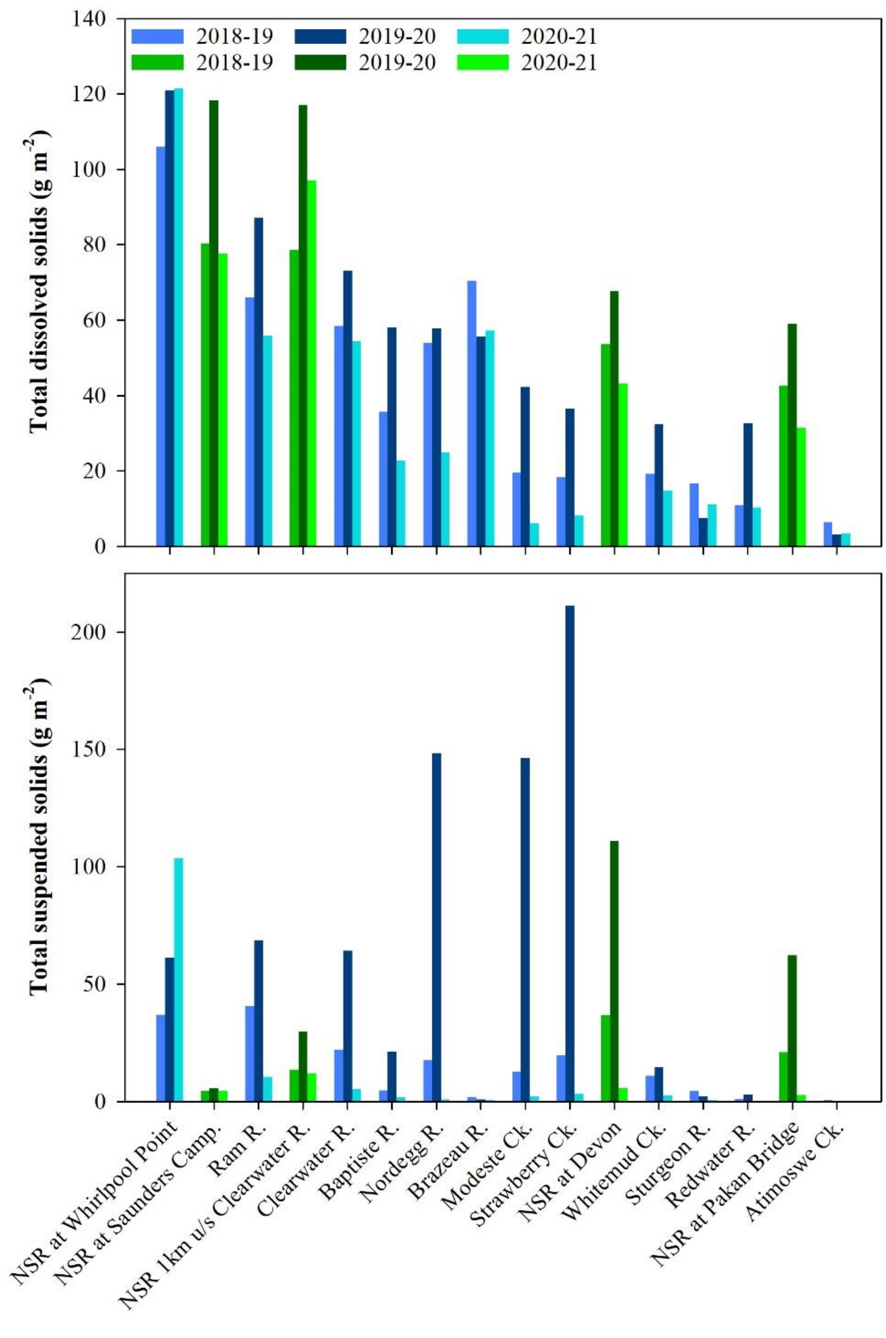

Figure 18. Grouped bar graphs of annual yields of total dissolved solids (above) and total suspended solids (below) from selected WaterSHED monitoring stations from all samples from water years 2018-19 to 2020-21. Stations are organized upstream to downstream. Blue bars indicate WaterSHED tributary stations and green indicate NSR mainstem LTRN stations.

Together, TSS results showed a dynamic sediment regime in the NSR that is closely linked to hydrometeorological changes, catchment conditions, and sediment movement within the NSR channel. Seasonally, export of chemicals was generally highest during open water conditions (~April to October) when surface runoff occurred more consistently relative to frozen periods of November through to March. For d-Cl, seasonal export was still largest during the relatively heavy runoff and rainfall periods of March to July. However export of d-Cl in March was noticeably larger in the urbanized catchments, highlighting road salt runoff to waterways during annual spring melt. Nutrients-organics proxy parameters also showed greatest export from rivers during freshet with greater contributions in March in the plains regions that experience earlier melting conditions than those stations upstream. TDS export was better distributed between months than other chemicals likely a result of more seasonality-proof contributions from reservoirs and groundwater. TSS export was the most seasonal in nature of all proxy chemicals with almost all export occurring during the May to September period. Lower TSS export in shoulder seasons and winter aligns with periods of low erosion due to low flow and frozen soils.

Program learnings and ongoing work

After four years of establishing water quality and quantity monitoring stations, collecting and analyzing hundreds of water quality samples, and assessing spatial and temporal changes in water quality across stations, we are gaining a clearer understanding of the state of water resources across the NSRB. WaterSHED results have highlighted:

1. Step changes in the concentrations of many parameters that occur during the spatial progression from cordillera and foothills regions to lower elevation and developed plains landscapes;
2. The unique water quality conditions within urbanized and semi-arid, lake-influenced tributaries in the eastern NSRB;
3. The overarching influence of small urbanized and agriculturalized streams on the NSR particularly during wet years for urban contaminants and nutrients;
4. The major influence of in-channel sediments on the concentrations and mass export of TSS in the NSR;
5. The large impact of the foothills rivers on concentrations and export of DOC in the NSR; and
6. The considerable changes in export of chemicals driven by hydroclimatological extremes between years.

These findings will support on-the-ground work in the NSRB by various stakeholders to manage landscapes and sustain water quality for continued stewardship of this essential river basin.

Core monitoring of the WaterSHED monitoring stations will continue through the 2nd funding period (2022-26) and will provide refined estimates of chemical concentrations and mass export. New flow stations are expected to be reporting confident flow metrics through 2023, allowing for a full-network assessment of mass export for the next WaterSHED technical report, including an estimate of uncertainty in the mass export calculations. High-frequency sonde measurements from all stations continues to be collected and these data will be reported on in the next report. Assessment of focused studies outlined in the inaugural WaterSHED technical report is ongoing with updates expected for the next report cycle.

Considering the accumulation of data from the WaterSHED program is now exceeding four years, we expect that data will be used in upcoming studies across the NSRB. WaterSHED will continue to support grass-roots research across the NSRB and summaries of this research will be reported on in the next annual report.

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Appendix I

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

Chemicals monitored		Short label	Unit	Sampling method, Frequency
Observational				
Ice/snow cover, thickness		-	%, m	Visual, per visit
Cloud cover		-	%	Visual, per visit
Water condition: turbidity, foam, colour, flow, odor		-	0-1-2-3	Visual, per visit
General chemistry				
Water temperature		-	°C	Sonde,15-minute
Specific conductivity		Conductivity	µS cm^{-1}	Sonde,15-minute
pH		-	Unitless	Sonde,15-minute
Turbidity		-	NTU	Sonde,15-minute
Dissolved oxygen		DO	mg L^{-1}	Sonde,15-minute
Oxidation-Reduction potential		-	mV	Sonde,15-minute
Total suspended / dissolved solids		TSS / TDS	mg L^{-1}	Grab sample,per visit
Water colour		Colour	relative	Grab sample,per visit
Alkalinity/Hardness		-	mg L^{-1}	Grab sample,per visit
Major cations (sodium, potassium, calcium, magnesium)		Na^+, K^+, Ca^{2+} ,Mg^{2+}	mg L^{-1}	Grab sample,per visit
Major anions (chloride, bicarbonate, sulphate, carbonate)		Cl^-, HCO_3, SO_4^{2-},CO_3^{2-}	mg L^{-1}	Grab sample,per visit
Nutrients				
Total / dissolved organic carbon		TOC, DOC	mg L^{-1}	Grab sample, per visit
Total / dissolved nitrogen		TN, TDN	mg L^{-1}	Grab sample, per visit
Total / dissolved Kjeldahl nitrogen		TKN, DKN	mg L^{-1}	Grab sample, per visit
Nitrate / Nitrite / Ammonia		$NO3^-$, $NO2^-$, $NH3^+$	mg L^{-1}	Grab sample, per visit
Total / dissolved phosphorus / orthophosphate		TP, TDP, $PO4^{2-}$	mg L^{-1}	Grab sample, per visit
Biological				
Chlorophyll-*a*		Chl-a	mg m^{-3}	Grab sample, per visit
Escherichia coli, fecal coliforms		E. coli	CFU	Grab sample, per visit
Total recoverable (t-) / Dissolved (d-) metals				
Aluminum	Lithium	Al, Li	µg L^{-1}	Grab sample, per visit
Antimony	Manganese	Sn, Mn	µg L^{-1}	Grab sample, per visit
Arsenic	Mercury	As, Hg	µg L^{-1}	Grab sample, per visit
Barium	Molybdenum	Ba, Mo	µg L^{-1}	Grab sample, per visit
Beryllium	Nickel	Be, Ni	µg L^{-1}	Grab sample, per visit
Bismuth	Selenium	Bi, Se	µg L^{-1}	Grab sample, per visit
Boron	Silver	B, Ag	µg L^{-1}	Grab sample, per visit
Cadmium	Strontium	Cd, Sr	µg L^{-1}	Grab sample, per visit
Calcium	Thallium	Ca, Tl	µg L^{-1}	Grab sample, per visit
Chlorine	Thorium	Cl, Th	µg L^{-1}	Grab sample, per visit
Chromium	Tin	Cr, Sn	µg L^{-1}	Grab sample, per visit
Cobalt	Titanium	Co, Ti	µg L^{-1}	Grab sample, per visit
Copper	Uranium	Cu, U	µg L^{-1}	Grab sample, per visit
Iron	Vanadium	Fe, V	µg L^{-1}	Grab sample, per visit
Lead	Zinc	Pb, Zn	µg L^{-1}	Grab sample, per visit

Appendix II

Table A2.1. Descriptive statistics of dissolved chloride concentrations (mg L-1) from WaterSHED monitoring stations from 2019 - 2021.

River	N	#<RDL	Mean	Se	Median	SD	Min.	Max.	5th	95th
NSR - Whirlpool Pt.	**39**	**29**	**0.69**	**0.056**	**<1**	**0.35**	**<1**	**1.7**	**<1**	**1.6**
Siffleur R.	26	15	0.83	0.080	<1	0.41	<1	1.6	<1	1.6
Cline R.	6	5	0.62	0.12	<1	0.29	<1	1.2	<1	-
Bighorn R.	31	19	0.76	0.065	<1	0.36	<1	1.8	<1	1.6
NSR - Saunders Camp.	**34**	**19**	**0.89**	**0.085**	**<1**	**0.50**	**<1**	**2.3**	**<1**	**1.9**
Ram R.	40	25	0.86	0.10	<1	0.64	<1	4.0	<1	1.7
NSR - Clearwater R.	**33**	**24**	**0.72**	**0.066**	**<1**	**0.38**	**<1**	**1.7**	**<1**	**1.6**
Clearwater R.	40	9	1.3	0.087	1.4	0.55	<1	2.7	<1	2.4
Baptiste R.	39	2	1.8	0.16	1.6	1.0	<1	7.2	<1	3.7
Nordegg R.	39	23	0.83	0.067	<1	0.42	<1	2.0	<1	1.5
Brazeau R.	37	20	0.89	0.086	<1	0.52	<1	2.9	<1	1.8
Rose Ck.	34	0	3.5	0.27	3.1	1.6	1.7	9.4	2.1	8.1
Modeste Ck.	28	0	9.7	0.73	9.0	3.8	4.6	18	5.1	18
Tomahawk Ck.	25	0	8.6	0.55	8.0	2.8	4.8	18	5.0	16
Strawberry Ck.	35	0	16	0.78	17	4.6	9.1	33	9.8	25
Weed Ck.	26	0	28	1.7	30	8.9	8.8	43	9.9	42
Conjuring Ck.	25	0	43	4.6	36	23	12	120	14	107
NSR - Devon	**36**	**11**	**1.3**	**0.15**	**1.3**	**0.88**	**<1**	**4.0**	**<1**	**3.8**
Whitemud Ck.	27	0	99	15	81	77	38	450	38	330
Sturgeon R.	26	0	33	3.0	31	15	15	88	15	80
Redwater R.	26	0	36	2.6	36	13	15	59	16	58
NSR - Pakan	**36**	**0**	**6.9**	**0.63**	**5.7**	**3.8**	**3.3**	**20**	**3.4**	**19**
Atimoswe Ck.	25	0	20	0.57	20	2.9	13	27	14	26
Vermilion R.	26	0	25	1.3	27	6.9	13	36	13	35

N=number of grab samples, S.E=standard error of the mean; SD=standard deviation; Min.=minimum; Max.=maximum; 5th=5th percentile; 95th=95th percentile. RDL: laboratory reported detection limit.

Table A2.2. Descriptive statistics of dissolved organic carbon concentrations (mg L-1) from WaterSHED monitoring stations from 2019 - 2021.

River	N	#<RDL	Mean	Se	Median	SD	Min.	Max.	5^{th}	95^{th}
NSR - Whirlpool Pt.	**39**	**27**	**0.48**	**0.068**	**0.25**	**0.42**	**<0.50**	**1.8**	**<0.50**	**1.8**
Siffleur R.	26	16	0.52	0.086	0.25	0.44	0.25	2.1	0.25	1.8
Cline R.	6	6	0.25	0.0000	0.25	0.0000	<0.50	0.25	<0.50	0.25
Bighorn R.	31	4	1.4	0.17	1.0	0.96	<0.50	3.7	<0.50	3.5
NSR - Saunders Camp.	**33**	**20**	**0.68**	**0.13**	**0.25**	**0.73**	**<0.50**	**3.2**	**<0.50**	**2.7**
Ram R.	40	2	2.5	0.30	2.2	1.9	<0.50	7.4	0.26	7.2
NSR - Clearwater R.	**32**	**8**	**1.0**	**0.16**	**0.82**	**0.90**	**<0.50**	**4.3**	**<0.50**	**3.5**
Clearwater R.	40	2	1.7	0.19	1.4	1.2	<0.50	6.2	0.27	4.5
Baptiste R.	39	0	7.9	0.50	7.6	3.1	2.9	16	3.5	14
Nordegg R.	39	0	6.5	0.57	5.2	3.6	2.7	18	3.0	16
Brazeau R.	37	0	3.7	0.24	3.4	1.4	1.4	7.9	1.8	6.5
Rose Ck.	34	0	16	1.1	16	6.2	5.3	30	5.9	29
Modeste Ck.	28	0	15	0.82	15	4.3	9.8	25	9.8	25
Tomahawk Ck.	25	0	33	3.3	32	16	8.9	71	9.2	68
Strawberry Ck.	35	0	16	1.1	14	6.6	3.8	29	7.3	29
Weed Ck.	26	0	20	1.3	19	6.8	5.7	36	7.6	35
Conjuring Ck.	25	1	13	1.2	12	5.9	<0.50	26	2.2	25
NSR - Devon	**36**	**0**	**3.4**	**0.51**	**1.9**	**3.0**	**0.86**	**14**	**1.1**	**11**
Whitemud Ck.	27	0	14	1.0	12	5.4	6.8	28	7.2	26
Sturgeon R.	26	0	17	0.88	16	4.5	8.4	26	9.3	25
Redwater R.	26	0	27	1.7	24	8.5	15	48	16	45
NSR - Pakan	**35**	**0**	**4.4**	**0.64**	**2.8**	**3.8**	**1.1**	**16**	**1.3**	**14**
Atimoswe Ck.	25	0	19	0.52	19	2.6	14	24	15	24
Vermilion R.	26	0	20	1.1	20	5.6	6.8	29	7.3	29

N=number of grab samples, S.E=standard error of the mean; SD=standard deviation; Min.=minimum; Max.=maximum; 5^{th}=5^{th} percentile; 95^{th}=95^{th} percentile. RDL: laboratory reported detection limit.

Table A2.3. Descriptive statistics of total nitrogen concentrations (mg L-1) from WaterSHED monitoring stations from 2019 - 2021.

River	N	#<RDL	Mean	Se	Median	SD	Min.	Max.	5th	95th
NSR - Whirlpool Pt.	**39**	**4**	**0.11**	**0.0088**	**0.11**	**0.055**	**<0.0055**	**0.27**	**<0.0055**	**0.23**
Siffleur R.	26	0	0.15	0.012	0.14	0.060	0.066	0.30	0.072	0.28
Cline R.	6	1	0.11	0.032	0.10	0.078	<0.0055	0.24	<0.0055	-
Bighorn R.	31	0	0.20	0.014	0.19	0.078	0.090	0.41	0.096	0.36
NSR - Saunders Camp.	**34**	**3**	**0.11**	**0.010**	**0.099**	**0.059**	**<0.0055**	**0.24**	**<0.0055**	**0.23**
Ram R.	40	1	0.20	0.029	0.13	0.18	<0.0055	0.83	0.058	0.64
NSR - Clearwater R.	**33**	**5**	**0.11**	**0.013**	**0.084**	**0.077**	**<0.0055**	**0.31**	**<0.0055**	**0.30**
Clearwater R.	40	4	0.19	0.018	0.16	0.11	<0.0055	0.54	<0.0055	0.40
Baptiste R.	39	0	0.33	0.012	0.31	0.072	0.20	0.50	0.23	0.49
Nordegg R.	39	0	0.29	0.013	0.30	0.084	0.14	0.50	0.15	0.42
Brazeau R.	37	0	0.18	0.010	0.17	0.063	0.093	0.43	0.097	0.30
Rose Ck.	34	0	0.76	0.074	0.66	0.43	0.40	2.6	0.41	2.1
Modeste Ck.	28	0	1.2	0.16	0.92	0.83	0.52	4.2	0.56	3.6
Tomahawk Ck.	25	0	2.0	0.16	1.9	0.81	0.72	3.9	0.77	3.8
Strawberry Ck.	35	0	1.7	0.27	0.84	1.6	0.54	7.3	0.56	5.9
Weed Ck.	26	0	2.4	0.38	1.6	2.0	0.81	8.0	0.84	7.8
Conjuring Ck.	25	0	1.3	0.19	0.94	0.93	0.38	3.6	0.40	3.5
NSR - Devon	**36**	**0**	**0.43**	**0.13**	**0.18**	**0.80**	**0.094**	**4.1**	**0.097**	**3.2**
Whitemud Ck.	26	0	2.2	0.28	1.7	1.4	0.84	7.5	0.85	6.3
Sturgeon R.	26	0	2.1	0.16	2.1	0.84	0.55	3.7	0.62	3.7
Redwater R.	26	0	2.3	0.17	2.1	0.86	1.1	5.2	1.1	4.6
NSR - Pakan	**36**	**0**	**0.92**	**0.14**	**0.68**	**0.84**	**0.36**	**5.0**	**0.37**	**2.8**
Atimoswe Ck.	25	0	1.9	0.14	1.8	0.68	1.2	3.9	1.2	3.8
Vermilion R.	26	0	2.1	0.24	1.9	1.2	0.40	6.2	0.48	5.5

N=number of grab samples, S.E=standard error of the mean; SD=standard deviation; Min.=minimum; Max.=maximum; 5th=5th percentile; 95th=95th percentile. RDL: laboratory reported detection limit.

Table A2.4. Descriptive statistics of total phosphorus concentrations (mg L-1) from WaterSHED monitoring stations from 2019 - 2021.

River	N	#<RDL	Mean	Se	Median	SD	Min.	Max.	5^{th}	95^{th}
NSR - Whirlpool Pt.	**39**	**17**	**0.021**	**0.0076**	**0.0052**	**0.047**	**<0.0030**	**0.28**	**<0.0030**	**0.088**
Siffleur R.	26	12	0.005	0.0012	0.0031	0.0061	<0.0030	0.028	<0.0030	0.025
Cline R.	6	3	0.007	0.0042	0.0029	0.010	<0.0030	0.028	<0.0030	-
Bighorn R.	31	11	0.031	0.010	0.0063	0.057	<0.0030	0.26	<0.0030	0.20
NSR - Saunders Camp.	**34**	**13**	**0.008**	**0.0017**	**0.0040**	**0.010**	**<0.0030**	**0.051**	**<0.0030**	**0.032**
Ram R.	40	10	0.039	0.013	0.0054	0.080	<0.0030	0.45	<0.0030	0.18
NSR - Clearwater R.	**33**	**8**	**0.014**	**0.0035**	**0.0057**	**0.020**	**<0.0030**	**0.072**	**<0.0030**	**0.066**
Clearwater R.	40	15	0.027	0.0073	0.0044	0.046	<0.0030	0.19	<0.0030	0.15
Baptiste R.	39	8	0.015	0.0034	0.0063	0.021	<0.0030	0.12	<0.0030	0.049
Nordegg R.	39	14	0.008	0.0018	0.0043	0.011	<0.0030	0.064	<0.0030	0.026
Brazeau R.	37	13	0.007	0.0016	0.0053	0.010	<0.0030	0.056	<0.0030	0.026
Rose Ck.	34	0	0.070	0.032	0.023	0.19	0.0033	1.1	0.0041	0.43
Modeste Ck.	29	0	0.18	0.061	0.057	0.33	0.010	1.7	0.010	1.1
Tomahawk Ck.	25	0	0.19	0.021	0.15	0.11	0.075	0.52	0.080	0.49
Strawberry Ck.	35	0	0.17	0.043	0.029	0.25	0.010	1.0	0.011	0.92
Weed Ck.	26	0	0.15	0.031	0.062	0.16	0.026	0.60	0.026	0.56
Conjuring Ck.	25	0	0.11	0.024	0.066	0.12	0.0085	0.47	0.0085	0.42
NSR - Devon	**36**	**3**	**0.092**	**0.047**	**0.0062**	**0.28**	**<0.0030**	**1.5**	**<0.0030**	**0.90**
Whitemud Ck.	26	0	0.23	0.038	0.16	0.19	0.035	0.62	0.036	0.59
Sturgeon R.	26	0	0.22	0.024	0.18	0.12	0.040	0.47	0.047	0.47
Redwater R.	26	0	0.18	0.020	0.16	0.10	0.044	0.50	0.053	0.45
NSR - Pakan	**36**	**0**	**0.12**	**0.060**	**0.015**	**0.36**	**0.0044**	**2.1**	**0.0054**	**0.85**
Atimoswe Ck.	25	0	0.28	0.033	0.22	0.16	0.094	0.74	0.095	0.71
Vermilion R.	26	0	0.35	0.043	0.30	0.22	0.030	0.85	0.053	0.80

N=number of grab samples, S.E=standard error of the mean; SD=standard deviation; Min.=minimum; Max.=maximum; 5^{th}=5^{th} percentile; 95^{th}=95^{th} percentile. RDL: laboratory reported detection limit.

Table A2.5. Descriptive statistics of total dissolved solids concentrations (mg L-1) from WaterSHED monitoring stations from 2019 - 2021.

River	N	#<RDL	Mean	Se	Median	SD	Min.	Max.	5th	95th
NSR - Whirlpool Pt.	**39**	**0**	**142**	**5.7**	**140**	**35**	**87**	**190**	**88**	**190**
Siffleur R.	26	0	178	9.7	160	50	120	290	120	287
Cline R.	6	0	188	22	170	54	130	280	130	-
Bighorn R.	31	0	237	8.4	230	47	160	310	172	304
NSR - Saunders Camp.	**34**	**0**	**161**	**2.6**	**160**	**15**	**130**	**210**	**138**	**195**
Ram R.	40	0	287	14	295	86	150	440	161	430
NSR - Clearwater R.	**33**	**0**	**173**	**2.6**	**170**	**15**	**140**	**200**	**140**	**200**
Clearwater R.	40	0	270	5.9	280	37	200	340	210	330
Baptiste R.	39	0	193	7.5	180	47	130	300	130	280
Nordegg R.	39	0	199	7.7	180	48	120	290	120	280
Brazeau R.	37	0	197	3.5	200	21	160	240	160	231
Rose Ck.	34	0	197	12	190	73	97	310	98	310
Modeste Ck.	28	0	203	14	195	72	93	350	96	346
Tomahawk Ck.	25	0	315	35	300	173	84	620	88	608
Strawberry Ck.	35	0	350	21	360	122	97	540	139	516
Weed Ck.	26	0	359	23	355	118	92	570	109	556
Conjuring Ck.	25	0	406	31	410	155	98	660	114	657
NSR - Devon	**36**	**0**	**191**	**3.2**	**190**	**19**	**140**	**220**	**149**	**212**
Whitemud Ck.	27	0	524	32	520	168	190	960	210	880
Sturgeon R.	26	0	444	37	410	186	170	940	174	884
Redwater R.	26	0	387	21	375	109	180	670	180	635
NSR - Pakan	**36**	**0**	**219**	**3.8**	**220**	**23**	**160**	**270**	**177**	**253**
Atimoswe Ck.	25	0	350	17	360	83	170	490	176	478
Vermilion R.	26	0	603	29	650	149	220	770	262	770

N=number of grab samples, S.E=standard error of the mean; SD=standard deviation; Min.=minimum; Max.=maximum; 5th=5th percentile; 95th=95th percentile. RDL: laboratory reported detection limit.

Table A2.6. Descriptive statistics of total suspended solids concentrations (mg L-1) from WaterSHED monitoring stations from 2019 - 2021.

River	N	#<RDL	Mean	Se	Median	SD	Min.	Max.	5th	95th
NSR - Whirlpool Pt.	**39**	**6**	**28**	**7.4**	**6.5**	**46**	**<1**	**200**	**<1**	**150**
Siffleur R.	26	8	6.8	2.0	4.1	10	<1	45	<1	40
Cline R.	6	2	18	12	7.3	30	<1	78	<1	-
Bighorn R.	31	5	39	15	4.7	81	<1	360	<1	276
NSR - Saunders Camp.	**34**	**0**	**9.1**	**2.1**	**5.2**	**12**	**1.3**	**69**	**1.3**	**36**
Ram R.	40	3	47	15	5.9	97	<1	520	<1	209
NSR - Clearwater R.	**33**	**1**	**18**	**4.7**	**6.2**	**27**	**<1**	**97**	**1.3**	**96**
Clearwater R.	40	5	35	9.8	4.2	62	<1	260	<1	235
Baptiste R.	39	4	11	2.3	5.1	14	<1	63	<1	51
Nordegg R.	39	6	8.0	2.0	2.9	13	<1	70	<1	32
Brazeau R.	37	11	2.9	0.45	2.5	2.8	<1	12	<1	9.6
Rose Ck.	35	5	70	36	6.7	212	<1	1200	<1	544
Modeste Ck.	29	0	96	55	16	299	1.5	1600	1.8	960
Tomahawk Ck.	25	0	36	15	9.3	77	1.7	350	1.9	305
Strawberry Ck.	35	0	122	46	17	273	4.7	1500	4.7	756
Weed Ck.	26	1	35	12	11	63	<1	250	1.3	240
Conjuring Ck.	25	0	24	7.1	7.7	36	1.3	120	1.9	120
NSR - Devon	**36**	**1**	**121**	**56**	**9.6**	**336**	**<1**	**1800**	**1.2**	**1069**
Whitemud Ck.	27	0	75	17	26	90	3.9	360	4.1	320
Sturgeon R.	26	0	50	11	27	57	2.9	260	3.3	215
Redwater R.	26	1	15	2.7	9.3	14	<1	53	1.1	51
NSR - Pakan	**36**	**4**	**125**	**67**	**11**	**402**	**<1**	**2300**	**<1**	**1017**
Atimoswe Ck.	25	0	12	2.1	12	11	2.6	53	2.9	45
Vermilion R.	26	0	74	19	35	99	3.5	380	3.9	359

N=number of grab samples, S.E=standard error of the mean; SD=standard deviation; Min.=minimum; Max.=maximum; 5th=5th percentile; 95th=95th percentile. RDL: laboratory reported detection limit.

Appendix III

Table A3.1. Linear mixed model results from comparing landscape classifications of WaterSHED stations (i.e., Catchment Structural Units; see Methods section) for concentrations of dissolved chloride.

CSU Class	Mean (mg L^{-1})	Standard Error	df	Lower 95% C.I	Upper 95% C.I
Dissolved chloride					
plains-mixed	22.244	6.494	15.953	8.473	36.014
plains-coarse	48.086	10.617	16.024	25.583	70.590
cordillera	0.753	8.287	16.451	-16.775	18.282
foothills	1.209	9.140	15.647	-18.202	20.620
Dissolved organic carbon					
plains-mixed	19.042	1.629	15.595	15.582	22.501
plains-coarse	16.847	2.661	15.639	11.195	22.500
cordillera	1.028	2.163	17.736	-3.521	5.577
foothills	4.590	2.289	15.199	-0.285	9.464
Total nitrogen					
plains-mixed	1.760	0.134	15.824	1.476	2.044
plains-coarse	2.047	0.219	15.987	1.582	2.513
cordillera	0.158	0.178	17.257	-0.218	0.533
foothills	0.237	0.187	14.831	-0.161	0.635
Total phosphorus					
plains-mixed	0.168	0.015	97.621	0.138	0.198
plains-coarse	0.286	0.025	99.697	0.236	0.335
cordillera	0.022	0.020	90.035	-0.019	0.062
foothills	0.013	0.021	86.572	-0.028	0.054
Total dissolved solids					
plains-mixed	334.313	30.319	15.949	270.023	398.603
plains-coarse	503.800	49.539	15.985	398.775	608.826
cordillera	211.147	39.516	17.402	127.921	294.372
foothills	213.674	42.680	15.657	123.034	304.313
Total suspended solids					
plains-mixed	67.494	13.443	15.708	38.952	96.035
plains-coarse	51.777	22.056	16.006	5.022	98.532
cordillera	28.249	18.049	16.008	-10.012	66.510
foothills	13.932	18.311	13.511	-25.475	53.338

Appendix IV

Table A4.1. Ranges of annual dissolved chloride mass export at both Tributary Monitoring Network (TMN) and Long Term River Network (LTRN) stations in the North Saskatchewan River Basin using four different mass export calculations (see Methods). Relative contribution of TMN exports to downstream LTRN stations also shown. *Indicates seasonal fluxes taken from annual station. **Indicates seasonal fluxes available only.

	2019 (tonne)		2020 (tonne)		2021 (tonne)		2019 (%)		2020 (%)		2021 (%)	
Station	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
NSR - Whirlpool Pt.	1,295	1,452	1,417	1,786	1,305	1,658	51	52	44	49	58	62
Ungauged (by difference)	1,253	1,324	1,771	1,844	961	1,002	49	48	56	51	42	38
NSR - Saunders Camp.	**2,548**	**2,776**	**3,188**	**3,630**	**2,266**	**2,659**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Saunders Camp.	2,548	2,776	3,188	3,630	2,266	2,659	83	79	117	98	86	87
Ram R.	476	511	629	661	242	326	15	14	23	18	9	11
*Ungauged (by difference)	49	240	-1,085	-588	129	86	2	7	-40	-16	5	3
***NSR - Clearwater R.**	**3,073**	**3,527**	**2,732**	**3,703**	**2,636**	**3,071**	**100**	**100**	**100**	**100**	**100**	**100**
*NSR - Clearwater R.	3,073	3,527	2,732	3,703	2,636	3,071	25	27	21	19	45	47
Clearwater R.	842	1,000	1,130	1,429	625	835	7	8	9	7	11	13
Baptiste R.	382	484	446	691	233	240	3	4	3	4	4	4
Nordegg R.	211	241	226	243	89	111	2	2	2	1	2	2
Brazeau R.	2,012	2,326	1,238	1,472	1,304	1,469	17	18	9	8	22	23
**Modeste Ck.	962	1,012	1,549	2,031	347	394	8	8	12	10	6	6
**Strawberry Ck.	537	609	1,015	1,224	221	255	4	5	8	6	4	4
Ungauged (by difference)	4,069	3,805	4,720	8,599	443	151	34	29	36	44	8	2
NSR - Devon	**12,089**	**13,004**	**13,056**	**19,390**	**5,898**	**6,526**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Devon	12,089	13,004	13,056	19,390	5,898	6,526	25	24	20	21	19	17
Whitemud Ck.	3,061	4,565	5,598	7,216	2,725	4,326	6	8	8	8	9	11
Sturgeon R.	4,947	5,402	1,859	2,431	2,235	2,841	10	10	3	3	7	7
Redwater R.	1,116	1,676	3,477	3,786	1,344	1,612	2	3	5	4	4	4
Ungauged (by difference)	28,114	30,535	42,714	61,621	18,516	24,164	57	55	64	65	60	61
NSR - Pakan	**49,326**	**55,182**	**66,704**	**94,443**	**30,717**	**39,469**	**100**	**100**	**100**	**100**	**100**	**100**
Atimoswe Ck.	144	159	69	77	70	79	-	-	-	-	-	-

Table A4.2. Ranges of annual dissolved organic carbon mass export at both Tributary Monitoring Network (TMN) and Long Term River Network (LTRN) stations in the North Saskatchewan River Basin using four different mass export calculations (see Methods). Relative contribution of TMN exports to downstream LTRN stations also shown. *Indicates seasonal fluxes taken from annual station. **Indicates seasonal fluxes available only.

	2019 (tonne)		2020 (tonne)		2021 (tonne)		2019 (%)		2020 (%)		2021 (%)	
Station	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
NSR - Whirlpool Pt.	840	1,030	686	918	580	973	41	40	30	35	38	48
Ungauged (by difference)	1,208	1,554	1,563	1,686	932	1,047	59	60	70	65	62	52
NSR - Saunders Camp.	**2,048**	**2,583**	**2,248**	**2,604**	**1,513**	**2,020**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Saunders Camp.	2,048	2,583	2,248	2,604	1,513	2,020	45	48	46	40	56	45
Ram R.	2,337	2,554	2,412	3,921	821	1,122	51	47	50	60	30	25
*Ungauged (by difference)	212	295	188	-3	382	1,355	5	5	4	-0	14	30
***NSR - Clearwater R.**	**4,596**	**5,432**	**4,848**	**6,522**	**2,716**	**4,497**	**100**	**100**	**100**	**100**	**100**	**100**
*NSR - Clearwater R.	4,596	5,432	4,848	6,522	2,716	4,497	14	14	11	12	27	33
Clearwater R.	1,681	2,174	1,813	2,409	657	1,031	5	5	4	4	7	8
Baptiste R.	3,106	3,326	4,391	6,300	892	1,110	9	8	10	11	9	8
Nordegg R.	3,025	3,490	2,019	3,958	512	697	9	9	5	7	5	5
Brazeau R.	9,997	11,772	5,826	6,791	3,593	5,815	30	30	13	12	36	43
**Modeste Ck.	2,144	2,648	5,220	5,510	464	633	6	7	12	10	5	5
**Strawberry Ck.	871	1,012	1,949	2,434	140	280	3	3	4	4	1	2
Ungauged (by difference)	8,151	9,865	18,598	21,390	997	-393	24	25	42	39	10	-3
NSR - Devon	**33,570**	**39,720**	**44,664**	**55,315**	**9,951**	**13,670**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Devon	33,570	39,720	44,664	55,315	9,951	13,670	74	76	62	64	81	69
Whitemud Ck.	873	1,097	1,386	1,871	291	501	2	2	2	2	2	3
Sturgeon R.	2,738	3,031	1,119	1,360	880	1,126	6	6	2	2	7	6
Redwater R.	1,430	1,553	3,392	4,844	845	1,034	3	3	5	6	7	5
Ungauged (by difference)	6,528	6,645	21,506	22,824	338	3,425	14	13	30	26	3	17
NSR - Pakan	**45,139**	**52,046**	**72,066**	**86,214**	**12,305**	**19,756**	**100**	**100**	**100**	**100**	**100**	**100**
Atimoswe Ck.	175	189	72	78	67	73	-	-	-	-	-	-

Table A4.3. Ranges of annual total nitrogen mass export at both Tributary Monitoring Network (TMN) and Long Term River Network (LTRN) stations in the North Saskatchewan River Basin using four different mass export calculations (see Methods). Relative contribution of TMN exports to downstream LTRN stations also shown. *Indicates seasonal fluxes taken from annual station. **Indicates seasonal fluxes available only.

	2019 (tonne)		2020 (tonne)		2021 (tonne)		2019 (%)		2020 (%)		2021 (%)	
Station	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
NSR - Whirlpool Pt.	127	195	205	229	221	279	38	55	50	52	77	84
Ungauged (by difference)	207	159	204	207	66	53	62	45	50	48	23	16
NSR - Saunders Camp.	**333**	**354**	**408**	**436**	**288**	**332**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Saunders Camp.	333	354	408	436	288	332	60	49	62	54	122	64
Ram R.	156	179	244	331	77	95	28	25	37	41	33	18
*Ungauged (by difference)	71	191	5	43	-129	91	13	26	1	5	-55	18
***NSR - Clearwater R.**	**560**	**724**	**658**	**811**	**236**	**518**	**100**	**100**	**100**	**100**	**100**	**100**
*NSR - Clearwater R.	560	724	658	811	236	518	21	25	16	16	24	43
Clearwater R.	176	192	269	450	89	126	7	7	6	9	9	11
Baptiste R.	102	114	164	231	40	45	4	4	4	5	4	4
Nordegg R.	88	124	82	300	27	31	3	4	2	6	3	3
Brazeau R.	445	493	295	379	270	297	17	17	7	8	27	25
**Modeste Ck.	170	206	579	718	39	51	6	7	14	14	4	4
**Strawberry Ck.	102	135	260	528	22	30	4	5	6	10	2	2
Ungauged (by difference)	1,015	935	1,829	1,622	269	98	38	32	44	32	27	8
NSR - Devon	**2,658**	**2,924**	**4,136**	**5,038**	**992**	**1,197**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Devon	2,658	2,924	4,136	5,038	992	1,197	39	39	42	37	27	28
Whitemud Ck.	140	177	232	284	57	79	2	2	2	2	2	2
Sturgeon R.	372	399	142	248	112	143	6	5	1	2	3	3
Redwater R.	130	146	349	390	83	90	2	2	4	3	2	2
Ungauged (by difference)	3,470	3,899	5,041	7,499	2,422	2,808	51	52	51	56	66	65
NSR - Pakan	**6,771**	**7,545**	**9,901**	**13,458**	**3,666**	**4,316**	**100**	**100**	**100**	**100**	**100**	**100**
Atimoswe Ck.	23	29	7	9	8	8	-	-	-	-	-	-

Table A4.4. Ranges of annual total phosphorus mass export at both Tributary Monitoring Network (TMN) and Long Term River Network (LTRN) stations in the North Saskatchewan River Basin using four different mass export calculations (see Methods). Relative contribution of TMN exports to downstream LTRN stations also shown. *Indicates seasonal fluxes taken from annual station. **Indicates seasonal fluxes available only.

	2019 (tonne)		2020 (tonne)		2021 (tonne)		2019 (%)		2020 (%)		2021 (%)	
Station	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
NSR - Whirlpool Pt.	24	51	51	70	72	132	103	154	271	261	532	625
Ungauged (by difference)	-1	-18	-32	-43	-58	-111	-3	-54	-171	-161	-432	-525
NSR - Saunders Camp.	**23**	33	**19**	**27**	**14**	**21**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Saunders Camp.	23	33	19	27	14	21	34	31	14	11	29	25
Ram R.	47	83	48	129	12	20	70	76	37	53	26	24
*Ungauged (by difference)	-3	-7	64	88	21	41	-4	-7	49	36	45	50
***NSR - Clearwater R.**	**68**	**109**	**131**	**244**	**46**	**83**	**100**	**100**	**100**	**100**	**100**	**100**
*NSR - Clearwater R.	68	109	131	244	46	83	14	14	16	10	62	61
Clearwater R.	35	65	64	239	9	12	7	9	8	9	12	9
Baptiste R.	5	9	12	35	2	2	1	1	1	1	2	2
Nordegg R.	5	10	3	35	1	1	1	1	<1	1	1	1
Brazeau R.	22	33	9	19	4	10	4	4	1	1	6	7
**Modeste Ck.	21	33	152	227	3	6	4	4	19	9	4	4
**Strawberry Ck.	11	18	35	145	2	3	2	2	4	6	2	2
Ungauged (by difference)	319	482	411	1,593	8	20	66	63	50	63	11	15
NSR - Devon	**486**	**760**	**817**	**2,537**	**75**	**136**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Devon	486	760	817	2,537	75	136	79	95	70	129	65	93
Whitemud Ck.	22	34	34	39	4	12	4	4	3	2	4	8
Sturgeon R.	48	52	15	26	10	16	8	6	1	1	9	11
Redwater R.	13	14	32	34	5	7	2	2	3	2	5	5
Ungauged (by difference)	42	-63	265	-671	20	-25	7	-8	23	-34	18	-17
NSR - Pakan	**612**	**798**	**1,163**	**1,965**	**114**	**146**	**100**	**100**	**100**	**100**	**100**	**100**
Atimoswe Ck.	3	4	1	1	1	1	-	-	-	-	-	-

Table A4.5. Ranges of annual total dissolved solids mass export at both Tributary Monitoring Network (TMN) and Long Term River Network (LTRN) stations in the North Saskatchewan River Basin using four different mass export calculations (see Methods). Relative contribution of TMN exports to downstream LTRN stations also shown. *Indicates seasonal fluxes taken from annual station. **Indicates seasonal fluxes available only.

	2019 (tonne)		2020 (tonne)		2021 (tonne)		2019 (%)		2020 (%)		2021 (%)	
Station	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
NSR - Whirlpool Pt.	201	210	216	237	219	236	42	40	41	39	77	59
Ungauged (by difference)	272	312	308	374	67	161	58	60	59	61	23	41
NSR - Saunders Camp.	**473**	**522**	**524**	**611**	**286**	**397**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Saunders Camp.	473	522	524	611	286	397	70	68	63	65	47	58
Ram R.	134	136	160	165	103	106	20	18	19	18	17	16
*Ungauged (by difference)	71	108	142	165	220	181	10	14	17	18	36	26
***NSR - Clearwater R.**	**678**	**766**	**826**	**941**	**609**	**683**	**100**	**100**	**100**	**100**	**100**	**100**
*NSR - Clearwater R.	678	766	826	941	609	683	44	47	48	53	55	58
Clearwater R.	209	210	212	242	168	179	13	13	12	14	15	15
Baptiste R.	52	54	73	84	29	31	3	3	4	5	3	3
Nordegg R.	50	53	44	53	21	22	3	3	3	3	2	2
Brazeau R.	433	470	287	332	325	331	28	29	17	19	30	28
**Modeste Ck.	22	24	46	53	7	8	1	1	3	3	1	1
**Strawberry Ck.	10	12	20	23	5	5	1	1	1	1	<1	<1
Ungauged (by difference)	96	48	228	37	-64	-91	6	3	13	2	-6	-8
NSR - Devon	**1,550**	**1,637**	**1,737**	**1,765**	**1,099**	**1,170**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Devon	1,550	1,637	1,737	1,765	1,099	1,170	85	85	79	76	96	89
Whitemud Ck.	19	23	33	38	13	19	1	1	2	2	1	1
Sturgeon R.	55	60	23	31	31	40	3	3	1	1	3	3
Redwater R.	16	21	48	56	16	17	1	1	2	2	1	1
Ungauged (by difference)	187	194	359	446	-18	65	10	10	16	19	-2	5
NSR - Pakan	**1,828**	**1,935**	**2,199**	**2,336**	**1,141**	**1,311**	**100**	**100**	**100**	**100**	**100**	**100**
Atimoswe Ck.	2	3	1	1	1	1	-	-	-	-	-	-

Table A4.6. Ranges of annual total suspended solids mass export at both Tributary Monitoring Network (TMN) and Long Term River Network (LTRN) stations in the North Saskatchewan River Basin using four different mass export calculations (see Methods). Relative contribution of TMN exports to downstream LTRN stations also shown. *Indicates seasonal fluxes taken from annual station. **Indicates seasonal fluxes available only.

	2019 (tonne)		2020 (tonne)		2021 (tonne)		2019 (%)		2020 (%)		2021 (%)	
Station	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**
NSR - Whirlpool Pt.	43	91	98	141	122	243	184	313	382	492	696	998
Ungauged (by difference)	-19	-62	-72	-112	-105	-219	-84	-213	-282	-392	-596	-898
NSR - Saunders Camp.	**23**	**29**	**26**	**29**	**18**	**24**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Saunders Camp.	23	29	26	29	18	24	26	23	20	7	24	23
Ram R.	69	84	79	209	18	22	78	67	60	50	25	21
*Ungauged (by difference)	-3	12	27	179	37	61	-3	10	21	43	51	57
***NSR - Clearwater R.**	**89**	**125**	**131**	**416**	**72**	**108**	**100**	**100**	**100**	**100**	**100**	**100**
*NSR - Clearwater R.	89	125	131	416	72	108	14	8	9	7	66	58
Clearwater R.	49	99	82	360	14	19	7	6	5	6	13	10
Baptiste R.	4	9	15	44	2	3	1	1	1	1	2	1
Nordegg R.	6	27	4	259	1	1	1	2	<1	4	<1	<1
Brazeau R.	11	14	4	7	2	4	2	1	<1	<1	2	2
**Modeste Ck.	9	18	133	210	2	3	1	1	9	3	2	2
**Strawberry Ck.	8	15	35	257	1	2	1	1	2	4	1	1
Ungauged (by difference)	483	1,261	1,099	4,649	16	46	73	80	73	75	14	25
NSR - Devon	**659**	**1,569**	**1,504**	**6,201**	**110**	**186**	**100**	**100**	**100**	**100**	**100**	**100**
NSR - Devon	659	1,569	1,504	6,201	110	186	106	143	118	126	118	149
Whitemud Ck.	10	16	11	20	2	5	2	1	1	<1	2	4
Sturgeon R.	12	17	4	10	1	4	2	2	<1	<1	2	3
Redwater R.	1	2	4	5	<1	1	<1	<1	<1	<1	<1	<1
Ungauged (by difference)	-61	-506	-246	-1,318	-20	-71	-10	-46	-19	-27	-21	-57
NSR - Pakan	**620**	**1,098**	**1,277**	**4,919**	**93**	**125**	**100**	**100**	**100**	**100**	**100**	**100**
Atimoswe Ck.	<1	<1	<1	<1	<1	<1	-	-	-	-	-	-