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PRAIRIE PROVINCES WATER BOARD

Report #[illegible]

Long-Term Trends in Water Quality Parameters at Twelve Transboundary River Reaches (From the beginning of the data record until the end of 2018)

Technical Report **Prepared for the Prairie Provinces Water Board**

April 2024

Long-Term Trends in Water Quality Parameters at Twelve Transboundary River Reaches
(From the beginning of the data record until the end 2018).

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By the Committee on Water Quality

Executive Summary

Long-term water quality monitoring has been undertaken on transboundary prairie rivers by Environment and Climate Change Canada (ECCC) since the late 1960's. This monitoring has been undertaken on eastward flowing prairie rivers to fulfill the monitoring requirements of the Master Agreement on Apportionment (MAA). The MAA is a multi-jurisdictional agreement that was signed in 1969 by the governments of Alberta, Saskatchewan, Manitoba, and Canada. The agreement provides for equitable sharing of surface water in eastward flowing rivers across the Canadian prairie.

The Prairie Provinces Water Board (PPWB) is accountable for the administration of the agreement and reporting of findings and results to governments. Schedule E to the MAA defines the water quality mandate of the PPWB in interprovincial water quality management and the duties of the Board. The PPWB has an established and active water quality program. The program includes the development and setting of interprovincial water quality objectives at its 12 transboundary river sites. These objectives are included as part of Schedule E and were last updated in 2021.

As part of the long-term water quality monitoring program, water samples were collected on a regular monthly basis from transboundary rivers, with the exception of three locations that were sampled regularly but on a less frequent basis ranging from quarterly to six times a year (Cold, Churchill, and Red Deer [SK/MB boundary] rivers). Currently, 11 of the 12 monitoring locations are monitored monthly, while the Churchill River is monitored on a quarterly basis. Water samples are collected and analyzed for a range of water quality parameters including nutrients, major ions, general water chemistry and metals.

Trend assessments are an important part of the PPWB water quality program as the identification of changes in water quality can be difficult to detect due to natural variations in water quality and anthropogenic influences. Identifying long-term changes in water quality assists the PPWB in its interprovincial water quality management responsibilities by providing information on changes in water quality that can be used to inform future evaluations, investigations, and work prioritization at the transboundary sites either by the Board or the participating jurisdictions.

The purpose of this report is to summarize the long-term trend assessments conducted for a range of water quality parameters at the 12 transboundary rivers from the inception of water quality monitoring program until the end of 2018. This is the third trend analysis report to be completed for these transboundary sites. All three reports use the same non-parametric seasonal Mann-Kendall/Mann-Kendall (and Sen Slope Estimator) to analyze trends. Trend assessments can be reported as increasing (statistically significant positive slope), decreasing (statistically significant negative slope), or as showing no statistically significant change over time. As water chemistry can be affected by river discharge, trend assessments were flow-weighted to adjust for the influence of flow.

Long-term flow-weighted trend assessments at the 12 transboundary river sites found increasing and decreasing trends at each of the sites. Overall, a total of 651 trend assessments were performed on the 12 transboundary rivers incorporating five nutrients, four major ions and total dissolved solids (TDS), four general water chemistry parameters and 21 different metals including the total and dissolved components of the same metal.

Of the 651 trend assessments performed (excluding dissolved oxygen) 25% showed statistically significant increasing trends on flow-adjusted data. Major ions and total dissolved solids (TDS) showed the greatest number of statistically significant increasing trends followed by general water chemistry parameters, nutrients, and metals. Of the total number of trend assessments completed for all 12 transboundary rivers (again excluding dissolved oxygen), 24% showed statistically significant decreasing trends, with nutrients showing the greatest number of decreasing trends followed by major ions, metals, and general water chemistry parameters.

On the Alberta/Saskatchewan boundary, six transboundary rivers were assessed for long-term water quality trends. Of these, the South Saskatchewan River, followed by the Battle River and the Red Deer River showed the greatest number of statistically significant monotonic increasing trends. For all three of these transboundary rivers there were increasing trends in sodium, chloride, sulphate, TDS, pH, cadmium (dissolved), and uranium (total).

In addition to the above, the South Saskatchewan River also had increasing trends in nitrate-nitrate, sodium adsorption ratio (SAR), barium (total and dissolved), cadmium (total), nickel (dissolved) and thallium (total). The Battle River also had increasing trends in total phosphorus (TP), and total dissolved phosphorus (TDP). This was the only river on this boundary to have statistically significant increasing trends in phosphorus. Other increasing trends for this river included total suspended solids (TSS), manganese (dissolved), thallium (dissolved) and uranium (dissolved). The Red Deer River also had increasing monotonic trends in total ammonia-nitrogen (NH_3-N), total nitrogen (TN), boron (total), selenium(total), and uranium (dissolved). On the Alberta/Saskatchewan boundary the major ions (sodium, chloride, sulphate) and TDS, cadmium (dissolved), and uranium (total) had statistically significant increasing trends in at least four of the six rivers.

For the six Alberta/Saskatchewan boundary rivers, the Cold River had the least number of statistically significant increasing trends, while the North Saskatchewan River had the greatest number of statistically significant decreasing trends. Decreasing trends on the North Saskatchewan River were observed for all the nutrients trended, fluoride, TSS and twenty-eight of the metals trended, and for many metals including both the total and dissolved components. The parameters that had decreasing trends in four or more rivers on this boundary included TP, TDP, fluoride, lead (dissolved), and molybdenum (dissolved).

Trend assessments were also conducted on six transboundary rivers on the Saskatchewan/Manitoba boundary. On this boundary the Assiniboine and Qu'Appelle rivers had the most number of statistically significant increasing trends. For each of these two transboundary rivers statistically significant increasing trends were observed for NH_3-N, TN, sulphate, pH, TSS, barium (total and dissolved), cobalt (total), nickel (total and dissolved), selenium (total and dissolved), thallium (total), uranium (total and dissolved), and zinc (total).

Also, of note on this boundary, was that due to the lower number of metal trends, the Red Deer River had fewer statistically significant increasing trends overall as compared to the Assiniboine and Qu'Appelle rivers. The Red Deer River had more statistically significant increasing trends in the other parameters groups including nutrients, major ions, TDS, pH and SAR.

On the Saskatchewan/Manitoba boundary the parameters that had statistically significant increasing trends in four or more rivers on this boundary included NH_3-N, TN, sodium, sulphate, TDS, pH, barium (dissolved), cobalt (dissolved), uranium (total and dissolved). The Churchill River had the fewest number of statistically increasing trends on the Saskatchewan/Manitoba boundary. However, for the Churchill River increasing trends were shown for sodium, TDS, pH, and several metals, particularly in the dissolved fraction including barium, boron, cobalt, molybdenum, and uranium.

The two rivers with the most statistically significant decreasing trends on the Saskatchewan/Manitoba border were the Red Deer and the Saskatchewan rivers.

The Red Deer River had 15 statistically significant decreasing trends, with all metals accounting for all decreasing trends. The majority of metals with decreasing trends were for the total metal fraction, with only beryllium, boron and lead having decreasing trends for the dissolved component. No other parameter groups showed decreasing trends for this river. The other parameters analyzed for this river had statistically significant increasing trends, except for TSS, and dissolved oxygen which had no trend. For the Saskatchewan River, decreasing trends were found for nutrients (NO3, TP and TDP), fluoride, TSS and metals including both the total and dissolved component for three metals (cadmium, chromium, and molybdenum). Other metals that showed decreasing trends included aluminium (total), barium (total), lead (dissolved), and nickel (total).

Comparison of this analysis (to the end of 2018) with earlier trend analysis assessments (*i.e.,* to the end of 2013) for non-metal parameters showed that, overall, the direction of the flow-weighted trends (*i.e.,* either increasing or decreasing, or no change) were similar between 2013 and 2018. Where there were differences in the statistical pattern of the trend results between analyses ending in 2013 and 2018 in most cases the trend direction was not reversed from increasing to decreasing or decreasing to increasing but rather it changed from a significant trend to a non-significant trend or non-significant trend to a significant trend.

Comparison of the non-metal parameters' trend results between this analysis (to the end of 2018) with the first trend assessment (to the end of 2008) found a greater number of changes in trend direction. However, similar to the comparison between 2013 and 2018, a large portion of the changes in direction did not reflect a reversal in trend direction (from significantly increasing to significantly decreasing or visa versa) but rather a change from either a statistically significant trend to no trend (or vice versa).

The identification of the causes of the identified trends is beyond the scope identified for this analysis. Review of trend results and identification of parameters of greatest priority will be undertaken followed by more detailed assessment to understand cause.

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Trends in Water Quality Parameters at Twelve Transboundary River Reaches

1. Introduction

Long-term water quality monitoring has been conducted on 11 major transboundary rivers crossing the Alberta/Saskatchewan or Saskatchewan/Manitoba boundary for around fifty years, although on some rivers sampling began in the late 1960's. A twelfth transboundary river, Cold River, on the Alberta/Saskatchewan boundary was added to the long-term monitoring network in 1994. Environment and Climate Change Canada (ECCC) undertakes the water quality monitoring on these 12 transboundary prairie rivers to fulfill the monitoring requirements under the Master Agreement on Apportionment (MAA). The MAA is a multi-jurisdictional agreement, signed in 1969, by the governments of Alberta, Saskatchewan, Manitoba and Canada. The agreement provides for equitable sharing of surface water in eastward flowing rivers across interprovincial boundaries. The Prairie Provinces Water Board (PPWB) is accountable for the administration of the agreement and reporting of results and findings to governments.

Schedule E to the MAA defines the water quality mandate of the PPWB, which is *"to foster and facilitate interprovincial water quality management among the parties that encourages the protection and restoration of the aquatic environment*". As part of Schedule E water quality objectives have been established at the 12 transboundary river reaches to protect various water uses. The 12 transboundary river reaches that are monitored annually and that have established water quality objectives include six rivers on the Alberta/Saskatchewan boundary (Battle River, Beaver River, Cold River, North Saskatchewan River, Red Deer River and the South Saskatchewan River) (Figure 1) and six transboundary rivers on the Saskatchewan/Manitoba boundary (Assiniboine River, Carrot River, Churchill River, Red Deer River, Qu'Appelle River and the Saskatchewan River) (Figure 2).

Where water quality objectives are not met the parties have agreed to take all reasonable and practical measures to meet the objectives where excursions of those objectives are a result of human activities. All parties also recognized in Schedule E that changes in water quality should be assessed, and that long-term trend analysis is an important component of the PPWB water quality program. Schedule E states that "*where the water quality is better than the agreed upon water quality objectives, and if trend analysis indicates that water quality has been or may be significantly altered, the parties shall agree as to the reasonable and practical measures that will be taken to maintain the water quality in the river reaches*".

The identification of causes for change in water quality can be difficult due to natural variations in water quality, anthropogenic influences, or some combination of these two factors. To better understand potential patterns of change in water quality the PPWB conducts long-term monotonic trend analysis to determine if specific water quality variables are statistically increasing, decreasing, or remaining the same over time. Identifying long-term increasing trends or deteriorating water quality will assist the Board in its interprovincial water quality management responsibilities and in its assessment of potential areas of concern before water quality objectives are exceeded or the downstream jurisdictions are negatively affected.

1.1 Objectives and Scope of this Report

This report represents the third in a series to provide an analysis of the long-term water quality data that has been collected from the PPWB interprovincial transboundary sites using the Seasonal Mann-Kendall/Mann Kendal non-parametric method. Monitoring data for these transboundary sites can include up to 50 years of data depending on the parameter and the site. The first report completed the trend analysis from the earliest available sample dates up to and including the end of 2008, the second report was up to the end of 2013 (PPWB 2018). This report extends the period of record by an additional five years and includes data from the beginning of the data record until the end of 2018. Similar to the earlier reports, the purpose of this report was to identify long-term trends in water quality at the boundary sites. However, the intention of this report is not to investigate the potential causes of any identified trends. This trend analysis work was undertaken to provide a basis for future evaluations, investigation, and work prioritization at these sites and to assess changes in water quality over the long-term. The report describes the trend assessment method used by the PPWB, the parameters assessed, and the results of the trend assessment for the 12 transboundary river reaches. Trends were assessed for a variety of parameters including nutrients, major ions, general water chemistry and metals (total and dissolved).

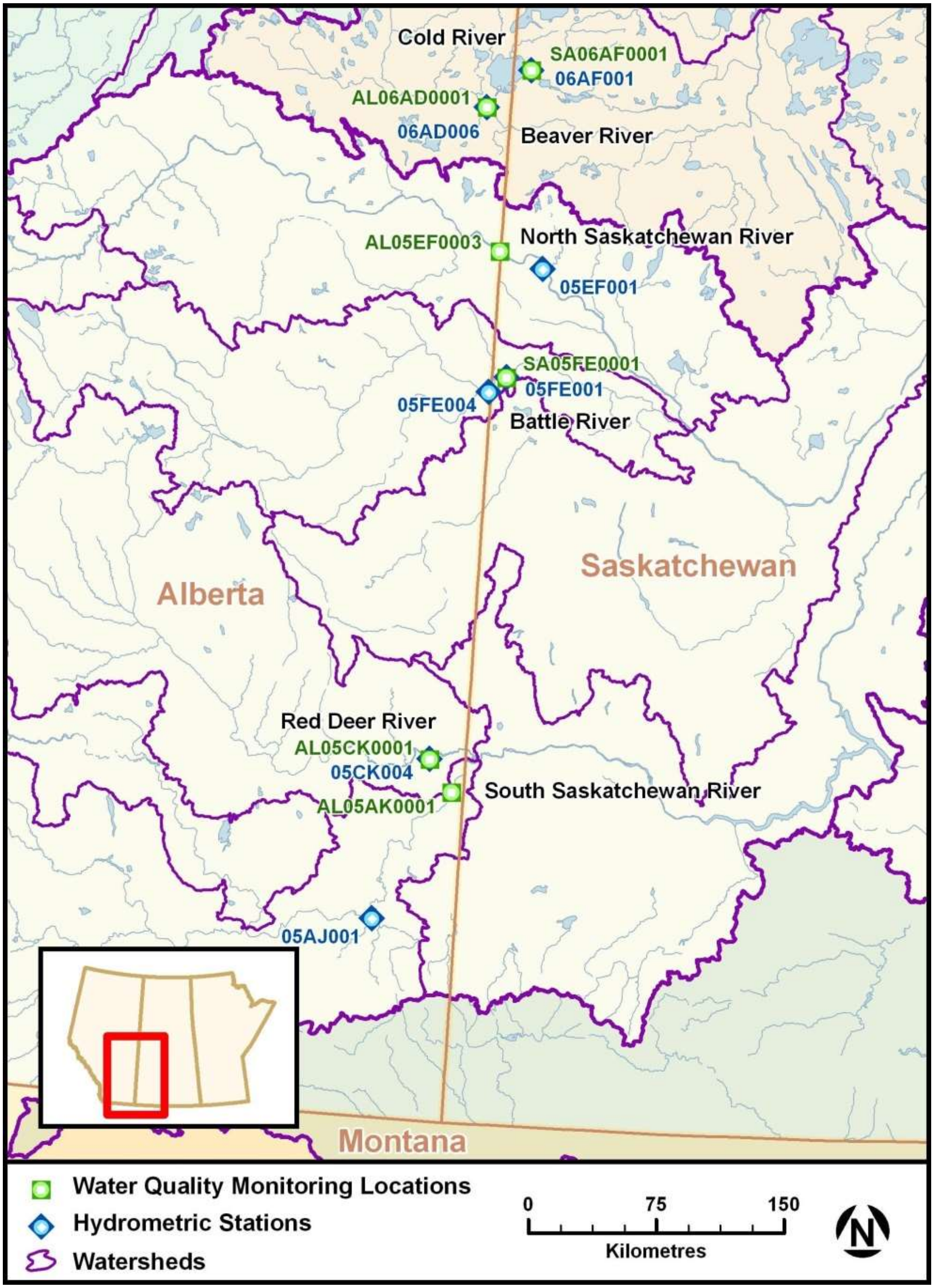

Figure 1 **PPWB Water Quality Monitoring Locations on the Alberta/Saskatchewan Boundary**

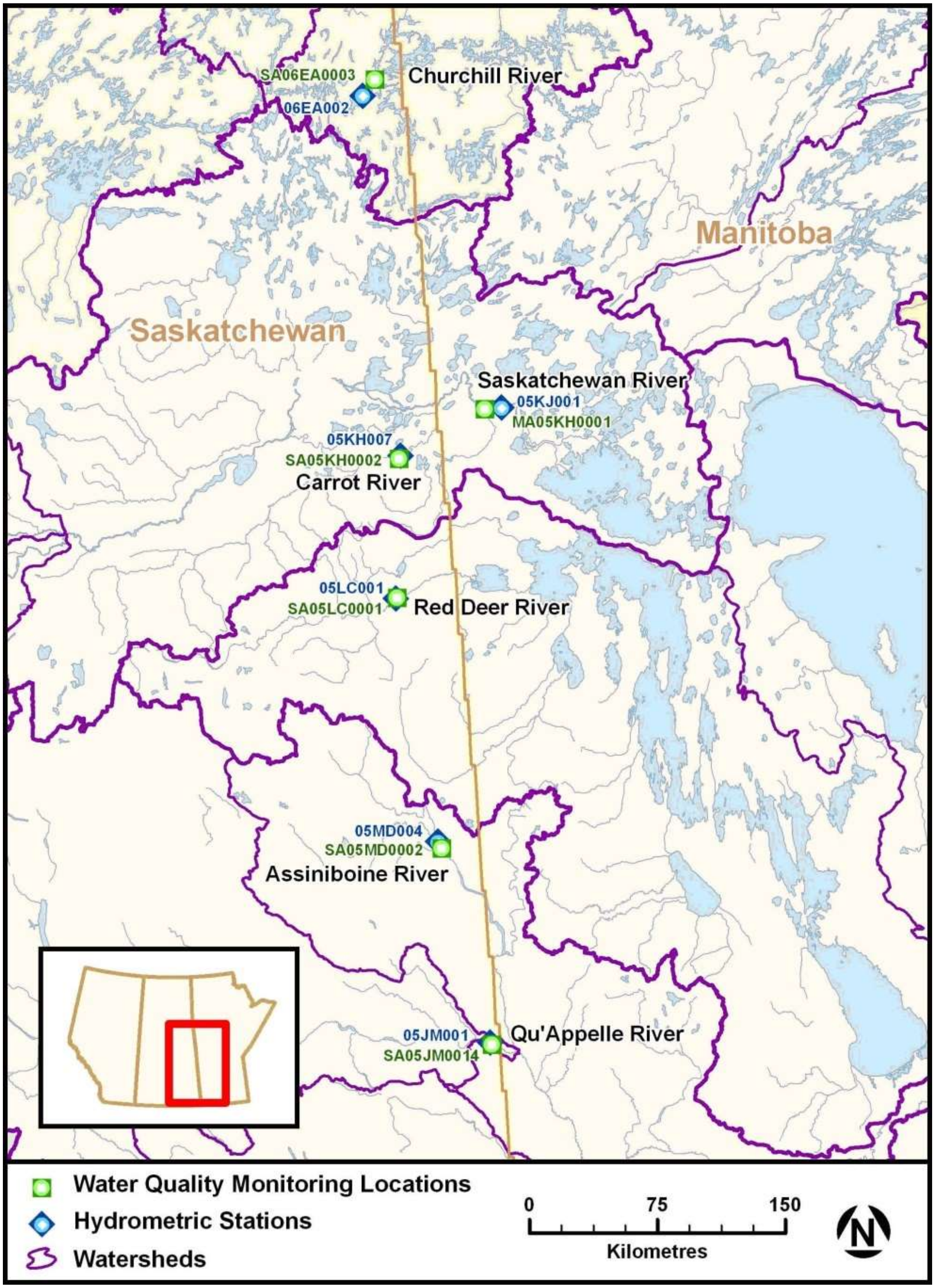

Figure 2 PPWB Water Quality Monitoring Locations on the Saskatchewan/Manitoba Boundary

2. Monitoring Stations

As part of the administration of the MAA, long-term water quantity and quality monitoring has been conducted on major transboundary rivers flowing eastward across the Canadian prairies, crossing the Alberta/Saskatchewan and/or Saskatchewan/Manitoba boundaries. Environment and Climate Change Canada monitors water quantity and quality for the transboundary river including a network of hydrometric stations and 12 water quality monitoring stations (Table 1).

For long-term trend analysis, water quality sampling should be conducted at the same location, using comparable sample collection techniques and samples analyzed in a consistent manner for the time period being assessed. With the exception of the Cold River and the North Saskatchewan River, water quality has been monitored at the same transboundary river locations since the late 1960s to early 1970s. Monitoring on the Cold River was initiated in 1993 at the outlet from Cold Lake. The monitoring station on the North Saskatchewan River has been moved three times over the period of record. The current monitoring location for the North Saskatchewan River was established in 1988. Apart from the North Saskatchewan River, trend assessments at each transboundary site included data from the beginning of the period of record until the end of 2018. For the North Saskatchewan River, trends were assessed from 1988 to the end of 2018.

The frequency of water quality monitoring, at the transboundary river sites, has varied since the start of the program but in general has been conducted monthly. However, for parts of the period of record, the Cold River and the Churchill River were monitored quarterly, and the Red Deer River at Erwood (Saskatchewan/Manitoba boundary) was monitored six times per year. Currently, all transboundary rivers are monitored monthly, with the exception of, the Churchill River which has retained a quarterly monitoring regime. Water quality parameters incorporated in the long-term monitoring program and included in the trend assessment were nutrients, major ions, metals, and general water chemistry parameters such as dissolved oxygen, pH, total suspended solids (TSS) and sodium adsorption ratio (SAR).

Table 1 PPWB Water Quality Monitoring

Station Name	Water Quality Station Number	Year Water Quality Monitoring Started	Hydrometric Station Number
Alberta/Saskatchewan border			
Battle River near Unwin, Saskatchewan	SA05FE0001	1966	05FE004
Beaver River at Beaver Crossing	AL06AD0001	1966	06AD006
Cold River at Outlet of Cold Lake	SA06AF0001	1993	06AF001
North Saskatchewan River at Highway #17 Bridge	AL05EF0003	1988	05EF001
Red Deer River near Bindloss, Alberta	AL05CK0001	1967	05CK004
South Saskatchewan River at Hwy 41	AL05AK0001	1970	05AJ001*
Saskatchewan/Manitoba border			
Assiniboine River at Hwy 8 Bridge	SA05MD0002	1968	05MD004
Carrot River near Turnberry	SA05KH0002	1974	05KH007
Churchill River Below Wasawakasik	SA06EA0003	1974	06EA002
Qu'Appelle River	SA05JM0014	1975	05JM001
Red Deer River at Erwood	SA05LC0001	1967	05LC001
Saskatchewan River Above Carrot River	MA05KH0001	1974	05KJ001**

*Estimated flow at the South Saskatchewan River is based on recorded flow at Medicine Hat (05AJ001), plus the recorded flow at Seven Person Creek (05AH005) and Ross Creek (05A H052) with a two-day lag.
** Estimated flow at the Saskatchewan River is Saskatchewan River at the Pas (05KJ001) minus the Carrot River near Turnberry (05KH007).

3. Methods

Long-term monotonic trend analysis was used to determine statistically significant changes in water quality over time (*i.e.* increasing, decreasing or no change). Several factors can influence the detection of trends including seasonality, serial correlation (or auto correlation), missing data, outliers and censored data. Depending on the statistical technique used for trend assessment assumptions about the data set must be considered, including data distribution and independence. Except where noted, all statistical analyses were conducted with WQStat Plus v.9 © 2009 (Sanitas Technologies 2009).

3.1 Trend Analysis

Trend assessment was performed using the non-parametric Mann-Kendall/Seasonal Mann Kendall method (Hirsch *et al.*, 1982). A non-parametric method was selected because most water quality data do not follow standard normal distribution curves whereas an assumption of parametric trend methods is that the data have a normal distribution. In addition, non-parametric methods tend to be more robust to missing data, outliers and censored data. In addition, the Mann Kendall/Seasonal Mann Kendall non-parametric method is used by several jurisdictions involved in the PPWB. It was also established as part of the background evaluations undertaken when selecting a method for the PPWB before undertaking its first trending analysis that results from parametric methods used elsewhere (WQTrend: Vecchia 2003) compared well with the Mann Kendall/Seasonal Mann-Kendall method. The comparison criteria included similarity of slope direction/magnitude and determination of statistical significance when comparing these two methods using the same time series data from a PPWB station.

Prior to running the trend assessments, water quality data were reviewed for censored data, missing data, outliers, anomalies in the individual data points and seasonality. Erroneous data or anomalies were typically related to database, laboratory or field analysis issues and were removed prior to trend analysis.

3.1.1 Seasonality

Water quality parameters frequently exhibit seasonal patterns. Changes in water chemistry often follow changes in hydrologic patterns, temperature, and biological activity. For the trend assessments in this report two seasons were used for each transboundary river. Seasons were defined to be five to seven months long depending on the river. The period length of the two seasons was determined visually through a consensus exercise by the Committee while reviewing the entire PPWB data set. Approximately 35 years of water quality monitoring data were summarized graphically to show the annual distribution of the water quality parameter of interest. The Committee ultimately decided on using two seasons. In selecting the seasons, the Committee also considered major ecological periods such as: ice-cover *versus* open-water; more stable *versus* highly variable flows, and low/stable water temperatures in fall/winter *versus* higher and more variable temperatures and biological growth during the open-water period. Where possible, the two seasons were defined for the transboundary river rather than for individual parameters; however, there were some exceptions. Where possible, seasons were also selected to be consistent with those selected previously by jurisdictions based on their review of these data sets.

The Committee selected season for the Alberta/Saskatchewan boundary rivers as being April to October for the open-water season and November to March for the ice-covered season for all parameters. For the Saskatchewan/Manitoba boundary, the open-water season began in either April or May depending on the transboundary river and/or water quality parameter (Table 2) (PPWB, 2015).

Table 2 Seasons for Water Quality Parameters at the Saskatchewan/Manitoba border sites

Station Name	Parameter	Season	
		Summer	Winter
Churchill River below Wasawakasik	TP, TDP, TN, TDS, TSS, metals and major ions	May to Oct	Nov to Apr
Saskatchewan River above Carrot River	TP, TDP, TN, TDS, TSS, metals and major ions	Apr to Oct	Nov to Mar
Carrot River near Turnberry	TP, TDP, TN, TDS, major ions	May to Oct	Nov to Apr
	TSS, metals	Apr to Oct	Nov to Mar
Red Deer River at Erwood	TP, TDP, TN, TDS, TSS, metals and major ions	May to Oct	Nov to Apr
Assiniboine River at Hwy 8 Bridge	TP, TDP, TN, TDS, TSS, metals and major ions	Apr to Oct	Nov to Mar
Qu'Appelle River	TP, TDP, TN, TDS, major ions	May to Oct	Nov to Apr
	TSS, metals	Apr to Oct	Nov to Mar

The significance of seasonality was tested with the non-parametric Kruskal-Wallis test for each parameter at each site. Data were considered seasonal if the Kruskal-Wallis test was significant at a 95% significant level ($\alpha \leq 0.05$). If the dataset for a specific parameter at a specific location showed seasonality, then the Seasonal Mann-Kendall was used for the trend analysis. If the dataset did not have significant seasonality, then the Mann-Kendall/Sen Slope Estimator test was used for the trend assessment. The seasonal Mann-Kendall adjusts for seasonal differences, in this case the two defined seasons, whereas the Mann Kendall/Sen slope estimator does not consider season.

3.1.2. Time period

Trend assessments were completed for nutrients, major ions, general water chemistry and metals. Trend analysis included all the PPWB monitoring data from the initiation of sampling until the end of 2018. Seasons used for trend analysis were those previously defined in Section 3.1.1 (Table 2). Annual regular consecutive monitoring for at least 10 years was the minimum period length requirement for conducting trend analysis.

3.1.3. Censored data

For parameters with observations less than the analytical detection limit (censored data) the less-than value was replaced with a constant value. The approach used for censored data was to substitute the less than value with half the detection limit value (Gilbert 1987). These constant values were then used in all statistical analysis. While different approaches to generating censored data exist (Helsel 2005), the approach in this application is valid because the Mann-Kendall/Seasonal Mann-Kendall uses relative magnitude of adjacent data rather than the actual value. The method is based on ranks *versus* actual values. However, since changes in the detection limit do influence the trend assessment, a parameter was only considered for trend analysis if the censored data made up less than 20% of the data results for the entire period. This criterion mainly affected the number of metals that could be analyzed. There have been numerous analytical method changes for metals over the period of record. As the methods have changed, detection limits have improved and in more recent years there are significantly fewer censored data.

3.1.4 Step in Data

Changes in analytical methods can result in substantial changes in method detection limits (MDLs) and/or result in steps in the dataset. This was true for a number of the metals where there have been a number of method changes over the period of record of the PPWB.
In 2003 the laboratory changed the detector to sector field mass spectrometry (ICP-SFMS) resulting in substantial improvements in the resolution of the method and improved detection limits. In the first trend report in this series analyzing trends to the end of 2008 only some metals data collected prior to 2003 was included in the analysis with the criterion for inclusion being whether there was a statistically significant step in the data (PPWB 2016). However, to eliminate the complications of changing analytical methods and periods of record for different metals given the increased timeframe only metals data from 2003 to 2018 were included in the trend analysis. This is same approach taken in the previous trend analysis report that included data to 2013 (PPWB 2018).

In addition to metals, for total nitrogen (TN), a change in the laboratory analytical method in October 1993 resulted in a step in the concentration of these data between the pre and post method change (Glozier *et al*, 2004). The pre and post 1993 data are not directly comparable. Therefore, in this report only data post 1993 were included in the trend analysis.

3.1.5. Serial Correlation (autocorrelation)

One key assumption of the Mann-Kendall/Season Mann-Kendall is that the data are independent (Mann, 1945; Kendall 1975; Hirsch *et al*. 1982; Hirsch and Slack 1984). Most water quality data that are collected monthly are not independent. The closer water samples are collected in time the greater the typical amount of the serial correlation. The presence of serial correlation can increase the chance of a type I error. A type 1 error occurs when the null hypothesis is rejected, and a trend is reported when there is none. While there are techniques that can be used to correct for serial correlation, thereby reducing type I errors, this can lead to an increase in type II errors. Type II errors occur when it is incorrectly concluded that there is no significant trend when there is a trend. In this trend assessment work, water quality data were not corrected for serial correlation.

3.1.6 Flow-adjusted

Water chemistry can be affected by river discharge, with the result that a constituent could be higher or lower under different flow conditions. For example, some constituents may increase with river discharge resulting from a greater influx of surface runoff, while other constituents may decrease because of dilution. Point sources and groundwater influences are often diluted with increased river discharges while other parameters influenced by instream energy (such as suspended solids) or overland inputs may be higher under higher flow conditions.

Flow adjustment techniques are often used in trend assessments to remove its influence on the concentration of a parameter. In this study, prior to completing the trend assessments, the concentration of variables were adjusted for flow. All data were flow-adjusted with a regression equation based on the flow *versus* concentration relationship:

Log [Concentration] = Log [flow] b+a
Where:
Concentration = lab-reported concentration of parameter
Flow = Flow of the river
b = slope
a = intercept

It should be noted that in some cases, particularly for dissolved oxygen, the regression log-log adjustment flow method, does not always fit well with some of the more extreme parameters in the dataset. This means the adjusted values can appear high. However, because the trend method is a non-parametric analysis and is a ranking method these higher values do not affect the overall assessment of significance.

3.2 Descriptive Statistics

Descriptive statistics including mean, standard deviation, median, minimum, maximum, number of samples and the 90^{th} and 10^{th} percentile were produced using Sigma Plot v. 11.2 © 2008 Systat Software Inc. The median, 90^{th} and 10^{th} percentiles were calculated using the Cleveland method.

3.3 Trend Significance

The goal for undertaking trend analyses was to assess whether there were significant trends among different parameters at different sites. The null hypothesis was therefore that there would be no trends with the alternate hypothesis being that there were trends for some parameters at some sites (increasing or decreasing trends). The significant trend results summarized in this report are based on an alpha ≤ 0.05. The results provide a means to prioritize further assessment based on the level of significance and the magnitude of the slope.

4. Results and Discussion

Descriptive statistics for each water quality parameter are included in Appendix A. Time series, seasonality and flow-weighted trending graphs for the various parameters analyzed are presented in Appendices B to E. Trend summaries including slopes of the trend are presented in Appendix F, magnitude of the change (%) are shown in Appendix G and trending direction and comparison to previous trend reports are shown in Appendix H.

4.1 Nutrients

Nutrients are an important part of the aquatic ecosystem; however, increases in nutrient concentrations can lead to eutrophication of river systems and their receiving waterbodies, causing water quality to deteriorate. Prairie river systems and lakes are known to be naturally high in nutrients. However, human activities can increase nutrients within river systems through increased non-point inputs from agriculture, forestry or other land disturbance activities and point source nutrients inputs from wastewater and industrial effluent discharges (Rock and Mayer 2006; Leavitt *et al.* 2006; Carlson *et al.* 2013; Yates *et al.* 2013).

Two nutrients, nitrogen and phosphorus were included in the long-term trend assessment at the 12 transboundary river monitoring locations. Five nutrient forms were assessed: total ammonia-nitrogen (NH_4+NH_3-N, hereafter NH_3-N), nitrate-nitrite nitrogen (NO_3+NO_2-N, hereafter NO_3) total nitrogen (TN), total phosphorus (TP) and total dissolved phosphorus (TDP). In 2015, the PPWB established water quality objectives for all five of these nutrients. Two of the objectives (NH_3-N and NO3) are toxicological-based objectives for the protection of aquatic life and the remaining nutrients (TP, TDP and TN) were set as site-specific objectives with the aim of maintaining and managing water quality within these prairie inter-jurisdictional rivers.

Alberta/Saskatchewan Boundary

A total of 30 flow-weighted trend assessments were conducted for the five nutrients forms on the six Alberta/Saskatchewan transboundary rivers. Of these flow-weighted trends, 40% showed statistically significant decreasing trends, while 23% showed increasing trends, with 37% showing no statistical trend (Table 3). The North Saskatchewan, South Saskatchewan, and the Red Deer are three of the larger river systems that originate on the eastern slopes of the Rocky Mountains and flow eastward through Alberta into Saskatchewan. For these three river systems, the North Saskatchewan (Figure 3) and South Saskatchewan rivers had decreasing trends in TP and TDP, while the Red Deer River had a decreasing trend in TDP and no significant change in TP concentration over time. The North Saskatchewan River also had decreasing trends in NH_3-N, NO3 and TN (Figure 4), suggesting an overall improvement in nutrient water quality for this river since the late 1980's. This improvement in nitrogen water quality has previously been observed and is attributed to improvements to the Gold Bar and Capital region wastewater treatment plants in Edmonton (Anderson 2012; Gongchen Li, personnel Comm.).

The Beaver River also showed decreasing trends in TP and TDP, as well as statistically significant decreasing trend in NO3. The Battle River, also part of the Saskatchewan River system had a significant decreasing trend in NO3-N, but this was the only nutrient form that had a decreasing trend on this river. The Battle and Beaver rivers, which tend to be lower flow rivers, also showed no change over the period of record for TN.

Despite improvements in nutrients for several of the Alberta/Saskatchewan transboundary rivers, not all the flow-weighted trend results had decreasing slopes and seven increasing trends in nutrients were identified on five of the Alberta/Saskatchewan transboundary rivers (Table 3). Total phosphorus and TDP were shown to have an increasing trend on the Battle River. This was the only river to have an increasing trend in phosphorus on this boundary. However, four rivers on this boundary had increasing trends in NH_3-N and NO3-N. This included an increasing trend for NO3-N on the Cold and South Saskatchewan rivers, NH_3-N on the Beaver and the Red Deer River. The Red Deer River also had an increasing trend in TN and was the only river on this boundary to have an increase in TN.

Table 3 Flow-weighted Trend Summary for Nutrients - Alberta/Saskatchewan Boundary

Parameter	Battle	Beaver	Cold	North Saskatchewan	Red Deer (AB)	South Saskatchewan
Nutrients						
Ammonia Nitrogen Total	↔	↑	↔	↓	↑	↔
Nitrate-nitrate as N	↓	↓	↑	↓	↔	↑
Nitrogen Total	↔	↔	↔	↓	↑	↔
Phosphorus Total	↑	↓	↔	↓	↔	↓
Phosphorus Total Dissolved	↑	↓	↔	↓	↓	↓

(yellow shading) No Seasonality in Data, Trend Analysis Completed with Sen Slope Estimator

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

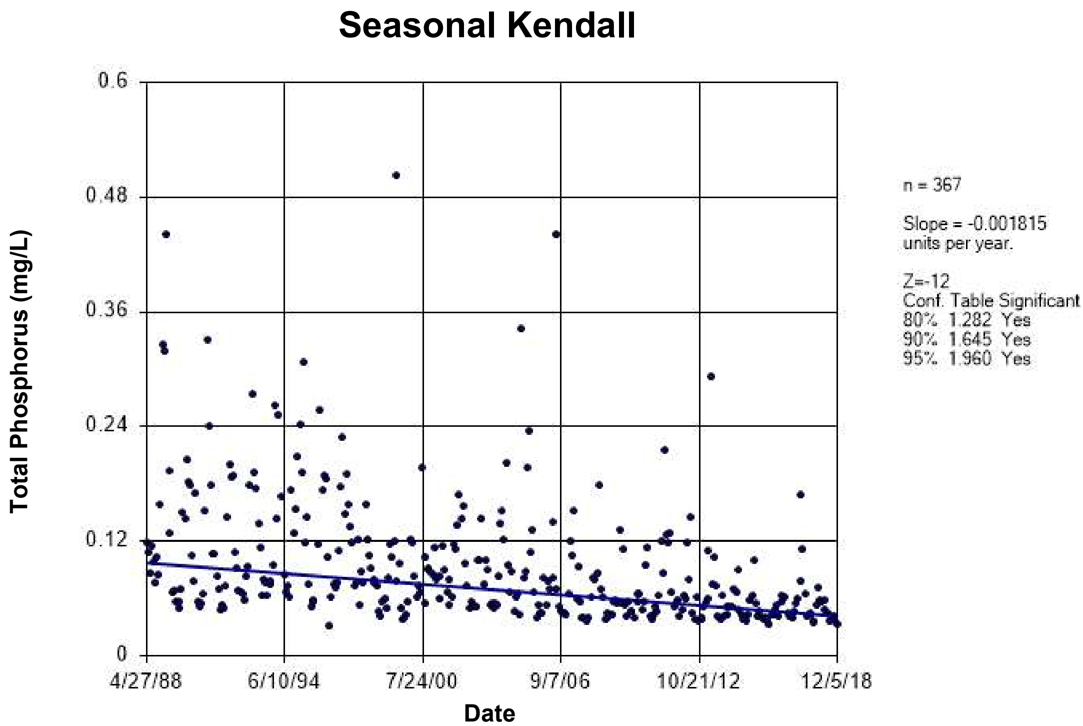

Figure 3 **Trend in Total Phosphorus Concentration for the North Saskatchewan River (1988 to 2018).**

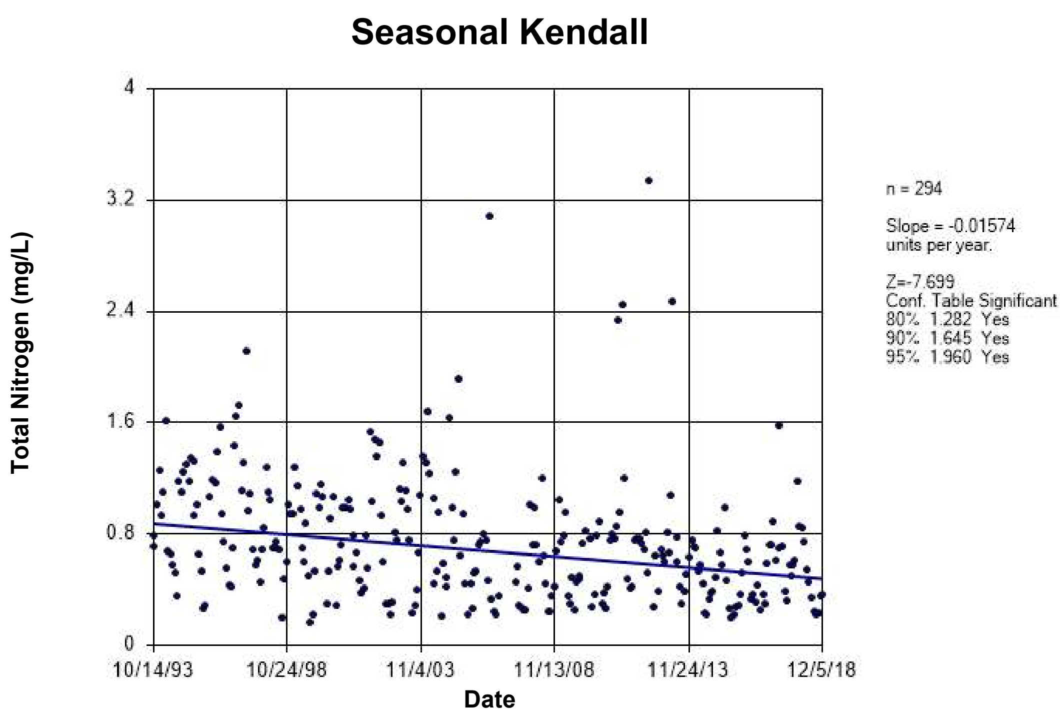

Figure 4 **Trend in Total Nitrogen Concentration for the North Saskatchewan River (1993 to 2018).**

Saskatchewan/Manitoba Boundary

On the Saskatchewan Manitoba boundary, long-term trend assessment for the five nutrient fractions showed overall, there was statistically significant increasing trends in 43% (13/30) of the trend assessments. Of the 30 trend assessments, 40% (12/30) showed no statistically significant flow-weighted monotonic trend over the period of record, while five of the 30-assessments showed decreasing trends. Three of these decreasing trends were attributed to the Saskatchewan River, with decreasing trends in TP, TDP and NO3-N-N. Total nitrogen and NH_3-N showed no statistically significant monotonic trend on the Saskatchewan River (Table 4).

Of note on this boundary was the Carrot and Red Deer rivers, which showed statistically significant increasing (positive) trends in the majority of the trend assessments for nutrients. The Carrot River had increasing trends in TP (Figure 5), TDP, TN (Figure 6) and NH_3-N, while the Red Deer River has increasing trends in all nutrient forms. These were the only two rivers on the Saskatchewan-Manitoba boundary to have increasing trends in phosphorus.

The Carrot River headwaters are near Wakaw Lake, Saskatchewan and the river flows northeast entering the Saskatchewan River near The Pas, Manitoba. The upper watershed is dominated with agricultural activities with forests and wetlands making up most of the downstream/eastern portion of the watershed. Similarly, for the Red Deer River, this is also a small watershed in eastern Saskatchewan with the western portion of the basin being dominated by agricultural lands, while the eastern portion is largely forested. Although this report did not look at the causes for the increases in nutrient concentrations and further investigation is warranted. A study completed for the PPWB on the Carrot River watershed concluded that most of the nutrient loads were attributed to non-point sources, with point sources being negligible (Golder Associates 2017). The report also concluded that land covered in agricultural crops (grain/seed crops) and forested areas (tree/forests) where the main sources of the TN and TP loads. A further study is currently on-going looking at the potential impacts of the hydrology for the Carrot River watershed on the nutrient loading at the transboundary site at Turnberry.

In addition to the Carrot and Red Deer rivers on this boundary, the Assiniboine and Qu'Appelle rivers also showed statistically significant increasing trends in TN and NH_3-N. Total nitrogen and NH_3-N showed statistically significant increasing trends in four of the six rivers on the Saskatchewan/Manitoba boundary, making the nitrogen the most increasing nutrient on this boundary. However, the Churchill River and the Saskatchewan rivers did have decreasing trends in NO3-N, but no statistically significant trend over time in TN, and NH_3-N.

Table 4 Flow-weighted Trend Summary for Nutrients - Saskatchewan/Manitoba Boundary

Parameter	Assiniboine	Carrot	Churchill	Qu'Appelle	Red Deer (MB)	Saskatchewan
Nutrients						
Ammonia Nitrogen Total	↑	↑	↔	↑	↑	↔
Nitrate-Nitrate as N	↔	↔	↓	↔	↑	↓
Nitrogen Total	↑	↑	↔	↑	↑	↔
Phosphorus Total	↔	↑	↔	↔	↑	↓
Phosphorus Total Dissolved	↓	↑	↔	↔	↑	↓

(Yellow) No Seasonality in Data, Trend Analysis Completed with Sen Slope Estimator

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

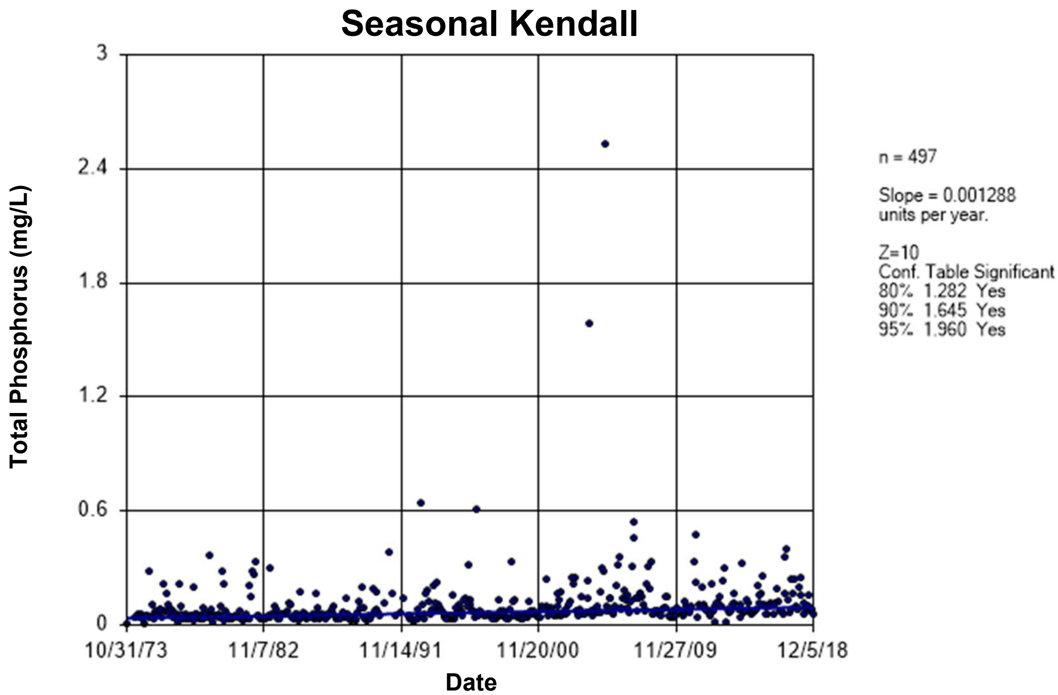

Figure 5 **Trend in Total Phosphorus Concentration for the Carrot River (1973 to 2018)**

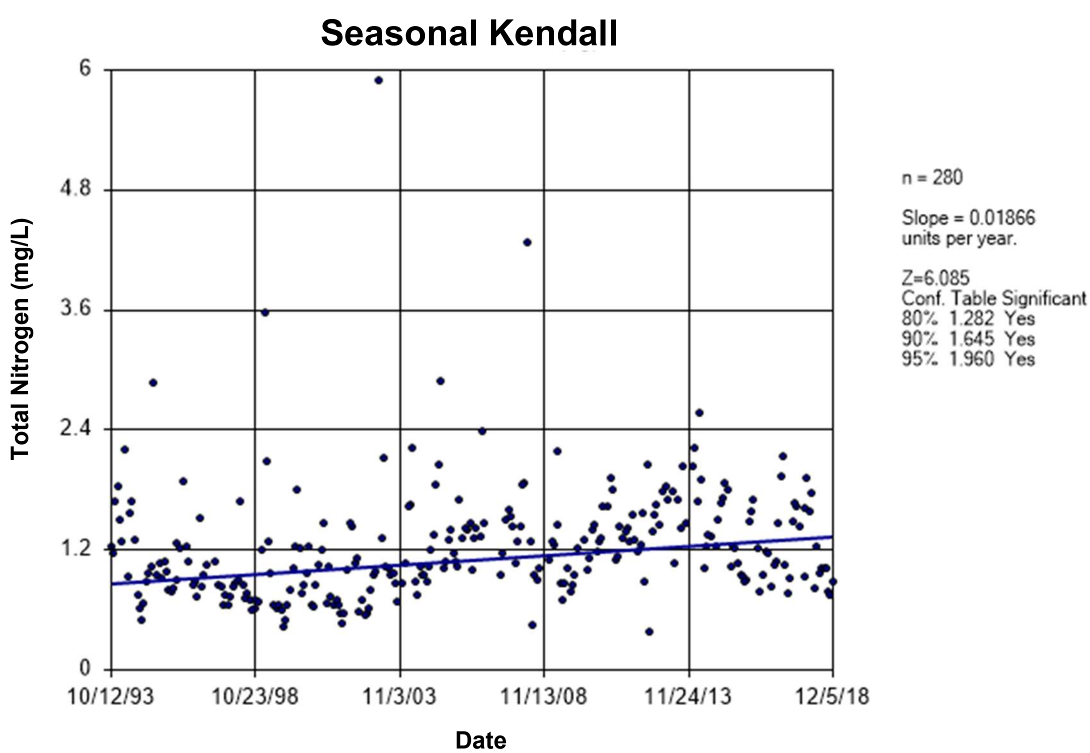

Figure 6 **Trend in Total Nitrogen Concentration for the Carrot River (1993 to 2018)**

4.2 Major Ions

Major ions are present in all natural waters and concentrations and composition of major ions are determined by the type of rock and soil that water comes into contact with throughout the watershed. Major ions are divided into cations (calcium, magnesium, sodium and potassium) and anions (bicarbonate, carbonate, sulphate, chloride, fluoride) and collectively contribute to water's salinity. For inland waters salinity is frequently measured as the concentration of total dissolved solids (TDS). The concentration of major ions in surface water can be affected by anthropogenic activities including wastewater discharges and land use activities. Major ions can also be affected by other factors, including changes in effective drainage area and groundwater inputs. Sodium and chloride are often associated with road salt and municipal waste discharges (Environment Canada 2001; Turnbull and Ryan 2012; Corsi *et al*., 2015). Fluoride occurs naturally in surface waters, but anthropogenic sources can include wastewater discharges from municipalities using fluorinated drinking water, and several industries that use fluoride including those that use or produce herbicides, insecticides, phosphate fertilizers, and involve aluminum smelting and chemical manufacturing.

Sulphate occurs naturally and is present in minerals and rocks including various salt forms of barite, epsomite and gypsum. Sodium, potassium, and magnesium sulphates are all soluble, whereas barium and calcium sulphates are not as soluble in water. Anthropogenic sources of sulphate can include industrial waste discharges and atmospheric deposition from the combustion of fossil fuels, as well as from fertilizers (Health Canada 2010). Sulphate salts are naturally common and abundant throughout the prairies and hence sulphate is found in surface and groundwater sources (Nachshon *et al*. 2013; Heagle *et al*. 2013).

Four major ions were included in the long-term trend assessment for the 12 transboundary prairie rivers: chloride, fluoride, sodium, sulphate. Additionally, TDS was included to assess the overall change in salinity. The PPWB has established water quality objectives for these five parameters, which protect a range of water uses including the protection of aquatic life, agricultural uses, and water treatability for drinking water.

Alberta/Saskatchewan Boundary

Of the 30 flow-weighted monotonic trend assessments that were run for four major ions and TDS on the Alberta/Saskatchewan boundary, 15/30 (50%) had statistically significant increasing trends (Table 5). For three of the rivers contributing to the Saskatchewan River system: South Saskatchewan, Red Deer and Battle rivers, all had statistically significant increasing trends in all the major ions (chloride, sulphate and sodium) and TDS, with the exception of fluoride. For the North Saskatchewan River, the fourth major river that contributes to the Saskatchewan River system, the major ions chloride, sulphate and TDS had statistically significant increasing trends, while there was no statistically significant trend for sodium. Fluoride had either no statistically significant trend (Battle and South Saskatchewan rivers) or a decreasing trend (Beaver, Cold, North Saskatchewan and Red Deer rivers).

Of the four transboundary rivers that make up the Saskatchewan River system the Battle River, which is a smaller tributary and unlike the others that arise in the mountains, had overall higher TDS values with a range of 218 to 1729 mg/L and a median of 629 mg/L. For the three larger rivers with headwaters in the mountains the North Saskatchewan and South Saskatchewan rivers had a similar TDS concentration, while the TDS of the Red Deer River was higher. The North Saskatchewan River had a TDS concentration ranging from 68 to 400 mg/L with a median of 207 mg/L. The South Saskatchewan River had a TDS concentration ranging from 98 to 400 mg/L with a median of 235 mg/L. While the Red Deer River had a TDS concentration ranging from 148 to 603 mg/L with a median of 291 mg/L. At these concentrations ranges TDS is unlikely to restrict the use of the water in these rivers; however, the potential cause of the significant changes in TDS should be further investigated.

Two key constituents of TDS, sulphate and chloride had increasing trends in the four rivers that comprise the Saskatchewan River system (Figure 7). Chloride had a median concentration ranging from 3.98 mg/L in the North Saskatchewan River to 22.8 mg/L in the Battle River. For these four rivers, the maximum concentration was reported in the Battle River with a concentration of 175 mg/L. Chloride is a conservative solute that remains unaffected by biological river processes and is often used as a tracer for groundwater inputs, or for tracking treated wastewater. Sulphate had a median concentration ranging from 48.6 mg/L in the North Saskatchewan River to 145.5 mg/L in the Battle River. Of these rivers the highest sulphate concentration reported was for the Battle River at 389 mg/L consistent with the higher TDS values and origin of this river.

Decreasing trends were observed over the period of record for 30% of the major ions and TDS that were assessed on the six rivers, while 17% had no trend over the period of record. The Beaver and the Cold rivers had the majority of the decreasing trends (7 out of 9 statistically significant decreasing trends). This included decreasing trends for fluoride, sodium and sulphate on the Beaver River and decreasing trends for chloride, fluoride, sodium and sulphate for the Cold River. Total dissolved solids showed no statistically significant trend for either of these two rivers. Chloride also had no significant trend on the Beaver River.

Fluoride was the major ion on the Alberta/Saskatchewan boundary that had the most number of decreasing trends with four of the six rivers having statistically significant decreasing trends. The other two rivers on this boundary (Battle and South Saskatchewan rivers) showed no statistical trend in fluoride. None of the six rivers had an increasing trend in fluoride and this was the only major ion not to have at least one increasing trend on this boundary. This was consistent with the trending reported earlier from the beginning of the dataset until 2013 (PPWB 2018).

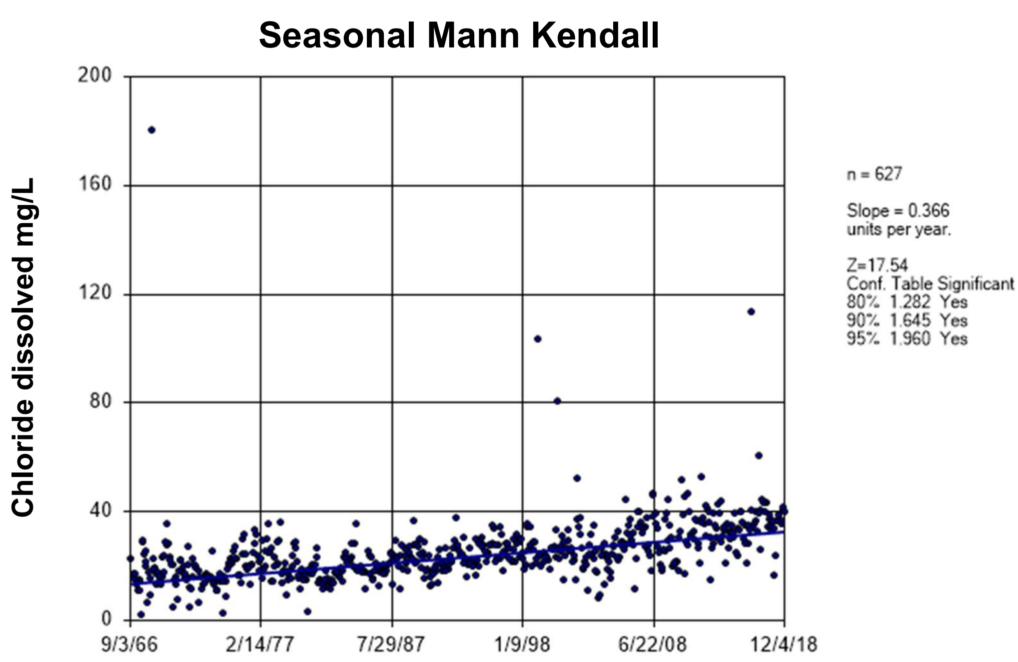

Figure 7 Trend in Chloride (dissolved) for the Battle River (1966 to 2018)

Table 5 Flow -Weighted Trend Summary for Major Ions - Alberta/Saskatchewan Boundary

Parameter	Battle	Beaver	Cold	North Saskatchewan	Red Deer (AB)	South Saskatchewan
Major Ions						
Chloride Dissolved	↑	↔	↓	↑	↑	↑
Fluoride Dissolved	↔	↓	↓	↓	↓	↔
Sodium Dissolved/Filtered	↑	↓	↓	↔	↑	↑
Sulphate Dissolved	↑	↓	↓	↑	↑	↑
Total Dissolved Solids (TDS)	↑	↔	↔	↑	↑	↑

[yellow] No Seasonality in Data, Trend Analysis completed with Sen Slope Estimator

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

Saskatchewan/Manitoba Boundary

Long-term trend assessment comprising of 30 analyses for four major ions and TDS on the Saskatchewan/Manitoba boundary found 57% of the trends increased significantly, 20% decreased and 23% had no significant trend over time (Table 6). Over the period of record, the Red Deer River had increasing trends in all four major ions and TDS. The Assiniboine and Saskatchewan rivers showed increasing trends in all the major ions and TDS with the exception of fluoride.

The Churchill River showed no changes over the period of record for chloride, fluoride, and sulphate, but did have statistically significant trends in sodium and TDS. The Qu'Appelle and Carrot rivers on the Saskatchewan/Manitoba boundary showed statistically significant increasing trends in sulphate. The Qu'Appelle River had decreasing trends for sodium, chloride, and fluoride over the period of record, while TDS was found to have no significant change over time. For the Carrot River, chloride and sodium had statistically significant decreasing trends, while TDS showed no change over time.

Of the major ions, sulphate had the greatest number of statistically significant increasing trends, which occurred at five of the six rivers (83%): the Assiniboine, Carrot, Qu'Appelle, Red Deer and Saskatchewan rivers. Total dissolved solids and sodium were also increasing in four of the six (67%) of the transboundary rivers. Total dissolved solids and sodium had increasing trends on the Assiniboine, Churchill, Red Deer and the Saskatchewan rivers. Median TDS concentrations for these four rivers were 675, 44, 307, and 224 mg/L, respectively. Of these four rivers the Assiniboine River had the highest TDS concentrations with a range from 198 to 1440 mg/L, while the Churchill River had the lowest TDS concentrations with a range of 25 to 187 mg/L. The median sodium concentrations for these four rivers were 44, 3, 15, and 17 mg/L, respectively. Chloride had statistically significant increasing trends in three of the six (50%) transboundary rivers, including Assiniboine, Red Deer, and Saskatchewan rivers, with a median concentration 20, 8, and 5 of mg/L, respectively.

Table 6 Flow-Weighted trending Summary for Major Ions - Saskatchewan/Manitoba Boundary

Parameter	Assiniboine	Carrot	Churchill	Qu'Appelle	Red Deer (MB)	Saskatchewan
Major Ions						
Chloride Dissolved	↑	↓	↔	↓	↑	↑
Fluoride Dissolved	↔	↔	↔	↓	↑	↓
Sodium Dissolved/Filtered	↑	↓	↑	↓	↑	↑
Sulphate Dissolved	↑	↑	↔	↑	↑	↑
Total Dissolved Solids (TDS)	↑	↔	↑	↔	↑	↑

[yellow] No Seasonality in Data, Trend Analysis completed with Sen Slope Estimator

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

4.3 General Water Chemistry

The PPWB has water quality objectives for four general water chemistry parameters: dissolved oxygen, pH, SAR and TSS.

Alberta/Saskatchewan Boundary

Twenty-four monotonic trend assessments were completed on the Alberta/Saskatchewan boundary for these general water quality parameters (Table 7). Overall, this group of parameters appeared to show either no statistical changes in concentration over time (46%) or statistically significant increasing trends over time (38%). Of the 24 trend assessments, completed only four decreasing trends were observed, two for TSS on the Cold and North Saskatchewan rivers and two for SAR on the Beaver and Cold rivers.

Of the general water chemistry parameters, pH had the greatest number of statistically significant increasing trends with four of the six rivers having an increasing trend (the Battle, Beaver, Red Deer and South Saskatchewan rivers). Dissolved oxygen showed an increasing trend on the Cold and North Saskatchewan rivers with the remaining four rivers showing no change over time. Total suspended solids also showed a significant increasing trend for the two smaller, lower flow rivers on this boundary, the Battle and Beaver rivers. The TSS concentration for the Battle River ranged from 0.5 to 1146 mg/L with a median of 13 mg/L. For the Beaver River the TSS ranged from 0.5 to 273 mg/L with a median of 6.8 mg/L. The North Saskatchewan and Cold rivers showed statistically significant decreasing trend over the period of record for TSS. For the Cold River the monitoring site was located at the outlet of Cold Lake and therefore TSS is generally limited because tributary delivery of TSS to Cold Lake will largely be deposited and retained within the lake itself. For the remaining two rivers on this boundary, the South Saskatchewan River and the Red Deer River the TSS showed no statistical trend over time.

Sodium adsorption ratio is a specific water use index used to assess the suitability of water for irrigation. Trends for SAR varied among the transboundary river sites. An increasing trend in SAR was observed for the South Saskatchewan River, consistent with the increasing trend of sodium on this river. Despite these increasing trends the mean sodium and SAR have remained low is this river with a mean concentration of 18.3 mg/L for sodium and a mean SAR below 1 over the trend period. The South Saskatchewan River is used for irrigation in southern Alberta and there is proposed expansion of the irrigation in Saskatchewan. The Beaver and Cold rivers showed a decreasing trend in SAR, consistent with the decreasing trend observed for sodium. No significant trends in SAR were observed for the Battle, North Saskatchewan, and Red Deer rivers, although all three rivers did show significant increasing sodium trends. This could have been because of the magnesium and calcium concentrations that are used to calculate SAR.

Table 7 Flow-Weighted trending Summary for General Water Chemistry Parameters-Alberta/Saskatchewan Boundary

Parameter	Battle	Beaver	Cold	North Saskatchewan	Red Deer	South Saskatchewan
General Water Chemistry						
Oxygen Dissolved	↔	↔	↑	↑	↔	↔
pH – Field	↑	↑	↔	↔	↑	↑
Sodium Adsorption Ratio	↔	↓	↓	↔	↔	↑
Total Suspended Solids	↑	↑	↓	↓	↔	↔

(Highlighted) No Seasonality in Data, Trend Analysis completed with Sen Slope Estimator

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

Saskatchewan/Manitoba Boundary

On the Saskatchewan/Manitoba boundary, of the 24 monotonic trend assessments completed for general water chemistry parameters, eleven (46%) showed statistically significant increasing trends and six (25%) showed statistically significant decreasing trends. Seven (29%) of the trend assessments showed no statistically significant change over the period of record for the six transboundary rivers (Table 8).

Increasing trends in pH were observed in five of the six Saskatchewan/Manitoba rivers (Assiniboine, Churchill, Qu'Appelle, Red Deer and Saskatchewan rivers). No significant change in pH over time was observed on the Carrot River. Three of the six rivers had increasing trends in TSS (Assiniboine, Carrot and Qu'Appelle rivers). The TSS concentration for the Assiniboine River ranged from 0.5 to 375 mg/L with a median of 13; from 0.5 to 1083 mg/L for the Carrot River with a median of 16 mg/L; and ranged from 0.5 to 917 mg/L, with a median of 39 mg/L for the Qu'Appelle River. Three of the six rivers also had increasing trends in SAR including the Assiniboine, Red Deer and Saskatchewan rivers. These increases in SAR corresponded to increases in sodium on these rivers.

Dissolved oxygen showed a decreasing trend in two rivers on the Saskatchewan/Manitoba boundary (Assiniboine and Carrot rivers), and no significant trend in the other four rivers (Churchill, Qu'Appelle, Red Deer and Saskatchewan rivers). For dissolved oxygen, a decreasing trend implies less oxygen within the river systems, although diurnal changes in dissolved oxygen can be large and saturation concentrations depend on temperature, so sampling time (time of day and weather on date) are important considerations for interpreting this analysis.

The Red Deer and Churchill rivers did not show any significant monotonic changes in TSS, while the Saskatchewan River had a decreasing trend in TSS. The Carrot and the Qu'Appelle rivers also showed decreasing trends in SAR, which also corresponded to decreasing trends in sodium for these rivers.

Table 8 Flow-Weighted Trend Summary for General Water Chemistry Parameters - Saskatchewan/Manitoba Boundary

Parameter	Assiniboine	Carrot	Churchill	Qu'Appelle	Red Deer	Saskatchewan
General Water Chemistry						
Oxygen Dissolved	↓	↓	↔	↔	↔	↔
pH – Field	↑	↔	↑	↑	↑	↑
Sodium Adsorption Ratio	↑	↓	↔	↓	↑	↑
Total Suspended Solids	↑	↑	↔	↑	↔	↓

No Seasonality in Data, Trend Analysis completed with Sen Slope Estimator

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

4.4 Metals

Trend assessments were completed over a sixteen-year period from 2003 to the end of 2018. Trends were analyzed separately for the total and dissolved components of the same metal. While metals have been monitored on the transboundary rivers since the inception of the monitoring program numerous analytical method changes over the historical record have made the data difficult to compare and trend using data prior to 2003.

Trace metals can be important given their potential to cause toxic responses in aquatic life and their effect on other water uses such as irrigation, livestock watering and municipal uses. Water quality objectives are established at the transboundary river sites for the protection of water uses including protection of aquatic life, agricultural uses (irrigation and livestock watering) and treatability of the water as a drinking water source. Metals can enter river water through natural processes such as erosion and weathering of soils, minerals, and ores. Anthropogenic sources can include industrial wastewaters, mining, and sewage effluents.

Alberta/Saskatchewan Boundary

For the six Alberta/Saskatchewan transboundary rivers, 240 trend assessments were performed incorporating 21 different metals for the total and dissolved components (Table 9). Over the 16-year period more than half of the metals (61%) exhibited no statistically significant change in concentration. Statistically significant decreasing trends were observed for 25% of the metals trended, while 14% had a statistically significant increasing trend. The number of increasing, decreasing and no statistically significant trends were similar between the dissolved and total metal fractions. However, it was not always the case that for a given metal the dissolved and total metal fractions had trends with the same trend direction.

To metals cadmium (dissolved) and uranium (total) showed statistically significant increasing trends in five of the six-transboundary rivers on the Alberta/Saskatchewan boundary. The Cold River was the river that did not have a statistically increasing trend in either of these two metals. In addition, cadmium (total) and uranium (dissolved) had increasing trends in three of the transboundary rivers. Boron (total) and selenium (total) had increasing trends in two of the six transboundary rivers. Overall, the South Saskatchewan and Beaver rivers had the greatest number of increasing trends in metals (total and dissolved) with eight and seven respectively, while the North Saskatchewan River had the least number of increasing trends with three trends in cadmium (dissolved) and uranium (total and dissolved).

Molybdenum (dissolved) and lead (dissolved) showed statistically significant decreasing trends, in five of the transboundary rivers. Aluminium (dissolved) and arsenic (dissolved) had decreasing trends in three rivers, whereas vanadium (dissolved) had decreasing trends in two of the six transboundary rivers. For the total metals, aluminum and molybdenum had statistically significant decreasing trends in three of the rivers, while arsenic, beryllium, boron, copper, lead, selenium and silver had decreasing trends in two of the transboundary rivers.

The North Saskatchewan River showed the greatest number of statistically significant decreasing trends with 28 out of the 41 (68%) metals trended having significant decreasing trends. The river with the next highest number of decreasing trends was the Cold River at 27%, while the Red Deer River had the least number of statistically significant decreasing trends with 5% of the metals trended.

Saskatchewan/Manitoba Boundary

Two hundred and forty-three trend assessments were completed for the metals on the Saskatchewan/Manitoba transboundary sites. Of the metals that were trended more than half (54%) did not have statistically significant trends (Table 10). Of the trends that were observed, these were evenly divided between statistically significant increasing (24% of all trends) and decreasing trends (22% of all trends). For the rivers on the Saskatchewan/Manitoba boundary, the number of statistically significant trends for the dissolved metals when compared to the total metals was also similar.

Metals showing statistically significant increasing monotonic trends in three or more of the rivers included barium (total and dissolved), cobalt (total and dissolved), uranium (total and dissolved) and zinc (total). Uranium (dissolved) was the only metal to have increasing trends in all six transboundary rivers on the Saskatchewan/Manitoba boundary.

The Qu'Appelle River had the greatest number of increasing trends for metals with 18 of 41 metals trended showing positive trends. The total metals had 11 trends and the dissolved metal component included seven positive trends (barium (total and dissolved), cobalt (total and dissolved), lead (total), manganese (total and dissolved), nickel (total and dissolved), selenium (total and dissolved), silver (total), thallium (total), uranium (total/dissolved), vanadium (total and dissolved) and zinc (total)). The Assiniboine had 17 increasing (positive) trends in metals, with the Carrot and Saskatchewan each having eight statistically significant increasing metal trends. The river on the Saskatchewan/Manitoba boundary with the least number of increasing trends in metals was the Red Deer River, which had a statistically positive trend for uranium total and dissolved. There were no other statistically significant increasing trends on this river.

The metals that had statistically significant decreasing trends in three or more of the rivers on the Saskatchewan/Manitoba boundary included aluminum (total), cadmium (total and dissolved), chromium (total and dissolved) and lead (dissolved). Of these metals, cadmium (dissolved) had a decreasing trend in all six of the transboundary rivers on this boundary, while lead (dissolved) had a decreasing trend in all the rivers except for the Qu'Appelle River. The transboundary river with the most number of decreasing trends was the Red Deer River with 15, followed by the Churchill with 11 statistically significant negative trends. The river with the least number of statistically significant decreasing trends was Carrot River, which had no significant decreasing trends for the total metals. Within the dissolved component decreasing trends were observed for cadmium, chromium, iron, lead, and selenium.

5. Comparison of the Trending results between 2008 and 2018

This report represents the third trending analysis report, with previous trending reports conducted to 2008 (PPWB 2016) and 2013 (PPWB 2018). This current report presents results with an additional five years of water quality monitoring data (data to the end of 2018). As noted previously, the metals in this report were only trended from 2003 to 2018 due to the numerous changes in analytical methodologies over the history of the water quality monitoring program. However, in the first report in this series (up to the end of 2008) a few metals were trended where the analytical methodologies were considered sufficiently compatible for comparison. Consequently, a comparison of the metal results was not undertaken between the two time periods 2008 to 2018; however, a comparison can be made between 2013 and 2018.

A comparison of the trend results from the three-time series ending in 2008, 2013 and 2018 for nutrients, major ions, general water chemistry and metals are summarized in Appendix H. Overall, the direction of the flow-weighted trends (*i.e.,* either increasing or decreasing, or no change) were the same between 2013 and 2018. In most cases where there were differences in the trend results between the two timelines, the trend direction was not reversed (*i.e*., from an increasing trend to a decreasing trend or vice versa) but went from either a directional trend to non-significant trend or from a non-significant trend to either an increasing or decreasing trend. This was likely a result of the magnitude of the slope of the trend and the resultant value being close to the *P*-value.

Alberta/Saskatchewan Boundary

Of the 84 trend assessments completed for the non-metal parameters (nutrients, major ions, and general water chemistry) on the Alberta-Saskatchewan boundary, 27% showed a change in direction of the trend with the addition of five years of monitoring data from 2013 to 2018. This was slightly higher than what was reported between 2008 and 2013 with a 20% change in trend direction. The change in trend direction between the trend results for the data to the end of 2008 and the addition of ten years of data (to the end of 2018) was 36%.

Of the changes in trend direction between 2013 and 2018, 30% of the directional changes were from no statistically significant trend to a statistically significant decreasing trend. While 26% of the changes in the trend direction were from a statistically significant increasing trend to no significant trend. Therefore, this would suggest that over half (56%) of the changes in trend directions between 2013 and 2018 showed an improvement in the trend directions.

Of the changes is trend directions between 2013 and 2018, 26% of the changes were from a statistically significant decreasing trend to no statistically significant trend. Therefore, between 2013 and 2018 over half (52%) of the trends became not statistically significant following the addition of five years of monitoring data.

For the non-metal parameters that were reported to have no statistically significant trends in the data to the end of 2013, the addition of five years of monitoring data showed 9% (2/23) of the trends went from not statistically significant trend to increasing statistically significant trend. In addition, 9% showed a reversal in direction changing from a decreasing to increasing trend. No parameters showed a change in direction from increasing to decreasing.

Table 9 Flow-Weighted Trend Summary for Metals - Alberta/Saskatchewan Boundary (2003-2018)

Parameter	Battle	Beaver	Cold	North Saskatchewan	Red Deer (AB)	South Saskatchewan
Metals						
Aluminum Dissolved	↓	↓	↔	↓	↔	↔
Aluminum Total	↓	↓	↔	↓	↔	↔
Arsenic Dissolved	↔	↔	↓	↓	↔	↓
Arsenic Total	↔	↔	↓	↓	↔	↔
Barium Dissolved	↔	↔	↔	↔	↔	↑
Barium Total	↔	↔	↔	↓	↔	↑
Beryllium Dissolved	↔	↔		↔	↔	↔
Beryllium Total	↓	↔		↓	↔	↔
Boron Dissolved	↔	↑	↔	↔	↔	↓
Boron Total	↔	↑	↓	↔	↑	↓
Cadmium Dissolved	↑	↑	↔	↑	↑	↑
Cadmium Total	↔	↑	↔	↔	↑	↑
Chromium Dissolved	↔	↔	↔	↔	↔	↑
Chromium Total	↔	↔	↑	↓	↔	↔
Cobalt Dissolved	↔	↔	↑	↓	↔	↔
Cobalt Total	↔	↔	↔	↓	↔	↔
Copper Dissolved	↔	↔	↔	↓	↔	↔
Copper Total	↓	↔	↔	↓	↔	↔
Iron Dissolved	↔	↔	↔	↓	↔	↔
Iron Total	↔	↔	↔	↓	↔	↔
Lead Dissolved	↓	↓		↓	↓	↓
Lead Total	↓	↔		↓	↔	↔
Lithium Dissolved	↔	↑	↓	↔	↔	↔
Lithium Total	↔	↑	↓	↔	↔	↔
Manganese Dissolved	↑	↔	↔	↓	↔	↔
Manganese Total	↔	↔	↔	↓	↔	↔
Molybdenum Dissolved	↔	↓	↓	↓	↓	↓
Molybdenum Total	↔	↔	↓	↓	↔	↓
Nickel Dissolved	↔	↔	↔	↓	↔	↑
Nickel Total	↔	↔	↔	↓	↔	↔
Selenium Dissolved	↔	↔	↑	↓	↔	↔
Selenium Total	↔	↓	↑	↓	↑	↔
Silver Dissolved	↓					↔
Silver Total	↓	↔		↓	↔	↔
Thallium Dissolved	↑	↔		↔	↔	↔
Thallium Total	↔	↔		↓	↔	↑
Uranium Dissolved	↑	↔	↔	↑	↑	↔
Uranium Total	↑	↑	↓	↑	↑	↑
Vanadium Dissolved	↔	↔	↔	↓	↔	↓
Vanadium Total	↓	↔	↔	↓	↔	↔
Zinc Dissolved	↔	↔	↓	↔	↔	↔
Zinc Total	↔	↔		↓	↔	↔

No Seasonality in Data, Trend Analysis completed with Sen Slope Estimator

<≥20% censored data

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

Table 10 Flow-Weighted Trending Summary for Metals - Saskatchewan/Manitoba Boundary (2003-2013)

Parameter	Assiniboine	Carrot	Churchill	Qu'Appelle	Red Deer MB	Saskatchewan River
Metals						
Aluminum Dissolved	↓	↔	↔	↓	↔	↔
Aluminum Total	↔	↔	↓	↔	↓	↓
Arsenic Dissolved	↔	↔	↔	↔	↔	↔
Arsenic Total	↓	↔	↔	↔	↓	↔
Barium Dissolved	↑	↑	↑	↑	↔	↔
Barium Total	↑	↑	↔	↑	↔	↓
Beryllium Dissolved	↔	↔	↔	↓	↓	↔
Beryllium Total	↑	↔	↓	↔	↓	↔
Boron Dissolved	↔	↔	↑	↓	↔	↑
Boron Total	↔	↔	↔	↓	↔	↑
Cadmium Dissolved	↓	↓	↓	↓	↓	↓
Cadmium Total	↔	↔	↓	↔	↓	↓
Chromium Dissolved	↓	↓	↔	↔	↔	↓
Chromium Total	↑	↔	↓	↔	↓	↓
Cobalt Dissolved	↔	↑	↑	↑	↔	↑
Cobalt Total	↑	↑	↔	↑	↓	↔
Copper Dissolved	↑	↔	↔	↔	↔	↔
Copper Total	↑	↔	↓	↔	↓	↔
Iron Dissolved	↔	↓	↔	↔	↔	↑
Iron Total	↔	↔	↓	↔	↓	↔
Lead Dissolved	↓	↓	↓	↔	↓	↓
Lead Total	↔	↔	↓	↑	↓	↔
Lithium Dissolved	↑	↔	↔	↔	↔	↑
Lithium Total	↔	↔	↔	↔	↔	↑
Manganese Dissolved	↔	↔	↓	↑	↔	↔
Manganese Total	↔	↔	↔	↑	↓	↔
Molybdenum Dissolved	↔	↑	↑	↓	↔	↓
Molybdenum Total	↔	↔	↑	↓	↔	↓
Nickel Dissolved	↑	↔	↔	↑	↔	↔
Nickel Total	↑	↔	↓	↑	↔	↓
Selenium Dissolved	↑	↓		↑	↔	↔
Selenium Total	↑	↔		↑	↔	↔
Silver Dissolved						
Silver Total	↔	↔		↑	↓	↔
Thallium Dissolved	↑	↔	↔	↔	↔	↔
Thallium Total	↑	↔	↔	↑	↔	↔
Uranium Dissolved	↑	↑	↑	↑	↑	↑
Uranium Total	↑	↑	↔	↑	↑	↑
Vanadium Dissolved	↔	↔	↔	↑	↔	↔
Vanadium Total	↔	↔	↔	↑	↓	↔
Zinc Dissolved	↓	↔	↔	↔	↔	↔
Zinc Total	↑	↑	↔	↑	↔	↔

No Seasonality in Data, Trend Analysis completed with Sen Slope Estimator

<>20% censored data

↑ statistically significant increasing trend; ↓ statistically significant decreasing trend; ↔ no significant trend

The parameters that changed from not statistically significant to a statistically significant increasing trends included sulphate on the Red Deer River and NO3-N on the South Saskatchewan. The rivers that showed a change in direction during the five years from no statistically significant change to a decreasing trend included TP on the Beaver River, fluoride, sodium and SAR on the Cold River, NH_3-N and TSS on the North Saskatchewan River, and fluoride on the Red Deer River. Several parameters that had statistically significant increasing trends in the data to the end of 2013 became non-significant trends with the addition of five years of data and included fluoride and sodium on the Battle River, sodium and SAR on the Red Deer River, and TN on the Cold and South Saskatchewan rivers.

For metals with the addition of five years of data from 2013 to 2018 the trend direction changed for 42% of the metals. Of these changes in directional trend 39% went from no statistically significant trend to a statistically significant decreasing trend and 30% went from a statistically significant increasing trend to no statistical trend. Thus 69% of the trends showed an improvement in the trend direction with the addition of the most recent five years of data. Nineteen percent changed from no statistically significant trend to a statistically significant increasing trend and 13% from a statistically significant decreasing trend to no statistically significant trend. The metals that showed an increasing trend following the addition of the five years of data to the end of 2018 were barium, boron, cadmium, chromium, lithium, manganese, nickel, thallium, and uranium for either the total or dissolved component and in at least one river. Of these, uranium (total) showed increasing trends in four of the six rivers including Battle, Beaver, North and South Saskatchewan rivers. However, for the metals there was no reversal in the trend directions and, as noted earlier, these changes could reflect the magnitude of the slope of the trend and the resultant value being close to the *P*-value.

For the non-metal parameters, as noted above, overall, there was a change in trend direction of 36% for the trends assessed from the beginning of the record to the end of 2008 when compared to the end of 2018. Of these trends 56% showed positive changes in trend direction, with 43% showing less favourable directional trends with the addition of ten years of data. Of the 30 trends that showed a changed in trend direction 87% (26/30) were a change from a statistically significant to a non-significant trend.

Saskatchewan/Manitoba Boundary

On the Saskatchewan/Manitoba boundary, of the 84 trend assessments completed for the nutrients, major ions, and the general water chemistry parameters on this boundary, 24% showed a change in the direction of the trend following the addition of five years of long-term water quality monitoring data from 2013 to 2018. This was the same as the reported percent change in trend directions between 2008 and 2013. The change in trend direction from the end of 2008 results to the end of 2018 was 48%.

Of the trends that were observed to have a directional change in the trend between 2013 and 2018, 30% of the trends went from no statistically significant trend to statistically significant increasing trends. Fifteen percent of the trend directions went from a decreasing trend to no statistically significant trend, and 10% of the trend directions went from decreasing to increasing trends. This would suggest that just over half of the trends (55%) that had a change in trend direction showed an increase with the addition of five years of long-term water quality monitoring data. Conversely, 45% of the trend directions showed a decrease in the trend direction with the addition of five years of data. However, of these changes in trend direction with the addition of five years of data, 85% (17/30) of the trends with changes moved from either a statistically significant trend to a non-significant trend or vice versa, rather than a change in trend direction. Of the trends that did show a change in trend direction with the addition of five years of data from 2013 to 2018 the Red Deer River showed increasing trends (from decreasing trends) in the nutrients NH_3-N and NO3-N. Fluoride which was increasing in the South Saskatchewan River in 2013 showed a trend reversal to a decreasing trend with the addition of data to the end of 2018.

For metals, the addition of five yeas of monitoring date from 2013 to 2018 resulted in the trend directions changing for 43% of the metals. Of these trends that showed a change in direction 28% went from no statistically significant trend to a statistically significant decreasing trend and 22% went from a statistically significant increasing trend to no statistical trend. In addition, 2% changed from an increasing trend to a decreasing trend. Thus 52% of the trends showed a change in direction away from increasing and towards decreasing with the addition of the recent five years of data. Conversely, 48% of the metal trends showed a change in direction away from decreasing and towards increasing with the addition of the recent five years of data. Of these 24% changed from no statistically significant trend to a statistically significant increasing trend and 22% from a statistically significant decreasing trend to no statistically significant trend. The Qu'Appelle River was the only river to show a reversal in trend direction from decreasing to increasing trends with the addition of five years of data. This included barium (total), lead (total) and zinc (total).

Comparison on the non-metal parameters trends between 2008 and 2018 showed a change in trend direction for 48% of the trends. Of these trends that showed a change in trend direction, 43% of the trends went from non-significant to statistically significant increasing trends. Twenty percent of the trends went from decreasing trends to non-statistically significant trends, and 5% showed a change from decreasing to increasing trends. Therefore, for the trends assessed from the beginning of the record to the end of 2008 when compared to the end of 2018, 68% showed a change in direction away from decreasing and towards increasing trends. Conversely, 32% of the trends showed a change in direction away from increasing and towards decreasing trends that includes trends that changed from an increasing trend to no statistically significant trend, increasing to decreasing trends and non trend to decreasing trends. Of the 40 trends that showed a changed in trend direction 32% (13/40) showed a change from a statistically significant to a non-significant trend and 60% (24/40) changed from a statistically non-significant trend to a significant trend. In these cases, this could have been the result of the magnitude of the slope of the trend and the resultant value being close to the *P*-value.

6. Summary and Conclusions

To assess water quality over time long-term monotonic trend assessments are an important component of the PPWB water quality monitoring program. Trend assessments are valuable as they can allow insight into subtle changes in water quality; particularly as the identification of changes in water quality can be difficult due to natural variations and anthropogenic influences.

The PPWB, through the MAA has an established a comprehensive long-term water quality monitoring program which has allowed long-term trend analysis to be completed for a wide variety of parameters. Overall trend assessments were completed for 56 parameters including nutrients, major ions, general water chemistry parameters and metals at 12 transboundary rivers.

Nutrients can lead to more eutrophic waters, which can affect ecosystem health and function and have been identified as a priority area for the PPWB. Trend assessment of nutrients (nitrogen and phosphorus) in the 12 transboundary rivers showed statistically significant trends for several of the transboundary rivers. Increasing trends in phosphorus (TP and TDP) were identified on the Battle River on the Alberta/Saskatchewan Boundary and the Carrot and Red Deer rivers on the Saskatchewan/Manitoba boundary. All the other transboundary rivers had a decreasing or had no significant trend for TP and TDP. Increasing trends in TN were identified on the Red Deer on the Alberta/Saskatchewan boundary and on the Assiniboine, Carrot, Qu'Appelle, and Red Deer rivers on the Saskatchewan/Manitoba boundary. Therefore, increasing TN trends were more prevalent in the transboundary rivers than increasing trends in phosphorus. Only the Carrot and Red Deer rivers on the Saskatchewan/Manitoba boundary had statistically significant increasing trends in TP, TDP and TN.

While a number of the transboundary rivers showed increasing trends in nutrients, there was also a number of decreasing nutrient trends observed for these rivers. Transboundary rivers where one or more forms of nutrient concentrations decreased included the Battle, Beaver, North Saskatchewan, Red Deer, and South Saskatchewan rivers on the Alberta/Saskatchewan boundary and the Assiniboine, Qu'Appelle, and Saskatchewan rivers on the Saskatchewan/Manitoba boundary.

Significantly decreasing concentrations in one or more forms of nitrogen (NH_3-N, NO3-N, or TN) were found on the Battle, Beaver, North Saskatchewan, South Saskatchewan, Churchill and Saskatchewan rivers. The North Saskatchewan River was the one river that had decreasing trends for all five nutrients forms trended. Overall, there were fewer decreasing trends for nutrients on the Saskatchewan/Manitoba boundary rivers. However, the Saskatchewan River was the one river on this boundary that had decreasing trends in three of the five nutrient fractions (TP, TDP, and NO3-N-NO_2-N). Total nitrogen and ammonia-nitrogen showed no statistically significant trend.

Of all the trend assessments completed for the 12 transboundary rivers, major ions had, proportionately, the most statistically significant increasing trends. On the Alberta/Saskatchewan boundary the Battle, Red Deer, and South Saskatchewan rivers each had four increasing trends for major ions and TDS, while the North Saskatchewan River had three increasing trends. Chloride, sulphate, and TDS had statistically significant increasing trends in all four of these rivers. On the Saskatchewan/Manitoba boundary all four major ions (chloride, fluoride, sodium, and sulphate) and TDS showed statistically significant increasing trends on the Red Deer River, while the Assiniboine and the Saskatchewan rivers had increasing trends in all major ions and TDS, except fluoride. Among all sits on this boundary sulphate had increasing trends in all rivers, except the Churchill River.

However, some decreasing trends for major ions and TDS were noted for the transboundary rivers. Of note was the Cold River on the Alberta/Saskatchewan boundary that had decreasing trends in all the major ions, despite having no trend in TDS. The Beaver River had statistically significant decreasing trends for fluoride, sodium, and sulphate. On the Saskatchewan/Manitoba boundary the Carrot River had decreasing trends for chloride and sodium and the Qu'Appelle River had decreasing trends for chloride, fluoride and sodium. Overall, across both boundaries' fluoride was the major ion with the greatest number of decreasing trends with 50% of the rivers showing statistically significant decreasing trends.

The general water chemistry parameters (dissolved oxygen, pH, SAR and TSS) showed a range of increasing, decreasing or no significant trends over the time period trended. Field pH had increasing trends in nine of the 12 transboundary rivers. Four of the transboundary rivers on the Alberta/Saskatchewan boundary including the Battle, Beaver, Red Deer and South Saskatchewan rivers had statistically significant increasing trends. Similarly, field pH was increasing in all the rivers except for the Carrot River on the Saskatchewan/Manitoba boundary. For the other general water chemistry parameters, increasing trends in TSS concentrations were found for the Battle and Beaver rivers on the Alberta/Saskatchewan boundary and the Assiniboine, Carrot and Qu'Appelle rivers on the Saskatchewan/Manitoba boundary. Total suspended solids are a measure of the sediment that is transported downstream, and this includes in-stream erosion and bedload suspension and inputs from the landscape. Sediment transports nutrients and metals in these riverine systems, depositing them during periods of lower flows or in locations with lower flow velocity, such as receiving lakes and reservoirs.

For the 12 transboundary rivers four rivers showed increasing trends in SAR and sodium including South Saskatchewan, Assiniboine, Red Deer (SK/MB) and Saskatchewan rivers. This is not unexpected since SAR is a ratio of sodium to calcium and magnesium in the water and is a specific water use objective for agricultural irrigation. Conversely, four rivers showed statistically significant decreasing trends including the Beaver, Cold, Carrot and Qu'Appelle rivers. These four rivers also had decreasing trends in sodium. Overall, for nine of the 12 transboundary rivers SAR followed the same trend as the sodium trends on each of the rivers.

Trend assessments were completed on the dissolved and total components of 21 metals for the 12 transboundary rivers where sufficient data were available. Trending of metals (total and dissolved) was only completed from 2003 to 2018 rather than for the entire data set. This was done as the metal analysis has seen a number of analytical method changes over the period of record and the 2003 to 2018 represented a 16-year period with the same analytical method. For the transboundary rivers on both boundaries, 57% of the metals showed no statistically significant change in flow-weighted concentration over time.

However, statistically significant increasing trends were observed in 19% of the metals trended across both boundaries. For the Alberta/Saskatchewan boundary increasing trends were observed for 13% of the metals, while for the Saskatchewan/Manitoba boundary this included 24% of the metals trended. In this trend assessment over the 16-year period the number of significantly increasing trends was similar between the total and the dissolved fractions for both boundaries, whereas in the earlier trending to the end of 2013 there were a greater number of statistically significant trends in the dissolved metals relative to the total metals (PPWB 2018).

For the transboundary rivers on the Alberta/Saskatchewan boundary the metals with increasing trends in two or more rivers included, boron (total), cadmium (total and dissolved), selenium (total), and uranium (total and dissolved). For the transboundary rivers on the Saskatchewan/Manitoba boundary the metals with increasing trends in two or more rivers included barium (total and dissolved), boron (dissolved), cobalt (total and dissolved), lithium (dissolved), molybdenum (dissolved), nickel (total and dissolved), selenium (total and dissolved), uranium (total and dissolved) and zinc (total). Across both boundaries uranium total and uranium dissolved showed statistically significant increasing trends for the most number of rivers with nine and 10 of the transboundary rivers respectively. On the Alberta/Saskatchewan boundary the South Saskatchewan River had the greatest number of increasing trends in metals, while on the Saskatchewan/Manitoba boundary this included the Assiniboine, and Qu'Appelle rivers.

Overall, a total of 651 trend assessments were performed on the 12 transboundary rivers incorporating two nutrients (five forms), four major ions and TDS, four general water chemistry parameters and 21 different metals including the total and dissolved components of the same metal. Of the 651 trend assessments performed (excluding dissolved oxygen) 25% showed statistically significant increasing trends on flow-adjusted data. Of the increasing trends the major ions and TDS parameter group exhibited the greatest number of increasing trends on a percentage basis with 53%, followed by general water chemistry parameters (50%), nutrients (33%) and metals (19%).

Of all the trend assessments conducted 24% of the total trend assessments performed (again excluding dissolved oxygen) showed a statistically significant decreasing trend. Within each of the parameter groupings nutrients exhibited the greatest number of decreasing trends based on percentage (28%), followed by major ions (25%), metals (24%), and general water chemistry parameters (19%).

The objective for dissolved oxygen, like the lower objective for pH, is met when measured values are greater than the objective, (*i.e.,* it has a lower threshold). This is different than other parameters where the objective represents an upper threshold. Thus, for situations where the objective is met, decreasing trends in oxygen mean that median oxygen values become closer to the objective with time. As a result, dissolved oxygen was not included in the overall or parameter group description above with respect to increasing or decreasing percentages. In the case of dissolved oxygen, two rivers (Cold and North Saskatchewan rivers) of the 12 transboundary rivers assessed had an increasing trend, and two rivers (Assiniboine, and Carrot rivers) had decreasing monotonic trends. The other eight rivers showed no statistically significant trend in dissolved oxygen.

Of the six transboundary rivers on the Alberta/Saskatchewan boundary, the South Saskatchewan, Battle, and Red Deer rivers showed the greatest number of statistically significant monotonic increasing trends (excluding dissolved oxygen). Of the trend assessments completed on the South Saskatchewan River, 27% had increasing trends, including three major ions (chloride, sodium and sulphate), NO3-N-N, pH, SAR, barium (total and dissolved), cadmium (total and dissolved), chromium (dissolved), nickel (dissolved), thallium (total) and uranium (total). For the Battle River, 23% of the trend assessments had statistically significant increasing trends including chloride, sodium, sulphate, TDS, TP, TDP, pH, SAR cadmium (dissolved), manganese (dissolved), thallium (dissolved, and uranium (total and dissolved). Twenty two percent of the trend assessments for the Red Deer River had statistically significant increasing monotonic trends. Like the Battle and South Saskatchewan rivers this included three of the major ions plus TDS. In addition, the Red Deer River showed increasing trends in NH_3-N, TN, pH, boron (total), cadmium (dissolved), selenium (total), uranium (total and dissolved).

The river with the least number of increasing trends on the Alberta/Saskatchewan boundary was the North Saskatchewan River, although the trend analysis for nutrients, major ions and general water chemistry parameters were run over a shorter timeline in comparison to the other transboundary rivers. On this river, 11% of the parameters trended showed statistically significant increasing trends. Major ions showed increasing trends in chloride, sulphate, and TDS, while metals had increasing trends in cadmium (dissolved) and uranium (total and dissolved).

For the Saskatchewan/Manitoba boundary the Assiniboine and Qu'Appelle rivers had the most number of statistically significant increasing trends at 44 and 43% respectively (excluding dissolved oxygen). Increasing trends in the Assiniboine River were observed for NH_3-N, TN, chloride, sodium, sulphate, TDS, pH, SAR, and TSS. For the metals this included barium (total and dissolved), beryllium (total), chromium (total), cobalt (total), copper (total and dissolved), lithium (dissolved), nickel (total and dissolved), selenium (total and dissolved), thallium (total and dissolved), and uranium (total and dissolved). The Qu'Appelle River had statistically significant flow-weighted increasing monotonic trends in NH_3-N, TN, sulphate, pH, TSS, barium (total and dissolved), cobalt (total and dissolved), lead (total), manganese (total and dissolved), nickel (total and dissolved), selenium (total and dissolved), silver (total), thallium (total), uranium (total and dissolved), vanadium (total and dissolved), and zinc (total).

On the Saskatchewan/Manitoba boundary the Churchill River had the least number of statistically significant increasing trends over the period of record. Statistically significant increasing trends were shown for sodium, TDS, pH, barium (dissolved), boron (dissolved), cobalt (dissolved), molybdenum (total and dissolved), uranium (dissolved).

Flow-weighted monotonic trend assessment highlighted a number of statistically significant increasing and decreasing trends over the period of record. Follow up work will continue to identify priority areas and parameters where significant trends have been identified. While the intent and scope of this report did not include investigation of potential causes of trends, further investigative work may be warranted by the PPWB or the participating jurisdictions to assess causes for priority parameters. This includes aspects related to the data and analysis, such as the effect of non-monotonicity, flow-correcting, the slope magnitude, evaluation of different methods to increase confidence and prioritize the most meaningful significant changes, and the evaluation of regional changes where similar trend observations occur at multiple PPWB sampling locations. The importance of non-instantaneous flow effects (e.g., changes in contributing area with changing precipitation patterns) may also be important at some locations.

Like the earlier report in this series, the goal of this analysis was to summarize sites with monotonic trends. The approach taken in this trend assessment exercise was conservative and maintained consistent methods for the analysis among analyses and with the previous trend reports. Overall, approximately half, of the analyses conducted had statistically significant trends, with half of these being statistically significant increasing trends.

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