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PRAIRIE PROVINCES WATER BOARD

Report #179

Long-Term Trends in Water Quality Parameters At Twelve Transboundary River Reaches (From the beginning of the data record until the end of 2013)

Prepared for the Prairie Provinces Water Board
By the Committee on Water Quality

March 2018

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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 12 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 established an active water quality program including the development of interprovincial water quality objectives at 12 transboundary rivers, which are included as part of Schedule E and were last updated in 2015.

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

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

The purpose of this report is to summarize analyses of the long-term trend assessments conducted for a range of water quality parameters at the 12 transboundary rivers from the inception of monitoring program until the end of 2013. This is the second report to be completed, for these transboundary sites, using the non-parametric seasonal Mann-Kendall/Mann-Kendall (Sen Slope Estimator). 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 adjusted for the influence of flow.

Long-term flow-weighted trend assessment at the 12 transboundary river sites found a number of increasing and decreasing trends at each of the sites. Overall a total of 648 trend assessments were performed on the 12 transboundary rivers incorporating five nutrients, four major ions and total dissolved solids (TDS), four physical and other parameters and 21 different metals including the total and dissolved components of the same metal. Of the 648 trend assessments performed 25% showed statistically significant increasing trends on flow-adjusted data. Major ions showed the greatest number of statistically significant increasing trends followed by physicals, nutrients and metals. Of the total number of trend assessments completed for all 12 transboundary rivers, 22% showed statistically significant decreasing trends, with nutrients showing the greatest number of decreasing trends followed by metals, major ions, and physicals.

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

The Battle River also had increasing trends in fluoride, sulphate, total phosphorus (TP), total dissolved phosphorus (TDP), total suspended solids (TSS), barium (dissolved), beryllium (total and dissolved), cadmium (total), selenium (dissolved), and thallium (total and dissolved). The Red Deer River also had increasing monotonic trends in total nitrogen (TN), aluminum (dissolved), beryllium (dissolved), boron (total and dissolved), iron (dissolved), and selenium (total). The South Saskatchewan River, similar to the Battle River, also showed increasing trends in all the four major ions and TDS, TN, iron (dissolved), selenium (total and dissolved), thallium (dissolved) and zinc (dissolved). For the six Alberta/Saskatchewan boundary rivers, the North Saskatchewan River had the least number of statistically significant increasing trends. The North Saskatchewan River also had the greatest number of decreasing trends. Decreasing trends on this river occurred for nutrients (TP, TN, TDP, and $NO_{3+}NO_2$-N) and metals, particularly within the dissolved component.

Trend assessments were also conducted on six transboundary rivers on the Saskatchewan/Manitoba boundary. On this border the Saskatchewan River had the most number of statistically significant increasing trends, followed by the Assiniboine River. For each of these two transboundary rivers all major ions and TDS, pH, SAR, beryllium (dissolved), copper (dissolved), lithium (total and dissolved), manganese (dissolved), selenium (total and dissolved), thallium (dissolved), and uranium (total and dissolved) had statistically significant increasing trends. The Churchill River was the river on the Saskatchewan/Manitoba boundary with the least number of statistically significant increasing trends over the period of record.

Of note on the Saskatchewan/Manitoba boundary was that the Saskatchewan River not only had the greatest number of statistically significant increasing trends it also had the most number of statistically significant decreasing monotonic trends. For the Saskatchewan River, decreasing trends were found for nutrients (NH_3-N, NO_3+NO_2-N, TP and TDP) and 16 metals. All the metals were for the total component of the metal, with no decreasing trends in the dissolved component. Overall, for this river, it appears that nutrients are decreasing but the major ions are increasing. Within the metals, the dissolved component showed a number of statistically significant increasing trends, whereas a number of the total metals were decreasing.

Similar to the earlier report, results of the long-term monotonic trend assessment do not describe variations, notably non-monotonic patterns in the trends over time. However, a comparison of the results between the first trend assessment completed (to the end of 2008) and the current assessment (to the end of 2013) showed that overall, the direction of the flow-weighted monotonic trends were the same between 2008 and 2013 for the nutrients, major ions and physical characteristics and other parameters. When there was a change in the results between the two different timelines it was not a reversal in trend direction but rather a change from a non-statistically significant trend to a statistically significant trend or from a statistically significant trend to a non-significant trend. Of the 37 trend assessments that did show a change in statistical significance about half (17) went from no statistically significant trend to a statistically significant positive trend. The identification of the causes of the identified trends was beyond the scope identified for the work in this report. Review of trend results and identification of parameters of greatest priority will be undertaken followed by more detailed assessment to understand cause.

Table of Contents

List of Figures

List of Tables

List of Appendices

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 either the Alberta/Saskatchewan or Saskatchewan/Manitoba boundary since the late 1960's. A twelfth transboundary river, Cold River, on the Alberta/Saskatchewan border was added to the long-term monitoring network in 1994. Water quality monitoring on these 12 transboundary prairie rivers has been undertaken by Environment and Climate Change Canada (ECCC) to fulfill the monitoring requirements under 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 interprovincial boundaries. 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, 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 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). The other six transboundary rivers are on the Saskatchewan/Manitoba boundary (Assiniboine River, Carrot River, Churchill River, Red Deer River, Qu'Appelle River and the Saskatchewan River) (Figure 2).

All parties to the agreement have agreed to take all reasonable and practical measures to meet these objectives within the transboundary river reaches where excursions of objectives are a result of human activities. All parties also recognized in Schedule E that any 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 and anthropogenic influences. 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 second report 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 45 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 (PPWB 2016). This second report has extended the period of record five years and includes data from the beginning of the period of record to the end of 2013. Similar to the earlier report, 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 trends identified.

The 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, physicals and metals (total and dissolved).

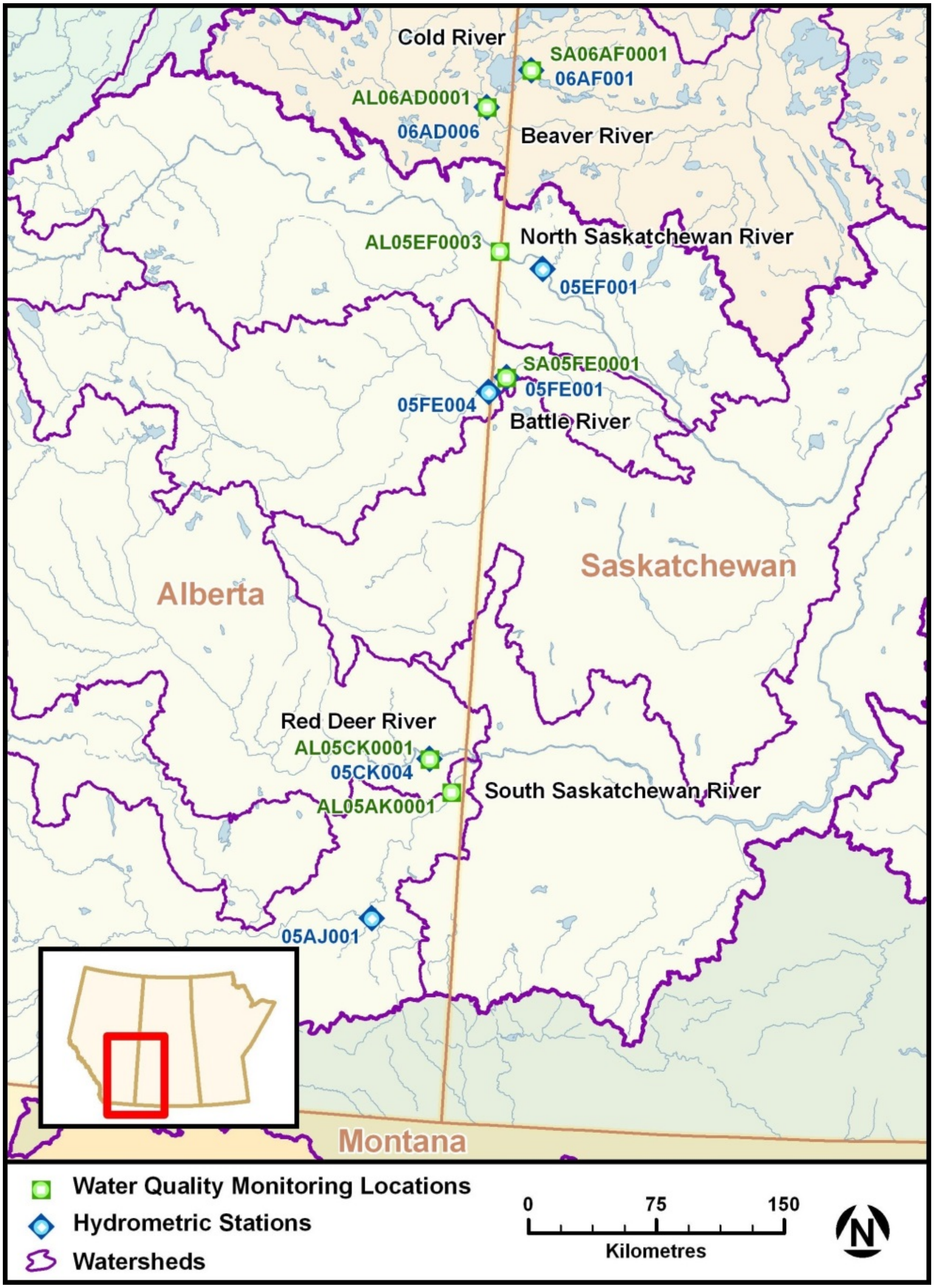

Figure 1 **PPWB Water Quality Monitoring Locations on the Alberta/Saskatchewan Boundary**

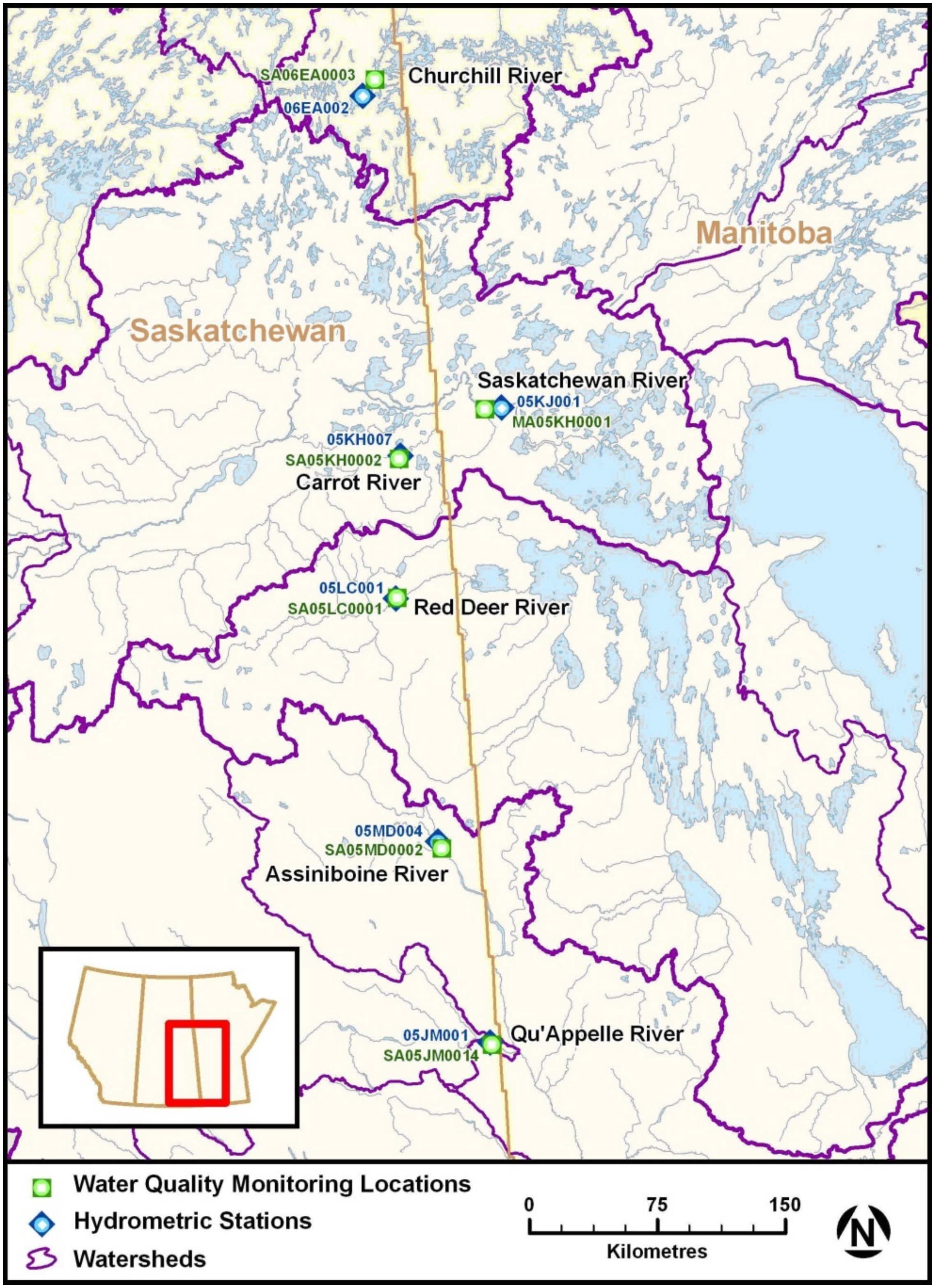

Figure 2 **PPWB Water Quality Monitoring Locations on the Saskatchewan/Manitoba Boundary**

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 currently monitors water quantity and quality for the transboundary river reaches 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 most recent site move for the North Saskatchewan River was in 1988. With the exception of the North Saskatchewan River, trend assessment at each site included data from the beginning of the period of record until the end of 2013. For the North Saskatchewan River, trends were assessed from 1988 to the end of 2013.

The frequency of 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 was monitored six times per year. Water quality parameters incorporated in the long-term monitoring program and included in the trend assessment were nutrients, major ions, metals, and physical and other 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
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*
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 the Medicine Hat, 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 minus the Carrot River near Turnberry.

3. Methods

Long-term monotonic trend analysis was used to determine statistically significant changes in water quality (*i.e*. increasing, decreasing or no change) over time. 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. The assumption for parametric trend methods is that the data distribution is normal. In addition, non-parametric methods tend to be more robust when there are 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 of this study that parametric methods used elsewhere (WQTrend from Vecchia 2003) compared well with the Mann Kendall/Seasonal Mann-Kendall method. The comparison criteria included similarity of slopes and determination of significance when using the same time series data from a PPWB station.

Prior to trend analysis, 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 two seasons were determined visually based on a review of 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 and the data were divided into 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. Where possible, seasons were also selected to be consistent with those selected previously by jurisdictions based on their review of these data sets.

As a result, the seasons selected for the Alberta/Saskatchewan boundary rivers were 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 showed seasonality then the Seasonal Mann-Kendall was used for the trend analysis. If the dataset was not seasonal 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 assessment was completed for nutrients, major ions, physical and other parameters and metals. Trend analysis included all of the PPWB monitoring data since the monitoring site inception until the end of 2013. Seasons for trend analysis were those previously defined in Section 3.1.1. For all parameters consecutive data for a minimum of 10 years was required to conduct the trend assessment.

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 can influence the trend assessment, a parameter was only considered for trend analysis if the censored data made up less than 20% of 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 later 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 for the PPWB.
In 2003 the laboratory changed the detector to sector field mass spectrometry (ICP-SFMS) and this resulted in subsequent improvements in the resolution of the methodology and improved detection limits. In the first trend report, that conducted trend analysis using data 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 insignificant step in the data. However, in this report to eliminate the complications of changing analytical methods and given that there is now more than 10 years of continuous data (2003 to 2013) available only metals data from 2003 to 2013 were included in the trend analysis.

In addition to metals, for dissolved nitrogen (DN) and total nitrogen (TN), a change in the laboratory analytical method in October 1993 resulted in a step in 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 the data post 1993 method change was 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 greater influx and surface runoff, while other constituents may decrease as a result 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:

$$\text{Log [Concentration]} = \text{Log [flow]}\, b + a$$

Where:
Concentration = 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 as a result the 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 trend result. Trends on flow-adjusted time series data were reported at the 95% significance level ($\alpha \leq 0.05$).

3.2 Descriptive Statistics

Descriptive statistics including mean, standard deviation, median, minimum, maximum, number of samples and the 90th and 10th percentile were produced using Sigma Plot v. 11.2 © 2008 Systat Software Inc. The 90th and 10th 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). Given that multiple tests were conducted within this hypothesis, there is an expectation that a proportion of the identified significant trends, based on an unadjusted significance level, would be of a type I error where the null hypothesis is incorrectly rejected. The significant trend results summarized in this report are based on an alpha ≤ 0.05. The alpha was not adjusted for the multiple trend assessments conducted, in part because this analysis is designed to identify potential trends and in part because of the lack of consistent approaches for correcting alpha in studies such as this. Regardless, the results provide a means to prioritize further assessment based on the level of significance and magnitude of 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 and magnitude of the change (%) are shown in Appendix G.

4.1 Nutrients

While nutrients are an important part of the aquatic ecosystem, 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 nutrients forms were assessed: total ammonia nitrogen (NH_3-N), nitrate-nitrite nitrogen (NO_3+NO_2-N), 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 NO_3+NO_2-N) are toxicological 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

Overall, 30 flow-weighted trend assessments were conducted for the five nutrients on the six Alberta/Saskatchewan transboundary rivers. Of these trend assessments, half of the assessments (50%) showed statistically significant decreasing trends (Table 3). The North and South Saskatchewan rivers had decreasing trends in TP (Figure 3) and TDP while the Red Deer River had a decreasing trend in TDP and no significant change in TP concentration over time. The Red Deer River also showed decreasing trends in NH_3-N and NO_3+NO_2-N with an increasing trend in TN. In the North Saskatchewan River, TN (Figure 4) and NO_3+NO_2-N showed decreasing trends, with no change in NH_3-N over the period of record. The South Saskatchewan River, similar to the Red Deer River, showed an increasing trend in TN, decreasing trend in NH_3-N and no change in NO_3+NO_2-N. The trend results for the North Saskatchewan River would suggest overall an improvement in the nutrient river water quality. As reported earlier (PPWB, 2016) this improvement in nitrogen concentrations is believed to be in direct response to improvements to the Gold Bar wastewater treatment plant in Edmonton in 2001 (Anderson 2012). The Battle and Beaver rivers, which tend to be lower flow rivers, also showed statistically significant decreasing trends in the toxicological parameters NH_3-N and NO_3+NO_2-N and no change over the period of record for TN.

Despite improvements in nutrients for a number of the Alberta/Saskatchewan transboundary rivers, five increasing trends in nutrients were identified on four 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, three rivers on this boundary had increasing trends in TN; the Cold, Red Deer and South Saskatchewan rivers.

The Cold River monitoring site is just downstream of Cold Lake, and hence water quality is reflective of the water quality in the lake, rather than a catchment watershed like the other rivers monitored in this program. Residence time of the water in the lake is approximately 33 years and hence changes in water quality could be due to in-lake changes. For the Cold River the different forms of phosphorus and the two toxicological parameters NH_3-N and NO_3+NO_2-N did not have statistically significant monotonic trends, and TN was the only nutrient on this river to have a statistically increasing trend. As the monitoring has been more limited on the Cold River (monitoring was initiated in 1993, and sampling was quarterly) there have been fewer samples collected. Monitoring was increased on the river to monthly samples since 2012.

While the Red Deer and the South Saskatchewan rivers both have significant increasing trends in TN, neither of these rivers demonstrated an increasing trend in any of the other nutrients, which had either decreasing trends or no significant monotonic trend over the period of record.

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-Nitrite 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

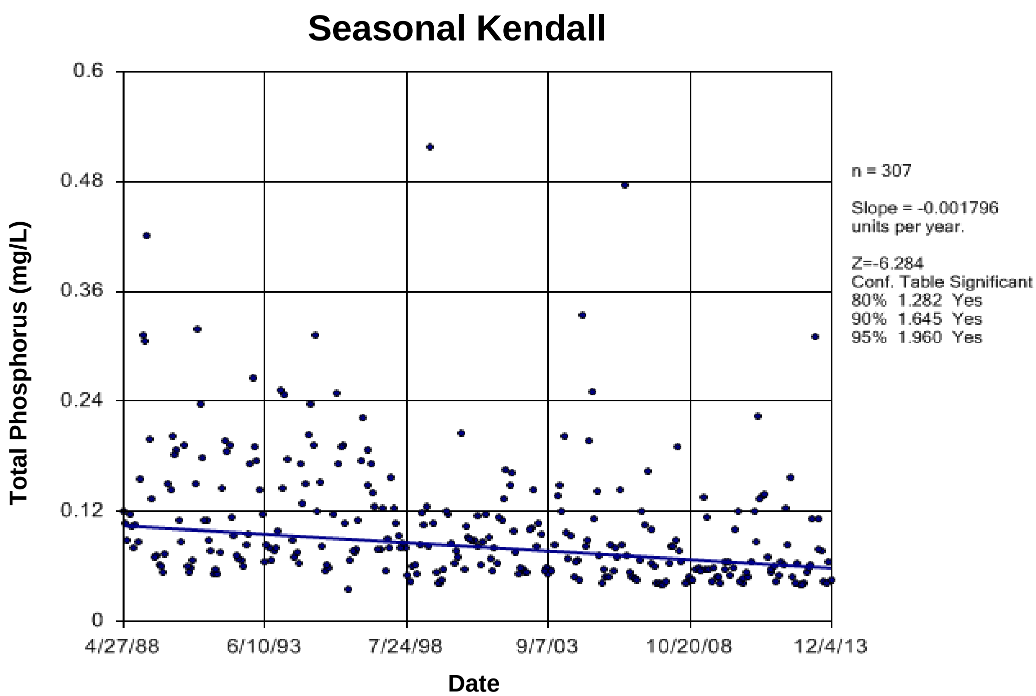

Figure 3 Trend in Total Phosphorus Concentration for the North Saskatchewan River (1988 to 2013).

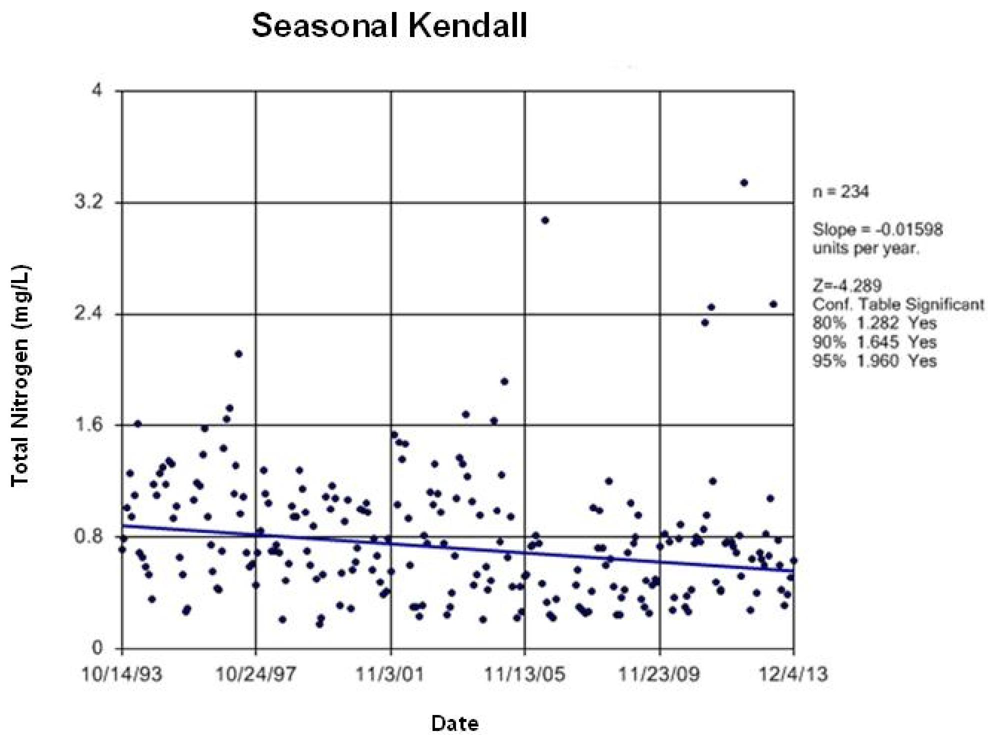

Figure 4 Trend in Total Nitrogen Concentration for the North Saskatchewan River (1993 to 2013).

Saskatchewan/Manitoba Boundary

Long-term trend assessment for the six transboundary rivers on the Saskatchewan/Manitoba boundary showed, overall, a fairly even distribution between statistically significant increasing, and decreasing trends and no change over the period of record. Of the 30 trend assessments a third (33.33%) showed increasing (positive) trends, while nine of the 30 (30%) showed significant decreasing (negative) trends (Table 4). Of note, was the Carrot River which showed statistically significant increasing trends in TP (Figure 5), TDP, TN (Figure 6), and NH_3-N. The Red Deer River also showed increasing trends in TP, TDP and TN.

The Carrot River headwaters are near Wakaw Lake, Saskatchewan and the river flows northeast entering the Saskatchewan River in the vicinity of The Pas, Manitoba. The upper watershed is dominated with agricultural activities with forests and wetlands making up most of the 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, drainage of wetland areas in other watersheds has been found to increase runoff and subsequent nutrient loads (Yates *et al.* 2014; Brunet and Westbrook 2012). A recent study completed for the PPWB on the Carrot River watershed concluded that the majority 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), or forested areas (tree/forests) where the main sources of the TN and TP loads.

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. Total nitrogen showed statistically significant increasing trends in four of the six rivers on the Saskatchewan/Manitoba boundary. The Saskatchewan River was the one river on the Saskatchewan/Manitoba boundary that showed statistically significant decreasing trends in all the nutrients trended (TP, TDP, NH_3-N and NO_3+NO_2-N), with the exception that TN did not have significant change in concentration over time. The Churchill River also showed decreasing trends in NH_3-N and NO_3+NO_2-N, but no statistically significant trend over time in TN, TDP and TP.

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-Nitrite 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

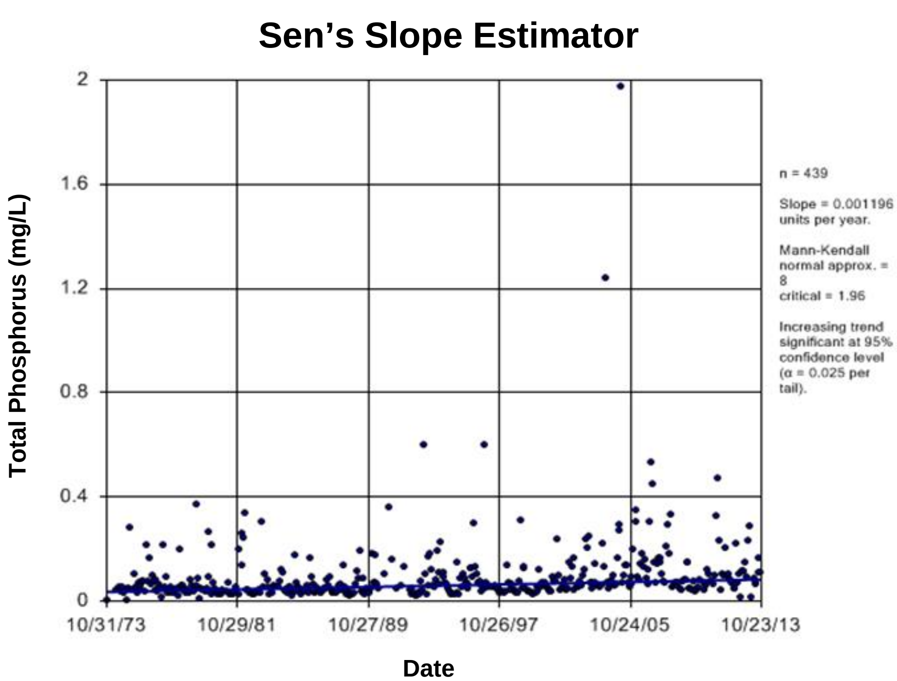

Figure 5 Trend in Total Phosphorus Concentration for the Carrot River (1973 to 2013)

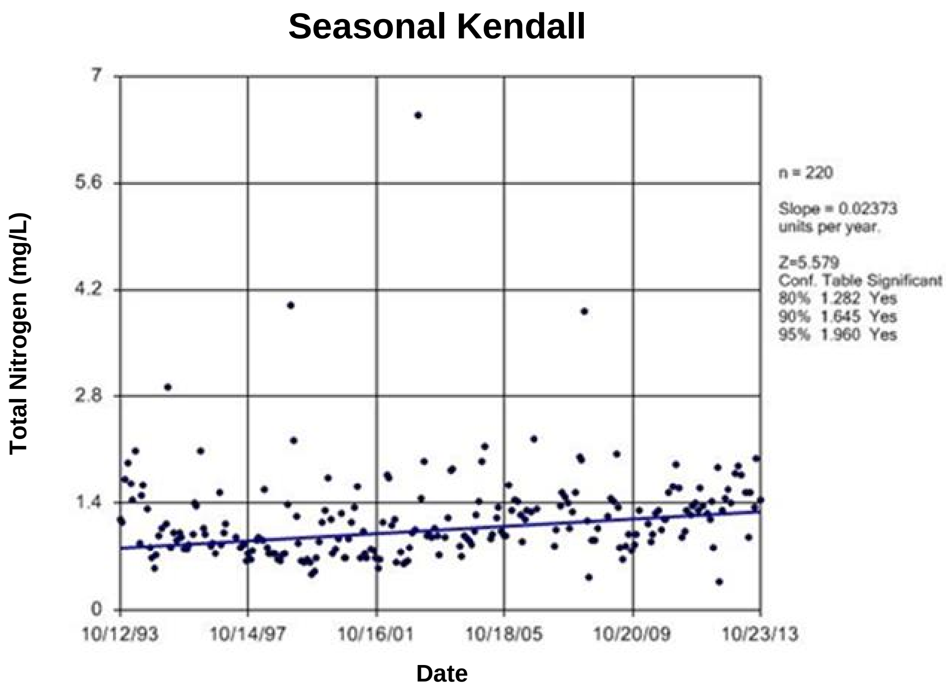

Figure 6 **Trend in Total Nitrogen Concentration for the Carrot River (1993 to 2013)**

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 the water contacts throughout the watershed. Major ions are divided into cations (calcium, magnesium, sodium and potassium) and anions (bicarbonate, sulphate, chloride, fluoride) and contribute to water's salinity, 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. 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 a number of 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 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 common throughout the prairies and hence sulphate can be found in surface and groundwater resources (Nachshon *et al*. 2013; Heagle *et al*. 2013).

Total dissolved solids concentration is a measure of inland salinity (Williams and Sherwood 1994). 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

On the Alberta/Saskatchewan boundary, of the 30 flow-weighted monotonic trend assessments that were run, just over half of the major ions (53%) had statistically significant increasing trends (Table 5). For two of the Alberta/Saskatchewan transboundary rivers, the Battle and South Saskatchewan rivers, all the major ions and TDS showed increasing trends over time. The Red Deer River also showed three increasing trends in three of the five parameters trended including sodium, chloride and TDS. The North Saskatchewan River also had increasing trends in chloride, sulphate and TDS. Decreasing trends were observed over the period of record for 27% of the major ions that were assessed on the six rivers, with 20% of the major ions showing no change in concentration.

Three rivers on the Alberta/Saskatchewan boundary had at least one decreasing trend for major ions. The Beaver River had decreasing trends for all the major ions and TDS, while the Cold River had two decreasing trends chloride and sulphate. The North Saskatchewan River had a decreasing trend for fluoride.

Total dissolved solids showed statistically significant increasing trends on four of the six transboundary rivers. This occurred for all four rivers contributing to the Saskatchewan River system: North Saskatchewan, South Saskatchewan, Red Deer and Battle rivers.

Over the period of record, the North Saskatchewan River had a TDS concentration ranging from 68 to 317 mg/L with a median of 203 mg/L. The South Saskatchewan River had a TDS concentration ranging from 98 to 400 mg/L with a median of 238 mg/L. While the Red Deer River had a TDS concentration ranging from 148 to 603 mg/L with a median of 294mg/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. The Battle River, which is a smaller tributary of the Saskatchewan River system, had overall higher TDS values with a range of 218 to 1729 mg/L and a median of 623 mg/L.

Two key constituents of TDS, chloride and sulphate, also showed statistically significant increasing trends in four out of six (67%) and three out of six 50%, respectively of the Alberta/Saskatchewan transboundary rivers. Chloride showed statistically significant increasing trends in the Battle River, South Saskatchewan, North Saskatchewan River, and Red Deer River (Figure 5). Chloride is a conservative solute that remains unaffected by biological river processes and is often used as a tracer for groundwater inputs, tracking different sources of water or from treated wastewater.

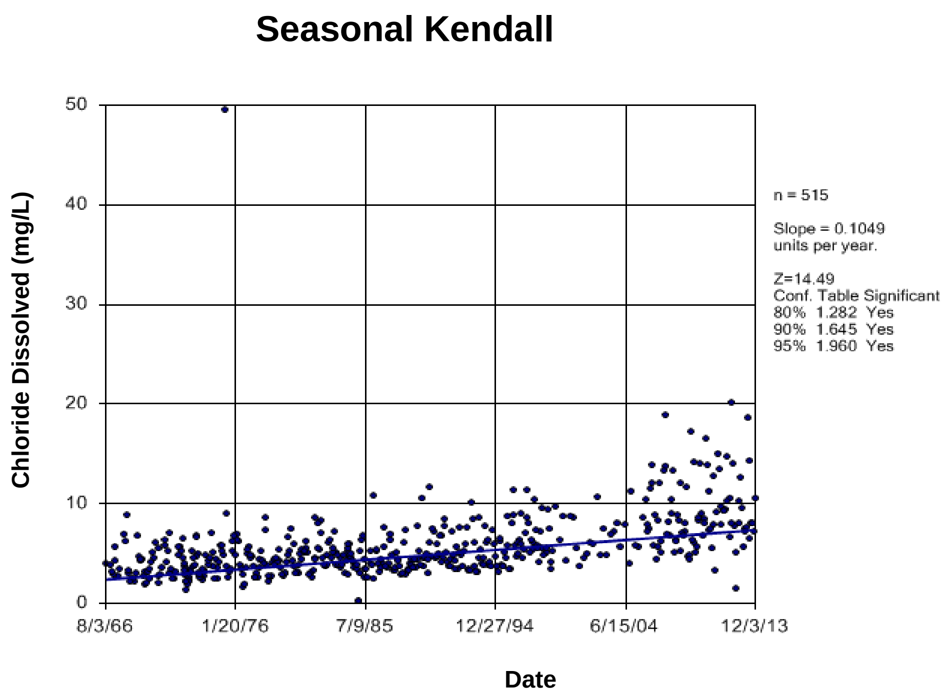

Figure 7 Trend in Chloride (dissolved) for the Red Deer River (1966 to 2013)

Increases in chloride in river systems have been attributed to sources such as municipal waste water and road salt (Turnbull 2012; Environment Canada 2001; Kerr, 2017). Chloride levels in the Battle River ranged from 0.4 to 175 mg/L, with a median of 21.6 mg/L. For the Red Deer River chloride ranged from 0.05 to 45 mg/L with a median of 5.1 mg/L. While chloride in the South Saskatchewan River ranged from 0.05 to 63.5 mg/L with a median of 6.3 mg/L.

Sulphate showed increasing trends in the North Saskatchewan, South Saskatchewan and the Battle rivers. Sulphate concentrations over the period of record ranged from 2.4 to 75 mg/L with a median value of 47.7 mg/L for the North Saskatchewan River; from 20.8 to 151 mg/L with a median of 60.5 mg/L for the South Saskatchewan River and from 14 to 389 mg/L with a median value of 142 mg/L for the Battle River.

Fluoride showed statistically significant increasing trends in two of the six rivers on the Alberta/Saskatchewan boundary (Battle, and South Saskatchewan rivers). While fluoride does occur naturally in water, it can also enter water from a number of anthropogenic sources. Wastewater from municipalities using fluoridated drinking water can discharge significant amounts of fluoride into the environment. For the Battle River the fluoride concentration ranged from 0.025 to 0.79 mg/L, with a median concentration of 0.23 mg/L. The fluoride on the South Saskatchewan ranged from 0.005 to 0.36 mg/L with a median concentration of 0.15 mg/L.

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)	↑	↓	↔	↑	↑	↑

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 of five major ions on the Saskatchewan/Manitoba boundary found 60% of the trends increased significantly (Table 6). Over the period of record the Assiniboine and Saskatchewan rivers showed increasing trends in all major ions and TDS. The Red Deer River had increasing trends in all the major ions and TDS with the exception of sulphate. Of the 30 trend assessments completed for the five major ions on the six Saskatchewan/Manitoba transboundary rivers, 27% showed no change with time. Thirteen percent of the major ions assessed for the Saskatchewan/Manitoba transboundary rivers showed statistically significant decreasing trends.

The Churchill River generally showed no changes in major ions over the period of record except for fluoride which showed an increasing trend. The Qu'Appelle and Carrot rivers were the only two rivers on the Saskatchewan/Manitoba boundary to have increasing and decreasing trends in major ion constituents. For the Qu'Appelle River, sodium and fluoride showed a decreasing trend over the period of record, while sulphate showed an increasing trend. Chloride and TDS showed no significant changes over time. For the Carrot River fluoride and sulphate has a statistically significant increasing trend, while chloride and sodium had statistically significant decreasing monotonic trends. Total dissolved solids showed no change over time in the Carrot River.

Fluoride showed increasing trends in all the rivers with the exception of the Qu'Appelle River. Sulphate also showed increasing trends in four of the six rivers (67%): the Assiniboine, Carrot, Qu'Appelle and Saskatchewan rivers. Total dissolved solids and chloride were also increasing in 50% of the transboundary rivers. Total dissolved solids and chloride had increasing trends on the Assiniboine, Red Deer at Erwood and the Saskatchewan rivers. Total dissolved solids median concentrations for the three rivers were 664, 294 and 221 mg/L respectively. While for chloride the median concentrations for these three rivers were 19.4, 4.5 and 7.4 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	↑	↑	↔ (highlighted)	↑	↔	↑
Total Dissolved Solids (TDS)	↑	↔	↔	↔	↑	↑

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

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

4.3 Physicals

Water Quality objectives have been established by the PPWB for four physicals or other parameters including dissolved oxygen, pH, SAR and total TSS.

Alberta/Saskatchewan Boundary

Twenty-four monotonic trend assessments were completed on the Alberta/Saskatchewan boundary (Table 7). Overall, this group of parameters appeared to either show statistically significant increasing trends (46%) or no change in concentrations over time (41.6%). Of the 24 trend assessments completed three decreasing trends were observed; SAR on the Beaver River and TSS on the Cold and South Saskatchewan rivers.

On the Alberta/Saskatchewan boundary, pH showed the most number of statistically significant increasing trends with four of the six rivers having an increasing trend. Dissolved oxygen showed an increasing trend on the Cold and North Saskatchewan rivers. For TSS, there was no change over time for several of the larger flow rivers including the North Saskatchewan River and the Red Deer River; however, the South Saskatchewan River did show a decreasing trend in TSS. Cold River also showed a statistically significant decreasing trend over the period of record for TSS. This 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. Statistically significant increasing trends for TSS were observed for the two smaller, lower flow rivers, the Battle and Beaver rivers on the Alberta/Saskatchewan boundary. The TSS concentration for the Battle River ranged from 0.5 to 1146 mg/L with a median of 13.6 mg/L. For the Beaver River the TSS ranged from 0.5 to 273 mg/L with a median of 6.6 mg/L.

Sodium adsorption ratio is a specific water use index and is important for assessing suitability if water for irrigation. Sodium adsorption ratio trends varied among the transboundary river sites. Increasing trends in SAR were observed for the Battle River, Red Deer River and the South Saskatchewan River, and this was consistent with the increasing trend of sodium for these three rivers. The Beaver River showed a decreasing trend in SAR and this was also consistent with the decreasing trend observed for sodium. No significant trends in SAR were observed over the last 20 years for the Cold River, and the last 25 years for the North Saskatchewan River. Again this is consistent with no significant increase of sodium in these rivers.

Table 7 Flow-Weighted trending Summary for Physical and Other Parameters-Alberta/Saskatchewan Boundary

Parameter	Battle	Beaver	Cold	North Saskatchewan	Red Deer (AB)	South Saskatchewan
Physicals						
Oxygen Dissolved	↔	↔	↑	↑	↔	↔
pH – Field	↑	↑	↔	↔	↑	↑
Sodium Adsorption Ratio	↑	↓	↔	↔	↑	↑
Total Suspended Solids	↑	↑	↓	↔	↔	↓

[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

Of the 24 monotonic trend assessments completed on the Saskatchewan/Manitoba boundary for physical and other parameters, 50% showed no change in these measured parameters over the period of record for the six PPWB transboundary rivers. Eight parameters showed statistically significant increasing trends and four showed statistically significant decreasing trends (Table 8).

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. pH in the Saskatchewan/Manitoba rivers had increasing trends in five of the six rivers (Assiniboine, Carrot, Churchill, Red Deer and Saskatchewan rivers). While for the Qu'Appelle River no significant change in pH over time was observed.

The Assiniboine River and the Carrot River showed increasing trends in TSS. Increasing trends in SAR over the period of record were also observed in the Assiniboine and Red Deer rivers. Similar, to the Alberta/Saskatchewan boundary rivers, this increase in SAR corresponds to increases in sodium on these rivers. The Churchill River also showed an increasing trend in SAR, although this result was not consistent with sodium for this river which showed no change over the period of record.

The Qu'Appelle River and the Saskatchewan River did not show any significant monotonic changes in TSS. This lack of change might be attributed to the number of lakes/reservoirs that the rivers pass through prior to reaching the Saskatchewan/Manitoba boundary. These reservoirs have been found to sequester a large proportion of TSS and nutrients (Donald *et al.* 2015).

Table 8 Flow-Weighted Trend Summary for Physical and Other Parameters - Saskatchewan/Manitoba Boundary

Parameter	Assiniboine	Carrot	Churchill	Qu'Appelle	Red Deer (MB)	Saskatchewan
Physicals						
Oxygen Dissolved	↓	↓	↔	↔	↔	↔
pH – Field	↑	↑	↑ (highlighted)	↔	↑	↑
Sodium Adsorption Ratio (SAR)	↑	↓	↑	↓ (highlighted)	↑	↑
Total Suspended Solids (TSS)	↑	↑	↔	↔	↔	↔

(highlighted) 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

Trace metals can be important given their potential to cause toxic responses in aquatic life and the effects 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 waste waters, mining and sewage effluents.

For the 12 transboundary rivers, the total and dissolved components of the same metal were trended from 2003 to 2013. While a number of metals have been monitored on the transboundary rivers since the inception of the monitoring program numerous analytical method changes over this time period have made the data difficult to compare and trend.

Alberta/Saskatchewan Boundary

In total 237 trend assessments were performed for the six Alberta/Saskatchewan transboundary rivers incorporating 21 different metals for the total and dissolved components (Table 9). More than half of the metals (60%) exhibited no significant change in concentration over the 11 year period (2003 to 2013). Statistically significant increasing trends were observed for 22% of the metals trended, with 18% having a statistically significant decreasing trend. For the dissolved metals there appeared to be a greater number of increasing trends in metals (32%) compared to the total metals (12%). Overall the total metals had a higher proportion of non-significant trends (67%) compared to the dissolved metals (53%).

Cadmium (dissolved) and chromium (dissolved) showed statistically significant increasing trends for all six transboundary rivers on the Alberta/Saskatchewan boundary, and thallium (dissolved) had statistically significant increasing trends in four of the six rivers including the Battle, Beaver, North and South Saskatchewan rivers. Zinc (dissolved) and iron (dissolved) also had increasing trends in half of the rivers monitored. Selenium (dissolved) had increasing trends in the Battle and Beaver rivers.

Fewer metals could be trended for the Cold River given the large amount of censored data for metals at this site. However, statistically significant increasing trends were found for eight metals of which seven were for the dissolved metal component.

For the total metals cadmium had increasing trends in four rivers, while beryllium, thallium and selenium had increasing trends in two of the six transboundary rivers. Overall, the Battle and the Red Deer rivers had the most number of increasing trends in metals (total and dissolved) with 11 and 10 respectively.

Molybdenum (dissolved) showed statistically significant decreasing trends, in four of the transboundary rivers. Vanadium (dissolved) had decreasing trends in three rivers whereas, dissolved arsenic, lead and lithium had decreasing trends in two of the six transboundary rivers. For the total metals arsenic and vanadium had decreasing trends in four of the transboundary rivers. Molybdenum had statistically significant decreasing trends in three of the rivers, while aluminum, silver and iron had decreasing trends in two of the transboundary rivers.

The North Saskatchewan and South Saskatchewan rivers showed the greatest number of statistically significant decreasing trends; however, of note was that for the North Saskatchewan River the majority of the decreasing trends were for the dissolved metals, while this was the reverse for the South Saskatchewan river, where the total metals had a greater portion of the decreasing trends (nine out of 12).

Saskatchewan/Manitoba Boundary

A total of 243 trend assessments were completed for the metals on the Saskatchewan/Manitoba transboundary sites. Of the metals that were trended more than half (56%) did not have statistically significant trends (Table 10). Of the trends that were observed, these were fairly evenly divided between increasing (23% of the total trends) and decreasing trends (21% of the total trends). Similar to the Alberta/Saskatchewan boundary, for the rivers on the Saskatchewan/Manitoba boundary there appeared to be a greater number of statistically significant increasing trends for the dissolved metals (32%) as compared to the total metals (14%). However, the numbers of metals with no significant change over time were similar between the total and dissolved metals.

Dissolved metals showing statistically significant increasing monotonic trends in three or more of the rivers included barium, beryllium, boron, copper, lithium, manganese, selenium, thallium, and uranium. The Qu'Appelle River had the most number of increasing trends for dissolved metals with 11 dissolved metals showing positive trends. The Assiniboine and Saskatchewan rivers each had eight increasing (positive) trends in dissolved metals. For the transboundary rivers on the Saskatchewan/Manitoba boundary there were fewer decreasing trends in the dissolved metals (10%). The river with the least number of trends in the dissolved metals was the Churchill River. Only two trends were observed, which included an increasing trend in beryllium (dissolved) and a decreasing trend in manganese (dissolved).

For the total metals trended, 68% showed no statistically significant trend from 2003 to 2013. Increasing (positive) trends were observed in 14% of the total metals trended. This included uranium on five rivers, selenium on four rivers, and lithium on three rivers. Other total metals that showed statistically significant increasing trends included arsenic, barium, beryllium, boron, manganese and thallium. For the total metals the Assiniboine River had the greatest number of increasing trends followed by the Saskatchewan River, while the Churchill River showed no statistically significant increasing trends for total metals.

Thirty one percent of the total metals trended for the Saskatchewan/Manitoba boundary rivers had significant decreasing (negative) trends. The total metals that had statistically significant decreasing trends in at least three of the transboundary rivers included aluminum, cadmium, chromium, iron, and zinc. The Saskatchewan River had 16 significant decreasing trends representing 76% of the total metals trended for that river. The Churchill and Qu'Appelle rivers also had a higher number of total metals with decreasing trends with 10 and 9, respectively. The other three rivers on the Saskatchewan/Manitoba boundary showed few decreasing trends in total metals. The Red Deer River had no statistically significant decreasing trends for total metals, while the Carrot River had two (cadmium and chromium) and the Assiniboine River had one (molybdenum).

5. Comparison of the Trending results between 2008 and 2013

This report represents the second in a series where the long-term flow-weighted monotonic trend analysis for the twelve transboundary rivers has been completed using the same Seasonal Mann-Kendall/Mann-Kendall non-parametric methodology. The first trend series was completed for the period of record until the end of 2008, while this current report presents the results with the addition of five years of water quality monitoring data to the end of 2013. As noted earlier, the metals in this report were only trended from 2003 to 2013 due to the numerous changes in analytical methodologies over the period of the water quality monitoring program. However, in the earlier report (up to the end of 2008) a few metals were trended where methodologies were considered to be compatible for comparison. Consequently, a comparison of the metal results was not undertaken between the two reports.

A comparison of the trend results from the two time series up to 2008 and up to 2013 for nutrients, major ions and physical and other parameters are summarized in Appendix H. Overall, the direction of the flow-weighted trends (*i.e.* either increasing or decreasing) were the same between 2008 and 2013. Consequently, the additional five years of flow-weighted data did not change the direction of significant trends in one direction to a significant trend in the opposite direction. In the 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. A comparison of the slopes for the two time lines is shown in Appendix H.

Alberta/Saskatchewan Boundary

For the six Alberta/Saskatchewan transboundary rivers, of the 84 trend assessments completed for the non-metal parameters (nutrients, major ions, and physicals), 20% showed a change in direction of the trend with the addition of five years of monitoring data from 2008 to 2013. Of these, 41% of the directional changes went from no statistically significant trend to a statistically significant increasing trend. Twenty four percent of the changes in the trend direction went from no statistically significant trend to a significant decreasing trend. Therefore, a greater portion of the trends became statistically significant following the addition of the monitoring data from 2008 to 2013. For the non-metal parameters that were reported to have a statistically significant trends in the data to the end of 2008, the addition of five years of monitoring data also showed 29% of the trends went from statistically significant increasing trends to no significant trend, and 6% (1/17) went from a decreasing trend to no statistically significant trend.

Table 9 Flow-Weighted Trend Summary for Metals - Alberta/Saskatchewan Boundary (2003-2013)

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	↔	↔		↔	↔	↔

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

[grey] <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	↔	↔	↓	↓	↔	↓

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

[grey] <20% censored data

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

The Red Deer River and the Cold River on the Alberta/Saskatchewan boundary showed the most number of directional changes in the trend results from 2008 to 2013 each with 36%. The Red Deer River showed the greatest number of changes in the direction of the trend from not statistically significant to statistically significant increasing trends. No one parameter appeared to show a change in the trend direction for all the rivers, as a result of the additional five years of data. The parameters that changed from not statistically significant to a statistically significant increasing trend included TDP on the Battle River NO_3+NO_2-N on the Cold River; chloride and dissolved oxygen on the North Saskatchewan River and TN, sodium, and SAR on the Red Deer River. The rivers that showed a change in direction during the five years from no statistically significant change to a decreasing trend included chloride and TDS on the Beaver River, and TSS on the Cold and South Saskatchewan rivers. A number of parameters that had increasing trends in the data to the end of 2008 became not statistically significant with the additional five years of data; this included; NH_3-N, fluoride, and pH on the Cold River; pH on the North Saskatchewan River and fluoride on the Red Deer River.

Saskatchewan/Manitoba Boundary

On the Saskatchewan/Manitoba boundary, of the 84 trend assessments completed for the nutrients, major ions and the physical parameters on this boundary, 24% showed a change in direction of the trend following the addition of five years of long-term water quality monitoring data from 2008 to 2013. Of the trends that were observed to have a directional change in the trend more than half (55%) of the trends went from no statistically significant trend to statistically significant increasing trends. Fifteen percent of the non-statistically significant trends reported up to the end of the 2008 became statistically significant decreasing trends as a result of the additional data. Of the parameters that had trends in the dataset up to 2008, 30% of the decreasing trends became non-statistical significant trends to the end of 2013. None of the increasing trends that were reported in 2008 changed direction with the addition of five years of long-term water quality monitoring data *i.e.* these trends remained as increasing trends.

Of the six rivers on the Saskatchewan/Manitoba boundary the Qu'Appelle River had the greatest number of significant trend changes with the additional five years of data. Total nitrogen was one parameter that did have a change from non-significant to significant (or vice versa) in the trends in half of the Saskatchewan/Manitoba boundary rivers. The parameters that went from no statistically significant trend to a significant increasing trend included NH_3-N, TN, and pH on the Assiniboine River; NH_3-N and sulphate on the Carrot River; TN and sulphate on the Qu'Appelle River; TN and pH on the Red Deer River and sodium and SAR on the Saskatchewan River. The rivers that showed a change in direction from no statistically significant change to a decreasing trend included NO_3+NO_2-N on the Churchill River, SAR on the Qu'Appelle River and dissolved oxygen on the Carrot River. A number of parameters changed from a statistically significant decreasing trend to no trend including NO_3+NO_2-N on the Assiniboine and Carrot rivers; TDP, dissolved oxygen on the Qu'Appelle River; and the Saskatchewan River.

6. Summary and Conclusions

Long-term monotonic trend assessments are an important component of the PPWB water quality monitoring program. While the PPWB has water quality objectives established at the 12 transboundary sites, trend assessment allows the PPWB to assess changes in water quality over time (positive, negative or no change). Trend assessments are valuable as they can allow insight into more subtle changes in water quality to be highlighted; particularly as the identification of changes in water quality can be difficult due to natural variations and anthropogenic influences. This process is therefore complementary to annual excursion reporting of water quality objectives and assists the Board in setting water quality priorities and undertaking its water quality management responsibilities.

The PPWB, through the MAA has established a comprehensive long-term water quality monitoring program which has allowed long-term trend analysis to be undertaken for a wide variety of parameters. Overall trend assessments were completed for 56 parameters including nutrients, major ions, physical and other parameters and metals at the12 transboundary rivers.

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 effect of non-monotonicity, magnitude of slope, 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. For some trends, notably the metals, the period of analysis is relatively short so ongoing evaluation of data post 2013 is of particular importance. For example, some metals that had a frequent number of increasing trends among sites (e.g. dissolved beryllium and cadmium). Some of these sites also had high trend magnitudes (Appendix H); however, data since 2014 suggests these monotonic increasing trends do not continue at all sites. A more thorough examination of this will be undertaken elsewhere and the next trend analysis report update will include data from 2013 to 2018. The importance of non-instantaneous flow effects (e.g. changes in contributing area with changing precipitation patterns) may also be important at some locations.

Nutrients have been identified as a priority area for the PPWB, because increasing levels of nutrients can lead to more eutrophic waters, which can affect ecosystem health and function. Trend assessment of nutrients (nitrogen and phosphorus) in the 12 transboundary rivers showed a number of statistically significant trends. Increasing trends in TN were identified on the Red Deer, South Saskatchewan and the Cold rivers on the Alberta/Saskatchewan boundary and on the Assiniboine, Carrot, Qu'Appelle and Red Deer rivers on the Saskatchewan/Manitoba boundary. Statistically significant increasing trends in phosphorus occurred for TP and TDP on the Battle River on the Alberta/Saskatchewan boundary and Carrot and Red Deer River on the Saskatchewan/Manitoba boundary.

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 North Saskatchewan, Red Deer, Battle, South Saskatchewan, and Beaver rivers on the Alberta/Saskatchewan boundary and the Churchill, Qu'Appelle, Red Deer and Saskatchewan rivers on the Saskatchewan/Manitoba boundary.

With the exception of the Battle River, all the other Alberta/Saskatchewan transboundary rivers had a decreasing or had no significant trend for TP. Significantly decreasing concentrations in one or more forms of nitrogen (NH_3-N, NO_3+NO_2-N, or TN) were found on the Battle, Beaver, North Saskatchewan, Red Deer, and South Saskatchewan rivers. The North Saskatchewan River was the one river on this boundary that had decreasing trends for four of the five nutrients trended and no significant change over time for NH_3-N.

Overall there were fewer decreasing trends for nutrients on the Saskatchewan/Manitoba boundary rivers. However, the Saskatchewan River was the one river that did have decreasing trends in most nutrients (TP, TDP, NH_3-N, and NO_3-NO_2-N).

Of all the trend assessments completed for the 12 transboundary rivers, major ions were the one parameter group that had, proportionately, the most statistically significant increasing trends. All four major ions (chloride, fluoride, sodium, sulphate) and TDS showed statistically significant increasing trends for the Battle and South Saskatchewan rivers on the Alberta/Saskatchewan boundary. On this boundary the North Saskatchewan and Red Deer rivers also had at least two increasing trends for major ions, as well as, TDS over the period of record. Chloride was the one parameter on this boundary that was found to have statistically increasing trends in four of the transboundary rivers, while sulphate was increasing in half of the rivers. On the Saskatchewan/Manitoba boundary the Assiniboine and the Saskatchewan rivers had increasing trends in all four major ions and TDS. The Red Deer River had increasing trends in three major ions and TDS, with only sulphate showing not statistically significant trend. Among all sites on this boundary, all major ions (fluoride, chloride, sulphate, sodium) and TDS were shown to be statistically increasing in 50% or more of the rivers.

However, some decreasing trends for major ions and TDS were noted for the transboundary rivers. Of note was the Beaver River on the Alberta/Saskatchewan boundary where all four major ions and TDS were shown to have statistically significant decreasing trends. The Cold River had statistically significant decreasing trends for chloride and sulphate, with the other two major ions and TDS showing non-significant trends. On the Saskatchewan/Manitoba boundary the Carrot River had decreasing trends for chloride and sodium and the Qu'Appelle River had decreasing trends for fluoride and sodium. Overall, for the 12 transboundary rivers, 20% of the major ions and TDS showed statistically significant decreasing trends.

The physical and other parameters (dissolved oxygen, pH, SAR and TSS) showed a range of increasing, decreasing or no significant trends over the time period trended. Three decreasing trends were observed on the Alberta/Saskatchewan boundary (including SAR on the Beaver River and TSS on the Cold and South Saskatchewan rivers) and four decreasing trends were observed on the Saskatchewan/Manitoba boundary. For 11 of the 12 transboundary rivers SAR followed the same trend as the sodium trends on each of the 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. For the 12 transboundary rivers six rivers showed increasing trends in SAR and sodium including; Battle, Red Deer (AB/SK) and South Saskatchewan, Assiniboine, Red Deer (SK/MB) and Saskatchewan rivers.

Field pH had increasing trends in four of the transboundary rivers on the Alberta/Saskatchewan boundary including the Battle, Beaver, Red Deer and South Saskatchewan rivers. Similarly, field pH was increasing in all of the rivers except for the Qu'Appelle River on the Saskatchewan/Manitoba boundary. For the other physical parameters, increasing trends in TSS concentrations were found for the Battle and Beaver rivers on the Alberta/Saskatchewan boundary and the Assiniboine and Carrot 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.

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 2013 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 2013 represented an 11 year period with the same analytical method. For the transboundary rivers on both boundaries, a large number of metals showed no statistically significant change in concentration with time. However, statistically significant increasing trends were observed on both boundaries. For the Alberta/Saskatchewan boundary increasing trends were observed for 22% of the metals, while for the Saskatchewan/Manitoba boundary this included 23% of the metals trended. Of note, was that for the transboundary rivers there were a greater number of significant increasing trends found for dissolved metals relative to total metals for both boundaries. For the transboundary rivers on the Alberta/Saskatchewan boundary the dissolved metals with increasing trends in two or more rivers included beryllium, cadmium, chromium, copper, iron, selenium, thallium, uranium, and zinc. For the total metals this included beryllium, cadmium, selenium, thallium and uranium. For the transboundary rivers on the Saskatchewan/Manitoba boundary the dissolved metals with increasing trends in two or more rivers included; barium, beryllium, boron, copper, lithium, manganese, selenium, thallium and uranium, while for the total metals this included lithium, selenium and uranium. On the Alberta/Saskatchewan boundary the Battle and the Red Deer rivers had the most number of increasing trends in metals, while on the Saskatchewan/Manitoba boundary this included the Assiniboine, Qu'Appelle and Saskatchewan rivers.

Overall a total of 648 trend assessments were performed on the 12 transboundary rivers incorporating two nutrients (five forms), four major ions and TDS, four physical parameters and 21 different metals including the total and dissolved components of the same metal. Of the 648 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 57%, followed by physical and other parameters (56%), nutrients (27%) and metals (23%). However, if the dissolved metals fraction was broken down into the total and dissolved metal components then the dissolved component showed a greater number of statistically significant increasing trends (32%), as compared to the total metal component (14%).

Of all the trend assessments conducted 22% of the total trend assessments performed (again excluding dissolved oxygen) showed a statistical significant decreasing trend. Within each of the parameter groupings nutrients exhibited the greatest number of decreasing trends (40%), followed by metals (21%), major ions (20%) and physical and others parameters (14%). However, metals again showed a difference between the metal components with 31% of the total metals showing a decreasing trend and 10% of the dissolved metals showing a decreasing trend.

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.

Of the six transboundary rivers on the Alberta/Saskatchewan boundary, the Battle River followed by the Red Deer River and South Saskatchewan River showed the most number of statistically significant monotonic increasing trends. Of the trend assessments completed on the Battle River 38% had increasing trends and this included all the major ions and TDS, TP, TDP, pH, SAR, TSS and barium (dissolved), beryllium (total and dissolved), cadmium (total and dissolved), chromium (dissolved), selenium (dissolved), thallium (total and dissolved) and uranium (total and dissolved). For the Red Deer River, 30% of the trend assessments had statistically significant increasing trends including chloride, sodium, TDS, TN, pH, SAR aluminum (dissolved), beryllium (dissolved), boron (total and dissolved), cadmium (dissolved), chromium (dissolved), iron (dissolved), uranium (total and dissolved), and selenium (total).

Twenty eight percent of the trend assessments for the South Saskatchewan River showed statistically significant increasing monotonic trends. Similar to the Battle River, this included all the major ions, TDS, TN, pH and SAR, cadmium (dissolved), chromium (dissolved), iron (dissolved), selenium (total and dissolved), thallium (dissolved), and zinc (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 physical parameters were run over a shorter timeline in comparison to the other transboundary rivers. On this river, 9% 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 beryllium (dissolved), cadmium (total and dissolved), chromium (dissolved), thallium (dissolved) and zinc (dissolved).

For the Saskatchewan/Manitoba boundary the Saskatchewan River had the most number of statistically significant increasing trends at 35% of the trend assessments completed for this river (excluding dissolved oxygen). Increasing trends were observed for all the major ions, TDS, pH, SAR, beryllium (dissolved), boron (total and dissolved), copper (dissolved), lithium (total and dissolved), manganese (dissolved), selenium (total and dissolved), thallium (dissolved) and uranium (total and dissolved).

The Assiniboine River had statistically significant flow-weighted increasing monotonic trends in 32% of the parameters trended. These included: all the major ions, TDS, TN, NH_3-N, pH, SAR, TSS, barium (dissolved), beryllium (total and dissolved), copper (dissolved), lithium (total and dissolved), manganese (total and dissolved), selenium (total and dissolved), thallium (total and dissolved), and uranium (total and dissolved). The Churchill River was the river on the Saskatchewan/Manitoba boundary with the least number of statistically significant increasing trends over the period of record. Statistically significant increasing trends were shown for fluoride, pH, SAR and beryllium (dissolved).

Similar to 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 report. Overall, a high proportion, approximately half, of the analyses conducted had statistically significant trends. No attempt was made to explain the trends, and the findings from this report can be used to prioritize more detailed assessment of specific parameters in specific river reaches. This prioritization may include specific parameters, parameters with consistent trends among sites, and/or the significance level and slope magnitude for specific trend results.

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