Chloride in surface waters of Alberta's rivers

Condition of the Environment Report 2021

Alberta

Chloride in Surface Waters of Alberta's Rivers - Condition of the Environment Report 2021

J. Patrick Laceby, Cecilia Chung, and Jason G. Kerr

This publication can be found at: https://open.alberta.ca/publications/chloride-in-surface-waters-of-albertas-rivers.

Comments, questions, or suggestions regarding the content of this document may be directed to:
Office of the Chief Scientist, Alberta Environment and Parks
10th Floor, 9888 Jasper Avenue NW, Edmonton, Alberta, T5J 5C6
Email: AEP.OCS@gov.ab.ca
Website: environmentalmonitoring.alberta.ca

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

Recommended citation:

Laceby, P, J., Chung, C., Kerr, J.G. 2021. Chloride in Surface Waters of Alberta's Rivers - Condition of the Environment Report 2021. ISBN 978-1-4601-5395-6. Available at: https://open.alberta.ca/publications/chloride-in-surface-waters-of-albertas-rivers.

Date of publication: March, 2022
ISBN: 978-1-4601-5395-6

Acknowledgements

We would like to thank multiple staff at Alberta Environment and Parks for obtaining and processing water quality samples and managing the data generated, Mina Nasr for generating the maps presented online, along with Mark Kruk and Nadine Taube for guidance with statistical analyses and coding. We would also like to thank Craig Emmerton and John Orwin for providing internal reviews of this report.

Executive Summary

The salinization of freshwater environments presents a potential threat to water resources. As freshwater salinity increases, so does the risk of contamination of groundwater and surface water resources. Elevated salinity in our rivers and streams may also degrade transportation and water supply infrastructure, thus potentially resulting in economic, environmental and social consequences. There are two main types of salinization that typically occur in freshwater environments: primary salinization that is driven by a variety of natural processes, and secondary salinization that is driven by societal factors.

Chloride (Cl^-), a component of several salts and dissolves into water, is regularly analyzed in water quality monitoring and research programs to help guide the stewardship of water resources. The Canadian Council of Ministers of the Environment (CCME) has developed chronic and acute surface water guidelines for Cl^-, above which, there are elevated risks to freshwater aquatic life. Crop specific irrigation guidelines also exist for Cl^- concentrations in irrigation water.

This report presents the methods used to generate the web-based Condition on Environment information published online (*https://www.alberta.ca/condition-of-the-environment-water-indicators.aspx*) for Cl^-, including the steps taken to obtain and prepare the data, assess the quality of the data and conduct the spatial and temporal analyses. The results and discussion presented in this report are more comprehensive than what is presented on the online platform.

The Alberta Environment and Parks (AEP) Long-Term River Network (LTRN) program has been sampling surface water in the major rivers of Alberta since the 1970s. AEP's Tributary Monitoring Network (TMN) program was initiated in April 2016 to sample surface water in generally smaller rivers and streams not currently monitored by the LTRN program. Cl^- has been routinely monitored by the LTRN program since the mid-1980s and is currently analyzed in all of AEP's river monitoring initiatives, including the TMN program.

A spatial analysis was undertaken to present Cl^- concentrations across the province using data from LTRN and TMN sites (n = 97) generated over the last four years (i.e. 2016 through 2019). A temporal analysis was conducted to evaluate the change in Cl^- concentrations over time at LTRN sites with more than 10 years of data (n = 29). The trend analysis was first conducted for all annual samples. For sites with significant differences between the open water (i.e. April-October) and ice-covered (i.e. November-March) seasons, separate trend tests were performed on data from these two distinct seasons.

From 3,858 samples in the spatial analysis, five samples had Cl^- concentrations that exceeded the CCME protection of aquatic life (PAL) acute guideline, including two in Nose Creek (Bow River), and one each in Fish Creek (Bow River), Waskasoo Creek (Red Deer River) and Threehills Creek Site 2 (Red Deer River). Sites in the Bow River watershed around Calgary accounted for 55 of the 79 (70%) irrigation guideline exceedances, with almost half (47%) of all irrigation guideline exceedances occurring at the Nose Creek site. In fact, 84% of the 88 samples from Nose Creek exceeded the irrigation guideline and 66% exceeded the PAL chronic guideline. Additionally, both Waskasoo Creek and the Battle River Site 1 each had 11 irrigation guideline exceedances.

Headwaters sites generally have lower Cl^- concentrations, as illustrated by their lower detection frequencies. Median Cl^- concentrations typically increase progressing downstream across the province with the exception of the Bow and Battle Rivers. In the Bow River, Cl^- median concentrations increase towards their peak in the Calgary region and have relatively similar main stem distributions downstream. In the Battle River, Cl^- concentrations decreased progressing downstream. In several watersheds, tributary sites had higher Cl^- concentrations than their main stem river counterparts.

Seven of the 29 LTRN sites had insufficient detection frequencies to conduct the trend analyses without potentially introducing bias when addressing censored data. For the remaining 22 sites in the annual dataset, 16 had significant trends, two of which (both in Northern Alberta) were found to be decreasing over time. Of the 14 sites with significantly increasing trends, the sites near and downstream of Calgary generally had the largest annual percent increases (+3 to +4% yr^{-1}).

When examining the ice-covered season, there were five sites with significant decreasing trends in Northern Alberta compared to 14 sites with significant increasing trends in Central and Southern Alberta. In contrast, for the open water season, there was only one site with a significant decreasing trend in Northern Alberta and 13 with significant increasing trends in Central and Southern Alberta. In general, the rate of increase is greater during the open water season in Southern Alberta. Sites in South and Central Alberta typically have significant trends of increasing Cl^- concentrations whereas in Northern Alberta there are either no significant trends, significant decreasing trends, or situations where low Cl^- concentrations make it challenging to conduct the trend analyses owing to significant numbers of samples being below the limits of detection.

In summary, there were five acute PAL guideline exceedances for Cl^-, 54 PAL chronic guideline exceedances and 79 irrigation guideline exceedances in the spatial analyses of 97 TMN and LTRN monthly monitoring samples taken from January 2016 to December 2019. Most of these Cl^- chronic guideline exceedances occurred in the Bow River watershed near Calgary, Waskasoo Creek in the Red Deer watershed and the Battle River Site 1 upstream of Driedmeat Lake. Decreasing Cl^- trends were evident in Northern Alberta, particularly during the ice-covered season. Headwater regions typically have lower Cl^- concentrations, which often increase progressing downstream. Additionally, tributary sites generally have higher Cl^- concentrations than their counterparts do on the main stem. The spatial and temporal trends in Cl^- concentrations likely reflect primary (i.e. natural) and secondary (i.e. societal) salinization processes occurring across Alberta.

Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

AEP	Alberta Environment and Parks
AR	Athabasca River
BR	Bow River
BTR	Battle River
BVR	Beaver River
Cl^-	Dissolved Chloride
CoE	Condition of Environment
CCME	Canadian Council of Ministers of the Environment
ER	Elbow River
LTRN	Long Term River Network
MDL	Method Detection Limit
MK	Mann-Kendall
MLK	Milk River
n	Number of units (e.g. number of sites or samples)
NSR	North Saskatchewan River
OMR	Old Man River
PAL	Protection of Aquatic Life (CCME water quality guidelines)
PR	Peace River

TMN	Tributary Monitoring Network
QC	Quality Control
RDR	Red Deer River
SMK	Seasonal Mann-Kendall
SMKY	Smoky River
SSR	South Saskatchewan River
SOP	Standard Operating Procedures
VMV	Valid Method Variable
UCL	Upper Confidence Limit
WR	Wapiti River

Introduction

The salinization of freshwater environments presents a threat to water resources in Alberta, across Canada and around the world. As freshwater salinity increases, so does the potential contamination of groundwater and surface water resources (Kaushal et al., 2005; Novotny et al., 2008). Elevated salinity levels in our rivers and streams may also potentially degrade transportation and water supply infrastructure (Kaushal, 2016; Shi et al., 2009). Accordingly, major increases in freshwater salinity may have economic, environmental and social consequences (e.g. Cañedo-Argüelles et al., 2016; Kaushal, 2016; Williams, 2001).

Two main types of salinization typically occur in freshwater environments. Primary salinization is driven by a variety of natural processes such as soil and atmospheric deposition, mineral salt deposits and rock weathering (Cañedo-Argüelles et al., 2013). Secondary salinization is driven by societal factors such as deicing salts, agricultural inputs, wastewater treatment plant and industrial effluent, land clearing and irrigation (Kelly et al., 2008; Thunqvist, 2004).

Specific salts potentially associated with salinization include base cations (sodium, magnesium, calcium and potassium) and major anions (sulphate, carbonates and chloride) which readily dissolve in water. Of these, previous research has demonstrated that chloride (Cl^-) is a relatively sensitive indicator of salinization in Alberta (Kerr, 2016; Laceby et al., 2019). Furthermore, unlike a number of other salts, Cl^- currently has established water quality guidelines. The Canadian Council of Ministers of the Environment (CCME) developed chronic (120 mg/L) and acute (640 mg/L) surface water Cl^- guidelines for the protection of aquatic life (PAL), above which there are elevated risks to freshwater aquatic life (Canadian Council of Ministers of the Environment, 2011). These Cl^- CCME chronic and acute surface water guidelines have been adopted by the Government of Alberta to provide guidance in the evaluation of aquatic conditions and water quality across the province (Government of Alberta, 2018). Crop specific guidelines also exist for Cl^- concentrations in irrigation water ranging from 100 - 960 mg/L (Government of Alberta, 2018). Drinking water aesthetic objectives and operational guidance for Cl^- are >250 mg/L (Health Canada, 1987, 2017).

To fulfill the responsibility of reporting to the public on the condition of Alberta’s ambient environment, as required by the province’s Environmental Protection and Enhancement Act, Alberta Environment and Parks developed an online platform to report on key components of Alberta’s ambient environment (https://www.alberta.ca/condition-of-the-environment-water-indicators.aspx). This report presents the methods used to generate the information presented on the online platform for Cl^-. In particular, this report outlines the steps taken to obtain and prepare the data, assess the quality of the data and conduct the spatial and temporal analyses. Additionally, the results and discussion below are more comprehensive than what is available online.

Methods

Study Area

Alberta's diverse landscape includes multiple river basins (Figure 1). The Athabasca, Peace and Hay River watersheds are situated in Northern Alberta. The North Saskatchewan, Battle and Beaver River watersheds are found in Central Alberta. The Milk River watershed and the South Saskatchewan River basin are situated in Southern Alberta, the latter of which includes the Oldman, Bow and Red Deer River watersheds. More detailed information on Alberta's major rivers is available in State of the Watershed Reports or Watershed Atlas products typically generated by Watershed Planning and Advisory Councils (e.g. Fiera, 2013; Halliday, 2009; MPWA, 2015; MRWCC, 2013; North Saskatchewan Watershed Alliance, 2012).

Water Quality Sampling

AEP's Long-Term River Network (LTRN) program has been sampling surface water in the major rivers of Alberta, with the exception of the Hay River, since the 1970s. Routine monthly monitoring of Cl^- started in the early 1980s with regular monitoring occurring at 10 sites before 1990 (Figure 2). Over the last several decades, the LTRN program has expanded to include over 30 sites across ten watersheds.

AEP's Tributary Monitoring Network (TMN) generally samples surface water in smaller tributaries. Although water quality samples have been obtained sporadically from tributaries since the 1960s, the TMN program was initiated in April 2016 to provide comprehensive information on the quality of surface water in smaller, typically wadeable rivers and streams not currently sampled by the LTRN program (Kerr and Cooke, 2019).

The TMN program initially included over 60 sites in Southern Alberta and the Upper Athabasca River watershed (Figure 1). Although an expansion of the TMN program in the North Saskatchewan River through a partnership with EPCOR started in 2019, there is insufficient data (i.e. less than one year) to include these tributary sites in this report. In April 2019, sampling was suspended at TMN sites in the Upper Athabasca River basin owing to logistical constraints, and discontinued at four TMN sites in the Red Deer River watershed that were part of a focused study on metal dynamics in the badlands region. Although sampling was discontinued at these sites, they have three years of data and thus were included in this report. In total, 64 TMN sites were incorporated in the data analyses outlined below. Data from Alberta's Oil Sands region are collected under the Oil Sands Monitoring (OSM) program, and thus not included in this report. Data from monitored tributaries within the OSM region can be found online.

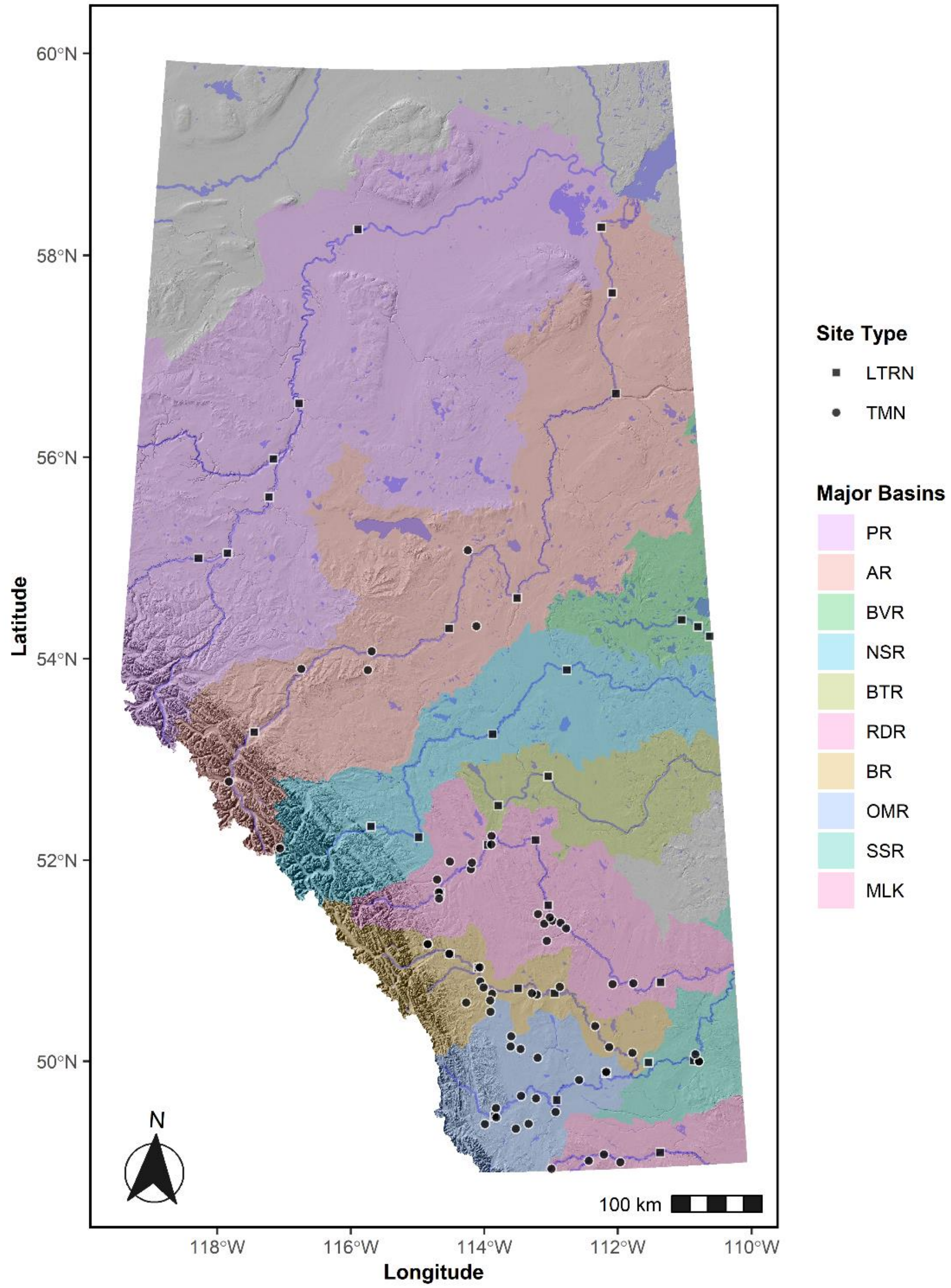

Figure 1: Location of all Long Term River Network (LTRN; triangle) and Tributary Monitoring Network (TMN; circle) water quality sampling stations along with the major watersheds of Alberta. The major watersheds include the Athabasca River (AR), Bow River (BR), Battle River (BTR), Beaver River (BVR), Milk River (MLK), North Saskatchewan River (NSR), the Peace River (PR), the Oldman River, the Red Deer River (RDR), and the South Saskatchewan River (SSR).

LTRN and TMN site locations are presented in Figure 1 with additional information provided in Appendix Table A1. Sampling protocols for the LTRN and TMN programs focus on the monthly collection of one litre grab samples of surface water with more information provided in AEP (2006). Data on surface water parameters generated by the LTRN and TMN programs supports the stewardship of Alberta's water resources, provincial evaluation and reporting products (e.g. Barrett et al., 2019; Chung et al., 2019), national water quality reports (Environment and Climate Change Canada, 2020), journal publications (e.g. Kerr and Cooke, 2017; Morales-Marín et al., 2017; Turnbull and Ryan, 2012) and other planning and reporting programs.

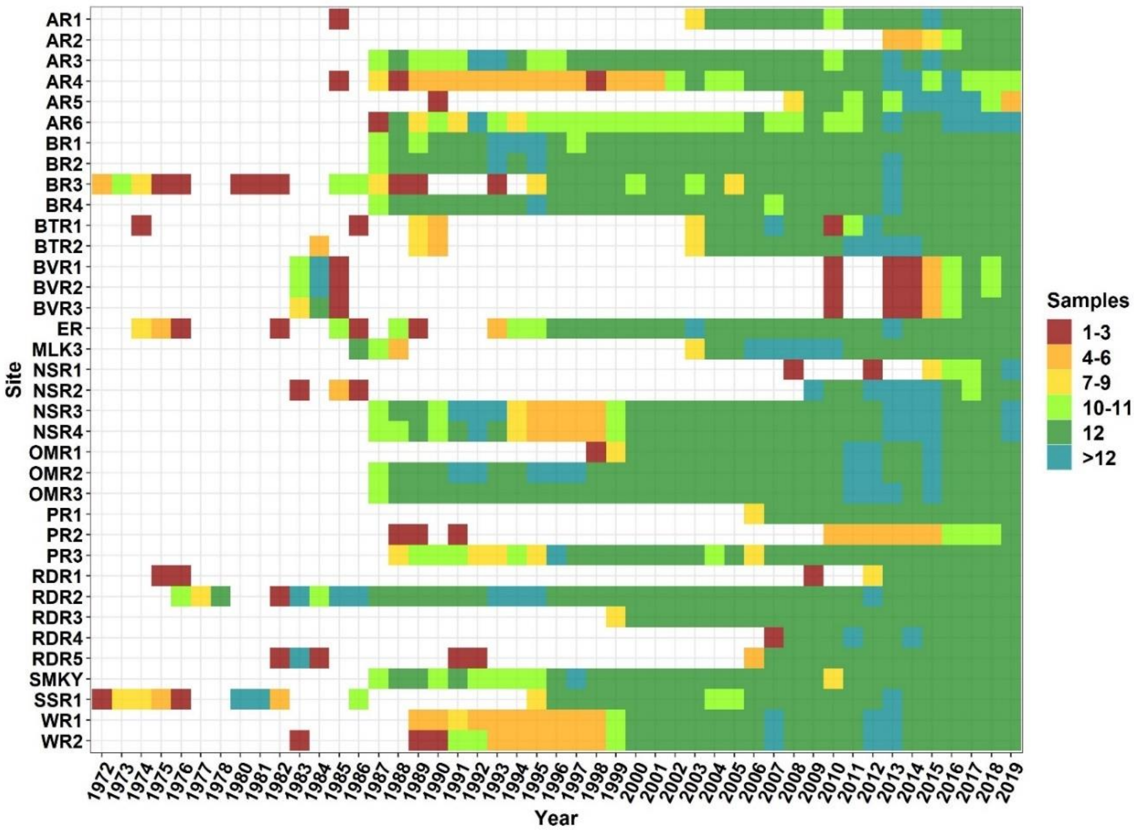

Figure 2: All annual Cl^- samples taken queried from the AEP Water Data System up to the end of 2019 for LTRN sites in the Athabasca River (AR), Bow River (BR), Battle River (BTR), Beaver River (BVR), Elbow River (ER), Milk River (MLK), North Saskatchewan River (NSR), Peace River (PR), Oldman River (OMR), Red Deer River (RDR), Smoky River (SMKY), South Saskatchewan River (SSR) and Wapiti River (WR).

Sample Analyses

Over the last 50 years, there have been six different analytical procedures with unique Valid Method Variables (VMVs) used to determine Cl^- concentrations (Figure 3). In the early 1970s, a titration method was used with mercuric nitrate and diphenylcarbazone indicators (VMV 17201). After 1975, Cl^- was predominantly analyzed via colourimetric methods with ferric ammonium sulphate and mercuric thiocyanate (VMV 17203) or ferric nitrate and mercury thiocyanate (VMV 17206) until around 2008 when the main analyses approach changed to the automated ferric thiocynate method (VMV 2003). Ion chromatography (VMV 17209) and flame photometry (VMV 102087) were also used sparingly between 1998 and 2012.

Research by AEP scientists on surface water in Albertan rivers demonstrated results from colourimetric analyses (VMVs 17203 & 17206), ion chromatography (VMV 17209) and the automated ferric thiocynate method (VMV 2003) are comparable (Kerr, 2017; Laceby et al., 2019). These different methodologies have different minimum detection limits (MDL) resulting in censored data, or data below the limits of detection, with MDLs ranging from 0.01 mg/L to 10 mg/L. The main MDL increased over time from 0.5 mg/L, predominantly with colourimetric methods (VMV 17203 & 17206), to 1.0 with the automated ferric thiocynate method (VMV 2003) (Table 1). Methods to address the MDL increase that occurred around 2008 are presented below.

Data Analyses

Quality Control

Data generated by the AEP lotic quality control (QC) program helps assess the quality of data generated by the LTRN and TMN programs. The AEP lotic QC program includes the sampling and analyses of: (i) field blank samples to examine the potential bias in environmental data from contamination during sampling and analysis processes; and (ii) duplicate samples to estimate the random error in environmental data resulting from processes in sample collection, storage and laboratory analyses (Laceby et al., 2022; Mueller et al., 2015; Riskin et al., 2018).

Methods for the QC analyses are found in the AEP lotic QC report for 84 water quality parameters from 2016 through 2019 (Laceby et al., 2022). The comprehensive analysis of field blank (n = 323) and duplicate samples (n = 318) contextualizes the quality of Cl^- data incorporated into the spatial and temporal analyses that provides the foundation for the Cl^- Condition of the Environment (CoE) report. The QC analyses only applies to the data generated with the automated ferric thiocynate method (VMV 2003).

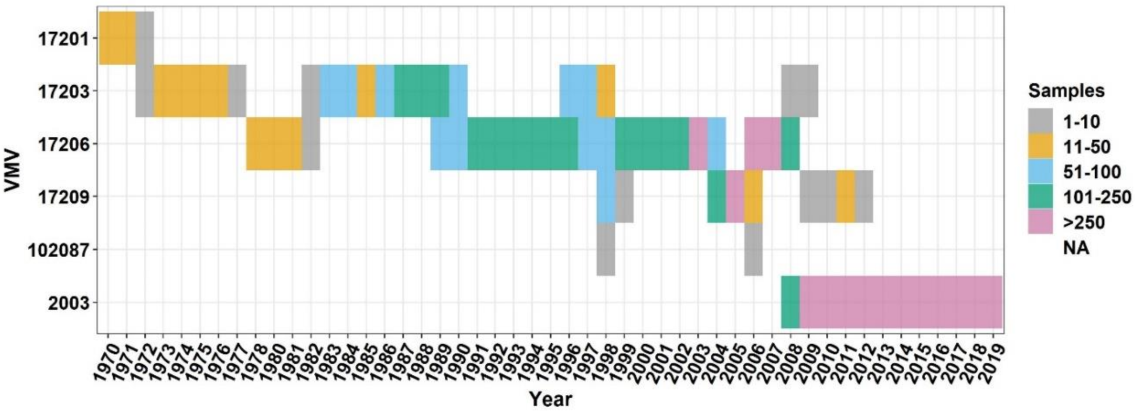

Figure 3: Valid Method Variables (VMVs) used over the history of LTRN monitoring across Alberta with the shading indicative of the number of sample numbers taken annually for each VMV. TMN samples are not included in this table as they were all collected with the 2003 VMV between 2016-2019.

Table 1: Valid Method Variables (VMVs) summary including the minimum detection limits (MDLs) that occur for each VMV along with the number of non detects for each VMV and the number of non detects for the various MDLs over the sampling period for the LTRN program.

VMV	Non-Detects	Detects	Total Samples	Detect Freq.	Min. Year	Max. Year	<0.01	<0.5	<1	<2	<10
2003	731	4067	4798	85%	2008	2019		4	724	1	2
17201	0	40	40	100%	1970	1972					
17203	50	961	1011	95%	1972	2009		1	49		
17206	109	3210	3319	97%	1978	2008	2	107			
17209	14	594	608	98%	1998	2012		14			
102087	0	11	11	100%	1998	2006					

Data preparation

Cl^- data was queried from the Government of Alberta's Water Data System in May 2020. The data was filtered to include all samples taken from January 1, 2016 to December 31, 2019 for projects focused on obtaining routine monthly water quality samples. During the study period, there were minor LTRN site modifications. The sampling location for the Red Deer River Site 4 at Morrin Bridge shifted from the center of the river (Station No: AB05CE0010) to the right bank (Station No: AB05CE0009) in 2007. The North Saskatchewan River Site 2 relocated from upstream of Rocky Mountain House (Station No: AB05DC0051) in 2008 to 1 km upstream of the confluence with the Clearwater River (Station No: AB05DC0050). The Athabasca River Site 7, located downstream of Devil's Elbow at the winter road crossing (Station No: AB07DD0105), provides a surrogate for inaccessible ice-covered season (November-March) samples for the Athabasca River Site 6 at Old Fort from the late 1990s to 2015.

Additionally, there were multiple instances where more than one sample was in the dataset for a given month at a particular site. There were around 50 instances where two samples occurred in one month for a site where there was a clear intention for one of these samples to reflect the previous or following month's routine monitoring sample. A new chronological month category was created to reflect the intended sample month in these instances where one of the two samples was obtained within five days of the intended month. There was also potentially un-flagged QC data including 100 duplicate and 18 triplicate samples. Furthermore, there were 20 instances where two samples were taken in one month that were neither duplicates nor clearly intended to represent the previous or following month. The monthly median of these double, duplicate and triplicate samples was incorporated into the spatial and temporal analyses.

Spatial Analyses

To facilitate the spatial comparison of Cl^- across monitoring sites, it is ideal to compare sites with data collected over a relatively similar period of time. Owing to the fact that the TMN and LTRN programs cover substantially different periods, Cl^- data will be presented for the time period where samples were obtained for both programs (i.e. January 1, 2016 to December 31, 2019). Owing to the challenges of obtaining water samples on smaller, potentially frozen, tributaries during winter, a significant proportion of TMN sites do not have data for the ice-covered season (Figure 4). Tributary sites may also have insufficient water for sampling during drier summer periods.

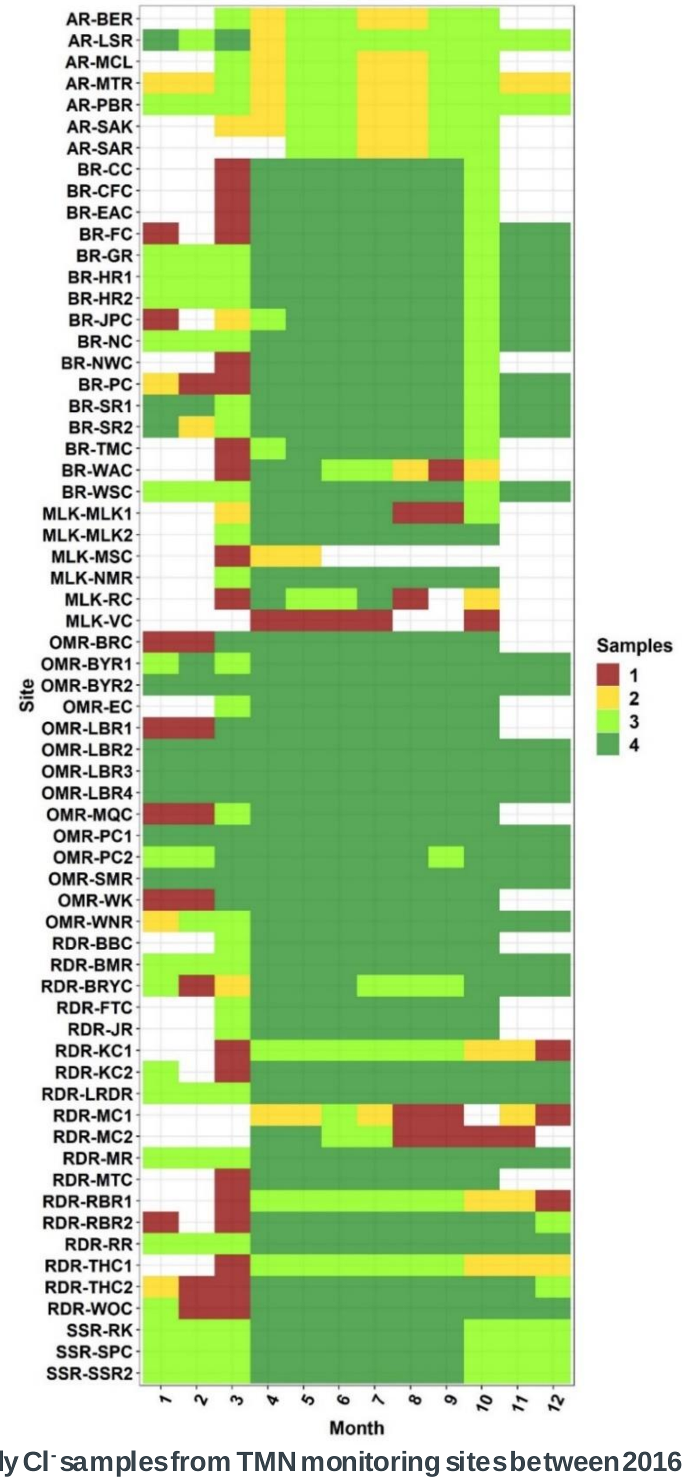

Figure 4: Monthly Cl⁻ samples from TMN monitoring sites between 2016 and 2019. Detailed site information including acronyms are listed in Table A1

Accordingly, sites were included in this spatial analysis if they had at least half of the potential ice-covered and open water (i.e. April through October) samples during the study period. This approach included all LTRN sites and all but three TMN sites that were missing more than 50% of the potential samples during the open water and ice-covered seasons (i.e. Miners Coulee and Verdigris Creek in the Milk River watershed and Michichi Creek Site 1 in the Red Deer River watershed). Sites where samples were not collected throughout the winter are marked with an asterisk (*) in the text and tables presented below.

Although the comparisons between sites with and without ice-covered data may introduce some bias into the inter-site comparisons, the fundamental objective of this spatial analysis was to maximize the number of sites assessed to report on the condition of Alberta's ambient environment as broadly as possible. In total, 97 LTRN and TMN sites were included in this spatial analysis providing a comprehensive comparison of Cl^- concentrations in Alberta including main stem and tributary sites over the four-year period.

All Cl^- data in the spatial analyses were determined with the automated ferric thiocynate method (VMV 2003). As over 99% of the censored data had the same MDL (<1.0 mg/L), this MDL was substituted in the data set, with the exception of two samples which had MDLs of <10 mg/L that were removed prior to analysis. Box plots of the data with standard and log scales illustrate the variation in Cl^- in each of the basins. The line in the middle of the box depicts the median (e.g. middle) of the dataset, the box edges represent the 25th and 75th percentiles and the area inside the box covers the interquartile range. The whiskers extend outward from the box to the highest or lowest value that is within 1.5 times the interquartile range. Data beyond the whiskers depict outliers, which are plotted as points on the boxplots (See Figure 5 for an example below).

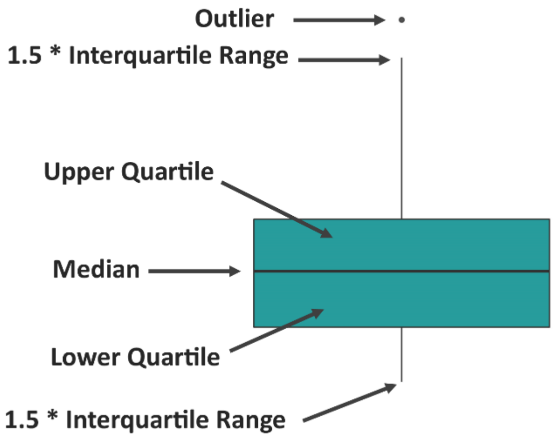

Figure 5: Illustration of different values incorporated into the box plots presented below

Maps of median and maximum Cl^- concentrations along with Cl^- detection frequency for the LTRN and TMN sites illustrate spatial Cl^- variation across Alberta. The percentile of each site's median and maximum Cl^- concentrations is used to group sites into bins based on the percentiles of all sites included in the analyses (i.e. 0-25, 25-50, 50-75 and 75-100 percentiles). Additional bins were created to reflect any potential irrigation (>100 mg/L), chronic (>120 mg/L) and acute (>640 mg/L) guideline exceedances. The objective of using percentiles to bin the Cl^- mapping results is to let the data, rather than the data analysts, drive the presentation of the results. For detection frequency, bins were created that are relevant to the interpretation of results (i.e. 0-20, 20-50, 50-80, and 80-100%). All analyses, figures and map production were conducted with R 4.0.5 in RStudio 1.2.5042 along with numerous R-packages.

Temporal Analyses

The objective of the temporal analyses is to capitalize on the long-term data sets collected at LTRN sites in order to investigate trends of Cl^- over time. Sites were selected for the trend analyses if they have more than 10 years of monthly monitoring data (*n* = 30). Only one of the excluded sites (*n* = 7) had more than 5 years of regular monthly data (Figure 2), the Red Deer River Site 1 at Sundre, which will be discussed in the presentation of results.

Multiple analyses methods with unique VMVs were used to determine Cl^- concentrations over the last 30 years (Figure 3). To facilitate the inclusion of different analyses, the highest main MDL (1.0 mg/L) was substituted for all censored data. Additionally, all data below the highest main MDL was changed to 1.0 mg/L to address the main MDL increase from 0.5 mg/L to 1.0 mg/L that occurred around 2008. Two samples which had MDLs of <10 mg/L were removed from the data set. Trend analyses were conducted only for sites with a detection frequency >80% (Helsel, 2011), including cases where the main MDL after 2008 was substituted for values <1.0 mg/L. Accordingly, sites with more than 20% censored data were omitted from this analyses.

Cl^- data for sites in the trend analyses were assessed for heterogeneity with the Van Belle-Hughes heterogeneity test (Van Belle and Hughes, 1984) and serial dependence with the Breusch-Godfrey test (Breusch, 1978; Godfrey, 1978). For sites with censored data, seasonality was determined with a test for censored empirical cumulative distribution functions differences (Helsel, 2005). For sites without censored data, a Kruskal-Wallis test (Kruskal and Wallis, 1952) determined whether or not the data had significant seasonal variation. This preliminary assessment determined whether a Seasonal Mann-Kendall (SMK) with or without continuity correction, or a Mann-Kendall (MK) test with or without pre-whitening was used for the trend analysis at each site. Where non-seasonal data was not serially dependent, trends were assessed with a MK test. For non-seasonal data that was serially dependent, the data was prewhitened before running the MK test. Where seasonality was evident, with or without serial dependency, a SMK test was conducted without or with a continuity correction respectively.

Owing to the geographical extent of Alberta, it is difficult to conduct these trend analyses with four standardized seasons as a factor in the analyses as the timing of the seasons can vary significantly from the south (49°N) to the north (60°N) of the province. Similarly, including a freshet season that covers the snow-melt run off in the trend analyses over this large region is difficult as the local snow melt and montane snow-melt timing can vary across Alberta. Accordingly, the most consistent seasonal variation in the study area is the delineation of the open water season from April through October and the ice-covered season from November through March. This seasonal division aligns with the periods chosen for the South Saskatchewan River Water Quality Management Framework (GOA, 2014), which was based on temperature and precipitation patterns.

As running trend tests with median values for these two seasons reduces the resolution of the data included in the analyses, a trend analysis was first run on all annual samples, using monthly data as the seasonal input for the tests outlined above. Second, seasonality tests were conducted to investigate whether there were significant differences in Cl^- in the open water and ice-covered seasons. Where significant differences were evident, third, all the aforementioned trend assumption and trend tests were conducted on both the ice-covered and open water seasons with monthly data used as the seasonal input in the analyses.

A significance level of 0.05 was adopted for all statistical analyses. The percent change per year (% yr^{-1}) was calculated by dividing the site's slope, as determined by the appropriate trend test, by the site's median Cl^- concentration over the study period. More detailed information on the methods used in this trend analysis can be found elsewhere (Helsel, 2011; Helsel and Hirsch, 1992; McKenzie et al., 2015), along with specific case studies in Alberta including research from the South Saskatchewan River Basin (Kerr, 2017) and the North Saskatchewan River (Laceby et al., 2019). Temporal trends with R 4.0.5 in RStudio 1.2.5042 along with numerous R-packages.

Results

Data Quality

Cl^- was detected at concentrations greater than the MDL (1.0 mg/L) in 3% of the field blank samples. The 90-percent Upper Confidence Limit (UCL) for the field blank samples is below the MDL up to the 97th percentile and the 90-percent UCL for Cl^- in the field blank samples at their 95th percentile (B95-90 value) is 1.0 mg/L (Figure A1). Therefore, extraneous contamination of Cl^- data with at least 90% confidence is estimated to be below detection in 97% of the sample population, exceeding 1.0 mg/L in no more than 3% of the samples. Extraneous contamination may affect the interpretation of the Cl^- environmental data up to 10 times the B95-90 value, or up to 10 mg/L. Accordingly, 69% of the samples, or the percent below 10 mg/L in the environmental data, may have some degree of extraneous contamination that could affect interpretation. As less than 3% of the samples in the environmental data are anticipated to be contaminated (i.e. the percent of field blanks above the MDL), it is estimated that there is a potential for 2% of the Cl^- environmental data to have extraneous contamination that may affect data interpretation. The field blank analysis determined that Cl^- is in Category C, the third highest level of potential for contamination (Table A2). Parameters listed in Category C have environmental data that is within an order of magnitude of the field blank data indicating that some extraneous bias may exist in the data and this contamination could potentially be relevant to the interpretation of environmental data.

For the duplicate analyses, there were two approaches to assessing the variability of the Cl^- data: i) variability in Cl^- detection and ii) variability in the duplicate samples relative to the environmental data based on the application of bias corrected log-log regression models. Regarding the variability in analyte detection, for the 318 duplicates, 269 had two detects, 37 had two non-detects and 12 had inconsistent detections resulting in a 4% inconsistent detection rate and a 90-percent UCL for the percentage of inconsistent detects of 6%. Cl^- is listed in Category B for the variability in analyte detection analyses indicative of generally low variability in the detection frequency for the duplicate samples. For variability in the duplicate samples relative to the environmental data analyses, Cl^- is again in Category B where the application of a bias correction factor to the log mean and log standard deviation of the duplicate samples determined that there is a mean confidence interval for all percentiles of the environmental Cl^- data of 10%. Variables belonging to Category B have a variability that is typically within or close to that of internal laboratory standards.

Spatial Analyses

In the Peace River basin, Cl^- was detected in <95% of samples at four out of the six LTRN sites monitored, including the Peace River Site 1 near the Shaftesbury Ferry (27%), the Wapiti River Site 1 at the Highway 40 bridge (54%), the Peace River Site 2 above the confluence with the Whitemud River (60%) and the Peace River Site 3 at Fort Vermilion (63%) (Figure 6, Table 2). Median Cl^- concentrations in this Northern Albertan basin ranged from around 1 mg/L at the most upstream site locations on the Peace and Wapiti Rivers to 5.3 mg/L at the downstream Wapiti Site 2 above the confluence with the Smoky River (Figures 7 & 8, Table 2). Maximum Cl^- concentrations varied from 2.3 mg/L at the Peace River Site 1 to 73 mg/L at the Wapiti River Site 2 (Figures 7 & 9, Table 2). In general, Cl^- concentrations slightly increase progressing downstream in the Wapiti and Peace Rivers. None of the samples in the Peace River basin exceeded the Cl^- irrigation, PAL acute or PAL chronic guidelines during the study period.

In the Athabasca River watershed, there were seven TMN sites and six LTRN sites included in this analysis. Detection frequencies for Cl^- were <20% at one upstream site: the Sunwapta River* (* indicates sites with predominantly open water samples) downstream of Sunwapta Lake (0%). Three other sites had detection frequencies less than 90% including the Berland River* upstream of the confluence with the Athabasca River (24%), the Athabasca River Site 1 at Old Entrance (29%) and the Miette River at Highway 16 (48%) (Figures 6, Table 2). Median Cl^- concentrations at all LTRN and TMN sites ranged from 1.0 mg/L at four sites (the Sunwapta River*, the Berland River*, the Miette River and the Athabasca River Site 1 at Old Entrance) to 16.0 mg/L at the Athabasca River Site 5 above the Firebag River (Figures 8 & 10, Table 2). Nine out of the 13 sites had maximum Cl^- concentrations <10 mg/L (Table 2, Figures 9 & 10). The four sites with maximum Cl^- concentrations >10 mg/L were the Mcleod River* upstream of the confluence with Groat Creek (14 mg/L), the Pembina River near Jarvie (15 mg/L), the Athabasca River Site 6 at Old Fort (40 mg/L) and the Athabasca River above the Firebag River (75 mg/L). There were no guideline exceedances for the LTRN and TMN water quality samples taken in the Athabasca River watershed during the study period.

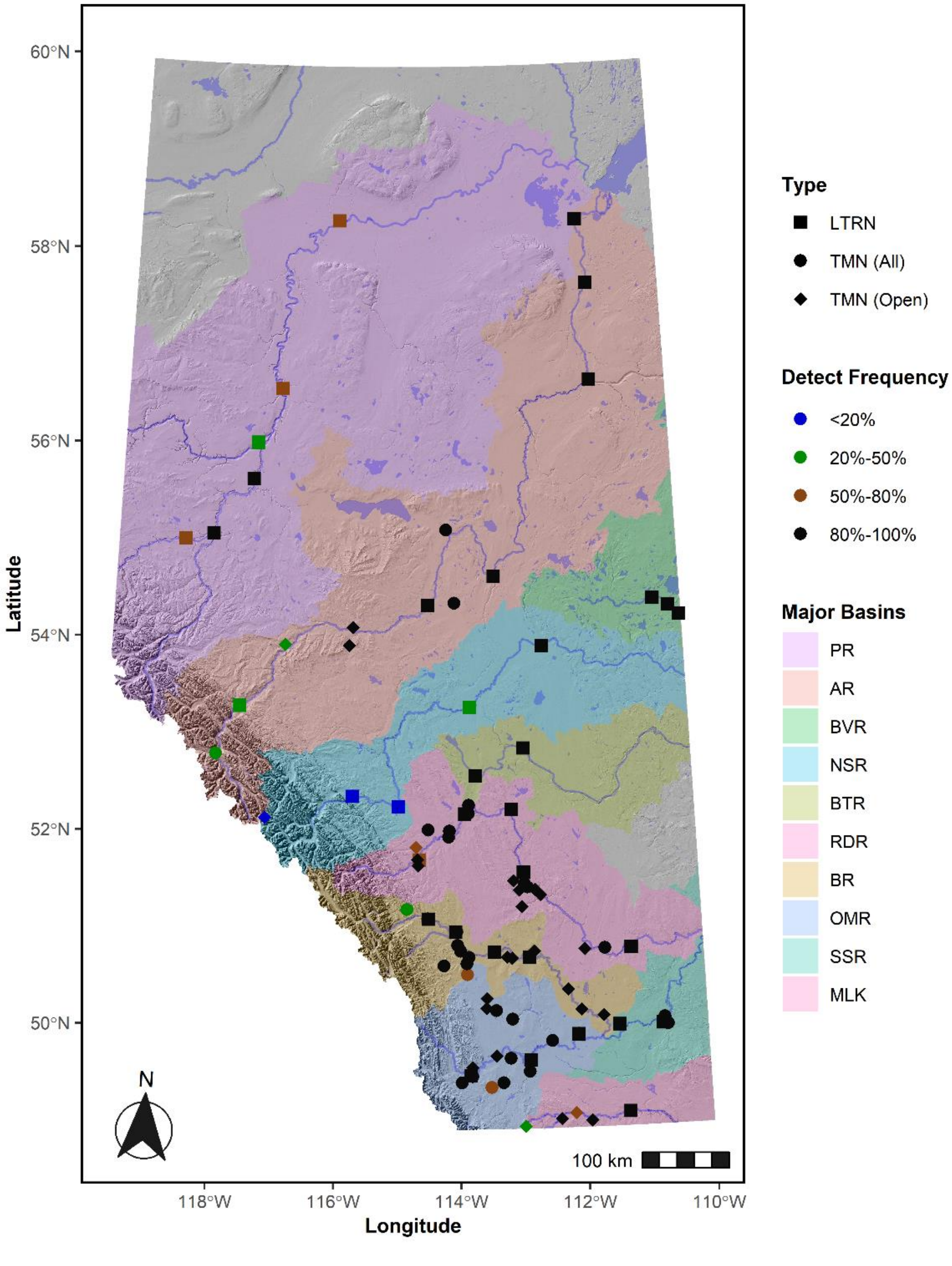

Figure 6: Map of the detection frequency of Cl^- at the LTRN and TMN sites. TMN (All) indicates that samples were obtained generally throughout the year whereas TMN (Open) indicates that samples were predominantly obtained during the open water season. Acronym information for the major basins is listed in the Acronyms and Abbreviations.

Table 2: Summary of the spatial analyses results for the LTRN and TMN sites between 2016-2020 including the number of samples below the limits of detection (Non-Detects), samples that detected Cl^- (Detects), the total number of samples (*n*), the detection frequency (Detect. Freq), along with the mean, median, maximum (Max), and minimum (Min) cl^- at each site. Asterisks (*) in the Site ID column indicates sites with predominantly open season water samples.

Site ID	Site Name	Non-Detects	Detects	n	Detect Freq.	Mean (mg/L)	Median (mg/L)	Max. (mg/L)
AR-AR1	ATHABASCA RIVER-AT OLD ENTRANCE TOWN SITE	34	14	48	29%	1.1	1.0	1.6
AR-AR2	ATHABASCA RIVER-AT VEGA FERRY (KLONDYKE)	1	45	46	98%	3.1	2.6	8.2
AR-AR3	ATHABASCA RIVER-AT TOWN OF ATHABASCA	2	46	48	96%	2.8	2.7	6.8
AR-AR4	ATHABASCA RIVER-US FORT MCMURRAY	0	43	43	100%	4.1	3.9	9.7
AR-AR5	ATHABASCA RIVER-TRANSECT ABOVE THE FIREBAG RIVER	0	41	41	100%	21	16.0	75
AR-AR6	ATHABASCA RIVER - OLD FORT AND DEVILS ELBOW	0	46	46	100%	16	13.0	40
AR-BER*	BERLAND RIVER-US OF THE CONFLUENCE WITH ATHABASCA RIVER	16	5	21	24%	1.0	1.0	1.3
AR-LSR	LESSER SLAVE RIVER-9.5 KM US OF ATHABASCA RIVER CONFLUENCE	0	37	37	100%	2.3	2.1	5.9
AR-MCL*	MCLEOD RIVER-US OF THE CONFLUENCE WITH GROAT CREEK	0	21	21	100%	3.2	2.0	14.0
AR-MTR	MIETTE RIVER-AT WSC GAUGE AT HWY 16	15	14	29	48%	1.4	1.0	3.0
AR-PBR	PEMBINA RIVER-AT WSC GAUGE NEAR JARVIE	0	33	33	100%	5.6	4.9	15
AR-SAK*	SAKWATAMAU RIVER-AT WSC GAUGE AT HWY 32	2	18	20	90%	2.0	1.4	8.6
AR-SAR*	SUNWAPTA RIVER-DOWNSTREAM OF SUNWAPTA LAKE	16	0	16	0%	1.0	1.0	1.0
BR-BR1	BOW RIVER-AT COCHRANE	1	47	47	100%	3.4	2.4	47.0
BR-BR2	BOW RIVER-BELOW CARSELAND DAM	1	47	47	100%	20	16	83
BR-BR3	BOW RIVER-AT CLUNY	0	48	48	100%	19	17	53
BR-BR4	BOW RIVER-NEAR RONALANE BRIDGE	0	48	48	100%	21	18	65
BR-CC*	COAL CREEK-12 MILE WEST OF BOW CITY	0	28	28	100%	16	14	41
BR-CFC*	CROWFOOT CREEK-ON HWY 1	0	28	28	100%	19	17	48
BR-EAC*	EAST ARROWWOOD CREEK-NEAR THE MOUTH	0	28	28	100%	11	11	13
BR-ER	ELBOW RIVER-AT 9TH AVE BRIDGE	0	48	48	100%	26	16	220
BR-FC	FISH CREEK-NEAR THE MOUTH NE	0	37	37	100%	109	74	690
BR-GR	GHOST RIVER-ABOVE CONFLUENCE WITH WAIPAROUS CREEK	30	14	44	32%	1.1	1.0	1.7
BR-HR1	HIGHWOOD RIVER-DS OF HIGH RIVER	11	33	44	75%	1.5	1.4	4.5
BR-HR2	HIGHWOOD RIVER-AT HWY 552	0	44	44	100%	7.3	5.5	32
BR-JPC	JUMPINGPOUND CREEK-NEAR MOUTH	0	37	37	100%	6.0	5.0	21
BR-NC	NOSE CREEK-NEAR THE MOUTH-MEMORIAL DRIVE	0	44	44	100%	192	145	770
BR-NWC*	NEW WEST COULEE-AT HWY 36 CROSSING	0	28	28	100%	14	13	27
BR-PC	PINE CREEK-NEAR THE MOUTH	0	39	39	100%	89	94	190
BR-SR1	SHEEP RIVER-APPROXIMATELY 1.0 KM DS WSC GAUGE	7	39	46	85%	1.9	1.3	14.0

Site ID	Site Name	Non-Detects	Detects	n	Detect Freq.	Mean (mg/L)	Median (mg/L)	Max. (mg/L)
BR-SR2	SHEEP RIVER-1.6 KM DS OF HWY 2	0	44	44	100%	10.1	7.7	27
BR-TMC*	TWELVE MILE CREEK-NEAR CECIL AT BRIDGE	0	27	27	100%	15	15	21
BR-WAC*	WEST ARROWWOOD CREEK-DS OF SYPHON	0	20	20	100%	32	36	42
BR-WSC	WAIPAROUS CREEK-ABOVE CONFLUENCE WITH GHOST RIVER	22	22	44	50%	1.2	1.0	2.4
BTR-BTR1	BATTLE RIVER-AT NORTH END OF DRIEDMEAT LAKE	0	48	48	100%	65.2	61.0	160.0
BTR-BTR2	BATTLE RIVER-APPROX 2 KM DS HWY 53	0	48	48	100%	11.4	10.0	21.0
BVR-BVR1	BEAVER RIVER-AT HIGHWAY 892 BRIDGE NORTH OF ARDMORE	0	45	45	100%	4.5	4.8	8.9
BVR-BVR2	BEAVER RIVER-AT HWY 28 BRIDGE NEAR BEAVER CROSSING	0	45	45	100%	5.7	5.4	11.0
BVR-BVR3	BEAVER RIVER-AT GRAVEL PIT, 6 KM US OF AB-SK BORDER	0	46	46	100%	6	6	14
MLK-MLK1*	MILK RIVER-NEAR WESTERN BOUNDARY, AT HWY 501	0	23	23	100%	5	3.5	39
MLK-MLK2*	MILK RIVER-US OF TOWN OF MILK RIVER	11	20	31	65%	2	1	5.9
MLK-MLK3	MILK RIVER-AT HWY 880	6	42	48	88%	5.3	4.5	15.0
MLK-NMR*	NORTH MILK RIVER-UPSTREAM OF HWY 501	18	13	31	42%	1.4	1.0	3.3
MLK-RC*	RED CREEK-NEAR THE MOUTH	0	18	18	100%	32.7	35.0	41
NSR-NSR1	NORTH SASKATCHEWAN RIVER-AT SAUNDERS CAMPGROUND	38	8	46	17%	1.1	1.0	2.3
NSR-NSR2	NORTH SASKATCHEWAN RIVER-US OF ROCKY MOUNTAIN HOUSE	40	6	46	13%	1.0	1.0	1.7
NSR-NSR3	NORTH SASKATCHEWAN RIVER-AT DEVON	29	19	48	40%	1.2	1.0	3.4
NSR-NSR4	NORTH SASKATCHEWAN RIVER-AT PAKAN BRIDGE	0	48	48	100%	5.4	4.9	11
OMR-BRC*	BEAVER CREEK-WEST OF PEIGAN INDIAN RESERVE	0	34	34	100%	6.6	6.3	16
OMR-BYR1	BELLY RIVER-JUS OF THE CONFLUENCE WITH THE WATERTON RIVER-BR3	6	40	46	87%	1.6	1.5	5.6
OMR-BYR2	BELLY RIVER-NEAR CONFLUENCE WITH OLDMAN RIVER	3	45	48	94%	1.8	1.8	5.0
OMR-EC*	EXPANSE COULEE-ADJACENT TO HWY 36 BRIDGE CROSSING OLDMAN RIVER	0	31	31	100%	32	23	130
OMR-LBR1*	LITTLE BOW RIVER-AT HWY 533 EAST OF NANTON	0	34	34	100%	4.8	3.4	19
OMR-LBR2	LITTLE BOW RIVER-DS OF TWIN VALLEY RESERVOIR	0	48	48	100%	6.9	6.4	29.0
OMR-LBR3	LITTLE BOW RIVER-AT CARMANGAY	0	48	48	100%	7.8	7.1	38.0
OMR-LBR4	LITTLE BOW RIVER-NEAR THE MOUTH	0	48	48	100%	10.8	11.0	28
OMR-MQC*	MOSQUITO CREEK-AT HWY 529 EAST OF PARKLAND	0	33	33	100%	11.0	6.5	80
OMR-OMR1	OLDMAN RIVER-NEAR BROCKET	6	42	48	88%	1.5	1.4	3.5
OMR-OMR2	OLDMAN RIVER-ABOVE LETHBRIDGE AT HWY 3	0	48	48	100%	4.1	2.6	37
OMR-OMR3	OLDMAN RIVER-AT HWY 36 BRIDGE NORTH OF TABER	0	48	48	100%	6.0	4.4	42.0
OMR-PC1	PINCHER CREEK-AT PINCHER CREEK	8	40	48	83%	1.6	1.5	3.0
OMR-PC2	PINCHER CREEK-AT HWY 3 NEAR THE MOUTH	0	45	45	100%	8.2	5.0	58.0
OMR-SMR	ST. MARY RIVER-NEAR CONFLUENCE WITH OLDMAN RIVER	3	45	48	94%	2.1	1.7	5.5

Site ID	Site Name	Non-Detects	Detects	n	Detect Freq.	Mean (mg/L)	Median (mg/L)	Max. (mg/L)
OMR-WK*	WILLOW CREEK-AT SEC HWY 811	0	34	34	100%	5.2	4.8	12.0
OMR-WNR	WATERTON RIVER-ADJACENT TO SEC HWY 810 BRIDGE-WR2	17	27	44	61%	1.3	1.1	4.3
PR-PR1	PEACE RIVER-US SMOKY RIVER NEAR SHAFTESBURY FERRY TRANSECT	35	13	48	27%	1.2	1.0	2.3
PR-PR2	PEACE RIVER-1.5 KM ABOVE CONFLUENCE OF WHITEMUD RIVER	16	24	40	60%	1.3	1.1	2.8
PR-PR3	PEACE RIVER-AT FORT VERMILION	18	30	48	63%	1.5	1.2	5.6
PR-SMKY	SMOKY RIVER-AT WATINO	2	46	48	96%	3.4	2.7	9.2
PR-WR1	WAPITI RIVER-AT HWY #40 BRIDGE	22	26	48	54%	2.0	1.1	32.0
PR-WR2	WAPITI RIVER-ABOVE CONFLUENCE WITH SMOKY RIVER	0	48	48	100%	8.3	5.3	73
RDR-BBC*	BEARBERRY CREEK-NEAR SUNDRE (NEAR WIER)REMOTE LOGGER SITE	0	31	31	100%	4.6	4.4	12
RDR-BMR	BLINDMAN RIVER-NEAR THE MOUTH, AT HWY 2A	0	45	45	100%	16	15	29
RDR-BRYC	BERRY CREEK-NEAR MOUTH	0	39	39	100%	15	12	29
RDR-FTC*	FALLEN TIMBER CREEK-NEAR MOUTH	2	29	31	94%	1.9	1.6	5.8
RDR-JR*	JAMES RIVER-NEAR JAMES RIVER BRIDGE	10	21	31	68%	1.8	1.3	17
RDR-KC1*	KNEEHILLS CREEK-AT RANGE ROAD 221	0	24	24	100%	29	27	43
RDR-KC2	KNEEHILLS CREEK-NEAR THE MOUTH AT HWY 575	0	40	40	100%	29	27	56
RDR-LRDR	LITTLE RED DEER RIVER-WEST OF INNISFAIL	0	45	45	100%	7.6	7.6	14.0
RDR-MC2*	MICHICHI CREEK-NEAR THE MOUTH	0	18	18	100%	34	18	190
RDR-MR	MEDICINE RIVER-AT HWY 54	0	45	45	100%	8.4	8.7	15
RDR-MTC*	MATZHIWIN CREEK-AT HWY 36	0	29	29	100%	21	18	41
RDR-RBR1*	ROSEBUD RIVER-AT ROSEBUD, HWY 840	0	24	24	100%	30	26	76
RDR-RBR2*	ROSEBUD RIVER-AT HWY 10	0	37	37	100%	31	32	64
RDR-RDR1	RED DEER RIVER-AT SUNDRE	13	35	48	73%	1.3	1.2	2.2
RDR-RDR2	RED DEER RIVER-1 KM US HWY 2 BRIDGE	0	48	48	100%	3.0	2.4	13
RDR-RDR3	RED DEER RIVER-AT NEVIS BRIDGE	0	48	48	100%	6.4	6.6	13.0
RDR-RDR4	RED DEER RIVER-AT MORRIN BRIDGE	0	48	48	100%	6.9	6.9	13
RDR-RDR5	RED DEER RIVER-DS DINOSAUR PROV PARK AT HWY 884 NEAR JENNER	0	48	48	100%	9.1	8.8	16
RDR-RR	RAVEN RIVER-AT RAVEN	0	45	45	100%	3.7	3.5	5.9
RDR-THC1*	THREEHILLS CREEK-AT HWY 836	0	25	25	100%	30	21	200
RDR-THC2	THREEHILLS CREEK-NEAR MOUTH AT HWY 837	0	39	39	100%	42	22	700
RDR-WOC	WASKASOO CREEK-NEAR CONFLUENCE WITH RED DEER RIVER	0	41	41	100%	101	78	870
SSR-RK	ROSS CREEK-NEAR MOUTH	0	42	42	100%	22	14.5	86
SSR-SPC	SEVEN PERSONS CREEK-NEAR THE MOUTH	0	42	42	100%	36	19.5	220
SSR-SSR1	SOUTH SASKATCHEWAN RIVER-ABOVE MEDICINE HAT	0	48	48	100%	15	13	39
SSR-SSR2	SOUTH SASKATCHEWAN RIVER-BELOW MEDICINE HAT	0	42	42	100%	12.9	11.0	32

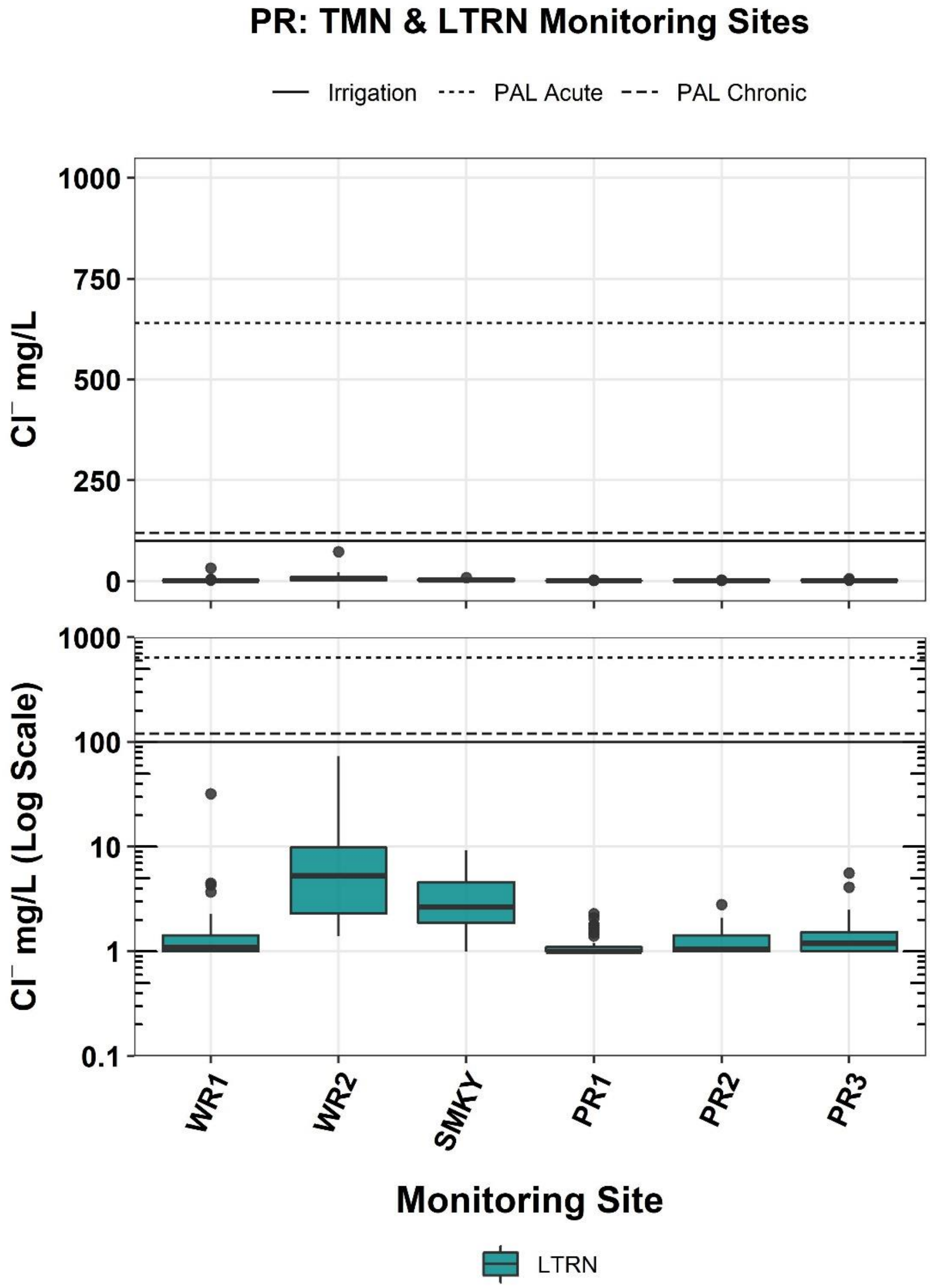

Figure 7: Cl^- concentrations for sites in the Peace River basin from January 2016 to December 2019 with site acronym information presented in the Table 2.

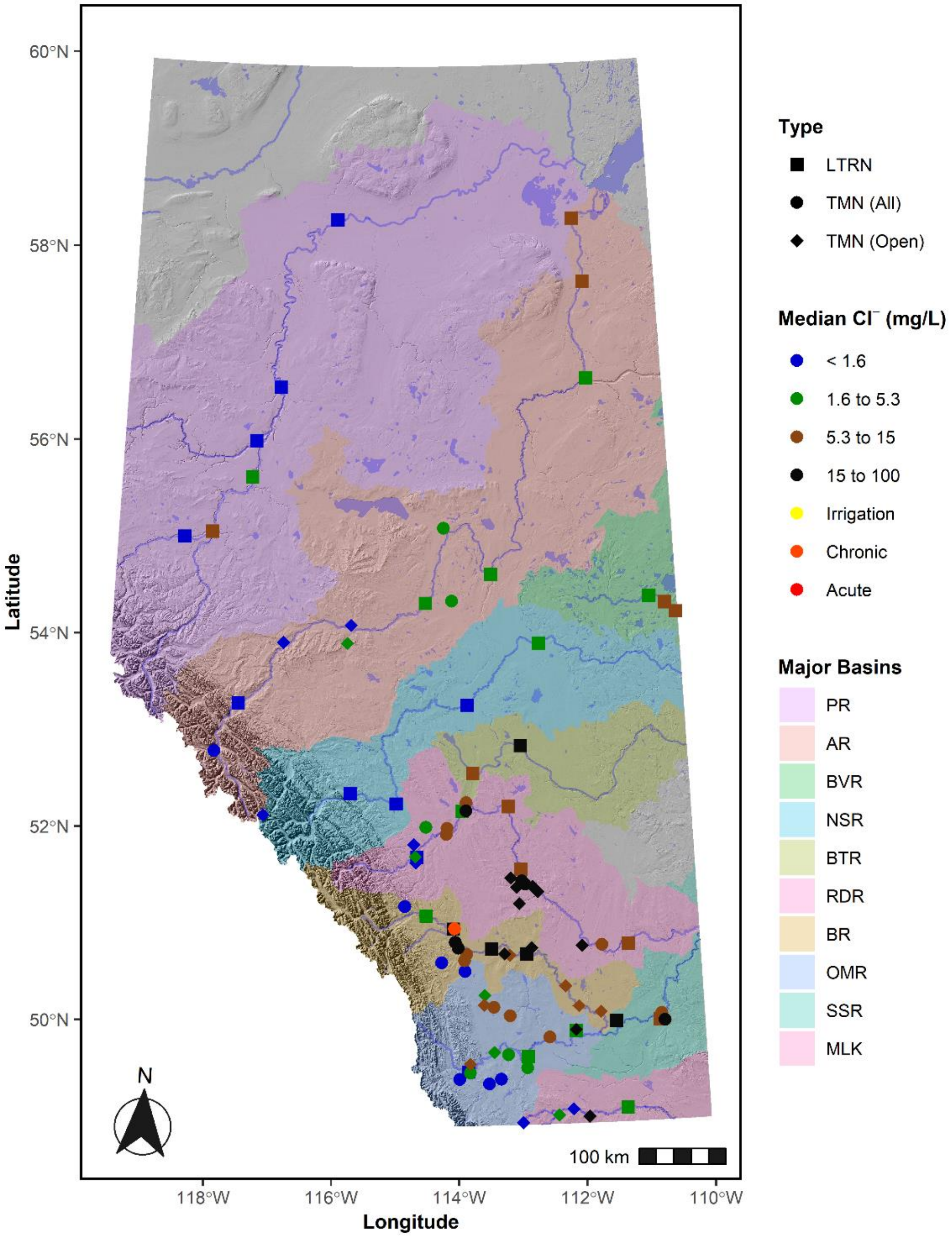

Figure 8: Map of the median Cl^- concentrations at LTRN and TMN sites from 2016 to the end of 2019. TMN (All) indicated that samples were obtained generally throughout the year whereas TMN (Open) indicates that samples were predominantly obtained during the open water season. Acronym information for the major basins is listed in the Acronyms and Abbreviations.

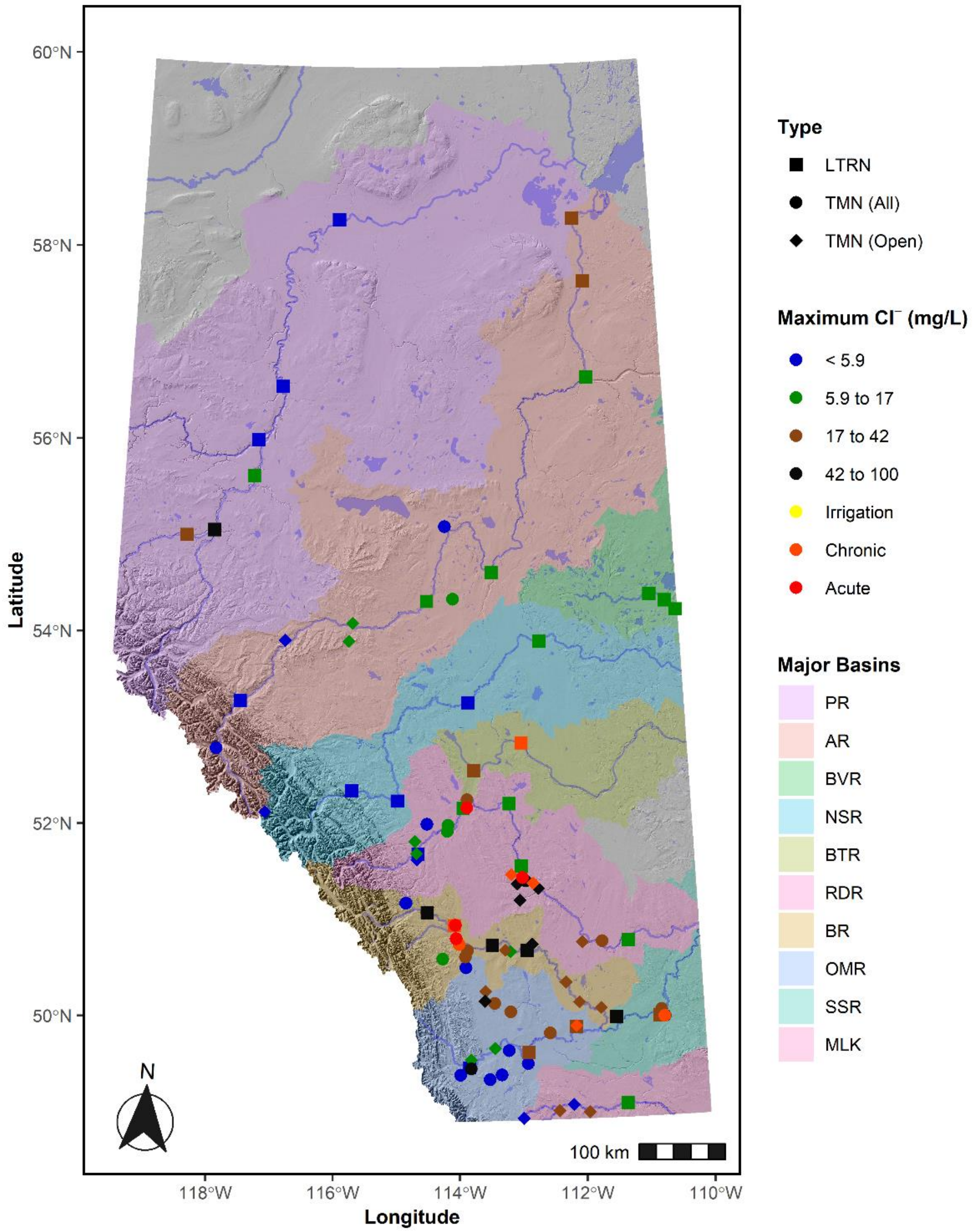

Figure 9: Map of the maximum Cl^- concentrations at LTRN and TMN sites from 2016 to the end of 2019. TMN (All) indicated that samples were obtained generally throughout the year whereas TMN (Open) indicates that samples were predominantly obtained during the open water season. Acronym information for the major basins is listed in the Acronyms and Abbreviations.

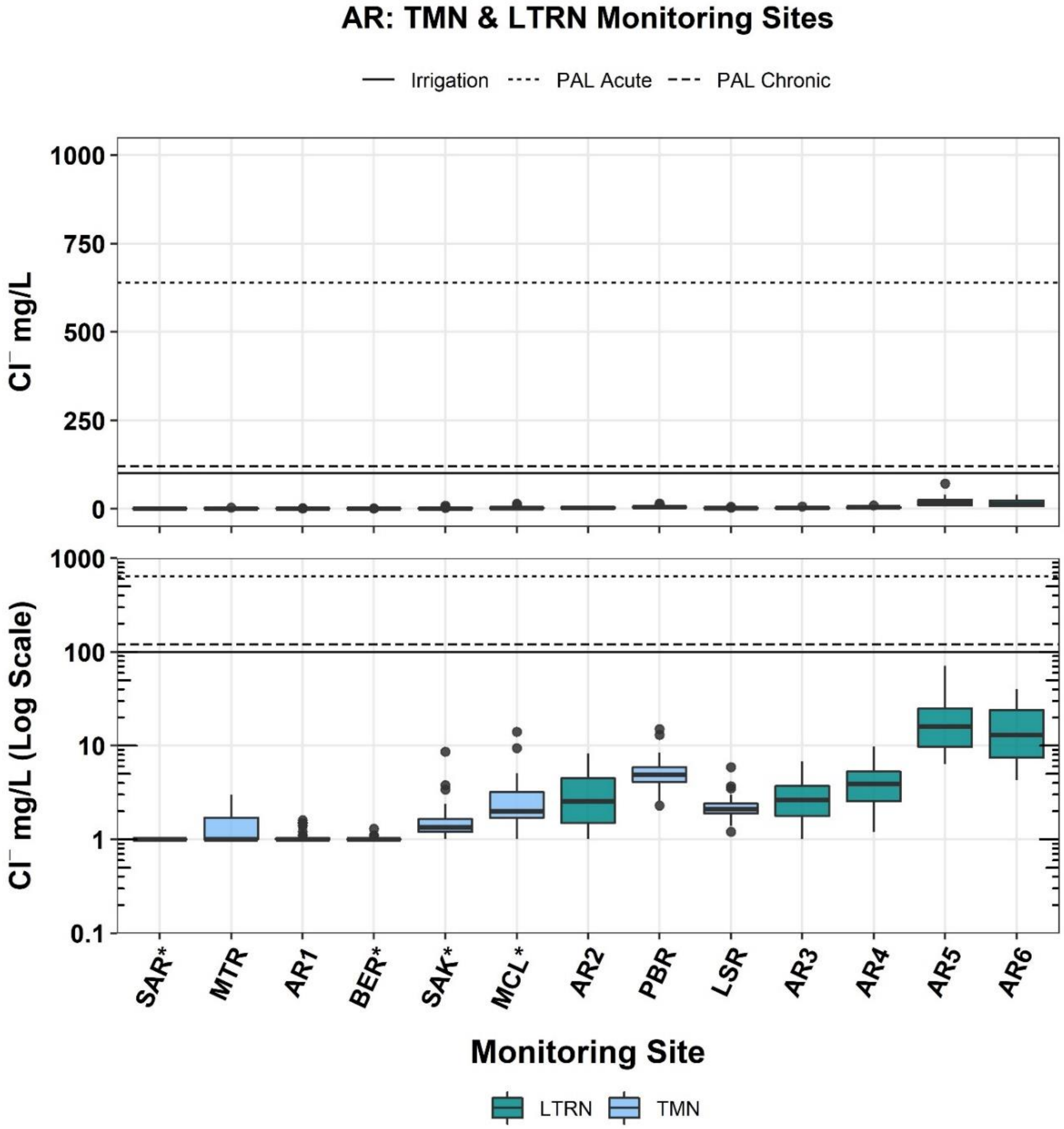

Figure 10: Cl^- concentrations for sites in the Athabasca River basin from January 2016 to December 2019 with site acronym information presented in the Table 2. Asterisks denote sites where predominantly open water samples were used in the analysis.

In Central Alberta, there were no tributary sites with sufficient data to warrant their inclusion in this analysis which includes the Beaver (*n* = 3), Battle (*n* = 2) and North Saskatchewan (*n* = 4) river basins. The only sites with <100% detection frequency were in the North Saskatchewan River where Cl^- was detected in 13% of samples at North Saskatchewan River Site 2 at Rocky Mountain House, 17% of samples at North Saskatchewan River Site 1 at Saunders Campground and 40% of samples at North Saskatchewan River Site 3 at Devon (Table 3, Figure 14) (Figure 6, Table 2). In the Beaver River, Cl^- abundances were relatively consistent with median concentrations ranging from 4.8 mg/L at Site 1 at Highway 892 to 6 mg/L at Site 3 upstream of the Alberta-Saskatchewan border with maximum concentrations ranging from 8.9 mg/L at Site 1 to 14 mg/L at Site 3 (Table 2, Figures 8 & 11). In the North Saskatchewan River, median Cl^- concentrations ranged from 1.0 mg/L for the three sites upstream of Edmonton to 4.9 mg/L at North Saskatchewan River Site 4 at Pakan Bridge downstream of Edmonton. Maximum Cl^- concentrations in the North Saskatchewan River ranged from 1.7 at North Saskatchewan River Site 2 to 11 mg/L at the North Saskatchewan River Site 4 (Table 2, Figures 9 & 11). In the Battle River, median Cl^- concentrations decreased from 61 mg/L in the upstream Site 1 at the north end of Driedmeat Lake to 10 mg/L at the downstream Site 2 at Highway 53. Maximum concentrations in the Battle River decreased from 160 mg/L at Site 1 to 21 mg/L at Site 2 (Table 2, Figures 9 & 11). There were 7 irrigation guideline exceedances (i.e. >100 mg/L) and two PAL chronic guideline exceedances (i.e. >120 mg/L) for Cl^- at the Battle River Site 1 at the north end of Driedmeat Lake.

In the Red Deer River watershed, there were five main stem LTRN sites and 17 TMN sites. Two sites in the Red Deer River watershed had Cl^- detection frequencies <90% including the Red Deer River Site 1 at Sundre (73%) and the James River* site near its bridge (68%) (Table 2, Figure 6). Median Cl^- concentrations ranged from 1.2 mg/L at the Red Deer River Site 1 to 78 mg/L at Waskasoo Creek near its confluence with the Red Deer River (Table 2, Figures 8 & 12). Maximum Cl^- concentrations ranged from 2.2 mg/L at the Red Deer River Site 1 to 870 mg/L at Waskasoo Creek (Table 2, Figures 9 & 12). In general, Cl^- concentrations increase for the LTRN and TMN sites as you progress downstream in the Red Deer River watershed. The TMN sites in the Red Deer River watershed typically have higher Cl^- concentrations relative to the LTRN sites on the main stem of the Red Deer River. In the Red Deer River there were 15 irrigation guideline exceedances for Cl^-, including 11 at Waskasoo Creek, two at Michichi Creek Site 2 near the mouth, and one at Threehills Creek Site 1* by Highway 836 and one at Threehills Creek Site 2 near Highway 837. There were 11 PAL chronic guideline exceedances, including 8 at Waskasoo Creek and one each at Michichi Creek Site 2, Threehills Creek Site 1 and Threehills Creek Site 2. Additionally, there were two PAL acute guideline exceedances (i.e. >640 mg/L), one each at Waskasoo Creek and Threehills Creek Site 2.

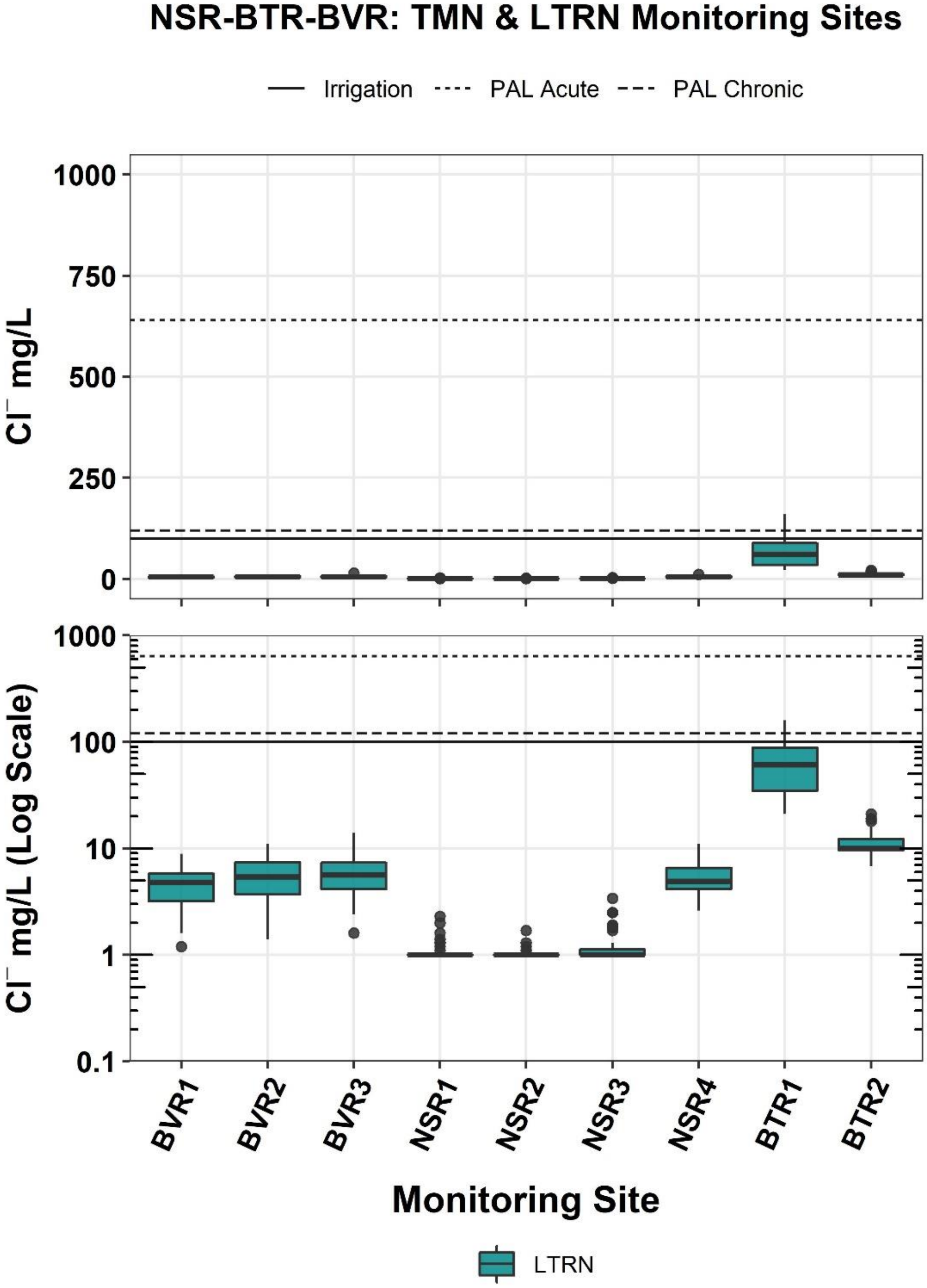

Figure 11: Cl^- concentrations for sites in the North Saskatchewan basin from January 2016 to December 2019 with site acronym information presented in the Table 2.

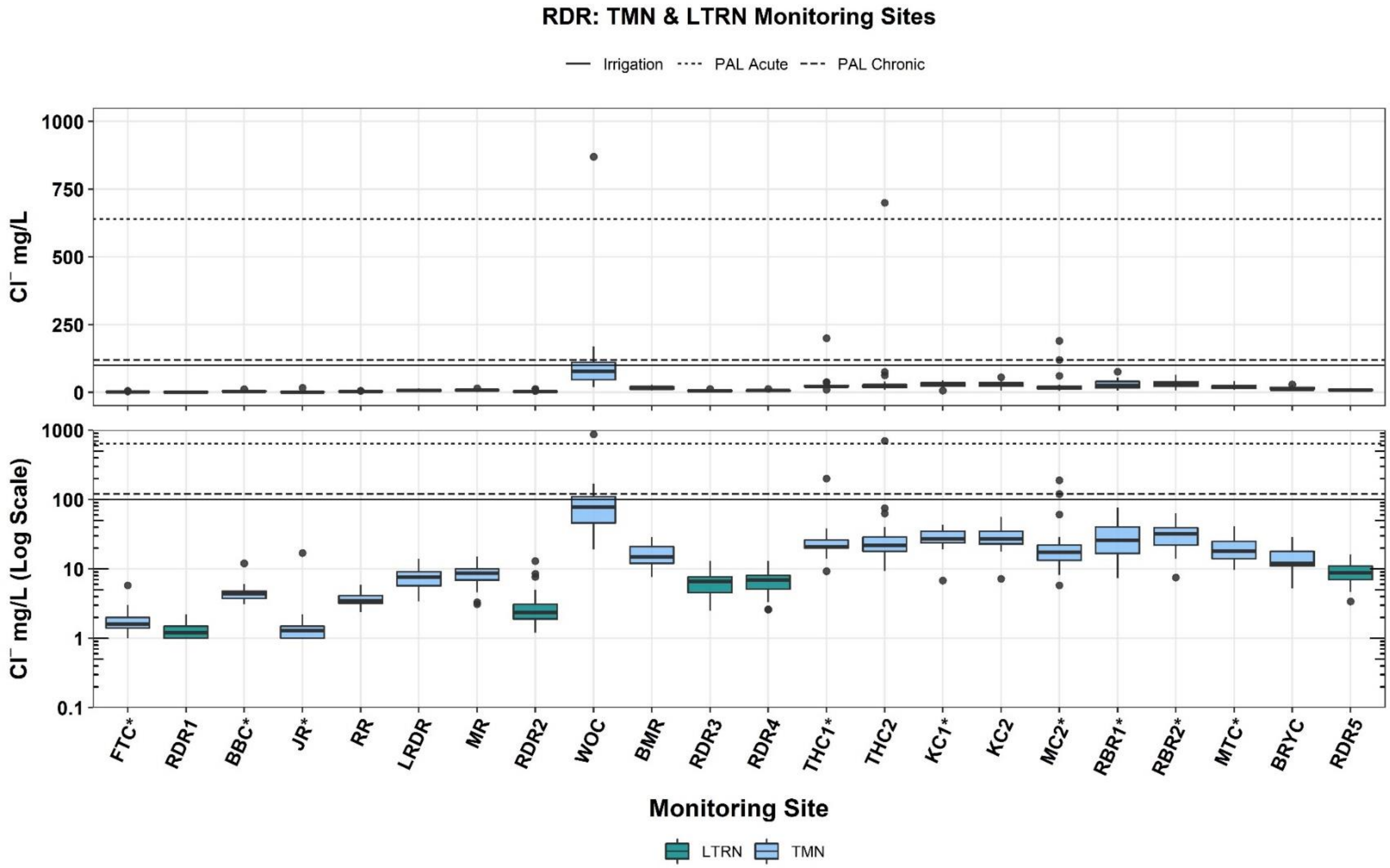

Figure 12: Cl^- concentrations for sites in the Red Deer River basin from January 2016 to December 2019 with site acronym information presented in the Table 2. Asterisks denote sites where predominantly open water samples were used in the analysis.

In the Bow River watershed, there are four main stem LTRN sites, one LTRN site on a tributary (i.e. the Elbow River), and 16 TMN sites. Four sites had detection frequencies less than 95%, all of which were TMN sites including the Ghost River (32%) above the confluence with Waiparous Creek, Waiparous Creek (50%) above the confluence with the Ghost River, Highwood River Site 1 downstream of High River (75%) and Sheep River Site 1, 1 km downstream of a Water Survey of Canada gauge (85%) (Table 2, Figure 6). Median Cl^- concentrations ranged from 1 mg/L at the Ghost River and Waiparous Creek sites to 145 mg/L at Nose Creek near its mouth in Calgary (Table 2, Figures 8 & 13). Maximum Cl^- concentrations ranged from 1.7 mg/L in the Ghost River to 770 mg/L in Nose Creek (Table 2, Figures 9 & 13). Cl^- concentrations increase as you progress downstream from headwaters sites (i.e. Ghost River, Waiparous Creek, Bow River at Cochrane and the upstream sites in the Highwood and Sheep rivers) to sites located near or downstream of Calgary (Figure 17). There were 55 samples in the Bow River watershed that had Cl^- concentrations that exceeded the irrigation guidelines including 37 from Nose Creek, 11 from Fish Creek, six from Pine Creek and one in the Elbow River. Additionally, there were 40 samples that exceeded the PAL chronic guideline, including 29 in Nose Creek, nine in Fish Creek and one each from Pine Creek and the Elbow River. Finally, there were three samples that exceeded the PAL acute guideline including two in Nose Creek and one in Fish Creek.

In the Oldman River, there are three main stem LTRN sites and 14 TMN sites. Four sites had detection frequencies <90% including the Waterton River (61%) at Highway 810, Pincher Creek Site 1 at the town of Pincher Creek (83%), the Belly River Site 1 near the confluence with the Waterton River (87%) and the Oldman River Site 1 at Brocket (88%) (Table 2, Figure 6). Median Cl^- concentrations ranged from 1.1 mg/L in the Waterton River to 23 mg/L at Expanse Coulee* adjacent to the Highway 36 crossing of the Oldman River and maximum Cl^- concentrations ranged from 3 mg/L at Pincher Creek Site 1 to 130 mg/L at Expanse Coulee* (Table 2, Figures 8,9 & 14). The Expanse Coulee* site is the only site in the Oldman River with a maximum Cl^- concentration >28 mg/L. The TMN sites in the Oldman River typically have higher Cl^- concentrations relative to the LTRN sites on the main stem. There was one irrigation guideline exceedance and one PAL chronic guideline exceedance both at the Expanse Coulee* site.

In the South Saskatchewan River watershed, downstream of the confluence of the Bow and Oldman Rivers, there is one LTRN main stem site, one TMN main stem site on the South Saskatchewan River and two standard TMN sites. Cl^- was detected in all of the samples in the South Saskatchewan River basin (Table 2, Figure 6). Median Cl^- concentrations range from 11 mg/L at the TMN South Saskatchewan River Site 2 downstream of Medicine Hat to 19.5 mg/L at Seven Persons Creek near the mouth (Table 2, Figures 8 & 15). Maximum Cl^- concentrations range from 32 mg/L at the TMN South Saskatchewan River Site 2 to 220 mg/L in Seven Persons Creek (Table 2, Figures 9 & 15). There was one irrigation guideline exceedance and one PAL chronic guideline exceedance at the Seven Persons Creek site.

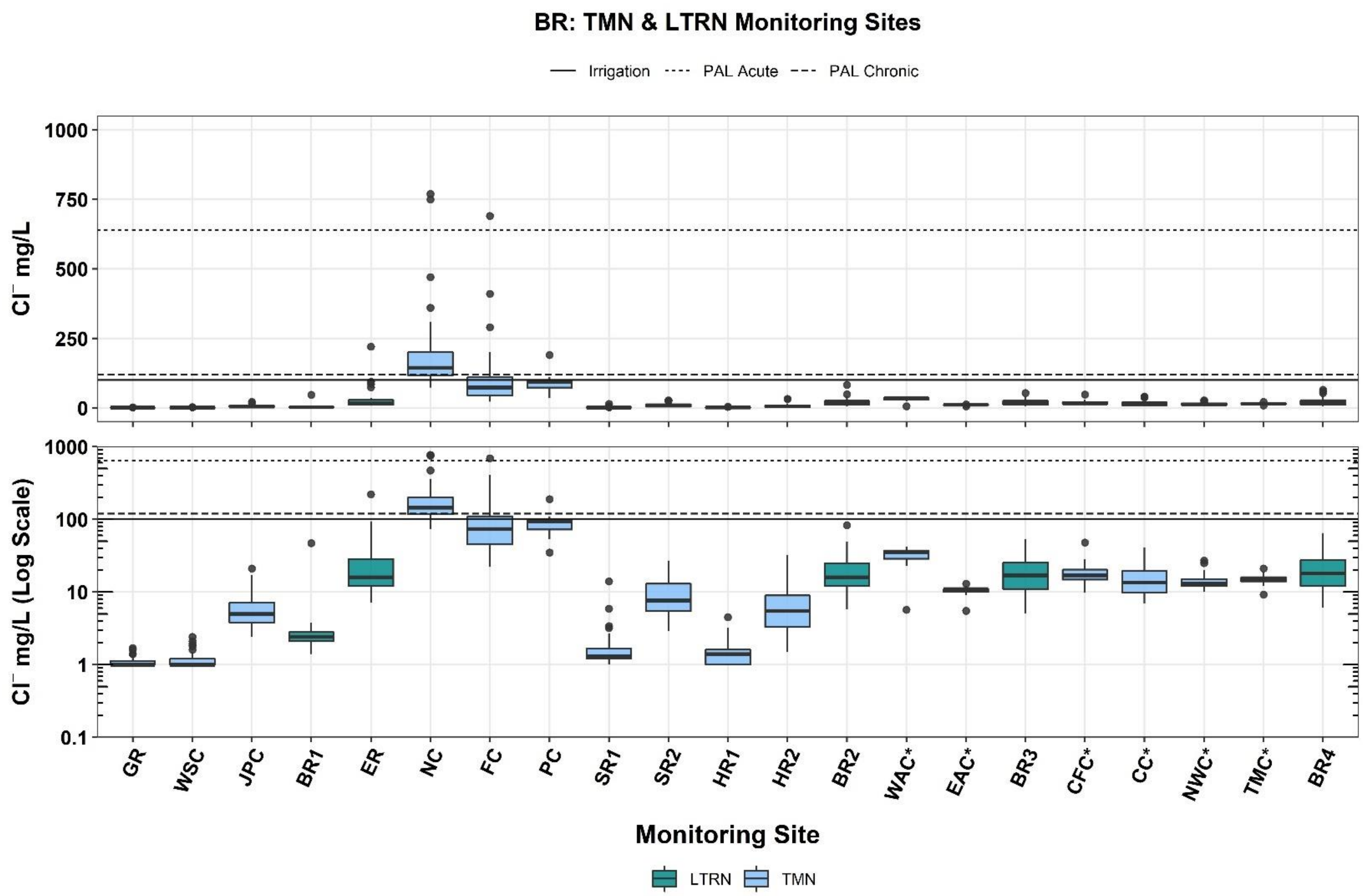

Figure 13: Cl^- concentrations for sites in the Bow River basin from January 2016 to December 2019 with site acronym information presented in the Table 2. Asterisks denote sites where predominantly open water samples were used in the analysis.

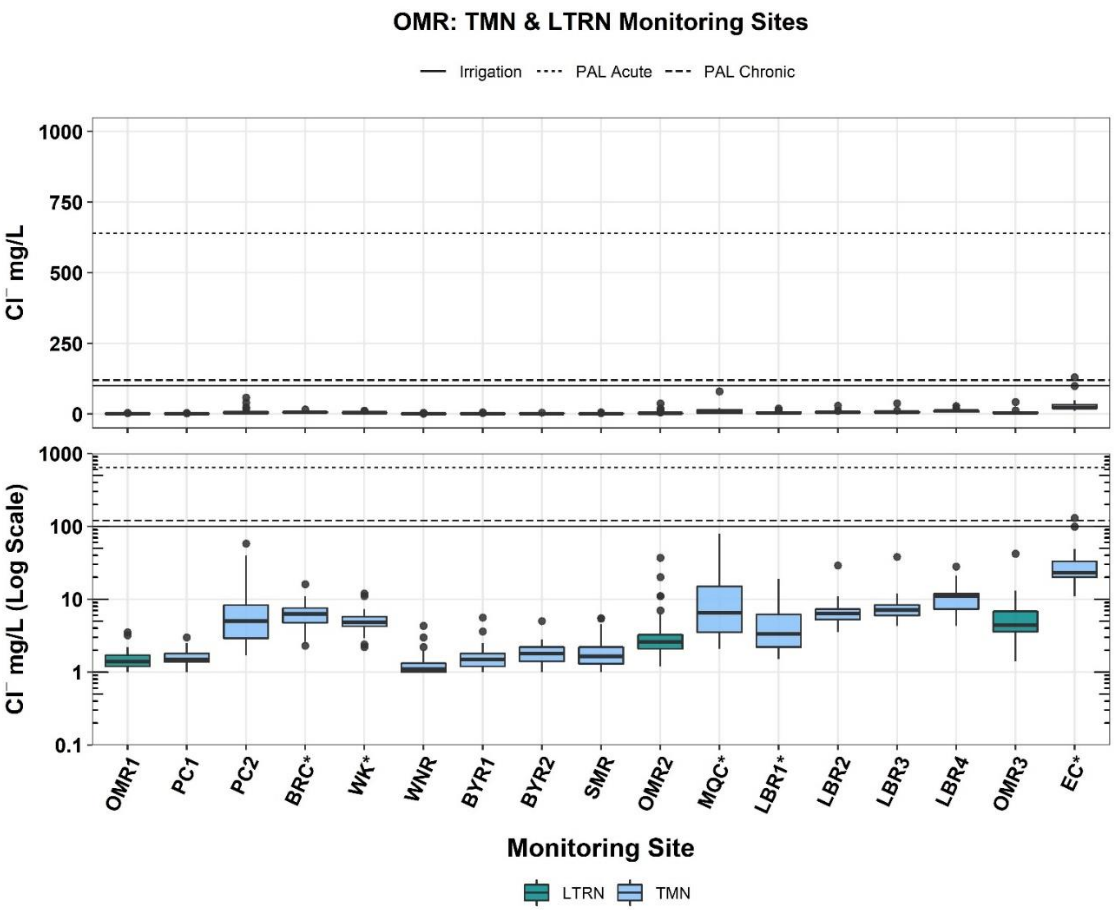

Figure 14: Cl^- concentrations for sites in the Oldman River basin from January 2016 to December 2019 with site acronym information presented in the Table 2. Asterisks denote sites where predominantly open water samples were used in the analysis.

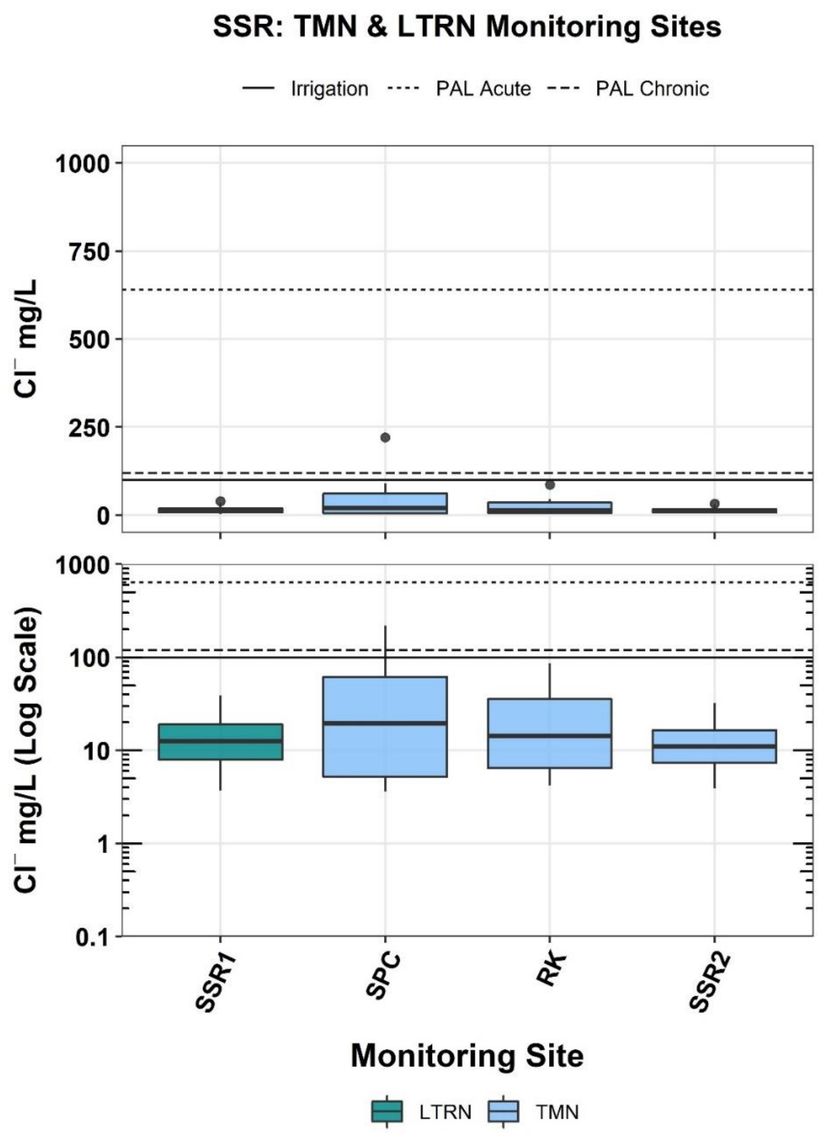

Figure 15: Cl^- concentrations for sites in the South Saskatchewan River basin from January 2016 to December 2019 with site acronym information presented in the Table 2.

Five sites were included in this analysis for the Milk River watershed including one LTRN site on the Milk River, two additional TMN sites on the main stem of Milk River and two standard TMN sites on tributaries. Three of these sites had Cl^- detection frequencies <100% including the North Milk River* near the international border (42%), the TMN Milk River Site 2* upstream of the town of Milk River (65%) and the LTRN Milk River Site 3 near Highway 880 (88%) (Table 2, Figure 6). Median Cl^- concentrations were below 5 mg/L for all sites in the Milk River watershed, except the site near the mouth of Red Creek*, which had a median of 35 mg/L (Table 2, Figures 8 & 16). Maximum Cl^- concentrations ranged from 3.3 mg/L in the North Milk River* to 41 mg/L in Red Creek* (Table 2, Figures 9 & 16). There were no guideline exceedances in the Milk River watershed during the study period.

When comparing Cl^- across Alberta (Figure 17), the median Cl^- concentration of 145 mg/L at the Nose Creek TMN site in Calgary stands out as being the only median above the PAL chronic guideline. Overall, 95% of sites in the LTRN and TMN analysis had median Cl^- concentrations <40 mg/L. In contrast, there were five sites with median Cl^- concentrations >40 mg/L including Nose Creek (145 mg/L), Pine Creek (94 mg/L) and Fish Creek (74 mg/L) in the Bow River watershed around Calgary, Waskasoo Creek (78 mg/L) in the Red Deer River watershed, and the Battle River Site 1 (61 mg/L). Cl^- concentrations are generally lower at upstream headwater sampling locations. Moving downstream, Cl^- concentrations often increase. In several watersheds, the tributary sites had typically higher median and maximum Cl^- concentrations.

There were five PAL acute guideline exceedances during the study period across Alberta, including two at Nose Creek and one in Fish Creek in the Bow River watershed and one each in Waskasoo Creek and Threehills Creek Site 2 in the Red Deer River watershed. There were 54 PAL chronic guideline exceedances which were predominantly at Nose Creek (n = 29), Fish Creek (n = 9) and Waskasoo Creek (n = 9). Finally, there were 79 irrigation guideline exceedances, most of which occurred in Nose Creek (n = 37), Fish Creek (n = 11), Waskasoo Creek (n = 11), the Battle River Site 1 (n = 7), and Pine Creek (n = 6).

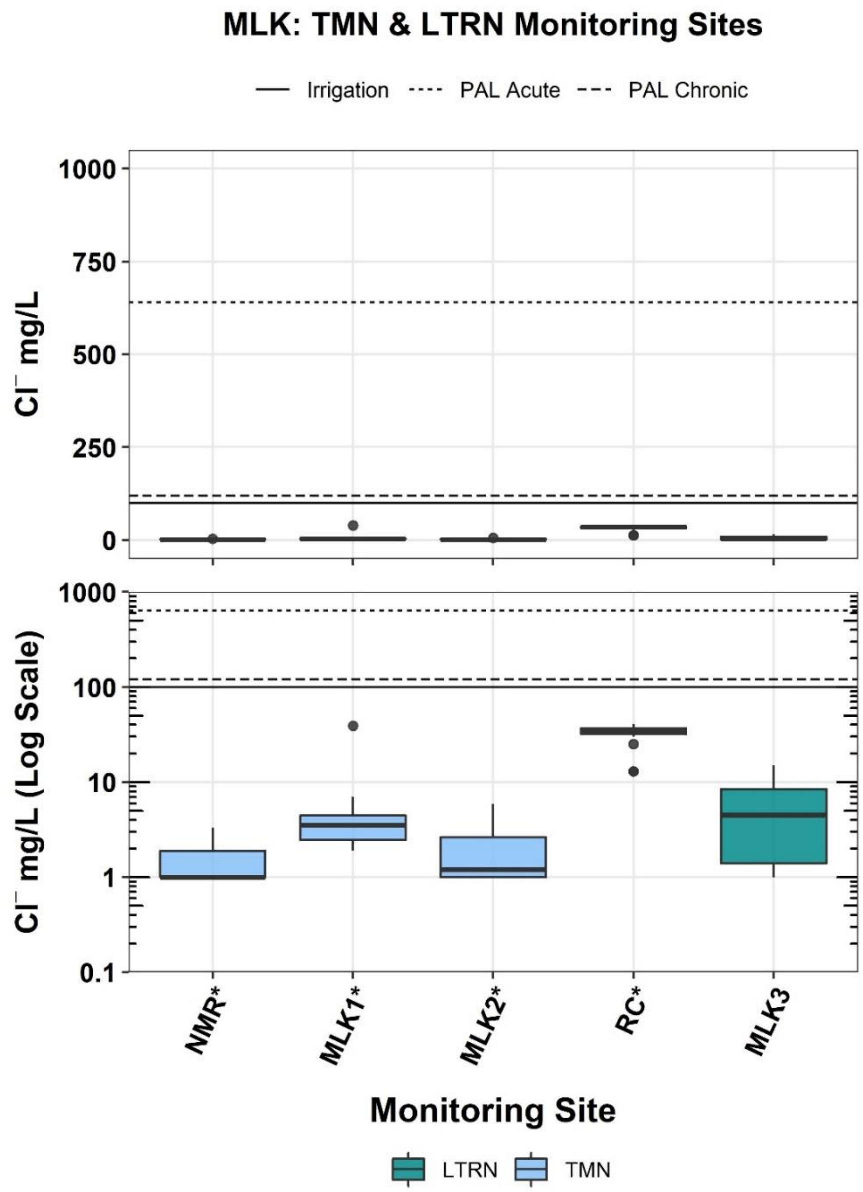

Figure 16: Cl^- concentrations for sites in the Milk River basin from January 2016 to December 2019 with site acronym information presented in the Table 2. Asterisks denote sites where predominantly open water samples were used in the analysis.

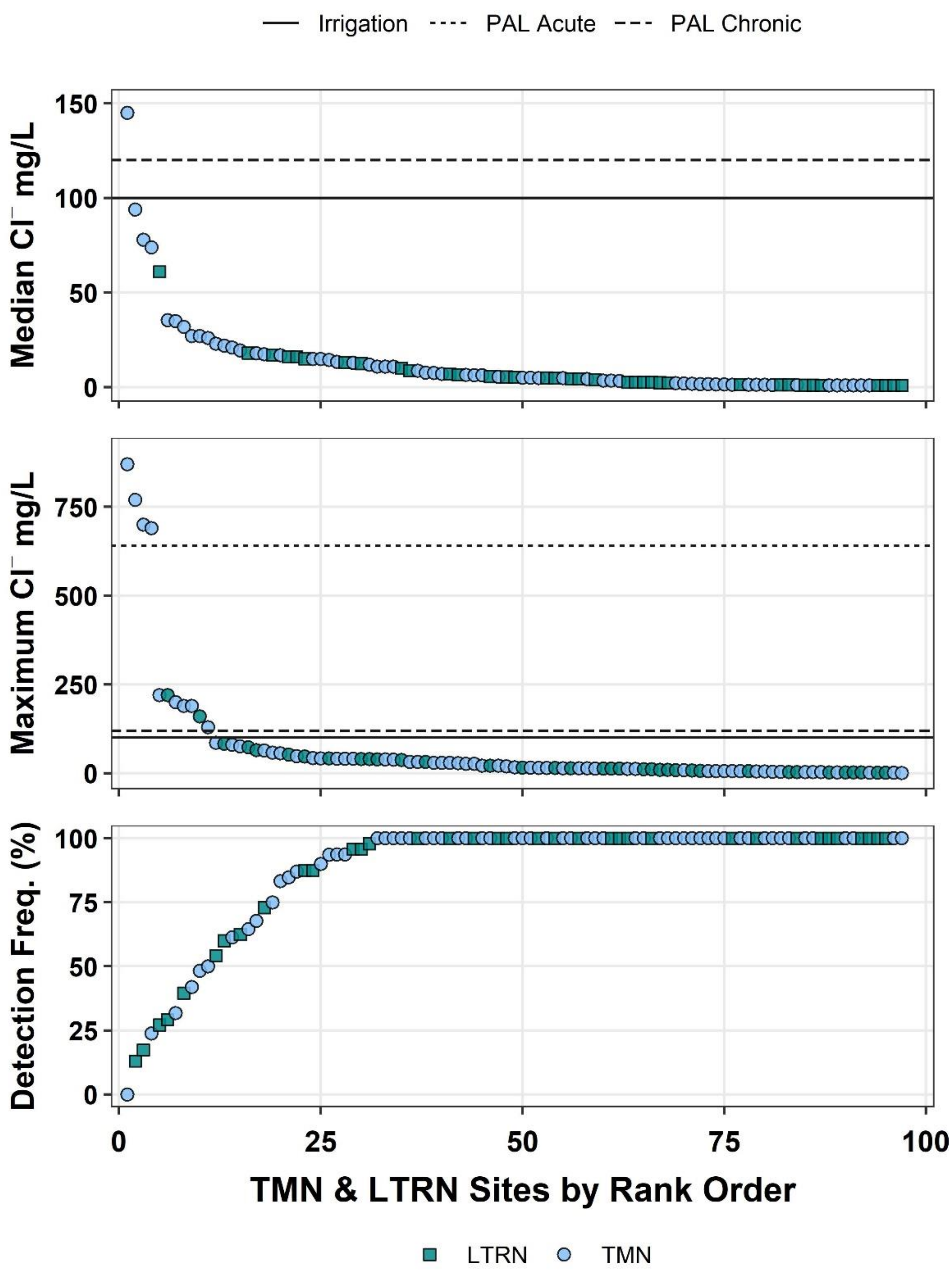

Figure 17: Plot of the rank order of median (top) and maximum (middle) Cl^- concentrations along with their detection frequency at sites from 2016 to the end of 2019.

Temporal Analyses

When examining all of the annual samples (i.e. including ice-covered and open water samples), seven out of the 29 sites were excluded from further analyses as they had detection frequencies <80% after re-censoring the data (Table 3). Although an argument could be made to include the Red Deer River Site 1 at Sundre in the temporal analyses as it has upwards of eight years of data, this site would have also been excluded from further analyses as more than 30% of its data are censored.

With respect to variation in the monthly data for all annual samples, both the Kruskal-Wallis test and the test for Censored empirical cumulative distribution functions Differences (CenDiff) indicated that there was only one site that did not have significant monthly variation, the Battle River Site 2 at Highway 53 (Table 3). As the data at the Battle River Site 2 was not serially dependent, a Mann-Kendall (MK) test was used to assess trends at this site. Cl^- data at three of the remaining sites was found to be serially dependent (Table 3). Accordingly, temporal trend tests for the Red Deer River Site 2 at Highway 2, Athabasca River Site 5 above the Firebag River and the Athabasca River Site 6 at Old Fort were conducted with a Seasonal Mann-Kendall (SMK) with the continuity correction. Trend tests for the remaining sites were assessed with a SMK without the continuity correction. Scatter plots with normal and log-scales of Cl^- concentrations over time for all sites included in this analysis are presented from north to south for the major basins and upstream to downstream for sites in these basins (Appendix Figures A2 to A30).

Statistically significant trends were evident at 16 out of the 22 LTRN sites with sufficient detection frequencies for this analysis. Cl^- concentrations were found to be decreasing over the time frame analyzed at the Smoky River site at Watino (-0.8% yr^{-1}) and the Athabasca River Site 6 at Old Fort (-0.5% yr^{-1}) (Table 3). In contrast to these Northern Alberta sites, the majority of sites in the rest of the province have significant trends of increasing Cl^- concentrations (Figure 18). There were six sites with annual Cl^- percent increases >2%: the Elbow River in Calgary (+4.1% yr^{-1}), the Bow River Site 3 at Cluny (+3.4% yr^{-1}), the Bow River Site 2 below Carseland Dam (+3.2% yr^{-1}), the Bow River Site 4 near Ronalane Bridge (+3.0% yr^{-1}), the South Saskatchewan River Site 1 upstream of Medicine Hat (+2.9% yr^{-1}), and the Red Deer River Site 3 at Nevis Bridge (+2.8% yr^{-1}). Additionally, there were five sites with annual Cl^- increases between 1-2% yr^{-1} and two with increases <1% (Table 3).

Table 3: Summary of the results from the trend analyses for LTRN sites for all annual samples with more than 10 years of data including pre-trend analyses tests including detection frequency (Detect Freq.) and the results when investigating the assumptions of seasonality (Seas.) with the test for censored empirical cumulative distribution functions difference (CD) and Kruskal Wallis (KW) tests, serial dependence (Ser. Dep) with the Breusch-Godfrey and heterogeneity (Hetero) with the Van Belle-Hughes test. These pre-trend analyses tests determined whether a Mann-Kendall (MK), a Seasonal Mann Kendall (SMK) without the continuity correction (SMK-1) or with the continuity correction (SMK-2) tested for trends with results significant (Sig.) at an alpha of 0.95.

		All Annual Samples Pre-trend Tests and Information							All Annual Samples Trend Analyses Results						
Basin & Site ID	Site Name	Min Year	Max Year	Detect Freq.	Seas. CD	Seas. KW	Ser. Dep.	Hetero Trend	Test	Sig. Trend	p value	Tau	Slope	Intercept	Annual Change (%)
AR-AR1	ATHABASCA RIVER-AT OLD ENTRANCE TOWN SITE	2004	2019	32%	--	--	--	--	--	--	--	--	--	--	--
AR-AR3	ATHABASCA RIVER-AT TOWN OF ATHABASCA	1987	2019	91%	Yes	Yes	No	No	SMK-1	No	0.142	-0.053	--	--	--
AR-AR4	ATHABASCA RIVER-US FORT MCMURRAY	2002	2019	99%	Yes	Yes	No	No	SMK-1	No	0.943	-0.003	--	--	--
AR-AR5	ATHABASCA RIVER-TRANSECT ABOVE THE FIREBAG RIVER	2008	2019	100%	Yes	Yes	Yes	No	SMK-2	No	0.354	-0.116	--	--	--
AR-AR6	ATHABASCA RIVER - OLD FORT AND DEVILS ELBOW	1988	2019	100%	Yes	Yes	Yes	No	SMK-2	Yes	0.048	-0.131	-0.078	187.51	-0.49
BR-BR1	BOW RIVER-AT COCHRANE	1987	2019	98%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.320	0.027	-48.08	1.35
BR-BR2	BOW RIVER-BELOW CARSELAND DAM	1987	2019	99%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.578	0.300	-668.17	3.19
BR-BR3	BOW RIVER-AT CLUNY	1995	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.538	0.368	-865.34	3.41
BR-BR4	BOW RIVER-NEAR RONALANE BRIDGE	1987	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.567	0.300	-704.78	3
BR-ER	ELBOW RIVER-AT 9TH AVE BRIDGE	1994	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.511	0.475	-947.01	4.09
BTR-BTR1	BATTLE RIVER-AT NORTH END OF DRIEDMEAT LAKE	2004	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.018	0.132	0.750	-1421.11	1.61
BTR-BTR2	BATTLE RIVER-APPROX 2 KM DS HWY 53	2004	2019	100%	No	No	No	--	MK	Yes	0.000	0.369	0.001	-5.42	0.01
MLK-MLK3	MILK RIVER-AT HWY 880	2003	2019	90%	Yes	Yes	No	No	SMK-1	No	0.059	0.098	--	--	--
NSR-NSR2	NORTH SASKATCHEWAN RIVER-US OF RMH	2009	2019	11%	--	--	--	--	--	--	--	--	--	--	--
NSR-NSR3	NORTH SASKATCHEWAN RIVER-AT DEVON	1999	2019	40%	--	--	--	--	--	--	--	--	--	--	--
NSR-NSR4	NORTH SASKATCHEWAN RIVER-AT PAKAN BRIDGE	1999	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.177	0.067	-122.49	1.67
OMR-OMR1	OLDMAN RIVER-NEAR BROCKET-LEFT BANK	1999	2019	75%	--	--	--	--	--	--	--	--	--	--	--
OMR-OMR2	OLDMAN RIVER-ABOVE LETHBRIDGE AT HWY 3	1987	2019	95%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.289	0.031	-54.46	1.56
OMR-OMR3	OLDMAN RIVER-AT HWY 36 BRIDGE NORTH OF TABER	1987	2019	98%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.160	0.040	-57.57	0.94

Basin & Site ID	Site Name	Min Year	Max Year	Detect Freq.	Seas. CD	Seas. KW	Ser. Dep.	Hetero Trend	Test	Sig. Trend	p value	Tau	Slope	Intercept	Annual Change (%)
		All Annual Samples Pre-trend Tests and Information							All Annual Samples Trend Analyses Results						
PR-PR1	PEACE RIVER-US SMOKY RIVER NEAR SHAFTESBURY FERRY	2006	2019	29%	--	--	--	--	--	--	--	--	--	--	--
PR-PR3	PEACE RIVER-AT FORT VERMILIONE	1995	2019	75%	--	--	--	--	--	--	--	--	--	--	--
PR-SMKY	SMOKY RIVER-AT WATINO	1987	2019	92%	Yes	Yes	No	No	SMK-1	Yes	0.000	-0.169	-0.025	28.82	-0.81
PR-WR1	WAPITI RIVER-AT HWY #40 BRIDGE	1999	2019	41%	--	--	--	--	--	--	--	--	--	--	--
PR-WR2	WAPITI RIVER-ABOVE CONFLUENCE WITH SMOKY RIVER	1999	2019	96%	Yes	Yes	No	No	SMK-1	No	0.134	-0.069	--	--	--
RDR-RDR2	RED DEER RIVER-1 KM US HWY 2 BRIDGE	1984	2019	91%	Yes	Yes	Yes	No	SMK-2	Yes	0.000	0.375	0.039	-70.61	1.96
RDR-RDR3	RED DEER RIVER-AT NEVIS BRIDGE	1999	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.353	0.140	-266.02	2.8
RDR-RDR4	RED DEER RIVER-AT MORRIN BRIDGE	2008	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.017	0.153	0.100	-118.29	1.6
RDR-RDR5	RED DEER RIVER-DS DINOSAUR PROV PARK AT HWY 884	2008	2019	100%	Yes	Yes	No	No	SMK-1	No	0.106	0.104	--	--	--
SSR-SSR1	SOUTH SASKATCHEWAN RIVER-ABOVE MEDICINE HAT	1995	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.496	0.259	-608.16	2.88

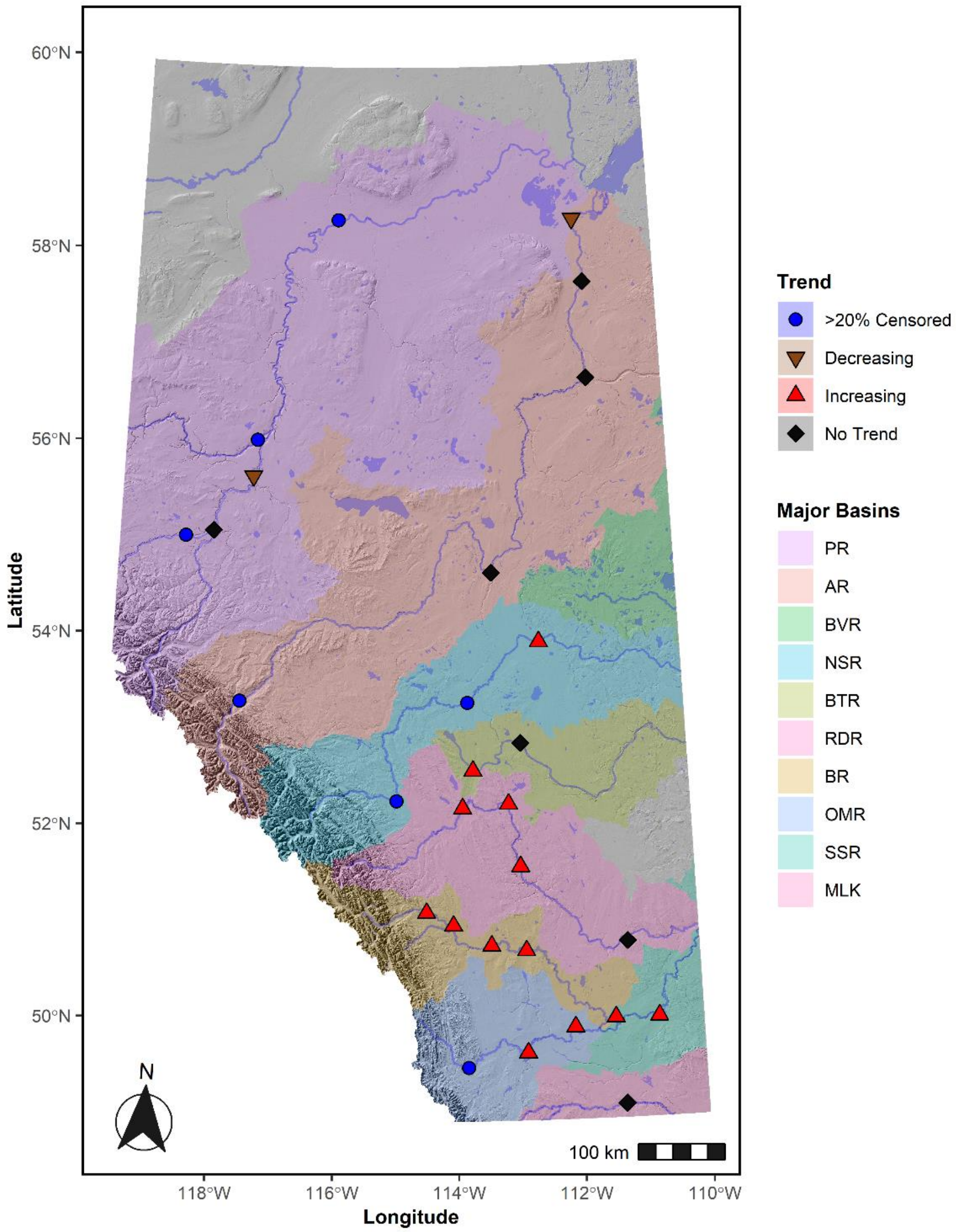

Figure 18: Results from the trend analyses for all annual samples highlighting locations in the province where Cl^- was found to be increasing or decreasing over time along with sites without significant trends or where there was too much censored data to conduct the analysis. Acronym information for the major basins is listed in the Acronyms and Abbreviations.

When testing for significant differences between the open water season and the ice-covered season, the CenDiff test indicated that two sites with censored data (i.e. Red Deer River Site 2 upstream of the Highway 2 Bridge and Bow River Site 1 at Cochrane) did not have significant seasonal differences (Table S3). Additionally, the Red Deer River Site 5 at Highway 884 near Jenner also was not found to have significant seasonal differences with the Kruskal Wallis test. Accordingly, trend tests on data from the open water and ice-covered season were not conducted for these three sites.

For the open water season, only two sites did not have significant monthly variation determined with the Kruskal Wallis and CenDiff tests compared to nine sites in the ice-covered season (Table 4 and 5). Only one of these 11 sites was determined to be serially dependent. For this site, the Bow River Site 3 at Cluny, a MK with trend free pre-whitening assessed the trend at this site, whereas a standard MK was used for the remaining sites without significant monthly variation, which were not serial dependent. There were 15 sites in the ice-covered season and 21 in the open water season that had significant monthly variation (Tables 4 and 5). Only three of these sites had datasets that were serially dependent and thus analyzed with the SMK with the continuity correction. The remaining sites were analyzed with a SMK test without the continuity correction. The Red Deer River Site 2 upstream of the Highway 2 bridge in the ice-covered season was the only site with a heterogenous trend (i.e. within month trends going in significantly different directions) in the entire database. As the trends at this particular site are based on both positive and negative trends, which may cancel each other out over time, there is increasingly confidence in the significance of the trend at this particular site.

In the open water season, there were 14 significant trends occurring at the LTRN monitoring sites (Figure 19). The Peace River Site 3 at Fort Vermillion was the only site with a decreasing Cl^- trend (- <0.01% yr^{-1}) (Table 4). Of the 13 sites with significant positive trends, five were increasing at rates >3% per year, all of which were near or downstream of Calgary: the Elbow River (+4.4% yr^{-1}), the Bow River Site 2 below Carseland Dam (+3.2% yr^{-1}), the Bow River Site 3 at Cluny (+3.2% yr^{-1}), the Bow River Site 4 near Ronalane Bridge (+3.1% yr^{-1}), and the South Saskatchewan River Site 1 upstream of Medicine Hat (+3.0% yr^{-1}). Additionally, three sites were increasing at rates between 2-3% yr^{-1}, including the Red Deer River Site 3 at Nevis Bridge (+2.5% yr^{-1}), the Battle River Site 1 at the north end of Driedmeat Lake (+2.2% yr^{-1}) and the Red Deer River Site 2 upstream of the Highway 2 bridge (+2.1% yr^{-1}). There were also three sites with Cl^- concentrations increasing significantly between 1-2% per year and two sites with increases that were <1% per year (Table 4).

Table 4: Summary of the results from the trend analyses for LTRN sites for open water samples with more than 10 years of data including pre-trend analyses tests including detection frequency (Detect Freq.) and the results when investigating the assumptions of seasonality (Seas.) with the test for censored empirical cumulative distribution functions difference (CD) and Kruskal Wallis (KW) tests, serial dependence (Ser. Dep) with the Breusch-Godfrey and heterogeneity (Hetero) with the Van Belle-Hughes test. These pre-trend analyses tests determined whether a Mann-Kendall (MK), a Seasonal Mann Kendall (SMK) without the continuity correction (SMK-1) or with the continuity correction (SMK-2) tested for trends with results significant (Sig.) at an alpha of 0.95.

		Open Water Pre-trend Tests and Information							Open Water Trend Analyses Results						
Basin & Site ID	Site Name	Min Year	Max Year	Detect Freq.	Seas. CD	Seas. KW	Ser. Dep.	Hetero Trend	Test	Sig. Trend	p value	Tau	Slope	Intercept	Annual Change (%)
AR-AR1	ATHABASCA RIVER-AT OLD ENTRANCE TOWN SITE	2004	2019	32%	--	--	--	--	--	--	--	--	--	--	--
AR-AR3	ATHABASCA RIVER-AT TOWN OF ATHABASCA	1987	2019	91%	Yes	Yes	No	No	SMK-1	No	0.142	-0.053	--	--	--
AR-AR4	ATHABASCA RIVER-US FORT MCMURRAY	2002	2019	99%	Yes	Yes	No	No	SMK-1	No	0.943	-0.003	--	--	--
AR-AR5	ATHABASCA RIVER-TRANSECT ABOVE THE FIREBAG RIVER	2008	2019	100%	Yes	Yes	Yes	No	SMK-2	No	0.354	-0.116	--	--	--
AR-AR6	ATHABASCA RIVER - OLD FORT AND DEVILS ELBOW	1988	2019	100%	Yes	Yes	Yes	No	SMK-2	Yes	0.048	-0.131	-0.078	187.51	-0.49
BR-BR1	BOW RIVER-AT COCHRANE	1987	2019	97%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.334	0.027	-48.28	1.36
BR-BR2	BOW RIVER-BELOW CARSELAND DAM	1987	2019	99%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.568	0.242	1.36	3.19
BR-BR3	BOW RIVER-AT CLUNY	1995	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.538	0.368	-865.34	3.41
BR-BR4	BOW RIVER-NEAR RONALANE BRIDGE	1987	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.567	0.300	-704.78	3
BR-ER	ELBOW RIVER-AT 9TH AVE BRIDGE	1994	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.511	0.475	-947.01	4.09
BTR-BTR1	BATTLE RIVER-AT NORTH END OF DRIEDMEAT LAKE	2004	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.018	0.132	0.750	-1421.11	1.61
BTR-BTR2	BATTLE RIVER-APPROX 2 KM DS HWY 53	2004	2019	100%	No	No	No	--	MK	Yes	0.000	0.369	0.001	-5.42	0.01
MLK-MLK3	MILK RIVER-AT HWY 880	2003	2019	90%	Yes	Yes	No	No	SMK-1	No	0.059	0.098	--	--	--
NSR-NSR2	NORTH SASKATCHEWAN RIVER-US OF RMH	2009	2019	11%	--	--	--	--	--	--	--	--	--	--	--
NSR-NSR3	NORTH SASKATCHEWAN RIVER-AT DEVON	1999	2019	40%	--	--	--	--	--	--	--	--	--	--	--

		Open Water Pre-trend Tests and Information							Open Water Trend Analyses Results						
Basin & Site ID	Site Name	Min Year	Max Year	Detect Freq.	Seas. CD	Seas. KW	Ser. Dep.	Hetero Trend	Test	Sig. Trend	p value	Tau	Slope	Intercept	Annual Change (%)
NSR-NSR4	NORTH SASKATCHEWAN RIVER-AT PAKAN BRIDGE	1999	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.177	0.067	-122.49	1.67
OMR-OMR1	OLDMAN RIVER-NEAR BROCKET-LEFT BANK	1999	2019	75%	--	--	--	--	--	--	--	--	--	--	--
OMR-OMR2	OLDMAN RIVER-ABOVE LETHBRIDGE AT HWY 3	1987	2019	95%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.289	0.031	-54.46	1.56
OMR-OMR3	OLDMAN RIVER-AT HWY 36 BRIDGE NORTH OF TABER	1987	2019	98%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.160	0.040	-57.57	0.94
PR-PR1	PEACE RIVER-US SMOKY RIVER NEAR SHAFTESBURY FERRY	2006	2019	29%	--	--	--	--	--	--	--	--	--	--	--
PR-PR3	PEACE RIVER-AT FORT VERMILION	1995	2019	75%	--	--	--	--	--	--	--	--	--	--	--
PR-SMKY	SMOKY RIVER-AT WATINO	1987	2019	92%	Yes	Yes	No	No	SMK-1	Yes	0.000	-0.169	-0.025	28.82	-0.81
PR-WR1	WAPITI RIVER-AT HWY #40 BRIDGE	1999	2019	41%	--	--	--	--	--	--	--	--	--	--	--
PR-WR2	WAPITI RIVER-ABOVE CONFLUENCE WITH SMOKY RIVER	1999	2019	96%	Yes	Yes	No	No	SMK-1	No	0.134	-0.069	--	--	--
RDR-RDR2	RED DEER RIVER-1 KM US HWY 2 BRIDGE	1984	2019	91%	Yes	Yes	Yes	No	SMK-2	Yes	0.000	0.375	0.039	-70.61	1.96
RDR-RDR3	RED DEER RIVER-AT NEVIS BRIDGE	1999	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.353	0.140	-266.02	2.8
RDR-RDR4	RED DEER RIVER-AT MORRIN BRIDGE	2008	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.017	0.153	0.100	-118.29	1.6
RDR-RDR5	RED DEER RIVER-DS DINOSAUR PROV PARK AT HWY 884	2008	2019	100%	Yes	Yes	No	No	SMK-1	No	0.106	0.104	--	--	--
SSR-SSR1	SOUTH SASKATCHEWAN RIVER-ABOVE MEDICINE HAT	1995	2019	100%	Yes	Yes	No	No	SMK-1	Yes	0.000	0.496	0.259	-608.16	2.88

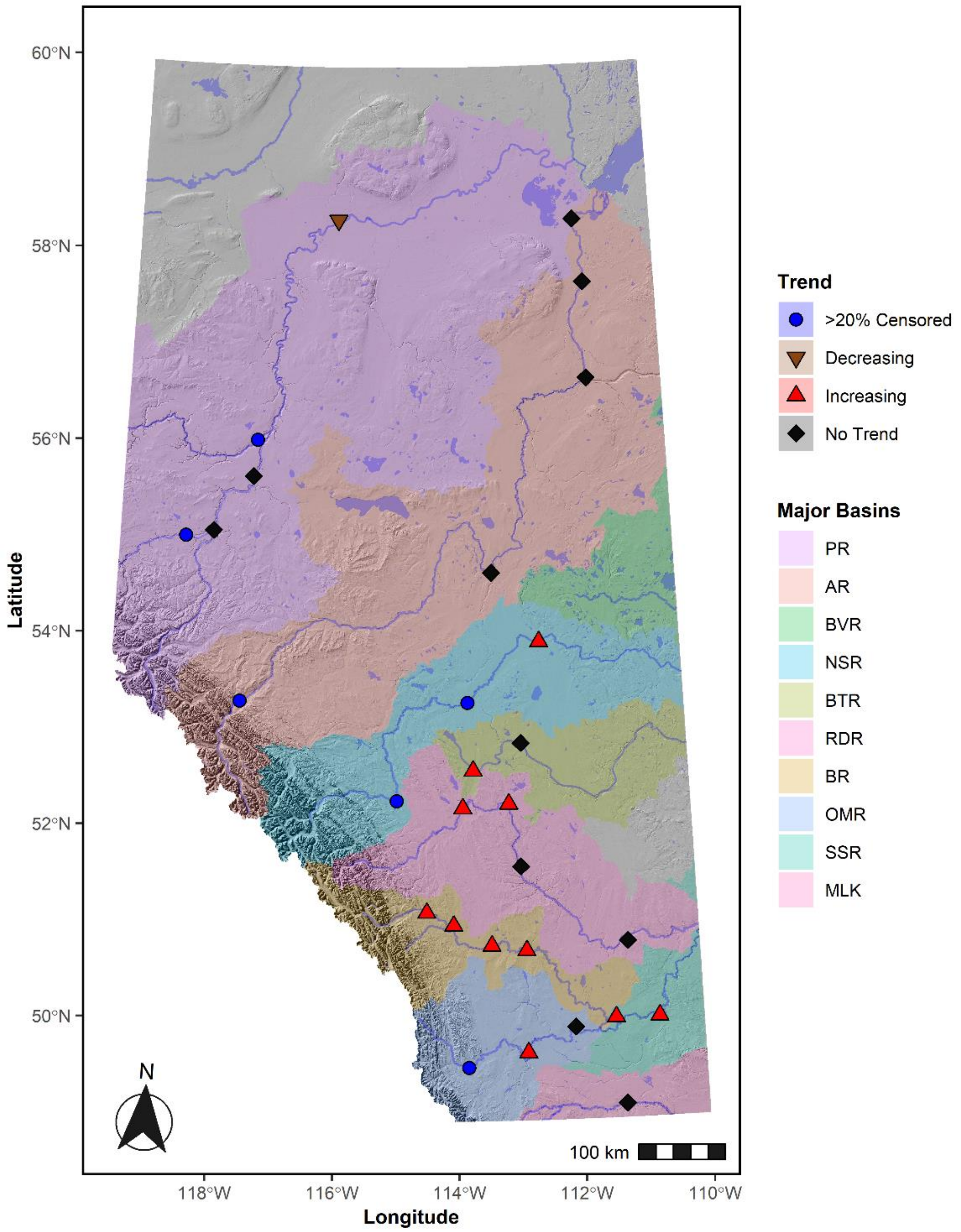

Figure 19: Results from the trend analyses for open water season samples highlighting locations in the province where Cl^- was found to be increasing or decreasing over time along with sites without significant trends or where there was too much censored data to conduct the analysis. Acronym information for the major basins is listed in the Acronyms and Abbreviations.

In the ice-covered season, there were 19 significant trends at the LTRN sites (Figure 20). There were five sites with significantly decreasing trends in Cl^- concentrations for the ice-covered season all in Northern Alberta including the Smoky River at Watino (-1.7% yr^{-1}), the Wapiti River upstream of the confluence with the Smoky River (-1.5% yr^{-1}), the Athabasca River Site 6 at Old Fort (-1.2% yr^{-1}), the Athabasca River upstream of Fort McMurray (-0.8% yr^{-1}), and the Athabasca River at the town of Athabasca (-0.9% yr^{-1}) (Table 5). In contrast, there were four sites with increasing Cl^- concentrations in the ice-covered season >3% per year including the Elbow River in Calgary (+4.1% yr^{-1}), the Bow River Site 2 below Carseland Dam (+3.5% yr^{-1}), South Saskatchewan River Site 1 upstream of Medicine Hat (+3.4% yr^{-1}), and the Red Deer River Site 3 at Nevis Bridge (+3.2% yr^{-1}). There were five additional sites with Cl^- concentrations increasing significantly between 1-2% per year and four increasing between 0-1% (Table 5).

Overall, sites in Northern Alberta either had significant decreasing trends for Cl^- concentrations, no significant trends or insufficient detection frequencies to conduct these analyses (Figure 21). In contrast, the majority of sites in Southern Alberta had increasing significant trends. The trends with the greatest magnitude or rate of change are typically in the Bow River watershed near or downstream of Calgary, in the Red Deer River near or downstream of Red Deer, or the Battle River Site 1. In general, there were more significant trends in the ice-covered season, though the trends with the largest annual percent increase typically occurred in the open water season in the region near or downstream of Calgary (Figure 21).

Discussion

Spatial Analyses

In general, the spatial analysis illustrated that headwaters sites generally have lower Cl^- concentrations as evidenced in their lower detection frequencies, with Cl^- median concentrations typically increasing as you progress downstream. Additionally, in several catchments it was evident that tributary sites generally have higher Cl^- concentrations than their counterparts on the main stem (i.e. Red Deer River & Oldman Rivers).

Sites in the Bow River watershed around Calgary accounted for 55 out of the 79 (70%) irrigation guideline exceedances with almost half (47%) of all irrigation exceedances occurring at the Nose Creek Site. In fact, 84% of the Nose Creek samples exceeded irrigation guidelines and 66% exceeded the PAL chronic guideline. Waskasoo Creek near Red Deer and the Battle River site 1 upstream of Driedmeat Lake both had 11 irrigation guideline exceedances. In total there were four sites with acute PAL guideline exceedances, including two at the Nose Creek site, one at the Fish Creek site, one at Waskasoo Creek and one at Threehills Creek site 2.

Table 5: Summary of the results from the trend analyses for LTRN sites for ice-covered samples with more than 10 years of data including pre-trend analyses tests including detection frequency (Detect Freq.) and the results when investigating the assumptions of seasonality (Seas.) with the test for censored empirical cumulative distribution functions difference (CD) and Kruskal Wallis (KW) tests, serial dependence (Ser. Dep) with the Breusch-Godfrey and heterogeneity (Hetero) with the Van Belle-Hughes test. These pre-trend analyses tests determined whether a Mann-Kendall (MK), a Seasonal Mann Kendall (SMK) without the continuity correction (SMK-1) or with the continuity correction (SMK-2) tested for trends with results significant (Sig.) at an alpha of 0.95.

		Ice-Covered Season Pre-trend Tests and Information							Ice-Covered Season Trend Analyses Results						
Basin & Site ID	Site Name	Min Year	Max Year	Detect Freq.	Seas. CD	Seas. KW	Ser. Dep.	Hetero Trend	Test	Sig. Trend	p value	Tau	Slope	Intercept	Annual Change (%)
AR-AR1	ATHABASCA RIVER-AT OLD ENTRANCE TOWN SITE	2004	2019	48%	--	--	--	--	--	--	--	--	--	--	--
AR-AR3	ATHABASCA RIVER-AT TOWN OF ATHABASCA	1987	2019	99%	Yes	--	No	No	SMK1	Yes	0.003	-0.165	-0.033	86.2	-0.9
AR-AR4	ATHABASCA RIVER-US FORT MCMURRAY	2002	2019	100%	--	Yes	No	No	SMK1	Yes	0.030	-0.166	-0.050	123.8	-0.9
AR-AR5	ATHABASCA RIVER-TRANSECT ABOVE THE FIREBAG RIVER	2008	2019	100%	--	No	No	--	MK	No	0.108	-0.149	--	--	--
AR-AR6	ATHABASCA RIVER - OLD FORT AND DEVILS ELBOW	1988	2019	100%	--	Yes	No	No	SMK1	Yes	<0.001	-0.255	-0.353	719.4	-1.2
BR-BR1	BOW RIVER-AT COCHRANE	1987	2019	99%	No	--	No	--	MK1	Yes	<0.001	0.286	<0.001	1.11	<0.01
BR-BR2	BOW RIVER-BELOW CARSELAND DAM	1987	2019	100%	--	Yes	No	No	SMK1	Yes	<0.001	0.593	0.04	-790.1	3.5
BR-BR3	BOW RIVER-AT CLUNY	1995	2019	100%	--	No	Yes	--	MK1	No	0.285	0.068	--	--	--
BR-BR4	BOW RIVER-NEAR RONALANE BRIDGE	1987	2019	100%	--	No	No	--	MK1	Yes	<0.001	0.540	0.001	-1.6	0.01
BR-ER	ELBOW RIVER-AT 9TH AVE BRIDGE	1994	2019	100%	--	Yes	No	No	SMK2	Yes	<0.001	0.468	0.625	-1462.4	4.1
BTR-BTR1	BATTLE RIVER-AT NORTH END OF DRIEDMEAT LAKE	2004	2019	100%	--	No	No	--	MK1	Yes	<0.001	0.385	0.001	-7.5	0.01
BTR-BTR2	BATTLE RIVER-APPROX 2 KM DS HWY 53	2004	2019	100%	--	No	No	--	MK2	No	0.615	0.040	--	--	--
MLK-MLK3	MILK RIVER-AT HWY 880	2003	2019	100%	--	Yes	No	No	SMK1	No	0.426	0.068	--	--	--
NSR-NSR2	NORTH SASKATCHEWAN RIVER-US OF RMH	2009	2019	6%	--	--	--	--	--	--	--	--	--	--	--
NSR-NSR3	NORTH SASKATCHEWAN RIVER-AT DEVON	1999	2019	26%	--	--	--	--	--	--	--	--	--	--	--
NSR-NSR4	NORTH SASKATCHEWAN RIVER-AT PAKAN BRIDGE	1999	2019	100%	--	Yes	Yes	No	SMK2	Yes	0.007	0.164	0.073	-129.1	1.6
OMR-OMR1	OLDMAN RIVER-NEAR BROCKET-LEFT BANK	1999	2019	88%	No	--	No	--	MK1	Yes	<0.001	0.233	<0.001	0.6	<0.01
OMR-OMR2	OLDMAN RIVER-ABOVE LETHBRIDGE AT HWY 3	1987	2019	99%	No	--	No	--	MK2	Yes	<0.001	0.289	<0.001	0.7	0.01
OMR-OMR3	OLDMAN RIVER-AT HWY 36 BRIDGE NORTH OF TABER	1987	2019	100%	--	Yes	No	No	SMK1	Yes	0.001	0.177	0.063	-91.4	1.1
PR-PR1	PEACE RIVER-US SMOKY RIVER NEAR SHAFTESBURY FERRY	2006	2019	18%	--	--	--	--	--	--	--	--	--	--	--
PR-PR3	PEACE RIVER-AT FORT VERMILION	1995	2019	64%	--	--	--	--	--	--	--	--	--	--	--

Basin & Site ID	Site Name	Ice-Covered Season Pre-trend Tests and Information							Ice-Covered Season Trend Analyses Results						
		Min Year	Max Year	Detect Freq.	Seas. CD	Seas. KW	Ser. Dep.	Hetero Trend	Test	Sig. Trend	p value	Tau	Slope	Intercept	Annual Change (%)
PR-SMKY	SMOKY RIVER-AT WATINO	1987	2019	100%	--	Yes	No	No	SMK1	Yes	<0.001	-0.307	-0.092	234.8	-1.7
PR-WR1	WAPITI RIVER-AT HWY #40 BRIDGE	1999	2019	46%	--	--	--	--	--	--	--	--	--	--	--
PR-WR2	WAPITI RIVER-ABOVE CONFLUENCE WITH SMOKY RIVER	1999	2019	100%	--	Yes	No	No	SMK2	Yes	0.004	-0.204	-0.185	487.5	-1.5
RDR-RDR2	RED DEER RIVER-1 KM US HWY 2 BRIDGE	1984	2019	93%	Yes	--	No	Yes	SMK1	Yes	<0.001	0.366	0.034	-68.1	2.0
RDR-RDR3	RED DEER RIVER-AT NEVIS BRIDGE	1999	2019	100%	--	Yes	No	No	SMK2	Yes	<0.001	0.420	0.177	-362.7	3.2
RDR-RDR4	RED DEER RIVER-AT MORRIN BRIDGE	2008	2019	100%	--	Yes	No	No	SMK1	Yes	0.014	0.245	0.125	-276.0	1.7
RDR-RDR5	RED DEER RIVER-DS DINOSAUR PROV PARK AT HWY 884	2008	2019	100%	--	Yes	No	No	SMK2	Yes	0.010	0.255	0.163	-441.5	1.8
SSR-SSR1	SOUTH SASKATCHEWAN RIVER-ABOVE MEDICINE HAT	1995	2019	100%	--	Yes	No	No	SMK1	Yes	<0.001	0.485	0.450	-663.7	3.4

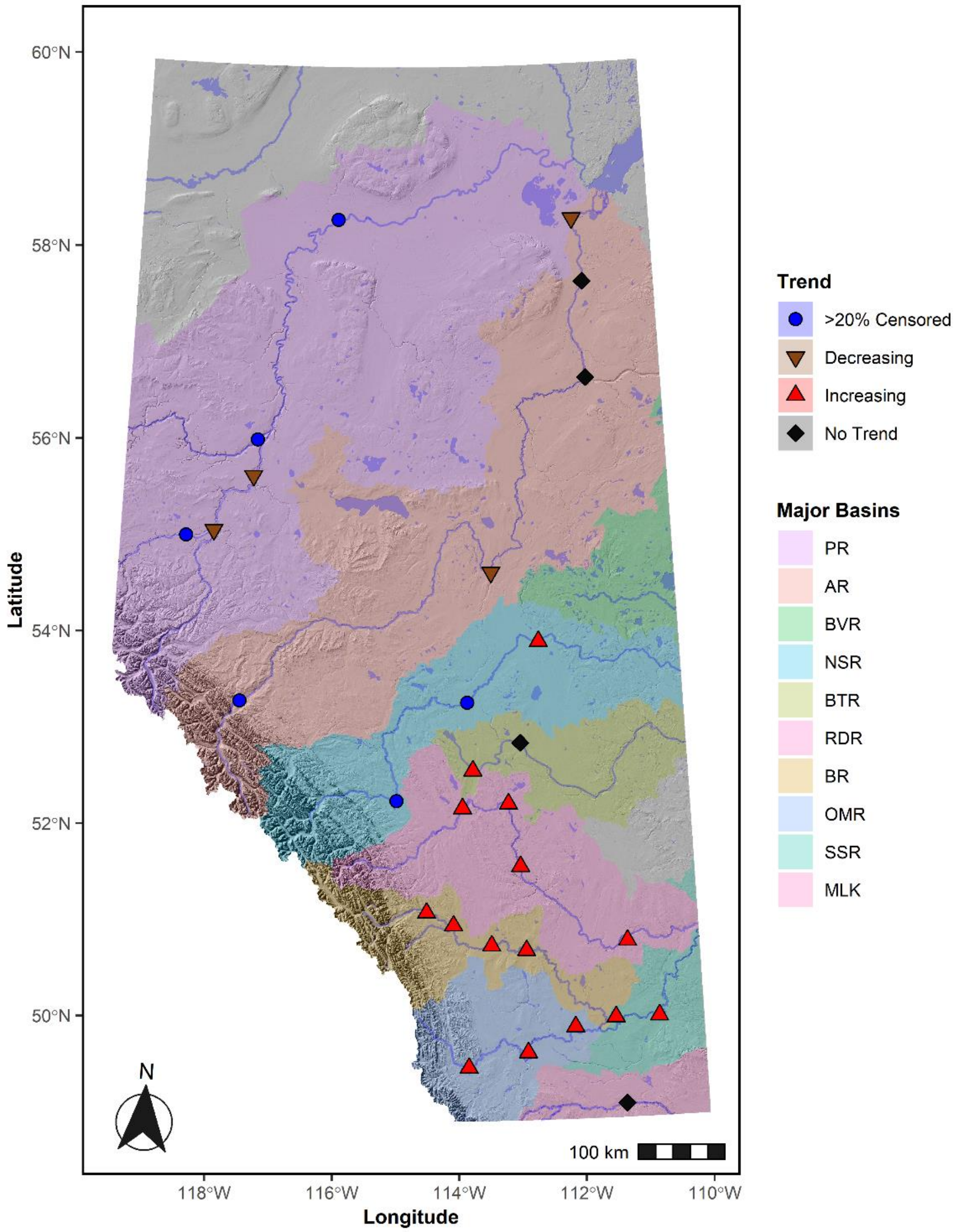

Figure 20: Results from the trend analyses for <u>ice-covered season</u> samples highlighting locations in the province where Cl^- was found to be increasing or decreasing over time along with sites without significant trends or where there was too much censored data to conduct the analysis. Acronym information for the major basins is listed in the Acronyms and Abbreviations.

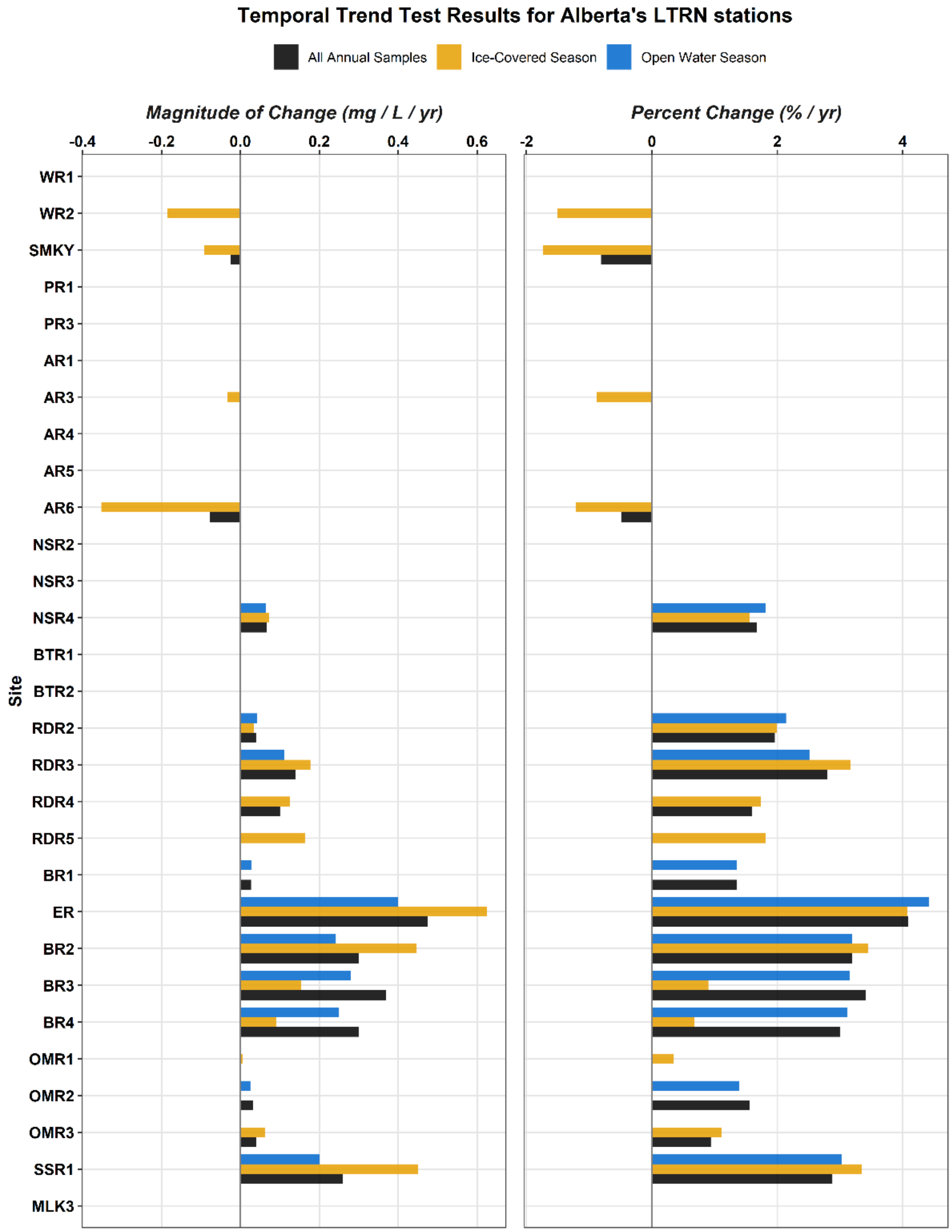

Figure 21: The magnitude (top) and percent change (bottom) for Cl^- at LTRN sites across Alberta for all annual samples, ice-covered season samples and open water samples determined by the trend analyses. Site acronym information is listed in Table A1.

Temporal Analyses

With respect to the temporal analysis, seven out of the 29 sites had an insufficient detection frequency to conduct the trend analyses without potentially introducing bias when addressing the censored data. For the remaining 22 sites in the annual dataset, 16 had statistically significant trends, two of which in Northern Alberta were found to be decreasing over time. Of the 14 sites with significantly increasing trends, five out of the six sites with increases >2% yr^{-1} were located in the Bow River watershed, near or downstream of Calgary. When examining the ice-covered season, there were five sites with significant decreasing trends in Northern Alberta compared to 14 sites with significant increasing trends in Central and Southern Alberta. In contrast, for the open water season, there was only one site with a significant decreasing trend in Northern Alberta and 13 with significant increasing trends in central and Southern Alberta. In general, the rate of increase in the trends is greater during the open water season in Southern Alberta (Figure 21). Overall, sites in Southern and Central Alberta have significant trends of increasing Cl^- concentrations whereas in Northern Alberta there are no significant trends, decreasing trends, or situations where low abundances of Cl^- make it difficult to conduct the trend analyses.

Sources of Chloride

This report's objective is to outline the methods and provide more comprehensive information than what is available on the online platform. Of note, the goal of this report is not to investigate nor summarize potential Cl^- sources. However, there are a number of other studies which have examined potential sources of Cl^- in parts of Alberta. For example, in Southern Alberta, Kerr (2017) reported that Cl^- had the highest annual increase (+1.4–3.0% yr^{-1}) relative to other major ions and attributed the trends in Cl^- concentrations in the Bow River downstream of Calgary to road salt inputs and to a lesser extent, waste water treatment plant effluent. Turnbull and Ryan (2012) reported increasing Cl^- trends downstream of urban areas in Southern Alberta, attributing these increases to waste water treatment plant effluent. In Central Alberta, Laceby et al. (2019) determined that Cl^- was increasing at the North Saskatchewan River Site 4 at Pakan bridge downstream of Edmonton at a rate of +1.1% yr^{-1}. These authors determined that road salts, including commercial deicers, were the largest source of dissolved chloride at the LTRN site downstream of Edmonton along with agricultural inputs and wastewater treatment plant effluent.

Limitations and Perspectives

There is a trade off when making a spatial comparison of sites with different timeframes. Here, we decided to include suspended, open water only, and ephemeral tributary sites in order to provide a greater spatial coverage of sites across Alberta even though several sites are missing data that may affect their direct spatial comparison in the spatial analysis.

A variety of trend tests and analyses could have been conducted on the AEP water quality datasets. There are different approaches to address seasonality, censored data and serial dependence. Here, we followed a conservative approach developed by leading scientists working with relatively similar water quality datasets (Helsel, 2005, 2011; Helsel and Hirsch, 1992). These approaches have been used in research on Cl^- by AEP scientists on datasets generated by sampling Albertan surface water (Kerr, 2017; Laceby et al., 2019). There may be an interest in using tests that are capable of working with datasets with >20% censored data. As the MDL for Cl^- increased in 2008, we believe that is important to retroactively incorporate this change throughout the temporal period by resubstituting the highest main MDL. There may be cases for where the MDL decreases or has no change at all. Therefore, different approaches to addressing censored data and/or different statistical trend tests are required on a case-by-case basis.

One major limitation of the trend analyses is that we did not incorporate discharge. Accordingly, there may be instances where significant trends, or even a lack of trends, are driven by trends in discharge. Unfortunately, co-located hydrometric monitoring stations do not exist for all of the LTRN sites. In fact, approximately only one third of the LTRN monitoring sites have co-located hydrometric monitoring stations. Modeling of discharge for all LTRN sites with a similar methodology would be required to include discharge in trend analyses.

Conclusions

There were five acute PAL guideline exceedances, 54 acute PAL chronic guideline exceedances and 79 irrigation guideline exceedances for Cl^- in the spatial analyses of data generated from 97 TMN and LTRN monthly monitoring sites from January 2016 to December 2019. Most of these Cl^- chronic guideline exceedances occurred in the Bow River watershed near Calgary, Waskasoo Creek near Red Deer and the Battle River Site 1 at the north end of Driedmeat Lake. Significant increasing trends of Cl^- are most evident in the Bow watershed around Calgary and the Battle River Site 1. Decreasing significant trends were evident in Northern Alberta, particularly during the ice-covered season. In general, headwater regions with montane runoff have lower Cl^- concentrations, which typically increase as you progress downstream. Additionally, tributary sites generally have higher Cl^- concentrations than their counterparts do on the main stem. The spatial and temporal trends in Cl^- concentrations highlighted in this report are likely representative of the culmination of multiple salinization processes occurring across the province of Alberta.

References

AEP, (2006) Aquatic Ecosystems Field Sampling Protocols, Alberta Environment and Parks (AEP), Edmonton, Canada, p. 138.

Barrett, D., Kruk, M., Ballard, N., (2019) 2017 Status of Surface Water Quality, Lower Athabasca Region, Alberta, in: Government of Alberta, E.a.P.I.-.-.-.-. (Ed.).

Breusch, T.S. (1978) Testing for autocorrelation in dynamic linear models. Australian Economic Papers 17, 334-355.

Canadian Council of Ministers of the Environment, (2011) Canadian water quality guidelines for the protection of aquatic life: Chloride, In: Canadian Environmental Quality Guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

Cañedo-Argüelles, M., Hawkins, C., Kefford, B., Schäfer, R., Dyack, B., Brucet, S., Buchwalter, D., Dunlop, J., Frör, O., Lazorchak, J. (2016) Saving freshwater from salts. Science 351, 914-916.

Cañedo-Argüelles, M., Kefford, B.J., Piscart, C., Prat, N., Schäfer, R.B., Schulz, C.J. (2013) Salinisation of rivers: an urgent ecological issue. Environmental Pollution 173, 157-167.

Chung, C., Zhu, D., Kromrey, N., Kerr, J.G., (2019) 2017-2018 Status of Surface Water Quality, South Saskatchewan Region, Alberta for April 2017 – March 2018, Government of Alberta, Ministry of Environment and Parks. ISBN 978-1-4601-4164-9. Available at: open.alberta.ca/publications/9781460141649.

Environment and Climate Change Canada, (2020) Canadian Environmental Sustainability Indicators: Water quality in Canadian rivers.

Fiera, (2013) State of the Watershed Report - Phase 3: Water Quantity and Basic Water Quality in the Athabasca Watershed. Report prepared for the Athabasca Watershed Council. Fiera Biological Consulting Report #1234, p. 802.

GOA, (2014) South Saskatchewan Region surface water quality management framework: for the mainstem Bow, Milk, Oldman and South Saskatchewan Rivers (Alberta), Edmonton.

Godfrey, L.G. (1978) Testing against general autoregressive and moving average error models when the regressors include lagged dependent variables. Econometrica: Journal of the Econometric Society 46, 1293-1301.

Government of Alberta, (2018) Environmental quality guidelines for Alberta surface waters, Water Policy Branch, Alberta Environment and Parks, Edmonton.

Halliday, R. (2009) From the mountains to the sea: The state of the Saskatchewan River Basin. Partners for the Saskatchewan River Basin, Saskatoon.

Health Canada, (1987) Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Chloride.

Health Canada, (2017) Guidelines for Canadian drinking water quality—Summary table, Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa.

Helsel, D.R. (2005) Nondetects and data analysis. Statistics for censored environmental data. Wiley-Interscience, Hoboken.

Helsel, D.R. (2011) Statistics for censored environmental data using Minitab and R. John Wiley & Sons, Hoboken, NJ.

Helsel, D.R., Hirsch, R.M. (1992) Statistical methods in water resources. Elsevier, Amsterdam.

Kaushal, S.S. (2016) Increased salinization decreases safe drinking water. Environment Science and Technology 50, 2765−2766.

Kaushal, S.S., Groffman, P.M., Likens, G.E., Belt, K.T., Stack, W.P., Kelly, V.R., Band, L.E., Fisher, G.T. (2005) Increased salinization of fresh water in the northeastern United States. Proceedings of the National Academy of Sciences 102, 13517-13520.

Kelly, V.R., Lovett, G.M., Weathers, K.C., Findlay, S.E., Strayer, D.L., Burns, D.J., Likens, G.E. (2008) Long-term sodium chloride retention in a rural watershed: legacy effects of road salt on streamwater concentration. Environmental Science and Technology 42, 410-415.

Kerr, J., Cooke, C., (2019) A five-year provincial water quality monitoring, evaluation and reporting plan for lotic systems. Government of Alberta, Ministry of Environment and Parks, Edmonton, Canada.

Kerr, J.G. (2017) Multiple land use activities drive riverine salinization in a large, semi-arid river basin in western Canada. Limnology and Oceanography 62, 1331-1345.

Kerr, J.G., Cooke, C.A. (2017) Erosion of the Alberta badlands produces highly variable and elevated heavy metal concentrations in the Red Deer River, Alberta. Science of The Total Environment 596, 427-436.

Kruskal, W.H., Wallis, W.A. (1952) Use of ranks in one-criterion variance analysis. Journal of the American statistical Association 47, 583-621.

Laceby, J.P., Chung, C., Kruk, M.K., Kerr, J.G., (2022) Investigation of quality control data from Alberta's lotic water monitoring programs, 2016-2019, Alberta Environment and Parks, Edmonton, Canada.

Laceby, J.P., Kerr, J.G., Zhu, D., Chung, C., Situ, Q., Abbasi, S., Orwin, J. (2019) Chloride inputs to the North Saskatchewan River watershed: the role of road salts as a potential driver of salinization downstream of North America's northern most major city (Edmonton, Canada). Science of The Total Environment 688, 1056-1068.

McKenzie, H., Westcott, K., Cooke, C., (2015) Analysis of Water Quality Conditions and Trends for Indicators Triggered in 2012 under the Surface Water Quality Management Framework for the Lower Athabasca River, in: Parks, A.E.a. (Ed.), Edmonton, p. 160.

Morales-Marín, L.A., Chun, K.P., Wheater, H.S., Lindenschmidt, K.-E. (2017) Trend analysis of nutrient loadings in a large prairie catchment. Hydrological Sciences Journal 62, 657-679.

MPWA, (2015) State of the Watershed. Mighty Peace Watershed Alliance (MPWA) McLennan, Alberta, Canada, p. 80.

MRWCC, (2013) Milk River Transboundary State of the Watershed Report, 2nd Edition. Compiled by Palliser Environmental Services Limited and prepared for the Milk River Watershed Council Canada (MRWCC)(Alberta) in collaboration with the Milk River Watershed Alliance (Montana). Milk River, Alberta, p. 238.

Mueller, D.K., Schertz, T.L., Martin, J.D., Sandstrom, M.W., (2015) Design, analysis, and interpretation of field quality-control data for water-sampling projects. US Geological Survey (From: https://pubs.er.usgs.gov/publication/tm4C4).

North Saskatchewan Watershed Alliance (2012) Atlas of the North Saskatchewan River Watershed in Alberta. The North Saskatchewan Watershed Alliance (NSWA) Society, Edmonton.

Novotny, E.V., Murphy, D., Stefan, H.G. (2008) Increase of urban lake salinity by road deicing salt. Science of The Total Environment 406, 131-144.

Riskin, M.L., Reutter, D.C., Martin, J.D., Mueller, D.K., (2018) Quality-control design for surface-water sampling in the National Water-Quality Network. US Geological Survey.

Shi, X., Fay, L., Yang, Z., Nguyen, T.A., Liu, Y. (2009) Corrosion of deicers to metals in transportation infrastructure: Introduction and recent developments. Corrosion Reviews 27, 23-52.

Thunqvist, E.L. (2004) Regional increase of mean chloride concentration in water due to the application of deicing salt. Science of The Total Environment 325, 29-37.

Turnbull, B., Ryan, M.C. (2012) Decadal and seasonal water quality trends downstream of urban and rural areas in southern Alberta rivers. Water Quality Research Journal 47, 406-420.

Van Belle, G., Hughes, J.P. (1984) Nonparametric tests for trend in water quality. Water Resources Research 20, 127-136.

Williams, W., (2001) Anthropogenic salinisation of inland waters, In: Saline Lakes. Springer, Dordrecht, pp. 329-337.

Appendix

Table A1: Station information of all LTRN and TMN sites including the short forms (Site ID and Basin ID) that are used throughout the report. The table is sorted by major basin and station number (No.).

Station No.	Station Name and Description	Site ID	Major Basin	Basin ID	Site Type	Latitude	Longitude
AB07AA0005	SUNWAPTA RIVER-AT WSC GAUGE 0.1 KM DOWNSTREAM OF SUNWAPTA LAKE	SAR	Athabasca River	AR	TMN	52.2170	117.2342
AB07AA0007	MIETTE RIVER-AT WSC GAUGE AT HWY 16	MTR	Athabasca River	AR	TMN	52.8640	118.1059
AB07AC0015	BERLAND RIVER-AT WSC GAUGE 10KM US OF ATHABASCA RIVER	BER	Athabasca River	AR	TMN	54.0121	116.9666
AB07AD0100	ATHABASCA RIVER-AT OLD ENTRANCE TOWN SITE - LEFT BANK	AR1	Athabasca River	AR	LTRN	53.3675	117.7225
AB07AG0345	MCLEOD RIVER-AT WSC GAUGE 4.5KM US OF GROAT CREEK	MCL	Athabasca River	AR	TMN	54.0130	115.8416
AB07AH0005	SAKWATAMAU RIVER-AT WSC GAUGE AT HWY 32	SAK	Athabasca River	AR	TMN	54.2012	115.7796
AB07BC0025	PEMBINA RIVER-AT WSC GAUGE NEAR JARVIE	PBR	Athabasca River	AR	TMN	54.4493	113.9924
AB07BD0010	ATHABASCA RIVER-AT VEGA FERRY (KLONDYKE) CENTRE OF RIVER	AR2	Athabasca River	AR	LTRN	54.4311	114.4606
AB07BE0010	ATHABASCA RIVER-AT TOWN OF ATHABASCA	AR3	Athabasca River	AR	LTRN	54.7222	113.2861
AB07BK0125	LESSER SLAVE RIVER-9.5 KM US OF ATHABASCA RIVER CONFLUENCE	LSR	Athabasca River	AR	TMN	55.2067	114.1225
AB07CC0030	ATHABASCA RIVER-US FORT MCMURRAY, 100 M US HORSE RIVER - LEFT BANK	AR4	Athabasca River	AR	LTRN	56.7203	111.4056
AB07DA0980	ATHABASCA RIVER-TRANSECT ABOVE THE FIREBAG RIVER	AR5	Athabasca River	AR	LTRN	57.7236	111.3792
AB07DD0010	ATHABASCA RIVER-AT OLD FORT - RIGHT BANK	AR6	Athabasca River	AR	LTRN	58.3828	111.5178
AB07DD0105	ATHABASCA RIVER-DS OF DEVILS ELBOW AT WINTER ROAD CROSSING	AR6	Athabasca River	AR	LTRN	58.3828	111.5178
AB05AJ0060	TWELVE MILE CREEK-NEAR CECIL AT BRIDGE ABOVE GAUGING STATION	TMC	Bow River	BR	TMN	50.1500	111.6667
AB05BG0090	GHOST RIVER-ABOVE CONFLUENCE WITH WAIPAROUS CREEK	GR	Bow River	BR	TMN	51.2832	114.8392
AB05BG0100	WAIPAROUS CREEK-ABOVE CONFLUENCE WITH GHOST RIVER	WSC	Bow River	BR	TMN	51.2824	114.8375
AB05BH0010	BOW RIVER-AT COCHRANE	BR1	Bow River	BR	LTRN	51.1831	114.4871
AB05BH0020	JUMPING POUND CREEK-ABOVE GAS PLANT	JPC	Bow River	BR	TMN	51.1269	114.5708
AB05BH0040	JUMPINGPOUND CREEK-NEAR MOUTH	JPC	Bow River	BR	TMN	51.1847	114.4958
AB05BH0370	NOSE CREEK-NEAR THE MOUTH-MEMORIAL DRIVE	NC	Bow River	BR	TMN	51.0464	114.0189
AB05BJ0450	ELBOW RIVER-AT 9TH AVE BRIDGE	ER	Bow River	BR	LTRN	51.0448	114.0419
AB05BK0070	FISH CREEK-#8 NEAR THE MOUTH NE 14-25-22-1-W5	FC	Bow River	BR	TMN	50.9052	114.0110
AB05BL0210	HIGHWOOD RIVER-DS OF HIGH RIVER AT BEND IN BACK ROAD TO HIGH RIVER	HR1	Bow River	BR	TMN	50.6013	113.8580
AB05BL0470	SHEEP RIVER-1.6 KM DS OF HWY 2	SR2	Bow River	BR	TMN	50.7160	113.8600
AB05BL0490	HIGHWOOD RIVER-AT HWY 552	HR2	Bow River	BR	TMN	50.7823	113.8259
AB05BL1440	SHEEP RIVER-APPROXIMATELY 1.0 KM DS WSC GAUGE	SR1	Bow River	BR	TMN	50.6968	114.2358
AB05BM0010	BOW RIVER-BELOW CARSELAND DAM	BR2	Bow River	BR	LTRN	50.8306	113.4167
AB05BM0145	PINE CREEK-NEAR THE MOUTH	PC	Bow River	BR	TMN	50.8450	113.9619
AB05BM0575	WEST ARROWWOOD CREEK-DS OF SYPHON	WAC	Bow River	BR	TMN	50.7792	113.2036
AB05BM0585	EAST ARROWWOOD CREEK-NEAR THE MOUTH	EAC	Bow River	BR	TMN	50.7647	113.1239
AB05BM0590	BOW RIVER-AT CLUNY	BR3	Bow River	BR	LTRN	50.7731	112.8455
AB05BM0620	CROWFOOT CREEK-ON HWY 1	CFC	Bow River	BR	TMN	50.8333	112.7611
AB05BN0010	BOW RIVER-NEAR RONALANE BRIDGE	BR4	Bow River	BR	LTRN	50.0478	111.4248

AB05BN0070	COAL CREEK-12 MILE WEST OF BOW CITY	CC	Bow River	BR	TMN	50.4306	112.2278
AB05BN0130	NEW WEST COULEE-AT HWY 36 CROSSING	NWC	Bow River	BR	TMN	50.2167	112.0208
AB05FA0340	BATTLE RIVER-AT NORTH END OF DRIEDMEAT LAKE	BTR1	Battle River	BTR	LTRN	52.9374	112.8486
AB05FA0060	BATTLE RIVER-APPROX 2 KM DS HWY 53	BTR2	Battle River	BTR	LTRN	52.6588	113.6751
AB06AC0100	BEAVER RIVER-AT HIGHWAY 892 BRIDGE NORTH OF ARDMORE	BVR1	Battle River	BVR	LTRN	54.4304	110.4825
AB06AD0060	BEAVER RIVER-AT HWY 28 BRIDGE NEAR BEAVER CROSSING - CENTRE	BVR2	Battle River	BVR	LTRN	54.3550	110.2144
AB06AD0130	BEAVER RIVER-AT GRAVEL PIT, 6 KM US OF AB-SK BORDER	BVR3	Battle River	BVR	LTRN	54.2514	110.0297
AB11AA0070	MILK RIVER-AT HWY 880	MLK3	Milk River	MLK	LTRN	49.1442	111.3108
AB11AA0100	VERDIGRIS CREEK-AT HWY 501	VC	Milk River	MLK	TMN	49.1553	111.8369
AB11AA0150	MILK RIVER-US OF TOWN OF MILK RIVER	MLK2	Milk River	MLK	TMN	49.1481	112.1673
AB11AA0270	NORTH MILK RIVER-NEAR INTERNATIONAL BOUNDARY, UPSTREAM OF HWY 501	NMR	Milk River	MLK	TMN	49.0219	112.9711
AB11AA0280	MILK RIVER-NEAR WESTERN BOUNDARY, AT HWY 501	MLK1	Milk River	MLK	TMN	49.0900	112.3983
AB11AA0290	RED CREEK-NEAR THE MOUTH	RC	Milk River	MLK	TMN	49.0672	111.9224
AB11AA0330	MINER'S COULEE-SITE B	MSC	Milk River	MLK	TMN	49.0347	111.3880
AB05DC0025	NORTH SASKATCHEWAN RIVER-AT SAUNDERS CAMPGROUND - TRANSECT	NSR1	North Sask. River	NSR	LTRN	52.4538	115.7595
AB05DC0050	NORTH SASKATCHEWAN RIVER- US OF ROCKY MOUNTAIN HOUSE	NSR2	North Sask. River	NSR	LTRN	52.3481	114.9818
AB05DF0010	NORTH SASKATCHEWAN RIVER-AT DEVON	NSR3	North Sask. River	NSR	LTRN	53.3689	113.7514
AB05EC0010	NORTH SASKATCHEWAN RIVER-AT PAKAN BRIDGE	NSR4	North Sask. River	NSR	LTRN	53.9909	112.4759
AB05AA0440	PINCHER CREEK-AT PINCHER CREEK	PC1	Oldman River	OMR	TMN	49.4819	113.9686
AB05AA0480	PINCHER CREEK-AT HWY 3 NEAR THE MOUTH	PC2	Oldman River	OMR	TMN	49.5463	113.7945
AB05AA1595	OLDMAN RIVER-NEAR BROCKET-LEFT BANK	OMR1	Oldman River	OMR	LTRN	49.5586	113.8222
AB05AB0100	BEAVER CREEK-WEST OF PEIGAN INDIAN RESERVE	BRC	Oldman River	OMR	TMN	49.6393	113.7952
AB05AB0260	WILLOW CREEK-AT SEC HWY 811	WK	Oldman River	OMR	TMN	49.7572	113.4069
AB05AC0100	LITTLE BOW RIVER-AT HWY 533 EAST OF NANTON	LBR1	Oldman River	OMR	TMN	50.3538	113.5428
AB05AC0160	MOSQUITO CREEK-AT HWY 529 EAST OF PARKLAND	MQC	Oldman River	OMR	TMN	50.2520	113.5535
AB05AC0175	LITTLE BOW RIVER-DS OF TWIN VALLEY RESERVOIR	LBR2	Oldman River	OMR	TMN	50.2253	113.3976
AB05AC0190	LITTLE BOW RIVER-AT CARMANGAY	LBR3	Oldman River	OMR	TMN	50.1344	113.1382
AB05AC0320	LITTLE BOW RIVER-NEAR THE MOUTH	LBR4	Oldman River	OMR	TMN	49.9017	112.5067
AB05AD0010	OLDMAN RIVER-ABOVE LETHBRIDGE AT HWY 3	OMR2	Oldman River	OMR	LTRN	49.7067	112.8629
AB05AD0070	BELLY RIVER-JUST US OF THE CONFLUENCE WITH THE WATERTON RIVER-BR3	BYR1	Oldman River	OMR	TMN	49.4772	113.3017
AB05AD0190	WATERTON RIVER-ADJACENT TO SEC HWY 810 BRIDGE-WR2	WNR	Oldman River	OMR	TMN	49.4303	113.4958
AB05AD0240	BELLY RIVER-NEAR CONFLUENCE WITH OLDMAN RIVER	BYR2	Oldman River	OMR	TMN	49.7275	113.1781
AB05AE0070	ST. MARY RIVER-NEAR CONFLUENCE WITH OLDMAN RIVER	SMR	Oldman River	OMR	TMN	49.5889	112.8806
AB05AG0010	OLDMAN RIVER-AT HWY 36 BRIDGE NORTH OF TABER	OMR3	Oldman River	OMR	LTRN	49.9611	112.0847
AB05AG0140	EXPANSE COULEE-ADJACENT TO HWY 36 BRIDGE CROSSING OLDMAN RIVER	EC	Oldman River	OMR	TMN	49.9717	112.0833
AB07FD0135	PEACE RIVER-US SMOKY RIVER NEAR SHAFTESBURY FERRY TRANSECT	PR1	Peace River	PR	LTRN	56.0932	117.5661
AB07GE0020	WAPITI RIVER-AT HWY #40 BRIDGE - CENTRE - KM 44	WR1	Peace River	PR	LTRN	55.0719	118.8047
AB07GJ0010	SMOKY RIVER-AT WATINO	SMKY	Peace River	PR	LTRN	55.7156	117.6219
AB07GJ0030	WAPITI RIVER-ABOVE CONFLUENCE WITH SMOKY RIVER - CENTRE - KM 0.5	WR2	Peace River	PR	LTRN	55.1367	118.3083

AB07HA0230	PEACE RIVER-1.5 KM ABOVE CONFLUENCE OF WHITEMUD RIVER - CENTRE	PR2	Peace River	PR	LTRN	56.6564	117.1467
AB07HF0010	PEACE RIVER-AT FORT VERMILION - CENTRE	PR3	Peace River	PR	LTRN	58.4044	116.1281
AB05CA0015	FALLEN TIMBER CREEK-NEAR MOUTH	FTC	Red Deer River	RDR	TMN	51.7367	114.6544
AB05CA0045	BEARBERRY CREEK-NEAR SUNDRE(NEAR WIER)REMOTE LOGGER SITE	BBC	Red Deer River	RDR	TMN	51.8000	114.6600
AB05CA0050	RED DEER RIVER-AT SUNDRE	RDR1	Red Deer River	RDR	LTRN	51.7958	114.6350
AB05CA0090	JAMES RIVER-NEAR JAMES RIVER BRIDGE	JR	Red Deer River	RDR	TMN	51.9269	114.6844
AB05CB0070	RAVEN RIVER-AT RAVEN	RR	Red Deer River	RDR	TMN	52.1042	114.4783
AB05CB0270	LITTLE RED DEER RIVER-WEST OF INNISFAIL	LRDR	Red Deer River	RDR	TMN	52.0278	114.1389
AB05CC0010	RED DEER RIVER-1 KM US HWY 2 BRIDGE	RDR2	Red Deer River	RDR	LTRN	52.2672	113.8636
AB05CC0100	MEDICINE RIVER-AT HWY 54	MR	Red Deer River	RDR	TMN	52.0917	114.1222
AB05CC0225	WASKASOO CREEK-NEAR CONFLUENCE WITH RED DEER RIVER	WOC	Red Deer River	RDR	TMN	52.2710	113.8022
AB05CC0460	BLINDMAN RIVER-NEAR THE MOUTH, AT HWY 2A BRIDGE	BMR	Red Deer River	RDR	TMN	52.3556	113.7944
AB05CD0250	RED DEER RIVER-AT NEVIS BRIDGE-RIGHT BANK	RDR3	Red Deer River	RDR	LTRN	52.3064	113.0792
AB05CE0009	RED DEER RIVER-AT MORRIN BRIDGE	RDR4	Red Deer River	RDR	LTRN	51.6506	112.9031
AB05CE0090	ROSEBUD RIVER-AT ROSEBUD,HWY 840	RBR1	Red Deer River	RDR	TMN	51.2972	112.9428
AB05CE0100	ROSEBUD RIVER-AT HWY 10	RBR2	Red Deer River	RDR	TMN	51.4153	112.6297
AB05CE0660	THREEHILLS CREEK-AT HWY 836	THC1	Red Deer River	RDR	TMN	51.5661	113.0731
AB05CE0680	THREEHILLS CREEK-NEAR MOUTH AT HWY 837	THC2	Red Deer River	RDR	TMN	51.5306	112.8869
AB05CE0685	KNEEHILLS CREEK-AT RANGE ROAD 221	KC1	Red Deer River	RDR	TMN	51.4698	112.9786
AB05CE0690	KNEEHILLS CREEK-NEAR THE MOUTH AT HWY 575	KC2	Red Deer River	RDR	TMN	51.4978	112.8414
AB05CE0695	MICHICHI CREEK-AT RANGE ROAD 190191	MC1	Red Deer River	RDR	TMN	51.5268	112.5572
AB05CE0700	MICHICHI CREEK-NEAR THE MOUTH	MC2	Red Deer River	RDR	TMN	51.4714	112.7167
AB05CH0120	BERRY CREEK-NEAR MOUTH	BRYC	Red Deer River	RDR	TMN	50.8422	111.6042
AB05CJ0030	MATZHIWIN CREEK-AT HWY 36	MTC	Red Deer River	RDR	TMN	50.8417	111.9306
AB05CJ0070	RED DEER RIVER-DS DINOSAUR PROV PARK AT HWY 884 NEAR JENNER-RB	RDR5	Red Deer River	RDR	LTRN	50.8386	111.1767
AB05AH0020	ROSS CREEK-NEAR MOUTH	RK	South Sask. River	SSR	TMN	50.0311	110.6431
AB05AH0050	SEVEN PERSONS CREEK-NEAR THE MOUTH	SPC	South Sask. River	SSR	TMN	50.0311	110.6439
AB05AK0020	SOUTH SASKATCHEWAN RIVER-ABOVE MEDICINE HAT	SSR1	South Sask. River	SSR	LTRN	50.0433	110.7222
AB05AK0990	SOUTH SASKATCHEWAN RIVER-BELOW MEDICINE HAT, US FERTILIZER PLANT	SSR2	South Sask. River	SSR	TMN	50.1048	110.6911

Table A2: Field blank contamination categories directly copied from Laceby et al., (in press) including an interpretation of how parameters were assigned to these different categories along with the number (n) and percent of parameters belonging to these categories.

Category	Relationship between environmental and blank data	Interpretation of contamination potential	Parameters in each category *n*	%
A	No detections in the field blank samples	No evidence of extraneous contamination.	7	8%
B	95% of environmental data is an order of magnitude greater than field blank data	Some contamination may exist, however the magnitude of any extraneous contamination is likely to be minimal relative to environmental concentrations for most, but not all samples.	28	33%
C	Environmental data is within an order of magnitude of the field blank data*	Some extraneous contamination may exist and the magnitude of this contamination may be relevant to the interpretation of environmental data. Interpretation will depend on the specific environmental sample concentration, the field blank concentration distribution and the specific purpose of the analysis.	41	49%
D	>25% of field blank data is greater than or equal to the environmental data	High potential for extraneous contamination in the environmental data and/or environmental data are frequently at or near the analytical limit of detection. Extraneous contamination of high relevance to the interpretation of environmental data or the existing analytical methodology cannot adequately assess contamination potential.	8	10%

[*] Less than 5% of the environmental data for Category C was an order of magnitude greater than the field blank data and less than 25% of their field blank data was greater than or equal to the environmental data

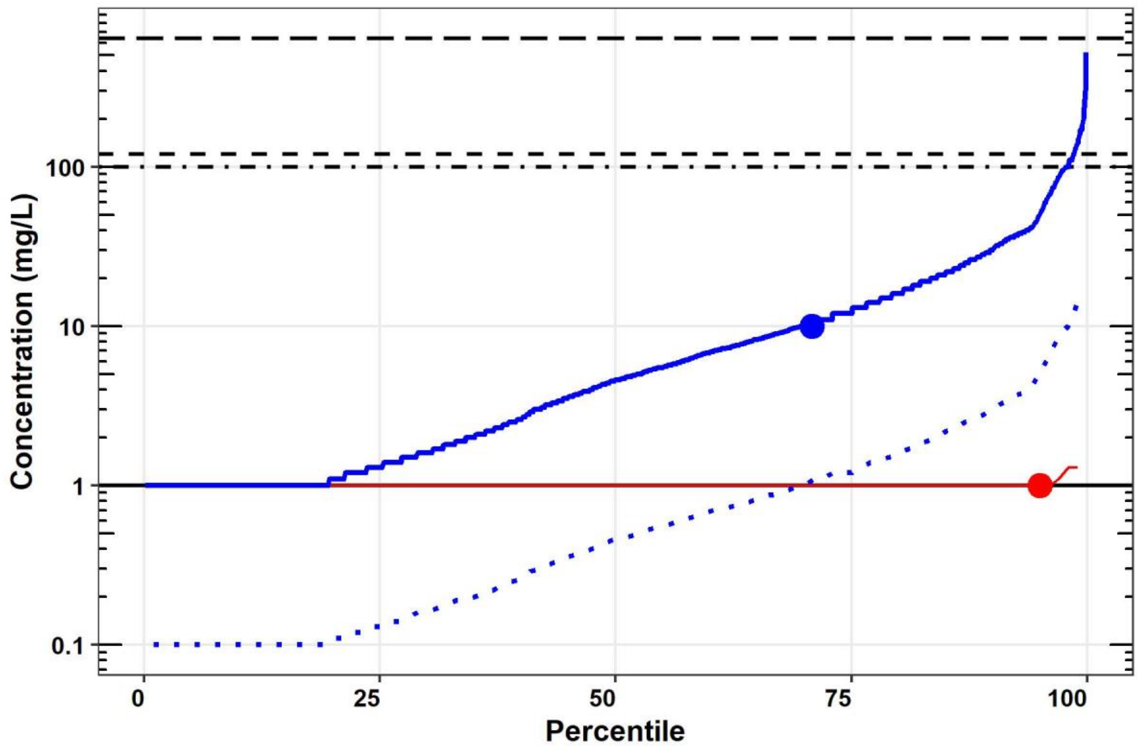

Figure A1: The relationship between Cl^- between the 90-percent UCL for the field blank concentrations (red line) and the distribution of environmental data (blue line). The solid reference line represents the MDL (1.0 mg/L), the dotted blue line depicts a distribution that is an order of magnitude less than environmental data, the red dot is the UCL of the 95th percentile for the field blank samples (B95-90) and the blue dot is the percentile of the environmental data that is an order of magnitude greater than the B95-90 value, with the three dashed references lines at the top of the plot representing the CCME acute (640 mg/L) and chronic (120 mg/L) PAL surface water guidelines along with crop specific guidelines also exist for Cl^- concentrations in irrigation water (100 mg/L).

Table A3: Results from the statistical analysis investigating for significant differences between the open water and ice-covered seasons.

Basin & Site ID	Site Name	Detect Freq.	Censored Difference Test Chi Square	Censored Difference Test p value	Censored Difference Test Seas. CD	Kruskal-Wallace Test Chi Square	Kruskal-Wallace Test p value	Kruskal-Wallace Test Seas. KW
AR-AR1	ATHABASCA RIVER-AT OLD ENTRANCE TOWN SITE	32%	--	--	--	--	--	--
AR-AR3	ATHABASCA RIVER-AT TOWN OF ATHABASCA	91%	211.48	<0.001	Yes	164.4	<0.001	Yes
AR-AR4	ATHABASCA RIVER-US FORT MCMURRAY	99%	120.98	<0.001	Yes	90.5	<0.001	Yes
AR-AR5	ATHABASCA RIVER-TRANSECT ABOVE THE FIREBAG RIVER	100%	78.89	<0.001	Yes	61.0	<0.001	Yes
AR-AR6	ATHABASCA RIVER - OLD FORT AND DEVILS ELBOW	100%	302.70	<0.001	Yes	210.3	<0.001	Yes
BR-BR1	BOW RIVER-AT COCHRANE	98%	5.89	0.880	No	5.7	0.0107	Yes
BR-BR2	BOW RIVER-BELOW CARSELAND DAM	100%	111.33	<0.001	Yes	96.9	<0.001	Yes
BR-BR3	BOW RIVER-AT CLUNY	100%	98.69	<0.001	Yes	81.6	<0.001	Yes
BR-BR4	BOW RIVER-NEAR RONALANE BRIDGE	100%	108.42	<0.001	Yes	93.2	<0.001	Yes
BR-ER	ELBOW RIVER-AT 9TH AVE BRIDGE	100%	55.25	<0.001	Yes	49.6	<0.001	Yes
BTR-BTR1	BATTLE RIVER-AT NORTH END OF DRIEDMEAT LAKE	100%	75.59	<0.001	Yes	61.1	<0.001	Yes
BTR-BTR2	BATTLE RIVER-APPROX 2 KM DS HWY 53	100%	7.90	0.722	No	7.6	0.006	Yes
MLK-MLK3	MILK RIVER-AT HWY 880	90%	141.17	<0.001	Yes	103.0	<0.001	Yes
NSR-NSR2	NORTH SASKATCHEWAN RIVER-US OF RMH	11%	--	--	--	--	--	--
NSR-NSR3	NORTH SASKATCHEWAN RIVER-AT DEVON	40%	--	--	--	--	--	--
NSR-NSR4	NORTH SASKATCHEWAN RIVER-AT PAKAN BRIDGE	100%	23.08	0.017	Yes	21.6	<0.001	Yes
OMR-OMR1	OLDMAN RIVER-NEAR BROCKET-LEFT BANK	75%	--	--	--	--	--	--
OMR-OMR2	OLDMAN RIVER-ABOVE LETHBRIDGE AT HWY 3	95%	33.26	0.000	Yes	31.0	<0.001	Yes
OMR-OMR3	OLDMAN RIVER-AT HWY 36 BRIDGE NORTH OF TABER	98%	122.29	<0.001	Yes	103.4	<0.001	Yes
PR-PR1	PEACE RIVER-US SMOKY RIVER NEAR SHAFTESBURY FERRY	29%	--	--	--	--	--	--
PR-PR3	PEACE RIVER-AT FORT VERMILION	75%	--	--	--	--	--	--
PR-SMKY	SMOKY RIVER-AT WATINO	92%	229.27	<0.001	Yes	172.6	<0.001	Yes
PR-WR1	WAPITI RIVER-AT HWY #40 BRIDGE	41%	--	--	--	--	--	--
PR-WR2	WAPITI RIVER-ABOVE CONFLUENCE WITH SMOKY RIVER	96%	183.35	<0.001	Yes	133.0	<0.001	Yes
RDR-RDR2	RED DEER RIVER-1 KM US HWY 2 BRIDGE	91%	8.33	0.683	No	8.5	0.004	Yes
RDR-RDR3	RED DEER RIVER-AT NEVIS BRIDGE	100%	17.63	0.091	No	16.7	<0.001	Yes
RDR-RDR4	RED DEER RIVER-AT MORRIN BRIDGE	100%	27.70	0.004	Yes	24.9	<0.001	Yes
RDR-RDR5	RED DEER RIVER-DS DINOSAUR PROV PARK AT HWY 884	100%	2.13	0.998	No	2.1	0.148	No
SSR-SSR1	SOUTH SASKATCHEWAN RIVER-ABOVE MEDICINE HAT	100%	143.13	<0.001	Yes	112.4	<0.001	Yes

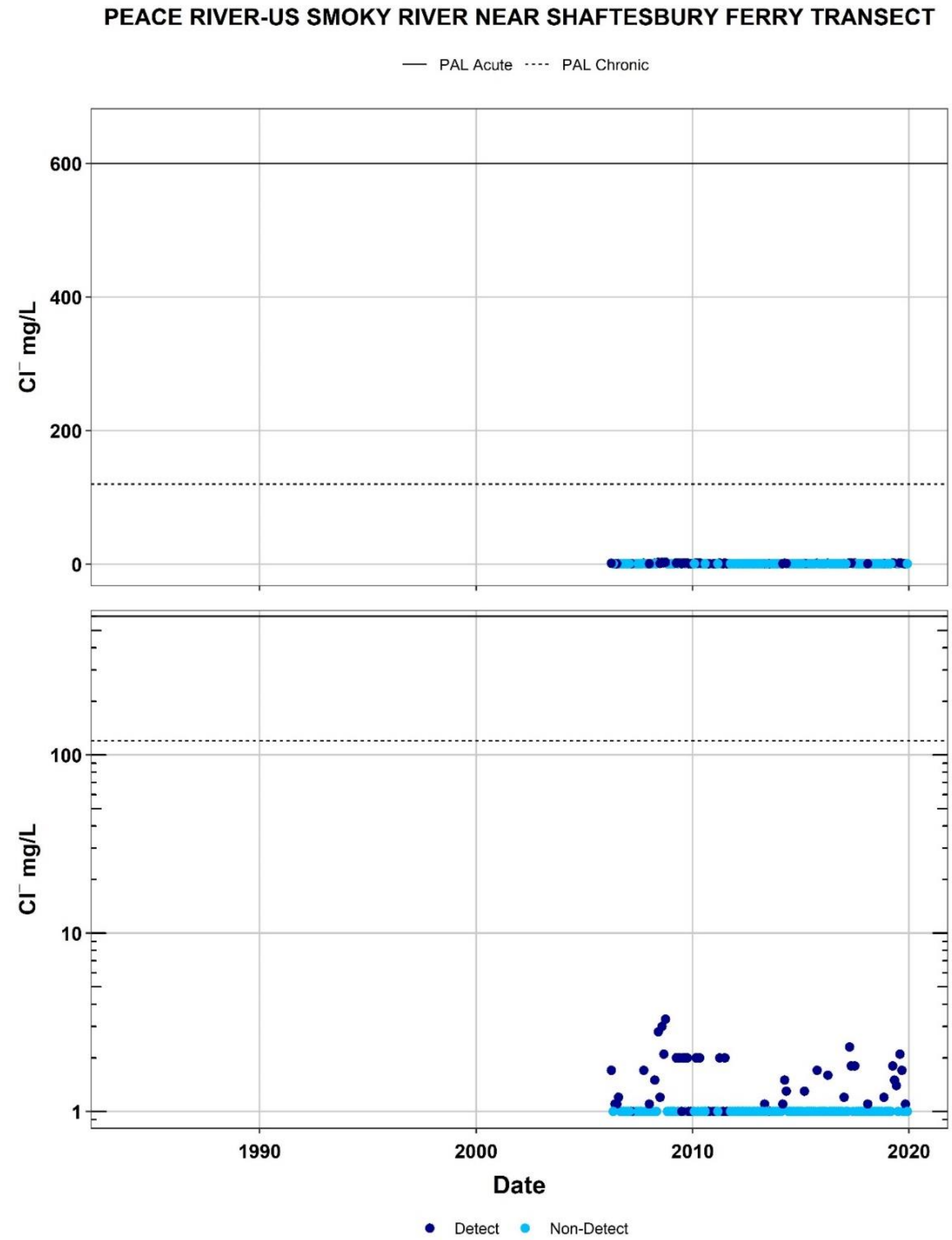

Figure A2: Scatter plots of Cl^- concentrations at the Peace River Site 1 near Shaftesbury ferry transect including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

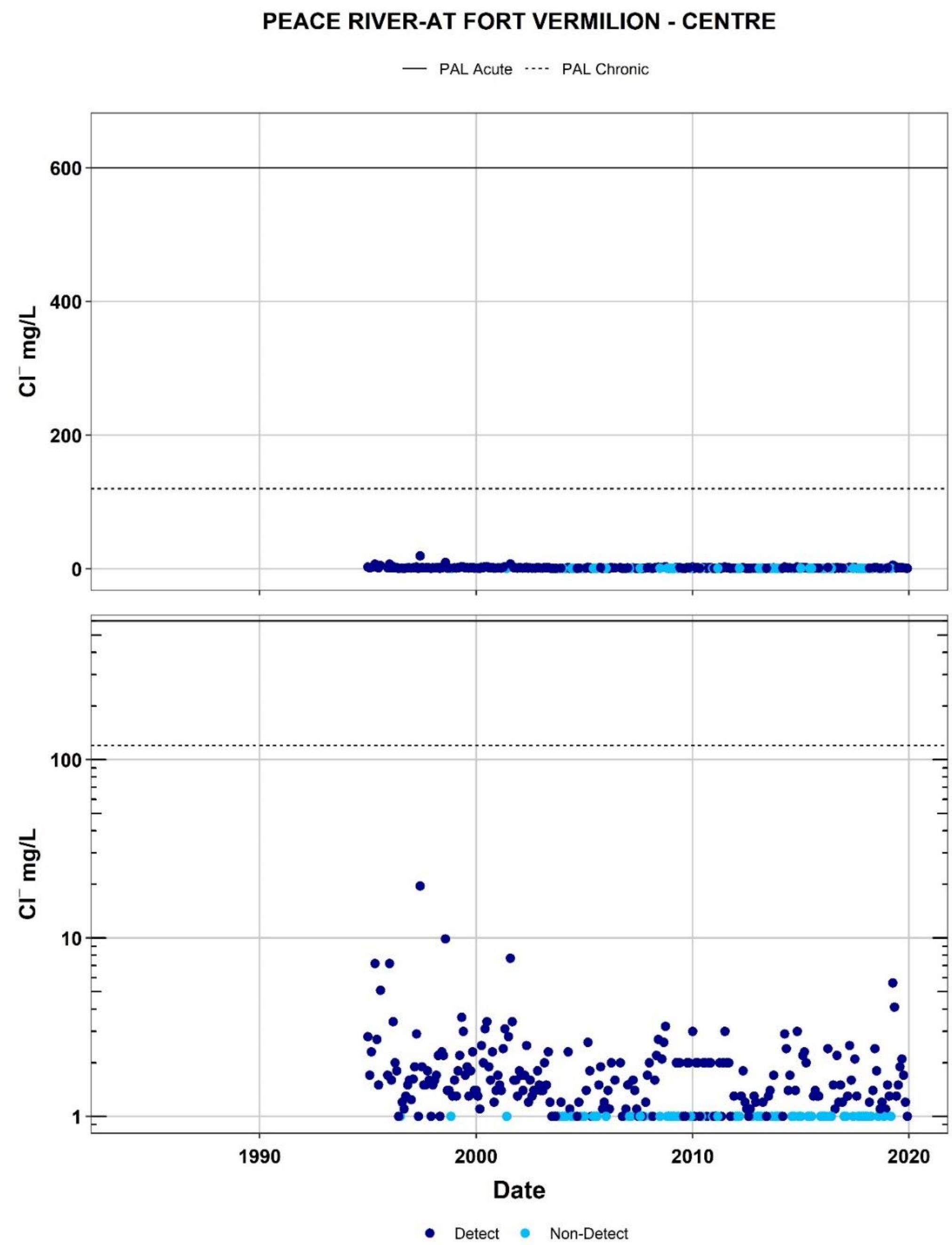

Figure A3: Scatter plots of Cl^- concentrations at the Peace River Site 3 at Fort Vermilion including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

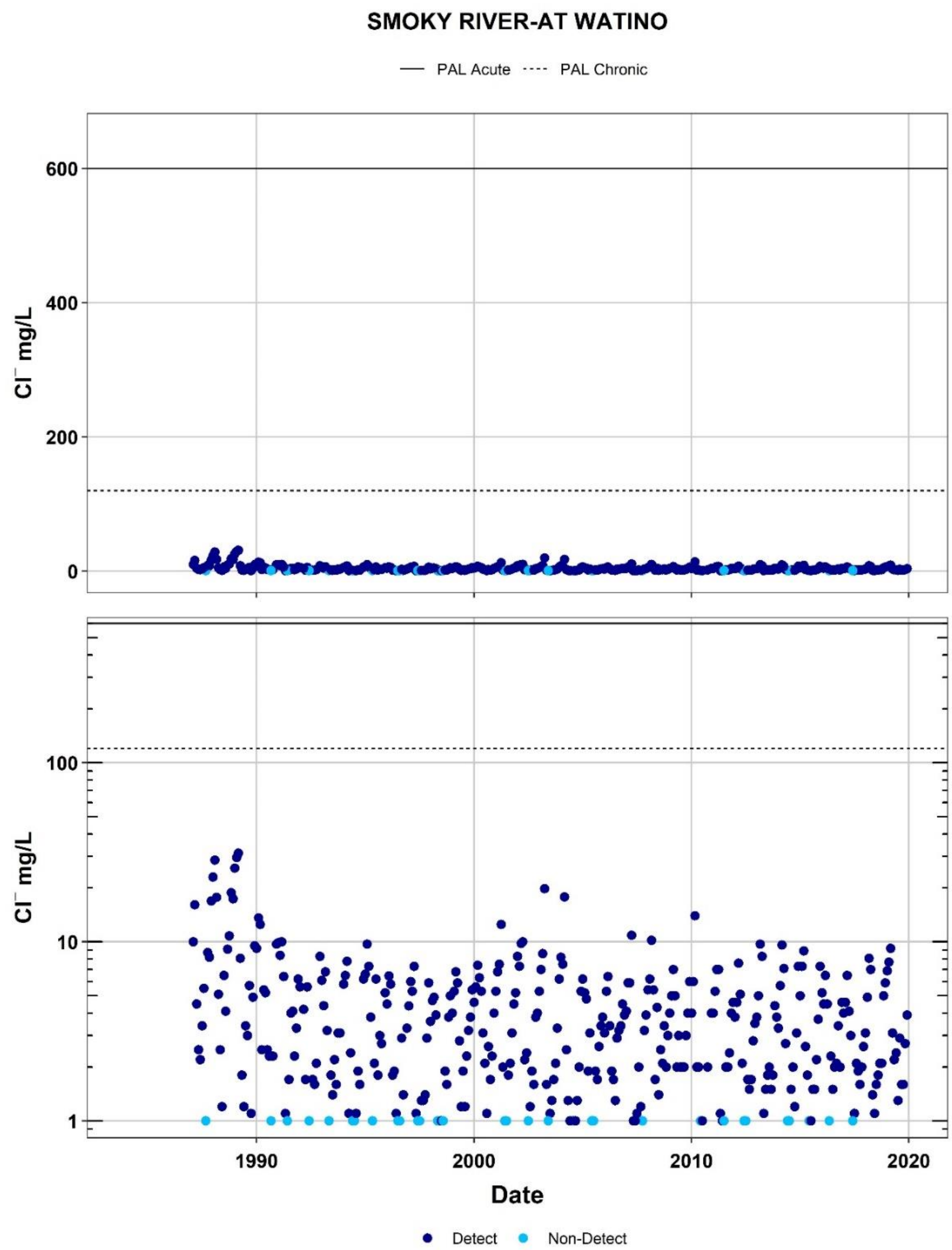

Figure A4: Scatter plots of Cl^- concentrations at the Smoky River at Watino including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

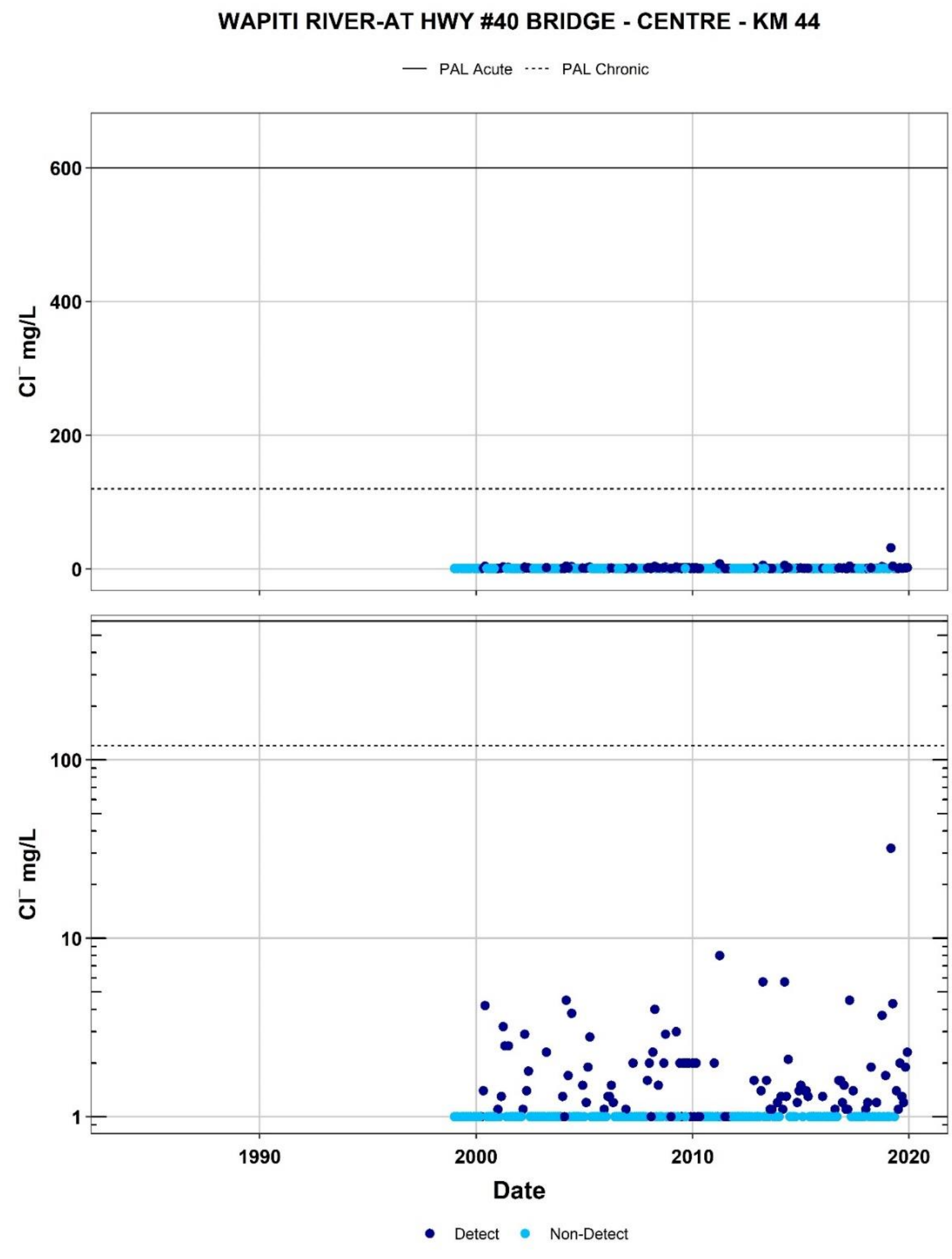

Figure A5: Scatter plots of Cl^- concentrations at the Wapiti River Site 1 at the Highway 40 Bridge including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

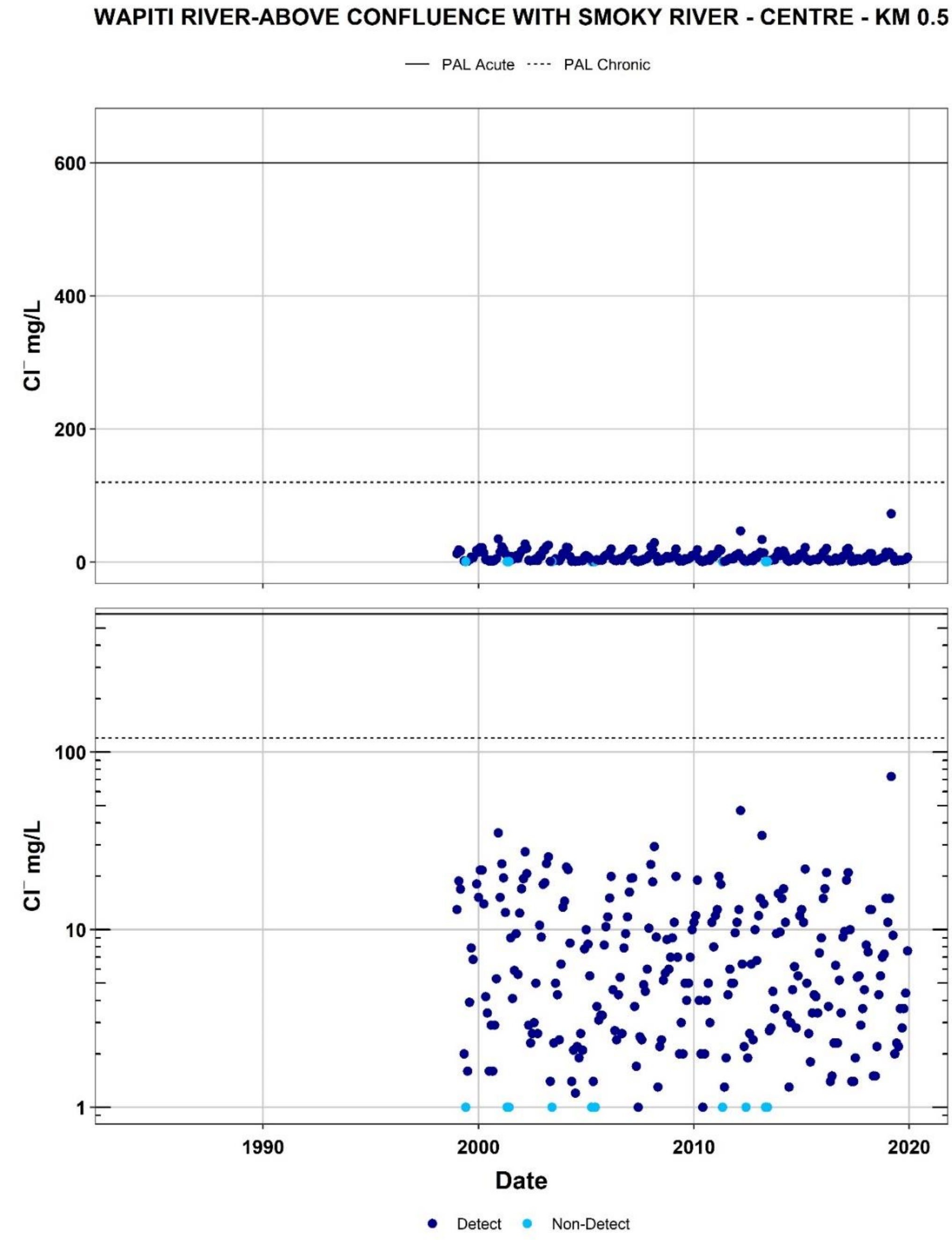

Figure A6: Scatter plots of Cl^- concentrations at the Wapiti River above the confluence with the Smoky River including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

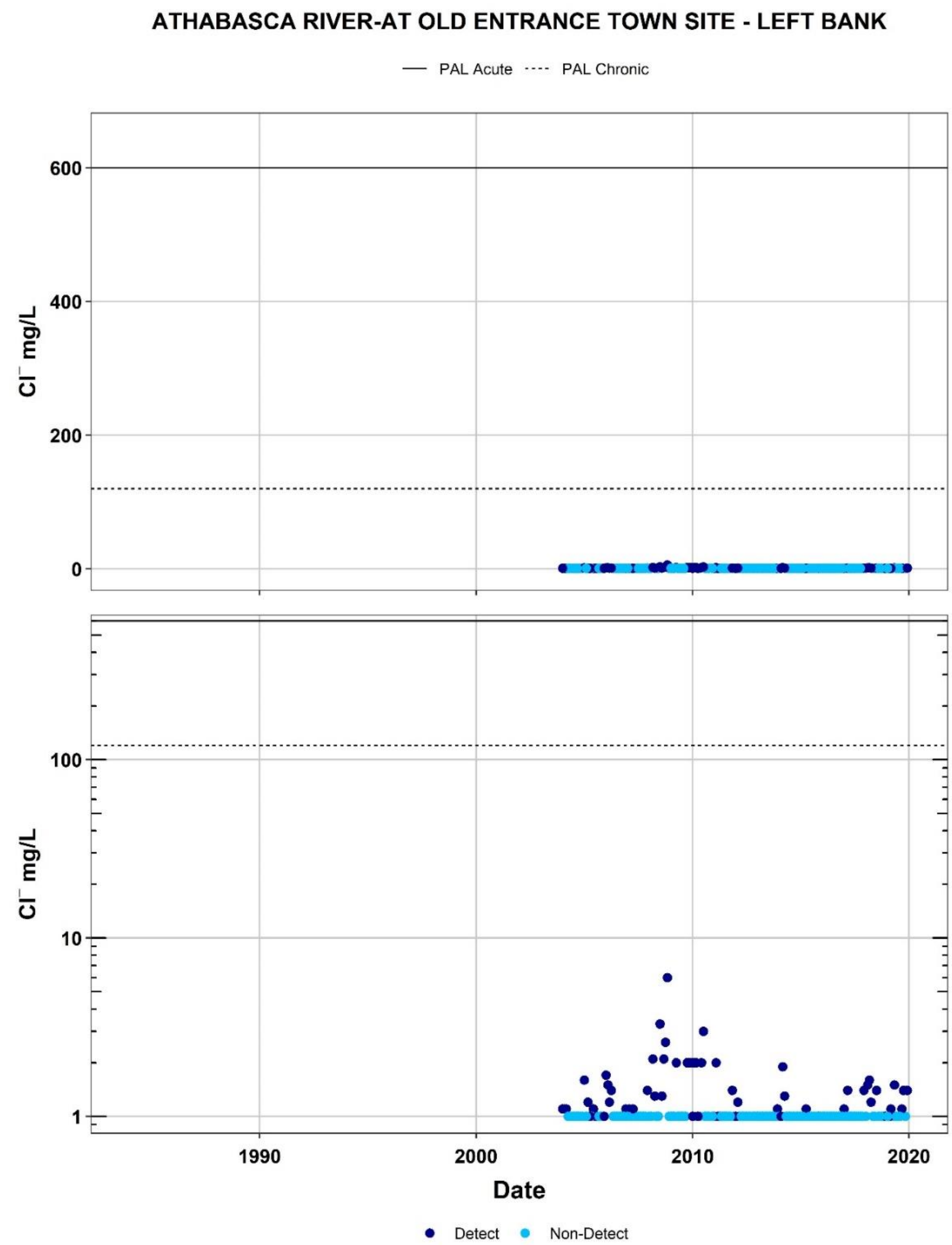

Figure A7: Scatter plots of Cl^- concentrations at the Athabasca River Site 1 at Old Entrance including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

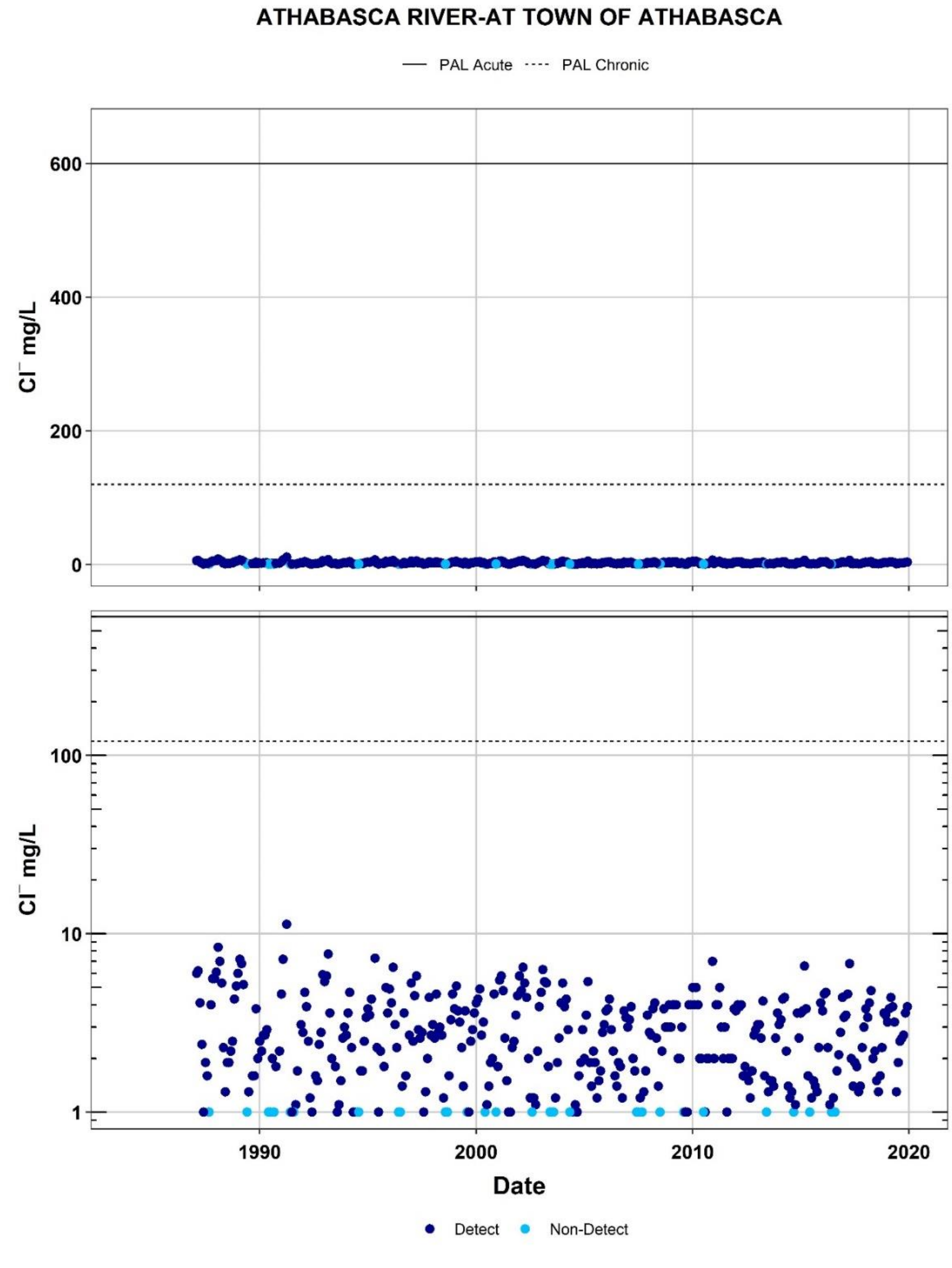

Figure A8: Scatter plots of Cl^- concentrations at the Athabasca River Site 3 at the Town of Athabasca including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

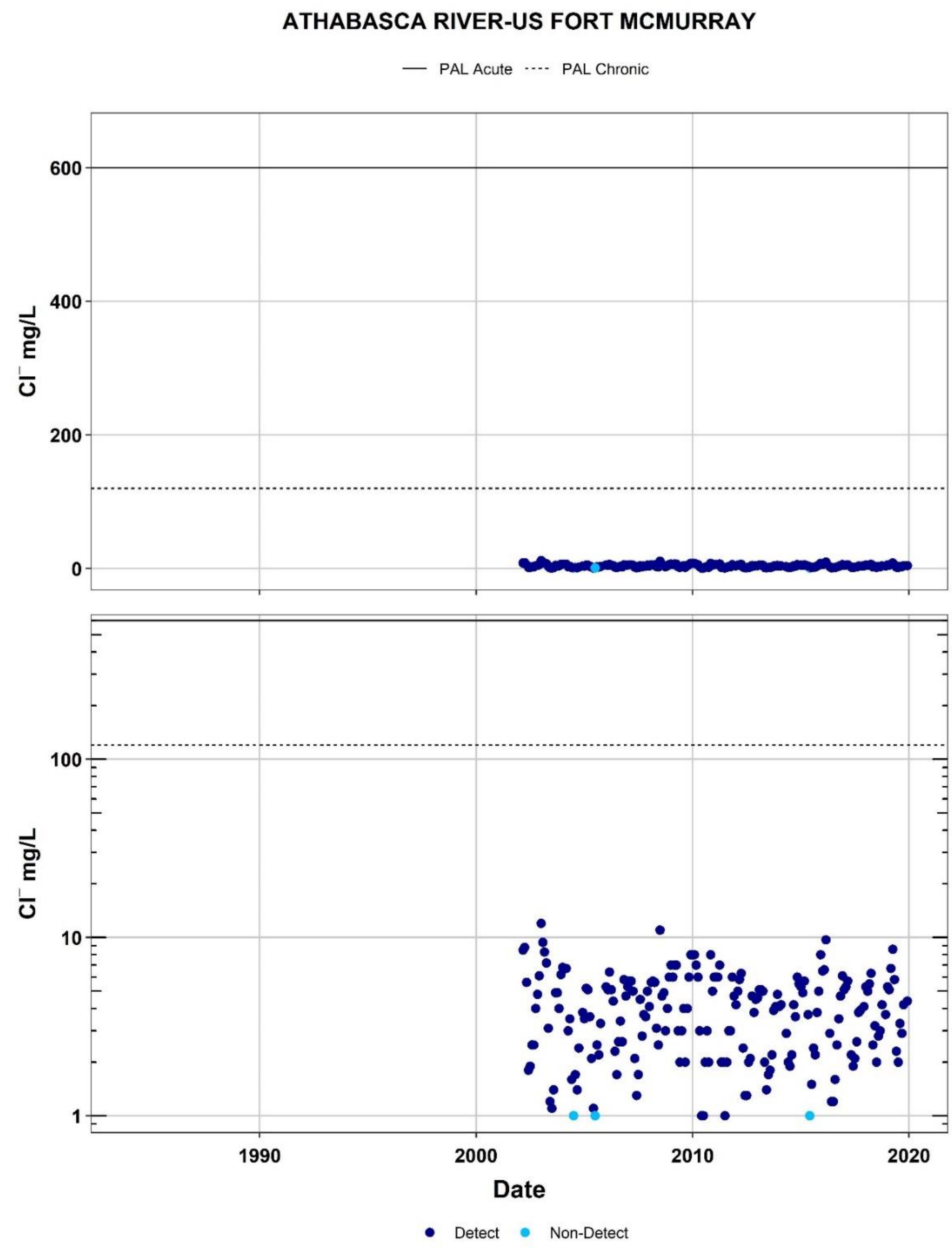

Figure A9: Scatter plots of Cl^- concentrations at the Athabasca River Site 4 upstream of Fort McMurray including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

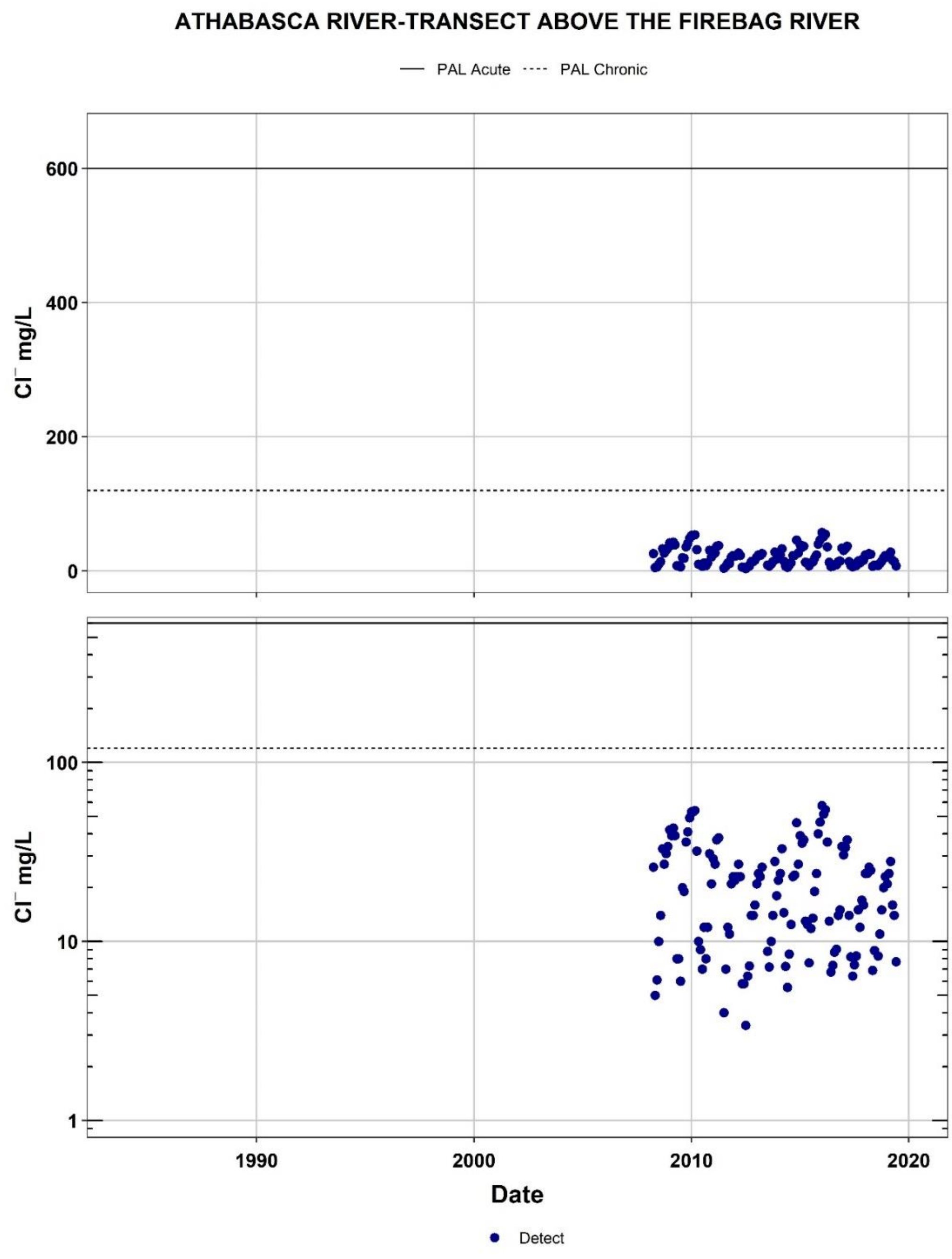

Figure A10: Scatter plots of Cl^- concentrations at the Athabasca River Site 5 above the Firebag River including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

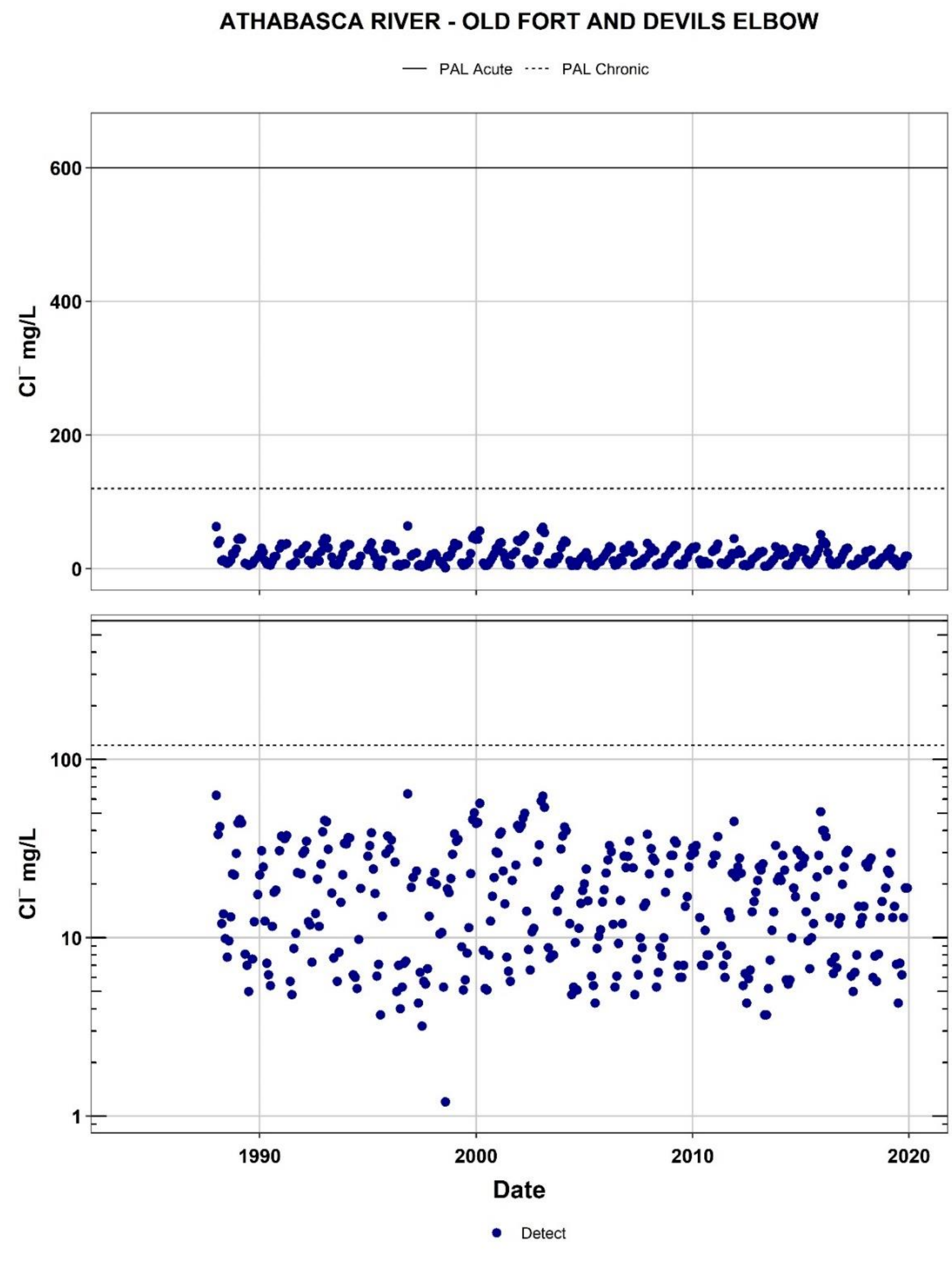

Figure A11: Scatter plots of Cl^- concentrations at the Athabasca River Site 6 near Old Fort and Devils Elbow including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

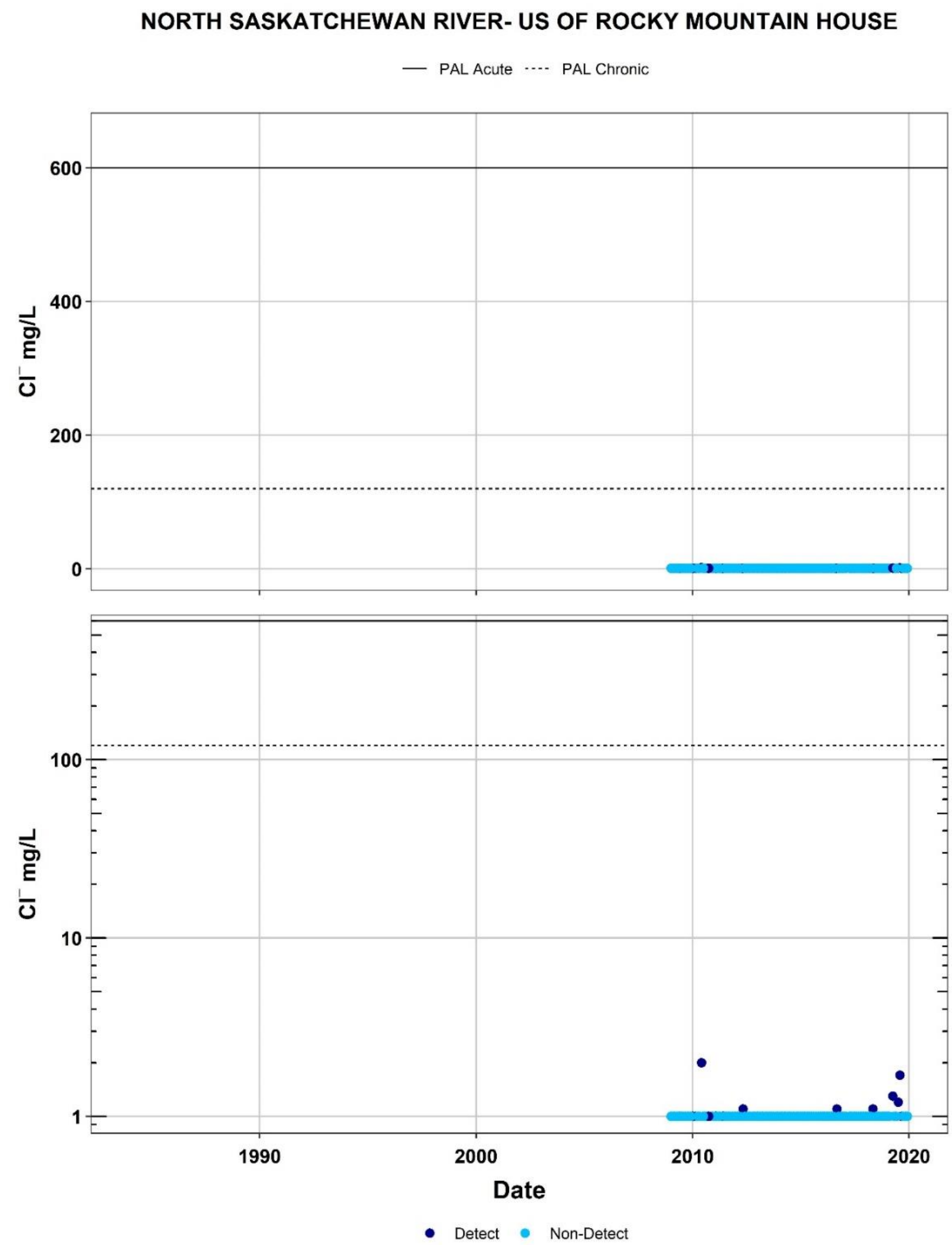

Figure A12: Scatter plots of Cl^- concentrations at the North Saskatchewan River Site 2 upstream of Rocky Mountain House including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

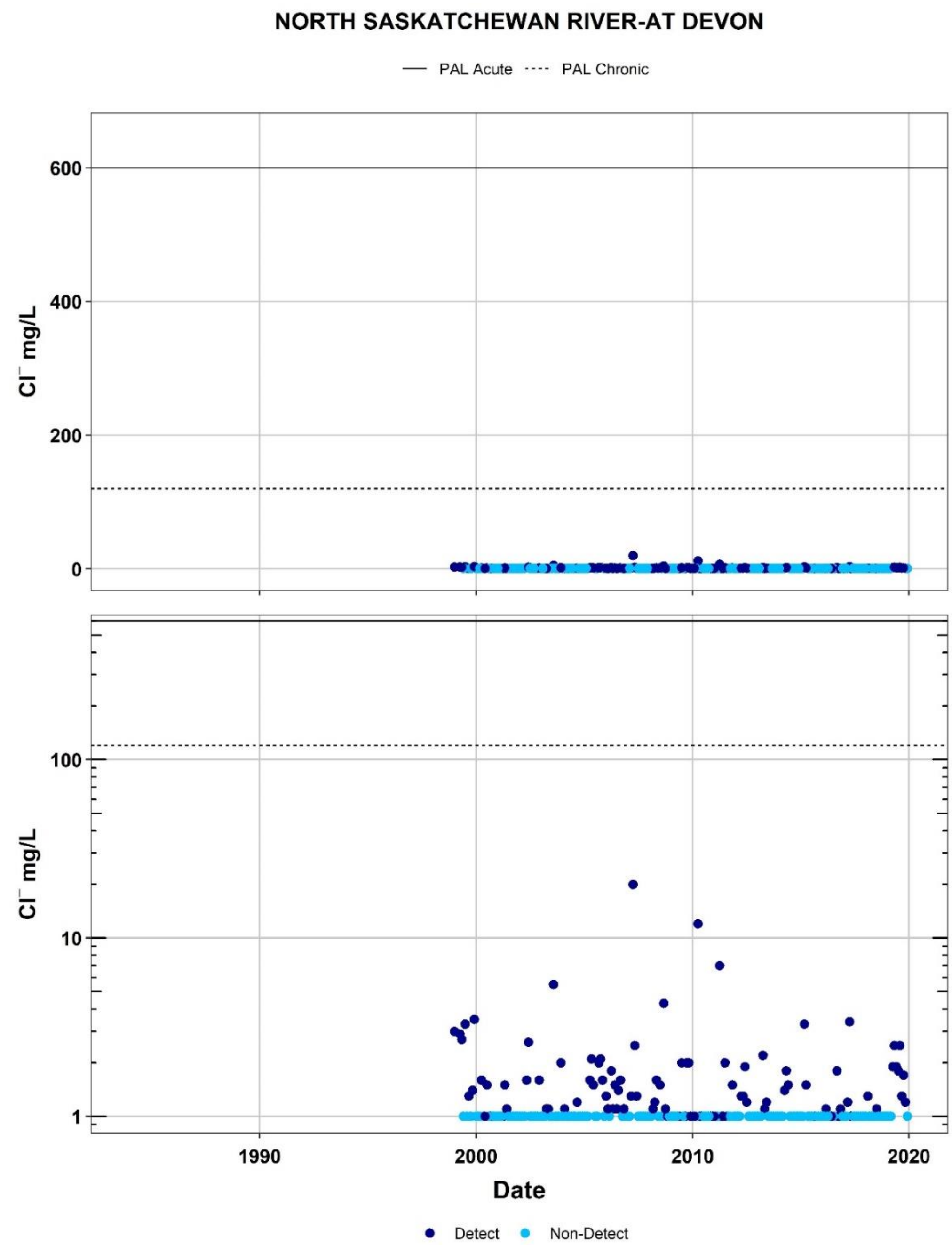

Figure A13: Scatter plots of Cl^- concentrations at the North Saskatchewan River Site 3 at Devon including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

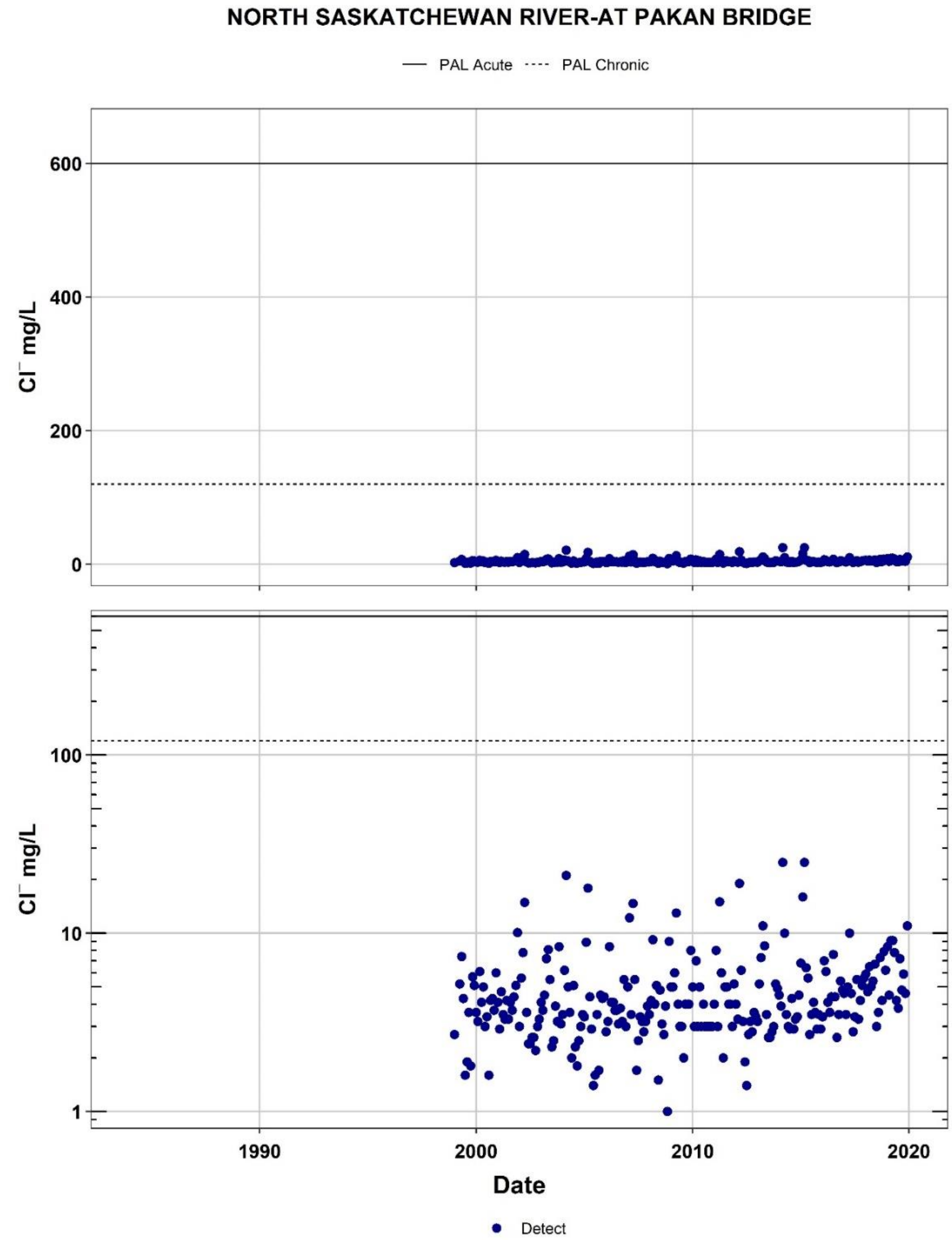

Figure A14: Scatter plots of Cl$^-$ concentrations at the North Saskatchewan River Site 4 at Pakan Bridge including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

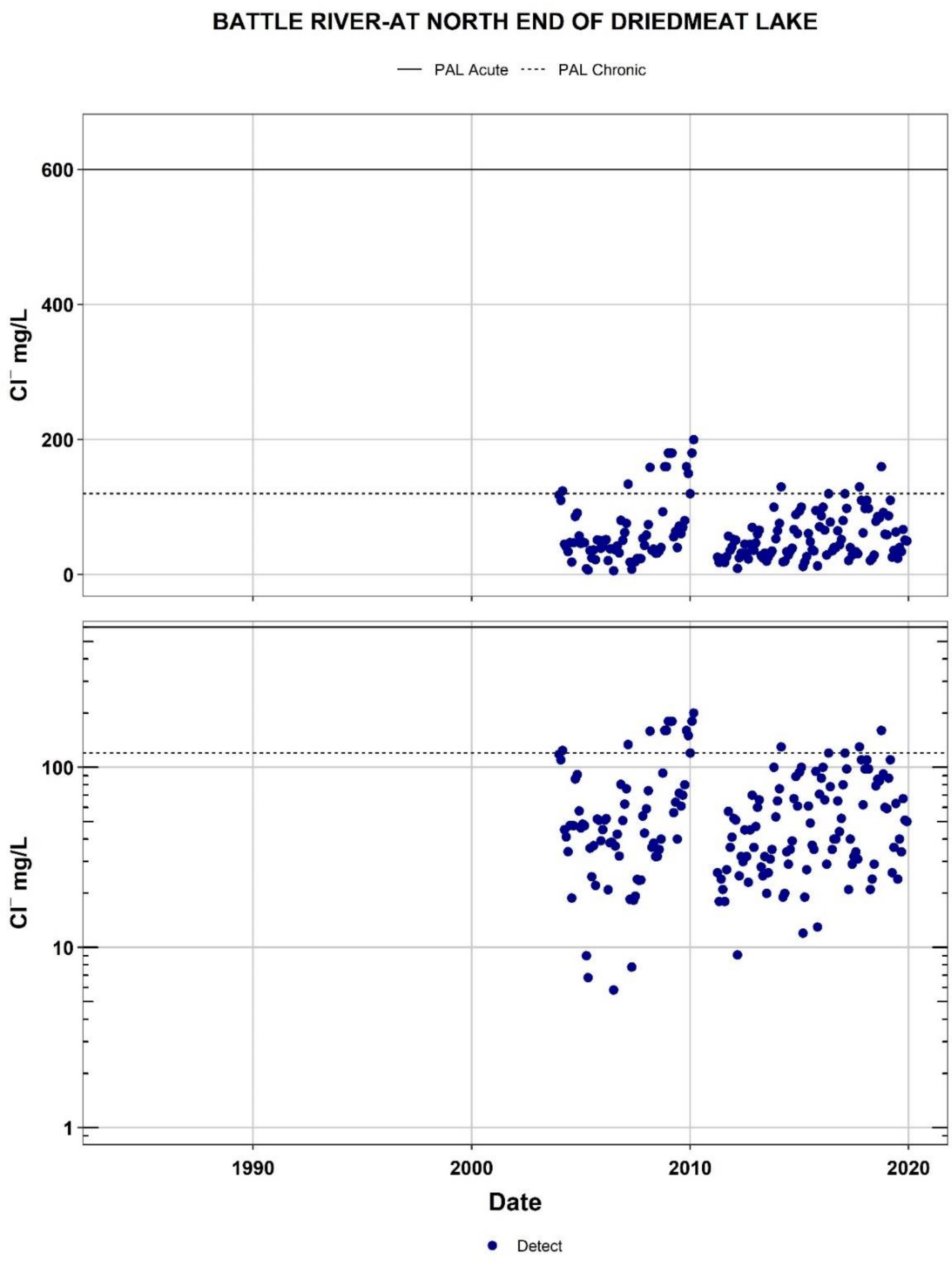

Figure A15: Scatter plots of Cl^- concentrations at the Battle River Site 1 at the north end of Driedmeat Lake including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

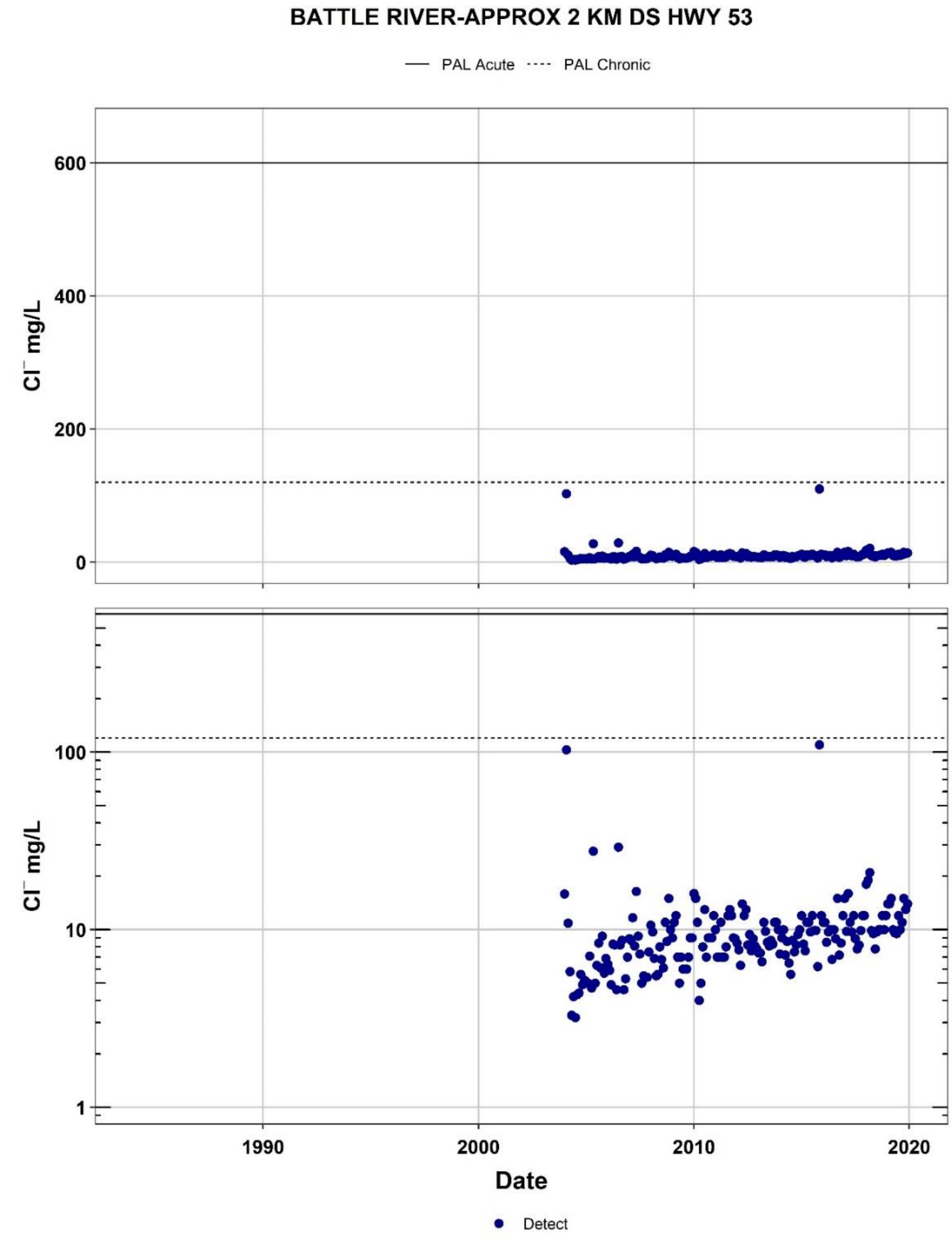

Figure A16: Scatter plots of Cl^- concentrations at the Battle River Site 2 downstream of Highway (HWY) 53 including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

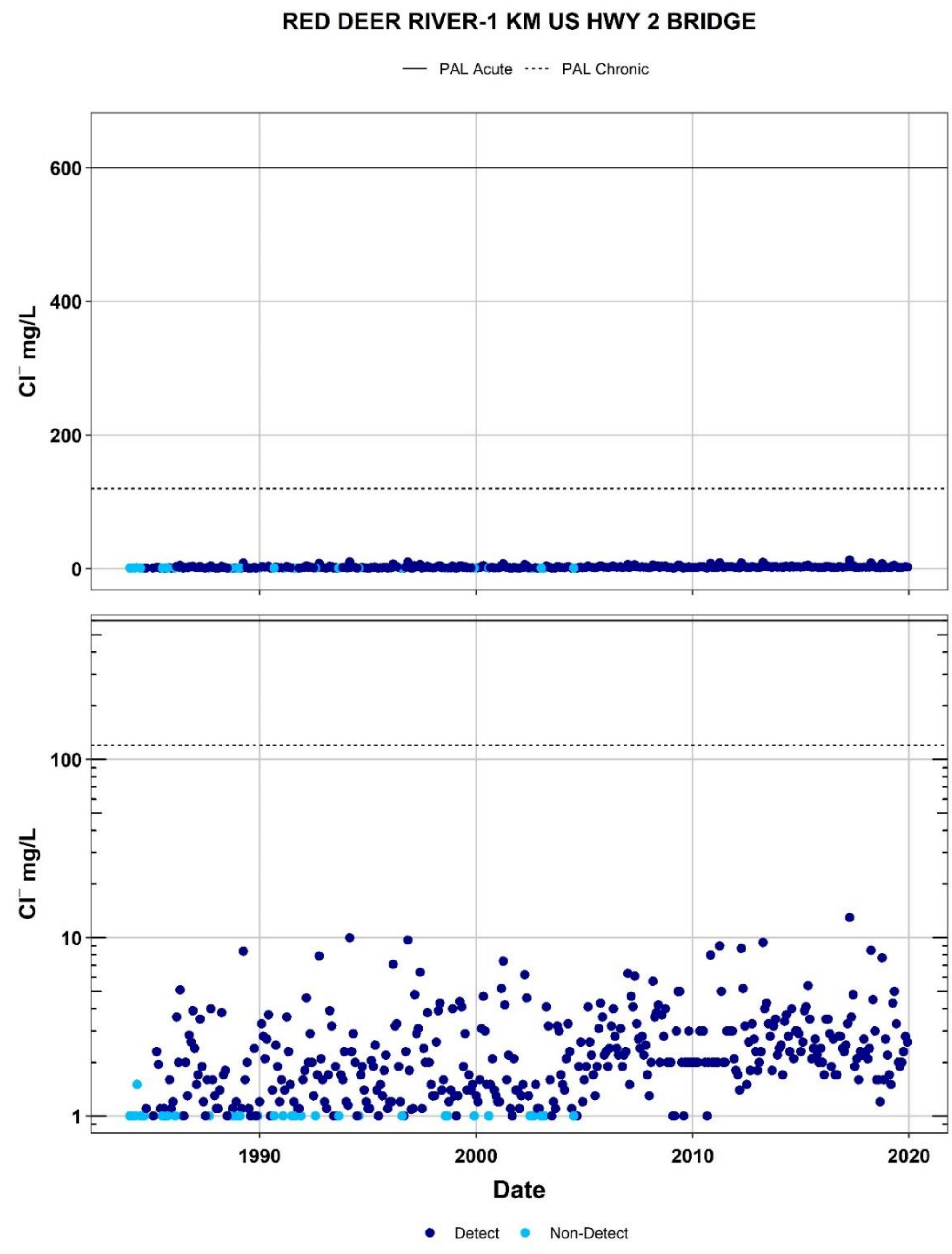

Figure A17: Scatter plots of Cl^- concentrations at the Red Deer River Site 2 near the Highway (HWY) 2 bridge including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

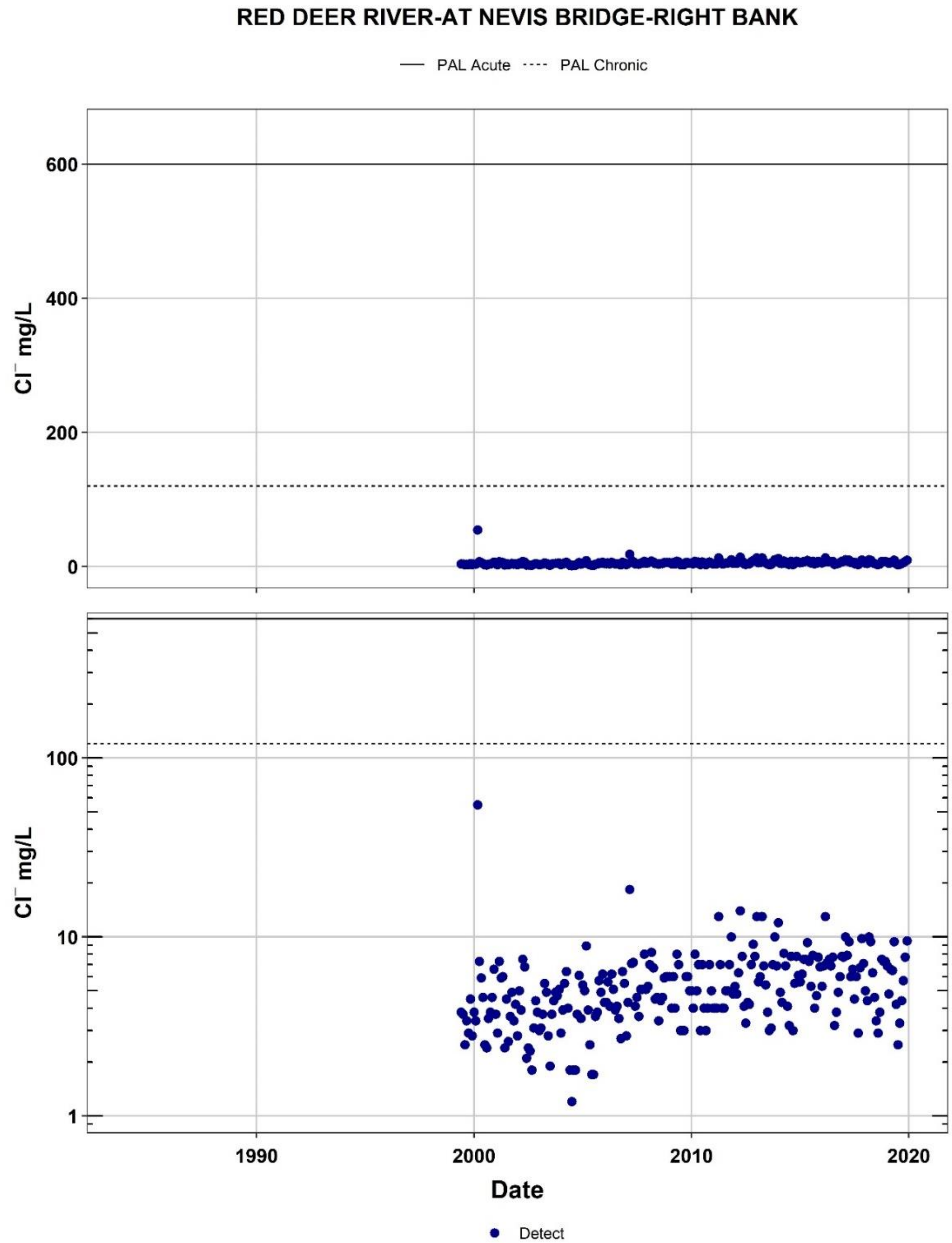

Figure A18: Scatter plots of Cl^- concentrations at the Red Deer River Site 3 at Nevis Bridge including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

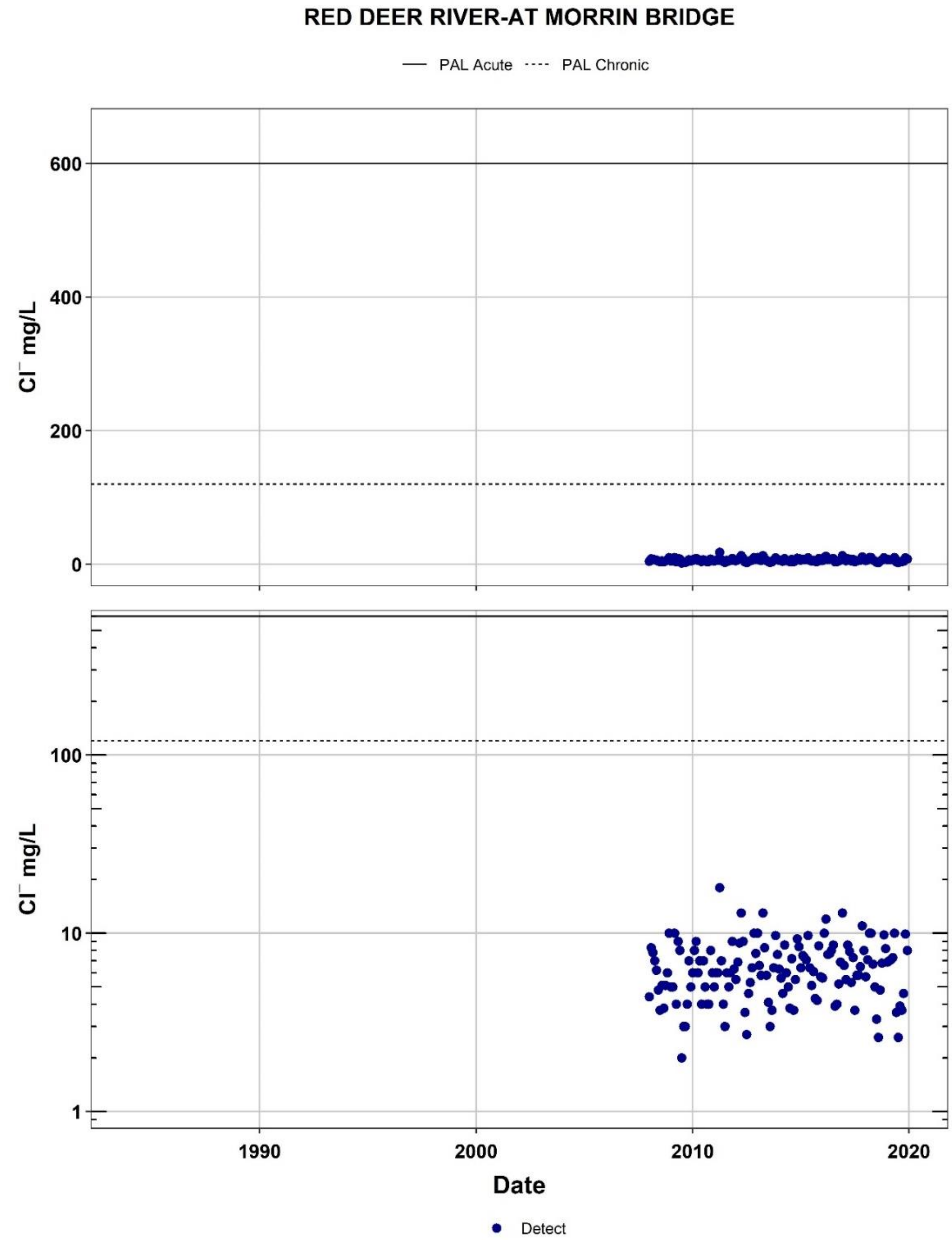

Figure A19: Scatter plots of Cl^- concentrations the Red Deer River Site 4 at Morrin Bridge including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

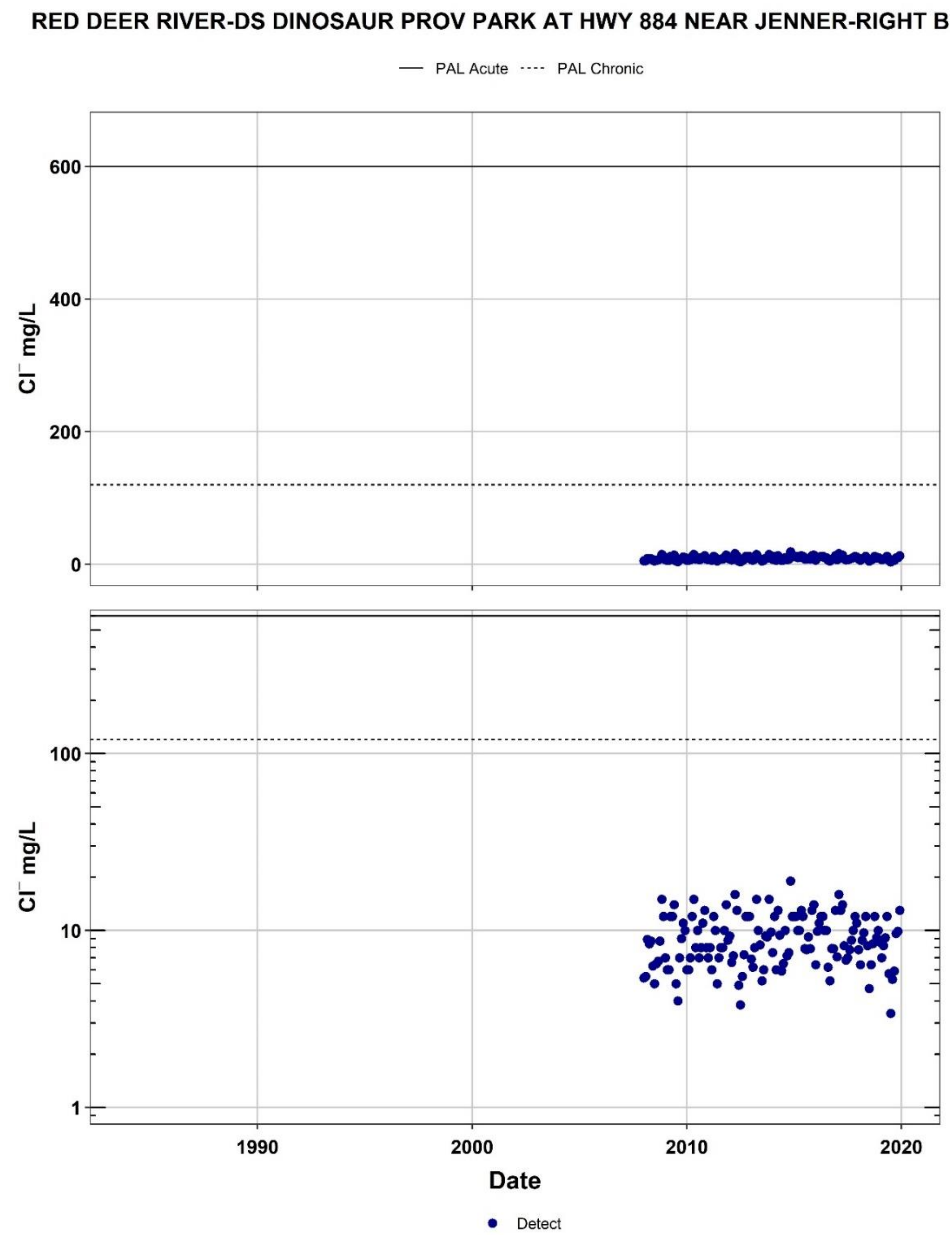

Figure A20: Scatter plots of Cl^- concentrations at the Red Deer River Site 5 at Highway (HWY) near Jenner including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

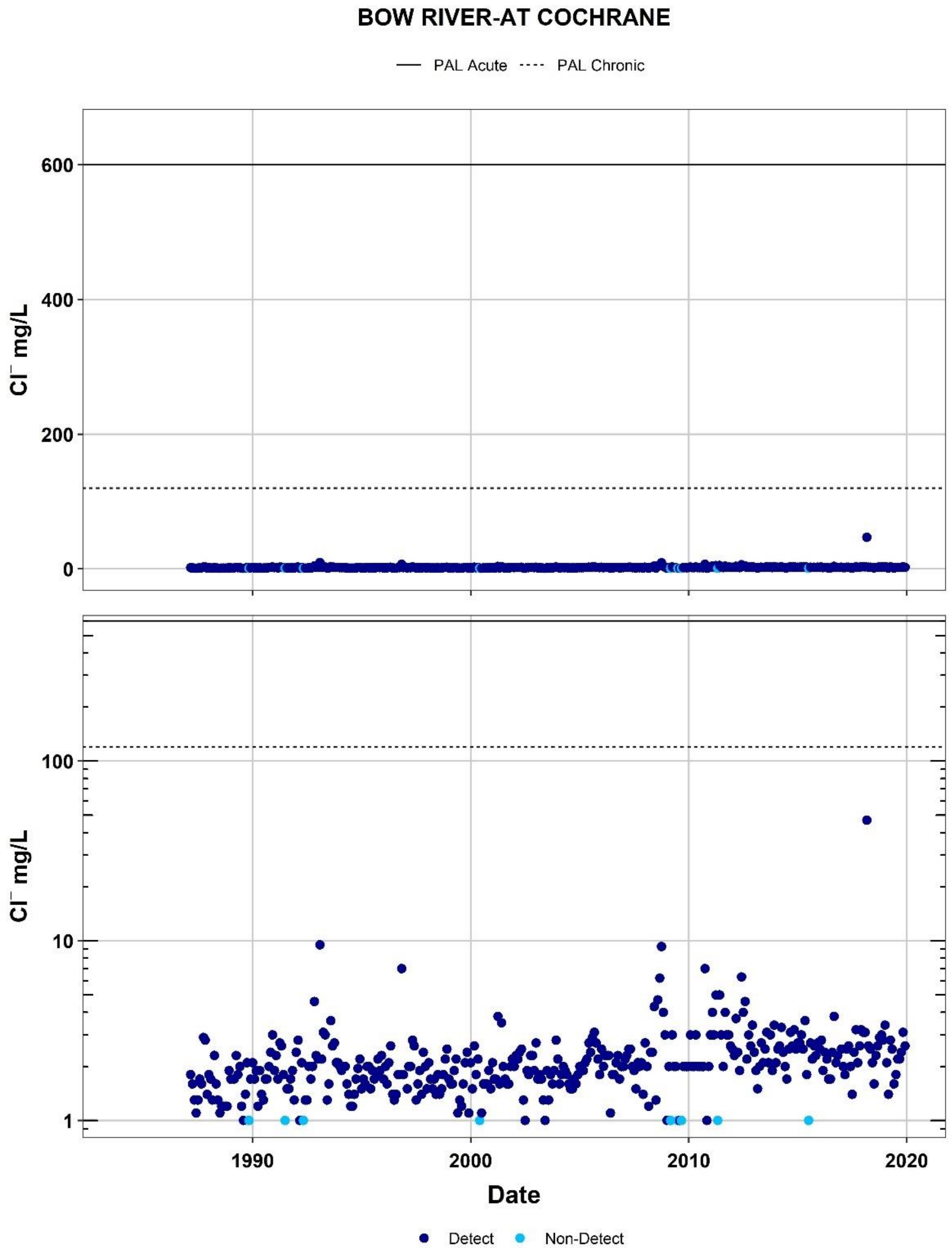

Figure A21: Scatter plots of Cl^- concentrations at the Bow River Site 1 at Cochrane including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

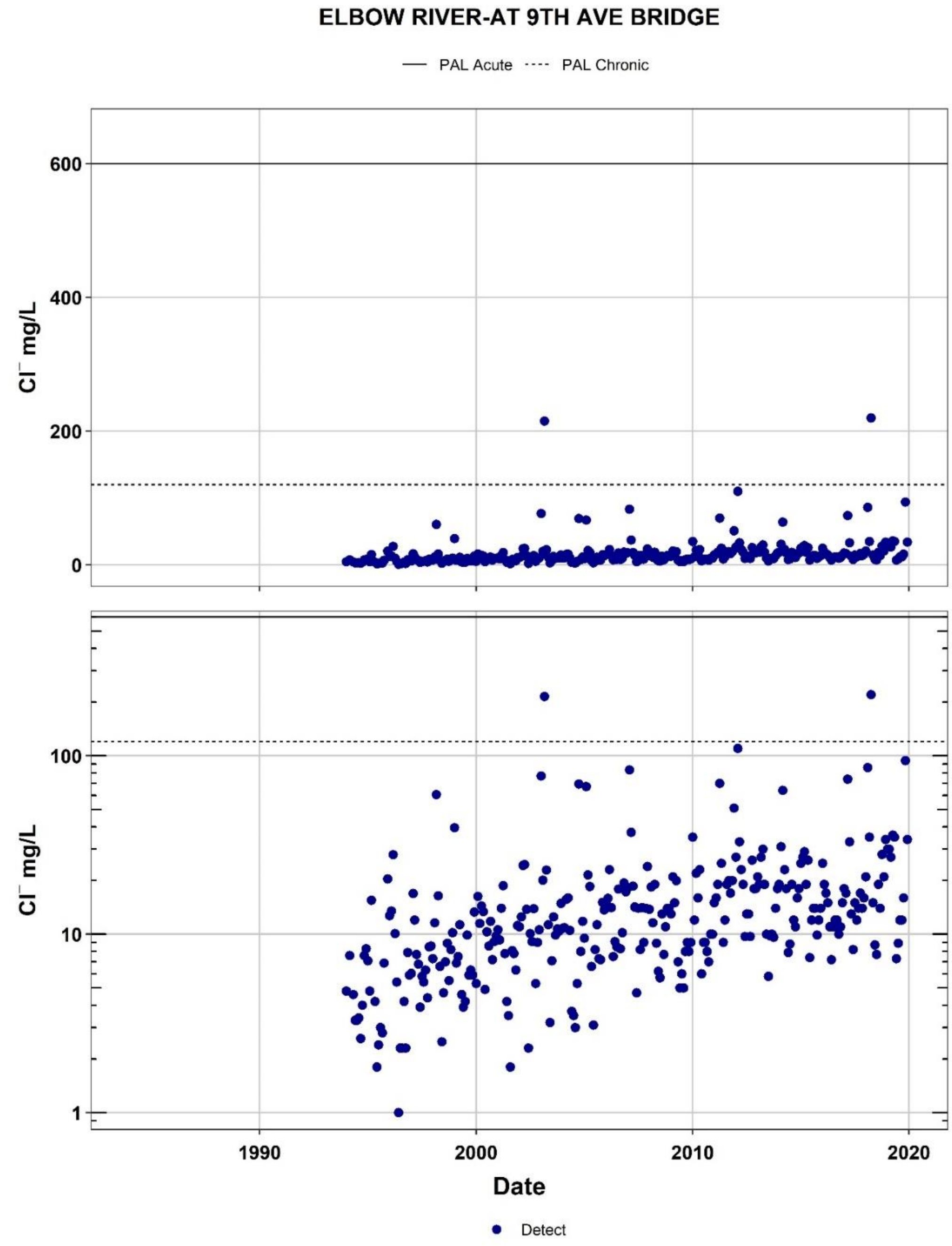

Figure A22: Scatter plots of Cl^- concentrations at the Elbow River Site at the 9th Avenue Bridge in Calgary including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

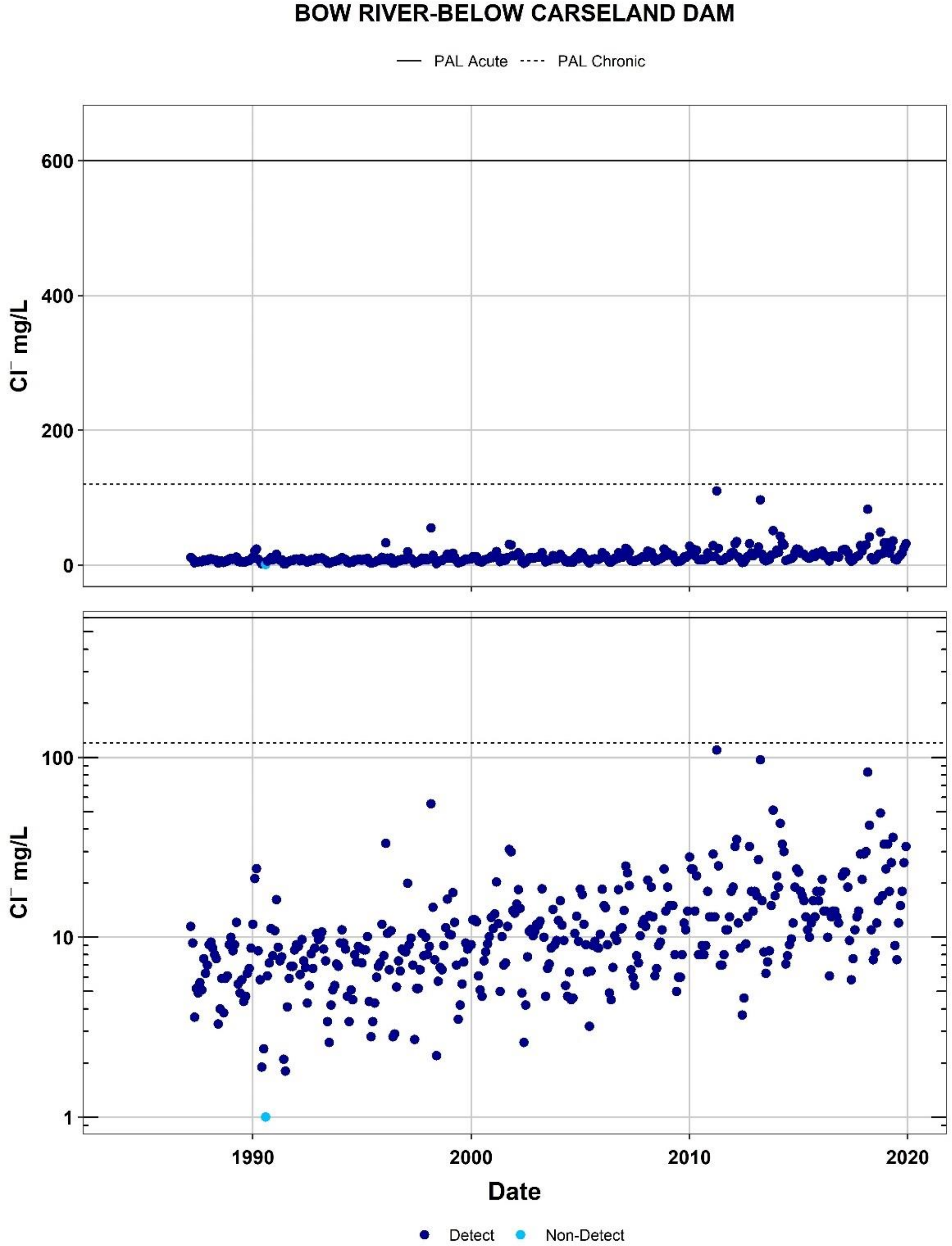

Figure A23: Scatter plots of Cl^- concentrations at the Bow River Site 2 below Carseland Dam including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

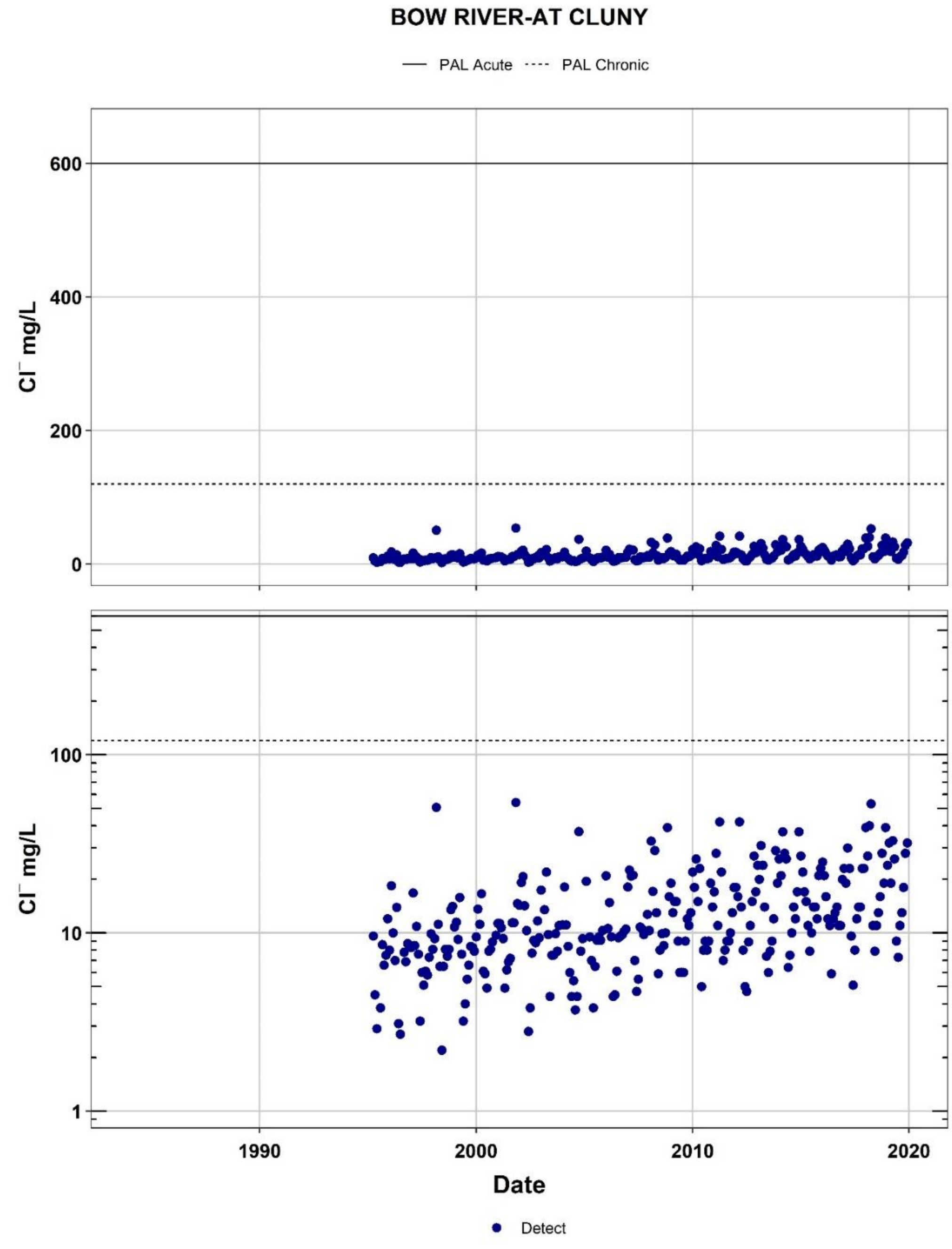

Figure A24: Scatter plots of Cl^- concentrations the Bow River Site 3 at Cluny including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

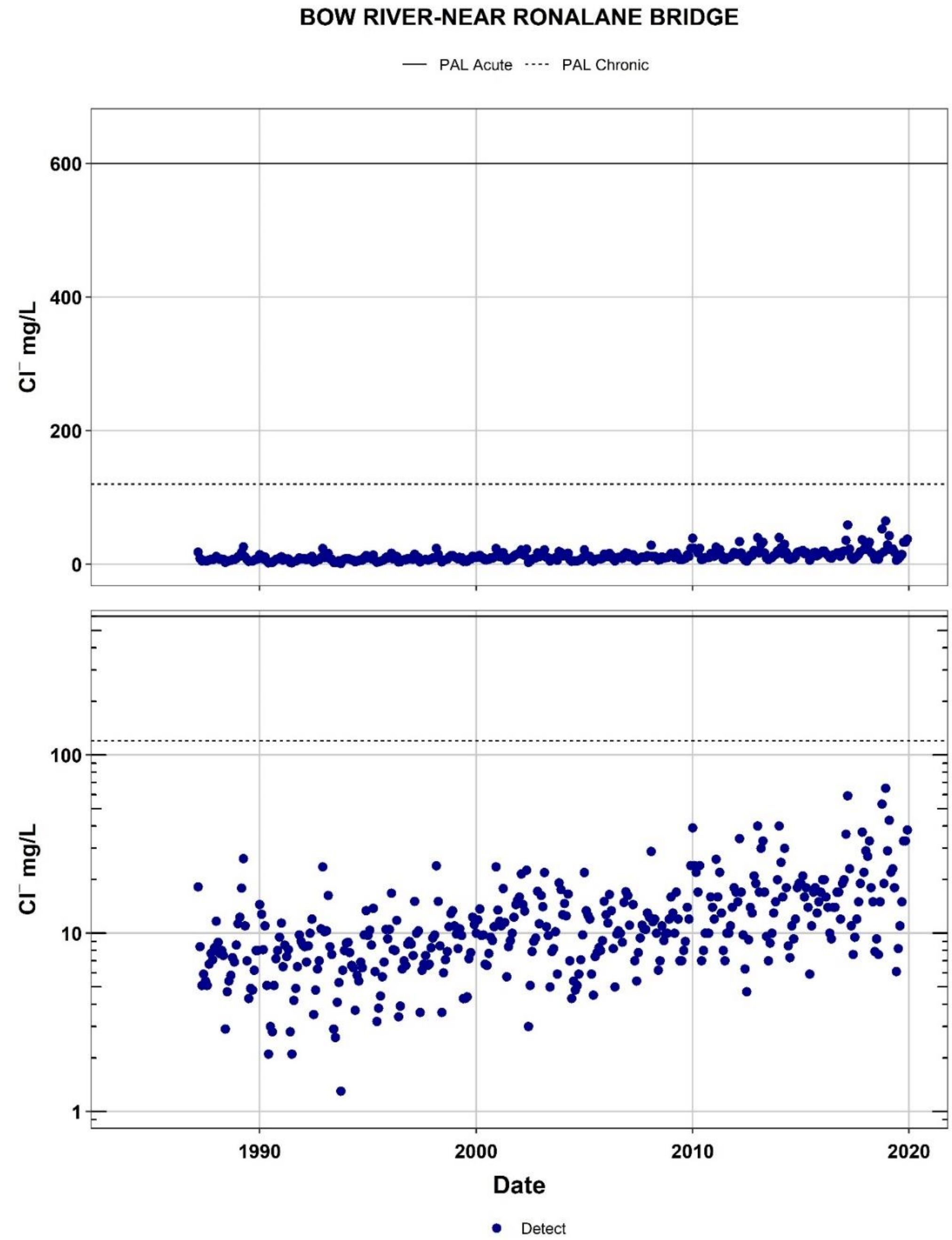

Figure A25: Scatter plots of Cl^- concentrations at the Bow River Site 4 at Ronalane Bridge including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

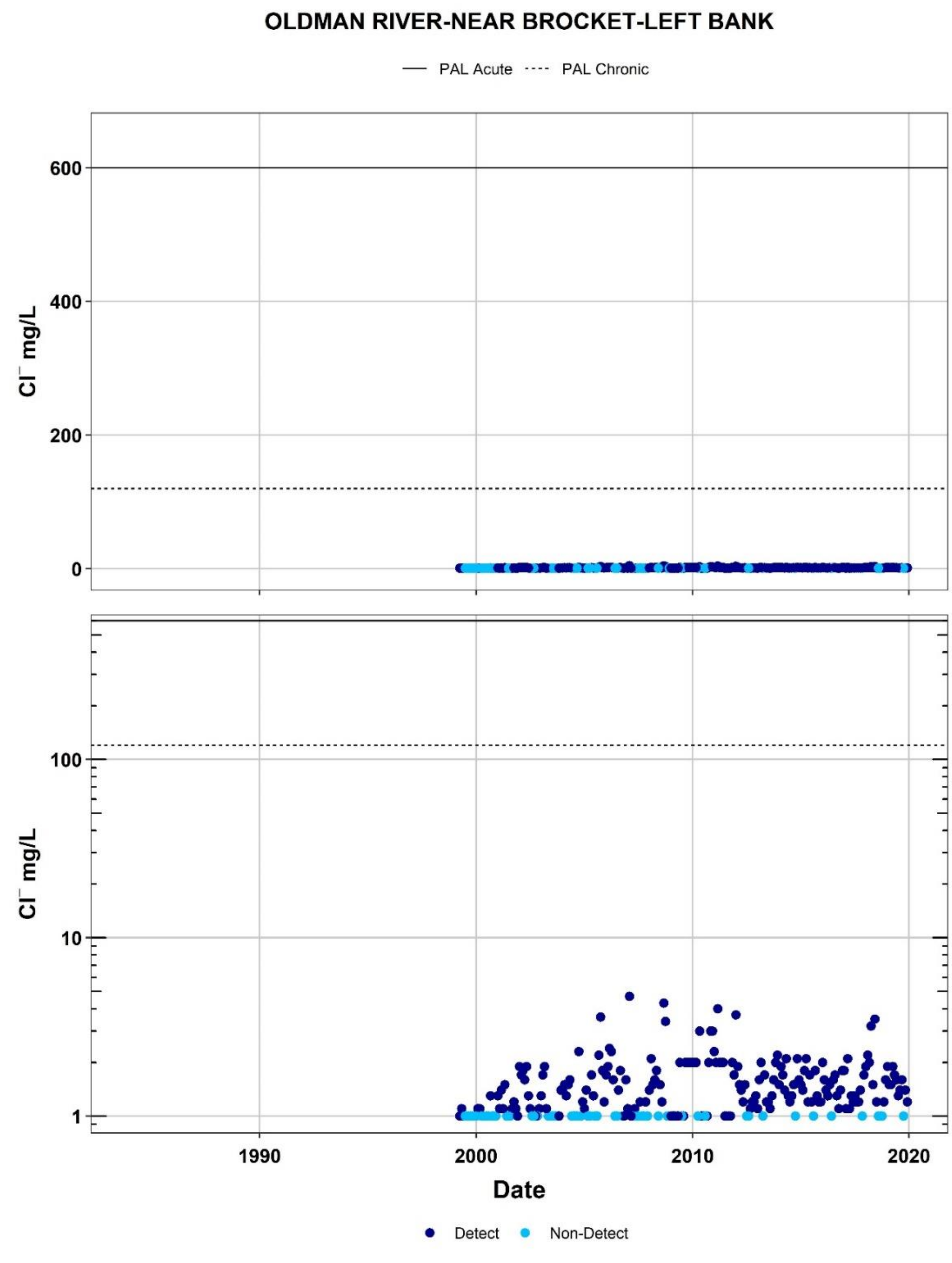

Figure A26: Scatter plots of Cl^- concentrations at the Oldman River Site 1 near Brocket including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

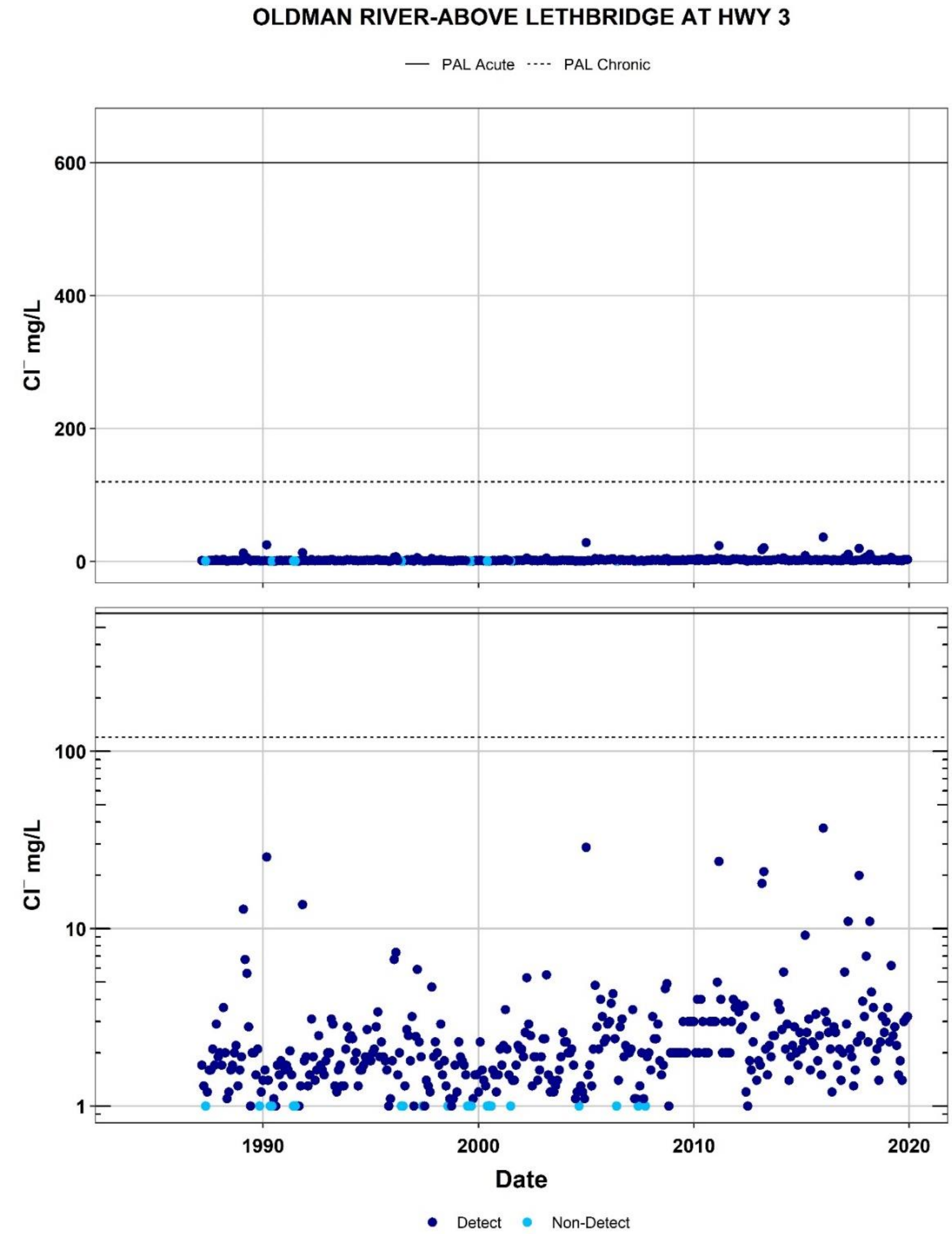

Figure A27: Scatter plots of Cl^- concentrations at the Oldman River Site 2 above Lethbridge at Highway (HWY) 3 including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

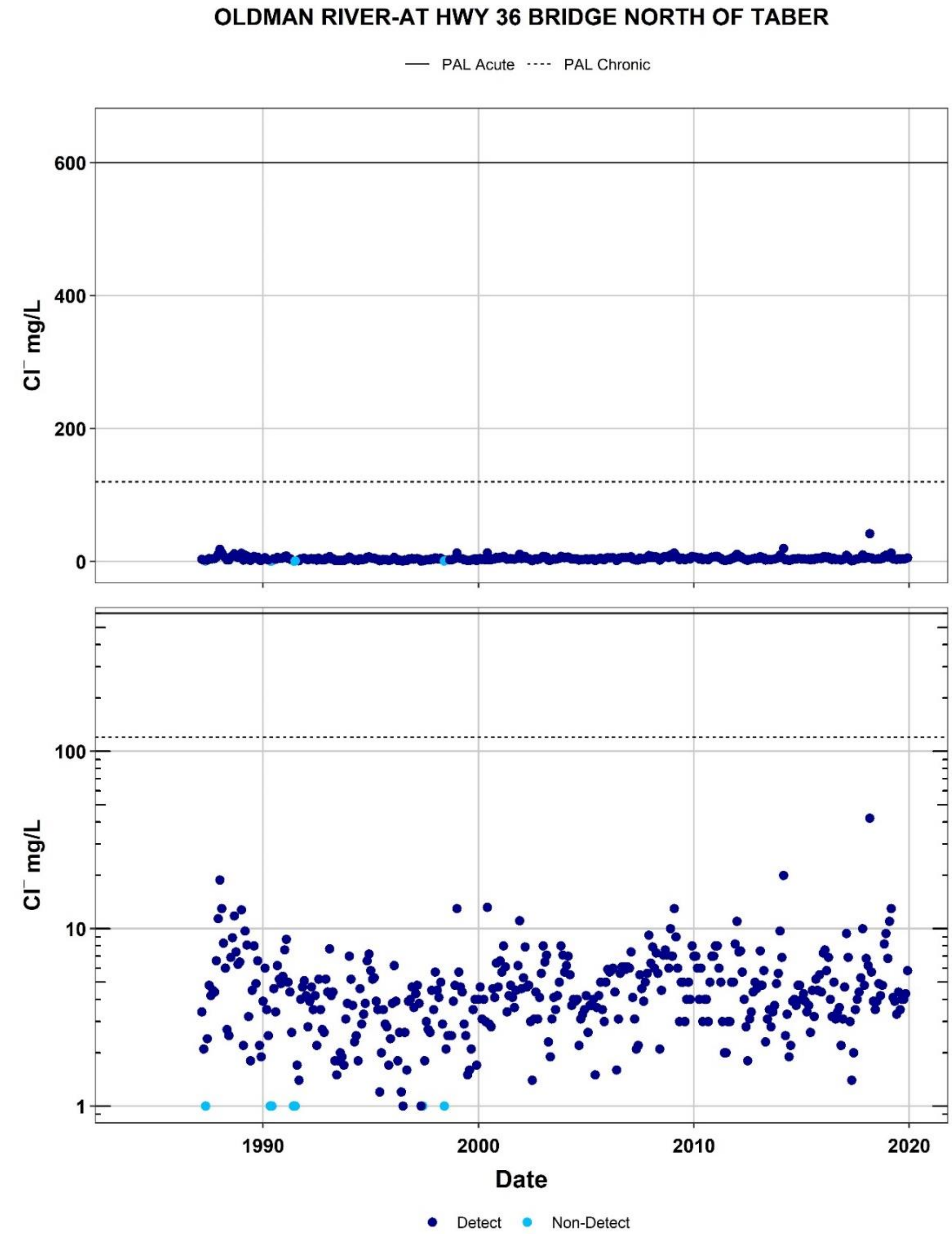

Figure A28: Scatter plots of Cl^- concentrations the Oldman River Site 3 at Highway (HWY) 36 bridge north of Taber including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

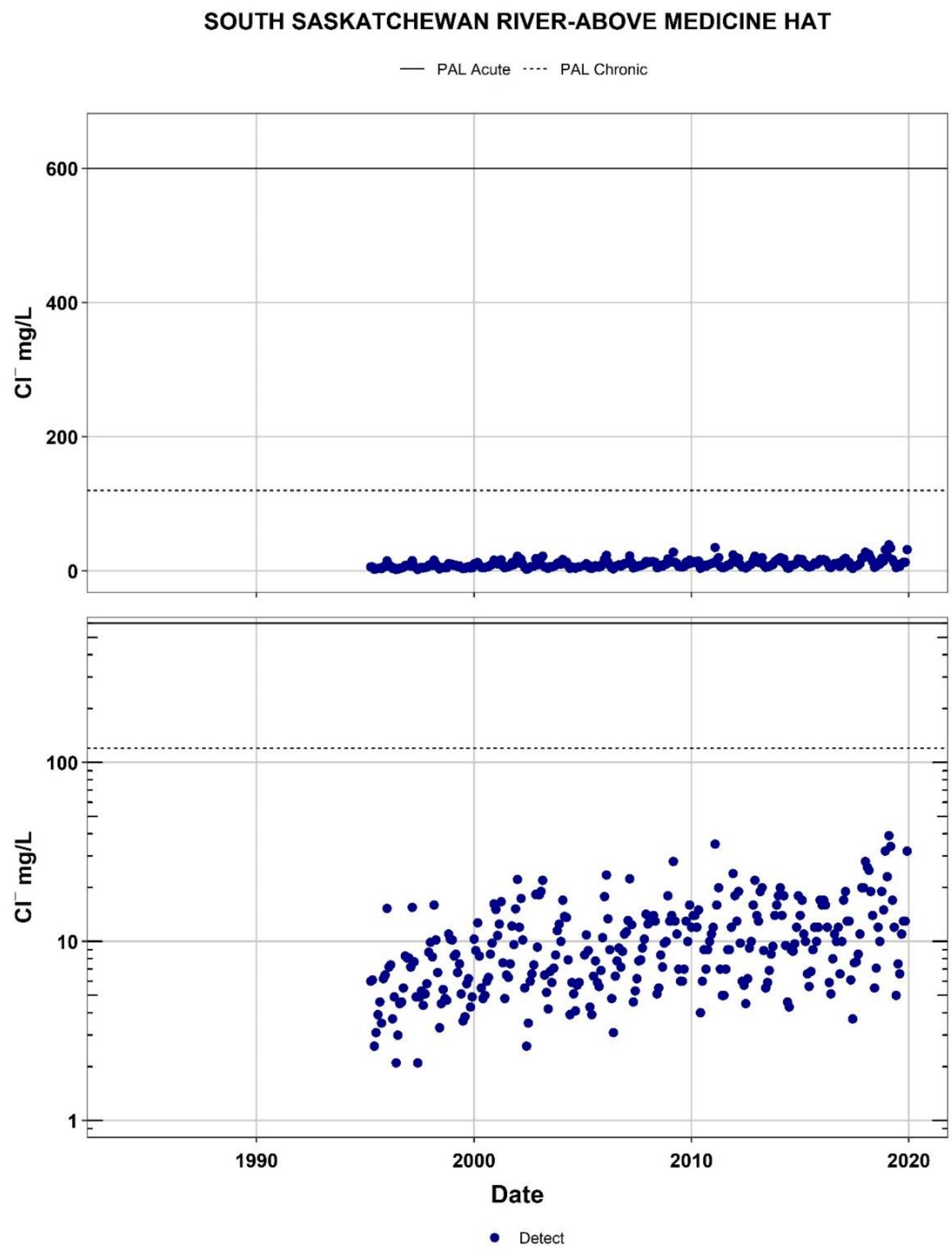

Figure A29: Scatter plots of Cl^- concentrations at the South Saskatchewan River Site 1 above Medicine Hat including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).

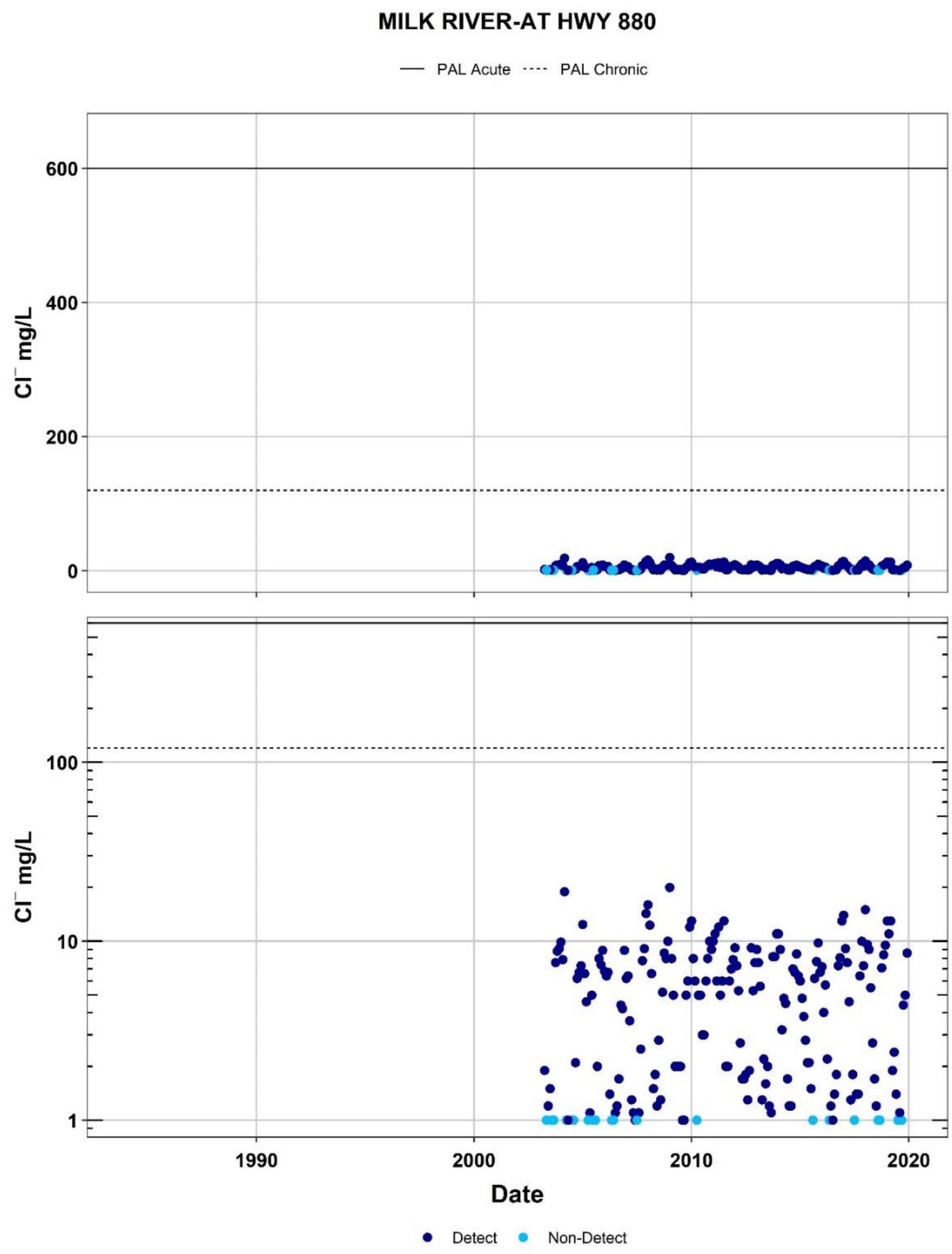

Figure A30: Scatter plots of Cl^- concentrations at the Milk River at Highway (HWY) 880 including the PAL acute and chronic guidelines and both standard (top) and log scale (bottom).