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PRAIRIE PROVINCES WATER BOARD

Report #hШ3ш

An Analysis of Non-Compliance Patterns to the Prairie Provinces Water Board Objectives in the Red Deer River at the Alberta/Saskatchewan Boundary

Technical Report **Prepared for the**
PPWB Committee on Water Quality

March 2020

Date: March 14th, 2020

RE: An Analysis of Non-Compliance Patterns to Prairie Provinces Water Board Objectives in the Red Deer River at the Alberta/Saskatchewan Boundary

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This report was prepared by Alberta Environment and Parks (AEP) in response to the non-compliance of the Red Deer River near Bindloss to the interprovincial water quality objectives established for this transboundary river.

The Red Deer River at the Alberta/Saskatchewan boundary has historically had a number of excursions to the interprovincial water quality objectives including metals, total dissolved solids, nutrients, major ions and bacteria. As part of the jurisdictional response to these excursions and the non-compliance of this river to the interprovincial water quality objectives, Alberta undertook a review of the historical data on the Red Deer River. A draft report was provide to the Prairie Provinces Water Board (PPWB), Committee on Water Quality (COWQ) for their review and comment.

Alberta's assessment of the Red Deer River included a review of the long-term monitoring data at the transboundary site, as well as, a review of data from upstream long-term monitoring sites monitored by AEP. The AEP sites included both the Red Deer River mainstem and several of its tributaries.

This jurisdictional report, on the non-compliance of the Red Deer River at the Alberta/Saskatchewan boundary was accepted by the COWQ on February 5th 2020. The PPWB accepted the report as a jurisdictional report and supports Alberta's recommendations for further study. This report was approved as a PPWB jurisdictional technical report in March 2020.

Yours Sincerely

Nadine Stiller, Chair
Prairie Provinces Water Board

AN ANALYSIS OF NON-COMPLIANCE PATTERNS TO PRAIRIE PROVINCES WATER BOARD OBJECTIVES IN THE RED DEER RIVER AT THE ALBERTA/SASKATCHEWAN BOUNDARY

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EXECUTIVE SUMMARY

This report is prepared as a regional response to the high number of excursions of the PPWB water quality objectives in the Red Deer River at Bindloss in 2015. A review was undertaken based on long-term data collected in the Red Deer River at Bindloss by Environment and Climate Change Canada, as well as long-term data at the upstream mainstem sites and short-term data at some tributary sites by Alberta Environment and Parks.

Long-term patterns in non-compliance with transboundary objectives were assessed for total metals, total suspended solids (TSS), nutrients, dissolved ions and bacteria at Bindloss. Correlations were assessed between TSS and variables of concern. Spatial patterns were analyzed for both long-term and short-term periods for upstream mainstem sites and tributary sites, respectively.

Analysis indicates that excursions primarily occurred in open-water season during 2015 and historically. The majority of excursions are due to total metals. Hydrographs from a series of hydrometric stations in 2015 infer that the high number of exceedances in August and September were likely attributable to two runoff events in the Red Deer-Drumheller and upstream Red Deer areas, respectively.

Over the years, strong correlations were shown between TSS and total metals. These substances appeared to be substantially elevated in the badlands reach. High sediment concentrations and highly variable sediment fluxes appear to be the direct cause for exceedances in the water quality objective and the high degree of variability in total metal concentrations. Erosion of relatively unenriched soils from the affected watersheds appears to contribute to the high levels of total metal concentrations. Studies have shown that the arid/semiarid climatic conditions lead to highly uncertain summer TSS production in the river, and the weak correlations between discharge and TSS.

Spatial patterns for total phosphorus and bacteria were similar to that for total metals in the open water season. Elevated levels of total nitrogen (in both seasons), and total phosphorus and dissolved phosphorus (in the ice-cover season) were observed at Nevis Bridge site (downstream of the City of Red Deer), which could be a possible focus for future investigations.

Most major ions in the Red Deer River (potassium, chloride, sodium, sulphate and TDS) show increasing levels and variations from upstream to downstream. TDS exceeded the objective multiple times over the past five decades, occurring mostly during low flow season. Results indicate that the TDS spikes were mainly driven by flow and jointly impacted by other factors such as: runoff over the disturbed lands in the arid area, increased population and associated wastewater discharges, and increased road salt use. Alberta is investigating basins with similar characteristics elsewhere.

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1. Background

The Prairie Provinces Water Board (PPWB), established under the Master Agreement on Apportionment, has been reporting on transboundary water quality at boundaries between Alberta, Saskatchewan and Manitoba since 1992. Excursions are evaluated by comparing water quality levels to PPWB transboundary water quality objectives. In 2015, these objectives were reviewed and updated. It was found that, among the sites monitored by the PPWB, the Red Deer River (near Bindloss) had the lowest adherence rate to the new water quality objectives in 2015 and had the largest variance in adherence rates in the 13 years based on the new objectives. Following an excursion management response process that was agreed upon by all participating parties, the Committee on Water Quality requested that Alberta compile and analyze available information on the Red Deer River and provide a regional response to the PPWB.

The objectives of the report are to discuss the non-compliance to the water quality objectives, provide an evaluation of the issues, explore potential sources related to natural or anthropogenic causes, and identify information gaps. Based on the report, the Committee will make a recommendation on whether further investigation is warranted. This report is prepared with the available information from upstream monitoring sites for the suites of variables that exhibited excursions in 2015 and other parameters of concern (i.e., copper, cadmium, mercury).

2. Basin Overview

The Red Deer River originates in the Canadian Rocky Mountains in Banff National Park and flows through mountains, foothills, parklands and grasslands (Figure 1). The River has a length of 724 km, a drainage area of 49,650 km^2 and a mean discharge rate of about 70 m^3/sec (RDRWA, 2008). The underlying bedrock of the basin is formed predominately of Upper Cretaceous and Tertiary deposits (Campbell, 1977; Kerr and Cooke, 2017). In the mid to lower reaches of the basin, the Red Deer River is flanked by the Alberta badlands for approximately 300 km from the town of Nevis to Atlee near the Alberta-Saskatchewan border (Campbell, 1970; Bryan and Campbell, 1980). Median annual precipitation across the basin is 393 mm but varies from more than 900 mm in the Rockies to 270–400 mm in the grasslands (AMEC, 2009). Land use in the basin is predominately agricultural with crops and pastures covering approximately 43% and 48% of the total basin area, respectively (RDRWA, 2008). The entire basin has a population of approximately 270,000 people and only about 1% of the land area is classified as urban. The largest urban centre in the basin is the city of Red Deer with a population of approximately 98,000 (Alberta Municipal Affairs, 2014; Kerr and Cooke, 2017). Oil and gas activities are common in the basin.

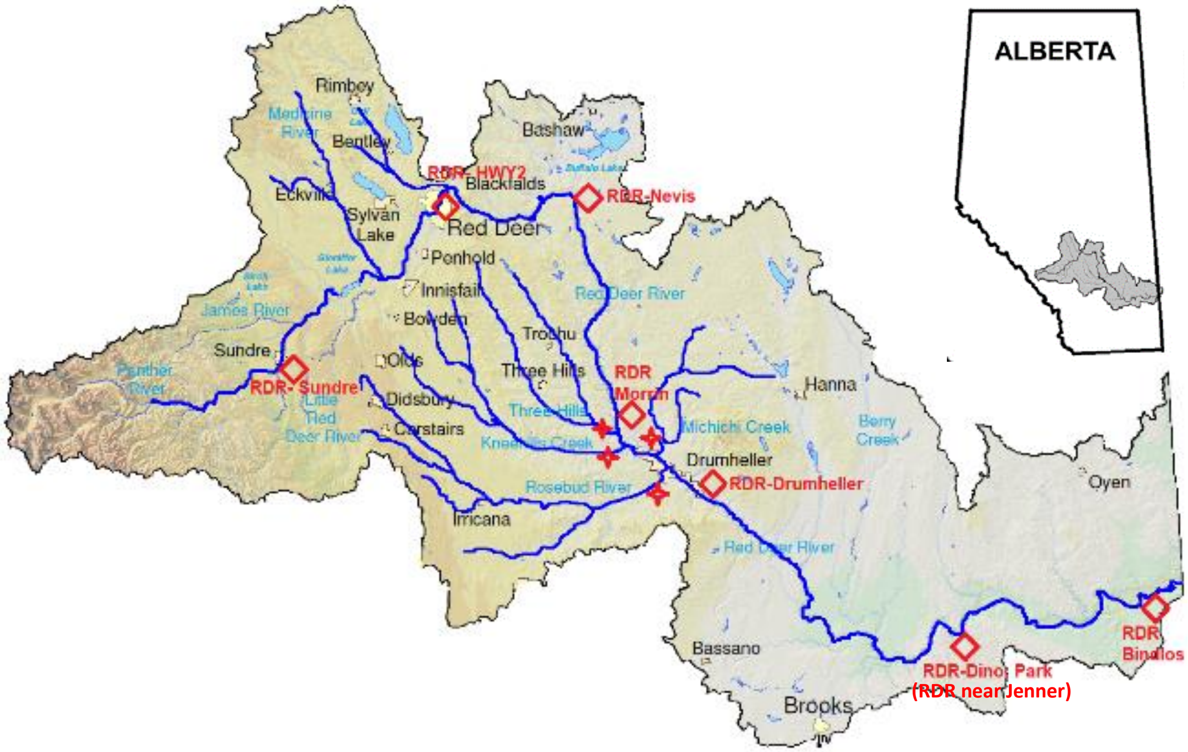

Figure 1. Red Deer River Basin and sampling locations

The Red Deer River has one of the highest flow weighted suspended sediment concentrations in Canada (den Hartog and Ferguson, 1978) and variability in sediment flux in the Red Deer River is among the highest of rivers globally (Meybeck et al., 2003). Frequent non-compliance of surface water quality objectives in the Red Deer River has been common throughout its history. In 1996, a report was written to investigate the causes of high excursion rates for copper, zinc, iron, lead and fecal coliforms in the Red Deer River (Anderson, A.-M., 1996). In 2005, the largest decrease in adherence rate occurred (PPWB, 2006). This decrease was mainly attributed to excursions of total metal objectives, and that all excursions were associated with 2-3 fold increases in suspended sediment concentrations associated with high discharge events. Literature shows that total metal concentrations in the Red Deer River basin are generally at the upper range of values reported elsewhere (Kerr and Cooke, 2017). Following the high levels of metal concentrations reported by Alberta Environment and Sustainable Resource Development in 2014, Alberta initiated an investigation on metal issues in the Red Deer River. Samples were collected at 7 sites in the badlands area and 2 sites upstream. This report is prepared based on the data/results from the aforementioned investigation and the historical data collected at the mainstem Long Term River Network (LTRN) sites (Sundre, Red Deer/HWY2, Nevis, Morrin Bridge, D/S Drumheller, Dinosaur Provincial Park/near Jenner) and Bindloss, as shown in Figure 1.

3. Non Compliances in 2015 and Historically

The August 2015 water quality data provided by Environment and Climate Change Canada were revised for dissolved iron and dissolved manganese from 2210 to 252 µg/L and from 67.3 to 7.74 µg/L, respectively (for the reason that dilution was not accounted for when initially reporting the values). While the initial values exceeded their transboundary objectives, the updated levels do not. Based on the updated data, the number of excursions in 2015 has decreased to a total of 24.5. Excursion occurred for 12 parameters, among which 9 excursions were from metals, 4 from bacteria, 8.5 from nutrients, 2 from TSS, and 1 from dissolved ions. Although there is presently no water quality objective set for cadmium or copper and no monitoring at the boundary for mercury (only scattered data available in Alberta), Alberta also discusses the cause of high levels of these three metals in the Red Deer River. In summary, this report covers the analysis of exceedance patterns for substances that repeatedly exceeded existing/proposed water quality objectives, including total arsenic, cadmium (proposed), copper (proposed), lead, mercury, selenium, silver and zinc, TSS, fecal coliforms, *E. Coli*, total dissolved solids, total nitrogen, total phosphorus and total dissolved phosphorus.

The majority of 2015 excursions for the Red Deer River (17.5 of the 24.5 excursions) occurred in August and September when suspended sediment concentrations were high (Appendix A). There were 15 metal, total suspended sediment and bacterial excursions in August and September. Total Nitrogen and total phosphorus also had excursions in other months (e.g., March, November). TDS and dissolved phosphorus didn't exceed objectives in August or September. To better understand the pattern of excursions historical data from the past 13 years were compared to their corresponding water quality objectives (Appendix B). Results show that the majority of the excursions were observed in open water season for total arsenic (15/15), total cadmium (13/15), total copper (44/48), total lead (26/28), total selenium (6/6) , total silver (16/16), total zinc (24/26), TSS (16/16), fecal coliforms (22/24) and *E. Coli* (14/16), with most observed in spring and summer.

TDS and Salinity

TDS exceeded the transboundary objectives 4 times throughout the 13 years (Table 1), with 3 occurrences in December and once in May of 2010 (Figure B11). Six dominating major ions are bicarbonate, sulphate, calcium, sodium, magnesium and chloride, accounting for 55%, 18%, 12%, 8%, 5% and 2% of the total weight of the these ions, respectively (Figure 2). TDS and associated major ions measured on dates adjacent to those with excursions do not demonstrate a strong temporal pattern for those months (Table 1). While flows were generally lower during months with TDS excursions, the short-term increase (relative to those in months preceding and following) suggest isolated occurrence. The low proportions of chloride (main constituent of deicers) suggests that road salt were not the main driver of the excursions, rather a joint effect with other factors that might have led to the spikes of TDS over the years. The excursions might be a result of the low flow and associated high groundwater input in these periods. This is supported by the negative correlation between TDS and flow

(Figure 3), with most of the excursions occurring in low flow conditions (e.g., three in December, one in January of 1982 over the record 1980-1982 and 1985-present).

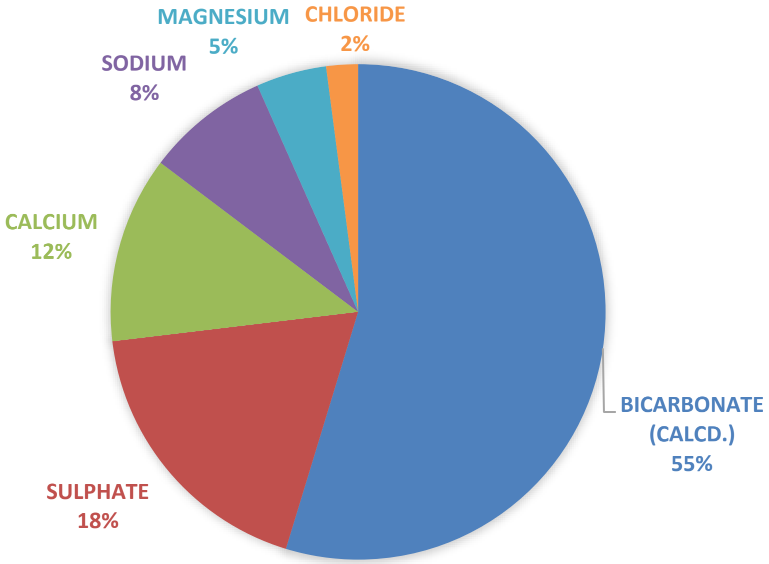

Figure 2. Average proportions of six major ions (based on concentration data collected between 2003 and 2016)

Table 1. Total dissolved solids values in the years in which it exceeded its objective of 500 mg/L (Red Deer River at Bindloss, between April 2003 and December 2016)

Sample Date	BICARBONATE (CALCD.) mg/L	SULPHATE mg/L	CALCIUM mg/L	SODIUM mg/L	MAGNESIUM mg/L	CHLORIDE mg/L	TDS (CALCD.) mg/L
2007.10	241	70	54	30	22	9	312
2007.11	272	75	60	35	23	11	350
2007.12	**421** *(+149)*	**129** *(+54)*	**89** *(+29)*	**54** *(+18)*	**35** *(+12)*	**18** *(+7)*	**540** *(+191)*
2008.01	313	65	75	21	24	6	355
2008.02	341	71	79	22	25	7	379
2010.03	190	82	41	39	15	8	289
2010.04	236	83	49	39	20	8	322
2010.05	**274** *(+38)*	**236** *(+153)*	**63** *(+14)*	**108** *(+69)*	**28** *(+8)*	**17** *(+9)*	**603** *(+281)*
2010.06	208	151	49	64	18	8	415
2010.07	184	79	39	43	14	7	286
2015.10	211	84	51	29	21	7	298
2015.11	238	105	56	43	23	12	359
2015.12	**363** *(+126)*	**151** *(+46)*	**83** *(+28)*	**67** *(+25)*	**35** *(+12)*	**15** *(+4)*	**538** *(+179)*
2016.01	294	85	72	26	25	8	371
2016.02	233	104	61	37	22	9	361
2016.10	245	70	56	31	20	10	313
2016.11	267	71	57	37	21	9	332
2016.12	**435** *(+168)*	**145** *(+74)*	**96** *(+39)*	**72** *(+36)*	**36** *(+15)*	**16** *(+7)*	**591** *(+260)*

Note: *italic* values in brackets *()* are increased values compared to levels of the past month.

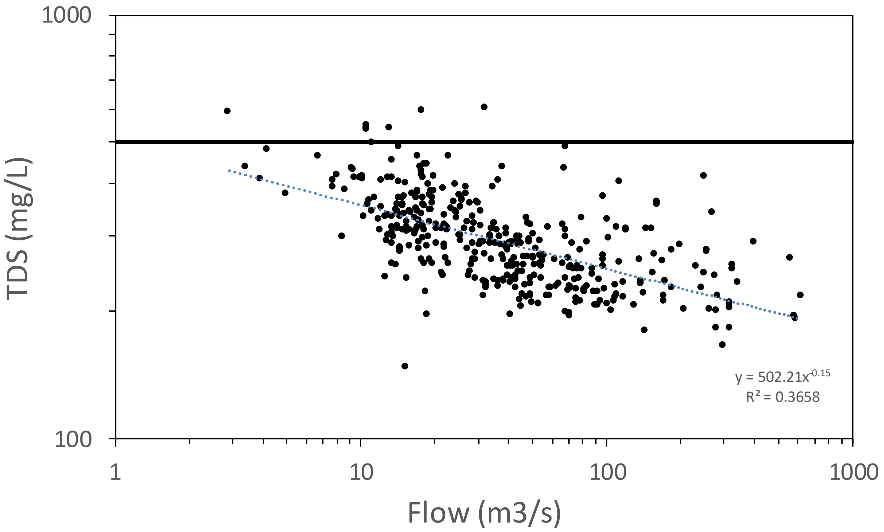

Figure 3. Negative correlations of TDS with flow in the Red Deer River at Bindloss

Although the latest flow-weighted trend analysis (PPWB, 2016) indicated significant increasing trends for TDS, chloride and sodium, the slopes are generally low (estimated rates of 5.1%, 12.7% and 2.9% in 10 years, respectively). Time series analysis of the specific major ions at the three mainstem sites (Figure 4) show that their levels generally remained static over the 5 decades, with spikes occurring periodically. The high levels of TDS were also observed in the 1970s. The relatively stable level of the major ions may, however, hide the changes that occurred on the landscape throughout the varying levels of flow. The flow-weighted Mann Kendal trend analysis may provide more discerning information in terms of identifying changes to the system.

Larger variations in concentration of potassium, chloride, sodium, sulphate and TDS were generally observed at lower stream stations (e.g., near Bindloss) compared to those at upper stream stations (Red Deer). The increase of chloride mainly occurred between Red Deer and Nevis Bridge, but the increase was smaller than those for sodium and sulphate. As the largest municipality in the basin, the City of Red Deer might contribute the largest amount of chloride in the reach. Despite the increased variations, the levels of magnesium, calcium and bicarbonate remain similar from upstream to downstream. The varying spatial patterns for the three groups of major ions (e.g., chloride vs. sulphate vs. calcium) imply that different factors along the reaches drive the changes in specific ions. Kerr's study (2017) concludes that increasing trends of dissolved ions in the Red Deer River are driven largely by climatic changes and soil processes, in which multiple land uses play an important role. The Red Deer River basin is predominately located in semiarid climate region (particularly the eastern portion). The Red Deer River basin contains naturally saline and sodic soils. The dominant soluble salts within central and southern Alberta soils is Na_2SO_4 (Pawluk and Bayrock 1969). Agricultural activities such as irrigation have expanded in the region over recent decades (Alberta Agriculture and Rural Development, 2010). Land clearing and subsequent increases in groundwater recharge (i.e., dryland salinity) has led to the formation of salt seeps throughout the region (Greenlee et al. 1968; Wiebe et al. 2007). Runoff over the disturbed lands in the semiarid area, as well as increased population and associated wastewater discharges and increased road salt use, might jointly contribute to the increased levels of TDS. Investigative efforts are undergoing in Alberta basins of similar characteristics (i.e., North Saskatchewan River basin).

Figure 4. Time series of major ions at three mainstem sites of the Red Deer River

Nutrients

Total nitrogen exceeded the closed water (ice-cover) objective in March and the open-water objective in August of 2015 (Figure B12). Similarly, total phosphorus exceeded the upper-bound seasonal objectives in March and August as well (Figure B13). In addition, the lower-bound seasonal objectives set for total phosphorus were exceeded in September and November (marginal), respectively. Dissolved phosphorus exceeded the seasonal site-specific objectives 3.5 times, in March, April, May and January (lower-bound objective), respectively (Figure B14). These objectives were set based on background statistics, with the upper-bound objectives at 90th percentiles and the lower-bound objectives at lowest 90th percentile value of the 10 year running (i.e., 90th percentile value for every 10 consecutive years of data) (PPWB, 2015). Theoretically, there should be 10 percent of the observations above the site-specific upper-bound objective. There is no readily calculated theoretical excursion rate for the lower-bound objective or the annual reported number of excursions (which is the average of the number of lower- and upper bound excursions). For nutrients in 2015, there were more exceedances than expected. Investigations on nutrient patterns are ongoing at the PPWB generally and for the Red Deer River basin specifically.

4. Explanatory Analysis

Given the fact that 71.4% of the excursions in 2015 occurred in August and September, the flow data in 2015 were first reviewed because flow is a frequent determinant of water quality parameters, notably many total metals. As shown in Figure 5, the two water samples were taken on August 12 and September 9 during two different smaller peak flow events. The peaking flow around August 12 appeared to be mainly contributed from catchment area between Red Deer and Drumheller, while the peaking flow around September 9 appeared to originate from catchment area upstream Red Deer. Although the discharge on August 12 wasn't the greatest peak throughout the year, the concentrations on August 12th were greater than those for the rest of the year (including September 9th sample) for the ten substances. Of note, TSS levels were elevated over 30 and 10 times in August and September compared to those in other open-water months, and appear to be related to the total metal increases observed in the two months.

Generally, TSS correlates with discharge in humid or sub-humid climatic regions. However, such correlation is weak for arid and semiarid climatic regions where intense local convection storms over highly erodible areas close to the main channel produce major inputs of sediment without corresponding major increases in discharge. Red Deer River is just such a case where sediment input is not related or is poorly related to discharge (Campbell, 1977). The western portion, particularly the mountain and foothills section that receives relatively higher precipitation, is in a humid (or sub-humid) climatic zone. With about six per cent of the entire basin, the headwater area contributes almost 50 per cent of the total mean annual discharge. In the southern and eastern portion of the basin a combination of the dry climate, its adverse effects on vegetation cover, and the highly erodible bedrock have produced extensive areas of badlands along the Red Deer River from Nevis to Atlee (near Bindloss) (Stelck, 1967). Within the arid zone, the badlands play a major role in the sediment–discharge relationship of the river. They contribute massive amounts of sediment from a very small area of the basin (Campbell, 1970, 1973, 1974). Rainfall of high intensity, which is usually the key factor in producing erosion and sediment yield, is not necessarily nor usually high in total amount in the dry climate there (Campbell, 1977). Campbell's (1977) study indicated that about 90 per cent of the sediments in the Red Deer River at Bindloss probably originate between Red Deer and Bindloss (that reach lined by badlands), and the badlands reach (with less than 2 per cent of the entire basin) has the potential to produce most of the TSS load. The installation of the Dickson Dam upstream of the City of Red Deer in the mid 1980s had a marked effect in reducing sediment transport in the river upstream (Campbell, 1992), resulting in an even higher percentage of sediment being produced from the badlands area. This analysis aligns with the discharge and sediment observations on August 12th and September 9th, where a relatively smaller discharge in August coincided with higher TSS observed at Bindloss due to its origin from the badlands between Red Deer and Drumheller.

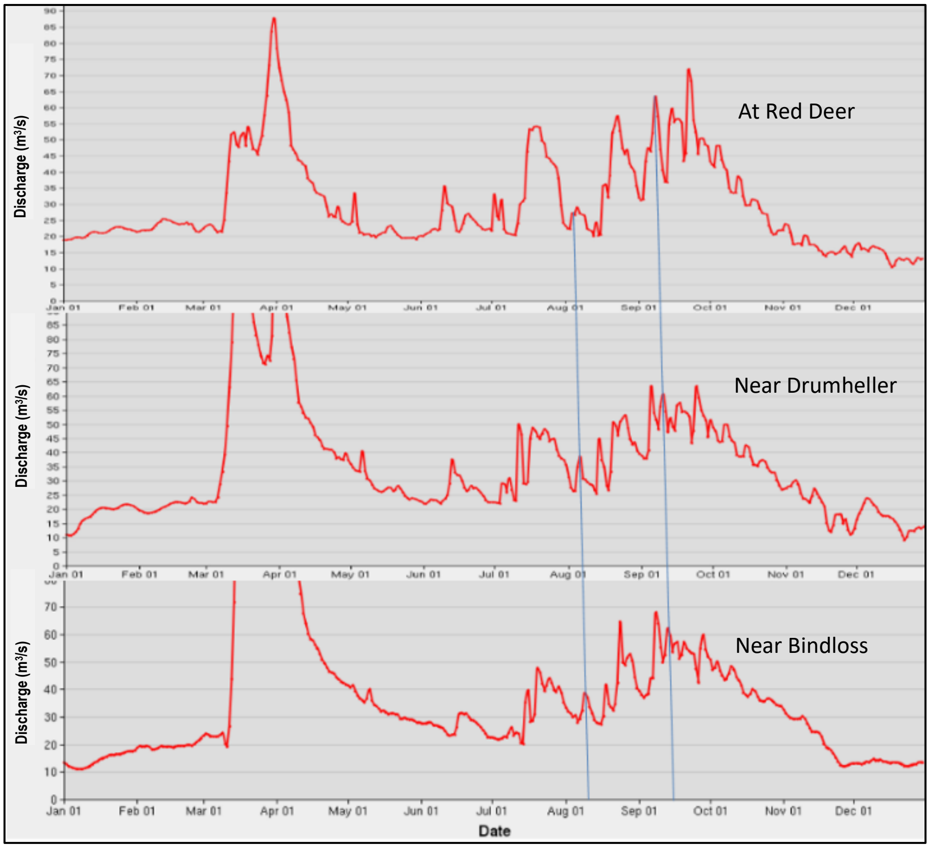

Figure 5. Red Deer River Daily Flow for 2015 (near Red Deer, Drumheller, Bindloss)

Compared to the elevated levels of total metals (i.e., As, Cd, Cu, Pb, Ag, Zn), as shown in Appendix B, dissolved metals concentrations remained low and relative stable in 2015 and didn't show large increases with the increased total metal levels in general. It infers that the increase in total metals is a result of suspended sediment and that the metals have a low probability of being bio-available because they're bound to sediment.

A correlation analysis was undertaken to analyze the relationships between TSS and the various variables of concern using post March 2003 data. Laboratory methods for analysis of metals changed in 2003, which is why that period was selected. Results in Table 2 show strong positive correlations between TSS and a number of total metals (i.e., arsenic, cadmium, chromium, copper, lead, silver and zinc) and total phosphorus. As illustrated in scatterplots in Appendix C, strong positive correlations with TSS exist for most of the total metal variables. The strong correlations with TSS infer that these substances are likely from the same origins with TSS. Kerr and Cooke's (2017) study on total lead, copper, cadmium and mercury in suspended sediment in Red Deer River badlands reach also indicates that the elevated total metals levels in water are mostly associated with increased sediments instead of increased metal concentrations in sediment. Figure 5 shows that the peak flow runoff during the two sampling events in August and September was mainly originated from the Red Deer-Drumheller area and upstream Red Deer area, respectively, indicating the possible origin areas for the elevated substances in the two months.

Results in Table 2 also show positive correlations between TSS and dissolved phosphorus, total nitrogen, fecal coliforms, *E.Coli* and total selenium, to various extents. Some previous studies revealed similar positive correlations between TSS and bacteria (Busse et al., 2007; Irvine et al., 2002). Trend assessments by the PPWB (2016) show a decreasing trend (flow-weighted) for dissolved phosphorus and an increasing trend for total nitrogen. Investigations are still ongoing by the PPWB to identify export hotspots for nutrients.

TDS exhibits certain negative correlation with TSS. As shown in Figure C14 in Appendix C, most TDS excursions occurred in low TSS water (typically in Dec.), and when they did in 2015 (Dec.) the flow was as low as 13 m^3/s (below 10th percentile). This is expected to occur when flows are low and the low volume overland flow and groundwater inputs become more dominated sources of river flow. In contrast, high TSS levels were usually associated with high-flow conditions, which resulted in low TDS levels due to dilution effect. However, full range of TDS concentration (from low to high) were also observed at low TSS levels, indicating the complex impacts of multiple factors on TDS levels (e.g., water source at that time).

Table 2. Correlation Analysis Results for Red Deer River at Bindloss

Parameters	Correlation coefficients with TSS (Spearman)	p-values
ARSENIC.TOTAL	0.926	<.0001
CADMIUM.TOTAL	0.846	<.0001
CHROMIUM.TOTAL	0.932	<.0001
COPPER.TOTAL	0.968	<.0001
LEAD.TOTAL	0.948	<.0001
SELENIUM.TOTAL	0.448	<.0001
SILVER.TOTAL	0.925	<.0001
ZINC.TOTAL	0.924	<.0001
FECAL COLIFORMS	0.655	<.0001

E.COLI	0.714	<.0001
NITROGEN.TOTAL	0.583	<.0001
PHOSPHOROUS.TOTAL	0.963	<.0001
PHOSPHOROUS.DISSOLVED	0.659	<.0001
TDS	-0.471	<.0001

5. Spatial Variations

Data from Alberta's LTRN sites between 2003 and 2016 were reviewed to better understand upstream water quality conditions relative to those at the PPWB Bindloss location. Results for total arsenic, cadmium, chromium, copper, lead, mercury, silver, zinc and TSS show similar spatial variations in the mainstem of the Red Deer River. Total arsenic levels at all the mainstem sites are generally greater in open-water season than those in the ice-cover season. As shown in Figure D1 and D2, general increasing trends are illustrated spatially from the upstream site at Sundre to the downstream site near Jenner (Dinosaur Provincial Park), and remain at the same range at Bindloss in both seasons (with median value decreases slightly). The maximum arsenic concentration of 15.9 µg/L was observed at the site near Jenner. The greatest increase in arsenic concentrations between sites in the open-water season occurred between Morrin Bridge and Jenner. In this reach several tributaries flow in the Red Deer River, including Threehills Creek, Kneehills Creek, Michichi Creek and Rosebud River. The reach and its tributaries are well known for their high erosivity.

Among the sites, total arsenic shows the greatest variance at Jenner site, followed by Bindloss, Morrin Bridge, Nevis Bridge, Red Deer (HWY2) and Sundre. Similar order was also observed for the site in ice-cover season. The variation in arsenic from Bindloss site is slightly smaller than that at Morrin Bridge, which may be attributed to the smaller number of samples taken at Bindloss. Variance value for samples taken in ice-cover season are generally over 1 magnitude lower than those in open-water season. Coincidently, the sites in badlands area (Morrin Bridge, Jenner, Bindloss) have shown greater variations than upstream sites in both open-water season and ice-cover seasons. The large variations in the reach can be attributable to the susceptible nature of the adjacent sub-watersheds to environmental factors (e.g., rainfall, erosion). As indicated in Kerr and Cooke's (2017) study, due to its highly erosive nature, the Alberta badlands contribute >70% of the sediment load to the Red Deer River despite making up only a small proportion (≈2%) of the overall watershed area (Campbell, 1977). Average annual erosion rates within the Alberta badlands have been estimated to be approximately 4 mm yr^{-1} (Campbell, 1987).

Selenium appears to demonstrate a seasonal pattern different from other metals (Figure D13, 14). Greater concentrations were observed at the upstream Sundre site. The decrease of the concentration downstream can be attributable to the dilution effect in Gleniffer Lake on the Red Deer River, given that total selenium exists mostly in the form of dissolved selenium. Total selenium levels remain relative stable at the other downstream sites, with close variance levels. The total selenium level doesn't show significant increase or variation even in the badland reach, indicating main inputs from upstream catchment area rather than downstream subbasins.

Similar spatial patterns are also illustrated for fecal coliforms, *E.Coli* and total phosphorus in open-water season (Figure D21, 23, 27), with elevated concentrations and large variances at Jenner and Bindloss sites. Total phosphorus shows similar spatial trends with total metals in open-water season. Total nitrogen levels appear be elevated at Nevis Bridge site in both seasons. Relatively greater concentrations and variations of bacteria (fecal coliforms, E.*Coli*), total nitrogen, dissolved phosphorus and total phosphorus were observed at Nevis Bridge site than in other sites upstream under ice. Major sources upstream the Nevis Bridge include major municipal (e.g., City of Red Deer), industrial discharges and agricultural non-point sources. However, insufficient data are readily available to quantify the major causes. TDS levels increase slightly from upstream to Morrin Bridge site, and elevate at Jenner and Bindloss in both seasons. Variations remain similar levels from upstream to Morrin Bridge, and increase substantially at Jenner.

6. Tributary impacts in August and September (2015)

An attempt was undertaken to investigate the potential sources contributing to the high excursions at Bindloss in August and September of 2015, based on an available dataset for tributaries in the badland area in open-water season of 2015. Assessments were focused on samples taken in August and September, spanning over the PPWB sampling events (August 12 and September 9) to provide more relevant reference. Alberta Environment and Parks sampled the mainstem on Aug 17 and Sep 21. More frequent samples were taken for the tributaries and mainstem between Morrin Bridge and Drumheller (August 6, 13, September 10).

Results show that total recoverable arsenic, lead, silver and zinc (functionally equivalent to PPWB's total metal), and TSS and total phosphorus had similar spatial patterns around August 17 and September 21. Taking total lead for example, two excursions of PPWB objective were observed in August and September at 45.4 and 17.4 µg/L, respectively. Upstream data show that total recoverable lead concentrations in August remained low at Nevis and upstream and started increasing at Morrin Bridge (Figure E2). Erosions at gullies and the banks become noticeable between Nevis and Morrin Bridge sites (Figure 6). Elevated levels of total recoverable lead were observed in the tributaries and mainstem (D/S Drumheller, D/S Dinosaur Provincial Park near Jenner) downstream Morrin Bridge. The greatest level was observed near Jenner in the mainstem, suggesting that largest loadings to the river mainstem were from the subbasins between D/S Drumheller and near Jenner. The greatest level was observed at the mainstem site near Jenner among all sites on August 17. Although much greater levels of total recoverable lead were observed on August 6, no mainstem data is available for the time to compare. Similar pattern was observed in September but at lower levels at each site than in August. Among the sites, greater levels were observed in the tributaries between Morrin Bridge and D/S Drumheller, with the greatest level observed at Michichi Creek. The change of locations for the greatest levels implies the changes of the dominant contributing areas that led to the increase of total lead in the river mainstem. In the former case, the dominant contribution was likely from the subbasins downstream D/S Drumheller, while in the latter case the dominant contribution was likely from the subbasins between Morrin Bridge and D/S Drumheller.

It is important to note from Figure E2 that total recoverable lead levels at each site vary significantly in the two months. A change of nearly ten folds could occur within one week (e.g., between August 6 and 13 of the year). Given that no sample was taken in over 100 km of river between Jenner and Bindloss around August 13 (near PPWB sampling event on August 12) or September 10 (near PPWB sampling event on September 9), impacts from subbasins in between could not be assessed sufficiently.

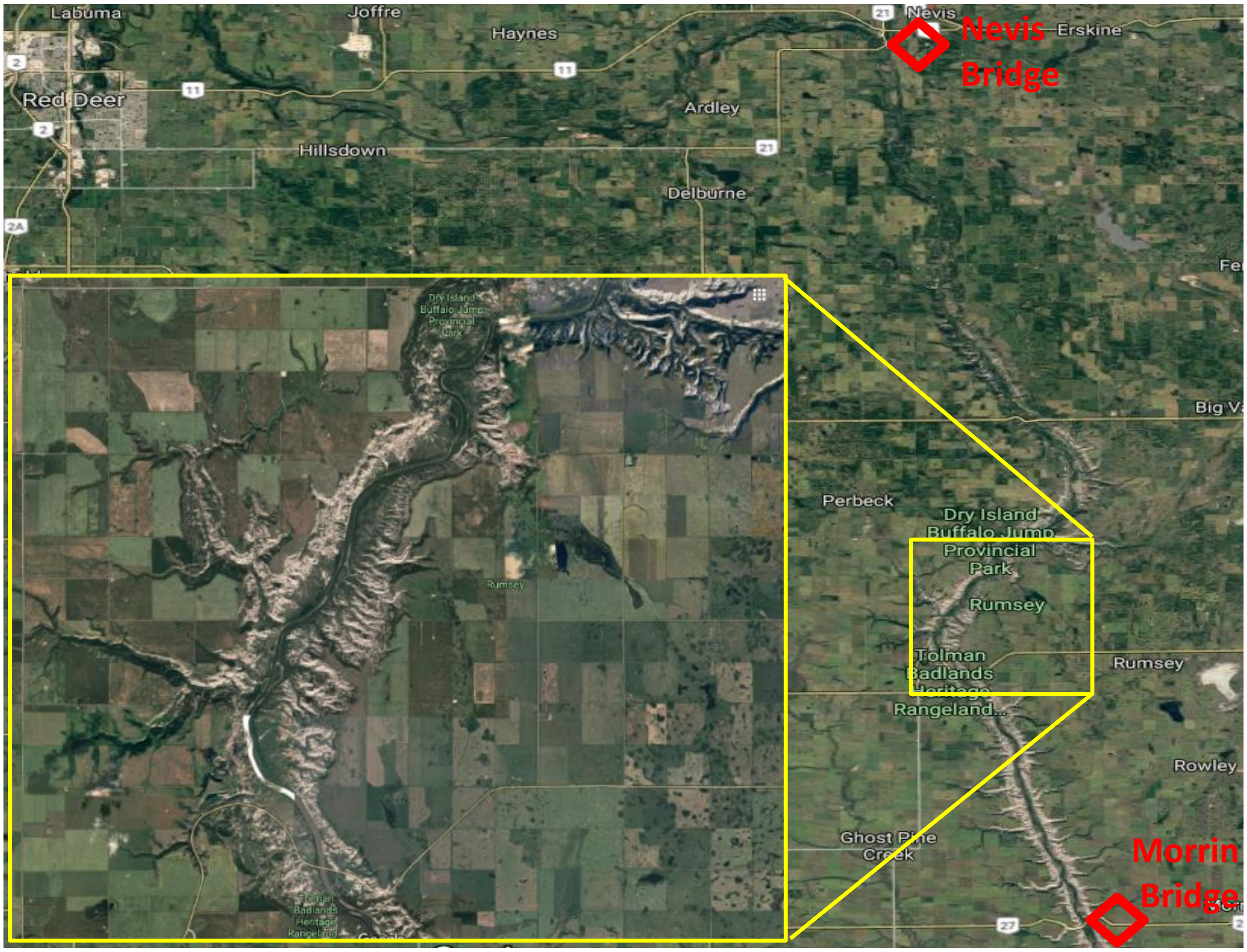

Figure 6. Satellite image of the Red Deer River mainstem between Nevis and Morrin Bridge (no major tributary in between)

It is also noted that the spatial distribution patterns for total lead are consistent with those for TSS (Figure E6). Kerr and Cooke's (2017) results of lead, copper, cadmium and mercury in suspended sediments show that metal concentrations associated with suspended sediment did not increase downstream of the badlands. It suggests that the primary driver of the increased riverine metal concentrations observed downstream of the badlands are increases in sediment mass. Within the badlands area, sediment fluxes to the Red Deer River are initiated primarily by intense but short lived convective rainstorms (Bryan and Campbell, 1980; Kerr and Cooke, 2017). Surface crusts develop rapidly on shale slopes upon wetting. Surface sealing contributes to low infiltration rates which generate substantial overland runoff over the sparsely vegetated surface (Campbell, 1970). This in turn leads to significant erosion primarily via sheet-flow and rilling (Campbell, 1987).

Although samples taken at the tributary sites were not analysed for total nitrogen, fecal coliforms or *E.Coli*, levels of the three variables elevated substantially from Morrin Bridge to D/S Dinosaur Park near Jenner in both August and September. All these variables demonstrated large temporal variability, similar to the other substances (i.e., total metals, total phosphorus, TSS) discussed above. Sometimes, levels of a substance may change over ten times even within one week. The large temporal variability at these sites (mainstem or tributary) poses a challenge to source investigation.

Total selenium appeared to be relative stable in the mainstem (except for a decrease between Sundre and HWY2 Bridge near Red Deer), despite the elevated levels of total selenium observed in the tributaries between Morrin Bridge and D/S Drumheller sites. As illustrated in Figure E3, levels of total selenium vary less significantly compared to those of other substances, especially in the river mainstem. This can be attributable to the high portions of dissolved form in total selenium.

7. Conclusions

Among the excursions in 2015, most of them (17.5 in total metals, TSS, bacteria, total nitrogen and phosphorus) were observed in August and September and were attributed to the two runoff events in the Red Deer-Drumheller and upstream Red Deer areas, respectively. For total nitrogen and total phosphorus, additional excursions were observed in other months as well. Excursions for dissolved phosphorus and TDS were only found in the months other than August or September during the year. Further comparisons using post 2003 data show repeated excursions for total metals, bacteria and TSS, most of which primarily occurred in open-water season.

Compared to flow, TSS appears to be more directly related to the high number of excursions for total metals, bacteria and total phosphorus. Total metal and total phosphorus levels were significantly elevated at the sites located in the badlands reach. Strong correlations are observed between total metal and TSS levels. High sediment concentrations and highly variable sediment fluxes appear to be the direct cause for both the water quality objective exceedances and the high degree of variability in total metal concentrations. Erosion of relatively unenriched soils from the related watersheds appears to contribute to the high levels of total metal concentrations. Studies have shown that the arid/semiarid climatic condition lead to the highly uncertain summer TSS yield in the River and the weak correlations between discharge and TSS.

Spatial patterns for total phosphorus and bacteria were generally similar to that of total metals in open water season. Elevated levels of total nitrogen (in both seasons), and total and dissolved phosphorus (ice-cover season) were observed at Nevis Bridge site. Meanwhile, trend assessments by the PPWB (2016) showed a decreasing trend (flow-weighted) for dissolved phosphorus and an increasing trend for total nitrogen. Investigations are still ongoing to identify hotspots for nutrients. A targeted investigation on total nitrogen between Red Deer and Nevis Bridge may be needed if repeated excursions and the trend continue.

Most major ions in the Red Deer River (potassium, chloride, sodium, sulphate and TDS) show increasing levels and variations from upstream to downstream. TDS exceeded the objective multiple times over the past five decades, occurring mostly during low flow season. Results indicate that the TDS spikes were mainly driven by flow and jointly impacted by other factors such as: runoff over the disturbed lands in the arid area, increased population and associated wastewater discharges, and increased road salt use. Alberta is investigating basins with similar characteristics elsewhere.

8. Next Steps

Water quality in the Red Deer River is largely influenced by the hydrology in this semi-arid watershed. For example, the elevated levels and increased variations in total metals, TSS and some of the major ions (e.g., sulphate, sodium) in water that flows through the lower reach, suggest strong connections between water quality and the special hydrology/geomorphology conditions in the bad lands (e.g., highly erodible landscape, varying effective drainage area). Further investigation of the mainstem and tributary contributions to the TSS levels in the Red Deer River might help further explain these elevated TSS levels and subsequent total metals. The lack of coordination in long-term monitoring of water quality and hydrology for the mainstem and tributaries of the Red Deer River posed challenges in further delineating the spatial and temporal contributions associated with the excursions.

In response, during the investigation of this report a five-year provincial water quality monitoring, evaluation and reporting plan for lotic systems (2016–2021) has been released by Alberta Environment and Parks to include five long-term monitoring stations on the mainstem and 17 stations on tributaries of the Red Deer River (Kerr and Cooke, 2019). Among the 17 tributary stations, 13 sites are monitored 12 times a year (January-December) and 4 are monitored 8 times a year (March-October) at monthly frequencies. This sampling regime is generally coordinated with the frequency of discharge measurements at these sites, and may change in the future in response to water quality assessment findings. This monitoring effort will help better understand the relative contribution of point versus non-point sources for the water quality parameters discussed in this report.

The PPWB's Committee on Water Quality's previous contract work on the Red Deer River identified large numbers of non-effective drainage areas in the lower Red Deer River basin (Golders Associates, 2019). However, the connectivity between the non-effective drainage areas and the river system has not been adequately investigated. The dynamics between the changing effective drainage areas and the river water quality have barely been studied. Further research is required to better understand the influence of the changing effective areas and their contributions to the water quality of the river.

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APPENDICES

APPENDIX A. Excursion summary table for Red Deer River at Bindloss in 2015

APPENDIX B. Comparison of time series data with PPWB transboundary water quality objectives (April 2003- December 2016)

APPENDIX C. Scatter plots between total suspended sediments and parameters with excursions in the Red Deer River at Bindloss

APPENDIX D. Spatial distribution of substances in the mainstem of the Red Deer River (April 2003-March 2016)

APPENDIX E. Spatial distribution of substances in the upstream river and tributaries close to the two sampling events in August and September of 2015

APPENDIX A. Excursion summary table for Red Deer River at Bindloss in 2015

Month	ARSENIC TOTAL	LEAD TOTAL	SELENIUM TOTAL	SILVER TOTAL	ZINC TOTAL	TSS	COLIFORMS FECAL	E. COLI	TDS (CAL.)	NITROGEN TOTAL (CAL.)	P. TOTAL	P. DISS'D
	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	NO/100mL	NO/100mL	mg/L	mg/L	mg/L	mg/L
January	0.71	0.23	0.43	0.003	3.5	8	13	17	498.0	0.73	0.021	0.011
February	0.49	0.21	0.42	0.003	1.8	8	4	4	383.6	0.69	0.019	0.006
March	0.93	0.73	0.44	0.009	4	22	L10	19	311.4	1.04	0.143	0.085
April	1.76	1.74	0.35	0.021	9.1	126	L10	L10	327.8	1.78	0.188	0.04
May	1.01	0.46	0.44	0.006	2.7	112	L10	13	438.3	1.47	0.232	0.052
June	1.1	0.51	0.33	0.006	3.5	37	19	7	392.2	0.44	0.086	0.01
July	1.23	0.91	0.33	0.012	4.8	66	7	7	314.2	0.54	0.080	0.006
August	7.41	45.4 (3.99)	1.07	0.37	200	3270	2262	1816	295.8	3.21	0.988	0.011
September	5.57	17.4 (6.19)	0.64	0.135	81.1	1010	750	831	298.3	1.34	0.467	0.014
October	1.01	1.24	0.32	0.012	6.3	76	6	L10	298.4	0.31	0.070	0.003
November	0.59	0.32	0.28	0.005	1.8	17	12	29	359.2	0.26	0.039	0.006
December	0.72	0.19	0.44	0.002	1.6	8	L2	L2	538.0	0.55	0.025	0.005
Objective (Close)	5	CAL.	1	0.1	30	30, 832.6	100	200	500	0.86	0.035, 0.069	0.008, 0.024
Objective (Open)										2.32	0.315, 0.563	0.023, 0.035
Statistical data (based on historical data between April 2003 and December 2016)												
min	0.31	0.007	0.03	0.001	0.03	1.8	1	1	147.6	0.26	0.007	0.001
25p	0.70	0.26	0.28	0.003	2.1	17	5	5	265.8	0.47	0.031	0.005
median	1.01	0.73	0.34	0.011	4.6	58	18	19	312.4	0.74	0.07	0.008
75p	2.00	3.02	0.44	0.032	14.3	209	77	68	369.5	1.07	0.184	0.017
90P	4.01	11.44	0.60	0.095	51.0	787	721	444	413.4	2.68	0.559	0.041
max	21.80	60.10	2.02	0.674	274	5410	5834	5067	602.9	16.49	1.850	0.085
Stand Dev	2.72	8.85	0.25	0.090	42.3	764	808	573	77.2	1.78	0.281	0.017
C. o Vari.	1.38	2.22	0.62	2.2	2.12	2.4	3	3	0.24	1.42	1.536	1.135
COUNTs	165	165	165	165	165	165	115	114	135	155	165	165

Note: A number in red indicates 1 excursion; a number in yellow is counted as 0.5 excursion which only exceeds the lower bound of a site-specific objective

APPENDIX B. Comparison of time series data with PPWB transboundary water quality objectives (April 2003- December 2016)

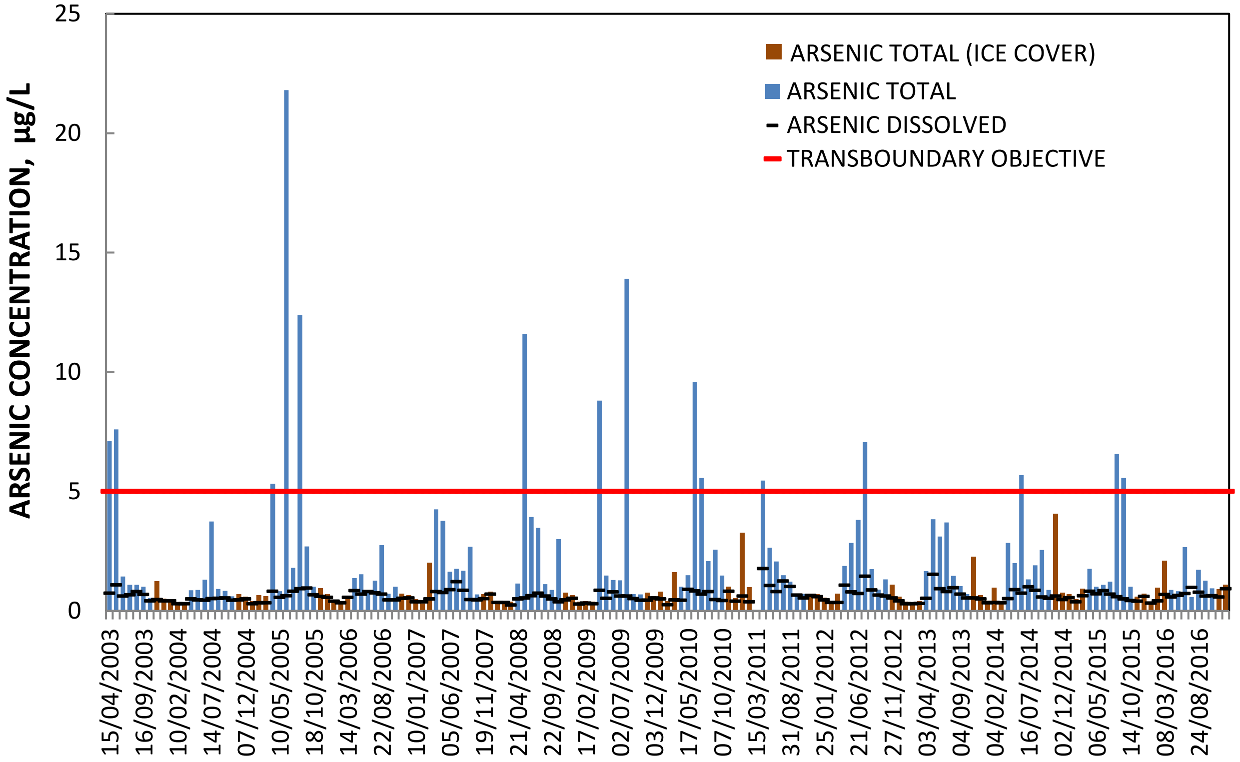


Figure B1. Comparison of arsenic levels with transboundary water quality objective

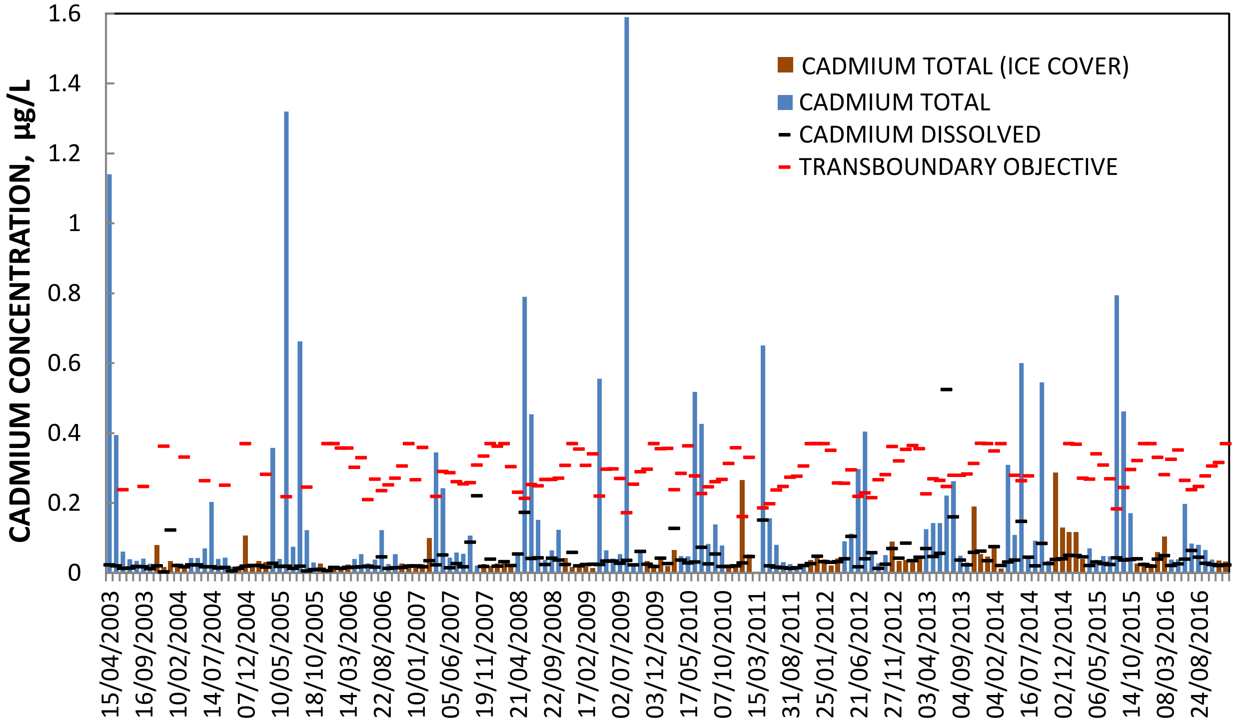


Figure B2. Comparison of total cadmium levels with transboundary water quality objectives (under review)

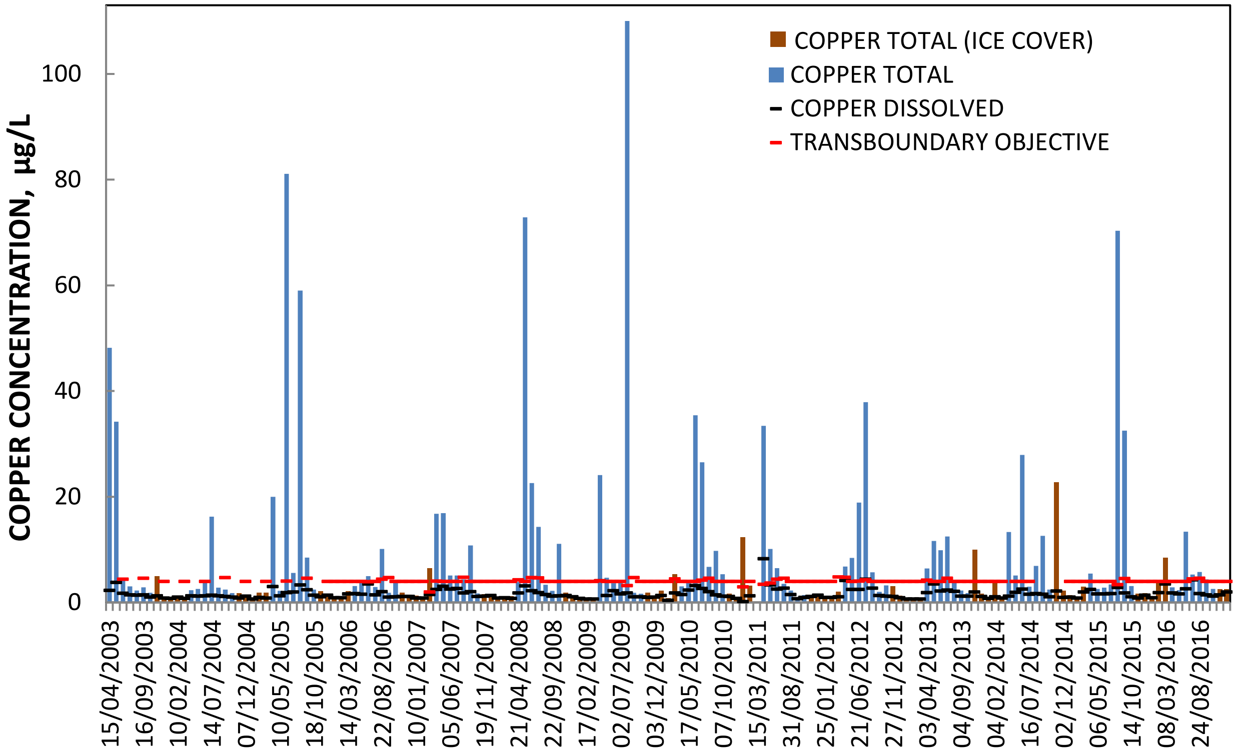


Figure B3. Comparison of total copper levels with transboundary water quality objectives

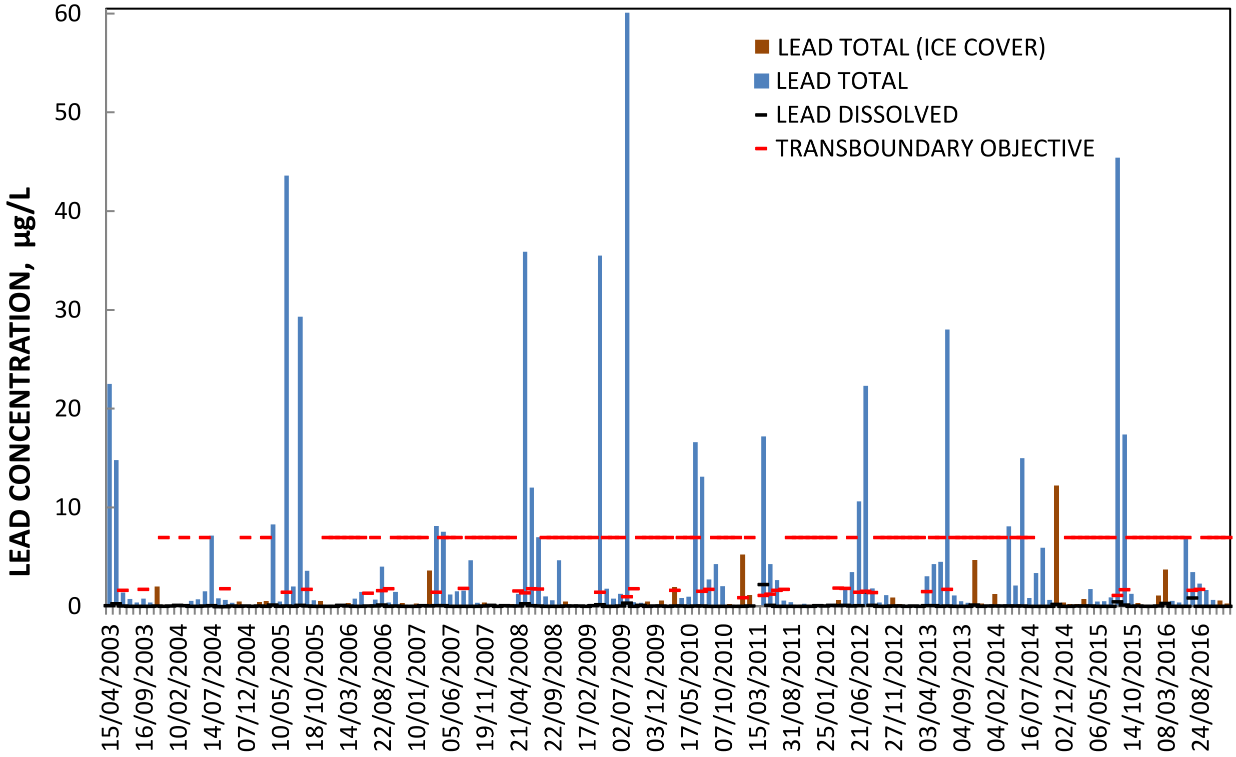


Figure B4. Comparison of total lead levels with transboundary water quality objectives

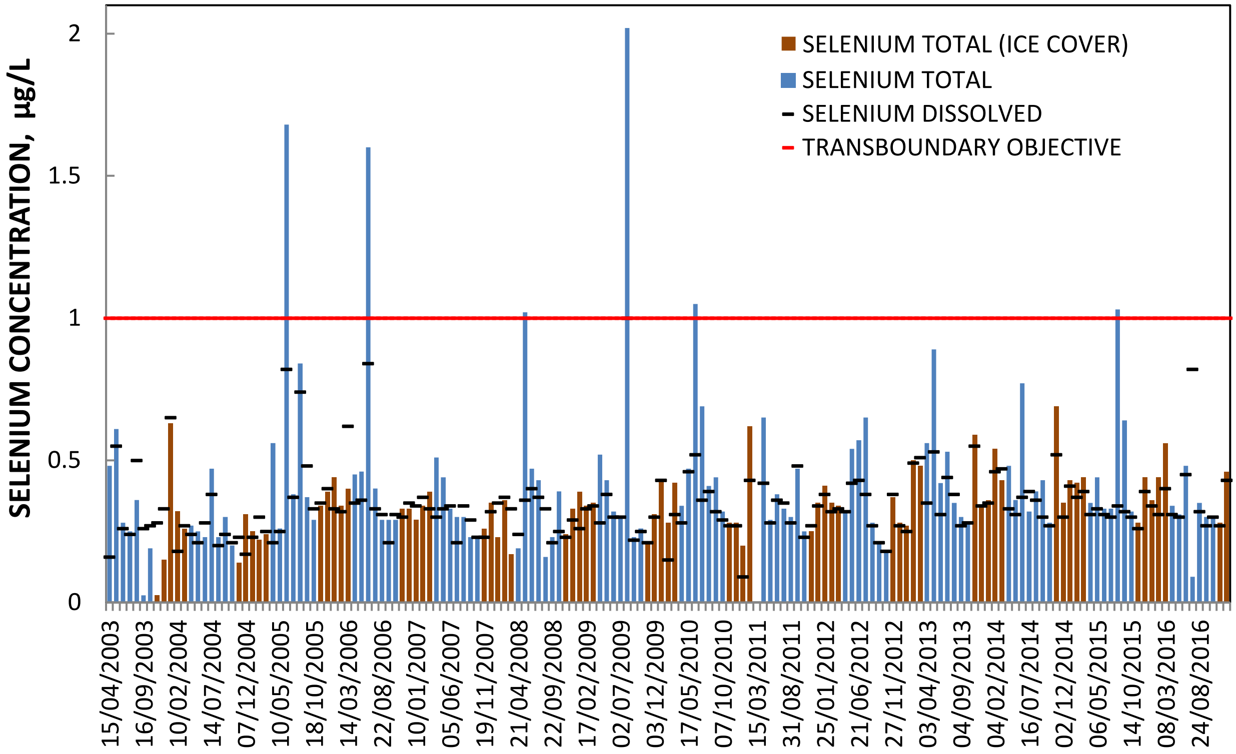


Figure B5. Comparison of total selenium levels with transboundary water quality objectives

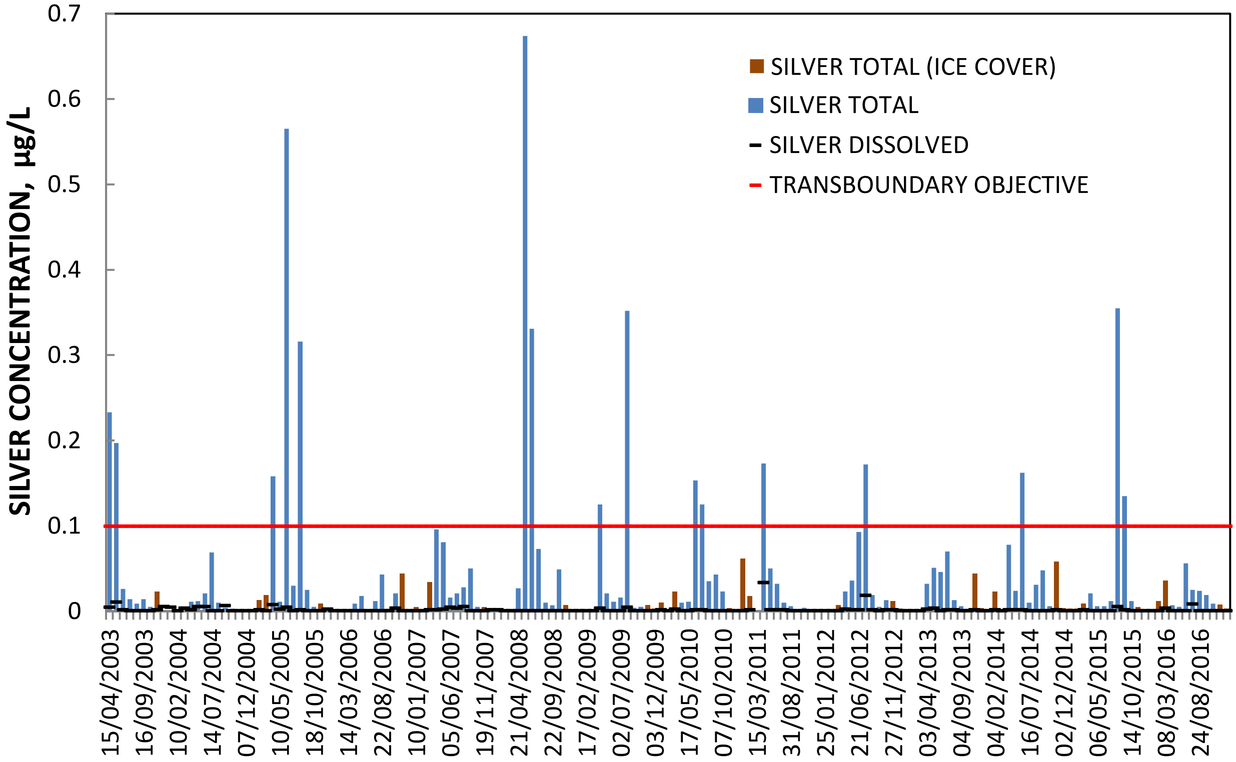


Figure B6. Comparison of total silver levels with transboundary water quality objectives

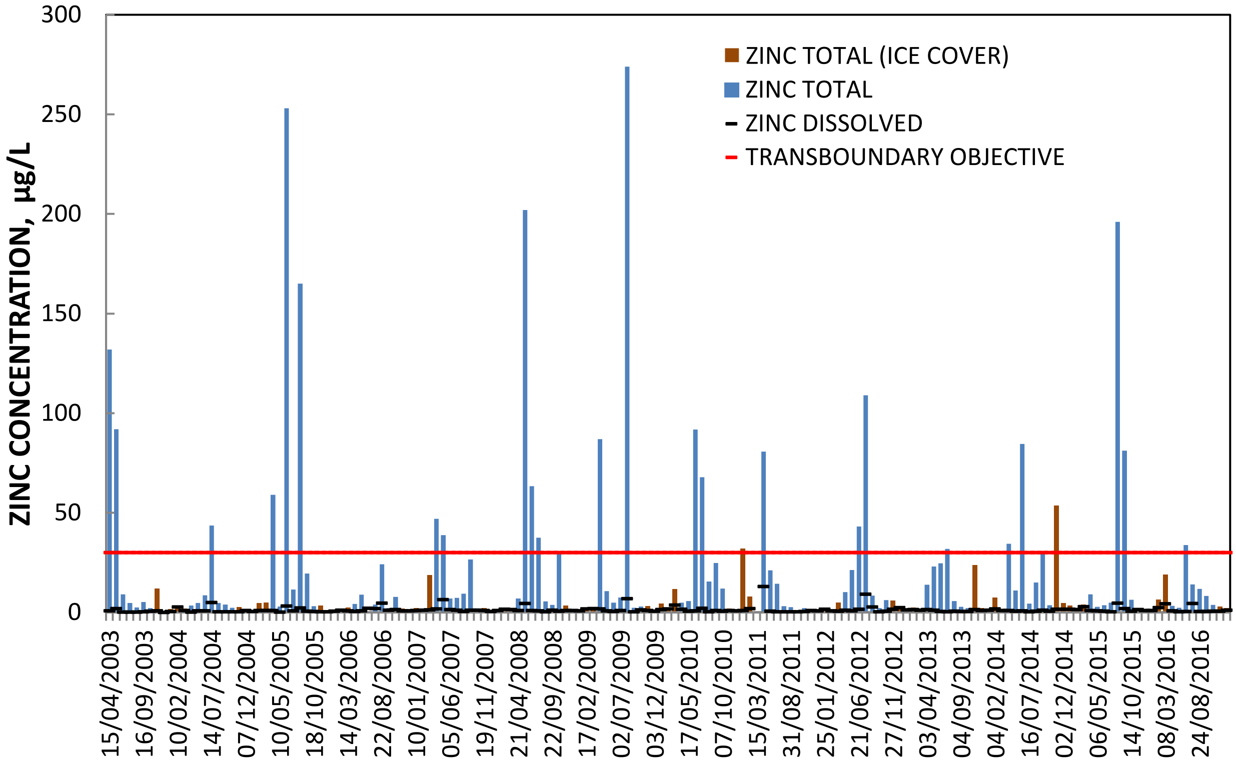


Figure B7. Comparison of total zinc levels with transboundary water quality objectives

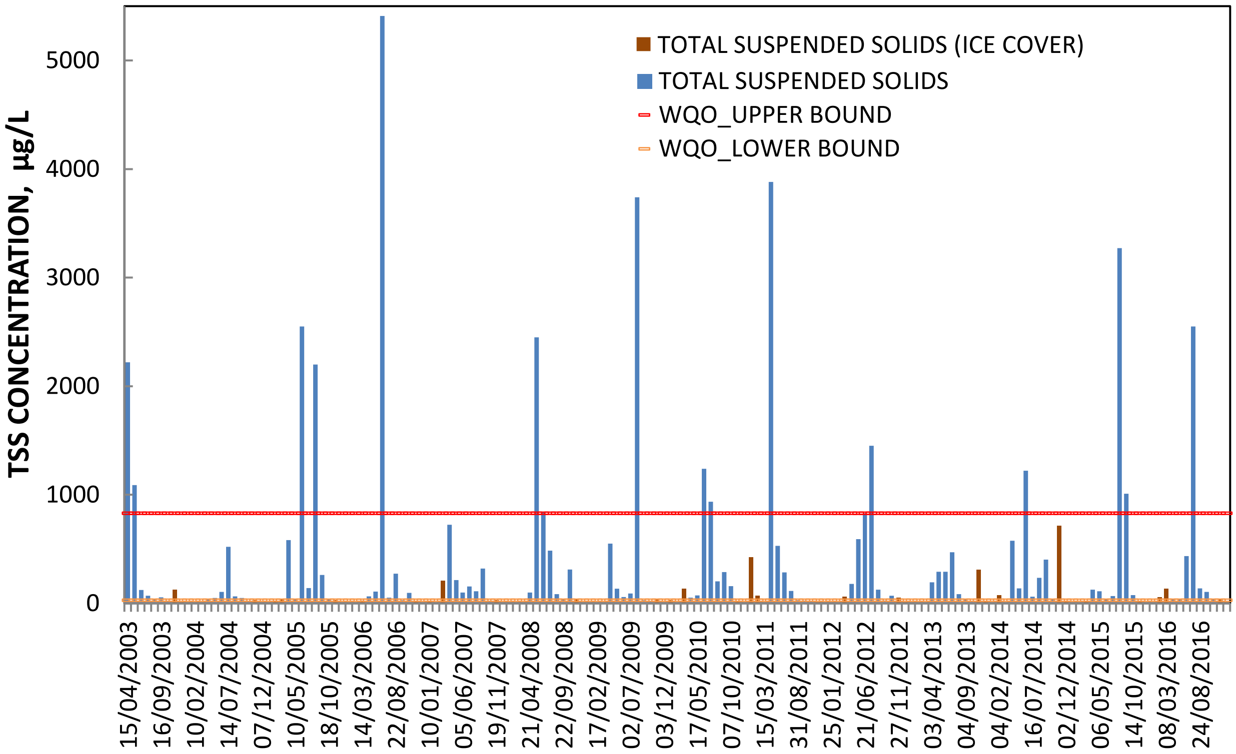


Figure B8. Comparison of TSS levels with transboundary water quality objectives

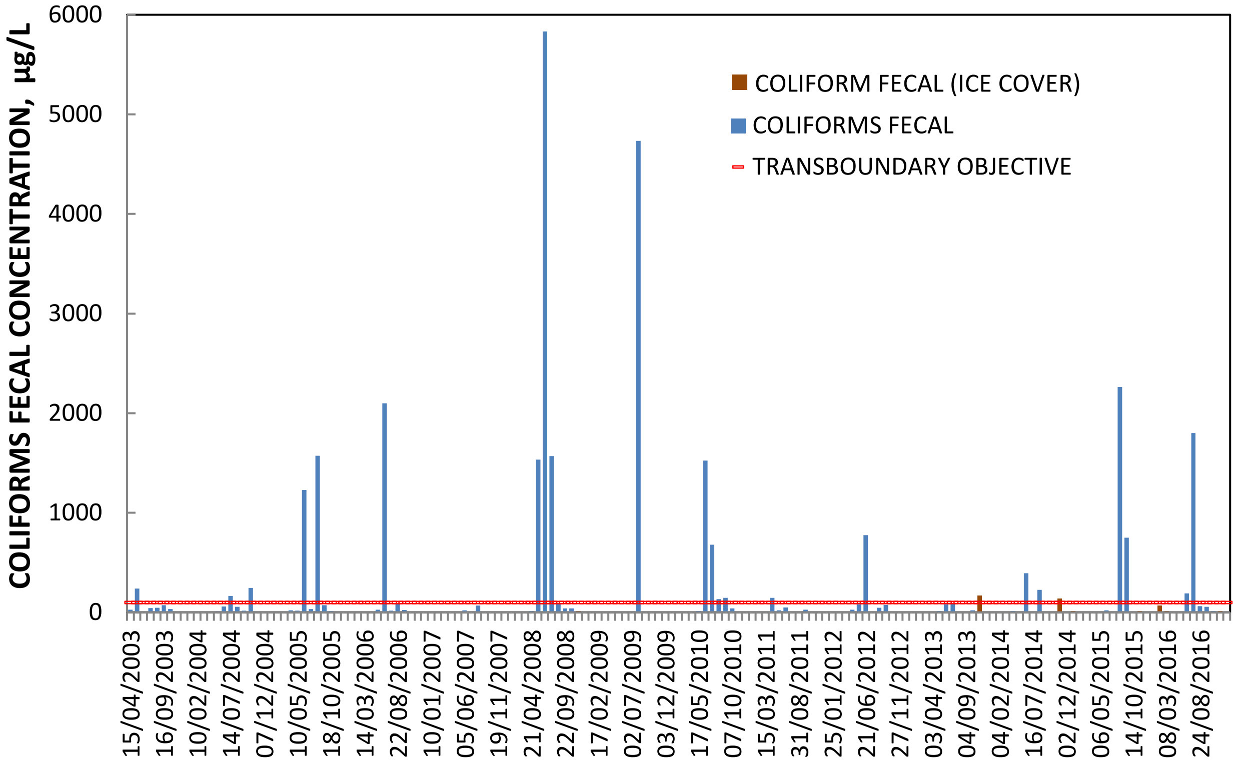


Figure B9. Comparison of fecal coliforms levels with transboundary water quality objectives

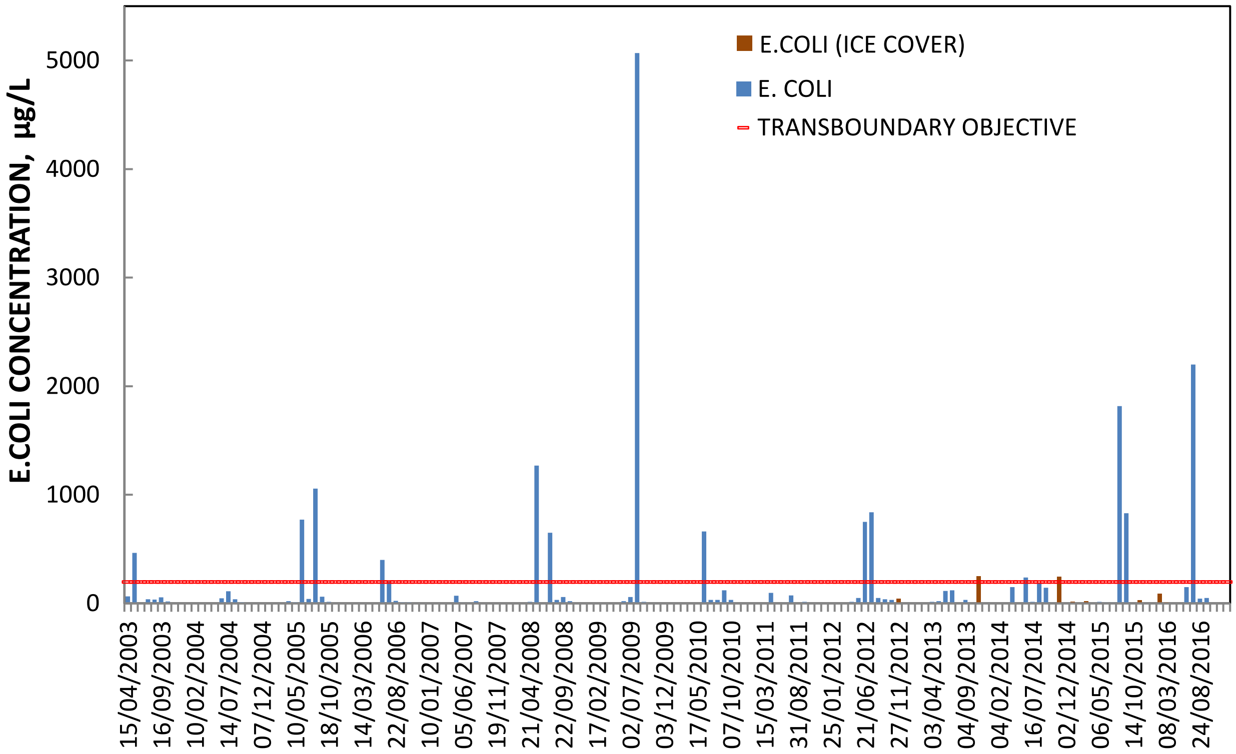


Figure B10. Comparison of E.Coli levels with transboundary water quality objectives

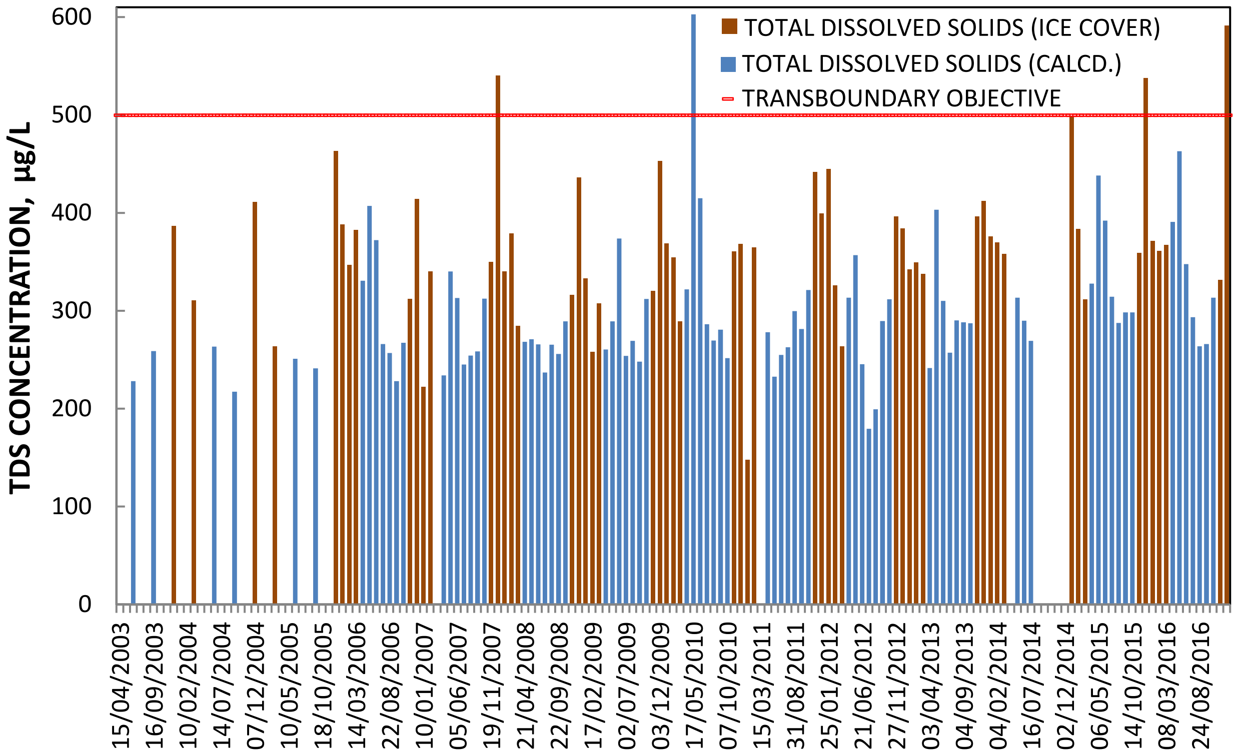


Figure B11. Comparison of TDS levels with transboundary water quality objectives

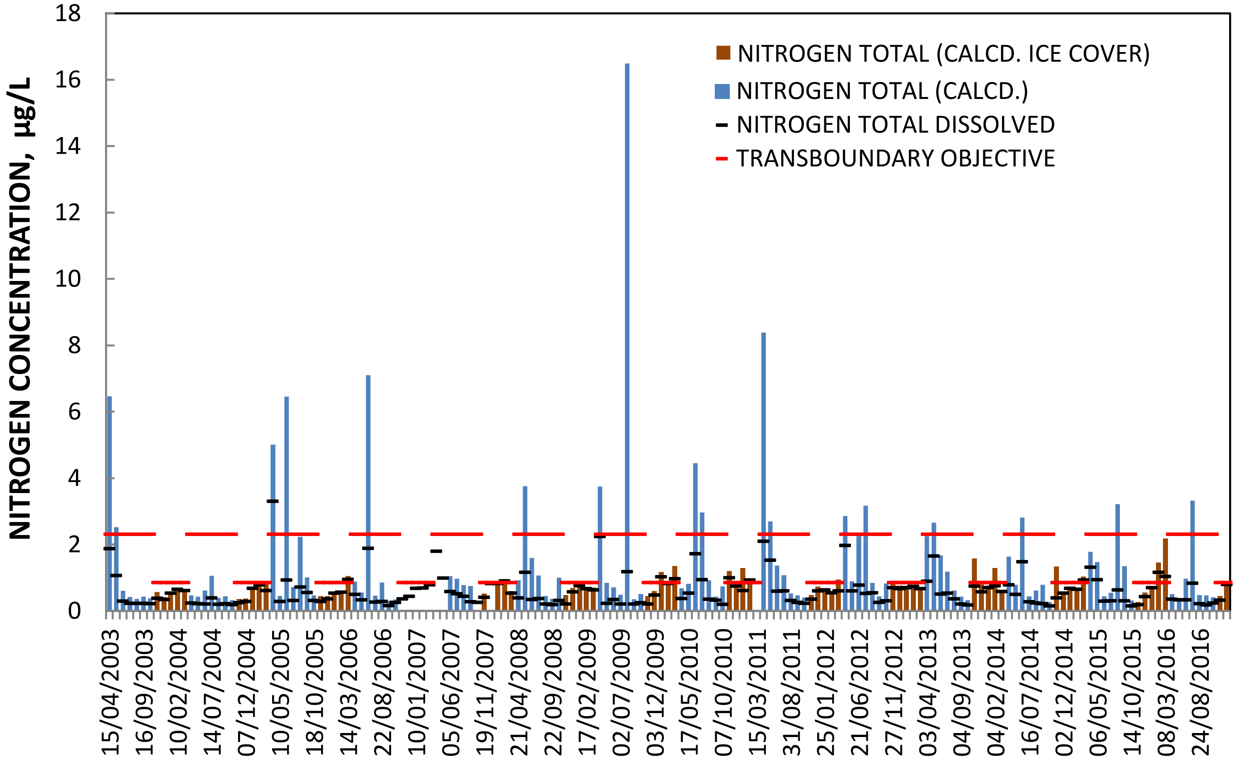


Figure B12. Comparison of total nitrogen levels with transboundary water quality objectives that consist of two levels in Open Water and Ice Cover seasons

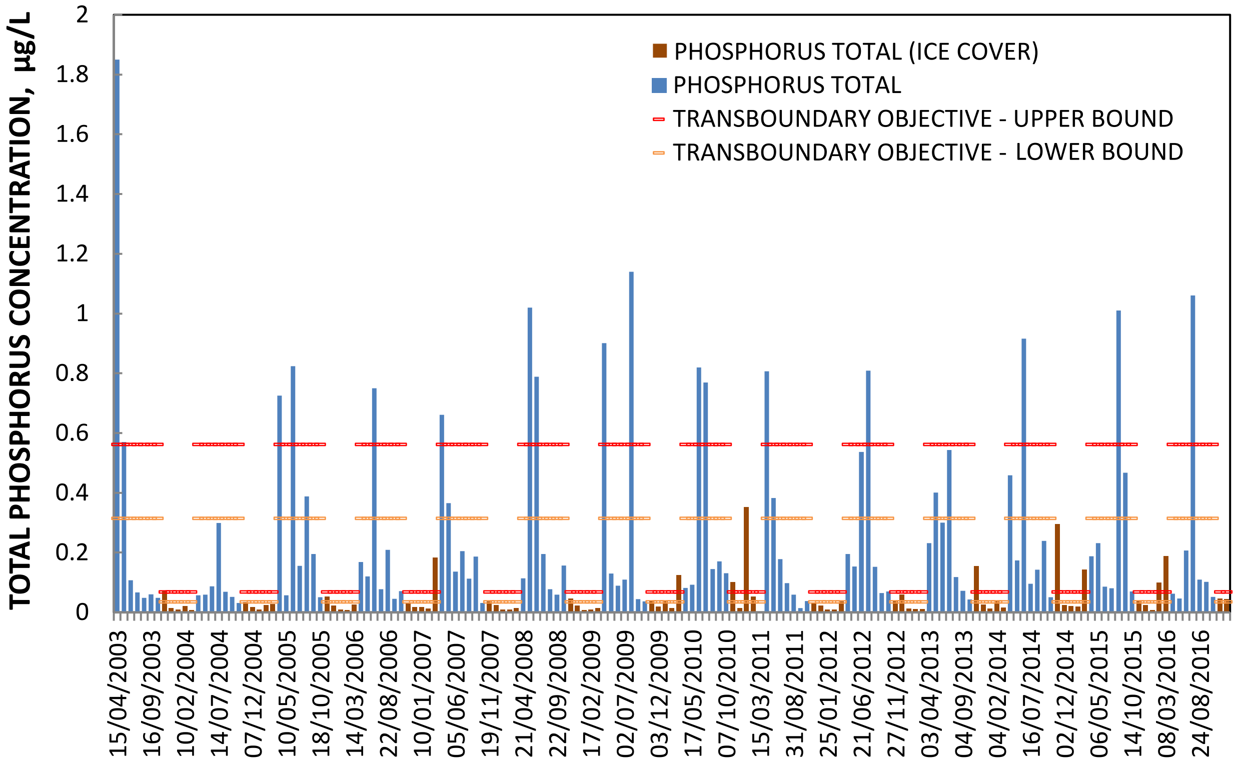


Figure B13. Comparison of total phosphorus levels with transboundary water quality objectives that consist of two levels in Open Water and Ice Cover seasons

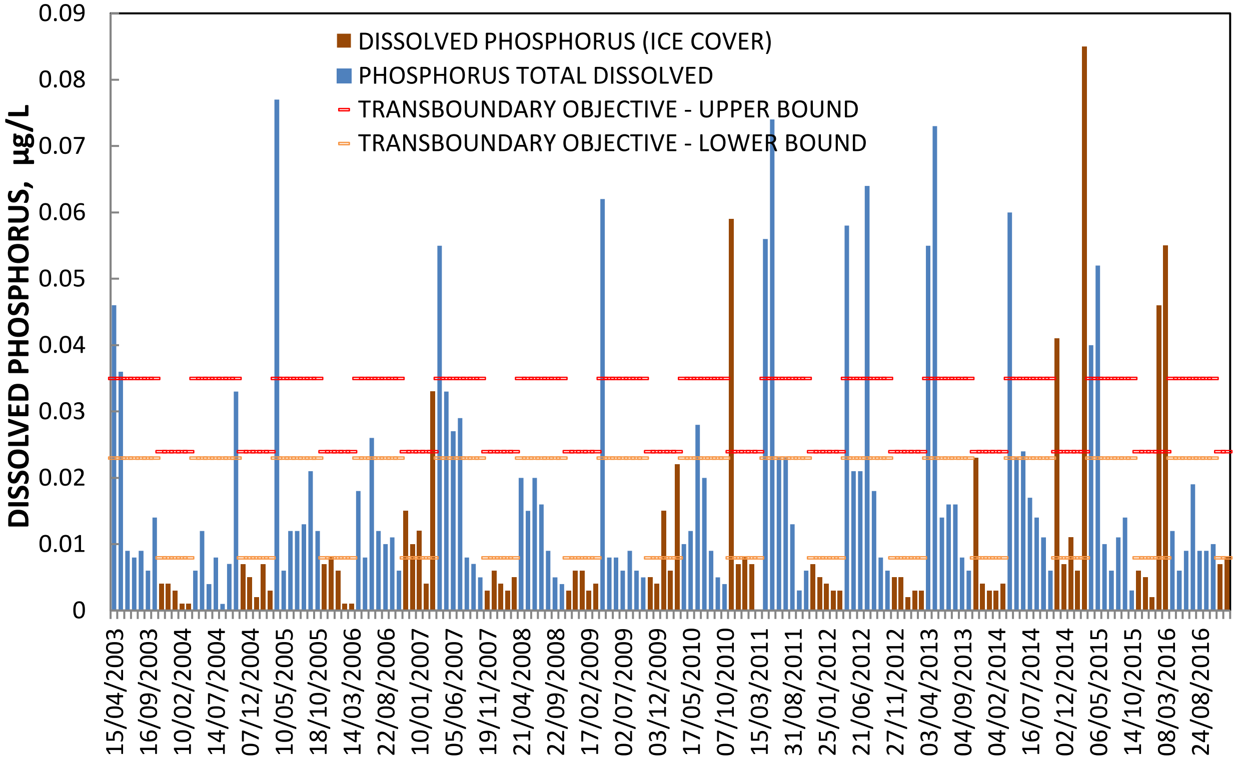


Figure B14. Comparison of total dissolved phosphorus levels with transboundary water quality objectives that consist of two levels in Open Water and Ice Cover seasons

APPENDIX C. Scatter plots between total suspended sediments and parameters with excursions in the Red Deer River at Bindloss

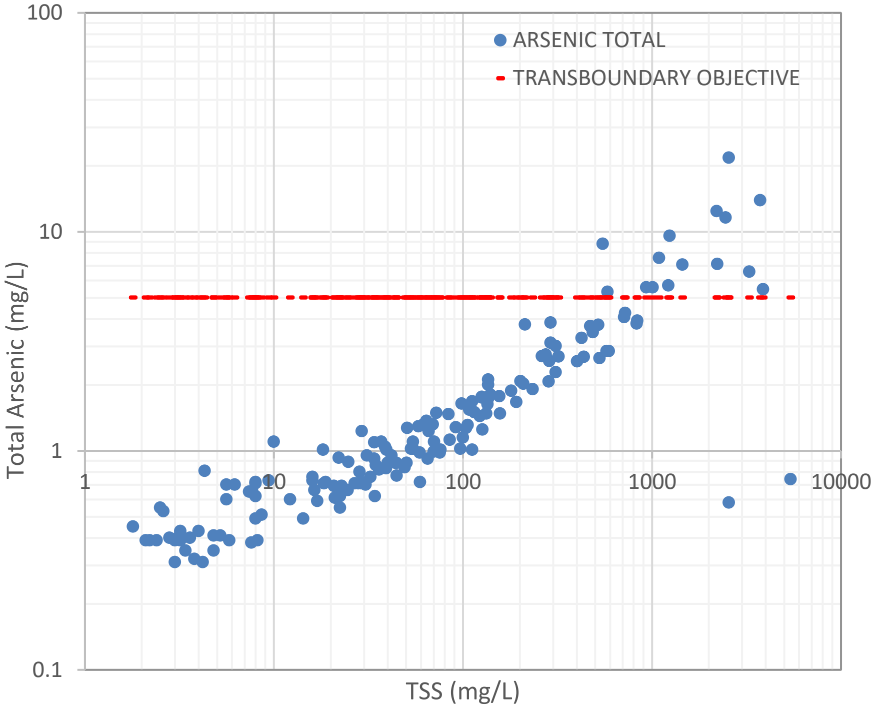


Figure C1. Scatter plot between TSS and total arsenic in the Red Deer River at Bindloss

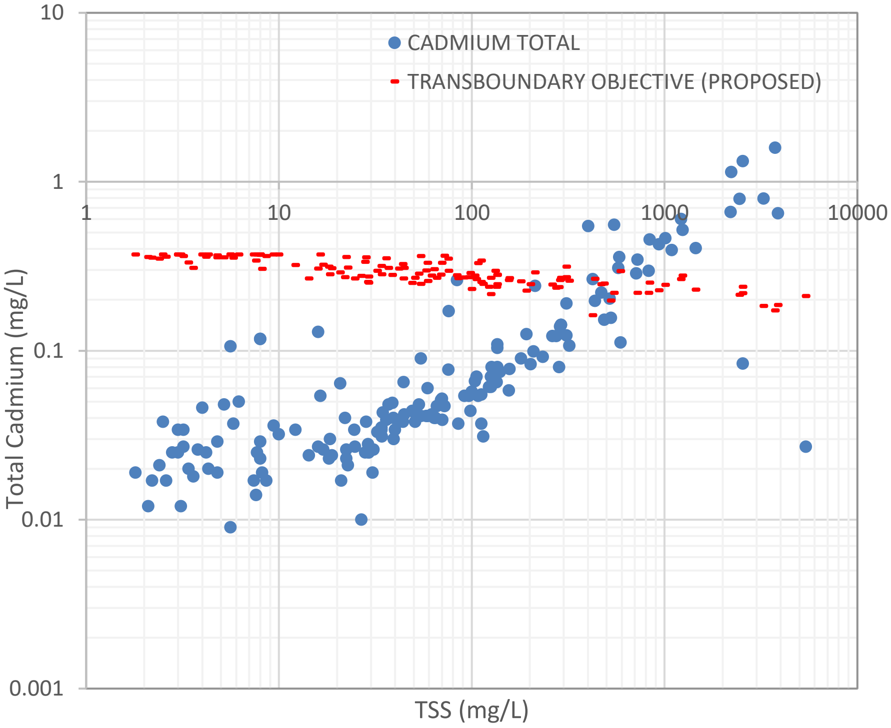


Figure C2 Scatter plot between TSS and total cadmium in the Red Deer River at Bindloss

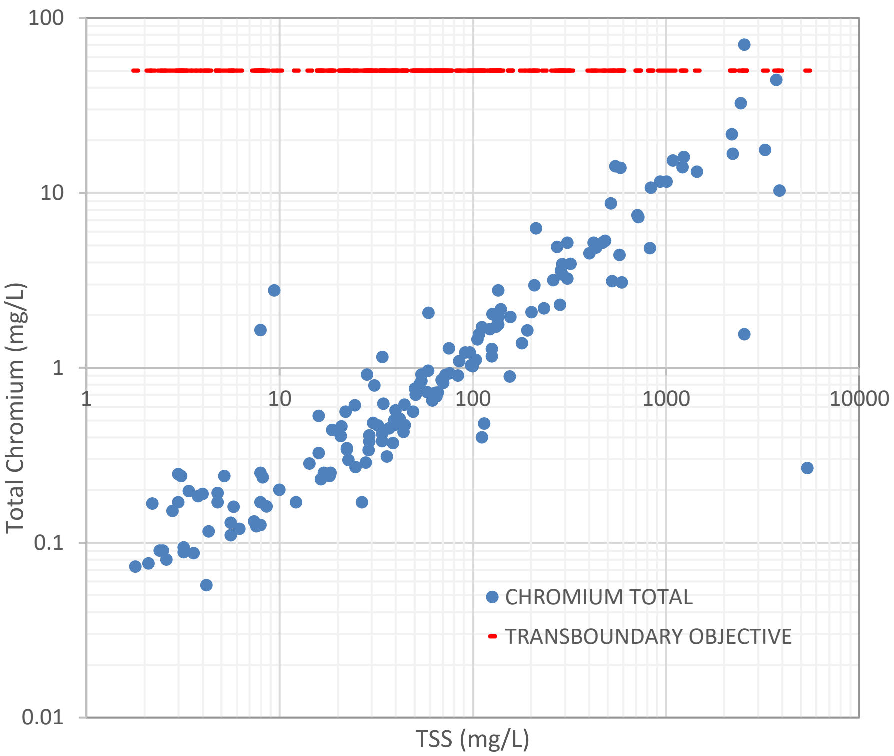


Figure C3. Scatter plot between TSS and total chromium in the Red Deer River at Bindloss

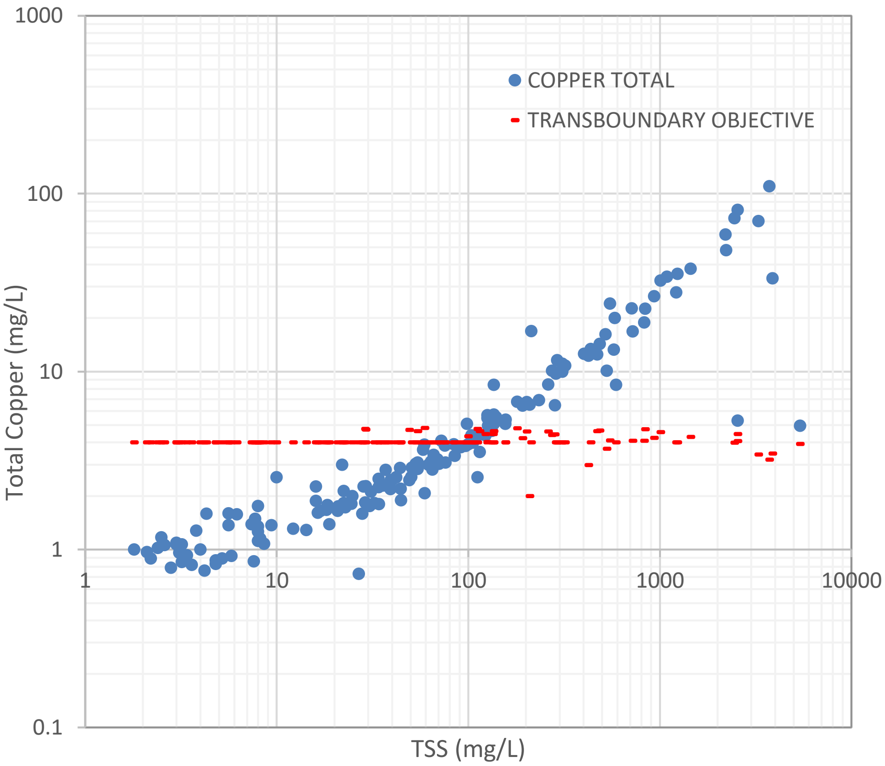


Figure C4. Scatter plots between TSS and total copper in the Red Deer River at Bindloss

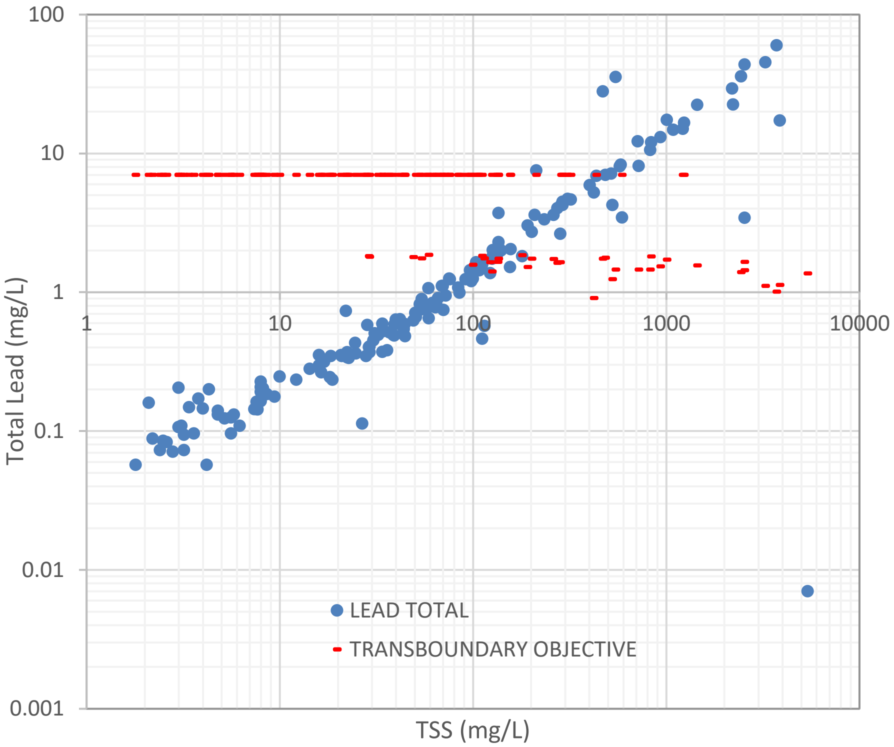


Figure C5. Scatter plot between TSS and total lead in the Red Deer River at Bindloss

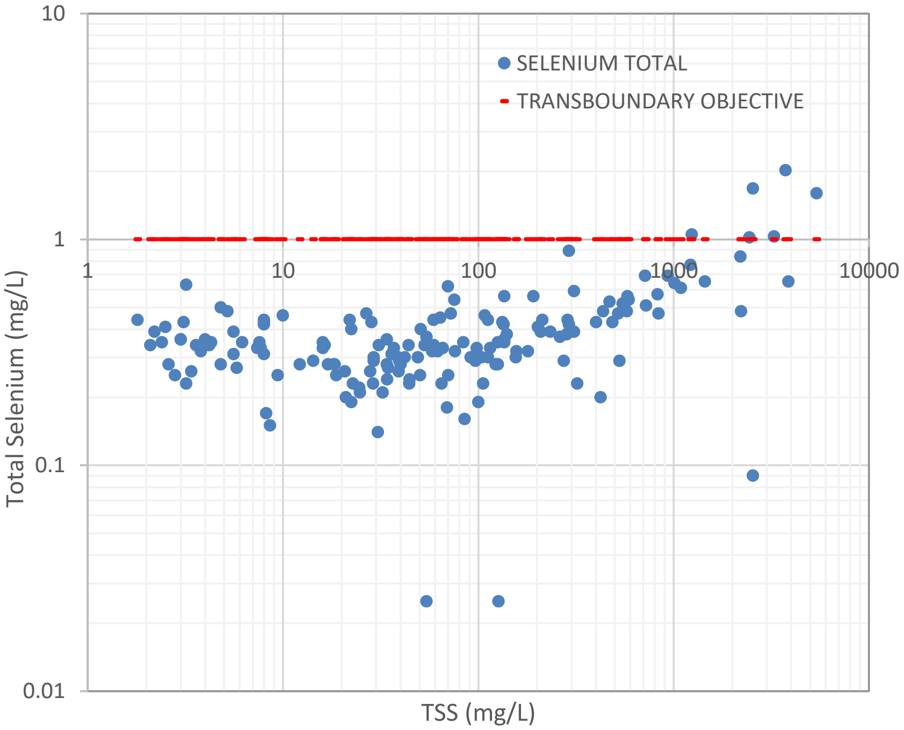


Figure C6. Scatter plot between TSS and total selenium in the Red Deer River at Bindloss

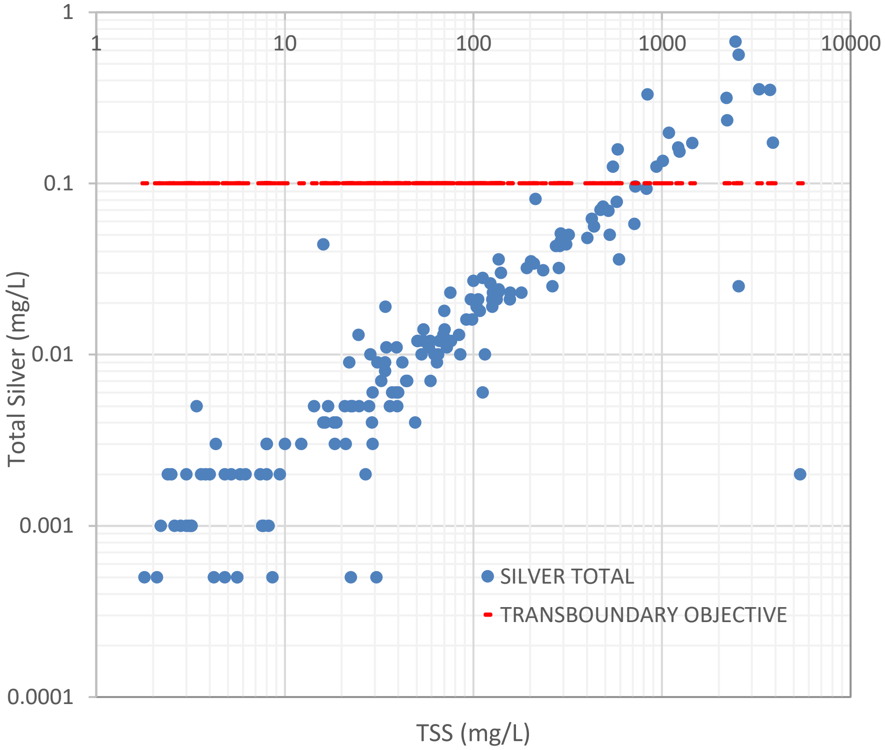


Figure C7. Scatter plot between TSS and total silver in the Red Deer River at Bindloss

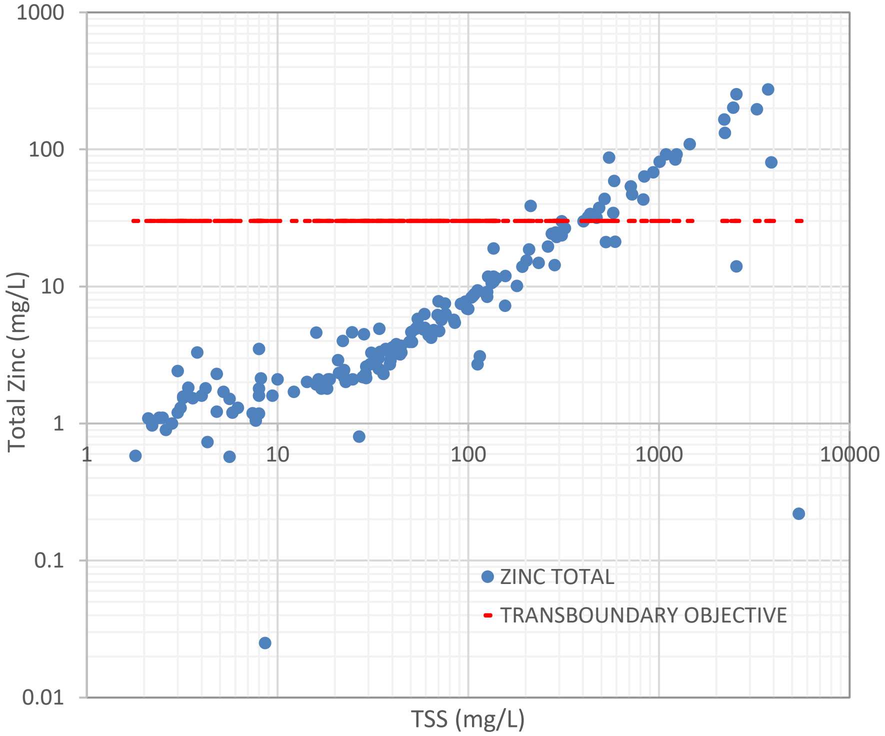


Figure C8. Scatter plot between TSS and total zinc in the Red Deer River at Bindloss

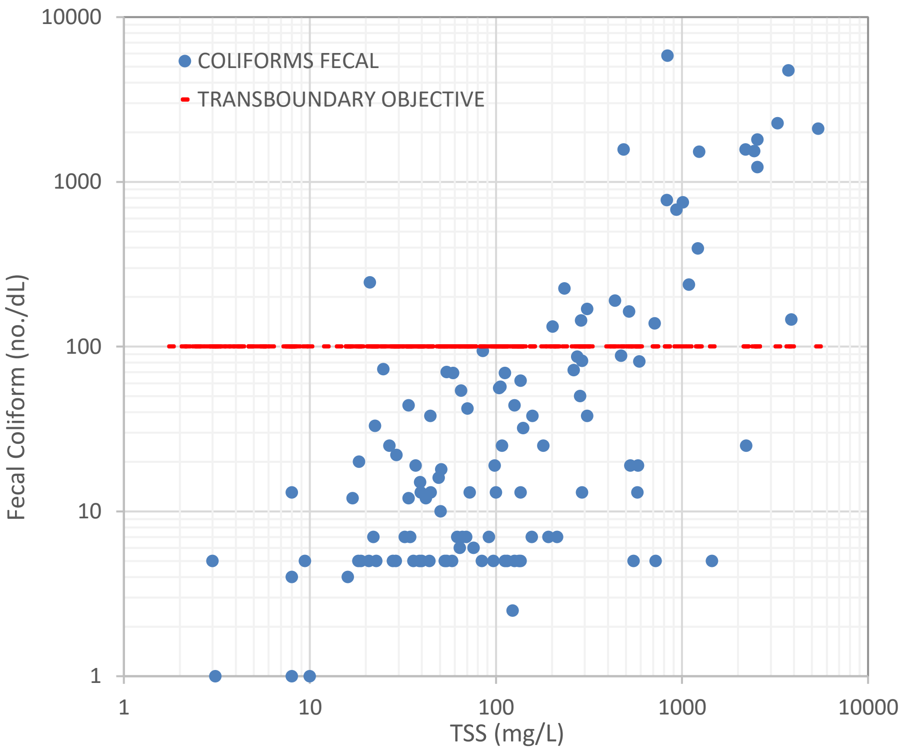


Figure C9. Scatter plot between TSS and fecal coliforms in the Red Deer River at Bindloss

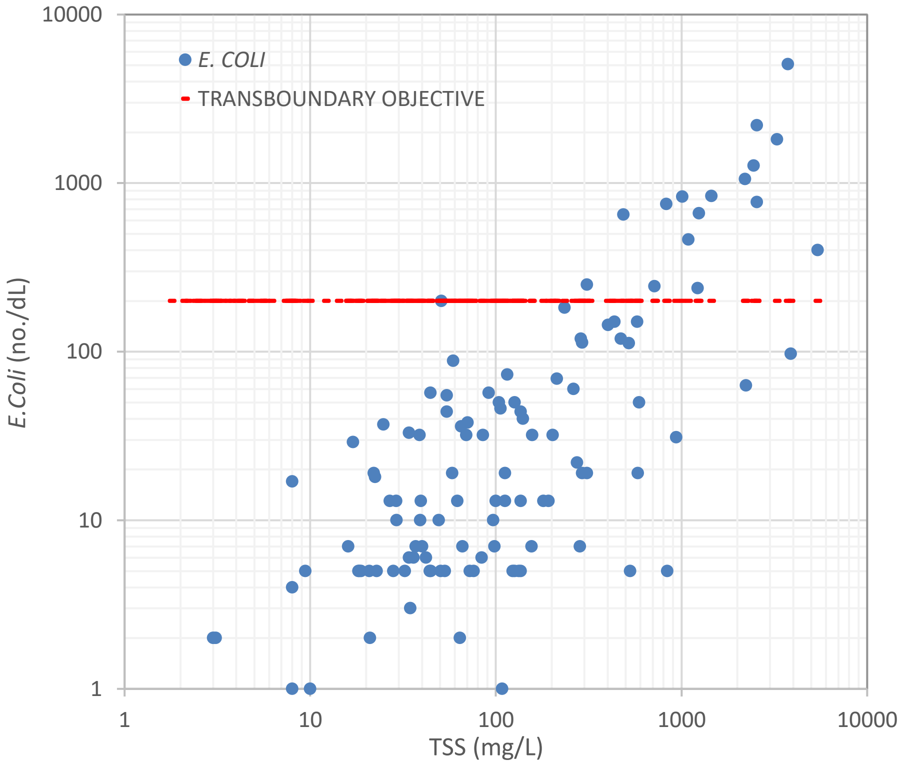


Figure C10. Scatter plot between TSS and *E.Coli* in the Red Deer River at Bindloss

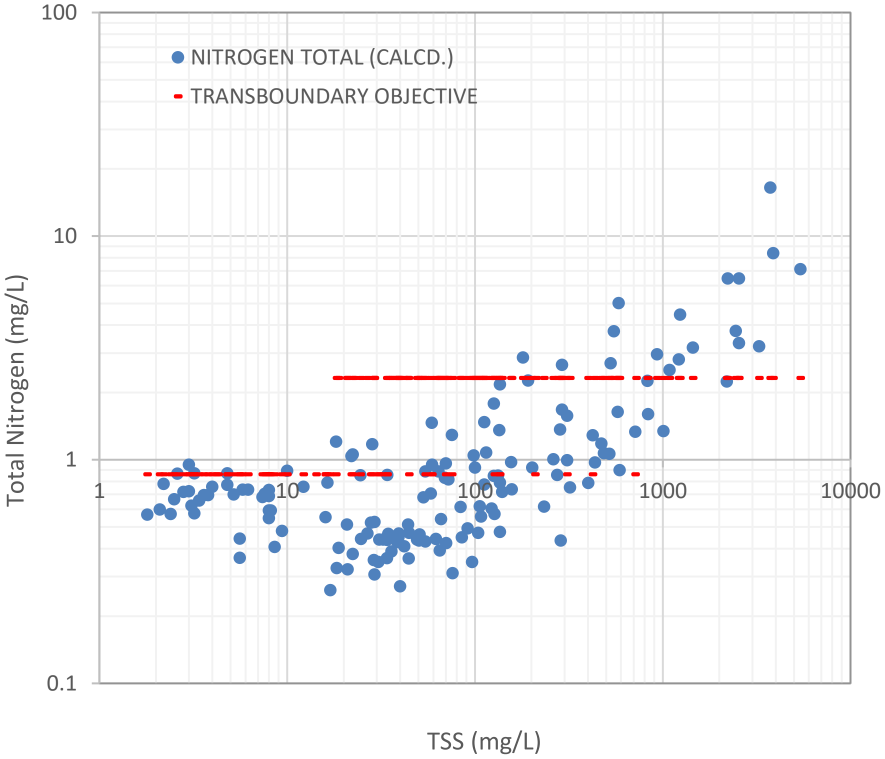


Figure C11. Scatter plot between TSS and total nitrogen in the Red Deer River at Bindloss

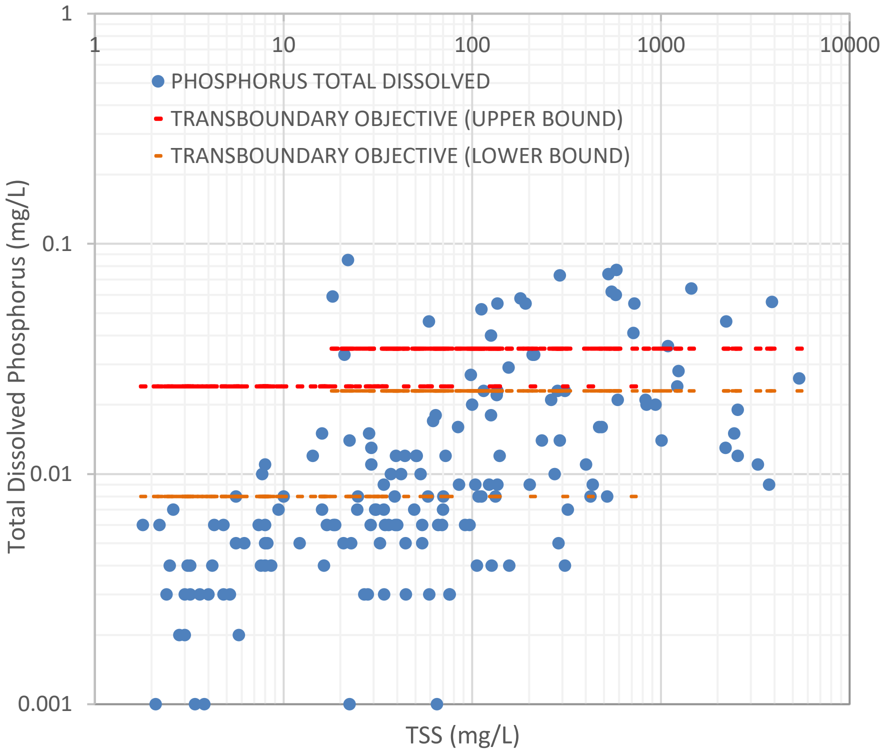


Figure C12. Scatter plot between TSS and total dissolved phosphorus in the Red Deer River at Bindloss

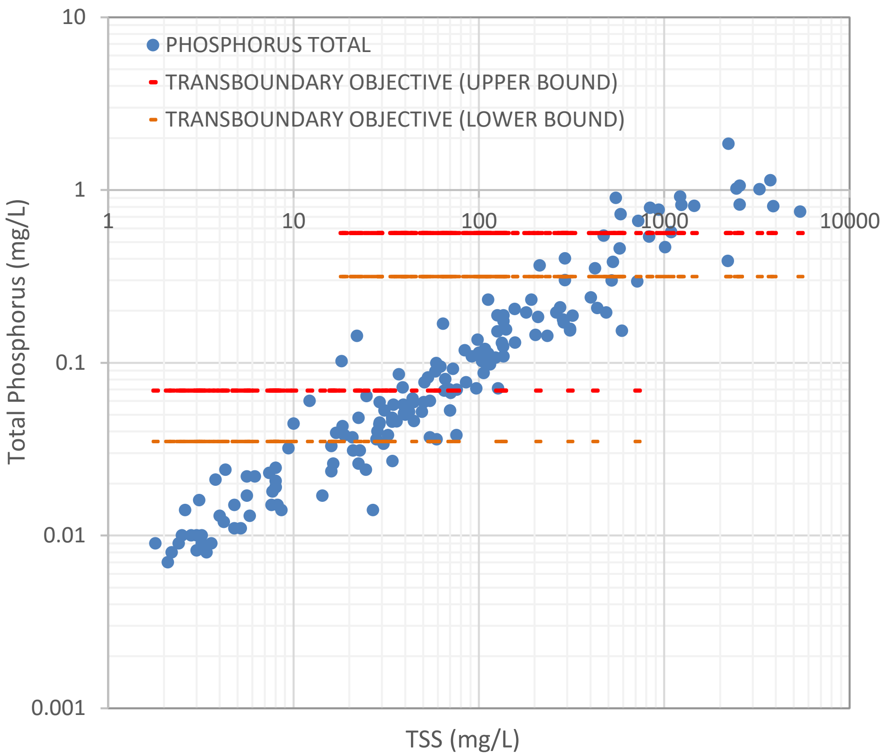


Figure C13. Scatter plot between TSS and total phosphorus in the Red Deer River at Bindloss

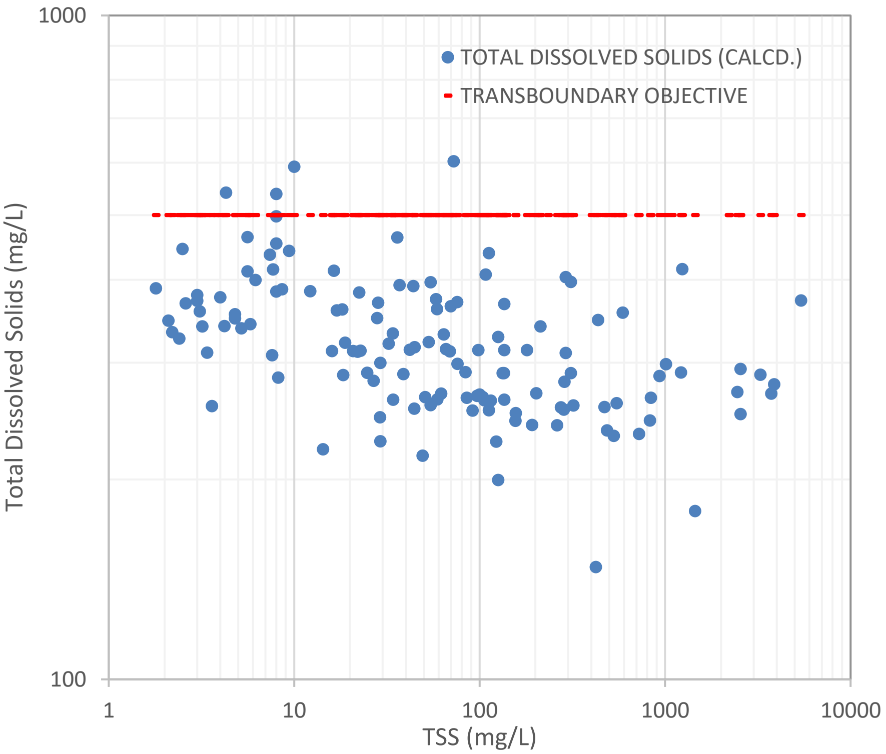
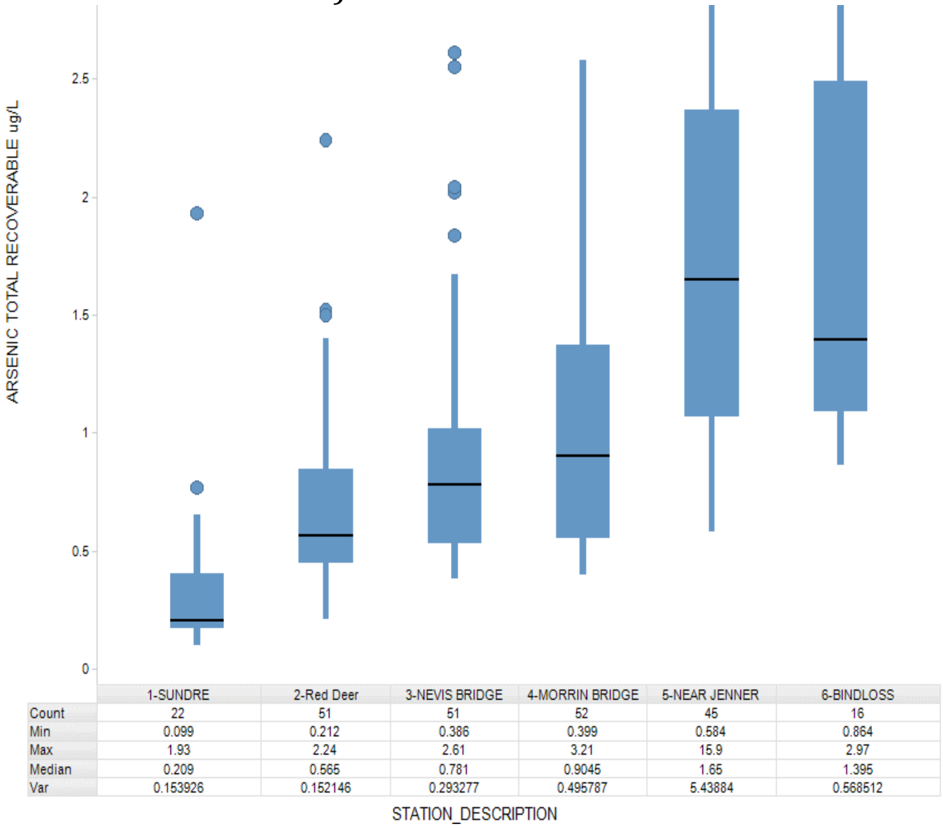


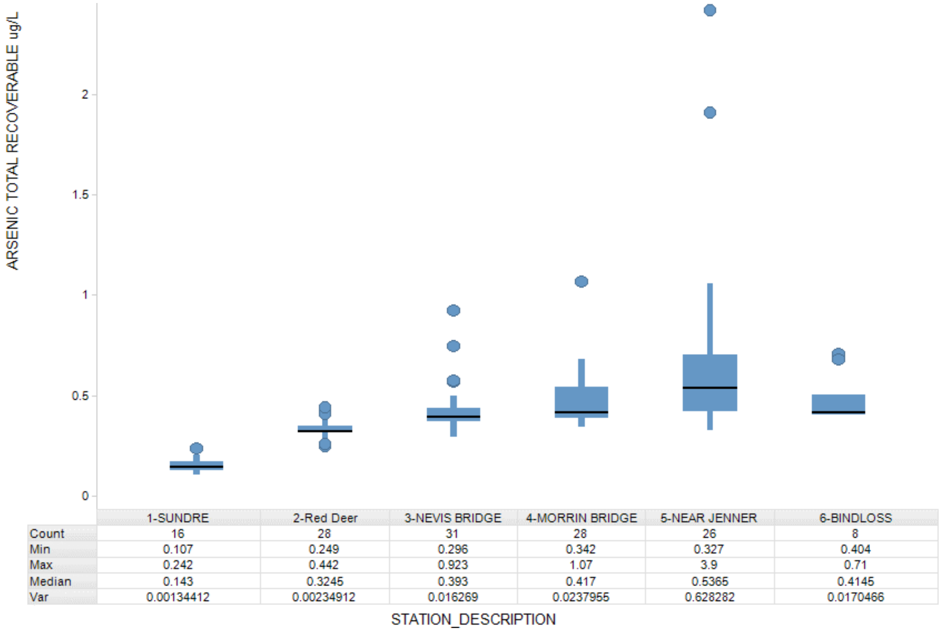
Figure C14. Scatter plot between TSS and TDS in the Red Deer River at Bindloss

APPENDIX D. Spatial distribution of substances in the mainstem of the Red Deer River (April 2003-March 2016)



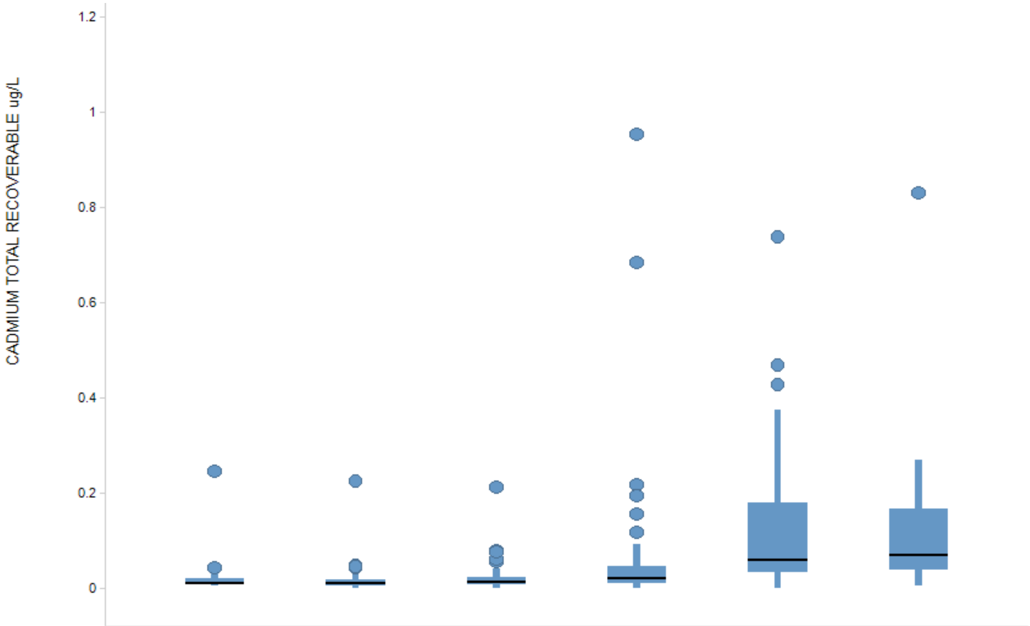
	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	51	51	52	45	16
Min	0.099	0.212	0.386	0.399	0.584	0.864
Max	1.93	2.24	2.61	3.21	15.9	2.97
Median	0.209	0.565	0.781	0.9045	1.65	1.395
Var	0.153926	0.152146	0.293277	0.495787	5.43884	0.568512

Figure D1. Spatial distribution of total recoverable arsenic in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.107	0.249	0.296	0.342	0.327	0.404
Max	0.242	0.442	0.923	1.07	3.9	0.71
Median	0.143	0.3245	0.393	0.417	0.5365	0.4145
Var	0.00134412	0.00234912	0.016269	0.0237955	0.628282	0.0170466

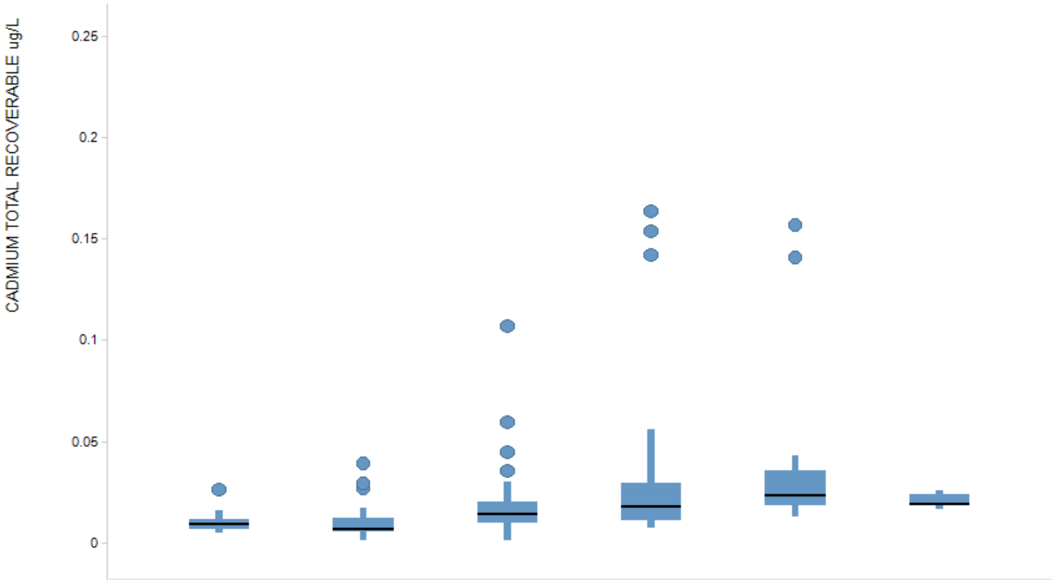
Figure D2. Spatial distribution of total recoverable arsenic in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	51	51	52	45	16
Min	0.0049	0.001	0.001	0.001	0.001	0.0062
Max	0.247	0.227	0.215	0.955	1.76	0.833
Median	0.01155	0.0109	0.0128	0.0216	0.06	0.0713
Var	0.00254707	0.00104779	0.0011216	0.0260127	0.13792	0.0397769

STATION_DESCRIPTION

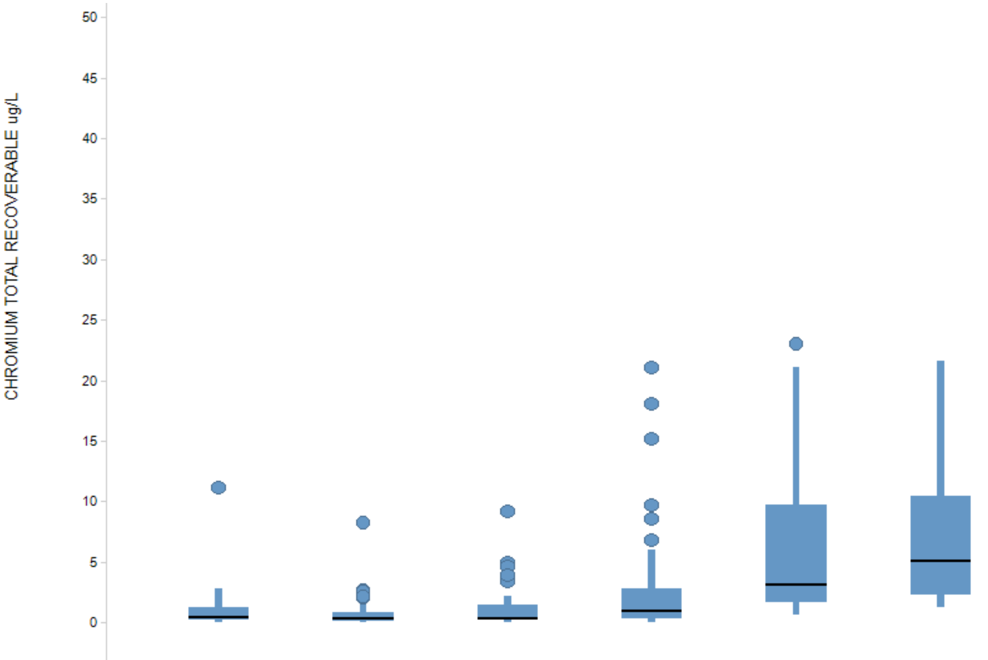
Figure D3. Spatial distribution of total recoverable cadmium in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.0046	0.001	0.001	0.0072	0.0127	0.0164
Max	0.026	0.039	0.107	0.164	0.424	0.0257
Median	0.00875	0.0064	0.0138	0.01775	0.02325	0.019
Var	2.97336e-05	7.58783e-05	0.000418057	0.00190869	0.00702822	1.3377e-05

STATION_DESCRIPTION

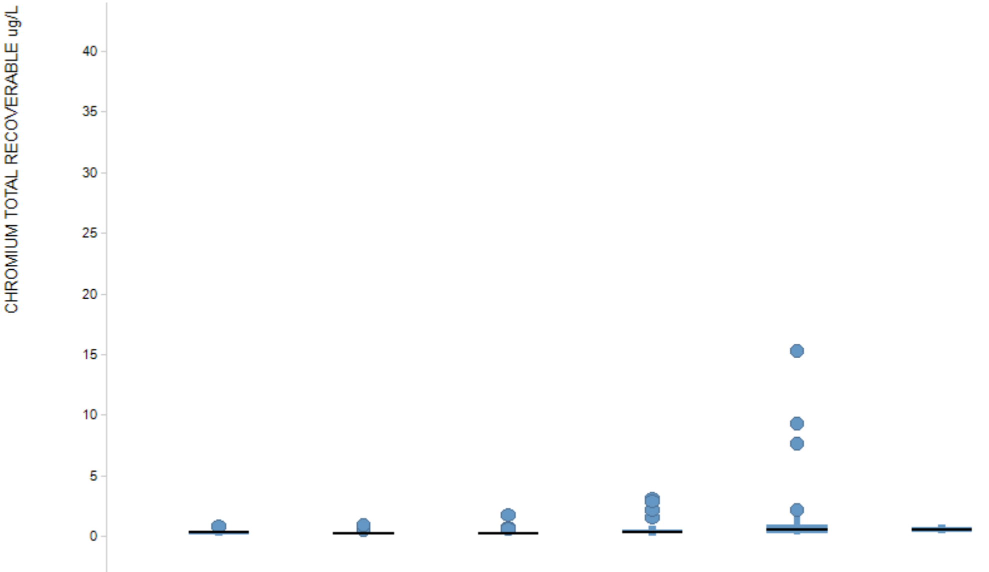
Figure D4. Spatial distribution of total recoverable cadmium in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	51	51	52	45	16
Min	0.0509	0.015	0.0526	0.0426	0.632	1.3
Max	11.2	8.24	9.21	21.1	70.9	21.6
Median	0.414	0.282	0.342	0.9615	3.12	5.065
Var	5.52928	1.64312	2.79931	20.3708	128.263	30.9018

STATION_DESCRIPTION

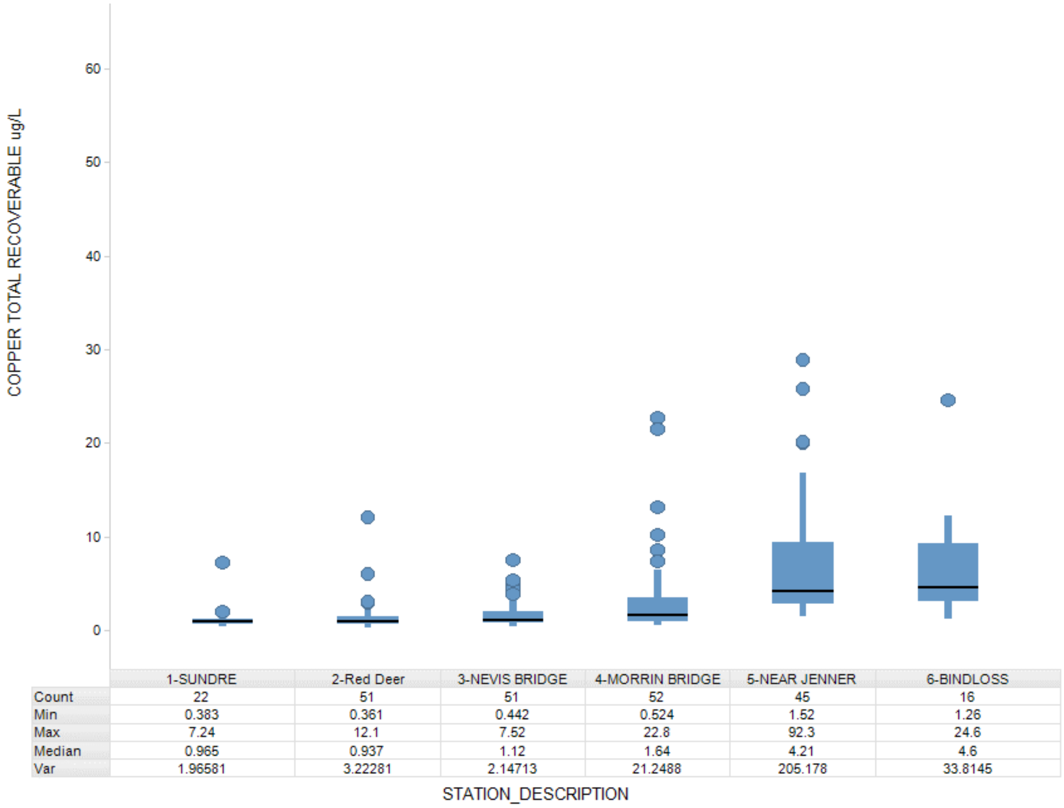
Figure D5. Spatial distribution of total recoverable chromium in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.015	0.015	0.06	0.0514	0.139	0.196
Max	0.831	0.909	1.77	3.12	15.3	0.901
Median	0.3445	0.172	0.25	0.3065	0.5275	0.4985
Var	0.0545984	0.0409555	0.0935817	0.652415	12.4951	0.0616477

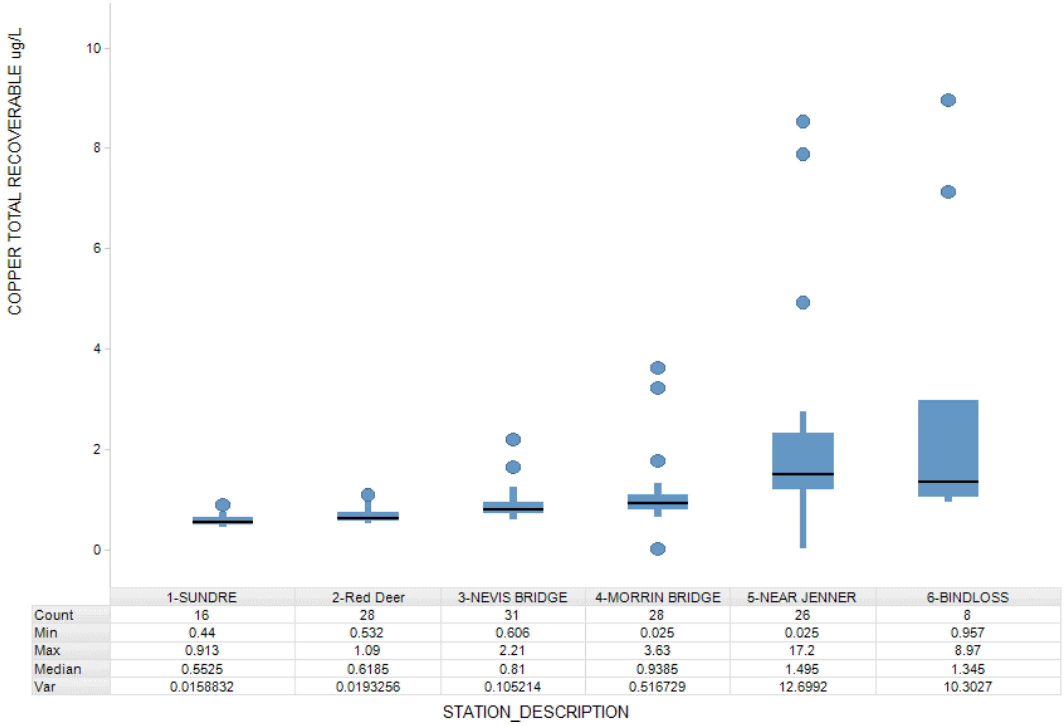
STATION_DESCRIPTION

Figure D6. Spatial distribution of total recoverable chromium in the mainstem of the Red Deer River in ice cover season (November-March)



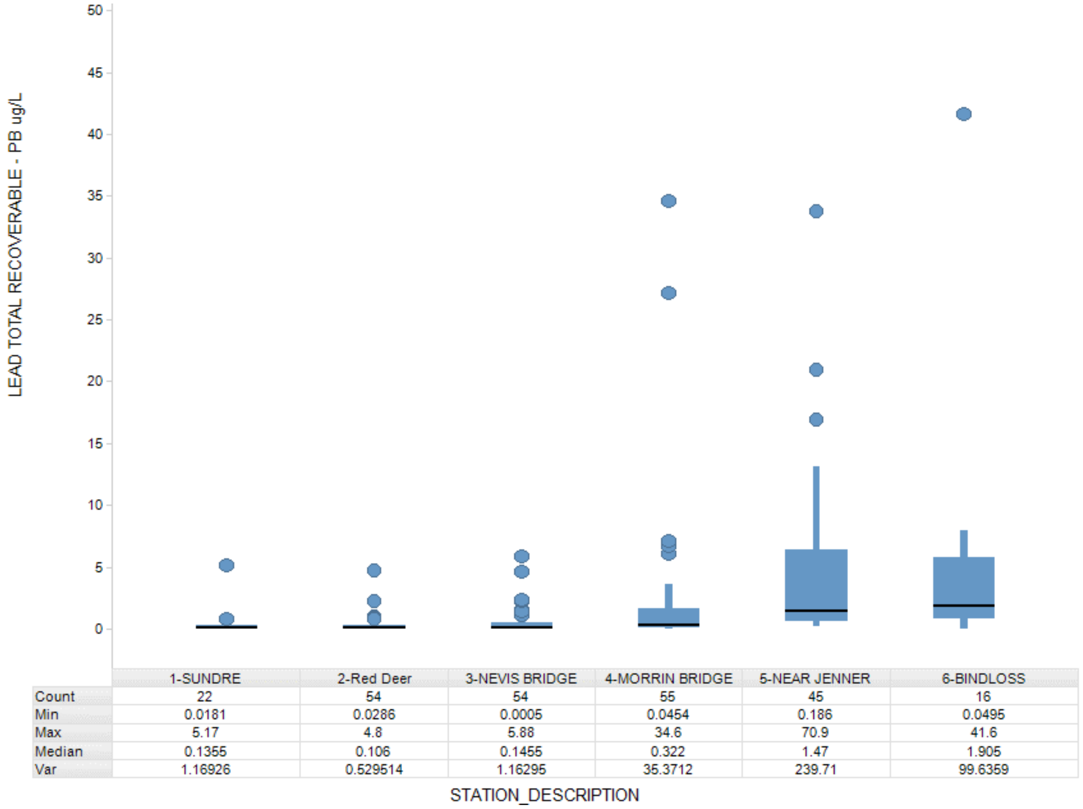
	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	51	51	52	45	16
Min	0.383	0.361	0.442	0.524	1.52	1.26
Max	7.24	12.1	7.52	22.8	92.3	24.6
Median	0.965	0.937	1.12	1.64	4.21	4.6
Var	1.96581	3.22281	2.14713	21.2488	205.178	33.8145

Figure D7. Spatial distribution of total recoverable copper in the mainstem of the Red Deer River in open water season (April-October)



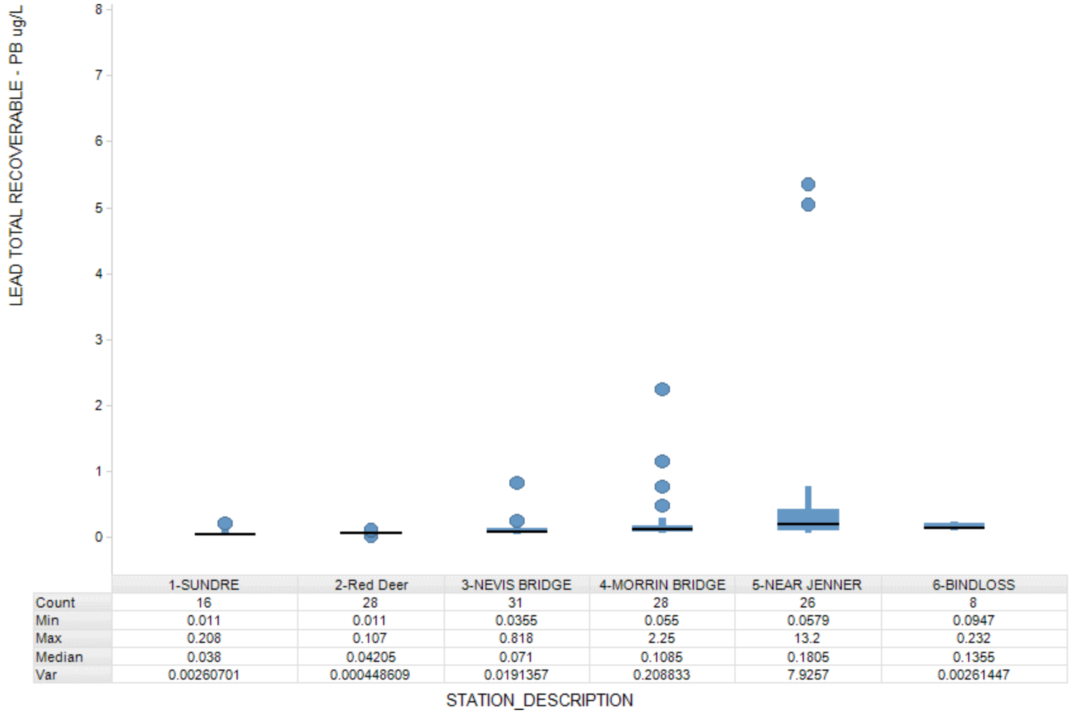
	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.44	0.532	0.606	0.025	0.025	0.957
Max	0.913	1.09	2.21	3.63	17.2	8.97
Median	0.5525	0.6185	0.81	0.9385	1.495	1.345
Var	0.0158832	0.0193256	0.105214	0.516729	12.6992	10.3027

Figure D8. Spatial distribution of total recoverable copper in the mainstem of the Red Deer River in ice cover season (November-March)



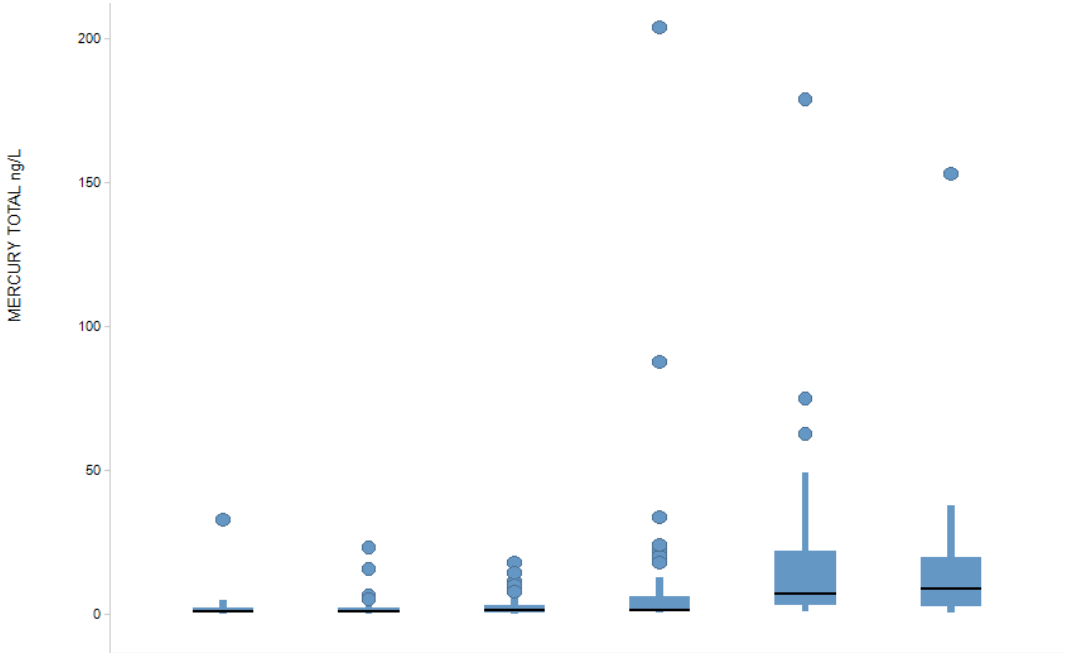
	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	16
Min	0.0181	0.0286	0.0005	0.0454	0.186	0.0495
Max	5.17	4.8	5.88	34.6	70.9	41.6
Median	0.1355	0.106	0.1455	0.322	1.47	1.905
Var	1.16926	0.529514	1.16295	35.3712	239.71	99.6359

Figure D9. Spatial distribution of total recoverable lead in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.011	0.011	0.0355	0.055	0.0579	0.0947
Max	0.208	0.107	0.818	2.25	13.2	0.232
Median	0.038	0.04205	0.071	0.1085	0.1805	0.1355
Var	0.00260701	0.000448609	0.0191357	0.208833	7.9257	0.00261447

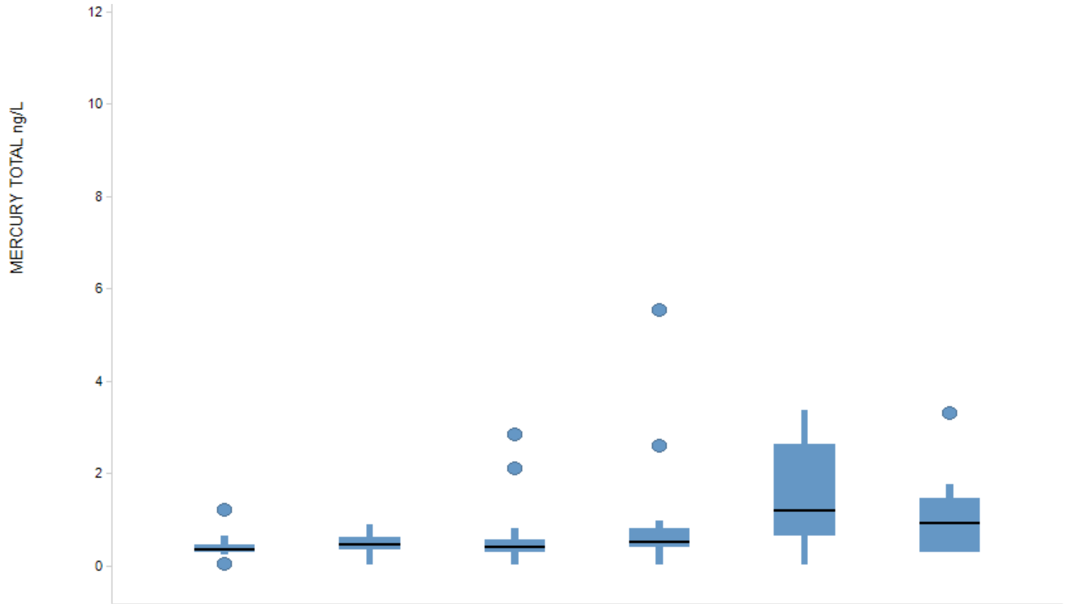
Figure D10. Spatial distribution of total recoverable lead in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	16
Min	0.04	0.0175	0.19	0.3	0.88	0.3
Max	32.8	23.1	18	204	301	153
Median	0.8945	0.91	1.165	1.51	7.15	8.79
Var	46.4404	14.8828	14.9088	883.688	3724.25	1370.58

STATION_DESCRIPTION

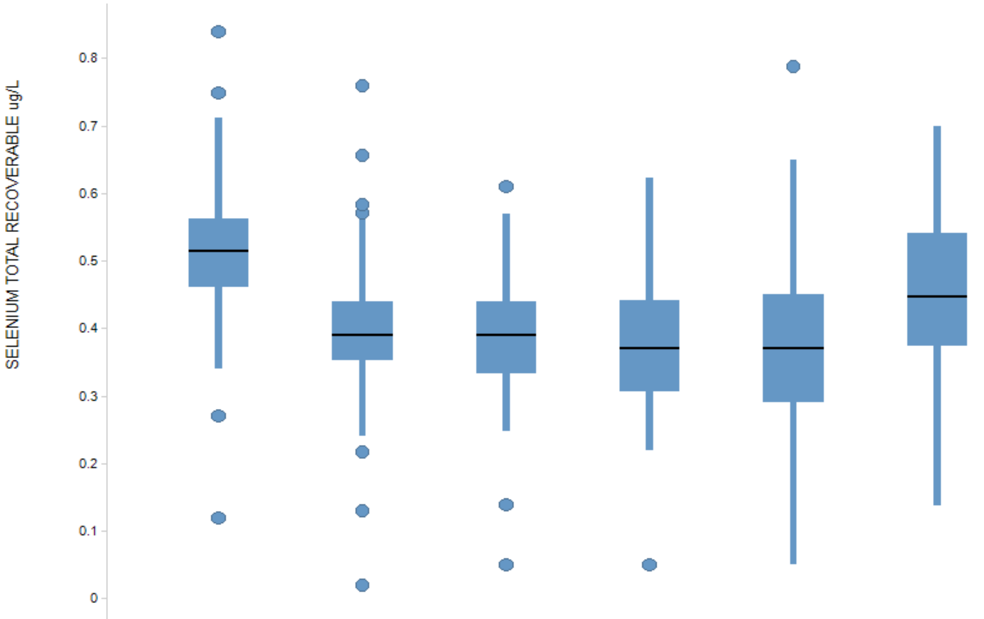
Figure D11. Spatial distribution of total mercury in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	28	28	26	8
Min	0.04	0.0175	0.0175	0.0175	0.0175	0.3
Max	1.22	0.89	2.86	5.55	43.1	3.31
Median	0.3545	0.46	0.405	0.5015	1.195	0.91
Var	0.0675623	0.039123	0.33923	1.0752	86.7091	1.09837

STATION_DESCRIPTION

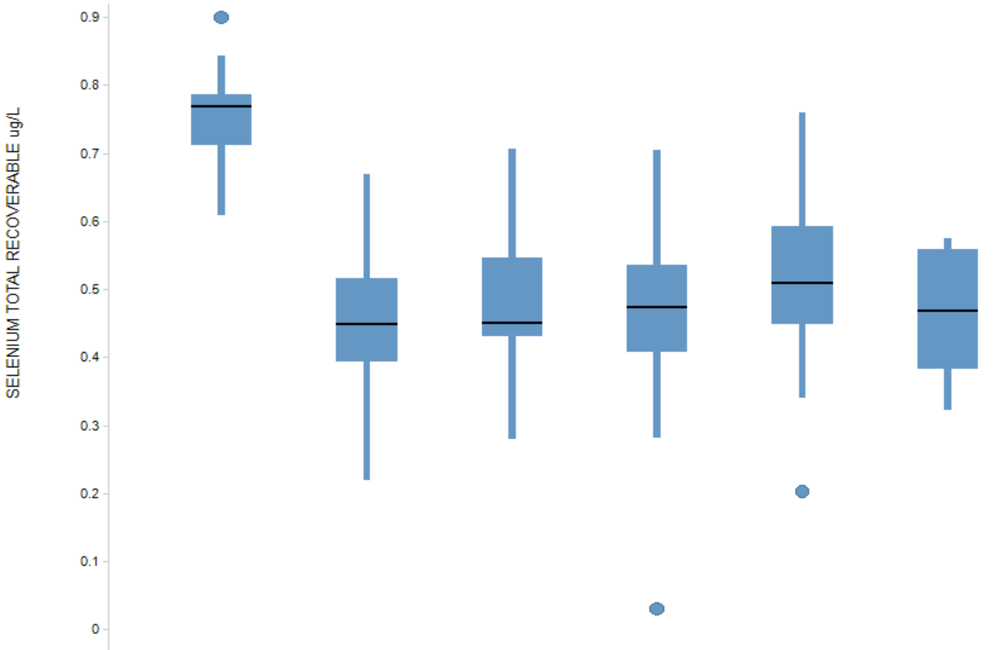
Figure D12. Spatial distribution of total mercury in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	51	51	52	45	16
Min	0.12	0.02	0.05	0.05	0.05	0.137
Max	0.839	0.76	0.61	0.622	0.789	0.947
Median	0.515	0.39	0.39	0.3695	0.37	0.4465
Var	0.0237907	0.0147068	0.0101397	0.0131923	0.0235002	0.0333206

STATION_DESCRIPTION

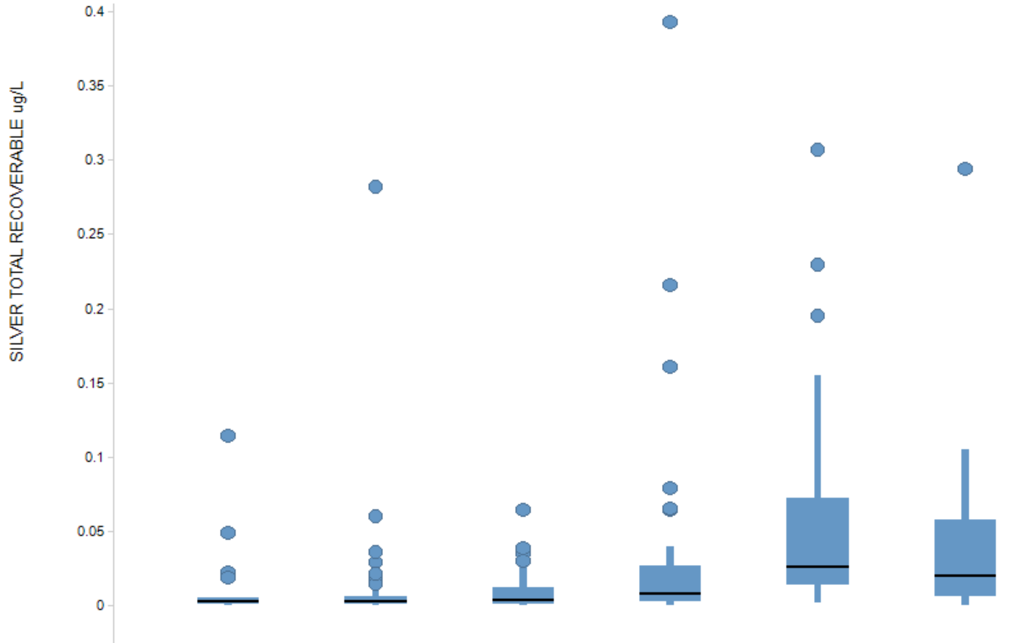
Figure D13. Spatial distribution of total recoverable selenium in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.608	0.22	0.279	0.03	0.203	0.322
Max	0.9	0.67	0.706	1.24	0.76	0.574
Median	0.768	0.448	0.45	0.4735	0.5095	0.4675
Var	0.00560983	0.013053	0.0100333	0.038501	0.0140076	0.0106307

STATION_DESCRIPTION

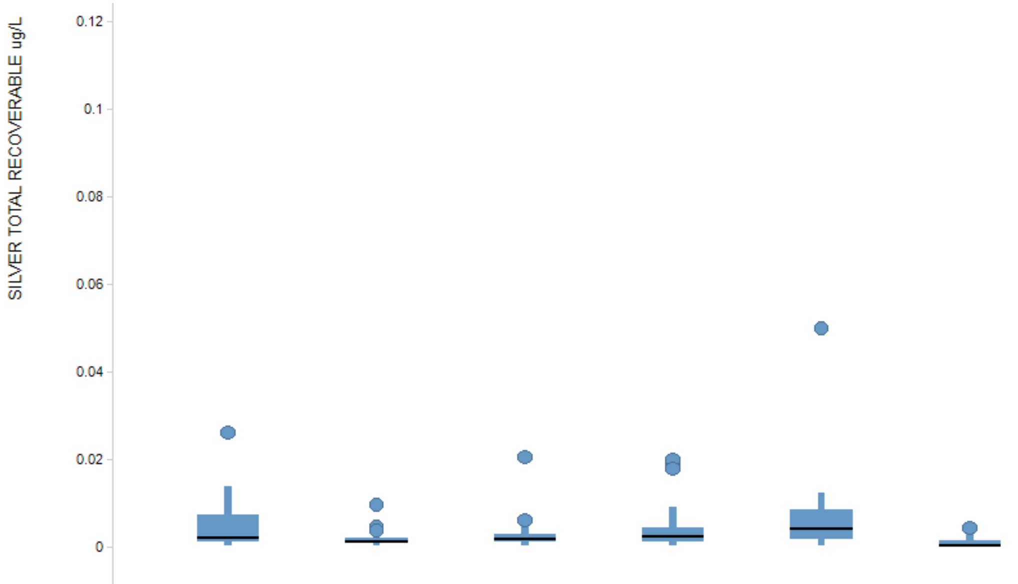
Figure D14. Spatial distribution of total recoverable selenium in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	51	51	52	45	16
Min	0.00025	0.00025	0.00025	0.00025	0.0016	0.00025
Max	0.115	0.282	0.558	0.393	0.59	0.294
Median	0.003	0.003	0.0034	0.0076	0.0263	0.02035
Var	0.000659127	0.00160132	0.00607672	0.00413994	0.0159031	0.00538956

STATION_DESCRIPTION

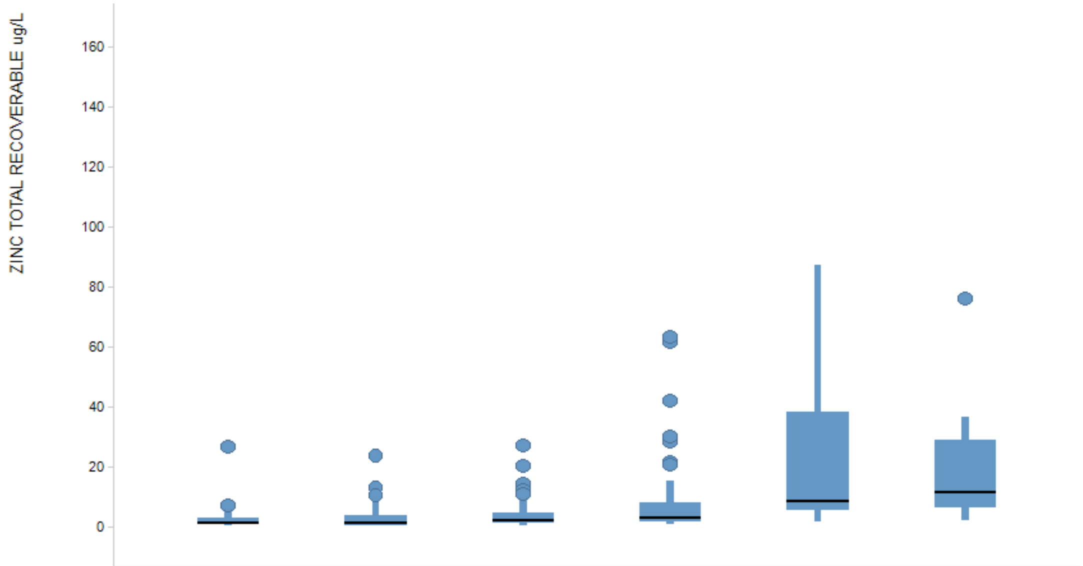
Figure D15. Spatial distribution of total recoverable silver in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025
Max	0.026	0.00968	0.0205	0.02	0.202	0.0043
Median	0.0019	0.001	0.0017	0.00235	0.00395	0.00025
Var	4.8716e-05	3.88612e-06	1.33654e-05	3.84332e-05	0.00247065	2.78388e-06

STATION_DESCRIPTION

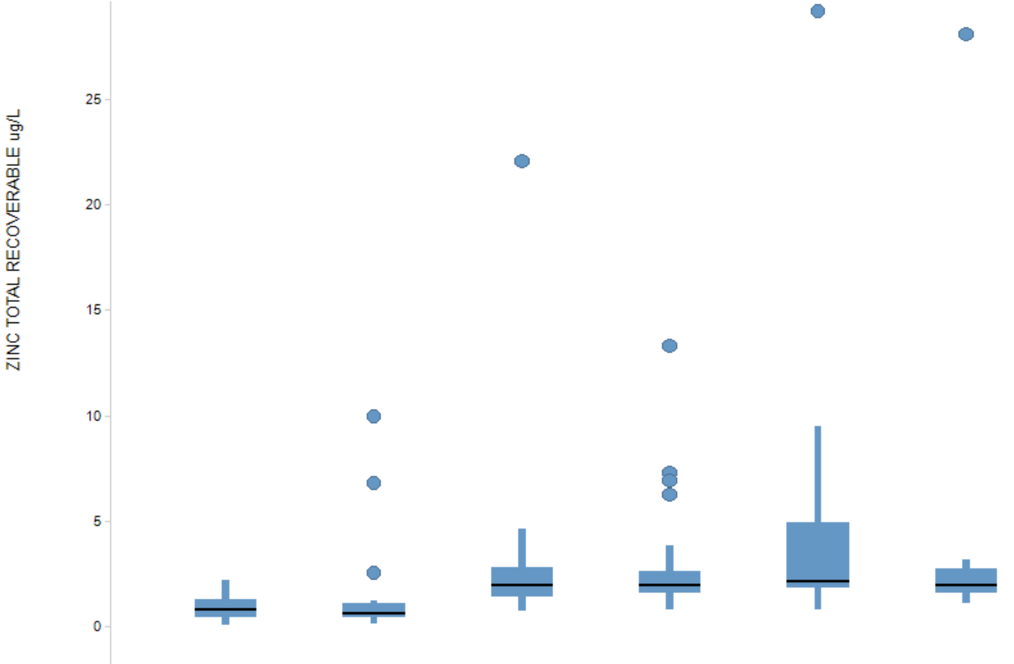
Figure D16. Spatial distribution of total recoverable silver in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	51	51	52	45	16
Min	0.6	0.338	0.663	0.786	1.9	2.39
Max	26.7	23.9	27.2	63.6	292	76.4
Median	1.325	1.4	2.04	2.825	8.77	11.65
Var	30.9434	17.8028	27.1251	192.079	2113.7	363.694

STATION_DESCRIPTION

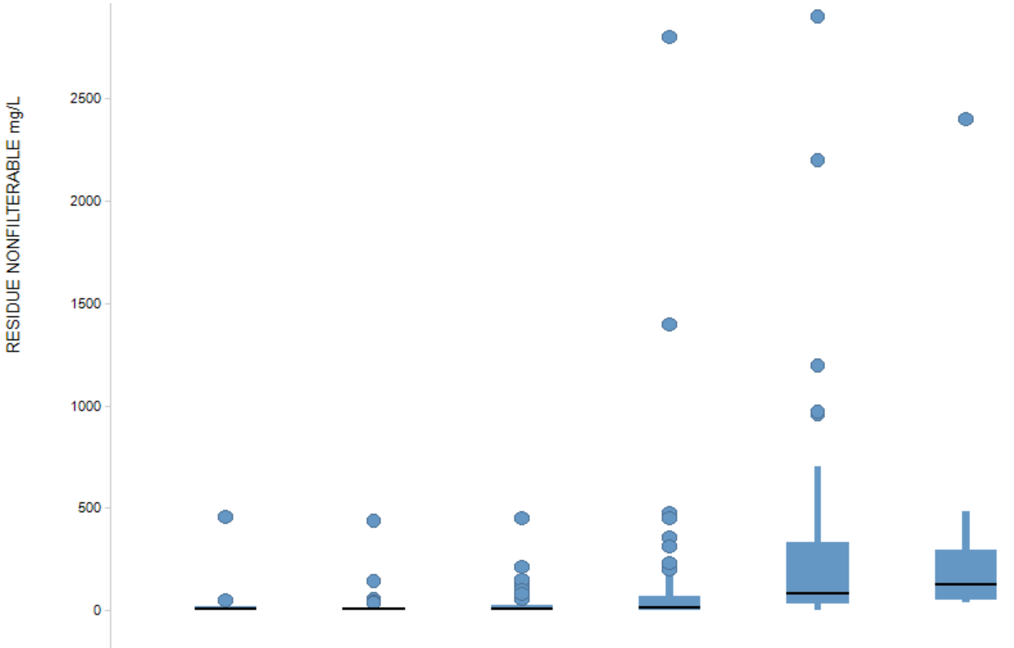
Figure D17. Spatial distribution of total recoverable zinc in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.05	0.1	0.7	0.8	0.798	1.09
Max	2.2	9.96	22.1	13.3	41.8	28.1
Median	0.803	0.6	1.96	1.935	2.105	1.95
Var	0.384236	4.47351	13.7988	7.05444	111.331	85.9437

STATION_DESCRIPTION

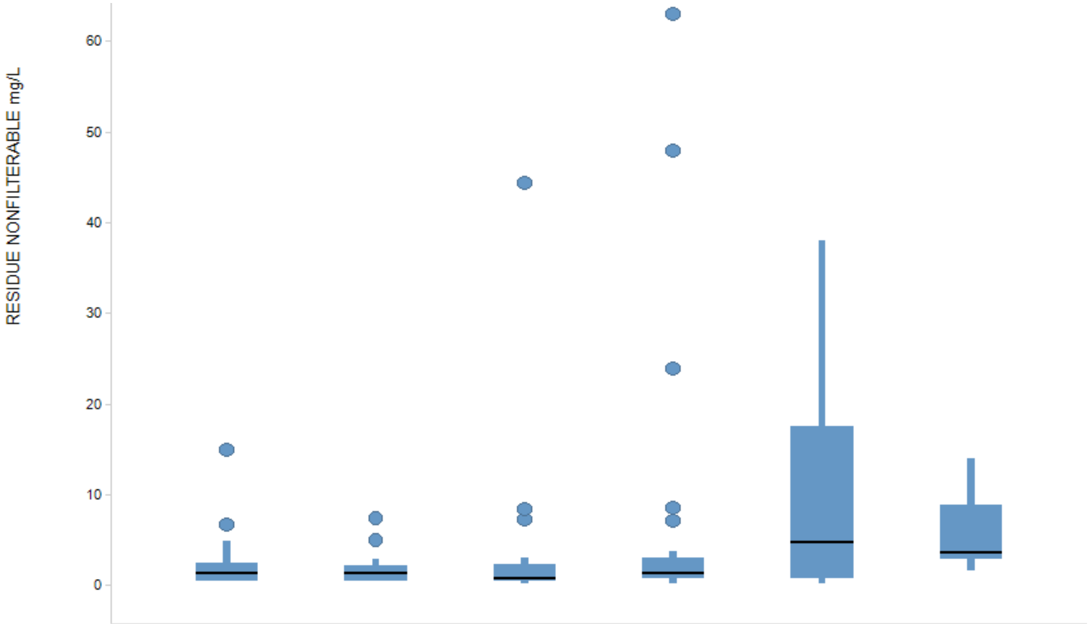
Figure D18. Spatial distribution of total recoverable zinc in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	16
Min	0.5	0.5	0.5	0.5	3	36.4
Max	460	438	452	2800	4300	2400
Median	6.2	4.6	7.25	15	84.8	123
Var	9345.41	3821.92	5059.98	178065	880210	331461

STATION_DESCRIPTION

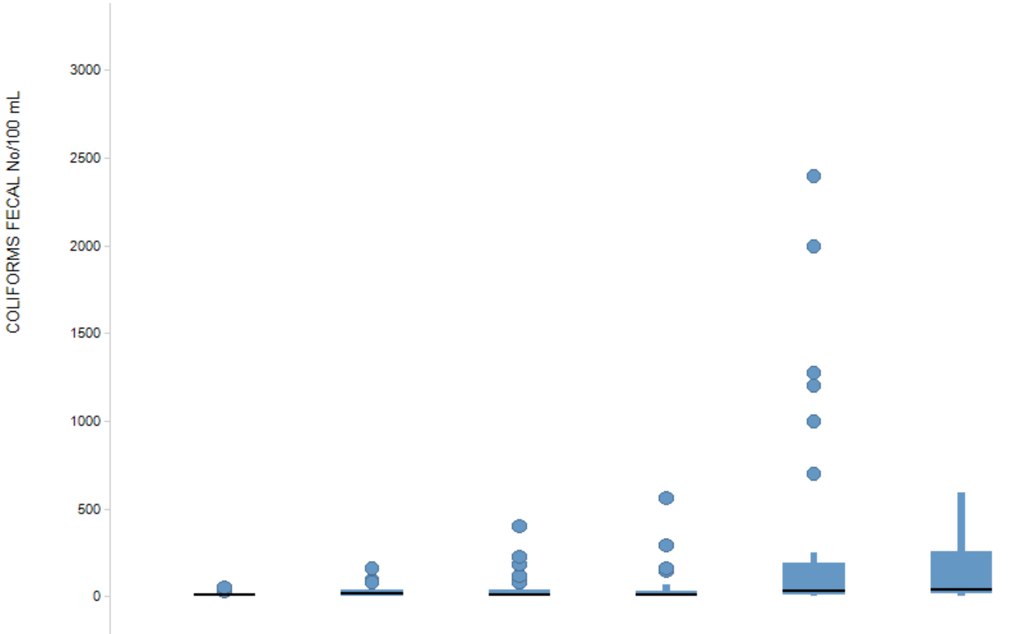
Figure D19. Spatial distribution of TSS in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.5	0.5	0.2	0.2	0.2	1.6
Max	15	7.4	44.4	63	730	14
Median	1.3	1.3	0.7	1.4	4.7	3.65
Var	14.3638	2.35148	62.5526	216.168	22474.9	21.007

STATION_DESCRIPTION

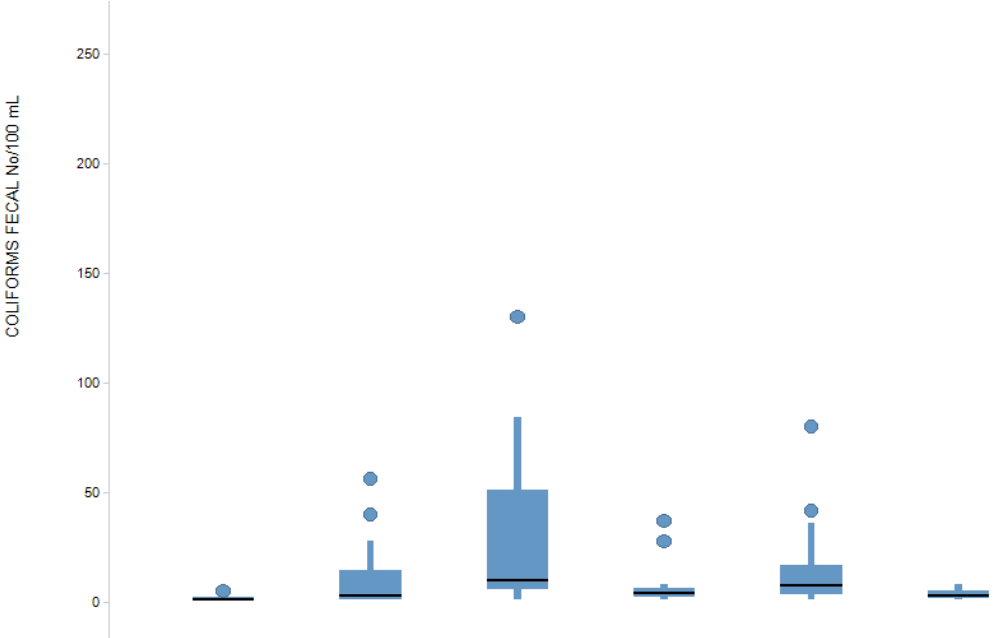
Figure D20. Spatial distribution of TSS in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	14
Min	1	1	1	1	1	2
Max	54	160	400	3600	5000	590
Median	6	15	10	10	32	35
Var	167.976	987.612	4361.62	447881	1.10515e+06	37725.1

STATION_DESCRIPTION

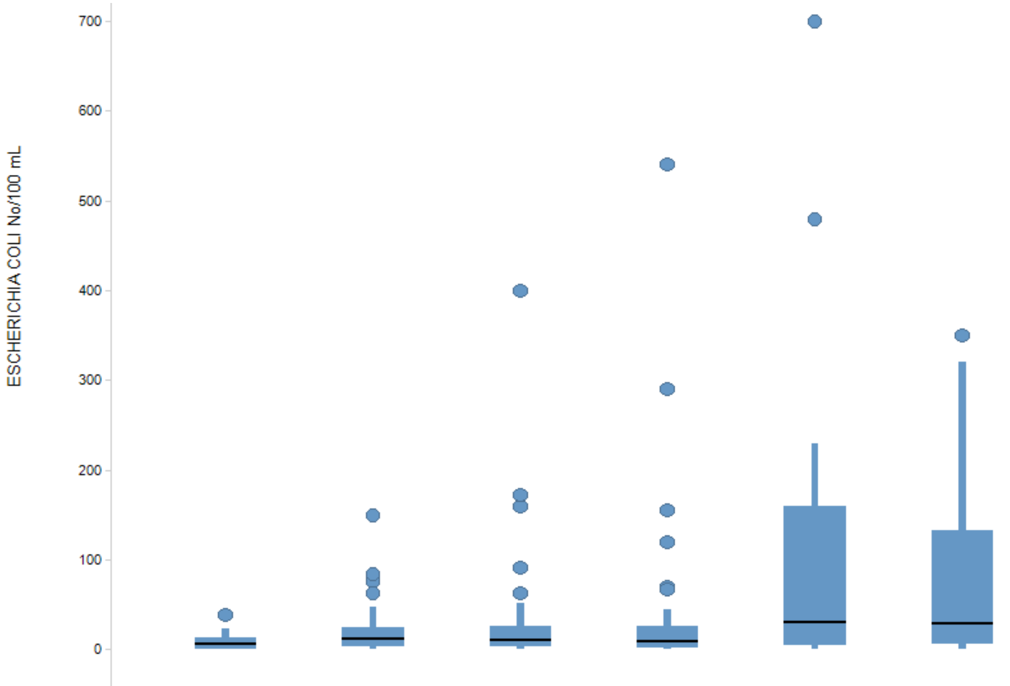
Figure D21. Spatial distribution of fecal coliforms in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	7
Min	1	1	1	1	1	1
Max	5	56	380	400	80	8
Median	1	3	10	4	7.5	3
Var	1.82917	181.358	5014.71	5596.04	337.035	6.95238

STATION_DESCRIPTION

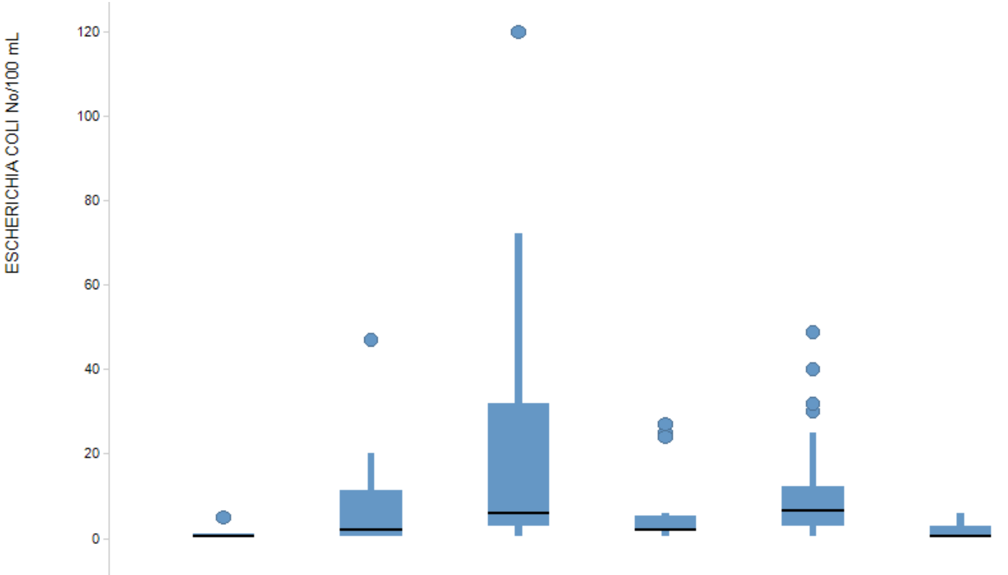
Figure D22. Spatial distribution of fecal coliforms in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	14
Min	0.5	0.5	0.5	0.5	0.5	1
Max	39	150	400	3600	5000	350
Median	6	12.5	10	9	30	28.5
Var	96.7711	741.712	3806.4	448572	849587	17516.7

STATION_DESCRIPTION

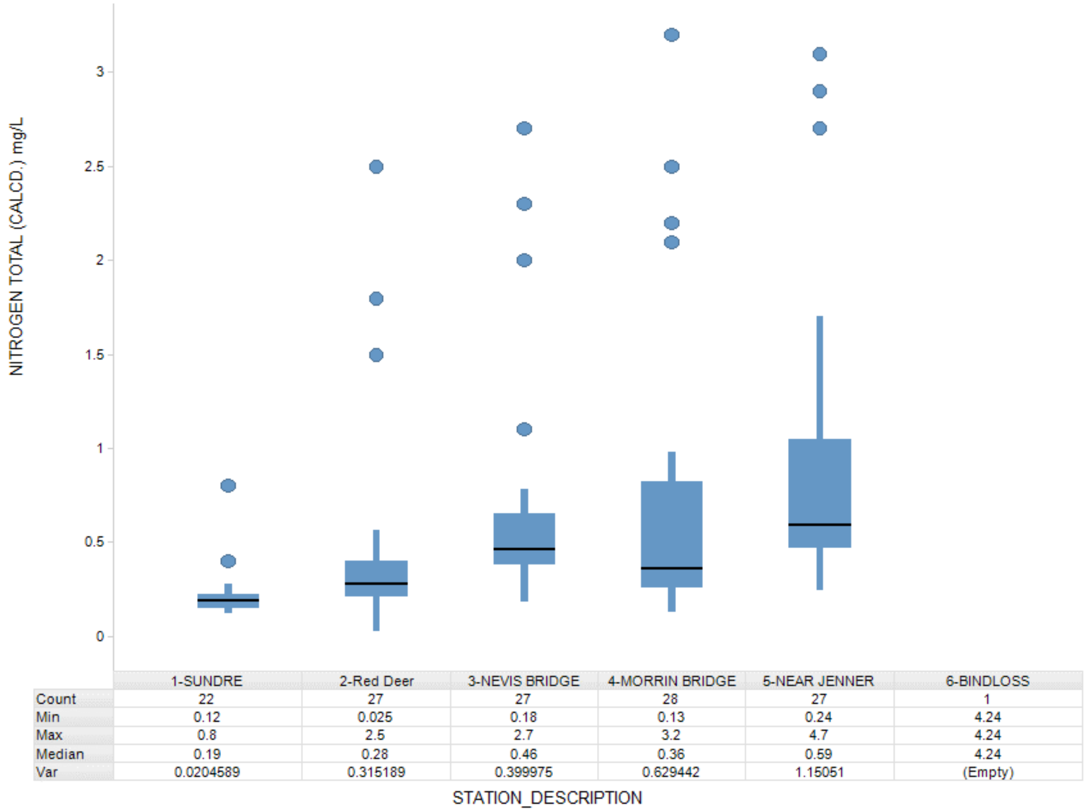
Figure D23. Spatial distribution of *E.Coli* in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	7
Min	0.5	0.5	0.5	0.5	0.5	0.5
Max	5	47	140	260	49	6
Median	0.5	2	6	2	6.5	0.5
Var	1.22917	104.668	1199.83	2374.73	171.023	5.83333

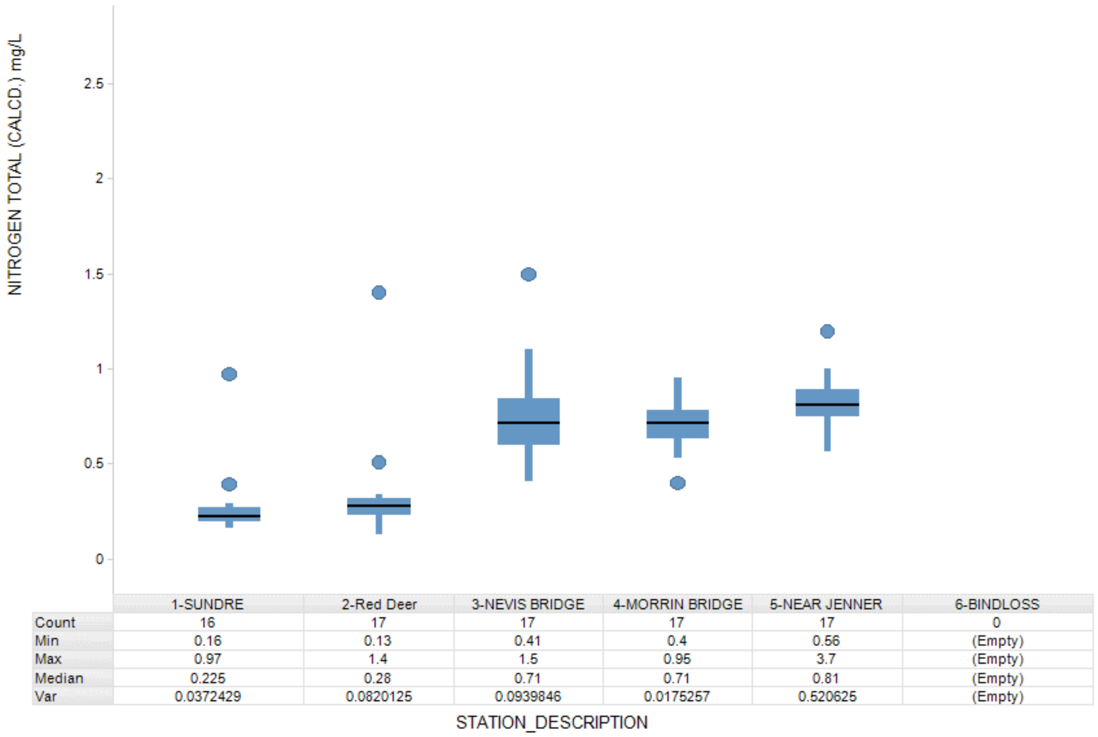
STATION_DESCRIPTION

Figure D24. Spatial distribution of *E.Coli* in the mainstem of the Red Deer River in ice cover season (November-March)



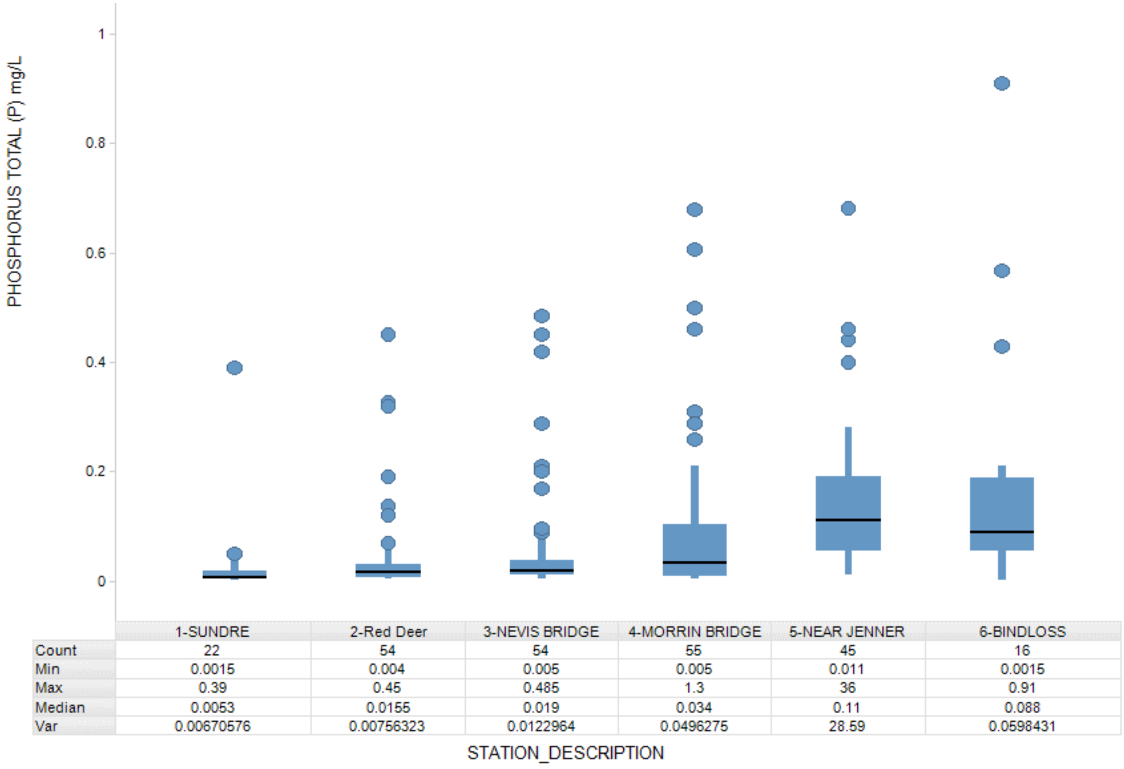
	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	27	27	28	27	1
Min	0.12	0.025	0.18	0.13	0.24	4.24
Max	0.8	2.5	2.7	3.2	4.7	4.24
Median	0.19	0.28	0.46	0.36	0.59	4.24
Var	0.0204589	0.315189	0.399975	0.629442	1.15051	(Empty)

Figure D25. Spatial distribution of total nitrogen in the mainstem of the Red Deer River in open water season (April-October)



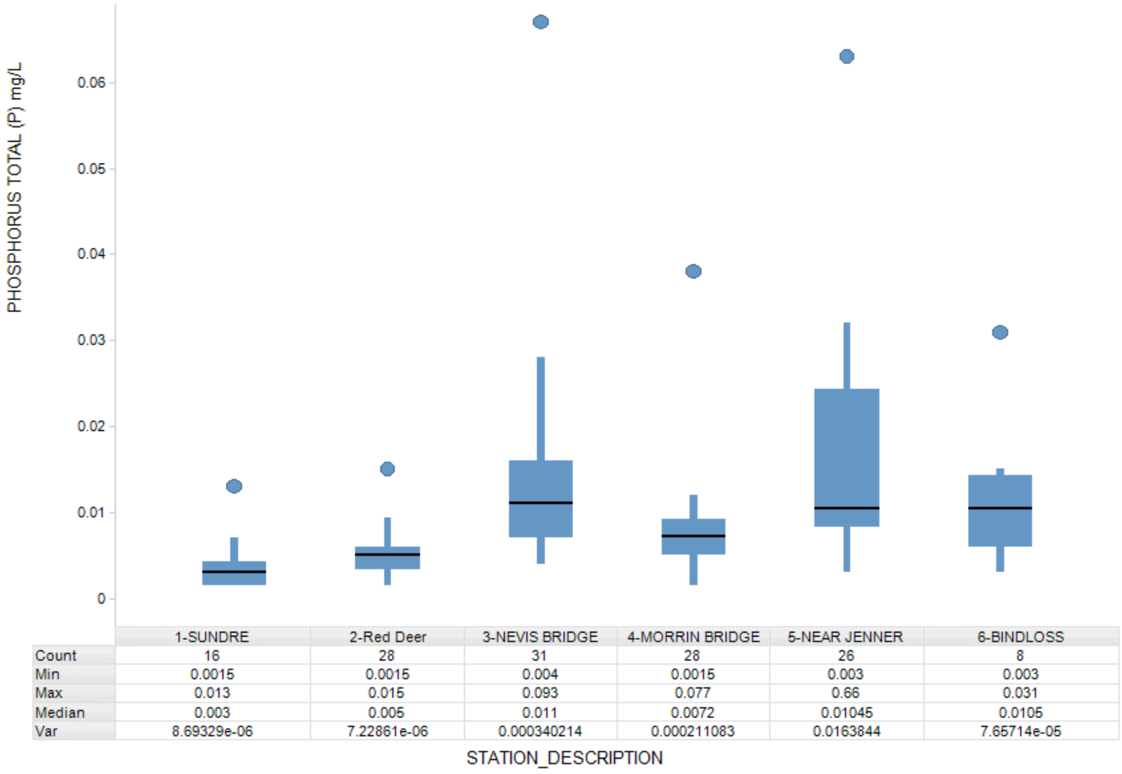
	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	17	17	17	17	0
Min	0.16	0.13	0.41	0.4	0.56	(Empty)
Max	0.97	1.4	1.5	0.95	3.7	(Empty)
Median	0.225	0.28	0.71	0.71	0.81	(Empty)
Var	0.0372429	0.0820125	0.0939846	0.0175257	0.520625	(Empty)

Figure D26. Spatial distribution of total nitrogen in the mainstem of the Red Deer River in ice cover season (November-March)



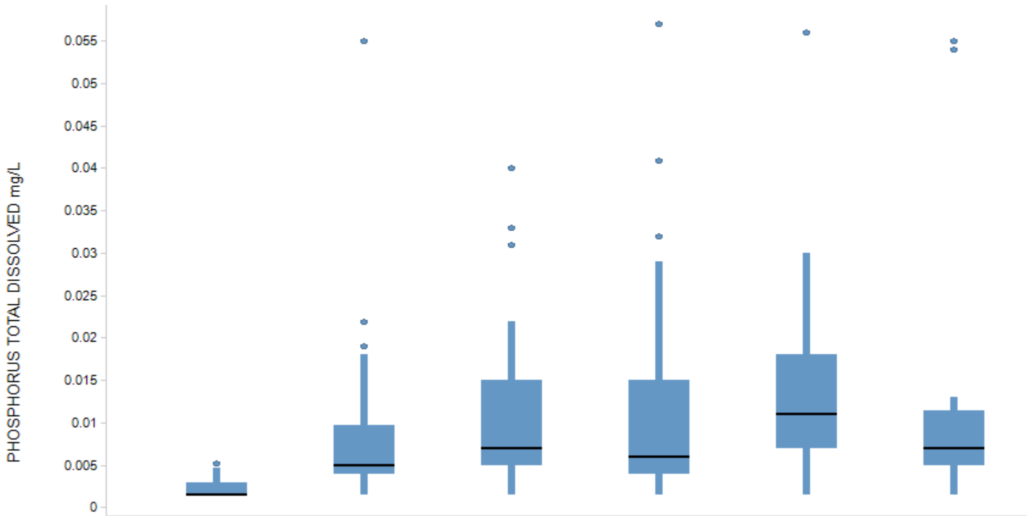
	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	16
Min	0.0015	0.004	0.005	0.005	0.011	0.0015
Max	0.39	0.45	0.485	1.3	36	0.91
Median	0.0053	0.0155	0.019	0.034	0.11	0.088
Var	0.00670576	0.00756323	0.0122964	0.0496275	28.59	0.0598431

Figure D27. Spatial distribution of total phosphorus in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.0015	0.0015	0.004	0.0015	0.003	0.003
Max	0.013	0.015	0.093	0.077	0.66	0.031
Median	0.003	0.005	0.011	0.0072	0.01045	0.0105
Var	8.69329e-06	7.22861e-06	0.000340214	0.000211083	0.0163844	7.65714e-05

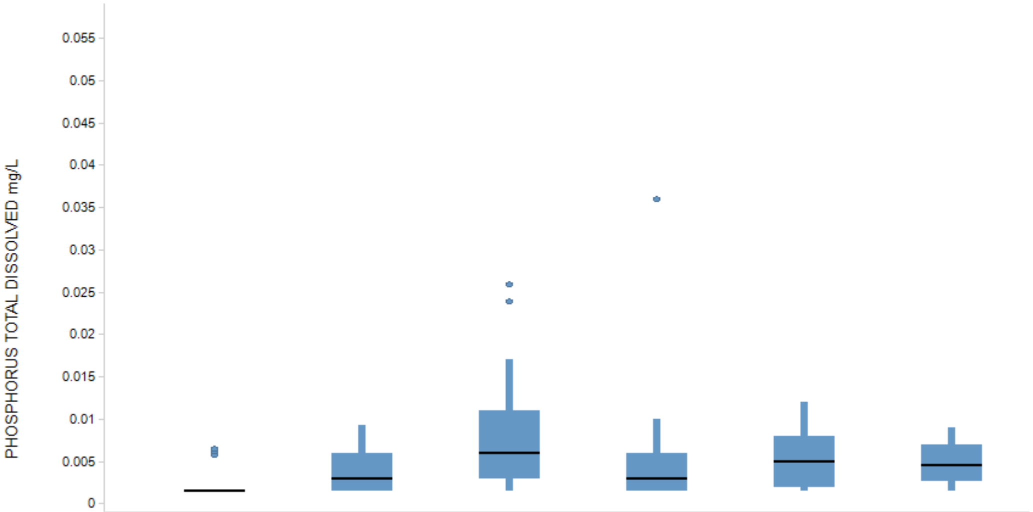
Figure D28. Spatial distribution of total phosphorus in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	16
Min	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Max	0.0053	0.25	0.3	0.29	0.15	0.065
Median	0.0015	0.005	0.007	0.006	0.011	0.007
Var	1.46087e-06	0.00153687	0.00252073	0.00236327	0.00101879	0.000440157

STATION_DESCRIPTION

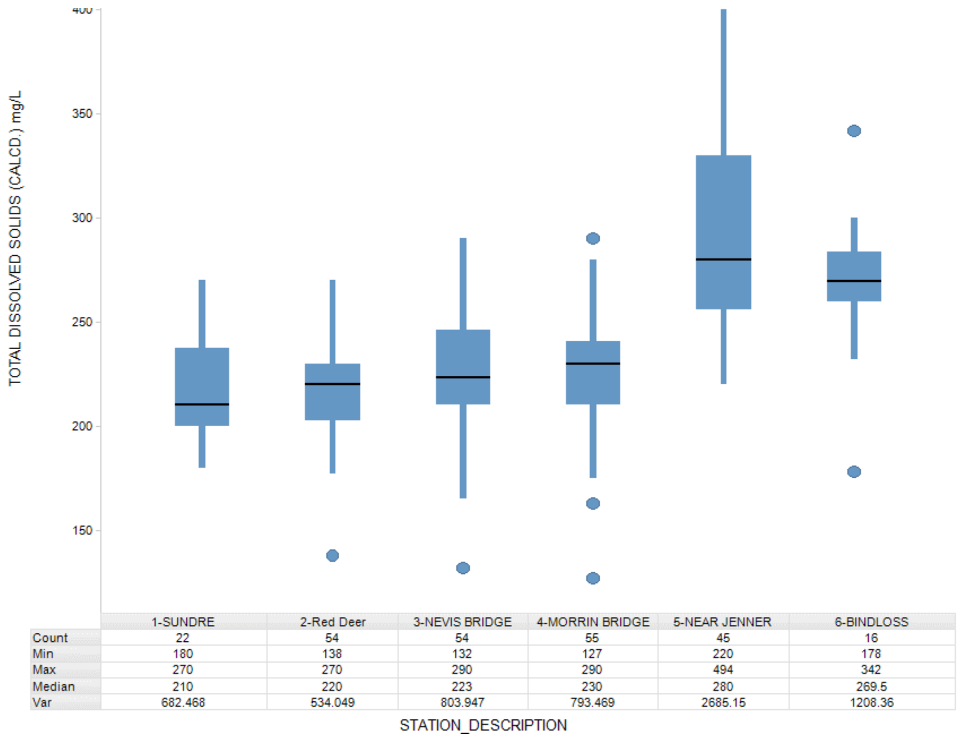
Figure D29. Spatial distribution of total dissolved phosphorus in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	0.0015	0.0015	0.0015	0.0015	0.0015	0.0015
Max	0.0066	0.0093	0.067	0.036	0.19	0.009
Median	0.0015	0.003	0.006	0.003	0.005	0.0045
Var	3.61096e-06	6.10819e-06	0.000231946	4.36203e-05	0.00141077	8.14286e-06

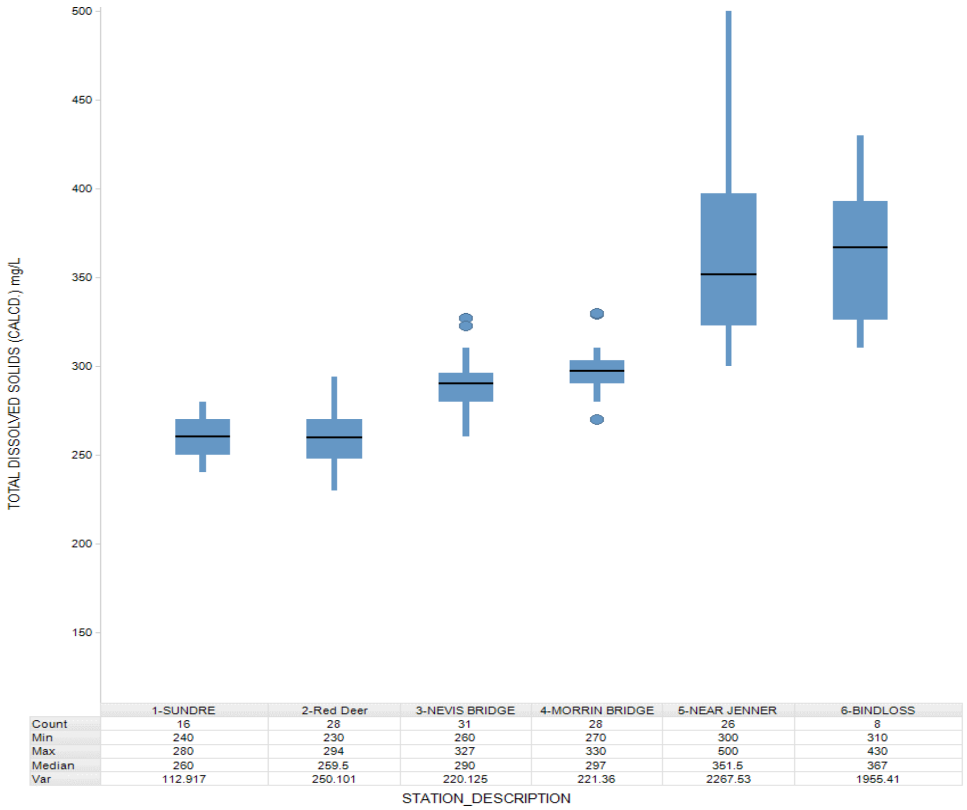
STATION_DESCRIPTION

Figure D30. Spatial distribution of total dissolved phosphorus in the mainstem of the Red Deer River in ice cover season (November-March)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	22	54	54	55	45	16
Min	180	138	132	127	220	178
Max	270	270	290	290	494	342
Median	210	220	223	230	280	269.5
Var	682.468	534.049	803.947	793.469	2685.15	1208.36

Figure D31. Spatial distribution of TDS in the mainstem of the Red Deer River in open water season (April-October)



	1-SUNDRE	2-Red Deer	3-NEVIS BRIDGE	4-MORRIN BRIDGE	5-NEAR JENNER	6-BINDLOSS
Count	16	28	31	28	26	8
Min	240	230	260	270	300	310
Max	280	294	327	330	500	430
Median	260	259.5	290	297	351.5	367
Var	112.917	250.101	220.125	221.36	2267.53	1955.41

Figure D32. Spatial distribution of TDS in the mainstem of the Red Deer River in ice cover season (November-March)

APPENDIX E. Spatial distribution of substances in the upstream river and tributaries close to the two sampling events in August and September of 2015

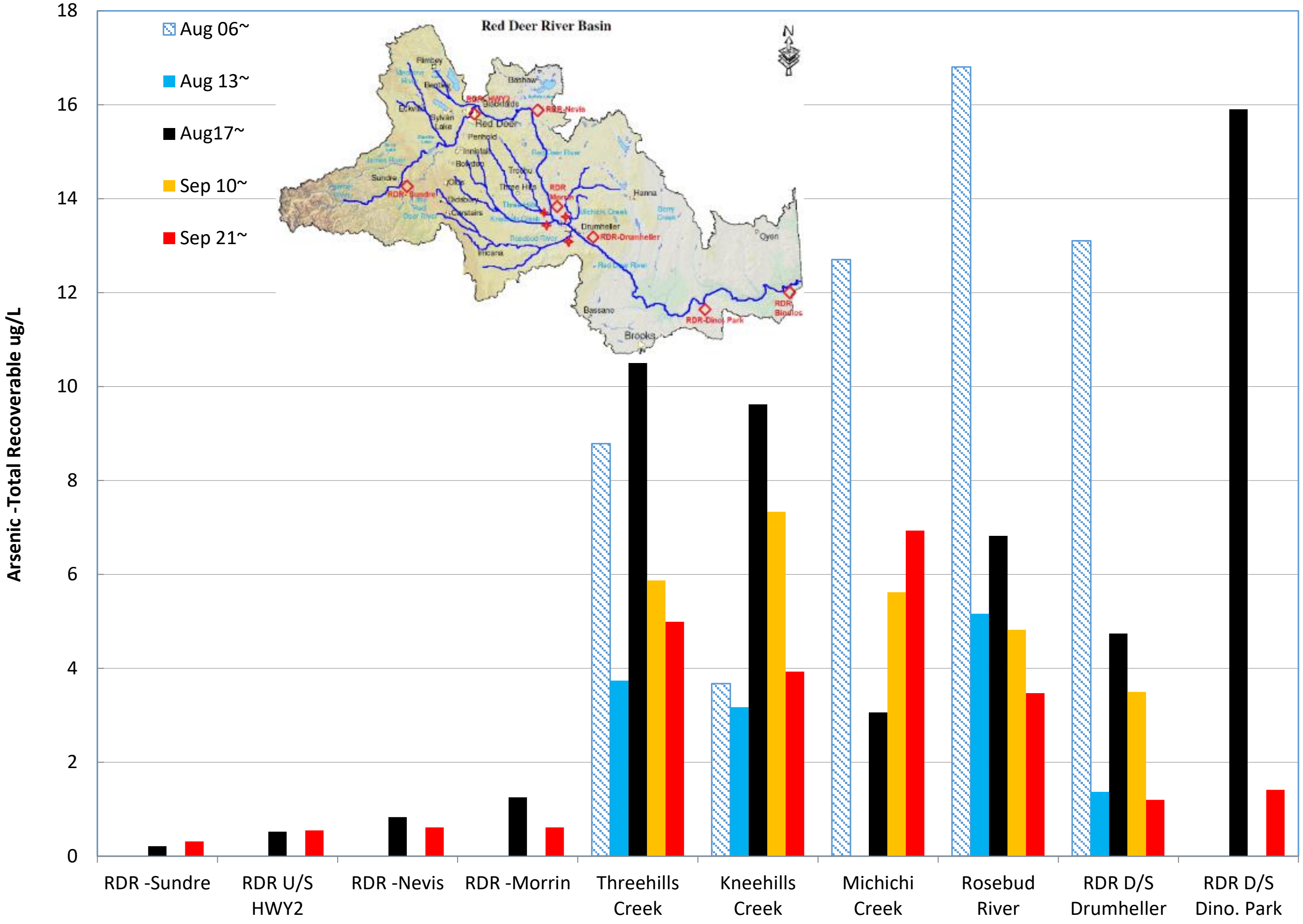


Figure E1. Spatial distribution of total recoverable arsenic in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

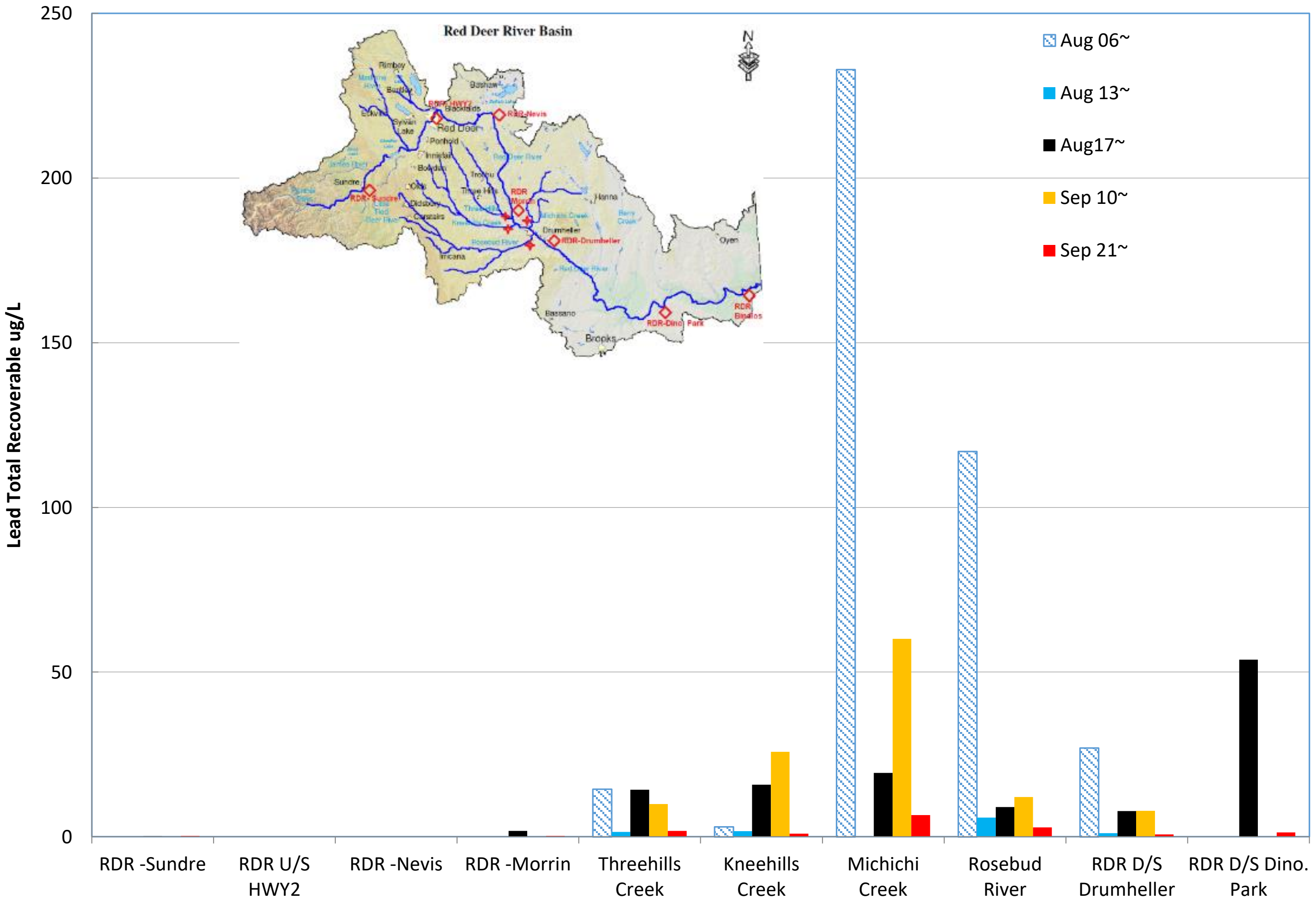


Figure E2. Spatial distribution of total recoverable lead in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

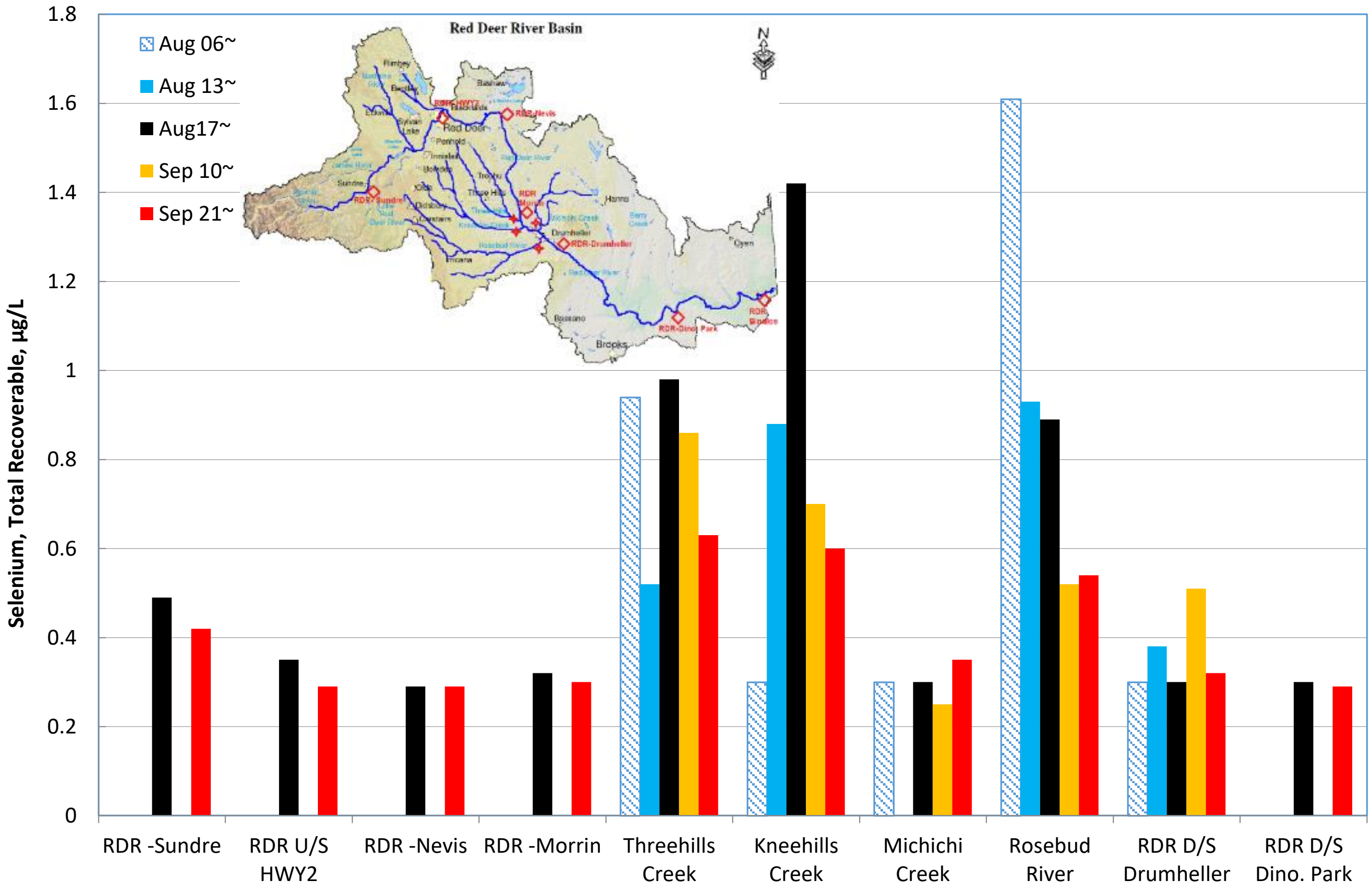


Figure E3. Spatial distribution of total recoverable selenium in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

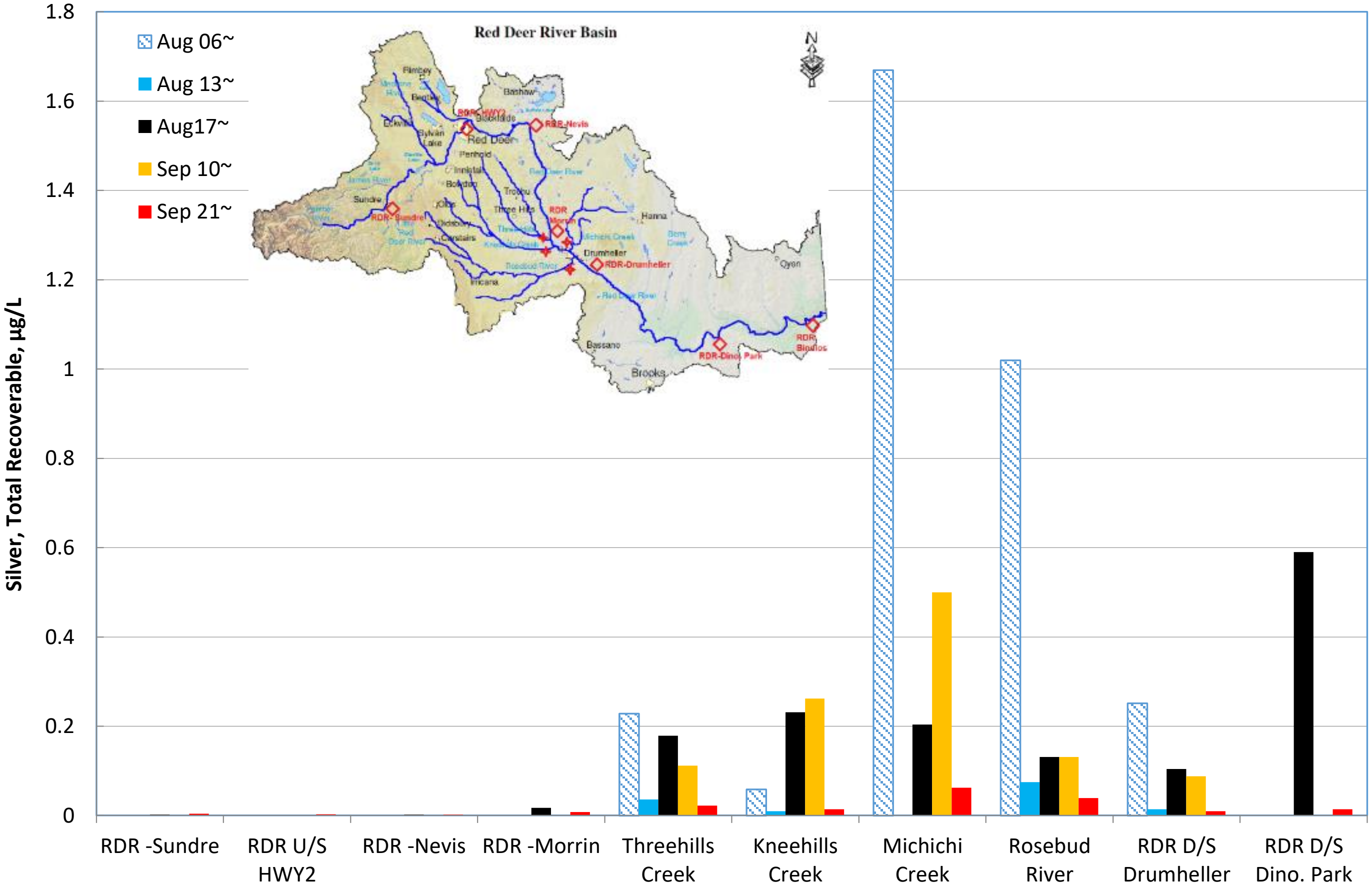


Figure E4. Spatial distribution of total recoverable silver in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

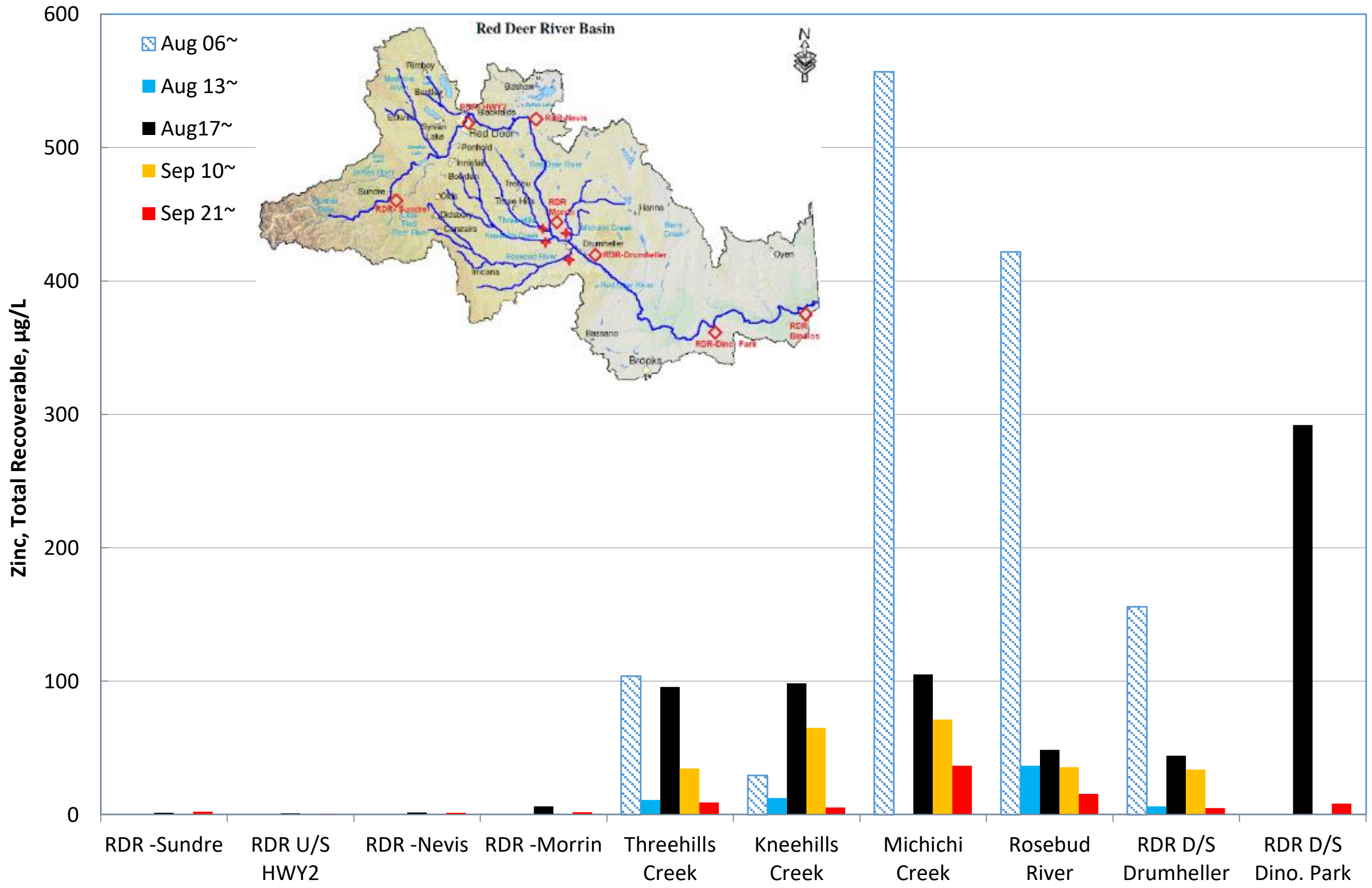


Figure E5. Spatial distribution of total recoverable zinc in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

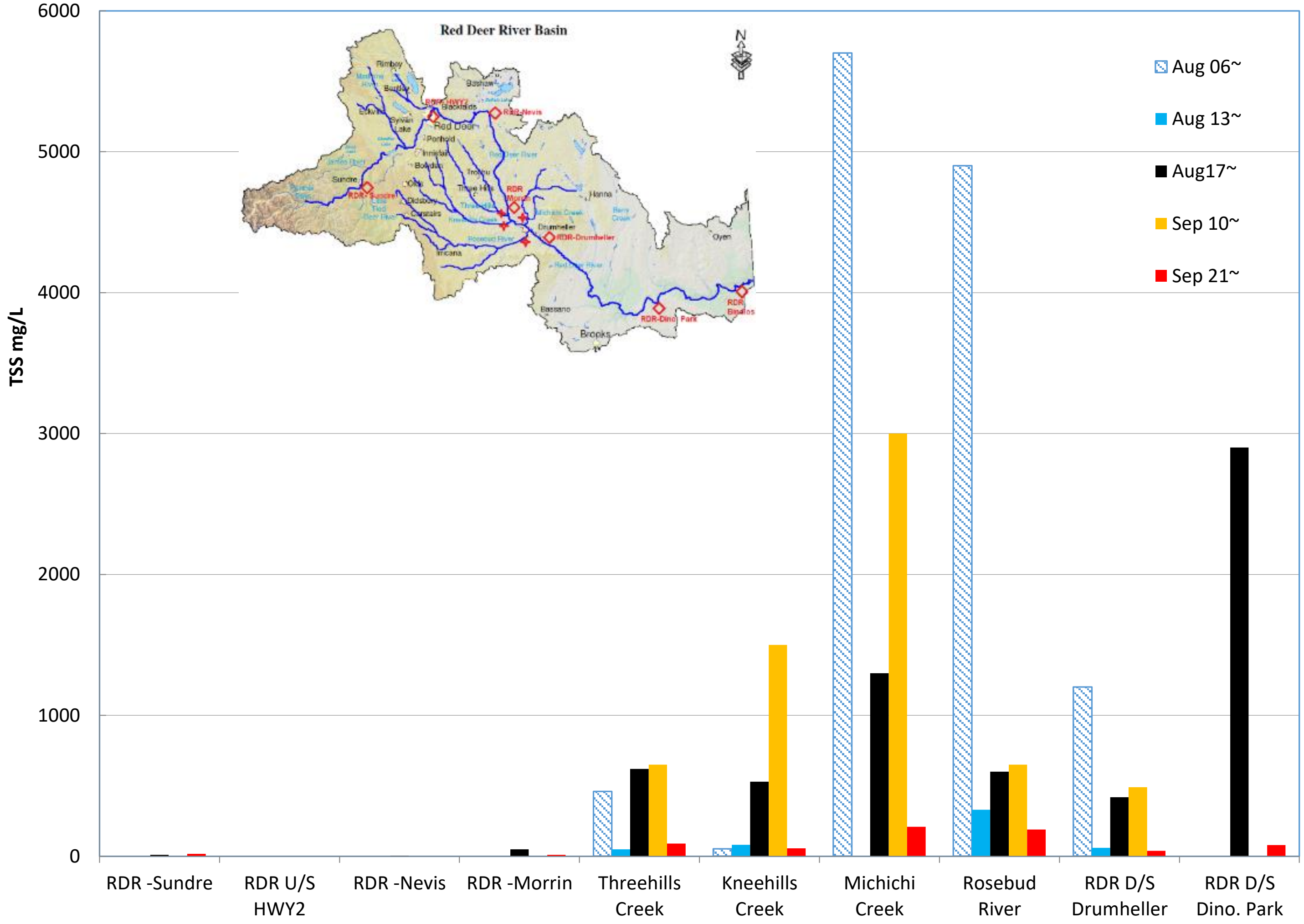


Figure E6. Spatial distribution of TSS in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

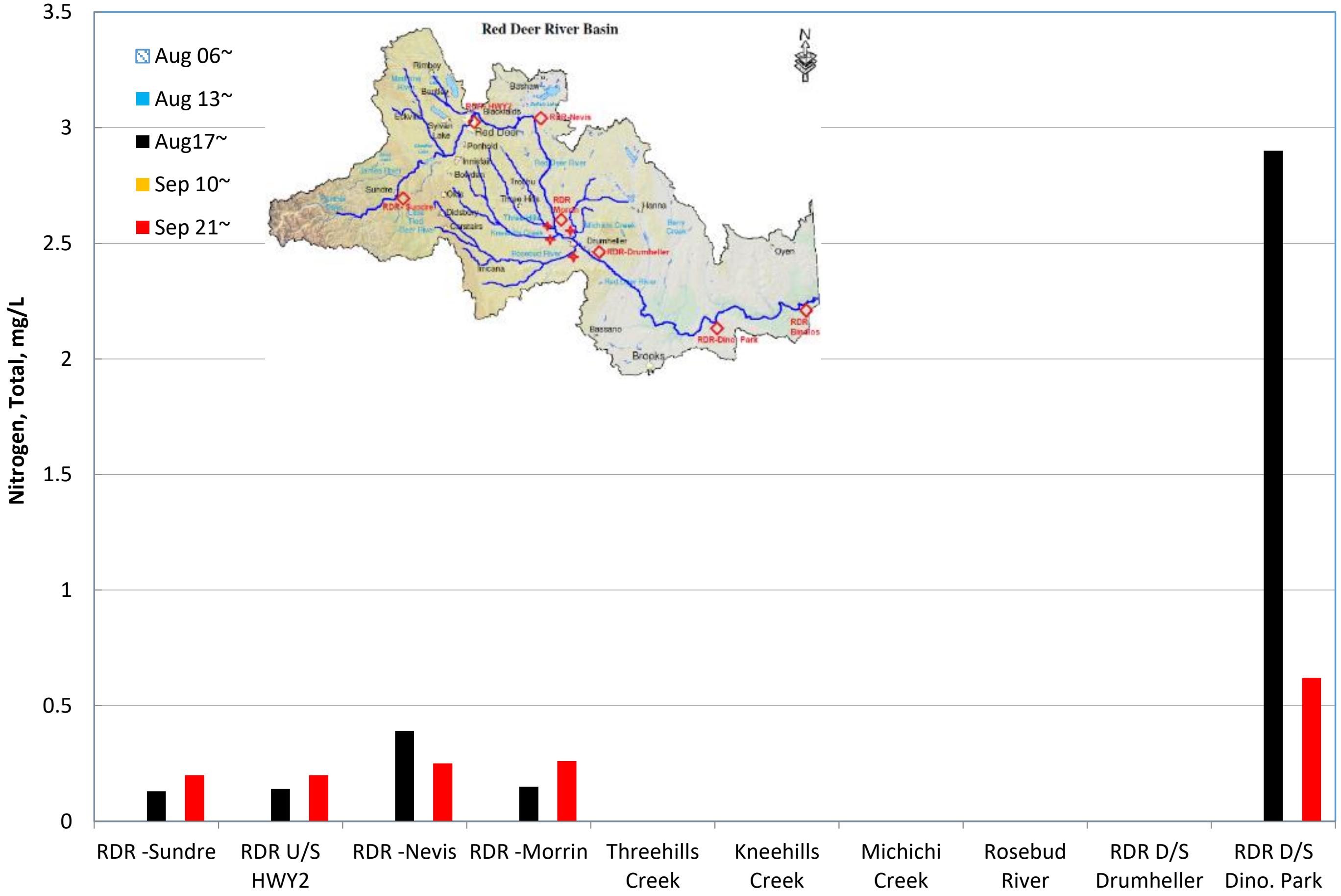


Figure E7. Spatial distribution of total nitrogen in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

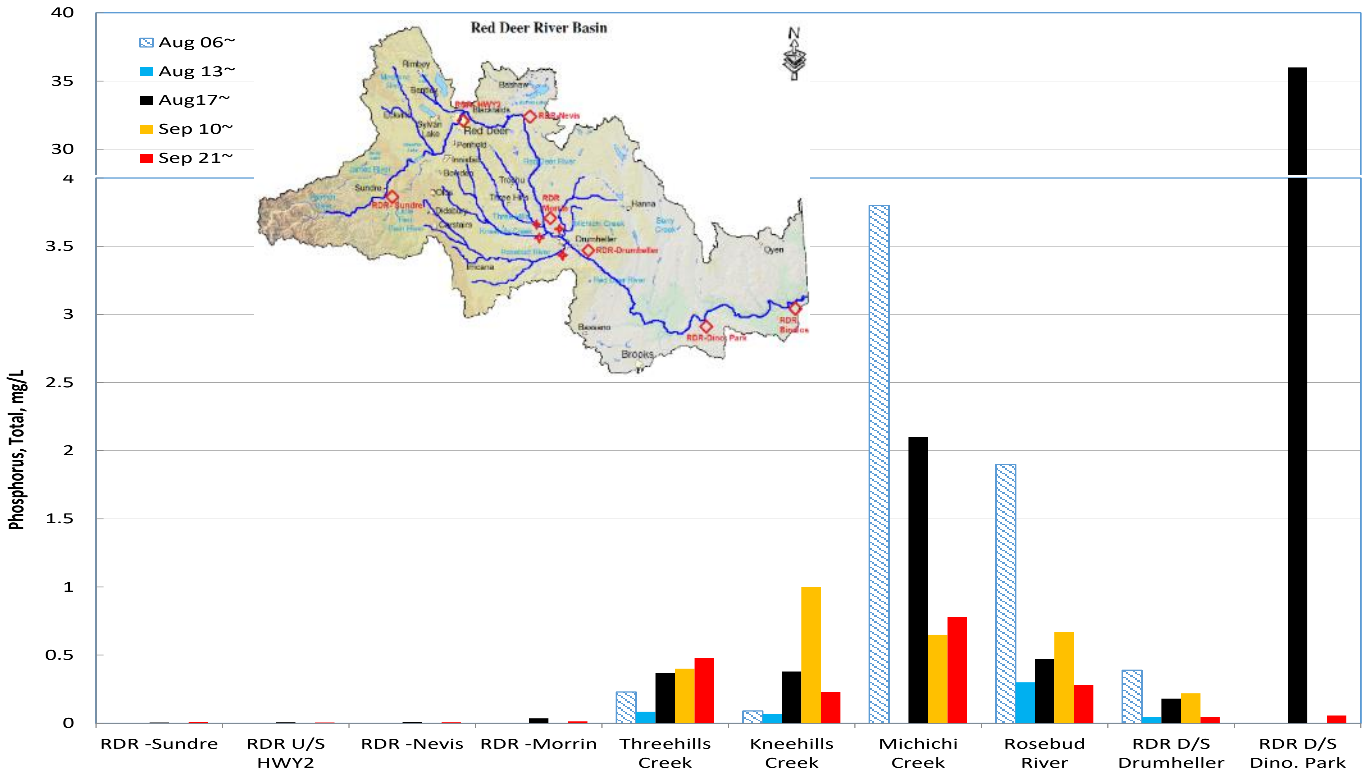


Figure E8. Spatial distribution of total phosphorus in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

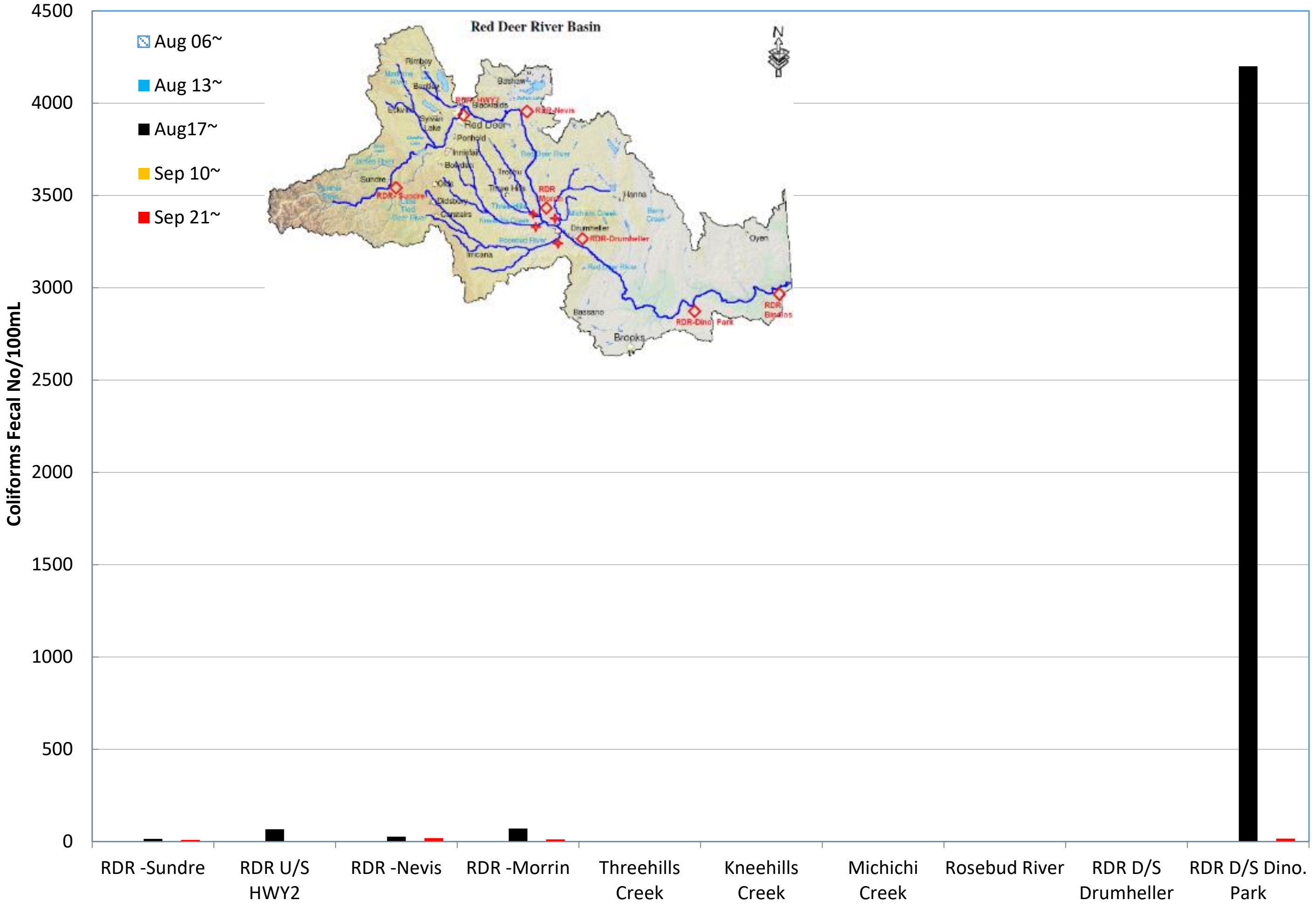


Figure E9. Spatial distribution of fecal coliforms in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

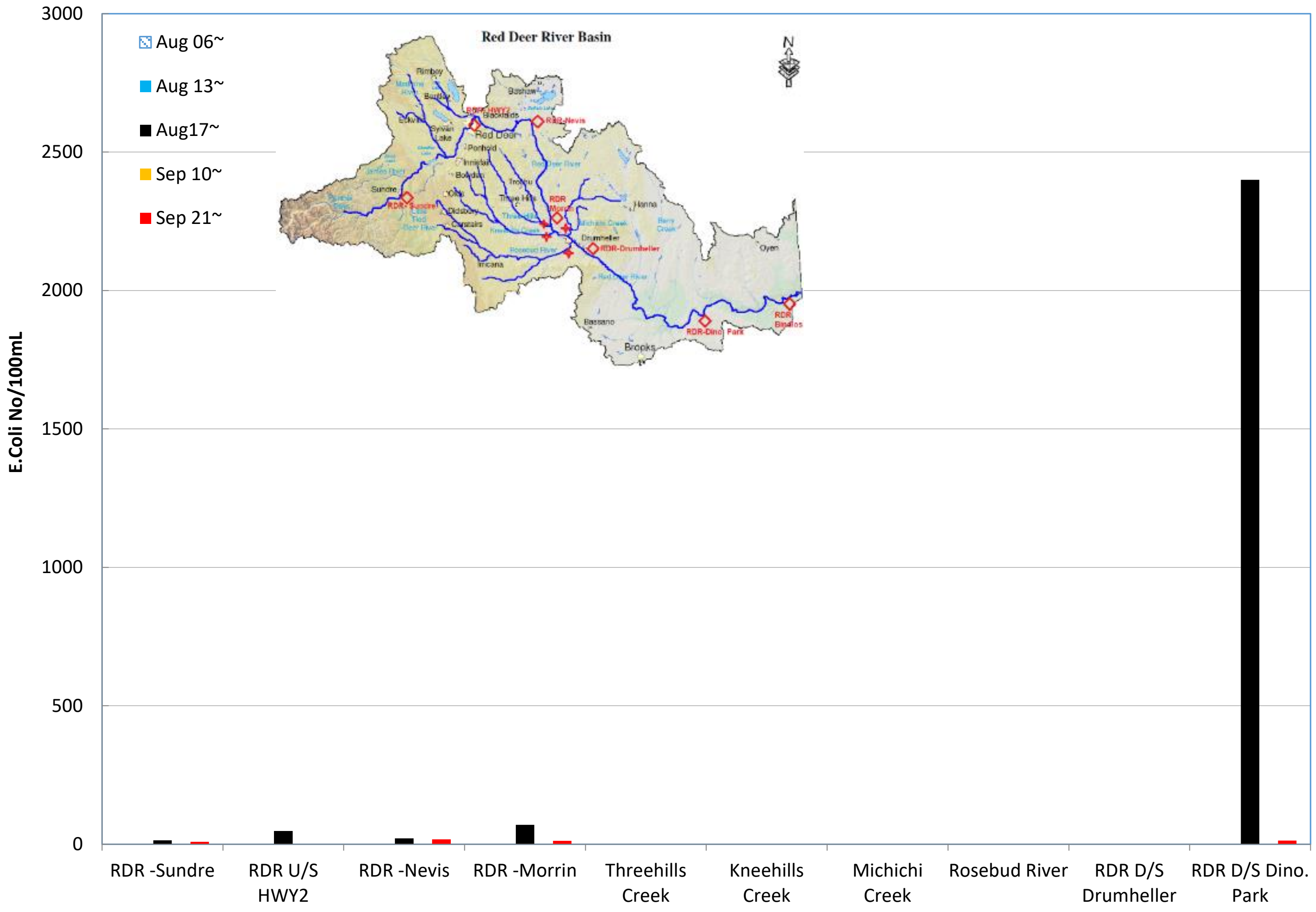


Figure E10. Spatial distribution of *E.Coli* in the Red Deer River and some tributaries close to the two sampling events in August and September of 2015

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