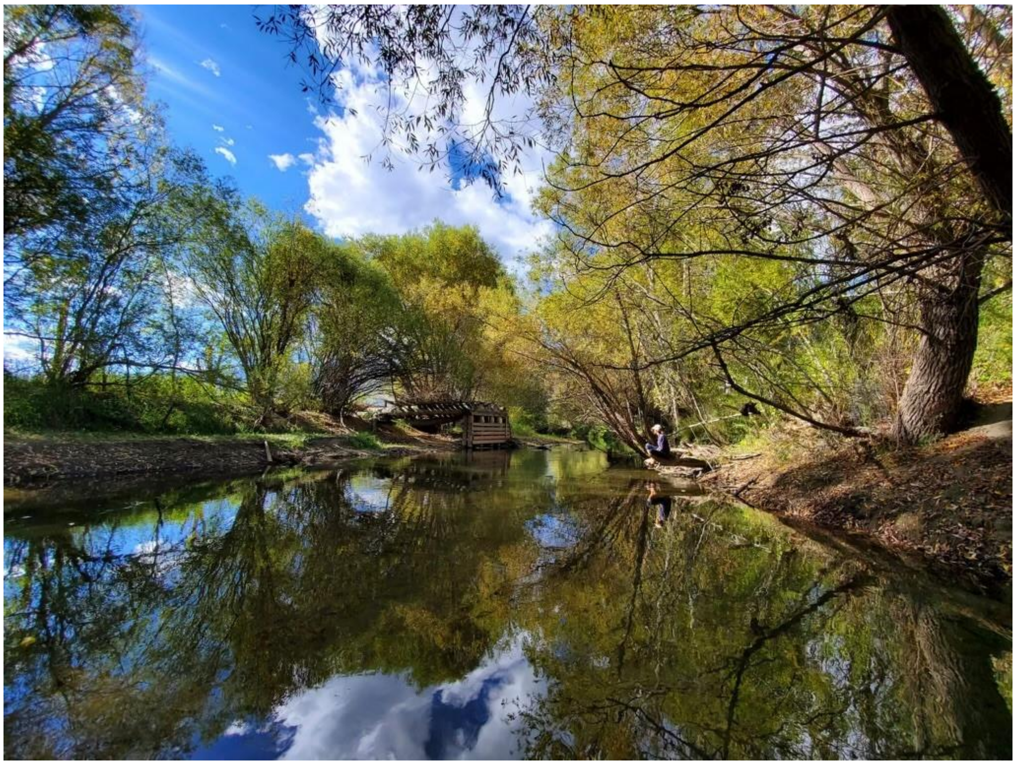
ENVIRONMENTAL QUALITY SERIES

Salmon River Water Quality Assessment

Annie Chalifour, Allison Schein, and Jesse Sinclair



June 2022

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ISBN: 978-0-7726-8098-3

Citation:
Chalifour, A., A. Schein, and J. Sinclair. 2022. Salmon River Water Quality Assessment. Environmental Quality Series. Prov. B.C., Victoria B.C.

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Cover Photograph:
Salmon River. Photo by: Holly Vivian.

Acknowledgements

We thank Julio Novoa for creating the map of monitoring stations and calculating the drainage area and distance from Shuswap Lake for each Salmon River station, and Yury Bychkov for his technical support with some of the data visualisation.

EXECUTIVE SUMMARY

Water Quality Objectives (WQOs) are water quality benchmarks used to inform resource management or land use decisions, promote water stewardship, and support long-term planning. The Salmon River, a tributary of Shuswap Lake in the Thompson-Okanagan region, has been influenced for decades by non-point source inputs from a variety of sources such as agricultural use, cattle-based industries, forestry activity, and rural residential development. In 1998, Water Quality Objectives (WQOs) were developed for water temperature, dissolved oxygen, pH, turbidity, total suspended solids (TSS), streambed substrate composition metrics, total ammonia, chlorophyll *a*, total fecal coliforms, *Escherichia coli,* and *Enterococcus* sp. A total phosphorus WQO was also developed for Tappen Bay in Shuswap Lake. The attainment of WQOs is determined through a monitoring program specifically developed for comparing and evaluating these water quality parameters to the benchmarks. From 2005 to 2010 and from 2016 to 2019, sampling events took place at seven stations (six in the former period) on the Salmon River and water quality parameters were measured at regular intervals. The objective of this report was to understand how water quality has changed in the Salmon River since 2005 and whether WQOs have been achieved. The specific objectives were to compare water quality data obtained to their respective WQOs and to determine if water quality was improving or degrading from upstream to downstream (spatial trend) and over time (temporal trend).

Temperature exceeded the long-term WQO of 14.2°C on average 14% of the time between 2005 and 2010 and 18% of the time between 2016 and 2019. Dissolved oxygen was below the long-term WQO of 11 mg/L 32% of the time and below the short-term WQO of 9 mg/L only 11% of the time between 2005 and 2010. Between 2016 and 2019, dissolved oxygen was below the long-term WQO of 11 mg/L 52% of the time but below the short-term WQO of 9 mg/L only 9.5% of the time. pH was only occasionally above the long-term WQO of 8.5 pH units (1.6% and 5.9% of the time in the first and second sampling event, respectively). No exceedances of nitrogen species were observed, but microbial indicators were more frequently above their WQOs than below. Chlorophyll a was not measured in the water column at any of the Salmon River stations studied.

Significantly higher mean concentrations of total phosphorus (clear flow periods) and orthophosphate (both clear and turbid flow periods) were observed over the period of record at the upstream most station compared to the downstream most station along the Salmon River. The upstream station (E206084) showed significantly lower concentrations when considering total phosphorus (turbid flow period only), total nitrogen (clear flow period only), total nitrate plus nitrite (clear and turbid flow periods), and *Escherichia coli* (clear and turbid flow periods).

Changes in selected parameters over time were observed at station E206092, the last monitoring station on the Salmon River upstream of Shuswap Lake. Specific conductivity increased by 13% between 2005 and 2019. Turbidity, total nitrate plus nitrite, and orthophosphate decreased over the same time period by 33%, 50%, and 22% respectively. Step trends due to a change in analytical methods in 2015 were found for several parameters (i.e., total suspended solids, total ammonia, and dissolved ammonia). The remaining parameters analysed (temperature, dissolved oxygen, pH, total nitrogen, dissolved nitrate plus nitrite, dissolved nitrate, total organic nitrogen, total phosphorus, and dissolved phosphorus) remained stable between 2005 and 2019. The microbial indicators (fecal coliforms and *E. coli*) showed variations within the time period, but an overall stable concentration.

Total phosphorus concentrations at the Tappen Bay monitoring site exceeded the 15 µg/L WQO in 5.9% and 17% of the samples collected from 2005 to 2010 and from 2016 to 2019, respectively, showing an increase in the input of this nutrient in the Salmon Arm of Shuswap Lake over the years.

Recommendations for future monitoring of the Salmon River are provided. Attainment monitoring should continue monthly in five- to six-year monitoring cycles at each station and should include an intensive sampling program (i.e., one or two 5-in30 day sampling events per year) during periods of high variability (i.e., low and high flows) or during periods of high recreational use for evaluating bacterial conditions. Another temporal trend analysis should be conducted after 2025 when more than 10 years of data have been collected with the same analytical method at station E206092. Changes in trophic status in both the Salmon River and Tappen Bay should be evaluated, and TN:TP should be tracked. In addition, hydrological monitoring at additional stations upstream of E206092 would allow for determination of load accumulation along the length of the Salmon River.

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FIGURES

<u>TABLES</u>

ACRONYMS

B.C.	British Columbia
DOC	dissolved organic carbon
EMS	Environmental Monitoring System
ENV	Ministry of Environment and Climate Change Strategy
n	number of data points
PARMA	periodic autoregressive moving average
p-value	probability value, or attained significance level
SD	standard deviation
TOC	total organic carbon
TN:TP	ratio of total nitrogen to total phosphorus
TSS	total suspended solids
t Statistic	statistical estimate of the magnitude of difference between the means of two groups
USGS	U.S. Geological Survey
WQG	water quality guideline
WQO	water quality objective
WSC	Water Survey of Canada

1. INTRODUCTION

The Salmon River is located in the Thompson-Okanagan region of B.C. It is a tributary of Shuswap Lake, which eventually drains into the South Thompson River. The Salmon River is a source of raw water for agricultural irrigation, livestock watering, and a small number of domestic water supplies. It also supports anadromous salmonids including Chinook (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*), and Sockeye (*Oncorhynchus nerka*) salmon and other resident fish species such as Rainbow Trout (*Oncorhynchus mykiss*) and Mountain Whitefish (*Prosopium williamsoni*). It provides recreational and aesthetic opportunities for local residents and tourists, such as fishing, swimming, canoeing, and bird watching.

Despite its ecological and recreational importance, the Salmon River is subject to a number of non-point source pressures that contribute to degradation in water quality. Contaminant loading from nearby agricultural fields, forest management, urbanization, and mineral extraction led to elevated concentrations of nitrogen, phosphorus, metals, and fecal coliforms in the Salmon River (Gwanikar et al. 1998a). Elevated nutrient concentrations can in turn lead to eutrophication and oxygen depletion, threatening aquatic life in the river (Mallin et al. 2006). In addition, annual water flows are expected to decrease due to smaller winter snowpacks and increasingly warm summers (MFLNRO 2016).

Water quality objectives (WQOs) for the Salmon River were developed in 1998 by the B.C. Ministry of Environment, Lands and Parks (BCMOE 1998) in order to provide benchmarks to which water quality parameters could be compared and evaluated. They aim at protecting the most sensitive designated use of the Salmon River and of Tappen Bay in Shuswap Lake and can be used by natural resource managers to direct policy and/or for permitting processes.

For the Salmon River, WQOs were developed for water temperature, dissolved oxygen, pH, turbidity, total suspended solids (TSS), streambed substrate composition metrics, total ammonia, chlorophyll *a*, total fecal coliforms, *Escherichia coli,* and *Enterococcus* sp. A total phosphorus WQO was included for Tappen Bay in Shuswap Lake. To assess whether these WQOs were met, water quality in the Salmon River was monitored in cycles of five to six years. A regular sampling event took place from 2005 to March 2010, with 782 water samples taken at six different locations on the river. In April 2016, another sampling cycle started, and 408 water samples were collected between April 2016 and the end of 2019 at seven stations. In addition, one station on the Salmon River (E206092) is part of a federal long-term trend monitoring program and water quality parameters have been measured there bi-weekly since 1988. The goal of this report is to determine how water quality has changed in the Salmon River since 2005 and whether WQOs have been achieved.

The specific objectives and tasks related to this goal were to:

1. Compare water quality parameters measured in the Salmon River to their respective WQOs;
2. Evaluate the frequency of exceedance of these WQOs and B.C. water quality guidelines (WQGs) at monitoring stations along the Salmon River;
3. Determine if water quality is improving or degrading from upstream to downstream;
4. Evaluate whether the water quality is improving or degrading over time; and,
5. Provide some recommendations on future monitoring of the Salmon River.

1.1 Study Area

Seven sites were selected along the Salmon River to evaluate water quality and trends (Figure 1). More details on these stations, including their river kilometre distance from Shuswap Lake and drainage area, are available in Table 1. The river kilometres and drainage areas for each station were calculated using

ArcGIS Pro (ArcGIS Pro 2.9 2022). The river kilometres calculation involved extracting relative positions along the Salmon River from its mouth up to each of the Environmental Monitoring System (EMS) stations. For calculating the drainage area, a synthetic hydrographic network of the Salmon River watershed was created, using each station as an outlet to model its drained area.

Only one site (E206092 – Salmon River at Hwy #1 Bridge near Salmon Arm) had sufficient data collected between 2005 and 2019 and associated hydrological data to conduct a temporal trend analysis. This station is associated with a stream gauge (08LE021) that measures stream flows continuously in the Salmon River (Figure 1). Water quality objectives for temperature, dissolved oxygen, pH, ammonia, and microbial indicators were evaluated at each of the Salmon River stations while one station on Shuswap Lake (E206771 – Shuswap Lake Tappen Bay # 5) was used to compare total phosphorus values to the corresponding WQO.

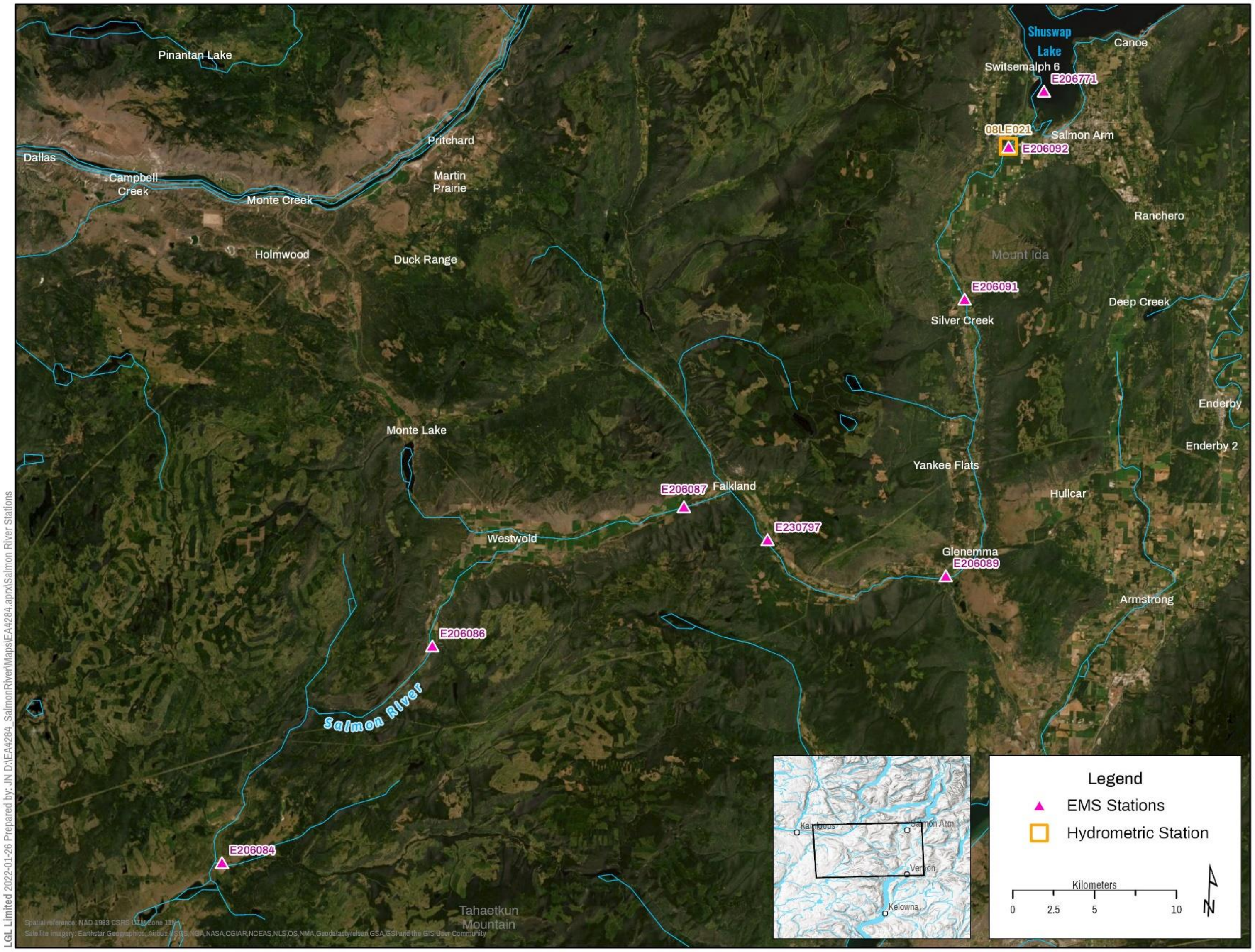

Figure 1: Map of the Salmon River with EMS and hydrometric stations.

Table 1: Summary of EMS stations from upstream to downstream.

EMS ID	Station Name	Distance from Shuswap Lake (km)	Drainage Area (km^2)	Latitude	Longitude	Years of Data Available
E206084	Salmon River upstream of McInnis Creek	119	241	50.2844	-119.9850	2005-2010; 2016-2017
E206086	Salmon River upstream of Adelphi Creek	95.6	539	50.4078	-119.8119	2005-2010; 2016-2019
E206087	Salmon River upstream of Falkland	66.1	799	50.4892	-119.6000	2005-2010; 2016-2019 [1]
E230797	Salmon River at Lapierre Farm	57.4	1,078	50.4727	-119.5271	2017-2019
E206089	Salmon River upstream of Glenemma	40.3	1,162	50.4561	-119.3728	2005-2010; 2016-2019 [2]
E206091	Salmon River downstream of Silver Creek	17.9	1,379	50.6083	-119.3642	2005-2010; 2016-2019
E206092	Salmon River at Hwy #1 Bridge near Salmon Arm	4.16	1,492	50.6926	-119.3303	2005-2019
E206771	Shuswap Lake Tappen Bay # 5	0	N/A	50.7239	-119.3014	2005-2008; 2010-2019

Hwy = Highway; N/A = not applicable.
[1]In addition, one sample was collected in 2014
[2]In addition, one sample was collected in 2011

2. METHODS

2.1 Data Compilation and Treatment

Water quality parameters from seven selected stations on the Salmon River (see Table 1) were obtained from the B.C. EMS database. Data were extracted from the EMS database using the R package (R Core Team 2022) "rems" (Teucher and Harker 2016). Water quality data from Tappen Bay site E206771 were provided by the B.C. Ministry of Environment and Climate Change Strategy (ENV) Water Protection and Sustainability Branch to ensure that the same data used during a recent update of WQOs for Tappen Bay were used in this report. The complete data set was translated and filtered using the "tidyverse" set of packages (Wickham 2021) to include water quality data for the period of record between 01 January 2005 and 31 December 2019. The dataset underwent several additional automated and manual data cleaning steps summarized below:

- For Tappen Bay lake samples, only one surface sample (upper depth < 10 m) per sampling date was included;
- Quality control/quality assurance (QA/QC) samples (i.e., equipment blanks and field blanks) were excluded;
- Samples were excluded where results were missing;
- For all parameters other than temperature and dissolved oxygen, samples were excluded where results were reported as 0 or negative values;
- Records where QA_INDEX_CODE = "F" were excluded. These data were coded by the EMS system to not be used due to issues that could lead to the data being misinterpreted;
- Field replicates (classified as "Replicate," "Replicate-First," or "Replicate-Second" in the EMS system) were treated as independent samples;
- Lab replicates were averaged prior to analyses;
- Data for parameters that could have been collected in the field and the lab (i.e., dissolved oxygen, pH, specific conductivity, temperature, turbidity), and where it wasn't clear if the EMS system accurately identified the collection location, were analysed together under the same name because they appeared to be similar values from a visual inspection of plots;
- Outliers (results greater than the upper inner fence of a box plot, defined as the 3rd quartile plus 1.5 times the interquartile range), as described in Reimann et al. (2005), were excluded prior to calculating summary statistics, WQO evaluation, and determination of spatial trends (methods for outlier identification of temporal trends are described in Section 2.2.4); and,
- Data were visually inspected, and samples were removed where results appeared to be obvious errors, assumed to be attributed to either data entry or analytical errors.

Fewer than 10% of samples were removed as outliers for most parameters (across all Salmon River stations), but some parameters (mainly total metals) had 10 to 23% of samples removed. For example, there were 93 (10.4%) outliers for fecal coliforms and 51 (23.3%) outliers for weak acid dissociable cyanide. Key parameters with > 10% outliers also include total organic carbon (TOC; 10.5%), ammonia nitrogen (dissolved; 12.2%), Enterococci (12.3%), turbidity (13.2%), and TSS (15%). The key parameters with > 10% outliers in the Tappen Bay data set were fecal coliforms (15.7%) and nitrite nitrogen (dissolved; 13.2%).

Summary statistics for each parameter, separated by time period (i.e., 2005-2010, 2011-2015, and 2016-2019) and station (and for all stations combined), as well as the frequency of exceedance of WQOs and B.C. WQGs for nitrate and nitrite, were calculated using the "tidyverse set of packages (R Core Team 2022; Wickham 2021).

2.2 Data Analysis

2.2.1 Hydrometric Data

Hydrometric data for the Salmon River near Salmon Arm were obtained from the Water Survey of Canada station 08LE021 located at a latitude of 50.6926 and longitude of -119.3303 (see Figure 1). The data were obtained using the package "tidyhydat" (Albers et al. 2021). The complete data set was filtered to include daily discharges for the period of record between 01 January 2005 and 31 December 2019. Flow rates were converted from cubic meter per second (m^3/s) to cubic feet per second (ft^3/s) using the equation: $ft^3/s = 35.3147*m^3/s$ in order to satisfy the requirements of the package R-QWTREND (Vecchia and Nustad 2020) developed by the U.S. Geological Survey (USGS).

2.2.2 Water Quality Data

Water quality parameters were obtained as described in Section 2.1 for EMS station E206092 (Salmon River at Highway #1 Bridge), located at the same latitude and longitude as the hydrometric station 08LE021 (i.e., 50.6926, -119.3303; see Figure 1). Temperature, dissolved oxygen, pH, TSS, turbidity, total phosphorus, total ammonia, fecal coliforms, and *E. coli* concentration were selected for analysis because WQOs were developed in 1998 for these parameters (BCMOE 1998). No WQOs were developed for total nitrogen or dissolved nitrate but values were compared to corresponding B.C. WQGs for the protection of aquatic life (ENV 2021b). Since different collection and analytical methods can cause variation in measured concentrations and detection limits and thus influence trend analysis, metadata describing collection method, presentation (calculated or measured), reporting units, and laboratory analysis method were considered carefully during data analysis.

2.2.3 Spatial Analysis

A spatial evaluation (i.e., comparisons of upstream and downstream water quality conditions) was conducted using data from two water quality stations along the Salmon River. The upstream most station (EMS site E206084) and the long-term monitoring location (EMS site E206902; upstream of Shuswap Lake) were selected to capture the changes in water quality between the upstream most and downstream most stations along the Salmon River. The spatial evaluation was conducted on a subset of the data with overlapping periods of record at the two selected stations (i.e., data collected between 25 April 2005 and 18 March 2010 and from 26 April 2016 to 27 April 2017). Selected parameters were used in the analysis, including total phosphorus, orthophosphate, total nitrogen, total nitrate plus nitrite, and *E. coli*. As streamflow data were not available for the upstream most station, turbidity and TSS were evaluated as potential covariates in the analysis to account for some of the variation in water quality condition. Based on data availability, turbidity was selected as the preferred covariate. The available water quality data were classified as either collected during clear flow or turbid flow conditions, where turbid flow conditions were specified as data associated with turbidity concentrations greater than 7.9 NTU, which corresponds to a TSS condition of 25 mg/L (the turbid flow threshold in ENV (2021c) based on the site-specific relationship between the two parameters (turbidity = $10^{(0.871(\log_{10}TSS) - 0.319)}$); $R^2 = 0.83$; $p < 0.05$).

Prior to testing for differences in parameter concentrations between the stations, the analytical chemistry data were assessed for normality. Both the total nitrate plus nitrite and *E. coli* concentrations were $\log_{10}$ transformed to reduce skewness. Student's t-tests (two-sided; $\alpha = 0.05$) were run to compare parameter concentrations between the upstream most and downstream most stations on the Salmon River in each flow period.

2.2.4 Temporal Trend Analysis

Water quality in the Salmon River is driven in large part by streamflow. Because a complete set of streamflow and long temporal record (greater than 10 years with a minimum of 4 samples per year) is necessary for temporal trend analysis, EMS site E206092 was selected for evaluation, since it is co-located with a Water Survey Canada site (08LE021) and is a long-term Federal-Provincial monitoring station.

Temporal trend analyses were conducted using a publicly available R package (R Core Team 2022) developed by the USGS called R-QWTREND (Vecchia and Nustad 2020). This package uses the Gaussian maximum likelihood estimation to determine complex trends that take into account flow-related variability and seasonal serial correlation. R-QWTREND relies on a series of functions that will fit the model parameters to the chosen dataset, identify potential trends, and determine a significance level (a *p*-value) associated with the trend. The time-series model is also using a periodic autoregressive moving average (PARMA) to correct for the auto-correlation of datapoints that show a periodic or seasonal interdependence. The model can interpret censored data (i.e., below detection limit) but they should not represent more than 25% of the full dataset. Once parameter values are normalized to account for flow variability (i.e., detrended), a one-period trend was tested on each dataset, and resulting models were compared with the null model (i.e., no trend). One-period trends were considered statistically significant at $\alpha = 0.05$. Generalized likelihood ratio tests were used to compare if the one-period trend model had a significantly better fit to the flow-normalized data than the null trend model ($\alpha = 0.05$). The magnitude of the trend obtained was expressed in percent change in concentrations between the start and end year (usually 2005 and 2019). Outliers were identified by R-QWTREND with a different method than described in Section 2.1, and outliers identified by the box plot's upper inner fence method were not removed prior to the temporal trend analysis. For the trend analysis, outliers were only removed when the absolute value of the standardized residuals from the trend model were larger than 3.5 (Vecchia and Nustad 2020). The number of outliers removed did not exceed 2% of the dataset for any parameters.

3. <u>RESULTS AND DISCUSSION</u>

3.1 Discharge

The hydrometric data for the period 2005 to 2019 at gauge station 08LE021 was summarized by calculating the mean daily discharge along with the 5^{th} and 95^{th} percentile daily discharge and is presented in Figure 2. Flow rates in the Salmon River usually increase in spring to peak during the month of May (i.e., freshet), after which flows decrease until August, when they then remain low through the fall and winter. The lowest flows (0.344 to 0.722 m^3/s) were measured in August 2009 and the highest flows (56.0 to 75.4 m^3/s) in May 2018.

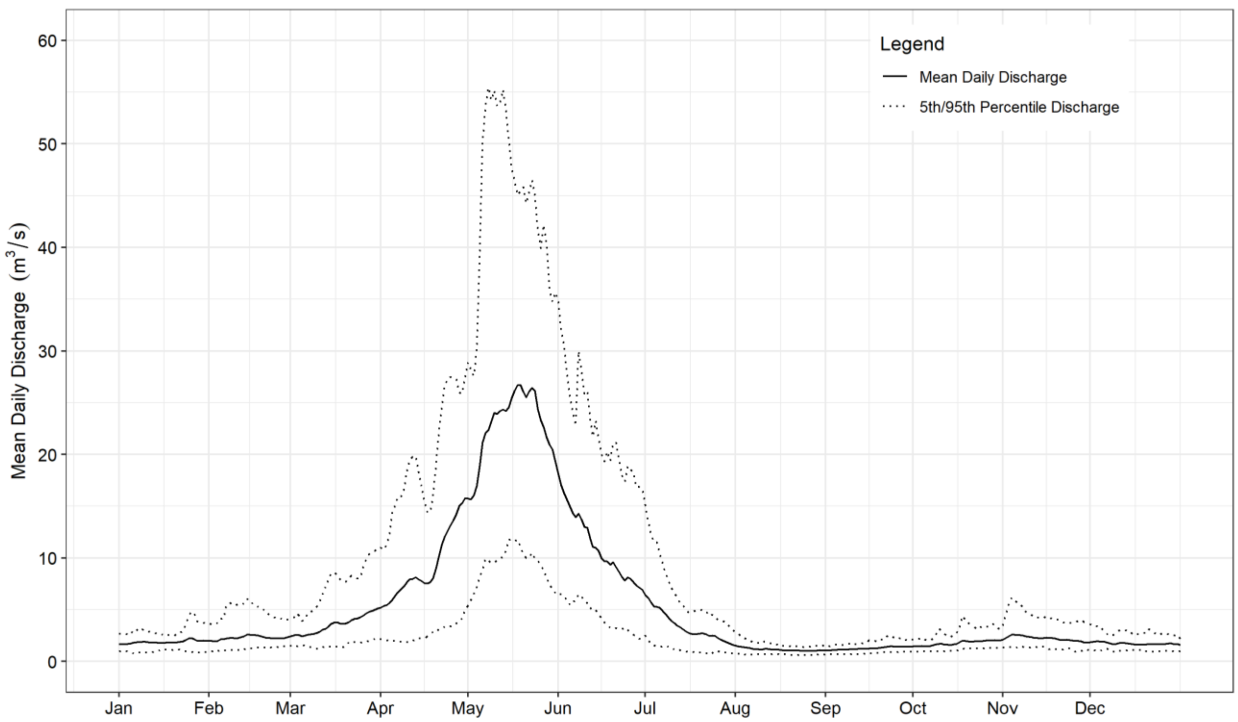

Figure 2: Daily discharge at station 08LE021 (Salmon River near Salmon Arm) between 2005 and 2019.

The presence of a potential increasing or decreasing trend in flow rates was tested using a linear model regression and a Mann-Kendall trend analysis on the yearly median discharge (Figure 3). Even though there is an apparent increasing trend in flow rates over time, this increase was not significant according to both statistical analyses ($p > 0.05$). Median flow rates were the lowest between 2007 and 2012, and the highest in 2016.

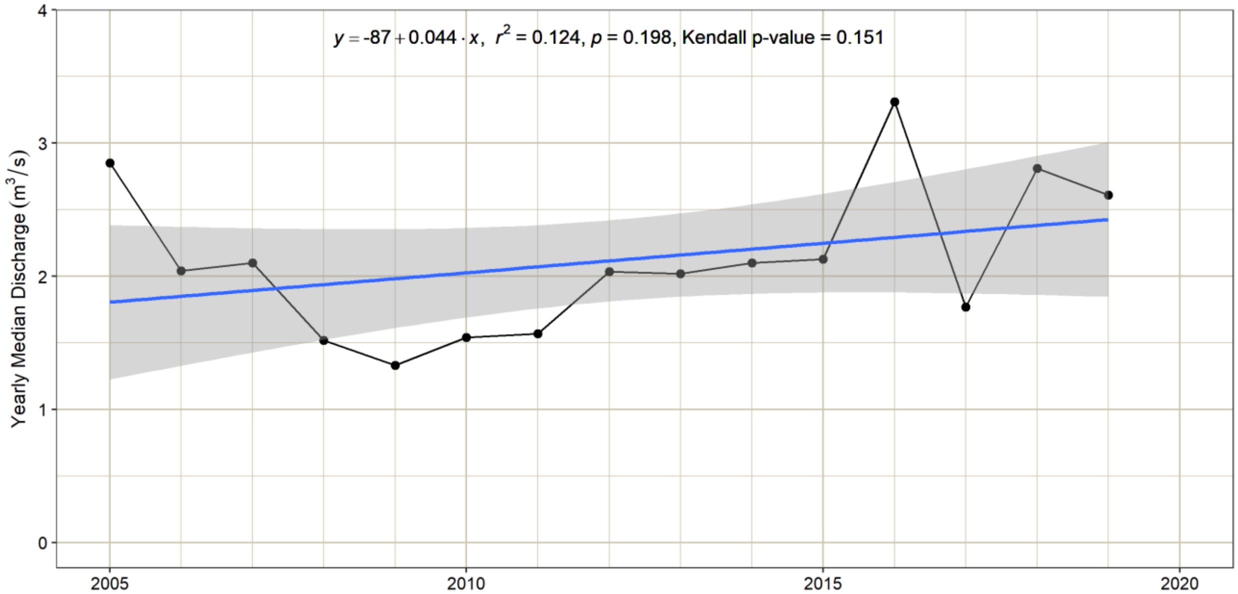

Figure 3: Yearly Median Discharge at station 08LE021 between 2005 and 2019 with linear regression.

3.2 Sampling Events for Periods of Interest

Two sampling cycles were investigated as part of this report. The distribution of sampling events at each EMS station between January 2005 and March 2010 is presented in Figure 4, while the number of sampling events for the period 2016 to 2019 (inclusive) is presented in Figure 5. In general, the sampling event was more intensive between 2005 and 2010 than between 2016 and 2019. During the former period, 53 samples were taken at E206089, 151 samples were taken at E206087, and around 145 samples were taken at each of the remaining stations. Station E230797 was not sampled before 2017.

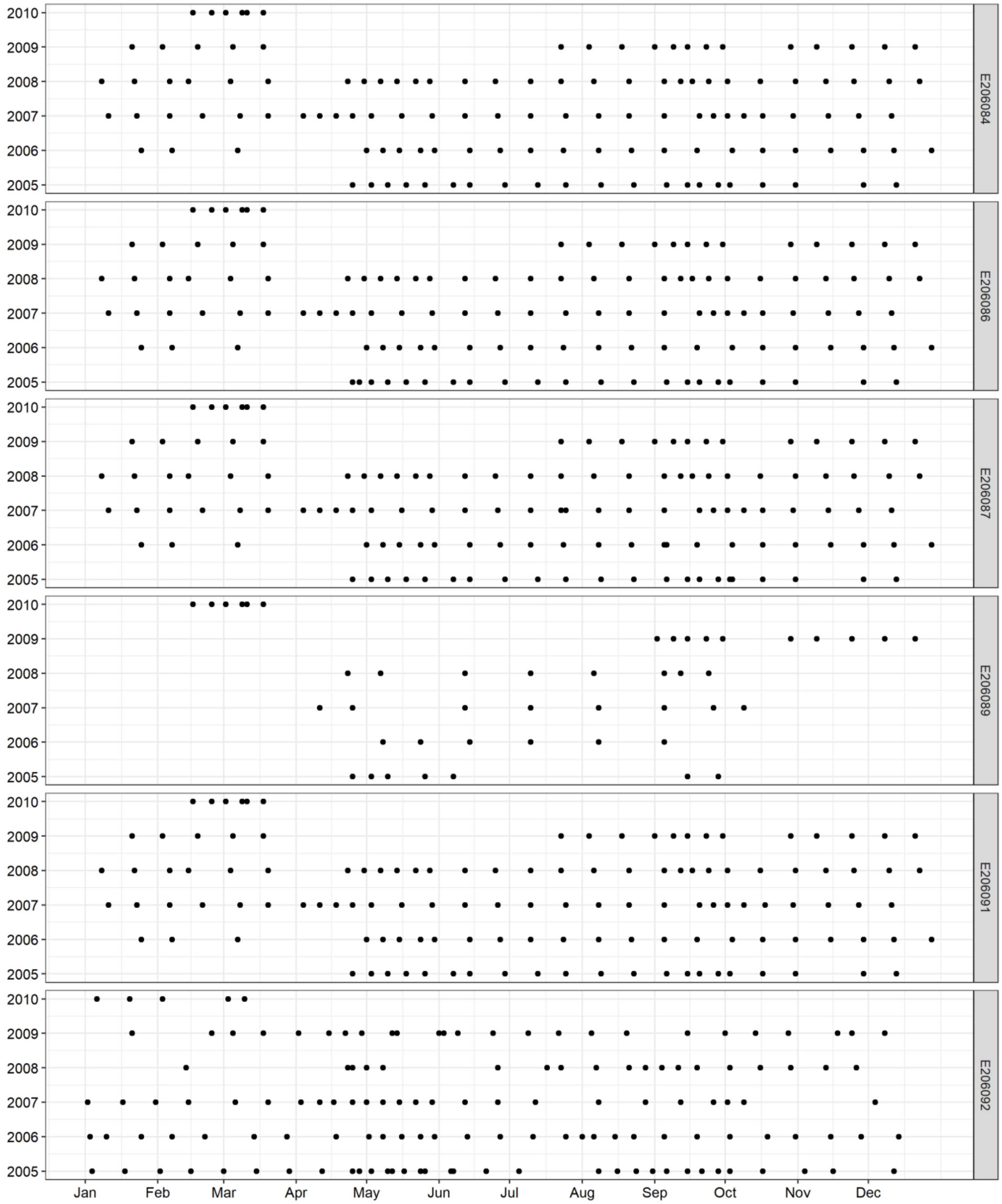

Figure 4: Sampling events for the different sites on the Salmon River (2005 to March 2010).

In comparison, station E206084 was sampled only 22 times over the period 2016 to 2019 (all in 2016 and early 2017), while station E206092 was sampled 106 times. Station E230797 was sampled 40 times, starting in 2017, while 60 to 65 samples were taken at each of the remaining stations between 2016 and 2019 (inclusive).

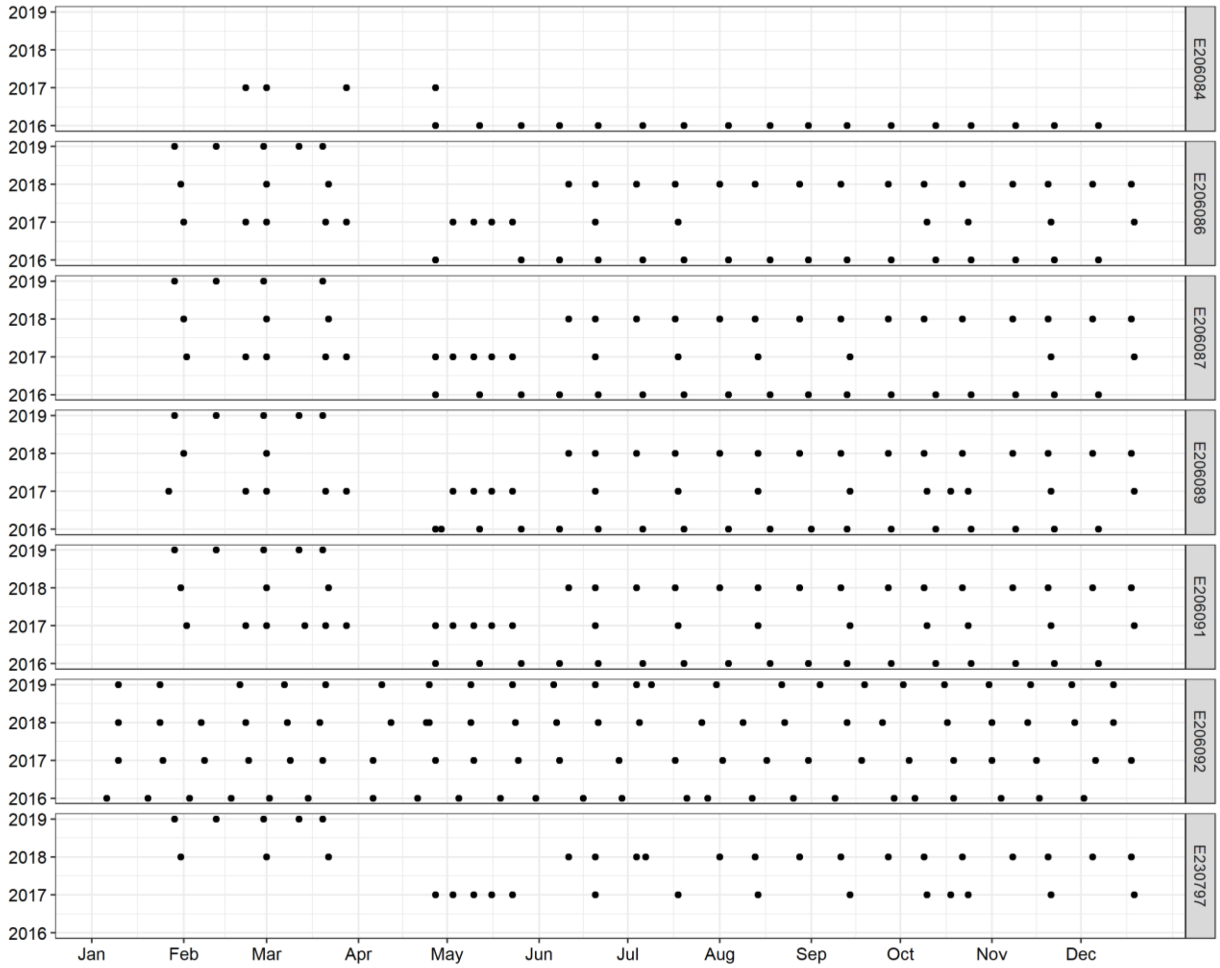

Figure 5: Sampling events for the different sites on the Salmon River (2016 to 2019).

Tables of summary statistics for the majority of the parameters measured during these two sampling periods are presented in Appendix A. Summary statistics of total metals are presented in Appendix B. Parameters were not measured with equal frequency at the different stations. For example, metals were measured about 20 times while microbial indicators were measured about 110 times and conventional parameters up to 126 times at station E206086 during the first sampling event. During the 2016 to 2019 sampling effort, parameters were measured more equally, possibly due to the lower cost of some analyses, such as measurements of metals and ions.

3.3 Salmon River Water Quality

3.3.1 Conventional Parameters

Conventional field parameters measured at each of the EMS stations are presented in Figure 6 along with the corresponding WQOs. All stations were monitored in both study periods, except E230797 which was only monitored after 2017. Several exceedances of WQOs are observed. Temperature exceeded the long-term WQO of 14.2°C on average 14% of the time between 2005 and 2010 and dissolved oxygen was below the long-term WQO of 11 mg/L 32% of the time (but below the short-term WQO of 9 mg/L only 11% of the time). In the 2016 – 2019 period, temperature exceeded the long-term WQO in 18% of all measurements taken and dissolved oxygen was below the long-term WQO of 11 mg/L 52% of the time (but below the short-term WQO of 9 mg/L only 9% of the time). There were a few very low dissolved oxygen values between 2005 and 2010 and the cause is not known but there were no values below 5 mg/L (the short-term minimum) between 2016 and 2019.

pH was occasionally higher (1.6% and 5.9% of the time in the 2005 – 2010 and 2016 – 2019 periods, respectively) than the upper end of the long-term WQO range (i.e., 8.5 pH units). Turbidity, TSS, and TOC concentrations could not be compared to their respective WQOs or WQGs because these WQOs and WQGs are based on background concentrations (e.g., the long-term TSS WQO is 10 mg/L over background). Based on visual recognition using high resolution satellite imagery from ArcGIS Pro (ArcGIS Pro 2.9 2022), no background or reference station is available for this study, since there are land disturbances such as farming or urbanization around all stations studied and no station was monitored further upstream. Turbidity ranged from 0.2 to 26.4 NTU in 2005 – 2010 (mean = 3.81 NTU) and from 0.285 to 23.2 NTU in 2016 – 2019 (mean = 3.36 NTU), while TSS ranged from <1 to 52 mg/L in 2005 – 2010 (mean = 6.09 mg/L) and from <1 to 47.3 mg/L in 2016 – 2019 (mean = 7.67 mg/L). TOC ranged from 2.21 to 15.5 mg/L (mean = 5.26 mg/L) in the 2016 to 2019 period. TOC was only measured once between 2005 and 2010 (at station E206089) and the value was 7.7 mg/L. Data summaries for each station are available in Appendix A.

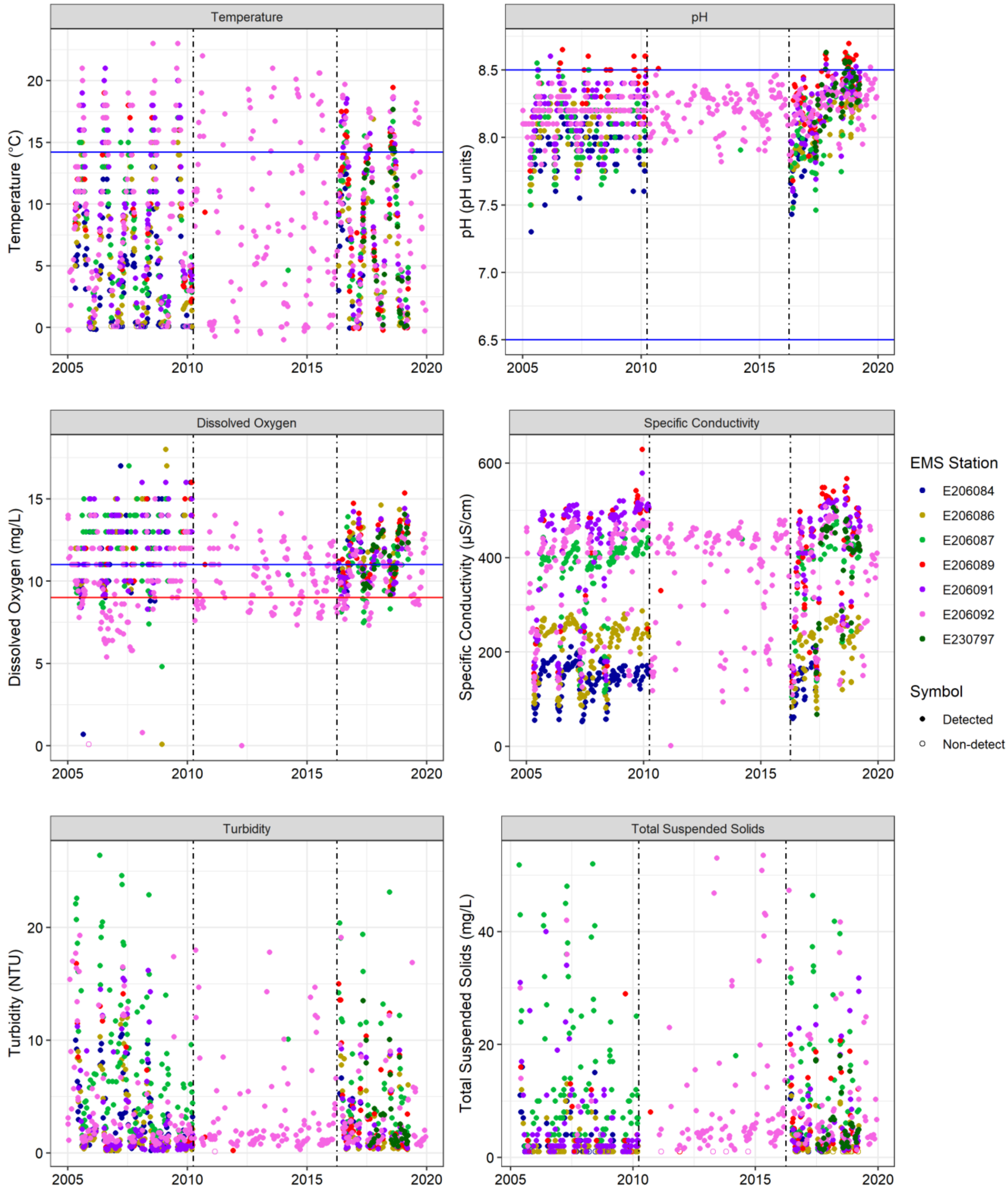

Figure 6: Conventional parameter values measured at each of the EMS stations in the Salmon River between 2005 and 2019. The blue line and the red line are the long-term WQO and the short-term WQO, respectively, for that parameter. The vertical dashed lines are the limits of the two periods of focus (2005 to March 2010 and April 2016 to 2019).

3.3.2 Nutrients

Several nitrogen species measured in the Salmon River are presented in Figure 7. None of these nitrogen species exceeded their respective WQO or WQG at any time during both monitoring periods.

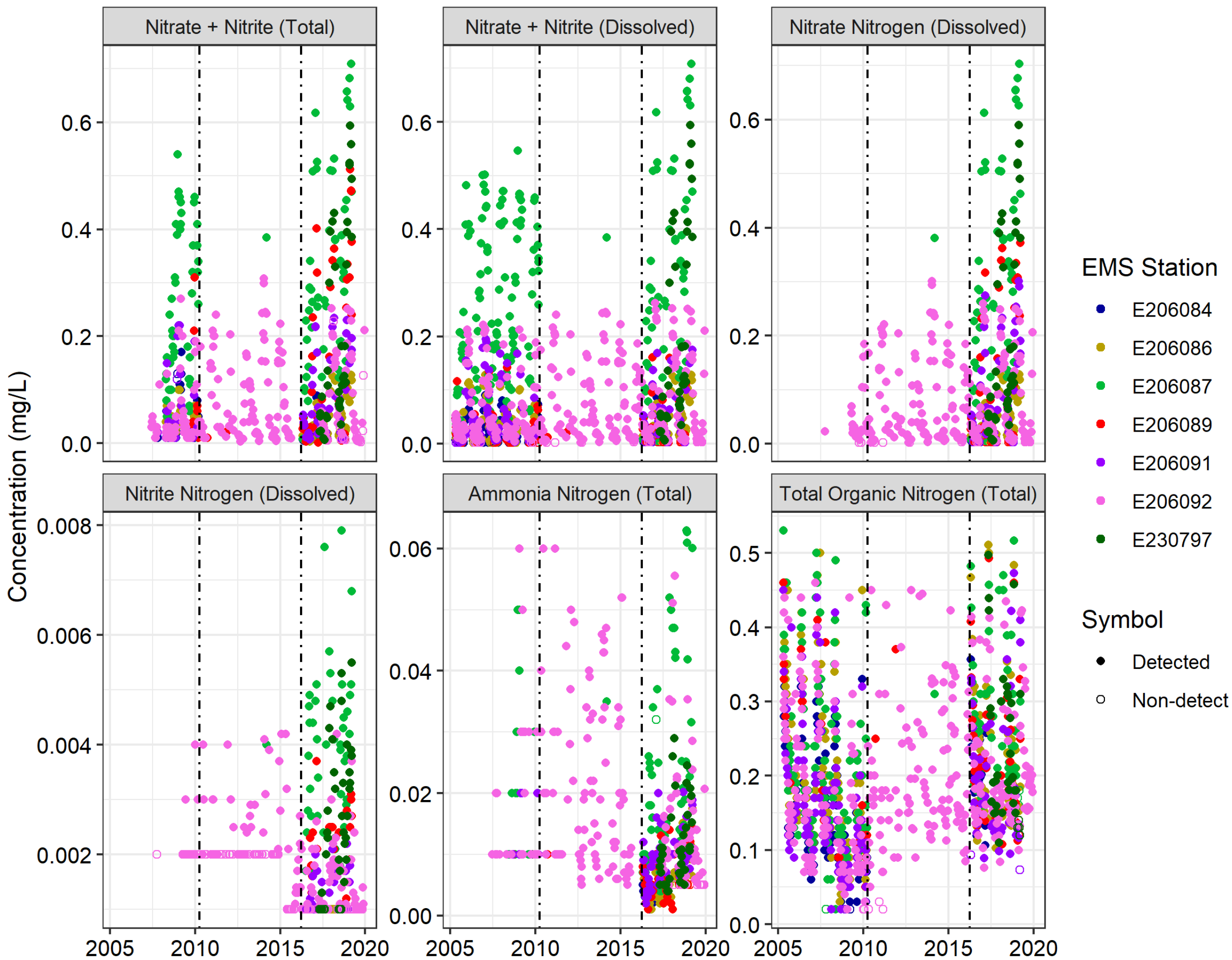

Figure 7: Concentrations of nitrogen species measured at each of the EMS stations in the Salmon River between 2005 and 2019. WQOs and WQGs that were far above the measured concentrations are not represented on the plots for improved visualisation. WQOs for Ammonia Nitrogen vary between 0.461 and 1.2 mg/L depending on the median pH and temperature at the respective EMS station. The B.C. WQG for Nitrate Nitrogen of 3 mg/L could also be compared to Nitrate + Nitrite (Total) and Nitrate + Nitrite (Dissolved) because the Nitrite concentrations are two orders of magnitude less than the Nitrate concentrations. The lowest B.C. WQG for Nitrite Nitrogen is 0.02 mg/L (when chloride < 2 mg/L). The vertical dashed lines are the limits of the two periods of focus (2005 to March 2010 and April 2016 to 2019).

Phosphorus species, TOC, dissolved organic carbon (DOC), and hardness are presented in Figure 8. No WQOs were developed for these parameters, except for total phosphorus in Tappen Bay, which will be discussed in Section 3.6. The B.C. WQG for TOC for the protection of aquatic life is dependent on ambient background concentrations; the 30-day median value of TOC must be within 20% of the seasonally-adjusted median background concentration (ENV 2021a). However, since there is no reference site on the Salmon River, no background concentration was available to calculate the long-term WQG. In Figure 8, TOC values are compared to the raw drinking water guideline (source water) of 4 mg/L (ENV 2020), which was exceeded in 58.8% of samples collected at the different stations between 2016 and 2019.

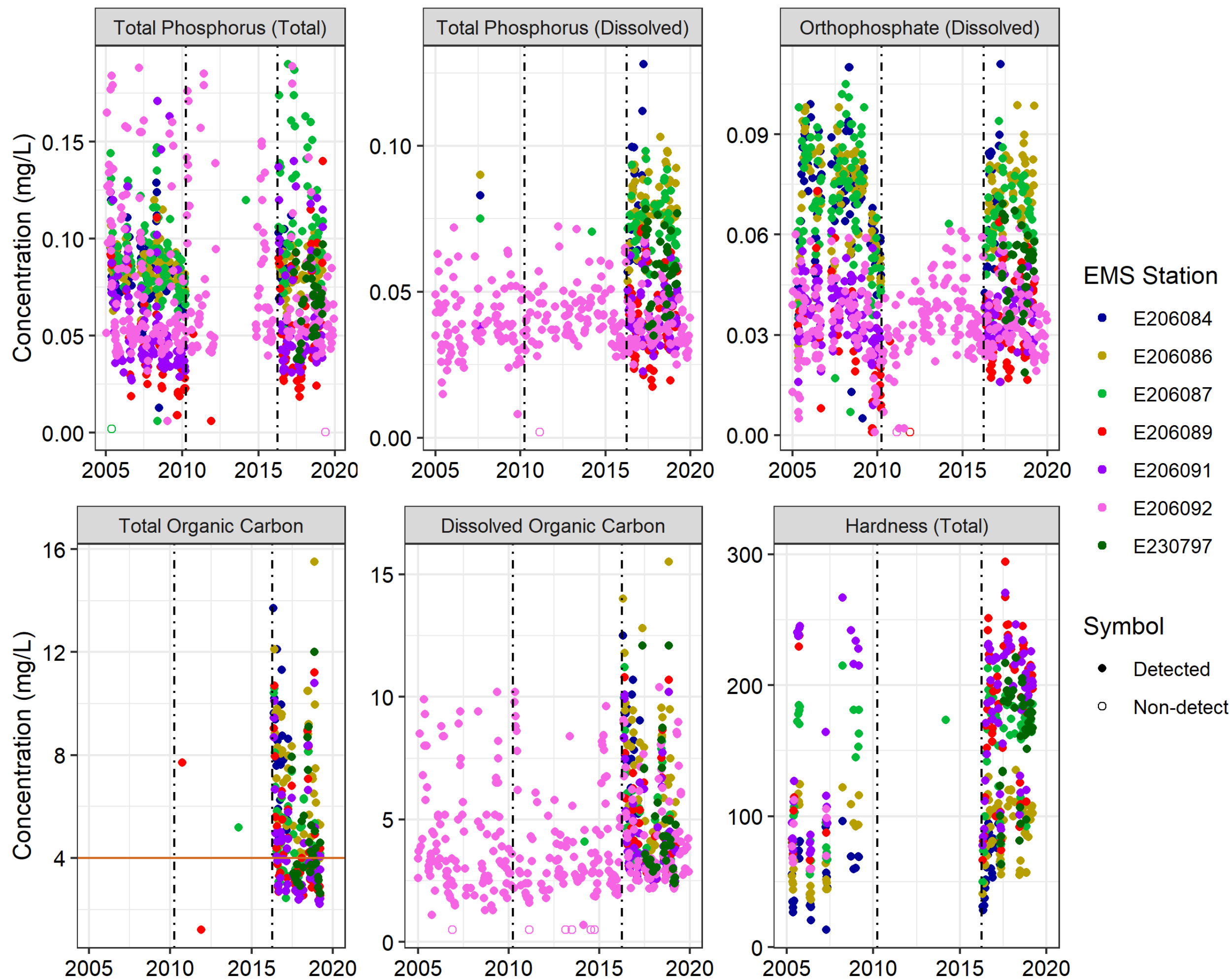

Figure 8: Concentrations of phosphorus species, dissolved or total organic carbon, and hardness measured at each of the EMS stations in the Salmon River between 2005 and 2019. The orange line is the total organic carbon WQG for raw drinking water (source water; ENV 2020). The vertical dashed lines are the limits of the two periods of focus (2005 to March 2010 and April 2016 to 2019).

3.3.3 Microbial Indicators

Fecal bacteria and Enterococci were only measured between 2005 and 2010 at all stations, with the exception of station E206092, which had measurements of fecal bacteria until the end of 2019 (Figure 9). The number of exceedances of short-term WQOs is high, about 79%, 88%, and 76% of samples for fecal coliforms (WQO = 10 colonies/100 mL), *Enteroccocus sp.* (WQO = 3 colonies/100 mL), and *E. coli* (WQO = 10 colonies/100 mL), respectively, in the first period of time, and in 93% and 77% of the samples for fecal coliforms and *E. coli,* respectively, during the period 2016 to 2019 (Enterococci were no longer measured at any station after 2010; Figure 9; Table A1; Appendix A). However, these statistics were calculated by comparing individual sample results to the WQOs, rather than comparing the 90th percentile of a minimum of five samples to the WQOs, as they were designed to be used. The 90th percentile of samples at each station within a time period was always higher than the short-term WQOs for microbial indicators. These short-term WQOs were based on the B.C. WQGs for drinking water (source water before treatment). However, the fecal coliforms WQG for drinking water (source water) has been archived since it was considered a poor risk indicator for waterborne illness in humans (ENV 2020). Therefore, the short-term WQO for fecal coliforms should also be rescinded.

In addition, B.C. has WQGs to protect general livestock use from microbial indicators: a maximum of 200 colonies/100 mL for *E. coli* and fecal coliforms, and 50 colonies/100 mL for Enterococci (ENV 2021d). When all stations were combined, *E. coli* and fecal coliforms exceeded this livestock WQG in 3.6% and 4.3% of samples collected between 2005 and 2010, respectively, while 3.9% and 14% of samples collected from 2016 to 2019 exceeded the *E. coli* and fecal coliforms livestock WQGs, respectively (Table A2; Appendix A). The Enterococci livestock WQG was exceeded in 25% of samples during the first time period, after which Enterococci were no longer measured (Figure 9; Table A2; Appendix A).

In recent years, B.C. has adopted Health Canada's guidelines of 200 *E. coli*/100 mL (geometric mean of 5 samples) or 400 *E. coli*/100 mL (one single sample) and 35 Enterococci/100 mL (geometric mean of 5 samples) or 70 Enterococci/100 mL (one single sample) for recreational waters (Health Canada 2012; ENV 2019). *E. coli* never exceeded the maximum single sample WQG of 400 *E. coli*/100 mL in any sample, but about 14% of all Salmon River samples collected from 2005 to 2010 exceeded the single sample maximum for Enterococci (Figure 9; Table A2; Appendix A). The frequency of exceedance of the general livestock use and recreation WQGs for each station is provided in Table A10, Appendix A. In the future, microbial indicators should be compared to these WQGs for general livestock use and recreational waters, rather than to the WQOs that are to protect raw drinking water sources, since the Salmon River is more likely to be used for livestock watering and for recreation than as a source of drinking water.

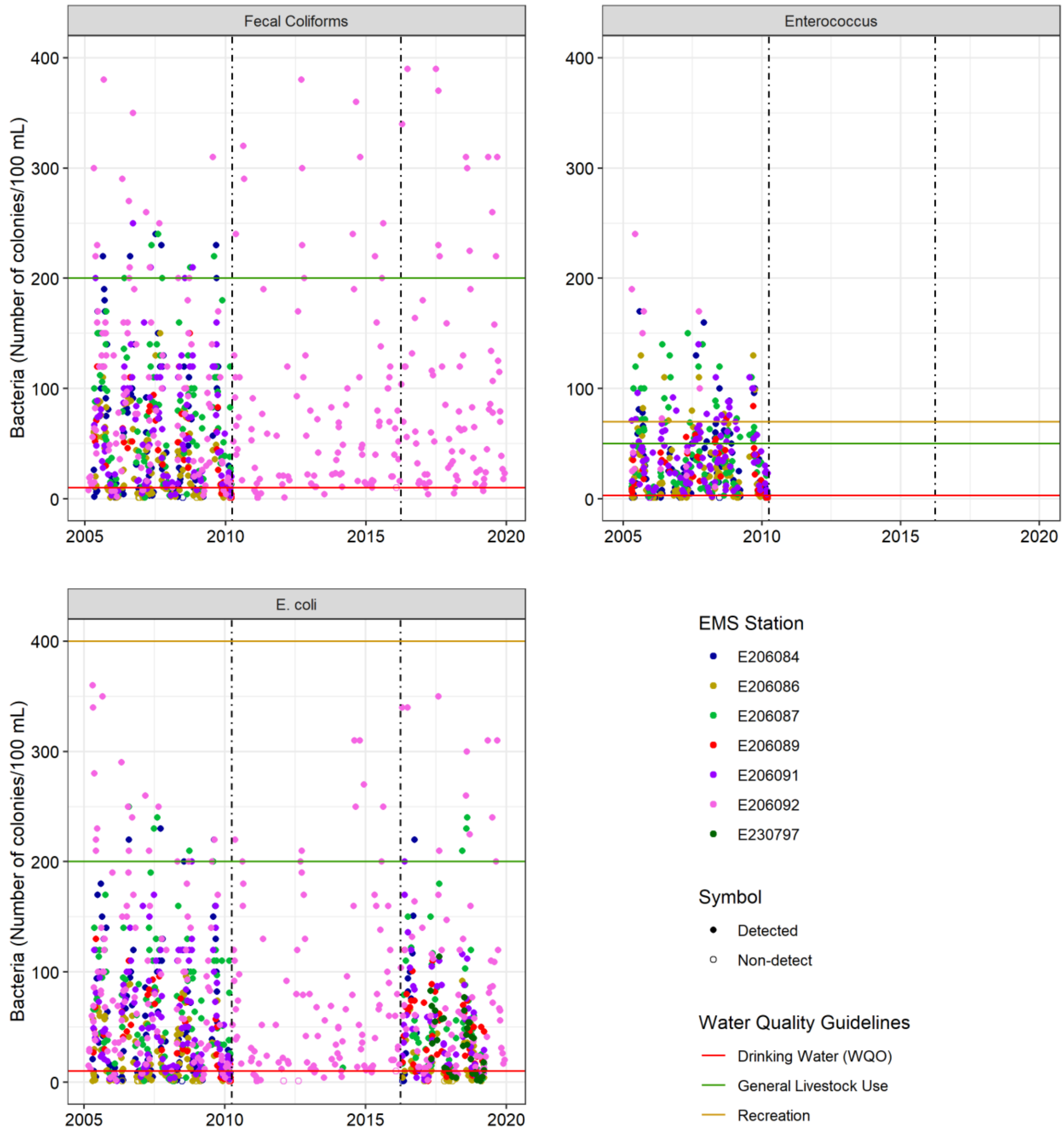

Figure 9: Microbial indicator concentrations measured at each of the EMS stations in the Salmon River between 2005 and 2019. The red line, green line, and gold line are the short-term WQO, the B.C WQG for general livestock use, and the Health Canada guideline for a single sample maximum concentration in recreational waters, respectively, for that parameter. The vertical dashed lines are the limits of the two periods of focus (2005 to March 2010 and April 2016 to 2019).

3.4 Spatial Analysis

Water quality in the Salmon River is influenced by land use. Land use information was gathered from Gwanikar et al. (1998a) and might have changed substantially since the publication of their report.

Intensive agriculture is conducted throughout most of the Salmon River watershed. Agriculture is linked to the degradation of riparian habitats, erosion of streambanks, and inputs of nutrients, fecal coliforms, and pesticides to watercourses. Station E206084 is the most upstream station in this analysis and located in the vicinity of a farm, but agriculture is less intensive than at the downstream stations. Around Falkland, just downstream of EMS site E206087, a number of livestock production operations contributed to the increase in total phosphorus and orthophosphate in the past (Gwanikar et al. 1998a). Finally, removal of forest cover around the Salmon River can also lead to increased nutrient and suspended sediment loads to the river.

Gwanikar et al. (1998b) presented results of the spatial variation in selected parameter concentrations from upstream to downstream on the Salmon River. Using data collected in May 1989, average orthophosphate concentrations stayed in the 0.025 to 0.058 mg/L range from E206084 to E206092, with the highest concentrations at E206087, just upstream of Falkland. Total phosphorus concentrations followed a similar pattern, except that the peak of measured concentrations (~0.2 mg/L) was found upstream of E206086. Fecal coliform concentrations were relatively low at E206084 (< 10 CFU/100 mL) but increased substantially after E206086, to peak at E206087 (~250 CFU/100 mL) and stay relatively high for the remainder of the Salmon River. In the summer of 1995, total nitrogen concentrations were the highest at E206087 (~0.75 mg/L), then decreased to and remained ~0.2 mg/L from E206089 to E206092 (Gwanikar et al. 1998b).

Using the data collected between 2005 and 2010 and 2016 to 2017, variations in water quality between the upstream most station (i.e., EMS site E206084) and the downstream most station (i.e., EMS site E206092) were characterized for selected parameters including total phosphorus, orthophosphate, total nitrate plus nitrite, total nitrogen, and *E. coli*. A summary of the results of these analyses are presented in **Error! Reference source not found.**.

Mean concentrations of total phosphorus were significantly higher at the upstream station E206084 (0.082 mg/L) compared to E206092 (0.061 mg/L; $p < 0.05$) during clear flow periods but were significantly higher downstream during turbid flow periods (0.097 mg/L upstream and 0.112 mg/L downstream; $p < 0.05$). Orthophosphate concentrations were significantly higher at E206084 during both the clear and turbid flow periods with mean concentrations of 0.070and 0.058 mg/L, respectively. Downstream, at EMS site E206902, mean concentrations were 0.035 and 0.040 mg/L during clear and turbid flows, respectively. The observed concentrations between 2005 and 2017 were generally similar to those reported in Gwanikar et al. (1998b; noted above).

Total nitrogen exhibited the opposite pattern compared to phosphorus. Upstream concentrations (E206084) were significantly lower, when compared to the downstream station (E206092) during clear flow periods. The mean concentration measured during clear flow periods was 0.169 mg/L upstream and 0.218 mg/L downstream ($p < 0.05$). During turbid periods, no significant difference in total nitrogen concentrations between upstream and downstream was observed (0.328 versus 0.349 mg/L; $p = 0.38$). Total nitrate plus nitrite geometric mean concentrations were significantly lower upstream at E206084 (0.009 mg/L) during clear flow periods relative to the downstream station (0.019 mg/L; $p < 0.05$). Similarly, during turbid flow periods, the geometric mean upstream concentration was 0.0073 mg/L while downstream, the geometric mean concentration was 0.038 mg/L ($p < 0.05$).

E. coli concentrations were significantly lower at the upstream station during both the clear and turbid flow periods with geometric mean concentrations of 22.0 CFU/100 mL and 10.5 CFU/100 mL, respectively. Downstream, at EMS site E206902, geometric mean concentrations were 48.3 and 67.5 CFU/100 mL during clear and turbid flows, respectively.

Table 2: Comparison of mean concentrations for selected parameters at EMS sites E206084 and E206092.

		Upstream (E206084)			Downstream (E206092)				
Parameter	**Flow Period**	**n**	**Mean**	**SD**	**n**	**Mean**	**SD**	***t* Statistic**	***p*-value**
Total Phosphorus (mg/L)	Clear	118	0.082	0.012	99	0.061	0.024	7.90	< 0.05
	Turbid	24	0.097	0.022	27	0.112	0.033	-1.85	< 0.05
Orthophosphate (mg/L)	Clear	108	0.070	0.017	100	0.035	0.015	16.4	< 0.05
	Turbid	22	0.058	0.023	39	0.040	0.022	3.14	< 0.05
Total Nitrogen (mg/L)	Clear	125	0.169	0.064	108	0.218	0.110	-4.01	< 0.05
	Turbid	23	0.328	0.084	34	0.349	0.084	-0.892	0.38
Nitrate plus Nitrite (Total; mg/L)	Clear	121	0.009[1]	0.032	89	0.019[1]	0.028	-4.67	< 0.05
	Turbid	24	0.0073[1]	0.015	50	0.038[1]	0.029	-6.40	< 0.05
***E. coli* (CFU/100 mL)**	Clear	113	22.0[1]	62.6	104	48.3[1]	72.3	-4.05	< 0.05
	Turbid	22	10.5[1]	60.0	43	67.5[1]	72.5	-5.80	< 0.05

E206084: Salmon River upstream of McInnis Creek; E206092: Salmon River at Hwy #1 Bridge near Salmon Arm; n = number of data points; SD = standard deviation; *t* Statistic = statistical estimate of the magnitude of difference between stations; *p*-value = probability value

1. Geometric mean is presented for $\log_{10}$-transformed data.

3.5 Temporal Trends Analysis at Station E206092

Water quality in the Salmon River is driven in large part by streamflow, as shown with the example of total phosphorus in Figure 10. Hence all parameters for the temporal trend analysis were normalized to the measured discharge values (i.e., detrended). Temporal trends were conducted for parameters that had recommended objectives in the 1998 Salmon River WQOs report (BCMOE 1998) using R-QWTREND (Vecchia and Nustad 2020). The list of outliers removed from the dataset is presented in Table C1 (Appendix C). Each studied parameter was scrutinised for a change in analytical (laboratory or field) method and step trends were tested if a substantial shift of methodology was observed (i.e., a different method was used over several years). The presence of a temporal trend or step trends are reported in Table 3 and discussed below. Large gaps in data or a shorter timeframe of analysis are also reported in Table 3.

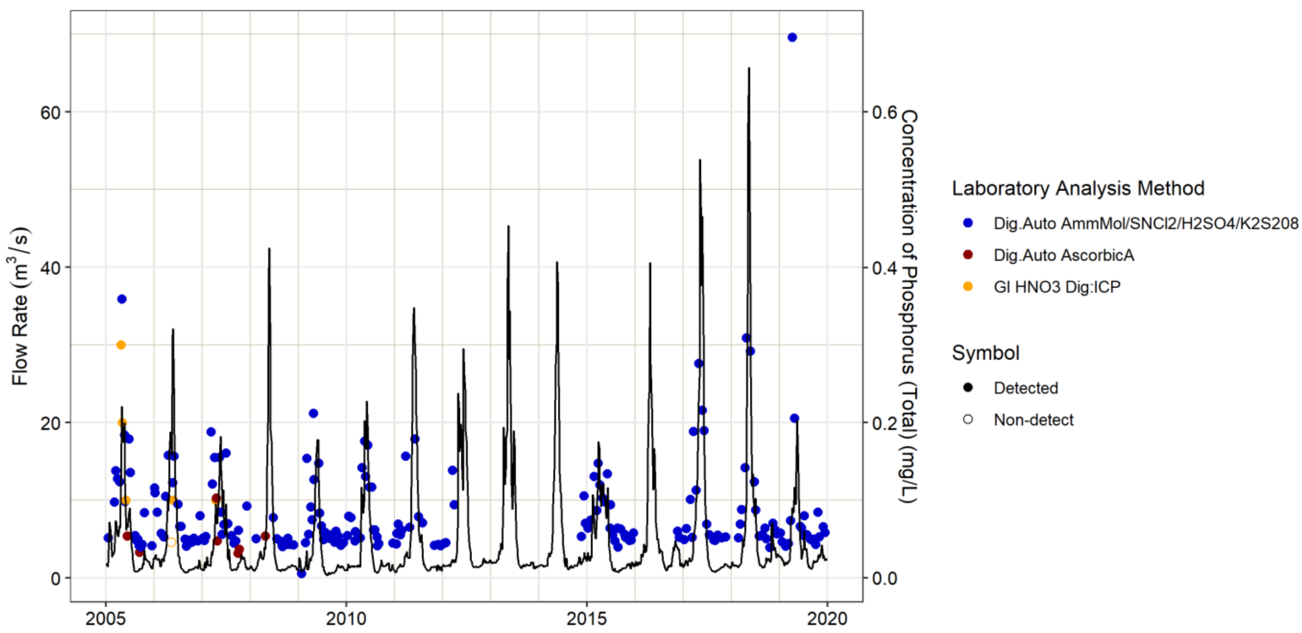

Figure 10: Concentration of total phosphorus (points, right y-axis) and flow rates (solid line, left y-axis) at Station E206092/08LE021 over the time period 2005-2019.

Table 3: Summary of temporal trend analysis for E206092 – Salmon River at Salmon Arm station.

Parameter	Unit	Trend period	Number of data points[1]	Best-fit trend model[2]	Percent change	Trend direction	*p*-value	Annual flow-weighted geometric mean concentration	
								start year	end year
Conventional Parameters									
Temperature	°C	2005-2019	354	Null					
Dissolved Oxygen	mg/L	2005-2019	318	Null					
pH	pH units	2005-2019	369	Null					
Specific Conductivity	µS/cm	2005-2019	369	1-period	13%	up	<0.001	320	363
Turbidity	NTU	2005-2019	366	1-period	33%	down	0.001	4.41	2.20
Total Suspended Solids[3]	mg/L	2005-2019	209	Step					
Nutrients									
Total Nitrogen	mg/L	2005-2019	355	Null					
Nitrate plus Nitrite (Total)[4]	mg/L	2007-2019	217	1-period	50%	down	0.014	0.077	0.028
Nitrate plus Nitrite (Dissolved)	mg/L	2005-2019	347	Null					
Nitrate Nitrogen (Dissolved)	mg/L	2009-2019	244	Null					
Nitrite Nitrogen (Dissolved)	Non-detect values > 25% of dataset								
Ammonia Nitrogen (Total)	mg/L	2007-2019	187	Step					
Ammonia Nitrogen (Dissolved)	mg/L	2005-2017	273	Step					
Total Organic Nitrogen	mg/L	2005-2019	347	Null					
Total Phosphorus (Total)[5]	mg/L	2005-2019	281	Null					
Total Phosphorus (Dissolved)	mg/L	2005-2019	323	Null					
Orthophosphate (Dissolved)	mg/L	2005-2019	337	1-period	22%	down	0.004	0.039	0.029

Parameter	Unit	Trend period	Number of data points[1]	Best-fit trend model[2]	Percent change	Trend direction	*p*-value	Annual flow-weighted geometric mean concentration	
								start year	end year
Total Organic Carbon	Not enough data to conduct trend analysis								
Dissolved Organic Carbon	mg/L	2005-2019	342	Null					
Bacterial Indicators									
Total Coliforms	Not enough data to conduct trend analysis								
Fecal Coliforms	CFU/100 mL	2005-2019	343	Null					
Escherichia coli	CFU/100 mL	2005-2019	342	Null					
Enterococcus sp.	Not enough data to conduct trend analysis								

1. Number of data points available before outliers were removed (see Appendix C) and serial correlation was corrected using PARMA filtration (see Section 2.2.4).
2. A null model result means that no statistically significant trend was detected for this data set over the time period. A 1-period trend result means that an upward or downward trend over the time period was significantly different from the null model. A step trend means that a change in analytical method (field or laboratory measurement) is causing a significant upward or downward trend.
3. Not enough data points prior to 2013; the model fit is compromised.
4. Total nitrate plus nitrite is based on a system calculation that could be hiding a step trend if measurement methods have changed during that time period.
5. Some years did not have any total phosphorus data (see Figure 10); the validity of the model is compromised.

3.5.1 Step Trends in Parameter Values

Datasets were analysed for the presence of trends due to a methodology change. Half-way through the year of 2015, several parameters were measured using a different method. For instance, dissolved phosphorus was measured using a method that included a reaction with ascorbic acid after digestion with several chemicals ("Dig.Auto AscorbicA") from 2005 to June 2015 and a more simple digestion with persulfate ("Persulfate Dig;Col'm") from June 2015 to December 2019. In many cases, this did not result in a step trend issue, especially when the concentrations of the parameter were above the detection limit. However, step trends affected three of the parameters that were analysed (i.e., TSS, total ammonia, and dissolved ammonia). Step trends often caused a decrease or increase in measured values that could be confused as a temporal trend. The example of total ammonia is provided in Figure 11. The change of method from a system calculation to “NH3-F-VA” (analysis of ammonia in water by fluorescence) caused a decrease in flow-weighted data, possibly because the newer method is more sensitive, or resulted in a higher number of non-detects than the former system calculation.

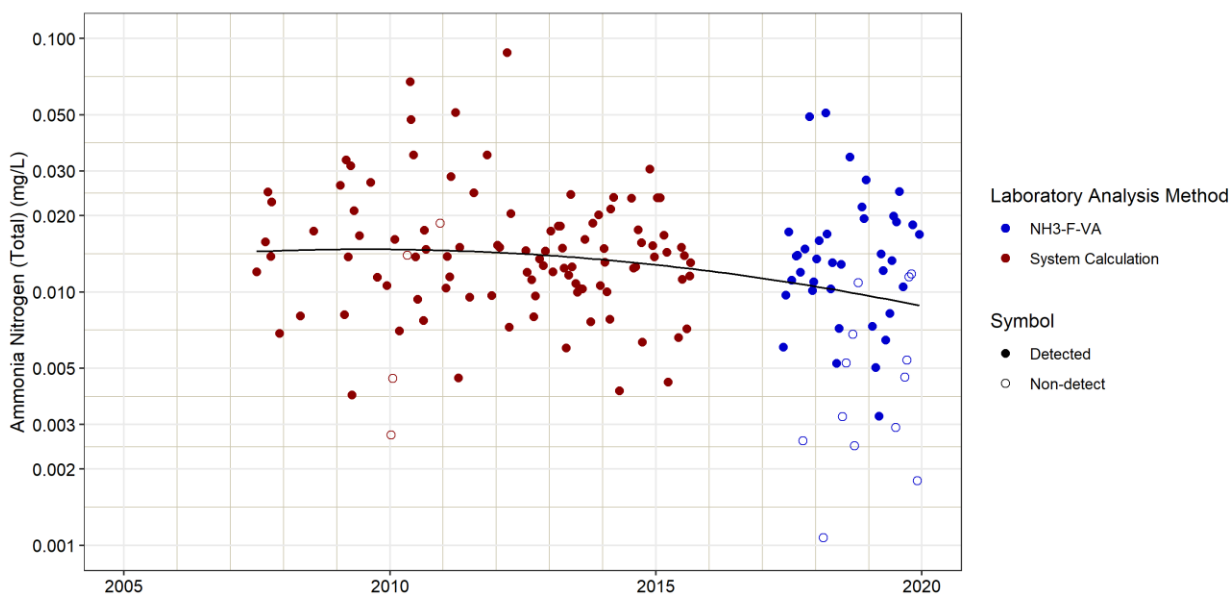

Figure 11: Trend analysis of total ammonia at E206092. Points are the flow-weighted and PARMA filtered measured total ammonia and the line is a quadratic spline fit on the measured data.

3.5.2 Trends in Conventional Parameters

No trends were observed for temperature, pH, and dissolved oxygen over the period extending from January 2005 to December 2019. Dissolved oxygen levels in the Salmon River were however quite low from 2006 to 2008, with 30% of the samples having concentrations below the short-term WQO of 9 mg/L at station E206092. In fact, these low dissolved oxygen values are found in 11% of all the samples collected on the Salmon River between 2005 and 2010; 32% of these samples were below the long-term WQO of 11 mg/L (Table A1; Appendix A).

Conductivity had a significant upward trend, with values increasing by 13% between 2005 and 2019 (Figure 12; Table 3). Turbidity, on the other hand, had a significant downward trend with a 33% decrease in NTU values between 2005 and 2019 (Figure 13; Table 3). Only 40 data points are available for TSS before 2013, so the dataset does not fully satisfy the requirements of the trend analysis package (i.e., at least 4 samples per year over a period of 10 years). Results of the trend analysis should be thus interpreted with this caveat. There was a non-significant increase in TSS concentration over the time period 2005 to 2019; however, this increase might be due to the change of method in 2015, that led to a significant step trend ($p = 0.041$). In fact, data collected using the method “Gravimetric 0.45u Filter” were on average 21% higher than the previous method “Grav; Subsamp Buch 105C”.

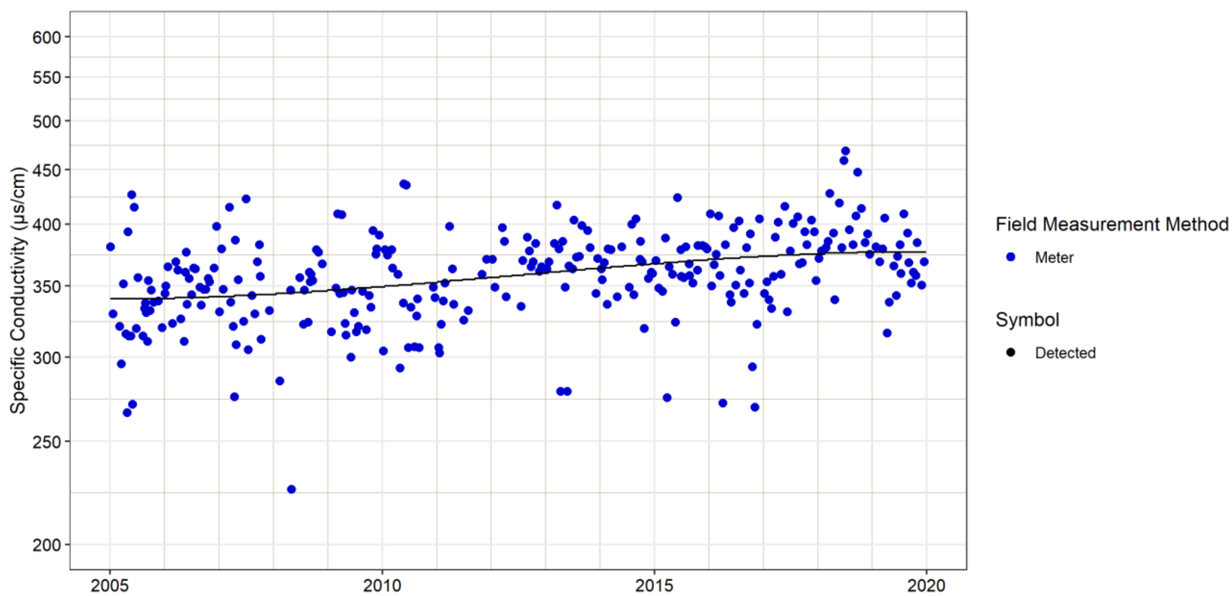

Figure 12: Trend analysis of specific conductivity at E206092. Points are the flow-weighted and PARMA-filtered measured specific conductivity, and the line is the fitted trend.

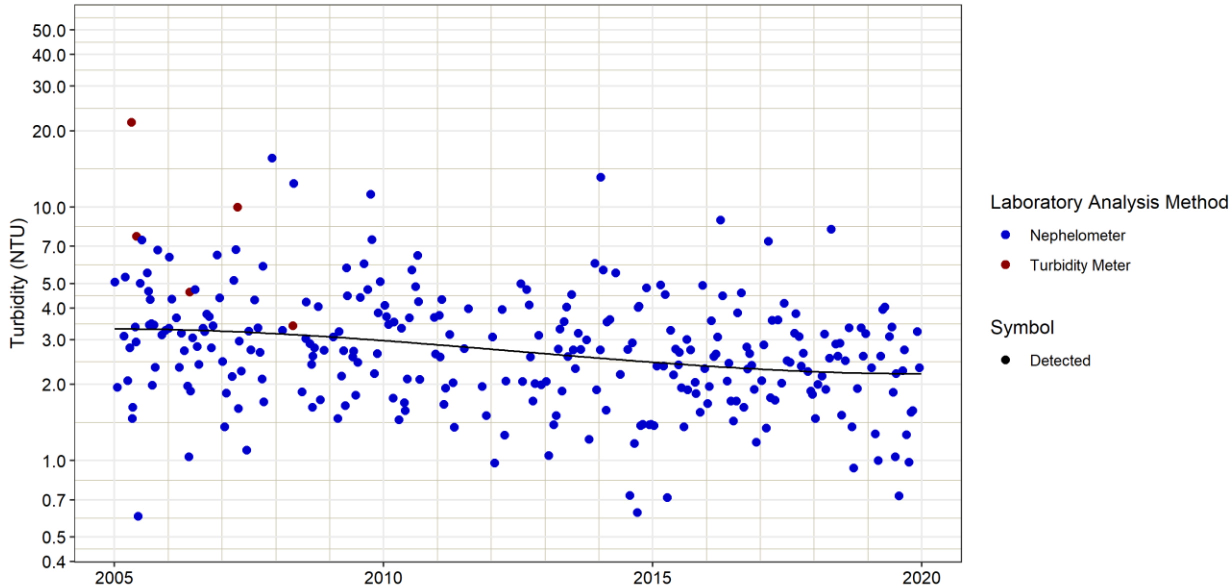

Figure 13: Trend analysis of turbidity at E206092. Points are the flow-weighted and PARMA filtered measured turbidity and the line is the fitted trend.

3.5.3 Trends in Nutrient Concentrations

Trends in total nitrogen, total nitrate plus nitrite, total and dissolved ammonia, total and dissolved phosphorus, orthophosphate, and DOC were investigated for the period 2005 to 2019. Total organic carbon was not analysed at station E206092. Out of these nutrients, only orthophosphate and total nitrate plus nitrite had significant downward trends. Orthophosphate concentrations were down by 22% from 2005 to 2019 (Figure 14). Total nitrate plus nitrite had a decrease of 50% in concentrations between 2007 and 2019 (Figure 15). However, since this parameter is based on a system calculation, there could have been a method change during this period of time that could not be identified during this analysis. More non-detect values are reported after 2015 and this could be an indication of a method change, which could be driving the trend downward. Further investigation in the measurement of this total nitrate plus nitrite would be required to confirm the presence of a downward trend in the Salmon River.

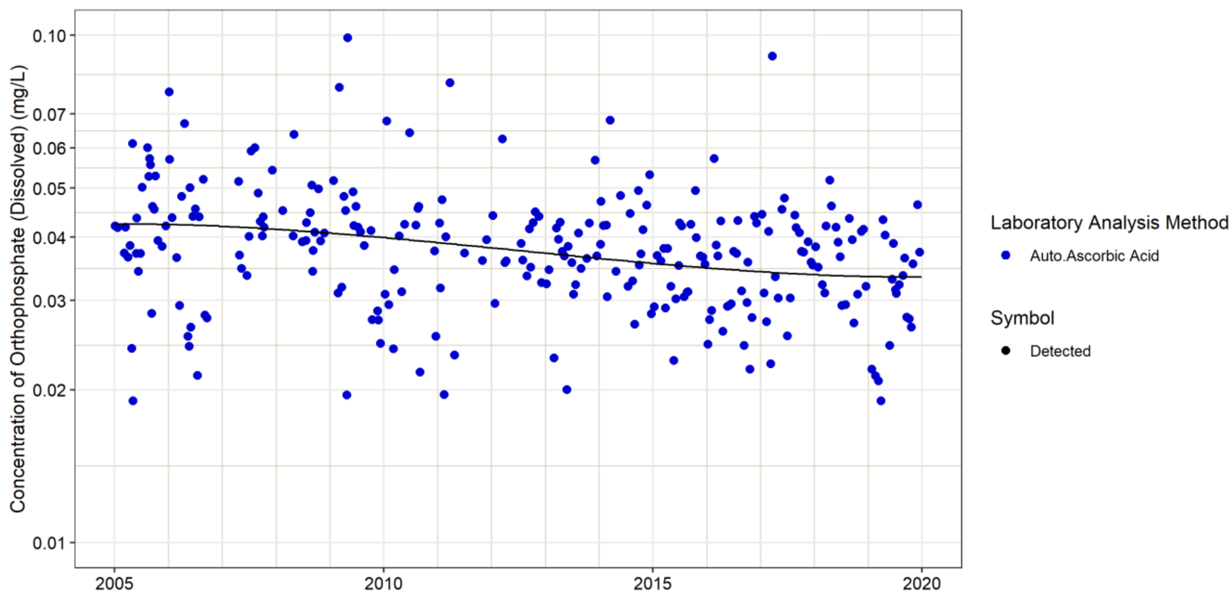

Figure 14: Trend analysis of dissolved orthophosphate at E206092. Points are the flow-weighted and PARMA filtered measured dissolved orthophosphate concentrations and the line is the fitted trend.

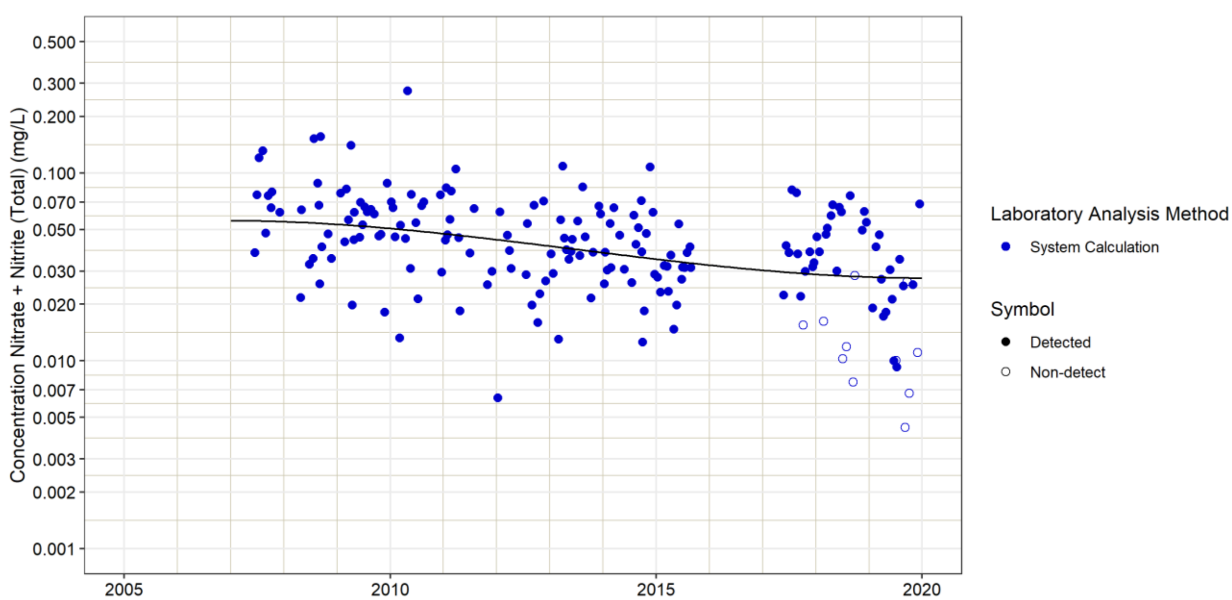

Figure 15: Trend analysis of total nitrate plus nitrite at E206092. Points are the flow-weighted and PARMA-filtered measured nitrate plus nitrite concentrations and the line is the fitted trend.

3.5.4 Trends in Microbial Indicators

There were no measurements of total coliforms and only 15 samples were available for *Enterococcus* sp.; hence, these two parameters were not included in the analysis. Summary statistics of the concentrations of *Enterococcus* sp. for all stations are presented in Appendix A and concentrations are shown in Figure 9. Trends were analysed for fecal coliforms and *E. coli* and both analyses resulted in a non-significant trend. Interestingly, there seem to have been variations in fecal coliform concentrations over the years, with a decrease from 2005 to 2010 followed by an increase from 2010 to 2015 and a subsequent decrease from 2015 to the end of 2019, resulting in an overall non-significant change over the whole period (Figure 16). Since the trend analysis approach needs a minimum period of 10 years to statistically identify a trend, we are unable to confirm the validity of these 5-year trends. The same patterns were observed in the analysis of *E. coli* (data not shown).

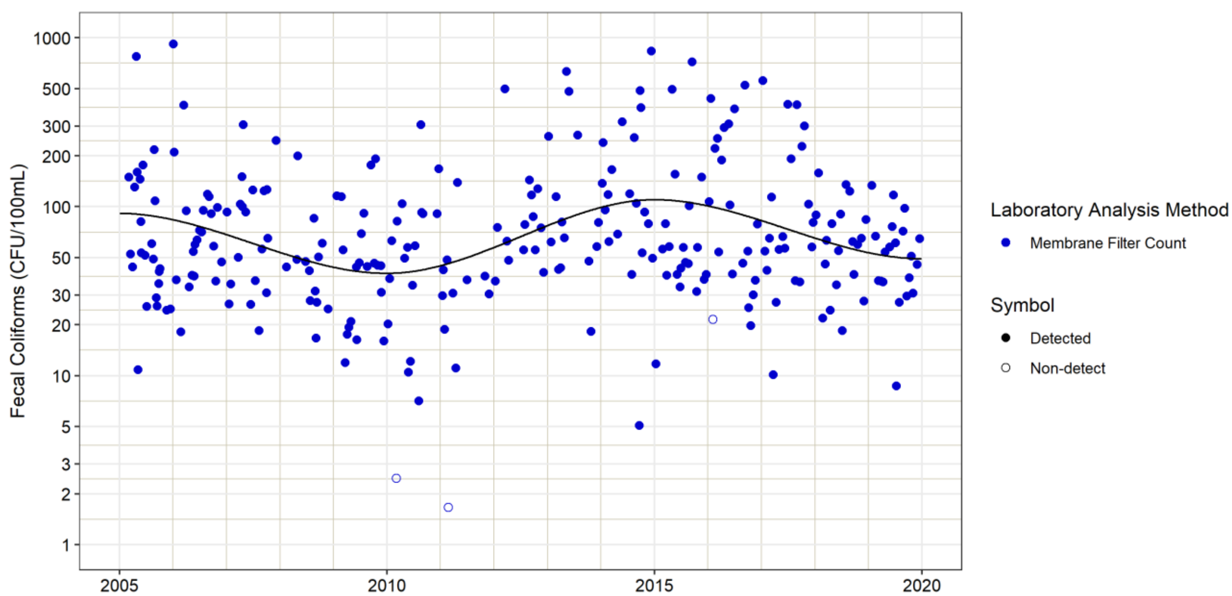

Figure 16: Trend analysis of fecal coliforms at E206092. Points are the flow-weighted and PARMA-filtered measured fecal coliform concentrations, and the line is the fitted trend.

3.6 Water Quality in Tappen Bay

The only WQO from the 1998 Salmon River WQOs report (BCMOE 1998) that applied to Tappen Bay (EMS site E206771) is a total phosphorus WQO of 15 µg/L. The total phosphorus concentration in samples collected between May 2005 and October 2019 are compared to the WQO in Figure 17. The 15 µg/L WQO was exceeded in 5.9% of the samples collected from 2005 to 2010, but in 17% of the samples collected from both the 2011 to 2015 and 2016 to 2019 time periods (Table A11; Appendix A). The long-term B.C. WQGs for aquatic life for ammonia, nitrate, and nitrite were not exceeded in any samples between 2005 and 2019 (Table A11; Appendix A).

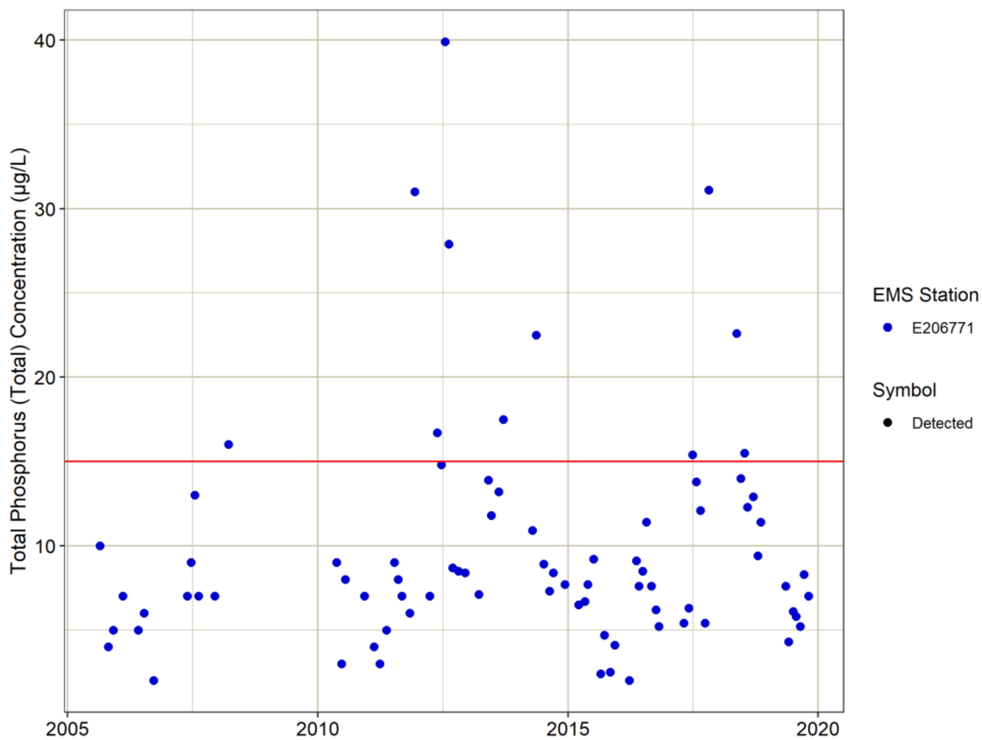

Figure 17: Total phosphorus concentration at E206771 in Tappen Bay. The horizontal red line is the WQO of 15 µg/L.

4. RECOMMENDATIONS

Attainment monitoring should continue monthly in five- to six-year monitoring cycles at each station and should include an intensive sampling program (i.e., one or two 5-in-30 day sampling events per year) during periods of high variability (i.e., low and high flows) or during periods of high recreational use for evaluating bacterial conditions. In addition, monitoring at E206084 (the most upstream station) should resume (it was stopped in April 2017) so that comparisons along a longer stretch of the river can be conducted.

B.C. Recreational Water Quality Guidelines for microbial indicators (i.e., Enterococci and *E. coli*) and B.C. WQGs for fecal coliforms, Enterococci, and *E. coli* to protect general livestock use should be added to the list of WQOs. These would be more appropriate WQOs for microbial indicators than the current WQOs based on WQGs for drinking water sources because the Salmon River is more likely to be used for livestock watering and for recreation than as a source of drinking water.

In June 2015, analytical methods were updated for a number of parameters (e.g., dissolved nitrate, dissolved nitrite, TOC, and DOC). For instance, ion chromatography and TOC Analyzer were used instead of colorimetric methods, leading to a higher number of non-detects, which could be caused by increased sample interferences with the new methods. This caused a step trend in the dataset analysed that could hide a potential temporal trend. In addition, the period 2015 to 2019 is too short to statistically identify a trend using the current method. A new iteration of this analysis using data from 2015 to 2025 will allow the comparison of two periods (2005 to 2015 and 2015 to 2025) and a better estimation of trends in the Salmon River.

Phosphorus loadings to Shuswap Lake have been calculated previously and the Salmon River was found to be the main contributor of phosphorus loading to Tappen Bay (Tri-Star Environmental Consulting 2014). In addition, land disturbances are the main contributor to phosphorus loading to the Salmon River (Ludwig and Curtis 2020). Hydrological monitoring at additional EMS stations upstream of E206092 would allow for a better determination of load accumulation along the length of the Salmon River. In the meantime, changes in trophic status in both the Salmon River and Tappen Bay should be evaluated, and TN:TP should be tracked, along with signs of eutrophication, such as macroalgae and periphyton overgrowth in the Salmon River. Mitigation measures to reduce phosphorus loading to the Salmon River should be considered, and could include exclusion fences to prevent cattle from accessing the river or larger vegetation strips on both shorelines to reduce leaching of phosphorus toward the river (Shukla et al. 2020; von Arb et al. 2021).

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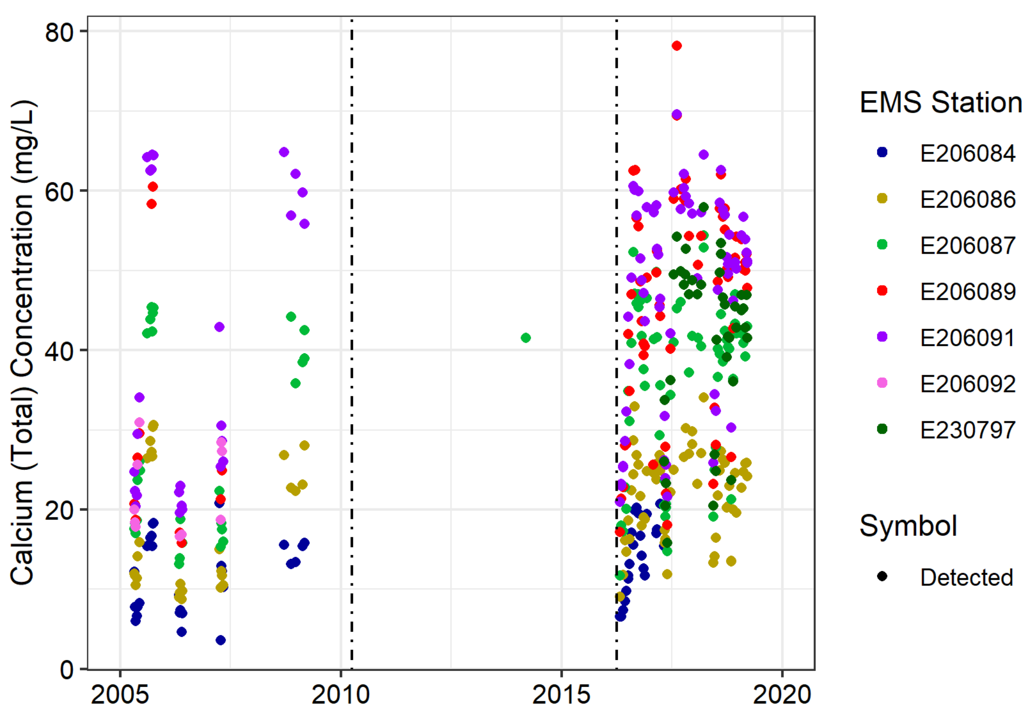
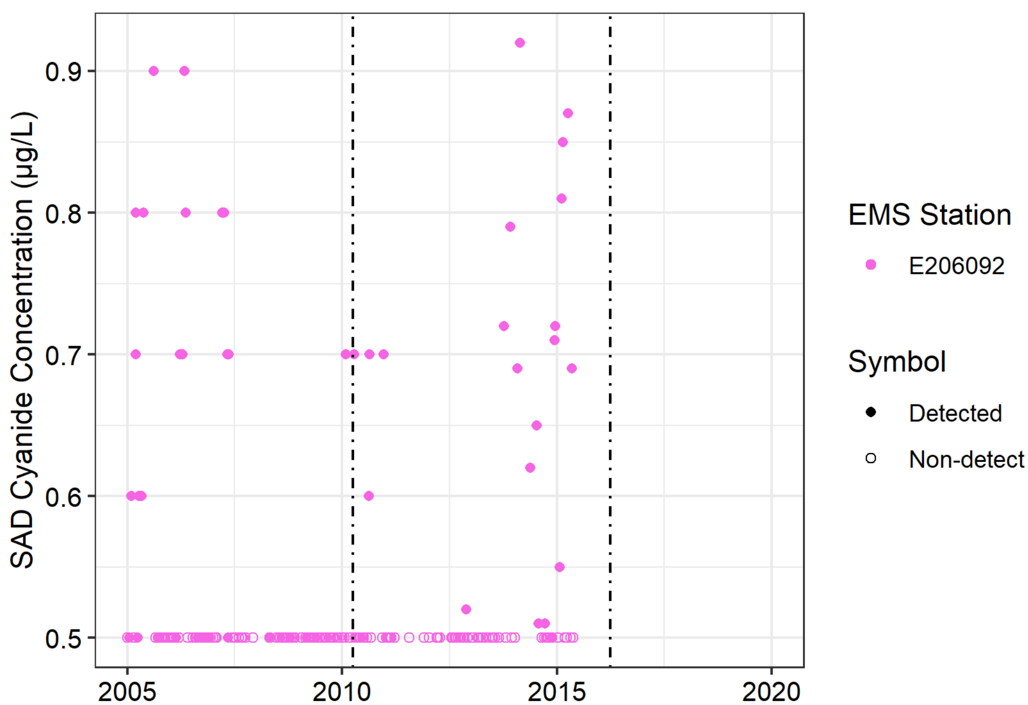
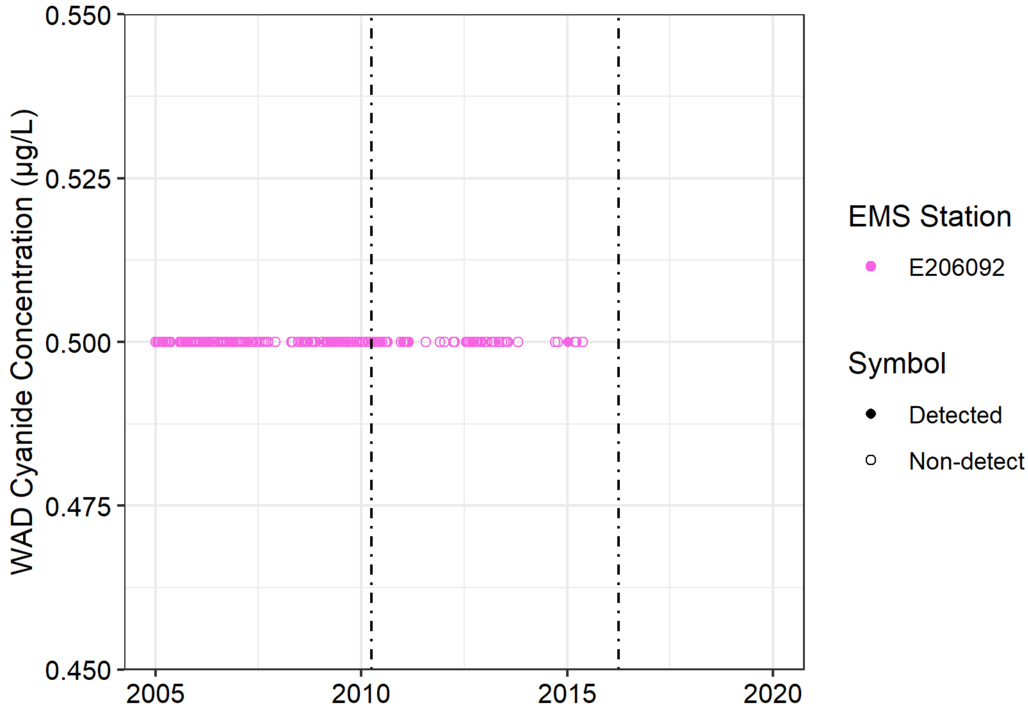
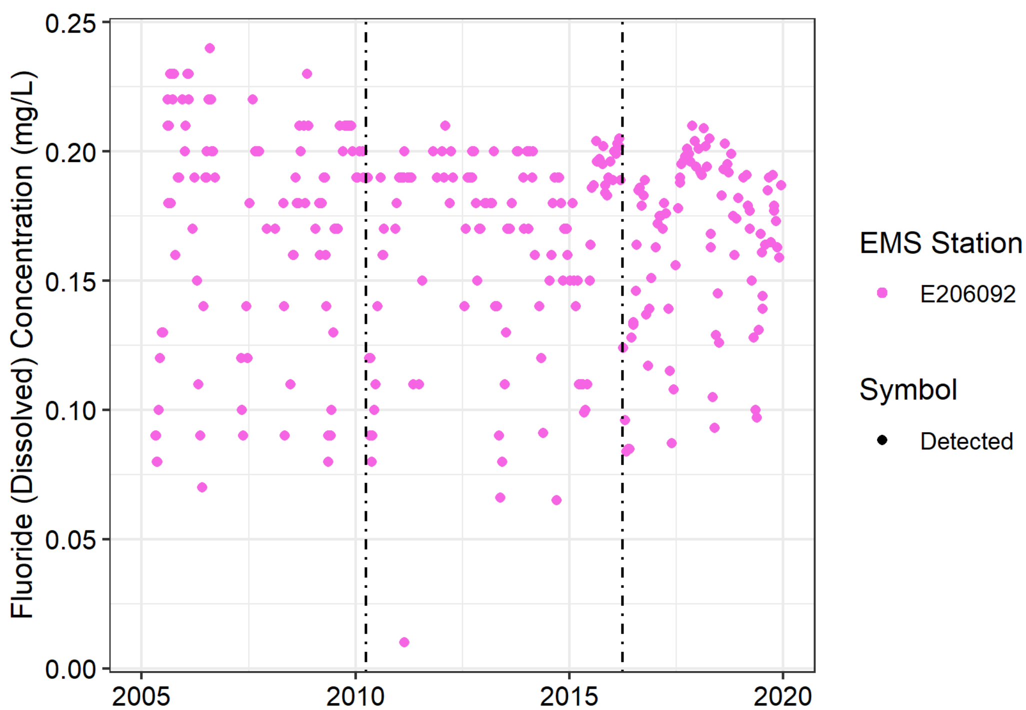
APPENDIX A: NON-METALS SUMMARY STATISTICS AND PLOTS

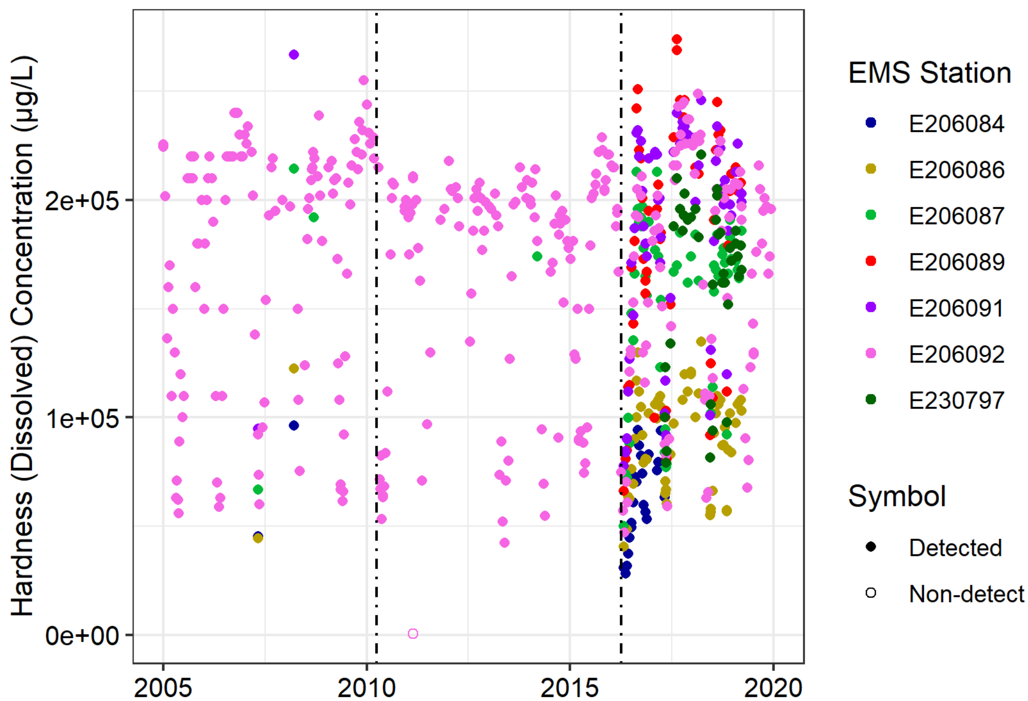


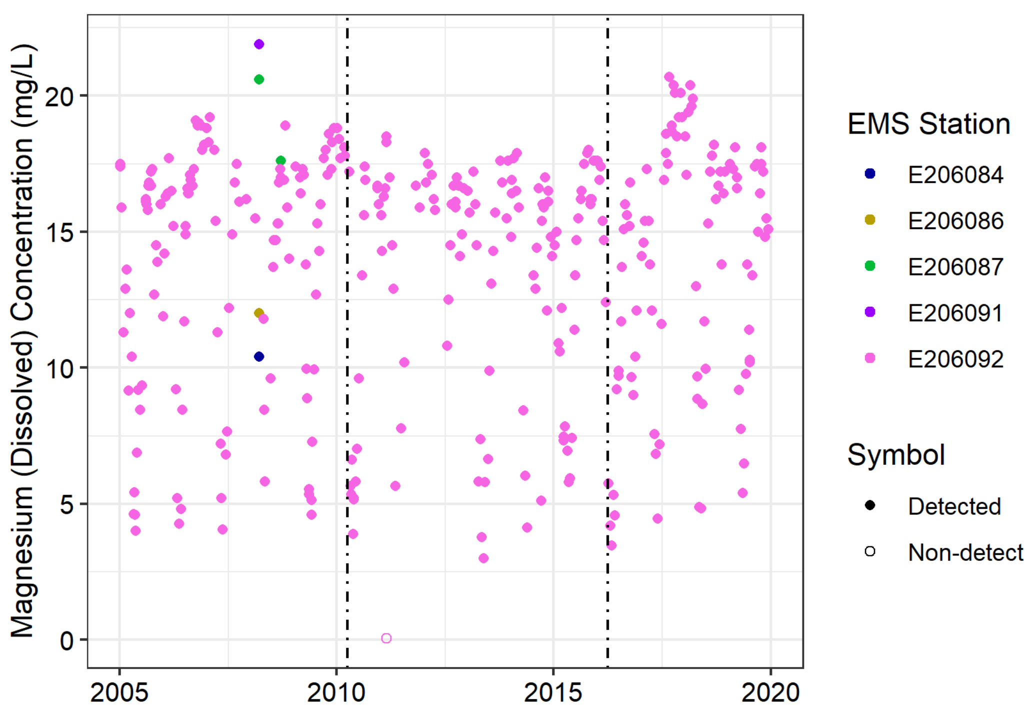

Chloride (Dissolved) Concentration (mg/L)
8
6
4
2
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

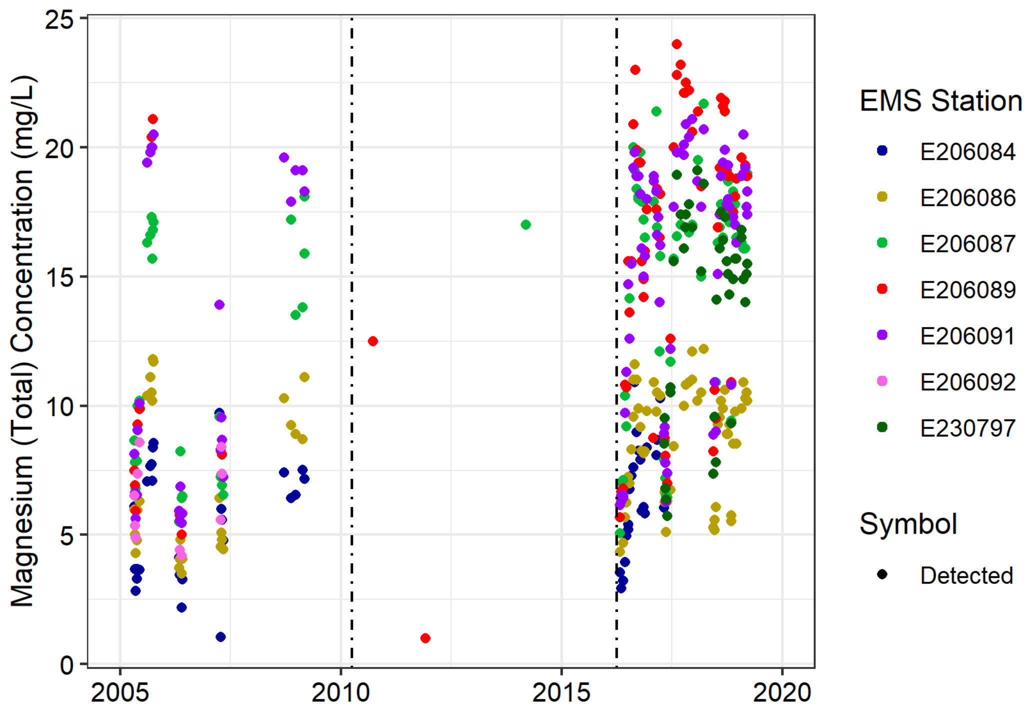

SAD Cyanide Concentration (µg/L)
0.9
0.8
0.7
0.6
0.5
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected
Non-detect

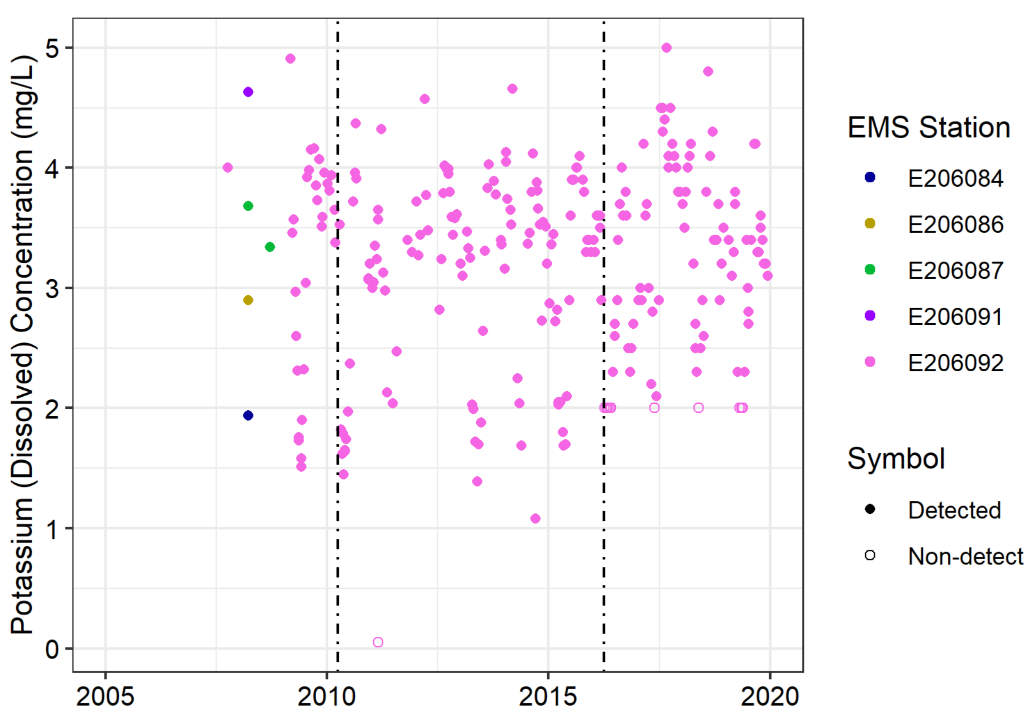

0.550
0.525
0.500
0.475
0.450
WAD Cyanide Concentration (µg/L)
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected
Non-detect

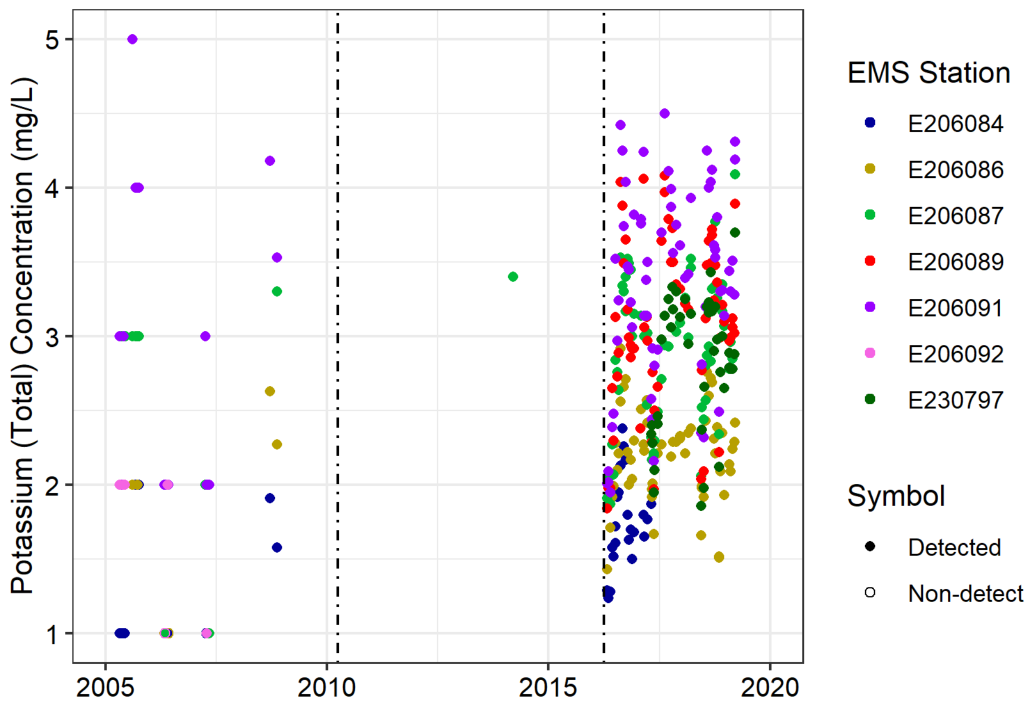

0.25
0.20
0.15
0.10
0.05
0.00
Fluoride (Dissolved) Concentration (mg/L)
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected


Hardness (Dissolved) Concentration (µg/L)
0e+00
1e+05
2e+05
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

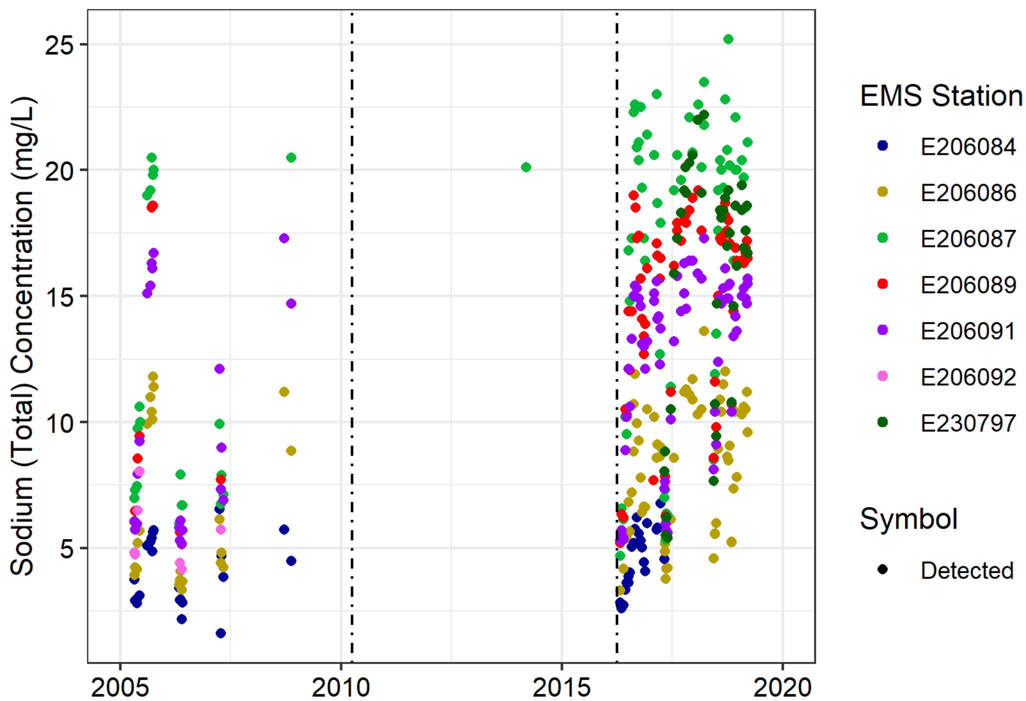

Magnesium (Dissolved) Concentration (mg/L)
0
5
10
15
20
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206091
E206092
Symbol
Detected
Non-detect


Magnesium (Total) Concentration (mg/L)
25
20
15
10
5
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

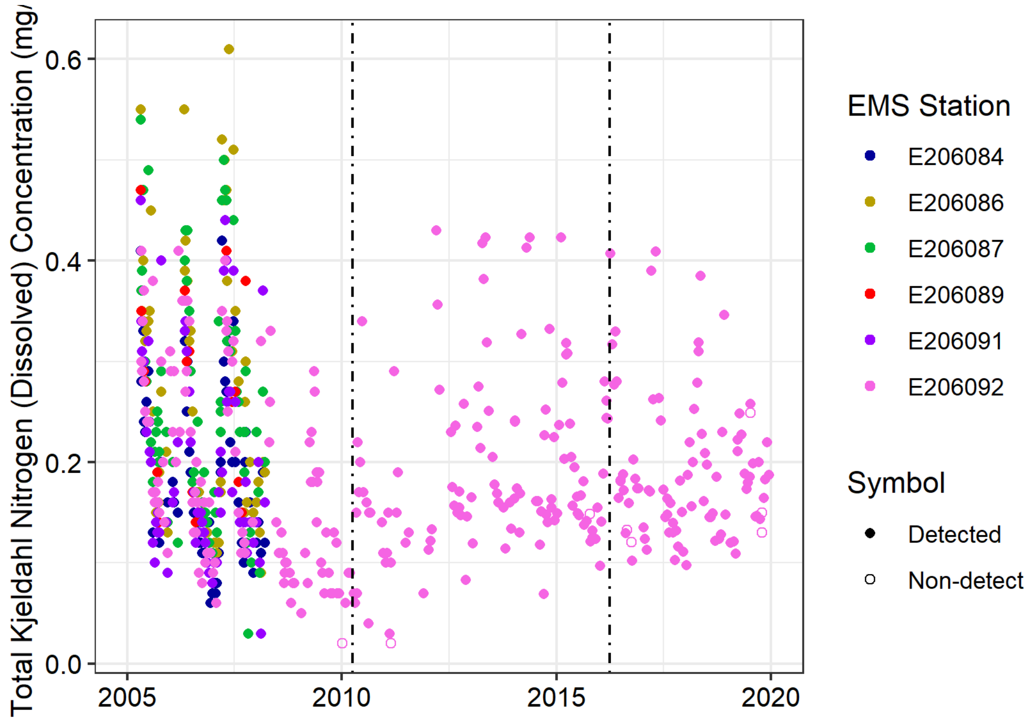

Potassium (Dissolved) Concentration (mg/L)
5
4
3
2
1
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206091
E206092
Symbol
Detected
Non-detect

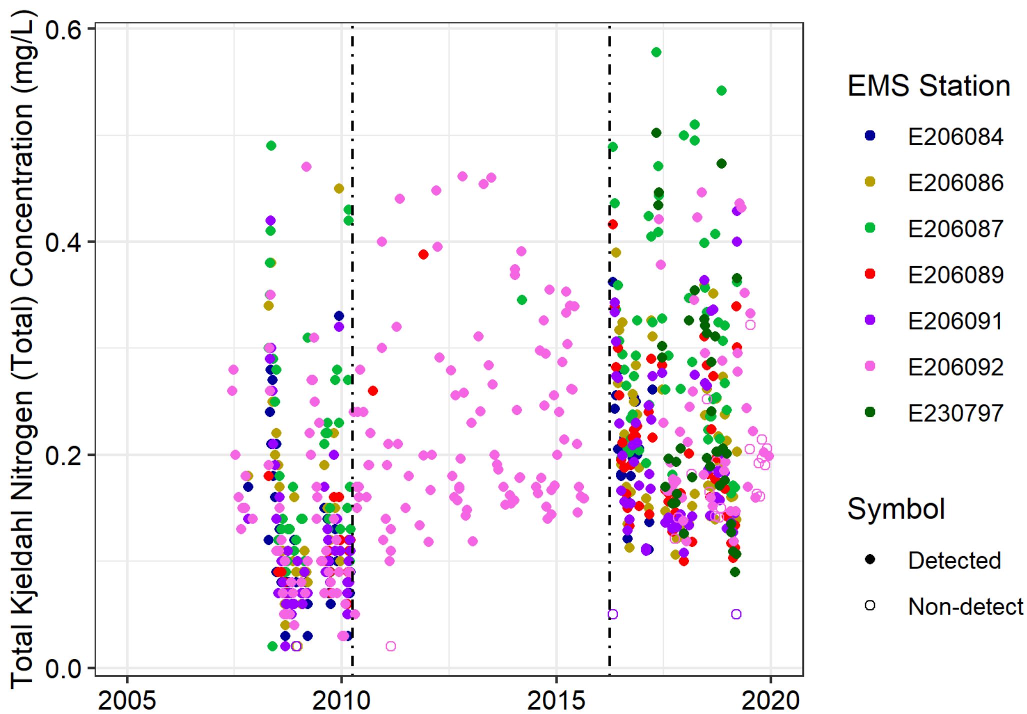

Potassium (Total) Concentration (mg/L)
1
2
3
4
5
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

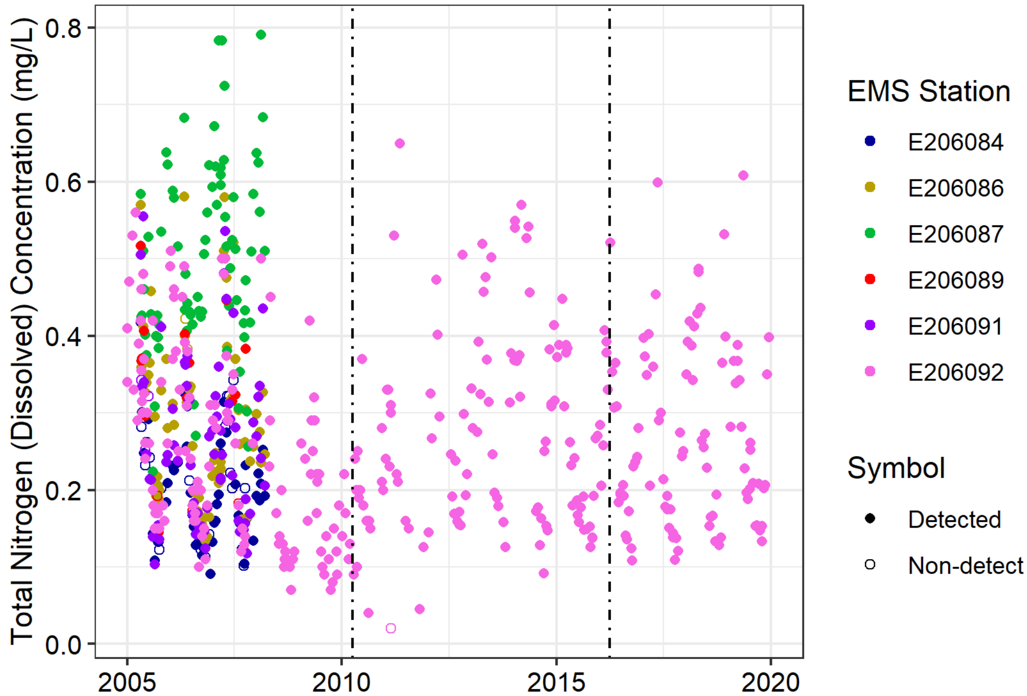

Sodium (Dissolved) Concentration (mg/L)
0
10
20
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206091
E206092
Symbol
Detected
Non-detect

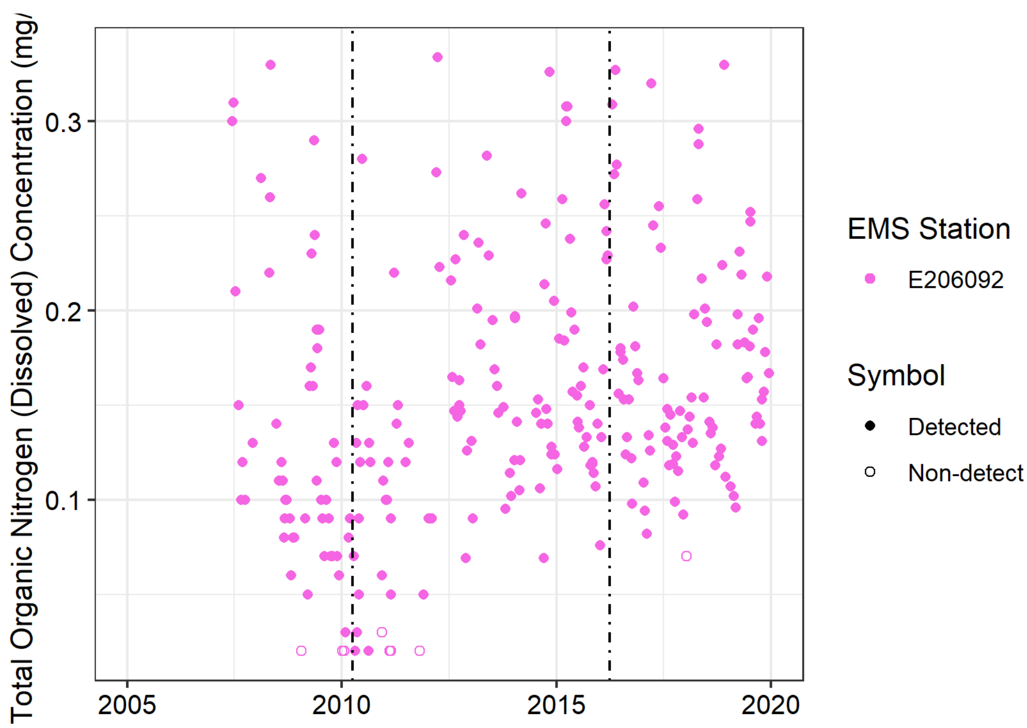

Sodium (Total) Concentration (mg/L)
25
20
15
10
5
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

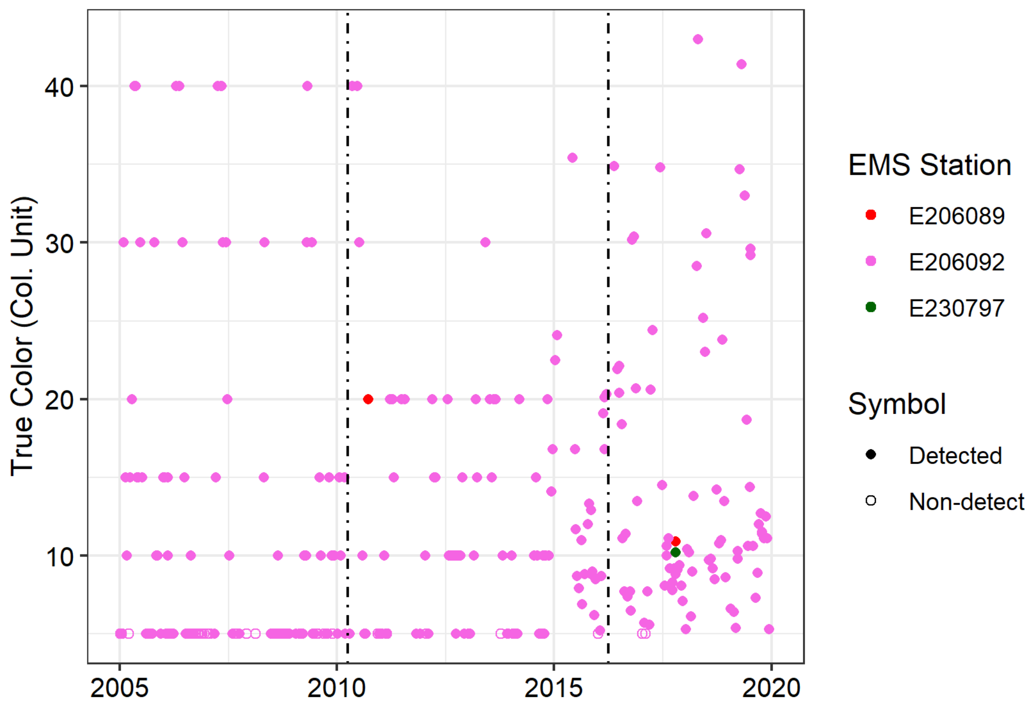

Sulfate (Dissolved) Concentration (mg/L)
60
40
20
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect


Total Kjeldahl Nitrogen (Dissolved) Concentration (mg/
0.6
0.4
0.2
0.0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
Symbol
Detected
Non-detect


Total Kjeldahl Nitrogen (Total) Concentration (mg/L)
0.6
0.4
0.2
0.0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

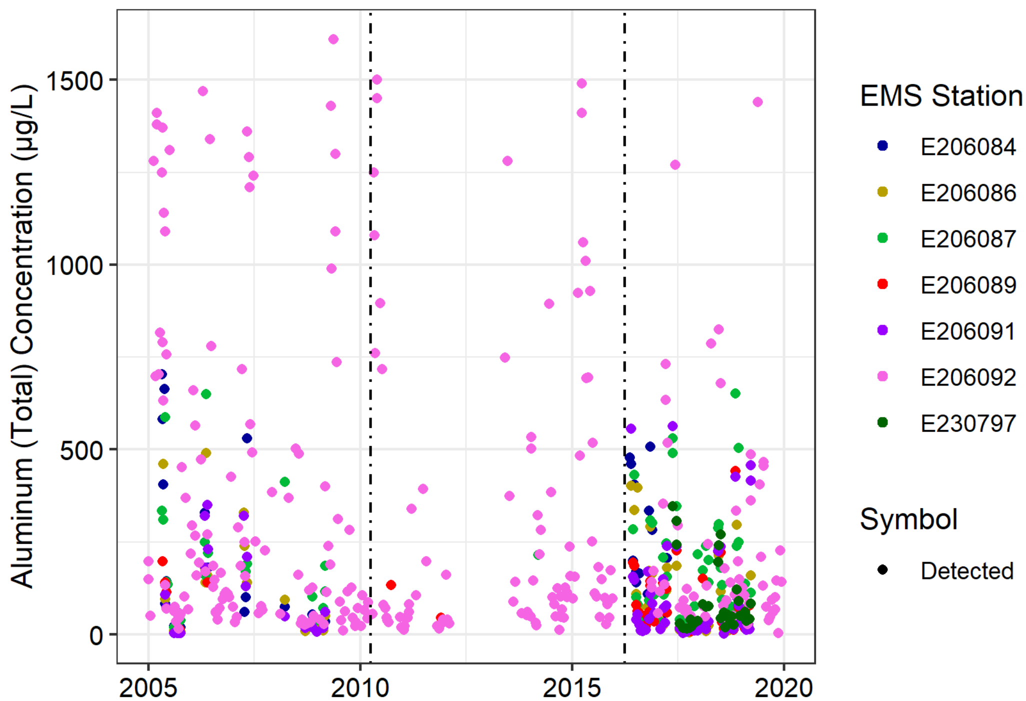

Total Nitrogen (Dissolved) Concentration (mg/L)
0.0
0.2
0.4
0.6
0.8
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
Symbol
Detected
Non-detect

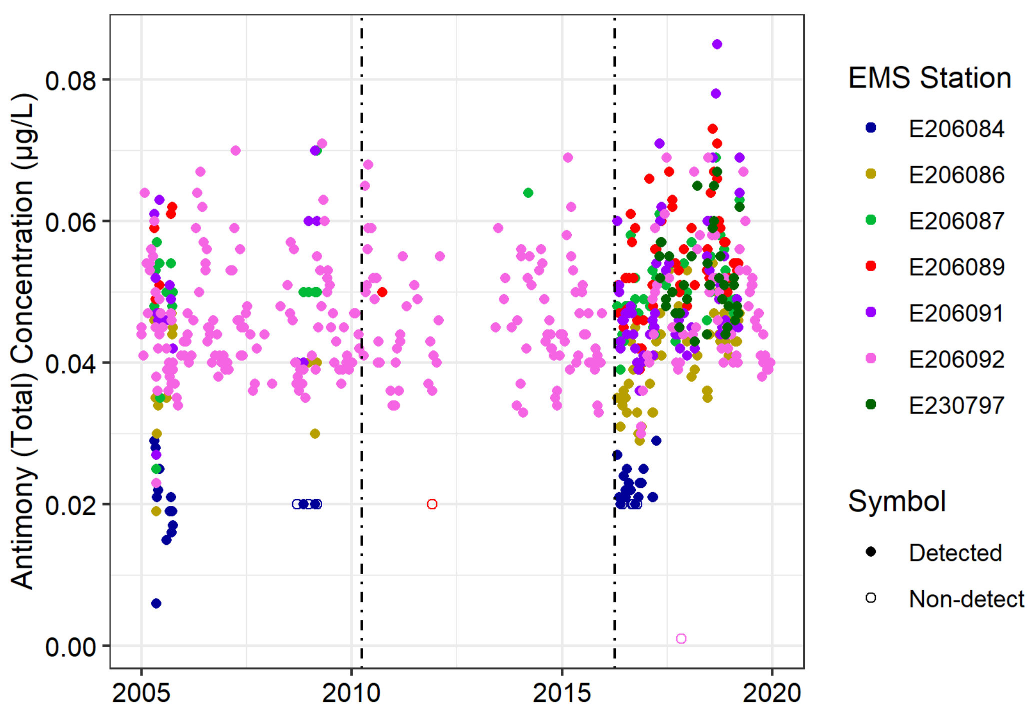

Total Organic Nitrogen (Dissolved) Concentration (mg/
0.1
0.2
0.3
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected
Non-detect

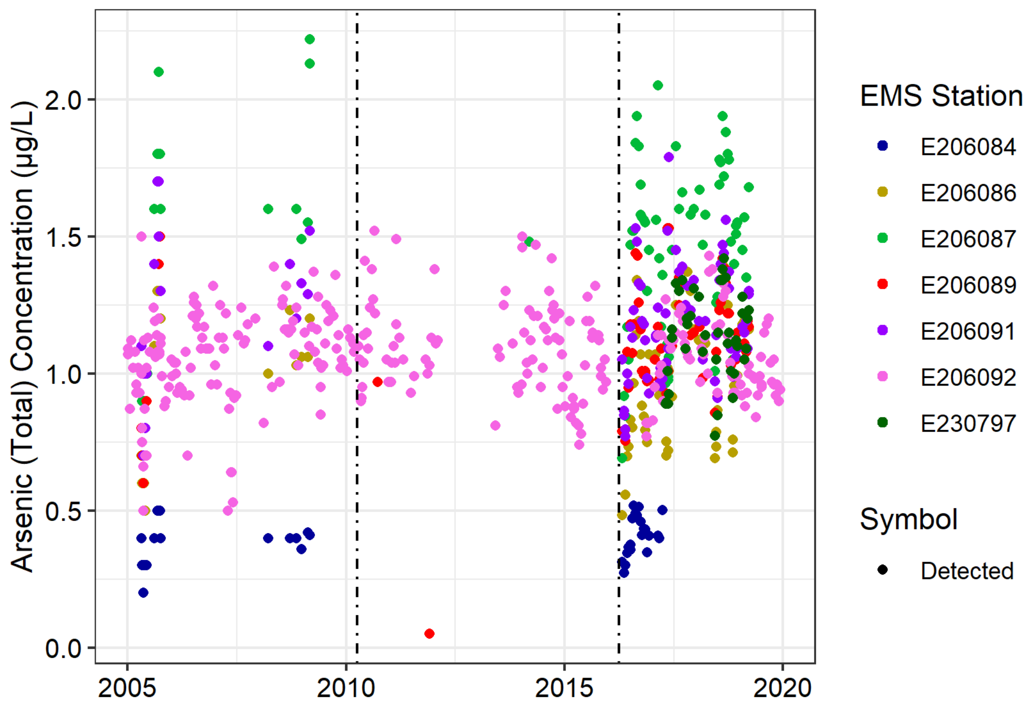


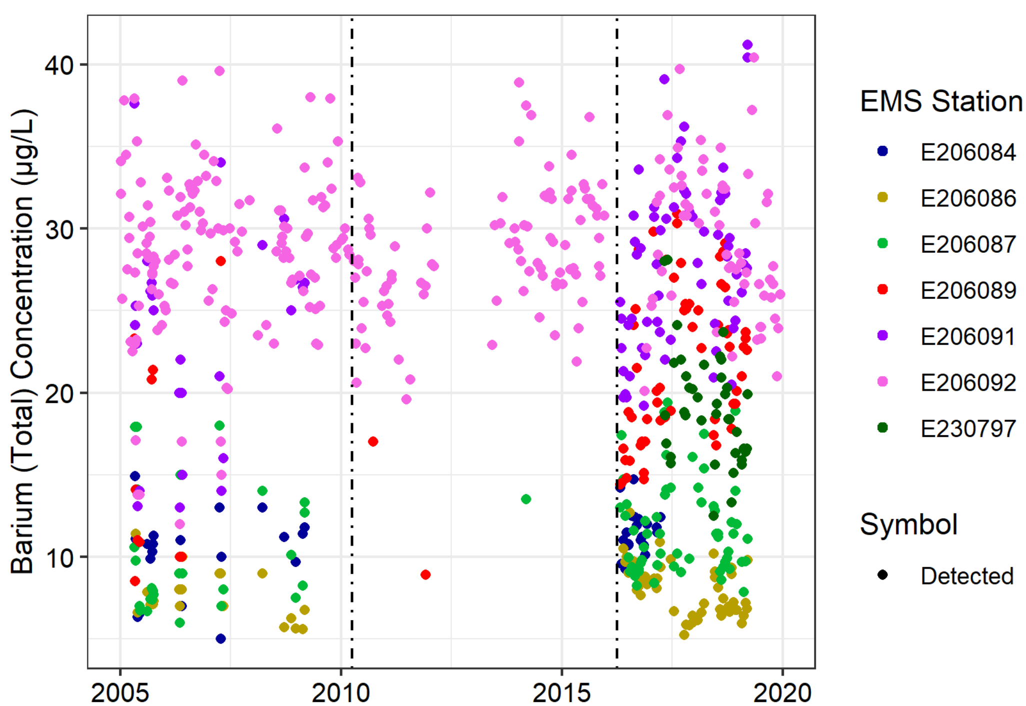
True Color (Col. Unit)
40
30
20
10
2005
2010
2015
2020
EMS Station
E206089
E206092
E230797
Symbol
Detected
Non-detect

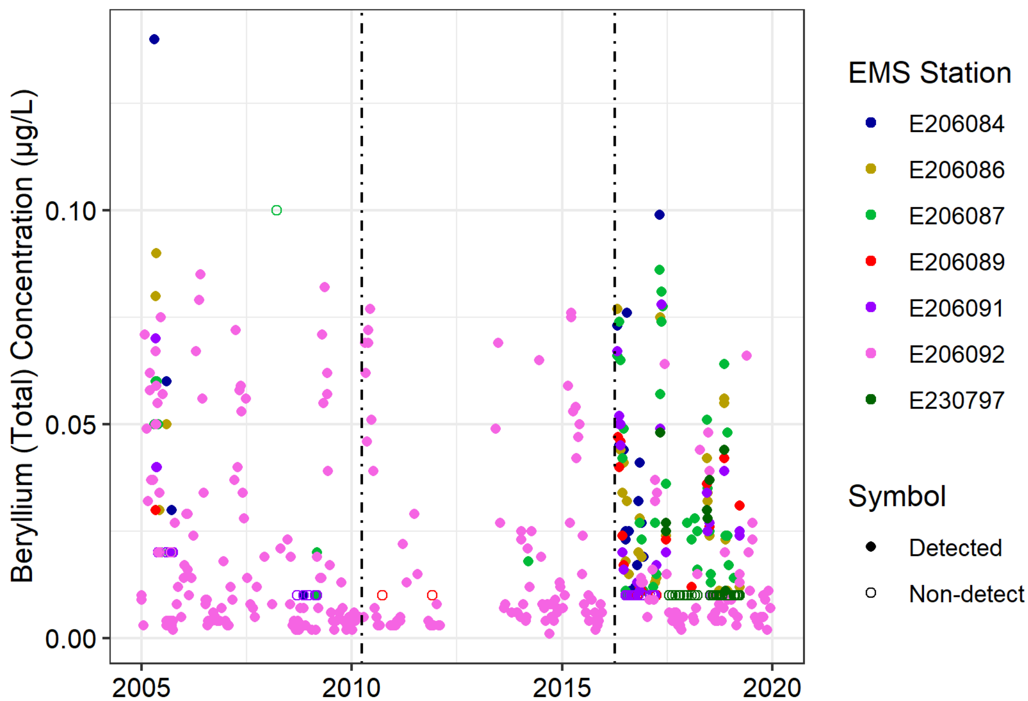
APPENDIX B: METALS SUMMARY STATISTICS AND PLOTS

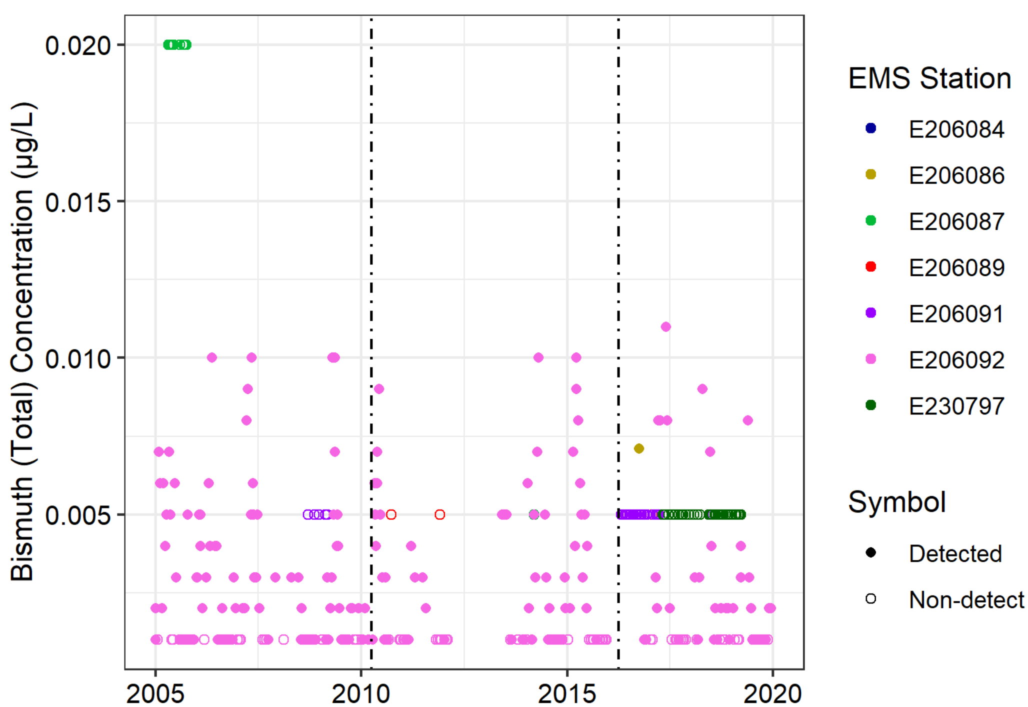


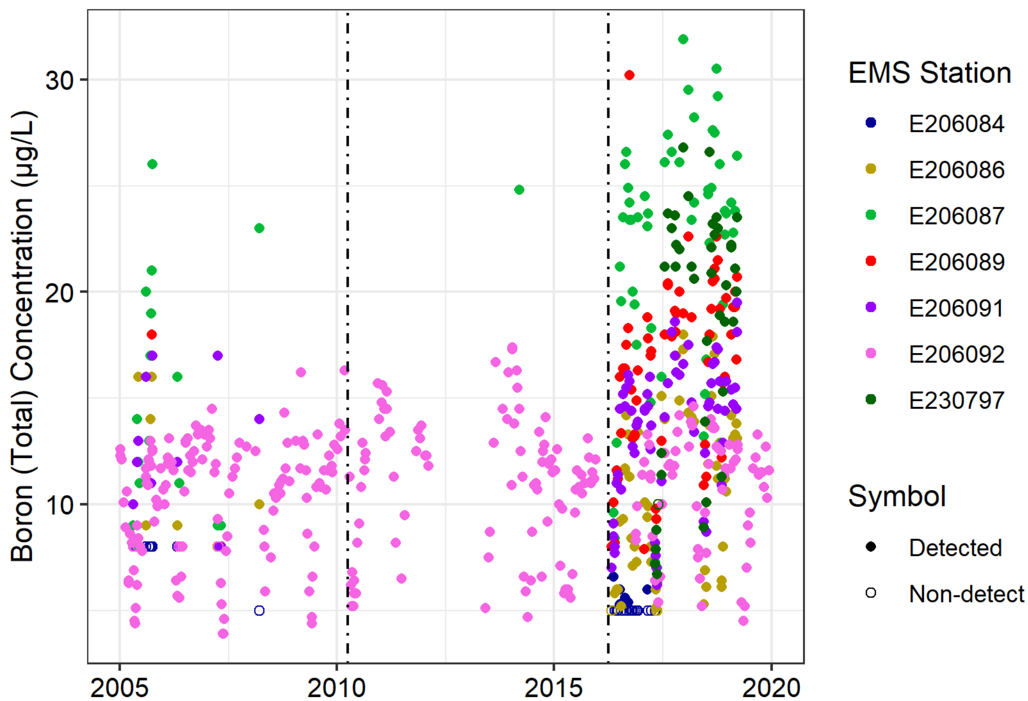



Arsenic (Total) Concentration (µg/L)
0.0
0.5
1.0
1.5
2.0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected


Barium (Total) Concentration (µg/L)
10
20
30
40
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

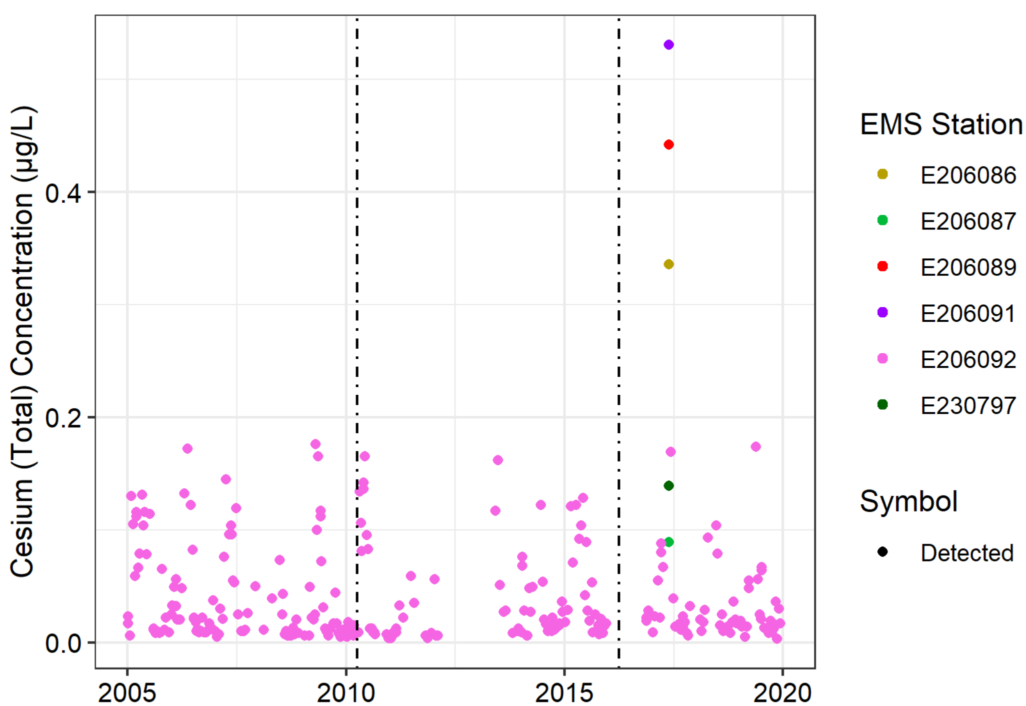

Beryllium (Total) Concentration (µg/L)
0.00
0.05
0.10
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect


Bismuth (Total) Concentration (µg/L)
0.005
0.010
0.015
0.020
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

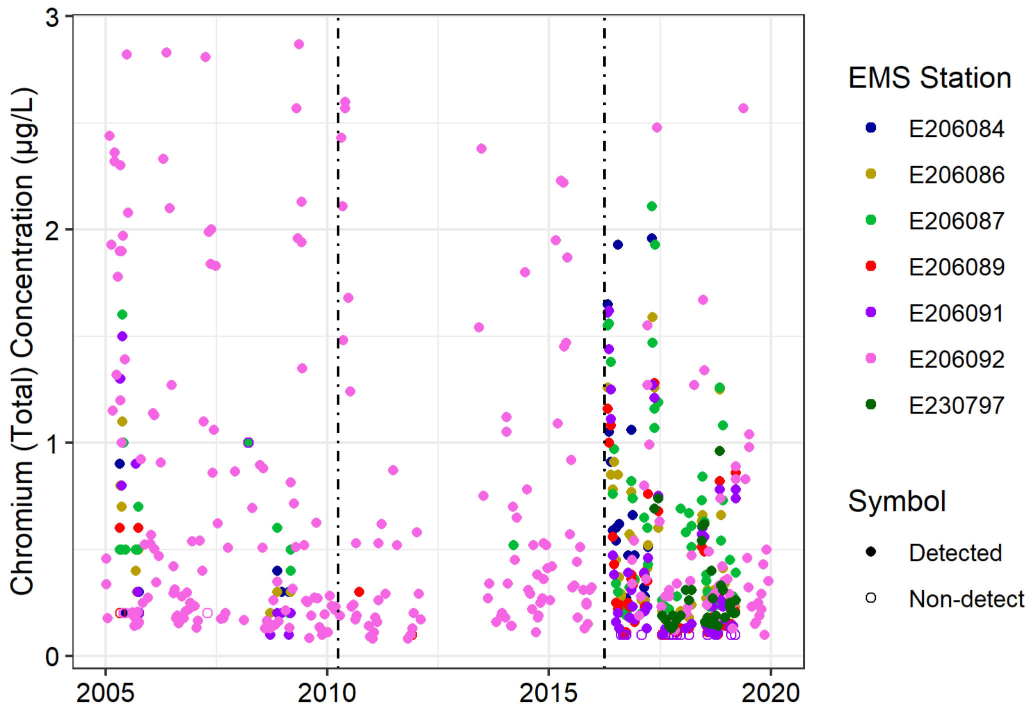

Boron (Total) Concentration (µg/L)
30
20
10
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

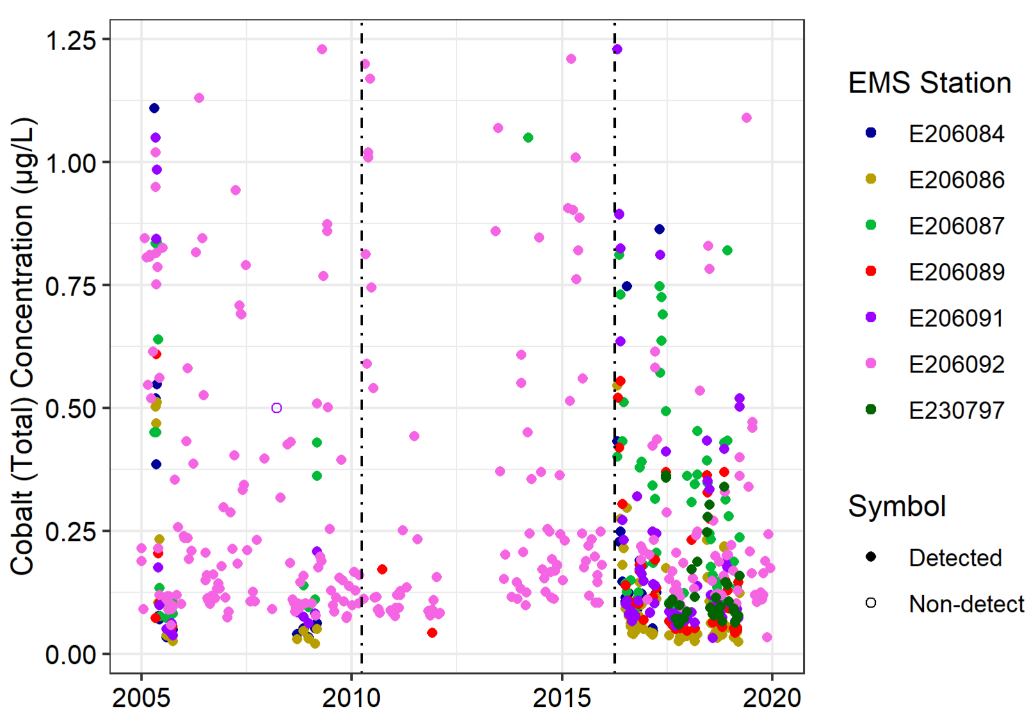

Cadmium (Total) Concentration (µg/L)
0.075
0.050
0.025
0.000
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

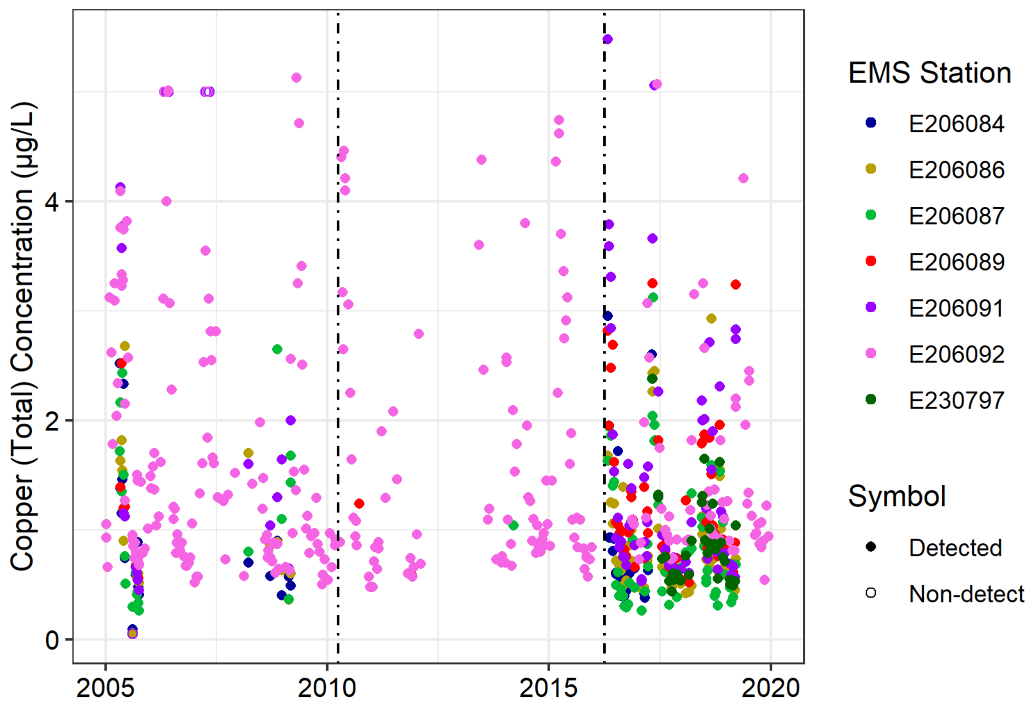
Cerium (Total) Concentration (µg/L)
0
1
2
3
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected



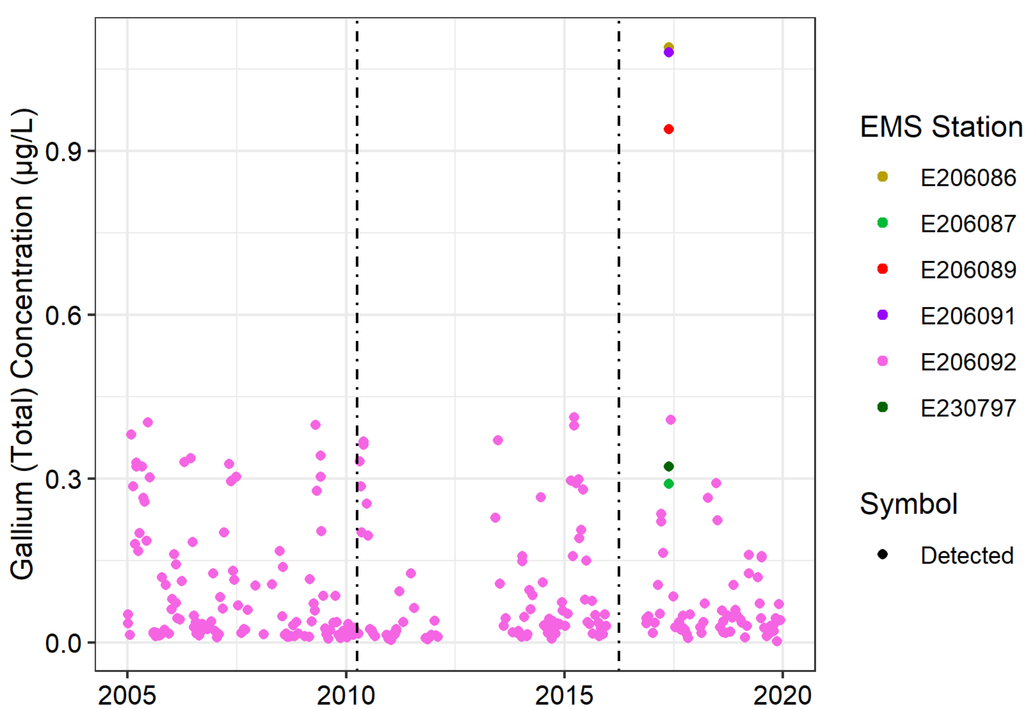
Cesium (Total) Concentration (µg/L)
0.0
0.2
0.4
2005
2010
2015
2020
EMS Station
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected


Chromium (Total) Concentration (µg/L)
0
1
2
3
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

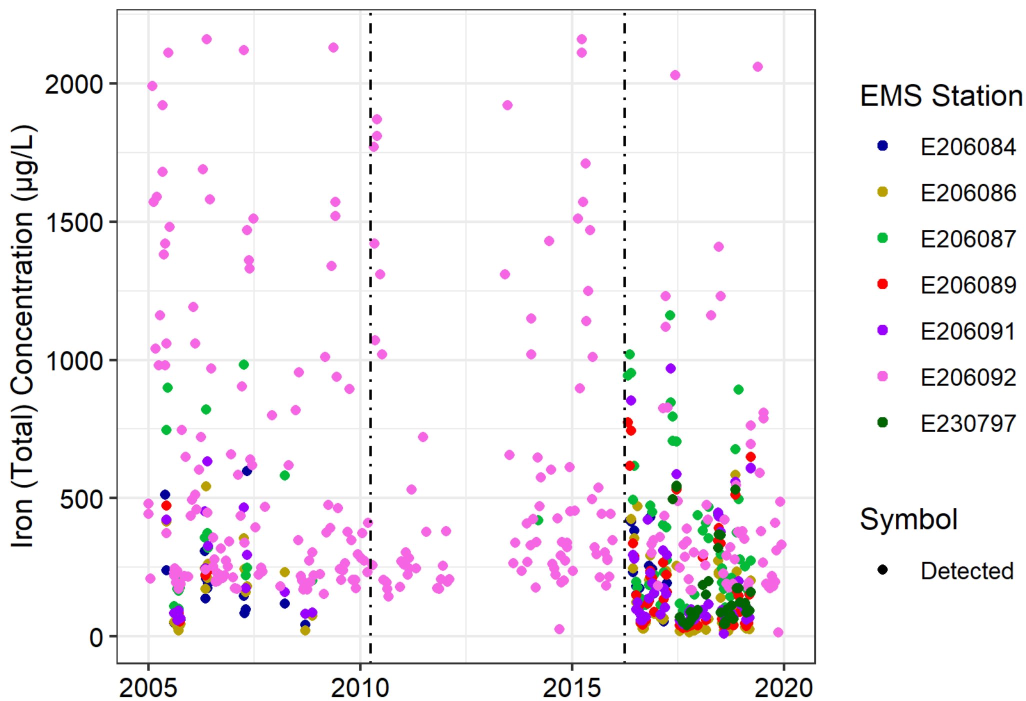

Cobalt (Total) Concentration (µg/L)
0.00
0.25
0.50
0.75
1.00
1.25
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

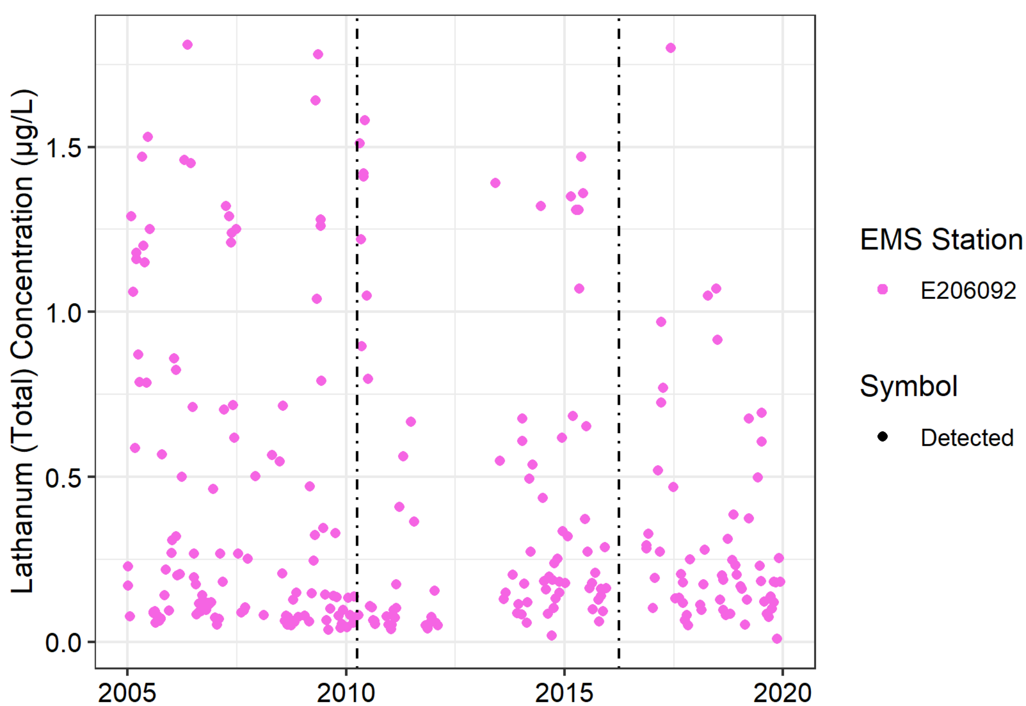


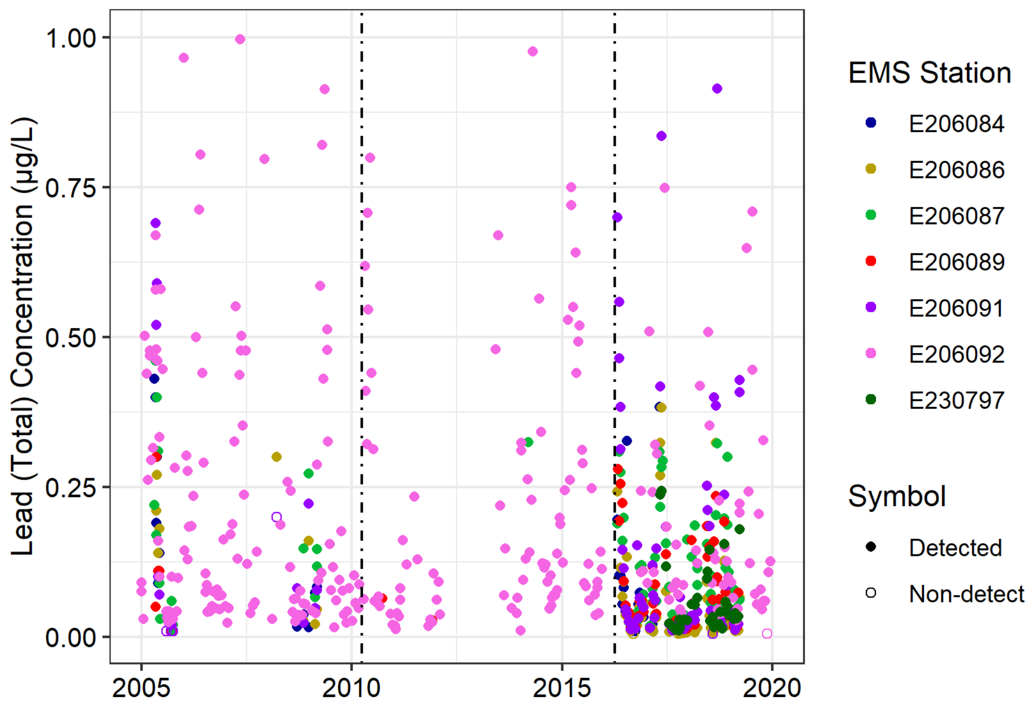
Copper (Total) Concentration (µg/L)
0
2
4
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

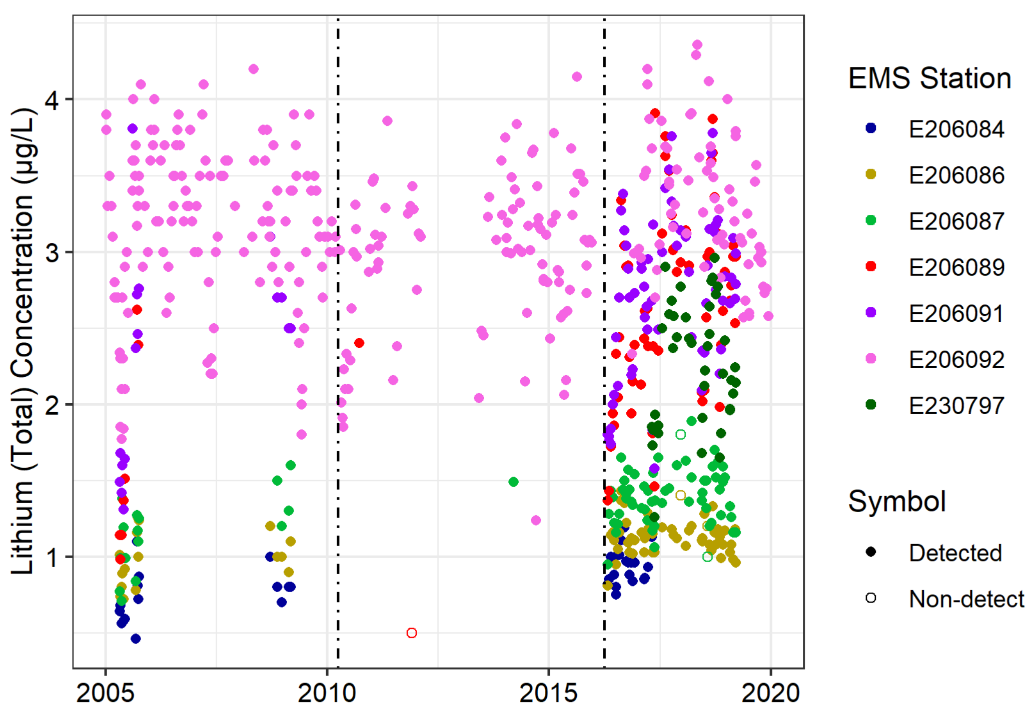


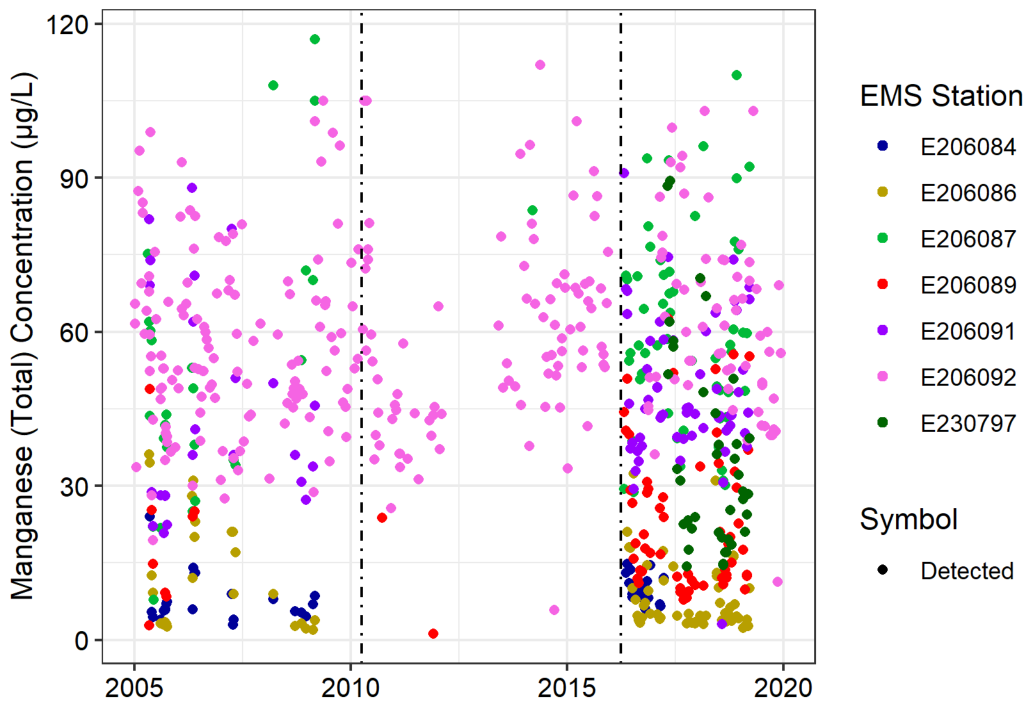
Gallium (Total) Concentration (µg/L)
0.0
0.3
0.6
0.9
2005
2010
2015
2020
EMS Station
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected


Iron (Total) Concentration (µg/L)
2000
1500
1000
500
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

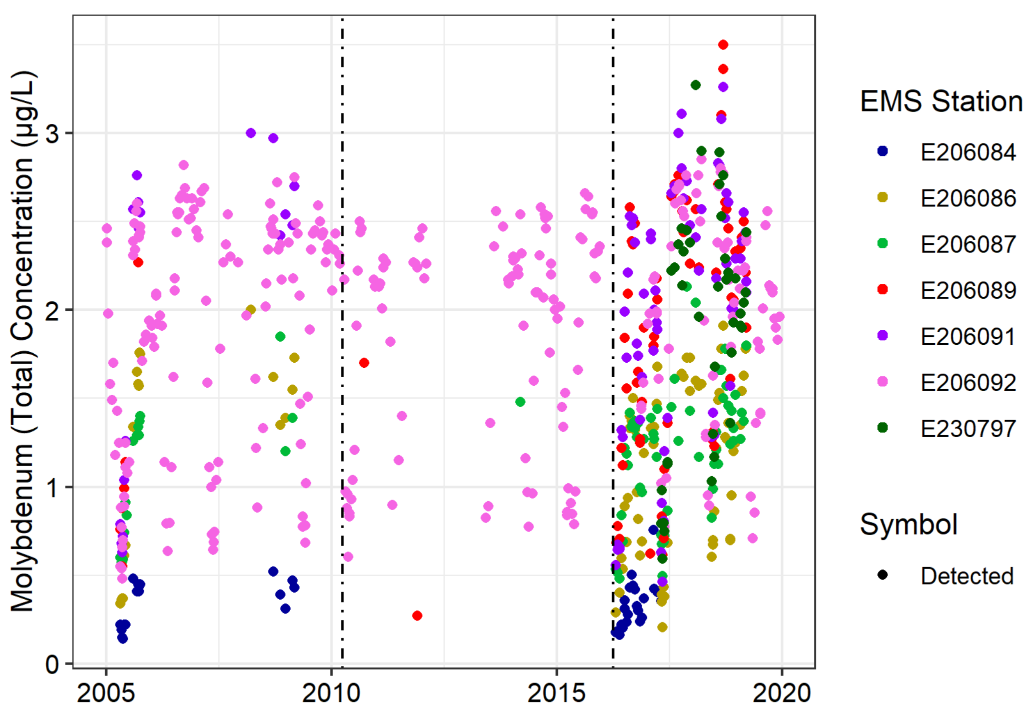

Lathanum (Total) Concentration (µg/L)
1.5
1.0
0.5
0.0
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected


Lead (Total) Concentration (µg/L)
1.00
0.75
0.50
0.25
0.00
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect


Lithium (Total) Concentration (µg/L)
4
3
2
1
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

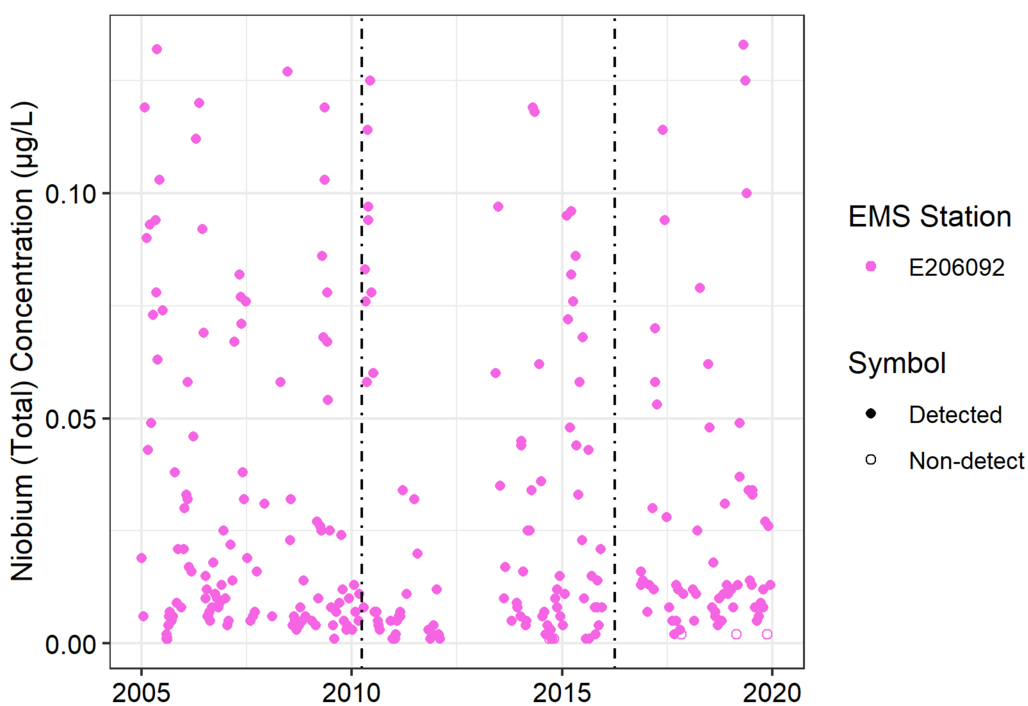


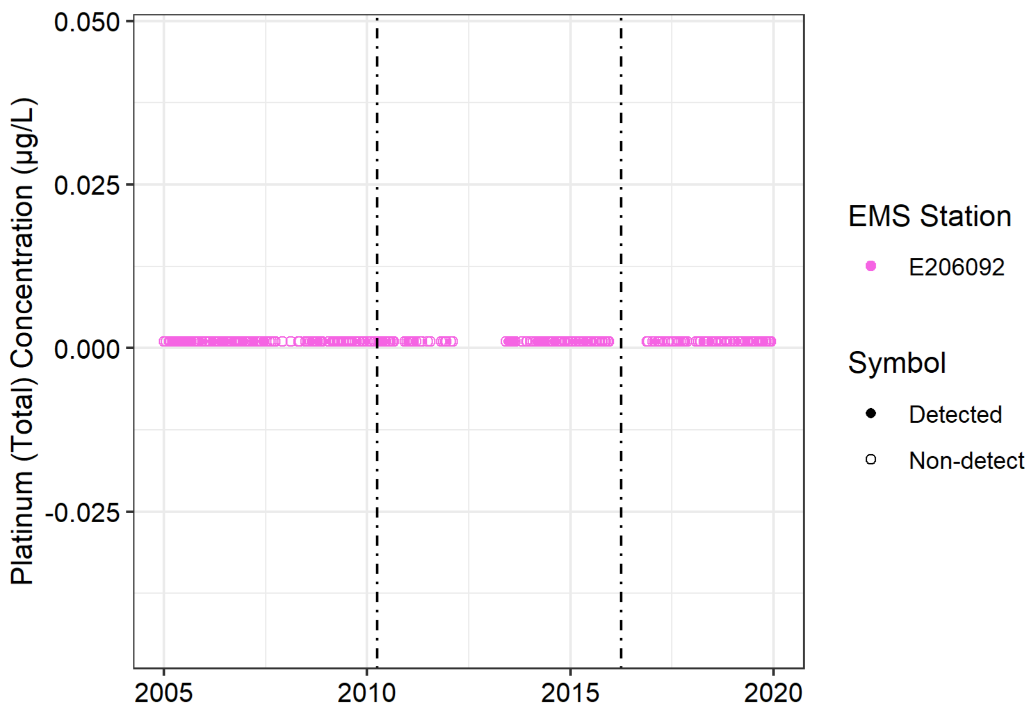
Manganese (Total) Concentration (µg/L)
120
90
60
30
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

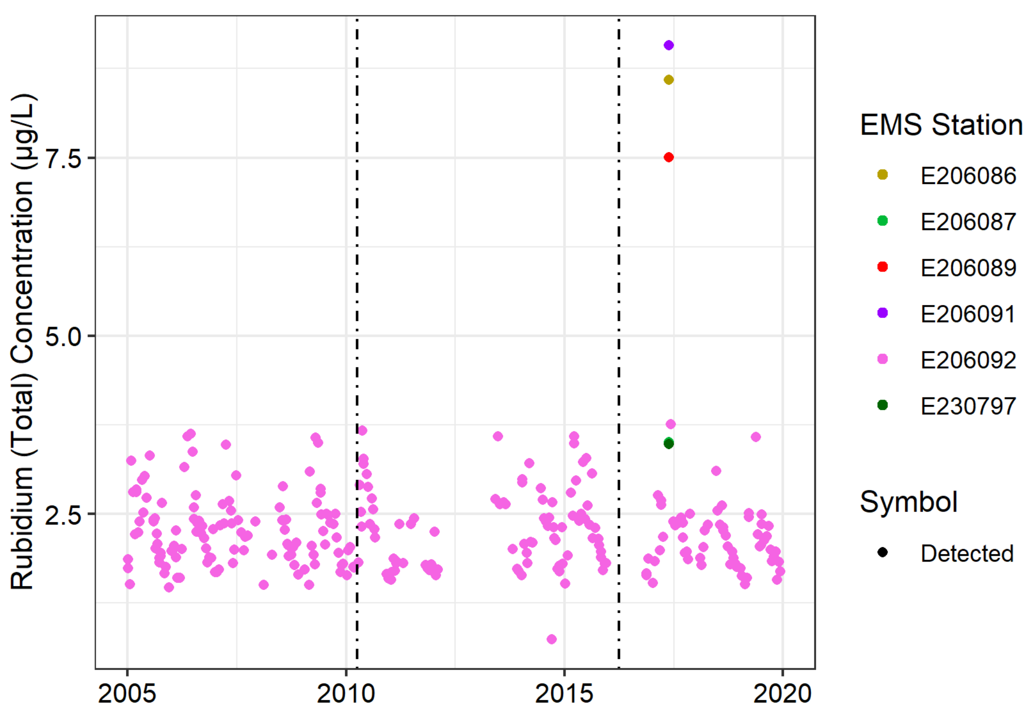


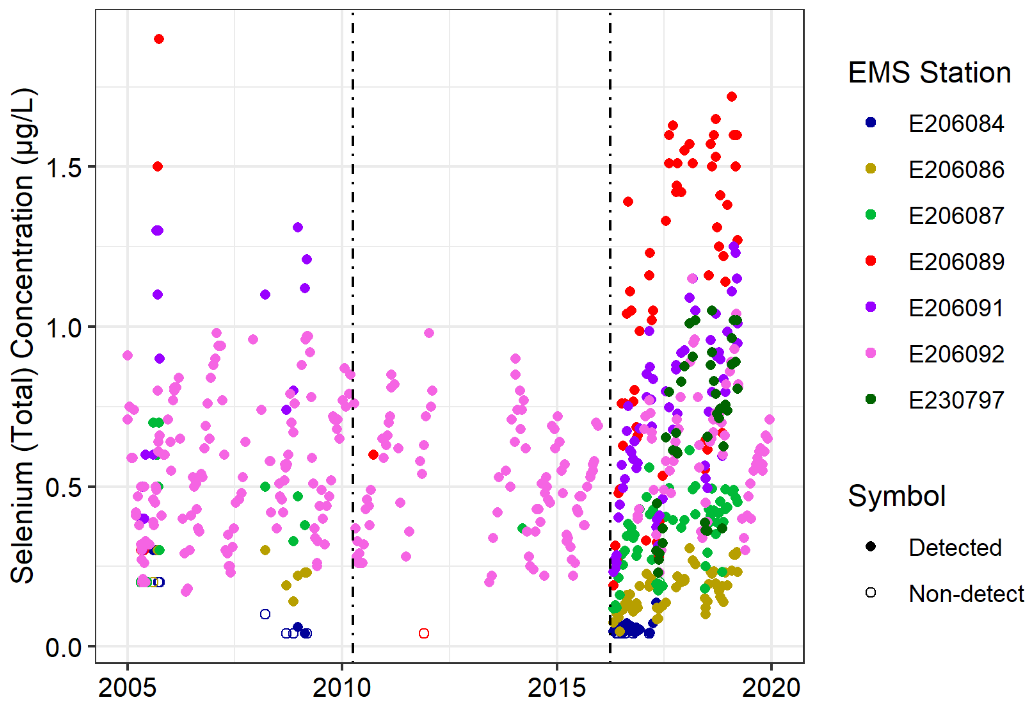
Molybdenum (Total) Concentration (µg/L)
3
2
1
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

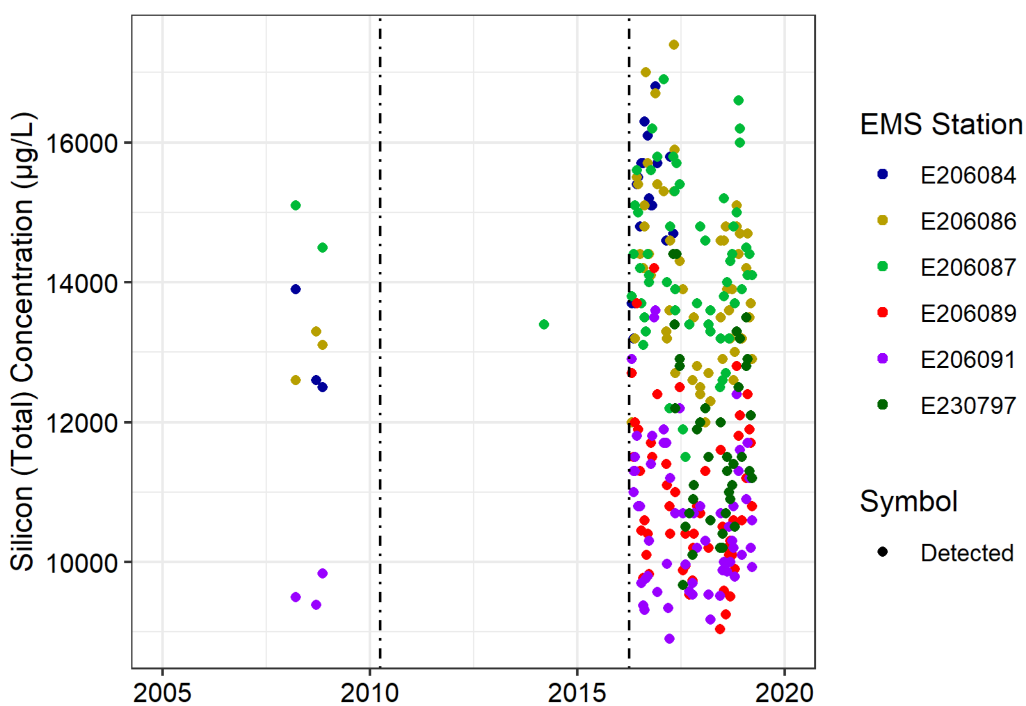

Nickel (Total) Concentration (µg/L)
0
1
2
3
4
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

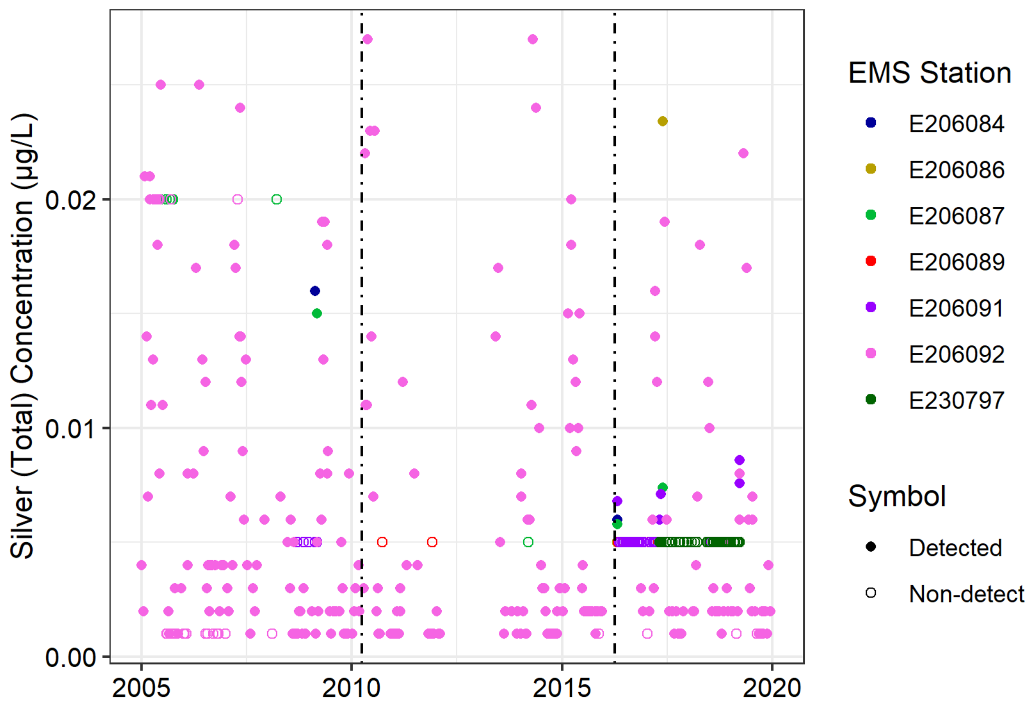

Niobium (Total) Concentration (µg/L)
0.00
0.05
0.10
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected
Non-detect


Platinum (Total) Concentration (µg/L)
0.050
0.025
0.000
-0.025
2005
2010
2015
2020
EMS Station
E206092
Symbol
Detected
Non-detect

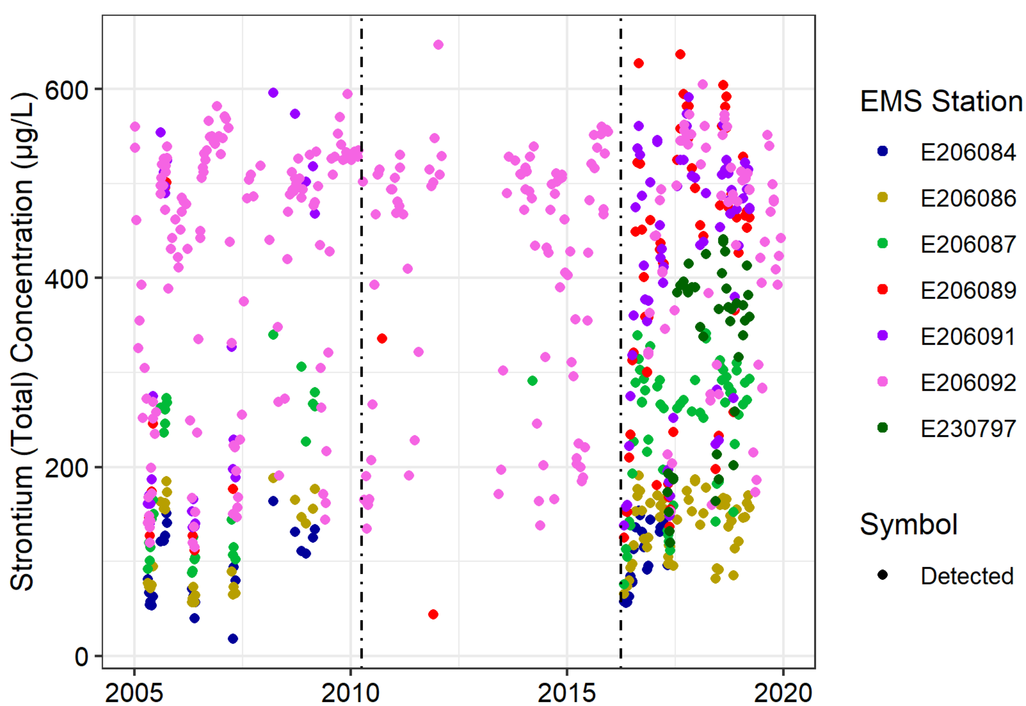

Rubidium (Total) Concentration (µg/L)
7.5
5.0
2.5
2005
2010
2015
2020
EMS Station
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected


Selenium (Total) Concentration (µg/L)
0.0
0.5
1.0
1.5
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

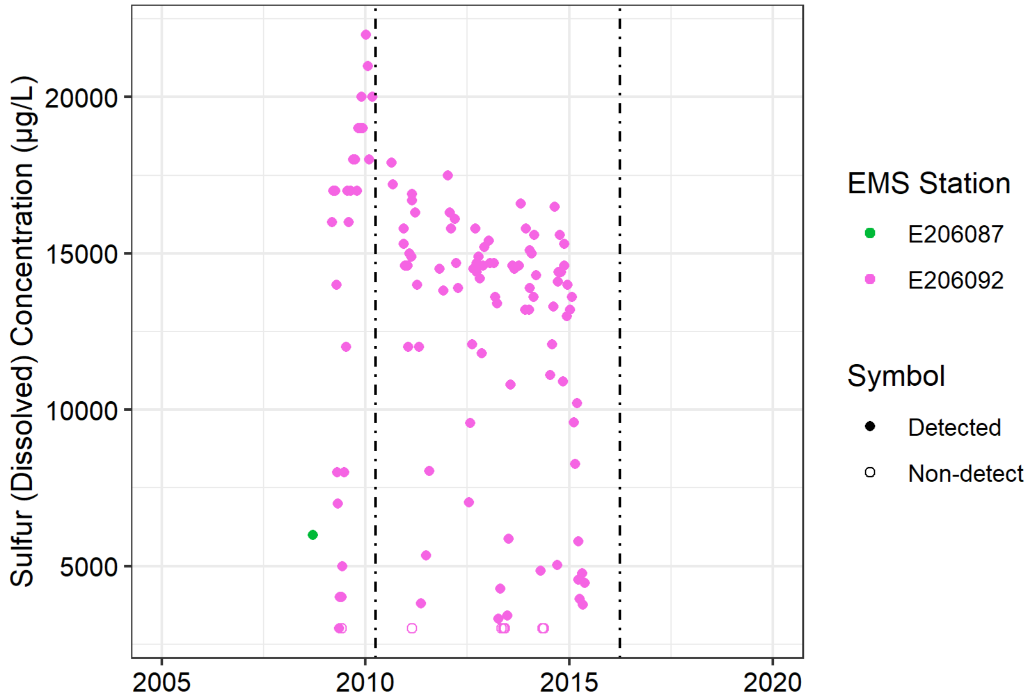

Silicon (Total) Concentration (µg/L)
10000
12000
14000
16000
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E230797
Symbol
Detected

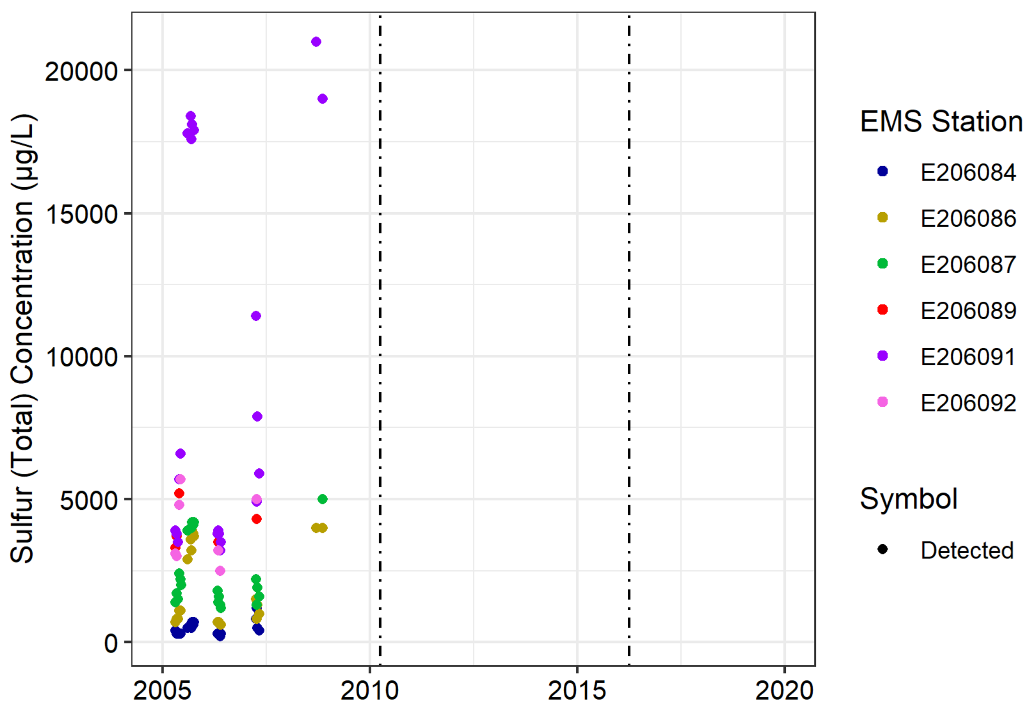


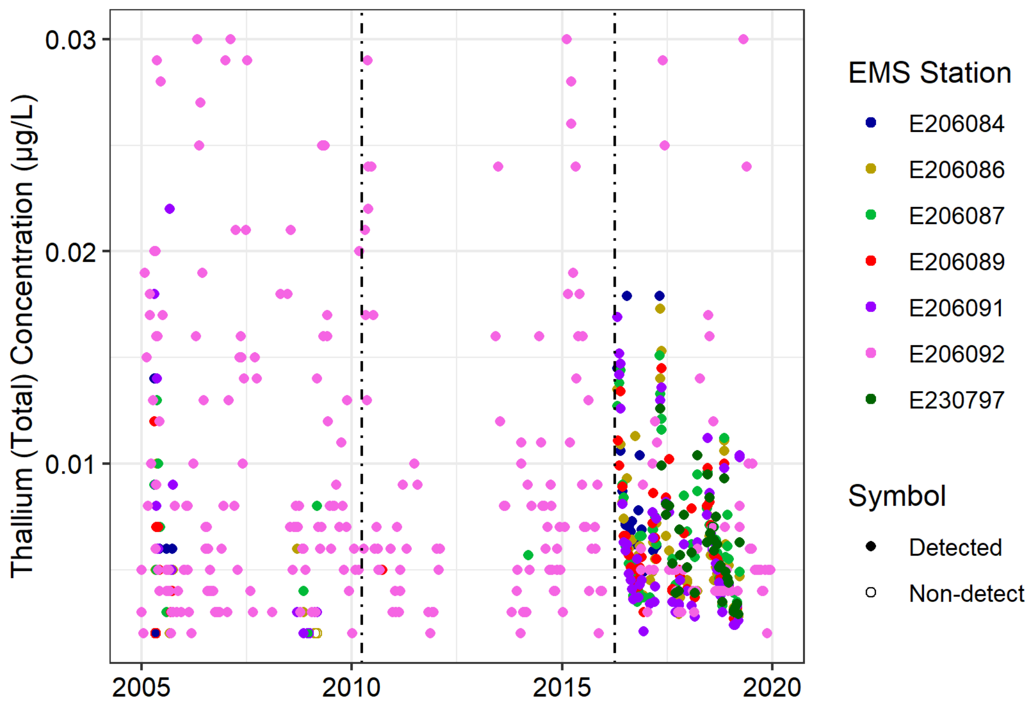
Silver (Total) Concentration (µg/L)
0.00
0.01
0.02
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

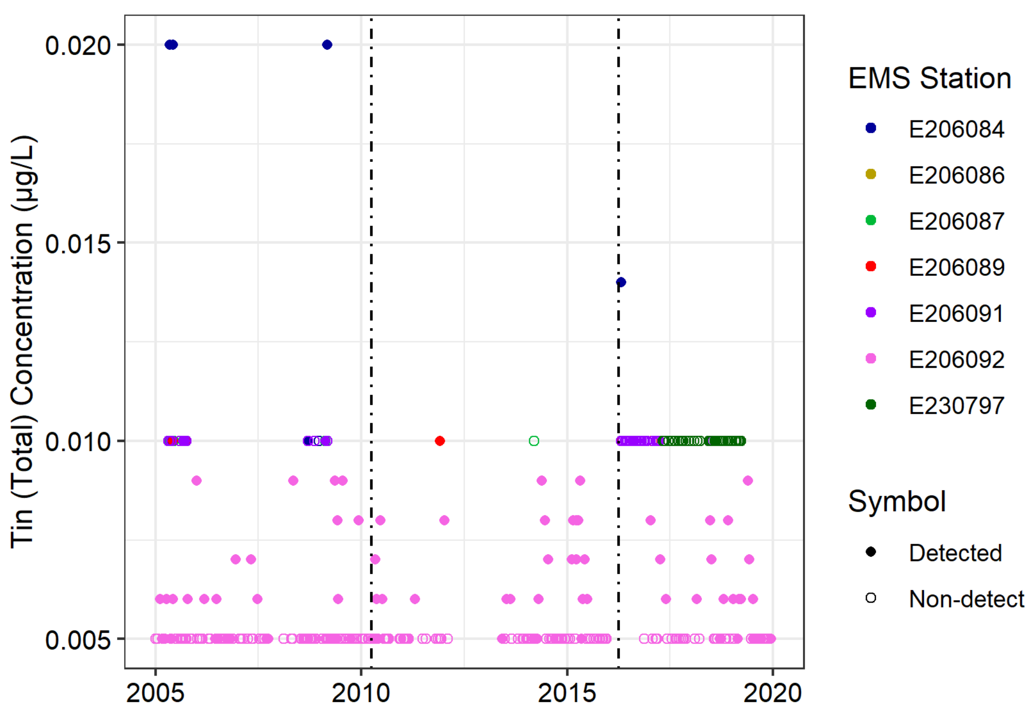


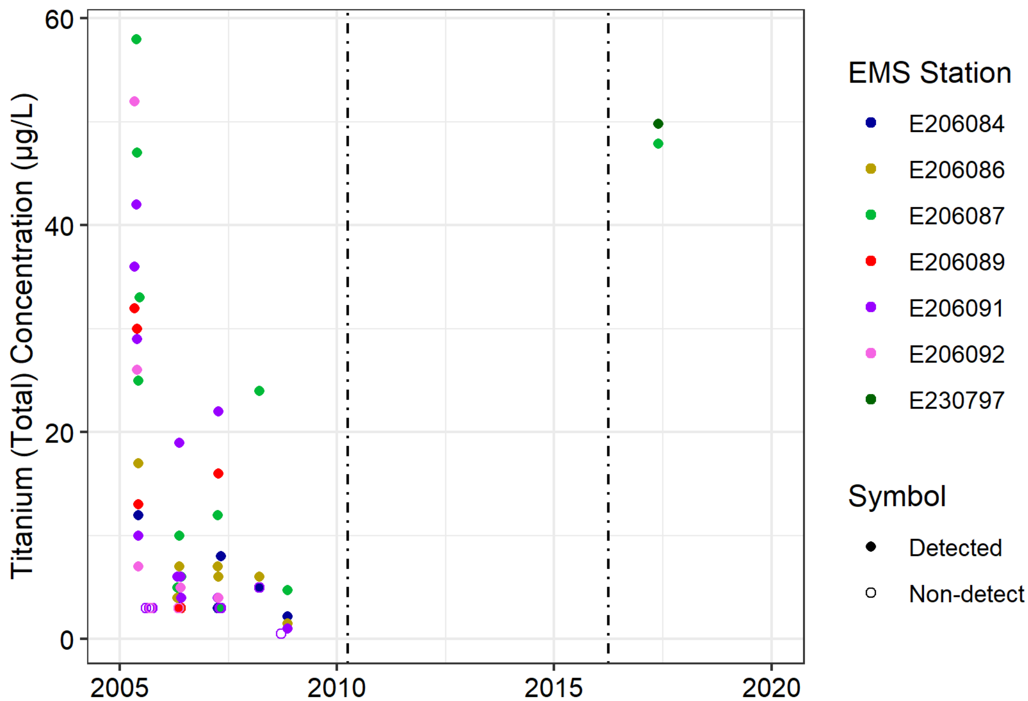
Strontium (Total) Concentration (µg/L)
0
200
400
600
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

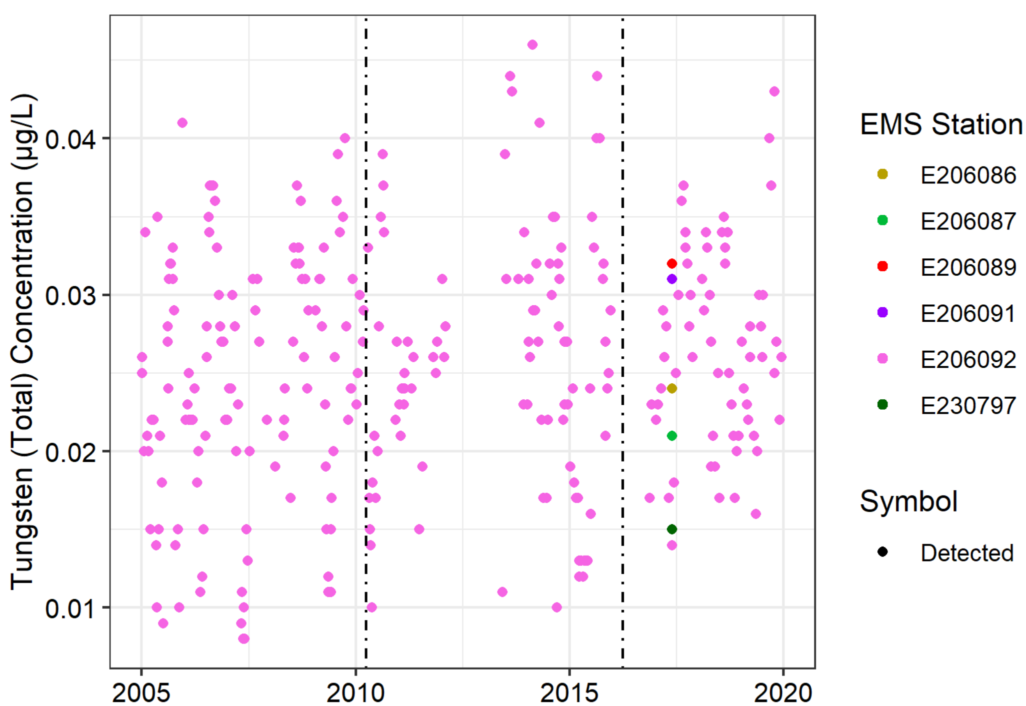

Sulfur (Dissolved) Concentration (µg/L)
20000
15000
10000
5000
2005
2010
2015
2020
EMS Station
E206087
E206092
Symbol
Detected
Non-detect


Sulfur (Total) Concentration (µg/L)
20000
15000
10000
5000
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
Symbol
Detected

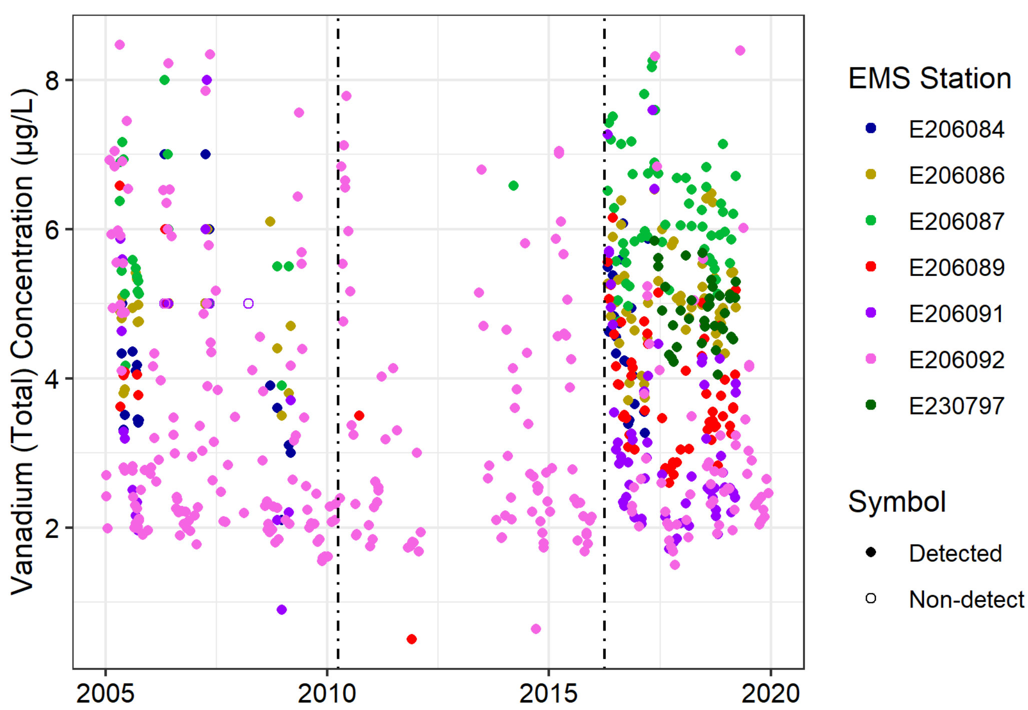

Thallium (Total) Concentration (µg/L)
0.03
0.02
0.01
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect


Tin (Total) Concentration (µg/L)
0.020
0.015
0.010
0.005
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

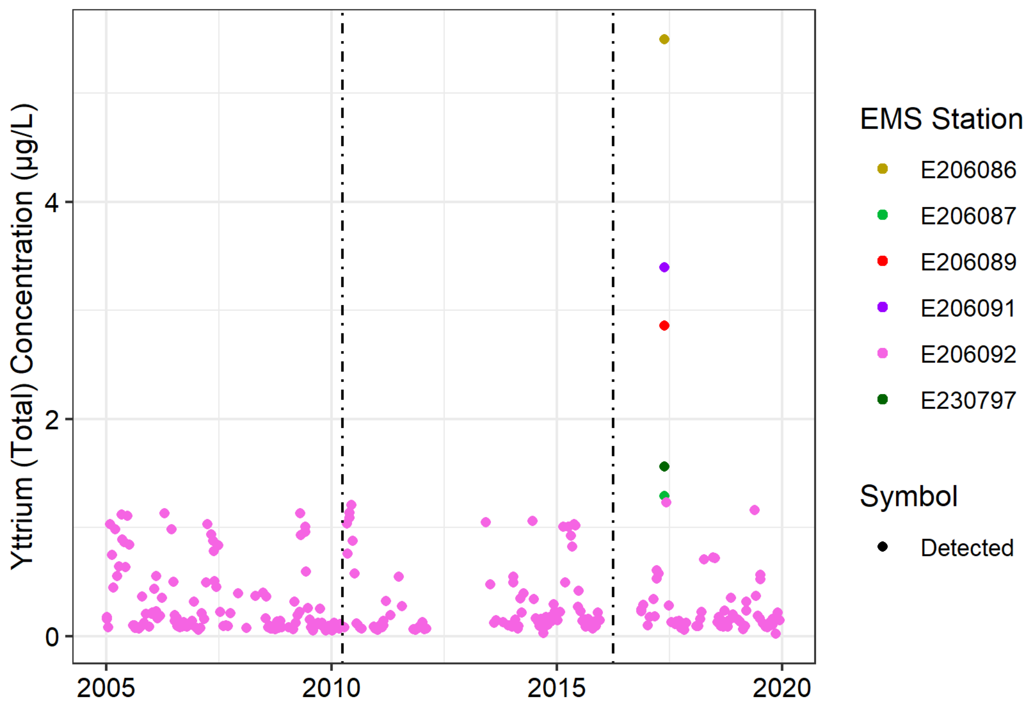

Titanium (Total) Concentration (µg/L)
60
40
20
0
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

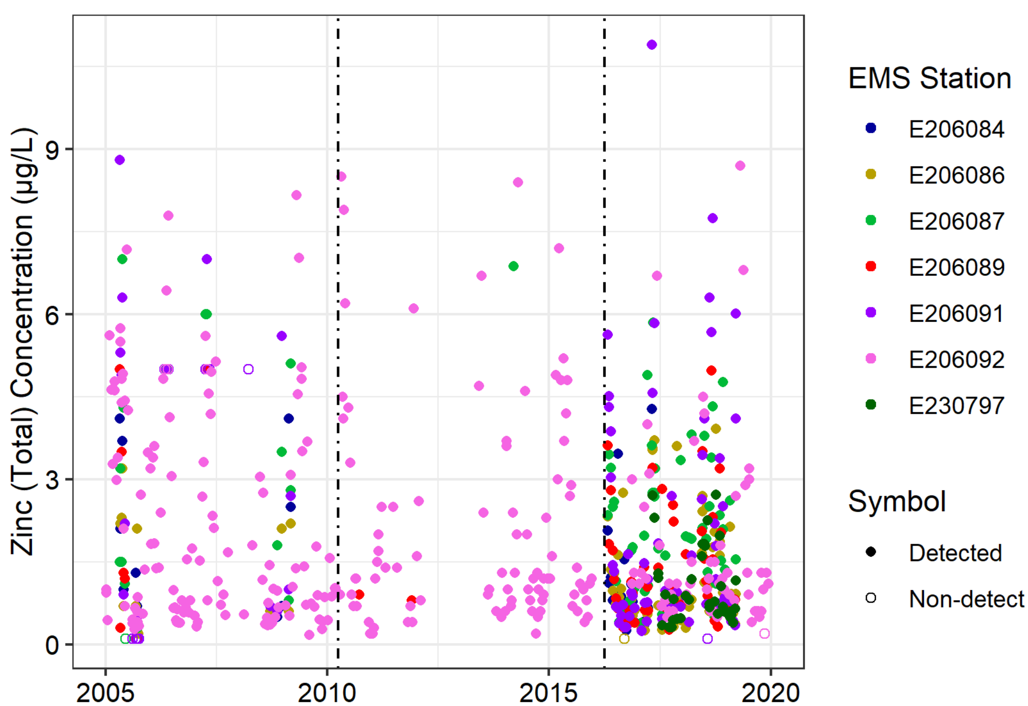

Tungsten (Total) Concentration (µg/L)
0.04
0.03
0.02
0.01
2005
2010
2015
2020
EMS Station
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected

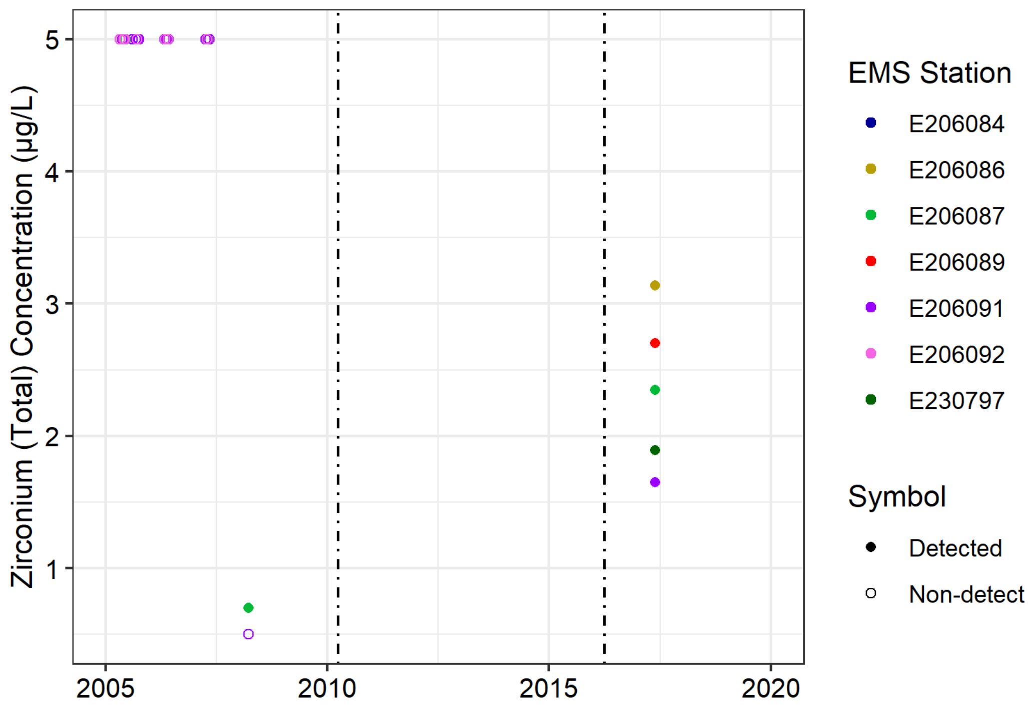
Uranium (Total) Concentration (µg/L)
0
1
2
3
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected



Vanadium (Total) Concentration (µg/L)
2
4
6
8
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect


Yttrium (Total) Concentration (µg/L)
0
2
4
2005
2010
2015
2020
EMS Station
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected


Zinc (Total) Concentration (µg/L)
0
3
6
9
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect


Zirconium (Total) Concentration (µg/L)
5
4
3
2
1
2005
2010
2015
2020
EMS Station
E206084
E206086
E206087
E206089
E206091
E206092
E230797
Symbol
Detected
Non-detect

APPENDIX C: OUTLIERS IDENTIFIED DURING TEMPORAL TREND ANALYSIS

Table C1: Outliers that were identified by R-QWTREND during model fit and removed from analysis.

Parameter	Unit	Sample Date	Outlier Value
Temperature	°C	2005-01-04	-6.9
		2006-11-28	0.05
		2006-12-14	0.05
		2009-12-08	0.05
		2013-12-04	0.04
		2013-12-11	0.03
Dissolved Oxygen	mg/L	2005-11-16	0.05
		2008-02-13	0.8
pH	pH units	no outliers were removed	
Specific Conductivity	µS/cm	2011-02-23	1
Turbidity	NTU	no outliers were removed	
Total Suspended Solids	mg/L	2013-04-09	0.5
Total Nitrogen	mg/L	2005-03-01	2.2
Nitrate plus Nitrite (Total)	mg/L	no outliers were removed	
Nitrate plus Nitrite (Dissolved)	mg/L	2006-06-12	0.001
		2006-07-11	0.001
		2009-11-18	0.001
Nitrate Nitrogen (Dissolved)	mg/L	2009-11-18	0.001
		2011-02-23	0.001
Ammonia Nitrogen (Total)	mg/L	no outliers were removed	
Dissolved Ammonia	mg/L	no outliers were removed	
Total Organic Nitrogen	mg/L	2008-02-13	0.78
		2010-01-20	0.01
		2010-04-27	0.01
		2011-02-23	0.01
Total Phosphorus (Total)	mg/L	2008-07-22	0.686
		2019-05-23	0.00025
Total Phosphorus (Dissolved)	mg/L	2009-06-24	0.188
		2009-10-28	0.008
		2010-08-18	0.152
		2015-01-27	0.225

Parameter	Unit	Sample Date	Outlier Value
Orthophosphate (Dissolved)	mg/L	2005-05-17	0.005
		2009-10-28	0.001
		2011-02-23	0.0005
		2011-04-11	0.002
		2011-07-26	0.002
Dissolved Organic Carbon	mg/L	2006-11-28	0.25
		2013-02-27	0.25
		2013-06-26	0.25
		2013-12-04	10.8
		2014-07-14	0.25
		2014-09-30	0.25
Fecal Coliforms	CFU/100 mL	no outliers were removed	
Escherichia coli	CFU/100 mL	no outliers were removed	