2019 Status of Surface Water Quality Lower Athabasca Region

Reporting on the Lower Athabasca Region Surface Water Quality Management Framework for January 2019 – December 2019

2019 Status of Surface Water Quality, Lower Athabasca Region, Alberta

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Acronyms and Abbreviations

AEP	Alberta Environment and Parks
EQGASW	Environmental Quality Guidelines for Alberta Surface Waters
GOA	Government of Alberta
LARP	Lower Athabasca Regional Plan
LAR SWQMF	Lower Athabasca Region Surface Water Quality Management Framework for the Lower Athabasca River
LTRN	Long Term River Network

Executive Summary

Background

This report was prepared by the Air and Watershed Stewardship Branch within the Resource Stewardship Division (RSD) at Alberta Environment and Parks (AEP) to fulfill reporting requirements mandated by the Lower Athabasca Region Surface Water Quality Management Framework for the Lower Athabasca River (LAR SWQMF; GOA 2012b), which supports the Lower Athabasca Regional Plan (LARP; GOA 2012a).

The 2019 report is the eighth annual report for the Lower Athabasca Region. Previous annual reports for the status of environmental conditions in the Lower Athabasca Region are accessible at: alberta.ca/lower-athabasca-regional-planning.aspx. The Government of Alberta (GOA) determines reporting requirements for the LARP and AEP has a responsibility for monitoring, evaluation and reporting under the Environmental Management Frameworks, including the LAR SWQMF. This report communicates the status of surface water quality at the Athabasca River at Old Fort monitoring site from January 1 to December 31, 2019.

Methodology

The LAR SWQMF identifies 61 surface water quality indicators that include major ions, nutrients, dissolved (filtered 0.45 µm) metals and total metals. Mean and peak (95^{th} percentile) triggers for each water quality indicator were calculated using historical monitoring data from the Old Fort monitoring station. Additional details about the calculation of mean and peak triggers are provided in the LAR SWQMF (GOA 2012b).

Mean triggers are intended to identify shifts in average annual values, whereas peak triggers are intended to identify shifts in the frequency of extreme values each year. In addition to mean and peak triggers, LAR SWQMF identifies surface water quality limits for 21 of the 61 water quality indicators. These limits were derived primarily from provincial or federal water quality guidelines where available (GOA 2012b). In this report, data from 61 surface water quality parameters collected monthly from January 1 to December 31, 2019 are compared against historical trigger and limit values, and assessed for any statistically significant deviations.

2019 Results Summary

For 2019, 61 water quality parameters were measured monthly at the Old Fort water quality monitoring station. The key results are:

- The mean triggers were exceeded in 2019 for potassium, dissolved barium, dissolved selenium, dissolved uranium and total uranium.
- The peak triggers were exceeded in 2019 for dissolved cobalt and dissolved uranium.
- No parameters exceeded water quality limits in 2019.

Lower Athabasca Regional Plan

The Lower Athabasca Regional Plan (LARP) was developed by the Government of Alberta under the Land Use Framework (GOA 2008). The plan sets outcomes that describe what the Government of Alberta wants to accomplish at a regional level and is given legislative authority under the *Alberta Land Stewardship Act* (GOA 2009). The LARP applies to the Lower Athabasca Region (LAR), an area approximately 93,212 km^2 in size located in northeastern Alberta (Figure 1). For more information, please see the LARP report (GOA 2012a).

The Air and Watershed Stewardship Branch within the Resource Stewardship Division of Alberta Environment and Parks (AEP) is responsible for monitoring, evaluation and reporting on the condition of the environment in the LAR. The 2019 Status of Surface Water Quality for the Lower Athabasca Region report fulfills the annual reporting requirements mandated by Lower Athabasca Region Surface Water Quality Management Framework for the Lower Athabasca River (LAR SWQMF; GOA 2012b), in support of the LARP.

Monitoring Stations

Water quality in the LAR is assessed based on data derived from monthly water quality sampling at the long-term regulatory site referred to as Old Fort (Figure 2). Old Fort refers to the combined historical data from two AEP Long Term River Network (LTRN) monitoring stations: Athabasca River at Old Fort - Right Bank (Station No. AB07DD0010) and Athabasca River downstream of Devil’s Elbow at Winter Road Crossing (Station No. AB07DD0105). The Devil's Elbow station is located approximately 20 km downstream of the Old Fort station, below the confluence of the Richardson River. Due to accessibility constraints at the Old Fort monitoring station, some surface water samples have been historically collected from the Devil's Elbow monitoring station during the ice-covered season. If both stations were sampled during the same month, the Old Fort monitoring station took priority in the dataset to maintain as much consistency in the location of the collected data as possible. The use of this combined monitoring station dataset was developed during the creation of LAR SWQMF using the best available data at the time. Since 2016, all samples have been taken from the Athabasca River at Old Fort - Right Bank station.

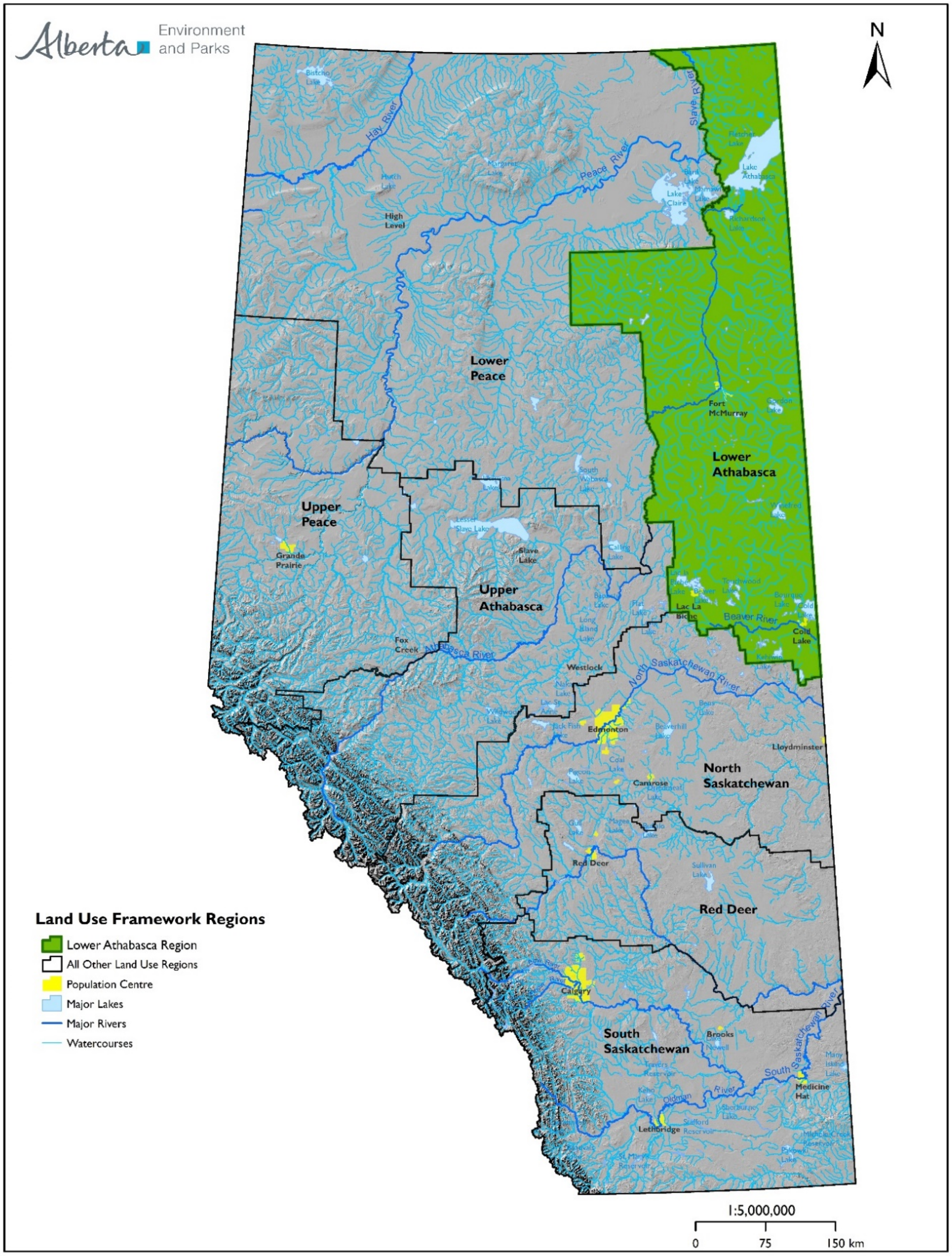

Figure 1. Location of the seven Land Use Framework Regions within Alberta. The Lower Athabasca Region is the area shaded green on the map.

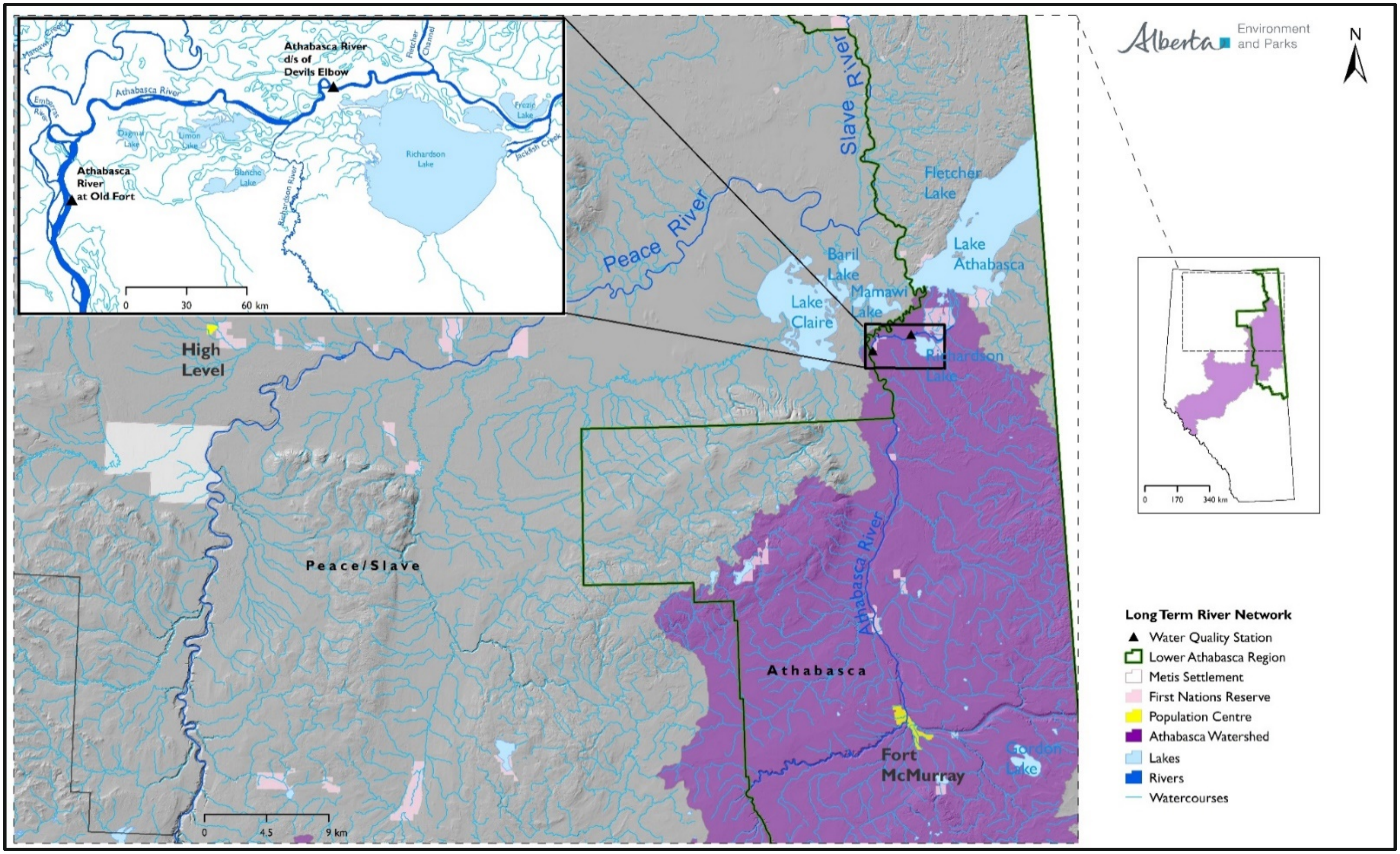

Figure 2. Locations of the AEP Long Term River Network Water Quality Stations on the Lower Athabasca River.

Methodology

Annual compliance data used in the 2019 report were taken from monthly water quality samples at the Old Fort monitoring station obtained from January to December 2019. Sixty-one water quality parameters, including 11 general indicators, 27 total metals and 23 dissolved metals (Table 1, 2), were chosen as indicators in the framework. Rationale for indicator selection is given in the LAR SWQMF (GOA 2012b). Sample collection, data verification and analyses follow recognized standards and protocols established by AEP for consistent sample collection and processing across the Province (AENV 2006).

Interim data for each surface water quality parameter refers to data collected between the end of the historical (generally spanning 1988-2009 with select metal indicators based on shorter time series) period and the current annual compliance periods (i.e., the interim period for the 2019 report would span from 2010-2019). Interim data were not included in the statistical assessment of triggers and limit exceedances, but were used to provide a continuous dataset for plotting water quality data for visual inspection.

Table 1. List of general indicators for the LAR SWQMF.

Calcium	Chloride
Magnesium	Potassium
Sodium	Sulphate
Total Dissolved Phosphorus	Total Phosphorus
Nitrate	Total Ammonia
Total Nitrogen	

Table 2. List of metal indicators for the LAR SWQMF. This includes total and dissolved fractions unless otherwise noted.

Aluminum	Antimony
Arsenic	Barium
Beryllium (total only)	Bismuth (total only)
Boron	Cadmium
Chromium	Cobalt
Copper	Iron
Lead	Lithium
Manganese	Mercury (total only)
Molybdenum	Nickel
Selenium	Silver (total only)
Strontium	Thallium
Thorium	Titanium
Uranium	Vanadium
Zinc	

Mean and peak (95^{th} percentile) triggers were calculated from historical Old Fort data (1988 to 2009 with select metals based on shorter time series). Annual mean and peak concentrations were first compared to historical triggers to determine if there was deviation in an undesirable direction from historical values; those that were greater than their respective trigger were then statistically assessed for significance. A mean trigger exceedance was defined as a statistically significant shift in central tendency in the annual compliance data relative to the historical record. A peak trigger exceedance was reported when the frequency of the annual compliance data, which exceeded the trigger value, was higher than the expected frequency given no significant change in condition. It also represented a statistically significant shift in the frequency of extreme values in the annual data. Details of the statistical analyses used to determine a mean or peak trigger exceedance are detailed in Appendix A. Identification of median and peak exceedances are intended to act as an early warning system of potential changes in surface water quality and as a signal to conduct further investigation.

Water quality limits were derived from provincial and federal water quality guidelines (GOA 2012b). A surface water quality limit is exceeded if the annual mean for a given surface water quality parameter exceeds the surface water quality limit for that indicator. For water quality indicators where the limit is calculated using toxicity modifying factors (i.e., total ammonia and total nickel), a limit was calculated for each sample in 2019 and the sample concentration was then compared against the calculated monthly limit**Error! Reference source not found.**. Additional details on the analytical and statistical methods are provided in Appendix A.

Historically, AEP replaced any censored data of a given parameter (i.e., observations measured below the method detection limit) with one-half of the detection limit value. This practice was adopted for this report with the calculation of the historical triggers, as well as with the annual compliance dataset. Statistical methods used in this report are noted in the LAR SWQMF (GOA 2012b) and in Appendix A of this report. All statistical assessments were performed using R statistical software (Millard 2013, R Development Core Team 2020).

Results

Summary statistics, including the annual and historical means and 95th percentiles (peaks), are presented in Appendix B.

Exceedances of Water Quality Triggers

In 2019, a statistically significant exceedance for the annual mean trigger value was observed for:

- potassium;
- dissolved barium;
- dissolved selenium;
- dissolved uranium; and
- total uranium.

There was a statistically significant difference in mean dissolved molybdenum concentrations when comparing 2019 and historical means. However, the annual mean concentration for dissolved molybdenum (0.696 µg/L) was lower than the mean trigger (0.7 µg/L). When rounded, the annual mean concentration is equal to, but does not exceed, the mean trigger. Therefore, it is not highlighted as an exceedance in this report.

A statistically significant exceedance of the annual peak trigger values was observed for:

- dissolved cobalt; and
- dissolved uranium.

Table 3. Mean and peak (95th percentile) values for indicators exhibiting a statistically significant trigger exceedance in the LAR during 2019. Cells shaded in green indicate where a statistically significant trigger exceedance has occurred based on Wilcoxon rank sum test (for mean) and binomial test (for peak) results. Detailed test results are available in Appendix C.

General Indicator	Units	Historical Mean Trigger	2019 Annual Mean	Historical Peak Trigger	2019 Annual Peak
Potassium	mg/L	1.4	1.8	2.1	3.0
Dissolved Barium	µg/L	52.6	55.1	73.7	67.6
Dissolved Cobalt	µg/L	0.07	0.08	0.11	0.16
Dissolved Selenium	µg/L	0.229	0.258	0.409	0.300
Dissolved Uranium	µg/L	0.313	0.426	0.381	0.497
Total Uranium	µg/L	0.4	0.5	0.7	0.8

Exceedances of Water Quality Limits

None of the surface water quality limits established under the LAR SWQMF (GOA 2012b) exceeded water quality limits (Table 4). No monthly samples exceeded the calculated monthly limits for total ammonia (based on pH and temperature) and total nickel (based on hardness).

Table 4. List of surface water quality limits for general indicators. Limit values were taken from the LAR SWQMF (GOA 2012b).

General Indicator	Units	Surface Water Quality Limit	General Indicator	Units	Surface Water Quality Limit
Calcium (Ca^{2+})	mg/L	1000	**Sulphate (SO_4^-)**	mg/L	500
Chloride (Cl^-)	mg/L	100	**Nitrate (NO_3-N)**	mg/L	2.935
Sodium (Na^+)	mg/L	200	**Total Ammonia (NH_{3+4}-N)**	mg/L	Varies with pH and temperature[A]

[A] Calculations are given in Environmental Quality Guidelines for Alberta Surface Waters (GOA 2018).

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Appendix A

Analytical and Statistical Methods Used to Assess Trigger and Limit Exceedances

The Lower Athabasca Region Surface Water Quality Management Framework (LAR SWQMF) establishes mean and peak (95th percentile) triggers for 61 surface water quality parameters. This list of 61 surface water quality parameters includes 27 total metals, 23 dissolved metals (0.45 µm filter) and 11 general parameters. Water samples for general parameters were analyzed by Maxxam Analytics (now Bureau Veritas) and metal parameters were analyzed by Innotech Alberta. All statistical analyses and plots were conducted using packages *Hmisc* (Harrell et al. 2020), *tidyverse* (Wickham et al. 2019), *reshape2* (Wickham 2007), *gdata* (Warnes et al. 2017), *gtools* (Warnes et al. 2020), *exactRankTests* (Hothorn and Hornik 2019), *tcltk* (R Development Core Team 2020), *RODBC* (Ripley and Lapsley 2020) and *doBy* (Højsgaard and Halekoh 20200 in R version 4.0.0. (R Development Core Team 2020).

Preliminary Data Screening

All water quality data used in the assessment were from two Long-Term River Network (LTRN) stations: Athabasca River at Old Fort – Right Bank (station no. AB07DD0010) and Athabasca River downstream of Devil's Elbow at Winter Road Crossing (station no. AB07DD0105), the latter of which provided winter surface water samples when the Old Fort station was inaccessible due to unsafe ice conditions. The combined historical dataset from the two sites is collectively referred to as "Old Fort". Since 2016, all samples have been taken from the Athabasca River at Old Fort - Right Bank station. If there were concurrent monthly sampling at both stations, the Old Fort sample took priority and the Devil's Elbow sample was removed. Any data point below the method detection limit (MDL) was substituted with a value of ½ MDL.

The historical dataset used for trigger development and comparisons against annual compliance data generally comprised data from 1988 to 2009, with the metals dataset being further constrained to 1999-2009, and some metals restricted to 2003-2009 due to analytical methodology changes (GOA 2012b). For this 2019 report, the annual compliance dataset includes samples obtained from January 1, 2019 and December 31, 2019. Mean and 95th percentile (peak) triggers were calculated for each water quality indicator using the historical dataset. Mean and 95th percentile concentrations were then calculated for each indicator in the annual compliance dataset. For each indicator, the compliance mean and peak value was compared to its respective historical trigger. If the compliance value exceeded the trigger value, the indicator was flagged for further statistical analyses to determine if there was a statistically significant deviation from historical triggers in an undesired direction. Mean compliance values were also compared to surface water quality limits for any exceedances.

Trigger Exceedances

Quantile-quantile (Q-Q) plots and the Shapiro-Wilk normality test were used to assess the normality of combined historical (1988-2009 general indicators [*n*~235]; 1999-2009 metal indicators [*n*~52]) and annual period being assessed (i.e., 2019 [*n*=12]), using a significance level of 0.05.

Mean Trigger Exceedances

The Welch's two sample t-test and Wilcoxon rank sum test assess whether there is a statistically significant shift in the central tendency of the annual data compared to the historical mean triggers. Statistical evaluations were conducted only when the mean of the 2019 water quality parameter was higher than the mean trigger, using one-sided hypothesis tests. The parametric Welch's two sample t-test was used for normal or lognormal distributions, while the nonparametric Wilcoxon rank sum test was used when the dataset did not meet the assumption of normality or lognormality. The significance level was set at 0.05.

Non-parametric tests do not rely on a normal sample distribution, are more statistically robust to outliers and appropriately incorporate censored data within the annual dataset. However, they have slightly less statistical power in comparison to parametric testing if the assumptions for parametric testing are met. The non-parametric Wilcoxon rank sum test was conducted to test the null hypothesis that the distribution of the 2019 water quality parameters were not statistically different than the historical data. This differs from a test for change in mean concentrations, but has historically been used in the LAR SWQMF as an alternative to the parametric Welch's t-test. The *exactRankTests* package in R was used to compute the Wilcoxon rank sum tests (Hothorn and Hormik 2012).

A permutation test for difference in means was included as part of the data verification process. Permutation tests are based on a randomization methodology and are used as an alternative to parametric tests to test for difference in means without assuming a distribution, can properly incorporate censored data, and minimize the effect of outliers (Helsel, 2017), with the assumption that the samples have equal variance. Given the large discrepancy in sample size between historical data (*n* ~ 235 general indicators; *n* ~ 52 metal indicators) and 2019 data (*n* = 12), the assumption of equal variance in the permutation test cannot be accurately assessed. However, because the permutation test correctly evaluates a statistically significant exceedance of the mean trigger, and has comparable statistical power to parametric tests without the distributional assumptions, it was considered a valuable addition to the data verification process. The *exactRankTests* package in R was used to compute the permutation test for mean (Hothorn and Hormik, 2012). The permutation test for mean was employed as a supplementary assessment to both the Welch's two sample t-test and Wilcoxon rank sum test. In 2019, the permutation test found potassium and dissolved uranium to have a statistically significant exceedance of the mean trigger. If any of the hypothesis tests returned a statistically significant result, they will be further examined in the management response.

Peak Trigger Exceedances

Binomial tests were conducted to test whether the historical 95th percentile (i.e., the peak trigger) for a given surface water quality parameter was exceeded more than 5% of the time. Binomial tests were conducted for a surface water quality parameter when one or more of the individual samples from 2019 was higher than the historical peak trigger. The binomial test was applied to the number of 2019 values that were greater than the peak trigger. If the binomial test indicates that the observed number of individual exceedances in 2019 based on the samples collected is likely to be greater than an acceptable degree of violation (i.e., 5%) when applied to the waterbody as a whole, a peak trigger exceedance has occurred.

Limit Exceedances

Limit exceedances were determined by comparing annual compliance mean concentrations to the limit values defined in LAR SWQMF (GOA 2012b). For water quality indicators that are affected by toxicity modifying factors (i.e., total ammonia and nitrate), a monthly limit was calculated for the compliance year using guideline equations (GOA 1999), and the compliance monthly mean concentration compared against the calculated monthly limit. If greater than 50% of all months exceeded their calculated limits for a specific parameter, this was identified as a limit exceedance.

Appendix B

Descriptive Statistics for Old Fort Monitoring Station

Table B-1. Summary statistics for 2019 data general parameters from the Old Fort monitoring site (all values are in mg/L; *n*=11; P=percentile, SD standard deviation, MDL=2019 method detection limit).

Indicator	Max	Min	Median	Mean	P99.9	P99	P95	Variance	SD	MDL
Calcium	49.0	29.0	35.5	37.8	49.0	48.6	46.8	43.1	6.6	0.3
Chloride	30.0	4.3	14.0	15.1	29.9	29.3	26.7	65.9	8.1	1.0
Magnesium	14.0	7.7	10.0	10.3	14.0	13.8	12.9	3.6	1.9	0.2
Nitrate	0.280	0.002	0.046	0.095	0.280	0.277	0.264	0.011	0.103	0.003
Potassium	3.9	1.1	1.6	1.8	3.9	3.7	3.0	0.6	0.8	0.3
Sodium	32.0	7.8	18.0	18.2	32.0	31.8	30.9	71.3	8.4	0.5
Sulphate	36.0	17.0	28.5	27.9	36.0	36.0	36.0	39.5	6.3	1.0
Total Ammonia	0.06	0.01	0.02	0.02	0.06	0.06	0.05	0.00	0.02	0.02
Total Dissolved Phosphorus	0.024	0.004	0.010	0.010	0.024	0.023	0.019	< 0.003	0.005	0.003
Total Nitrogen	1.100	0.430	0.550	0.646	1.099	1.089	1.045	0.046	0.214	0.055
Total Phosphorus	0.380	0.016	0.052	0.105	0.380	0.375	0.353	0.015	0.124	0.003

Table B-2. Summary statistics for 2019 data metal parameters from the Old Fort monitoring site (all values are in µg/L; *n*=11; P=percentile, SD=standard deviation; MDL= 2019 method detection limit; D=dissolved; T=Total).

Indicator	Max	Min	Median	Mean	P99.9	P99	P95	Variance	SD	MDL
Aluminum D	6	2	3	4	6	6	6	2	1	0.4
Aluminum T	5730	27	261	1266	5719	5618	5169	3839949	1960	0.4
Antimony D	0.120	0.045	0.045	0.051	0.119	0.112	0.079	0.001	0.022	0.09
Antimony T	0.158	0.050	0.061	0.078	0.158	0.153	0.131	0.001	0.034	0.008
Arsenic D	0.8	0.4	0.5	0.5	0.8	0.8	0.7	< 0.01	0.1	0.01
Arsenic T	3.5	0.5	0.8	1.3	3.5	3.4	2.7	0.8	0.9	0.01
Barium D	67.7	45.6	52.5	55.1	67.7	67.7	67.6	69.2	8.3	0.1
Barium T	166.0	55.3	69.3	81.4	165.3	159.4	133.0	1016.8	31.9	0.1
Beryllium T	0.269	0.002	0.023	0.063	0.268	0.255	0.196	0.007	0.082	0.003
Bismuth T	0.0670	0.0015	0.0080	0.0154	0.0666	0.0630	0.0472	0.0004	0.0196	0.003
Boron D	32	15	24	24	32	32	32	41	6	0.2
Boron T	32	17	25	24	32	32	32	36	6	0.2
Cadmium D	0.0170	0.0080	0.0110	0.0116	0.0170	0.0170	0.0170	< 0.002	0.0034	0.002
Cadmium T	0.2	< 0.01	< 0.01	< 0.01	0.1	0.1	0.1	< 0.01	< 0.01	0.01
Chromium D	0.50	0.15	0.15	0.19	0.50	0.48	0.39	0.01	0.11	0.3
Chromium T	8	< 0.1	1	2	7	7	7	7	3	0.1
Cobalt D	0.19	0.01	0.07	0.08	0.19	0.18	0.16	< 0.01	0.05	0.01

Indicator	Max	Min	Median	Mean	P99.9	P99	P95	Variance	SD	MDL
Cobalt T	4.4	0.0	0.4	1.0	4.4	4.2	3.2	1.6	1.3	0.002
Copper D	2.4	0.6	0.8	1.0	2.3	2.3	2.1	0.3	0.5	0.1
Copper T	11.4	0.7	1.3	2.8	11.3	10.7	8.0	9.9	3.2	0.1
Iron D	175	17	124	116	175	174	171	1875	43	2
Iron T	9450	424	840	2254	9397	8915	6777	7286143	2699	1
Lead D	0.10	0.01	0.04	0.04	0.10	0.10	0.08	< 0.02	0.03	0.02
Lead T	5.9	0.1	0.4	1.2	5.9	5.6	4.2	3.0	1.7	0.004
Lithium D	10	5	7	7	10	10	9	3	2	0.02
Lithium T	10	7	8	8	10	10	10	1	1	0.007
Manganese D	19	0.41	2	6	19	18	17	45	7	0.01
Manganese T	285	19	42	82	284	272	222	6650	82	0.04
Mercury T	7.3500	0.6200	2.3350	3.3183	7.3445	7.2950	7.0750	6.7345	2.5951	0.0600
Molybdenum D	0.9	0.6	0.7	0.7	0.9	0.9	0.8	0.006	0.1	0.005
Molybdenum T	0.9	0.6	0.7	0.7	0.9	0.9	0.9	0.015	0.1	0.002
Nickel D	2.1	0.8	1.1	1.4	2.1	2.1	2.1	0.3	0.5	0.03
Nickel T	14.4	1.1	2.8	4.0	14.3	13.5	9.9	14.5	3.8	0.03
Selenium D	0.300	0.100	0.300	0.258	0.300	0.300	0.300	0.005	0.067	0.200
Selenium T	0.600	0.200	0.300	0.350	0.599	0.589	0.545	0.014	0.117	0.200
Silver T	0.0690	0.0020	0.0050	0.0146	0.0685	0.0643	0.0453	0.0004	0.0198	0.001

Indicator	Max	Min	Median	Mean	P99.9	P99	P95	Variance	SD	MDL
Strontium D	296	178	214	225	296	295	293	1735	42	0.07
Strontium T	299	179	232	236	299	298	295	1463	38	0.07
Thallium D	0.0080	0.0040	0.0045	0.0053	0.0080	0.0080	0.0080	< 0.002	0.0017	0.002
Thallium T	0.1250	0.0040	0.0140	0.0322	0.1244	0.1191	0.0953	0.0014	0.0378	0.002
Thorium D	0.0400	0.0020	0.0075	0.0126	0.0398	0.0381	0.0306	0.0001	0.0108	0.002
Thorium T	1.85	0.01	0.09	0.35	1.84	1.73	1.26	0.30	0.55	0.002
Titanium D	2	1	1	1	2	2	1	0.08	0.29	0.03
Titanium T	67	1	5	15	67	63	48	387	20	0.03
Uranium D	0.498	0.375	0.413	0.426	0.498	0.498	0.497	0.002	0.041	0.002
Uranium T	0.9	0.4	0.5	0.5	0.9	0.9	0.8	0.021	0.1	0.002
Vanadium D	0.459	0.095	0.268	0.259	0.458	0.447	0.400	0.010	0.101	0.006
Vanadium T	14	0.277	1	4	14	14	14	25	5	0.007
Zinc D	1.1	0.2	0.6	0.5	1.1	1.1	0.9	0.1	0.3	0.3
Zinc T	21.3	1.0	2.3	5.4	21.2	20.2	16.0	37.6	6.1	0.2

Appendix C

Statistical Summary and Boxplots

Table C-1. Results of the statistical assessment of the 2019 mean values against LAR SWQMF triggers. The surface water quality parameters with concentrations that had statistically significant test results are highlighted in green.

				Welch's two sample t-test			Wilcoxon rank sum test		Permutation test		Distribution Type[A]
Indicator	Units	Mean Trigger	2019 Mean	T-Statistic	DF	P-Value	W-Statistic	P-Value	W-Statistic	P-Value	T=Normal F=Non-Normal
GENERAL INDICATORS											
Calcium	mg/L	34.7	37.8	1.554	13	0.072	1762	0.073	1547	0.100	F
Magnesium	mg/L	9.5	10.3	1.485	13	0.081	1731	0.093	1532	0.118	F
Potassium	mg/L	1.4	1.8	1.897	12	0.041	2001	0.007	562	0.046	F
Sulphate	mg/L	26.7	27.9	0.609	14	0.276	1530	0.312	1521	0.339	F
Total Phosphorus	mg/L	0.074	0.100	0.853	11	0.206	1536	0.267	727	0.097	F
Total Nitrogen	mg/L	0.60	0.65	0.769	13	0.228	1324	0.603	967	0.237	F
METAL INDICATORS											
Dissolved Arsenic	µg/L	0.5	0.5	1.323	24	0.099	369	0.090	270	0.159	F
Total Arsenic	µg/L	1.1	1.3	0.459	16	0.326	342	0.307	168	0.310	F
Dissolved Barium	µg/L	52.6	55.1	0.456	59	0.325	428	0.007	68	0.227	F
Total Barium	µg/L	79.3	81.4	0.196	19	0.423	345	0.289	130	0.401	F
Total Bismuth	µg/L	0.0172	0.020	-0.200	17	0.578	188	0.704	126	0.589	F

Dissolved Cobalt	µg/L	0.07	0.08	0.255	13	0.401	192	0.619	210	0.325	T[B]
Total Cobalt	µg/L	0.8	1.0	0.430	13	0.337	287	0.666	167	0.265	F
Total Iron	µg/L	1899	2254	0.429	14	0.337	308	0.796	183	0.647	F
Dissolved Lithium	µg/L	6	7	1.454	17	0.082	378	0.065	371	0.085	T
Total Manganese	µg/L	65	82	0.675	13	0.256	290	0.716	179	0.181	F
Total Nickel	µg/L	3.4	4.0	0.538	14	0.299	358	0.218	214	0.254	F
Dissolved Selenium	µg/L	0.229	0.3	0.208	41	0.418	276	0.036	104	0.422	F
Total Selenium	µg/L	0.333	0.4	-0.139	27	0.555	227	0.348	179	0.518	F
Dissolved Strontium	µg/L	215	225	1.287	11	0.103	360	0.120	2705	0.313	T[B]
Total Strontium	µg/L	225	236	1.420	37	0.082	378	0.106	2828	0.317	T[B]
Dissolved Uranium	µg/L	0.313	0.430	7.281	27	<0.001	396	<0.001	411	<0.001	T
Total Uranium	µg/L	0.4	0.5	1.632	15	0.062	465	0.004	312	0.051	F

[A] Normality tested using Shapiro-Wilk test. If the water quality parameter passed the test for normality (T), the results of parametric testing are recommended. If the parameter failed the test for normality (F), the results of the non-parametric tests are recommended.

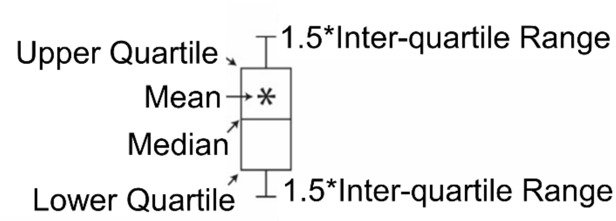
[B] Data were lognormally distributed, so t-tests were performed on the log-transformed data.

Table C-2. Statistical assessment of the 2019 results against LAR SWQMF peak triggers, using a binomial test. The surface water quality parameters with a statistically significant number of exceedances are highlighted in green.

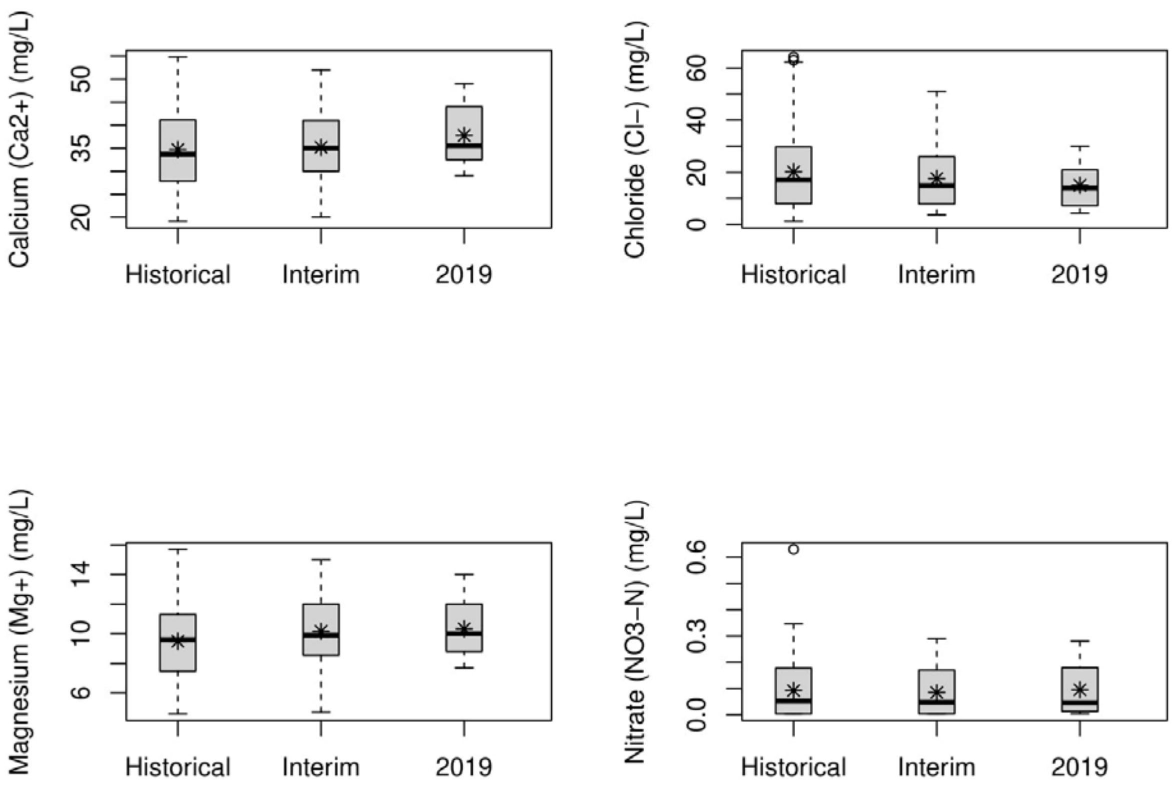
Indicator	Units	Peak Trigger	Number of Occurrences Higher Than Trigger	Months for which Occurrences were Higher than Trigger	Binomial Test p-value
GENERAL INDICATORS					
Calcium	mg/L	48.9	1	Jan	0.460
Magnesium	mg/L	13.7	1	Jan	0.460
Nitrate	mg/L	0.264	1	Apr	0.460
Potassium	mg/L	2.1	2	Apr, May	0.118
Total Nitrogen	mg/L	1.041	1	Jul	0.460
Total Phosphorus	mg/L	0.261	2	Jun, Jul	0.118
METAL INDICATORS					
Dissolved Arsenic	µg/L	0.7	1	Aug	0.460
Total Arsenic	µg/L	2.5	1	Jul	0.460
Total Barium	µg/L	147.6	1	Jul	0.460
Total Bismuth	µg/L	0.0564	1	Jul	0.460
Dissolved Cobalt	µg/L	0.11	3	Feb, Oct, Nov	0.020
Total Cobalt	µg/L	2.2	1	Jul	0.460
Total Copper	µg/L	7.2	1	Jul	0.460
Total Iron	µg/L	5821	1	Jul	0.460
Dissolved Lithium	µg/L	9	2	Feb, Mar	0.118
Total Manganese	µg/L	141	2	Jun, Jul	0.118
Total Nickel	µg/L	8.2	1	Jul	0.460
Total Selenium	µg/L	0.581	1	Jul	0.460
Total Silver	µg/L	0.0677	1	Jul	0.460
Total Thorium	µg/L	1.44	1	Jul	0.460
Dissolved Uranium	µg/L	0.381	11	Jan-Apr, Jun-Dec	<0.001

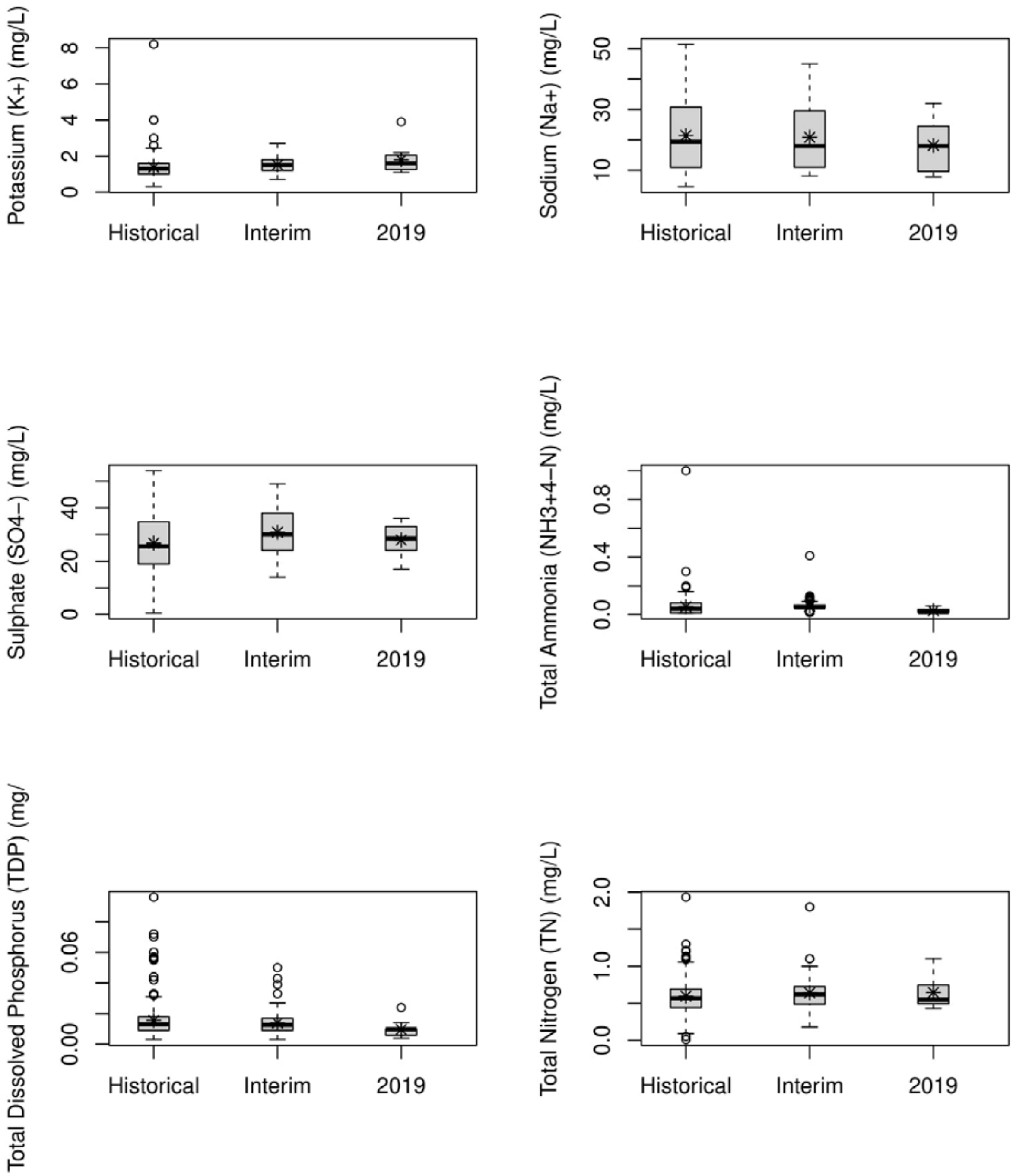
Indicator	Units	Peak Trigger	Number of Occurrences Higher Than Trigger	Months for which Occurrences were Higher than Trigger	Binomial Test p-value
Total Uranium	µg/L	0.7	1	Jul	0.460

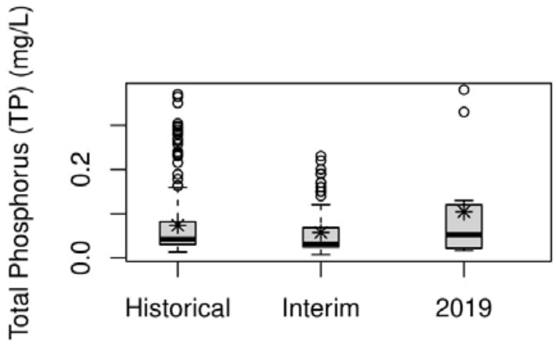
Figure C-1. Graphical presentations of the historical data (1988-2009 general parameters; 1999-2009 metal parameters), the interim data between historical and annual (i.e. 2019) datasets (2010-2019), and the 2019 data for water quality parameters measured at the Old Fort monitoring site. Legend illustrates boxplot statistics.



General Parameters

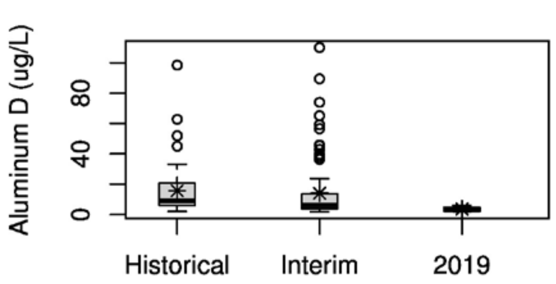


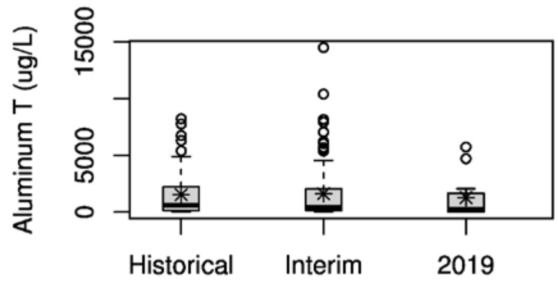

Potassium (K+) (mg/L)
0
2
4
6
8
Historical
Interim
2019
Sodium (Na+) (mg/L)
10
30
50
Historical
Interim
2019
Sulphate (SO4–) (mg/L)
0
20
40
Historical
Interim
2019
Total Ammonia (NH3+4–N) (mg/L)
0.0
0.4
0.8
Historical
Interim
2019
Total Dissolved Phosphorus (TDP) (mg/
0.00
0.06
Historical
Interim
2019
Total Nitrogen (TN) (mg/L)
0.0
1.0
2.0
Historical
Interim
2019

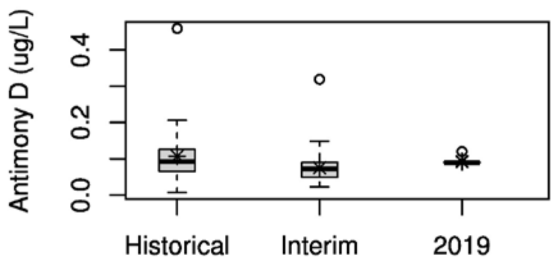


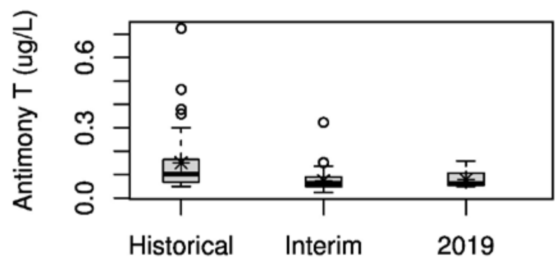
Metal Parameters

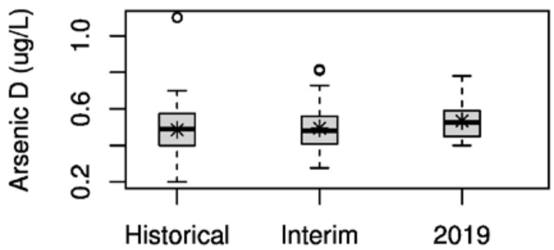
(D=Dissolved; T=Total)

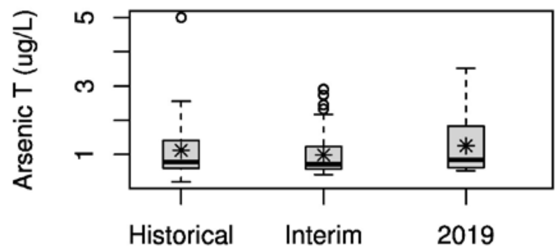


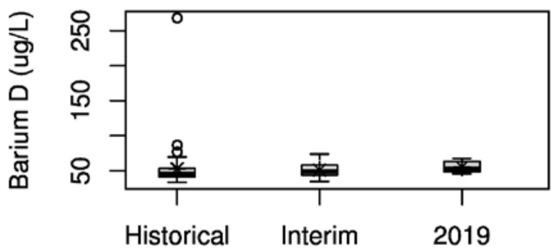


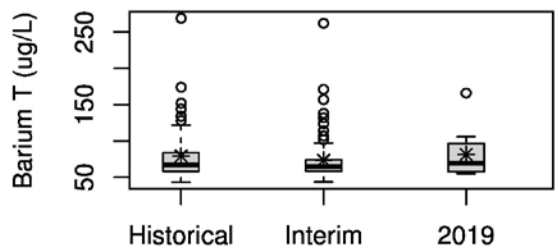


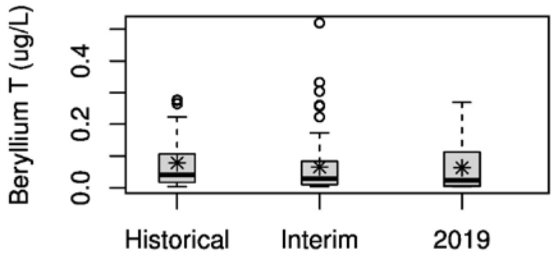


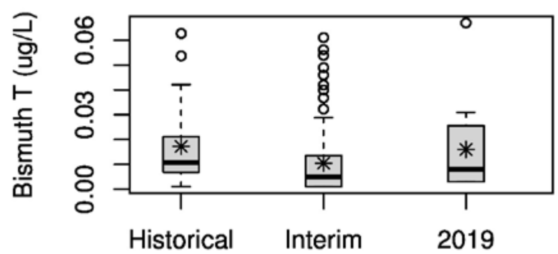

Arsenic D (ug/L)
0.2
0.6
1.0
Historical
Interim
2019

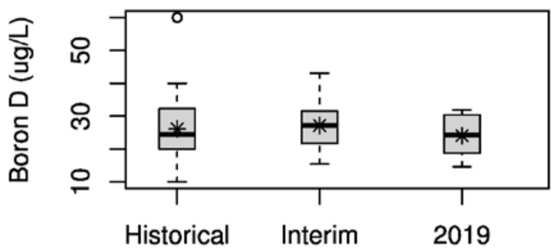

Arsenic T (ug/L)
1
3
5
Historical
Interim
2019

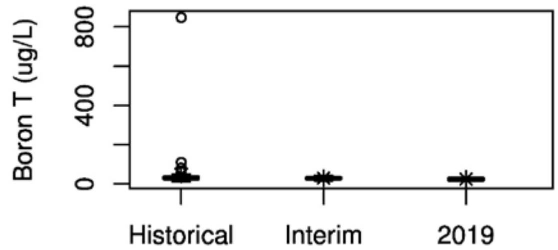

Barium D (ug/L)
50
150
250
Historical
Interim
2019

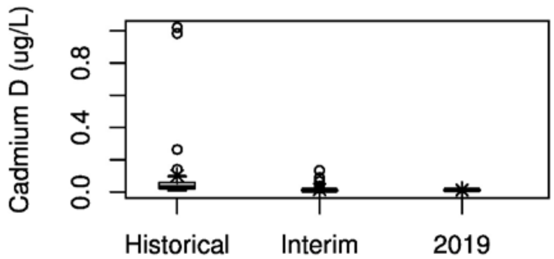

Barium T (ug/L)
50
150
250
Historical
Interim
2019

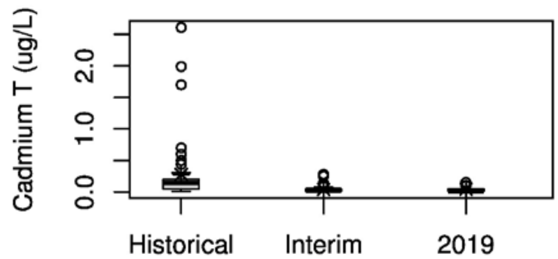

Beryllium T (ug/L)
0.0
0.2
0.4
Historical
Interim
2019

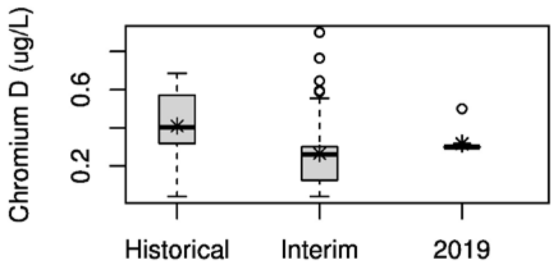

Bismuth T (ug/L)
0.00
0.03
0.06
Historical
Interim
2019

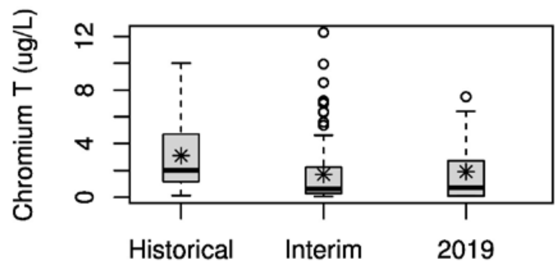

Boron D (ug/L)
10
30
50
Historical
Interim
2019

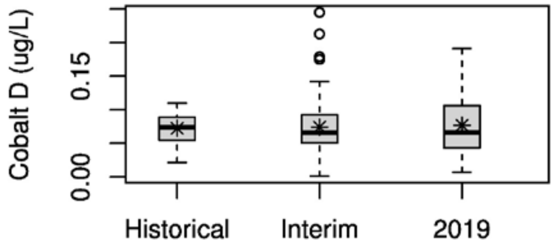

Boron T (ug/L)
0
400
800
Historical
Interim
2019

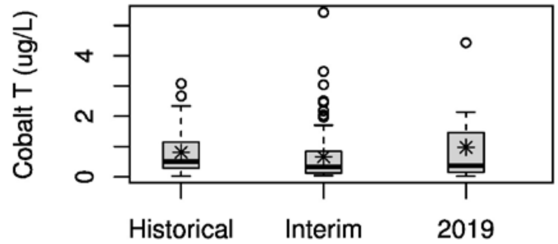

Cadmium D (ug/L)
0.0
0.4
0.8
Historical
Interim
2019

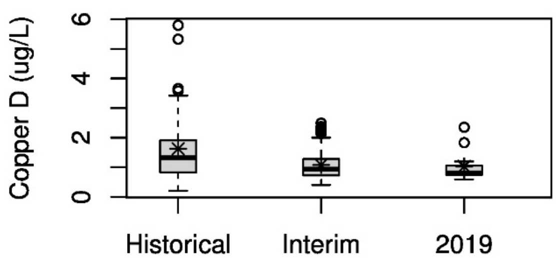

Cadmium T (ug/L)
0.0
1.0
2.0
Historical
Interim
2019

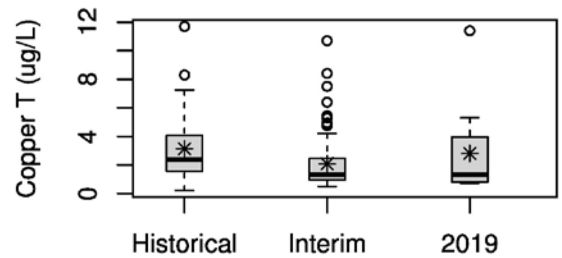

Chromium D (ug/L)
0.2
0.6
Historical
Interim
2019

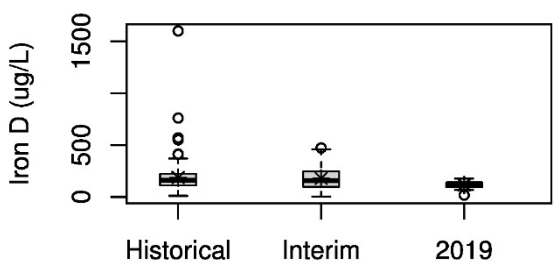

Chromium T (ug/L)
0
4
8
12
Historical
Interim
2019

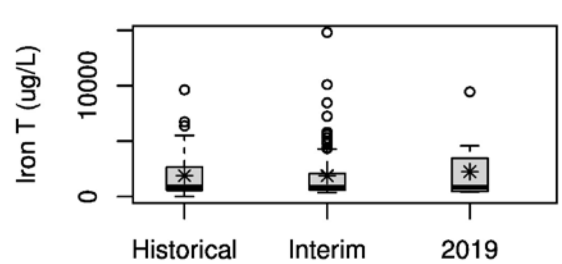

Cobalt D (ug/L)
0.00
0.15
Historical
Interim
2019

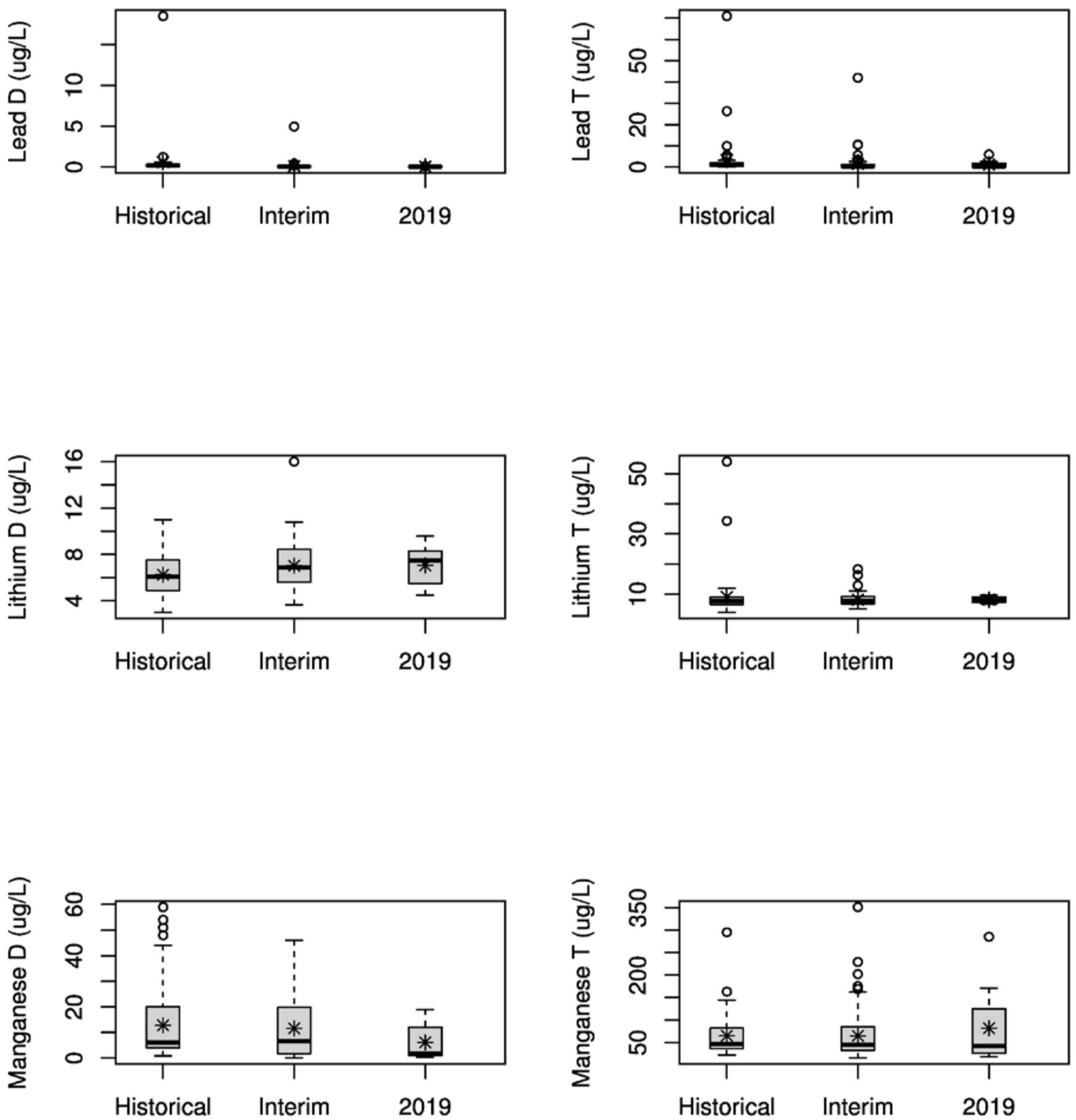

Cobalt T (ug/L)
0
2
4
Historical
Interim
2019

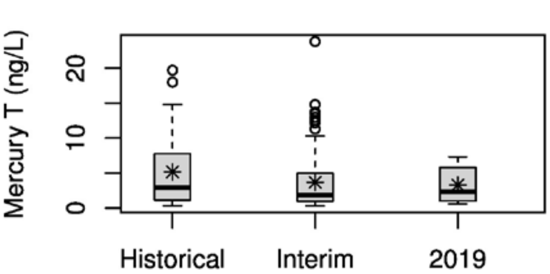

Copper D (ug/L)
0
2
4
6
Historical
Interim
2019

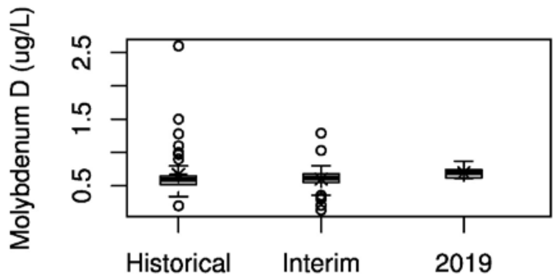

Copper T (ug/L)
0
4
8
12
Historical
Interim
2019

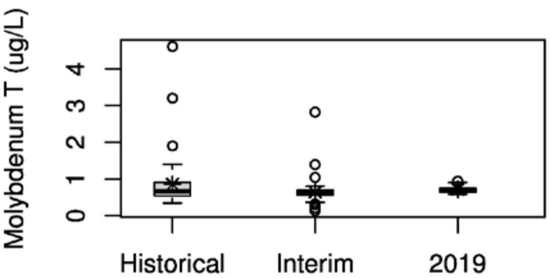

Iron D (ug/L)
0
500
1500
Historical
Interim
2019

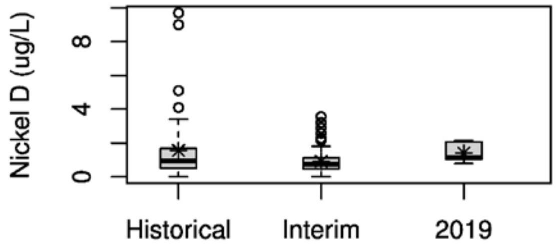

Iron T (ug/L)
0
10000
Historical
Interim
2019

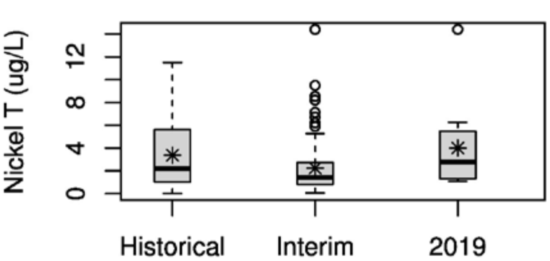

Lead D (ug/L)
0
5
10
Historical
Interim
2019
Lead T (ug/L)
0
20
50
Historical
Interim
2019
Lithium D (ug/L)
4
8
12
16
Historical
Interim
2019
Lithium T (ug/L)
10
30
50
Historical
Interim
2019
Manganese D (ug/L)
0
20
40
60
Historical
Interim
2019
Manganese T (ug/L)
50
200
350
Historical
Interim
2019

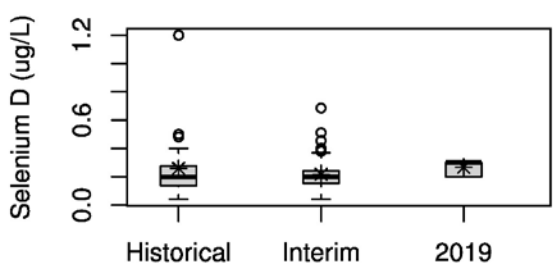

Mercury T (ng/L)
0
10
20
Historical
Interim
2019

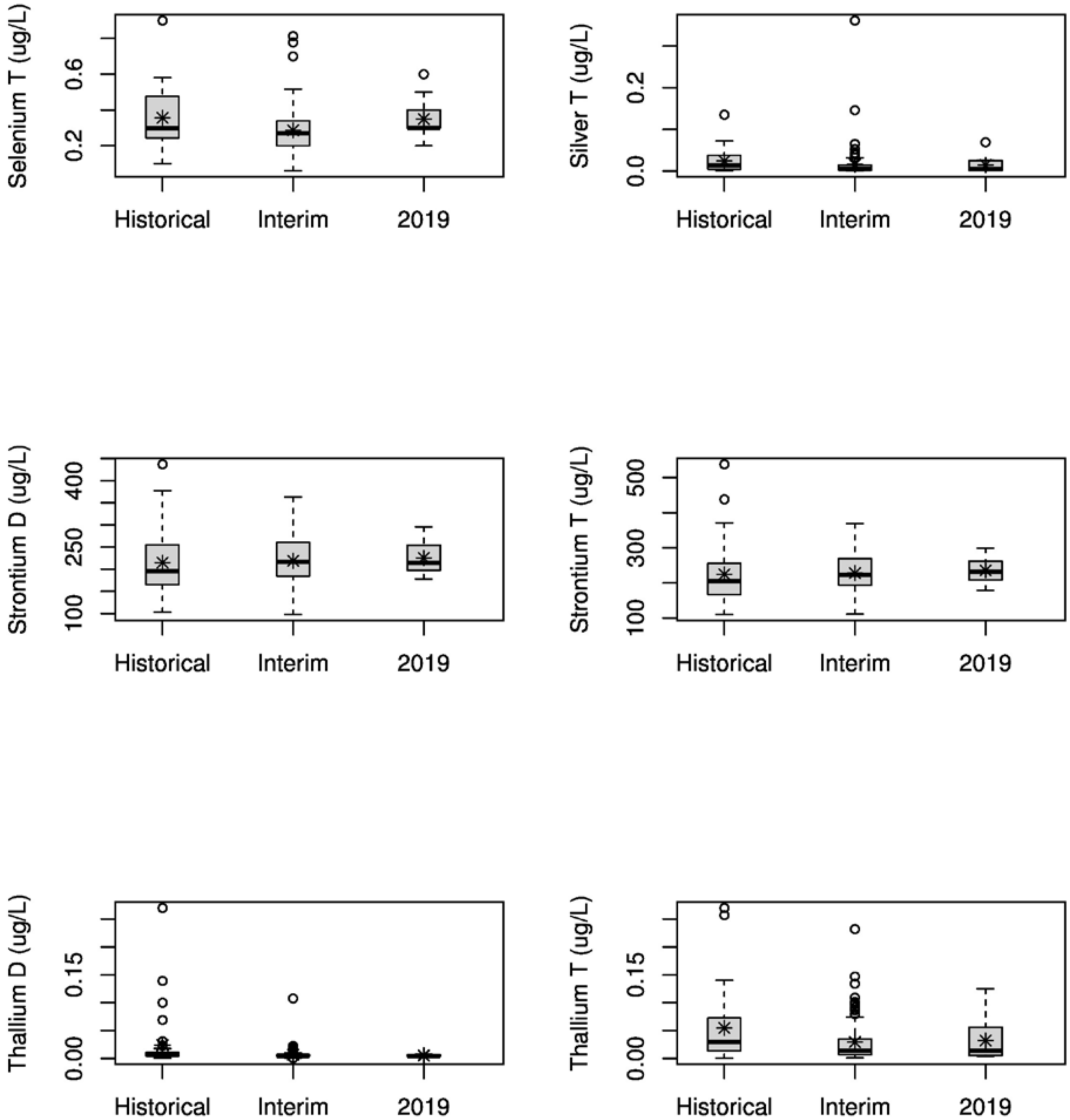

Molybdenum D (ug/L)
0.5
1.5
2.5
Historical
Interim
2019

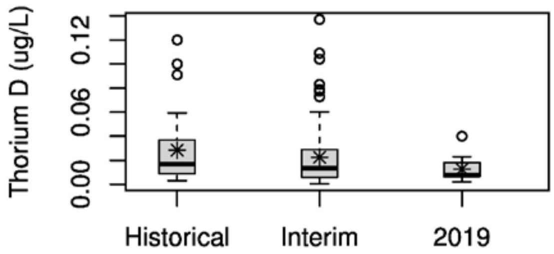

Molybdenum T (ug/L)
0
1
2
3
4
Historical
Interim
2019

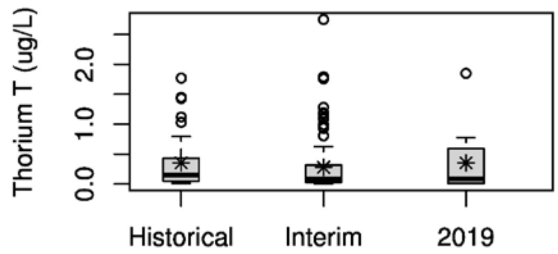

Nickel D (ug/L)
0
4
8
Historical
Interim
2019

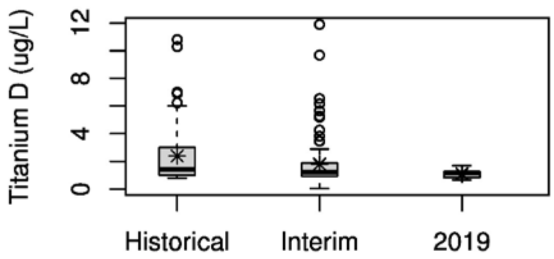

Nickel T (ug/L)
0
4
8
12
Historical
Interim
2019

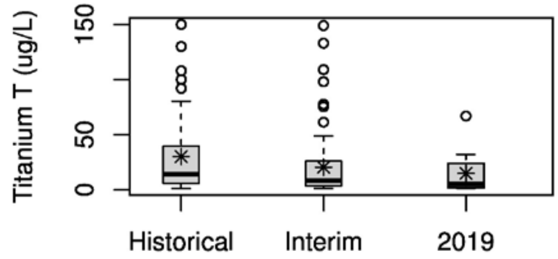

Selenium D (ug/L)
0.0
0.6
1.2
Historical
Interim
2019

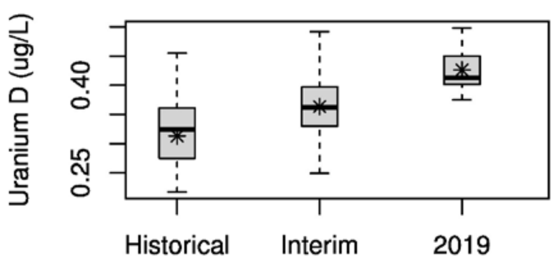

Selenium T (ug/L)
0.2
0.6
Historical
Interim
2019
Silver T (ug/L)
0.0
0.2
Historical
Interim
2019
Strontium D (ug/L)
100
250
400
Historical
Interim
2019
Strontium T (ug/L)
100
300
500
Historical
Interim
2019
Thallium D (ug/L)
0.00
0.15
Historical
Interim
2019
Thallium T (ug/L)
0.00
0.15
Historical
Interim
2019

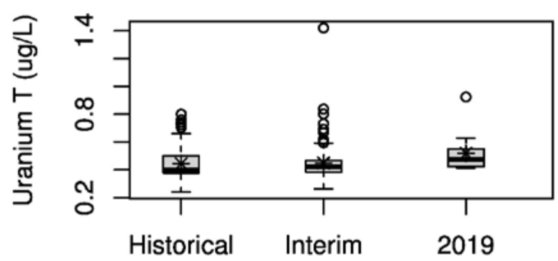

Thorium D (ug/L)
0.00
0.06
0.12
Historical
Interim
2019

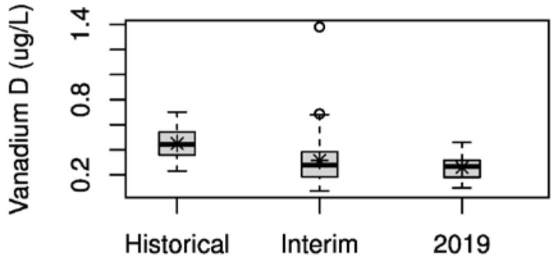

Thorium T (ug/L)
0.0
1.0
2.0
Historical
Interim
2019

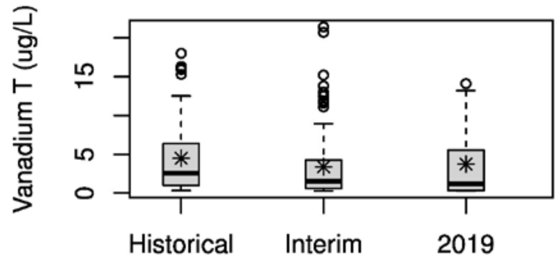

Titanium D (ug/L)
0
4
8
12
Historical
Interim
2019

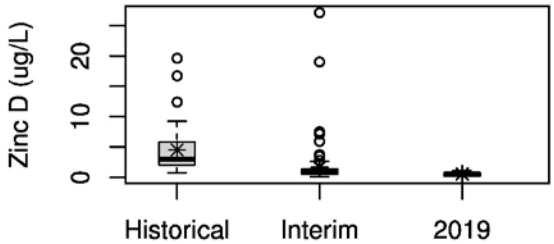

Titanium T (ug/L)
0
50
150
Historical
Interim
2019

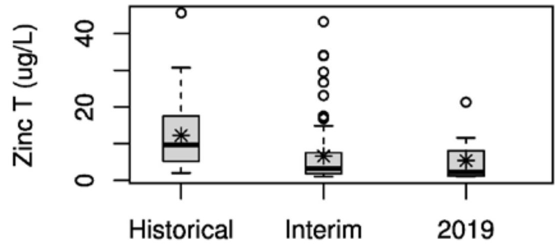

Uranium D (ug/L)
0.25
0.40
Historical
Interim
2019


Uranium T (ug/L)
0.2
0.8
1.4
Historical
Interim
2019


Vanadium D (ug/L)
0.2
0.8
1.4
Historical
Interim
2019


Vanadium T (ug/L)
0
5
15
Historical
Interim
2019


Zinc D (ug/L)
0
10
20
Historical
Interim
2019


Zinc T (ug/L)
0
20
40
Historical
Interim
2019