MILK RIVER RIDGE RESERVOIR

Data Report 09-16-2020 for the County of Warner

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Abstract

Improvements to water quality occurred in the Milk River Ridge Reservoir from 2014-2019 based on total phosphorous and total dissolved solids. These improvements may be due in part to the current rehabilitation project as these decreases coincide with the start of the rehabilitation project. In addition, residence time for water was lower in 2014-2019 than it was in the 2003-2007 monitoring period, which may also contribute to improving water quality. As the rehabilitation project is only five years old, the full impacts of the project might not be seen for several years yet.

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EXECUTIVE SUMMARY

The Milk River Ridge Reservoir (MRRR) was constructed by damming portions of both Kipp Coulee and Middle Coulee in 1956 (Mitchell and Prepas, 1990). Since 1976, water quality analyses were performed on water in the MRRR, as well as the Inlet Canal which feeds the MRRR, and surrounding waterbodies. Water quality within the MRRR has been impacted by agricultural practices in the area along with changes in residence time due to the diversion of water to the Raymond Reservoir Generating Station built by Irrican Power for power generation in 1995. Water diversion to the station changed the residence time in the MRRR from an average of 36 days to an average of 251 days. Concern about the water quality of the MRRR after the diversion led to a water quality monitoring program by the Prairie Farm Rehabilitation Administration which is a branch of Agriculture and Agri-Food Canada (PFRA/AAFC) which was active from 2003 to 2007. Following that program, since 2014, the County of Warner has had a water quality monitoring and rehabilitation project underway to improve the water quality of runoff entering the MRRR. The rehabilitation project has included the installation of a wetland at the west side of the MRRR, fencing to prevent livestock from accessing the reservoir and some tributaries, planting shrubs, and preventing cropping up to the shores of the reservoir. This study examines 43 years of water quality records, from 1976 to the fall of 2019, to determine how the water quality has changed in the MRRR and surrounding waterbodies.

Sixteen parameters at 15 sites were selected for analysis, based on the quality and extent of available data. Six parameters (chlorophyll *a*, *E. coli*, total phosphorus, total nitrogen, total dissolved solids, and turbidity) over the years 2003 to 2019, are shown graphically in the body of this report, based on recent sampling and the significance of these parameters to water quality. Graphs for all 16 parameters over all 43 years are presented in Appendix A. Note that there was a gap in sampling from October 2007 until May 2014.

Residence time of water in the MRRR averaged 382 days during the PFRA/AAFC sampling program from spring 2003 through fall 2007. During the County of Warner program, 2014 – 2019, the residence time of water in the MRRR averaged 157 days.

Chlorophyll *a* concentrations changed from being concentrated at the east end of the reservoir in 2005, to being concentrated in the center in 2014, and then being widespread at overall lower concentrations in 2019.

E. coli was measured in MRRR, but not in the inlet canal or tributaries during the PFRA/AAFC program (2003-2007), and has been measured in the Inlet Canal and tributaries but not the MRRR during the 2014-2019 program, making trends difficult to detect.

Total phosphorous (TP) was highest in the reservoir in 2014, and decreased steadily over the monitoring period until 2019, indicating improving water quality.

Trends in total nitrogen (TN) were difficult to detect on a whole reservoir scale, but changes from low total nitrogen in 2005 to increased TN in the west end of the reservoir in 2014 were evident. TN appeared to decrease in the west end of the reservoir in 2019.

Total dissolved solids (TDS) was only measured in the 2014-2019 sampling program, and this parameter was noted to have decreased during that time.

Turbidity had a wide range in the reservoir, but overall no distinct patterns of increase or decrease were noted.

The changes to the water quality of the MRRR did not appear to be due to changes in water quality coming from the Inlet Canal feeding the MRRR, as water quality in the Inlet Canal remained generally consistent from 1993 to 2019.

The improvements to water quality (2014-2019) based on TP and TDS may be due in part to the current rehabilitation project, therefore, as these decreases in TP and TDS coincide with the start of the rehabilitation project. In addition, residence time for water in the MRRR was lower in 2014-2019 than it was in the 2003-2007 monitoring period, and this may also have contributed to improving water quality. As the rehabilitation project is only five years old, the full impacts of the project might not be seen in chlorophyll *a* concentrations for several years yet, as chlorophyll *a* concentrations generally lag behind reductions in phosphorous. It is recommended that *E. coli* concentrations should be measured in the MRRR in future sampling programs.

INTRODUCTION

Milk River Ridge Reservoir Historical Summary

The Milk River Ridge Reservoir (MRRR) was built by the federal Prairie Farm Rehabilitation Administration in 1956 as an offstream storage and balancing reservoir for the St. Mary River Irrigation District (SMRID). Alberta Environment has been the owner of the reservoir and all structures since 1974 and operates them in cooperation with the SMRID (Mitchell and Prepas, 1990). The MRRR is the third largest of the 12 major reservoirs in the SMRID; only the St. Mary and Chin reservoirs are larger. The MRRR is a popular camping and fishing site in southern Alberta, and has a publically-owned but privately-run campground with 60 overnight campsites on the southern side. Agriculture in the area includes cattle grazing and cereals, with some dry beans, potatoes and specialty crops.

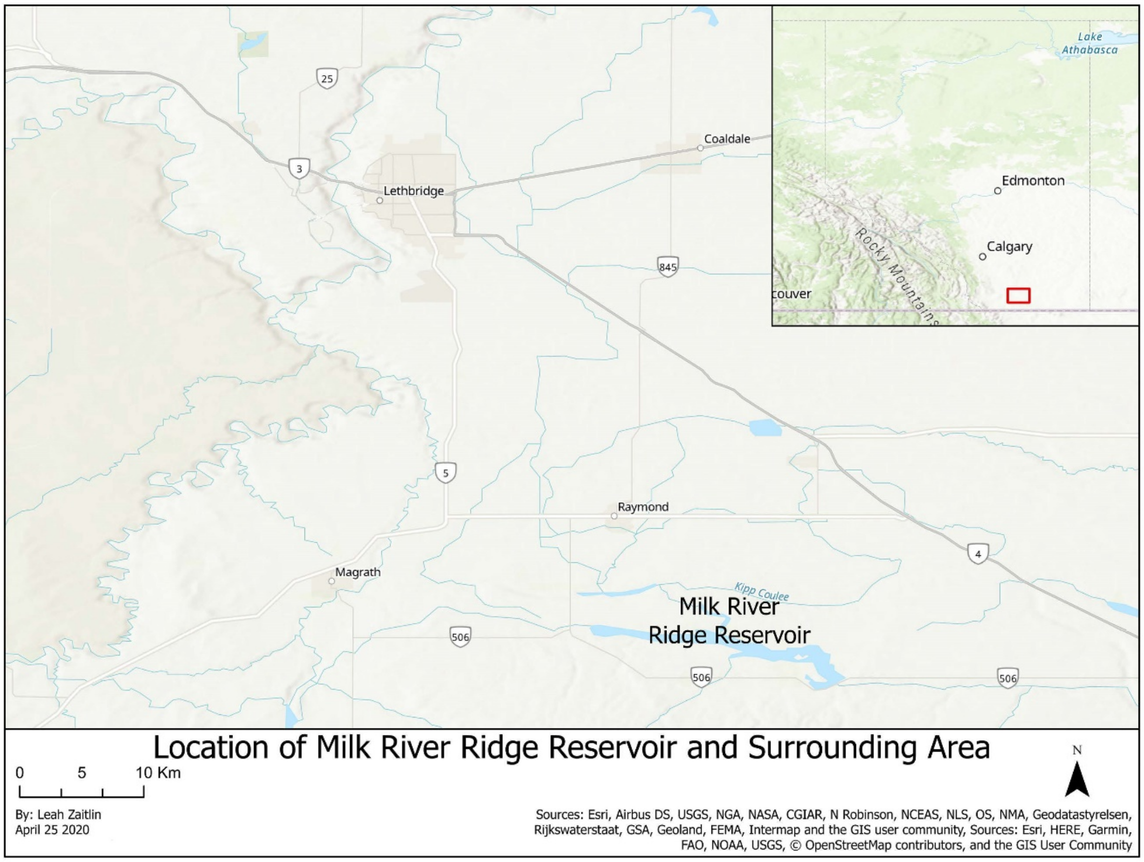
- **1956:** Reservoir is built by the Prairie Farm Rehabilitation Administration (PFRA) as a balancing reservoir and offstream storage for St. Mary River Irrigation District.
- **1974:** Alberta Environment owns the reservoir and all structures.
- **1993-2003:** St. Mary River Irrigation District (SMRID) begins monitoring water quality across the irrigation district. Reports prepared by Madawaska Consulting.
- **1994:** Raymond Reservoir Generating Station built by Irrican Power.
    - This generating station diverted 80-95% of the water from the canal leading to the Milk River Ridge Reservoir, greatly increasing residence time in the Milk River Ridge Reservoir.
- **1996:** St. Mary River Irrigation District alters the sites of their water quality monitoring program to determine changes associated with the diversion of water through the hydro plant at Raymond Reservoir. Madawaska Consulting prepared these reports from 1996-2003.
- **1998:** Ridge Water Users contacted PFRA with concerns about taste and odor in water delivered via pipeline from the Ridge Reservoir.
- **1999-2001:** Drought with water rationing in place
- **2003:** Ridge Reservoir Committee formed to develop and coordinate a collaborative study of the Ridge Reservoir and catchment basin.
    - **Committee Members:**
        - Town of Raymond
        - Prairie Farm Rehabilitation Administration (PFRA)
        - Environment Canada
        - University of Calgary
        - Health Canada
        - Chinook Health Region
- **2003-2007:** Study by Sue Watson (Environment Canada), Bunny Mah (PFRA), Shannon Braithewaite (University of Calgary)
    - Documented issues with water quality, livestock entering reservoir, dead livestock near or in reservoir, algal blooms
    - Water quality data taken from 2003-2007
- **2004:** St. Mary River Irrigation District Main Canal Drops #4, #5, #6 were brought on-line
- **2014-19:** Milk River Ridge Reservoir Water Quality Stewardship Initiative (MRRWQSI) begins.
    - **Stewardship working Group:**

        - Alberta Environment and Parks
        - Alberta Conservation Association
        - County of Warner
    - **Actions taken by the MRRWQSI**
        - Installed 45 km of fencing to keep livestock from accessing the Reservoir and tributaries (20 km of fencing planned)
        - 20 offsite watering units installed
        - 20,000 shrubs planted (20,000 additional planned)
        - 386 acres reseeded into wildlife habitat
        - 6.18 acre wetland developed on west end of reservoir
        - Phosphorous filter installed
        - Spraying, mowing and discing of areas to protect habitat enhancements and for weed control
        - Reclaimed 20 acres+ of Crown land that was being cropped by local farmers, some of which was on the shores of the Reservoir

Study Site

The Milk River Ridge Reservoir is located 8 km south of the town of Raymond in the County of Warner No. 5, Alberta, in Twp 4 and 5, Rge 19 and 20, W4 (Figure 1). The reservoir has a maximum length of approximately 17.3 km and a maximum width of approximately 1.4 km (ASRD 2003), with the long axis running approximately east to west (Figure 2). At its deepest point, the reservoir is 19.22 m deep (ASRD 2003).

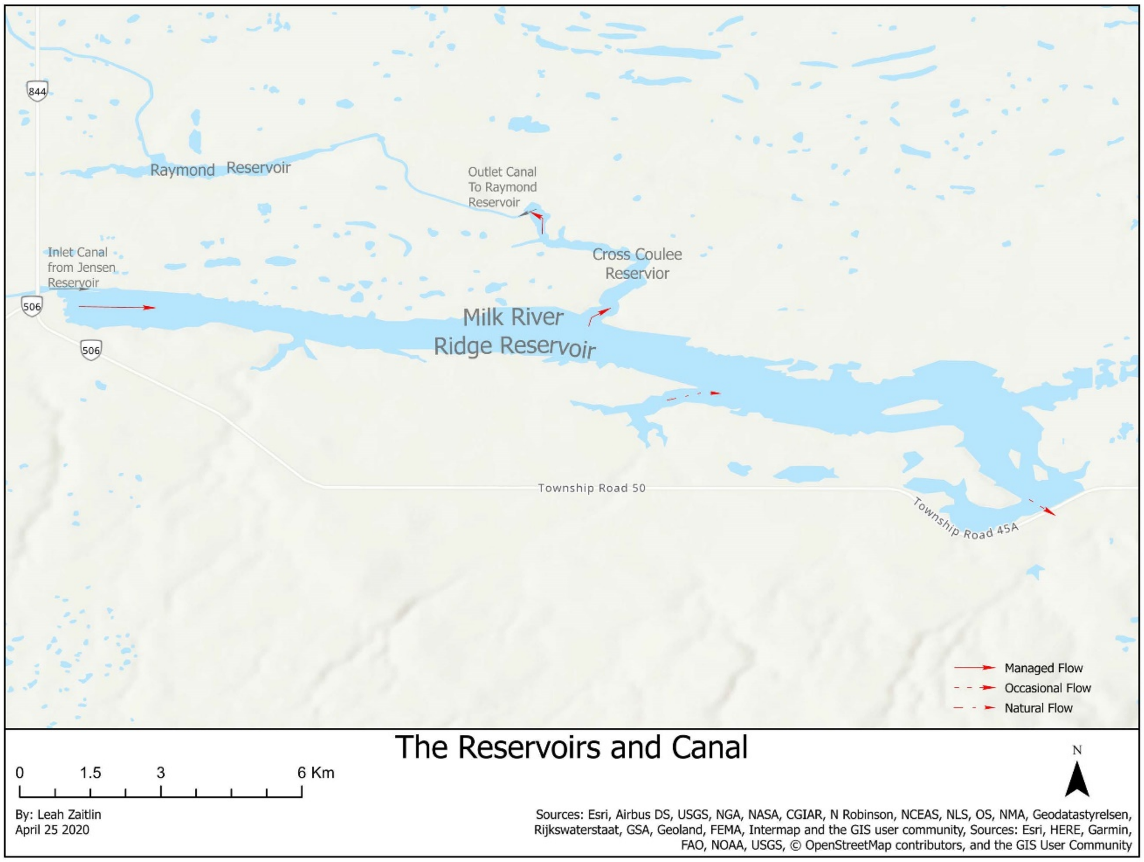
Figure 1. Location of Milk River Ridge Reservoir in relation to surrounding area



Water in the MRRR comes from the St. Mary - Milk River Ridge Headworks Canal, which generally is operated from April 1 until October 31. Unregulated contributions into the MRRR occur from small tributaries which drain a watershed of about 228 square kilometers, from direct precipitation on the reservoir, and from an unknown amount of groundwater inflow (or loss) (M. Sabur, unpublished, 2017). The water in the Headworks Canal is diverted from the St. Mary, Belly and Waterton rivers to St. Mary Reservoir; it then passes through Jensen Reservoir before making its way to Milk River Ridge Reservoir (Figure 2). Approximately 98% of the water flows out of the Milk River Ridge Reservoir via the North Ridge Dam to the Cross Coulee Reservoir (Figure 2), and then to Raymond Reservoir, which lies parallel to the Milk River Ridge Reservoir, about 2 km to the north (Figure 2). The water then moves through a series of canals and reservoirs to supply water for irrigation, municipal, domestic, industrial, and recreational use as far east as Medicine Hat (Mitchell and Prepas, 1990). The remaining 2% flows out of the Milk River Ridge Reservoir via the East Ridge Dam to Middle Coulee to supply local irrigation, domestic and municipal needs, and to support wildlife and recreational uses (Mitchell and Prepas, 1990). There are no groundwater monitoring wells in the vicinity of Ridge Reservoir, and it is unclear whether groundwater movement in the area is toward or away from the reservoir.

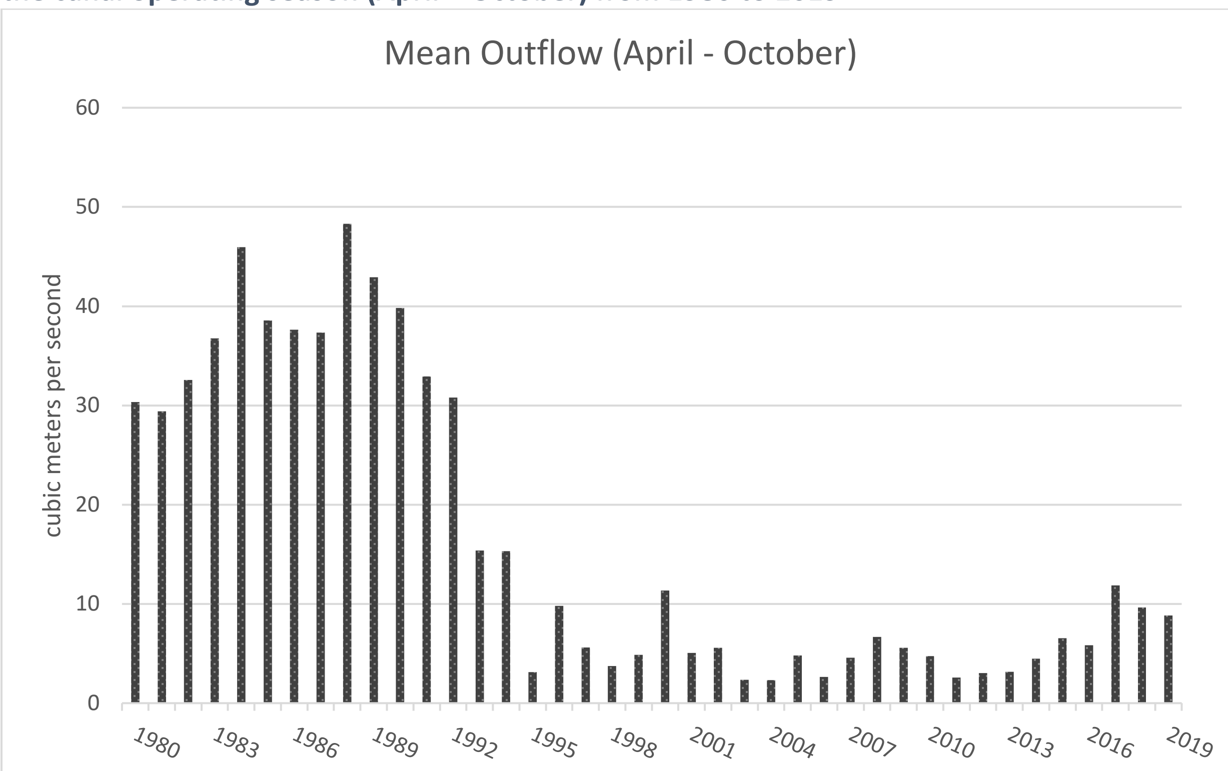
Climate in the area is classified as semi-arid, with average annual high temperatures of 12.8 C and average annual low temperatures of -0.6 C. The maximum temperature recorded in the area between 2003 and 2018 was 39.2 C, and the minimum in this period was -36.7 C. Average annual precipitation in the area is 438 mm, with much of that falling in June and July. Climate data was taken between 2003 and 2018, (Environment and Climate Change Canada 2020), from Warner West (Station Number 3046953) and Raymond AGDM (Station Number 3035422) climate stations.

Figure 2. Waterbodies in the area of the Milk River Ridge Reservoir and flow direction



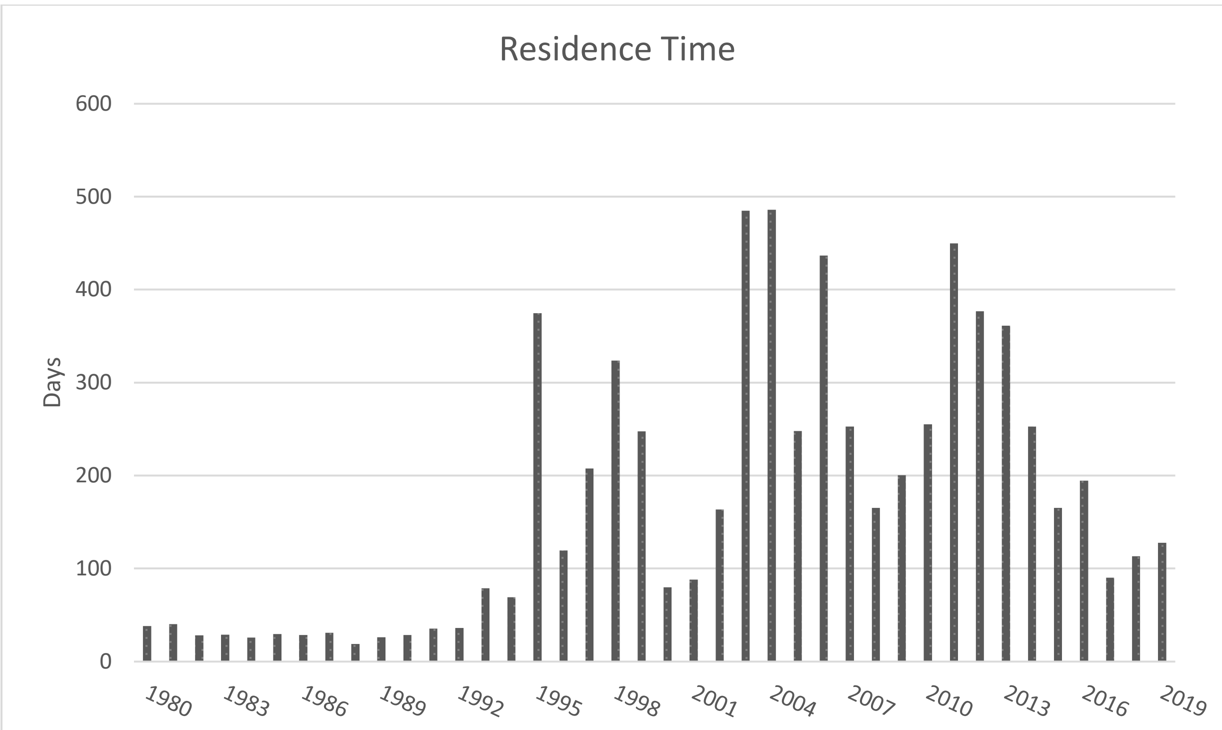
Water from the St. Mary – Milk River Ridge Headworks Canal was diverted in 1995 to provide generating power for the Raymond Reservoir Generating Station. Water from the Headworks Canal was sent through a generator and then the water was released directly to the Raymond Reservoir. Prior to the generating station being built, an average of approximately 34 m^3 per second of water had to be released from the MRRR via the North Outlet during the canal operating season to maintain the reservoir at an approximately constant volume of 95,000 cubic decameters (dam^3). After the diversion, an average of approximately 5.5 m^3 per second of water had to be released through the North Outlet to maintain the storage volume in the reservoir during the canal operating season (Figure 3) (M. Sabur, AEP, pers. comm.).

Figure 3. Mean outflow from the Milk River Ridge Reservoir through the North Outlet during the canal operating season (April – October) from 1980 to 2019



This reduction in flow volume into and out of the MRRR also caused an increase in residence time for water in the MRRR. Residence time for water is a calculation of the mean time that water and dissolved substances spend in a waterbody. Therefore, longer residence times may reduce flushing of nutrients and contaminants in a waterbody. Residence time in the MRRR increased from an average of 36 days before the diversion to an average of 251 days after the diversion (Figure 4) (M. Sabur, AEP, pers. comm.). During the 2003-2007 PFRA/AAFC water sampling program, residence time of water in the MRRR averaged 382 days. During the County of Warner program, 2014-2019, the residence time of water in the MRRR averaged 157 days.

Figure 4. Residence time of water and dissolved substances in the Milk River Ridge Reservoir from 1980 to 2019



METHODS

Water quality data for this report was taken from 4 separate agencies (Table 1).

Table 1: Sampling dates from four agencies sampling water quality in the Milk River Ridge Reservoir and surrounding area

Source	**Starting Date**	**Final Date for this Report**	**Number of Sampling Days**
Alberta Environment and Parks (AEP)	February 8, 1976	July 24, 2018	23
St. Mary River Irrigation District (Madawaska Reports)	May 25, 1993	Sept. 15, 2003	40
Prairie Farm Rehabilitation Administration and Agriculture and Agri-Food Canada (PFRA/AAFC)	March 2, 2003	Oct 17, 2007	96
County of Warner	May 12, 2014	Oct. 24, 2019	79

Each agency selected their own sampling sites (Figures 5 - 8), and had their own methods of water collection and analysis. For the purposes of this report, data was analyzed from 10 sites which were comparable between the four agencies (Table 2). Data was also analyzed from three sites (Sites TRIB1.2, TRIB4, and TRIB4.2, Figure 8) which were not comparable between agencies, and which had sampling locations changed during the course of the study. Two additional sites (TRIB5 INFLOW and TRIB5 OUTFLOW, Figure 8) were included as part of a study of a constructed wetland, which was installed in April 2017.

Sites were either were grab sampled just below the surface (surface samples) and/or sampled to twice Secchi depth (integrated samples) according to Alberta Environment field sampling protocols (2006). In some cases, discrete depths were also sampled, but these samples were excluded from this report because there were not enough discrete depth samples to provide adequate statistical analyses.

Table 2: Names of comparable sites from four agencies sampling water quality in the Milk River Ridge Reservoir and surrounding area

Alberta Environment and Parks (AEP)	**St. Mary River Irrigation District (Madawaska Reports)**	**PFRA/AAFC**	**County of Warner**
-	-	RS9	RR2
AB05AF0090	North Outlet	RS10	RR3
-	-	RS15	RR4
AB05AF0082	Main Canal and Cross Coulee Outlet	LD27	RR5
-	-	RS7	RR6
-	East Outlet	RS2	RR7
-	-	RS14	TRIB1
-	-	-	TRIB1.2
-	-	LD24	TRIB2
-	-	LD23	TRIB3
-	-	-	TRIB4
-	-	-	TRIB4.2
-	-	-	TRIB5 INFLOW
-	-	-	TRIB5 OUTFLOW
AB05AF0710	Inlet	LD21	TRIB6

Geographic data was taken from the source report if available. If no geographic data was available, latitude and longitude data was estimated from accompanying maps and site descriptions (Table 3).

Figure 5. Alberta Environment and Parks (AEP) sampling sites in the Milk River Ridge Reservoir and surrounding area

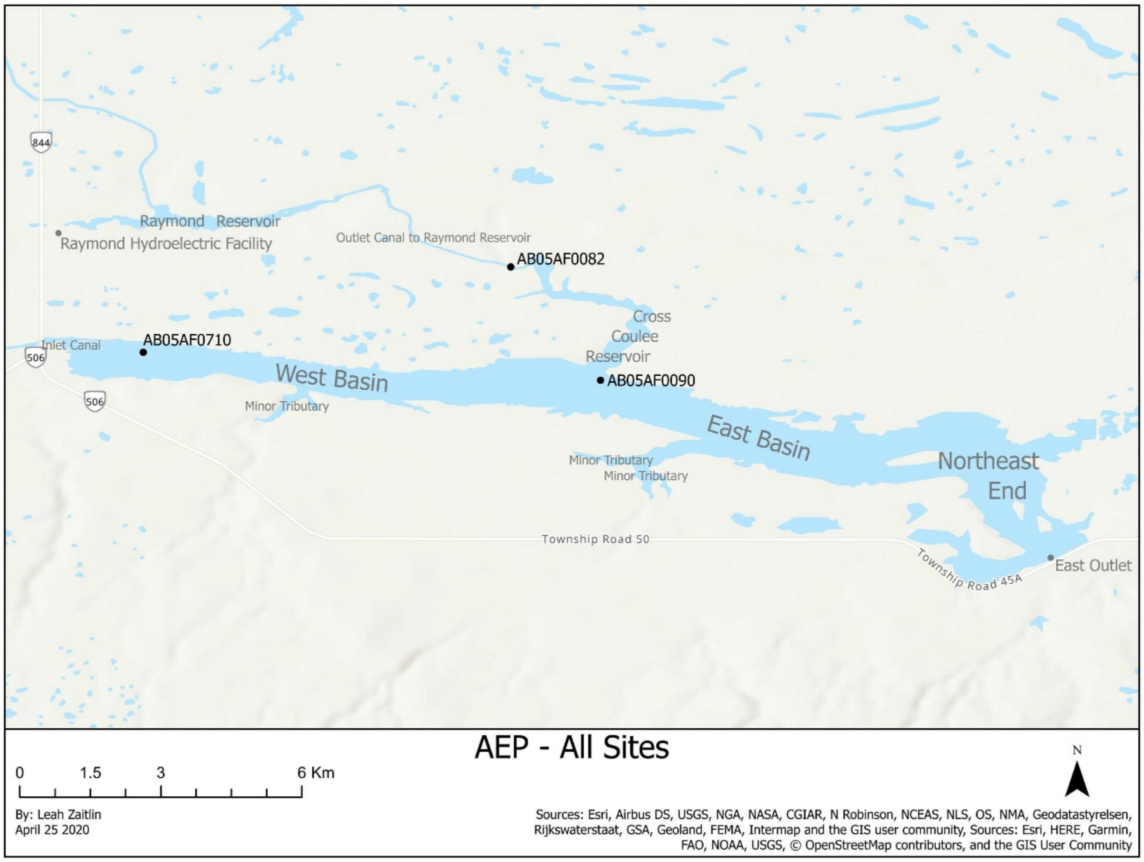


Figure 6. St. Mary River Irrigation District (SMRID) (Madawaska Consulting) sampling sites in the Milk River Ridge Reservoir and surrounding area

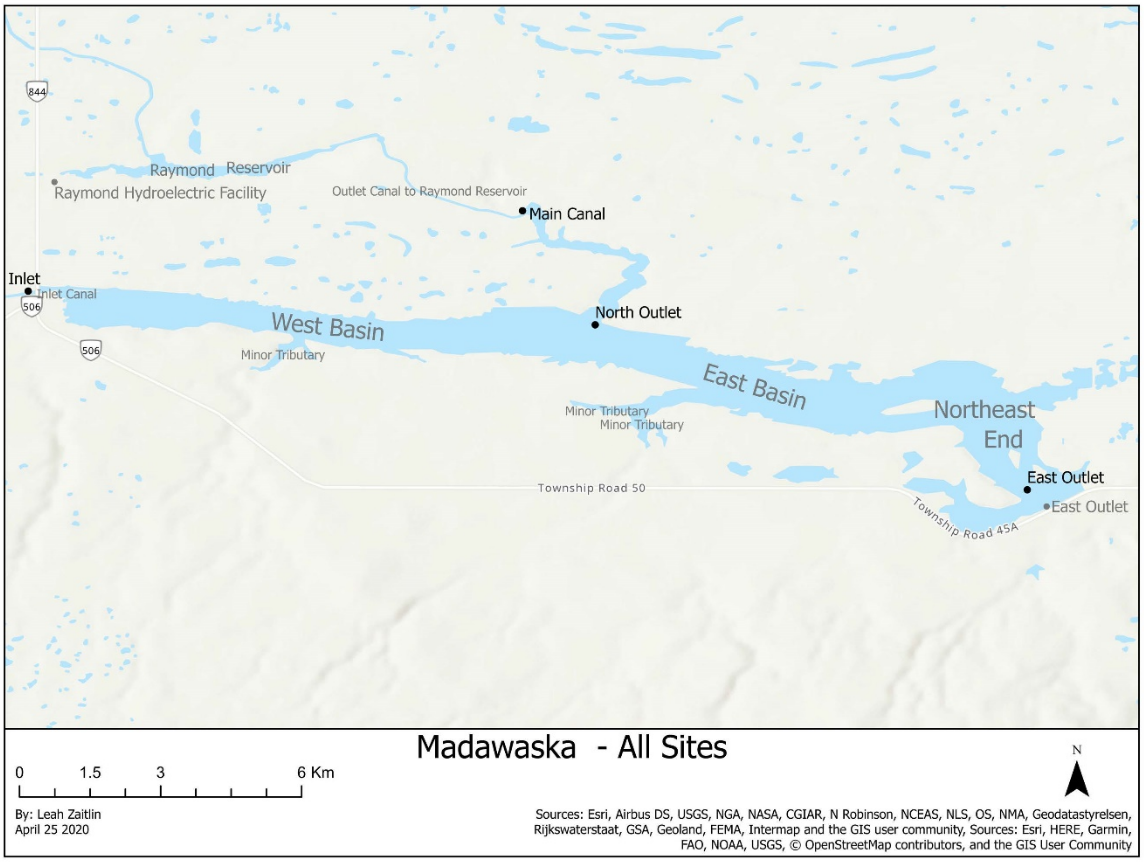


Figure 7. Prairie Farm Rehabilitation/Agriculture and Agri-Food Canada (PFRA/AAFC) sampling sites in the Milk River Ridge Reservoir and surrounding area

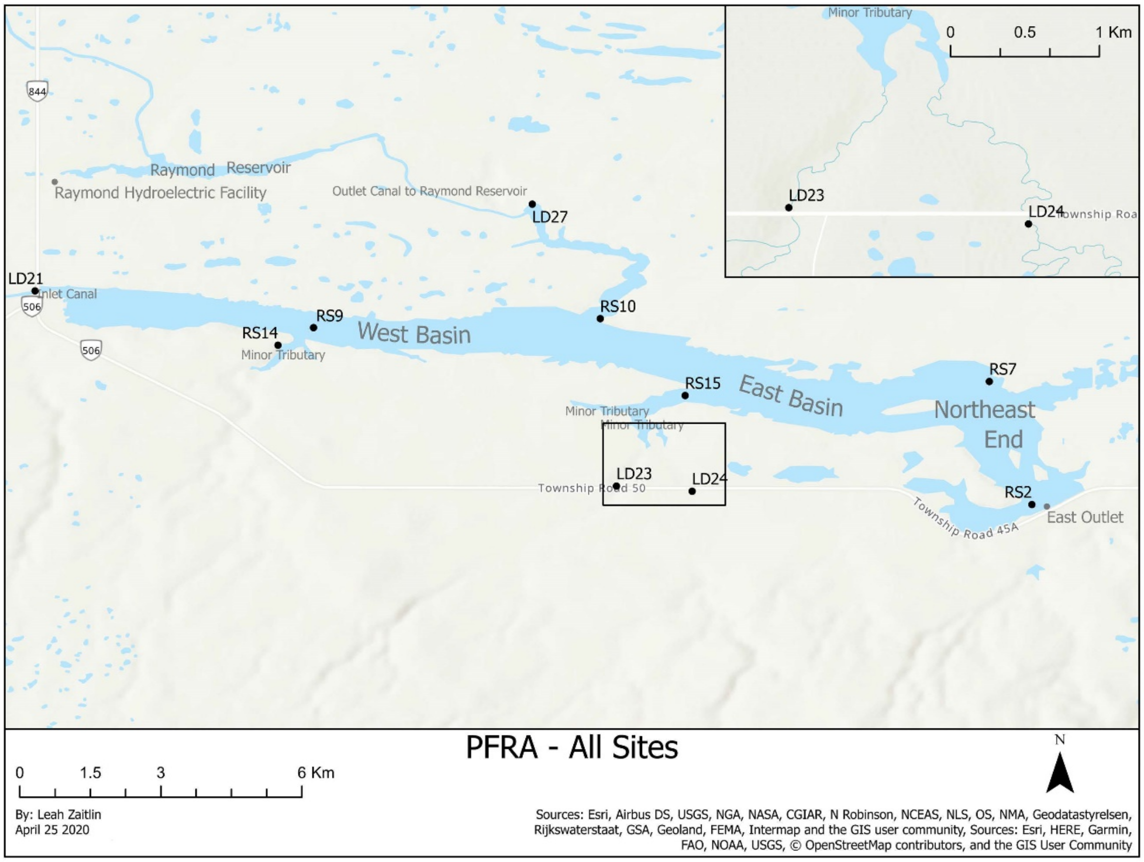
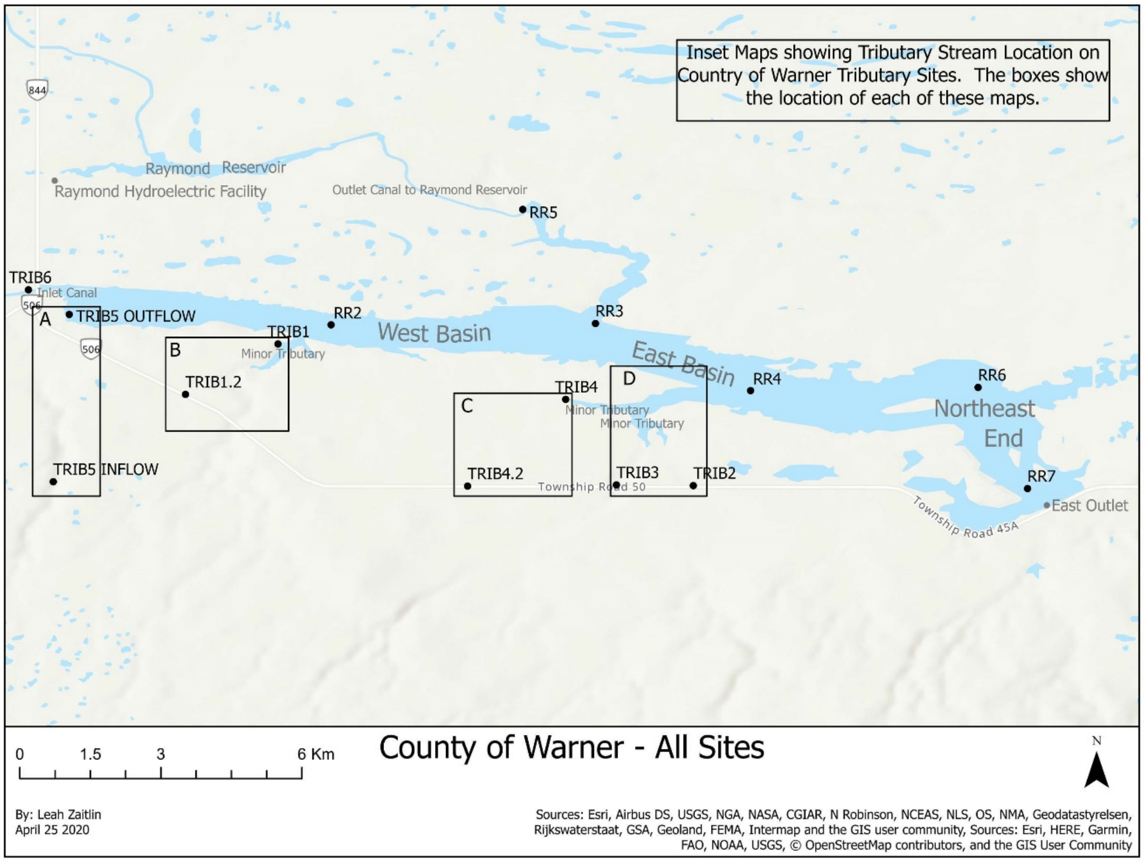


Figure 8. County of Warner (Warner) sampling sites in the Milk River Ridge Reservoir and surrounding area



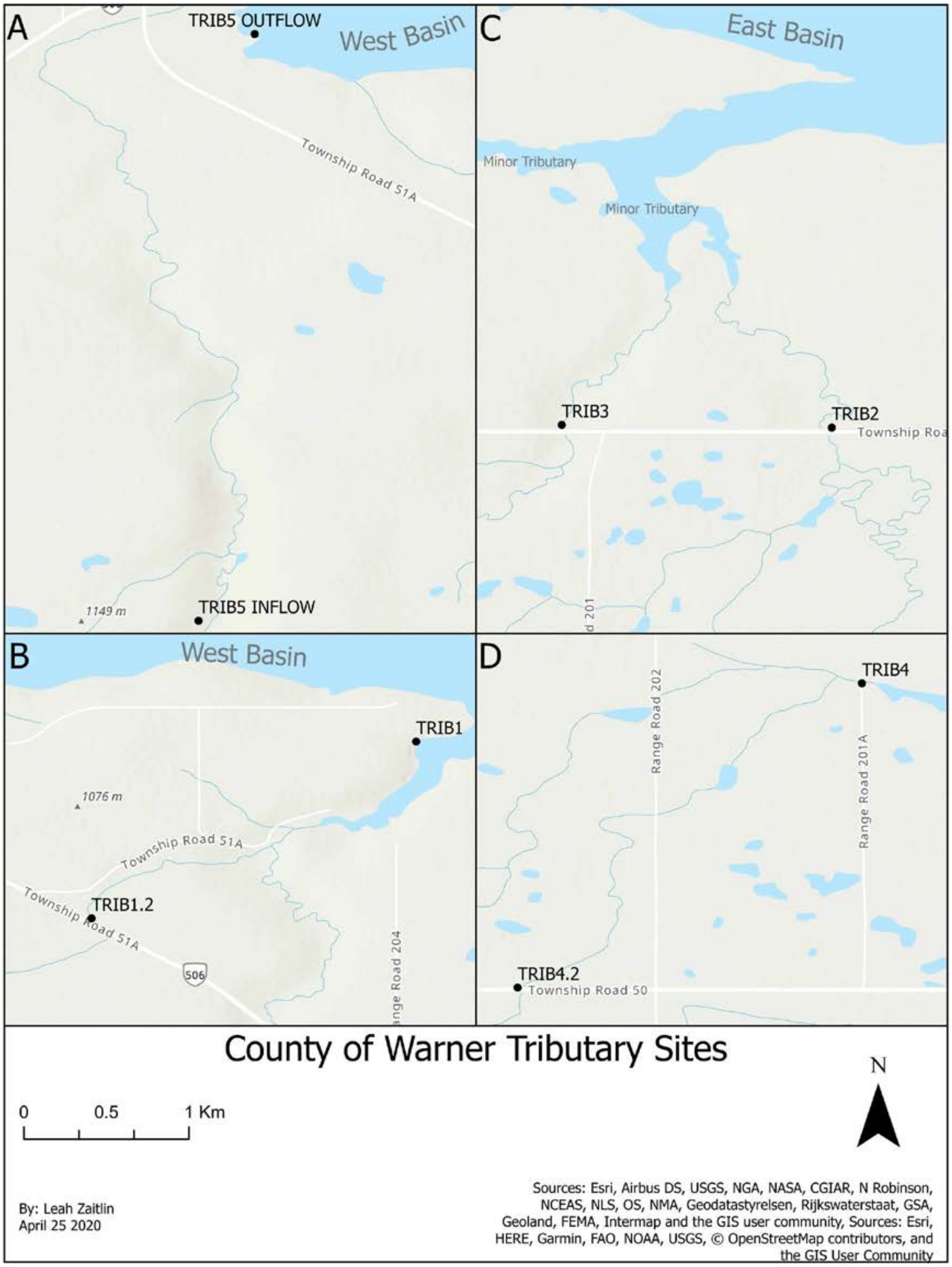

A
TRIB5 OUTFLOW
West Basin
Township Road 51A
1149 m
TRIB5 INFLOW
C
East Basin
Minor Tributary
Minor Tributary
TRIB3
TRIB2
Township Roa
d 201
B
West Basin
TRIB1
1076 m
Township Road 51A
Township Road 51A
TRIB1.2
506
ange Road 204
D
TRIB4
Range Road 202
Range Road 201A
TRIB4.2
Township Road 50
County of Warner Tributary Sites
N
0
0.5
1 Km
By: Leah Zaitlin
April 25 2020
Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Table 3: Sampling site names, agencies, and geographic locations of water quality samples in the Milk River Ridge Reservoir and surrounding area

Site Name	**Agency**	**Decimal Degrees Latitude**	**Decimal Degrees Longitude**
AB05AF0090	AEP	49.37884	-112.58901
AB05AF0082	AEP	49.40047	-112.60617
AB05AF0710	AEP	49.38417	-112.67639
North Outlet	Madawaska Reports	49.3796667	-112.58925
Main Canal	Madawaska Reports	49.40145	-112.60315
East Outlet	Madawaska Reports	49.34815	-112.5067
Inlet	Madawaska Reports	49.3861028	-112.6975861
RS2	PFRA/AAFC	49.3453333	-112.5058667
RS7	PFRA/AAFC	49.3688333	-112.51400
RS9	PFRA/AAFC	49.3791167	-112.6431167
RS10	PFRA/AAFC	49.3808333	-112.5883333
RS14	PFRA/AAFC	49.3757583	-112.6499139
RS15	PFRA/AAFC	49.36615	-112.5721167
LD21	PFRA/AAFC	49.386125	-112.6963222
LD23	PFRA/AAFC	49.3488556	-112.5852472
LD24	PFRA/AAFC	49.3478722	-112.5707833
LD27	PFRA/AAFC	49.4026861	-112.6013222
RR2	County of Warner	49.3794167	-112.6397667
RR3	County of Warner	49.3796667	-112.58925
RR4	County of Warner	49.36685	-112.5596167
RR5	County of Warner	49.40145	-112.60315
RR6	County of Warner	49.3674667	-112.51615
RR7	County of Warner	49.34815	-112.5067
TRIB1	County of Warner	49.3757583	-112.6499139
TRIB1.2	County of Warner	49.366133	-112.667581
TRIB2	County of Warner	49.3487111	-112.5705528
TRIB3	County of Warner	49.3488556	-112.5852472
TRIB4	County of Warner	49.3651861	-112.5949389
TRIB4.2	County of Warner	49.3486222	-112.6136806
TRIB5 INFLOW	County of Warner	49.3494556	-112.6928472
TRIB5 OUTFLOW	County of Warner	49.3814	-112.6897917
TRIB6	County of Warner	49.3861028	-112.6975861

Different water quality parameters were measured by each agency. The water quality parameters that were common to most of the agencies were selected for analysis (Table 4). Where data was below detection limits, half the detection limit was substituted for graphing purposes. The six parameters shown in the body of this report are marked in **bold**. Appendix A of this report contains graphs showing all results of all parameters and all years available.

Table 4: Water quality parameters measured by each agency. The number of measurements by each agency includes both surface (0.1 - 0.5 m) and integrated depth samples but not discrete depth samples.

Parameters Measured	**Number of Measurements by Agency (excluding nondetects)**				**Total number of measurements (excluding nondetects)**	**Total number of measurements including nondetects**
	County of Warner	**PFRA/AAFC**	**AEP**	**Madawaska Reports**		
Chlorophyll A	173	418	22	11	624	656
E. coli	168	5	24	123	320	335
Total Phosphorous	513	443	30	129	1115	1126
Total Dissolved Phosphorous	352	444	25	81	902	963
Total Kjehldahl Nitrogen	282	226	30	1	539	611
Total Nitrogen	189	8	25	0	222	345
Nitrate/Nitrite	140	372	8	103	623	910
Ammonia (NH_4)	107	362	8	0	477	775
Total Dissolved Solids	353	0	16	0	369	369
Total Suspended Solids	156	430	0	0	586	625
Total Organic Carbon	375	0	6	0	381	386
Dissolved Organic Carbon	30	439	28	0	497	497
Turbidity	337	224	30	0	591	591
Temperature	411	289	69	0	769	769
pH	320	314	40	0	674	674
Dissolved Oxygen	357	233	39	0	629	629

For the purposes of this report, sampling sites were grouped into 5 categories (Table 5) with subcategories:

1. **Surface Sites** - Sites sampled at 0.1 to 0.5 m depth, grab samples
    a. West Basin
    b. North Outlet
    c. East Basin
    d. Northeast End
    e. East Outlet
    f. Outlet Canal (Canal to Raymond Reservoir)
2. **Integrated Samples** - Sites sampled using an integrated tube sampler to twice the Secchi depth (considered to be the euphotic zone)
    a. West Basin
    b. North Outlet
    c. East Basin
    d. Northeast End
    e. East Outlet
    f. Outlet Canal (Canal to Raymond Reservoir)
3. **Tributaries**, which are those tributaries entering the reservoir from the south
4. **Inlet Canal**, the canal bringing water from the St. Mary, Waterton and Belly Rivers to the Milk River Ridge Reservoir (via the Jensen Reservoir)
5. **Constructed Wetland** - Water flowing into and out of the constructed wetland (TRIB5 INLET and TRIB5 OUTLET). Water leaving the TRIB5 OUTLET enters the MRRR at the western end of the reservoir, just south of where the water from the Inlet Canal enters the reservoir.

Table 5. Categories of water quality sampling sites in and near the Milk River Ridge Reservoir

Sampling Category	Sites Sampled	Years Sampled
Surface grab	AB05AF0080	1983
	AB05AF0090	1983-1986, 2011-2018
	Cross Coulee Outlet	1993-1994
	East Outlet	1998-2003
	Outlet Canal	1998-2003
	North Outlet	1998-2003
	LD27	2003-2005
	RS2	2003-2007
	RS7	2003-2007
	RS9	2003-2004
	RS10	2003-2007
	RS15	2003-2005
	RR2	2014, 2018
	RR3	2014, 2018
	RR4	2014, 2018
	RR5	2014-2019
	RR6	2014, 2016, 2018
	RR7	2014, 2018
Euphotic zone Integrated	AB05AF0080	1985-1986, 2011-2012
	AB05AF0090	1983, 2015-2017
	East Outlet	2001
	Outlet Canal	2000
	North Outlet	1998-2003
	RS2	2006-2007
	RS7	2003-2007
	RS9	2003-2004
	RS15	2003-2005
	RR2	2014-2019
	RR3	2014-2019
	RR4	2014-2019
	RR5	2016-2017
	RR6	2014-2019
	RR7	2014-2019
Tributaries	LD23	2003-2007
	LD24	2003-2007
	RS14	2003-2005
	TRIB1	2014-2016
	TRIB1.2	2017-2019
	TRIB3	2014-2019
	TRIB4	2014-2015
	TRIB4.2	2017-2019
Major Tributary	AB05AF0710	2011-2012
	Inlet Canal	1998-2003
	LD21	2003-2007
	TRIB6	2014-2019
Constructed Wetland	TRIB5 INLET	2017-2019
	TRIB5 OUTLET	2017-2019

Analytical and Graphing Methods

Data was graphed as scatterplots for each of the five sampling categories: Surface, Integrated, Inlet Canal, Tributaries and Constructed Wetland Boxplots were constructed for Surface, Integrated, Inlet Canal and Tributaries.

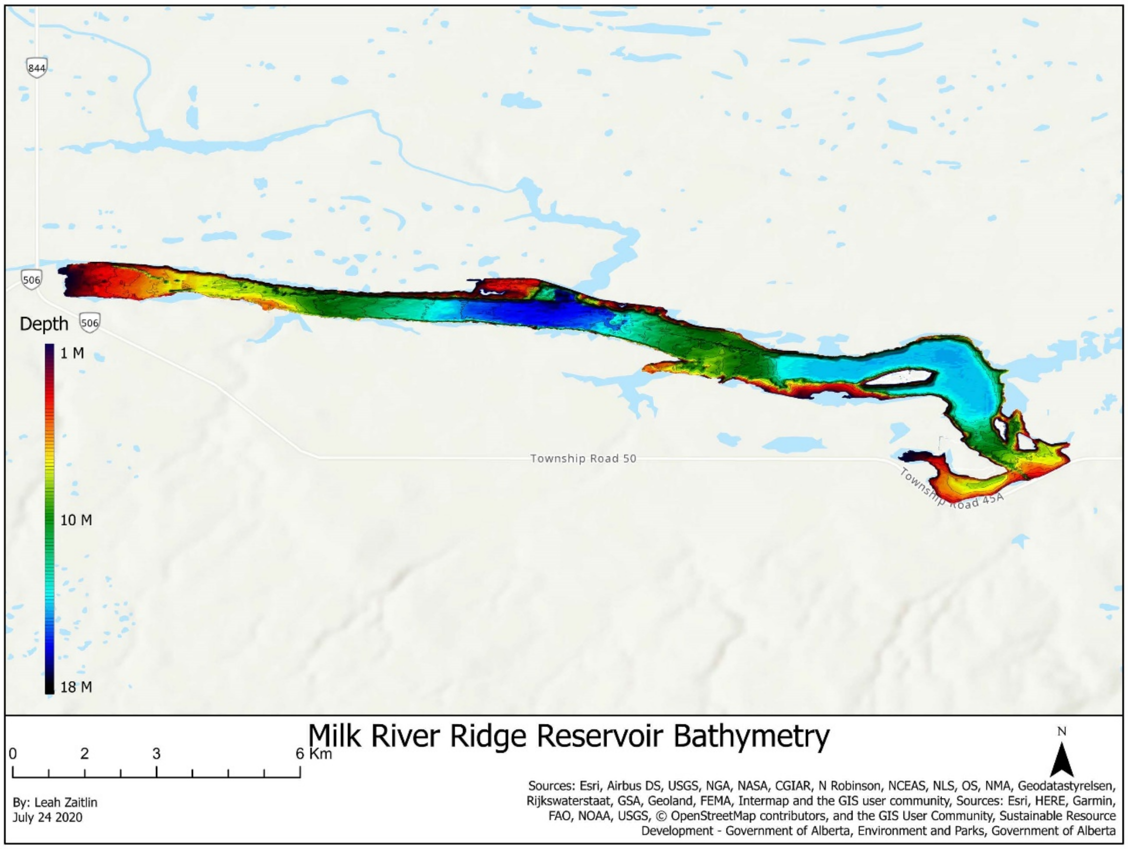
Each sampling category is displayed separately, and the different areas of the MRRR and surrounding locations are indicated through different colors. Where the data range was greater than two orders of magnitude, the y-axis of the graphs was transformed to log base 10. Outliers (below 0.001 µg/L in chlorophyll *a* and two individual high values, above 1200 mg/L, in TDS) were removed before graphing.

In the boxplots, the horizontal line in the box represents the median value. The upper and lower boxes represent the 25^{th} and 75^{th} percentiles, respectively. The vertical dashed lines represent the maximum data point, or, if there are outliers present, the dashed lines represent roughly two standard deviations. Points above and below two standard deviations are represented as circles. All data from within a given category and sampling area are grouped together to form the boxplots.

Where there were evident trends and adequate data (chlorophyll *a*, total phosphorous, total nitrogen, total dissolved solids and turbidity), heat maps were constructed to show trends in spatial distribution. Heat maps were constructed using the Spline toolset in ArcGIS Pro. The Spline type was tension, with a weight of 0.1 and the number of points set to 12 (the default settings for the tension test). An approximate polygon of the MRRR was used to determine the processing extent and the masking.

A bathymetric map of the Milk River Ridge Reservoir, produced by the ASRD, modified for this report (ASRD, 2003), shows the MRRR deepening progressively from the Inlet Canal to the centre, where water flows out to the Cross Coulee Reservoir. There is then a sill of shallower depths just to the east of the centre, with a deeper area further east (Figure 9).

Figure 9. Bathymetric map of the Milk River Ridge Reservoir (modified from ASRD 2003)



RESULTS

Graphs for all 16 parameters analyzed in this report, over all sites and all years available, are shown in Appendix A.

The six key parameters over the key years of 2003-2019 are shown graphically and discussed in the main body of this report.

Chlorophyll *a*

Chlorophyll *a* can be used as an indicator of the viable algae content of water since chlorophyll *a* reverts to phaeophytin-*a* upon death of the algae. The Canadian Council of Ministers of the Environment (CCME) and Alberta Environment and Parks (AEP) do not set guidelines for chlorophyll *a* concentration in surface water, however, the AEP does have guidelines for classification of the trophic state of surface waters based on chlorophyll *a* concentration (Table 6)(AEP 2013).

Table 6. Alberta Environment and Parks Guidelines for Classification of Surface Waters Based on Chlorophyll *a* Concentration

Trophic State	**Chlorophyll *a* (µg/L)**
Oligotrophic (low productivity)	<2.5
Mesotrophic (moderate productivity)	2.5 – 8.0
Eutrophic (high productivity)	8.0 – 25.0
Hypereutrophic (very high productivity)	>25.0

Chlorophyll *a* concentrations generally were in the mesotrophic to eutrophic range in the MRRR and Outlet Canal throughout all the years of sampling (1986-2019) and at most sites sampled (Appendix A).

Chlorophyll *a* concentrations in the main reservoir (Figure 10a-d) were roughly the same as in the Inlet Canal (Figure 11a and 11c) and tributaries (Figure 11b and 11d), with slightly higher values in the tributaries (Figure 11a-d). TRIB2 in particular has a wide range of chlorophyll *a* concentrations, ranging from less than 0.001 µg/L in 2004 to over 100 µg/L in 2007 (Figures 8b and 8d). Chlorophyll *a* concentrations overall have been fairly constant over time, although samples in the tributaries were primarily taken in 2003 – 2007, with few samples after that time.

Changes in chlorophyll *a* concentration may change more slowly than changes in non-biological parameters with restoration practices, as it takes time for nutrients to be removed from the system to levels that impact algae.

Chlorophyll *a* was not measured in the wetland.

Figure 10. Chlorophyll a concentrations in samples from the Milk River Ridge Reservoir and Outlet Canal. Dashed line indicates eutrophic conditions above this limit.

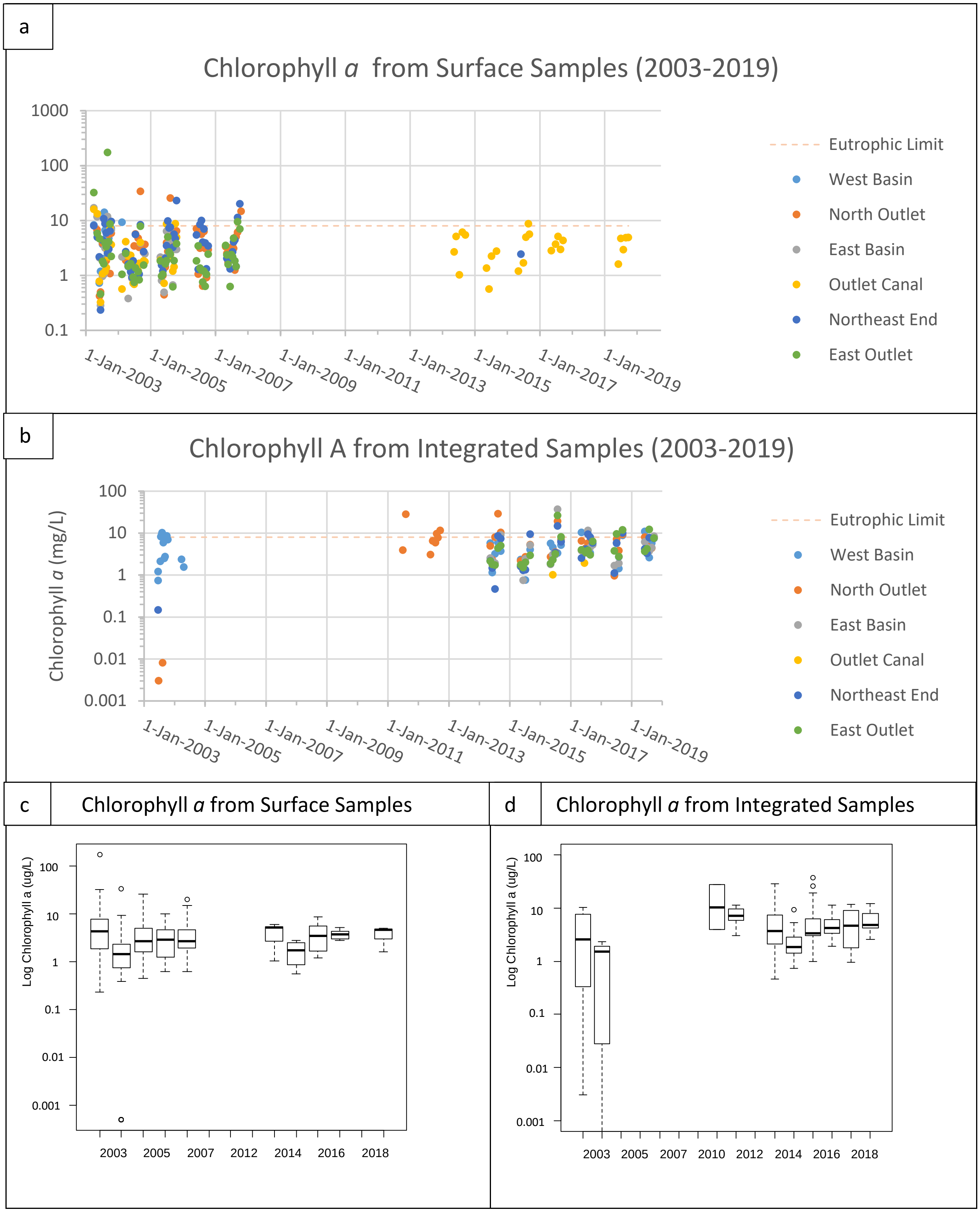
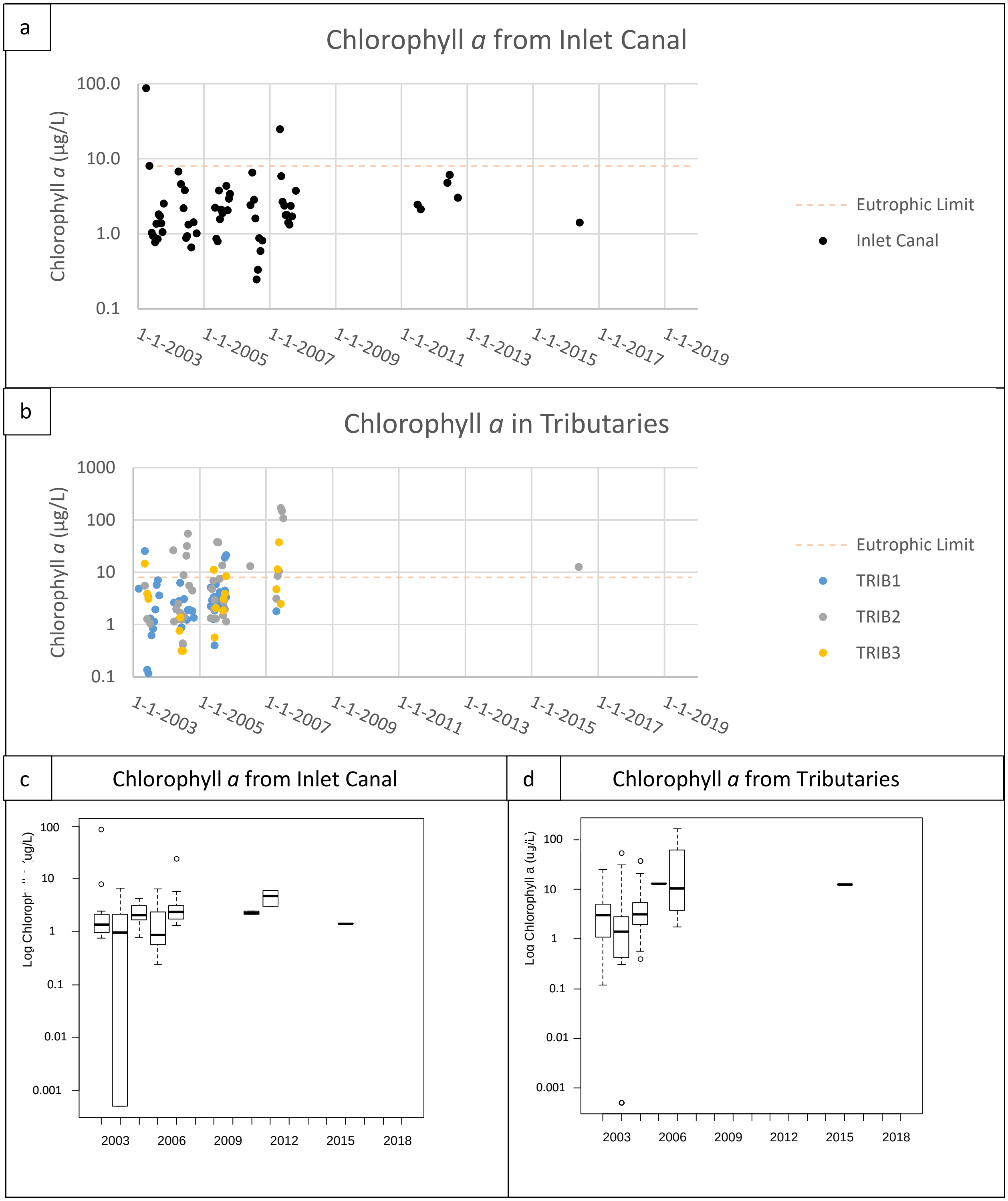


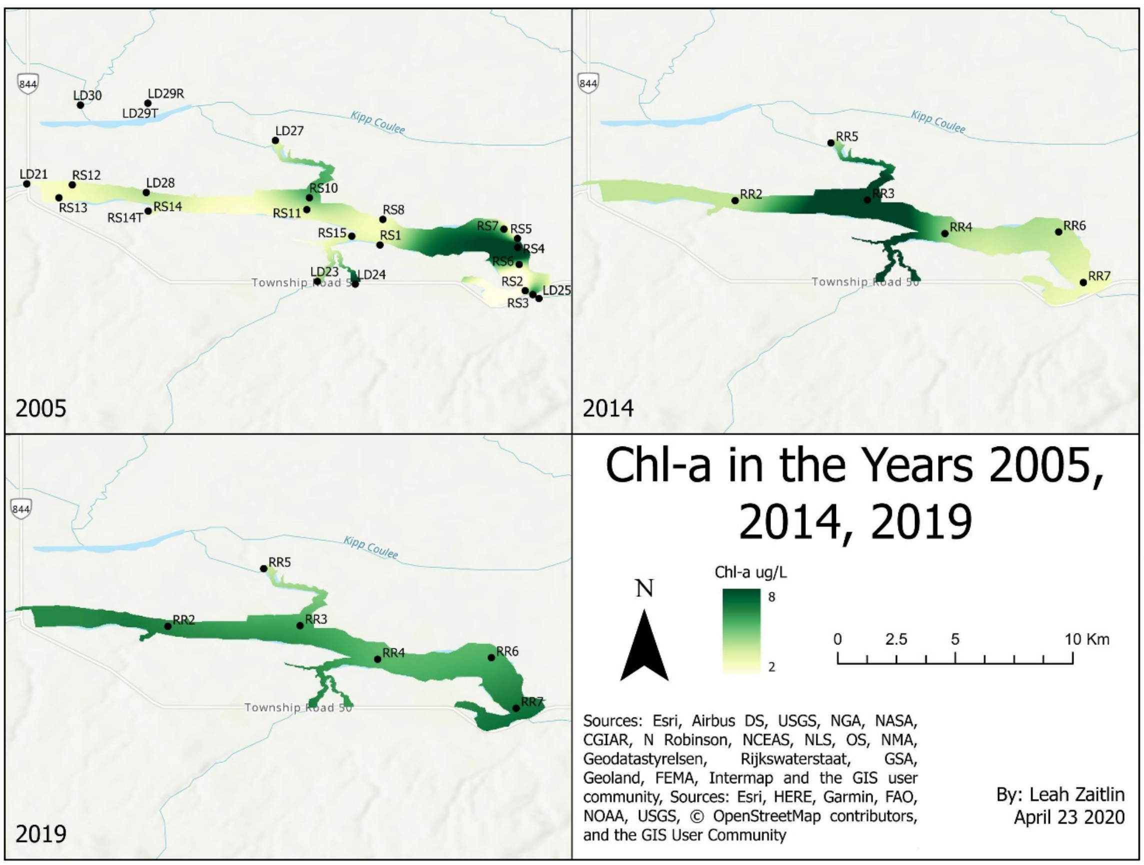
Figure 11. Chlorophyll a concentrations from the Inlet Canal and tributaries entering the Milk River Ridge Reservoir. Dashed line indicates eutrophic conditions exist above this limit.



Heat maps indicated that chlorophyll *a* was concentrated at the east end of the MRRR in 2005, in the center of the MRRR in 2014, and was present fairly evenly across the MRRR in 2019 (Figure 12). The Spline method used interpreted the tributaries as having high chlorophyll *a* concentrations in 2014, and moderate concentrations in 2019, however, no chlorophyll *a* samples were actually taken in the tributaries in 2014 or 2019, therefore, the possibility that chlorophyll *a* was coming in from these sources is only an interpretation.

The distribution of chlorophyll *a* in 2014 and 2019 is concordant with the distribution of total phosphorous (Figure 20), total nitrogen (Figure 24) and total dissolved solids (Figure 29) in 2014 and 2019, except that higher values for these parameters are shown in the west end of the reservoir. These parameters were measured in the tributaries and Inlet Canal in 2014 and 2019. This indicates that although the distribution of chlorophyll *a* is estimated for tributaries, the estimation is likely to be accurate based on the distribution of the other parameters.

Figure 12. Changes in annual average chlorophyll a distribution in the years 2005, 2014 and 2019



E. coli

E. coli is an indicator of fecal contamination, and an indicator of the potential presence of enteric bacterial pathogens such as Salmonella, Shigella, Campylobacter and *E. coli* O157:H7 (Health Canada 2012). For recreational waters used for primary contact activities, the guideline is less than 100 *E. coli* colonies with a minimum of four samples, taken once per week (AEP, 2018).

Although there appears to be a slight increasing trend for *E. coli* surface samples taken between 1998 and 2003 (Appendix A), there is no current sampling for *E. coli* in the reservoir. Surface samples were taken in 2003 and at the North Outlet in 2005 (Figure 13a and 13c), and only a few integrated samples were taken in 2003 (Figure 13b and 13d). There was no evident trend in these samples.

E. coli in the Inlet Canal was sampled from 1998 to 2019, and showed no evident trend over those years (Appendix A). Concentrations were generally below the single-sample guideline from 2003-2019 except for a single sample in 2014 (Figure 14a).

E. coli in the tributaries was often very high, however, up to a high of 170,000 in TRIB3 in March 2019 (Figure 14b and 14d). The highest readings may be coincident with rainfall or snowmelt runoff from livestock areas, which are located along these tributaries. The specific causes of unusually high values was not examined in this study, however.

E. coli was similar in the inflow and outflow of the wetland (Figure 15). This is not unexpected, as the value of wetlands is often to reduce the peaks during high flow events, which were not captured in this study.

Figure 13. *E. coli* concentrations in samples from the Milk River Ridge Reservoir and Outlet Canal. Dashed line indicates maximum allowable limit for contact recreation.

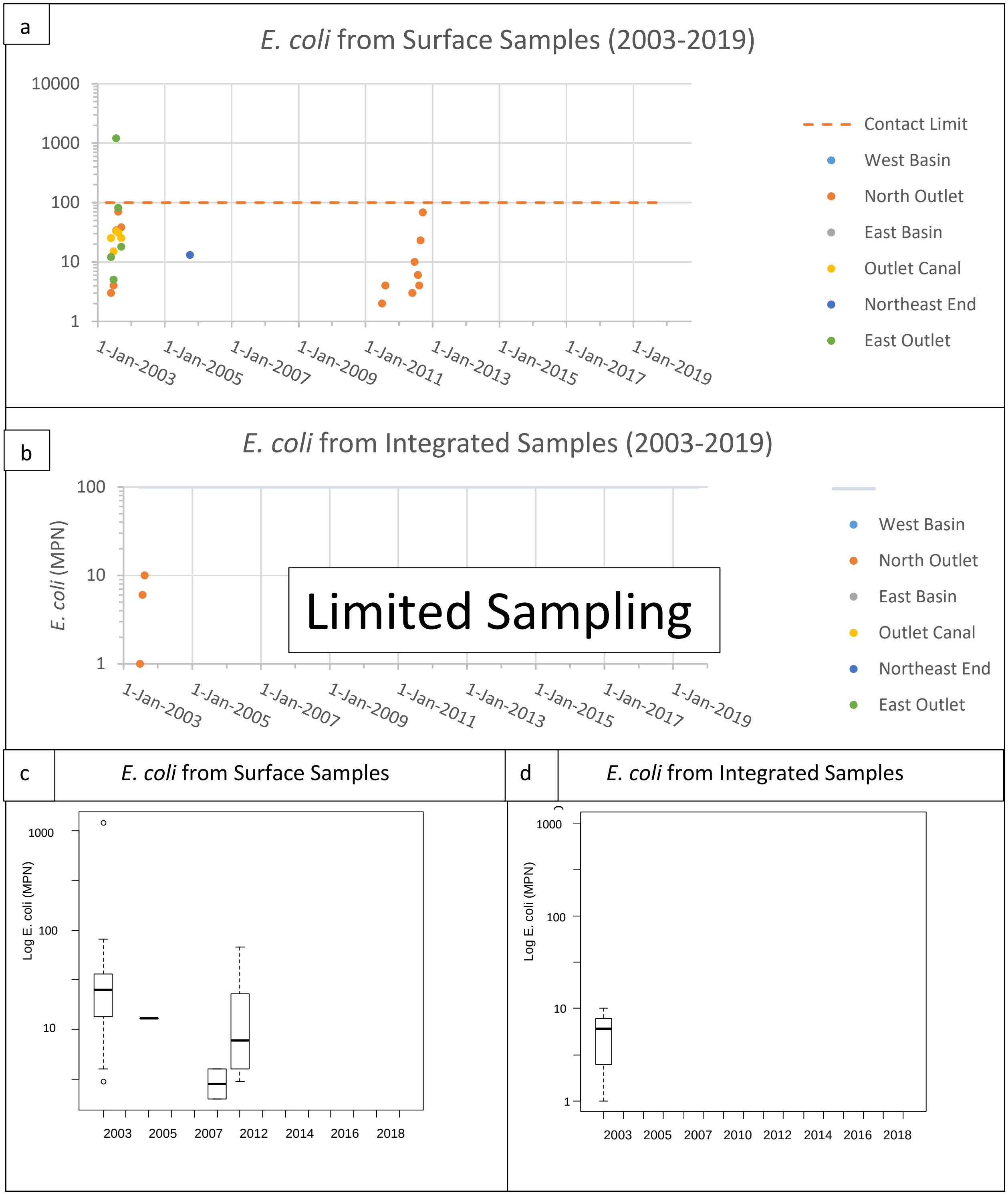


Figure 14. *E. coli* concentrations from the Inlet Canal and tributaries entering the Milk River Ridge Reservoir

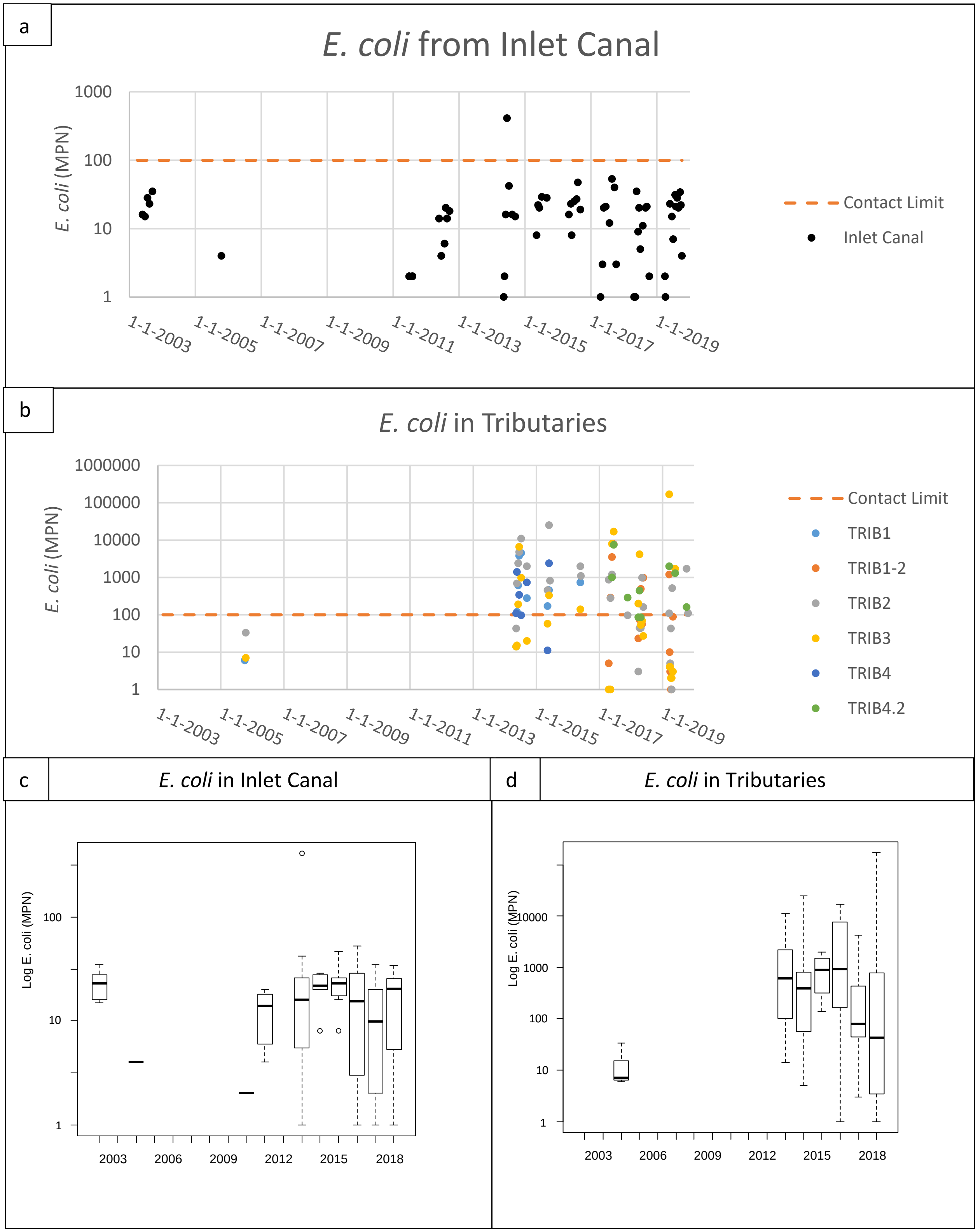
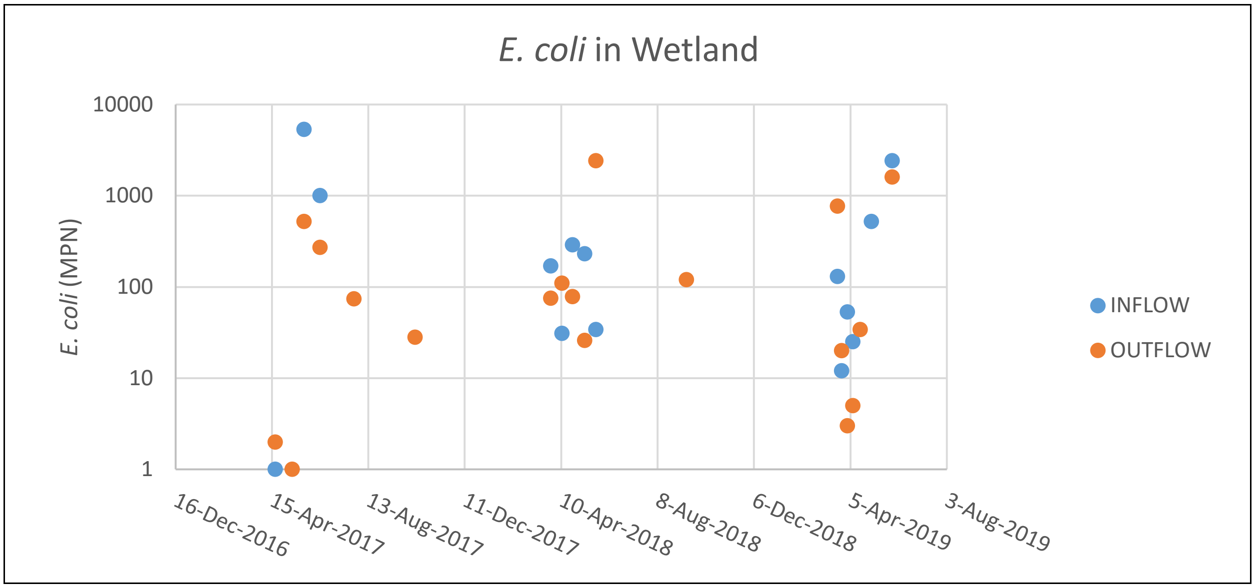


Figure 15. *E. coli* concentrations from the inflow and outflow of the constructed wetland that drains into the Milk River Ridge Reservoir.



Total Phosphorous

Phosphorous is an essential nutrient for all life. The Protection of Aquatic Life guidelines (CCME 1991) are intended more to deal specifically with toxic substances. Phosphorus does not fit this model because it is non-toxic to aquatic organisms at levels and forms present in the environment; however, secondary effects, such as eutrophication and oxygen depletion are serious concerns. In AEP (2018) there is a narrative statement for phosphorus in fresh water (prevent aquatic degradation). Therefore, Trigger Ranges are established for water bodies where changes to phosphorous above reference conditions may trigger further assessment (AEP 2018).

Table 6. Trigger Ranges for trophic status assessment of freshwater lakes and reservoirs using total phosphorous.

Trophic Status	Canadian Trigger Ranges Total phosphorus (mg/L)
Ultra-oligotrophic	< 0.004
Oligotrophic	0.004-0.01
Mesotrophic	0.01-0.02
Meso-eutrophic	0.020-0.035
Eutrophic	0.035-0.1
Hyper-eutrophic	> 0.1

TP concentrations in the MRRR ranged from a low at the detection limit of 0.0015 mg/L in numerous samples, to a high of 8.3 mg/L in April 2003 at the East Outlet (Figure 16a).

TP in surface samples appeared to increase from 1998 to 2007, and then decrease from 2014 to 2019 (Appendix A). In both surface samples (Figure 16a and 16c) and integrated samples (Figure 16b and 16d), the range of TP concentrations in 2014 was nearly non-overlapping with the range of TP concentrations in 2019. The largest decrease in median TP values was between 2014 and 2015, with lesser decreases in the median in subsequent years (Figure 16c and 16d).

The decrease in TP in the reservoir is not attributable to changes in phosphorous arriving in the primary water source of the reservoir, the Inlet Canal. TP levels in the Inlet Canal have held relatively constant or increased slightly since 1998 (Appendix A). Since 2003, there has been no discernable change in TP levels in the Inlet Canal (Figure 17a and 17c). However, water residence time in the reservoir has decreased since 2014 (Figure 4), and this may have contributed to the decrease in TP, although there was no strong direct correlation between residence time and total phosphorous (Figure 18).

TP in the tributaries ranged from 0.01 mg/L to 4.1 mg/L, averaging 0.28 mg/L. No discernable trend was noted from 2003 - 2019 (Figure 17b and 17d).

The slight increases in TP in the Inlet Canal and tributaries may not reflect the total deposition of phosphorous into the MRRR, since a major source of deposition of phosphorous to surface water occurs during runoff events, which would not be captured by this sampling program. The wetland may mitigate some of this runoff, despite no difference in TP between the inlet and outlet during normal flow conditions (Figure 19).

Figure 16. Total phosphorous concentrations in surface and integrated depth samples from the Milk River Ridge Reservoir and Outlet Canal

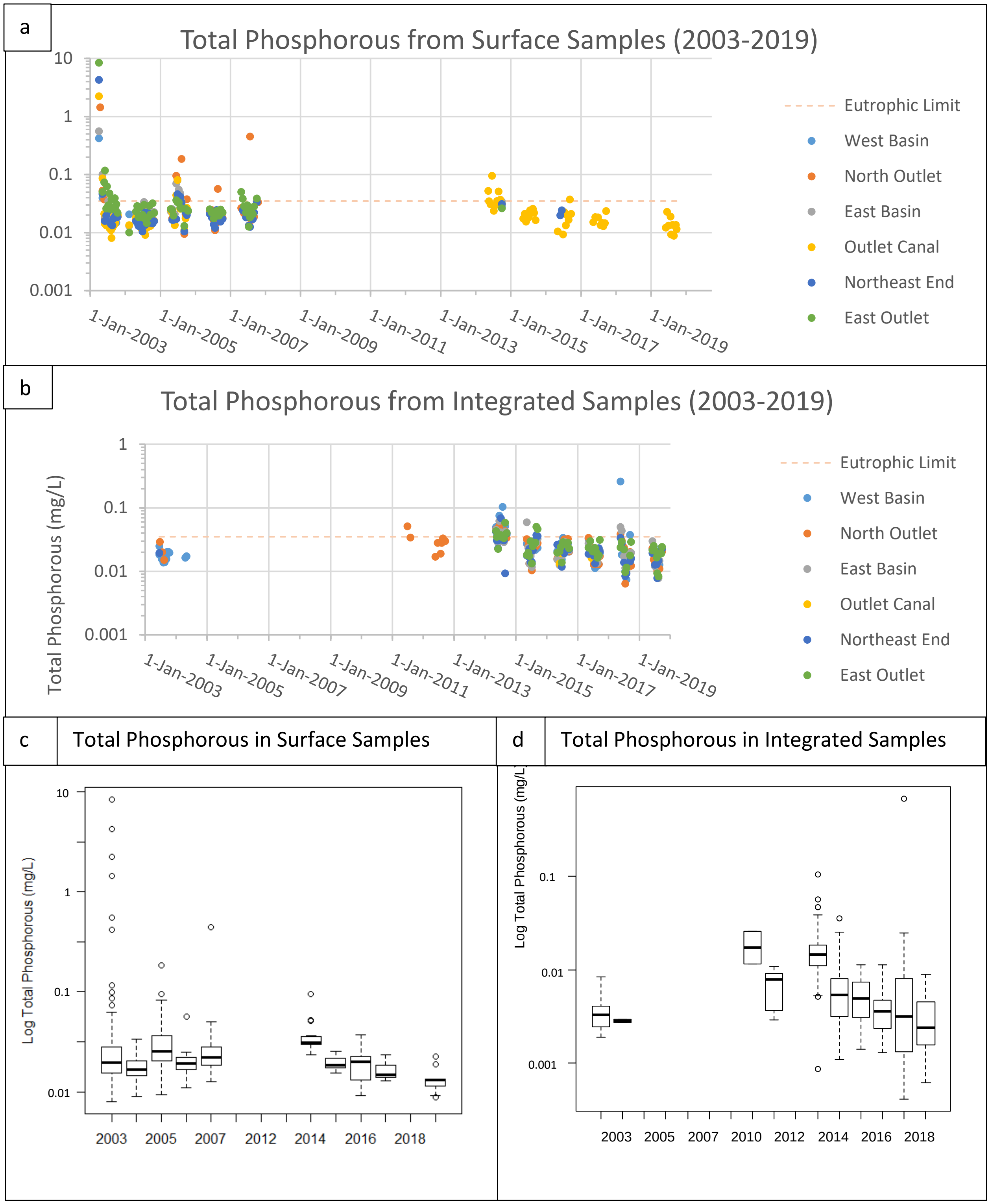


Figure 17. Total phosphorous concentrations from the Inlet Canal and tributaries entering the Milk River Ridge Reservoir

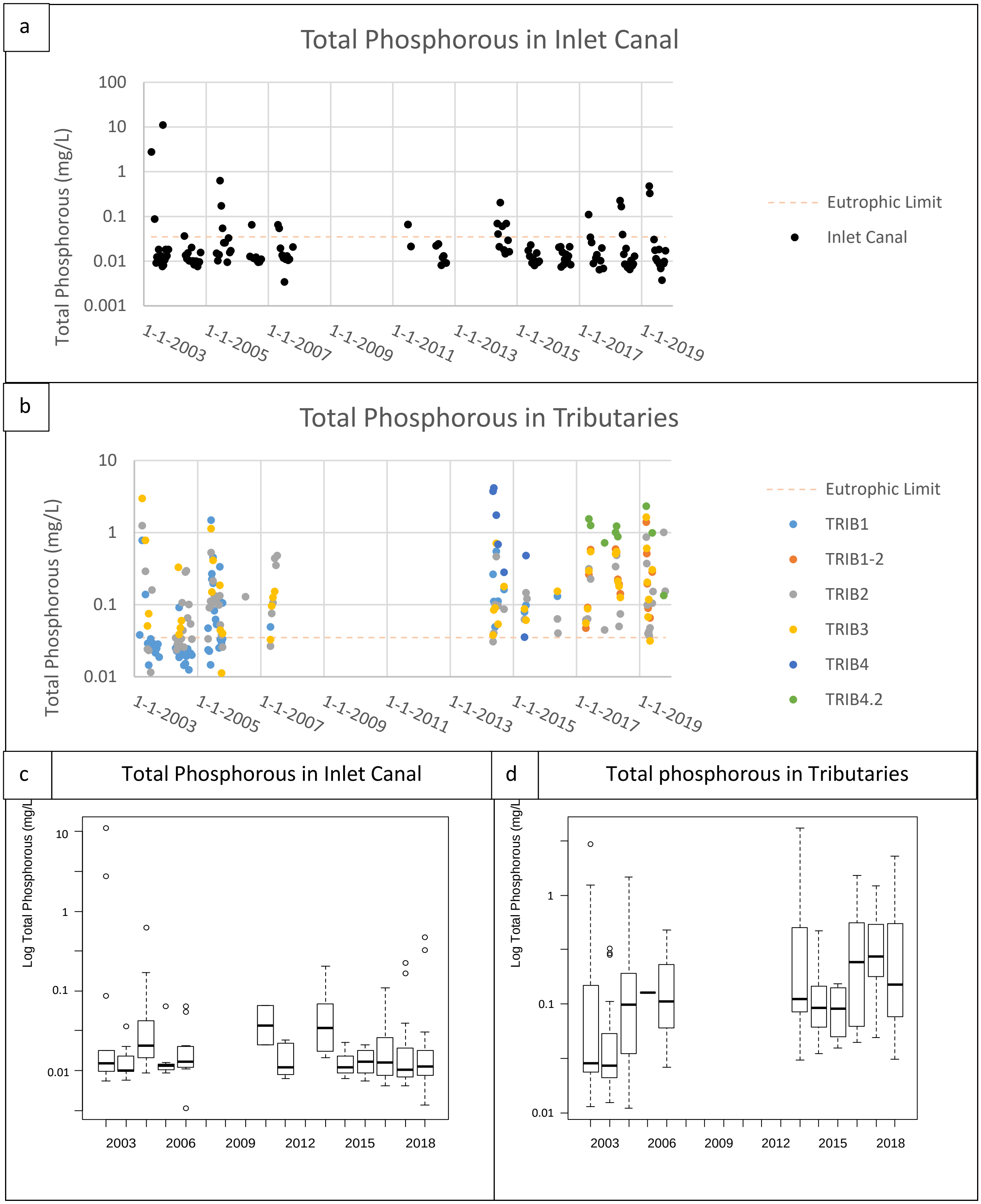


Figure 18. Average annual concentration of total phosphorous in surface and integrated samples plotted against average annual residence time in the Milk River Ridge Reservoir

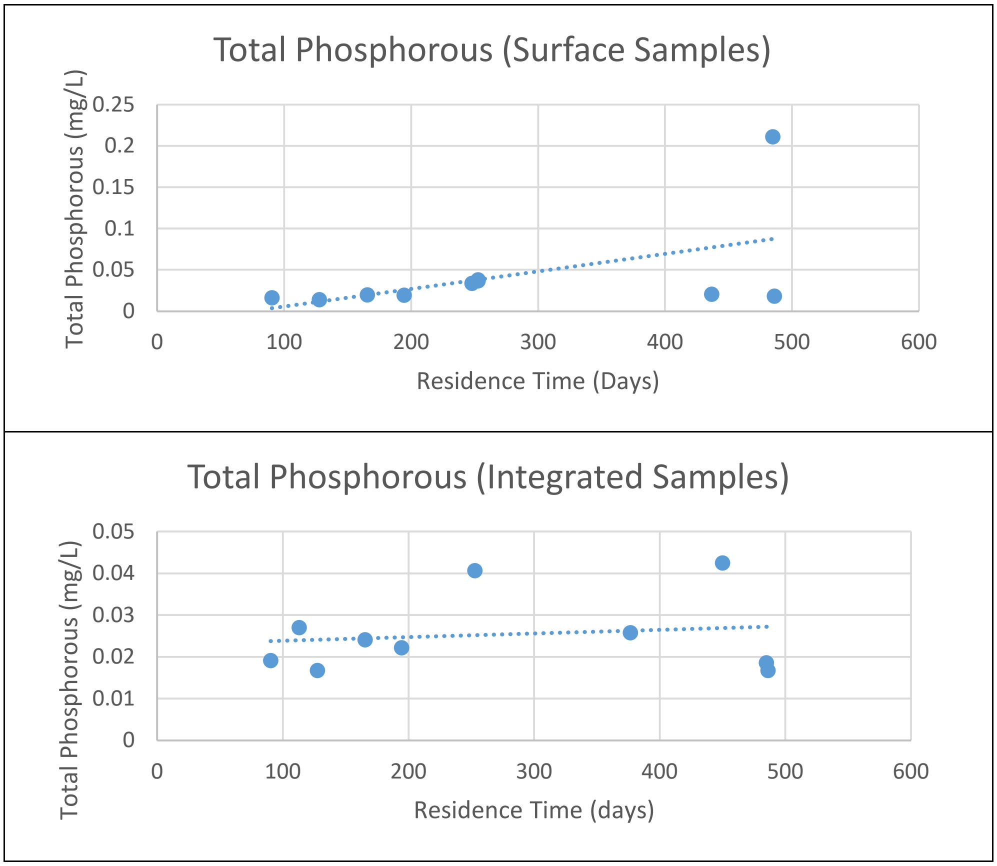
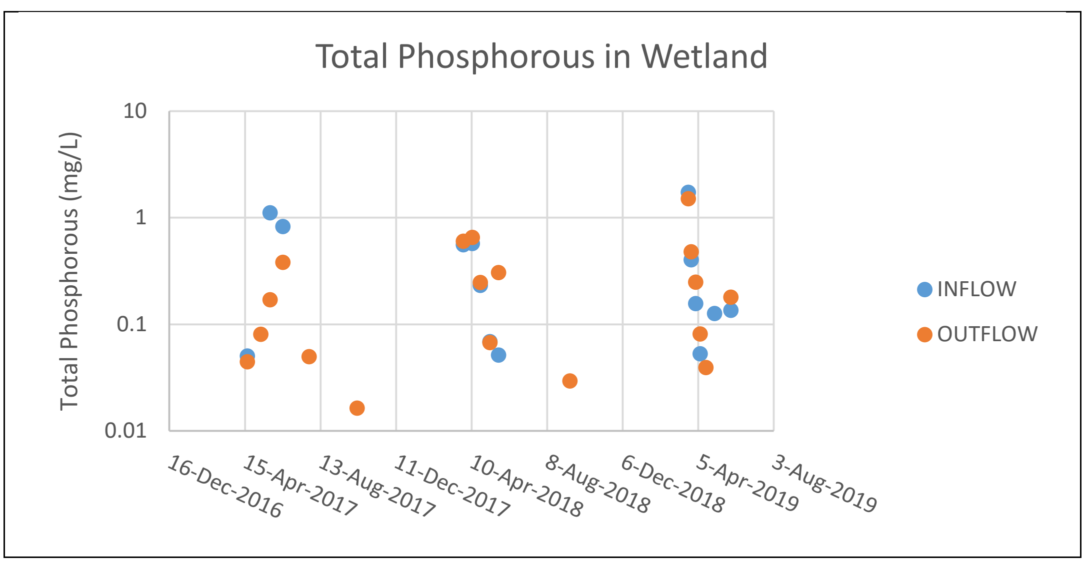
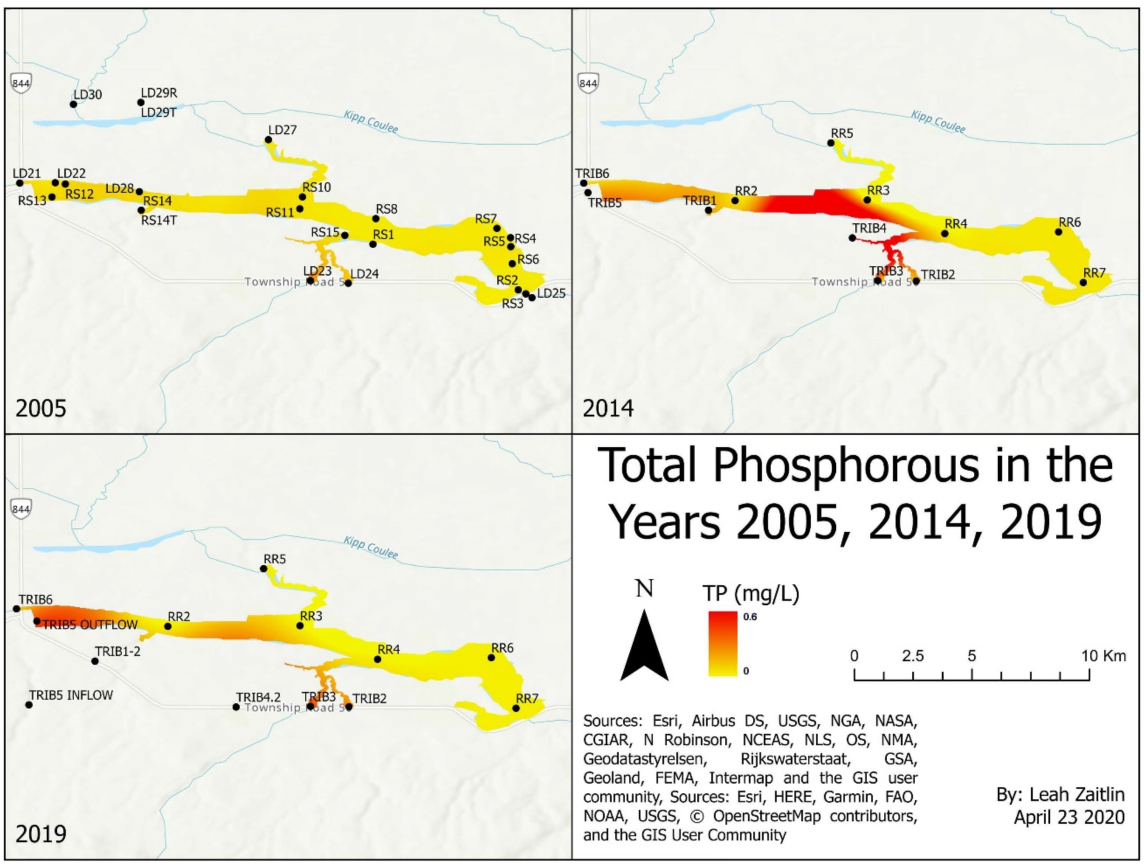


Figure 19. Total phosphorous concentrations from the inflow and outflow of the constructed wetland that drains into the Milk River Ridge Reservoir



Heat maps indicate that TP was evenly distributed across the MRRR in 2005, was concentrated in the center of the MRRR in 2014, and was present fairly evenly across the MRRR in 2019, with slight increases in concentration at the west end (Figure 20). In contrast to the chlorophyll *a* sampling distribution (Figure 12), TP was measured in tributaries and the Inlet Canal in all years of the sampling program, so the Spline method is likely to be accurate. However, the heat maps for chlorophyll *a* (Figure 12) resemble the heat maps for TP (Figure 20), especially in 2014, indicating both that the heat maps for chlorophyll *a* are accurate and that chlorophyll *a* concentration is influenced by the same factors that influence TP concentration, or by TP concentration itself.

Figure 20. Changes in annual average total phosphorous distribution in the years 2005, 2014 and 2019



Total Nitrogen

Total nitrogen (TN) is the sum of Total Kjeldahl Nitrogen (which is ammonia and organic nitrogen) plus nitrate (NO_3) and nitrite (NO_2).

In Alberta, no specific nitrogen levels are set for surface water guidelines. Instead, AEP guidelines are: **No increase in nitrogen (total) or phosphorus over existing conditions. Where nitrogen and/or phosphorus have increased due to human activity, develop lake-specific nutrient objectives and management plans where warranted** (AEP, 2018).

Neither surface samples nor integrated samples showed a definitive trend over the years of sampling (1985-2019) (Appendix A). TN concentrations ranged from 1.2 mg/L to 0.1 mg/L in the surface samples (Figure 21a and 21c) and 1.1 to 0.1 mg/L in the integrated samples (Figure 21b and 21d). However, a possible reason for no detection of definitive trends is that the minimum detection limit (MDL) for TN was 0.1 mg/L. Samples that were below detection for TN (that is, below detection for total Kjeldahl nitrogen, nitrate and/or nitrite) accounted for 57 out of 155 surface samples (37%) and 7 out of 150 integrated samples (5%). This relatively high detection limit may prevent the ability to determine if there are decreasing trends.

TN samples taken in the Inlet Canal were generally in the same range as in the main reservoir, that is, between 0.1 and 1 mg/L (Figure 22a and 22c). TN sampling in the Inlet Canal also was limited by an MDL of 0.1 mg/L. In the Inlet Canal, 21 out of 56 samples (38%) were below detection limit.

In the tributaries, TN was generally higher. TN concentration ranged from 28.6 mg/L to 0.1 mg/L (Figure 22b and 22d), but still 40 out of 103 (39%) samples were below detection limit.

In the wetland, as with TP, no difference could be seen in TN between inflow and outflow, although the outflow had a much wider range of TN concentrations (Figure 23).

Figure 21. Total nitrogen concentrations in surface and integrated depth samples from the Milk River Ridge Reservoir and Outlet Canal.

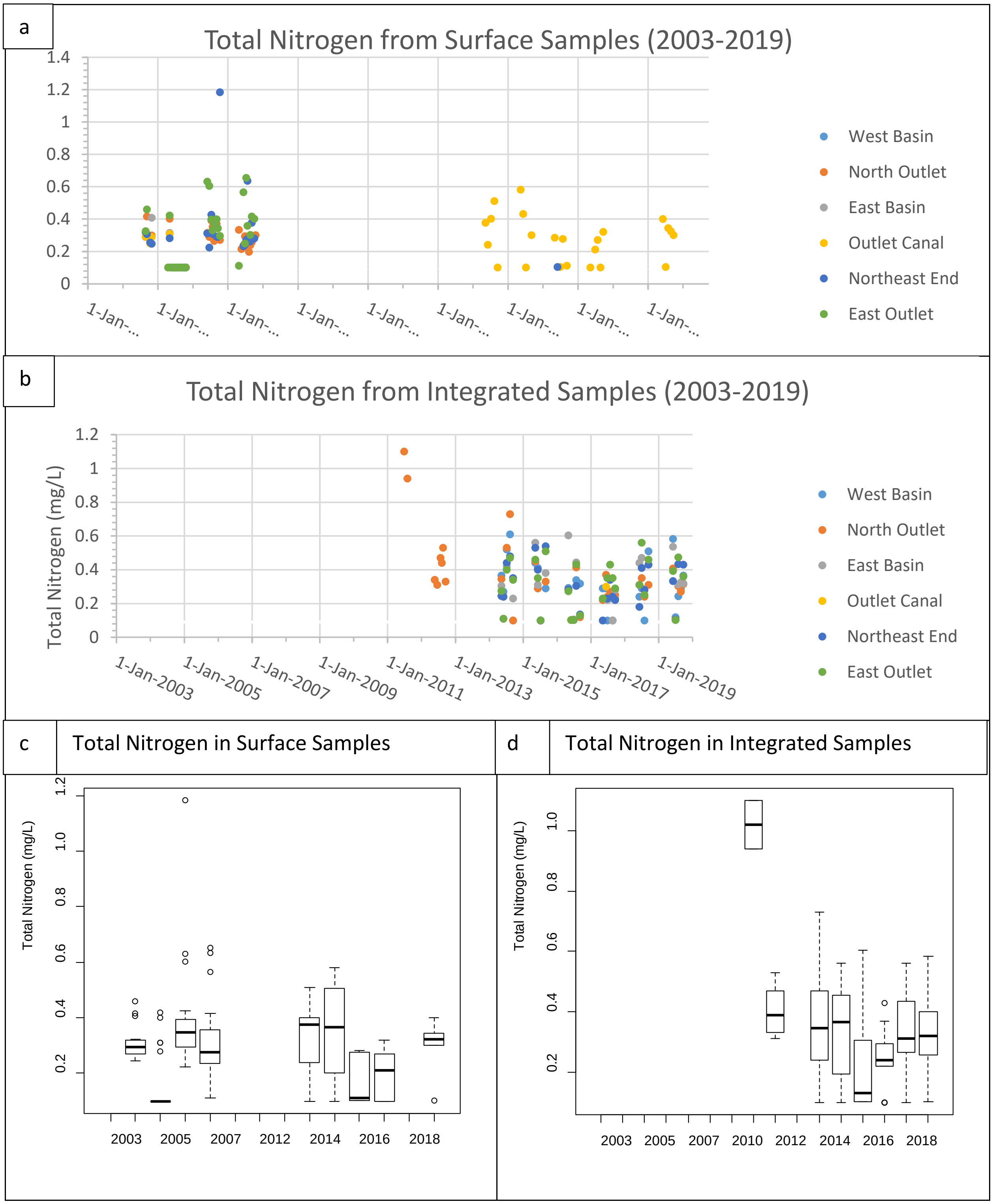


Figure 22. Total nitrogen concentrations from the Inlet Canal and tributaries entering the Milk River Ridge Reservoir.

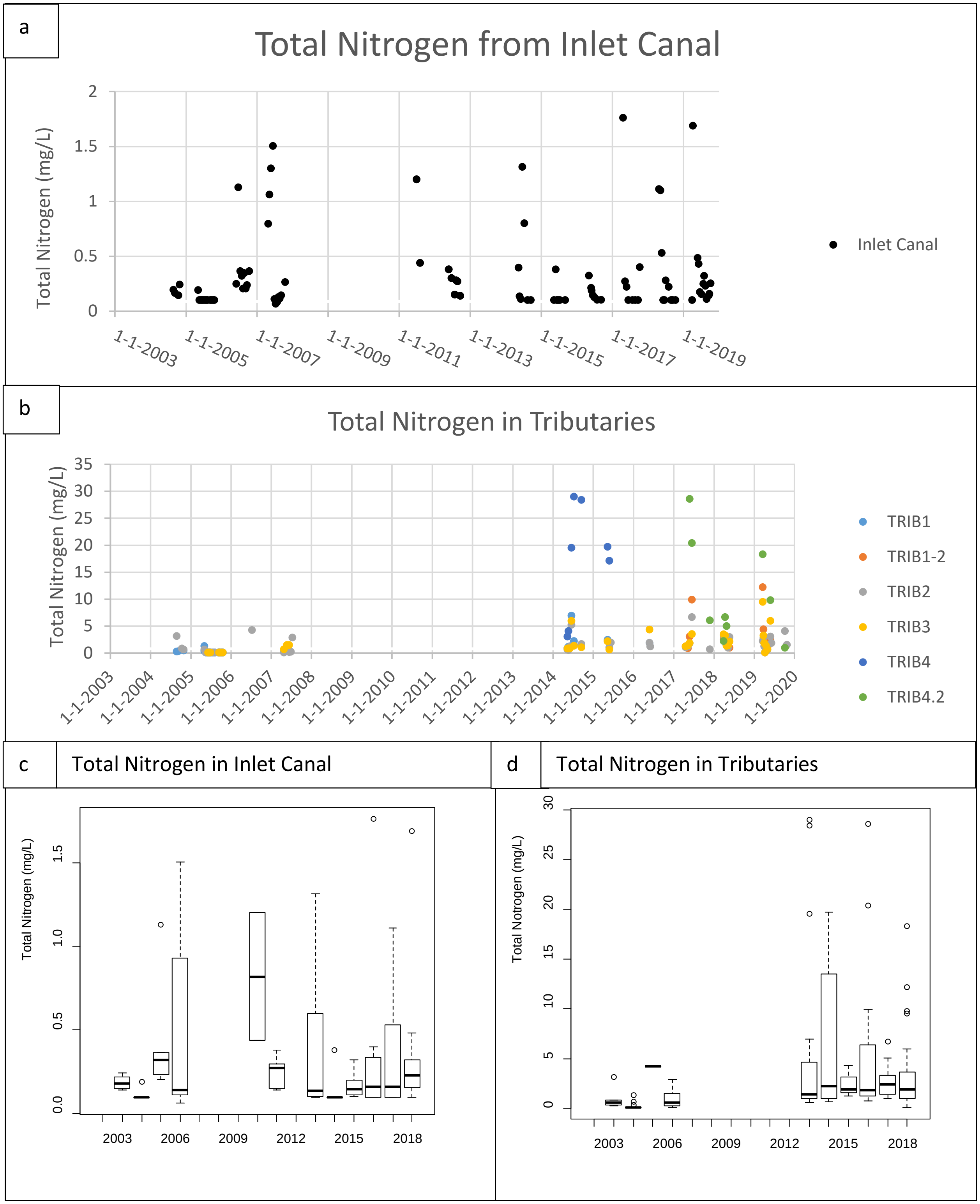
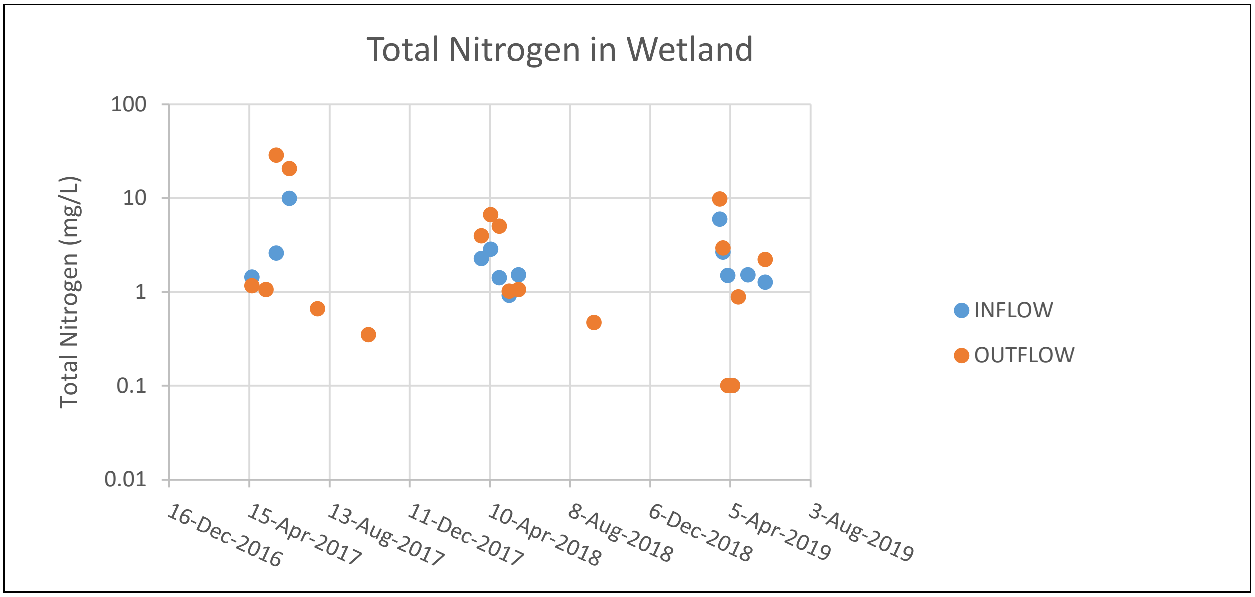
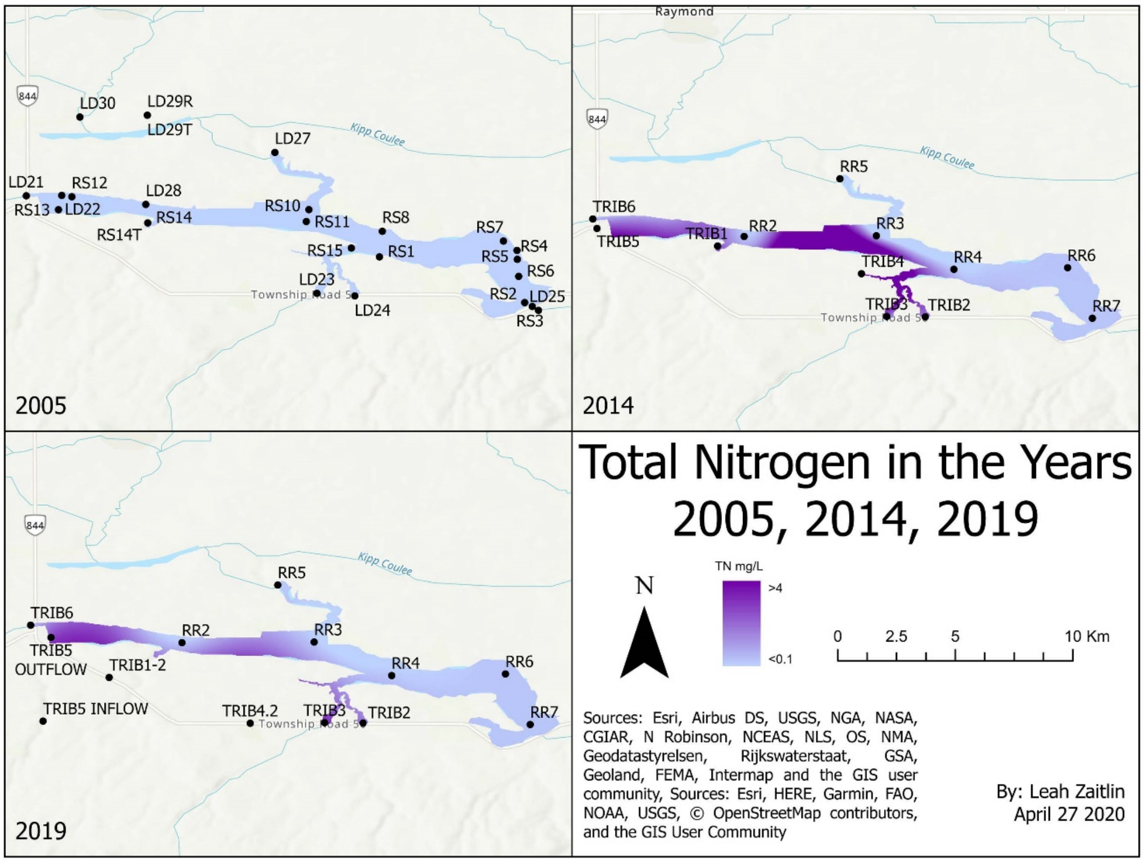


Figure 23. Total nitrogen concentrations from the inflow and outflow of the constructed wetland that drains into the Milk River Ridge Reservoir.



Heat maps indicate that TN was evenly distributed across the MRRR in 2005, was concentrated in the center and west end of the MRRR in 2014, and diminished across the MRRR in 2019, with slightly higher concentrations at the west end and in the center (Figure 24). The heat maps for TN closely resemble the heat maps for TP (Figure 20), indicating nutrients are coming from the same sources.

Figure 24. Changes in annual average total nitrogen distribution in the years 2005, 2014 and 2019



Total Dissolved Solids

TDS is a measurement of inorganic salts. Depending on the components of TDS, high levels (generally above 1,000 mg/L) may be toxic to aquatic life (Weber-Scanell and Duffy, 2007). There are no national or provincial standards for TDS in the protection of aquatic life. However, the main reason for testing for TDS is that increases in dissolved salt levels may indicate increased runoff and erosion entering the reservoir.

In the MRRR, TDS was tested in the 1970s and early 1980s by surface sampling at the North Outlet, then from 2014 to 2019 by surface sampling at the Outlet Canal (Appendix A). None of the samples from the 1970s nor the samples from 2014-2019 were over 300 mg/L, except for a single sample in June 2017 (Figure 25a and c).

Integrated sampling in the MRRR was not carried out until 2011. The highest recorded concentration of TDS from integrated sampling was 380 mg/L in June 2011, and TDS concentrations declined sharply from 2011 to 2019 (Figure 25b and 25d).

The decrease in TDS in the reservoir is not attributable to changes in the primary water source of the reservoir, the Inlet Canal. TDS concentrations were generally in the range of 90 to 370 mg/L, similar to the range in the reservoir (Figure 26a and 26c). However, water residence time in the reservoir has decreased since 2014 (Figure 4), and there appears to be a strong inverse relationship between water residence time and integrated TDS samples (Figure 27). Surface sampling was not done frequently enough to establish an association (Figure 27).

In the tributaries, TDS was measured from 2003 to 2019. TDS concentrations were generally in the range of 150 to 4300 mg/L, much higher than in the reservoir. The highest concentration recorded in the tributaries was in TRIB4 in May 2015, at 4830 mg/L. Concentrations in the tributaries declined from that peak, with a clear trend of reduced TDS over time (Figure 26b and 26d).

TDS in the wetland was in the same range as in the tributaries, ranging from 1430 mg/L to 121 mg/L (Figure 28). There was no difference in TDS between the inlet and the outlet during normal flow conditions, and this study provided no data on TDS during high flow periods. TDS in the wetland also showed no decline over the period the wetland was installed, from April 2017 to May 2019.

Figure 25. Total dissolved solids concentrations in surface and integrated depth samples from the Milk River Ridge Reservoir and Outlet Canal.

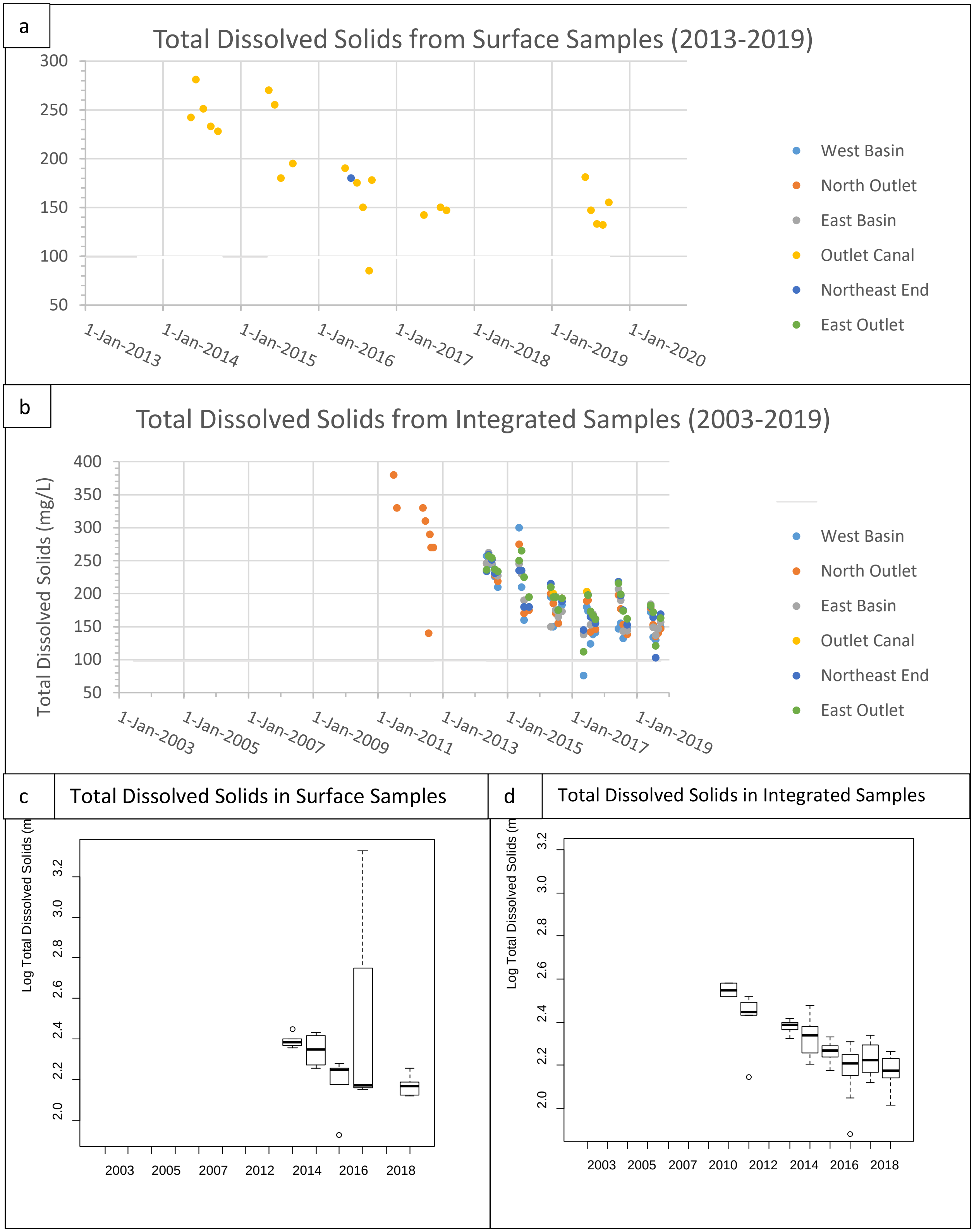


Figure 26. Total dissolved solids concentrations from the Inlet Canal and tributaries entering the Milk River Ridge Reservoir.

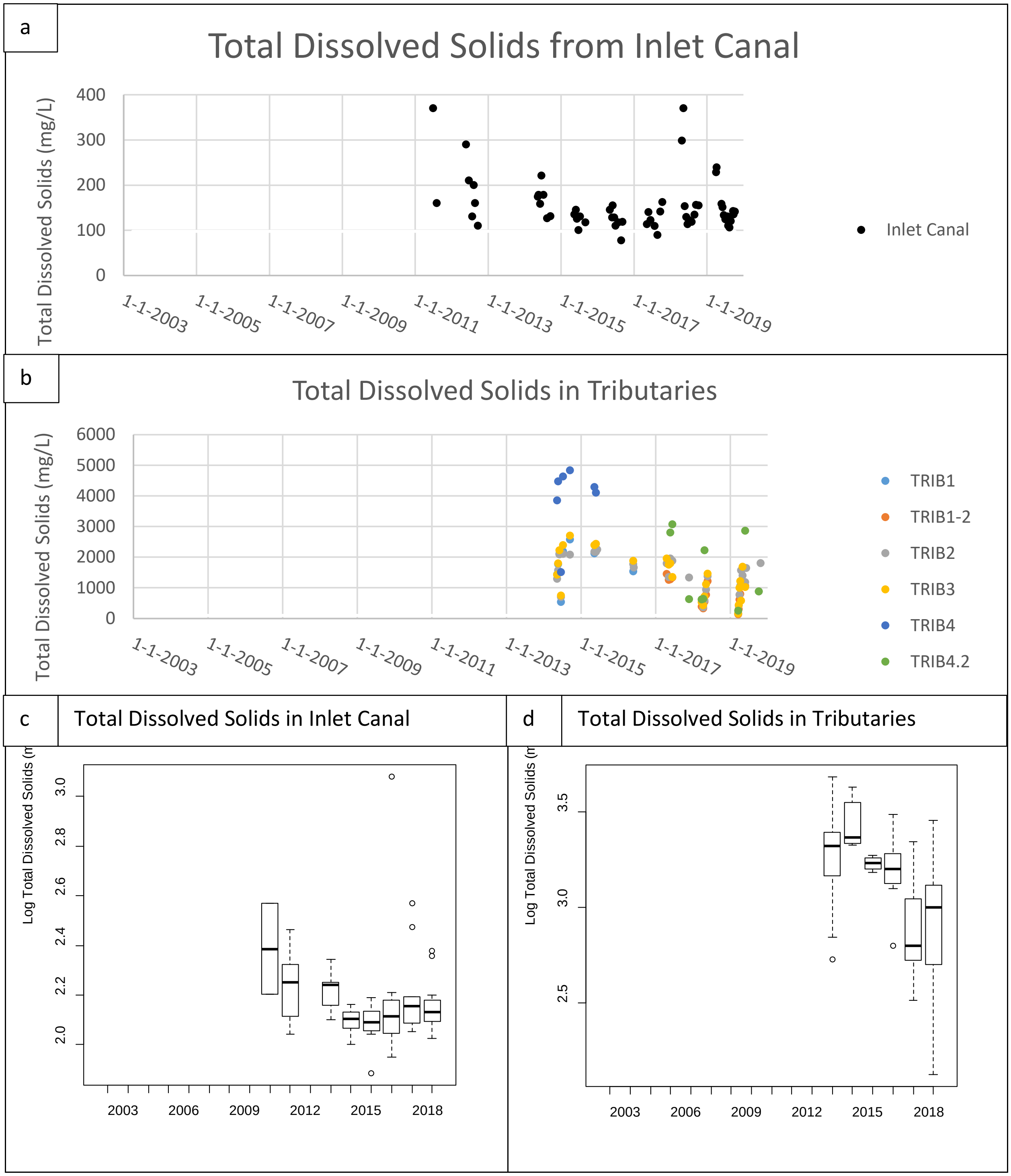


Figure 27. Average annual concentration of total dissolved solids in surface and integrated samples plotted against average annual residence time in the Milk River Ridge Reservoir.

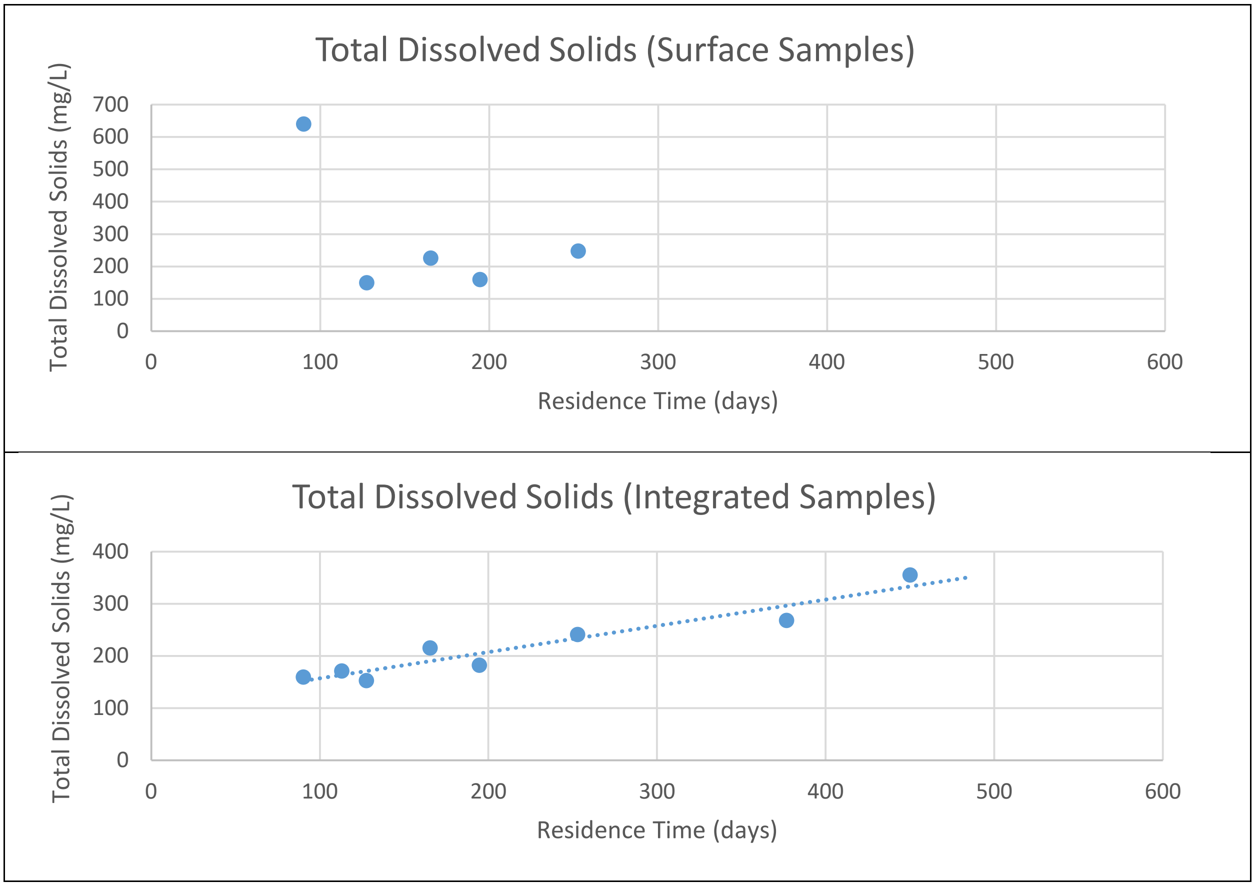
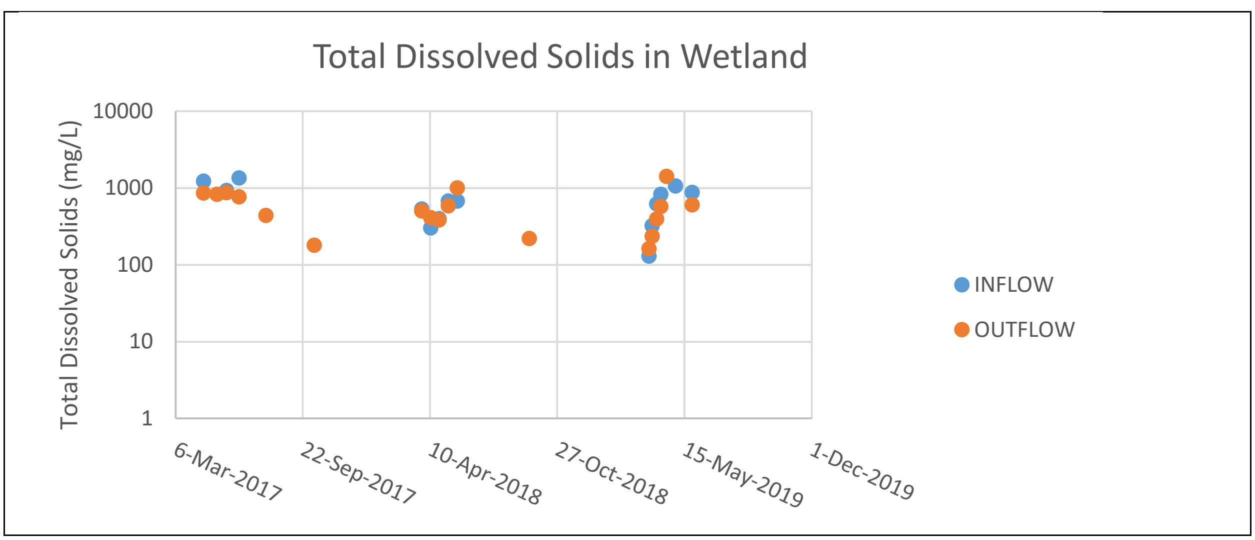
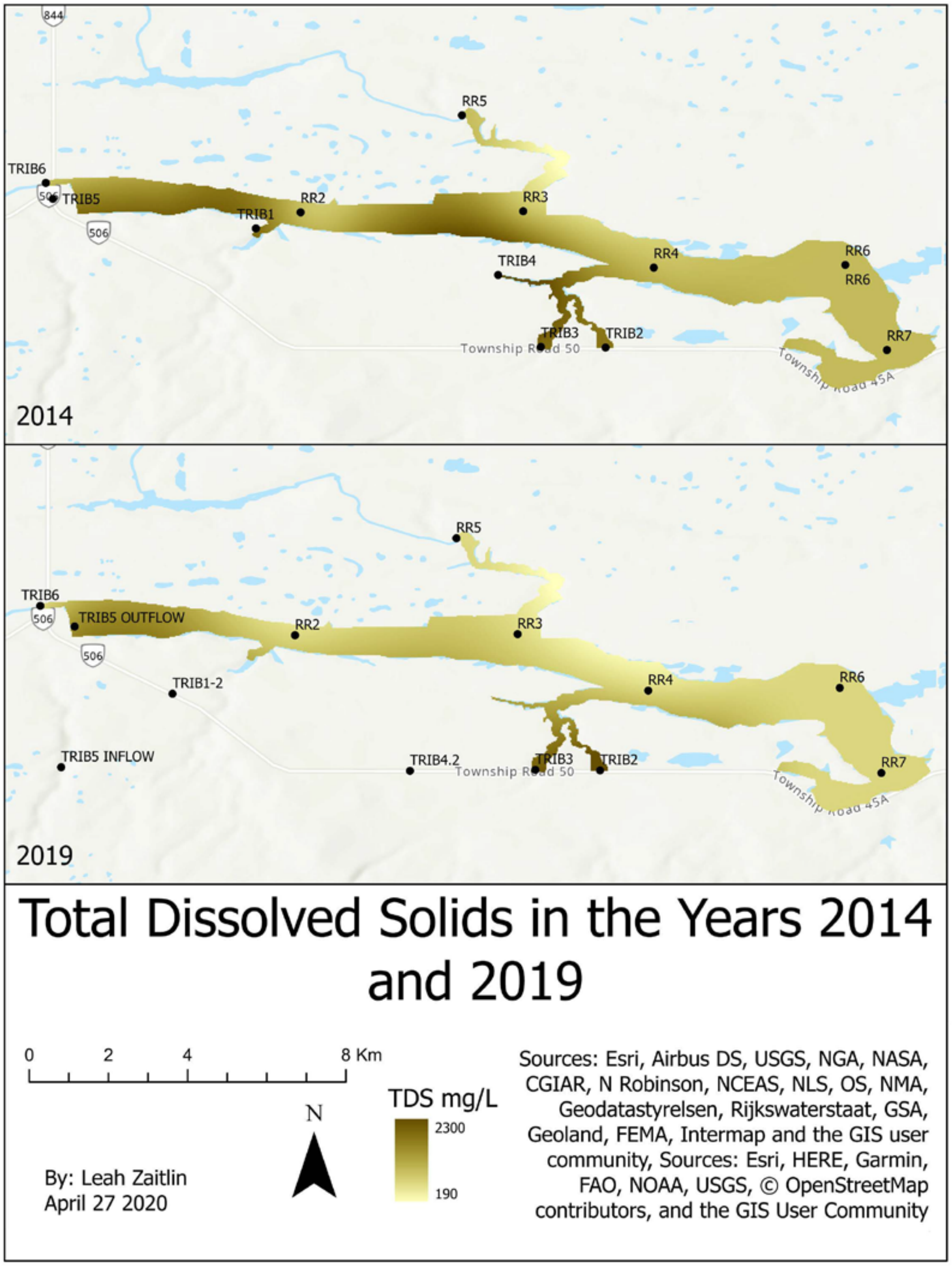


Figure 28. Total Dissolved Solids concentrations from the inflow and outflow of the constructed wetland that drains into the Milk River Ridge Reservoir.



Heat maps (Figure 29) indicate that TDS was higher across the entire MRRR in 2014, particularly at the center and west end. TDS was lower across the MRRR in 2019, with slightly higher concentrations at the west end (Figure 29).

Figure 29. Changes in annual average total dissolved solids distribution in the years 2014 and 2019



Turbidity

Turbidity is the measure of relative clarity of water. Material that causes water to be turbid include suspended clay, silt, organic matter, algae, dissolved colored organic compounds, zooplankton and other microscopic organisms.

The CCME (CCME 2002) and Alberta (AEP 2018) guidelines are:

For clear waters: Maximum increase of 8 NTU from background for any short-term exposure (e.g. 24-h period). Maximum average increase of 2 NTU from background levels for longer term exposures (greater than 24 h).

For high flow or turbid waters: Maximum increase of 8 NTU from background levels at any time when background levels are between 8 and 80 NTU. Should not increase more than 10% of background levels when background is > 80 NTU.

For turbidity, neither surface samples nor integrated samples showed clear trends. The earliest turbidity samples were surface samples taken at the North Outlet in 1976. These samples ranged from 2.5 to 30 NTU, roughly the same range as samples taken in 2014-2019, which ranged from 1.44 to 10 NTU (Appendix A). In the 2003-2019 surface sampling programs, turbidity was only sampled at the Outlet Canal except for a single sample in the northeast end. No distinct trends were noted (Figure 30a and 30c). The earliest integrated samples were taken in 1983 - 1986, and these samples ranged from 0.4 to 5.8 NTU, which is similar to the range of integrated samples taken in 2014 – 2019, which ranged from 1.06 to 10.2 (Appendix A). Integrated sampling in the 2003-2019 sampling program was much more extensive than surface sampling in terms of sites sampled, but again, no clear trends were noted (Figure 30b and 30d).

Turbidity in the Inlet Canal had a similar range to turbidity in the reservoir, ranging from 1.21 to 25 NTU (Figure 31a and 31c). The tributaries had a greater range of turbidity, from 196 NTU in May 2017 to a low in many cases of just above 1 NTU (Figure 31b and 31d). Turbidity values <10 NTU are described as having little to no impact on water clarity.

Figure 30. Turbidity in surface and integrated depth samples from the Milk River Ridge Reservoir and Outlet Canal.

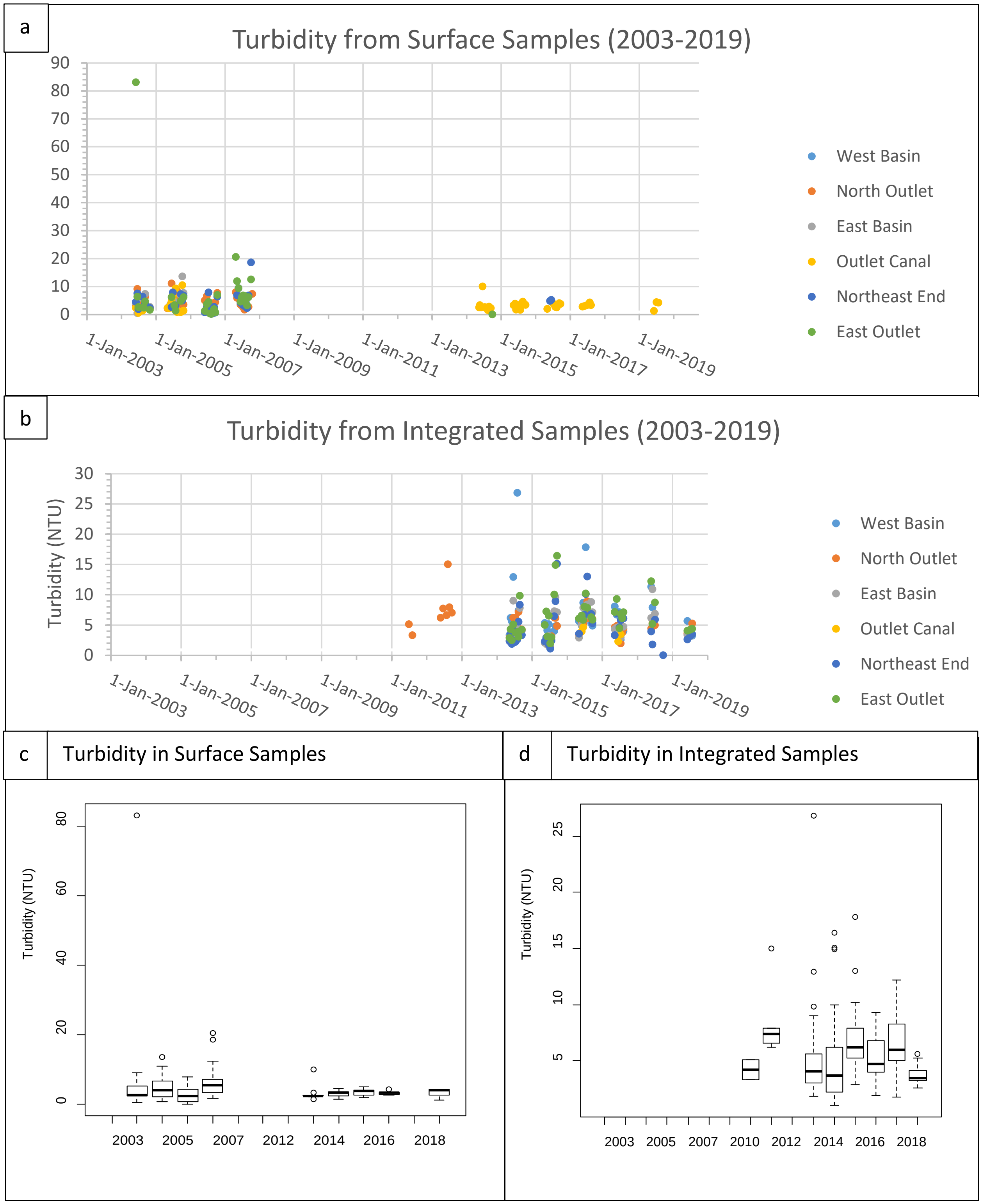


Figure 31. Turbidity in the Inlet Canal and tributaries entering the Milk River Ridge Reservoir

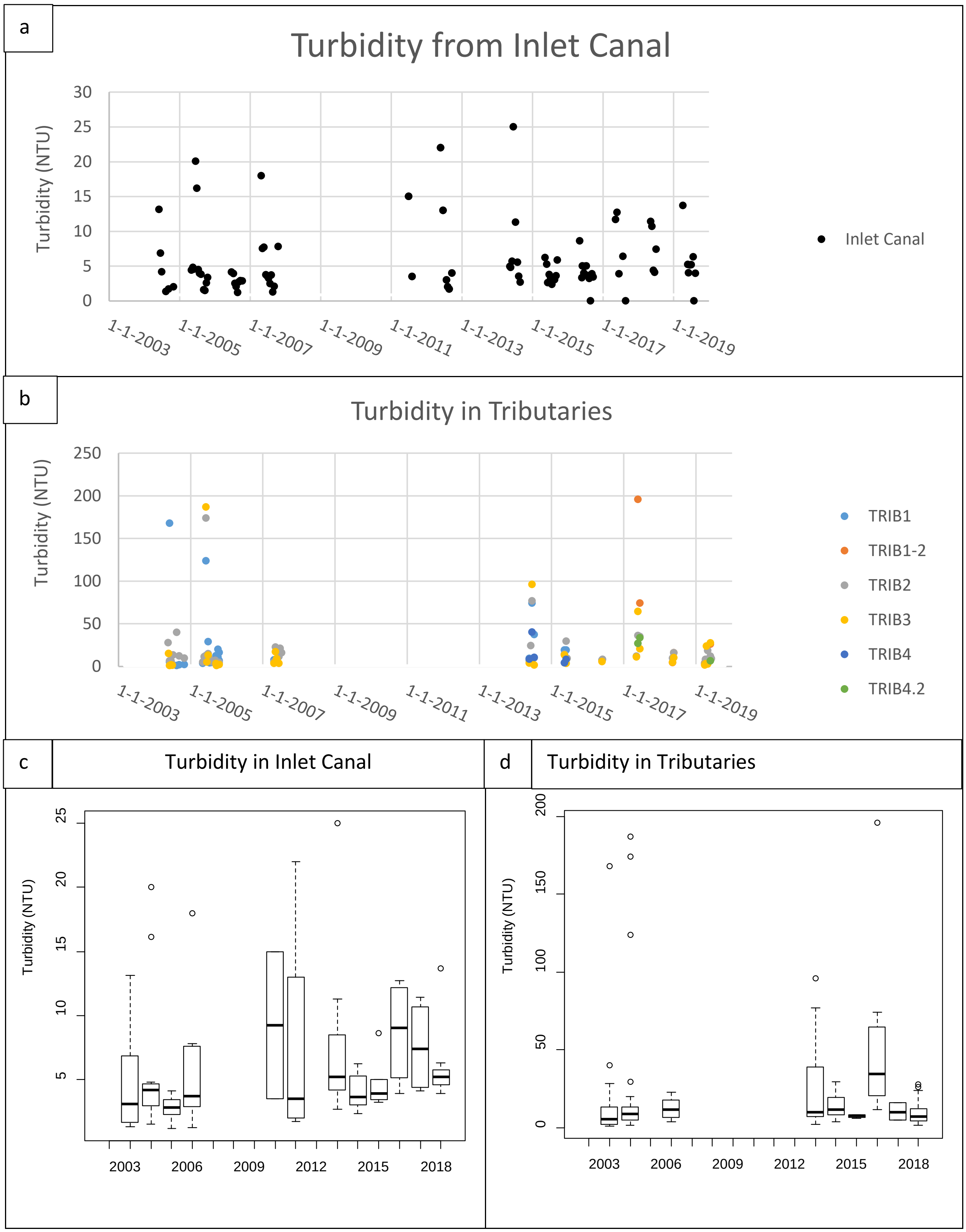
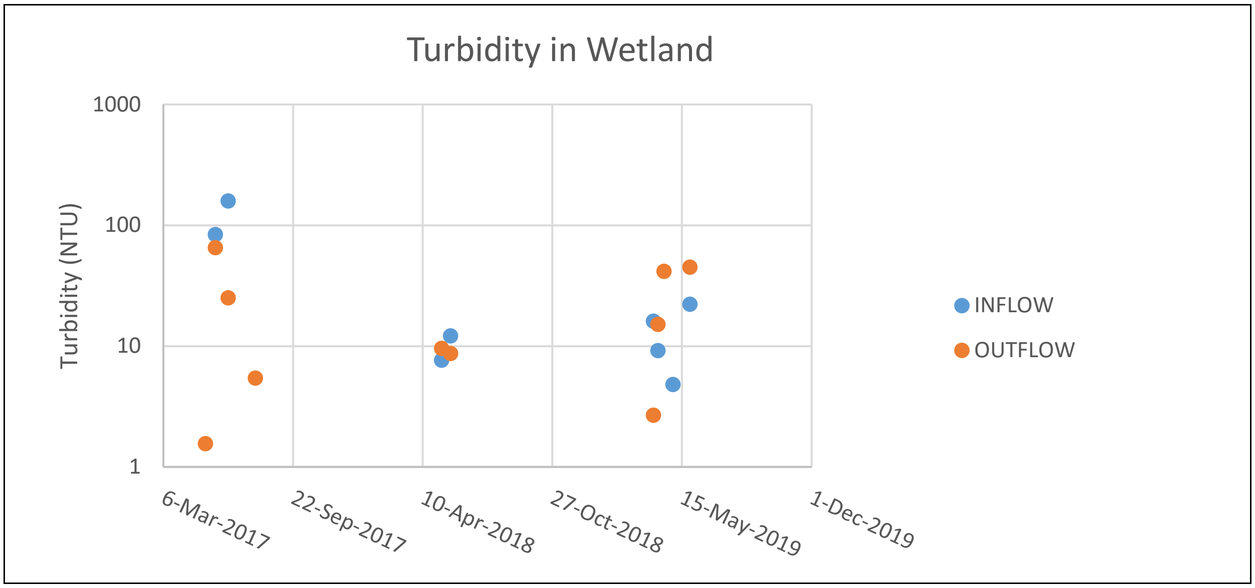
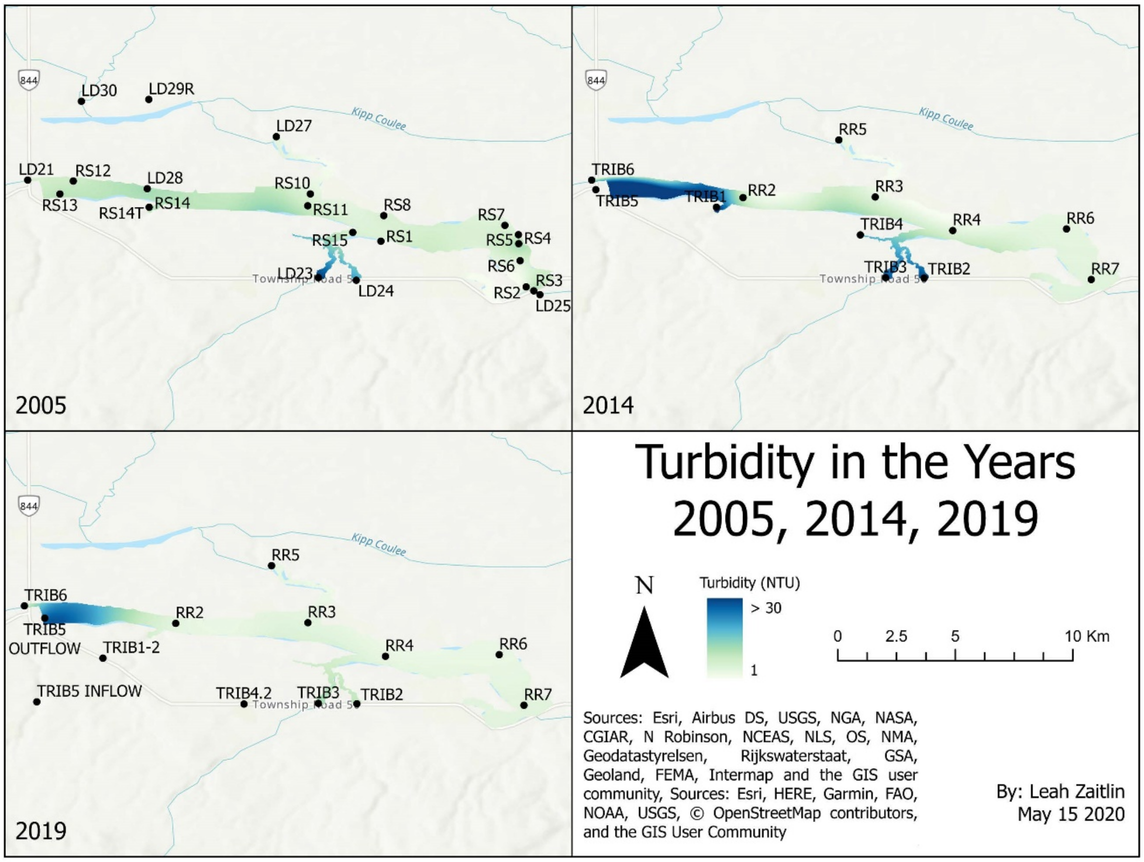


Figure 32. Turbidity in the inflow and outflow of the constructed wetland that drains into the Milk River Ridge Reservoir.



Heat maps (Figure 33) indicate that turbidity was low across the reservoir in 2005, increased at the west end and in the center in 2014, and decreased across the reservoir but continued to have elevated levels at the west end and in the center in 2019. This pattern is similar to the patterns seen in TP (Figure 20), TN (Figure 24) and TDP (Figure 29).

Figure 33. Changes in annual average turbidity between 2014 and 2019



OTHER PARAMETERS

Dissolved Phosphorous

Total phosphorous measures all forms of phosphate in the sample, including that which is attached to suspended particles. Dissolved phosphorous measures that fraction of the total phosphorus which is in solution in the water (as opposed to being attached to suspended particles). It is determined by first filtering the sample, then analyzing the filtered sample for total phosphorus.

Dissolved phosphorous increased in the MRRR and Cross Coulee after 2002, but there were no clear trends after that (Appendix A).

Total Kjeldahl Nitrogen

There are a large number of compounds in an aquatic environment which contain nitrogen. The Kjeldahl nitrogen test converts all the various organic nitrogen forms to ammonia, so that all of the nitrogen in all the different forms can be measured as one species. Therefore, the parameter Total Kjeldahl Nitrogen is a measure of all organic nitrogen and all ammonia together in the sample.

Total Kjeldahl nitrogen concentrations did not show any trends in subsurface (grab) samples or integrated samples from the Cross Coulee reservoir Exit and MRRR, nor was there any discernable trend in the Inlet Canal (Appendix A).

Nitrate-Nitrite

Nitrate-nitrite, or total oxidized nitrogen, is a measure of the total oxidized nitrogen species present in a sample.

Measurement of nitrate-nitrite in MRRR samples was done by different methodologies in the 2003-2007 sampling program compared to the 2014-2019 sampling program. The 2014-2019 sampling program had a minimum detection limit of 0.05 mg/L, which was well above the minimum detection limit in the prior sampling program. Therefore, no trends could be detected (Appendix A).

Ammonia

Ammonia exists in water as an equilibrium between ionized (NH_4^+) and unionized (NH_3) forms. The equilibrium is affected by the temperature and pH of water. High ammonia concentrations can be directly toxic to freshwater life, and lower concentrations may enhance the growth of algae and aquatic plants. Bacteria can also convert high ammonium to nitrate (NO_3^-) in the process of nitrification, which lowers dissolved oxygen. The CCME Water Quality Guidelines for the Protection of Aquatic Life uses the following table:

CCME Water Quality Guidelines for the Protection of Aquatic Life Ammonia limits based on pH and water temperature. Ammonia values are for Total Ammonia (both NH_4^+ and NO_3) in mg/L.

Temp (°C)	**pH**							
	6.0	**6.5**	**7.0**	**7.5**	**8.0**	**8.5**	**9.0**	**10**
0	189.97	60.04	19.00	6.02	1.92	0.62	0.21	0.03
5	125.83	39.72	12.58	3.98	1.27	0.41	0.14	0.03
10	83.88	26.65	8.47	2.68	0.86	0.28	0.10	0.02
15	57.32	18.09	5.74	1.83	0.59	0.20	0.07	0.02
20	39.48	12.50	3.96	1.27	0.41	0.14	0.06	0.02
25	27.55	8.72	2.77	0.89	0.29	0.10	0.04	0.02
30	19.49	6.17	1.97	0.63	0.21	0.08	0.04	0.02

The MRRR is a relatively alkaline reservoir, with a pH range of 6.9 to 9.1 (average 8.5), and highly variable temperature, with a range at 1m below surface of 3.8 °C to 22.8 °C.

Similarly to Total Nitrogen, ammonia concentration in MRRR samples was done by different methodologies in the 2003-2007 sampling program compared to the 2014-2019 sampling program. The 2014-2019 sampling program had a minimum detection limit of 0.05 mg/L, which was well above the minimum detection limit in the prior sampling program. Therefore, no trends could be detected (Appendix A). The main notable conclusion that can be drawn from the sampling program is that the Inlet Canal (TRIB6) had very low ammonia levels entering the MRRR from 2003 to current sampling in 2019 (Appendix A).

Total Suspended Solids

Total Suspended Solids (TSS) consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton, and other microscopic organisms. TSS is often closely related to turbidity. Increases in TSS may indicate disturbances of sediments upstream or increases in algae or microscopic organisms in the water column.

CCME guidelines are: **During clear flows or for clear waters: Maximum increase of 25 mg/L from background for any short-term exposure (e.g. 24-h period). Maximum average increase of 5 mg/L from background levels for longer term exposures (greater than 24 h).During high flow or for turbid waters: Maximum increase of 25 mg/L from background levels at any time when background levels are between 25 and 250 mg/L. Should not increase more than 10% of background levels when background is ≥250 mg/L (CCME 2002).**

In the MRRR, TSS was not sampled in the reservoir except for the PFRA/AAFC samples (2003-2007), and no distinct trends were noted during this period (Appendix A). TSS was sampled in 2003-2007 and 2014-2019 in the Inlet Canal, but no distinct trends were noted (Appendix A).

Total Organic Carbon

Total organic carbon (TOC) is a measure of the total amount of carbon in organic compounds in water. TOC in surface water may come from decaying organic matter as well as synthetic sources. Humic acid, fulvic acid, amines, and urea are examples of organic carbon from natural sources. There are no federal or provincial guidelines for TOC in water for the protection of aquatic life, although there are drinking water standards for TOC.

In the MRRR, Inlet Canal and tributaries, there were no discernable trends over time in TOC (Appendix A).

Dissolved Organic Carbon

Dissolved organic carbon (DOC) is the fraction of Total organic carbon that can pass through a filter smaller than 0.4 (or sometimes 0.22) microns. DOC can protect as well as harm aquatic life depending on concentration, chemical composition and system characteristics.

There are no federal or provincial guidelines for DOC.

DOC concentrations in the MRRR were measured mostly from 2003-2007, and only a few measurements were taken from 2014-2019. No discernable trends were found in the reservoir, in the Inlet Canal, or in the tributaries (Appendix A).

Temperature

Temperature exerts a major influence on biological activity and growth. Temperature governs the kinds of organisms that can live in rivers and lakes. Fish, insects, zooplankton, phytoplankton, and other aquatic species all have preferred temperature ranges.

Warm water holds less dissolved oxygen than cooler water, and some compounds, such as ammonia, are also more toxic to aquatic life at higher temperatures. Shallower water has greater temperature fluctuations than deeper water.

CCME and AEP guidelines relate to thermal additions to receiving waters (i.e. heated clean water from power plants or manufacturing facilities), and are not relevant to the MRRR. However, temperature fluctuations over time are an important parameter when considering the health of the MRRR.

No distinct trends were found from 2005-2019 in the Cross Coulee Outlet, MRRR, or the Inlet Canal. The tributaries show distinct decreases in temperature in 2018 and 2019, however, this appears to be a function of tributaries drying up in the summer, so water sampling in these tributaries only occurred in early spring (Appendix A).

pH

pH is a measure of the relative amount of free hydrogen ions and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. The range of pH goes from 0 to 14, with 7 being neutral. Lower than 7 is considered acidic, and higher than 7 is considered basic. pH is reported in logarithmic units. Each number represents a 10-fold change in the acidity/basicness of the water. Water with a pH of five is ten times more acidic than water having a pH of six. pH affects the biological activity of other compounds, most notably, in water, ammonia and aluminum. As pH increases, ammonia becomes toxic at progressively lower concentrations. Conversely, Aluminum is more toxic at lower pH levels (AEP, 2018).

The MRRR and surrounding area is naturally fairly basic, with pH levels generally above 7.5.

A generally increasing trend in pH was noted in the Inlet Canal from 2003 – 2007 (Appendix A), but this trend was not reflected in samples from the Cross Coulee Outlet or the MRRR (Appendix A). The reasons for this trend are not clear.

Dissolved Oxygen

Dissolved oxygen occurs in water due to aeration from the atmosphere and photosynthesis by aquatic plants and algae. More oxygen can be dissolved in water when water is cool than when water is warm. Due to the diurnal cycle of photosynthesis and respiration, dissolved oxygen has strong diurnal cycles in water bodies, with levels fluctuating much more when there are large numbers of macrophytes and algae present. When macrophytes and algal growth is heavy, these organisms release large amounts of Dissolved Oxygen during the day, and take up large amounts at night due to respiration. High levels of respiration by aquatic organisms can cause dissolved oxygen levels to dip below critical levels for fish, causing die-offs if the dip is too extreme.

CCME Guidelines recommend that Dissolved Oxygen remain above 9.5 mg/L to protect early life stages of aquatic organisms in cold water ecosystems such as the MRRR (CCME 1999).

In the Cross Coulee Outlet and MRRR sites, Dissolved Oxygen was often lower than this guideline in 2003-2007, but was generally above guideline in the 2014-2019 sampling period (Appendix A).

DISCUSSION

The changes in water quality over the 26 years of measurements show several distinct periods. Stress was put on the MRRR due to diversion of much of the water entering the MRRR for power generation in 1993, which increased residence time, followed by the drought from 1999-2001. Monitoring of water quality from 2003-2007 showed indications of poor water quality, with increases in chlorophyll *a*, *E. coli*, and TP. Gaps in monitoring prevented knowing what was occurring in the reservoir from 2007-2014, but levels of chlorophyll *a* and TP were still high when monitoring resumed in 2014. TP declined between 2014 and 2019, indicating that decreases in residence time and rehabilitation efforts may be having an effect. TDS levels also declined between 2014 and 2019.

E. coli was not measured in the MRRR in the 2104-2019 sampling program, however, it was noted to be increasing from 1998-2003.

The changes in the MRRR did not appear to be due to changes in water quality coming from the Inlet Canal feeding the MRRR, as the water quality in the Inlet Canal remained generally consistent from 1993 to 2019.

Heat maps from the reservoir showing spatial changes in chlorophyll *a*, TP, TN, TDS and turbidity, all showed distinct decreases in concentrations of these parameters between 2015 and 2019. These changes could be due to several factors, including decreases in residence time, rehabilitation efforts, and installation of the constructed wetland, which came into use in 2016.

It is recommended that *E. coli* concentrations should be measured in the MRRR in future sampling programs.

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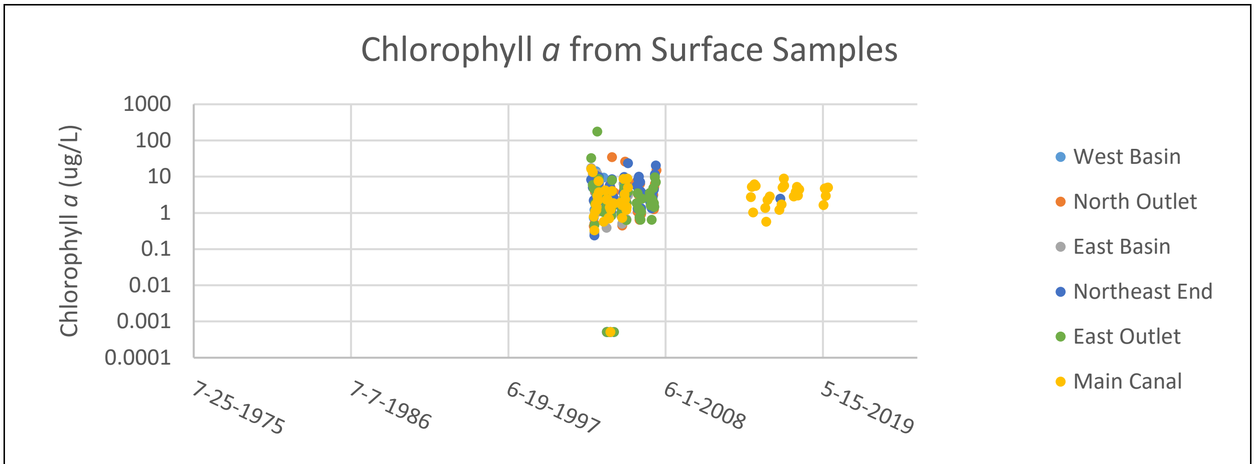
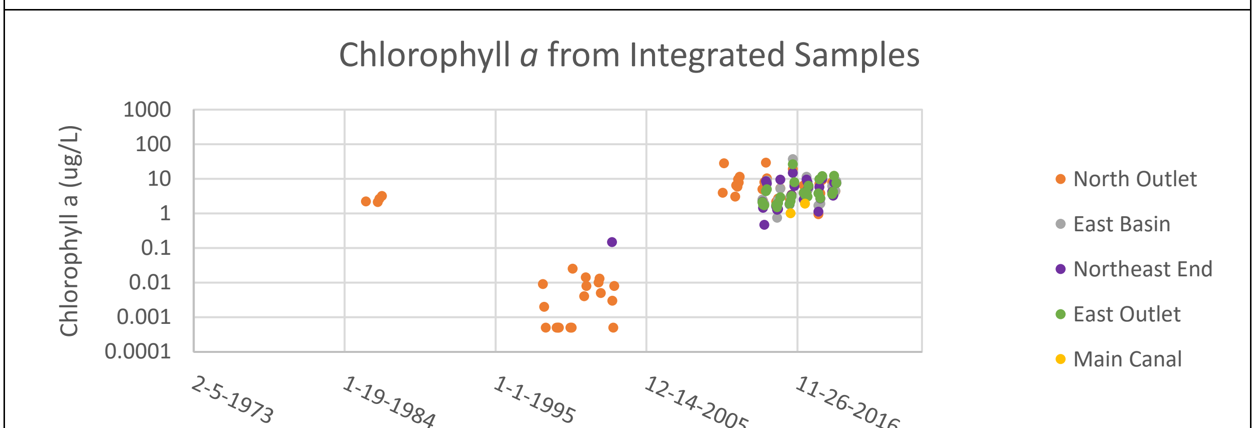
Data was provided by PFRA/AAFC, County of Warner, and Alberta Environment and Parks.

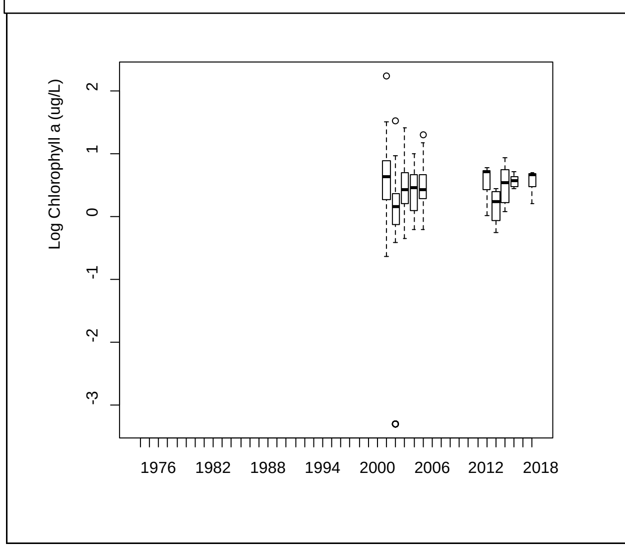
APPENDIX A

Main Reservoir Sampling Sites – Chlorophyll *a*

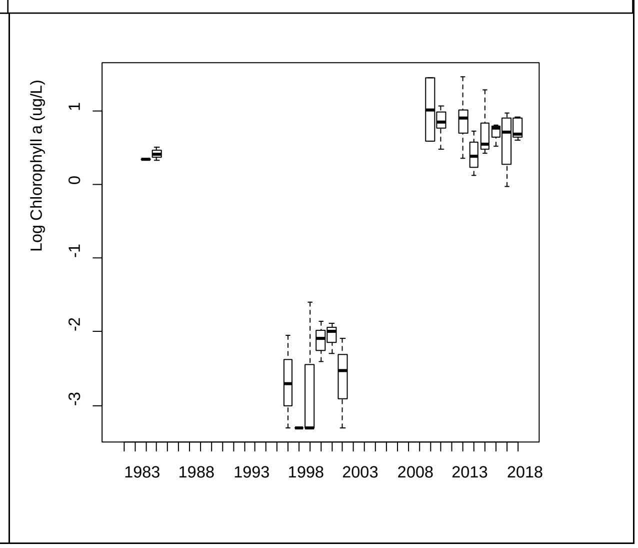




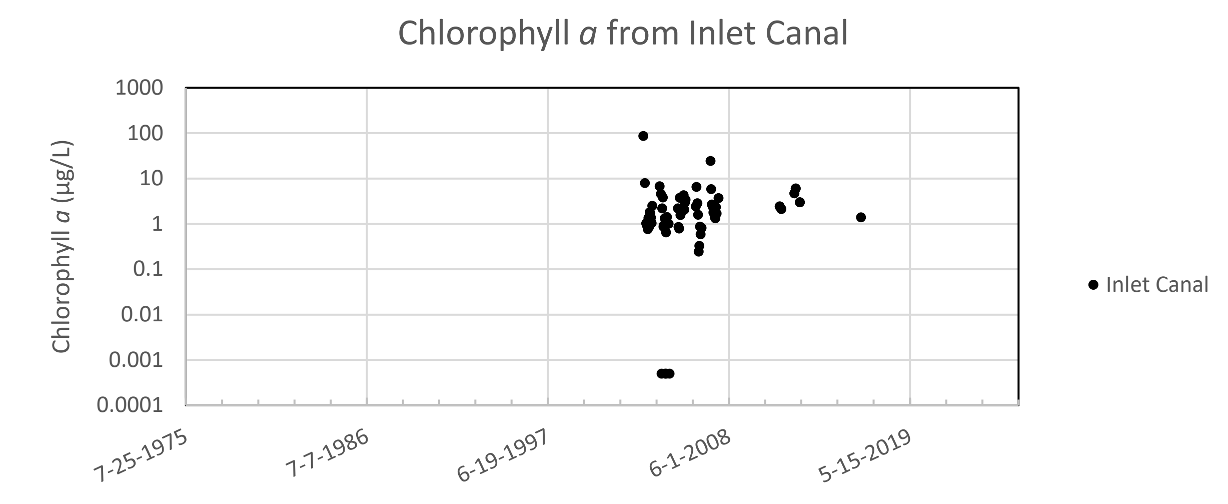
Chlorophyll *a* from Surface Samples

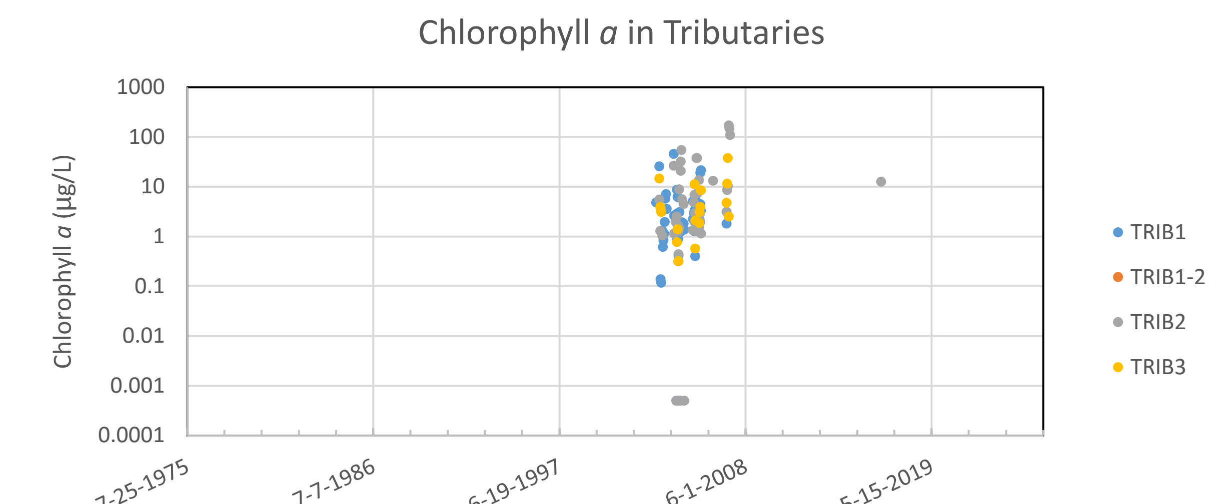


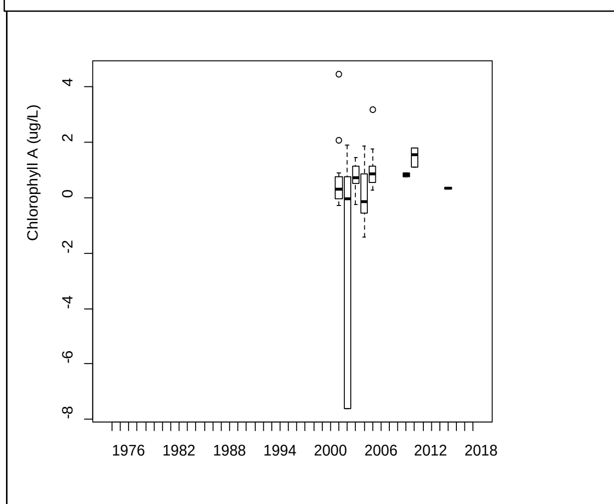
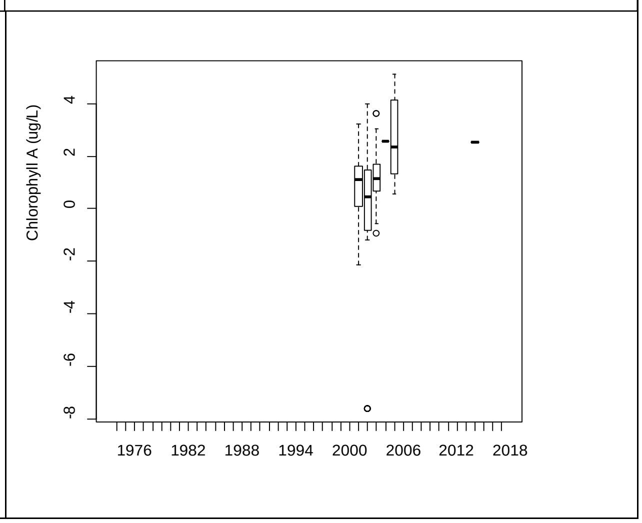
Chlorophyll *a* from Integrated Samples



Inlet Canal and Tributary Sampling Sites – Chlorophyll *a*

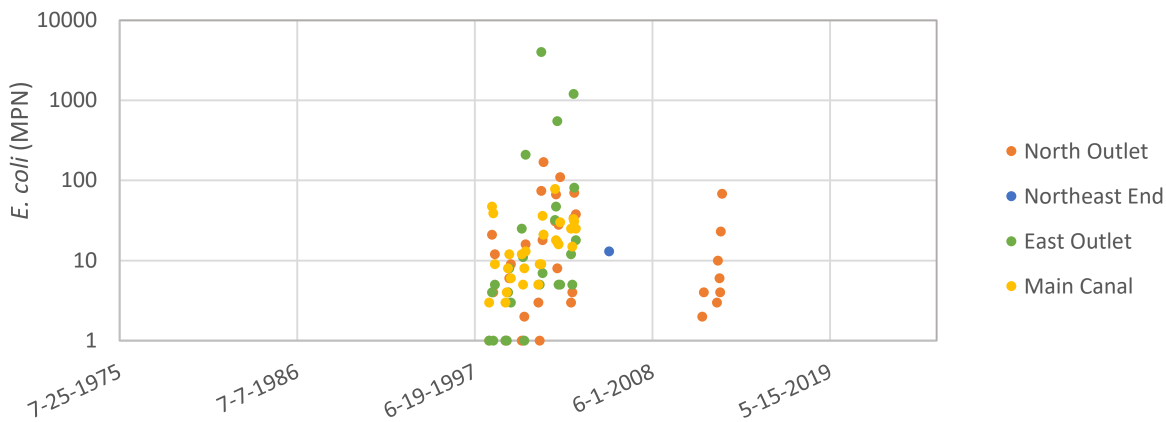




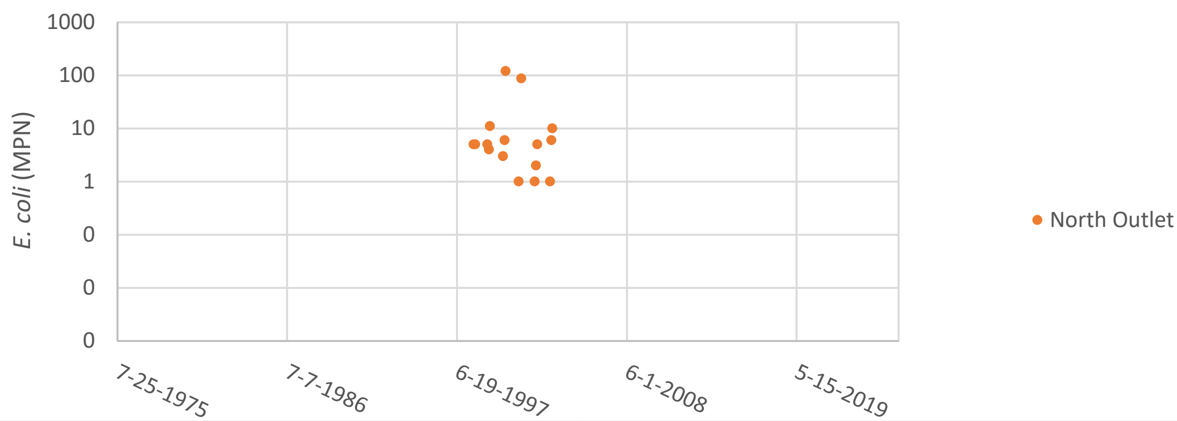
Chlorophyll *a* from Inlet Canal	Chlorophyll *a* from Tributaries
	

Main Reservoir Sample Sites – *E. coli*

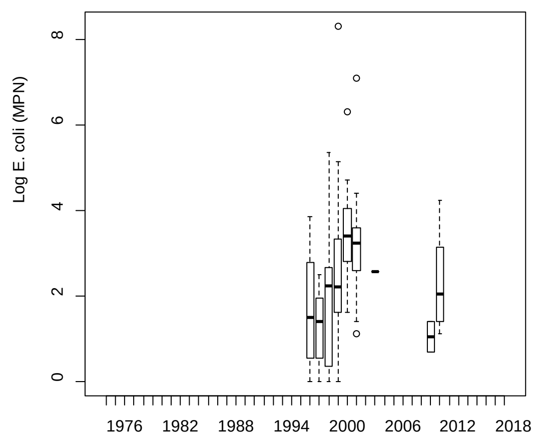
E. coli in Surface Samples



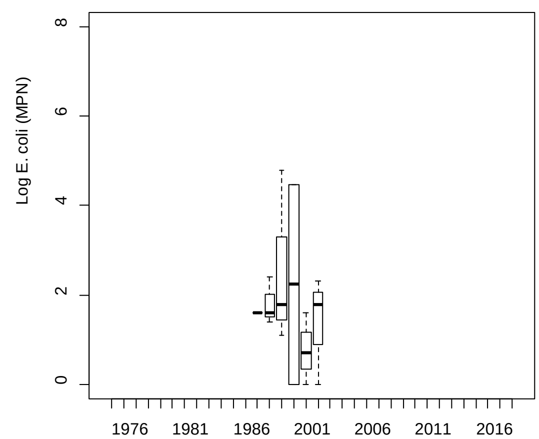
E. *coli* in Integrated Samples



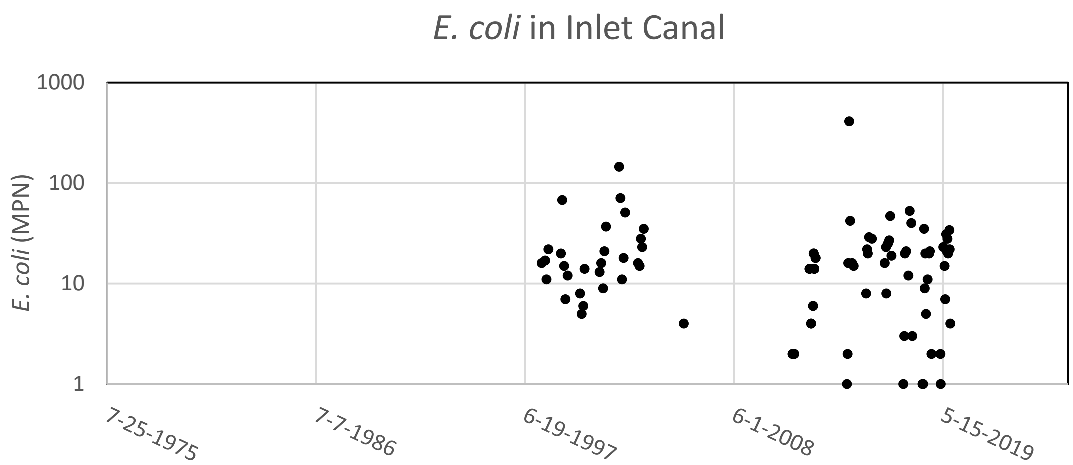
E. coli from Surface Samples

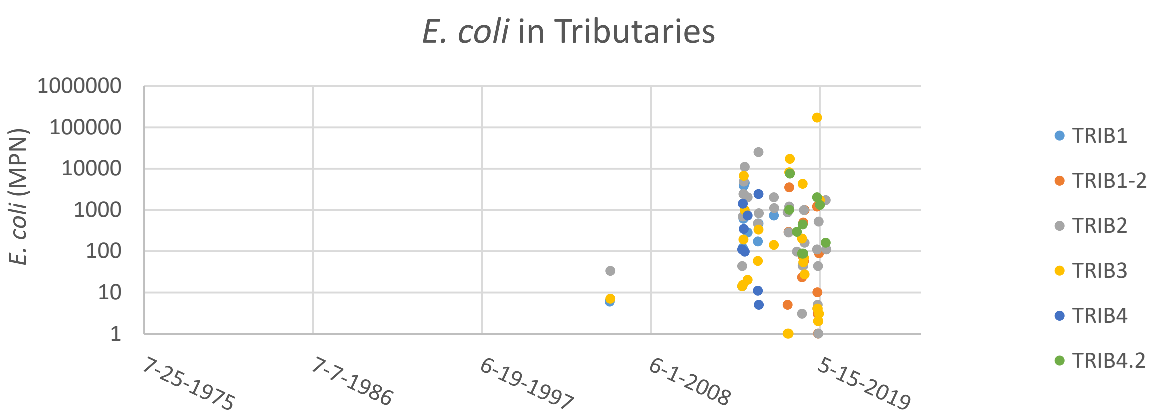


E. coli from Integrated Samples

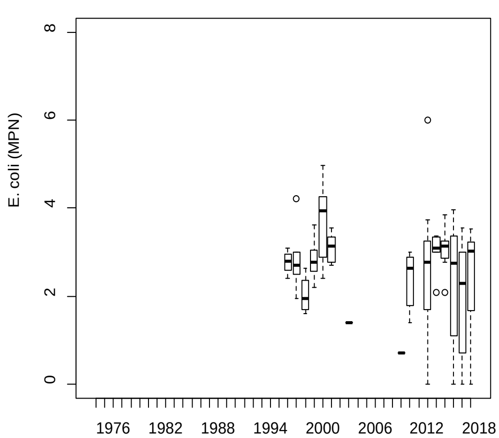


Inlet Canal and Tributary Sampling Sites – *E. coli*

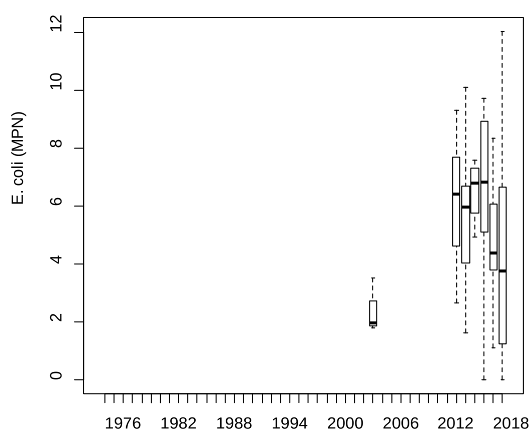




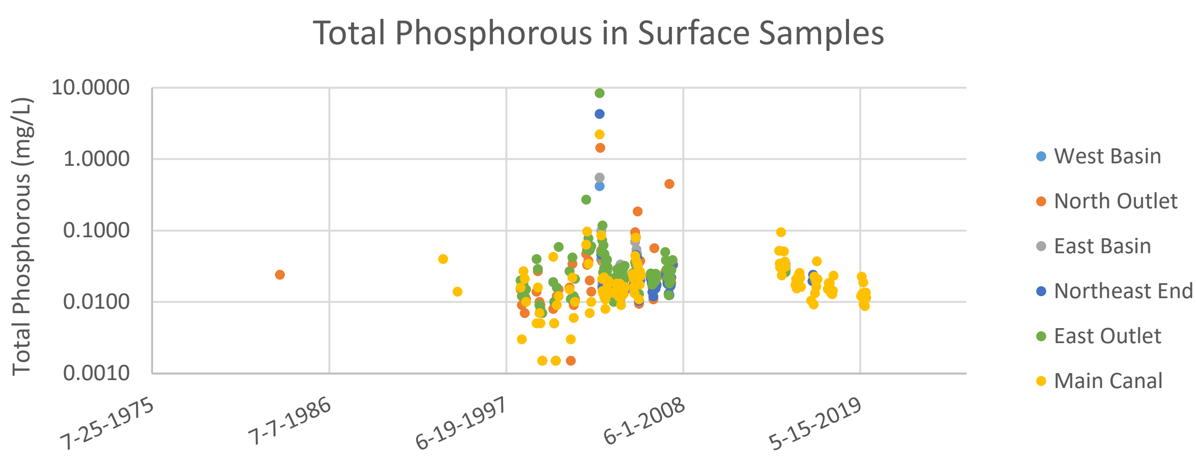
E. coli from Inlet Canal

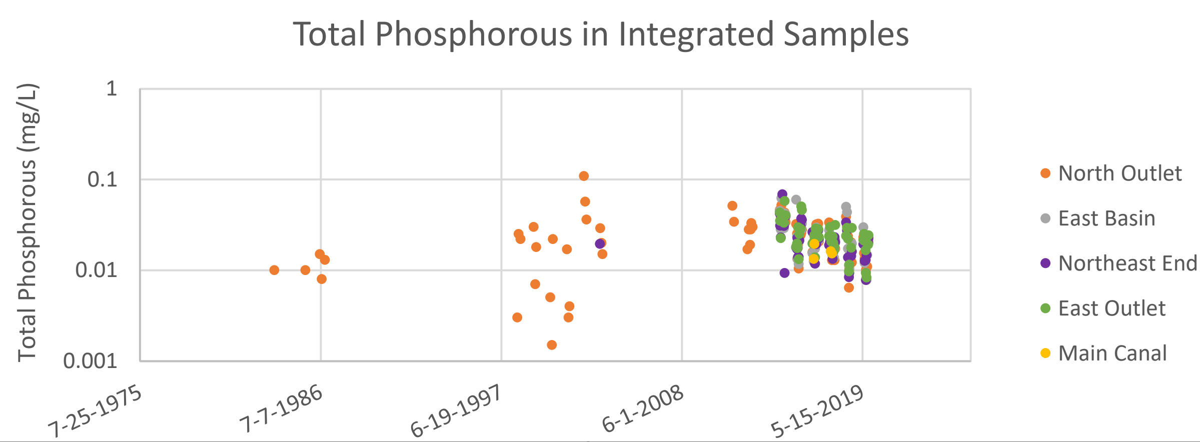


E. coli from Tributaries

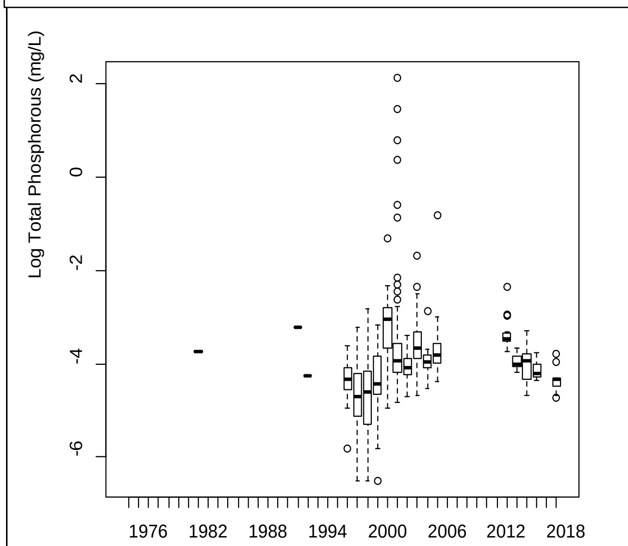


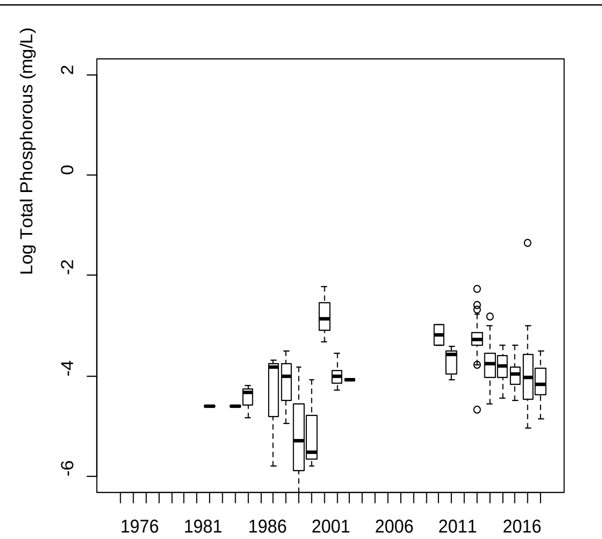
Main Reservoir Sample Sites – Total Phosphorous



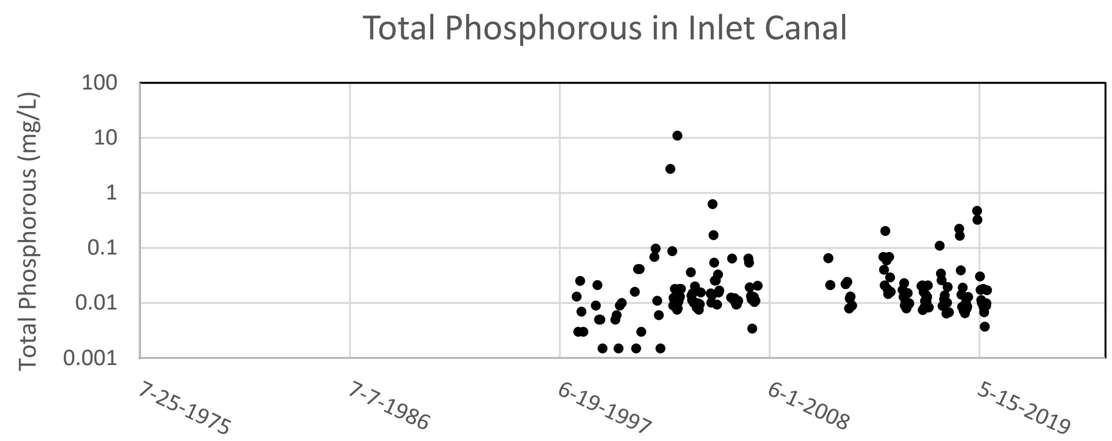


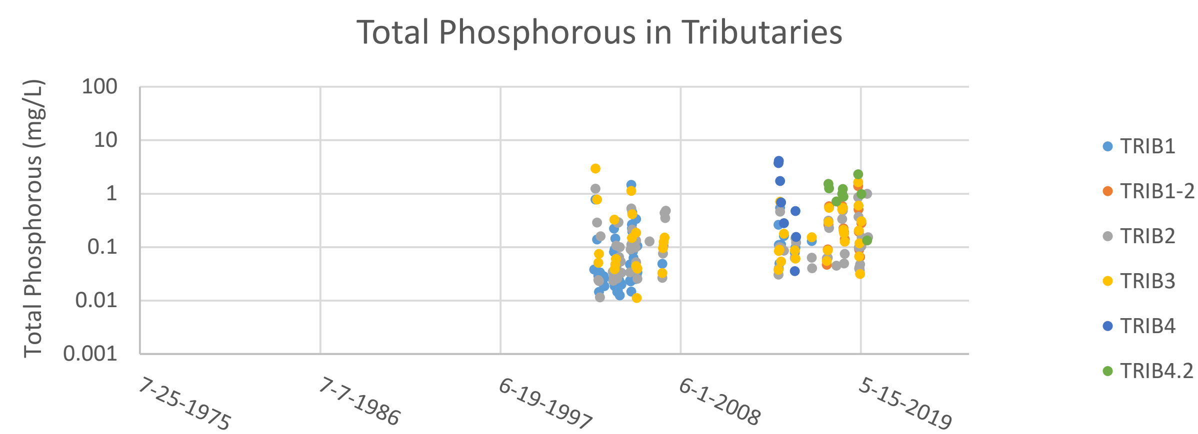
Total Phosphorous from Surface Samples	Total Phosphorous from Integrated Samples



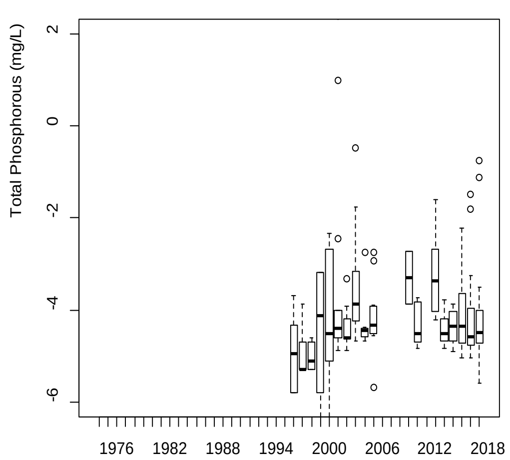


Inlet Canal and Minor Tributary Sampling Sites – Total Phosphorous

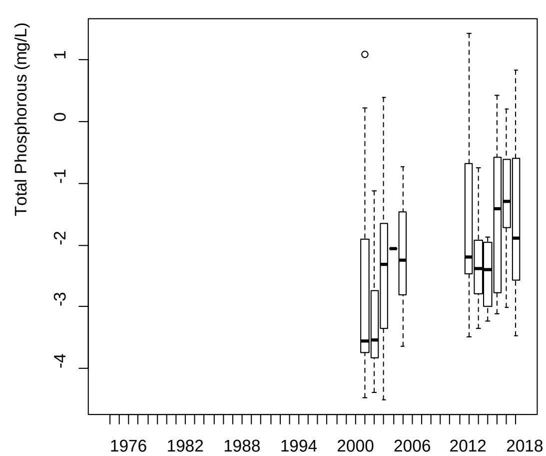




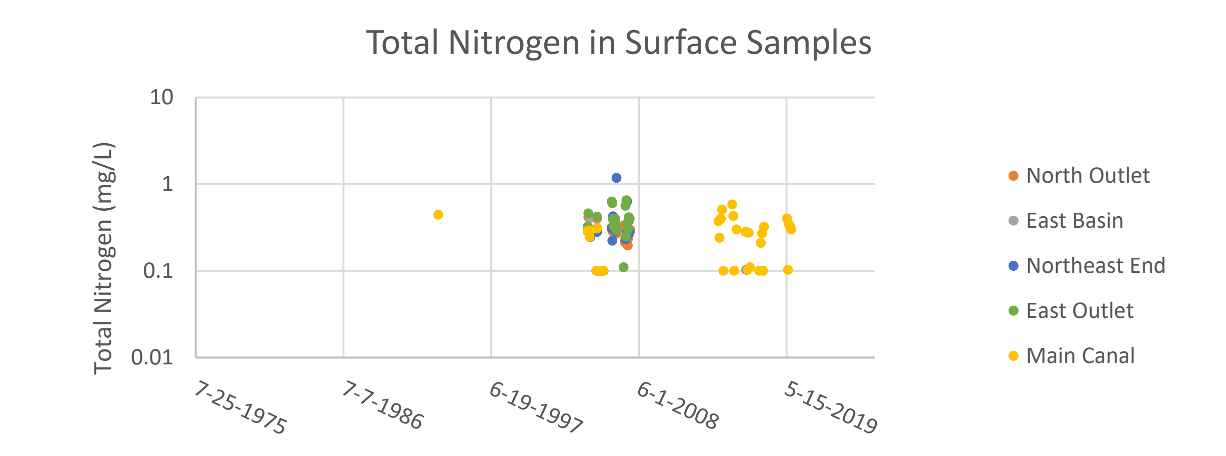
Total Phosphorous from Inlet Canal

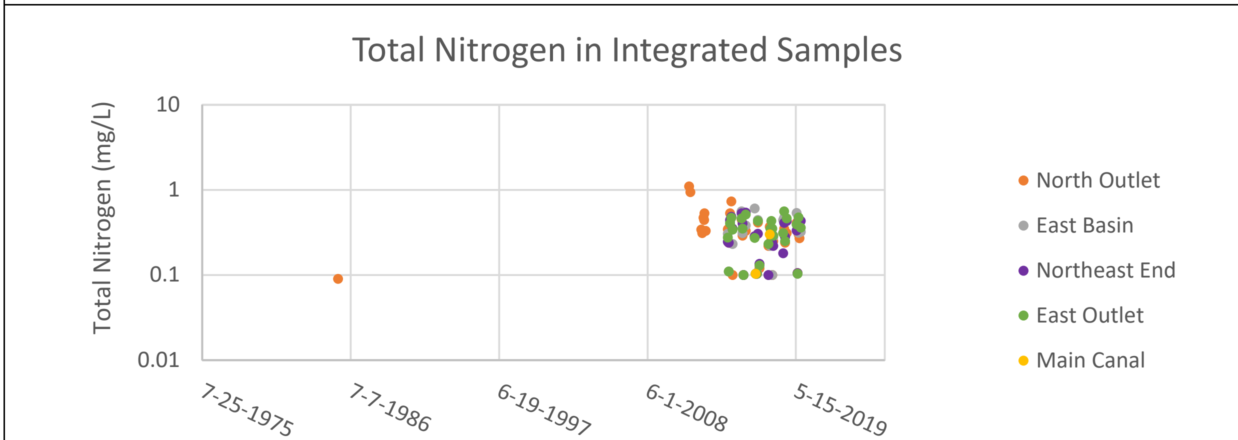


Total Phosphorous from Tributaries

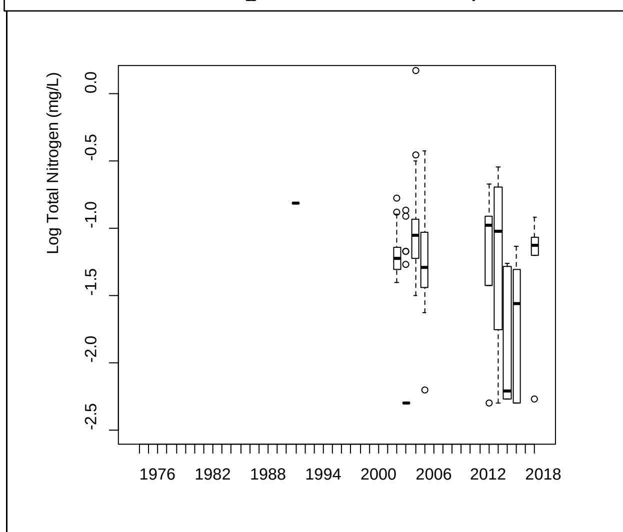


Main Reservoir Sample Sites – Total Nitrogen

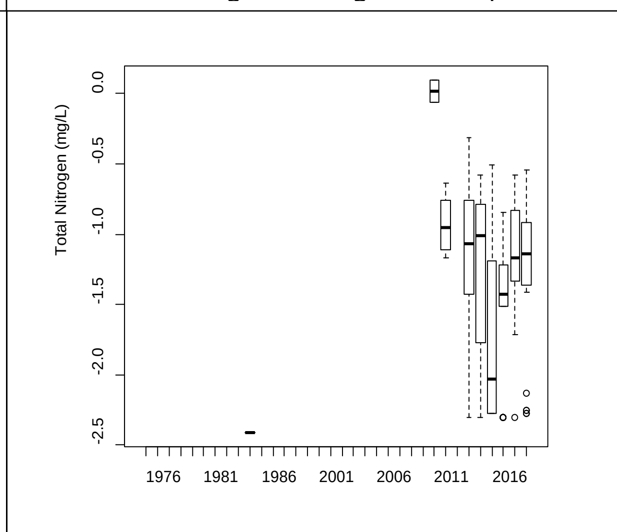




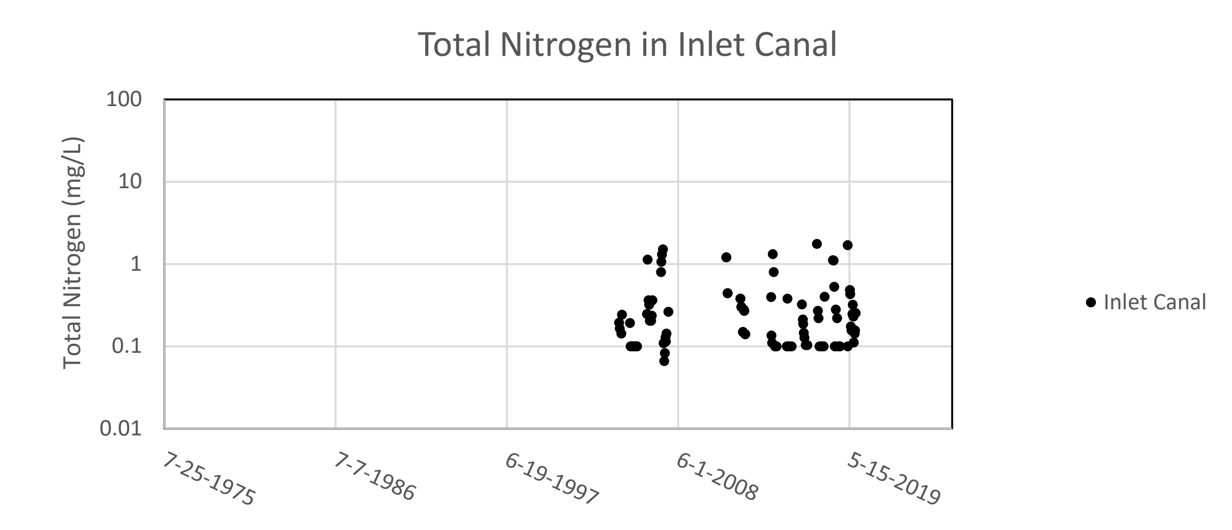
Total Nitrogen in Surface Samples

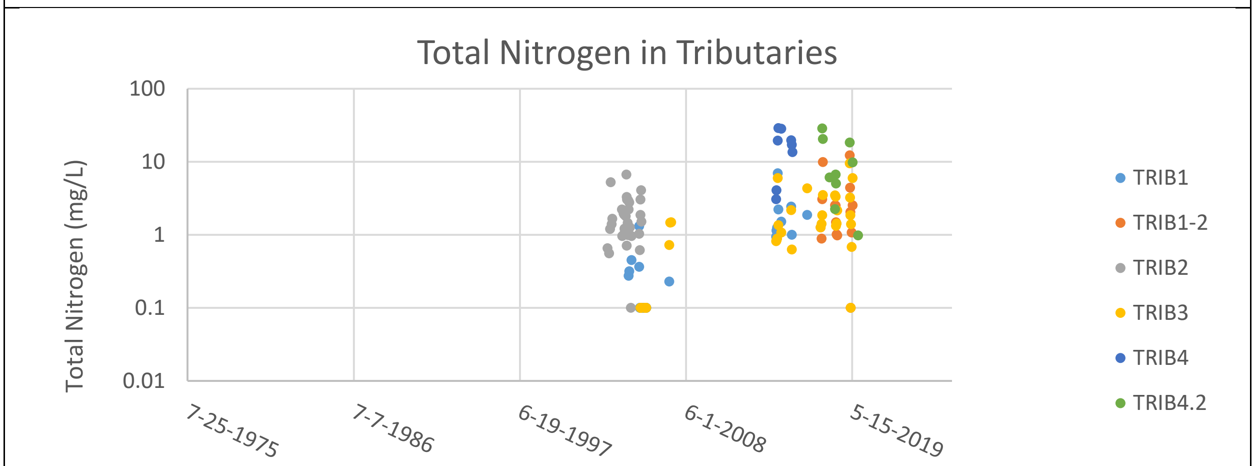


Total Nitrogen in Integrated Samples

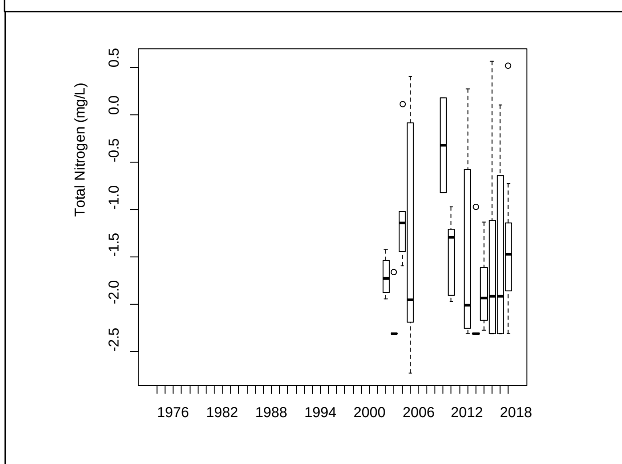


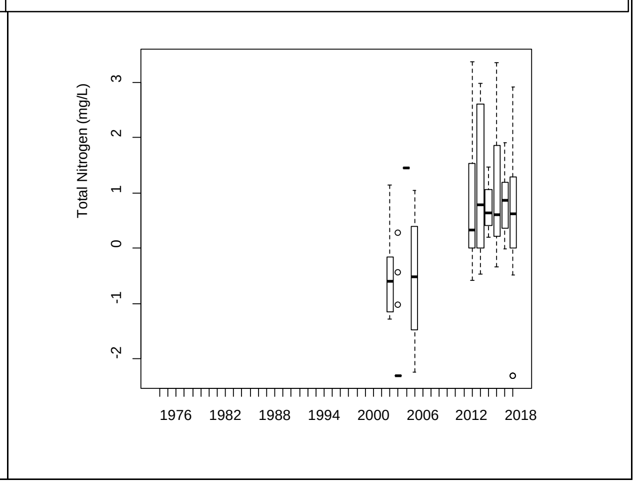
Inlet Canal and Minor Tributary Sampling Sites – Total Nitrogen



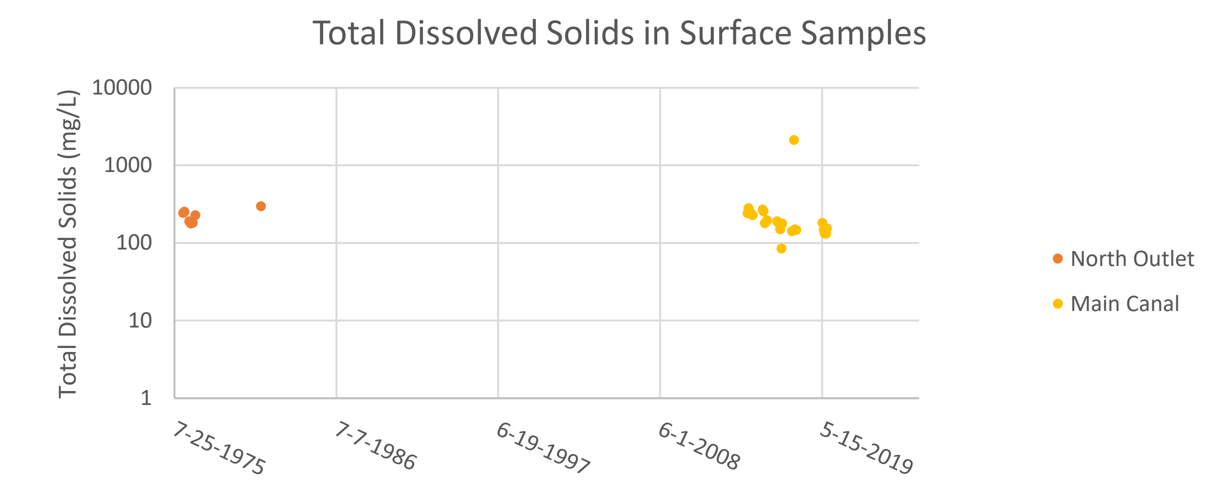


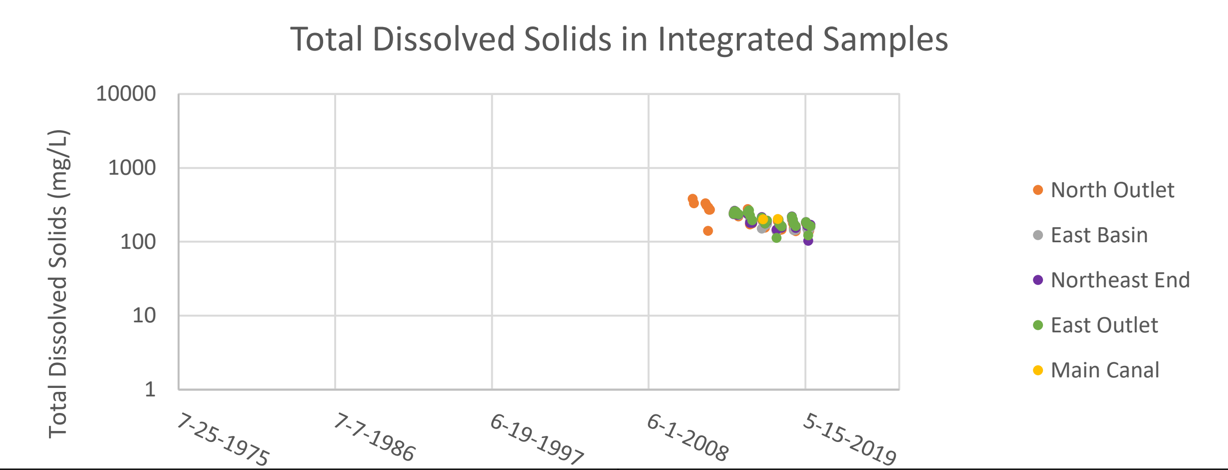
Total Nitrogen in Inlet Canal	Total Nitrogen in Tributaries



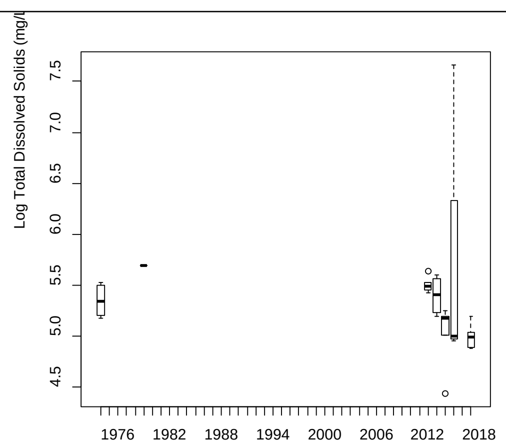


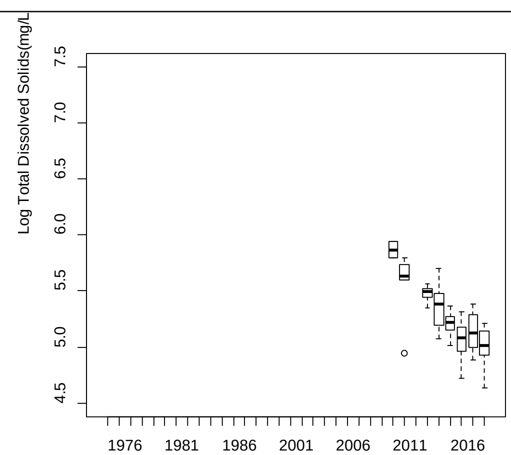
Main Reservoir Sample Sites – Total Dissolved Solids



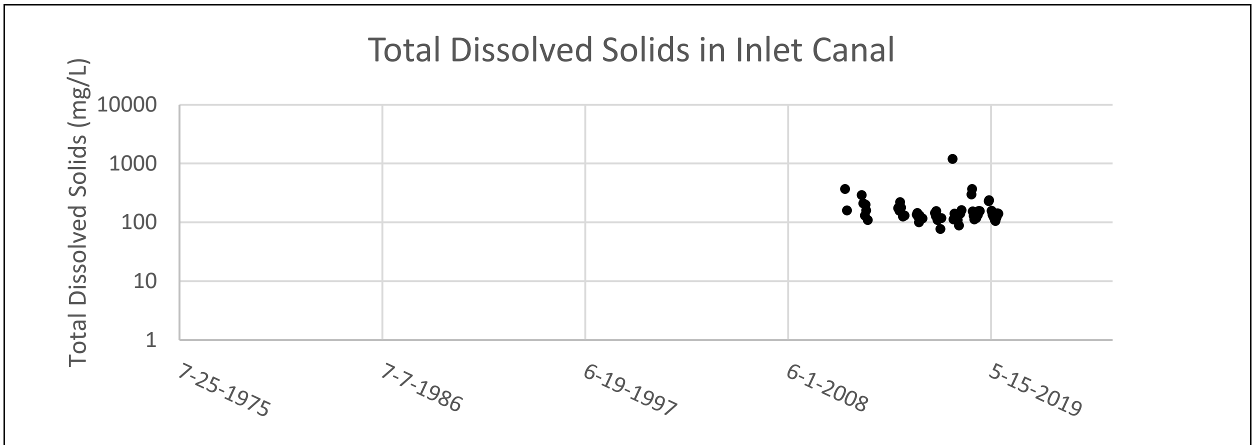


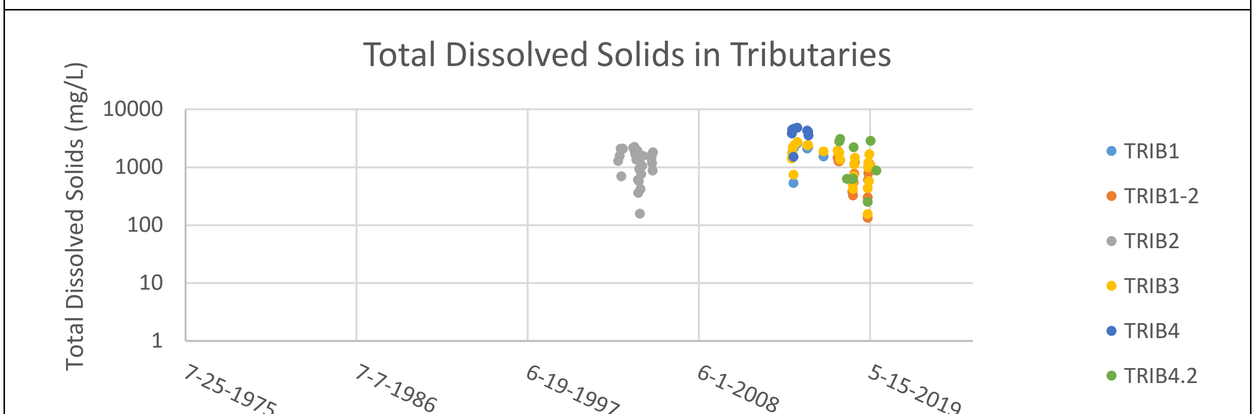
Total Dissolved Solids in Surface Samples	Total Dissolved Solids in Integrated Samples



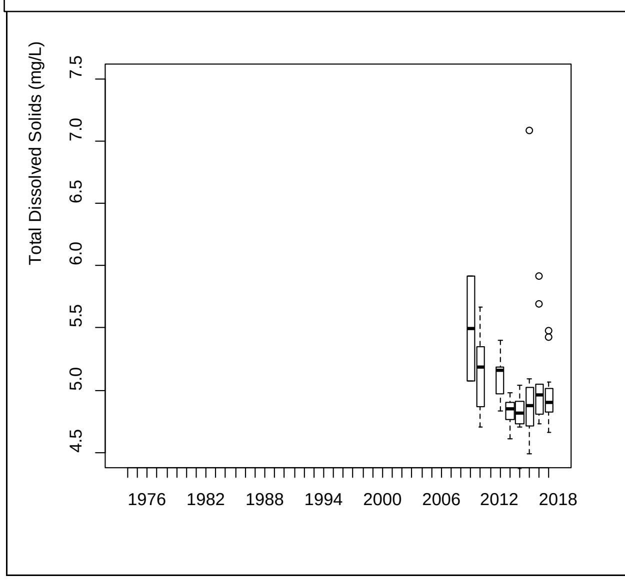


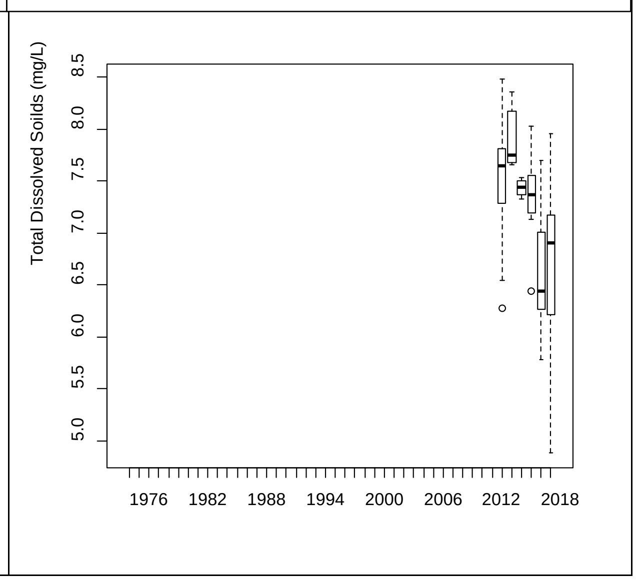
Inlet Canal and Minor Tributary Sampling Sites – Total Dissolved Solids



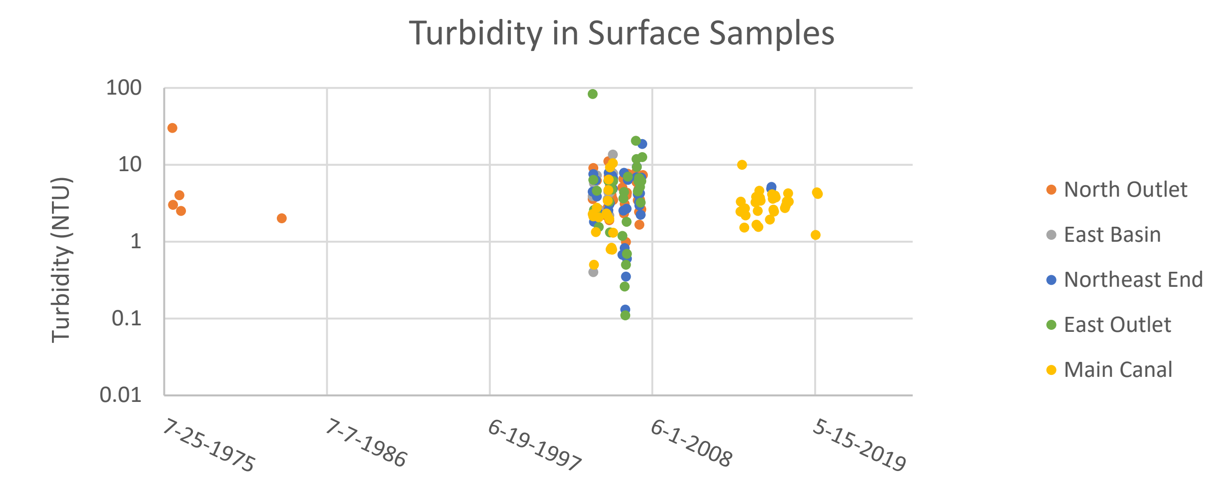


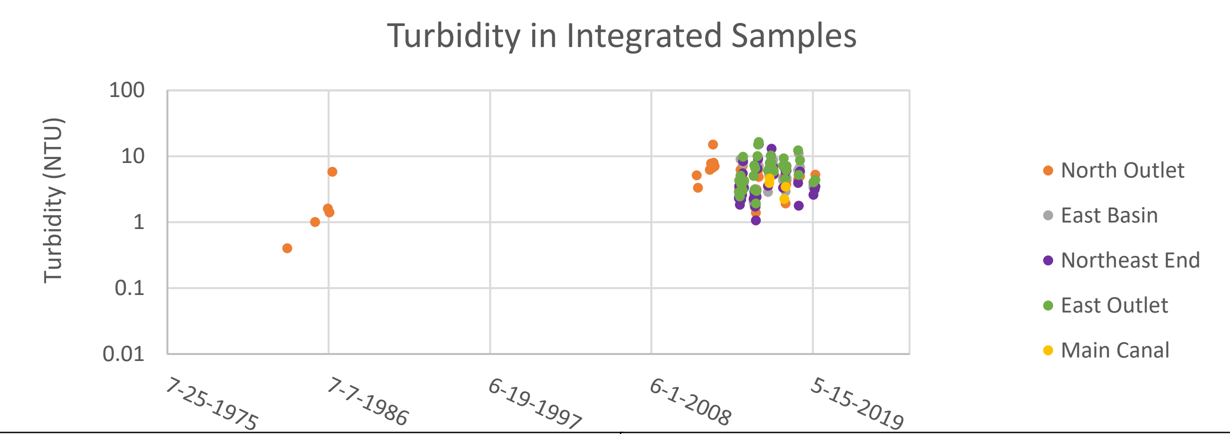
Total Dissolved Solids in Inlet Canal	Total Dissolved Solids in Tributaries



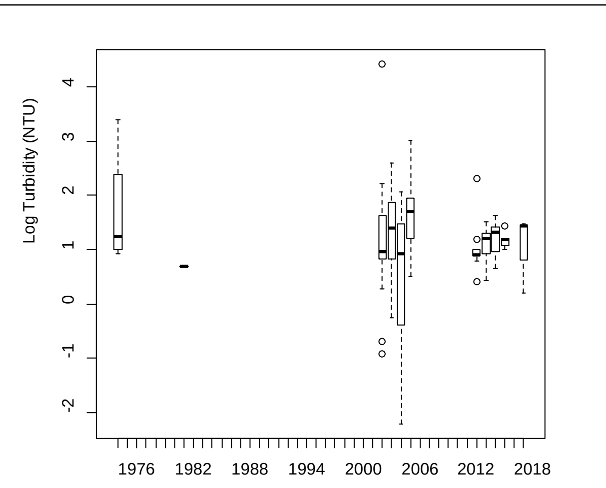


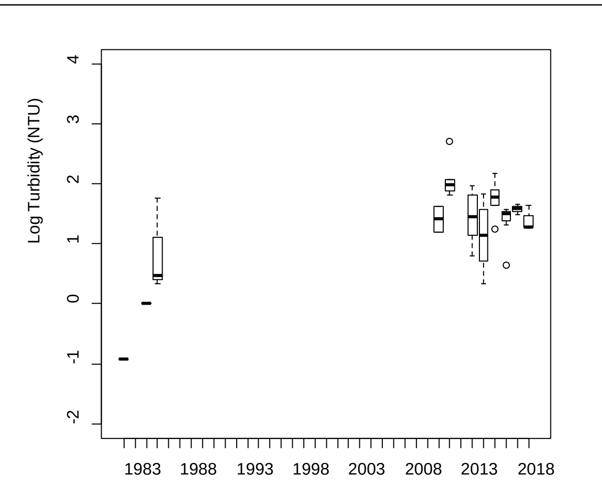
Main Reservoir Sample Sites – Turbidity



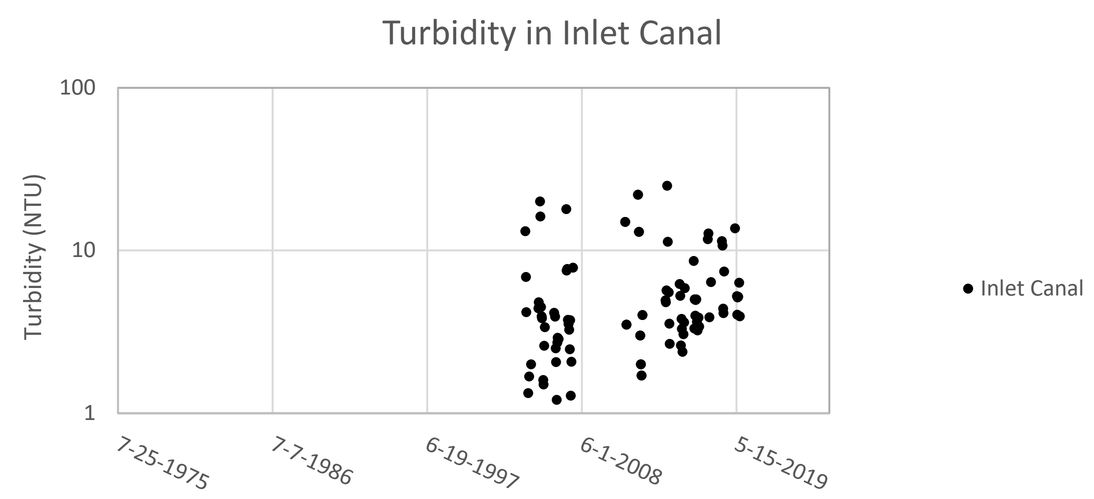


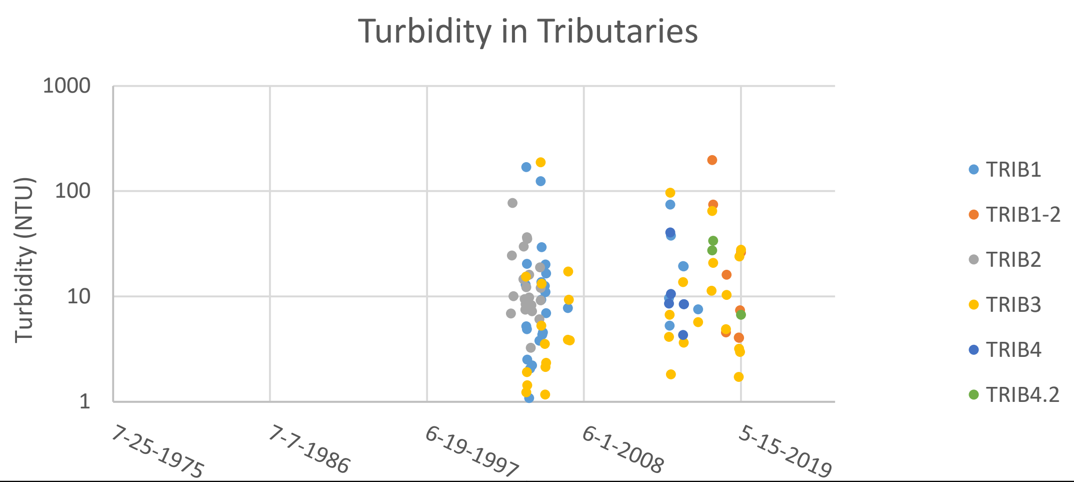
Turbidity in Surface Samples	Turbidity in Integrated Samples



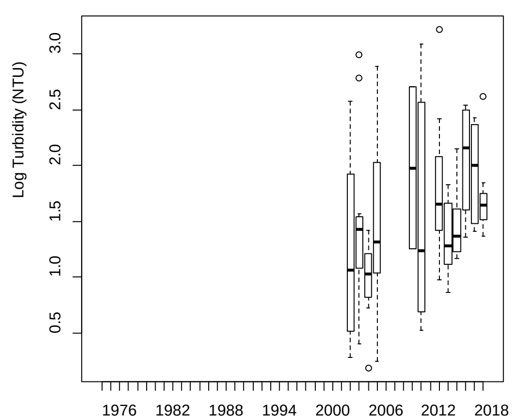


Inlet Canal and Minor Tributary Sampling Sites – Turbidity

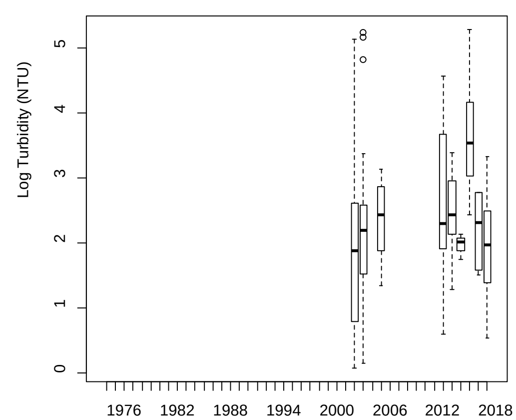




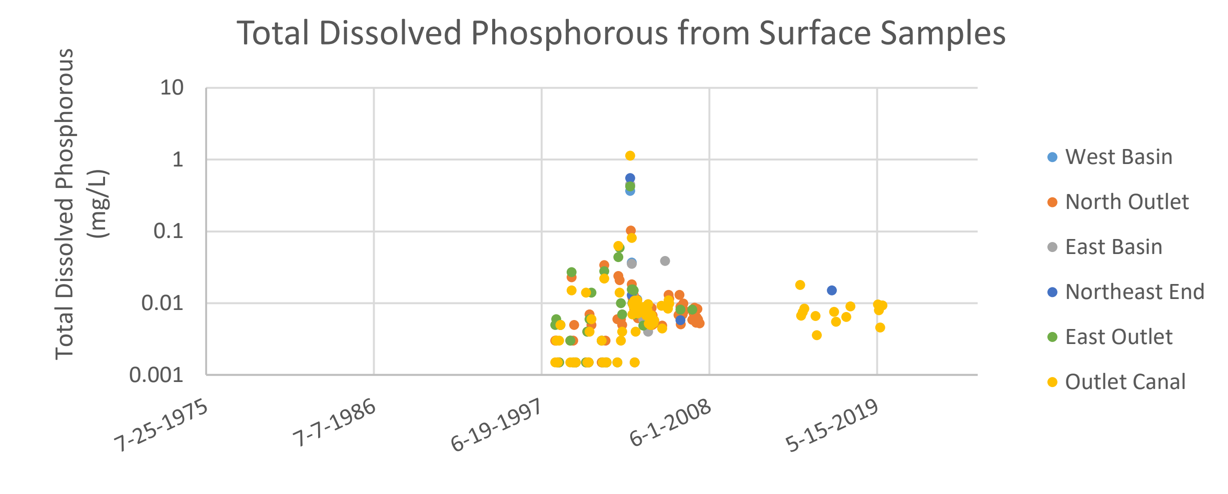
Total Dissolved Solids in Inlet Canal

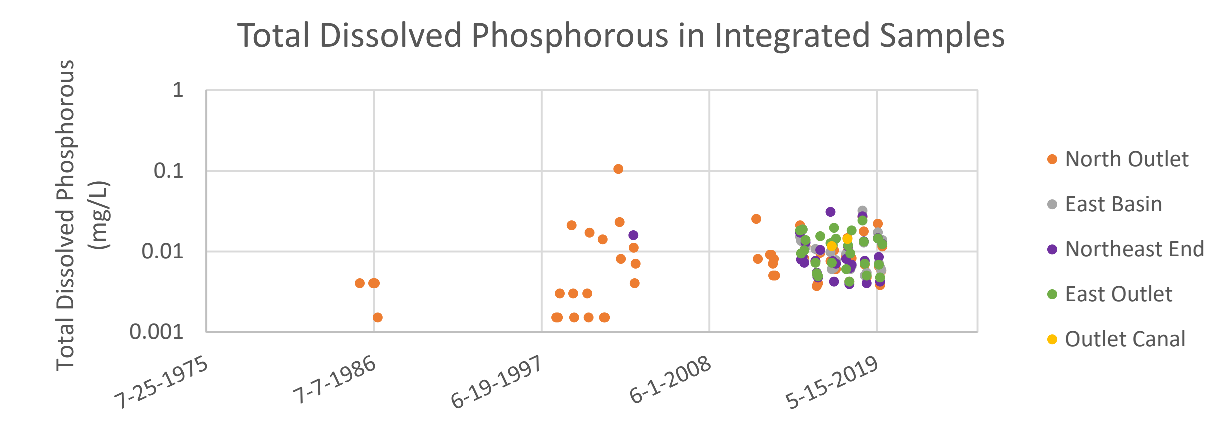


Total Dissolved Solids in Tributaries

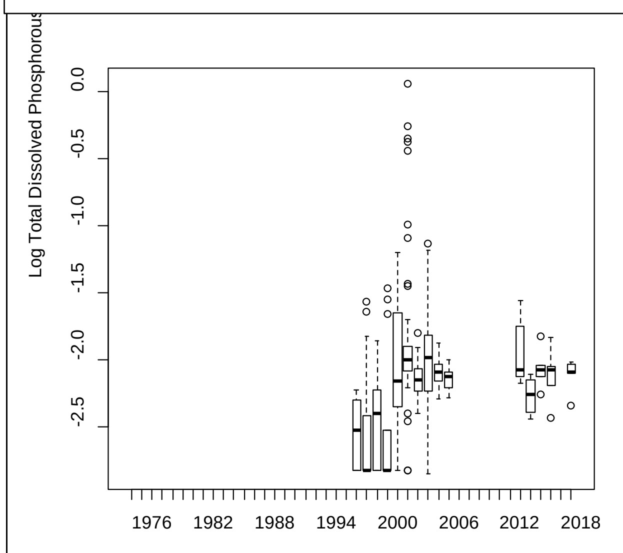


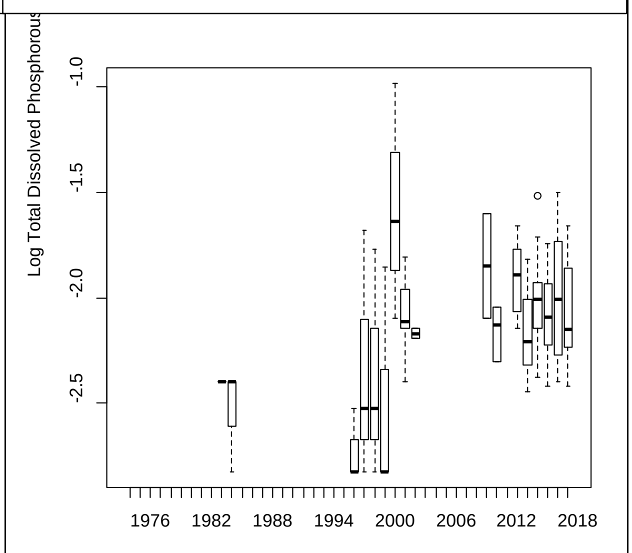
Main Reservoir Sample Sites – Dissolved Phosphorous



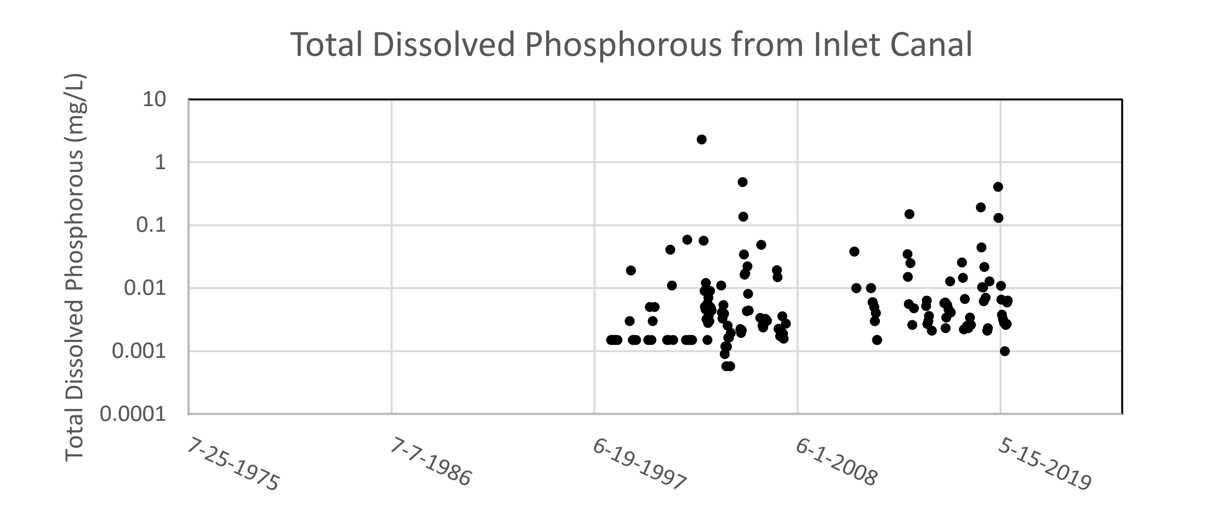


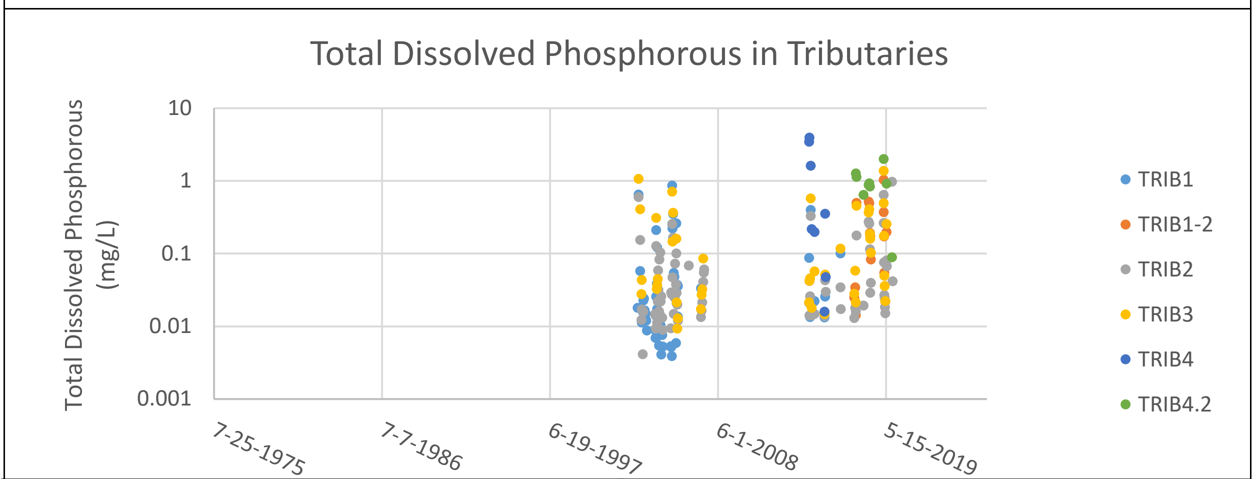
Total Dissolved Phosphorous in Surface Samples	Total Dissolved Phosphorous in Integrated Samples



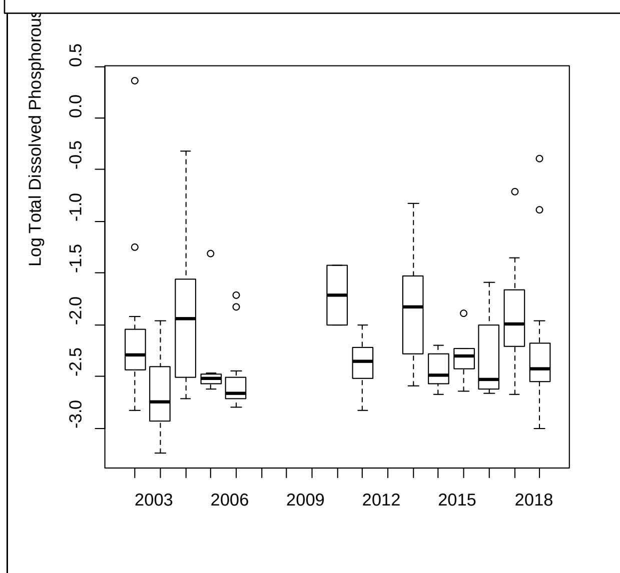


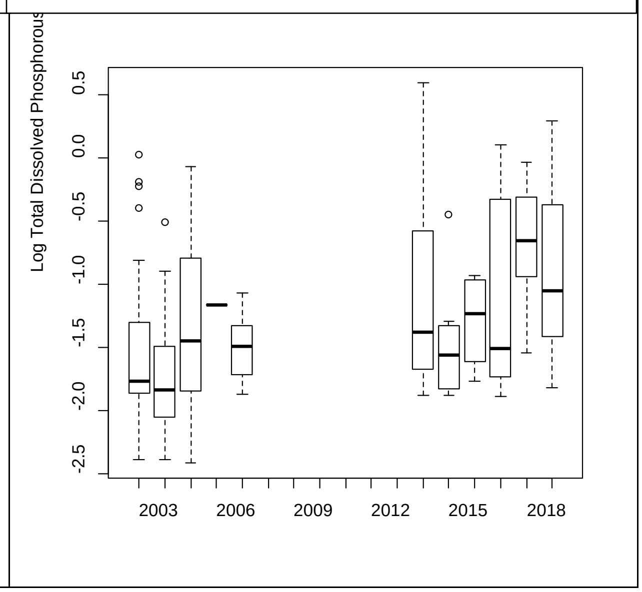
Inlet Canal and Minor Tributary Sampling Sites – Total Dissolved Phosphorous



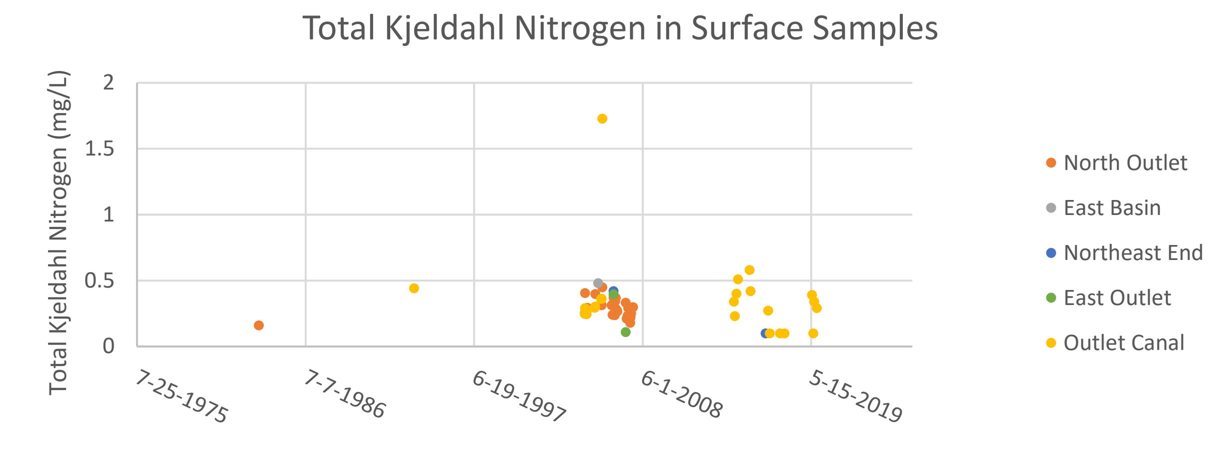


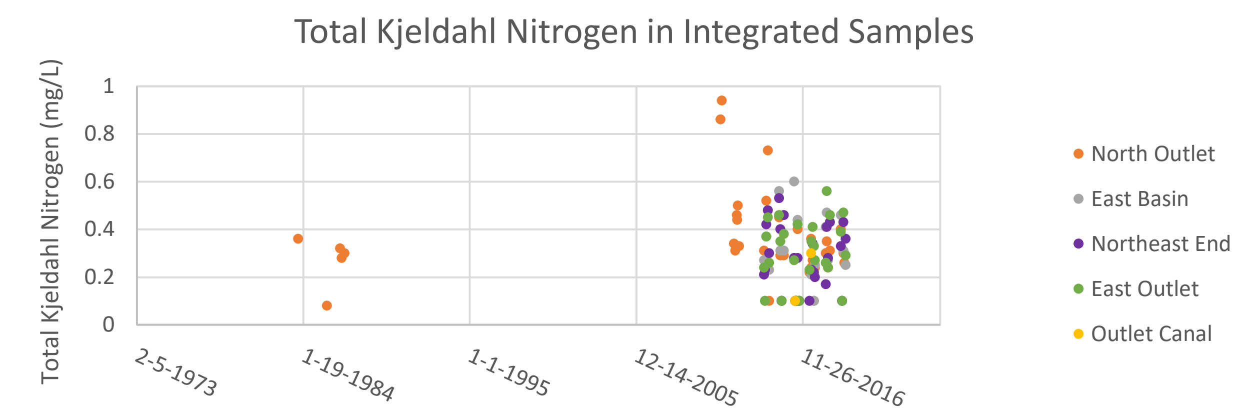
Total Dissolved Phosphorous in Inlet Canal	Total Dissolved Phosphorous in Tributaries



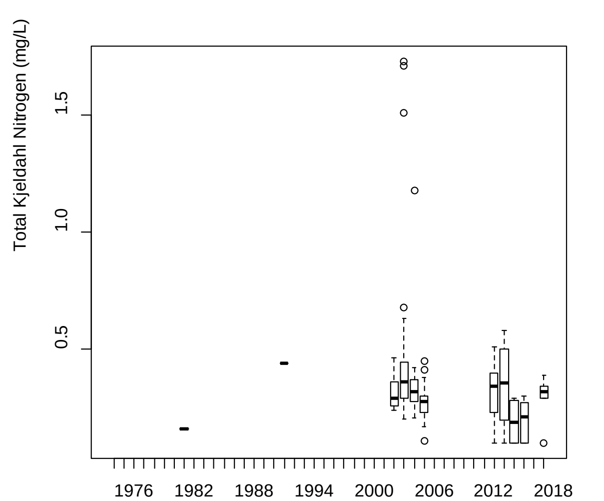


Main Reservoir Sample Sites – Total Kjeldahl Nitrogen

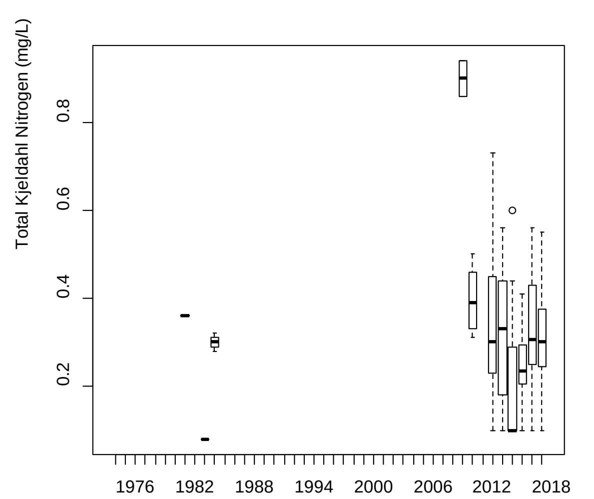




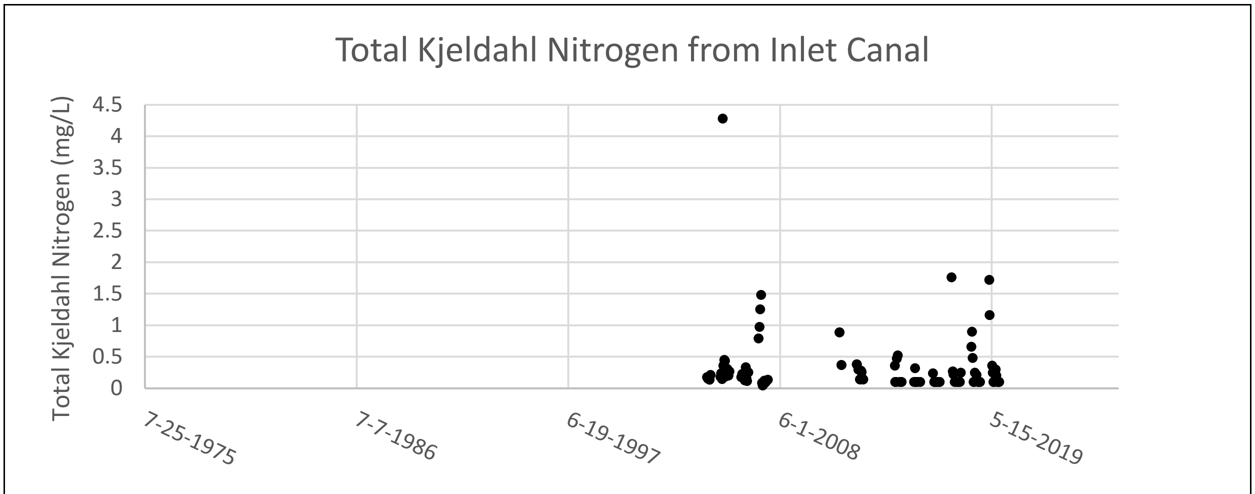
Total Kjeldahl Nitrogen in Surface Samples

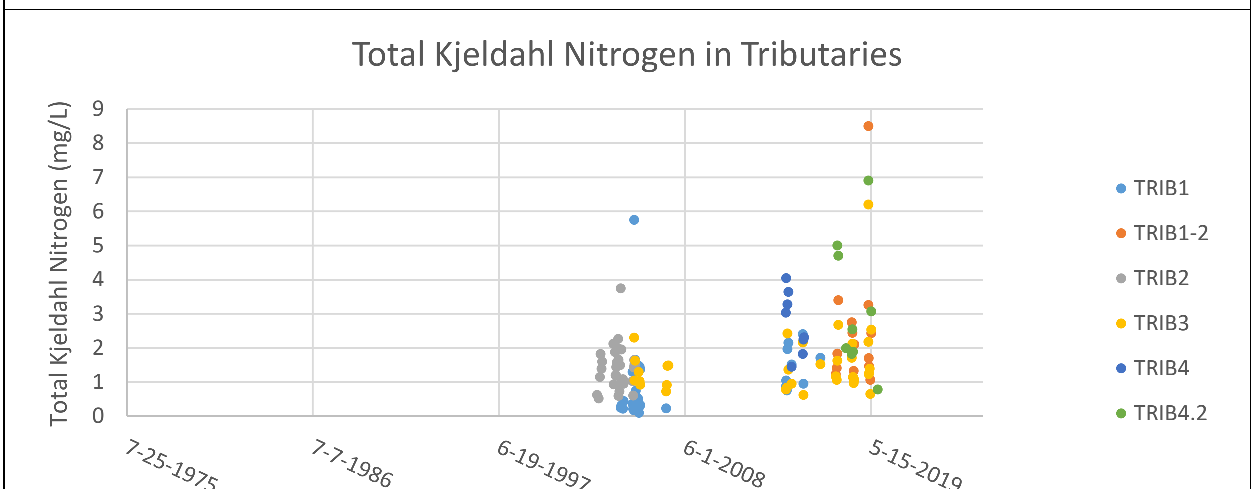


Total Kjeldahl Nitrogen in Integrated Samples

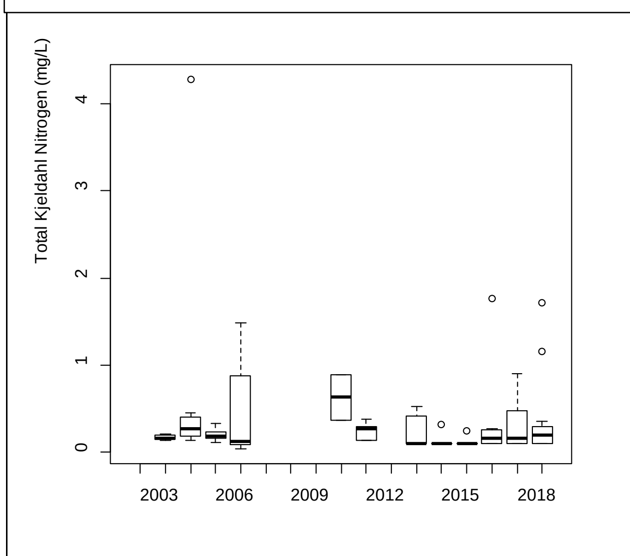


Inlet Canal and Minor Tributary Sampling Sites – Total Kjeldahl Nitrogen

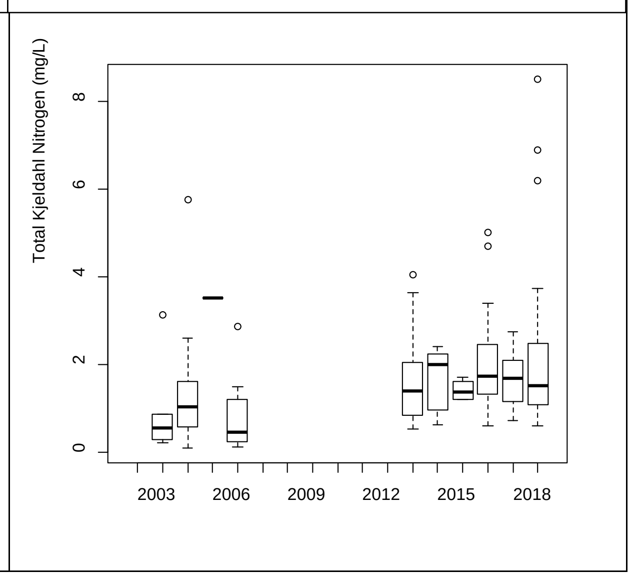




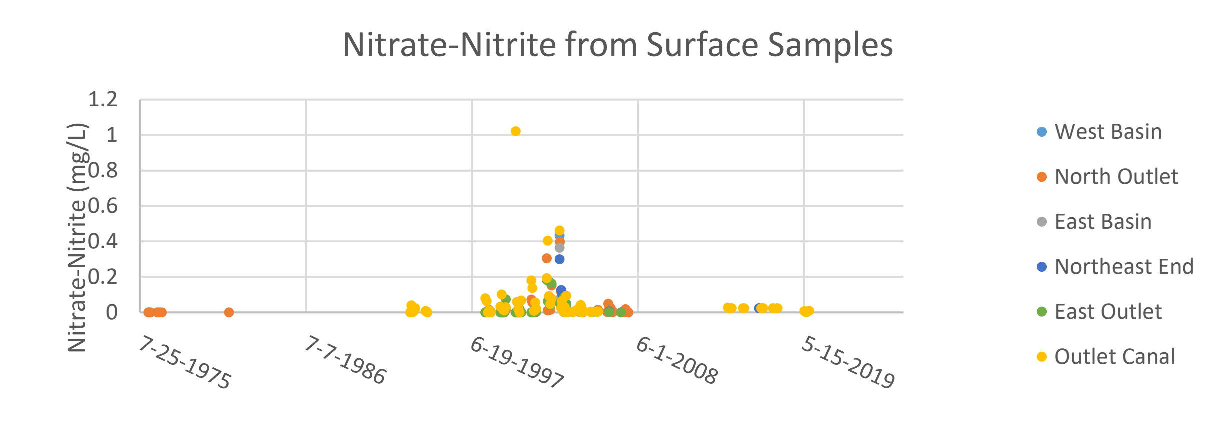
Total Kjeldahl Nitrogen in Inlet Canal

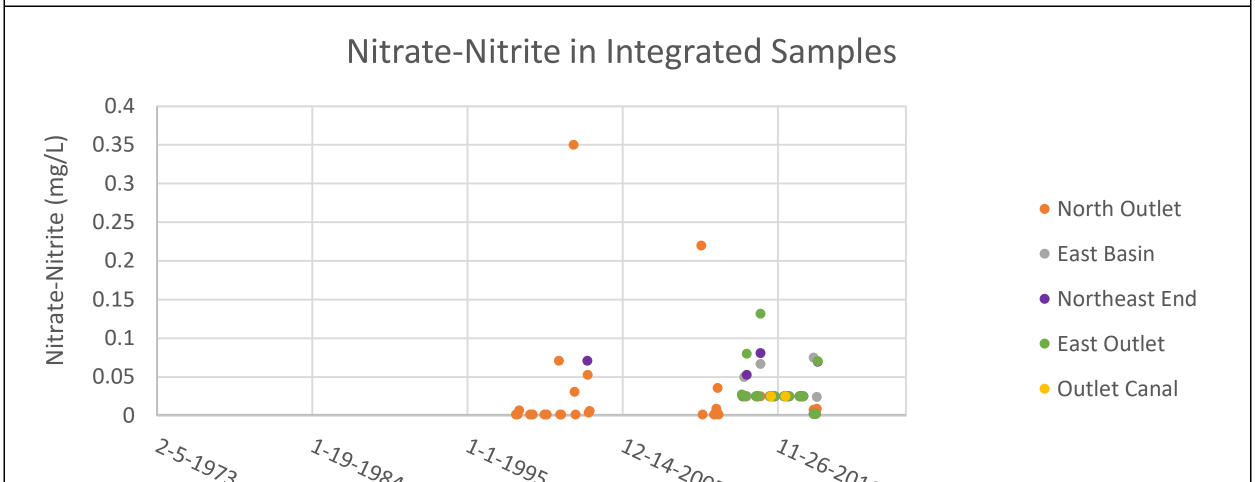


Total Kjeldahl Nitrogen in Tributaries

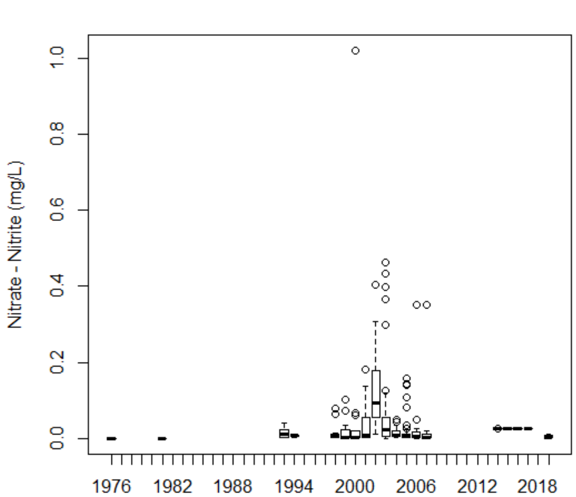


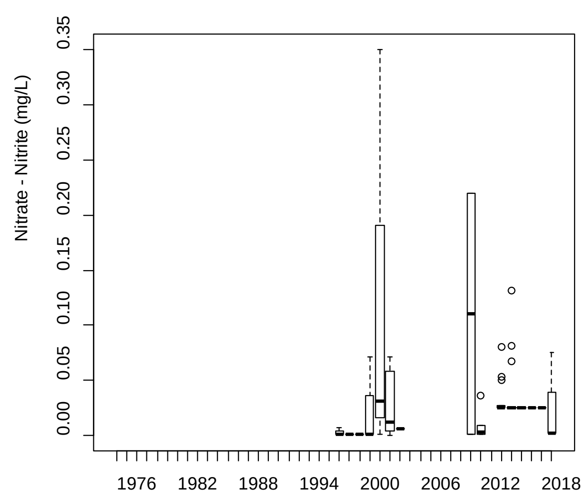
Main Reservoir Sample Sites – Nitrate-Nitrite



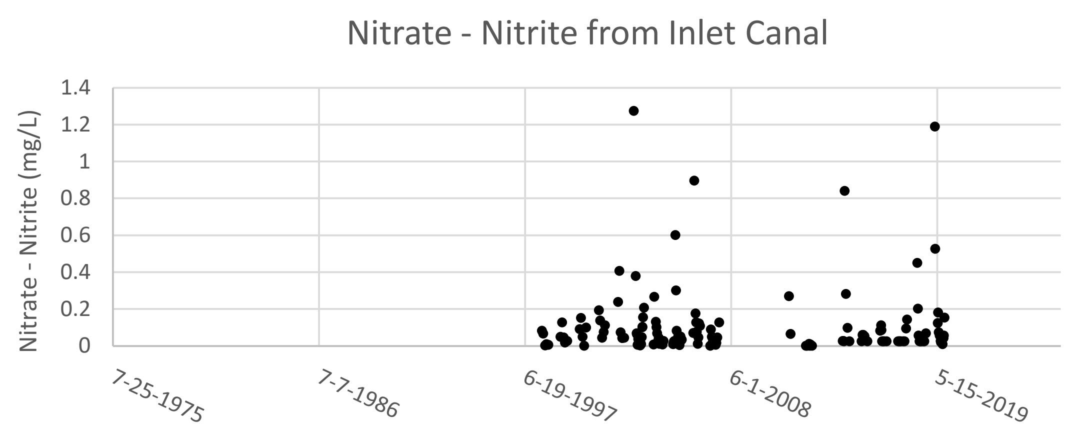


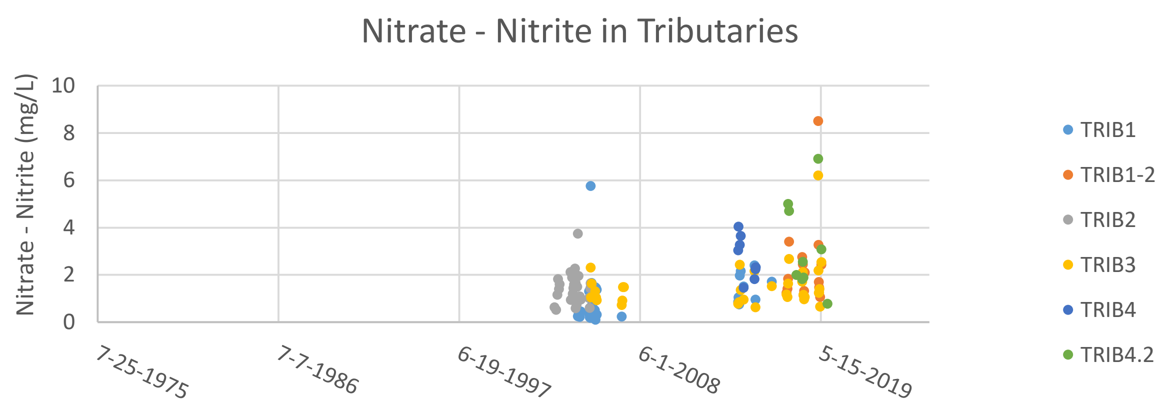
Nitrate – Nitrite in Surface Samples	Nitrate-Nitrite in Integrated Samples



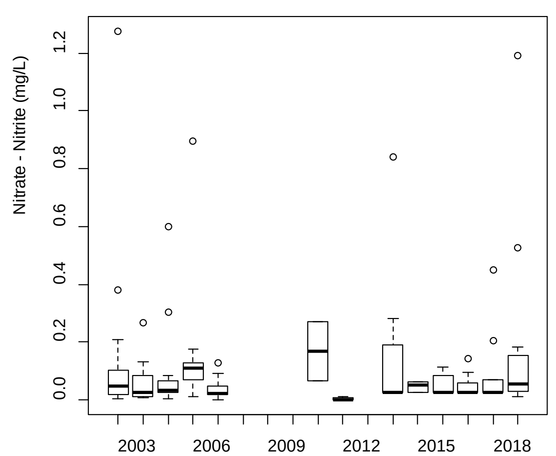


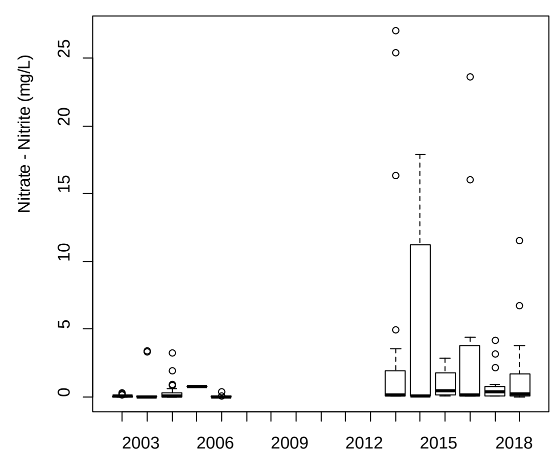
Inlet Canal and Minor Tributary Sampling Sites – Nitrate – Nitrite



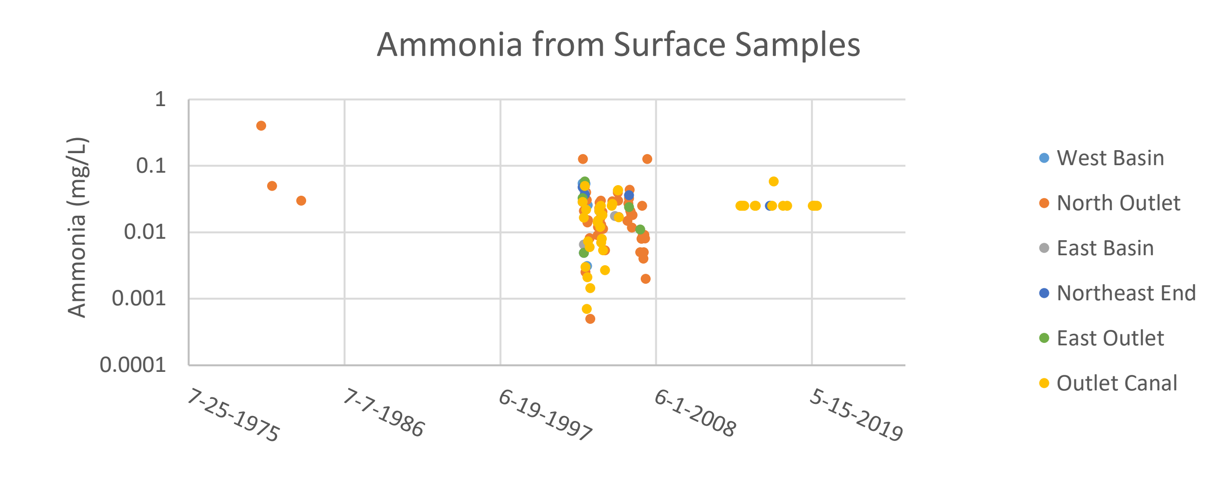


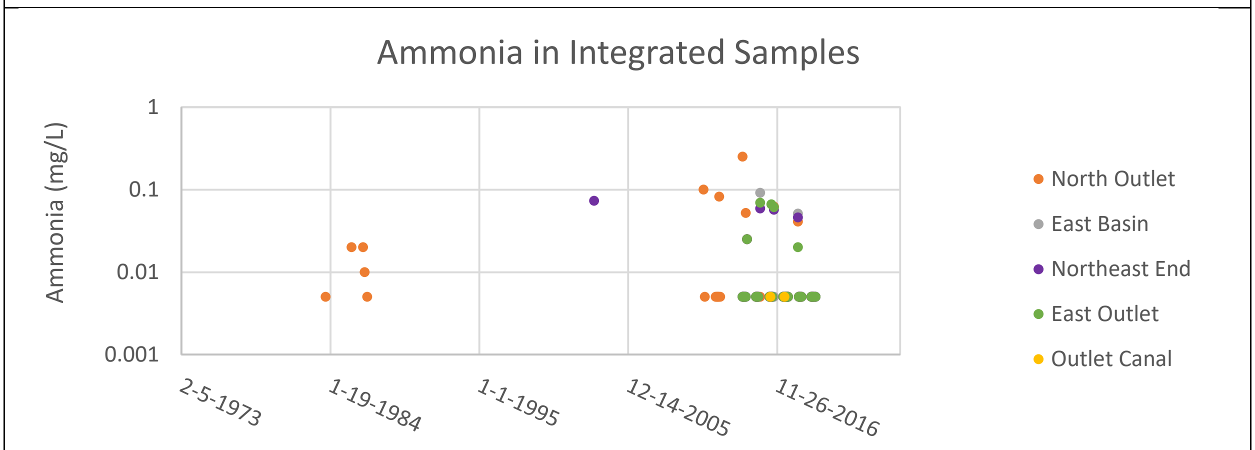
Nitrate – Nitrite in Inlet Canal	Nitrate – Nitrite in Tributaries



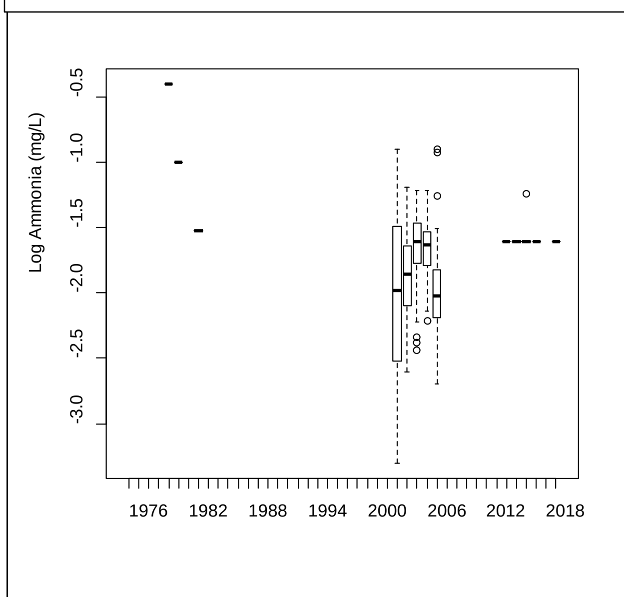


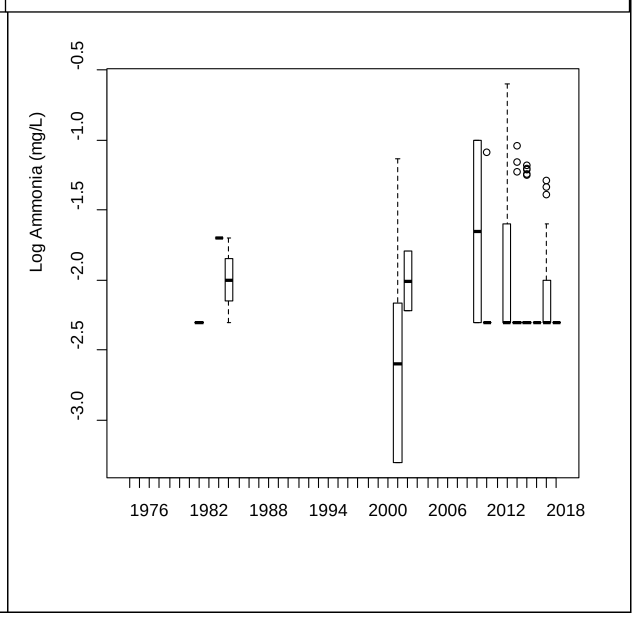
Main Reservoir Sample Sites – Ammonia



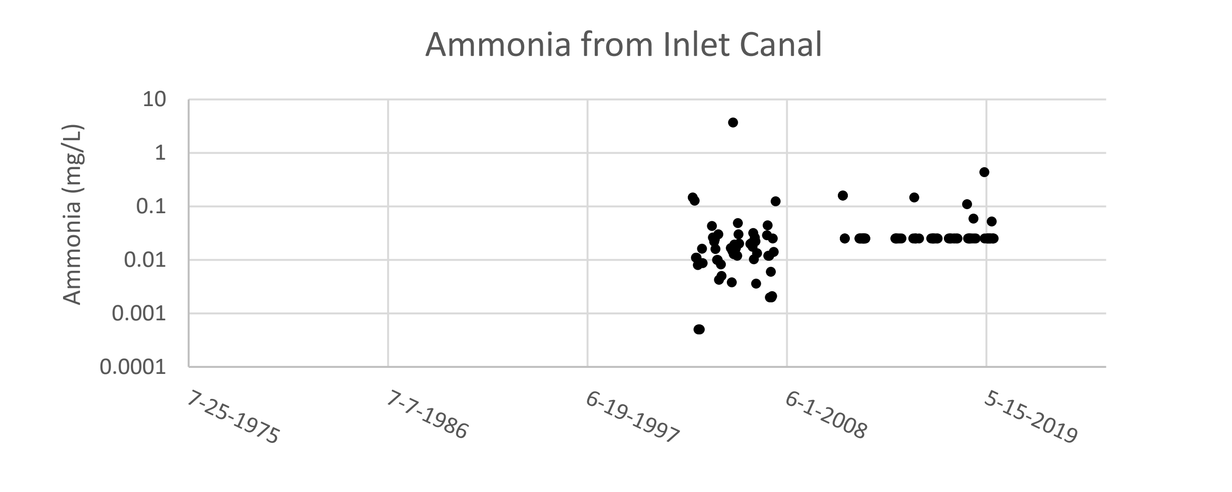


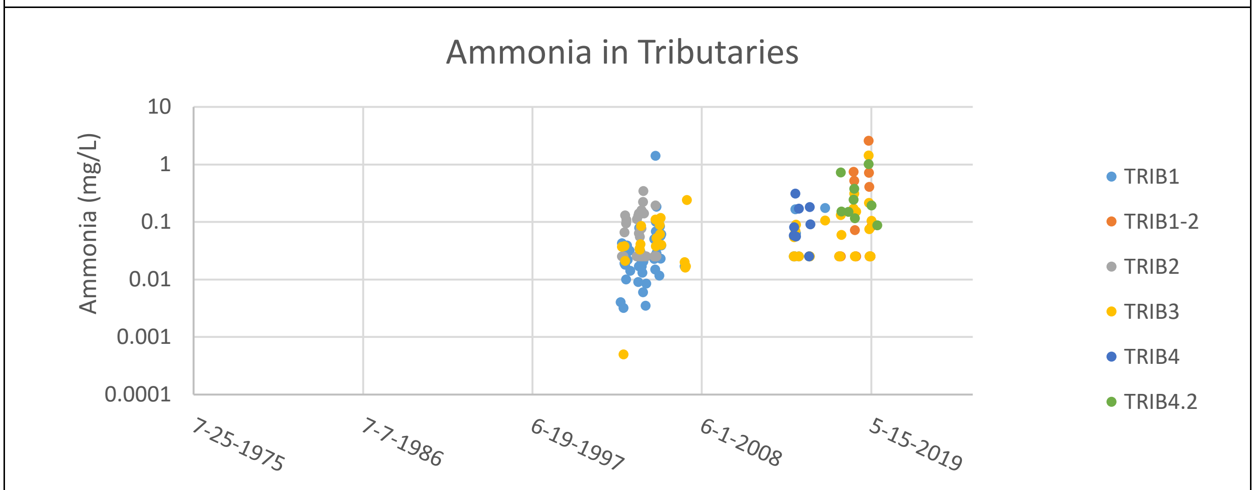
Ammonia in Surface Samples	Ammonia in Integrated Samples



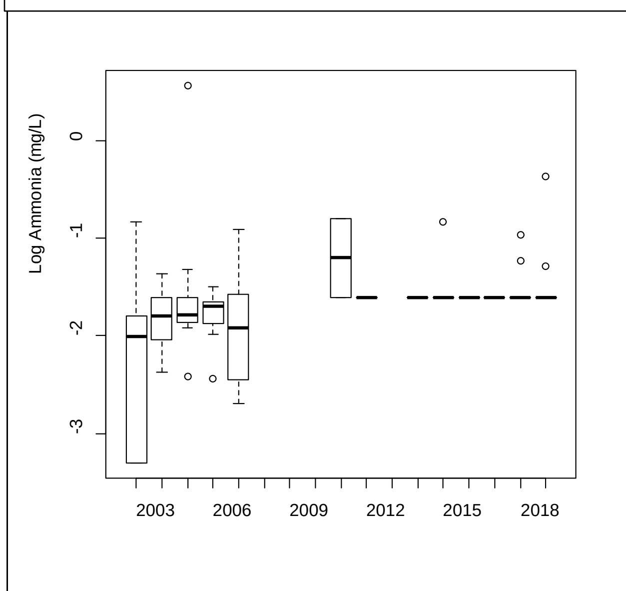


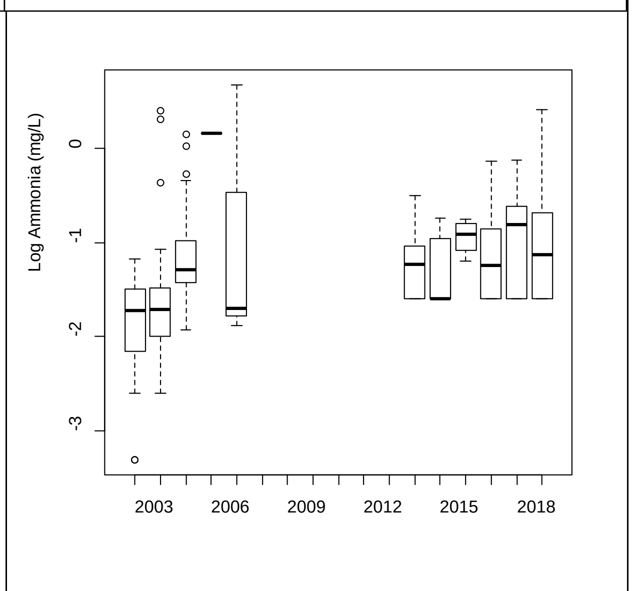
Inlet Canal and Minor Tributary Sampling Sites – Ammonia



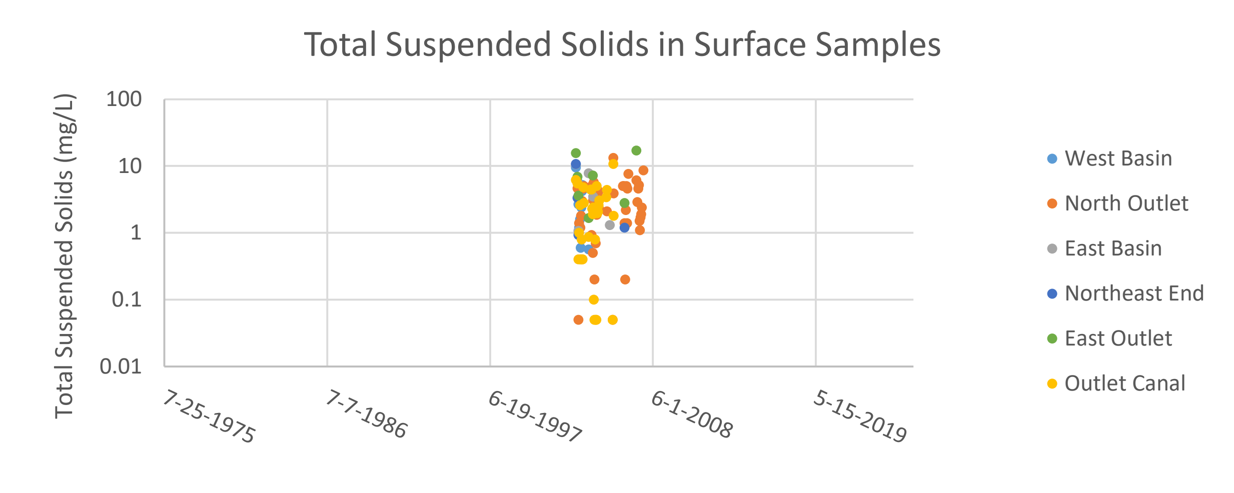


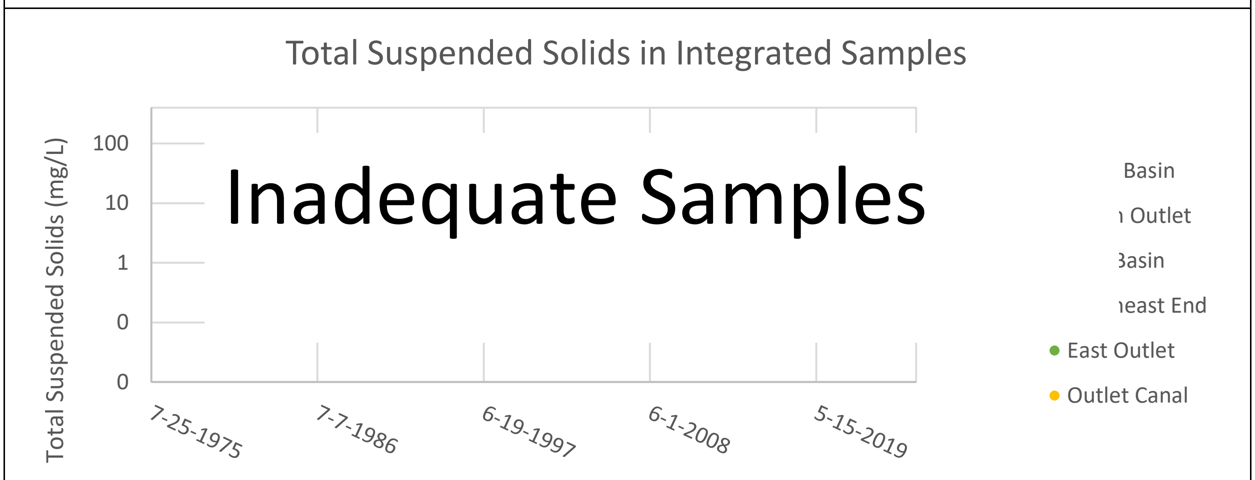
Ammonia in Inlet Canal	Ammonia in Tributaries



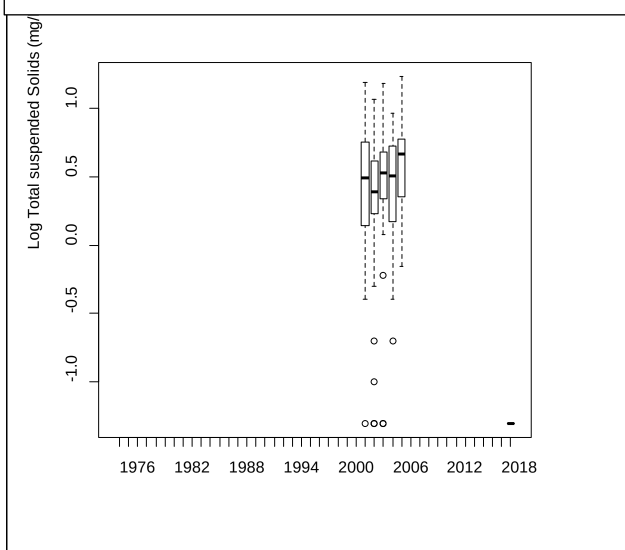


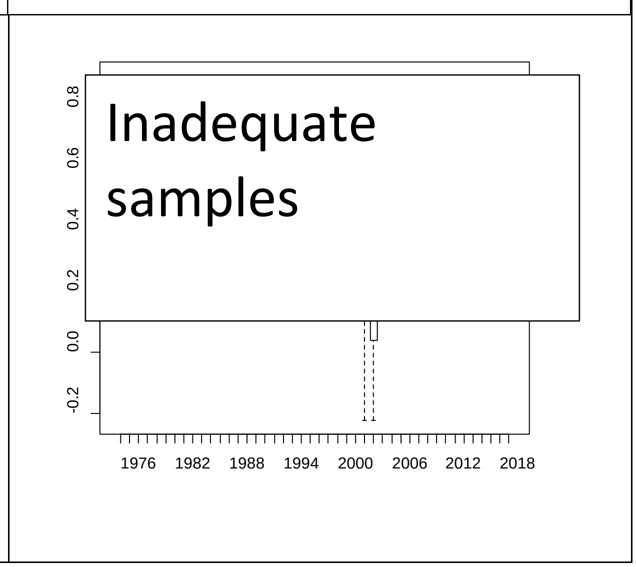
Main Reservoir Sample Sites – Total Suspended Solids



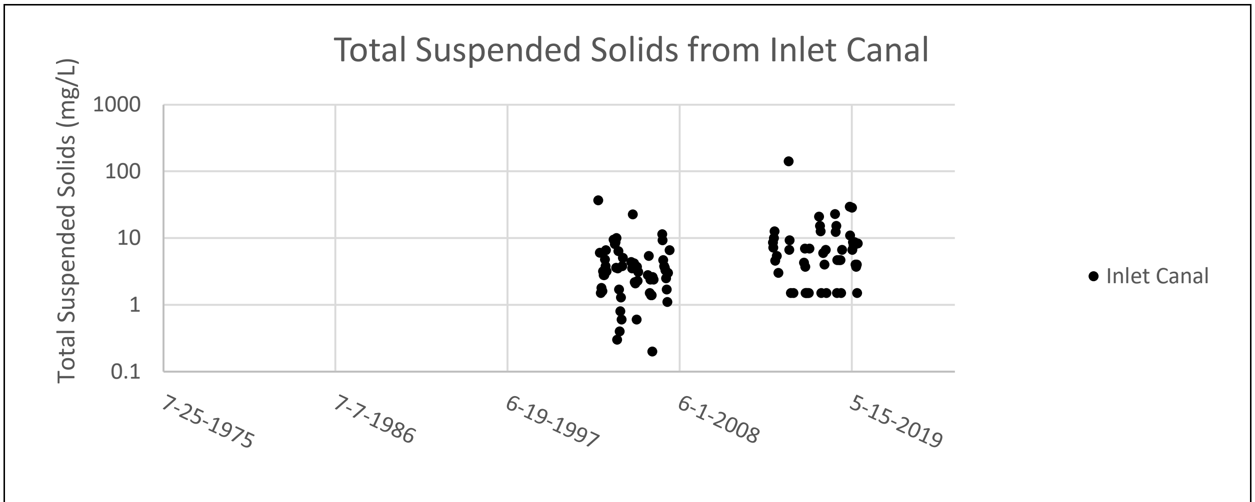


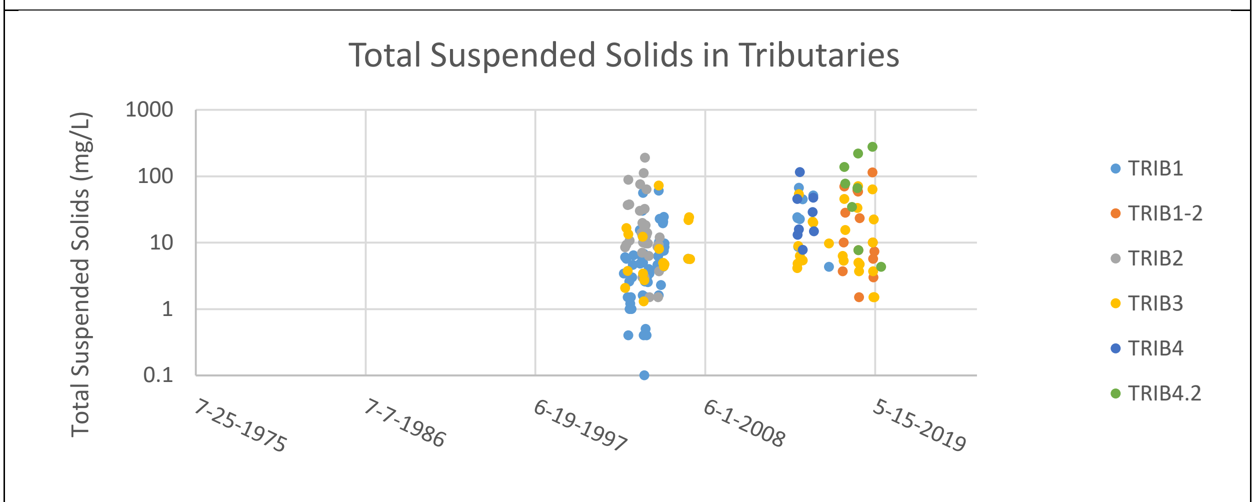
Total Suspended Solids in Surface Samples	Total Suspended Solids in Integrated Samples

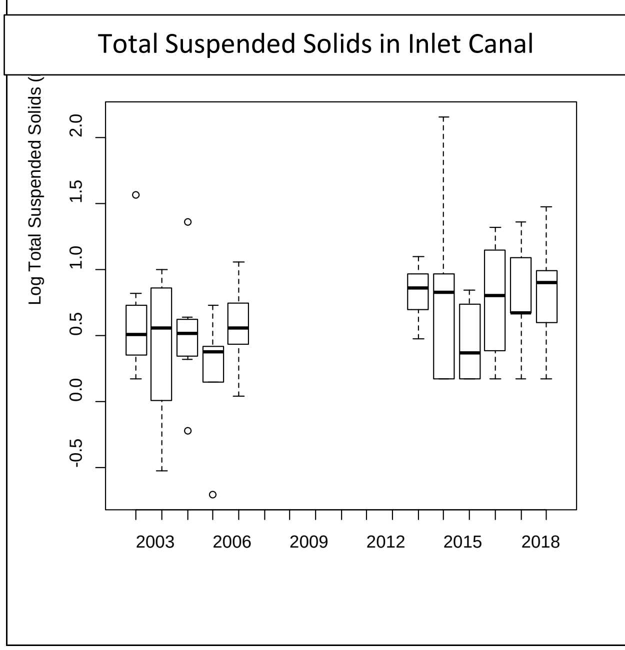


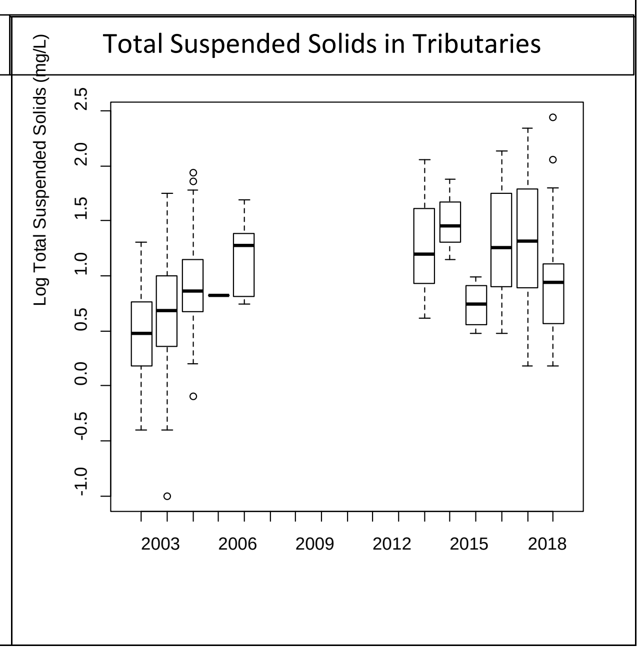


Inlet Canal and Minor Tributary Sampling Sites – Total Suspended Solids

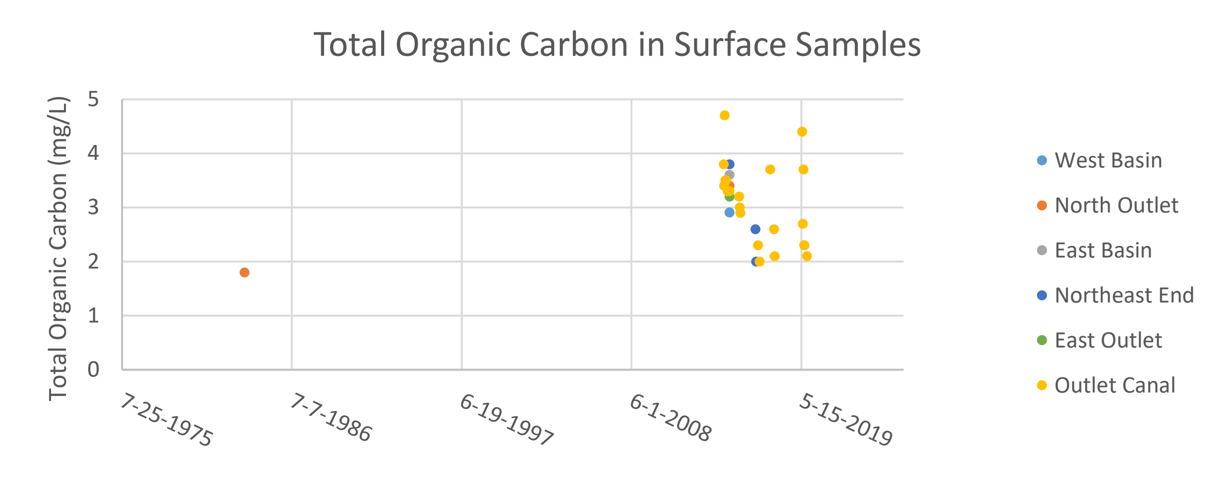


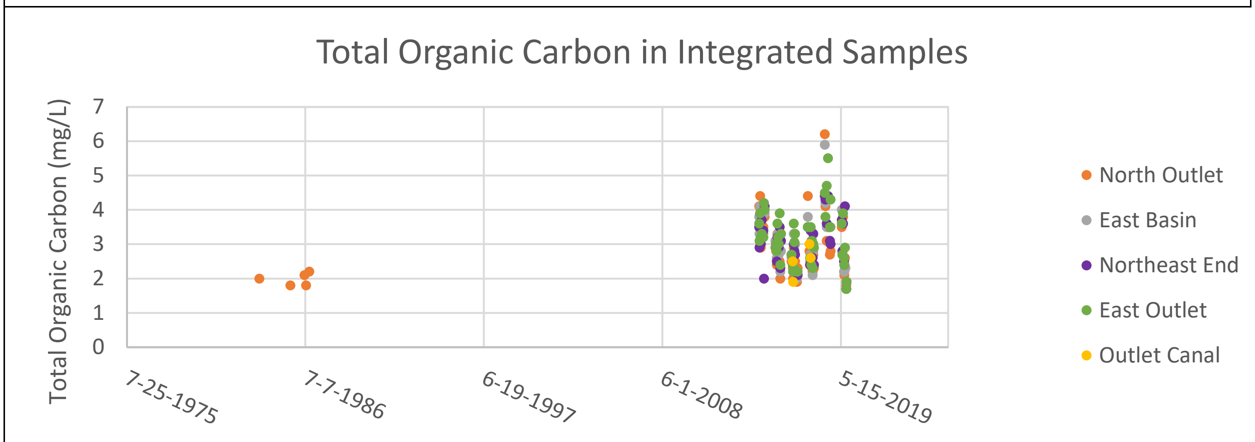




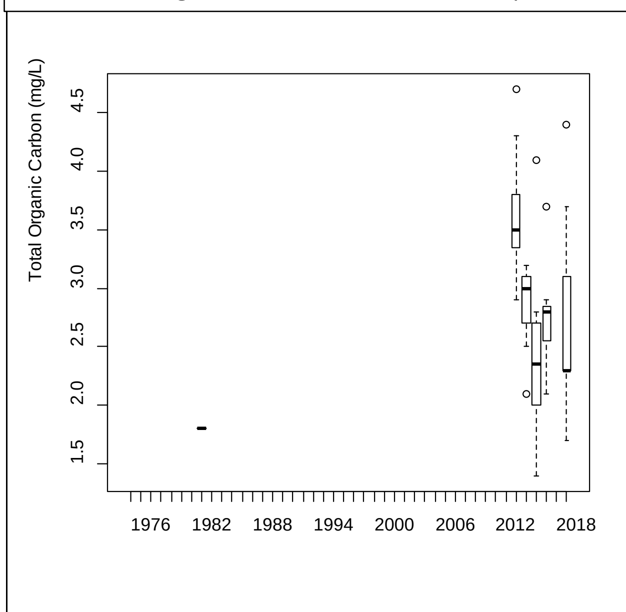


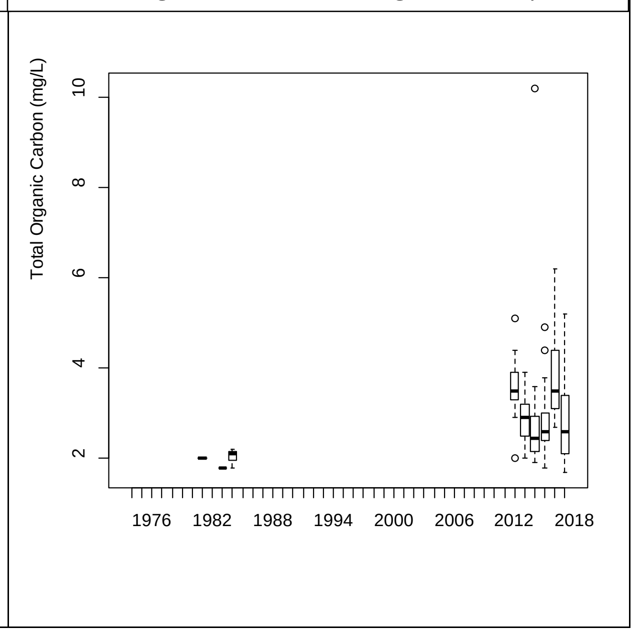
Main Reservoir Sample Sites – Total Organic Carbon





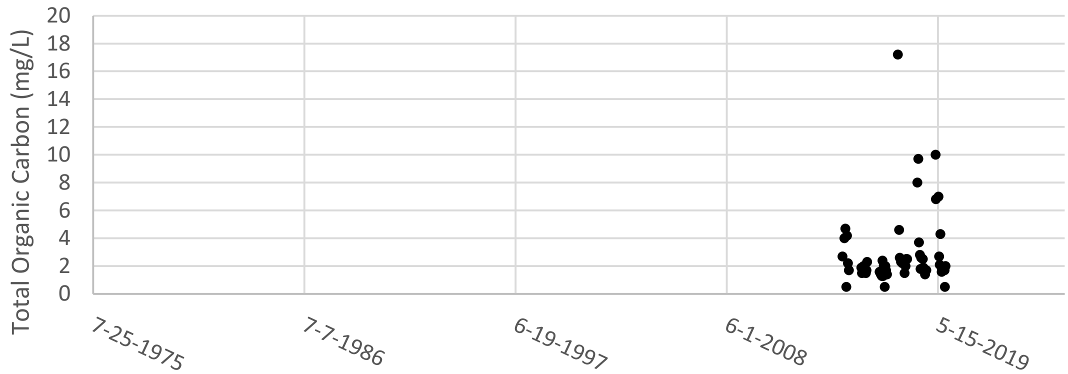
Total Organic Carbon in Surface Samples	Total Organic Carbon in Integrated Samples



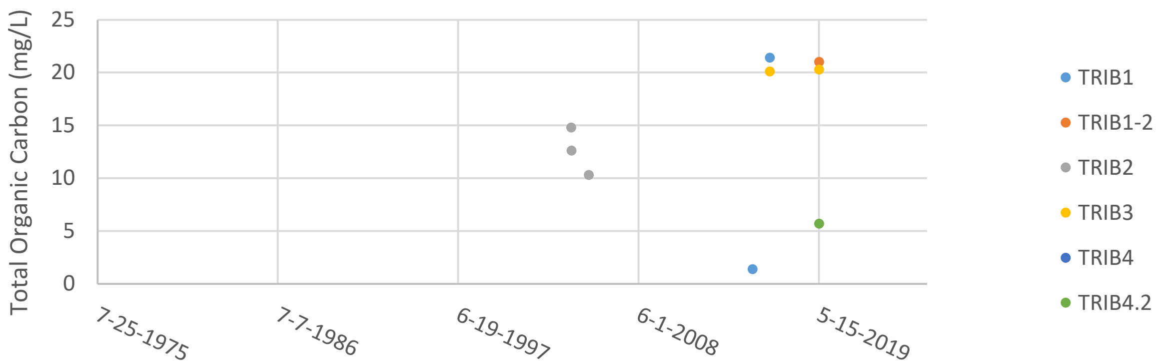


Inlet Canal and Minor Tributary Sampling Sites – Total Organic Carbon

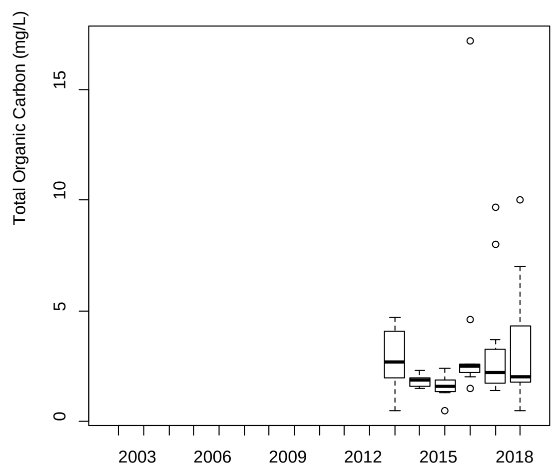
Total Organic Carbon from Inlet Canal



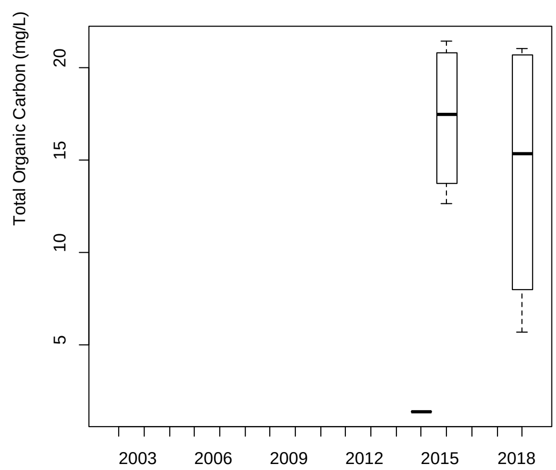
Total Organic Carbon in Tributaries



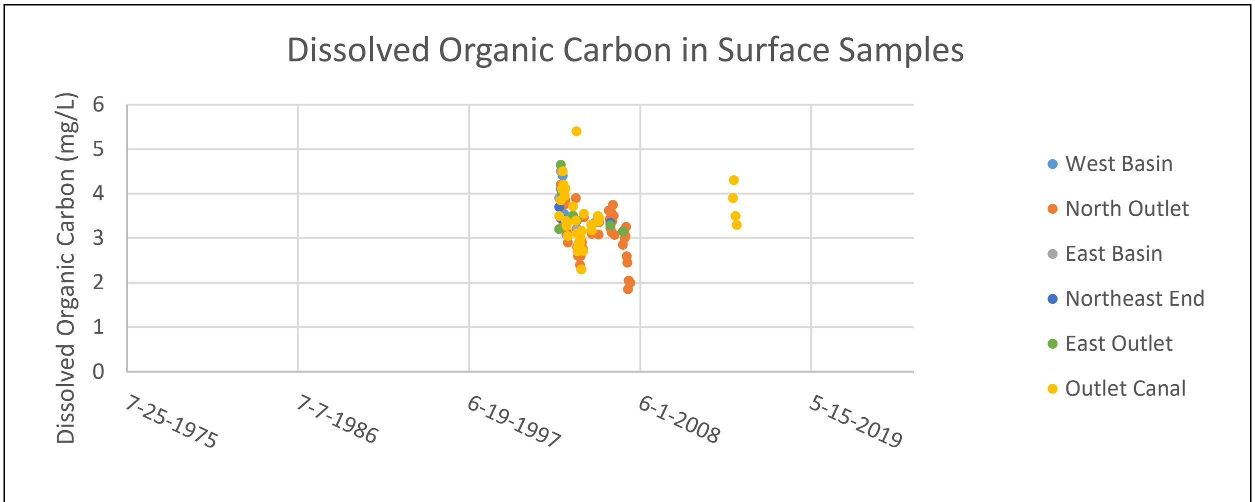
Total Organic Carbon in Inlet Canal

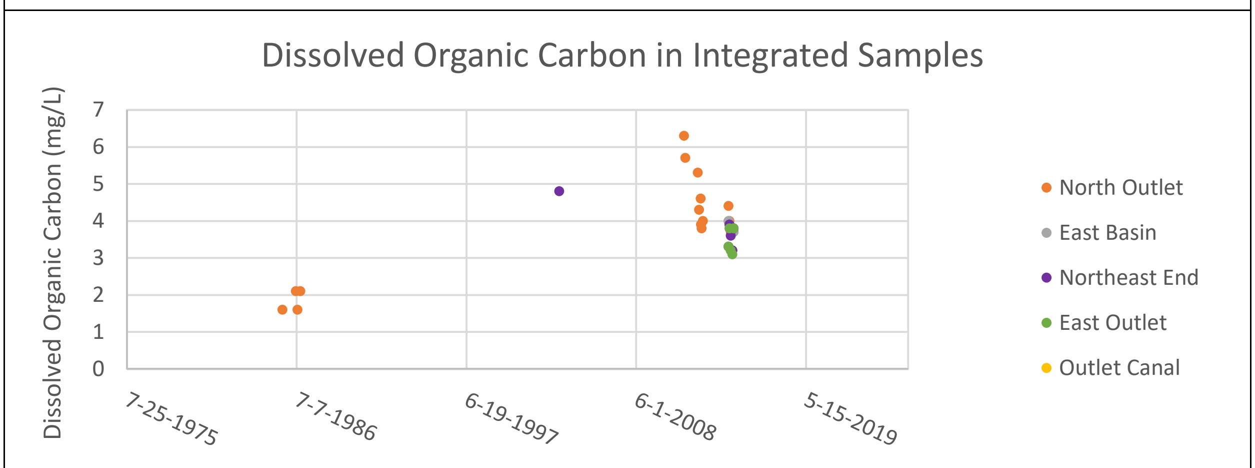


Total Organic Carbon in Tributaries

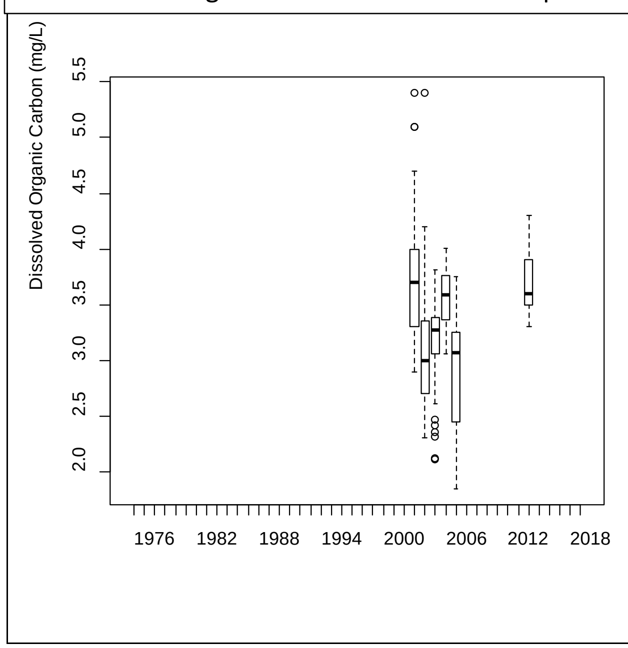


Main Reservoir Sample Sites – Dissolved Organic Carbon

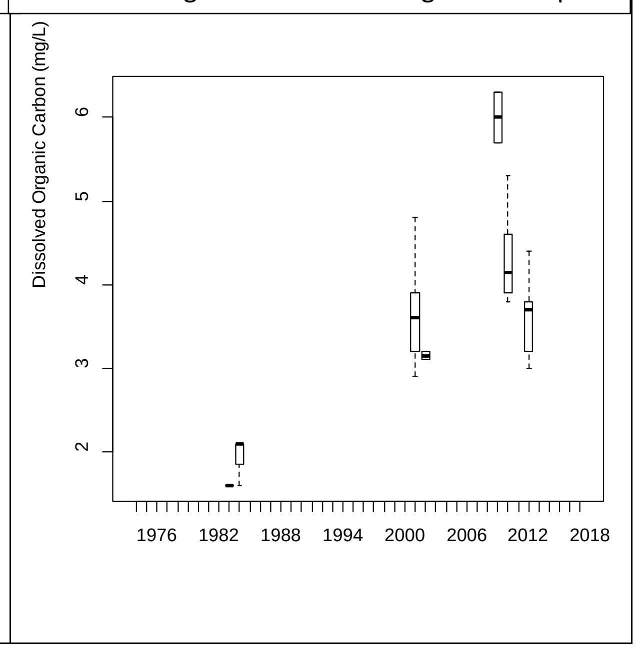




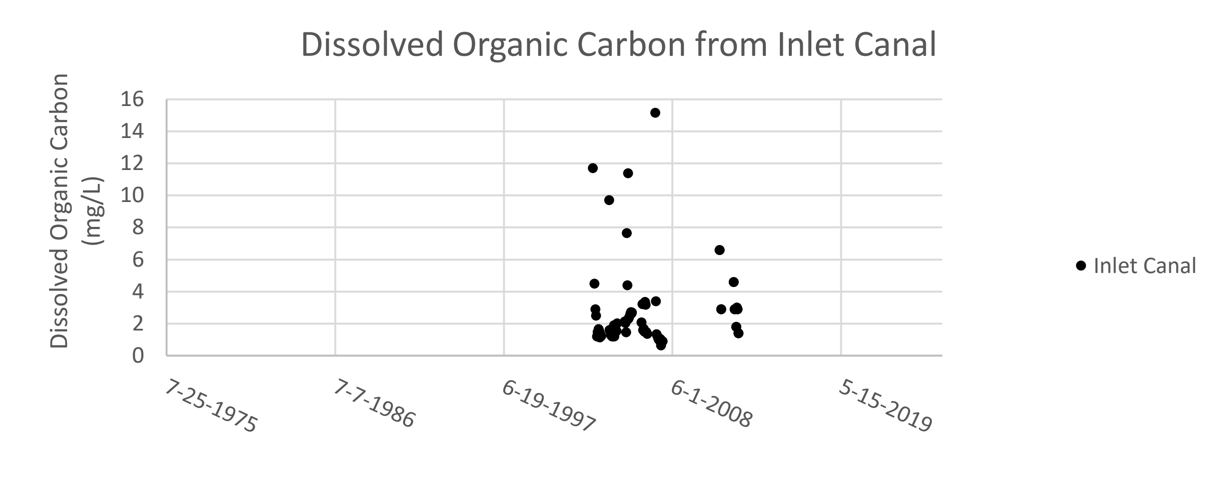
Dissolved Organic Carbon in Surface Samples

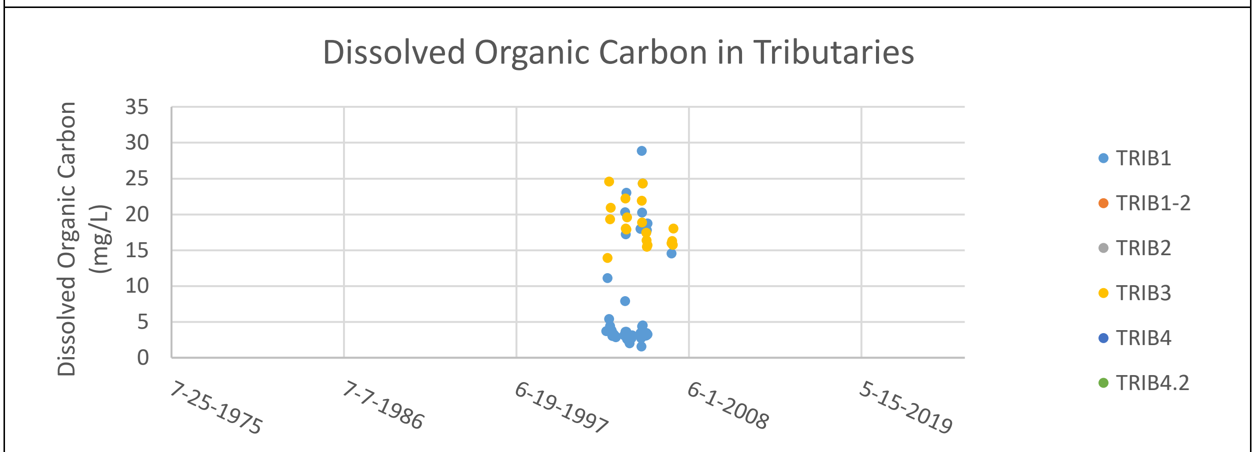


Dissolved Organic Carbon in Integrated Samples

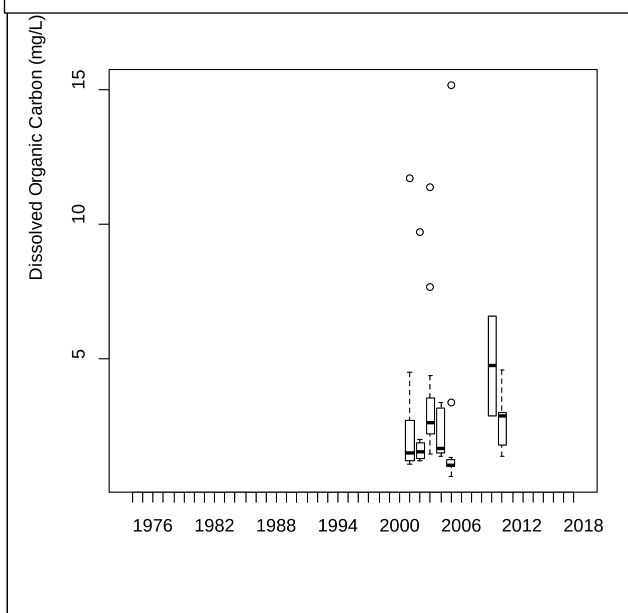


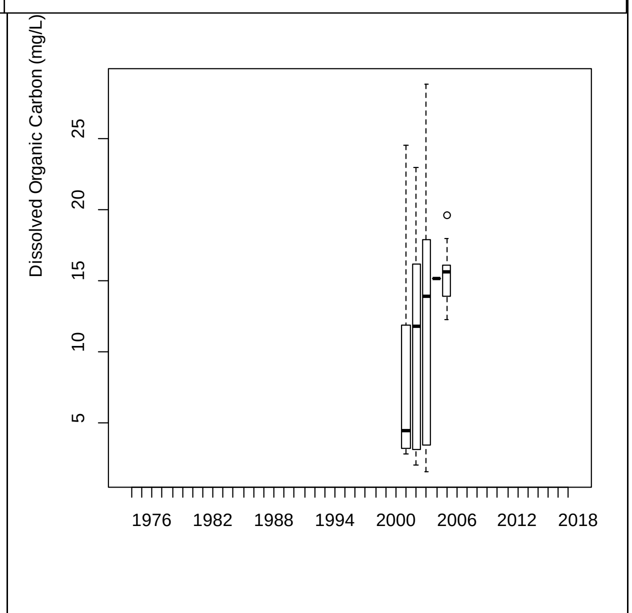
Inlet Canal and Minor Tributary Sampling Sites – Dissolved Organic Carbon



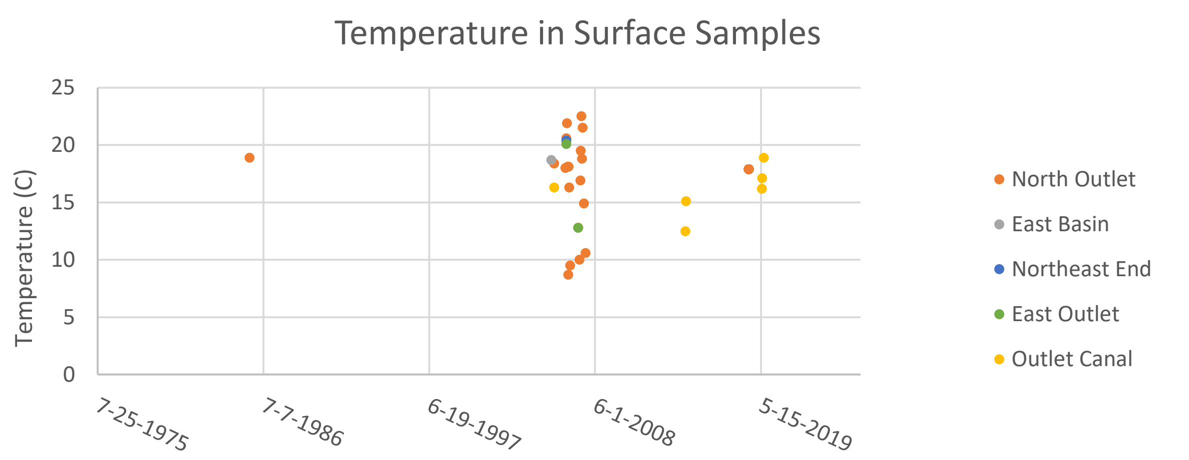


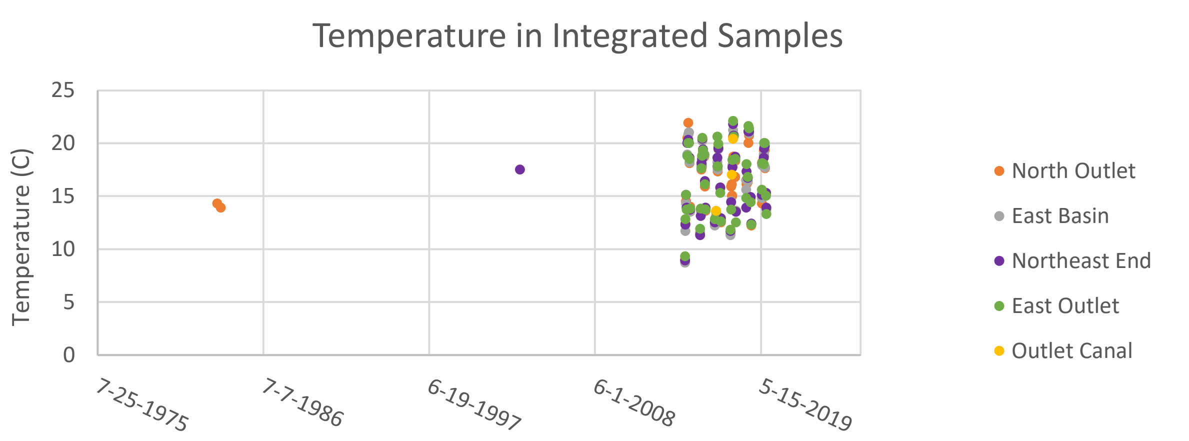
Dissolved Organic Carbon in Inlet Canal	Dissolved Organic Carbon in Tributaries



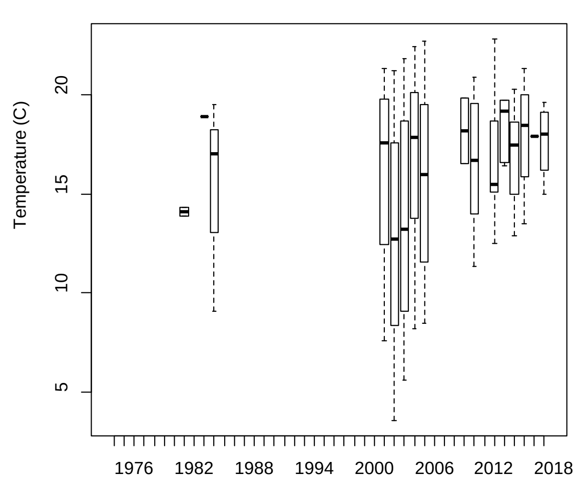


Main Reservoir Sample Sites – Temperature

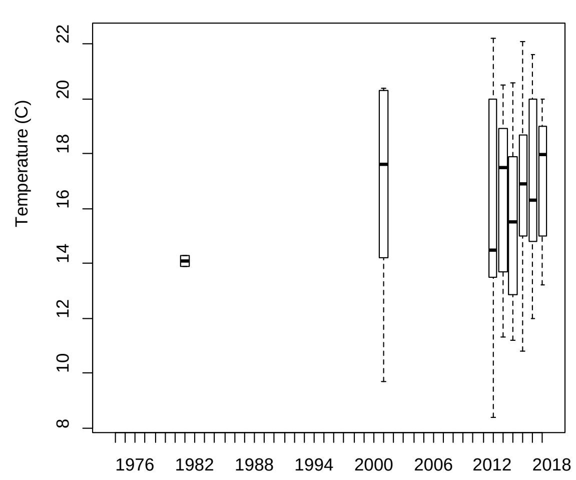




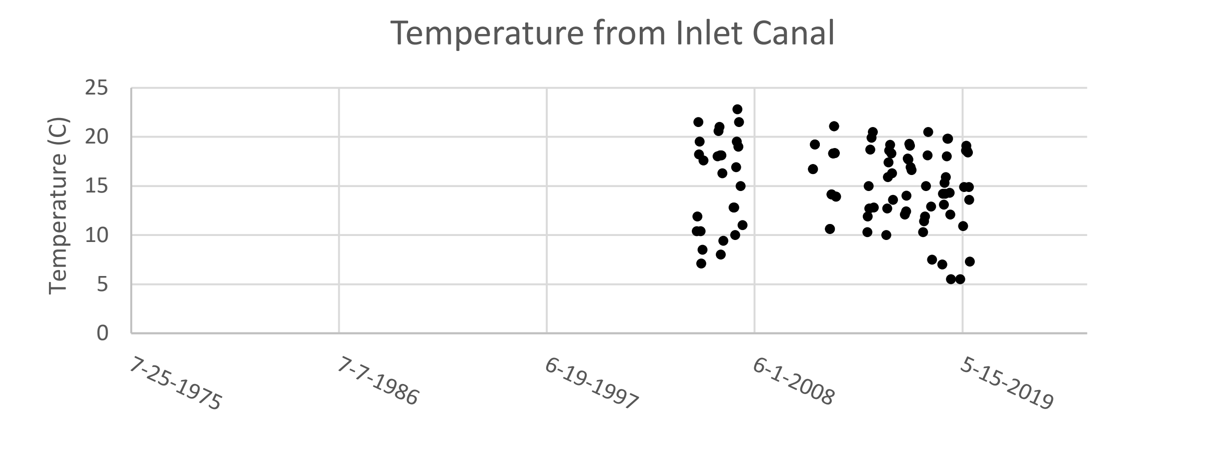
Temperature in Surface Samples

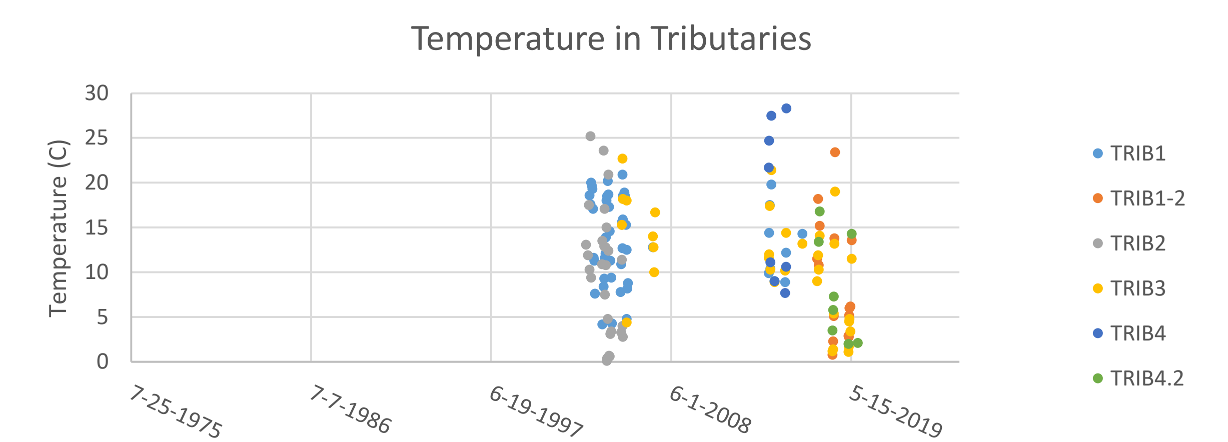


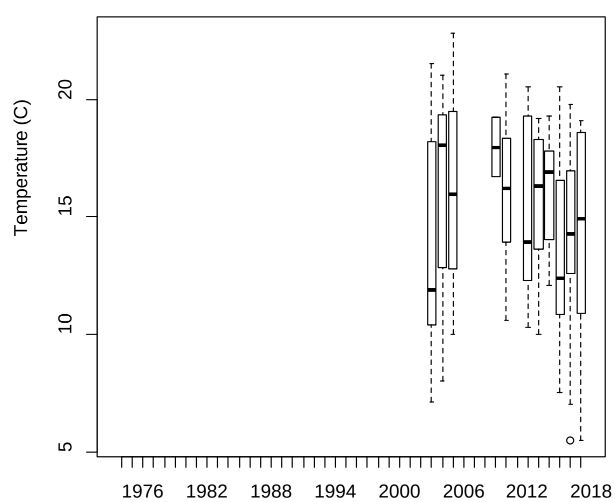
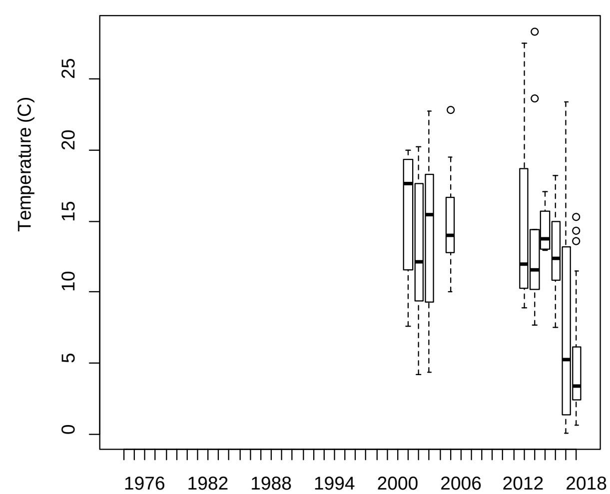
Temperature in Integrated Samples



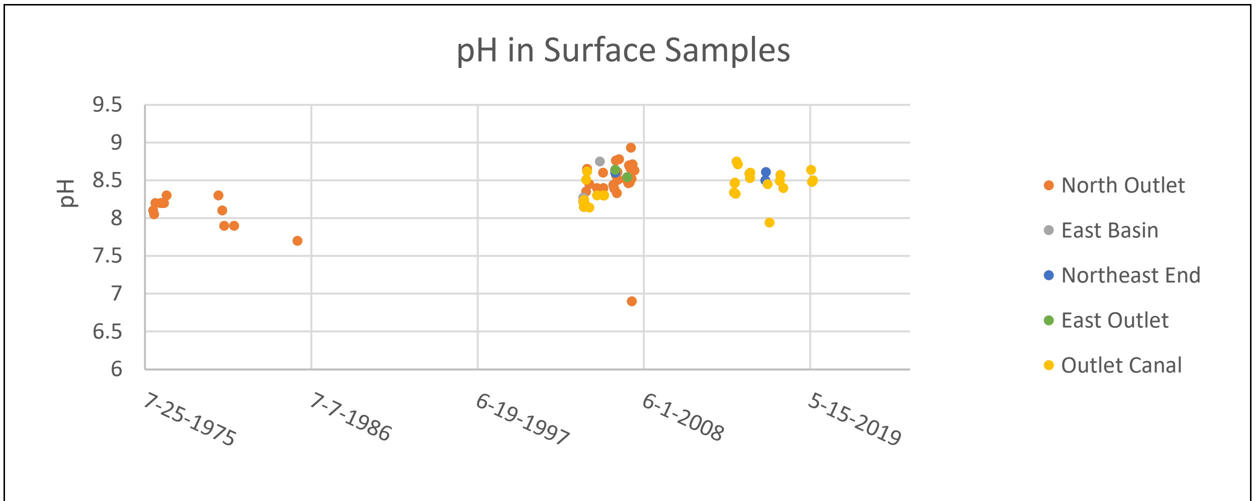
Inlet Canal and Minor Tributary Sampling Sites – Temperature

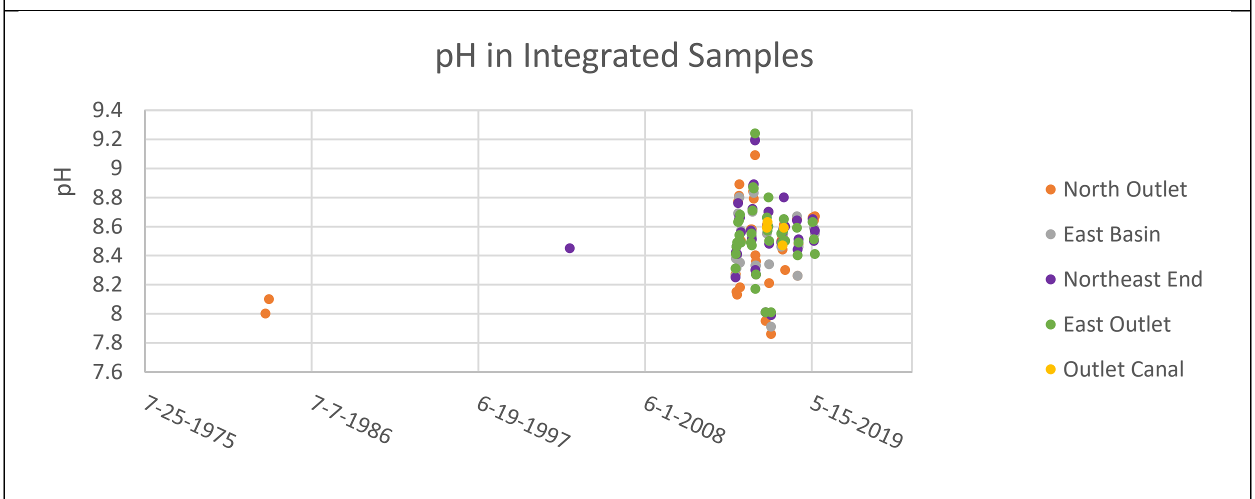




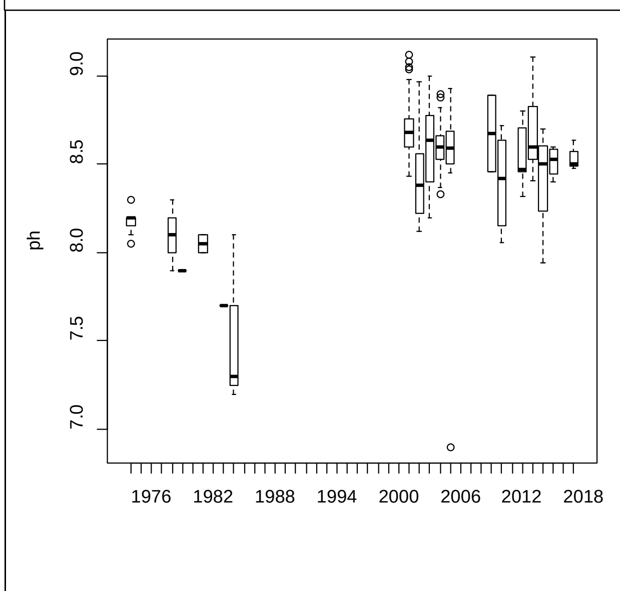
Temperature in Inlet Canal	Temperature in Tributaries
	

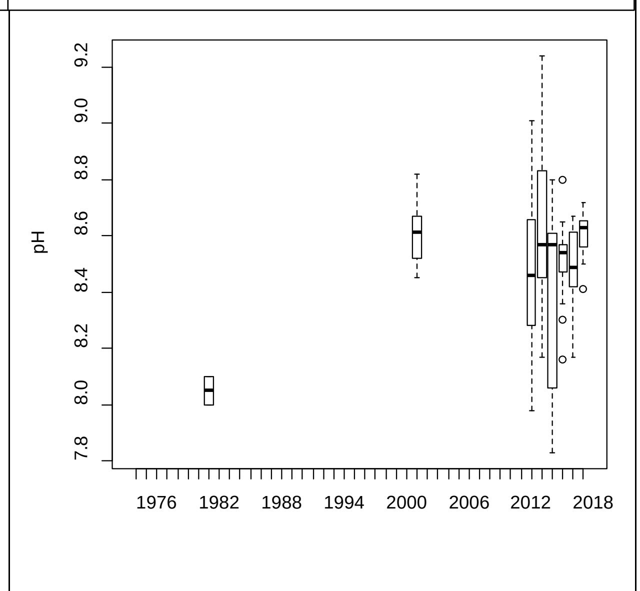
Main Reservoir Sample Sites – pH



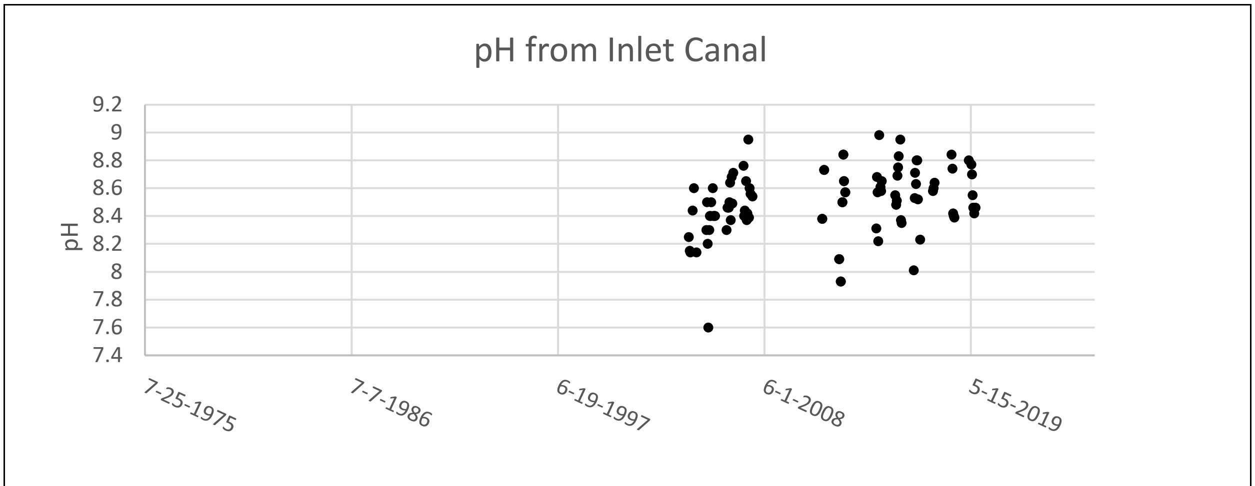


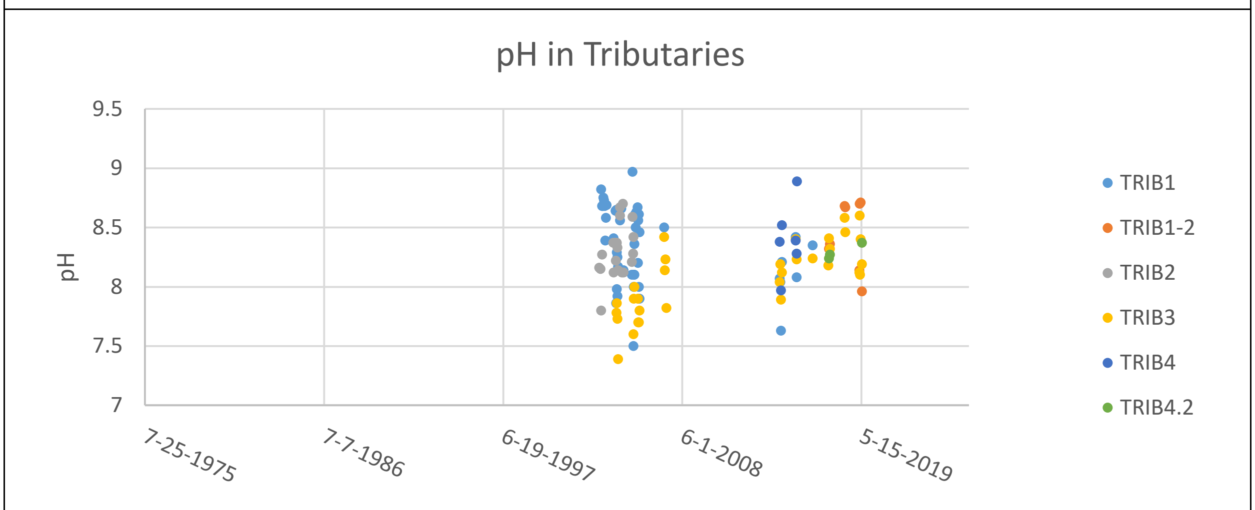
pH in Surface Samples	pH in Integrated Samples



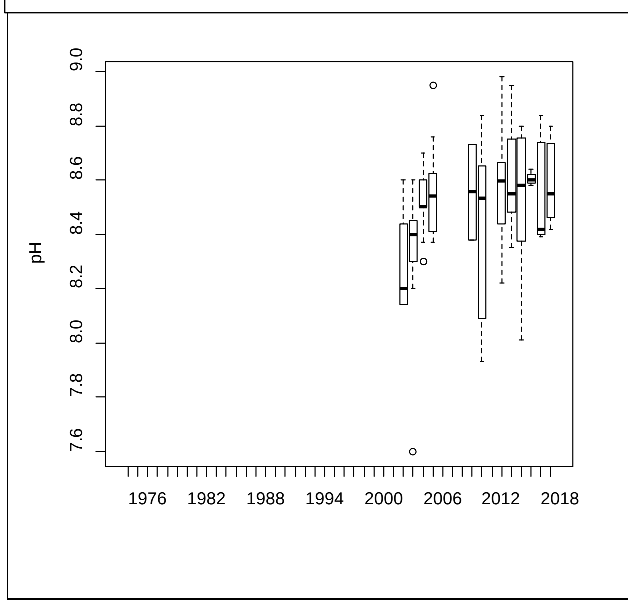


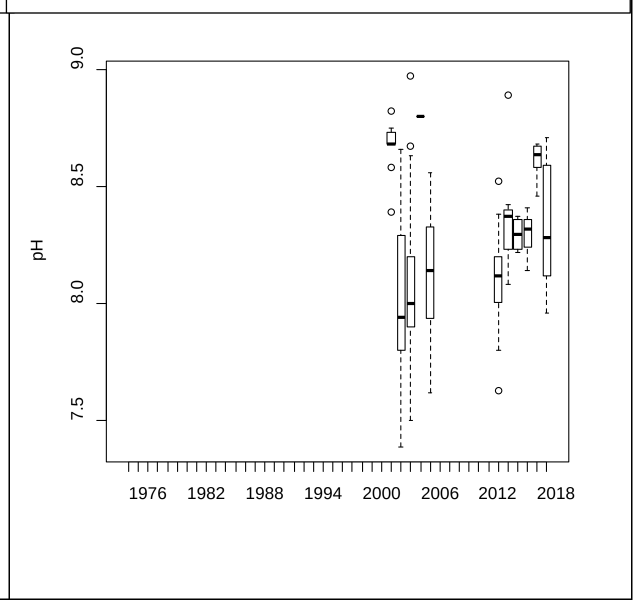
Inlet Canal and Minor Tributary Sampling Sites – pH



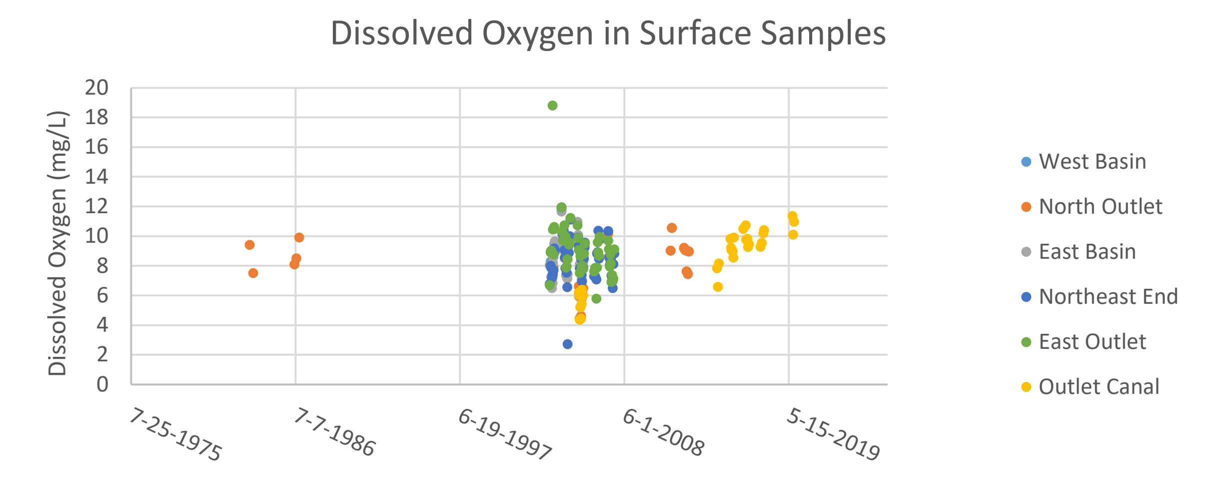


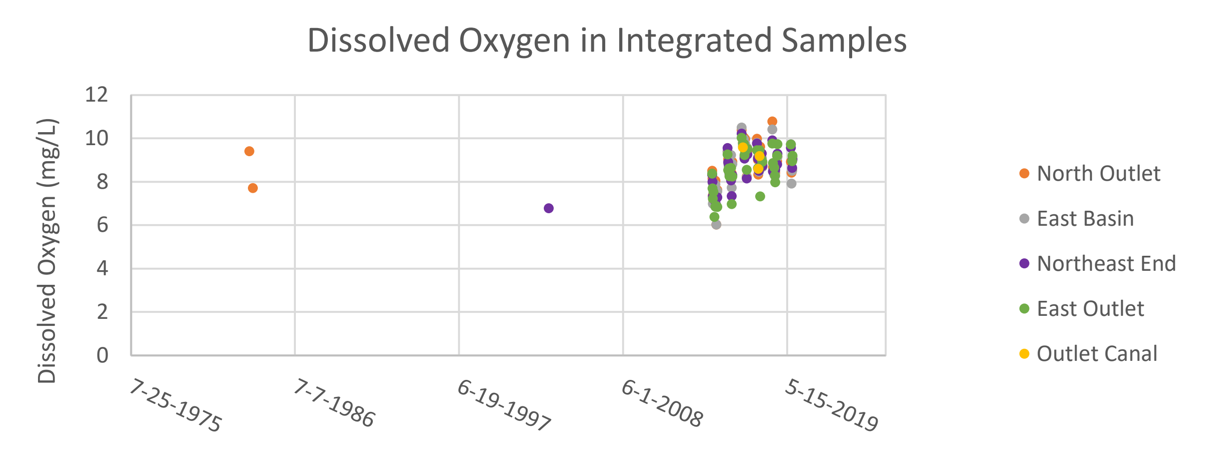
pH in Inlet Canal	pH in Tributaries



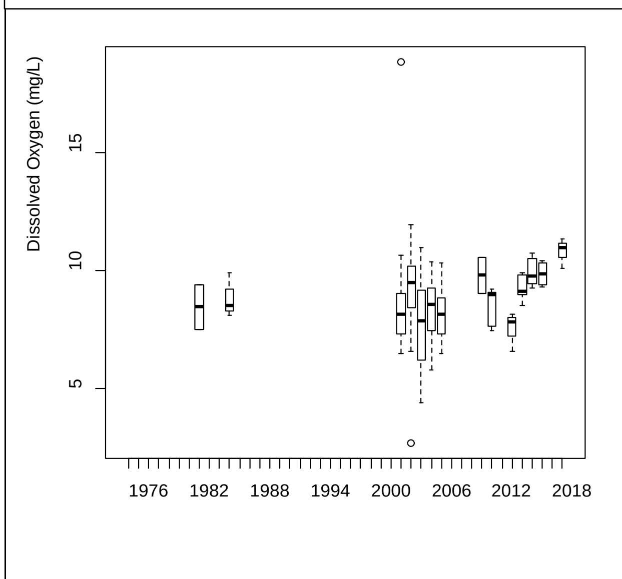


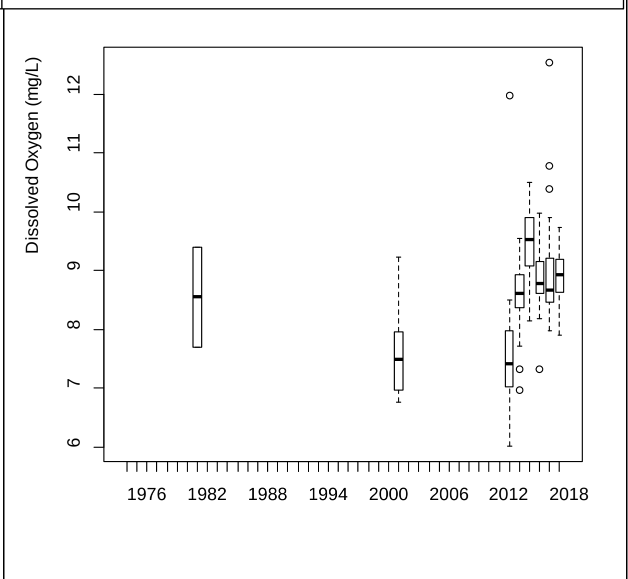
Main Reservoir Sample Sites – Dissolved Oxygen



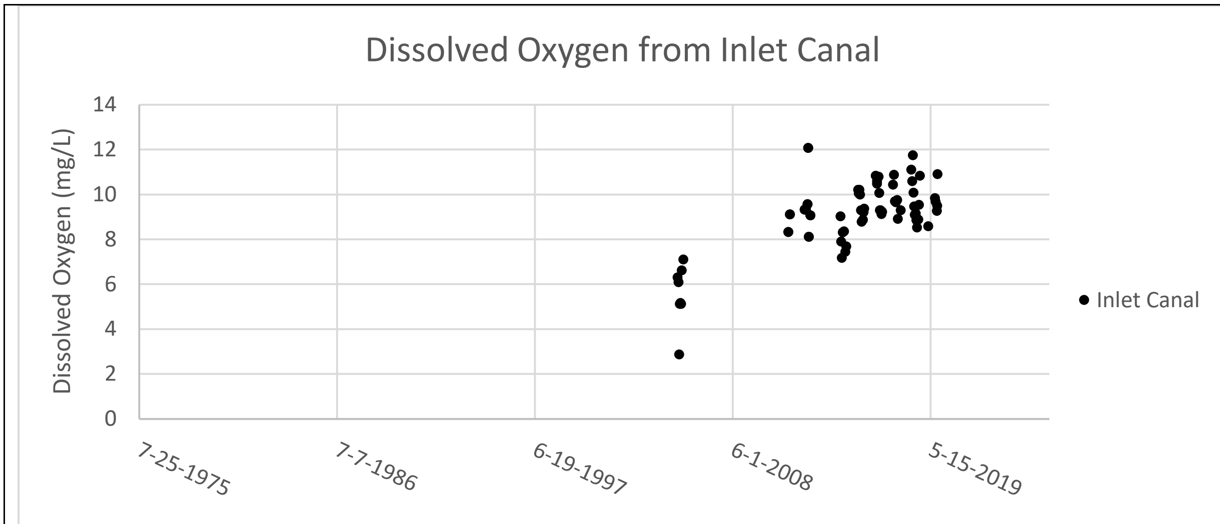


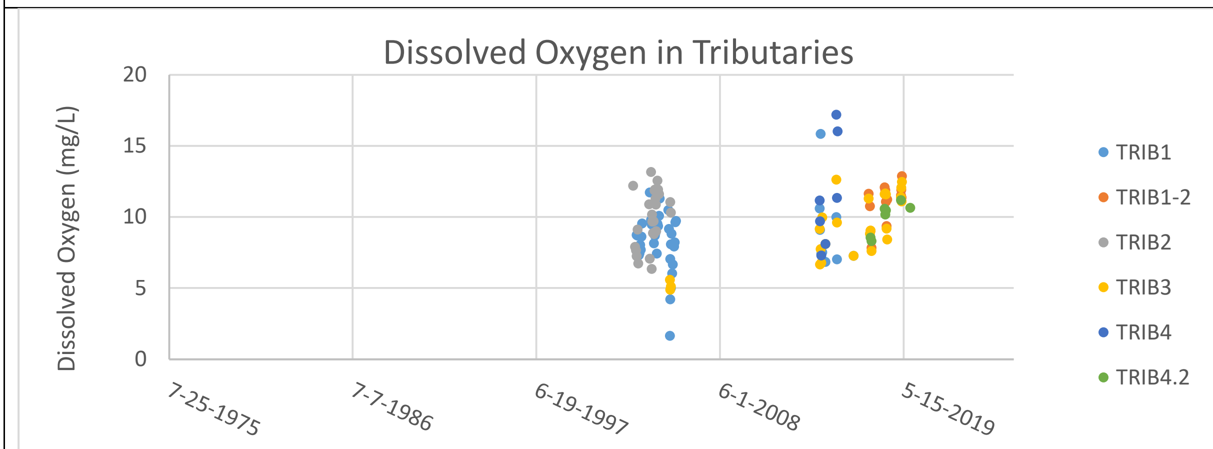
Dissolved Oxygen in Surface Samples	Dissolved Oxygen in Integrated Samples



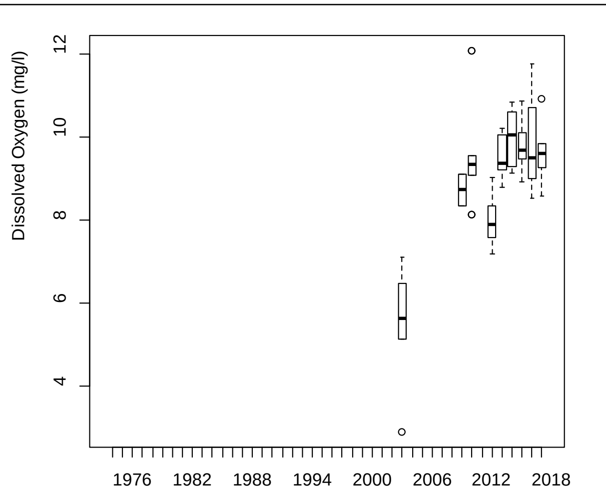


Inlet Canal and Minor Tributary Sampling Sites – Dissolved Oxygen





Dissolved Oxygen in Inlet Canal



Dissolved Oxygen in Tributaries