Little Bitterroot Lake
Water Quality Monitoring Program
2023 Annual Report

Prepared For:
Little Bitterroot Lake Association
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Glossary of Terms

Benthic	bottom region of a lake including the sediment surface
Bloom	significant increase in algae population triggered by favorable conditions for growth
Chlorophyll-*a*	green pigment found in photosynthetic plants and algae
Depth profile	chart showing a water chemistry parameter at various depths within a lake
Epilimnion	uppermost portion of a stratified lake
Eutrophic	having high biological productivity (meso-eutrophic is moderately high), high productivity is commonly an indicator of high nutrients and poor water quality
Hypolimnion	bottom layer of a stratified lake
Mesotrophic	having moderate biological productivity
Metalimnion	the middle (transitional) layer of a stratified lake
Oligotrophic	having low biological productivity (meso-oligotrophic is moderately low), low productivity is an indicator of low nutrient concentrations and good water quality
Trophic	relating to available nutrients (ex. trophic status)

List of Acronyms

AIS	aquatic invasive species
CFS	cubic feet per second
DEQ	Montana Department of Environmental Quality
DNRC	Montana Department of Natural Resources and Conservation
DO	dissolved oxygen
DOC	dissolved organic carbon
FLBS	Flathead Lake Biological Station
GPM	gallons per minute
LBLA	Little Bitterroot Lake Association
SAP	sampling and analysis plan
SC	specific conductance
TN	total nitrogen
TP	total phosphorus
TSI	trophic state index
TSS	total suspended sediment
USGS	United States Geological Survey
WLI	Whitefish Lake Institute

Executive Summary

Routine sampling was conducted on Little Bitterroot Lake on August 3-4, 2023, for field parameters (temperature, pH, dissolved oxygen, specific conductance) and nutrients (nitrogen and phosphorus) at 7 lake sites and 2 stream sites. Depth profiles were recorded at the lake center by Whitefish Lake Institute on August 8 for field parameters and chlorophyll-a. In August 2023, additional samples were collected from 12 near-shore sites for nutrients, bacteria, dissolved oxygen, and fluorescence, which may provide an indicator of failing or overused septic systems. These sites were also sampled on June 17, but only for dissolved oxygen and fluorescence. The additional sampling was conducted during pre-dawn hours when dissolved oxygen is expected to be lowest.

Little Bitterroot Lake has always displayed relatively excellent water quality, but several noteworthy results are evident in 2023. Chlorophyll-a concentrations were the highest on record in 2023, in both surface samples and in the depth profile data. Isolated areas with significant algae growth have been observed in recent years, which appear to be larger in 2023. The cause of these localized algae outbreaks cannot be identified without an extensive study, but they are likely caused by nutrient loading from failing or over-loaded septic systems. Total nitrogen (TN) concentrations have shown an increasing trend since 2012, and the trend is apparent more recently with Herrig Creek, the primary surface water source to the lake. Total phosphorus (TP) in the lake shows a decreasing trend over the same period; however, Herrig Creek has higher TP concentrations and a slight upward trend. Herrig Creek should be further evaluated in future sampling as a potential nutrient source.

Lake water temperature was relatively high in August 2023, a result of the warm summer which may have helped proliferate the algae growth measured in 2023. Dissolved oxygen was the lowest average on record, which is expected because warm water holds less oxygen. Other field parameters, such as pH and specific conductivity, were among the mid-range. Samples for calcium and alkalinity indicate the lake has low potential for colonization from invasive mussels. The additional near-shore sampling did not reveal conclusive trends about potential areas with failing septic systems, but does provide a baseline for comparison if future sampling is conducted.

Little Bitterroot Lake continues to be phosphorus limited, meaning that sufficient nitrogen is available for algae growth, and any available phosphorus may contribute to algae growth. This may be the case in 2023, which showed the highest concentrations of algae in the water column but also the lowest phosphorus on record.

The Little Bitterroot Lake has low primary productivity (oligotrophic) based on concentrations of chlorophyll-a and phosphorus, indicating the lake has very good water quality. Total nitrogen concentrations indicate the lake has potential for high productivity (eutrophic), but the lake is phosphorus limited which helps prevent nuisance algae blooms. When compared to 11 regional large lakes, Little Bitterroot Lake typically ranks in the top four for both major nutrients.

To improve or maintain water quality in Little Bitterroot Lake, efforts should be made to reduce sources of nutrients by limiting application of fertilizer, maintaining septic systems, keeping a vegetated buffer area, and reducing shoreline erosion. Fertilizers with little or no phosphorus are recommended to help maintain good water quality, so select fertilizers with a zero as the middle value (i.e. 16-0-0). Maintaining and not overloading septic systems is key for reducing nutrient inputs.

1.0 Introduction

Little Bitterroot Lake is the headwaters of the Little Bitterroot River located near the community of Marion at an approximate elevation of 3908 ft (1191 m) **(Figure 1)**. The lake has a maximum depth of 260 ft (80 m), a surface area of approximately 4.6 square miles (2,950 acres) and a drainage area of 34.4 square miles (22,000 acres). The area is in the Salish Mountains Ecoregion with a humid continental climate (Köppen classification Dfb) and an average annual precipitation of 21 inches. The geology of the watershed is primarily sedimentary rocks of the Belt series. The lake outlet is controlled by an earthen dam built in 1918 which is managed by the Flathead Irrigation Project for downstream irrigators. Herrig Creek is the only perennial stream flowing into the lake, although seven intermittent or ephemeral streams contribute seasonally. Groundwater contributes a substantial portion of water to the lake, especially from the Salish Mountains to the west and northeast. Local uses of the lake include water supply for domestic use, irrigation, fishing and recreation.

The Little Bitterroot Lake Association (LBLA) began in 1988 with the purpose of "preserving the high recreational value of Little Bitterroot Lake, maintaining its aesthetic integrity, and to educate the public and others as to the value of Little Bitterroot Lake as a recreational resource." Water quality monitoring has been conducted on the lake since 1999. The purpose of the monitoring program is to maintain a water quality and nutrient baseline for the inflow, outflow, and lake water during mid-summer, and to address emerging water quality issues as they arise. Information from this program may be used to make management decisions to help maintain the aesthetic and recreational conditions of the lake and surrounding drainages and to help prioritize future monitoring efforts. This report outlines the history of the monitoring program and presents water quality results from 2023 and past monitoring events. Long term trends in nutrient concentrations and trophic status are provided for consistent locations.

1.1 Monitoring Program History

Little Bitterroot Lake has been sampled 25 times since 1999. Data from 1999 to 2009 was collected sporadically from May to November; however, sampling from 2010 to 2023 has been consistently conducted in mid-summer to maintain continuity and evaluate long-term trends. Sampling is conducted during the first week of August in conjunction with the annual lake association meeting, although periodic spring and fall sampling has occurred to provide seasonal information. Data collected helps document existing water quality, track trends in nutrient concentrations, and characterize the lake's trophic status. Past monitoring events on Little Bitterroot Lake include:

November 30, 1999	May 24, 2000	September 27, 2004	September 1, 2005
September 25, 2006	October 8, 2007	October 13, 2008	October 5, 2009
June 3, 2010	August 23, 2010	September 20, 2011	September 10, 2012
May 20, 2013	August 29, 2013	August 11, 2014	August 11, 2015
August 3, 2016	August 2, 2017	June 13, 2018	July 31-August 1, 2018
August 7, 2019	August 5, 2020	August 4, 2021	August 3-4, 2022
August 3-4, 2023.			

Depth profile data is included which provides water quality information collected from depth at the lake center. This helps evaluate the stratification (layering) of the lake during mid-summer and identify where peak concentrations of algae may occur. These data were collected by Whitefish Lake Institute on August 9, 2023, as part of the Northwest Montana Lakes Volunteer Monitoring Network.

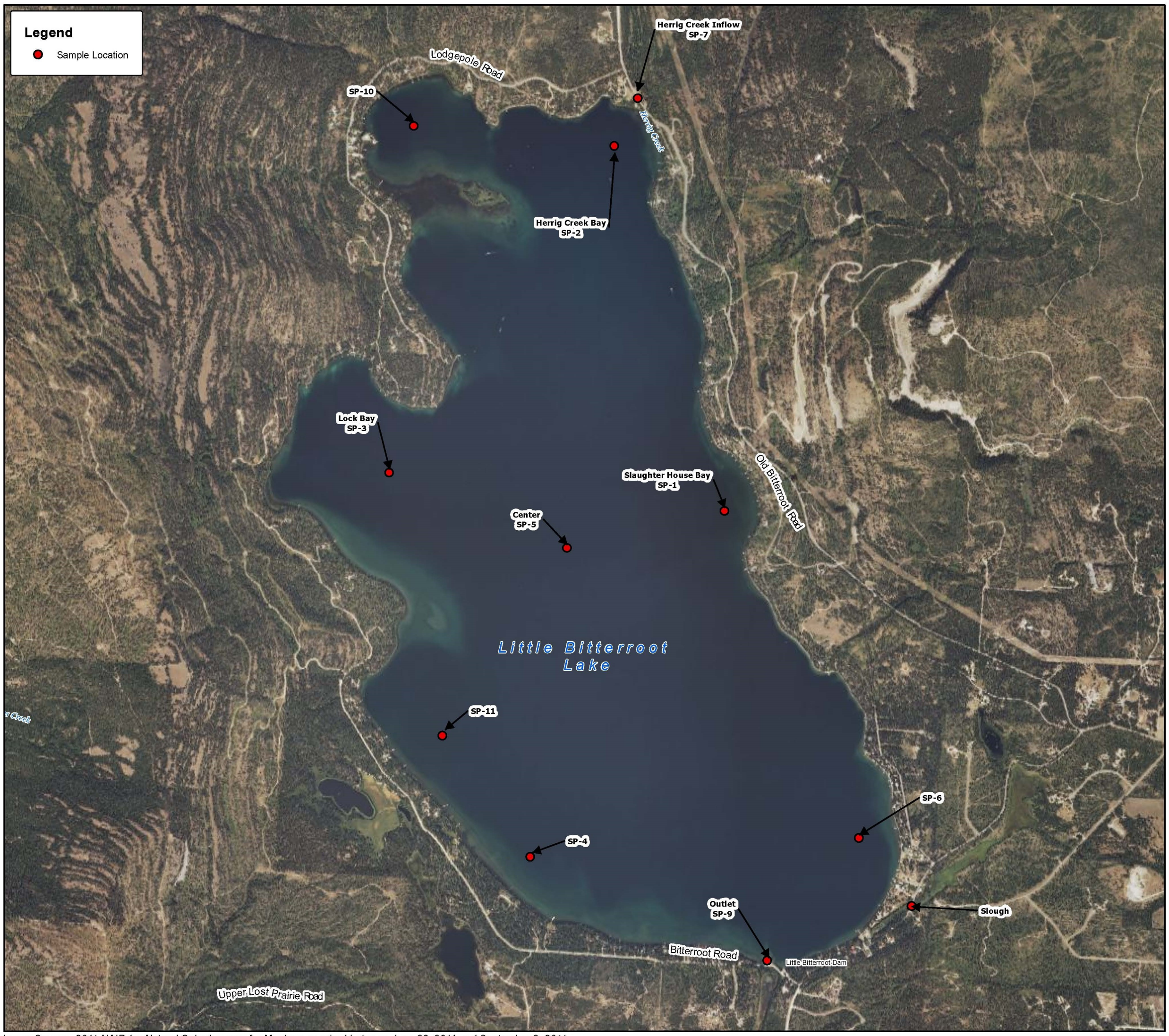

Image Source: 2011 NAIP 1m Natural Color Imagery for Montana acquired between June 23, 2011 and September 2, 2011

Figure 1. Little Bitterroot Lake Routine Sample Locations.

2.0 Field and Analytical Methods

Water quality monitoring is routinely conducted at 7 lake and 2 stream sites, including the inlet (Herrig Creek) and the outlet (Little Bitterroot River) (**Figure 1**). Routine monitoring is typically conducted in early August. In 2023, additional sampling was conducted at 12 near-shore sites for bacteria, nutrients, dissolved oxygen, and fluorescence, which may serve as an indicator of failing septic systems. These sites were sampled for all parameters during the August event and were sampled for dissolved oxygen and fluorescence during an extra June event. The sampling at these additional sites was conducted at early morning before sunrise in attempt to capture the lowest dissolved oxygen concentrations. Locations for these near-shore sites are shown with results in **Appendix A**.

Monitoring includes field measurements on-site and samples collected for lab analysis. Monitoring is routinely conducted at fixed locations although additional parameters and locations are added as warranted. Field parameters include water temperature, dissolved oxygen, specific conductance, and pH. Lab samples include nutrient parameters (total nitrogen and total phosphorus). Calcium and alkalinity samples are collected at several locations to evaluate the potential for colonization of aquatic invasive species, especially invasive mussels and non-native vegetation. Samples are also analyzed for chlorophyll-a from open water at several lake locations, and from rock surfaces at one or two sites annually. Chlorophyll-a samples provide a measure of algae growth in the water column. Bacteria (total coliform and E. coli) and fluorescence was added in 2023 at near-shore locations to help evaluate the potential of bacterial contamination from natural sources or septic sources. Depth profile monitoring is conducted annually at the lake center during mid-summer, which includes measurements of water temperature, specific conductance, dissolved oxygen, pH, and chlorophyll-a at depth. A summary of 2023 locations and parameters is provided below in **Table 1**.

Laboratory analyses in 2023 were provided by Energy Laboratories in Helena, MT, and funded by a grant from the Volunteer Monitoring Support Program administered by Montana Department of Environmental Quality (DEQ). Methods of each component of the monitoring program are summarized in the following sections. A complete description of field and analytical methods is available in the project Sampling and Analysis Plan (SAP) (Babcock, 2023), which is provided to Montana DEQ to procure funding from the volunteer monitoring grant program.

Table 1. 2023 Little Bitterroot Lake Sample Locations

Site ID	Site Description	Parameters	Rationale
SP-7	Inlet - Herrig Cr.	N/F/TSS/TOC/A/E	Inlet Stream
SP-2	Herrig Cr. Bay	N/F/CW	Bay near Inlet
SP-10	Northwest Bay	N/F/CW	Shallow Isolated Bay
SP-1	Slaughterhouse Bay	N/F/CW	Bay
SP-5	Lake Center – epi.	N/F/CW/TSS/TOC/A	Center, Deepest
SP-5-	Lake Center – meta.	N/F/CW	Center, metalimnion
SP-3	Locke Bay	N/F/CW/CB	Bay
SP-4	Southwest	N/F/CW	Near Development
SP-6	Southeast	N/F/CW/CB	Near Development
SP-9	Outlet - Ltl. Bitterroot	N/F/TSS/DOC/A/E	Outlet Stream
DO-1	Bitterroot Cove	N/F/E	Near Development
DO-2	Herrig Creek Bay	N/F/E	Near Development
DO-3	Northwest Bay	N/F/E	Near Development
DO-4	Lodgepole Bay	N/F/E	Near Development
DO-5	Locke Bay	N/F/E	Near Development
DO-6	Southwest 1	N/F/E	Near Development
DO-7	Southwest 2	N/F/E	Near Development
DO-8	Southeast 1	N/F/E	Near Development
DO-9	Southeast 2	N/F/E	Near Development
DO-10	Southeast 3	N/F/E	Near Development
DO-11	East Bay	N/F/E	Near Development
DO-12	Slaughterhouse Bay	N/F/E	Near Development

N=nutrients, F=field parameters, CW=chlorophyll-a in water, CB=chlorophyll-a from benthic substrate, TSS=total suspended sediment, DOC=dissolved organic carbon, A=alkalinity, E=E coli

2.1 Field Parameters

Field parameters are measured using a portable water quality meter (YSI brand) calibrated on the sample day. Measurements are taken in the upper 3' of the water column at lake locations, or within the flowing portion of stream locations. Parameters include water temperature, dissolved oxygen, specific conductance, and pH. Water clarity is measured at lake center using a Secchi disc. Stream flow is measured using a Marsh-McBirney electronic flow meter or visually estimated during low flow. Fluorescence was measured in 2023 using a hand-held fluorometer from Whitefish Lake Institute.

2.2 Laboratory Samples

Samples are collected for analysis in laboratory-provided bottles which are rinsed with sample water prior to collection. Bottles are filled from moving water at stream sites, and from just below the surface at lake sites. At the lake center, samples are collected from depth using a Van Dorn sampler. Samples are filtered or preserved as necessary and stored on ice or dry ice for delivery to the laboratory.

2.3 Algae Samples

Samples are collected from lake sites for chlorophyll-a, which provides a measure of algae growth in the water column. Chlorophyll-a samples are collected in amber glass bottles and are wrapped in aluminum foil to prevent exposure to sunlight, which can break down the chlorophyll and degrade sample integrity. Chlorophyll-a samples are collected from near the surface at 7 lake sites, and one sample was collected from a depth of 60' at the lake center using a Van-Dorn sampler. Samples are filtered in the field onto fiberglass filters which are stored on dry ice and then submitted to the laboratory for analysis.

Benthic algae samples are collected to measure the algal growth on shoreline rocks. For benthic algae samples, flat rocks are selected that display representative algae conditions for the area. A template is placed on the rock, and algae are removed from inside the template by scraping and brushing. The algae are filtered on a glass filter, placed in a centrifuge tube, wrapped in aluminum foil, and stored on dry ice for delivery to the laboratory. Several template samples are collected at each location.

2.4 Bacteria Samples

Bacteria samples were added to the routine monitoring program in 2023 at near-shore locations. Samples are analyzed for total coliform and E coli bacteria. Total coliform is a measure of background bacteria and may not reflect harmful bacteria, although high numbers indicate greater potential for harmful bacteria to be present. E coli is harmful bacteria that exists only in warm blooded animals and is an indicator of fecal contamination from animal or human sources. Bacteria samples have a short holding time and must be collected immediately prior to delivery to the laboratory. Samples are collected in laboratory-provided bottles which contain the appropriate preservative.

2.5 Depth Profile Sampling

Depth profile sampling is conducted at the lake center to evaluate changes in field parameters at depth, which indicate the degree of lake stratification, or layering, at the time of sampling. Depth profile sampling is conducted by Whitefish Lake Institute using a portable Hydrolab water quality meter which measures depth, chlorophyll-a, water temperature, specific conductance, dissolved oxygen, and pH. In 2023 the Hydrolab had a maximum sampling depth of 230 ft, which is close to the full depth of Little Bitterroot Lake. Past profiles prior to 2022 have been limited to 140 ft.

4.0 2023 Monitoring Results

Routine sampling for field and nutrient parameters was conducted on August 3. Air temperature ranged from 21 to 33°C (70 to 91°F) with full sun and a light breeze. Additional sampling at near-shore sites for bacteria, nutrients, dissolved oxygen, and fluorescence were conducted on the morning of August 4. An additional sampling event was conducted in spring on June 17 which was limited to dissolved oxygen and fluorescence during pre-dawn hours when dissolved oxygen was expected to be lowest. Depth profiles were collected on August 9, 2023, by Whitefish Lake Institute.

4.1 2023 Field Results

Field results from 2023 are provided in **Table 2** below. For a visual comparison over time and by location, statistical boxplots are also provided in **Appendix B** which show the range of field parameters from 2010 to 2023. The boxplots show the maximum, minimum, and interquartile values for each year. Long-term trends are also discussed in **Section 4.8** of this report.

Table 2. 2023 Routine Monitoring Results.

Site Description	Field Water Quality				Nutrients		Chlorophyll-a	
	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Specific Conductance (uS/cm)	pH	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Algae in Water (mg/L)	Benthic Algae (mg/m^2)
	Analytical Detection Limits →				0.04	0.003	0.1	0.1
North - Herrig Cr. Bay	21.0	7.1	108	7.98	**0.21**	0.002	0.1	
Northwest - Northwest Bay	21.1	7.4	108	7.93	**0.14**	0.002	0.1	
West - Lodgepole Bay	21.4	7.4	106	7.91	**0.16**	**0.003**	0.1	
East - Slaughter House Bay	21.8	7.3	108	7.80	**0.15**	**0.003**	0.2	
West - Locke Bay	21.2	7.3	108	7.91	**0.15**	**0.003**	0.2	
Lake Center - Near Surface	21.6	7.0	108	7.84	**0.16**	0.002	0.2	
Lake Center - 60' depth	6.7	11.9	105	7.88	**0.13**	0.001	3.4	
Southwest - Southwest Bay	21.3	7.5	108	7.79	**0.14**	**0.003**	0.1	
Southeast - Southeast Bay	21.8	7.1	108	7.88	**0.13**	0.001	0.1	
Herrig Creek - inlet	19.4	7.8	51	6.71	**0.25**	**0.014**		
Ltl. Bitterroot River - outlet	24.7	6.4	113	7.43	**0.20**	**0.003**		**6.4**

The analytical detection limit for water quality parameters are provided below the constituent name.
Values in **BOLD** are above the analytical detection limit.

During August 2023 event, the lake had a surface temperature ranging from 21.0 to 21.8°C (69.8 to 71.2°F). Herrig Creek was contributing cooler water around 19.4°C (66.9°F) at a flow of approximately 2.0 CFS (900 gallons per minute, GPM). The Little Bitterroot River at the outlet was warmer than all lake sites at 24.7°C (76.5°F) and had flow of 4.0 CFS (1800 GPM). 2023 was among the top four years in average water temperature from 2010 to present.

The pH at lake sites varied between 7.79 and 7.98, while the inlet and outlet streams measured 6.71 and 7.43, respectively. The average lake pH (7.88) was near the mid-range of all years from 2010 to 2023. Biological activity by plants and algae raises pH during daytime hours when photosynthesis is occurring, so pH can be influenced by time of sampling during biologically productive years.

Dissolved oxygen (DO) varied from 7.0 to 7.5 mg/L at the lake sites and was at 7.8 mg/L in the inlet stream and 6.4 mg/L in the outlet stream. Average DO in 2023 (7.3 mg/L) was among the lowest on record; however, DO can be quite variable depending on time of day. Dissolved oxygen is influenced by biological activity which raises DO during daytime hours, and cooler water can hold more dissolved oxygen, so the low DO measured in 2023 is likely due to the higher lake temperatures.

Specific conductance was quite low in the inlet stream (51 µS/cm) but uniformly around 106-108 µS/cm at the lake sites. The average SC in 2022 (108 µS/cm) was near the mid-range on record since 2010. Specific conductance a measure of dissolved constituents in water, and values are generally lower in surface water sources than groundwater.

4.2 2023 Nutrient Results

Nutrient results from 2023 are provided with field results above in **Table 2**. Data for total nitrogen (TN) and total phosphorus (TP) are also shown spatially below in **Figures 2-3**, organized left to right from the lake inlet (Herrig Creek) to the lake outlet (Little Bitterroot River).

In 2023, total nitrogen concentrations were relatively low and comparable throughout the lake, varying from 0.13 to 0.21 mg/L. Herrig Creek had the highest concentration (0.25 mg/L), and the outlet at the Little Bitterroot River (0.20 mg/L) was relatively high. The average TN in 2022 (0.154 mg/L) was above average for all lake samples collected from 2010-2022 (0.145 mg/L).

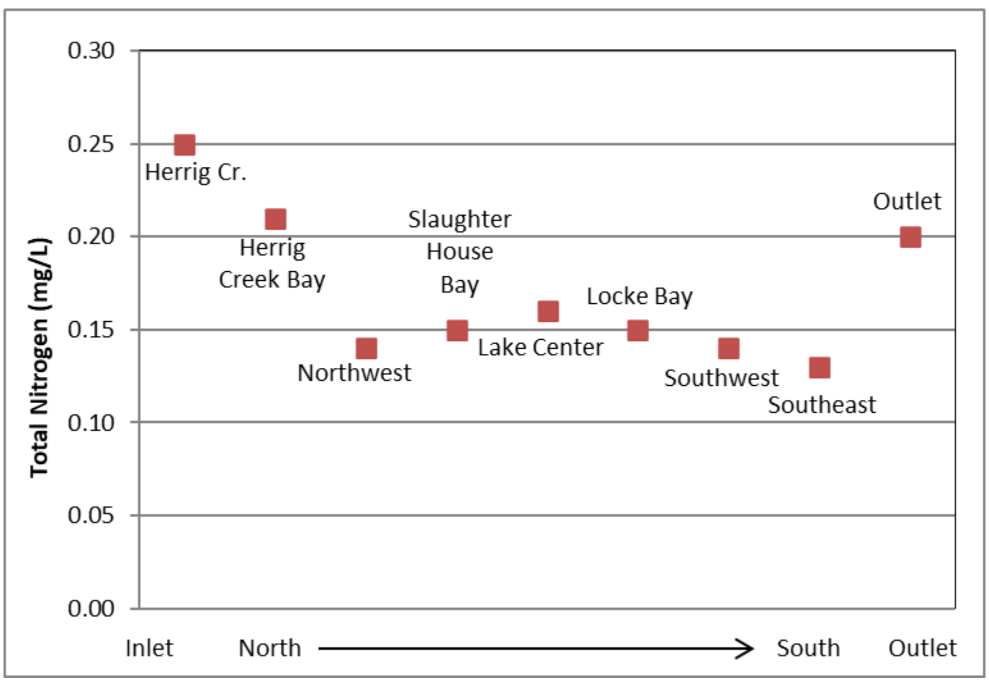

Figure 2. 2023 Total Nitrogen Results.

Total phosphorus measurements in 2023 ranged from 0.001-0.003 mg/L at lake sites. Herrig Creek measured 0.014 mg/L while the lake outlet was 0.003 mg/L. Little Bitterroot Lake has historically had low concentrations of total phosphorus and is phosphorus-limited. Inputs of phosphorus from the inlet stream or groundwater are likely consumed by algae and plants within the lake, resulting in lower measurements of TP in mid-summer. The average TP in 2023 (0.002 mg/L) was the lowest on record.

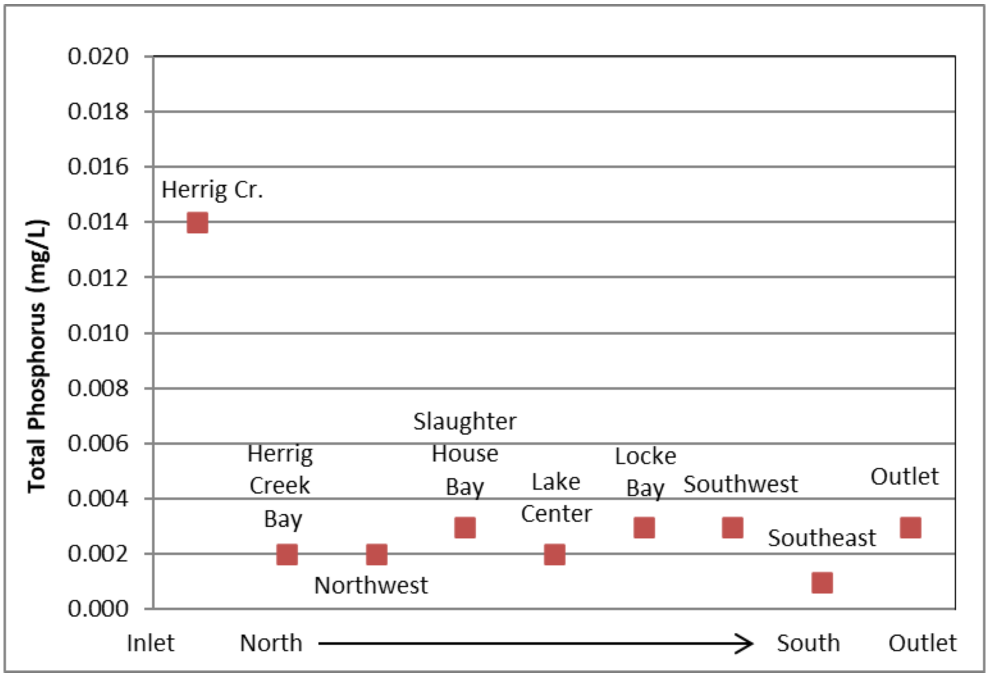

Figure 3. 2023 Total Phosphorus Results.

4.3 2023 Chlorophyll-a Results

Results from chlorophyll-a sampling in 2023 are presented above in **Table 2**. Samples were collected from 10 locations in August 2023, including 8 from the lake surface, 1 from 60' depth at lake center, and 1 benthic algae sample from natural substrate. In August 2023, algae growth in the lake water was above the analytical detection at all sample sites (<0.1 mg/L) which is uncommon for Little Bitterroot Lake. Algae typically peaks near a depth of 60'; however, Hydrolab data collected from Whitefish Lake Institute shows that chlorophyll-a peaked at a depth of 95' in August 2023 (6.69 mg/L) which is the second highest peak on record since 2014. Additional profile data are provided in **Section 4.6**.

Attached (benthic) algae was sampled at one location in August 2023 at the outlet channel of the Little Bitterroot River, which measured 6.4 mg/m^2. Benthic algae concentrations (apart from isolated algae blooms) have ranged from 0.1 to 8.8 mg/m^2 since sampling began in 2014. Prolific algae growth can be a problem because it consumes oxygen from the water column during the night, which can cause low oxygen levels for fish and other aquatic organisms. Algae can also be a physical nuisance to homeowners and recreationists due to prolific growth. Isolated benthic algae blooms are often spotted around the lake, especially in areas suspected of having an input of nutrient rich water; however, benthic algae results from sampling are generally low and below nuisance levels. The outlet channel of the Little Bitterroot River has been sampled for several years because it contains flat, undisturbed substrate suitable for sampling, and the water quality is similar to the lake.

4.4 2023 Additional Near-Shore Bacteria and Fluorescence Results

Additional sampling was conducted at 12 near-shore sites on the early mornings of July 17 and August 4, 2023, to evaluate dissolved oxygen concentrations in pre-dawn conditions and to look for indicators of septic leakage. These samples were collected between the hours of 05:00 and 07:00 when dissolved oxygen concentrations are expected to be lowest. In August, additional sampling was conducted for bacteria (total coliform and E coli) and total nutrients (nitrogen and phosphorus). These results are presented below in **Table 3**. Pre-dawn dissolved oxygen ranged from 8.1 to 8.6 mg/L in June 2023, and from 7.1 to 7.8 mg/L in August. These values are all above the threshold for aquatic life (5 mg/L) which indicates that Little Bitterroot Lake does not have oxygen limitation concerns.

Table 3. Additional Near-Shore Results for DO, Bacteria, Nutrients

Date	Site ID	Site Description	Field Water Quality			Bacteria		Nutrients	
			Water Temp. (°C)	Dissolved Oxygen (mg/L)	Fluor - escence	E Coli Bacteria (#/100ml)	Total Coliform (#/100ml)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
			Analytical Detection Limits →			1.0	1.0	0.04	0.003
06/17/23	DO-1	Bitterroot Cove	17.4	8.07	7.38				
06/17/23	DO-2	Herrig Creek Bay	17.2	8.50	7.73				
06/17/23	DO-3	Northwest Bay	17.2	8.61	6.94				
06/17/23	DO-4	Lodgepole Bay	17.2	8.55	6.48				
06/17/23	DO-5	Locke Bay	17.3	8.56	7.48				
06/17/23	DO-6	Southwest 1	17.1	8.59	8.38				
06/17/23	DO-7	Southwest 2	17.2	8.06	6.67				
06/17/23	DO-8	Southeast 1	17.3	8.33	6.98				
06/17/23	DO-9	Southeast 2	17.4	8.47	6.52				
06/17/23	DO-10	Southeast 3	17.3	8.50	8.06				
06/17/23	DO-11	East Bay	17.3	8.45	6.67				
06/17/23	DO-12	Slaughterhouse Bay	17.3	8.34	6.97				
08/04/23	SP-7	Inlet - Herrig Creek	19.4	7.82	79.50	70.8	2419.6	0.25	0.014
08/04/23	DO-1	Bitterroot Cove	21.0	7.20	5.43	0	29.9	0.17	0.001
08/04/23	DO-2	Herrig Creek Bay	20.9	7.14	6.17	0	28.5	0.14	0.002
08/04/23	DO-3	Northwest Bay	20.7	7.75	6.35	10.9	117.8	0.15	0.001
08/04/23	DO-4	Lodgepole Bay	20.9	7.24	5.57	6.3	178.5	0.13	0.001
08/04/23	DO-5	Locke Bay	20.9	7.28	6.30	0	18.5	0.22	0.001
08/04/23	DO-6	Southwest 1	21.2	7.07	6.34	0	52.9	0.20	0.001
08/04/23	DO-7	Southwest 2	21.2	7.25	6.78	0	105.0	0.21	0.001
08/04/23	DO-8	Southeast 1	21.6	7.21	6.88	0	226.0	0.20	1.000
08/04/23	DO-9	Southeast 2	21.8	7.18	6.98	2.0	248.9	0.21	0.001
08/04/23	DO-10	Southeast 3	21.8	7.09	5.40	0	159.1	0.22	0.001
08/04/23	DO-11	East Bay	21.8	7.25	6.40	0	108.6	0.21	0.001
08/04/23	DO-12	Slaughterhouse Bay	21.0	7.10	5.78	0	130.1	0.21	0.001

Concentrations of bacteria samples were highest in Herrig Creek, which suggests that the inlet stream is a source of bacterial contamination. Total coliform bacteria were highest near the south boat ramp and the highest sample of E coli in the lake was collected in the Northwest Bay. Total coliform provides a measure of background bacteria concentrations, and it was detected in all samples. High values of total coliform can indicate bacterial contamination, although not all bacteria are harmful. E coli is a harmful bacteria found in warm-blooded animals, so it's presence can be an indicator of contamination from human or animal waste, although differentiating between human and animal sources can be challenging.

Water quality standards for bacteria vary based on the water quality classification of the waterbody. Little Bitterroot Lake and Herrig Creek do not have a water quality classification; however, similar waters classified as B-1 require that "from April 1 through October 31, the geometric mean number of E-coli may not exceed 126 colony forming units per 100 milliliters and 10 percent of the total samples may not exceed 252 colony forming units per 100 milliliters during any 30-day period". The sample collected from Herrig Creek has previously exceeded the mean standard value for B-1 waters, however, all other lake samples were below this threshold. Based on these results, further bacteria sampling of Herrig Creek may be warranted in future years.

Fluorescence was measured at the 12 near-shore locations using a hand-held meter on loan from Whitefish Lake Institute. Fluorescence can act as an indicator of failing septic systems because fluorescent dyes are common in household products such as laundry detergent. The intent of fluorescence sample was to detect spatial differences around the lake that may indicate areas with failing or overloaded septic systems. These results do not provide concrete quantitative evidence but show relative differences between sites. Fluorescence results were ultimately inconclusive in 2023 because there were no obvious spatial patterns detected. The results of this study are described in more detail and shown graphically in **Appendix A**.

4.5 2023 AIS Related Parameters and Foaming Agents

AIS-related water quality parameters were added to the sampling program in 2018 to evaluate the potential for colonization from aquatic invasive species, especially mussels who rely on calcium for shell growth. Calcium and alkalinity were collected in August 2023 at the lake center and the inlet and outlet streams (**Table 4**). Calcium concentrations were lowest in Herrig Creek (5 mg/L) and highest at the lake center and outlet (13 mg/L). Previous calcium concentrations from lake samples have ranged from 12.1 – 14.6 mg/l, which indicates that calcium concentrations are relatively stable in Little Bitterroot Lake and the surrounding watershed. Alkalinity concentrations in 2023 ranged from 26 mg/L in Herrig Creek to 52 mg/L in the Little Bitterroot River.

Risk categories have been published for determining the likelihood of invasive mussel establishment (Wells et al., 2011). Risk categories based on calcium are defined as very low (<12 mg/L), low (12-15 mg/L), medium (15-25 mg/L), and high (>25 mg/l). Calcium concentrations measured in Little Bitterroot Lake would put the lake at a low risk of mussel establishment, however, established mussel populations have been found in lakes with significantly lower calcium concentrations (<10 mg/L) than Little Bitterroot Lake. Furthermore, alkalinity and bicarbonate concentrations are within the range of concentrations to support mussel establishment. Compared to regional large lakes, Little Bitterroot Lake has the second lowest concentrations of calcium and alkalinity.

Foaming agents, also called surfactants, were added to the routine sampling sites in 2023. These samples can also act as indicators of failing septic systems because they detect compounds commonly found in household detergents. These samples have a relatively high detection limit and were detected in just 4 locations, Slaughterhouse Bay, the lake center, and the southwest and southeast corners of the lake. This was the first year of sampling for foaming agents, and results were relatively inconclusive in 2023 because of the high detection limit. If foaming agents are sampled in future years, a lower laboratory detection limit is recommended, and samples should be collected at near-shore locations.

Table 4. AIS Parameters and Foaming Agents

Sample Info			Additional Samples			
Site	Date	Site Description	Calcium (mg/L)	Alkalinity (mg/L)	Total Organic Carbon (mg/L)	Foaming Agents (mg/L)
			1.0	1.0	0.5	1.0
SP-2	8/3/23	North - Herrig Cr. Bay				0.0
SP-10	8/3/23	Northwest - Northwest Bay				0.0
SP-12	8/3/23	West - Lodgepole Bay				0.0
SP-1	8/3/23	East - Slaughter House Bay				**1.0**
SP-3	8/3/23	West - Locke Bay				0.0
SP-5	8/3/23	Lake Center - Near Surface	**13**	**52**	0.0	**1.0**
SP-4	8/3/23	Southwest - Southwest Bay				**1.0**
SP-6	8/3/23	Southeast - Southeast Bay				**1.0**
SP-7	8/3/23	Herrig Creek - inlet	**5**	**26**	**1.0**	
SP-9	8/3/23	Ltl. Bitterroot River - outlet	**13**	**52**	**0.4**	

The analytical detection limit for water quality parameters are provided below the constituent name.
Values in **BOLD** are above the analytical detection limit.

4.6 2023 Depth Profile Results

Depth profile sampling was conducted on August 9, 2023, to show changes in water chemistry at depth. Results from the depth profile sampling are shown in **Figure 4**, including charts for water temperature, dissolved oxygen, pH, and chlorophyll-a. Results from 2014 to present are shown for comparison, with 2023 data highlighted in red. Large scale charts are also provided in **Appendix C**.

In August 2023 the lake was thermally stratified with an epilimnion (upper layer) from 0 to 25 feet, a metalimnion (transitional layer) from 25 to 80 feet, and a hypolimnion (bottom layer) from 80 feet to the lake bottom. Near-surface temperatures were among the highest on record, which may have contributed to the algae growth measured in 2023.

Depth profile measurements of pH in 2023 were among the lowest on record, which was somewhat unexpected because biological activity can raise pH values. pH typically increases to more than 8.0 within the photic zone where algae are most prevalent; however, in 2023 pH measured 7.9 in the photic zone. pH in the hypolimnion (deep portion of the lake) was also especially low in 2023.

Dissolved oxygen (DO) measured 7.9 mg/L in the upper epilimnion in August 2023, with the peak occurring 68' below the lake surface (12.2 mg/L). DO measurements were relatively low throughout the water column in 2023, which could be expected during a warm year because warm water holds less oxygen. DO peaks just above the area with the highest algae growth because algae produce oxygen during photosynthesis and the oxygen rises in the water column. Dissolved oxygen concentrations are well above the threshold for aquatic life (5 mg/L) throughout the water column, which is typical of a lake with good water quality.

The depth profile for chlorophyll-a in August 2023 showed the highest concentrations on record, with a peak concentration of 6.6 ug/L at 95’ depth. This was a stark contrast with 2022 which had no detectable concentrations above 60’ and the lowest peak on record. Chlorophyll-a is a measurement of algae production within the water column, and photosynthetic algae (phytoplankton) peak at the depth where availability of light, nutrients, and water density are optimal for algae growth. 2023 was a relatively warm year which likely contributed to the higher algae concentrations measured in August.

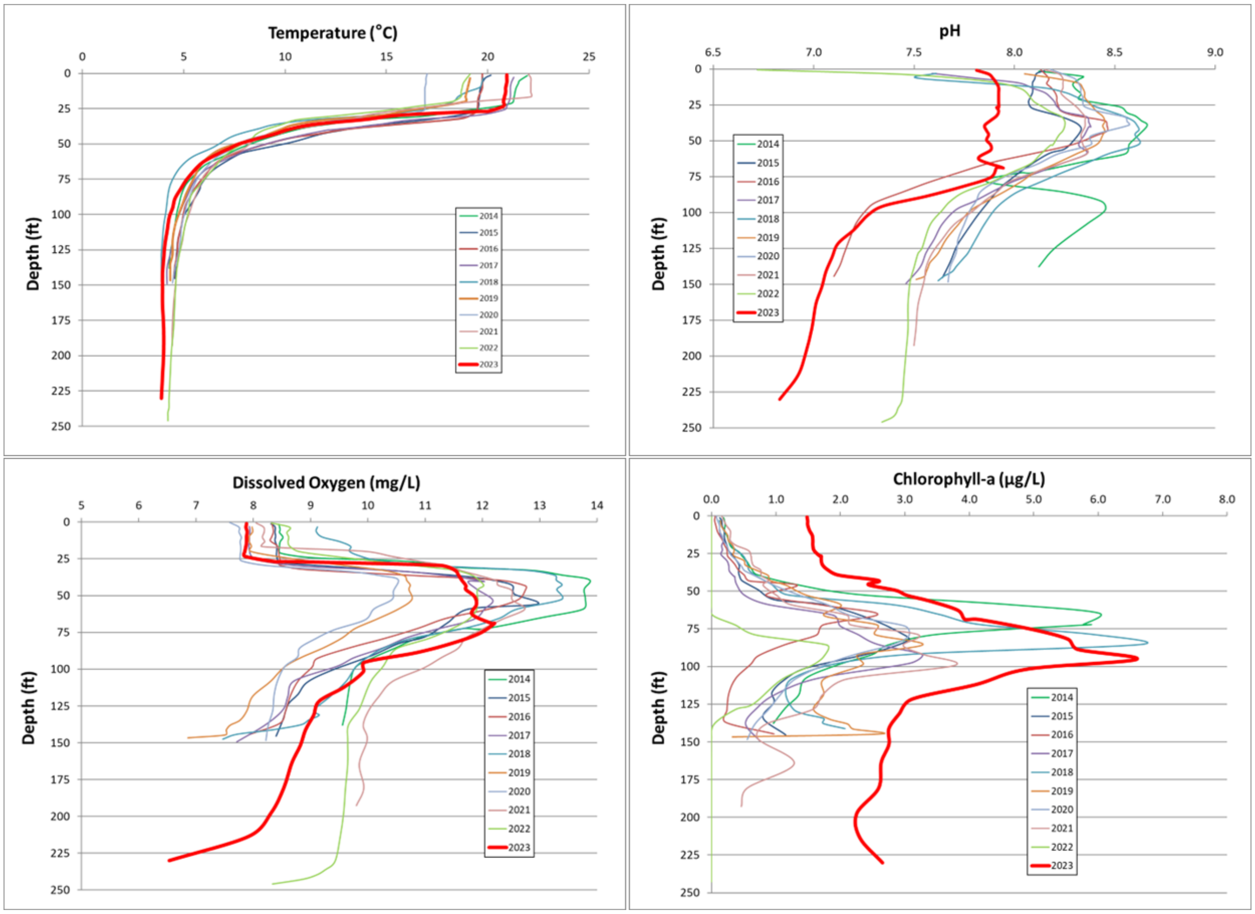

Figure 4. 2023 Depth Profile Results.

4.7 Trophic Status

Trophic status is a lake’s ability to produce and sustain populations of algae in response to available nutrients, also referred to as biological productivity. High biological productivity is an indicator of high nutrients and poor water quality, whereas low productivity is an indicator of low nutrient concentrations and good water quality. The trophic status of Little Bitterroot Lake was determined using the Carlson’s Trophic State Index (TSI) for measurements of total nitrogen, total phosphorus, and chlorophyll-a (Carlson, 1977). The TSI for Little Bitterroot Lake is shown in **Figure 5** for data from 2010 to present.

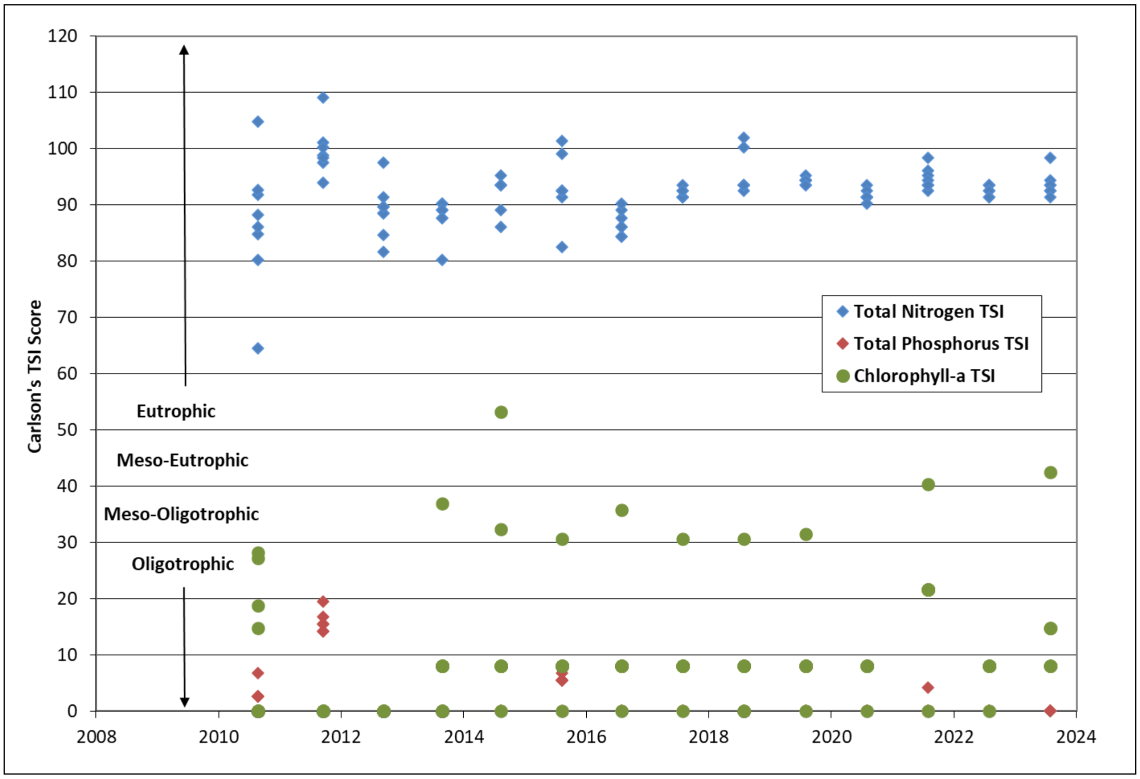

Figure 5. Carlson's Trophic State Index 2010-2023.

TSI data suggest that Little Bitterroot Lake is eutrophic based on concentrations of total nitrogen; however, measurements of total phosphorus and chlorophyll-a indicate that the lake is oligotrophic with low biological productivity. Despite having relatively high concentrations of total nitrogen, Little Bitterroot Lake typically does not experience large blooms of nuisance algae and has shown low concentrations of chlorophyll-a from 2010 to 2023. The low productivity is likely because the lake's morphology is favorable to oligotrophic conditions and limited by low phosphorus concentrations. Little Bitterroot Lake has steep sides, limited shallow shoreline habitat, and a low watershed/lake ratio of 4.8 (Ellis et al, 1998), all which help limit biological production. The lake is also phosphorus-limited, meaning that it has an adequate amount of nitrogen compared to the amount of phosphorus needed to support algae growth. Lakes that are phosphorus-limited often show increased algae growth when phosphorus concentrations increase, but not necessarily when nitrogen concentrations increase. Total phosphorus is commonly associated with sediment, so high concentrations often occur in years following land disturbance (such as road building or logging) or increased precipitation and runoff.

4.8 Long Term Trends

Little Bitterroot Lake has been sampled since 1999, although dates and locations have only been consistent since 2010 when mid-summer sampling became standard. As a result, data collected prior to 2010 is often outside the mid-summer window and may not be directly comparable for long-term trend analysis, but the data are still valuable for providing seasonal water quality information. Therefore, long-term trends are evaluated for lake sites only from the period of 2010 to present to ensure data are comparable based on location and time of year. Long-term trend results from 2010 to 2023 are shown below in **Figure 6** for total nitrogen and phosphorus, which shows concentrations for lake sites as well as the inlet and outlet streams for comparison, but trend lines are for lake data only. Long-term data are provided for individual sites in **Appendix D**.

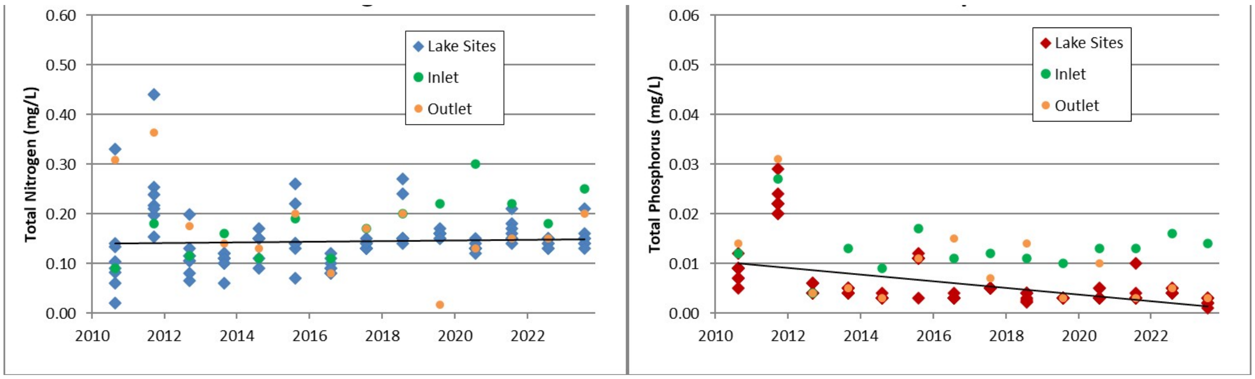

Figure 6. Long-term Trends 2010-2023.

Total nitrogen concentrations show a slightly increasing trend since 2010, however, the highest values were recorded in 2011 and the upward trend is more apparent past 2012. Total phosphorus shows a decreasing trend from 2010 to 2023, however, this trend is influenced by high values in 2011. Still, TP concentrations have been very low in recent sampling years, and TP typically shows its highest concentrations during high runoff years such as 2011 because it is commonly bound with sediment.

The decreasing trend in TP concentration is encouraging but data should be interpreted with caution because of the limited seasonal data available for Little Bitterroot Lake. Nutrient concentrations can vary between seasons or change rapidly due to episodic events such as runoff, blooms, or lake turnover, so sample events may not coincide with periods of peak nutrient concentrations. Data and trends become more robust as future measurements are added to the dataset, and continuity and consistency are maintained within the monitoring program.

The ratio between nitrogen and phosphorus is also analyzed for long term trends. Within a lake system, algae growth is optimized when the ratio between nitrogen and phosphorus is near 16:1. A ratio higher than 16:1 indicates that the system has sufficient nitrogen for algae growth, but phosphorus is limited. Conversely, a ratio lower than 16:1 indicates that the system has limited nitrogen for algae growth but has enough phosphorous. **Figure 7** displays the trend in N:P ratio from 2010 to present on Little Bitterroot Lake. The 16:1 ratio is indicated by the green line on the graph, and the trend line is shown as the dashed line. In 2023, the average N:P ratio was 27.3 (indicating that the lake is phosphorus limited), and the N:P ratio appears to be increasing from 2010 to 2022. This is occurring because concentrations of total nitrogen show an increasing trend from 2010 to present, while concentrations of total phosphorus have been decreasing over the same period.

This trend with increasing nitrogen is prevalent across the western United States and is expected with increased human occupation around lake communities. Nitrogen is a nutrient that is commonly associated with human sources such as septic systems or fertilizers and increasing trends in nitrogen concentrations are commonly seen around growing lake communities. Phosphorus is more commonly associated with natural sources such as surrounding geology or soils, and human sources can more easily be controlled with appropriate erosion or sediment control practices (although septic systems are also a primary source of phosphorus to lake systems). As a result, Little Bitterroot Lake has become increasingly phosphorus limited during this period of study, and land management around the lake should encourage practices that limited additional inputs of phosphorus by maintaining shoreline vegetation, limiting land clearing, and avoiding fertilizers that are high in phosphorus. Proper maintenance of septic systems will also help reduce nutrient inputs to Little Bitterroot Lake.

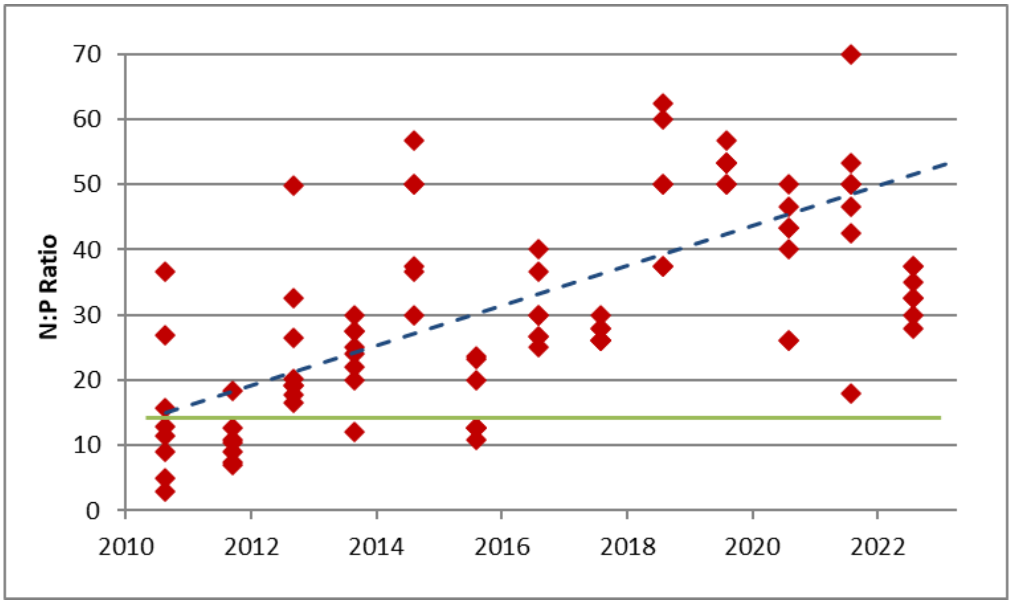

Figure 7. Nitrogen:Phosphorus Ratio 2010-2023.

4.9 Spatial Trends

Nutrient data are collected routinely at 7 locations on Little Bitterroot Lake which helps evaluate spatial trends such as influences from Herrig Creek, isolated bays, or areas with increased development. Spatial data are shown in **Figure 8** from 2010-2023 for all lake sites and the inlet and outlet streams. Data are organized from left to right in the direction of flow through the lake. Since 2010, the highest average concentration of total nitrogen is from Herrig Creek, which influences concentrations in Herrig Creek Bay to have the second highest average concentration. The lowest average concentration of TN is at Slaughterhouse Bay. Total phosphorus shows similar trends with the highest concentrations coming from Herrig Creek, although the lowest average concentration of TP is measured at the lake center. In general, the lake shows little spatial variability, but by maintaining consistency with locations and sample timing these trends will become more robust over time and may reveal spatial differences in nutrient concentrations. Spatial data are also provided as statistical boxplots in **Appendix B**, which show the minimum, maximum, and interquartile range for each site.

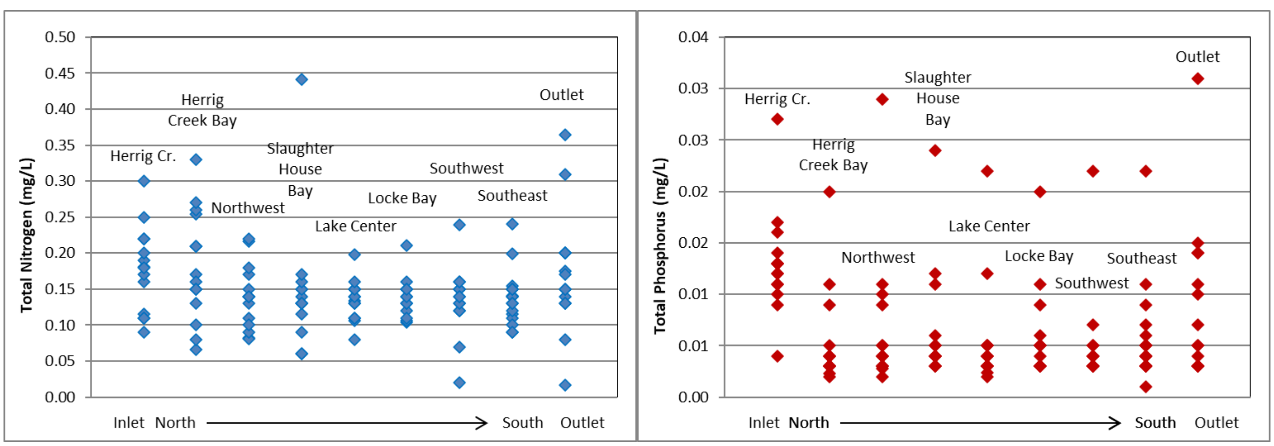

Figure 8. Spatial Trends 2010-2023.

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Appendix A – 2023 Near-Shore Sampling

Little Bitterroot Lake – Spring Sampling Summary June 2023

Introduction: Little Bitterroot Lake was sampled on the morning of June 18, 2023, to evaluate spatial differences in pre-dawn dissolved oxygen and fluorescence around the lake as required for the Volunteer Monitoring Grant Program of Montana DEQ and the equipment grant provided by Flathead Lake Biological Station.

Methods: Spring monitoring was conducted between the hours of 05:00 and 06:00 AM on June 18, 2023, under overcast skies with intermittent light rain and air temperature near 50°F. Dissolved oxygen (DO), water temperature, and optical fluorescence were measured at 12 locations on Little Bitterroot Lake, including isolated bays and areas close to development. DO and temperature were measured using a YSI Pro 20 meter which was calibrated on the morning of sampling. Fluorescence was measured using a handheld meter. DO and temperature measurements were taken from approximately 3' below the lake surface. Fluorescence was measured using water collected from near the lake surface. The ampule for the fluorometer was rinsed three times prior to sample collection.

Results: **Table 1** below presents results from the June 2023 sampling event. DO values ranged from 8.06 to 8.61 mg/L, which represents 97.0% to 103.6% saturation. This indicates that DO was near full saturation on the morning of June 18 with no impairment due to low oxygen. There were no obvious spatial patterns with DO concentration in June 2023. Fluorescence values ranged from 6.48 to 8.38. The lowest reading was measured in the small bay north of Locke Bay, and the highest reading was recorded in the southwest corner of the lake. No spatial patterns existed with fluorescence on the morning of June 18.

Conclusion: No spatial patterns were detected for DO or Fluorescence in June 2023, and DO concentrations were near saturation and well above concentrations detrimental to aquatic life.

Table 1. June and August 2023 DO and Fluorescence Results

Site	Location	June 2023			August 2023		
		Temp. (°C)	DO (mg/L)	Fluor.	Temp. (°C)	DO (mg/L)	Fluor.
DO-1	Bitterroot Cove	17.4	8.07	7.38	21.0	7.20	5.43
DO-2	Herrig Creek Bay	17.2	8.50	7.73	20.9	7.14	6.17
DO-3	Northwest Bay	17.2	8.61	6.94	20.7	7.75	6.35
DO-4	Smaller NW Bay	17.2	8.55	6.48	20.9	7.24	5.57
DO-5	Locke Bay	17.3	8.56	7.48	20.9	7.28	6.30
DO-6	SW #1	17.1	8.59	8.38	21.2	7.07	6.34
DO-7	SW #2	17.2	8.06	6.66	21.2	7.25	6.78
DO-8	SE #1	17.3	8.33	6.98	21.6	7.21	6.88
DO-9	SE #2 Bailey's	17.4	8.47	6.52	21.8	7.18	6.98
DO-10	SE #3 Kelcey Ct	17.3	8.50	8.06	21.8	7.09	5.40
DO-11	East Bay	17.3	8.45	6.67	21.8	7.25	6.40
DO-12	Slaughterhouse Bay	17.3	8.34	6.96	21.0	7.10	5.78

Little Bitterroot Lake – Summer Sampling Summary August 2023

Introduction: Little Bitterroot Lake was sampled on the mornings of August 3 and 4, 2023, to evaluate spatial differences in nutrient concentrations, pre-dawn dissolved oxygen and fluorescence around the lake. Routine nutrient monitoring was conducted on the morning of August 3, and pre-dawn DO and fluorescence was measured on August 4 similar to the June event.

Methods: Routine water quality monitoring was conducted between the hours of 10:00 and 05:00 PM on August 3, 2023, under sunny skies with air temperature near 80-90°F. Field measurements and laboratory samples were collected at 8 locations on Little Bitterroot Lake and at the inlet and outlet stream. These results will be analyzed for long-term trends and presented in the annual summary report.

Pre-dawn dissolved oxygen (DO) and optical fluorescence were measured at 12 lake locations on the morning of August 4, 2023, between the hours of 05:30 and 07:00 AM. DO, temperature, and fluorescence were measured using the same methods as the June event.

Results: **Table 1** above presents DO and fluorescence results from the August 2023 sampling event for comparison with data collected in June. DO values ranged from 7.07 to 7.28 mg/L with saturation ranging from 90.5% to 94.7%. There were no obvious spatial patterns with DO concentration. Fluorescence values ranged from 5.40 to 6.98. No spatial patterns existed with fluorescence on the morning of August 4.

Conclusion: This represents the second DO/fluorescence sampling event of 2023. **Figure 1** presents the relative ranking of fluorescence results for June and August 2023. No spatial patterns were detected for DO or fluorescence in spring or summer, and DO concentrations were near saturation and well above concentrations detrimental to aquatic life.

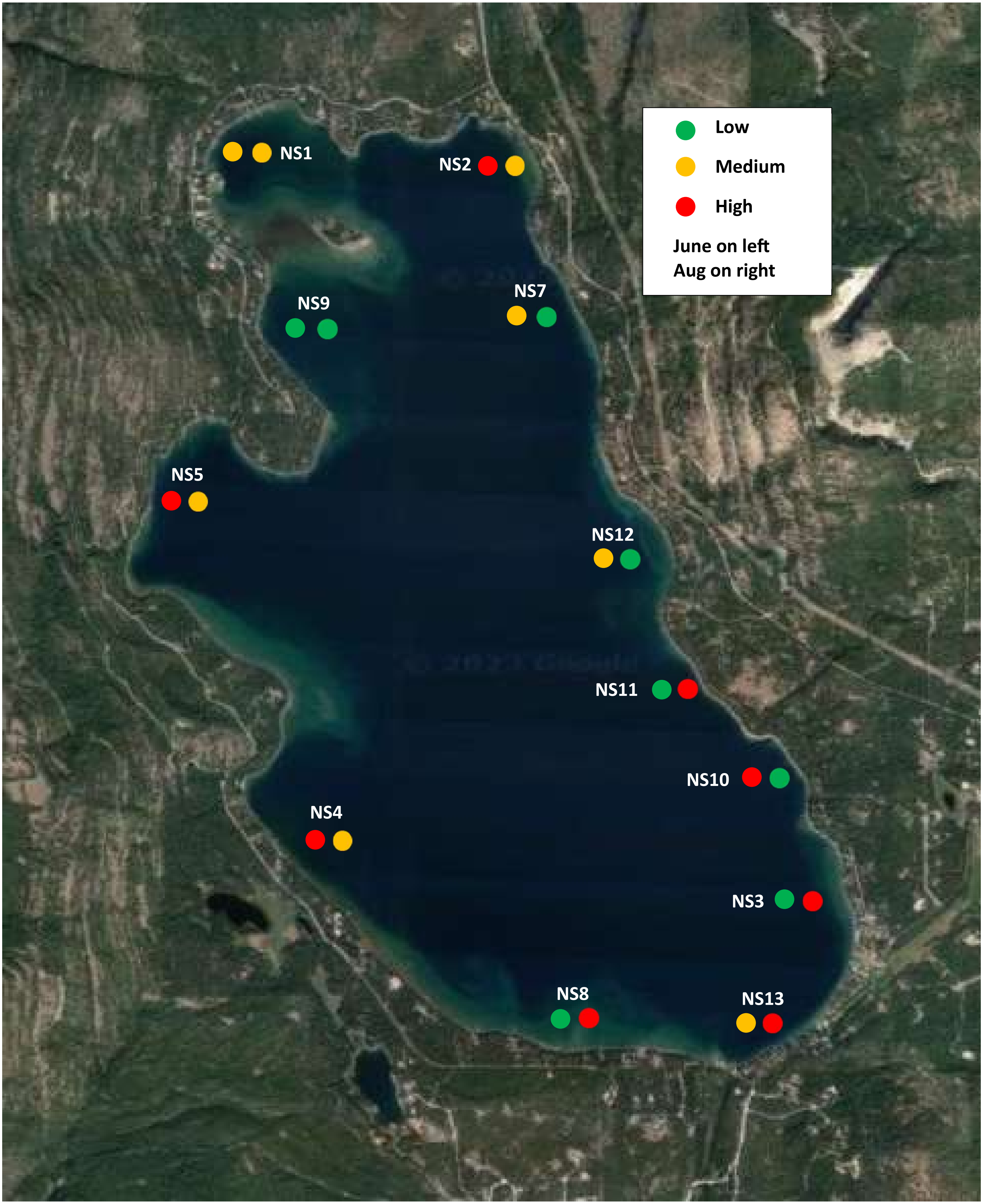
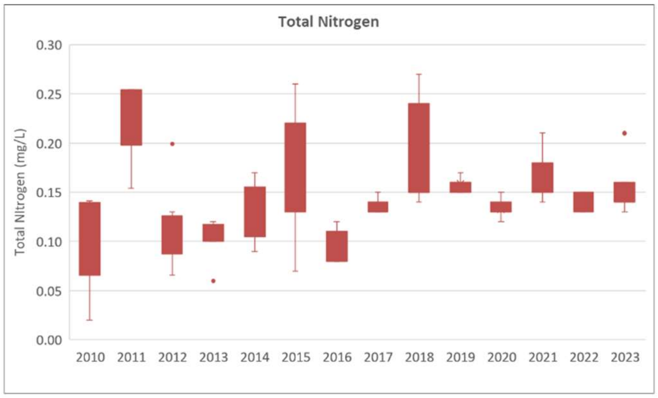
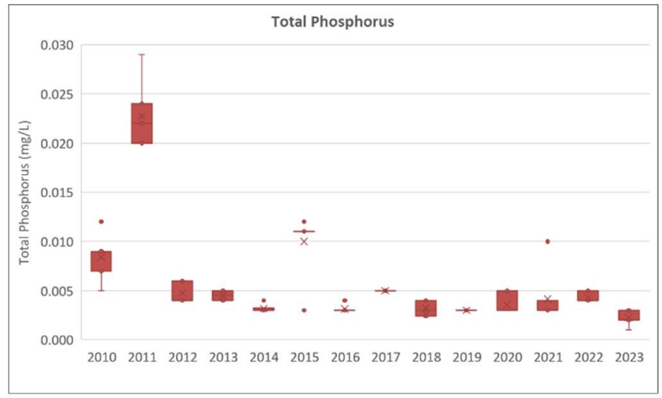


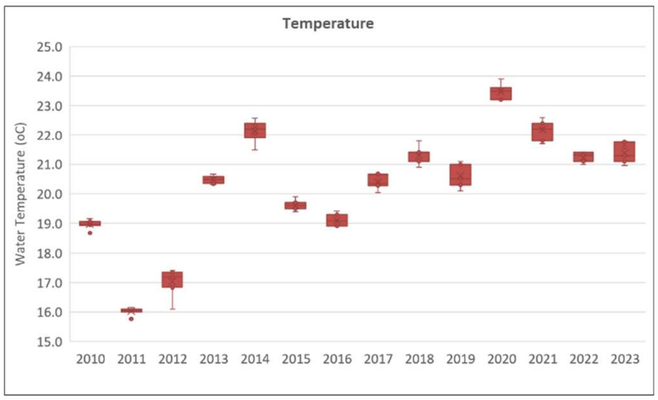
Figure 1. June and August 2023 Near-Shore Sampling Locations and Fluorescence Results

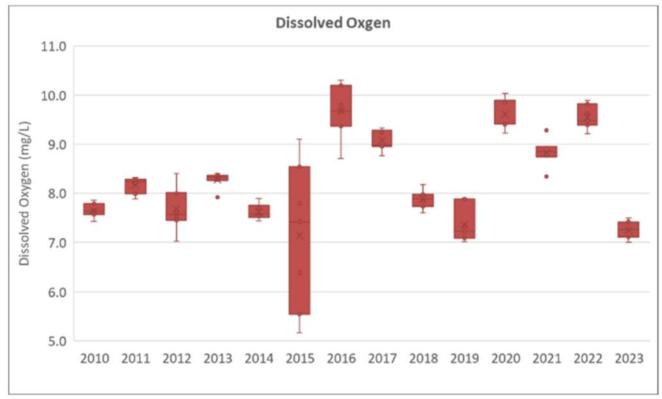
Appendix B – 2023 Statistical Boxplots

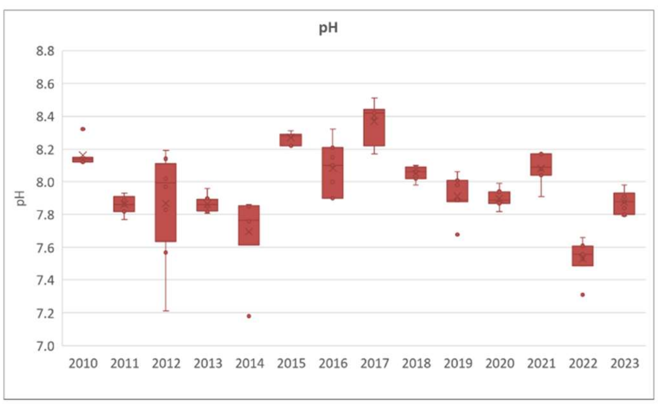
Boxplots – Nutrient and Field Parameters 2010 – 2023 by Year

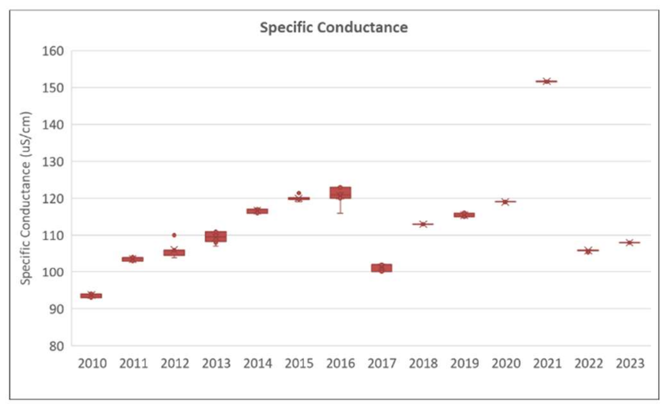


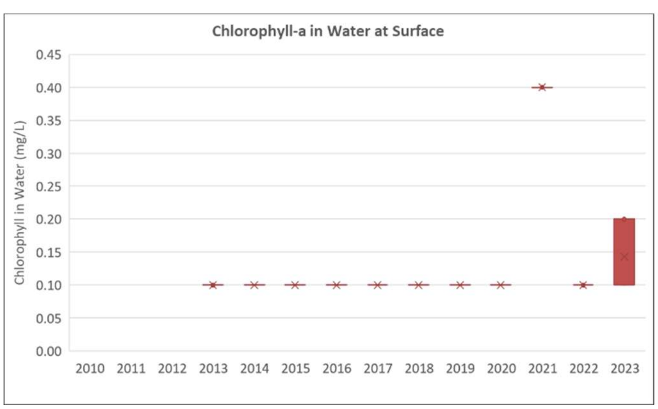


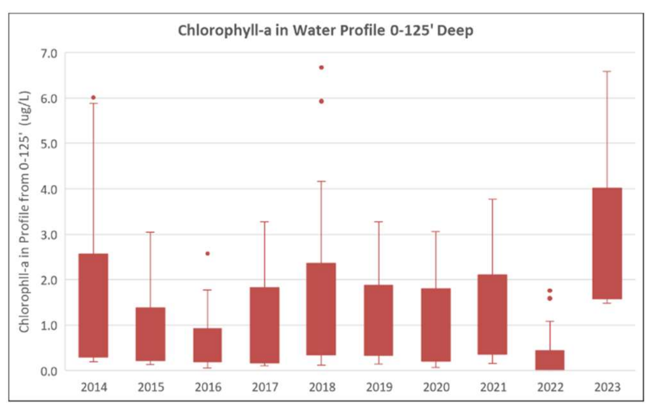




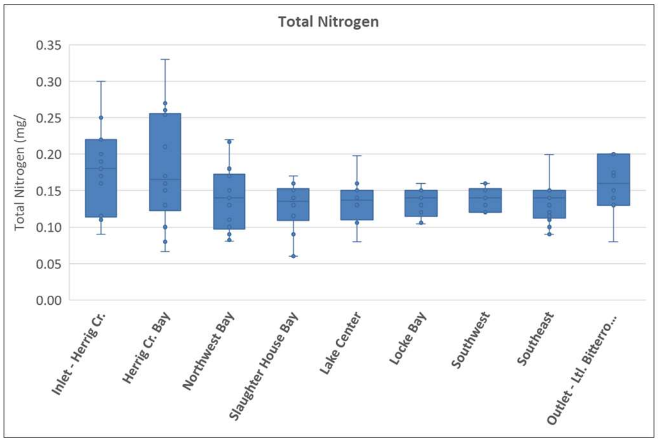


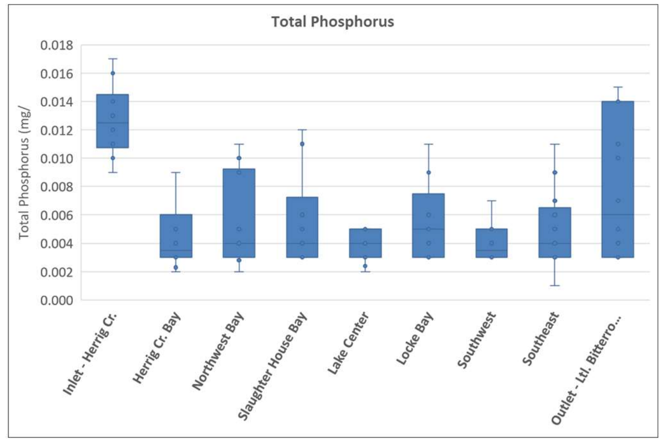


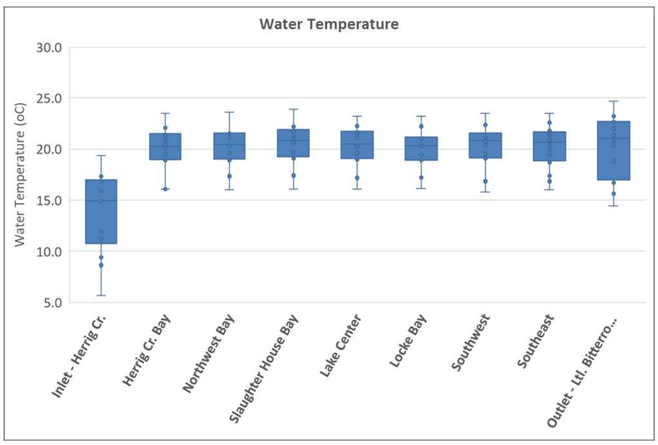


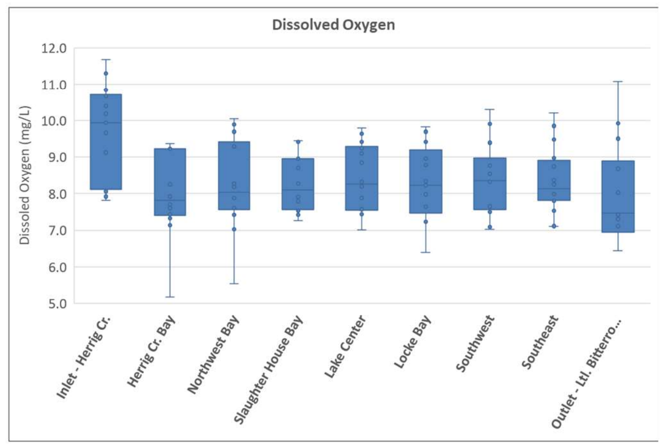


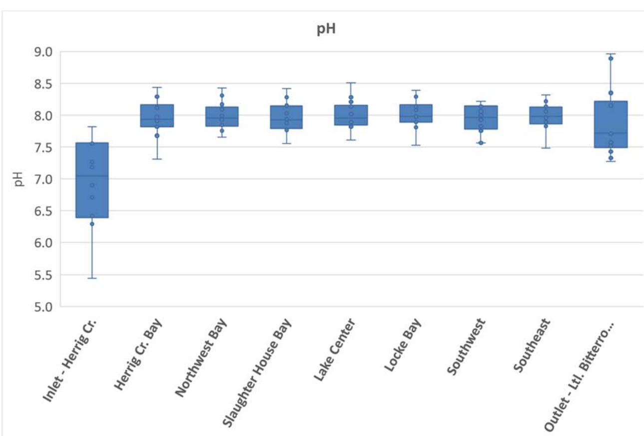
Boxplots – Nutrient and Field Parameters 2010 – 2023 by Location

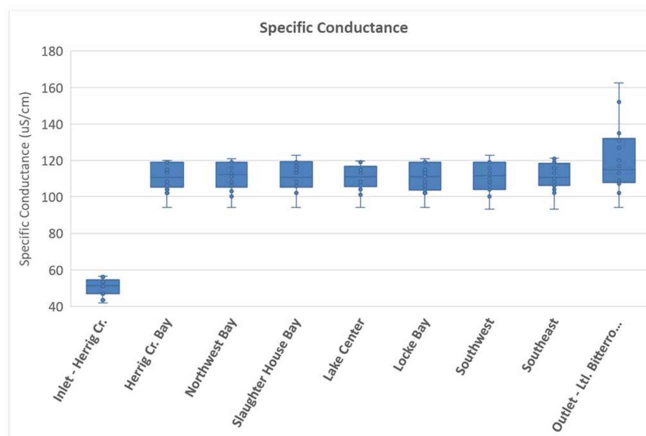






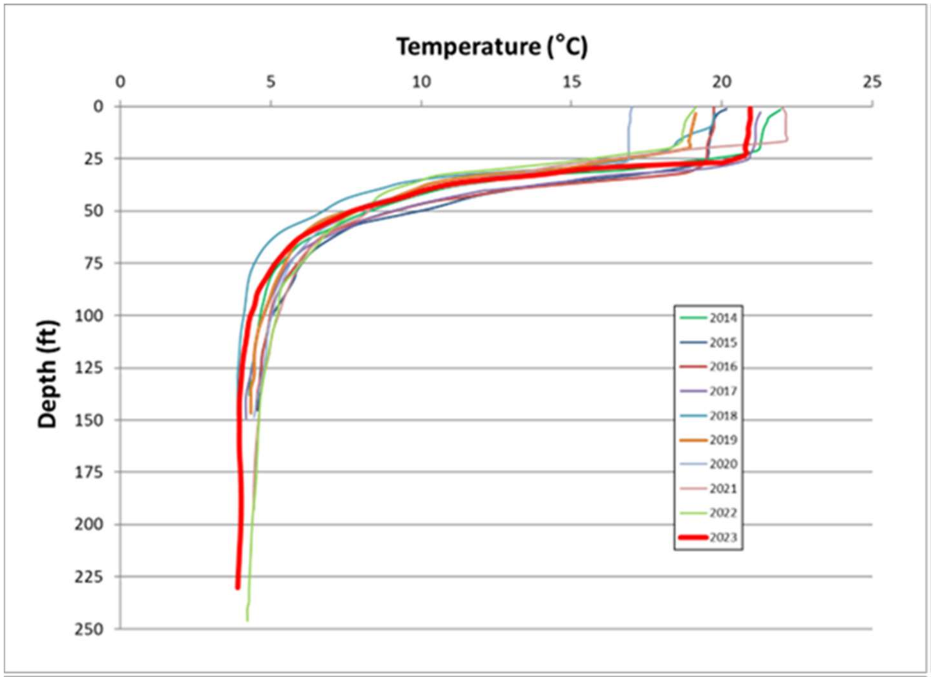


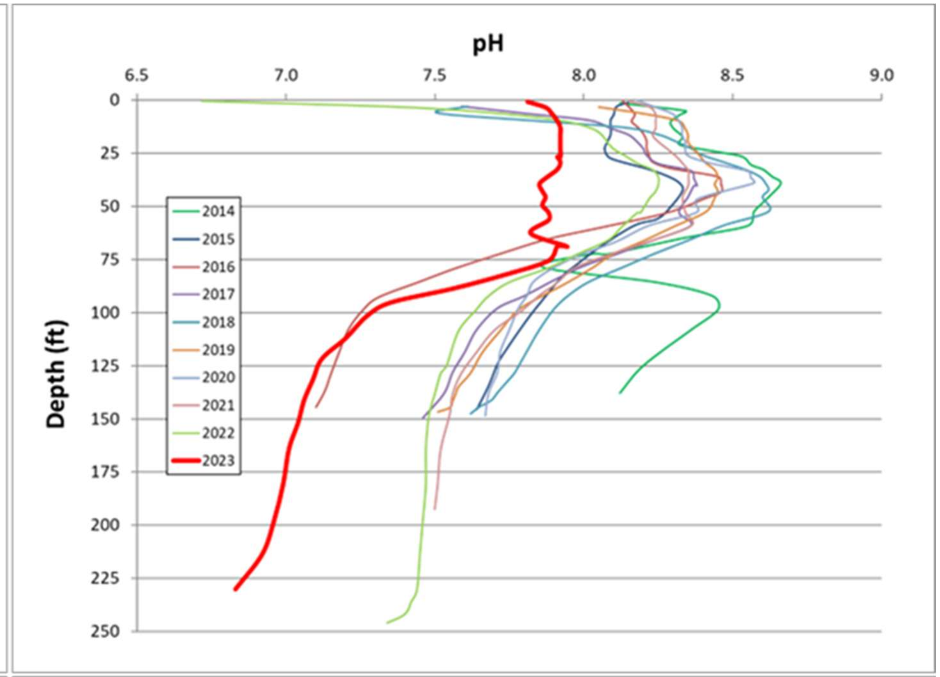


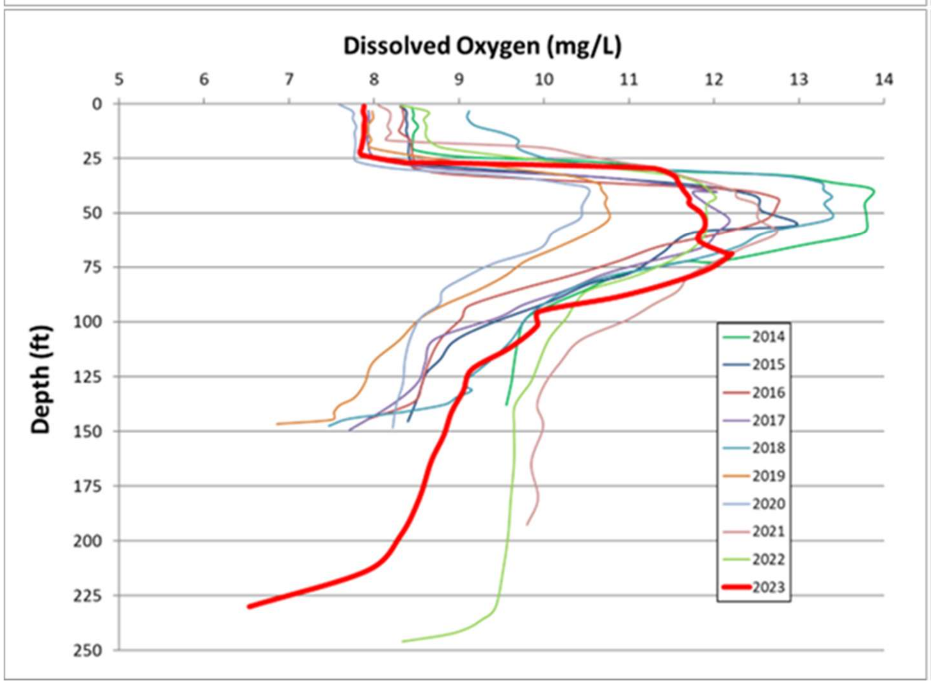


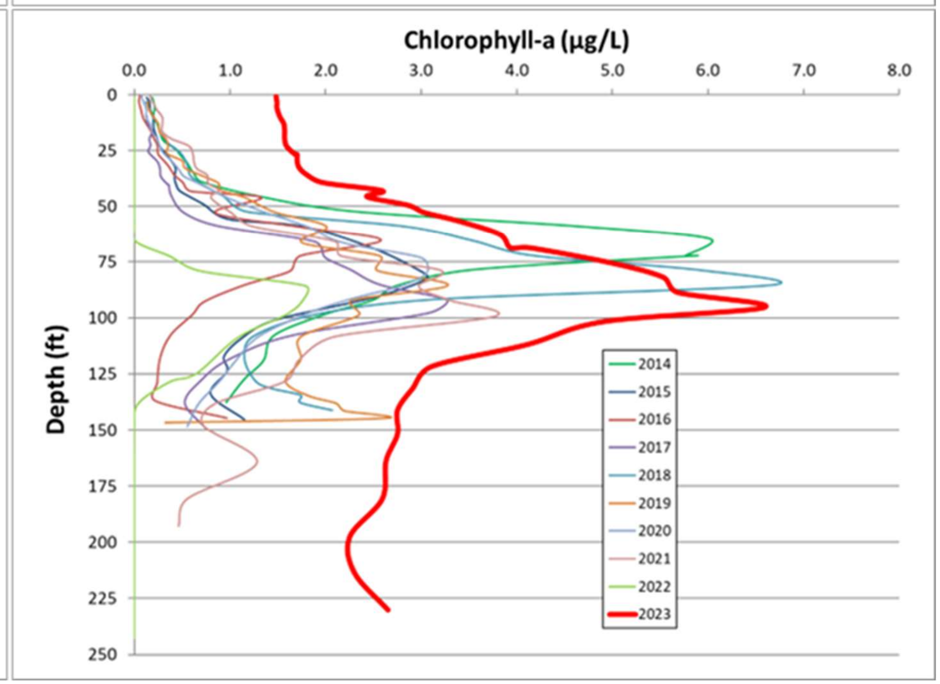
Appendix C – Depth Profiles for Individual Parameters

Depth Profiles (data collected 8/9/2023 by Whitefish Lake Institute)



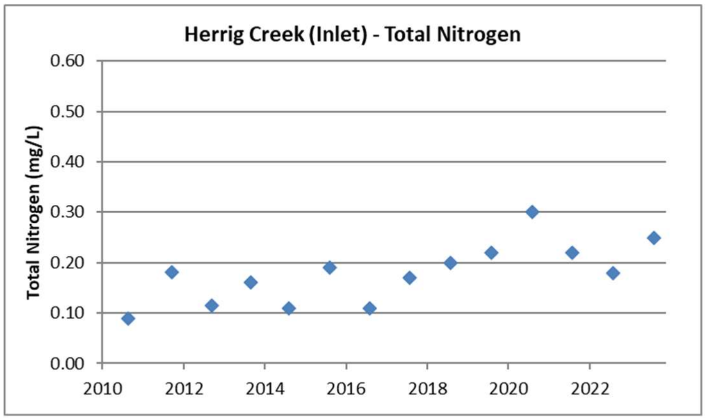


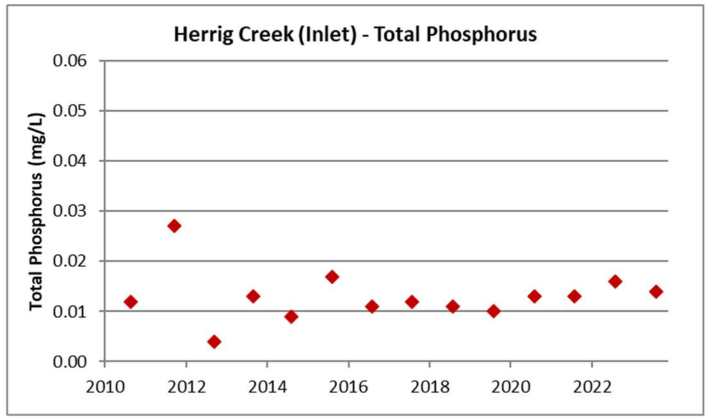


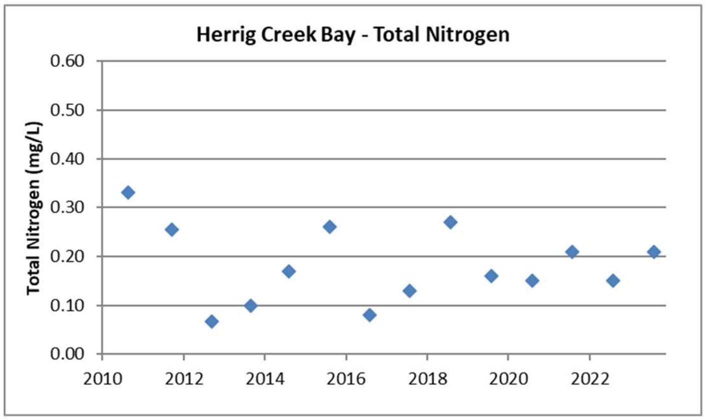


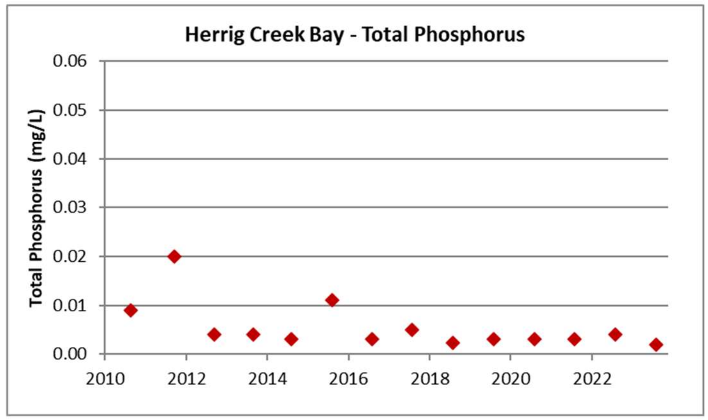
Appendix D – Nutrients at Individual Sites 2010-2023

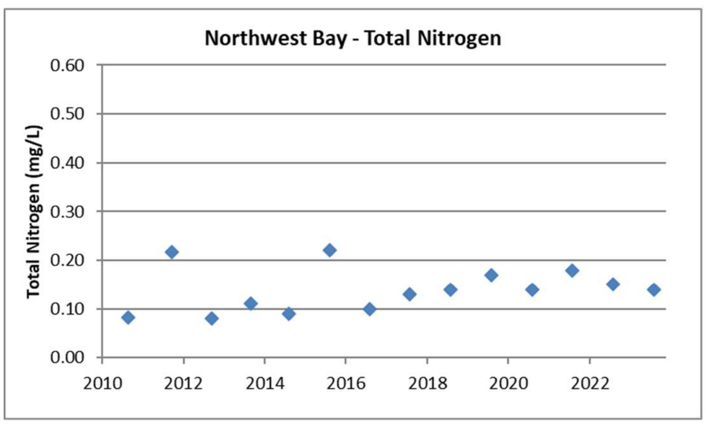
Nutrients at Individual Sites 2010 - 2023

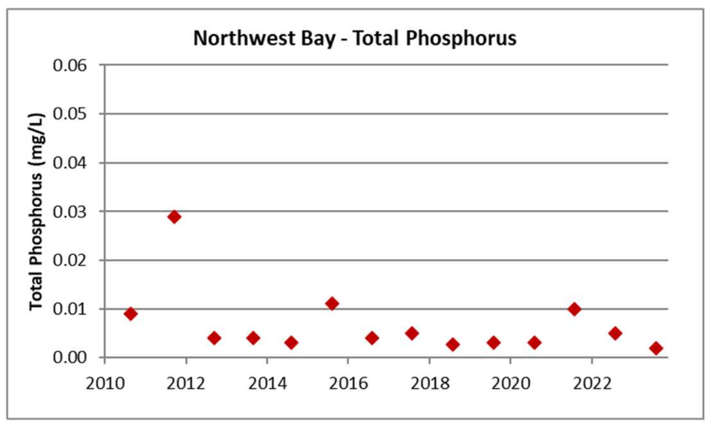


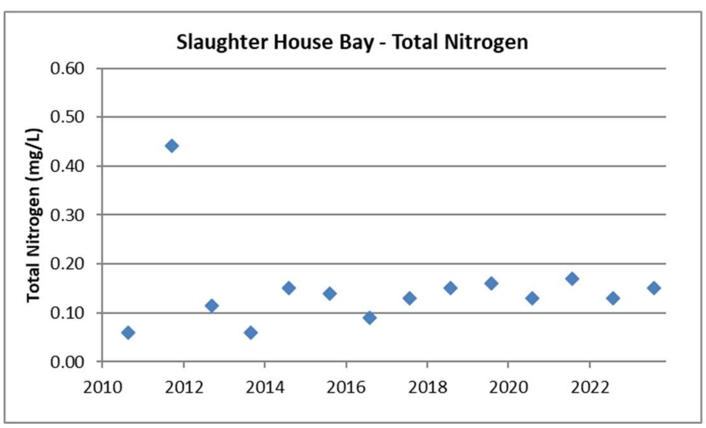


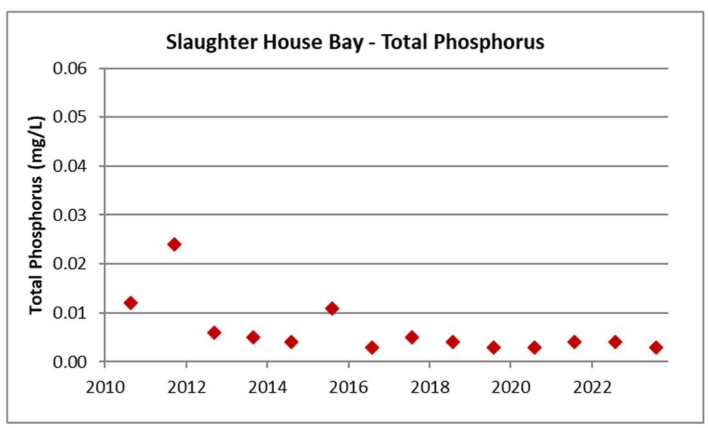


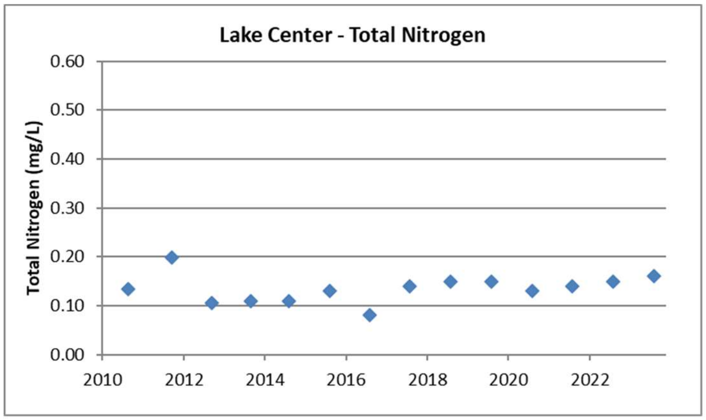


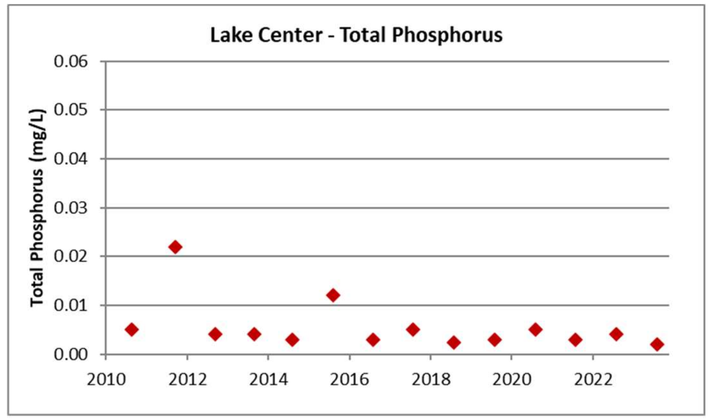


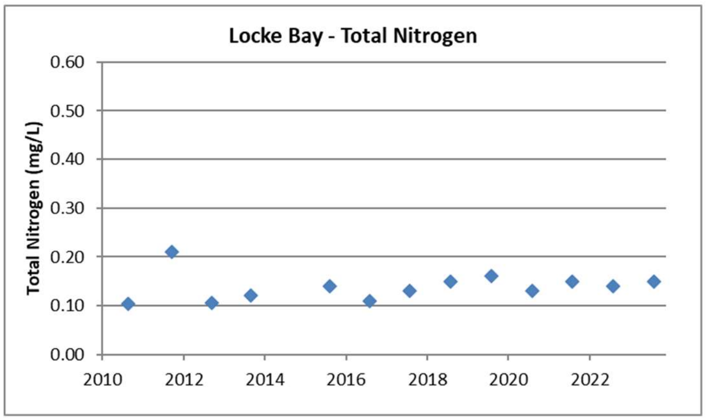


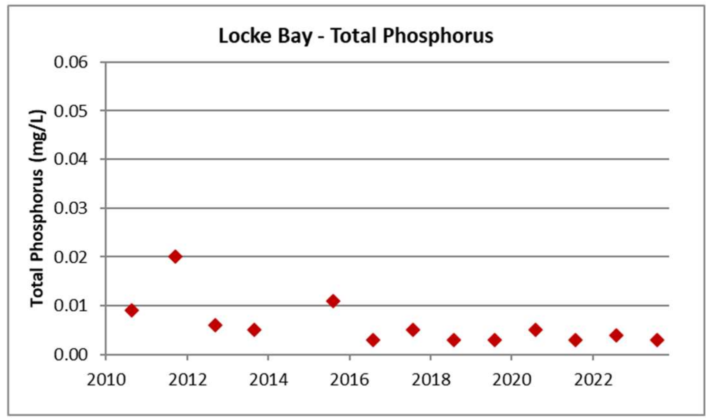


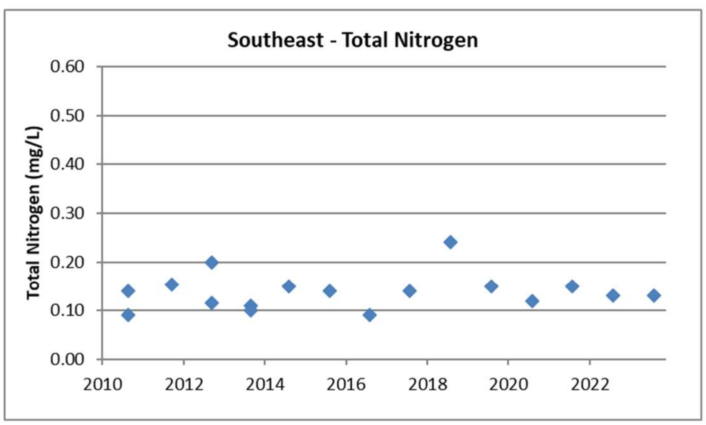


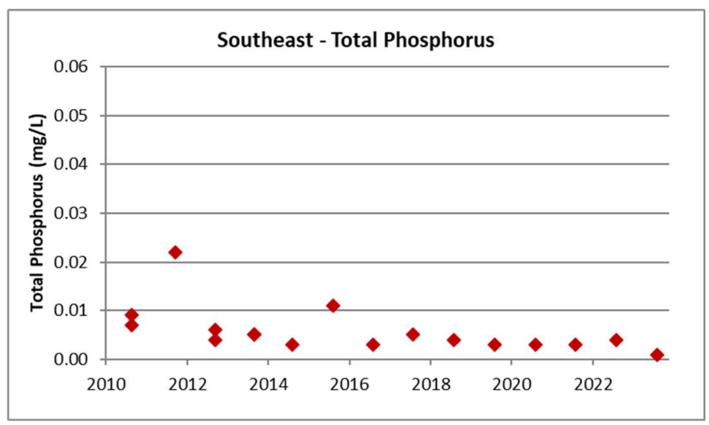

Lake Center - Total Nitrogen
Total Nitrogen (mg/L)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2010
2012
2014
2016
2018
2020
2022

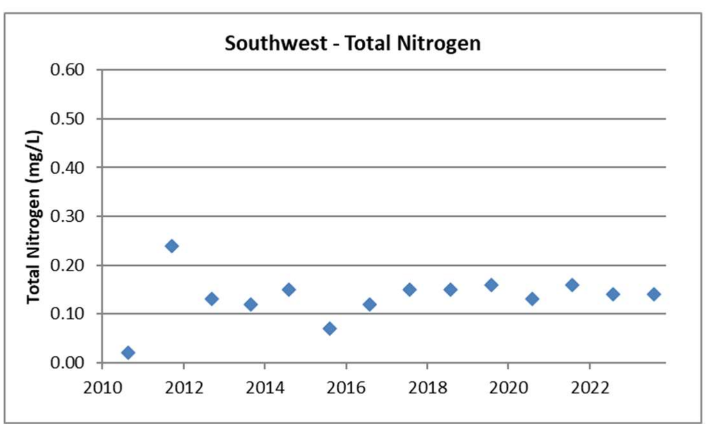

Lake Center - Total Phosphorus
Total Phosphorus (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
2010
2012
2014
2016
2018
2020
2022

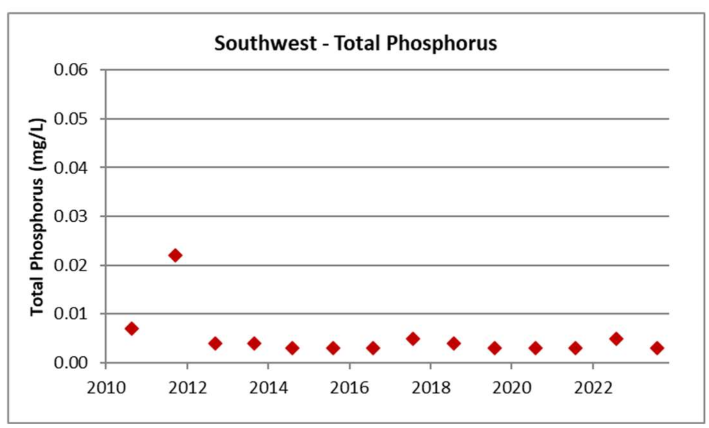

Locke Bay - Total Nitrogen
Total Nitrogen (mg/L)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2010
2012
2014
2016
2018
2020
2022

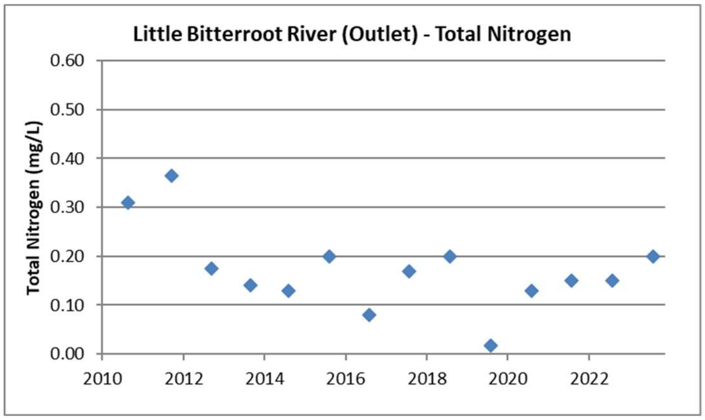

Locke Bay - Total Phosphorus
Total Phosphorus (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
2010
2012
2014
2016
2018
2020
2022

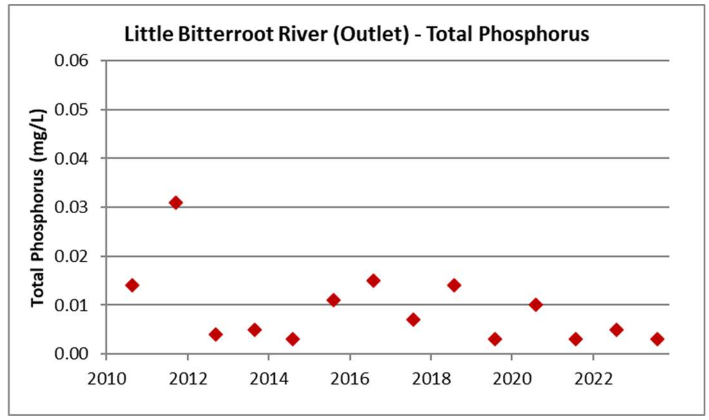

Southeast - Total Nitrogen
Total Nitrogen (mg/L)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2010
2012
2014
2016
2018
2020
2022


Southeast - Total Phosphorus
Total Phosphorus (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
2010
2012
2014
2016
2018
2020
2022


Southwest - Total Nitrogen
Total Nitrogen (mg/L)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2010
2012
2014
2016
2018
2020
2022


Southwest - Total Phosphorus
Total Phosphorus (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
2010
2012
2014
2016
2018
2020
2022





Nutrients at All Sites 2010 - 2023 (trendline shown for lake sites)