Little Bitterroot Lake
Water Quality Monitoring Program
2022 Annual Report

Prepared For:
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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

Little Bitterroot Lake was sampled on August 3-4, 2022, which was the 24th sampling event since 1999. Routine sampling for field and nutrient parameters was conducted on seven lake sites and two stream sites. In 2022, four additional near-shore sites were sampled for field and nutrient parameters and bacteria (total coliform and *E coli*). The lake outlet (Little Bitterroot River) was sampled for attached algae. Depth profiles were recorded at the lake center by Whitefish Lake Institute on July 12, 2022.

Water quality in Little Bitterroot Lake was very good in 2022, with low concentrations of nutrients and no detection of chlorophyll-a in the water column. Nutrient concentrations have generally been low since consistent monitoring has been occurring since 2010, although elevated concentrations were exhibited in 2011 during a high precipitation year. Water temperatures were relatively cool in 2022 and a cooler spring with prolific rain helped keep algae from thriving in mid-summer. As a result, chlorophyll-a concentrations were the lowest on record in 2022 in both analytical and field data. Total phosphorus was slightly elevated in 2022 when compared to 2021, possibly because less algae was growing in mid-summer to consume the available nutrients. Nitrogen concentrations were slightly lower in 2022 than 2021 but near the long-term average.

One benthic algae sample was collected in 2022 from the Little Bitterroot River which was slightly above average (5.0 vs 3.3 mg/m^2) but did not reach nuisance levels. Documenting observable patches of algae is important for identifying areas with potential nutrient impacts, such as failing septic systems.

Bacteria sampling was added in 2022 and samples were collected at 10 locations, including 8 near-shore sites, the inlet stream, and the outlet. Data indicates that Herrig Creek is the highest source of bacteria to the lake, and elevated concentrations of total coliform and E coli were also recorded in Herrig Creek Bay. A sample collected near the south boat ramp also exhibited higher concentrations of E coli than the rest of the lake, which could be due to human or animal activity in that area. Bacteria sampling will be continued during future sampling events so that spatial and temporal trends in bacteria concentrations can be evaluated, and a baseline can be established.

Water quality parameters such as calcium and alkalinity indicate that Little Bitterroot Lake has low potential for colonization by invasive mussels based on water chemistry; however, invasive mussels have been detected in lakes with lower concentrations than those measured in Little Bitterroot Lake.

The trophic state index for Little Bitterroot Lake suggests eutrophic conditions could exist due to elevated concentrations of total nitrogen, but measurements of total phosphorus and chlorophyll-a indicate oligotrophic conditions with low biological productivity and very good water quality. Little Bitterroot Lake has typically been phosphorus-limited, meaning it has an inadequate amount of phosphorus compared to the amount of nitrogen needed to support algae growth. Based on this observation, Little Bitterroot Lake is more likely to experience algae blooms with the addition of phosphorus since concentrations of nitrogen are already relatively elevated. However, nutrient concentrations can vary significantly, and efforts to reduce inputs of both phosphorus and nitrogen should be encouraged to help maintain the water quality of Little Bitterroot Lake and limit algae growth.

Overall, Little Bitterroot Lake has shown excellent water quality throughout its monitoring history. Nutrient and chlorophyll-a concentrations are low, algae blooms are rare, and field data indicate suitable ranges of temperature, dissolved oxygen, and pH to support a viable fishery. Little Bitterroot Lake also displays excellent water quality when compared to other regional lakes. 41 lakes are presently monitored annually through the Northwest Montana Lakes Network (NMLN), including 11 lakes with surface areas greater than 500 acres (WLI, 2022). Among the large lakes monitored, Little Bitterroot Lake ranked 7th lowest in nitrogen concentration and 7rd lowest in phosphorus concentration in 2021.

In order to improve or maintain water quality in Little Bitterroot Lake, efforts should be made to reduce sources of nutrients, such as limiting application of fertilizer, maintaining septic systems, keeping a vegetated buffer area, and reducing shoreline erosion. Little Bitterroot Lake is phosphorus limited, meaning that additional inputs of phosphorus are more likely to cause undesirable algae blooms. Fertilizers with little or no phosphorus are recommended to help maintain good water quality. This can be accomplished by selecting fertilizers with a zero as the middle value (i.e. 16-0-0). Little Bitterroot Lake has routinely shown excellent water quality; however, nitrogen concentrations have been steadily increasing since 2012, which is a common trend for lakes in developed areas. Maintaining and not overloading septic systems is a key practice for reducing nutrient inputs into Little Bitterroot Lake.

Notes: The routine sampling program was continued in 2022 and data continues to show low concentrations of nutrients (nitrogen and phosphorus) and algae. Chlorophyll-a was undetected at near-surface samples in 2022. The lake also shows low potential for colonization of invasive mussels based on present water chemistry.

Warnings: Concentrations of total nitrogen have shown a slight increase since 2012, and the ratio of nitrogen to phosphorus (N:P ratio) continues to increase. This indicates that chronic loading of nitrogen continues to happen within the watershed, which is likely associated with an increase in human development or the effects of aging, unmaintained, or overused septic systems.

Cautions: Isolated patches of algae growth continue to be identified throughout the lake. The cause of these localized outbreaks cannot be identified without an extensive study, but they are likely caused by nutrient loading from failing or overused septic systems. These spots have been monitored visually for several years, and their continued presence has raised concern among the lake association. Bacteria data from 2022 indicate that Herrig Creek is a source of bacteria to the lake and values may exceed state standards. The source of bacteria may be non-human in origin, although Herrig Creek should be further evaluated for bacterial sources in future sampling events, as well as increased near-shore sampling for bacteria.

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 exists within 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 monitoring 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 collected in 2022 and past monitoring events. Long term trends in nutrient concentrations and trophic status are provided for locations that have been consistently sampled.

1.1 Monitoring Program History

Little Bitterroot Lake has been sampled 24 times since 1999. Early data from 1999 to 2009 was collected sporadically from May to November; however, more recent sampling from 2010 to 2022 has focused on mid-summer sampling to maintain continuity and evaluate long-term trends. Sampling is generally conducted during the first week of August in conjunction with the annual lake association meeting, although periodic spring and fall sampling has occurred to help 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.

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 July 12, 2023, as part of the Northwest Montana Lakes Volunteer Monitoring Network.

Figure 1. Little Bitterroot Lake Sample Locations 2022.

2.0 Field and Analytical Methods

Water quality monitoring is routinely conducted at 7 lake sites and 2 stream sites, including the inlet stream (Herrig Creek) and the outlet stream (Little Bitterroot River) (**Figure 1**). In 2022, four additional near-shore sites were added for bacteria parameters which may serve as an indicator of failing septic systems. Monitoring includes field measurements on-site and sample collection for laboratory analysis. Monitoring is routinely conducted at fixed locations although additional parameters and locations are added as warranted. Field parameters are collected at all locations and include water temperature, dissolved oxygen, specific conductance, and pH. Samples are also collected at all locations for analysis of nutrient parameters, including total nitrogen and total phosphorus. Calcium and alkalinity 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 collected for chlorophyll-a at all lake locations, which provides a measure of algae growth in the water column. Algae growth on rock surfaces is also measured by collecting a benthic algae sample from one or two sites each year, which is also analyzed for chlorophyll-a. Bacteria sampling (total coliform and E. coli) was added in 2022 at near-shore locations to help evaluate the potential of bacterial contamination from natural or septic sources. Depth profile monitoring is conducted annually at the lake center during late July or early August, and includes measurements of water temperature, specific conductance, dissolved oxygen, pH, and chlorophyll-a at depth. A summary of 2022 locations and parameters is provided below in **Table 1**.

Table 1. 2022 Sample Locations and Parameters.

Type	Location	Parameters
Lake Sites	Herrig Cr. Bay	Field, Nutrients, Algae, Bacteria
	Northwest Bay	Field, Nutrients, Algae, Bacteria
	Slaughterhouse Bay	Field, Nutrients, Algae
	Lake Center	Field, Nutrients, Algae, Depth Profile, AIS
	Lake Center at 60' deep	Field, Nutrients, Algae
	Locke Bay	Field, Nutrients, Algae, Bacteria
	Southwest	Field, Nutrients, Algae
	Southeast	Field, Nutrients, Algae, Bacteria
Stream Sites	Inlet - Herrig Creek	Field, Nutrients, Algae, AIS, Bacteria
	Outlet - Ltl. Bitterroot Riv.	Field, Nutrients, Benthic Algae, AIS, Bacteria
Near-Shore Sites	Near-shore - North	Field, Nutrients, Bacteria
	Near-shore - West	Field, Nutrients, Bacteria
	Near-shore - East	Field, Nutrients, Bacteria
	Near-shore - South	Field, Nutrients, Bacteria

Laboratory analyses in 2022 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) (WET, 2022), which is provided to Montana DEQ to procure funding from the volunteer monitoring grant program.

2.1 Field Parameters

Field parameters are measured using a portable water quality meter 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 the stream at stream locations. Parameters include water temperature, dissolved oxygen, specific conductance, and pH. Water clarity is measured at the lake center using a Secchi disc. Stream flow is measured using a Marsh-McBirney electronic flow meter or visually estimated during low flow.

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 2022 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 2022 the Hydrolab had a maximum sampling depth of 260 ft, which is close to the full depth of Little Bitterroot Lake. Past profiles have been limited to 140 ft.

3.0 2022 Monitoring Results

In 2022, routine monitoring was conducted on August 3. Air temperatures ranged from 18 to 29°C (65 to 85°F) with full sun and a light breeze. Bacterial sampling was conducted on the morning of August 4. Depth profiles were collected on July 12, 2022, by Whitefish Lake Institute. Results from 2022 are presented and summarized below for field parameters, nutrients, chlorophyll-a, bacteria, aquatic invasive species (AIS) parameters, and depth profiles. Carlson's Trophic State Index (TSI) is also calculated to evaluate the potential for eutrophication based on nutrient results. Long term and spatial trends are also provided for routine water quality measurements from 2010-2022.

3.1 2022 Field Parameter Results

Field results from 2022 are provided in **Table 2** below and summarized in the following sections.

Table 2. 2022 Field Parameter Results.

Site Description	Water Temperature (°C)	Dissolved Oxygen (mg/L)	Specific Conductance (uS/cm)	pH	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
	Analytical Detection Limits →				0.04	0.003
Herrig Creek - mouth	15.0	11.3	44	6.42	**0.18**	**0.016**
North - Herrig Cr. Bay	21.3	9.2	105	7.31	**0.15**	**0.004**
Northwest - Northwest Bay	21.1	9.9	106	7.66	**0.15**	**0.005**
East - Slaughter House Bay	21.4	9.4	106	7.56	**0.13**	**0.004**
West - Locke Bay	21.0	9.8	106	7.53	**0.14**	**0.004**
Lake Center - Near Surface	21.1	9.4	106	7.61	**0.14**	**0.004**
Lake Center - 60' depth	6.9	11.9	109	8.13	**0.28**	**0.011**
Southwest - Southwest Bay	21.3	9.4	106	7.57	**0.14**	**0.005**
Southeast - Southeast Bay	21.4	9.5	106	7.49	**0.13**	**0.004**
Nearshore - North	21.0	9.6	106	7.19	**0.20**	**0.005**
Nearshore - West	20.9	9.1	107	6.81	**0.20**	**0.020**
Nearshore - East	21.1	9.3	106	7.16	**0.10**	**0.007**
Nearshore - South	20.9	9.5	106	7.25	**0.20**	**0.004**
Ltl. Bitterroot River - outlet	22.9	9.9	108	7.61	**0.15**	**0.005**

Data colleccted 8/3-8/4/2022 except field data at lake center - 60' depth collected by WLI on 7/12/2022.
The analytical detection limit for water quality parameters are provided below the constituent name.
Values in **BOLD** are above the analytical detection limit.

During the August 2022 event, the lake had a surface temperature ranging from 20.9 to 21.4°C (69.6 to 72.7°F) with an average of 21.2°C (70.5°F) which was the 4th highest average since 2010. Herrig Creek was contributing cooler water around 15.0°C (59.0°F) at a flow of approximately 2.5 CFS (1100 gallons per minute, GPM). The Little Bitterroot River at the outlet was warmer than all lake sites at 22.9°C (73.2°F) and had flow of 5.0 CFS (2250 GPM).

The pH at lake sites varied between 7.31 and 7.66, while the inlet and outlet streams measured 6.42 and 7.61, respectively. The average lake pH (7.53) was the lowest on record from 2010 to 2022. Biological activity by plants and algae raises pH during daytime hours when photosynthesis is occurring, so pH was likely low in 2022 due to limited biological activity.

Dissolved oxygen (DO) varied from 9.4 to 9.9 mg/L at the lake sites and was measured at 11.3 mg/L in the inlet stream and 9.9 mg/L in the outlet stream. Dissolved oxygen is also influenced by biological activity which raises DO during daytime hours. Additionally, cooler water can holder more dissolved oxygen, so Herrig Creek typically has the highest DO. Average DO in 2022 (9.6 mg/L) was the third highest on record from 2010-2022; however, DO is quite variable depending on the time of day.

Specific conductance was quite low in the inlet stream (44 µS/cm) but uniformly around 105-108 µS/cm at the lake sites and the lake outlet. The average SC in 2022 (105.9 µS/cm) was the third lowest on record since 2010. Specific conductance a measure of dissolved constituents in water, and values are generally lower in surface water sources than groundwater, so years with more snowpack and surface runoff tend to have lower values of specific conductance.

3.2 2022 Nutrient Results

Nutrient results from 2022 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 2022, total nitrogen concentrations were comparable throughout the lake, varying from 0.13 to 0.15 mg/L. The sample collected at a depth of 60’ had the highest concentration of 0.28 mg/L. Herrig Creek was slightly higher than lake sites (0.18 mg/L), and the outlet at the Little Bitterroot River (0.15 mg/L) was comparable to lake sites. The average TN in 2022 (0.141 mg/L) was close to the average for all lake samples collected from 2010-2022 (0.144 mg/L).

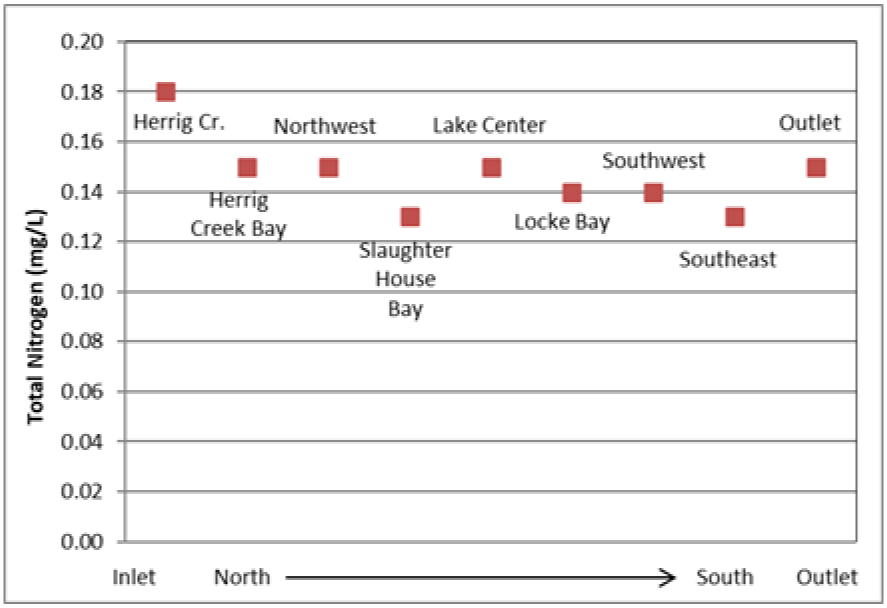

Figure 2. 2022 Total Nitrogen Results.

Total phosphorus measurements in 2022 ranged from 0.004-0.005 mg/L at lake sites. Herrig Creek measured 0.016 mg/L while the lake outlet was 0.005 mg/L. Little Bitterroot Lake has historically had low concentrations of total phosphorus and is phosphorus limited. Inputs of phosphorus from streams or groundwater are likely consumed by algae and plants within the lake, resulting in lower measurements in the sample data. The average TP in 2022 (0.0043 mg/L) was lower than the average for all samples from 2010-2022 (0.0062 mg/L).

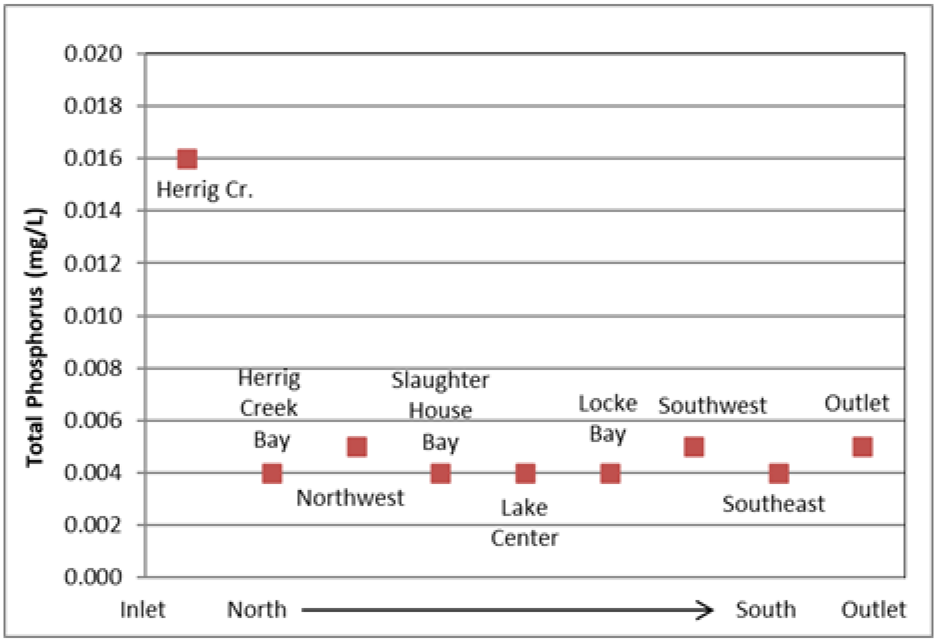

Figure 3. 2022 Total Phosphorus Results.

3.3 2022 Chlorophyll-a Results

Results from biological sampling in 2022 are presented below in **Table 3**, including chlorophyll-a (algae) and bacteria sampling. Samples for chlorophyll-a were collected from 9 locations in August 2022, including 7 samples from the lake surface, 1 sample from 60' depth at lake center, and 1 benthic algae sample from natural substrate. In August 2022, algae growth in the lake water was below analytical detection at all sample sites (<0.1 mg/L). Algae concentration typically peaks in the hypolimnion of Little Bitterroot Lake near a depth of 60'; however, the sample collected at 60' depth in 2022 was below detection. Hydrolab data collected from Whitefish Lake Institute shows that chlorophyll-a peaked at a depth of 85' in July 2022 (1.75 mg/L); however, concentrations were the lowest on record since depth profiles have been collected since 2014. Additional depth profile data are provided in **Section 4.6**.

Attached (benthic) algae was sampled at one location in August 2022 at the outlet channel of the Little Bitterroot River, which measured 5.0 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.

Table 3. 2022 Biological Results.

Site Description	**Chlorophyll-a**		**Bacteria**		**AIS and Additional Parameters**		
	Algae in Water (mg/L)	**Benthic Algae (mg/m^2)**	**Total Coliform (#/100ml)**	**E Coli Bacteria (#/100ml)**	**Calcium (mg/L)**	**Alkalinity (mg/L)**	**Total Organic Carbon (mg/L)**
Analytical Detection Limits →	0.1	0.1	1.0	1.0	1.0	1.0	0.5
North - Herrig Cr. Bay	0.1		**2420**	**6.3**			
Northwest - Northwest Bay	0.1		**138**	1.0			
East - Slaughter House Bay	0.1						
West - Locke Bay	0.1		**17**	1.0			
Lake Center - Near Surface	0.1				**13**	**51**	**2.9**
Lake Center - 60' depth	0.1						
Southwest - Southwest Bay	0.1						
Southeast - Southeast Bay	0.1		**345**	1.0			
Nearshore - North			**142**	1.0			
Nearshore - West			**127**	1.0			
Nearshore - East			**31**	1.0			
Nearshore - South			**387**	**24.6**			
Herrig Creek - mouth			**>2420**	**178.5**	**4**	**21**	**4.0**
Ltl. Bitterroot River - outlet		**5.0**	**308**	1.0	**13**	**52**	**2.9**

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

3.4 2022 Bacteria Results

Ten bacteria samples were collected on the morning of August 4, 2022, for total coliform and E coli bacteria (**Table 3**). Concentrations of both were highest in Herrig Creek, which suggests that the inlet stream is a source of bacterial contamination in the north part of the lake. As a result, Herrig Creek Bay shows elevated concentrations of E coli and total coliform bacteria concentrations are higher than the rest of the lake. The highest sample of E coli in the lake was collected near the south boat ramp. Total coliform provides a measure of background bacteria concentrations, and it was detected at some level in all samples. High values of total coliform can be an indicator of bacterial contamination, although not all bacteria are harmful. E coli, however, 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 sampled. Little Bitterroot Lake and Herrig Creek do not presently have a water quality classification assigned; 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 exceeds 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.

3.5 2022 AIS Related Parameters

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 2022 at the lake center and the inlet and outlet streams (**Table 3**). Calcium concentrations were lowest in Herrig Creek (4 mg/L) and highest at the lake center (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 2022 ranged from 21 mg/L in Herrig Creek to 52 mg/L in the Little Bitterroot River.

Risk categories have been published for determining the likelihood of dreissenid mussel establishment based on multiple field and laboratory studies (Wells et al., 2011). Risk categories based on calcium concentration 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 to medium 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 dreissenid mussel establishment. Compared to regional large lakes, Little Bitterroot Lake has the second lowest concentrations of calcium and alkalinity.

3.6 2022 Depth Profile Results

Depth profile sampling was conducted on July 12, 2022, to show changes in water chemistry at depth. Results from 2022 sampling are shown in **Figure 4**, including water temperature, dissolved oxygen, pH, and chlorophyll-a. Results from 2014 to 2022 are shown for comparison, with 2022 data shown in red.

In July 2022 the lake was thermally stratified with an epilimnion (upper layer) from 0 to 18 feet, a metalimnion (transitional layer) from 18 to 80 feet, and a hypolimnion (bottom layer) from 80 feet to the lake bottom. Near-surface temperatures on July 12, 2022, were the second lowest on record, which may have inhibited algae growth in summer 2022. The epilimnion is typically deeper (25 ft) and the metalimnion generally transitions into the hypolimnion around 60', which suggests that stratification in Little Bitterroot Lake was still developing in July 2022 due to cooler spring temperatures.

Depth profile measurements of pH in July 2022 were among the lowest on record, which could be expected during cooler years with less algae growth. pH typically ranges from 7.5 to 8.2 in the upper epilimnion and increases to more than 8.6 within the photic zone of the metalimnion where phytoplankton are most prevalent; however, in 2022 pH measured 6.7 in the epilimnion and peaked at 8.25 in the photic zone. pH in the hypolimnion (deep portion of the lake) decreases with depth, measuring 7.34 at 246' in July 2022.

Dissolved oxygen (DO) measured 8.3 mg/L in the upper epilimnion in July 2022, with the peak occurring 43' below the lake surface (12.0 mg/L). In general, DO measurements in 2022 were high in the epilimnion, low in the metalimnion, and high in the hypolimnion. This is expected for a cool year because cool water in the epilimnion holds more oxygen, but oxygen is lower in the metalimnion due to lower algae growth. 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 an oligotrophic lake with good water quality.

The depth profile for chlorophyll-a in July 2022 reflected the lowest concentrations on record, with no detectable chlorophyll-a in the upper 66' of the water column. This was consistent with sampling in August 2022, which also had no detectable concentrations above 60'. Chlorophyll-a peaked at a depth of 86' (1.79 ug/L) in July 2022, which was 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.

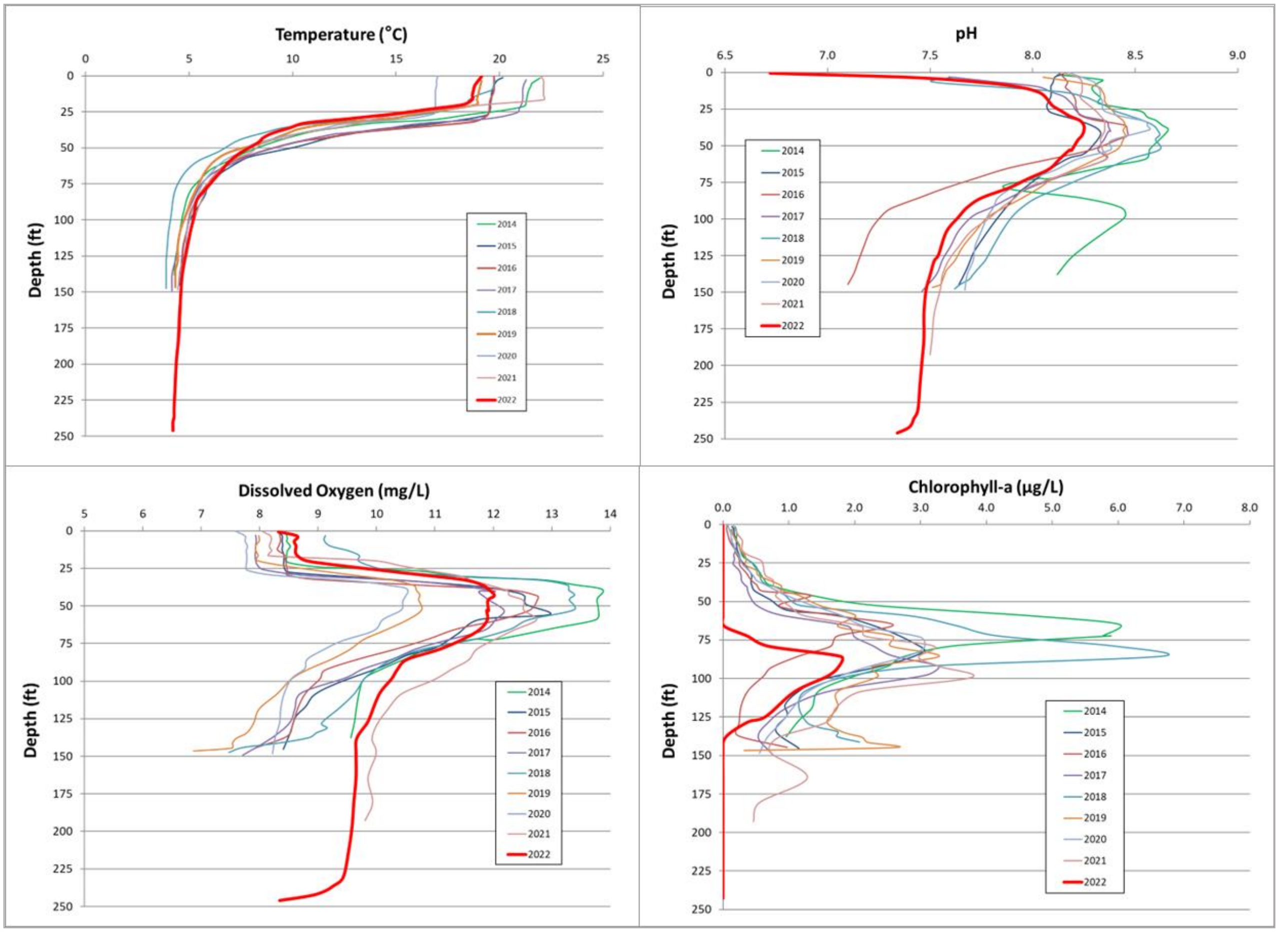

Figure 4. 2022 Depth Profile Results.

3.7 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 2022.

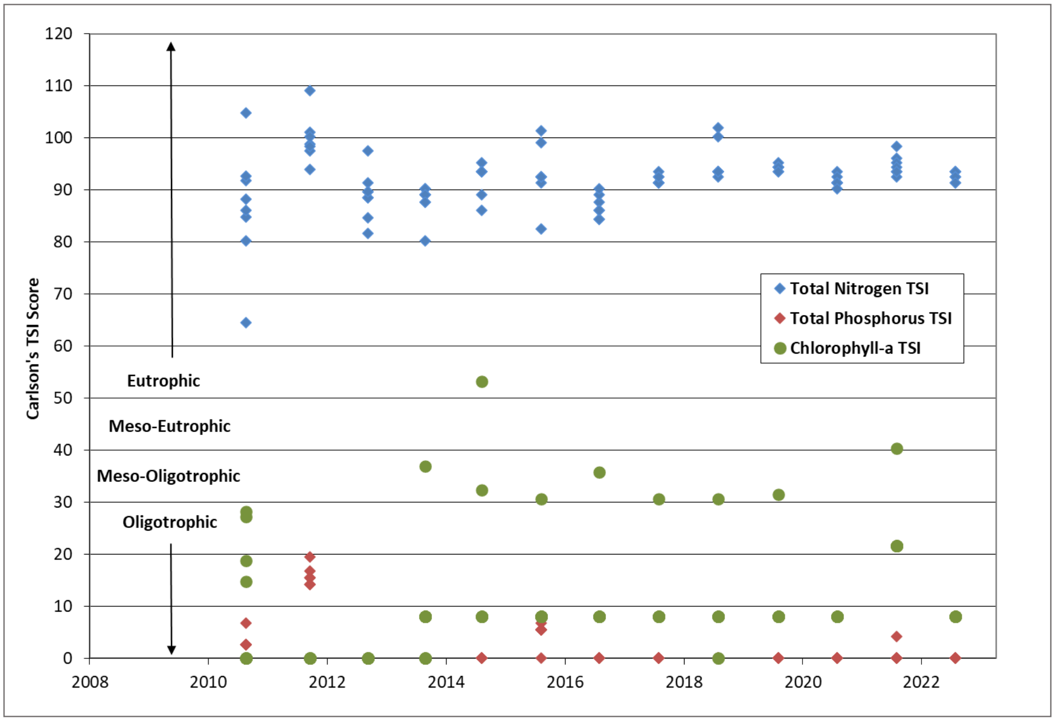

Figure 5. Carlson's Trophic State Index 2010-2022.

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 2022. 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.

3.8 Long Term Trends

Little Bitterroot Lake has been sampled since 1999; however, sampling 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 2022 to ensure data are comparable based on location and time of year. Long-term trend results from 2010 to 2022 are shown below in **Figure 6** for total nitrogen and total phosphorus. Figures show concentrations for lake sites as well as the inlet and outlet streams for comparison, but trend lines are for lake data only. Boxplots showing long term trends are also provided in **Appendix A** for field and nutrient parameters. Boxplots show the range of values for each year, as well as statistical parameters such as the maximum and minimum values, median, and the interquartile range.

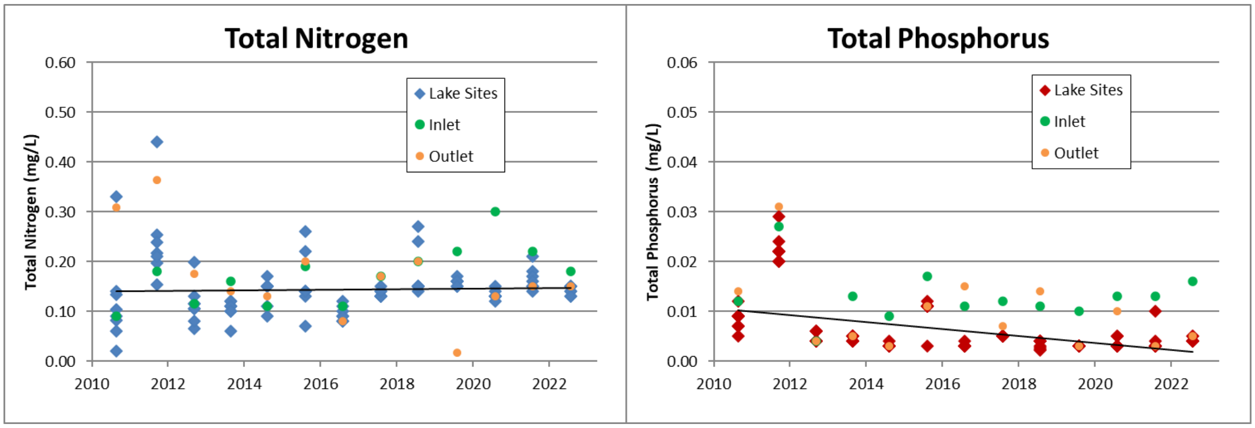

Figure 6. Long-term Trends 2010-2022.

Total nitrogen concentrations show a slightly increasing trend since 2010, however, the highest values were recorded in 2011 and a more apparent upward trend is evident from 2012 to 2022. Total phosphorus shows a decreasing trend from 2010 to 2022, however, this trend is also 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 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 sampling may not coincide with peaks. Trends become more robust as future data are added 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 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 2022 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 2022, 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.

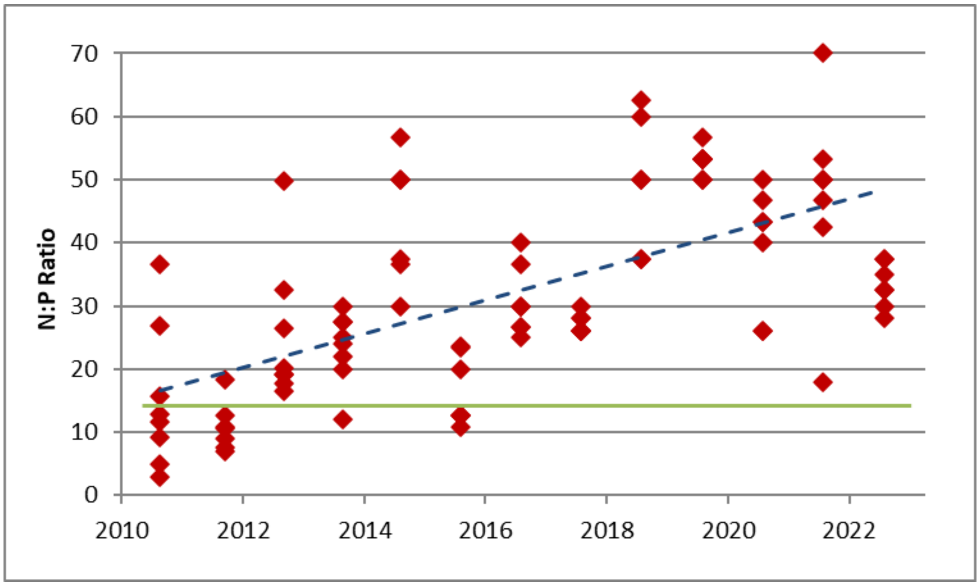

Figure 7. Nitrogen:Phosphorus Ratio 2010-2022.

3.9 Spatial Trends

Nutrient data are collected 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 from 2010-2022 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 sites show little variability with nutrient data, but by maintaining consistency with locations and timing these trends will become more robust and may reveal spatial differences in nutrient concentrations. Boxplots showing data from 2010-2022 for routine monitoring locations are provided in **Appendix B** for field and nutrient parameters. Spatial boxplots show the range of values for each location and statistical parameters such as the maximum and minimum values, median, and interquartile range.

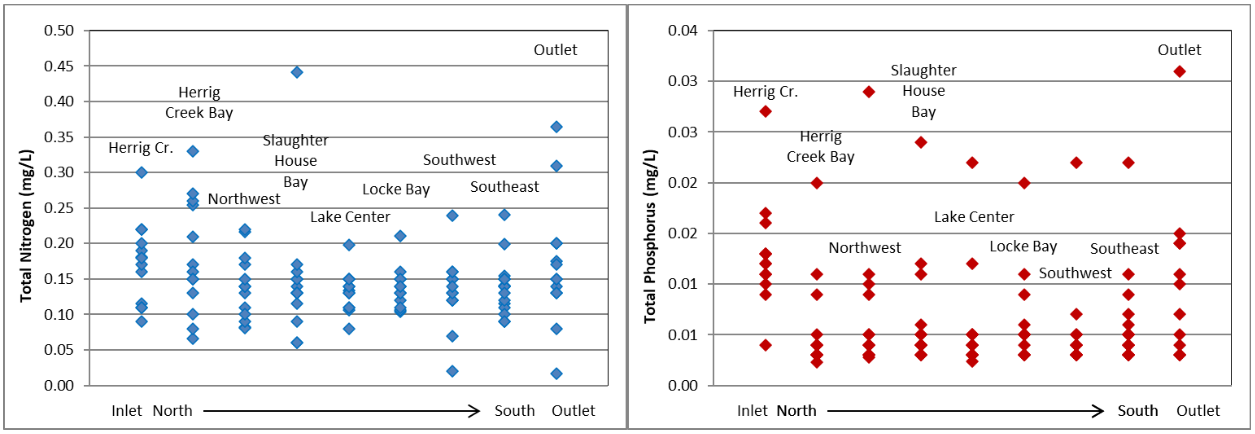

Figure 8. Spatial Trends 2010-2022.

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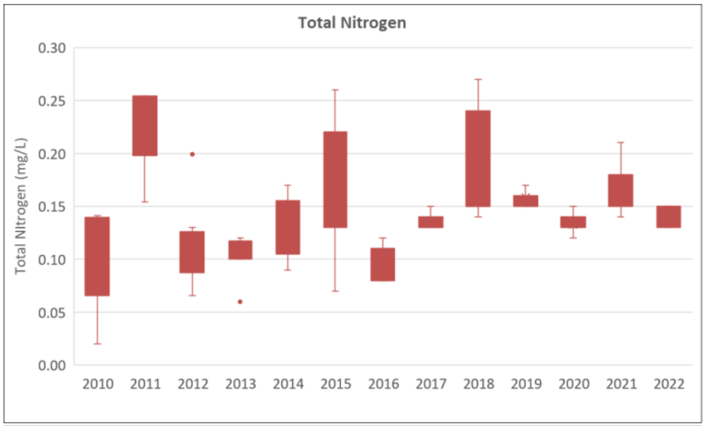
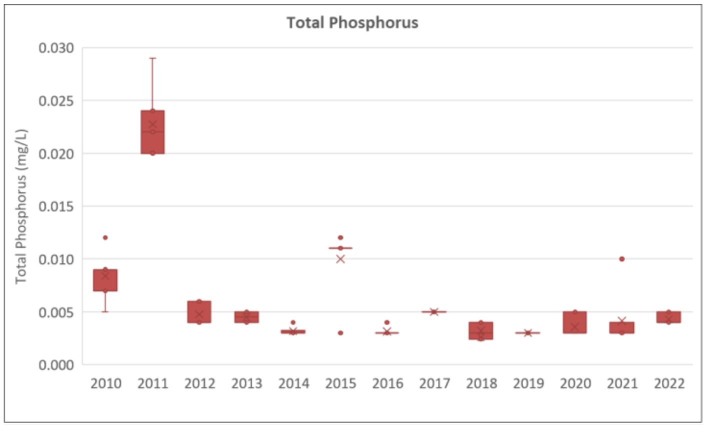
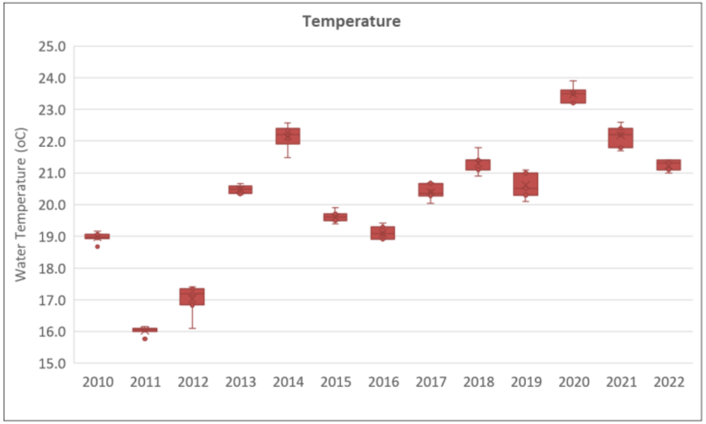
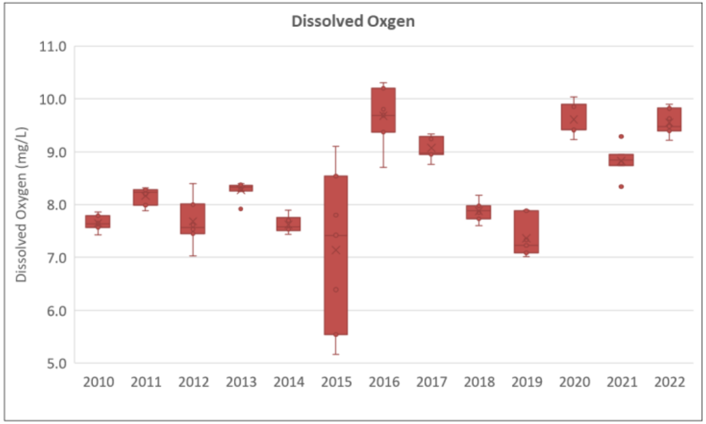
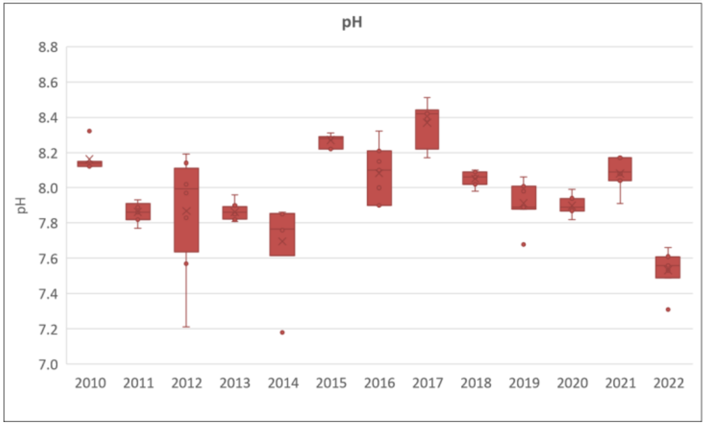
Appendix A – Temporal Boxplots

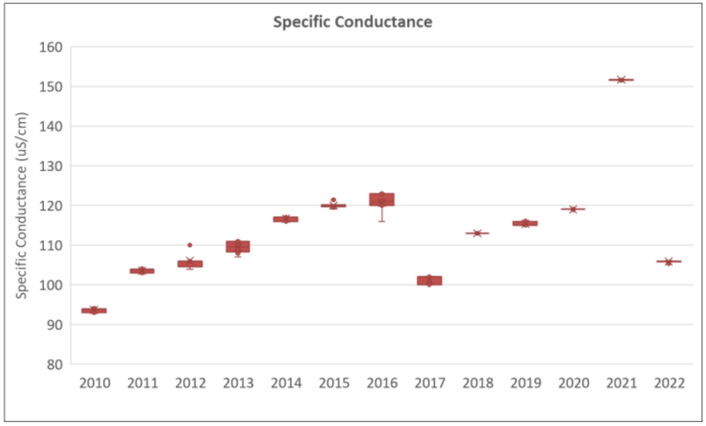




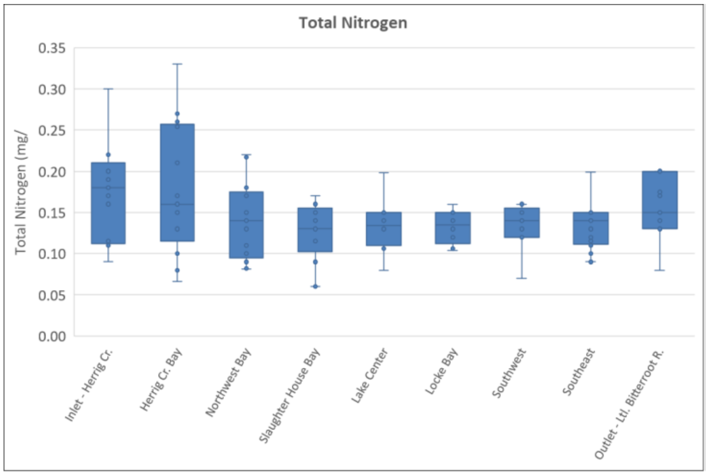








Appendix B – Spatial Boxplots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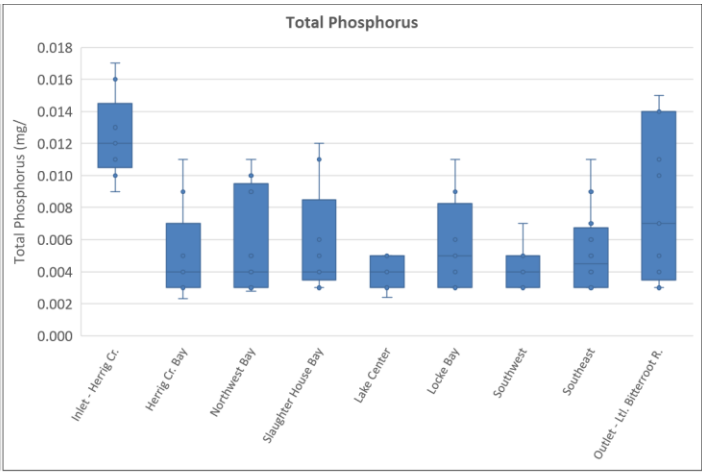
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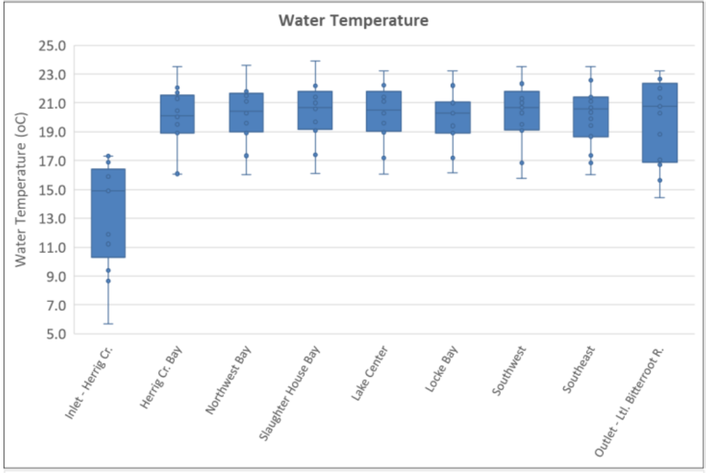
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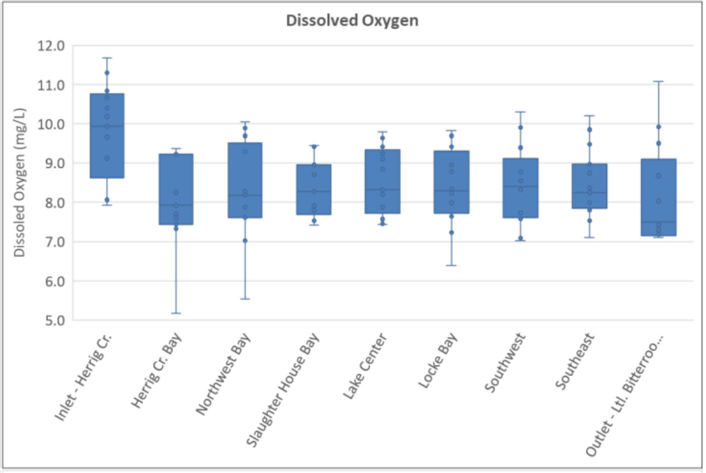
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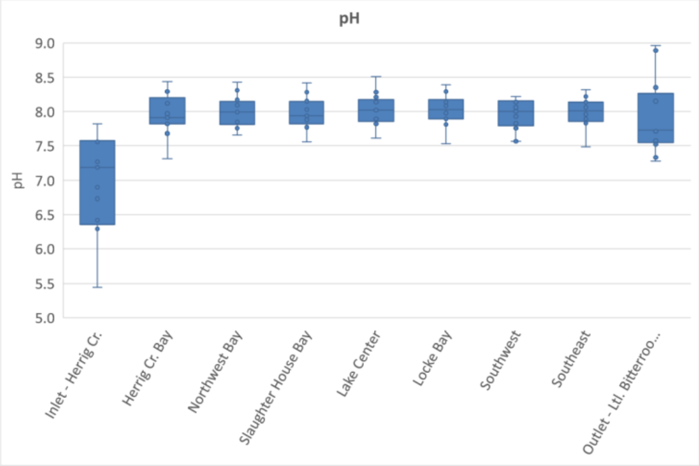
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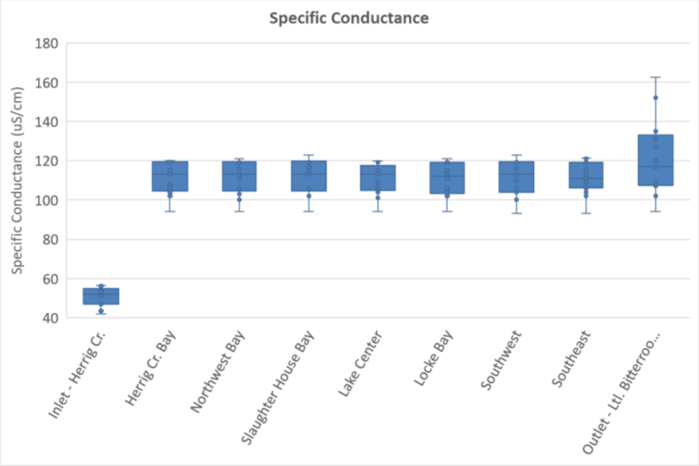
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