Little Bitterroot Lake
Water Quality Monitoring Program
2021 Annual Report

LITTLE BITTERROOT LAKE ASSOCIATION

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Glossary of Terms

Benthic – the bottom region of a lake including the sediment surface

Bloom – a significant increase in algae population triggered by favorable conditions for growth

Chlorophyll-*a* – a green pigment found in photosynthetic plants and algae

Depth profile – a chart showing a water chemistry parameter at various depths within a lake

Epilimnion – the 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 – the 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)

Trophic status – a lake's ability to produce and sustain populations of algae in response to available nutrients, also referred to as lake productivity or biological productivity

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
WET – Water & Environmental Technologies
WLI – Whitefish Lake Institute

Executive Summary

Little Bitterroot Lake was sampled on August 4, 2021, which was the 23st sampling event since 1999. Seven lake sites were sampled for field parameters, nutrients, and chlorophyll-a, and two stream sites were sampled for field parameters, nutrients, and total organic carbon. The lake outlet (Little Bitterroot River) was also sampled for attached algae. Depth profiles were recorded at the lake center by Whitefish Lake Institute on July 12, 2021.

Little Bitterroot Lake continued to show excellent water quality in 2021. Average total nitrogen in 2021 was slightly higher than 2020 and was near the mid-range of all years sampled. Total nitrogen continues to show a slightly upward trend since 2012, which is common for many lakes in developed areas. The average total phosphorus concentration in 2021 was the among the lowest on record with only three samples measuring above the analytical detection limit. Nitrogen concentrations were highest in the inlet stream and in the north bays. Total phosphorus was also highest in the inlet stream and the northwest bay, which suggests that the Herrig Creek watershed is a source of nutrients to the lake in mid-summer. Little Bitterroot Lake continues to be phosphorus limited, meaning that sufficient nitrogen is available for algae growth, and algae blooms are more likely to occur with inputs of phosphorus. The low concentrations of phosphorus are encouraging; however, during mid-summer available nutrients are consumed by algae in the water column and results may not represent worst-case conditions.

Near surface lake temperatures in August 2021 were around 21.7 to 22.6°C (71.0 to 72.7°F). The lake was thermally stratified with an epilimnion from 0 to 20 feet, a metalimnion from 20 to 60 feet, and a hypolimnion below 60 feet. Temperatures in the upper stratified layer (the epilimnion) were the highest on record in July 2021, and the epilimnion was approximately 5 feet shallower than normal.

Algae in the water column (chlorophyll-a) was above average in August 2021, with all samples above the analytical detection limit. Concentrations in the north and middle sections of the lake averaged 0.4 mg/L, and the highest concentrations was at a depth of 60' in the lake center (2.7 mg/L). Although algae concentrations were higher than normal, algae did not reach nuisance levels in August 2021. One attached (benthic) algae sample was collected in 2021 from the Little Bitterroot River outlet channel. Attached algae concentrations were relatively low compared to previous samples (2.7 mg/L) and did not reach nuisance levels. Documenting observable patches of algae is important for documenting areas with potential nutrient impacts, such as locations of failing septic systems. The higher algae observed in 2021 could be attributed to higher surface water temperatures and more available nutrients.

The trophic state index for Little Bitterroot Lake was oligotrophic based on concentrations of chlorophyll-a and phosphorus, meaning the lake has low primary productivity and good water quality. Total nitrogen concentrations indicate the lake has potential to be eutrophic, but the lake is phosphorus limited and the low concentrations of available phosphorus help prevent nuisance algae blooms. When compared to 11 regional large lakes, Little Bitterroot Lake ranks 7th lowest in nitrogen concentration, and 7rd lowest in phosphorus, which is lower standing than last year for both nutrients.

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 2021 and data continues to show low concentrations of nutrients (nitrogen and phosphorus) and algae. 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 and occupation over this period.

Cautions: Isolated areas with significant algae growth have been identified. 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. These spots have been monitored visually for several years, and their continued presence has raised concern among the lake association. More detectable concentrations of total phosphorus were observed in 2021 than usual, and the lake had the highest surface water temperature on record. Chlorophyll-a in the water column was also above average in 2021, possibly due to increased water temperatures and available nutrients.

1.0 Introduction

Little Bitterroot Lake is the headwaters for the Little Bitterroot River located southwest of Kalispell near the community of Marion at an elevation of approximately 3900 feet (**Attachment A**, **Figure 1**). The lake has a maximum depth of 260 feet, 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 and 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 establish a water quality and nutrient baseline for the inflow, outflow, and lake water in conjunction with prior water quality projects. 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 from 2021 and past monitoring events. Long term trends in nutrient concentrations and trophic status are provided for locations that have been sampled consistently since 1999.

2.0 Monitoring Program History

Water & Environmental Technologies (WET) have conducted 23 sampling events on Little Bitterroot Lake since 1999 with assistance from the Little Bitterroot Lake Association. Data collected during sampling helps document existing water quality, track changes in nutrient concentrations over time, and to characterize the lake's productivity and trophic status. Additional data have been collected by the Flathead Lake Biological Station, Flathead Basin Commission, Flathead High School, Montana DEQ, University of Montana, and Whitefish Lake Institute.

Past monitoring events conducted by WET 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.	

Depth profiles included with this report were measured in Little Bitterroot Lake on July 12, 2021, by Whitefish Lake Institute, which oversees the Northwest Montana Lakes Volunteer Monitoring Network. The following sections describe the locations, dates, and methods for field sampling conducted in 2021 on Little Bitterroot Lake and the surrounding watershed.

3.0 Field and Analytical Methods

The water quality monitoring program on Little Bitterroot Lake includes annual field measurements and sample collection for laboratory analysis. Monitoring is conducted during mid-summer, typically the first week of August, although additional monitoring events have been conducted in spring and fall to evaluate seasonal changes in water quality. Monitoring is routinely conducted at 7 lake sites and 2 stream sites, although additional parameters or sites are added as warranted. Routine measurements of field parameters include water temperature, dissolved oxygen, specific conductance, and pH. Routine samples collected for laboratory analysis include basic nutrient parameters, including total nitrogen and total phosphorus. Calcium and alkalinity were added to the program at select sites in 2018 to evaluate the potential for colonization of aquatic invasive species, especially invasive mussels and non-native vegetation. Lake samples are also collected for chlorophyll-a, which is a measure of algae growth. Sites have been sampled for chlorophyll-a on near-shore rocks since 2014 as a means of monitoring algae growth on natural substrate. Depth profile monitoring is conducted annually by Whitefish Lake Institute at the lake center during late July or early August, and includes measurements of water temperature, specific conductance, dissolved oxygen, and pH at depth.

In 2021 sampling events were conducted by WET on August 4, and by Whitefish Lake Institute on July 12 with assistance from members of LBLA. Water quality sampling in 2021 was conducted at 7 lake locations and 2 stream locations, including sites on the inlet stream (Herrig Creek) and the outlet stream (Little Bitterroot River) (**Figure 1**).

Laboratory analyses in 2021 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 are provided in the project Sampling and Analysis Plan (SAP) (WET, 2021), which is provided to Montana DEQ to procure funding from the volunteer monitoring grant program.

3.1 Field Parameters

Field parameters are measured using a portable water quality meter (YSI Pro-Plus). Measurements are taken in the upper 3’ of the water column at lake locations, or within the flowing portion of the stream at surface water locations. Field parameters include water temperature, dissolved oxygen, specific conductance and pH. The water quality meter is calibrated during the day of sampling. Water clarity is measured at the lake center using a Secchi disc. Stream flow is measured at surface water locations using a Marsh-McBirney electronic flow meter.

3.2 Water Chemistry Samples

Samples are collected for laboratory analysis of nutrients at each lake and stream location. Bottles are filled from moving water at the inlet and outlet streams, and from just below the surface at lake sites. At the lake center, samples are collected at various depths using a Van Dorn type sampler. All sample bottles are triple-rinsed with sample water prior to collection. Samples are filtered or preserved if necessary, and stored in a cooler on ice for delivery to the laboratory. Nutrient parameters analyzed at the laboratory include various forms of nitrogen (nitrate+nitrite, ammonia, total Kjeldahl, organic, total) and phosphorous (dissolved and total). Samples for total organic carbon (TOC) were also collected in 2021 from the lake center, and the inlet and outlet streams. All laboratory analyses were performed by Energy Laboratories in Helena, MT, using standard analytical methods, which are described in detail in the project SAP.

3.3 Algae Samples

Samples are collected from lake sites to analyze the concentration of chlorophyll-a, which provides a measurement of algae growth in the water column. Chlorophyll-a samples from open water 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 type sampler.

Benthic algae samples were collected from one location in 2021 to measure the algae growth on shoreline rocks. For benthic algae collection, large rocks are selected from the wadeable portion of the lake that displays typical 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 removed 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 Energy Laboratories in Helena, MT. Eleven template samples are collected at each location per the sampling protocol, which is described in the project SAP and based on standard collection methods approved by DEQ.

3.4 Depth Profile Sampling

Depth profile sampling is conducted at the lake center to evaluate changes in field parameters at depth, which indicates the degree of lake stratification at the time of sampling. Depth profile sampling was conducted by Whitefish Lake Institute on July 12, 2021, using a portable Hydrolab water quality meter which measures depth, chlorophyll-a concentration, water temperature, specific conductance, dissolved oxygen, and pH. The Hydrolab has a maximum sampling depth of 140 feet, which is sufficient to monitor for stratification in Little Bitterroot Lake.

4.0 2021 Monitoring Results

Results from 2021 are provided in **Attachments A** and summarized in the following sections below.

4.1 2021 Field Parameter Results

Field parameter results from 2021 are provided in **Table 1** in **Appendix A**.

During the August sampling event, weather was cool in the morning (65°F) increasing to 90°F in the afternoon. Skies were clear with very little wind. The lake had a surface temperature ranging from 21.7 to 22.6°C (71.0 to 72.7°F) which was warm compared to previous years. Herrig Creek was contributing cooler water around 14.9°C (58.8°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 23.2°C (73.8°F) and had flow of 5.0 CFS (2250 GPM). The pH at lake sites varied between 8.04 and 8.17, while the inlet and outlet streams measured 7.56 and 8.18, respectively. Biological activity by plants and algae raise pH during daytime hours when photosynthesis is occurring, which can attribute to the higher pH measurements at certain locations. Dissolved oxygen (DO) varied from 8.7 to 9.3 mg/L at the lake surface, while DO measured 10.4 mg/L in the inlet stream and 9.5 mg/L in the outlet stream. Specific conductance was quite low in the inlet stream (69.7 µS/cm) but uniformly around 152 µS/cm at the lake sites and the lake outlet.

Measurements of pH and dissolved oxygen in 2021 were higher than those recorded in 2020, which could be attributed to the higher lake temperatures which increase biological productivity and raise the pH and dissolved oxygen concentration during daytime hours. The specific conductance of the lake was also higher in 2021 when compared to 2020, which could be due to drier conditions in 2021.

4.2 2021 Nutrient Results

Nutrient results from 2021 are provided in **Table 1**, and data for total nitrogen (TN) and total phosphorus (TP) are shown spatially in **Figure 2**, organized left to right from the lake inlet (Herrig Creek) to the lake outlet (Little Bitterroot River).

In 2021, total nitrogen concentrations were relatively low and very comparable throughout the lake, varying from 0.14 to 0.21 mg/L. The highest values (0.21mg/L) was recorded Herrig Creek Bay, which receives more direct input from Herrig Creek. The lowest nitrogen values were measured the lake center and at the southeast location. Samples collected from Herrig Creek were higher than lake sites (0.22 mg/L), and the outlet at the Little Bitterroot River was comparable to lake sites (0.15 mg/L).

Total phosphorus measurements were below detection (<0.003 mg/L) at all lake sites apart from the northwest bay (0.01 mg/L), Slaughter House Bay (0.004 mg/L) and at the lake center at 60' depth (0.006 mg/L) in August 2021. Samples collected from Herrig Creek were 0.013 mg/L while the lake outlet was below detection. Little Bitterroot Lake has historically shown low concentrations of total phosphorus and is described as "phosphorus-limited". Inputs of phosphorus from the inlet stream are likely consumed by algae and aquatic plants within the lake, resulting in lower measurements of total phosphorus in the lake samples.

4.3 2021 Chlorophyll-a Results

Samples for chlorophyll-a were collected from 9 locations in August 2021, including 7 samples from the lake surface, 1 sample from 60' depth at lake center, and 1 sample from natural substrate. In August 2021, algae growth in the lake water was higher than normal, which could be attributed to higher lake temperatures and additional nutrients. Samples were composited into one sample for each of the north, middle, and south portions of the lake. The north and middle lake composite samples both measured

0.4 mg/L, while the south portion of the lake measured 0.1 mg/L. The sample from 60' depth measured 2.7 mg/L, which is common for samples collected from depth. In the depth profile from July 2021, the highest concentration of chlorophyll-a (3.7 mg/L) was recorded 100' below the lake surface, which is slightly deeper than the typical depth for peak chlorophyll-a in the water column.

Attached algae, also called benthic algae, were sampled at one shoreline location in August 2021 at the outlet channel on the Little Bitterroot River. Benthic algae concentrations measured 2.8 mg/m^2 in the Little Bitterroot River. 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.

4.4 2021 Depth Profile Results

Depth profile sampling was conducted on July 12, 2021, to show changes in water chemistry at depth. Results from the depth profile sampling are shown in **Figure 3**, including charts for water temperature, dissolved oxygen, pH, and chlorophyll-a. Results from 2014 to 2021 are shown for comparison. Overall, depth profile measurements from July 2021 were comparable to previous years showing similar trends at depth, although near surface readings of temperature in July 2021 were the highest on record.

In July 2021 the lake was thermally stratified with an epilimnion (upper layer) from 0 to 20 feet, a metalimnion (transitional layer) from 20 to 60 feet, and a hypolimnion (bottom layer) from approximately 60 feet to the lake bottom, which is typical for Little Bitterroot Lake in mid-summer. Near-surface temperatures on July 12, 2020, were the highest on record, although other field measurements did not exhibit extremes. Temperatures in the metalimnion and hypolimnion (middle and lower lake) were within the range of previous measurements.

Dissolved oxygen (DO) measured 8.1 mg/L in the upper epilimnion in July 2021, with the peak occurring 60' below the lake surface (12.7 mg/L). DO measurements in 2021 were typically higher than previous readings in all lake layers. DO typically 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.

Depth profile measurements of pH in July 2021 were comparable to previous years, ranging from 8.15 near the lake surface to 8.35 in the metalimnion. 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. These results are expected because photosynthetic activity from algae raises the pH during daytime hours. pH in the hypolimnion (deep portion of the lake) decreased with depth, measuring 7.50 at 190' in July 2021.

The depth profile for chlorophyll-a in July 2021 was also comparable to previous years, although the peak concentration was deeper than normal at 100 feet. Chlorophyll-a serves as a measurement of algae production within the water column, and photosynthetic algae (phytoplankton) commonly peak at depth where availability of light, nutrients, and water density are optimal for algae growth.

4.5 Long Term Trends

Results from 2004 to 2021 are shown for all sample locations in **Figure 4**, and **Figure 6** shows minimum, maximum, and average nutrient concentrations from 2004-2021 for mid-summer concentrations at lake sites only. Nutrient concentrations have generally shown a decreasing trend since consistent yearly monitoring began in 2004, although total nitrogen concentrations have been increasing steadily since 2012. In August 2021, total nitrogen and total phosphorus concentrations in Little Bitterroot Lake were comparable to samples collected since 2012, although nitrogen and phosphorus were both higher in 2021 than in 2020. Elevated concentrations of nutrients were last recorded during the high water year of 2011.

The downward trends in nutrient concentrations are encouraging from the standpoint of improving water quality but should be interpreted with caution because of the limited temporal data available for Little Bitterroot Lake. Nutrient concentrations can vary between seasons or change rapidly due to episodic events such as runoff 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 data collected since 2012 is best for evaluating mid-summer trends due to consistency with timing and methods of the sampling 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 around 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 6** displays the trend in N:P ratio from 2004 to 2021 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 2021, the N:P ratio was 42.5 (indicating that the lake is phosphorus limited), and the N:P ratio appears to be increasing from 2004 to 2021 even though concentrations of both nutrients are declining over this period. This result is occurring because concentrations of nitrogen are not declining as rapidly as phosphorus, and total nitrogen even shows an increasing trend from 2012 to present.

This trend with increasing nitrogen is prevalent across the western United States and is typically considered a result from 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.

4.6 Trophic Status

Trophic status refers to 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 biological productivity is an indicator of low nutrient concentrations and good water quality. The trophic status of Little Bitterroot Lake was determined by calculating the Carlson's Trophic State Index (TSI) from measurements of total nitrogen, total phosphorus and chlorophyll-a (Carlson, 1977). The TSI for Little Bitterroot Lake is shown in **Figure 7** for data from 2004 to 2021.

TSI data suggest that Little Bitterroot Lake is classified as 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. Total phosphorus concentrations in 2021 were typically below detection at most sites, indicating oligotrophic conditions.

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 during sample events conducted from 2010 to 2021. The low biological 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 littoral (shallow shoreline) habitat, and a low watershed/lake ratio of 4.8 (Ellis et al, 1998). 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.

4.7 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 2021 at the lake center and the inlet and outlet streams. Calcium concentrations were lowest in Herrig Creek (5 mg/L) and highest at the lake center (15 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 2021 ranged from 25 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 dreissenid 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.

6.0 Discussion and Conclusions

Water quality in Little Bitterroot Lake was again very good in 2021, with low concentrations of nutrients and chlorophyll-a. Total nutrient concentrations (nitrogen and phosphorus) have generally been decreasing since the inception of the monitoring program in 1999. Elevated concentrations of both nutrients were exhibited in 2011, which was a high precipitation year during which excess nutrients may have been flushed into Little Bitterroot Lake from the surrounding watershed, although this result has not been exhibited in other high water years such as 2018. Past sampling events indicate that lake water quality is strongly influenced by ground water with less input from Herrig Creek and other intermittent streams.

The trophic state index for Little Bitterroot Lake suggests eutrophic conditions 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. Water quality parameters (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 of calcium and alkalinity than those measured in Little Bitterroot Lake.

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 classified as large lakes with surface areas greater than 500 acres (WLI, 2022). Among the large lakes monitored through NMLN, Little Bitterroot Lakes ranked 7th lowest in nitrogen concentration and 7rd lowest in phosphorus concentration in 2021.

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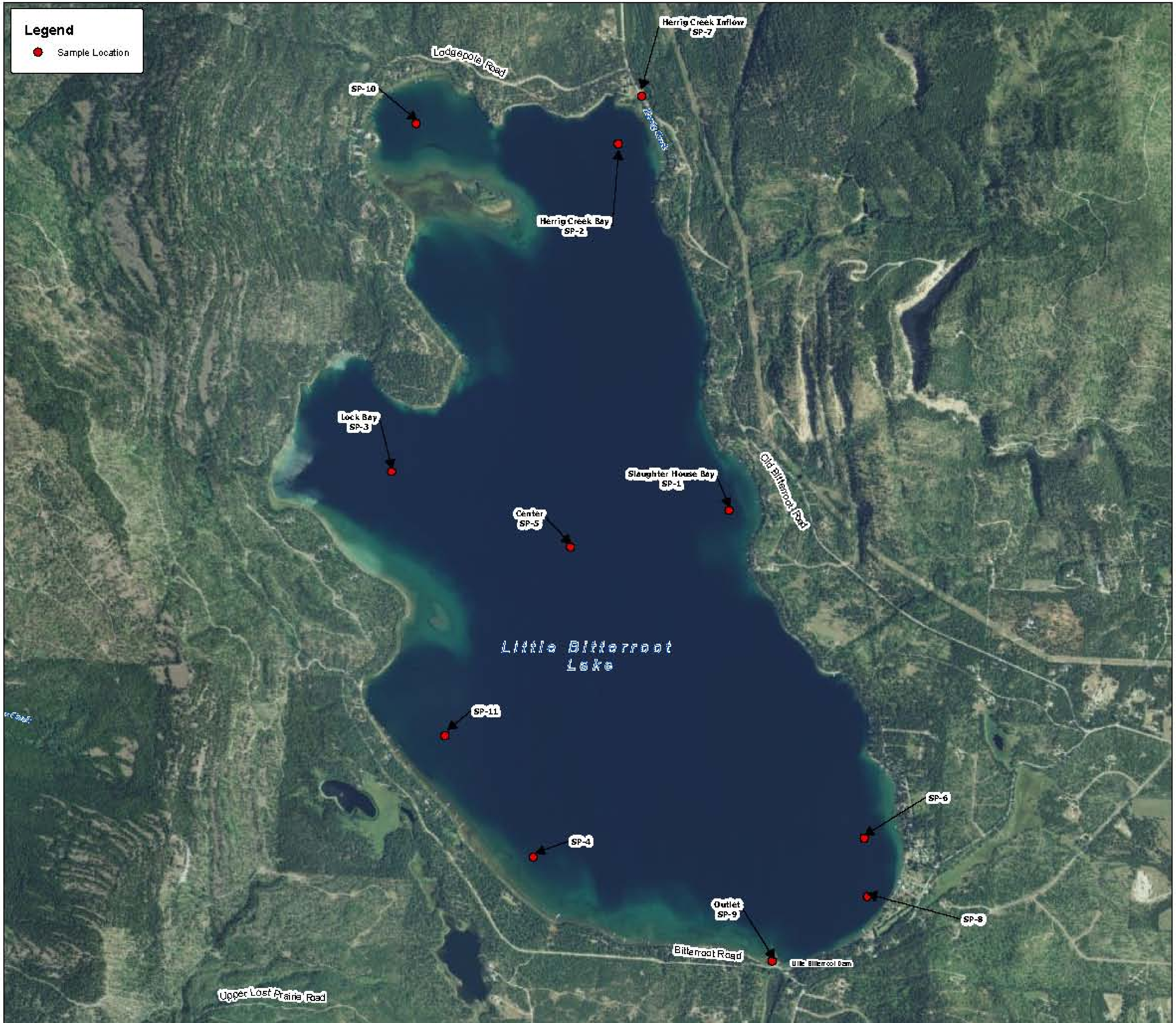
Attachment A – Tables and Figures

Table 1. 2021 Water Quality Data.

Sample Info			Field Water Quality						Chlorophyll-a		Additional Samples		
Site	**Date**	**Site Description**	**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)**	**Calcium (mg/L)**	**Alkalinity (mg/L)**	**Total Organic Carbon (mg/L)**
			Analytical Detection Limits →				**0.04**	**0.003**	**0.1**	**0.1**	**1.0**	**1.0**	**0.5**
SP-2	8/4/21	North - Herrig Cr. Bay	21.7	8.3	152	7.91	**0.21**	0.003	**0.4**				
SP-10	8/4/21	Northwest - Northwest Bay	21.8	9.3	152	8.17	**0.18**	**0.010**	**0.4**				
SP-1	8/4/21	East - Slaughter House Bay	22.2	9.0	152	8.08	**0.17**	**0.004**	**0.4**				
SP-3	8/4/21	West - Locke Bay	22.2	8.8	152	8.10	**0.15**	0.003	**0.4**				
SP-5	8/4/21	Lake Center - Near Surface	22.4	8.8	152	8.04	**0.14**	0.003	**0.4**		**15**	**51**	**2.8**
SP-5-60	8/4/21	Lake Center - 60' depth	7.1	12.7	102	8.36	**0.19**	**0.006**	**2.7**				
SP-4	8/4/21	Southwest - Southwest Bay	22.4	8.8	152	8.17	**0.16**	0.003	0.1				
SP-6	8/4/21	Southeast - Southeast Bay	22.6	8.7	152	8.09	**0.15**	0.003	0.1				
SP-7	8/4/21	Herrig Creek - mouth	14.9	10.4	70	7.56	**0.22**	**0.013**			**5**	**25**	**4.1**
SP-9	8/4/21	Ltl. Bitterroot River - outlet	23.2	9.5	152	8.18	**0.15**	0.003		**2.8**	**14**	**52**	**2.7**

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



1 inch = 2,000 feet

Feet

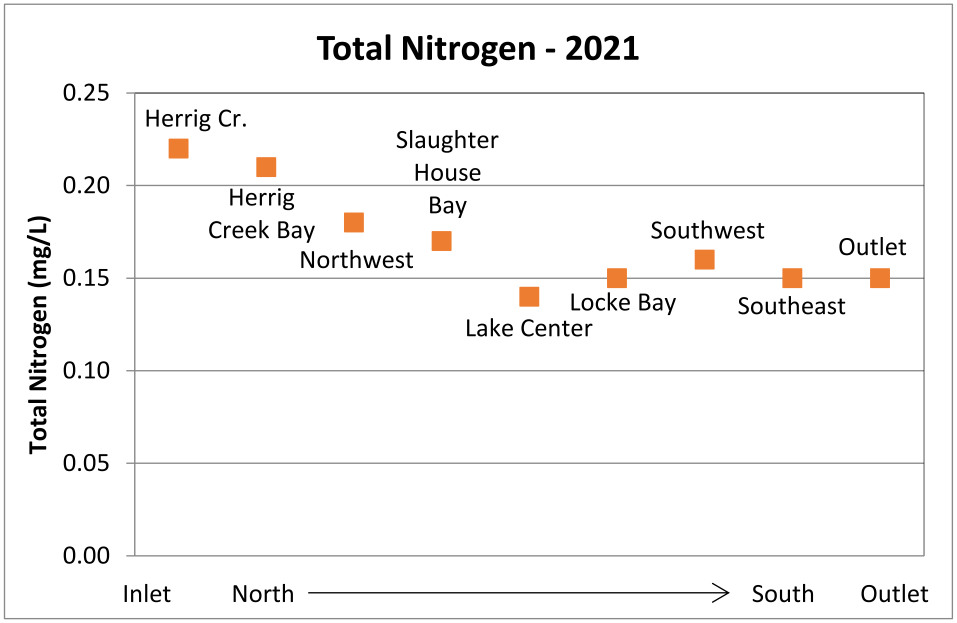
0 1,000 2,000

WATER & ENVIRONMENTAL TECHNOLOGIES, PC

Little Bitterroot Lake Site Location

LBHHM01	FIGURE 1
10/30/09	

Image Source: 2009 NAIP 1m Natural Color Imagery for Montana acquired between June 23, 2009 and September 2, 2009.



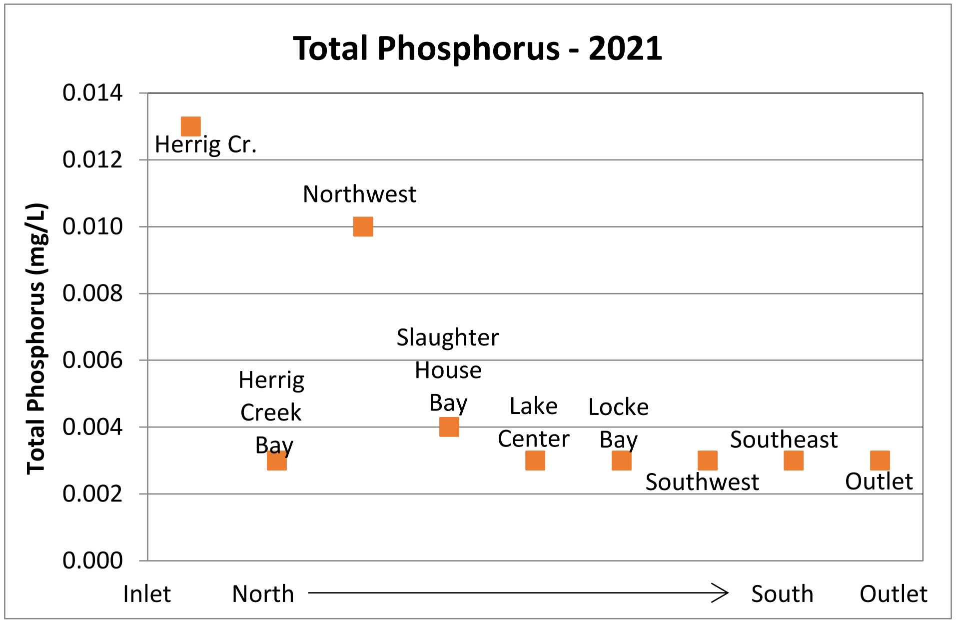


Figure 2. Total Nitrogen and Total Phosphorus Results for 2021.

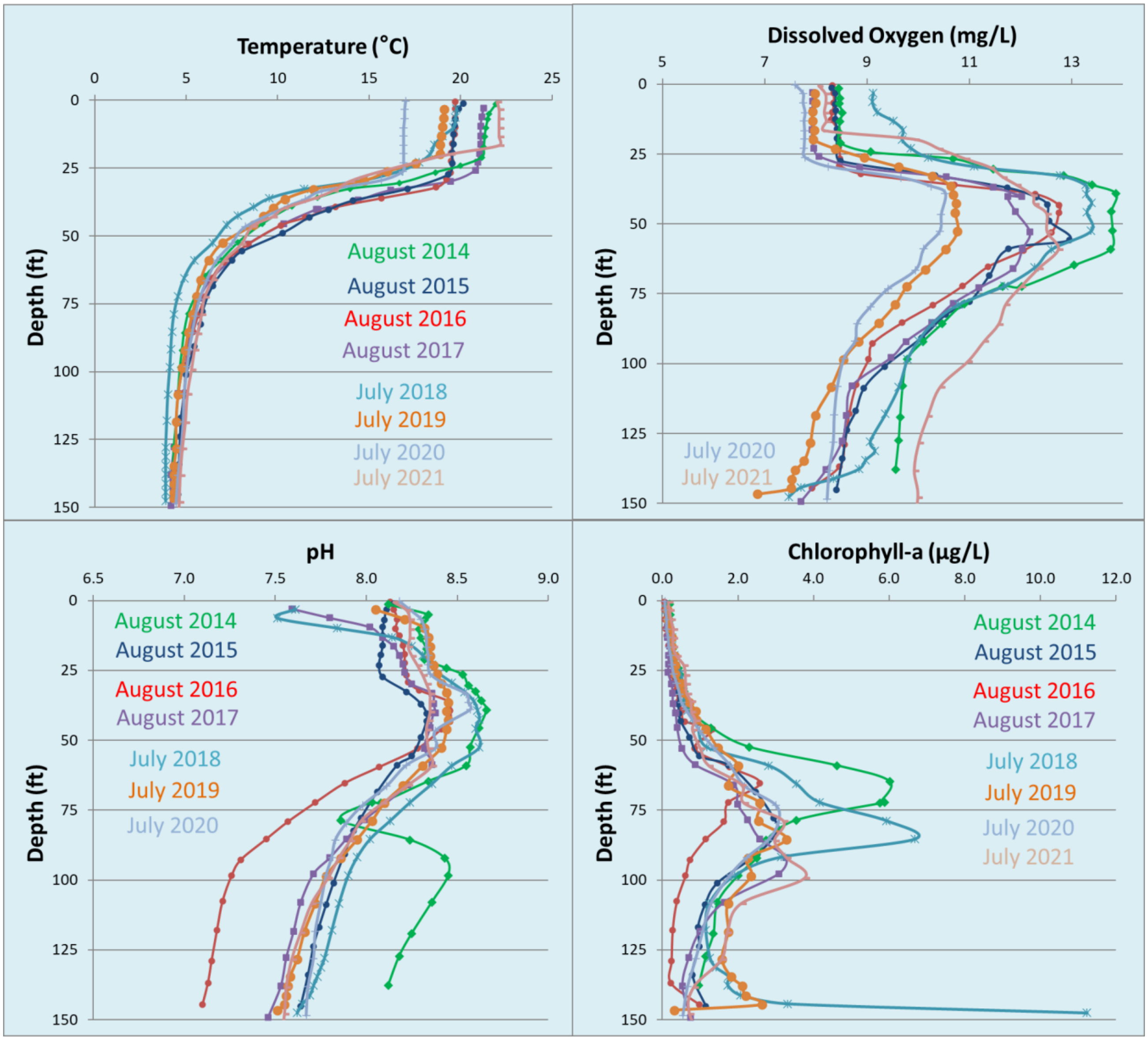


Figure 3. Depth Profile Results for 2021.

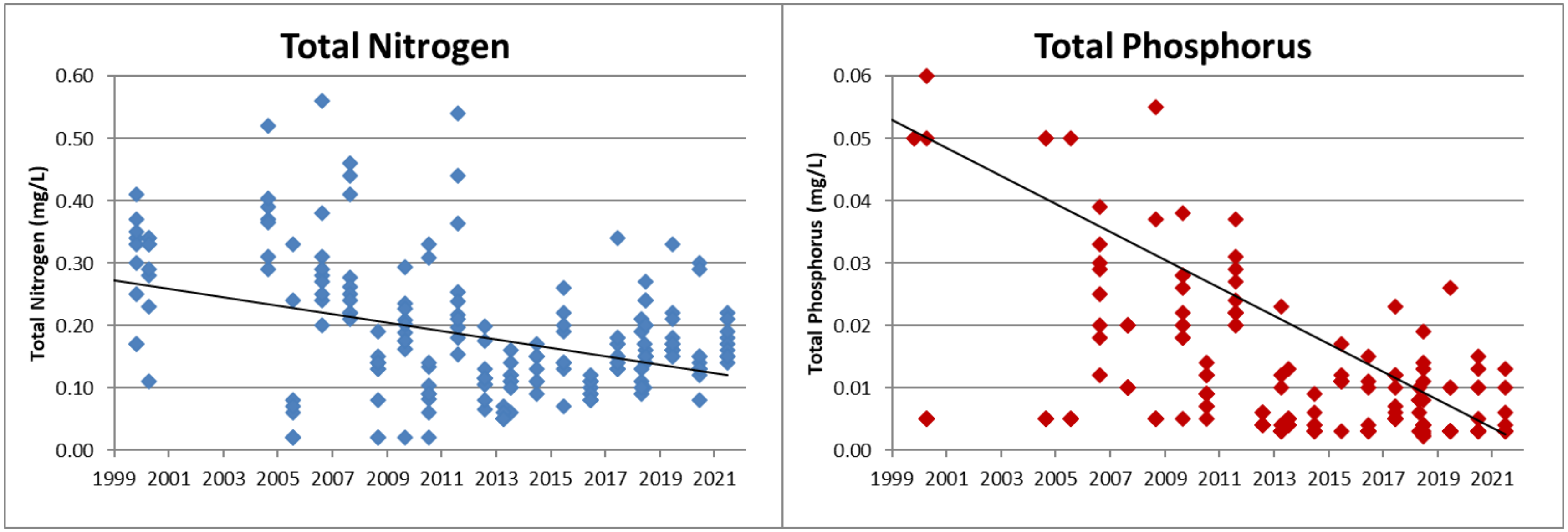


Figure 4. Total Nitrogen and Total Phosphorus Results for 2004-2021.

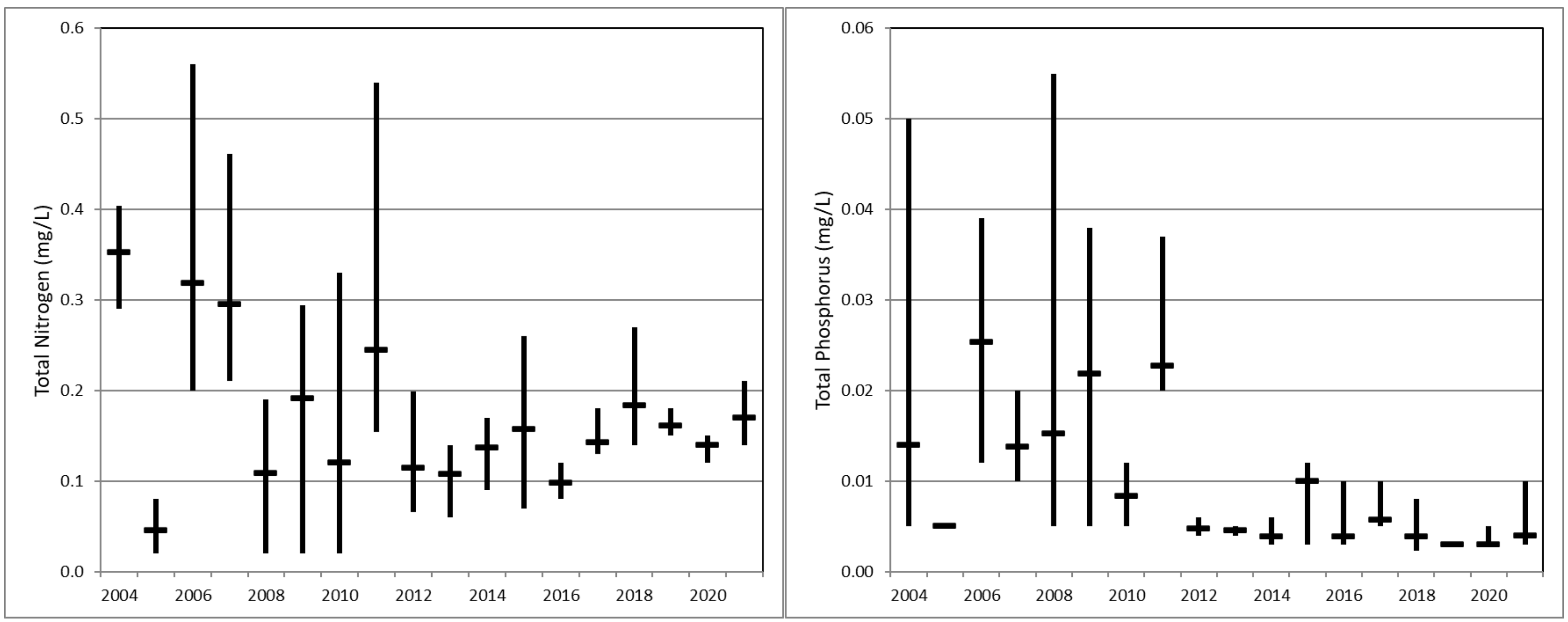


Figure 5. Yearly Nutrient Statistics (Minimum, Maximum, Average) from 2004-2020.

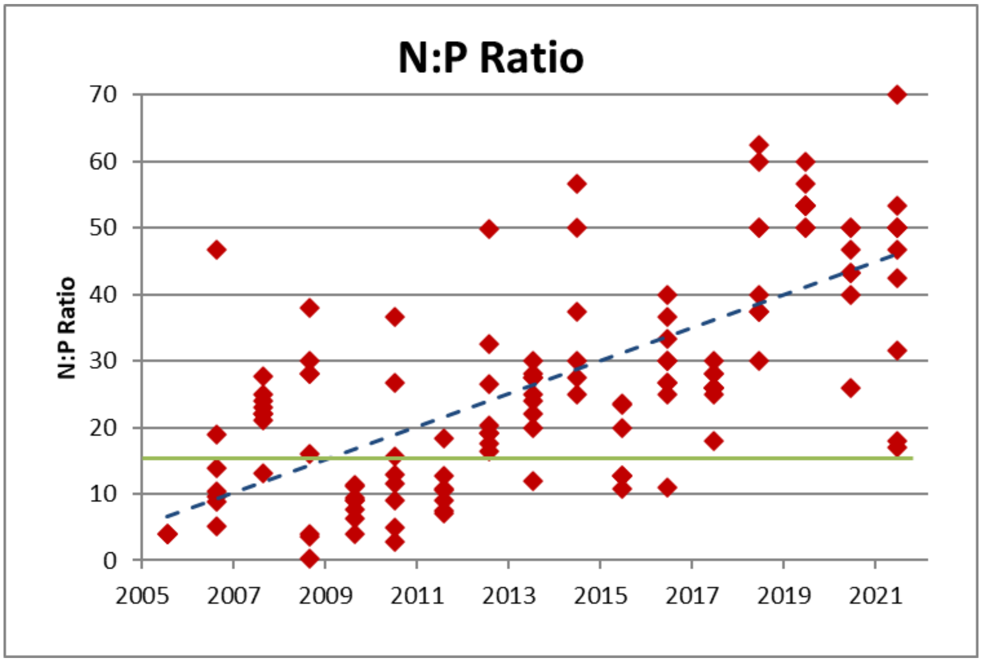


Figure 6. Nitrogen:Phosphorus Ratio from 2004-2021.

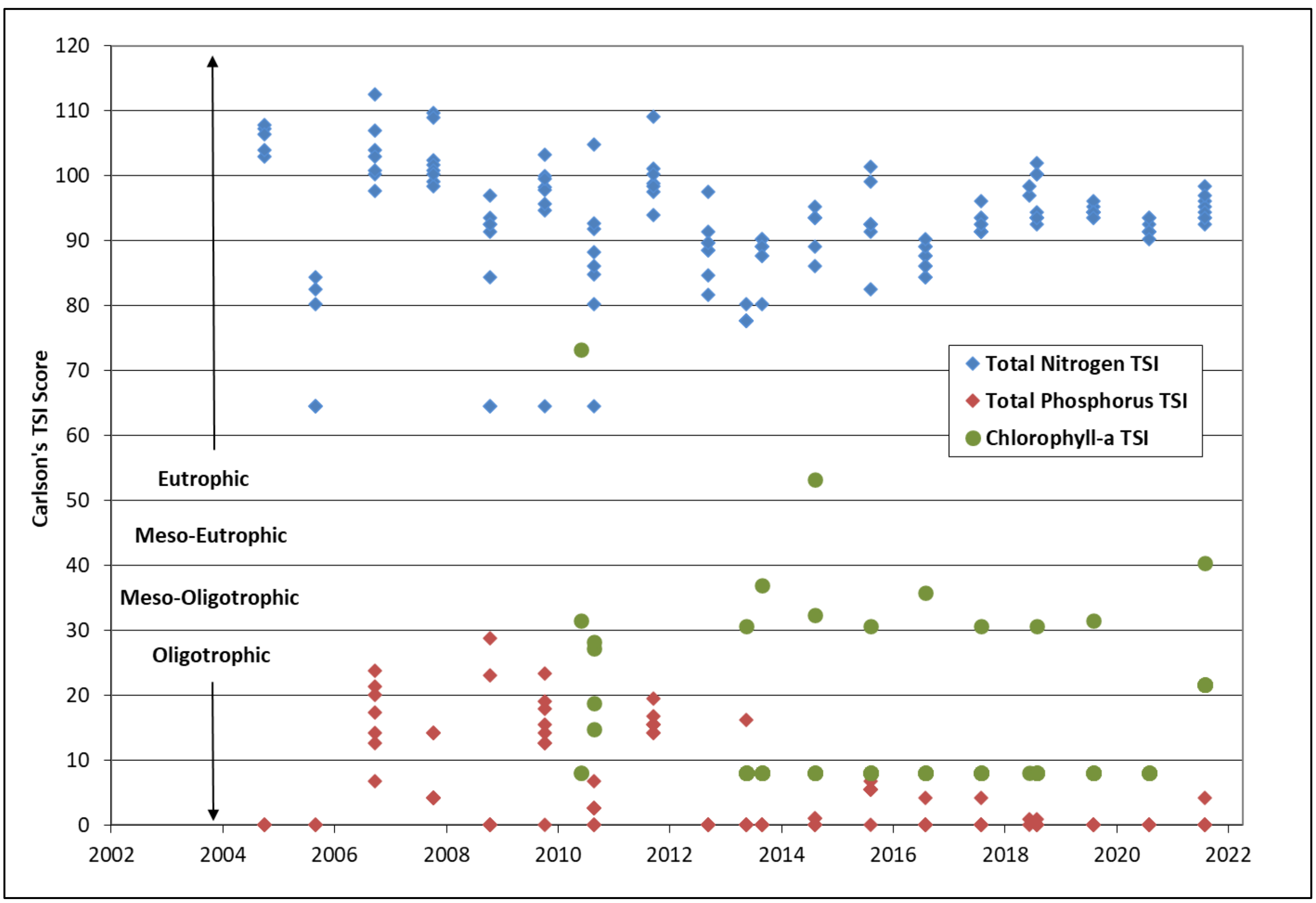


Figure 7. Trophic Status of Little Bitterroot Lake from 2004-2021.