Water Quality of Hayden Lake with Special Emphasis on Other Potential Areas of High Plant Growth Nutrient Concentration

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Introduction

Hayden Lake is the second largest of Kootenai County Idaho's eight lakes. The water quality of Hayden Lake was fully characterized by Soltero and his students (Soltero et al., 1986) during the mid-1980s. Soltero's assessment was followed by seventeen years of monitoring by Robert Black participating in Idaho Department of Environmental Quality's citizen water quality monitoring program (Harvey 2005). Similar but more extensive water quality monitoring was completed by the Hayden Lake Watershed Association Inc. (Harvey, 2005; Harvey, 2006), participating in the same volunteer program. The data from all these efforts demonstrate that Hayden Lake's central body is water low in plant growth nutrients, especially phosphorus, which limits algal growth. Phosphorus is present at an average of 7.5 micrograms total phosphorus per liter. This value persisted over seventeen years from the completion of Soltero's work through the monitoring by Black. Water quality assessment in 2005 and 2006 reflected this same average value. The total phosphorus concentration found is well in the range of a water body defined as oligotrophic. Low chlorophyll a concentration in the range of 1 to 1.5 micrograms per liter as well as the high clarity of the water of the central body reinforce the assessment of the lake's main body. The Mid-lake station monitoring completed in 2019 reflected this same pattern of water quality after thirteen additional years (Harvey 2021).

However, Hayden Lake is not a lake unaltered by man's activities. The construction of the dike in 1910 and plugging of high infiltration areas in the lake's bottom in what is now Honeysuckle Bay altered the hydrology of the lake (Harvey 2019). Areas that would have drained after spring high discharge and become mid-and late summer pastures are now inundated year around most years. Areas of the lake like the North Arm north of Henry Point, Mokins Slough, eastern O'Rourke Bay and even Honeysuckle Bay now hold water year around as a result of the hydrologic alteration.

Water quality assessment by Soltero's group, Black and the Watershed Association all demonstrate that the North Arm has a very different water quality. Total phosphorus is in the range of 25 micrograms per liter or greater in this limited area of the lake. Chlorophyll a ranged between 2 and 17 micrograms per liter dependent on the location (Harvey 2005). The water is shallow except in the former channel of Hayden Creek, but water clarity is much lower. These results indicate the North Arm above Henry's Point is eutrophic in nature. More recent water quality monitoring by the Watershed Improvement District further defined the eutrophic nature of the lake waters north of Henrys Point (North Arm) (Harvey 2020.) Mokins Slough and eastern end of O'Rourke Bay share some of the same characteristics of the North Arm, although cyanobacteria blooms have not been documented in these waters. The other shallow embayment of the lake (Honeysuckle Bay) currently does not exhibit any of these eutrophic characteristics. This may be attributable to the bay's close proximity and less restricted water exchange with the main body of Hayden Lake and/or the flux of water from the bay into the porous matrix of the Rathdrum Prairie Aquifer.

Water quality monitoring by the Watershed Improvement District shifted during the spring, summer and fall 2020 to characterization of the waters of Mokins Slough and inner O'Rourke Bay. These two areas of the lake are shallow like the North Arm and were likely modified to year around inundation by construction of the dike. O'Rourke Bay receives Yellowbanks Creek the lake's second largest tributary, while Mokins Sough receives Mokins Creek, the lake's third largest tributary. The objective of the 2020 monitoring was to characterize the water quality of these two lake embayments at locations, where more nutrient rich conditions might be expected. The mid-lake station was monitored for reference and to add to the over thirty year record of data on Hayden Lake's main body.

Methods and Materials:

Water quality samples were collected bi-monthly between April and October. Lake Watershed Management Inc. collected the samples under contract to the District and supplied these samples to Silver Valley Laboratory (2195 Ironwood Ct., Ste. C, Coeur d'Alene, ID 83814), Am Test Inc. (13600 NE 126TH PL Suite C Kirkland, WA 98034) and Advanced Eco-Solutions Inc. (25011 E Trent Ave. Newman Lake, WA 99025). Water samples were initially supplied to Silver Valley Laboratory, but it was found after a year of sampling that this laboratory was incapable of the detection levels necessary to provide meaningful, orthophosphate and nitrogen chemical species data. The analysis was shifted to Am Test Inc. in the last two years to develop the necessary chemical resolution.

Precipitation received during the years of monitoring was gauged using two sources of data; monthly precipitation for each water year between October and May and snow pack water equivalent for the same period. Precipitation over this time frame best estimates the relative amount of water together with the nutrients carried from the watershed into the lake. Unfortunately, no precipitation or snow pack recording stations are located in the Hayden Lake Watershed. The closest precipitation station is at Boyington Field a few miles west of the lake. However, the orographic effect of elevation creates greater precipitation on the high slopes of the watershed as compared to the air field at low elevation and in the rain shadow of Mount Spokane. The two snow gauging stations operated by the Natural Resource Conservation Service (NRCS) closest to Hayden Lake are located on Rathdrum Mountain and on Mosquito Ridge near the head of the North Fork Coeur d'Alene watershed. Totals from these two Snowtel Stations were averaged to provide an estimate snow pack equivalent stored for the effective period.

Three locations along the expanse of the North Arm were sampled for the initial two years (figure 1 Map with GPS locations). These are the Bob's Bay (47° 48' 23.2"N; 116° 41' 42.5"W), Ross Point (47° 47' 36.4"N; 116° 41' 50.7"W), and Gonzaga (47° 47' 01.0"N; 116° 41' 55.0"W) sampling locations. These sites are located from the north end of the North Arm to midway south on its length and finally just south of Henrys Point where the lake deepens to over forty feet. For the 2019 sampling season the mid-lake station (47° 45' 18.3"N; 116° 44' 37.1"W) that was sampled by Soltero, Black and Harvey was added to the sampling sites. This addition allows comparison of the lake condition at this site as well as comparison to the Gonzaga location.

A Eureka Manta field water quality monitoring unit (model 40) was used to collect temperature, dissolved oxygen and conductivity data. The Manta output was downloaded onto the laptop computer as Excel files. Water clarity was measured with a Secchi Disc.

Water quality samples were collected as water column composite samples with a Kemmerer Sampler and placed into a churn splitter. Samples were collected a meter below the surface and then at two meter intervals until a meter above the lake bottom at the Bob's Bay, Ross Point and Gonzaga sampling locations. At the mid-lake station sample collection terminated at 19 meters. Once samples were thoroughly mixed, water nutrient samples were drawn. A Nitrite-Nitrate, Ammonia and Total phosphorus sample was placed into new clean 250 ml polyethylene sample bottles supplied by the laboratory and with sulfuric acid added as preservative. A separate filtered (<0.45 um) sample was prepared for total dissolved solids and ortho-phosphate analysis. Water samples were stored in an ice chest with ice packets (zero centigrade) and delivered overnight to the laboratory. Chlorophyll samples were collected in brown (darkened) polyethylene bottle supplied by Ecosystem Analysts. Chlorophyll samples held in the ice chest. Chlorophyll a samples were delivered the day of sampling to Advanced Eco-Solutions. Plankton samples were placed in a tin foil covered one liter polyethylene supplied by Ecosystem Analysts. The sample bottle contained Lugol's preservative solution. These samples were placed on ice and delivered to Silver Valley Laboratories for filtering. Preserved filters were supplied to Advanced Eco-Solutions for analysis of the plankton present.

Figure 1: Water quality sampling sites

Water quality samples were analyzed for Total phosphorus (SVL using method EPA 200.7; Am Test using method SM 4500 PF); ortho-phosphorus (SVL using method 200.7 ; Am Test using method SM

4500 P E); ammonia (SVL using method EPA 350.1; Am test using method EPA 350.1); nitrite-nitrate (SVL using method EPA 353.2 Am Test using method EPA 300.0);and total Kjeldahl nitrogen (SVL using method EPA 351.2), persulfate nitrogen (Am Test using method SM#20 4500-N C) and total dissolved solids (SVL using method SM 2540CAm Test using method SM 2540C. Silver Valley Laboratory reported out in milligrams per liter. Many of Silver Valley Laboratory's results were below the detection limit. Am Test reported out data in micrograms per liter, reporting far fewer values below the methods' detection limits.

Phytoplankton samples were preserved in the field in acid Lugol's iodine preservative and shipped to Advanced Eco-Solutions Inc. in Newman Lake, WA for enumeration. The samples were gently shaken for 60 seconds and poured into 25 mL settling chambers and allowed to settle for a minimum of 3 hrs prior to quantitative enumeration using the Utermohl Method (Utermohl 1958). Counts were done using a plankton microscope. All cells within a random transect of 3.5 mm in length were counted at high power (900X magnification) that permitted a semi-quantitative enumeration of minute (<2 µ) autotrophic pico-cyanobacteria cells (1.0-2.0 µ) [Class Cyanophyceae], and of small, delicate auto-, mixo-, and hetero-trophic nano-flagellates (2.0-20.0 µ) [Classes Chrysophyceae and Cryptophyceae]. Comments on the relative density of ciliates in each sample were also noted on count sheets. Where feasible, from 250-300 cells were enumerated in each sample to assure counting consistency and statistical accuracy (Lund et al. 1958). The compendium of Canter-Lund and Lund (1995) was used as a taxonomic reference. The results were presented as cells/mL and bio-volume/Liter.

Chlorophyll samples were held in the ice chest and delivered to SVL Analytical for filtering through a 0.75 um nominal glass fiber filter. The filters were frozen and delivered to Advanced Eco-Solutions Inc. where they remained frozen until analyzed. The samples were analyzed following EPA method 445.0 and reported in Chlorophyll a in ug/L.

Reported nutrient data was placed in Excel spreadsheets and the programs graphing function used to create simple line graphs for each sampling location. Non-detection values were recorded for graphing at one-half of detection.

Quality Assurance/Quality Control:

The Manta field monitor was calibrated before each sampling event using standard solutions. Hydrogen ion concentration (pH) was calibrated with pH 7.0 and pH 10.0 solutions. Conductivity was calibrated with a standard 957 micro-Siemans solution. Dissolved oxygen was calibrated with an oxygen saturated solution. Pressure sensors were calibrated a standard barometric pressure.

All sample containers were supplied clean by the participating laboratories. All sampling equipment and sample containers were rinsed three times with the sample water before the sample was placed in the container. All containers were filled to the brim and then the lid placed. Chain of custody forms were prepared documenting each sample. Samples were delivered to the participating laboratory the same day in the case of Silver Valley Laboratory and Advanced Eco-Solutions and overnight in the case of AmTech.

Silver Valley Laboratory, Am Tech and Ecosystem Analysts are all EPA certified analytical laboratories. Laboratories conducted blank and duplicate analysis to assure analysis quality. Samples were retained for re-test. Data reported out of the laboratories was reviewed and assessed for its correctness based on blanks, duplicates and for consistency with other time contiguous analytical results. In at least two cases data points were questioned and re-analysis requested of the laboratory.

Results and Discussion:

Physical Measurement and Dissolved Oxygen:

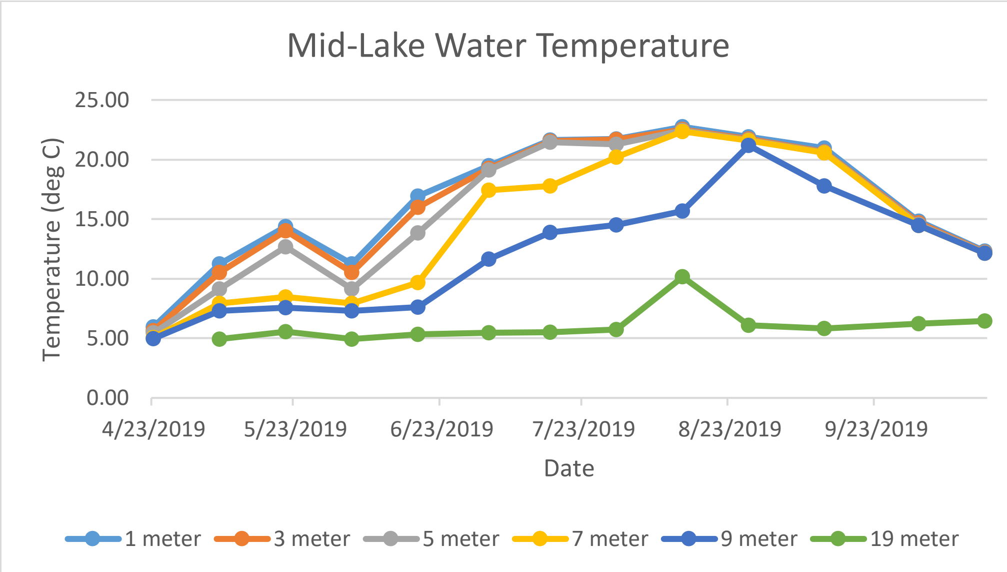
The water of the four stations monitored is quite similar in many of the physical measurements collected during the monitoring effort (Tables 1; Figure 2 and 3) with the exception of temperature. Hydrogen ion content (pH) and conductivity (micro-Siemans (uS) are similar for the mid-lake, Gonzaga and Ross Point Stations. Both pH and conductivity are slightly higher and more variable in the shallow waters at Bob's Bay likely due to the higher concentrations of solutes and water borne organisms at this station. Water clarity is highest at the mid-lake and Gonzaga sampling sites and declines at Ross Point. Clarity likely declines even further at Bob' Bay, but the methodology (Secchi Disc visibility depth) is not applicable in waters that do not exceed three meters in depth. Average dissolved oxygen were all at levels of the saturation of oxygen in water for the particular water temperature. Only the minimum value measured at the Bob's Bay station approached the standard for dissolved oxygen in water.

Table 1: pH, conductivity, clarity and dissolved oxygen average and variances of the four monitoring stations on Hayden Lake

Physical Measurement	Station	Average	Maximum	Minimum
pH	Mid-Lake	8.2	9.1	7.0
	Gonzaga	8.1	9.0	7.0
	Ross Point	8.1	8.5	7.2
	Bob' Bay	8.7	9.4	7.9
Conductivity (uS)	Mid-Lake	62	65	59
	Gonzaga	62	65	58
	Ross Point	62	68	55
	Bob' Bay	68	79	51
Clarity (meters)	Mid-Lake	7.4	9.0	5.0
	Gonzaga	6.9	8.0	5.0
	Ross Point	5.8	7.5	4.5
	Bob' Bay	1.8	3.0	1.0
Dissolved Oxygen	Mid-Lake	10.3	13.2	8.2
	Gonzaga	9.8	12.2	8.1
	Ross Point	9.7	12.4	8.2
	Bob' Bay	10.3	12.6	6.2

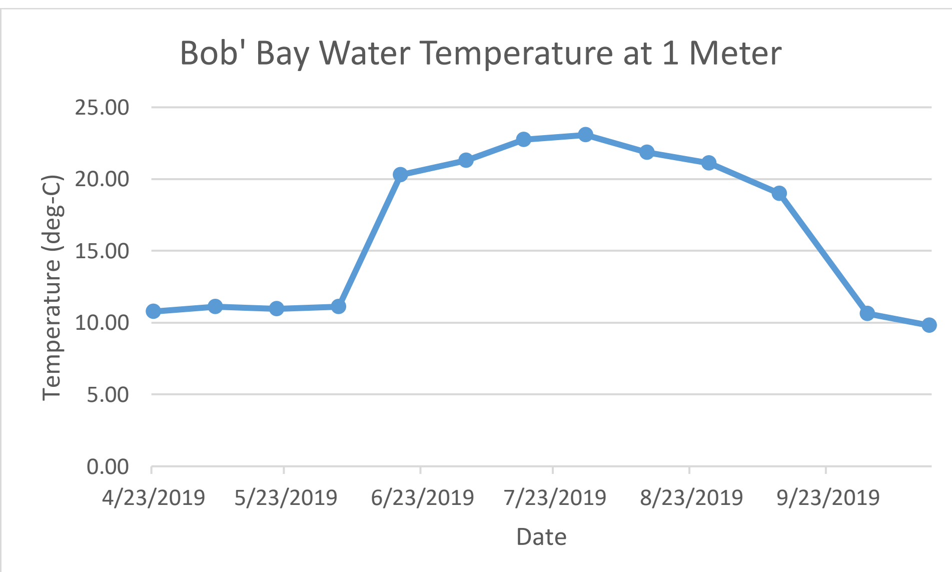
Water temperature varies through the monitoring season and with depth in the lake. The dynamics of this change is demonstrated by the graph of mid-lake water temperature (Figure 2). Lake water warms as expected as the summer season progresses and begins to cool in early September. Lake water at increasing depths warms slower until the warm water layer (epilimnion) reaches its greatest depth in late August. The epilimnion reached to in excess of the top 9 meters of water. Water below this level remains constantly in the range of 5 degrees centigrade.

Figure 2: Mid-Lake Water Temperature at various depths.



Water temperatures follow this same pattern at the Gonzaga and Ross Point Stations (Appendix A). However, both sites are considerably shallower than the mid-lake station; Gonzaga approximately 12 meters; Ross Point approximately 8 meters. Thus most of the water column at Gonzaga Point warms to the annual high water temperature, while all of the water column at Ross Point warms to the high temperature. The column fully warms at the shallower Ross Point Station before nearly all the water column at Gonzaga reaches peak temperature.

Figure 3: Water temperature at the shallow Bob's Bay Monitoring Station.



Bob's Bay is the shallowest station with a maximum depth of 3 meters. At this station the entire water columns heats up in late May or early June and remains at the warmest temperatures until late August or early September (Figure 3).

The water temperature data indicate that lake temperature stratification occurs at the mid-lake and likely at the Gonzaga Stations. However, the entire water column is warmed early in the year at the Ross Point and Bob's Bay Stations and remains at that uniform high temperature until early September. The stratification at mid-lake and Gonzaga isolate the bottom sediments of the lake from the warm upper layer (epilimnion) during the growing season. This isolation from the bottom sediments, a source of plant growth nutrients, does not occur at the Ross Point and Bob's Bay Stations.

The physical characteristics measured for the four monitoring stations demonstrate that the mid-lake and Gonzaga Stations are very similar. Both have sufficiently deep water to support thermal stratification, while the other average and bounding measurements are similar. The Ross Point Station does not share the thermal characteristics of the Mid-lake and Gonzaga Stations, but the other physical characteristics are more allied with these two stations. The Bob's Bay Station is unique due to its quite shallow water depth that affects both the water temperature and through this warm layer reaching to the bottom direct access to plant growth nutrient sources in the bottom sediment. The higher average values of pH and conductivity and the wider variance of the data set suggests greater solute content and biological activity in these waters.

Watershed Precipitation and Snow Pack:

Watershed precipitation and snow pack water equivalent were estimated from measuring stations outside the watershed. The precipitation and average snow pack equivalent received over the period of October to May before the monitoring year maximum discharge is provided in Table 2. The Snowtel data clearly demonstrates the orographic effect of high elevation. Both the Snowtel and airport data demonstrate the same pattern of the highest precipitation in 2017, the next highest in 2018 and the lowest in 2019.

Table 2: October to May water year precipitation at Boyington Field and average precipitation equivalent for the Rugged Mountain and Mosquito Ridge Snowtel Stations.

Station	Water Year	Precipitation (cm)
Boyington Field	2017	54
	2018	43
	2019	28
Rugged-Mosquito Average	2017	144
	2018	114
	2019	93

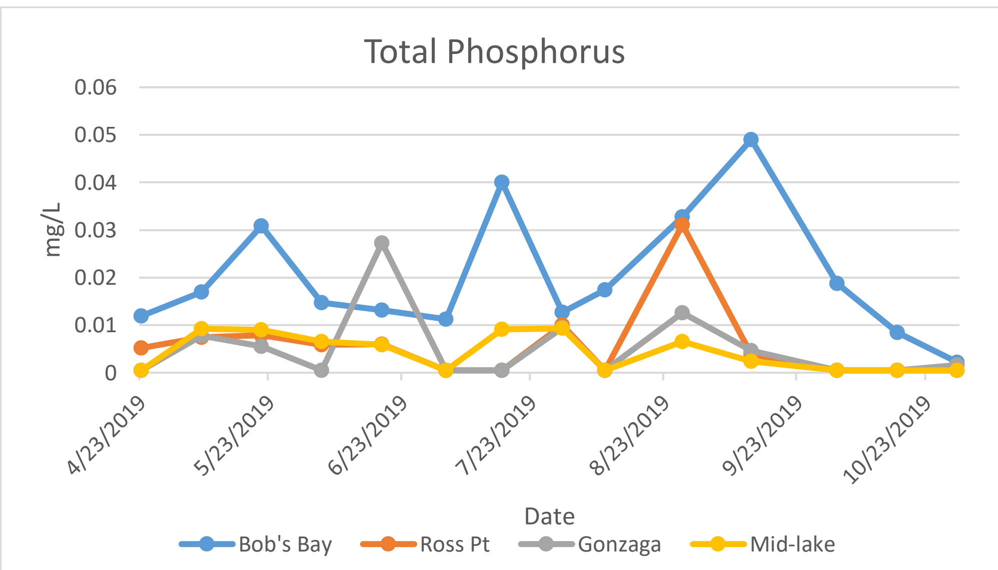
Plant (Algae) Growth Nutrients:

Plant growth in general and specifically the growth of planktonic algae in a lake is dependent on nine macro-nutrients and a host of micro-nutrients required in vanishingly low concentrations. Of the nine macro-nutrients, phosphorus and nitrogen are known to limit the growth of algae in most lakes including those of North Idaho. Typically phosphorus as ortho-phosphate limits algal growth in lakes, however, in those situations where phosphorus is not the limiting nutrient, nitrogen in the chemical forms of nitrite- nitrate and occasionally ammonia may limit algal growth. This is most often the case in eutrophic lakes where total phosphorus exceeds 25 micrograms per liter and ortho-phosphate the chemical form required by plants is measureable (exceed 1 microgram per liter).

Phosphorus:

Total phosphorus measured at the four monitoring stations during the 2019 monitoring year is graphed in figure 4 and the average and variances are provided in Table 3. Gonzaga and Ross Point stations have total phosphorus in the oligotrophic range with a couple of excursions at each station. High total phosphorus concentrations were routinely measured at the Bob's Bay Station. The average value at Bob's bay approaches the eutrophic limit of 25 micrograms per liter, while this value is often exceeded. The mid-lake station was constantly in the oligotrophic range. Total phosphorus measurements made during the 2017 and 2018 monitoring seasons excluded the mid-lake station. These provide a similar results (Appendix A). The 2017 values are striking, because the detection limit was five times higher when these measurements were made.

Figure 4: Total phosphorus in milligrams per liter of water measured at the four water quality monitoring stations during the 2019 season. Total phosphorus averages low for the mid-lake



Detection level 0.001 milligram per liter; values below detection were recorded at one-half detection to facilitate graphing and statistics

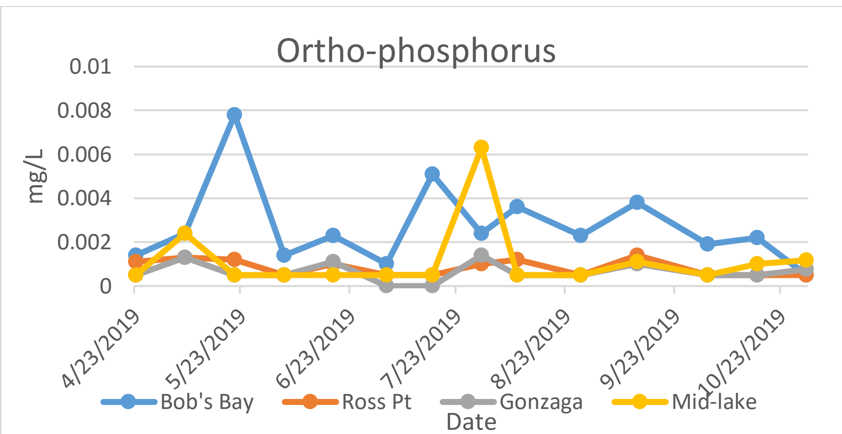
Table 3: Total phosphorus average, maximum and minimum values.

Station	Average	Maximum	Minimum
Bob's Bay	0.0200	0.0490	0.0022
Ross Point	0.0057	0.0311	0.0005
Gonzaga	0.0052	0.0273	0.0005
Mid-Lake	0.0044	0.0093	0.0005

TP reported in mg/L

Ortho-phosphorus is the chemical species actively absorbed by algae. Typically it is present in lake water below the level of detection at 0.001 milligrams per liter of water. The ortho-phosphorus concentrations measured at the four lake stations during the 2019 monitoring season are provided in Figure 5 and the average, maximum and minimum values are provided in Table 4. Ortho-phosphorus values are generally near or below detection at the mid-lake, Gonzaga and Ross Point Stations. The high value recorded in August at the mid-lake station is believed to be a laboratory or contamination error, because a correspondingly high total phosphorus was not detected at the same time. The measurements at Bob's Bay are uniquely and often high. The maximum and very high concentrations of late May and early August respectively are exceedingly high. Ortho-phosphorus measurements collected in 2017 (Appendix A) are of little value due to the detection limit that is five times that of the 2018 and 2019 measurements. Measurements made in 2018 (Appendix A) for the three northern

Figure 5: Ortho-phosphorus measurements for the four lake monitoring stations made during the 2019 monitoring season.



Detection level 0.001 milligram per liter; values below detection were recorded at one-half detection to facilitate graphing and statistics

Table 4: Ortho-phosphorus average, maximum and minimum for the four lake stations.

Station	Average	Maximum	Minimum
Bob's Bay	0.0027	0.0078	0.0005
Ross Point	0.0008	0.0014	0.0005
Gonzaga	0.0007	0.0014	0.0005
Mid-Lake	0.0012	0.0063	0.0005

Ortho-P reported in mg/L

stations reflect a similar pattern of high ortho-phosphorus concentration in the waters at the Bob's Bay Station.

The total phosphorus and ortho-phosphorus measurements clearly demonstrate that the mid-lake, Gonzaga and typically the Ross Point Stations have phosphorus concentrations generally considered in the oligotrophic range (1 to 15 micrograms per liter of water). The Bob's Bay Station total phosphorus averages in the eutrophic condition, 25 micrograms per liter of water or higher. The prevalence of detectable and at times quite high ortho-phosphate concentrations supports this conclusion. Based on three years of water quality monitoring the waters of Hayden Lake's North Arm in the vicinity of Bob's

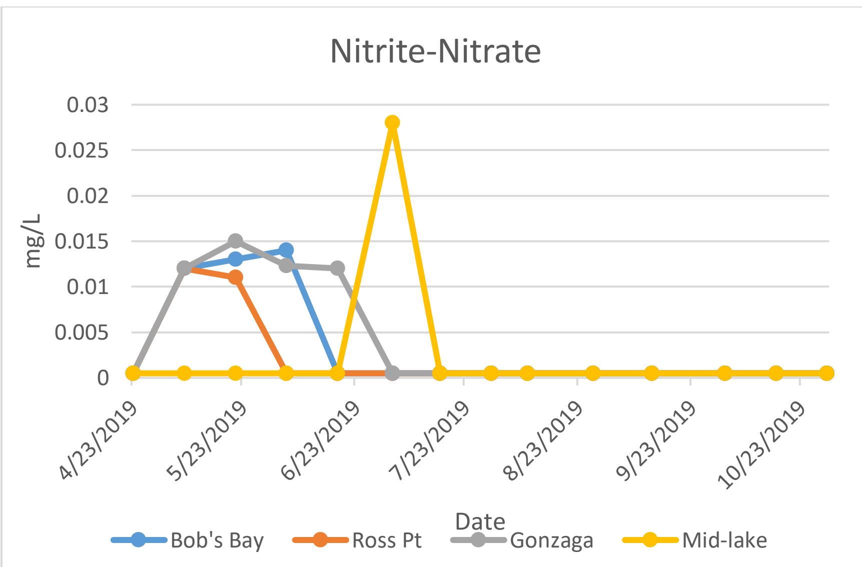
Bay are so high in total and ortho-phosphorus that it is likely that the nitrogen chemical species, nitrite, nitrate and ammonia limit the growth of all algal species except the cyanobacteria (blue green algae) that are capable of atmospheric nitrogen fixation when other nitrogen sources are depleted.

Nitrogen Plant Growth Nutrients:

Nitrite-Nitrate:

The primary source of nitrogen to plant (algal) metabolism is nitrate, the inorganic nitrogen compound in which nitrogen is fully oxidized. Some nitrite a less oxidized compound of nitrogen may also be present, but in much lower concentrations. These basic nitrogen sources are typically measures in water as the concentration of the composite nitrite-nitrate. Total nitrite-nitrate was measured at the four monitoring stations. The data from the 2019 monitoring season is graphed in figure 6. The average maximum and minimum values measured at each station are provided in table 5. During the 2019

Figure 6: Total nitrite-nitrate concentrations found at each monitoring stations through the 2019 season.



Detection limit 0.001 mg/L

Table 5: Average, maximum and minimum values for the 2019 nitrite-nitrate data set.

Station	Average	Maximum	Minimum
Bob's Bay	0.0032	0.0140	0.0005
Ross Point	0.0021	0.0120	0.0005
Gonzaga	0.0040	0.0150	0.0005
Mid-Lake	0.0025	0.0280	0.0005

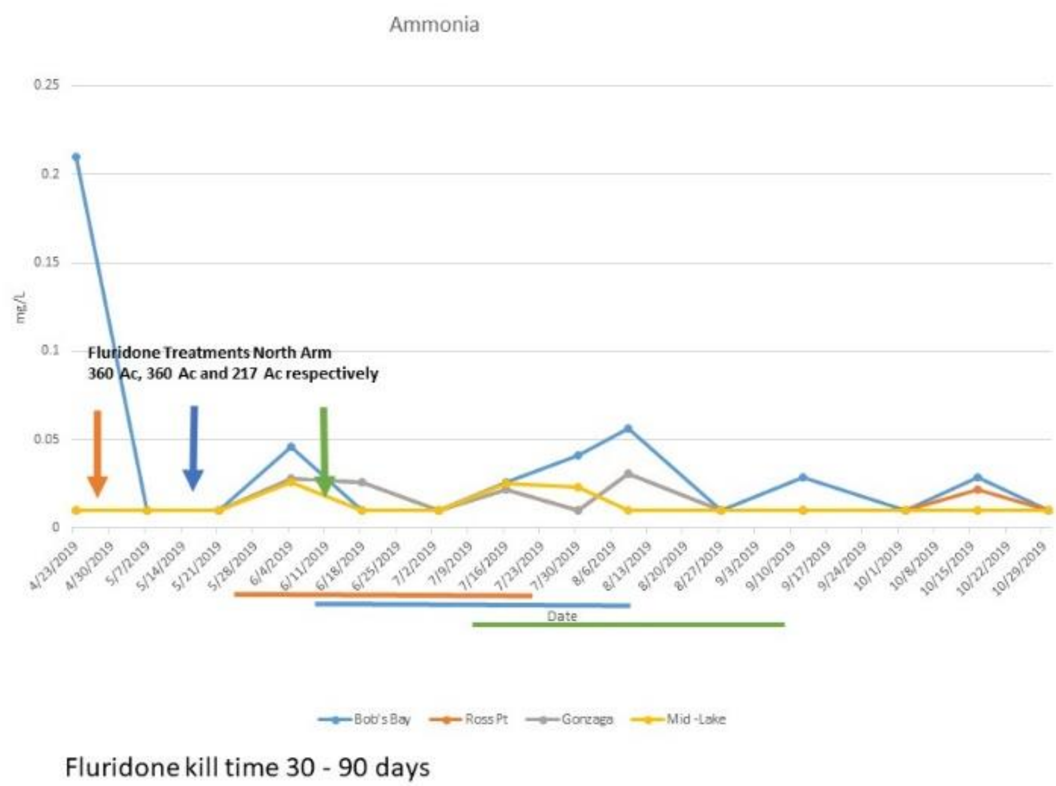
Nitrate-nitrite reported in mg/L

season, nitrite-nitrate concentration fell below detection after mid-July and never recovered to detectable concentrations. A similar pattern was observed in the three northern stations during 2017, but the depletion below detection occurred much later in the year (Appendix A). The depletion recovered during the fall season. Nitrite-nitrate concentration only fell below detection at one time during the 2018 monitoring year. The data collected indicate that nitrite-nitrate concentration patterns vary from year to year. The concentration of nitrite-nitrate may be associated with inorganic nitrogen loading from the watershed in some years as opposed to others. The precipitation data provided demonstrates more discharge to the lake in 2017 with declining discharge through 2018 and 2019. Less discharge likely contributed successively less nitrite-nitrate to the lake, allowing the depletion observed in 2019

Ammonia:

The other form of inorganic nitrogen that algae can absorb from the water is ammonium ion, which is nitrogen in its most reduced form. Ammonium ion measured as ammonia is rather uncommon in lake water or elsewhere in the environment. Ammonia is rather quickly oxidized to nitrite and further to nitrate. Ammonia is only typically detectable when organic matter is decaying in the water column. The concentration of ammonia detected from water at the four monitoring stations during 2019 is graphed in figure 7. The average, maximum and minimum values from the data set are provided in table 6. The mid-lake, Gonzaga, and Ross Point Stations only on occasion just exceed the level of detection. The increases observed at the mid-lake station appear in time frames when algal populations may be senescing. The peaks from mid-June and later in mid-August at the Gonzaga, Ross Point and especially the Bob's Bay stations may be associated with the die-back of aquatic weeds treated by the Idaho Department of Agriculture. The fluridone treatments for curly leaf pondweed occurred on April 24, May 15, and June 12. This systemic herbicide is lethally effective for 30 to 90 days. The dates of fluridone treatment and corresponding lethal periods are included in figure 7. Ammonia peaks correspond with the kill periods of each treatment. The initial value for Bob's Bay may be contamination or possibly a laboratory error given its anomalously high concentration. An added complication is the fact that a lower detection limit was used in 2019 than in the two previous years. The peaks are of lower concentration and broader in the 2019 monitoring when compared to the ammonia concentration measurement collected in the 2017 and 2018 monitoring years (Appendix A).   The Ammonia peaks recorded at the lower detection level of 0.005 mg/L are quite sharp and the increase appears at each measuring station, just with less intensity the further south. These peaks may also coincide with herbicide treatments of invasive aquatic weeds. During 2017 no treatments occurred. During 2018, diquat was used again on July 10^{th} and July 26^{th}. Diquat results in more rapid death (5-6 days) of the

Figure 7: Ammonia concentration found at each monitoring stations through the 2019 season.



Detection limit 0.02 mg/L

Table 6: Average, maximum and minimum values for the 2019 ammonia data set.

Station	Average	Maximum	Minimum
Bob's Bay	0.0362	0.2100	0.0100
Ross Point	0.0156	0.0310	0.0100
Gonzaga	0.0159	0.0450	0.0100
Mid-Lake	0.0131	0.0260	0.0100

Ammonia reported in mg/L

aquatic weeds. Ammonia peaks occur shortly after the treatments (Appendix A). Aquatic weed decay and the release of ammonia at higher concentrations over a shorter time span appears to occur after the herbicide treatments.

The release of ammonia after nitrite-nitrate is depleted in the water column may have another affect. Typically when the nitrite-nitrate is depleted, the green algae, diatoms and most other algae types cease growth. However the cyanobacteria (blue-green algae) are not limited because these organisms have the ability to fix atmospheric nitrogen. Algal blooms of the cyanobacteria often occur in waters where ortho-phosphorus is not limiting after the water soluble nitrogen sources are depleted. The appearance of ammonia in the water column as the result of invasive aquatic weed die off and decay may forestall, the cyanobacteria blooms by supplying a soluble nitrogen compound the green algae, diatom and other algae types can utilize.

Organic Nitrogen:

Organic nitrogen was measured indirectly. The Total nitrogen in water samples was measured using the persulfate method. This method measures the nitrite-nitrate, ammonia and the combined or organically bound nitrogen present in the sample. By subtraction of the nitrite-nitrate and ammonia concentrations independently measured from the total nitrogen, the organic nitrogen present can be calculated. The organic nitrogen is an assessment of all nitrogen combined in organic compounds, however, the great majority of the organic nitrogen will be housed in living biomass. Hence the organic nitrogen parameter is a useful assessment of the relative amount of biomass present in the waters of each station. However, the value is calculated and such mathematically derived values can be below zero. These are artifacts of variance of parameters reflected in the calculation. Hence organic nitrogen reflects large trends, but small variances are likely not significant.

The total persulfate nitrogen graphs are in Appendix A together with the average, maximum and minimum values. The organic nitrogen values calculated from the 2019 monitoring data is graphed in figure 8. The average, maximum and minimum values are provided in table 7. The value below zero for Bob's Bay is an example of a derived value being well below zero. The high ammonia value pointed out earlier assures this result.

The calculated organic nitrogen does show definite trends. The values are generally lowest at the mid-lake station, while the average value is nearly identical at Gonzaga and Ross Point, while it is greatest at the Bob's Bay sampling station. The peak values likely reflect increase in the density of various algal groups and subsequent population declines. Clearly, the Bob's Bay location is the most productive while Ross Point and Gonzaga are less productive but still higher than the lowest productivity of the mid-lake station. The data from the 2017 and 2018 monitoring (Appendix A) reflect this same pattern, but suggest Ross Point is more productive at least in these years than the waters of the Gonzaga Station.

In summary, the nutrient data collected over three summers of monitoring paints a clear picture of Hayden Lake. The mid-lake is low in total phosphorus and the active compound ortho-phosphorus is typically below detection. The values are consistent with the low productivity and an oligotrophic condition. These data reflect the earlier assessments of the lake's core by Soltero et al (1985), Black, and Harvey (2005, 2006). The nitrite-nitrate, ammonia and total organic nitrogen data support this interpretation. The Gonzaga Station located just south of Henry's Point is quite similar to the mid-lake with slightly higher phosphorus data and slightly higher productivity. Ross Point is intermediate, but still exhibits lower phosphorus and low productivity as compared to the Bob's Bay Station.

At Bob's Bay both total and ortho-phosphorus attain values so high that phosphorus most likely does not limit algal growth, but rather the nitrite-nitrate concentration is now limiting the growth of diatoms green, and most other algae. Once the nitrite-nitrate is depleted, the cyanobacteria which are capable of using atmospheric nitrogen as a source establish a competitive advantage and dominate the biomass; bloom. Ironically, the ammonia data suggests that recent invasive weed herbicide treatments during the summer causing weed die off and decay produces sufficient nitrogen in the form of the ammonium ion to support balanced algal growth. This recycling of nitrogen allows the Bob's Bay algal communities to be the most productive measured in the lake.

Figure 8: Calculated organic nitrogen values for the 2029 monitoring season.

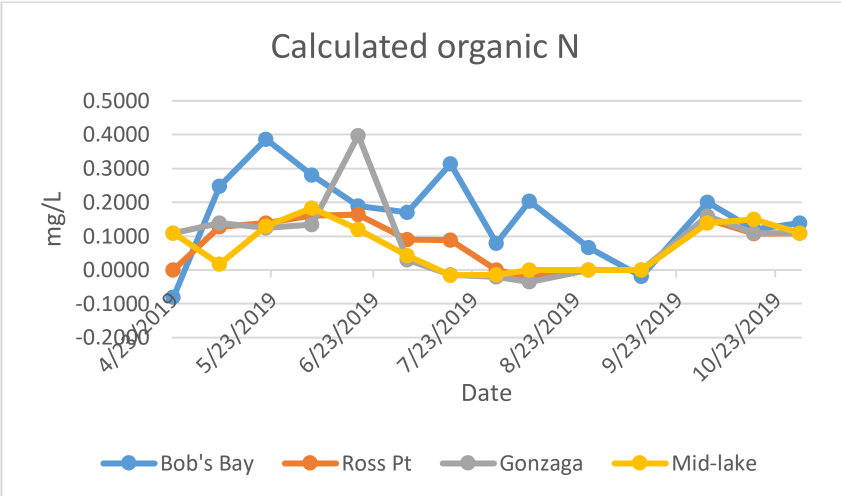


Table 7: Average, maximum and minimum calculated organic nitrogen values for the four station monitored during the 2019 season.

Station	Average	Maximum	Minimum
Bob's Bay	0.1639	0.3870	-0.0805
Ross Point	0.0795	0.1635	-0.0215
Gonzaga	0.0887	0.3980	-0.0355
Mid-Lake	0.0693	0.1835	-0.0155

Calculated organic nitrogen reported in mg/L

Chlorophyll a:

Chlorophyll a concentrations are used as an indicator of the standing stock of phytoplankton within a system. It can be used as a rough surrogate for primary productivity but that is typically not advised due to numerous food web interactions that can alter the chlorophyll a concentration. The higher the chlorophyll a concentration the higher the standing crop of phytoplankton. Hayden Lake is considered to be a low nutrient (oligotrophic) water. As such we would expect to see chlorophyll a concentrations less than 3.0 ug/L. Values greater than 3.0 ug/L are indicative of excess nutrients. Chlorophyll a samples were sampled inconsistently between years. Due to the seasonality that can exist in chlorophyll concentrations this inconsistency precludes comparing years through yearly averages. There are some general conclusions that can be drawn from the data set. The highest chlorophyll a concentrations were observed at the Bob's Bay station, followed by Gonzaga and Ross Point. Another general trend is for the highest concentrations to be observed in the months of July through September, or late summer. The Bob's Bay area is well into the eutrophic range of chlorophyll a concentrations while Gonzaga and Ross Point remain in the oligotrophic to mesotrophic/oligotrophic range.

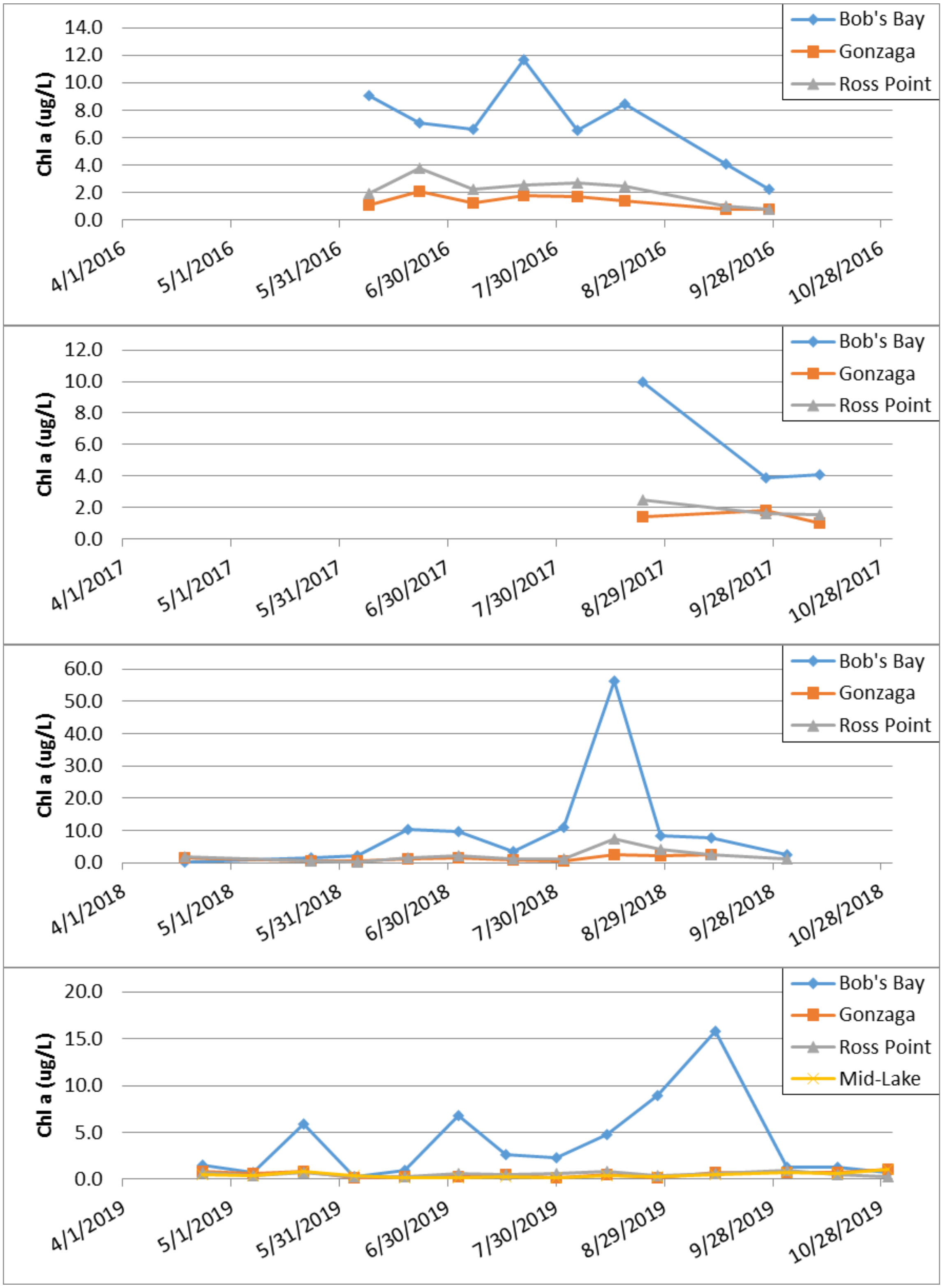


Figure 9. Chlorophyll a concentration by year for three Hayden Lake Stations

Phytoplankton Community:

Phytoplankton density is related to chlorophyll a concentrations, however, it provides additional information regarding the type of phytoplankton in the system. As with chlorophyll a, the phytoplankton densities increase from the spring into late summer when they peak (Figure 10). There is considerable variation between years with 2018 and 2019 having lower densities than 2017 and 2016.

Bob's Bay had the highest yearly average phytoplankton densities when compared to the other 2 sites (2016-2018) and three sites (2019). The majority of the phytoplankton community consisted of the blue-green taxa. It is common for the most abundant taxa to be blue-green algae due to the organism's small cell size and frequency for the formation of colonies. There was a difference in the blue-green taxa between the sites with the majority of the blue-green taxa observed in the Bob's Bay samples and to a lesser degree at Ross Point consisting of Dolichospermum sp. Dolichospermum sp. that can produce toxins and is indicative of a nitrogen limited system. The Gonzaga and Mid-Lake stations blue-green taxa consisted primarily of the non-toxic taxa (Synechococcus sp. and Aphanothece minutissimus).

Microcystis sp. was also observed in Bob's Bay, but was not the dominant taxa. Microcystis sp. is the taxa most likely to produce the toxin microcystin. The fact that this taxa was not very prevalent is one of the reasons the toxicity of the system has not been higher.

Based on the sample analysis performed, the area of the lake that is producing significant number of bloom forming toxic algae taxa is limited to the extreme northern end of the lake. This is likely due to the shallow water depth, warm water temperatures, and high phosphorus concentration observed at Bob's Bay.

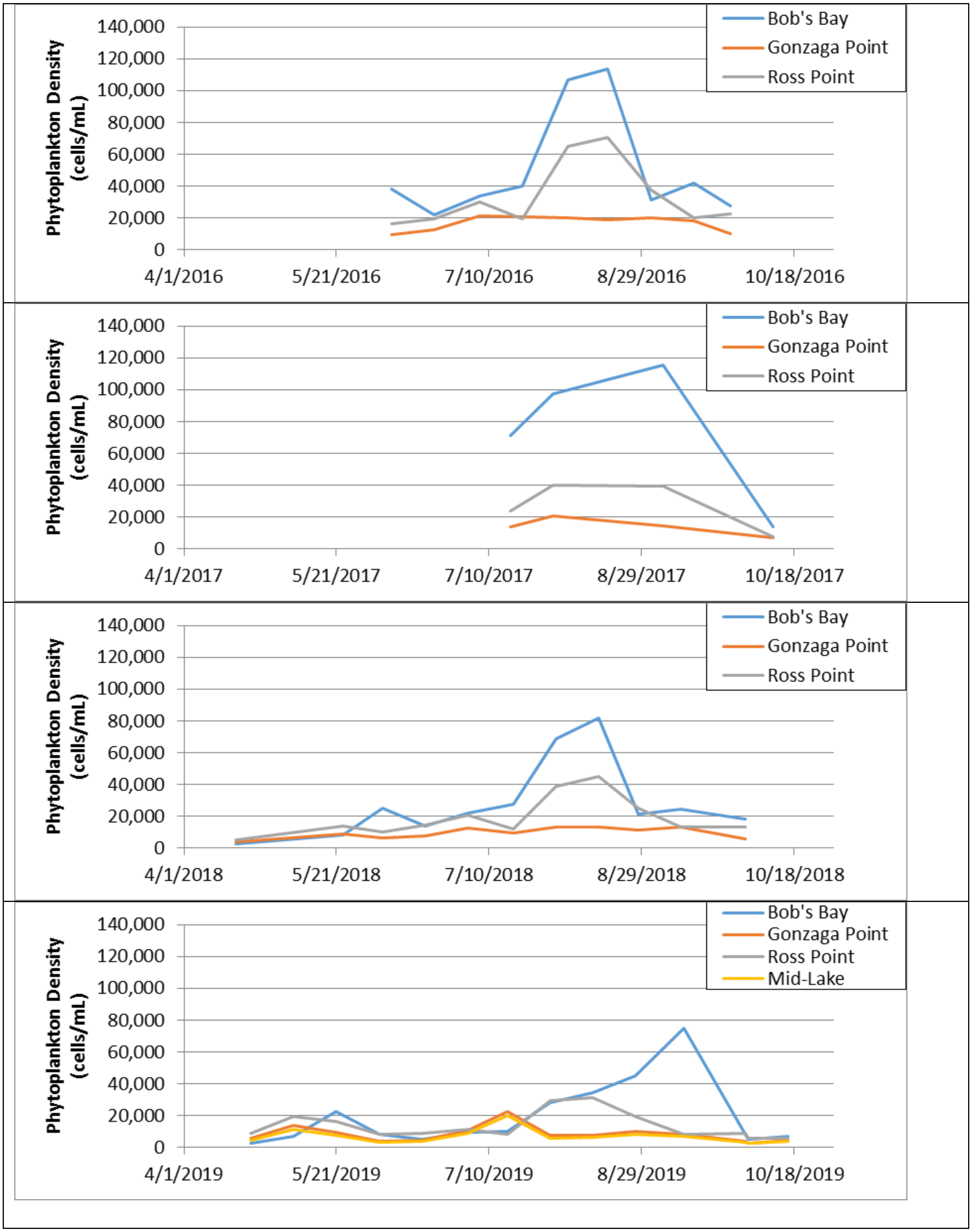


Figure 10. Phytoplankton density by date.

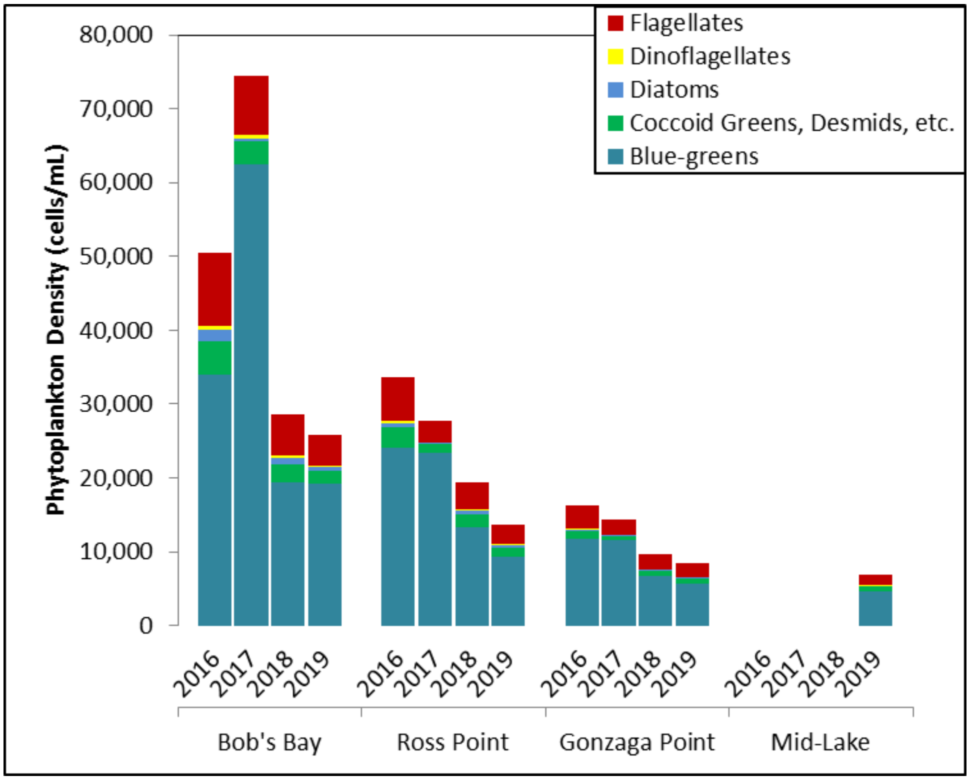


Figure 11. Phytoplankton Density by class, year and station.

Conclusions

As assessed by earlier investigators and better defined by this study, the core of Hayden Lake remains of quite high water quality. Nutrients and especially phosphorus are at levels that limit algal growth. However the area north of Henry's Point and especially the waters near Sportsman's Access are very high in phosphorus and receive sufficient nitrogen to foster very high productivity. This is likely the result of the area's shallow nature. The shallow character allows unimpeded contact between the bottom sediments which are a phosphorus source. In the main lake this contact is restricted by the thermocline as the lake thermally stratifies each summer. With phosphorus unrestricted in the area of Bob's Bay, the nitrogen compounds limit the growth of the green algae, diatoms, and most other algae but not the cyanobacteria. This group of atmospheric nitrogen fixing organisms is given free rein to grow when soluble nitrogen is depleted. Ironically, invasive aquatic weed treatment over the past few years are likely causing the release of ammonia from decaying weed biomass. The supply of this ammonia after nitrite-nitrate is depleted is likely forestalling cyanobacteria blooms. The key to managing the eutrophic northern end of Hayden Lake is managing the amount of available phosphorus and nitrogen.

Some other areas of the lake were created by the impoundment and retarded infiltration into the aquifer. These areas include Mokins Slough and the eastern portion of O'Rourke Bay. Visual inspection of these areas suggests they share at least some of the characteristics of the Hayden Lake north of Henry's Point.

Recommendations:

Phosphorus concentration could be managed by two approaches, while nitrogen could be managed by another. The approaches supply a range of options. These approaches are:

- limit stirring of the lake bottom sediments by boat propellers;
- add a small amount of nitrate to maintain the nitrogen-phosphorus balance;
- alum (aluminum sulfate) treat the worst areas of the lake's North Arm to sequester excess phosphorus in a chemically unavailable form in the lake bed sediment.

The second alternative would likely be more effective if the first was implemented as well. All of these management strategies would have positive and negative effects that must be managed. These are further examined in Appendix C. to assess the positive and negative environmental effects.

The two areas of the lake similar the area north of Henry's Point (Mokins Bay and eastern O'Rourke Bay) should be monitored to assess their level of eutrophy and potential management requirements.

References:

Soltero , R.A., K.R. Merrill, 1986, M.R. Cather and L.N. Appel, 1986. Completion Report for the Investigation entitled Water Quality Assessment of Hayden Lake ID. Eastern Washington University. Cheney WA. 92p.

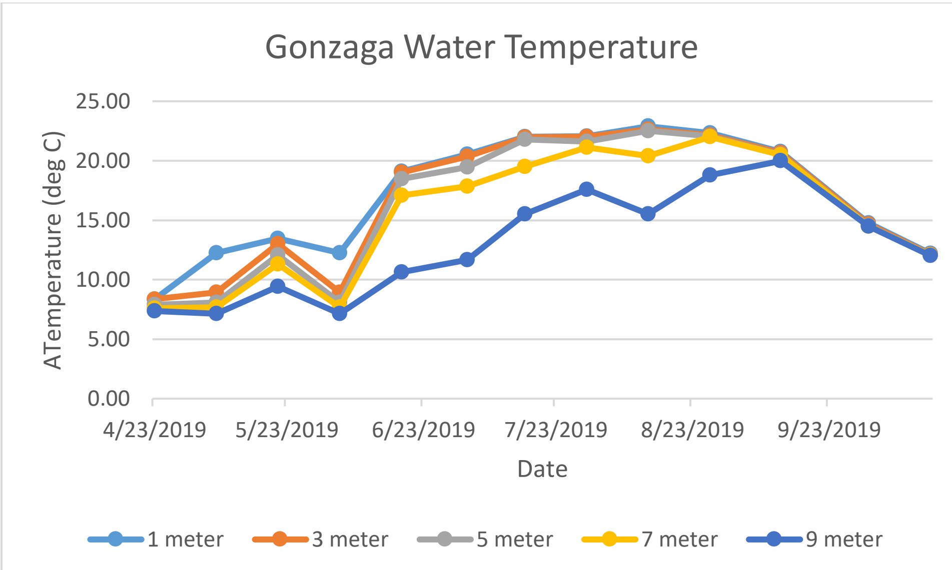
Harvey, G.W. and T Walker, 2005. Hayden Lake Water Quality Report – 2005. Hayden Lake Watershed Association Inc. in cooperation with the Division of Environmental Quality's Citizen's Volunteer Monitoring Program. 6p.

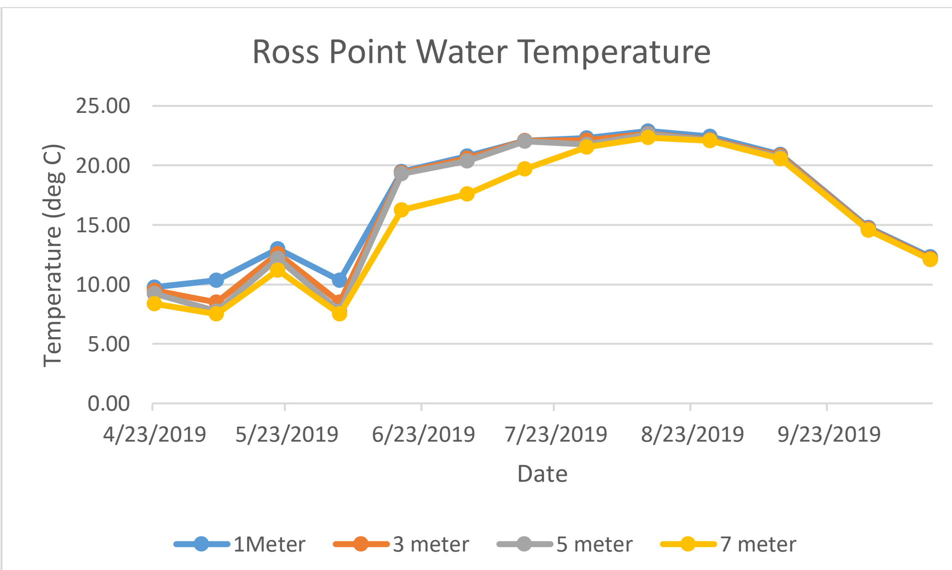
Harvey, G.W. and T Walker, 2006. Hayden Lake Water Quality Report – 2006. Hayden Lake Watershed Association Inc. in cooperation with the Division of Environmental Quality's Citizen's Volunteer Monitoring Program. 9p.

Harvey, G.W. 2019. Hayden Lake: A Brief Primer. Amazon KDP Publishing, Seattle WA. 87p.

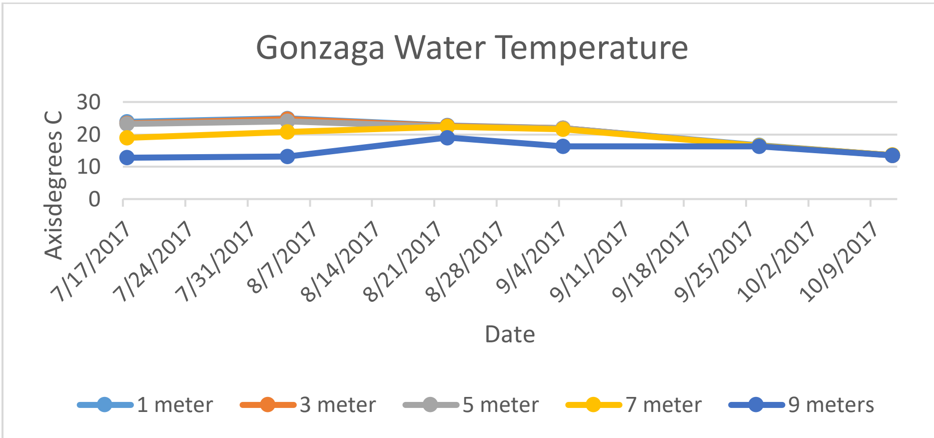
Appendix A: Additional Water Temperature and Plant Growth Nutrient Graphs.

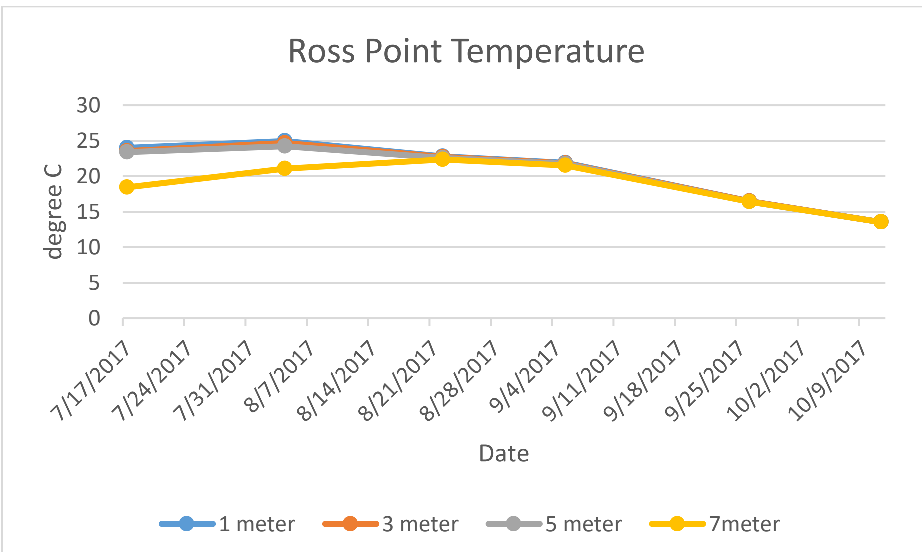
Water Temperature

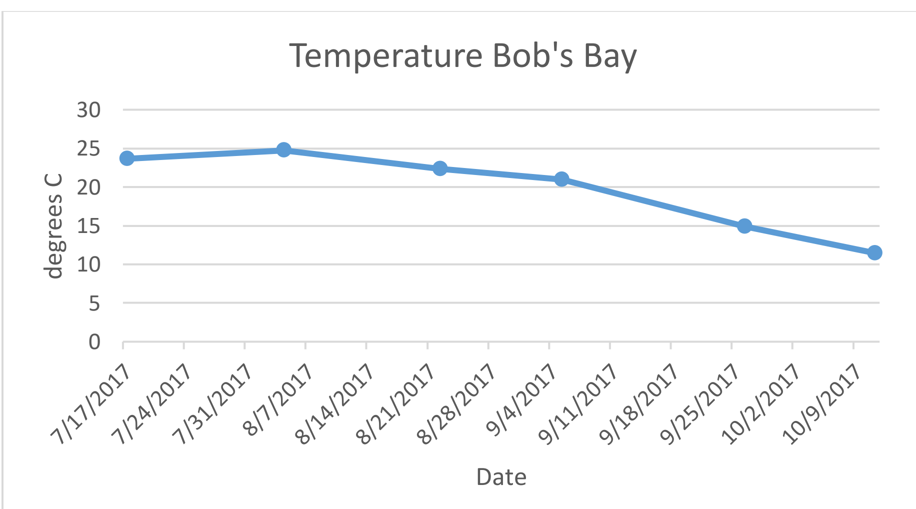




2017


Gonzaga Water Temperature
30
20
10
0
Axisdegrees C
7/17/2017
7/24/2017
7/31/2017
8/7/2017
8/14/2017
8/21/2017
8/28/2017
9/4/2017
9/11/2017
9/18/2017
9/25/2017
10/2/2017
10/9/2017
Date
1 meter
3 meter
5 meter
7 meter
9 meters


Ross Point Temperature
30
25
20
15
10
5
0
degree C
7/17/2017
7/24/2017
7/31/2017
8/7/2017
8/14/2017
8/21/2017
8/28/2017
9/4/2017
9/11/2017
9/18/2017
9/25/2017
10/2/2017
10/9/2017
Date
1 meter
3 meter
5 meter
7meter


Temperature Bob's Bay
30
25
20
15
10
5
0
degrees C
7/17/2017
7/24/2017
7/31/2017
8/7/2017
8/14/2017
8/21/2017
8/28/2017
9/4/2017
9/11/2017
9/18/2017
9/25/2017
10/2/2017
10/9/2017
Date

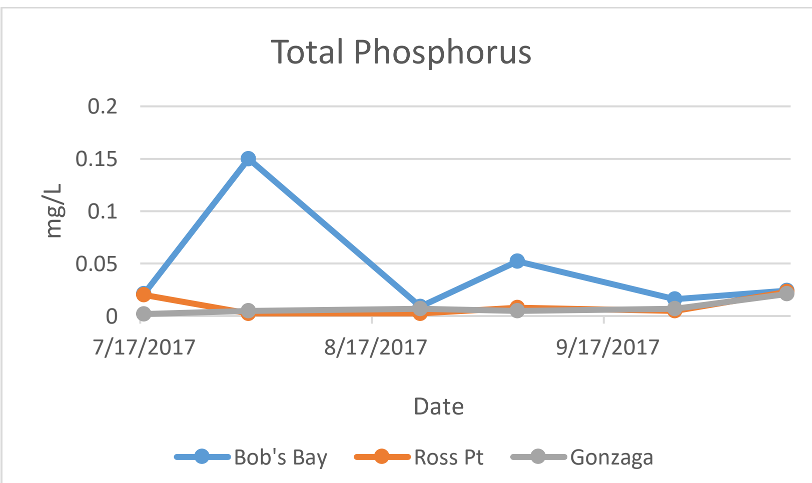
Physical Measurement	Station	Average	Maximum	Minimum
pH	Gonzaga	8.8	12.6	7.1
	Ross Point	8.1	10.7	7.0
	Bob's Bay	7.7	9.1	6.6
Conductivity (us/cm)	Gonzaga	62	64	58
	Ross Point	63	66	59
	Bob's Bay	76	124	62
Dissolved Oxygen (mg/L)	Gonzaga	9.83	14.36	8.60
	Ross Point	9.17	10.96	6.00
	Bob's Bay	8.80	10.34	5.06

2018 Due to Hydrolab failure and replacement time, no 2018 physical data taken.

Plant (Algal) Growth Nutrients:

phosphorus:

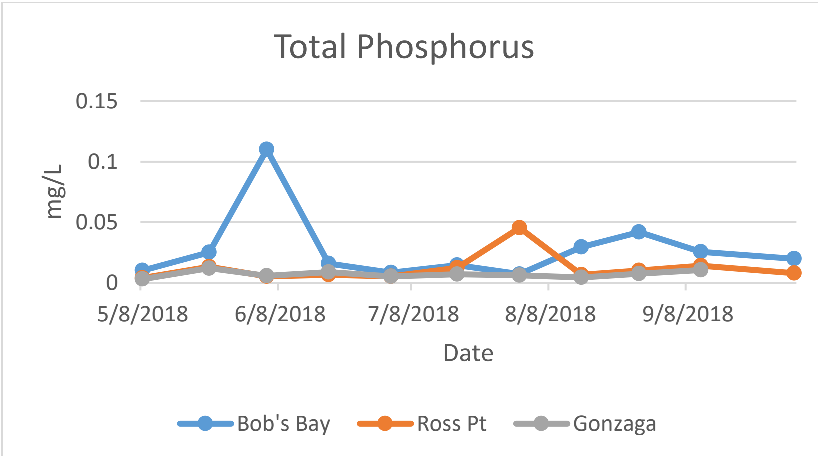
2017



Detection limit 0.005 mg/L

	Average	Max	Min
Bob's Bay	0.0453	0.1500	0.0090
Ross Point	0.0102	0.0230	0.0025
Gonzaga	0.0078	0.0210	0.0019

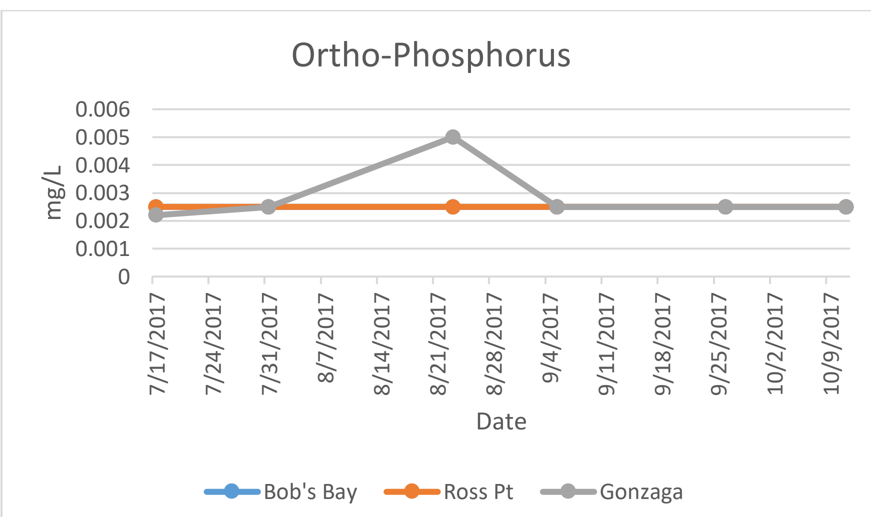
2018



Detection limit 0.001 mg/L

	Average	Max	Min
Bob's Bay	0.0280	0.11	0.0072
Ross Point	0.0119	0.0454	0.004
Gonzaga	0.007	0.0121	0.003

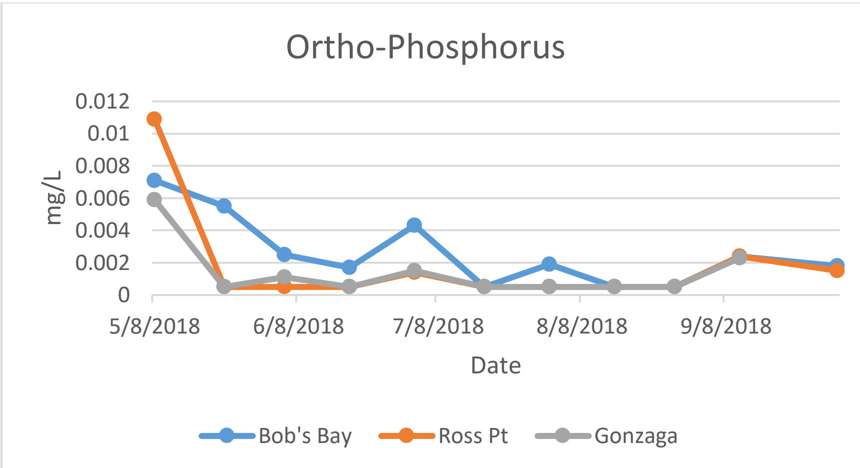
2017



Detection limit 0.005 mg/L

	Average	Max	Min
Bob's Bay	0.0025	0.0025	0.0025
Ross Point	0.0025	0.0025	0.0025
Gonzaga	0.0025	0.005	0.0022

2018

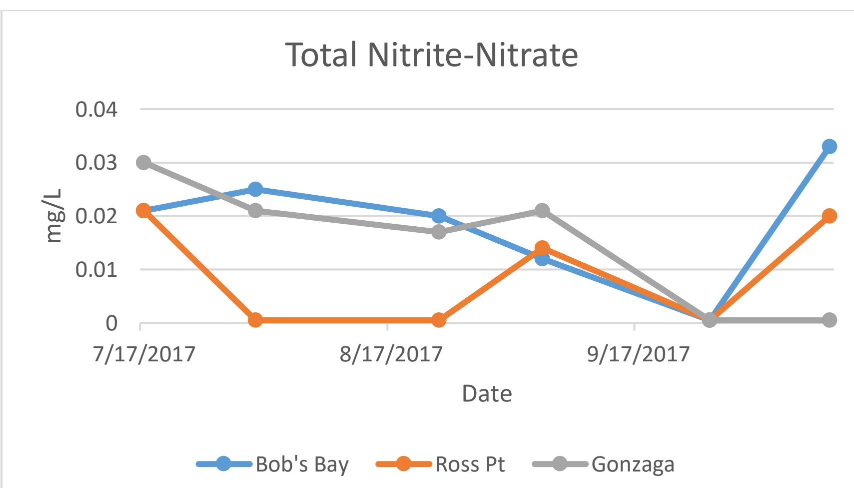


Detection limit 0.001 mg/L

	Average	Max	Min
Bob's Bay	0.0026	0.0071	0.0005
Ross Point	0.0018	0.0109	0.0005
Gonzaga	0.0014	0.0059	0.0005

Nitrogen Compounds

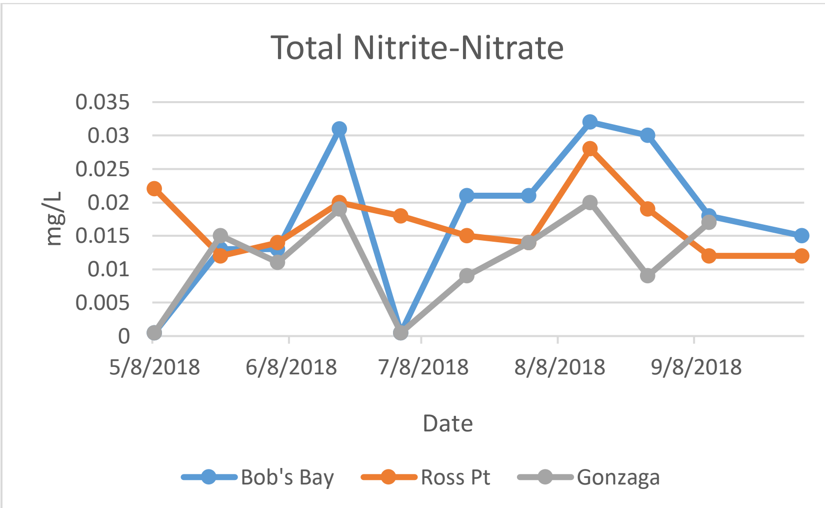
2017



Detection limit 0.001 mg/L

	Average	Max	Min
Bob's Bay	0.0186	0.0330	0.0005
Ross Point	0.0094	0.0210	0.0005
Gonzaga	0.0150	0.0300	0.0005

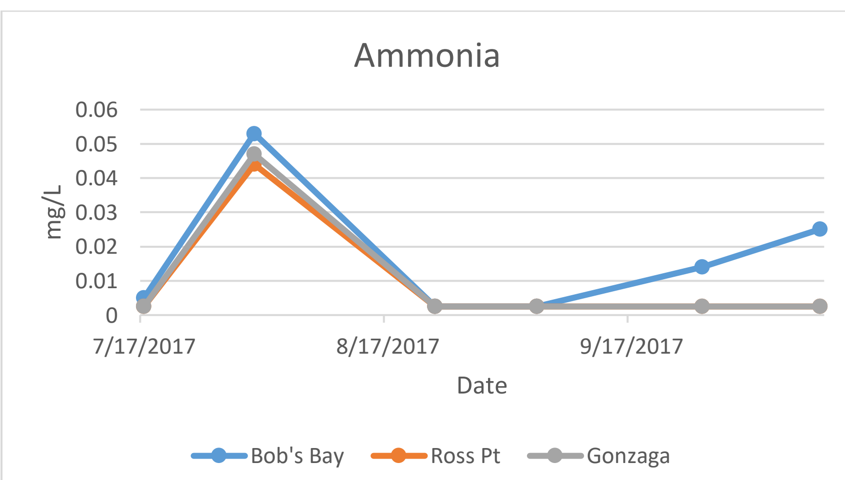
2018



Detection limit 0.001 mg/L

	Average	Max	Min
Bob's Bay	0.0186	0.0330	0.0005
Ross Point	0.0094	0.0210	0.0005
Gonzaga	0.0150	0.0300	0.0005

2017



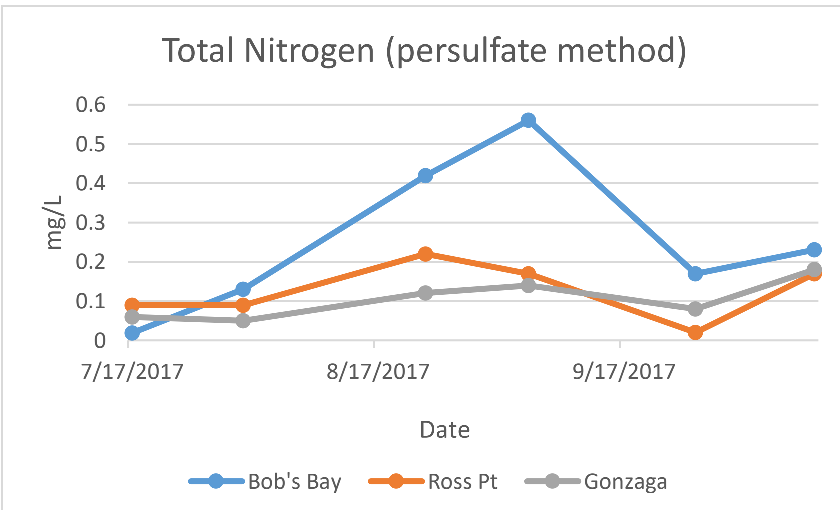
Detection level 0.005

	Average	Max	Min
Bob's Bay	0.0170	0.0530	0.0025
Ross Point	0.0094	0.0440	0.0025
Gonzaga	0.0099	0.0470	0.0025

Detection level 0.005

	Average	Max	Min
Bob's Bay	0.031	0.1370	0.0025
Ross Point	0.0115	0.052	0.0025
Gonzaga	0.0068	0.034	0.0025

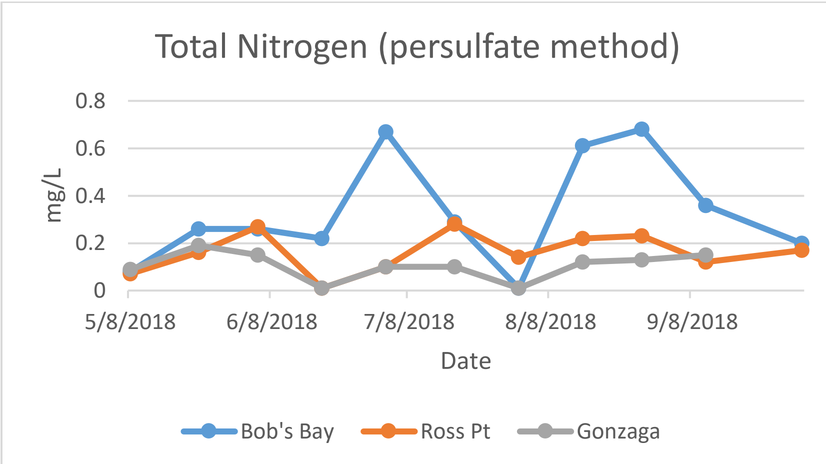
2017



Detection level 0.02 mg/L

	Average	Max	Min
Bob's Bay	0.2548	0.5600	0.019
Ross Point	0.1267	0.2200	0.0200
Gonzaga	0.1050	0.1800	0.0500

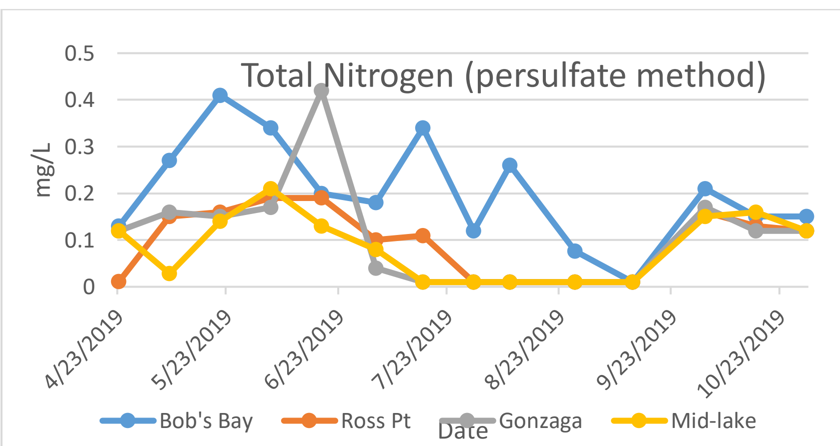
2018



Detection level 0.02 mg/L

	Average	Max	Min
Bob's Bay	0.145	0.170	0.120
Ross Point	0.161	0.28	0.01
Gonzaga	0.105	0.19	0.01

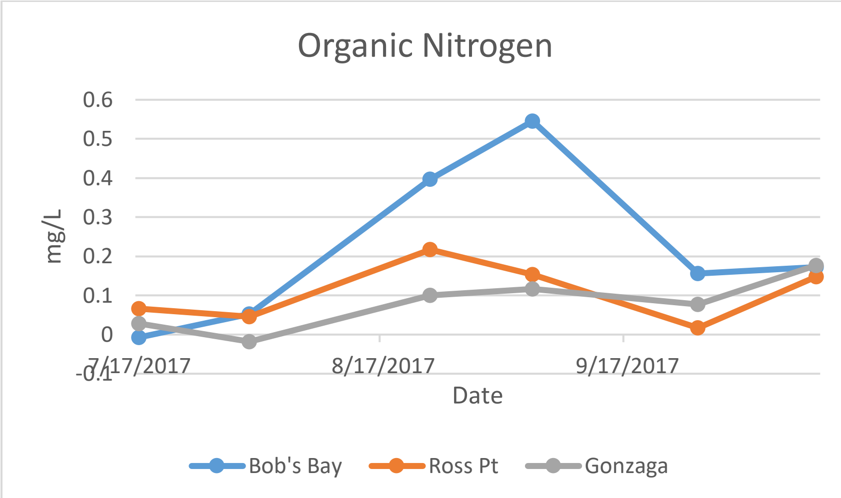
2019



Detection level 0.02 mg/L

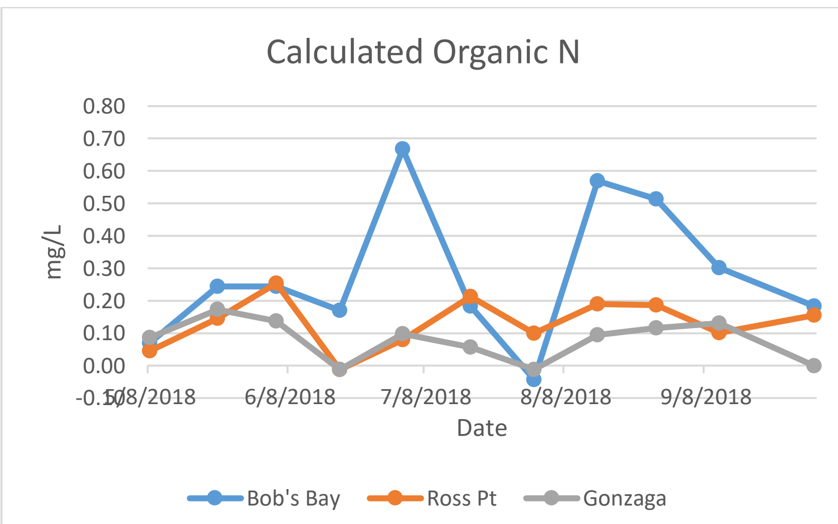
	Average	Max	Min
Bob's Bay	0.2033	0.4100	0.0100
Ross Point	0.1367	0.1700	0.1200
Gonzaga	0.1086	0.4200	0.0100
Mid-Lake	0.0849	0.2100	0.0100

2017



	Average	Max	Min
Bob's Bay	0.219	0.5455	-0.007
Ross Point	0.108	0.217	0.017
Gonzaga	0.080	0.177	-0.018

2018



	Average	Max	Min
Bob's Bay	0.28	0.67	-0.04
Ross Point	0.13	0.25	-0.0125
Gonzaga	0.08	0.17	-0.012

Appendix B: Raw Data Sets

Physical Data:

Temperature Data

	Water Year	Oct	Nov	Dec	Jan	Feb	Mar	April	May	Sum (in)
Mosquito Ridge	2017	14.9	6.5	6.5	3	10.1	11.9	5.7	2.2	60.8
	2018	5.3	10.4	7	8.5	4.2	6.3	6.5	0	48.2
	2019	3.5	6.8	7.6	5.7	5.7	1.7	5	1.6	37.6
Ragged Mountain	2017	12.3	4.6	4.7	4	9.4	9.1	5	3.6	52.7
	2018	4	7.5	5	9.1	4.4	3.8	7.1	0.9	41.8
	2019	3.7	5.5	6.8	4.6	4.9	2.1	3.7	4.2	35.5
Average Mq & Rg	2017	57	144							
	2018	45	114							
	2019	37	93							

Pappy Boyington Field

Year	Oct	Nov	Dec	Jan	Feb	Mar	April	May	Sum(in)	Sum (cm)
2017	3.38	2.22	0.83	0.71	4.62	4.7	2.6	2.26	21.32	54
2018	2.69	2.82	2.58	3.51	1.58	0.6	2.85	0.27	16.9	43
2019	0	3.28	1.67	1.37	1,49	0.56	2.58	1.51	10.97	28

2017 Manta Data

Bob's Bay

Date	Depth m	Temp °C	DO mg/l	EC (µs/cm)	pH
7/17/2017	1	23.63	9.76	70.1	8.94
7/17/2017	2	23.34	9.95	69.9	8.73
8/4/2017	1	24.73	8.75	74	9.05
8/4/2017	2	23.57	5.06	124	7.61
8/22/2017	1	22.38	8.71	74.4	6.84
9/5/2017	1	20.99	7.94	72.5	6.64
9/26/2017	1	14.88	10.34	64	6.58
10/11/2017	1	11.45	9.89	61.6	7.38
		Average	8.8	76.3	7.7
		Maximum	10.3	124.0	9.1
		Minimum	5.1	61.6	6.6

Ross Point

Date	Depth m	Temp °C	DO mg/l	EC (µs/cm)	pH
7/17/2017	1	23.97	8.62	61.9	6.98
7/17/2017	3	23.55	8.66	61.9	7.43
7/17/2017	5	23.43	8.64	61.4	7.55
7/17/2017	7	18.48	10.96	59.1	7.82
8/4/2017	1	24.96	8.85	63.8	8.14
8/4/2017	3	24.69	8.78	62.7	8.16
8/4/2017	5	24.23	8.88	62.1	8.11
8/4/2017	7	21.08	10.25	60.4	8.24
8/22/2017	1	22.84	8.64	65.4	7
8/22/2017	3	22.7	8.67	65.4	7.32
8/22/2017	5	22.59	8.64	64.8	7.53
8/22/2017	7	22.37	8.45	64.7	7.6
9/5/2017	1	21.9	8.76	64.7	7.74
9/5/2017	3	21.85	8.77	64.1	7.4
9/5/2017	5	21.78	8.7	65.7	7.66
9/5/2017	7	21.55	8.6	64.9	7.78
9/26/2017	1	16.5	9.46	62.6	7.64
9/26/2017	3	16.47	9.48	62.6	8.16
9/26/2017	5	16.44	9.47	62.3	8.52
9/26/2017	7	16.41	9.48	62.8	8.69
10/11/2017	1	13.54	9.82	61.5	8.57
10/11/2017	3	13.55	9.82	62.2	9.45
		Average	9.2	63	8.1
		Maximum	11.0	66	10.7
		Minimum	6.0	59	7.0

Gonzaga

Date	Depth m	Temp °C	DO mg/l	EC (µs/cm)	pH
7/17/2017	1	23.88	8.65	61.4	7.12
7/17/2017	3	23.4	8.74	61.3	7.34
7/17/2017	5	23.23	8.75	60.9	7.5
7/17/2017	7	18.9	10.73	59.2	7.78
7/17/2017	9	12.78	13.31	58.2	7.84
8/4/2017	1	24.95	8.61	62.3	7.78
8/4/2017	3	24.7	8.68	62.5	7.93
8/4/2017	5	24.01	8.96	62	8.07
8/4/2017	7	20.72	11.04	60.4	8.43
8/4/2017	9	13.14	14.36	59.2	8.57
8/22/2017	1	22.71	8.6	63.4	7.15
8/22/2017	3	22.59	8.65	63.9	7.44
8/22/2017	5	22.47	8.65	63.5	7.56
8/22/2017	7	22.35	8.6	63.7	7.68
8/22/2017	9	19.01	12.94	60.3	8.46
9/4/2017	1	21.91	8.83	63.6	7.97
9/4/2017	3	21.87	8.86	62.9	8.3
9/4/2017	5	21.85	8.83	63.5	8.51
9/4/2017	7	21.49	9.03	62.4	8.59
9/4/2017	9	16.34	12.92	59.9	9.06
9/26/2017	1	16.6	9.54	62.5	9.25
9/26/2017	3	16.5	9.54	62	9.36
9/26/2017	5	16.44	9.53	62.1	9.45
9/26/2017	7	16.42	9.52	62	9.5
9/26/2017	9	16.35	9.51	62.9	9.52
10/11/2017	1	13.55	9.88	62	10.93
10/11/2017	3	13.55	9.9	61.4	11.5
10/11/2017	5	13.55	9.89	62.2	11.94
10/11/2017	7	13.57	9.88	62.2	12.24
10/11/2017	9	13.55	9.92	62	12.56
		Average	9.83	62	8.84
		Maximum	14.36	64	12.56
		Minimum	8.60	58	7.12

2018
Manta
Data
Manta
Broken
down

2019 Manta data

Bob's Bay

Date	Depth (M)	Temp. (Degrees C)	PH	Sp Con (us)	D.O> (mg/L)	Secchi Depth (M)
4/23/2019	1.0	10.77	8.26	51.4	12.61	2.00
5/7/2019	1.0	11.13	8.72	58.6	12.41	2.50
5/21/2019	1.0	10.95	9.05	59.9	12.35	2.50
6/4/2019	1.0	11.13	8.72	58.6	12.41	2.50
6/18/2019	1.0	20.31	9.29	63.6	10.33	3.00
6/18/2019	2.0	15.90	8.15	72.0	8.17	
7/3/2019	1.0	21.29	9.41	71.0	10.55	1.50
7/3/2019	2.0	18.13	8.36	78.6	8.96	
7/16/2019	1.0	22.76	7.89	74.1	6.19	1.00
7/30/2019	1.0	23.07	8.03	72.9	8.70	1.50
8/13/2019	1.0	21.84	8.04	72.5	8.54	1.50
8/27/2019	1.0	21.12	9.05	72.5	9.35	1.50
9/12/2019	1.0	19.01	9.41	72.5	12.06	1.00
10/2/2019	1.0	10.63	8.54	67.7	10.66	1.50
10/16/2019	1.0	9.81	8.84	67.8	10.82	1.50
		Average	8.65	67.58	10.27	1.81
		Maximum	9.41	78.60	12.61	3.00
		Minimum	7.89	51.40	6.19	1.00
		Average	8.65	67.58	10.27	1.81

Ross Point

Date	Depth (M)	Temp. (Deg C)	PH	Sp Con (us)	D.O. (mg/L)	Secchi Depth (m)
4/23/2019	1.0	9.77	7.22	55.4	11.52	
	3.0	9.47	7.35	55.9	11.71	
	5.0	9.22	7.47	55.3	11.81	
	7.0	8.38	7.53	55.2	11.87	
5/7/2019	1.0	10.36	7.42	59.8	11.48	
	3.0	8.49	7.80	59.7	11.66	
	5.0	7.75	7.93	59.7	11.69	
	7.0	7.50	8.01	59.7	11.68	
5/21/2019	1.0	12.99	8.23	60.2	10.32	
	3.0	12.59	8.39	60.2	11.04	
	5.0	12.17	8.40	60.1	11.25	
	7.0	11.17	8.53	60.0	11.66	
6/4/2019	1.0	10.36	7.42	59.8	12.41	5.00
	3.0	8.49	7.80	59.9	11.66	
	5.0	7.75	7.93	59.7	11.69	
	7.0	7.50	8.01	59.7	11.68	
6/18/2019	1.0	19.48	8.22	62.1	9.02	7.50
	3.0	19.38	8.21	62.1	9.03	
	5.0	19.30	8.22	62.1	9.03	
	7.0	16.27	8.20	61.5	9.39	
7/3/2019	1.0	20.76	8.20	63.1	8.70	5.00
	3.0	20.60	8.29	63.1	8.76	
	5.0	20.36	8.31	62.8	8.82	
	7.0	17.59	8.29	61.5	9.17	
7/16/2019	1.0	22.08	7.89	64.6	8.29	5.50
	3.0	22.06	8.09	64.5	8.32	
	5.0	22.02	8.10	64.6	8.33	
	7.0	19.72	8.27	62.6	8.66	
7/30/2019	1.0	22.29	7.85	65.6	8.27	5.00
	3.0	22.12	8.00	65.4	8.30	
	5.0	21.75	8.11	64.5	8.37	
	9.0	21.52	8.10	64.1	8.45	
8/13/2019	1.0	22.89	8.28	64.2	8.72	4.50
	3.0	22.66	8.34	64.3	8.76	
	5.0	22.60	8.34	64.4	8.71	
	7.0	22.33	8.20	67.6	8.51	
8/27/2019	1.0	22.41	8.27	65.9	8.15	5.50
	3.0	22.18	8.38	66.0	8.28	
	5.0	22.11	8.39	66.1	8.38	
	7.0	22.06	8.40	66.3	8.35	
9/12/2019	1.0	20.92	8.48	64.7	8.85	6.00
	3.0	20.81	8.48	64.7	8.86	
	5.0	20.70	8.46	64.5	8.87	

	7.0	20.57	8.47	64.7	8.88	
10/2/2019	1.0	14.76	8.40	63.4	9.59	7.00
	3.0	14.68	8.42	63.5	9.64	
	5.0	14.61	8.44	63.5	9.65	
	7.0	14.57	8.44	63.4	9.66	
10/16/2019	1.0	12.31	8.29	63.1	10.05	7.00
	3.0	12.17	8.36	63.0	10.15	
	5.0	12.10	8.39	63.0	10.20	
	7.0	12.08	8.41	63.0	10.22	
		Average	8.14	62.38	9.74	5.80
		Maximum	8.53	67.60	12.41	7.50
		Minimum	7.22	55.20	8.15	4.50

Gonzaga:

Date	Depth (M)	Temp. (Degrees C)	PH	Sp Con (us)	D.O> (mg/L)	Secchi Depth (M)
4/23/2019	1.0	8.36	6.95	58.3	11.60	8.00
	3.0	8.37	7.14	58.2	11.78	
	5.0	7.89	7.26	58.6	11.86	
	7.0	7.60	7.39	58.6	11.89	
	9.0	7.37	7.47	58.6	11.95	
5/7/2019	1.0	12.24	7.50	60.5	10.71	
	3.0	8.93	7.48	59.8	11.49	
	5.0	8.07	7.77	59.8	11.49	
	7.0	7.69	7.92	59.8	11.70	
	9.0	7.14	8.00	59.9	11.71	
5/21/2019	1.0	13.47	8.16	60.3	10.60	5.00
	3.0	12.99	8.20	60.3	10.81	
	5.0	12.08	8.30	60.0	11.13	
	7.0	11.29	8.34	60.1	11.46	
	9.0	9.42	8.36	60.1	12.08	
6/4/2019	1.0	12.24	7.50	60.5	10.71	7.00
	3.0	8.93	7.48	59.8	11.49	
	5.0	8.07	7.77	59.8	11.66	
	7.0	7.69	7.92	59.8	11.70	
	9.0	7.14	8.00	59.9	11.71	
6/18/2019	1.0	19.10	8.18	62.0	8.89	7.50
	3.0	19.03	8.15	62.0	8.96	
	5.0	18.47	8.15	61.9	9.05	
	7.0	17.11	8.18	61.6	9.39	
	9.0	10.65	8.17	60.7	10.61	
7/3/2019	1.0	20.53	7.54	62.7	8.52	8.00
	3.0	20.35	7.85	62.7	8.66	
	5.0	19.48	7.97	62.3	8.77	
	7.0	17.84	8.10	61.7	9.03	
	9.0	11.69	8.29	60.4	10.55	
7/16/2019	1.0	22.01	8.05	64.0	8.29	7.00
	3.0	21.98	8.09	63.9	8.30	
	5.0	21.80	8.14	63.9	8.32	
	7.0	19.51	8.33	62.5	8.76	
	9.0	15.53	8.47	61.8	9.58	
7/30/2019	1.0	22.07	7.62	64.8	8.07	6.00
	3.0	22.02	7.85	64.8	8.19	
	5.0	21.62	8.03	64.3	8.38	
	7.0	21.13	8.11	63.7	8.51	
	9.0	17.57	8.31	62.4	9.13	
8/13/2019	1.0	22.89	8.34	63.8	8.39	6.50
	3.0	22.64	8.30	63.8	8.61	

	5.0	22.52	8.32	63.7	8.71	
	7.0	20.39	8.55	62.2	9.65	
	9.0	15.52	8.98	60.9	12.19	
8/27/2019	1.0	22.31	8.06	65.4	8.10	7.00
	3.0	22.13	8.14	65.4	8.13	
	5.0	22.06	8.18	65.3	8.14	
	7.0	22.00	8.16	65.3	8.16	
	9.0	18.79	8.61	62.9	9.94	
9/12/2019	1.0	20.74	8.36	64.3	8.64	7.00
	3.0	20.67	8.35	64.3	8.72	
	5.0	20.55	8.39	64.5	8.74	
	7.0	20.47	8.47	64.3	8.76	
	9.0	19.98	8.44	64.2	8.78	
10/2/2019	1.0	14.76	8.40	63.4	9.59	7.00
	3.0	14.65	8.38	63.3	9.64	
	5.0	14.55	8.41	63.3	9.64	
	7.0	14.51	8.42	63.3	9.67	
	9.0	14.49	8.42	63.3	9.68	
10/16/2019	1.0	12.20	8.35	62.9	9.98	7.00
	3.0	12.11	8.38	62.9	10.11	
	5.0	12.09	8.40	63.0	10.16	
	7.0	12.06	8.43	63.0	10.21	
	9.0	12.04	8.44	63.0	10.22	
		Average	8.09	62.13	9.85	6.92
		Maximum	8.98	65.40	12.19	8.00
		Minimum	6.95	58.20	8.07	5.00

Mid-Lake

Date	Depth (M)	Temp. (Degrees C)	PH	Sp Con (us)	D.O> (mg/L)	Secchi Depth (M)
4/23/2019	1.0	5.97	6.95	59.4	11.41	8.00
	3.0	5.65	6.98	59.4	11.48	
	5.0	5.45	7.19	59.4	12.02	
	7.0	5.07	7.32	59.5	12.00	
	9.0	4.99	7.42	59.5	11.97	
5/7/2019	1.0	11.23	7.73	60.1	10.64	
	3.0	10.55	7.76	60.1	11.02	
	5.0	9.13	7.85	60.0	11.69	
	7.0	7.91	8.00	60.0	11.58	
	9.0	7.31	8.07	60.0	11.69	
	20.0	4.94	7.87	60.5	11.39	
5/21/2019	1.0	14.38	8.27	60.3	10.38	5.00
	3.0	14.03	8.30	60.3	10.46	
	5.0	12.66	8.32	60.3	10.68	
	7.0	8.47	8.29	60.0	11.92	
	9.0	7.59	8.26	60.1	12.51	
	19.0	5.57	8.14	60.3	12.08	
6/4/2019	1.0	11.23	7.73	60.1	10.64	8.00
	3.0	10.55	7.76	60.1	11.02	
	5.0	9.13	7.85	60.0	11.39	
	7.0	7.91	8.00	60.0	11.58	
	9.0	7.31	8.07	60.0	11.69	
	19.0	4.94	7.87	60.5	11.39	
6/18/2019	1.0	16.95	8.36	61.3	9.80	7.50
	3.0	16.00	8.55	61.3	9.47	
	5.0	13.86	8.47	60.9	10.48	
	7.0	9.69	8.54	60.7	11.27	
	9.0	7.63	8.49	60.6	11.92	
	19.0	5.35	8.10	60.9	11.38	
7/3/2019	1.0	19.48	7.86	62.0	8.74	9.00
	3.0	19.25	7.93	62.0	8.79	
	5.0	19.13	7.99	61.9	8.85	
	7.0	17.43	8.08	61.5	9.13	
	9.0	11.65	8.24	60.5	10.65	
	19.0	5.48	7.66	60.5	11.72	
7/16/2019	1.0	21.64	7.57	63.4	8.28	6.50
	3.0	21.54	7.87	63.4	8.34	
	5.0	21.47	8.02	63.4	8.37	
	7.0	17.78	8.37	62.1	9.04	
	9.0	13.87	8.67	61.4	10.18	
	19.0	5.52	8.20	61.0	11.93	
7/30/2019	1.0	21.74	7.95	63.7	8.31	7.00

	3.0	21.66	7.96	63.7	8.31	
	5.0	21.27	8.03	63.6	8.36	
	7.0	20.22	8.25	63.1	9.31	
	9.0	14.51	8.61	61.5	10.51	
	19.0	5.73	8.23	61.0	12.17	
8/13/2019	1.0	22.74	8.30	63.3	8.57	6.50
	3.0	22.51	8.31	63.2	8.69	
	5.0	22.44	8.34	63.2	8.71	
	7.0	22.36	8.36	63.2	8.72	
	9.0	15.67	9.06	61.0	11.55	
	19.0	10.15	9.02	60.0	13.16	
8/27/2019	1.0	21.91	8.13	64.6	8.24	8.00
	3.0	21.73	8.13	64.7	8.26	
	5.0	21.64	8.15	64.7	8.26	
	7.0	21.59	8.17	64.6	8.25	
	9.0	21.18	8.24	64.0	8.39	
	19.0	6.11	8.14	61.3	10.98	
9/12/2019	1.0	20.98	8.38	63.9	8.78	8.00
	3.0	20.65	8.40	63.9	8.83	
	5.0	20.59	8.40	63.8	8.83	
	7.0	20.55	8.37	63.9	8.85	
	9.0	17.80	8.95	62.0	11.85	
	19.0	5.84	8.18	60.5	12.50	
10/2/2019	1.0	14.85	8.41	63.0	9.65	8.00
	3.0	14.69	8.45	63.0	9.68	
	5.0	14.54	8.50	63.0	9.71	
	9.0	14.46	8.95	63.0	9.72	
	19.0	6.25	8.25	60.7	10.82	
10/16/2019	1.0	12.33	8.35	62.7	10.31	7.00
	3.0	12.22	8.37	62.7	10.34	
	5.0	12.18	8.39	62.7	10.36	
	7.0	12.16	8.42	62.7	10.37	
	9.0	12.13	8.44	62.7	10.37	
	19.0	6.46	8.27	60.7	10.97	
		Average	8.16	61.68	10.29	7.38
		Maximum	9.06	64.70	13.16	9.00
		Minimum	6.95	59.40	8.24	5.00

Nutrient Data:

Lake Sampling Summer 2017						
Date	7/17/2017	7/31/2017	8/23/2017	9/5/2017	9/26/2017	10/11/2017
Bob's Bay						
Ammonia N (mg/L)	0.005	0.053	<0.005	<0.005	0.014	0.025
Total Nitrate-Nitrite (mg/L)	0.021	0.025	0.02	0.012	<0.001	0.033
Total Persulfate Nitrogen (mg/L)	0.019	0.13	0.42	0.56	0.17	0.23
Ortho-phosphate (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Total phosphorus (mg/L)	0.021	0.15	0.009	0.052	0.016	0.024
Total Dissolved Solids (mg/L	79	20	76	84	66	48
Ross Point						
Ammonia N (mg/L)	<0.005	0.044	<0.005	<0.005	<0.005	<0.005
Total Nitrate-Nitrite (mg/L)	0.021	<0.001	<0.001	0.014	<0.001	0.02
Total Persulfate Nitrogen (mg/L)	0.09	0.09	0.22	0.17	0.02	0.17
Ortho-phosphate (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Total Phosphorus (mg/L)	0.02	<0.005	<0.005	0.008	0.005	0.023
Total Dissolved Solids (mg/L	54	60	15	110	64	32

Gonzaga						
Ammonia N (mg/L)	<0.005	0.047	<0.005	<0.005	<0.005	<0.005
Total Nitrate-Nitrite (mg/L)	0.03	0.021	0.017	0.021	<0.001	<0.001
Total Persulfate Nitrogen (mg/L)	0.06	0.05	0.12	0.14	0.08	0.18
Ortho-phosphate (mg/L)	0.0022	<0.005	0.005	<0.005	<0.005	<0.005
Total Phosphorus (mg/L)	0.0019	0.005	0.007	0.005	0.007	0.021
Total Dissolved Solids (mg/L	160	51	63	88	60	32

2018 Lake Monitoring Data											
Date	5/8	5/23	6/5	6/19	7/3	7/18	8/1	8/15	8/28	9/11	10/2
Bob's Bay											
Ammonia N (mg/L)	0.009	<0.005	<0.005	0.019	<0.005	0.086	0.032	0.008	0.137	0.04	<0.005
Total Nitrate-Nitrite (mg/L)	<0.001	0.013	0.013	0.031	<0.001	0.021	0.021	0.032	0.03	0.018	0.015
Total Persulfate Nitrogen (mg/L)	0.08	0.26	0.26	0.22	0.67	0.29	<0.02	0.61	0.68	0.36	0.2
Ortho-phosphate (mg/L)	0.0071	0.0055	0.0025	0.0017	0.0043	<0.001	0.0019	<0.001	<0.001	0.0024	0.0018

Total Phosphorus (mg/L)	0.01	0.0251	0.11	0.016	0.0085	0.0146	0.0072	0.0293	0.0418	0.0255	0.0197
Total Dissolved Solids (mg/L)	43	37	36	55	79	58	65	43	50	49	43
Ross Point											
Ammonia N (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	0.052	0.026	<0.005	0.024	0.007	<0.005
Total Nitrate-Nitrite (mg/L)	0.022	0.012	0.014	0.02	0.018	0.015	0.014	0.028	0.019	0.012	0.012
Total Persulfate Nitrogen (mg/L)	0.07	0.16	0.27	<0.02	0.1	0.28	0.14	0.22	0.23	0.12	0.17
Ortho-phosphate (mg/L)	0.0109	<0.001	<0.001	<0.001	0.0014	<0.001	<0.001	<0.001	<0.001	0.0024	0.0015
Total Phosphorus (mg/L)	0.004	0.013	0.0053	0.0067	0.0053	0.0123	0.0454	0.0067	0.0103	0.014	0.0081
Total Dissolved Solids (mg/L	47	32	40	49	70	48	55	40	44	48	45
Gonzaga											
Ammonia N (mg/L)	<0.005	<0.005	<0.005	<0.005	<0.005	0.034	0.008	0.005	0.006	<0.005	
Total Nitrate-Nitrite (mg/L)	<0.001	0.015	0.011	0.019	<0.001	0.009	0.014	0.02	0.009	0.017	
Total Persulfate Nitrogen (mg/L)	0.09	0.19	0.15	<0.02	0.1	0.1	<0.2	0.12	0.13	0.15	
Ortho-phosphate (mg/L)	0.0059	<0.001	0.0011	<0.00 1	0.0015	<0.001	<0.001	<0.001	<0.001	0.0023	
Total Phosphorus (mg/L)	0.003	0.0121	0.0056	0.0088	0.0055	0.007	0.006	0.0043	0.0073	0.0104	

Total Dissolved Solids (mg/L	59	35	31	44	69	32	49	41	34	40	

Lake Monitoring Data 2019														
Date	4/23/2019	5/7/2019	5/21/2019	6/4/2019	6/18/2019	7/3/2019	7/16/2019	7/30/2019	8/9/2019	8/27/2019	9/12/2019	10/2/2019	10/16/2019	10/30/2019
Bob's Bay														
Ammonia N (mg/L)	0.21	<0.02	<0.02	0.046	<0.02	<0.02	0.026	0.041	0.056	0.01	0.029	<0.02	0.029	<0.02
Total Nitrate-Nitrite (mg/L)	<0.001	0.012	0.013	0.014	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total Persulfate Nitrogen (mg/L)	0.13	0.27	0.41	0.34	0.2	0.18	0.34	0.12	0.26	0.076	<0.02	0.21	0.15	0.15
Ortho-phosphate (mg/L)	0.0014	0.0024	0.0078	0.0014	0.0023	0.001	0.0051	0.0024	0.0036	0.0023	0.0038	0.0019	0.0022	<0.001
Total Phosphorus (mg/L)	0.0119	0.017	0.0308	0.0147	0.0132	0.0113	0.04	0.0127	0.0174	0.0328	0.049	0.0187	0.0085	0.0022
Total Dissolved Solids (mg/L)	39	28	29	47	53	66	60	60	42	48	47	34	42	30
Ross Point														
Ammonia N (mg/L)	<0.02	<0.02	<0.02	0.028	0.026	<0.02	0.022	<0.02	0.031	<0.02	<0.02	<0.02	0.022	<0.02
Total Nitrate-Nitrite (mg/L)	<0.001	0.012	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total Persulf	0.011	0.15	0.16	0.19	0.19	0.1	0.11	<0.02	<0.02	<0.02	<0.02	0.16	0.13	0.12

ate Nitrogen (mg/L)														
Ortho-phosphate (mg/L)	0.0011	0.0013	0.0012	<0.001	0.001	<0.001	<0.001	0.001	0.0012	<0.001	0.0014	<0.001	<0.001	<0.001
Total Phosphorus (mg/L)	0.0052	0.0074	0.0079	0.0059	0.006	<0.001	<0.001	0.01	<0.001	0.0311	0.0038	<0.001	<0.001	<0.001
Total Dissolved Solids (mg/L	44	28	30	31	56	46	66	53	40	40	46	34	33	29
Gonzaga														
Ammonia N (mg/L)	<.,02	<0.02	<0.02	0.023	<0.02	<0.02	0.024	0.03	0.045	<0.02	<0.02	<0.02	<0.02	<0.02
Total Nitrate-Nitrite (mg/L)	<0.001	0.012	0.015	0.0123	0.012	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total Persulfate Nitrogen (mg/L)	0.12	0.16	0.15	0.17	0.42	0.04	<0.02	<0.02	<0.02	<0.02	<0.02	0.17	0.12	0.12
Ortho-phosphate (mg/L)	<0.001	0.0013	<0.001	<0.001	0.0011	<0.001	<0.001	0.0014	<0.001	<0.001	0.001	<0.001	<0.001	<0.001
Total Phosphorus (mg/L)	<0.001	0.0078	0.0055	<0.001	0.0273	<0.001	<0.001	0.0095	<0.001	0.0126	0.0046	<0.001	<0.001	0.0016
Total Dissolved Solids (mg/L	41	29	30	64	51	49	56	59	43	42	49	31	33	29
Mid-Lake														
Ammonia N (mg/L)	<0.02	<0.02	<0.02	0.026	<0.02	<0.02	0.025	0.023	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Nitrate	<0.001	<0.001	<0.001	<0.001	<0.001	0.028	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

-Nitrite (mg/L)														
Total Persulfate Nitrogen (mg/L)	0.12	0.028	0.14	0.21	0.13	0.08	<0.02	<0.02	<0.02	<0.02	<0.02	0.15	0.16	0.12
Ortho-phosphate (mg/L)	<0.001	0.0024	<0.001	<0.001	<0.001	<0.001	<0.001	0.0063	<0.001	<0.001	0.0011	<0.001	0.0021	0.001
Total Phosphorus (mg/L)	<0.001	0.0092	0.009	0.0065	0.0059	<0.001	0.024	0.0093	<0.001	0.0065	0.0024	<0.001	<0.001	<0.001
Total Dissolved Solids (mg/L	60	29	29	63	53	49	59	51	47	50	52	31	14	30

Chlorophyl a data, 2016-2019, all sample locations

2016 Chl a data									Ave	
Bob's Bay	9	7	6.5	12	6.5	8.1	4	2.1	6.9	Taken from graph in 2019 report date indeterminant
Ross Point	1.8	3.8	2	2.2	2.7	2.1	1	1	2.1	
Gonzaga	1	2	1.5	1	1.8	1.7	1	1	1.4	

2017 Chl a data				Ave	
Bob's Bay	10	4	4	6.0	Taken from graph in 2019 report date indeterminant
Ross Point	2.2	1.8	1.8	1.9	
Gonzaga	1.8	1.9	1	1.6	

2018 Chl a data											Ave	
Bob's Bay	1	2	3	10	9	4	10	57	9	8	2	10.5	Taken from graph in 2019 report date indeterminant
Ross Point	1	1	1	2	2	2	2	8	5	2	1	2.5	
Gonzaga	1	1	1	1	1	1	1	3	2	2	0.5	1.3	

Average of Chla	***Date collected***														Chl a Ave
Sample	10/16/2019	10/2/2019	10/30/2019	4/23/2019	5/21/2019	5/7/2019	6/18/2019	6/4/2019	7/16/2019	7/3/2019	7/30/2019	8/13/2019	8/27/2019	9/12/2019	Grand Total	
Bob's Bay	1.33	1.34	0.73	1.48	5.88	0.71	0.90	0.28	2.61	6.75	2.30	4.75	8.88	15.82	3.84	
Gonzaga	0.71	0.67	1.05	0.79	0.86	0.58	0.28	0.17	0.53	0.29	0.14	0.49	0.13	0.73	0.53	
Mid-Lake	0.59	0.75	1.02	0.47	0.79	0.42	0.17	0.35	0.32	0.19	0.17	0.35	0.29	0.48	0.45	
Ross Point	0.46	0.93	0.31	0.75	0.73	0.42	0.25	0.28	0.45	0.62	0.66	0.83	0.44	0.58	0.55	
Grand Total	**0.77**	**0.92**	**0.78**	**0.87**	**2.07**	**0.53**	**0.40**	**0.27**	**0.98**	**1.96**	**0.82**	**1.61**	**2.44**	**4.40**	**1.34**	

2018 Chlorophyll and Phaeophyton Analysis for all sample sites

Sample	Date collected	Chla	Phae
Bob's Bay	4/18/2018	0.31	0.10
Ross Point	4/18/2018	1.78	0.01
Gonzaga	4/18/2018	1.46	0.06
Bob's Bay	5/23/2018	1.56	0.12
Ross Point	5/23/2018	0.60	0.03
Gonzaga	5/23/2018	0.47	0.04
Bob's Bay	6/5/2018	2.32	0.00
Ross Point	6/5/2018	0.30	0.03
Gonzaga	6/5/2018	0.61	0.00
Bob's Bay	6/19/2018	10.45	0.00
Ross Point	6/19/2018	1.45	0.00
Gonzaga	6/19/2018	1.11	0.15
Bob's Bay	7/3/2018	9.82	2.50
Ross Point	7/3/2018	2.06	0.00
Gonzaga	7/3/2018	1.67	0.00
Bob's Bay	7/18/2018	3.64	0.62
Ross Point	7/18/2018	1.16	0.07
Gonzaga	7/18/2018	0.98	0.08
Bob's Bay	8/1/2018	10.97	2.11
Ross Point	8/1/2018	1.33	0.12
Gonzaga	8/1/2018	0.67	0.04
Bob's Bay	8/15/2018	56.34	2.05
Ross Point	8/15/2018	7.53	0.16
Gonzaga	8/15/2018	2.60	0.01
Bob's Bay	8/28/2018	8.42	0.75
Ross Point	8/28/2018	4.02	0.75
Gonzaga	8/28/2018	2.33	0.15
Bob's Bay	9/11/2018	7.69	2.18
Ross Point	9/11/2018	2.59	0.26
Gonzaga	9/11/2018	2.43	0.01
Bob's Bay	10/2/2018	2.46	0.65
Ross Point	10/2/2018	1.36	0.10

2019 Chlorophyll and Phaeophyton Analysis for all sample sites

Lake	Sample	Depth	Date collected	Time	Chla	Chl a data qualifier	Phae	*Phaeophyton Data Qualifier (j=Estimate, result less than MQL)*
Hayden	Bob's Bay	NP	4/23/2019	19:30	1.48		0.10	j
Hayden	Ross Point	NP	4/23/2019	19:30	0.75		0.06	j
Hayden	Gonzaga	NP	4/23/2019	19:40	0.79		0.05	j
Hayden	Mid-Lake		4/23/2019	19:40	0.47		0.04	j
Hayden	Bob's Bay	NP	5/7/2019	11:46	0.71		0.13	j
Hayden	Ross Point	NP	5/7/2019	12:11	0.42		0.03	j
Hayden	Gonzaga	NP	5/7/2019	12:35	0.58		0.04	j
Hayden	Mid-Lake	NP	5/7/2019	13:15	0.42		0.03	j
Hayden	Bob's Bay	NP	5/21/2019	12:14	5.88		0.89	

Hayden	Ross Point	NP	5/21/2019	12:34	0.73		0.04	j
Hayden	Gonzaga	NP	5/21/2019	12:57	0.86		0.04	j
Hayden	Mid-Lake	NP	5/21/2019	13:33	0.79		0.03	j
Hayden	Bob's Bay	NP	6/4/2019	11:54	0.28	j	0.04	j
Hayden	Ross Point	NP	6/4/2019	12:12	0.28	j	0.02	j
Hayden	Gonzaga	NP	6/4/2019	12:37	0.17	j	0.01	j
Hayden	Mid-Lake	NP	6/4/2019	13:17	0.35		0.01	j
Hayden	Bob's Bay	NP	6/18/2019	11:31	0.90		0.06	j
Hayden	Ross Point	NP	6/18/2019	12:03	0.25	j	0.06	j
Hayden	Gonzaga	NP	6/18/2019	12:31	0.28	j	0.06	j
Hayden	Mid-Lake	NP	6/18/2019	16:19	0.17	j	0.04	j
Hayden	Bob's Bay	NP	7/3/2019	12:48	6.75		0.69	
Hayden	Ross Point	NP	7/3/2019	13:18	0.62		0.04	j
Hayden	Gonzaga	NP	7/3/2019	13:37	0.29	j	0.02	j
Hayden	Mid-Lake	NP	7/3/2019	14:04	0.19	j	0.02	j
Hayden	Bob's Bay	NP	7/16/2019	11:54	2.61		1.49	
Hayden	Ross Point	NP	7/16/2019	12:32	0.45		0.13	j
Hayden	Gonzaga	NP	7/16/2019	12:48	0.53		0.12	j
Hayden	Mid-Lake	NP	7/16/2019	13:16	0.32		0.11	j
Hayden	Bob's Bay	NP	7/30/2019	10:50	2.30		1.31	
Hayden	Ross Point	NP	7/30/2019	11:19	0.66		0.19	j
Hayden	Gonzaga	NP	7/30/2019	11:36	0.14	j	0.04	j
Hayden	Mid-Lake	NP	7/30/2019	12:20	0.17	j	0.03	j
Hayden	Bob's Bay	NP	8/13/2019	12:03	4.75		2.48	
Hayden	Ross Point	NP	8/13/2019	12:17	0.83		0.11	j
Hayden	Gonzaga	NP	8/13/2019	12:45	0.49		0.11	j
Hayden	Mid-Lake	NP	8/13/2019	13:21	0.35		0.08	j
Hayden	Bob's Bay	NP	8/27/2019	12:00	8.88		1.12	
Hayden	Ross Point	NP	8/27/2019	12:33	0.44		0.08	j
Hayden	Gonzaga	NP	8/27/2019	12:53	0.13	j	0.02	j
Hayden	Mid-Lake	NP	8/27/2019	13:18	0.29	j	0.10	j
Hayden	Bob's Bay	NP	9/12/2019	13:37	15.82		0.67	
Hayden	Ross Point	NP	9/12/2019	13:57	0.58		0.07	j
Hayden	Gonzaga	NP	9/12/2019	14:18	0.73		0.07	j
Hayden	Mid-Lake	NP	9/12/2019	14:49	0.48		0.06	j
Hayden	Bob's Bay	NP	10/2/2019	14:08	1.34		0.40	
Hayden	Ross Point	NP	10/2/2019	14:34	0.93		0.13	j
Hayden	Gonzaga	NP	10/2/2019	14:50	0.67		0.12	j
Hayden	Mid-Lake	NP	10/2/2019	15:15	0.75		0.08	j
Hayden	Bob's Bay	NP	10/30/2019	13:13	0.73		0.30	
Hayden	Ross Point	NP	10/30/2019	13:34	0.31		0.10	j
Hayden	Gonzaga	NP	10/30/2019	13:57	1.05		0.11	j
Hayden	Mid-Lake	NP	10/30/2019	14:17	1.02		0.22	j
Hayden	Bob's Bay	NP	10/16/2019	14:21	1.33		0.72	
Hayden	Ross Point	NP	10/16/2019	14:44	0.46		0.12	j
Hayden	Gonzaga	NP	10/16/2019	14:56	0.71		0.16	j
Hayden	Mid-Lake	NP	10/16/2019	15:21	0.59		0.12	j

Appendix C: Analysis of Nutrient Management Approaches

Before further assessing the management approaches it is useful to step back and view the North Arm of Hayden Lake through the period before and after impoundment of the lake and plugging of the large bottom outlets (whirlpool area) at the other end of the lake. Before the lake was impounded the area of the lake's current bed north of Henry's Point was seasonally inundated during the high discharge portion of the year. Likely by mid to late July this area of the lake drained as the lake volume declined by loss of water into the Rathdrum Aquifer. After July this area of the current lake became a rich pasture along the course of Hayden Creek. The pasture's biomass would die in the fall and in time be incorporated into the soil with hemicellulose and polyphenolic compounds creating a rich humus that would bind phosphorus compounds.

Once the dike was placed in 1910 and the areas of rapid infiltration were plugged, the lake inundated the North Arm year around. The humus would likely not break down in the more anaerobic conditions of the now permanent lake bottom, but sediments that were each year incorporated into the pasture soil would simply settle to the bottom each year after washed into the lake. No humus was formed to bind phosphorus only more easily oxidized organic material. The biomass created each year by algal, protozoan and large organism would also settle into the sediments. The same process occurred lake wide before and after the dike. Nutrients including phosphorus would be liberated from all the sediments, but those of the main lake body are isolated by the constant cold temperatures of the bottom waters (hypolimnion) and the annual stratification of the lake during the summer (growing) season. In the shallow North Arm, especially in the vicinity of Sportmans Access, these sediments are not isolated from the shallow warm surface waters.

It took many years to build up sediments in the North Arm. As these built up the amount of phosphorus available to liberate increased as did a bed for aquatic plants to prosper. Now over a hundred years after the lake's natural cycle was altered, the sediment layer is robust enough to donate phosphorus to the water column in concentrations sufficient to permit the detection of orthophosphate on a regular basis. Certainly, phosphorus is at levels typical of a eutrophic situation.

Prohibit Bottom Sediment Stirring:

An approach to limiting phosphorus at least somewhat would be a restriction on boat speeds. Liberation of phosphorus into the water column from the sediments is dependent on temperature and accelerated by agitation. Agitation or stirring increases surface area which increase any chemical reaction. Little can be done to limit temperature in this shallow section of the lake, especially during a period of generally warming temperatures. However, boat propellers operating in such shallow waters stir the bottom increasing phosphorus liberation. Reducing the agitation of bottom sediments would possibly lower the productivity of the area and possibly decrease soluble nitrogen depletion and the result cyanobacteria blooms.

The approach would be an inconvenience to the boating public. Speeds would be reduced to less than 5 miles per hour. The approach if effective would decrease algal productivity somewhat, but likely not to a level that would adversely impact the food chains leading up to the fishery. Aquatic plants including the invasive species would not be greatly affected.

Mid-Summer Nitrate Addition:

Nitrate addition approaches the problem from the nitrogen depletion side of the equation. This approach would add a small amount of nitrate nitrogen to pre-empt soluble nitrogen depletion. The algal communities would remain as or even more productive. Algal growth would remain balanced. Cyanobacteria blooms should be pre-empted. For this approach to be most effective bottom stirring by boat propellers should be restricted.

The approach would not affect the food chains supporting the fishery. Aquatic plants including the invasive species would not be affected. The inconvenience to the boating community would be in place. The approach would require annual nitrate application. Monitoring of biotic communities might be employed to optimize the nitrate application.

Alum Application:

Alum (aluminum sulfate) treatment of the shallowest and most productive areas of the North Arm would be at one time the more permanent and the most evasive approach. Alum will bind both phosphorus and nitrogen and precipitate it to the bottom sediments in a chemical complexes that will greatly restrict any remobilization into the water column. The result would be a radical decrease in algal and likely aquatic weed productivity. After treatment phosphorus and nitrogen from the watershed and other locations in the lake would restart algal productivity, but not nearly at the present level.

The decrease in plant productivity would cause a simultaneous decline in the productivity of the fishery, especially the bass fishery. Boat restrictions and nitrate addition would not be necessary. The areas of the North Arm treated would be essentially set back to a condition akin to those just after the impoundment. Over time, likely decades, new sediments would form and the alum treated bottom would be buried beneath these. Eventually the current conditions will be re-established requiring another treatment.

The table below compares the management approaches.

Management Approach	Effect on Algal Productivity	Effect of Aquatic Plants	Effect on Food Chain Ultimately Fishery	Required annual maintenance	Permanence/ Long Term effectiveness
Boating Restriction	small	none	small	enforcement	Short term
Nitrate Addition	none to increase/ stop blooms	none	slight increase	required	long term
Alum Treatment	large decrease/stop blooms	large decrease	large decline	none	Long term