**To:** Ron Steg, Jeremy ZumBerge, Tavis Eddy, Gwen Gerber, Joe Deromedi

**From:** Mike Wachtendonk

**Re:** Technical Memo summarizing results of Brooks Lake Phase 1 Monitoring

# Executive Summary

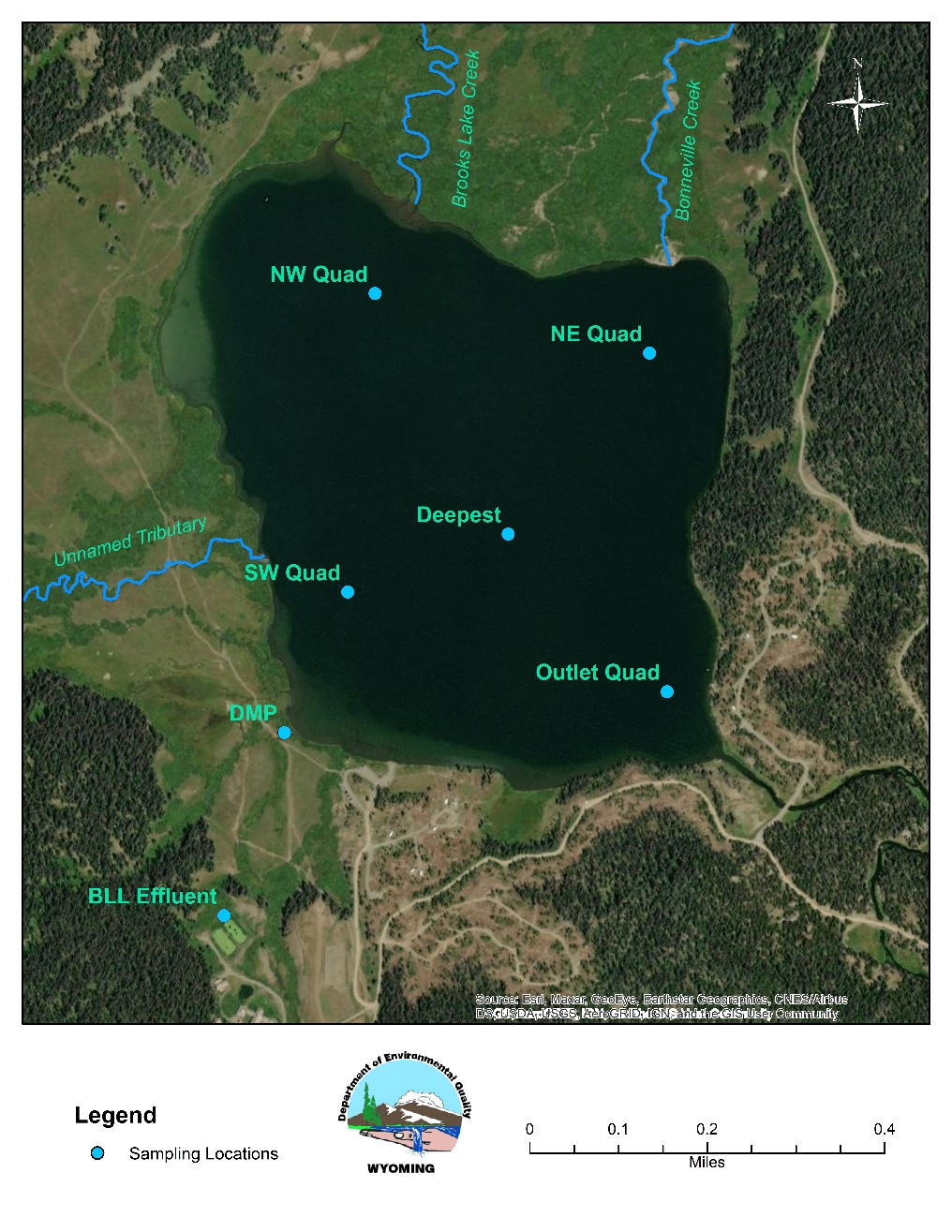
Water quality data were collected on Brooks Lake during 2020 – 2021 with monitoring objectives primarily associated with monitoring nutrient and productivity trends, characterizing the phytoplankton community, evaluating potential public health risks associated with cyanobacteria, and monitoring the quality of the wastewater effluent from the Brooks Lake Lodge. The following provides a summary of major takeaways learned during these first two years of sampling that will inform future monitoring efforts on Brooks Lake. Monitoring suggests Brooks Lake is dimictic, with spring and fall turnover typically occurring around mid-June and mid-October, respectively. Summer stratification resulted in anoxic conditions in the bottom several meters of the lake, while the epilimnion had plenty of dissolved oxygen (DO) during daylight sampling hours to support early life stage and adult cold water fish. No measurements of DO occurred during night-time or pre-dawn hours when the diurnal DO fluctuation would be at its daily minima. Measured pH values regularly exceeded 9.0 SU during both study years. Epilimnetic pH values were often >9.0 SU during July, August, and September, and even exceeded 10.0 SU at each site during September 2020. High pH values persisted immediately following turnover, with pH values >11.0 SU in October 2020. Due to low DO in the hypolimnion and high pH in the epilimnion during summer stratification, a narrow band of ~1.5 – 3 meters of the water column was considered suitable for adult stages of cold water fish and other aquatic life. Total phosphorus (TP) was typically found in detectable concentrations at the surface of Brooks Lake during most sampling events. The greatest surface TP concentration observed was 0.1 mg/L, during an October 2021 fall turnover mixing event; the greatest surface TP concentrations tended to be during June or October events, which represented post-turnover whole lake mixing events.  Surface TP concentrations were lower during the stratification months of July, August, and September, and ranged from <0.01-0.04 mg/L.  Total phosphorus was present in reportable concentrations in every bottom sample, with a maximum bottom TP concentration of 0.6 mg/L at Deepest during August 2021.  Mean bottom TP concentrations were greatest during August and September of both years.  Orthophosphate comprised the majority of total phosphorus in bottom samples. Orthophosphate was only present in reportable concentrations at the surface during the turnover months of June and October, no reportable orthophosphate was found during events when stratified conditions were present. Surface total nitrogen (TN) concentrations tended to be highest during the post-turnover months of June and October, as well as the stratified month of September.  The greatest surface TN concentration (0.4 mg/L) was observed during the October 2021 post-turnover sampling event.  Bottom TN concentrations tended to be greatest during August and September, with the maximum bottom TN concentration of 1.6 mg/L observed during August. The vast majority of TN:TP ratios suggested nitrogen-limitation conditions existed at the surface and bottom of Brooks Lake. Conditions of co-limitation also existed and were generally more common at the surface during non-turnover months. Nitrate+nitrite (NO2+NO3) concentrations were only detected in reportable concentrations during the months of June and July.  During the post-turnover event of June 2021, NO2+NO3 was distributed equally throughout the water column.  During June 2020 and July 2021, reportable concentrations of NO2+NO3 were found at the bottom of two sites.  This suggests the inorganic, bioavailable form of nitrogen is not often available in reportable concentrations in Brooks Lake. At DMP, about 64-100% of the TP was comprised of the more bioavailable orthophosphate, and about <21-80% of the TN was comprised of the more bioavailable NO­­2+NO3.  The water entering Brooks Lake from this tributary is reflective of the Brooks Lake Lodge wastewater lagoons.  As measured by chlorophyll a, primary productivity appeared to peak during September in Brooks Lake.  The maximum chlorophyll α concentration was 66.9 µg/L during September 2020.  Mean chlorophyll α concentration during July 2020 was 1.27 µg/L, indicative of high seasonal variation in chlorophyll.  Chlorophyll α concentrations remained high during October 2020, following turnover. After spring turnover, the phytoplankton community in Brooks Lake was relatively diverse and balanced with representation from major phytoplankton divisions which included Bacillariophyta, Chlorophyta, Cyanophyta, Cryptophyta, and Pyrrhophyta.  The phytoplankton community later in the growing season during August and September was heavily dominated by cyanobacteria such as *Aphanizomenon* and *Aphanocapsa*.  Cyanobacteria dominance continued after fall turnover during the October sampling events. Results from ambient phytoplankton samples indicate cyanobacteria densities exceeded the recreational use advisory threshold of 20,000 cells/mL. Data from surface samples at Deepest were highly comparable to results at the four quadrant sites.  This indicates the observed variability in the vast majority of parameters fell within the accepted variability for original and duplicate samples, and suggests surface samples collected at Deepest would be representative of conditions at the four quadrant sites. For bottom samples, nutrient concentration results at Deepest were less comparable to nutrient concentration results at the four quadrant sites.  We learned that nutrient concentrations in the hypolimnion are usually greatest at Deepest, and noticeable spatial differences in nutrient concentrations exist within the hypolimnion that may be associated with the depth the sample was collected at.  Bathymetry data collected revealed the deepest point in Brooks Lake is just east of Deepest; this site will be relocated a short distance to the east for Phase 2 sampling activities.

## **Introduction**

The aquatic life other than fish, cold water fish, and nongame fish designated uses in Brooks Lake were listed as impaired due to nutrients and pH in Wyoming’s 2016/2018 Integrated 305(b) and 303(d) Report (WDEQ/WQD 2018a). A Sampling and Analysis Plan (SAP) was prepared in 2020 to collect additional data to enhance our understanding of the impairment (i.e. stressor/response relationship), better quantify all nutrient loads from natural and anthropogenic sources, and define endpoint water quality goals (e.g. in-lake nitrogen and phosphorus concentration targets). The SAP (WDEQ/WQD 2021a) outlined a three phased approach. Phase 1 featured an abbreviated monitoring plan to track trends in Brooks Lake and in the effluent quality from Brooks Lake Lodge. Phase 2 will focus on enhancing our understanding of the impairment (i.e. stressor/response relationship), and identifying and quantifying nutrient loads from all natural and anthropogenic sources. Phase 3 will build on subsequent phases and focus on defining in-lake water quality goals for Brooks Lake. The data collected from this three-phase effort will provide the foundation for taking corrective actions to address the impairment if, in fact, the results confirm that the nutrient and pH impairments are primarily the result of anthropogenic influence. Phase 1 monitoring activities were conducted in 2020 and 2021. This memo provides a technical summary and analysis of the Phase 1 data to facilitate internal “Brooks Lake Team”[[1]](#footnote-1) discussion and planning for Phases 2 and 3. The conclusions presented herein are considered preliminary and should not be distributed beyond our internal and external collaborators until a final report is prepared at the completion of Phase 3.

Five lake sites on Brooks Lake, in addition to the Brooks Lake Lodge wastewater lagoon effluent and its associated Downstream Monitoring Point (DMP), were monitored on a monthly basis from June through October in 2020 and 2021 in support of Phase 1 objectives (***Figure 1***). Phase 1 objectives were to: 1) track potential nutrient reductions in the discharge associated with facility upgrades at Brooks Lake Lodge, 2) monitor nutrient and productivity trends in Brooks Lake, 3) evaluate potential public health risks associated with cyanobacteria, 4) prepare for Phases 2 and 3 (i.e. use Phase 1 results to inform subsequent Phases), and 5) characterize the phytoplankton community present in Brooks Lake. Results from Phase 1 monitoring are summarized in this memo, as well as data analysis in support of the attainment of study objectives.

**Figure 1. Map of sampling locations on Brooks Lake for Phase 1 monitoring.**



## **Quality Assurance Quality Control**

Data collection followed methods, procedures, and techniques listed in the Manual of Standard Operating Procedures (WDEQ/WQD 2022), the Quality Assurance Project Plan (QAPP) (WDEQ/WQD 2021b), and the Brooks Lake Targeted Water Quality Monitoring Study- Phase I Sampling and Analysis Plan (WDEQ/WQD 2021a). Data collected during 2020 – 2021 were evaluated using QAPP criteria. All data were suitable for analytical consideration unless otherwise noted in ***Appendix 1*** (Data Package Review Letter from WDEQ QA/QC Officer); data that were excluded from analytical consideration are listed below. A field audit of sample collection efforts was performed by the WDEQ QA/QC Officer during the June 15, 2021 sampling event (***Appendix 2***).

* Chlorophyll α samples from the July and September 2021 sampling events are not considered suitable for analytical consideration. Sample analysis was sub-contracted to a private laboratory, and these samples exceeded the recommended temperature (≤6°C) upon receipt at Energy Laboratories.
* Conductivity values for the September and October 2021 sampling events are not considered suitable for analytical consideration due to issues with calibration of the conductivity probe.
* Orthophosphate samples from June, July, and August 2020 sampling events are not considered suitable for analytical consideration due to laboratory analytical issues.

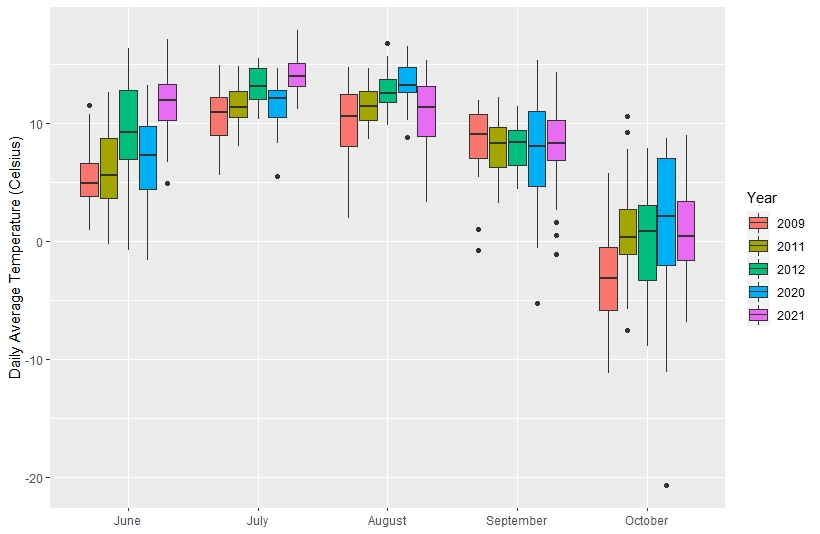
## **Hydrology and Weather Data**

Daily mean discharge data from 2009, 2011-2012, and 2020-2021, as well as the period of record mean are provided from USGS 06218500 Wind River near Dubois, WY (***Figure 2***). Data from this nearby gaging station provides a reasonable representation of snow and snowmelt runoff conditions during each of the study years, relative to the period of record mean. Data from 2009, 2011, and 2012 are provided in order to offer perspective for temporal analyses provided within this document.

Daily mean air temperature from the Togwotee Pass, WY Global Historical Climatology Network station (USS0010F09S) is presented for summer growing season months during 2009, 2011-2012, and 2020-2021 (**Figure 3**). Data from this nearby weather station provides important information on air temperature during our study years as temperature is one of the many factors that influence primary productivity within lakes and reservoirs.

**Figure 2. Daily mean discharge (period of record 1946-2021) and 2009, 2011-2012, 2020-2021 daily mean discharge of the Wind River near Dubois, WY (USGS 06218500).**

**Figure 3. Daily average air temperature at Togwotee Pass (GHCND USS0010F09S) for 2009, 2011-2012, and 2020-2021.**



## **Vertical Profiles**

### 2020

Select vertical profiles of temperature, pH, and dissolved oxygen for 2020 are presented in **Figure 4**, **Figure 5**, ***Figure 6***, ***Figure 7***, and ***Figure 8***. Vertical profile data during our mid-June sampling event were suggestive that spring turnover had occurred relatively recently. Water temperatures ranged from a little over 8°C at the surface down to around 4.5°C in the hypolimnion of the deepest site. Dissolved oxygen (DO) concentrations ranged from around 10.6 mg/L near the water surface to around 5 mg/L in the hypolimnion. All pH values were within the 6.5 – 9.0 SU criteria, and decreased slightly with depth.

Summer growing season stratification was apparent during July monitoring. Surface water temperatures ranged from around 14.5 – 16°C at the surface, then decreased with depth down to near 5.5°C in the hypolimnion. Most pH values tended to be 8.0 to near 9.0 SU, with a few values exceeding 9.0 SU at 5 – 7 meters of depth. Dissolved oxygen concentrations in the epilimnion were above 8 mg/L and got as high as 10.65 mg/L at 6 meters of depth at Outlet Quad. Dissolved oxygen sharply decreased below 6 meters and dropped below 4 mg/L at around 9 – 11 meters of depth.

As the summer growing season continued into late August, stratification became more intense with anoxia present from approximately 9 meters down to the bottom of the lake (~16 meters). Dissolved oxygen concentrations were near 10 mg/L in the epilimnion, but decreased sharply around 6 meters of depth, and concentrations were generally <4 mg/L below 7 meters from the water surface. All epilimnetic pH values were >9.0 SU, with the highest value of 9.84 SU observed at multiple sites. The pH values dropped below 9.0 SU around 4.5 – 6.5 meters of depth. Water temperatures were similar to those in July, with surface temperatures around 16°C and hypolimnetic temperatures near 5.5 – 6.0°C.

During our mid to late September sampling event, surface water temperatures decreased to around 10.5°C. Epilimnetic pH values continued to rise and exceeded 10.0 SU at the surface at each site. The greatest pH value (10.59 SU) occurred at 7 meters of depth at NW Quad; pH also was found to increase with depth at SW Quad, with the maximum pH of 10.51 SU at 6-7 meters greater than surface pH values (10.33 SU). Epilimnetic DO concentrations also continued to rise, and the greatest concentration (11.96 mg/L) was observed at Deepest. Dissolved oxygen decreased quickly around 5 meters of depth, with DO concentrations at all sites dropping below 8 mg/L by 7.5 meters of depth and 4 mg/L by 9.5 meters.

Vertical profiles during October indicated fall-turnover had recently occurred. Water temperatures were isothermal, and ranged 5.02 – 5.44°C from surface to bottom at all three monitored sites. Measurements of pH were notable in that values tended to increase with depth, with the maximum value of 11.17 SU recorded at 14 meters of depth at Deepest; surface pH measurements remained above 9.0 SU. Turnover had re-distributed oxygen throughout the water column, and DO concentrations remained above 8 mg/L at every site except the bottom measurement (16 meters of depth) at Deepest (7.68 mg/L). Vertical profiles of temperature, DO, and pH at Deepest are provided below in **Figure 4**, **Figure 5**, and ***Figure 6*** to illustrate typical conditions in Brooks Lake by month during 2020.

**Figure 4. Vertical profiles of temperature by month during 2020 monitoring at Deepest.**

**Figure 5. Vertical profiles of DO by month during 2020 monitoring at Deepest with applicable numeric criteria.**

**Figure 6. Vertical profiles of pH by month during 2020 monitoring at Deepest with applicable numeric criteria.**

In consideration of WDEQ numeric criteria protective of aquatic life and adult cold water fish (WDEQ/WQD 2018b), the amount/thickness of water column that was 6.5 – 9.0 SU and >4 mg/L DO was evaluated for all sampling months. During June, all DO concentrations were >4 mg/L and all pH measurements were 6.5 – 9.0 SU, therefore the entire water column was considered supportive of aquatic life and adult cold water fish. July pH measurements were all between 6.5 and 9.0 SU, with the exception of measurements that exceeded 9.0 SU around 5-7 meters at two sites; pH values remained below 9.0 SU at the other three sites. Dissolved oxygen dropped below 4 mg/L at about 9 – 11 meters of depth. Therefore, water column depths considered supportive of aquatic life and adult cold water fish were from the surface down to 11 meters. Summer growing season conditions during August decreased the amount of the water column that was considered supportive of aquatic life and adult cold water fish. Epilimnetic pH values were >9.0 SU down to a depth of around 4.5 – 6.5 meters, and DO concentrations dropped below 4 mg/L at 6.5 – 7.5 meters. This resulted in depths considered supportive of aquatic life and adult cold water fish around 4.5 – 7.5 meters, a thickness of about 3 meters. Summer stratification conditions during September were similar, with depths of approximately 6.5 – 9.5 meters considered supportive of aquatic life and adult cold water fish, a thickness of about 3 meters (***Figure 7***, ***Figure 8***). Fall turnover did result in a re-distribution of oxygen throughout the water column; however, pH values remained ≥9.0 SU at all depths and the entire water column was considered not supportive of aquatic life and adult cold water fish.

**Figure 7. Vertical profiles of pH by site during September 2020 monitoring with applicable numeric criteria.**

**Figure 8. Vertical profiles of DO by site during September 2020 monitoring with applicable numeric criteria.**

### 2021

Select vertical profiles of temperature, pH, and dissolved oxygen for 2021 are presented in ***Figure 9***, ***Figure 10***, ***Figure 11***, ***Figure 12***, and ***Figure 13***. Profile data during our mid-June sampling event were suggestive that some time had elapsed since spring turnover. Surface to bottom water temperatures ranged from approximately 4.5-10°C. Dissolved oxygen ranged from approximately 5-6 mg/L at the surface to around 1.5-4 mg/L at the bottom. The majority of pH values were around 6.5-7.0 SU, with a few results <6.5 SU.

Summer growing season stratification was evident during our next sampling event in mid-July. Dissolved oxygen dropped below 4 mg/L at about 6 meters of depth, with the bottom 4 meters at our deepest site having <1 mg/L DO. Epilimnetic DO concentrations were >8 mg/L, with DO saturation well in excess of 100%, indicative of photosynthetic activity. Epilimnetic pH values were all >9.0 SU, with the highest value (9.77 SU) measured at NE Quad. Epilimnetic water temperatures were the highest of the season, with the highest value (17.18°C) measured at Outlet Quad.

Stratification conditions continued during our late-August sampling event, although epilimnetic water temperatures cooled to approximately 12-13°C. Epilimnetic pH values remained similar to those during mid-July, with the maximum value of 9.73 SU observed at NE Quad. Anoxia in the hypolimnion continued, with dissolved oxygen dropping to <4 mg/L at approximately 6-7 meters of depth. Epilimnetic dissolved oxygen concentrations remained >8 mg/L, yet were slightly lower than mid-July.

Stratification persisted into mid-September, despite cooling epilimnetic water temperatures (~10°C). Dissolved oxygen concentrations in the epilimnion continued to be >8 mg/L, with concentrations dropping to <4 mg/L at around 7-9 meters of depth. Epilimnetic pH values continued to be >9.0 SU, with the highest recorded value of the season (9.81 SU) measured at NW Quad.

During our last visit of the season (October 20) we were only able to sample three lake sites due to time and cold ambient air temperatures, so we repeated the sites we sampled during October 2020 (Outlet Quad, Deepest, NW Quad). Profile data indicated fall turnover had recently occurred. Water temperatures were isothermal (~5°C), and oxygen had been redistributed throughout the water column; DO concentrations were approximately 6-8 mg/L from surface to bottom. Measured pH values were primarily 7.0-7.5 SU. Profile data from our 2021 sampling events suggested the summer growing season during 2021 lasted from approximately early-June to mid-October, which equates to just over 4 months. Vertical profiles of temperature, DO, and pH at Deepest are presented below in ***Figure 9***, ***Figure 10***, and ***Figure 11*** to illustrate typical conditions in Brooks Lake by month during 2021.

**Figure 9. Vertical profiles of temperature by month during 2021 monitoring at Deepest.**

**Figure 10. Vertical profiles of DO by month during 2021 monitoring at Deepest with applicable numeric criteria.**

**Figure 11. Vertical profiles of pH by month during 2021 monitoring at Deepest with applicable numeric criteria.**

In consideration of WDEQ/WQD numeric criteria protective of aquatic life and adult cold water fish (WDEQ/WQD 2018b), the amount/thickness of water column that was 6.5 – 9.0 SU and >4 mg/L DO was evaluated for all sampling months. During June, DO dropped below 4 mg/L at 8-11 meters below the water surface. Vertical pH profiles show portions of the water column at 2 sites dropped below 6.5 SU; this occurred from 1.5 – 3 meters at Outlet Quad and 13.5 – 16 meters at Deepest. Since not all sites dropped below 6.5 SU in the upper part of the water column, the top 11 meters of the water column was considered supportive of aquatic life and adult cold water fish. During July, epilimnetic pH was >9.0 SU at all sites, down to a depth of around 4.5 – 5.5 meters. Then at approximately 9 – 9.5 meters pH dropped below 6.5 SU. Dissolved oxygen dropped below 4 mg/L at depths of 5.5 – 6.5 meters. Therefore, water column depths considered supportive of aquatic life and adult cold water fish during July were approximately 4.5 – 6.5 meters, a thickness of approximately 2 meters. August vertical profiles were relatively similar to those in July, and the depths considered supportive of aquatic life and adult cold water fish were 5.5 – 7 meters, a thickness of approximately 1.5 meters (***Figure 12***, ***Figure 13***). Vertical profiles were again similar during September, with epilimnetic pH >9.0 SU and hypolimnetic DO <4 mg/L. Depths considered supportive of aquatic life and adult cold water fish were 6.5 – 8.5 meters, a thickness of approximately 2 meters. Fall turnover and subsequent mixing brought the entire water column back into attainment with pH and DO criteria supportive of aquatic life and adult cold water fish. All water temperatures during all sampling events in 2021 were <20°C.

**Figure 12. Vertical profiles of pH by site during August 2021 monitoring with applicable numeric criteria.**

**Figure 13. Vertical profiles of DO by site during August 2021 monitoring with applicable numeric criteria.**

## **Chemical Quality**

A discussion of 2020 – 2021 chemical results, by parameter, follows. Bottom samples from SW Quad were included in tables, yet omitted from analytical narrative, as it was later determined the bottom depth at this site was not deep enough to be consistently representative of conditions within the hypolimnion; bottom sample depth from SW Quad was typically around 5-7 meters from the surface, whereas bottom samples from the other 4 lake sites were typically collected from 9-15 meters below the surface.

### Total Phosphorus

A summary of the total phosphorus (TP) data is provided in ***Table 1***. June 2021 TP results are flagged due to contamination at the method reporting limit found within the field blank sample (***Appendix 1***). Surface total phosphorus (TP) concentrations in 2020 ranged from 0.02 – 0.09 mg/L. The greatest monthly mean surface TP concentrations occurred during June (0.084 mg/L) and October (0.06 mg/L), which were both post-turnover sampling events. Mean surface TP concentration then decreased during the summer growing season from July (0.04 mg/L) to August (0.02 mg/L), and increased slightly during September (0.024 mg/L). Bottom TP concentrations ranged 0.05 – 0.53 mg/L, with the greatest single concentration of 0.53 mg/L observed at Deepest during August. Mean bottom TP concentration increased from June (0.1 mg/L) to July (0.21 mg/L) and August (0.29 mg/L), then decreased during both September (0.243 mg/L) and October (0.067 mg/L).

Surface TP concentrations in 2021 ranged from <0.01 – 0.1 mg/L, and all non-detects occurred during August. The greatest mean surface TP concentrations were found during June (0.088 mg/) and October (0.1 mg/L), which represented post-turnover conditions. Mean surface TP concentrations were much lower during the summer growing season months of July (0.012 mg/L), August (<0.01 mg/L), and September (0.02 mg/L). Bottom TP concentrations ranged 0.05 – 0.6 mg/L with the greatest concentration (0.6 mg/L) found at Deepest during August. Mean bottom TP concentration increased throughout the summer growing season and reached its peak of 0.31 mg/L during August; September mean bottom TP concentration decreased only slightly to 0.275 mg/L. Mean bottom TP concentrations during the post-turnover months of June (0.103 mg/L) and October (0.113 mg/L) were very similar to surface TP concentrations, which is consistent with expectations following a whole-lake mixing event.

**Table 1. Total phosphorus concentrations by site and month (mg/L).**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **2020** | | | | | **2021** | | | | |
| June | July | Aug. | Sept. | Oct. | June1 | July | Aug. | Sept. | Oct. |
| ***Surface*** | | | | | | | | | | |
| NW Quad | 0.09 | 0.04 | 0.02 | 0.02 | 0.06 | 0.09 | 0.01 | <0.01 | 0.02 | 0.1 |
| NE Quad | 0.08 | 0.04 | 0.02 | 0.03 | nc | 0.08 | 0.01 | <0.01 | 0.02 | nc |
| Deepest | 0.09 | 0.04 | 0.02 | 0.02 | 0.06 | 0.09 | 0.01 | <0.01 | 0.02 | 0.1 |
| SW Quad | 0.08 | 0.04 | 0.02 | 0.03 | nc | 0.09 | 0.02 | <0.01 | 0.02 | nc |
| Outlet Quad | 0.08 | 0.04 | 0.02 | 0.02 | 0.06 | 0.09 | 0.01 | <0.01 | 0.02 | 0.1 |
| ***Bottom*** | | | | | | | | | | |
| NW Quad | 0.1 | 0.1 | 0.18 | 0.13 | 0.07 | 0.1 | 0.24 | 0.27 | 0.3 | 0.1 |
| NE Quad | 0.1 | 0.12 | 0.36 | 0.35 | nc | 0.09 | 0.18 | 0.2 | 0.33 | nc |
| Deepest | 0.11 | 0.5 | 0.53 | 0.44 | 0.07 | 0.12 | 0.36 | 0.6 | 0.42 | 0.12 |
| SW Quad | 0.08 | 0.05 | 0.08 | 0.03 | nc | 0.1 | 0.07 | 0.1 | 0.02 | nc |
| Outlet Quad | 0.09 | 0.12 | 0.09 | 0.05 | 0.06 | 0.1 | 0.17 | 0.17 | 0.05 | 0.12 |

nc- not collected

1 June 2021 TP results flagged due to contamination in field blank sample (FB qualifier).

### Orthophosphate

A summary of orthophosphate data is provided in ***Table 2***. Due to analytical difficulties in the laboratory during 2020, only orthophosphate results from September and October samples were considered suitable for analysis during this year. Surface orthophosphate concentrations ranged from <0.01 – 0.05 mg/L, with all September results <0.01 mg/L and an October mean of 0.029 mg/L. Orthophosphate during October comprised 32 – 83% of the total phosphorus in the surface of Brooks Lake, whereas <50% of surface total phosphorus during September was orthophosphate. Bottom orthophosphate ranged from 0.013 – 0.421 mg/L, with a September mean of 0.215 mg/L and an October mean of 0.02 mg/L. The proportion of total phosphorus that was orthophosphate in bottom samples ranged from 60 – 96% during September, and 29 – 33% during October.

Orthophosphate was only detected in 2021 surface samples during June and October, with all July – September results <0.01 mg/L. During June and October, surface orthophosphate samples were all 0.06 mg/L, which comprised 60-75% of the total phosphorus during these months; this indicates the majority of surface phosphorus during post-turnover conditions was in an inorganic, bioavailable form. All bottom orthophosphate samples had detectable concentrations and ranged 0.04 – 0.55 mg/L. Bottom orthophosphate increased throughout the summer growing season, as evidenced by monthly means of 0.07, 0.188, and 0.29 mg/L during June, July, and August, respectively. The greatest concentration (0.55 mg/L) was observed at Deepest during August. September mean bottom orthophosphate (0.258 mg/L) decreased slightly from August, followed by a more noticeable decrease in October (0.067 mg/L). Orthophosphate accounted for 58 – 100% of the total phosphorus in the bottom of Brooks Lake.

**Table 2. Orthophosphate concentrations by site and month (mg/L).**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **2020** | | | | | **2021** | | | | |
| June | July | Aug. | Sept. | Oct. | June | July | Aug. | Sept. | Oct. |
| ***Surface*** | | | | | | | | | | |
| NW Quad | rac | rac | rac | <0.01 | 0.019 | 0.06 | <0.01 | <0.01 | <0.01 | 0.06 |
| NE Quad | rac | rac | rac | <0.01 | nc | 0.06 | <0.01 | <0.01 | <0.01 | nc |
| Deepest | rac | rac | rac | <0.01 | 0.05 | 0.06 | <0.01 | <0.01 | <0.01 | 0.06 |
| SW Quad | rac | rac | rac | <0.01 | nc | 0.06 | <0.01 | <0.01 | <0.01 | nc |
| Outlet Quad | rac | rac | rac | <0.01 | 0.019 | 0.06 | <0.01 | <0.01 | <0.01 | 0.06 |
| ***Bottom*** | | | | | | | | | | |
| NW Quad | rac | rac | rac | 0.106 | 0.02 | 0.06 | 0.19 | 0.26 | 0.28 | 0.06 |
| NE Quad | rac | rac | rac | 0.304 | nc | 0.07 | 0.14 | 0.19 | 0.33 | nc |
| Deepest | rac | rac | rac | 0.421 | 0.023 | 0.08 | 0.29 | 0.55 | 0.38 | 0.07 |
| SW Quad | rac | rac | rac | 0.011 | nc | 0.07 | 0.05 | <0.01 | <0.01 | nc |
| Outlet Quad | rac | rac | rac | 0.03 | 0.018 | 0.07 | 0.13 | 0.16 | 0.04 | 0.07 |

rac- removed from analytical consideration

nc- not collected

### Total Nitrogen

A summary of total nitrogen (TN) data is provided in ***Table 3***. Surface TN concentrations during 2020 ranged from <0.1 – 0.36 mg/L, with only two non-detects that both occurred during July. On average, surface TN concentrations were greatest during September (0.29 mg/L), with the single greatest concentration of 0.36 mg/L observed at NE Quad during September. Mean surface TN concentration during both July (<0.136 mg/L) and August (0.15 mg/L) were less than June (0.206 mg/L). Mean surface TN concentration decreased slightly in October (0.273 mg/L). Bottom TN concentrations ranged from 0.13 – 1.01 mg/L, with the greatest concentration (1.01 mg/L) observed at Deepest during August. Mean bottom TN concentration was relatively low during June (0.325 mg/L) and July (0.313 mg/L), then increased during both August (0.585 mg/L) and September (0.618 mg/L). Following fall-turnover, mean bottom TN concentrations in October decreased to 0.23 mg/L.

Surface TN concentrations during 2021 ranged from <0.1 – 0.4 mg/L, and all non-detects occurred during July. The greatest mean surface TN concentrations occurred during the post-turnover months of June (0.34 mg/L) and October (0.4 mg/L). Following spring-turnover, mean surface TN concentrations decreased in July to <0.1 mg/L, then slightly increased during August (0.2 mg/L) and September (0.2 mg/L). Bottom TN concentrations were generally greater than surface TN concentrations and ranged from 0.3 – 1.6 mg/L. The greatest bottom TN concentration (1.6 mg/L) occurred at Deepest during August. Mean bottom TN concentration was lowest during June (0.35 mg/L), then increased during the growing season and peaked during August (0.75 mg/L). September mean bottom TN concentration (0.725 mg/L) was very similar to August, with October mean concentration (0.433 mg/L) continuing to decrease.

**Table 3. Total nitrogen concentrations by site and month (mg/L).**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **2020** | | | | | **2021** | | | | |
| June | July | Aug. | Sept. | Oct. | June | July | Aug. | Sept. | Oct. |
| ***Surface*** | | | | | | | | | | |
| NW Quad | 0.27 | 0.18 | 0.12 | 0.28 | 0.28 | 0.3 | 0.1 | 0.2 | 0.2 | 0.4 |
| NE Quad | 0.22 | <0.01 | 0.19 | 0.36 | nc | 0.4 | <0.01 | 0.2 | 0.2 | nc |
| Deepest | 0.2 | <0.01 | 0.1 | 0.29 | 0.29 | 0.3 | <0.01 | 0.2 | 0.2 | 0.4 |
| SW Quad | 0.24 | 0.15 | 0.15 | 0.29 | nc | 0.4 | <0.01 | 0.2 | 0.2 | nc |
| Outlet Quad | 0.1 | 0.15 | 0.19 | 0.23 | 0.25 | 0.3 | <0.01 | 0.2 | 0.2 | 0.4 |
| ***Bottom*** | | | | | | | | | | |
| NW Quad | 0.38 | 0.17 | 0.64 | 0.46 | 0.24 | 0.3 | 0.5 | 0.6 | 0.8 | 0.4 |
| NE Quad | 0.41 | 0.25 | 0.54 | 0.74 | nc | 0.3 | 0.4 | 0.4 | 0.8 | nc |
| Deepest | 0.35 | 0.7 | 1.01 | 0.96 | 0.23 | 0.4 | 0.7 | 1.6 | 1.0 | 0.4 |
| SW Quad | 0.24 | 0.12 | 0.21 | 0.29 | nc | 0.3 | 0.2 | 0.2 | 0.2 | nc |
| Outlet Quad | 0.16 | 0.13 | 0.15 | 0.31 | 0.22 | 0.4 | 0.4 | 0.4 | 0.3 | 0.5 |

nc- not collected

### TN:TP Ratios

A summary of inferred nutrient limitation by total nitrogen to total phosphorus ratios (TN:TP) is provided in ***Table 4*** using comparisons to literature-based thresholds (Downing and McCauley 1992). Surface sample TN:TP ratios during 2020 indicated nitrogen-limited conditions prevailed during June, July, and October. Conditions of co-limitation were common during the summer growing season months of August and September. Nearly all bottom TN:TP ratios indicated conditions of nitrogen-limitation in the hypolimnion, with the exception of a single sample in September that indicated co-limitation.

During 2021, surface TN:TP ratios for June and October were indicative of nitrogen-limited conditions (***Table 4***). As a result of non-detect results in July TN samples, three of the TN:TP ratios during July were <10, which could indicate either co-limitation or nitrogen-limitation. Similar to 2020, September surface TN:TP ratios indicated co-limitation. August, on the other hand, had TN:TP ratios indicative of phosphorus-limitation. With the exception of one instance in September of co-limitation, all bottom TN:TP ratios were indicative of nitrogen-limited conditions in the hypolimnion of Brooks Lake.

**Table 4. Total nitrogen to total phosphorus ratios binned by nutrient limitation category.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Month** | **Surface** | | | **Bottom** | | |
| # of samples N-limited (TN:TP≤5) | # of samples co-limited (5<TN:TP<20) | # of samples P-limited (TN:TP≥20) | # of samples N-limited (TN:TP≤5) | # of samples co-limited (5<TN:TP<20) | # of samples P-limited (TN:TP≥20) |
| ***2020*** | | | | | | |
| June | 5 | 0 | 0 | 4 | 0 | 0 |
| July | 5 | 0 | 0 | 4 | 0 | 0 |
| August | 1 | 4 | 0 | 4 | 0 | 0 |
| September | 0 | 5 | 0 | 3 | 1 | 0 |
| October | 3 | 0 | 0 | 3 | 0 | 0 |
| ***2021*** | | | | | | |
| June1 | 5 | 0 | 0 | 4 | 0 | 0 |
| July | 1 | 4\* | 0 | 4 | 0 | 0 |
| August | 0 | 0 | 5 | 4 | 0 | 0 |
| September | 0 | 5 | 0 | 3 | 1 | 0 |
| October | 3 | 0 | 0 | 3 | 0 | 0 |

\*Three samples with TN:TP ratios <10 placed in co-limitation category, although could be N-limited; inherent challenge with censored data

1 June 2021 TP results flagged due to contamination in field blank sample (FB qualifier).

### Nitrate+nitrite

A summary of nitrate+nitrite (NO2+NO3) data is provided in ***Table 5***. All surface NO2+NO3 concentrations were <0.05 mg/L during 2020, indicating inorganic nitrogen was not abundant. Bottom NO2+NO3 concentrations were also all <0.05 mg/L, with the exception of two samples (0.051 - 0.057 mg/L) during June.

All reportable surface NO2+NO3 concentrations in 2021 were found during June (all samples 0.11 mg/L), suggesting only a seasonal availability of inorganic nitrogen during post-turnover conditions. Reportable NO2+NO3 concentrations in the bottom of Brooks Lake were also found during June (all samples 0.11 mg/L), as well as two of the sites during July (0.07, 0.08 mg/L). During the rest of the year all NO2+NO3 concentrations were <0.05 mg/L, suggesting inorganic nitrogen availability may be scarce throughout the entire summer growing season.

**Table 5. Nitrate+nitrite concentrations by site and month (mg/L).**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **2020** | | | | | **2021** | | | | |
| June | July | Aug. | Sept. | Oct. | June | July | Aug. | Sept. | Oct. |
| ***Surface*** | | | | | | | | | | |
| NW Quad | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.11 | <0.05 | <0.05 | <0.05 | <0.05 |
| NE Quad | <0.05 | <0.05 | <0.05 | <0.05 | nc | 0.11 | <0.05 | <0.05 | <0.05 | nc |
| Deepest | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.11 | <0.05 | <0.05 | <0.05 | <0.05 |
| SW Quad | <0.05 | <0.05 | <0.05 | <0.05 | nc | 0.11 | <0.05 | <0.05 | <0.05 | nc |
| Outlet Quad | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.11 | <0.05 | <0.05 | <0.05 | <0.05 |
| ***Bottom*** | | | | | | | | | | |
| NW Quad | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.11 | <0.05 | <0.05 | <0.05 | <0.05 |
| NE Quad | 0.051 | <0.05 | <0.05 | <0.05 | nc | 0.11 | 0.07 | <0.05 | <0.05 | nc |
| Deepest | 0.057 | <0.05 | <0.05 | <0.05 | <0.05 | 0.11 | <0.05 | <0.05 | <0.05 | <0.05 |
| SW Quad | <0.05 | <0.05 | <0.05 | <0.05 | nc | 0.11 | <0.05 | <0.05 | <0.05 | nc |
| Outlet Quad | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.11 | 0.08 | <0.05 | <0.05 | <0.05 |

nc- not collected

### Ammonia

A summary of ammonia data is provided in ***Table 6***. Several of the August 2020 ammonia results were flagged due to an exceedance of the recommended holding time. During 2020, 53% of bottom ammonia samples (n=19) had reportable concentrations of ammonia. All surface ammonia results were <0.05 mg/L. One concentration of ammonia (0.75 mg/L) in the hypolimnion at Deepest during September exceeded the chronic criterion protective of early life stages of fish (0.7 mg/L). However, given the observed dissolved oxygen concentration (0.0 mg/L) at the sample depth (15 m), no fish would be expected to be found in the hypolimnion during this time of the season.

During 2021, 95% of bottom ammonia samples (n=19) had reportable concentrations of ammonia. Instances of reportable concentrations of ammonia in surface samples occurred during June (0.07 – 0.08 mg/L) and October (0.26 – 0.27 mg/L), presumably associated with recent turnover. All bottom and surface ammonia concentrations were in attainment with pH and temperature-dependent chronic criteria protective of early life stages of fish.

**Table 6. Ammonia concentrations by site and month (mg/L).**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **2020** | | | | | **2021** | | | | |
| June | July | Aug. | Sept. | Oct. | June | July | Aug. | Sept. | Oct. |
| ***Surface*** | | | | | | | | | | |
| NW Quad | <0.05 | <0.05 | <0.051 | <0.05 | <0.05 | 0.07 | <0.05 | <0.05 | <0.05 | 0.26 |
| NE Quad | <0.05 | <0.05 | <0.05 | <0.05 | nc | 0.08 | <0.05 | <0.05 | <0.05 | nc |
| Deepest | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.07 | <0.05 | <0.05 | <0.05 | 0.26 |
| SW Quad | <0.05 | <0.05 | <0.051 | <0.05 | nc | 0.08 | <0.05 | <0.05 | <0.05 | nc |
| Outlet Quad | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.27 |
| ***Bottom*** | | | | | | | | | | |
| NW Quad | 0.092 | <0.05 | 0.15 | 0.21 | <0.05 | 0.12 | 0.31 | 0.47 | 0.69 | 0.27 |
| NE Quad | 0.1 | <0.05 | 0.42 | 0.51 | nc | 0.11 | 0.23 | <0.05 | 0.81 | nc |
| Deepest | 0.15 | 0.55 | 0.8 | 0.75 | <0.05 | 0.16 | 0.52 | 1.34 | 1.0 | 0.32 |
| SW Quad | <0.05 | <0.05 | <0.051 | <0.05 | nc | 0.13 | <0.05 | <0.05 | <0.05 | nc |
| Outlet Quad | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | 0.15 | 0.15 | 0.26 | 0.17 | 0.34 |

nc- not collected

### Alkalinity

A summary of alkalinity data is provided in ***Table 7***. Surface alkalinity concentrations during 2020 ranged from 27 – 33 mg/L, and concentrations gradually increased throughout the summer growing season. The lowest concentrations occurred during June (27 mg/L) and the greatest concentrations occurred during September (33 mg/L). Very little spatial variability in alkalinity concentrations was observed. Bottom alkalinity concentrations ranged from 26 – 33 mg/L and also tended to gradually increase throughout the summer growing season. The greatest concentrations in the hypolimnion of Brooks Lake were observed during September and October. During 2021, surface alkalinity concentrations ranged from 28 – 35 mg/L, and also tended to increase throughout the summer growing season; the greatest concentrations were observed during September and October. Bottom alkalinity concentrations also ranged from 28 – 35 mg/L, with the greatest concentrations typically observed during September and October.

**Table 7. Alkalinity concentrations (mg/L) by site and month.**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **2020** | | | | | **2021** | | | | |
| June | July | Aug. | Sept. | Oct. | June | July | Aug. | Sept. | Oct. |
| ***Surface*** | | | | | | | | | | |
| NW Quad | 27 | 30 | 31 | 33 | 31 | 28 | 31 | 33 | 34 | 34 |
| NE Quad | 27 | 30 | 31 | 33 | nc | 28 | 31 | 33 | 34 | nc |
| Deepest | 27 | 30 | 31 | 33 | 32 | 28 | 31 | 33 | 34 | 34 |
| SW Quad | 27 | 30 | 31 | 33 | nc | 28 | 31 | 33 | 34 | nc |
| Outlet Quad | 27 | 30 | 31 | 33 | 32 | 29 | 31 | 33 | 34 | 35 |
| ***Bottom*** | | | | | | | | | | |
| NW Quad | 27 | 27 | 26 | 33 | 32 | 28 | 30 | 31 | 33 | 35 |
| NE Quad | 27 | 27 | 27 | 30 | nc | 28 | 30 | 30 | 34 | nc |
| Deepest | 27 | 30 | 28 | 33 | 32 | 29 | 31 | 34 | 34 | 35 |
| SW Quad | 27 | 28 | 29 | 33 | nc | 29 | 29 | 33 | 34 | nc |
| Outlet Quad | 27 | 27 | 28 | 33 | 32 | 29 | 29 | 31 | 33 | 35 |

nc- not collected

### Downstream Monitoring Point

A summary of data from the Downstream Monitoring Point (DMP) is provided in ***Table 8***. At the DMP, total phosphorus ranged from 0.07 – 0.24 mg/L, with the greatest concentrations found during July (0.22 mg/L) and August (0.24 mg/L) of 2021. Orthophosphate ranged from 0.047 – 0.24 mg/L, and accounted for 64 – 100% of the available phosphorus, indicating the vast majority of phosphorus at DMP was in the bioavailable form. Total nitrogen ranged from 0.1 – 1.55 mg/L, with the greatest concentrations observed during October 2020 (1.55 mg/L) and August 2021 (1.0 mg/L). Nitrate+nitrite concentrations ranged from <0.05 – 1.24 mg/L, with the greatest concentration of 1.24 mg/L in October 2020. Nitrate+nitrite accounted for <21 – 80% of the available nitrogen; this more bioavailable form of nitrogen comprised the majority of available nitrogen during the month of October. All ammonia concentrations at DMP were <0.05 mg/L, except during July 2021 when 0.1 mg/L was present. This concentration of ammonia was in attainment with pH and temperature-dependent chronic criteria protective of early life stages of fish. Alkalinity concentrations ranged from 30 – 51 mg/L. Measurements of pH ranged from 7.46 – 9.34 SU, and the single excursion of the pH criterion protective of aquatic life occurred during September 2020. Dissolved oxygen ranged 7.42 – 11.5 mg/L, and DO saturation ranged from 94.6 – 125.7%. Water temperature ranged from 5.2 – 17.04°C, and conductivity ranged from 58.9 – 121.7 µS/cm.

**Table 8. Downstream Monitoring Point data.**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameter** | **2020** | | | | | **2021** | | | | |
| **6/23** | **7/21** | **8/25** | **9/22** | **10/21** | **6/15** | **7/20** | **8/24** | **9/21** | **10/20** |
| Ammonia (mg/L) | <0.05 | <0.05 | <0.051 | <0.05 | <0.05 | <0.05 | 0.1 | <0.05 | <0.05 | <0.05 |
| Nitrate+nitrite (mg/L) | 0.09 | <0.05 | <0.05 | <0.05 | 1.24 | 0.14 | 0.25 | 0.37 | <0.05 | 0.47 |
| Total Nitrogen (mg/L) | 0.28 | 0.15 | 0.19 | 0.24 | 1.55 | 0.3 | 0.5 | 1.0 | 0.1 | 0.7 |
| Total Phosphorus (mg/L) | 0.08 | 0.08 | 0.07 | 0.07 | 0.17 | 0.08 | 0.22 | 0.24 | 0.11 | 0.1 |
| Orthophosphate (mg/L) | rac | rac | rac | 0.047 | 0.108 | 0.06 | 0.19 | 0.24 | 0.09 | 0.08 |
| Alkalinity (mg/L) | 30 | 37 | 41 | 44 | 46 | 32 | 48 | 51 | 42 | 46 |
| Temperature (°C) | 13.38 | 17.04 | 10.19 | 9.9 | 5.84 | 8.73 | 11.78 | 13.19 | 9.58 | 5.2 |
| pH (SU) | 8.03 | 8.58 | 8.48 | 9.34 | 8.13 | 7.47 | 7.46 | 8.58 | 8.32 | 8.04 |
| Conductivity (µS/cm) | 59 | 70.71 | 84 | 101.45 | 121.7 | 58.89 | 93.08 | 107.64 | rac | rac |
| Dissolved Oxygen (mg/L) | 8.27 | 7.74 | 9.4 | 9.8 | 9.61 | 8.91 | 7.42 | 9.45 | 9.78 | 11.5 |
| Dissolved Oxygen (% saturation) | 109.7 | 111.37 | 115.7 | 120.2 | 108.3 | 106.06 | 94.61 | 125.12 | 117.93 | 125.71 |

rac- removed from analytical consideration

1 Result flagged due to an exceedance of the recommended holding time.

### Brooks Lake Lodge Effluent

Permitted point source discharge from the Brooks Lake Lodge varied during 2020 and 2021 due to lower than normal occupancy attributed to the Covid-19 Pandemic, as well as sewage lagoon infrastructure upgrades during 2017. As a result, the typical discharge regime was altered, and samplers were only able to collect two samples during Phase 1 monitoring. The first sample was collected on 9/22/2020, and was taken during a “non-discharging” timeframe; Lodge personnel had to turn on the discharge from the lagoons in order to collect a sample. As a result, data from this sample are not considered representative of typical discharge conditions, thus were omitted from analytical consideration. With the benefit of enhanced communication with Lodge personnel, the second sample was collected on 6/15/2021, and was during a normal discharging timeframe. The quality of the effluent during this sample is considered more representative of typical effluent quality from the Brooks Lake Lodge wastewater lagoons. Results from this single sample on 6/15/2021 are as follows: 1.26 mg/L ammonia, 0.19 mg/L NO2+NO3, 2.0 mg/L TN, 0.54 mg/L TP, 0.49 mg/L orthophosphate, 52 mg/L alkalinity, 13.8°C water temperature, 7.17 SU pH, 5.52 mg/L & 72.65% DO, and 117.43 µS/cm conductivity. The observed ammonia concentration is in attainment with pH and temperature-dependent chronic criteria protective of early life stages of fish. The TN result was flagged due to an exceedance of the recommended holding time.

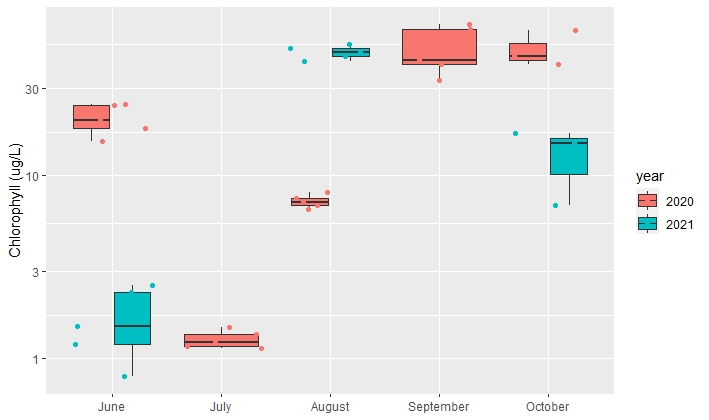
### Horse Corral Trib

During the 8/25/2020 sampling event, an exploratory sample was collected from a small tributary to Brooks Lake that drains the area around the Brooks Lake Lodge. Results from this single sample are as follows: <0.05 mg/L ammonia, <0.05 mg/L NO2+NO3, 0.18 mg/L TN, 0.04 mg/L TP, 50 mg/L alkalinity, 9.12°C water temperature, 7.91 SU pH, 107.8 µS/cm conductivity, and 7.78 mg/L & 93.54% DO. The ammonia result was flagged due to an exceedance of the recommended holding time.

## **Biological and Physical Quality**

Chlorophyll α samples from the August 2020 sampling event are considered estimated due to triple peak chromatogram results noted by the analytical laboratory (***Appendix 1***). Mean chlorophyll concentrations in 2020 were lowest during July (1.27 µg/L), following an apparent post-turnover bloom during June (20.5 µg/L) (***Figure 14***). Mean chlorophyll concentrations then increased throughout the summer growing season, with an August mean concentration of 7.24 µg/L prior to peak productivity during September (49.4 µg/L) and October (49.4 µg/L). The single highest chlorophyll concentration (66.9 µg/L) was observed at NW Quad during September. During 2021, mean chlorophyll concentration in Brooks Lake was lowest during June (1.66 µg/L) and then increased throughout the summer growing season until maximum productivity was observed during August (mean= 47.2 µg/L). It is unknown if peak productivity in 2021 actually occurred during August; September 2021 chlorophyll results were not considered suitable for analysis, and results from 2020 suggest productivity in Brooks Lake peaks during September. The maximum chlorophyll concentration of 52 µg/L was observed at NE Quad during August. Following fall-turnover in mid-October, chlorophyll concentrations decreased from concentrations observed during August 2021, while chlorophyll concentrations during mid-October 2020 remained high.

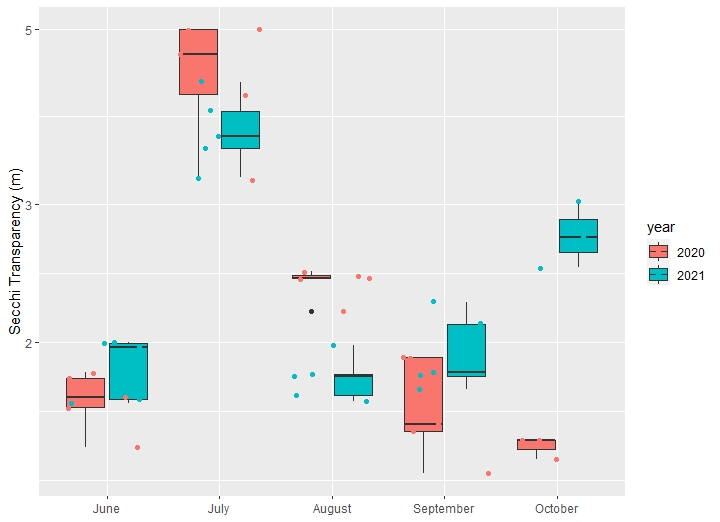
**Figure 14. Chlorophyll α concentrations grouped by month at all sites during 2020 and 2021.**



Mean secchi transparency in 2020 was greatest during July (4.4 m), with the single greatest secchi measurement of 5.0 m observed at both SW Quad and NE Quad (***Figure 15***). Water clarity then decreased throughout the summer growing season during each month, with post-fall turnover water clarity conditions during October (1.47 m) even lower than during September (1.66 m). Mean water clarity during June (1.69 m) was also relatively low, which is likely due to a combination of a post-spring turnover algal bloom and snowmelt runoff conditions introducing non-algal related turbidity.

During 2021, water clarity was greatest during July (3.73 m), and lowest during August (1.8 m) (***Figure 15***). Water clarity was slightly greater during September (1.95 m), and high primary productivity—as measured by chlorophyll α—likely contributed to decreased water clarity during these months. Mean secchi transparency was relatively low during June (1.86 m), which was likely associated with recent spring turnover and snowmelt runoff rather than primary productivity. Fall turnover appeared to diminish the algal blooms that were observed during August and September, as mean secchi transparency increased from September (1.95 m) to October (2.74 m).

**Figure 15. Secchi transparency depths grouped by month at all sites during 2020 and 2021**.

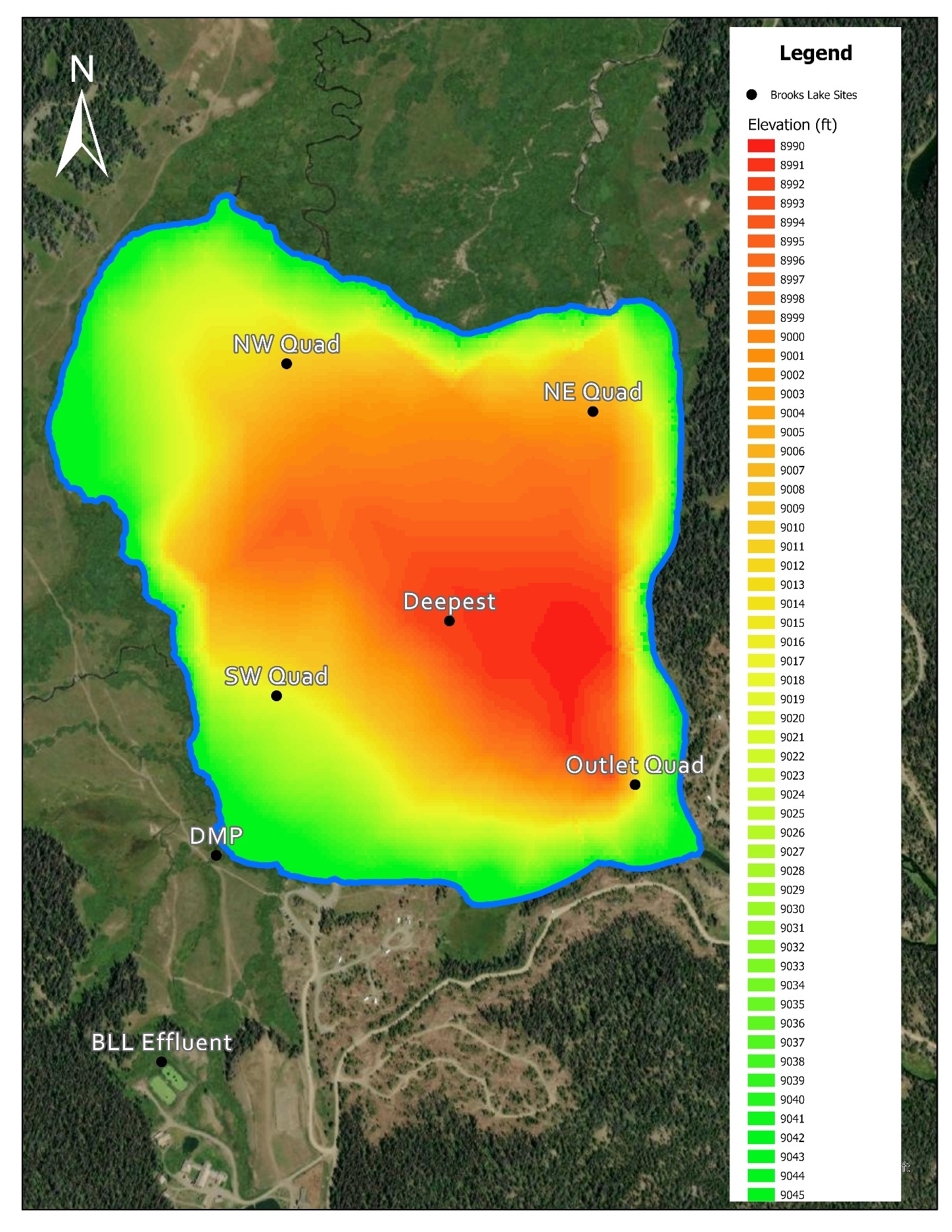


## **Supplementary Results and Information**

### Bathymetry

On August 25, 2020, WDEQ/WQD personnel collected water depth data at dozens of pre-determined locations in Brooks Lake. These data were utilized by the WDEQ/WQD GIS expert to create a bathymetric map of Brooks Lake (***Figure 16***).

**Figure 16. Bathymetry map of Brooks Lake and sampling sites 2020 – 2021.**



### Deep Chlorophyll Maxima

Vertical profiles of DO and pH (i.e., response variables of primary productivity) have often been observed to increase with depth in Brooks Lake. When observed, the maximum DO and pH measurements are found deeper than the standard sampling depth for chlorophyll α of 0.5 meters below the water surface, and is therefore suggestive of primary production at depths greater than 0.5 meters. Saros et al. (2005) found a deep chlorophyll maxima (DCM) in a set of high elevation lakes in the Beartooth Mountains near the Wyoming/Montana border, with one lake DCM observed at 16 meters of depth. For these reasons, additional chlorophyll samples were collected at Deepest during the August 2020 monitoring event to investigate the possibility of substantial chlorophyll variation with water depth. On 8/25/2020, samplers collected chlorophyll samples from the standard depth (0.5 m), ½ the secchi depth (1.22 m), and where the greatest DO concentration (10.8 mg/L, 148% saturation) was observed (4 meters) in the vertical profile. Chlorophyll results for these samples were as follows: 6.52 µg/L at 0.5 meters, 5.99 µg/L at 1.22 meters, and 5.27 µg/L at 4 meters. All three of these chlorophyll samples were within 30% relative percent difference (RPD) of each other, which is the data quality objective (DQO) used for original and duplicate chlorophyll α samples. This suggests chlorophyll concentrations throughout the epilimnion during August were similar. Vertical profile data suggests the thermocline at Deepest was around 6 meters of depth, thus the 4 meter sample was just above the thermocline. Results from Saros et al. (2005) also suggested greater nutrient availability and adequate photosynthetically active radiation below the thermocline allowed a DCM to form in their alpine study lakes. On Brooks Lake during summer stratification, the vast majority of hypolimnetic nutrient concentrations were greater than surface nutrient concentrations. Despite evidence that chlorophyll α concentrations were similar from 0.5 – 4 meters of depth, future exploratory monitoring on Brooks Lake could be expanded to include chlorophyll and nutrient concentration collections at multiple depths at the Deepest site on Brooks Lake, including depths below the thermocline.

### Spatial Variability

When WDEQ monitoring first started on Brooks Lake in 2009, the lake was divided into four quadrants and one monitoring site was placed within each quadrant to adequately represent nutrient and productivity conditions across Brooks Lake. Monitoring at these four quadrant sites occurred during 2009-2012. An additional site was added for monitoring during 2020 – 2021 to reflect the typical methodology WDEQ/WQD uses for site selection on a lake/reservoir using waterbody surface area. For the development of numeric nutrient criteria in the Wyoming Basin ecoregion lakes/reservoirs, WDEQ/WQD considers waterbodies that are 101-500 acres in surface area to require one sampling location at the “Open water pelagic-deepest location” (WDEQ/WQD 2013). Therefore, this additional site (Deepest) was established on Brooks Lake (214 acres) near the center of the lake, in a pelagic environment, at the deepest known point, and all five lake sites were monitored during 2020-2021. An important element of the Phase 1 data analysis is the evaluation of both the spatial variability of all parameters within Brooks Lake, and how representative this single Deepest site is of the four quad sites. This analysis will inform site selection on Brooks Lake during Phase 2 monitoring.

For each sampling event, chemical and biological results at Deepest were compared to the range and mean of results at the four quad sites (***Table 9***). Any result from Deepest that did not fall within the range of values observed at the four quad sites is highlighted in gold in ***Table 9***. The relative percent difference (RPD) between the single result at Deepest and the mean of the four quad sites was also calculated for each parameter during each sampling event. In the event the result from Deepest and the quad site mean were both censored data (i.e. “less-thans”), the RPD was not able to be calculated. WDEQ has established parameter-specific DQOs used for original and duplicate samples (WDEQ/WQD 2021b); these DQOs were utilized in the comparison of the single sample result from Deepest to the mean of results from the four quad sites. Relative percent differences between Deepest and the mean of quad sites that met parameter-specific WDEQ/WQD (2021b) DQOs for original and duplicate samples are highlighted in green, while RPDs highlighted in red did not meet DQOs (***Table 9***).

Relative percent differences between Deepest and the mean of quad sites attained parameter-specific DQOs for original and duplicate samples for all surface samples, except chlorophyll during October 2020 (37% RPD) and October 2021 (42.9% RPD) (***Table 9***). This indicates the observed variability in the vast majority of parameters fell within the accepted variability for original and duplicate samples collected concurrently. The vast majority of instances when RPDs did not attain DQOs (highlighted red) occurred in the bottom samples, during the summer growing season months when stratification was present. In each of these instances for TN, TP, orthophosphate, and ammonia, the result at Deepest was greater than the results at any of the quad sites. Due to total water depth at each site, the depth each of these bottom samples was collected at differed between sites. Our bottom samples indicate that 1) nutrient concentrations are typically greatest at Deepest, and 2) noticeable spatial differences in nutrient concentrations exist within the hypolimnion that may be associated with the depth the sample was collected at. WDEQ/WQD does not have DQOs for secchi transparency. For secchi transparency, the range of RPDs was 1.1 – 18.4%. The greatest RPD occurred during September 2021; secchi transparency at Deepest was 2.25 m, while the mean secchi transparency of the four quad sites was 1.87 m.

**Table 9. Parameter-specific comparison between results at Deepest and the four quad sites for each sampling event.**

| **Sampling Event** | **Sample Type** | **Parameter and Units** | **Quad Sites Range1, 2** | **Quad Site Mean1, 2** | **Deepest Result** | **Deepest & Quad Site Mean RPD** |
| --- | --- | --- | --- | --- | --- | --- |
| June 2020 | Surface | Alkalinity (mg/L) | 27 – 27 | 27 | 27 | 0% |
| Total Nitrogen (mg/L) | 0.1 – 0.27 | 0.208 | 0.2 | 3.9% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | 0.08 – 0.09 | 0.083 | 0.09 | 8.1% |
| Chlorophyll (µg/L) | 15.5 – 24.6 | 20.6 | 20.1 | 2.5% |
| Secchi Depth (m) | 1.47 – 1.83 | 1.66 | 1.8 | 8.1% |
| Bottom | Alkalinity (mg/L) | 27 – 27 | 27 | 27 | 0% |
| Total Nitrogen (mg/L) | 0.16 – 0.41 | 0.317 | 0.35 | 9.9% |
| NO2+NO3 (mg/L) | <0.05 – 0.051 | <0.05 | 0.057 | >13.1% |
| Ammonia (mg/L) | <0.05 – 0.1 | <0.081 | 0.15 | >59.7% |
| Total Phosphorus (mg/L) | 0.09 – 0.1 | 0.097 | 0.11 | 12.6% |
| July 2020 | Surface | Alkalinity (mg/L) | 30 – 30 | 30 | 30 | 0% |
| Total Nitrogen (mg/L) | <0.1 – 0.18 | <0.145 | 0.1 | <36.7% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | 0.04 – 0.04 | 0.04 | 0.04 | 0% |
| Chlorophyll (µg/L) | 1.17 – 1.48 | 1.31 | 1.14 | 13.9% |
| Secchi Depth (m) | 3.22 – 5 | 4.47 | 4.13 | 7.9% |
| Bottom | Alkalinity (mg/L) | 27 – 27 | 27 | 30 | 10.5% |
| Total Nitrogen (mg/L) | 0.13 – 0.25 | 0.183 | 0.7 | 117% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | 0.55 | >167% |
| Total Phosphorus (mg/L) | 0.1 – 0.12 | 0.113 | 0.5 | 126% |
| August 2020 | Surface | Alkalinity (mg/L) | 31 – 31 | 31 | 31 | 0% |
| Total Nitrogen (mg/L) | 0.12 – 0.19 | 0.163 | 0.1 | 47.9% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | 0.02 – 0.02 | 0.02 | 0.02 | 0% |
| Chlorophyll (µg/L) | 6.87 – 8.13 | 7.42 | 6.52 | 12.9% |
| Secchi Depth (m) | 2.19 – 2.46 | 2.37 | 2.43 | 2.5% |
| Bottom | Alkalinity (mg/L) | 26 – 28 | 27 | 28 | 3.6% |
| Total Nitrogen (mg/L) | 0.15 – 0.64 | 0.443 | 1.01 | 78% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 – 0.42 | <0.207 | 0.8 | >118% |
| Total Phosphorus (mg/L) | 0.09 – 0.36 | 0.21 | 0.53 | 86.5% |
| September 2020 | Surface | Alkalinity (mg/L) | 33 – 33 | 33 | 33 | 0% |
| Total Nitrogen (mg/L) | 0.23 – 0.36 | 0.29 | 0.29 | 0% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | 0.02 – 0.03 | 0.025 | 0.02 | 22.2% |
| Orthophosphate (mg/L) | <0.01 - <0.01 | <0.01 | <0.01 | nc |
| Chlorophyll (µg/L) | 33.2 – 66.9 | 51.6 | 40.7 | 23.6% |
| Secchi Depth (m) | 1.36 – 1.91 | 1.69 | 1.54 | 9.3% |
| Bottom | Alkalinity (mg/L) | 30 – 33 | 32 | 33 | 3.1% |
| Total Nitrogen (mg/L) | 0.31 – 0.74 | 0.503 | 0.96 | 62.5% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 – 0.51 | <0.257 | 0.75 | >97.9% |
| Total Phosphorus (mg/L) | 0.05 – 0.35 | 0.177 | 0.44 | 85.3% |
| Orthophosphate (mg/L) | 0.03 – 0.304 | 0.147 | 0.421 | 96.5% |
| October 2020 | Surface | Alkalinity (mg/L) | 31 – 32 | 31.5 | 32 | 1.6% |
| Total Nitrogen (mg/L) | 0.25 – 0.28 | 0.265 | 0.29 | 9.0% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | 0.06 – 0.06 | 0.06 | 0.06 | 0% |
| Orthophosphate (mg/L) | 0.019 – 0.019 | 0.019 | 0.05 | 89.9% |
| Chlorophyll (µg/L) | 40.6 – 45.1 | 42.9 | 62.4 | 37% |
| Secchi Depth (m) | 1.5 – 1.5 | 1.5 | 1.42 | 5.5% |
| Bottom | Alkalinity | 32 – 32 | 32 | 32 | 0% |
| Total Nitrogen | 0.22 – 0.24 | 0.23 | 0.23 | 0% |
| NO2+NO3 | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus | 0.06 – 0.07 | 0.065 | 0.07 | 7.4% |
| Orthophosphate | 0.018 – 0.02 | 0.019 | 0.023 | 19% |
| June 2021 | Surface | Alkalinity (mg/L) | 28 – 29 | 28.3 | 28 | 1.1% |
| Total Nitrogen (mg/L) | 0.3 – 0.4 | 0.35 | 0.3 | 15.4% |
| NO2+NO3 (mg/L) | 0.11 – 0.11 | 0.11 | 0.11 | 0% |
| Ammonia (mg/L) | <0.05 – 0.08 | <0.07 | 0.07 | >0% |
| Total Phosphorus (mg/L) | 0.08 – 0.09 | 0.088 | 0.09 | 2.2% |
| Orthophosphate (mg/L) | 0.06 – 0.06 | 0.06 | 0.06 | 0% |
| Chlorophyll (µg/L) | 0.8 – 2.5 | 1.7 | 1.5 | 12.5% |
| Secchi Depth (m) | 1.67 – 2 | 1.91 | 1.69 | 12.2% |
| Bottom | Alkalinity (mg/L) | 28 – 29 | 28.3 | 29 | 2.4% |
| Total Nitrogen (mg/L) | 0.3 – 0.4 | 0.333 | 0.4 | 18.3% |
| NO2+NO3 (mg/L) | 0.11 – 0.11 | 0.11 | 0.11 | 0% |
| Ammonia (mg/L) | 0.11 – 0.15 | 0.127 | 0.16 | 23% |
| Total Phosphorus (mg/L) | 0.09 – 0.1 | 0.097 | 0.12 | 21.2% |
| Orthophosphate (mg/L) | 0.06 – 0.07 | 0.067 | 0.08 | 17.7% |
| July 2021 | Surface | Alkalinity (mg/L) | 31 – 31 | 31 | 31 | 0% |
| Total Nitrogen (mg/L) | <0.1 – 0.1 | <0.1 | <0.1 | nc |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | 0.01 – 0.02 | 0.013 | 0.01 | 26.1% |
| Orthophosphate (mg/L) | <0.01 - <0.01 | <0.01 | <0.01 | nc |
| Secchi Depth (m) | 3.24 – 3.94 | 3.59 | 4.29 | 17.8% |
| Bottom | Alkalinity (mg/L) | 29 – 30 | 29.7 | 31 | 4.3% |
| Total Nitrogen (mg/L) | 0.4 – 0.5 | 0.433 | 0.7 | 47.1% |
| NO2+NO3 (mg/L) | <0.05 – 0.08 | <0.067 | <0.05 | nc |
| Ammonia (mg/L) | 0.15 – 0.31 | 0.23 | 0.52 | 77.3% |
| Total Phosphorus (mg/L) | 0.17 – 0.24 | 0.197 | 0.36 | 58.5% |
| Orthophosphate (mg/L) | 0.13 – 0.19 | 0.153 | 0.29 | 61.9% |
| August 2021 | Surface | Alkalinity (mg/L) | 33 – 33 | 33 | 33 | 0% |
| Total Nitrogen (mg/L) | 0.2 – 0.2 | 0.2 | 0.2 | 0% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | <0.01 - <0.01 | <0.01 | <0.01 | nc |
| Orthophosphate (mg/L) | <0.01 - <0.01 | <0.01 | <0.01 | nc |
| Chlorophyll (µg/L) | 42 – 52 | 46.5 | 50 | 7.3% |
| Secchi Depth (m) | 1.68 – 1.98 | 1.80 | 1.82 | 1.1% |
| Bottom | Alkalinity (mg/L) | 30 – 31 | 30.7 | 34 | 10.2% |
| Total Nitrogen (mg/L) | 0.4 – 0.6 | 0.467 | 1.6 | 110% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 – 0.47 | <0.26 | 1.34 | >135% |
| Total Phosphorus (mg/L) | 0.17 – 0.27 | 0.213 | 0.6 | 95.2% |
| Orthophosphate (mg/L) | 0.16 – 0.26 | 0.203 | 0.55 | 92.2% |
| September 2021 | Surface | Alkalinity (mg/L) | 34 – 34 | 34 | 34 | 0% |
| Total Nitrogen (mg/L) | 0.2 – 0.2 | 0.2 | 0.2 | 0% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Total Phosphorus (mg/L) | 0.02 – 0.02 | 0.02 | 0.02 | 0% |
| Orthophosphate (mg/L) | <0.01 - <0.01 | <0.01 | <0.01 | nc |
| Secchi Depth (m) | 1.74 – 2.11 | 1.87 | 2.25 | 18.4% |
| Bottom | Alkalinity (mg/L) | 33 – 34 | 33.3 | 34 | 2.1% |
| Total Nitrogen (mg/L) | 0.3 – 0.8 | 0.633 | 1.0 | 44.9% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | 0.17 – 0.81 | 0.557 | 1.0 | 56.9% |
| Total Phosphorus (mg/L) | 0.05 – 0.33 | 0.227 | 0.42 | 59.7% |
| Orthophosphate (mg/L) | 0.04 – 0.33 | 0.217 | 0.38 | 54.6% |
| October 2021 | Surface | Alkalinity (mg/L) | 34 – 35 | 34.5 | 34 | 1.5% |
| Total Nitrogen (mg/L) | 0.4 – 0.4 | 0.4 | 0.4 | 0% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | 0.26 – 0.27 | 0.265 | 0.26 | 1.9% |
| Total Phosphorus (mg/L) | 0.1 – 0.1 | 0.1 | 0.1 | 0% |
| Orthophosphate (mg/L) | 0.06 – 0.06 | 0.06 | 0.06 | 0% |
| Chlorophyll (µg/L) | 6.9 – 15 | 11.0 | 17.0 | 42.9% |
| Secchi Depth (m) | 2.49 – 2.72 | 2.61 | 3.02 | 14.6% |
| Bottom | Alkalinity (mg/L) | 35 – 35 | 35 | 35 | 0% |
| Total Nitrogen (mg/L) | 0.4 – 0.5 | 0.45 | 0.4 | 11.8% |
| NO2+NO3 (mg/L) | <0.05 - <0.05 | <0.05 | <0.05 | nc |
| Ammonia (mg/L) | 0.27 – 0.34 | 0.305 | 0.32 | 4.8% |
| Total Phosphorus (mg/L) | 0.1 – 0.12 | 0.11 | 0.12 | 8.7% |
| Orthophosphate (mg/L) | 0.06 – 0.07 | 0.065 | 0.07 | 7.4% |

1SW Quad results omitted from Bottom Results Range and Mean.

2SW Quad and NE Quad were not sampled during October of both 2020 and 2021.

nc= not calculated due to censored data for both Deepest result and mean of quad sites.

## **Objective 1**

Objective 1 involved tracking potential nutrient reductions in the discharge associated with facility upgrades at Brooks Lake Lodge. Throughout this study, only two samples were collected from the Brooks Lake Lodge wastewater lagoon effluent. The first sample was collected on 9/22/20, and was collected during a non-discharging timeframe for the Lodge; the Covid-19 pandemic reduced Lodge occupancy, and therefore altered the magnitude and frequency of their permitted discharge during 2020. Lodge staff had to initiate discharge in order for us to collect this sample; this sample is not deemed representative of normal conditions. The second sample was collected on 6/15/21, and was collected during their regular discharging timeframe. This sample is considered more representative of the typical Lodge discharging timeframe. ***Table 10*** below provides the single sample results from the more representative 2021 sample, as well as the 2009-2012 mean and range (n=7) for comparison. As described above, only a single, representative sample was collected during the Phase 1 study. As a result, very limited information is available to reach any conclusions regarding trends in nutrient concentrations in discharges from Brooks Lake Lodge. Additional data will be collected in Phase 2.

**Table 10. Nutrient results from Brooks Lake Lodge wastewater lagoon permitted discharge.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **6/15/2021 Result** | **2009-2012 Mean** | **2009-2012 Range** |
| Ammonia, as N | 1.26 mg/L | 1.8 mg/L | 0.6 – 3.0 mg/L |
| Total Nitrogen | 2.0 mg/L | 9.694 mg/L | 2.43 – 31.9 mg/L |
| Nitrate+nitrite, as N | 0.19 mg/L | 3.116 mg/L | 0.01 – 17.9 mg/L |
| Total Phosphorus | 0.54 mg/L | 0.602 mg/L | 0.37 – 0.99 mg/L |
| Orthophosphate, as P | 0.49 mg/L | Not collected | Not collected |

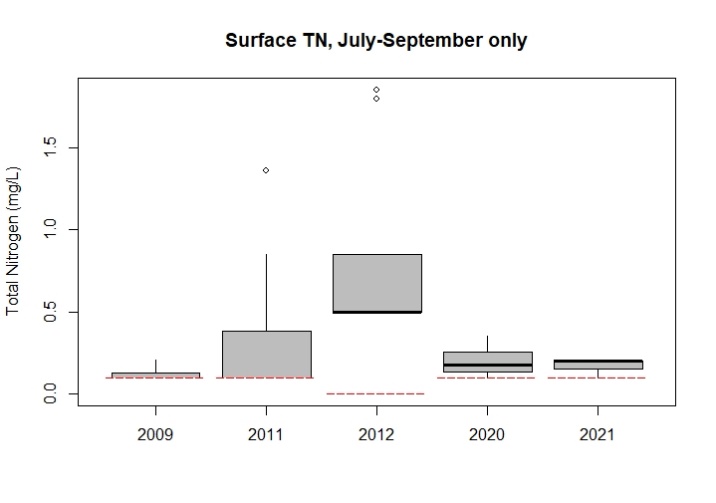
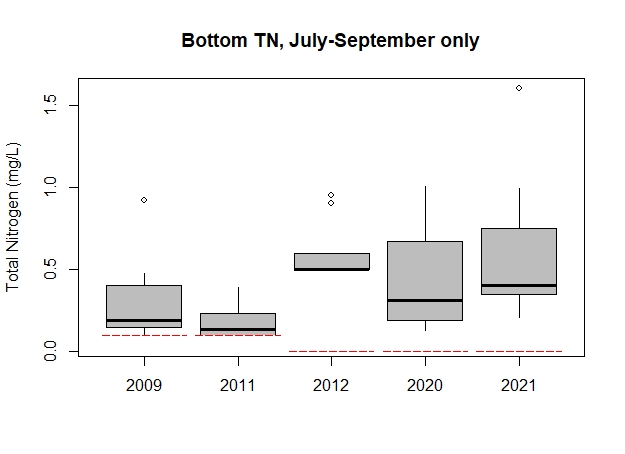
## **Objective 2**

Objective 2 involved monitoring nutrient and productivity trends in Brooks Lake. Data collected in 2009 – 2012 occurred during the months of July through September at four quad sites whose locations approximated the location of the four quad sites monitored during 2020 – 2021. Data collected in 2020 – 2021 occurred during the months of June through October at four quad sites in addition to one Deepest site. For maximum comparability to data collected during 2009-2012, only data from the months of July through September were pooled and compared across all sampling years (2009 – 2021). Additional data to supplement this trend analysis will be collected in Phase 2.

### TN

Surface TN concentrations were greatest during 2012 and lowest in 2009 and 2011 (***Figure 17***), and median surface TN concentration was greater in 2020-2021 than 2009 and 2011. Bottom TN concentrations were similar to surface concentrations in that the greatest observed median concentration occurred during 2012, and median concentration during 2020-2021 was greater than 2009 and 2011.

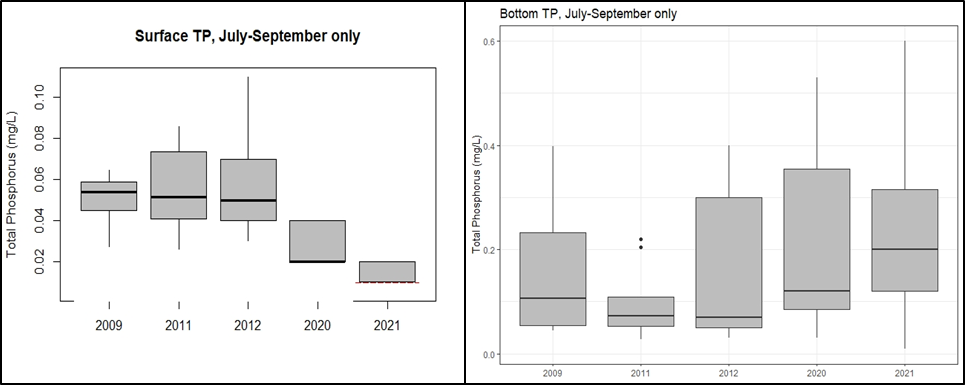
**Figure 17. Censored boxplots of pooled surface and bottom TN concentrations from July – September grouped by year.**



### TP

Median surface TP concentration decreased during 2020-2021 as compared to 2009-2012 (***Figure 18***). Median bottom TP concentration was greatest during 2021, although the interquartile range of observed concentrations has appeared to remain relatively similar to 2009-2012.

**Figure 18. Censored and regular boxplots of pooled surface and bottom TP concentrations from July – September grouped by year.**



### TN:TP Ratios

Total nitrogen to total phosphorus ratios in both surface and bottom samples were evaluated to determine which nutrient may be primarily responsible for limiting primary productivity within Brooks Lake. ***Table 11*** below gives the number of samples during each year that fell into each nutrient limitation category, grouped by where in the water column the sample was collected. Thresholds for each nutrient limitation category were chosen from available scientific literature (Downing and McCauley 1992). Nutrient concentrations within the bottom of Brooks Lake primarily tended to be in quantities that suggested limitation by nitrogen, except during 2012 when nitrogen was more abundant relative to phosphorus and conditions of co-limitation were slightly more common than N-limited conditions. Surface nutrient concentrations tended to be primarily indicative of either co-limitation or nitrogen limitation. Conditions of phosphorus-limitation were present during August 2021 when TN:TP ratios at all five sites were >20.

**Table 11. Total nitrogen to total phosphorus ratios binned by nutrient limitation category.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Surface** | | | **Bottom** | | |
| # of samples N-limited (TN:TP≤5) | # of samples co-limited (5<TN:TP<20) | # of samples P-limited (TN:TP≥20) | # of samples N-limited (TN:TP≤5) | # of samples co-limited (5<TN:TP<20) | # of samples P-limited (TN:TP≥20) |
| 2009 | 12 | 0 | 0 | 9 | 0 | 0 |
| 2011 | 8 | 3 | 1 | 8 | 1 | 0 |
| 2012 | 0 | 10 | 2 | 4 | 5 | 0 |
| 2020 | 6 | 9 | 0 | 13 | 2 | 0 |
| 2021 | 1 | 9\* | 5 | 12 | 2 | 1 |

\*Three samples with TN:TP<10 considered co-limited, although could be N-limited; inherent challenge with censored data

### Nitrate+nitrite

Severe censoring (>50%) was found within all the surface and bottom NO2+NO3 data sets, except during 2012. All NO2+NO3 concentrations during 2012 were at or above the reporting limit, with a maximum concentration of 0.09 mg/L observed during July in the hypolimnion. This maximum observed NO2+NO3 concentration during 2012 was greater than the maximum concentration observed during 2011, 2020, and 2021, yet less than the maximum concentration observed in 2009 (0.18 mg/L). This information suggests the majority of nitrogen in Brooks Lake is not in inorganic form.

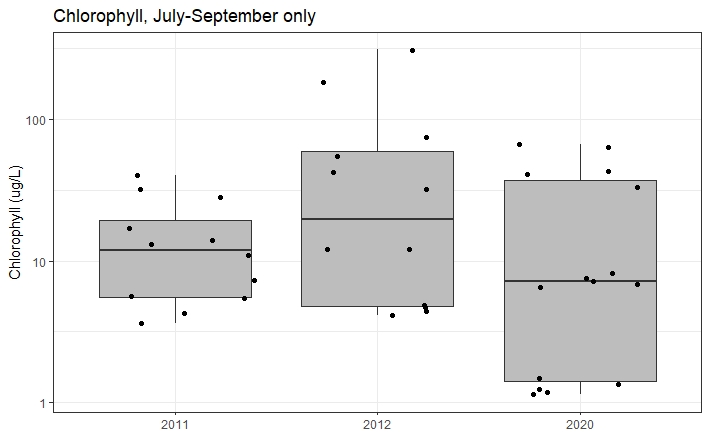
### Ammonia

During all sampling years, reportable levels of ammonia were found in 12% of surface samples and 58% of bottom samples. All ammonia concentrations were in attainment with their pH and temperature-dependent chronic criterion protective of early life stages of fish.

### Chlorophyll

Chlorophyll concentrations from 2021 were omitted from this analysis, since both July and September 2021 chlorophyll concentrations were not considered suitable for analytical consideration. As a result, this temporal comparison has limited utility. Mean chlorophyll concentration was greatest in 2012 (61.3 µg/L), followed by 2020 (19.3 µg/L), and 2011 (15.1 µg/L). The greatest single chlorophyll concentration (310 µg/L) was observed during July 2012 (***Figure 19***). A Kruskal-Wallis test did not find enough evidence to suggest either of these data sets differed significantly from each other (p=0.32). Additional years of chlorophyll data would be required to make statements regarding productivity trends through time at Brooks Lake.

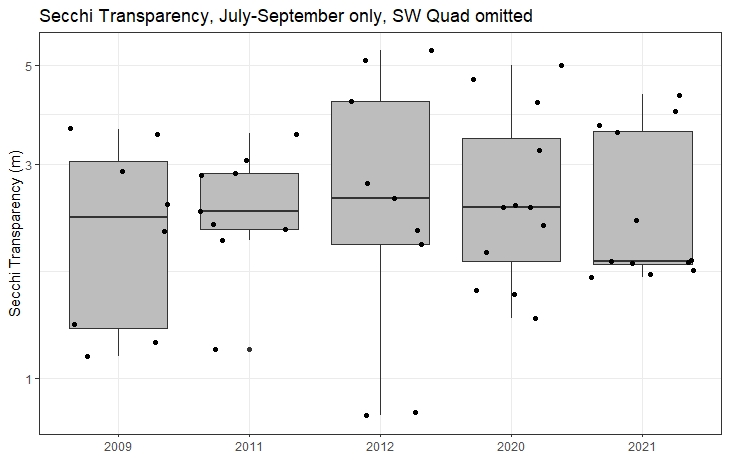
**Figure 19. Pooled chlorophyll concentrations from July – September grouped by year.**



### Secchi Transparency

For the purposes of comparing temporal trends in water clarity, data from SW Quad were omitted from this analysis due to three instances when the secchi was visible on the bottom of the lake. These were from the 2009-2012 sampling years when the “Lodge Quad” site was more of a littoral environment rather than a pelagic environment. Furthermore, only data from July through September were employed for maximum comparability across years. Median water clarity was greatest during 2012, and lowest during 2021 (***Figure 20***). A Kruskal-Wallis test found no evidence to suggest any of the data sets from any year were different from the others (p=0.92), therefore it is reasonable to conclude that water clarity in Brooks Lake during the summer growing season has remained relatively unchanged from 2009-2021.

**Figure 20. Pooled secchi transparency depths less SW Quad from July – September grouped by year.**



## **Objective 3**

Objective 3 involved evaluating potential public health risks associated with cyanobacteria. During regular monitoring trips, samplers watched for cyanobacteria blooms. An *Aphanizomenon* bloom was observed both in 2020 and 2021. Cyanotoxin and cyanobacteria samples were collected on 8/14/2020 from the densest portion of the bloom at the boat launch area which represented a location with relatively high likelihood for potential public exposure; all cyanotoxin results were below their respective laboratory reporting limits, and cyanobacteria cell density (20,516 cells/mL) exceeded the recreational use advisory threshold of 20,000 cells/mL. During the September 2021 sampling event, cyanotoxin samples were collected from the boat launch area, and all parameter results were below laboratory reporting limits. Results from ambient phytoplankton samples revealed cyanobacteria cell densities in both 2020 and 2021 exceeded the recreational use advisory threshold of 20,000 cells/mL (see Objective 5). The observed *Aphanizomenon* bloom during September 2021 along with the Secchi disk for reference is depicted in ***Photo 1***. Additional sampling is necessary to better understand the timing of blooms and toxin production on Brooks Lake.

**Photo 1. Aphanizomenon bloom observed at SW Quad during September 2021 visit.**



## **Objective 4**

This is a relatively broad-ranging objective, and its original purpose was to ensure all Phase 1 results were adequately and rigorously evaluated to inform and guide Phases 2 and 3. The Brooks Lake Team continues to meet on a regular basis, and agenda items from our January 2022 meeting focused on the analysis of the Phase 1 data. The Brooks Lake Team is currently drafting a detailed proposed activities list for 2022. These proposed activities will help answer outstanding questions as the Team prepares for Phase 2 monitoring to start in 2023.

## **Objective 5**

Objective 5 involved characterizing the phytoplankton community present in Brooks Lake. Phytoplankton data were only collected from NW Quad, Deepest, and Outlet Quad during 2020 and 2021.

Phytoplankton community richness and abundance was averaged across the three sites for each month and year (***Figure 21***). Mean richness during 2020 was greatest during June then decreased throughout the growing season, whereas mean richness during 2021 was greatest during July with the months of June and October also having relatively high richness. September was the month of lowest mean richness for both 2020 and 2021. Phytoplankton community abundance peaked in September during both 2020 and 2021, which is expected during the peak of the summer growing season. While phytoplankton community abundance was generally greater during 2021 than 2020, both years followed a similar pattern of an increase in abundance throughout the growing season followed by a decrease in abundance associated with fall turnover.

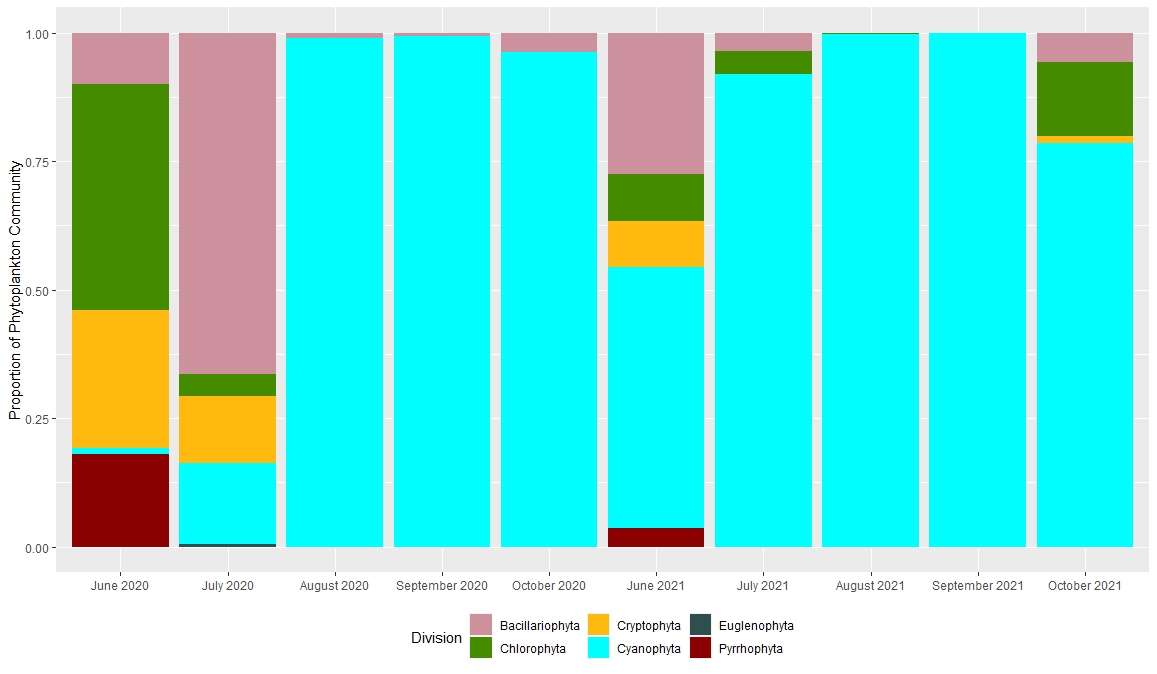
**Figure 21. Phytoplankton community richness and abundance by month and year.**

During 2020, a relatively balanced community was found during June, following spring turnover, and this continued into July. During July, diatoms (Bacillariophyta) had the greatest cell density, with *Asterionella* and *Stephanodiscus* being the dominant diatom taxa; these diatoms are considered indicative of eutrophic conditions (Rawson 1956). Diatom cell density increased each month from June through October. Cyanophyta (blue-green algae) cell density increased each month, and the most dramatic increase occurred from July to August and September; the September Cyanophyta mean cell density of 25,775,987 cells/L exceeded the recreational use advisory threshold of 20,000 cells/mL. The two most dominant Cyanophyta taxa were *Aphanocapsa* and *Aphanizomenon*, with *Aphanocapsa* more dominant during August and *Aphanizomenon* heavily dominant during September. *Aphanizomenon* is a known N2-fixing genus and considered a nuisance alga (Paerl et al. 2001), and *Aphanocapsa* seems to survive high pH waters well (Reynolds et al. 2002). During September peak productivity timeframe, only cyanobacteria and diatoms were found within Brooks Lake. Following fall turnover, green algae (Chlorophyta) and cryptomonads (Cryptophyta) were once again found. The only cryptomonad found in Brooks Lake was *Cryptomonas*, which are considered a nuisance algae taxon that prefer nitrogen and phosphorus enriched waters (Paerl et al. 2001). Chlorophyta cell density tended to decrease throughout the growing season from its highest density during June. During periods of higher green algae cell density, the dominant Chlorophyte taxa were *Chlamydomonas*, *Oocystis*, *Dictyosphaerium*, and *Sphaerocystis*. *Chlamydomonas* is common in shallow eutrophic waters and sewage ponds, tolerant of high organic pollution, and can be associated with cyanobacterial blooms. *Oocystis* has a variable response to nutrient enrichment, but some species respond favorably to nitrogen or phosphorus enrichment. *Sphaerocystis* prefer eutrophic, nitrogen and phosphorus-enriched waters (Paerl et al. 2001).

During 2021, a relatively balanced community was again found in June, with representation from Cyanophyta, Bacillariophyta, Chlorophyta, Cryptophyta, and Pyrrhophyta. Cyanophyta was the dominant division during June, comprised of *Leptolyngbya* and *Dolichospermum*. *Dolichospermum* (formerly *Anabaena*) is a N2-fixing nuisance alga that prefers phosphorus-enriched, warm, stratified, long-residence time, high irradiance conditions (Paerl et al. 2001). Eleven different diatom taxa were found throughout Brooks Lake during June, with mean Bacillariophyta relative abundance around 27.5% of the community. The more abundant diatoms were *Navicula,* *Stephanodiscus*, *Aulacoseira*, and *Nitzschia*. The lone Chlorophyte observed during June was *Oocystis*, which comprised 9.1% of the community on average. Dominance of Cyanophyta increased during July, with *Dolichospermum*, *Aphanocapsa*, and *Aphanizomenon* collectively accounting for >90% of the phytoplankton community. Chlorophyta richness and cell density increased during July, with five distinct taxa observed. Cyanophyta cell density and dominance of the phytoplankton community continued to increase in August, and breached the recreational use advisory threshold of 20,000 cells/mL. Cyanophyta comprised >99% of the phytoplankton community during August. *Aphanizomenon* was the dominant taxon at each site, with densities up to 38,723,949 cells/L observed at Deepest. Three diatom taxa (*Fragilaria*, *Stephanodiscus*, *Asterionella*) and three green algae taxa (*Dictyosphaerium*, *Oocystis*, *Staurastrum*) were found amid the intense Cyanophyta dominance during August. According to Rawson (1956), all three of these diatom taxa are indicative of eutrophic conditions. Mean Cyanophyta cell density peaked in September at 107,254,643 cells/L, with *Aphanizomenon* still the dominant taxa and densities up to 127,363,201 cells/L observed at Deepest. Cyanophyta again comprised >99% of the phytoplankton community during September. Chlorophyte richness and cell density increased in September, whereas Bacillariophyte richness and cell density decreased. Following fall turnover, October Cyanophyta cell densities dropped below the recreational use advisory threshold. Cyanophyta dominance decreased to 78.6% of the phytoplankton community, and modest cell density increases in Bacillariophyta, Chlorophyta, and Cryptophyta were observed. *Cryptomonas* was the only Cryptophyte observed during 2021, with peak density (25,314 cells/L) observed during August and peak mean relative abundance observed during June (10.5%).

***Figure 22*** below chronologically displays the major phytoplankton divisions as a proportion of the phytoplankton community during each month for 2020 – 2021. The phytoplankton community during June was the most balanced of the whole season, with representation from Bacillariophyta, Cyanophyta, Chlorophyta, Cryptophyta, and Pyrrhophyta. This relatively balanced community continued into July, although diatoms started to dominate the community. Dramatic change in phytoplankton community composition occurred from July to August with Cyanophyta comprising nearly the entire community. This heavy dominance of Cyanophyta continued into September, as well as after fall turnover during mid-October.

**Figure 22.**  **Stacked barchart of the proportion of each major phytoplankton division within the community grouped by sampling event.**



# Next Steps

The Brooks Lake Team met on January 5, 2022 and discussed the results and data analysis activities that had occurred on Phase 1 of the project. It was agreed that the initiation of Phase 2 monitoring should be delayed until 2023 due to a variety of factors, and instead the Team would use 2022 to more rigorously prepare for Phase 2 activities. Various meetings and reconnaissance activities in support of Phase 2 occurred during 2022. The Team most recently met on December 13, 2022 to discuss action items and work that needed to be accomplished in preparation for the beginning of Phase 2 activities during 2023. The primary deliverable from Phase 1 of this project is this technical memo that summarizes the Phase 1 sampling effort and describes results specific to the five study objectives. The Brooks Lake Team will coordinate with the Monitoring Program Supervisor regarding the progress of the Technical Memo, as well as Sampling and Analysis plan development for Phase 2.

# Data Availability

All data collected to date are currently considered provisional and for internal use only until a final report is prepared at the completion of Phase 3.

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# Appendices

**Appendix 1. Data Package Review Letter from WDEQ/WQD QAQC Officer.**

**Data Review QA/QC Summary:**

**Brooks Lake Targeted Water Quality Monitoring Study – Phase I:**

**2020 - 2021**

Thank you for your submission of the 2020 - 2021 Brooks Lake Phase I data package forQuality Assurance/Quality Control (QA/QC) review.

Based on the current QA/QC criteria and the specific information provided in your raw data package, I am pleased to inform you that the data has passed QA/QC review.

Overall, the data were reported accurately, and the QA/QC measures required by the 2020 - 2021 [Brooks Lake Targeted Water Quality Monitoring Study - Phase I Sampling and Analysis Plan](https://wyomingcloud.sharepoint.com/sites/020DEQ-WQD/QAQC/Records/Forms/AllItems.aspx?id=%2Fsites%2F020DEQ%2DWQD%2FQAQC%2FRecords%2F2021%2D0617%2DWDEQ%2DFinal%2DBrooksLakePhase%2DI%5FSAP%5F2021Amendment%2Epdf&parent=%2Fsites%2F020DEQ%2DWQD%2FQAQC%2FRecords) (Amended June 2021), Wyoming Department of Environmental Quality (WDEQ) [Standard Operating Procedures](https://deq.wyoming.gov/water-quality/data-quality-assurance/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyODcyOTFhNjFkYTBkYzAwZDA4MTQzN2Q3YThiODM5ZjklMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFtRTNPaC1ZWk9Udi1CY2xjSDN6SFVKQzBHTlYxWEdrNCUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4YlVVelQyZ3RXVnBQVkhZdFFtTnNZMGd6ZWtoVlNrTXdSMDVXTVZoSGF6UWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMXowUTBYSkkzLXNtZ1ItZW5FX2FxVGdaS28yamZrRl9pJTIyJTdE) (SOPs), [WDEQ Assessment Methods](https://deq.wyoming.gov/water-quality/watershed-protection/water-quality-assessment/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyMzUxNWE1YTc4MzI3ZTFjODllOTQ0NjlhNjI5NGZkNWUlMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFlQWR4ZXpNOE0wQmo2cTRYb1h4OHNRU19HQWlkcHJtcyUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4WlVGa2VHVjZUVGhOTUVKcU5uRTBXRzlZZURoelVWTmZSMEZwWkhCeWJYTWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMVBfU2pBcFdsYm03QmUtb1U5YzVsdk5mT0tUZ3JhTXFHJTIyJTdE), and the [WDEQ Watershed Section Quality Assurance Project Plan](https://deq.wyoming.gov/water-quality/data-quality-assurance/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyM2JhNzZiYzU1OGFlYjNhNzBmMzNjNjUzYjdmM2E5ZDglMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFWVTNBYXdXZEJfVzNISzRxUGVZOTUyLUR0YUhaU3RKUSUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4VmxVelFXRjNWMlJDWDFjelNFczBjVkJsV1RrMU1pMUVkR0ZJV2xOMFNsRWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMUx3SWdfRUI1ZUtRMGpoNXJNRmdHVF8zTTlKNE85REV3JTIyJTdE) (QAPP) were adhered to. Below is a summary of the QA/QC data quality objectives (DQOs) and issues encountered during the Brooks Lake 2020 - 2021 Phase I study:

**Blank Data:**

**Chemical Blanks**

Chemistry Field Blanks

Field blanks were collected at an 11.4% frequency of all site visits and subject to all sample collection, processing, handling, and analysis processes as the samples collected for the Brooks Lake Phase I study. Of the twelve (12) field blanks collected during the 2020 - 2021 monitoring seasons, the data show one (1) field blank exceedance above the method reporting limit. The field blank collected during the 6/15/2021 sampling event showed elevated results at the method reporting limit for total phosphorus (0.01 mg/L). I recommend flagging all total phosphorus samples collected for that event (n = 15).

| **Brooks Lake Phase I Study 2020 – 2021 Field Blank Exceedance Summary:** | | | |
| --- | --- | --- | --- |
| **Laboratory Work Order Number:** | **Sample Collection Date(s):** | **Waterbody/Site Collection:** | **Parameter(s):** |
| **2021 Data:** | | | |
| 2021-06-16-002 | 6/15/2021 | DMP | Total Phosphorus |

Cyanotoxin Field Blanks

Cyanotoxin (total microcystins & nodularins and cylindrospermopsin) field blanks were collected at a 21.7% frequency for all site visits and were subject to all sample collection, processing, handling, and analysis processes as the samples collected for the Brooks Lake Phase I study. All five (5) field blanks collected showed results below the method reporting limits.

Chemistry Laboratory Reagent Blanks (LRBs)

All laboratory reagent blank (LRB) results were below the respective reporting limits for the parameters of interest for the Brooks Lake Phase I study.

**Duplicate Data:**

**Chemical Duplicates**

Water Chemistry Field Duplicates

Field duplicate samples were collected concurrently at 11.4% of the site visits for all chemical parameters. All twelve (12) field duplicates collected met project DQOs for the Brooks Lake study data collected during the 2020 - 2021 monitoring seasons.

Cyanotoxin Field Duplicates

Cyanotoxin (total microcystins & nodularins and cylindrospermopsin) duplicates were collected concurrently at 21.7%. There are no set DQOs for cyanotoxins, and all original and duplicate results were below their respective method reporting limits.

Field Parameter Field Replicates

Sequential field replicate measurements were collected at two sites (Brooks Lake – Lodge WWTF and Brooks Lake – DMP) during the 2020-2021 site visits. All direct measurements met project DQOs. No vertical profile replicates or duplicates were conducted per the project SAP.

Laboratory Duplicates

The data show one (1) laboratory duplicate that exceeded the method RPD acceptance limits. The batch of samples ran with the Brooks Lake samples collected for the 8/25/2020 sampling event exceeded the method RPD limit (15%) for total phosphorus with a calculated RPD of 15.2%. The duplicate sample ran (AF01442) was not a project sample, and both sample and duplicate results (0.01 mg/L and 0.02 mg/L, respectively) were at or near the reporting limit (0.01 mg/L), so the difference between the two results is negligible. These data should be considered acceptable.

**Biological Duplicates**

Phytoplankton Duplicates

Phytoplankton duplicates were collected concurrently at 13.3% of the site visits in 2020 & 2021. There are no set DQOs for phytoplankton. For precision and repeatability comparisons, if the same DQO criteria as macroinvertebrates are used (abundance = 50%/richness = 15%), the calculated RPDs in 2020 were met for abundance; however, the two duplicates collected exceeded the 15% metric for richness at a calculated 22.2% and 18.2%. The 2021 data show similar richness exceedances (22.2% and 33.3%) but also exceed the density DQO for the sample collected at the Brooks Lake Deepest location at a calculated 65.5%.

Chlorophyll-a Duplicates

Chlorophyll-a sample duplicates were collected concurrently at 16.7% of the site visits for the Brooks Lake Phase I study. All results met the 30% DQO set for chlorophyll-a.

**Laboratory Quality Control & Matrix Spike (MS)/Matrix Spike Duplicate (MSD) Data:**

**Laboratory Matrix Spikes**

All laboratory matrix spikes met method acceptance limits for the parameters of interest for the Brooks Lake 2020-2021 monitoring seasons.

**Sample Preservation, Containers, COC, & Holding Times:**

| **Brooks Lake Phase I Study 2020 - 2021 Temperature Exceedance Summary:** | | | | |
| --- | --- | --- | --- | --- |
| **Laboratory Work Order Number:** | **Sample Collection Date(s):** | **Waterbody/Site(s):** | **Parameter(s):** | **Qualifier(s):** |
| **2021 Data:** | | | | |
| 2021-06-16-003/ H21070739 | 7/20/2021 | SW Quad, NW Quad, Deepest, Deepest Dup, NE Quad, & Outlet Quad | Chlorophyll-a | TE = Sample was received above the recommended temperature (n = 6) |
| 2021-09-22-004/ H21090703 | 9/21/2021 | Outlet Quad, Deepest, NW Quad, NE Quad, & SW Quad | Chlorophyll-a | TE = Sample was received above the recommended temperature (n = 5) |

The chlorophyll-a samples subbed to Energy Labs via the DEQ Water Quality Lab for the July 2021 and Sept 2021 sampling events were received above the recommended temperature of < 6°C (10.4°C and 21.2°C, respectively). All other samples were preserved properly and were received at the analyzing laboratories at the appropriate temperature/pH.

All samples were collected in the appropriate container supplied by the analyzing laboratories, and all proper chain of custody (COC) procedures were adhered to.

Ammonia samples collected on 8/25/2020 exceeded the EPA-recommended holding time of 28 days. Two (2) total nitrogen samples collected in June 2021 exceeded the EPA-recommended holding time of 28 days. All other EPA recommended holding times were adhered to for the study parameters of interest. The table below is a summary of the associated data that was flagged and qualified:

| **Brooks Lake Phase I Study 2020 - 2021 Holding Time Exceedance Summary:** | | | | |
| --- | --- | --- | --- | --- |
| **Laboratory Work Order Number:** | **Sample Collection Date(s):** | **Waterbody/Site(s):** | **Parameter(s):** | **Qualifier(s):** |
| **2020 Data:** | | | | |
| 2020-08-26-002 | 8/25/2020 | Field Blank (DMP), SW Quad Surface, SW Quad Bottom, NW Quad Surface, NW Quad Surface Dup, DMP, & Horse Corral Tributary | Ammonia | H = The EPA recommended holding time was exceeded (n = 7) |
| **2021 Data:** | | | | |
| 2021-06-16-002 | 6/15/2021 | Lodge WWTF & Lodge WWTF Dup | Total Nitrogen | H = The EPA recommended holding time was exceeded (n = 2) |

**Calibration Logs, Accuracy, & Documentation:**

**Field Meter & Turbidimeter Data:**

| **Brooks Lake Phase I Study 2020 – 2021 Field Calibration/CCV Exceedances:** | | | |
| --- | --- | --- | --- |
| **Exceedance Type** | **Calibration/CCV Date:** | **Waterbody/Site:** | **Parameter(s):** |
| **2021 Data:** | | | |
| CCV Check | 9/21/2021 | Deepest, Outlet Quad, NE Quad, NW Quad, SW Quad, & DMP | Conductivity |
| CCV Check (missing) | 9/21/2021 | Deepest, Outlet Quad, NE Quad, NW Quad, SW Quad, & DMP | DO |
| Calibration (missing) | 10/20/2021 | Deepest, Outlet Quad, NW Quad, & DMP | Conductivity |

All 2020 – 2021 sampling events for the Brooks Lake Phase I study have documented calibration and; continuing calibration verification (CCV) checks for all field parameters of interest except for conductivity on 10/20/2021. I recommend excluding the vertical profile & DMP conductivity data from that event. There was no documentation of a CCV check for DO on 9/21/21. All other frequencies, instrument models, and serial numbers are documented on the calibration logs and are consistent with the project SAP.

All calibration standards used to collect field parameter data for the Brooks Lake Phase I 2020 – 2021 monitoring seasons were thoroughly documented on the project calibration logs. There were two instances (6/23/2020 and 9/21/2021) where no standard traceability was documented on the calibration logs for conductivity expiration. It is assumed that since all prior traceability is within the shelf life for conductivity, that these events are no different.

**Data Confidence & Completeness:**

Completeness is a measure of the amount of valid data obtained from a monitoring program/project compared to the amount of valid data expected to be obtained. Completeness is calculated by dividing the number of valid measurements completed (samples collected and/or analyzed) by the total number of measurements planned for the project's dataset and is expressed as a percentage. The Brooks Lake Phase I project goal for completeness was set at 95% for the parameters of interest in the project SAP. Completeness considers the confidence in each parameter's overall dataset and was evaluated for both chemical and biological parameters collected for the study. There were three (3) parameters that failed to meet project DQOs for completeness:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Brooks Lake Phase I Study 2020 – 2021 Completeness Exceedances:** | | | | | |
| Waterbody Name | Station Name | Total Possible # of Visits | Field Parameters | Biological Parameters | Chemical Parameters**1** |
| Conductivity | Chlorophyll-a | Orthophosphate |
| Brooks Lake | Deepest | 10 | 8 | 7 | 14 |
| Brooks Lake | Outlet Quad | 10 | 8 | 7 | 14 |
| Brooks Lake | NE Quad | 8 | 6 | 5 | 10 |
| Brooks Lake | NW Quad | 10 | 8 | 6 | 14 |
| Brooks Lake | SW Quad | 8 | 6 | 5 | 10 |
| Brooks Lake | Lodge WWTF | 1 | 1 | 0 | 1 |
| Brooks Lake | DMP | 10 | 8 | 0 | 7 |
| Brooks Lake | Horse Corral Tributary | 1 | 1 | 0 | 0 |
| **Total Sites Sampled** | | **58** | **46** | **30** | **70** |
| **DQO Completeness (%)** | | | **79.3** | **65.2** | **67.3** |

**1** All chemical parameter sample collection included both surface and bottom sampling for the Brooks Lake Deepest and four quadrant sites.

In 2021 there were issues with the conductivity calibration for the September and October sampling events. I recommend omitting these vertical profiles and direct measurement conductivity data from sample analysis. The August 2020 chlorophyll-a results had triple peak chromatogram results, and the data was considered estimated per the laboratory. Additionally, the chlorophyll-a July 2021 and Sept 2021 samples received at Energy Labs exceeded the recommended temperature of < 6°C (10.4°C and 21.2°C, respectively). Due to the uncertainty surrounding the chromatogram data and sample integrity issues with temperature exceedances, I recommend removing these chlorophyll-a data from analytical consideration. Finally, due to laboratory analytical deficiencies in 2020, only orthophosphate results from September and October 2020 and all 2021 monitoring event sample sets should be considered suitable for analysis. All other parameters met the project completeness targets for the 2020 – 2021 monitoring seasons.

**Field Audit:**

On June 15, 2021, the Wyoming Department of Environmental Quality (WDEQ) performed a field audit for the WDEQ Lander Field Office (LFO) Monitoring Program for the Brooks Lake Targeted Water Quality Monitoring Study – Phase I. Field audits are conducted periodically to ensure that sample collection methods are performed properly and; data collection efforts are scientifically defensible. The primary elements focused on during these audits are adherence to Sampling and Analysis Plan (SAP) objectives and study design, [Standard Operating Procedure](https://deq.wyoming.gov/water-quality/data-quality-assurance/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyODcyOTFhNjFkYTBkYzAwZDA4MTQzN2Q3YThiODM5ZjklMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFtRTNPaC1ZWk9Udi1CY2xjSDN6SFVKQzBHTlYxWEdrNCUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4YlVVelQyZ3RXVnBQVkhZdFFtTnNZMGd6ZWtoVlNrTXdSMDVXTVZoSGF6UWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMXowUTBYSkkzLXNtZ1ItZW5FX2FxVGdaS28yamZrRl9pJTIyJTdE) (SOP) methods and protocols, [Quality Assurance Program Plans](https://deq.wyoming.gov/water-quality/data-quality-assurance/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyM2JhNzZiYzU1OGFlYjNhNzBmMzNjNjUzYjdmM2E5ZDglMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFWVTNBYXdXZEJfVzNISzRxUGVZOTUyLUR0YUhaU3RKUSUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4VmxVelFXRjNWMlJDWDFjelNFczBjVkJsV1RrMU1pMUVkR0ZJV2xOMFNsRWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMUx3SWdfRUI1ZUtRMGpoNXJNRmdHVF8zTTlKNE85REV3JTIyJTdE) (QAPPs), and [Wyoming’s Methods for Determining Surface Water Quality Conditions](https://deq.wyoming.gov/water-quality/watershed-protection/water-quality-assessment/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyMzUxNWE1YTc4MzI3ZTFjODllOTQ0NjlhNjI5NGZkNWUlMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFlQWR4ZXpNOE0wQmo2cTRYb1h4OHNRU19HQWlkcHJtcyUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4WlVGa2VHVjZUVGhOTUVKcU5uRTBXRzlZZURoelVWTmZSMEZwWkhCeWJYTWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMVBfU2pBcFdsYm03QmUtb1U5YzVsdk5mT0tUZ3JhTXFHJTIyJTdE). Field audits alongside other QA/QC procedures, help establish data credibility and compliance with state and federal requirements.

Sample collection efforts were performed by Mike Wachtendonk (WDEQ/LFO, Monitoring Program Natural Resources Analyst) and Tavis Eddy (WDEQ/LFO, Monitoring Program Natural Resources Analyst) on the above-mentioned date. The 2021 field audit was conducted by Jillian Scott (WDEQ, QA/QC Officer) with Valarie Shao (WDEQ, Intern), Joe Deromedi (WGFD, Fisheries Biologist), Gwen Gerber (USFS, Hydrologist), and Jeremy Ward (USFS, Seasonal Technician) in attendance for all seven (7) of the Project monitoring locations: Downstream Monitoring Point (DMP), Brooks Lake – Outlet Quad, Brooks Lake – NE Quad, Brooks Lake – Deepest, Brooks Lake – NW Quad, Brooks Lake – SW Quad, and BLL Effluent. The LFO Monitoring Program [Brooks Lake Targeted Water Quality Monitoring Study - Phase I Sampling and Analysis Plan](https://wyomingcloud.sharepoint.com/sites/020DEQ-WQD/QAQC/Records/Forms/AllItems.aspx?id=%2Fsites%2F020DEQ%2DWQD%2FQAQC%2FRecords%2F2021%2D0617%2DWDEQ%2DFinal%2DBrooksLakePhase%2DI%5FSAP%5F2021Amendment%2Epdf&parent=%2Fsites%2F020DEQ%2DWQD%2FQAQC%2FRecords) was reviewed and approved (pending signatures) prior to conducting the field audit. Overall, the audit showed that data collection methods were representative of environmental field conditions and should yield credible data results.

**Summary & Conclusions:**

Chemical and biological samples were collected during the 2020 – 2021 monitoring seasons and show proper documentation of QA/QC processes applied to the environmental data collection efforts for the Brooks Lake Phase I study. The data collected were found to be of a known and; suitable quality needed to meet the goals and objectives of this phase of the study. Overall, data collection and analysis methods were representative of environmental field conditions and yielded credible data results. All sample collection efforts adhered to the objectives and study design of the SAP, and methods were conducted per all applicable WDEQ SOPs.

The 2021 Amended [Brooks Lake Targeted Water Quality Monitoring Study - Phase I Sampling and Analysis Plan](https://wyomingcloud.sharepoint.com/sites/020DEQ-WQD/QAQC/Records/Forms/AllItems.aspx?id=%2Fsites%2F020DEQ%2DWQD%2FQAQC%2FRecords%2F2021%2D0617%2DWDEQ%2DFinal%2DBrooksLakePhase%2DI%5FSAP%5F2021Amendment%2Epdf&parent=%2Fsites%2F020DEQ%2DWQD%2FQAQC%2FRecords), [Wyoming’s Methods for Determining Surface Water Quality Condition](https://deq.wyoming.gov/water-quality/watershed-protection/water-quality-assessment/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyMzUxNWE1YTc4MzI3ZTFjODllOTQ0NjlhNjI5NGZkNWUlMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFlQWR4ZXpNOE0wQmo2cTRYb1h4OHNRU19HQWlkcHJtcyUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4WlVGa2VHVjZUVGhOTUVKcU5uRTBXRzlZZURoelVWTmZSMEZwWkhCeWJYTWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMVBfU2pBcFdsYm03QmUtb1U5YzVsdk5mT0tUZ3JhTXFHJTIyJTdE)(2020), [Wyoming’s 2020 Integrated 305(b) and 303(d) Report](https://deq.wyoming.gov/water-quality/watershed-protection/water-quality-assessment/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyZTEzYzQwNzMxZDM4MzFjYWJlNGUxMmJlOTc0MTAwMjAlMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFsRXA5WkdsOFJ3OG84VTM0LWhObTE2bmc1N3A4SXFBUyUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4YkVWd09WcEhiRGhTZHpodk9GVXpOQzFvVG0weE5tNW5OVGR3T0VseFFWTWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMXJiOW1pbldhaGo0cHVDZmg3a19henNjZVd4eEdudzFLJTIyJTdE)(2020), [Chapter 1 of the Wyoming Water Quality Rules and Regulations](https://rules.wyo.gov/) (2018), [Wyoming Surface Water Classification List](https://drive.google.com/file/d/1nmOuMrhhAoEwNKv5wB5cj7TDdfmdrut6/view) (2021), WDEQs [Quality Assurance Program Plan for Watershed Protection Program Water Quality Monitoring](https://deq.wyoming.gov/water-quality/data-quality-assurance/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyM2JhNzZiYzU1OGFlYjNhNzBmMzNjNjUzYjdmM2E5ZDglMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFWVTNBYXdXZEJfVzNISzRxUGVZOTUyLUR0YUhaU3RKUSUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4VmxVelFXRjNWMlJDWDFjelNFczBjVkJsV1RrMU1pMUVkR0ZJV2xOMFNsRWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMUx3SWdfRUI1ZUtRMGpoNXJNRmdHVF8zTTlKNE85REV3JTIyJTdE) (2021), and WDEQs [Manual of Standard Operating Procedures for Sample Collection and Analysis](https://deq.wyoming.gov/water-quality/data-quality-assurance/?wpcp_link=JTdCJTIyc291cmNlJTIyJTNBJTIyODcyOTFhNjFkYTBkYzAwZDA4MTQzN2Q3YThiODM5ZjklMjIlMkMlMjJhY2NvdW50X2lkJTIyJTNBJTIyMTEzMTQyMjM3OTUwMTUyNjI3MzcyJTIyJTJDJTIybGFzdEZvbGRlciUyMiUzQSUyMjFtRTNPaC1ZWk9Udi1CY2xjSDN6SFVKQzBHTlYxWEdrNCUyMiUyQyUyMmZvbGRlclBhdGglMjIlM0ElMjJXeUl4YlVVelQyZ3RXVnBQVkhZdFFtTnNZMGd6ZWtoVlNrTXdSMDVXTVZoSGF6UWlYUSUzRCUzRCUyMiUyQyUyMmZvY3VzX2lkJTIyJTNBJTIyMXowUTBYSkkzLXNtZ1ItZW5FX2FxVGdaS28yamZrRl9pJTIyJTdE) (2022) were used as references.

If you have any questions or comments, please feel free to contact me.

Sincerely,

Jillian Scott

Quality Assurance Officer

Wyoming Department of Environmental Quality

Water Quality Division

**Appendix 2. Field audit report from Lander Field Office Monitoring Program 2021 field audit at Brooks Lake.**

June 18, 2021

Mike Wachtendonk/ Tavis Eddy

Lander Field Office Monitoring Program

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Re: Lander Field Office Monitoring Program 2021 Field Audit

On June 15, 2021, the Wyoming Department of Environmental Quality (WDEQ) performed a field audit for the WDEQ Lander Field Office (LFO) Monitoring Program for the Brooks Lake Targeted Water Quality Monitoring Study – Phase I. Field audits are conducted periodically to ensure that sample collection methods are performed properly, and data collection efforts are scientifically defensible. The primary elements focused on during these audits are adherence to Sampling and Analysis Plan (SAP) objectives and study design, [Standard Operating Procedure](http://deq.wyoming.gov/media/attachments/Water%20Quality/Quality%20Assurance%20Quality%20Control/Manual/2021-Final-SOP-Manual.pdf) (SOP) methods and protocols, [Quality Assurance Program Plans](http://deq.wyoming.gov/media/attachments/Water%20Quality/Quality%20Assurance%20Quality%20Control/QAPP/2021-Final-QAPP.pdf) (QAPP), [Wyoming’s Methods for Determining Surface Water Quality Conditions](http://deq.wyoming.gov/media/attachments/Water%20Quality/Water%20Quality%20Assessment/Guidance/Wyomings%20Methods%20for%20Determing%20Surface%20Water%20Quality%20Condition.pdf), and other quality control elements that can provide assurance that credible data requirements will be met.

Sample collection efforts were performed by Mike Wachtendonk (WDEQ/LFO, Monitoring Program Natural Resources Analyst) and Tavis Eddy (WDEQ/LFO, Monitoring Program Natural Resources Analyst) on the above-mentioned date. The 2021 field audit was conducted by Jillian Scott (WDEQ, QA/QC Officer) with Valarie Shao (WDEQ, Intern), Joe Deromedi (WGFD, Fisheries Biologist), Gwen Gerber (USFS, Hydrologist), and Jeremy Ward (USFS, Seasonal Technician) in attendance for all seven (7) of the Project monitoring locations: Downstream Monitoring Point (DMP), Brooks Lake – Outlet Quad, Brooks Lake – NE Quad, Brooks Lake – Deepest, Brooks Lake – NW Quad, Brooks Lake – SW Quad, and BLL Effluent. The LFO Monitoring Program SAP *Brooks Lake Targeted Water Quality Monitoring Study – Phase I* was reviewed and approved (pending signatures) prior to conducting the field audit.

Overall, the audit showed that data collection methods were representative of environmental field conditions and should yield credible data results. The form used during the field audit documenting the quality control elements defined above is provided as an attachment below. Summary and conclusions, as well as the recommendations for the LFO Monitoring Program, are described at the end of the form.

If you have any questions or concerns, please feel free to contact me.

Sincerely,

Jillian Scott

Quality Assurance Officer

Wyoming Department of Environmental Quality

Water Quality Division

Watershed Protection Program

1. The “Brooks Lake Team” is an interagency collaborative group that includes representatives from the Wyoming Department of Environmental Quality, Wyoming Game and Fish Department, and the Shoshone National Forest. [↑](#footnote-ref-1)