Water Quality Condition for Brooks Lake, Wind/Bighorn Basin, 2009, 2011-2012

Wyoming Department of Environmental Quality/Water Quality Division

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Wyoming Department of Environmental Quality

Water Quality Division

Chapter 1 Standards Attainment/Non-Attainment

Quick Summary

Waterbody ID	Brooks Lake HUC100800010104
Basin Name	Wind/Bighorn
Waterbody Classification	Class 2AB
Location	Fremont County, Wyoming
Extent of Evaluation	Brooks Lake, Brooks Lake Creek
Years Evaluated	2009, 2011, 2012
Assigned Designated Uses	Cold-water fisheries, non-game fisheries, drinking water, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture, and scenic value.
Chapter 1 Standards Attainment/Non-Attainment	Non-attainment of Section 26 (pH) in Brooks Lake and Brooks Lake Creek due to pH values in excess of 9.0 S.U. Non-attainment of Section 32 (Biological Criteria) in Brooks Lake based on a weight of evidence approach that suggests accelerated eutrophication, triggered by excess nutrients, is causing physical changes to the lake that are adversely affecting the intentionally introduced cold-water fishery.
Extent of Attainment/Non-Attainment	Brooks Lake, and Brooks Lake Creek from the outlet of Brooks Lake an undetermined distance downstream not to exceed 4.5 stream miles.
Pollutants/Pollution that Result in Non-Attainment	Nitrogen and/or Phosphorus
Source(s) of Pollutants/Pollution	Natural, horse corrals, wastewater lagoon

Cover Page Photograph: Looking east across the north end of Brooks Lake

Contents

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This document was peer reviewed by Karri Cary (USFS), Joe Deromedi (WGFD), Eric Hargett (WDEQ/WQD), Rick Metzger (USFS), Catherine Norris (WDEQ/WQD), Richard Thorp (WDEQ/WQD), and Jeremy ZumBerge (WDEQ/WQD). WDEQ/WQD also requested a review of the draft report from the manager of Brooks Lake Lodge, but received no comments.

Executive Summary

The Monitoring Program of the Wyoming Department of Environmental Quality-Water Quality Division (WDEQ/WQD) evaluates water quality of streams, rivers, lakes, reservoirs and wetlands in Wyoming. Water quality conditions are determined using water quality standards, with findings of standards attainment and observed pollutant problems and sources described within a water quality monitoring and evaluation report. Monitoring and evaluation reports are then used to assess support of designated water uses using standardized criteria (WDEQ/WQD 2014) and ultimately incorporated into the State's biennial Integrated 305(b) and 303(d) Report that is submitted to the U.S. Environmental Protection Agency (USEPA).

Brooks Lake is located in Fremont County, near Togwotee Pass. Its watershed, with a drainage area of 12.9 mi^2, is relatively small and flow is predominately snowmelt driven. Brooks Lake is categorized as a Class 2AB water (WDEQ/WQD 2013) and is protected for cold-water fisheries, non-game fisheries, drinking water, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture, and scenic value designated uses. Two fish kills were documented by the Wyoming Game and Fish Department (WGFD) in 2001 and 2008 in Brooks Lake and the outlet stream, Brooks Lake Creek. High algal production was observed by WGFD employees during both fish kills, therefore low dissolved oxygen conditions were suspected as the cause of the fish kills. In response to these fish kills WGFD contacted WDEQ/WQD, who also involved the United States Forest Service (USFS). WDEQ/WQD then led an investigation of the nutrient and productivity conditions of Brooks Lake. During 2009, 2011, and 2012, chemical information was collected on Brooks Lake, Brooks Lake Creek and other nearby waterbodies during nine total sampling events. The objectives were to 1) determine the probable cause of the fish kills, 2) evaluate water quality conditions of Brooks Lake and suitable reference lakes, with emphasis on nutrients and algal productivity, 3) investigate sources of nutrients to Brooks Lake, and 4) determine whether pollutants of concern caused non-attainment of applicable Wyoming surface water quality standards.

Results from the three years of sampling include pH values in Brooks Lake and Brooks Lake Creek that exceed WDEQ/WQD (2013) water quality criteria. Chlorophyll α was significantly higher in Brooks Lake than in suitable reference lakes, and secchi transparency was significantly lower in Brooks Lake than in the reference lakes. Total phosphorus concentrations were similar between Brooks Lake and the reference lakes indicating phosphorus was abundant in this watershed and was probably not the limiting nutrient. Nitrogen to phosphorus ratios and nutrient to chlorophyll α relationships suggest nitrogen limits primary productivity in Brooks Lake, except during times of extreme productivity, when phosphorus limitation occurs. Another response variable to nutrient enrichment, dissolved oxygen (DO), was relatively low on occasion. Additional investigation during more critical time periods may be necessary. Data from WDEQ/WQD sampling suggests DO values <8 mg/L and pH values >9.0 can occur naturally in the Brooks Lake watershed. Multiple sources appear to contribute to the nutrient enrichment of Brooks Lake. Phosphorus-rich volcanic rocks in the watershed allow this nutrient to be relatively abundant. Studies of other lakes within the Greater Yellowstone Ecosystem have found them to be more productive than typical high-mountain lakes, meaning Brooks Lake may be naturally more productive. However, comparison to reference lakes within the Brooks Lake watershed suggest

anthropogenic activity, particularly effluent from wastewater lagoons and drainage from horse corrals, has accelerated eutrophication in Brooks Lake. Estimated annual nutrient loads from these sources are relatively low when compared to natural nutrient sources; however, unknowns associated with the lagoons prior to the issuance of its first WYPDES permit in 1984, potential groundwater contributions, as well as the occurrence of illegal discharges and lagoon spill-overs adds uncertainty to the estimation of their magnitude. An additional analysis using less conservative assumptions for total nitrogen loading to Brooks Lake suggests the horse corrals and wastewater lagoons may collectively contribute up to 24% of the total nitrogen load. Other sources of nutrients are atmospheric nitrogen deposition and natural groundwater. It is widely accepted that current air quality regulations are inadequate to protect ecosystems from the acidification and/or nutrient enrichment effects of atmospheric deposition. Available literature suggests current atmospheric nitrogen deposition rates do not exceed critical nitrogen deposition loads for the Brooks Lake watershed. While groundwater is not believed to be a major nutrient contributor to Brooks Lake, uncertainty exists regarding lagoon wastewater interaction with groundwater, and its possible impact on Brooks Lake. Brooks Lake appears to be experiencing biotic and abiotic changes that are consistent with the effects of eutrophication. Some of these effects include blue-green algae blooms, decreased water clarity, increased productivity, an anoxic hypolimnion, fish kills, and the decline of lake trout. Lake trout once maintained a healthy, naturally reproducing population, but appear to be barely persisting now, while lake trout in a nearby reference lake continue to sustain themselves through natural reproduction. Available data and evidence suggest accelerated eutrophication within Brooks Lake from multiple sources, which has resulted in adverse impacts to the intentionally introduced cold-water fish community, and has manifested itself in pH values that regularly exceeded applicable water quality criterion. These pH criterion exceedances occurred frequently in Brooks Lake and in Brooks Lake Creek at the outlet. No pH criterion exceedances were documented in Brooks Lake Creek at a point approximately 4.5 miles downstream from the outlet.

Introduction and Purpose

The Monitoring Program of the Wyoming Department of Environmental Quality-Water Quality Division (WDEQ/WQD) evaluates water quality of streams, rivers, lakes, reservoirs and wetlands in Wyoming. Water quality conditions are determined using water quality standards, with findings of standards attainment and observed pollutant problems and sources described within a water quality monitoring and evaluation report. Monitoring and evaluation reports are then used to assess support of designated water uses using standardized criteria (WDEQ/WQD 2014) and ultimately incorporated into the State's biennial Integrated 305(b) and 303(d) Report that is submitted to the U.S. Environmental Protection Agency (USEPA).

On July 24th, 2001, a fish kill in Brooks Lake Creek prompted the Wyoming Game and Fish Department to visit Brooks Lake on July 25th and 26th, 2001. Dead and dying trout and sucker were observed in Brooks Lake Creek and Brooks Lake near the outlet, and high algal production in the Lake was noted. During their visit, WGFD employees noted supersaturated dissolved oxygen conditions in Brooks Lake and a water temperature of 65°F (18.3°C) at mid-day (Deromedi 2001). Some fish appeared to have been dead for a day or two, while others had more recently expired. Dead fish exhibited flared gills and arched backs, suggesting death by asphyxiation. WGFD believed fish mortality was caused by low dissolved oxygen concentrations during nighttime, which persisted for several nights. The fish kill was not age-class or species specific. Algal samples were collected and identified as *Anabaena* or *Aphanizomenon* cyanobacteria (Blue-green algae). *Aphanizomenon* is known for noxious blooms that kill fish either by release of toxins or reducing oxygen concentrations (Hall 2008). *Anabaena* is a common and widespread cyanobacteria that is also capable of producing toxins and causing depressed dissolved oxygen conditions. In mid-September of 2008, another algal bloom was documented in Brooks Lake, following another fish kill in the outlet stream, Brooks Lake Creek. This was the third time that WGFD has documented an algal bloom in Brooks Lake (Deromedi 2008). The WGFD responded and collected algal samples which were sent to the University of Wyoming Department of Zoology and Physiology for identification. Again, the dominant algae was identified as *Aphanizomenon*. Similar to the first fish kill in 2001, this kill was not age-class or species specific, and flared gills and arched backs of dead fish suggested asphyxiation as the cause. Following this fish kill, WGFD contacted WDEQ/WQD, which along with USFS, initiated sampling of Brooks Lake in 2009 that continued into 2011 and 2012.

In 2009 and 2011, sampling focused on characterizing nutrient and productivity conditions in Brooks Lake. In addition, three input tributaries, the outlet stream, and the Brooks Lake Lodge wastewater lagoon effluent were sampled to better understand sources of nutrients to the lake. Sampling at these locations occurred again in 2012 along with the addition of two minimally-disturbed reference lakes (Upper Brooks Lake and Lower Jade Lake) to provide a better idea of natural productivity and expected condition within the Brooks Lake watershed. The objectives of these evaluations were to 1) determine the probable cause of the fish kills, 2) evaluate water quality conditions of Brooks Lake and suitable reference lakes, with emphasis on nutrients and algal productivity, 3) investigate sources of nutrients to Brooks Lake, and 4) determine whether pollutants of concern caused non-attainment of applicable Wyoming surface water quality standards. This report describes the analysis and findings from 2009, 2011, and 2012 WDEQ/WQD monitoring of Brooks Lake, Brooks Lake Creek, and other nearby waterbodies.

Description of Evaluation Area

Waterbody Description

Brooks Lake is located near the headwaters of the Wind River in the Shoshone National Forest, near Togwotee Pass (Figure 1). The watershed has a drainage area of 12.9 mi^2 and flow is predominately snowmelt driven. Elevations in the Brooks Lake watershed range from over 11,000 feet to about 9,050 feet at the Lake. The watershed lies entirely within the Middle Rockies level III ecoregion (Omernik and Gallant 1987), and contains two level IV ecoregions - Absaroka Volcanic Subalpine Zone and Alpine Zone (Chapman et al. 2003; Figure 2). The dominant bedrock geology is comprised of the Wiggins Formation and landslide deposits. The Wiggins formation is comprised of light-gray volcanic conglomerate and white tuff, containing clasts of igneous rocks (Love and Christiansen 1985). Intrusive igneous rocks of the Aycross formation from the Thorofare Creek group, glacial deposits, and alluvium and colluvium also are present within this watershed (Figure 3). The Aycross formation is comprised of brightly variegated bentonnitic claystone and tuffaceous sandstone, grading laterally into greenish-gray sandstone and claystone (Love and Christiansen 1985). The Wiggins formation and Aycross formation are both part of the Thorofare Creek group of intrusive igneous rocks from the Absaroka Volcanic supergroup. Rocks of volcanic origin are known to be rich in phosphorus (Dillon and Kirchner 1975). Hydrology is predominately snowmelt driven, with peak flows typically occurring during May and June. The primary land uses in the watershed are recreation and wildlife habitat, and in the area immediately surrounding Brooks Lake, some horse grazing occurs. Brooks Lake Lodge is a resort that sits along the southwest side of lake. The lodge has a permit (WY0028045) with the Wyoming Pollutant Discharge Elimination System (WYPDES) Program to discharge wastewater lagoon effluent to an unnamed tributary of Brooks Lake. Upper Brooks Lake and Lower Jade Lake both lie within the Brooks Lake watershed, and feed tributaries of Brooks Lake. Brooks Lake, Upper Brooks Lake, and Lower Jade Lake have surface areas of approximately 214, 23, and 16 acres and maximum depths of around 47, 16, and 54 feet, respectively. These particular reference lakes were deemed the best available comparators for Brooks Lake.

Figure 1. Brooks Lake watershed with associated WYPDES permitted facilities and WDEQ/WQD monitoring sites.

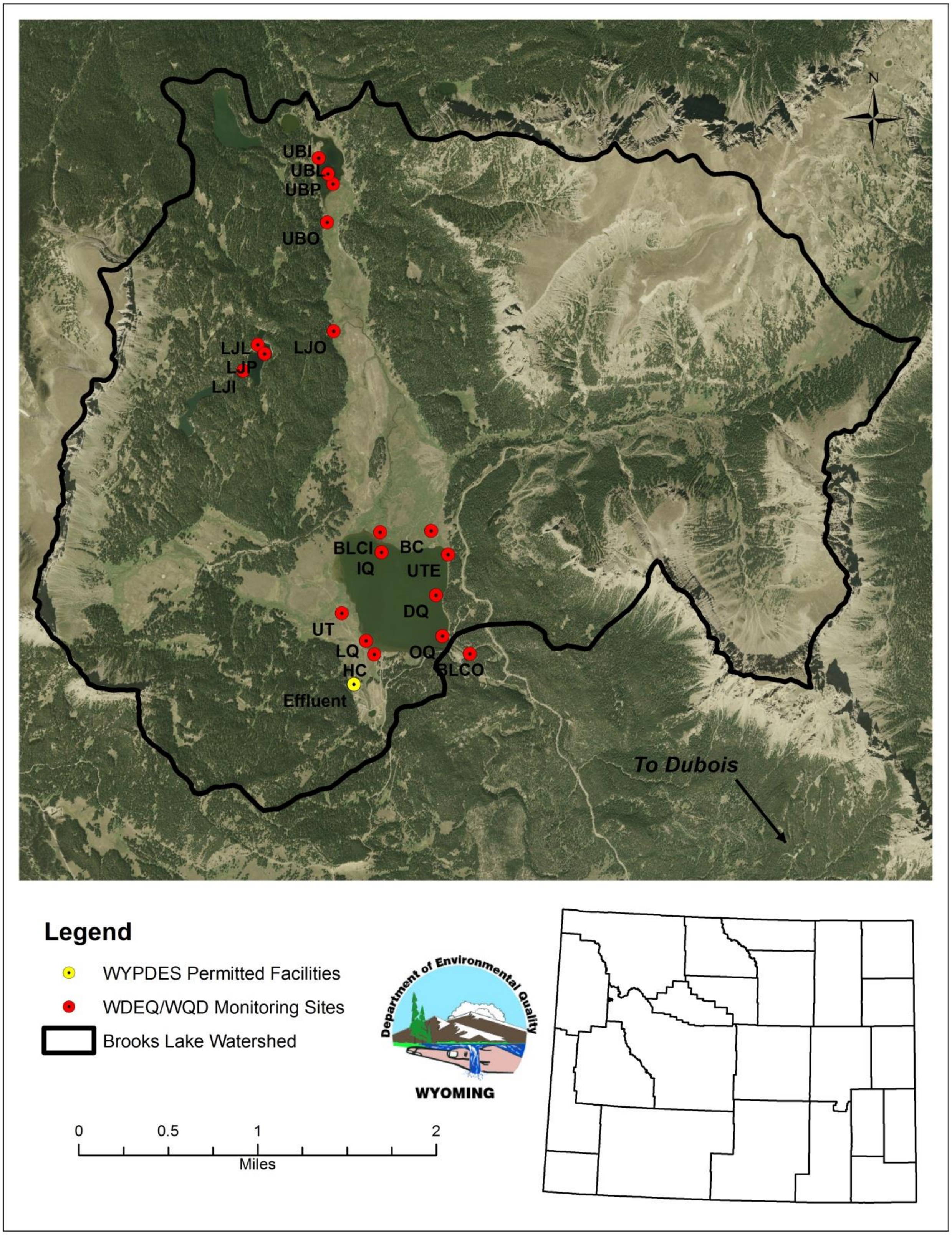


Figure 2. Level IV Ecoregions in the Brooks Lake Watershed (Chapman et al. 2003).

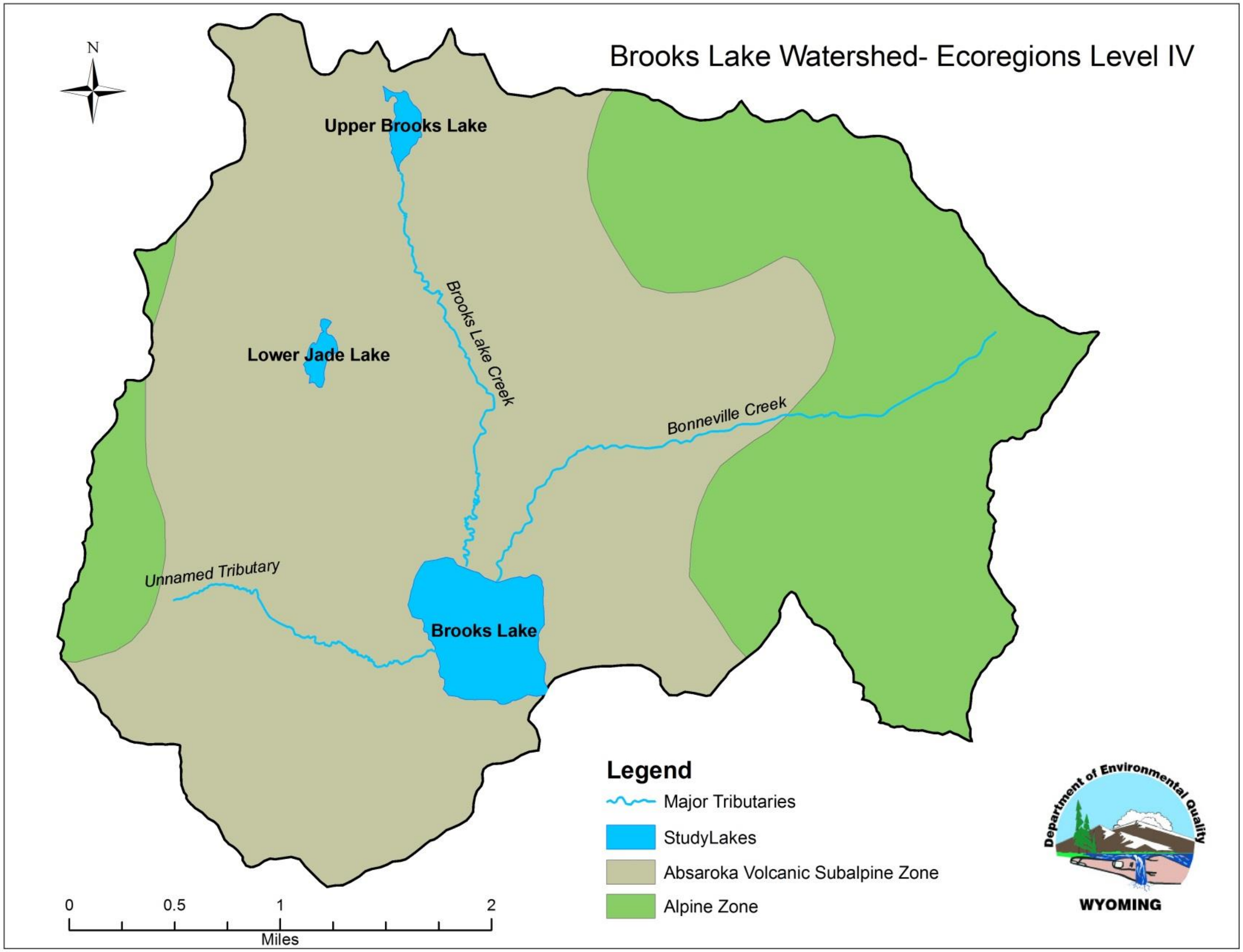
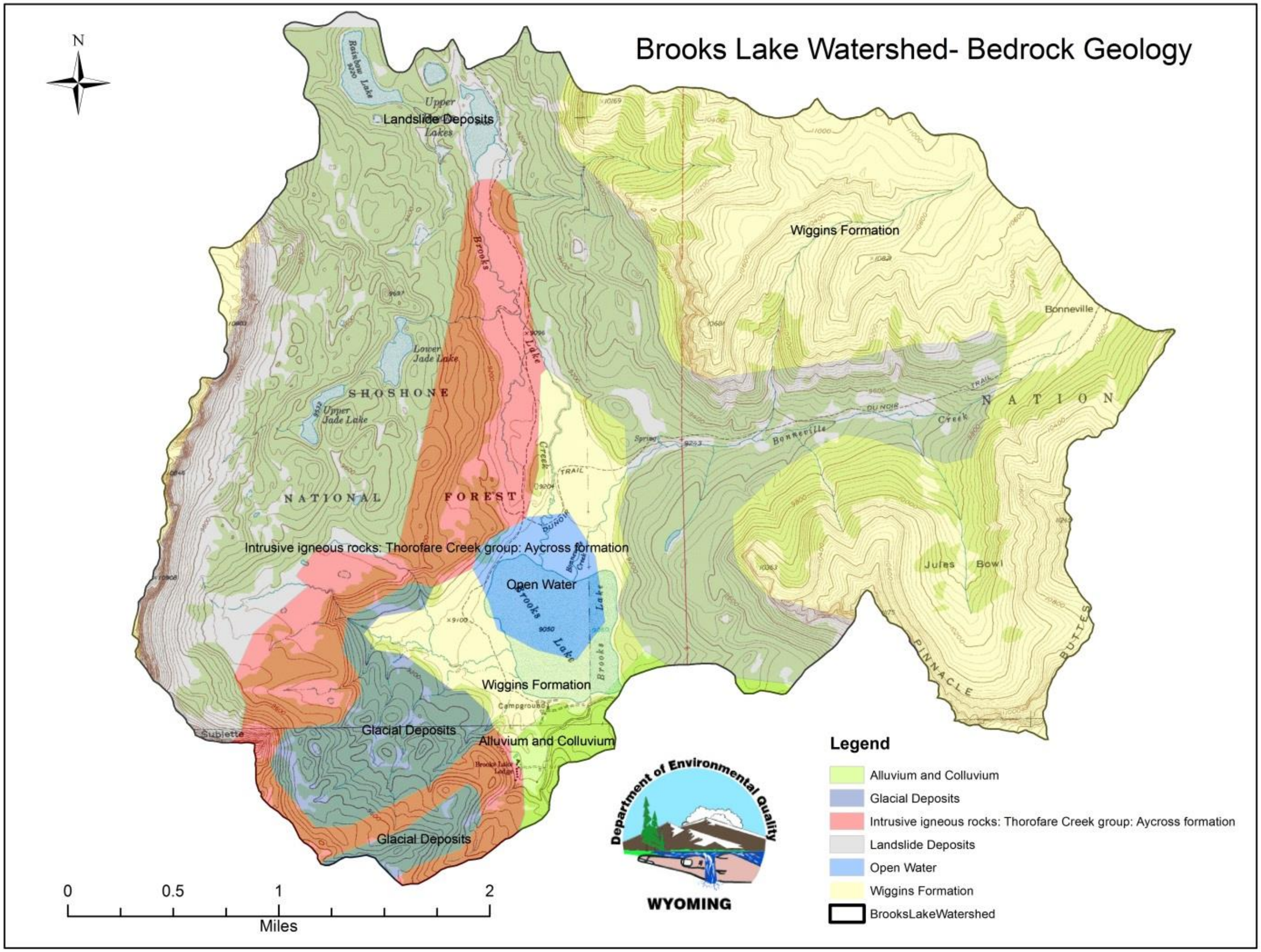


Figure 3. Bedrock Geology of the Brooks Lake watershed (Love and Christiansen 1985).



Waterbody Classification

Brooks Lake, Upper Brooks Lake, Lower Jade Lake, and Brooks Lake Creek are all classified as 2AB (WDEQ/WQD 2007). Class 2AB waters are protected for the following designated uses: cold-water fisheries, non-game fisheries, drinking water, fish consumption, aquatic life other than fish, recreation, wildlife, industry, agriculture and scenic value.

Methods and Materials

Site Selection

A total of eleven monitoring sites were located on or around Brooks Lake, nine of which were visited during every sampling event (Figure 1, Table 1). The eleven sites included three pelagic sites and one littoral site on Brooks Lake, one site on each of five tributaries to Brooks Lake, one on Brooks Lake Creek outlet stream, and the Brooks Lake Lodge effluent. Two inlets to Brooks Lake were sampled infrequently for exploratory purposes: Horse Corral Tributary and Unnamed Tributary East. Horse Corral Tributary drains an area around several horse corrals near Brooks Lake Lodge, while Unnamed Tributary East flows into the northeast end of Brooks Lake and represents mostly groundwater contributions with no known anthropogenic influence. While not every surface water inflow to Brooks Lake was sampled during this study, we attempted to include the major tributaries in our monitoring. Upper Brooks Lake and Lower Jade Lake each had four monitoring sites located at the inlet, outlet, and a pelagic and littoral location (Figure 1, Table 1). During sampling trips to Lower Jade Lake no surface water outflow was observed, despite visual evidence of surface water inflow. Directly down gradient from Lower Jade Lake in the Brooks Lake Creek valley a spring was sampled after being identified as a possible subsurface outlet for Lower Jade Lake. However, many of these springs were observed throughout this valley during sampling trips and the origins of water at this site could be from many sources. The data were retained in this report to represent probable quality of groundwater contributions to Brooks Lake. There were several tributaries to Upper Brooks Lake; the largest tributary was selected for the inlet site.

Table 1. Descriptive information for Brooks Lake, Upper Brooks Lake, and Lower Jade Lake monitoring sites. Horse Corral Tributary site was only visited on 8/21/12 and 9/11/12. Unnamed Tributary East site was only visited on 8/21/12.

Site Name	Site ID	Type	Latitude/ Longitude	Legal (Sec/T/R)	Parameters
Brooks Lake Lodge Quadrant	LQ	Littoral	43.752658°N -110.00706°W	NWNW of Sec. 25, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Brooks Lake Outlet Quadrant	OQ	Pelagic	43.752975°N -109.998512°W	NWNE of Sec. 25, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Brooks Lake Deep Quadrant	DQ	Pelagic	43.756285°N -109.999178°W	SWSE of Sec. 24, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Brooks Lake Inlet Quad	IQ	Pelagic	43.759815°N -110.005193°W	SWSW of Sec. 24, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Bonneville Creek Inlet	BC	Inlet	43.76151°N -109.999633°W	SESW of Sec. 24, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Brooks Lake Creek Inlet	BLCI	Inlet	43.761457°N -110.005323°W	NESW of Sec. 24, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Unnamed Tributary to Brooks Lake	UT	Inlet	43.754922°N -110.009743°W	NWNW of Sec. 25, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Brooks Lake Lodge WYPDES effluent	BLL	Effluent	43.749118 -110.008487	SWNW of Sec. 25, T44N, R110W	Nutrients, alkalinity, field parameters, discharge

Brooks Lake Creek Outlet	BLCO	Outlet	43.7515°N -109.995467°W	SENE of Sec. 25, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Horse Corral Tributary	HC	Inlet	43.751554°N -110.006165°W	NENW of Sec. 25, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Unnamed Tributary East	UTE	Inlet	43.759575°N -109.997757°W	NWSE of Sec. 24, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Lower Jade Lake Pelagic	LJP	Pelagic	43.776034°N -110.018043°W	SENW of Sec. 14, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Lower Jade Lake Littoral	LJL	Littoral	43.776775°N -110.018791°W	NWSE of Sec. 14, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Lower Jade Lake Inlet	LJI	Inlet	43.774689°N -110.020451°W	NESW of Sec. 14, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Lower Jade Lake Outlet	LJO	Outlet	43.777804°N -110.010276°W	SWNE of Sec. 14, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Upper Brooks Lake Pelagic	UBP	Pelagic	43.79057°N -110.010689°W	NWSW of Sec. 12, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Upper Brooks Lake Littoral	UBL	Littoral	43.789725°N -110.01015°W	NWSW of Sec. 12, T44N, R110W	Nutrients, alkalinity, chlorophyll, depth profile, Secchi transparency
Upper Brooks Lake Inlet	UBI	Inlet	43.79186°N -110.011718°W	NWSE of Sec. 11, T44N, R110W	Nutrients, alkalinity, field parameters, discharge
Upper Brooks Lake Outlet	UBO	Outlet	43.786631°N -110.010864°W	NWSE of Sec. 11, T44N, R110W	Nutrients, alkalinity, field parameters, discharge

Data Collection

All WDEQ/WQD equipment calibration and data collection methods used during this study were conducted in accordance with approved procedures (WDEQ/WQD 2011). Water chemistry grab samples, depth profiles, Secchi disc transparency, and chlorophyll α were collected at all lake sites. Water chemistry grab samples were analyzed for alkalinity, total phosphorus (TP), nitrate+nitrite as nitrogen (NO_2+NO_3), total Kjeldahl nitrogen (TKN), ammonia, and total nitrogen (TN). Ammonia was only sampled during 2011. Water chemistry grab and chlorophyll α samples were collected one-half (0.5) meter below the surface at all lake sites. Additional chemistry grab samples were collected at or near the bottom at pelagic lake sites. At all lake sites, depth profiles for temperature, pH, dissolved oxygen (DO), and specific conductance were measured directly in the field with a Hach Hydrolab MS5 multi-parameter sonde. These parameters were collected every 0.5 m from the surface down to a depth of 3 m, and then every meter after that until the bottom of the lake was reached. Water chemistry grab samples and field parameters (temperature, pH, DO and specific conductance) were collected at the base of a riffle for all tributary and outlet sites, while discharge typically was measured in a glide feature. The wastewater lagoon effluent was sampled just prior to where it enters the unnamed tributary to Brooks Lake and its discharge rate was measured using a timed bucket-fill method. Only seven samples were collected from the lagoon effluent during 2009, 2011 and 2012 due to lack of flow on two occasions. Due to the remoteness of Upper Brooks Lake and Lower Jade Lake, samplers carried a soft cooler filled with wet ice to begin the cooling process for the water chemistry samples. Upon return to the vehicle, water chemistry samples were placed in a larger plastic cooler with wet ice.

During each sampling trip in 2012 samplers took temperature, pH, conductivity, and DO measurements at Brooks Lake Creek Outlet at dusk and dawn. The purpose of these extra measurements was to estimate the daily minimum and maximum for pH and DO. Sampling of Brooks Lake Creek also occurred with the purpose of trying to determine how far downstream the high pH values persisted. Two sites were sampled in the evening during 2012. Pinnacle Heights is approximately 4.5 stream miles downstream of Brooks Lake, while Above Waterfall is approximately 5.7 stream miles downstream of Brooks Lake. No measurements, besides those at Brooks Lake Creek- Outlet, were taken between Pinnacle Heights and Brooks Lake. Above Waterfall was only visited once, as samplers did not consider a measurement at that location to be informative unless pH at Pinnacle Heights exceeded 9.0.

Data Analysis

Data are directly compared to applicable water quality standards with acute and/or chronic numeric criteria. For water quality standards with narrative criteria, multiple lines of ‘credible data’ are evaluated using a weight-of-evidence approach (WDEQ/WQD 2013). The weight-of-evidence approach may include the use of several appropriate analytical procedures, statistical tests and/or validation data for determining attainment of water quality standards with narrative criteria (WDEQ/WQD 2014).

For Brooks Lake, interpretation of parameters without numeric or narrative aquatic life criteria (e.g. chlorophyll α, TP, TN, TKN and NO_2+NO_3), and identification of natural background conditions for some parameters with numeric criteria, suitable reference lakes within the Brooks lake watershed were used. While neither Upper Brooks Lake nor Lower Jade Lake replicate all the physical attributes of Brooks Lake, they collectively possess many characteristics of Brooks Lake. Together they inform an understanding of water quality expectations for Brooks Lake.

Carlson’s (1977) trophic state index (TSI) was utilized as a tool to compare productivity conditions within the study lakes. Carlson’s TSI is a quantitative way to assess the primary productivity of lakes and reservoirs. In three equations, algal biomass (a measure of primary production) is related to three water quality measures: secchi transparency, total phosphorus, and chlorophyll α. Therefore, the TSI score of a lake or reservoir derived from these relationships is an indicator of primary productivity. The TSI values are calculated as follows:

Total Phosphorus TSI (TSIP) = $14.42 * \ln(TP) + 4.15$
Chlorophyll α TSI (TSIC) = $9.81 * \ln(Chl\text{-}\alpha) + 30.6$
Secchi transparency TSI (TSIS) = $60 - 14.41 * \ln(SD)$

As a general reference, TSI classifies a waterbody into one of three trophic categories: oligotrophy, mesotrophy, or eutrophy based on scores that range from 0 (ultra-oligotrophic) to 100 (hyper-eutrophic). Oligotrophic (TSI<30) waterbodies are generally the least productive and typically are dominated by cold-water fishes, such as salmonids. Mesotrophic (40<TSI<50) waterbodies are more productive than oligotrophic systems, have moderately clear water, and can often support warm-water fisheries. Eutrophic systems (TSI>50) are the most productive, often contain nuisance amounts of macrophytes and algae, commonly have an anoxic hypolimnion, and are dominated by warm-water fisheries. The TSI calculated from chlorophyll α may be the best of the three for estimating algal biomass within a lake and priority should be given for its use as a trophic state indicator (Carlson 1977). Since the TSI was developed using a large data set of North American lakes, the TSI is not particularly reliable for determining an exact trophic state (oligotrophic, mesotrophic, eutrophic) of these study lakes, or departure from expected primary productivity, without placing values into a local geographic context. Therefore, we compared the TSI of Brooks Lake to the TSI of Lower Jade Lake and Upper Brooks Lake to estimate the departure from expected trophic state and primary productivity.

Nitrogen to phosphorus ratios can be utilized to infer what nutrient limits primary productivity within a waterbody (Dodds 2002), and were used as a tool to compare nutrient conditions within the study lakes. In order to infer nutrient limitation, boundaries must be established for nitrogen and phosphorus limitation. The Colorado Department of Public Health and Environment/Water Quality Control Division (CDPHE/WQCD) examined available literature (Table 2) and chose 20:1 as a lower boundary of phosphorus limitation and 5:1 as an upper boundary of nitrogen limitation (CDPHE/WQCD 2011).

Table 2. Boundaries for nutrient limitation, from CDPHE/WQCD (2011). Nitrogen limitation expected when TN:TP falls below the value in the first column, whereas phosphorus limitation is expected when TN:TP exceeds the value in the second column.

Upper Boundary of N-limitation	Lower Boundary of P-limitation	Source
9:1	22.6:1	Guildford and Hecky 2000
10:1	17:1	Sakamoto (cited in Smith 1982)
5:1	20:1	Thomann and Mueller 1987
5:1	20:1	Downing and McCauley 1994

Statistical tests of significance, including T-tests and regression analysis, were used to compare Brooks Lake to Upper Brooks Lake and Lower Jade Lake, with $p<0.05$ being considered significant for t-tests. In some instances Secchi disk data were omitted from analysis when the disk was visible resting on the bottom of the lake. Supplementary data and information, including WGFD fisheries data, baseflow nutrient concentration modeling, weather data from the Global Historical Climatology Network and University of Utah MesoWest online, and WDEQ files regarding Brooks Lake Lodge wastewater lagoons, were also used in the evaluation of Brooks Lake.

Quality Assurance and Quality Control

Monitoring data collected by WDEQ/WQD from Brooks Lake were collected in accordance with methods, procedures, and techniques listed in the Methods and Materials section of this report, standard operating procedures (WDEQ/WQD 2011), the Quality Assurance Project Plan (QAPP) (WDEQ/WQD 2001) and the Brooks Lake Sampling and Analysis Plan (WDEQ/WQD 2012). Chemical and physical data collected during 2009, 2011, and 2012 were evaluated using QAPP criteria. A thorough review of all data raised minor concerns due to two instances of field blank contamination and two duplicate samples whose relative percent differences (RPD) were unusually high. One field blank had 0.09 mg/L NO_2+NO_3 while another had 0.02 mg/L TP. For the field duplicates, an RPD of 76% was returned from original and duplicate sample results of 0.06 and 0.027 mg/L TP, and an RPD of 120% from original and duplicate sample results of 0.08 and 0.02 mg/L TP. Nonetheless, the data associated with these samples were found suitable for use in analysis because 1) WDEQ/WQD does not have numeric nutrient criteria in place for TP or NO_2+NO_3, therefore a waterbody use-support determination can't be made from the results of these samples alone, and 2) these data were analyzed collectively, with many other samples from Brooks Lake, to assess the relative impact of all contributing sources of nutrients to Brooks Lake, therefore the large-scale impact of these particular samples should be minor. All other data was determined to be complete and accurate.

Results

Water Chemistry Grab Samples

All results are in Appendix A. Reporting limits were identical in 2009 and 2011 for TN (100 µg/L), TP (10 µg/L), and TKN (100 µg/L). NO_2+NO_3 changed from 50 µg/L in 2009 to 10 µg/L in 2011. In 2012, reporting limits for alkalinity, TN, NO_2+NO_3, and TKN increased to 10 mg/L, 500 µg/L, 50 µg/L, and 500 µg/L, respectively due to a change in laboratories. For parameters below the reporting limit, one-half of the reporting limit was used for analyses.

Brooks Lake

Surface TP concentrations were similar among sites. Averages were 57.2 (range: 27-110), 53.4 (range: 27-71), 48.4 (range: 26-80), and 59.1 (range: 40-86) µg/L, for the Deep Quad, Inlet Quad, Outlet Quad, and Lodge Quad, respectively. The Lodge Quad is proximate to where the Brooks Lake Lodge effluent enters Brooks Lake. Generally speaking, the highest TP concentrations occurred during the early summer (July), presumably just prior to peak productivity. The second highest TP concentrations were in early fall (mid-late September), perhaps associated with lake overturn (Figure 4). Surface TN concentrations ranged from 50-1850 µg/L among Brooks Lake sites. No one site consistently had higher concentrations than the others. The greatest TN concentrations occurred during late summer (August) of 2011 and early summer of 2012 (Figure 5). Similar to surface TN concentrations, the surface TKN concentrations did not vary significantly by site and were greatest during late summer 2011 and early summer 2012. Surface NO_2+NO_3 concentrations were always near or below the reporting limit. Sample events with elevated TKN and corresponding low NO_2+NO_3 concentrations suggest the associated high TN concentrations on these days were of organic origin. Ammonia was not detected in any surface samples from Brooks Lake at a detection limit of 50 µg/L.

Figure 4. Box and whisker plot of Brooks Lake surface TP concentrations, grouped by season and categorized by year. Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.

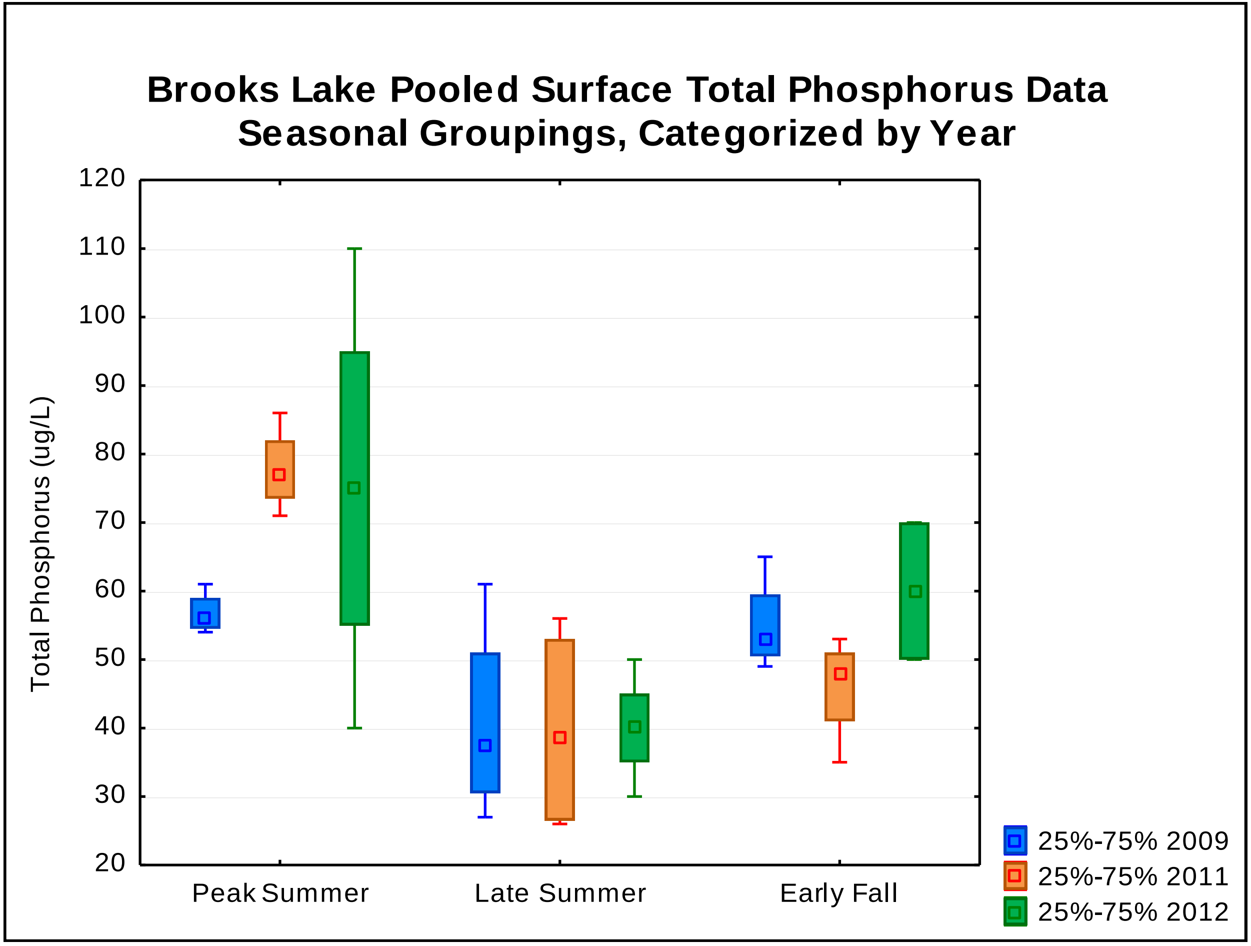
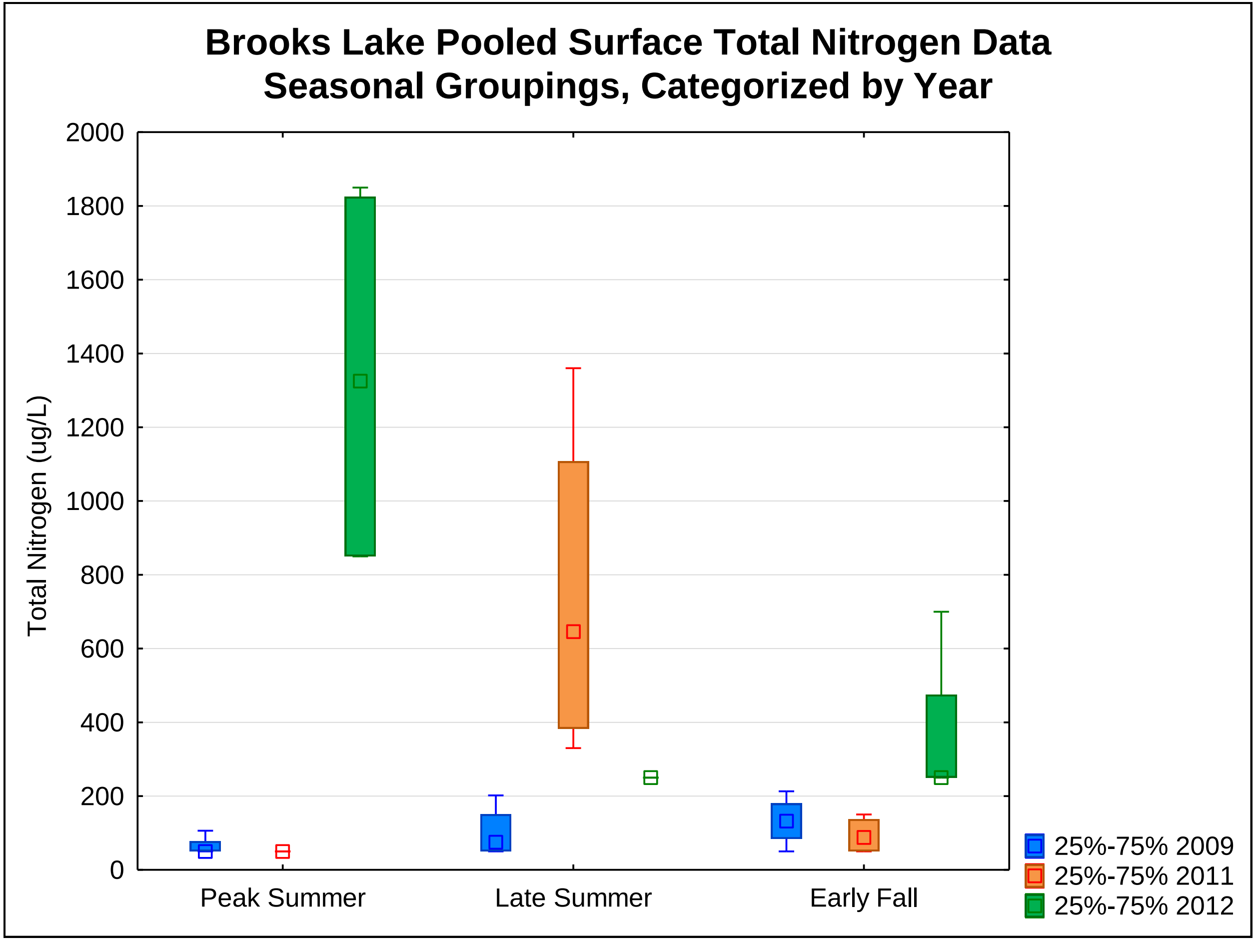


Figure 5. Box and whisker plot of Brooks Lake surface TN concentrations, grouped by season and categorized by year. Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.



Bottom TP concentrations were more variable between sites, with the deepest sites having the greatest concentrations of TP. The greatest TP concentration (400 µg/L) was in the Deep Quad on 9/11/12. Seasonal variation was only apparent in the Deep Quad, where the early summer samples always had the lowest TP concentrations while the later fall samples exhibited greater concentrations. The greatest bottom TN concentration (950 µg/L) occurred in the Outlet Quad on July 24, 2012. Similar to bottom TP concentrations, the bottom TN concentrations in the Deep Quad were greatest during the fall sampling events and lowest during the earlier summer sampling events. Overall, bottom TKN concentrations were greatest in the Deep Quad. Seasonally, the greatest TKN concentrations in the Deep Quad occurred during fall sampling events. The greatest bottom TKN concentration (906 µg/L) was found in the Deep Quad on September 21, 2009. Bottom NO_2+NO_3 concentrations were generally low, but were greatest in the Deep Quad. The greatest NO_2+NO_3 concentration (180 µg/L) was found on August 17, 2009 in the Deep Quad. Ammonia was below the reporting limit for all bottom samples in 2011 with the exception of three samples. All of these detections occurred in the Deep Quad and were 100, 170, and 190 µg/L. These values were all below applicable ammonia toxicity criteria for fish with early life stages present (WDEQ/WQD 2013).

Alkalinity is a measure of the capacity of a waterbody to buffer against changes in pH. For all sites on Brooks Lake, alkalinity averaged 31.7 mg/L with no apparent spatial or temporal variation.

Reference Lakes

All TKN and TN samples in Lower Jade Lake and Upper Brooks Lake were below the reporting limit (<500 µg/L). In both Upper Brooks Lake and Lower Jade Lake, all NO_2+NO_3 concentrations were at or below the reporting limit (<50 µg/L). Surface TP concentrations were greater in Upper Brooks Lake than in Lower Jade Lake. In general, surface TP concentrations were highest during early summer followed by late fall. Bottom TP concentrations were greater, on average, in Lower Jade Lake (110 µg/L, range: 70-180) than in Upper Brooks Lake (76.7 µg/L, range: 60-90). Bottom TP concentrations in both lakes were always greatest during early summer followed by late fall. To compare reference condition hypolimnetic TP concentrations to Brooks Lake, another stratifying waterbody, Lower Jade Lake, was utilized. Additionally, only data from the Deep Quad in Brooks Lake was used, because it is much more similar in depth and stratification tendencies than the other quads in Brooks Lake. Hypolimnetic TP concentrations were found to be significantly greater in Brooks Lake than in Lower Jade Lake (t(10)=2.3213, p=0.043). Lake stratification and subsequent anoxic hypolimnion causes a release of bound phosphorus from sediment which can often be the main summer phosphorus load to lakes (Nürnberg 2009). The same statistical analysis for TN revealed no significant difference between Brooks Lake and Lower Jade Lake hypolimnetic TN concentrations, although all Lower Jade Lake hypolimnetic TN concentrations were below the detection limit of 500 µg/L (t(10)=1.38, p=0.197).

Alkalinity concentrations were similar between the two lakes, with Upper Brooks Lake (41.7 mg/L, range: 35-50) having a slightly greater average than Lower Jade Lake (38.9 mg/L, range: 30-45).

Inlets and Outlets

Brooks Lake - Of the four tributaries to Brooks Lake with multiple sample collections, the Horse Corral tributary had the highest average TP concentration (170, range: 160 – 180 µg/L), followed by Unnamed tributary (89.6, range: 72-110 µg/L) , Brooks Lake Creek (89.6, range: 72-100 µg/L) and Bonneville Creek (65.4, range: 51-90 µg/L). The sole sample collected at Unnamed Tributary East in August 2012 exhibited a TP concentration of 100 µg/L, which was similar to TP concentrations in Brooks Lake Creek inlet and Unnamed Tributary on the same date of sampling. The outlet stream, Brooks Lake Creek, exhibited the lowest average TP concentration (45.8, range: 20-100 µg/L) relative to the five tributaries. TP concentrations were generally greatest during late fall in Bonneville Creek and Brooks Lake Creek inlet, while TP concentrations in Brooks Lake Creek outlet were highest during early summer. No consistent seasonal variation was evident in Unnamed tributary. The Horse Corral tributary had the highest average TN concentration as well (1250, range: 500-2000 µg/L). TKN and TN concentrations in Horse Corral Tributary were the same, therefore the nitrogen was in organic form. The majority of TN and TKN concentrations in Brooks Lake Creek, Unnamed Tributary, and Bonneville Creek were below the reporting limit, with all samples at a reportable concentration occurring during the month of September. Brooks Lake Creek outlet had detectable total nitrogen on a more frequent basis than the three main inlets, although the majority of detections were relatively low concentrations overall. The two greatest total nitrogen concentrations at this site occurred in July 2012 (1850 µg/L) and August 2012 (900 µg/L). All NO_2+NO_3 concentrations for the five tributary inlets to Brooks Lake and the Brooks Lake Creek outlet were at or below the reporting limit (≤50 µg/L). The few NO_2+NO_3 samples that had reportable concentrations all occurred during early summer.

Brooks Lake Creek had the greatest average flow of the tributaries (11.91, range: 3.55-31.46 cfs), followed by Bonneville Creek (6.91, range: 0.85-32.74 cfs), Unnamed tributary (5.39, range: 1.22-20.99 cfs), and Horse Corral tributary (0.025, range: 0.01-0.04 cfs). During the single visit to Unnamed Tributary East flow was 0.15 cfs. Brooks Lake Creek outlet averaged 28.54 cfs (range: 5.76-100.51). On average, sampled inflow to Brooks Lake accounted for 92% (range: 73-130%) of the measured outflow.

Brooks Lake Creek outlet generally had the highest pH, DO concentration and percent saturation of all the inlets and outlets. Super-saturated DO conditions and pH well in excess of 9.0 were commonly measured. Brooks Lake Creek inlet occasionally had pH greater than 9.0, as well as super-saturated DO conditions. Bonneville Creek had one pH value that was much lower than expected, 6.33, which occurred on 7/15/09. Other tributaries' pH on this day were also relatively low, however no others were below 6.50. Brooks Lake Creek inlet, Bonneville Creek, Unnamed tributary, and Horse Corral tributary were occasionally below 8 mg/L DO, but always maintained percent saturations of at least 86%. All other field parameter results fell within ranges that would be expected.

Reference Lakes - Total phosphorus concentrations were similar among inlet and outlet sites at Upper Brooks Lake and Lower Jade Lake. TP concentrations did not vary greatly seasonally, but were generally highest during the early summer sampling event and lowest during the early fall sampling event. NO_2+NO_3 concentrations varied more among the Upper Brooks Lake and Lower Jade Lake inlets and outlets with the highest concentrations at the Lower Jade Lake outlet (range: <50-100 µg/L). The NO_2+NO_3 concentrations in Lower Jade Lake were generally higher at the outlet than at the inlet. NO_2+NO_3 concentrations at the Upper Brooks Lake inlet were fairly similar. Similar to TP, NO_2+NO_3 concentrations were generally greatest during early summer and lowest during early fall. All TN and TKN samples for the reference lake inlets and outlets were below the reporting limit of 500 µg/L. Alkalinities were very similar for Lower Jade Lake inlet, Lower Jade Lake outlet, Upper Brooks Lake inlet, and Upper Brooks Lake outlet.

Flows for the reference lake inlets and outlets averaged 2.08 cfs (range: 1.38-2.54) at Upper Brooks Lake inlet, 2.87 cfs (range: 1.89-3.8) at Upper Brooks Lake outlet, 0.27 cfs (range: 0.19-0.38) at Lower Jade Lake inlet, and 1.27 cfs (range: 1.03-1.51) at Lower Jade Lake outlet.

Upper Brooks Lake outlet generally had the highest pH, D.O. concentration and percent saturation of all reference lakes inlets and outlets. Both measured pH values in Upper Brooks Lake outlet were above 9.0. Super-saturated D.O. conditions were present during both sampling events at this site. The inlet to Lower Jade Lake was below 8 mg/L D.O. during all visits, but maintained percent saturation of at least 97%.

Brooks Lake Creek Outlet – Diurnal Field Measurements - The greatest dissolved oxygen and pH values occurred during the July 2012 event. In August, the dawn pH was slightly higher than the previous nights' pH, and may be attributable to the natural variability expected with a pH probe measurement. Dissolved oxygen was the lowest during the September dawn event. This event was also the first time the pH dropped below 9.0. A DO concentration of 6.88 mg/L (85.5% sat.) coupled with the pH decrease suggests photosynthetic activity had decreased and bacterial decomposition of organic material had accelerated respiration. No diurnal measurements were conducted at any lake site. Table 3 below presents all results from this sampling.

Table 3. Dawn and dusk monitoring results at Brooks Lake Creek- Outlet.

Date	Time	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Dissolved Oxygen (% sat.)
7/24/12	20:27	17.2	9.97	70	11.53	163.7
7/25/12	6:11	15.96	9.89	64.9	10.07	139.4
8/21/12	20:19	16.99	9.51	63	8.62	122.3
8/22/12	6:40	15.11	9.62	61.7	7.14	97.69
9/11/12	20:12	12	9.38	61.8	7.72	98.5
9/12/12	6:42	10.87	8.60	60.5	6.88	85.5

Pinnacle Heights pH measurements ranged from 8.12-8.42, while D.O. ranged from 7.24-8.08 mg/L on 3 visits. The photo below captured abundant filamentous algal growth in Brooks Lake Creek, and was taken approximately 0.5 stream miles downstream of Brooks Lake on 8/21/12.

Figure 6. Photo of Brooks Lake Creek approximately one-half mile below Brooks Lake, on August 21, 2012.

Wastewater Lagoon Effluent

The average TKN concentration in the Brooks Lake Lodge wastewater lagoon effluent was 6583 µg/L (range: 2320-14,000 µg/L), while the average NO_2+NO_3 concentration was 3116 µg/L (range: 10-17,900 µg/L), TN was 9694 µg/L (range: 2430-31,900 µg/L), ammonia was 1800 µg/L (range: 600-3000 µg/L), and TP was 602 µg/L (range: 370-990 µg/L). Ammonia concentrations did not exceed applicable aquatic life criteria (WDEQ 2013). Effluent flow from the lagoons averaged 0.0067 cfs (range: 0.0003-0.02 cfs) though does not flow continuously as no flow was observed on two occasions (9/21/09 and 9/20/11). Average flow during snowmelt time (0.011 cfs) was greater than both summer (0.006 cfs) and fall (0.0005 cfs) seasons.

Nutrient Loads

While nutrient concentration data are helpful and useful for identifying pollutant sources, nutrient loads (lbs/day) better represent the relative magnitude of contributing sources. Discharge was measured at each inlet and outlet along with each nutrient sample so that nutrient loads could be estimated. The following formula was used to convert nutrient concentrations (mg/L) to nutrient loads (lbs/day):

$L = C * Q * 5.382457$
Where:
Q = Discharge (ft^3/s)
L = Nutrient load (lbs/day)
C = Nutrient concentration (mg/L)
Conversion factor derived from: $(86{,}400 s/day)*(28.3168 L/ft^3)*(kg/1{,}000{,}000 mg)*(2.20 lb/kg)$

Box and whisker plots in Figures 7-10 present daily loads of the four nutrient parameters observed in all tributaries and the outlet of Brooks Lake. Despite providing the most nutrient-rich inflow to Brooks Lake, the Brooks Lake Lodge effluent contributed some of the smallest daily nutrient loads to Brooks Lake for all nutrient parameters. Horse Corral tributary also provided small daily nutrient loads. Brooks Lake Creek inlet contributed the largest daily nutrient loads to Brooks Lake, which is mostly due to its greater flow. Brooks Lake Creek generally carried a greater daily nutrient load leaving Brooks Lake than it did upon entry into Brooks Lake. Some seasonal variation was evident in daily nutrient loads delivered to Brooks Lake, as the largest loads generally occurred earlier in the season during snowmelt periods. All daily nutrient loads are presented in Table 4.

Figure 7. Total phosphorus daily loads for inlets and outlets of Brooks Lake 2009-2012. Site abbreviations are consistent with Table 1. Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.

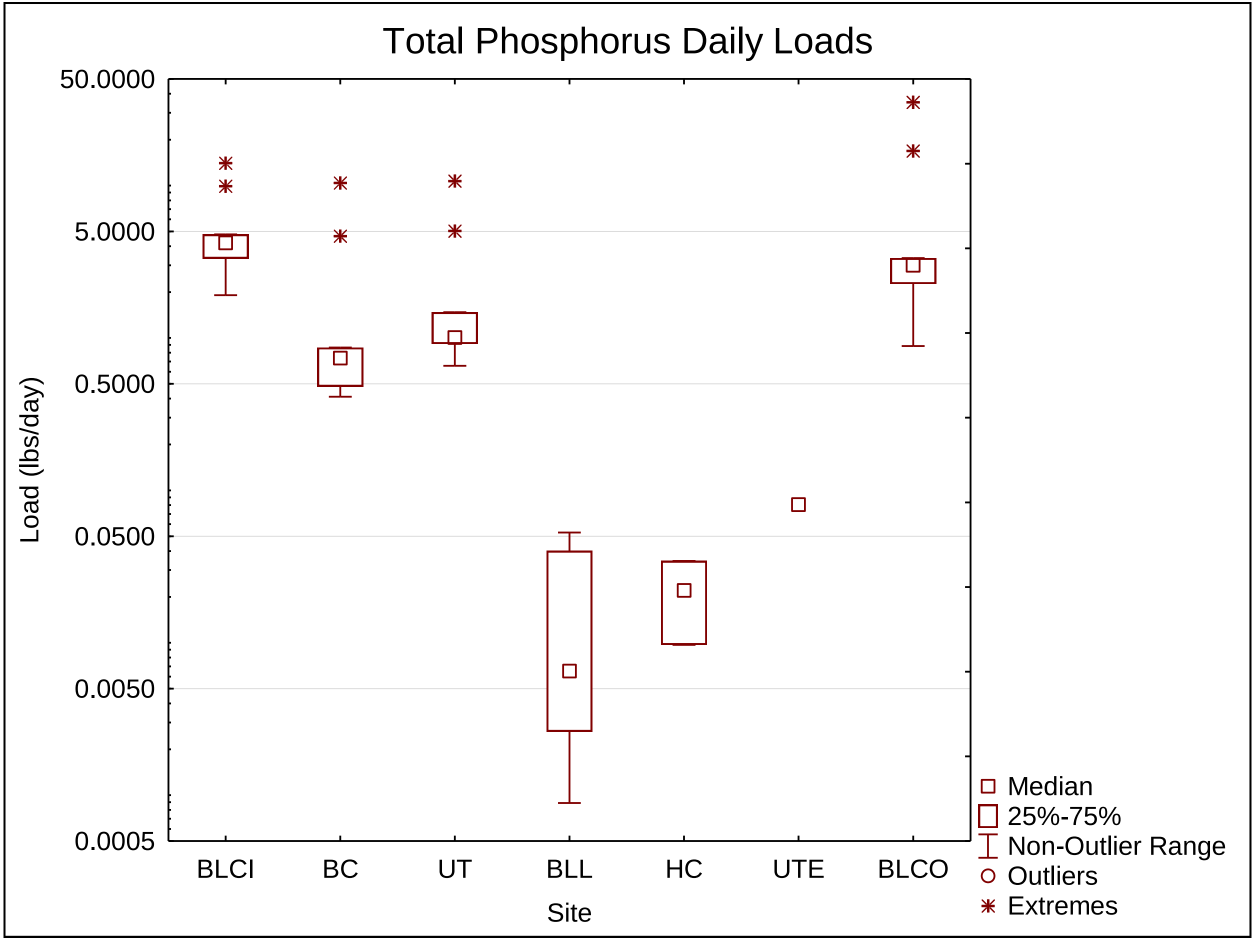


Figure 8. Total nitrogen daily loads for inlets and outlets of Brooks Lake 2009-2012. Site abbreviations are consistent with Table 1. Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.

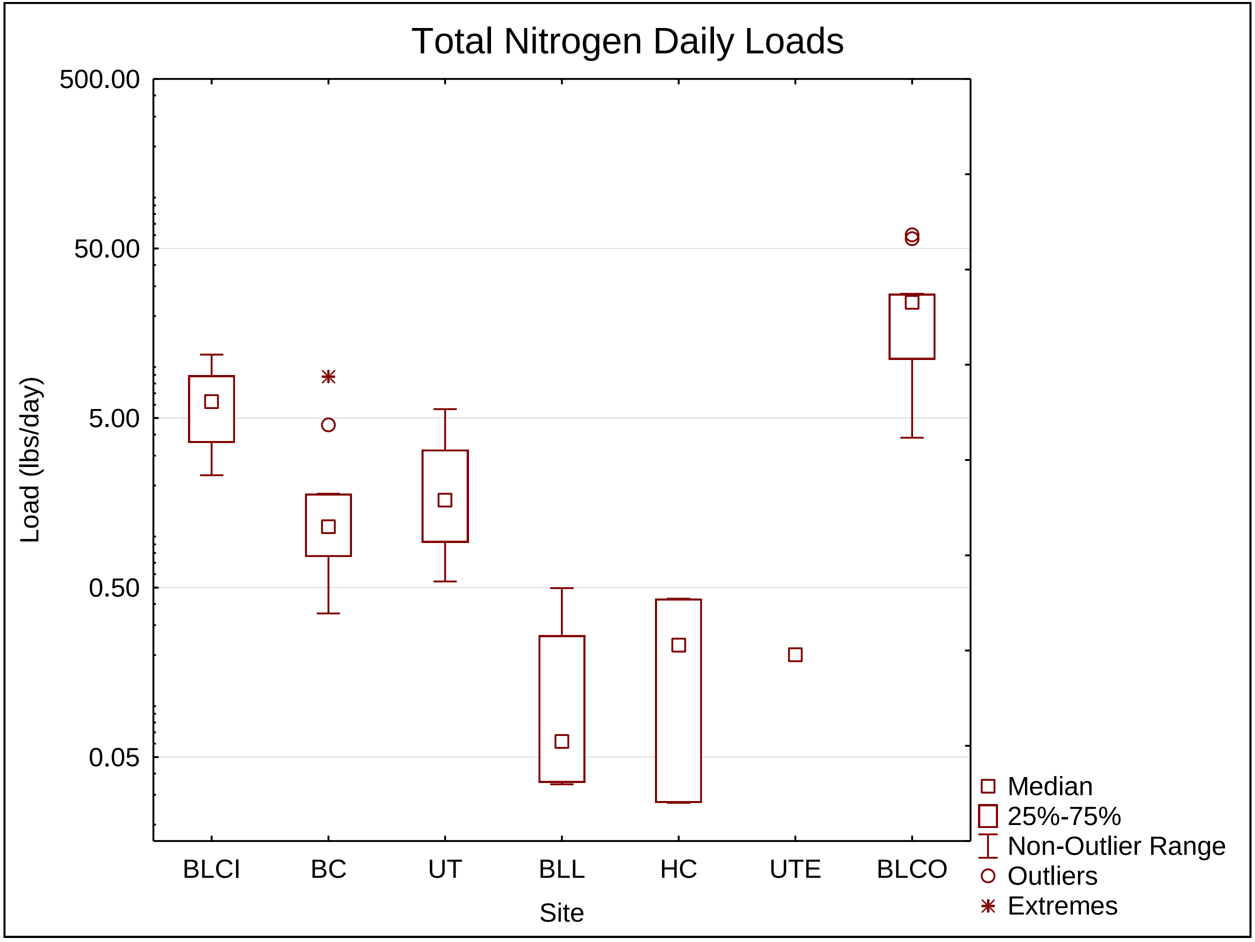


Figure 9. Nitrate+nitrite daily loads for inlets and outlets of Brooks Lake 2009-2012. Site abbreviations are consistent with Table 1. Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.

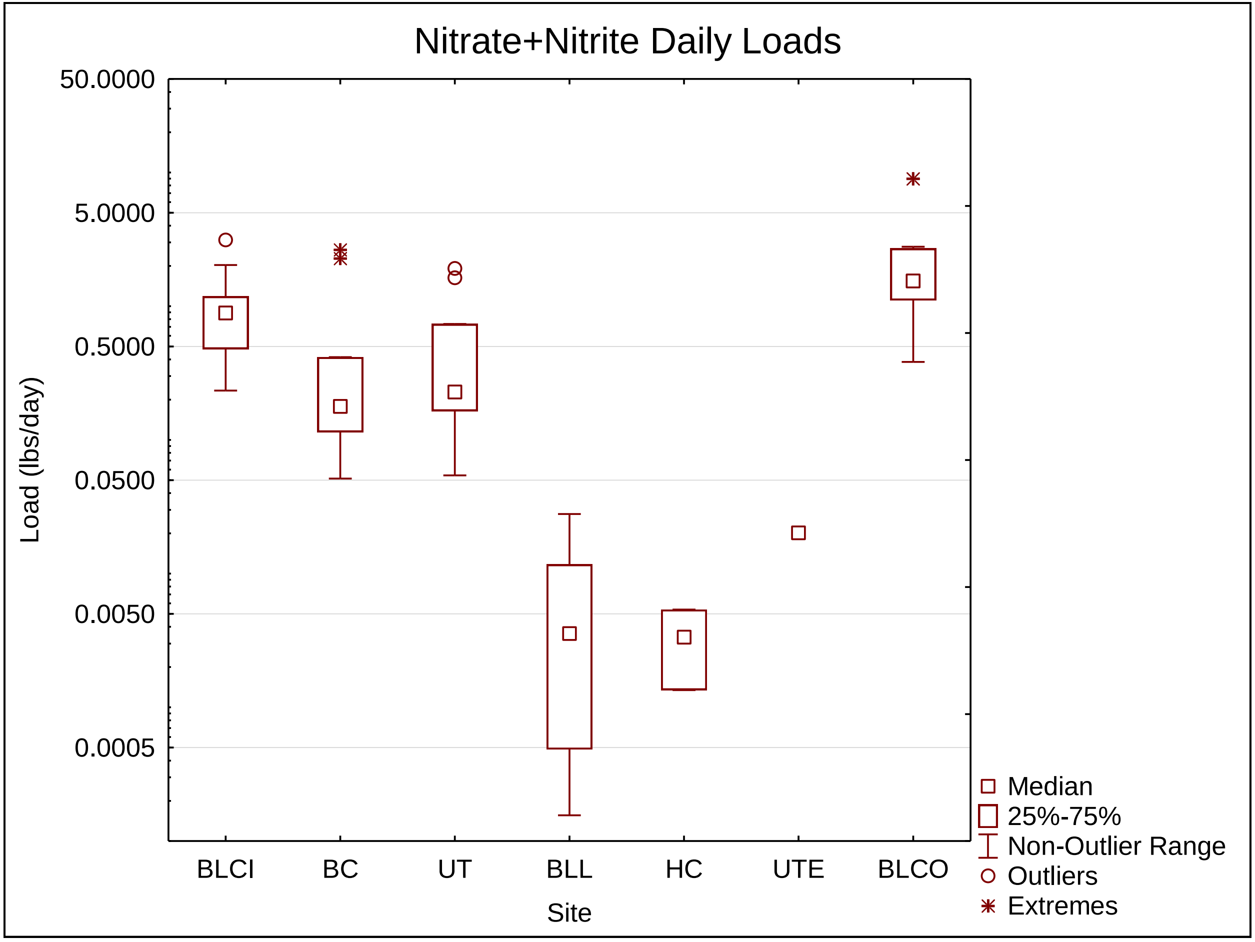


Figure 10. Total Kjeldahl Nitrogen daily loads for inlets and outlets of Brooks Lake 2009-2012. Site abbreviations are consistent with Table 1. Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.

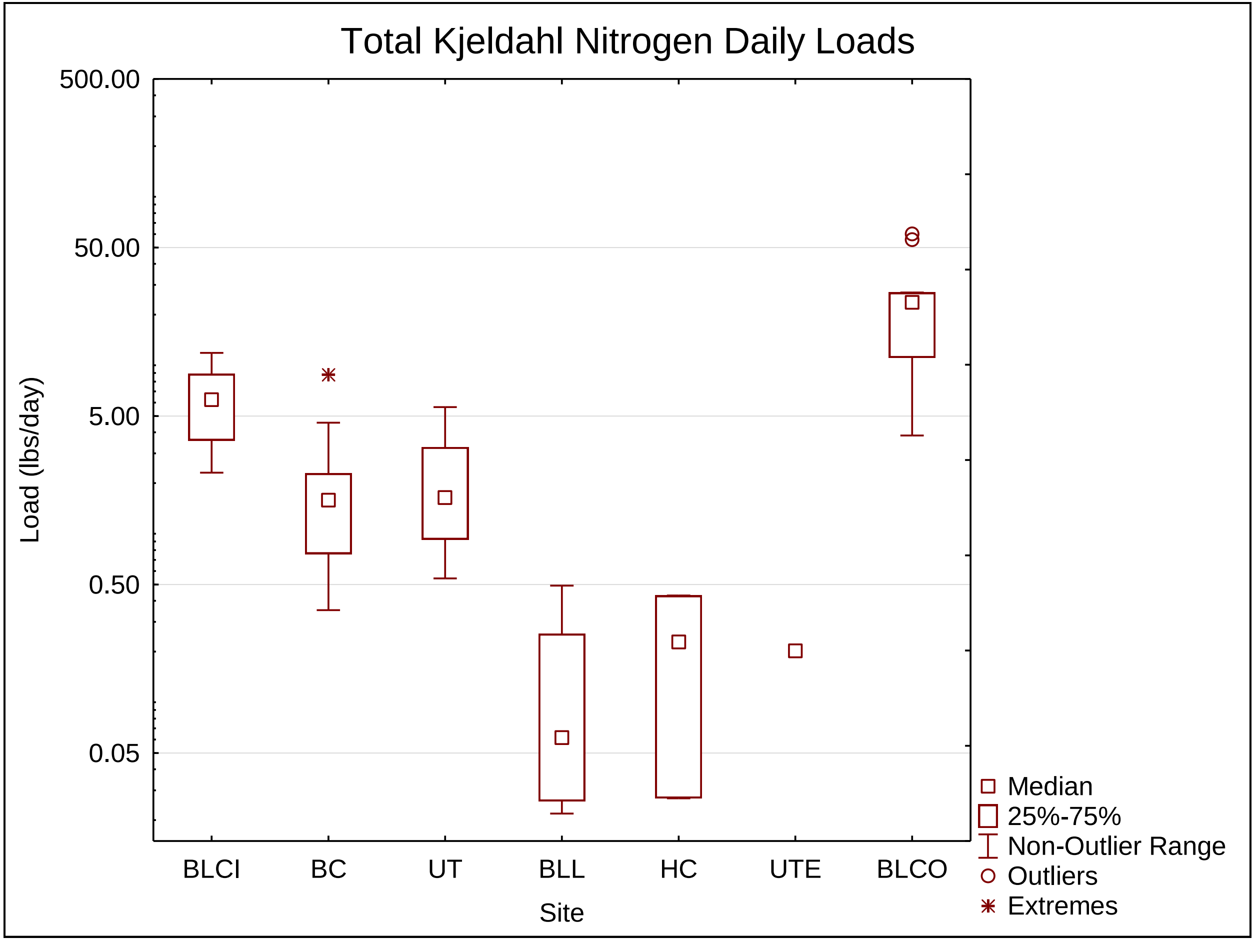


Table 4. Daily nutrient loads for inlets and outlets of Brooks Lake.

	Total Phosphorus Daily Load (lbs/day)	Total Nitrogen Daily Load (lbs/day)	Nitrate+Nitrite Daily Load (lbs/day)	Total Kjeldahl Nitrogen (lbs/day)
Brooks Lake Creek Inlet				
7/15/09	9.90	6.27	3.13	6.27
8/17/09	3.32	2.30	1.15	2.30
9/21/09	2.20	3.57	0.69	3.57
7/25/11	14.05	8.46	2.03	8.46
9/6/11	4.78	9.32	0.30	8.90
9/20/11	4.21	2.34	0.23	2.34
7/24/12	1.91	4.77	0.48	4.77
8/21/12	4.27	11.85	1.18	11.85
9/11/12	3.57	8.93	0.89	8.93
Bonneville Creek				
7/15/09	4.65	4.56	2.28	4.56
8/17/09	0.86	0.83	0.42	0.83
9/21/09	0.48	0.35	0.18	0.35
7/25/11	10.39	8.81	2.64	8.81
9/6/11	0.86	0.76	0.08	0.76
9/20/11	0.74	0.51	0.05	0.51
7/24/12	0.44	1.59	0.32	1.59
8/21/12	0.50	1.79	0.18	1.79
9/11/12	0.41	1.14	0.11	2.29
Unnamed Tributary				
7/15/09	5.03	3.27	1.63	3.27
8/17/09	1.33	0.92	0.46	0.92
9/21/09	0.88	1.34	0.23	1.34
7/25/11	10.73	5.65	1.92	5.65
9/6/11	1.01	0.70	0.07	0.70
9/20/11	0.91	0.54	0.05	0.54
7/24/12	1.47	3.68	0.74	3.68
8/21/12	0.97	2.21	0.22	2.21
9/11/12	0.66	1.64	0.16	1.64
Wastewater Effluent				
7/15/09	0.040	0.26	0.0117	0.25
8/17/09	0.024	0.26	0.0026	0.26
7/25/11	0.007	0.03	0.0005	0.03
9/6/11	0.006	0.06	0.0002	0.06
7/24/12	0.053	0.50	0.0036	0.49
8/21/12	0.001	0.05	0.0279	0.02
9/11/12	0.003	0.04	0.0096	0.03
Horse Corral Tributary				
8/21/12	0.03	0.43	0.005	0.43
9/11/12	0.01	0.03	0.001	0.03
Unnamed Tributary East				
8/21/12	0.08	0.20	0.02	0.20
Brooks Lake Creek Outlet				
7/15/09	16.85	17.92	8.96	17.92
8/17/09	3.00	24.14	2.78	23.58
9/21/09	2.26	8.48	1.25	8.48
7/25/11	35.14	27.03	2.70	27.03
9/6/11	2.26	26.49	0.51	25.88
9/20/11	2.76	3.83	0.38	3.83
7/24/12	3.10	57.32	1.55	55.77
8/21/12	3.34	60.13	1.67	60.13
9/11/12	0.89	11.07	1.11	11.07

Average Annual Loads

To take nutrient loading one step further, an annual nutrient loading budget was estimated for Brooks Lake. For this analysis, three seasons were assumed: snowmelt, summer, and fall. For each inlet/tributary to Brooks Lake the average flow for each season was calculated, as well as the average TP, TN, TKN, and NO_2+NO_3 concentration during each season. Since monitoring only occurred once at Unnamed Tributary East and twice at Horse Corral tributary, we estimated flow at these sites for the missing seasons. To do this, the proportion of snowmelt, summer, and fall flows to each other at the three main inlets (Brooks Lake Creek, Bonneville Creek, and Unnamed Tributary) were used to estimate flows at these sites during seasons when monitoring didn't occur. For example, summer flows at the three main inlets were, on average, 1.44 times (range: 1.18-1.58) greater than fall flows. Therefore, from a summer flow at Unnamed Tributary East of 0.15 cfs, it was estimated the fall flow was 0.10 cfs (0.15/1.44). Estimates for snowmelt flows at Unnamed Tributary East and Horse Corral tributary were made using this method. Table 5 provides average flow and nutrient concentration by season for each inflow to Brooks Lake. Sampling events were grouped by season as follows:

Snowmelt: 7/15/09 and 7/25/11
Summer: 8/17/09, 9/6/11, 7/24/12, and 8/21/12
Fall: 9/21/09, 9/20/11, and 9/11/12

From this information a monthly load for each site-season could be calculated using the following formula:

$M = Q * C * 0.1614737$
Where:
M= Monthly load (lbs/month)
Q= Average discharge (ft^3/s)
C= Average concentration (μg/L)
Conversion factor derived from: (2,592,000s/month)*(28.3168L/ft^3)*(kg/1,000,000,000μg)*(2.20lb/kg)

For simplicity, it was assumed there were 30 days in a month. Next, months were assigned a season based on best professional judgment of what flow conditions best represented actual field conditions during each month of the year. It was assumed that negligible flow occurred during January, February, and March. The wastewater lagoons typically discharge for six months out of the year, which was taken into account when an average annual load was estimated. Available discharge monitoring report (DMR) flow data during January, February, and March was averaged to estimate flow during winter months, and average nutrient concentrations from WDEQ/WQD sampling in 2009, 2011, and 2012 was used as an estimate for nutrient concentrations during winter months. Months were assigned a season as follows:

Snowmelt: May, June, and July
Summer: August
Fall: September, October, November, December, and April
Winter: January, February, March

Finally, the monthly loads by season were utilized to calculate an annual nutrient load for each site. Figures 11-14 show the annual nutrient budget for Brooks Lake and Table 5 gives average flow and nutrient concentration data by season that was used for calculation of average annual nutrient loads.

Table 5. Average flow and nutrient concentrations by season for all inflows to Brooks Lake. Data used to compute average annual nutrient loads to Brooks Lake.

	Average Flow (cfs)	Average TP (µg/L)	Average TN (µg/L)	Average NO_2+NO_3 (µg/L)	Average TKN (µg/L)
Brooks Lake Creek Inlet					
Snowmelt	27.38	81	50	18.5	50
Summer	8.01	85.5	176.5	20	174.8
Fall	6.81	90	143.3	18.3	143.3
Bonneville Creek					
Snowmelt	24.85	55	50	20	50
Summer	2.11	62.25	150	26.25	150
Fall	1.36	76.67	116.67	18.33	200
Unnamed Tributary					
Snowmelt	16.57	86	50	21	50
Summer	2.60	88.5	150	26.25	150
Fall	1.65	93.33	148.67	18.33	148.67
Unnamed Tributary East					
Snowmelt	1.08	100	250	25	250
Summer	0.15	100	250	25	250
Fall	0.10	100	250	25	250
Horse Corral Tributary					
Snowmelt	0.29	160	2000	25	2000
Summer	0.04	160	2000	25	2000
Fall	0.01	180	500	25	500
Wastewater Effluent					
Snowmelt	0.011	490.5	2822.5	77	2745
Summer	0.006	561	12,202.5	4505	7697.5
Fall	0.00049	990	13,400	3640	9800
Winter	0.00791	602.1	9693.6	3116.3	6582.9

Figure 11. Estimated annual total phosphorus load delivery to Brooks Lake from inflows and tributaries.

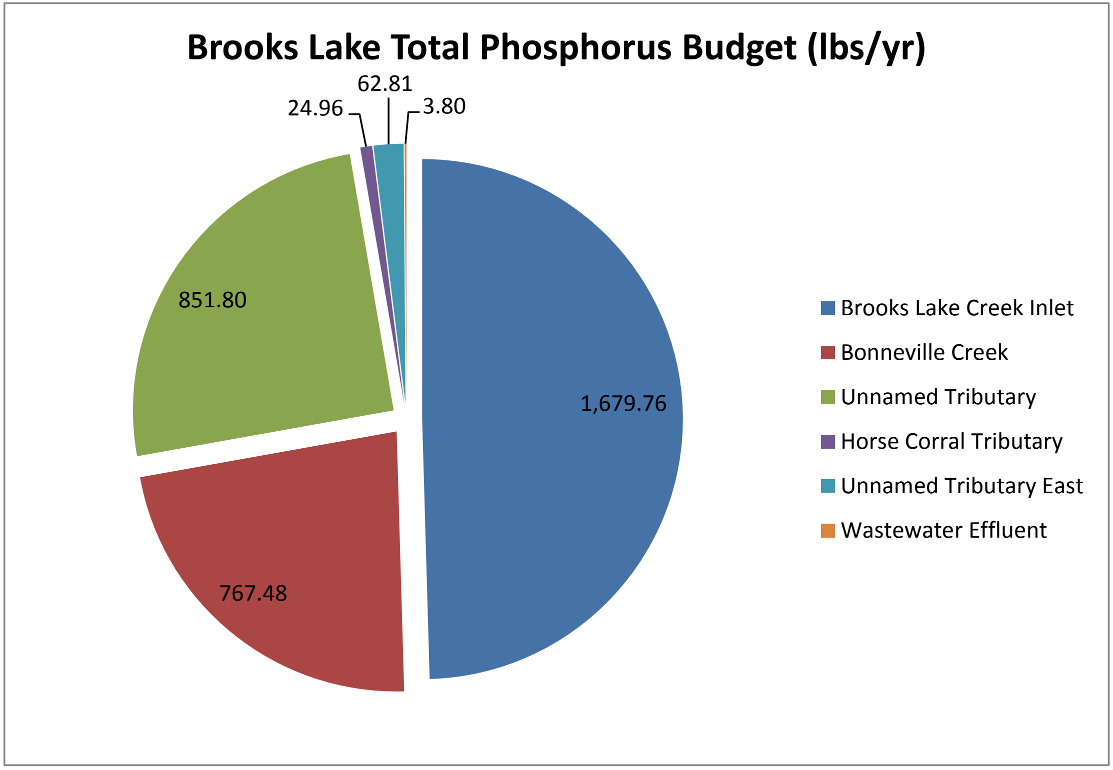


Figure 12. Estimated annual total nitrogen load delivery to Brooks Lake from inflows and tributaries.

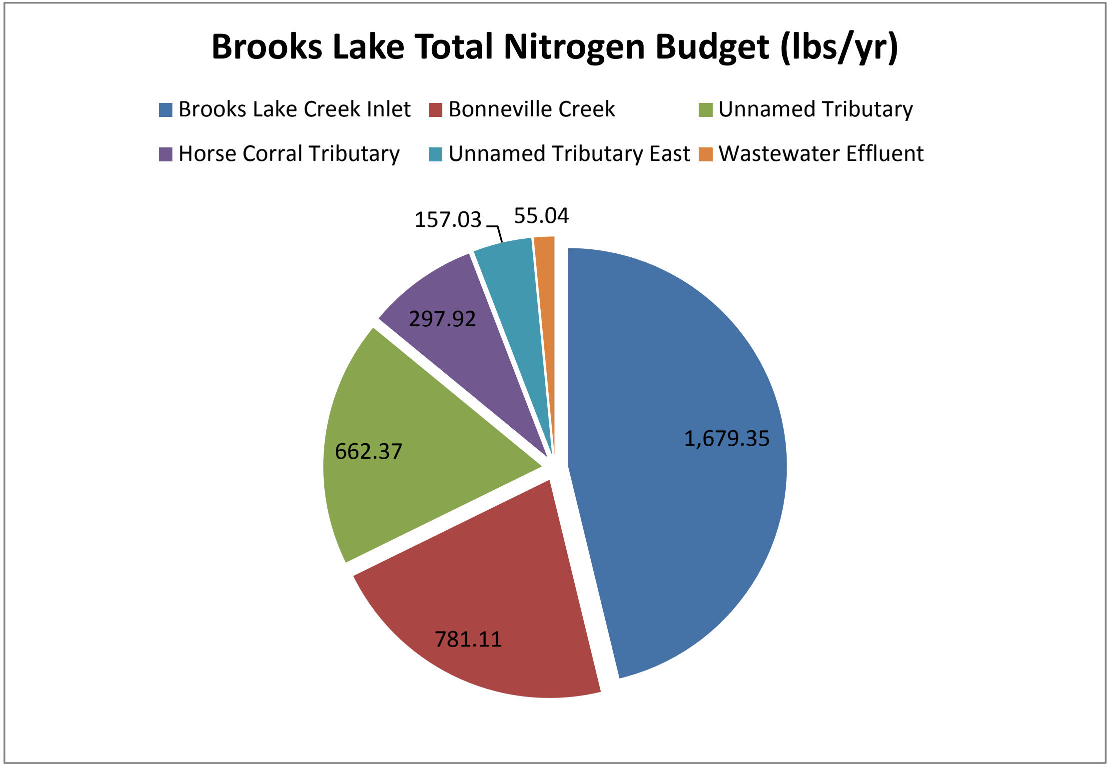


Figure 13. Estimated annual NO_2+NO_3 load delivery to Brooks Lake from inflows and tributaries.

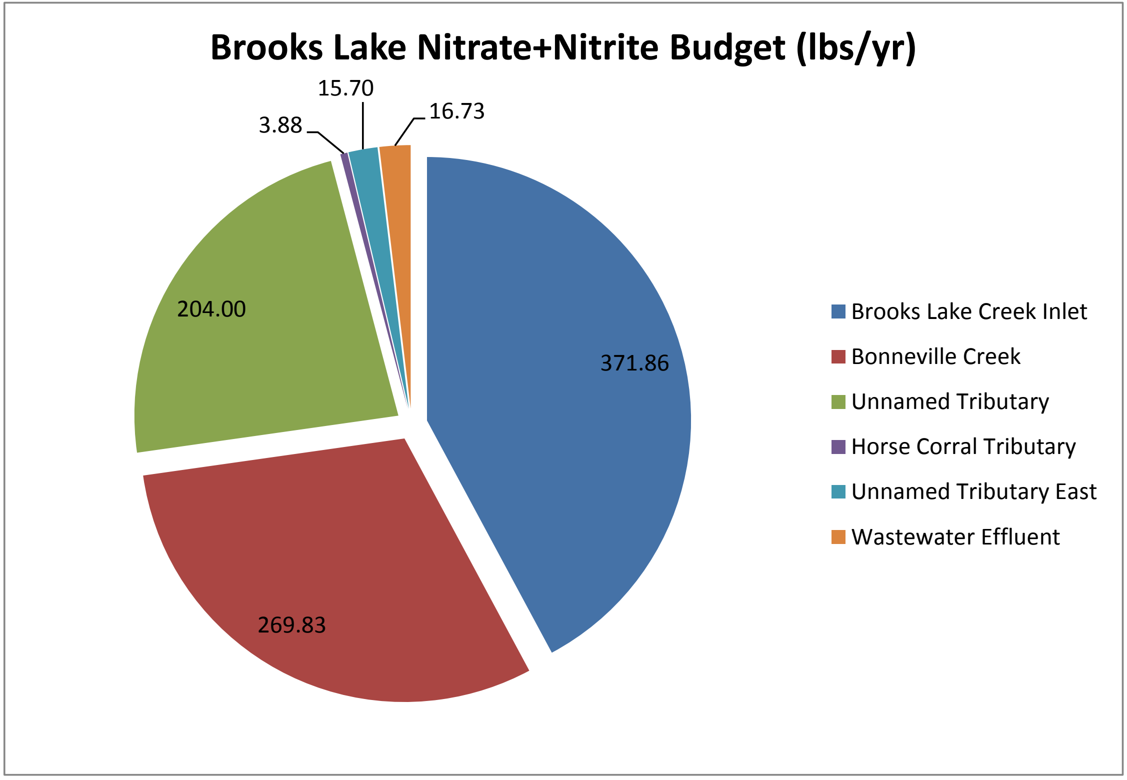
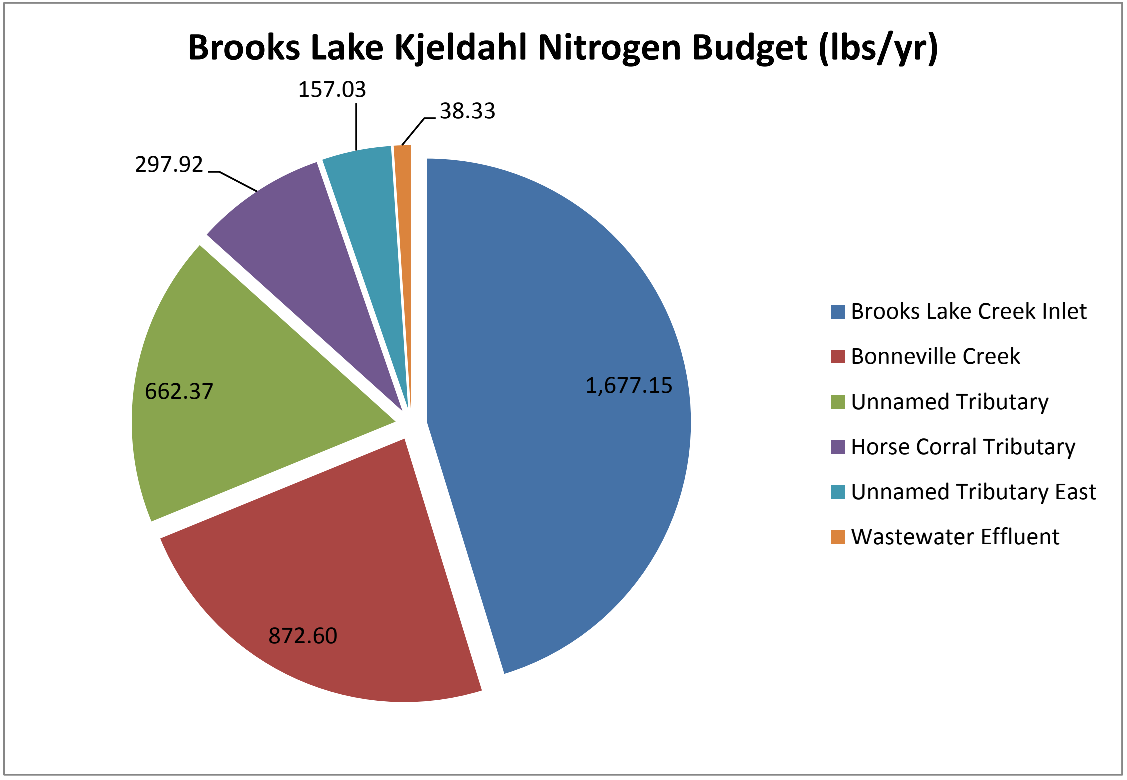


Figure14. Estimated annual TKN load delivery to Brooks Lake from inflows and tributaries.



The results of this average annual nutrient load analysis reveal that Brooks Lake Creek, Bonneville Creek, and Unnamed Tributary are the three main sources of nutrients to Brooks Lake. It is noteworthy that for these three main tributaries, nearly all total nitrogen samples were below the reporting limit. Therefore, as previously stated in Methods and Materials, one-half of the reporting limit was utilized for analysis. A closer look at the data reveals that when total nitrogen was detected above the reporting limit in the three main tributaries, it was never greater than 156 µg/L. The TN reporting limit in 2012 was 500 µg/L, which means 250 µg/L was used in analysis for those non-detect values. This likely resulted in a significant overestimation of the average annual total nitrogen load for those three main tributaries. Therefore, an additional analysis of average annual total nitrogen loads was provided in order to understand the relative contribution of each source, while utilizing less conservative assumptions. For this analysis, we altered two elements. First, instead of using 50% of the reporting limit for non-detect values we used 20% of the reporting limit for analysis. This should be a more accurate estimate of in-stream conditions when concentrations of total nitrogen were below the reporting limit, particularly because of a high reporting limit (500 µg/L) in 2012. Second, the design flow (12,500 gallons/day) of the wastewater lagoons was utilized in our calculations. This flow represents the potential flow from the lagoons, and may be a more accurate estimate if significant wastewater interaction with groundwater is occurring. The intent of this additional analysis is to understand the relative magnitude of each total nitrogen source under less conservative assumptions.

Results of the additional analysis suggest the total nitrogen load to Brooks Lake was overestimated in the first analysis, and may be closer to 2000 lbs/yr. Of the 2000 lbs, approximately 180 lbs is from the wastewater lagoons and 298 lbs is from Horse Corral Trib, which means human influenced sources in Brooks Lake could collectively be accounting for around 478 lbs (24%) of the total nitrogen budget to Brooks Lake. For the three main tributaries, their loading is 845 lbs for Brooks Lake Creek, 312 lbs for Bonneville Creek, and 304 lbs for Unnamed Tributary. A small load of 63 lbs is delivered by Unnamed Tributary East. Since the majority of the nitrogen in Brooks Lake was in organic form, it is also likely the original average annual TKN load calculation overestimated the annual TKN budget in Brooks Lake.

While the above additional analysis better estimated the relative magnitude of each total nitrogen source under less conservative assumptions, it is also appropriate to assess all sources with more conservative assumptions. We ran one more analysis using 100% of the reporting limit for TN non-detect values, and utilized the design flow of the wastewater lagoons in our flow estimates. Results of this analysis suggest the total nitrogen load to Brooks Lake may be 6684 lbs/yr. This lowered the overall percent of the total nitrogen load that human influenced sources accounted for to 7%. Taking into account both additional analyses, it seems probable that human influenced sources account for approximately 7-24% of the annual total nitrogen load to Brooks Lake.

Chlorophyll α

Chlorophyll α provides an estimate of the amount of algal production (photosynthetic activity) in a reservoir or lake and can be an indicator of nutrient enrichment. For this study, chlorophyll α was only collected in 2011 and 2012.

Brooks Lake

In 2011, the average chlorophyll α concentration at all lake sites in Brooks Lake was 15.1 mg/m^3 and ranged from 3.6 – 40 mg/m^3. No one site consistently had the highest or lowest concentrations of chlorophyll α. Chlorophyll α concentrations varied seasonally, as expected, and were greatest during the 9/6/11 sampling event (Figure 15). Dissolved oxygen concentrations, pH, and TN concentrations were also greatest in 2011 during the late summer (9/6/11) sampling event.

Brooks Lake exhibited much greater chlorophyll α concentrations (average 61.3 mg/m^3, range: 4.1-310 mg/m^3) during 2012 (Figure 16). The highest concentrations were observed during the first sampling event on 7/24/12. During this first sampling event (early summer) in 2012, dissolved oxygen concentrations, pH, and TN concentrations were also greatest. Average chlorophyll α concentrations varied seasonally and were 154.8 mg/m^3 in July, 24.5 mg/m^3 in August, and 4.5 mg/m^3 in September. Similar to 2011, no one site exhibited the highest or lowest chlorophyll α concentrations. Differences in average chlorophyll α concentration by site may be attributed to prevailing westerly winds causing phytoplankton accumulation on the east side of Brooks Lake.

Figure 15. Chlorophyll α concentrations in Brooks Lake during 2011.

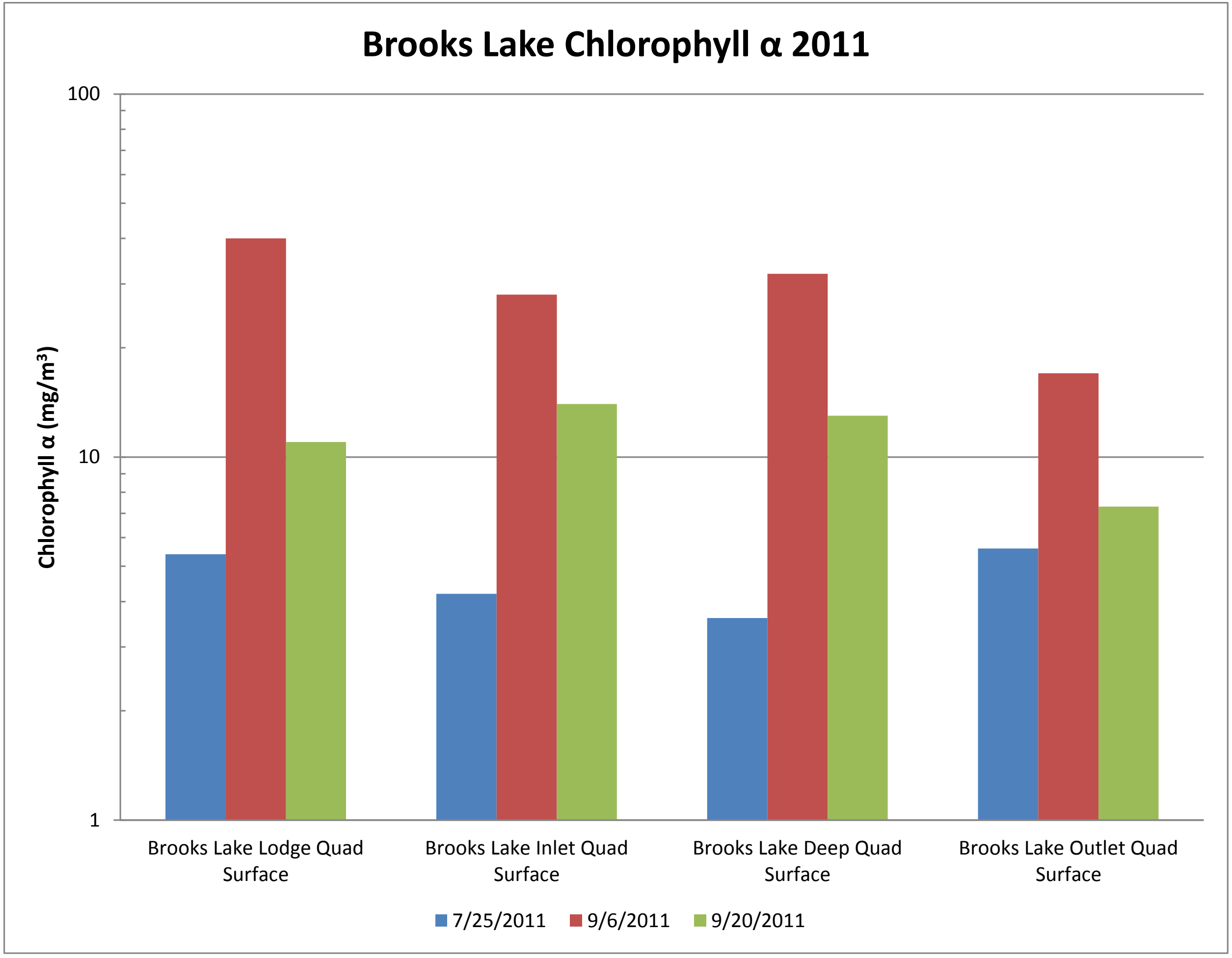
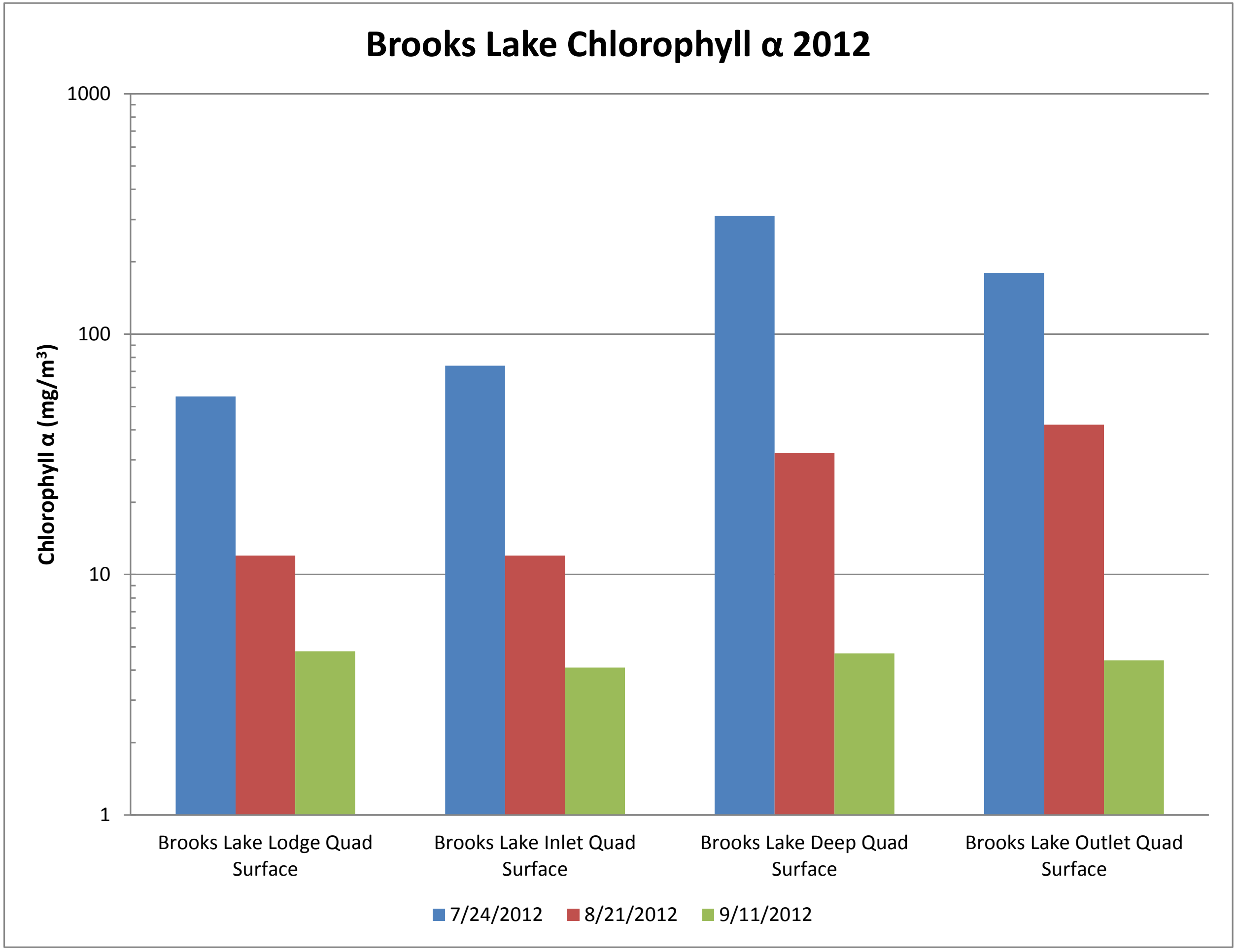


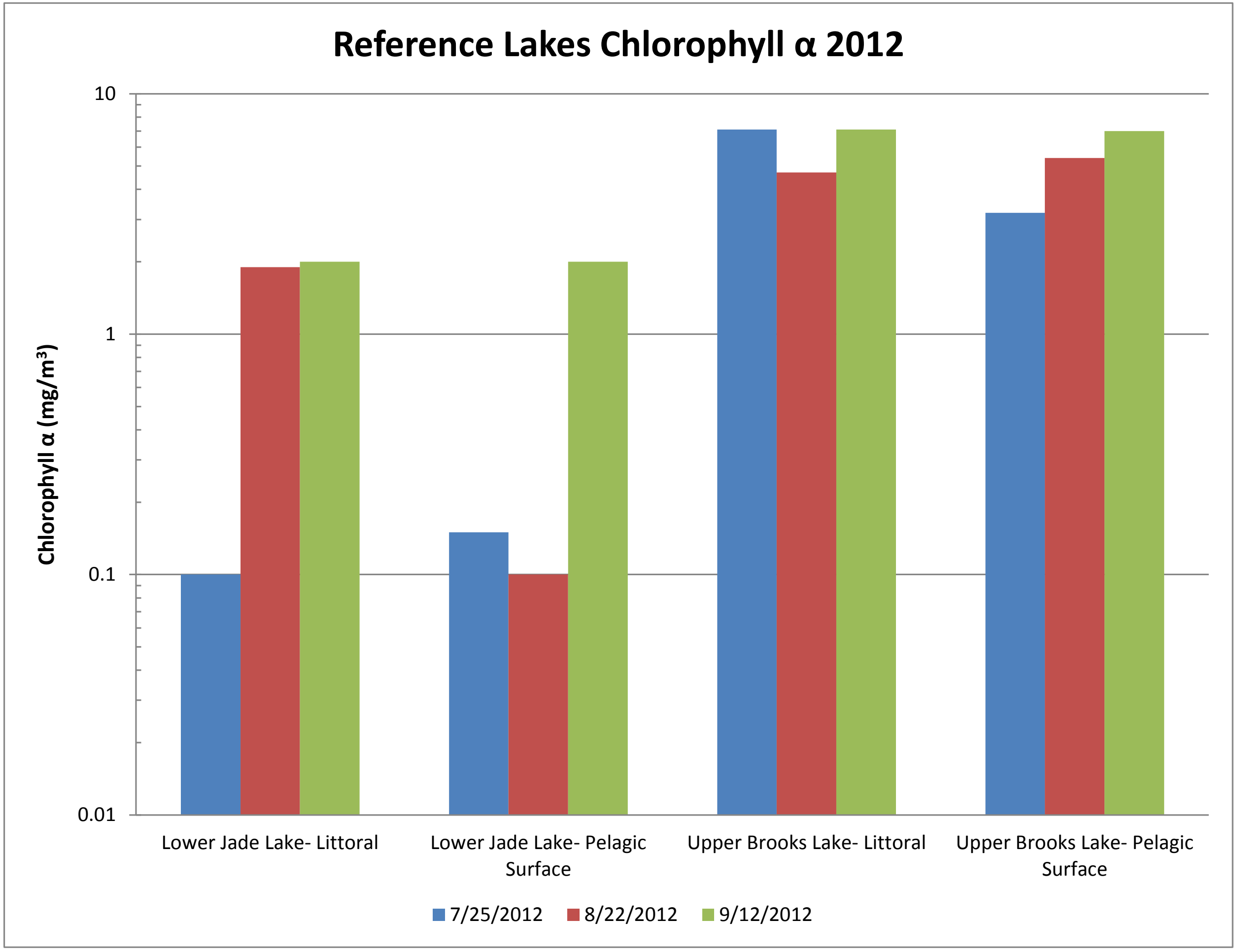
Figure 16. Chlorophyll α concentrations in Brooks Lake during 2012.



Reference Lakes

Chlorophyll α in Upper Brooks Lake and Lower Jade Lake during 2012 was significantly lower than in Brooks Lake (t(22)=2.154, p=0.042). Upper Brooks Lake (range: 3.2-7.1 mg/m^3, mean: 5.8 mg/m^3) was generally more productive than Lower Jade Lake (range: <0.2-2.0, mean: 1.0 mg/m^3). Chlorophyll α concentrations were similar between sites within each lake. Unlike in Brooks Lake where chlorophyll α spiked during the early summer of 2012, chlorophyll α concentrations in both Upper Brooks Lake and Lower Jade Lake were generally greatest in late summer of the same year (Figure 17).

Figure 17. Chlorophyll α concentrations in Upper Brooks Lake and Lower Jade Lake during 2012.



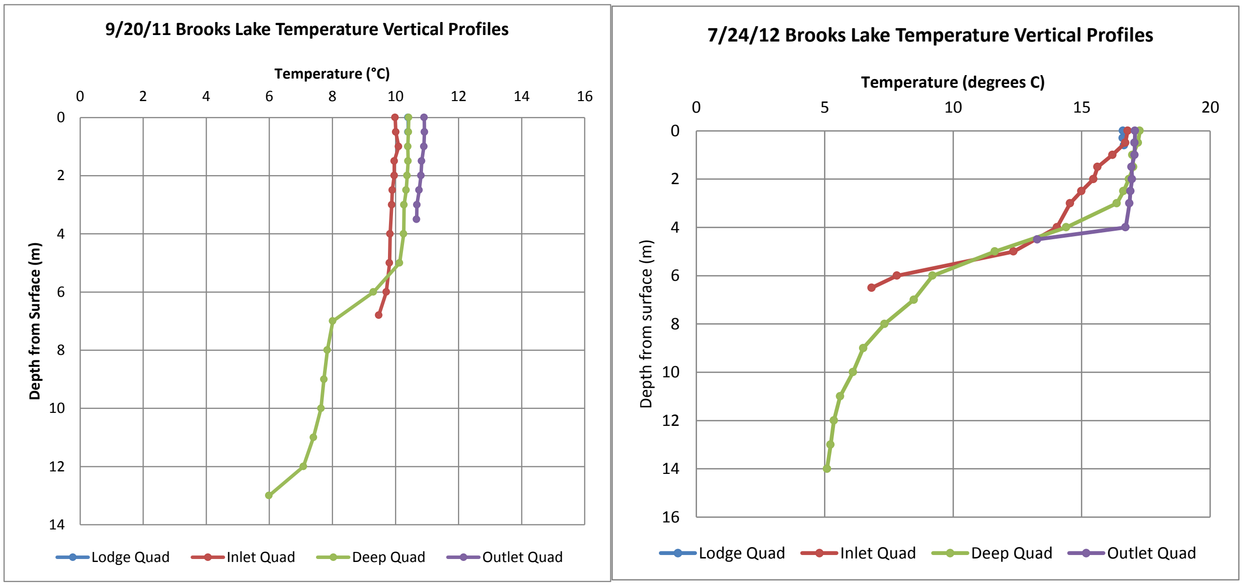
Depth Profiles

All depth profile data is available in Appendix B.

Brooks Lake

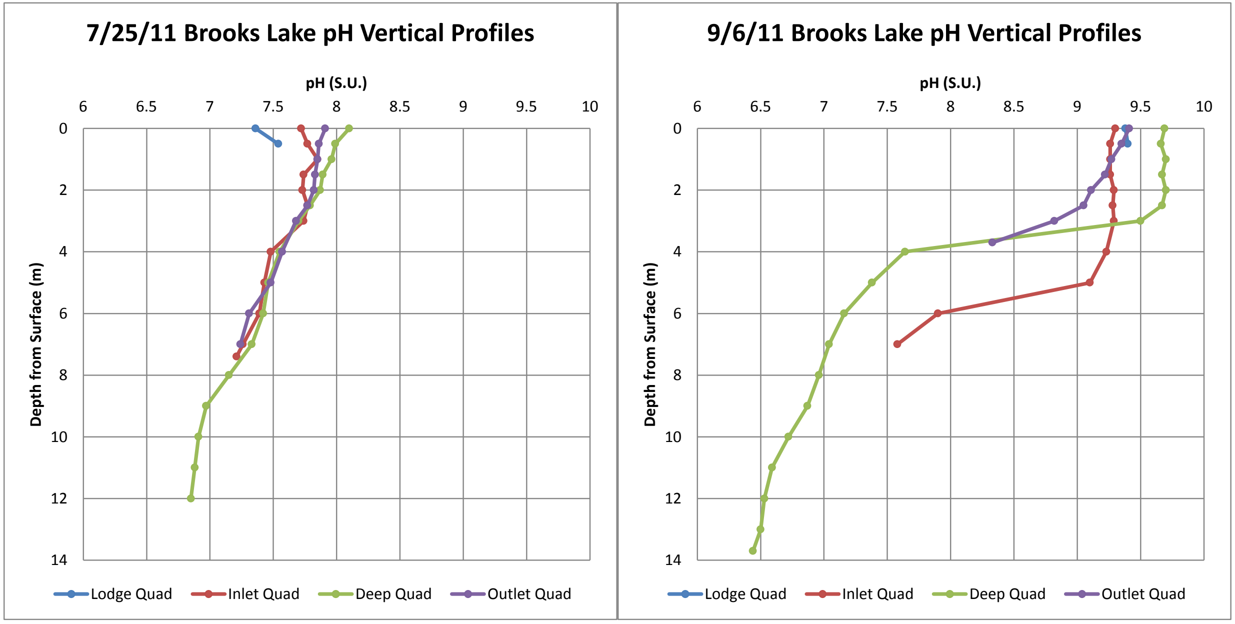
Temperature - Thermal stratification was evident in Brooks Lake during all three sampling years, and was generally most pronounced during August and September. Thermal stratification was present during each sampling event in 2009, and was most evident at the Deep Quad and Inlet Quad. Thermal stratification in 2011 was less pronounced than in 2009, possibly due to greater snowpack and later snowmelt in 2011. Unlike 2009, stratification was observed at the Outlet Quad in 2011, as the exact site location may have varied slightly from one monitoring event to the next. Brooks Lake was nearly isothermal on 9/20/2011 (Figure 18). A warmer and drier spring in 2012 contributed to higher temperatures within Brooks Lake. Thermal stratification was present during all monitoring events in 2012, as demonstrated with the July event (Figure 18). No temperatures in Brooks Lake exceeded the criterion of 20°C protective of cold-water fishery use (WDEQ/WQD 2013).

Figure 18. Vertical temperature profiles for Brooks Lake in an isothermal state in fall 2011 and stratified in early summer 2012.



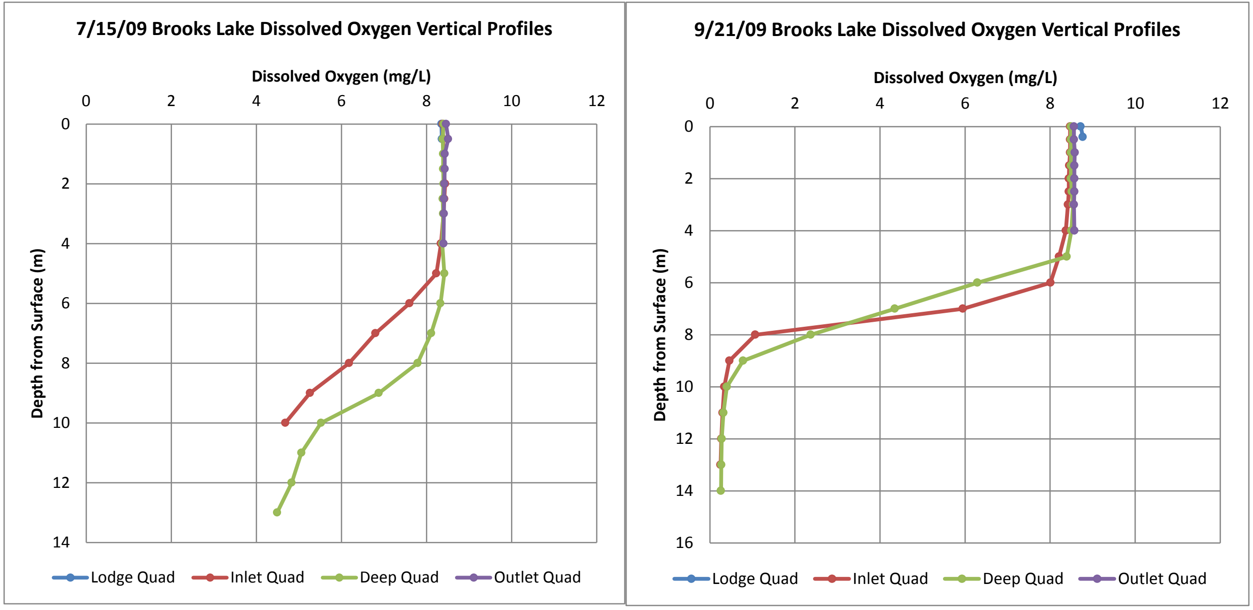
pH - Many pH values in Brooks Lake exceeded the criterion of 9.0 SU protective of aquatic life (WDEQ/WQD 2013), and in some cases exceeded 10.0 SU. These values generally occurred in or near the epilimnion (0-7 meters) during late summer and fall in 2009 and 2011, and during all monitoring events in 2012. Some pH values were less than the criterion of 6.50 SU protective of aquatic life – primarily occurring in the anoxic hypolimnion (10-14 meters deep), and only during fall sampling events in 2009 and 2011. Stratification of pH was evident during late summer and fall sampling events in 2009 and 2011, while stratification in 2012 was evident from early summer through fall. In 2009, pH values across all sites ranged from 7.05-8.07 SU on July 15, 6.50-9.28 SU on August 17, and 6.29-9.46 SU on September 21. During 2011, pH across sites ranged from 6.85-8.1 SU on July 25, 6.44-9.70 SU on September 6, and 6.16-9.18 SU on September 20. When pH values first exceeded 9.0 SU during 2011, chlorophyll α concentrations were at their greatest. In 2012, pH values across all sites ranged from 6.77-10.01 SU on July 24, 7.72-10.18 SU on August 21, and 7.19-9.28 on September 11. Unlike 2009 and 2011, Brooks Lake in 2012 was already experiencing high pH values during the month of July. July of 2012 was also the same time of highest algal biomass. Figure 19 demonstrates typical pH vertical profiles in Brooks Lake during stratified and mixed states.

Figure 19. pH vertical profiles for Brooks Lake during July and September of 2011 demonstrating the stratification of pH.



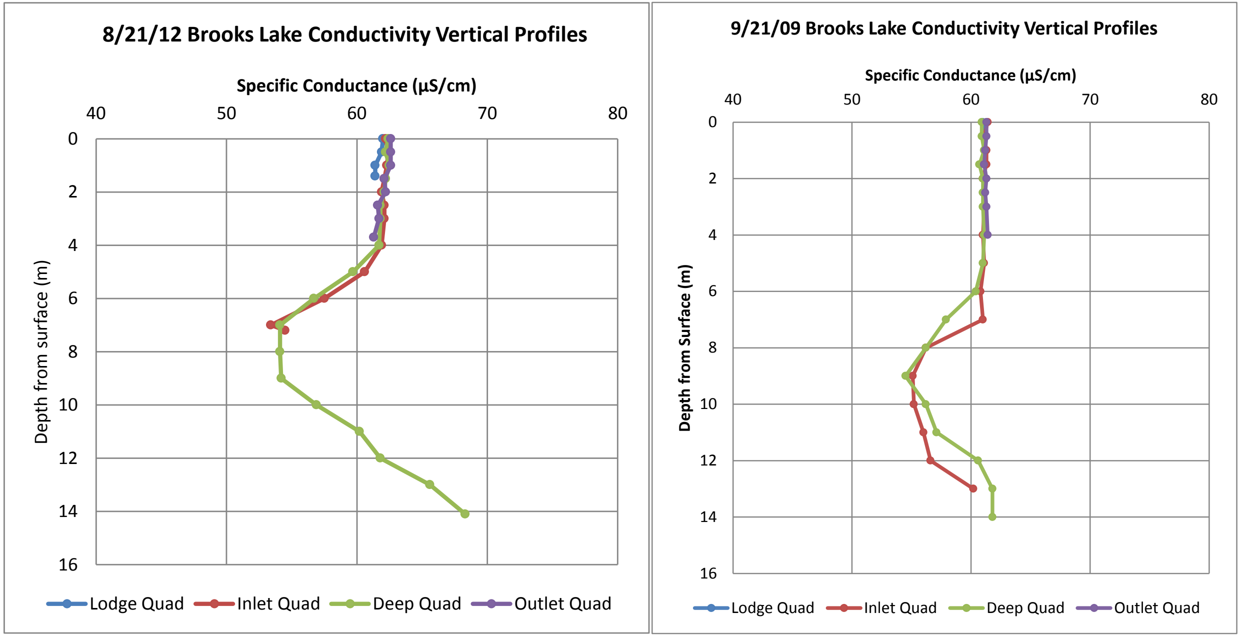
Dissolved Oxygen - The thermally stratified Deep Quad consistently had the lowest DO in the hypolimnion, while the highest DO was found in the epilimnion of the lake. If we consider a condition of <4 mg/L to be hypoxic, then across all years, the bottom 5-7 meters of Brooks Lake could be considered hypoxic. These hypoxic conditions generally occurred in late summer and fall. Stratification was strongest in August and September, while Brooks Lake in July was more mixed (Figure 20). Similar to 2009, DO stratification in 2011 was strongest during the latter two sampling events. In 2012, DO stratification was evident during all three sampling events, and the highest recorded DO concentrations during this study were recorded. The greatest DO concentrations and percent saturations occurred on July 25, 2011 in the epilimnion, where the greatest chlorophyll α concentrations were found.

Figure 20. Brooks Lake dissolved oxygen vertical profiles in 2009, with greater stratification in fall than in early summer.



Specific Conductance - In 2009 and 2011 specific conductance generally increased across all Brooks Lake Quads from early summer to fall, while in 2012 a seasonal pattern was not evident. In late summer and fall of 2009 and 2011 specific conductance in the Deep Quad decreased in the metalimnion and into the hypolimnion and then increased towards the bottom of the lake. A similar pattern in the depth profile was observed in all three monitoring events at the Deep Quad during 2012 (Figure 21).

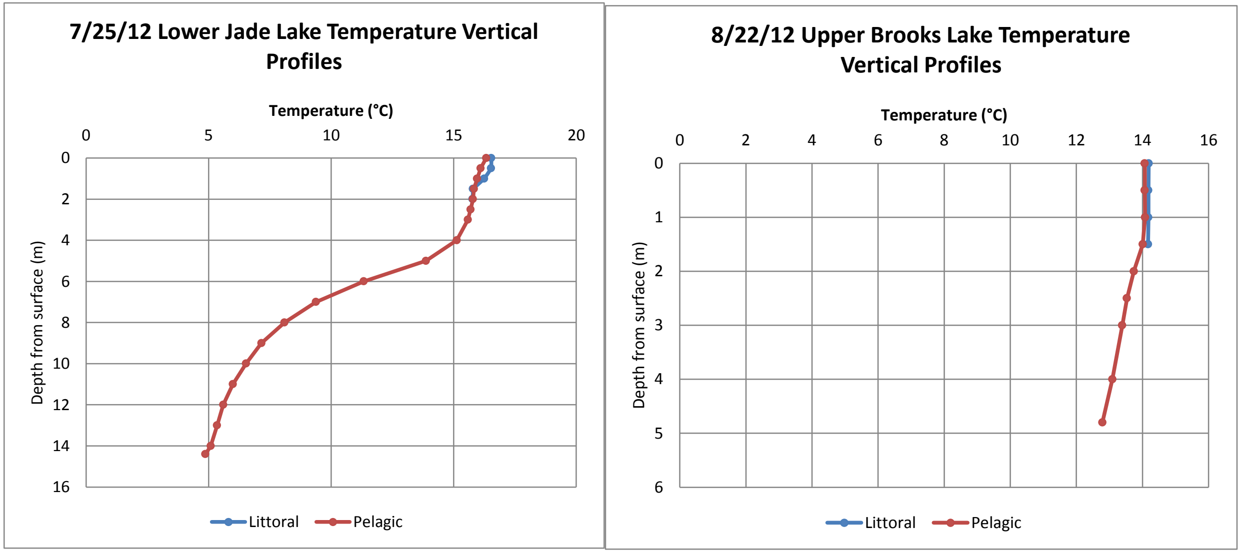
Figure 21. Brooks Lake specific conductance vertical profiles from fall 2009 and late summer 2012.



Reference Lakes

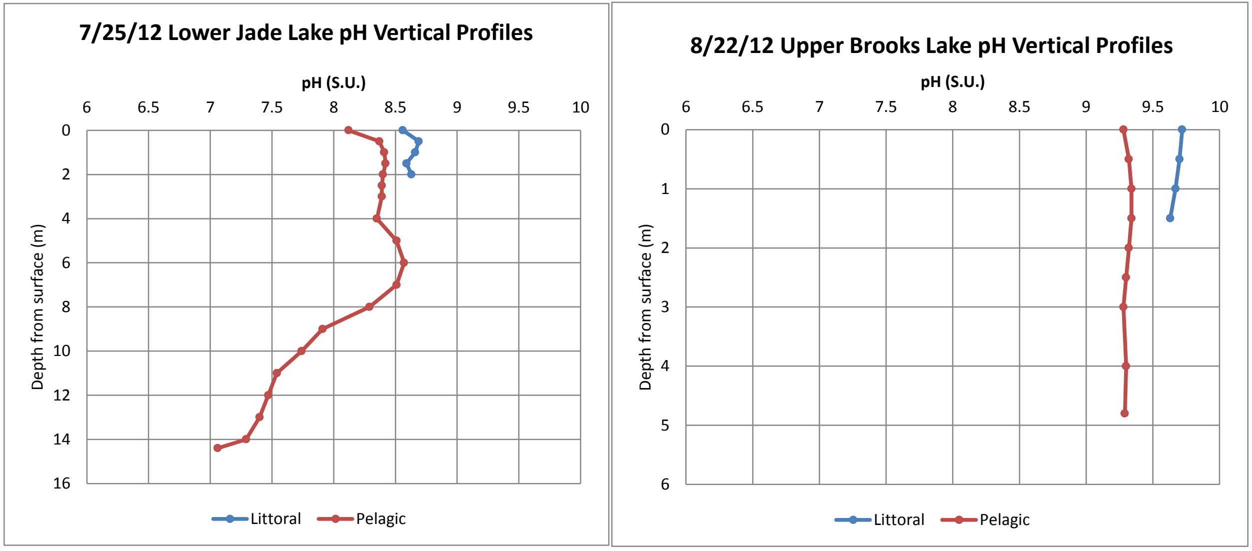
Temperature - Thermal stratification was observed in Lower Jade Lake during all sampling events (Figure 22). During the fall monitoring event Lower Jade Lake was isothermal from 0-9 meters, which indicated the start of fall turn-over. Temperatures in Upper Brooks Lake were generally warmer, but similar to Lower Jade Lake, never exceeded the 20°C criterion protective of cold-water fishery use (WDEQ/WQD 2013). No thermal stratification was present in Upper Brooks Lake, presumably due to its shallow depth and mixing from wind (Figure 22).

Figure 22. Typical temperature vertical profiles in Lower Jade Lake and Upper Brooks Lake.



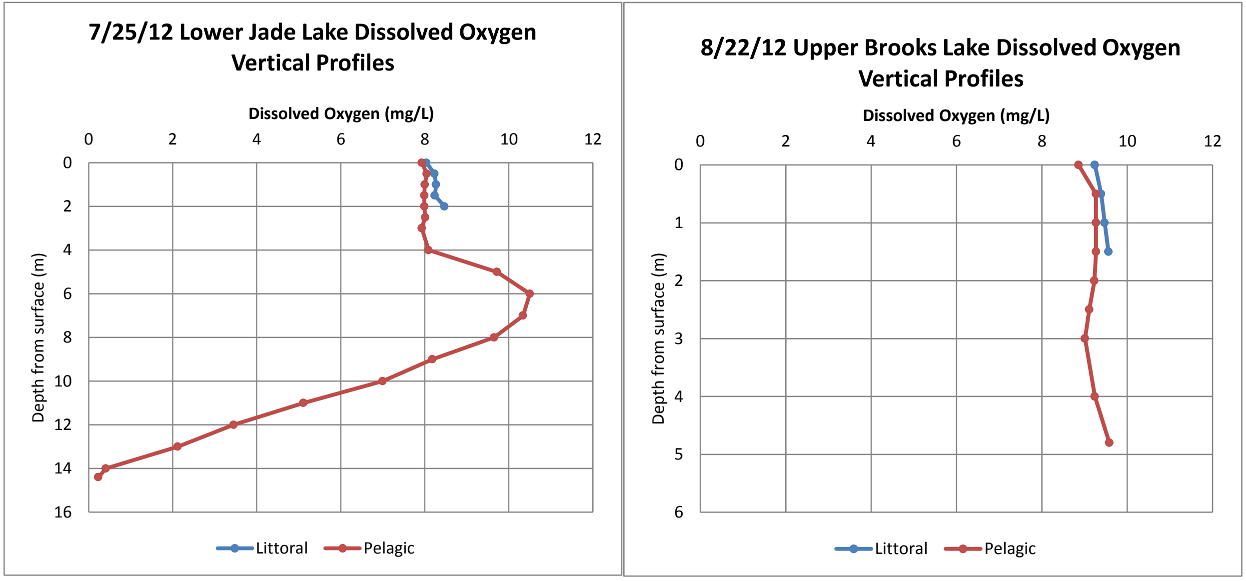
pH - Elevated pH values were recorded in both reference lakes, including many values well over the criterion of 9.0 protective of cold-water fishery use (WDEQ/WQD 2013). The majority of pH exceedances occurred in Upper Brooks Lake during late summer and early fall, when the entire water column was greater than 9.0 (Figure 23). Lower Jade Lake only exceeded the pH criterion during late summer. Lower Jade Lake exceeded the pH criterion on one occasion, but the value was not as high as they were in Upper Brooks Lake. In Lower Jade Lake, pH generally decreased with depth, although higher pH readings near the metalimnion during early summer and late summer were observed (Figure 23).

Figure 23. Example pH vertical profiles for Lower Jade Lake and Upper Brooks Lake.



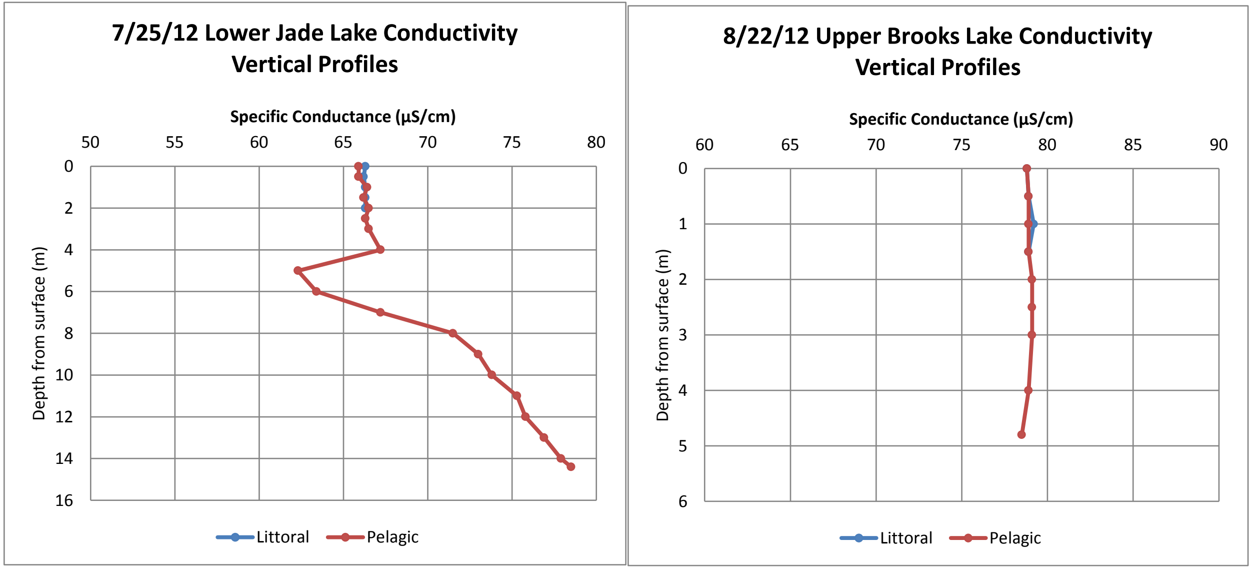
Dissolved Oxygen - A lack of stratification in Upper Brooks Lake kept DO concentrations high, while Lower Jade Lake stratified and experienced hypoxia in its hypolimnion (Figure 24). Using <4 mg/L as a condition of hypoxia, the bottom 1-2.5 meters of Lower Jade Lake could be considered hypoxic. Supersaturated conditions in these lakes are indicative of photosynthetic activity, although percent saturation values were not as extreme as those seen in Brooks Lake during these same sampling events.

Figure 24. Dissolved oxygen vertical profiles for Lower Jade Lake during stratification and mixed Upper Brooks Lake.



Specific Conductance - Specific conductance in Upper Brooks Lake did not vary greatly with depth and did not exhibit seasonal trends. In Lower Jade Lake, specific conductance was typically greatest in the hypolimnion, and decreased in the metalimnion during early summer (Figure 25). Greater depth in Lower Jade Lake allowed for a larger range of specific conductance values, and the greatest values were typically found in the hypolimnion.

Figure25. Specific conductance vertical profiles for Lower Jade Lake and Upper Brooks Lake.



Secchi Transparency

Secchi disk transparency is a measure of water clarity and is one of the most simple and commonly used limnological measurements. Higher secchi transparency readings mean clearer, less productive water, while more productive waters with greater algal biomass can result in lower secchi transparencies.

Brooks Lake

Across all three sampling years, secchi transparency averaged 2.54 m and ranged from 0.83-5.38 m. Secchi transparency varied between sampling trips during all years (Figures 26-28). In 2011 and 2012, the lowest secchi transparencies occurred during the same sampling events that yielded the highest chlorophyll α concentrations.

Figure 26. Secchi disk transparency at Brooks Lake sites in 2009.

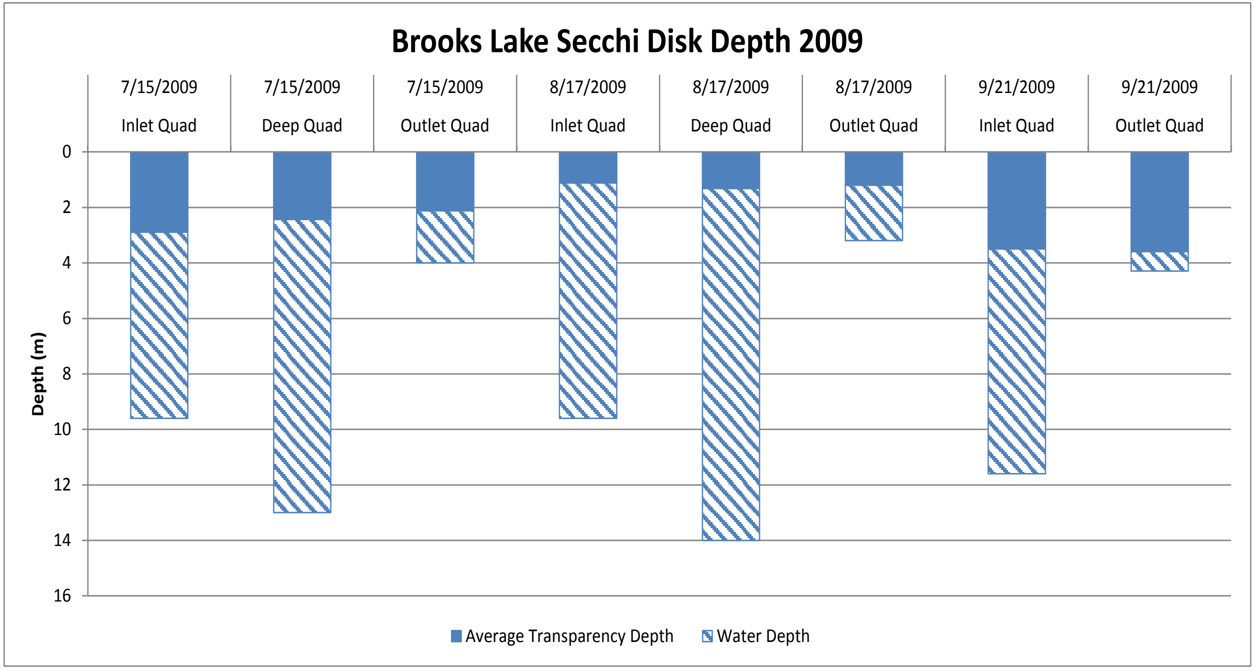


Figure 27. Secchi disk transparency at Brooks Lake sites in 2011.

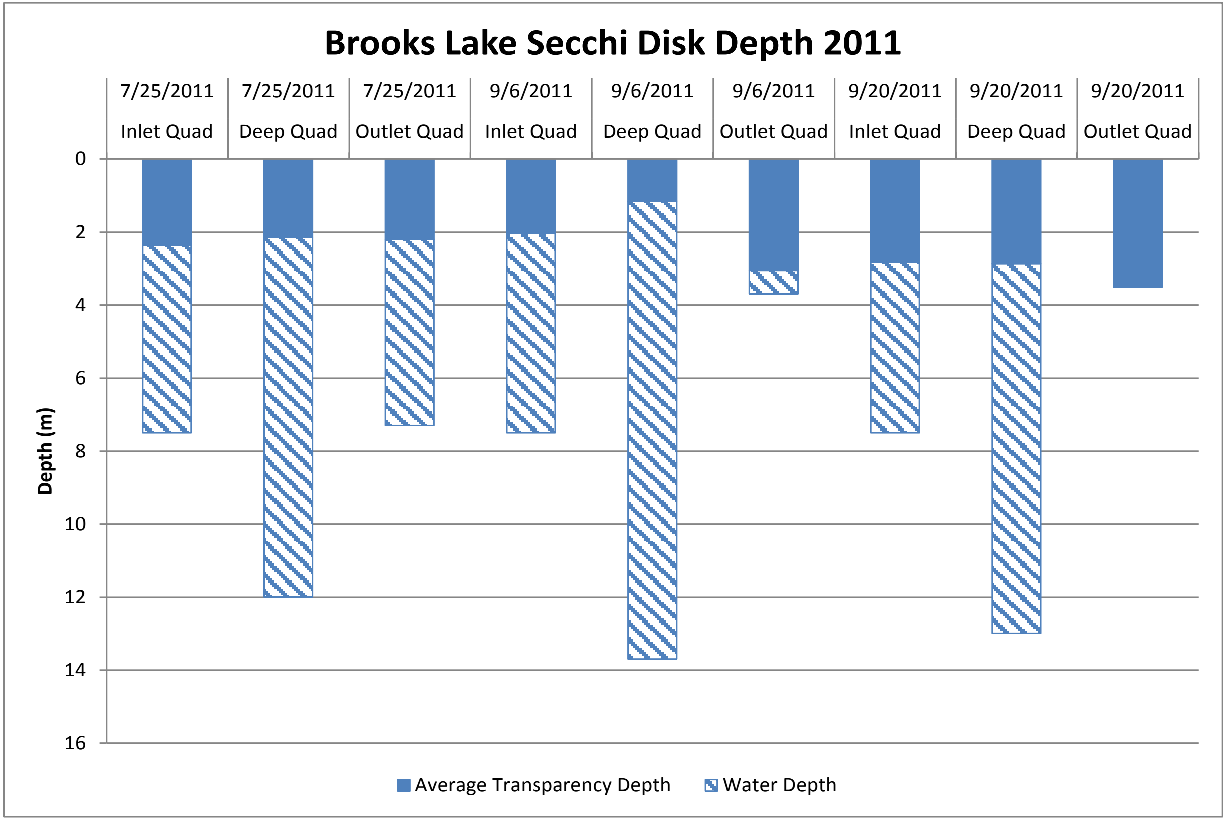
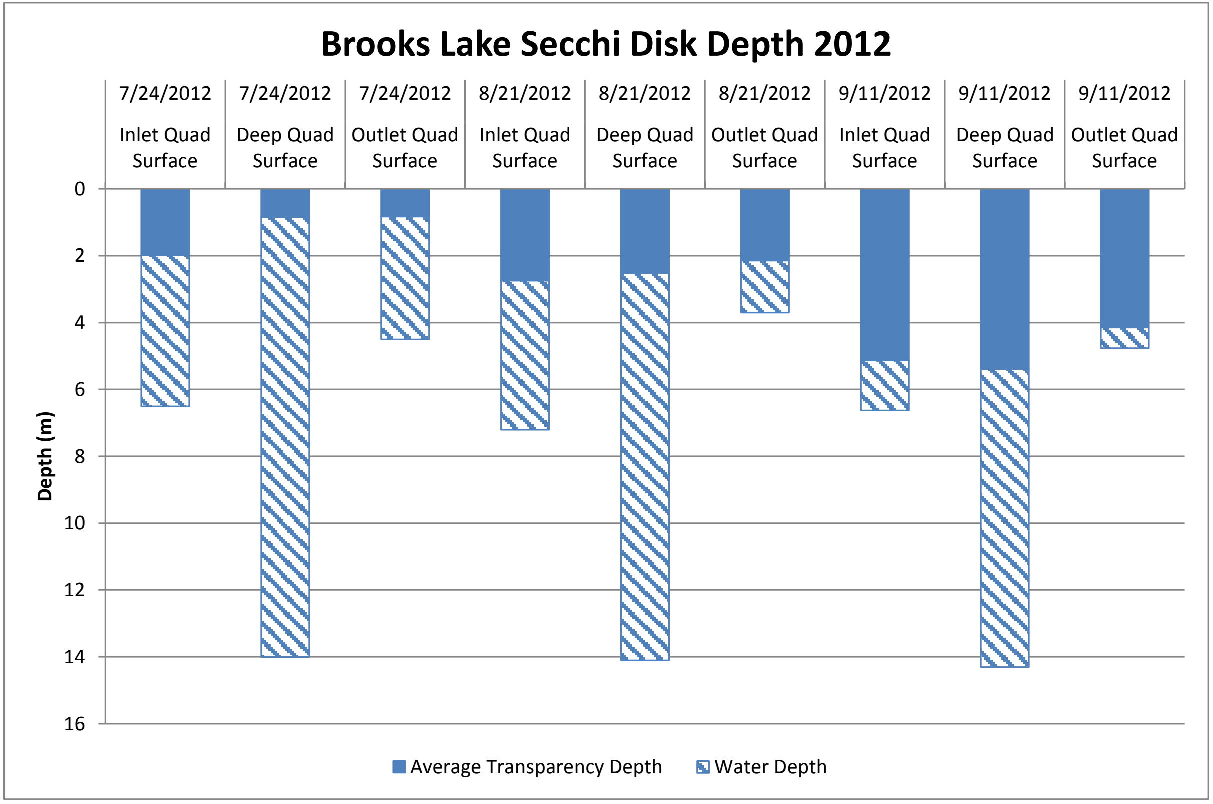


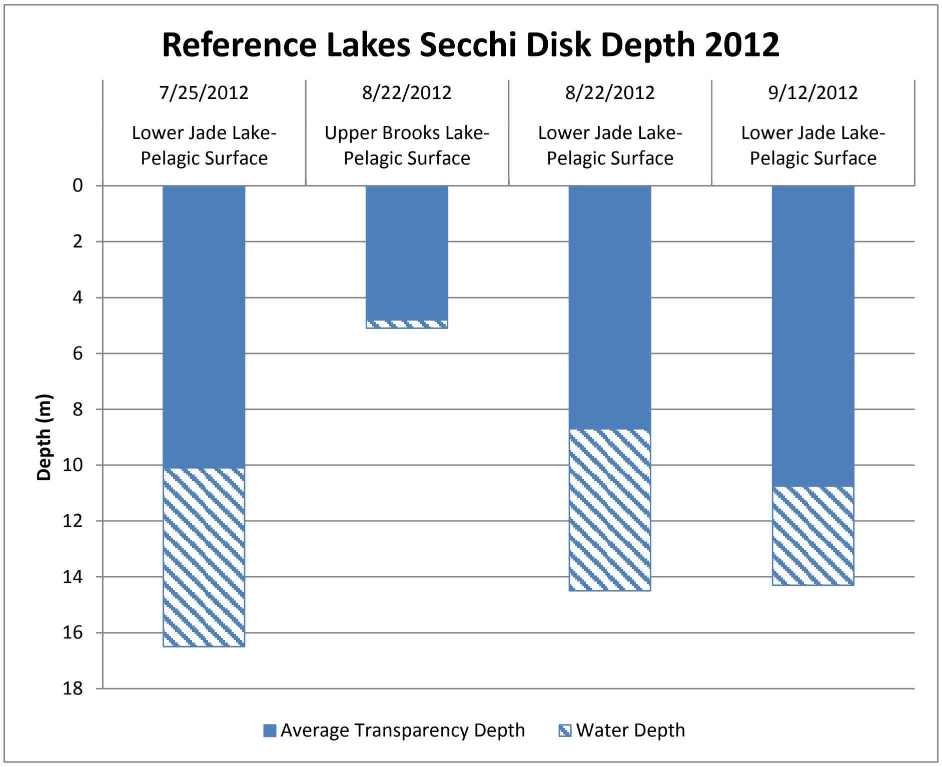
Figure 28. Secchi disk transparency at Brooks Lake sites in 2012.



Reference Lakes

Secchi disk transparency was significantly greater in Upper Brooks Lake and Lower Jade Lake than in Brooks Lake in 2012 (t(11)=4.76, p=0.00059). Average secchi transparency in Lower Jade Lake was 9.85 m (range: 8.7-10.75 m), while only one measurement of 4.8 m was obtained in Upper Brooks Lake. The secchi disk was visible resting on the bottom of Upper Brooks Lake during two sampling visits, meaning the secchi transparency was at least 4.75 m on 7/25/12 and at least 5.0 m on 9/12/12. At both littoral sites for both reference lakes, the secchi was always visible on the bottom of the lake, which ranged from 1.2-3.3 m of depth. Seasonal differences were not as pronounced in Lower Jade Lake (Figure 29), as they were in Brooks Lake.

Figure 29. Secchi disk transparency at Lower Jade Lake and Upper Brooks Lake during 2012. Secchi was visible resting on the lake bottom for littoral sites for both lakes, as well as during the 7/25/12 and 9/12/12 visit to the Upper Brooks Lake Pelagic site.



Carlson Trophic State Index

All TSI scores are listed in Table 6. The average TSI value (using data from 2009, 2011, and 2012) by parameter, for each waterbody, was calculated to compare TSI scores between the lakes (Figure 30). For Brooks Lake the mean TSIS was 48.18 (n=26), while the reference lakes average TSIS was 29.63 (n=4). These scores translate to mesotrophy for Brooks Lake and oligotrophy for the reference lakes. A T-Test for independent samples was performed between these populations and found a significant difference in TSIS score (t (28) =4.87, p=0.00004). The same statistical test was performed for mean TSIC values. Similar to TSIS, a significant difference was found in TSIC score between Brooks Lake and the reference lakes (t (34) = 4.64, p=0.00005). Mean TSIC scores were 57.73 for Brooks Lake and 35.30 for the reference lakes, which translates to eutrophy and oligo-mesotrophy, respectively. Conversely, no significant difference was found between the study lakes for TSIP values (t (46) = 1.06, p=0.29). Mean TSIP scores were 61.06 for Brooks Lake and 58.99 for the reference lakes, which translates to eutrophy for both.

Figure 30. Box and whisker plot of average TSI scores for Brooks Lake and reference lakes, categorized by parameter. Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.

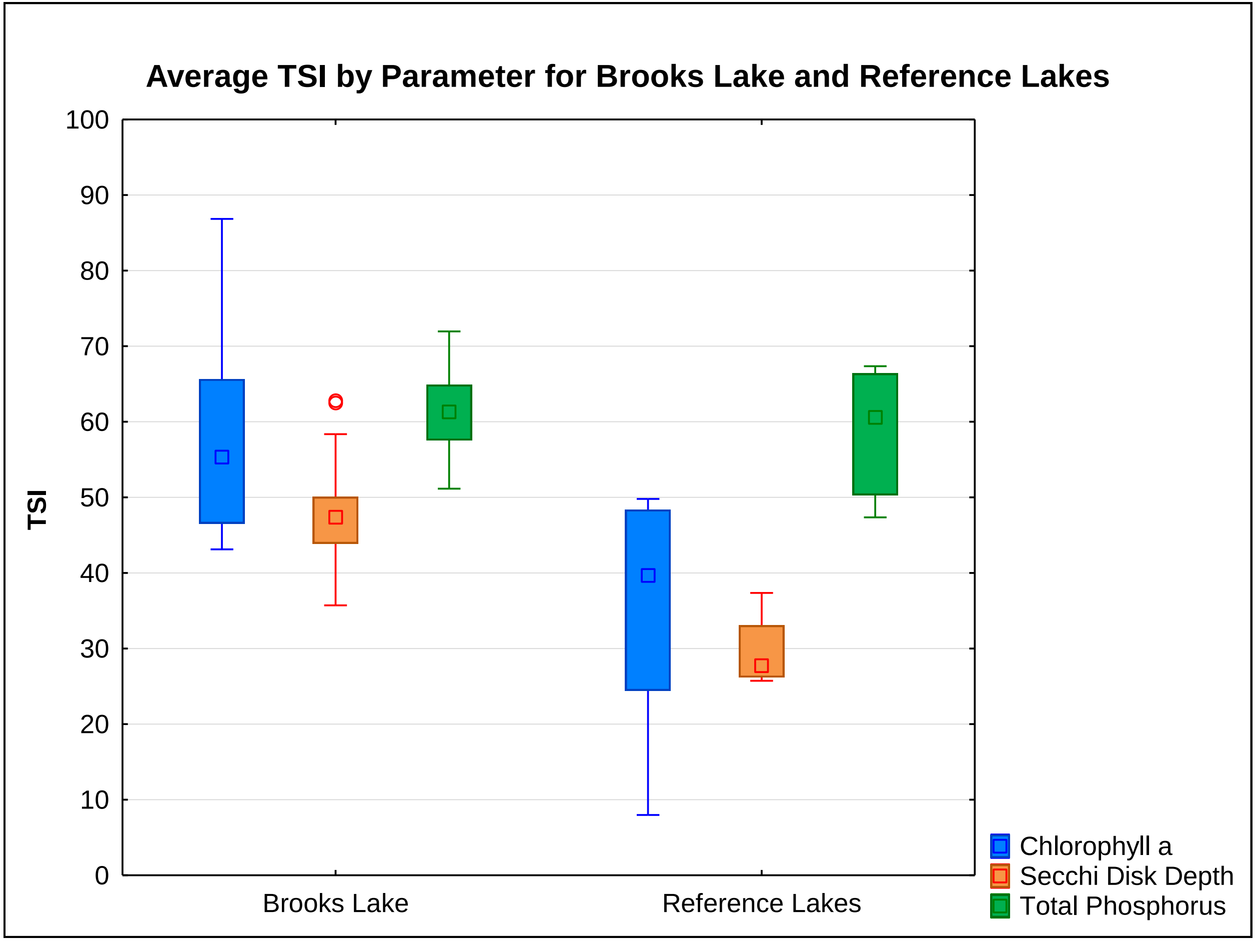


Table 6. Trophic State Indices for Brooks Lake and reference lake sites as calculated using secchi disk transparency (TSIS), chlorophyll α (TSIC), and total phosphorus (TSIP).

	Deep Quad			**Inlet Quad**			**Outlet Quad**		
Collection Date	*7/15/09*	*8/17/09*	*9/21/09*	*7/15/09*	*8/17/09*	*9/21/09*	*7/15/09*	*8/17/09*	*9/21/09*
TSIS	47.13	55.99	NC	44.64	58.37	41.93	49.09	57.37	41.52
TSIP	61.96	51.70	61.70	62.48	57.73	61.15	61.70	55.03	60.30

	Deep Quad			**Inlet Quad**			**Outlet Quad**		
Collection Date	*7/25/11*	*9/6/11*	*9/20/11*	*7/25/11*	*9/6/11*	*9/20/11*	*7/25/11*	*9/6/11*	*9/20/11*
TSIS	48.96	57.86	44.79	47.61	49.79	44.99	48.62	43.86	41.89
TSIC	43.14	64.57	55.73	44.65	63.26	56.46	47.47	58.36	50.07
TSIP	66.63	62.22	59.70	65.65	51.70	61.43	67.00	51.15	55.44

	Deep Quad			**Inlet Quad**			**Outlet Quad**		
Collection Date	*7/24/12*	*8/21/12*	*9/11/12*	*7/24/12*	*8/21/12*	*9/11/12*	*7/24/12*	*8/21/12*	*9/11/12*
TSIS	62.52	46.67	35.72	50.07	45.56	36.41	62.78	49.02	39.50
TSIC	86.85	64.57	45.75	72.79	54.95	44.41	81.51	67.24	45.10
TSIP	71.96	57.37	60.59	65.44	57.37	65.44	67.37	53.22	60.59

	Upper Brooks Lake Pelagic			**Upper Brooks Lake Littoral**			**Lower Jade Lake Pelagic**			**Lower Jade Lake Littoral**		
Collection Date	*7/25/12*	*8/22/12*	*9/12/12*	*7/25/12*	*8/22/12*	*9/12/12*	*7/25/12*	*8/22/12*	*9/12/12*	*7/25/12*	*8/22/12*	*9/12/12*
TSIS	<37.52	37.37	<36.78	<57.37	<52.34	<57.37	26.64	28.79	25.74	<48.62	<42.78	<54.15
TSIC	41.98	47.11	49.66	49.80	45.75	49.80	11.96	7.98	37.37	7.98	36.87	37.37
TSIP	67.37	60.59	67.37	67.37	63.22	65.44	60.59	47.37	47.37	60.59	47.37	53.22

Total Nitrogen to Total Phosphorus Ratios

Brooks Lake

Across all sites and sampling events in 2009, surface TN:TP ratios ranged from 0.87-3.31, whereas bottom TN:TP ratios ranged from 0.93-4.04 (Figure 31). Ratios in these ranges suggest nitrogen limitation. In 2011, TN:TP ratios were greater and a seasonal pattern was evident. Across all sites, surface TN:TP ratios ranged from 0.58-27.2, while bottom samples ranged from 0.46-5.07 (Figure 32). The TN:TP ratios were greatest during late summer, which suggests co-limitation or phosphorus limitation. TN:TP ratios during early summer and fall are suggestive of nitrogen limitation. Greater chlorophyll α concentrations were also observed during late summer in 2011. In 2012, surface TN:TP ratios across all sites ranged from 3.57-23.13, while bottom TN:TP ratios ranged from 1.67-19.0 (Figure 33). Similar to 2011, a seasonal pattern was evident in TN:TP ratios during 2012, with the greatest surface TN:TP ratios occurring during early summer. In contrast, bottom sample TN:TP ratios were greatest for two of the sites during fall, however the greatest individual TN:TP ratio occurred during early summer. The greatest chlorophyll α concentrations were also observed during early summer in 2012. Generally speaking, in 2012, surface TN:TP ratios were greater than bottom TN:TP ratios, although this difference was most prominent during the 7/24/12 sampling event when the highest productivity occurred. Phosphorus limitation or co-limitation may be present during early summer while nitrogen limitation or co-limitation may be present during late summer and fall.

Figure 31. Brooks Lake epilimnetic and hypolimnetic TN:TP ratios by monitoring event in 2009.

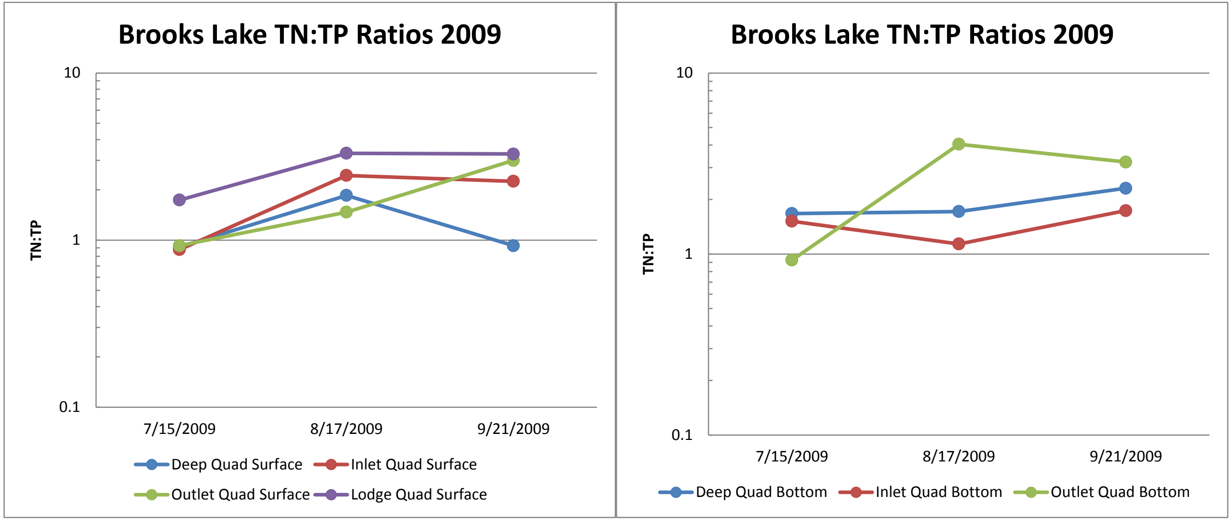


Figure 32. Brooks Lake epilimnetic and hypolimnetic TN:TP ratios by monitoring event in 2011.

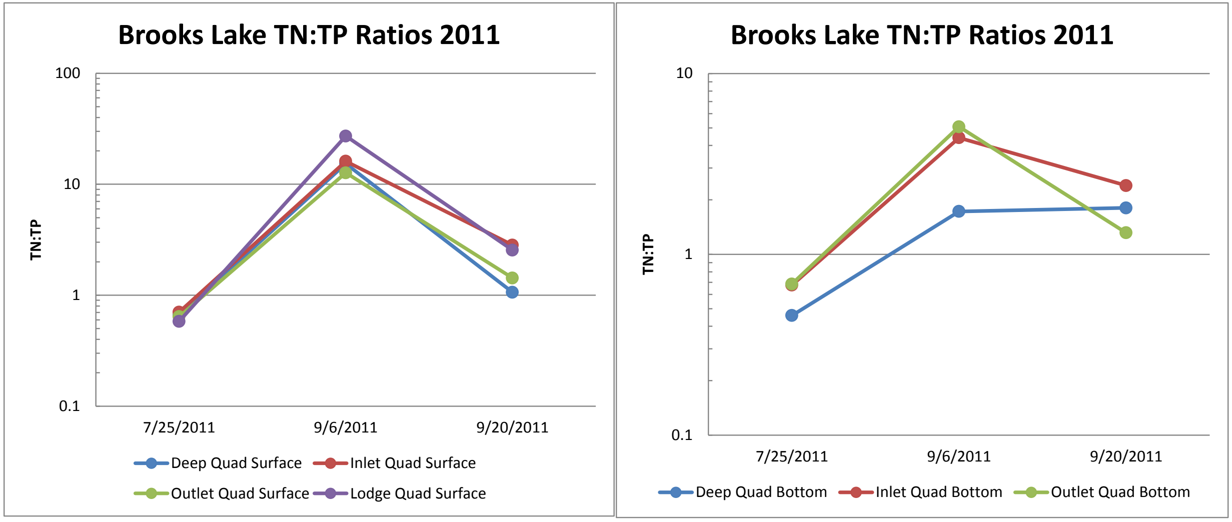
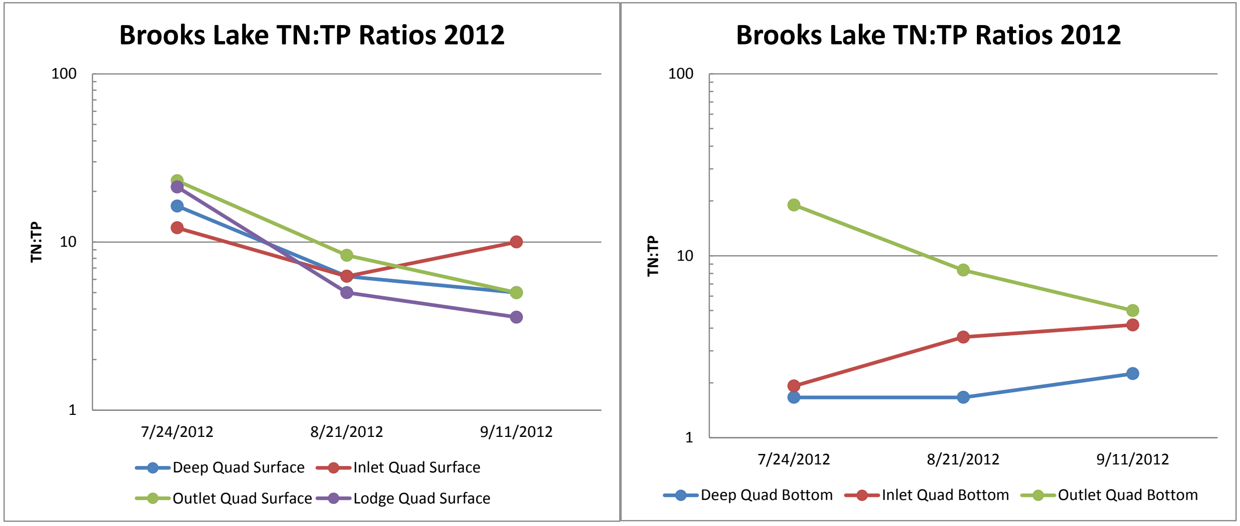


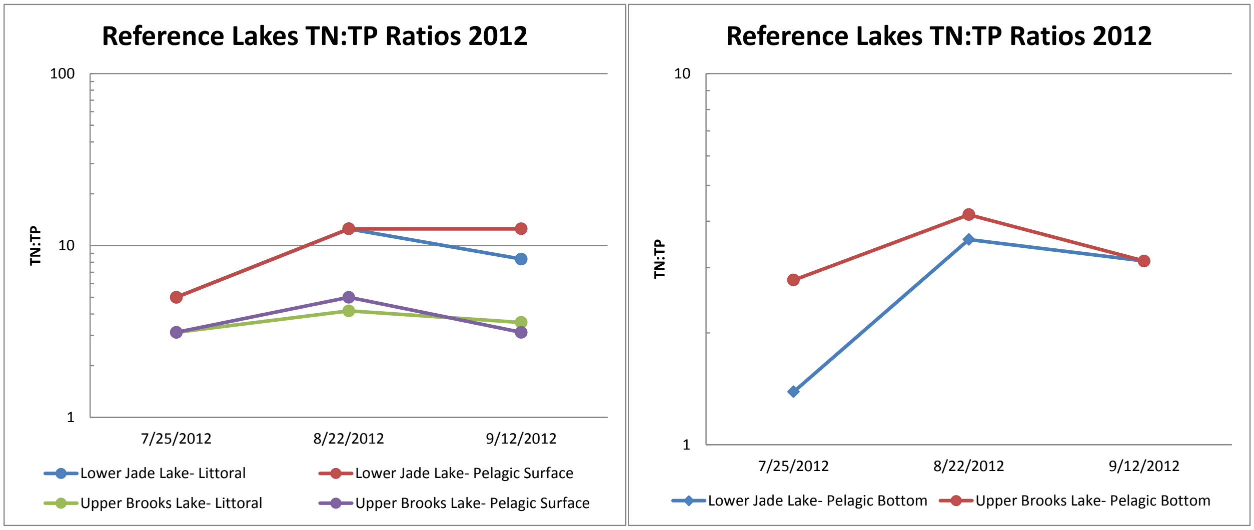
Figure 33. Brooks Lake epilimnetic and hypolimnetic TN:TP ratios by monitoring event for 2012.



Reference Lakes

The surface TN:TP ratios in Lower Jade Lake (range 5-12.5) were generally greater than those in Upper Brooks Lake (3.13-5). These ratios are suggestive of predominately nitrogen limitation or co-limitation. Bottom TN:TP ratios ranged from 1.39-3.57 in Lower Jade Lake and 2.78-4.17 in Upper Brooks Lake. These ratios suggest nitrogen limitation in the bottom of both reference lakes. A slight seasonal pattern was evident in both lakes with the greatest TN:TP ratios, in both surface and bottom samples, occurring during early summer (Figure 34).

Figure 34. Epilimnetic and hypolimnetic TN:TP ratios for Upper Brooks Lake and Lower Jade Lake in 2012 by monitoring event.


Reference Lakes TN:TP Ratios 2012

Reference Lakes TN:TP Ratios 2012

Nitrogen to Phosphorus Ratios and Chlorophyll α

The greatest chlorophyll α concentrations in Brooks Lake occurred when TN:TP ratios were highest (Figure 35). This relationship suggests phosphorus limits the highest levels of primary productivity in Brooks Lake. A coefficient of determination of 0.565 (n=24) indicates some of the variation in chlorophyll α can be explained by TN:TP ratios, although there are other factors that influence chlorophyll α within Brooks Lake. In the reference lakes, the opposite was generally true; the greatest chlorophyll α concentrations occurred when TN:TP ratios were lowest (Figure 36). This suggests nitrogen limits primary productivity in Upper Brooks Lake and Lower Jade Lake. The coefficient of determination for this relationship was 0.432 (n=12). A greater sample size spanning additional years would be needed to better understand this relationship.

Figure 35. Relationship between TN:TP ratios and chlorophyll α concentrations in Brooks Lake.

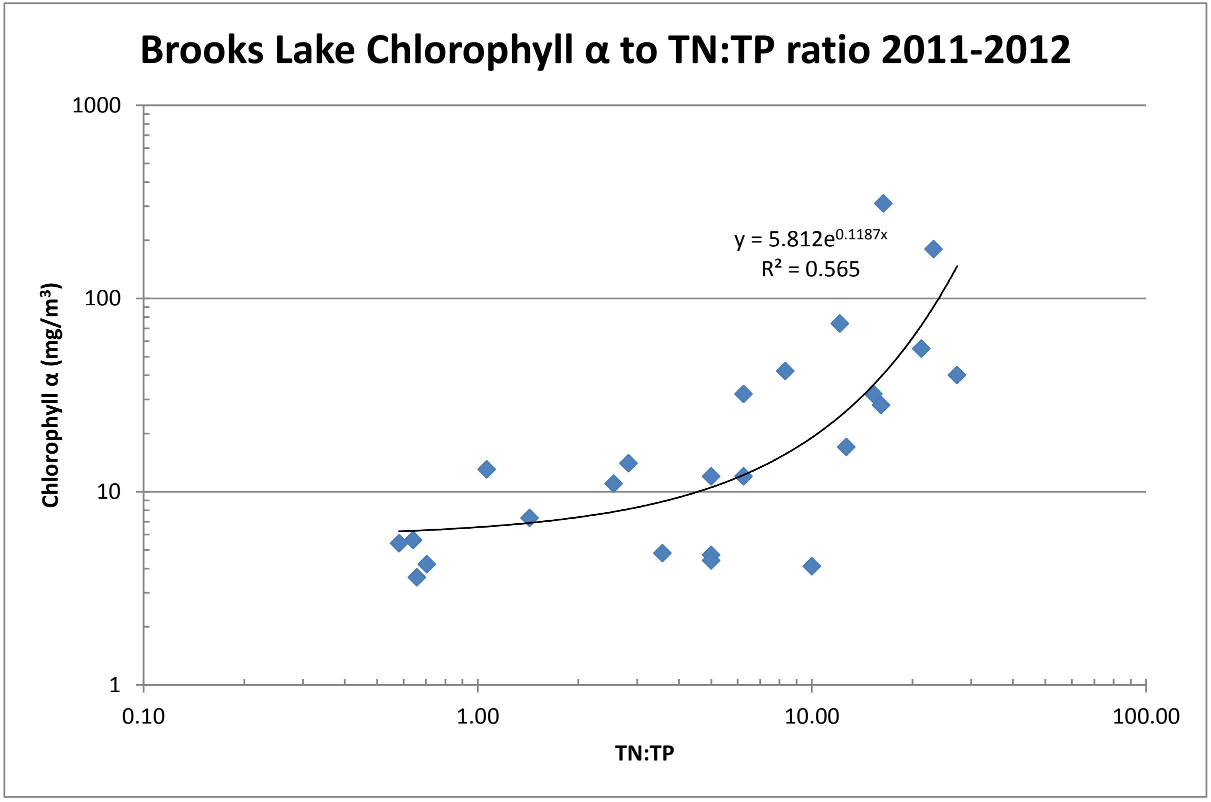
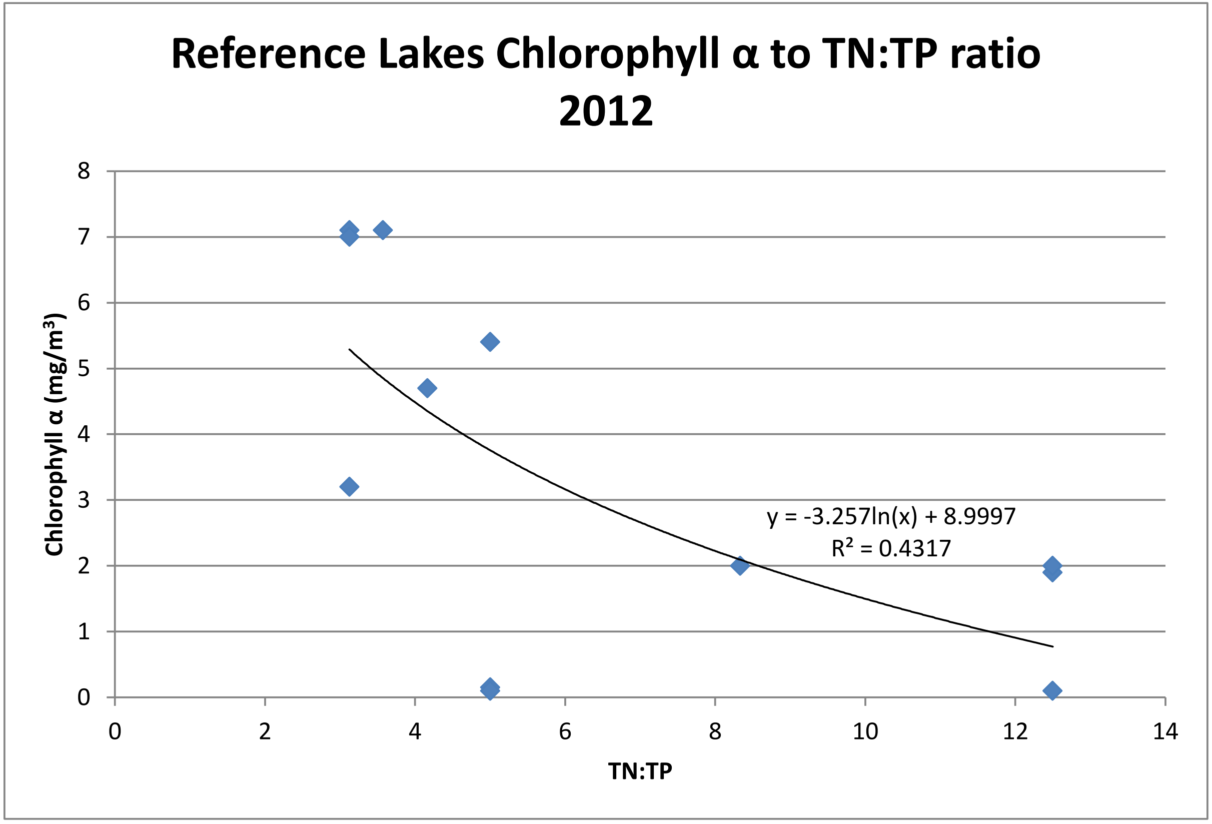


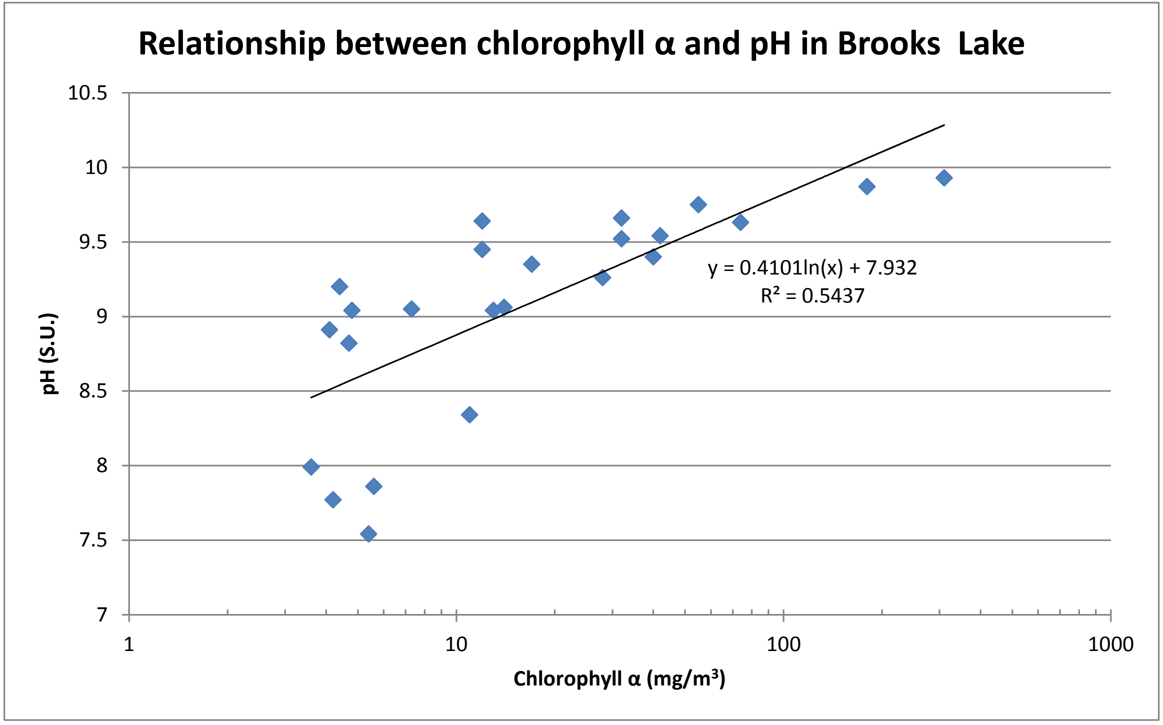
Figure 36. Relationship between TN:TP ratios and chlorophyll α concentrations in Lower Jade Lake and Upper Brooks Lake.



Relationship Between pH and Chlorophyll α

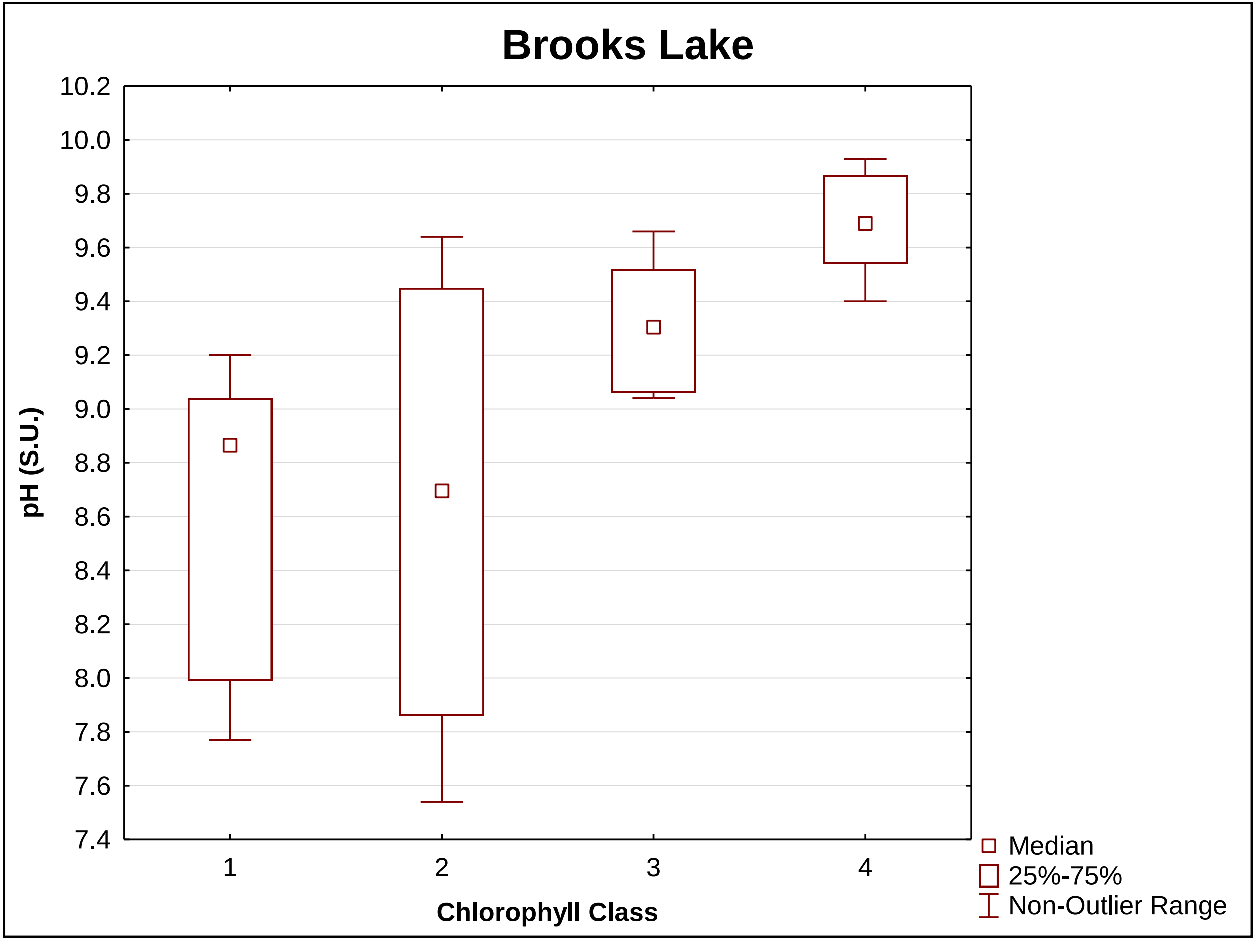
The respiration and photosynthesis of algae can alter the pH of Brooks Lake by adding or removing inorganic carbon. Photosynthesis consumes inorganic carbon which increases the pH, while respiration produces carbon dioxide, which raises the concentration of inorganic carbon and decreases the pH (Wetzel 2001). When algae are abundant and experiencing rapid growth, the demand for inorganic carbon is greatest and pH increases. Simultaneous measurements of chlorophyll α and pH at Brooks Lake have allowed an examination of the relationship between these two variables (Figure 37). For this analysis the pH value at 0.5m from the appropriate vertical profile was used to compare to the chlorophyll α concentration, which was also collected at 0.5m. The higher pH values are generally associated with the greater chlorophyll α concentrations.

Figure 37. The relationship between chlorophyll α and pH in Brooks Lake during 2009, 2011, and 2012.



The influence of high chlorophyll α on pH is easier to see when the pH values are aggregated into four chlorophyll α "classes" of increasing chlorophyll concentration (Figure 38). Each class contains 6 data points, which is 25% of the total Brooks Lake data points.

Figure 38. Box and whisker plot of pH values within 4 classes of increasing chlorophyll α concentration in Brooks Lake. Each chlorophyll class represents 25% of the total data points. Chlorophyll classes are as follows: 1 is <5 mg/m^3, 2 is 5-12 mg/m^3, 3 is 12-35 mg/m^3, and 4 is >35 mg/m^3 chlorophyll α.



Relationship Between Chlorophyll α and Nutrients

Brooks Lake

Chlorophyll α data for 2011 and 2012 in Brooks Lake was regressed against total phosphorus and total nitrogen. Total nitrogen concentrations explained much more of the chlorophyll α variability than total phosphorus did, and had a coefficient of determination of 0.8797 and 0.8129 for 2011 and 2012, respectively (Figures 39 and 40). These relationships suggest nitrogen, in general, is quite influential on chlorophyll α concentrations in Brooks Lake, while phosphorus does not explain nearly as much of the variability in chlorophyll α concentrations. The coefficient of correlation for total phosphorus and chlorophyll α was 0.2293 in 2011 and 0.5917 in 2012. As stated earlier, phosphorus appears to limit the highest levels of productivity in Brooks Lake, while nitrogen limits the lower to intermediate levels of productivity. Much greater chlorophyll α concentrations were measured in 2012 than in 2011, which may explain the difference between correlation coefficients for phosphorus and chlorophyll α (Figure 40). Lower to intermediate chlorophyll α concentrations in 2011 may be due to greater snowpack, later runoff, and lower air temperatures (Figures 42 and 43). The analysis of nitrogen to phosphorus ratios also suggested that nitrogen is the limiting nutrient in Brooks Lake, although periods of phosphorus limitation occur during the highest levels of productivity.

Figure 39. The relationship between chlorophyll α and total nitrogen surface site data in Brooks Lake during 2011 (n=12) and 2012 (n=12).

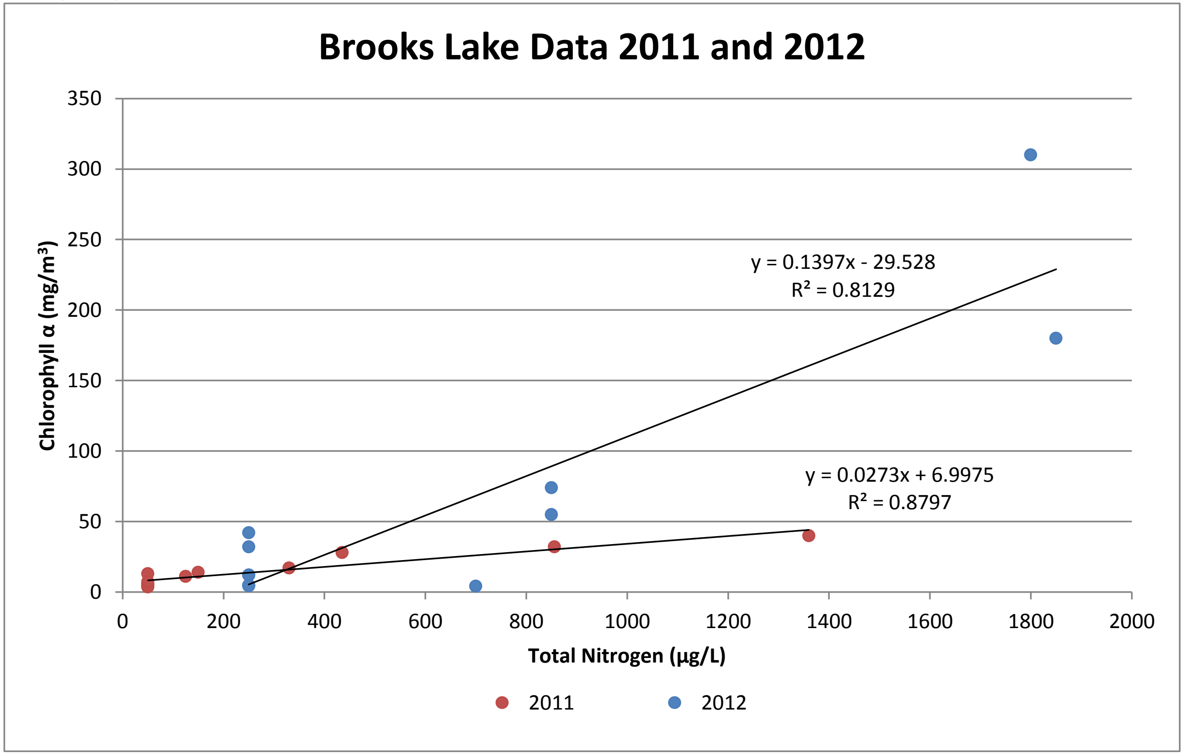
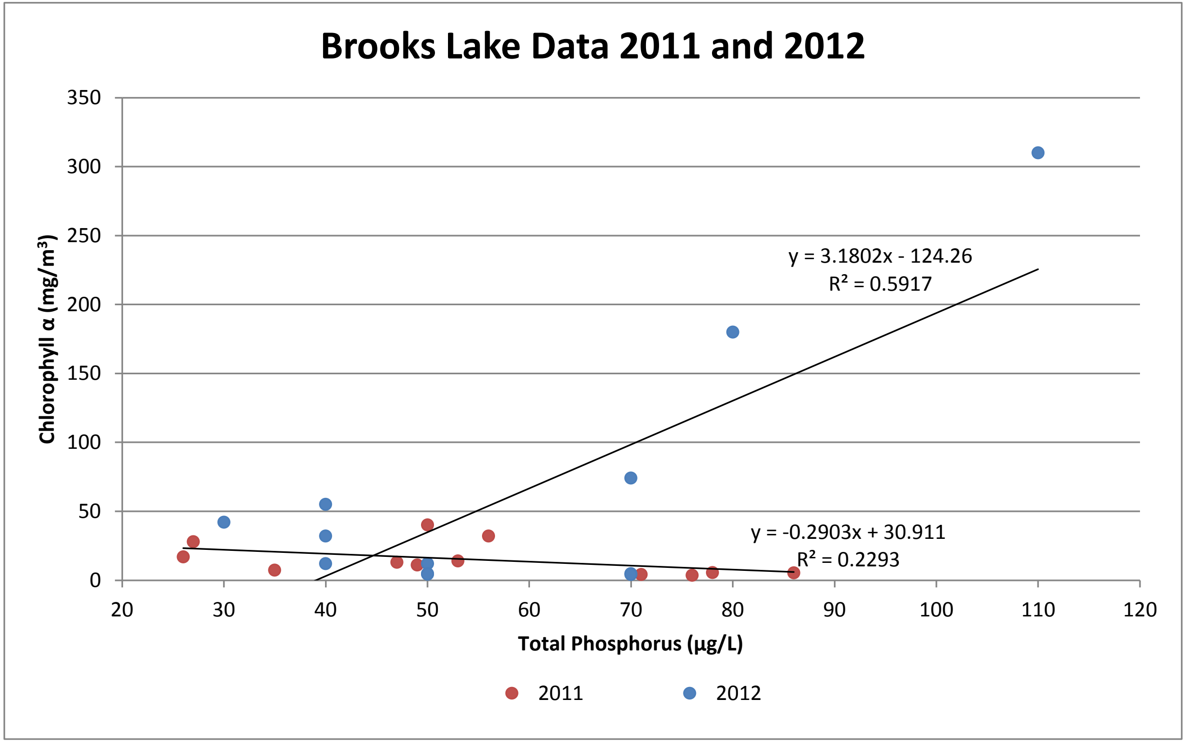


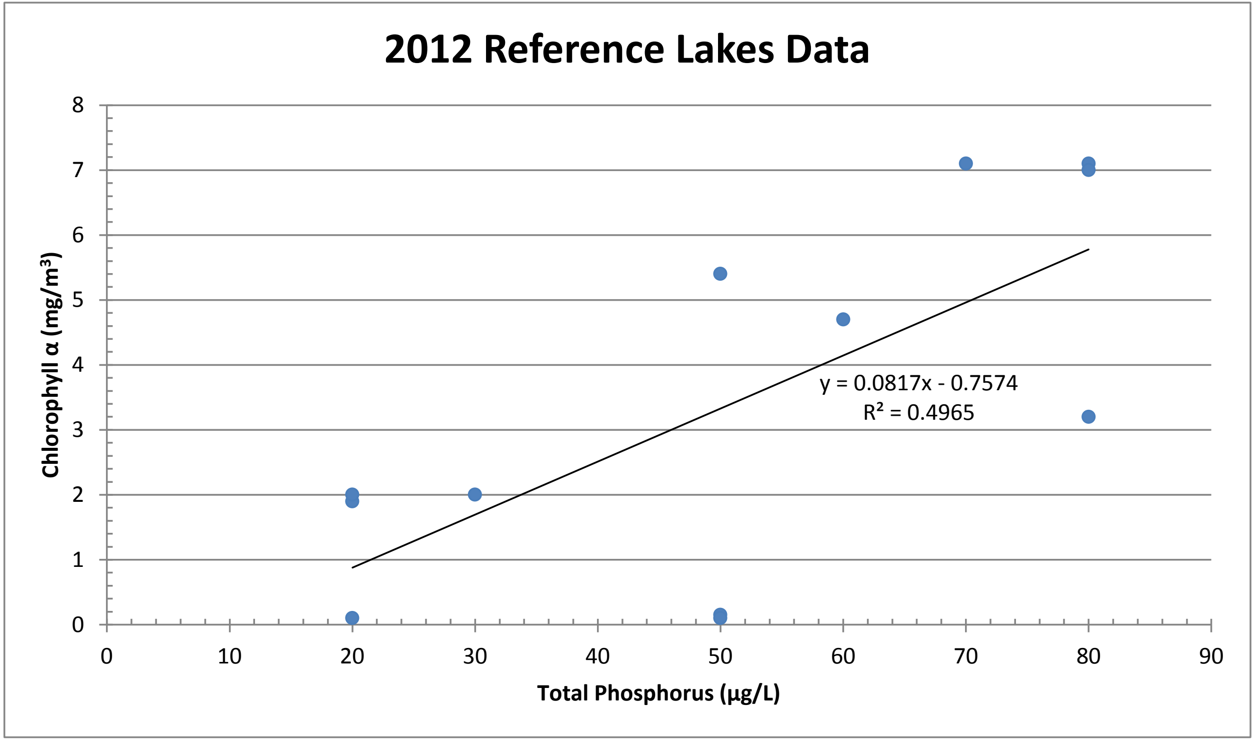
Figure 40. The relationship between chlorophyll α and total phosphorus in Brooks Lake during 2011 and 2012.



Reference Lakes

Chlorophyll α data from Upper Brooks Lake and Lower Jade Lake was pooled and regressed against total phosphorus. Since every total nitrogen sample from these lakes was below detection, a regression was not possible for this parameter. The coefficient of determination for chlorophyll α and total phosphorus in the reference lakes was 0.4965 (Figure 41). This suggests phosphorus is not greatly influential on chlorophyll α concentrations and there are multiple factors that influence chlorophyll α in the reference lakes. Nitrogen to phosphorus ratios were suggestive of nitrogen limitation and co-limitation in the reference lakes.

Figure 41. The relationship between chlorophyll α and total phosphorus surface site data in the reference lakes during 2012.



Supplementary Information

History of Brooks Lake Lodge Wastewater Lagoons

The Brooks Lake Lodge wastewater lagoons discharge to Brooks Lake via an unnamed tributary and are permitted with the WYPDES Program (Permit #WY0028045). The wastewater lagoons were constructed during the summer of 1977 and have a design flow of 12,500 gallons/day. Typically, the lagoons only discharge during the summer and winter months, when occupancy is at its highest. The original plans called for three, unlined cells, although only two have been constructed due to space constraints (Hoppe 1983). During construction, a WDEQ inspector noted that ground water was a significant problem in both cells (Armstrong 1977). It was suggested the cells be lined with a bentonite liner, although it is unknown if this was ever completed. Illegal discharges were reported on multiple occasions prior to the issuance of a WYPDES permit to discharge (e.g. Wagner 1980, Wagner 1983). In addition, multiple WDEQ inspections have reported evidence of wastewater having overtopped the dikes of the lagoons, and noted severe erosion of the dikes (e.g. LaBarge 1983, Hermansky 1996). Their first WYPDES permit was issued in October of 1984, despite the original intent to be a non-discharging system. While drafting their first permit to discharge, WDEQ expressed concern about the additional nutrient inputs to Brooks Lake and the potential effect this could have on the quality of the lake. Based on available literature and two methods to predict in-lake phosphorus concentrations, Collins (1984) concluded that the wastewater lagoon discharge would have very minimal impact to both the water quality and aesthetic properties of Brooks Lake. These calculations were based on the assumptions that phosphorus was the limiting nutrient in Brooks Lake, Brooks Lake should be ultra-oligotrophic, and the in-lake phosphorus concentration should not exceed 0.005 mg/L. This document also stated the lodge had been in existence since the early 1920's without any reported or documented algae nuisance problems in Brooks Lake. Total phosphorus limits were included in their first WYPDES permit and for many years thereafter, which they have had difficulty meeting. Permit limits for total phosphorus were 2.0 mg/L for a monthly average, 3.0 mg/L weekly average, and 4.0 mg/L daily maximum concentration. These permit limits were established in order to insure that in-lake TP concentrations would not exceed the "problem" criteria of 0.01 mg/L for oligotrophic lakes. Available DMR data shows the effluent TP averaged 6.27 mg/L (range: 0.1-29.0, n=27). In spring of 2004, the operator at Brooks Lake Lodge notified WDEQ that their effluent was out of compliance during the winter, and WDEQ stated an engineer would be needed to design a facility, other than lagoons, that would give proper treatment to the wastewater (Hermansky 2004). Parameters that were out of compliance during winter/spring 2004 include TP, biochemical oxygen demand, and fecal coliforms (Nelson 2004). WDEQ has suggested Brooks Lake Lodge use non-phosphate laundry detergents to reduce phosphorus in their effluent (Hermansky 2005). Lodge personnel informed WDEQ they would discontinue use of detergents containing phosphorus in June of 2005 (Hardwick 2005). A modified permit to discharge was issued on 3/28/2006 without total phosphorus limits. The TP permit limits were removed because the downstream monitoring point, just prior to confluence with Brooks Lake, had consistently been under 2.0 mg/L. Monitoring requirements for TP are still in the permit, and available DMR data showed a TP concentration of 2.6 mg/L at the downstream monitoring point in September of 2006. Their current permit to discharge was issued on 12/3/2012 and will expire on 6/30/2017.

Weather Data

Daily maximum air temperature and water equivalent snow depth data from Global Historical Climatology Network station USS0010F09S (Togwotee Pass) was utilized to assess the varying environmental conditions that occurred during each of the Brooks Lake sampling years. Water equivalent snow depth (snowpack) on Togwotee Pass varied during the three sampling years, and was greatest in 2011 and least in 2012 (Figure 42). Figure 42 also demonstrates the timing of snowmelt runoff. It is evident the amount of snowpack and timing of snowmelt runoff during the three sampling years on Brooks Lake varied greatly. Daily maximum air temperature during June through September (summer growing season) is also presented (Figure 43). For the months of June, July, and August, the median monthly temperature increased during each sampling year, meaning 2012 experienced the warmest air temperatures during these months.

The greatest chlorophyll α concentrations in Brooks Lake occurred in 2012, which was the warmest summer growing season and lowest snowpack year out of the three sampling years. This was also the year when the highest pH was observed in Brooks Lake. Warmer air temperatures may have caused an earlier ice-off date and exacerbated productivity conditions within Brooks Lake during 2012.

Available weather data was evaluated to determine conditions during the fish kills. Wind data from Union Pass weather station DW0993 was obtained through the University of Utah MesoWest online, courtesy of APRSWXNET/Citizen Weather Observer Program and Meteorological Assimilation Data Ingest System. This weather station sits at 8432 ft. and is approximately 15 miles southeast of Brooks Lake, which was deemed close enough to provide a good estimate of conditions at Brooks Lake. Table 7 below gives relevant weather parameters for September 12-18, 2008. WGFD collected their algae samples from Brooks Lake on 9/18/08, which makes it safe to assume the algal bloom was occurring at least a couple days prior to their visit. Weather data indicates conditions at Brooks Lake during the week prior to the algal bloom and subsequent fish kill in 2008 were warm with a moderate wind that persisted out of the southwest and brought gusts up to 31 mph (Table 7).

Table 7. Relevant weather parameters at MesoWest station D0993- Union Pass for the dates 9/12/08 – 9/18/08.

Date	Avg. Wind Speed (mph)	Avg. Wind Gust (mph)	Max. Wind Gust (mph)	Wind Direction (degrees)	Wind Direction	Avg. Temperature (°F)	Max. Temperature (°F)
9/12/08	6.2	11.7	23	249°	W	43.2	58
9/13/08	6.5	11.9	25	233°	SW	44.9	59
9/14/08	5.4	10.7	31	243°	SW	46.3	62
9/15/08	4.6	9.1	20	231°	SW	48.1	69
9/16/08	5.1	9.6	18	235°	SW	51.2	70
9/17/08	5.0	9.6	22	208°	SW	51.3	69
9/18/08	4.3	9.0	29	203°	SW	50.6	66

Due to data availability, two weather stations were utilized to summarize weather data for sampling days in the Brooks Lake watershed. Table 8 presents relevant weather parameters from Togwotee Pass and Union Pass, which were deemed to be reasonably reflective of conditions at Brooks Lake. A small amount of precipitation fell at Togwotee Pass in the 7 days prior to most sampling events. Wind gust daily maximums were at least 16 mph for all sampling events (with the exception of two sampling events that had no available wind gust data), and the greatest wind gust speed experienced was 31 mph. Sustained winds were typically out of the southwest or west and averaged less than 9 mph for all sampling events. The effect a strong, persistent wind may have on phytoplankton and accompanying chlorophyll α concentrations is unknown.

Table 8. Relevant weather parameters for all sampling events. Maximum temperature and previous 7 days precipitation data obtained from the Global Historical Climatology Network Station USS0010F09S (Togwotee Pass WY USA). All other data obtained from MesoWest station D0993- Union Pass.
NA- Data not available

Sampling Date	Avg. Wind Speed (mph)	Avg. Wind Gust (mph)	Max. Wind Gust (mph)	Wind Direction (degrees)	Wind Direction	Max. Temperature (°F)	Previous 7 days precipitation (in)
7/15/09	7.0	13.8	29	231°	SW	61	0
8/17/09	5.0	9.7	22	243°	SW	52	0.4
9/21/09	4.3	9.3	23	258°	W	44.1	0.2
7/25/11	8.8	NA	NA	227°	SW	72	0
9/6/11	2.9	9.5	16	152°	SE	53.1	0.1
9/20/11	2.8	NA	NA	162°	S	50	0.3
7/24/12	7.5	13.3	24	240°	SW	63	0.1
7/25/12	7.6	14.2	27	248°	W	64	0.2
8/21/12	3.3	8.1	22	237°	SW	66.9	0.2
8/22/12	6.9	13.0	25	260°	W	64.9	0.2
9/11/12	8.4	15.4	31	245°	SW	55	0.2
9/12/12	4.0	9.2	27	245°	SW	53.1	0.2

Figure 42. Water Equivalent Snow Depth data for 2009, 2011, and 2012, from the Global Historical Climatology Network Station USS0010F09S (Togwotee Pass WY USA).

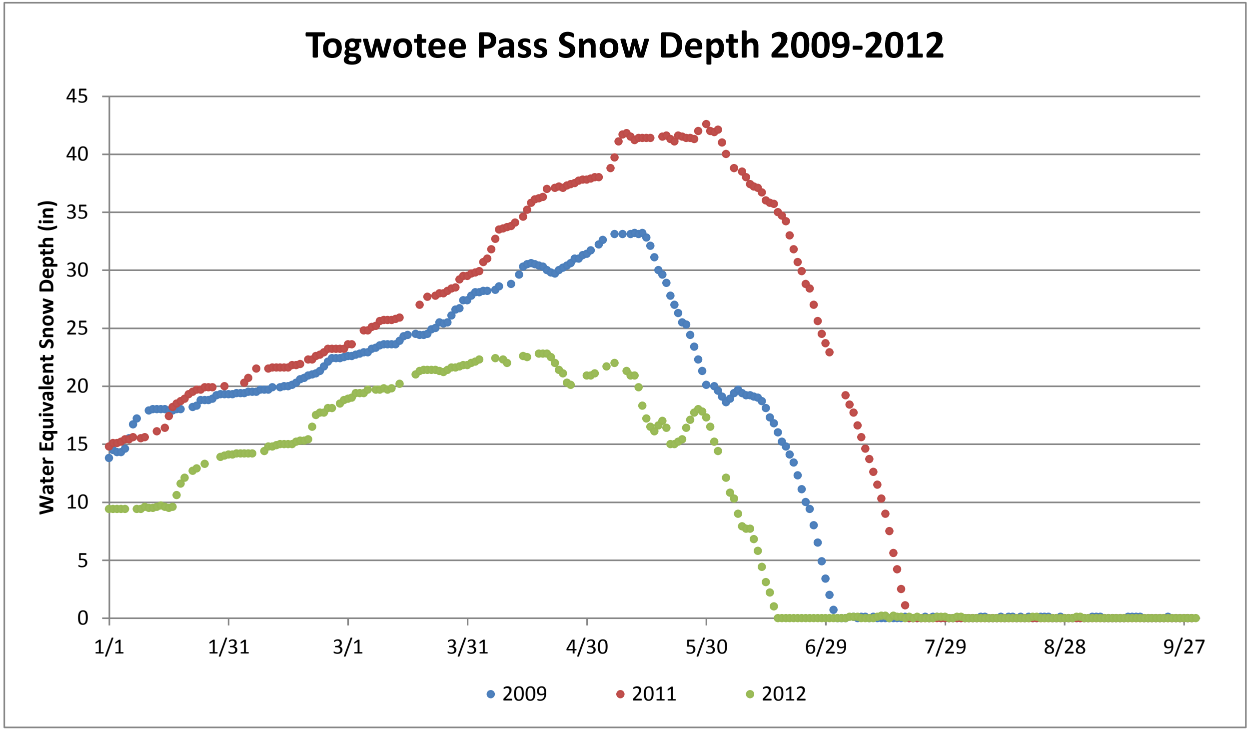
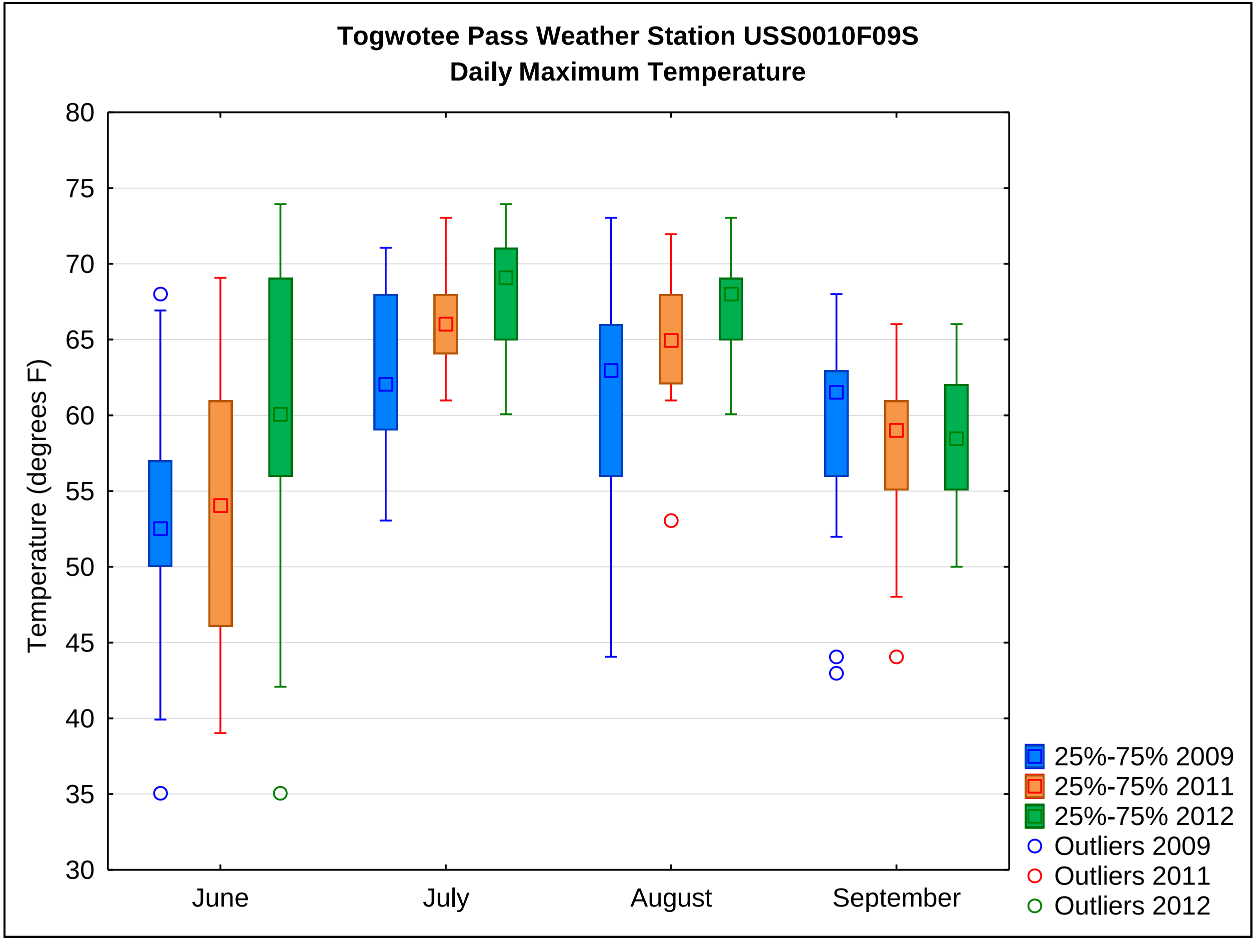


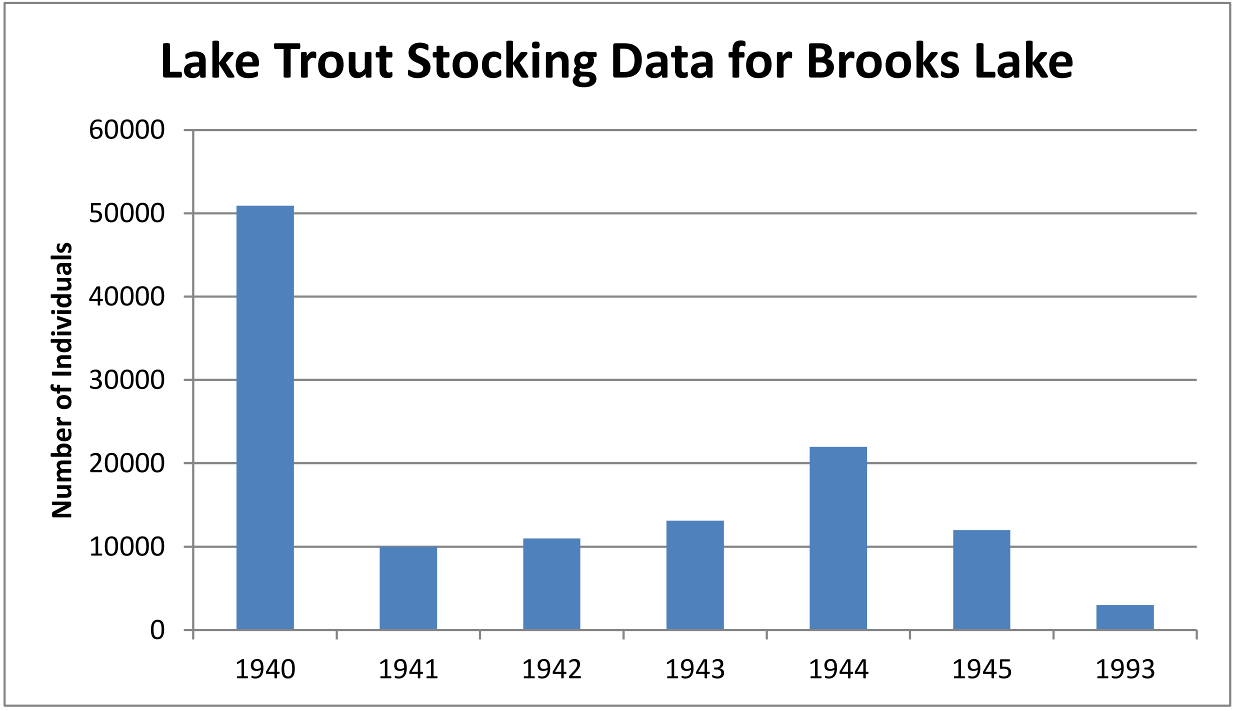
Figure 43. Daily maximum temperatures during the summer growing season, grouped by month and categorized by year for Global Historical Climatology Network Station USS0010F09S (Togwotee Pass WY USA). Boxes represent 25th-75th percentile, whiskers denote the non-outlier range, outliers are circles, and squares represent the median of a population.



Fisheries Data

The fishery of Brooks Lake, Lower Jade Lake, and Upper Brooks Lake is managed by the WGFD. Lake trout (*Salvelinus namaycush*) and rainbow trout (*Oncorhynchus mykiss*) are two of the more prevalent species that have been stocked in Brooks Lake. Lake trout stocking by WGFD occurred each year from 1940-1945, and then again in 1993 (Figure 44). All lake trout stocked in the 1940's were between 2 and 3 inches long, while the 3,000 individuals stocked in 1993 were 5.5 inches. Other trout species have been stocked annually in Brooks Lake by the WGFD since the late 1930's, including rainbow trout and splake (*Salvelinus namaycush* X *Salvelinus fontinalis*). With the exception of a few years, stocking has typically ranged from 10,000-50,000 fish annually. Prior to 2006, the majority of stocked trout ranged from 3-7 inches, and stocking often consisted of multiple events. Since 2006, the majority of stocked trout exceeded 7 inches. The following information about Brooks Lake, Lower Jade Lake, Upper Jade Lake, and Upper Brooks Lake is from Deromedi (2015a). Lake trout abundance in Brooks Lake has been dependent on natural recruitment, and the presence of juvenile fish for many decades following stocking in the 1940's confirms a wild lake trout fishery. Lower Jade Lake is stocked with 2,000-3,000 cutthroat trout every other year that generally range from 1.5-2 inches, and also supports a wild lake trout fishery that originated with stocking prior to 1948. No known fish kills have occurred, and these lake trout have maintained their presence through natural reproduction, which is supporting evidence that fish kills have not occurred in Lower Jade Lake. In 1978 a Dubois WGFD game warden reported dead fish after ice off on Upper Jade Lake, which is directly upstream of Lower Jade Lake. Upper Jade Lake is stocked with 2,000-3,000 cutthroat trout every other year. Upper Brooks Lake is managed as a wild trophy brook trout fishery, and was last stocked in 1953 with brook trout. Rainbow Lake is upstream of Upper Brooks Lake and contains brown trout and splake. There no knowledge of fish kills in Upper Brooks Lake.

Figure 44. Available lake trout stocking data for Brooks Lake.



Lake trout inhabit deep, clear, cold, well-oxygenated lakes (Marcus et al. 1984). In a study of 2500 Canadian lakes, Ryder (1965) found lake trout inhabited lakes that had mean depths greater than 6 meters, total dissolved solids concentrations below 50 mg/L, and average hypolimnetic oxygen concentrations greater than or equal to 6 mg/L. Temperature is a critical factor influencing lake trout, and a review of literature by Marcus et al. (1984) reported that lake trout were rarely found at water temperatures greater than 10-12°C during field studies. Dissolved oxygen is another critical factor influencing lake trout, and Chapman (1986) found reduced growth of lake trout and rainbow trout at 5 mg/L or less DO. At 7 and 10°C, DO concentrations below 6 mg/L have been reported to adversely affect lake trout embryo development and survival (Carlson and Siefert 1974). Brooks Lake was deemed suitable for lake trout due to its depth and steep, rocky spawning substrate along the eastern shoreline between the Bonneville Creek inlet and Brooks Lake Creek outlet (Deromedi 2015a). Deromedi (2015a) also reported lake trout spawning in Brooks Lake likely occurs along this eastern shoreline, during September, when water temperature is decreasing. Lake trout spawning depths have been found to range from 15 centimeters to over 55 meters (e.g. Merriman 1939; Carlander 1969; DeRoche 1969;

Johnson 1975); after hatching, lake trout fry move from spawning areas to deeper water, possibly to avoid predation or higher light intensities (Martin and Olver 1980).

WGFD conducted gillnetting in Brooks Lake in 1957, 1970, 1971, 1977, 1981, 1983, 1986, 1993, 1994, 2002, 2007, and 2013. Figure 45 presents gillnetting data for lake trout and rainbow trout. On the October 6, 1971 gillnetting event, six lake trout were captured that ranged in length from 14.7-36.5 inches, with four of these individuals between 14 and 17 inches. This is particularly noteworthy, because juvenile lake trout were found 26 years after the last WGFD stocking event (besides the 1993 stocking event). Furthermore, 10 years later, on June 18, 1981, WGFD found seven lake trout in gillnets that ranged from 15.3-18.8 inches. The presence of juveniles suggests lake trout were reproducing naturally for a period of time in Brooks Lake, despite likely predation on early life stages of lake trout by larger lake trout. Figure 46 breaks down the WGFD lake trout gillnetting data between juvenile and adult lake trout. WGFD did not capture lake trout in gillnets in 2002 and 2007 (Figure 45, 46), and it was believed a lake trout population no longer existed (Deromedi 2015a). However, one lake trout was captured in 2013 and it was 34.5 inches; no weight was taken of this individual, but samplers noted it was a skinny fish. Information suggests this individual was a stocked fish from 1993 and may be one of the last remaining lake trout in Brooks Lake. In 2014, sampling yielded one lake trout that was 6.6 inches and 0.10 pounds. Besides the influence 1993 stocking had on 1994 gillnetting, data suggests a general decline of both adult and juvenile lake trout in Brooks Lake (Figure 46).

Figure 45. Catch per unit effort (CPUE) for lake trout (LAT) and rainbow trout (RBT) from WGFD gillnetting.

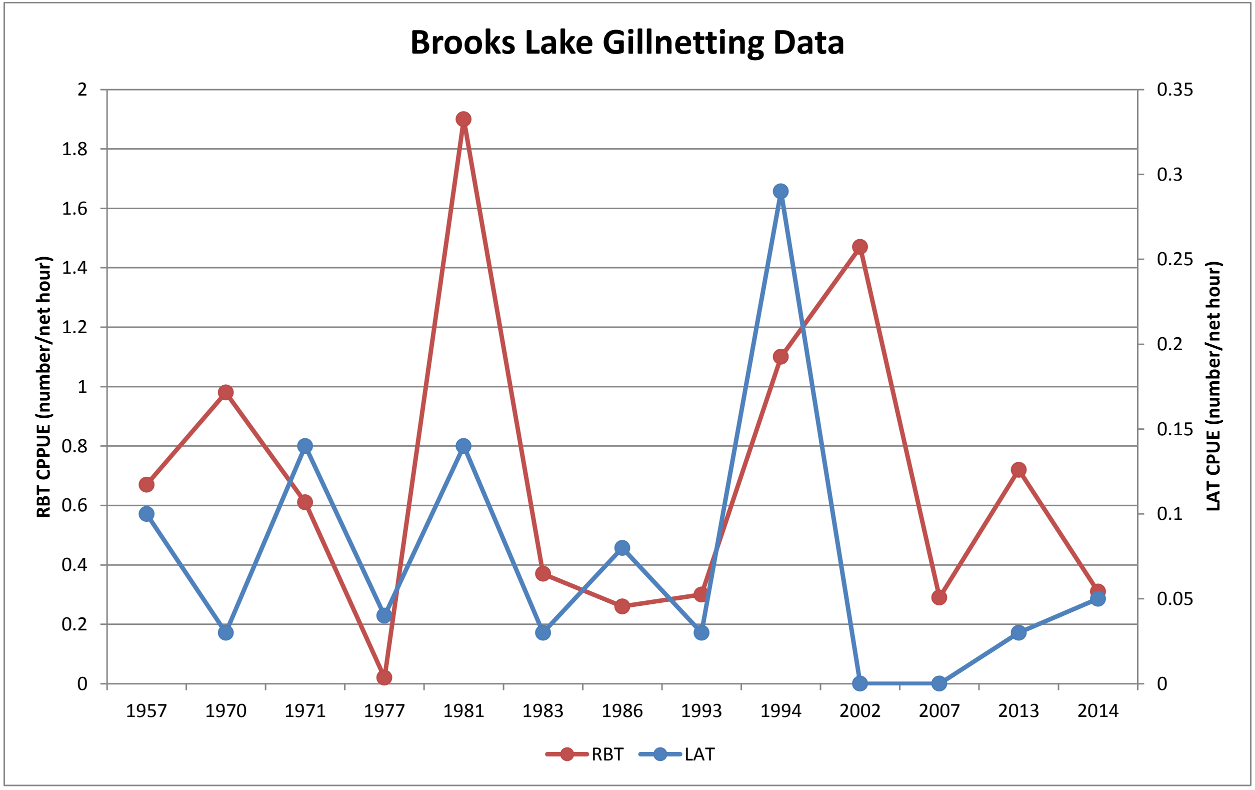
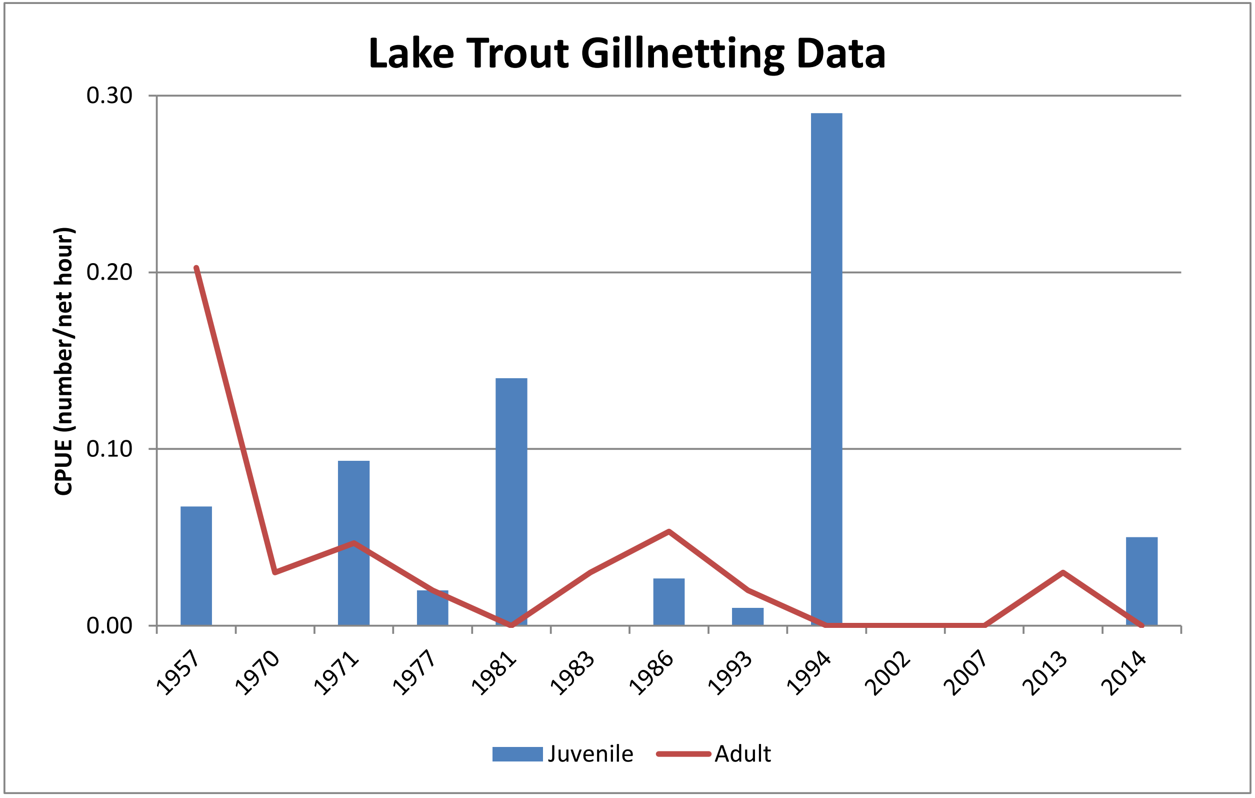


Figure 46. Catch per unit effort (CPUE) for lake trout juveniles (<20 inches) and adults (>20 inches) in Brooks Lake, from WGFD gillnetting.



Condition of fish can be measured by relative weight (Wr), which is a length-specific standard weight (Nielsen, et al. 1983). Reduced condition of fish may be indicative of stress; for example, low DO in Brooks Lake may depress appetite, and consequently reduce growth rates of fish (Deromedi 2015a). Relative weight of fish provided by WGFD from their gillnetting data on Brooks Lake and Lower Jade Lake was used to assess fish condition. Only relative weights from fish in the “Stock” size category (12-19.9” for lake trout, 10-15.9” for rainbow trout) were assessed since this category wouldn’t be influenced by newly stocked fish or older weak fish, and it had the greatest sample size. Lake trout condition in Brooks Lake generally declines from 1971-1994, while Lower Jade Lake exhibits similarly high average lake trout condition during 1996 and 2003 (Figure 47). When compared to another lake within the same drainage, Torrey Lake (230 acres, 7,411 feet above sea level), the relative weights of stock size lake trout were similar, but there was a greater decrease over time of average relative weight in Brooks Lake than in Torrey Lake (Deromedi 2015a). Relatively consistent stocking of medium (3-7”) and large (>7”) trout during the 1970-1990’s likely resulted in a high abundance (50 to >200 trout/acre) of forage in Brooks Lake for the piscivorous lake trout, suggesting other factors were responsible for the observed relative weight decreases (Deromedi 2015b). Available rainbow trout relative weight data suggests worse fish condition in recent years when compared to older records (Figure 48); relative weight near 70 is a concern (Deromedi 2015a). When compared to Torrey Lake, the relative weights of rainbow trout in Brooks Lake were generally lower and had decreased noticeably over time (Deromedi 2015a).

Figure 47. Comparison of average relative weight of Stock size lake trout sampled during WGFD gillnetting in Brooks Lake and Lower Jade Lake. Error bars represent the standard error of each year's sample; standard error was not calculated for years with low sample size.

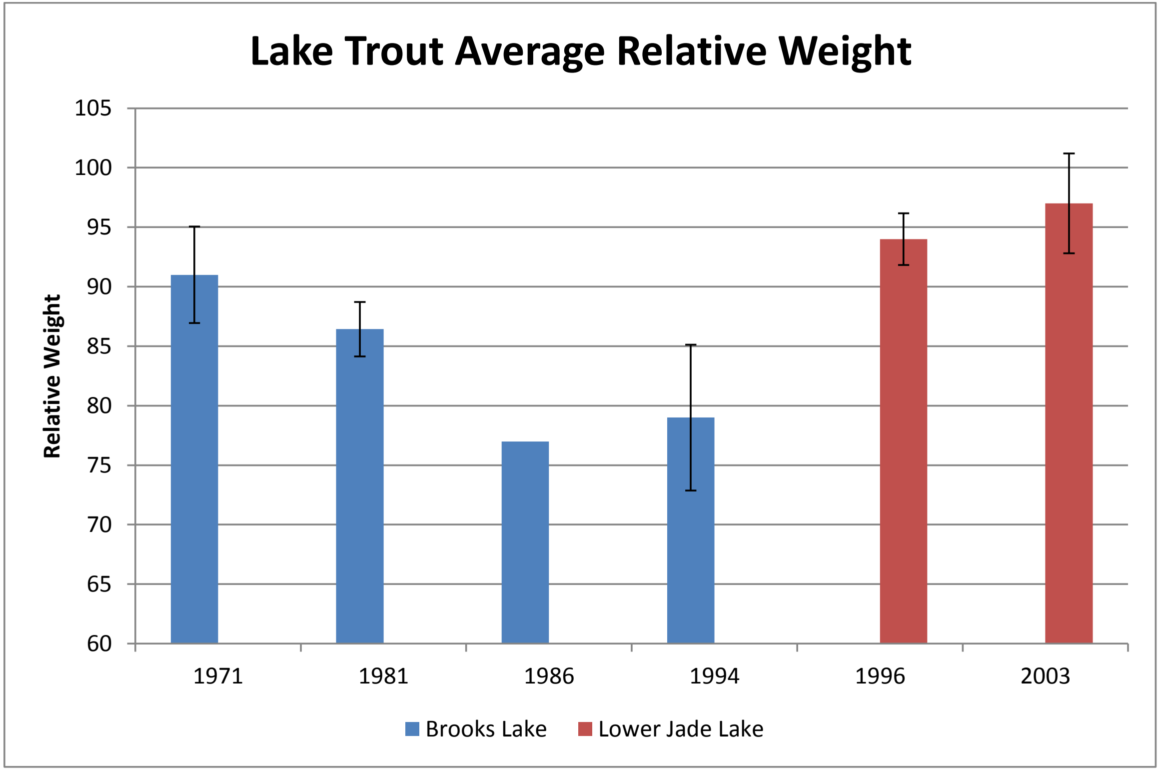
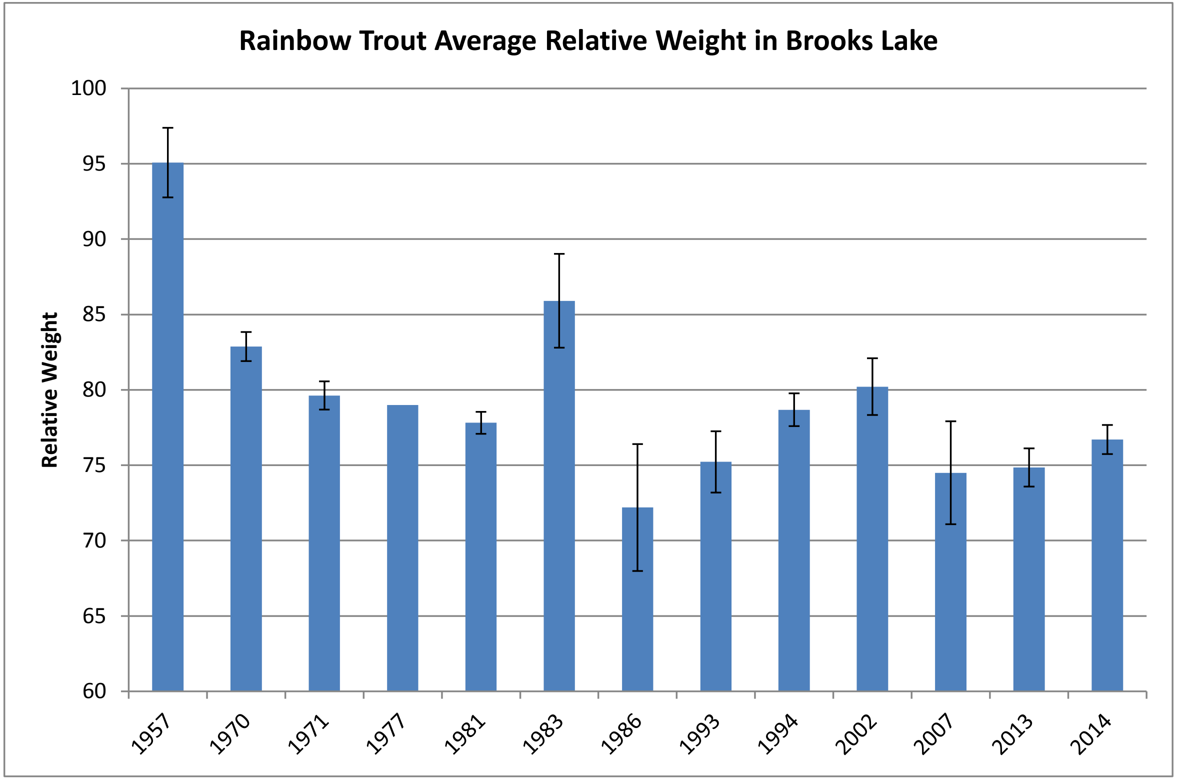


Figure 48. Average relative weight of Stock size rainbow trout from WGFD gillnetting in Brooks Lake. Error bars represent the standard error of each year's sample; standard error was not calculated for years with low sample size.



Atmospheric Nitrogen Deposition

Emissions from fossil fuels and agricultural activity are the largest sources of nitrogen to high-elevation watersheds (Fenn et al. 2003, Howarth 2008). Several factors influence watershed sensitivity to atmospheric nitrogen deposition, including bedrock and surficial geology, soil depth, vegetation, and slope. Areas underlain by intrusive igneous rocks, typical of western mountains, are of particular concern for surface-water acidification (Charles and Christie 1991). High-elevation lakes with unvegetated watersheds are more susceptible to immediate consequences of atmospheric nitrogen deposition than waterbodies whose watersheds contain more vegetation (Baron et al. 2011). A common approach is to estimate critical loads, the point at which a waterbody experiences a significant biological community composition shift, and then compare that value to the current rate of deposition. Saros et al. (2011) looked at diatom assemblages in lake sediment cores and determined a critical load of 1.4 kg N/ha*year for the eastern Sierra Nevada and the Greater Yellowstone Ecosystem. Baron et al. (2011) empirically derived critical nitrogen loads using measured chemical and biological changes in nitrogen deposition using published literature and data sets. They determined a critical load of 1.0-3.0 kg N ha^{-1} yr^{-1} for the western lakes, but note that this reflects high elevation watersheds with nearly non-existent vegetation. Nanus et al. (2012) utilized a geostatistical approach to determine critical loads of atmospheric nitrogen deposition. Based on the map produced by Nanus et al. (2012), the vicinity around Brooks Lake has a critical nitrogen load of 5.0-10.0 kg N ha^{-1} yr^{-1}. Current atmospheric nitrogen deposition near the Brooks Lake watershed was calculated as 2.0-4.0 kg N ha^{-1} yr^{-1} using data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) and National Atmospheric Deposition Program (NADP) (Baron et al. 2011). Considering the above-estimated critical loads, current nitrogen deposition estimates, and the relatively high vegetation density in the Brooks Lake watershed, atmospheric nitrogen deposition appears to contribute to nutrient enrichment in Brooks Lake, though at a rate below the critical load and therefore is not likely to be a dominant source.

Nutrient Modeling

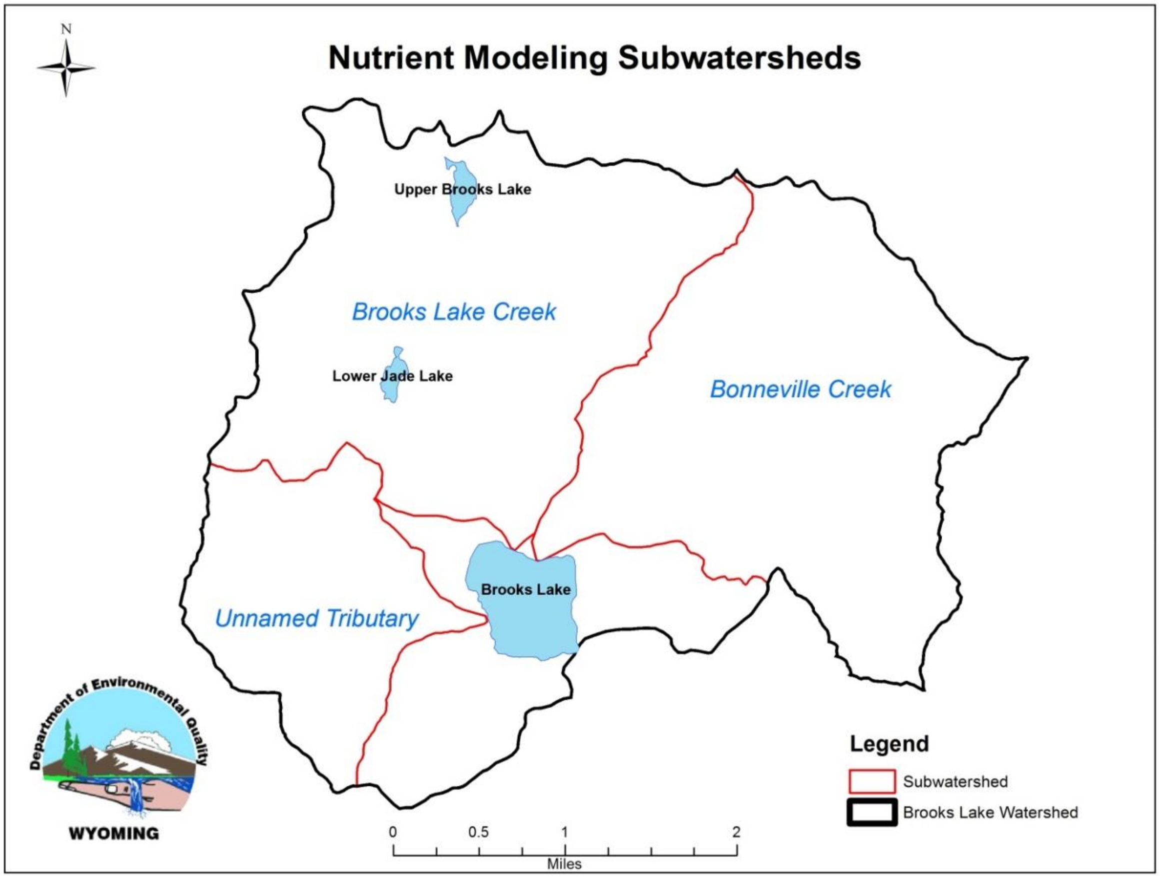
Olson and Hawkins (in review) have developed a model that predicts baseflow concentrations of TP in western U.S. streams in the absence of anthropogenic activity. This model was used to predict TP concentrations in 2009 and 2011 for the Bonneville Creek subwatershed, Brooks Lake Creek subwatershed, Unnamed tributary subwatershed, and for the whole Brooks Lake watershed at the outlet of Brooks Lake (Figure 49). The upper 95th percentile of the model predictions were deemed a reasonable conservative predictor of instream TP concentration (Olson 2013a). Table 9 below presents the upper 95th percentile predictions along with the actual instream measured TP.

Table 9. Olson and Hawkins (in review) TP predictions for subwatersheds within the Brooks Lake watershed and actual measured TP concentrations.
*Actual concentration is the average of 3 TP samples that were collected during each year.

Catchment	2009 Prediction	2009 Actual*	2011 Prediction	2011 Actual*
Bonneville Creek	39	57	39.6	62.7
Unnamed Tributary	38.1	81.7	38.5	83.7
Brooks Lake Creek	36.4	77	37.2	84.3
Brooks Lake Creek-Outlet	37.3	39.7	38	41

The model most accurately predicts TP concentrations for Brooks Lake Creek- Outlet, suggesting actual TP concentrations are very similar to what would be expected under conditions of minimal or no anthropogenic influence. Inaccuracy of the model predictions for the three subwatersheds most likely is due to the large amount of bedrock geology classified as landslide deposits. The model essentially treats landslide deposits as “no data” which adds a degree of uncertainty and makes it difficult to predict and know what is in those deposits. Phosphorus-rich volcanic rocks could be obscured by these landslides. The small watershed scale at which these predictions are being applied may also add uncertainty to the predictions. Despite the differences in predicted and actual concentrations, these subwatersheds are probably contributing mostly naturally derived TP, considering the degree of uncertainty the landslide deposits add and the minimal anthropogenic activity (Olson 2013b).

Figure 49. Subwatersheds used in nutrient modeling by Dr. John Olson.



Effects of High pH on Fish

The majority of literature investigating the effects of high pH on fish is associated with aquaculture and fish stocking, though some laboratory studies on cold-water fishes provide a better understanding of this stressor. Daye and Garside (1975) found the lethal upper limit of pH for brook trout (*Salvelinus fontinalis*) to be 9.8 at 10 and 20°C. Another study by Daye and Garside (1976) looked at histopathologic changes to tissues of brook trout exposed to high pH levels in order to better understand the actual causes of mortality in highly alkaline waters. At pH levels above 9.0 they observed excessive secretion and hypertrophy of mucous from gill, integument and nare cells, as well as epithelial necrosis and sloughing of gills, corneae, integument and esophagus at lethal pH levels of 9.8. Daye and Garside (1980) observed the effects of high pH on Atlantic salmon (*Salmo salar* L.) embryos and alevins. No developmental or hatching effects at pH 9.5 were observed. However, sublethal changes in embryos occurred, including cell necrosis, sloughed rudimentary epidermis, and metaplasia of the brain stem. Alevin cumulative mortality at pH 9.0 was 0.4%, but increased to 18% at pH 9.5. Noted injuries to alevins include injury to mucous cells, deleterious alterations in the branchial epithelium, erythrocytes, myocardium, blood vessels of the viscera, liver, brain, and optic lenses. Murray and Ziebell (1984) observed how the rate of acclimation to higher pH waters impacted the maximum tolerable pH of rainbow trout (*Oncorhynchus mykiss*). Under gradual acclimation conditions (0.2-1.0 S.U. per day) rainbow trout didn't experience mortality until the pH reached 10.2, while rapid acclimation (pH increase every 15 minutes) resulted in mortality at 9.5 S.U. Another study by Wilkie et al. (1993) tested the ability of Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) to tolerate even higher pH values than their naturally alkaline environment in Pyramid Lake, Nevada. These trout are uniquely adapted to highly alkaline waters (pH 9.4) in Pyramid Lake, and desiccation of the lake has led to continued pH increases. The purpose of the study was to understand the response to future potential environmental conditions. Greater than 50% mortality was observed after 72 hour exposure at pH 10. The study suggested a combination of ammonia toxicity and ionoregulatory failure led to the mortality. Highly alkaline environments caused by high rates of photosynthesis are often accompanied by extremes in other parameters, such as dissolved oxygen. Serafy and Harrell (1993) found that 3 species of warmwater fish did not avoid areas, such as dense macrophyte beds, when high pH levels (9.5-10.0) were accompanied by high dissolved oxygen saturation levels (200-260% saturation). They suggested that under conditions of oxygen supersaturation the effects of high pH may be nullified, as high pH itself may not cause fish mortality, but rather high pH may cause impairment to the ability of a fish to uptake oxygen through its gills.

This literature helps understand the pH mortality thresholds of the cold-water fish in Brooks Lake. It is unknown if the Brooks Lake fish kills were directly due to high pH, but the physical environment is approaching the mortality thresholds described in the above literature, as pH in excess of 10.1 was observed in 2012. It is likely these localized extremes are simply avoided by fish, however, the presence of an anoxic hypolimnion decreases the amount of habitat suitable for cold-water fish in Brooks Lake.

Discussion

Water Quality

The pH of lakes in the Brooks Lake watershed appears to be naturally elevated; however nutrient enrichment and subsequent increased photosynthetic activity may have exacerbated the already-high pH. Brooks Lake exhibited pH values during all three sampling years that fell outside the WDEQ/WQD (2013) criterion range of 6.5 - 9.0 S.U for protection of aquatic life. Vertical profiles revealed that several meters of the water column frequently exhibited pH greater than 9.0. For only two of nine sampling events during the three years of monitoring did Brooks Lake attain the pH criterion. The greatest pH value observed in Brooks Lake was 10.18, while 9.72 was the greatest pH value in the reference lakes. The epilimnion of Brooks Lake constitutes the outflow, which means high pH conditions in the lake will also be typical in the outlet stream. Of the nine total sampling events, pH at Brooks Lake Creek Outlet was above 9.0 for seven of those events.

Another response variable associated with eutrophication, dissolved oxygen, was low at times as well. Brooks Lake commonly had an anoxic hypolimnion, although Lower Jade Lake also exhibited an anoxic hypolimnion. If we were to use <4 mg/L DO as a threshold for hypoxia, the bottom 5-7 meters of Brooks Lake would be considered hypoxic during summer and fall sampling trips, while only the bottom 1-2.5 meters of Lower Jade Lake would be considered hypoxic. Even though Brooks Lake's lower position in the watershed may play a role in its "thicker" hypoxic hypolimnion, it is probable the heavier anthropogenic impact is strongly influencing the hypoxic conditions found in Brooks Lake. Lower DO concentrations (<8 mg/L) in Brooks Lake Creek during dawn hours in the fall suggest depressed DO conditions may occur during the winter. It is unknown if applicable water quality criterion for DO are attained during winter in Brooks Lake and Brooks Lake Creek. DO concentrations below 8 mg/L were also documented in Brooks Lake Creek inlet, Bonneville Creek, and Unnamed tributary, indicating the minimum concentration for early life stages of cold-water fishes of 8 mg/L may not always be attainable in this watershed under natural conditions.

The chlorophyll α concentrations in Brooks Lake were significantly greater than those in the reference lakes. In two years of sampling on Brooks Lake the average chlorophyll α concentration was 38.2 mg/m^3. The reference lakes averaged 3.4 mg/m^3 and never exceeded 7.1 mg/m^3, while Brooks Lake exhibited concentrations up to 310 mg/m^3. WDEQ/WQD does not have numeric water quality criteria for chlorophyll α. As a comparison, Colorado is proposing chlorophyll α concentration not to exceed 8 mg/m^3 for protection of cold-water aquatic life. Minnesota recommends not exceeding 3 mg/m^3 for lakes supporting natural populations of lake trout, and 6 mg/m^3 for lakes containing other species of trout (CDPHE/WQCD 2011).

Data from the Horse Corral Tributary indicates there may be non-point nutrient sources in and around Brooks Lake Lodge. A small retention pond, from where the tributary flows, is located adjacent to the horse corrals for the lodge; although it does not appear the horses have unrestricted access to this pond. Average TP, TN, and TKN concentrations from this site were the greatest of all tributaries to Brooks Lake, however it contributes a relatively small nutrient load due to its limited flow. The wastewater lagoons are also a rich source of nutrients to Brooks Lake, but its low flow results in delivery of a small nutrient load. However, due to a large number of total nitrogen samples that were below detection, a closer look at total nitrogen loading using less conservative assumptions in an additional analysis revealed the wastewater lagoons may contribute approximately 9% of the total nitrogen budget, while the Horse Corral Trib may contribute about 15% of the Brooks Lake total nitrogen budget. One uncertainty regarding the wastewater lagoons is the potential for groundwater interaction with wastewater and the subsequent underground flow into Brooks Lake. The greatest average seasonal flows from the effluent were during the snowmelt time (July), and were 0.011 cfs (7100 gallons/day). This is about half of the facility design flow of 12,500 gallons/day. Summer average flows were 0.006 cfs (3950 gallons/day) and fall flows were 0.00049 cfs (320 gallons/day). Not accounting for evaporation, these data suggest Brooks Lake Lodge frequently operates well-below capacity, or there is significant loss of wastewater to groundwater if the lagoons are not lined. A DEQ inspector noted significant groundwater problems during construction of the lagoons.

Measured inflows to Brooks Lake accounted for, on average, 92% of the measured outflow. Unmeasured inflows to Brooks Lake exist, including surface water contributions originating from springs and direct groundwater contributions. Natural groundwater quality was not measured during this study, though two springs (Unnamed Tributary East and Lower Jade Lake outlet) believed to be absent of anthropogenic influence were sampled that both contained relatively low nutrient concentrations. Although the nutrient loading to Brooks Lake from natural groundwater cannot be quantified, it is believed to be lower than nutrient loading from surface water.

Nitrogen to phosphorus ratios in Brooks Lake were generally suggestive of nitrogen limitation, except during times of the highest chlorophyll α concentrations; ratios during these times were more suggestive of phosphorus limitation or co-limitation. The nutrient to chlorophyll α relationships also suggest that nitrogen is more influential on chlorophyll α in Brooks Lake. Nitrogen appears to limit primary production in the reference lakes, although periods of co-limitation may occur.

Internal Nutrient Loading

One potentially significant nutrient source to Brooks Lake is internal loading. Internal phosphorus loading is one of the most challenging subjects regarding lake and reservoir eutrophication, yet it is often the greatest summer phosphorus load to a lake (Nürnberg 2009). The flux of phosphorus from benthic sediment during anoxic conditions is a major source of internal phosphorus to lakes and reservoirs. James et al. (2002) examined multiple external and internal sources of phosphorus to a shallow, urban lake in Wisconsin. They found internal recycling of phosphorus accounted for 80% of the summer phosphorus budget for the lake. One internal source of phosphorus, flux from the sediment, accounted for 42% of the total phosphorus budget. Other significant internal sources to the phosphorus budget included decomposition of macrophytes, recycling of macrophyte phosphorus during the summer, and phosphorus re-suspension from motorboat activity. Internal nutrient loading is undoubtedly a source of nutrients to Brooks Lake, however, the magnitude of this source is currently unknown. This is particularly true, because hypolimnetic phosphorus concentrations were significantly greater in Brooks Lake than in Lower Jade Lake. Brooks Lake may benefit from a relatively short residence time though. Residence time is a measure of the amount of time a substance spends in a lake or reservoir before it is replaced. Essentially, it is a measure of how often the water in a lake or reservoir is replaced by incoming flows. Residence time can be calculated by dividing the total volume of the waterbody by the input or output. Using a hand-drawn WGFD bathymetric map, the volume of Brooks Lake was estimated with a grid approach to determining average depth. Total annual inflow and outflow was estimated using measured flows in inlets and outlets and extrapolating that data to other months. It was assumed there was negligible flow in any of the inlets or outlets during January through March due to freezing conditions. With a total volume of 246,842,323 ft^3, and an annual outflow of 836,334,720 ft^3, calculated residence time was 0.30 years. Using annual inflow data (703,883,520 ft^3), residence time was calculated to be 0.35 years. This means the water in Brooks Lake is replaced approximately 3 times every year.

From a management perspective, lakes that have experienced a reduction in external nutrient sources may not see an immediate improvement in water quality, because phosphorus release from sediment may be so intense and persistent that it takes a considerable period of time following load reductions for any noticeable improvement to occur (Scharf 1999). In the case of Brooks Lake, we would expect a quicker response to load reductions due to its relatively small size and short residence time.

Carlson's Trophic State Index

The TSIS and TSIC were both significantly greater in Brooks Lake than in the reference lakes. It is interesting to classify the trophic state of the study lakes for each of the three variables. The TSIC and TSIP both classify Brooks Lake as eutrophic, while the TSIS classifies Brooks Lake as mesotrophic. For the reference lakes, average TSIS and TSIC classify these lakes as oligotrophic, while the TSIP classify both lakes as eutrophic. Generally speaking, the TSIC is the most commonly relied upon index of the three for estimation of algal biomass and trophic state. These classifications must not be evaluated too critically, as these lakes were compared to a large data set of North American lakes with Carlson's TSI. Similarities in TSIP between Brooks Lake and the reference lakes suggest that phosphorus is abundant in the watershed and may not solely limit algal biomass growth. It is worth noting again that Brooks Lake's more downstream position in the watershed relative to the reference lakes may or may not be influencing its productivity conditions. Nonetheless, evidence suggests Brooks Lake is significantly more productive than the reference lakes.

Fisheries

Available data suggests Brooks Lake was once capable of supporting a lake trout fishery, with natural reproduction. With the exception of one large, older individual in 2013, and one juvenile in 2014, no lake trout have been captured in WGFD gillnets since 1994 and anecdotal information from anglers during sampling visits suggests very few lake trout are caught anymore. The lake trout fishery in Brooks Lake appears to be barely sustaining itself (Deromedi 2015a). Odum (1985) describes expected trends in stressed ecosystems, and cites whole-lake experiments where nutrient additions greatly altered the species composition of plankton and fish. Colby et al. (1972) examined the effects of eutrophication on salmonid communities in oligotrophic lakes, and found they respond to progressive eutrophication by a series of predictable events. Eutrophication through greater nutrient loads increases primary production which results in changes to the abiotic environment, including changes in the color and transparency of the water, increased turbidity, oxygen depletion in the hypolimnion, and increased chemical stratification. These abiotic changes bring about biotic changes amongst the phytoplankton, zooplankton, littoral algae, benthos, and fish communities. Salmonid communities may initially respond with increased body growth rates and a higher incidence of parasitism, with an inhibition of natural reproduction to follow, which results in replacement of taxa by others that are able to survive in the changed environment. Furthermore, phytoplankton communities generally increase in abundance but change in species composition, with typical changes being a shift from diatoms and green algae to blue-green algae (Colby et al. 1972). Lienesch et al. (2005) obtained similar results in a small arctic lake in Alaska when nitrogen and phosphorus were added from 1990 to 1994. They initially observed increased growth rates and increased average size of lake trout. Increased nutrient loading caused physical changes to the lake, including decreased dissolved oxygen in the hypolimnion, which reduced lake trout habitat availability. Lake trout spawn in the fall over clean rocky substrate and the eggs over-winter in the interstitial spaces in the substrate. These eggs are susceptible to stressors such as burial in sediment or low dissolved oxygen conditions over the winter as organic material decomposes, which ultimately decreases recruitment. Other physical changes to the lake, such as decreased clarity, impact the lake trout's ability to detect prey because they are visual feeders. Results from this study suggest extended periods of fertilization could extirpate lake trout from these systems (Lienesch et al. 2005). It is possible the decline of lake trout in Brooks Lake may be due to the stress that increased nutrient loads and subsequent eutrophication have placed on this system. In particular, low dissolved oxygen levels may be significantly impacting lake trout recruitment.

Carlson and Siefert (1974) demonstrated DO concentrations less than 6 mg/L depress lake trout embryo survival, and Chapman (1986) found reduced growth of lake trout and rainbow trout most noticeably at 5 mg/L or less DO. Our deepest sampling sites on Brooks Lake and Lower Jade Lake were both about 14 meters deep. In Brooks Lake in 2012, 6 mg/L or less DO was encountered about 5.5-7.5 meters below the surface; while in Lower Jade Lake, these conditions were not encountered until 10.5-11.5 meters below the surface. Water temperature is another influential factor on lake trout. In 2012, the preferred temperature (10-12°C) occurred between 5 and 8 meters from the surface in Brooks Lake, and from 5.5-9.5 meters from the surface in Lower Jade Lake. If we consider 6 mg/L DO as a threshold for early life stages of lake trout and 12°C as a maximum preferred water temperature, we can use vertical profile data to estimate the amount (vertical thickness) of favorable lake trout habitat in both lakes for each sampling event (Table 10).

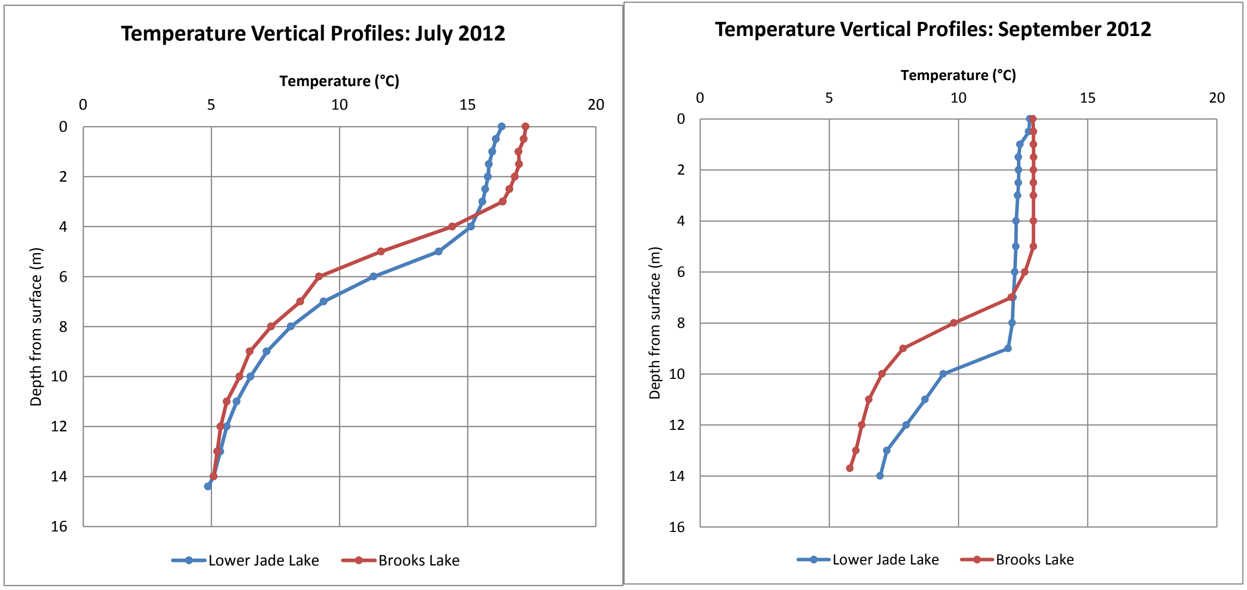
Table 10. Approximate vertical thickness (meters) of preferred lake trout habitat (<12°C and >6 mg/L DO) in Brooks Lake and Lower Jade Lake during three sampling events in 2012.

	July 2012	August 2012	September 2012
Brooks Lake	2	1	0
Lower Jade Lake	5	4	3.5

Another study suggested the preferred water temperature range of lake trout may be between 8 and 15°C (Johnson 1975). In 2012, epilimnetic water temperatures in Brooks Lake were greater than in Lower Jade Lake, while hypolimnetic temperatures were greater in Lower Jade Lake than in Brooks Lake (Figure 50). However, water temperatures were generally similar between these two lakes. Dissolved oxygen vertical profiles for these two lakes were quite different (Figure 51). The most noticeable difference between Brooks Lake and Lower Jade Lake was the greater amount of DO available to lake trout in the hypolimnion. When water conditions (e.g. DO) in Brooks Lake are not favorable, lake trout and rainbow trout likely move to more suitable areas like stream inlets or surface water (Deromedi 2015a). During the summer growing season, the epilimnion in Brooks Lake regularly experienced high pH conditions. These high pH conditions may deter trout from utilizing the epilimnion for periods of time during the summer. Murray and Ziebell (1984) found that with gradual acclimation in a laboratory experiment rainbow trout did not experience mortality until pH of 10.2, although fish experienced reduced activity at pH >8.9 and signs of distress at pH >9.7. High pH may be a factor in the reduced rainbow trout condition in Brooks Lake. No literature was found describing the effects of high pH on lake trout, although literature regarding brook trout may be relevant since both are members of the same genus (*Salvelinus*). Daye and Garside (1975, 1976) found the lethal upper limit of pH for brook trout to be 9.8, and noted physiological stress at pH above 9.0. Nonetheless, brook trout in Upper Brooks Lake had a relative weight of 102 during 2011 WGFD sampling, and were noted as being very healthy (Deromedi 2015a) despite being exposed to pH levels frequently greater than 9.0. Supersaturated DO conditions (200-260% saturation) were reported to nullify the effects of high pH on warmwater fish (Serafy and Harrell 1993). Dissolved oxygen saturation in Brooks Lake and Upper Brooks Lake was only as high as 180 and 130% respectively, yet the supersaturated conditions may partially alleviate the stress of high pH on these trout. Regardless, trout in Brooks Lake appear to have a relatively small amount of habitat that offers preferred living conditions due to low DO in the hypolimnion, and high pH and temperature in the epilimnion. This greater stress in Brooks Lake, relative to the reference lakes, may be responsible for the lower relative weights of lake trout and rainbow trout.

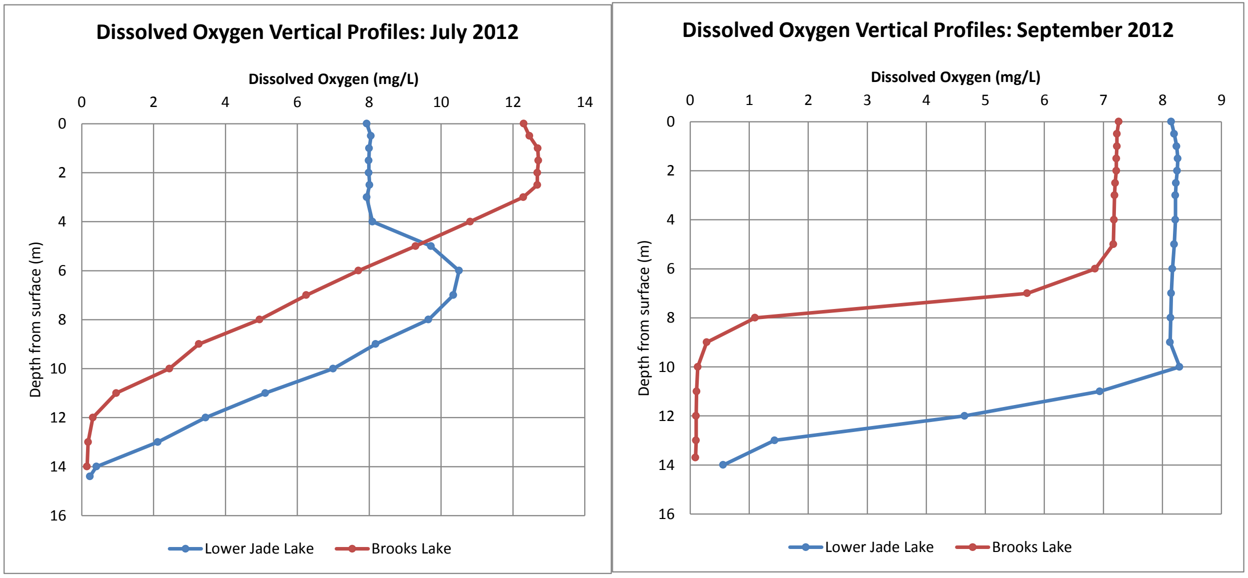
Since oxygen depletion in the hypolimnion is a symptom of eutrophication, increased productivity stemming from greater nutrient loading is likely having a significant impact on available lake trout habitat in Brooks Lake. Evidence suggests Brooks Lake was once a lake trout fishery with natural reproduction, but now the lake trout appear to be barely sustaining themselves (Deromedi 2015a) and Brooks Lake may no longer be suitable for lake trout (Deromedi 2013). In contrast, the lake trout population in Lower Jade Lake continues to sustain itself without stocking.

Figure 50. A comparison of temperature vertical profiles at the deepest site from both Brooks Lake and Lower Jade Lake in July and September 2012.


Temperature Vertical Profiles: July 2012

Temperature Vertical Profiles: September 2012

Figure 51. A comparison of dissolved oxygen vertical profiles at the deepest site from both Brooks Lake and Lower Jade Lake in July and September 2012.



Summary

The frequent pH excursions that exceed WDEQ/WQD criterion combined with two known fish kills since 2001 suggest Brooks Lake is not supporting its cold-water fisheries use. Anecdotal information states no known or documented nuisance algae blooms occurred from the early 1920's to the mid-1980's, and no fish kills were documented prior to those that occurred in 2001 and 2008. Lake trout, a species that prefers deep, clear, cold, well-oxygenated lakes, once maintained a population through natural reproduction in Brooks Lake. With the exception of one individual caught in both 2013 and 2014, no lake trout have been found in WGFD gillnets since 1994, which was one year after a stocking event. Relative weight data suggests a decline in lake trout condition, in addition to a decrease in rainbow trout condition in Brooks Lake. In contrast, Lower Jade Lake contains a naturally reproducing population of lake trout that exhibit higher relative weights. A typical response to increased nutrient loading and eutrophication is an increase in phytoplankton abundance, followed by a decrease in transparency of the water, as well as a shift in the species composition, with blue-green algae commonly replacing diatoms and green algae (Colby et al. 1972). Algal blooms were observed each year of WDEQ/WQD sampling, and appear to now be common within Brooks Lake. Blue-green algae were identified in Brooks Lake after both fish kills, although it is unknown if an actual shift in the algal community has occurred or if blue-greens occur more episodically. Additionally, Brooks Lake exhibited significantly higher chlorophyll α concentrations and significantly lower water transparency when compared to the reference lakes. An anoxic hypolimnion is also common within Brooks Lake, which is typical of lakes experiencing nutrient enrichment. Lower Jade Lake also displayed an anoxic hypolimnion, albeit a “thinner” one. These changes within Brooks Lake appear to be similar to those described by Lienesch et al. (2005) and Colby et al. (1972), which describe the biotic and abiotic changes due to eutrophication of oligotrophic lakes. These lines of evidence suggest Brooks Lake is experiencing the effects of accelerated eutrophiciation from one or more nutrient sources.

Evidence suggests there are several different sources of nutrients to Brooks Lake. Available data and information suggests the wastewater lagoons may contribute anywhere from 2-9% of the total nitrogen load, while the area around the Lodge and horse corrals contributes approximately 4-15% of the total nitrogen load in a non-point source nature. Together, these human influenced sources contribute about 7-24% of the total nitrogen budget to Brooks Lake, and nitrogen appears to be the limiting nutrient. Prior to the issuance of their first permit-to-discharge in 1984, illegal discharges and overflows occurred, which make it difficult to understand the magnitude of their nutrient load contribution to Brooks Lake. If these lagoons were never lined there could also be groundwater nutrient contribution of an undetermined magnitude to the lake as well, although this is unknown. Additionally, this lodge existed for decades prior to the construction of the wastewater lagoons, but no information was found on how they handled their wastewater. Quality and quantity of natural groundwater contributions to Brooks Lake were not measured during this study, though two springs (Unnamed Tributary East and Jade Lake outlet) believed to be absent of anthropogenic influence were sampled that both contained relatively low nutrient concentrations. Atmospheric nitrogen (N) deposition is a source of N to the Brooks Lake watershed. A review of available literature and communication with Dr. Jill Baron lead us to believe that current N deposition rates do not exceed the critical N load for Brooks Lake. In other words, atmospheric N deposition is a source of N for Brooks Lake, but does not appear to be a major source. Naturally derived phosphorus from volcanic rocks within the Brooks Lake watershed appears to be the primary source of phosphorus to Brooks Lake. A significant portion of the watershed has bedrock geology classified as landslide deposits, which adds a degree of uncertainty as to what it might contribute. Differences in the nutrient model predictions of baseflow TP to the actual measured concentrations suggests the landslide deposits in the watershed may also be composed of phosphorus-rich rocks. Model predictions that were very similar to actual instream measurements in the outlet stream of Brooks Lake imply existing TP concentrations coming out of Brooks Lake are within expectations of what would occur naturally. Furthermore, phosphorus concentrations within Brooks Lake were very similar to those in the reference lakes.

An oligotrophic condition cannot necessarily be expected of every lake, particularly in the Greater Yellowstone Ecosystem. Naturally phosphorus-rich geology allows certain watersheds to be more productive than others, even in the absence of anthropogenic activity. Available limnologic and diatom assemblage data from 5 lakes within Yellowstone National Park and Grand Teton National Park indicated mesotrophic to moderately eutrophic conditions (Kilham et al. 1996). The authors note the bedrock geology of these lakes is volcanic in origin, and primarily consists of rhyolite. Additionally, these watersheds from Kilham et al. (1996) have seen little anthropogenic impact, except for fire suppression activity in the last century.

Furthermore, increasing atmospheric CO_2 and subsequent climate change encourages abiotic changes in lakes. The average daily maximum air temperature on Togwotee Pass for the months of June, July, and August increased each sampling year. Warmer summer temperatures, earlier ice-off, and later ice-on dates will undoubtedly result in increased phytoplankton production rates.

Considerations

Available data and literature suggest the chlorophyll maxima may not always be near the surface. Environmental factors such as nutrient availability, UV radiation, temperature, and photosynthetically active radiation (PAR) influence where phytoplankton gather. Saros et al. (2005) investigated the location of the chlorophyll maximum over spatial and temporal scales in high-elevation lakes in the Beartooth Mountains of Wyoming and Montana. They found that greater nutrient availability and adequate PAR below the thermocline led to the development of a deep chlorophyll maximum up to 16 meters below the water surface in some alpine lakes. Upon close examination of vertical profiles collected at Brooks Lake and Lower Jade Lake, data suggests the highest chlorophyll concentration within each lake may not have always been captured. Photosynthetic activity will increase local pH and dissolved oxygen concentrations, and therefore can be used as an indicator of the location of the greatest photosynthetic activity. Furthermore, dissolved oxygen percent saturation can be used as an indicator to the intensity of photosynthetic activity. A look at Brooks Lake vertical profiles on 7/25/12 reveals the highest pH and dissolved oxygen concentrations occurred between 0-3 meters from the surface (Figure 52). At these depths, dissolved oxygen percent saturation ranged from 170.6-180.5%. In Lower Jade Lake on 7/26/12, the greatest pH and dissolved oxygen concentrations were found around 5-7 meters from the surface (Figure 53). Dissolved oxygen percent saturation ranged from 124.3-132.1% at these depths. This suggests that the chlorophyll maximum may have been captured from Brooks Lake, while the Lower Jade Lake chlorophyll sample may be underestimating primary production within this lake. Additionally, phytoplankton diurnal migration may also affect nutrient concentrations, particularly in Lower Jade Lake where PAR penetrates to greater depths than in Brooks Lake.

Figure 52. Dissolved oxygen and pH vertical profiles for Brooks Lake on 7/24/12.

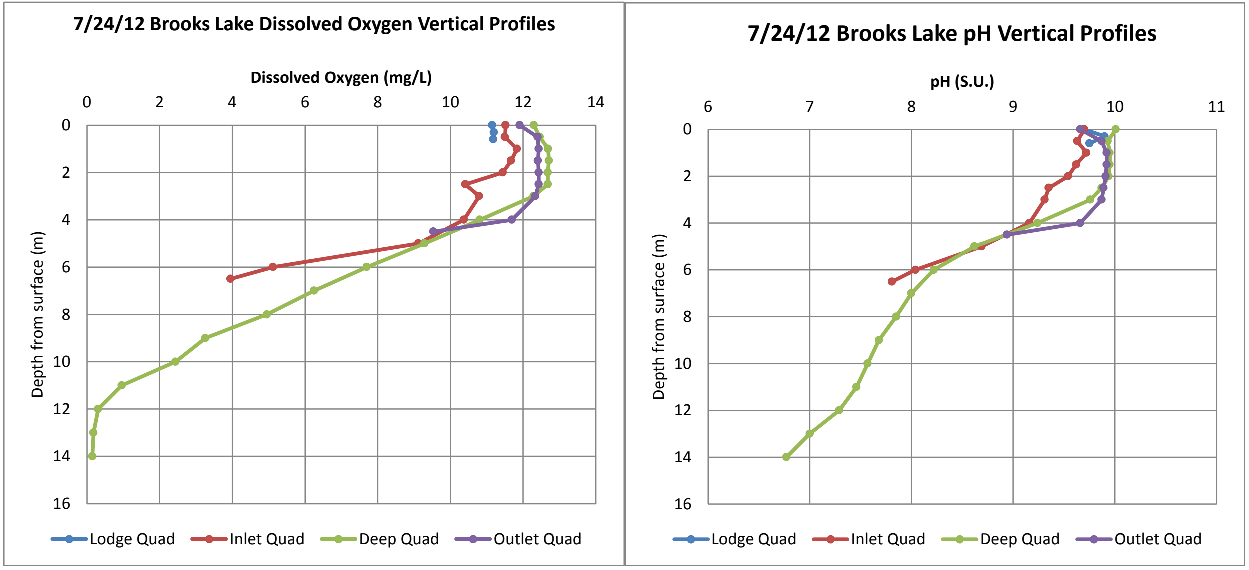
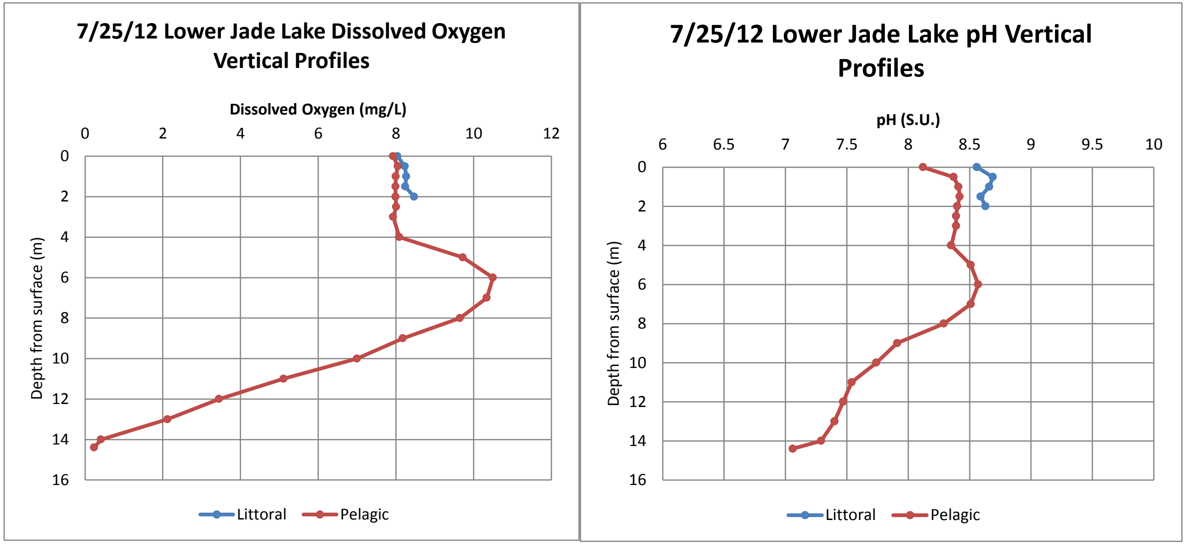


Figure 53. Dissolved oxygen and pH vertical profiles for Lower Jade Lake on 7/25/12.



Conclusions

Results from three years of sampling on Brooks Lake reveal pH frequently exceeded the WDEQ/WQD criterion range in both the lake and in the outlet stream, Brooks Lake Creek. Dissolved oxygen concentrations in the outlet stream were occasionally below 8 mg/L, and it is unknown if low DO concentrations persist during more critical time periods (i.e. winter). WDEQ/WQD data indicate pH conditions greater than 9.0 and DO concentrations below 8 mg/L can occur naturally in the Brooks Lake watershed. Dissolved oxygen and pH are response variables for nutrient enrichment. Some minimally influenced lakes within the Greater Yellowstone Ecosystem exhibit properties of mesotrophy and eutrophy, primarily due to their geology. Multiple sources contribute nutrients to Brooks Lake. The volcanic geology in this watershed contributes phosphorus. Atmospheric nitrogen deposition enriches these waterbodies, which appear to be nitrogen limited. The area around Brooks Lake Lodge, particularly the horse corrals, appears to provide a small non-point source nutrient load to Brooks Lake via the Horse Corral Trib. Available data and information suggest the wastewater lagoons contribute a small nutrient load. The exact magnitude of these two sources is unknown due to various uncertainties, but collectively, the Horse Corral Trib and wastewater lagoons may contribute 7-24% of the total nitrogen load to Brooks Lake. Uncertainties in how the lodge handled wastewater prior to the construction of the lagoons, combined with the fact that illegal discharges and spill-overs of the lagoons have occurred, adds uncertainty to our nutrient load calculations from this source. Additional uncertainty regarding wastewater interaction with groundwater and its contribution to Brooks Lake makes it difficult to know the exact load contributed by this source. Evidence suggests many sources have contributed and continue to contribute to the eutrophication of Brooks Lake, although the majority are natural based on available data. Reference lakes within the Brooks Lake watershed are exposed to many of the same factors that Brooks Lake is, but do not exhibit the high productivity conditions of Brooks Lake. Besides differences in size, the most notable differences from Brooks Lake to the reference lakes are the presence of the Brooks Lake Lodge wastewater lagoons and the horse corrals. The nutrient load from these sources appears to be small relative to natural sources; however, it has undoubtedly contributed to and likely accelerated eutrophication in Brooks Lake, particularly because those sources combined may contribute 7-24% of the nitrogen load, which appears to be the limiting nutrient. Available literature helps us understand the consequences of eutrophication to the biotic and abiotic components of oligotrophic systems. When compared to nearby suitable reference lakes, Brooks Lake has exhibited symptoms of accelerated eutrophication, including blue-green algal blooms, increased productivity, decreased water transparency, an anoxic hypolimnion, and fish kills. In addition, cold-water fish condition in Brooks Lake has declined over time, and lake trout, a population that once reproduced naturally, are now apparently barely sustaining themselves. In contrast, the lake trout population in Lower Jade Lake demonstrates good condition, and continues to reproduce naturally.

Chapter 1 Standards Attainment/Non-Attainment

Evaluation of data and information collected on Brooks Lake in 2009, 2011, and 2012 using Chapter 1 surface water quality standards and associated numeric and narrative criteria yields the following conclusion for Brooks Lake and Brooks Lake Creek:

- Section 26 (pH)-
    - Non-attainment for Brooks Lake, and Brooks Lake Creek from the outlet of Brooks Lake an undetermined distance downstream that does not exceed 4.5 stream miles.
    - Non-attainment based on pH values greater than 9.0 S.U. during all three years of sampling as well as a weight-of-evidence approach that demonstrates nutrient enrichment in Brooks Lake.
    - Potential sources of nutrients causing non-attainment of pH criterion include natural sources, horse corrals, and the Brooks Lake Lodge wastewater lagoons.
- Section 32 (Biological Criteria)-
    - Non-attainment for Brooks Lake.
    - Non-attainment based on a weight of evidence approach that suggests accelerated eutrophication in Brooks Lake, triggered by excess nutrients, is causing physical changes to the lake that are adversely affecting the intentionally introduced cold-water fishery.
    - Potential sources of nutrients causing non-attainment of biological criteria include natural sources, horse corrals, and the Brooks Lake Lodge wastewater lagoons.

Recommendations

Available chemical and physical data suggest significantly different productivity conditions between Brooks Lake and the reference lakes. These differences in chlorophyll α and secchi transparencies between Brooks Lake and the reference lakes could be further corroborated by phytoplankton data. Phytoplankton data would provide many benefits for understanding the magnitude of anthropogenic influence on Brooks Lake. Phytoplankton data from these lakes would allow a comparison of community composition, help understand if blue-green algae are common within Brooks Lake, and provide valuable, local information for a TMDL target value if a TMDL were to ever be developed in this watershed. Additionally, more paired chlorophyll α, nutrient, and pH data could help corroborate a

TMDL target value, as it would provide more data to further develop and understand the relationships between these variables presented in this report. Furthermore, Brooks Lake sediment cores could be beneficial to understanding the history of the diatom assemblage and help provide biological substantiation to the eutrophication of the lake. A full bioassessment on Brooks Lake Creek above and below Brooks Lake may also help us better understand the degree of nutrient enrichment that occurs in Brooks Lake. Brooks Lake should be closely monitored for future fish kills as well. A closer look at diurnal pH and DO swings in the lake and outlet stream would be beneficial to understand if depressed DO is common during the summer growing season. Winter DO monitoring would be valuable, as this would be a critical time period for DO. Lastly, due to many uncertainties about the wastewater lagoons, it needs to be determined whether or not these are lined. In addition to gathering information from Brooks Lake Lodge personnel, a more sophisticated flow monitoring system for the wastewater lagoon effluent would be beneficial, as well as an influent flow monitoring system; this information combined with calculations of evaporation should provide a reasonable estimate of the extent of groundwater interaction.

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Appendix A

Water chemistry results for Brooks Lake in 2009, 2011, 2012 & depth profile values for Lower Jade Lake and Upper Brooks Lake 2012.

	Site Name	Bonneville Creek Inlet								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	30	17	24	26	35	30	30
Conductivity	µS/cm	32.4	45.2	52.8	30.2	45.8	49.4	44.1	52	54.8
Dissolved Oxygen	mg/L	8.97	7.89	9.27	8.42	8.58	9.14	7.86	7.66	8.18
Dissolved Oxygen Saturation	% sat	98.8	88.4	100.6	98	99.8	102.1	101.1	98.9	100.5
Flow	cfs	16.95	3.09	1.31	32.74	2.82	1.91	1.18	1.33	0.85
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	<100	<100	<100	<100	<100	<500	<500	500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	15	<10	<10	50	<50	<50
Nitrogen, Total	µg/L	<100	<100	<100	<100	<100	<100	<500	<500	<500
pH	SU	6.33	7.65	7.47	7.73	8.1	7.29	7.25	8.79	8.24
Phosphorus, Total as P	µg/L	51	52	68	59	57	72	70	70	90
Temperature	deg C	7.54	6.93	5.84	8.68	8.56	6.74	12.65	12.75	10.36

	Site Name	Brooks Lake Creek Inlet								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	44	35	39	40	45	40	40
Conductivity	µS/cm	60.8	72.9	79	65.1	79.1	77.6	75.6	76.8	78.1
Dissolved Oxygen	mg/L	8.64	7.91	9.66	7.87	8.9	9.35	8.27	8.15	8.91
Dissolved Oxygen Saturation	% sat	101.2	91.8	105.3	101.1	107	106.8	117.5	109.8	110.1
Flow	cfs	23.3	8.56	5.11	31.46	11.11	8.69	3.55	8.81	6.64
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	<100	130	<100	149	<100	<500	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	12	<10	<10	<50	<50	<50
Nitrogen, Total	µg/L	<100	<100	130	<100	156	<100	<500	<500	<500
pH	SU	7.56	7.56	7.85	7.08	8.16	7.82	7.9	9.28	8.69
Phosphorus, Total as P	µg/L	79	72	80	83	80	90	100	90	100
Temperature	deg C	8.67	8.34	5.99	12.23	9.94	7.68	17.16	14.6	10.57

	Site Name	Brooks Lake Creek Outlet								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012

Alkalinity, Total as CaCO3	mg/L	NM	NM	32	26	28	30	35	30	30
Conductivity	µS/cm	45	55.7	61	46.8	61.9	61.7	70.1	63.3	61.4
Dissolved Oxygen	mg/L	8.52	9.07	8.77	9.21	9.76	9.26	11.91	9.27	9.58
Dissolved Oxygen Saturation	% sat	111.4	127.3	109.6	116.5	124	116.4	174.3	134.2	126.2
Flow	cfs	66.63	20.68	9.33	100.51	19.09	14.23	5.76	12.42	8.23
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	212	169	<100	252	<100	1800	900	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	<10	<10	<10	50	<50	<50
Nitrogen, Total	µg/L	<100	217	169	<100	258	<100	1850	900	<500
pH	SU	7.25	9.04	9.09	7.89	9.35	9.08	9.93	9.45	9.44
Phosphorus, Total as P	µg/L	47	27	45	65	22	36	100	50	20
Temperature	deg C	13.21	14.69	11.65	12.07	12.29	11.64	18.62	17.89	13.39

	Site Name	**Brooks Lake Lodge Effluent**						
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	7/25/2011	9/6/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	48	59	75	120	130
Conductivity	µS/cm	137.6	263.1	142.8	192.7	191	604.1	513.1
Dissolved Oxygen	mg/L	5.86	5.08	5.75	4.97	3.02	3.1	2.63
Dissolved Oxygen Saturation	% sat	76.4	61.5	75.3	56.4	39.6	42	32.1
Flow	cfs	0.02	0.008	0.002	0.0029	0.013275	0.00029	0.00049
Nitrogen, Ammonia as N	mg/L	NM	NM	0.6	3	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	2320	5930	3170	3960	6900	14000	9800
Nitrogen, Nitrate+Nitrite as N	µg/L	109	60	45	10	50	17900	3640
Nitrogen, Total	µg/L	2430	5990	3215	3970	6950	31900	13400
pH	SU	7.72	7.47	8.28	7.32	7.57	6.72	7.61
Phosphorus, Total as P	µg/L	373	564	608	370	740	570	990
Temperature	deg C	13.89	10.47	13.76	8.14	14.01	15.18	12.16

	Site Name	**Unnamed Tributary to Brooks Lake**								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	48	37	43	45	50	50	50
Conductivity	µS/cm	67	79.9	87.5	69.1	86.6	87.4	84.1	86.3	86.9
Dissolved Oxygen	mg/L	8.98	8.11	9.86	7.84	9.06	9.73	7.39	7.48	8.57
Dissolved Oxygen Saturation	% sat	96.8	86.8	100.7	95.7	102.9	102.5	107	99.5	101.2
Flow	cfs	12.14	3.43	1.7	20.99	2.6	2.02	2.74	1.64	1.22
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	<100	146	<100	<100	<100	<500	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	17	<10	<10	50	<50	<50
Nitrogen, Total	µg/L	<100	<100	146	<100	<100	<100	<500	<500	<500

pH	SU	6.9	7.9	8.05	7.39	7.97	7.84	8.02	8.97	8.22
Phosphorus, Total as P	µg/L	77	72	96	95	72	84	100	110	100
Temperature	deg C	5.43	5.05	3.52	10.62	7.65	4.46	18.09	14.09	8.7

	Site Name	**Brooks Lake- Horse Corral Tributary**		**Brooks Lake- Unnamed Tributary East**
Chemistry Parameter	**Date**	8/21/2012	9/11/2012	8/21/2012
Alkalinity, Total as CaCO3	mg/L	40	30	30
Conductivity	µS/cm	76.8	75.2	66.7
Dissolved Oxygen	mg/L	7.42	8.24	8.78
Dissolved Oxygen Saturation	% sat	99.7	102.6	96.4
Flow	cfs	0.04	0.01	0.15
Nitrogen, Kjeldahl, Total as N	µg/L	2000	500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50
Nitrogen, Total	µg/L	2000	500	<500
pH	SU	8.51	8.67	7.61
Phosphorus, Total as P	µg/L	160	180	100
Temperature	deg C	14.55	10.91	6.05

	Site Name	**Brooks Lake Deep Quad Surface**								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	33	26	28	30	40	30	30
Chlorophyll α	mg/m^3	NM	NM	NM	3.6	32	13	310	32	4.7
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	<100	<100	<100	856	<100	1800	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	<10	<10	<10	<50	<50	<50
Nitrogen, Total	µg/L	<100	<100	<100	<100	856	<100	1800	<500	<500
Phosphorus, Total as P	µg/L	55	27	54	76	56	47	110	40	50
Secchi disk depth	m	2.44	1.32	NM	2.15	1.16	2.87	0.84	2.52	5.38

	Site Name	**Brooks Lake Deep Quad Bottom**								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	NM	25	33	29	30	30	30
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	0.1	0.17	0.19	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	203	220	906	<100	341	397	<500	600	900
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	180	<50	45	13	<10	90	<50	<50
Nitrogen, Total	µg/L	246	400	919	<100	354	397	500	600	900
Phosphorus, Total as P	µg/L	147	233	398	109	205	220	300	360	400
Grab sample collection depth	m	13	13	15	11	13	13	14	14	14

	Site Name	Brooks Lake Inlet Quad Surface								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	33	30	29	33	40	40	30
Chlorophyll α	mg/m^3	NM	NM	NM	4.2	28	14	74	12	4.1
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	147	117	<100	435	150	800	<500	700
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	10	<10	<10	50	<50	<50
Nitrogen, Total	µg/L	<100	100	117	<100	435	150	850	<500	700
Phosphorus, Total as P	µg/L	57	41	52	71	27	53	70	40	70
Secchi disk depth	m	2.9	1.12	3.5	2.36	2.03	2.83	1.99	2.72	5.13

	Site Name	Brooks Lake Inlet Quad Bottom								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	30	25	30	30	35	30	30
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	133	107	465	<100	234	156	<500	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	<10	<10	<10	60	<50	<50
Nitrogen, Total	µg/L	161	100	481	<100	234	156	<500	<500	<500
Phosphorus, Total as P	µg/L	106	88	277	74	53	65	130	70	60
Grab sample collection depth	m	9	8	13	7.5	7	6	6	8	6

	Site Name	Brooks Lake Outlet Quad Surface								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	33	26	28	29	35	30	30
Chlorophyll α	mg/m^3	NM	NM	NM	5.6	17	7.3	180	42	4.4
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	<100	147	<100	330	<100	1800	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	<10	<10	<10	50	<50	<50
Nitrogen, Total	µg/L	<100	<100	147	<100	330	<100	1850	<500	<500
Phosphorus, Total as P	µg/L	54	34	49	78	26	35	80	30	50
Secchi disk depth	m	2.13	1.2	3.6	2.2	3.06	3.51	0.825	2.14	4.14

	Site Name	Brooks Lake Outlet Quad Bottom								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	NM	24	30	29	35	30	30
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<100	186	145	<100	137	<100	900	<500	<500

Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	<10	<10	<10	60	<50	<50
Nitrogen, Total	µg/L	<100	190	145	<100	137	<100	950	<500	<500
Phosphorus, Total as P	µg/L	54	47	45	73	27	38	50	30	50
Grab sample collection depth	m	4	3	3.5	6.5	3.5	3	4.5	3.5	4.5

	Site Name	**Brooks Lake Lodge Quad Surface**								
Chemistry Parameter	**Date**	7/15/2009	8/17/2009	9/21/2009	7/25/2011	9/6/2011	9/20/2011	7/24/2012	8/21/2012	9/11/2012
Alkalinity, Total as CaCO3	mg/L	NM	NM	33	24	26	30	40	30	30
Chlorophyll α	mg/m^3	NM	NM	NM	5.4	40	11	55	12	4.8
Nitrogen, Ammonia as N	mg/L	NM	NM	NM	<0.05	<0.05	<0.05	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	106	197	213	<100	1360	125	800	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	<10	<10	<10	50	<50	<50
Nitrogen, Total	µg/L	106	202	213	<100	1360	125	850	<500	<500
Phosphorus, Total as P	µg/L	61	61	65	86	50	49	40	50	70
Secchi disk depth	m	>0.96	>0.76	>0.7	>0.5	>0.88	>0.76	>0.6	>1.58	>2.83

	Site Name	**Lower Jade Lake- Inlet**			**Lower Jade Lake- Outlet**		
Chemistry Parameter	**Date**	7/25/2012	8/22/2012	9/12/2012	7/25/2012	8/22/2012	9/12/2012
Alkalinity, Total as CaCO3	mg/L	35	40	40	45	40	40
Conductivity	µS/cm	75.1	76.7	78.3	NM	77.4	72
Dissolved Oxygen	mg/L	6.79	7.31	7.32	NM	8.89	8.41
Dissolved Oxygen Saturation	% sat	97.1	102.1	93.4	NM	99.9	93.2
Flow	cfs	0.25	0.38	0.19	NM	1.03	1.51
Nitrogen, Kjeldahl, Total as N	µg/L	<500	<500	<500	<500	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	50	<50	<50	100	<50	70
Nitrogen, Total	µg/L	<500	<500	<500	<500	<500	<500
pH	SU	8.17	8.64	8.68	NM	7.56	8.86
Phosphorus, Total as P	µg/L	80	70	80	90	70	70
Temperature	deg C	16.87	16.09	11.85	NM	6.88	6.16

	Site Name	**Lower Jade Lake- Littoral**			**Lower Jade Lake- Pelagic Surface**			**Lower Jade Lake- Pelagic Bottom**		
Chemistry Parameter	**Date**	7/25/2012	8/22/2012	9/12/2012	7/25/2012	8/22/2012	9/12/2012	7/25/2012	8/22/2012	9/12/2012
Alkalinity, Total as CaCO3	mg/L	35	40	40	30	40	40	45	40	40
Chlorophyll α	mg/m^3	<0.2	1.9	2	<0.3	<0.2	2	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<500	<500	<500	<500	<500	<500	<500	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	<50	<50	<50	<50	<50	<50	<50	<50	<50
Nitrogen, Total	µg/L	<500	<500	<500	<500	<500	<500	<500	<500	<500
Phosphorus, Total as P	µg/L	50	20	30	50	20	20	180	70	80

Secchi disk depth	m	>2.2	>3.3	>1.5	10.1	8.7	10.75	NM	NM	NM
Grab sample collection depth	m	-	-	-	-	-	-	16.5	14	13.5

	Site Name	**Upper Brooks Lake- Inlet**			**Upper Brooks Lake- Outlet**		
Chemistry Parameter	**Date**	7/25/2012	8/22/2012	9/12/2012	7/25/2012	8/22/2012	9/12/2012
Alkalinity, Total as CaCO3	mg/L	50	40	50	45	40	40
Conductivity	µS/cm	82.4	82	83.1	NM	76.1	78.4
Dissolved Oxygen	mg/L	8.62	8.88	9.13	NM	11.11	10.29
Dissolved Oxygen Saturation	% sat	94.1	101	96	NM	148.2	128.1
Flow	cfs	1.38	2.54	2.32	1.89	3.8	2.92
Nitrogen, Kjeldahl, Total as N	µg/L	<500	<500	<500	<500	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	70	<50	70	60	<50	<50
Nitrogen, Total	µg/L	<500	<500	<500	<500	<500	<500
pH	SU	7.97	8.82	8.92	NM	9.37	9.33
Phosphorus, Total as P	µg/L	90	70	80	80	60	70
Temperature	deg C	7.57	7.28	4.17	NM	14.04	11.02

	Site Name	**Upper Brooks Lake- Littoral**			**Upper Brooks Lake- Pelagic Surface**			**Upper Brooks Lake- Pelagic Bottom**		
Chemistry Parameter	**Date**	7/25/2012	8/22/2012	9/12/2012	7/25/2012	8/22/2012	9/12/2012	7/25/2012	8/22/2012	9/12/2012
Alkalinity, Total as CaCO3	mg/L	50	40	40	40	40	40	35	40	50
Chlorophyll α	mg/m^3	7.1	4.7	7.1	3.2	5.4	7	NM	NM	NM
Nitrogen, Kjeldahl, Total as N	µg/L	<500	<500	<500	<500	<500	<500	<500	<500	<500
Nitrogen, Nitrate+Nitrite as N	µg/L	50	<50	<50	50	<50	<50	50	<50	<50
Nitrogen, Total	µg/L	<500	<500	<500	<500	<500	<500	<500	<500	<500
Phosphorus, Total as P	µg/L	80	60	70	80	50	80	90	60	80
Secchi disk depth	m	>1.2	>1.7	>1.2	>4.75	4.8	>5	NM	NM	NM
Grab sample collection depth	m	-	-	-	-	-	-	4.5	4.8	4.8

NM- Not measured

Appendix B

Depth profile values for Brooks Lake (BL) in 2009, 2011, 2012; & depth profile values for Lower Jade Lake (LJL) & Upper Brooks Lake (UBL) 2012.

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Lodge Quad	7/15/2009	0.0	9:27	10.81	7.74	44.5	8.35	103.6	417
BL Lodge Quad	7/15/2009	0.5	9:29	11.21	7.80	45.1	8.36	103.5	405
BL Lodge Quad	8/17/2009	0.0	10:14	12.50	8.94	55.0	8.95	114.5	282
BL Lodge Quad	8/17/2009	0.5		12.41	8.96	55.0	9.25	118.8	208
BL Lodge Quad	9/21/2009	0.0	11:15	11.36	8.71	61.0	8.72	108.3	396
BL Lodge Quad	9/21/2009	0.4	11:17	11.34	8.98	61.1	8.77	108.7	389

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Lodge Quad	7/25/2011	0.0	11:24	13.94	7.36	49.6	8.86	117.0	300
BL Lodge Quad	7/25/2011	0.5	11:25	13.66	7.54	49.4	9.03	118.7	289
BL Lodge Quad	9/6/2011	0.0	10:58	12.6	9.38	63.3	10.69	136.8	277
BL Lodge Quad	9/6/2011	0.5	10:59	12.51	9.40	63.6	10.79	137.7	273
BL Lodge Quad	9/20/2011	0.0	11:09	10.4	7.85	61.3	9.06	110.7	277
BL Lodge Quad	9/20/2011	0.5	11:10	10.4	8.34	61.0	9.07	110.8	275

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Lodge Quad	7/24/2012	0.0	11:24	16.61	9.70	64.3	11.15	156.4	308
BL Lodge Quad	7/24/2012	0.3	11:25	16.60	9.90	64.4	11.20	157.3	303
BL Lodge Quad	7/24/2012	0.6	11:26	16.65	9.75	64.7	11.18	157.0	303
BL Lodge Quad	8/21/2012	0.0	12:44	16.47	10.18	62.0	8.31	116.8	-
BL Lodge Quad	8/21/2012	0.5	12:47	15.79	9.64	61.9	8.33	115.0	-
BL Lodge Quad	8/21/2012	1.0	12:48	15.34	9.59	61.4	8.33	114.0	-
BL Lodge Quad	8/21/2012	1.4	12:49	15.32	9.37	61.4	7.98	109.4	-
BL Lodge Quad	9/11/2012	0.0	12:35	12.71	9.04	60.7	7.34	95.0	-
BL Lodge Quad	9/11/2012	0.5	12:39	12.68	9.04	60.9	7.26	94.2	-

Site	Date	Depth (m)	Time	Temp (C°)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Inlet Quad	7/15/2009	0.0	10:21	10.93	7.73	44.9	8.38	103.5	404
BL Inlet Quad	7/15/2009	0.5	10:22	11.02	7.75	44.8	8.39	103.5	400
BL Inlet Quad	7/15/2009	1.0	10:23	10.99	7.86	44.8	8.40	103.4	395
BL Inlet Quad	7/15/2009	1.5	10:23	10.83	7.89	44.6	8.40	103.2	393
BL Inlet Quad	7/15/2009	2.0	10:25	10.59	7.87	44.7	8.44	103.0	395
BL Inlet Quad	7/15/2009	2.5	10:25	10.57	7.87	44.5	8.42	102.8	394
BL Inlet Quad	7/15/2009	3.0	10:26	10.55	7.86	44.2	8.40	102.5	395
BL Inlet Quad	7/15/2009	4.0	10:27	10.32	7.88	45.0	8.34	101.1	393
BL Inlet Quad	7/15/2009	5.0	10:28	10.05	7.80	47.3	8.23	99.4	393
BL Inlet Quad	7/15/2009	6.0	10:29	7.68	7.61	44.3	7.60	86.0	398
BL Inlet Quad	7/15/2009	7.0	10:30	6.33	7.47	42.0	6.80	74.7	399
BL Inlet Quad	7/15/2009	8.0	10:31	5.73	7.33	42.7	6.18	66.5	401
BL Inlet Quad	7/15/2009	9.0	10:32	5.48	7.18	44.1	5.26	56.3	402
BL Inlet Quad	7/15/2009	10.0	10:33	5.32	7.05	44.6	4.68	50.1	403
BL Inlet Quad	8/17/2009	0.0	11:04	12.50	8.93	55.1	8.60	111.1	377
BL Inlet Quad	8/17/2009	0.5		12.27	9.07	55.2	9.09	115.7	366
BL Inlet Quad	8/17/2009	1.0		11.98	9.09	55.1	9.08	115.3	362
BL Inlet Quad	8/17/2009	1.5		11.87	9.12	55.0	9.13	115.0	359
BL Inlet Quad	8/17/2009	2.0		11.84	9.17	54.7	9.07	114.2	356
BL Inlet Quad	8/17/2009	2.5		11.81	9.20	54.8	9.04	113.8	355
BL Inlet Quad	8/17/2009	3.0		11.78	9.17	55.0	8.97	112.5	356
BL Inlet Quad	8/17/2009	4.0		11.71	9.15	54.7	8.62	108.1	352
BL Inlet Quad	8/17/2009	5.0		11.60	9.17	55.3	8.50	106.1	350
BL Inlet Quad	8/17/2009	6.0		10.97	8.97	56.6	8.27	101.7	354
BL Inlet Quad	8/17/2009	7.0		8.05	7.88	48.8	3.64	41.3	386
BL Inlet Quad	8/17/2009	8.0		7.60	7.73	48.3	3.16	35.6	-
BL Inlet Quad	8/17/2009	8.9		7.46	7.33	48.5	2.65	30.0	375
BL Inlet Quad	9/21/2009	0.0	11:46	11.34	9.24	61.4	8.47	105.1	381
BL Inlet Quad	9/21/2009	0.5	11:48	11.37	9.10	61.1	8.47	105.2	386
BL Inlet Quad	9/21/2009	1.0	11:48	11.37	9.23	61.3	8.47	105.1	381
BL Inlet Quad	9/21/2009	1.5	11:49	11.37	9.27	61.3	8.45	104.9	377
BL Inlet Quad	9/21/2009	2.0	11:50	11.33	9.29	61.0	8.44	104.7	374
BL Inlet Quad	9/21/2009	2.5	11:50	11.29	9.34	61.1	8.44	104.4	371
BL Inlet Quad	9/21/2009	3.0	11:51	11.27	9.36	61.1	8.42	104.3	369
BL Inlet Quad	9/21/2009	4.0	11:52	11.23	9.35	61.0	8.37	103.6	367
BL Inlet Quad	9/21/2009	5.0	11:53	11.08	9.34	61.1	8.21	101.0	367
BL Inlet Quad	9/21/2009	6.0	11:53	10.84	9.29	60.8	8.01	97.5	366
BL Inlet Quad	9/21/2009	7.0	11:55	10.37	8.67	61.0	5.95	73.9	377
BL Inlet Quad	9/21/2009	8.0	11:57	8.73	7.76	56.2	1.07	12.0	406
BL Inlet Quad	9/21/2009	9.0	11:58	8.03	7.33	55.1	0.46	5.2	393
BL Inlet Quad	9/21/2009	10.0	11:59	7.48	7.10	55.2	0.34	3.9	270
BL Inlet Quad	9/21/2009	11.0	11:59	7.10	6.92	56.0	0.30	3.3	231
BL Inlet Quad	9/21/2009	12.0	11:59	6.67	6.74	56.6	0.27	3.0	189
BL Inlet Quad	9/21/2009	13.0	12:00	6.29	6.50	60.2	0.25	2.8	119

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Inlet Quad	7/25/2011	0.0	13:18	13.38	7.72	50.2	9.00	117.2	277
BL Inlet Quad	7/25/2011	0.5	13:19	13.42	7.77	52.4	8.96	116.3	274
BL Inlet Quad	7/25/2011	1.0	13:20	13.25	7.85	50.5	9.00	117.0	270
BL Inlet Quad	7/25/2011	1.5	13:21	13.07	7.74	56.2	8.77	113.3	274
BL Inlet Quad	7/25/2011	2.0	13:21	13.06	7.73	53.4	8.72	112.8	271
BL Inlet Quad	7/25/2011	2.5	13:22	13.00	7.77	56.4	8.79	113.3	273
BL Inlet Quad	7/25/2011	3.0	13:22	9.88	7.74	53.4	9.09	108.9	274
BL Inlet Quad	7/25/2011	4.0	13:23	8.78	7.48	50.1	8.51	99.5	282
BL Inlet Quad	7/25/2011	5.0	13:24	8.54	7.43	47.6	8.45	98.0	285
BL Inlet Quad	7/25/2011	6.0	13:25	8.18	7.39	46.3	8.28	94.5	287
BL Inlet Quad	7/25/2011	7.0	13:26	7.65	7.26	44.8	7.31	82.7	292
BL Inlet Quad	7/25/2011	7.4	13:26	7.65	7.21	45.0	7.12	81.2	294
BL Inlet Quad	9/6/2011	0.0	11:54	12.49	9.30	62.8	10.27	130.2	256
BL Inlet Quad	9/6/2011	0.5	11:55	12.44	9.26	62.8	10.28	130.9	260
BL Inlet Quad	9/6/2011	1.0	11:56	12.37	9.26	62.8	10.32	131.2	261
BL Inlet Quad	9/6/2011	1.5	11:57	12.35	9.26	62.9	10.33	131.5	261
BL Inlet Quad	9/6/2011	2.0	12:00	12.29	9.29	62.3	10.35	131.5	261
BL Inlet Quad	9/6/2011	2.5	12:01	12.25	9.28	62.4	10.38	131.5	262
BL Inlet Quad	9/6/2011	3.0	12:02	12.21	9.29	62.3	10.30	130.6	261
BL Inlet Quad	9/6/2011	4.0	12:02	12.17	9.23	62.2	10.23	129.2	261
BL Inlet Quad	9/6/2011	5.0	12:04	11.75	9.10	63.9	9.88	123.5	264
BL Inlet Quad	9/6/2011	6.0	12:05	9.99	7.90	60.3	7.21	85.3	294
BL Inlet Quad	9/6/2011	7.0	12:06	8.92	7.58	54.7	5.43	63.1	187
BL Inlet Quad	9/20/2011	0.0	12:00	9.99	9.18	61.1	9.05	109.5	275
BL Inlet Quad	9/20/2011	0.5	12:01	10.01	9.06	61.3	9.04	109.6	279
BL Inlet Quad	9/20/2011	1.0	12:03	10.10	9.05	61.0	9.05	109.4	276
BL Inlet Quad	9/20/2011	1.5	12:04	9.96	9.05	61.5	9.02	109.1	272
BL Inlet Quad	9/20/2011	2.0	12:04	9.96	9.01	61.4	9.02	109.1	278
BL Inlet Quad	9/20/2011	2.5	12:05	9.90	8.94	61.4	8.97	108.1	279
BL Inlet Quad	9/20/2011	3.0	12:05	9.88	8.90	61.2	8.90	107.4	278
BL Inlet Quad	9/20/2011	4.0	12:06	9.83	8.79	60.8	8.42	101.4	279
BL Inlet Quad	9/20/2011	5.0	12:07	9.81	8.85	60.7	8.42	101.5	278
BL Inlet Quad	9/20/2011	6.0	12:08	9.71	8.40	59.0	7.93	94.0	287
BL Inlet Quad	9/20/2011	6.8	12:09	9.47	8.62	64.3	8.47	101.0	285

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Inlet Quad	7/24/2012	0.0	13:50	16.79	9.70	64.3	11.52	162.3	238
BL Inlet Quad	7/24/2012	0.5		16.70	9.63	64.0	11.50	162.4	239
BL Inlet Quad	7/24/2012	1.0	13:52	16.20	9.72	63.2	11.83	164.9	237
BL Inlet Quad	7/24/2012	1.5	13:53	15.62	9.62	61.0	11.67	159.3	239
BL Inlet Quad	7/24/2012	2.0	13:54	15.46	9.54	61.0	11.44	156.5	243
BL Inlet Quad	7/24/2012	2.5	13:55	14.99	9.35	61.1	10.41	147.1	246
BL Inlet Quad	7/24/2012	3.0	13:55	14.55	9.31	61.8	10.79	144.5	250
BL Inlet Quad	7/24/2012	4.0	13:56	14.04	9.16	61.6	10.37	137.1	255
BL Inlet Quad	7/24/2012	5.0	13:57	12.35	8.69	56.8	9.12	116.7	268
BL Inlet Quad	7/24/2012	6.0	13:57	7.81	8.04	54.7	5.12	58.1	299

BL Inlet Quad	7/24/2012	6.5	13:59	6.83	7.81	55.1	3.95	43.1	309

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Inlet Quad	8/21/2012	0.0	13:33	15.88	9.43	62.2	8.32	115.4	-
BL Inlet Quad	8/21/2012	0.5		15.82	9.45	62.4	8.39	116.0	-
BL Inlet Quad	8/21/2012	1.0		15.82	9.52	62.3	8.40	116.2	-
BL Inlet Quad	8/21/2012	1.5		15.69	9.56	62.1	8.43	116.3	-
BL Inlet Quad	8/21/2012	2.0		15.67	9.56	61.9	8.44	116.3	-
BL Inlet Quad	8/21/2012	2.5		15.61	9.59	62.1	8.44	116.1	-
BL Inlet Quad	8/21/2012	3.0		15.56	9.59	62.1	8.44	116.0	-
BL Inlet Quad	8/21/2012	4.0		13.83	9.45	61.9	8.49	112.1	-
BL Inlet Quad	8/21/2012	5.0		13.37	9.40	60.6	8.81	115.4	-
BL Inlet Quad	8/21/2012	6.0		12.64	9.33	57.5	9.11	116.7	-
BL Inlet Quad	8/21/2012	7.0		10.11	8.93	53.4	5.51	57.8	-
BL Inlet Quad	8/21/2012	7.2	13:41	9.10	8.64	54.5	3.79	44.3	-
BL Inlet Quad	9/11/2012	0.0	13:15	12.69	8.95	61.1	7.33	95.0	-
BL Inlet Quad	9/11/2012	0.5	13:17	12.72	8.91	61.1	7.32	95.0	-
BL Inlet Quad	9/11/2012	1.0	13:18	12.72	8.95	61.0	7.31	95.0	-
BL Inlet Quad	9/11/2012	1.5	13:18	12.73	8.93	61.0	7.30	94.9	-
BL Inlet Quad	9/11/2012	2.0	13:19	12.75	8.95	61.2	7.31	95.0	-
BL Inlet Quad	9/11/2012	2.5	13:19	12.74	8.98	61.5	7.31	94.9	-
BL Inlet Quad	9/11/2012	3.0	13:20	12.71	8.99	61.2	7.29	94.5	-
BL Inlet Quad	9/11/2012	4.0	13:21	12.59	8.97	61.2	7.19	92.7	-
BL Inlet Quad	9/11/2012	5.0	13:22	12.49	8.98	61.2	7.09	91.4	-
BL Inlet Quad	9/11/2012	6.0	13:22	12.00	8.80	61.2	6.70	84.5	-

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Deep Quad	7/15/2009	0.0	11:16	11.25	7.72	44.6	8.40	104.1	436
BL Deep Quad	7/15/2009	0.5	11:17	11.27	7.78	44.7	8.38	104.1	426
BL Deep Quad	7/15/2009	1.0	11:18	11.31	7.87	44.7	8.39	104.1	420
BL Deep Quad	7/15/2009	1.5	11:19	11.27	7.92	44.8	8.39	104.0	418
BL Deep Quad	7/15/2009	2.0	11:20	11.20	7.95	44.6	8.40	104.0	417
BL Deep Quad	7/15/2009	2.5	11:21	11.22	7.96	44.6	8.38	103.7	415
BL Deep Quad	7/15/2009	3.0	11:22	11.18	7.95	44.6	8.39	103.8	415
BL Deep Quad	7/15/2009	4.0	11:23	11.18	8.01	44.7	8.37	103.7	409
BL Deep Quad	7/15/2009	5.0	11:24	10.40	7.99	45.1	8.42	102.4	410
BL Deep Quad	7/15/2009	6.0	11:25	9.53	7.86	44.6	8.33	99.0	413
BL Deep Quad	7/15/2009	7.0	11:26	9.24	7.75	43.4	8.11	95.5	414
BL Deep Quad	7/15/2009	8.0	11:27	8.15	7.61	42.5	7.79	89.5	416
BL Deep Quad	7/15/2009	9.0	11:28	6.53	7.44	41.4	6.88	75.9	420
BL Deep Quad	7/15/2009	10.0	11:29	5.48	7.28	44.1	5.52	58.7	423
BL Deep Quad	7/15/2009	11.0	11:30	5.32	7.22	44.5	5.06	54.0	424
BL Deep Quad	7/15/2009	12.0	11:31	5.18	7.18	44.8	4.83	51.4	423
BL Deep Quad	7/15/2009	13.0	11:33	5.15	7.06	45.0	4.49	47.9	423
BL Deep Quad	8/17/2009	0.0	12:23	12.62	9.02	55.2	8.97	115.8	415
BL Deep Quad	8/17/2009	0.5		12.64	9.08	55.3	8.99	115.6	411
BL Deep Quad	8/17/2009	1.0		12.39	9.17	55.0	9.05	115.6	406
BL Deep Quad	8/17/2009	1.5		12.05	9.18	55.0	9.02	114.3	403

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Deep Quad	8/17/2009	2.0		12.02	9.15	54.9	8.90	112.4	402
BL Deep Quad	8/17/2009	2.5		11.93	9.06	54.8	8.64	109.8	402
BL Deep Quad	8/17/2009	3.0		11.91	9.05	54.4	8.46	106.6	401
BL Deep Quad	8/17/2009	4.0		11.69	8.65	54.8	7.66	95.8	408
BL Deep Quad	8/17/2009	5.0		11.35	8.19	55.1	6.96	86.6	415
BL Deep Quad	8/17/2009	6.0		10.22	7.81	52.2	5.67	68.0	427
BL Deep Quad	8/17/2009	7.0		9.21	7.49	50.2	4.46	52.5	432
BL Deep Quad	8/17/2009	8.0		7.81	7.26	48.6	3.32	36.9	437
BL Deep Quad	8/17/2009	9.0		6.34	6.99	47.7	1.64	17.9	442
BL Deep Quad	8/17/2009	10.0		5.94	6.83	48.8	0.88	9.3	444
BL Deep Quad	8/17/2009	11.0		5.84	6.69	49.2	0.50	5.2	445
BL Deep Quad	8/17/2009	12.0		5.68	6.56	50.0	0.29	3.1	334
BL Deep Quad	8/17/2009	12.8		5.59	6.50	51.2	0.26	2.8	288
BL Deep Quad	9/21/2009	0.0	13:00	11.47	9.12	60.9	8.49	105.7	343
BL Deep Quad	9/21/2009	0.5		11.47	9.20	60.9	8.49	105.7	337
BL Deep Quad	9/21/2009	1.0		11.47	9.28	61.1	8.49	105.6	330
BL Deep Quad	9/21/2009	1.5		11.46	9.34	60.7	8.49	105.6	326
BL Deep Quad	9/21/2009	2.0		11.43	9.37	61.0	8.49	105.6	323
BL Deep Quad	9/21/2009	2.5		11.40	9.41	61.0	8.51	105.8	321
BL Deep Quad	9/21/2009	3.0		11.39	9.44	61.0	8.54	106.1	320
BL Deep Quad	9/21/2009	4.0		11.35	9.44	61.1	8.50	105.4	319
BL Deep Quad	9/21/2009	5.0		11.22	9.44	61.0	8.39	103.5	317
BL Deep Quad	9/21/2009	6.0		10.82	8.76	60.4	6.29	76.9	330
BL Deep Quad	9/21/2009	7.0		10.16	8.04	57.9	4.35	52.3	348
BL Deep Quad	9/21/2009	8.0		9.50	7.66	56.2	2.37	27.9	357
BL Deep Quad	9/21/2009	9.0		8.59	7.32	54.5	0.78	8.9	356
BL Deep Quad	9/21/2009	10.0		6.72	6.95	56.2	0.40	4.4	219
BL Deep Quad	9/21/2009	11.0		6.50	6.76	57.1	0.32	3.5	181
BL Deep Quad	9/21/2009	12.0		6.19	6.53	60.6	0.28	3.1	111
BL Deep Quad	9/21/2009	13.0		6.05	6.45	61.8	0.27	2.9	88
BL Deep Quad	9/21/2009	14.0		6.03	6.29	61.8	0.26	2.8	65
BL Deep Quad	7/25/2011	0.0	12:22	13.69	8.10	48.6	8.74	115.9	269
BL Deep Quad	7/25/2011	0.5	12:23	13.70	7.99	48.2	9.05	118.3	271
BL Deep Quad	7/25/2011	1.0	12:23	13.09	7.96	48.1	9.04	116.8	270
BL Deep Quad	7/25/2011	1.5	12:24	12.11	7.89	47.2	9.06	114.5	273
BL Deep Quad	7/25/2011	2.0	12:25	11.44	7.87	46.1	8.97	111.8	275
BL Deep Quad	7/25/2011	2.5	12:25	10.57	7.79	46.1	9.01	110.4	278
BL Deep Quad	7/25/2011	3.0	12:26	10.13	7.70	44.5	8.90	107.0	282
BL Deep Quad	7/25/2011	4.0	12:26	9.22	7.55	44.5	8.67	101.4	288
BL Deep Quad	7/25/2011	5.0	12:27	8.80	7.46	45.5	8.48	99.1	292
BL Deep Quad	7/25/2011	6.0	12:28	8.63	7.42	44.9	8.53	99.1	293
BL Deep Quad	7/25/2011	7.0	12:29	8.41	7.33	45.0	8.11	93.6	296
BL Deep Quad	7/25/2011	8.0	12:31	7.14	7.15	44.7	6.64	74.5	303
BL Deep Quad	7/25/2011	9.0	12:33	6.05	6.97	44.9	5.52	60.6	308
BL Deep Quad	7/25/2011	10.0	12:34	5.29	6.91	45.4	5.00	53.3	310
BL Deep Quad	7/25/2011	11.0	12:35	5.22	6.88	45.2	4.93	52.5	311

BL Deep Quad	7/25/2011	12.0	12:36	5.20	6.85	45.4	4.85	51.7	309

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Deep Quad	9/6/2011	0.0		13.06	9.69	63.2	11.07	143.1	217
BL Deep Quad	9/6/2011	0.5		13.05	9.66	63.2	11.02	142.5	218
BL Deep Quad	9/6/2011	1.0		13.00	9.70	63.4	10.91	140.9	215
BL Deep Quad	9/6/2011	1.5		12.94	9.67	63.1	10.84	139.7	213
BL Deep Quad	9/6/2011	2.0		12.89	9.70	63.4	10.69	138.1	212
BL Deep Quad	9/6/2011	2.5		12.86	9.67	63.0	10.62	136.8	208
BL Deep Quad	9/6/2011	3.0	15:30	12.84	9.50	62.6	9.32	128.2	202
BL Deep Quad	9/6/2011	4.0	15:22	10.26	7.64	57.0	6.61	80.4	300
BL Deep Quad	9/6/2011	5.0	15:23	9.48	7.38	54.6	5.49	65.1	307
BL Deep Quad	9/6/2011	6.0	15:24	9.16	7.16	53.2	5.30	62.0	314
BL Deep Quad	9/6/2011	7.0	15:25	8.71	7.04	52.0	4.32	50.1	319
BL Deep Quad	9/6/2011	8.0	15:25	8.23	6.96	51.2	3.65	42.1	321
BL Deep Quad	9/6/2011	9.0	15:26	7.59	6.87	49.7	2.80	31.2	324
BL Deep Quad	9/6/2011	10.0	15:26	6.67	6.72	48.7	1.13	12.6	329
BL Deep Quad	9/6/2011	11.0	15:27	6.15	6.59	49.3	0.47	4.9	334
BL Deep Quad	9/6/2011	12.0	15:28	5.90	6.53	50.0	0.26	2.6	330
BL Deep Quad	9/6/2011	13.0	15:28	5.56	6.50	52.3	0.14	1.5	307
BL Deep Quad	9/6/2011	13.7	15:29	5.41	6.44	54.0	0.11	1.2	252
BL Deep Quad	9/20/2011	0.0	13:38	10.42	8.99	60.9	9.08	110.9	276
BL Deep Quad	9/20/2011	0.5	13:38	10.41	9.04	61.0	9.06	110.8	273
BL Deep Quad	9/20/2011	1.0	13:39	10.39	9.04	61.0	9.09	110.9	273
BL Deep Quad	9/20/2011	1.5	13:40	10.40	9.02	61.6	9.05	110.6	273
BL Deep Quad	9/20/2011	2.0	13:40	10.37	8.95	61.2	9.06	110.5	277
BL Deep Quad	9/20/2011	2.5	13:41	10.34	8.97	61.0	9.05	110.3	275
BL Deep Quad	9/20/2011	3.0	13:41	10.27	8.98	61.3	9.04	110.1	273
BL Deep Quad	9/20/2011	4.0	13:42	10.26	8.99	61.5	9.04	110.0	273
BL Deep Quad	9/20/2011	5.0	13:43	10.13	8.98	61.5	9.06	109.8	276
BL Deep Quad	9/20/2011	6.0	13:44	9.30	7.82	54.9	4.98	48.8	322
BL Deep Quad	9/20/2011	7.0	13:45	8.01	6.94	52.6	1.80	17.4	339
BL Deep Quad	9/20/2011	8.0	13:45	7.84	6.69	52.2	1.17	13.2	346
BL Deep Quad	9/20/2011	9.0	13:46	7.73	6.59	52.1	0.96	10.7	348
BL Deep Quad	9/20/2011	10.0	13:47	7.64	6.51	52.6	0.78	8.7	349
BL Deep Quad	9/20/2011	11.0	13:47	7.40	6.43	52.2	0.44	4.9	350
BL Deep Quad	9/20/2011	12.0	13:48	7.08	6.33	52.4	0.22	2.4	339
BL Deep Quad	9/20/2011	13.0	13:49	5.99	6.16	55.1	0.14	1.6	245

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Deep Quad	7/24/2012	0.0	12:24	17.26	10.01	68.2	12.30	175.0	273
BL Deep Quad	7/24/2012	0.5	12:24	17.19	9.93	68.7	12.46	177.0	274
BL Deep Quad	7/24/2012	1.0	12:25	16.98	9.95	69.0	12.69	179.4	272
BL Deep Quad	7/24/2012	1.5	12:26	17.01	9.95	68.8	12.71	179.8	272
BL Deep Quad	7/24/2012	2.0	12:27	16.84	9.94	69.1	12.68	180.5	273
BL Deep Quad	7/24/2012	2.5	12:28	16.63	9.87	67.6	12.68	177.0	275
BL Deep Quad	7/24/2012	3.0	12:29	16.37	9.76	66.7	12.29	170.6	278
BL Deep Quad	7/24/2012	4.0	12:29	14.40	9.24	58.0	10.81	143.1	297
BL Deep Quad	7/24/2012	5.0	12:30	11.62	8.62	55.9	9.29	114.9	323

BL Deep Quad	7/24/2012	6.0	12:30	9.20	8.22	55.0	7.70	91.2	343
Site	**Date**	**Depth (m)**	**Time**	**Temp (C˚)**	**pH**	**Conductance (uS/cm)**	**D.O. (mg/L)**	**D.O. (% Sat.)**	**ORP**
BL Deep Quad	7/24/2012	7.0	12:31	8.47	8.00	54.2	6.25	72.4	354
BL Deep Quad	7/24/2012	8.0	12:31	7.33	7.85	54.8	4.95	55.6	360
BL Deep Quad	7/24/2012	9.0	12:32	6.50	7.68	54.3	3.26	35.8	356
BL Deep Quad	7/24/2012	10.0	12:33	6.10	7.57	54.6	2.44	26.4	370
BL Deep Quad	7/24/2012	11.0	12:33	5.60	7.46	56.1	0.96	10.9	374
BL Deep Quad	7/24/2012	12.0	12:33	5.36	7.29	57.5	0.31	3.0	348
BL Deep Quad	7/24/2012	13.0	12:35	5.23	7.00	61.1	0.18	1.9	286
BL Deep Quad	7/24/2012	14.0	12:36	5.09	6.77	65.7	0.15	1.6	269
BL Deep Quad	8/21/2012	0.0	14:30	16.60	9.51	62.4	8.49	119.7	-
BL Deep Quad	8/21/2012	0.5		16.36	9.52	62.2	8.53	119.3	-
BL Deep Quad	8/21/2012	1.0		16.17	9.55	62.5	8.54	119.0	-
BL Deep Quad	8/21/2012	1.5		16.01	9.59	62.2	8.53	118.6	-
BL Deep Quad	8/21/2012	2.0		15.77	9.61	62.1	8.54	117.9	-
BL Deep Quad	8/21/2012	2.5		15.38	9.59	61.8	8.52	116.3	-
BL Deep Quad	8/21/2012	3.0		15.20	9.59	61.8	8.46	115.4	-
BL Deep Quad	8/21/2012	4.0		14.83	9.52	61.7	8.40	114.0	-
BL Deep Quad	8/21/2012	5.0		13.75	9.43	59.7	8.70	114.5	-
BL Deep Quad	8/21/2012	6.0		12.45	9.27	56.7	9.37	120.0	-
BL Deep Quad	8/21/2012	7.0		10.58	9.03	54.1	8.26	100.2	-
BL Deep Quad	8/21/2012	8.0		9.26	8.67	54.1	4.71	55.7	-
BL Deep Quad	8/21/2012	9.0		8.21	8.46	54.2	2.30	26.0	-
BL Deep Quad	8/21/2012	10.0		6.82	8.24	56.9	0.87	9.5	-
BL Deep Quad	8/21/2012	11.0		6.25	8.08	60.2	0.43	4.6	-
BL Deep Quad	8/21/2012	12.0		5.90	7.93	61.8	0.27	2.9	-
BL Deep Quad	8/21/2012	13.0		5.61	7.81	65.6	0.21	2.2	-
BL Deep Quad	8/21/2012	14.1	14:42	5.49	7.72	68.3	0.17	1.9	-
BL Deep Quad	9/11/2012	0.0	14:49	12.88	9.22	61.0	7.26	94.6	-
BL Deep Quad	9/11/2012	0.5	14:51	12.90	8.82	61.2	7.23	94.3	-
BL Deep Quad	9/11/2012	1.0	14:52	12.90	9.16	61.1	7.23	94.3	-
BL Deep Quad	9/11/2012	1.5	14:55	12.91	9.17	60.8	7.22	94.1	-
BL Deep Quad	9/11/2012	2.0	14:56	12.90	9.18	61.0	7.22	94.1	-
BL Deep Quad	9/11/2012	2.5	14:57	12.90	9.18	61.0	7.20	93.9	-
BL Deep Quad	9/11/2012	3.0	14:59	12.90	9.19	61.2	7.19	93.8	-
BL Deep Quad	9/11/2012	4.0	15:01	12.90	9.18	61.1	7.18	93.6	-
BL Deep Quad	9/11/2012	5.0	15:02	12.90	9.20	61.1	7.17	93.5	-
BL Deep Quad	9/11/2012	6.0	15:05	12.57	9.16	61.0	6.86	88.7	-
BL Deep Quad	9/11/2012	7.0	15:06	12.04	8.84	60.6	5.71	72.9	-
BL Deep Quad	9/11/2012	8.0	15:08	9.82	8.23	57.0	1.10	13.0	-
BL Deep Quad	9/11/2012	9.0	15:10	7.86	7.97	58.6	0.28	3.0	-
BL Deep Quad	9/11/2012	10.0	15:13	7.04	7.57	59.8	0.13	1.5	-
BL Deep Quad	9/11/2012	11.0	15:14	6.53	7.44	61.3	0.11	1.2	-
BL Deep Quad	9/11/2012	12.0	15:16	6.26	7.35	62.8	0.10	1.1	-
BL Deep Quad	9/11/2012	13.0	15:17	6.03	7.26	66.2	0.10	1.1	-
BL Deep Quad	9/11/2012	13.7	15:18	5.80	7.19	70.2	0.09	1.0	-

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Outlet Quad	7/15/2009	0.0	12:05	11.86	7.79	45.0	8.46	106.2	452
BL Outlet Quad	7/15/2009	0.5	12:06	11.75	7.76	45.0	8.51	106.3	450
BL Outlet Quad	7/15/2009	1.0	12:07	11.56	7.93	45.2	8.43	105.4	438
BL Outlet Quad	7/15/2009	1.5	12:09	11.50	7.95	45.1	8.43	105.1	433
BL Outlet Quad	7/15/2009	2.0	12:10	11.41	7.99	45.2	8.42	104.8	430
BL Outlet Quad	7/15/2009	2.5	12:12	11.40	8.00	44.9	8.41	104.6	428
BL Outlet Quad	7/15/2009	3.0	12:12	11.37	8.02	45.2	8.41	104.6	424
BL Outlet Quad	7/15/2009	4.0	12:13	11.30	8.07	44.8	8.40	104.2	420
BL Outlet Quad	8/17/2009	0.0	12:50	13.28	9.12	55.1	9.24	120.2	389
BL Outlet Quad	8/17/2009	0.5		13.21	9.18	55.3	9.27	120.6	386
BL Outlet Quad	8/17/2009	1.0		13.15	9.24	55.0	9.35	120.5	384
BL Outlet Quad	8/17/2009	1.5		13.14	9.26	55.5	9.35	121.4	384
BL Outlet Quad	8/17/2009	2.0		13.13	9.27	55.1	9.37	121.6	384
BL Outlet Quad	8/17/2009	2.5	12:56	13.10	9.28	55.0	9.37	121.6	384
BL Outlet Quad	9/21/2009	0.0	13:18	11.56	9.32	61.3	8.56	106.7	138
BL Outlet Quad	9/21/2009	0.5		11.57	9.13	61.3	8.56	106.8	157
BL Outlet Quad	9/21/2009	1.0		11.57	9.27	61.2	8.58	107.0	157
BL Outlet Quad	9/21/2009	1.5		11.56	9.37	61.1	8.57	106.8	158
BL Outlet Quad	9/21/2009	2.0		11.55	9.41	61.3	8.57	106.8	161
BL Outlet Quad	9/21/2009	2.5		11.57	9.42	61.2	8.57	106.8	165
BL Outlet Quad	9/21/2009	3.0		11.56	9.42	61.3	8.56	106.9	169
BL Outlet Quad	9/21/2009	4.0		11.54	9.46	61.4	8.57	106.8	172

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Outlet Quad	7/25/2011	0.0	11:56	14.00	7.91	48.1	8.94	117.6	280
BL Outlet Quad	7/25/2011	0.5	11:57	11.38	7.86	46.4	9.22	114.2	283
BL Outlet Quad	7/25/2011	1.0	11:58	10.87	7.85	46.3	9.30	114.6	282
BL Outlet Quad	7/25/2011	1.5	11:59	10.67	7.83	46.8	9.32	114.0	283
BL Outlet Quad	7/25/2011	2.0	12:00	10.54	7.82	46.1	9.28	113.2	282
BL Outlet Quad	7/25/2011	2.5	12:01	9.92	7.77	45.4	9.29	110.7	285
BL Outlet Quad	7/25/2011	3.0	12:01	9.16	7.68	45.8	9.13	106.9	289
BL Outlet Quad	7/25/2011	4.0	12:02	8.99	7.57	45.0	8.77	102.8	294
BL Outlet Quad	7/25/2011	5.0	12:03	8.71	7.48	44.6	8.44	98.2	298
BL Outlet Quad	7/25/2011	6.0	12:04	8.30	7.31	44.3	7.66	88.3	304
BL Outlet Quad	7/25/2011	7.0	12:04	8.29	7.24	44.1	7.50	86.7	304
BL Outlet Quad	9/6/2011	0.0	15:01	12.57	9.41	62.8	10.05	128.6	238
BL Outlet Quad	9/6/2011	0.5	15:02	12.28	9.35	62.4	10.07	128.3	240
BL Outlet Quad	9/6/2011	1.0	15:03	12.07	9.27	62.2	9.97	125.8	241
BL Outlet Quad	9/6/2011	1.5	15:06	11.94	9.22	61.8	9.44	119.6	243
BL Outlet Quad	9/6/2011	2.0	15:07	11.70	9.11	61.3	9.43	117.3	244
BL Outlet Quad	9/6/2011	2.5	15:08	11.52	9.05	61.1	9.27	114.9	246
BL Outlet Quad	9/6/2011	3.0	15:09	11.26	8.82	60.9	8.91	110.2	251
BL Outlet Quad	9/6/2011	3.7	15:09	10.77	8.33	59.5	7.62	93.2	262

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Outlet Quad	9/20/2011	0.0	14:05	10.91	8.90	61.8	8.83	109.7	237
BL Outlet Quad	9/20/2011	0.5	14:05	10.92	9.05	61.6	9.08	112.2	241
BL Outlet Quad	9/20/2011	1.0	14:06	10.90	9.07	61.7	9.09	112.3	241
BL Outlet Quad	9/20/2011	1.5	14:07	10.83	9.08	61.9	9.06	111.8	-
BL Outlet Quad	9/20/2011	2.0	14:07	10.81	9.09	61.6	9.04	111.4	243
BL Outlet Quad	9/20/2011	2.5	14:08	10.75	9.05	61.6	9.03	111.2	248
BL Outlet Quad	9/20/2011	3.0	14:09	10.68	9.05	61.4	9.05	111.3	250
BL Outlet Quad	9/20/2011	3.5	14:10	10.67	9.03	61.6	9.09	111.7	247

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
BL Outlet Quad	7/24/2012	0.0	11:52	17.08	9.66	68.6	11.91	170.9	293
BL Outlet Quad	7/24/2012	0.5	11:53	17.06	9.87	68.5	12.40	175.8	290
BL Outlet Quad	7/24/2012	1.0	11:54	17.06	9.92	68.6	12.43	176.1	287
BL Outlet Quad	7/24/2012	1.5	11:55	16.94	9.92	68.2	12.41	175.5	286
BL Outlet Quad	7/24/2012	2.0	11:55	16.96	9.91	68.2	12.43	175.6	286
BL Outlet Quad	7/24/2012	2.5	11:56	16.90	9.89	67.9	12.43	174.9	286
BL Outlet Quad	7/24/2012	3.0	11:57	16.86	9.87	67.7	12.34	174.0	287
BL Outlet Quad	7/24/2012	4.0	11:58	16.71	9.66	63.0	11.69	162.8	292
BL Outlet Quad	7/24/2012	4.5	11:58	13.27	8.94	58.7	9.53	124.5	318
BL Outlet Quad	8/21/2012	0.0	15:02	16.85	9.50	62.6	8.29	117.9	-
BL Outlet Quad	8/21/2012	0.5		16.82	9.54	62.6	8.59	121.3	-
BL Outlet Quad	8/21/2012	1.0		16.47	9.59	62.6	8.60	120.4	-
BL Outlet Quad	8/21/2012	1.5		16.09	9.63	62.1	8.59	119.7	-
BL Outlet Quad	8/21/2012	2.0		15.45	9.63	62.2	8.65	118.0	-
BL Outlet Quad	8/21/2012	2.5		15.19	9.61	61.6	8.25	112.3	-
BL Outlet Quad	8/21/2012	3.0		15.09	9.59	61.7	8.29	112.8	-
BL Outlet Quad	8/21/2012	3.7	15:06	15.07	9.57	61.3	8.07	109.6	-
BL Outlet Quad	9/11/2012	0.0	15:36	12.89	9.28	61.2	7.29	95.0	-
BL Outlet Quad	9/11/2012	0.5	15:39	12.89	9.20	60.8	7.27	94.8	-
BL Outlet Quad	9/11/2012	1.0	15:40	12.94	9.22	61.0	7.28	95.0	-
BL Outlet Quad	9/11/2012	1.5	15:41	12.93	9.21	61.1	7.27	94.8	-
BL Outlet Quad	9/11/2012	2.0	15:42	12.94	9.21	60.8	7.26	94.8	-
BL Outlet Quad	9/11/2012	2.5	15:43	12.90	9.21	61.2	7.21	94.1	-
BL Outlet Quad	9/11/2012	3.0	15:45	12.90	9.22	61.0	7.22	94.2	-
BL Outlet Quad	9/11/2012	4.0	15:46	12.88	9.22	60.7	7.19	93.8	-

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
LJL Littoral	7/25/2012	0.0	14:04	16.54	8.56	66.3	8.04	114.5	297
LJL Littoral	7/25/2012	0.5	14:04	16.53	8.69	66.2	8.23	117.0	292
LJL Littoral	7/25/2012	1.0	14:05	16.25	8.66	66.3	8.27	116.9	296
LJL Littoral	7/25/2012	1.5	14:06	15.79	8.59	66.3	8.24	115.1	296
LJL Littoral	7/25/2012	2.0	14:07	15.77	8.63	66.3	8.47	118.5	297
LJL Littoral	8/22/2012	0.0	15:25	16.27	8.96	67.8	8.78	123.0	-
LJL Littoral	8/22/2012	0.5	15:26	16.24	8.97	68.0	8.77	122.9	-
LJL Littoral	8/22/2012	1.0	15:27	15.67	8.99	67.8	9.07	125.9	-
LJL Littoral	8/22/2012	1.5	15:28	15.28	8.98	67.8	8.90	122.1	-
LJL Littoral	8/22/2012	2.0	15:29	15.20	8.99	67.6	8.82	120.8	-
LJL Littoral	8/22/2012	2.5	15:30	15.16	9.01	67.3	8.82	120.7	-
LJL Littoral	8/22/2012	3.0	15:31	15.14	9.02	67.4	8.86	121.2	-
LJL Littoral	8/22/2012	3.3	15:32	15.14	9.02	67.7	8.92	122.2	-
LJL Littoral	9/12/2012	0.0	14:40	12.92	8.50	68.4	8.62	113.3	-
LJL Littoral	9/12/2012	0.5	14:41	12.94	8.43	68.4	8.57	112.9	-
LJL Littoral	9/12/2012	1.0	14:42	12.97	8.42	68.2	8.76	115.7	-

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
LJL Pelagic	7/25/2012	0.0	13:43	16.33	8.12	65.9	7.93	112.5	-
LJL Pelagic	7/25/2012	0.5	13:44	16.10	8.37	65.9	8.05	113.3	-
LJL Pelagic	7/25/2012	1.0	13:45	15.96	8.41	66.4	8.00	112.3	-
LJL Pelagic	7/25/2012	1.5	13:46	15.83	8.42	66.2	7.99	111.8	-
LJL Pelagic	7/25/2012	2.0	13:46	15.79	8.40	66.5	7.99	111.6	-
LJL Pelagic	7/25/2012	2.5	13:47	15.69	8.39	66.3	8.01	111.4	-
LJL Pelagic	7/25/2012	3.0	13:47	15.58	8.39	66.5	7.93	110.4	-
LJL Pelagic	7/25/2012	4.0	13:48	15.13	8.35	67.2	8.09	111.5	-
LJL Pelagic	7/25/2012	5.0	13:49	13.87	8.51	62.3	9.72	130.1	-
LJL Pelagic	7/25/2012	6.0	13:50	11.33	8.57	63.4	10.50	132.1	-
LJL Pelagic	7/25/2012	7.0	13:51	9.38	8.51	67.2	10.34	124.3	-
LJL Pelagic	7/25/2012	8.0	13:51	8.10	8.29	71.5	9.65	111.1	-
LJL Pelagic	7/25/2012	9.0	13:53	7.16	7.91	73.0	8.18	93.6	-
LJL Pelagic	7/25/2012	10.0	13:53	6.53	7.74	73.8	7.00	78.4	-
LJL Pelagic	7/25/2012	11.0	13:54	5.99	7.54	75.3	5.11	56.8	-
LJL Pelagic	7/25/2012	12.0	13:55	5.60	7.47	75.8	3.45	31.5	-
LJL Pelagic	7/25/2012	13.0	13:55	5.35	7.40	76.9	2.12	18.2	-
LJL Pelagic	7/25/2012	14.0	13:56	5.09	7.29	77.9	0.41	4.4	-
LJL Pelagic	7/25/2012	14.4	13:57	4.87	7.06	78.5	0.23	2.4	-
LJL Pelagic	8/22/2012	0.0	14:33	16.02	8.62	67.7	8.40	117.4	-
LJL Pelagic	8/22/2012	0.5	14:34	15.54	8.67	67.6	8.56	118.2	-
LJL Pelagic	8/22/2012	1.0	14:35	15.34	8.70	67.4	8.62	118.3	-
LJL Pelagic	8/22/2012	1.5	14:36	15.26	8.72	67.4	8.66	118.8	-
LJL Pelagic	8/22/2012	2.0	14:38	15.19	8.74	67.6	8.62	118.2	-
LJL Pelagic	8/22/2012	2.5	14:38	15.16	8.76	67.6	8.62	118.0	-
LJL Pelagic	8/22/2012	3.0	14:39	15.16	8.78	67.8	8.62	117.9	-
LJL Pelagic	8/22/2012	4.0	14:40	15.09	8.78	67.8	8.59	117.3	-

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
LJL Pelagic	8/22/2012	5.0	14:41	15.02	8.79	67.8	8.52	116.3	-
LJL Pelagic	8/22/2012	6.0	14:42	14.93	8.80	67.6	8.52	116.1	-
LJL Pelagic	8/22/2012	7.0	14:43	14.09	8.75	67.2	10.30	137.7	-
LJL Pelagic	8/22/2012	8.0	14:44	11.12	8.64	70.2	10.48	130.9	-
LJL Pelagic	8/22/2012	9.0	14:45	9.98	8.46	71.5	9.64	117.0	-
LJL Pelagic	8/22/2012	10.0	14:48	8.64	8.24	72.7	8.33	98.3	-
LJL Pelagic	8/22/2012	11.0	14:50	7.98	8.06	73.4	7.05	81.6	-
LJL Pelagic	8/22/2012	12.0	14:51	7.32	8.01	73.5	5.30	60.4	-
LJL Pelagic	8/22/2012	13.0	14:57	6.92	7.73	73.9	3.68	41.2	-
LJL Pelagic	8/22/2012	14.0	14:59	6.50	7.57	75.0	2.40	26.7	-
LJL Pelagic	8/22/2012	14.5	15:00	6.31	7.46	76.9	0.68	7.3	-
LJL Pelagic	9/12/2012	0.0	15:11	12.76	8.94	68.3	8.15	106.8	-
LJL Pelagic	9/12/2012	0.5		12.72	8.90	68.4	8.20	107.3	-
LJL Pelagic	9/12/2012	1.0		12.38	8.86	68.3	8.24	106.9	-
LJL Pelagic	9/12/2012	1.5		12.32	8.86	68.1	8.26	107.0	-
LJL Pelagic	9/12/2012	2.0		12.33	8.83	68.2	8.25	107.0	-
LJL Pelagic	9/12/2012	2.5		12.32	8.83	68.6	8.23	106.7	-
LJL Pelagic	9/12/2012	3.0		12.29	8.82	68.2	8.22	106.4	-
LJL Pelagic	9/12/2012	4.0		12.23	8.81	68.2	8.22	106.3	-
LJL Pelagic	9/12/2012	5.0		12.22	8.81	68.2	8.20	106.0	-
LJL Pelagic	9/12/2012	6.0		12.18	8.81	68.0	8.17	105.4	-
LJL Pelagic	9/12/2012	7.0		12.12	8.80	68.4	8.15	105.1	-
LJL Pelagic	9/12/2012	8.0		12.08	8.79	68.5	8.14	104.9	-
LJL Pelagic	9/12/2012	9.0		11.92	8.78	68.4	8.13	104.3	-
LJL Pelagic	9/12/2012	10.0		9.41	8.45	73.2	8.29	98.1	-
LJL Pelagic	9/12/2012	11.0		8.71	8.21	73.1	6.94	81.3	-
LJL Pelagic	9/12/2012	12.0		7.98	8.07	74.0	4.65	43.8	-
LJL Pelagic	9/12/2012	13.0		7.23	7.90	76.1	1.43	15.6	-
LJL Pelagic	9/12/2012	14.0		6.97	7.79	78.0	0.56	5.6	-

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
UBL Littoral	7/25/2012	0.0	11:02	14.91	8.76	74.9	8.57	118.5	321
UBL Littoral	7/25/2012	0.5	11:03	14.87	8.83	75.3	9.32	126.2	319
UBL Littoral	7/25/2012	1.0	11:03	14.82	8.85	74.8	9.35	126.6	319
UBL Littoral	7/25/2012	1.2	11:04	14.89	8.87	74.7	9.58	130.0	315
UBL Littoral	8/22/2012	0.0	10:15	14.19	9.72	78.8	9.24	124.3	-
UBL Littoral	8/22/2012	0.5		14.18	9.70	78.9	9.39	125.9	-
UBL Littoral	8/22/2012	1.0		14.18	9.67	79.2	9.47	127.0	-
UBL Littoral	8/22/2012	1.5		14.17	9.63	78.9	9.56	128.2	-
UBL Littoral	9/12/2012	0.0	10:33	10.89	9.64	80.4	8.61	107.9	-
UBL Littoral	9/12/2012	0.5	10:33	10.88	9.62	80.1	8.81	109.3	-
UBL Littoral	9/12/2012	1.0	10:34	10.88	9.60	79.7	8.95	111.9	-

Site	Date	Depth (m)	Time	Temp (C˚)	pH	Conductance (uS/cm)	D.O. (mg/L)	D.O. (% Sat.)	ORP
UBL Pelagic	7/25/2012	0.0	10:21	14.67	8.59	74.9	9.05	122.7	313
UBL Pelagic	7/25/2012	0.5	10:22	14.65	8.70	75.1	9.22	124.4	314
UBL Pelagic	7/25/2012	1.0	10:23	14.51	8.70	74.5	9.31	125.1	314
UBL Pelagic	7/25/2012	1.5	10:24	14.42	8.69	75.6	9.28	124.4	313
UBL Pelagic	7/25/2012	2.0	10:24	14.12	8.69	74.6	9.41	125.8	314
UBL Pelagic	7/25/2012	2.5	10:25	13.79	8.63	75.4	9.23	122.1	315
UBL Pelagic	7/25/2012	3.0	10:26	13.72	8.60	75.6	9.19	121.9	317
UBL Pelagic	7/25/2012	4.0	10:27	13.12	8.57	75.8	9.19	120.0	316
UBL Pelagic	7/25/2012	4.4	10:28	13.04	8.61	74.0	9.84	127.6	313
UBL Pelagic	8/22/2012	0.0	10:55	14.07	9.28	78.8	8.86	119.3	-
UBL Pelagic	8/22/2012	0.5		14.07	9.32	78.9	9.27	123.8	-
UBL Pelagic	8/22/2012	1.0		14.08	9.34	78.9	9.27	124.0	-
UBL Pelagic	8/22/2012	1.5		14.01	9.34	78.9	9.27	123.8	-
UBL Pelagic	8/22/2012	2.0		13.74	9.32	79.1	9.23	122.2	-
UBL Pelagic	8/22/2012	2.5		13.53	9.30	79.1	9.11	120.2	-
UBL Pelagic	8/22/2012	3.0		13.39	9.28	79.1	9.01	118.5	-
UBL Pelagic	8/22/2012	4.0		13.09	9.30	78.9	9.24	121.0	-
UBL Pelagic	8/22/2012	4.8		12.79	9.29	78.5	9.58	124.8	-
UBL Pelagic	9/12/2012	0.0	11:22	10.94	9.40	80.5	8.70	108.0	-
UBL Pelagic	9/12/2012	0.5	11:23	10.95	9.39	80.7	8.71	108.2	-
UBL Pelagic	9/12/2012	1.0	11:24	10.92	9.41	80.6	8.71	108.2	-
UBL Pelagic	9/12/2012	1.5	11:25	10.86	9.41	80.4	8.69	107.5	-
UBL Pelagic	9/12/2012	2.0	11:25	10.69	9.41	80.5	8.48	104.6	-
UBL Pelagic	9/12/2012	2.5	11:26	10.66	9.41	80.4	8.44	104.1	-
UBL Pelagic	9/12/2012	3.0	11:27	10.50	9.42	80.3	8.38	103.1	-
UBL Pelagic	9/12/2012	4.0	11:28	10.38	9.41	80.7	8.44	103.5	-
UBL Pelagic	9/12/2012	4.8	11:28	10.27	9.41	79.9	8.86	108.7	-