



6-30-2011

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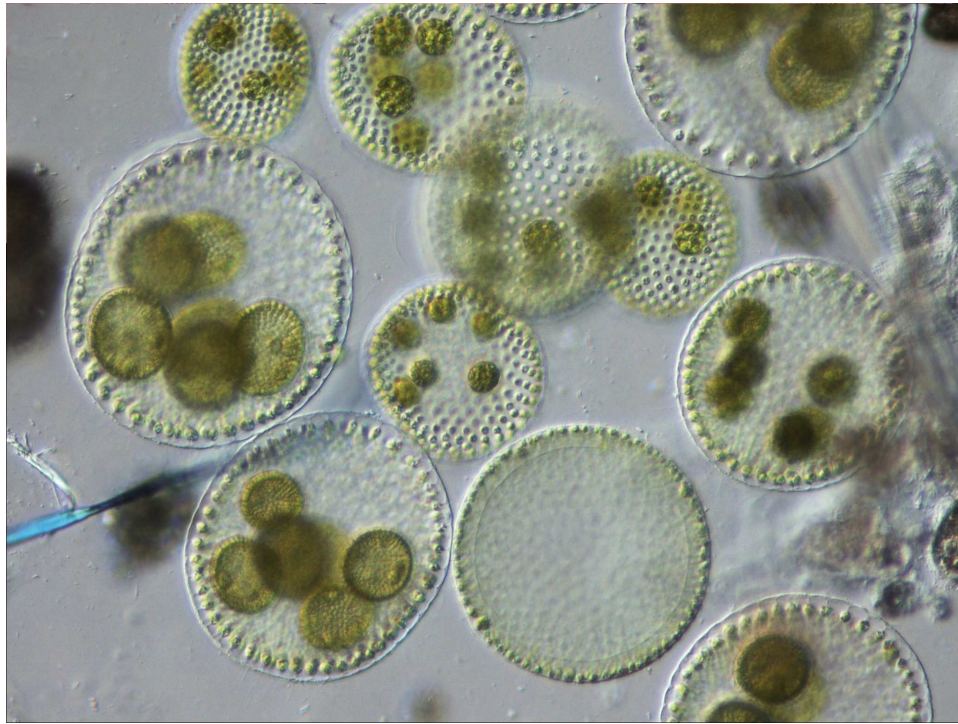
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Matthews, Robin A. and Vandersypen, Joan, "Birch Bay Village Lakes 2011 Final Report" (2011). *Birch Bay/Village Lakes*. 3.

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June 30, 2011

Funding for this project was provided by the Birch Bay Village Lakes Committee.
We thank Marilyn Desmul, Jessie Rosanbalm, and Kate Lewis for assistance with the project.

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1 Project Description and Sampling Methods

The Institute for Watershed Studies was contracted by the Birch Bay Village Lakes Committee to continue water testing at two sites in Kwann Lake and two sites in Thunderbird Lake (Figure 1, page 4). The sampling effort began in August 2007, and samples have been collected approximately 3–4 times each year through spring 2011. This report provides an update to the 2008 and 2009 data reports submitted to the Birch Bay Village Lakes Committee.

Water samples were collected on the following dates:

2007	2008	2009	2010	2011
Aug 21	Feb 28	Feb 19	Jul 14	Mar 10
Oct 25	Apr 17	Apr 24	Aug 11	Apr 14
Dec 11	Jun 12	Jun 16	Sep 16	
		Aug 21	Nov 17	

Temperature and dissolved oxygen concentrations were measured in the field at the surface (0.3 m) and at 1 meter depth intervals using a YSI field meter. Both lakes are very shallow, so the deepest collection depth at any site was 3 meters.

Surface water samples were collected at each lake site and transported to the Institute for Watershed Studies (IWS) laboratory to measure pH, conductivity, phosphorus (total phosphorus and orthophosphate), nitrogen (total nitrogen, nitrate/nitrite¹, ammonium), turbidity, and alkalinity. Separate surface water samples were collected to measure chlorophyll concentrations. All water samples collected in the field were stored on ice and in the dark until they reached the IWS laboratory and were analyzed as described in Table 1. Beginning in 2009, surface coliform samples were collected and analyzed by Exact Scientific Services, Inc.

¹Nitrate and nitrite were analyzed together because nitrite concentrations are usually very low in surface water and require low level analytical techniques to measure accurately.

Analyte	Method Reference [†]	Detection Limit/ Sensitivity
Alkalinity	SM2320, titration	±0.5 mg CaCO ₃ /L
Chlorophyll	SM10200 H, acetone extract, phaeophytin corrected	±0.1 µg/L
Conductivity	SM2510, lab meter	±0.1 units
Dissolved oxygen - field	SM4500-O G., membrane electrode (field meter)	±0.1 mg/L
Dissolved oxygen - lab	SM4500-O C., Winkler with azide modification	±0.1 mg/L
Fecal coliforms [‡]	SM9222 D, membrane filter	1 cfu/100 mL
Nitrogen - ammonium	SM4500-NH ₃ H., flow injection, phenate	10 µg NH ₃ -N/L
Nitrogen - nitrate/nitrite	SM4500-NO ₃ I., flow injection, Cd reduction	10 µg NO ₃ -N/L
Nitrogen - total	SM4500-NO ₃ I., flow injection, persulfate digest	20 µg N/L
pH - lab	SM4500-H, electrometric	±0.1 units
Phosphorus - ortho	SM4500-P G., flow injection	3 µg PO ₄ -P/L
Phosphorus - total	SM4500-P G., flow injection, persulfate digest	5 µg P/L
Temperature - field	SM2550 thermistor (field meter)	±0.1 C
Turbidity	SM2130, nephelometric	±0.2 NTU

[†]APHA, 2005. Standard Methods for the Examination of Water and Wastewater, 20th Ed., Amer. Public Health Assoc., Amer. Water Works Assoc., Water Env. Fed., Washington, DC.

[‡]Analyses done by Exact Scientific Services, Inc., 3929 Spur Ridge Ln, Bellingham, WA 98226

Table 1: Summary of analytical methods for the Birch Bay Village Lakes project.

2 Results

All of the 2007–2011 Birch Bay Village Lakes water quality data are included in Appendix A of this report. In addition, each parameter has been plotted (Figures 2–16, pages 5–19) and included in the report. Each figure includes descriptive captions that discuss the general patterns in the data. It is beyond the scope of this project to provide a detailed analysis of the data; however, if you have additional questions, please contact Dr. R. Matthews at the Institute for Watershed Studies.

To facilitate pattern descriptions, the figures are discussed in the following order:

- Figure 1: Sampling locations
- Figures 2–8: Physical structure of the lake (temperature, dissolved oxygen)
- Figures 6–8: Chemical structure of the lake (conductivity, pH, turbidity)
- Figures 9–13: Algal nutrients (nitrogen and phosphorus)
- Figures 14–15: Lake trophic state (chlorophyll and trophic index)
- Figure 16 (page 19): Bacterial indicators (fecal coliforms - 2009 only)

3 Quality Control

Ten percent of the water samples were collected in duplicate (field duplicates) to estimate variation between samples collected at the same location, depth, and time. Ten percent of all laboratory samples were measured in duplicate to estimate analytical variation for samples from the same bottle. Laboratory blanks, matrix spikes, and laboratory control/check samples were included with all analytical runs to estimate background noise and recovery of known concentrations of each analyte. All of the quality control data are included in Appendix B of this report.



GPS Coordinates for Sampling Sites:

K1	48.94211°N, 122.77848°W	T1	48.93774°N, 122.78495°W
K2	48.94195°N, 122.77327°W	T2	48.93766°N, 122.78697°W

Figure 1: Kwann Lake and Thunderbird Lake sampling sites.

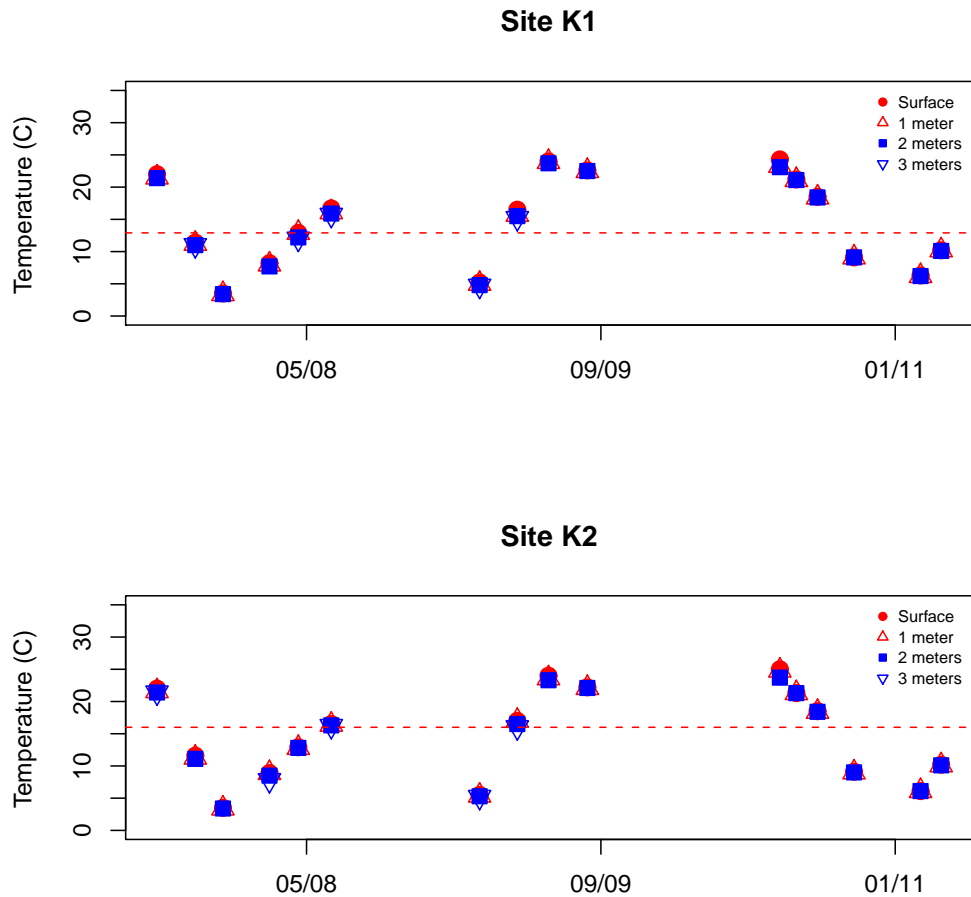


Figure 2: Temperature measurements were collected at the surface and at 1 meter intervals in Kwann Lake. All sites were shallow (≤ 3 m), so the water column was thoroughly mixed on each sampling date, resulting in similar temperatures at all depths. Seasonal warming and cooling was evident; temperatures were warm during the summer and cold during the winter. The dashed red lines show median water temperatures. Site K1 was slightly cooler (median = 12.9°C) compared to Site K2 (median = 16.0°C).

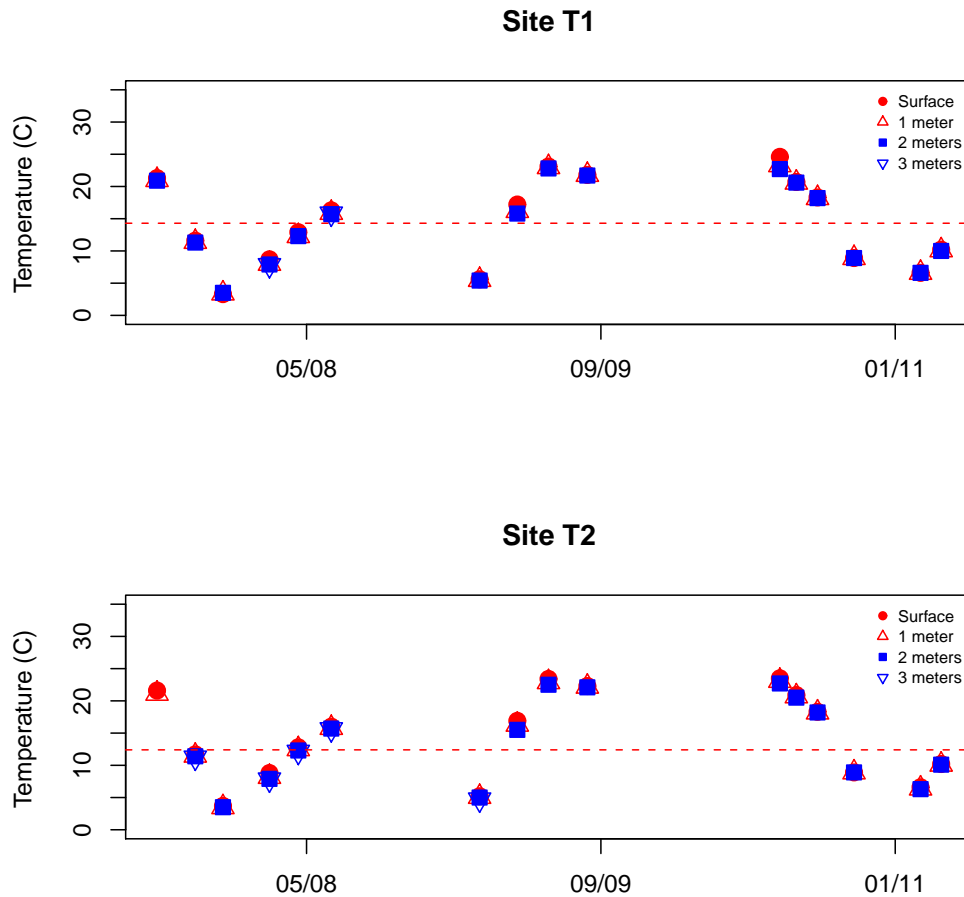


Figure 3: Temperature measurements were collected at the surface and at 1 meter intervals in Thunderbird Lake. All sites were shallow (≤ 3 m), so the water column was thoroughly mixed on each sampling date, resulting in similar temperatures at all depths. Seasonal warming and cooling was evident; temperatures were warm during the summer and cold during the winter. The dashed red lines (median water temperatures) show that Site T1 was slightly warmer (median = 14.3 °C) compared to Site T2 (median = 12.4 °C).

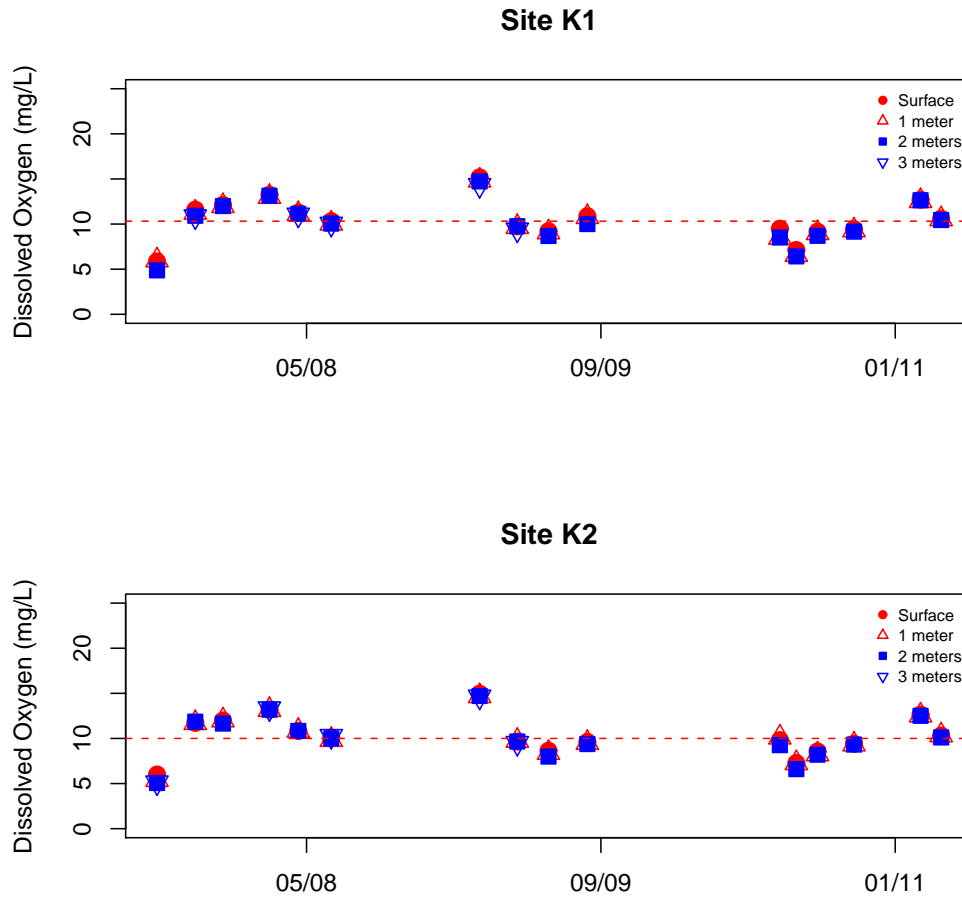


Figure 4: Dissolved oxygen measurements were collected at the surface and at 1 meter intervals in Kwann Lake. All sites were shallow (≤ 3 m), and the lakes contain aerators that introduce oxygen into the water column, so oxygen concentrations were more or less similar at all depths. Higher oxygen concentrations were measured during the winter (cold water holds more oxygen than warm water) compared to the summer, when warm water temperatures and high rates of organic matter decomposition work together to produce lower oxygen levels in the water column. The median dissolved oxygen levels (dashed red lines) were nearly the same at both sites (K1 median = 10.3 mg/L, K2 median = 10.0 mg/L). The Kwann Lake sites had slightly higher median oxygen levels than the Thunderbird Lake sites (Figure 5).

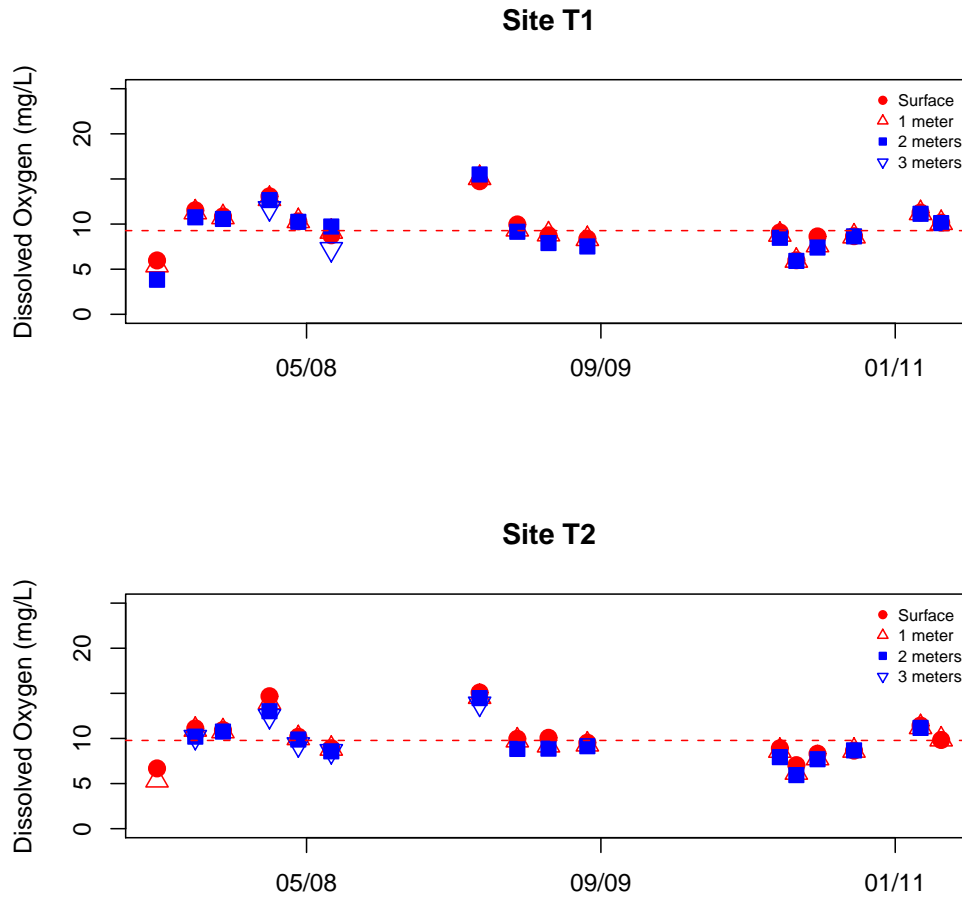


Figure 5: Dissolved oxygen measurements were collected at the surface and at 1 meter intervals in Thunderbird Lake. All sites were shallow (≤ 3 m), and the lakes contain aerators that introduce oxygen into the water column, so oxygen concentrations were more or less similar at all depths. Higher oxygen concentrations were measured during the winter (cold water holds more oxygen than warm water) compared to the summer, when warm water temperatures and high rates of organic matter decomposition work together to produce lower oxygen levels in the water column. The median dissolved oxygen levels (dashed red lines) were nearly the same at both sites (T1 median = 9.3 mg/L, T2 median = 9.8 mg/L). The Thunderbird Lake sites had slightly lower median oxygen levels than the Kwann Lake sites (Figure 4).

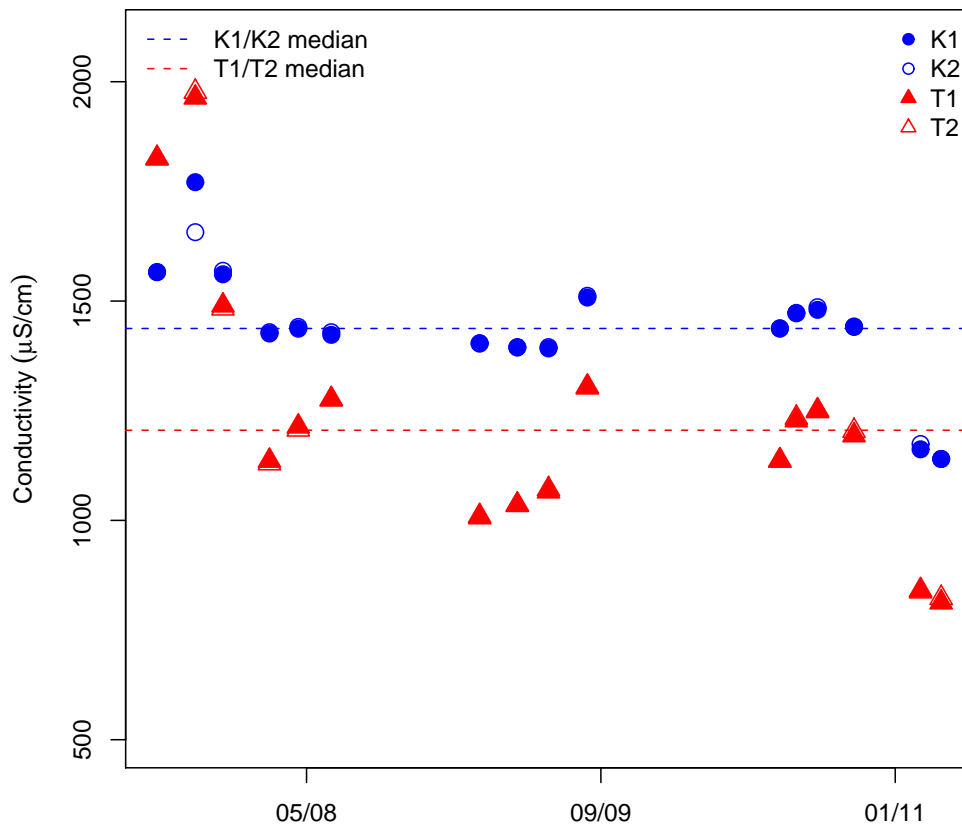


Figure 6: Conductivities were measured in the laboratory using surface water samples collected at 0.3 m. The Kwann Lake conductivity levels were relatively high for freshwater samples (median = 1438 $\mu\text{S}/\text{cm}$). Thunderbird Lake conductivities were typically lower, but were still fairly high for freshwater (median = 1206 $\mu\text{S}/\text{cm}$). The August and October 2007 Thunderbird Lake conductivities were unusually high, suggesting saltwater influence. The conductivities in both lakes were lower during the winter and spring, probably due to the inflow of surface runoff.

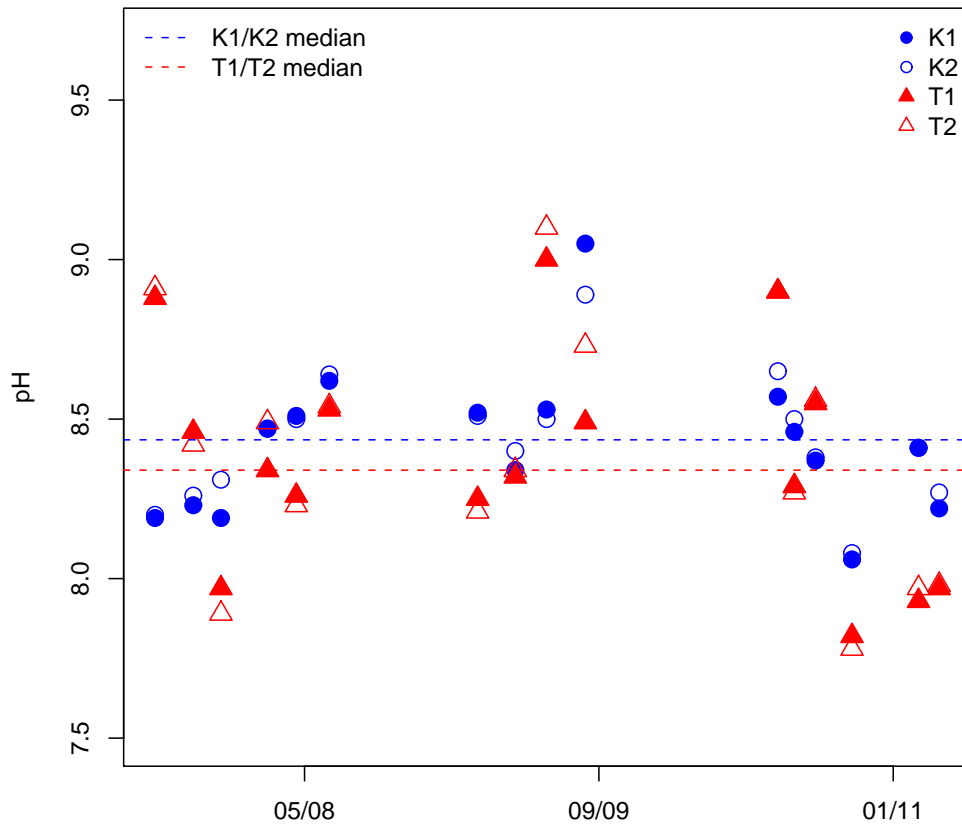


Figure 7: The pH levels were measured in the laboratory using surface water samples collected at 0.3 m. The median pH values for both lakes were very similar (8.3-8.4). All pH levels were slightly alkaline (>7), and most were >8.0 , which is typical for lakes with high conductivities and high algal concentrations (Figure 14, page 17)

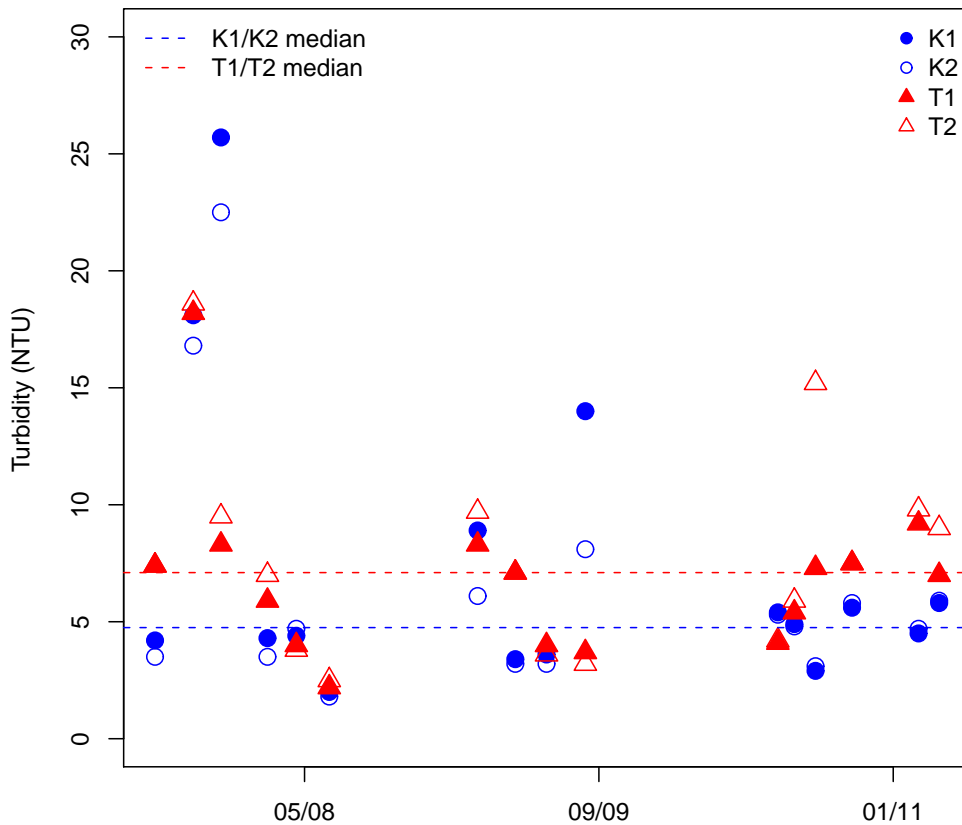


Figure 8: Turbidity values were measured in the laboratory using surface water samples collected at 0.3 m. Turbidity indicates the amount of suspended particles, including algae and other types of suspended sediments. The highest turbidities levels occurred in December 2007, probably due to storm events causing sediments to enter the lakes via surface runoff or from wind-related lake turbulence that resuspended lake bottom sediments. The median turbidity was slightly higher in Thunderbird Lake (7.1 NTU) compared to Kwann Lake (4.8 NTU).

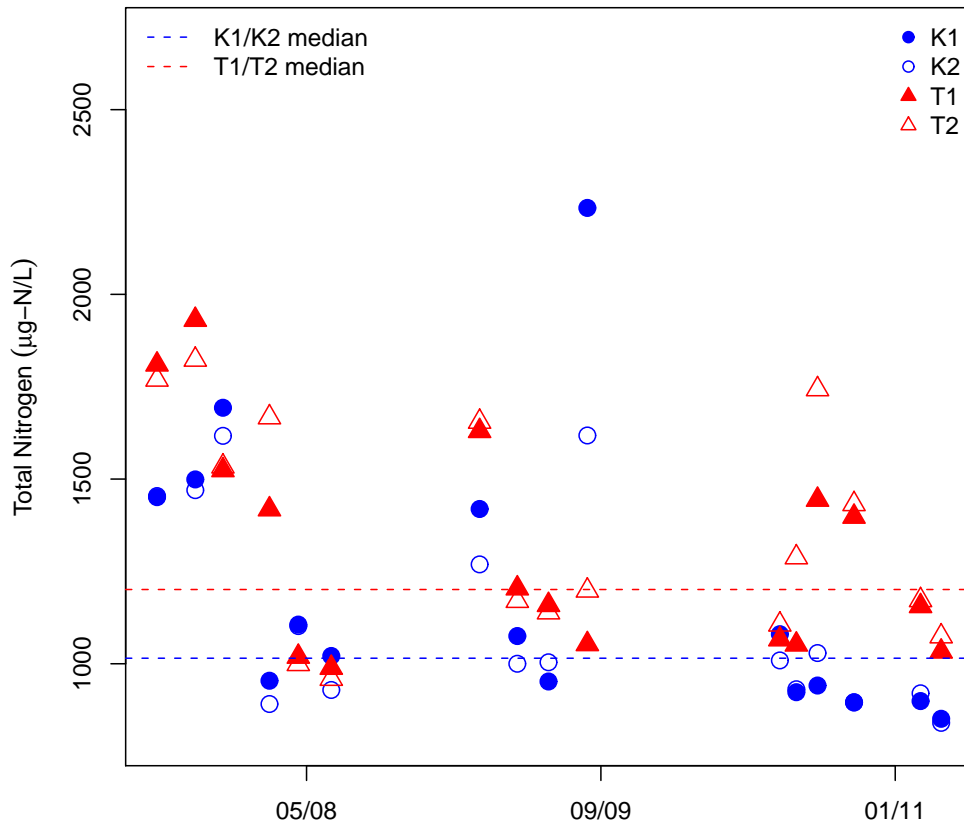


Figure 9: Total nitrogen concentrations were measured in the laboratory using surface water samples collected at 0.3 m. Total nitrogen represents the combined concentrations of organic nitrogen (nitrogen associated with algae and other biota) and dissolved inorganic nitrogen (nitrate, nitrite, and ammonium). Usually, total nitrogen concentrations are similar to nitrate concentrations (Figure 10, page 13), but in the Birch Bay Village Lakes, total nitrogen concentrations were much higher than nitrate concentrations. This indicates that the lakes contain large amounts of organic nitrogen, which is consistent with the high chlorophyll concentrations and eutrophic trophic state (Figures 14–15, pages 17–18). The median total nitrogen concentration was higher in Thunderbird Lake (1201 µg-N/L) than in Kwann Lake (1015 µg-N/L).

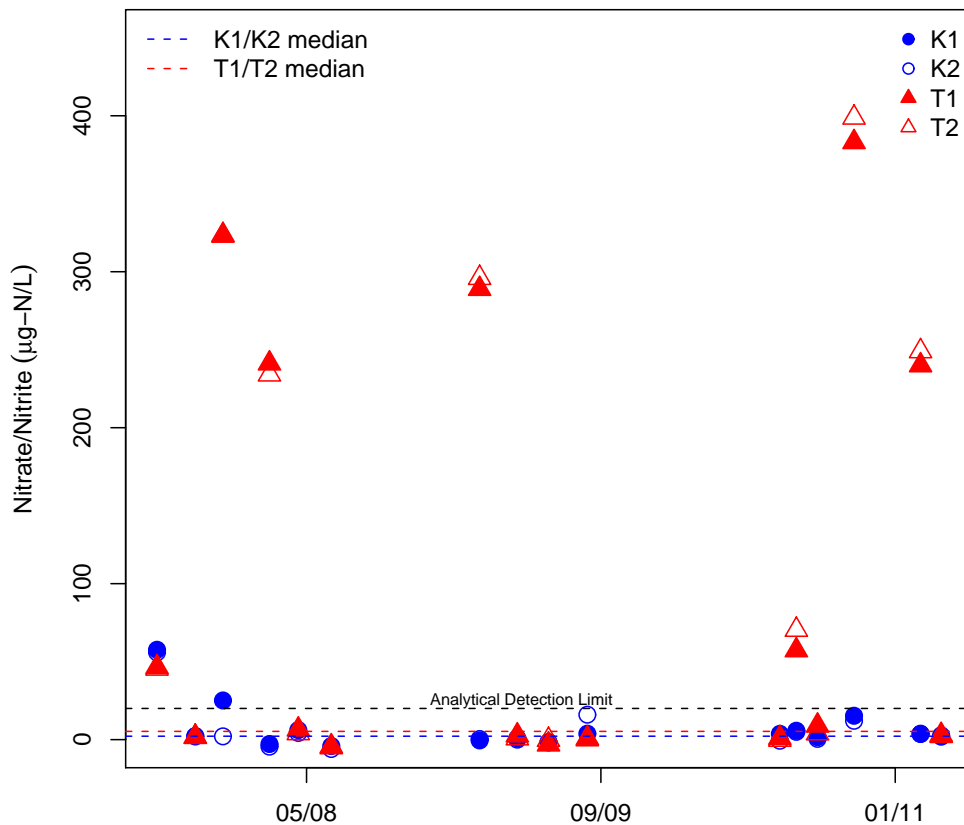


Figure 10: Nitrate concentrations were measured in the laboratory using surface water samples collected at 0.3 m. The results include both nitrate (NO_3) and nitrite (NO_2), which are normally measured in combination. Nitrate, along with nitrite and ammonium (Figure 11, page 14) are important nutrients for most algae, and when the concentrations of these nutrients are low, conditions favor the growth of cyanobacteria or bluegreen algae. (Cyanobacteria can use dissolved N_2 , which is replenished from the atmosphere). Nitrate concentrations were usually very low. The median concentrations at both sites were below the analytical detection limits ($20 \mu\text{g-N/L}$), indicating that conditions probably favored cyanobacteria growth most of the year. Thunderbird Lake periodically had high nitrate concentrations (usually during the winter), so Thunderbird Lake may support algae that are not cyanobacteria (e.g., diatoms) during the winter and early spring. This determination was beyond the scope of the monitoring project.

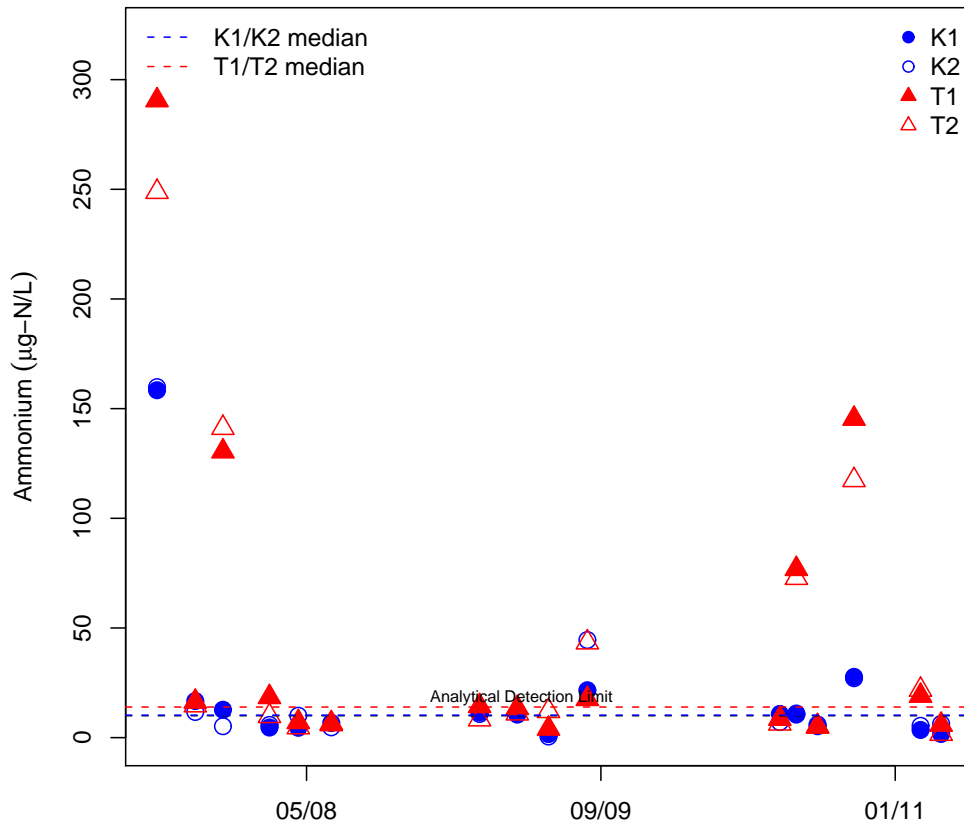


Figure 11: Ammonium concentrations were measured in the laboratory using surface water samples collected at 0.3 m. Ammonium concentrations are usually very low in oxygenated water, and are typically associated with anaerobic lake sediments or other low oxygen environments. On most dates the ammonium concentrations were near the analytical detection limits ($10 \mu\text{g-N/L}$), and the median concentrations at both sites were near the detection limit (Kwannon = $10.2 \mu\text{g-N/L}$; Thunderbird = $14.0 \mu\text{g-N/L}$). High concentrations of ammonium were occasionally detected, especially at the Thunderbird Lake sites. There was no obvious pattern for the occasional ammonium peaks, but typical sources would include the lake sediments and runoff from a local source (e.g., septic overflow, fertilizer leaching, ammonium from marshy soils).

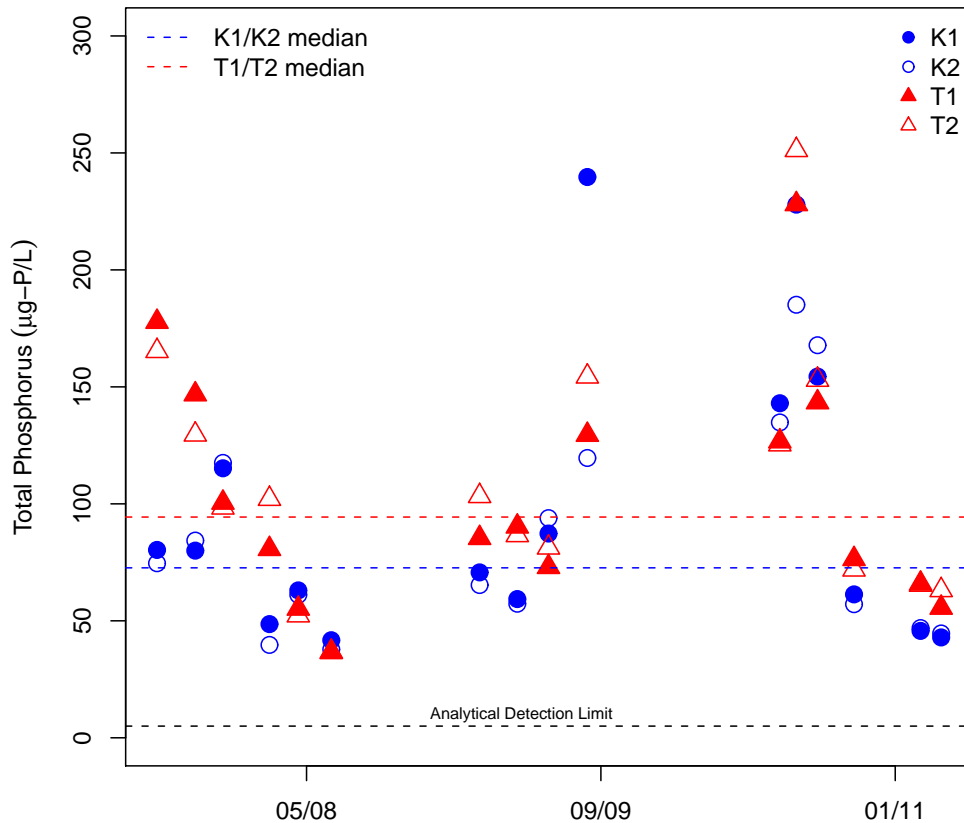
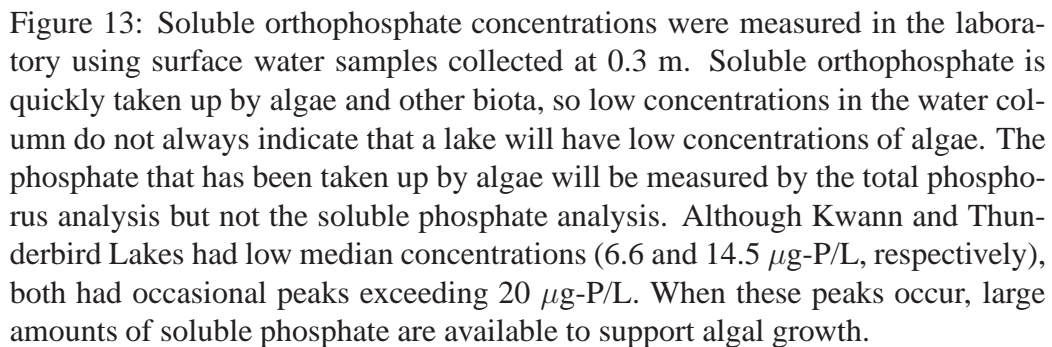


Figure 12: Total phosphorus concentrations were measured in the laboratory using surface water samples collected at 0.3 m. Total phosphorus includes organic phosphorus (phosphorus associated with algae and other biota) and dissolved phosphate (primarily soluble or orthophosphate). Phosphorus is an important nutrient for algae, and is generally considered the nutrient that limits the amount of algae in a lake. Although the median total phosphorus concentration was slightly lower in Kwann Lake (72.6 µg-P/L) than Thunderbird Lake (94.4 µg-P/L), both lakes had relatively high concentrations on all sampling dates (≥ 35 µg-P/L). This indicates that both lakes can support a large amount of algal biomass, which is consistent with the chlorophyll and trophic state results (Figures 14 and 15).



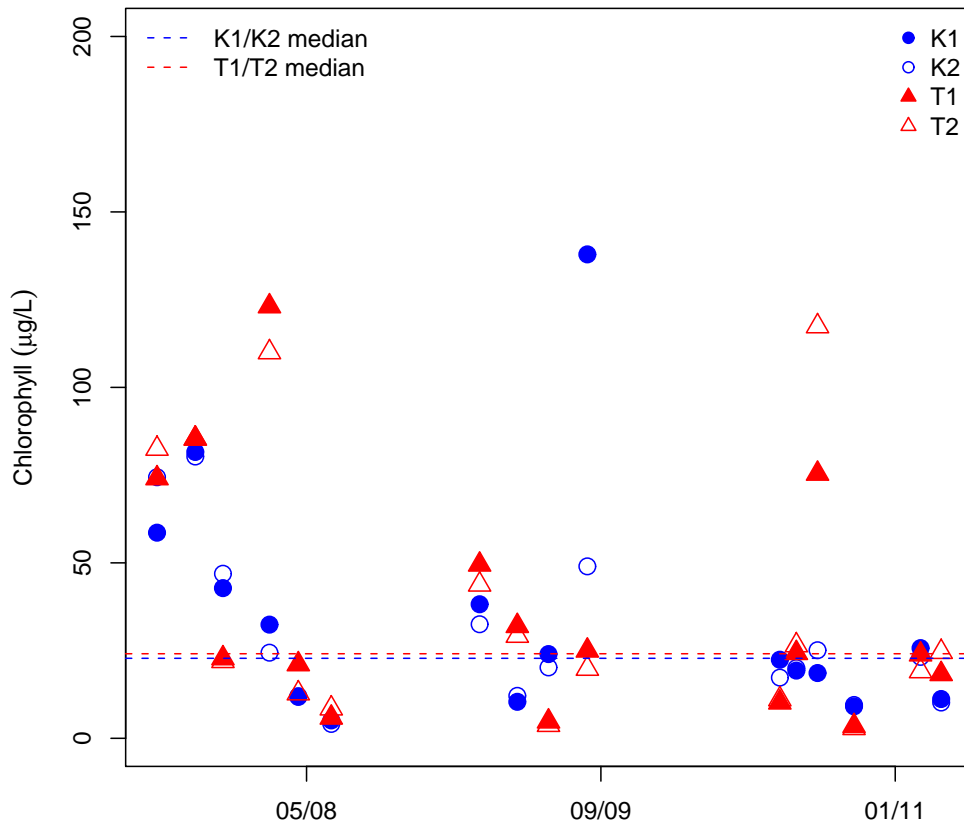


Figure 14: Chlorophyll concentrations were measured in the laboratory using surface water samples collected at 0.3 m. The highest chlorophyll concentrations were usually collected in late summer/early fall, when cyanobacteria biomass often peaks in local lakes. The median chlorophyll concentrations were nearly the same for both lakes (Kwann median = 22.8 $\mu\text{g/L}$; Thunderbird median = 24.1 $\mu\text{g/L}$). Prior to 2010, both lakes appeared to have periodic blooms (indicated by high chlorophyll concentrations). Beginning in 2010, the chlorophyll concentrations were lower, with only one set of high chlorophyll measurements collected in Thunderbird Lake on September 16, 2010.

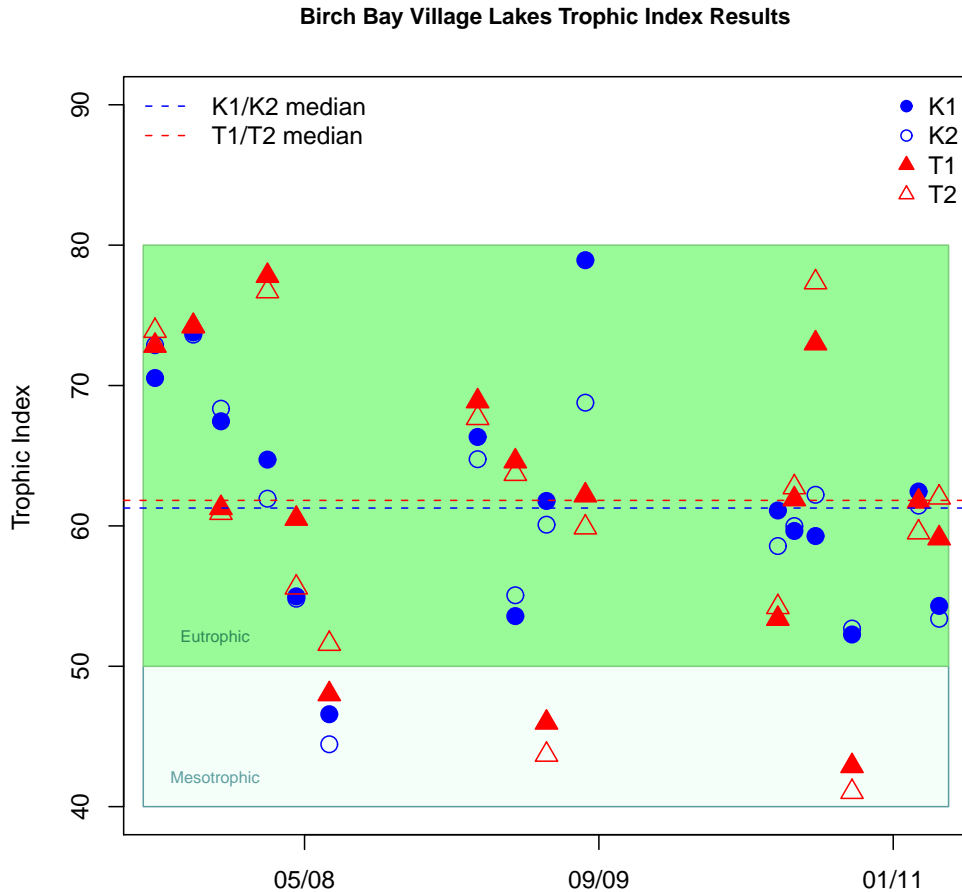


Figure 15: Carlson's Trophic State Index is a simple tool used to classify lakes based on the chlorophyll concentrations collected during the peak algal growth period (usually late summer and early fall). Lakes with low concentrations of chlorophyll are biologically unproductive or *oligotrophic* ($TSI_{chl} < 30$); lakes that have high chlorophyll concentrations are biologically productive or *eutrophic* ($TSI_{chl} > 50$); lakes that fall between these classifications are moderately productive or *mesotrophic* ($TSI_{chl} 40-50$) or *oligomesotrophic* ($TSI_{chl} 30-40$). Carlson's Index is calculated as: $TSI_{chl} = 9.81(\ln Chl, \mu g/L) + 30.6$. Nearly all of the TSI values for Kwann and Thunderbird Lakes fell within the eutrophic range. The median TSI values were nearly identical for both lakes (Kwann median = 61.3; Thunderbird median = 61.8).

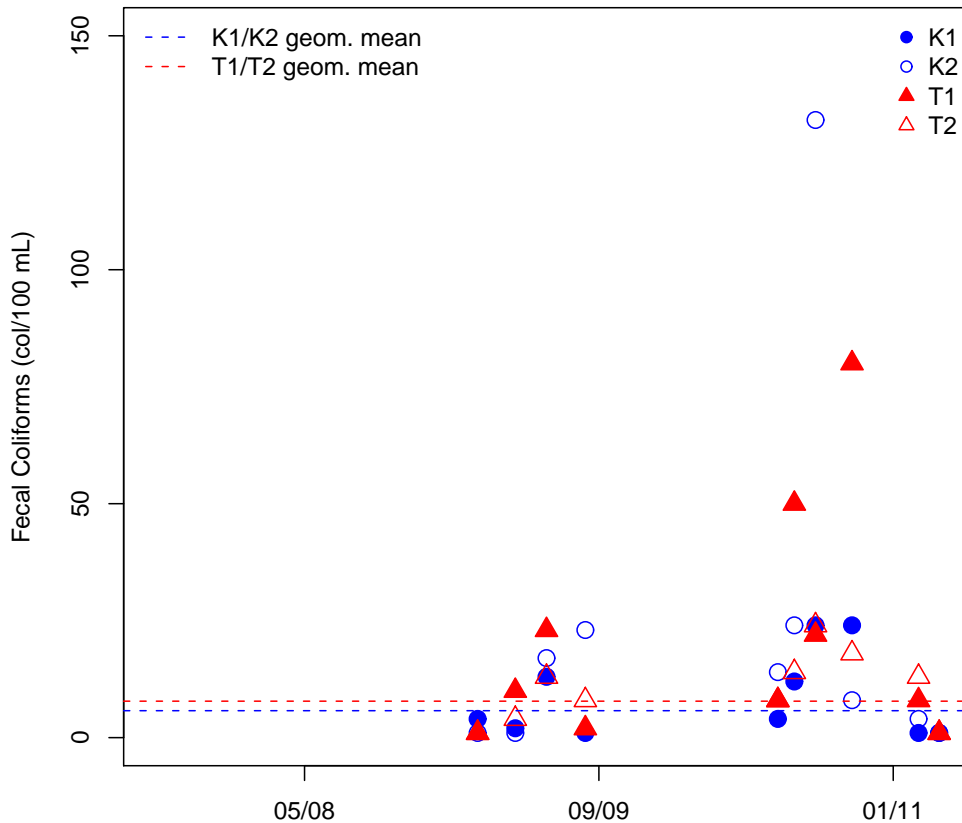


Figure 16: Fecal coliform counts were measured using surface water samples collected at 0.3 m. Fecal coliform bacteria are normally present in the intestinal tract of warm-blooded animals, and their presence in surface water is considered to be an indication that the water may be contaminated by fecal material from wildlife, domestic animals, or human sewage. Most of the coliform counts were low (≤ 50 cfu/100 mL), and the geometric means* for both lakes were below 10 cfu/100 mL (Kwann geometric mean = 5.8 cfu/100 mL; Thunderbird geometric mean = 7.8 cfu/100 mL). It is important to note, however, that the samples were collected mid-basin, not in swimming areas.

*The geometric mean is the average of the \log_{10} coliform values.

4 Comparison to Surface Water Quality Standards

The Washington State Department of Ecology has developed surface water quality criteria to ensure that a waterbody meets specific “designated use” standards.² In most cases, these standards are not directly applicable to the Kwann and Thunderbird Lakes, but the criteria are useful for determining whether there are water quality problems that might affect aquatic life or recreational use of the lakes. Table 2 lists the current surface water quality criteria compared to water quality in Kwann and Thunderbird Lakes.

	WAC-173-201A	K1	K2	T1	T2
Temperature (C) [†] (June - Sept maximum)	<16°C,	24.3 (n=22)	25.0 (n=23)	24.6 (n=22)	23.5 (n=21)
Dissolved oxygen (mg/L) [†] (1-day minimum)	>9.5 mg/L	4.9 (n=53)	5.1 (n=53)	3.8 (n=50)	5.3 (n=51)
pH [†] (range)	6.5–8.5	8.1–9.1 (n=16)	8.1–8.9 (n=16)	7.8–9.0 (n=16)	7.8–9.1 (n=16)
Fecal coliforms (cfu/100 mL) [‡] (geometric mean)	<50 cfu/100 mL	4.4 (n=10)	7.5 (n=10)	8.7 (n=10)	6.9 (n=10)
Fecal coliforms (%) [‡] (percent >100 cfu/100 mL)	<10%	0% (n=10)	10% (n=10)	0% (n=10)	0% (n=10)
Total phosphorus (μg-P/L) [§] (June - Sept mean)	>20 μg-P/L	139 (n=7)	116 (n=7)	131 (n=7)	138 (n=7)

[†] Based on summer salmonid habitat requirements

[‡] Based on extraordinary primary contact recreation (swimming)

[§] Based on level that may initiate a lake study

Table 2: Comparison of water quality in Kwann and Thunderbird Lakes to WAC-173-201A-200 criteria.

²WAC-173-201A-200, Table 200 (1)(c), <http://www.ecy.wa.gov/programs/wq/swqs/criteria.html>, downloaded June 29, 2011.

The results from Kwann and Thunderbird Lakes indicate that the lake temperatures are probably too high, the dissolved oxygen levels too low, and the pH levels too high to sustain a healthy salmonid population, even if the salmonids are not reared in the lake. The data are from the mid-basin portions of the lake, so it is possible that there are some regions in the lakes that fit more closely to the habitat needs for salmonids, but this assessment was beyond the scope of our study.

Most of the fecal coliform counts were low enough to meet the basic criteria for recreational contact (e.g., swimming and boating). But, as stated earlier, we collected mid-basin samples and sampled only 3–4 times each year. If the lakes are used for swimming, we recommend following the WAC–173–201A sampling guidelines, which include averaging the counts by season, collecting at least five samples per season, and sampling from the swimming beaches.

The total phosphorus concentrations in both lakes is above the “action level” described in WAC–173–201A. This action level is used by the state to identify lakes that may be impacted by high phosphorus levels and should be considered for a more extensive water quality assessment. The phosphorus action level does not indicate a specific human health threat or threat to aquatic life, but it does identify lakes that are likely to have high chlorophyll concentrations and algal blooms.

A Water Quality Data