11-8-2011

Lake Samish Water Monitoring Project 2011b Final Report

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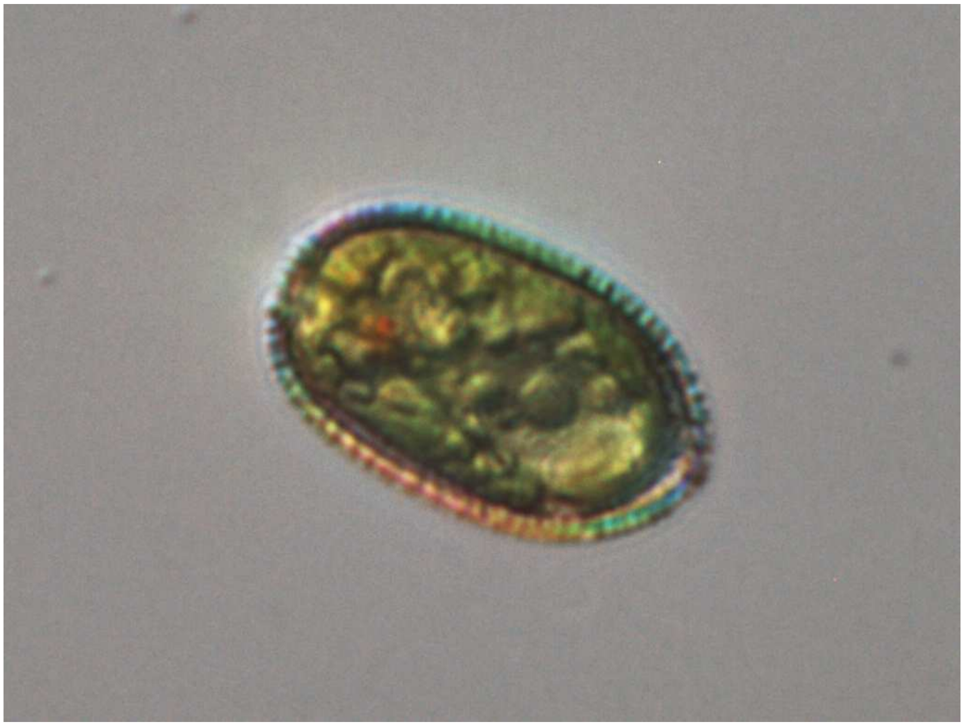

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November 8, 2011

Funding for this project was provided by the Samish Water District. We thank IWS staff Michael Hilles and Marilyn Desmul; students Clay Bailes, Jeff Edwards, Rachael Gravon, Kara Hitchko, Kris Kannarr, Andrew Majeske, Jessie Rosanbalm, Jordan Sly, Maggie Taylor, Dan Whealdon-Haught; Huxley College GIS Specialist Stefan Freelan; and volunteers Mark Herrenkohl, Gordon Nolan, John Ploeger, and Kathy Ploeger for their assistance.

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Background Information

Lake Samish is a valuable aquatic resource, providing public access for boating, fishing, swimming, picnicking, and other water and lakeshore activities. Residents around the lake enjoy outstanding views of both the lake and its surrounding watershed, and the lake serves as a water supply for many of the lakeshore residents. Lake Samish is located in the Washington State Department of Ecology's Water Resource Inventory Area #3 (WRIA 3), and discharges into Friday Creek, a salmon spawning tributary of the Samish River.

Lake Samish experiences periodic algal blooms, including blooms of potentially toxic cyanobacteria. The major goal of the monitoring project was to collect data that would help identify the causes of the blooms, and possibly provide insight into how to protect the lake from water quality degradation.

The Lake Samish monitoring project was initiated in June 2005 to collect water quality data from the lake and from major tributaries in the watershed. This report describes data collected in 2011. Additional information is available in previous summary reports (Matthews, et al., 2006; Matthews and Vandersypen, 2007; 2008; 2010; 2011).

Although the primary goal for this project was to collect baseline water quality data, a second goal was to begin looking as options for protecting water quality in the lake. A full assessment of lake management options is beyond the scope of this project, but several important observations can be made concerning the direction of future lake management efforts.

Lake Samish features that affect management choices: First, is it important to recognize the features of Lake Samish that will affect management options and factor heavily into the success of any lake management effort. Lake Samish is predominantly a shallow, mesotrophic lake. With the exception of the west arm, which is unusual in itself, the lake favors the growth of aquatic plants, whether they are algae, cyanobacteria, or shoreline vegetation. The mean depth in the east arm is only 9.4 m (Bortleson, et al., 1976), and all of the east arm sites have had high chlorophyll concentrations at some point during the monitoring project. While the lake is shallow enough to support algal growth throughout the water column, it is deep enough to stratify in both arms. Because of it's mesotrophic state, the hypolimnion in both arms becomes anoxic, releasing phosphorus. The water column in the west arm may not mix thoroughly during winter (Figure 3, page 10), which can result in extended periods of anoxia in the hypolimnion that persist past winter and into the next period of stratification. This has the potential to release of large amounts of phosphorus into the lake from the sediments (Figure 7, page 14). The release of phosphorus from sediments due to low oxygen concentrations in the hypolimnion is called *internal phosphorus loading*, and is one of the items that must be considered in the future management of Lake Samish.

A second important feature that affects lake management is land use in the Lake Samish watershed. The tributary data (Matthews and Vandersypen, 2011a) shows that there is *external phosphorus loading* from the watershed. The lakeshore is developed, mostly with single-family homes, and the upper watershed is largely devoted to forestry and timber harvesting. A major interstate highway, with heavy truck and vehicle traffic, passes along the eastern side of the lake. Although these land use activities are not necessarily incompatible with recreational use of the lake, they are not particularly desirable in a lake that provides drinking water for lakeshore residents.

Recommendations for maintaining Lake Samish water quality: Our recommendations for Lake Samish focus on controlling external phosphorus loading, minimizing internal phosphorus loading, and educating watershed residents about drinking water issues and lake stewardship. These recommendations are not intended to serve as a substitute for developing a comprehensive lake management plan.

This list of recommendations was presented in an earlier Lake Samish annual report by Matthews and Vandersypen (2008); the original text has been updated to provide continuity.

- Develop an environmental education program to help residents of the Lake Samish watershed understand the water quality issues in the lake, and what can be done at the individual level. While it may be difficult to measure the direct success of public education programs in terms of water quality improvement, an educated public is more likely to understand and support watershed and lake management actions.

- Develop strategies for controlling external phosphorus loading. Phosphorus is very difficult to remove after it get into streams or lakes, so where possible, source control remains the best approach. This means either reducing the amount of phosphorus that enters surface runoff (e.g., using phosphorus-free fertilizers) or decreasing the amount of surface runoff that enters the lake (e.g., adding retention/detention basins that facilitate infiltration into the groundwater). Because of the scale of this task, the Samish Water District should work with an experienced storm water consultant to develop a comprehensive storm water management plan for the watershed.

  Lake Samish is already mesotrophic, and in some cases eutrophic, so reducing external phosphorus loading from the watershed will probably not eliminate cyanobacteria blooms. If external loading is reduced, however, the lake should stabilize around its current levels of productivity, and possibly even show some improvement over a long period of time.

- Optionally, after external phosphorus loading has been addressed, develop strategies for reducing internal phosphorus loading. There are many lake management techniques that, given sufficient funding for installation *and maintenance*, can be used to reduce internal loading. The addition of chemicals such as alum will bind with phosphorus, often resulting in years of reduced algal densities. The effect is temporary, and reapplication of the chemical is required on a periodic basis. Hypolimnetic aerators are available that can maintain sufficient oxygen in the hypolimnion to prevent internal phosphorus loading. Aerators are also available that circulate the entire water column, but in most stratified lakes, this is not a desirable approach, and may even increase algal growth. All of these techniques require a significant initial investment, long-term funding for maintenance, and are unlikely to be effective if external loading is not controlled.

- Consider developing a public drinking water supply and distribution system. The algal densities in the lake were very high and probably contribute to the formation of harmful disinfection by-products, particularly in systems that disinfect the water by chlorination. Although the coliform levels were low in the lake, the results may not reflect conditions at private drinking water intakes. Finally, the lake is subject to potentially hazardous cyanobacteria blooms and exposed to potentially hazardous chemicals from boating activities and the nearby highway. These represent an ongoing risk to individuals drawing domestic drinking water from the lake.

The Washington State Department of Ecology maintains a web page at http://www.ecy.wa.gov/programs/wq/plants/algae/monitoring that includes information about freshwater algae in lakes and how to recognize and report potentially harmful algal blooms.

- Conduct an evaluation of on-site sewage disposal in the upper watershed, and its potential influence on water quality in Lake Samish. This evaluation should be included in the assessment of external phosphorus loading into the lake. On-site sewage disposal may be a minor factor in phosphorus loading into the lake because the Lake Samish shoreline is served by a public sewer line, so only portions of the upper watershed are likely to have on-site sewage disposal.

- Although monitoring priority pollutants is beyond the scope of this project, The west arm of Lake Samish was placed on Washington State's 2004 and 2008 Water Quality Assessment 303(d) list due to the high levels of PCBs in sports fish collected from the lake. The levels of PCBs were high enough to generate a "Category 5" listing, which results in placement on the 303(d) list. The lake was also listed at Category 2 ("waters of concern") based on mercury levels in fish, but this level does not result in a 303d listing.

  High levels of mercury and PCBs have been found in fish tissue from many other lakes in Washington, and throughout North America, so the presence of these pollutants in Lake Samish reflects widespread contamination of freshwater lakes rather than a unique local source. Nevertheless, due to the popularity of sports fishing in Lake Samish, we recommend additional monitoring of priority pollutants in water, sediments, and fish tissue in Lake Samish.

Methods

Water samples were collected at representative sites in Lake Samish (Figure 1, page 8) and analyzed following the protocols in Table 1 (page 27). The original scope of work specified monthly sampling at four lake sites (Sites A–D) from June 2005 through July 2006. The contract was amended to include quarterly sampling from June 2007 through October 2010 and twice annual sampling in 2011. This effort has supplemented by IWS, at no additional cost, to provide additional sampling at two lake sites (Sites A and B) when resources were available. Water samples were also collected from Barnes Creek, Finney Creek, Friday Creek (outlet), and two unnamed tributaries[1] approximately twice each year through 2010 (Tables 2–4, pages 28–30).

Lake sampling methods: Temperature and dissolved oxygen field measurements were collected at 1 meter depth intervals from the surface to the bottom at each site using a Hydrolab or YSI field meter. From March 2006 through March 2011, conductivity and pH profiles were collected at 1 meter depth intervals using the Hydrolab field meter. The Hydrolab field meter was retired from service in the spring of 2011, so the August 2011 pH and conductivity data were collected from water samples analyzed in the laboratory. Secchi depth was measured at each site by lowering a black and white disk into the water and recording the depth at which it was no longer visible from the lake surface. The field measurement protocols are summarized in Table 1 (page 27).

Surface and bottom water samples were collected at each lake site and transported to the laboratory to measure pH, conductivity, phosphorus (total phosphorus and soluble orthophosphate), nitrogen (total nitrogen, nitrate/nitrite[2], ammonium), turbidity, and alkalinity following the protocols listed in Table 1. Separate surface and bottom water samples were collected to measure fecal coliform counts; the coliform samples were delivered on ice to the Samish Water District or to a certified laboratory contracted by the District.

From June 2005 through May 2007, chlorophyll fluorescence was measured in the field (*in vivo*) at 1 meter depth intervals from the surface to the bottom us-

[1] The unnamed tributaries are listed as Mia Creek and Mud Creek in the results and discussion.

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

ing a field fluorometer. Water samples were collected from approximately 10-20% of the depths where fluorescence was measured, and the water samples were used to measure chlorophyll biomass (Table 1). A linear regression between the paired *in vivo* fluorescence and chlorophyll biomass data was used to estimate chlorophyll biomass at all depths along the fluorescence profiles.[3] Due to equipment failure, the field fluorometer was not used after May 2007. Beginning in June 2007, chlorophyll biomass was measured using water samples collected at approximately 5 meter depth intervals. For more information about *in vivo* fluorometric chlorophyll measurements, refer to the previous Lake Samish annual reports (Matthews, et al., 2006; Matthews and Vandersypen, 2007; 2008; 2010; 2011).

Creek sampling methods: *No additional creek samples were collected in 2011. The following methods were used for sampling from 2005–2010.*

Temperature and dissolved oxygen were measured using a field meter. Water samples were collected at each stream site and transported to the laboratory to measure pH, conductivity, phosphorus (total phosphorus and soluble orthophosphate), nitrogen (total nitrogen, nitrate/nitrite, ammonium), turbidity, and alkalinity. Separate water samples were collected to measure fecal coliform counts; the coliform samples were delivered on ice to the Samish Water District or to a certified commercial laboratory contracted by the District. All water samples collected in the field were stored on ice and in the dark until they reached the laboratory, and were analyzed as described in Table 1.

[3]Chlorophyll biomass is more commonly used to describe lake trophic status than fluorescence, but fluorescence is easier to measure in the field.

1 Annotated Figures and Tables

The Lake Samish monitoring project started in June 2005 and has resulted in the accumulation of more than six years of lake and creek data. The lake data are summarized in a series of annotated figures (Figures 1–15, pages 8–22) designed to show seasonal and annual patterns in the lake. Each figure includes a descriptive caption that provides background information as well as a brief interpretation of the Lake Samish results. The creek data are summarized in earlier reports (Matthews, et al., 2006; Matthews and Vandersypen, 2007; 2008, 2009; 2011).

The field Hydrolab profiles and chlorophyll depth profiles for 2011 are plotted in Appendices A–B, beginning on page 32. Raw data reports are included in Appendix C of the printed report; online reports do not contain the raw data, but electronic data files are available from the Institute for Watershed Studies.

As discussed in the methods section, some lake sites were sampled more frequently than others. Sites A and B, in particular, have been sampled more frequently to provide additional water quality data from the deepest sites in the lake's east and west arms. As a result, the plots on the following pages have fewer sample points for Sites C and D than for Sites A and B.

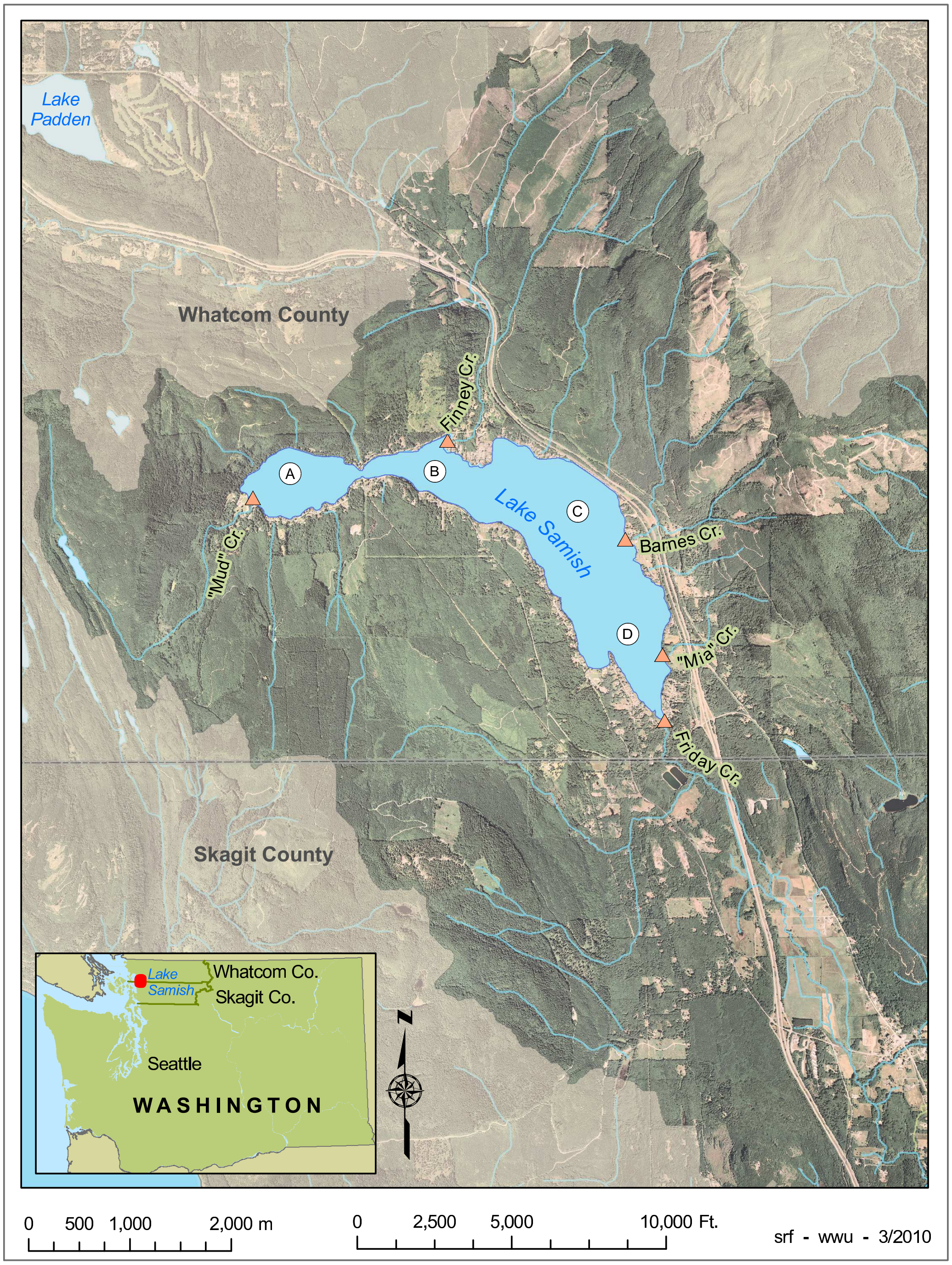


Figure 1: Lake Samish tributary and lake sampling sites, 2005–2011 (map provided by S. Freelan, Institute for Spatial Information and Analysis, Huxley College of the Environment, Western Washington University).

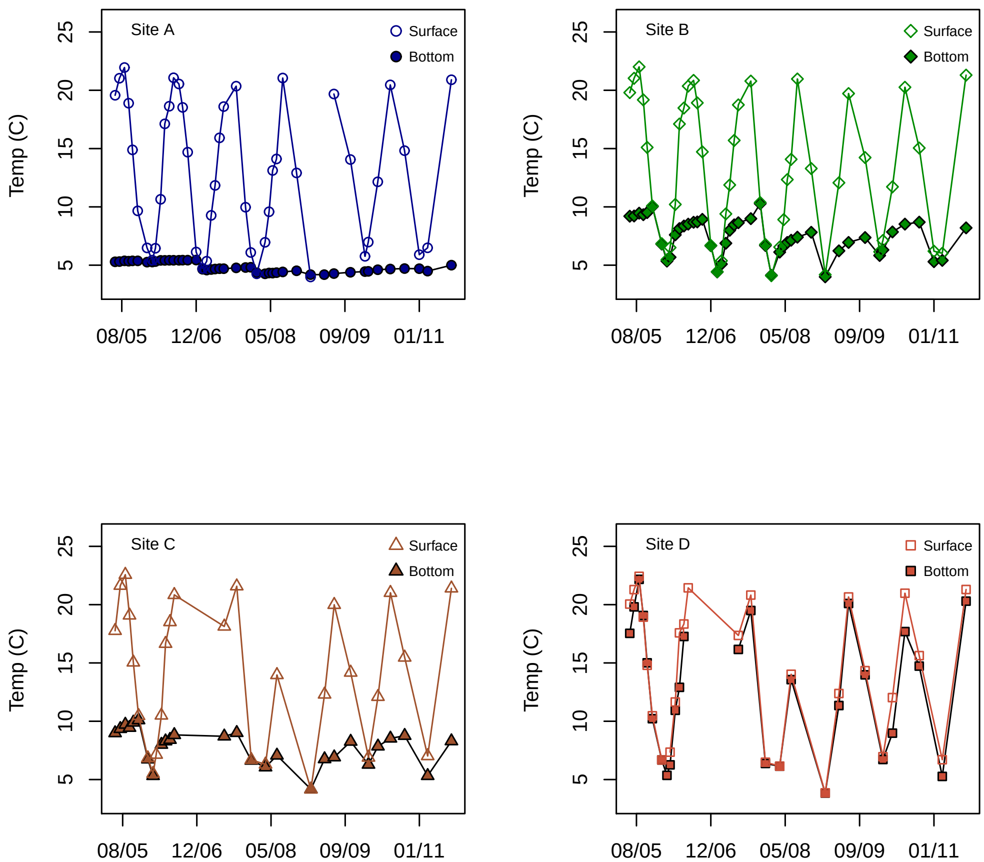


Figure 2: Surface and bottom water temperatures, June 2005 through August 2011. Temperature profiles show that much of the lake is stratified from spring through early fall (see Appendix A). Only Site D, which is very shallow, remains thermally unstratified throughout the year. During stratification the warmer upper portion of the water column (*epilimnion*) does not mix with the colder water near the bottom (*hypolimnion*). In the fall, after the surface water cools, the water column will start to mix again (*destratify*), and will continue to mix throughout the winter and early spring unless there is ice cover.

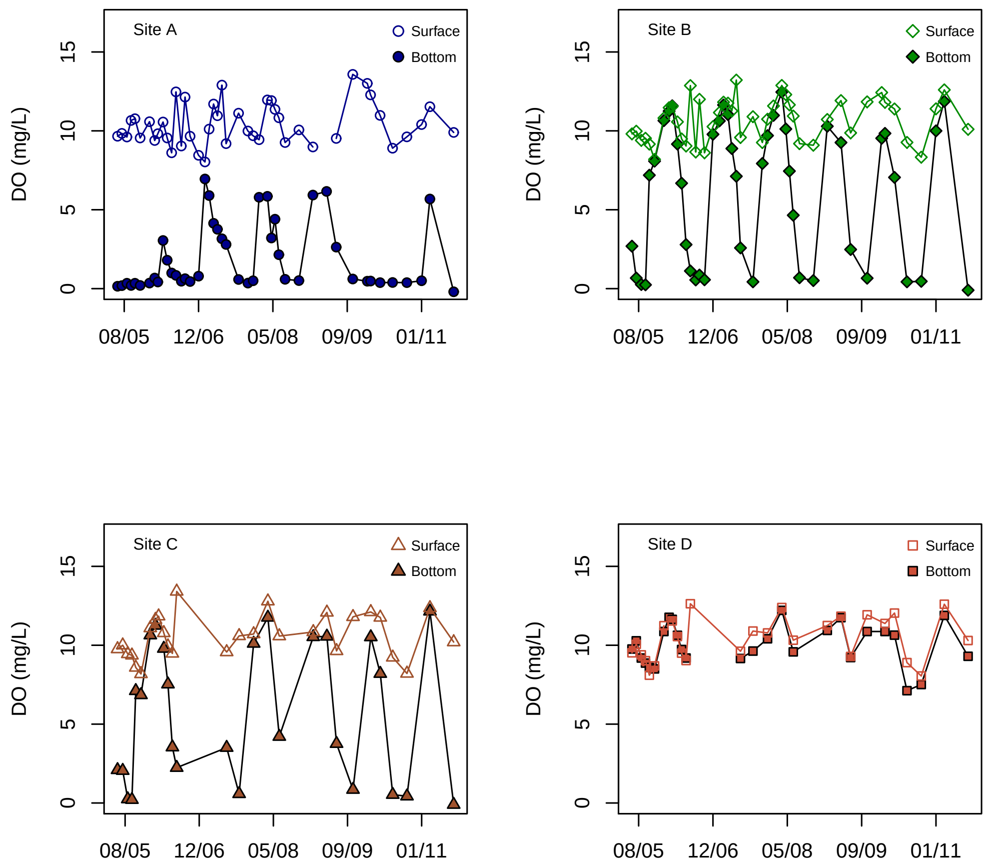


Figure 3: Dissolved oxygen concentrations, June 2005 through August 2011. The primary source of dissolved oxygen is the atmosphere. Algal photosynthesis is a source of oxygen during the day, but algae consume oxygen at night for respiration, so the net oxygen gain is minimal. All of the stratified sites in Lake Samish experience oxygen depletion in the hypolimnion, which is usually caused by bacteria decomposing organic matter (e.g., dead algae, leaf fragments, and other organic debris). When the lake destratifies, oxygen mixes throughout the water column, so the winter oxygen concentrations are similar for the surface and bottom samples at Sites B–D. Site A exhibits intermittent meromixis (Matthews and Vandersypen, 2008), where the water column does not always mix completely during the winter.

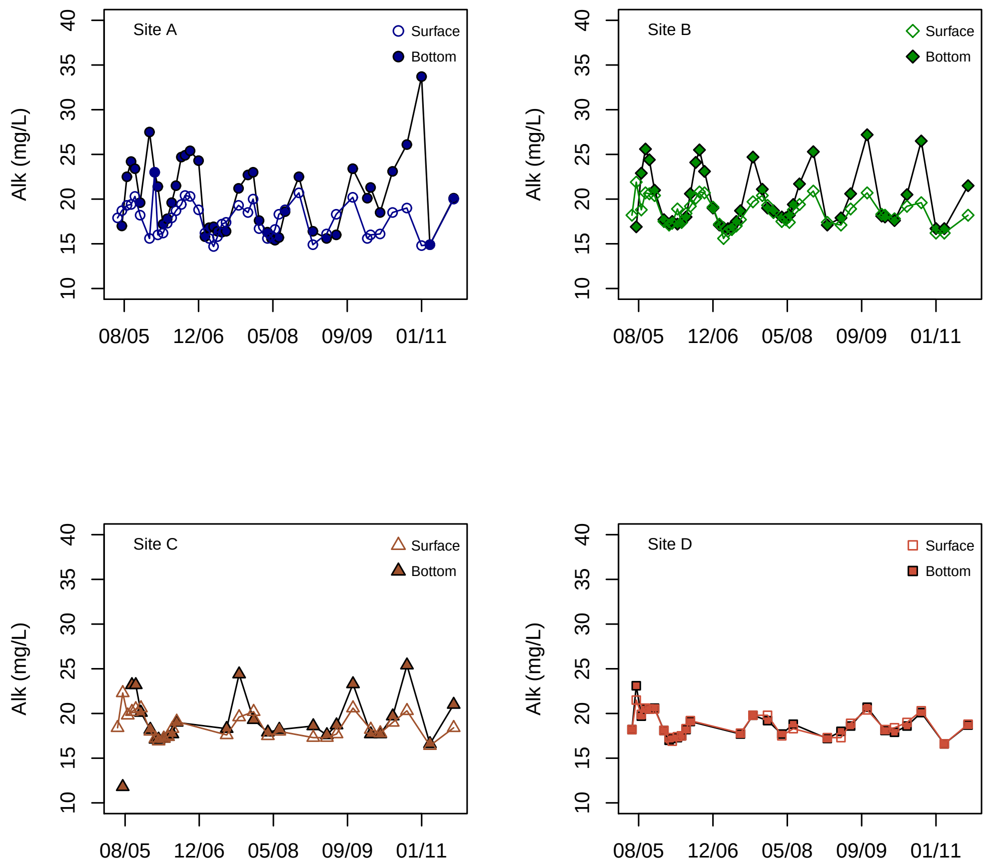


Figure 4: Alkalinity concentrations, June 2005 through August 2011. Alkalinity, pH, and specific conductance (conductivity) are related in surface waters. Alkalinity measures the *buffering capacity* or how resistant water is to pH changes. The alkalinity levels in Lake Samish are low, indicating that the water is poorly buffered against pH changes. This is typical for lakes in our region. The alkalinity levels fluctuate seasonally, especially in surface samples. During photosynthesis, algae remove dissolved CO_2 from the water, which can temporarily raise pH and lower alkalinity.

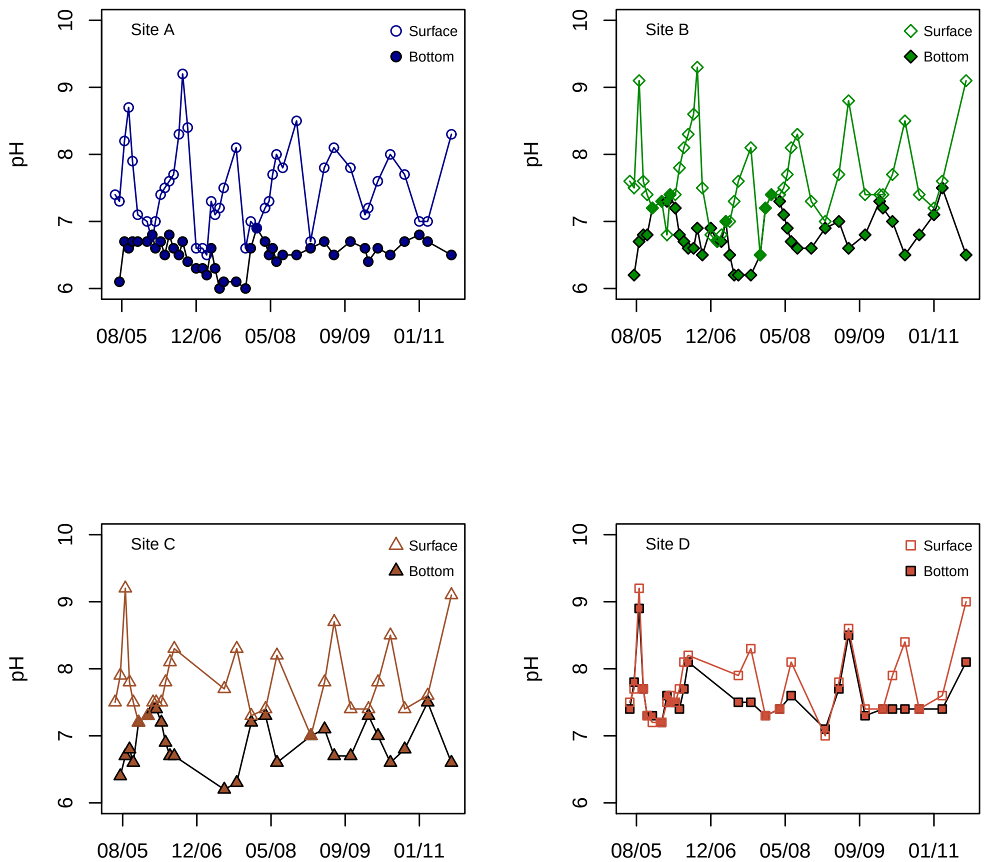


Figure 5: Surface and bottom pH concentrations (laboratory analysis), June 2005 through August 2011. Alkalinity, pH, and specific conductance (conductivity) are related in surface waters. The pH in water is determined by the concentration of H^+ ions. During photosynthesis, algae remove dissolved CO_2 from the water, which can temporarily raise pH by reducing the concentration of dissolved carbonic acid, which is formed when CO_2 reacts with water: $H_20 + CO_2 \leftrightarrow H_2CO_3$ (carbonic acid). This relationship is illustrated very clearly in the summer surface samples at Sites A and B.

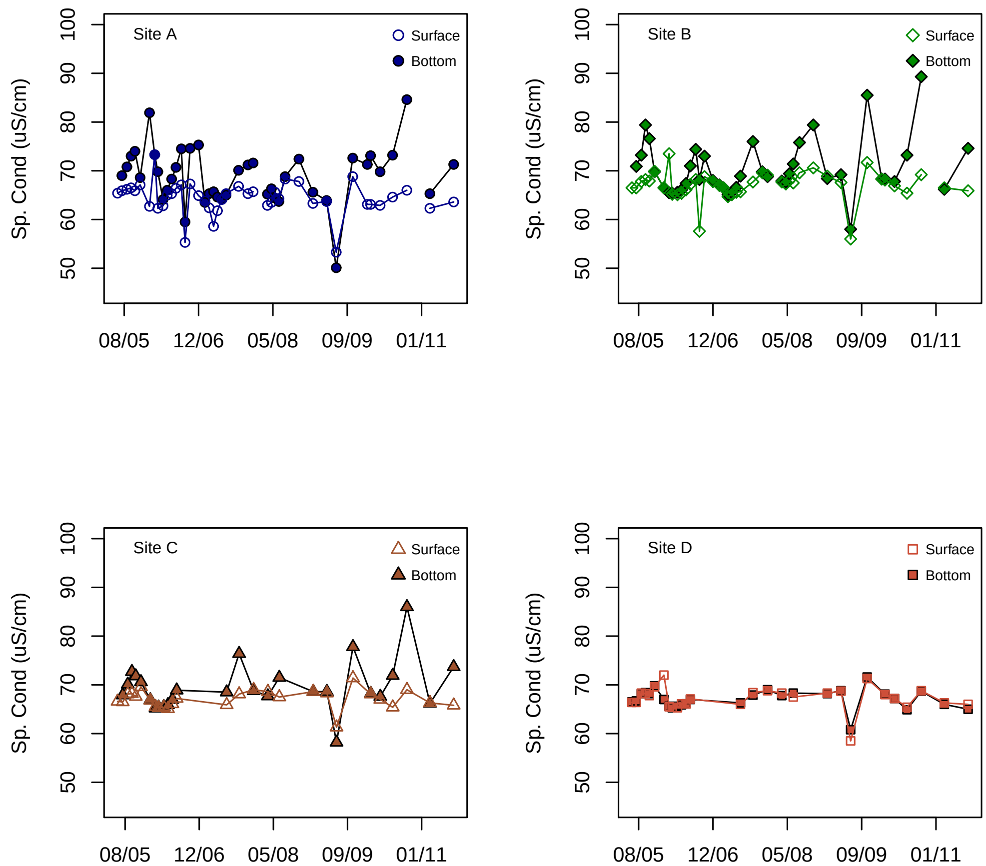


Figure 6: Conductivity concentrations (laboratory analysis), June 2005 through August 2011. Alkalinity, pH, and specific conductance (conductivity) are related in surface waters. Conductivity is determined by the types and amount of dissolved ions in the water. The soil type and land use in the watershed influence the amount of dissolved ions entering the lake from runoff and groundwater. Biological activity and chemical interactions determine whether dissolved ions remain in the water column. In Lake Samish, the conductivity levels are fairly low, which is typical for low-alkalinity lakes. The conductivity levels are slightly elevated near the bottom of the lake at Sites A and B, which is typical for stratified lakes with low oxygen concentrations near the sediments.

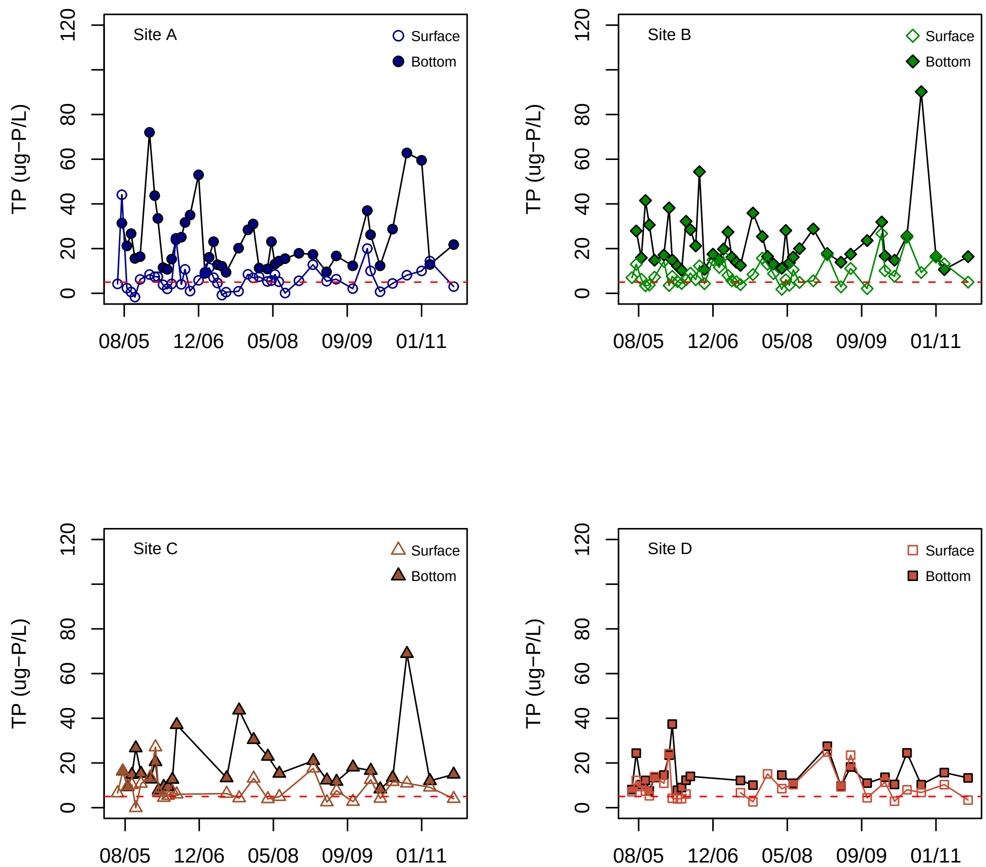


Figure 7: Total phosphorus concentrations, June 2005 through August 2011 (horizontal red line = detection limit of 5 μg-P/L). Total phosphorus includes organic phosphorus (phosphorus associated with algae and other biota) and dissolved phosphorus (primarily soluble orthophosphate). Phosphorus is an important nutrient for algae and is usually the nutrient that limits the amount of algae in a lake. Phosphorus is released from anaerobic sediments, so the bottom samples at Sites A and B often contained high concentrations of total and soluble phosphorus (see Figure 8). Although median total phosphorus concentrations were fairly low at each site (10–15 μg-P/L), the bottom concentrations often exceeded 30 μg-P/L.

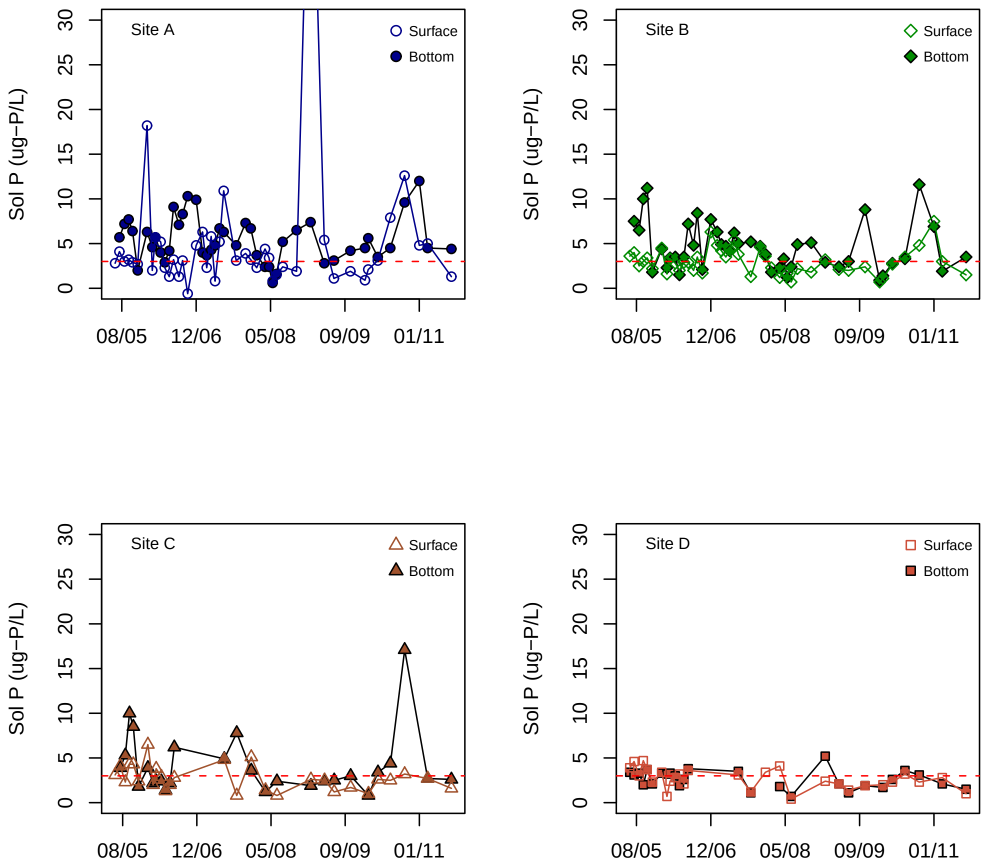


Figure 8: Soluble orthophosphate concentrations, June 2005 through August 2011 (horizontal red line = detection limit of 3 μg-P/L). Soluble orthophosphate is the soluble inorganic portion of total phosphorus. Soluble phosphate concentrations are often low in the water column, even when algal concentration are high, because this form of phosphorus is easily and rapidly taken up by algae and other microbiota. Soluble phosphate is released from anaerobic sediments, which accounts for the high concentrations occasionally measured in the bottom samples. The atypical surface sample outlier (59.7 μg-P/L at Site A on Jan 25, 2009) probably resulted from sample contamination because the total phosphorus concentrations in the sample was only 12.8 μg-P/L.

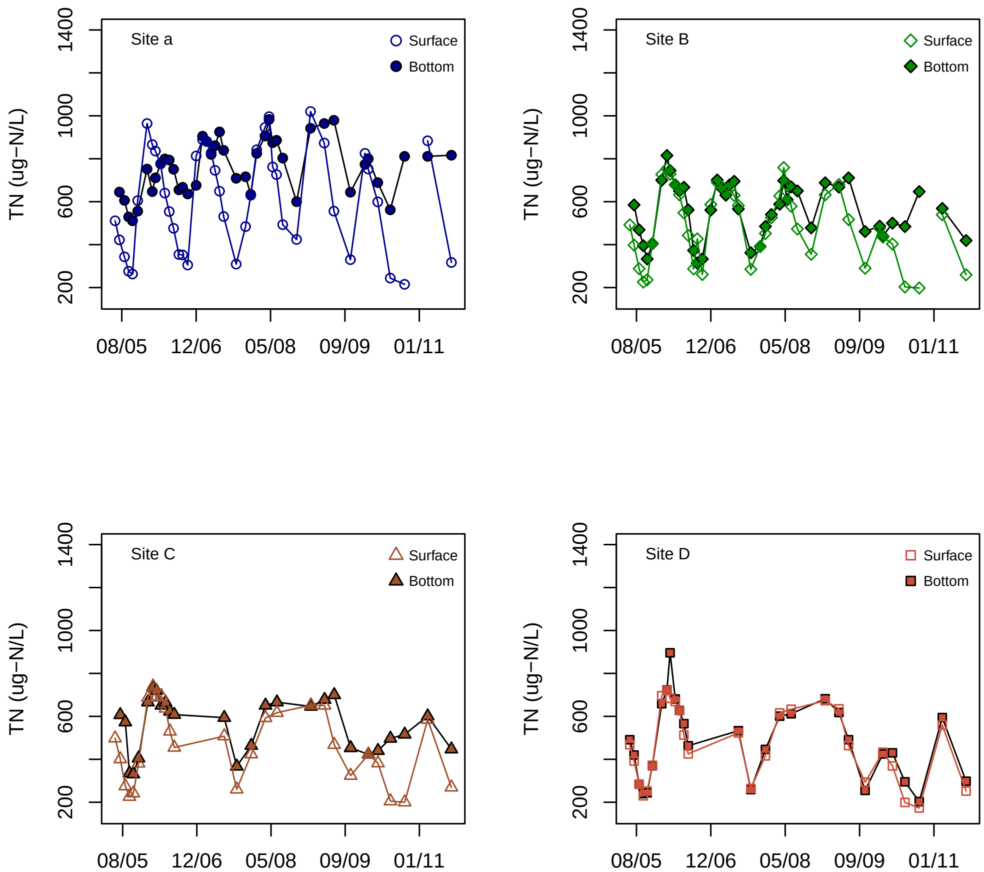


Figure 9: Total nitrogen concentrations, June 2005 through October 2010. Total nitrogen represents the combined concentrations of organic nitrogen (nitrogen associated with algae and other biota) and dissolved inorganic nitrogen (DIN = nitrate + nitrite + ammonium). In Lake Samish, about two thirds of the total nitrogen was inorganic ($\text{average } \frac{\text{DIN}}{\text{TN}} = 67\%$). Algae use inorganic nitrogen for growth, so it is common to see depletion of total nitrogen and DIN during the summer in samples collected at $\leq$10 meters. (Photosynthesis is usually limited by insufficient light in deeper samples.) Nitrogen rarely limits total algal growth because cyanobacteria can convert dissolved nitrogen gas (N_2) into inorganic nitrogen. Low concentrations of inorganic nitrogen, however, will limit the growth of certain types of algae and favor the growth of cyanobacteria.

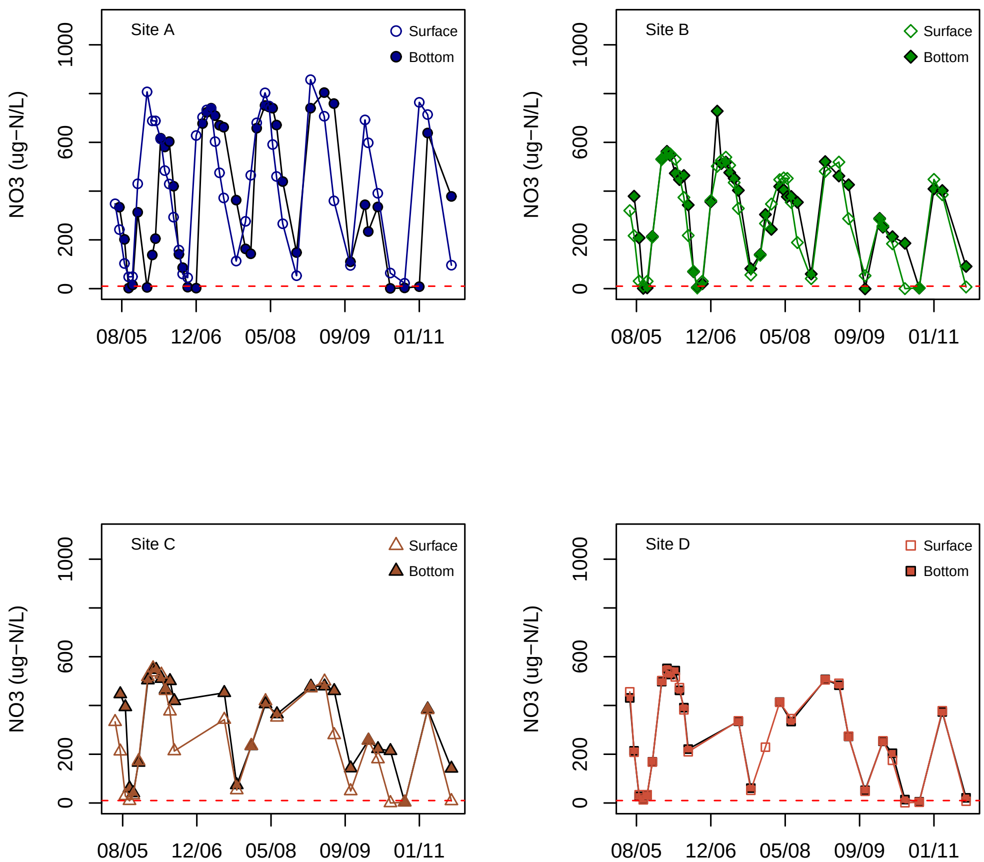


Figure 10: Nitrate/nitrite concentrations, June 2005 through August 2011 (horizontal red line = detection limit of 10 μg-P/L). Nitrate and nitrite are often measured simultaneously because nitrite concentrations are usually negligible and below analytical detection levels. Nitrate/nitrite is usually the major component of dissolved inorganic nitrogen (DIN), the primary nitrogen source for algal growth. In Lake Samish, most DIN was in the form of nitrate/nitrite (average $\frac{\mathrm{NO}_{2+3}}{\mathrm{DIN}} = 83\%$). The Lake Samish nitrate/nitrite concentrations were depleted in both the surface and bottom samples during the summer, but for different reasons. The depletion in samples $\leq$10 meters was due to algal uptake; the depletion in deeper samples (bottom samples at Sites A and B) was due to nitrate reduction by anaerobic bacteria that use nitrate (and nitrite) as an alternative to oxygen.

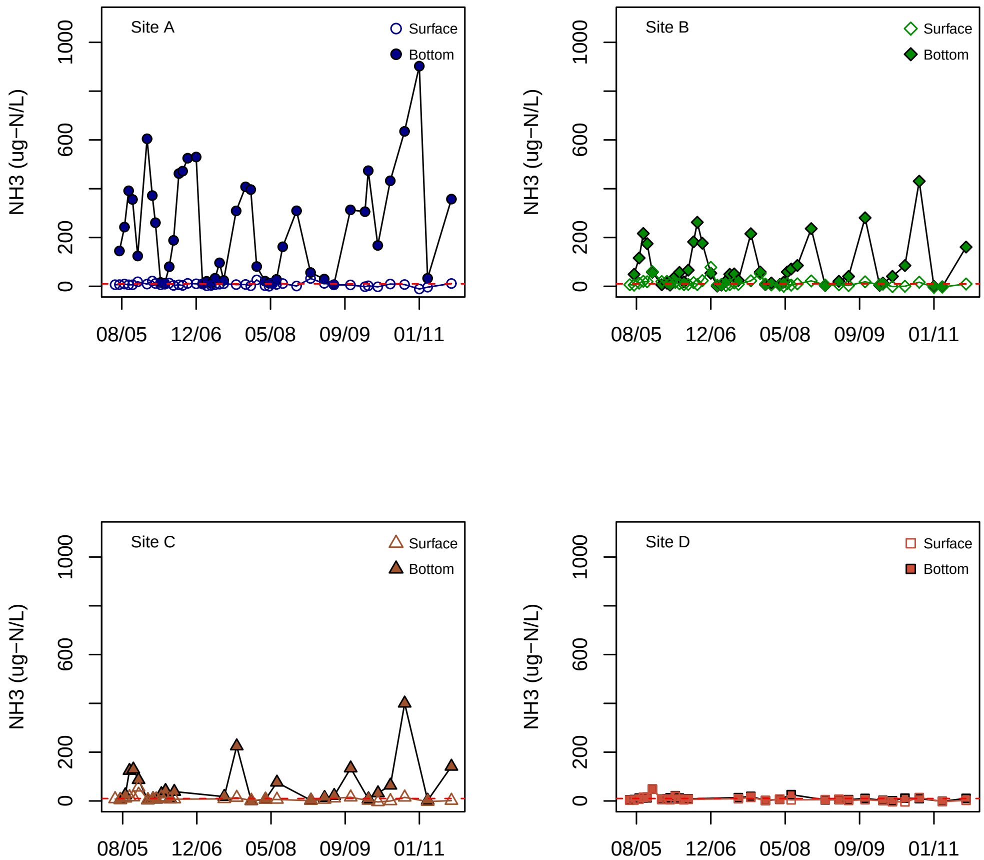


Figure 11: Lake Samish ammonium concentrations, June 2005 through August 2011 (horizontal red line = detection limit of 10 μg-P/L). Ammonium is easily taken up by algae as a nitrogen source. Most of the ammonium in surface waters comes from decomposition of organic matter or is excreted by animals. In aerobic water, ammonium is rapidly converted into nitrite and nitrate by bacteria or lost through volitization. When oxygen concentrations are low, however, these bacteria are inactive, so ammonium can build up, especially in the hypolimnion. In Lake Samish, ammonium concentrations were low except in bottom samples during periods of stratification at sites that developed anoxia in the hypolimnion. The highest ammonium concentrations were from bottom samples at Site A, which may be due to incomplete water column mixing at that site.

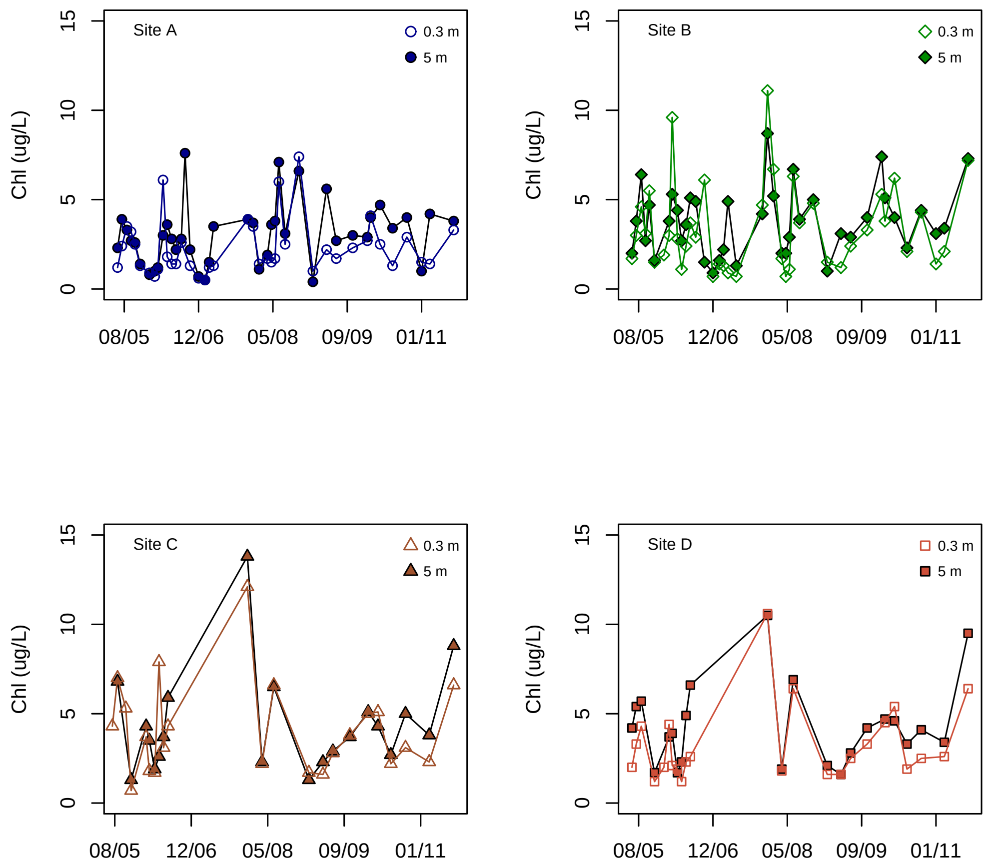


Figure 12: Lake Samish near-surface chlorophyll concentrations, June 2005 through August 2011. Chlorophyll is the primary photosynthetic pigment in algal cells and is generally the best indicator of the amount of algae present in lakes. In Lake Samish, as in most lakes, chlorophyll levels were usually low during the winter, with peaks in the spring and summer coinciding with spring/summer algal blooms. This figure shows chlorophyll biomass that was either measured in the laboratory (preferred method), or estimated from *in vivo* fluorescence measured in the field. For more information about these methods, see Matthews, et al. (2008).

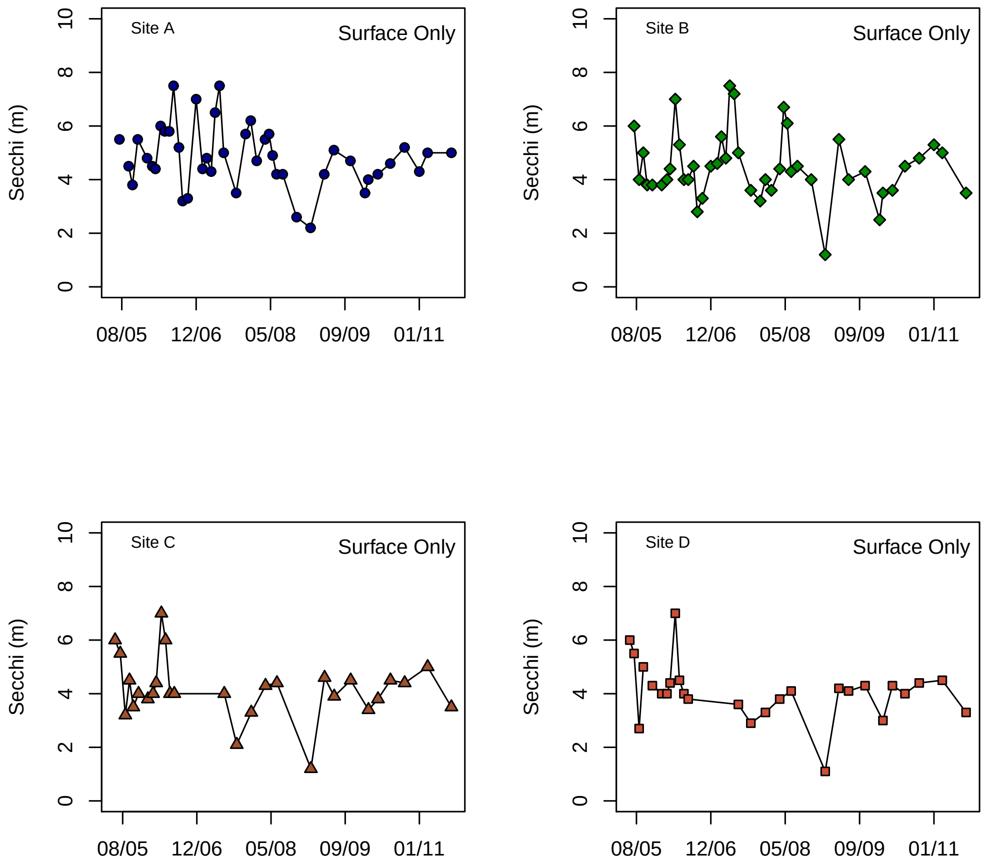


Figure 13: Secchi depths, June 2005 through August 2011. Secchi depth is an indicator of lake transparency and is defined as the depth at which a black and white disk is no longer visible from the lake surface. Secchi depth determines the approximate depth of the *photic* zone, where light conditions favor photosynthesis. Lake Samish Secchi depths were usually 4–6 meters (average = 4.5 m), consistent with peak chlorophyll concentrations, but for any particular sampling date, the relationship between Secchi depth and chlorophyll was weak. This indicates that inorganic and non-algal sediments contribute to the cloudiness of the water column.

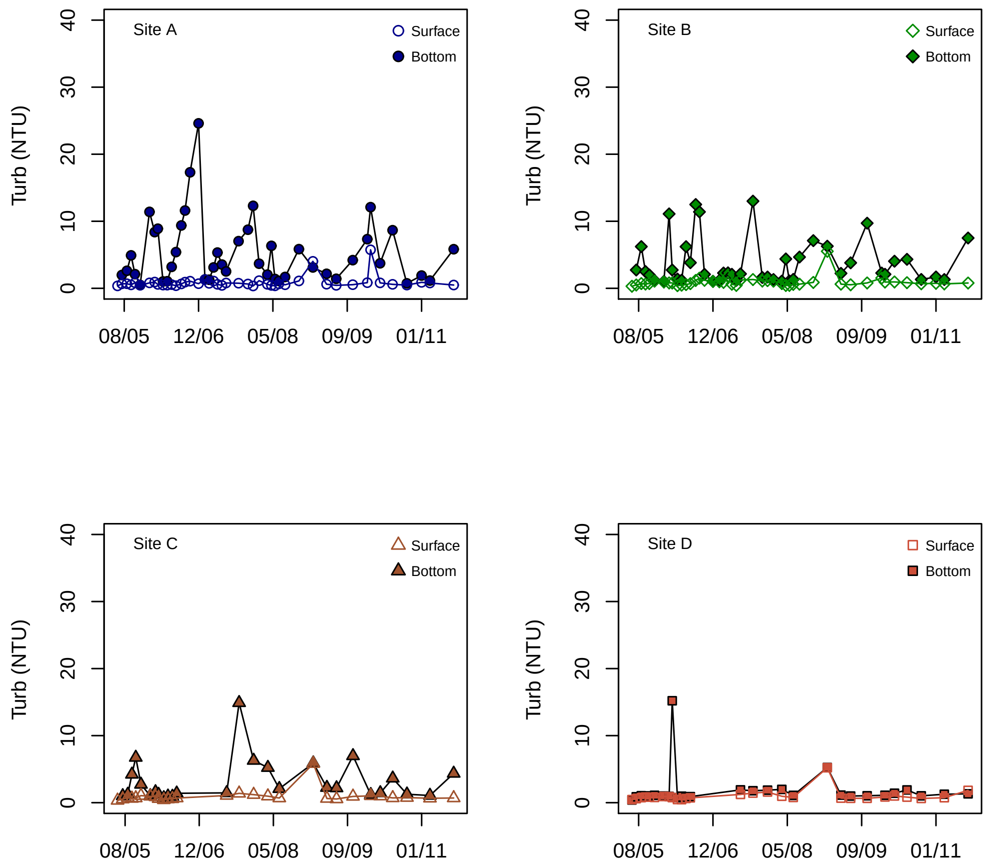


Figure 14: Turbidity concentrations, June 2005 through August 2011. Turbidity is a measure of the suspended particles in water, which include algae, inorganic particles, and non-living organic matter. When most of the suspended particles in the water column are algae, chlorophyll concentrations are closely related to Secchi depth and turbidity. If non-algal particles are abundant, the relationship between Secchi depth and turbidity is still good, but neither are closely related to chlorophyll. Turbidity levels in the lake did not show typical near-surface summer peaks. Instead, the turbidity peaks were related to suspended particles in the hypolimnion.

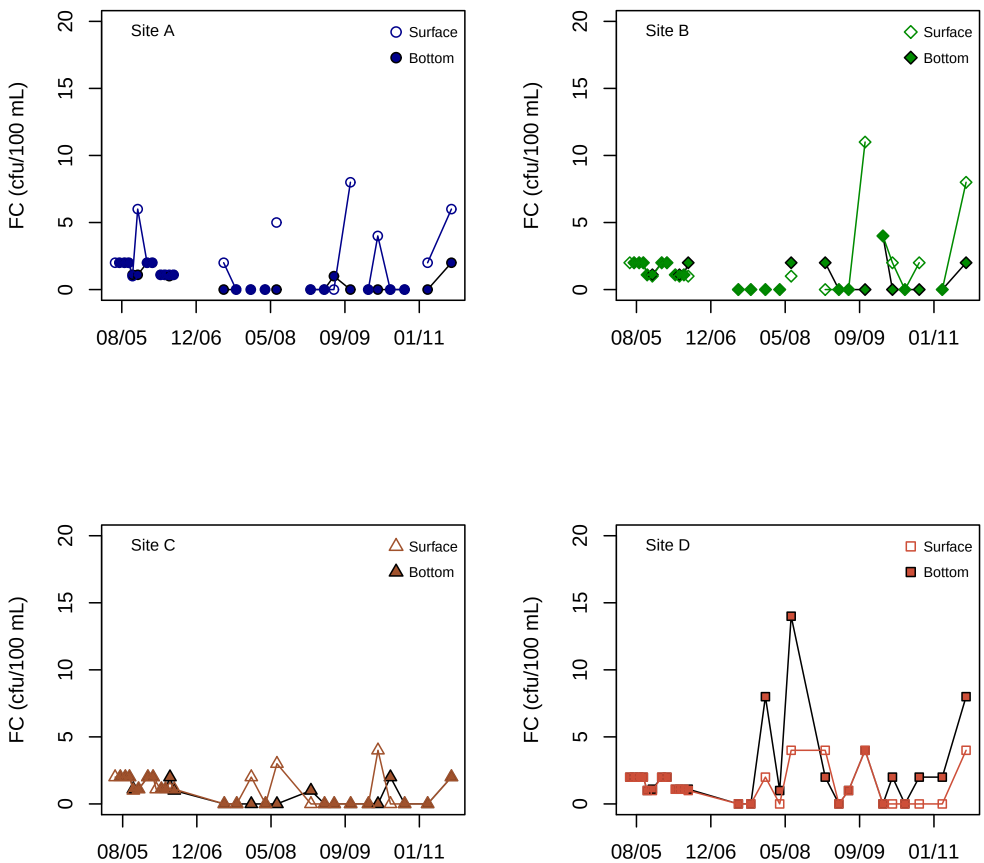
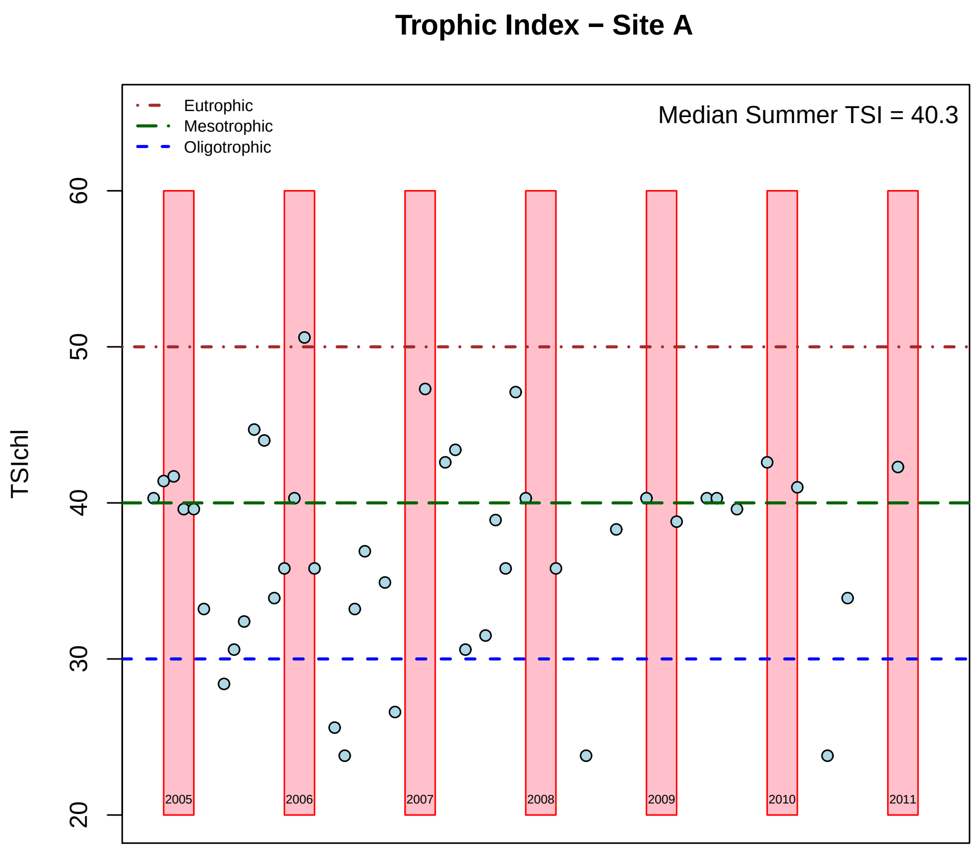
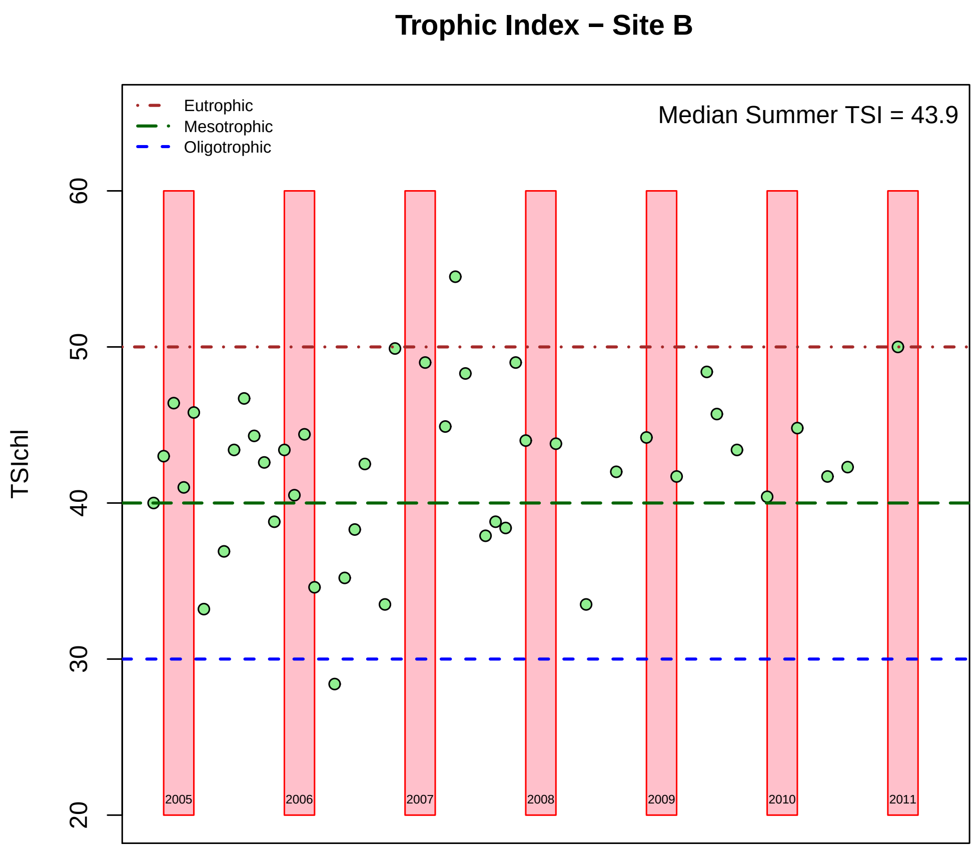


Figure 15: Fecal coliform counts, June 2005 through August 2011. Fecal coliforms are normally found in the intestinal tract and feces of warm blooded animals, so their presence in water samples can be used to detect sewage or fecal contamination. Most types of fecal coliforms are not pathogenic, but if fecal coliforms are present, other potentially harmful pathogens may also be present. The fecal coliform counts in Lake Samish were low, with only two samples exceeding 10 cfu/100 mL (cfu=colony-forming unit). If there are concerns about swimming beaches or drinking water safety, however, additional samples should be collected following the protocols described by the Washington Administrative Code Section 173-201A, which deals with coliform standards in recreational waters.



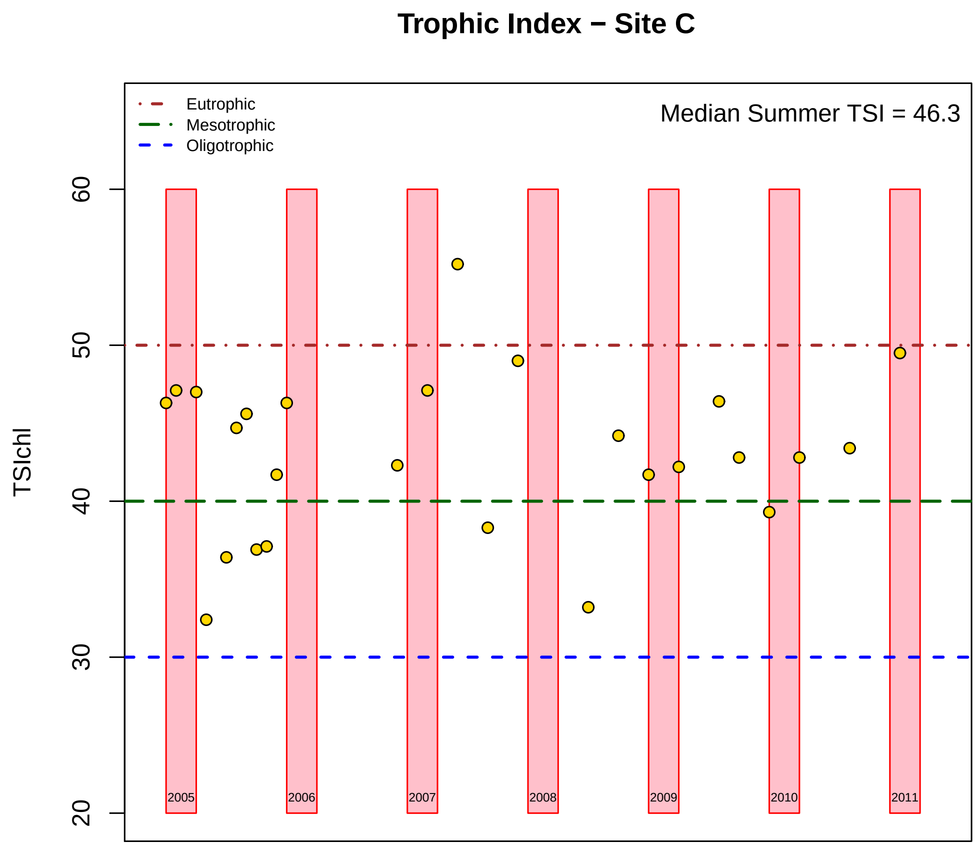
$$TSI_{chl} = 9.81\ (\ln \text{Chl}\ (\mu g/L) + 30.6)$$

Figure 16: Median TSI_{chl} values at Site A, June 2005 through August 2011. Carlson's Trophic State Index (TSI_{chl}; Carlson and Simpson, 1966) is a simple way to classify lakes based on biological productivity using chlorophyll measurements. The shaded rectangles show summer months (July-October), which are often described as having higher TSIs compared to the rest of the year. This is not always true for Lake Samish. Most of the Site A values fell between the oligotrophic and mesotrophic ranges, indicating that this site had lower algal concentrations and would be less likely to experience algal blooms than other portions of the lake.



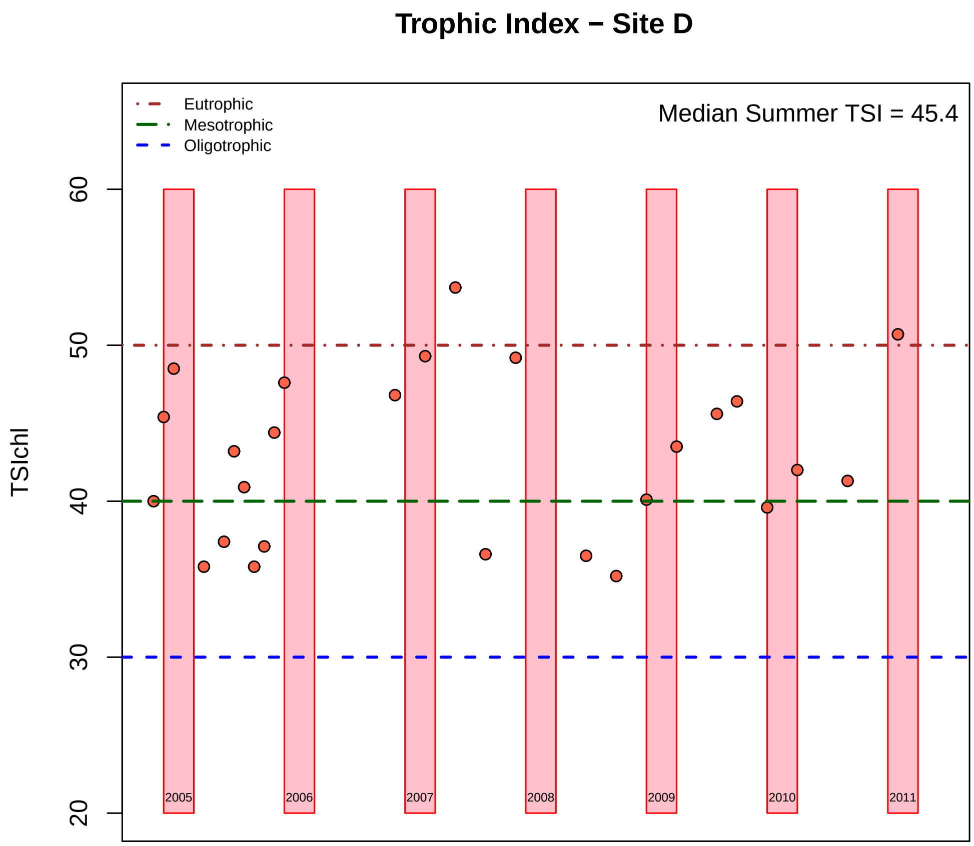
$$\text{TSI}_{chl} = 9.81\ (\ln \text{Chl}\ (\mu\text{g/L}) + 30.6)$$

Figure 17: Median Lake Samish TSI_{chl} values at Site B, June 2005 through August 2011; the shaded rectangles show summer months (July-October). The TSI values at Site B were higher than Site A, and most were near the level that indicates a mesotrophic or moderately productive lake. Sites B–D, located in the shallower arm of Lake Samish, are more likely to experience algal blooms than Site A.



$$TSI_{chl} = 9.81\ (\ln \text{Chl}\ (\mu\text{g/L}) + 30.6)$$

Figure 18: Median Lake Samish TSI_{chl} values at Site C, June 2005 through August 2011; the shaded rectangles show summer months (July-October). The TSI values at Site C were higher than Site A, and some of the values were in the eutrophic range, indicating high levels of algal productivity. Sites B–D, located in the shallower arm of Lake Samish, are more likely to experience algal blooms than Site A.



$$\mathrm{TSI}_{chl} = 9.81\ (\ln \mathrm{Chl}\ (\mu\mathrm{g/L}) + 30.6)$$

Figure 19: Median Lake Samish $\mathrm{TSI_{chl}}$ values at Site D, June 2005 through August 2011; the shaded rectangles show summer months (July-October). The TSI values at Site D were higher than Site A, and some of the values were in the eutrophic range, indicating high levels of algal productivity. Sites B–D, located in the shallower arm of Lake Samish, are more likely to experience algal blooms than Site A.

Analyte	Abbr.	Method Reference (APHA 2005)	Detection Limit/ Sensitivity
Alkalinity	Alk	SM2320, titration	$\pm$0.5 mg $CaCO_3$/L
Chlorophyll - field	Chl	Turner fluorometer (field meter)	NA
Chlorophyll - lab	Chl	SM10200 H, acetone extraction	$\pm$0.1 μg/L
Conductivity - field/lab	Sp. Cond	SM2510, lab or field meter	$\pm$0.1 units
Dissolved oxygen - field	DO	SM4500-O G.,membrane electrode (field meter)	$\pm$0.1 mg/L
Dissolved oxygen - lab	DO	SM4500-O C., Winkler, azide	$\pm$0.1 mg/L
Fecal coliforms	FC	SM9221 E , MPN*	$<$2
Nitrogen - ammonium	NH_3	SM4500-NH3 H., flow inject, phenate	10 μg NH_3-N/L
Nitrogen - nitrate/nitrite	NO_3	SM4500-NO3 I., flow inject, Cd reduction	10 μg NO_3-N/L
Nitrogen - total	TN	SM4500-NO3 I., flow inject, persulfate digest	10 μg N/L
pH - field/lab	pH	SM4500-H, electometric lab or field meter	$\pm$0.1 units
Phosphorus - soluble	Sol P	SM4500-P G., flow inject	3 μg PO_4-P/L
Phosphorus - total	TP	SM4500-P G., flow inject, persulfate digest	5 μg P/L
Temperature - field	Temp	SM2550 thermistor (field meter)	$\pm$0.1 C
Turbidity	Turb	SM2130, nephelometric	$\pm$0.2 NTU

*Fecal coliform analyses were provided by Edge Analytical, 805 Orchard Dr., Bellingham, WA and Exact Scientific Services, 3929 Spur Ridge Ln., Bellingham, WA.

Table 1: Summary of analytical methods used by the Institute for Watershed Studies in the Lake Samish monitoring project.

Date	Measured Parameters†	Chlorophyll Measurements
June 21, 2005	all field/lab analyses except pH/cond	chl profiles (A, B, D)
July 20, 2005	all field/lab analyses except pH/cond	chl profiles
August 23, 2005	all field/lab analyses except pH/cond	chl profiles
September 20, 2005	all field/lab analyses except pH/cond	chl profiles (A, B)
October 16, 2005	all field/lab analyses except pH/cond	chl profiles (A, B)
November 20, 2005	all field/lab analyses except pH/cond	chl profiles
January 22, 2006	all field/lab analyses except pH/cond	chl biomass(misc. depths)
February 26, 2006	all field/lab analyses	chl profiles
March 19, 2006	all field/lab analyses	chl profiles
April 23, 2006	all field/lab analyses	chl profiles
May 21, 2006	all field/lab analyses	chl profiles
June 20, 2006	all field/lab analyses	chl profiles
July 19, 2006	all field/lab analyses	chl profiles
June 21, 2007	all field/lab analyses	chl biomass(misc. depths)
September 13, 2007	all field/lab analyses (no coliforms)	chl biomass (misc. depths)
December 20, 2007	all field/lab analyses	chl biomass (5 m intervals)
March 25, 2008	all field/lab analyses	chl biomass (5 m intervals)
June 10, 2008	all field/lab analyses	chl biomass (5 m intervals)
January 25, 2009	all field/lab analyses	chl biomass (5 m intervals)
April 27, 2009	all field/lab analyses	chl biomass (5 m intervals)
July 1, 2009	all field/lab analyses	chl biomass (5 m intervals)
October 20, 2009	all field/lab analyses	chl biomass (5 m intervals)
February 17, 2010	all field/lab analyses	chl biomass (5 m intervals)
April 22, 2010	all field/lab analyses	chl biomass (5 m intervals)
July 15, 2010	all field/lab analyses	chl biomass (5 m intervals)
October 19, 2010	all field/lab analyses	chl biomass (5 m intervals)
March 23, 2011	all field/lab analyses	chl biomass (5 m intervals)
August 30, 2011	all field/lab analyses	chl biomass (5 m intervals)

† Field/lab analyses include Secchi depth, dissolved oxygen, water temperature, pH, conductivity, alkalinity, total nitrogen, nitrate/nitrite, ammonium, total phosphorus, soluble orthophosphate, turbidity, chlorophyll, and fecal coliforms.

Table 2: Lake Samish contract sampling dates for Sites A–D. Table 3 lists supplemental (no-cost) lake sampling dates and Table 4 lists tributary sampling dates.

Date	Measured Parameters[†]	Chlorophyll Measurements
August 24, 2006	all field/lab analyses (no coliforms)	chl profiles
September 18, 2006	all field/lab analyses (no coliforms)	chl biomass (misc. depths)
October 22, 2006	all field/lab analyses (no coliforms)	chl profiles
December 18, 2006	all field/lab analyses (no coliforms)	chl profiles
January 30, 2007	all field/lab analyses (no coliforms)	chl profiles
February 27, 2007	all field/lab analyses (no coliforms)	chl profiles
March 29, 2007	all field/lab analyses (no coliforms)	chl profiles
April 24, 2007	all field/lab analyses (no coliforms)	no chl data
May 24, 2007	all field/lab analyses (no coliforms)	chl profiles
November 15, 2007	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)
January 29, 2008	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)
April 21, 2008	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)
May 15, 2008	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)
July 22, 2008	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)
October 23, 2008	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)
January 26, 2010	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)
January 26, 2011	all field/lab analyses (no coliforms)	chl biomass (5 m intervals)

[†] Field/lab analyses include Secchi depth, dissolved oxygen, water temperature, pH, conductivity, alkalinity, total nitrogen, nitrate/nitrite, ammonium, total phosphorus, soluble orthophosphate, turbidity, chlorophyll, and fecal coliforms.

Table 3: Lake Samish supplemental (no-cost) lake sampling dates for Sites A–B. Table 2 lists contract sampling dates when all four sites (A–D) were sampled and Table 4 lists tributary sampling dates.

Date	Measured Parameters†	Sampling Locations
July 15, 2005	all field/lab analyses	Barnes, Finney, Mia, Mud
August 9, 2005	all field/lab analyses	Friday
November 10, 2005	all field/lab analyses	Barnes, Finney, Friday, Mia, Mud
July 16, 2007	all field/lab analyses	Barnes, Finney, Friday, (Mia dry), Mud
March 17, 2008	all field/lab analyses	Barnes, Finney, Friday, Mia, Mud
February 18, 2009	all field/lab analyses	Barnes, Finney, Friday, Mia, Mud
July 13, 2009	all field/lab analyses	Barnes, Finney, Friday, Mia, Mud
February 18, 2010	all field/lab analyses	Barnes, Finney, Friday, Mia, Mud
July 16, 2010	all field/lab analyses	Barnes, Finney, Friday, Mia, Mud

† Field/lab analyses include dissolved oxygen, water temperature, pH, conductivity, alkalinity, total nitrogen, nitrate/nitrite, ammonium, total phosphorus, soluble orthophosphate, turbidity, and fecal coliforms.

Table 4: Lake Samish tributary sampling dates. Table 2 lists dates when all four lakes sites (A–D) were sampled and Table 3 lists supplemental dates when Sites A–B were sampled.

2 References

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Matthews, R. A. and J. Vandersypen. 2011. Lake Samish Monitoring Project 2011 Final Report. Final Report prepared by the Institute for Watershed Studies, Western Washington University, for the Samish Water District, March 11, 2011, Bellingham, WA.

A Lake Samish Hydrolab Profiles (2011)

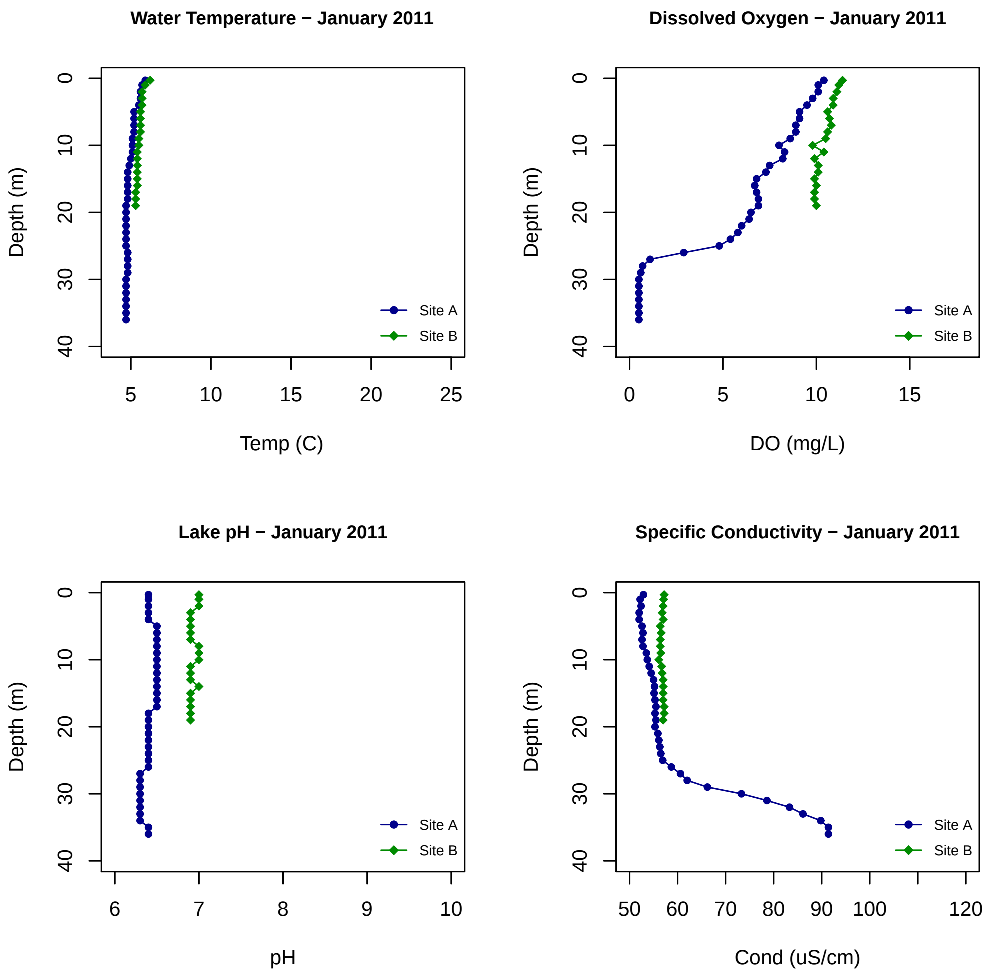

Figure 20: Lake Samish Hydrolab profiles for Sites A & B, January 26, 2011.

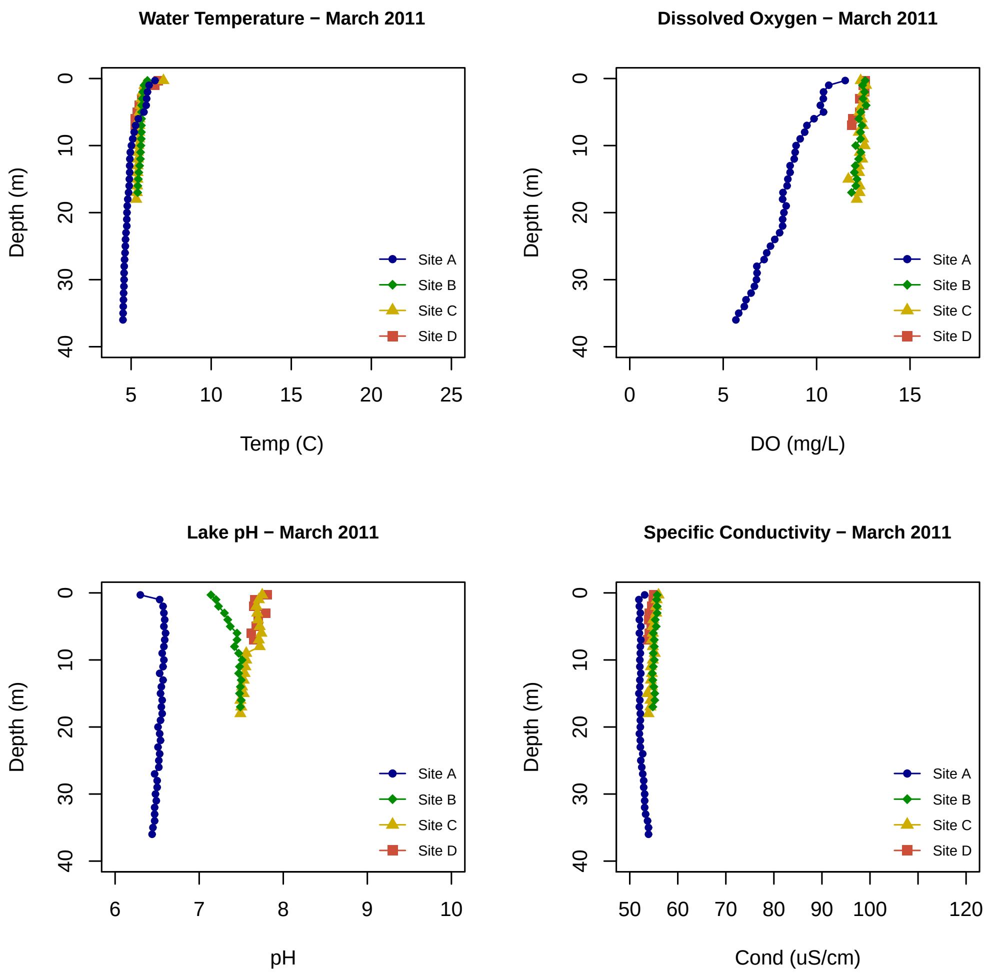

Figure 21: Lake Samish Hydrolab profiles for Sites A–D, March 23, 2011.

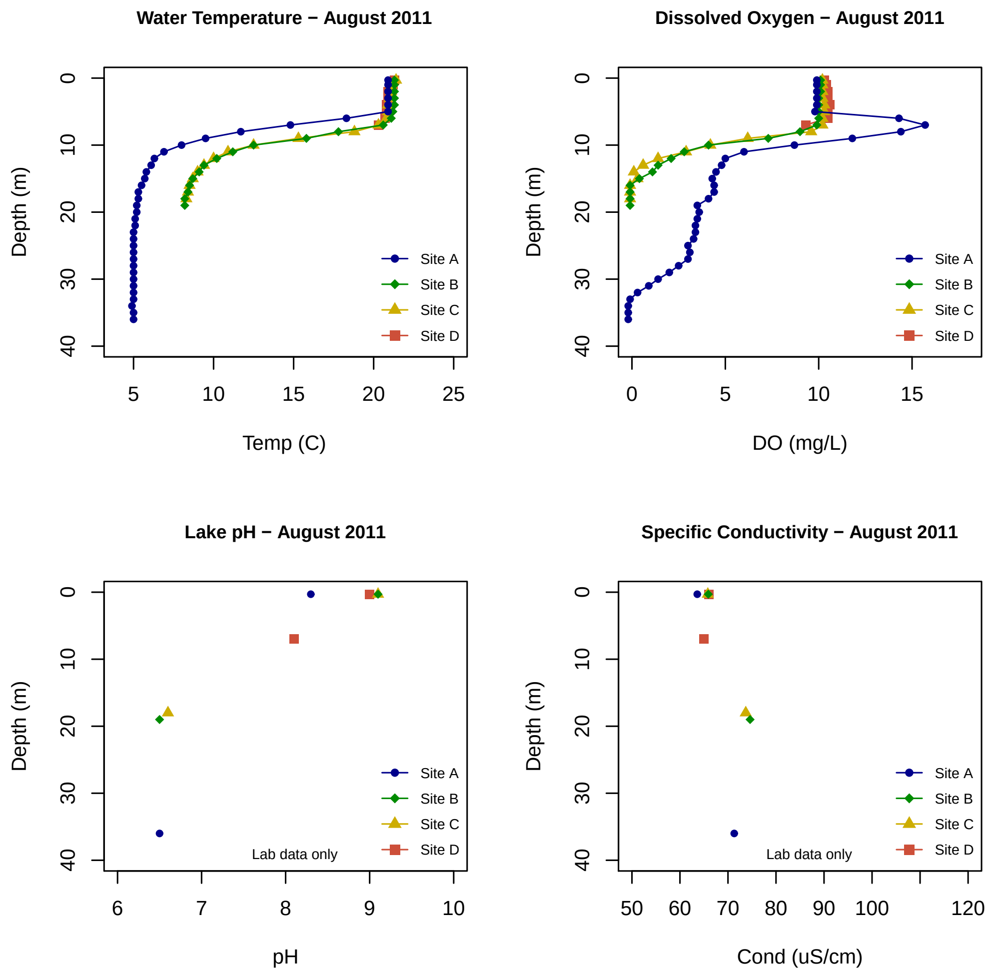

Figure 22: Lake Samish YSI profiles for Sites A–D, August 30, 2011. The YSI field meter only measures temperature and dissolved oxygen, so pH and conductivity data are from water samples analyzed in the laboratory.

B Lake Samish Chlorophyll Profiles (2011)

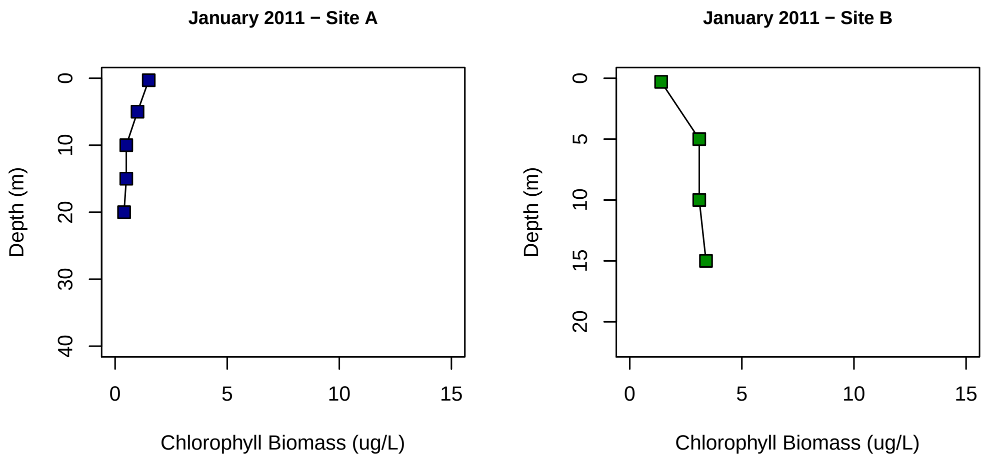

Figure 23: Lake Samish chlorophyll data for Sites A & B, January 26, 2011. All sites were sampled at 5 meter depth intervals.

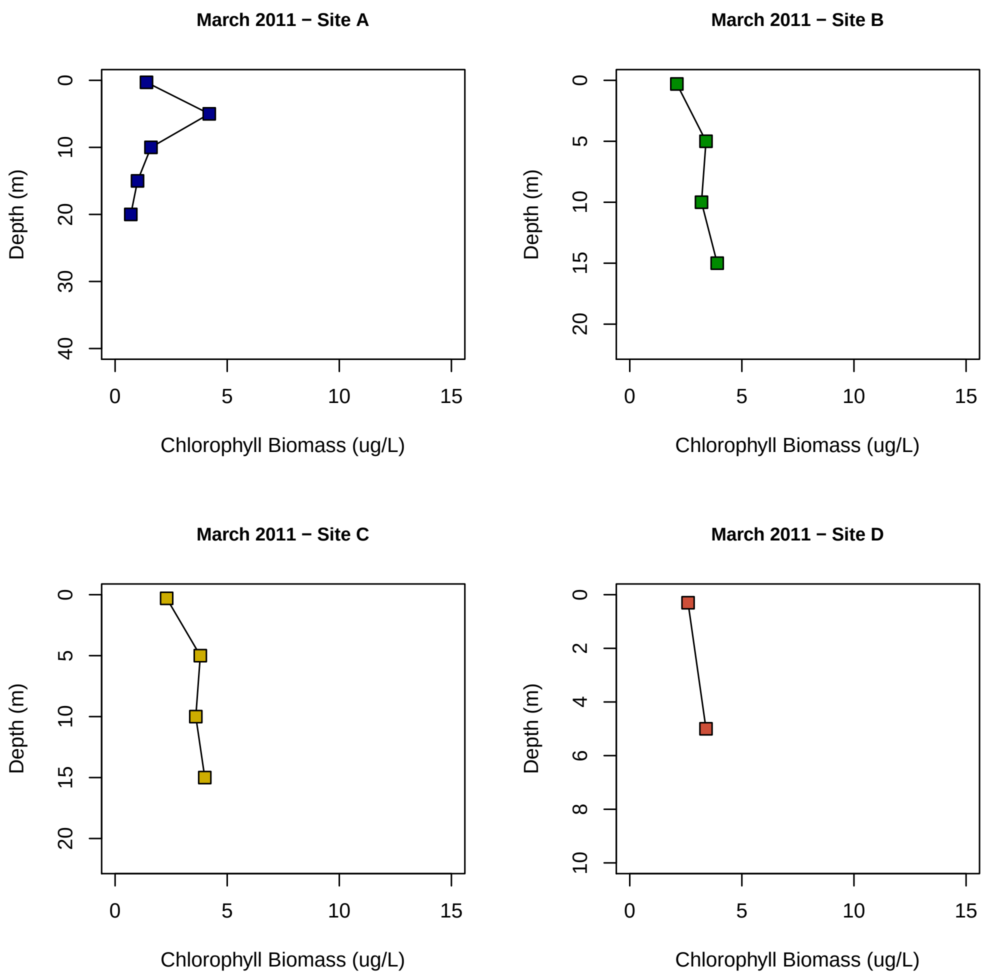

Figure 24: Lake Samish chlorophyll data for Sites A–D, March 23, 2011. All sites were sampled at 5 meter depth intervals.

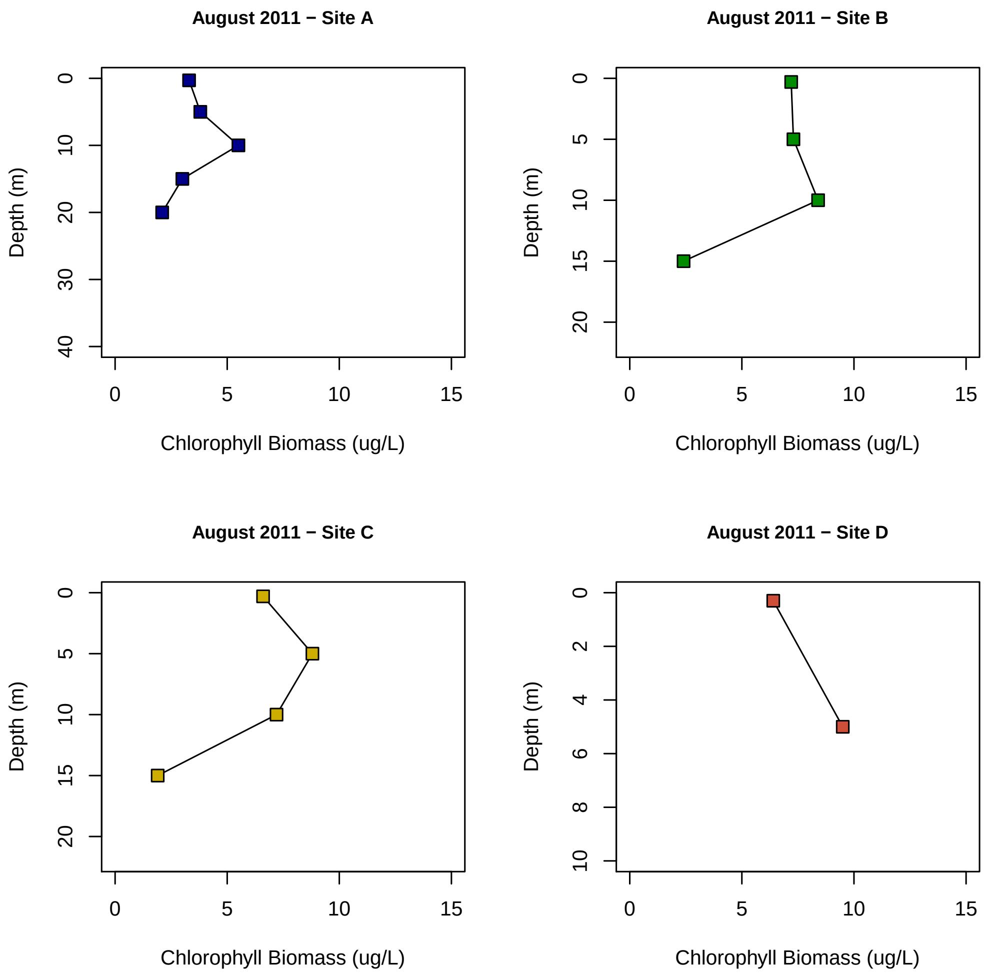

Figure 25: Lake Samish chlorophyll data for Sites A–D, August 30, 2011. All sites were sampled at 5 meter depth intervals.

C Lake Samish Monitoring Data (2005-2011)

This appendix includes the lake data from 2005 through the current sampling year, edited to show detection limits and updated to include corrections or modifications made since the last summary report. All abbreviations are listed in Table 1 (page 27). Electronic copies of these files are available from the Institute for Watershed Studies.