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# Lake Whatcom Monitoring Project 2010/2011 Report

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# Lake Whatcom Monitoring Project
# 2010/2011 Report

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# Executive Summary

- This report describes the results from the 2010/2011 Lake Whatcom monitoring program. The objectives of this program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; collect high flow water quality data from selected tributaries; continue collection of hydrologic data from Austin and Smith Creeks; and update the hydrologic model for Lake Whatcom.

- This report is part of an on-going series of annual reports and special project reports that provide a complete documentation of the monitoring program over time. A summary of the Lake Whatcom reports, including special project reports, is included in Section 6.2, beginning on page 97.

- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The water temperatures were unusually cool throughout most of the spring and summer. The lake was stratified at Sites 1–4 by early June.

- The levels of hypolimnetic oxygen have declined over time at Site 1, causing the lake to be listed by the Department of Ecology on the 1998 303d list of impaired waterbodies in the State of Washington. Following the onset of stratification, the hypolimnetic oxygen concentrations dropped, but not as quickly as in 2010. This may have been related to the unusually cool spring and summer conditions in 2011.

- Nitrate depletion was evident at all sites in the photosynthetic zone during the summer due to algal uptake of this essential nutrient. Low nitrate in the photosynthetic zone favors the growth of Cyanobacteria. Nitrate depletion also occurred in the hypolimnion at Sites 1 and 2 due to nitrate reduction by bacteria.

- Anaerobic conditions in the hypolimnion at Sites 1 and 2 resulted in slightly elevated concentrations of ammonium and hydrogen sulfide by the end of the summer. These indicators were lower than usual, which may have been related to the cool spring and summer conditions.

- The summer near-surface total phosphorus and chlorophyll concentrations have increased significantly over time at most sites. The patterns continue to be somewhat variable, but it does not appear that the trends have reversed or stabilized.

- Summer algal blooms developed that were associated with poor water filtration rates at the City's water treatment facility. The dominant algae associated with this bloom were *Aphanocapsa* and *Aphanothece* (nontoxic Cyanobacteria), as well as diatoms *Cyclotella* and *Thalassiosira*.

- The concentrations of trihalomethanes in Bellingham's treated drinking water have been increasing over time, particularly during the late summer/fall (third quarter), which is consistent with the chlorophyll and algal data.

- All of the mid-basin fecal coliforms counts were less than 10 cfu/100 mL. The coliform counts at the Bloedel-Donovan recreational area (collected offshore from the swimming area) were slightly higher than mid-basin counts, but passed the freshwater *Extraordinary Primary Contact Recreational* bacteria standard for Washington State.

- Iron and zinc were often detectable, but were within normal ranges for the lake. Other metals were occasionally detected, but the concentrations were near the limits of detection. Lead was detected in many samples, but this was due to analytical changes that lowered the detection limit from 0.001 mg/L to 0.00005 mg/L.

- Beginning in January 2010, the tributaries were sampled monthly to collect baseline data. Most of the tributaries had relatively low concentrations of total and dissolved solids, low alkalinities and conductivities, and low levels of nitrate and ammonium. Residential streams had higher concentrations of total and dissolved solids, higher alkalinities and conductivities, higher coliform counts, and higher nutrient concentrations.

- A water balance was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage. The major inputs into the lake during WY2011[1] included surface and subsurface runoff (75.1%), direct precipitation (18.0%), and water diverted from the Middle Fork of the Nooksack River (6.9%). Outputs included Whatcom Creek (81.2%), the

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[1] Water Year 2011 covers the period from October 1, 2010 through September 30, 2011

City of Bellingham (9.0%), evaporation (7.0%), the Whatcom Falls Hatchery (2.1%), the Lake Whatcom Water and Sewer District (0.6%)[2], and the Puget Sound Energy Co-Generation (0.1%)[3].

- Six storm events were monitored in Silver Beach Creek using an automated sampler to collect flow-paced, discrete samples. The storm runoff contained elevated levels of total suspended solids and phosphorus that were significantly correlated with flow rates. In addition, total suspended solids and total phosphorus concentrations were highly correlated with each other.

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[2] Formerly Water District #10

[3] This facility currently operates at the former Georgia Pacific site.

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# 1 Introduction

This report is part of an on-going series of annual reports and special project reports that document the Lake Whatcom monitoring program over time. Many of the reports are available online at http://www.wwu.edu/iws (follow links under Lake Studies to Lake Whatcom); older reports are available in the IWS library and through the City of Bellingham Public Works Department. A summary of the Lake Whatcom reports, including special project reports, is included in Section 6.2, beginning on page 97.

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom also serves as a water source for the Puget Sound Energy Co-Generation Plant, which is located at the former Georgia-Pacific Corporation site on Bellingham Bay.[4] The lake and parts of the watershed provide recreational opportunities, as well as providing important habitats for fish and wildlife. The lake is used as a storage reservoir to buffer peak storm water flows in Whatcom Creek. Much of the watershed is zoned for forestry and is managed by state or private timber companies. Because of its aesthetic appeal, much of the watershed is highly valued for residential development.

The City of Bellingham and Western Washington University have collaborated on investigations of the water quality in Lake Whatcom since the early 1960s. Beginning in 1981, a monitoring program was initiated by the City and WWU that was designed to provide long-term data for Lake Whatcom for basic parameters such as temperature, pH, dissolved oxygen, conductivity, turbidity, nutrients (nitrogen and phosphorus), and other representative water quality measurements. The major goal of the long-term monitoring effort is to provide a record of Lake Whatcom's water quality over time.

The major objectives of the 2010/2011 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; collect high flow water quality data from selected tributary streams; continue collection of hydrologic data from Austin and Smith Creeks; and update the hydrologic model for Lake Whatcom.

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[4] The Georgia-Pacific Corporation closed its Bellingham pulp mill operations in 2001, reducing its water requirements from 30–35 MGD to 7–12 MGD. By 2007 the water requirements had been reduced to 0.6–3.88 MGD; the mill closed its operations in December 2007.

Detailed site descriptions can be found in Appendix A. The historic lake data are plotted in Appendix B. The current quality control results can be found in Appendix C. The monitoring data are available online at http://www.wwu.edu/iws as described in Appendix D (page 337). Table 1 (page 17) lists abbreviations and units used to describe water quality analyses in this document.

# 2 Lake Whatcom Monitoring

## 2.1 Site Descriptions

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (Figure A1, page 105 in Appendix A.1). Sites 1–2 are located at the deepest points in their respective basins. The Intake site is located adjacent to the underwater intake point where the City of Bellingham withdraws lake water from basin 2. Site 3 is located at the deepest point in the northern sub-basin of basin 3 (north of the Sunnyside sill), and Site 4 is located at the deepest point in the southern sub-basin of basin 3 (south of the Sunnyside sill). Water samples were also collected at the City of Bellingham Water Treatment Plant gatehouse, which is located onshore and west of the intake site.

## 2.2 Field Sampling and Analytical Methods

The lake was sampled on October 5 & 7, November 2 & 4 and December 1 & 2, 2010; and February 1 & 3, April 12 & 14, May 3 & 5, June 7 & 9, July 5 & 7, August 2 & 4, and September 6 & 8, 2011. Each sampling event is a multi-day task; all samples were collected during daylight hours, typically between 10:00 am and 3:00 pm.

A DataSonde 5 and Surveyor 4 Hydrolab field meter was used to measure temperature, pH, dissolved oxygen, and conductivity. The Hydrolab pH and conductivity probes failed repeatedly during the 2010/2011 sampling season.[5] Attempts to repair the probes met with limited success, so the Hydrolab was replaced in November 2011 with a new YSI field meter. The new YSI meter was not used during the

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[5] If the field meter is not functioning, conductivity and pH measurements are done using laboratory meters and water sample collected in the field.

2010/2011 monitoring period, which corresponds to the October to September water year. Side-by-side quality control meter comparisons will be included in next year's report.

All water samples (including bacteriological 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 (page 17). Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.[6] Plankton samples were placed in a cooler and returned to the laboratory unpreserved. The plankton sample volumes were measured in the laboratory and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham.

## 2.3 Results and Discussion

The lake monitoring data include monthly field measurements (conductivity, dissolved oxygen, pH, Secchi depth, and water temperature); laboratory analyses for ambient water quality parameters (ammonium[7], nitrate/nitrite, total nitrogen, soluble phosphate, total phosphorus, alkalinity, turbidity, chlorophyll); plankton and bacteria counts; and biannual metals and total organic carbon measurements.

Tables 2–6 (pages 18–22) summarize the current field measurements, ambient water quality, and coliform data. The raw data are available online at http://www.wwu.edu/iws as described in Appendix D (page 337). The monthly Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 111–160).

The 2010/2011 lake data are plotted with historic lake data in Figures B51–B130 (pages 162–242). These figures are scaled to plot the full range of Lake Whatcom water quality data including minimum, maximum, and outlier values, and do not provide the best illustration of trends that occur in the lake. Separate tables and figures are provided to show trends and illustrate specific patterns in the data.

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[6] AmTest, 13600 Northeast 126th Place, Suite C, Kirkland, WA, 98034–8720.

[7] Ammonium ($NH_4^+$) is ionized ammonia ($NH_3$). Nearly all ammonia is ionized in surface water. Earlier IWS reports used the term ammonia and ammonium interchangeably to describe ammonium concentrations because it is generally understood that ammonia is usually ionized. To improve clarity, IWS has switched to the term "ammonium" to indicate that we are reporting the concentration of ionized ammonia. This does not represent any change in analytical methods.

### 2.3.1 Water temperature

The mid-winter Hydrolab profiles (e.g., Figures B16–B20, pages 126–130) and the multi-year temperature profiles (Figures B51–B55, pages 162–166) show that the water column mixes during the fall, winter, and early spring. During this time, water temperatures, dissolved oxygen concentrations, pH levels, and conductivities are fairly uniform from the surface to the bottom of the lake, even at Site 4, which is over 300 ft (100 m) deep.

The summer Hydrolab profiles (e.g., Figures B46–B50, pages 156–160) show how the lake stratifies into a warm surface layer (*epilimnion*), and cool bottom layer (*hypolimnion*). The transition zone between the epilimnion and hypolimnion (the *metalimnion*), is a region of rapidly changing water temperature. When stratified, the profiles show distinct differences between surface and bottom temperatures.

Stratification develops gradually, and once stable, persists until fall or winter, depending on location in the lake. Seasonal weather differences alter the timing of lake stratification; if the spring is cool, cloudy, and windy, the lake may stratify later than when it has been hot and sunny.

In Lake Whatcom, all sites except the Intake are usually stratified by late spring or early summer. (The Intake is too shallow to develop a stable stratification.) Stratification may begin as early as April, but is often not stable until May or June. The stability of stratification is determined in part by the temperature differences in the water column, but also by water circulation and local weather patterns. Once the water column temperature differs by at least 5° C ($\Delta$T $\geq$5°C), it is unlikely that the lake will destratify.[8]

The lake cools as the weather becomes colder and days shorten. As the lake cools, the surface and bottom water temperatures become more similar, and eventually the lake will destratify and the water column will mix from the surface to the bottom. Although destratification is relatively abrupt, the process is not instantaneous. In addition, when the lake begins to destratify, water temperatures may be uniform from the surface to the bottom, but the rate of water circulation may not be sufficient to replenish hypolimnetic oxygen concentrations (see November 2006 Hydrolab profiles from Sites 1–2: Figures B6 and B7 in Matthews, et al., 2008). Basins 1 and 2 (Sites 1–2) usually destratify by the end of October but basin 3 (Sites 3–4) is often still stratified in November or early December. Com-

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[8] The $\Delta$T is the difference between the epilimnion and hypolimnion temperatures.

plete destratification of basin 3 usually occurs in December or early January, so by February the temperatures are relatively uniform throughout the water column at all sites. During the current sampling period, Sites 1–2 were completely destratified by November 4, 2010 (Figures B6–B7, pages 116–117) and Sites 3–4 were destratified by December 1, 2010 (Figures B14–B15, pages 124–125).

Historic data reveal that water temperatures in basin 3 are generally cooler than in basins 1 and 2, but the two shallow basins experience more extreme temperature variations. The lowest and highest temperatures measured in the lake since 1988 were at Site 1 (4.2° C on February 1, 1988 and February 26, 1989; 24.1° C on August 4, 2009). The large water volume in basin 3 moderates temperature fluctuations, so water temperatures in basin 3 change slower in response to weather conditions compared to the shallow basins.

The surface water temperatures were cooler than usual during the spring and summer of 2011 (Figure 1, page 28). The lake was unstratified in April and unstratified or very weakly stratified in May (Figures B21–B30, pages 136–135). Stable stratification was not present until June (Figures B31–B35, pages 141–145).

### 2.3.2 Dissolved oxygen

Low oxygen conditions are associated with a number of unappealing water quality problems in lakes, including loss of aquatic habitat; release of phosphorus from the sediments; increased rates of algal production due to release of phosphorus; unpleasant odors during lake destratification; fish kills, particularly during lake destratification; release of metals and organics from the sediments; increased mercury methylation; increased drinking water treatment costs; increased taste and odor problems in drinking water; and increased risks associated with disinfection by-products created during the drinking water treatment process.

As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures B41–B42 and B56–B57, pages 151–152 and 167–168). Hypolimnetic oxygen depletion only becomes apparent after stratification, when the lower waters of the basin are isolated from the lake's surface and biological respiration consumes the oxygen dissolved in the water. Biological respiration usually increases when there is an abundant supply of organic matter (e.g., decomposing algae). In basin 3, which has a very large, well-oxygenated hypolimnion, biological respiration has little influence on hypolimnetic oxygen concentrations

(Figures B50 and B60, pages 160 and 171). In contrast, there is rapid depletion of the hypolimnetic oxygen concentrations at Sites 1–2 (Figures B46–B47, and B56–B57, pages 156–157 and 167–168). These two sites are in shallow basins that have small hypolimnions compared to their photic zones, so decomposition of algae and other organic matter causes a measurable drop in hypolimnetic oxygen over the summer.[9]

The levels of hypolimnetic oxygen have declined over time at Site 1, causing the lake to be listed by the Department of Ecology as an "impaired" waterbody (Pelletier, 1998).[10] The increasing rate of oxygen loss is most apparent during July and August, after the lake develops a stable thermal stratification but before oxygen levels drops near zero.

To illustrate this trend we fitted the July and August data using an exponential function (see discussion by Matthews, et al., 2004). As indicated in Figures 2–5 (pages 29–32), there were significant negative correlations between dissolved oxygen and time for all hypolimnetic samples collected during July and August.[11]

The rate of Site 1 hypolimnetic oxygen loss was not as rapid in 2011 as in 2010. In 2010, the hypolimnetic dissolved oxygen concentrations dropped 6–8 mg/L from June to August, averaging 0.13 mg/L per day. By comparison, during the same period in 2011 the oxygen loss was 5–6 mg/L, averaging 0.10 mg/L per day. The difference may be related to water temperature because cooler temperatures can slow down the rate of bacterial growth and respiration. Although both years were characterized by cool spring and summer temperatures, the average hypolimnetic water temperatures were about 2°C warmer in July and August 2010 compared to 2011:

Site 1 Avg. Hypolimnion Water Temp. (10-20 m)

| | 2010 | 2011 | Difference |
|---|---|---|---|
| July | 11.7°C | 9.8°C | 1.9° |
| August | 11.9°C | 9.9°C | 2.0 ° |

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[9] The photic zone is the portion of the lake with enough light to support algal photosynthesis. In Lake Whatcom, peak chlorophyll levels are usually at 5–10 meters, so photic zone volumes will be defined as the percent volume $\leq$10 meters. Using this definition, the photic zones for basins 1, 2, and 3 occupy 75%, 70%, and 17%, respectively (Mitchell, et al., 2010).

[10] http://www.ecy.wa.gov/programs/wq/303d.

[11] Correlation analyses examine the relationships between two variables. The test statistic ranges from –1 to +1; the closer to ±1, the stronger the correlation. The significance is measured using the p-value; significant correlations have p-values $<$0.05.

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in July (Figure B36, page 146). This was caused by the accumulation of phytoplankton along the density gradient between the epilimnion and hypolimnion where light and nutrients are sufficient to support very high levels of photosynthesis. Chlorophyll concentrations within the metalimnetic oxygen peak may be 4-5 times higher than those measured near the surface of the lake (Matthews and DeLuna, 2008).

Site 3 developed an oxygen sag near the bottom during late summer and fall in both 2010 and 2011 (Figures B9 and B49, pages 119 and 159). Sites 3 and 4 developed small oxygen sags near the thermocline (e.g., Figures B4 and B5, pages 114 and 115), which are caused by respiration of heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (Matthews and DeLuna, 2008).

### 2.3.3 Conductivity and pH

Due to equipment problems, Hydrolab pH and conductivity profiles are not available for some of the lake sampling dates. When the Hydrolab was not functioning reliably,[12] pH and conductivity data were generated by collecting discrete water samples and measuring the samples using a laboratory meter. The Hydrolab meter was replaced in November 2011.

The pH and conductivity data followed trends that were, for the most part, typical for Lake Whatcom (Figures B61–B70, pages 172–181). Surface pH values increased during the summer due to photosynthetic activity. Hypolimnetic pH values decreased and conductivities increased due to decomposition and the release of dissolved compounds from the sediments.

Previous reports describe a significant increase in the maximum pH values over time (see Matthews, et al., 2011). As discussed above, on-going equipment problems meant that some of the pH and conductivity data were generated by collecting discrete water samples and measuring the samples using a laboratory meter. Although the field and laboratory pH results were comparable, the number of pH samples collected in 2010/2011 was lower, so pH trend analysis was not included in this year's report.

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[12] The meter either failed or did not meet IWS quality control requirements

There was also a significant long-term trend in the conductivity data. This trend has been attributed to using increasingly sensitive equipment during the past two decades and does not indicate any actual change in the conductivity in the lake (Matthews, et al., 2004).

### 2.3.4 Alkalinity and turbidity

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures B71–B75, pages 183–187). During the summer the alkalinity values at the bottom of Sites 1–2, and occasionally Site 3, increased due to decomposition and the release of dissolved compounds in the lower waters.

Turbidity values in the lake were usually low (1–3 NTU) except during late summer in samples from the bottom of the lake. The high turbidity levels during this time are an indication of increasing turbulence in the lower hypolimnion as the lake begins to destratify. The highest turbidity peaks were measured at Sites 1–2 (Figures B76–B80, pages 188–192).

Suspended sediments in storm runoff can also cause elevated turbidity levels in the lake. Major storm events usually occur during winter or early spring when the lake is destratified, so the turbidity levels will be high throughout the water column. Storm-related turbidity peaks are easier to see in samples from the Intake and basin 3 because there are fewer distracting late summer hypolimnetic turbidity peaks (see February 2009 storm-related turbidity peaks in Figures B78 and B79–B80).

### 2.3.5 Nitrogen and phosphorus

Figures B81–B105 (pages 193–217) show the nitrogen and phosphorus data for Lake Whatcom. Nitrogen and phosphorus are important nutrients that influence the amount and type of microbiota (e.g., algae) that grow in the lake. We measured inorganic forms of nitrogen and phosphorus (nitrite, nitrate, ammonium, and soluble phosphate) as well as total nitrogen and total phosphorus, which includes inorganic and organic compounds.[13]

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[13] Organic nitrogen and phosphorus comes from living or decomposing plants and animals, and may include bacteria, algae, leaf fragments, and other organic particles.

**Nitrogen:** Most algae require inorganic nitrogen in the form of nitrate or ammonium for growth, but some types of algae can use organic nitrogen or even dissolved nitrogen gas.[14] Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 198–202), particularly at Site 1, where the epilimnetic nitrate concentrations often drop below 20 $\mu$g-N/L by the end of the summer. Epilimnetic nitrogen depletion is an indirect measure of phytoplankton productivity, and because algal densities have been increasing throughout the lake, epilimnetic dissolved inorganic nitrogen concentrations (DIN)[15] have been declining over time (Figure 6, page 33). Low epilimnetic DIN concentrations favor the growth of Cyanobacteria because many types of Cyanobacteia can use dissolved $N_2$ gas as a nitrogen source.

Hypolimnetic nitrate concentrations dropped below 20 $\mu$g-N/L at Sites 1 and 2. In anaerobic environments, bacteria reduce nitrate ($NO_3^-$) to nitrite ($NO_2^-$) and nitrogen gas ($N_2$). The historic data indicate that nitrate reduction has been common in the hypolimnion at Site 1, but was not common at Site 2 until the summer of 1999. At Site 2 the hypolimnetic nitrate concentrations dropped below 20 $\mu$g-N/L from 1999–2006 and 2008–2011, but not in 2007. Matthews, et al. (2008) hypothesized that the higher levels in 2007 were the result of late stratification, which shortened the period of anoxia in the hypolimnion and resulted in less nitrate reduction. Although the summer of 2011 was unusually cool, the lake was stratified by June and the hypolimnetic nitrogen levels were $<$20 $\mu$g-N/L at 20 meters in October and November. The onset of stratification is only one factor involved in hypolimnetic nitrate depletion; the duration of stratification is also important. In 2007, the water column at Site 2 was nearly destratified by early October and completely mixed by November, so the period of anoxia was fairly short. In 2011, Site 2 was strongly stratified in October ($\Delta$T = 5.9°C) and weakly stratified in November ($\Delta$T = 2.6°C), resulting in a longer period of stratification compared to 2007.

Ammonium, along with hydrogen sulfide, is often an indicator of hypolimnetic anoxia. Ammonium is produced during decomposition of organic matter. Ammonium is readily taken up by plants as a growth nutrient. In oxygenated environments, ammonium is rarely present in high concentrations because it is rapidly converted to nitrite and nitrate through biological and chemical processes. In low oxygen environments, ammonium accumulates until the lake destratifies. High

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[14] Only Cyanobacteria and a few uncommon species of diatoms can use nitrogen gas.

[15] Dissolved inorganic nitrogen includes ammonium, nitrate, and nitrite. Under most conditions, epilimnetic concentrations of ammonium and nitrite are very low, so epilimnetic DIN is nearly equivalent to nitrate.

ammonium and hydrogen sulfide concentrations were measured just prior to destratification in the hypolimnion at Sites 1 and 2 (Table 7, page 23; Figures B81 & B82, pages 193 & 194). Elevated hypolimnetic ammonium concentrations have been common at both sites throughout the monitoring period, but beginning in 1999 the concentrations increased noticeably at Site 2 (Figure B82, page 194).

The hypolimnetic ammonium concentrations in October 2011 were relatively low compared to previous years, which might be related to the cooler water temperatures. As discussed above, Site 2 was still weakly stratified on November 1 ($\Delta$T = 2.6°C), and had an ammonium concentration of 456 $\mu$g-N/L at 20 meters. Site 1 was not stratified ($\Delta$T = 0.8°C), and the October ammonium concentrations were low and nearly uniform throughout the water column (21–33 $\mu$g-N/L)

Sites 3 and 4 often have slightly elevated ammonium concentrations at 20 m (metalimnion) or near the bottom at 80–90 m (Figures B84–B85, pages 196–197). This is caused by bacterial decomposition of organic matter, but the concentrations never approach the levels found in the hypolimnion at Sites 1–2.

**Site 2 hypolimnetic ammonium and hydrogen sulfide:** The hypolimnion at Site 2 usually has higher concentrations of ammonium and hydrogen sulfide than Site 1 (Table 7, page 23). Although the oxygen concentrations drop to near zero at both sites, basin 2 is slightly shallower than basin 1 (Mitchell, et al., 2010), so a sample from 20 meters is slightly closer to the bottom at Site 2 than Site 1. As a result, the 20 m samples from Site 2 typically contain more of the soluble compounds leaching from the sediments (e.g., ammonium and hydrogen sulfide).

Hydrogen sulfide concentrations are measured in October, which is the latest month that is *consistently* stratified at Sites 1–2. When the lake stratifies late or is unusually cool, as in 2011, the October ammonium and hydrogen sulfide levels will not be as high as in warmer years. But the general pattern remained the same: the October 2011 ammonium and hydrogen sulfide levels were higher at Site 2 than Site 1.

**Phosphorus:** Although the Lake Whatcom microbiota require nitrogen, phosphorus is usually what limits microbial growth (Bittner, 1993; Liang, 1994; Matthews, et al., 2002a; McDonald, 1994). The total phosphorus concentration in the water column is a complex mixture of soluble and insoluble phosphorus compounds, only some of which can be used by algae to sustain growth. Soluble forms of phosphorus (e.g., orthophosphate) are easily taken up by algae and other microbiota, and, as a result, are rarely found in high concentrations in the water column. Insoluble phosphorus can be present in the water column bound to the surface of tiny particles or as suspended organic matter (e.g., live or dead algae). Because competition for phosphorus is so intense, microbiota have developed many mechanisms for obtaining phosphorus from the surface of particles or from decomposing organic matter. Liang (1994) and Groce (2011) found that $\sim$50% of the total persulfate phosphorus in soils in the Lake Whatcom watershed was "bioavailable" and could be extracted by algae.

When hypolimnetic oxygen concentrations are low, sediment-bound phosphorus becomes soluble and leaches into the overlying water. Prior to destratification, hypolimnetic phosphorus may be taken up by microbiota in the hypolimnion or metalimnion (see Section 2.3.2 and Matthews and DeLuna, 2008). When the lake mixes in the fall, the hypolimnetic phosphorus will be mixed throughout the water column. As oxygen concentrations increase during mixing, any soluble phosphorus that has not been taken up by biota will usually be converted back into insoluble phosphorus. Because phosphorus moves back and forth between soluble and insoluble forms and between organic and inorganic compounds, it can be difficult to interpret total phosphorus trends. For example, when algal densities increase, their growth usually results in the reduction of soluble and bioavailable fractions of phosphorus in the epilimnion, similar to the epilimnetic DIN reduction that was described for nitrogen. But, since this uptake simply moves the phosphorus into the "live-algae" fraction of organic phosphorus, total phosphorus concentrations may actually increase in the epilimnion.

In Lake Whatcom, total phosphorus and soluble phosphate concentrations were usually low except in the hypolimnion at Sites 1 and 2 just prior to destratification (Figures B96–B100, pages 208–212 and B101–B105, pages 213–217). Epilimnetic total phosphorus concentrations are usually lower than late-summer hypolimnetic peaks. Prior to 2000, the median epilimnetic phosphorus concentrations were $<5$ $\mu$g-P/L at Sites 2–4 and approximately 5–8 $\mu$g-P/L at Site 1 (Figure 7, page 34). The epilimnetic phosphorus levels have increased significantly at all sites (Figure 7, page 34); however, the pattern is quite erratic, reflecting the complicated nature of phosphorus movement in the water column. It is important to note that low water column phosphorus concentrations do not always match up with low algal densities, and may instead indicate rapid and efficient cycling of phosphorus among the lake biota.

### 2.3.6 Chlorophyll, plankton, and Secchi depth

Site 1 continued to have the highest chlorophyll concentrations of all the sites (Figures B106–B110, pages 218–222). Peak chlorophyll concentrations were usually collected at 0–15 m, while samples from 20 m had relatively low chlorophyll concentrations because light levels are not optimal for algal growth at this depth.

The Lake Whatcom plankton counts were usually dominated by Chrysophyta, consisting primarily *Dinobryon*, *Mallomonas*, and diatoms (Figures B121–B130, pages 233–242). Substantial blooms of bluegreen bacteria (Cyanobacteria) and green algae (Chlorophyta) were also measured at all sites during summer and late fall. Previous analyses of algal biomass in Lake Whatcom indicated that although Chrysophyta dominate the numerical plankton counts, Cyanobacteria and Chlorophyta often dominate the plankton biomass, particularly in late summer and early fall (Ashurst, 2003; Matthews, et al., 2002b). In addition, most of the Cyanobacteria in these samples are counted by colony rather than as individual cells because of the tiny cell size. When the Cyanobacteria cells are estimated, as in the settled counts discussed later in Section 2.3.6, the plankton counts are dominated by tiny Cyanobacteria.

Secchi depths (Figures B111–B115, pages 223–227) showed no clear seasonal pattern because transparency in Lake Whatcom is affected by particulates from storm events and the Nooksack River diversion as well as algal blooms.

**Indications of eutrophication:** Eutrophication is the term used to describe a lake that is becoming more biologically productive. It can apply to an unproductive lake that is becoming slightly more eutrophic, or a productive lake that is becoming extremely eutrophic (see Wetzel, 2001, for more about eutrophication and Matthews, et al., 2005, for a description of the chemical and biological indicators of eutrophication in Lake Whatcom).

The median near-surface summer chlorophyll concentrations were slightly lower in 2011, probably due to the cool spring and summer, but were still following an increasing trend throughout the lake (Figure 8, page 35). The 2011 algae counts (all sites combined) were about the same as in 2010 (Figures 9–10, pages 36–37). This discrepancy between chlorophyll and algae counts reflects the difference between numerical density and biomass. Chlorophyll is a direct measure of algal biomass and is best used to evaluate trophic changes in the lake (e.g., is the lake becoming more biologically productive?). Algal counts are a numerical way to look for trends within the same type of algae (e.g., are the numbers of Cyanobacteria increasing?). The relationship between chlorophyll and cell density is complex. The amount of chlorophyll in an algal cell is influenced by the physiological age and condition of the cell, light intensity, nutrient availability, and many other factors. In addition, while most types of algae are counted by individual cells, a few types must be counted by colonies because the cells are too difficult to see. Even if the amount of chlorophyll was constant in each cell, it would take many tiny cells to equal the chlorophyll biomass in one large colony.

One of the eutrophication trends in Lake Whatcom has been a fairly steady increase in the numbers of Cyanobacteria. This trend is best viewed using a $\log_{10}$ plot (Figure 10, page 37), which shows the counts increasing from 1994 through 2004 or 2005. The Cyanobacteria counts have been more or less consistent since 2005, going up or down slightly depending on the site and year.

**Lake Whatcom algal blooms:** An unusual algal bloom developed during the summer of 2009 that caused the City's water treatment filters to clog very rapidly. This affected the rate at which water could be treated and resulting in the City imposing mandatory restrictions on water use. In order to help identify the source of the problem, IWS analyzed plankton samples collected during August 2009 from raw water after it passed through the screen house to see whether there were algae present that might be affecting the water treatment rates (Matthews, et al., 2010). Most of the algae in the August 2009 samples were tiny rod-shaped and spherical Cyanobacteria that have been collectively referred to as *Aphanocapsa* and *Aphanothece* (Figure 11, page 38). Unlike the closely related *Microcystis flos-aquae*, *Aphanocapsa* and *Aphanothece* are not considered to be toxic Cyanobacteria (Granéli and Turner, 2006). They are, however, exceedingly slimy because the individual cells are embedded in a thick, sticky colonial mucilage.

Beginning in December 2009, IWS started collecting supplemental monthly plankton samples from 10 meters at Site 2 and the Intake and from the City's raw water gatehouse. Our goal was to generate detailed information about the algae responsible for filter clogging events using samples collected at the gatehouse and at depths close to the water withdrawal depth in basin 2. The supplemental algal counts were identified to a much lower taxonomic level than our regular algal counts using a settling chamber method (Hamilton, et al., 2001) that captures tiny individual algal cells ($<20$ $\mu$m diameter) that can pass through our regular plankton net. Because of the different concentration methods and sampling depths, the settled algae counts are not directly comparable to the historic algal counts collected using a plankton net (Figures B121–B130, pages 233–242), but the general taxonomic patterns will be similar.

*Aphanocapsa* and *Aphanothece* dominated the algae counts (Tables 10–11, pages 26–27), representing 76.6% of the total count. Several other Cyanobacteria were moderately abundant, especially *Cyanothece* (6.9% of the total count) and *Snowella* (4.2% of the total count). The samples also contained large numbers of diatoms, especially *Cyclotella* and *Thalassiosira* (2.7% of the total count). Both of these diatoms excrete long thread-like filaments that probably benefit the diatoms by slowing sinking rates or discouraging predation by filter-feeding zooplankton (Figures 12–13, pages 39–40. In the City's water filters, however, the filaments may help create an algal mat stuck together by Cyanobacteria glue.

Although the *Aphanocapsa* and *Aphanothece* cell counts were very high, these Cyanobacteria are exceedingly tiny, usually on the order of 1–2 $\mu$m in diameter. A typical "pill-box" shaped *Cyclotella* cell is about 30 $\mu$m in diameter and about 10–15 $\mu$m in height, making the *Cyclotella* cell volume 1500–2500$\times$ greater than a single *Aphanocapsa* or *Aphanothece* cell. A common way to adjust for differences in cell size is to calculate algae *biovolume* by multiplying the number of each type of algae by its average cell volume. This approach has been used in several scientific publications on Lake Whatcom (e.g., Matthews and DeLuna, 2008), but is beyond the scope of the annual reports.

The City of Bellingham Public Works Department provided water production rate data for the period from 2007 through 2011. The data were reported in units of "unit filter run volume" (UFRV), which is the product of the filtration rate (gal/min), filter run length (min), and filter surface area (ft$^2$). Good water production rates are usually $\geq$5000 (P. Wendling and B. Evans, City of Bellingham Public Works Department, personal communications). The UFRVs were plotted with Intake chlorophyll concentrations and Cyanobacteria counts from plankton net samples (Figures 14–15, pages 41–42), which revealed a good correlation, especially for Cyanobacteria counts and water production rates. Similarly, the settled algae counts from the Gatehouse revealed a strong link between Cyanobacteria densities and low water production rates (Figure 16, page 43). Although the exact mechanisms for slow water production can't be determined from our data, both chlorophyll concentration and Cyanobacteria density can be used to predict when water production rates will decline.

### 2.3.7 Coliform bacteria

The current surface water standards are based on "designated use" categories, which for Lake Whatcom is "Extraordinary Primary Contact Recreation." The standard for bacteria is described in Chapter 173–201A of the Washington Administrative Code, Water Quality Standards for Surface Waters of the State of Washington:

> *Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.*

All of the mid-basin (Sites 1–4) and Intake values for fecal coliforms were less than 10 cfu[16]/100 mL (Figures B116–B120, pages 228–232) and passed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

Coliform samples collected offshore from the Bloedel-Donovan swimming area had slightly higher counts than at Site 1 (mid-basin). None of the Bloedel-Donovan counts exceeded 100 cfu/100 mL and the geometric mean was 3.3 cfu/100 mL, so this site passed both parts of the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

### 2.3.8 Metals

The metals data for Lake Whatcom are included in Table 8 (page 24). This table includes only the metals listed in our monitoring contract (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); the online electronic data files contain concentrations for 24 additional metals that are included as part of the analytical procedure used by AmTest. In 1999, AmTest upgraded their equipment and analytical procedures for most metals. In 2011, AmTest changed the analytical method for measuring lead, decreasing the detection limit from 0.001 mg/L to 0.00005 mg/L. As a result, many of the analyses now have lower detection limits, resulting in fewer "below detection" data (bdl). These detections probably do not represent increased metals concentrations in the lake.

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[16] Colony forming unit/100 mL; cfu/100 mL is sometimes labeled "colonies/100 mL."

The metals concentrations were within normal concentration ranges for the lake. Iron and zinc were all in the detectable range. The highest iron concentration was measured in August at the bottom of Site 1. The elevated iron concentration was the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water. Chromium, copper, and mercury were detected in many of the samples, but at levels close to detection limits, which is typical for Lake Whatcom. Lead was often detected, but as indicated above, this represents a change in the analytical method, not an increase in the lead levels. All of the lead concentrations were lower than the historic detection level (<0.001 mg/L).

### 2.3.9 Total organic carbon and disinfection by-products

Total organic carbon concentrations, along with plankton and chlorophyll data, are used to help assess the likelihood of developing potentially harmful disinfection by-products through the reaction of chlorine with organic compounds during the drinking water treatment process. Algae excrete dissolved organic carbon into water, which, along with other decaying organic material, can react with chlorine to form disinfection by-products, predominately chloroform and other trihalomethanes (THMs). As algal densities increase, we expect to see an increase in THMs.

The 2010/2011 total organic carbon levels at the Intake were fairly typical for the lake (Table 9, page 25). The long-term data indicate that total organic carbon concentrations have become more variable. The minimum concentrations measured each year may be <1–2 mg/L but the maximums have increased (Figure 17, page 44). Because of the within-year variability, the only significant trend in the raw data was from the gatehouse, where the large sample size produced statistical significance despite a low correlation statistic (Figure 18, page 45).[17]

The THMs have been increasing in Bellingham's treated drinking water, particularly during the late summer/fall (third quarter; Figure 19, page 46). Haloacetic acids (another disinfection by-product) are not as closely linked to algal concentrations and chlorine dose (Sung, et al., 2000). The Jan-Dec HAAs results were marginally correlated with time (due to the large sample size), but the the third quarter data were not significantly correlated with time.

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[17] Gatehouse data were provided by the City of Bellingham Public Works Department.

| Abbrev. | Parameter | Method | Historic DL$^\dagger$ | 2010/2011 MDL$^\dagger$ | Sensitivity or Confidence limit |
|---|---|---|---|---|---|
| **Hydrolab field meter:** | | Hydrolab (1997) | | | |
| cond | Conductivity | | – | – | ± 2 $\mu$S/cm |
| do | Dissolved oxygen | | – | – | ± 0.1 mg/L |
| ph | pH | | – | – | ± 0.1 pH unit |
| temp | Temperature | | – | – | ± 0.1° C |
| **IWS field measurements:** | | | | | |
| disch | Discharge | Rantz et al. (1982); SOP-IWS-6 | – | – | – |
| secchi | Secchi depth | Lind (1985) | – | – | ± 0.1 m |
| **IWS laboratory analyses:** | | | | | |
| alk | Alkalinity | APHA (2005) #2320; SOP-IWS-15 | – | – | ± 0.6 mg/L |
| cond | Conductivity | APHA (2005) #2510; SOP-LW-19 | – | – | ± 1.7 $\mu$S/cm |
| do | Dissolved oxygen | APHA (2005) #4500-O.C.; SOP-IWS-12 | – | – | ± 0.1 mg/L |
| ph | pH-lab | APHA (2005) #4500-H$^+$; SOP-IWS-8 | – | – | ± 0.02 pH unit |
| tss | T. suspended solids | APHA (2005) #2540 D; SOP-IWS-22 | 2 mg/L | 0.4 mg/L | ± 1.4 mg/L |
| turb | Turbidity | APHA (2005) #2130; SOP-IWS-11 | – | – | ± 0.2 NTU |
| nh3 | Ammonium (auto) | APHA (2005) #4500-NH$_3$ H; SOP-IWS-19 | 10 $\mu$g-N/L | 5.8 $\mu$g-N/L | ± 7.1 $\mu$g-N/L |
| no3 | Nitrite/nitrate (auto) | APHA (2005) #4500-NO$_3$ I; SOP-IWS-19 | 20 $\mu$g-N/L | 2.9 $\mu$g-N/L | ± 3.9 $\mu$g-N/L |
| tn | T. nitrogen (auto) | APHA (2005) #4500-N C; SOP-IWS-19 | 100 $\mu$g-N/L | 14.4 $\mu$g-N/L | ± 43.8 $\mu$g-N/L |
| srp | Sol. phosphate (auto) | APHA (2005) #4500-P G; SOP-IWS-19 | 5 $\mu$g-P/L | 0.7 $\mu$g-P/L | ± 1.7 $\mu$g-P/L |
| tp | T. phosphorus (auto) | APHA (2005) #4500-P H; SOP-IWS-19 | 5 $\mu$g-P/L | 3.3 $\mu$g-P/L | ± 2.9 $\mu$g-P/L |
| **IWS plankton analyses:** | | | | | |
| chl | Chlorophyll | APHA (2005) #10200 H; SOP-IWS-16 | – | – | ± 0.1 $\mu$g/L |
| chlo | Chlorophyta | Lind (1985), Schindler trap | – | – | – |
| cyan | Cyanobacteria | Lind (1985), Schindler trap | – | – | – |
| chry | Chrysophyta | Lind (1985), Schindler trap | – | – | – |
| pyrr | Pyrrophyta | Lind (1985), Schindler trap | – | – | – |
| **City coliform analyses:** | | | | | |
| fc | Fecal coliform | APHA (2005) #9222 D | | 1 cfu/100 mL | – |
| **AmTest analyses:** | | | | | |
| As | T. arsenic | EPA (1994) 200.7 | – | 0.01 mg/L | – |
| Cd | T. cadmium | EPA (1994) 200.7 | – | 0.0005 mg/L | – |
| Cr | T. chromium | EPA (1994) 200.7 | – | 0.001 mg/L | – |
| Cu | T. copper | EPA (1994) 200.7 | – | 0.001 mg/L | – |
| Fe | T. iron | EPA (1994) 200.7 | – | 0.005 mg/L | – |
| Pb | T. lead | EPA (1979) 239.2 | 0.001 mg/L | 0.00005 mg/L$^\ddagger$ | – |
| Hg | T. mercury | EPA (1994) 245.1 | – | 0.0001 mg/L | – |
| Ni | T. nickel | EPA (1994) 200.7 | – | 0.005 mg/L | – |
| Zn | T. zinc | EPA (1994) 200.7 | – | 0.001 mg/L | – |
| TOC | T. organic carbon | EPA (1979) 415.1 | – | 1.0 mg/L | – |

$^\dagger$ Historic detection limits (DL) are usually higher than current method detection limits (MDL).

$^\ddagger$Method change in 2011 resulted in lower detection limit

Table 1: Summary of IWS, AmTest, and City of Bellingham analytical methods and parameter abbreviations.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 18.8 | 20.1 | 20.5 | 29.5 |
| Conductivity ($\mu$S/cm) | 57.9 | 60.0 | 61.1 | 77.6 |
| Dissolved oxygen (mg/L) | 0.2 | 9.9 | 8.7 | 12.2 |
| pH | 6.4 | 7.4 | 7.3 | 8.6 |
| Temperature (°C) | 5.8 | 9.8 | 11.1 | 21.1 |
| Turbidity (NTU) | 0.7 | 1.1 | 1.5 | 8.2 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | 25.3 | 331.3 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | $<20$ | 219.0 | 194.0 | 343.0 |
| Nitrogen - total ($\mu$g-N/L) | 186.9 | 434.1 | 391.4 | 539.7 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | $<5$ | $<5$ | $<5$ | 10.0 |
| Phosphorus - total ($\mu$g-P/L) | $<5$ | 9.4 | 12.9 | 90.7 |
| | | | | |
| Chlorophyll ($\mu$g/L) | 0.7 | 3.1 | 4.2 | 11.2 |
| Secchi depth (m) | 2.4 | 4.0 | 3.9 | 5.3 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 1 | 1 | 4 |

[†] Uncensored arithmetic means except coliforms (geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 2: Summary of Site 1 ambient water quality data, Oct. 2010 – Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 18.1 | 19.0 | 19.2 | 20.5 |
| Conductivity ($\mu$S/cm) | 56.8 | 58.4 | 58.4 | 60.0 |
| Dissolved oxygen (mg/L) | 8.6 | 10.7 | 10.6 | 12.1 |
| pH | 7.2 | 7.6 | 7.7 | 8.6 |
| Temperature (°C) | 6.5 | 13.2 | 13.3 | 20.4 |
| Turbidity (NTU) | 0.5 | 0.7 | 0.7 | 1.1 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<$10 | $<$10 | $<$10 | 22.5 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 88.2 | 230.3 | 229.3 | 362.4 |
| Nitrogen - total ($\mu$g-N/L) | 243.8 | 378.9 | 379.2 | 505.3 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | $<$5 | $<$5 | $<$5 | 6.0 |
| Phosphorus - total ($\mu$g-P/L) | $<$5 | 6.2 | 6.4 | 13.1 |
| | | | | |
| Chlorophyll ($\mu$g/L) | 1.1 | 2.8 | 3.0 | 5.2 |
| Secchi depth (m) | 3.6 | 4.6 | 5.2 | 7.7 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<$1 | 1 | 1 | 2 |

[†] Uncensored arithmetic means except coliforms (geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3: Summary of Intake ambient water quality data, Oct. 2010– Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 17.2 | 18.8 | 19.2 | 28.7 |
| Conductivity ($\mu$S/cm) | 56.5 | 58.3 | 58.9 | 75.2 |
| Dissolved oxygen (mg/L) | 0.3 | 10.4 | 9.7 | 12.1 |
| pH | 6.5 | 7.4 | 7.4 | 8.4 |
| Temperature (°C) | 6.2 | 10.3 | 11.7 | 19.9 |
| Turbidity (NTU) | 0.4 | 0.7 | 0.8 | 6.4 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | 22.6 | 511.3 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | $<20$ | 251.8 | 248.8 | 366.0 |
| Nitrogen - total ($\mu$g-N/L) | 243.9 | 435.9 | 421.4 | 676.9 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | $<5$ | $<5$ | $<5$ | 7.7 |
| Phosphorus - total ($\mu$g-P/L) | $<5$ | 7.3 | 9.8 | 54.6 |
| | | | | |
| Chlorophyll ($\mu$g/L) | 0.5 | 2.4 | 2.6 | 5.7 |
| Secchi depth (m) | 3.6 | 5.0 | 5.6 | 7.6 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 1 | 1 | 1 |

[†] Uncensored arithmetic means except coliforms (geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 4: Summary of Site 2 ambient water quality data, Oct. 2010 – Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 16.7 | 18.5 | 18.6 | 20.3 |
| Conductivity ($\mu$S/cm) | 56.3 | 58.2 | 58.1 | 60.4 |
| Dissolved oxygen (mg/L) | 6.0 | 9.9 | 10.0 | 12.1 |
| pH | 6.5 | 7.2 | 7.3 | 8.3 |
| Temperature (°C) | 6.2 | 7.4 | 9.8 | 19.7 |
| Turbidity (NTU) | 0.2 | 0.5 | 0.6 | 4.6 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | 16.7 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 132.9 | 365.9 | 317.2 | 404.9 |
| Nitrogen - total ($\mu$g-N/L) | 270.8 | 459.5 | 437.3 | 542.6 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | $<5$ | $<5$ | $<5$ | 7.6 |
| Phosphorus - total ($\mu$g-P/L) | $<5$ | 6.1 | 6.5 | 17.3 |
| | | | | |
| Chlorophyll ($\mu$g/L) | 0.6 | 2.8 | 2.6 | 5.2 |
| Secchi depth (m) | 3.8 | 5.7 | 6.1 | 9.7 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 1 | 1 | 2 |

[†] Uncensored arithmetic means except coliforms (geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 5: Summary of Site 3 ambient water quality data, Oct. 2010 – Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 17.8 | 18.4 | 18.5 | 20.2 |
| Conductivity ($\mu$S/cm) | 56.2 | 58.0 | 58.0 | 60.1 |
| Dissolved oxygen (mg/L) | 7.6 | 10.0 | 10.1 | 12.2 |
| pH | 6.7 | 7.2 | 7.2 | 8.2 |
| Temperature (°C) | 6.3 | 7.3 | 9.5 | 19.3 |
| Turbidity (NTU) | 0.2 | 0.5 | 0.5 | 0.8 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | 17.4 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 137.7 | 375.2 | 334.1 | 418.8 |
| Nitrogen - total ($\mu$g-N/L) | 271.9 | 460.0 | 444.6 | 581.7 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | $<5$ | $<5$ | $<5$ | 5.2 |
| Phosphorus - total ($\mu$g-P/L) | $<5$ | 6.1 | 6.2 | 15.5 |
| | | | | |
| Chlorophyll ($\mu$g/L) | 0.5 | 2.2 | 2.4 | 5.3 |
| Secchi depth (m) | 4.2 | 6.7 | 6.5 | 8.3 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 1 | 1 | 3 |

[†] Uncensored arithmetic means except coliforms (geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 6: Summary of Site 4 ambient water quality data, Oct. 2010 – Sept. 2011.

| | $H_2S$ (mg/L) | | $NH_3$ ($\mu$g-N/L) | |
|---|---|---|---|---|
| Year | Site 1 | Site 2 | Site 1 | Site 2 |
| 1999[†] | 0.03–0.04 | 0.40 | 268.3 | 424.4 |
| 2000[†] | 0.27 | 0.53 | 208.8 | 339.5 |
| 2001[†] | 0.42 | 0.76 | 168.7 | 331.9 |
| 2002[†] | 0.09 | 0.32 | 203.9 | 383.8 |
| 2003[†] | 0.05 | 0.05 | 333.8 | 340.0 |
| 2004[†] | 0.25 | 0.25 | 300.3 | 378.3 |
| 2005[‡] | 0.13<br>0.12 | 0.25<br>0.42 | 257.5 | 450.4 |
| 2006 | 0.20 | 0.42 | 334.1 | 354.1 |
| 2007 | 0.40 | 0.20 | 324.5 | 79.3[§] |
| 2008 | 0.28 | 0.38 | 294.5 | 404.9 |
| 2009 | 0.15 | 0.47 | 271.3 | 301.2 |
| 2010 | 0.38 | 0.40 | 331.3 | 511.3 |
| 2011 | 0.12 | 0.16 | 180.9 | 209.4 |

[†] $H_2S$ samples analyzed by HACH test kit.
[‡] HACH (first value) vs. Edge Analytical (second value)
[§] Atypical result; see discussion by Matthews, et al. (2008)

Table 7: October hypolimnetic ammonium and hydrogen sulfide concentrations at Sites 1 and 2 (20 m). The $H_2S$ samples have been analyzed by Edge Analytical since 2005. Earlier samples were analyzed using a HACH field test kit.

| | Depth (m) | Date | T. As (mg/L) | T. Cd (mg/L) | T. Cr (mg/L) | T. Cu (mg/L) | T. Fe (mg/L) | T. Hg (mg/L) | T. Ni (mg/L) | T. Pb (mg/L) | T. Zn (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Site 1 | 0 | Feb 3, 2011 | <0.01 | <0.0005 | <0.001 | <0.001 | 0.020 | <0.0001 | <0.005 | <0.00005 | 0.004 |
| Site 1 | 20 | Feb 3, 2011 | <0.01 | <0.0005 | <0.001 | <0.001 | 0.041 | <0.0001 | <0.005 | 0.00009 | 0.005 |
| Intake | 0 | Feb 3, 2011 | <0.01 | <0.0005 | <0.001 | <0.001 | 0.020 | <0.0001 | <0.005 | <0.00005 | 0.005 |
| Intake | 10 | Feb 3, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.012 | <0.0001 | <0.005 | <0.00005 | 0.004 |
| Site 2 | 0 | Feb 3, 2011 | <0.01 | <0.0005 | <0.001 | <0.001 | 0.013 | 0.0001 | <0.005 | <0.00005 | 0.006 |
| Site 2 | 20 | Feb 3, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.016 | 0.0003 | <0.005 | 0.00039 | 0.010 |
| Site 3 | 0 | Feb 1, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.022 | <0.0001 | <0.005 | <0.00005 | 0.004 |
| Site 3 | 80 | Feb 1, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.013 | <0.0001 | <0.005 | <0.00005 | 0.005 |
| Site 4 | 0 | Feb 1, 2011 | <0.01 | <0.0005 | <0.001 | <0.001 | 0.026 | <0.0001 | <0.005 | 0.00007 | 0.005 |
| Site 4 | 90 | Feb 1, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.028 | 0.0002 | <0.005 | <0.00005 | 0.006 |
| | | | | | | | | | | | |
| Site 1 | 0 | Aug 4, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.018 | <0.0001 | <0.005 | <0.00005 | 0.004 |
| Site 1 | 20 | Aug 4, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.158 | <0.0001 | <0.005 | 0.00010 | 0.006 |
| Intake | 0 | Aug 4, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.017 | <0.0001 | <0.005 | 0.00006 | 0.003 |
| Intake | 10 | Aug 4, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.016 | 0.0005 | <0.005 | <0.00005 | 0.004 |
| Site 2 | 0 | Aug 4, 2011 | <0.01 | <0.0005 | 0.001 | 0.002 | 0.010 | 0.0001 | <0.005 | 0.00006 | 0.004 |
| Site 2 | 20 | Aug 4, 2011 | <0.01 | <0.0005 | 0.001 | 0.002 | 0.033 | 0.0003 | <0.005 | 0.00006 | 0.005 |
| Site 3 | 0 | Aug 2, 2011 | <0.01 | <0.0005 | <0.001 | <0.001 | 0.008 | <0.0001 | <0.005 | <0.00005 | 0.005 |
| Site 3 | 80 | Aug 2, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.018 | 0.0001 | <0.005 | <0.00005 | 0.004 |
| Site 4 | 0 | Aug 2, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.010 | <0.0001 | <0.005 | 0.00038 | 0.004 |
| Site 4 | 90 | Aug 2, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.013 | 0.001 | <0.005 | <0.00005 | 0.004 |

Table 8: Lake Whatcom 2010/2011 total metals data. Only the metals specified in the monitoring plan are included in this table; the results for 24 additional metals are available from IWS. The total lead (T. Pb) method changed in 2011, resulting in a much lower detection limit (<0.00005 vs. <0.001 in previous years).

| Site | Date | Depth | TOC (mg/L) | Date | Depth | TOC (mg/L) |
|---|---|---|---|---|---|---|
| Site 1 | Feb 3, 2011 | 0 | 2.9 | Aug 4, 2011 | 0 | 2.4 |
| | Feb 3, 2011 | 20 | 2.8 | Aug 4, 2011 | 20 | 8.4 |
| Intake | Feb 3, 2011 | 0 | 2.8 | Aug 4, 2011 | 0 | 2.4 |
| | Feb 3, 2011 | 10 | 2.8 | Aug 4, 2011 | 10 | 2.2 |
| Site 2 | Feb 3, 2011 | 0 | 2.5 | Aug 4, 2011 | 0 | 2.3 |
| | Feb 3, 2011 | 20 | 3.0 | Aug 4, 2011 | 15 | 1.7 |
| Site 3 | Feb 1, 2011 | 0 | 2.0 | Aug 2, 2011 | 0 | 2.2 |
| | Feb 1, 2011 | 80 | 4.0 | Aug 2, 2011 | 80 | 1.5 |
| Site 4 | Feb 1, 2011 | 0 | 3.1 | Aug 2, 2011 | 0 | 2.2 |
| | Feb 1, 2011 | 90 | 3.5 | Aug 2, 2011 | 90 | 1.5 |

Table 9: Lake Whatcom 2010/2011 total organic carbon data.

| | Pct. of Count Including *Aphanocapsa*/ *Aphanothece* | Pct. of Count Excluding *Aphanocapsa*/ *Aphanothece* | Total Count Including *Aphanocapsa*/ *Aphanothece* |
|---|---|---|---|
| Cyanobacteria (bluegreen algae) | | | |
| *Anabaena* Bory de Saint-Vincent & Bornet & Flahault | 0.4 | 1.9 | 3,496 |
| *Aphanocapsa* Nägeli and *Aphanothece* Nägeli | 76.6 | NA | 595,877 |
| *Chroomonas* Hansgirg and *Eucapsis* Clements & Shantz | <0.1 | 0.1 | 106 |
| *Cyanodictyon* Pascher and *Pseudanabaena* Lauterborn | 6.9 | 29.4 | 53,497 |
| *Merismopedia* Meyen | <0.1 | 0.1 | 248 |
| *Microcystis* Lemmermann | 0.4 | 1.8 | 3,204 |
| *Phormidium* Kützing ex Gomont | <0.1 | 0.1 | 142 |
| *Rhabdoderma* Schmidle & Lauterborn | <0.1 | <0.1 | 18 |
| *Snowella* Elenkin | 4.2 | 18.2 | 33,027 |
| *Woronichinia naegeliana* (Unger) Elekin | 0.1 | 0.4 | 801 |
| | | | |
| Chrysophyta (golden algae) | | | |
| *Bitrichia chodatii* (Reverdin) Chodat | <0.1 | 0.1 | 177 |
| *Chrysamoeba* G. A. Klebs | <0.1 | <0.1 | 9 |
| *Dinobryon bavaricum* Imhof | 0.1 | 0.4 | 774 |
| *Dinobryon divergens* Imhof | 0.3 | 1.3 | 2,324 |
| *Dinobryon sertularia* Ehrenberg | <0.1 | 0.2 | 314 |
| *Epipyxis* Ehrenberg | <0.1 | 0.1 | 204 |
| *Mallomonas* Perty | 0.1 | 0.3 | 461 |
| *Ochromonas* Vysotskii [Wissotsky], *Chromulina* L. Cienkowsky, and *Chrysochromulina* Lackey | <0.1 | <0.1 | 18 |
| *Stichogloea* Chodat | 0.1 | 0.3 | 621 |
| *Stylochrysalis* F. Stein | <0.1 | <0.1 | 4 |
| | | | |
| Chrysophyta (diatoms) | | | |
| *Asterionella formosa* Hassall | 0.5 | 2.0 | 3,709 |
| *Aulacoseira* Thwaites | 0.4 | 1.9 | 3,368 |
| *Cyclotella* (Kützing) Brébisson and *Thalassiosira* Cleve | 2.7 | 11.7 | 21,308 |
| *Fragilaria* Lyngbye | 0.4 | 1.7 | 3,036 |
| *Melosira* C. Agardh | <0.1 | <0.1 | 22 |
| *Stephanodiscus* Ehrenberg | <0.1 | 0.2 | 284 |
| *Synedra* Ehrenberg | 0.6 | 2.6 | 4,745 |
| *Tabellaria fenistrata* (Lyngbye) Kützing | 0.7 | 2.9 | 5,231 |
| *Urosolenia longiseta* (O. Zacharias) Edlund & Stoermer | 0.4 | 1.8 | 3,217 |
| diatoms, misc | 0.2 | 0.9 | 1,580 |

Table 10: Total count and percent of Cyanobacteria (bluegreen algae) and Chrysophyta (golden algae and diatoms) in samples collected at the gatehouse, Intake (10 m), and Site 2 (10 m) between December 2009 and December 2012.

| | Pct. of Count Including *Aphanocapsa*/ *Aphanothece* | Pct. of Count Excluding *Aphanocapsa*/ *Aphanothece* | Total Count Including *Aphanocapsa*/ *Aphanothece* |
|---|---|---|---|
| Chlorophyta (green algae) | | | |
| *Ankistrodesmus* Corda | <0.1 | <0.1 | 4 |
| *Ankyra* Fott | <0.1 | <0.1 | 4 |
| *Asterococcus* Scherffel and *Planktosphaeria* G. M. Smith | <0.1 | 0.1 | 129 |
| *Botryococcus* Kützing | 0.5 | 2.0 | 3,604 |
| *Chlamydomonas* Ehrenberg | <0.1 | 0.1 | 133 |
| *Chlorella* M. Beijerinck | <0.1 | <0.1 | 13 |
| *Crucigenia tetrapedia* (Kirchner) Kuntze | 0.2 | 0.7 | 1,239 |
| *Crucigeniella* Lemmermann | <0.1 | <0.1 | 89 |
| *Dictyosphaerium pulchellum* H. C. Woods | 0.1 | 0.3 | 463 |
| *Elakatothrix gelatinosa* Wille | 0.1 | 0.3 | 624 |
| *Monoraphidium* Komárková-Legnerová | <0.1 | <0.1 | 18 |
| *Oocystis* Nägeli & A. Braun | 0.1 | 0.3 | 540 |
| *Pandorina morum* (O. F. Müller) Bory de Saint-Vincent | <0.1 | <0.1 | 35 |
| *Pediastrum* Meyen | <0.1 | 0.1 | 257 |
| *Pediastrum tetras* (Ehrenberg) Ralfs | <0.1 | <0.1 | 80 |
| *Quadrigula* Printz | <0.1 | 0.2 | 359 |
| *Scenedesmus* Meyen | 0.8 | 3.5 | 6,315 |
| *Sphaerocystis schroeteri* Chodat | 0.1 | 0.4 | 766 |
| *Tetraedron minimum* (A. Braun) Hansgirg | <0.1 | 0.2 | 292 |
| *Tetraspora lacustris* Lemmermann | 0.1 | 0.3 | 531 |
| desmids (misc.) | 0.1 | 0.3 | 602 |
| | | | |
| Pyrrhophyta (dinoflagellates | | | |
| *Gymnodinium* Stein | 0.1 | 0.3 | 460 |
| *Peridinium* Ehrenberg | <0.1 | 0.1 | 138 |
| *Peridinium umbonatum* F. Stein | 0.1 | 0.5 | 908 |
| | | | |
| Euglenophyta (euglenoids) | | | |
| *Trachelomonas* Ehrenberg | <0.1 | <0.1 | 13 |
| | | | |
| Cryptophyta (cryptomonads) | | | |
| *Cryptomonas* Ehrenberg | 0.5 | 1.9 | 3,532 |
| *Komma* D. R. A. Hill and *Chroomonas* Hansgirg | 1.9 | 8.0 | 14,595 |

Table 11: Total count and percent of Chlorophyta (green algae) and miscellaneous other types of algae in sampled collected at the gatehouse, Intake (10 m), and Site 2 (10 m) between December 2009 and December 2012.

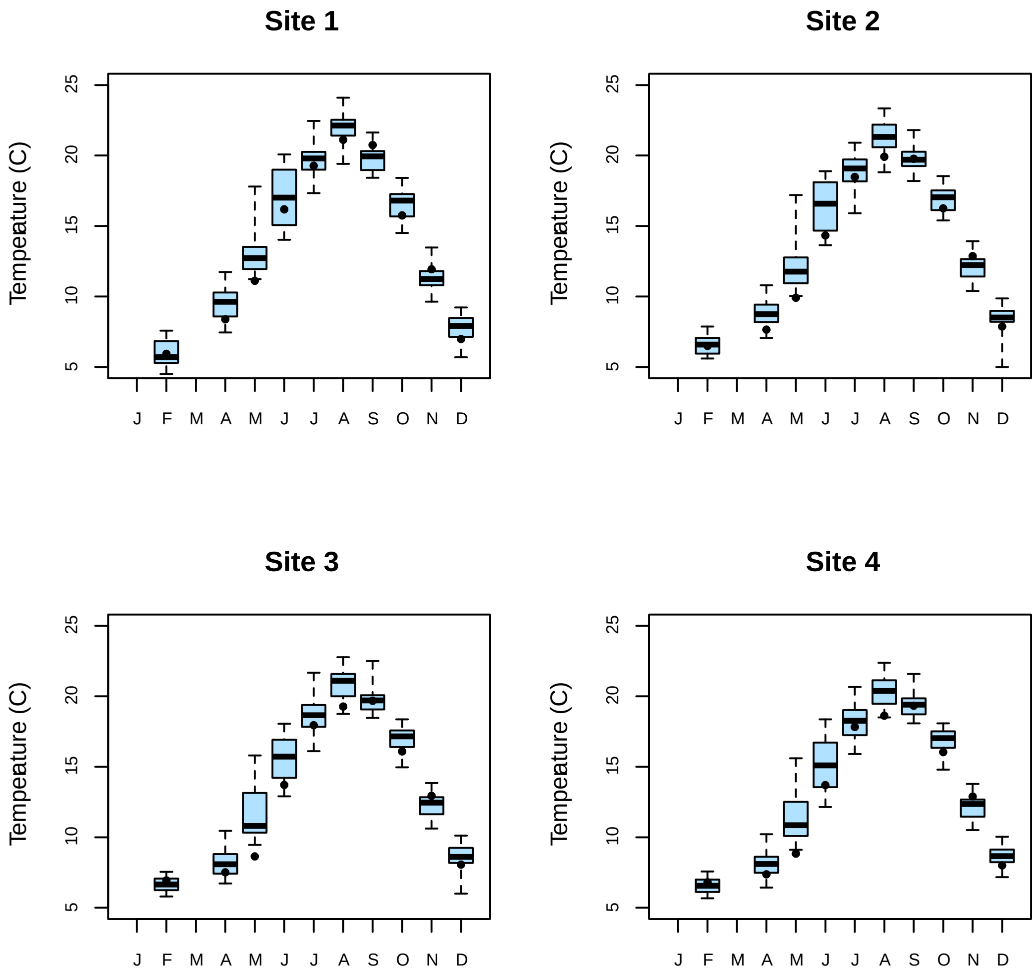


Figure 1: Boxplots showing 1988–2010 surface water temperatures (depth <1 m, all sites and years) with monthly 2011 data (●). Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

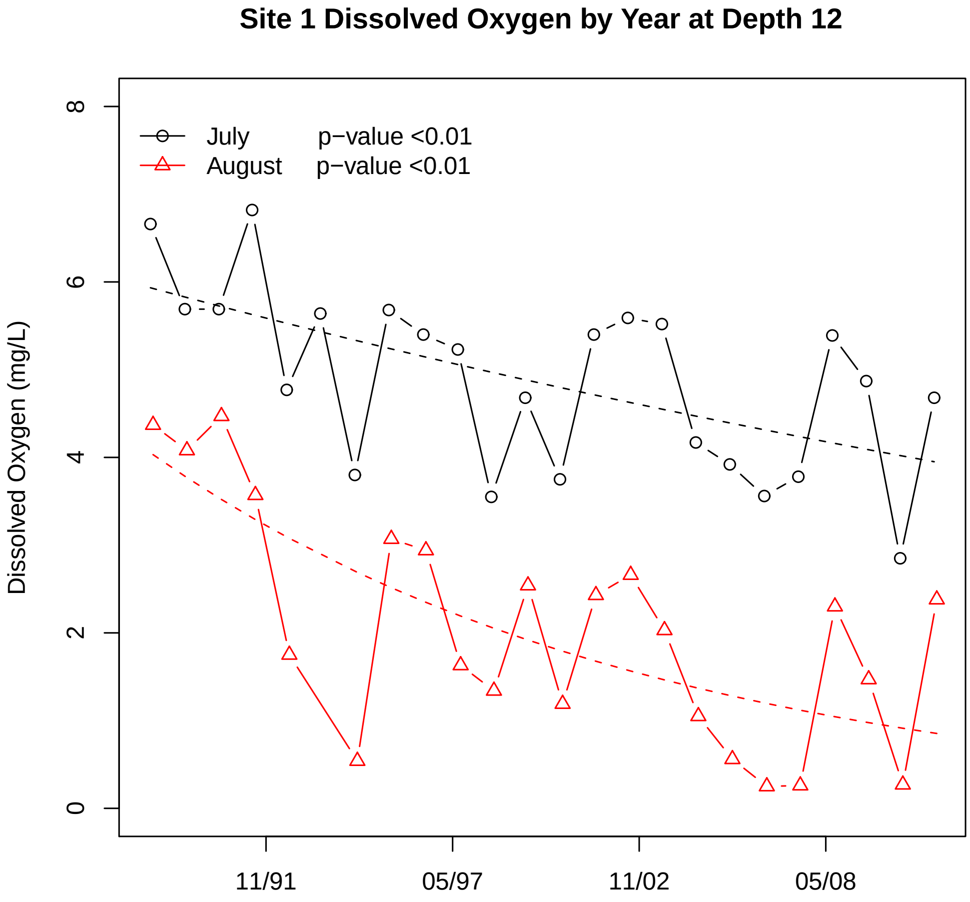


Figure 2: Relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

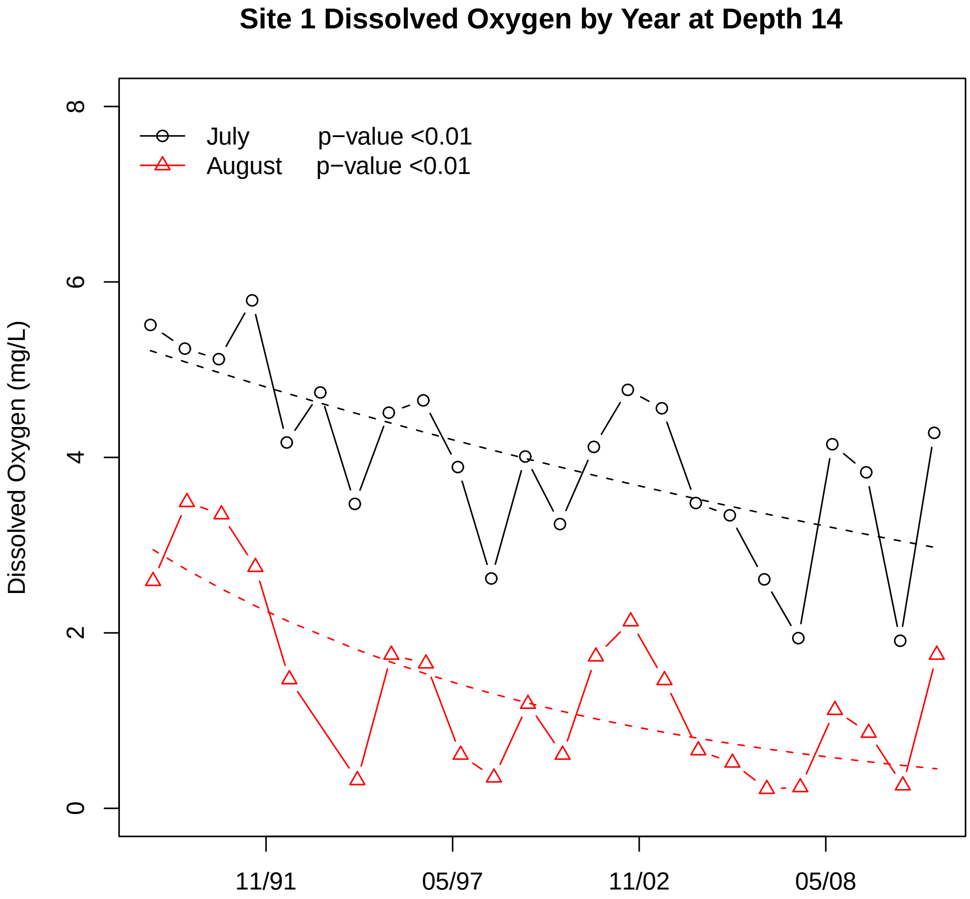


Figure 3: Relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

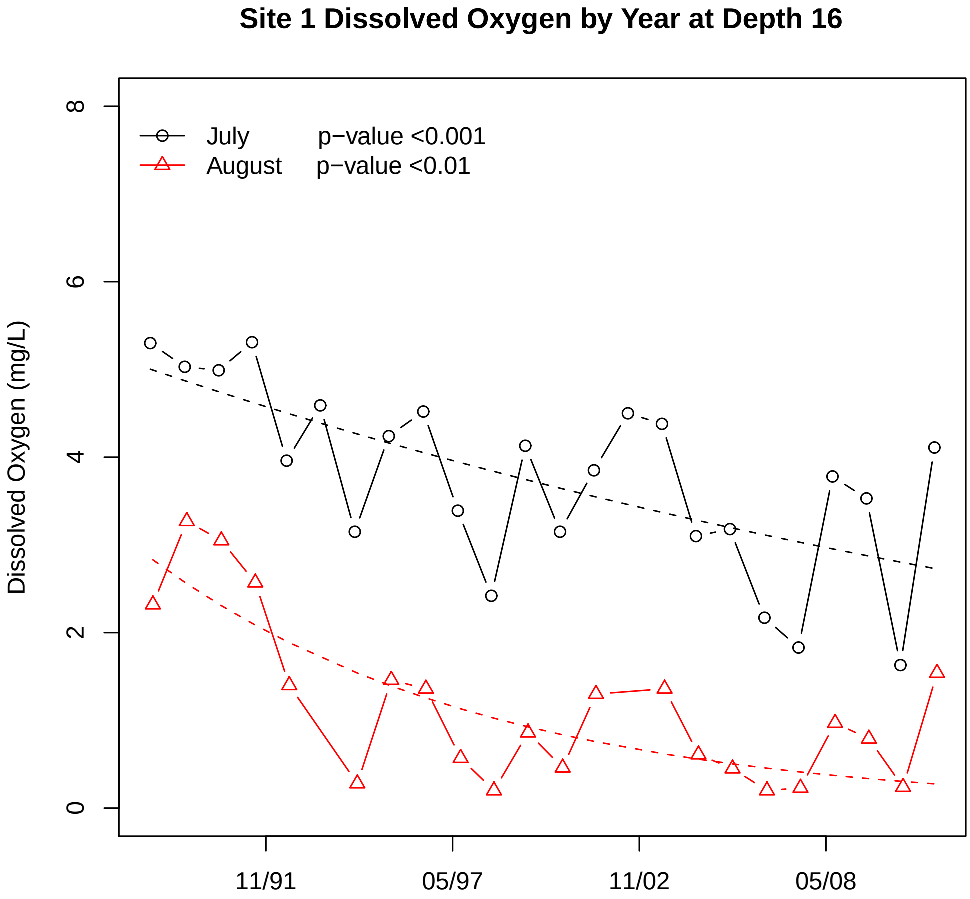


Figure 4: Relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

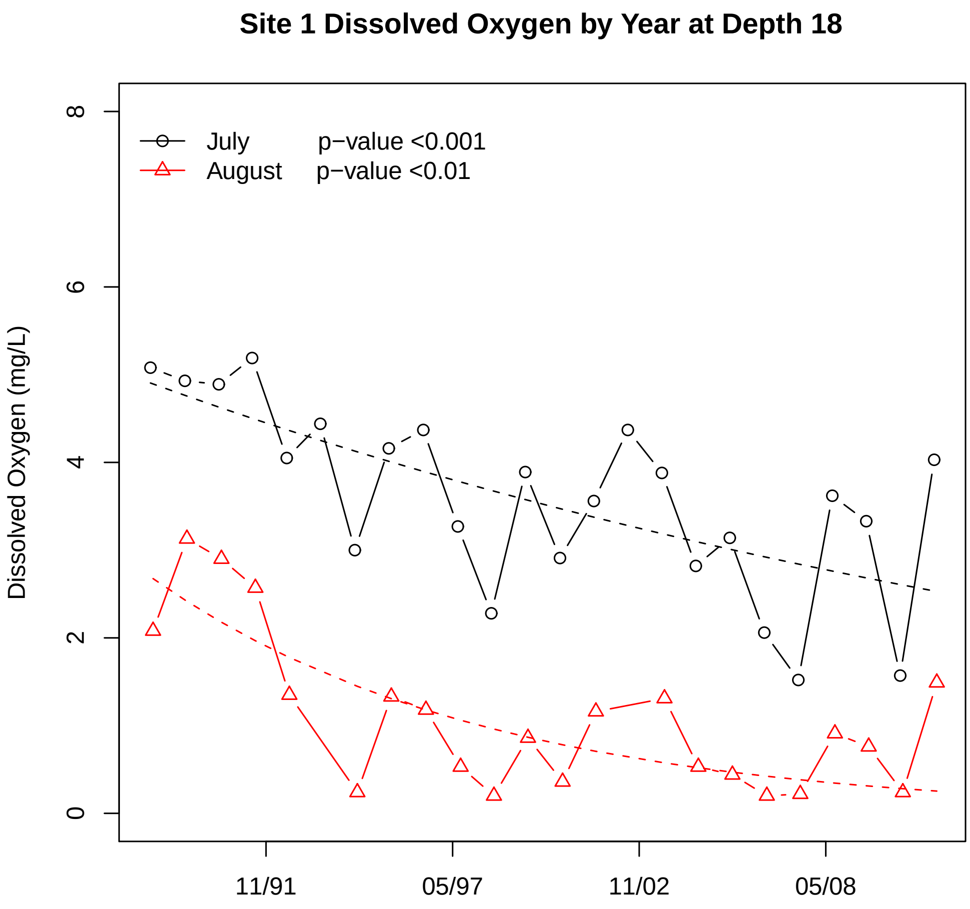


Figure 5: Relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

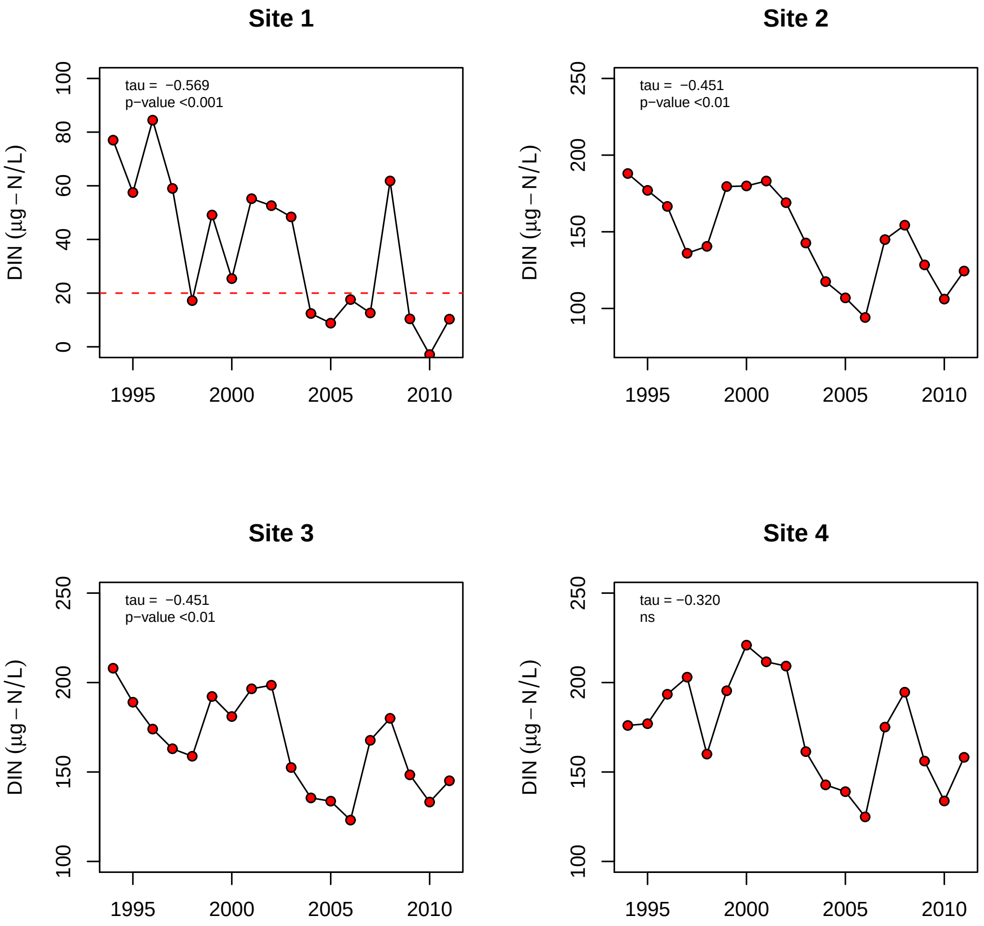


Figure 6: Minimum summer, near-surface dissolved inorganic nitrogen concentrations (1994–2011, June-Oct, depths $\leq$5 m). Uncensored (raw) data were used to illustrate that minimum values are dropping below analytical detection limits (dashed red line). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; correlations were significant at Sites 1–3.

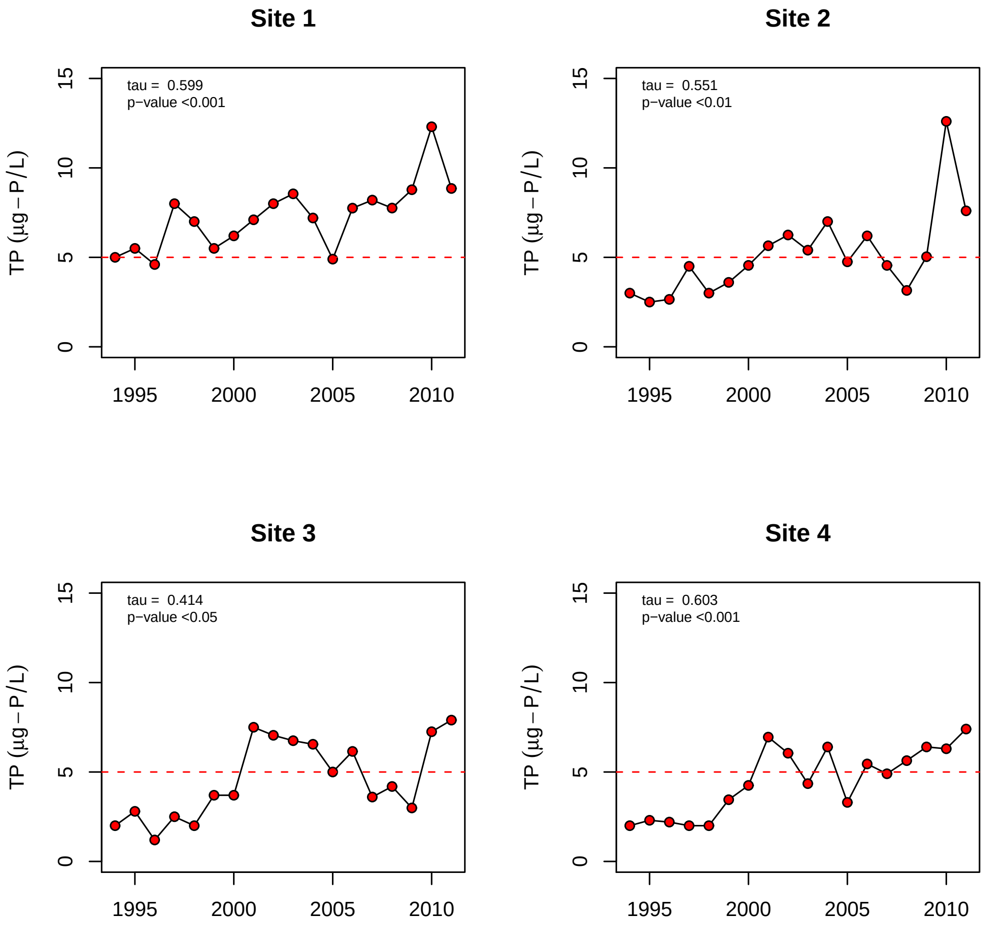


Figure 7: Median summer, near-surface total phosphorus concentrations (1994–2011, June-Oct, depths $\leq$5 m). Uncensored (raw) data were used to illustrate that median values are increasingly above analytical detection limits (dashed red line). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

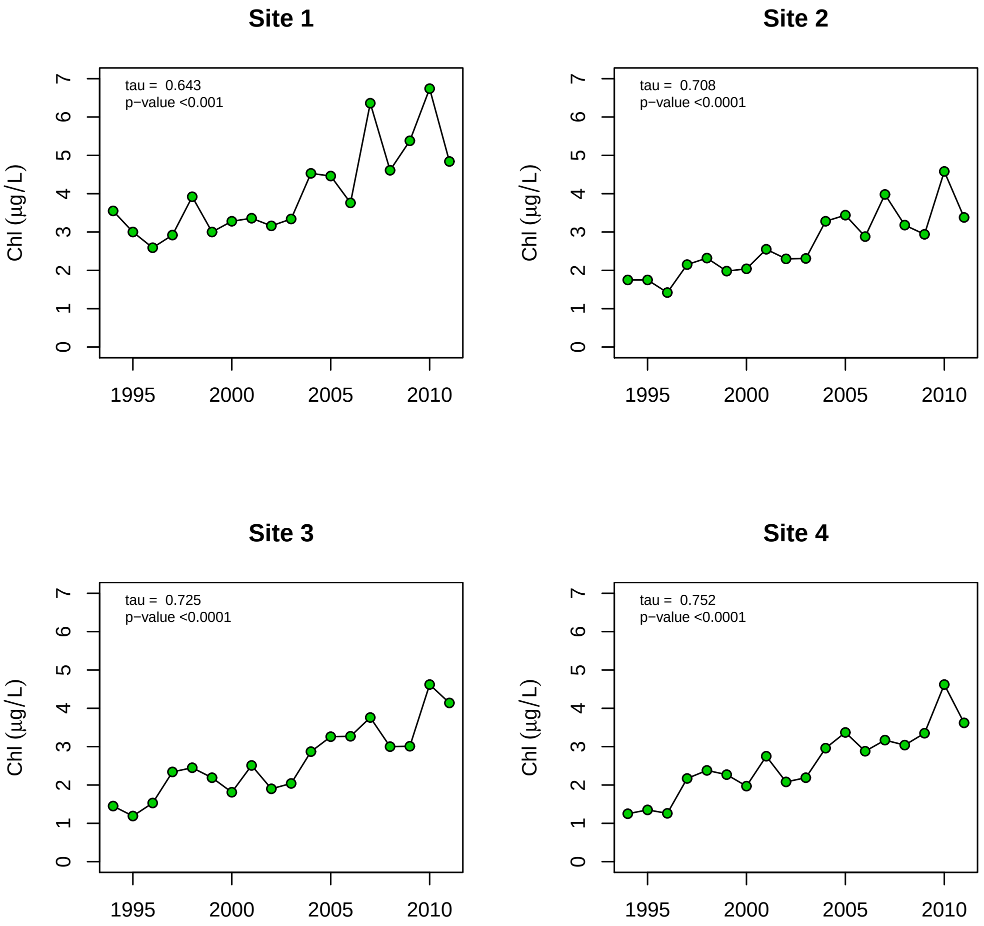
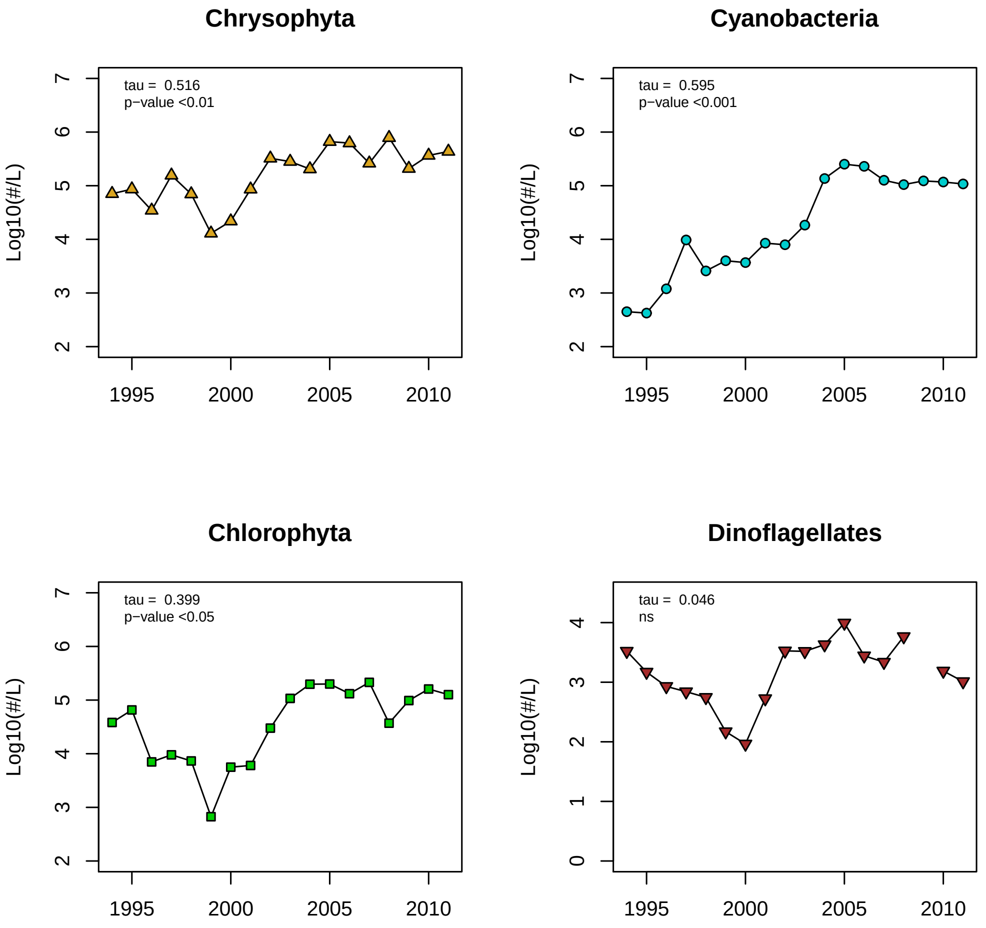


Figure 8: Median summer near-surface chlorophyll concentrations (1994–2010, June-October, depths $\leq$5 m). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.


Chrysophyta

Cyanobacteria

Chlorophyta

Dinoflagellates

Figure 9: $\text{Log}_{10}$ plots of median summer, near-surface algae counts (1994-2011, June-October, all sites and depths). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations except Dinoflagellates were significant.

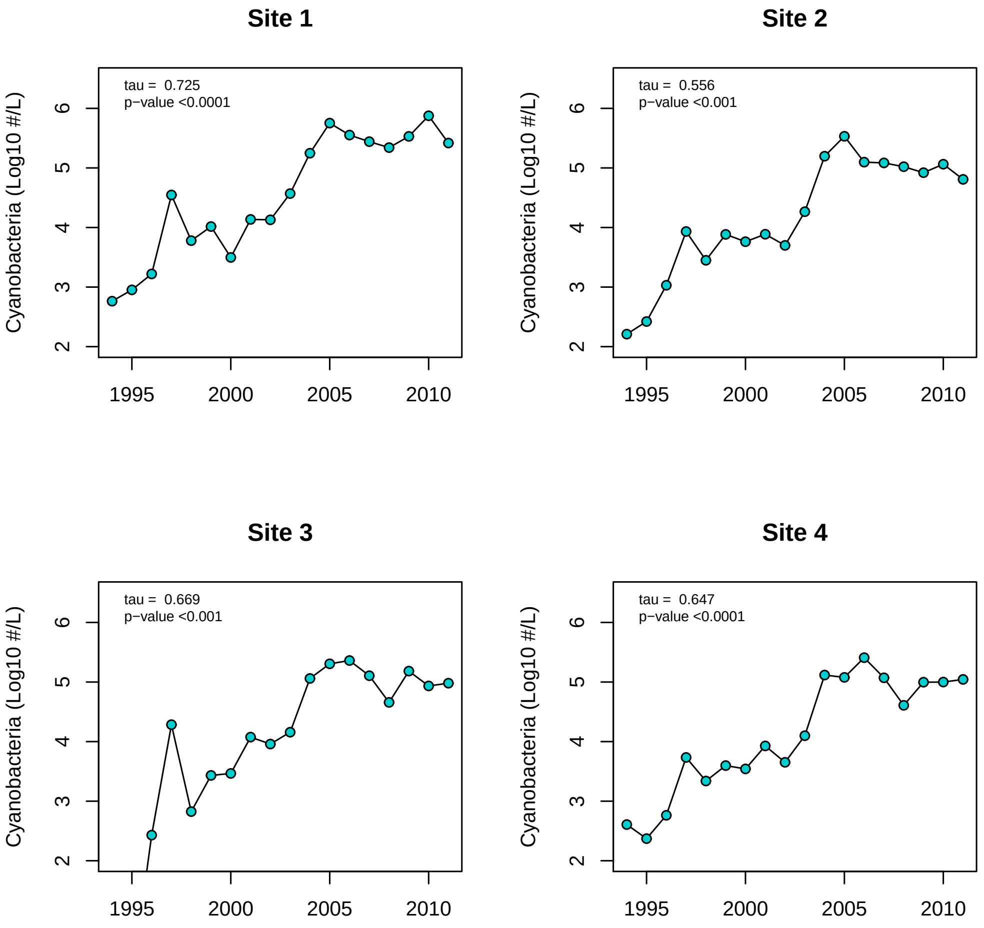


Figure 10: Log$_{10}$ plots of median summer, near-surface Cyanobacteria counts (1994–2010, June-October, depths $\leq$5 m). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

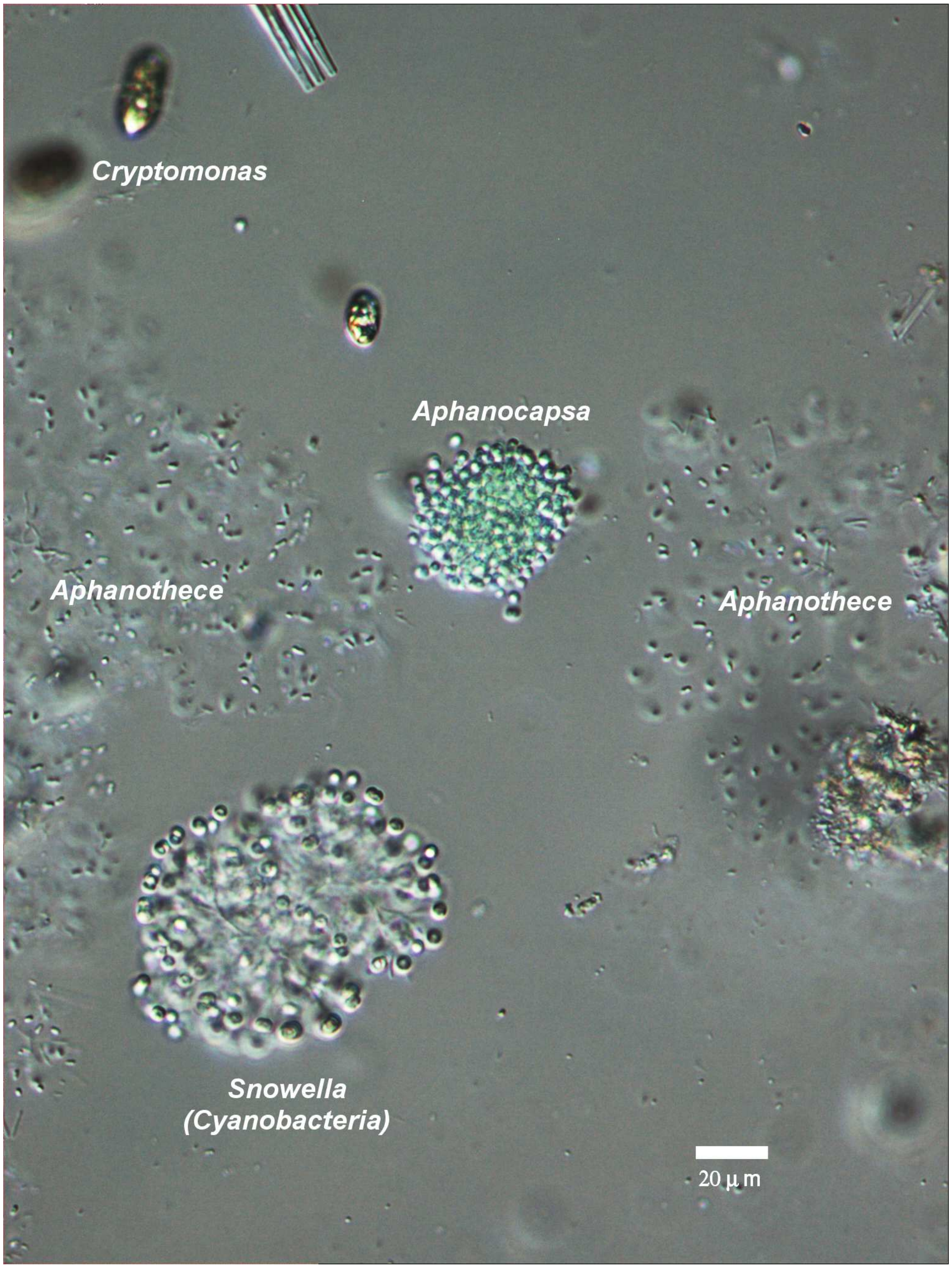


Figure 11: Lake Whatcom *Aphanocapsa* and *Aphanothece* colonies. Several other common Lake Whatcom algae taxa are also shown, including *Snowella* and *Cryptomonas*. See Tables 10–11 (pages 26–27) for a list of algae found in the lake.

Figure 12: *Cyclotella* cell showing extracellular fibers. See Tables 10–11 (pages 26–27) for a list of algae found in the lake.

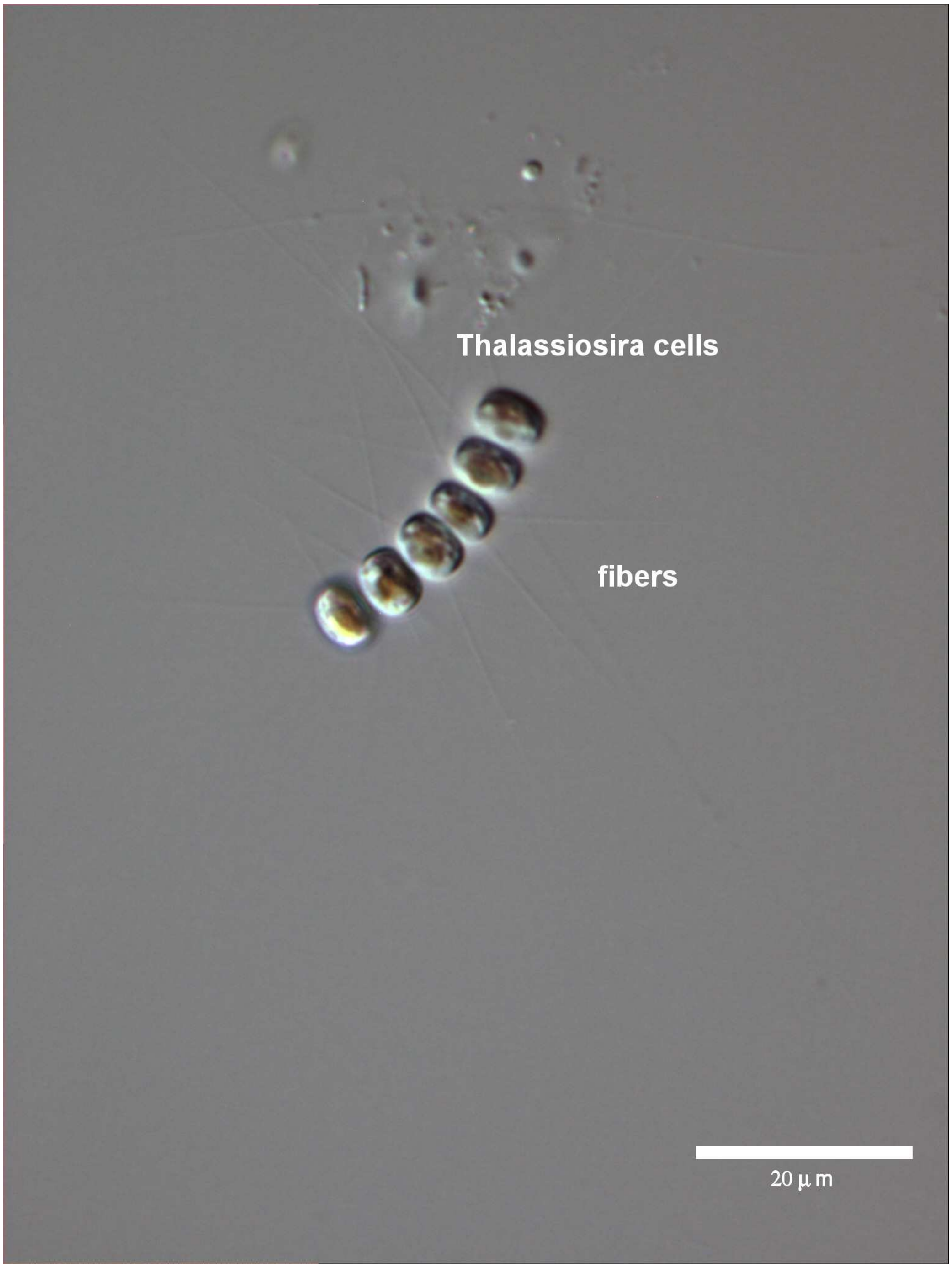
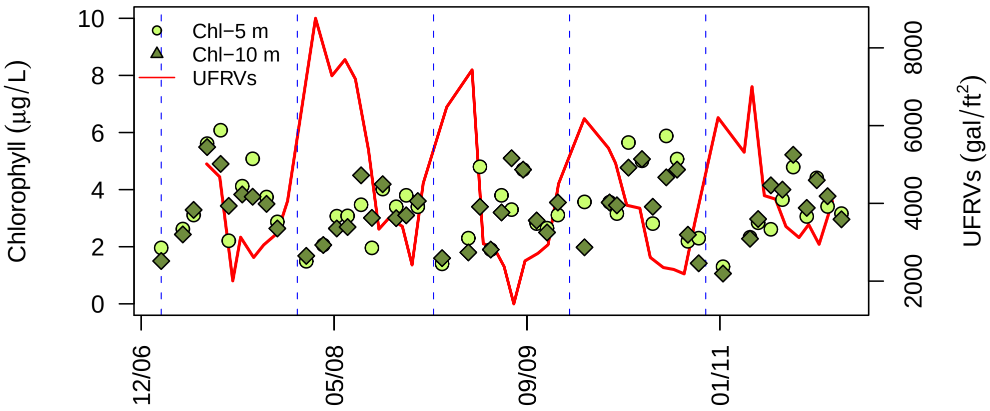


Figure 13: *Thalassiosira* cells showing extracellular fibers. See Tables 10–11 (pages 26–27) for a list of algae found in the lake.



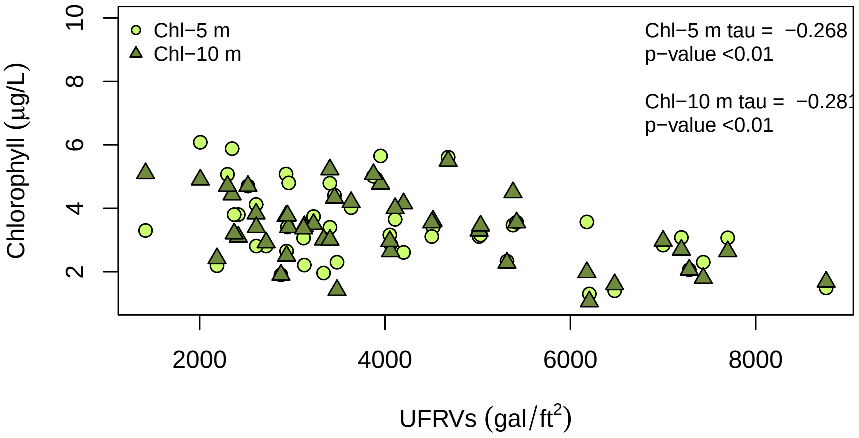


Figure 14: Intake chlorophyll concentrations at 5 and 10 meters vs. UFRVs, 2007–2011. Upper figure shows the chlorophyll concentrations ($\mu$g/L) and UFRVs (gal/ft$^2$) over time. The lower figure show the significant correlations between chlorophyll concentrations and UFRVs. Vertical blue lines show Jan. 1 of each year.

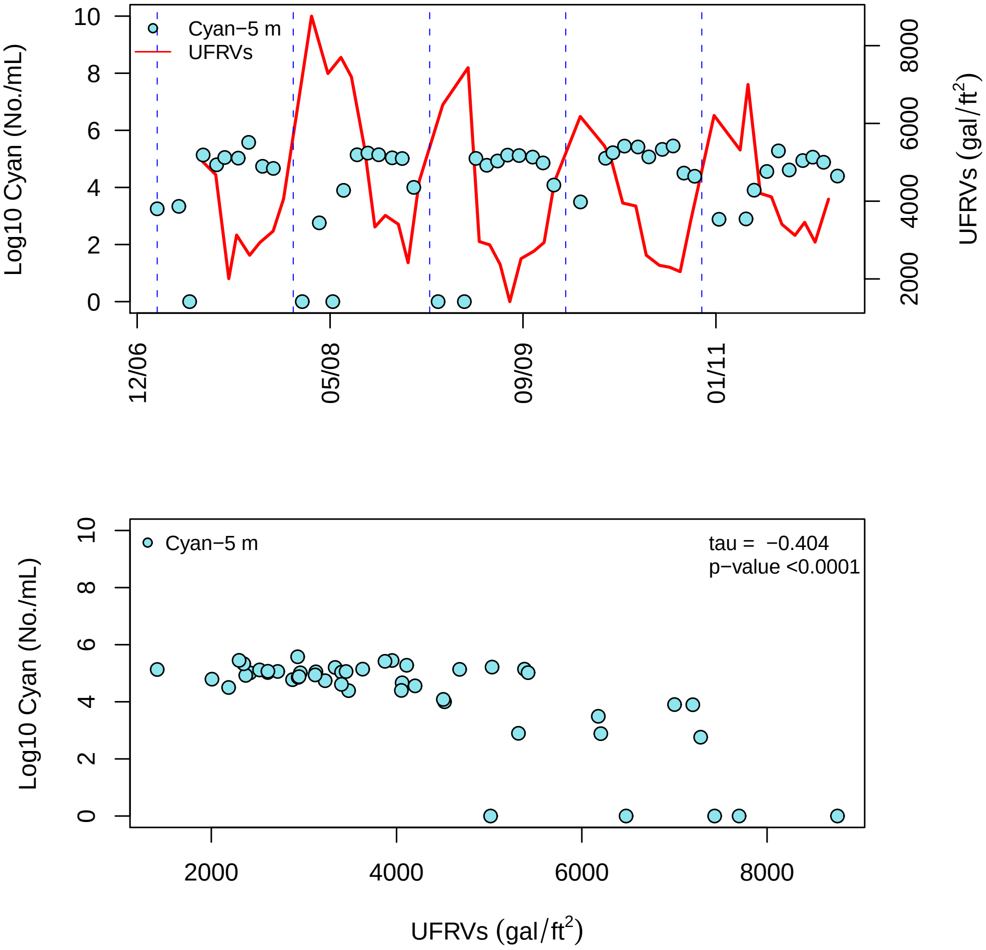
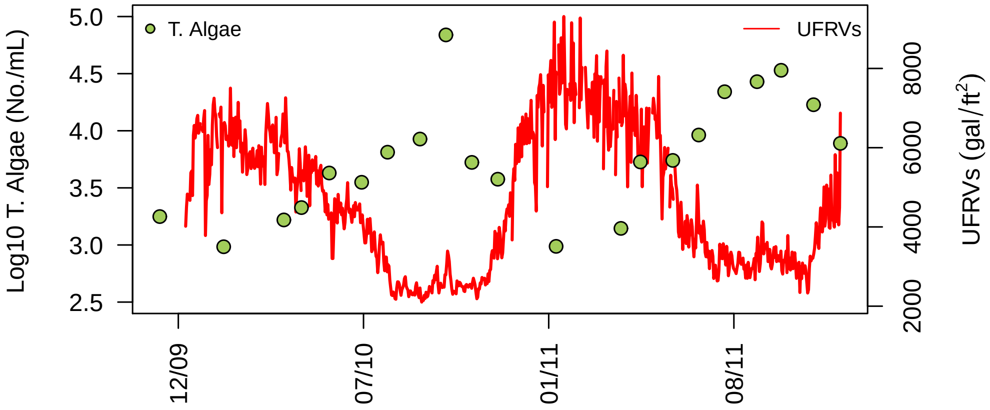


Figure 15: Intake Cyanobacteria counts (5 meters) vs. UFRVs, 2007–2011. The upper figure shows cyanobacteria collected using a plankton net (cells/mL or colonies/mL) and UFRVs (gal/ft$^2$) over time. The lower figure show the significant correlation between cyanobacteria counts and UFRVs. *Aphanocapsa*, *Aphanothece*, and similar Cyanobacteria were counted as colonies. Vertical blue lines show Jan. 1 of each year.



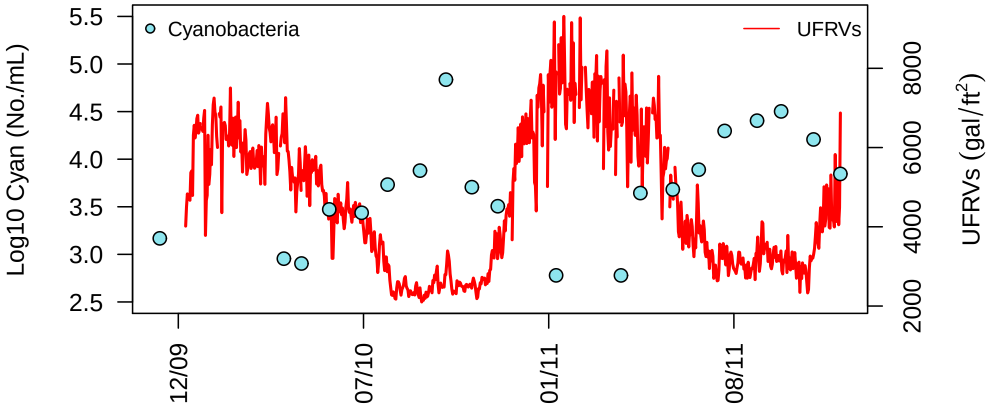


Figure 16: Gatehouse total algae and settled Cyanobacteria counts vs. UFRVs, December 2009–November 2011. Upper figure shows total algae counts (cells/mL) and UFRVs (gal/ft$^2$) over time. The lower figure shows Cyanobacteria counts (cells/mL) and UFVRs over time. *Aphanocapsa*, *Aphanothece* and similar Cyanobacteria were counted using cell estimates and dominated most of the total cell counts. February 9, 2010 cyanobacteria count is not plotted (off-scale – 0 cells/mL).

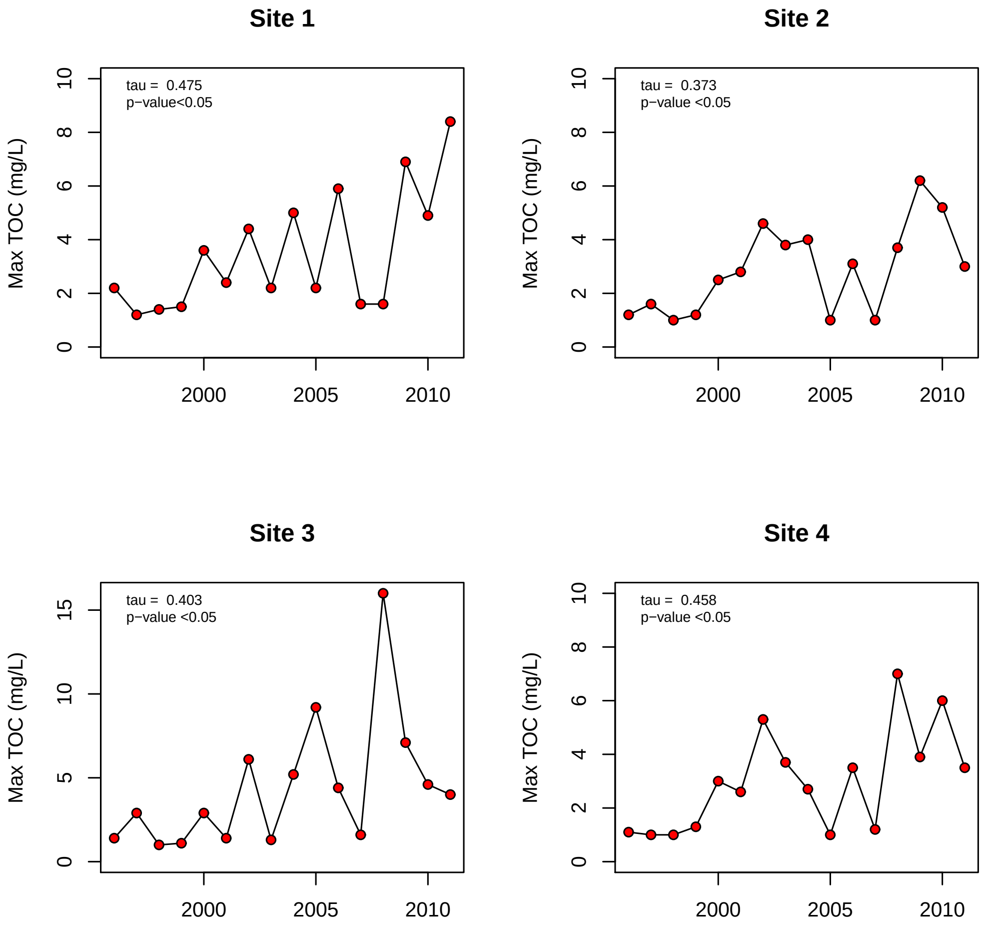


Figure 17: Maximum annual total organic carbon concentrations at Sites 1–4. Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

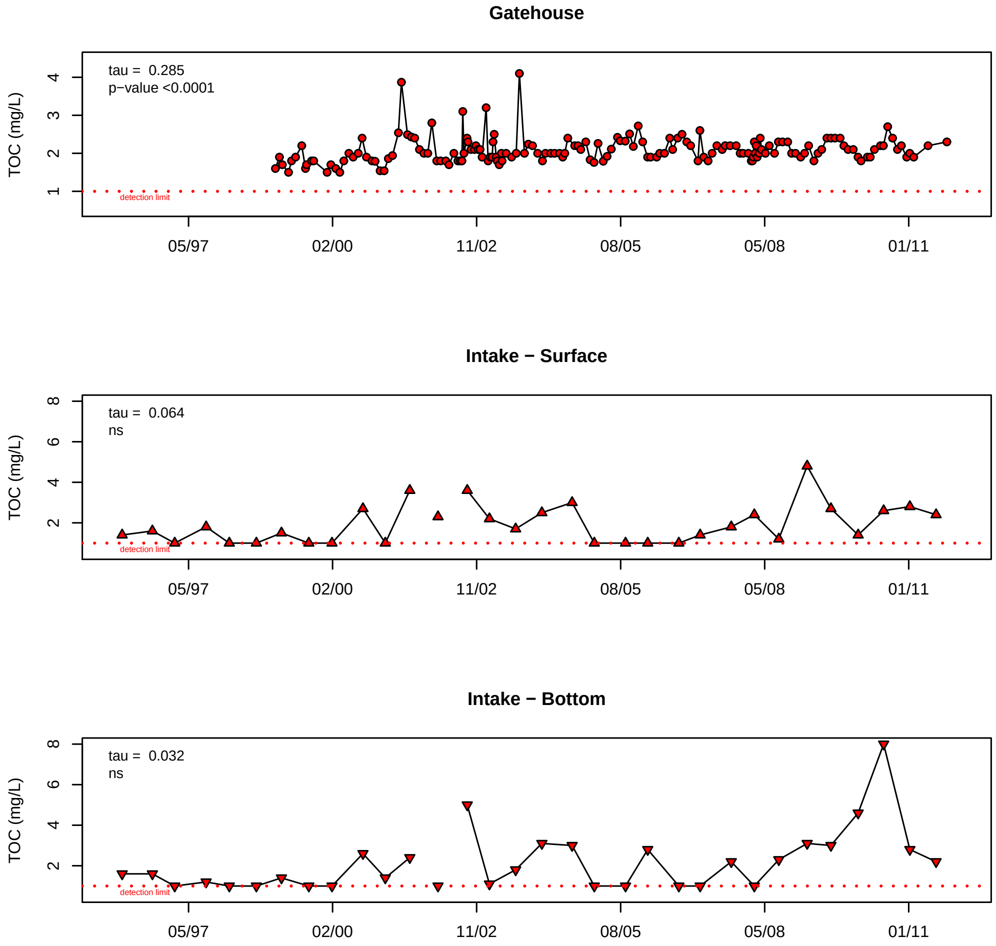


Figure 18: Total organic carbon concentrations at the Intake (off-shore, surface and bottom) and gatehouse. Gatehouse data were provided by the City of Bellingham Public Works Department. Kendall's $\tau$ correlations were used because the data were not monotonic-linear; only the gatehouse correlation was significant.

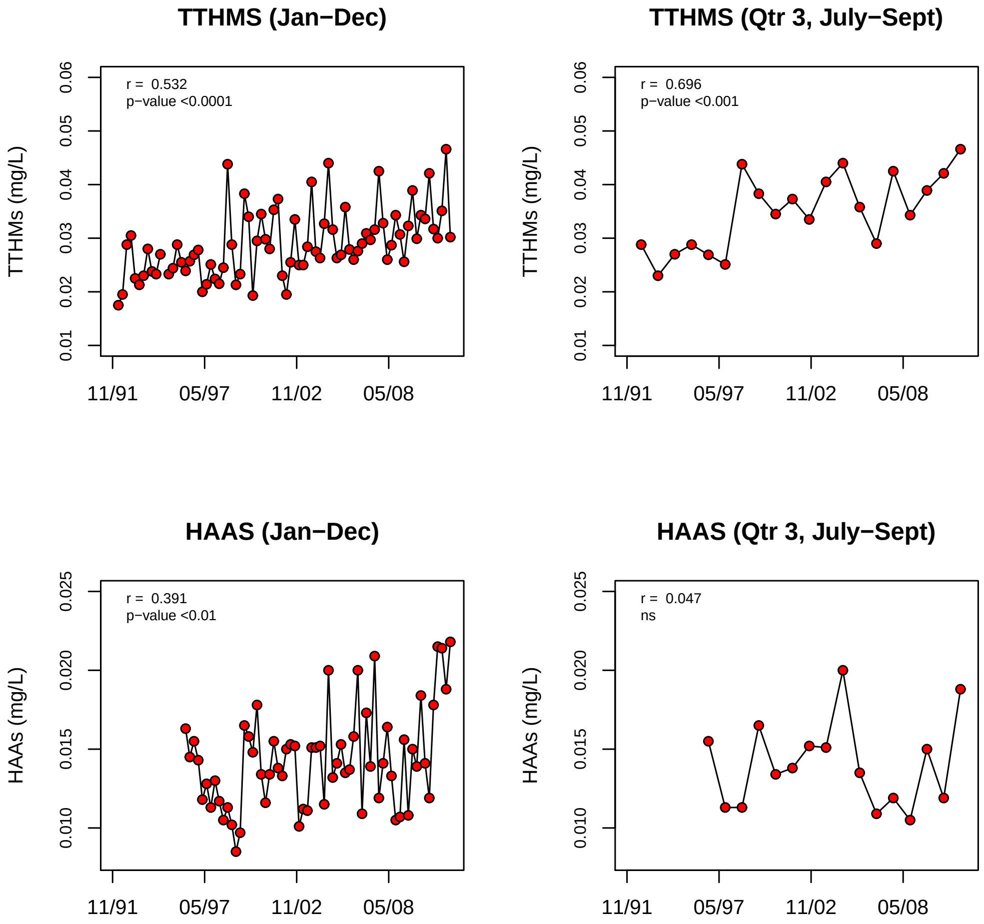


Figure 19: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2011. Data were provided by the City of Bellingham Public Works Department. Kendall's $\tau$ correlations were used because the data were not monotonic-linear; correlations for THMS (Jan-Dec and Qtr 3) and Jan-Dec HAAs were significant.

# 3 Tributary Monitoring

The major objective for the tributary monitoring was to provide baseline data for the major tributaries that flow into Lake Whatcom. Whatcom Creek was also sampled to provide baseline data for the lake's outlet. Monthly samples were collected from 2004–2006. The level of effort was reduced from 2007–2009, with samples collected twice each year. Beginning in January 2010, monthly sampling was reinitiated, and is scheduled to continue through 2012.

## 3.1 Site Descriptions

Samples were collected from Anderson, Austin, Blue Canyon, Brannian, Carpenter, Euclid, Mill Wheel, Olsen, Silver Beach, Smith, and Whatcom Creeks and the Park Place drain. The sampling locations for these sites are described in Appendix A.2 and shown on Figure A2, page 106.

## 3.2 Field Sampling and Analytical Methods

The tributaries were sampled on October 12, November 9, and December 7, 2010; and on January 11, February 8, March 8, April 19, May 20, Jun 1, July 11, August 9, and September 13, 2011.

The analytical procedures for sampling the tributaries are summarized in Table 1 (page 17). All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory. Once in the laboratory the handling procedures that were relevant for each analysis were followed (see Table 1). The bacteria samples were analyzed by the City of Bellingham. Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.[18] All other analyses were done by WWU.

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[18] AmTest, 13600 Northeast 126th Place, Suite C, Kirkland, WA, 98034–8720.

## 3.3 Results and Discussion

The monthly data are summarized in Tables 12–24 (pages 50–62) and the biannual metals and total organic carbon data are listed in Tables 25–26 (pages 63–64). Historic data from 2004 through the current monitoring period are plotted in Appendix B.4 (Figures B131–B169, pages 244–282). These figures include a dashed (blue) horizontal line that shows the median value for Smith Creek and a solid (red) horizontal line that shows the median value for each creek. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted.

Water temperatures and dissolved oxygen concentrations followed predictable seasonal cycles, with most sites having colder temperatures and higher oxygen concentrations during the winter, and warmer temperatures and lower oxygen concentrations during the summer (Figures B131–B136). Whatcom Creek had higher temperatures and lower oxygen concentrations than most other sites, reflecting the influence of Lake Whatcom (Figures B131 and B134). The residential tributaries (Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) often had slightly elevated temperatures and lower dissolved oxygen concentrations, which is typical for streams in developed watersheds (Figures B133 and B136).

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by pH levels near 6.5–7.5, median conductivities $\leq$100 $\mu$S, and median alkalinities $\leq$20 mg/L (Table 24; Figures B137–B145). Sites that did not match this description included the residential tributaries (Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$5 mg/L) and low turbidities ($\leq$5 NTU) except during periods of high precipitation and runoff (Figures B146–B151).

Ammonium concentrations were generally low ($\leq$10 $\mu$g-N/L) except in the residential streams (Table 24; Figures B152–B154). Ammonium does not persist long in oxygenated surface waters. When present in streams, it usually indicates a near-by source such as an upstream wetland with anaerobic soils or a pollution source.

Most of the creeks had lower total nitrogen and nitrate/nitrate concentrations than Smith Creek (Figures B155– B160). The relatively high nitrate and total nitrogen concentrations in Smith Creek is probably due to the presence of nitrogen-fixing alders (*Alnus rubra*) in the riparian zone upstream from the sampling site. High nitrate and total nitrogen concentrations are not necessarily an indication of water pollution, and low nitrate concentrations actually favor the growth of nuisance Cyanobacteria. The exceptionally low concentrations in Whatcom Creek reflect algal uptake of nitrogen in the lake.

Soluble inorganic phosphate is quickly removed from surface water by biota, so high concentrations of soluble phosphate usually indicate a near-by source such as an anaerobic wetland or a pollution source. In 2010/2011, the median soluble phosphate concentrations were $\leq$10 $\mu$g-P/L at all sites except Euclid and Silver Beach Creeks and the Park Place drain. The historic data indicate that although soluble phosphate concentrations were generally low, nearly all sites have had a few high peaks, and high concentrations were common in residential streams.

Total phosphorus concentrations were higher than soluble phosphate concentrations (Figures B161–B166). The median 2010/2011 concentrations were $\leq$20 $\mu$g-P/L at all sites except Euclid, Mill Wheel, and Silver Beach Creeks and the Park Place drain. As with soluble phosphate, nearly all sites have had occasional high total phosphorus peaks, and high concentrations were common in samples from residential sites.

High coliform counts are an indicator of residential pollution (Table 24; Figures B167–B169). Although most of the sites had low coliform counts in 2010/2011, three sites exceeded a geometric mean of 50 cfu/100 mL (Carpenter, Millwheel, and Silver Beach Creeks) and five sites had more than 10% of the samples with counts $>$100 cfu/100 mL (Carpenter, Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain).

The total organic carbon and metals concentrations were within expected ranges for surface waters in the watershed (Tables 25–26). Most of the metals concentrations were at or below detection levels. Chromium, copper, iron, and zinc were often detectable, but were within normal ranges . Lead was often detected, but as indicated in Section 2.3.8 (page 15), this represents a change in the analytical method, not an increase in the lead levels. All of the lead concentrations were less than or equal to the historic detection level of 0.001 mg/L.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 15.3 | 17.3 | 17.6 | 22.5 |
| Conductivity ($\mu$S/cm) | 46.4 | 55.6 | 56.4 | 65.3 |
| Dissolved oxygen (mg/L) | 9.3 | 11.4 | 11.4 | 13.3 |
| pH | 6.8 | 7.0 | 7.0 | 7.2 |
| Temperature (°C) | 2.8 | 7.8 | 8.0 | 12.5 |
| Total suspended solids (mg/L) | $<2$ | 2.7 | 4.5 | 18.2 |
| Turbidity (NTU) | 0.7 | 2.4 | 5.0 | 22.7 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | 27.5 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 62.7 | 467.9 | 390.4 | 661.9 |
| Nitrogen - total ($\mu$g-N/L) | 160.1 | 615.0 | 509.6 | 776.9 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 5.1 | 6.3 | 6.8 | 11.1 |
| Phosphorus - total ($\mu$g-P/L) | 10.5 | 16.0 | 19.8 | 47.2 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 13 | 9 | 46 |
| (Percent of samples $>$100 cfu/100 mL = 0) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 12: Summary of Anderson Creek water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 12.3 | 15.5 | 19.6 | 38.0 |
| Conductivity ($\mu$S/cm) | 48.0 | 57.3 | 72.8 | 141.9 |
| Dissolved oxygen (mg/L) | 9.7 | 11.7 | 11.6 | 13.5 |
| pH | 7.2 | 7.3 | 7.4 | 7.7 |
| Temperature (°C) | 2.9 | 7.8 | 8.2 | 13.7 |
| Total suspended solids (mg/L) | $<2$ | $<2$ | 2.1 | 6.7 |
| Turbidity (NTU) | 0.5 | 1.5 | 1.8 | 4.9 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | 12.5 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 238.4 | 504.5 | 495.6 | 836.5 |
| Nitrogen - total ($\mu$g-N/L) | 300.1 | 612.4 | 590.1 | 920.6 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 5.5 | 7.6 | 8.5 | 12.5 |
| Phosphorus - total ($\mu$g-P/L) | 8.6 | 15.1 | 14.5 | 17.8 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | 1 | 13 | 14 | 120 |
| (Percent of samples $>$100 cfu/100 mL = 8) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 13: Summary of Austin Creek water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 81.5 | 133.3 | 129.4 | 157.9 |
| Conductivity ($\mu$S/cm) | 199.8 | 286.0 | 275.7 | 310.0 |
| Dissolved oxygen (mg/L) | 9.8 | 11.6 | 11.7 | 14.1 |
| pH | 8.0 | 8.3 | 8.3 | 8.4 |
| Temperature (°C) | 2.7 | 8.5 | 8.6 | 14.8 |
| Total suspended solids (mg/L) | $<2$ | 2.1 | 2.3 | 3.8 |
| Turbidity (NTU) | 0.9 | 1.9 | 2.0 | 3.6 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | 16.0 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 128.4 | 305.1 | 339.0 | 904.8 |
| Nitrogen - total ($\mu$g-N/L) | 186.4 | 404.5 | 482.2 | 1056.7 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 6.5 | 9.1 | 9.0 | 11.5 |
| Phosphorus - total ($\mu$g-P/L) | $<5$ | 11.7 | 10.7 | 14.8 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 7 | 5 | 32 |
| (Percent of samples $>$100 cfu/100 mL = 0) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);

[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 14: Summary of Blue Canyon Creek water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 7.0 | 8.9 | 11.0 | 23.4 |
| Conductivity ($\mu$S/cm) | 33.7 | 39.6 | 41.2 | 62.2 |
| Dissolved oxygen (mg/L) | 0.8 | 11.4 | 10.4 | 13.3 |
| pH | 6.6 | 6.9 | 6.9 | 7.1 |
| Temperature (°C) | 3.0 | 8.1 | 8.3 | 13.9 |
| Total suspended solids (mg/L) | $<$2 | $<$2 | $<$2 | 2.6 |
| Turbidity (NTU) | 0.1 | 1.3 | 1.2 | 2.1 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<$10 | $<$10 | $<$10 | 13.1 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 170.2 | 526.4 | 550.8 | 1023.9 |
| Nitrogen - total ($\mu$g-N/L) | 220.6 | 655.7 | 643.9 | 1111.0 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | $<$5 | $<$5 | $<$5 | 5.9 |
| Phosphorus - total ($\mu$g-P/L) | $<$5 | 10.0 | 10.6 | 25.0 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<$1 | 4 | 4 | 12 |
| (Percent of samples $>$100 cfu/100 mL = 0) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 15: Summary of Brannian Creek water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 13.9 | 19.0 | 24.1 | 45.0 |
| Conductivity ($\mu$S/cm) | 60.3 | 68.6 | 75.9 | 115.7 |
| Dissolved oxygen (mg/L) | 9.4 | 11.4 | 11.4 | 13.7 |
| pH | 7.3 | 7.4 | 7.4 | 7.7 |
| Temperature (°C) | 2.5 | 7.9 | 8.6 | 15.4 |
| Total suspended solids (mg/L) | $<2$ | 2.1 | 2.0 | 3.3 |
| Turbidity (NTU) | 0.7 | 3.3 | 3.1 | 4.9 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | $<10$ |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 294.5 | 889.1 | 855.3 | 1747.0 |
| Nitrogen - total ($\mu$g-N/L) | 428.4 | 1160.0 | 1083.3 | 1954.7 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 5.2 | 7.6 | 10.5 | 20.7 |
| Phosphorus - total ($\mu$g-P/L) | 16.3 | 19.6 | 20.0 | 25.8 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | 31 | 100 | 94 | 370 |
| (Percent of samples $>$100 cfu/100 mL = 55) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);

[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 16: Summary of Carpenter Creek water quality data, Oct. 2010–Sept. 2011. Carpenter Creek had negligible flow on September 13, 2011; no water quality samples were collected under these conditions.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 20.8 | 26.6 | 33.8 | 57.6 |
| Conductivity ($\mu$S/cm) | 80.0 | 101.9 | 107.3 | 141.9 |
| Dissolved oxygen (mg/L) | 8.2 | 10.8 | 10.7 | 12.3 |
| pH | 7.1 | 7.4 | 7.3 | 7.5 |
| Temperature (°C) | 3.6 | 8.4 | 8.6 | 14.0 |
| Total suspended solids (mg/L) | $<2$ | 2.8 | 3.5 | 13.1 |
| Turbidity (NTU) | 1.1 | 3.7 | 3.9 | 11.2 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | 28.9 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 109.3 | 504.1 | 576.3 | 1123.4 |
| Nitrogen - total ($\mu$g-N/L) | 255.6 | 776.9 | 747.8 | 1291.5 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 7.2 | 11.1 | 11.5 | 17.4 |
| Phosphorus - total ($\mu$g-P/L) | 17.6 | 23.0 | 23.7 | 30.9 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | 6 | 36 | 43 | 390 |
| (Percent of samples $>$100 cfu/100 mL = 27) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 17: Summary of Euclid Creek water quality data, Oct. 2010–Sept. 2011. Euclid Creek had negligible flow on September 13, 2011; no water quality samples were collected under these conditions.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 19.4 | 32.1 | 38.6 | 79.7 |
| Conductivity ($\mu$S/cm) | 80.3 | 91.5 | 106.9 | 174.1 |
| Dissolved oxygen (mg/L) | 1.0 | 11.0 | 9.7 | 12.9 |
| pH | 7.1 | 7.3 | 7.3 | 7.9 |
| Temperature (°C) | 3.0 | 8.1 | 9.4 | 20.5 |
| Total suspended solids (mg/L) | $<2$ | 5.6 | 9.5 | 35.8 |
| Turbidity (NTU) | 4.4 | 7.4 | 8.5 | 17.2 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | 43.9 | 291.7 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | $<20$ | 684.7 | 829.8 | 1932.3 |
| Nitrogen - total ($\mu$g-N/L) | 523.3 | 1250.7 | 1318.4 | 2231.8 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 6.7 | 8.5 | 10.0 | 22.6 |
| Phosphorus - total ($\mu$g-P/L) | 22.4 | 32.8 | 52.8 | 180.3 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | 40 | 120 | 149 | 1100 |
| (Percent of samples >100 cfu/100 mL = 70) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);

[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 18: Summary of Millwheel Creek water quality data, Oct. 2010–Sept. 2011. Millwheel Creek had negligible flow on August 9 and September 13, 2011; no water quality samples were collected under these conditions.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 12.4 | 16.6 | 22.1 | 48.9 |
| Conductivity ($\mu$S/cm) | 47.3 | 59.7 | 68.8 | 129.8 |
| Dissolved oxygen (mg/L) | 9.7 | 11.5 | 11.6 | 13.9 |
| pH | 7.2 | 7.3 | 7.4 | 7.8 |
| Temperature (°C) | 2.4 | 7.7 | 8.6 | 15.1 |
| Total suspended solids (mg/L) | $<2$ | 3.3 | 6.0 | 25.4 |
| Turbidity (NTU) | 0.6 | 3.2 | 4.6 | 17.6 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | 11.0 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 420.1 | 742.4 | 805.8 | 1356.6 |
| Nitrogen - total ($\mu$g-N/L) | 498.6 | 875.5 | 915.5 | 1478.4 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 5.3 | 9.5 | 10.8 | 18.2 |
| Phosphorus - total ($\mu$g-P/L) | 11.1 | 18.4 | 18.4 | 23.6 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 11 | 7 | 106 |
| (Percent of samples $>100$ cfu/100 mL = 9) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 19: Summary of Olsen Creek water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 63.6 | 88.5 | 86.0 | 110.3 |
| Conductivity ($\mu$S/cm) | 174.2 | 221.0 | 224.7 | 289.0 |
| Dissolved oxygen (mg/L) | 7.2 | 10.0 | 9.7 | 11.9 |
| pH | 7.4 | 7.5 | 7.6 | 8.0 |
| Temperature (°C) | 5.1 | 11.1 | 11.5 | 18.8 |
| Total suspended solids (mg/L) | $<2$ | $<2$ | $<2$ | 3.4 |
| Turbidity (NTU) | 1.3 | 2.4 | 2.7 | 4.8 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | 18.1 | 28.2 | 83.6 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 161.9 | 514.9 | 599.8 | 1211.9 |
| Nitrogen - total ($\mu$g-N/L) | 423.3 | 775.8 | 851.6 | 1468.4 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 14.5 | 23.4 | 24.8 | 47.2 |
| Phosphorus - total ($\mu$g-P/L) | 25.4 | 35.2 | 40.4 | 73.5 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | 8 | 35 | 35 | 160 |
| (Percent of samples $>$100 cfu/100 mL = 17) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 20: Summary of Park Place drain water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 43.0 | 71.5 | 79.4 | 142.3 |
| Conductivity ($\mu$S/cm) | 126.5 | 181.0 | 198.4 | 335.0 |
| Dissolved oxygen (mg/L) | 9.2 | 10.9 | 11.0 | 13.2 |
| pH | 7.7 | 7.9 | 7.9 | 8.2 |
| Temperature (°C) | 3.0 | 9.7 | 9.9 | 15.8 |
| Total suspended solids (mg/L) | $<$2 | 2.3 | 2.4 | 3.9 |
| Turbidity (NTU) | 2.2 | 4.1 | 4.8 | 8.0 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<$10 | $<$10 | $<$10 | 15.7 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 341.4 | 554.9 | 605.5 | 1377.9 |
| Nitrogen - total ($\mu$g-N/L) | 599.5 | 799.0 | 882.5 | 1672.8 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 9.4 | 15.9 | 18.3 | 33.2 |
| Phosphorus - total ($\mu$g-P/L) | 24.7 | 30.5 | 32.8 | 47.1 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | 24 | 150 | 152 | 2200 |
| (Percent of samples $>$100 cfu/100 mL = 58) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 21: Summary of Silver Beach Creek water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 11.8 | 14.4 | 18.1 | 33.8 |
| Conductivity ($\mu$S/cm) | 44.7 | 54.4 | 58.8 | 96.5 |
| Dissolved oxygen (mg/L) | 9.9 | 11.8 | 11.9 | 14.1 |
| pH | 7.2 | 7.3 | 7.4 | 7.7 |
| Temperature (°C) | 2.6 | 7.6 | 8.3 | 14.6 |
| Total suspended solids (mg/L) | $<2$ | 2.0 | 2.3 | 5.4 |
| Turbidity (NTU) | 0.3 | 1.5 | 1.7 | 4.0 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<10$ | $<10$ | $<10$ | $<10$ |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | 333.0 | 769.8 | 830.1 | 1401.7 |
| Nitrogen - total ($\mu$g-N/L) | 421.0 | 888.1 | 935.2 | 1518.4 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | 5.3 | 8.2 | 8.8 | 13.4 |
| Phosphorus - total ($\mu$g-P/L) | 8.9 | 13.5 | 13.7 | 18.1 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<1$ | 4 | 4 | 46 |
| (Percent of samples $>100$ cfu/100 mL = 0) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 22: Summary of Smith Creek water quality data, Oct. 2010–Sept. 2011.

| Variable | Min. | Med. | Mean[†] | Max. |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 19.2 | 20.4 | 20.5 | 21.5 |
| Conductivity ($\mu$S/cm) | 60.3 | 62.0 | 62.1 | 63.4 |
| Dissolved oxygen (mg/L) | 8.6 | 10.6 | 10.5 | 12.1 |
| pH | 7.4 | 7.5 | 7.5 | 8.0 |
| Temperature (°C) | 5.1 | 11.8 | 12.3 | 21.0 |
| Total suspended solids (mg/L) | $<$2 | $<$2 | $<$2 | 3.7 |
| Turbidity (NTU) | 0.9 | 1.2 | 1.2 | 1.7 |
| | | | | |
| Nitrogen - ammonium ($\mu$g-N/L) | $<$10 | $<$10 | $<$10 | 30.6 |
| Nitrogen - nitrate/nitrite ($\mu$g-N/L) | $<$20 | 192.9 | 186.2 | 345.2 |
| Nitrogen - total ($\mu$g-N/L) | 231.3 | 363.0 | 365.1 | 494.6 |
| | | | | |
| Phosphorus - soluble ($\mu$g-P/L) | $<$5 | $<$5 | $<$5 | 5.1 |
| Phosphorus - total ($\mu$g-P/L) | $<$5 | 11.1 | 10.4 | 18.0 |
| | | | | |
| Coliforms - fecal (cfu/100 mL)[‡] | $<$1 | 5 | 4 | 18 |
| (Percent of samples $>$100 cfu/100 mL = 0) | | | | |

[†] Uncensored arithmetic means except coliforms(geometric mean);
[‡] Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 23: Summary of Whatcom Creek water quality data, Oct. 2010–Sept. 2011.

| | Typical range | Anderson | Austin | Brannian | Olsen | Smith | Whatcom |
|---|---|---|---|---|---|---|---|
| Alkalinity | med. $\leq$20 mg/L | yes | yes | yes | yes | yes | yes |
| Conductivity | med. $\leq$100 $\mu$S | yes | yes | yes | yes | yes | yes |
| pH | 6.5–7.5 | yes | yes | yes | yes | yes | yes |
| T. susp. solids | med. $\leq$5 mg/L | yes | yes | yes | yes | yes | yes |
| Turbidity | med. $\leq$5 NTU | yes | yes | yes | yes | yes | yes |
| Ammonium | med. $\leq$10 $\mu$g-N/L | yes | yes | yes | yes | yes | yes |
| Sol. phosphate | med. $\leq$10 $\mu$g-P/L | yes | yes | yes | yes | yes | yes |
| T. phosphorus | med. $\leq$20 $\mu$g-P/L | yes | yes | yes | yes | yes | yes |
| F. coliforms | GM $\leq$50 cfu | yes | yes | yes | yes | yes | yes |
| | More than 10% exceed 100 cfu | no | no | no | no | no | no |

| | Typical range | Blue Canyon | Carpenter | Euclid | Mill Wheel | Park Place | Silver Beach |
|---|---|---|---|---|---|---|---|
| Alkalinity | med. $\leq$20 mg/L | no | yes | no | no | no | no |
| Conductivity | med. $\leq$100 $\mu$S | no | yes | no | yes | no | no |
| pH | 6.5–7.5 | no | yes | yes | yes | yes | no |
| T. susp. solids | med. $\leq$5 mg/L | yes | yes | yes | no | yes | yes |
| Turbidity | med. $\leq$5 NTU | yes | yes | yes | no | yes | yes |
| Ammonium | med. $\leq$10 $\mu$g-N/L | yes | yes | yes | yes | no | yes |
| Sol. phosphate | med. $\leq$10 $\mu$g-P/L | yes | yes | no | yes | no | no |
| T. phosphorus | med. $\leq$20 $\mu$g-P/L | yes | yes | no | no | no | no |
| F. coliforms | GM $\leq$50 cfu | yes | no | yes | no | yes | no |
| | More than 10% exceed 100 cfu | no | yes | yes | yes | yes | yes |

Table 24: Comparison of water quality features in Lake Whatcom tributaries.

|  | Date | T. As (mg/L) | T. Cd (mg/L) | T. Cr (mg/L) | T. Cu (mg/L) | T. Fe (mg/L) | T. Hg (mg/L) | T. Ni (mg/L) | T. Pb (mg/L) | T. Zn (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|
| Anderson | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | <0.001 | 0.191 | <0.0001 | <0.005 | 0.00018 | <0.001 |
| Austin (lower) | Feb 16, 2011 | <0.01 | <0.0005 | 0.002 | 0.001 | 0.190 | <0.0001 | <0.005 | 0.00017 | <0.001 |
| Blue Canyon | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.131 | <0.0001 | <0.005 | 0.00052 | <0.001 |
| Brannian | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.134 | <0.0001 | <0.005 | 0.00029 | <0.001 |
| Carpenter | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.253 | <0.0001 | <0.005 | 0.00020 | <0.001 |
| Euclid | Feb 16, 2011 | <0.01 | <0.0005 | 0.001 | 0.002 | 0.214 | <0.0001 | <0.005 | 0.00026 | <0.001 |
| Millwheel | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.449 | <0.0001 | <0.005 | 0.00030 | 0.002 |
| Olsen | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.243 | <0.0001 | <0.005 | 0.00014 | <0.001 |
| Park Place | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | 0.003 | 0.339 | <0.0001 | <0.005 | 0.00026 | 0.010 |
| Silver Beach | Feb 16, 2011 | <0.01 | <0.0005 | 0.002 | 0.002 | 0.510 | <0.0001 | <0.005 | 0.00026 | 0.004 |
| Smith | Feb 16, 2011 | <0.01 | <0.0005 | 0.001 | 0.001 | 0.145 | <0.0001 | <0.005 | 0.00013 | 0.002 |
| Whatcom | Feb 16, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.059 | <0.0001 | <0.005 | 0.00014 | 0.003 |
| Anderson | Jul 13, 2011 | <0.01 | <0.0005 | 0.001 | 0.002 | 0.582 | <0.0001 | <0.005 | 0.00016 | 0.003 |
| Austin (lower) | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.158 | <0.0001 | <0.005 | 0.00005 | 0.003 |
| Blue Canyon | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.503 | <0.0001 | <0.005 | 0.00023 | 0.009 |
| Brannian | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.268 | <0.0001 | <0.005 | 0.00009 | 0.004 |
| Carpenter | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.129 | <0.0001 | <0.005 | <0.00005 | 0.004 |
| Euclid | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.005 | 0.458 | <0.0001 | <0.005 | 0.00009 | 0.004 |
| Millwheel | Jul 13, 2011 | <0.01 | <0.0005 | 0.002 | 0.003 | 2.120 | <0.0001 | <0.005 | 0.00036 | 0.004 |
| Olsen | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.106 | <0.0001 | <0.005 | <0.00005 | 0.004 |
| Park Place | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.004 | 0.388 | <0.0001 | <0.005 | 0.00011 | 0.005 |
| Silver Beach | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.003 | 0.301 | <0.0001 | <0.005 | <0.00005 | 0.005 |
| Smith | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.002 | 0.034 | <0.0001 | <0.005 | <0.00005 | 0.004 |
| Whatcom | Jul 13, 2011 | <0.01 | <0.0005 | <0.001 | 0.001 | 0.079 | <0.0001 | <0.005 | 0.00026 | 0.007 |

Table 25: Lake Whatcom tributary data: total metals. Only the metals specified in the monitoring plan are included in this table; the results for 24 additional metals are available from IWS. This parameter is sampled twice each year. The total lead (T. Pb) method changed in 2011, resulting in a much lower detection limit (<0.00005 vs. <0.001 in previous years).

| Site | Date | TOC (mg/L) | Date | TOC (mg/L) |
|---|---|---|---|---|
| Anderson | Feb 8, 2011 | $<1$ | Jul 11, 2011 | 1.4 |
| Austin (lower) | Feb 8, 2011 | $<1$ | Jul 11, 2011 | 1.8 |
| Blue Canyon | Feb 8, 2011 | 7.6 | Jul 11, 2011 | 1.4 |
| Brannian | Feb 8, 2011 | $<1$ | Jul 11, 2011 | 2.1 |
| Carpenter | Feb 8, 2011 | 2.6 | Jul 11, 2011 | 2.0 |
| Euclid | Feb 8, 2011 | 2.4 | Jul 11, 2011 | 3.0 |
| Millwheel | Feb 8, 2011 | 5.9 | Jul 11, 2011 | 12.0 |
| Olsen | Feb 8, 2011 | 3.4 | Jul 11, 2011 | 2.1 |
| Park Place | Feb 8, 2011 | 5.8 | Jul 11, 2011 | 4.9 |
| Silver Beach | Feb 8, 2011 | 5.4 | Jul 11, 2011 | 5.6 |
| Smith | Feb 8, 2011 | 2.9 | Jul 11, 2011 | 1.7 |
| Whatcom | Feb 8, 2011 | 3.4 | Jul 11, 2011 | 2.5 |

Table 26: Lake Whatcom tributary data: total organic carbon. This parameter is sampled twice each year.

# 4 Lake Whatcom Hydrology

## 4.1 Hydrograph Data

Recording hydrographs are installed in Austin Creek and Smith Creek; the data are plotted in Figures 20–21 (pages 71–72). The location of each hydrograph is described in Appendix A.2. All hydrograph data, including data from previous years, are online at http://www.wwu.edu/iws. Detailed field notes and rating curves for each water year are available from the Institute for Watershed Studies. All results are reported as Pacific Standard Time, without Daylight Saving Time adjustment.

## 4.2 Water Budget

A water balance was applied to Lake Whatcom to identify major water inputs and outputs and to examine runoff and storage. The traditional method of estimating a water balance was employed, where inputs – outputs = change in storage (Table 27, page 68). Inputs into the lake include direct precipitation, runoff (surface runoff + groundwater), and water diverted from the Middle Fork of the Nooksack River. Outputs include evaporation, Whatcom Creek, the Whatcom Falls Fish Hatchery, City of Bellingham, Puget Sound Energy Co-Generation Plant [19], and the Lake Whatcom Water and Sewer District.[20] The change in storage is estimated from daily lake-level changes. All of these are measured quantities provided by the City of Bellingham except for evaporation, diverted water, and runoff.

Daily direct-precipitation magnitudes on the lake surface were estimated using the precipitation data recorded at the Bloedel Donovan, Geneva gatehouse, North Shore, and Brannian Creek gauges. Due to an equipment malfunction at the North Shore gauge, rainfall data from January 18 to February 13 were replaced with rainfall data from the Geneva gatehouse gauge. The minimum yearly rainfall (44.5 inches) was recorded at the Bloedel Donovan gauge, the maximum (62.4 inches) was recorded at the Brannian creek gauge. A daily weighted average rainfall average was calculated using a Python script that employed a spatial interpolation technique (inverse distance weighted) in ArcGIS to distribute rainfall from the

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[19] Located at the Georgia Pacific site

[20] Formerly Water District #10

four gauges over a 10 meter raster of the lake. The average direct-precipitation depth (inches) for a given day was converted to volume in millions of gallons (MG) via a rating curve generated from the lake level-area data (Mitchell et al., 2010). The rating curve accounts for changes in surface area of the lake due to lake level changes. The average annual direct rainfall to the lake for the water year 2010/2011 was 51.2 inches (6,900 MG); 71% of which occurred between October 1 and April 1.

Daily diversion volumes were estimated using a hydrograph separation technique based on daily discharge data from the Anderson Creek USGS stream gauge (USGS 12201950), modeled streamflow using the Distributed Hydrology-Soils-Vegetation Model (DHSVM), and the outfall valve log-sheet provided by the City of Bellingham. The DHSVM is a spatially distributed, physically based numerical model that was calibrated to the Anderson Creek basin (Matthews et al., 2007). The log-sheet documents the dates and times that the diversion was operating and the valve opening percent. These dates and times were located on the hydrograph. The natural streamflow was estimated by the DHSVM and manually removed from the USGS hydrograph. The remaining volume was used to estimate a daily volume discharging to the lake from the diversion. The outfall gate was never open more than 30%, which on average accounted for about 18–20 MG per day during dry periods. As such, if the hydrograph separation technique yielded a value greater than 20 MG during a storm event, it was set to 20 MG. Approximately 2,629 MG were diverted into the lake in 2010/2011.

Daily lake evaporation was estimated using a model based on the Penman method (Dingman, 1994). The Penman method is theoretically based model that estimates free-water evaporation using both energy-balance and mass transfer concepts. The method requires daily average incident solar radiation, air temperature, dew point temperature, and wind speed. Hourly data from the North Shore weather station in the watershed were used to estimate daily averages. The daily evaporation depths (inches) predicted by the model were converted to volumes (MG) via a rating curve generated from the lake level-area data developed by Mitchell et al. (2010). The estimated yearly evaporation from the lake is 20.5 inches (2,770 MG), 82% of which occurred between April and September.

Daily change in storage was determined by subtracting each day's lake level by the subsequent day's level. This resulted in negative values when the lake level was decreasing and positive values when the lake level was increasing. The change in storage magnitudes are sensitive to the accuracy of the lake level measurements;

small lake level changes correspond to large lake volumes. The daily net change in lake level (inches) was converted to a volume (MG) via a rating curve generated from the lake level-volume data developed by Mitchell et al. (2010). The rating curve accounts for changes in volume of the lake due to lake level changes. The median total lake volume in 2010/2011 was 252,637 MG. Figure 22 (page 73) shows daily lake-volume values for the past five years. There was a spike in lake volume when the lake rose from a level of 312.0 feet on January 4, to 315.0 feet on January 9, 2009 due to a 6.3 inch storm event.

Surface runoff and groundwater were combined into a single runoff component that was determined by adding the outputs to the change in storage and subtracting precipitation and diversion volumes. Negative values of runoff estimated from the water budget are likely due to noise in the change in storage estimates or may represent a loss of lake water to deep aquifer systems. The DHSVM was also used to simulate runoff into the lake.

The daily water balance quantities were summed into 7-day totals, which were used to generate Figures 23–26 (pages 74–77). Figure 23 shows 7-day summed totals for inputs, outputs, and change in storage. All the inputs except runoff are shown in Figure 24; all outputs except Whatcom Creek are shown in Figure 25. Due to their much higher magnitude, runoff and Whatcom Creek data are included on Figure 26.

Yearly water balance totals are listed in Table 27 (page 68) along with data from four previous water years. The total volume of outputs in WY2011 were 15.8% of the median total volume of the lake. Under the assumption that the lake is completely mixed and flow is steady state (inputs = outputs), this would correspond to a 6.3 year residence time.[21] Tables 28 and 29 (pages 69–70) show the 2010/2011 total input and output volumes along with the corresponding monthly percentage of each total.

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[21] Although the lake is not completely mixed and the flow is not steady state, these assumptions are commonly used to provide a simple estimate of residence time for water in lakes.

| | WY2011<br>(9/30/10–10/1/11) | WY2010<br>(9/30/09–10/1/10) | WY2009<br>(9/30/08–10/1/09) | WY2008<br>(9/30/07–10/1/08) | WY2007<br>(9/30/06–10/1/07) |
|---|---|---|---|---|---|
| **Inputs (MG)**† | | | | | |
| Direct Precipitation | 6,900 (18.0%) | 7,350 (23.7%) | 5,712 (17.7%) | 6,006 (16.7%) | 7,063 (18.2%) |
| Diversion | 2,629 (6.9%) | 860 (2.8%) | 0 (0.0%) | 4,902 (13.7%) | 2,920 (7.5%) |
| Runoff | 28,709 (75.1%) | 22,762 (73.5%) | 26,491 (82.3%) | 24,989 (69.6%) | 28,717 (74.2%) |
| Total | 38,238 (100%) | 30,973 (100%) | 32,203 (100%) | 35,896 (100%) | 38,700 (100%) |
| **Outputs (MG%)** | | | | | |
| Whatcom Creek | 32,351 (81.2%) | 22,311 (75.4%) | 26,598 (77.5%) | 25,793 (76.1%) | 30,359 (77.1%) |
| Hatchery | 851 (2.1%) | 875 (3.0%) | 856 (2.5%) | 931 (2.7%) | 1,002 (2.5%) |
| Puget Sound Co-Gen | 57 (0.1%) | 51 (0.2%) | 4 (0.01%) | 240 (0.7%) | 807 (2.0%) |
| City of Bellingham | 3,593 (9.0%) | 3,522 (11.9%) | 3,886 (11.3%) | 3,874 (11.4%) | 4,145 (10.5%) |
| LW Water/Sewer Distr. | 226 (0.6%) | 239 (0.8%) | 250 (0.7%) | 237 (0.7%) | 232 (0.6%) |
| Evaporation | 2,770 (7.0%) | 2,592 (8.8%) | 2,723 (7.9%) | 2,807 (8.3%) | 2,831 (7.2%) |
| Total | 39,847 (100%) | 29,589 (100%) | 34,317 (100%) | 33,883 (100%) | 39,376 (100%) |
| **Net change in storage** | -1,609 | 1,384 | -2,115 | 2,033 | -520 |
| **Median lake volume (MG)** | 252,637 | 252,074 | 252,433 | 253,003 | 252,759 |
| **Outflow percent of volume** | 15.8% | 11.7% | 13.6 | 13.4% | 15.6% |
| **Residence time (years)**‡ | 6.3 | 8.5 | 7.4 | 7.5 | 6.4 |

†Runoff = surface runoff + groundwater; no diversion inputs in WY2009.

‡Based on the assumption that water in the lake is completely mixed and flow is steady state (i. e., inputs = outputs)

Table 27: Annual water balance quantities for the Lake Whatcom watershed, WY2007–WY2011.

| | Input Percents[†] | | | |
|---|---|---|---|---|
| Month | Diversion | Precipitation | Runoff | Total |
| Oct | 7.88 | 6.60 | 3.04 | 4.02 |
| Nov | 15.24 | 10.91 | 9.39 | 10.06 |
| Dec | 3.15 | 15.87 | 21.01 | 18.86 |
| Jan | 1.67 | 18.05 | 24.75 | 21.95 |
| Feb | 3.84 | 7.56 | 6.22 | 6.30 |
| Mar | 6.69 | 13.00 | 13.36 | 12.84 |
| Apr | 5.13 | 10.45 | 13.83 | 12.62 |
| May | 13.92 | 9.25 | 10.88 | 10.79 |
| Jun | 21.27 | 2.04 | 0.84 | 2.46 |
| Jul | 20.66 | 2.94 | -0.74 | 1.39 |
| Aug | 0.55 | 0.64 | -2.01 | -1.35 |
| Sep | 0.00 | 2.69 | -0.56 | 0.06 |
| | Input Volume (MG) | | | |
| Total | 2,629 | 6,900 | 28,709 | 38,238 |

[†] Runoff = surface runoff + groundwater;

Table 28: Monthly input water balance quantities for the Lake Whatcom watershed, October 2010–September 2011.

| | Output Percents[†] | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | WC | Hatch | PSE | COB | WSD | Evap | Total |
| Oct | 9.88 | 10.44 | 6.81 | 7.85 | 8.11 | 4.25 | 9.31 |
| Nov | 10.70 | 11.14 | 6.67 | 7.25 | 8.52 | 2.02 | 9.78 |
| Dec | 19.36 | 12.19 | 3.02 | 7.18 | 8.09 | 1.28 | 16.76 |
| Jan | 21.54 | 12.35 | 10.23 | 7.54 | 7.80 | 1.07 | 18.56 |
| Feb | 9.61 | 7.98 | 27.45 | 6.59 | 6.94 | 3.16 | 8.87 |
| Mar | 1.42 | 8.26 | 0.73 | 7.19 | 7.79 | 5.93 | 2.44 |
| Apr | 12.33 | 7.73 | 30.21 | 7.01 | 7.68 | 8.14 | 11.46 |
| May | 10.52 | 7.98 | 0.55 | 7.59 | 8.22 | 11.36 | 10.23 |
| Jun | 1.25 | 6.12 | 0.14 | 8.92 | 8.52 | 15.74 | 3.09 |
| Jul | 0.83 | 5.77 | 1.88 | 10.40 | 9.40 | 16.66 | 2.95 |
| Aug | 1.14 | 5.21 | 3.57 | 12.24 | 9.92 | 18.44 | 3.48 |
| Sep | 1.43 | 4.83 | 8.75 | 10.24 | 8.99 | 11.94 | 3.08 |
| | Output Volume (MG) | | | | | | |
| Total | 32,351 | 851 | 57 | 3,593 | 226 | 2,770 | 39,847 |

[†] WC = Whatcom Creek; Hatch = Whatcom Falls Hatchery; PSE = Puget Sound Energy Co-Generation Plant; COB = City of Bellingham; WSD = Lake Whatcom Water Sewer District; Evap = Evaporation

Table 29: Monthly output water balance quantities for the Lake Whatcom watershed, October 2010–September 2011.

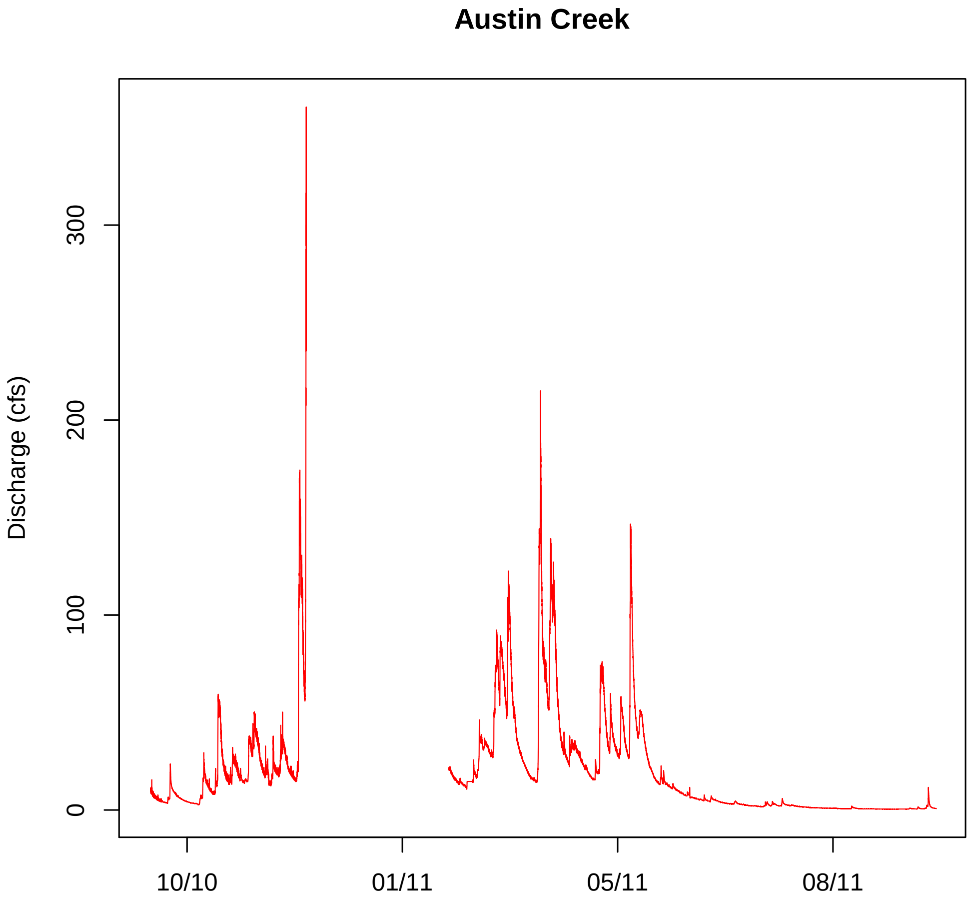

Figure 20: Austin Creek hydrograph, October 1, 2010–September 30, 2011. Data were recorded at 15 minute intervals.

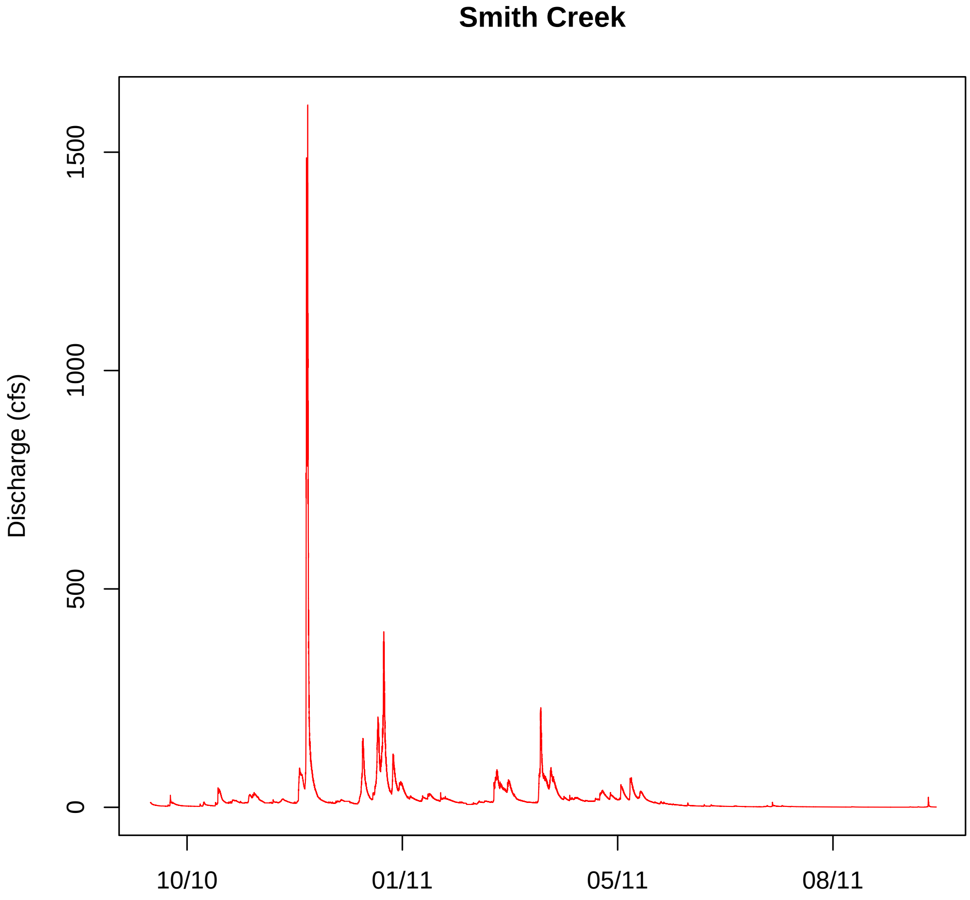

Figure 21: Smith Creek hydrograph, October 1, 2010–September 30, 2011. Data were recorded at 15 minute intervals.

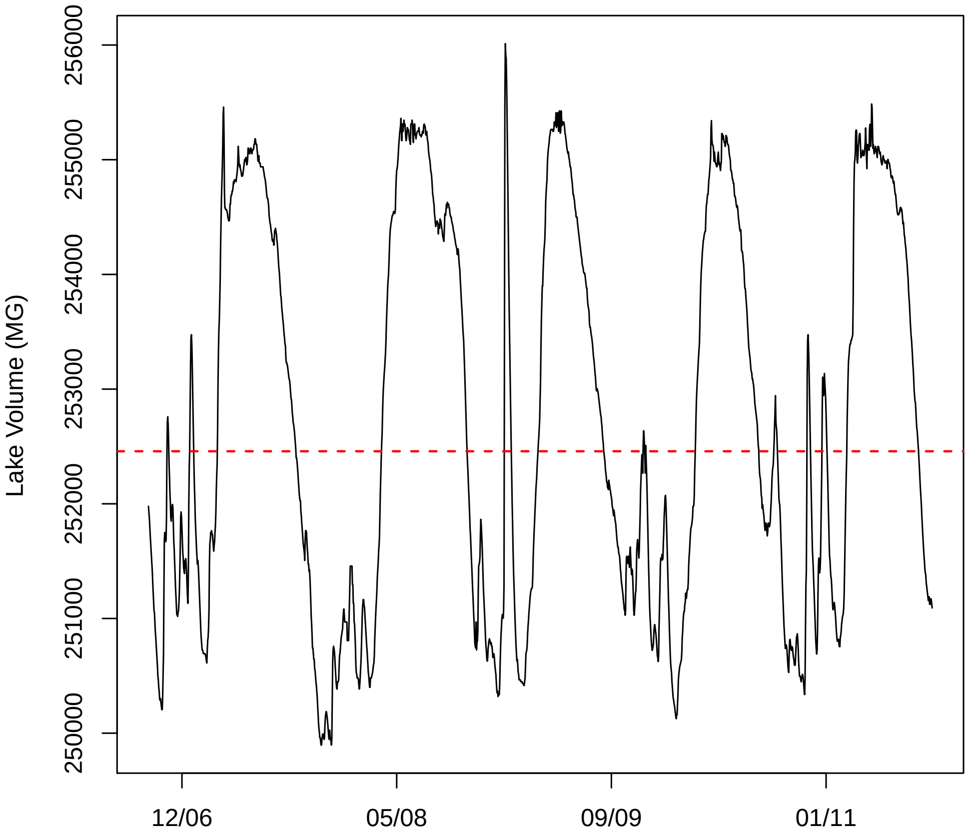

Figure 22: Comparison of Lake Whatcom daily lake volumes for WY2007–WY2011. Horizontal line represents median lake volume for the period plotted.

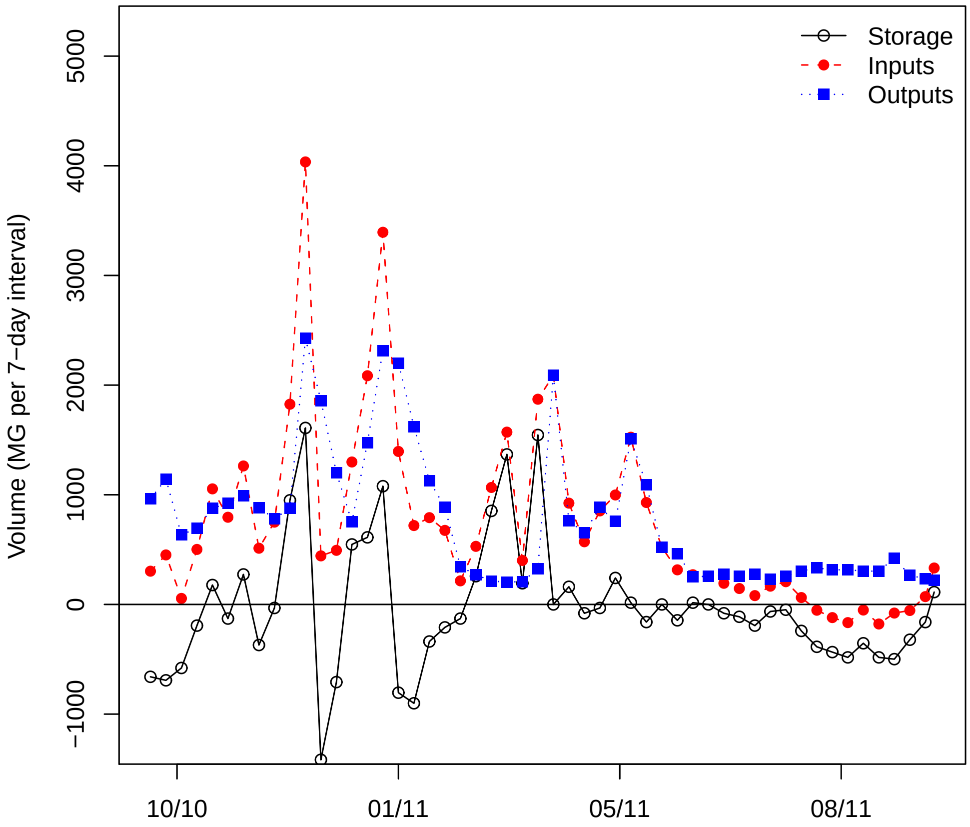

Figure 23: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2010–September 30, 2011.

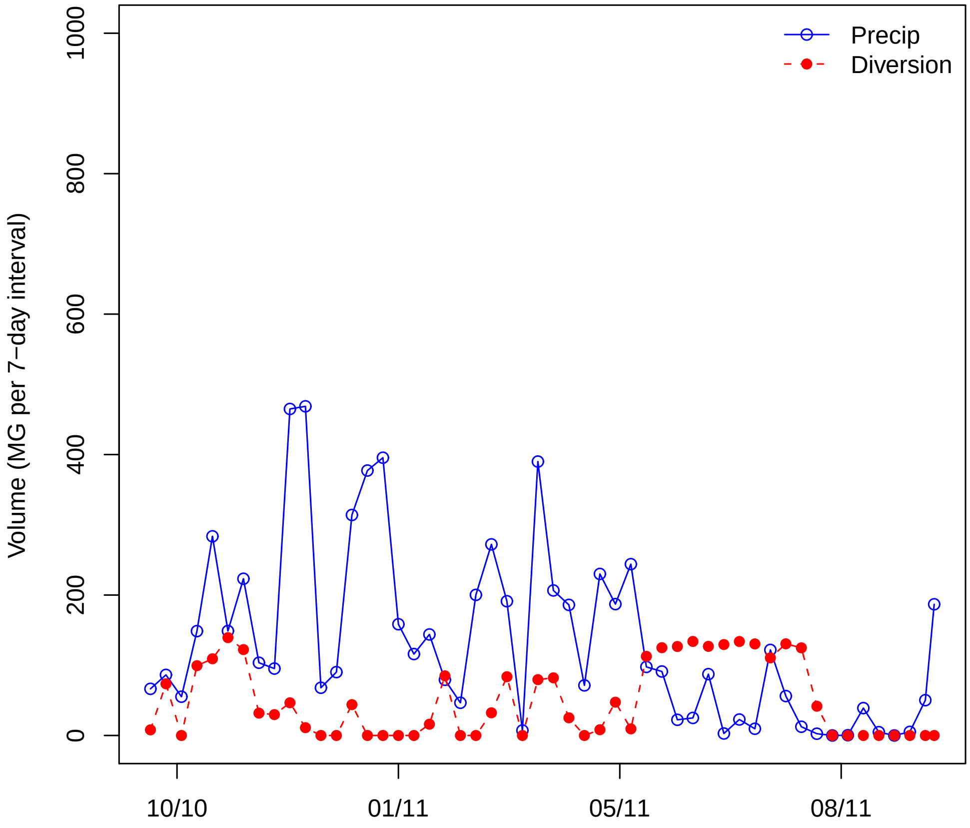

Figure 24: Lake Whatcom watershed direct hydrologic inputs, October 1, 2010–September 30, 2011. Runoff is included on Figure 26 as described in Section 4.2.

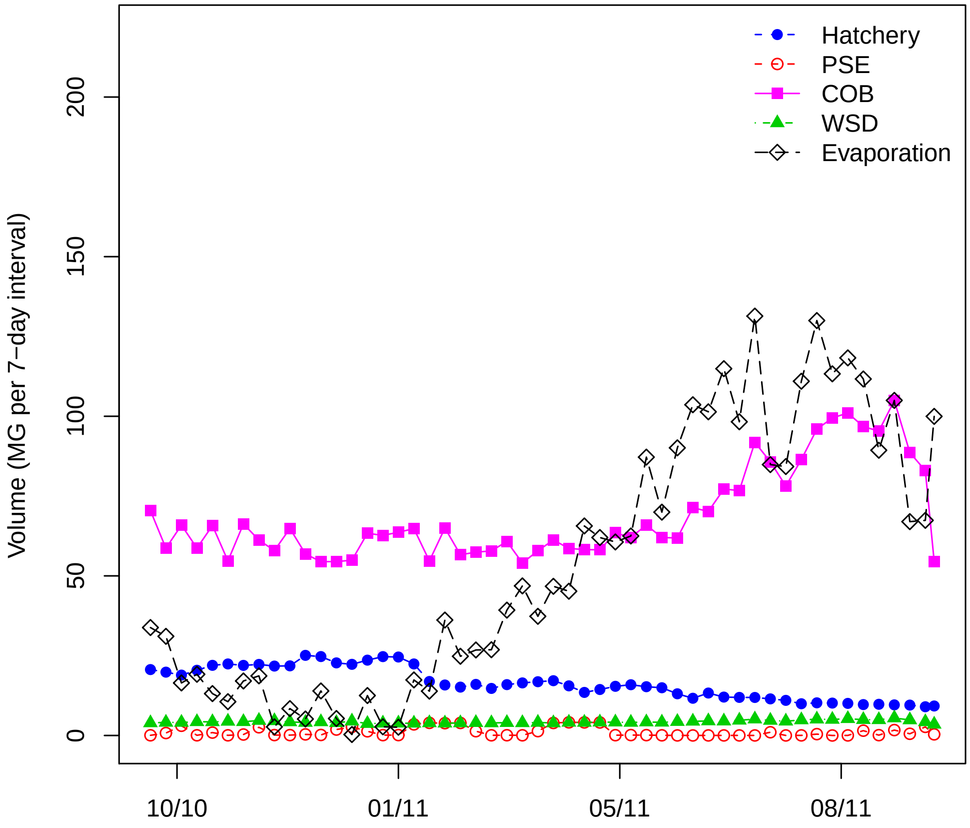

Figure 25: Lake Whatcom watershed hydrologic withdrawals, October 1, 2010–September 30, 2011. Whatcom Creek output is included on Figure 26 as described in Section 4.2.

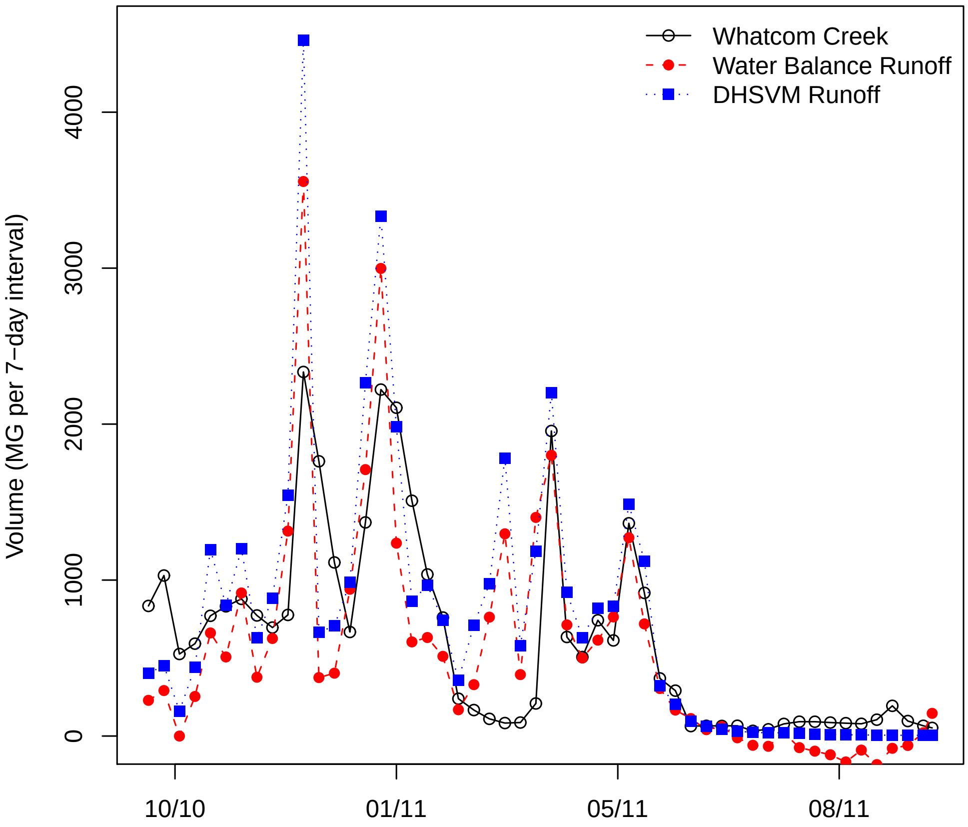

Figure 26: Summary of 7-day Whatcom Creek flows, water balance runoff estimates, and DHSVM runoff estimates, October 1, 2010–September 30, 2011.

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# 5 Storm Water Monitoring

## 5.1 Site Descriptions

The storm water monitoring program was revised in 2009 to focus on collecting baseline data at the Silver Beach Creek outlet and the North Shore Drive overlay. Both sites were monitored in 2009/2010 (see Matthews, et al., 2011). During the 2010/2011 monitoring period, the emphasis was on collecting additional storm water samples from Silver Beach Creek. For information about other storm water sites that have been monitored by IWS, refer to the annual reports listed in Section 6.2 (page 97).

## 5.2 Field Sampling and Analytical Methods

Flow-paced discrete samples were collected at the USGS gauging site near the mouth of Silver Beach Creek (Figure A3, page 107) using an ISCO sampler provided by the City of Bellingham. A total of six storm events were sampled between October 2010 and April 2011 (Table 30, page 82). All of these storms met the precipitation goal ($\geq$1 cm in 24 hr) and included samples from the rising and falling leg of the hydrograph. Each storm event was given a unique number (Events #11–16; Events #1–10 were discussed in Matthews, et al., 2011).

The sampler was calibrated to collect 20–24 flow-paced samples during each storm event. The samples were analyzed to measure total suspended solids, total phosphorus, soluble phosphate, total nitrogen, and nitrate/nitrite following the methods summarized in Table 1 (page 17). Stream elevation (stage height) was recorded at 15 minute intervals during each storm event and when a water sample was collected.[22] Stream flow was estimated from stage height (ft) using the following rating curves.

Oct - Dec 2010: Flow (cfs) = $(2.6402 \times \text{stage height} - 9.1803)^2$
Feb - Apr 2011: Flow (cfs) = $(2.7103 \times \text{stage height} - 9.3703)^2$

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[22] The flow-paced water samples were collected at irregular intervals based on stream flow, so the sampling time rarely coincided with the automatic 15-min stage height measurements.

Sample stage height data (and estimated flow rates) were not collected for a few samples due to instrumentation error. For these samples, the stage height at the time of sampling was estimated using a time-weighted average of adjacent 15-min interval stage height data.

## 5.3 Results and Discussion

The amount and intensity of precipitation varied between storm events. Four events (11, 12, 13, and 15) had a maximum 24-hr total of 1.0–1.3 cm and two events (14 and 16) had a maximum 24-hr total of 3.6 cm (Table 30). Although Events 14 and 16 had similar maximum 24-hr precipitation totals (3.6 cm), Event 14 had much higher flow rates (see solid blue lines on Figures 27–31, pages 83–87).

Total suspended solids and total phosphorus increased with stream flow, especially during high flow events (Figures 27–28, Events 14 & 16). Events 11 and 12 also had high suspended solids and phosphorus peaks, despite relatively low flow rates. Soluble phosphate and total nitrogen, were less consistent, sometimes increasing with flow and other times showing little relationship to the hydrograph (Figures 29–30). Nitrate concentrations were usually diluted by precipitation (Figure 31).

Correlation analysis was used to test the relationship between stream flow, stream elevation (stage height), and water quality (Figures 32–38, pages 88–94). Both stage height and stream flow were included because stream flow is estimated from a rating curve, so it contains uncertainty; stage height is a direct measurement of the height of water in the stream.

Total suspended solids and total phosphorus were significantly correlated with stream flow and stage height (Figures 32 and 33). This was consistent with the results illustrated in Figures 27 and 28. In addition, total suspended solids and total phosphorus were highly correlated with each other (Figure 34). Total phosphorus is often adsorbed to the surface of sediment particles and is transported with sediments in storm runoff.

Figures 32 and 33 suggest that the correlations between flow, sediment, and phosphorus are excellent at high flow rates but very poor at low rates. This is mostly an artifact from combining storm event data. If the total phosphorus data are separated by storm event, the individual correlations are significant regardless of flow rate (Figure 35). In theory, the “best” statistical approach would be to evaluate all data separately by storm event, but this is not always feasible, or even desirable, especially if the the goal is to develop a simple model of pollutant transport as a function of stream flow.

The soluble phosphate, total nitrogen, and nitrate concentrations were also significantly correlated with stream flow and stage height (Figures 36–38). As with total suspended solids and total phosphorus, there were obvious differences between storm events, and more information could be obtained by examining the data separately by event. This is beyond the scope of the current lake monitoring project, but the data will be made available to the City to assist with their assessment of storm water mitigation in the Silver Beach Creek watershed.

| Event | Sampling Period | Event Duration (hr) | Max. 24-hr Precip | Qualify? |
|---|---|---|---|---|
| 11 | 18:45 Oct 8 to 13:00 Oct 11, 2010 | 67 | 0.50 in<br>(1.3 cm) | Yes |
| 12 | 15:45 Oct 23 to 11:15 Oct 26, 2010 | 68 | 0.49 in<br>(1.2 cm) | Yes |
| 13 | 19:30 Nov 29 to 12:30 Dec 2, 2010 | 65 | 0.50 in<br>(1.3 cm) | Yes |
| 14 | 19:30 Dec 8 to 14:00 Dec 11, 2010 | 67 | 1.43 in<br>(3.6 cm) | Yes |
| 15 | 22:00 Feb 27 to 23:45 Mar 1, 2011 | 49 | 0.40<br>(1.0 cm) | Yes |
| 16 | 21:57 Mar 30 to 23:45 Apr 2, 2011 | 74 | 1.41<br>(3.6 cm) | Yes |

Table 30: Summary of Silver Beach Creek storm events and maximum 24-hr precipitation total at the Bloedel/Donovan precipitation gauge. Precipitation data were provided by the City of Bellingham.

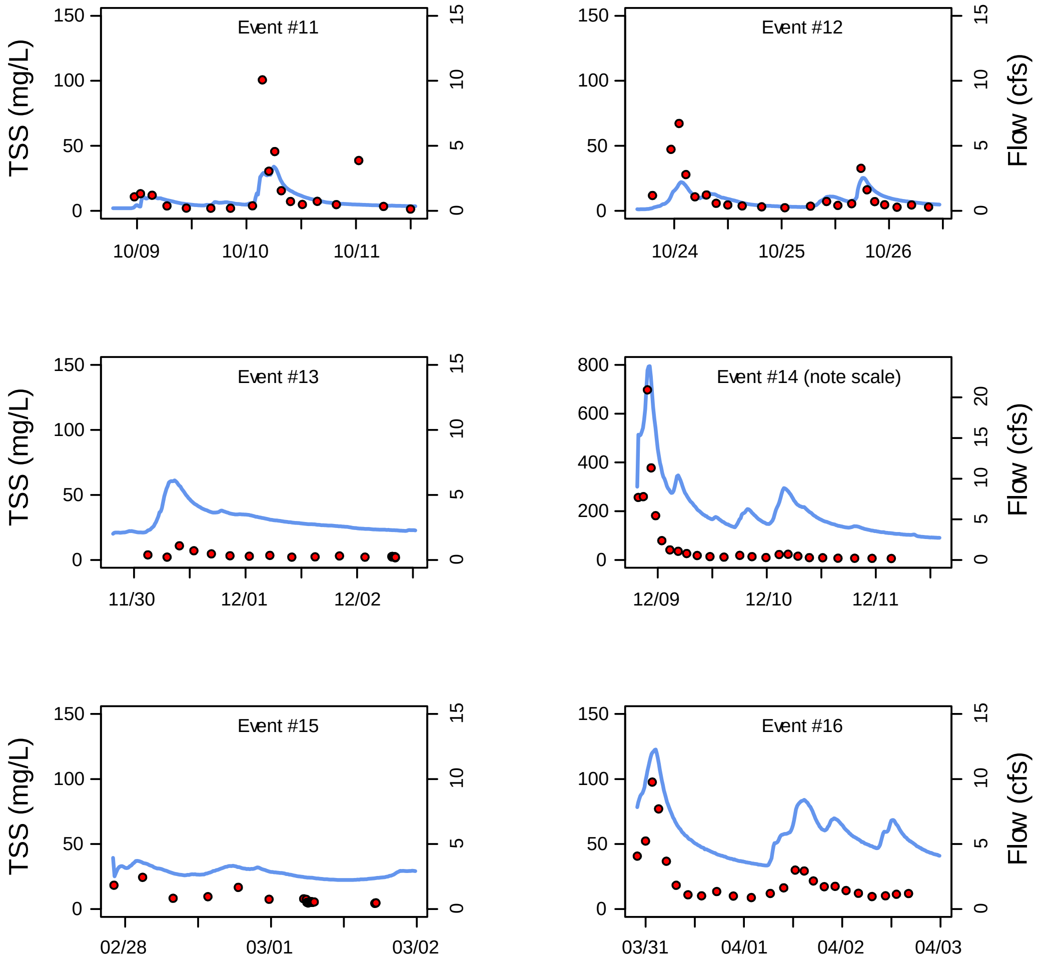


Figure 27: Silver Beach Creek storm water monitoring results for Events 11–16: total suspended solids (●) vs. stream flow (—). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011).

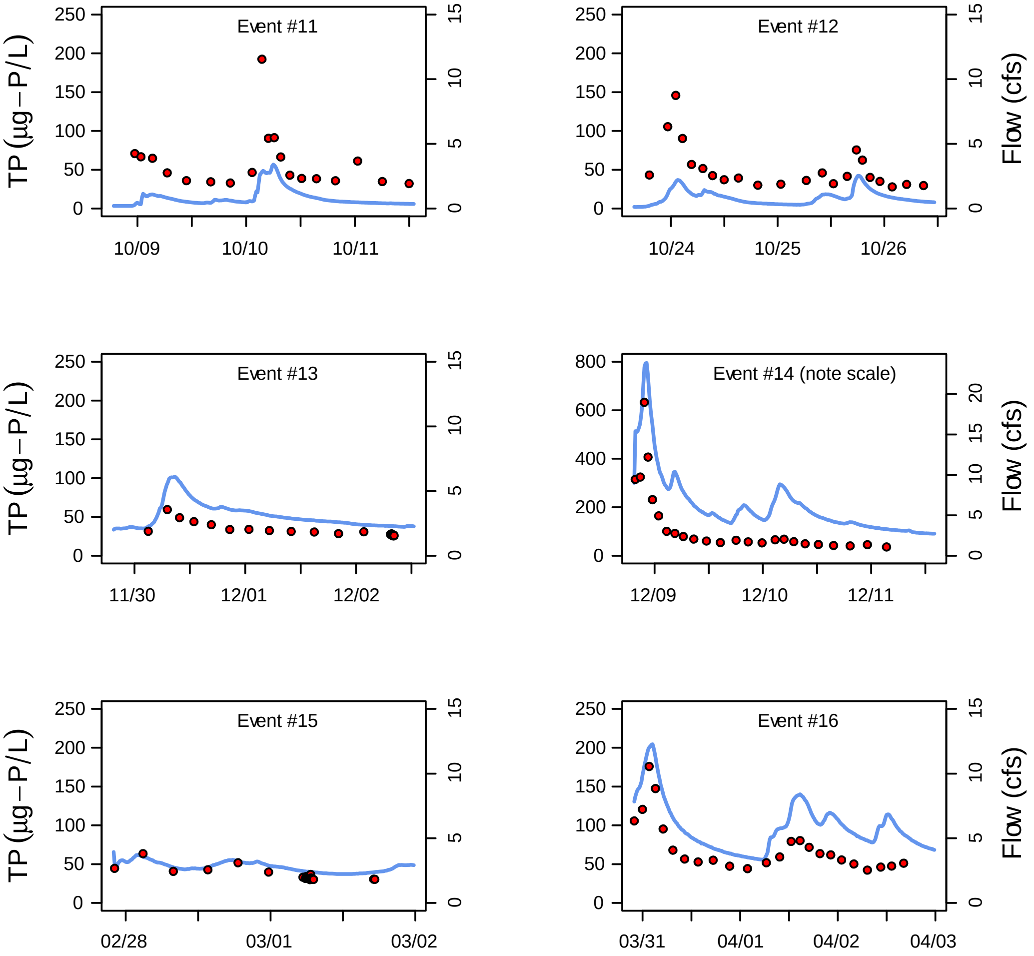


Figure 28: Silver Beach Creek storm water monitoring results for Events 11–16: total phosphorus (●) vs. stream flow (—). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011).

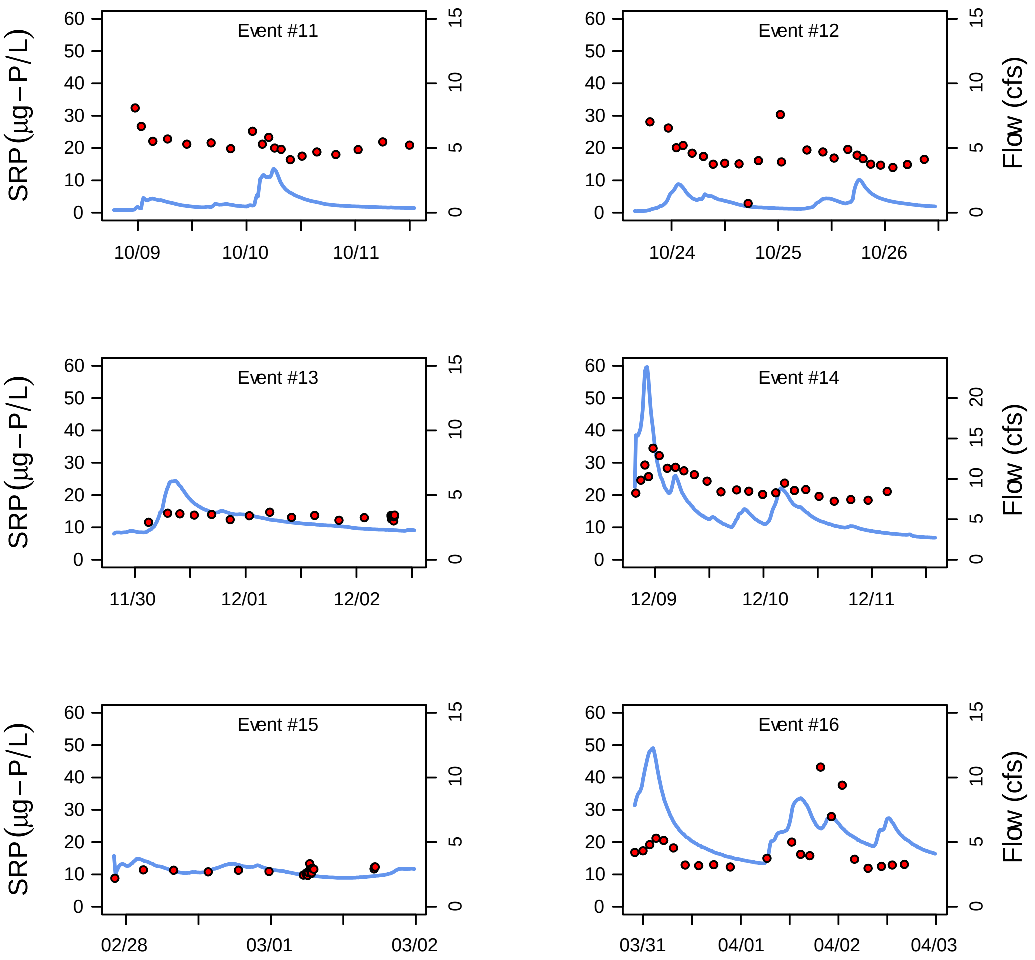


Figure 29: Silver Beach Creek storm water monitoring results for Events 11–16: soluble phosphate (●) vs. stream flow (—). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011).

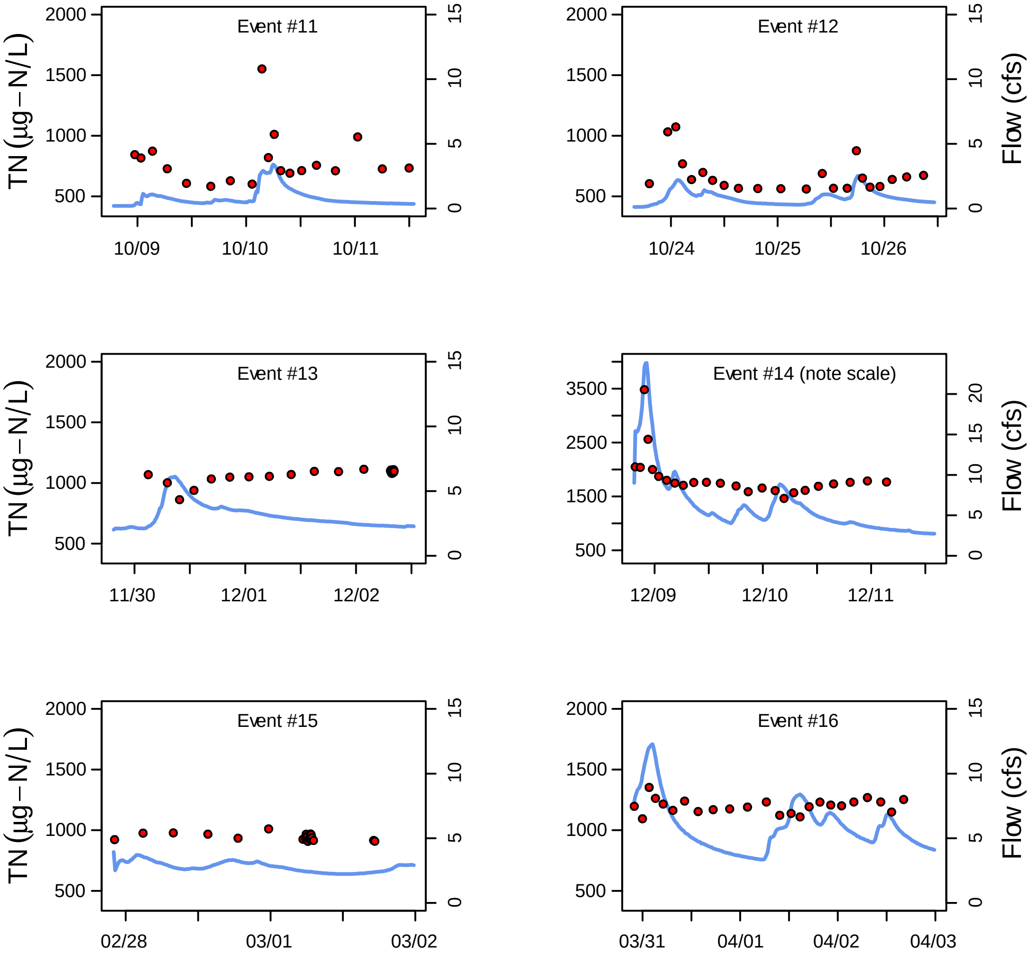


Figure 30: Silver Beach Creek storm water monitoring results for Events 11–16: total nitrogen (●) vs. stream flow (—). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011).

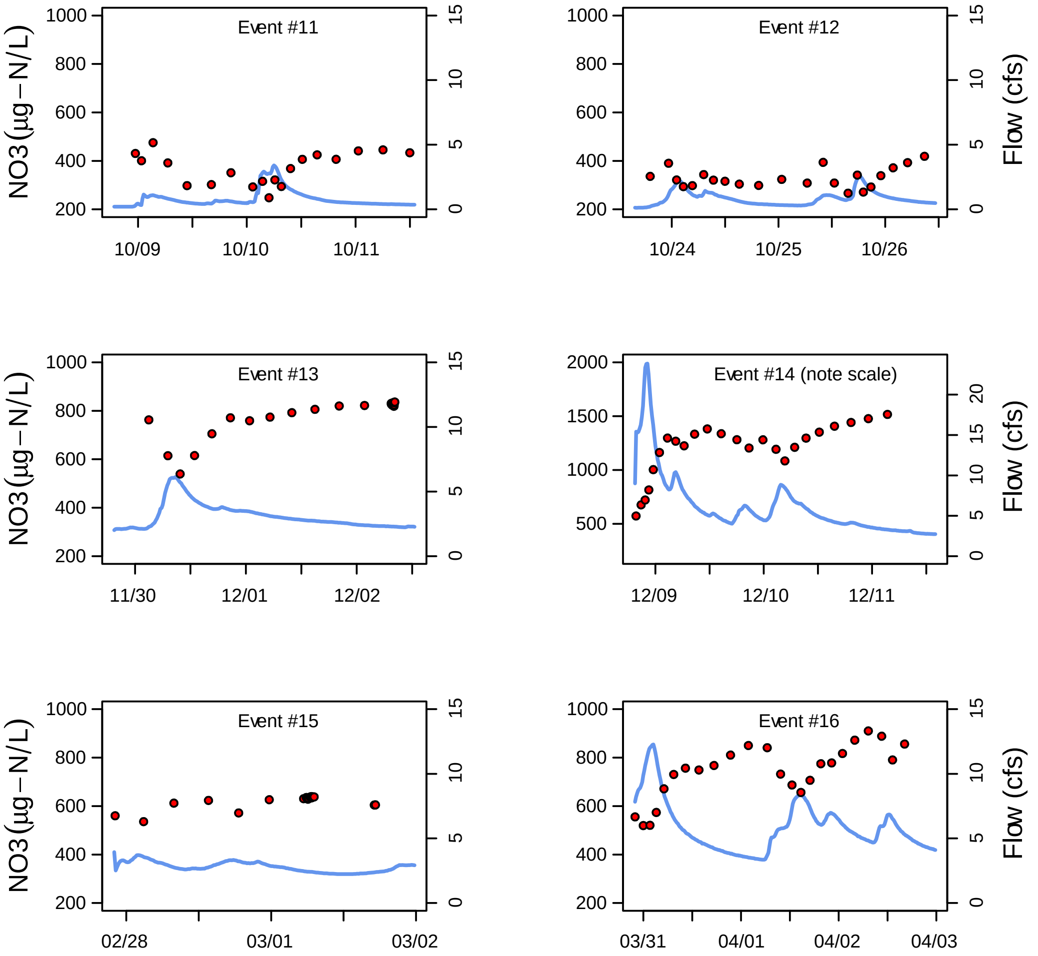


Figure 31: Silver Beach Creek storm water monitoring results for Events 11–16: nitrate/nitrite (●) vs. stream flow (—). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011).

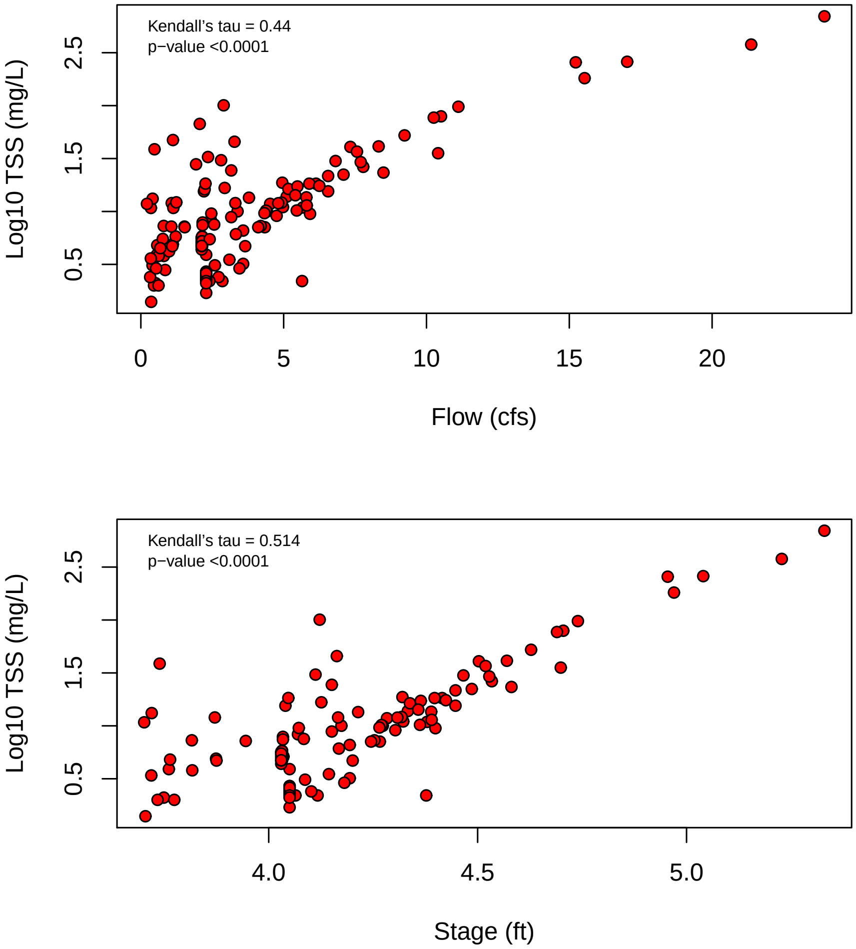
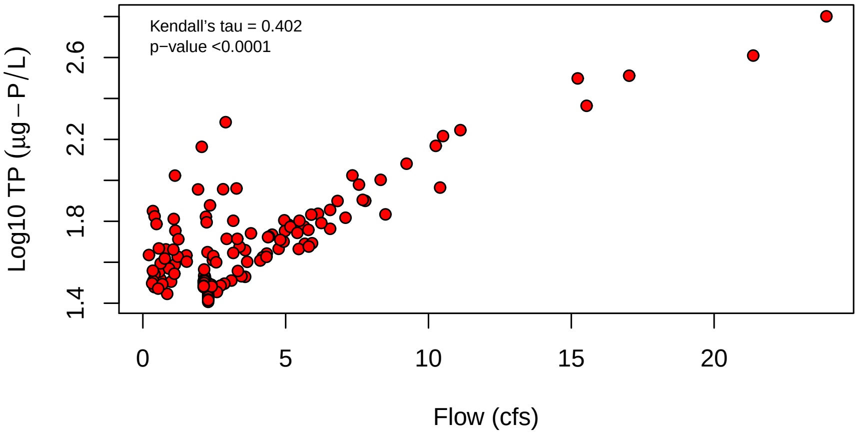


Figure 32: Correlation between stream flow or stage height and total suspended solids in Silver Beach Creek (Events 11–16). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.



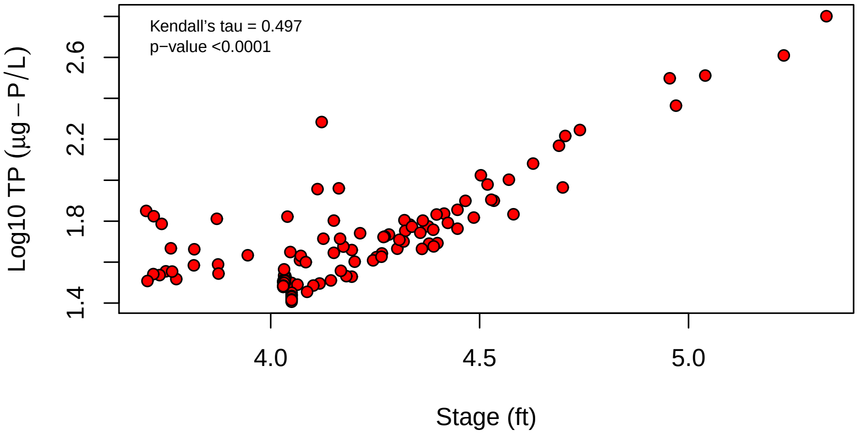


Figure 33: Correlation between stream flow or stage height and total phosphorus in Silver Beach Creek (Events 11–16). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

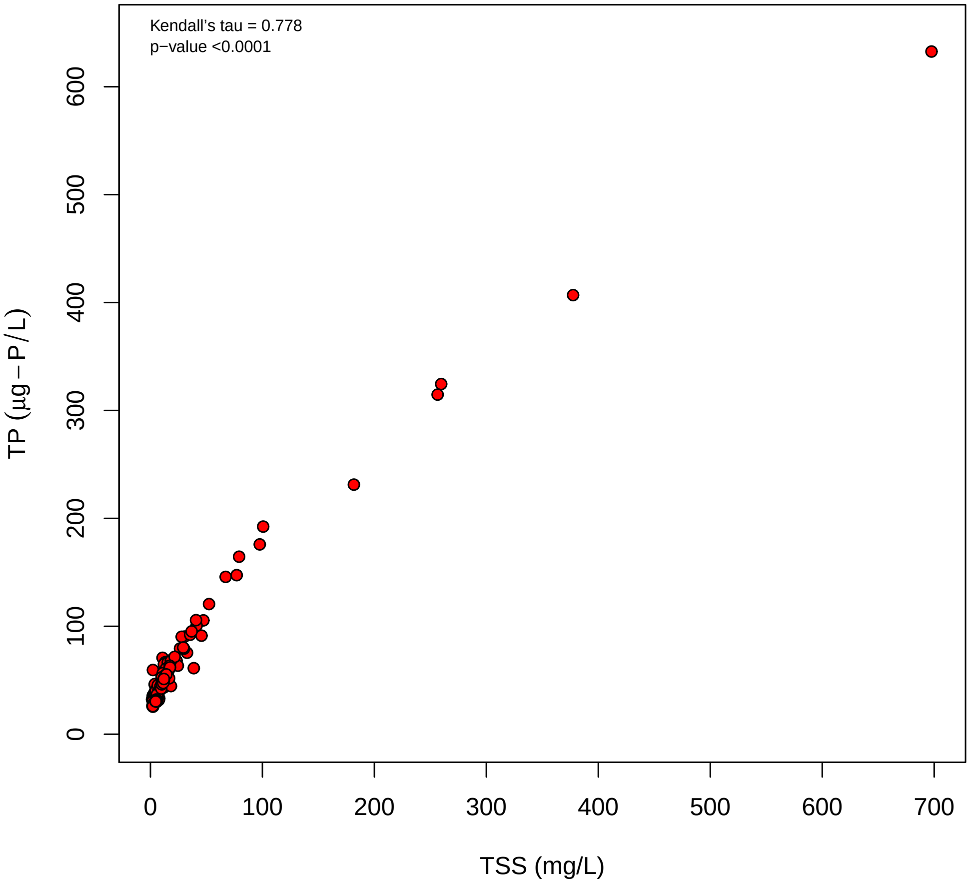


Figure 34: Correlation between total suspended solids and total phosphorus in Silver Beach Creek (Events 11–16). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

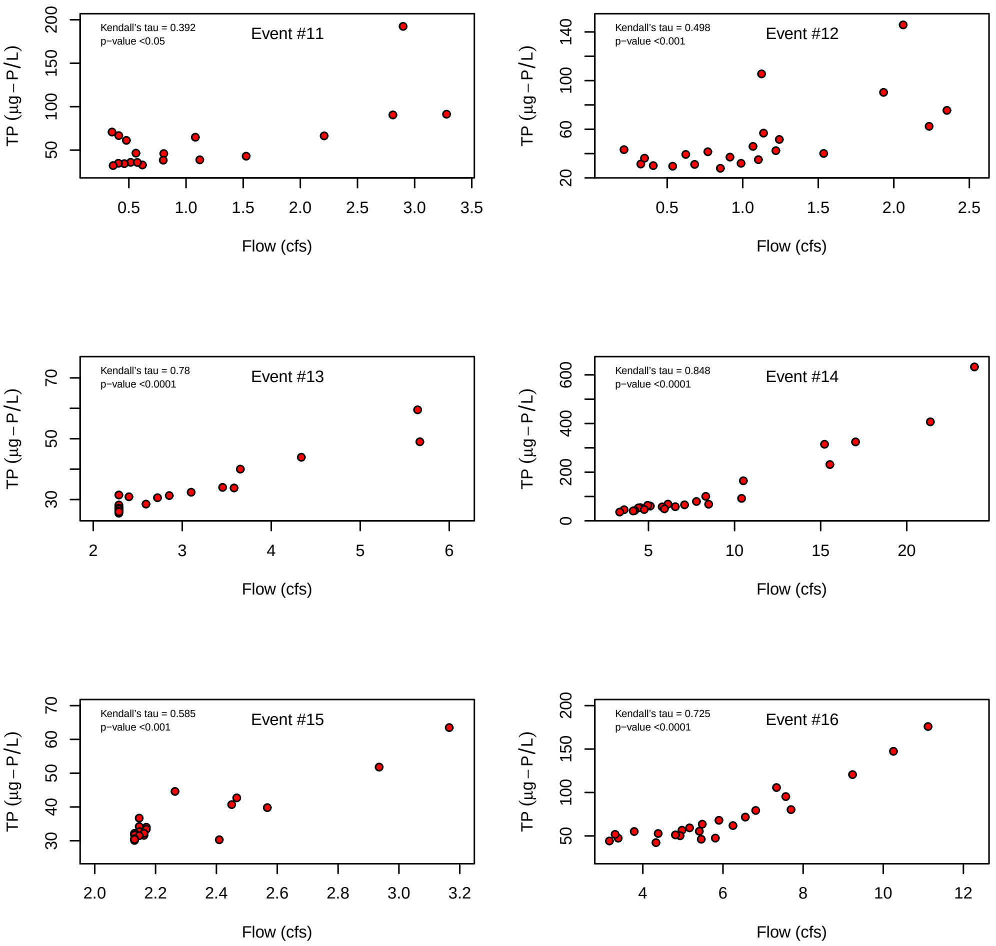


Figure 35: Correlation between stream flow and total phosphorus by storm event in Silver Beach Creek (Events 11–16). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

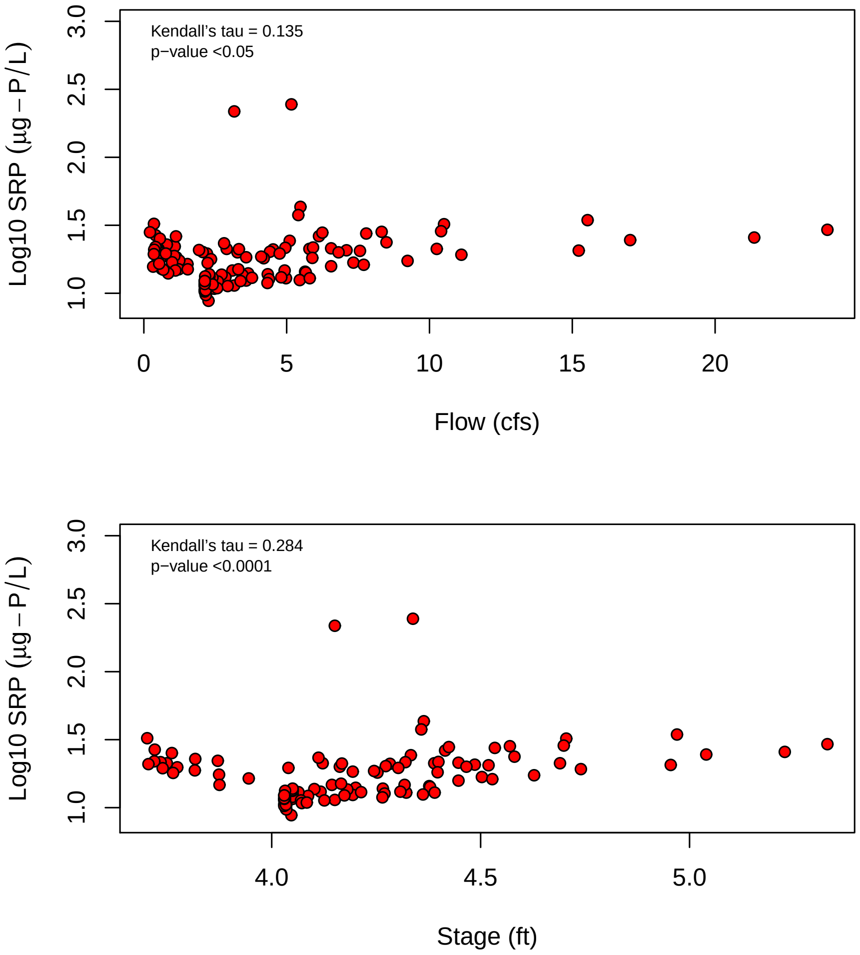


Figure 36: Correlation between stream flow or stage height and soluble phosphate in Silver Beach Creek (Events 11–16). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

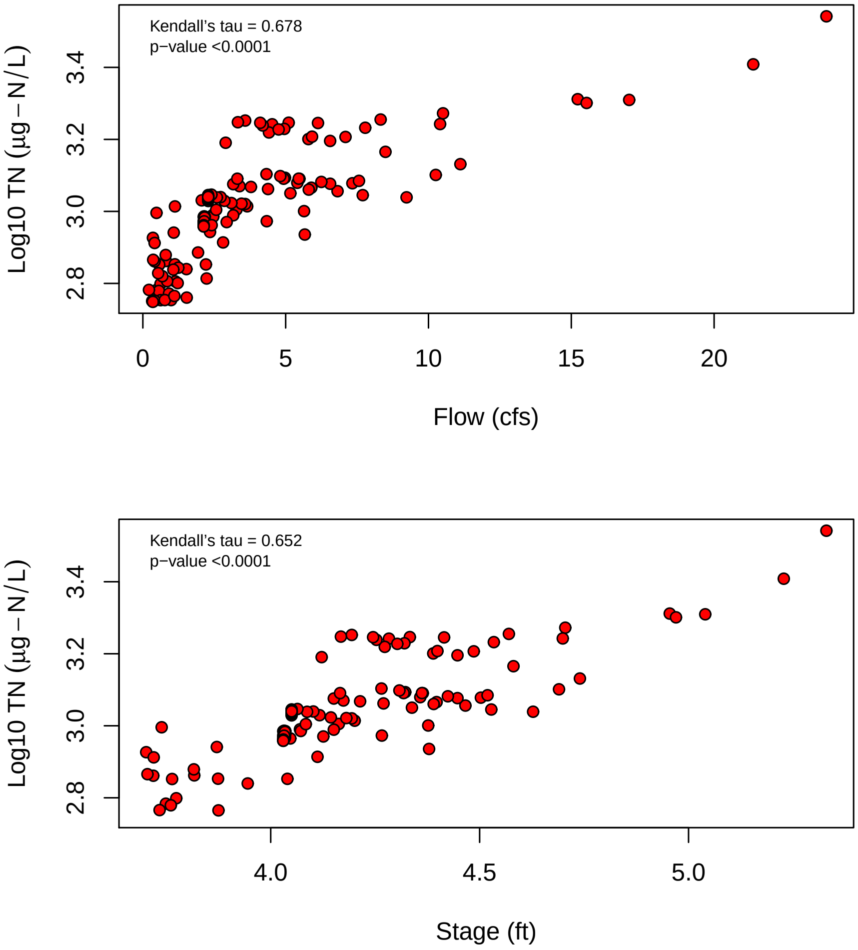


Figure 37: Correlation between stream flow or stage height and total nitrogen in Silver Beach Creek (Events 11–16). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

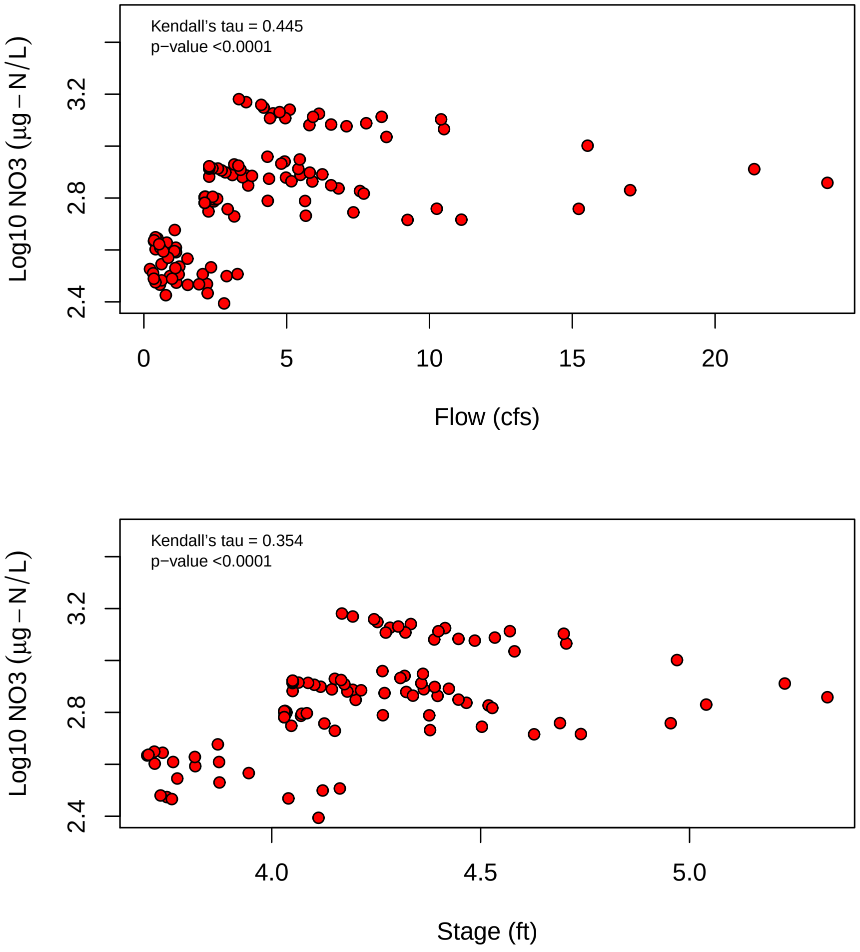


Figure 38: Correlation between stream flow or stage height and nitrate in Silver Beach Creek (Events 11–16). Results for Events 1–10 were presented in the 2009/2010 report (Matthews, et al., 2011). Kendall's $\tau$ correlations were used because the data were not monotonic-linear; all correlations were significant.

# 6 References and Related Reports

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## 6.2 Related Reports

The following is a list of annual reports and special project reports produced by the Institute for Watershed Studies since 1987 as part of the Lake Whatcom monitoring program sponsored by the City of Bellingham and Western Washington University. Many of the reports are available online at http://www.wwu.edu/iws (follow links to the Lake Whatcom project under Lake Studies); older reports are available in the IWS library and through the city of Bellingham Public Works

Department. This list does not include research reports, student projects, or publications that were not prepared specifically for the City of Bellingham. Contact IWS for information about additional Lake Whatcom publications.

**Annual monitoring reports:**

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2009/2010 Final Report, March 1, 2011. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2008/2009 Final Report, March 10, 2010. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2007/2008 Final Report, March 19, 2009. Report to the City of Bellingham, WA.

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Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1996/97 Final Report, February 10, 1998. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1995/96 Final Report, March 24, 1997. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1994/95 Final Report, February 9, 1996. Report to the City of Bellingham, WA.

Matthews, R. A. and G. B. Matthews. Lake Whatcom Monitoring Project, 1993–1994 Final Report, March 2, 1995. Report to the City of Bellingham, WA.

Matthews, R. and G. Matthews. Lake Whatcom Monitoring Project, 1992–1993 Final Report, January 31, 1994. Report to the City of Bellingham, WA.

Matthews, R. and G. Matthews. Lake Whatcom Monitoring Project, 1991–1992 Final Report, March 19, 1993. Report to the City of Bellingham, WA.

Rector, J. M. and R. A. Matthews. Lake Whatcom Monitoring Program, August 1987 Final Report. Institute for Watershed Studies Report, Western Washington University, Bellingham, WA.

**Other Lake Whatcom reports:**

Matthews, R. A., M. Hilles and J. Vandersypen. Austin Creek and Beaver Creek Sampling Project, October 11, 2005. Report to the City of Bellingham, WA.

Matthews, R. A. Relationship between Drinking Water Treatment Chemical Usage and Lake Whatcom water Quality and Algal Data, October 4, 2004. Report to the City of Bellingham, WA.

Matthews, R. A. Strawberry Sill Water Quality Analysis, March 19, 2004. Report to the City of Bellingham, WA.

Matthews, R. A., M. Saunders, M A. Hilles, and J. Vandersypen. Park Place Wet Pond Monitoring Project, 1994–2000 Summary Report, February 2, 2001. Report to the City of Bellingham, WA.

Carpenter, M. R., C. A. Suczek, and R. A. Matthews. Mirror Lake Sedimentation Study Summary Report, February, 1992. Report to the City of Bellingham, WA.

Walker, S., R. Matthews, and G. Matthews. Lake Whatcom Storm Runoff Project, Final Report, January 13, 1992. Report to the City of Bellingham, WA.

Creahan, K., T. Loranger, B. Gall, D. Brakke, and R. Matthews. Lake Whatcom Watershed Management Plan, December, 1986, revised July, 1987. Institute for Watershed Studies Report, Western Washington University, Bellingham, WA.

# A Site Descriptions

Figures A1–A3 (pages 105–107) show the locations of the current monitoring sites and Table A1 (page 104) lists the approximate GPS coordinates for the lake and creek sites. All site descriptions, including text descriptions and GPS coordinates, are approximate because of variability in satellite coverage, GPS unit sensitivity, boat movement, stream bank or channel alterations, stream flow rates, weather conditions, and other factors that affect sampling location. Text descriptions contain references to local landmarks that may change over time. For detailed information about exact sampling locations, contact IWS.

## A.1 Lake Whatcom Monitoring Sites

**Site 1** is located at 20 m in the north central portion of basin 1 along a straight line from the Bloedel Donovan boat launch to the house located at 171 E. North Shore Rd. The depth at Site 1 should be at least 25 meters.

**Site 2** is located at 18–20 m in the south central portion of basin 2 just west of the intersection of a line joining the boat house at 73 Strawberry Point and the point of Geneva sill.

The **Intake Site** location is omitted from this report at the City's request.

**Site 3** is located in the northern portion of basin 3, mid-basin just north of a line between the old railroad bridge and Lakewood. The depth at Site 3 should be at least 80 m.

**Site 4** is located in the southern portion of basin 3, mid-basin, and just north of South Bay. The depth at Site 4 should be at least 90 m.

## A.2 Tributary Monitoring Sites

**Anderson Creek** samples are collected 15 m upstream from South Bay Rd. Water samples and discharge measurements are collected upstream from the bridge. The Anderson Creek hydrograph[23] is mounted in the stilling well on the east side of Anderson Creek, directly adjacent to the bridge over Anderson Creek (South Bay Rd.), approximately 0.5 km from the mouth of the creek.

The **Austin Creek** hydrograph gauge and sampling site is located approximately 15 m downstream from Lake Whatcom Blvd. From October 2004 through September 2006, three additional sampling sites were sampled in the Austin Creek watershed, so for clarification, the gauged site has been renamed **Lower Austin Creek**.

**Blue Canyon Creek** samples are collected downstream from the culvert under Blue Canyon Rd. in the second of three small streams that cross the road. This site can be difficult to locate and may be dry or have minimal flow during drought conditions; contact IWS for detailed information about the site location.

**Brannian Creek** samples are collected approximately 40 m downstream from South Bay Rd. near the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

**Carpenter Creek** samples are collected approximately 7 m upstream from North Shore Dr. near the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

**Euclid Ave.** samples are collected from an unnamed tributary located off Decator Rd. near the USGS hydrograph gauge. The site is named for its proximity to Euclid Ave., and was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

**Millwheel Creek** samples are collected approximately 8 m upstream from Flynn St. near the USGS hydrograph gauge. The creek is unnamed on most topographic maps, but has been called "Millwheel Creek" by residents of the watershed due to its proximity to the old mill pond. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

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[23] This hydrograph is no longer maintained by IWS; contact the City of Bellingham for data.

**Olsen Creek** samples are collected just downstream from North Shore Dr. near the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

**Park Place** samples are collected from the storm drain that empties into Lake Whatcom at Park Place Ln. Samples from this site include outlet flow from the Park Place storm water treatment facility.

**Silver Beach Creek** samples are collected approximately 15 m upstream from the culvert under North Shore Rd.

The **Smith Creek** hydrograph is mounted on the south wall of a sandstone bluff directly underneath the bridge over Smith Creek (North Shore Rd.) approximately 1 km upstream from the mouth of the creek. Water samples are collected at the gaging station approximately 15 m downstream from North Shore Dr.

**Whatcom Creek** samples are collected approximately 2 m downstream from the foot bridge below the Lake Whatcom outlet spillway. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

## A.3 Storm Water Monitoring Sites

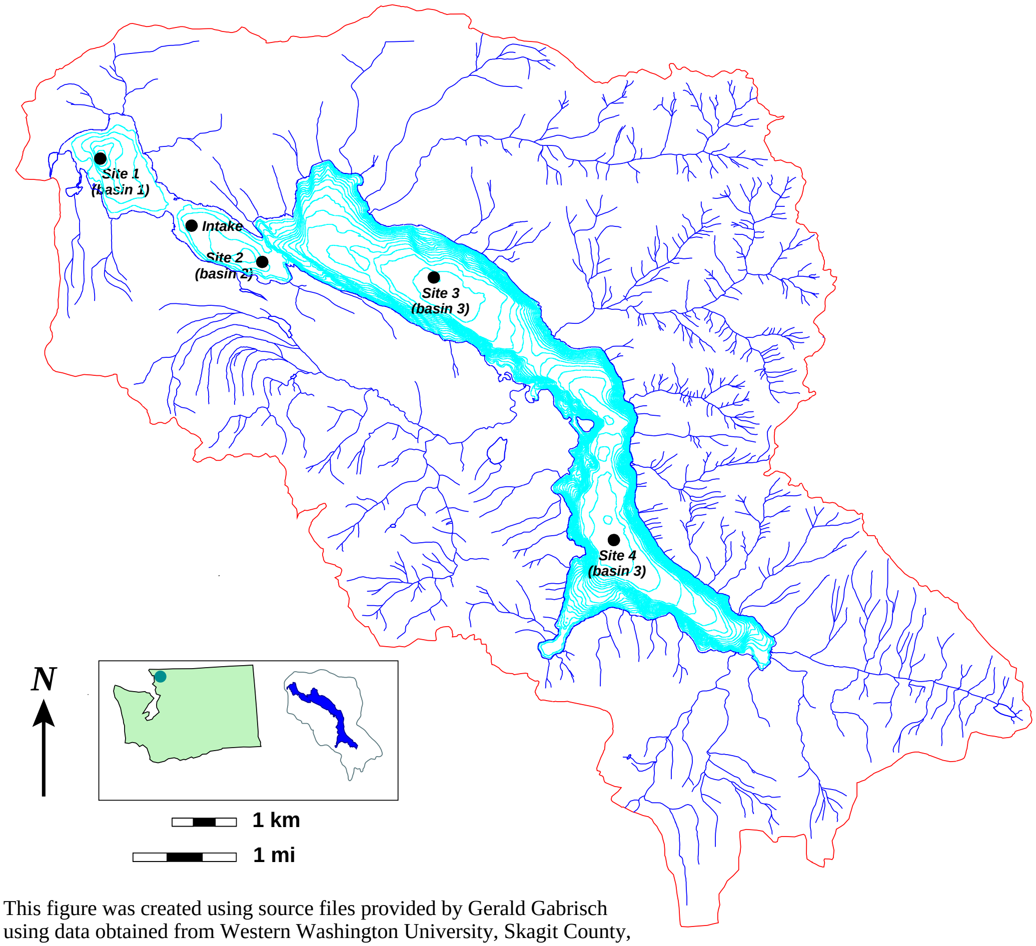
The storm water monitoring program was revised in 2009/2010 to focus on collecting baseline data at the Silver Beach Creek outlet and the North Shore Drive overlay. Both sites were monitored in 2009/2010 (see Matthews, et al., 2011). During the 2010/2011 monitoring period, the emphasis was on collecting additional storm water samples from Silver Beach Creek. For information about other storm water sites that have been monitored by IWS, refer to the annual reports listed in Section 6.2 (page 97).

**Silver Beach** storm runoff samples were collected at the USGS gauging site behind the house at 3007 Maynard Place and approximately 150 m upstream from the culvert at North Shore Dr.

| Lake Sites | Latitude (°N) | Longitude (°W) |
|---|---|---|
| Site 1 | 48.4536 | 122.2438 |
| Intake | (GPS omitted) | |
| Site 2 | 48.4436 | 122.2254 |
| Site 3 | 48.4416 | 122.2009 |
| Site 4 | 48.4141 | 122.1815 |

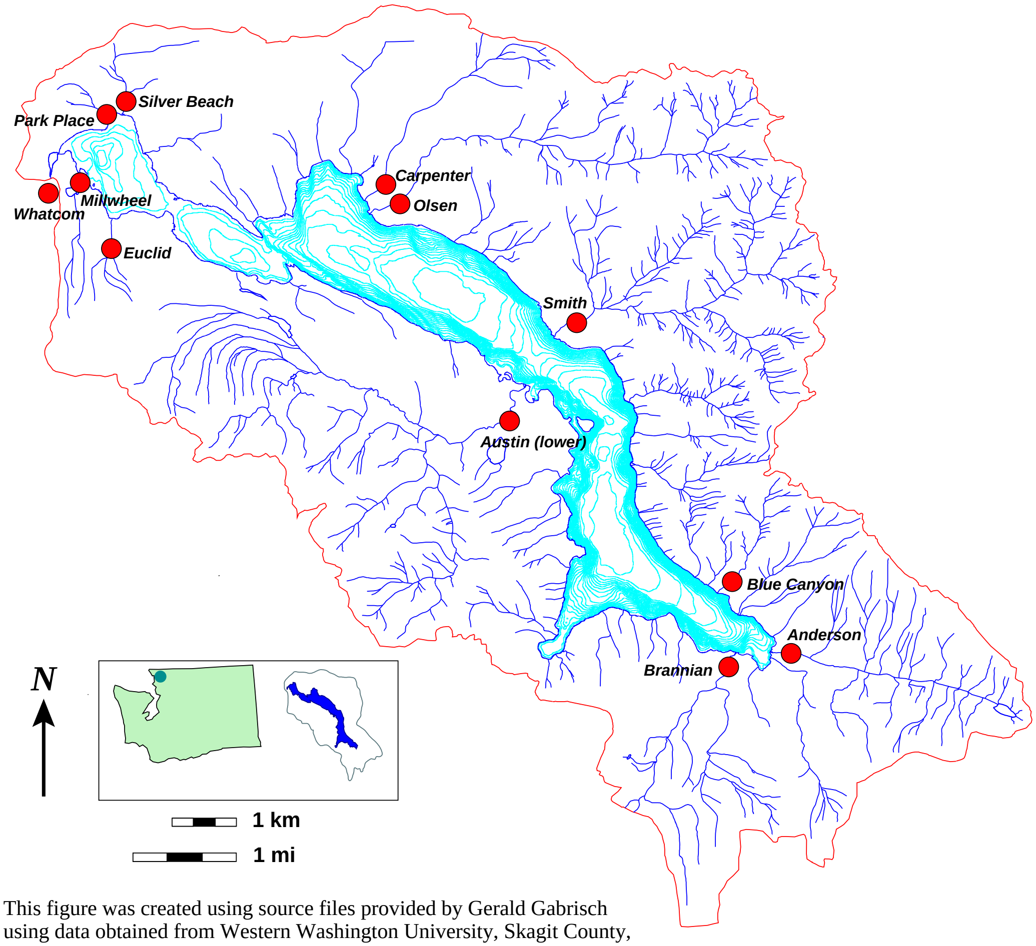
| Creek Sites | Latitude (°N) | Longitude (°W) |
|---|---|---|
| Anderson | 48.67335 | 122.26751 |
| Austin (lower) | 48.71312 | 122.33076 |
| Blue Canyon | 48.68532 | 122.28295 |
| Brannian | 48.66910 | 122.27949 |
| Carpenter | 48.75432 | 122.35449 |
| Euclid | 48.74844 | 122.41005 |
| Millwheel | 48.75507 | 122.41635 |
| Olsen | 48.75129 | 122.35353 |
| Park Place | 48.76894 | 122.40915 |
| Silver Beach | 48.76859 | 122.40700 |
| Smith | 48.73191 | 122.30864 |
| Whatcom | 48.75715 | 122.42229 |

Table A1: Approximate GPS coordinates for Lake Whatcom sampling sites.



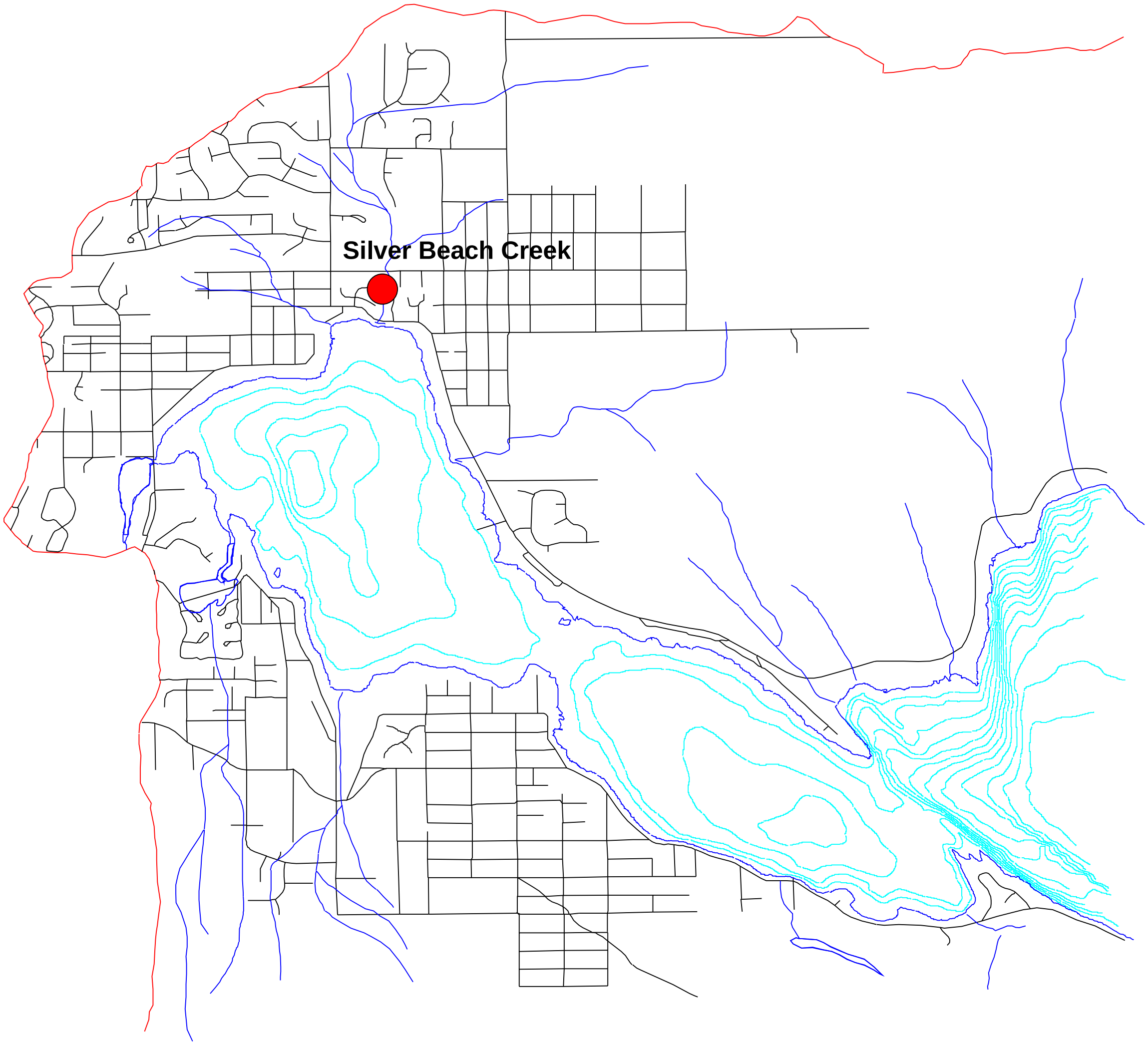
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A1: Lake Whatcom lake sampling sites.



This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A2: Lake Whatcom tributary sampling sites.



This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A3: Silver Beach Creek storm water site.

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# B Long-Term Water Quality Figures

The current and historic Lake Whatcom water quality data are plotted on the following pages. Detection limits and abbreviations for each parameter are listed in Table 1 (page 17).

The historic detection limits for each parameter were estimated based on recommended lower detection ranges (APHA, 1998; Hydrolab, 1997; Lind, 1985), instrument limitations, and analyst judgment on the lowest repeatable concentration for each test. Over time, some analytical techniques have improved so that current detection limits are lower than defined below (see current detection limits in Table 1, page 17). Because the Lake Whatcom data set includes long-term monitoring data that have been collected using a variety of analytical techniques, this report sets conservative historic detection limits to allow comparisons between all years.

In the Lake Whatcom report, unless indicated, no data substitutions are used for below detection values (“bdl” data). Instead, we identify summary statistics that include bdl values, and, if appropriate, discuss the implications of including these values in the analysis.

Because of the length of the data record, many of the figures reflect trends related to improvements in analytical techniques over time, and introduction of increasingly sensitive field equipment (see, for example, Figures B66–B70, pages 177–181, which show the effect of using increasingly sensitive conductivity probes). These changes generally result in a reduction in analytical variability, and sometimes result in lower detection limits.

## B.1 Monthly Hydrolab Profiles

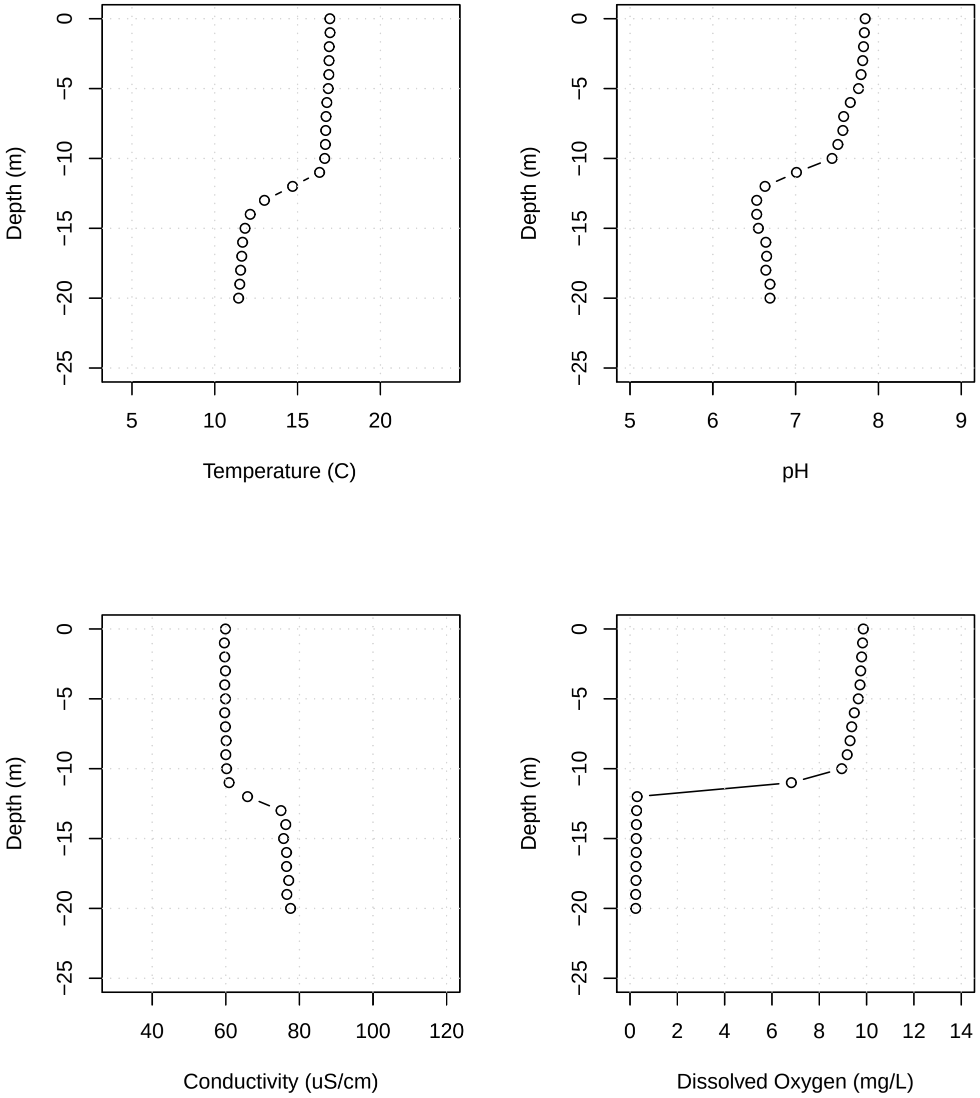


Figure B1: Lake Whatcom Hydrolab profiles for Site 1, October 7, 2010.

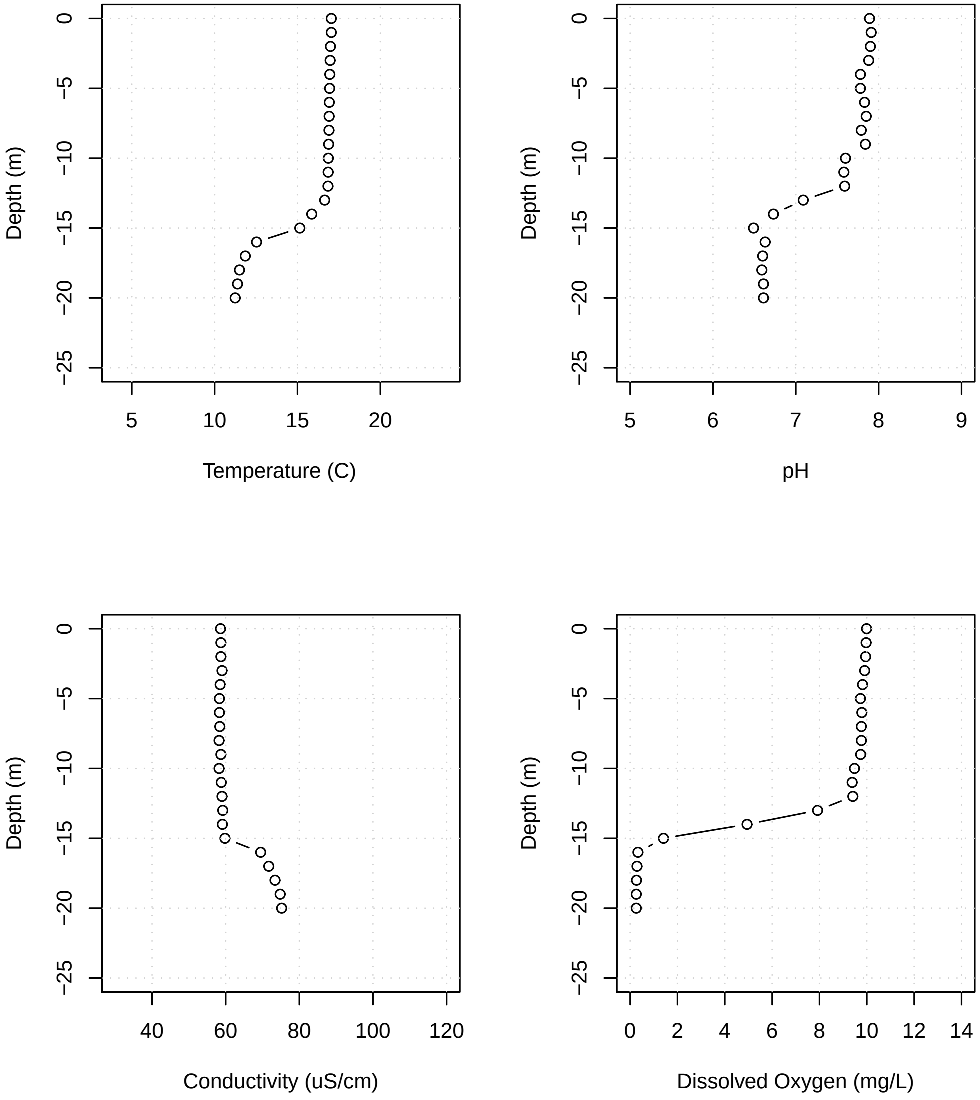


Figure B2: Lake Whatcom Hydrolab profiles for Site 2, October 7, 2010.

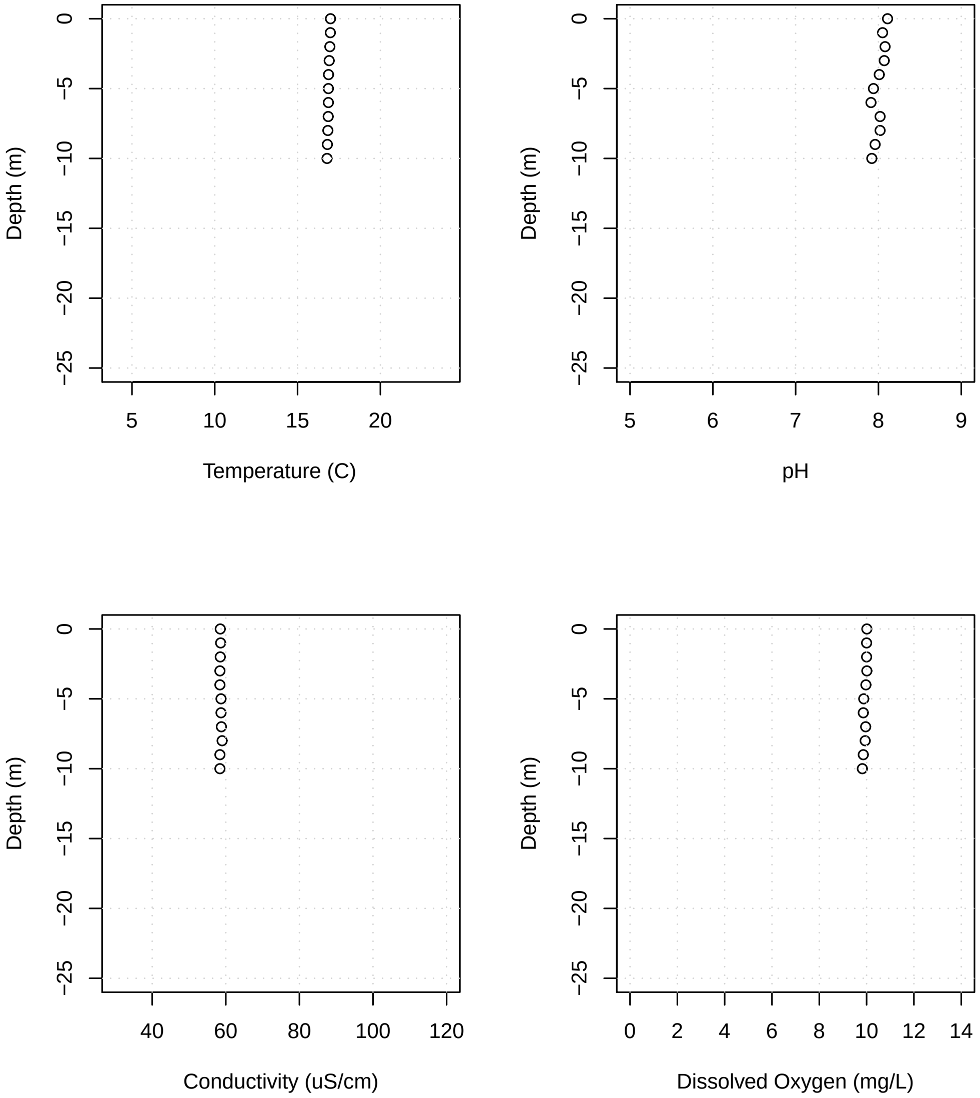


Figure B3: Lake Whatcom Hydrolab profiles for the Intake, October 7, 2010.

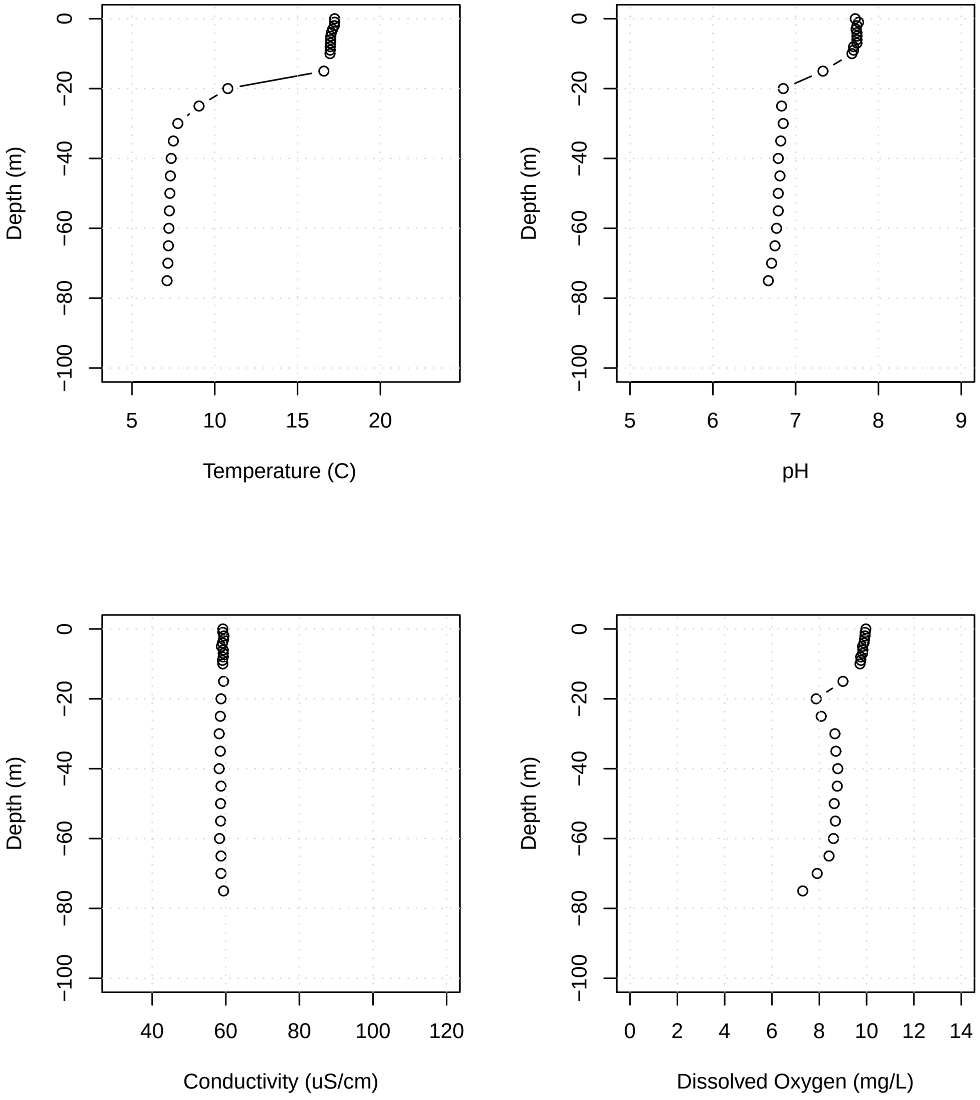


Figure B4: Lake Whatcom Hydrolab profiles for Site 3, October 8, 2010.

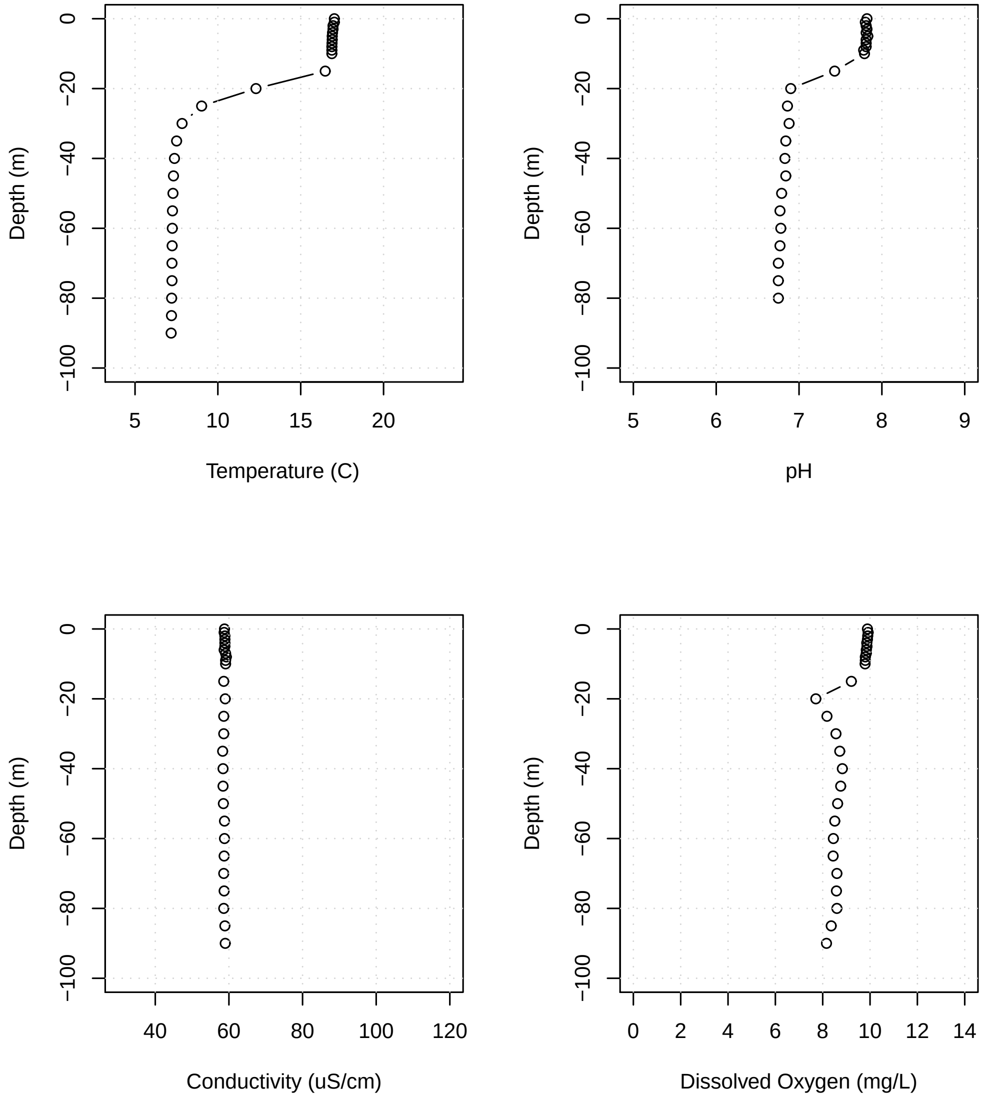


Figure B5: Lake Whatcom Hydrolab profiles for Site 4, October 8, 2010.

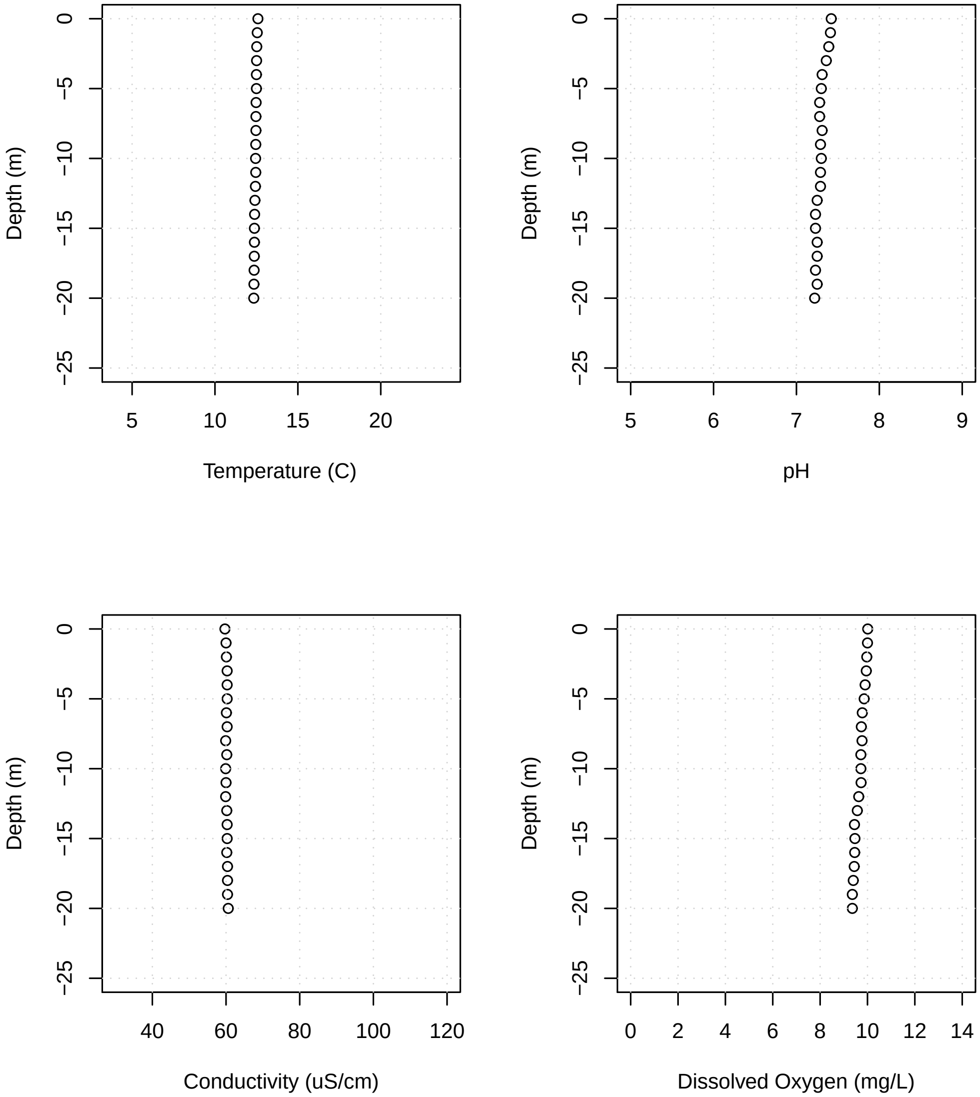


Figure B6: Lake Whatcom Hydrolab profiles for Site 1, November 4, 2010.

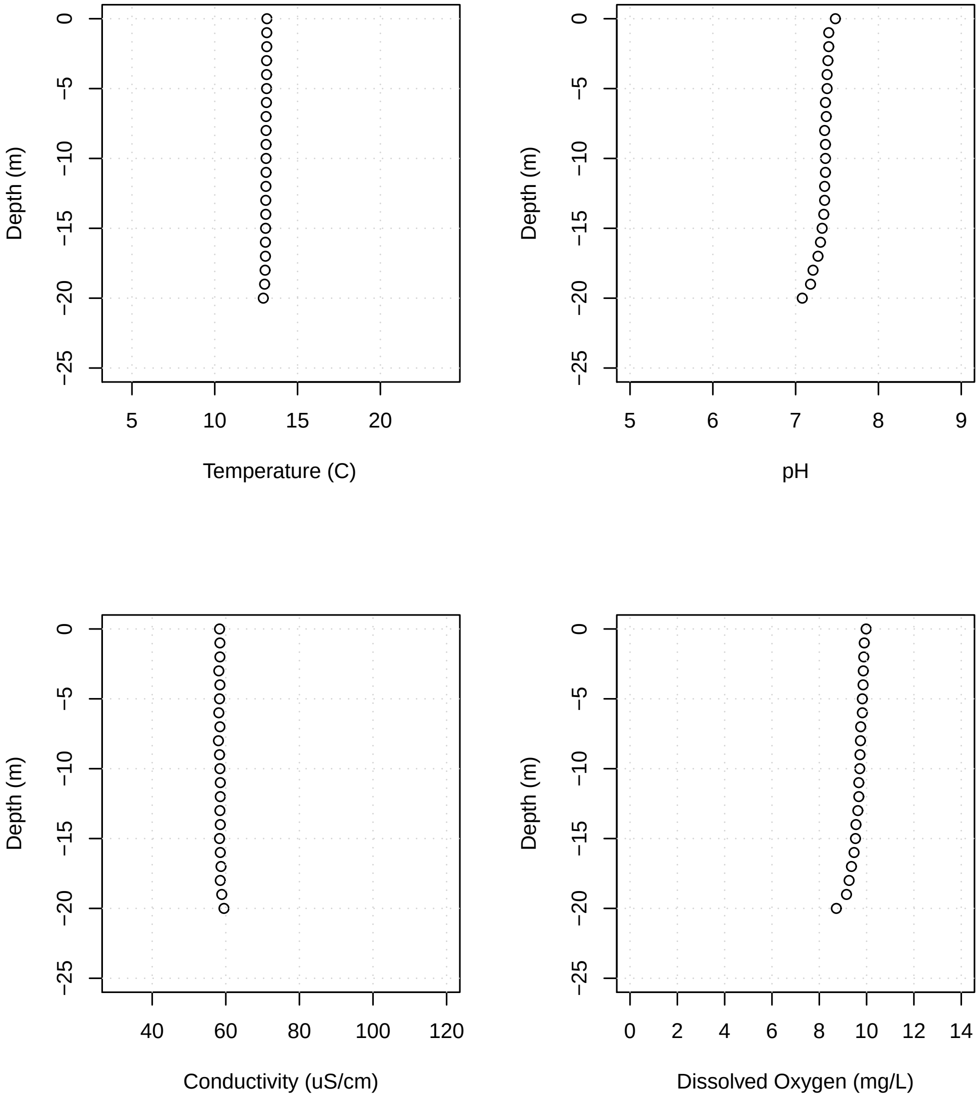


Figure B7: Lake Whatcom Hydrolab profiles for Site 2, November 4, 2010.

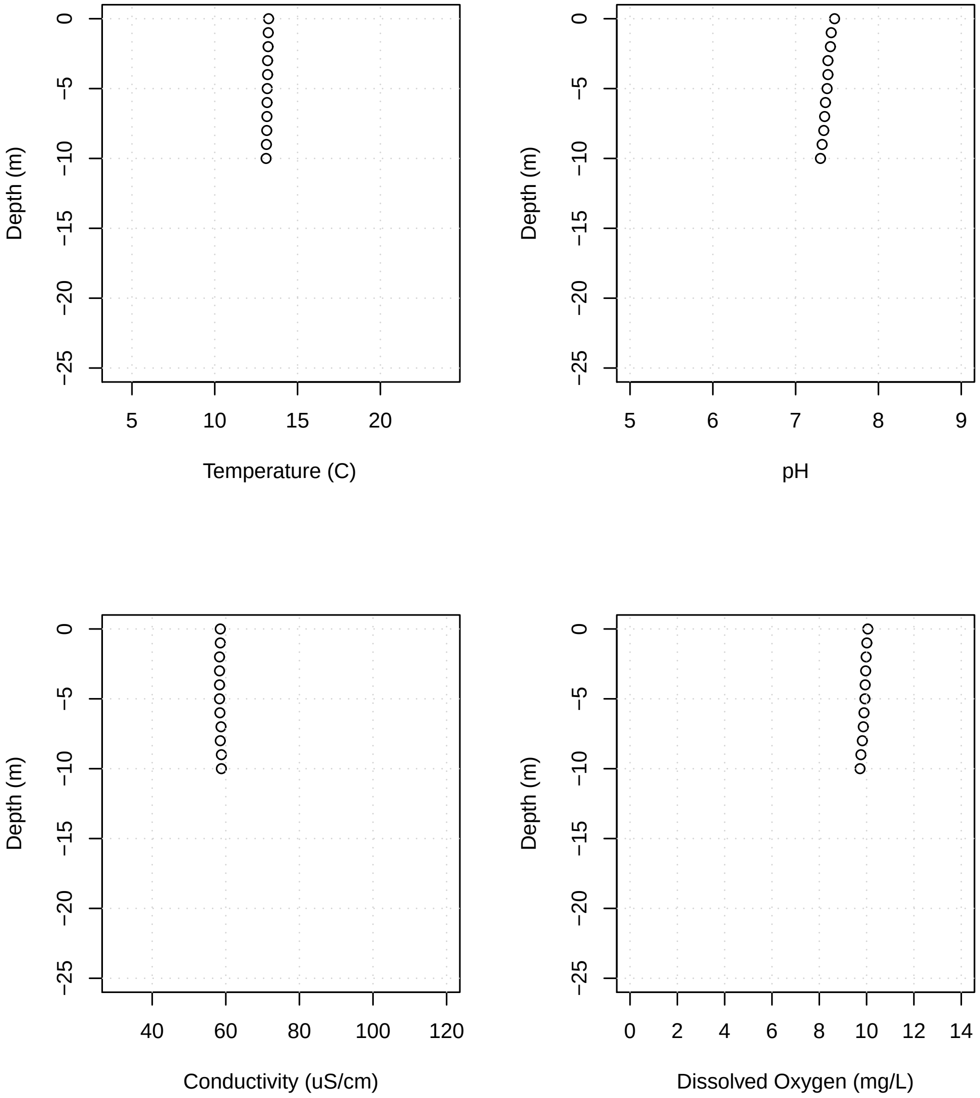


Figure B8: Lake Whatcom Hydrolab profiles for the Intake, November 4, 2010.

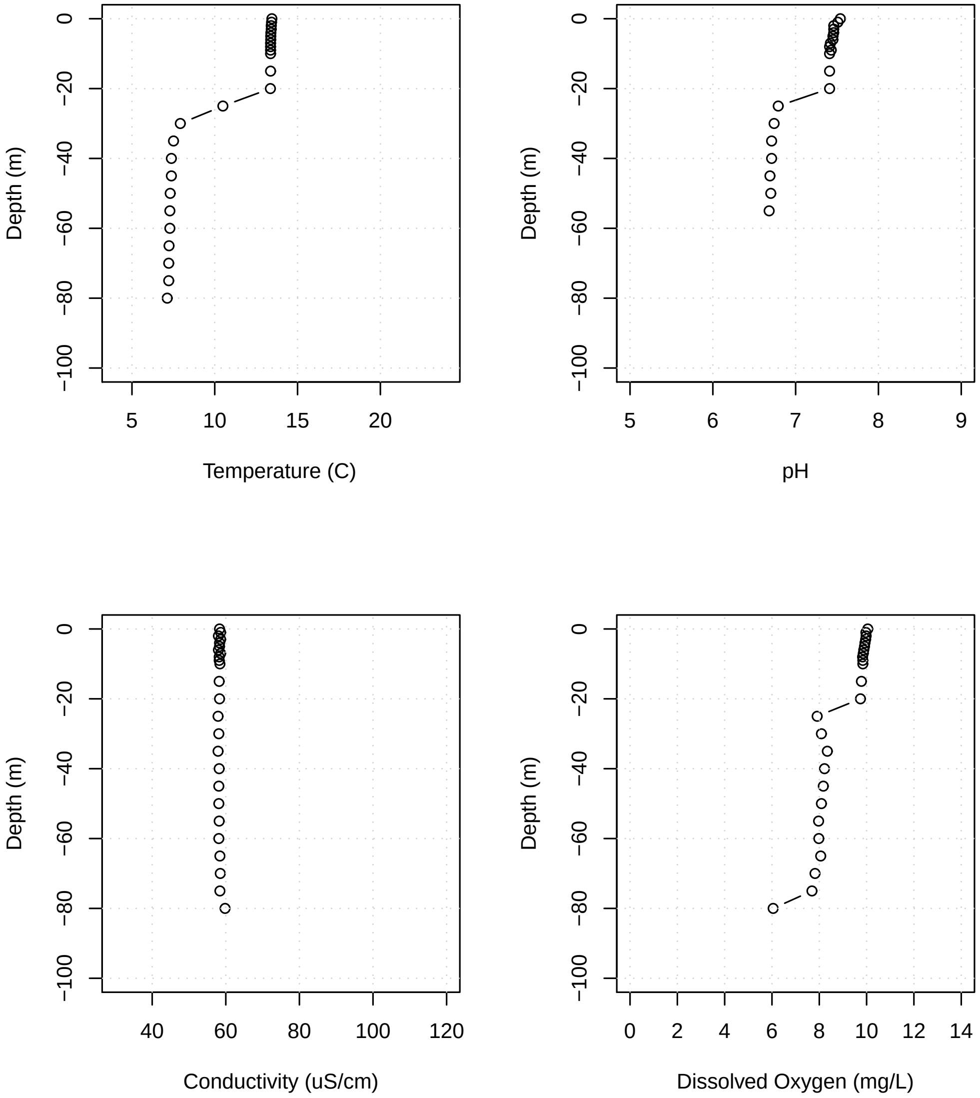


Figure B9: Lake Whatcom Hydrolab profiles for Site 3, November 2, 2010.

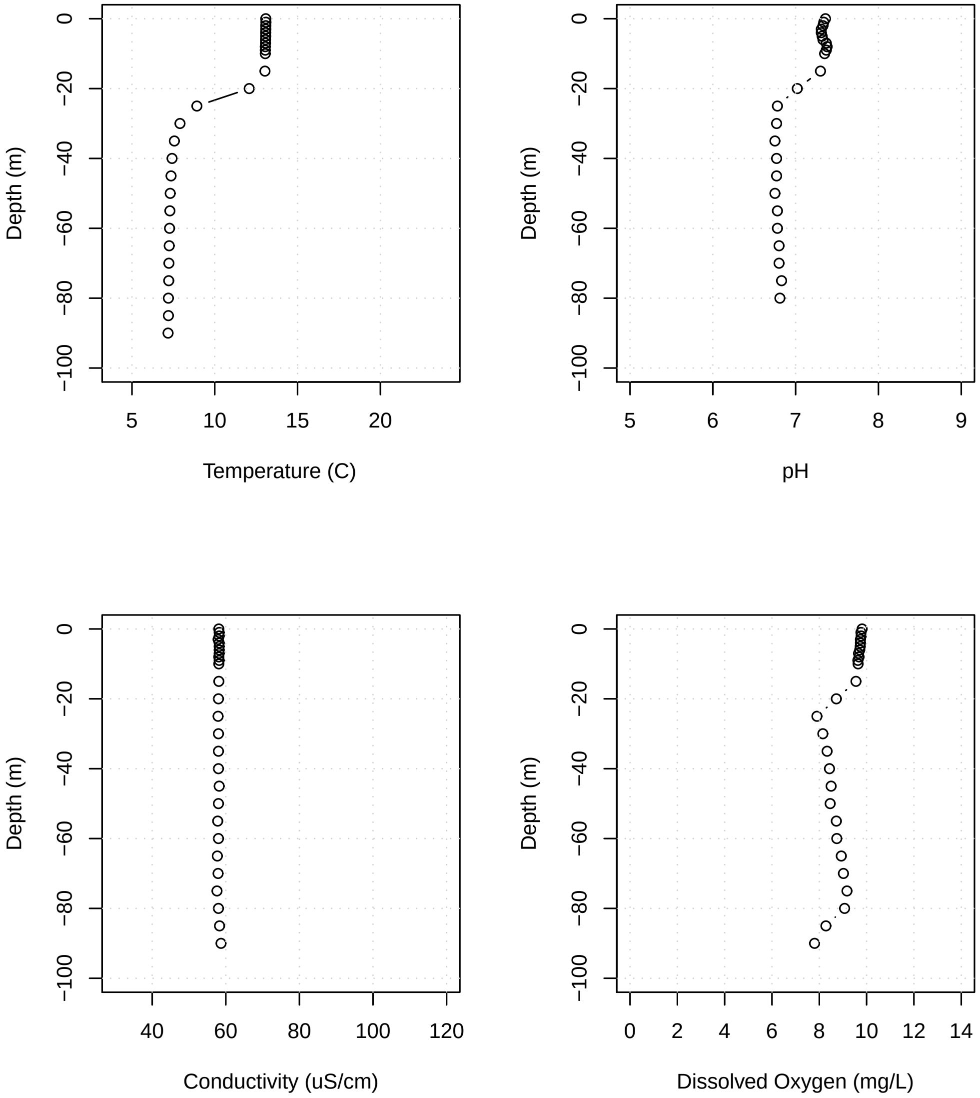


Figure B10: Lake Whatcom Hydrolab profiles for Site 4, November 2, 2010.

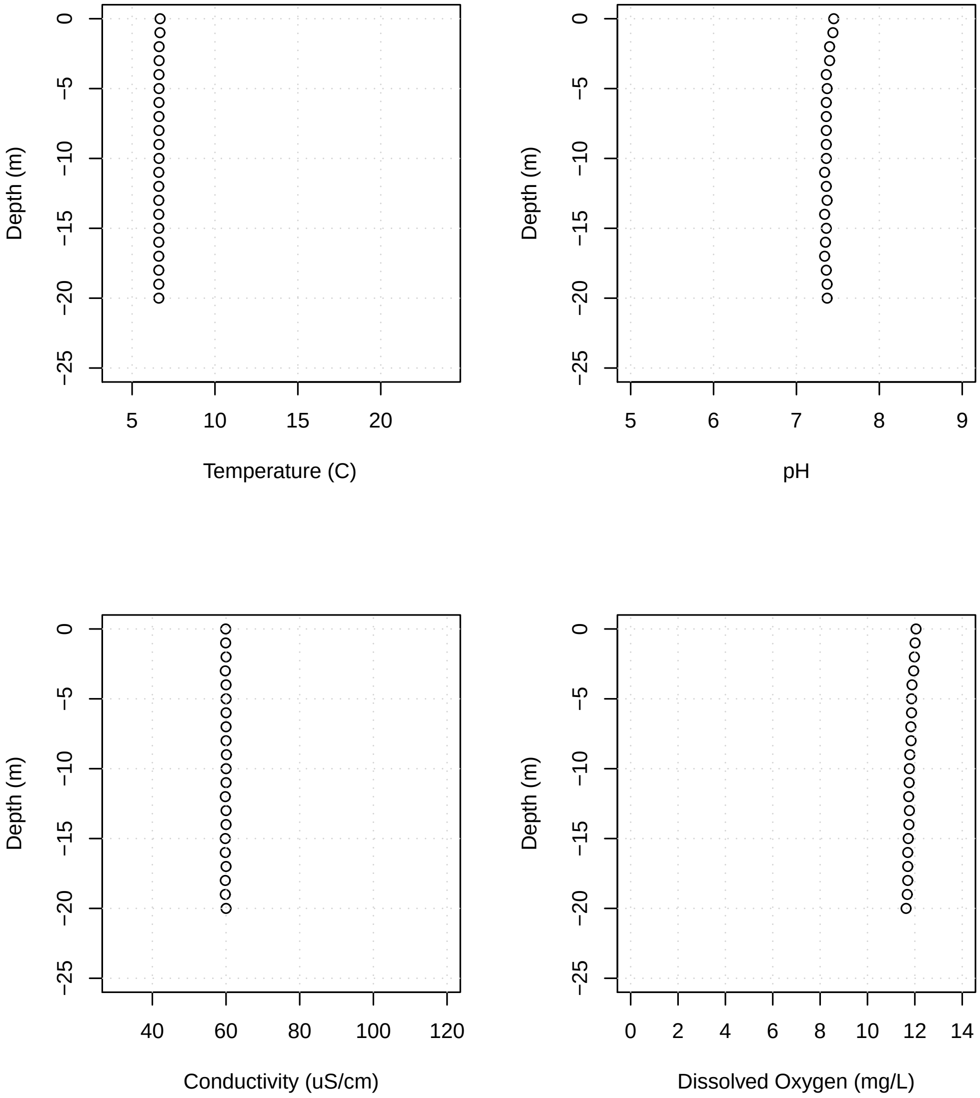


Figure B11: Lake Whatcom Hydrolab profiles for Site 1, December 2, 2010.

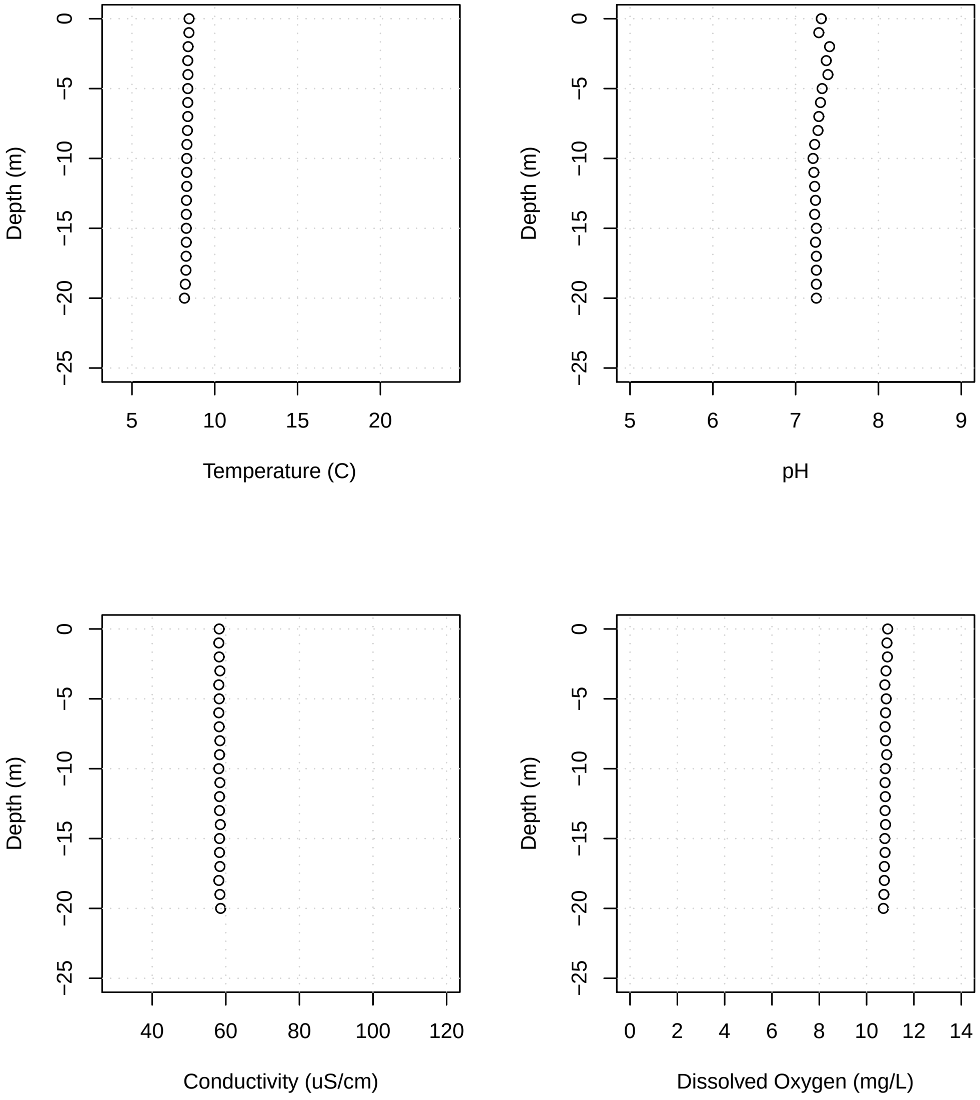


Figure B12: Lake Whatcom Hydrolab profiles for Site 2, December 2, 2010.

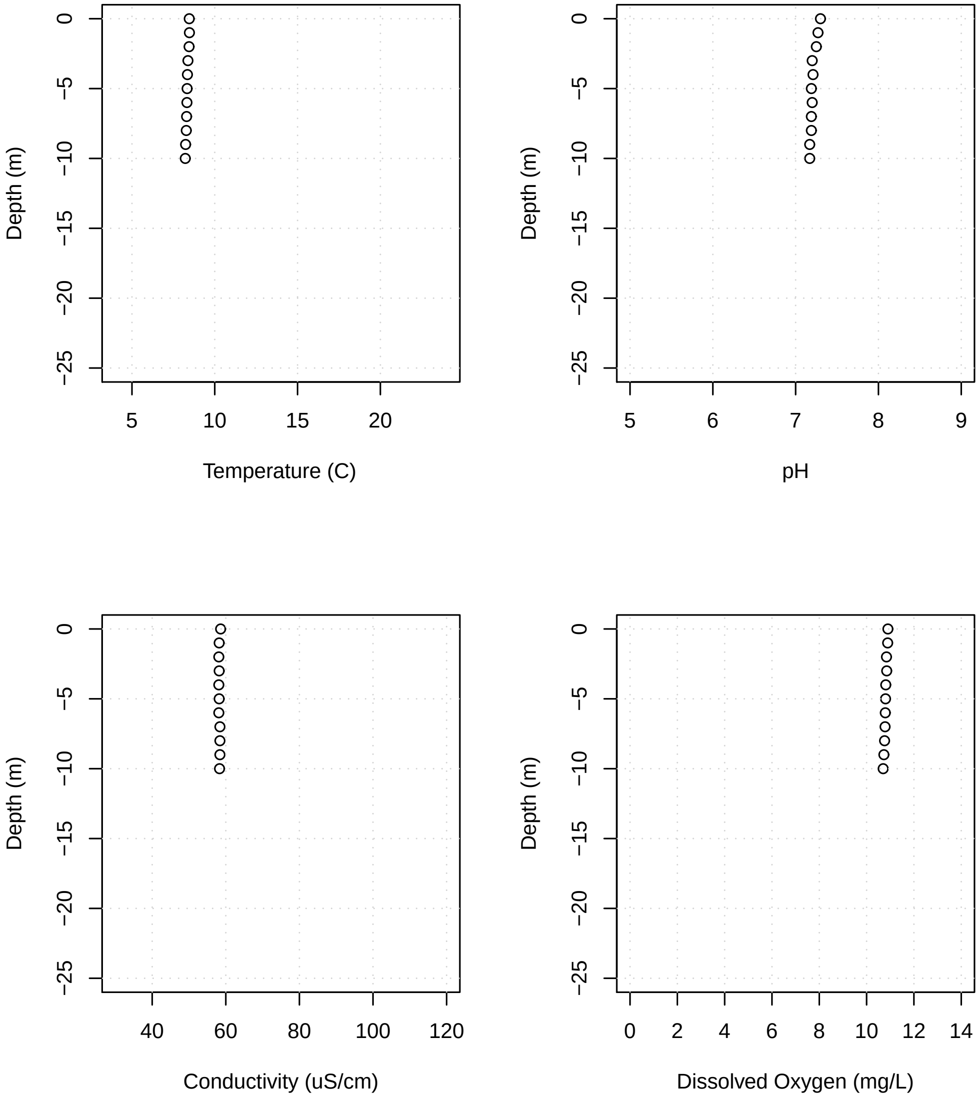


Figure B13: Lake Whatcom Hydrolab profiles for the Intake, December 2, 2010.

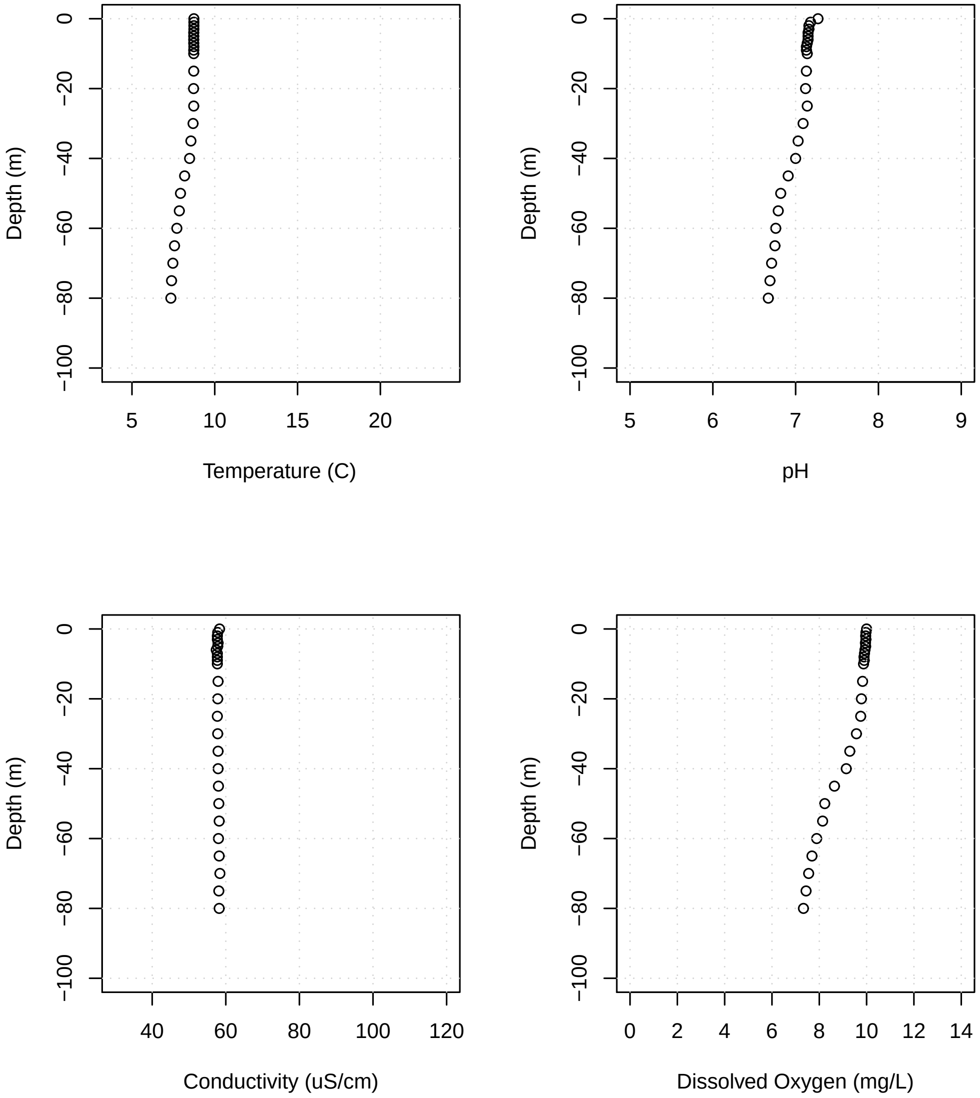


Figure B14: Lake Whatcom Hydrolab profiles for Site 3, December 1, 2010.

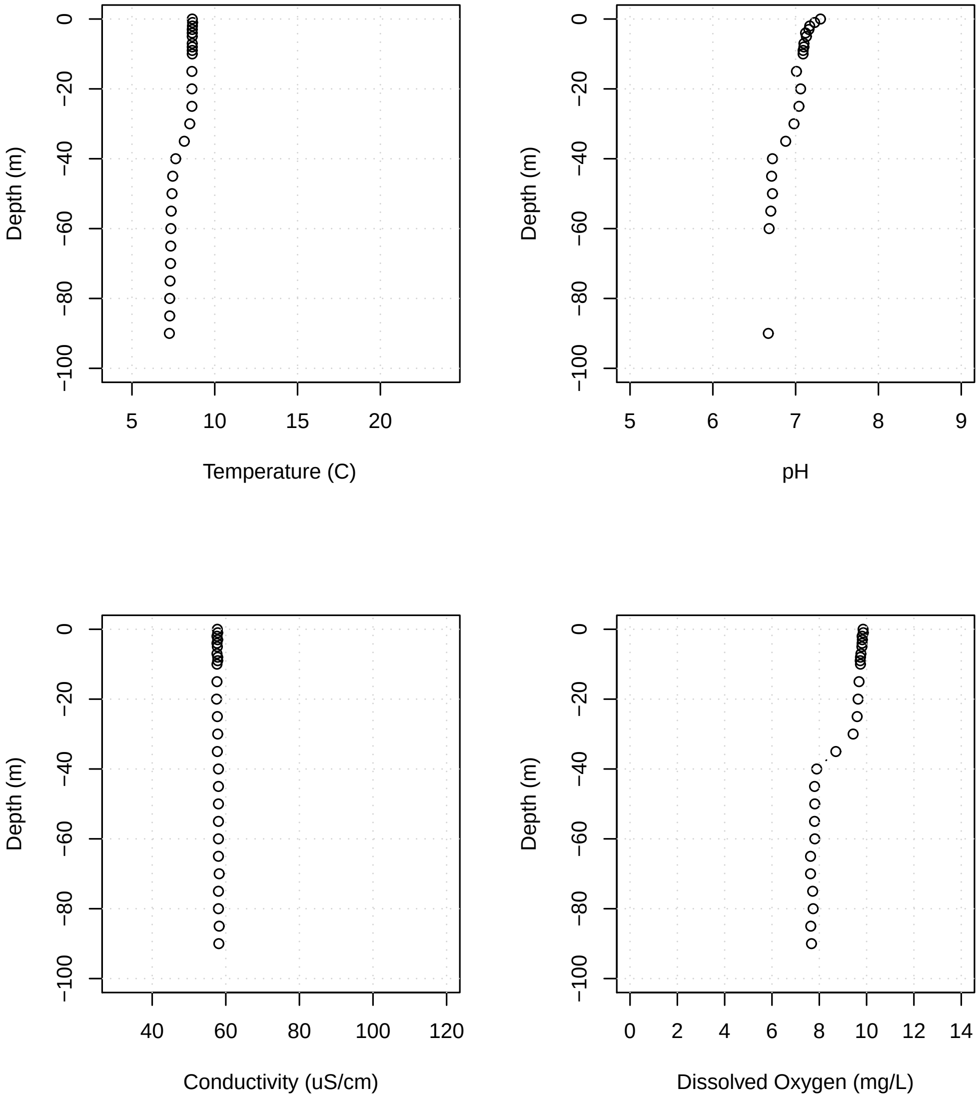


Figure B15: Lake Whatcom Hydrolab profiles for Site 4, December 1, 2010. The pH data from 65–85 meters are not available due to equipment malfunction.

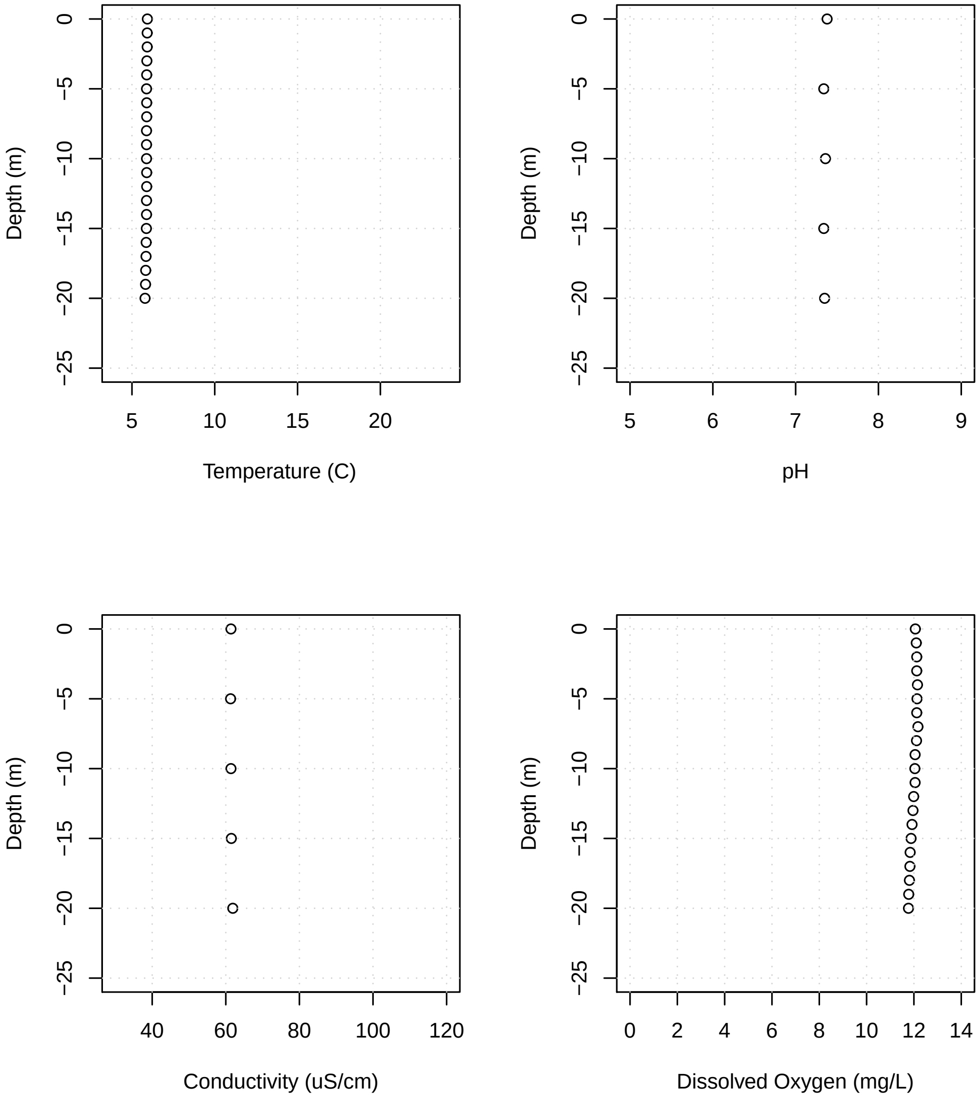


Figure B16: Lake Whatcom Hydrolab profiles for Site 1, February 3, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

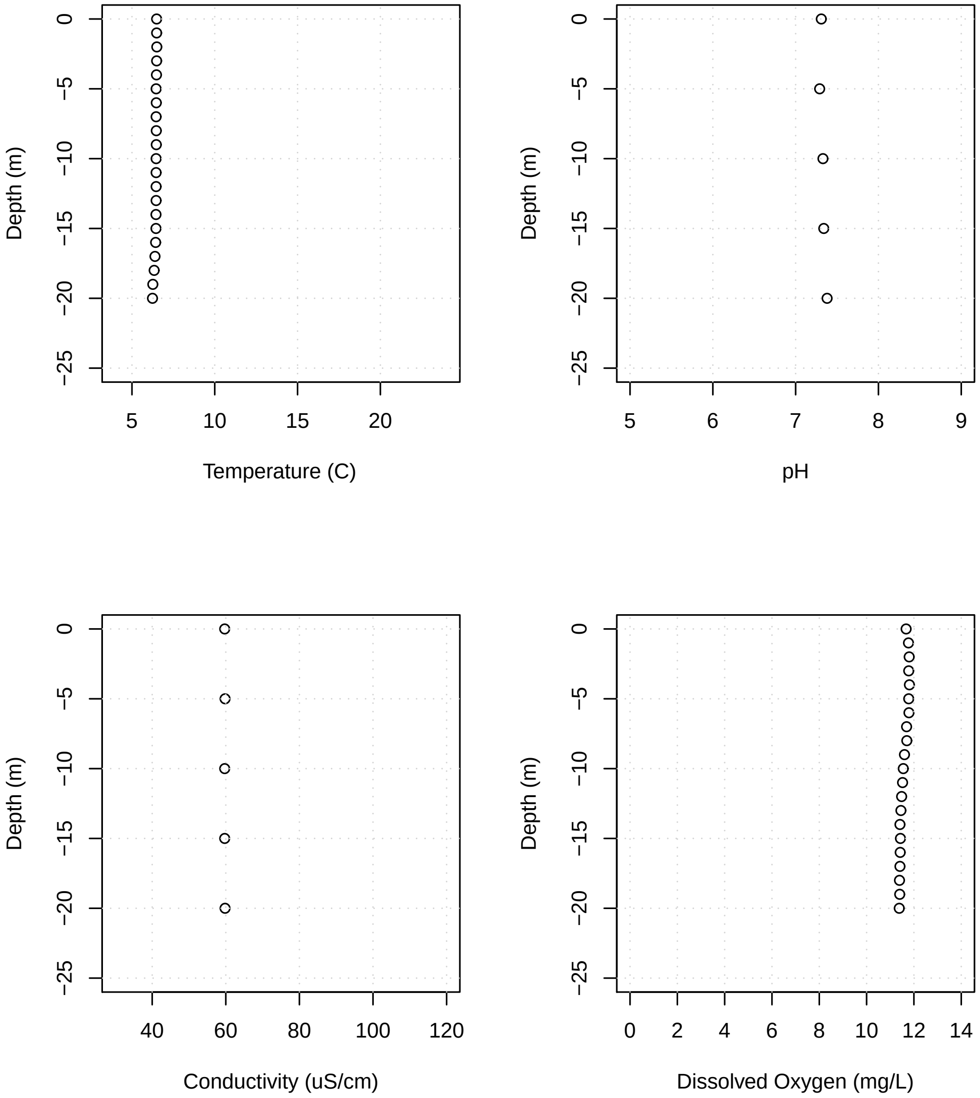


Figure B17: Lake Whatcom Hydrolab profiles for Site 2, February 3, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

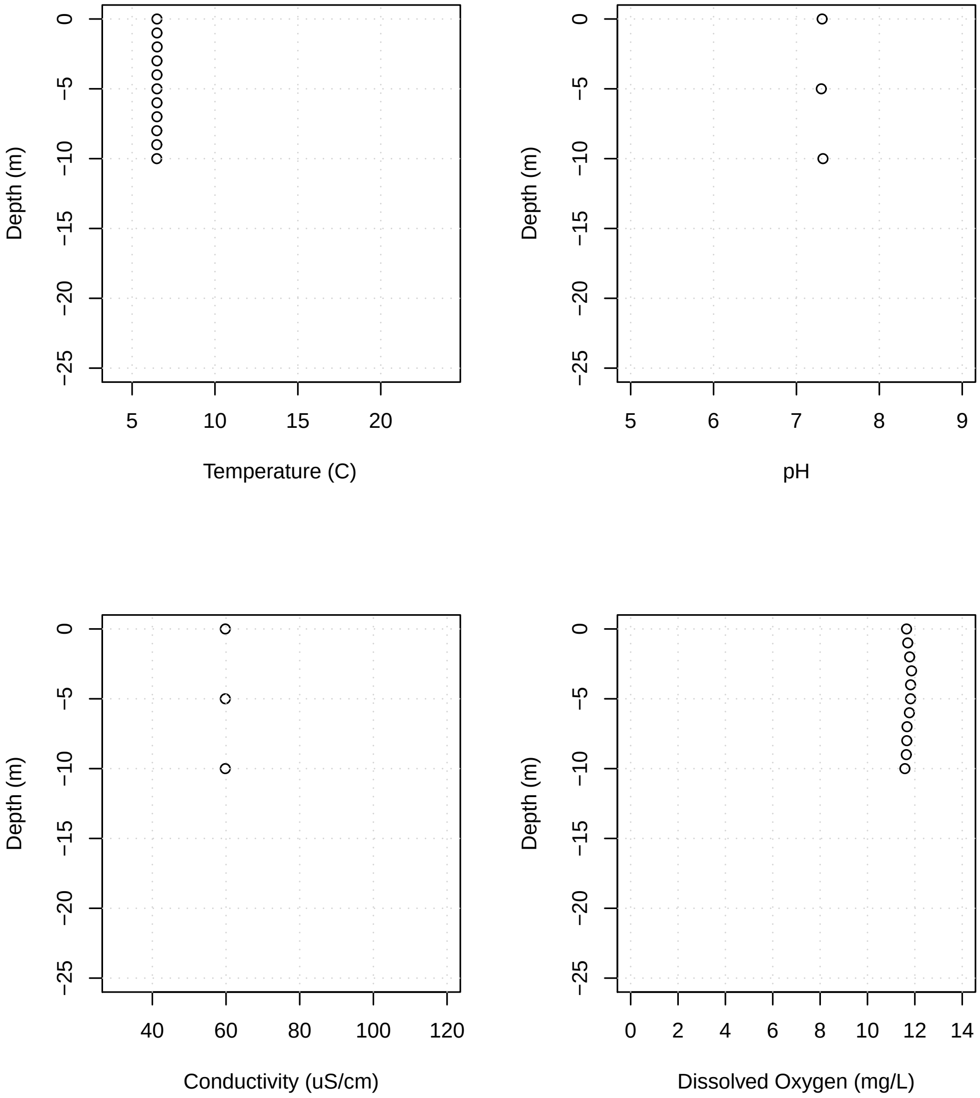


Figure B18: Lake Whatcom Hydrolab profiles for the Intake, February 3, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

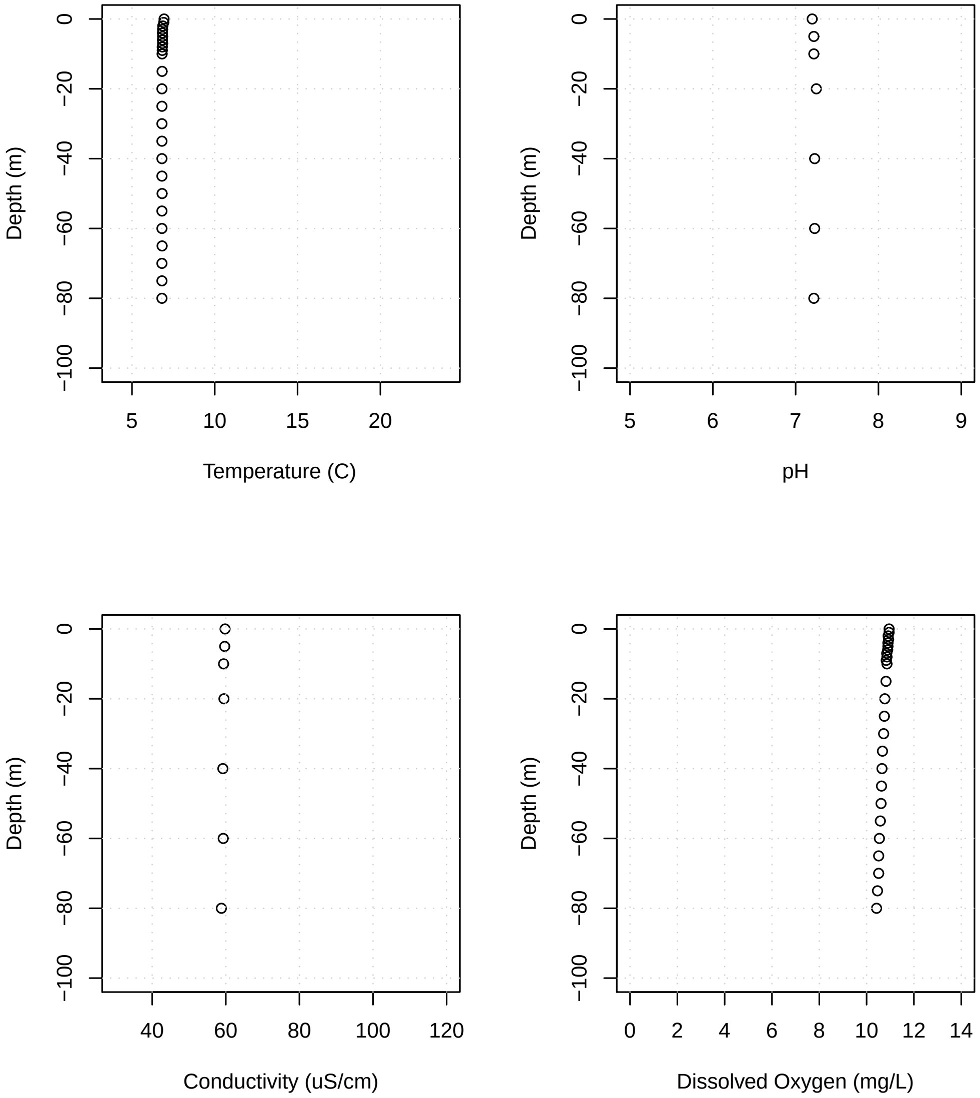


Figure B19: Lake Whatcom Hydrolab profiles for Site 3, February 1, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

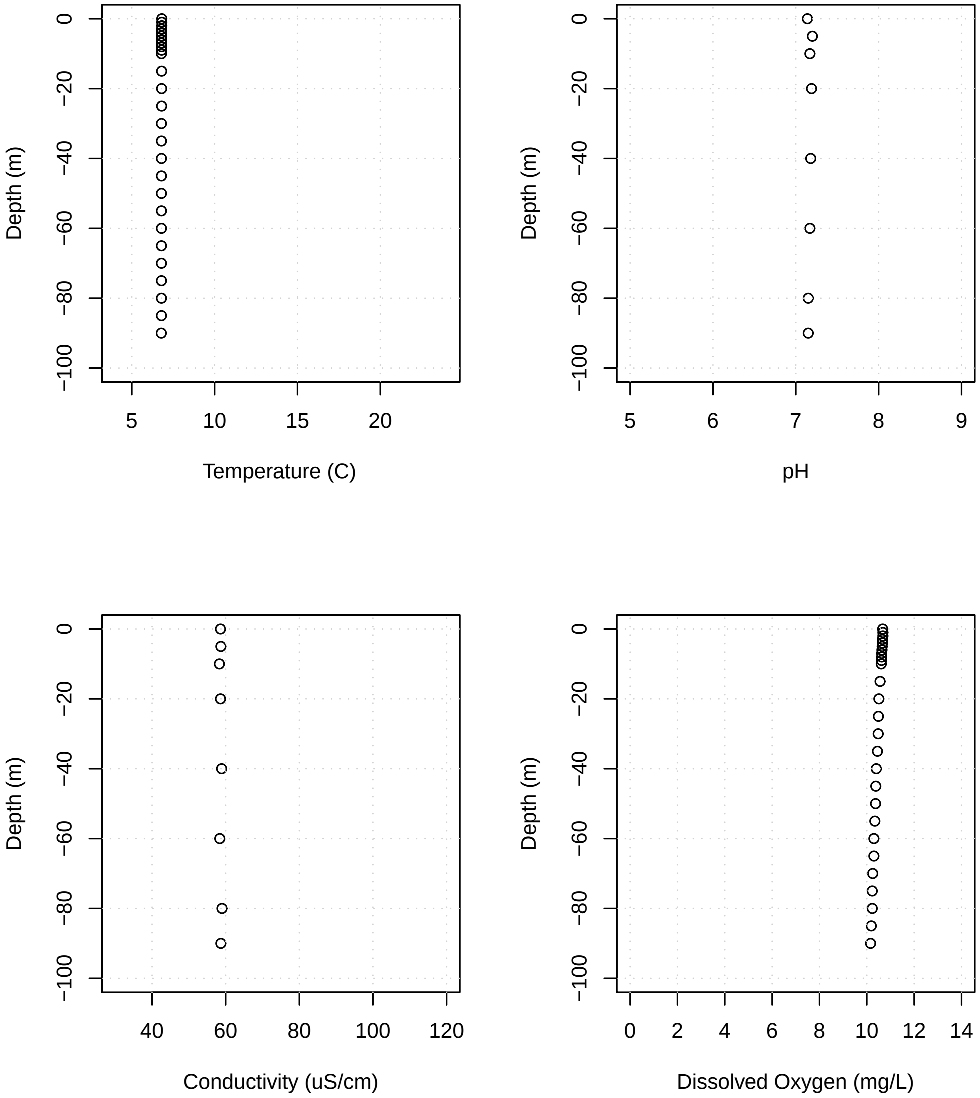


Figure B20: Lake Whatcom Hydrolab profiles for Site 4, February 1, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

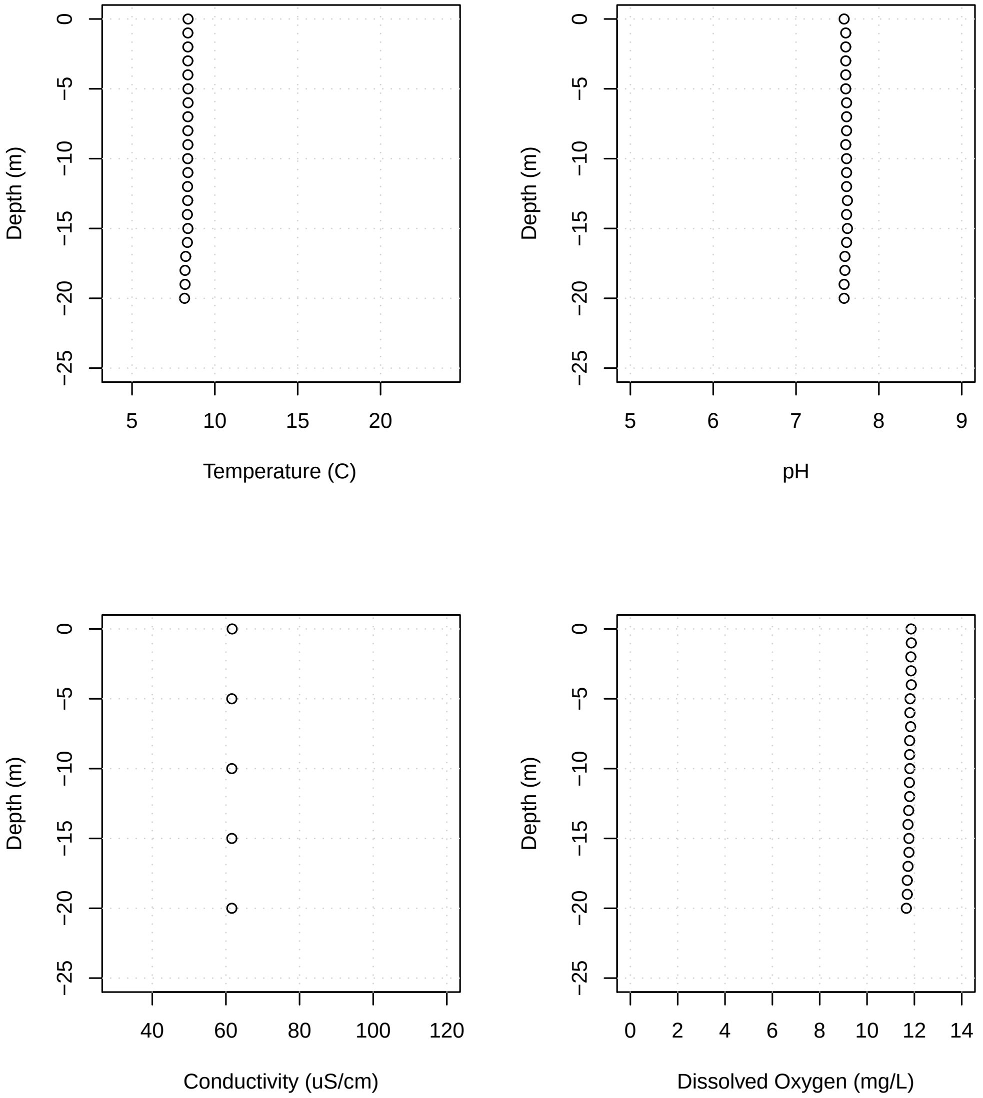


Figure B21: Lake Whatcom Hydrolab profiles for Site 1, April 14, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

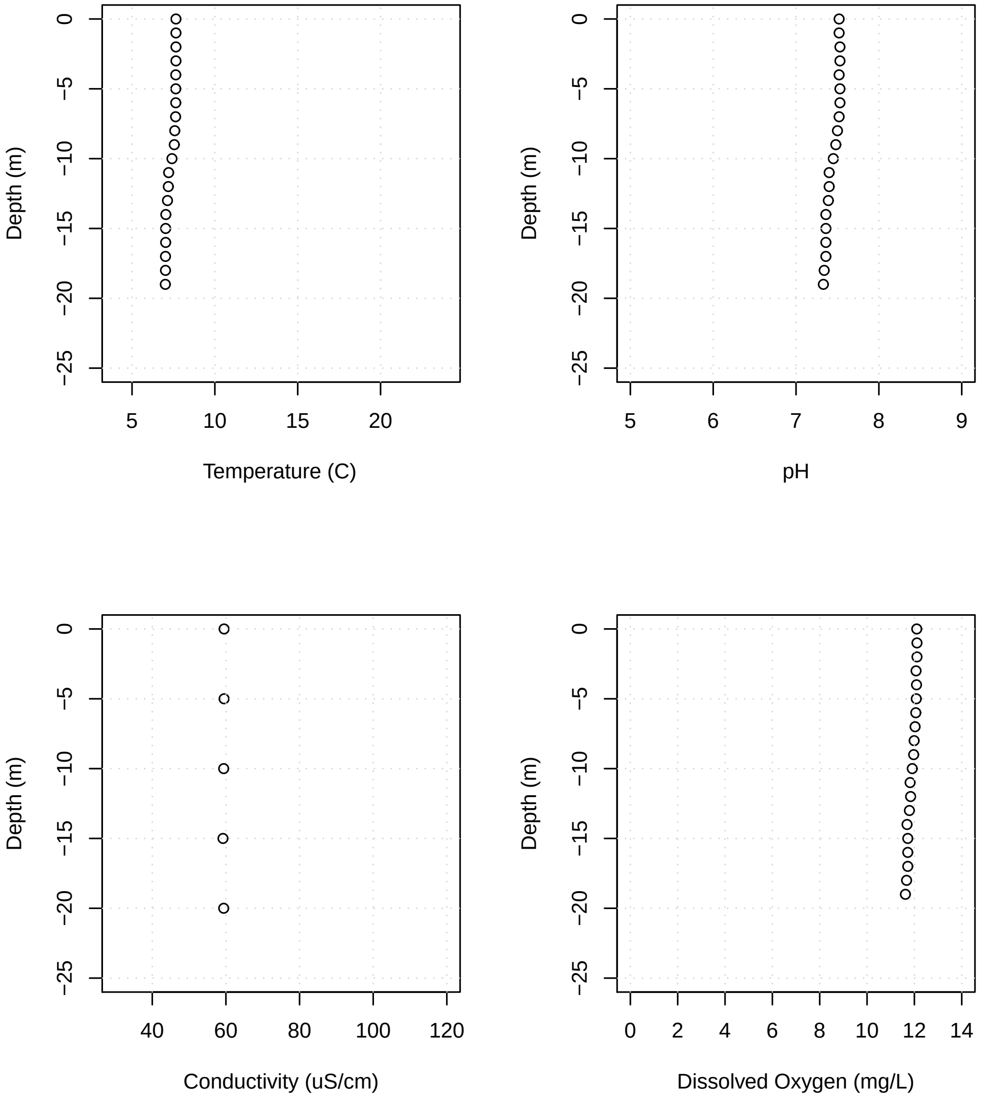


Figure B22: Lake Whatcom Hydrolab profiles for Site 2, April 14, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

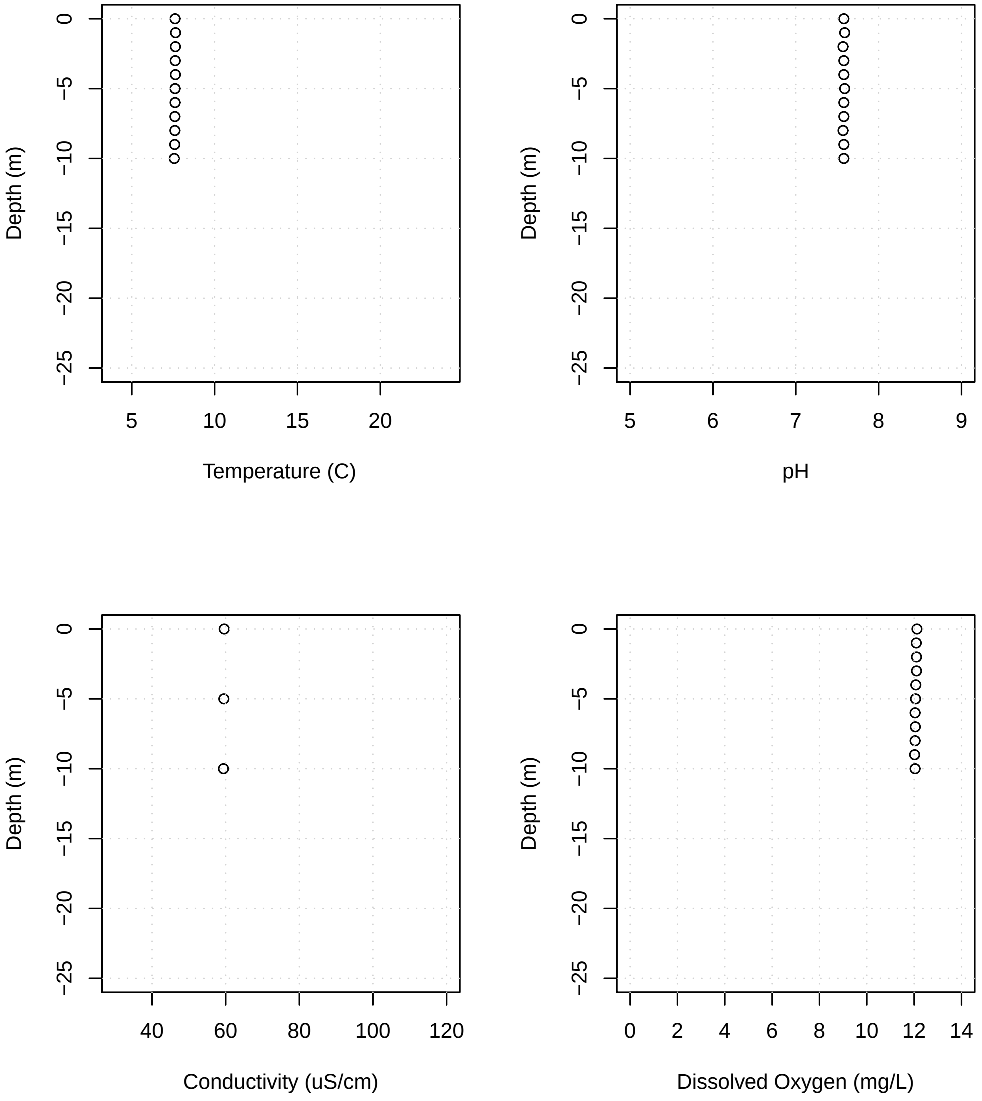


Figure B23: Lake Whatcom Hydrolab profiles for the Intake, April 14, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

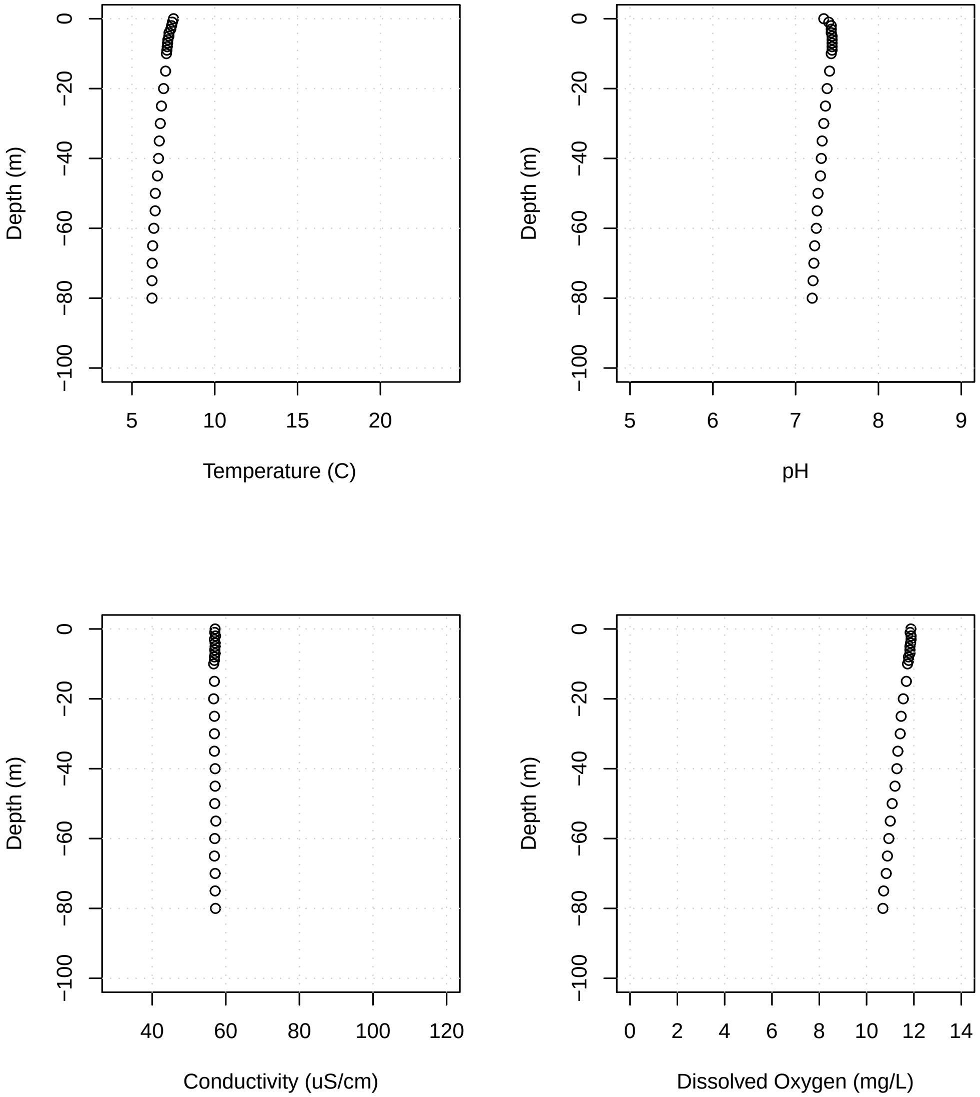


Figure B24: Lake Whatcom Hydrolab profiles for Site 3, April 12, 2011.

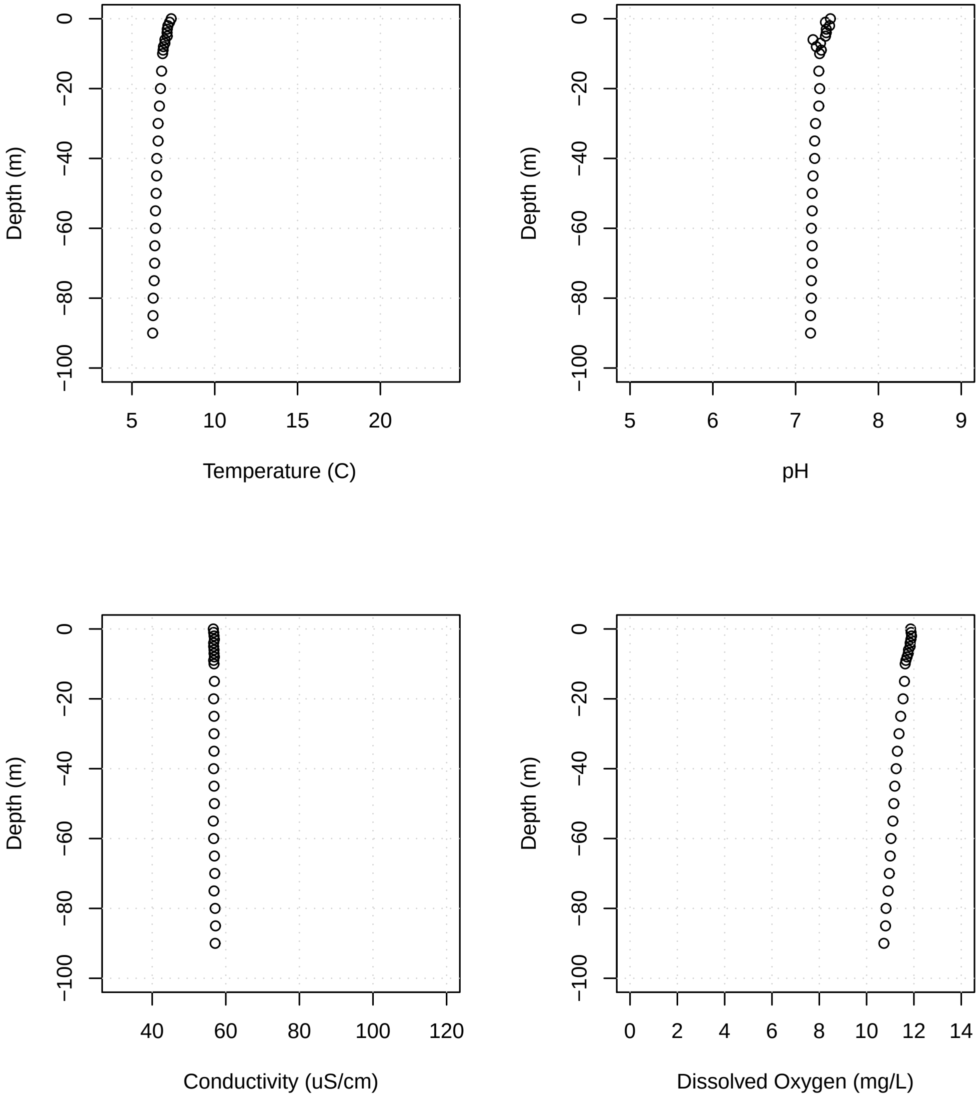


Figure B25: Lake Whatcom Hydrolab profiles for Site 4, April 12, 2011.

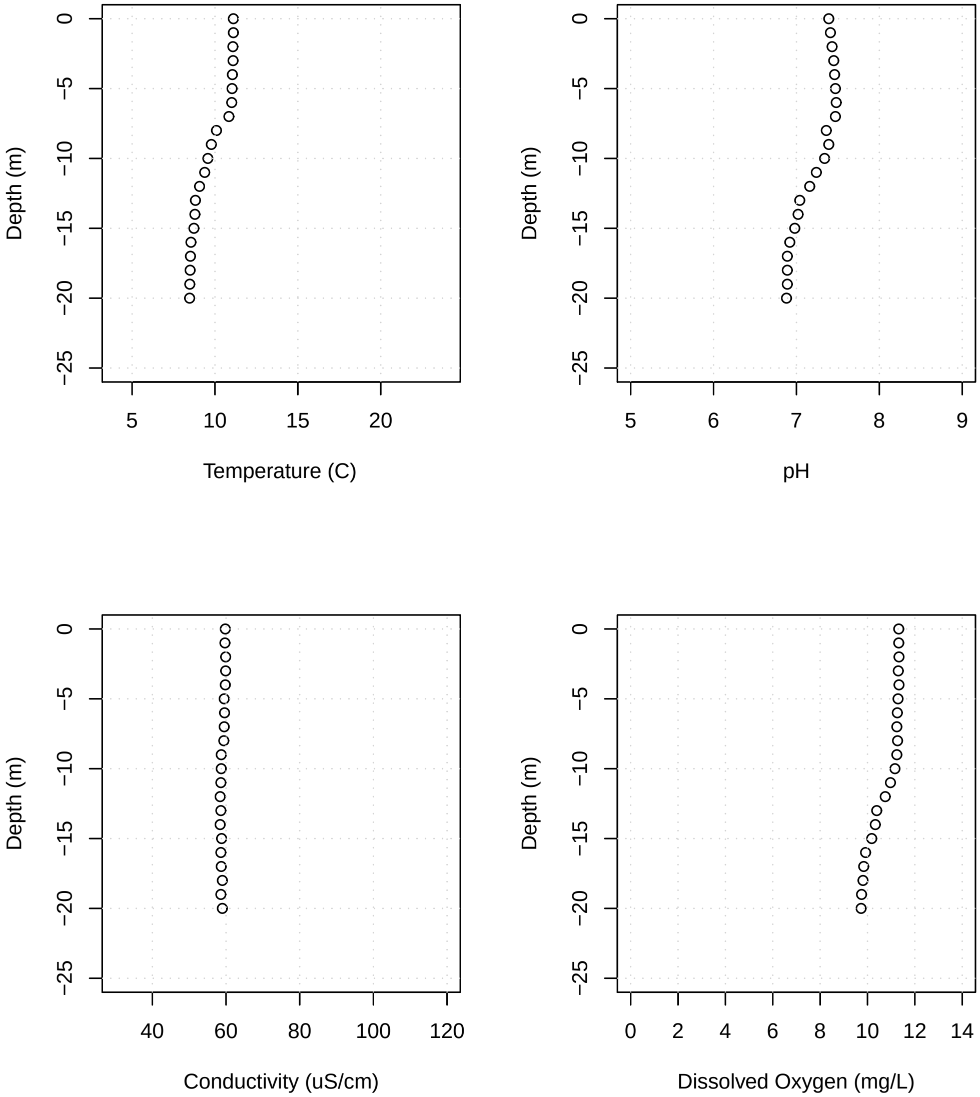


Figure B26: Lake Whatcom Hydrolab profiles for Site 1, May 5, 2011.

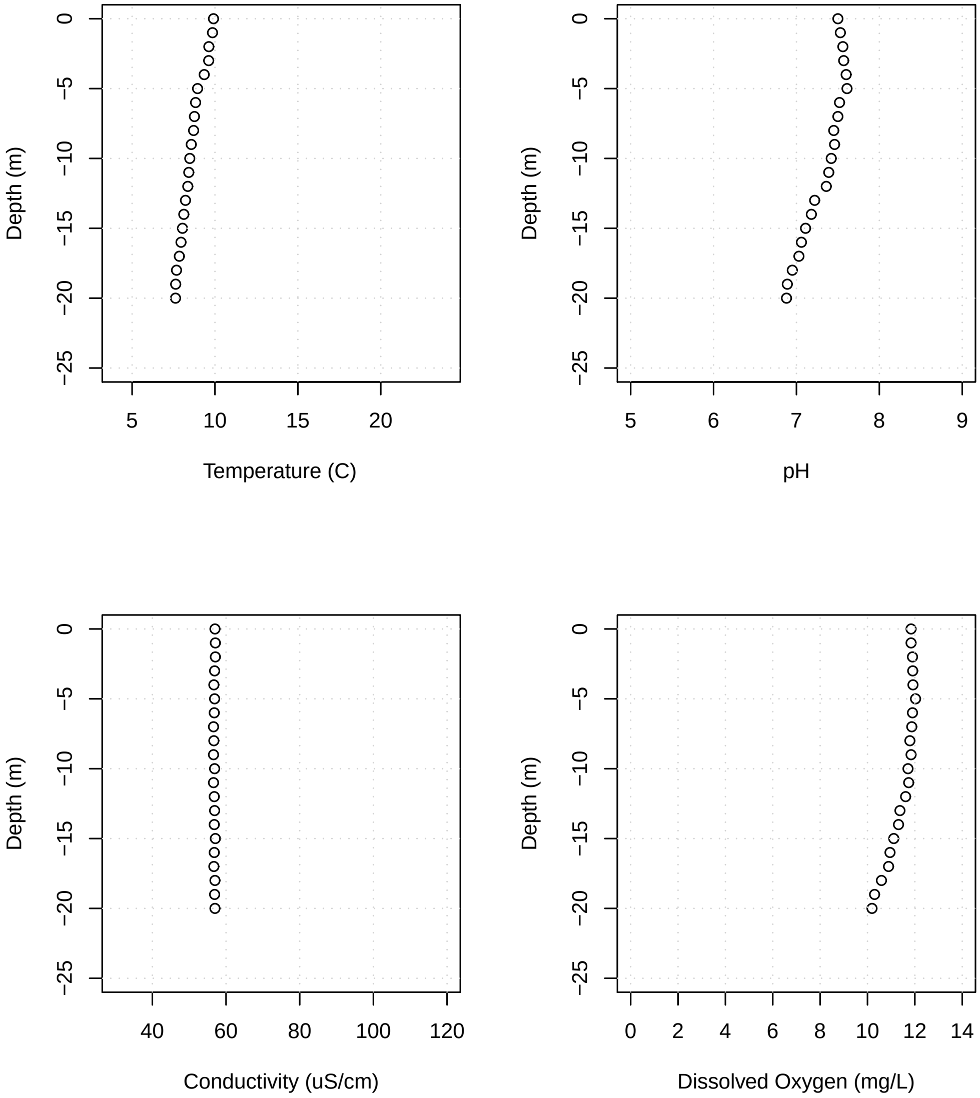


Figure B27: Lake Whatcom Hydrolab profiles for Site 2, May 5, 2011.

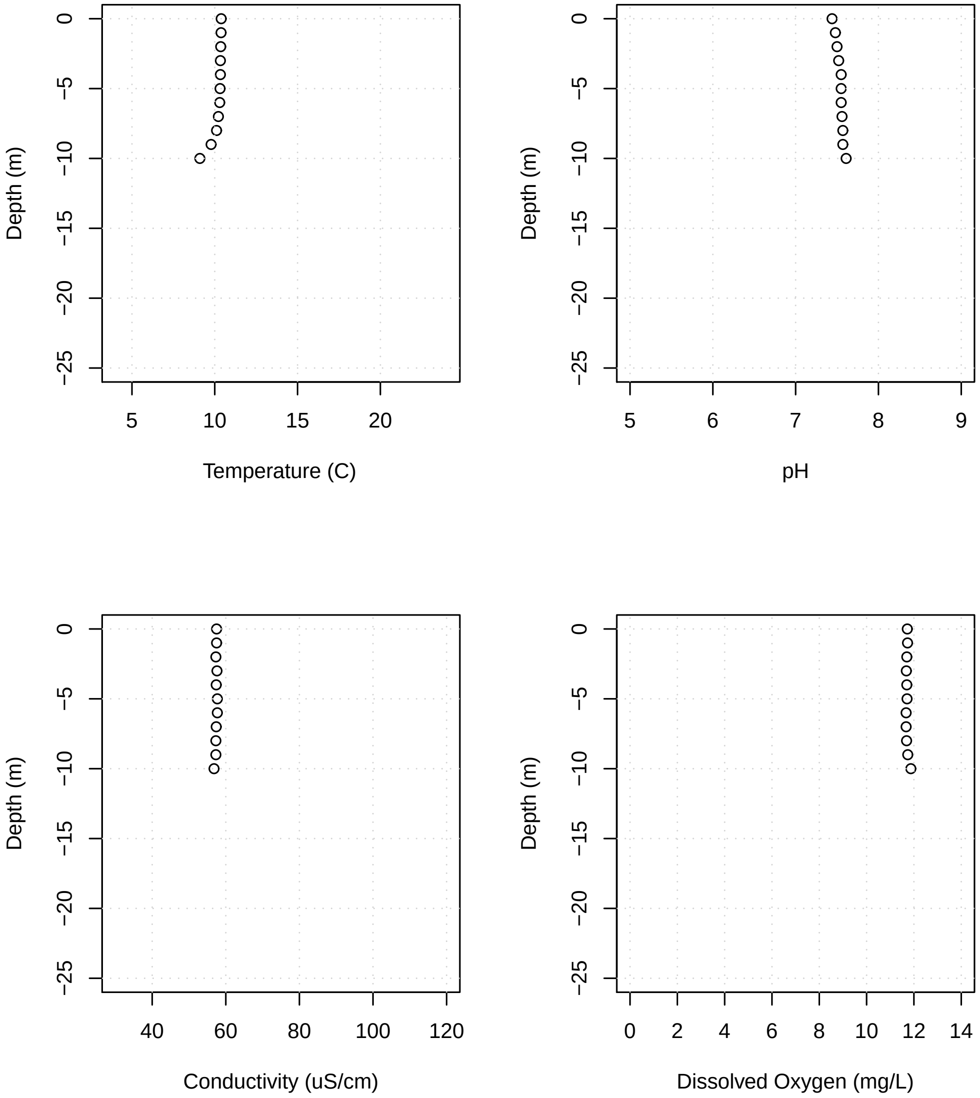


Figure B28: Lake Whatcom Hydrolab profiles for the Intake, May 5, 2011.

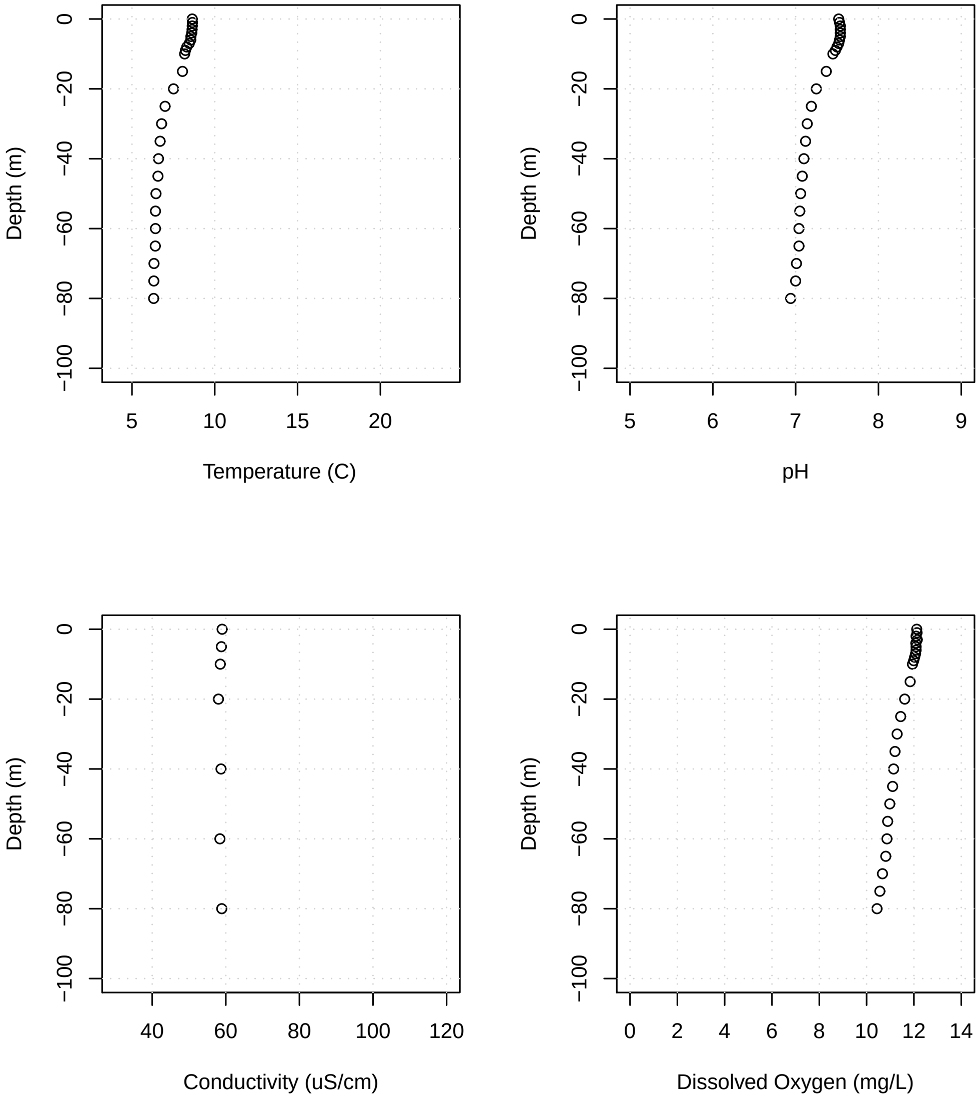


Figure B29: Lake Whatcom Hydrolab profiles for Site 3, May 3, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

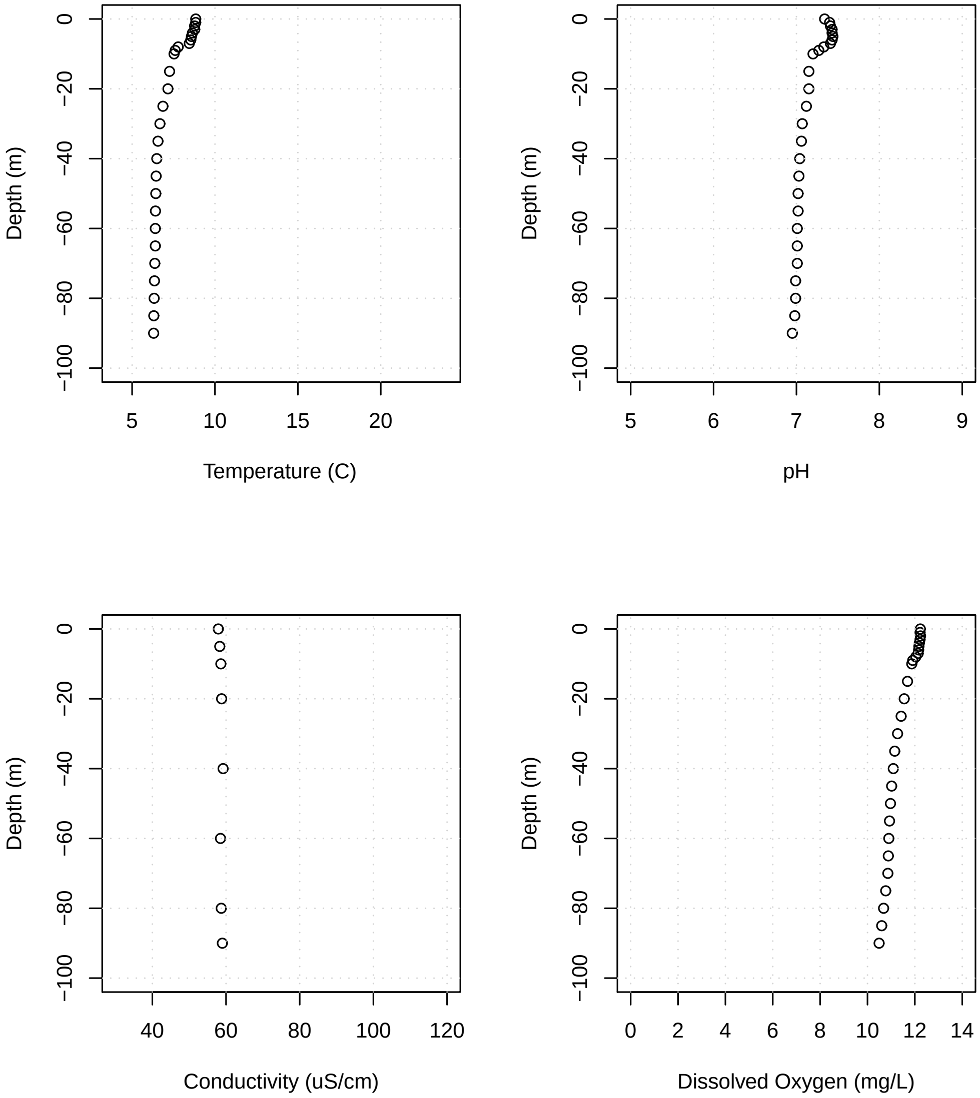


Figure B30: Lake Whatcom Hydrolab profiles for Site 4, May 3, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

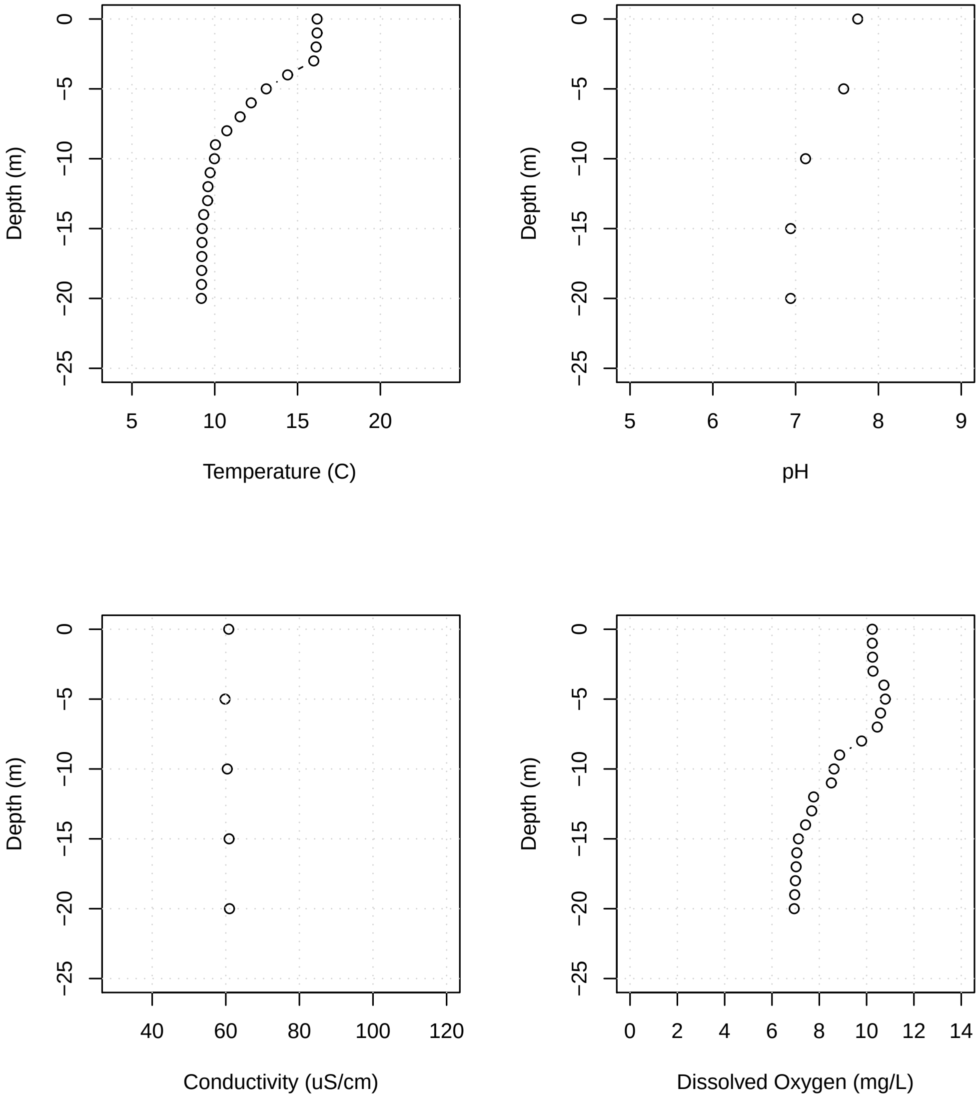


Figure B31: Lake Whatcom Hydrolab profiles for Site 1, June 7, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

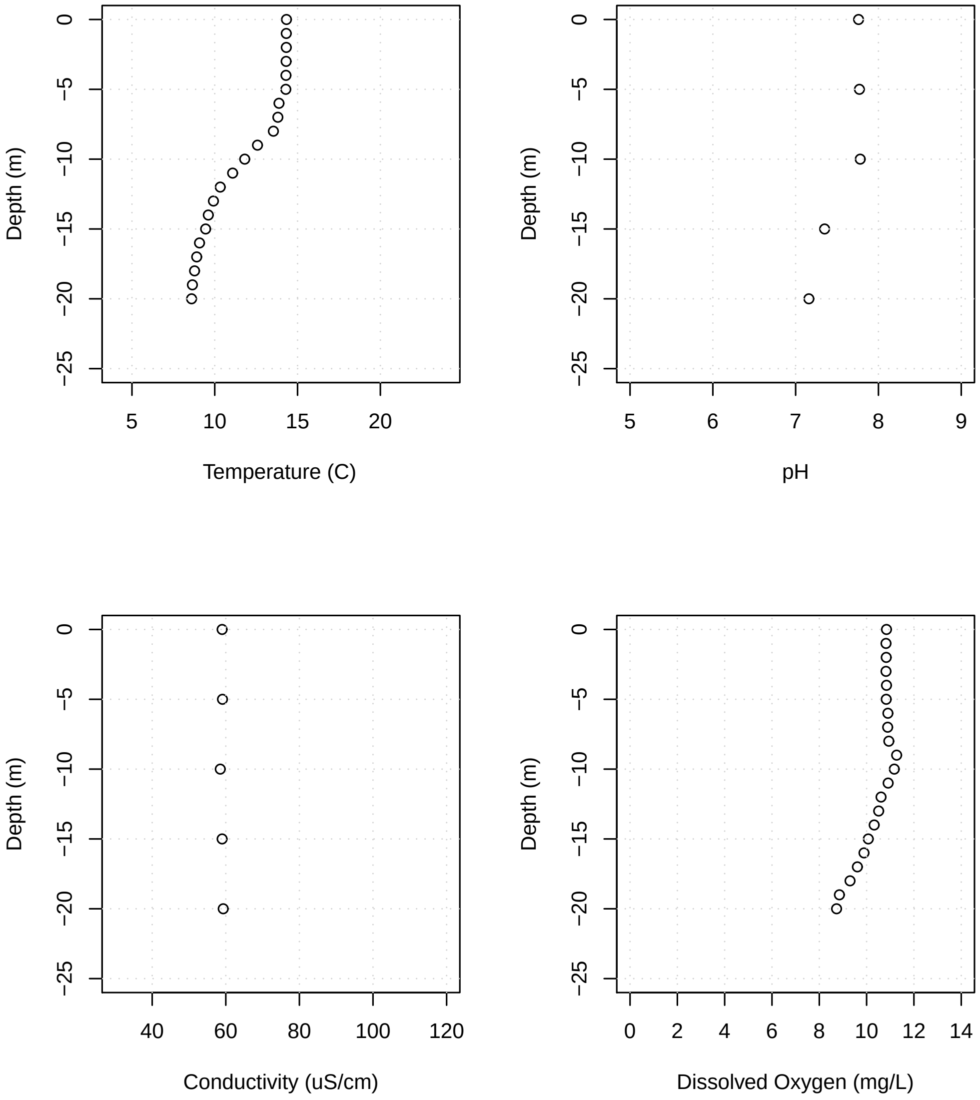


Figure B32: Lake Whatcom Hydrolab profiles for Site 2, June 7, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

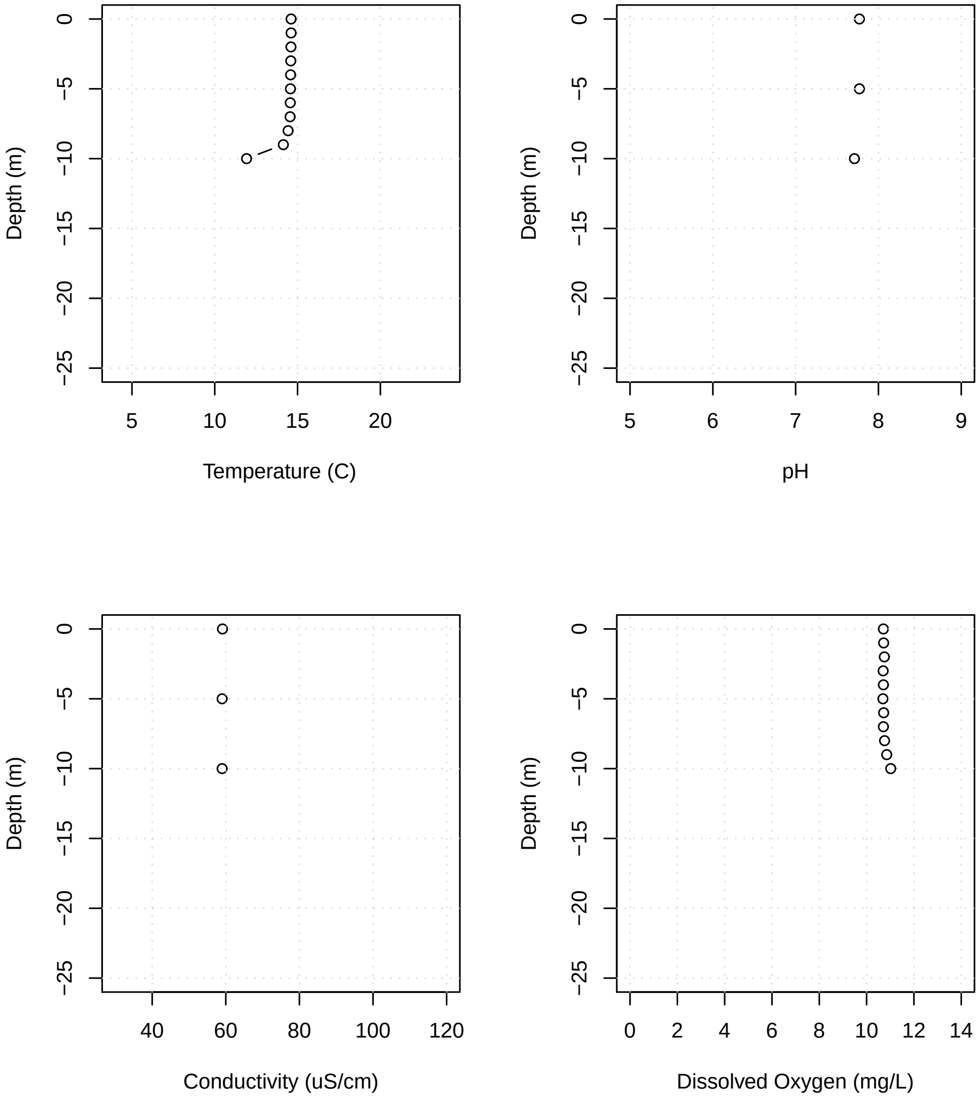


Figure B33: Lake Whatcom Hydrolab profiles for the Intake, June 7, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

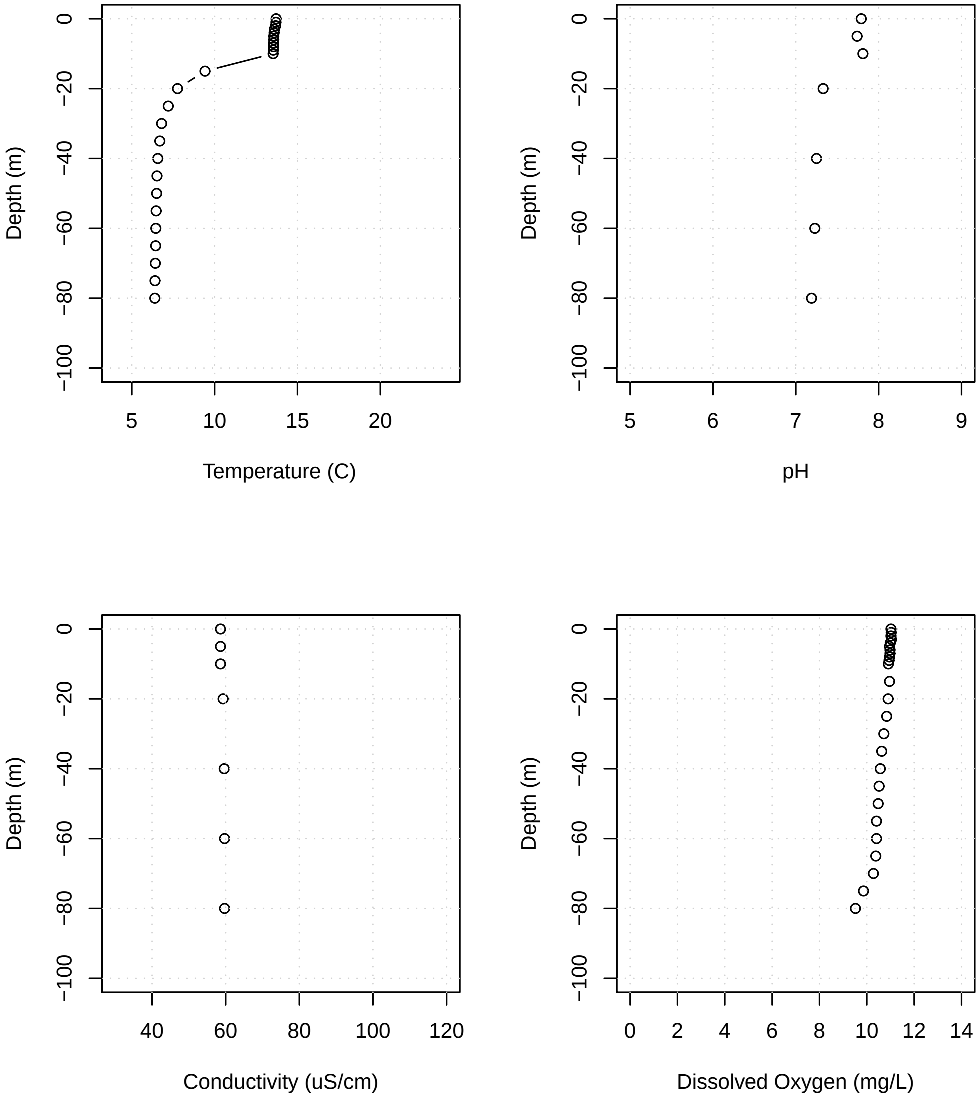


Figure B34: Lake Whatcom Hydrolab profiles for Site 3, June 9, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

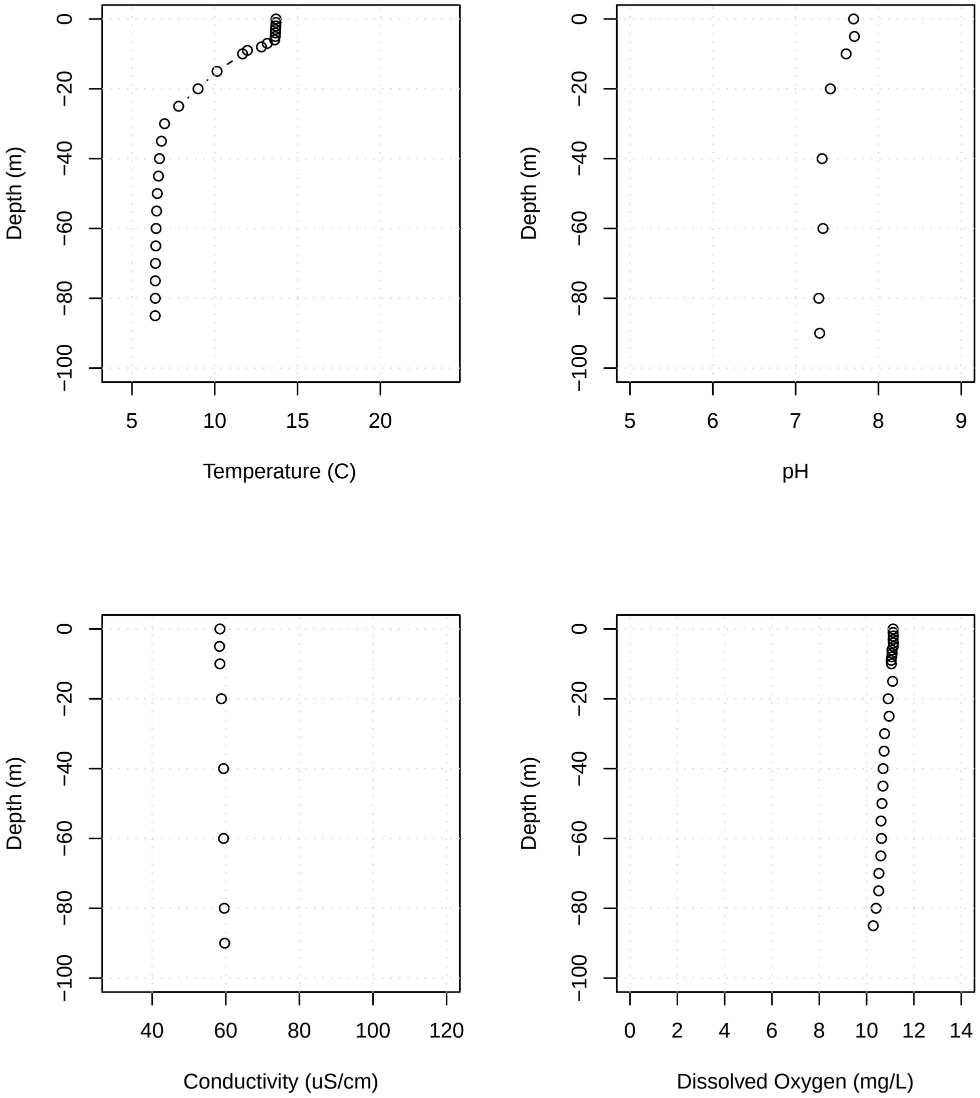


Figure B35: Lake Whatcom Hydrolab profiles for Site 4, June 9, 2011. The conductivity and pH profiles are not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

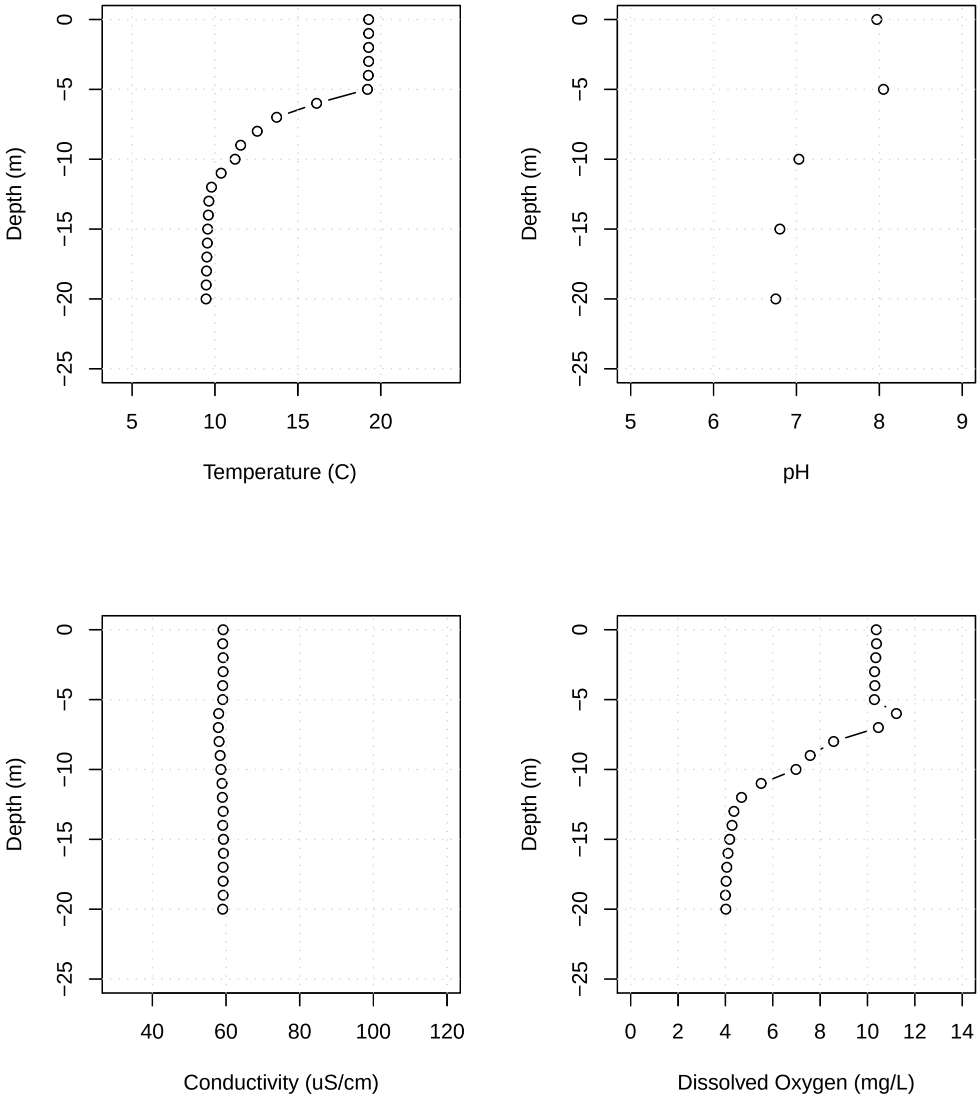


Figure B36: Lake Whatcom Hydrolab profiles for Site 1, July 7, 2011. The pH profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

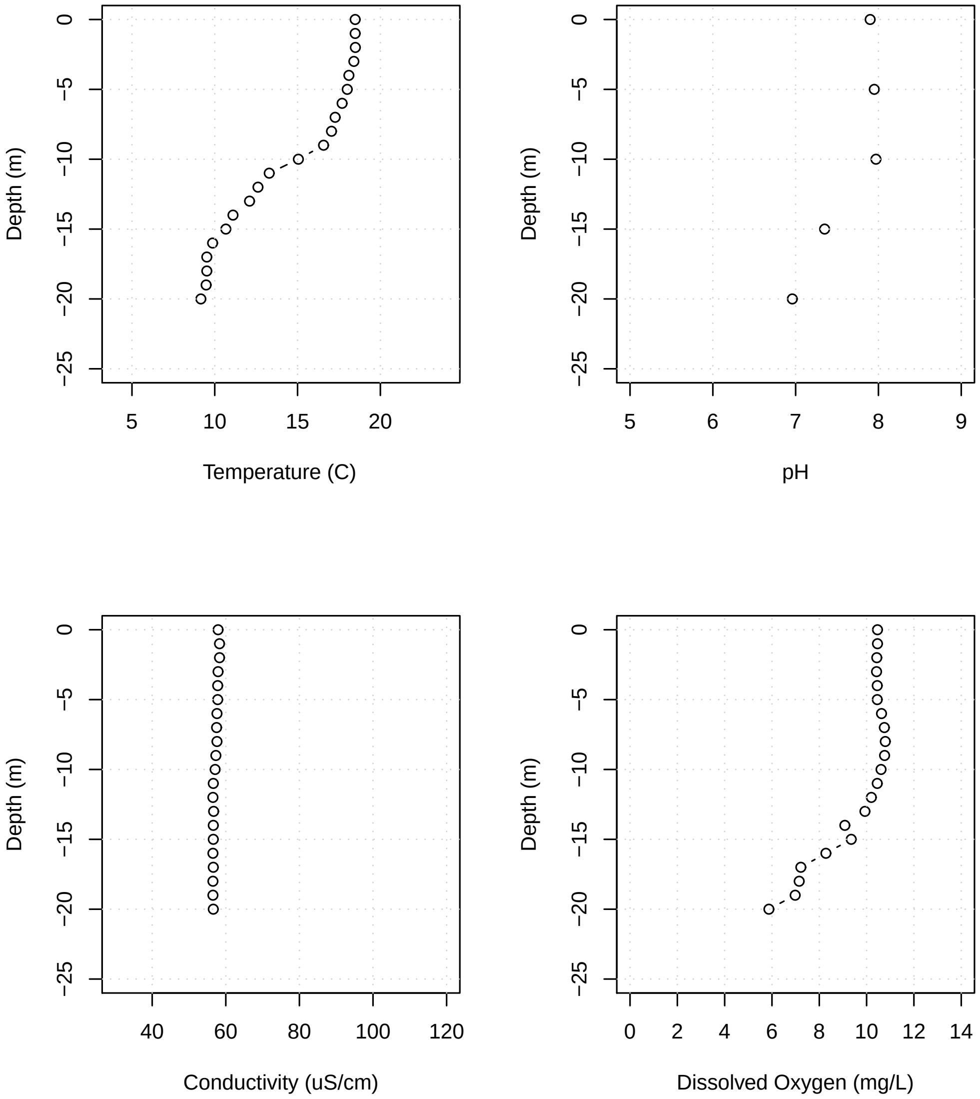


Figure B37: Lake Whatcom Hydrolab profiles for Site 2, July 7, 2011. The pH profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

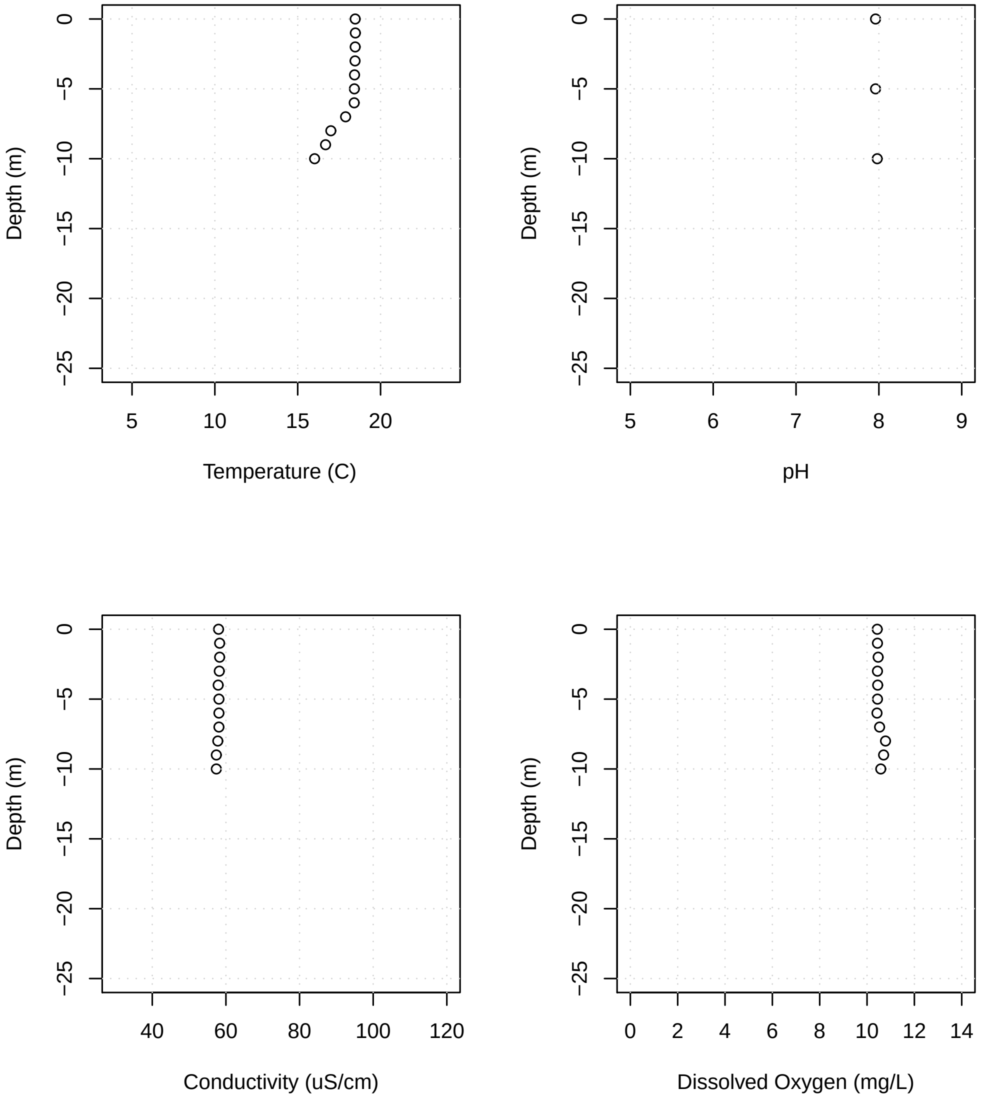


Figure B38: Lake Whatcom Hydrolab profiles for the Intake, July 7, 2011. The pH profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

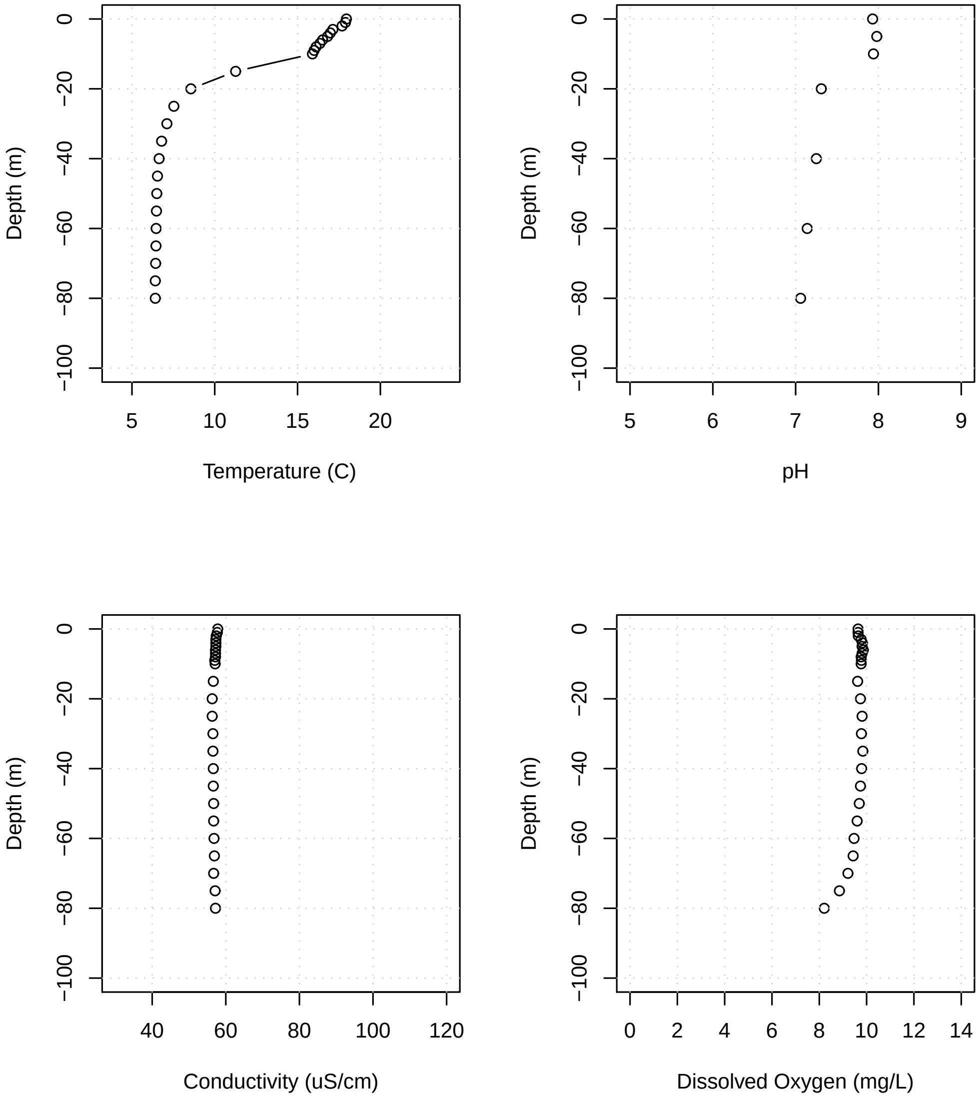


Figure B39: Lake Whatcom Hydrolab profiles for Site 3, July 5, 2011. The pH profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

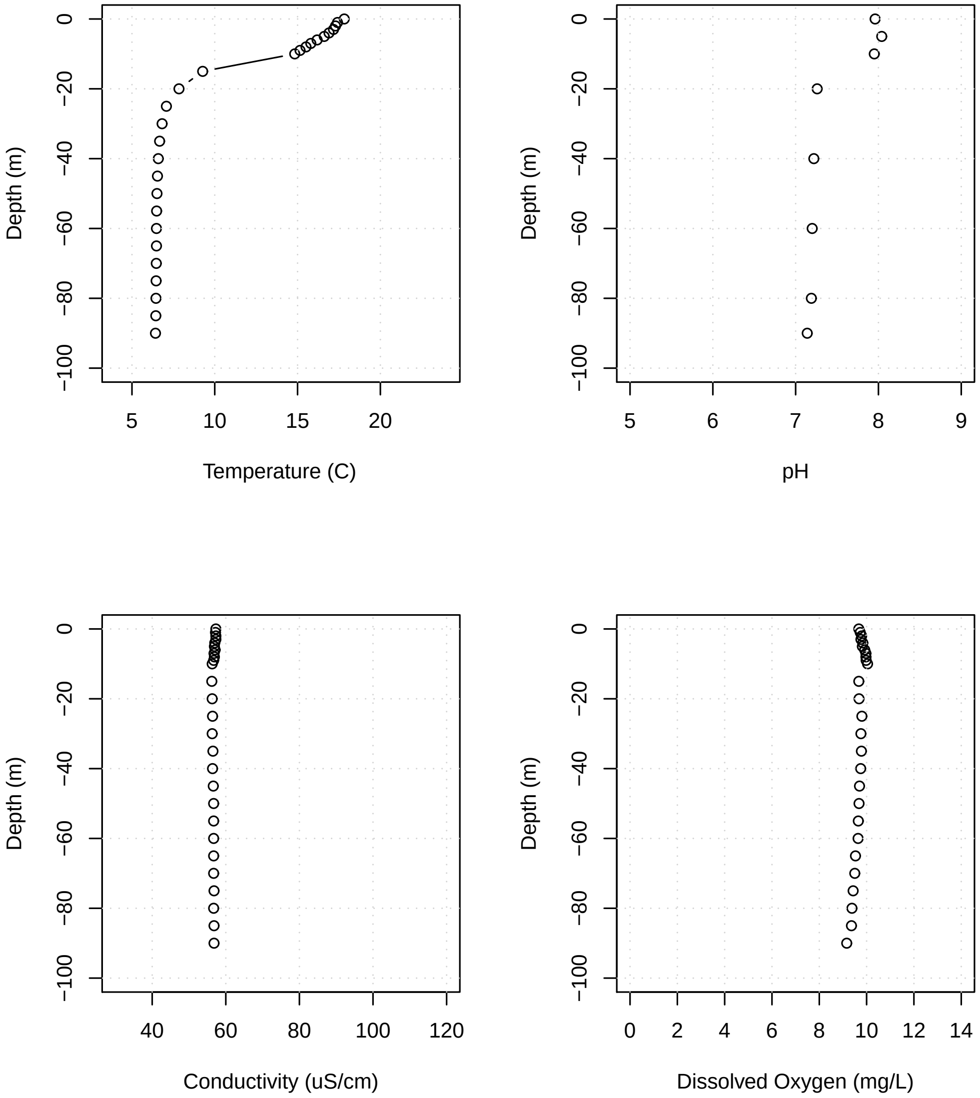


Figure B40: Lake Whatcom Hydrolab profiles for Site 4, July 5, 2011. The pH profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

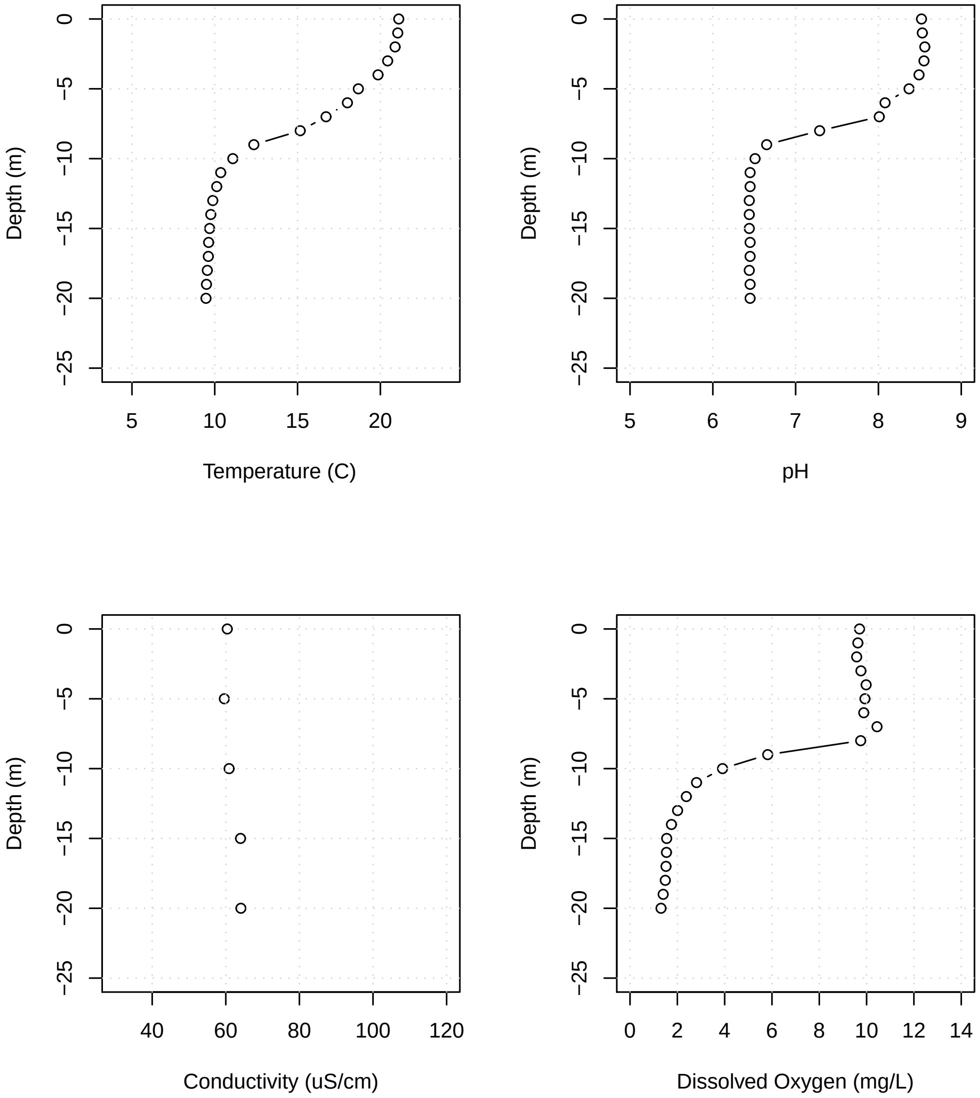


Figure B41: Lake Whatcom Hydrolab profiles for Site 1, August 4, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

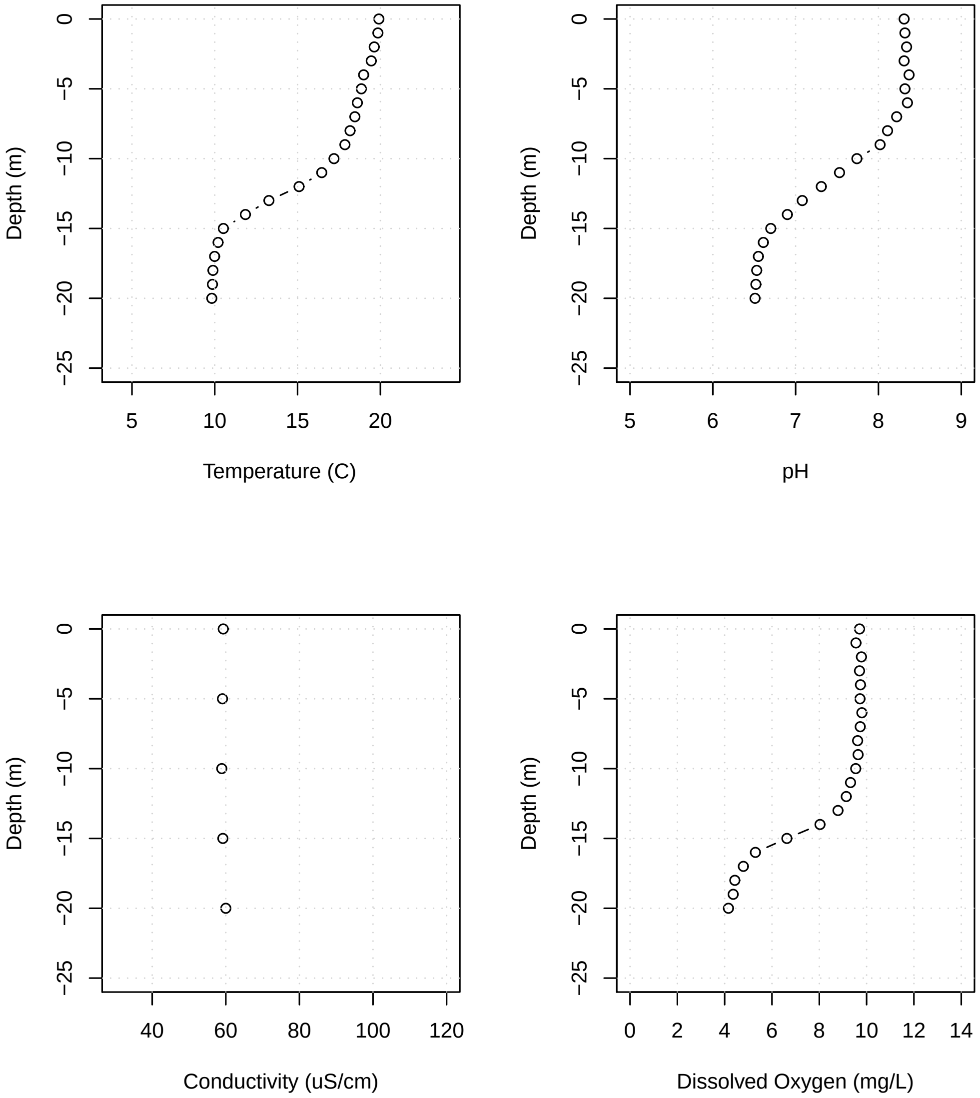


Figure B42: Lake Whatcom Hydrolab profiles for Site 2, August 4, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

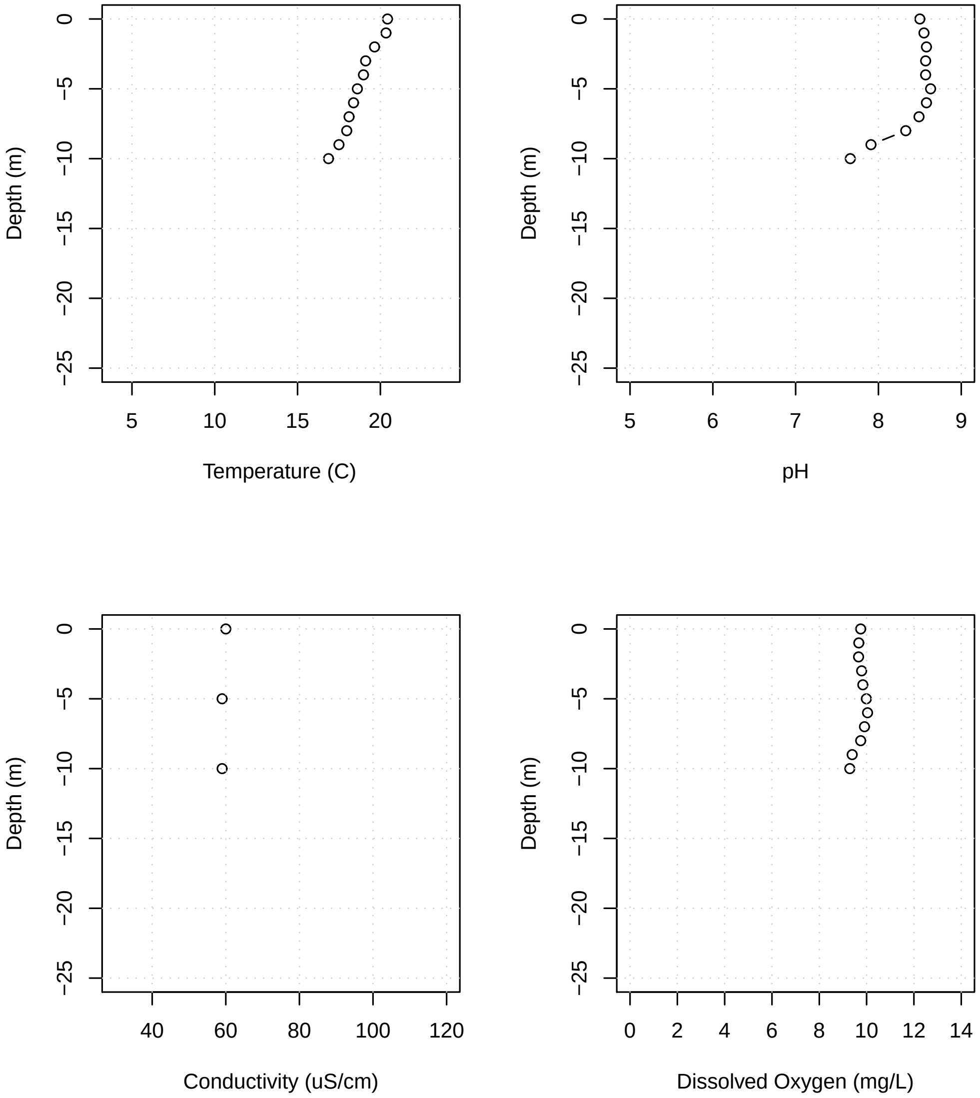


Figure B43: Lake Whatcom Hydrolab profiles for the Intake, August 4, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

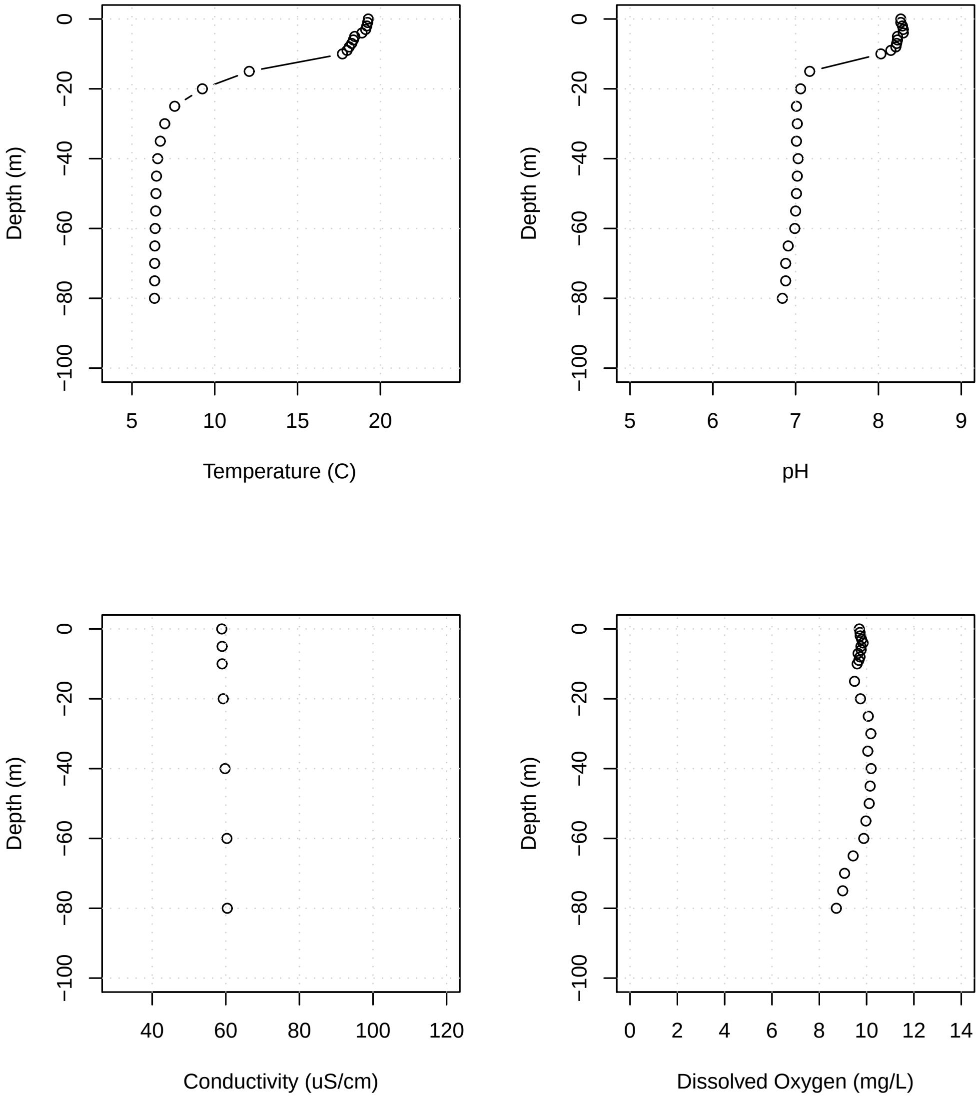


Figure B44: Lake Whatcom Hydrolab profiles for Site 3, August 2, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

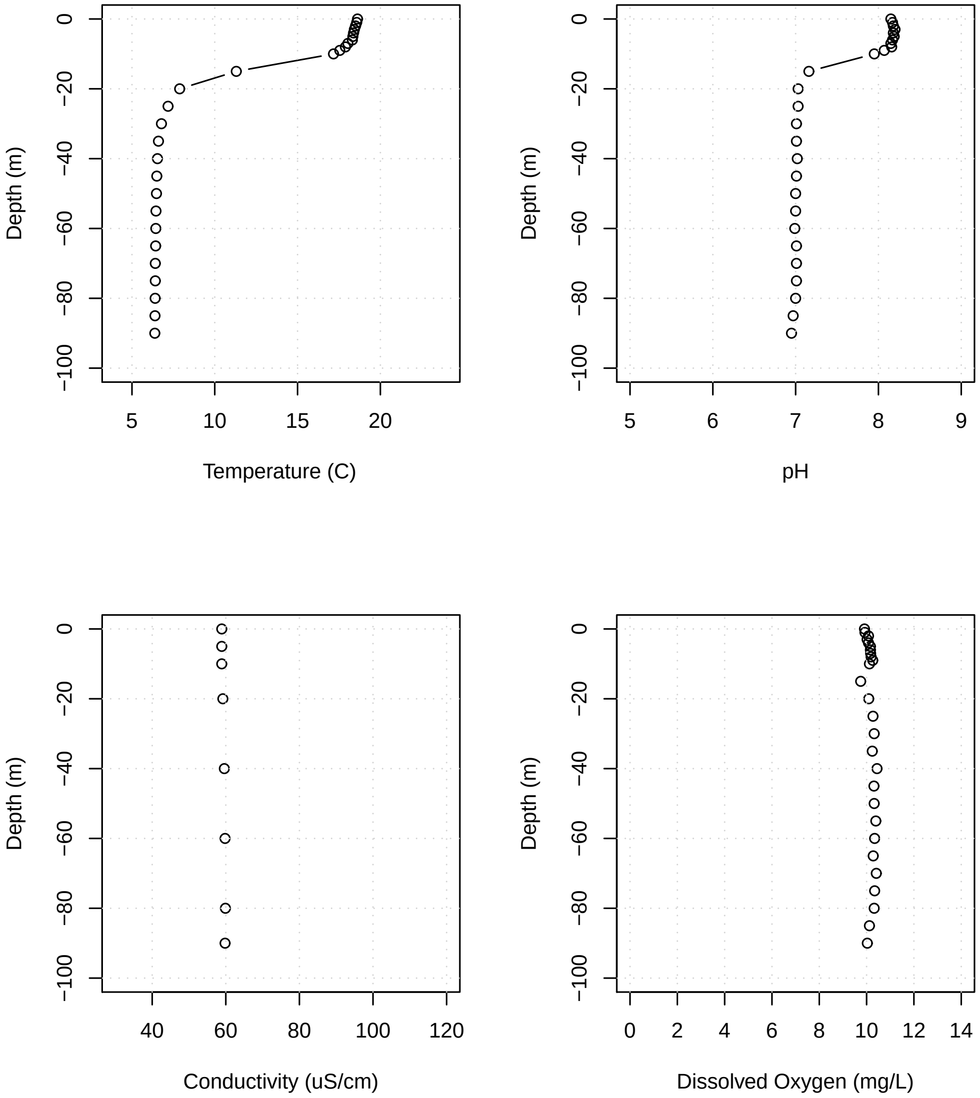


Figure B45: Lake Whatcom Hydrolab profiles for Site 4, August 2, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

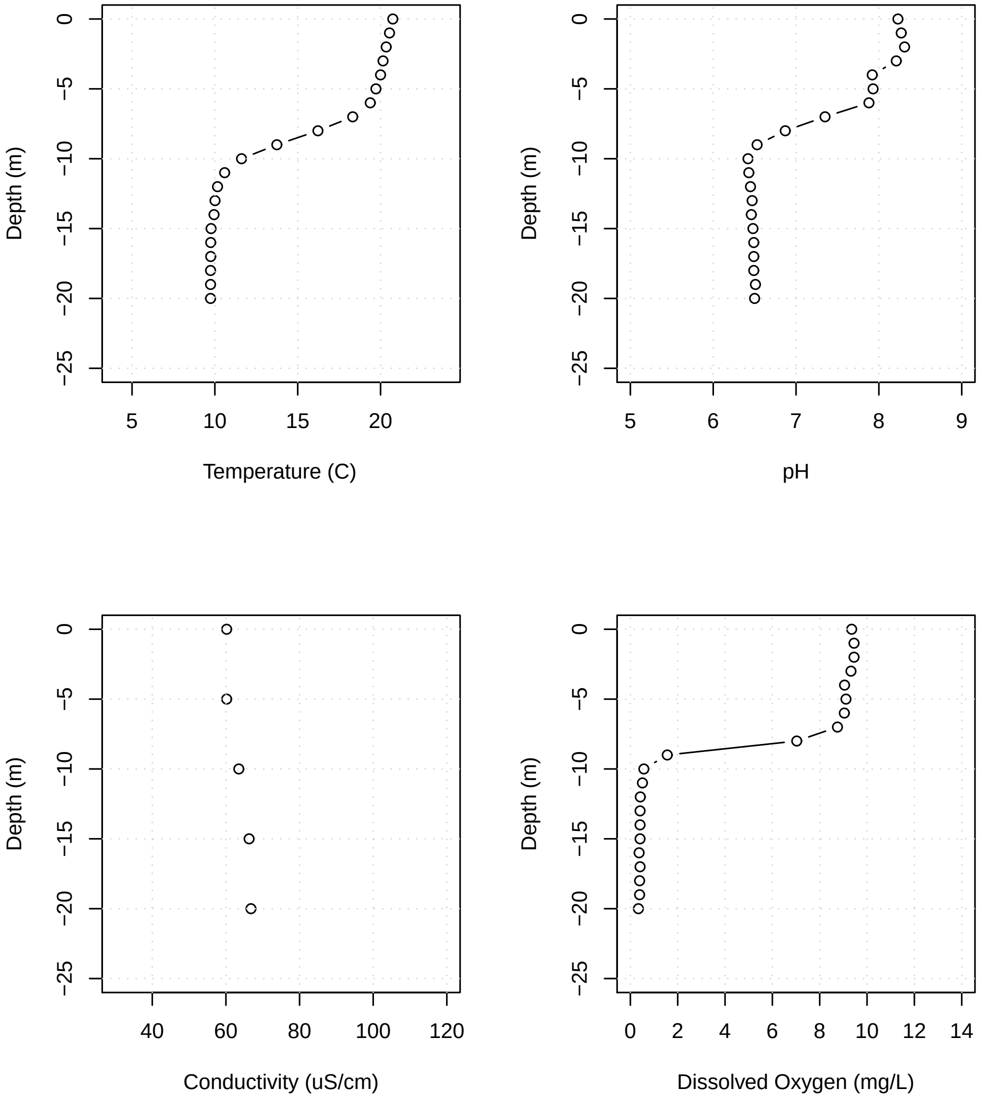


Figure B46: Lake Whatcom Hydrolab profiles for Site 1, September 8, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

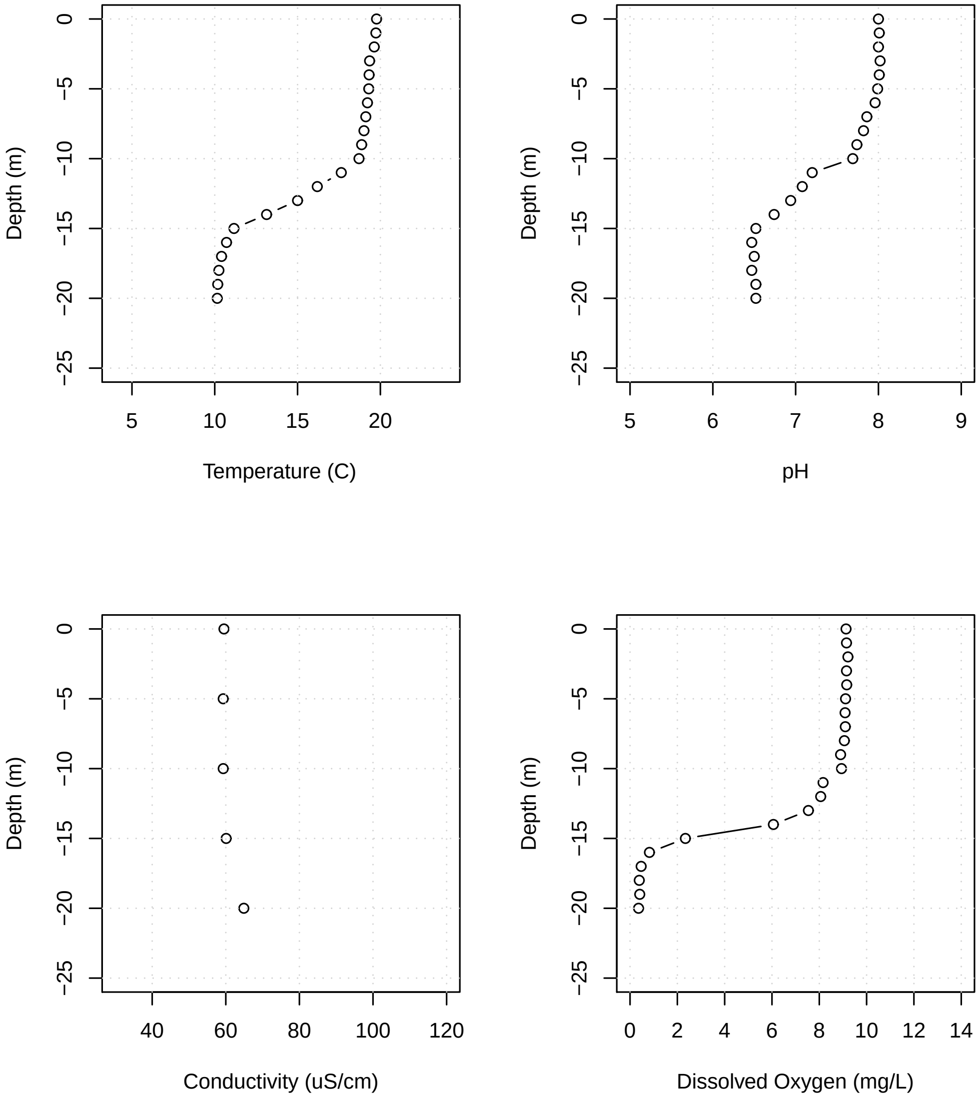


Figure B47: Lake Whatcom Hydrolab profiles for Site 2, September 8, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

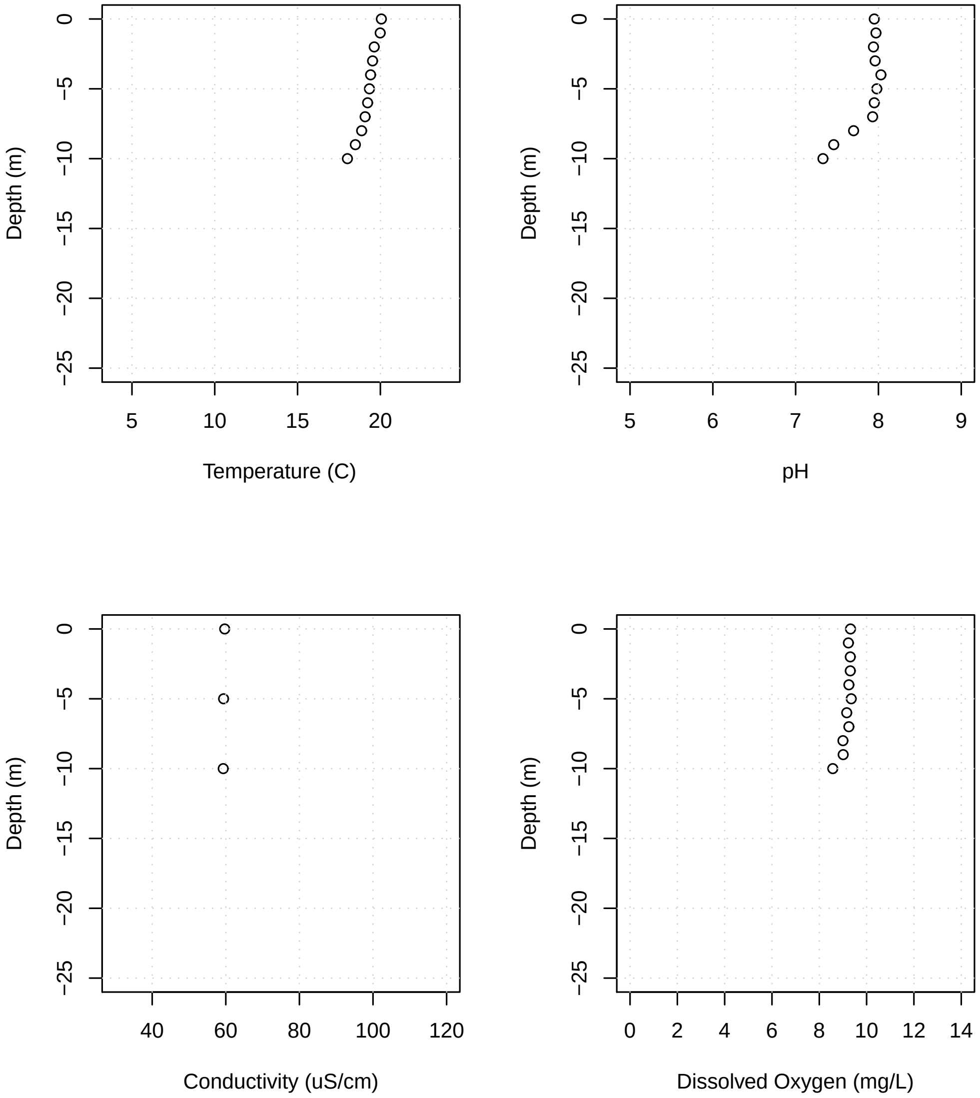


Figure B48: Lake Whatcom Hydrolab profiles for the Intake, September 8, 2011 The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory..

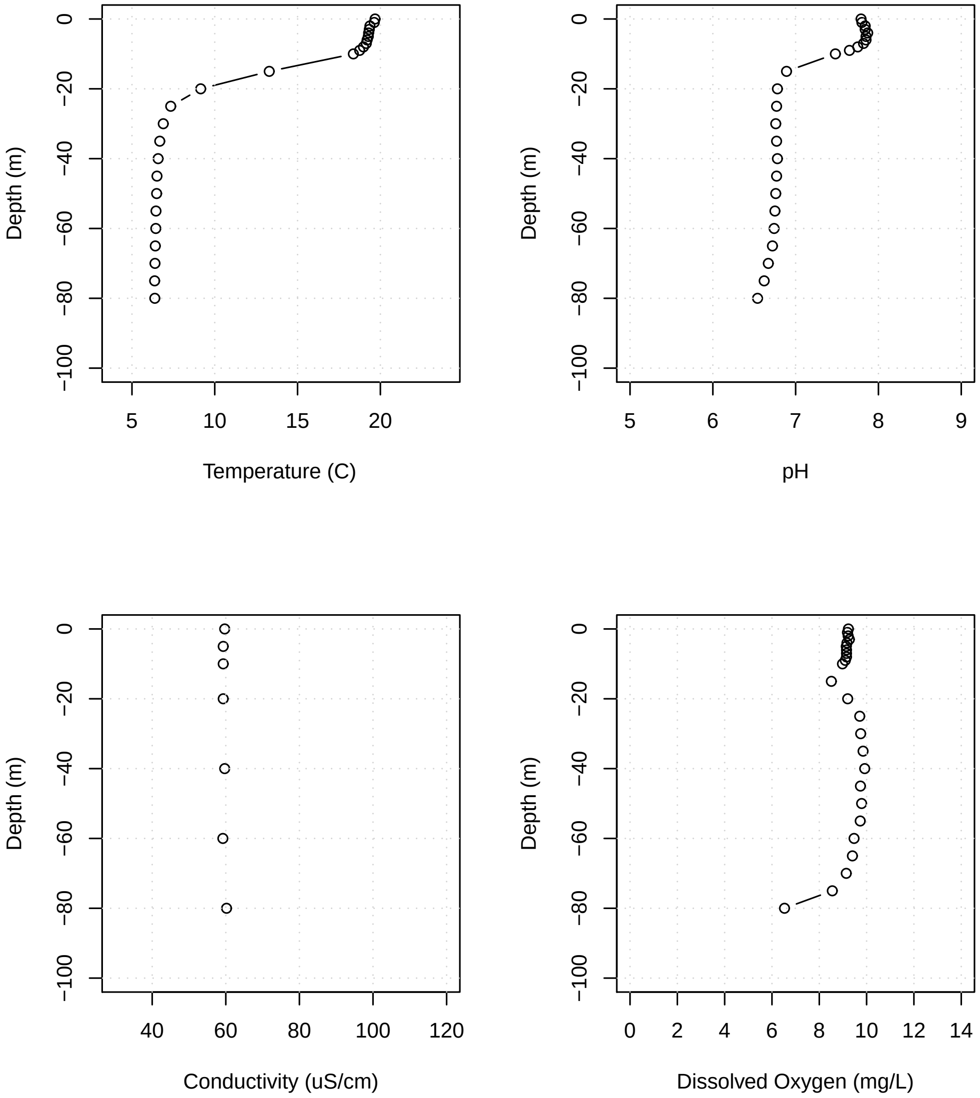


Figure B49: Lake Whatcom Hydrolab profiles for Site 3, September 6, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

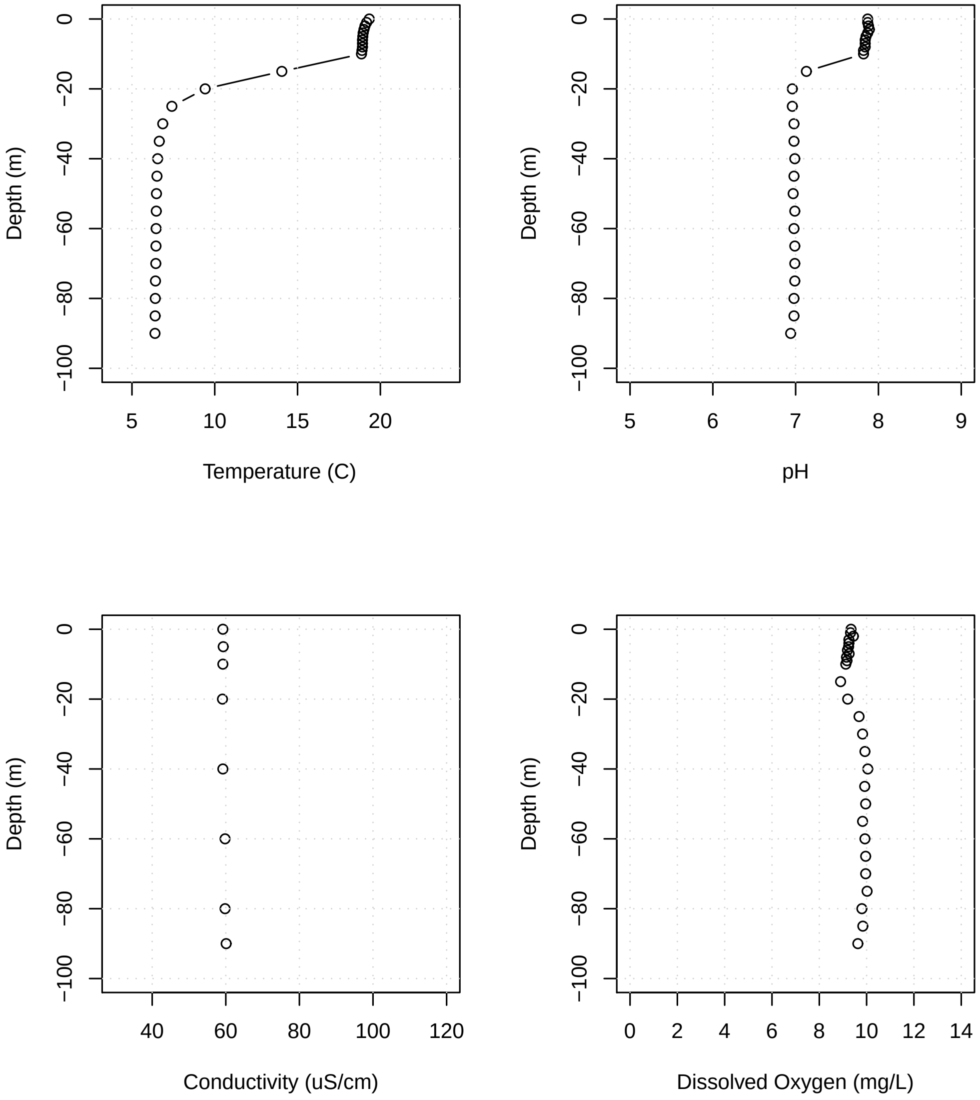


Figure B50: Lake Whatcom Hydrolab profiles for Site 4, September 6, 2011. The conductivity profile is not available due to equipment malfunction; discrete results were generated from water samples measured in the laboratory.

## B.2 Long-term Hydrolab Data (1988-present)

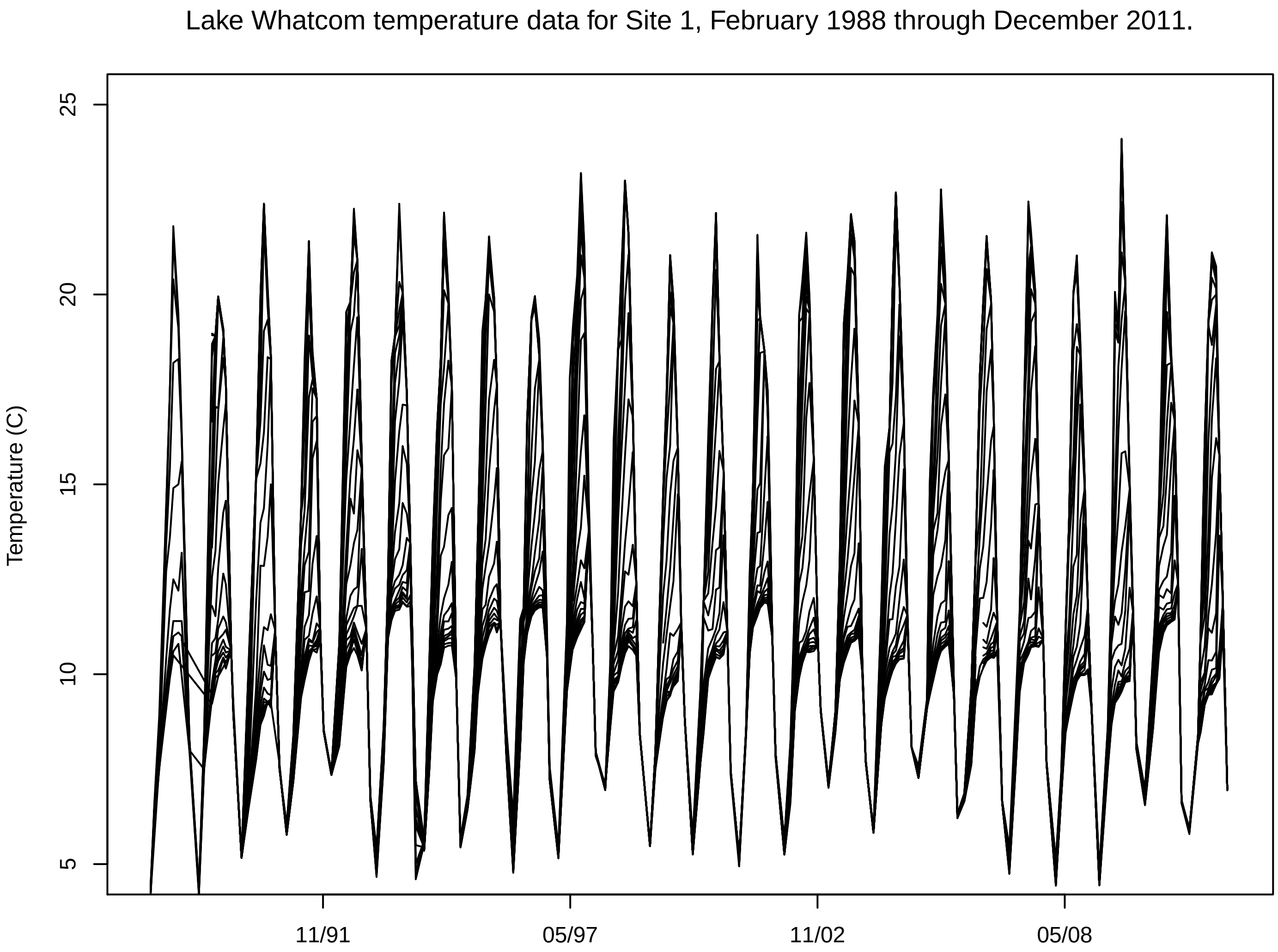


Figure B51: Lake Whatcom historic temperature data for Site 1.

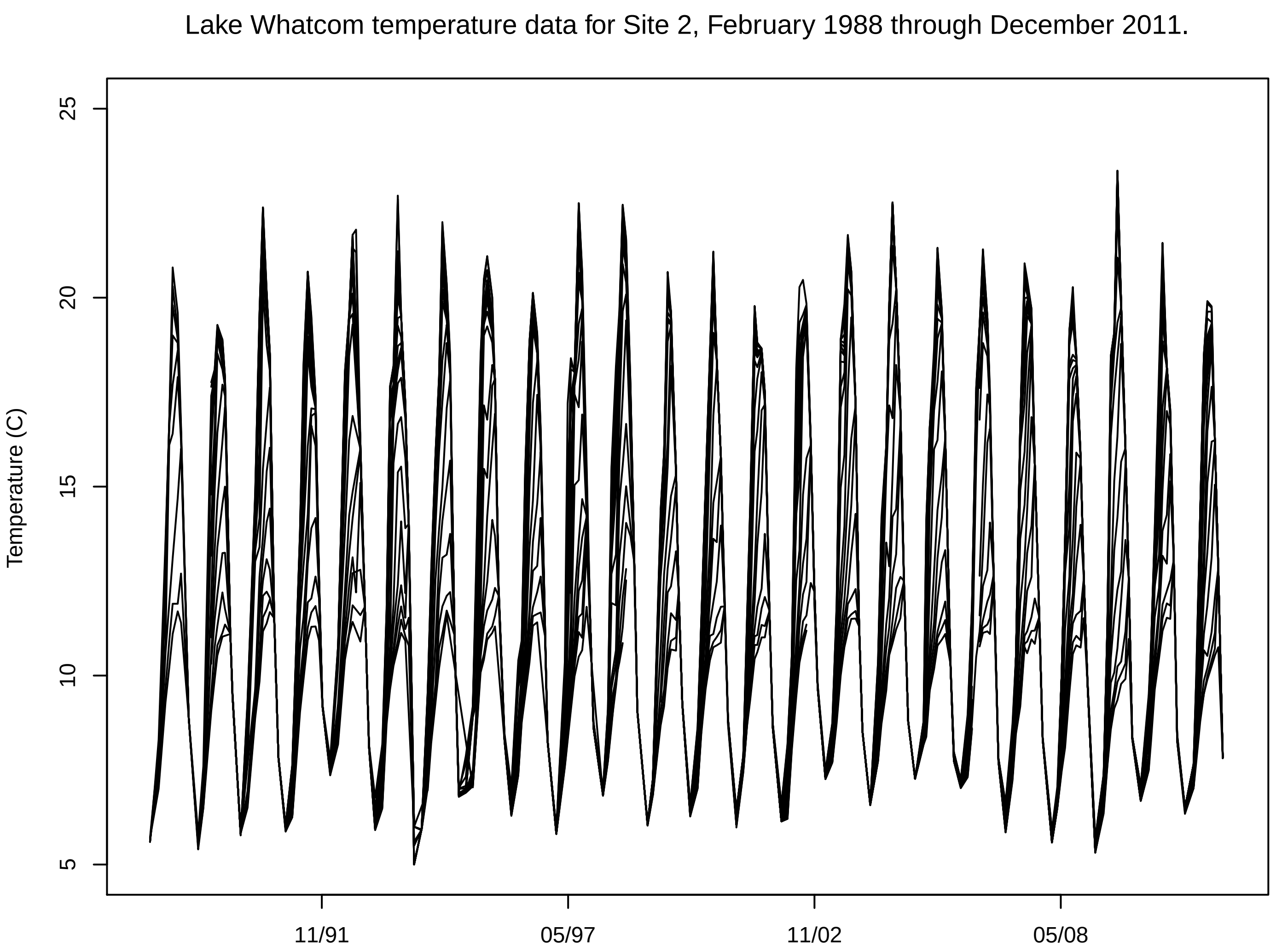


Figure B52: Lake Whatcom historic temperature data for Site 2.

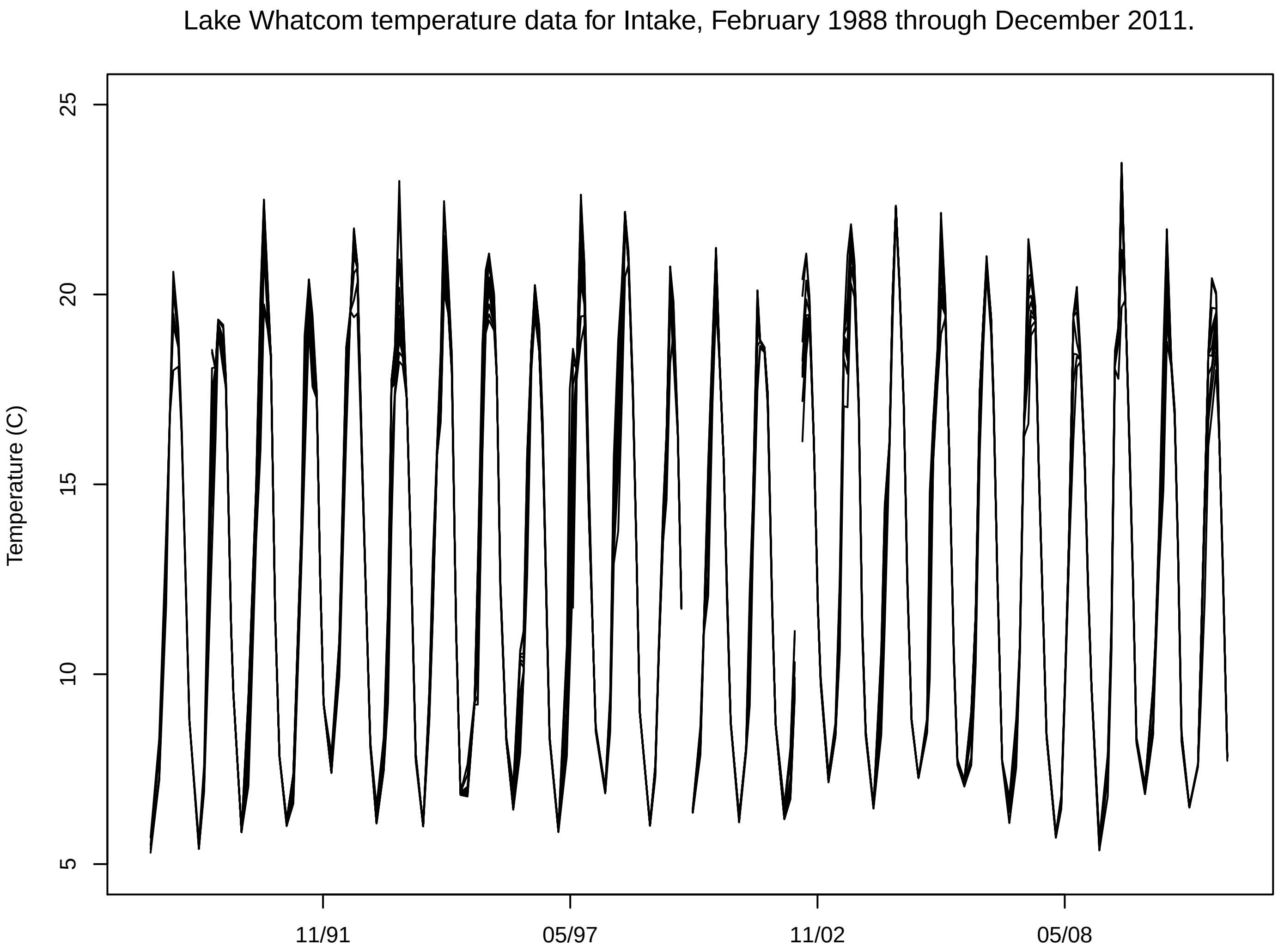


Figure B53: Lake Whatcom historic temperature data for the Intake.

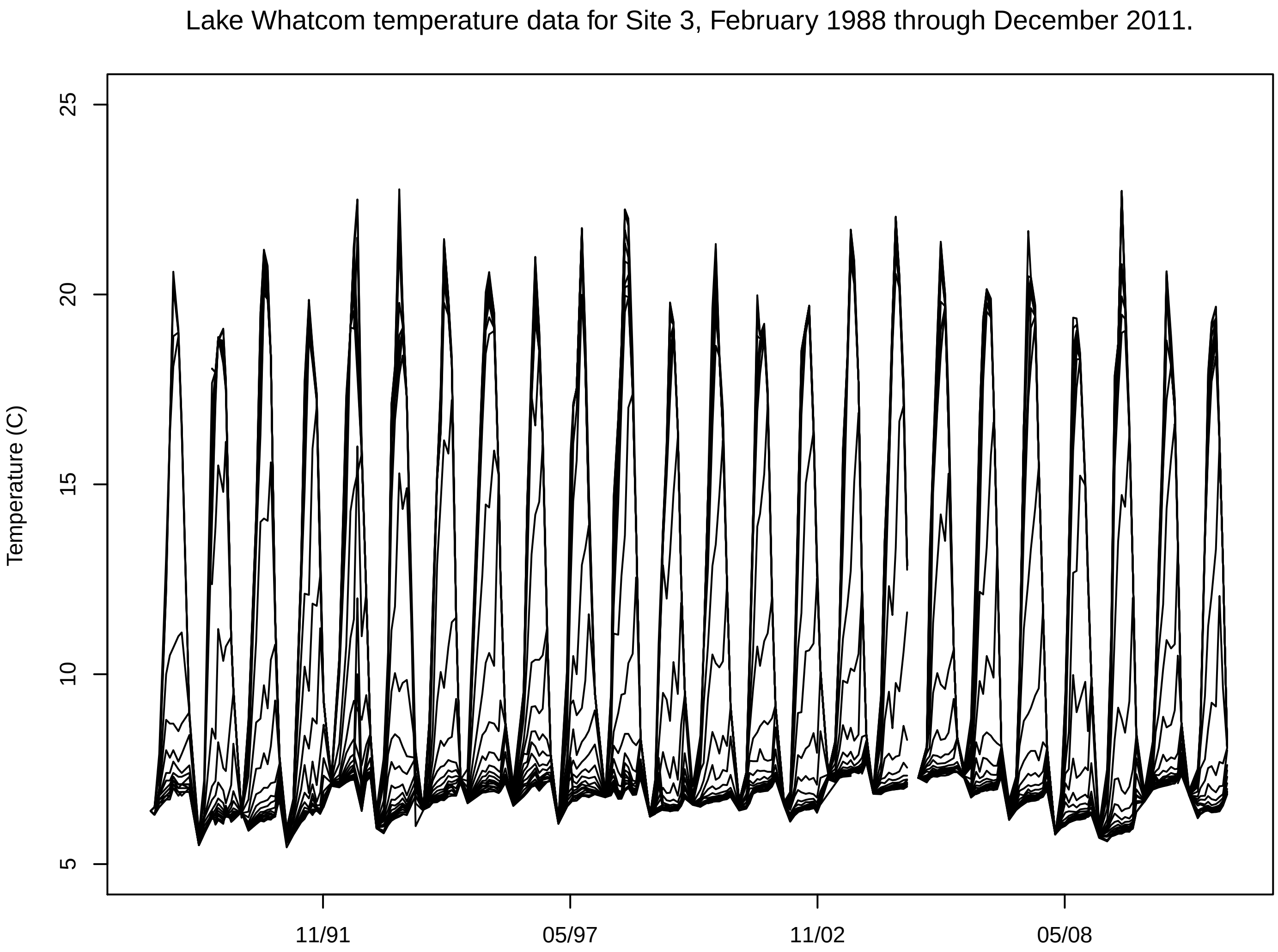


Figure B54: Lake Whatcom historic temperature data for Site 3.

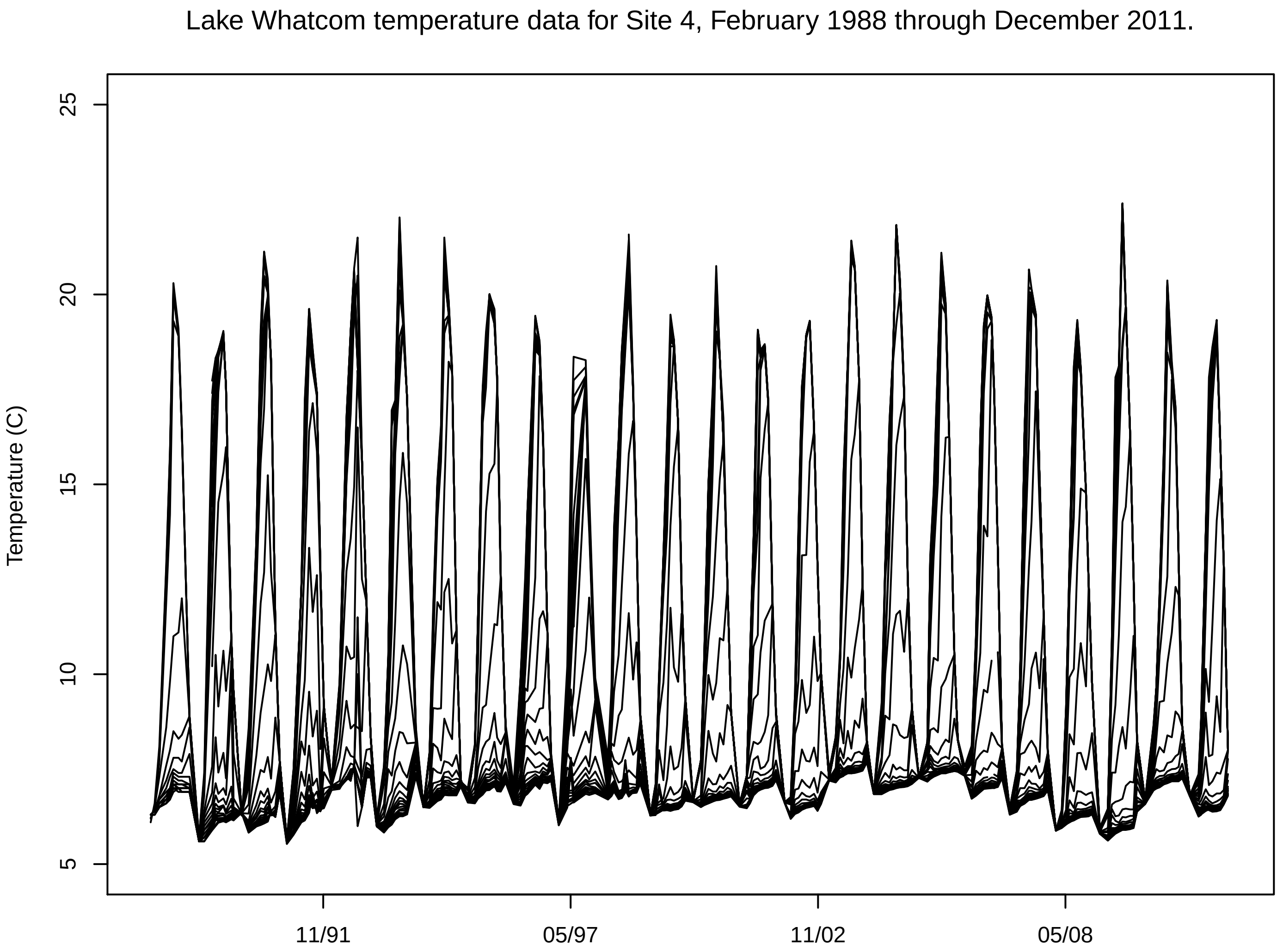


Figure B55: Lake Whatcom historic temperature data for Site 4.

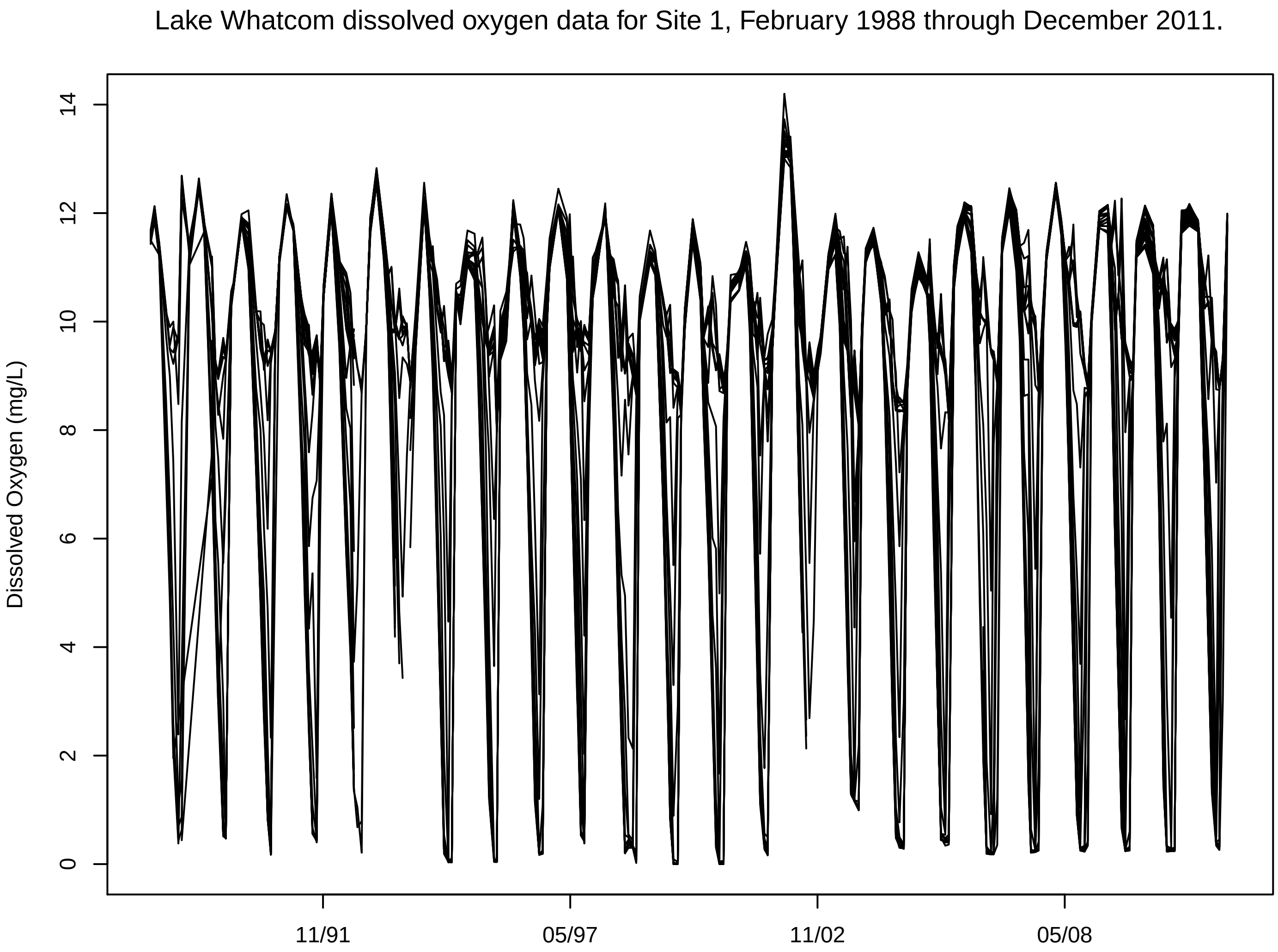


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

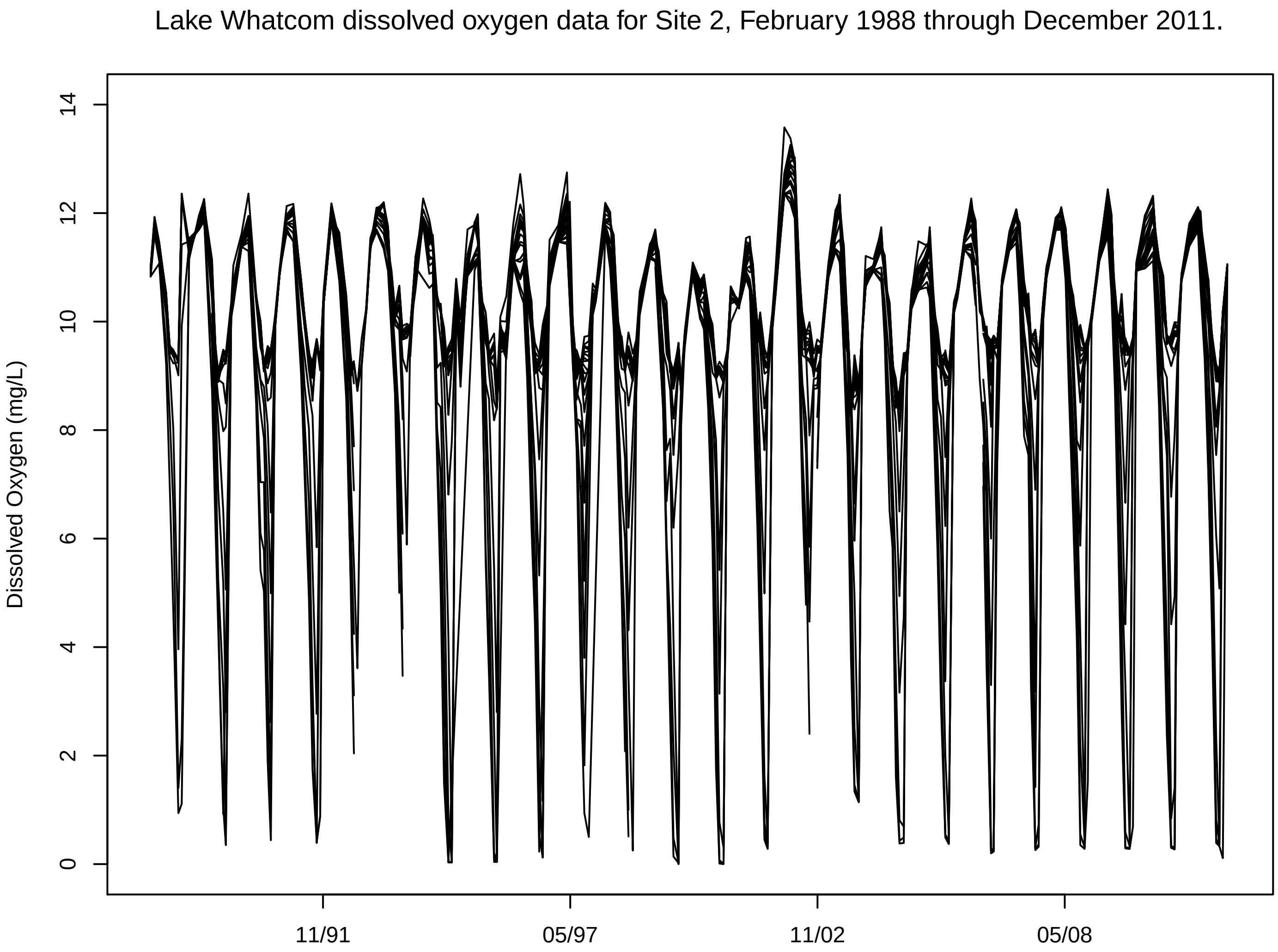


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

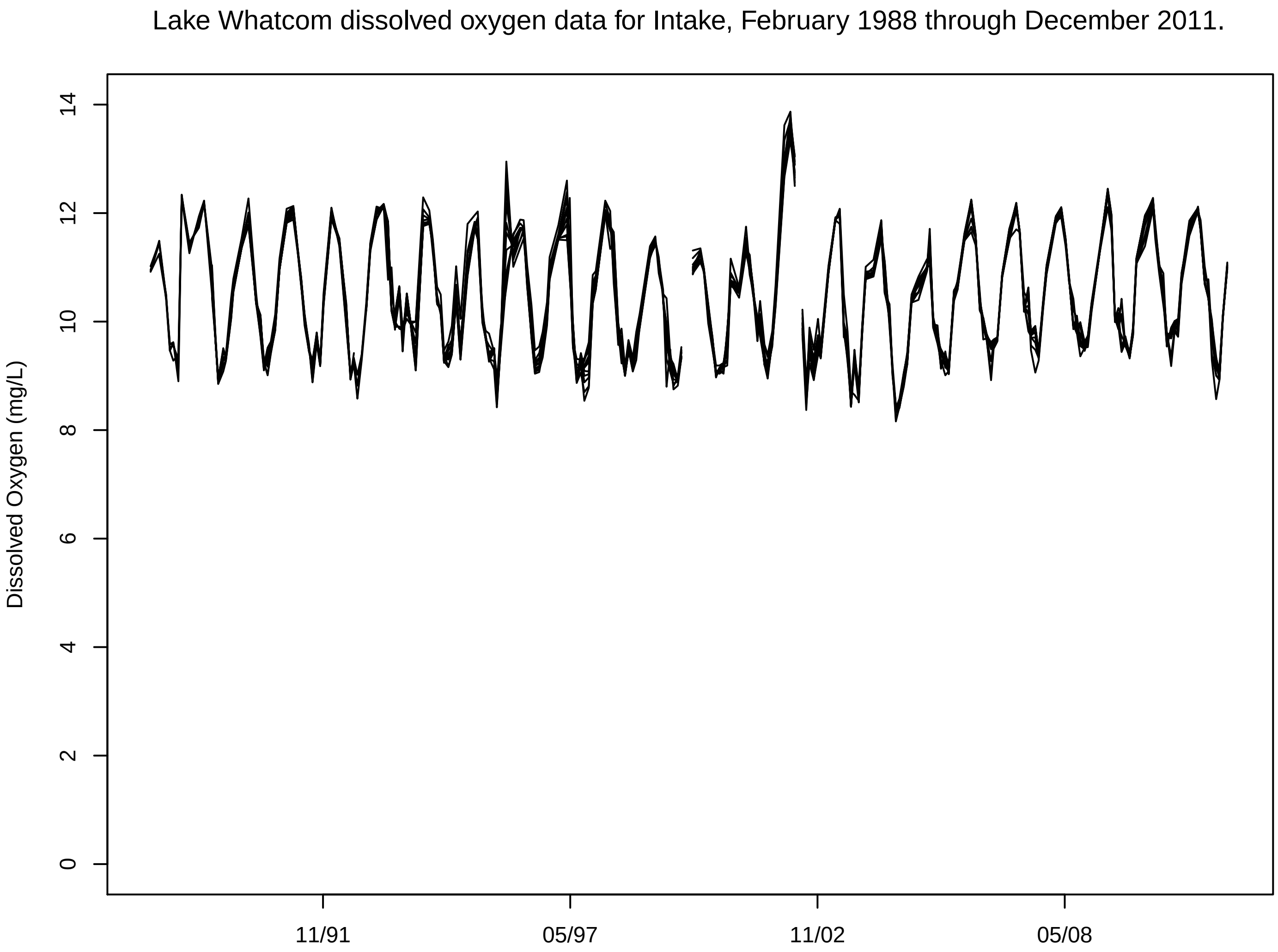


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake.

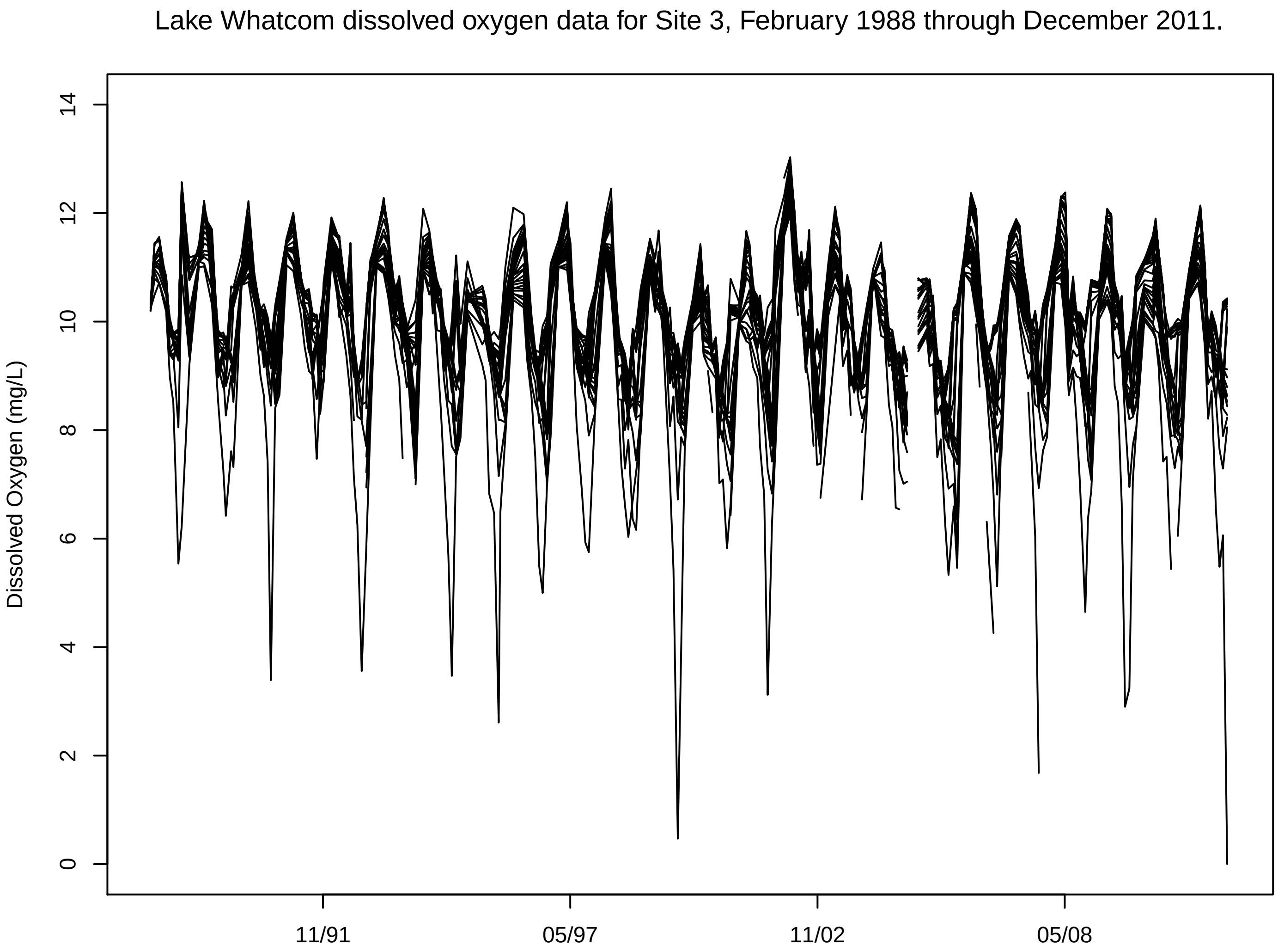
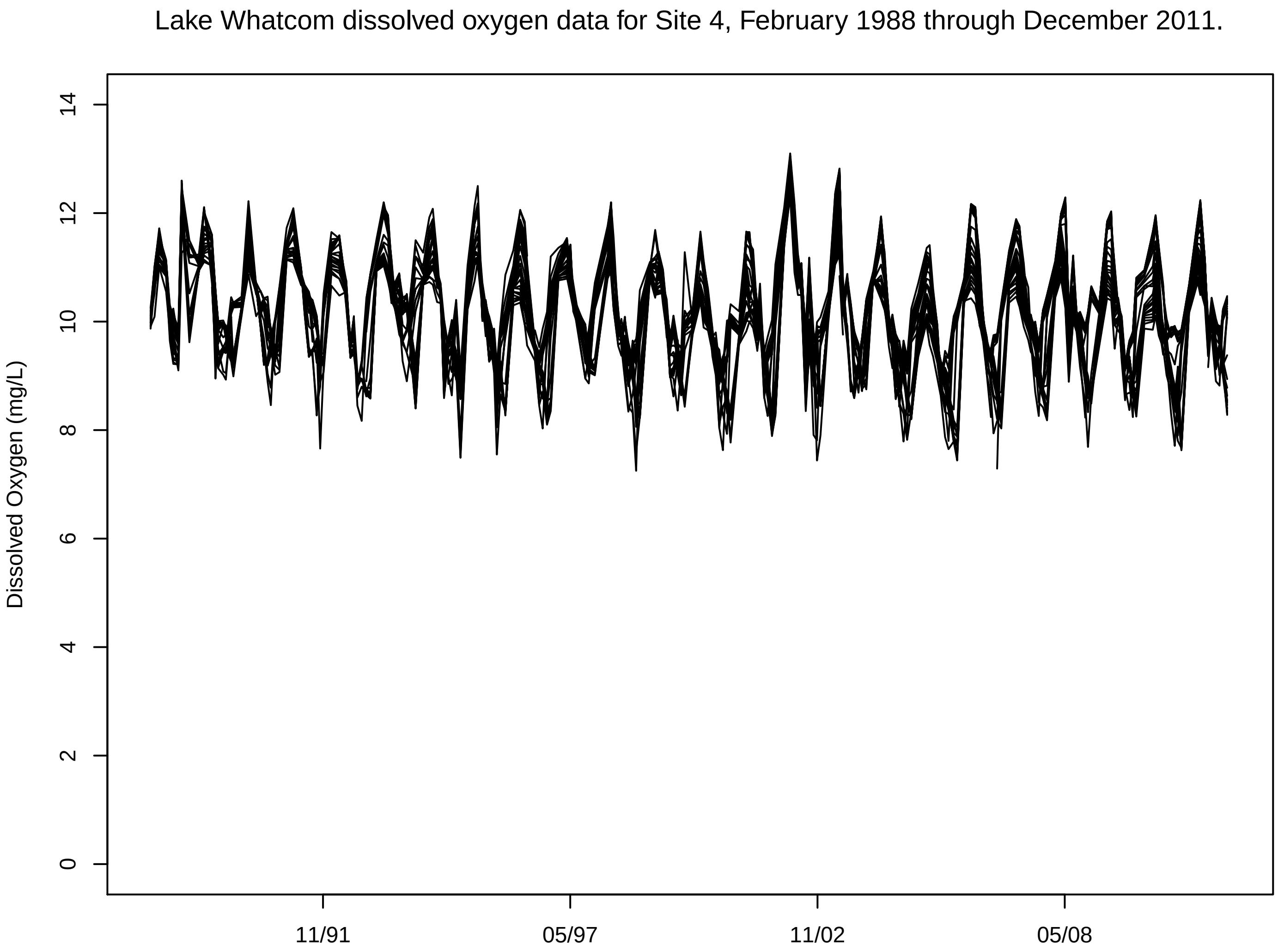

Lake Whatcom dissolved oxygen data for Site 3, February 1988 through December 2011.

Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.



Lake Whatcom dissolved oxygen data for Site 4, February 1988 through December 2011.

Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

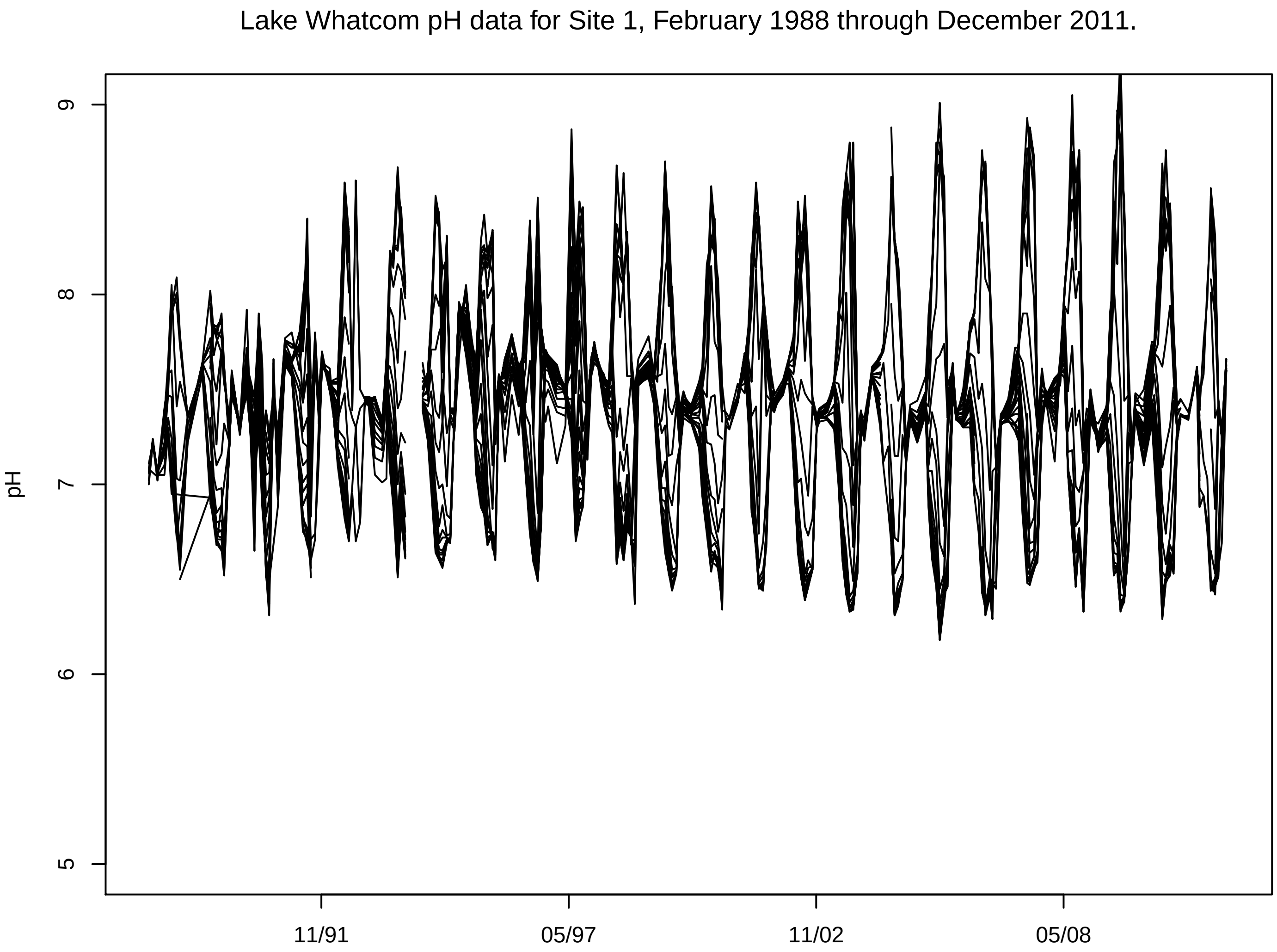


Figure B61: Lake Whatcom historic pH data for Site 1.

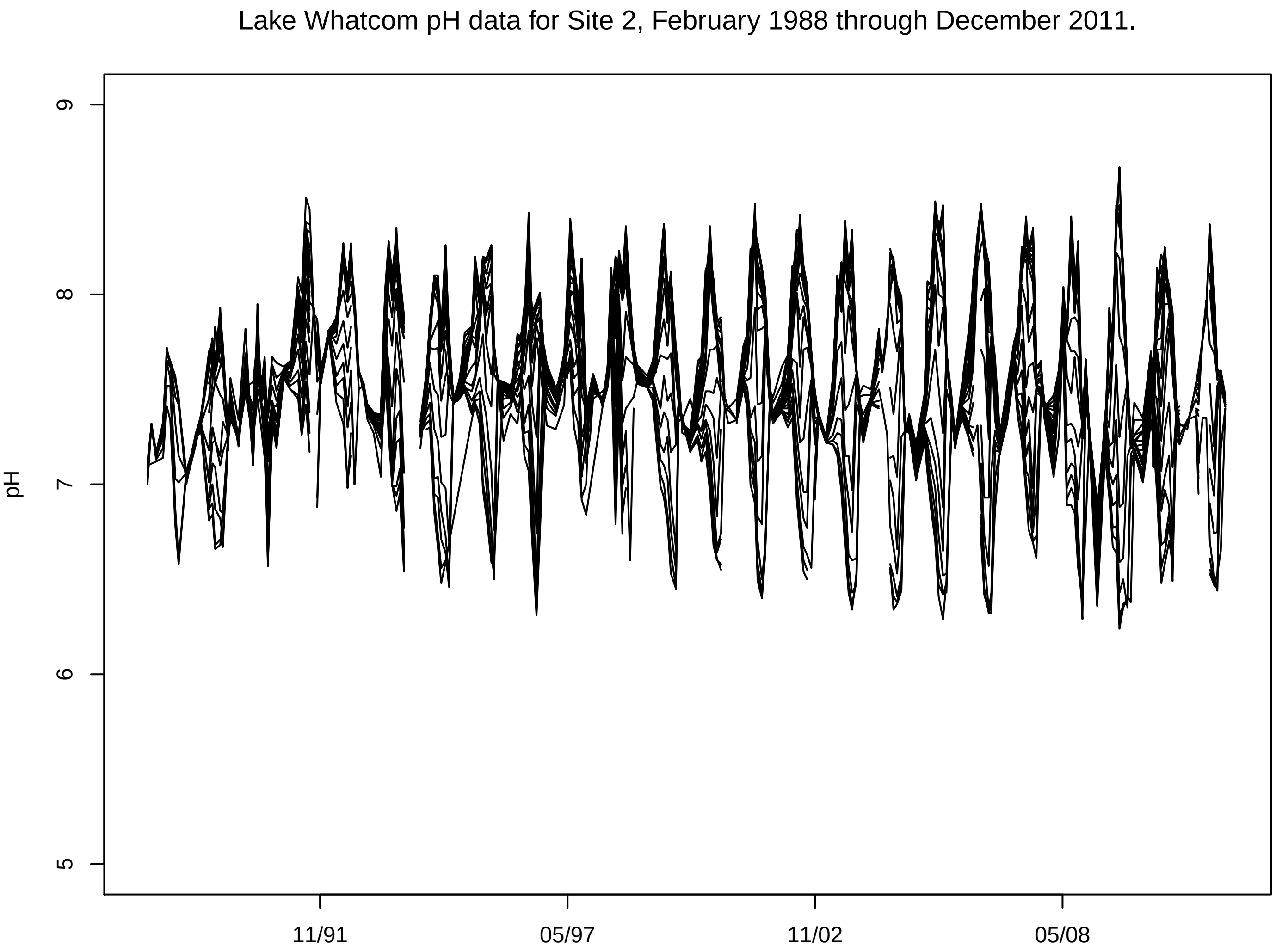


Figure B62: Lake Whatcom historic pH data for Site 2.

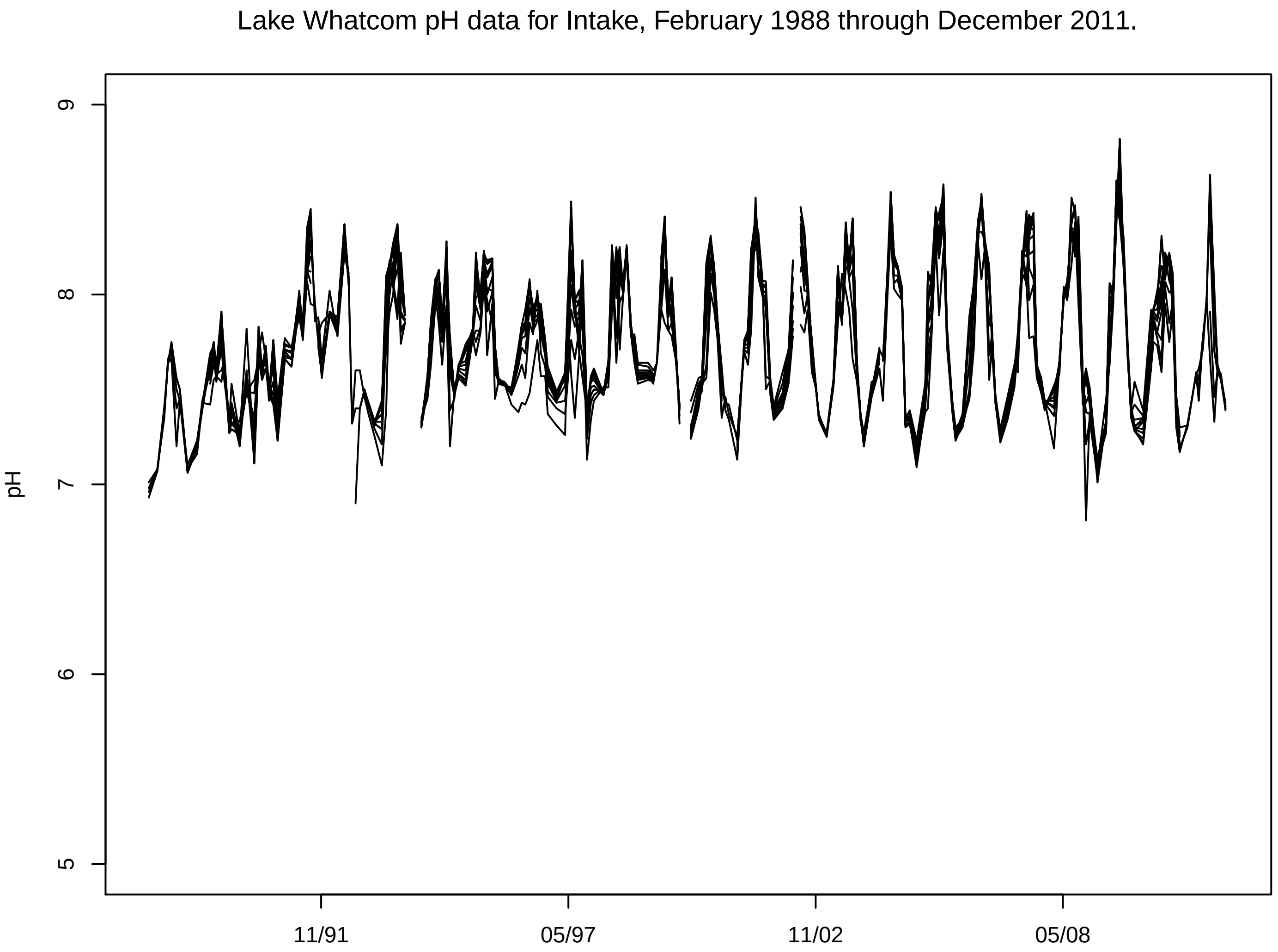
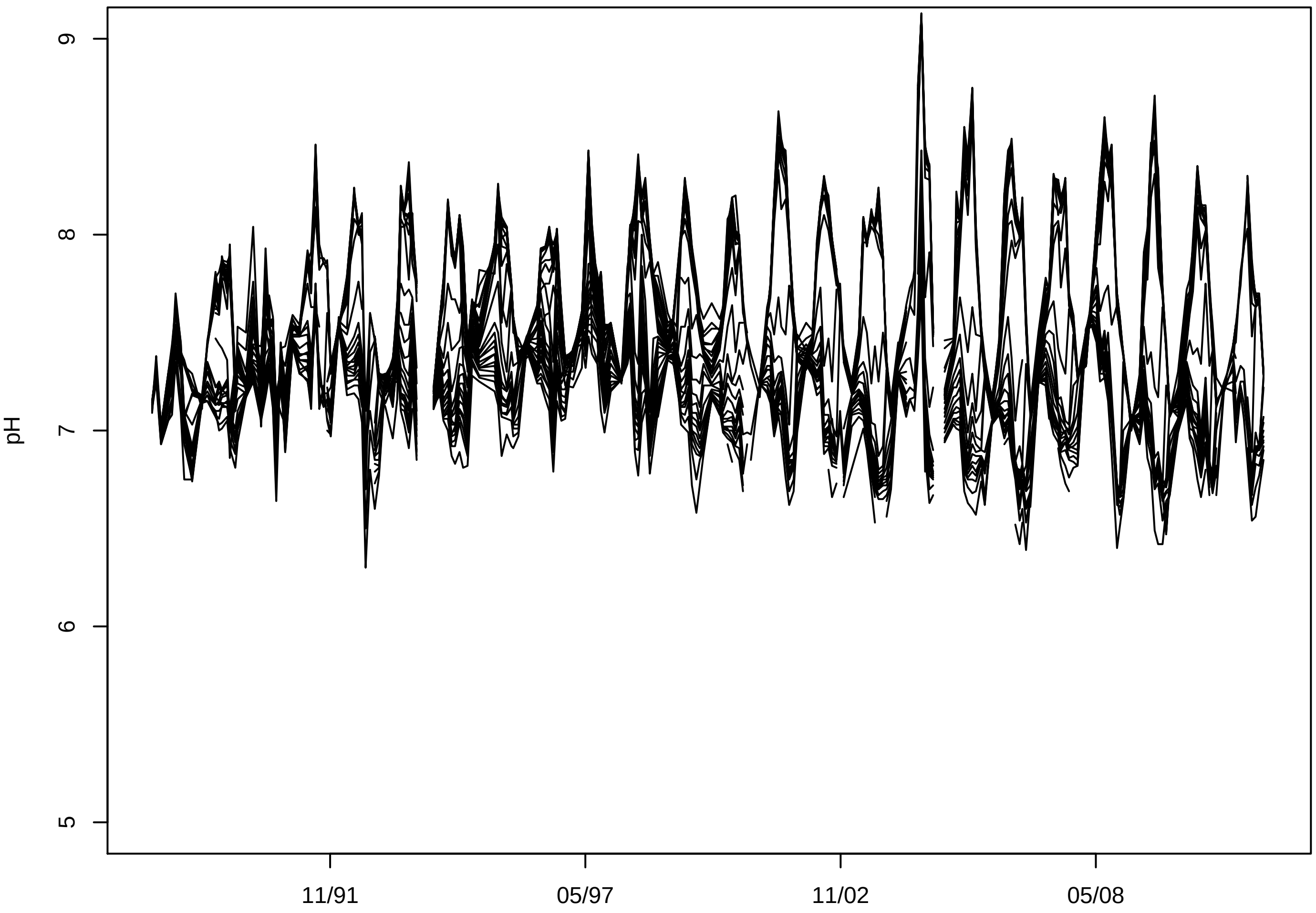
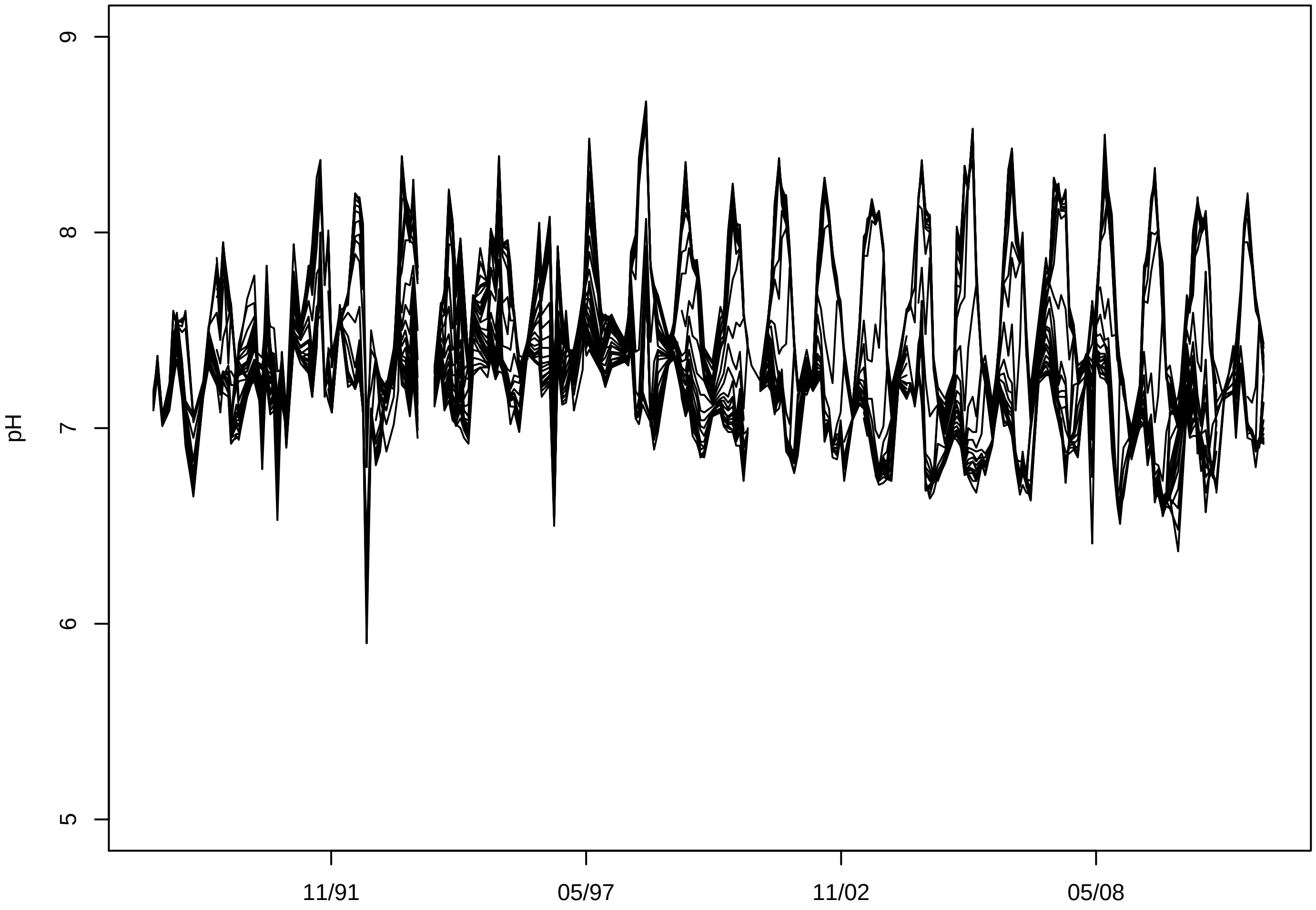


Figure B63: Lake Whatcom historic pH data for the Intake.



Lake Whatcom pH data for Site 3, February 1988 through December 2011.

Figure B64: Lake Whatcom historic pH data for Site 3.



Lake Whatcom pH data for Site 4, February 1988 through December 2011.

Figure B65: Lake Whatcom historic pH data for Site 4.

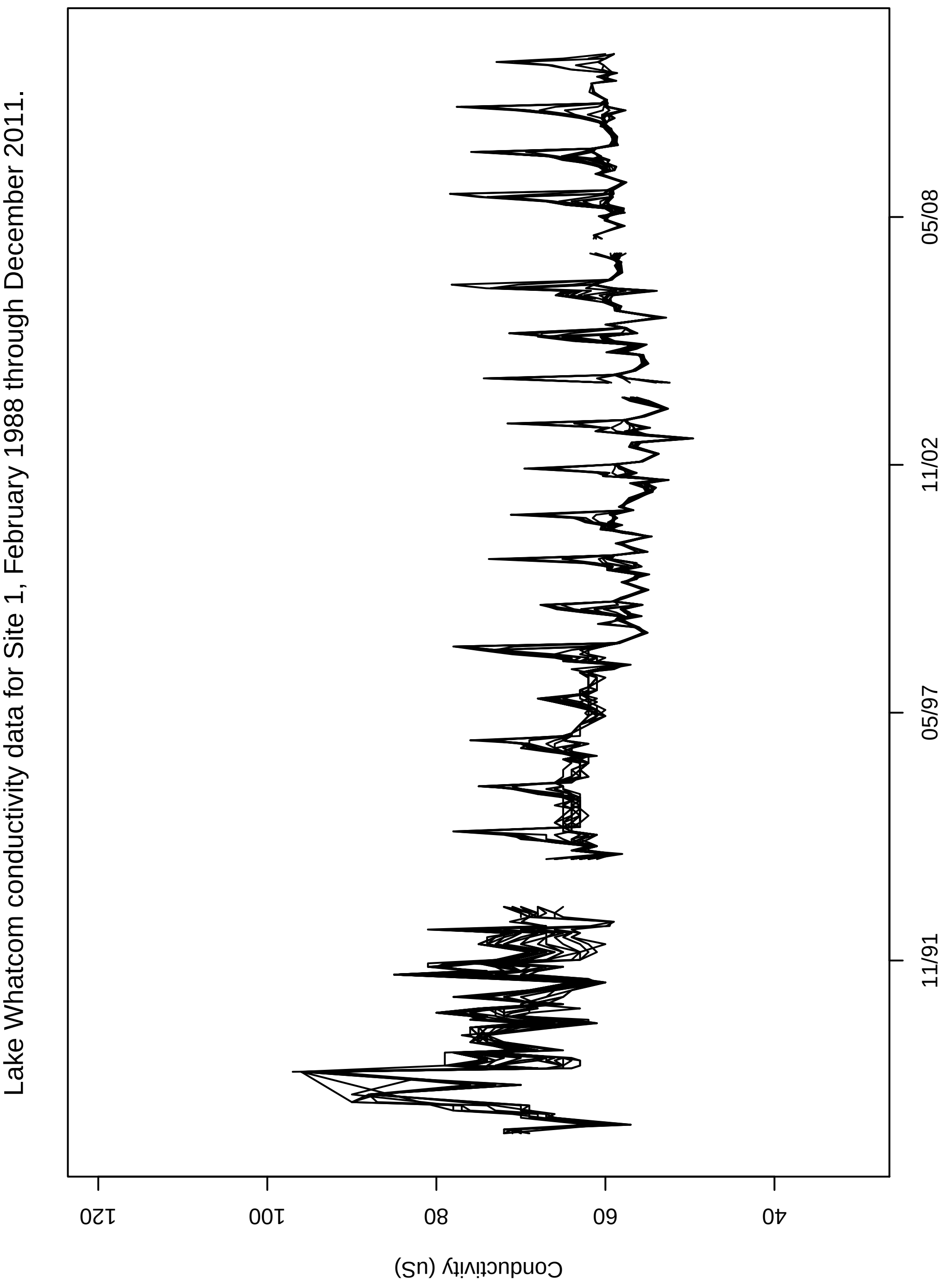


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to more sensitive equipment.

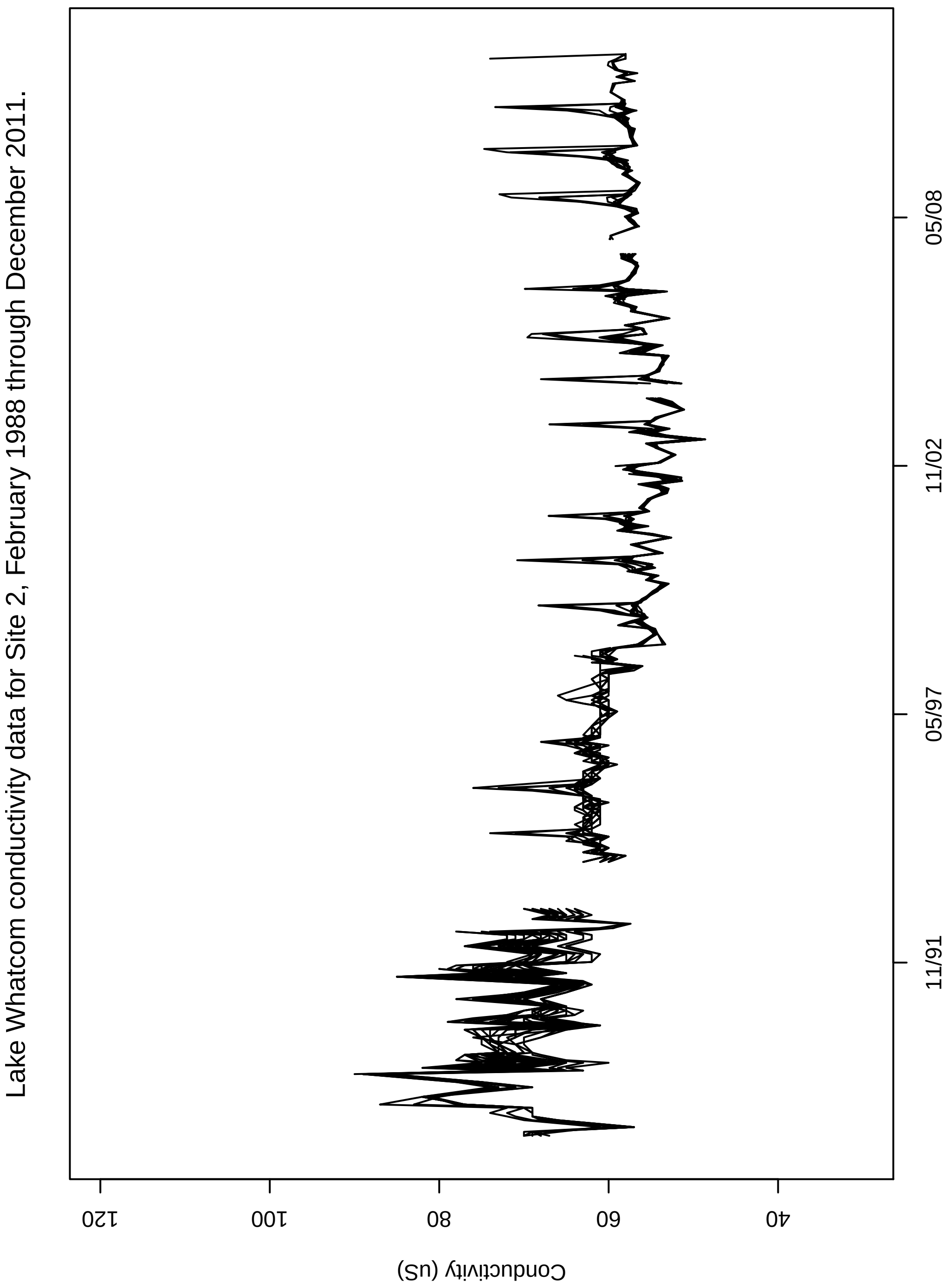


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to more sensitive equipment.

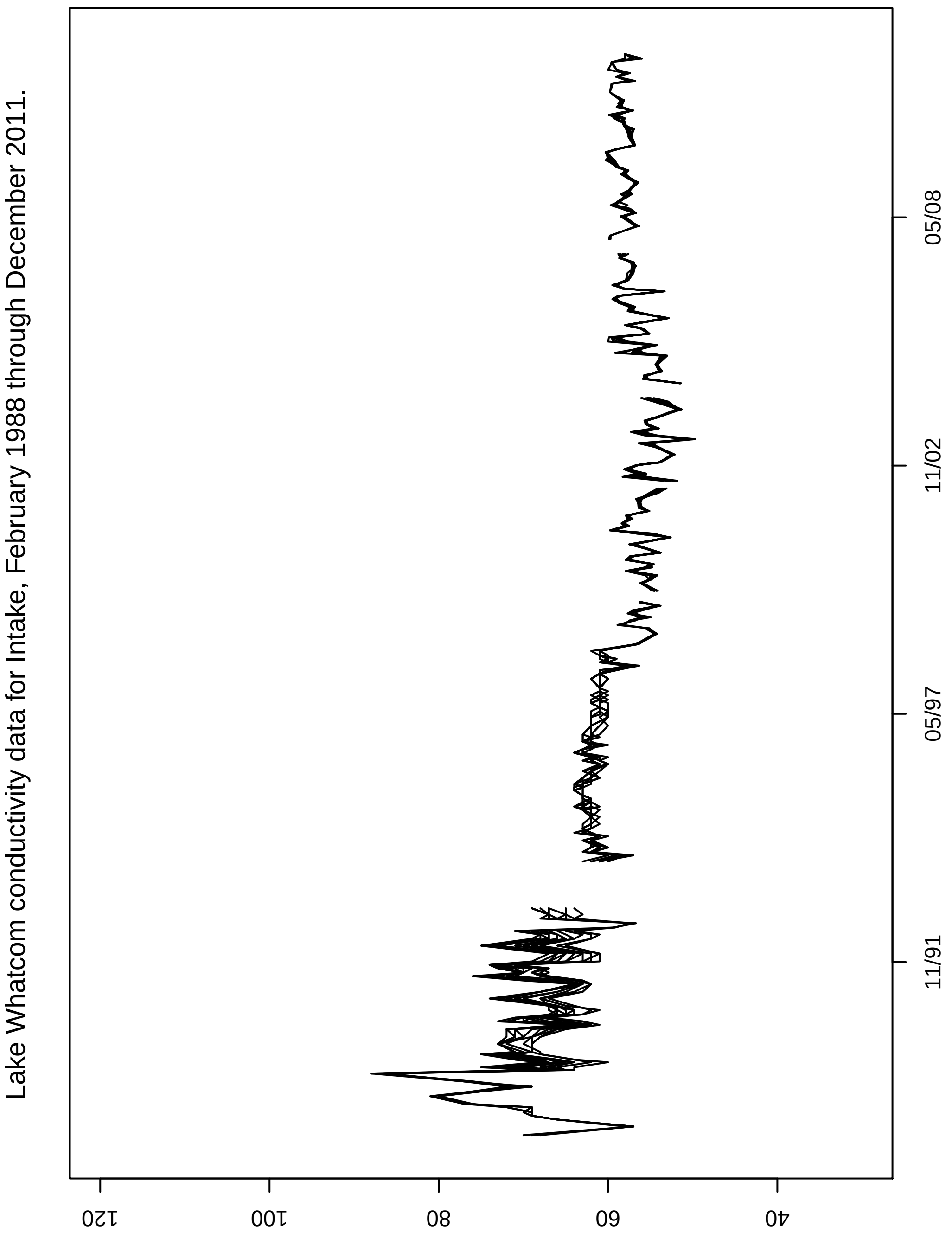


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to more sensitive equipment.

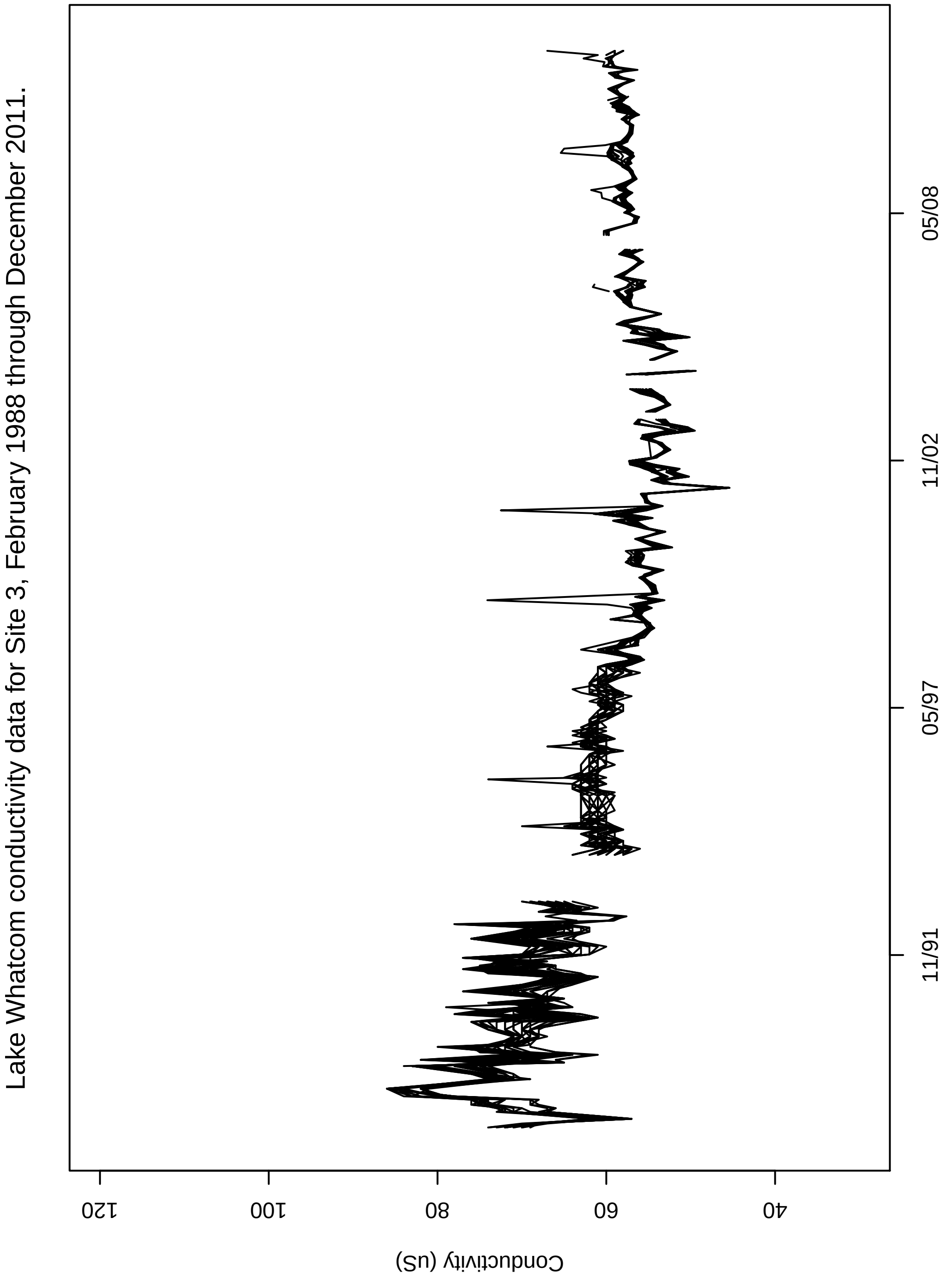


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to more sensitive equipment.

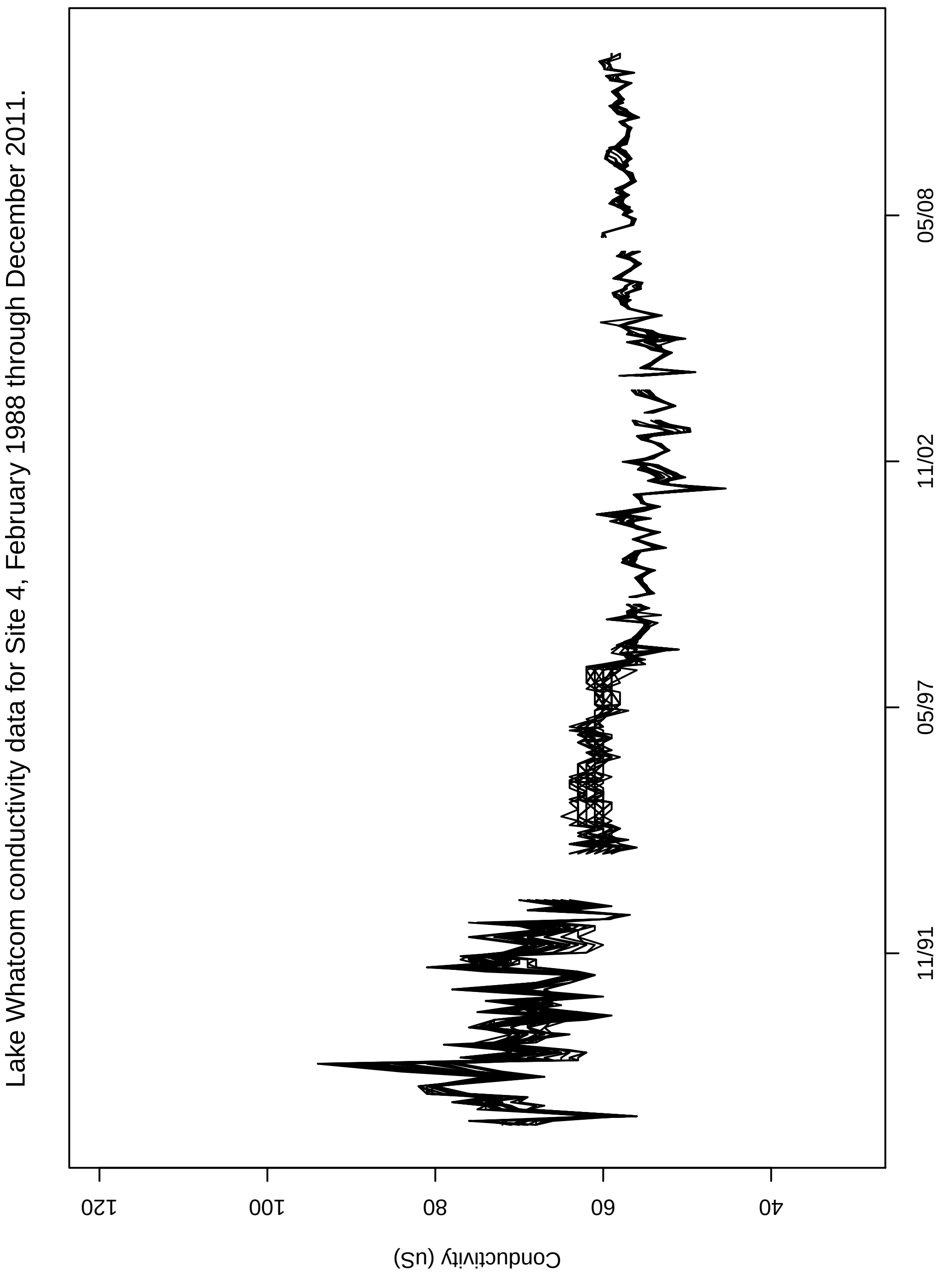


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to more sensitive equipment.

## B.3 Long-term Water Quality Data (1988-present)

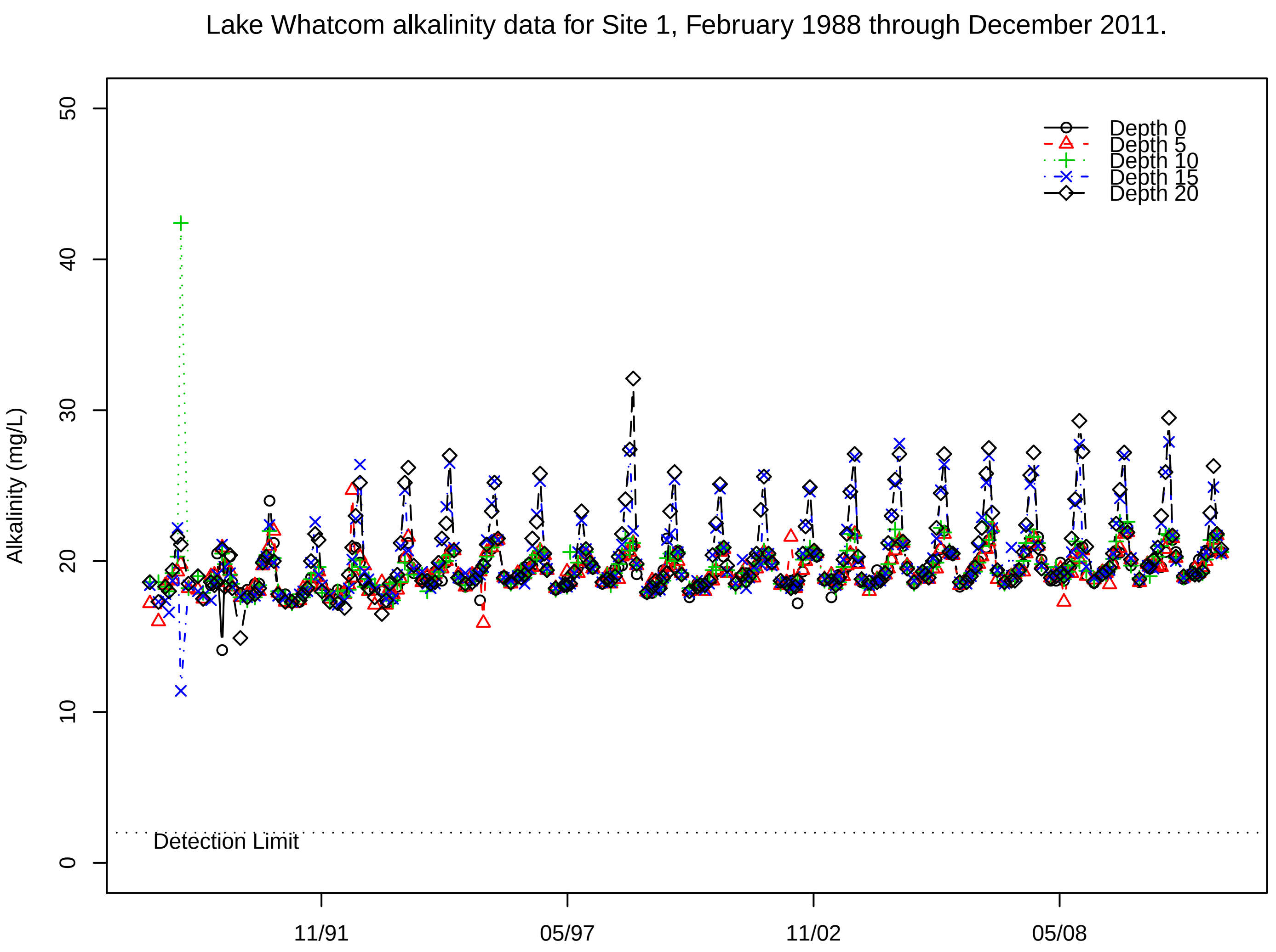


Figure B71: Lake Whatcom alkalinity data for Site 1.

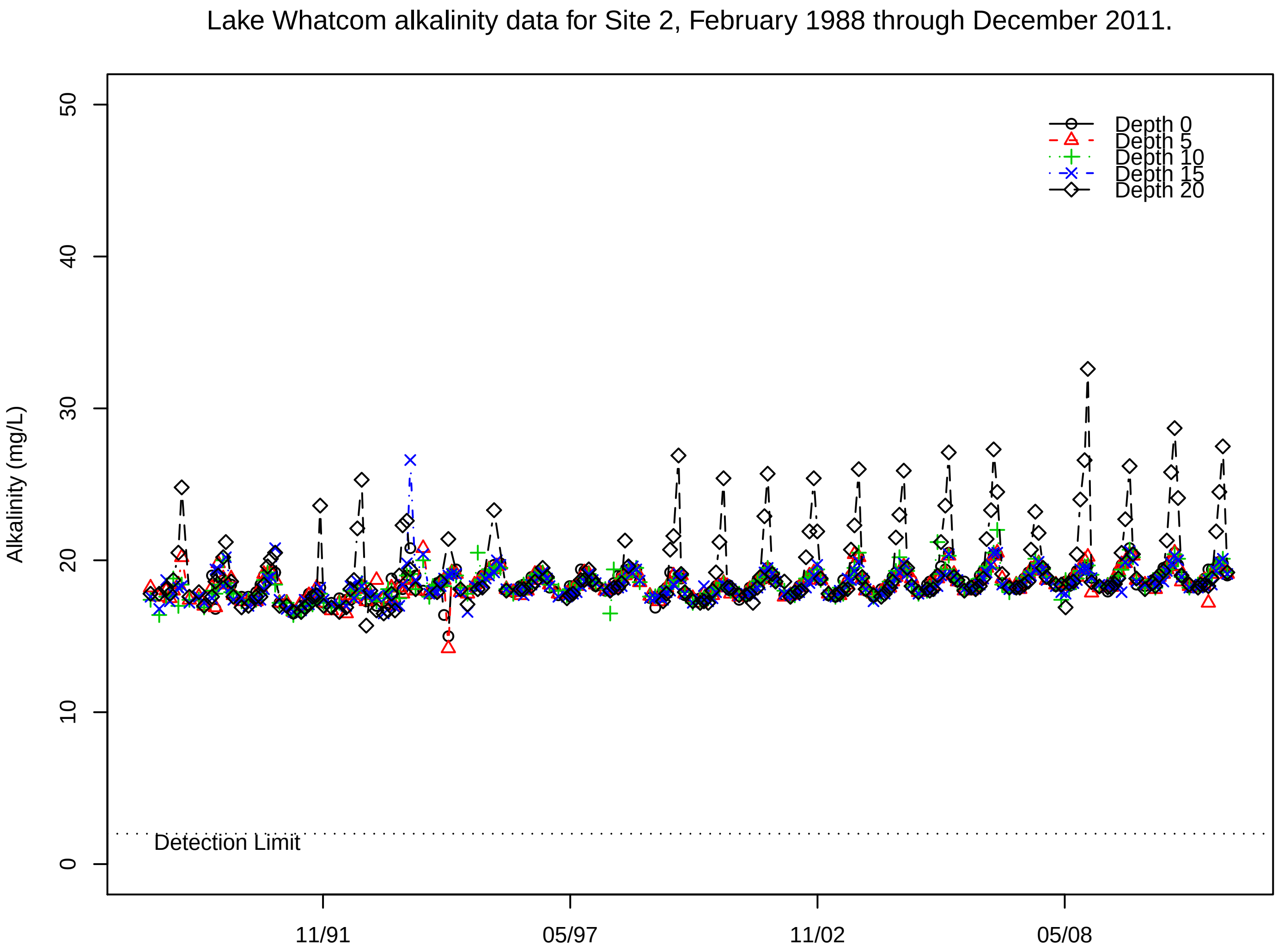


Figure B72: Lake Whatcom alkalinity data for Site 2.

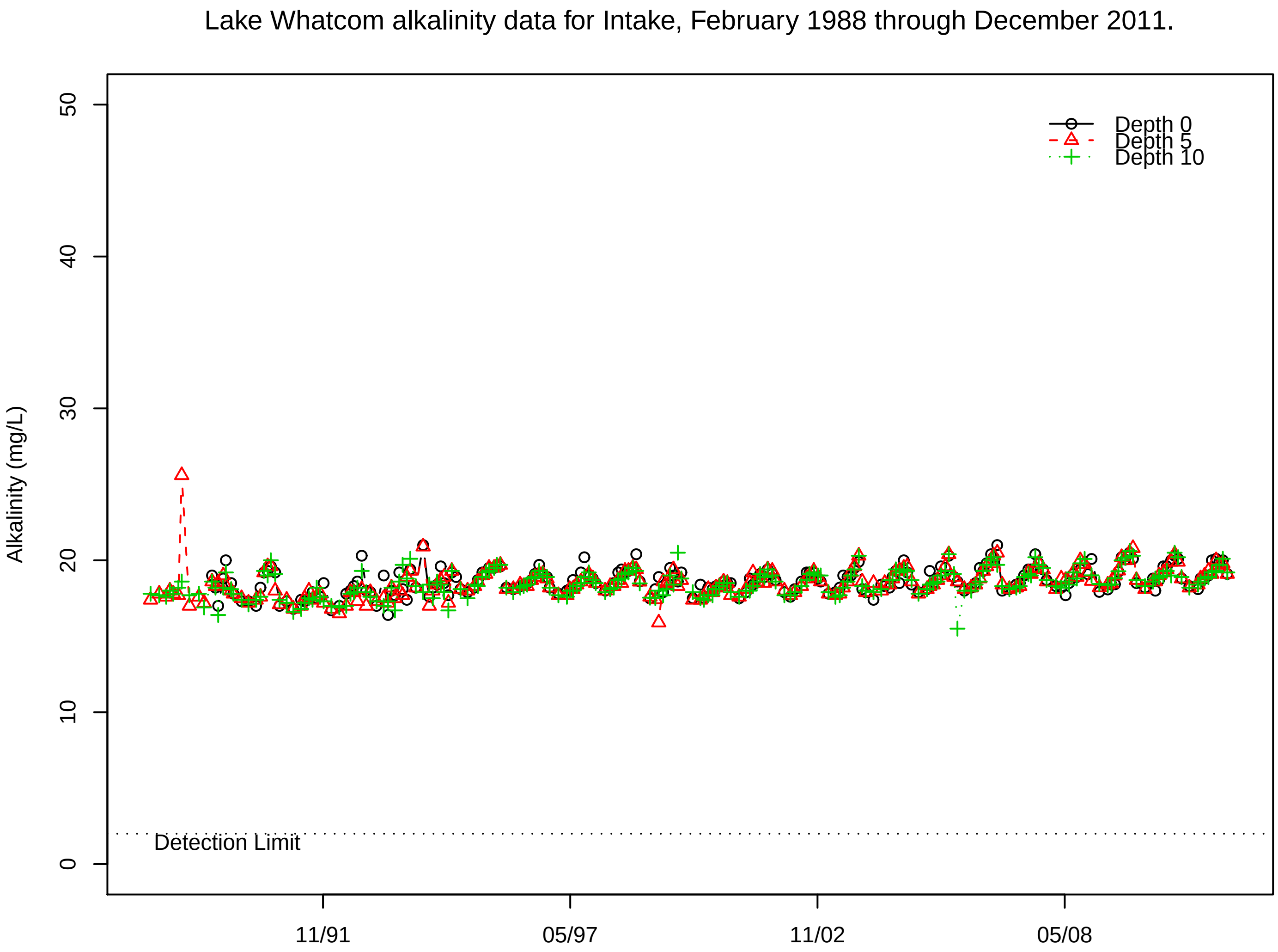


Figure B73: Lake Whatcom alkalinity data for the Intake site.

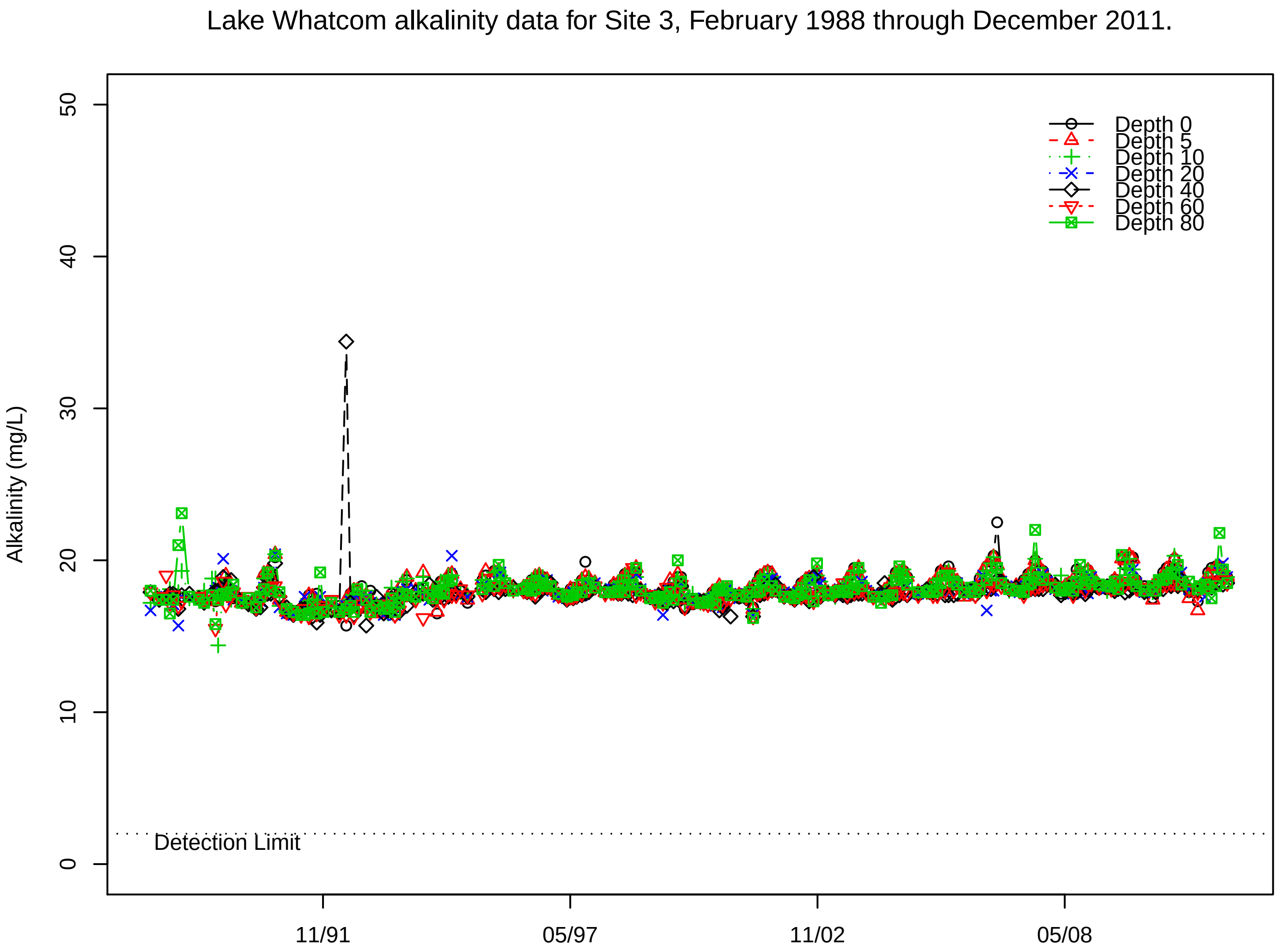


Figure B74: Lake Whatcom alkalinity data for Site 3.

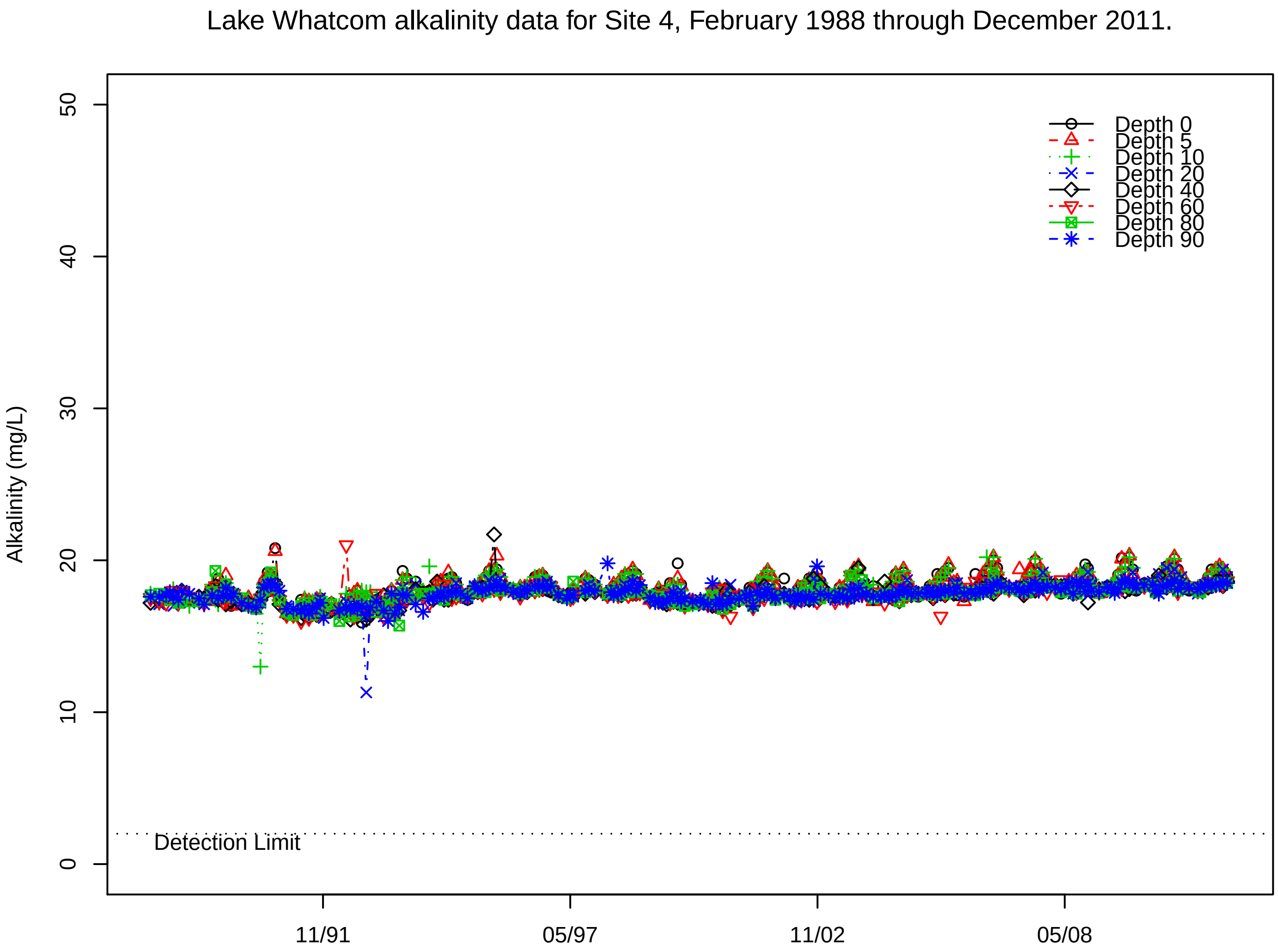


Figure B75: Lake Whatcom alkalinity data for Site 4.

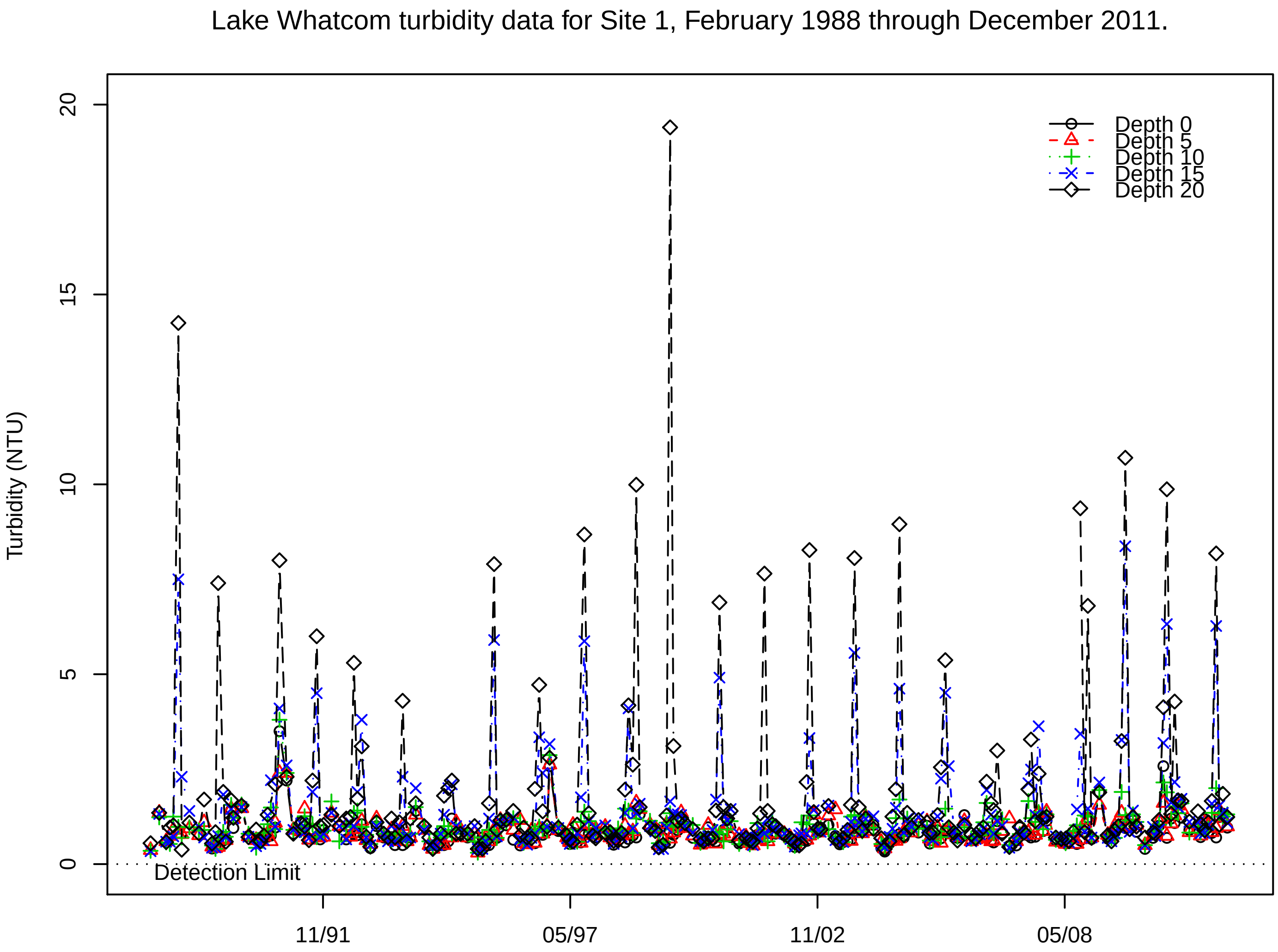


Figure B76: Lake Whatcom turbidity data for Site 1.

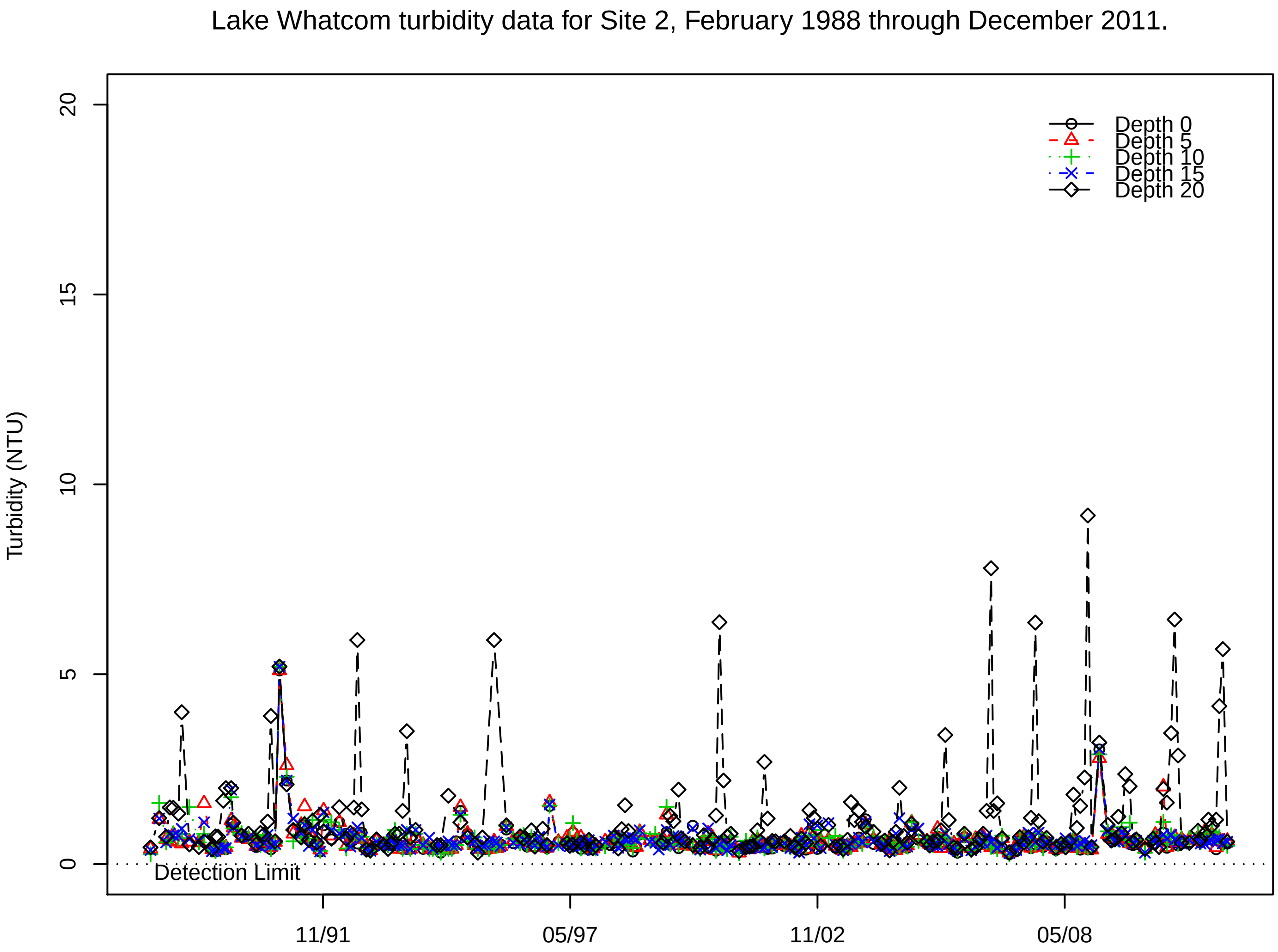
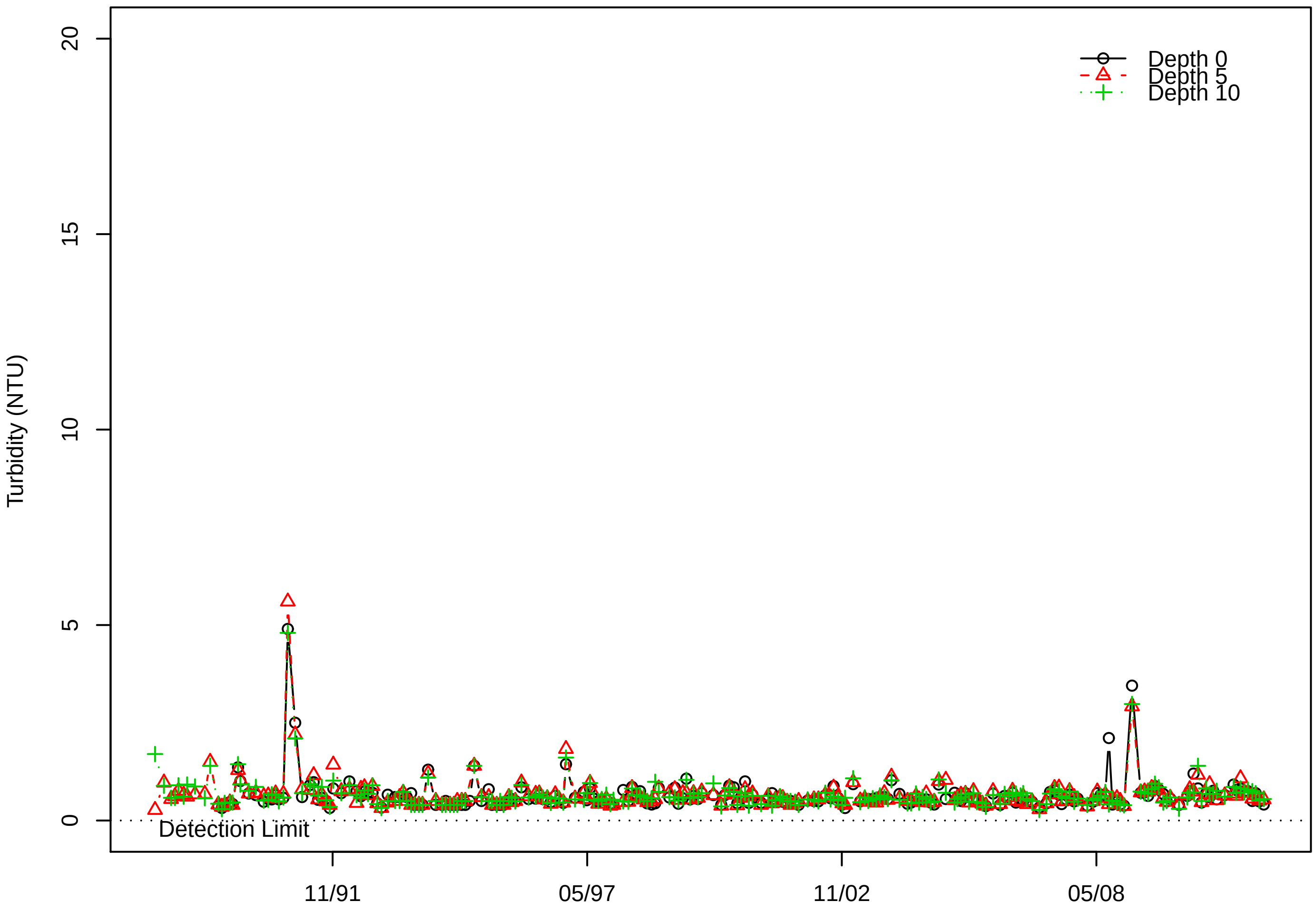


Figure B77: Lake Whatcom turbidity data for Site 2.



Lake Whatcom turbidity data for Intake, February 1988 through December 2011.

Figure B78: Lake Whatcom turbidity data for the Intake site.

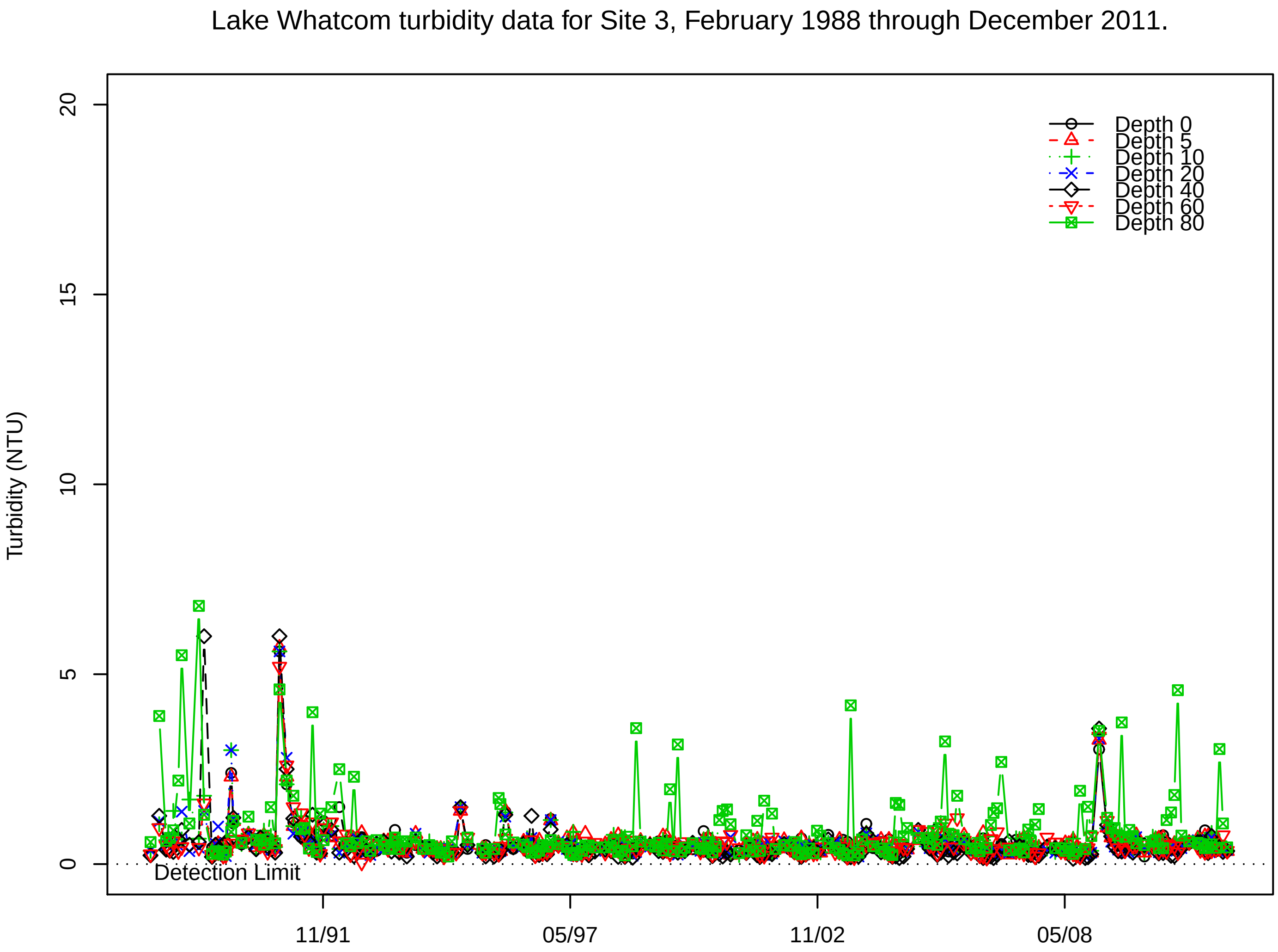


Figure B79: Lake Whatcom turbidity data for Site 3.

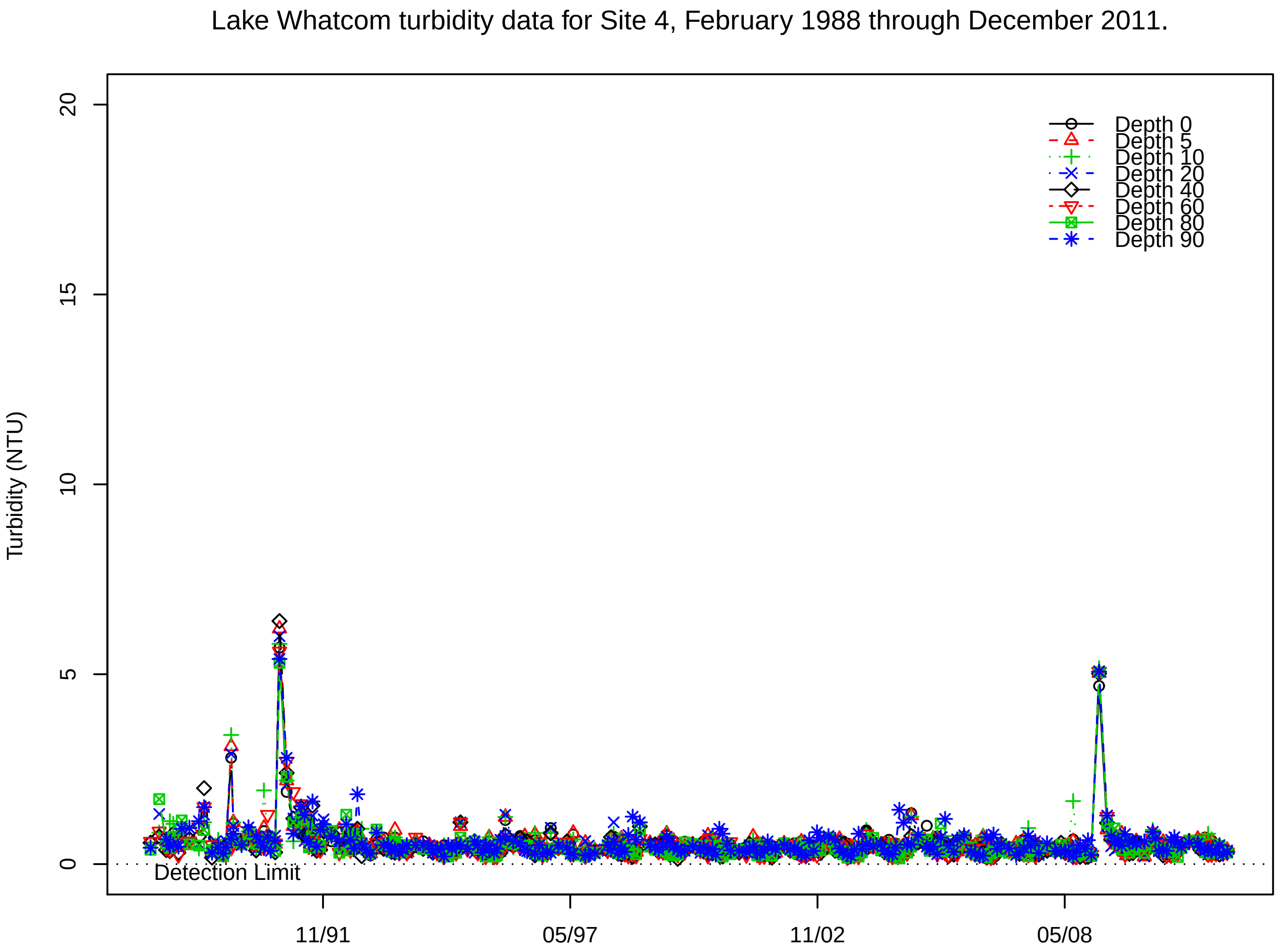
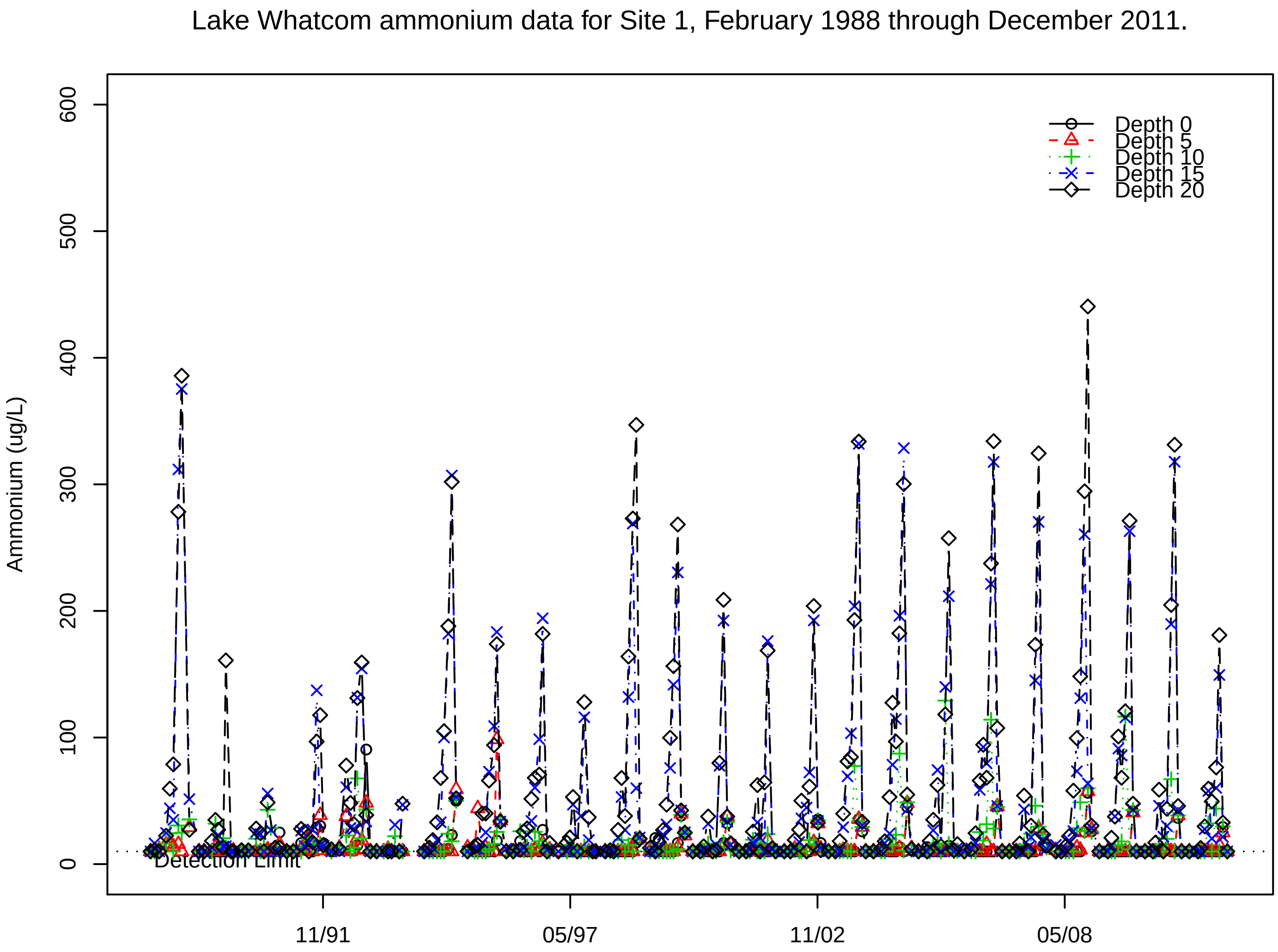


Figure B80: Lake Whatcom turbidity data for Site 4.



Lake Whatcom ammonium data for Site 1, February 1988 through December 2011.

Figure B81: Lake Whatcom ammonium data for Site 1.

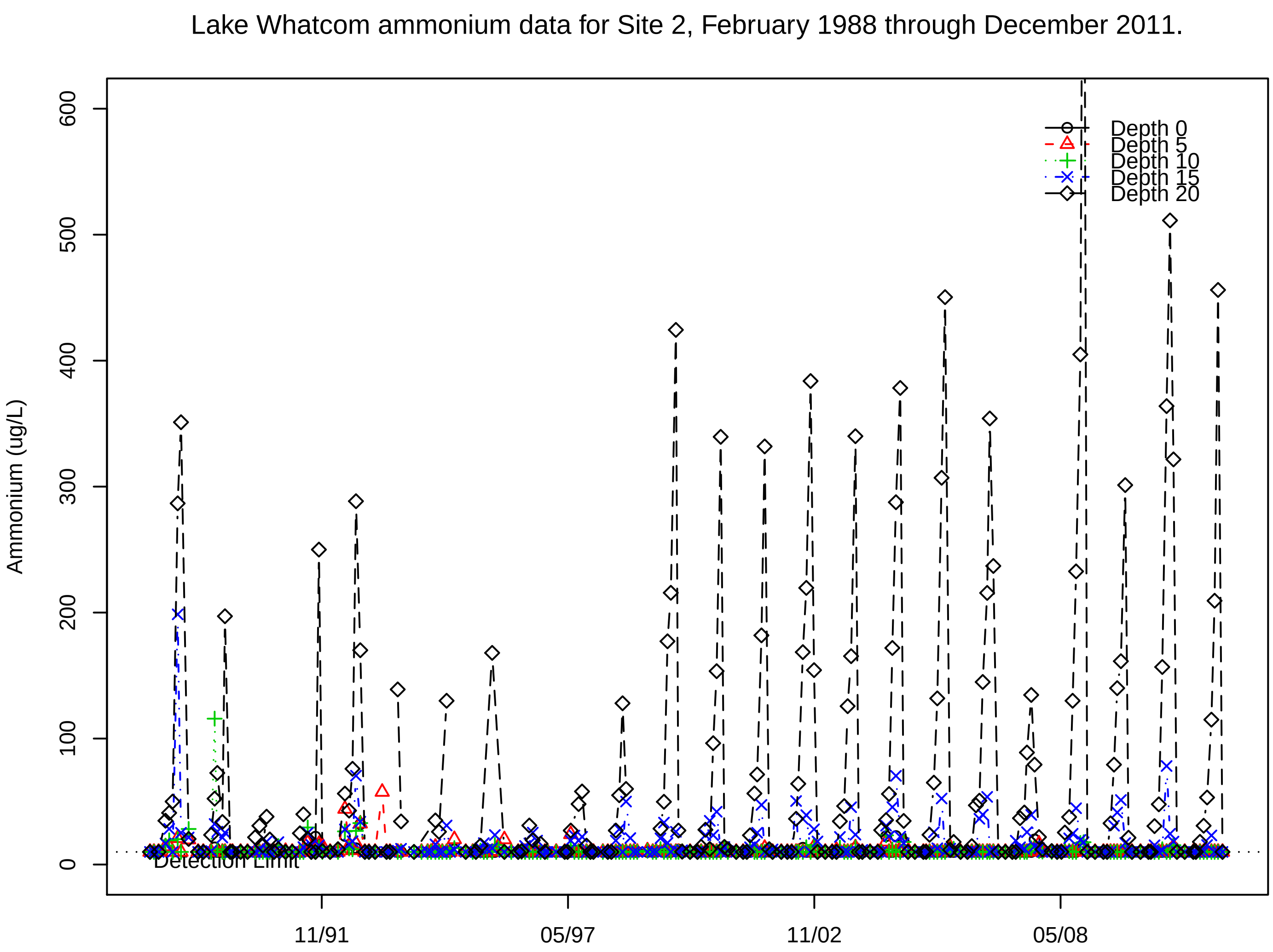


Figure B82: Lake Whatcom ammonium data for Site 2.

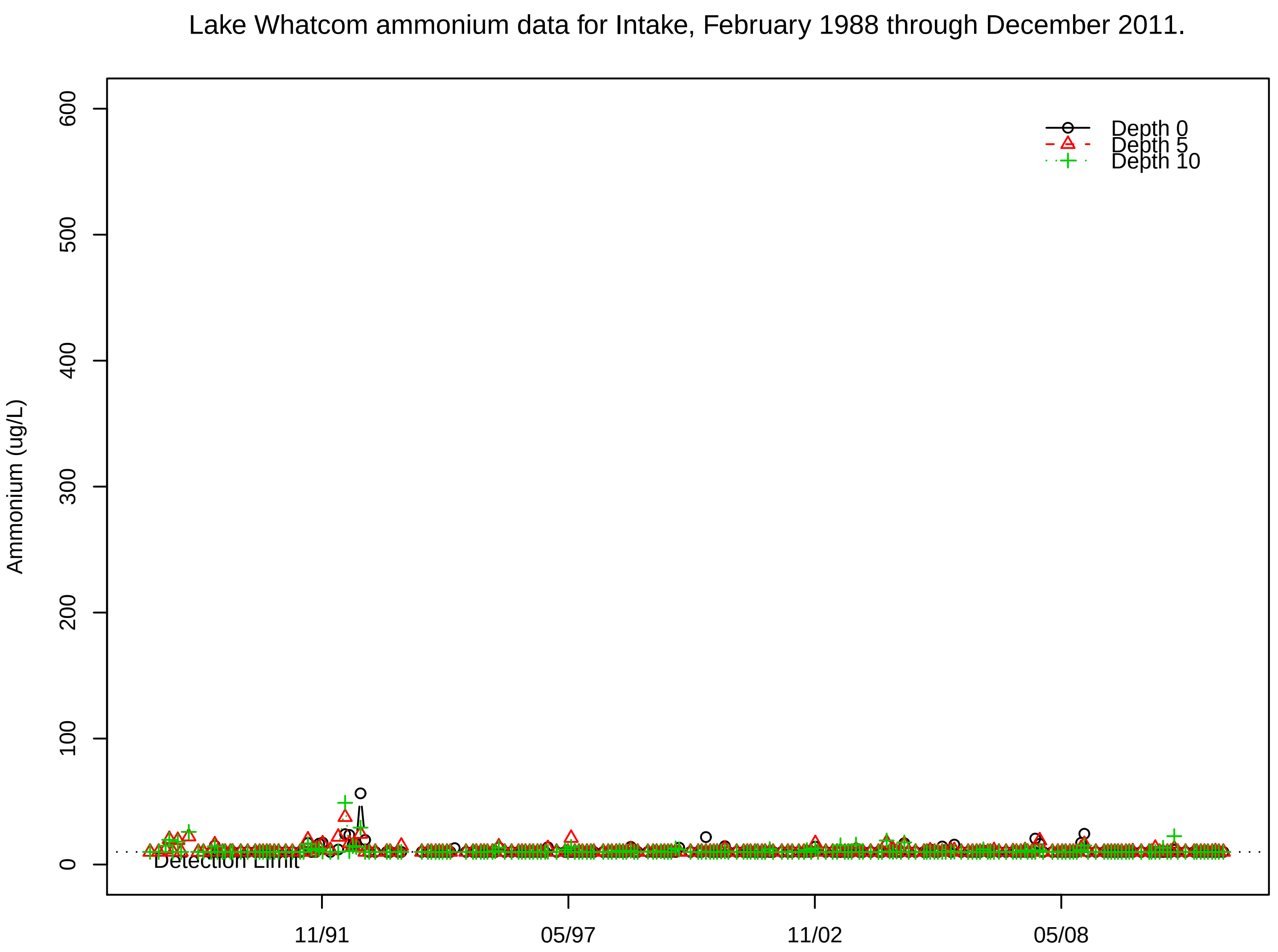


Figure B83: Lake Whatcom ammonium data for the Intake site.

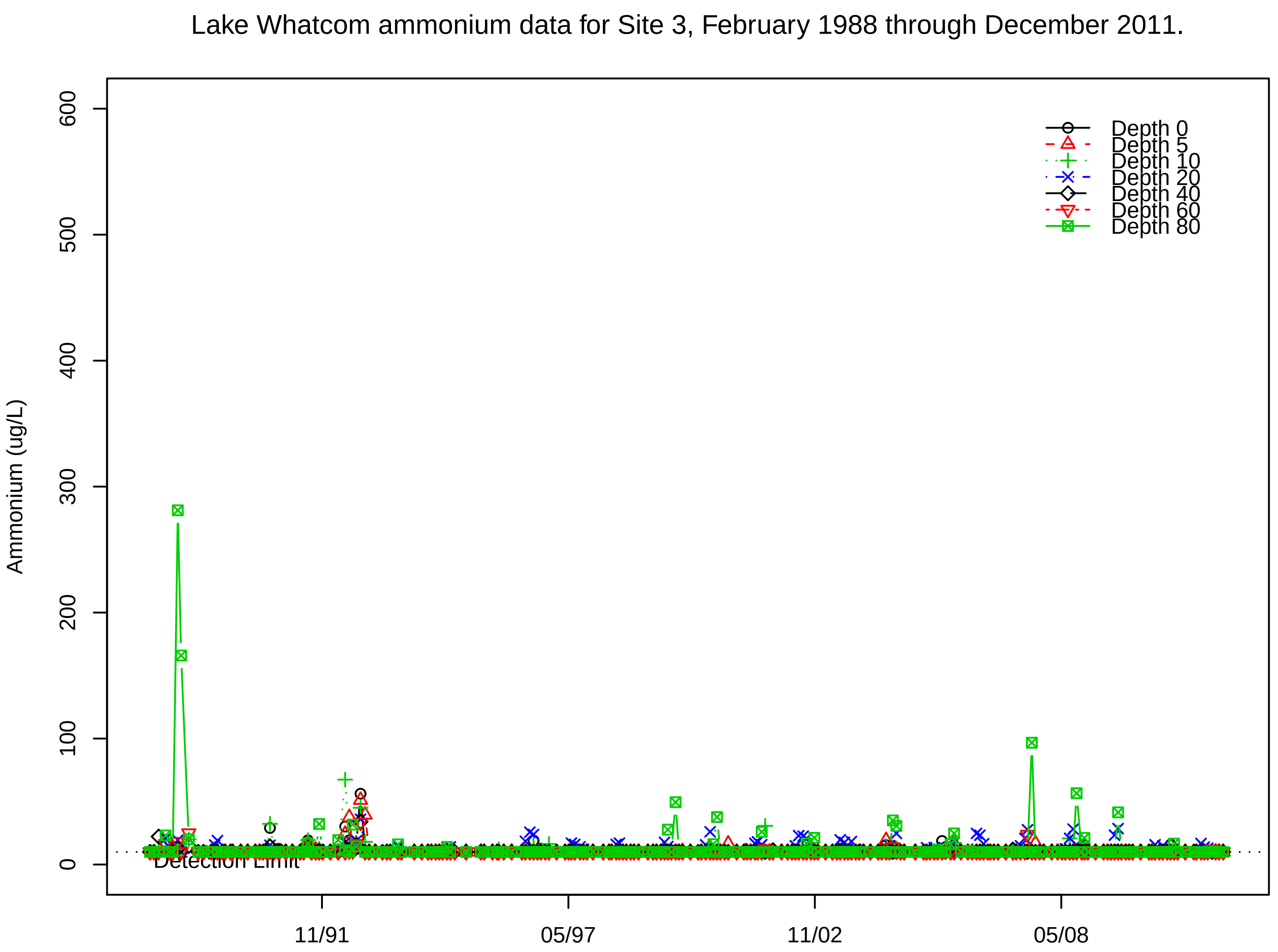


Figure B84: Lake Whatcom ammonium data for Site 3.

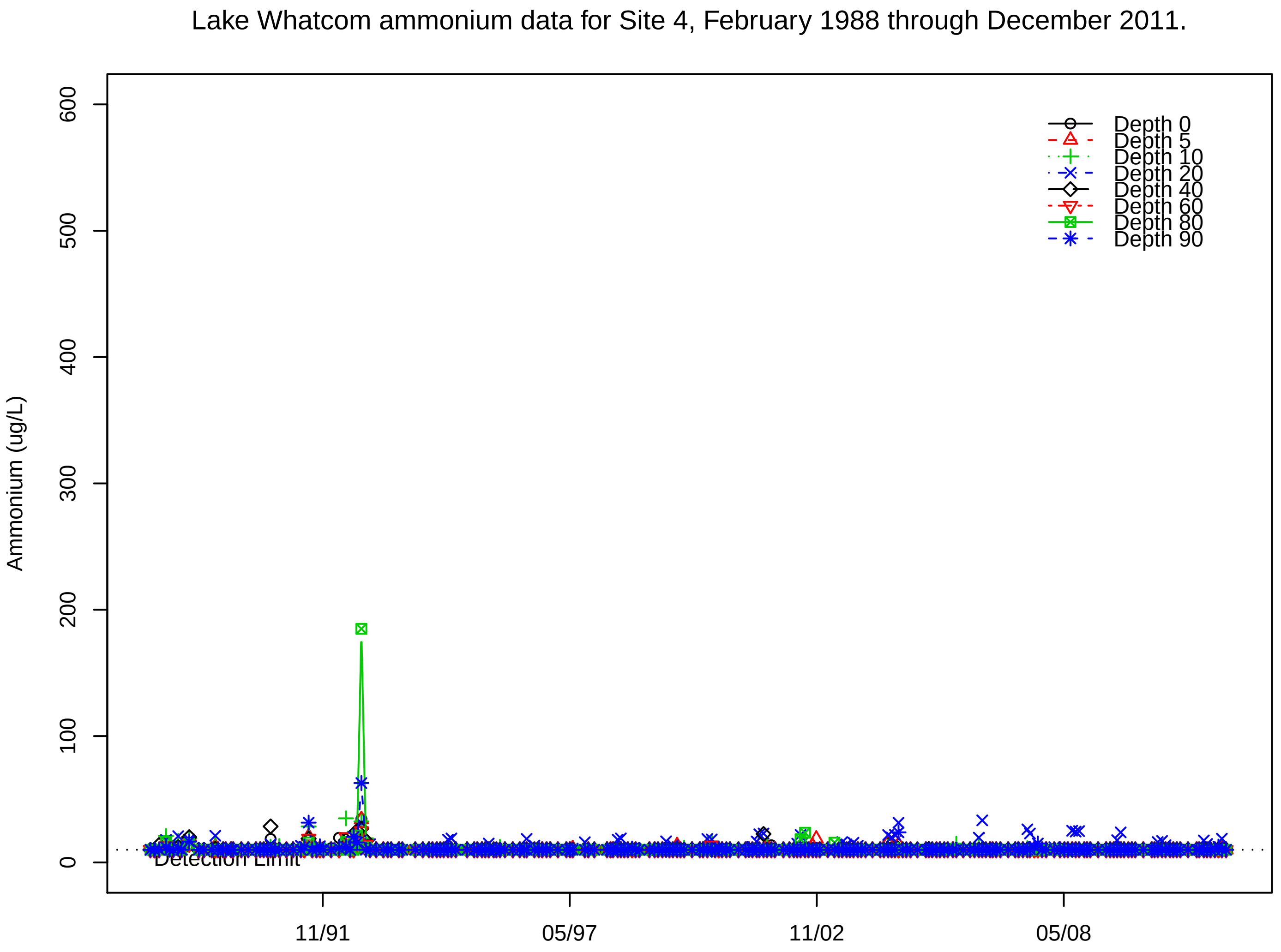
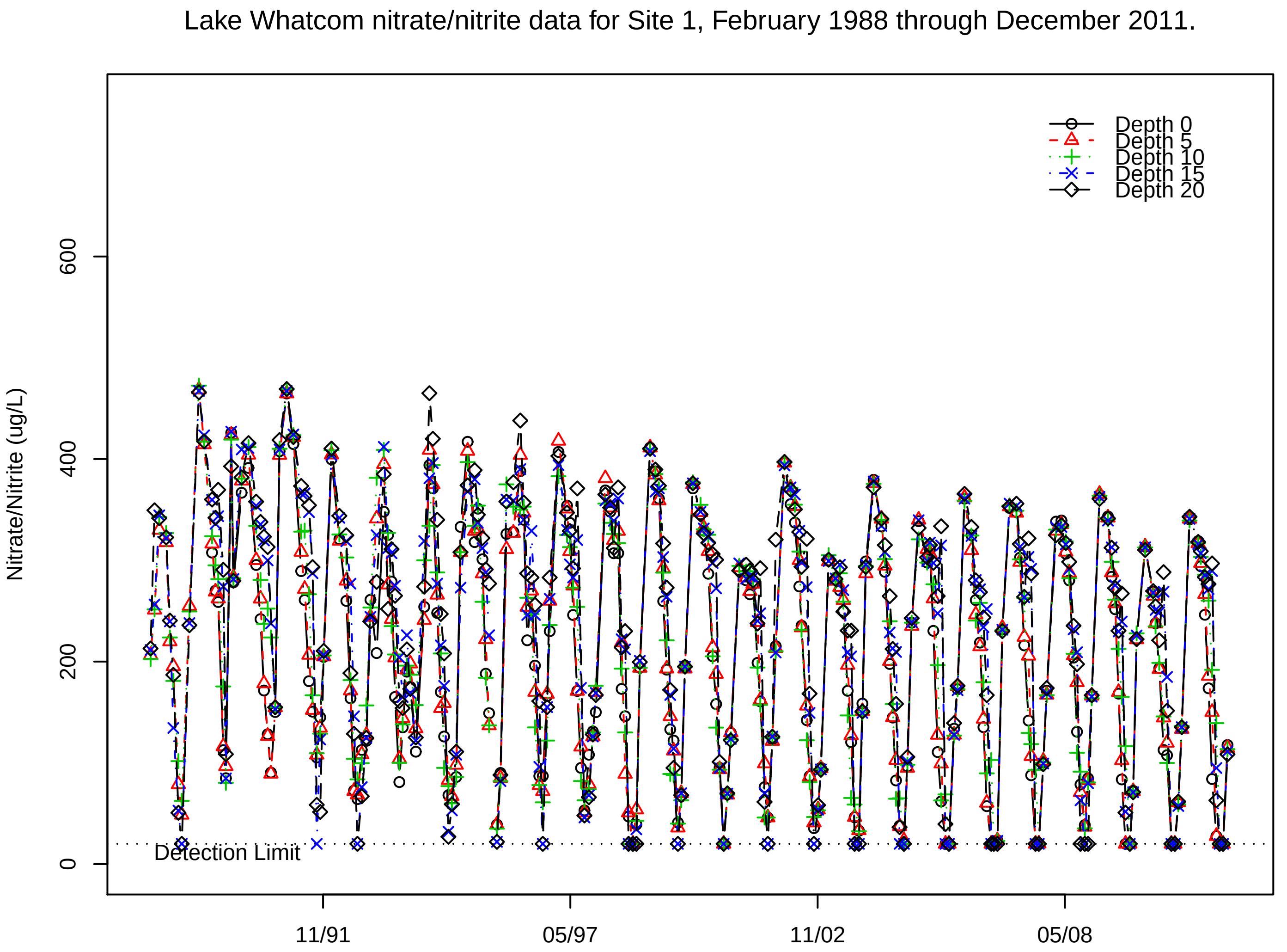


Figure B85: Lake Whatcom ammonium data for Site 4.



Lake Whatcom nitrate/nitrite data for Site 1, February 1988 through December 2011.

Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.

Lake Whatcom nitrate/nitrite data for Site 2, February 1988 through December 2011.

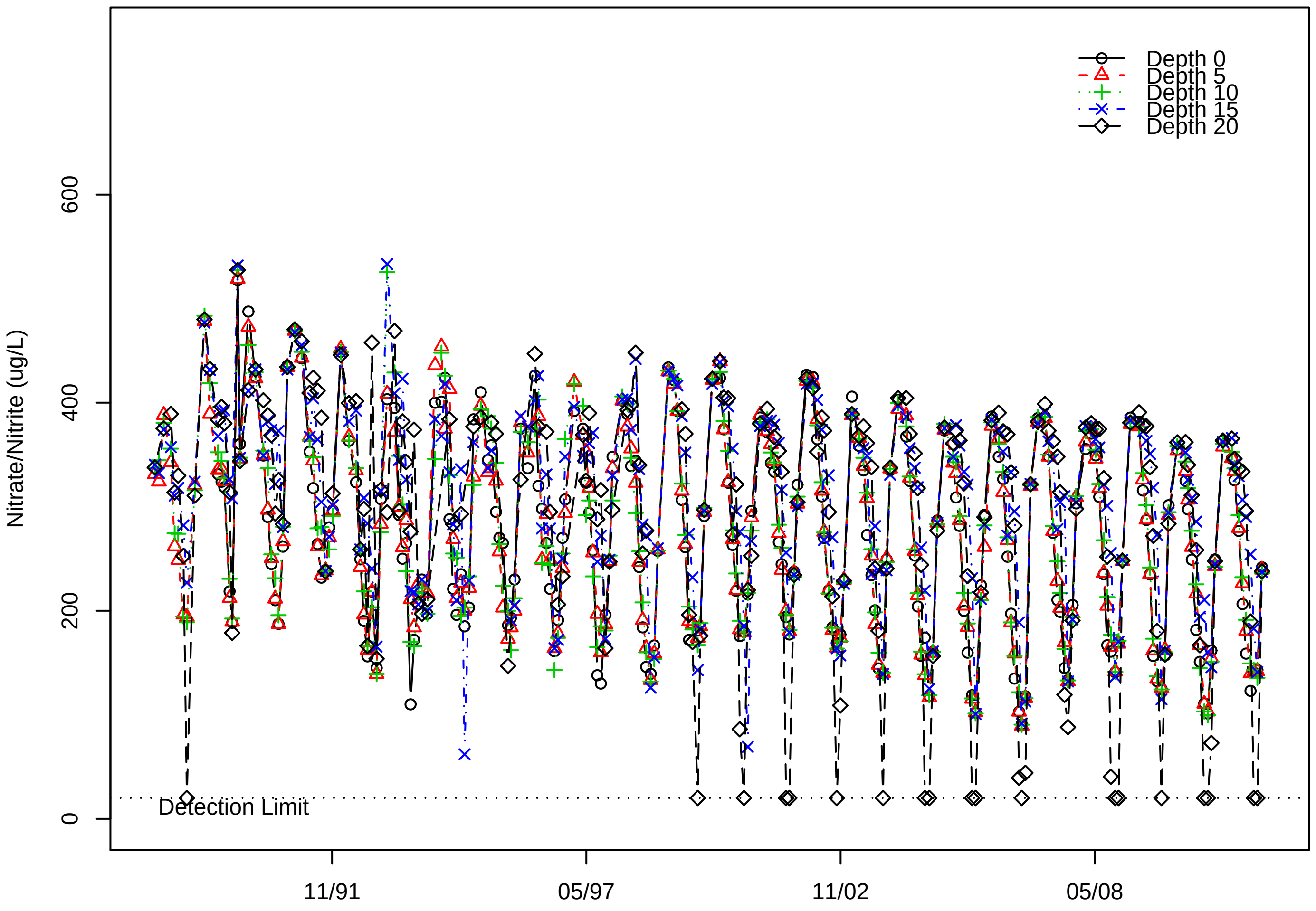


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

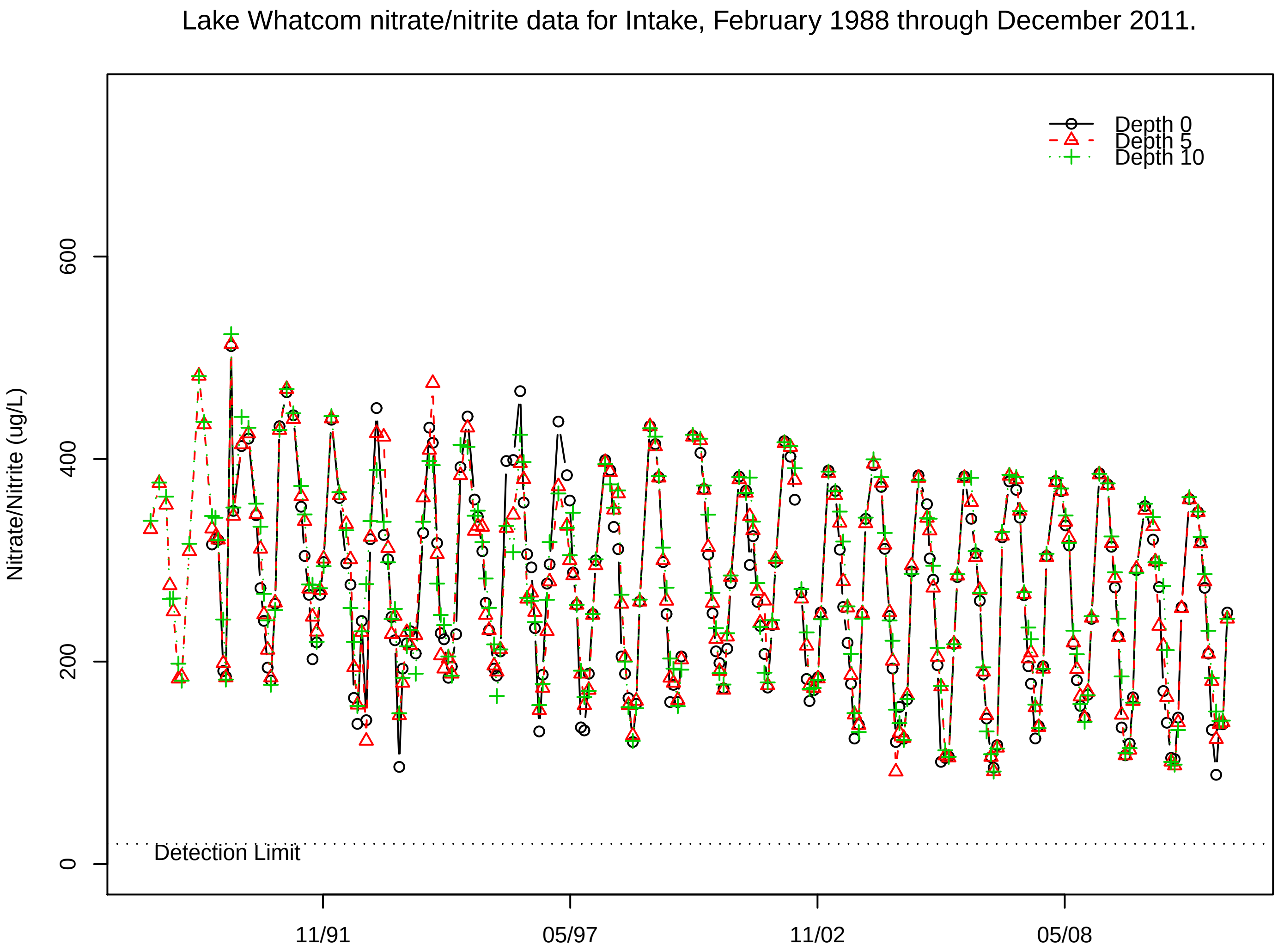


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

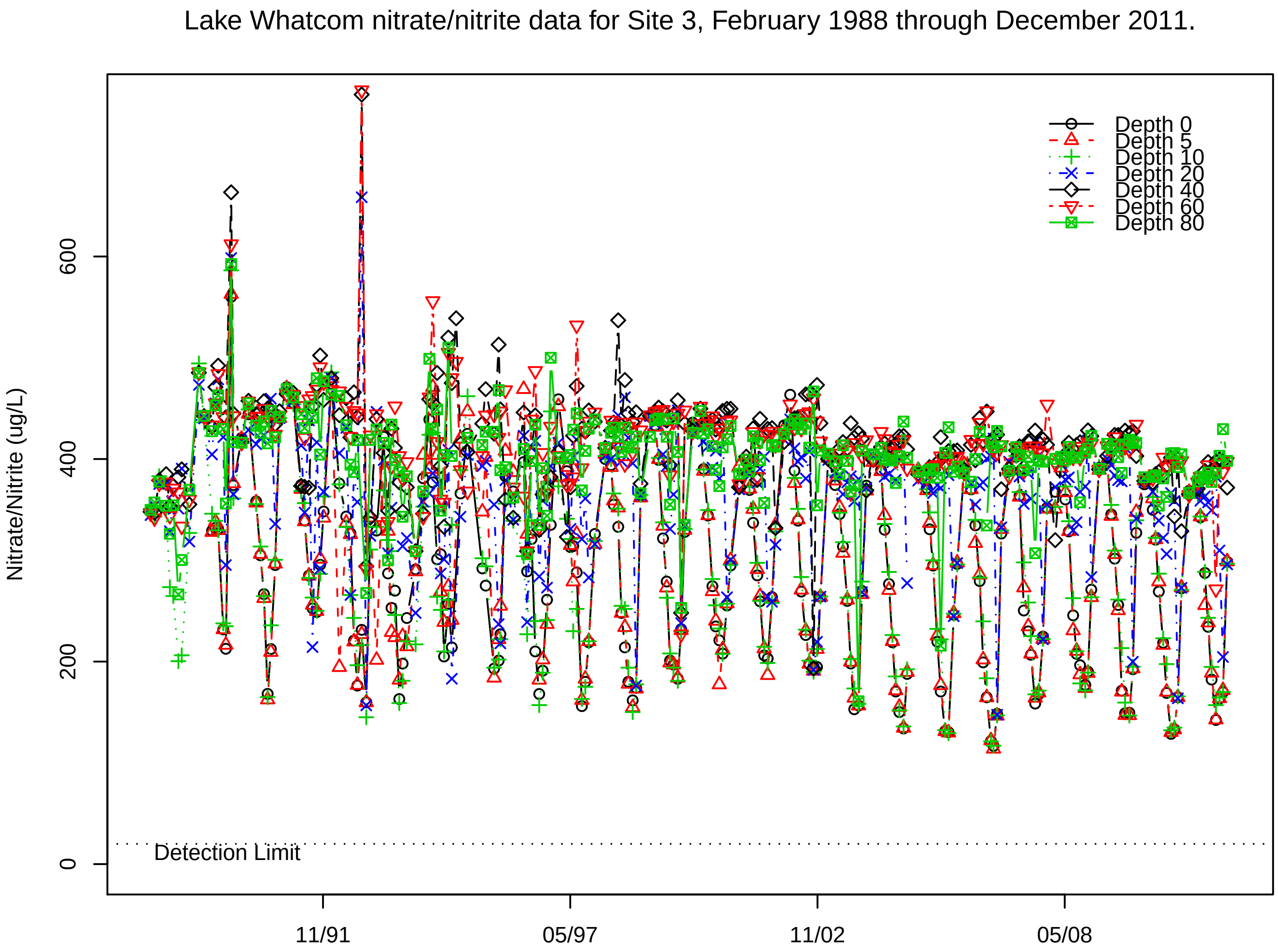


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

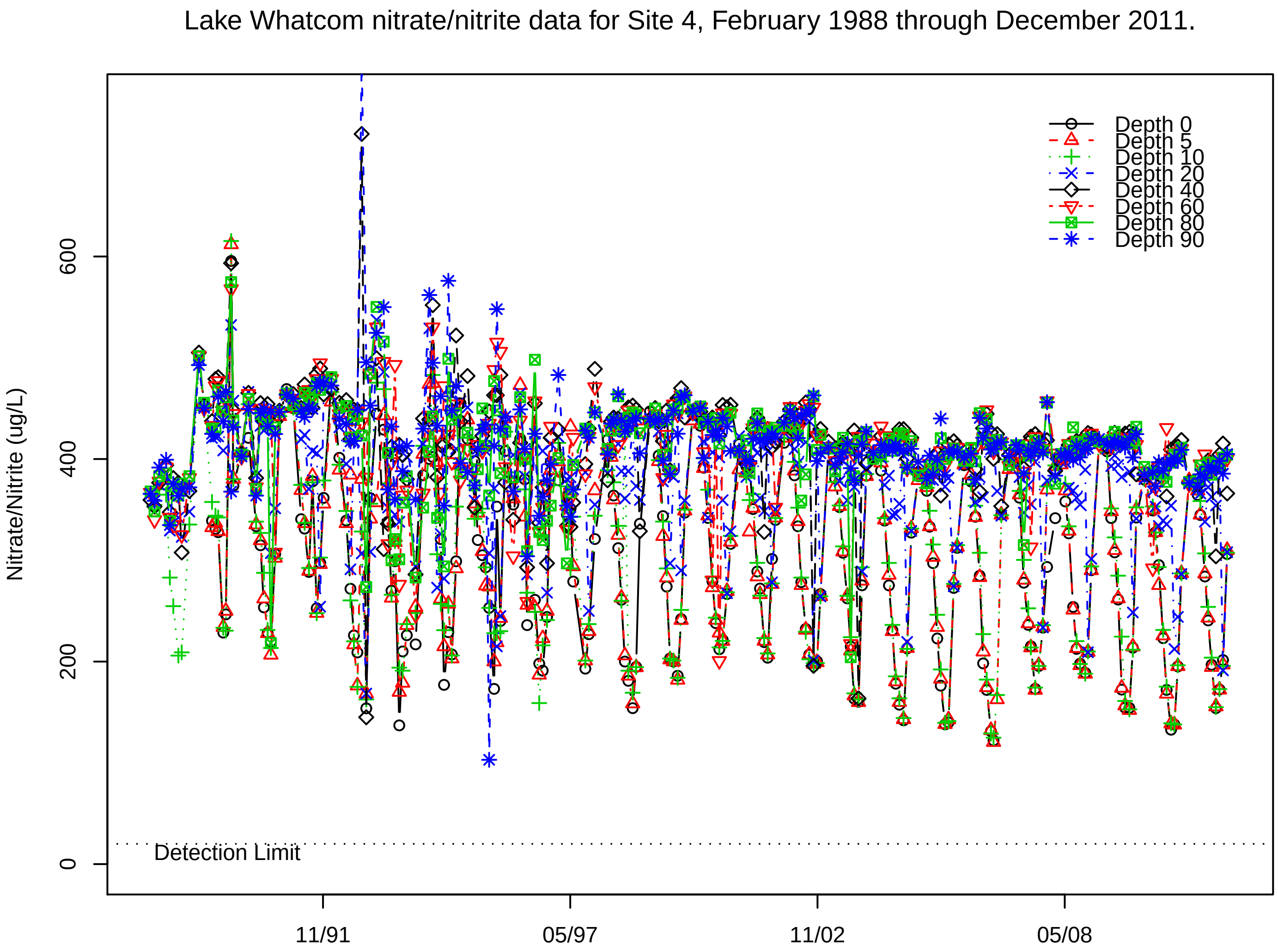
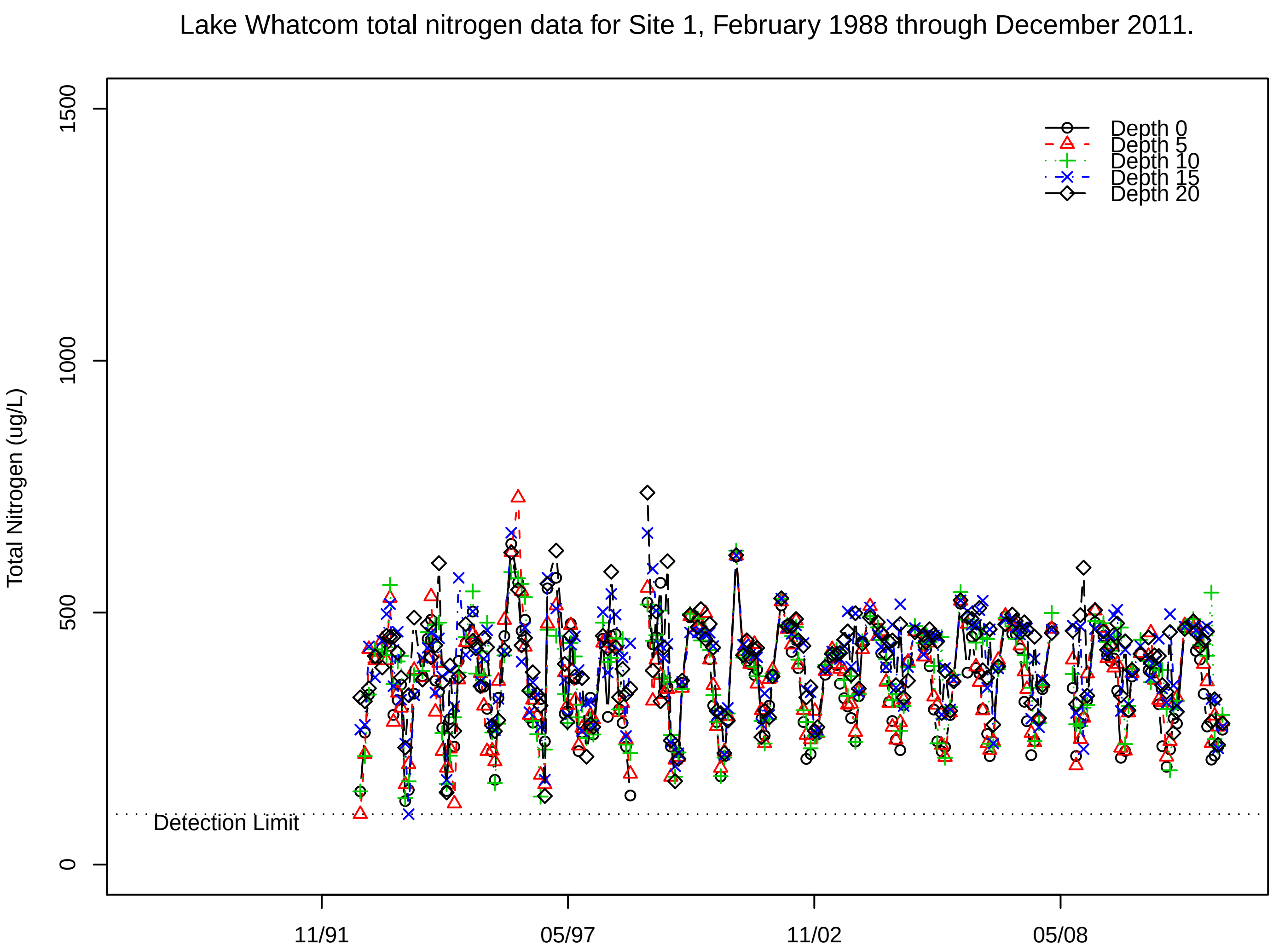


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4.



Lake Whatcom total nitrogen data for Site 1, February 1988 through December 2011.

Figure B91: Lake Whatcom total nitrogen data for Site 1.

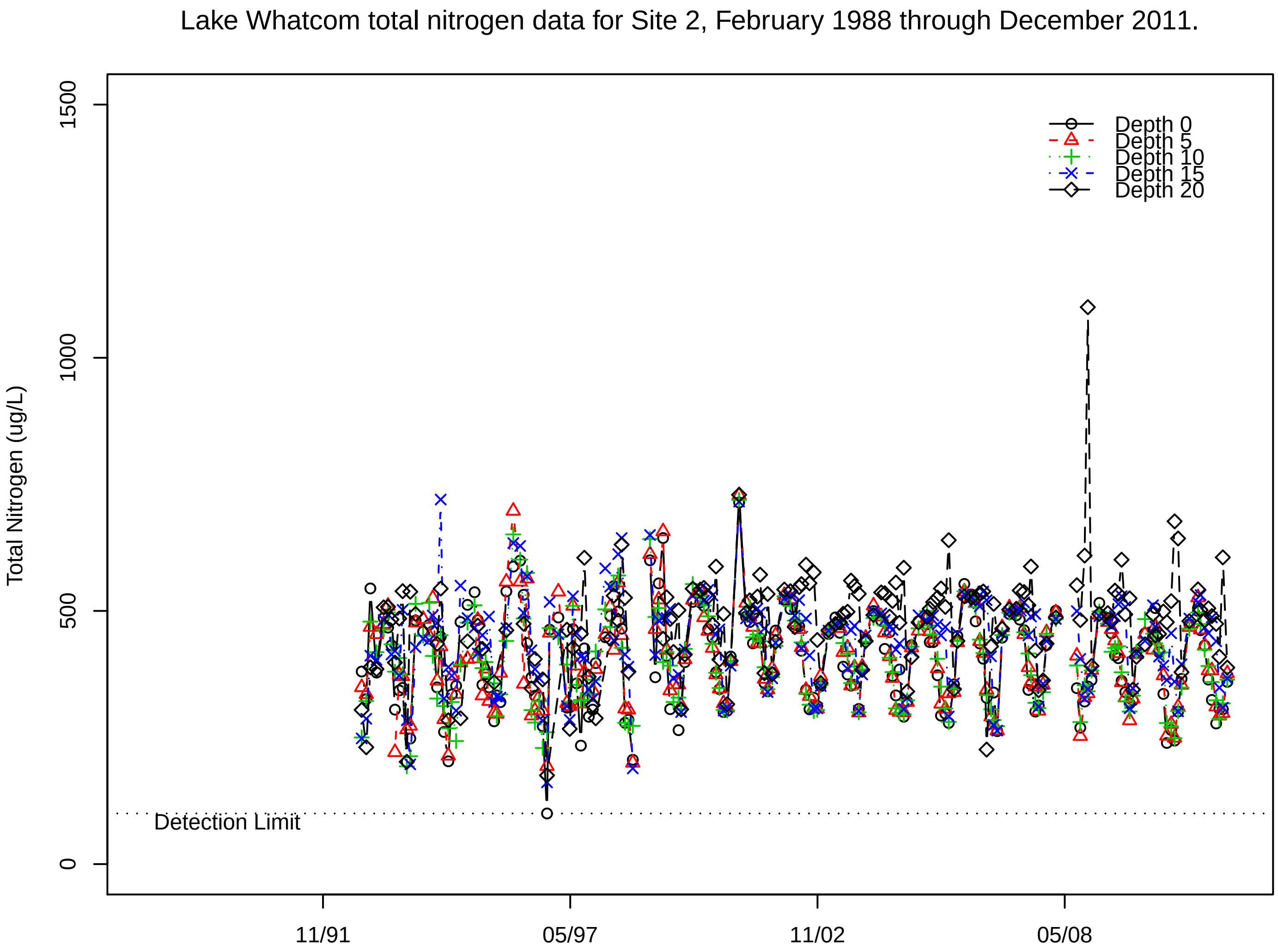
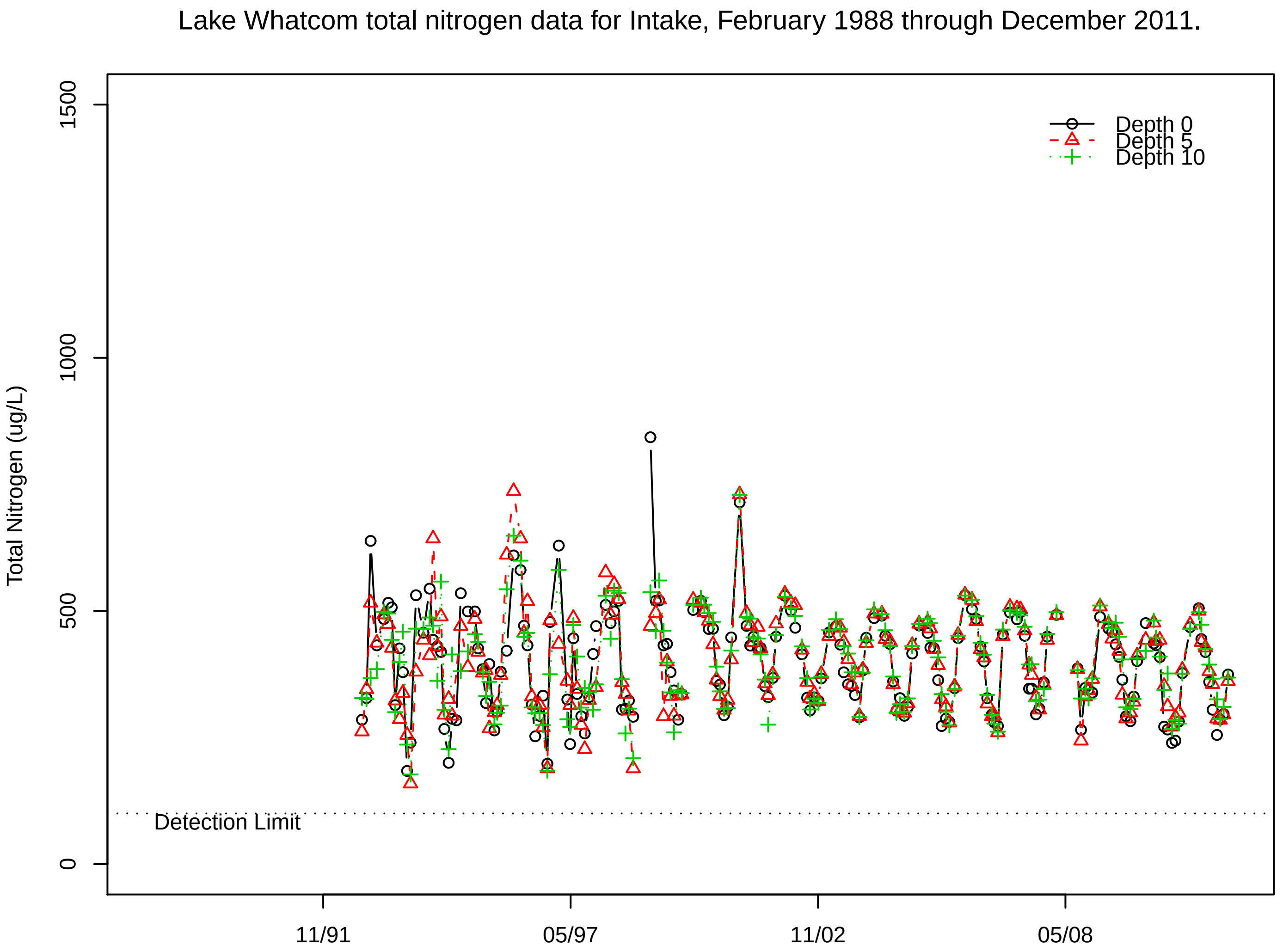


Figure B92: Lake Whatcom total nitrogen data for Site 2.

Figure B93: Lake Whatcom total nitrogen data for the Intake site.



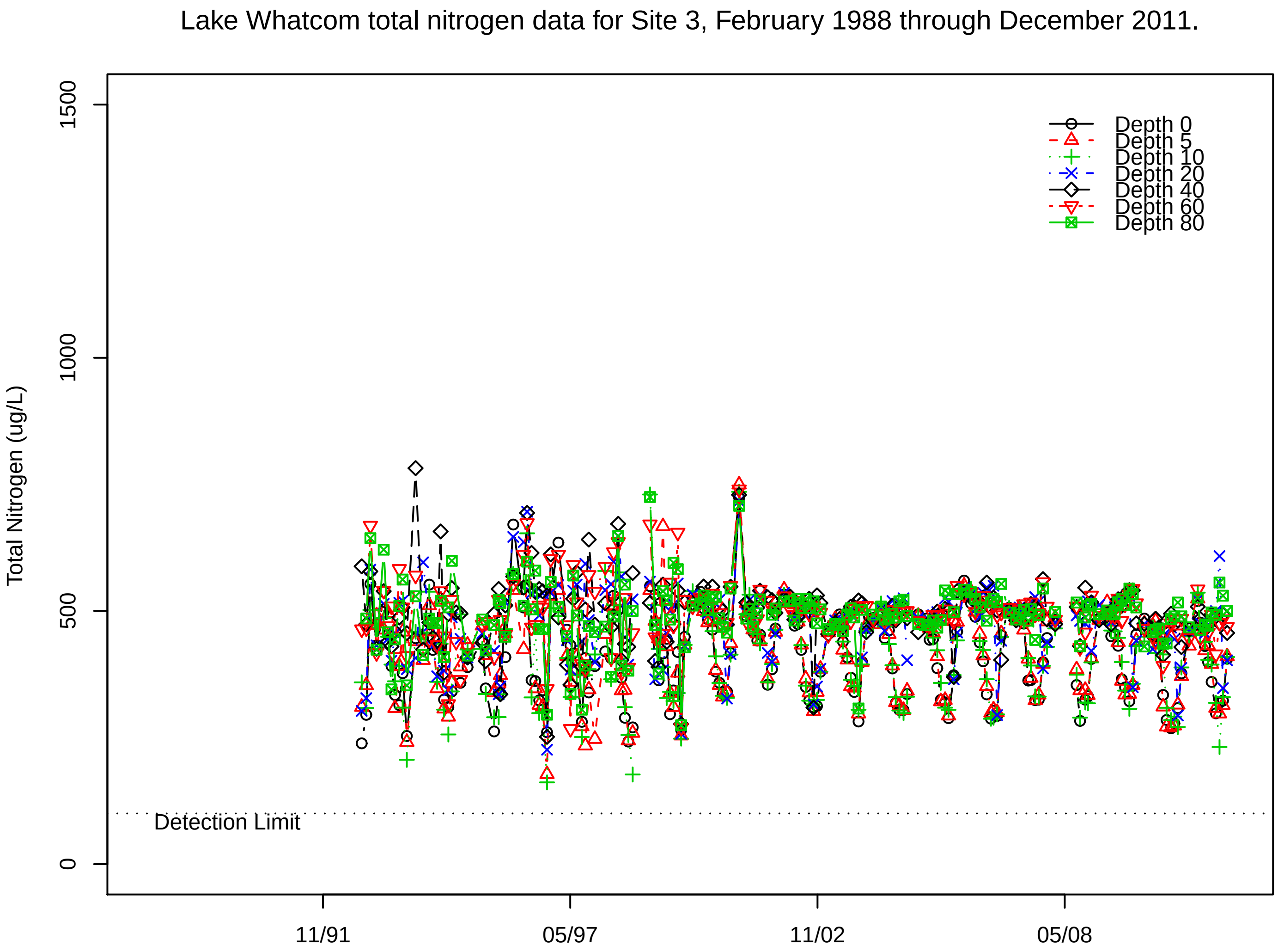


Figure B94: Lake Whatcom total nitrogen data for Site 3.

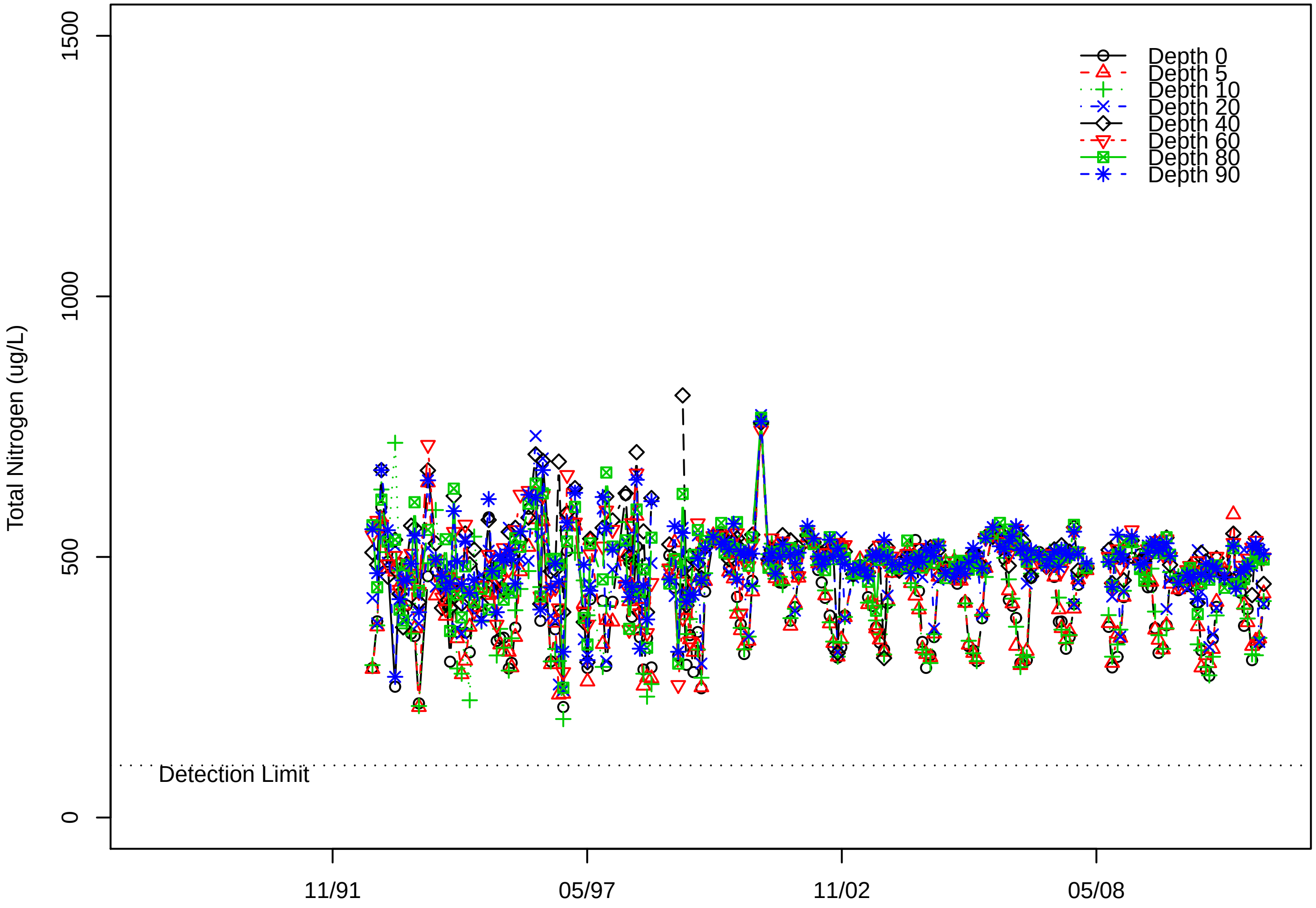

Lake Whatcom total nitrogen data for Site 4, February 1988 through December 2011.

Figure B95: Lake Whatcom total nitrogen data for Site 4.

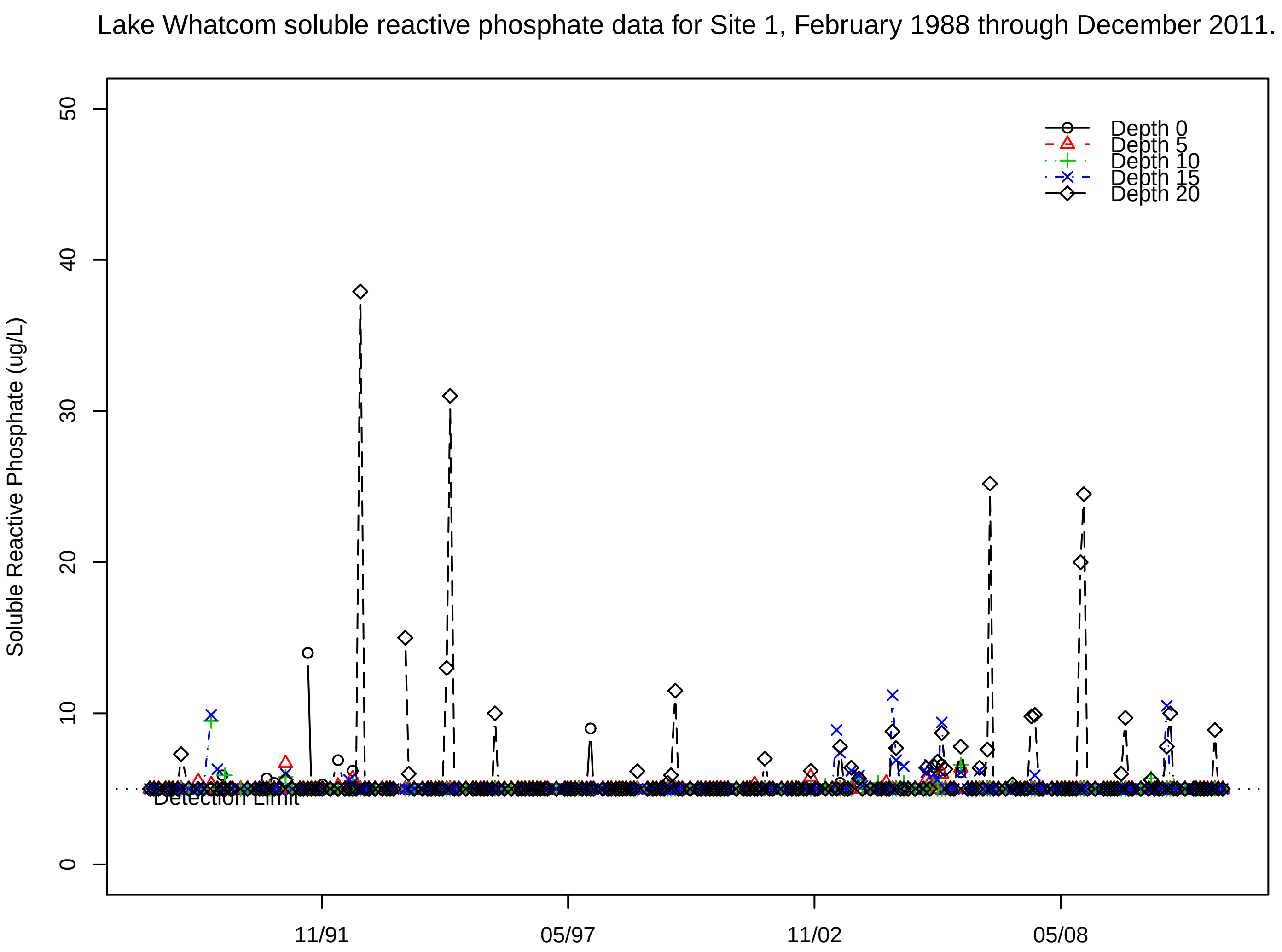
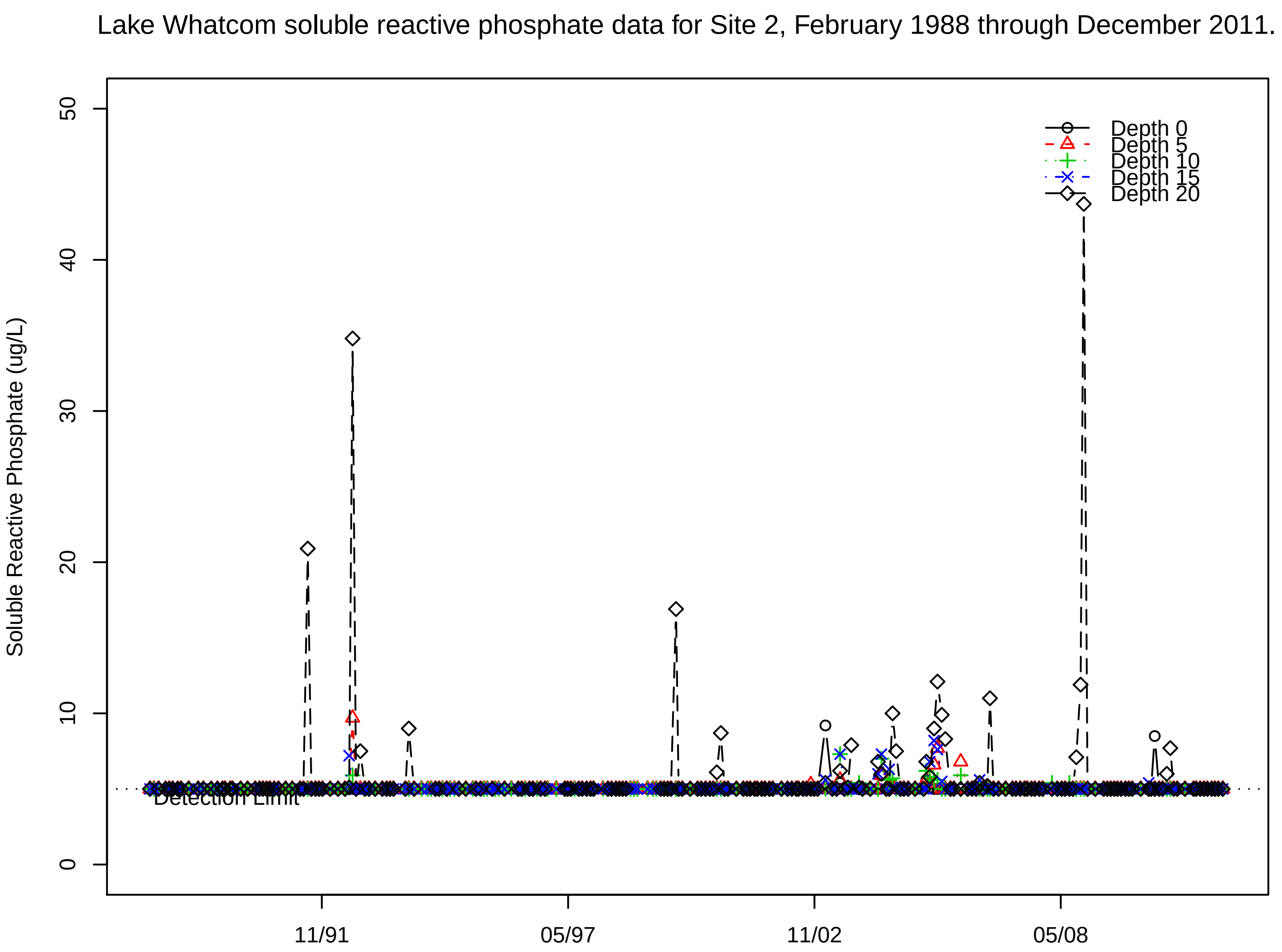


Figure B96: Lake Whatcom soluble phosphate data for Site 1.



Lake Whatcom soluble reactive phosphate data for Site 2, February 1988 through December 2011.

Figure B97: Lake Whatcom soluble phosphate data for Site 2.

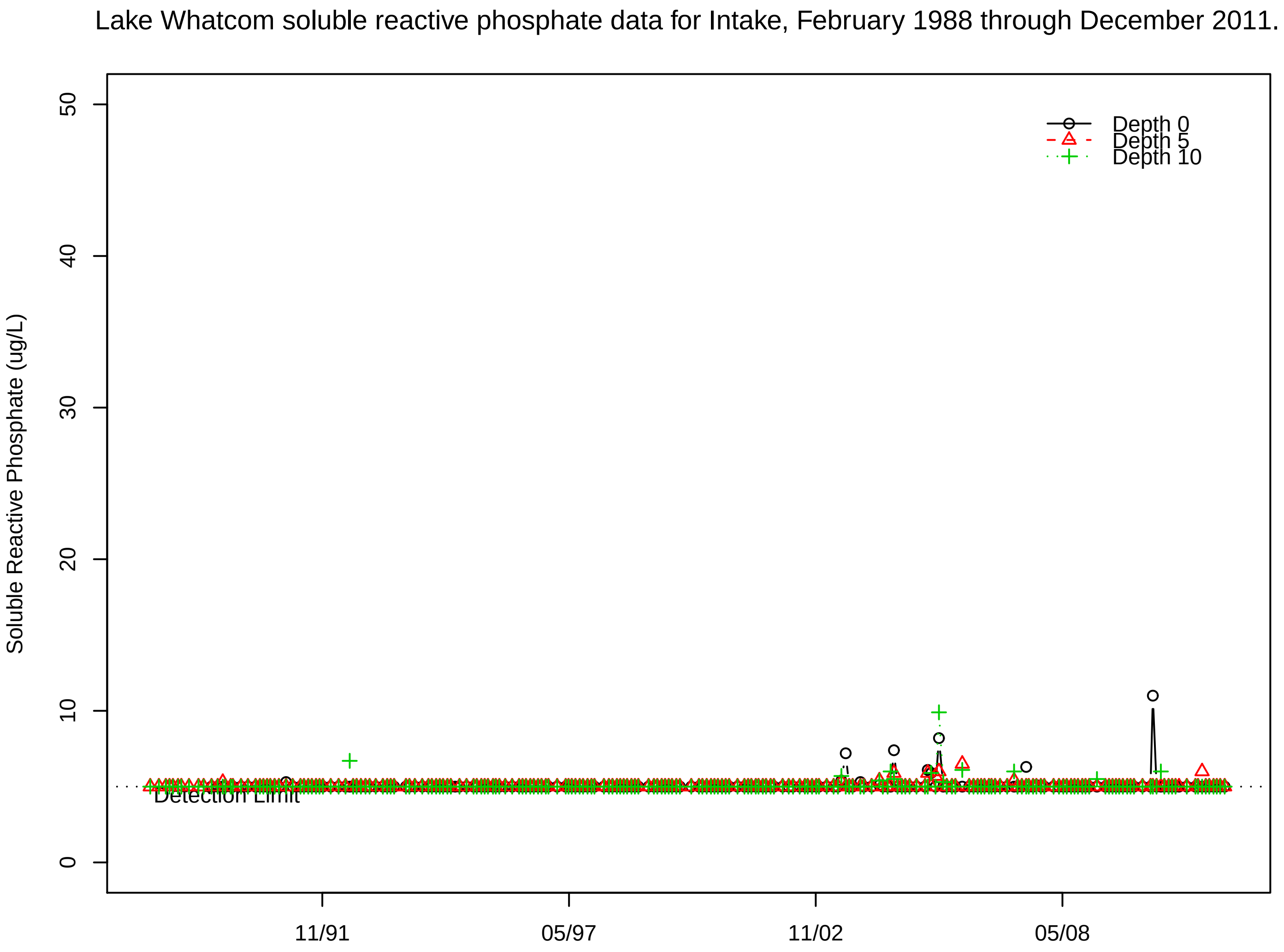


Figure B98: Lake Whatcom soluble phosphate data for the Intake site.

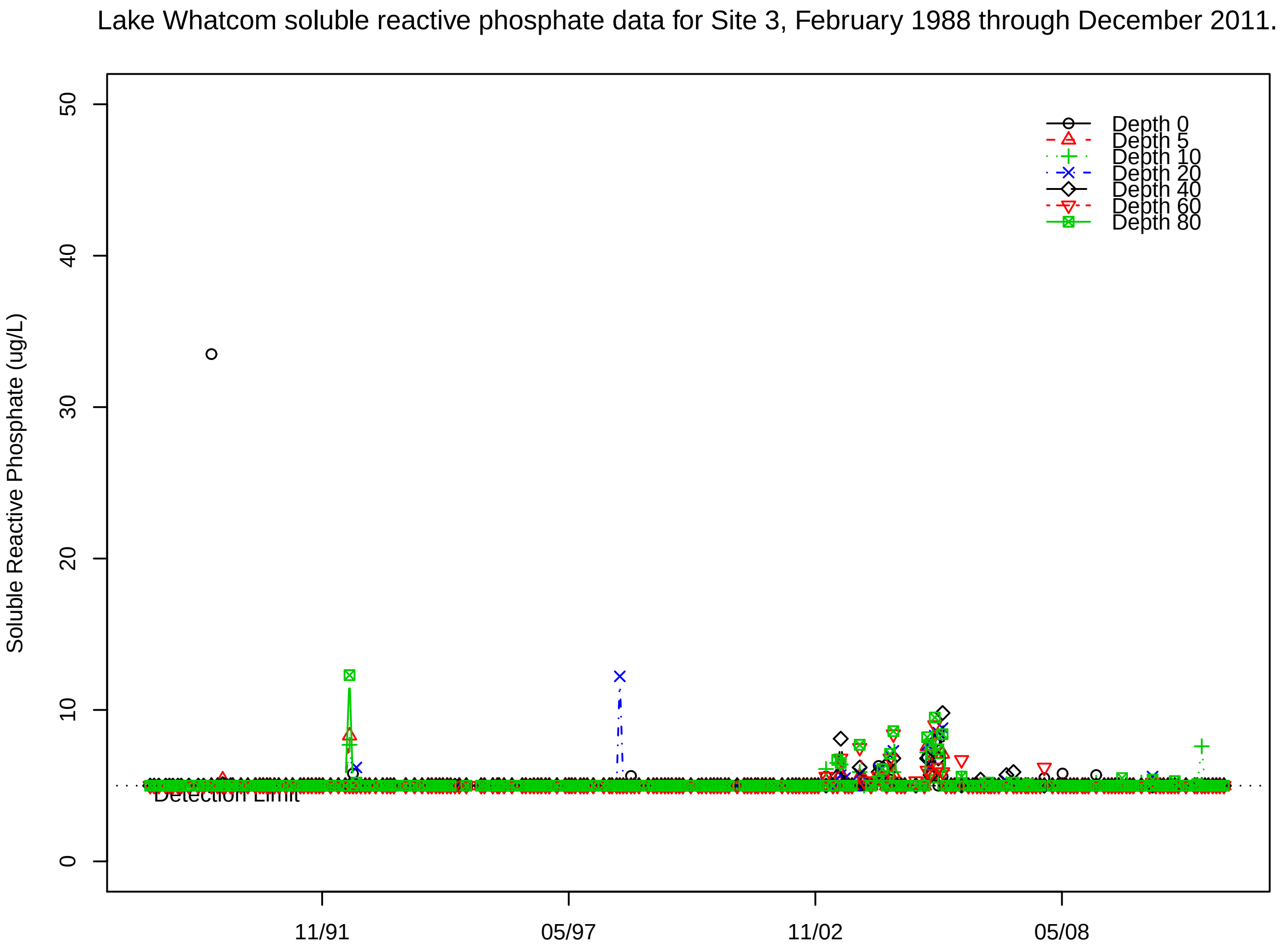
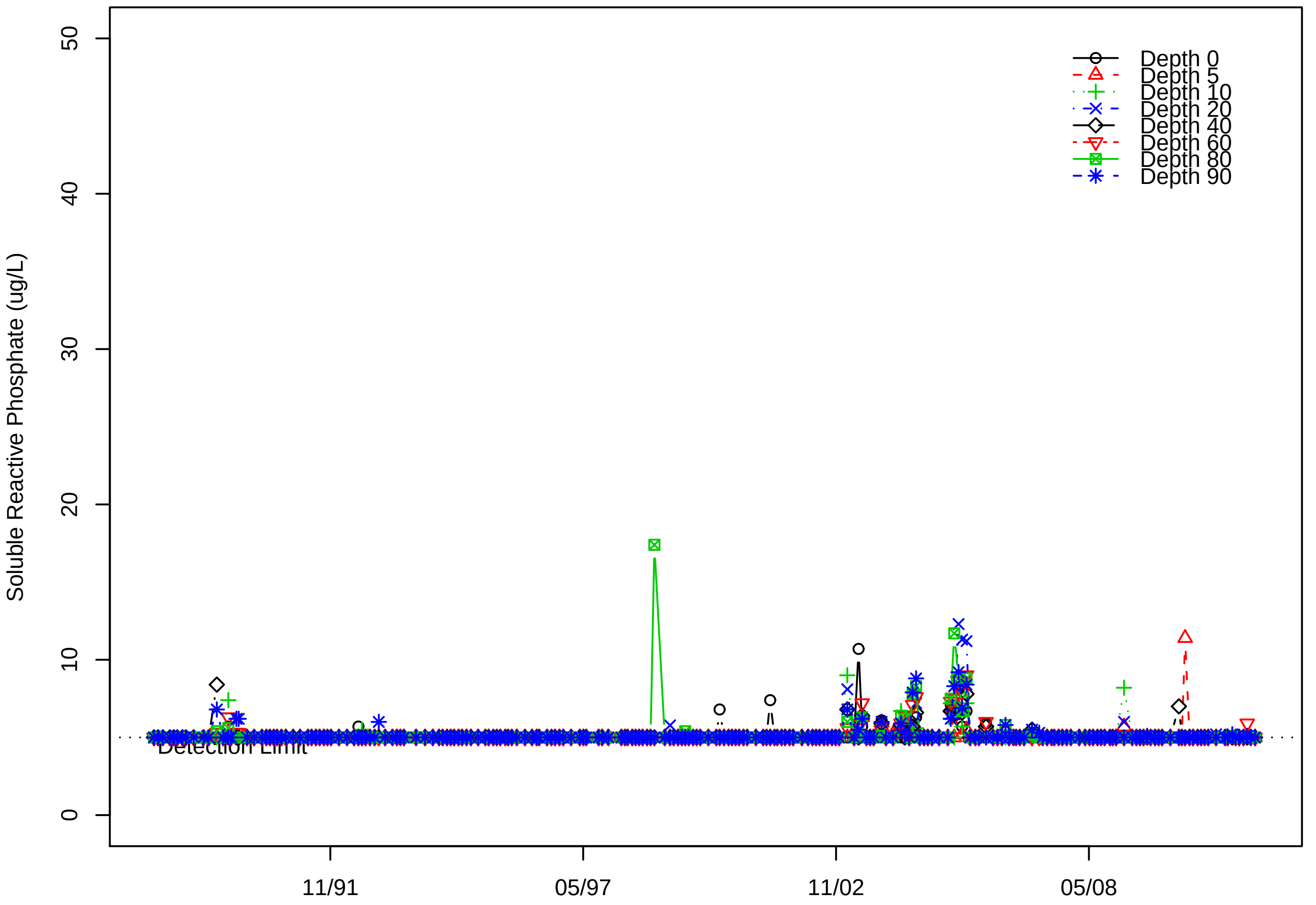


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

Figure B100: Lake Whatcom soluble phosphate data for Site 4.

Lake Whatcom soluble reactive phosphate data for Site 4, February 1988 through December 2011.



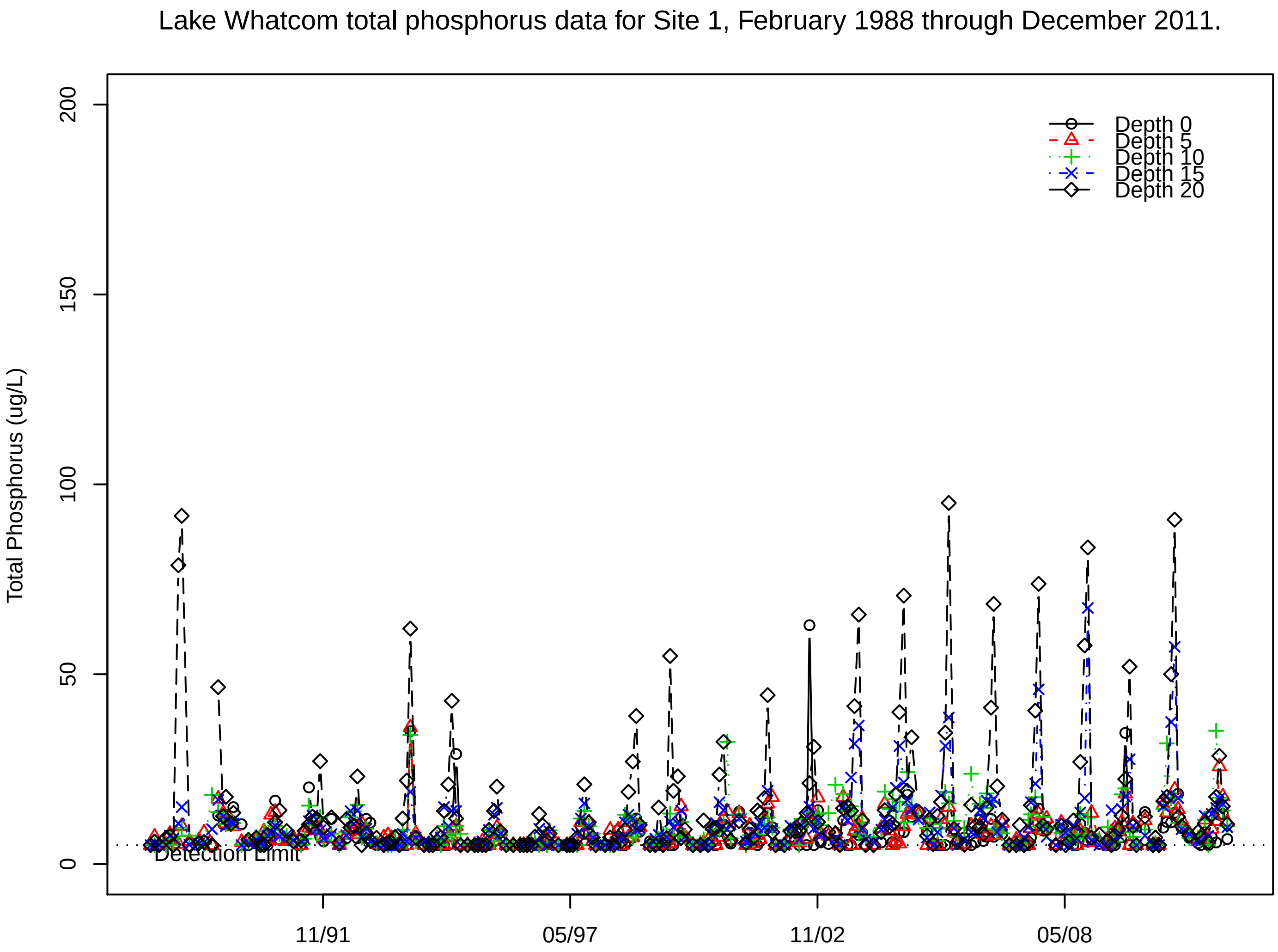


Figure B101: Lake Whatcom total phosphorus data for Site 1.

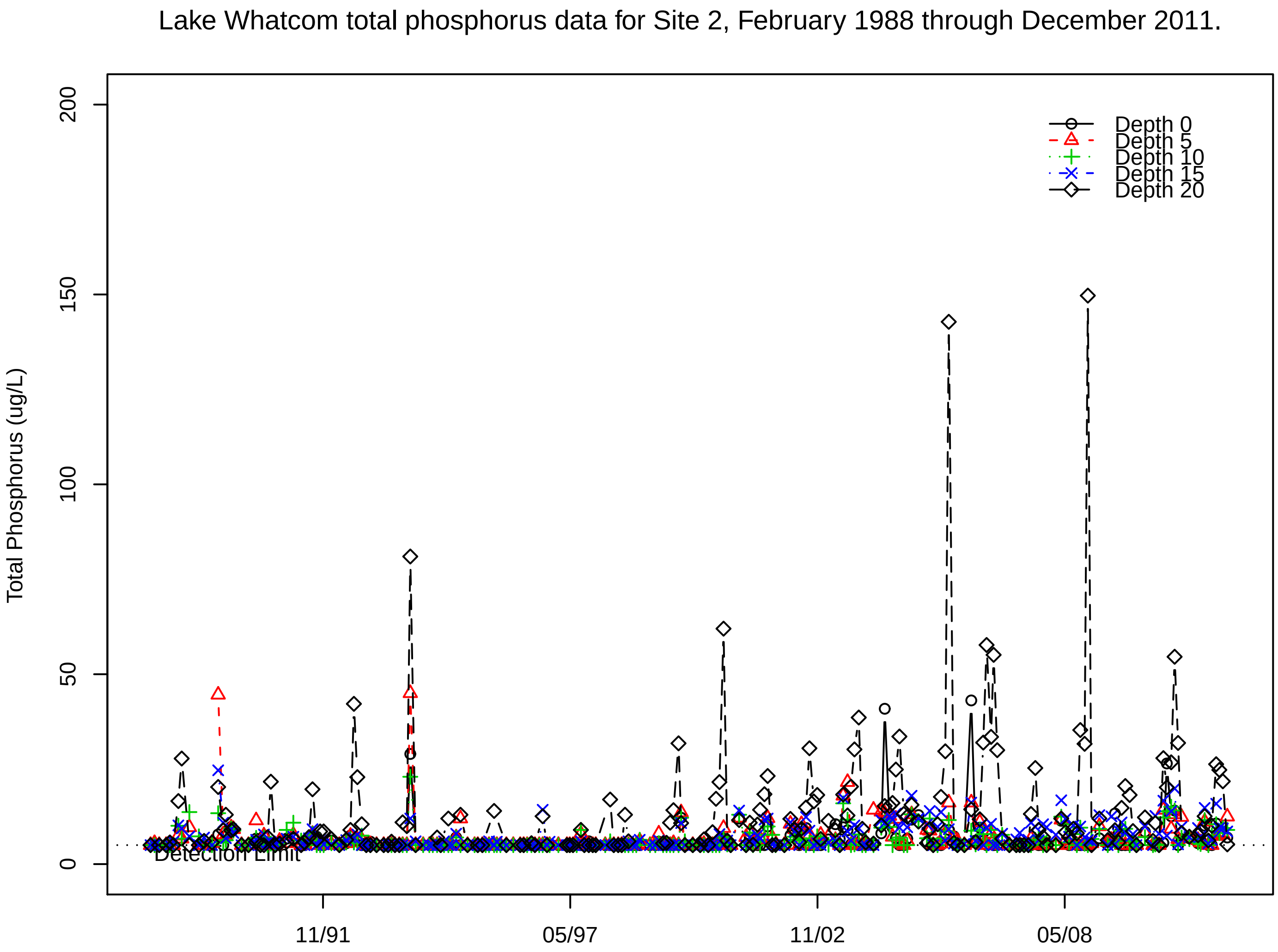


Figure B102: Lake Whatcom total phosphorus data for Site 2.

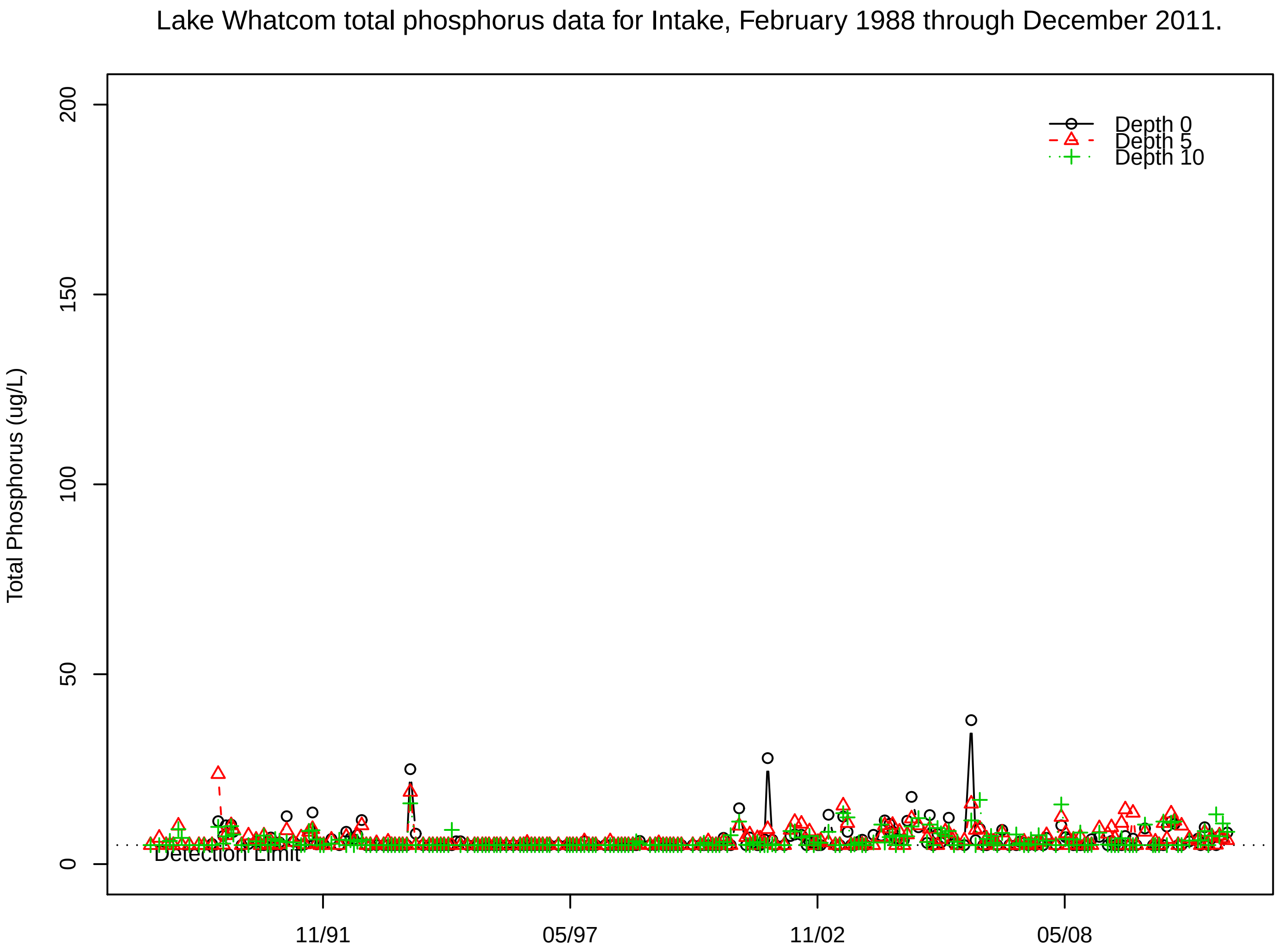


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

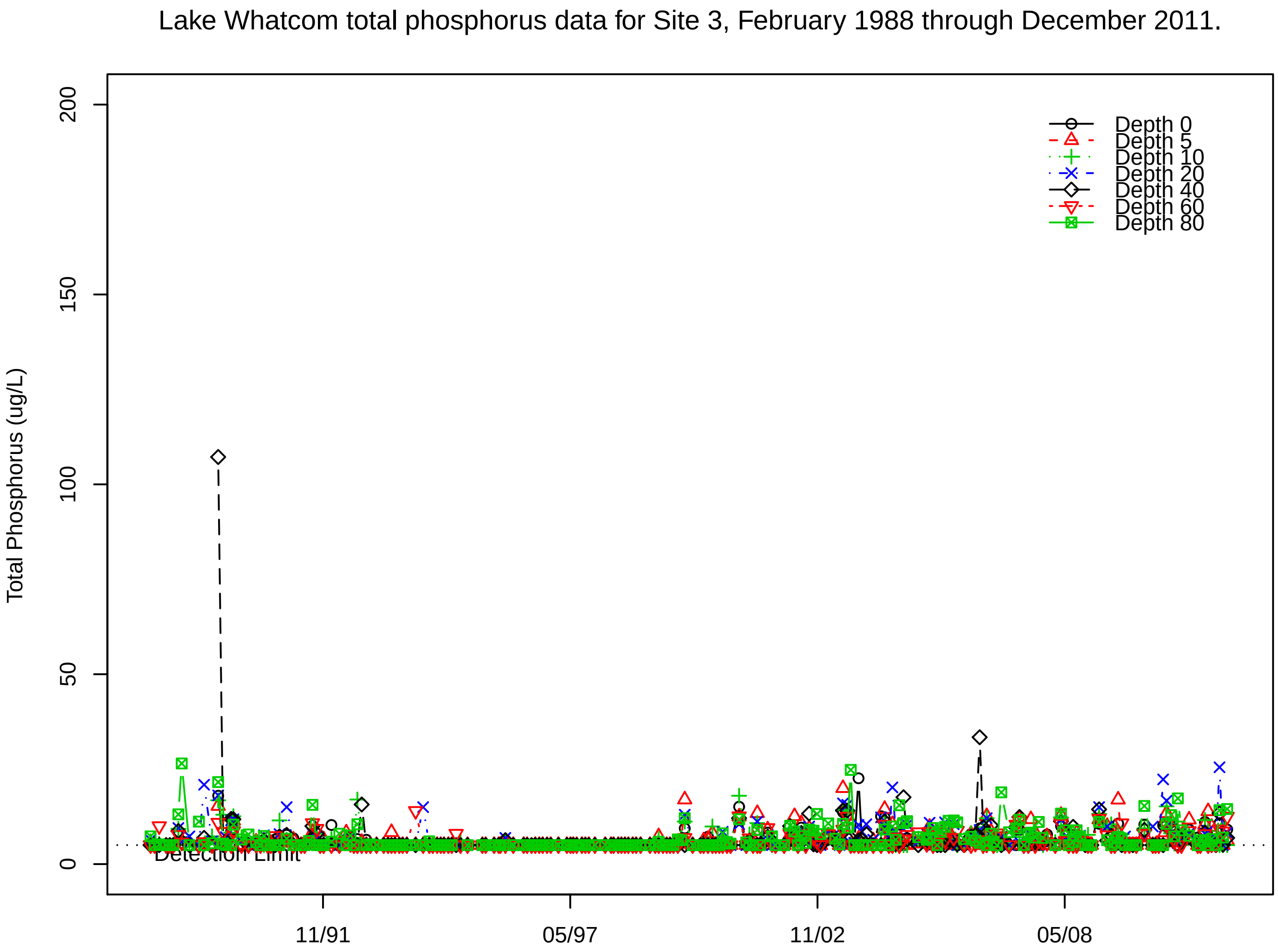


Figure B104: Lake Whatcom total phosphorus data for Site 3.

Lake Whatcom total phosphorus data for Site 4, February 1988 through December 2011.

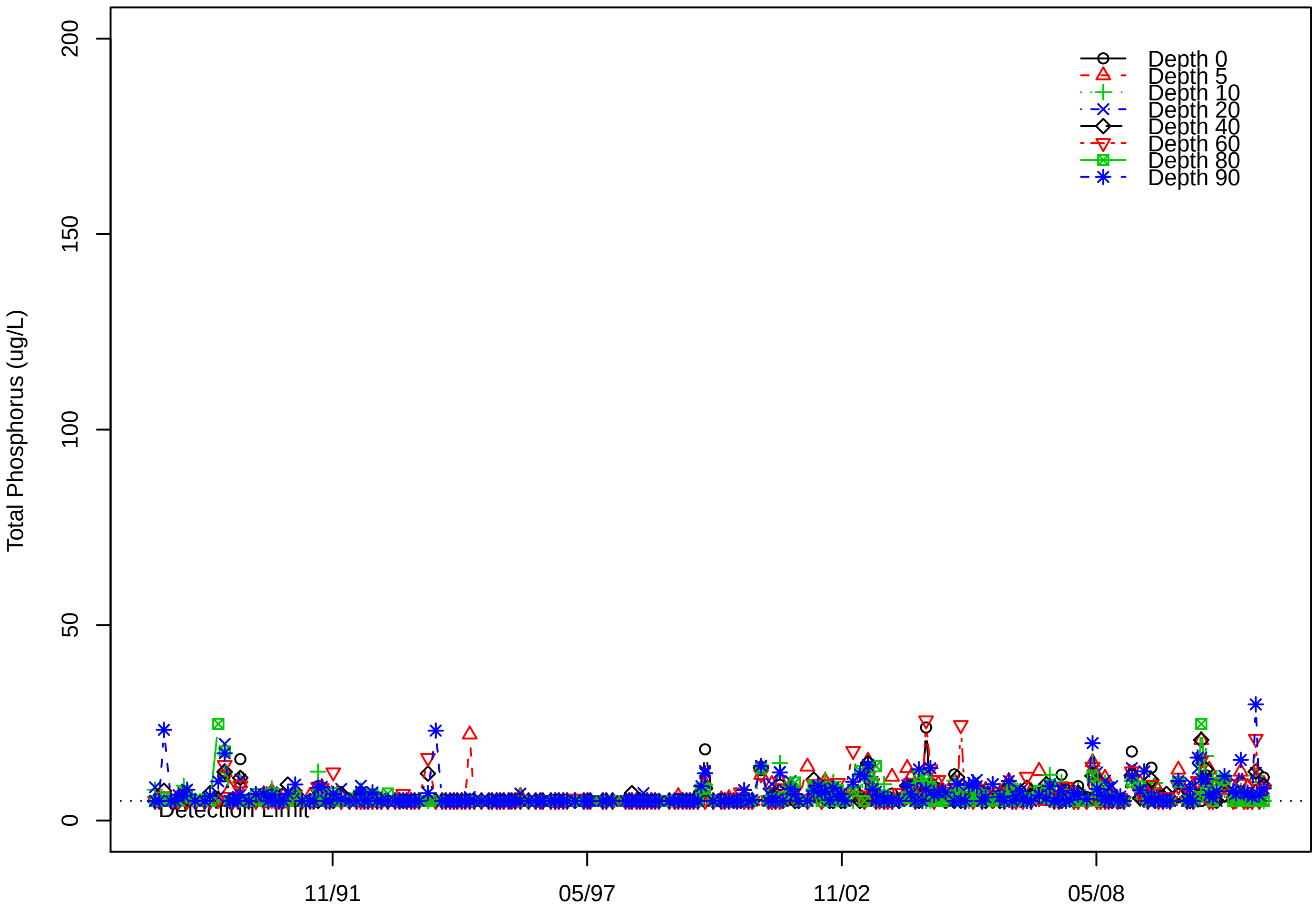


Figure B105: Lake Whatcom total phosphorus data for Site 4.

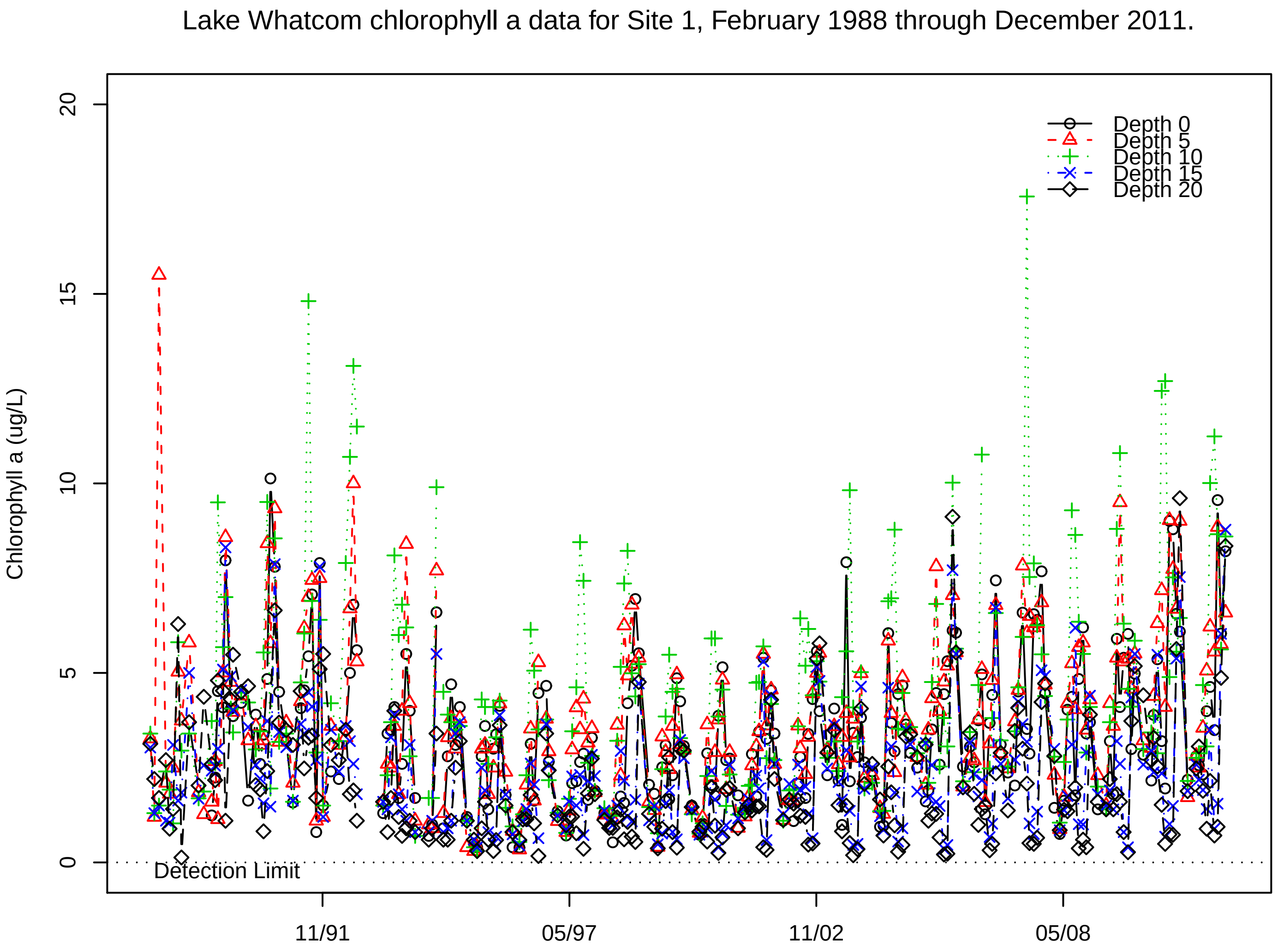


Figure B106: Lake Whatcom chlorophyll data for Site 1.

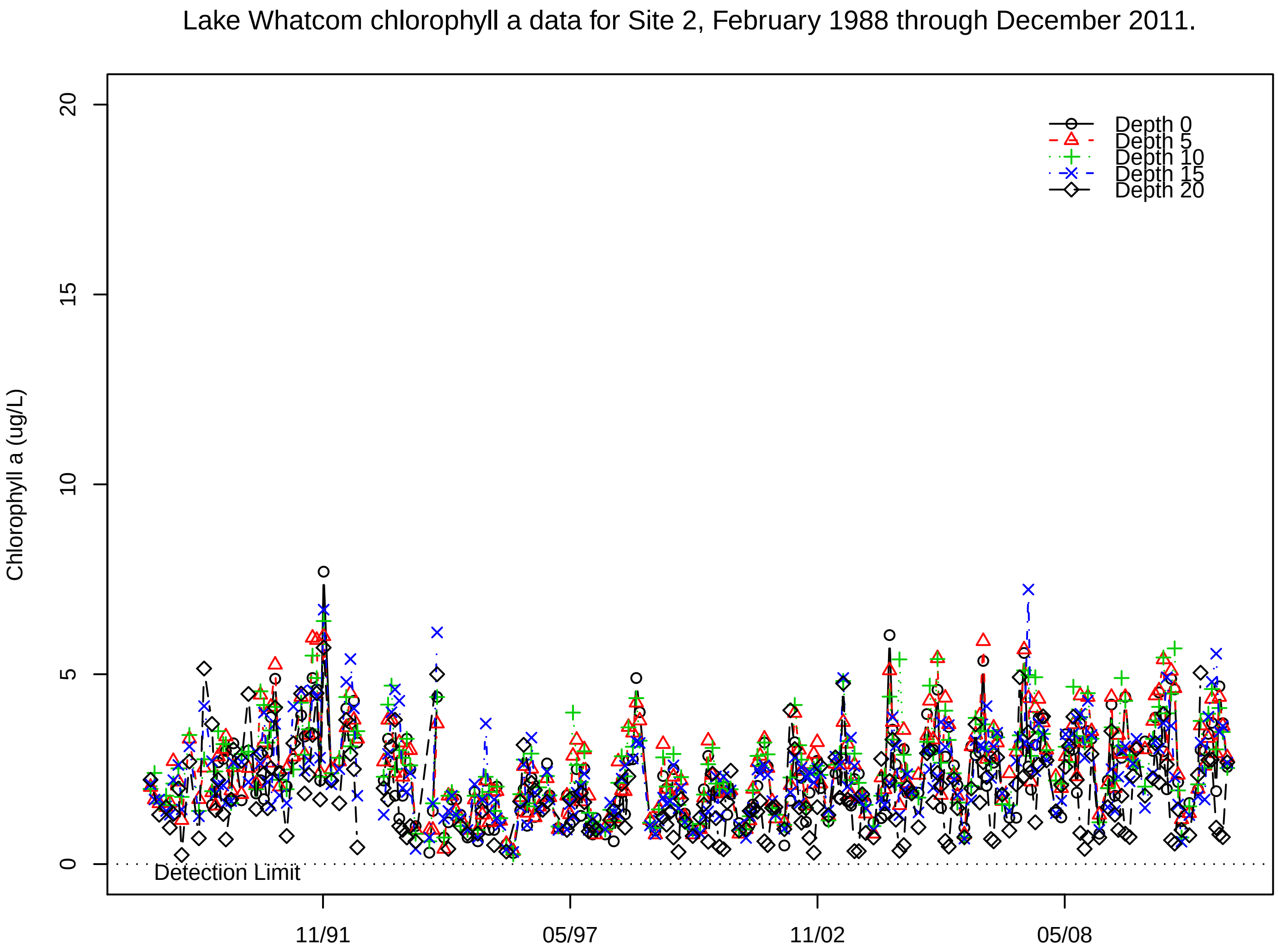


Figure B107: Lake Whatcom chlorophyll data for Site 2.

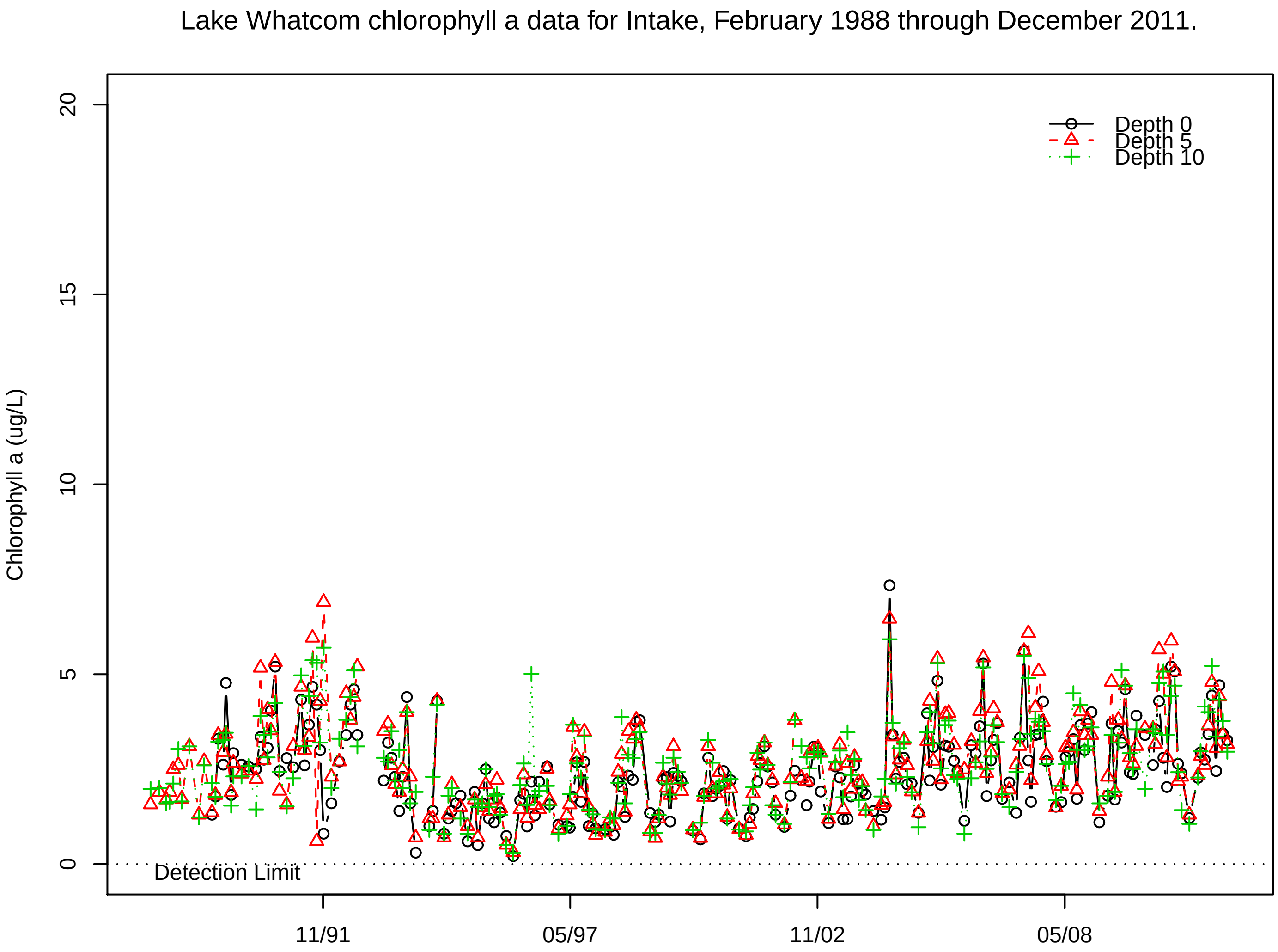


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

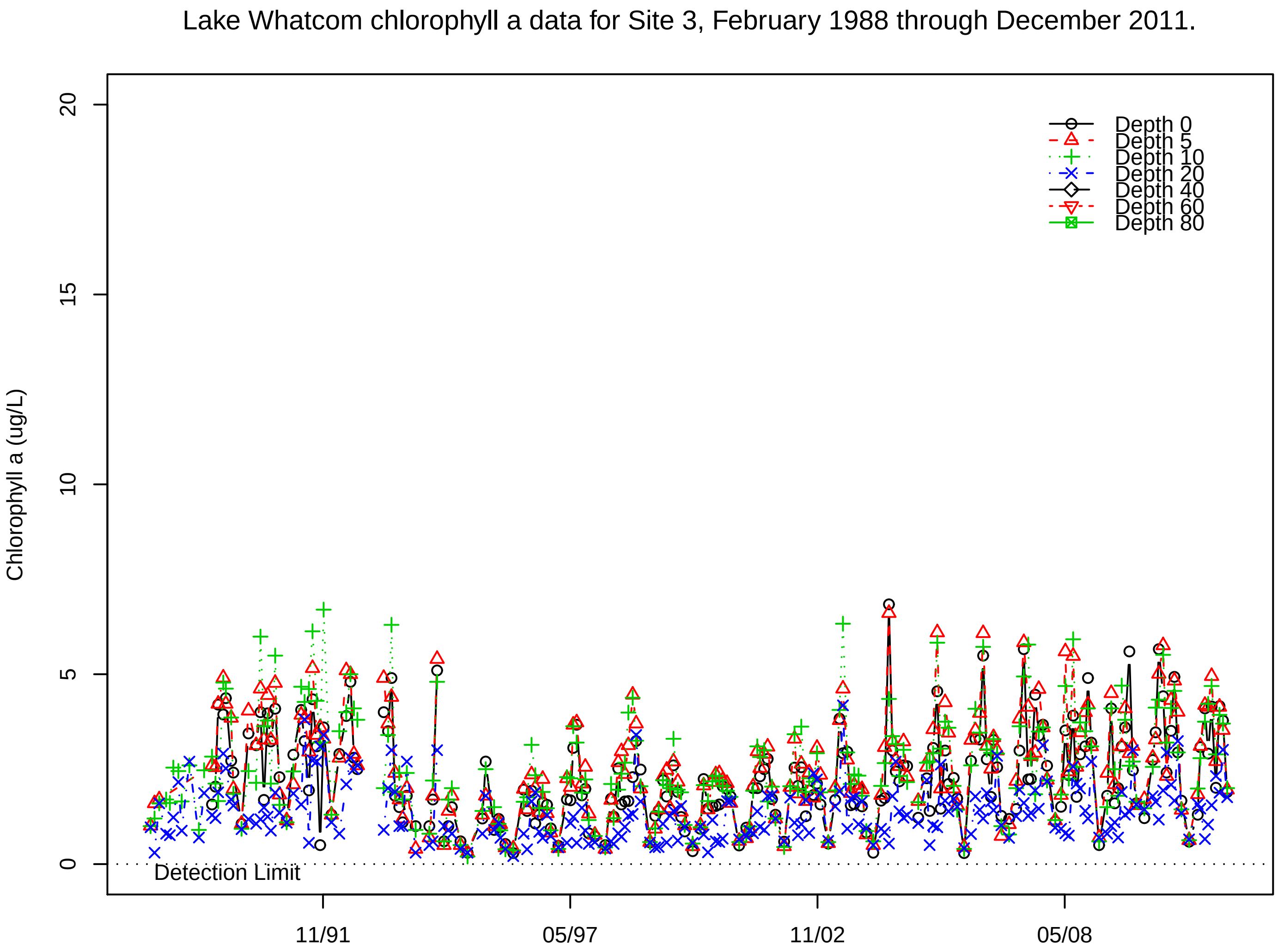
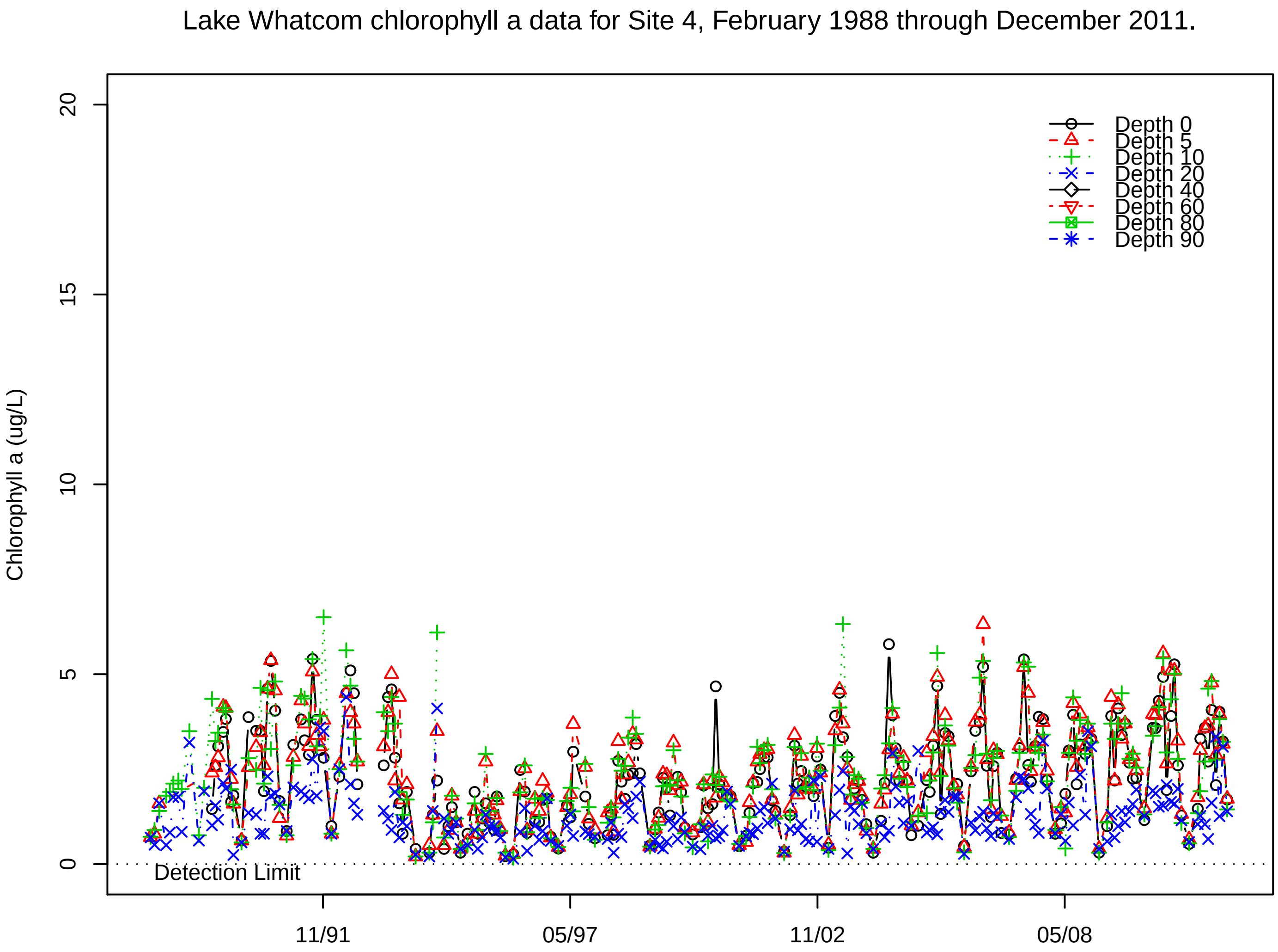


Figure B109: Lake Whatcom chlorophyll data for Site 3.

Figure B110: Lake Whatcom chlorophyll data for Site 4.



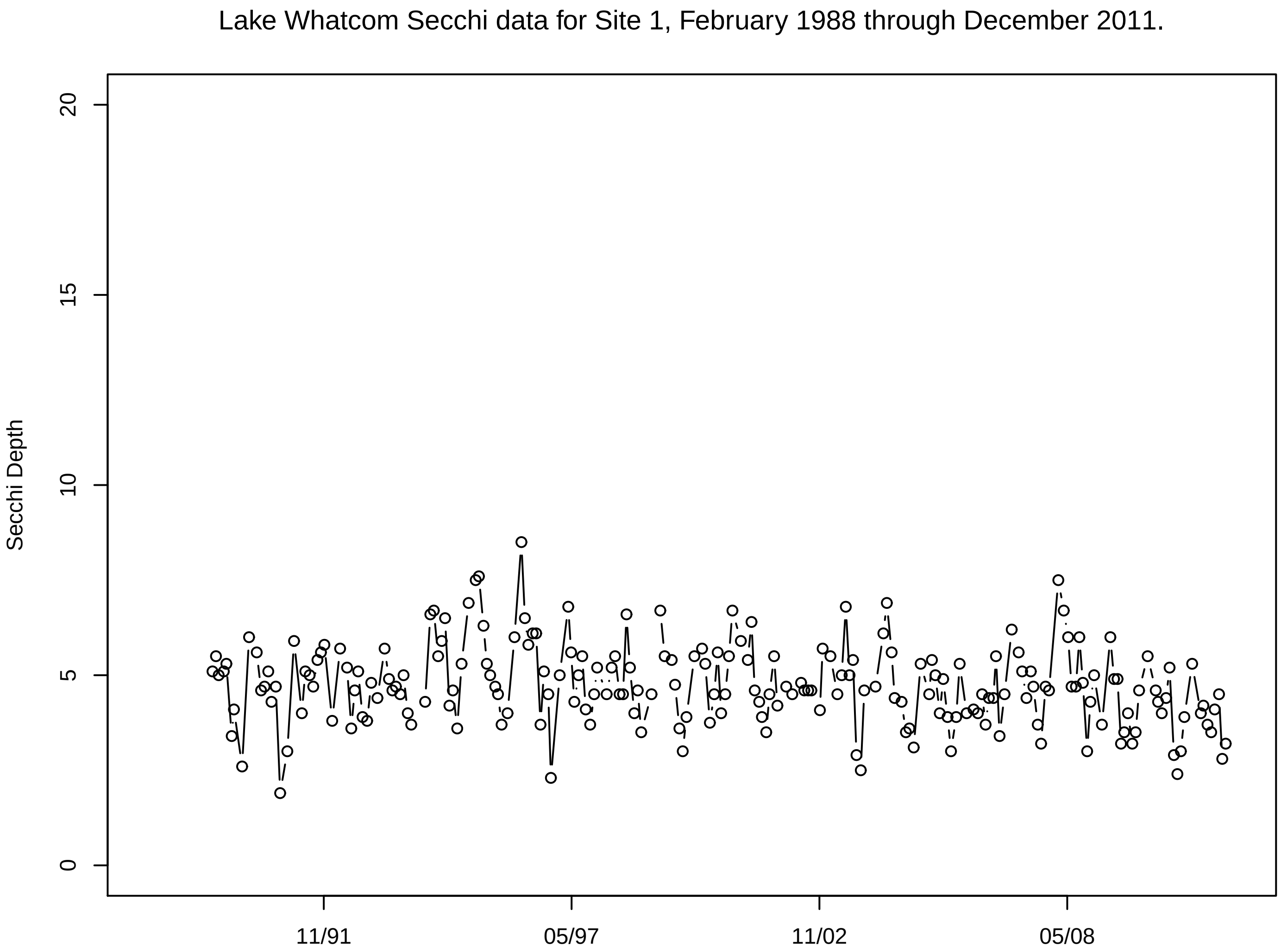


Figure B111: Lake Whatcom Secchi depths for Site 1.

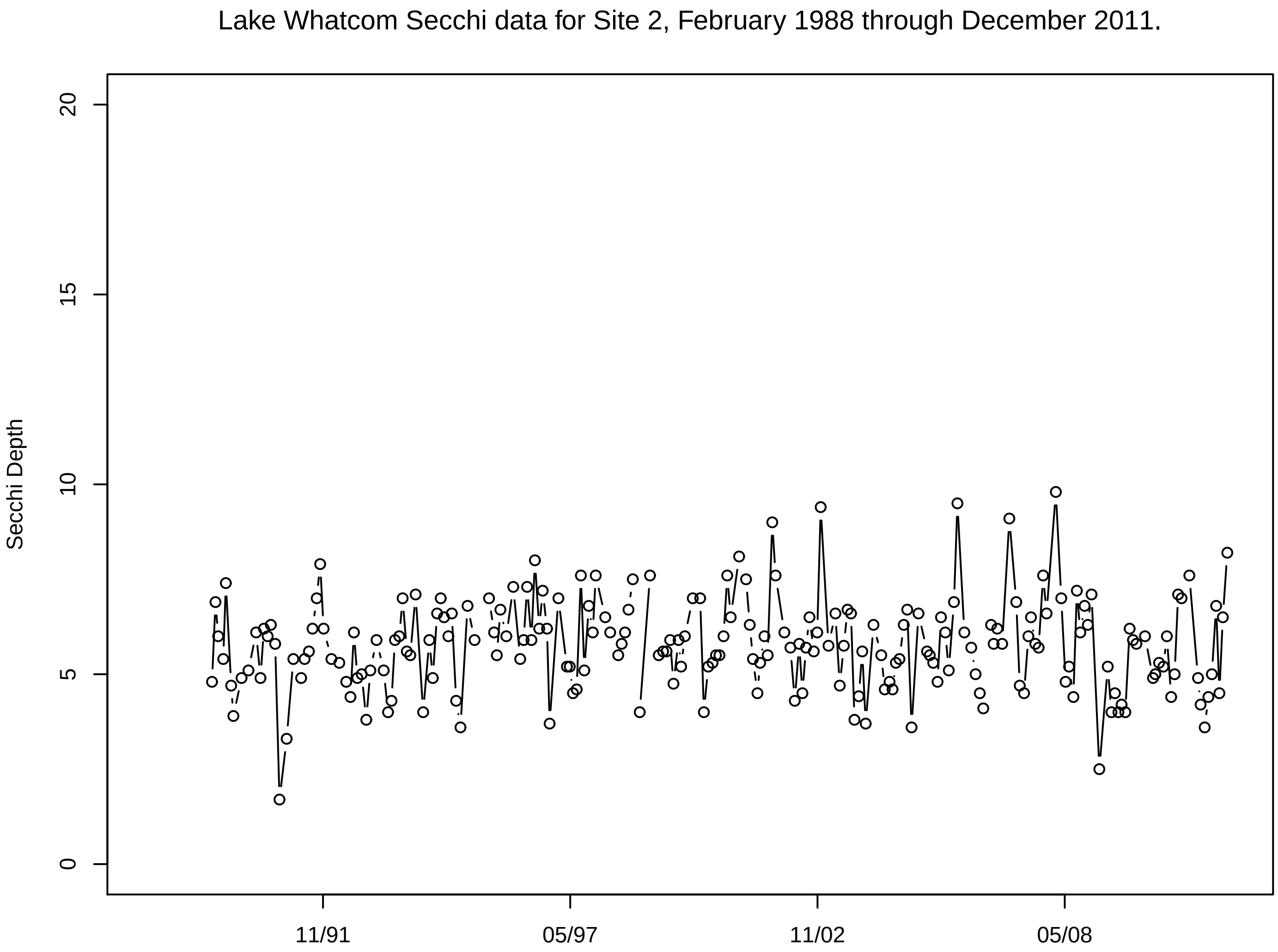


Figure B112: Lake Whatcom Secchi depths for Site 2.

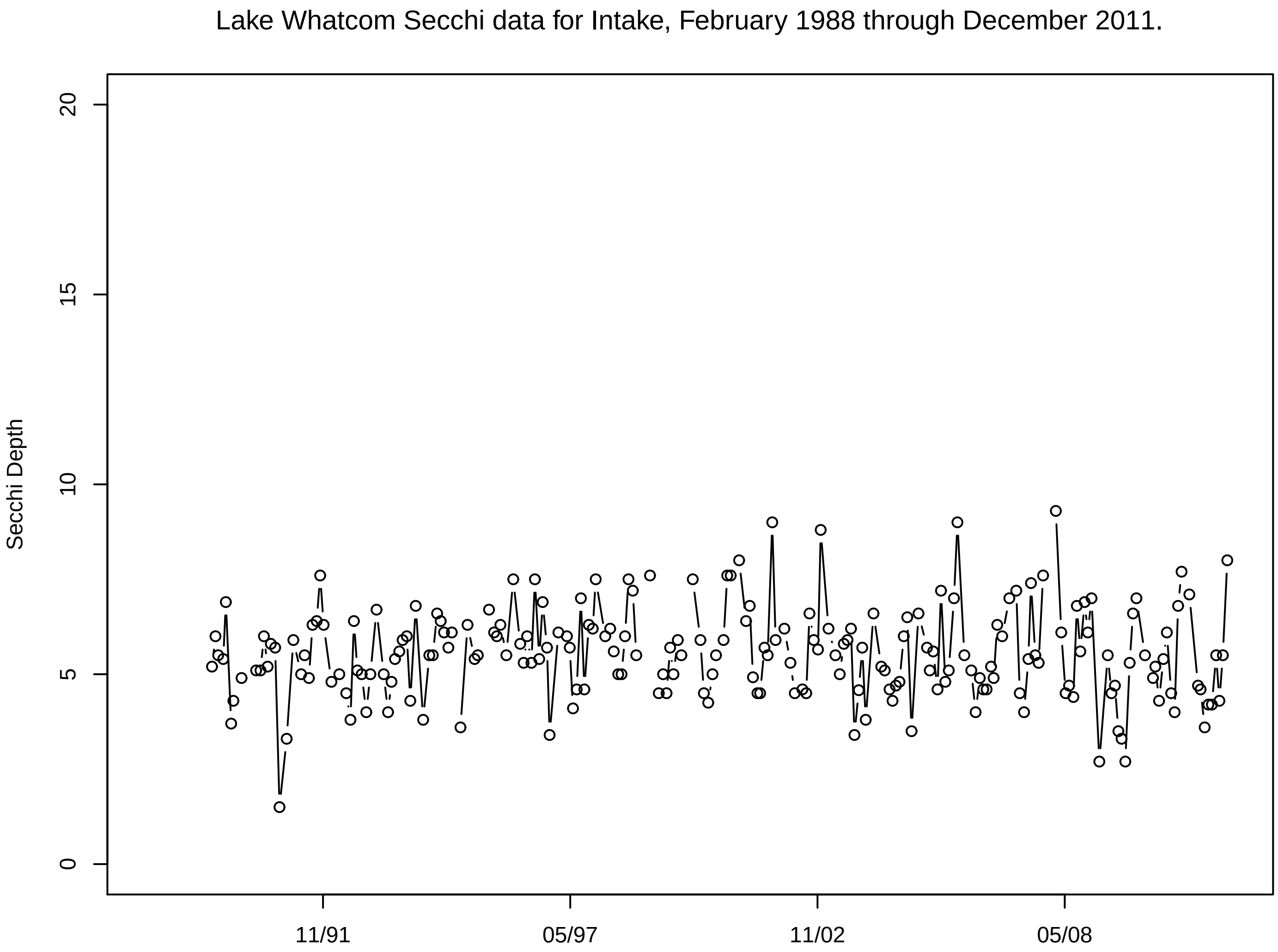


Figure B113: Lake Whatcom Secchi depths for the Intake site.

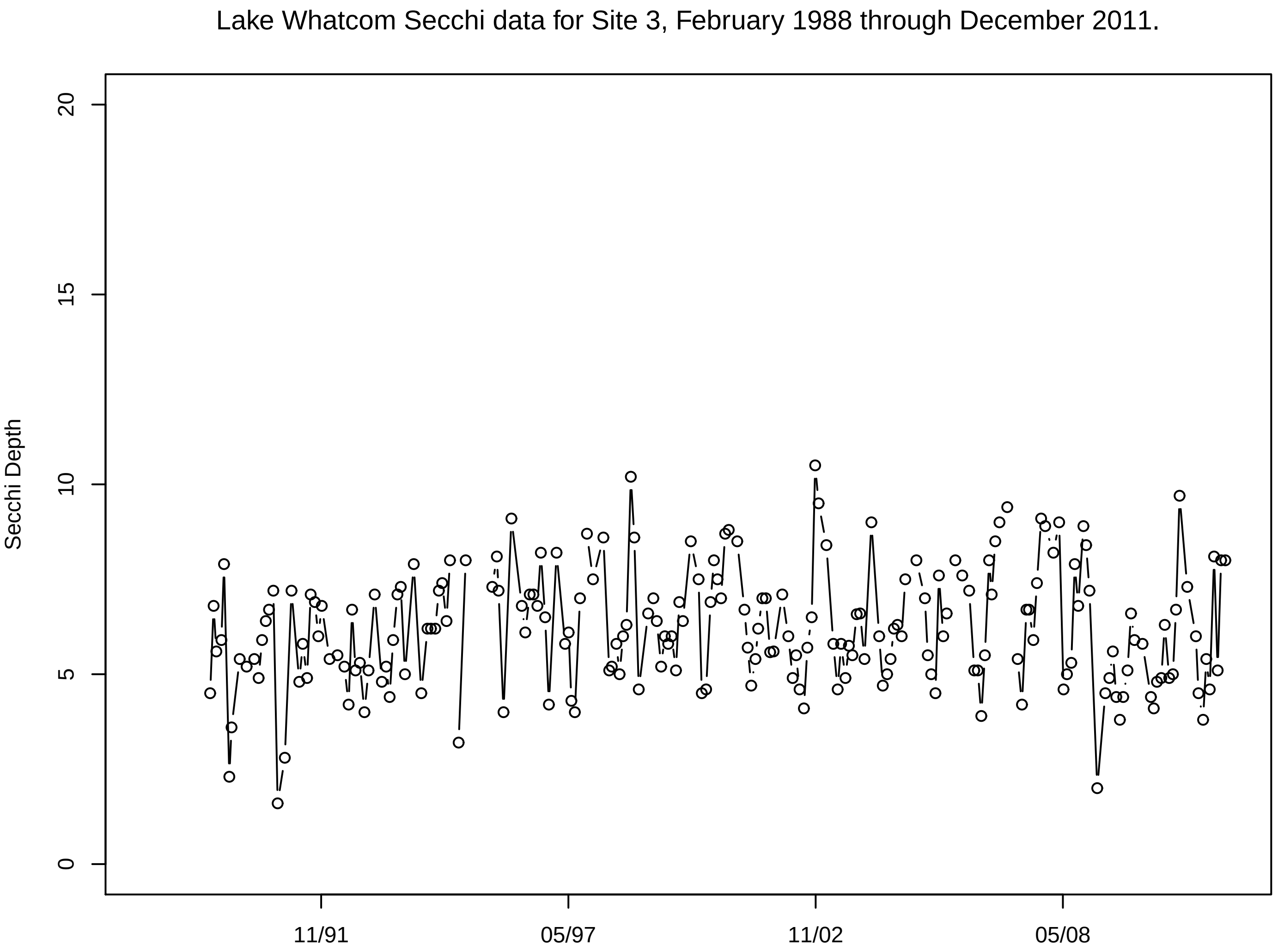


Figure B114: Lake Whatcom Secchi depths for Site 3.

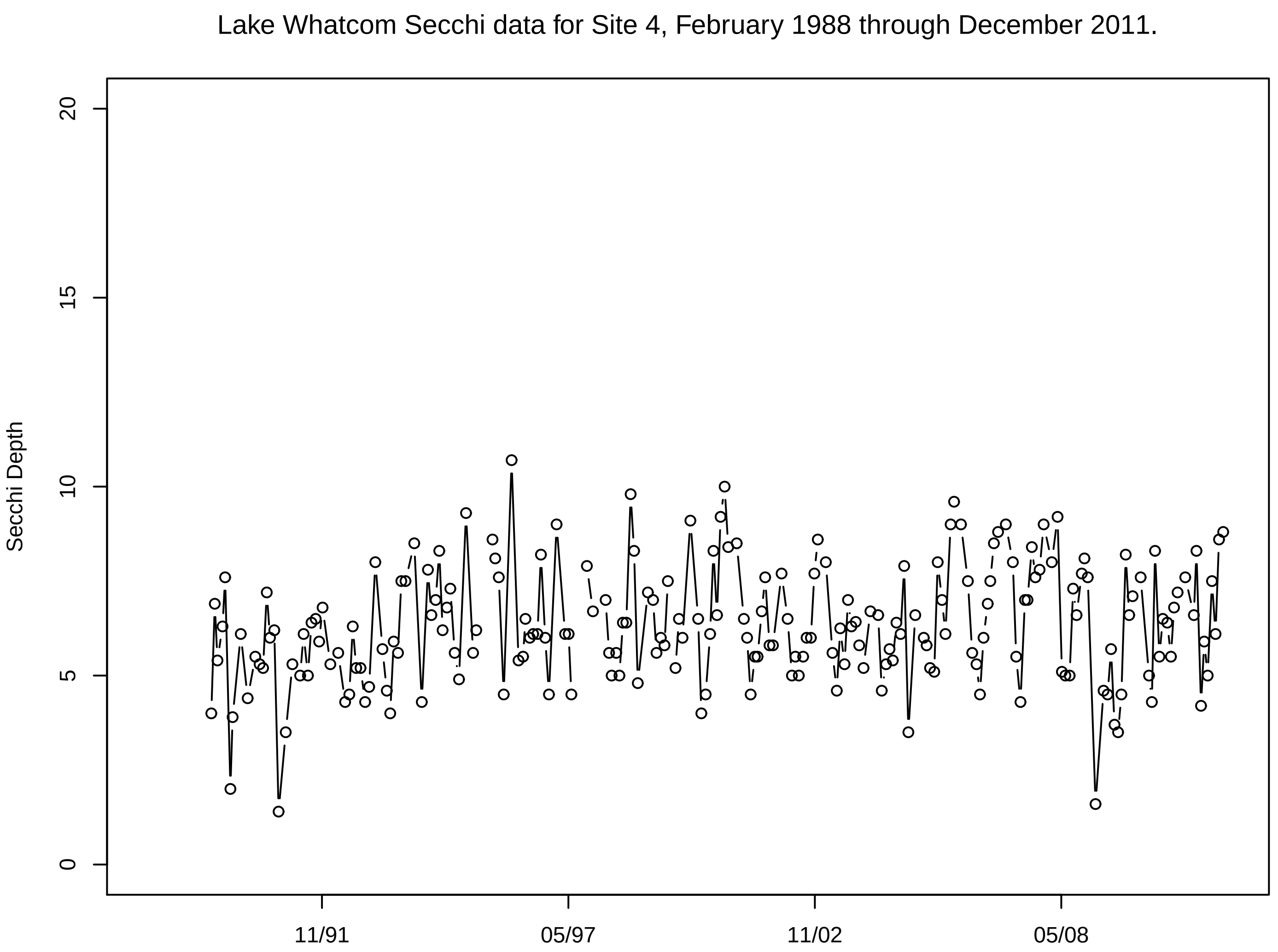


Figure B115: Lake Whatcom Secchi depths for Site 4.

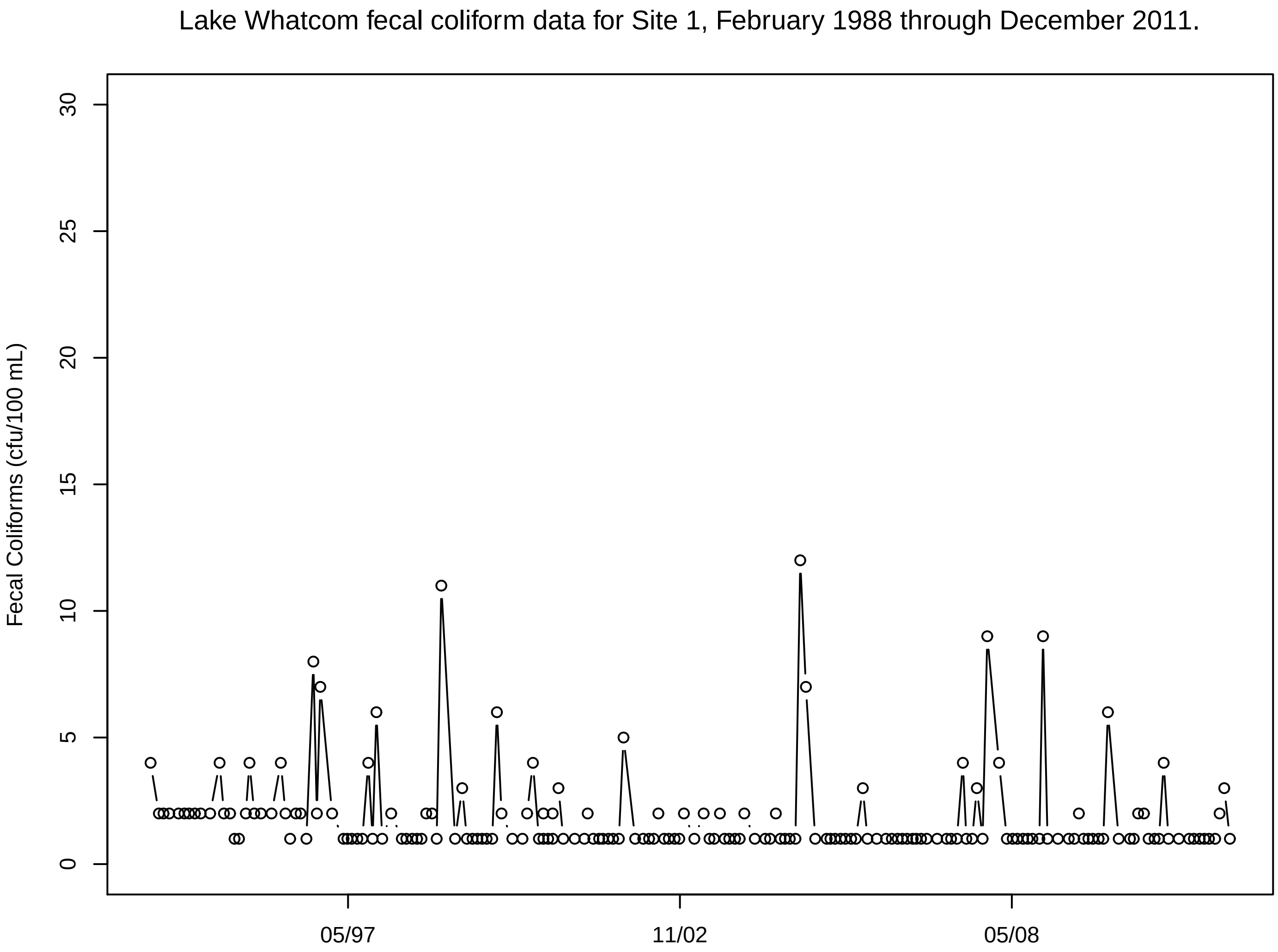


Figure B116: Lake Whatcom fecal coliform data for Site 1.

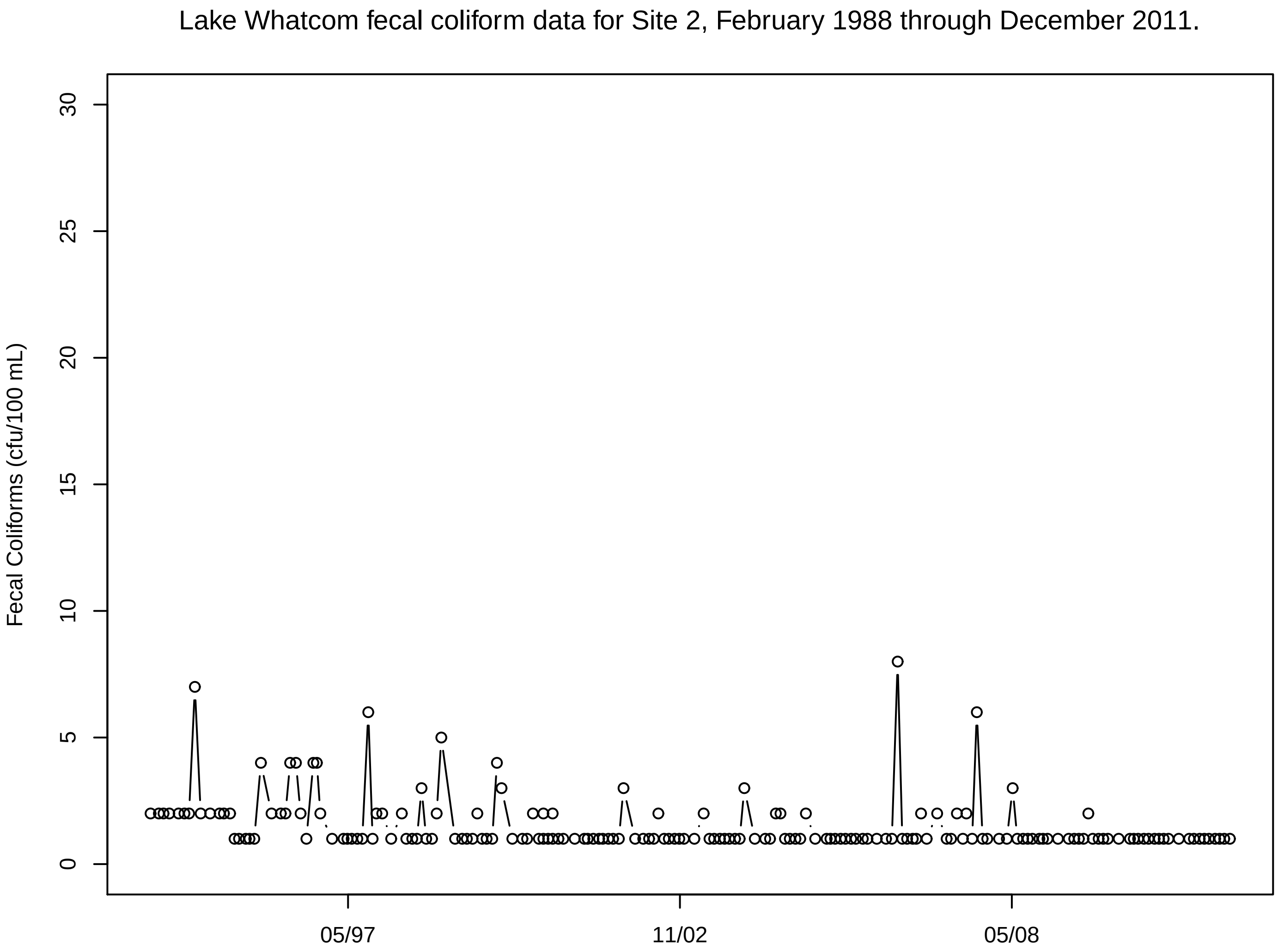


Figure B117: Lake Whatcom fecal coliform data for Site 2.

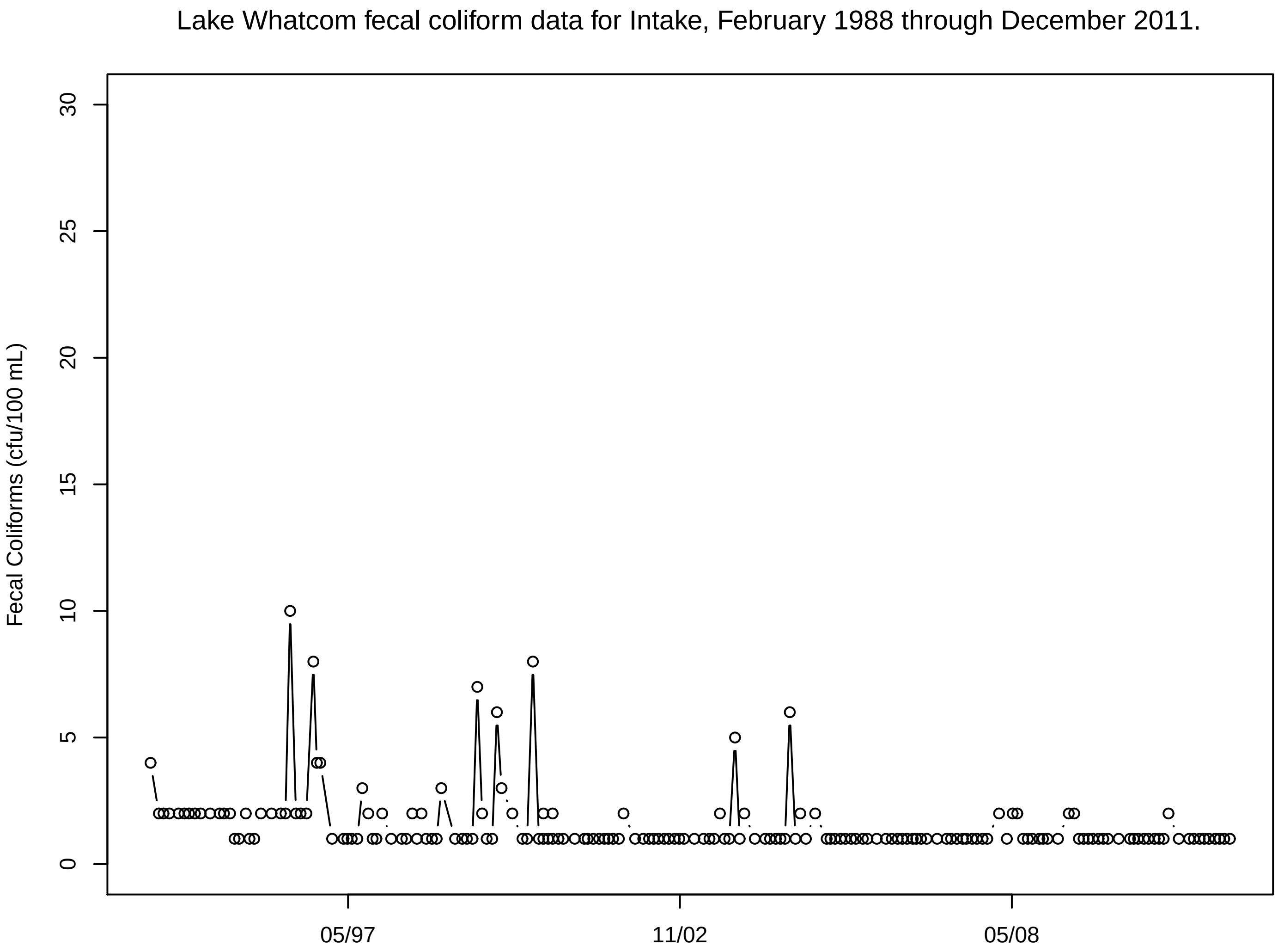


Figure B118: Lake Whatcom fecal coliform data for the Intake site.

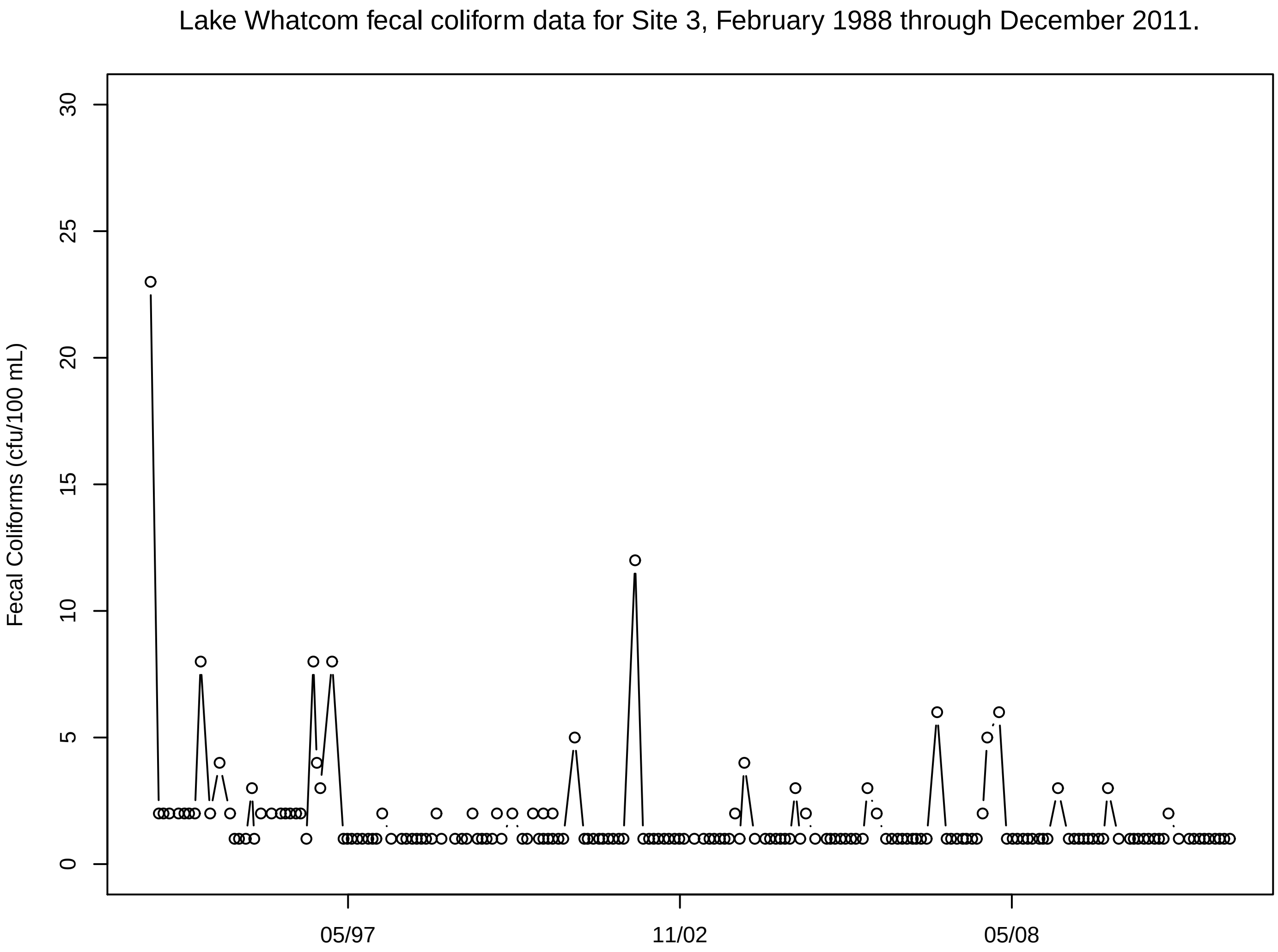
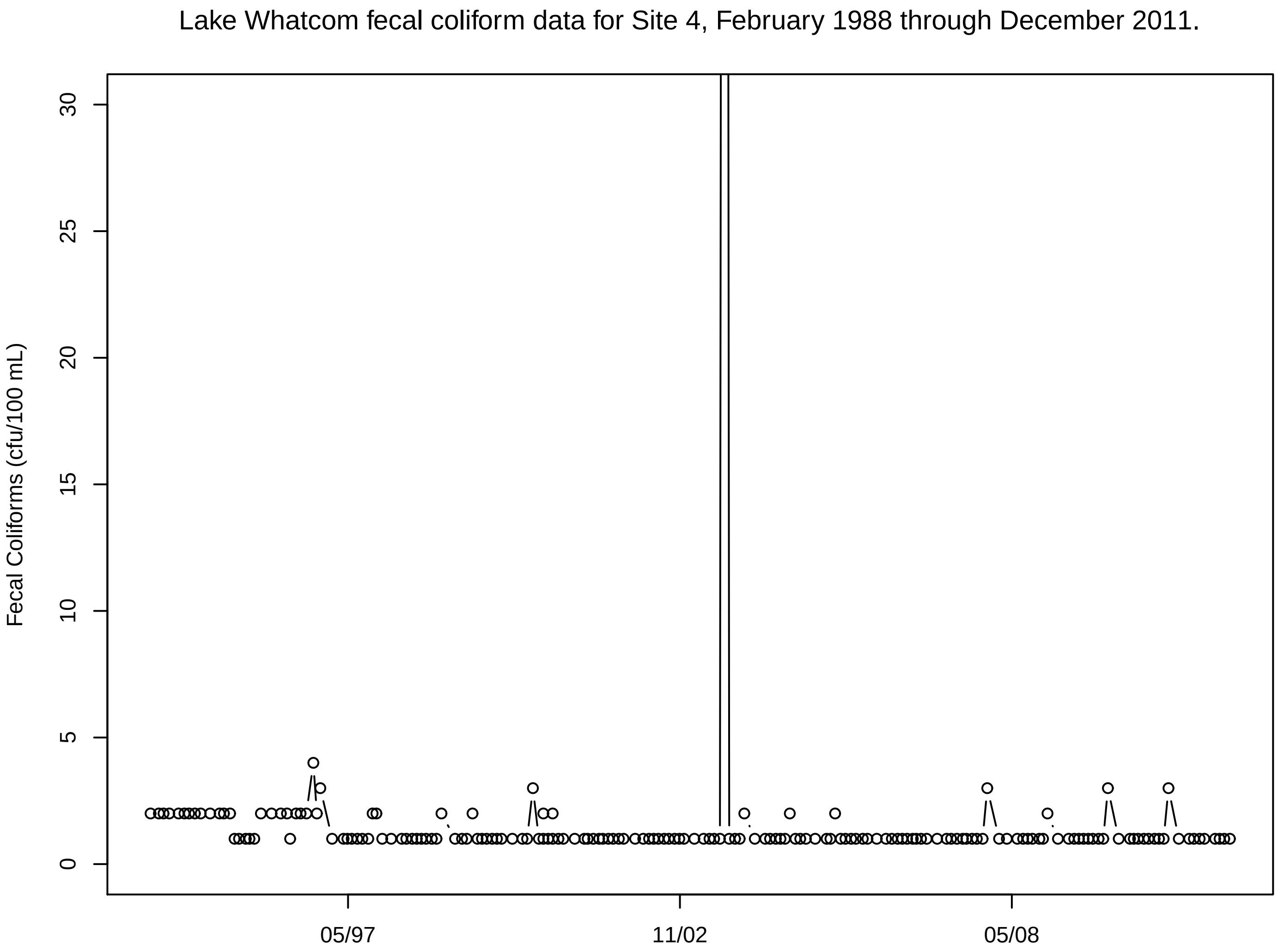

Lake Whatcom fecal coliform data for Site 3, February 1988 through December 2011.

Figure B119: Lake Whatcom fecal coliform data for Site 3.



Lake Whatcom fecal coliform data for Site 4, February 1988 through December 2011.

Figure B120: Lake Whatcom fecal coliform data for Site 4.

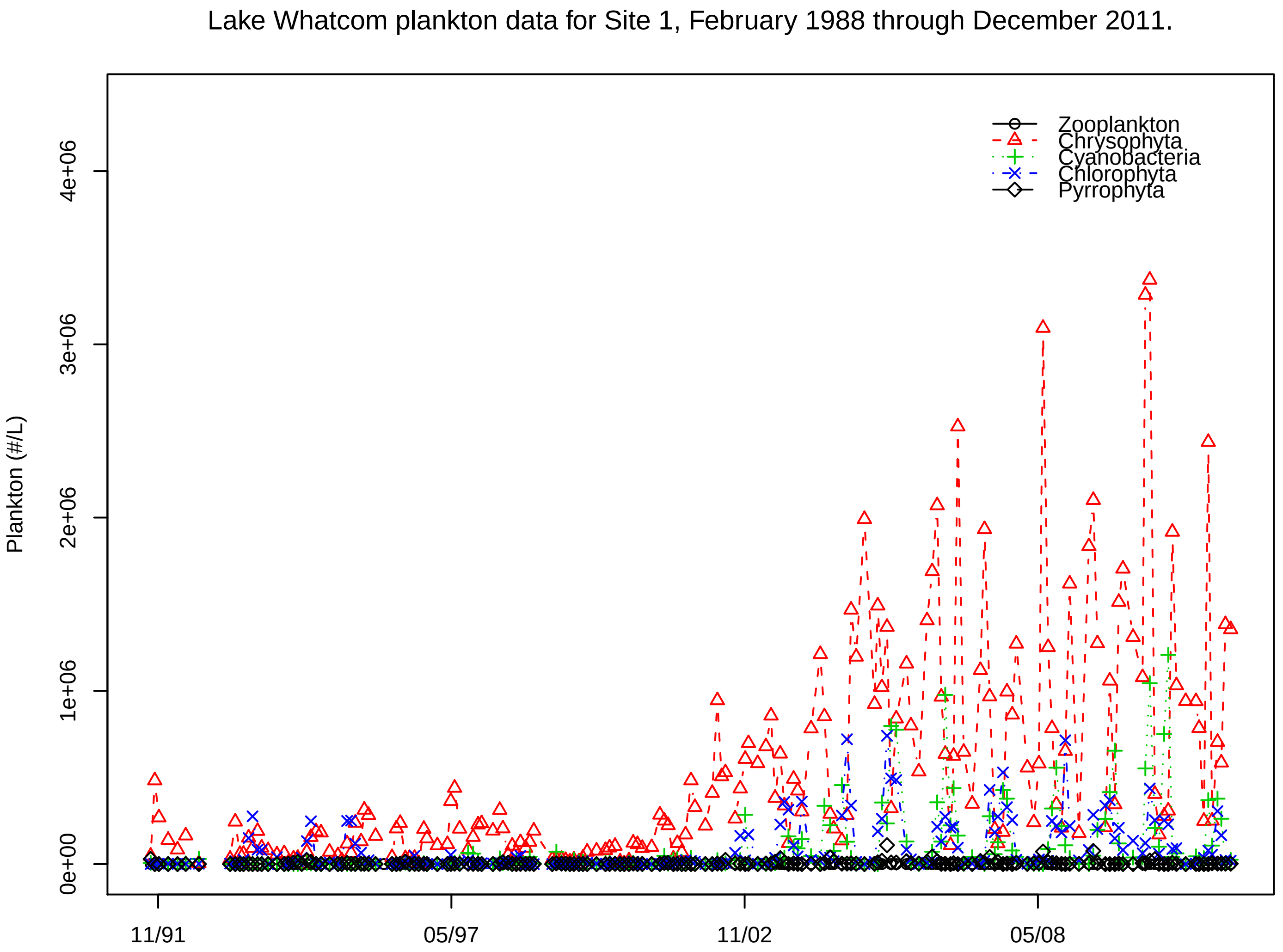


Figure B121: Lake Whatcom plankton data for Site 1.

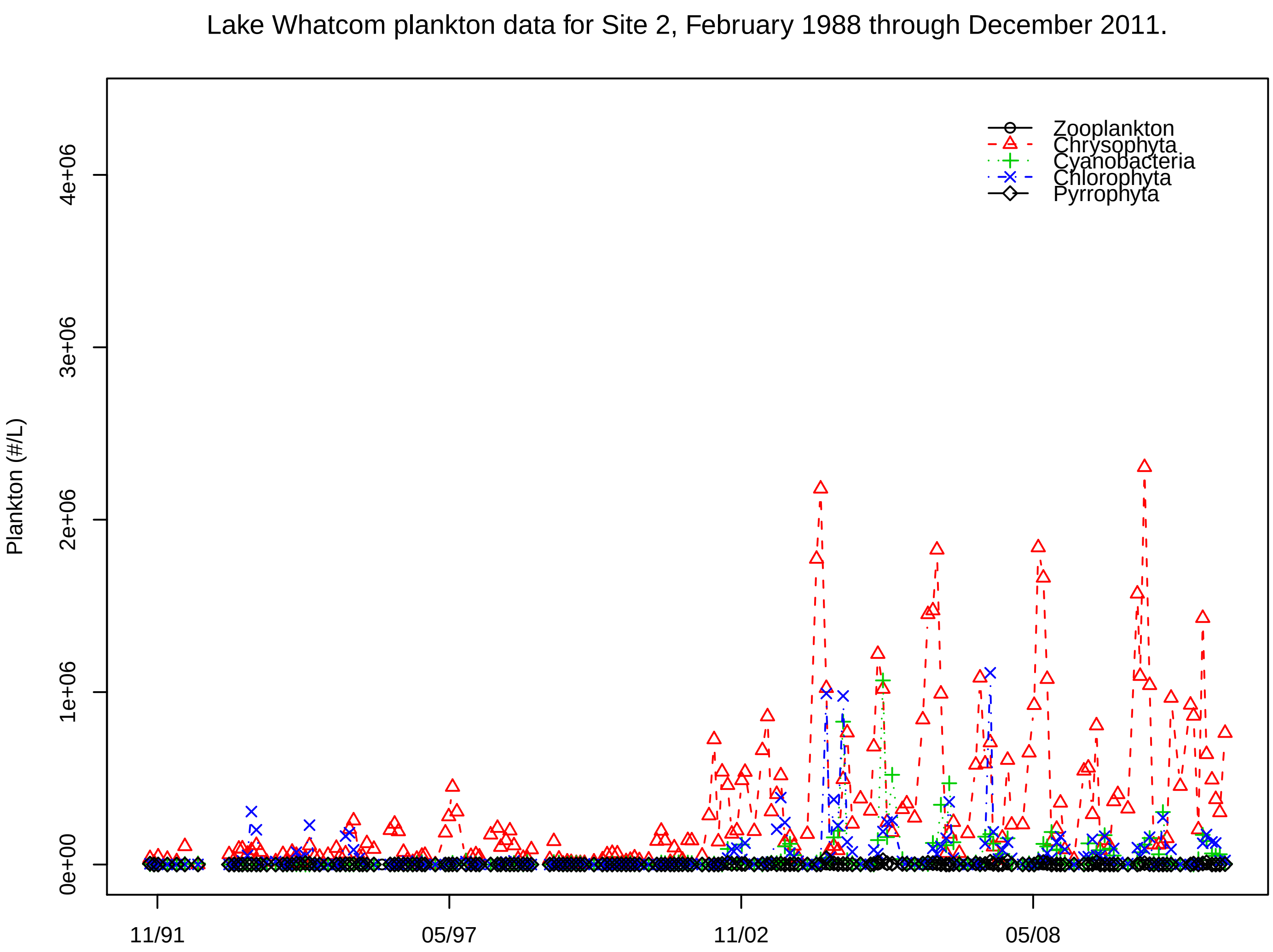


Figure B122: Lake Whatcom plankton data for Site 2.

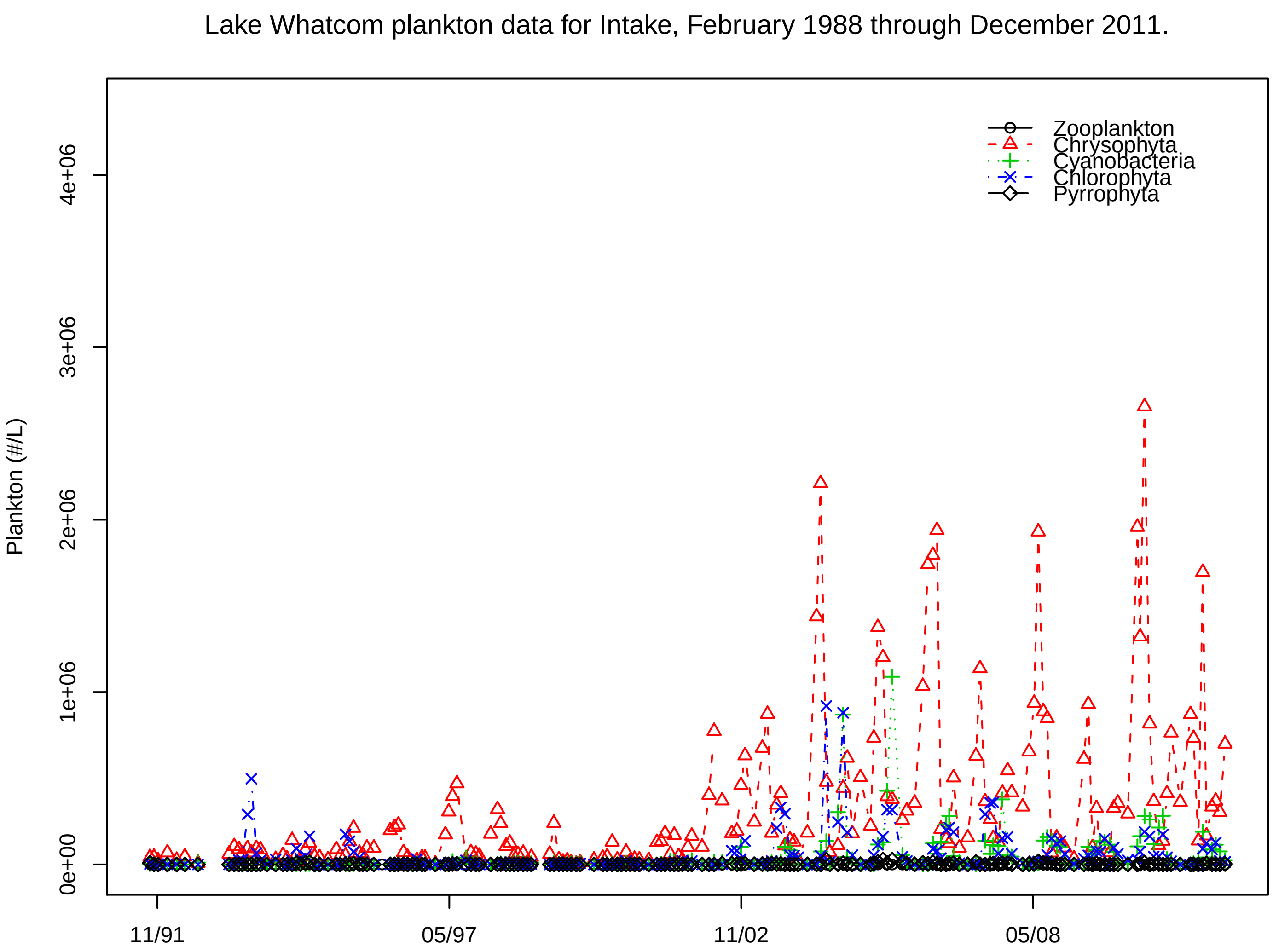


Figure B123: Lake Whatcom plankton data for the Intake Site.

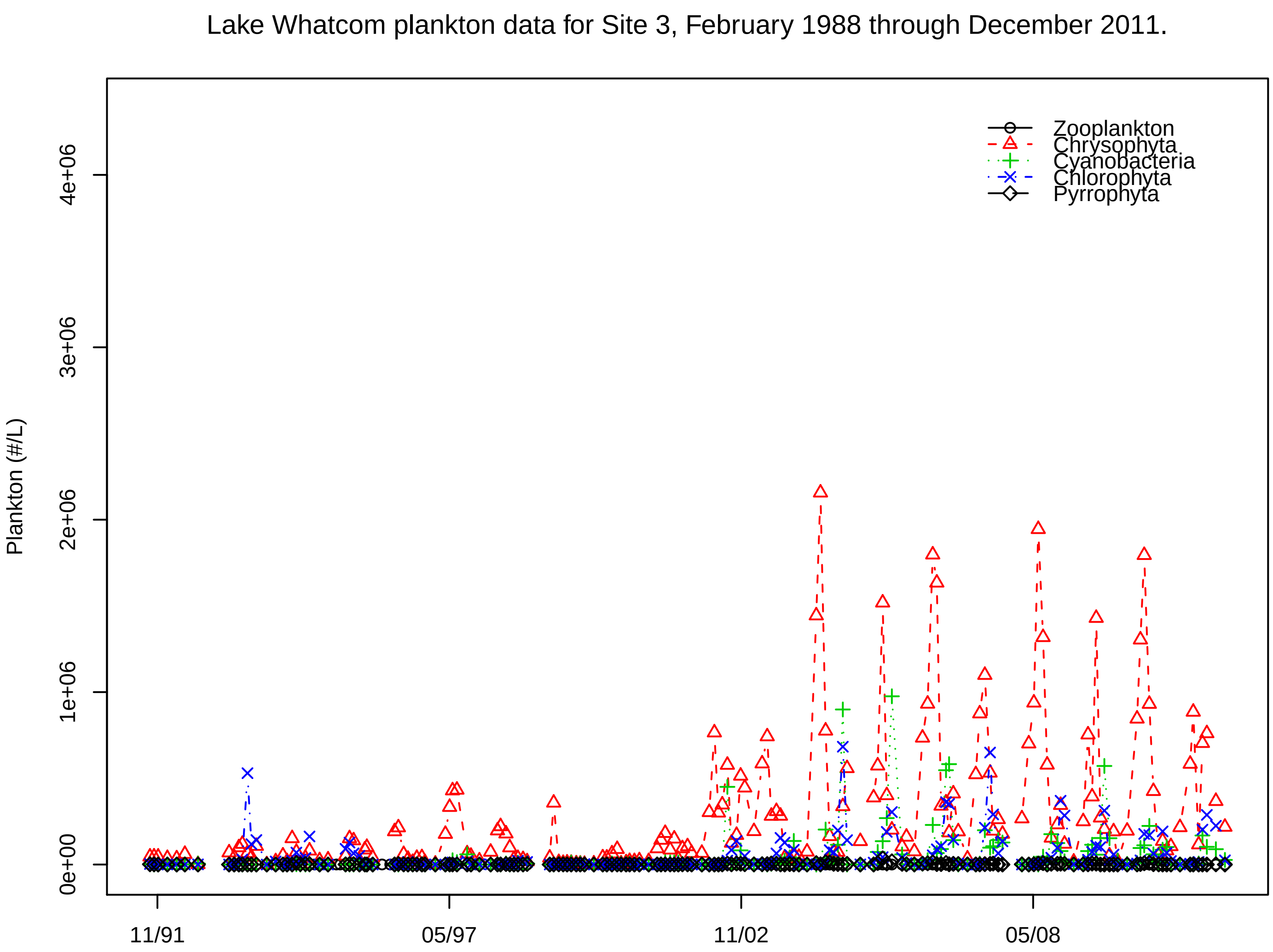


Figure B124: Lake Whatcom plankton data for Site 3.

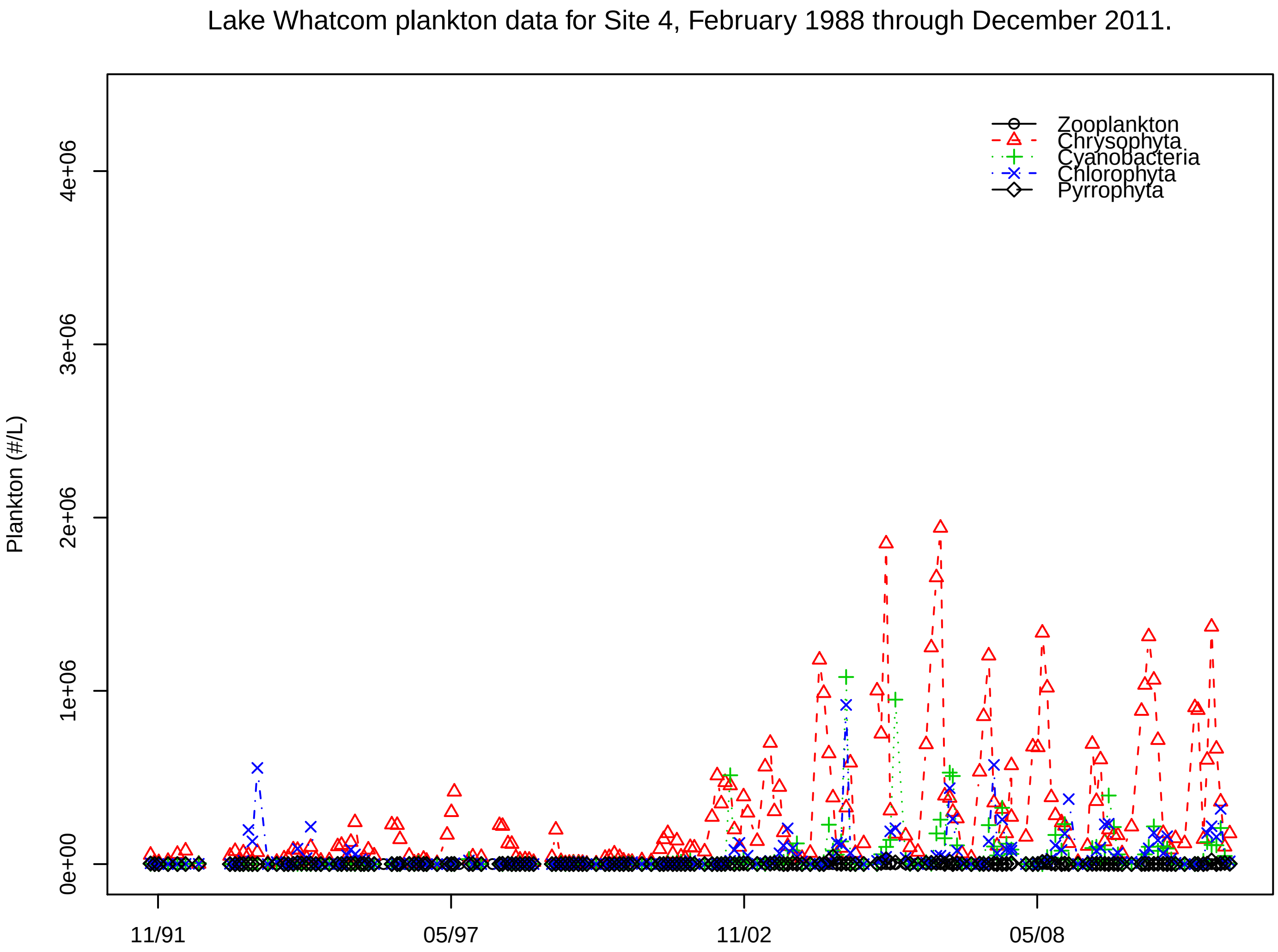


Figure B125: Lake Whatcom plankton data for Site 4.

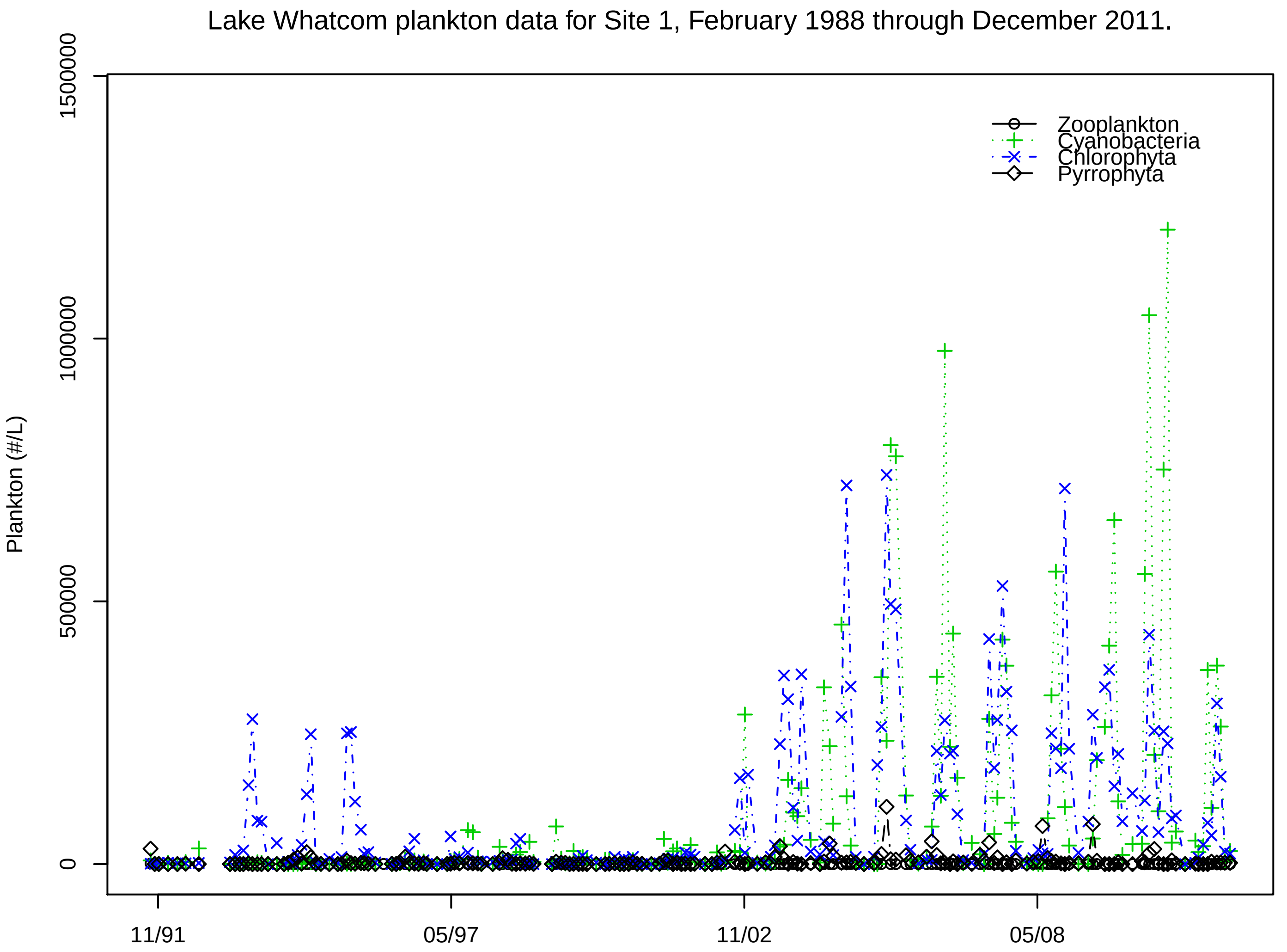


Figure B126: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

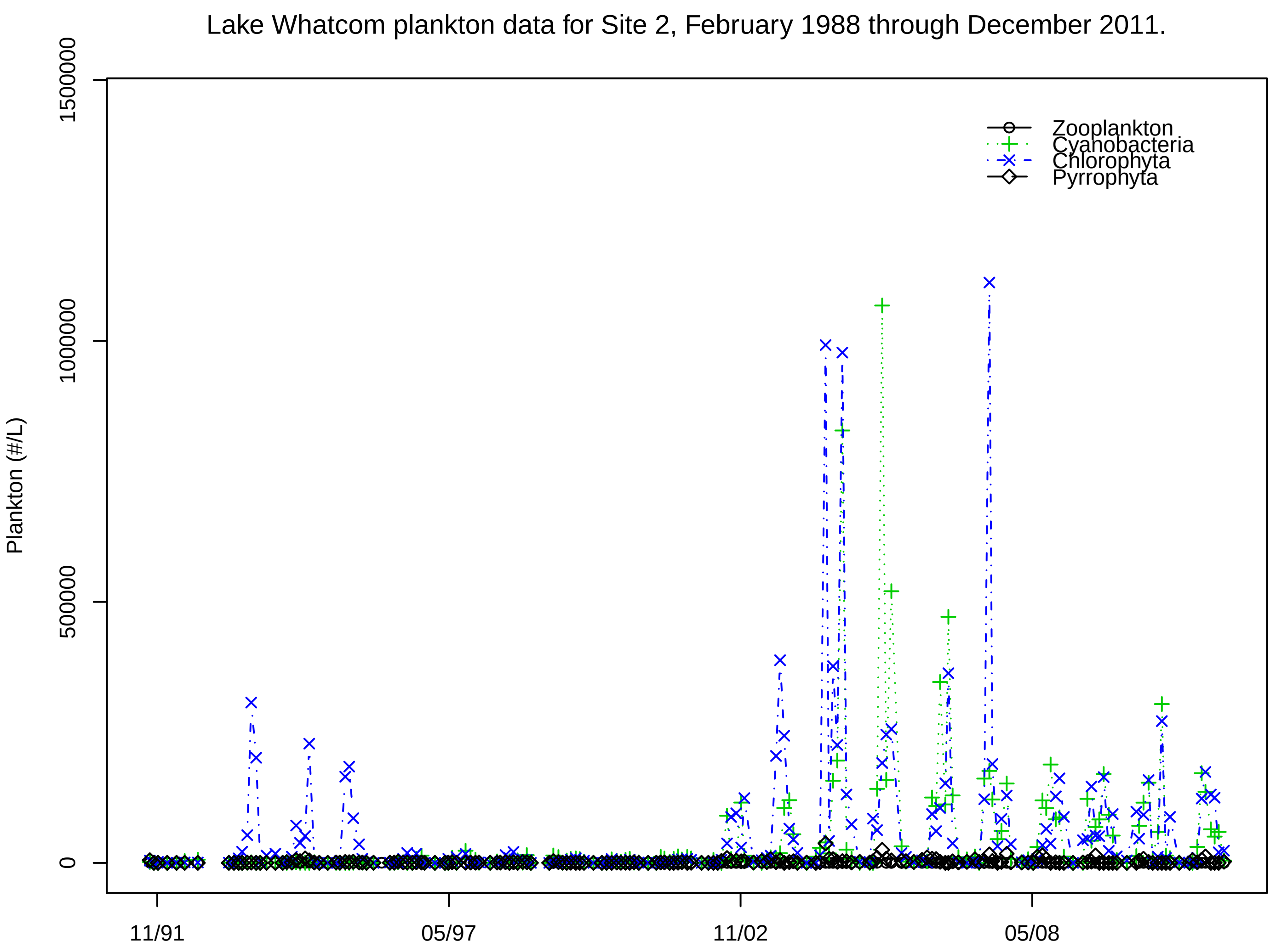


Figure B127: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

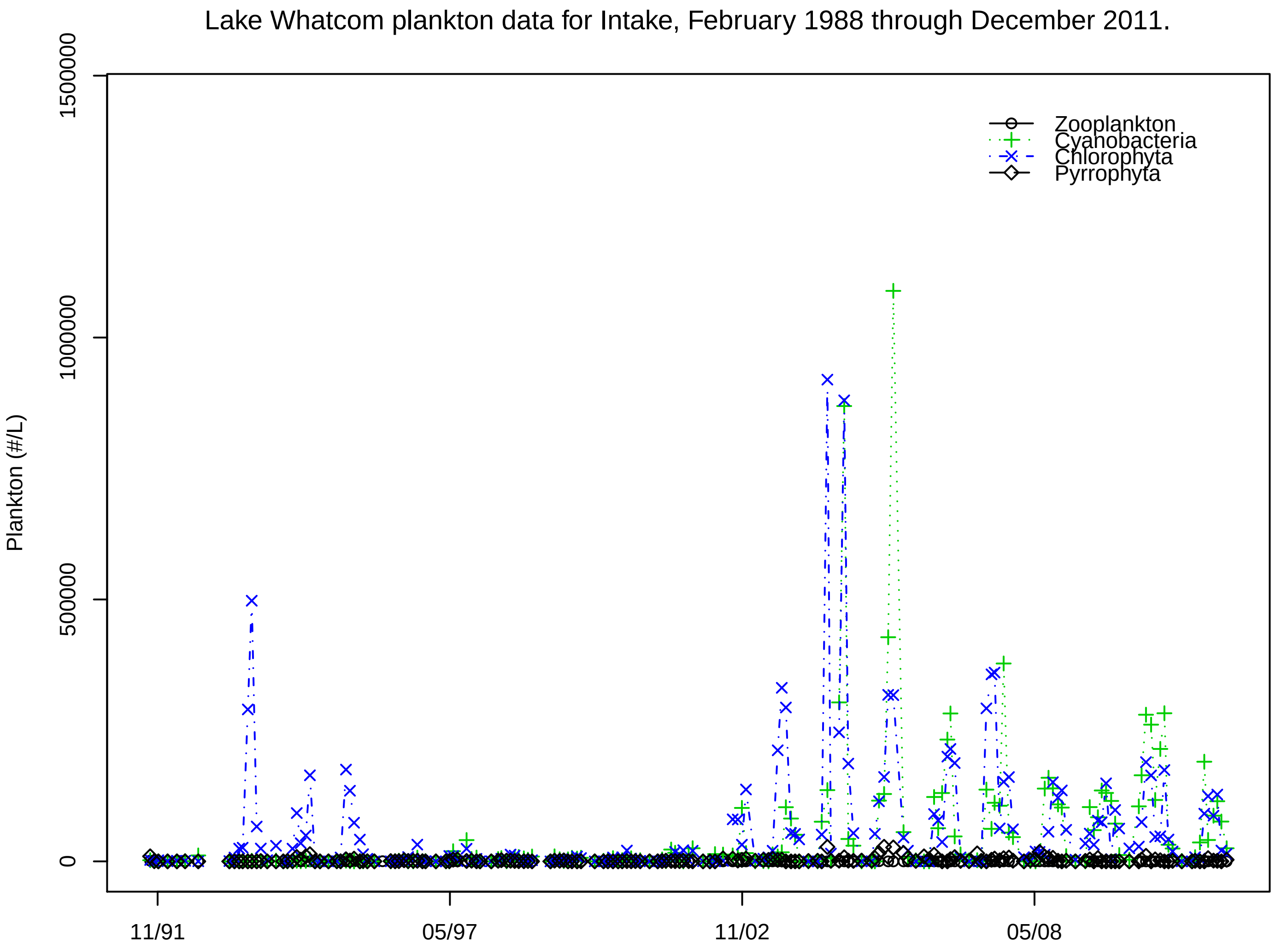


Figure B128: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

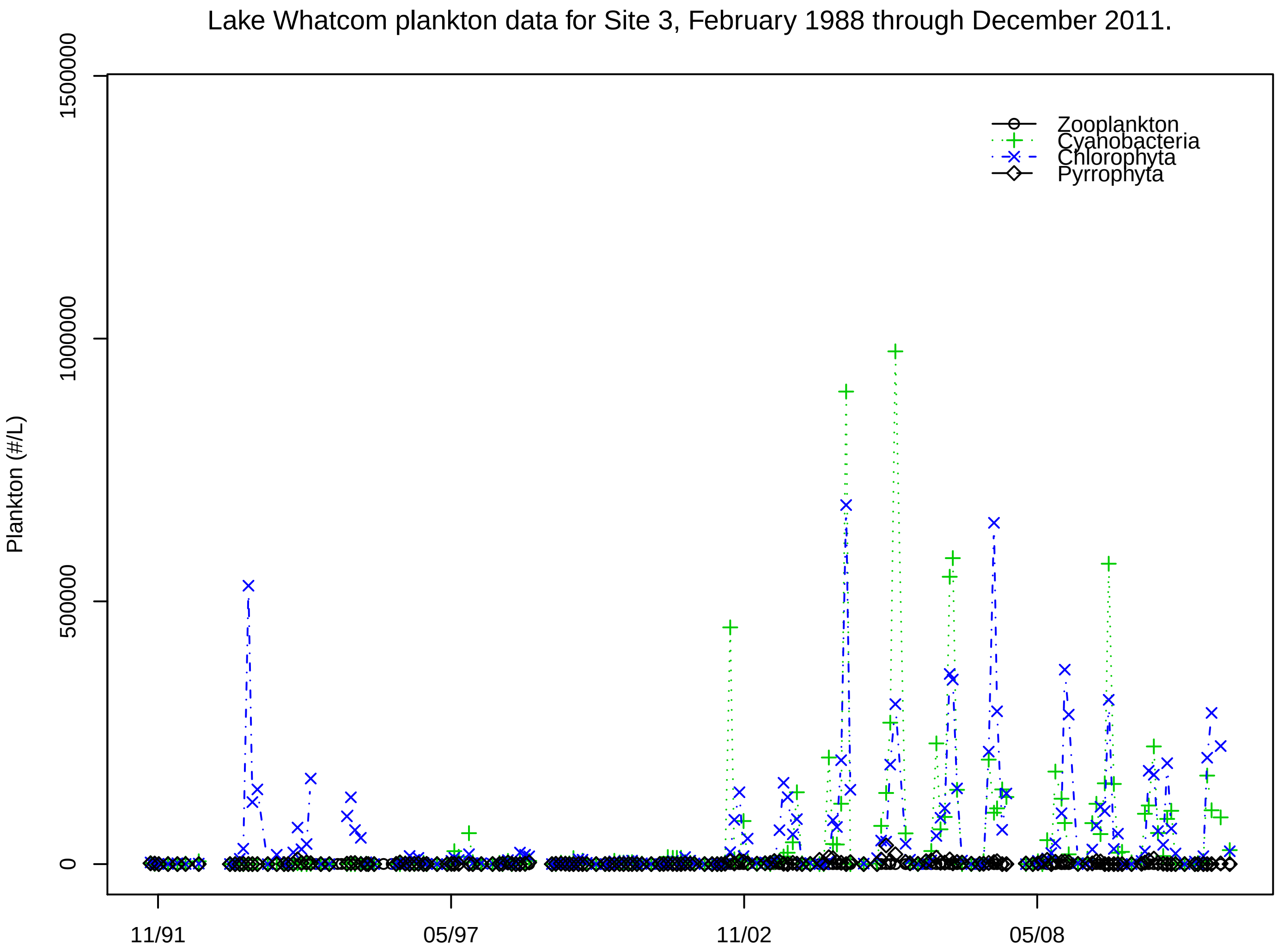


Figure B129: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

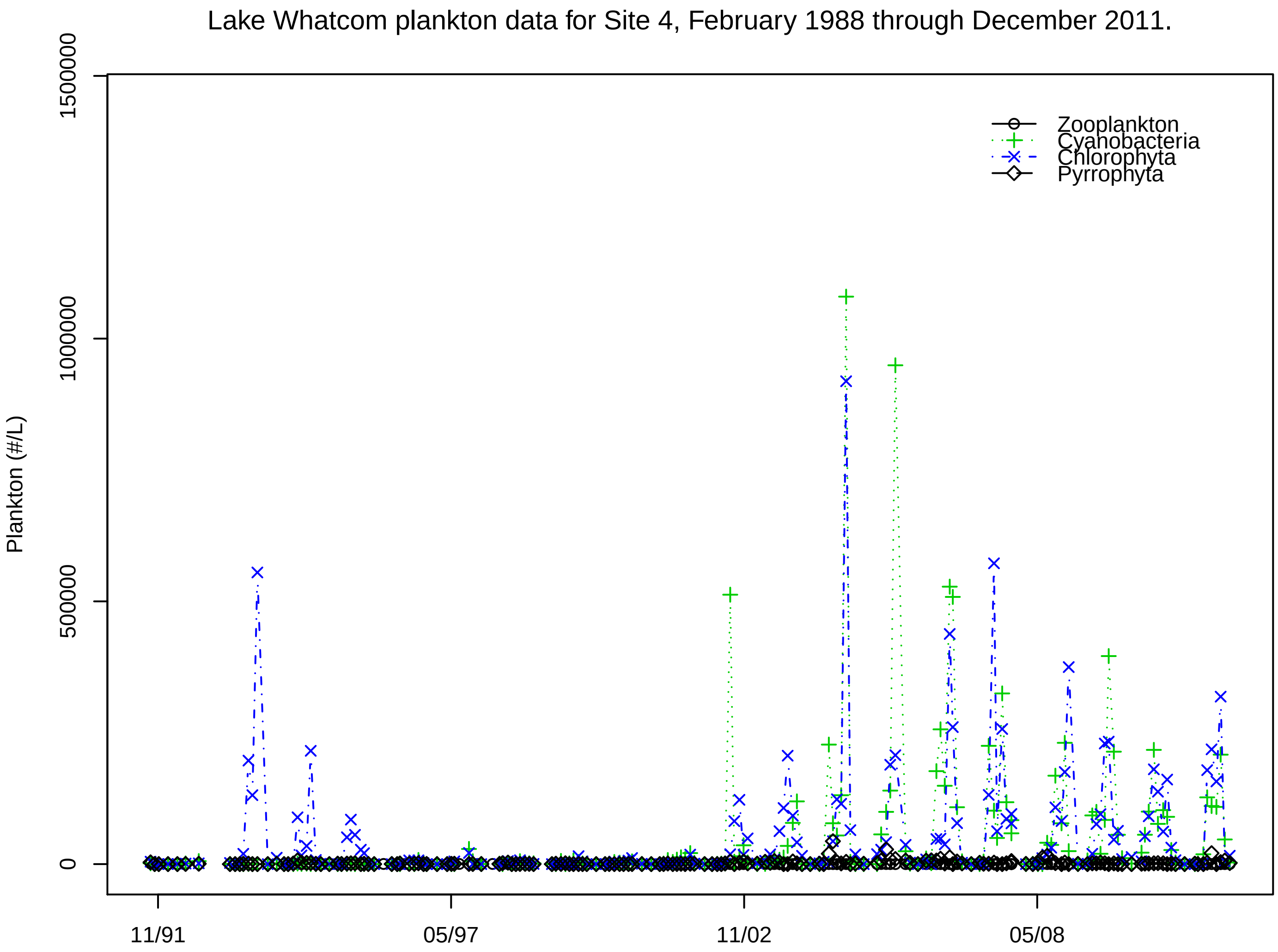


Figure B130: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

## B.4 Lake Whatcom Tributary Data (2004-present)

The figures in this appendix include the monthly baseline data collected from October 2004 through September 2006, biannual data collected from February 2007 through September 2009, and monthly data collected during the current monitoring period. Each figure includes a dashed (blue) horizontal line that shows the median value for Smith Creek and a solid (red) horizontal line that shows the median value for each creek. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted. Extreme outliers have been omitted to provide more informative plotting scales; all original data, including outliers, are available online at http://www.wwu.edu/iws.

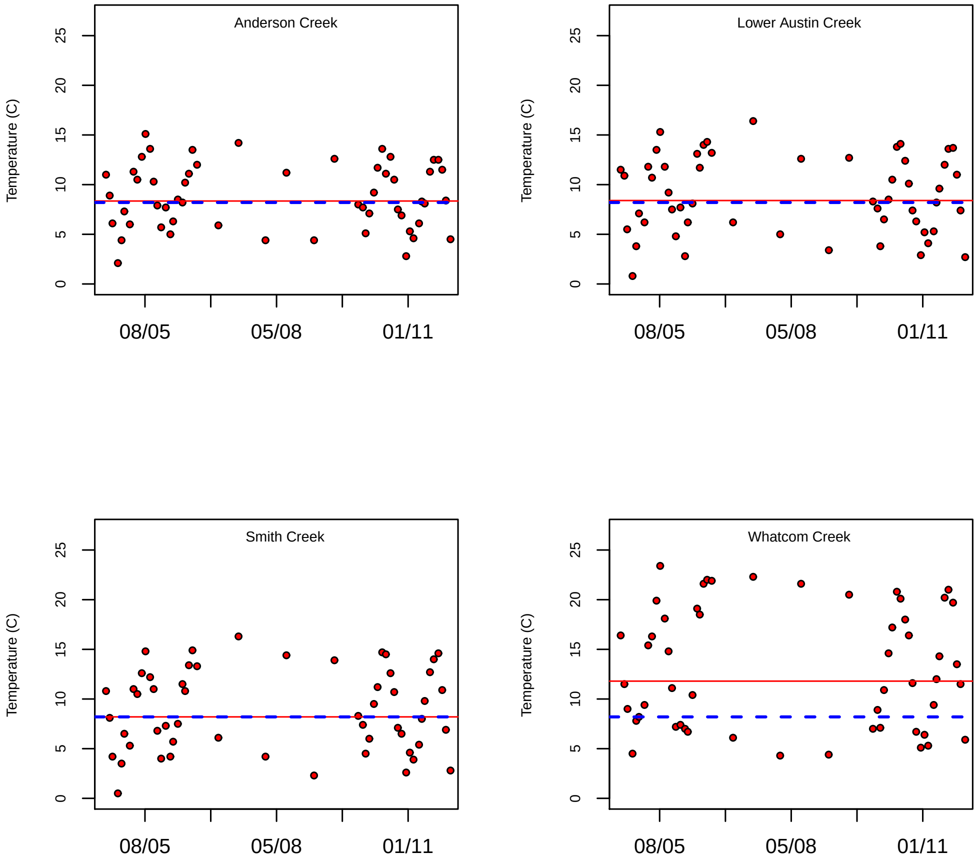


Figure B131: Temperature data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

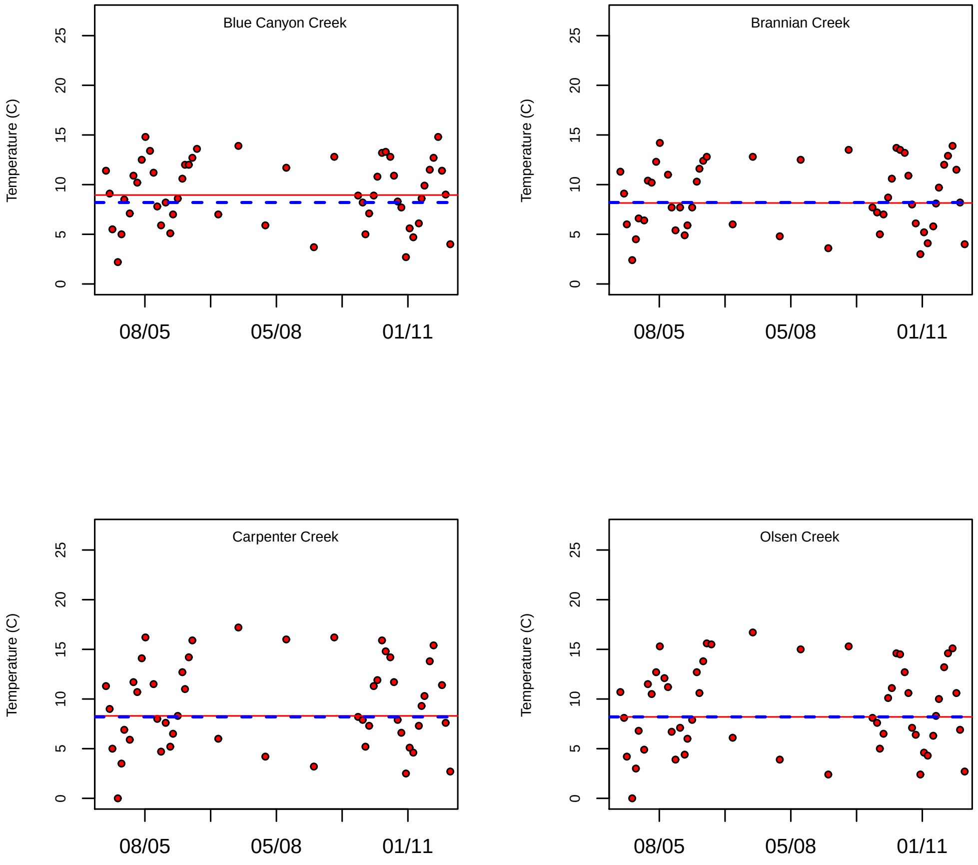


Figure B132: Temperature data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

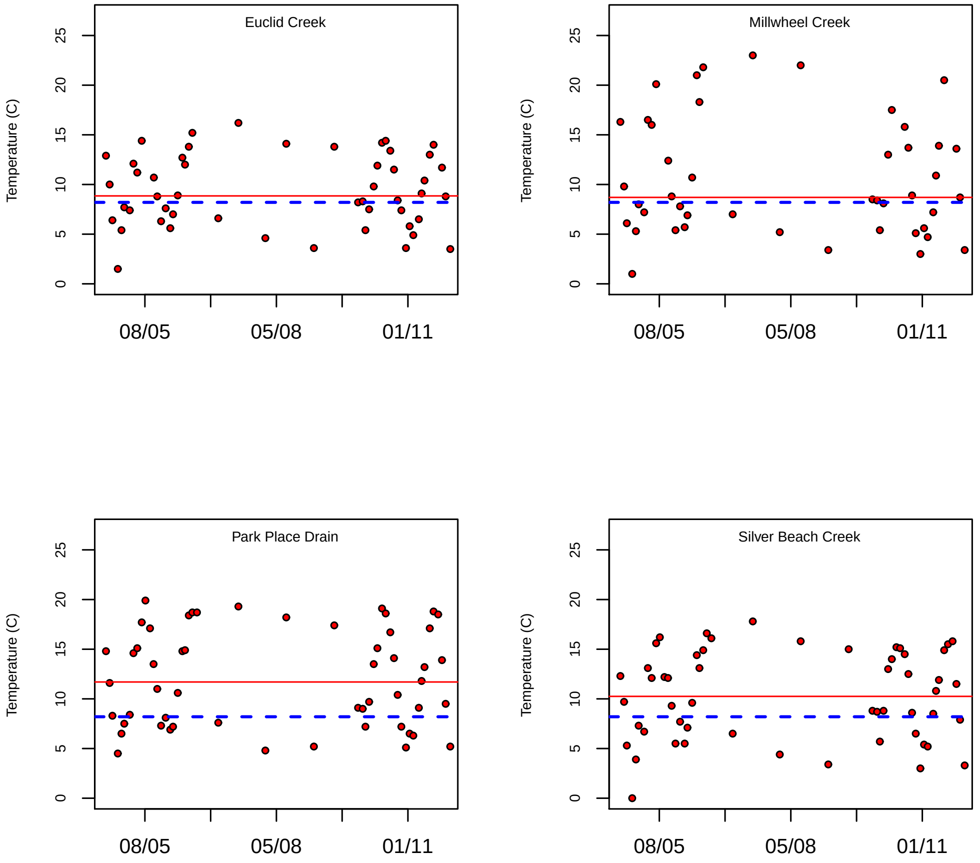


Figure B133: Temperature data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

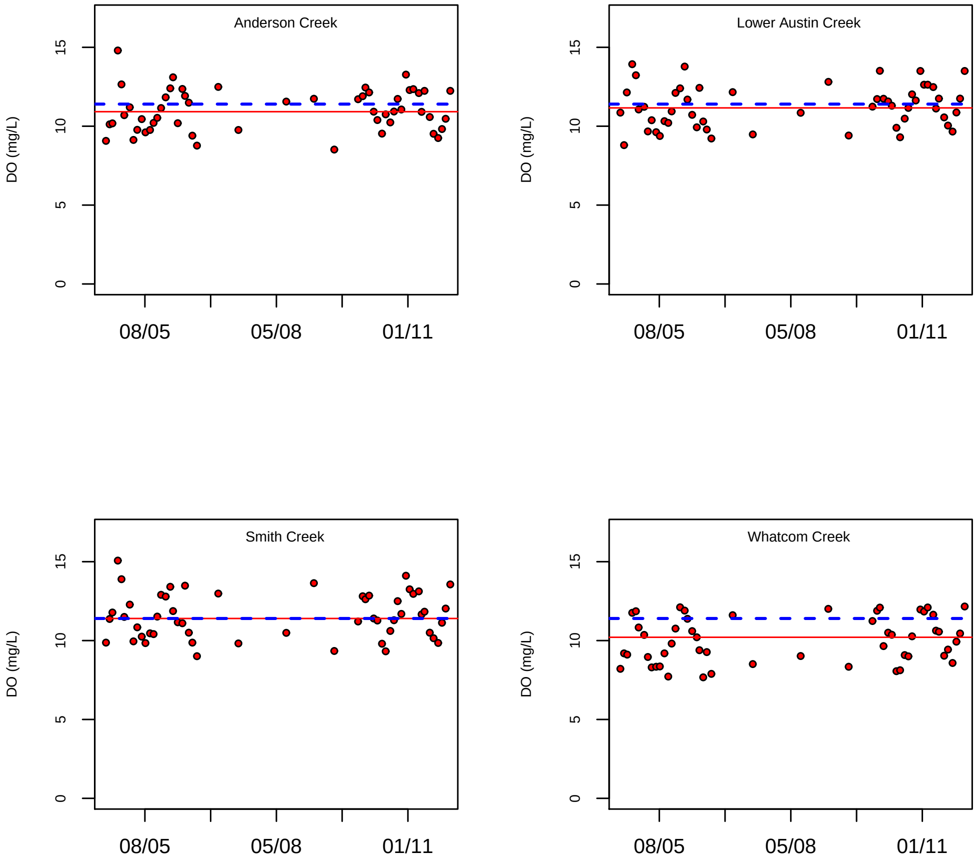


Figure B134: Dissolved oxygen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

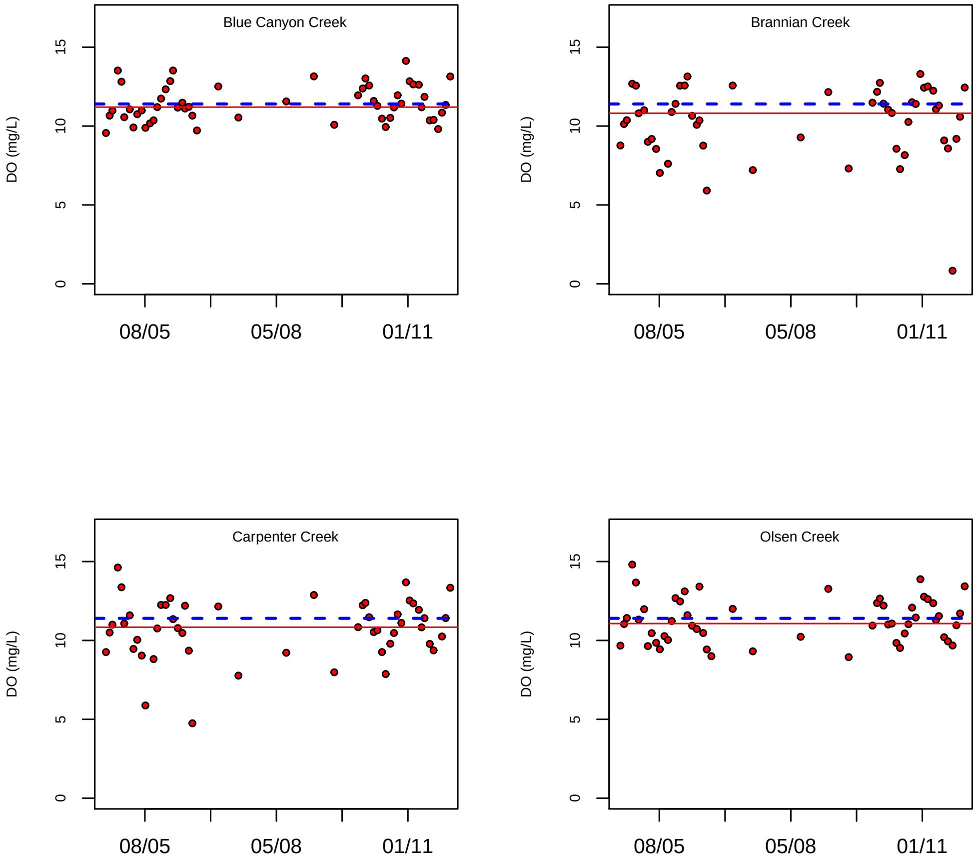


Figure B135: Dissolved oxygen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

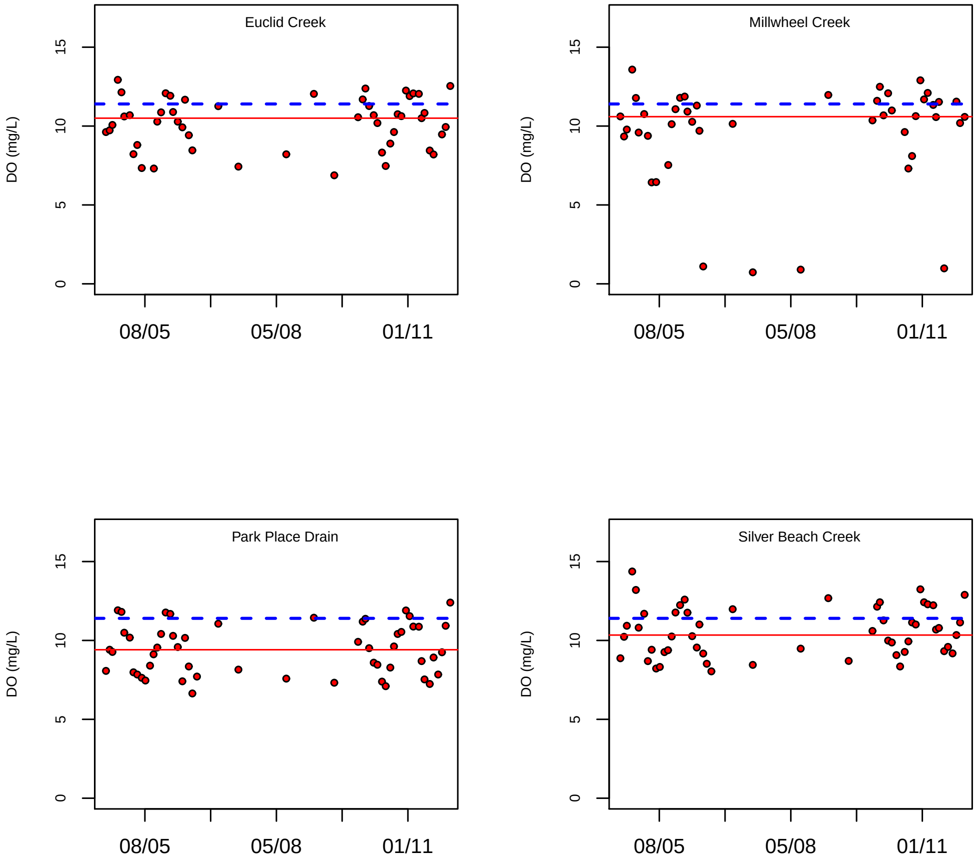


Figure B136: Dissolved oxygen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

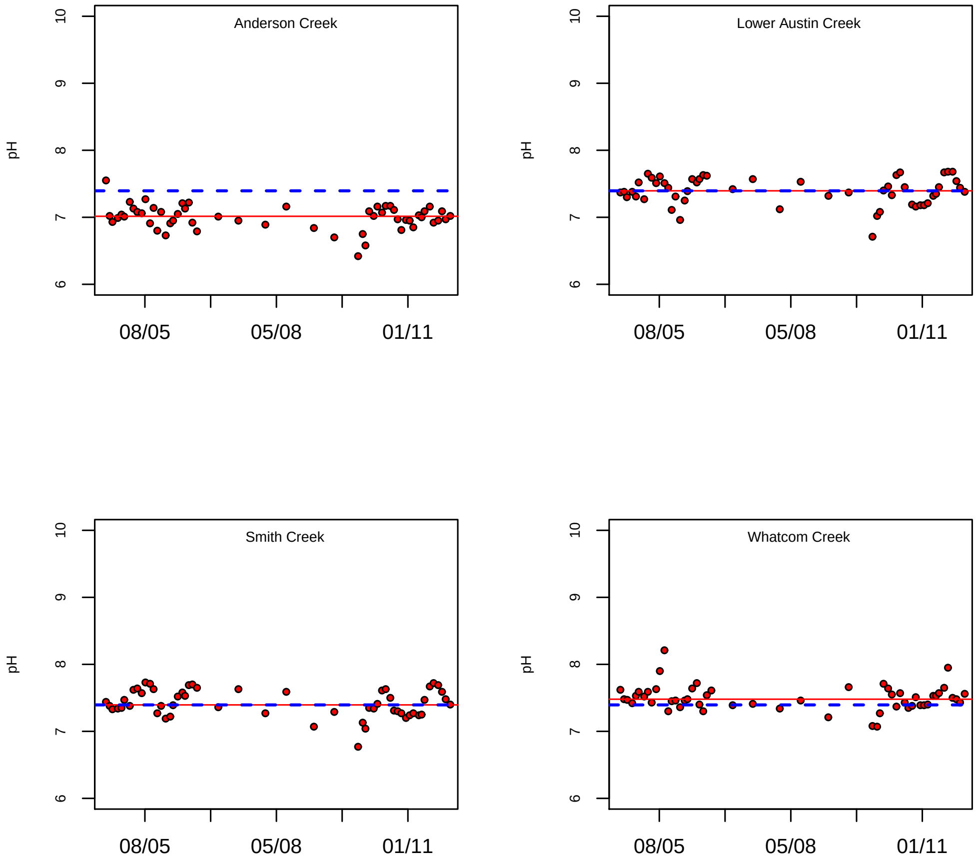


Figure B137: Tributary pH data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

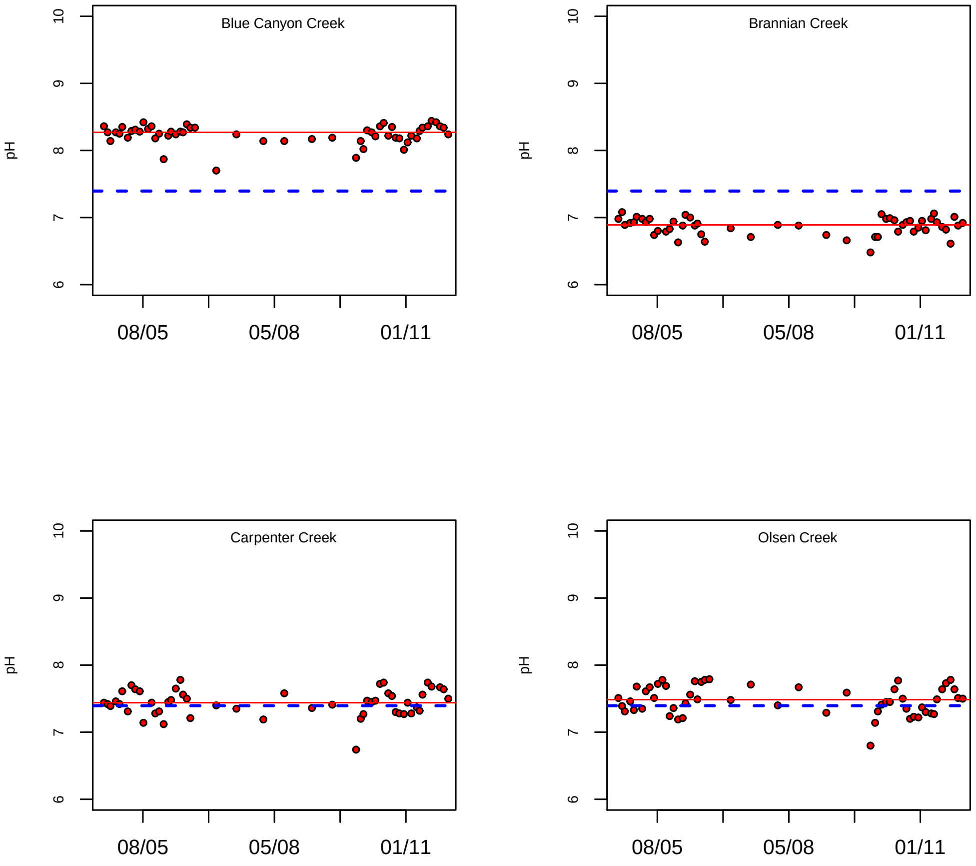


Figure B138: Tributary pH data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

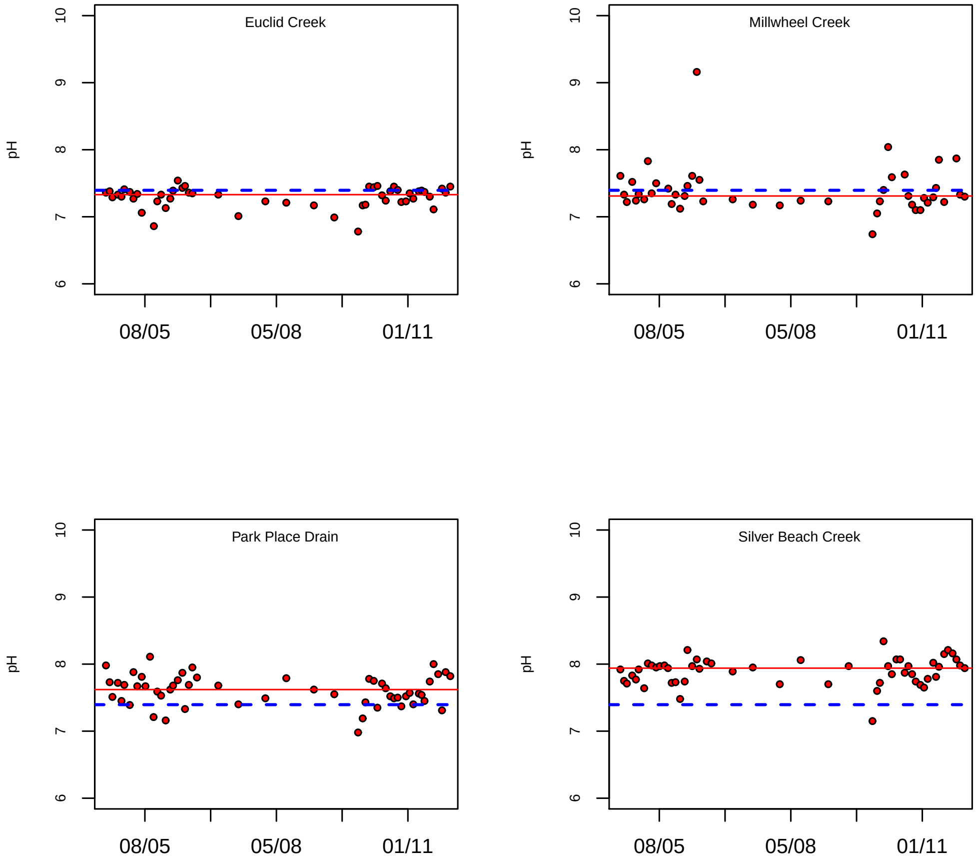


Figure B139: Tributary pH data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

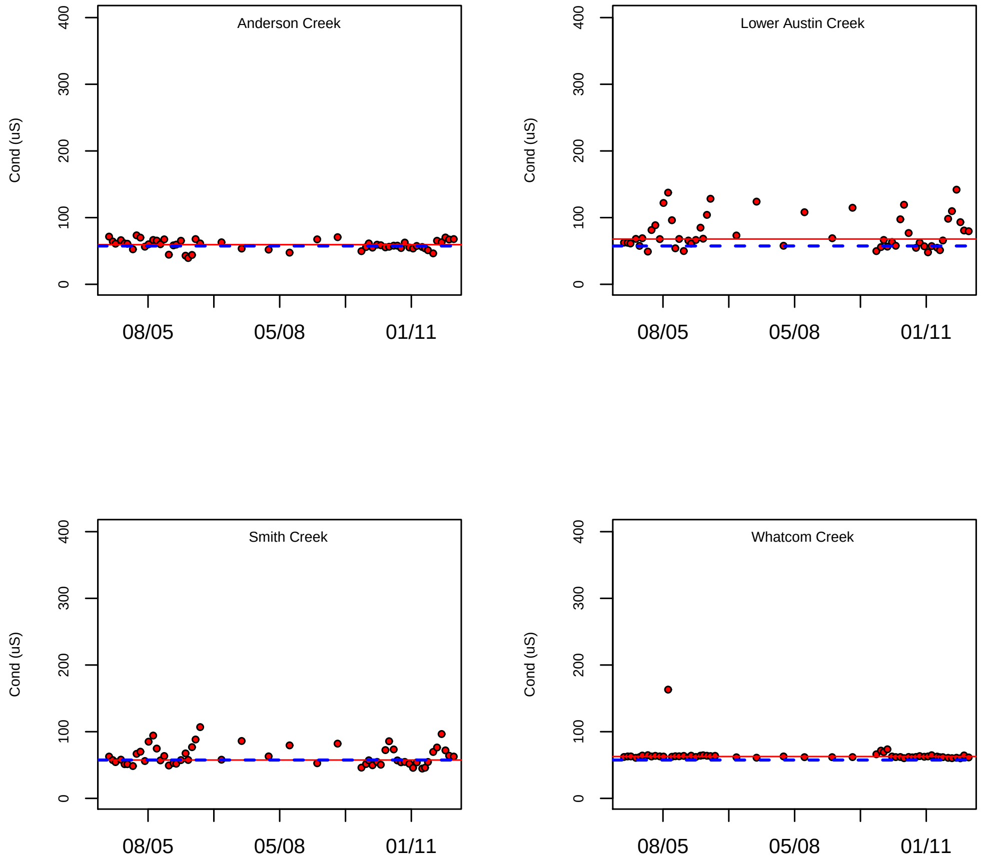


Figure B140: Conductivity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

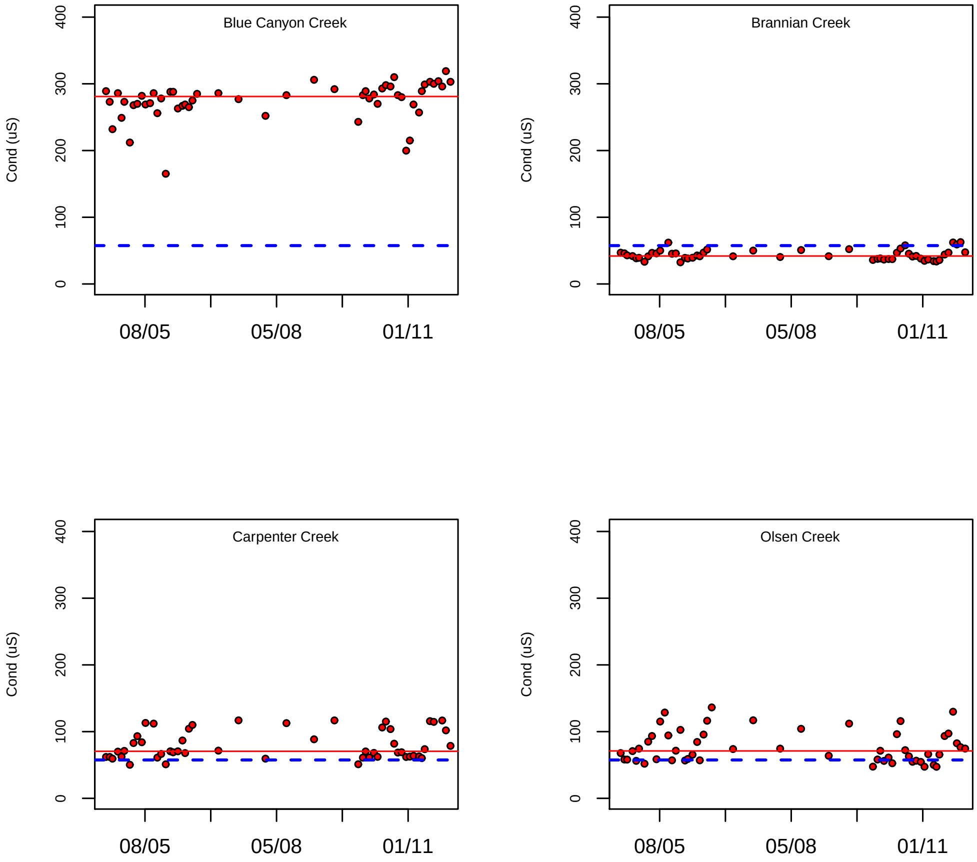


Figure B141: Conductivity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

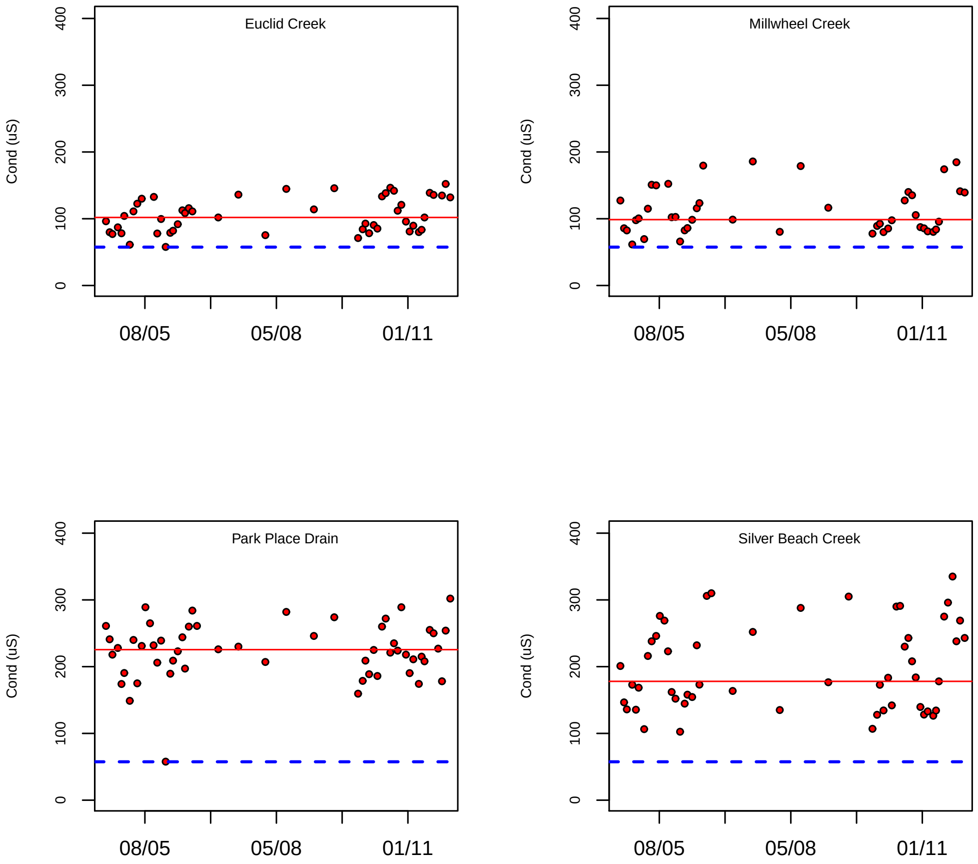


Figure B142: Conductivity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

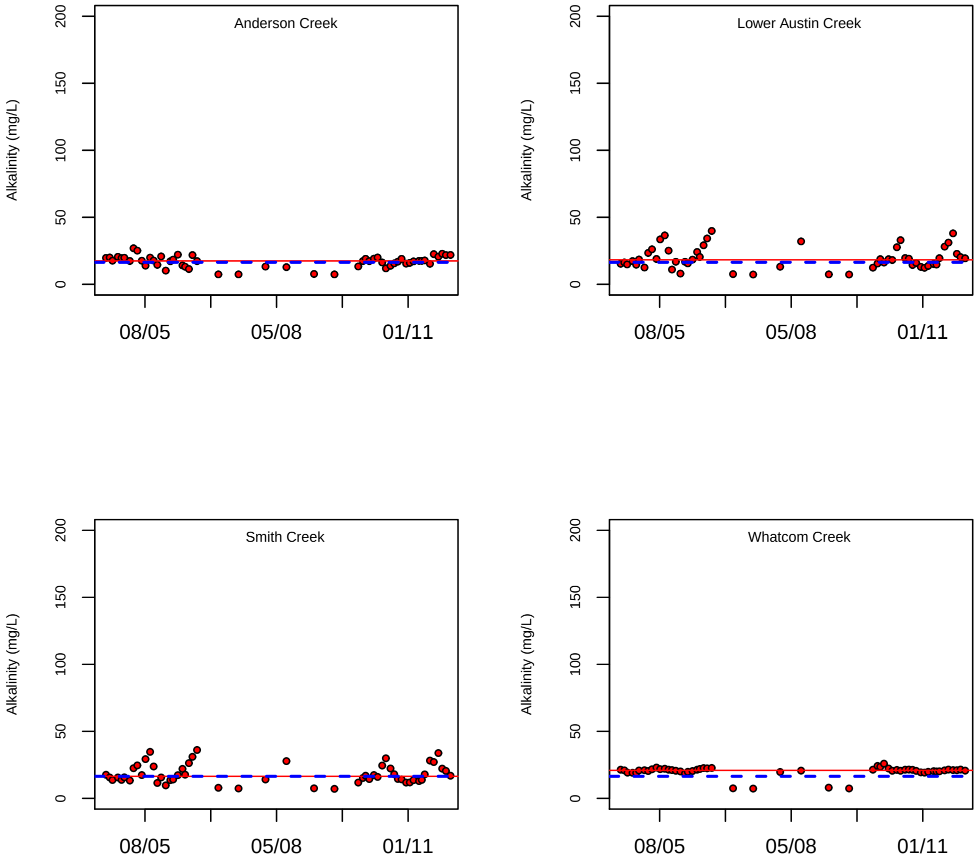


Figure B143: Alkalinity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

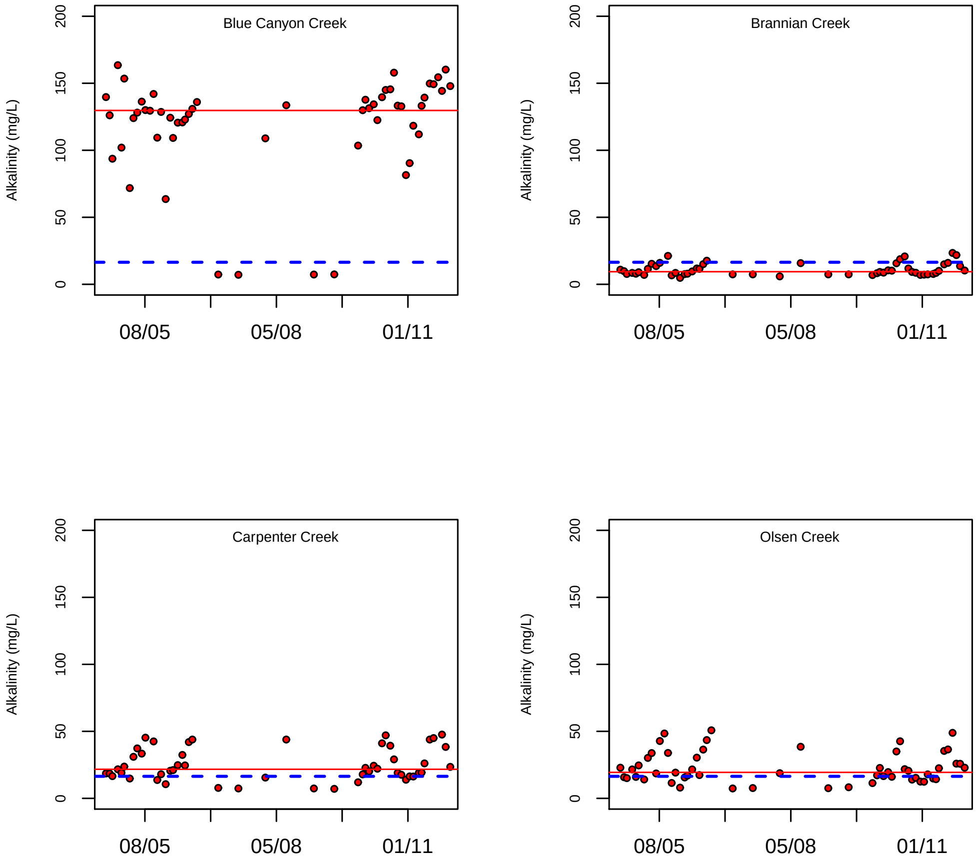


Figure B144: Alkalinity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

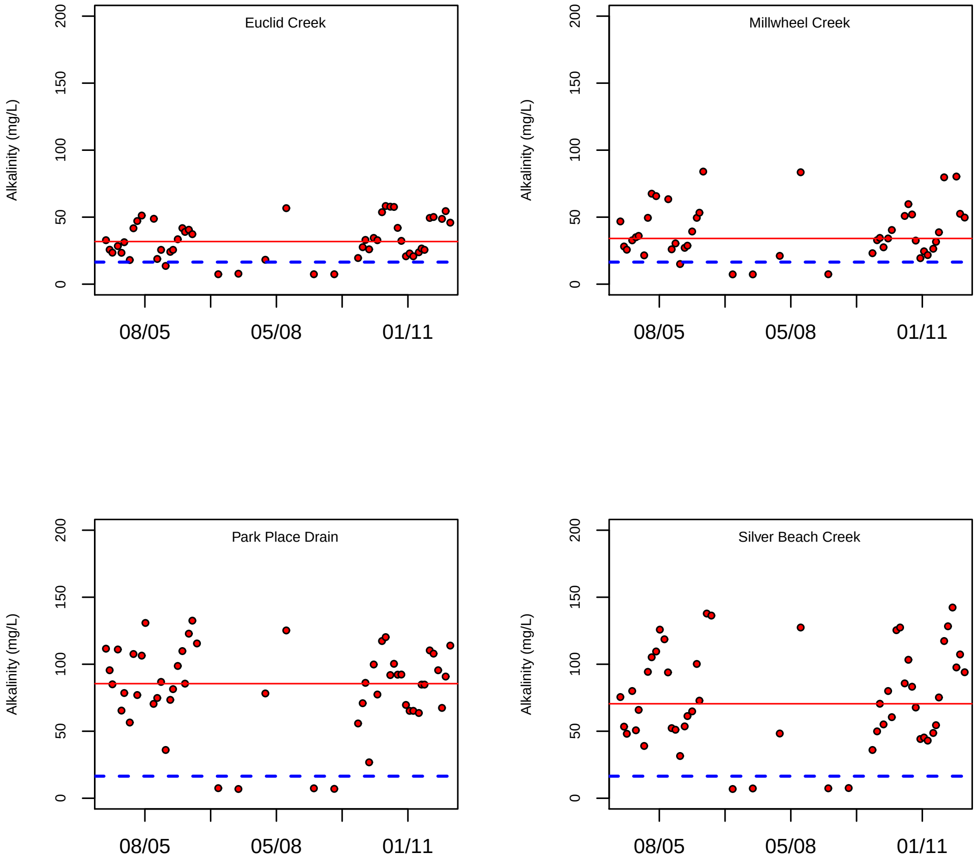


Figure B145: Alkalinity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

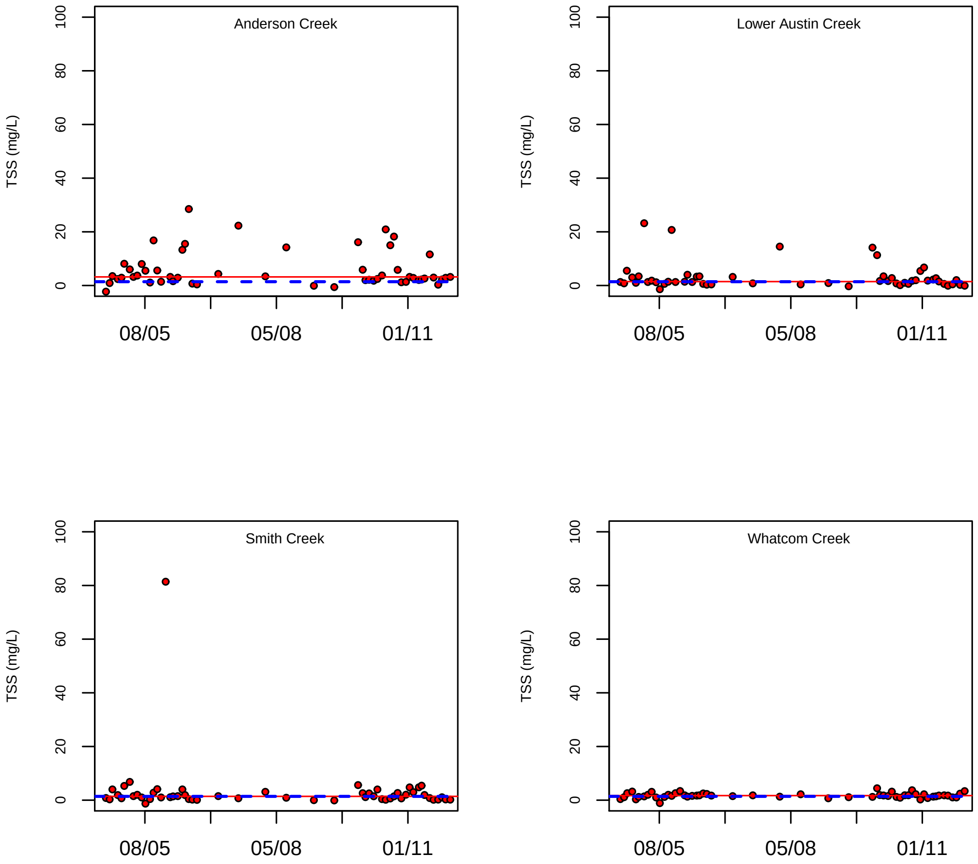


Figure B146: Total suspended solids data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

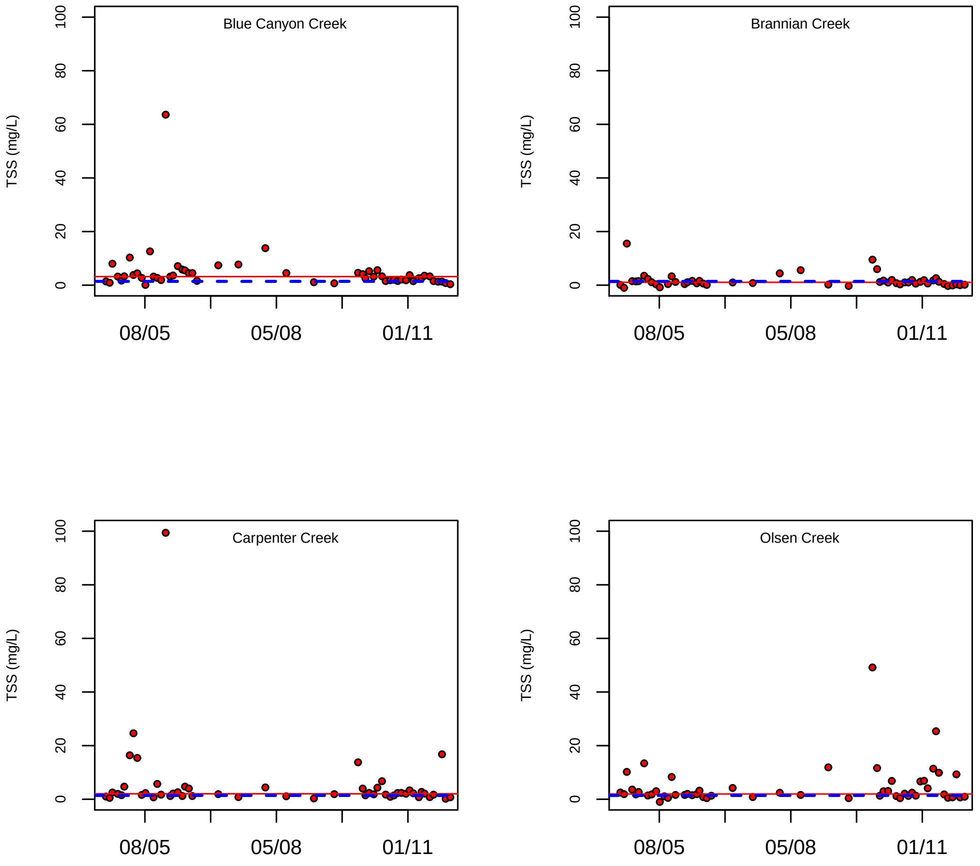


Figure B147: Total suspended solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

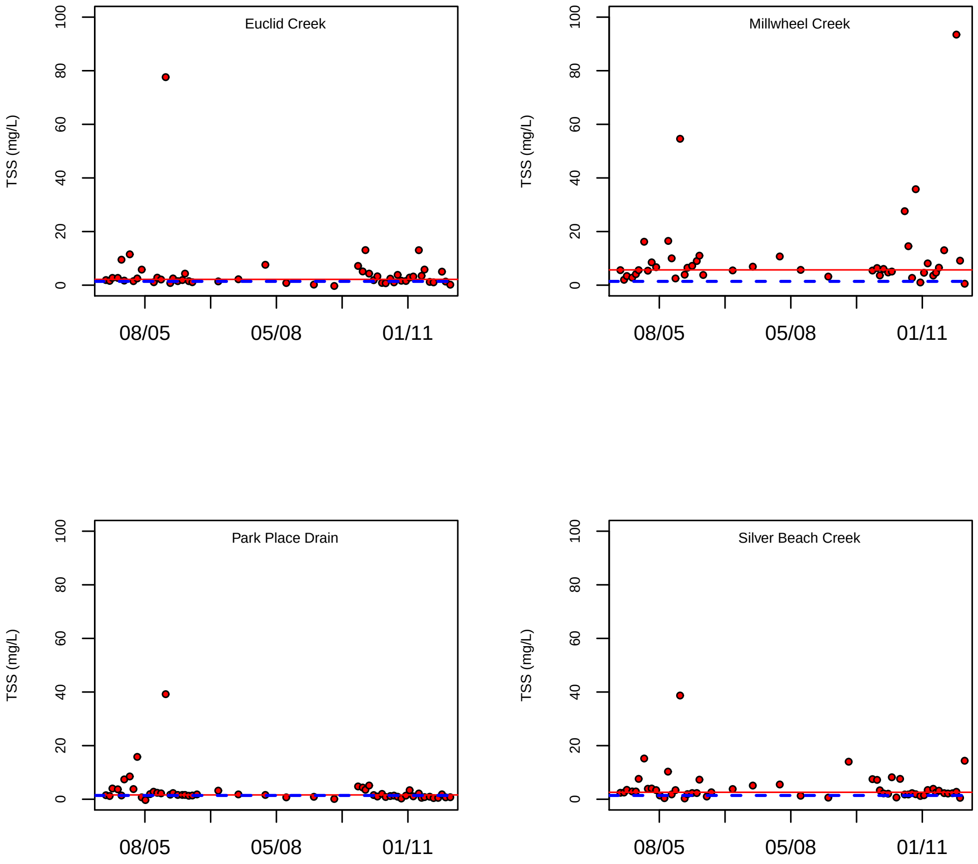


Figure B148: Total suspended solids data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

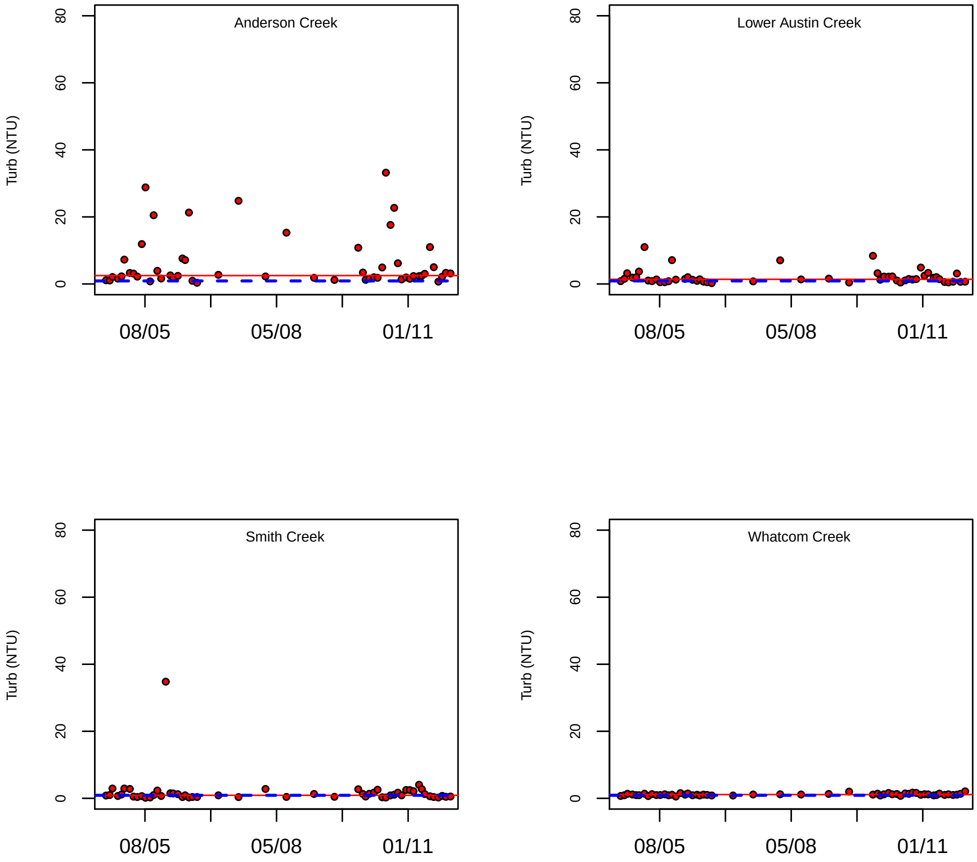


Figure B149: Turbidity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

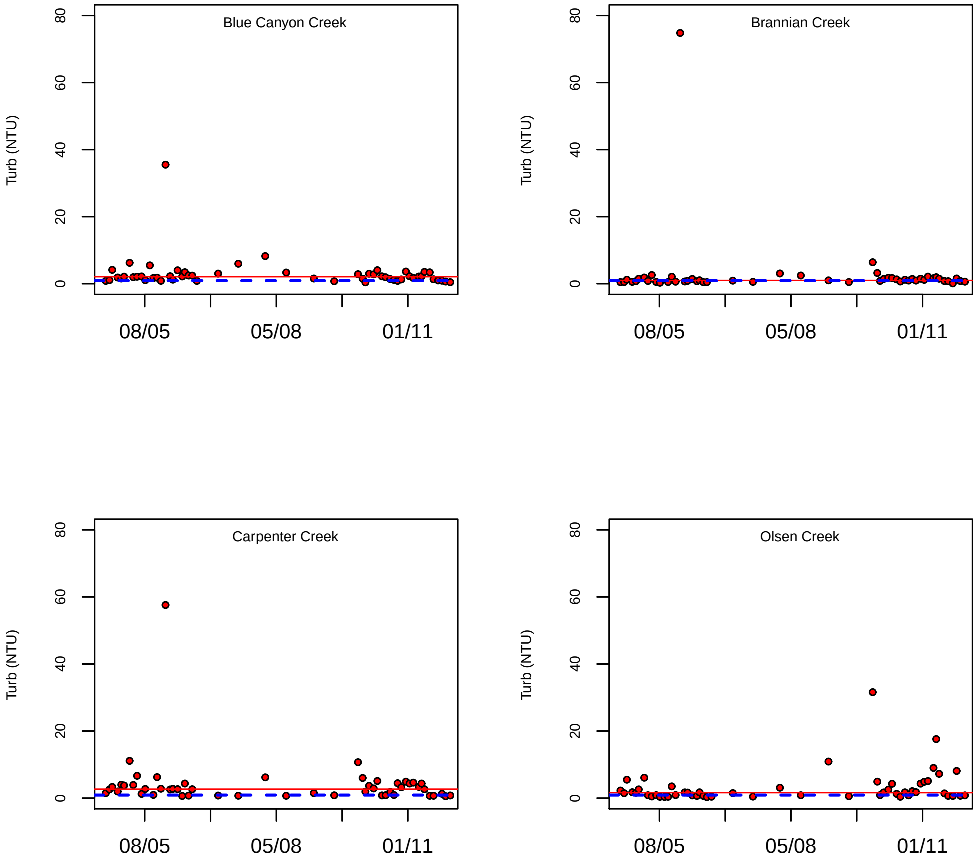


Figure B150: Turbidity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

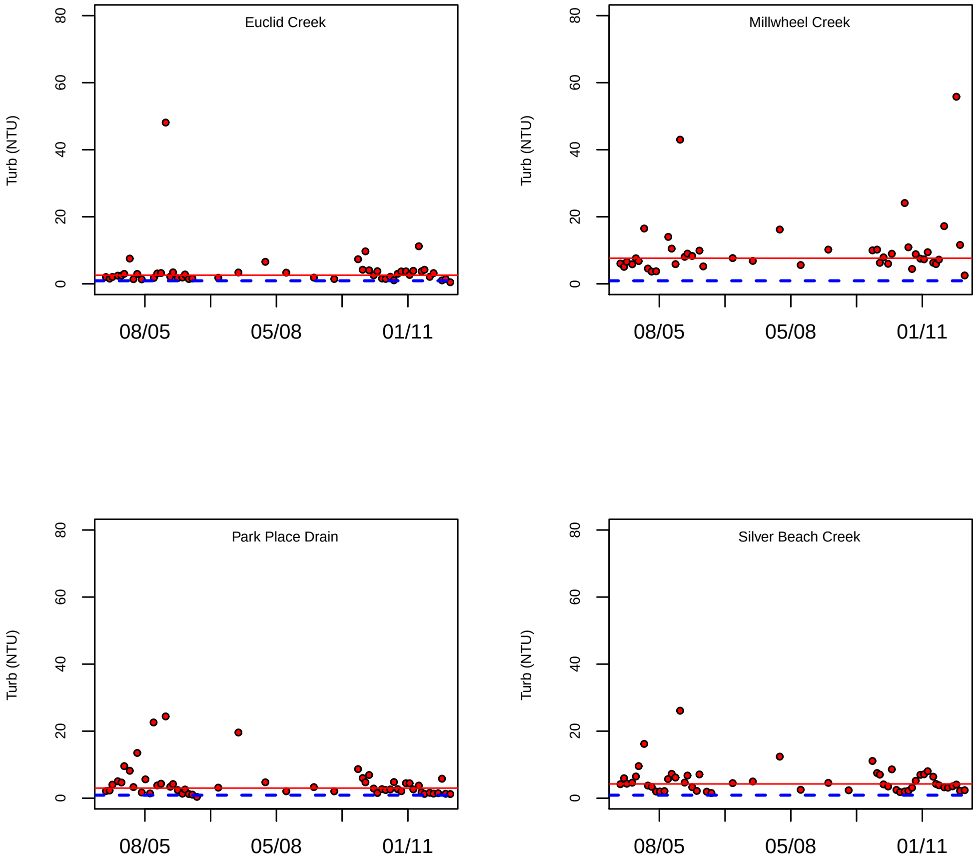


Figure B151: Turbidity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

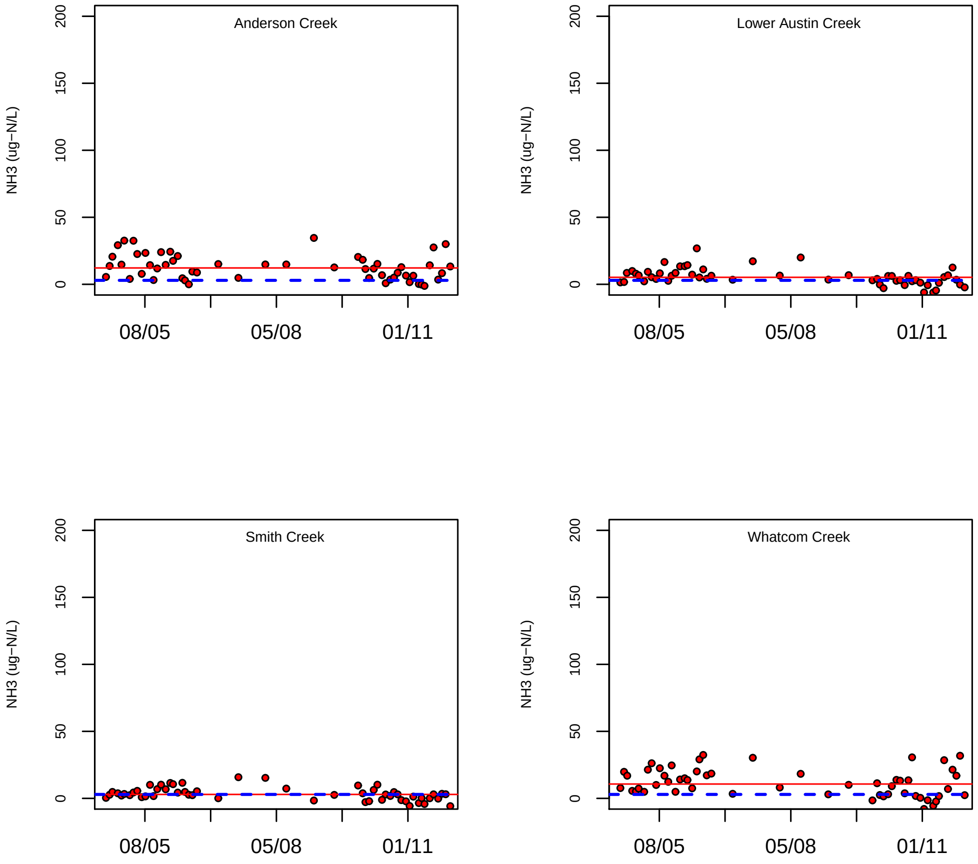


Figure B152: Ammonium data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

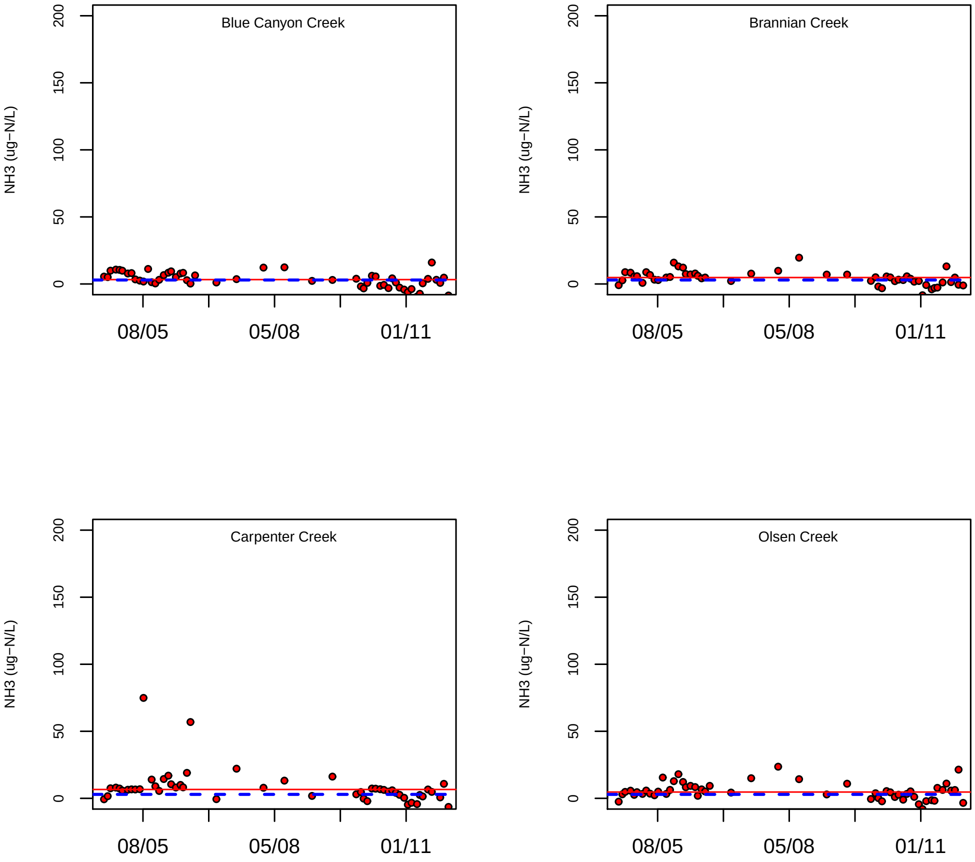


Figure B153: Ammonium data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

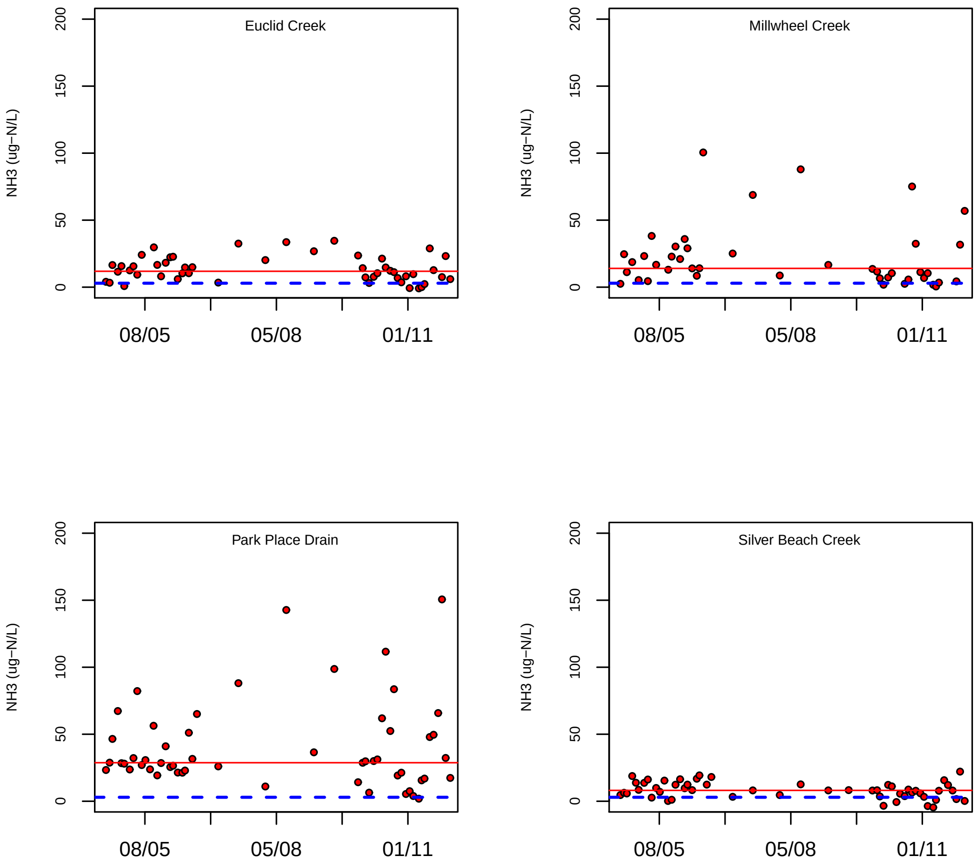


Figure B154: Ammonium data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

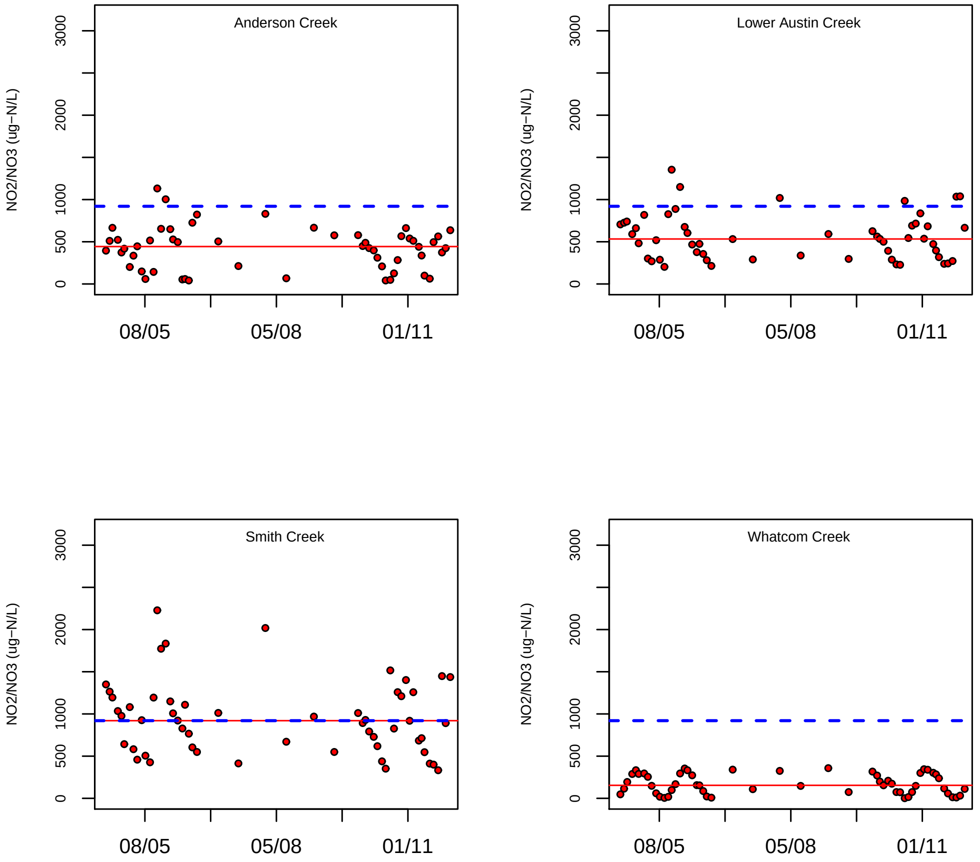


Figure B155: Nitrate/nitrite data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

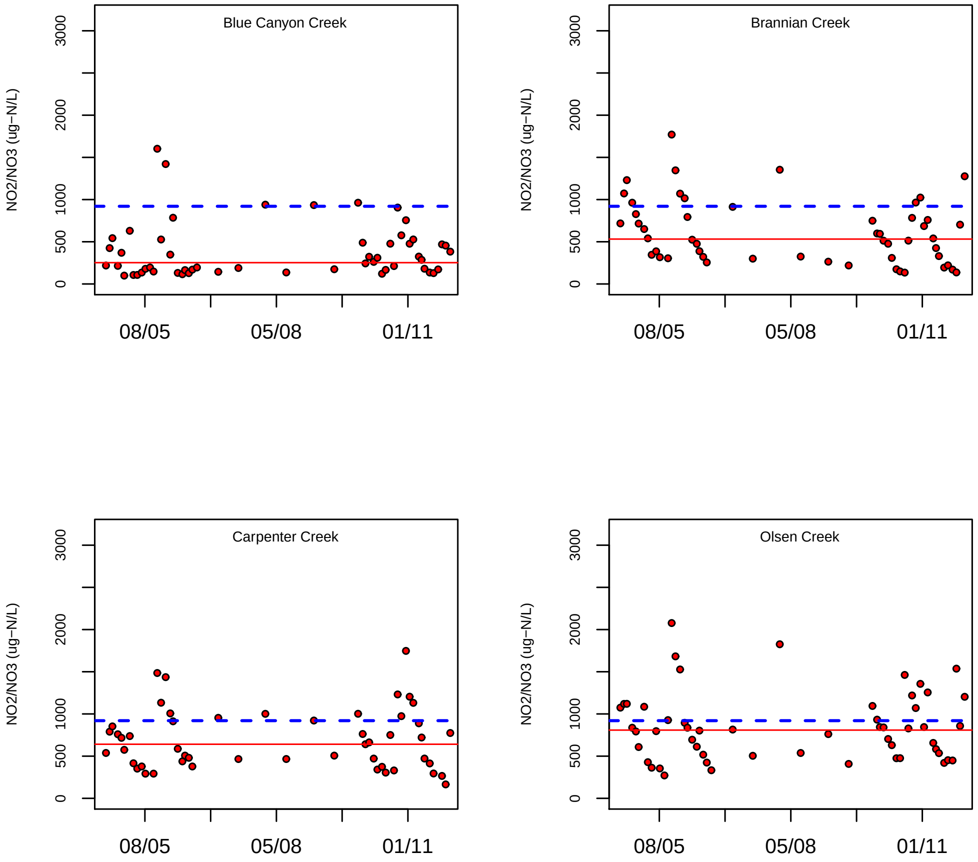


Figure B156: Nitrate/nitrite data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

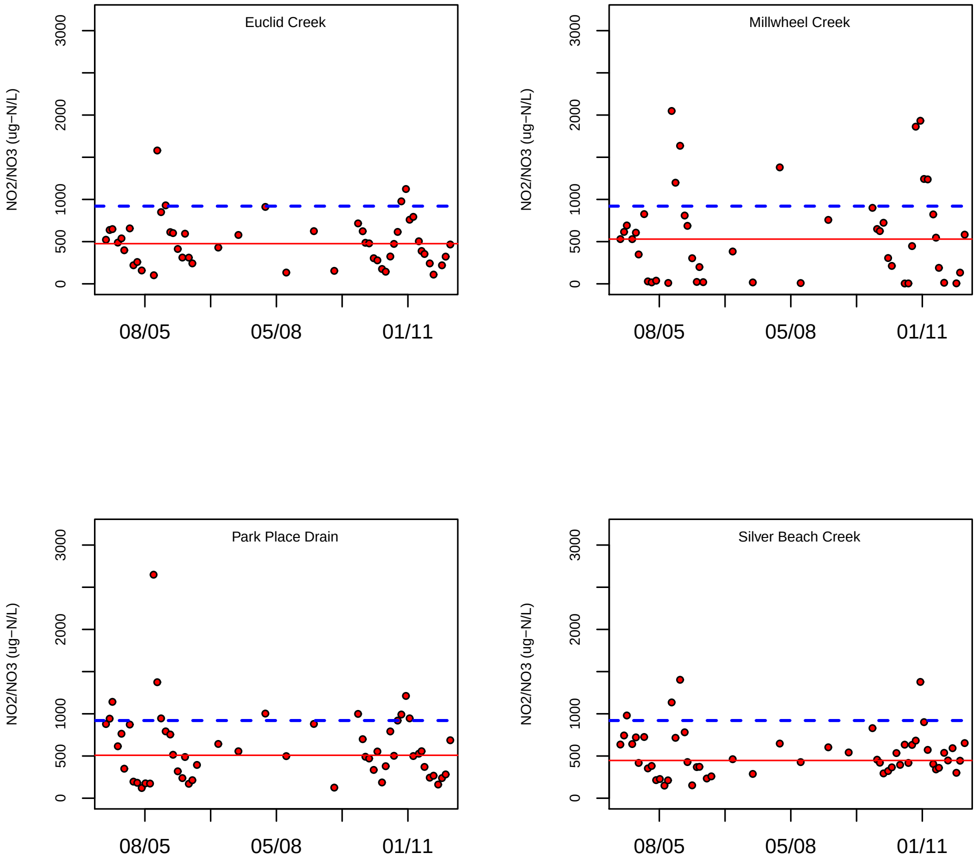


Figure B157: Nitrate/nitrite data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

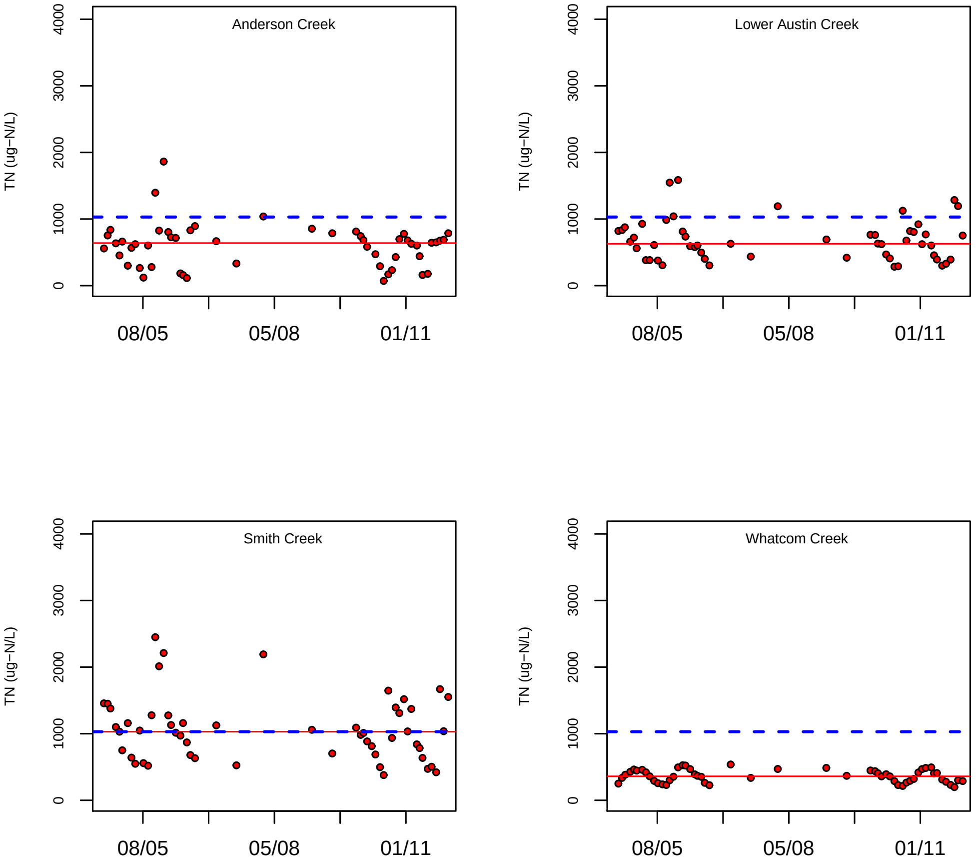


Figure B158: Total nitrogen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

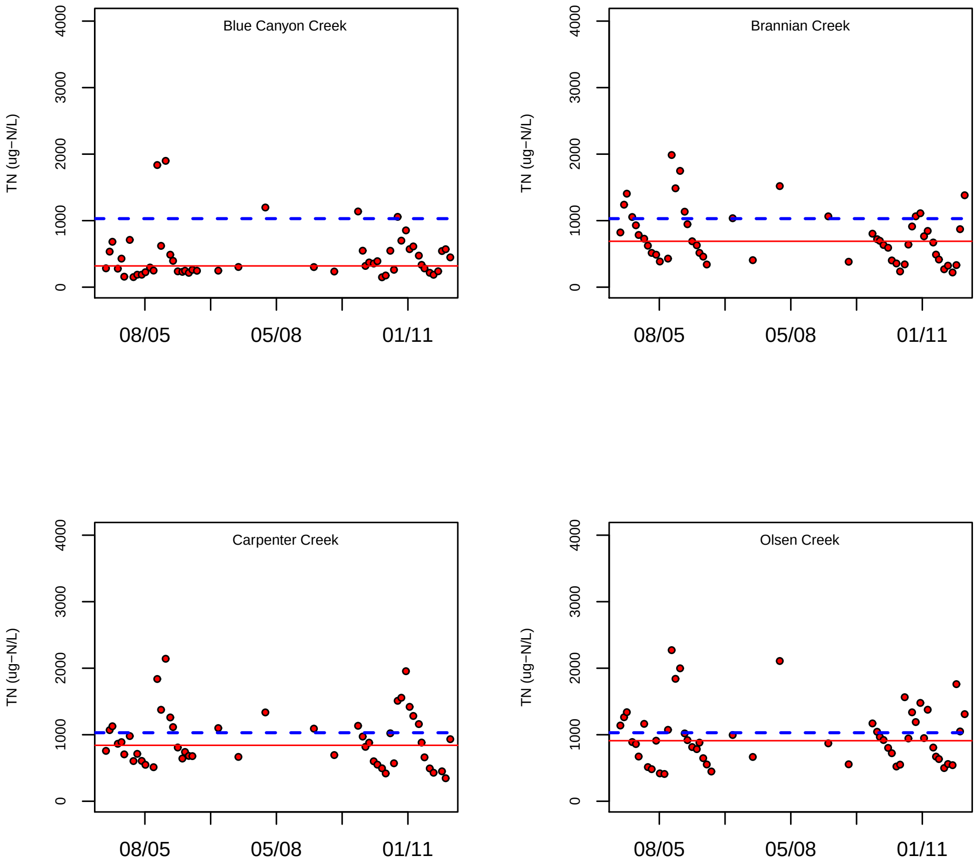


Figure B159: Total nitrogen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

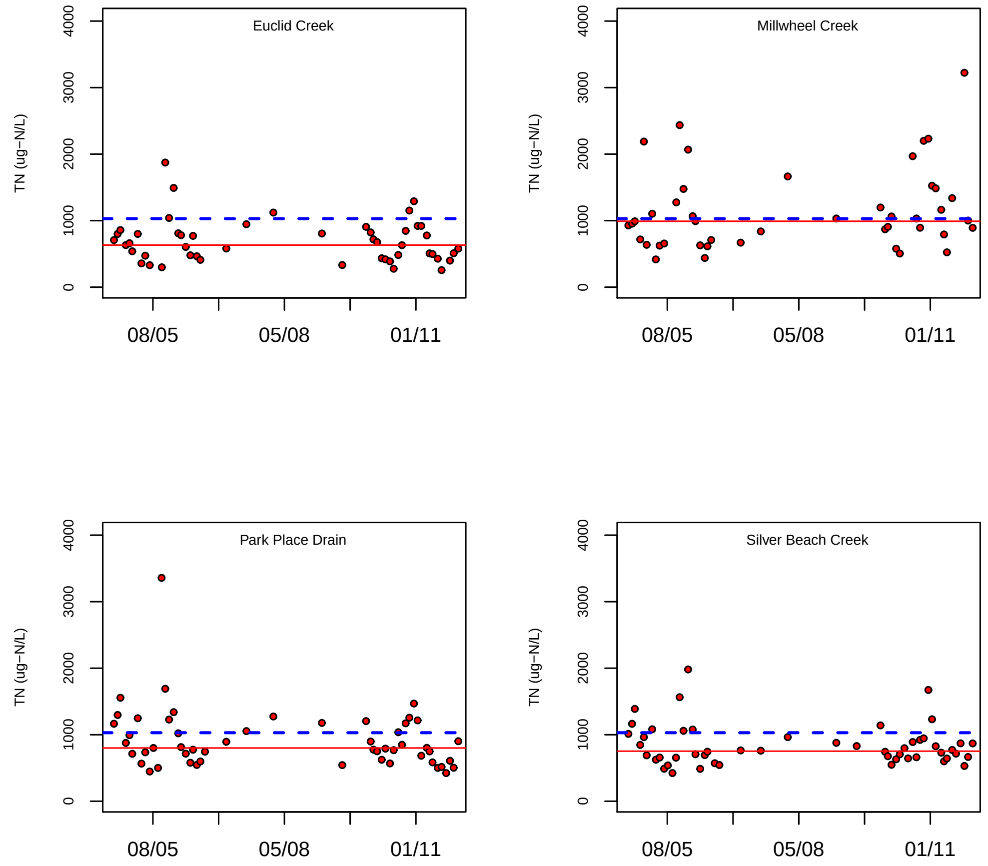


Figure B160: Total nitrogen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

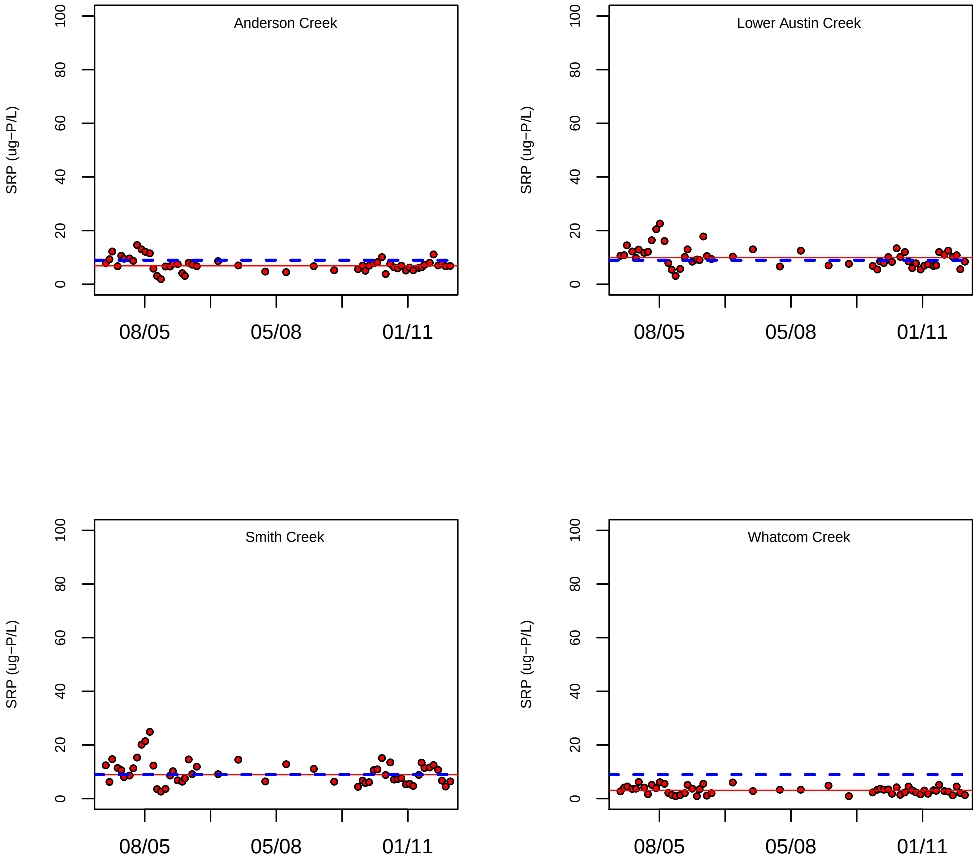


Figure B161: Soluble phosphate data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

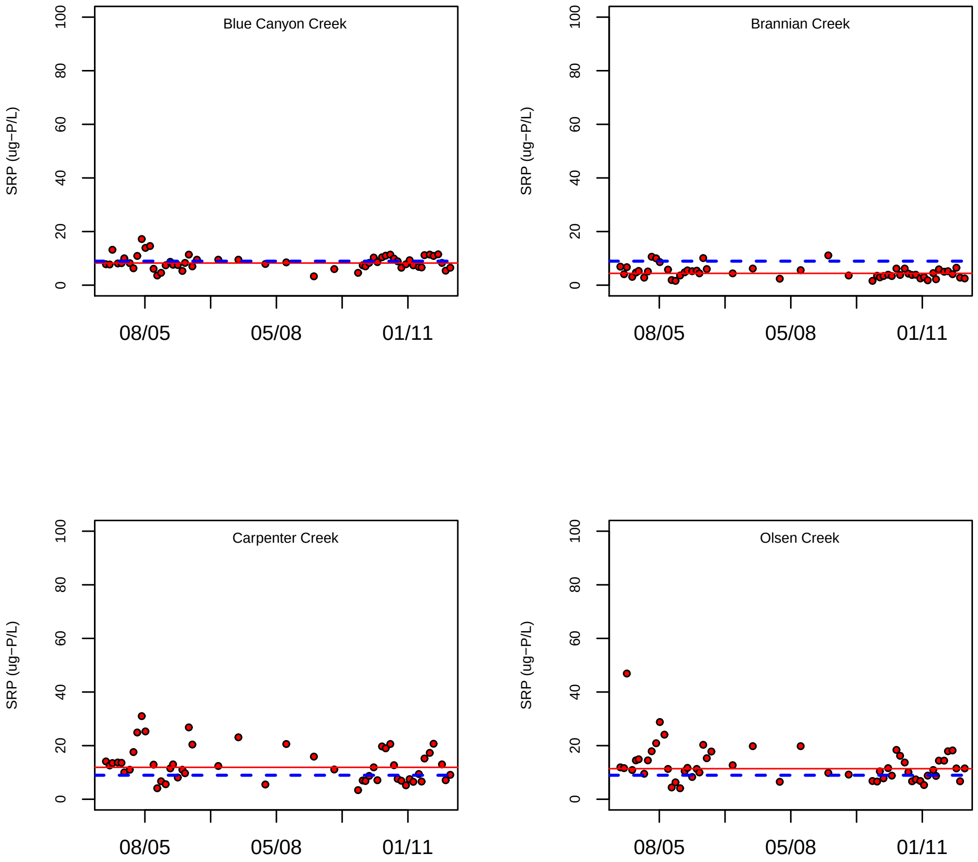


Figure B162: Soluble phosphate data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

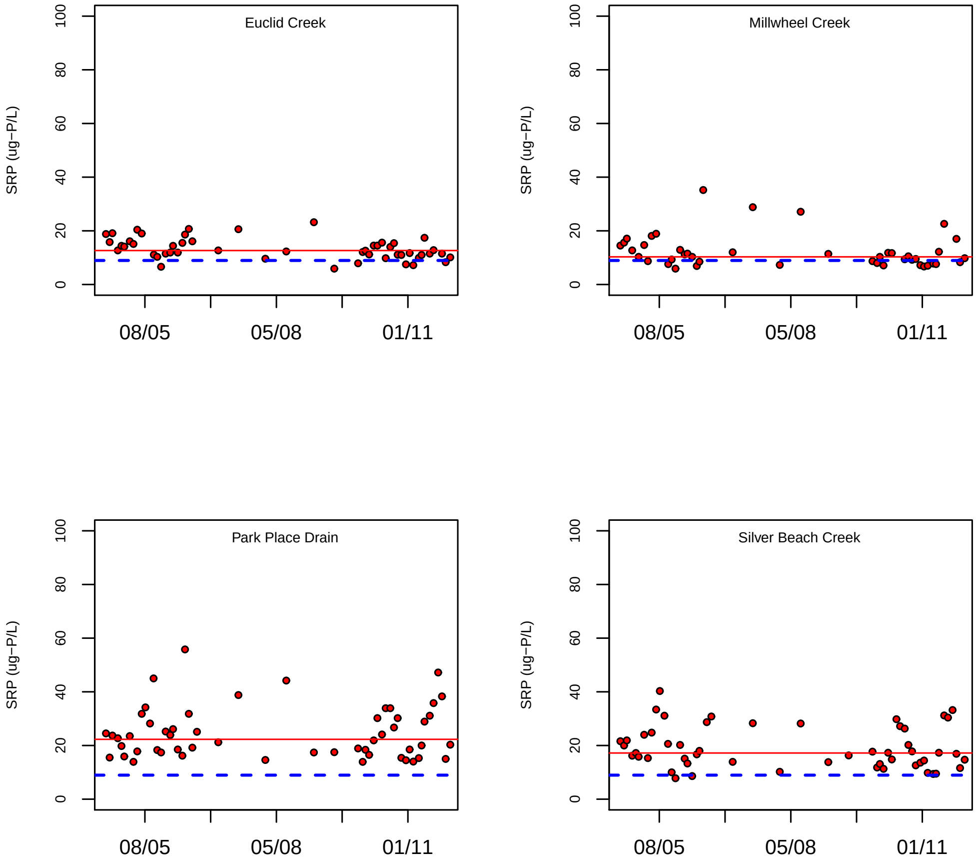


Figure B163: Soluble phosphate data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

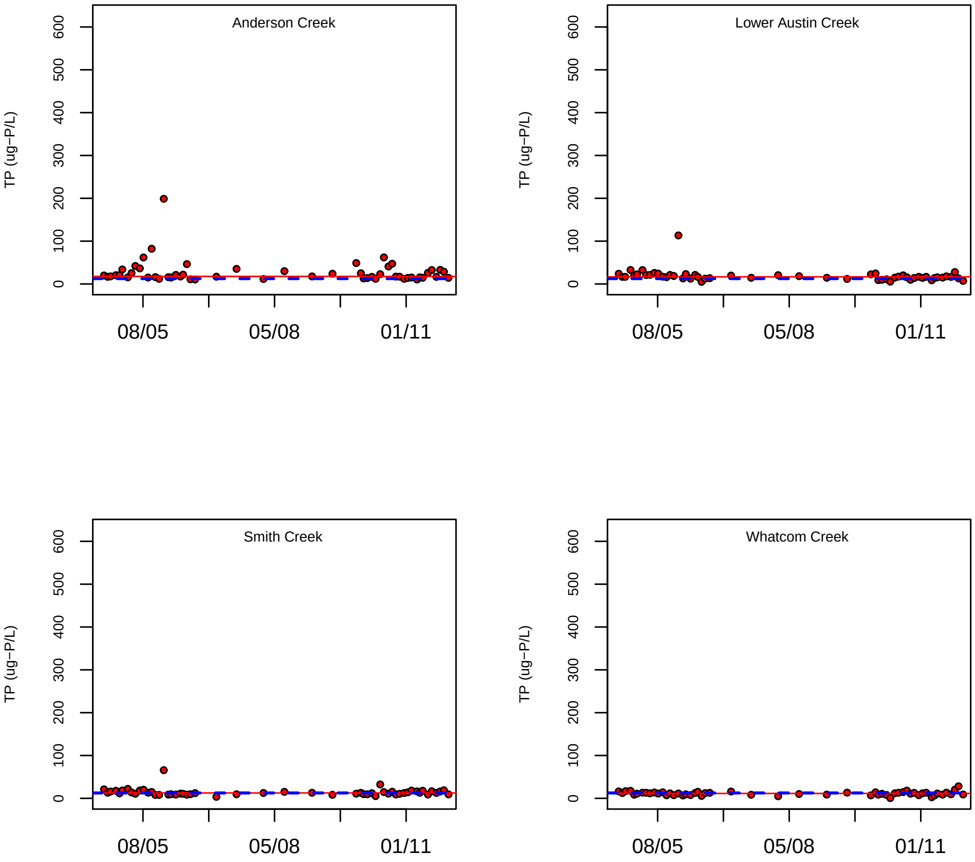


Figure B164: Total phosphorus data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

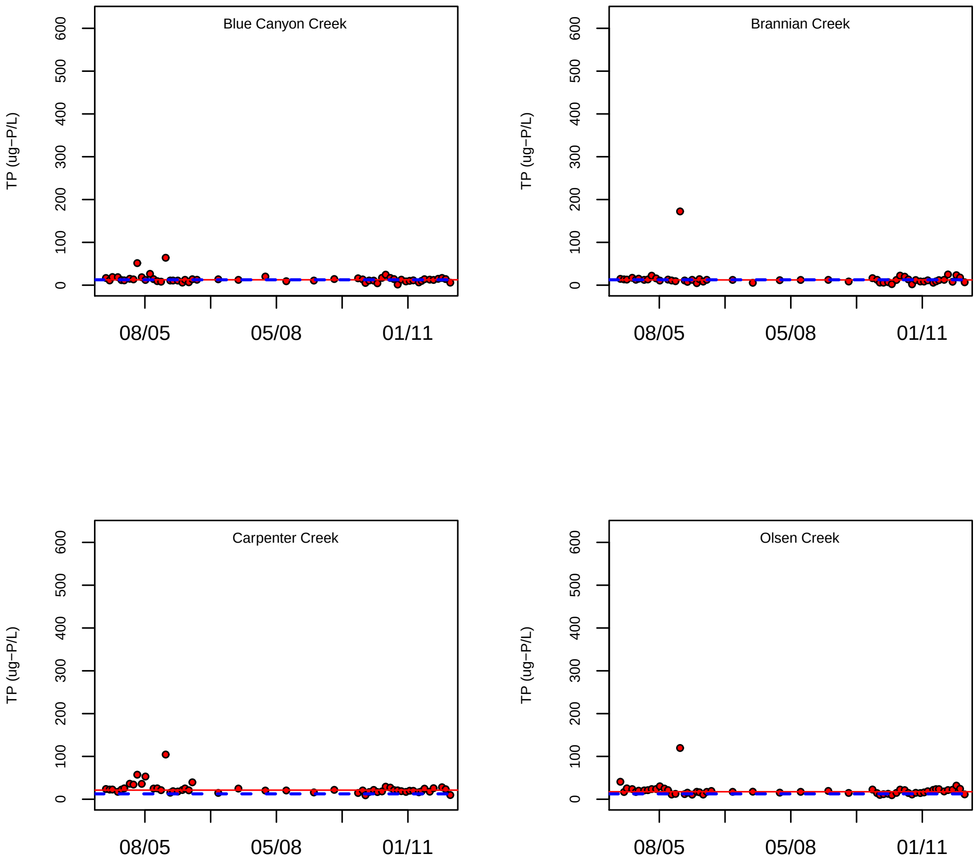


Figure B165: Total phosphorus data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

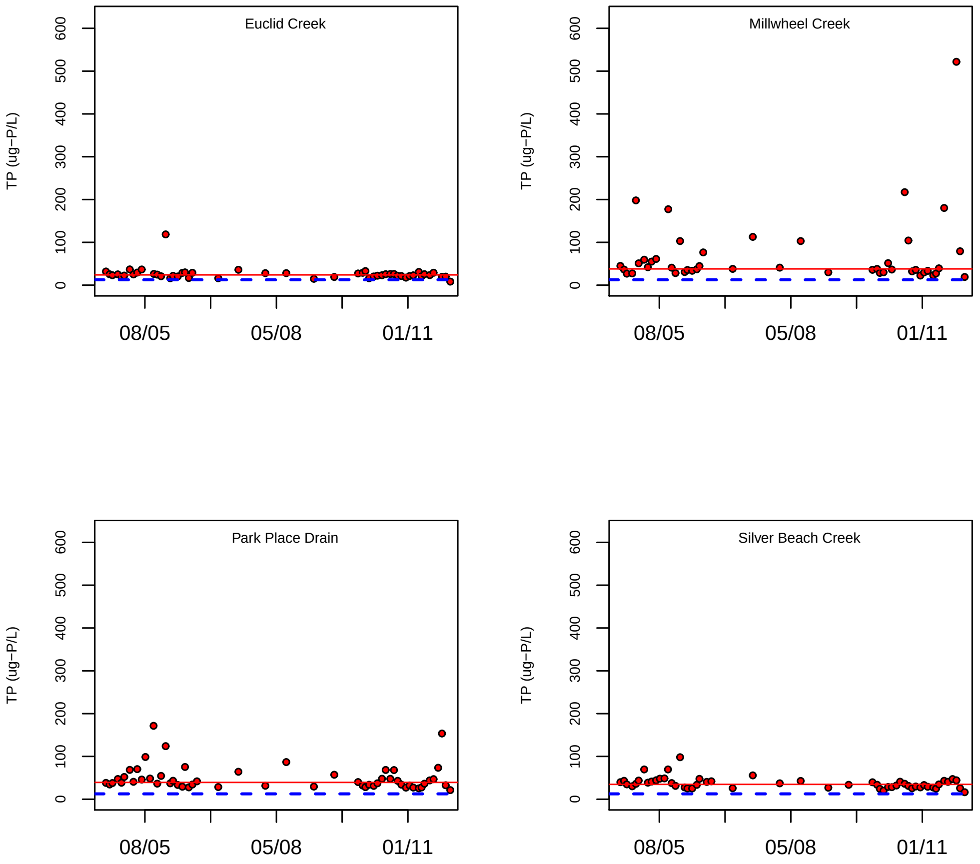


Figure B166: Total phosphorus data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

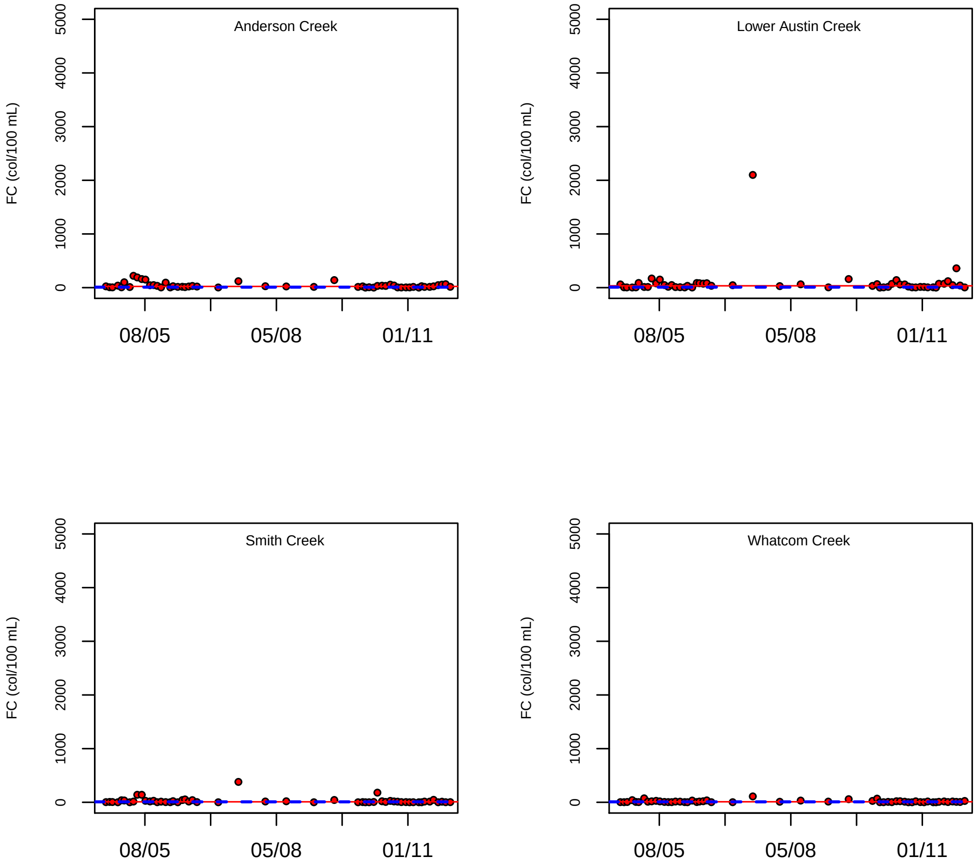
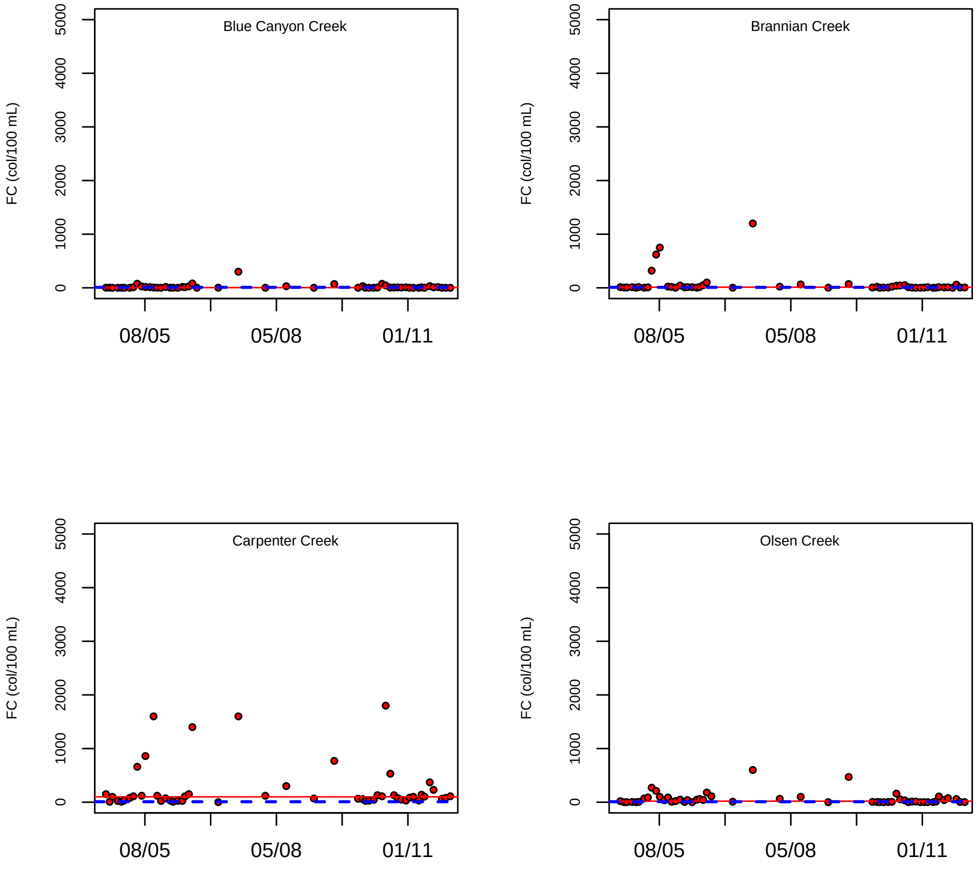


Figure B167: Fecal coliform data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.


Blue Canyon Creek

Brannian Creek

Carpenter Creek

Olsen Creek

Figure B168: Fecal coliform data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

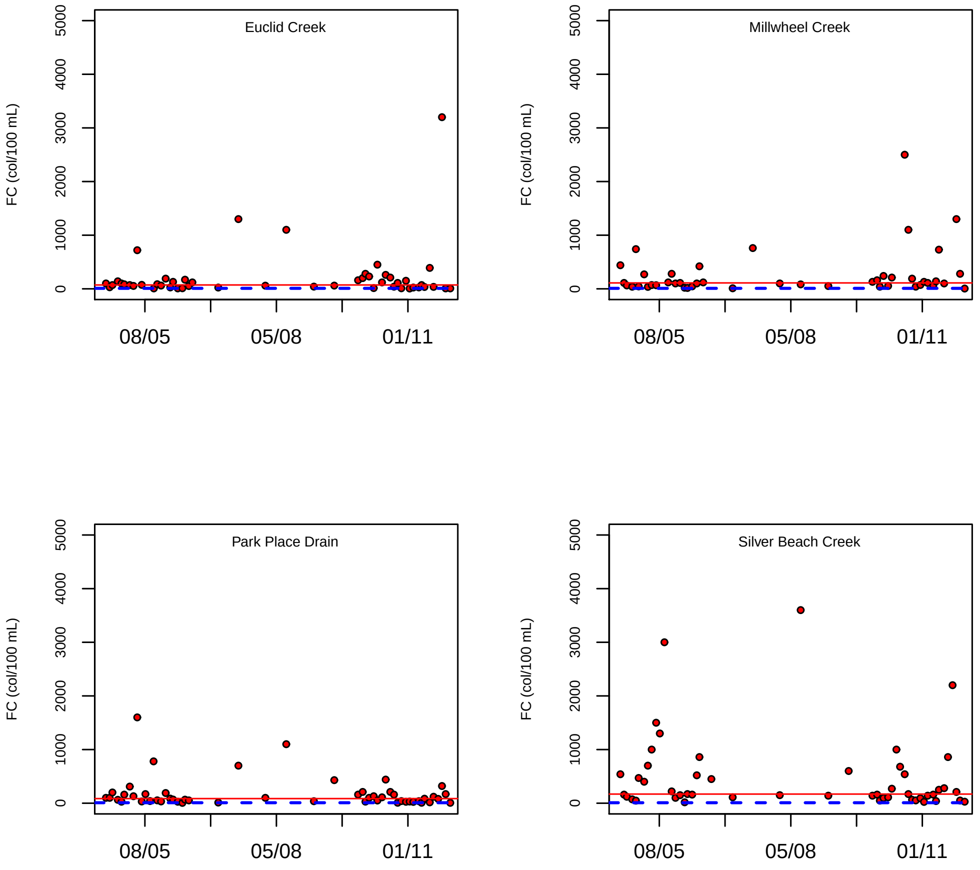


Figure B169: Fecal coliform data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

# C Quality Control

## C.1 Performance Evaluation Report

In order to maintain a high degree of accuracy and confidence in the water quality data all personnel associated with this project were trained according to standard operating procedures for the methods listed in Table 1 (page 17). Single-blind quality control tests were conducted as part of the IWS laboratory certification process (Table C1). All results from the single-blind tests were within acceptance limits.

| | Reported Value† | True Value† | Acceptance Limits | Test Result |
|---|---|---|---|---|
| Specific conductivity ($\mu$S/cm at 25°C) | 397 | 395 | 353–437 | accept |
| Total alkalinity (mg/L as $CaCO_3$) | 54.0 | 56.3 | 49.0–63.6 | accept |
| Ammonium nitrogen, manual (mg-N/L) | 8.95 | 9.04 | 6.68–11.3 | accept |
| Ammonium nitrogen, autoanalysis (mg-N/L) | 9.45 | 9.04 | 6.68–11.3 | accept |
| Nitrate nitrogen, autoanalysis (mg-N/L) | 17.0 | 16.2 | 13.2–18.8 | accept |
| Nitrite nitrogen, autoanalysis (mg-N/L) | 2.96 | 2.98 | 2.53–3.43 | accept |
| Orthophosphate, manual (mg-P/L) | 3.50 | 3.57 | 2.93–4.24 | accept |
| Orthophosphate, autoanalysis (mg-P/L) | 3.54 | 3.57 | 2.93–4.24 | accept |
| Total phosphorus, manual (mg-P/L) | 2.80 | 2.92 | 2.37–3.53 | accept |
| Total phosphorus, autoanalysis (mg-P/L) | 2.85 | 2.92 | 2.37–3.53 | accept |
| pH | 7.96 | 7.90 | 7.70–8.10 | accept |
| Solids, non-filterable (mg/L) | 71.9 | 77.0 | 62.6–85.9 | accept |
| Turbidity (NTU) | 2.62 | 2.52 | 1.95–3.11 | accept |

Table C1: Single-blind quality control results, WP–170 (04/15/2011).

## C.2 Laboratory Duplicates, Spikes, and Check Standards

Ten percent of all lake, storm water, and tributary samples analyzed in the laboratory were duplicated to measure analytical precision. Sample matrix spikes were analyzed during each analytical run to evaluate analyte recovery for the nutrient analyses (ammonium, nitrate/nitrite, total nitrogen, soluble reactive phosphate, and total phosphorus). External check standards were analyzed during each analytical run to evaluate measurement precision and accuracy.[24]

The quality control results for laboratory duplicates, matrix spikes, and check standards are plotted in control charts. Upper and lower acceptance limits (± 2 std. dev. from mean pair difference) and upper and lower warning limits (± 3 std. dev. from mean pair difference) were developed using data from September 2006 through September 2009 (upper examples in Figures C1–C30, pages 286–315), and used to evaluate data from October 2009 through September 2010 (lower examples in Figures C1–C30).

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[24] External check standards are not available for all analytes.

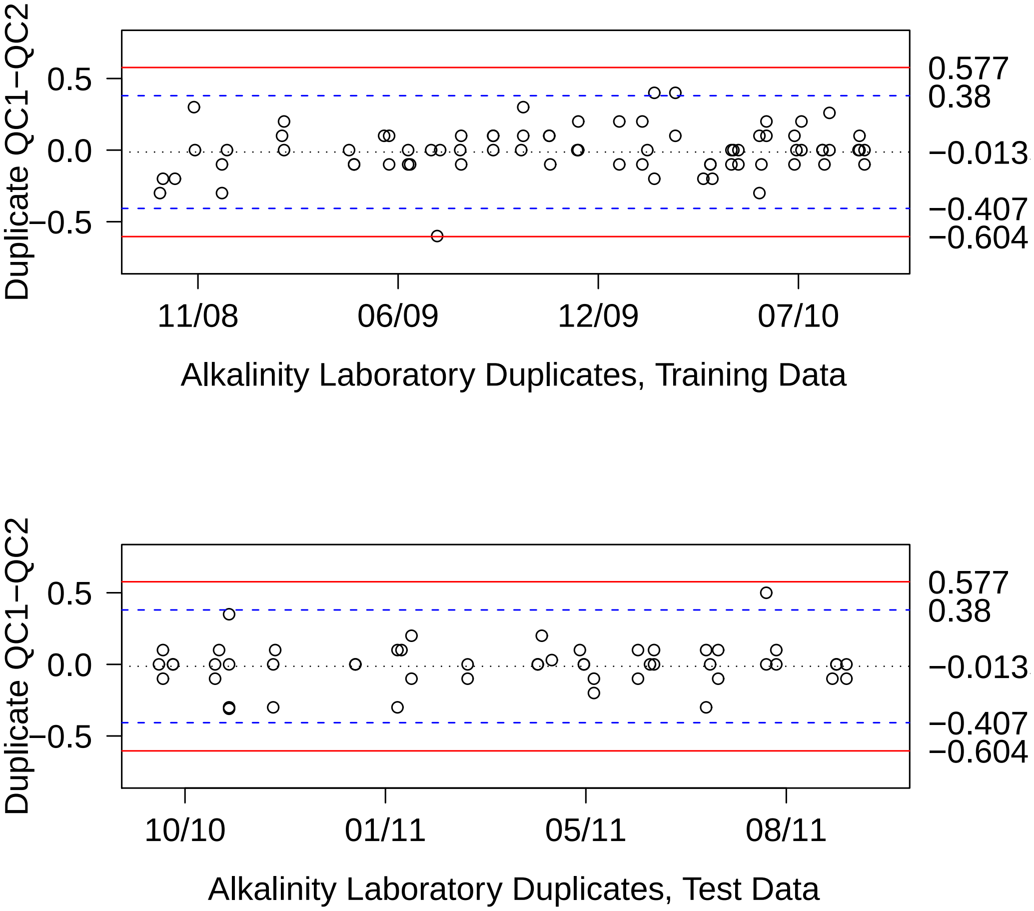
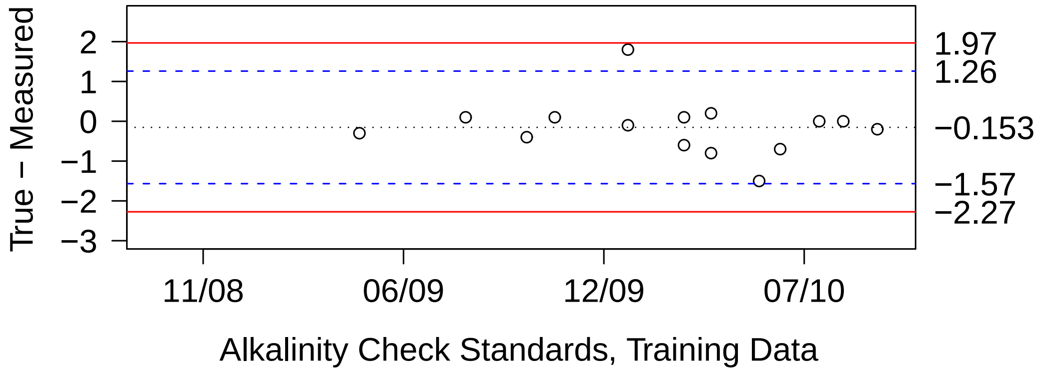


Figure C1: Alkalinity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



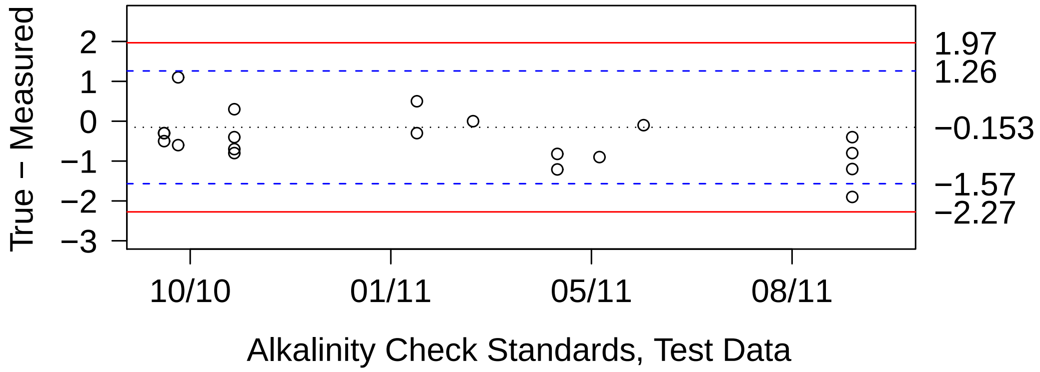
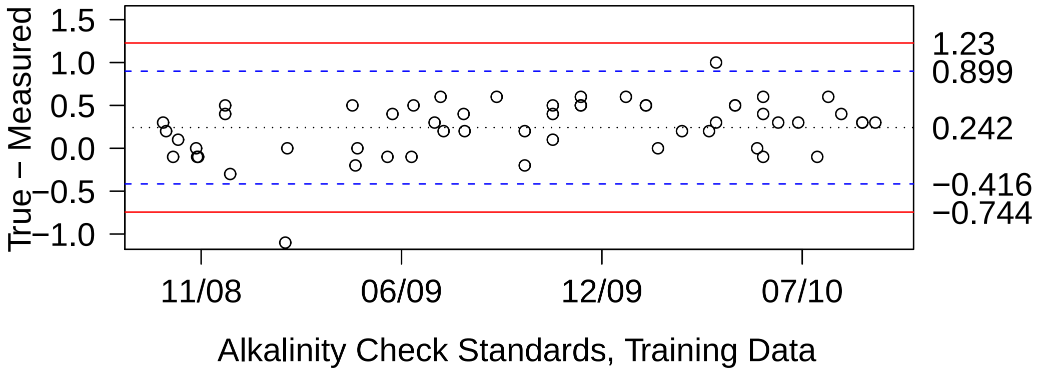


Figure C2: Alkalinity high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



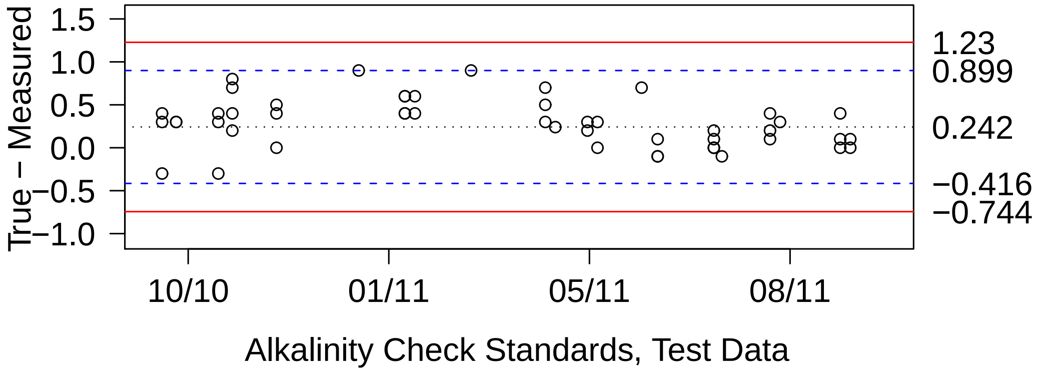
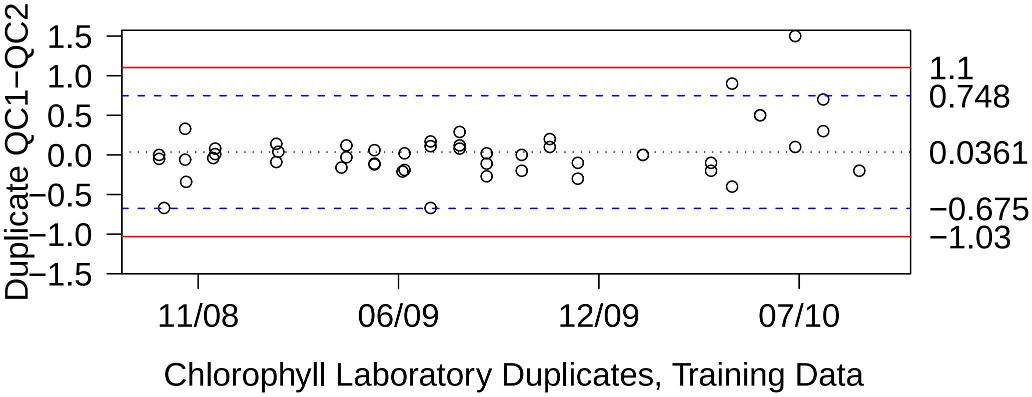


Figure C3: Alkalinity low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



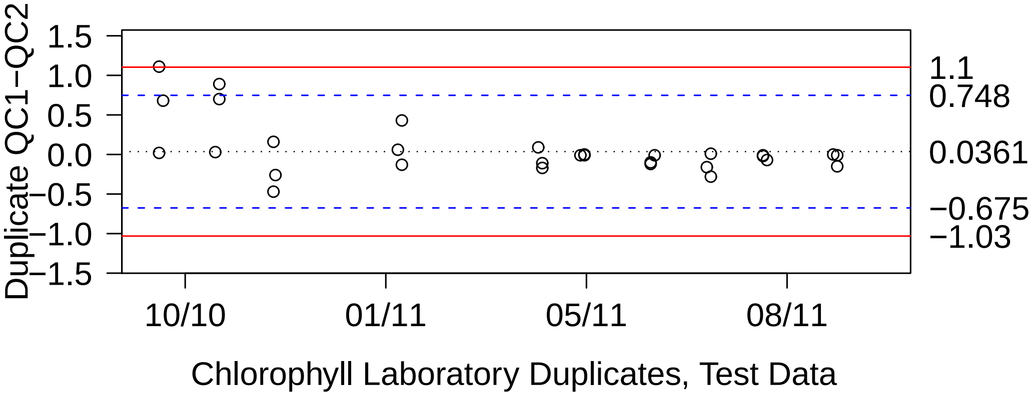
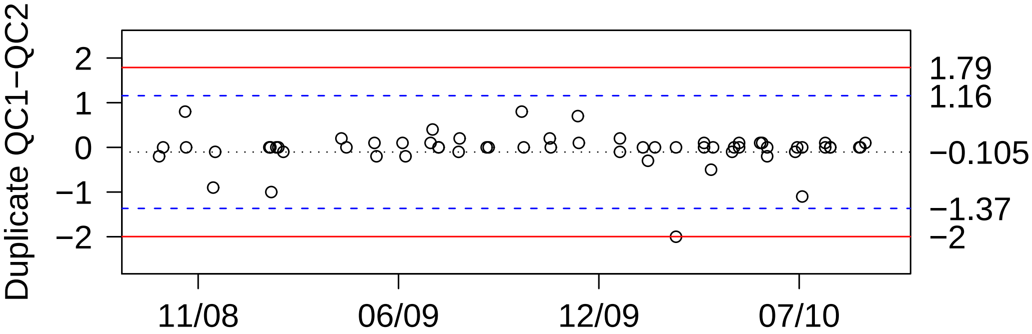
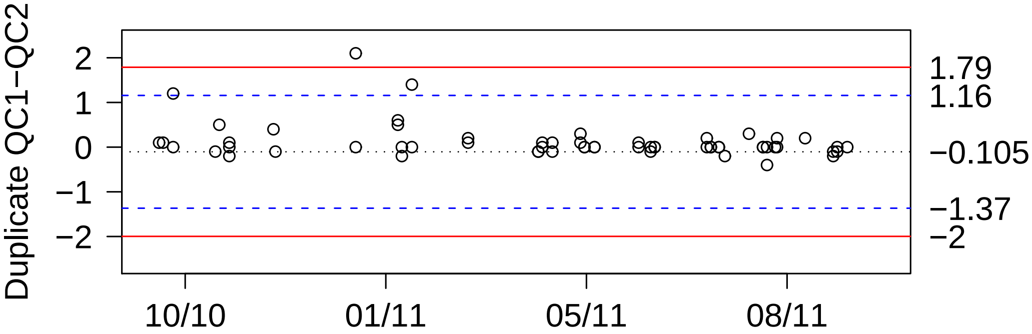


Figure C4: Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program (lake samples). Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

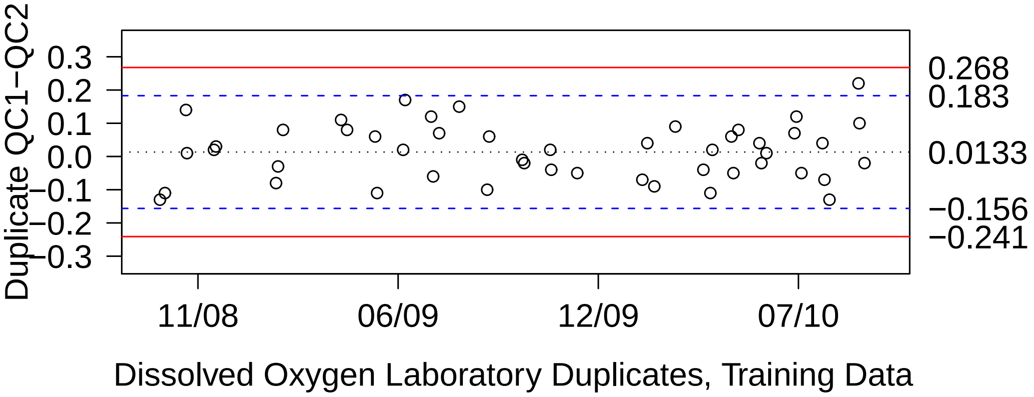


Conductivity Laboratory Duplicates, Training Data



Conductivity Laboratory Duplicates, Test Data

Figure C5: Conductivity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



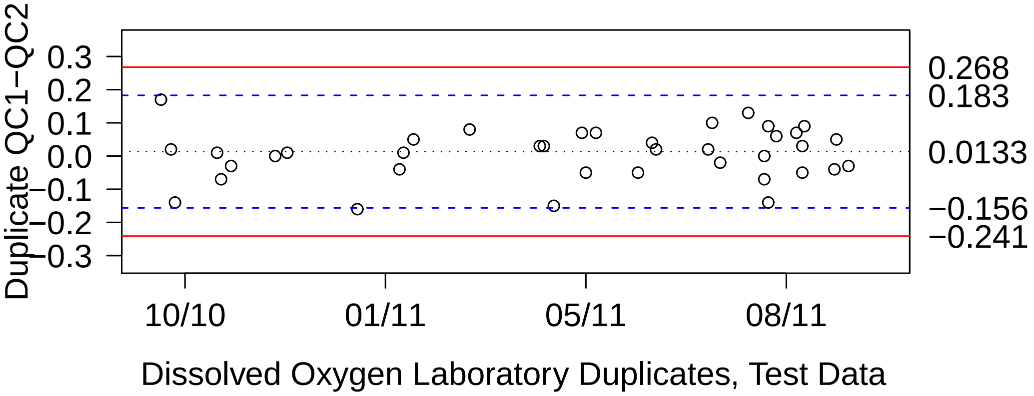


Figure C6: Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

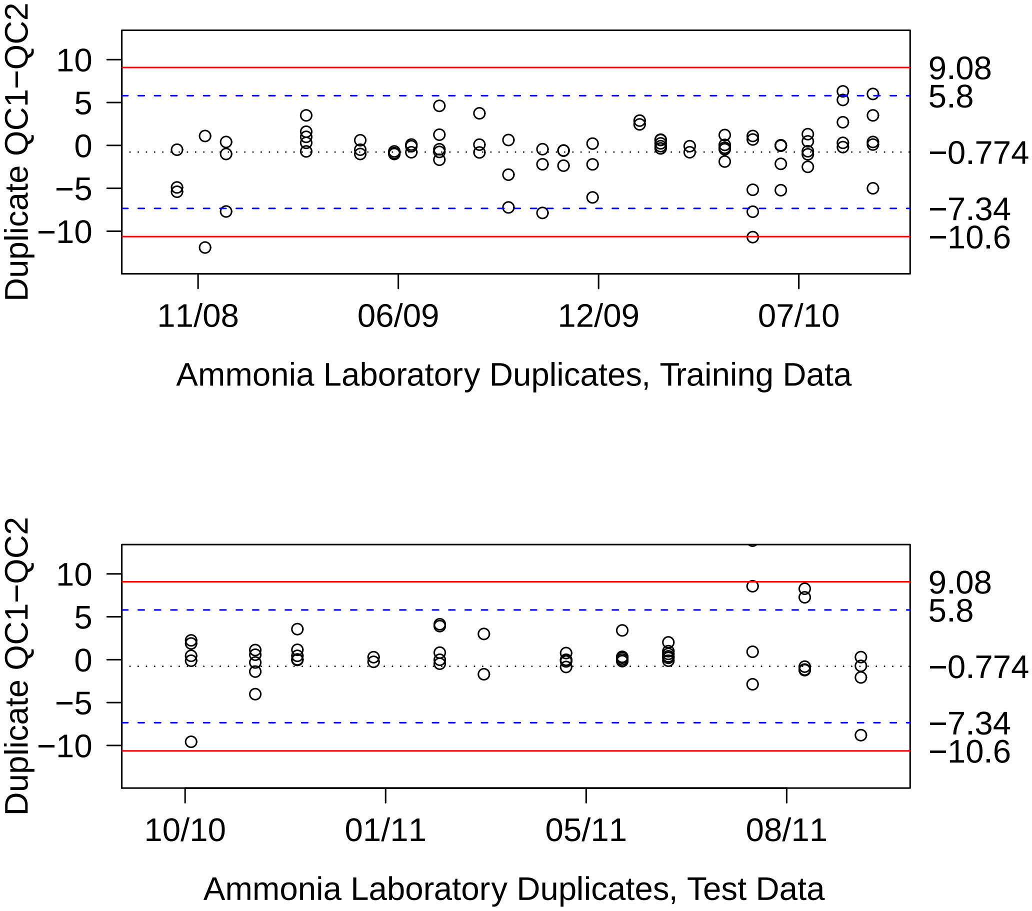
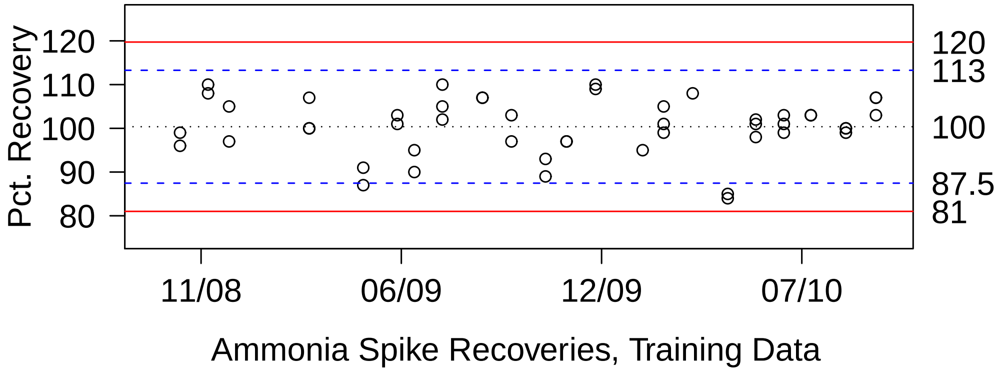


Figure C7: Ammonium laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



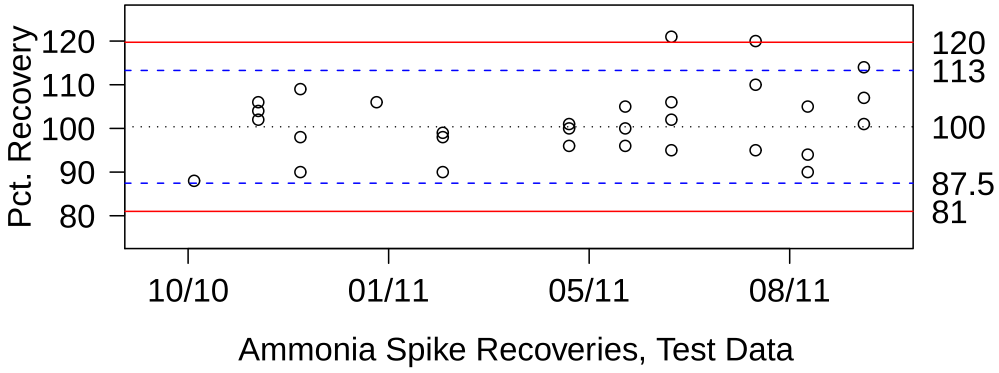
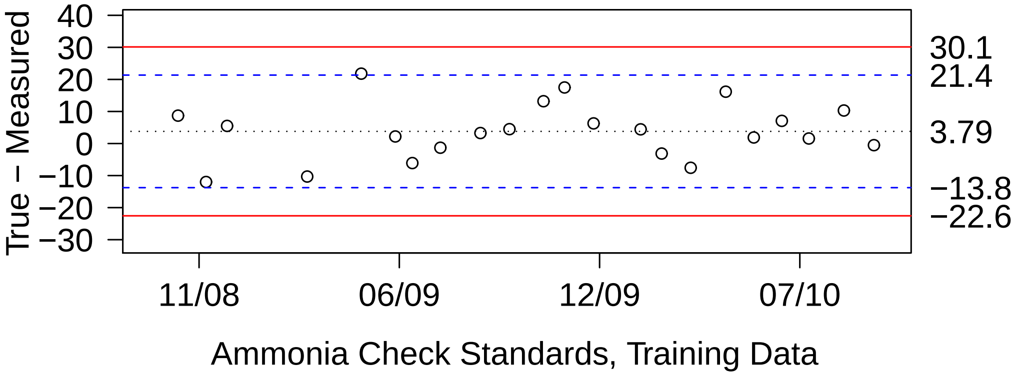


Figure C8: Ammonium matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data. Although the training



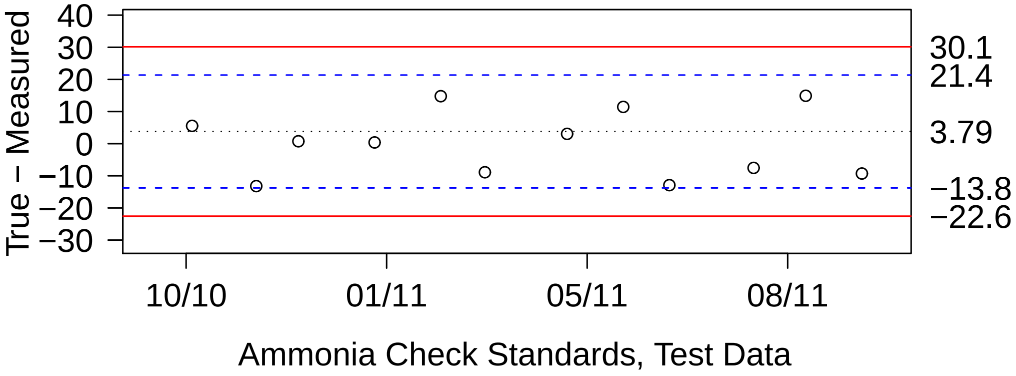


Figure C9: Ammonium high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

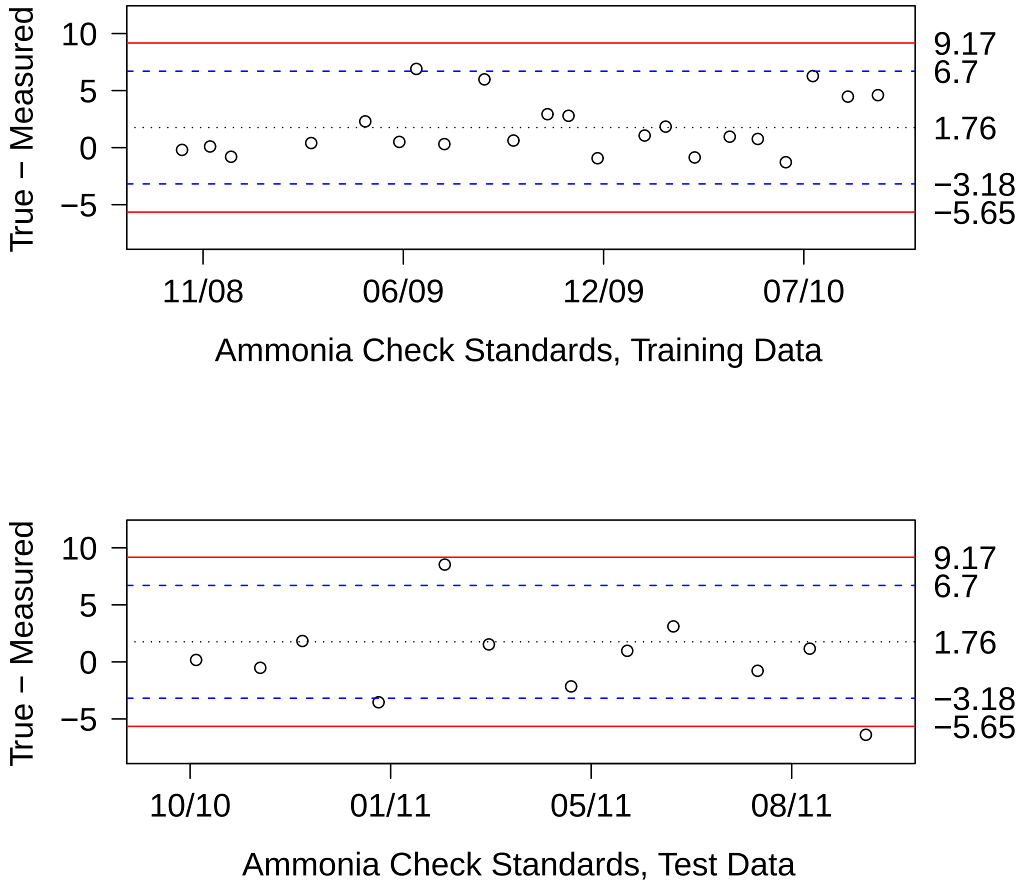
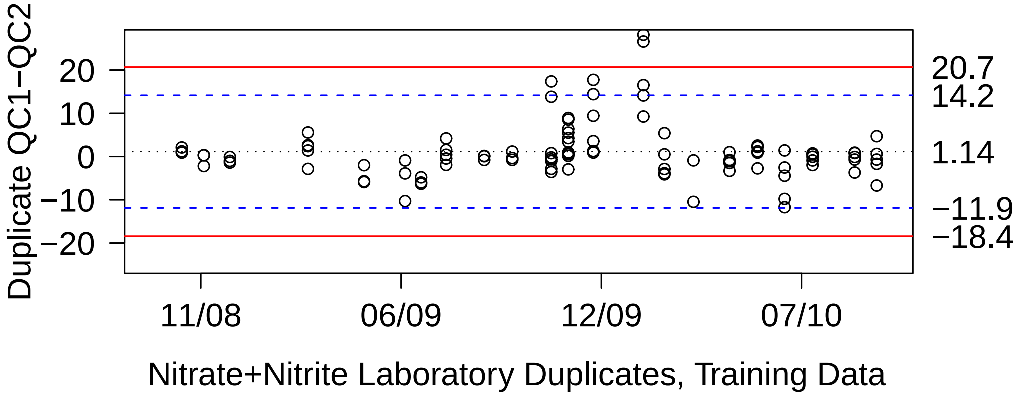


Figure C10: Ammonium low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



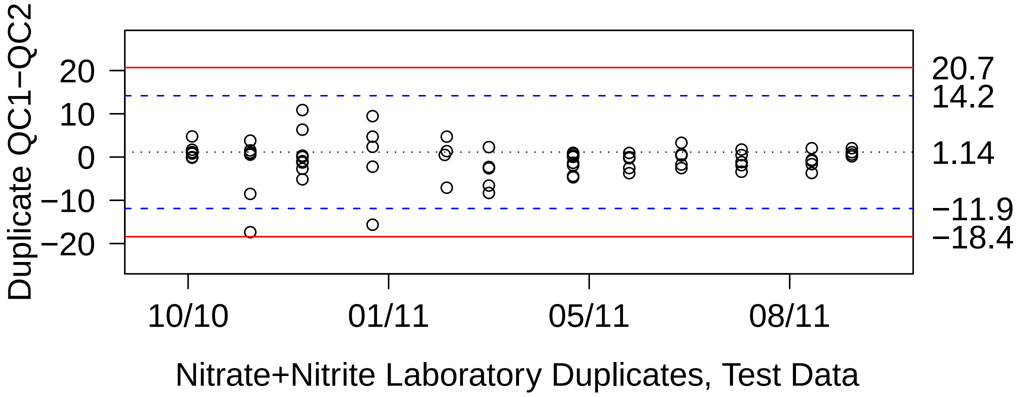
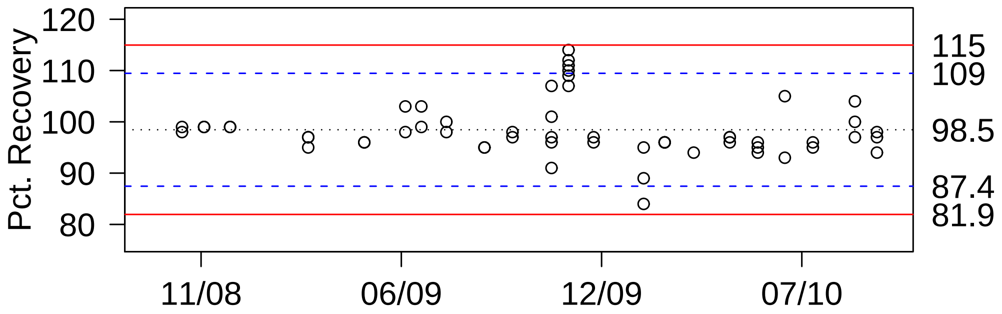
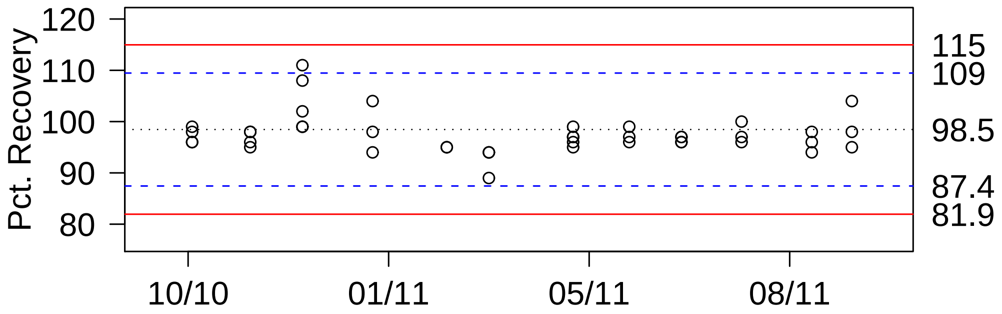


Figure C11: Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data. Increased variability was noted in February 2009; instrument repaired in March 2009.

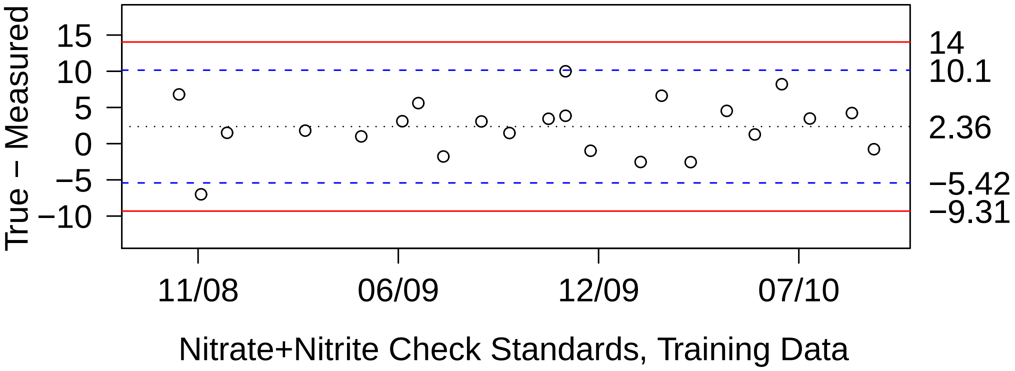


Nitrate+Nitrite Spike Recoveries, Training Data



Nitrate+Nitrite Spike Recoveries, Test Data

Figure C12: Nitrate/nitrite matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



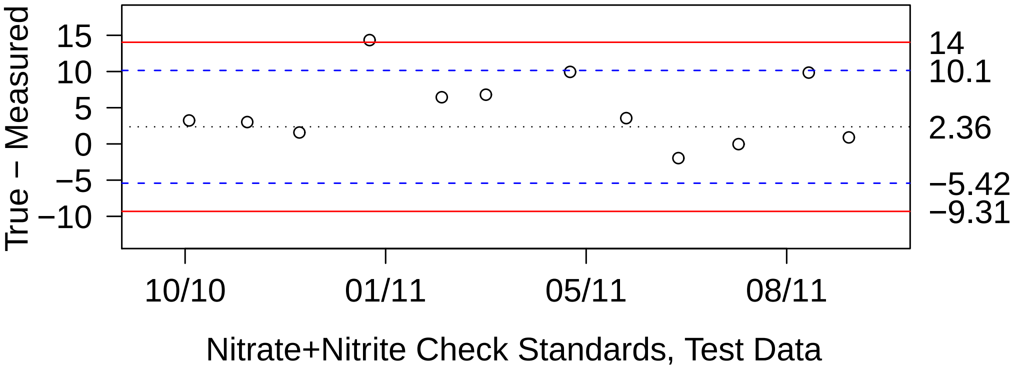
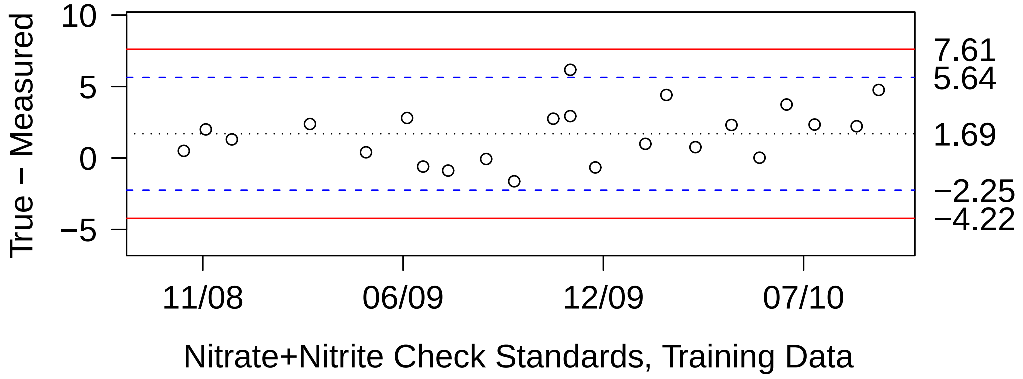


Figure C13: Nitrate/nitrite high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



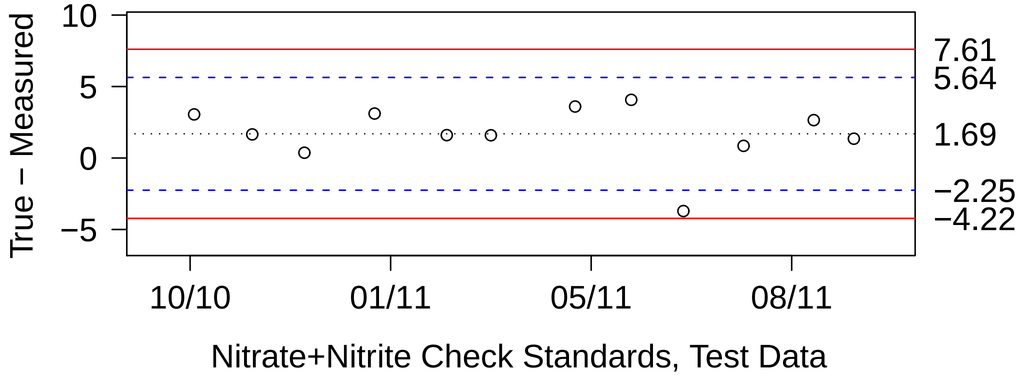
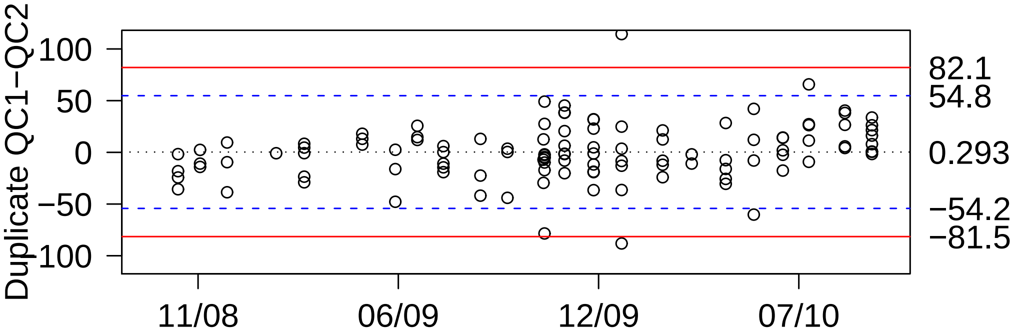
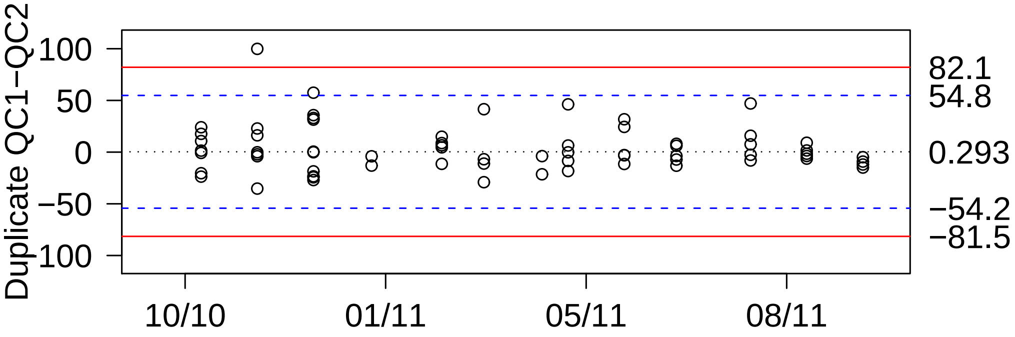


Figure C14: Nitrate/nitrite low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

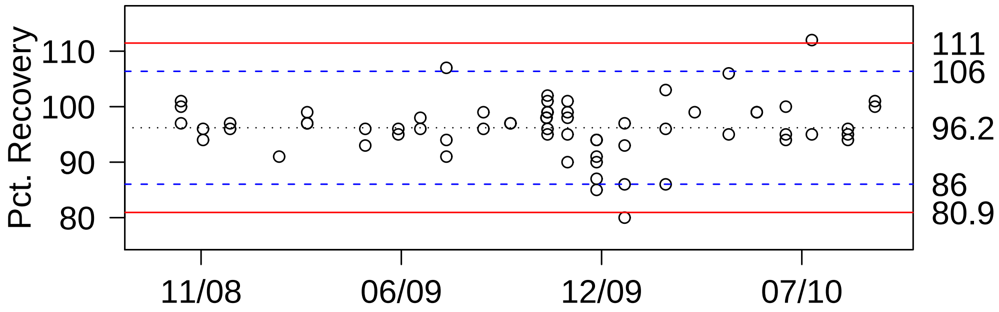


Total Persulfate Nitrogen Laboratory Duplicates, Training Data

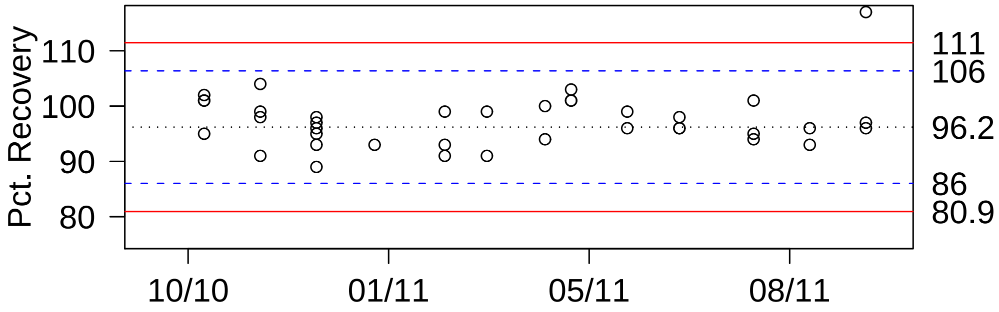


Total Persulfate Nitrogen Laboratory Duplicates, Test Data

Figure C15: Total nitrogen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

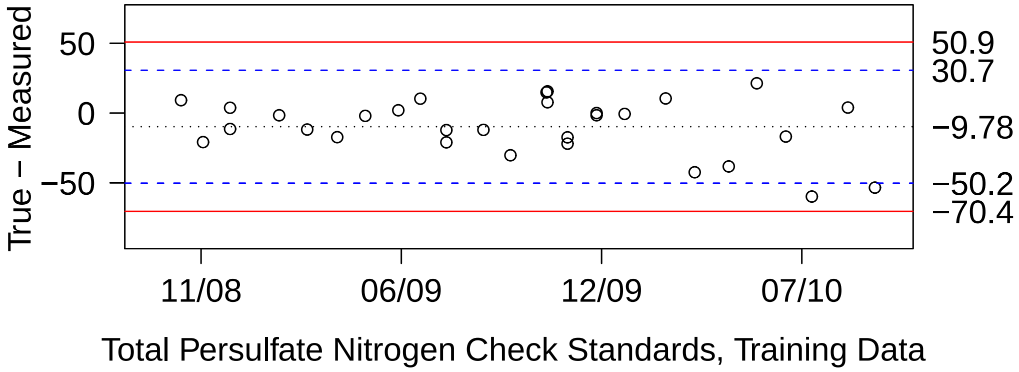


Total Persulfate Nitrogen Spike Recoveries, Training Data



Total Persulfate Nitrogen Spike Recoveries, Test Data

Figure C16: Total nitrogen matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



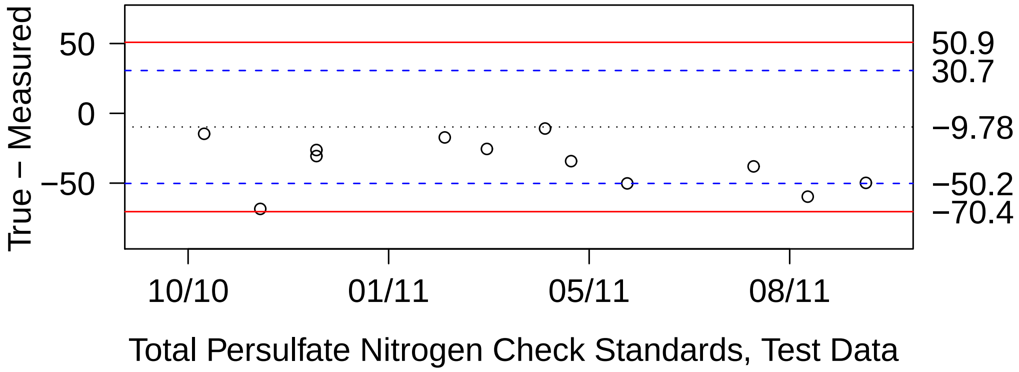
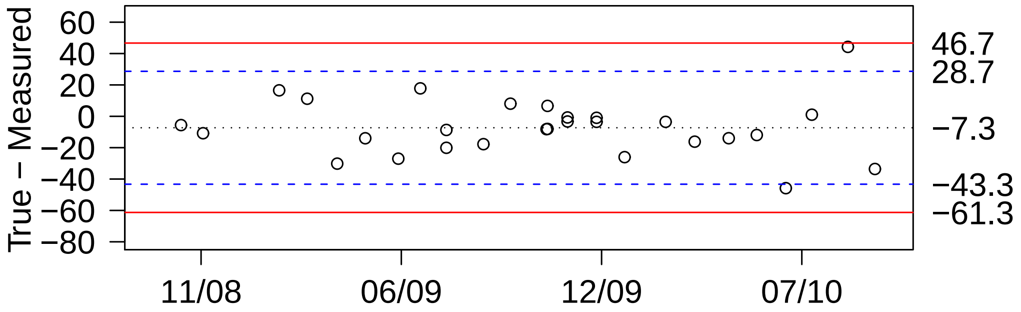
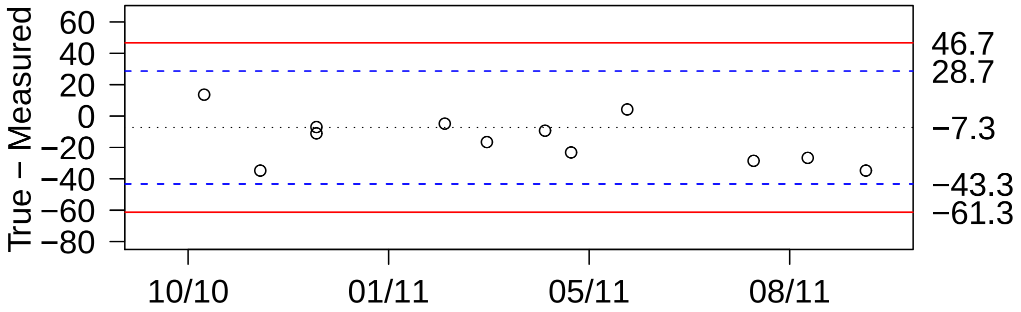


Figure C17: Total nitrogen high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

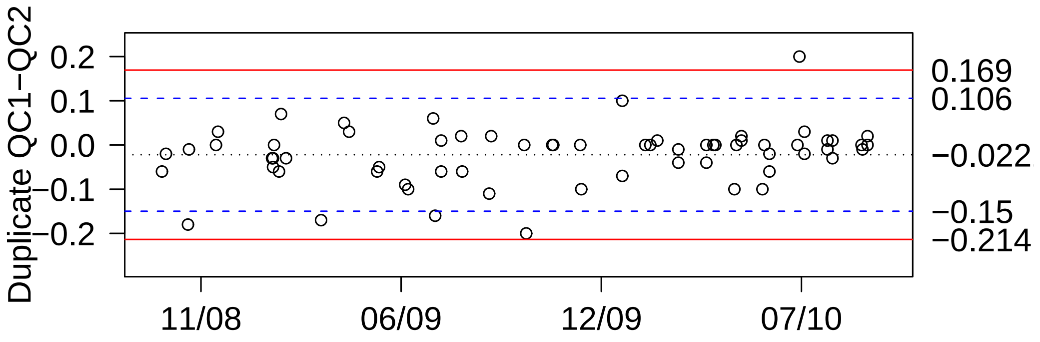


Total Persulfate Nitrogen Check Standards, Training Data

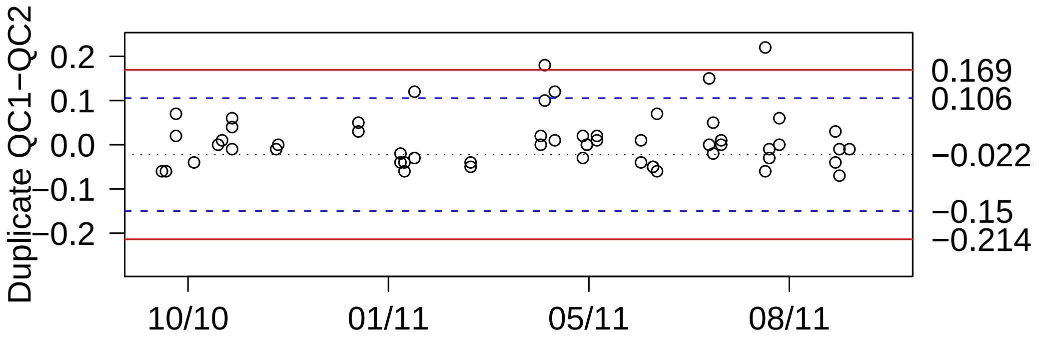


Total Persulfate Nitrogen Check Standards, Test Data

Figure C18: Total nitrogen low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

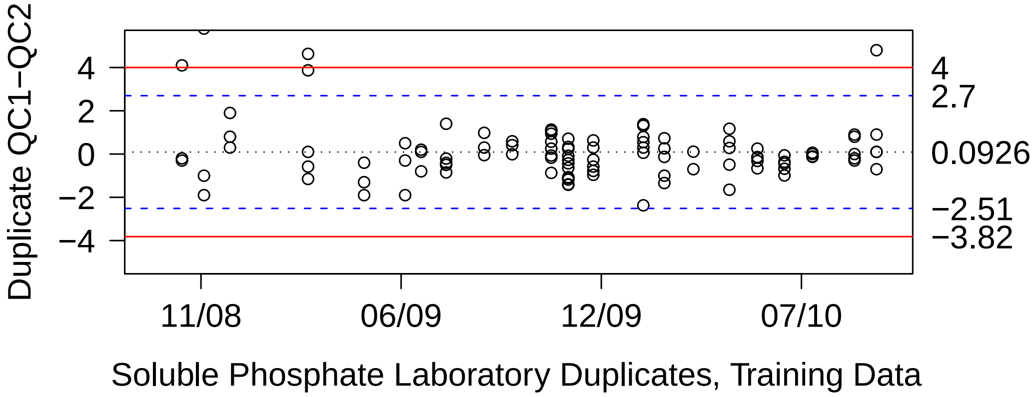


ph Laboratory Duplicates, Training Data



ph Laboratory Duplicates, Test Data

Figure C19: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



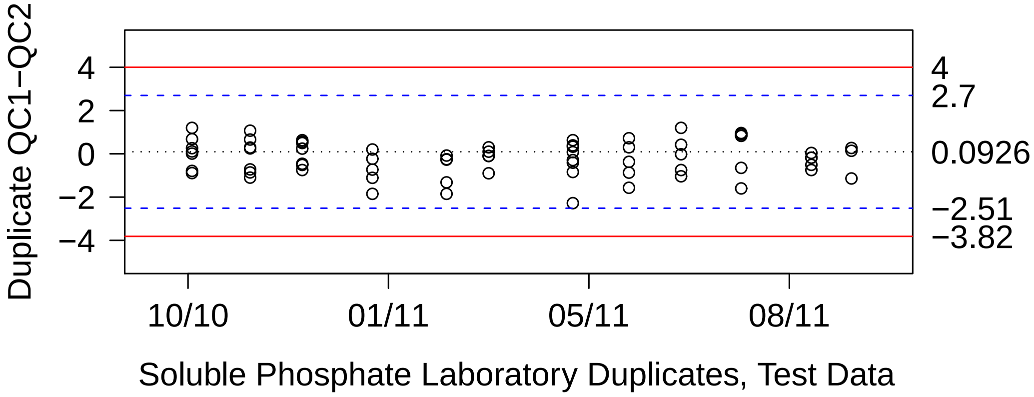
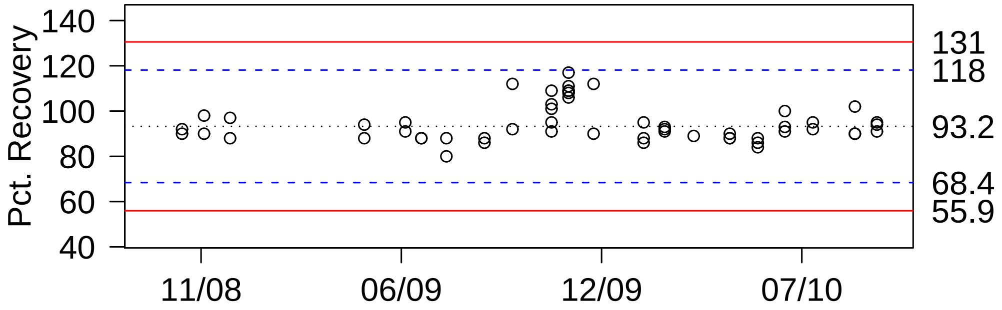
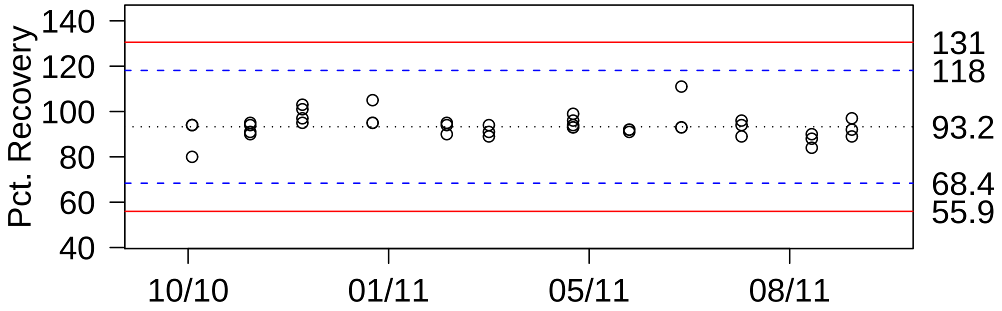


Figure C20: Soluble reactive phosphate laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



Soluble Phosphate Spike Recoveries, Training Data



Soluble Phosphate Spike Recoveries, Test Data

Figure C21: Soluble reactive phosphate matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

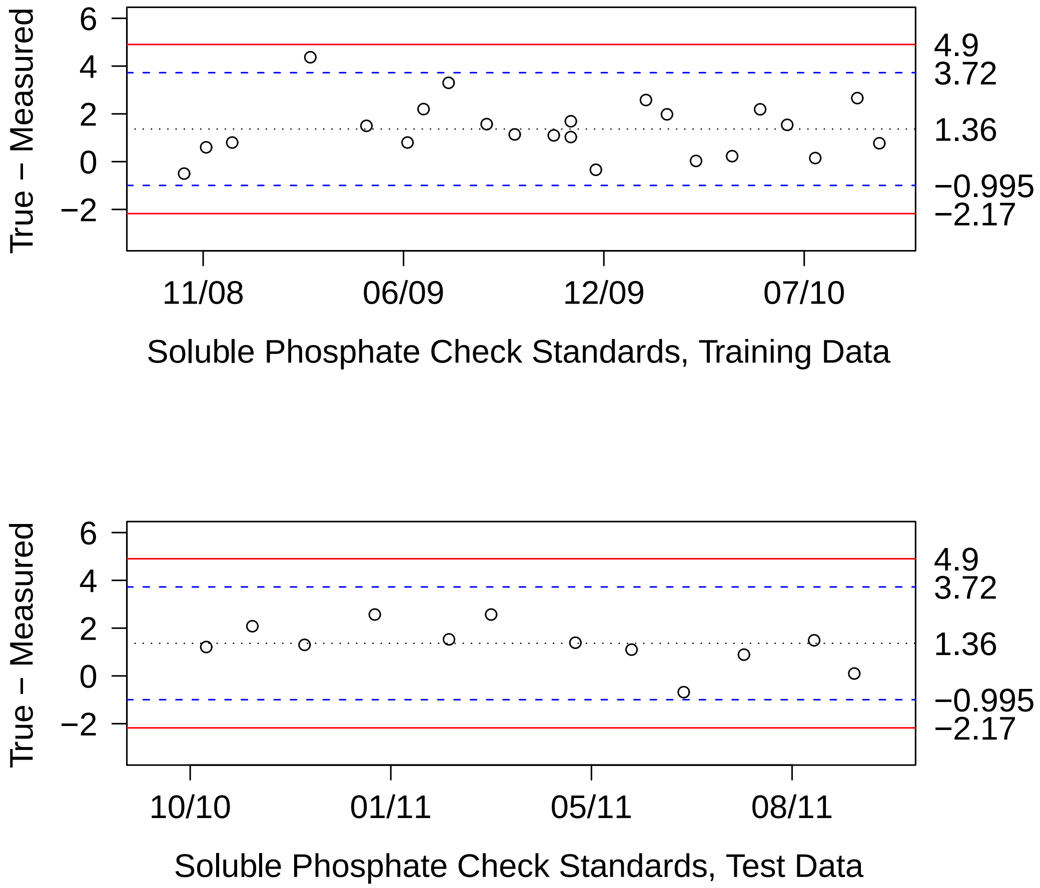
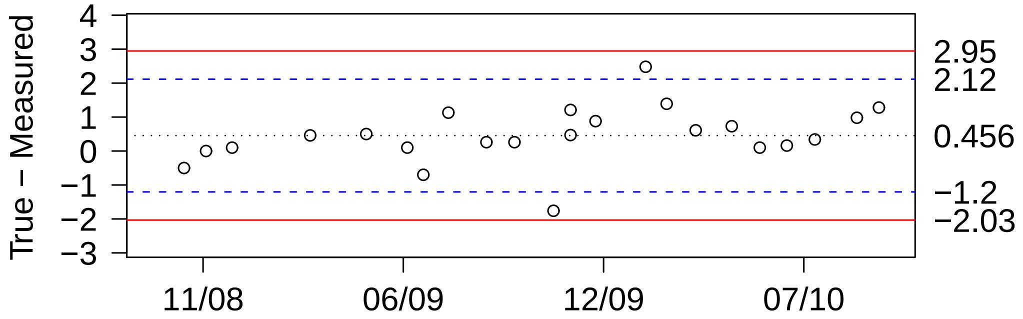
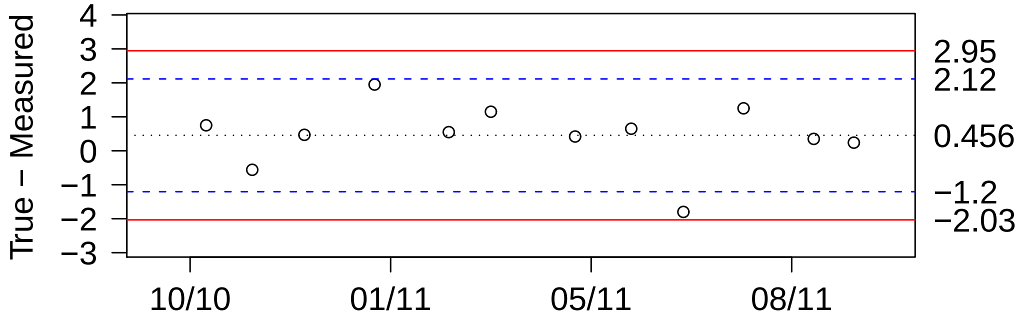


Figure C22: Soluble reactive phosphate high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

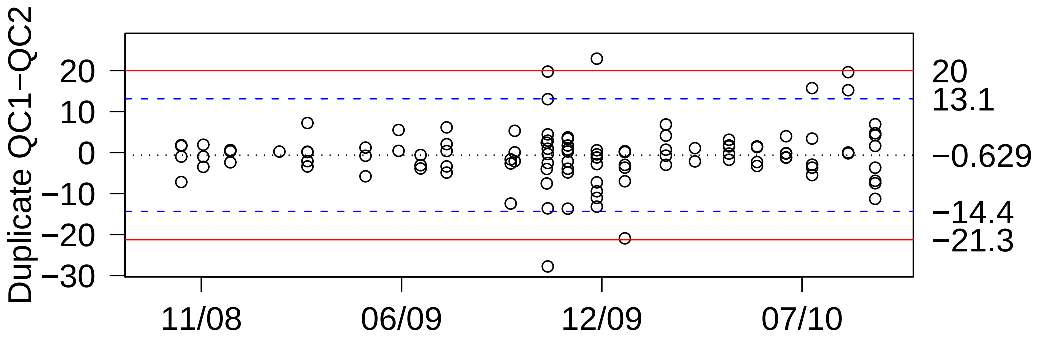


Soluble Phosphate Check Standards, Training Data

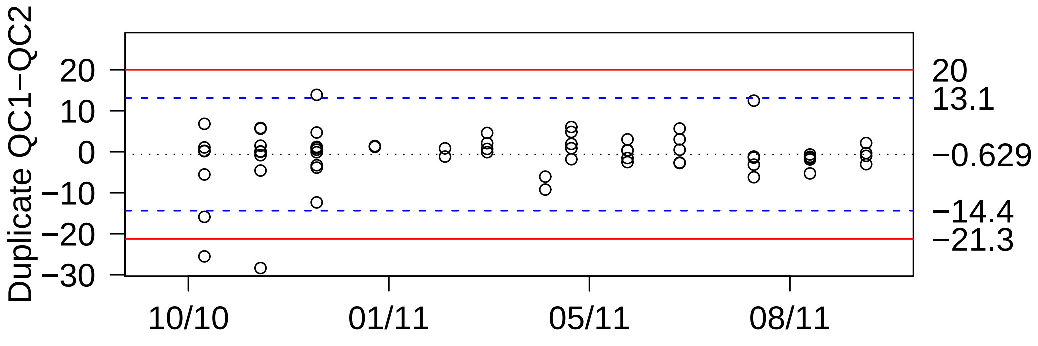


Soluble Phosphate Check Standards, Test Data

Figure C23: Soluble reactive phosphate low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

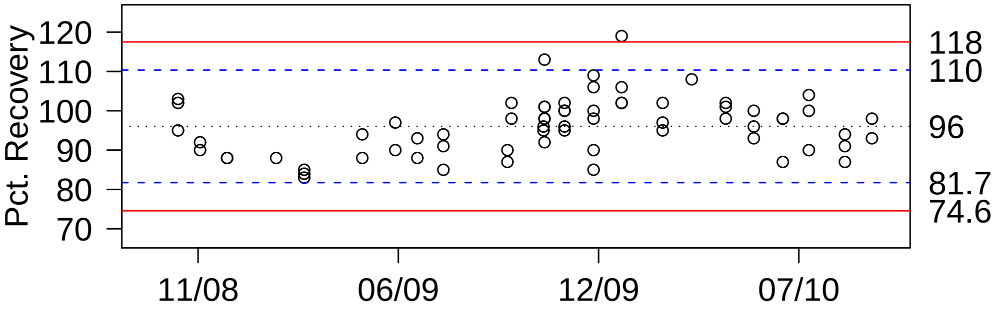


Total Phosphorus Laboratory Duplicates, Training Data

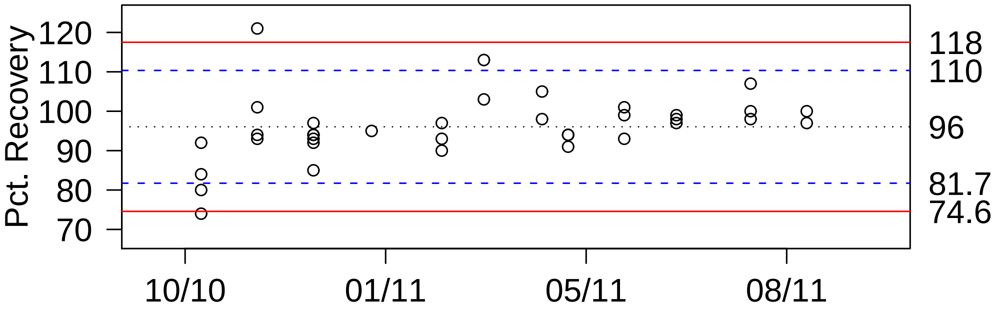


Total Phosphorus Laboratory Duplicates, Test Data

Figure C24: Total phosphorus laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data. Slight increase in variability may be due to insufficient persulfate concentration; method revised to increase concentration.

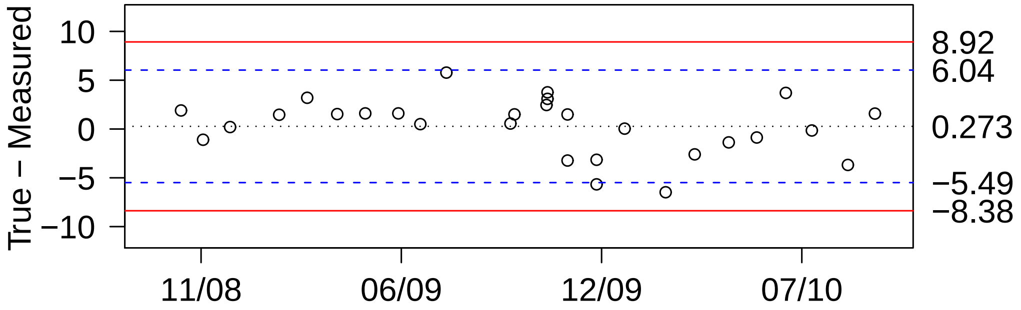


Total Phosphorus Spike Recoveries, Training Data

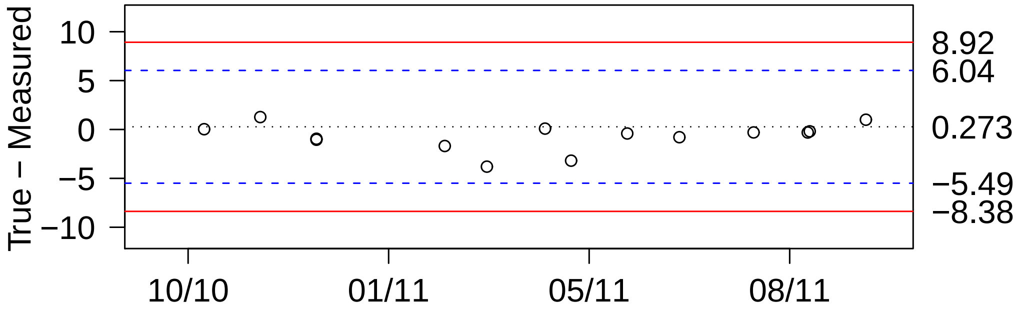


Total Phosphorus Spike Recoveries, Test Data

Figure C25: Total phosphorus matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

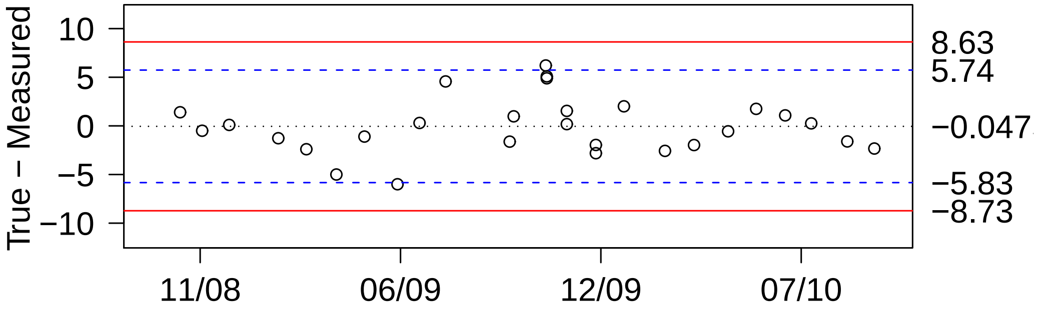


Total Phosphorus Check Standards, Training Data

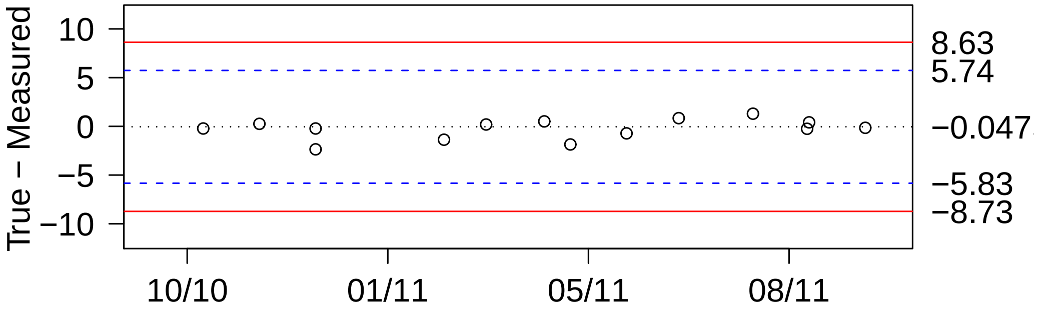


Total Phosphorus Check Standards, Test Data

Figure C26: Total phosphorus high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



Total Phosphorus Check Standards, Training Data



Total Phosphorus Check Standards, Test Data

Figure C27: Total phosphorus low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

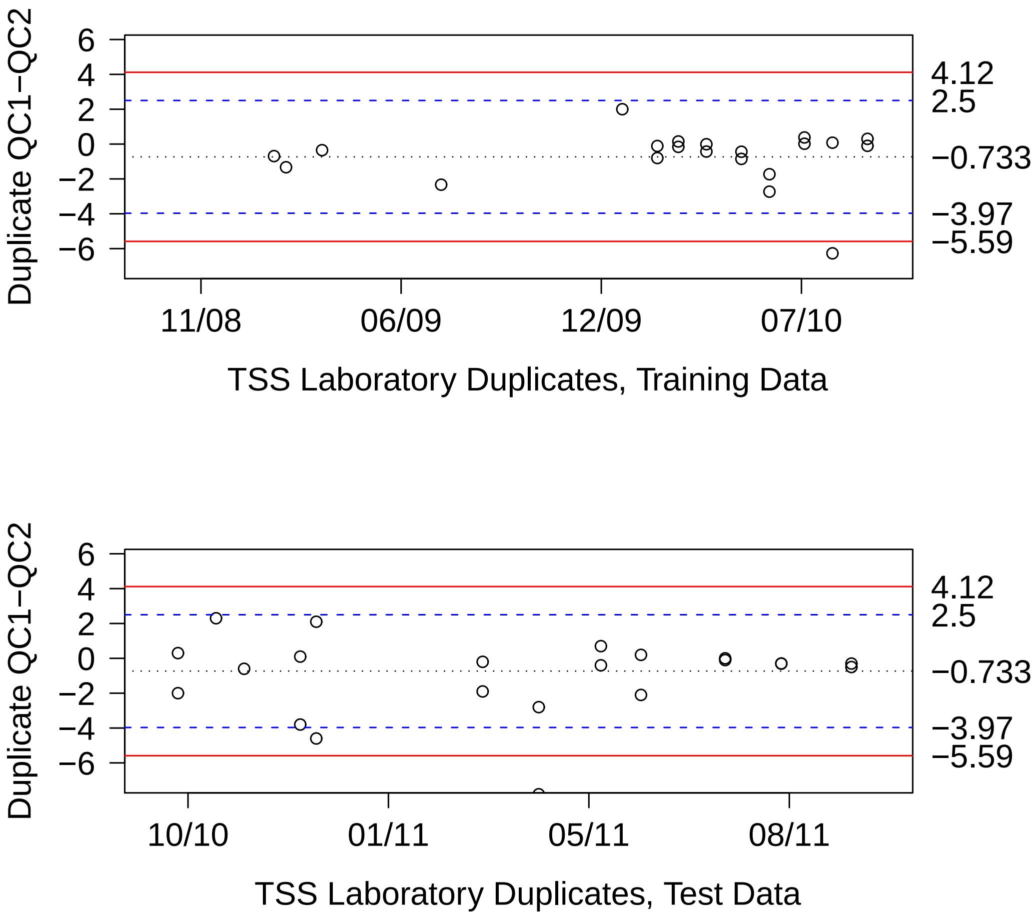
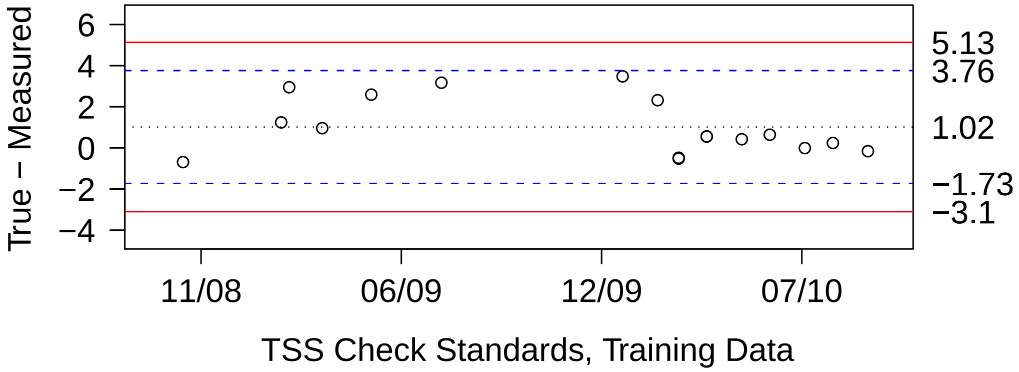


Figure C28: Total suspended solids laboratory duplicates for the Lake Whatcom monitoring program (creek and storm water samples). Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



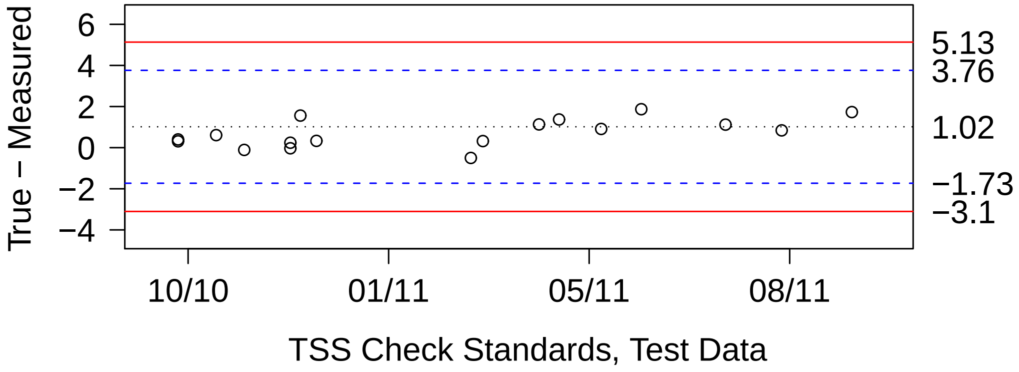
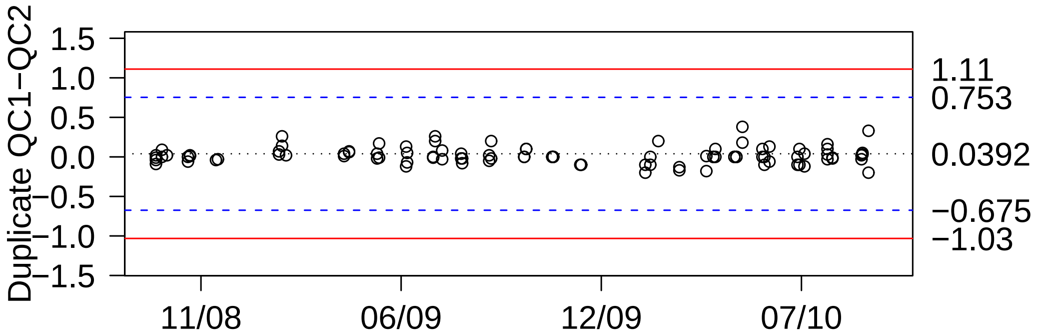
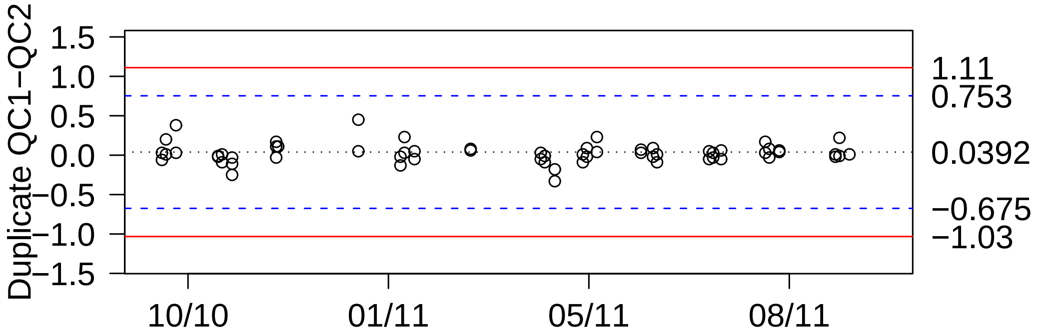


Figure C29: Total suspended solids check standards for the Lake Whatcom monitoring program (creek and storm water samples). Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



Turbidity Laboratory Duplicates, Training Data



Turbidity Laboratory Duplicates, Test Data

Figure C30: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

## C.3 Field Duplicate Results

Separate field duplicates were collected and analyzed for a minimum of 10% of all of the water quality parameters except the Hydrolab data (Figures C31–C49, pages 317–335). To check the Hydrolab measurements, duplicate samples were analyzed for at least 10% of the Hydrolab measurements using water samples collected from the same depth as the Hydrolab measurement. The absolute mean difference was calculated using the following equation:

$$\text{Absolute mean difference} = \frac{\sum |\text{Original Sample} - \text{Duplicate Sample}|}{n}$$

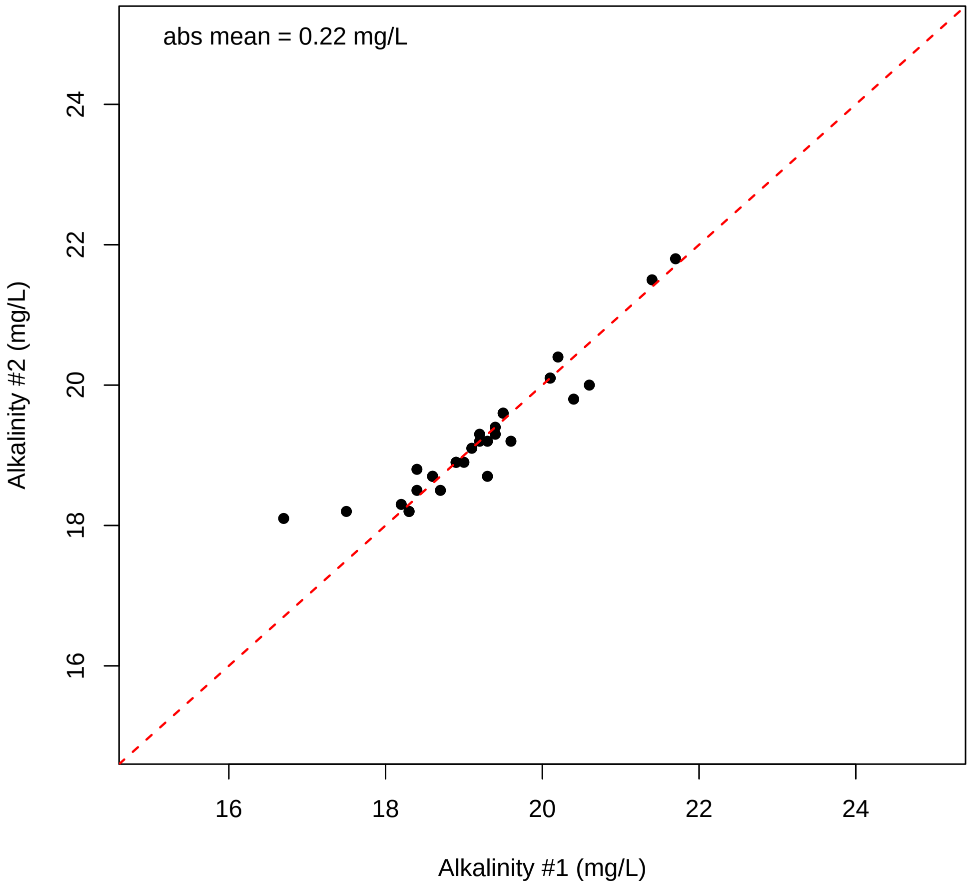


Figure C31: Alkalinity field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

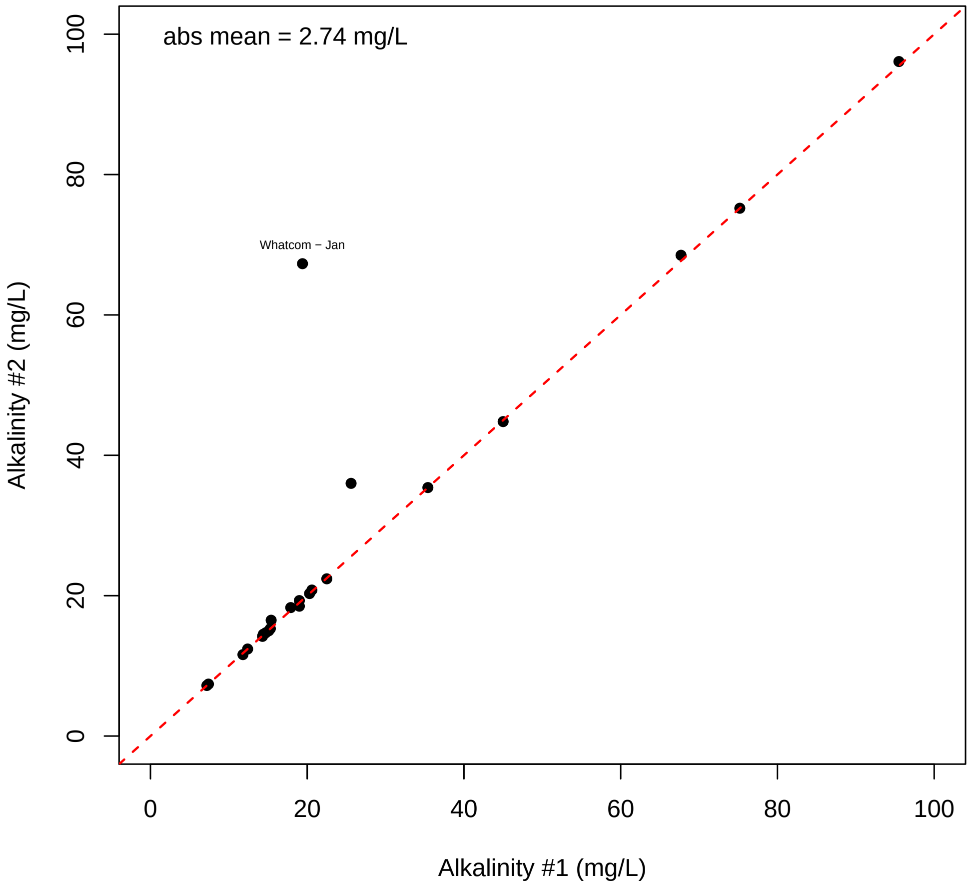


Figure C32: Alkalinity field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship.

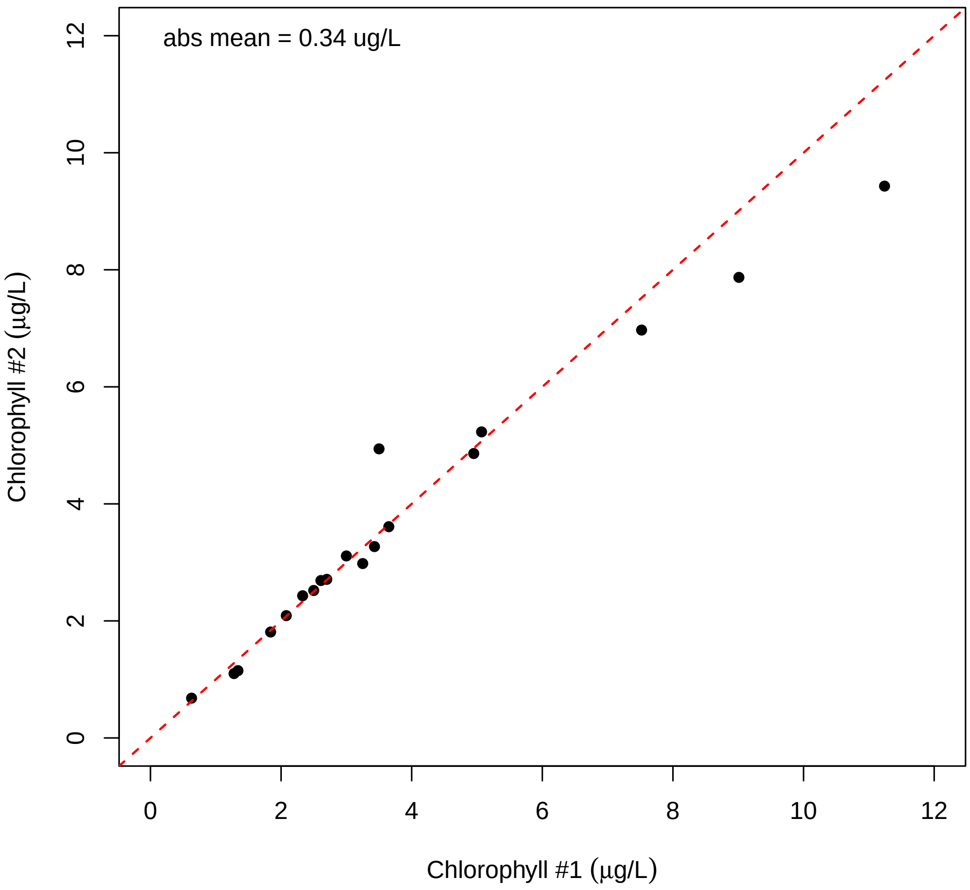


Figure C33: Chlorophyll field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

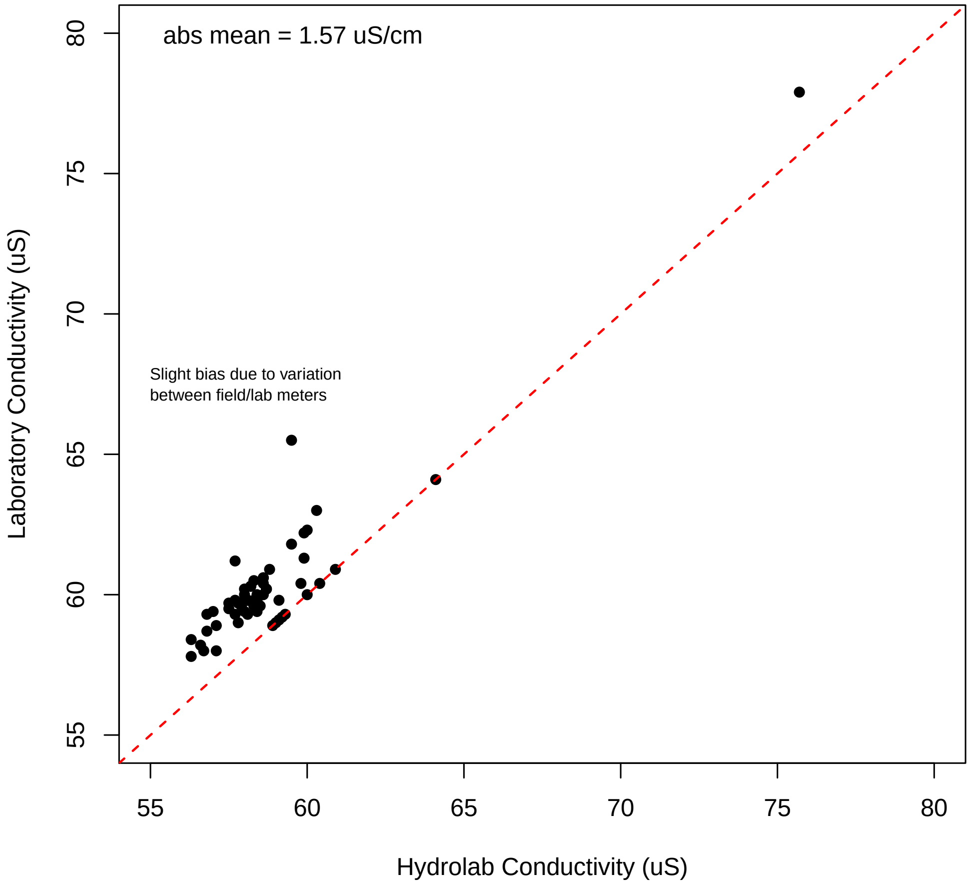


Figure C34: Conductivity field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

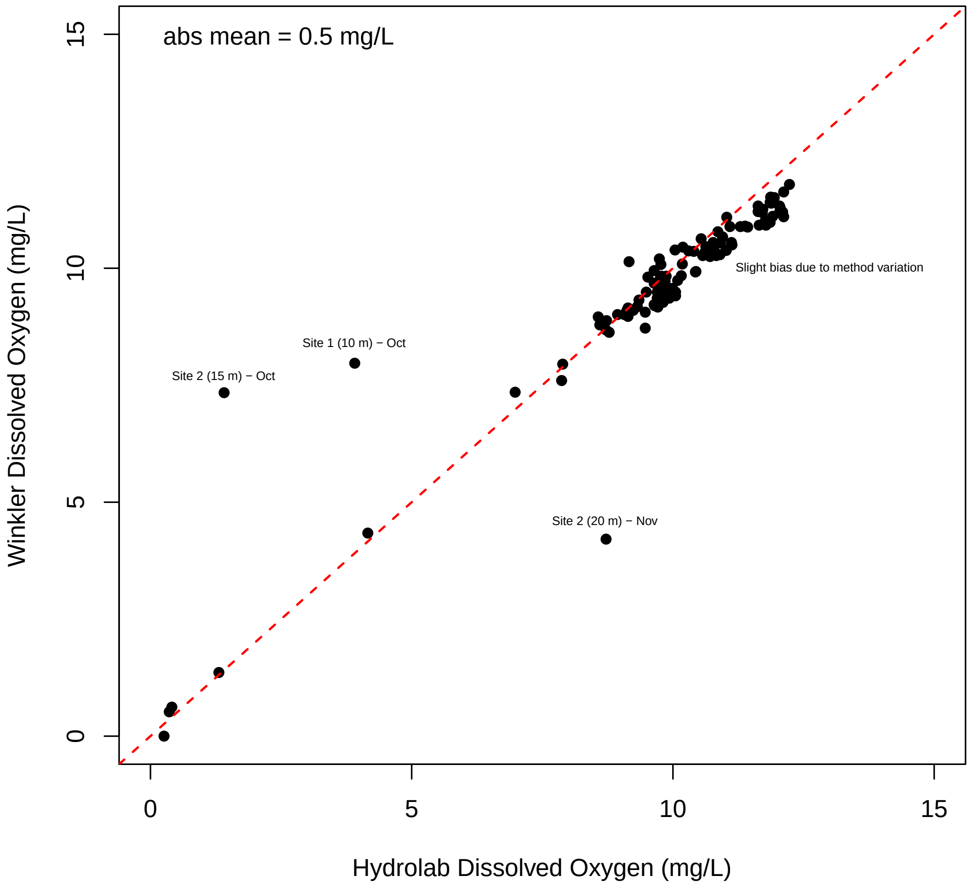


Figure C35: Dissolved oxygen field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. Most outliers were collected when the lake was stratified at depths were extreme oxygen gradients were present.

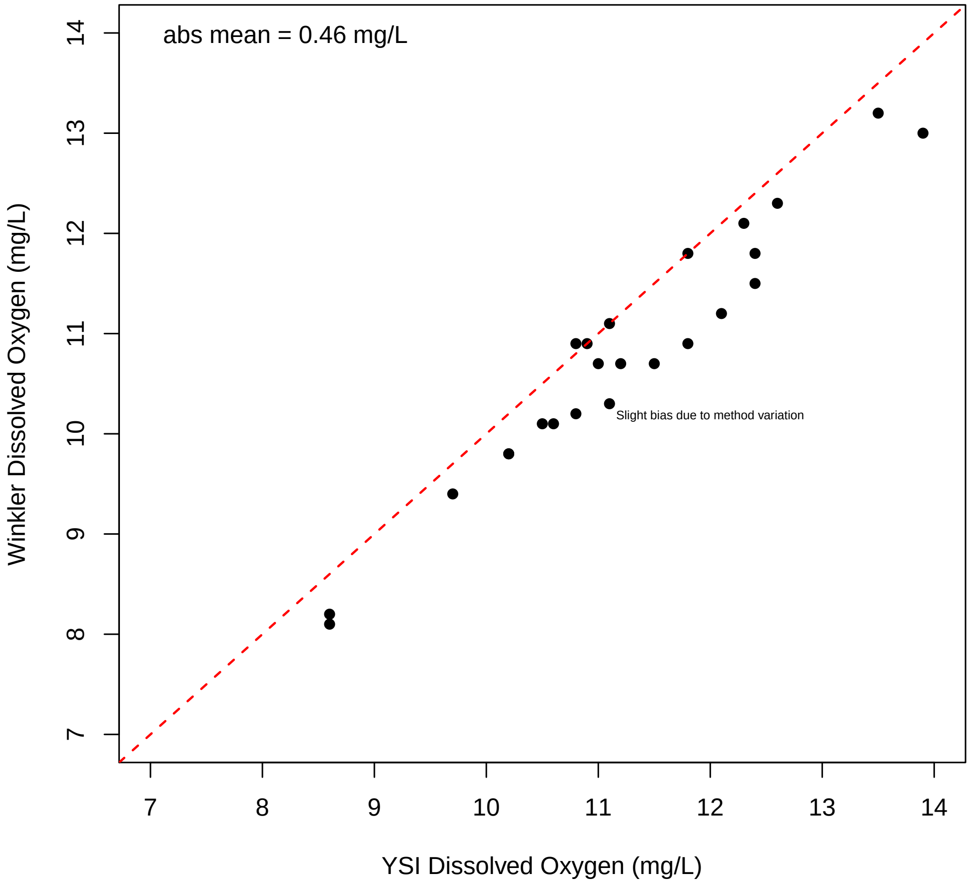


Figure C36: Dissolved oxygen field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship.

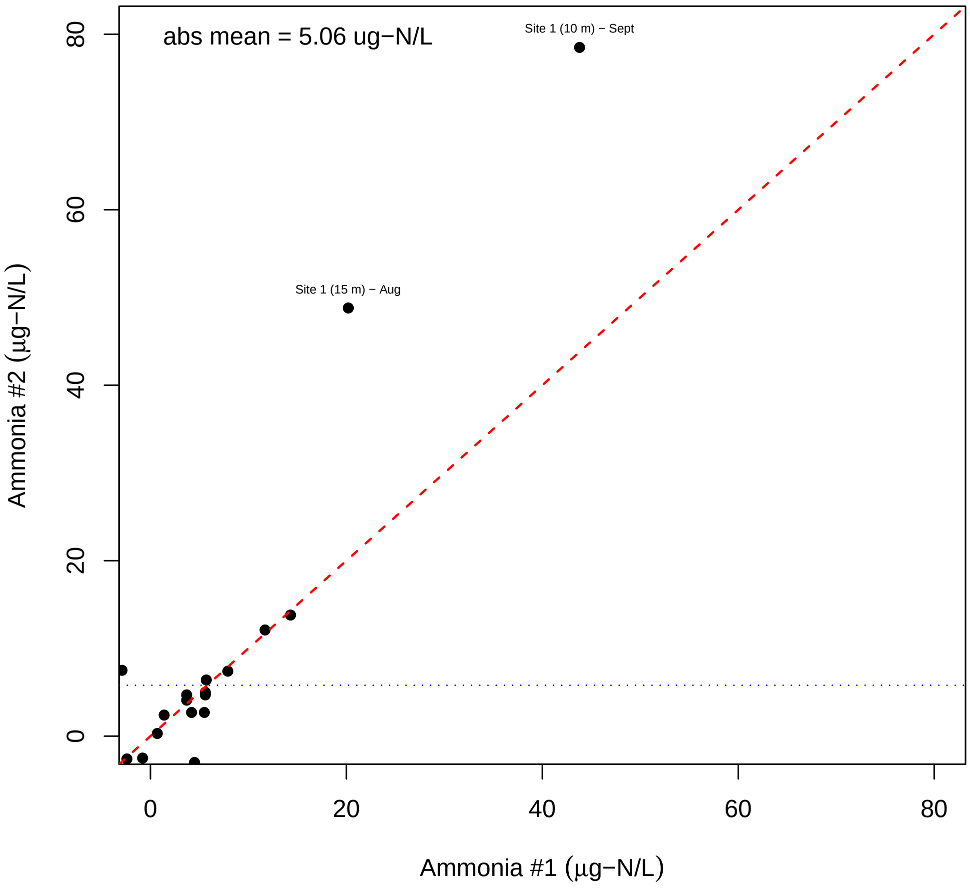


Figure C37: Ammonium field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

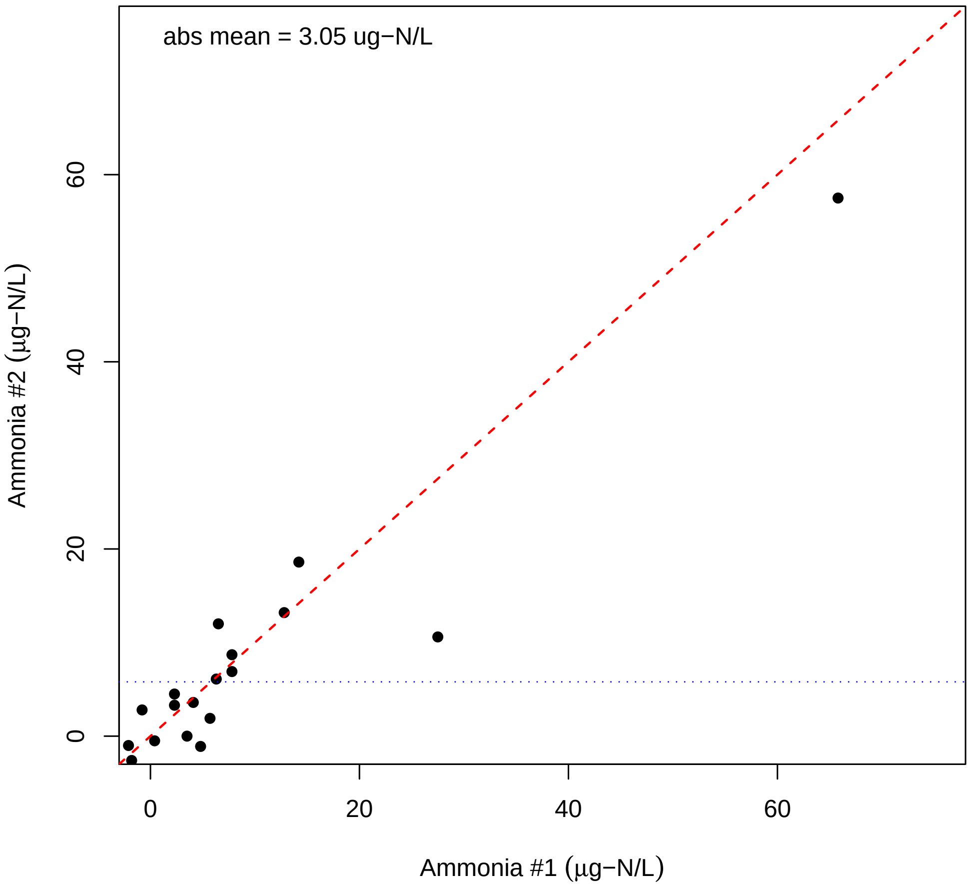


Figure C38: Ammonium field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

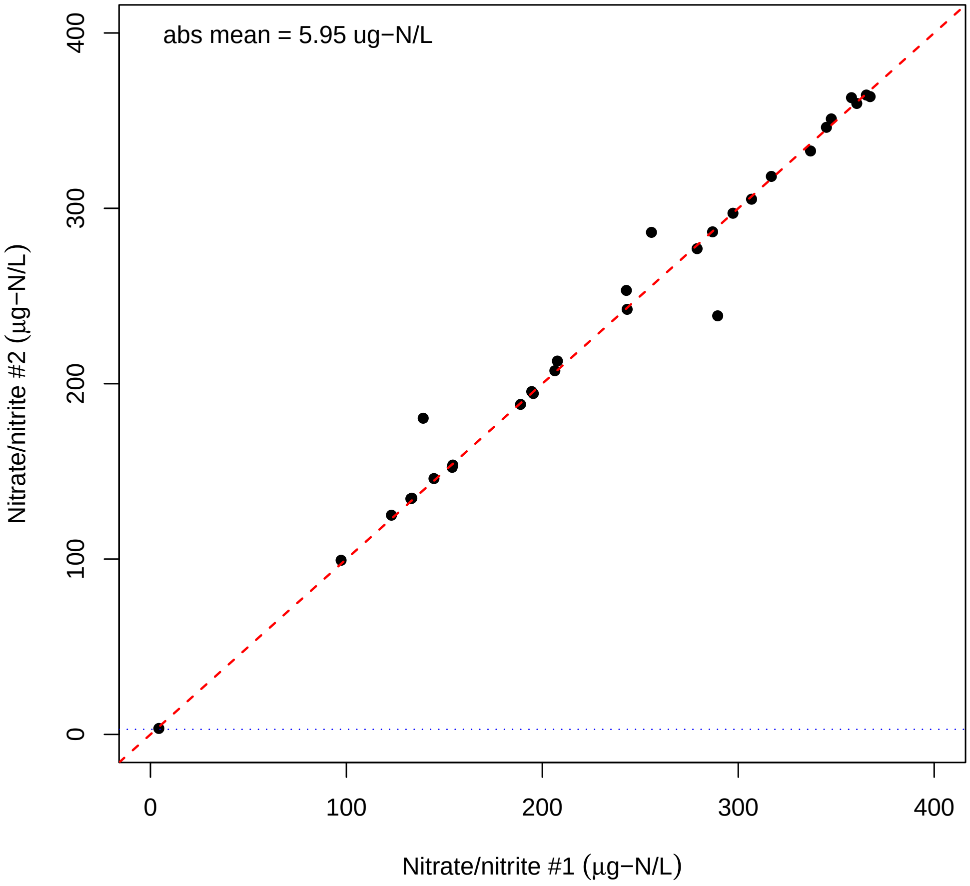


Figure C39: Nitrate/nitrite field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

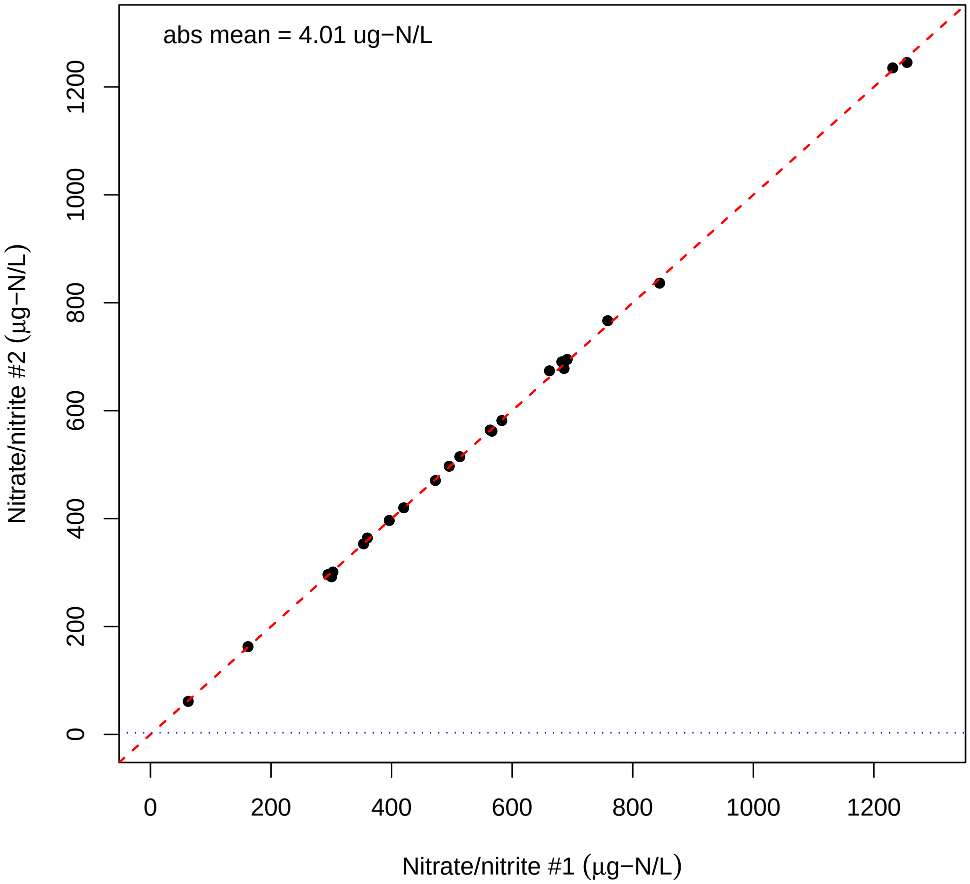


Figure C40: Nitrate/nitrite field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

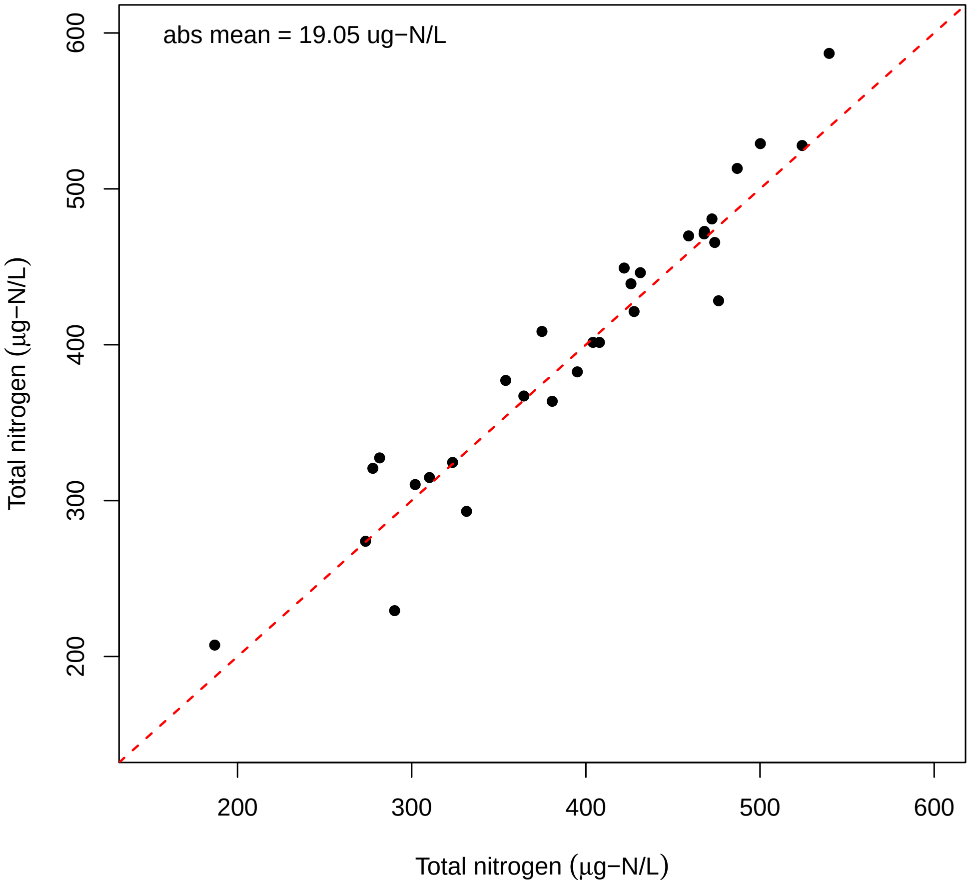


Figure C41: Total nitrogen field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

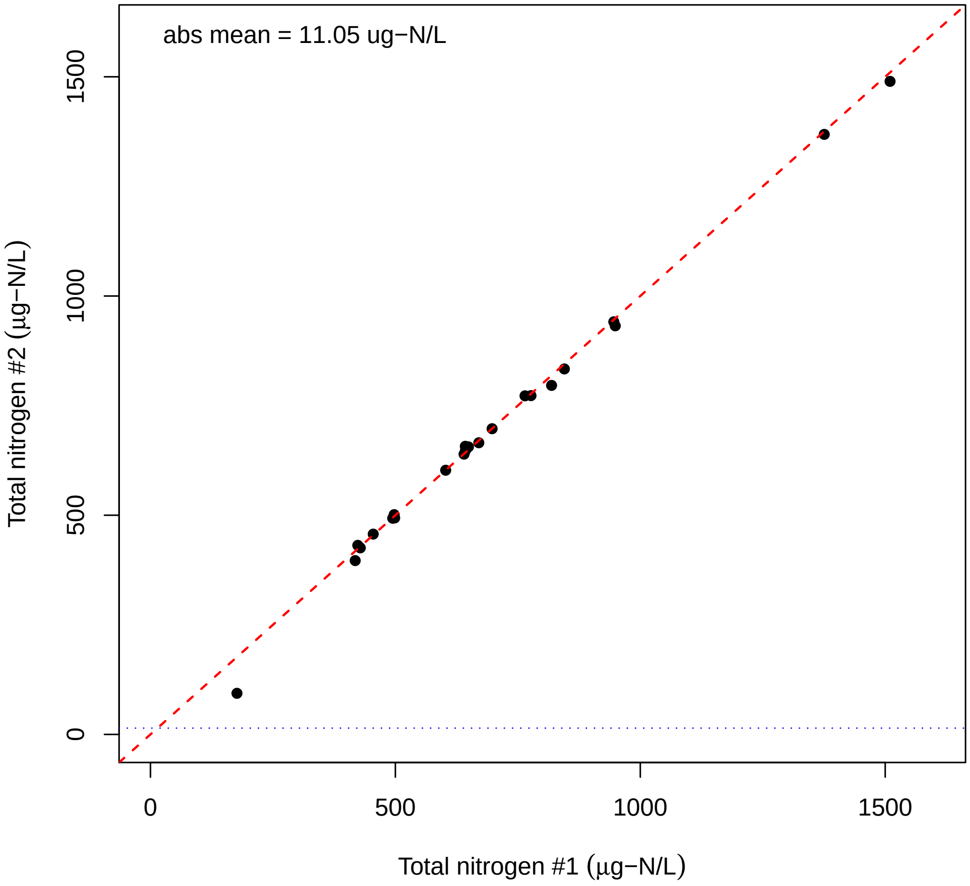


Figure C42: Total nitrogen field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

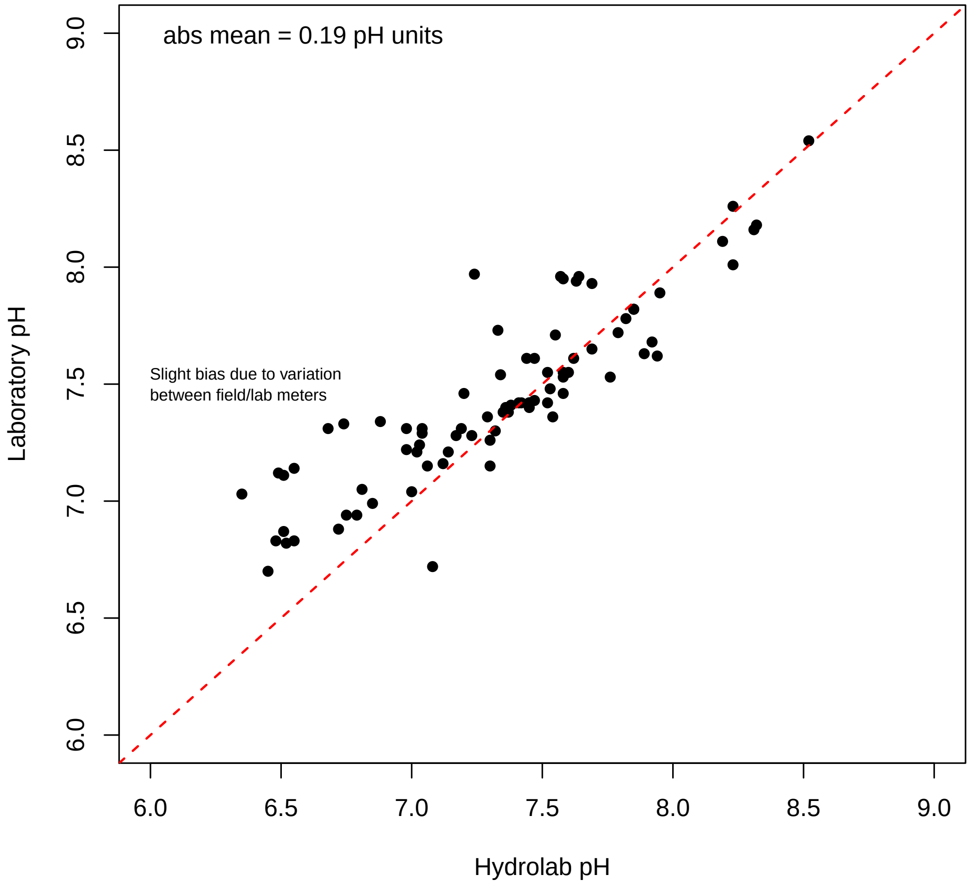


Figure C43: Field duplicates for pH from the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

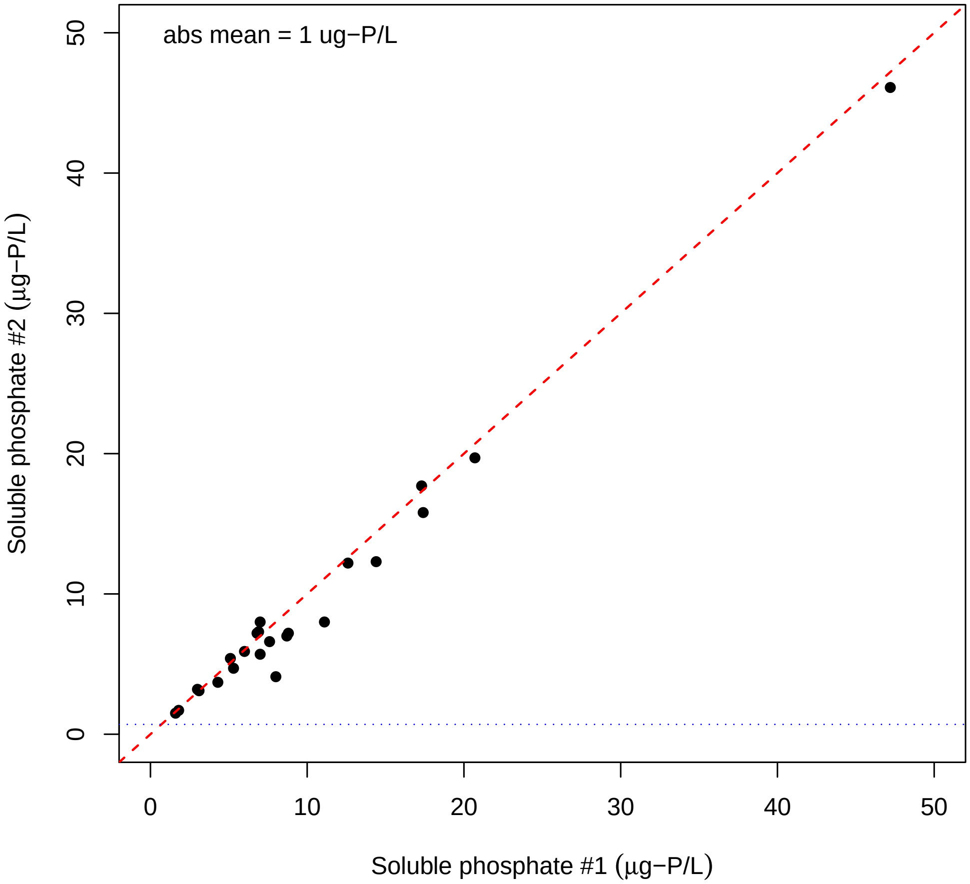


Figure C44: Soluble phosphorus field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

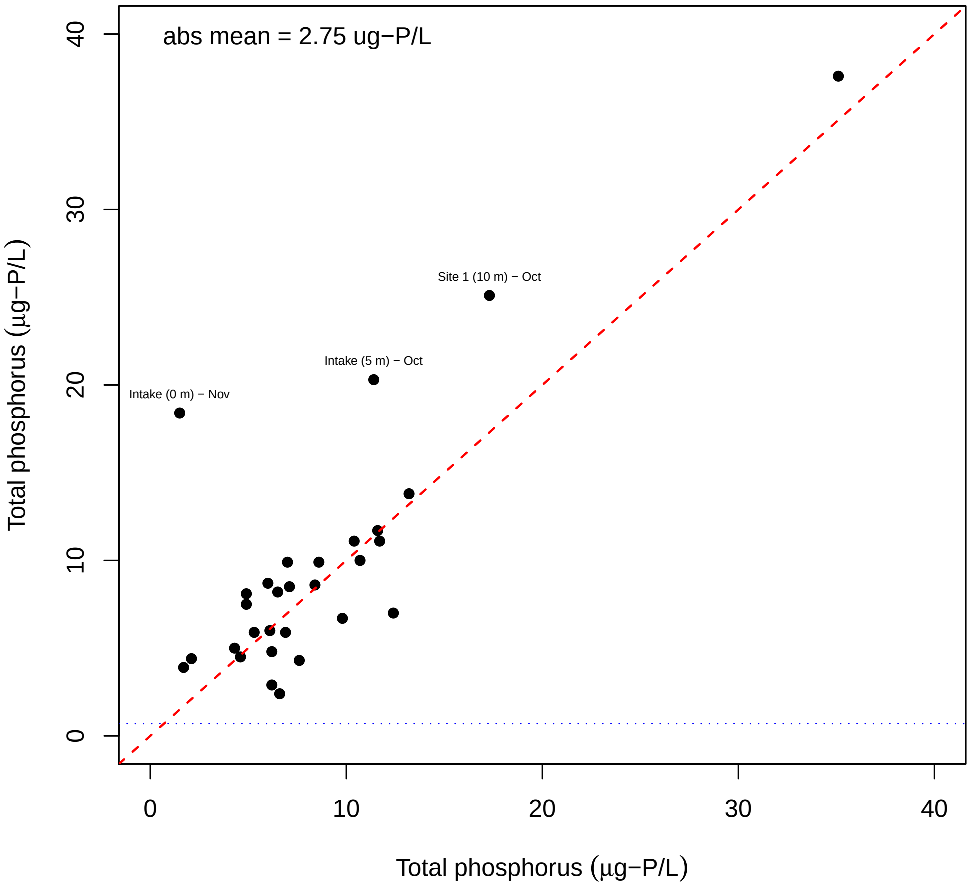


Figure C45: Total phosphorus field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

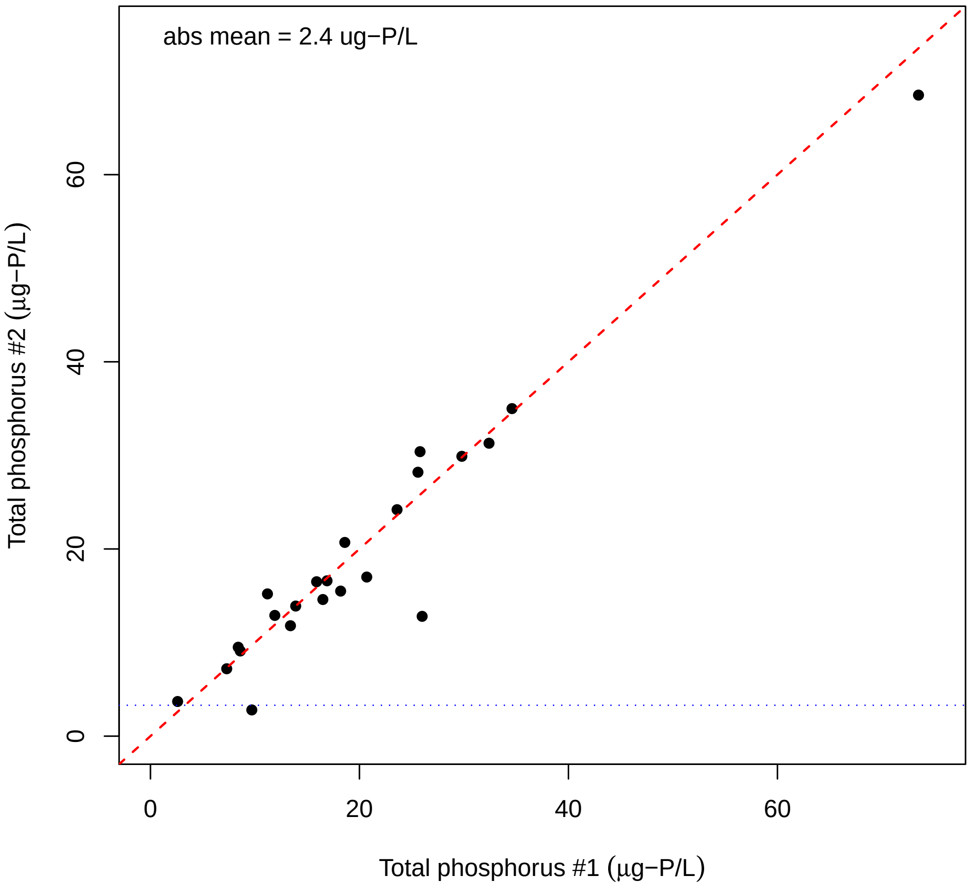


Figure C46: Total phosphorus field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

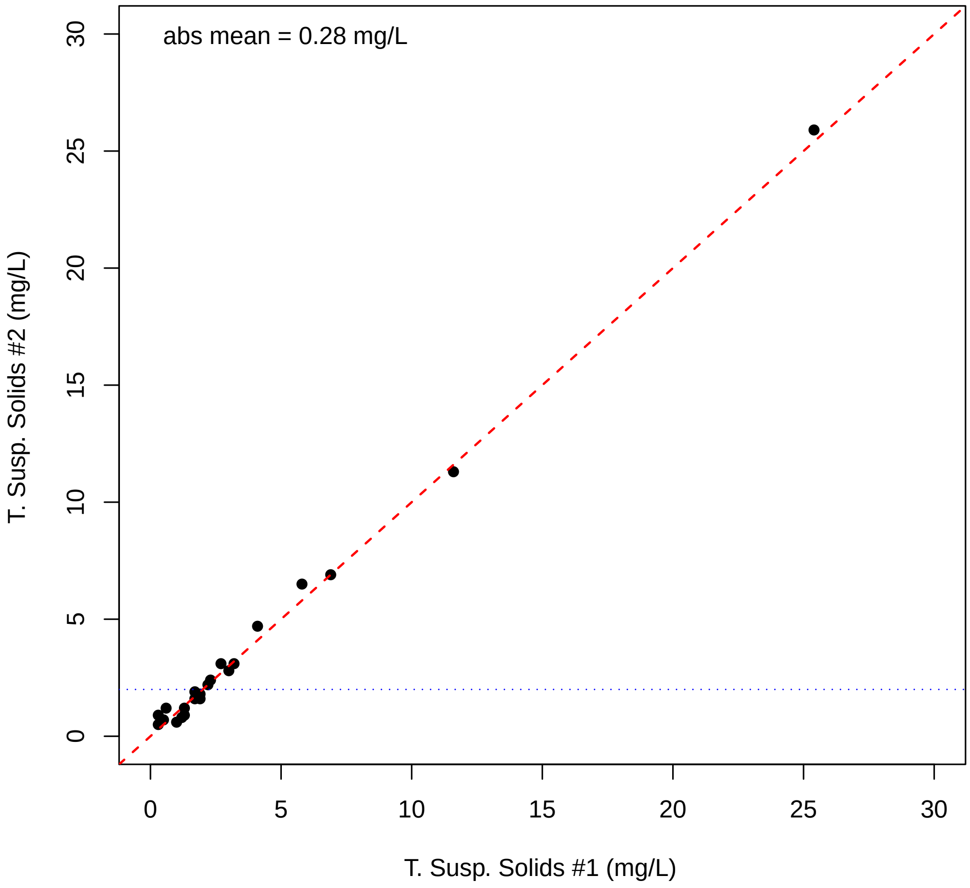


Figure C47: Total suspended solids field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship.

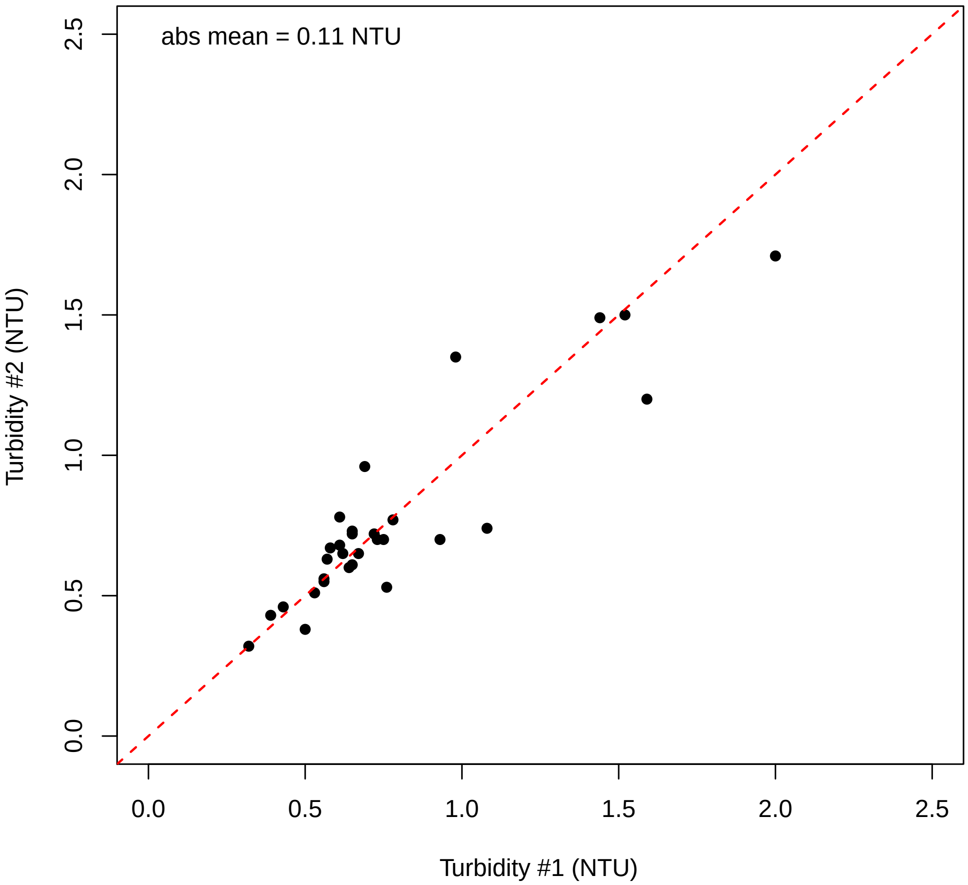


Figure C48: Turbidity field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

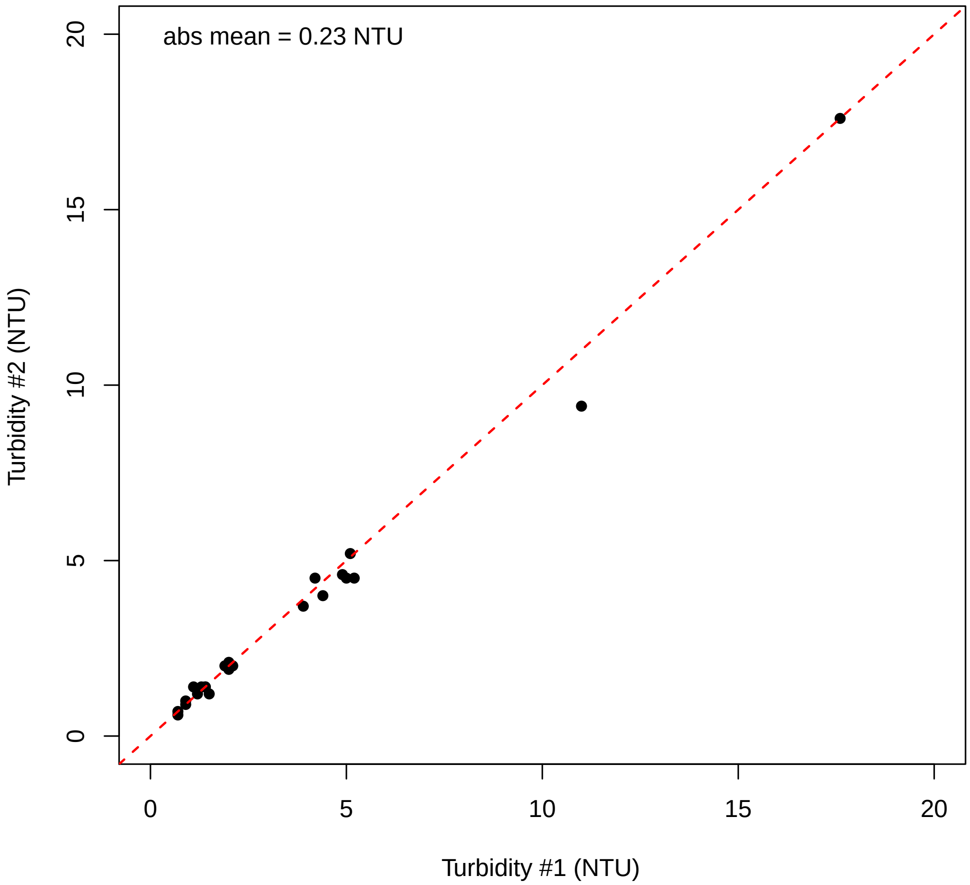


Figure C49: Turbidity field duplicates for the 2010/2011 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship.

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# D Lake Whatcom Online Data

The following **readme** file describes the electronic data posted at the IWS web site. Please contact the Director of the Institute for Watershed Studies if you have questions or trouble accessing the online data.

```
*************************************************************
* README FILE - LAKE WHATCOM ONLINE DATA
* THIS FILE WAS UPDATED FEBRUARY 22, 2012
*************************************************************
The historic Lake Whatcom data are available in electronic format at the IWS
website (http://www.wwu.edu/iws), with the exception of the coliform data,
which are available from the City of Bellingham Public Works Department.

The historic and current detection limits and abbreviations for each parameter
are listed in the annual reports.  The historic detection limits for each
parameter were estimated based on recommended lower detection ranges,
instrument limitations, and analyst judgment on the lowest repeatable
concentration for each test.  Over time, some analytical techniques have
improved so that current detection limits are usually lower than historic
detection limits.  Because the Lake Whatcom data set includes long-term
monitoring data, which have been collected using a variety of analytical
techniques, this report sets conservative historic detection limits to allow
comparisons between years.

All files are comma-separated ascii data files.  The code "NA" has been
entered into all empty cells in the ascii data files to fill in unsampled
dates and depths, missing data, etc.  Questions about missing data should be
directed to the IWS Director.

Unless otherwise indicated, the electronic data files have NOT been censored
to flag or otherwise identify below detection and above detection values.  As
a result, the ascii files may contain negative values due to linear
extrapolation of the standards regression curve for below detection data.  It
is essential that any statistical or analytical results that are generated
using these data be reviewed by someone familiar with statistical uncertainty
associated with uncensored data.

*************************************************************
* LAKE DATA FILES:
*************************************************************
Hydrolab data        Water quality        Plankton
1988_hl.csv          1988_wq.csv          plankton.csv
1989_hl.csv          1989_wq.csv
1990_hl.csv          1990_wq.csv
1991_hl.csv          1991_wq.csv          Metals/TOC
1992_hl.csv          1992_wq.csv          lakemetalstoc.csv
1993_hl.csv          1993_wq.csv
1994_hl.csv          1994_wq.csv
1995_hl.csv          1995_wq.csv
1996_hl.csv          1996_wq.csv
1997_hl.csv          1997_wq.csv
1998_hl.csv          1998_wq.csv
1999_hl.csv          1999_wq.csv
```

```
2000_hl.csv          2000_wq.csv
2001_hl.csv          2001_wq.csv
2002_hl.csv          2002_wq.csv
2003_hl.csv          2003_wq.csv
2004_hl.csv          2004_wq.csv
2005_hl.csv          2005_wq.csv
2006_hl.csv          2006_wq.csv
2007_hl.csv          2007_wq.csv
2008_hl.csv          2008_wq.csv
2009_hl.csv          2009_wq.csv
2010_hl.csv          2010_wq.csv
2011_hl.csv          2011_wq.csv
```

The hydrolab data files contain the following variables: site, depth (sample collection depth, m), month, day, year, temp (water temperature, C), pH, cond (specific conductivity, uS/cm), do (dissolved oxygen, mg/L), lcond (lab conductivity quality control data, uS/cm), secchi (secchi depth, m).

The water quality data files contain the following variables: site, depth (sample collection depth, m), month, day, year, alk (alkalinity, mg/L as CaCO3), turb (turbidity. NTU), nh3 (ammonium, ug-N/L), tn (total persulfate nitrogen, ug-N/L), nos (nitrate/ nitrite, ug-N/L), srp (soluble reactive phosphate, ug-P/L), tp (total persulfate phosphorus, ug-P/L), chl (chlorophyll, ug/L).

The plankton data file contains the following variables: site, depth (sample collection depth, m), month, day, year, zoop (zooplankton, #/L), chry (chrysophyta, #/L), cyan (cyanobacteria, #/L), chlo (chlorophyta, #/L), pyrr (pyrrophyta, #/L).

The lake metals and toc data file contains the following variables: site, depth (sample collection depth, m), month, day, year, TOC (total organic carbon, mg/L), Al (aluminum, mg/L), Sb (antimony, mg/L), As (arsenic, mg/L), B (boron, mg/L), Ba (barium, mg/L), Be (beryllium, mg/L), Ca (calcium, mg/L), Cd (cadmium, mg/L), Co (cobalt, mg/L), Cr (chromium, mg/L), Cu (copper, mg/L), Fe (iron, mg/L), Hg (mercury, mg/L), K (potassium, mg/L), Li (lithium, mg/L), Mg (magnesium, mg/L), Mn (manganese, mg/L), Mo (molybdenum, mg/L), Na (sodium, mg/L), Ni (nickel, mg/L), P (phosphorus, mg/L), Pb (lead, mg/L), S (sulfur, mg/L), Se (selenium, mg/L), Si (silicon, mg/L), Ag (silver, mg/L), Sn (tin, mg/L), Sr (strontium, mg/L), Ti (titanium, mg/L), Tl (thallium, mg/L), V (vanadium, mg/L), Y (yttrium, mg/L), Zn (zinc, mg/L)

```
*************************************************************
* HYDROGRAPH DATA FILES:
*************************************************************
WY1998.csv
WY1999.csv
WY2000.csv (revised Feb 22, 2012)
WY2001.csv
WY2002.csv
WY2003.csv
WY2004_rev.csv (revised June 21, 2006)
WY2005.csv
WY2006.csv
WY2007.csv (revised July 31, 2008)
WY2008.csv
WY2009.csv
```

WY2010.csv
WY2011.csv

The current hydrograph data files contain the following variables: month, day, year, hour, min, sec, austin.g (austin gage height, ft), austin.cfs (austin discharge, cfs), smith.g (smith gage height, ft), smith.cfs (smith discharge, cfs). WY1998-WY2007 also contained ander.g (anderson gage height, ft), ander.cfs (anderson discharge, cfs).

Beginning with WY2002, the variable "time" replaced "hour, min, sec," with time reported daily on a 24-hr basis.

All data are reported in as Pacific Standard Time without Daylight Saving Time adjustment.

*************************************************************
* STORM WATER DATA FILES
*************************************************************
CURRENT:
In 2009 the storm water monitoring goals changed to focus on storm event sampling in Silver Beach Creek and visual monitoring of flow in the North Shore Drive overlay system. The electronic data from Silver Beach Creek are not available online but may be obtained by contacting the Institute for Watershed Studies. The North Shore Drive overlay observations are not available as an electronic data file but are described in the 2009/2010 annual report.

HISTORIC STORM WATER MONITORING DATA:
comps.csv
grab.csv

Historic storm water monitoring data will continue to be posted online. Most of the variables in comps.csv and grab.csv are measured infrequently, resulting in many NA entries in the data. Printed versions of the raw data that are included in the annual reports are edited to remove variables that were not measured during that sampling period. The electronic files retain all variable columns.

Many of the values are below detection. Data obtained from AmTest has been censored and include "<" to indicate values below the detection limit.

The storm water treatment composite data file (comps.csv) is a comma-separated file and contains the following variables: site, source (inlet/outlet or sample collection description), startmonth, endmonth, startday, endday, year, TSS, (total suspended solids, mg/L), TS (total solids, mg/L), TOC (total organic carbon, mg-C/L), TN (total nitrogen, mg-N/L), TP (total phosphorus, mg-P/L), Al (aluminum, mg/L), Sb (antimony, mg/L), As (arsenic, mg/L), B (boron, mg/L), Ba (barium, mg/L), Be (beryllium, mg/L), Ca (calcium, mg/L), Cd (cadmium, mg/L), Co (cobalt, mg/L), Cr (chromium, mg/L), Cu (copper, mg/L), Fe (iron, mg/L), Hg (mercury, mg/L), K (potassium, mg/L), Li (lithium, mg/L), Mg (magnesium, mg/L), Mn (manganese, mg/L), Mo (molybdenum, mg/L), Na (sodium, mg/L), Ni (nickel, mg/L), P (phosphorus, mg/L), Pb (lead, mg/L), S (sulfur, mg/L), Se (selenium, mg/L), Si (silicon, mg/L), Ag (silver, mg/L), Sn (tin, mg/L), Sr (strontium, mg/L), Ti (titanium, mg/L), Tl (thallium, mg/L), V (vanadium, mg/L), Y (yttrium, mg/L), Zn (zinc, mg/L)

The storm water treatment grab data file (grab.csv) is a comma- separated file and contains the following variables: site, source (inlet/outlet or sample collection description), sample (A-D, in order of collection), month, day, year, time (24-hr basis), am.pm (relative time: am or pm), temp (water temperature, C), pH, do (dissolved oxygen, mg/L), cond (specific conductivity, uS/cm), tc (total coliforms, cfu/100 mL), fc (fecal coliforms, cfu/100 mL), ec (enterococcus, cfu/100 mL), ecoli( E.coli, cfu/100 mL), TSS (total suspended solids, mg/L), TS (total solids, mg/L), TOC (total organic carbon, mg-C/L), TN (total nitrogen, mg-N/L), TP (total phosphorus, mg-P/L), NO3 (nitrite+nitrate, mg-N/L), SRP (soluble reactive phosphate, mg-P/L), NH3 (ammonium, mg-N/L), Al (aluminum, mg/L), Sb (antimony, mg/L), As (arsenic, mg/L), B (boron, mg/L), Ba (barium, mg/L), Be (beryllium, mg/L), Ca (calcium, mg/L), Cd (cadmium, mg/L), Co (cobalt, mg/L), Cr (chromium, mg/L), Cu (copper, mg/L), Fe (iron, mg/L), Hg (mercury, mg/L), K (potassium, mg/L), Li (lithium, mg/L), Mg (magnesium, mg/L), Mn (manganese, mg/L), Mo (molybdenum, mg/L), Na (sodium, mg/L), Ni (nickel, mg/L), P (phosphorus, mg/L), Pb (lead, mg/L), S (sulfur, mg/L), Se (selenium, mg/L), Si (silicon, mg/L), Ag (silver, mg/L), Sn (tin, mg/L), Sr (strontium, mg/L), Ti (titanium, mg/L), Tl (thallium, mg/L), V (vanadium, mg/L), Y (yttrium, mg/L), Zn (zinc, mg/L), gasoline (mg/L), diesel (mg/L), and oil (mg/L).

*************************************************************
* TRIBUTARY DATA FILES:
*************************************************************
creeks.csv (2004-present)
creeksmetaltoc.csv (2005-present)
creekwalk.csv (Nov 20, 2004)
48h.csv (2004-2006)
nonstd_discharge.csv (2004-2007)

The monthly tributary data file (creeks.csv) is a comma-separated file and contains the following variables: code (IWS site code), site (descriptive site name), month, day, year, time (24-hr basis), temp (water temperature, C), ph, do (dissolved oxygen, mg/L), cond (specific conductivity, uS/cm), turb (turbidity, NTU), alk (alkalinity, mg/L as CaCO3), tp (total phosphorus, ug-P/L), tn (total nitrogen, ug-N/L), nos (nitrite+nitrate, ug-N/L), srp (soluble reactive phosphate, ug-P/L), nh3 (ammonium, ug-N/L), tss (total suspended solids, mg/L), ts (total solids, mg/L), ecoli (E.coli, cfu/100 mL), fc (fecal coliforms, cfu/100 mL)

The creek metals and toc data file (creeksmetaltoc.csv) contains the following variables: site, month, day, year, TOC (total organic carbon, mg/L), Al (aluminum, mg/L), Sb (antimony, mg/L), As (arsenic, mg/L), B (boron, mg/L), Ba (barium, mg/L), Be (beryllium, mg/L), Ca (calcium, mg/L), Cd (cadmium, mg/L), Co (cobalt, mg/L), Cr (chromium, mg/L), Cu (copper, mg/L), Fe (iron, mg/L), Hg (mercury, mg/L), K (potassium, mg/L), Li (lithium, mg/L), Mg (magnesium, mg/L), Mn (manganese, mg/L), Mo (molybdenum, mg/L), Na (sodium, mg/L), Ni (nickel, mg/L), P (phosphorus, mg/L), Pb (lead, mg/L), S (sulfur, mg/L), Se (selenium, mg/L), Si (silicon, mg/L), Ag (silver, mg/L), Sn (tin, mg/L), Sr (strontium, mg/L), Ti (titanium, mg/L), Tl (thallium, mg/L), V (vanadium, mg/L), Y (yttrium, mg/L), Zn (zinc, mg/L)

The Austin Creek and Beaver Creek intensive sampling data file (creekwalk.csv) is a comma-separated file and contains the following variables: creek (Austin or Beaver), site, ID (field code - see report discussion), instream (y=instream sample from Austin or Beaver Creeks), month, day, year, time, (original time in hr+min), time2 (corrected time interval in hr+[min/60]), temp (water temperature, C), adj.temp (adjusted temperature - see report discussion), do.ysi (YSI dissolved oxygen, mg/L), do.win (Winkler dissolved oxygen, mg/L), turb (turbidity, NTU), fc (fecal coliforms, cfu/100 mL), ecoli (E.coli, cfu/100 mL), tss (total suspended solids, mg/L), tn (total nitrogen, ug-N/L), tp (total phosphorus, ug-P/L).

The 48-hr creek data file (48f.csv) is a comma-separated file and contains the following variables: code (IWS site code), date (month/day/year), time (24-hr basis), temp (water temperature, C), pH, do (dissolved oxygen, mg/L), cond (specific conductivity, uS/cm), turb (turbidity, NTU), alk (alkalinity, mg/L as CaCO3), tp (total phosphorus, ug-P/L), tn (total nitrogen, ug-N/L), nos (nitrate+nitrite, ug-N/L), srp (soluble reactive phosphate, ug-{/L), nh3 (ammonium, ug-N/L), tss (total suspended solids, mg/L), ts (total solids, mg/L), fc (fecal coliforms, cfu/100 mL). => THIS FILE WAS UPDATED IN THE 2005/2006 REPORT TO CORRECT A DATA ENTRY ERROR IN THE 2004/2005 REPORT.

The ungauged discharge data file (nonstd_discharge.csv) is comma- separated and contains the following variables: code (IWS site code), site (descriptive site name), month, day, year, time (24-hr basis), discharge (cfs). Beginning in 2007, ungauged discharge is only measured at Blue Canyon; these data are available from the Institute for Watershed Studies.

```
*************************************************************
* SITE CODES (ALL DATA FILES - INCLUDES DISCONTINUED SITES)
*************************************************************
The site codes in the data are as follows:
    11  = Lake Whatcom Site 1
    21  = Lake Whatcom Intake site
    22  = Lake Whatcom Site 2
    31  = Lake Whatcom Site 3
    32  = Lake Whatcom Site 4
    33  = Strawberry Sill site S1
    34  = Strawberry Sill site S2
    35  = Strawberry Sill site S3

    AlabamaVault inlet     = Alabama canister vault inlet
    AlabamaVault outlet    = Alabama canister vault outlet
    Brentwood inlet        = Brentwood wet pond inlet
    Brentwood outlet       = Brentwood wet pond outlet
    ParkPlace cell1        = Park Place wet pond cell 1
    ParkPlace cell2        = Park Place wet pond cell 2
    ParkPlace cell3        = Park Place wet pond cell 3
    ParkPlace inlet        = Park Place wet pond inlet
    ParkPlace outlet       = Park Place wet pond outlet
    Parkstone_swale inlet  = Parkstone grass swale inlet
    Parkstone_swale outlet = Parkstone grass swale outlet
    Parkstone_pond inlet   = Parkstone wet pond inlet
    Parkstone_pond outlet  = Parkstone wet pond outlet
    SouthCampus inlet      = South Campus storm water facility inlet
    SouthCampus outletE    = South Campus storm water facility east outlet
    SouthCampus outletW    = South Campus storm water facility west outlet
    Sylvan inlet           = Sylvan storm drain inlet
    Sylvan outlet          = Sylvan storm drain outlet
    Wetland outlet         = Grace Lane wetland

    CW1 = Smith Creek (see alternate code below)
    CW2 = Silver Beach Creek (see alternate code below)
    CW3 = Park Place drain (see alternate code below)
```

CW4 = Blue Canyon Creek (see alternate code below)
CW5 = Anderson Creek (see alternate code below)
CW6 = Wildwood Creek (discontinued in 2004)
CW7 = Austin Creek (see alternate code below)

The following tributary site codes were used for the expanded 2004-2006 and current tributary monitoring project:

AND = Anderson Creek (same location as CW5 above)
BEA1 = Austin.Beaver.confluence
AUS = Austin.lower (same location as CW7 above)
BEA2 = Austin.upper
BEA3 = Beaver.upper
BLU = BlueCanyon (same location as CW4 above)
BRA = Brannian
CAR = Carpenter
EUC = Euclid
MIL = Millwheel
OLS = Olsen
PAR = ParkPlace (same location as CW3 above)
SIL = SilverBeach (same location as CW2 above)
SMI = Smith (same location as CW1 above)
WHA = Whatcom

*************************************************************
* VERIFICATION PROCESS FOR THE LAKE WHATCOM DATA FILES
*************************************************************

During the summer of 1998 the Institute for Watershed Studies began creating an electronic data file that would contain long term data records for Lake Whatcom. These data were to be included with annual Lake Whatcom monitoring reports. This was the first attempt to make a long-term Lake Whatcom data record available to the public. Because these data had been generated using different quality control plans over the years, a comprehensive re-verification process was done.

The re-verification started with printing a copy of the entire data file and checking 5% of all entries against historic laboratory bench sheets and field notebooks. If an error was found, the entire set of values for that analysis were reviewed for the sampling period containing the error. Corrections were noted in the printed copy and entered into the electronic file; all entries were dated and initialed in the archive copy.

Next, all data were plotted and descriptive statistics (e.g., minimum, maximum) were computed to identify outliers and unusual results. All outliers and unusual data were verified against original bench sheets. A summary of decisions pertaining to these data is presented below. All verification actions were entered into the printed copy, dated, and initialed by the IWS director.

The following is a partial list of the changes made to the verified Lake Whatcom data files. For detailed information refer to the data verification archive files in the IWS library.

Specific Deletions: 1) Rows containing only missing values were deleted. 2) All lab conductivity for February 1993 were deleted for cause: meter inadequate for low conductivity readings (borrowed Huxley’s student meter). 3) All Hydrolab conductivity from April - December 1993 were deleted for cause: Hydrolab probe slowly lost sensitivity. Probe was replaced and Hydrolab was reconditioned prior to the February 1994 sampling. 4) All 1993 Hydrolab dissolved oxygen data less than or equal to 2.6 mg/L were deleted for cause: Hydrolab probe lost sensitivity at low oxygen concentrations. Probe was replaced and Hydrolab was reconditioned prior to February 1994 sampling. 5) All srp and tp data were deleted (entered as "missing" in 1989) from the July 10, 1989 wq data due to sample contamination in at least three samples. 6) December 2, 1991, Site 3, 0 m conductivity point deleted due to inconsistency with adjacent points. 7) December 15, 1993, Site 4, 80 m lab conductivity point deleted because matching field conductivity data are absent and point is inconsistent with all other lab conductivity points. 8) November 4, 1991, Site 2, 17-20 m, conductivity points deleted due to evidence of equipment problems related to depth. 9) February 2, 1990, Site 1, 20 m, soluble reactive phosphate and total phosphorus points deleted due to evidence of sample contamination. 10) August 6, 1990, Site 1, 0 m, soluble reactive phosphate and total phosphorus points deleted due to evidence of sample contamination. 11) October 5, 1992, Site 3, 80 m, all data deleted due to evidence of sample contamination in turbidity, ammonium, and total phosphorus results. 12) August 31, 1992, Site 3, 5 m, soluble reactive phosphate and total phosphorus data deleted due to probable coding error. 13) All total Kjeldahl nitrogen data were removed from the historic record. This was not due to errors with the data but rather on-going confusion over which records contained total persulfate nitrogen and which contained total Kjeldahl nitrogen. The current historic record contains only total persulfate nitrogen. Total Kjeldahl nitrogen data were retained in the IWS data base, but not in the long-term Lake Whatcom data files.

*************************************************************
* ROUTINE DATA VERIFICATION PROCESS
*************************************************************

1994-present: The Lake Whatcom data are verified using a four step method: 1) The results are reviewed as they are generated. Outliers are checked for possible analytical or computational errors. This step is completed by the Laboratory Analyst and IWS Laboratory Supervisor. 2) The results are reviewed monthly and sent to the City. Unusual results are identified. This step is completed by the IWS Director. 3) The results are reviewed on an annual basis and discussed in the Lake Whatcom Monitoring Program Final Report. Unusual results are identified, and explained, if possible. This step is completed by the IWS Director, IWS Laboratory Supervisor, and Laboratory Analyst. 4) Single-blind quality control samples, laboratory duplicates, and field duplicates are analyzed as specified in the Lake Whatcom Monitoring Program contract and in the IWS Laboratory Certification requirements. Unusual results that suggest instrumentation or analytical problems are reported to the IWS Director and City. The results from these analyses are summarized in the annual report.

1987-1993: The lake data were reviewed as above except that the IWS Director’s responsibilities were delegated to the Principle Investigator in charge of the lake monitoring contract (Dr. Robin Matthews).

Prior to 1987: Data were informally reviewed by the Laboratory Analyst and IWS Director. Laboratory and field duplicates were commonly included as part of the analysis process, but no formal (i.e., written) quality control program was in place. Laboratory logs were maintained for most analyses, so it is possible to verify data against original analytical results. It is also possible to review laboratory quality control results for some analyses.