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Lake Whatcom Monitoring Project 2008/2009 Report

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Lake Whatcom Monitoring Project 2008/2009 Final Report

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Executive Summary

- This report describes the results from the 2008/2009 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; monitor the effectiveness of storm water treatment systems; 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 76.

- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The water temperature in 2009 was fairly typical except during the summer; record high surface temperatures were measured in August 2009. The lake was partially stratified in May, and stable stratification was present 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 2009 hypolimnetic oxygen concentrations dropped rapidly, and by September the oxygen levels were <1 mg/L at all depths below 11 meters.

- There is a significant trend developing in the pH data: the minimum pH values are decreasing slightly over time and the maximum pH values are increasing slightly over time. This trend is most likely due the increasing levels of photosynthesis and decomposition of dead algae.

- 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 elevated concentrations of ammonia and hydrogen sulfide by the end of the summer.

- The summer near-surface total phosphorus and chlorophyll concentrations and Cyanobacteria counts have increased significantly over time at most sites, but the patterns are erratic, and it is not clear whether the upward trends have stabilized.

- An unusual, filter-clogging algal bloom developed during the summer of 2009. The dominant algae associated with this bloom were Cyanobacteria and diatoms; IWS will collect additional plankton samples in 2010 to help identify conditions associated with filter clogging events.

- 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 in detectable, but were within normal ranges for the lake. Other metals were occasionally detected, but the concentrations were near the limits of detection.

- Tributaries were sampled in February and July 2009 to collect baseline data from locations that were sampled monthly in 2004–2006. Most of the tributaries had relatively low concentrations of total and dissolved solids, low alkalinities and conductivities, and low levels of nitrate and ammonia. 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 WY2009[1] included surface and subsurface runoff (82.3%)

[1]Water Year 2009 covers the period from October 1, 2008 through September 30, 2009

and direct precipitation (17.7%). No water was diverted from the Middle Fork of the Nooksack River in WY2009. Outputs included Whatcom Creek (77.5%), the City of Bellingham (11.3%), evaporation (7.9%), the Whatcom Falls Hatchery (2.5%), the Lake Whatcom Water and Sewer District (0.7%)[2], and the Puget Sound Energy Co-Generation (0.01%)[3].

- The Park Place sand filter[4] was the only storm water treatment site monitored during 2008/2009. Additional monitoring was initiated in October 2009 to provide baseline storm event data for Silver Beach Creek, the proposed location for a watershed restoration project, and to evaluate the effectiveness of a state-of-the art storm water treatment design installed along Northshore Drive.

- The Park Place sand filter provided excellent solids removal (79% reduction when solids were detectable) and coliform removal (85–90% reduction) but was not effective at removing phosphorus (-13 – 19%).

[2]Formerly Water District #10
[3]This facility currently operates at the former Georgia Pacific site.
[4]Formerly the Park Place wet ponds

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.ac.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 76.

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.[5] 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 2008/2009 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; monitor the effectiveness of storm water treatment systems; continue collection of hydrologic data from Austin and Smith Creeks; and update the hydrologic model for Lake Whatcom.

[5]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 2008/2009 monitoring data are available online at http://www.ac.wwu.edu/∼iws as described in Appendix D (page 343). Table 1 (page 16) 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 83 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 9 & 14, November 4 & 5 and December 2 & 4, 2008; and February 3 & 5, April 9 & 14, May 12 & 14, June 9 & 11, July 7 & 9, August 4 & 5, and September 1 & 3, 2009. 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 Surveyor IVa Hydrolab was used to measure temperature, pH, dissolved oxygen, and conductivity. 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 16). 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 at their water treatment plant.

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 (ammonia, 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 17–21) summarize the current field measurements, ambient water quality, and coliform data. The raw data are available online at http://www.ac.wwu.edu/∼iws as described in Appendix D (page 343). The monthly Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 96–145).

The 2008/2009 lake data are plotted with historic lake data in Figures B51–B130 (pages 147–227). 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.

2.3.1 Water temperature

The mid-winter Hydrolab profiles (e.g., Figures B16–B20, pages 111–115) and the multi-year temperature profiles (Figures B51–B55, pages 147–151) 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.

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

The summer Hydrolab profiles (e.g., Figures B46–B50, pages 141–145) illustrate how the lake stratifies into a warm surface layer, the *epilimnion*, and a cool bottom layer, the *hypolimnion*. The transition zone between the epilimnion and hypolimnion, the *metalimnion*, is a region of rapidly changing water temperature. When stratified, the Hydrolab profiles reveal distinct differences between surface and bottom temperatures.

Stratification develops gradually, and once stable, persists until fall or winter, depending on location in the lake. Climatic 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, it is unlikely that the lake will destratify.

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; Matthews, et al., 2008). Basins 1 and 2 (Sites 1–2) usually destratify by the end of October; basin 3 (Sites 3–4) is often still stratified in November or early December. Complete destratification probably occurs in late December or early January in basin 3. By February the temperatures are relatively uniform throughout the water column at all sites.

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 2009 surface water temperatures were fairly typical most of the year, but were exceptionally warm in June and August (Figure 1, page 26). The August 2009 near-surface temperatures set new high temperature records at Sites 1, 2 and the Intake.[7] The lake was unstratified in April and moderately stratified by early May (Δ T $\leq 5°$ C; Figures B21–B30, pages 116–125). Stable stratification was present at Sites 1–4 by early June (Figures B31–B35, pages 126–130).

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 136–137 and 152–153). 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 145 and 156). In contrast, there is rapid depletion of the hypolimnetic oxygen concentrations at Sites 1–2 (Figures B46–B47, and

[7] Lake Whatcom temperature records are based on 1988–2009 data collected by IWS.

B56–B57, pages 141–142 and 152–153). 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.[8]

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).[9] 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 27–30), there were significant negative correlations between dissolved oxygen and time for all samples collected from the hypolimnion during July and August.[10] The 2008 data are somewhat atypical, showing relatively high July and August hypolimnetic oxygen levels. This was probably caused by the extremely cold, cloudy spring that delayed stratification until June 2008. The 2009 data were more typical, and by September 2009 the oxygen levels were $<$1 mg/L at all depths below 11 meters (Figure B46, page 141).

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in June and August (e.g., Figures B31 and B41, pages 126 and 136). 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).

[8]The photic zone is the portion of the lake with enough light to support algal photosynthesis. In Lake Whatcom, peak chlorophyll levels may occur from 0–15 meters, but are more likely to be at 5–10 meters. Therefore, photic zone volumes were defined conservatively as the percent volume $\leq$10 meters. Using this definition, the photic zones for basins 1, 2, and 3 would occupy 75%, 69%, and 17%, respectively (basin volumes provided br Robert Mitchell, March 9, 2010).

[9]Information about Ecology's list of impaired waterbodies in Washington is available at http://www.ecy.wa.gov/programs/wq/303d.

[10]Correlation analyses were used to examine the strength of relationships between two variables. Correlation test statistics range from –1 to +1; the closer to $\pm$1, the stronger the correlation. The significance is measured using the p-value; significant correlations have p-values $<$0.05. Monotonic linear correlations were measured using Pearson's r; monotonic nonlinear (e.g., exponential) correlations were measured using Kendall's τ.

Site 3 developed an oxygen sag near the bottom during late summer and fall (e.g., Figure B49, page 144). Sites 3 and 4 developed small oxygen sags near the thermocline (e.g., Figures B4 and B5, pages 99 and 100), 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

The Hydrolab pH and conductivity data followed trends that were typical for Lake Whatcom, with only small differences between sites and depths (Figures B61–B70, pages 157–166). 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. The influence of photosynthesis on pH is nicely illustrated in Figure B41, page 136, which shows a distinct metalimnetic oxygen peak from photosynthesis that coincided with a metalimnetic pH peak.

There is a significant trend developing in the pH data: the minimum pH values are decreasing slightly over time (Figure 6, page 31), the maximum pH values are increasing slightly over time (Figure 7, page 32), and, as a result, the pH variation is increasing (Figure 8, page 33; Figures B61–B65, pages 157–161).

There is also a significant long-term trend in the conductivity data. This trend is the result of changing to increasingly sensitive equipment during the past two decades, resulting in lower values over time, 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 168–172). 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, followed by Site 3 (Figures B76–B80, pages 173–177).

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 178–202) 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.[11]

Nitrogen: Most algae require inorganic nitrogen in the form of nitrate or ammonia for growth, but some types of algae can use organic nitrogen or even dissolved nitrogen gas.[12] Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 183–187), particularly at Site 1, where the epilimnetic nitrate concentrations often drop below 50 μg-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)[13] have been declining over time (Figure 9, page 34). Low epilimnetic DIN concentrations favor the growth of Cyanobacteria because many types of cyanobacteia can use dissolved N_2 gas as a nitrogen source.

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

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

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

Hypolimnetic nitrate concentrations dropped below 20 μg-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 μg-N/L from 1999–2006 and 2008–2009, 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. The onset of stratification was also late in 2008, but the lake destratified later (mid-November), so the period of anoxia in 2008 was long enough to develop hypolimnetic nitrate reduction. In 2009, the length of stratification at Sites 1–2 was typical (stratified from May through October; destratified by early November) and hypolimnetic nitrate concentrations dropped below 20 μg-N/L.

Ammonia, along with hydrogen sulfide, is often an indicator of hypolimnetic anoxia. Ammonia is produced during decomposition of organic matter. Ammonia is readily taken up by plants as a growth nutrient. In oxygenated environments, ammonia is rarely present in high concentrations because it is rapidly converted to nitrite and nitrate through biological and chemical processes. In low oxygen environments, ammonia accumulates until the lake destratifies. High ammonia and hydrogen sulfide concentrations were measured just prior to destratification in the hypolimnion at Sites 1 and 2 (Table 7, page 22; Figures B81 & B82, pages 178 & 179). Elevated hypolimnetic ammonia 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 179). The highest ammonia concentration measured since 1988 was collected in November 2008 at the bottom of Site 2 (976 μg-N/L).

Sites 3 and 4 often have slightly elevated ammonia concentrations at 20 m (metalimnion) or near the bottom at 80–90 m (Figures B84–B85, pages 181–182). This is caused by bacterial decomposition of organic matter, but the concentrations never approach the levels found in the hypolimnion at Sites 1–2.

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) found that 50% of the total phosphorus bound to the surface of soil collected from a construction site 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 193–197 and B101–B105, pages 198–202). Epilimnetic total phosphorus concentrations are usually lower than late-summer hypolimnetic peaks. Prior to 2000, the median epilimnetic phosphorus concentrations were <5 μg-P/L at Sites 2–4 and approximately 5–8 μg-P/L at Site 1 (Figure 10, page 35). The epilimnetic phosphorus levels have increased significantly at Sites 1, 2, and 4 (Figure 10, page 35); however, the pattern is quite erratic, and it is not clear whether the epilimnetic phosphorus concentrations are continuing to increase.

Site 2 hypolimnetic ammonia and hydrogen sulfide: The bottom samples from Site 2 usually have higher concentrations of ammonia and hydrogen sulfide than Site 1 (Table 7, page 22). These compounds are by-products of anoxia. Although the late summer hypolimnetic oxygen concentrations are near zero at both sites, the shape of basin 2 allows us to sample slightly closer to the lake bottom at Site 2. As a result, samples collected at 20 meters from Site 2 may contain more of the soluble compounds leaching from the sediments (e.g., ammonia and hydrogen sulfide) than samples from 20 meters at Site 1.

In 2007, the concentrations of these compounds dropped noticeably at Site 2, seemingly in response to the short period of lake stratification (Matthews, et al., 2008). Hypolimnetic oxygen depletion does not occur as fast at Site 2 as at Site 1, so late stratification should result in lower concentrations of anoxic by-products at Site 2. In 2007 the lake stratified late and destratified early. As a result, the hypolimnion was anoxic for no more than two months, which may not have been long enough to develop high concentrations of hydrogen sulfide or ammonia at Site 2. In 2008, stratification was again late, but the period of stratification persisted until mid-November, so there was a substantial accumulation of ammonia and hydrogen sulfide at both sites. The 2009 period of stratification was typical, with higher ammonia and hydrogen sulfide levels at Site 2.

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 203–207). 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 of diatoms, *Dinobryon*, and *Mallomonas* (Figures B121–B130, pages 218–227). 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).

Secchi depths (Figures B111–B115, pages 208–212) 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 2009 median near-surface summer chlorophyll concentrations were about the same or slightly higher compared to 2008 (Figure 11, page 36). There were slightly more Chlorophyta and Cyanobacteria than in 2008, and fewer Chrysophyta (Figures 12–14, pages 37–39). The lower Chrysophyta counts did not produce a similar drop in chlorophyll biomass. Most Chrysophyta are counted as individual cells while many Cyanobacteria and Chlorophyta are counted by colonies because the individual cells are very tiny. Colonies of Cyanobacteria and Chlorophyta contain more algal biomass than individual Chrysophyta cells, so smaller numbers of Chrysophyta may not cause in a decrease in chlorophyll if there are more Cyanobacteria or Chlorophyta. Numerical counts are best used to look for trends within the same type of algae (e.g., are the numbers of Cyanobacteria increasing?) and algal biomass or chlorophyll is best used to evaluate changing trophic status (e.g., is the lake becoming more biologically productive?).

One of the eutrophication trends in Lake Whatcom has been a fairly steady increase in the numbers of Cyanobacteria at all sites (Figures 13 and 14, pages 38 and 39). This trend is best viewed using a $\log_{10}$ plot (Figure 14), which shows the counts increasing from 1994 through 2004 or 2005, depending on site, then flattening or decreasing through 2008. In 2009, the counts increased again at Sites 1, 3, and 4, so it is too early to tell whether the trend will continue upward.

Lake Whatcom algal taxonomy: 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.[14] In order to help identify the

[14] P. Wendling, City of Bellingham Public Works Department, personal communications.

source of the problem, IWS analyzed plankton samples collected during August from raw water after it passed through the screen house. The algae in the samples were concentrated using a settling chamber (Hamilton, et al., 2001) and counted to see which types of algae were likely to be affecting the filtration rate (Table 10, page 25; Figures B131–B160 in Appendix B.4, beginning on page 228).

Most of the algae present in the August samples were tiny rod-shaped and spherical Cyanobacteria that have been collectively referred to as *Aphanocapsa* and *Aphanothece* (Figures B143–B144, pages 241–242). These types of Cyanobacteria are very difficult to identify because taxonomic keys are incomplete and the cells are exceedingly tiny. *Aphanocapsa* cells are spherical while *Aphanothece* cells are usually rod-shaped, but *Aphanocapsa* cells look rod-shaped just before they divide, so this distinction is not always helpful. 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. The density of *Aphanocapsa* and *Aphanothece* was very high in all of the August samples.

In addition to the Cyanobacteria that dominated the cell counts, there were several types of diatoms present that may have added to the filter-clogging problem. *Cyclotella* (Figure B152, page 250) and *Thalassiosira* (Figure B157, page 255) excrete long thread-like filaments that probably benefit the diatoms by slowing sinking rates or discouraging predation by filter-feeding zooplankton. In the City's water filters, however, the filaments may help create an algal mat stuck together by Cyanobacteria glue. These threads were clearly visible in the Lake Whatcom samples, both attached to diatom cells and settled on the glass slide surface (Figures B152 and B153, pages 250–251).

Beginning in 2010, IWS will collect additional plankton samples from Site 2, the Intake, and the City's raw water gatehouse to generate detailed species lists and counts of the algae present throughout the year. The goal is to help isolate the algae responsible for filter clogging events.

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[15]/100 mL (Figures B116–B120, pages 213–217) 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 3.1 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 23). 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. 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.

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

Most of the metals concentrations were within normal concentration ranges for the lake. Iron and zinc were often in the detectable range. The highest iron concentration was measured in August at the bottom of Site 1. These elevated iron concentrations were the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water. The iron concentrations were also elevated throughout the water column in basin 3 during February. This was probably caused by suspended sediments that entered the lake during the winter 2008/2009 storms. Chromium, copper, mercury, and lead were detected in many of the samples, but at levels close to detection limits, which is typical for Lake Whatcom.

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. It can be difficult and expensive to remove THMs from drinking water (Viessman & Hammer, 1985).

The 2008/2009 total organic carbon levels at the Intake were higher than usual (Table 9, page 24). The long-term data indicate that total organic carbon concentrations have become more variable. The minimum concentrations measured each year may be $<$2 mg/L but the maximums have increased (Figure 15, page 40). 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 16, page 41).[16]

As illustrated in Figure 17 (page 42), THMs have been increasing in Bellingham's treated drinking water, particularly during the late summer/fall (third quarter). Haloacetic acids (another important disinfection by-product) are not as closely linked to algal concentrations and chlorine dose (Sung, et al., 2000), and were not significantly correlated with time.

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

Abbrev.	Parameter	Method	Historic DL†	2008/2009 MDL†	Sensitivity or Confidence limit
Hydrolab field meter:		Hydrolab (1997)			
cond	Conductivity		–	–	$\pm$ 2 μS/cm
do	Dissolved oxygen		–	–	$\pm$ 0.1 mg/L
ph	pH		–	–	$\pm$ 0.1 pH unit
temp	Temperature		–	–	$\pm$ 0.1° C
IWS field measurements:					
disch	Discharge	Rantz et al. (1982); SOP-IWS-6	–	–	–
secchi	Secchi depth	Lind (1985)	–	–	$\pm$ 0.1 m
IWS laboratory analyses:					
alk	Alkalinity	APHA (2005) #2320; SOP-IWS-15	–	–	$\pm$ 0.8 mg/L
cond	Conductivity	APHA (2005) #2510; SOP-LW-19	–	–	$\pm$ 2.8 μS/cm
do	Dissolved oxygen	APHA (2005) #4500-O.C.; SOP-IWS-12	–	–	$\pm$ 0.1 mg/L
ph	pH-lab	APHA (2005) #4500-H^+; SOP-IWS-8	–	–	$\pm$ 0.03 pH unit
ts	T. solids	APHA (2005) #2540 B; SOP-IWS-22	2 mg/L	9.2 mg/L	$\pm$ 11.7 mg/L
tss	T. suspended solids	APHA (2005) #2540 D; SOP-IWS-22	2 mg/L	1.1 mg/L	$\pm$ 2.7 mg/L
turb	Turbidity	APHA (2005) #2130; SOP-IWS-11	–	–	$\pm$ 0.2 NTUs
nh3	Ammonia (auto)	APHA (2005) #4500-NH_3 H; SOP-IWS-19	10 μg-N/L	8.5 μg-N/L	$\pm$ 7.1 μg-N/L
no3	Nitrite/nitrate (auto)	APHA (2005) #4500-NO_3 I; SOP-IWS-19	20 μg-N/L	8.7 μg-N/L	$\pm$ 3.4 μg-N/L
tn	T. nitrogen (auto)	APHA (2005) #4500-N C; SOP-IWS-19	100 μg-N/L	13.6 μg-N/L	$\pm$ 41.8 μg-N/L
srp	Sol. phosphate (auto)	APHA (2005) #4500-P G; SOP-IWS-19	5 μg-P/L	2.1 μg-P/L	$\pm$ 1.1 μg-P/L
tp	T. phosphorus (auto)	APHA (2005) #4500-P H; SOP-IWS-19	5 μg-P/L	2.2 μg-P/L	$\pm$ 4.0 μg-P/L
IWS plankton analyses:					
chl	Chlorophyll	APHA (2005) #10200 H; SOP-IWS-16	–	–	$\pm$ 0.1 mg/m^3
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	–
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	–

† Historic detection limits (DL) are usually higher than current method detection limits (MDL).

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

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	18.4	19.8	20.6	29.3	2.3	50
Conductivity (μS/cm)‡	57.5	60.2	61.2	78.4	3.6	209
Dissolved oxygen (mg/L)	0.2	9.7	8.3	12.3	3.9	209
pH	6.3	7.3	7.3	9.3	0.7	209
Temperature (°)	4.4	10.1	11.3	24.1	4.4	209
Turbidity (NTU)	0.6	1.0	1.6	10.7	1.9	50
Nitrogen - ammonium (μg-N/L)	$<$10	19.4	47.5	440.5	82.3	50
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	191.2	194.3	365.5	121.2	50
Nitrogen - total (μg-N/L)	211.8	425.2	402.7	589.0	87.3	50
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	24.5	4.1	50
Phosphorus - total (μg-P/L)	$<$5	7.9	13.2	83.4	15.7	50
Chlorophyll (mg/m^3)	0.4	3.0	3.4	10.8	2.3	50
Secchi depth (m)	3.0	4.2	4.2	6.0	0.9	10
Coliforms - fecal (cfu100 mL)§	$<$1	1.0	1.0	9.0	NA	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
§Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 2: Summary of Site 1 ambient water quality data, Oct. 2008 – Sept. 2009.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.9	19.0	19.1	20.2	0.8	28
Conductivity (μS/cm)[‡]	56.4	58.2	58.4	60.3	1.1	110
Dissolved oxygen (mg/L)	9.4	10.1	10.4	12.4	1.0	110
pH	6.8	7.6	7.8	8.8	0.5	110
Temperature (°)	5.4	14.1	14.2	23.5	5.5	110
Turbidity (NTU)	0.4	0.7	0.9	3.4	0.8	30
Nitrogen - ammonium (μg-N/L)	$<$10	$<$10	$<$10	24.4	6.7	30
Nitrogen - nitrate/nitrite (μg-N/L)	107.3	242.3	240.9	385.9	94.8	30
Nitrogen - total (μg-N/L)	287.5	406.6	401.6	510.8	68.8	30
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	5.5	1.0	30
Phosphorus - total (μg-P/L)	$<$5	$<$5	5.5	14.4	3.0	30
Chlorophyll (mg/m^3)	1.1	3.3	3.2	5.1	1.1	30
Secchi depth (m)	2.7	4.6	4.7	7.0	1.6	10
Coliforms - fecal (cfu100 mL)[§]	$<$1	1.0	1.0	2.0	NA	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[§]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3: Summary of Intake ambient water quality data, Oct. 2008 – Sept. 2009.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.9	18.8	19.4	32.6	2.4	50
Conductivity (μS/cm)‡	56.3	58.0	58.9	86.6	3.5	210
Dissolved oxygen (mg/L)	0.3	10.0	9.3	12.4	3.0	210
pH	6.2	7.3	7.3	8.7	0.6	210
Temperature (°)	5.3	11.0	12.2	23.4	5.0	210
Turbidity (NTU)	0.4	0.7	1.1	9.2	1.4	50
Nitrogen - ammonium (μg-N/L)	<10	<10	43.2	975.6	148.7	50
Nitrogen - nitrate/nitrite (μg-N/L)	<20	260.4	259.8	390.7	105.0	50
Nitrogen - total (μg-N/L)	321.0	435.8	446.9	1099.9	121.1	50
Phosphorus - soluble (μg-P/L)	<5	<5	<5	43.7	6.0	50
Phosphorus - total (μg-P/L)	<5	6.2	10.5	149.7	21.1	48
Chlorophyll (mg/m^3)	0.4	2.9	2.7	4.9	1.2	50
Secchi depth (m)	2.5	4.4	4.9	7.1	1.5	10
Coliforms - fecal (cfu100 mL)§	<1	1.0	1.0	2.0	NA	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
§Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 4: Summary of Site 2 ambient water quality data, Oct. 2008 – Sept. 2009.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.8	18.3	18.5	20.4	0.6	70
Conductivity (μS/cm)[‡]	56.4	57.7	57.8	65.4	1.0	250
Dissolved oxygen (mg/L)	2.9	10.2	10.0	12.1	1.2	250
pH	6.4	7.1	7.3	8.7	0.6	250
Temperature (°)	5.6	6.8	9.8	22.7	5.1	250
Turbidity (NTU)	0.2	0.6	0.9	3.7	0.9	70
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	41.4	7.6	70
Nitrogen - nitrate/nitrite (μg-N/L)	147.2	391.4	344.9	428.3	91.2	70
Nitrogen - total (μg-N/L)	317.6	486.5	463.6	546.1	63.3	70
Phosphorus - soluble (μg-P/L)	<5	<5	<5	5.7	1.2	70
Phosphorus - total (μg-P/L)	<5	<5	5.9	17.0	3.7	70
Chlorophyll (mg/m^3)	0.5	2.4	2.5	4.9	1.3	50
Secchi depth (m)	2.0	4.7	5.4	8.9	2.2	10
Coliforms - fecal (cfu100 mL)[§]	<1	1.0	1.0	3.0	NA	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[§]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 5: Summary of Site 3 ambient water quality data, Oct. 2008 – Sept. 2009.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.2	18.2	18.4	20.2	0.6	80
Conductivity (μS/cm)‡	56.1	57.5	57.6	59.8	0.8	270
Dissolved oxygen (mg/L)	7.7	10.1	10.0	12.0	0.9	270
pH	6.5	7.0	7.2	8.3	0.5	270
Temperature (°)	5.6	6.4	9.4	22.4	4.9	270
Turbidity (NTU)	0.2	0.6	1.0	5.2	1.4	80
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	23.8	5.0	80
Nitrogen - nitrate/nitrite (μg-N/L)	154.4	412.4	360.0	426.9	87.5	80
Nitrogen - total (μg-N/L)	308.3	497.0	473.7	551.2	63.5	80
Phosphorus - soluble (μg-P/L)	<5	<5	<5	8.2	1.3	80
Phosphorus - total (μg-P/L)	<5	5.6	5.7	17.6	4.0	78
Chlorophyll (mg/m^3)	0.3	3.1	2.5	4.5	1.3	50
Secchi depth (m)	1.6	4.6	5.2	8.1	2.1	10
Coliforms - fecal (cfu100 mL)§	<1	1.0	1.0	2.0	NA	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
§Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 6: Summary of Site 4 ambient water quality data, Oct. 2008 – Sept. 2009.

Date		H_2S (mg/L)	NH_3 (μg-N/L)
October 1999	Site 1 (bottom)	0.03–0.04	268.3
	Site 2 (bottom)	0.40	424.4
October 2000	Site 1 (bottom)	0.27	208.8
	Site 2 (bottom)	0.53	339.5
October 2001	Site 1 (bottom)	0.42	168.7
	Site 2 (bottom)	0.76	331.9
October 2002	Site 1 (bottom)	0.09	203.9
	Site 2 (bottom)	0.32	383.8
October 2003	Site 1 (bottom)	0.05	333.8
	Site 2 (bottom)	0.05	340.0
October 2004	Site 1 (bottom)	0.25	300.3
	Site 2 (bottom)	0.25	378.3
October 2005	Site 1 (bottom)	0.13, 0.12[†]	257.5
	Site 2 (bottom)	0.25, 0.42[†]	450.4
October 2006	Site 1 (bottom)	0.20[†]	334.1
	Site 2 (bottom)	0.42[†]	354.1
October 2007	Site 1 (bottom)	0.40[†]	324.5
	Site 2 (bottom)	0.20[†]	79.3
October 2008	Site 1 (bottom)	0.28[†]	294.5
	Site 2 (bottom)	0.38[†]	404.9
October 2009	Site 1 (bottom)	0.15[†]	271.3
	Site 2 (bottom)	0.47[†]	301.2

[†]Samples analyzed by Edge Analytical.

Table 7: October hypolimnetic ammonia and hydrogen sulfide concentrations at Sites 1 and 2, 1999–2009. The H_2S samples were analyzed in the field using a HACH test kit until 2005, when duplicate samples were analyzed by Edge Analytical, Bellingham, WA. After 2005, samples were analyzed by Edge Analytical.

	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 20, 2009	<0.01	<0.0005	<0.001	0.001	0.046	<0.0001	<0.005	0.003	0.002
Site 1	20	Feb 20, 2009	<0.01	<0.0005	<0.001	<0.001	0.049	0.0002	<0.005	0.001	0.002
Intake	0	Feb 20, 2009	<0.01	<0.0005	<0.001	0.003	0.064	<0.0001	<0.005	0.001	0.003
Intake	10	Feb 20, 2009	<0.01	<0.0005	<0.001	0.002	0.066	0.0002	<0.005	0.001	0.002
Site 2	0	Feb 20, 2009	<0.01	<0.0005	<0.001	0.003	0.054	<0.0001	<0.005	0.002	0.004
Site 2	20	Feb 20, 2009	<0.01	<0.0005	<0.001	0.002	0.072	0.0002	<0.005	<0.001	0.003
Site 3	0	Feb 3, 2009	<0.01	<0.0005	0.002	0.001	0.100	0.0001	<0.005	<0.001	<0.001
Site 3	80	Feb 3, 2009	<0.01	<0.0005	0.003	<0.001	0.146	<0.0001	<0.005	0.002	<0.001
Site 4	0	Feb 3, 2009	<0.01	<0.0005	0.002	0.002	0.144	<0.0001	<0.005	<0.001	<0.001
Site 4	90	Feb 3, 2009	<0.01	<0.0005	0.006	0.002	0.177	0.0002	<0.005	0.006	0.001
Site 1	0	Aug 4, 2009	<0.01	<0.0005	<0.001	0.003	0.034	0.0004	<0.005	<0.001	0.001
Site 1	20	Aug 4, 2009	<0.01	<0.0005	0.003	0.001	0.424	0.0004	<0.005	0.002	0.005
Intake	0	Aug 4, 2009	<0.01	<0.0005	<0.001	0.003	0.023	0.0004	<0.005	0.001	0.003
Intake	10	Aug 4, 2009	<0.01	<0.0005	<0.001	<0.001	0.027	0.0002	<0.005	0.001	0.003
Site 2	0	Aug 4, 2009	<0.01	<0.0005	<0.001	0.002	0.018	0.0003	<0.005	0.002	0.002
Site 2	20	Aug 4, 2009	<0.01	<0.0005	<0.001	0.006	0.084	0.0003	<0.005	0.005	0.007
Site 3	0	Aug 5, 2009	<0.01	<0.0005	0.005	0.003	0.018	0.0001	<0.005	0.005	0.001
Site 3	80	Aug 5, 2009	<0.01	<0.0005	<0.001	0.003	0.045	0.0001	<0.005	0.002	0.003
Site 4	0	Aug 5, 2009	<0.01	<0.0005	0.002	0.002	0.017	0.0005	<0.005	0.001	0.003
Site 4	90	Aug 5, 2009	<0.01	<0.0005	<0.001	0.004	0.019	0.0001	<0.005	0.002	0.001

Table 8: Lake Whatcom 2008/2009 total metals data. Only the metals specified in the monitoring plan are included in this table; the results for 24 additional metals are included in the online data files (http://www.ac.wwu.edu∼iws).

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 20, 2009	0	4.1	Aug 4, 2009	0	6.9
	Feb 20, 2009	20	3.9	Aug 4, 2009	20	3.6
Intake	Feb 20, 2009	0	4.8	Aug 4, 2009	0	2.7
	Feb 20, 2009	10	3.1	Aug 4, 2009	10	3.0
Site 2	Feb 20, 2009	0	3.3	Aug 4, 2009	0	6.2
	Feb 20, 2009	20	3.7	Aug 4, 2009	15	2.5
Site 3	Feb 3, 2009	0	4.3	Aug 5, 2009	0	5.8
	Feb 3, 2009	80	7.1	Aug 5, 2009	80	4.5
Site 4	Feb 3, 2009	0	2.2	Aug 5, 2009	0	3.7
	Feb 3, 2009	90	2.9	Aug 5, 2009	90	3.9

Table 9: Lake Whatcom 2008/2009 total organic carbon data.

Algae Counts (cells per mL)	Sampling Date Aug 13	Aug 20	Aug 26	Aug 31
Chlorophyta (Green Algae)				
Ankistrodesmus falcatus (Corda) Ralfs (Figure B131)	9	12	0	0
Botryococcus sp. Kützing (Figure B132)	77	0	0	0
Closterium spp. Nitzsch ex Ralfs (Figure B133)	0	0	33	31
Cosmarium spp. Ralfs (Figure B134)	3	0	0	2
Crucigenia sp. Morren (no image available)	0	0	0	13
Crucigenia tetrapedia (Kirchner) West & West (Figure B135)	18	0	35	13
Elakatothrix gelatinosa Wille (Figure B136)	10	4	46	7
Gloeocystis sp. Nägeli (Figure B137)	0	0	0	0
Oocystis spp. Braun (Figure B138)	24	9	26	7
Pediastrum spp. Meyen (Figure B139)	0	0	0	20
Quadrigula closteroides (Bohlin) Printz (Figure B140)	0	0	0	0
Scenedesmus spp. Meyen (Figure B141)	53	72	158	64
Sphaerocystis schroeteri Chodat (Figure B142)	15	0	0	0
Cyanobacteria (Bluegreen Algae)†				
Aphanocapsa spp. Nägeli (Figure B143) and *Aphanothece* spp. Nägeli (Figure B144)	63,858	32,439	65,561	29,226
Chroococcus turgida (Kützing) Nägeli (Figure B145)	26	31	0	11
Snowella lacustris (Chodat) Komárek & Hindák (Figure B146)	0	685	7,563	4,199
Cryptophyta (Cryptomonads)				
Cryptomonas spp. Ehrenberg (Figure B147)	19	29	26	32
unk. Cryptophyta (Figure B148)	56	173	228	96
Chrysophyta (Golden Algae)‡				
Dinobryon spp. Ehrenberg (Figure B149)	15	22	7	0
Mallomonas spp. Perty (Figure B150)	0	1	0	0
Chrysophyta - diatoms‡				
Aulacoseira sp. Thwaites (Figure B151)	0	11	22	7
Cyclotella sp. (Kützing) & Brébisson (Figure B152)	82	209	329	169
Fragilaria spp. Lyngbye (Figure B154)	18	29	110	0
Melosira sp. Agardh (Figure B155)	0	2	0	0
Synedra spp. Ehrenberg (Figure B156)	103	54	66	73
Thalassiosira pseudonana Hasle & Heimdal (Figure B157)	61	44	101	46
misc. diatoms	24	31	59	10
Dinoflagellates				
Gymnodinium sp. (Ehrenberg) Stein (Figure B158)	1	0	0	0
Peridinium umbonatum Stein (Figure B159)	0	1	0	0
Peridinium sp. Ehrenberg (Figure B160)	2	0	0	0

†Cyanobacteria cell counts are approximate.
‡These types of algae are uncommon during August but are usually abundant during the rest of the year

Table 10: Algae cell counts in untreated lake samples collected at the screenhouse in August 2009.

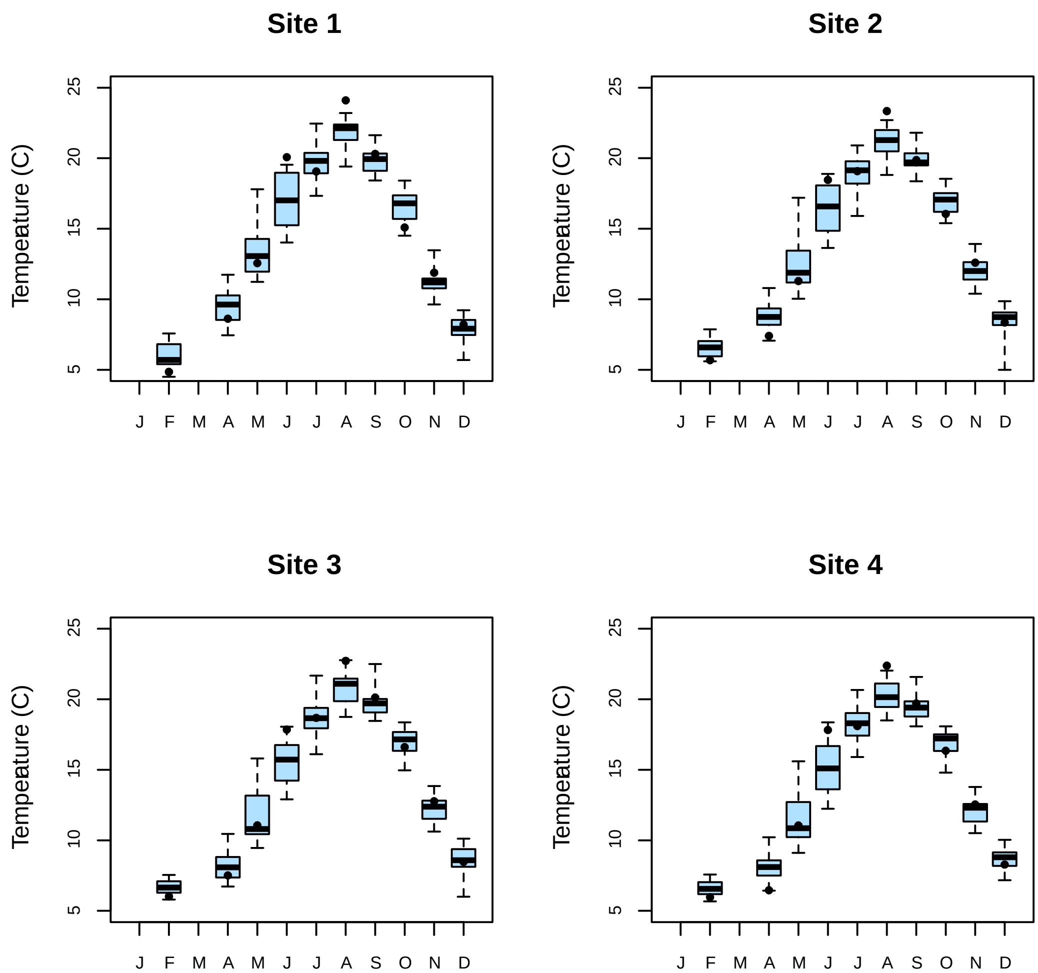


Figure 1: Boxplots showing 1988–2008 surface water temperatures (depth <1 m, all sites and years) with monthly 2009 data (•). Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

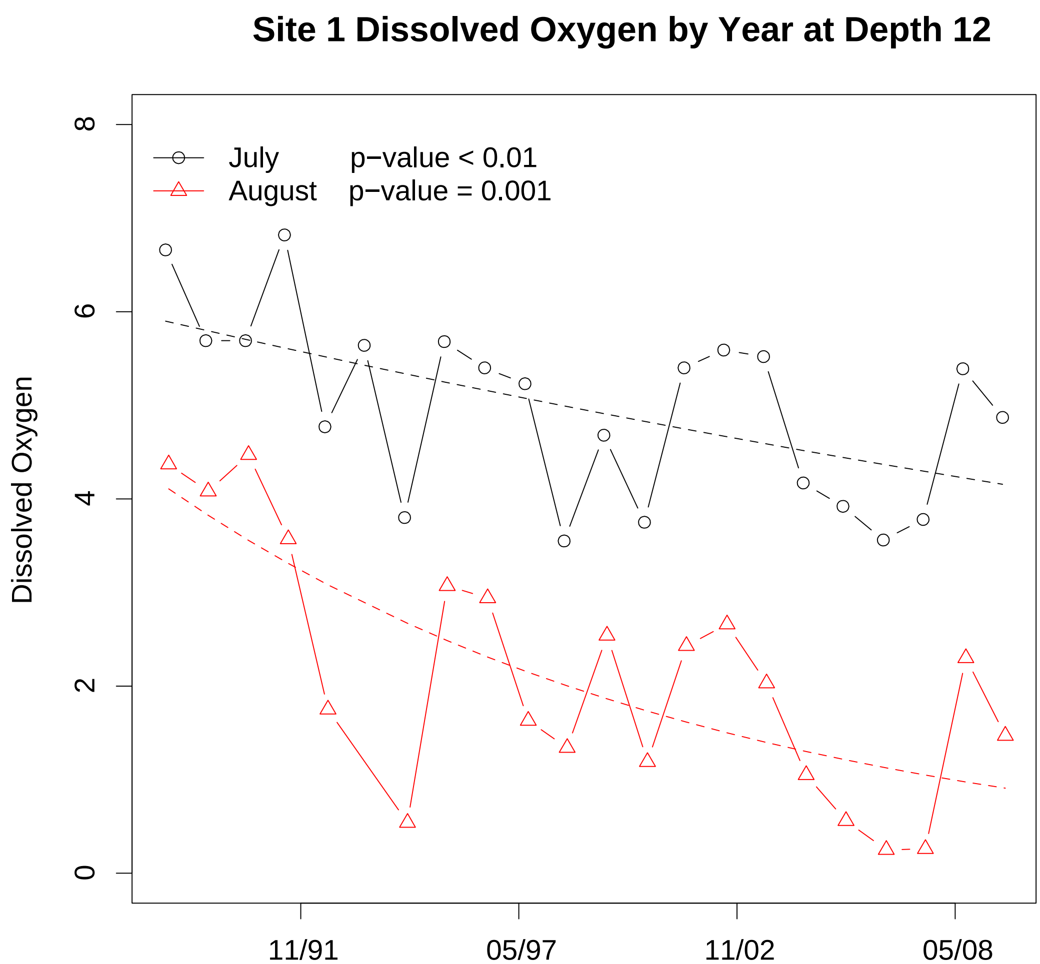


Figure 2: Nonlinear relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

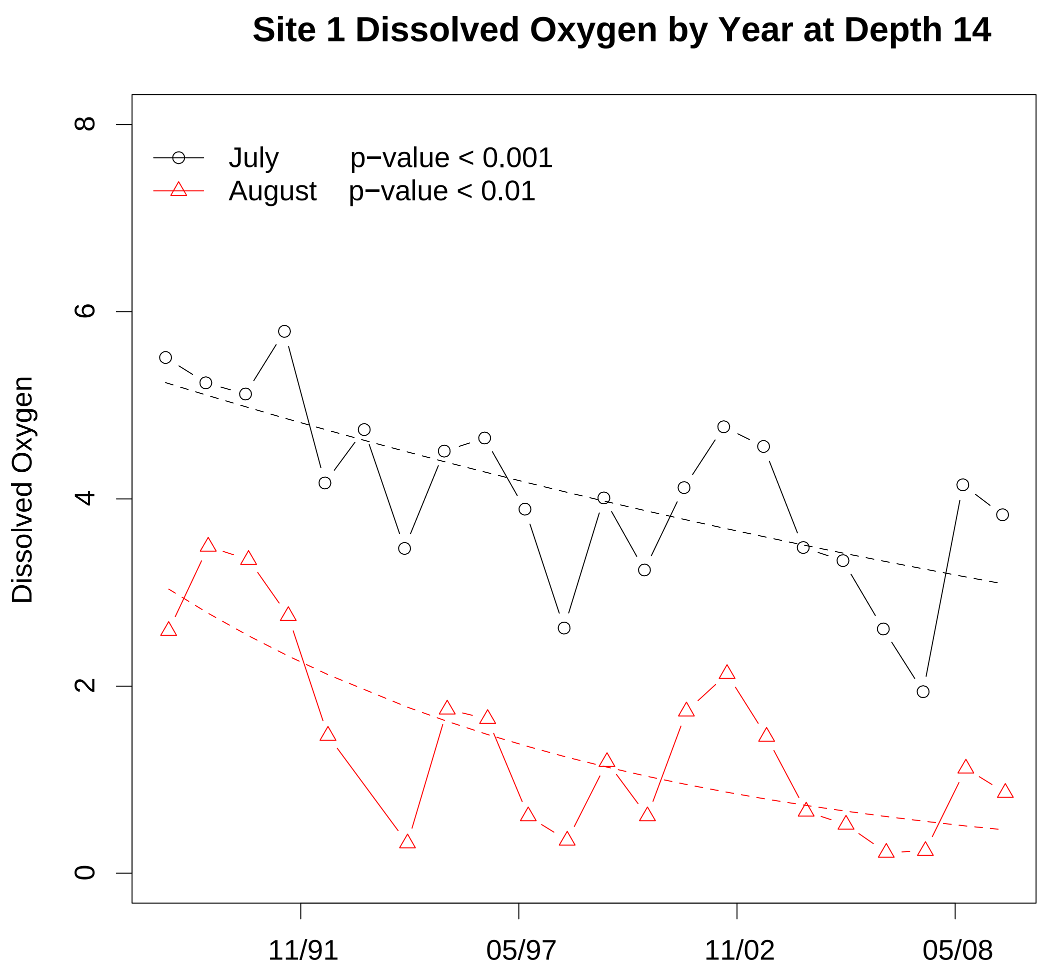


Figure 3: Nonlinear relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

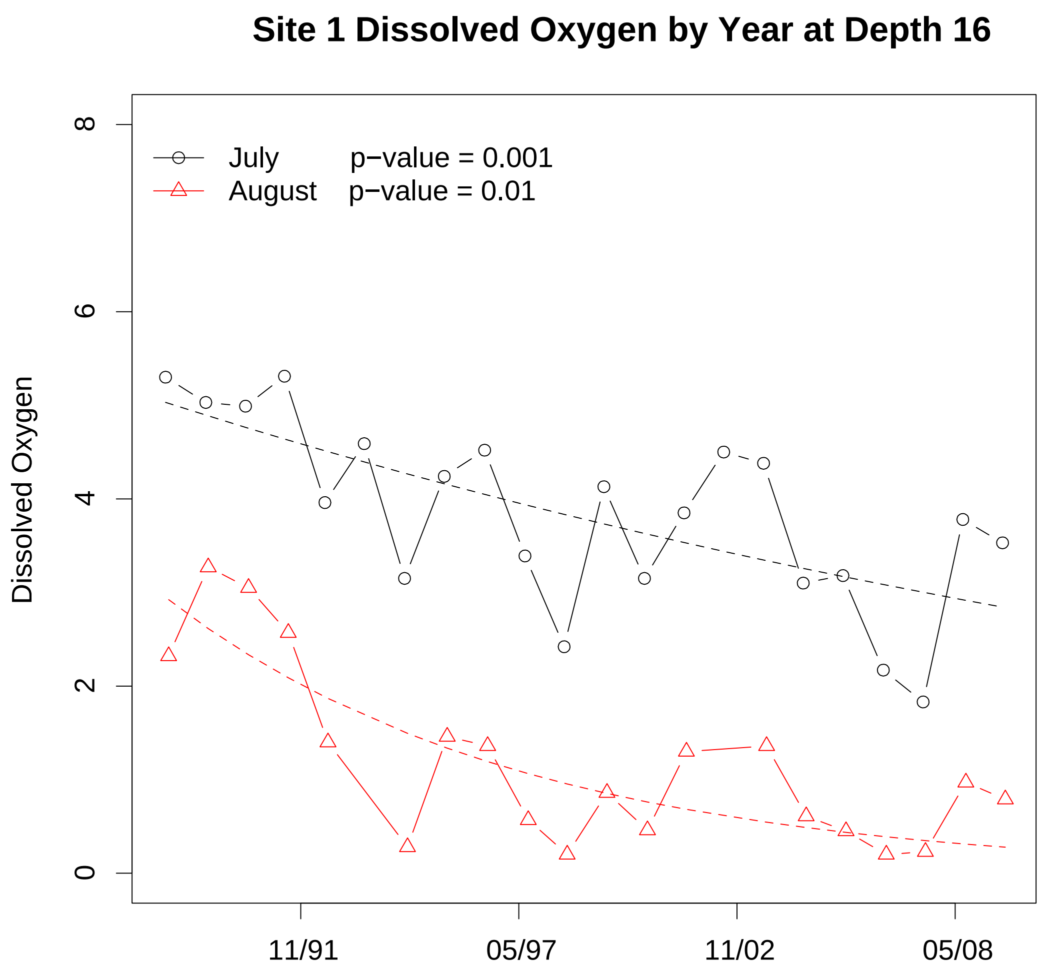


Figure 4: Nonlinear relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

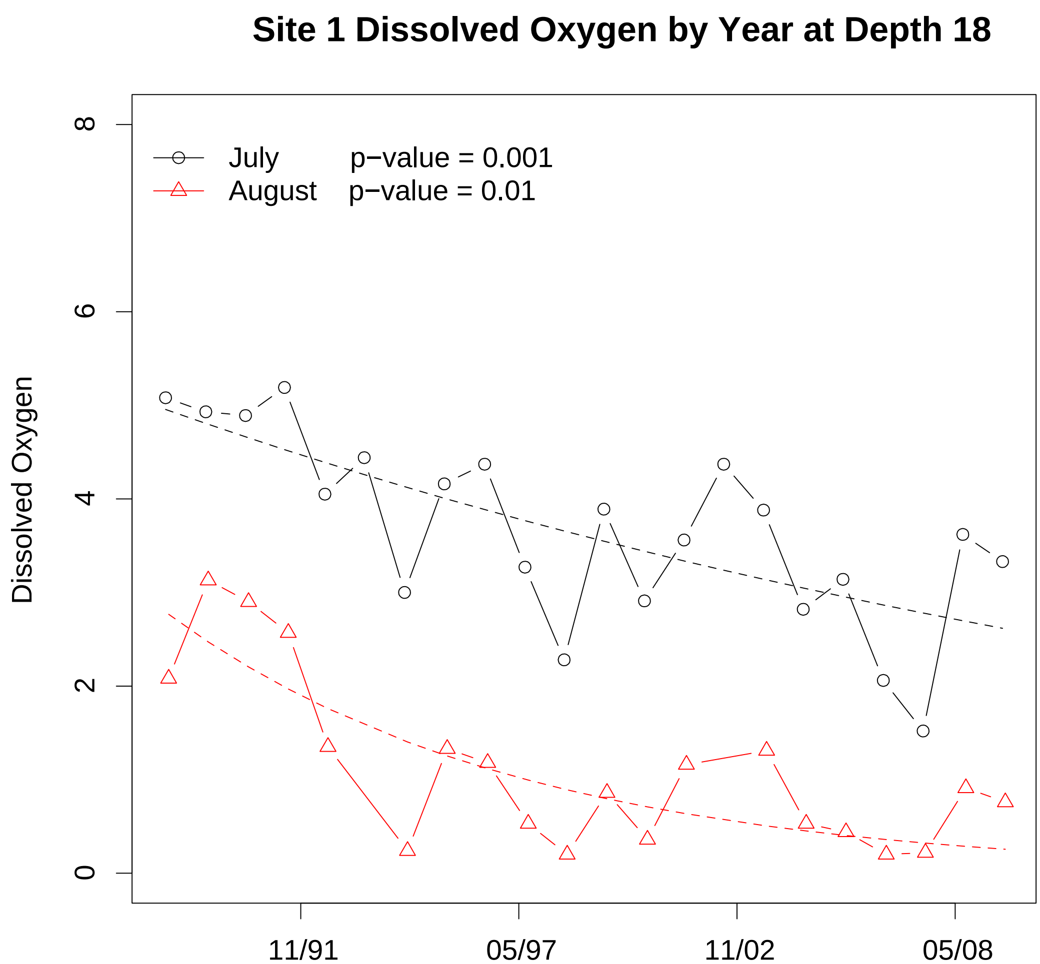


Figure 5: Nonlinear relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

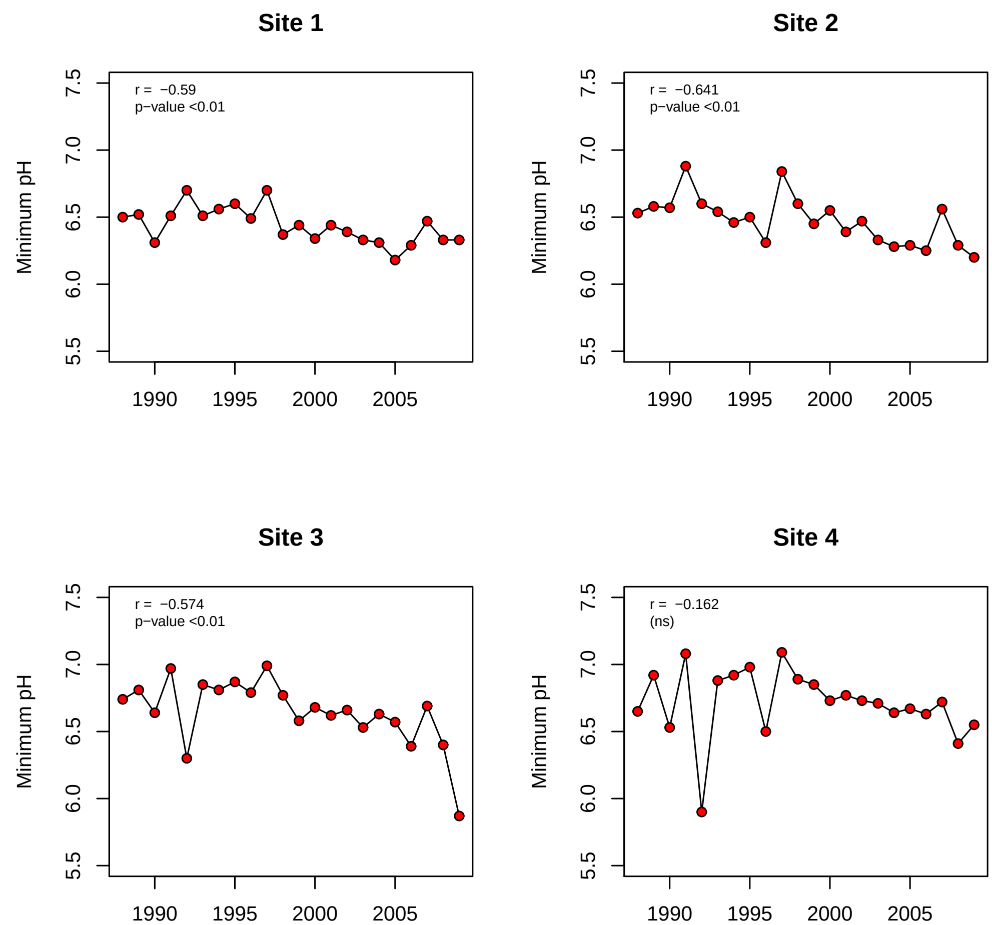


Figure 6: Correlation between minimum annual pH (all months and depths) vs. year. Pearson's r correlations were used because the data were approximately monotonic-linear; correlations were significant at Sites 1–3.

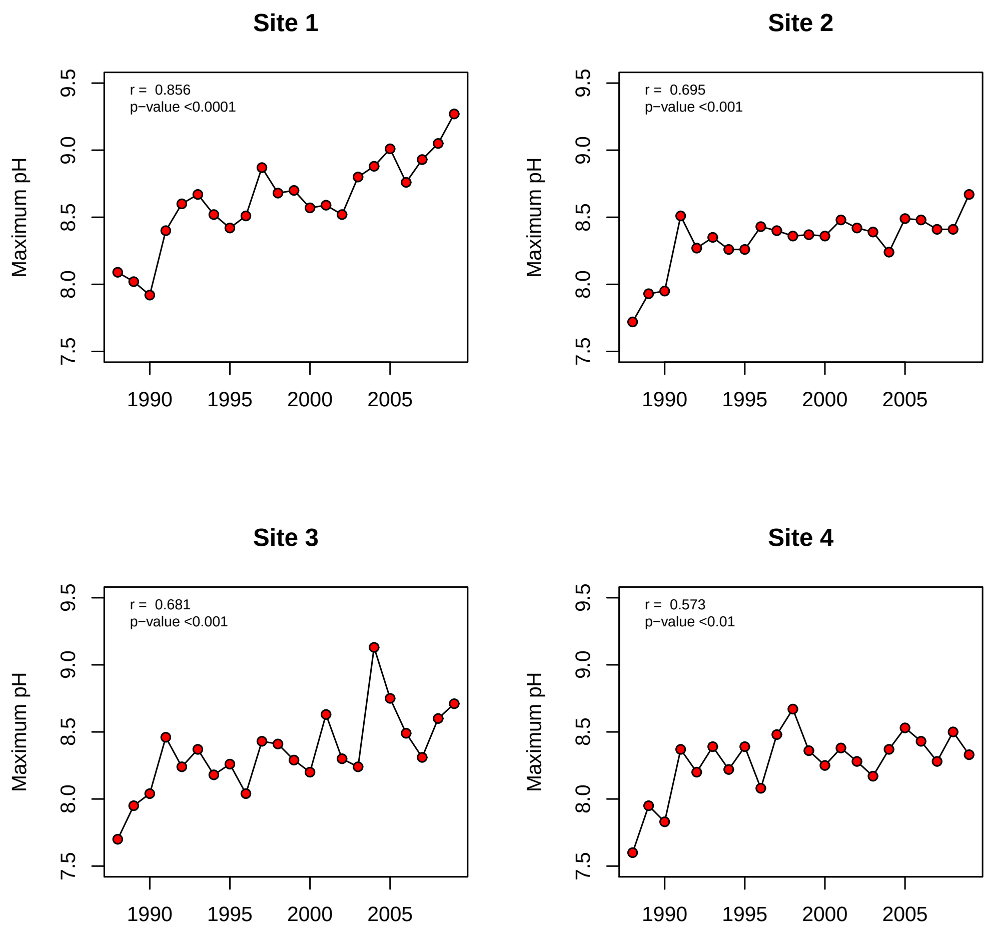


Figure 7: Correlation between maximum annual pH (all months and depths) vs. year. Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

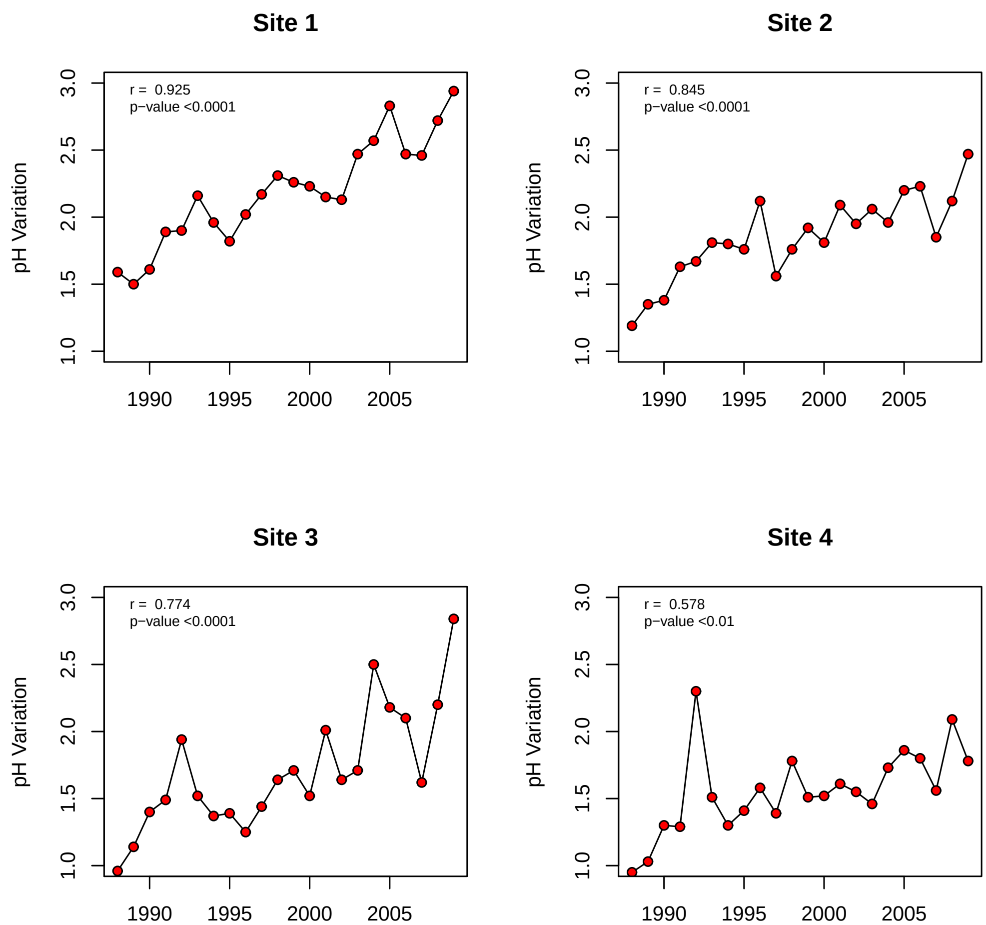


Figure 8: Change in annual pH variation (annual maximum – annual minimum). Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

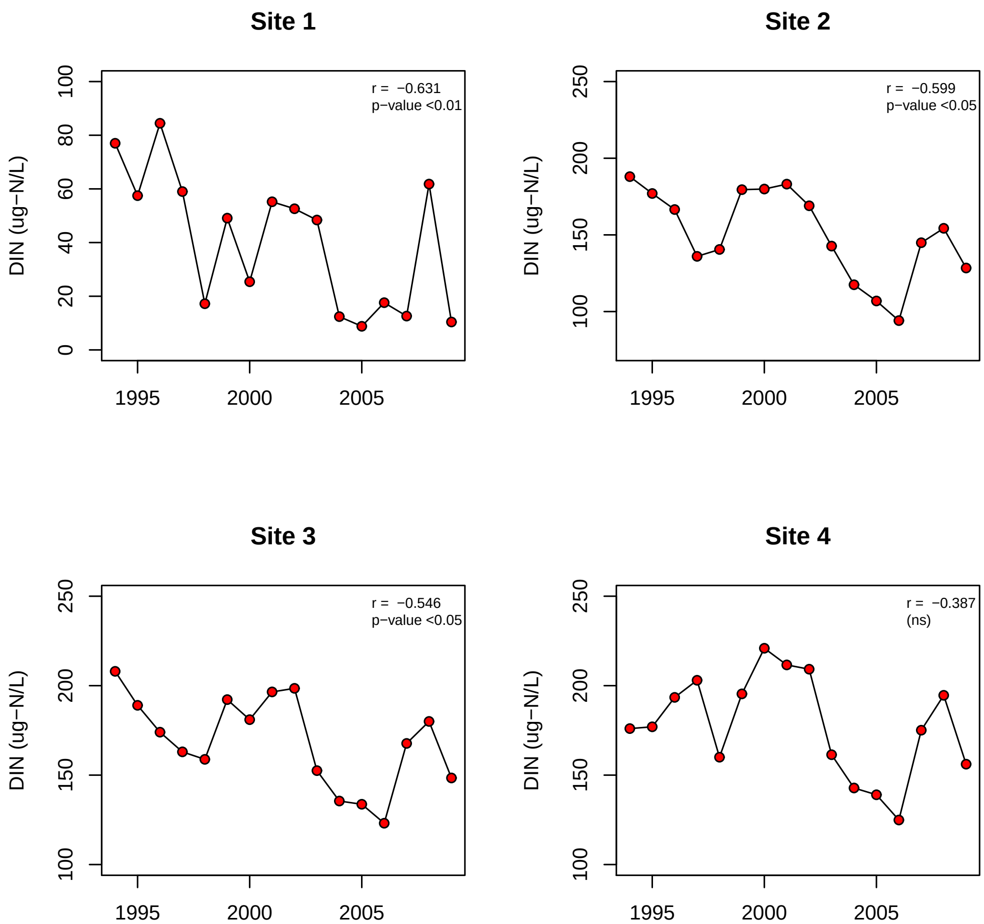


Figure 9: Minimum summer, near-surface dissolved inorganic nitrogen concentrations (1994–2009, June-Oct, depths $\leq$5 m). Pearson's r correlations were used because the data were approximately monotonic-linear; correlations were significant at Sites 1–3.

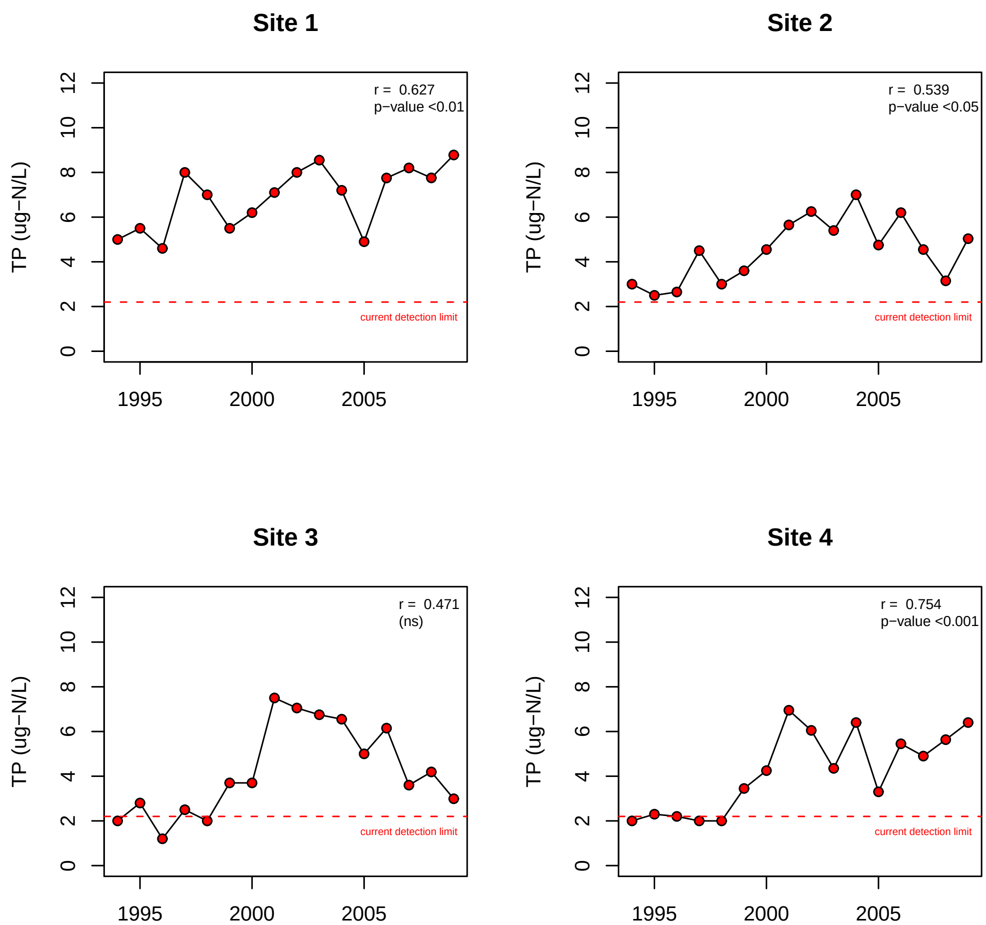


Figure 10: Median summer, near-surface total phosphorus concentrations (1994–2009, June-Oct, depths ≤5 m). Uncensored (raw) data were used to illustrate that median values are increasingly above analytical detection limits (Table 1). Pearson's r correlations were used because the data were approximately monotonic-linear; correlations were significant at Sites 1, 2, and 4.

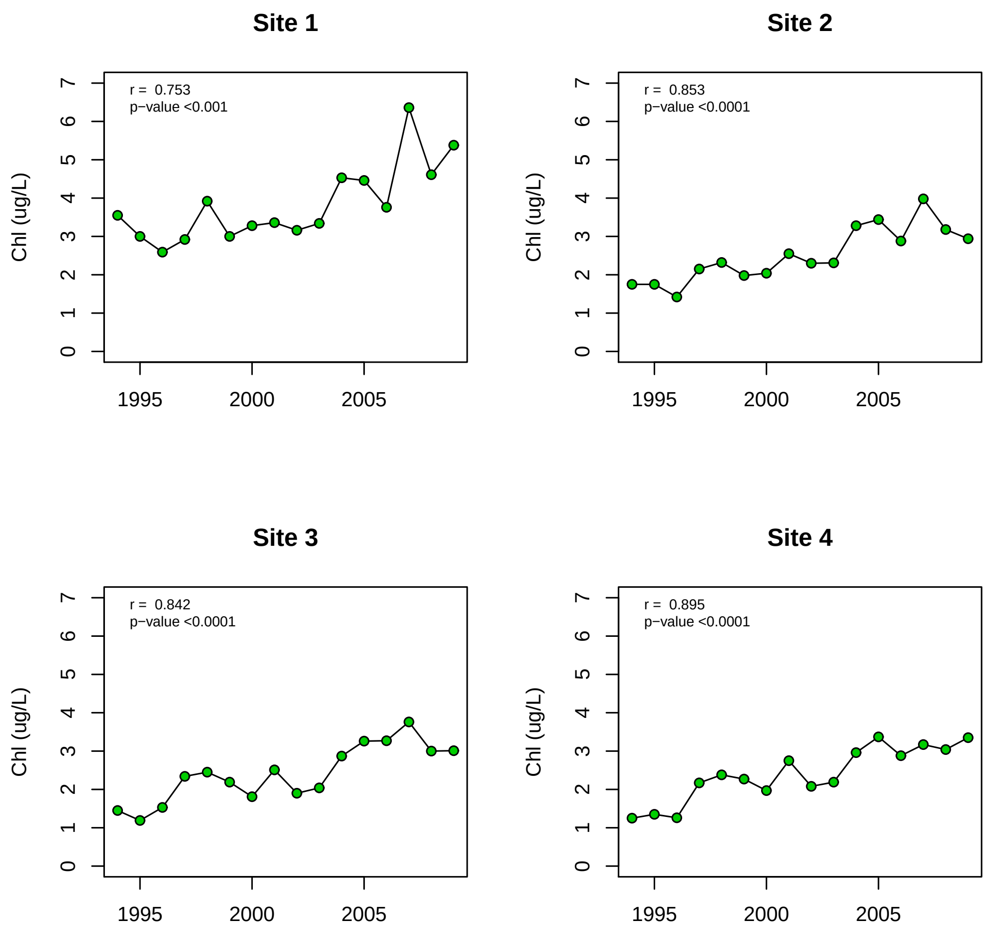


Figure 11: Median summer near-surface chlorophyll concentrations (1994–2009, June-October, depths $\leq$5 m). Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

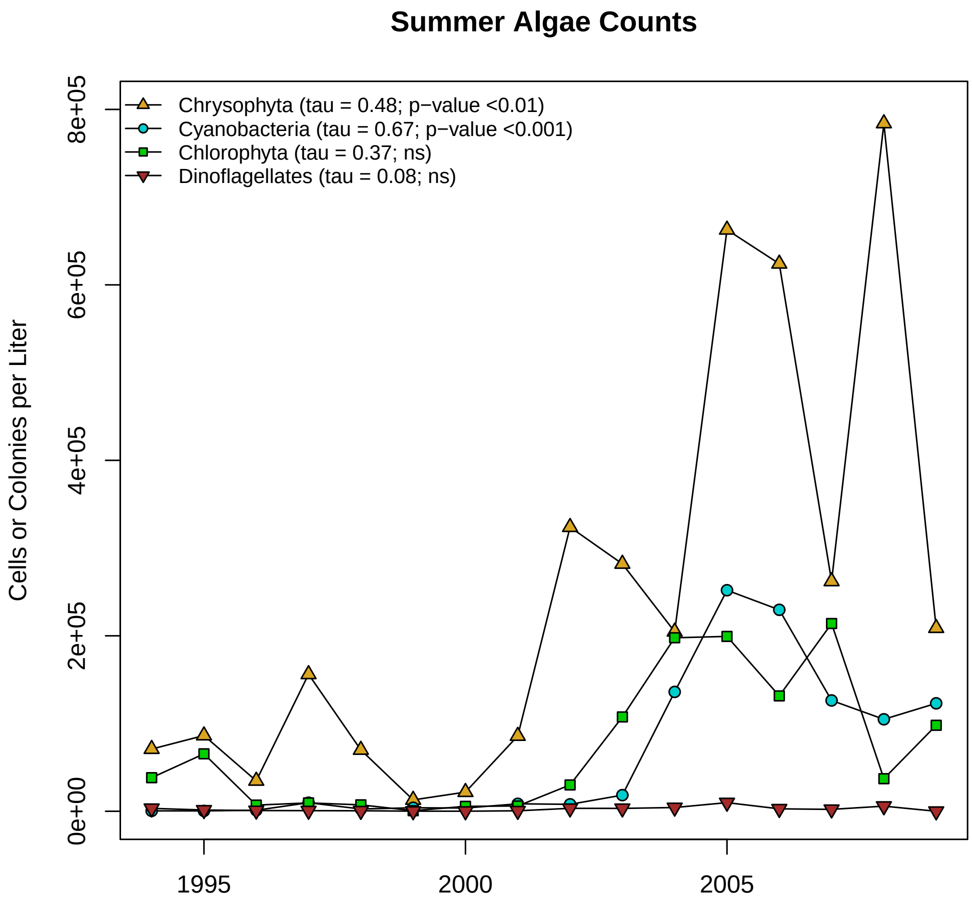


Figure 12: Median summer, near-surface algae counts (1994-2009, June-October, all sites and depths). Kendall's τ correlations were used because the data were not monotonic-linear; correlations for Chrysophyta and Cyanobacteria were significant.

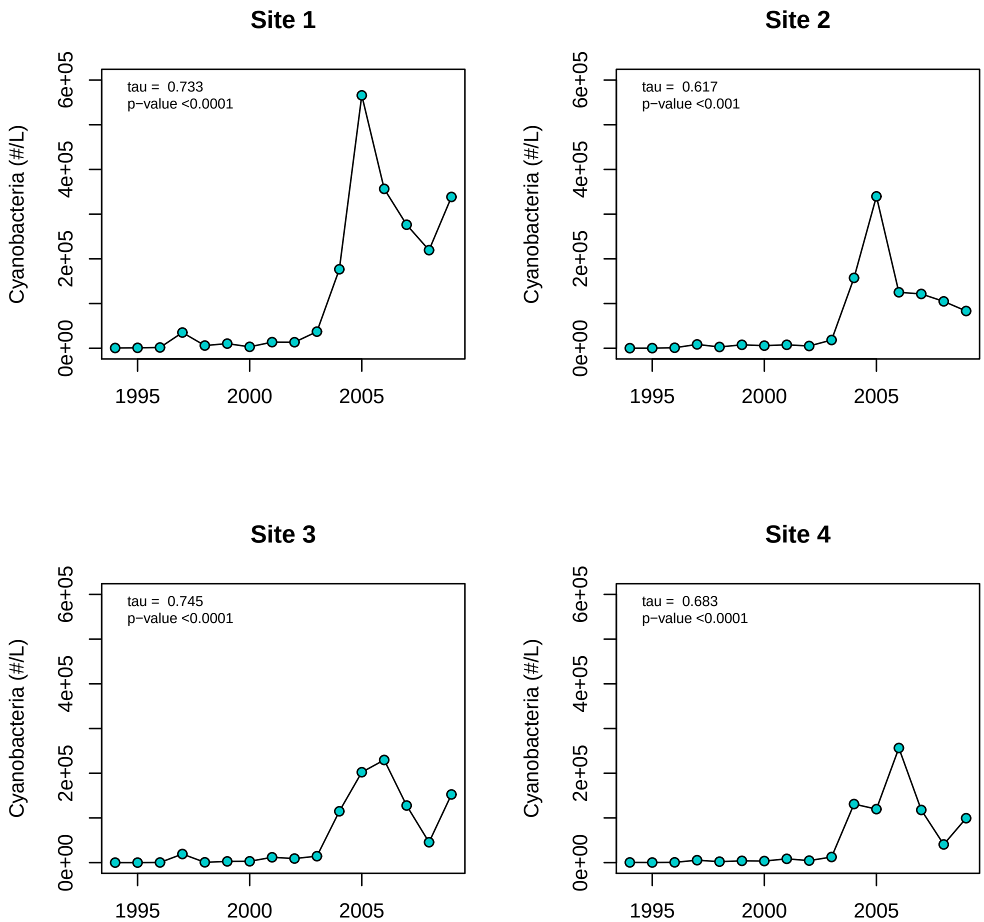


Figure 13: Median summer, near-surface Cyanobacteria counts (1994–2009, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

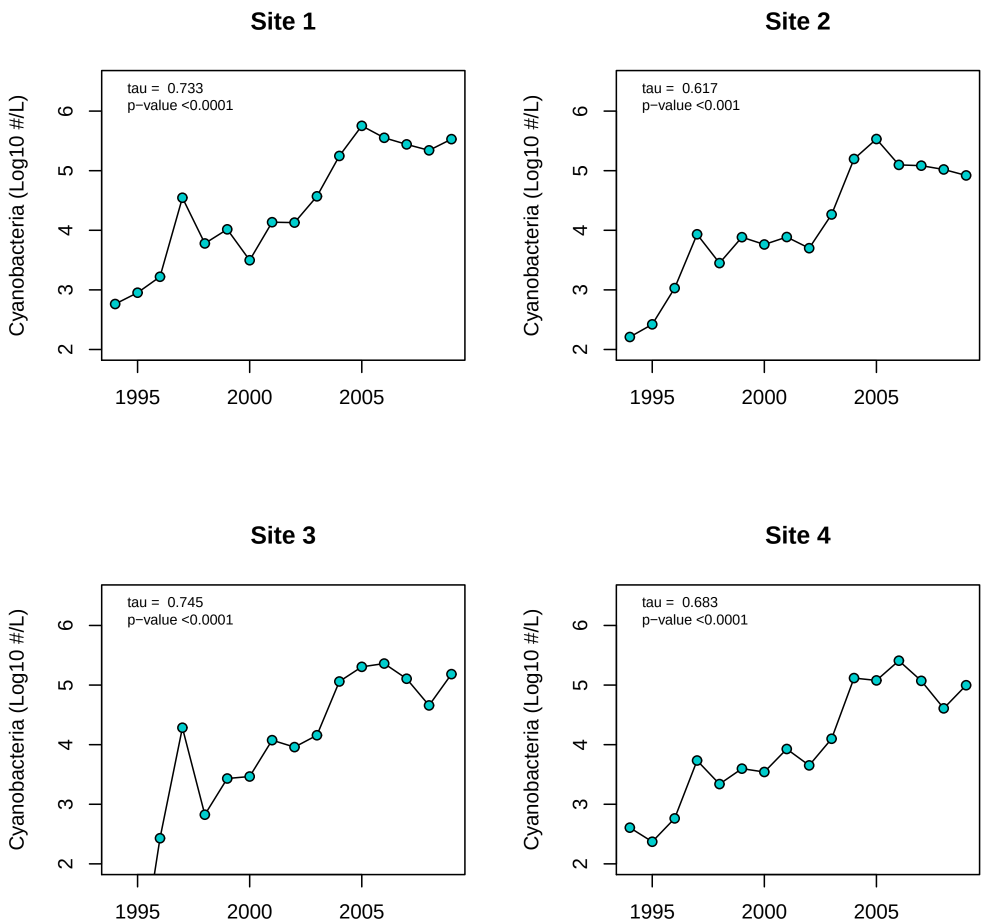


Figure 14: Log_{10} plots of median summer, near-surface Cyanobacteria counts (1994–2009, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant. The correlation results in this figure are identical to Figure 13 because Kendall's τ is based on ranks.

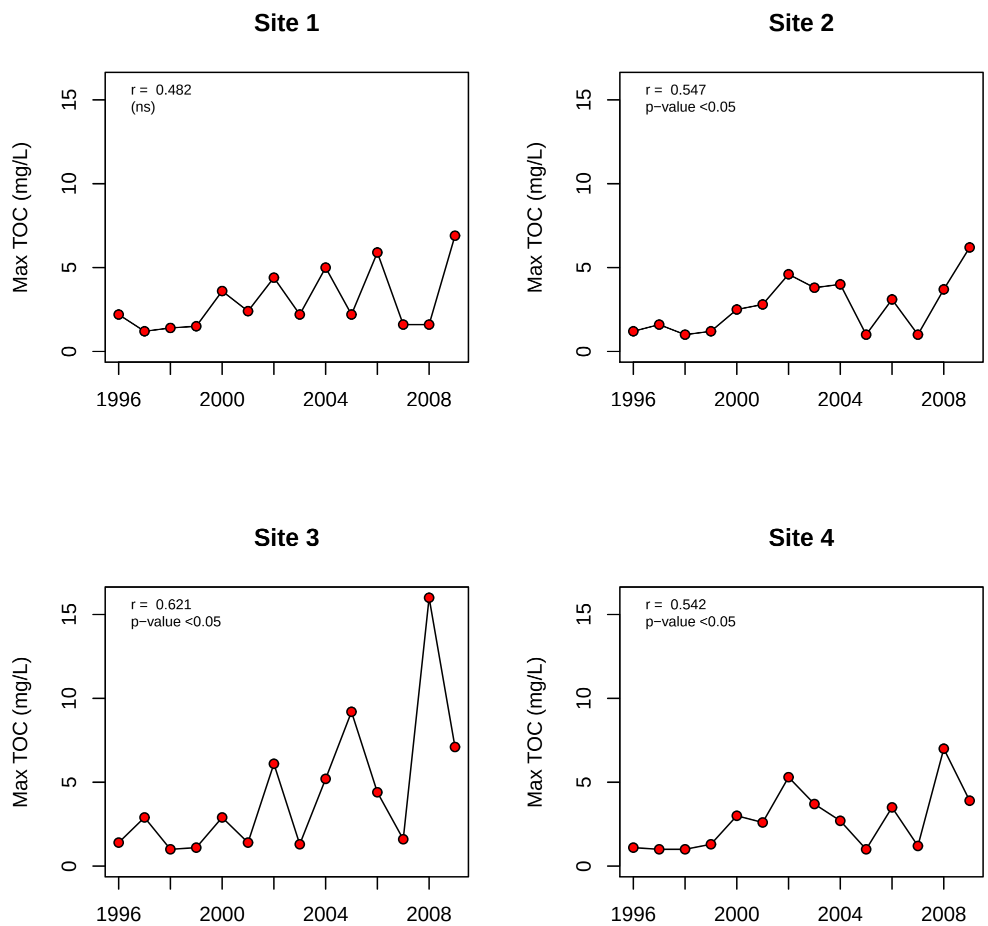


Figure 15: Maximum annual total organic carbon concentrations at Sites 1–4. Pearson's r correlations were used because the data were approximately monotonic-linear; correlations at Sites 2–4 were significant.

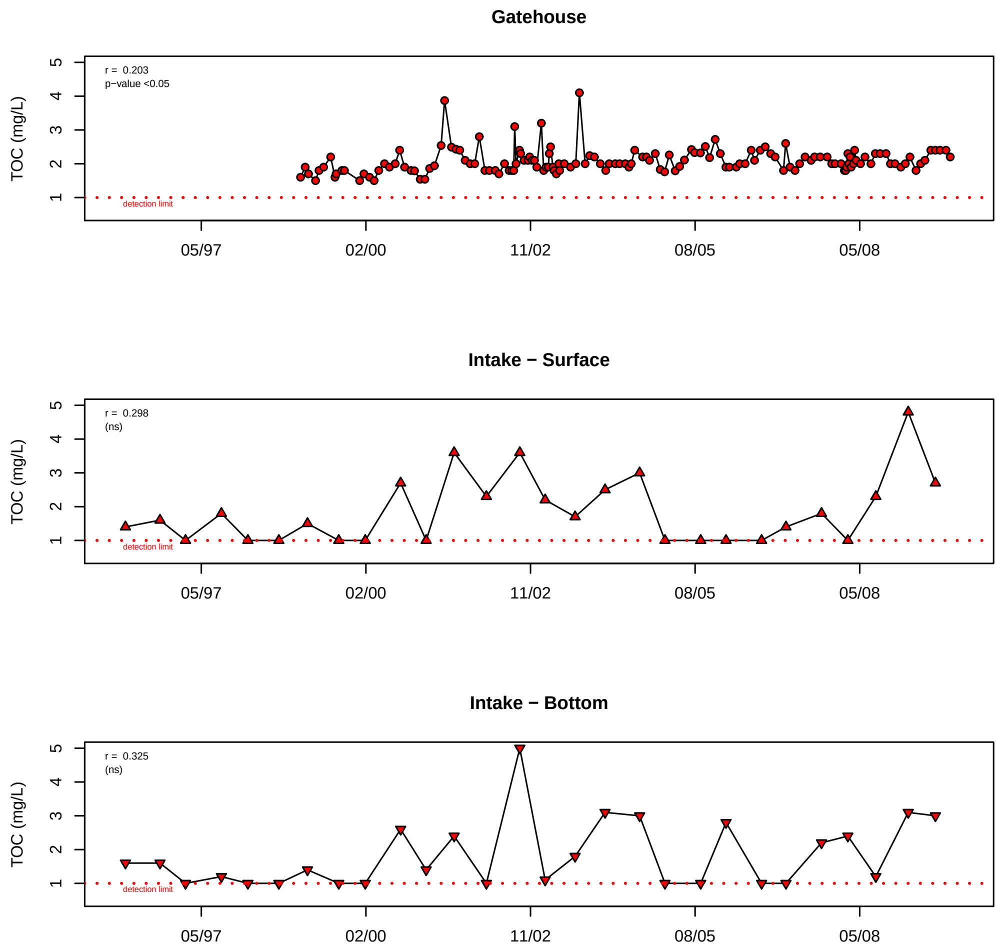


Figure 16: Total organic carbon concentrations at the Intake (off-shore, surface and bottom) and from the gatehouse. Gatehouse data were provided by the City of Bellingham Public Works Department. Pearson's r correlations were used because the data were approximately monotonic-linear; only the gatehouse correlation was significant.

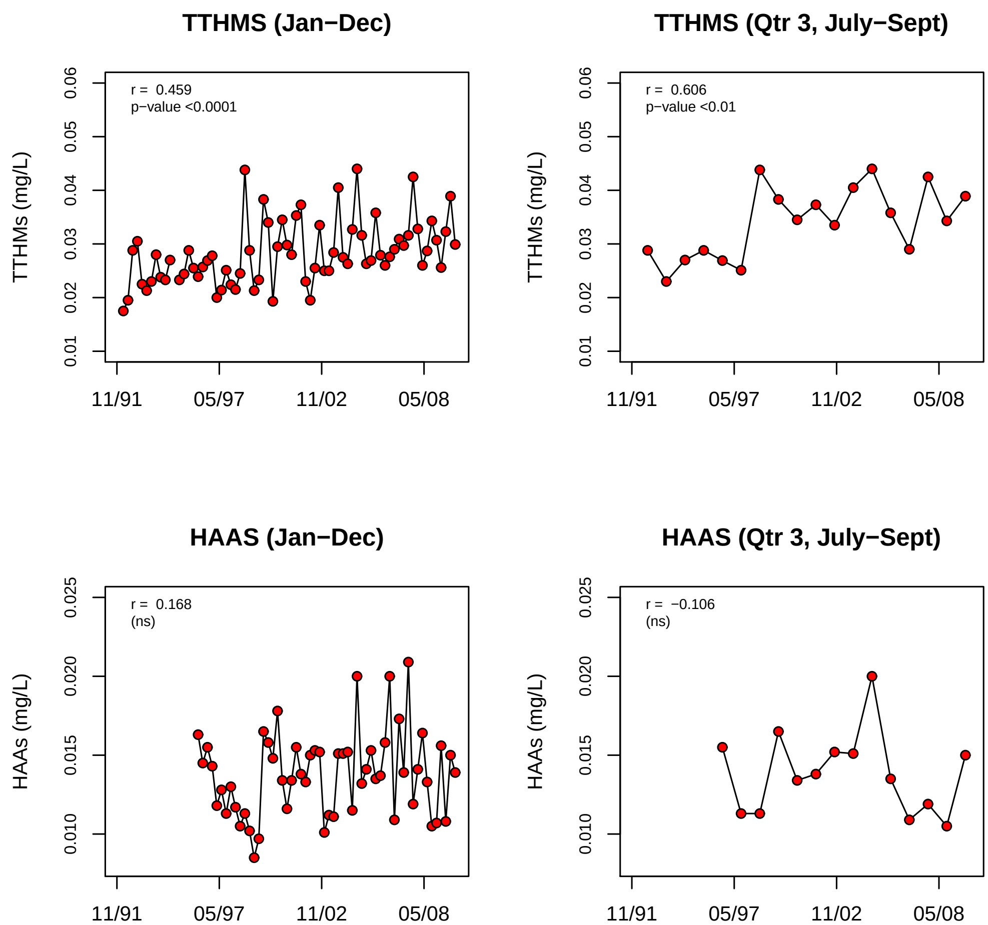


Figure 17: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2009. Data were provided by the City of Bellingham Public Works Department. Pearson's r correlations were used because the data were approximately monotonic-linear; correlations for Jan-Dec THMs and Qtr 3 THMs 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 baseline data were collected from 2004–2006. This level of effort was reduced in 2007, and tributary data are currently collected twice each year. Beginning in January 2010, tributary data will again be collected monthly.

3.1 Site Descriptions

The tributaries were sampled on February 10 and July 15, 2009. Samples were collected from Anderson, Austin, Blue Canyon, Brannian, Carpenter, Euclid, Mill Wheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. The sampling locations for these sites are described in Appendix A.2 and shown on Figure A2, page 84.

3.2 Field Sampling and Analytical Methods

The analytical procedures for sampling the tributaries are summarized in Table 1 (page 16). 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 at their water treatment plant. All other analyses were done by WWU.

3.3 Results and Discussion

The current data are listed in Tables 11–14 (pages 46–49) and plotted in Appendix B.5 (Figures B161–B202, pages 260–301). The plots in Appendix B.5 also include the monthly data collected from October 2004 through September 2006 data to show the typical ranges for each site. 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 B161–B166). Whatcom Creek had higher temperatures and lower oxygen concentrations than most other sites, reflecting the influence of Lake Whatcom (Figures B161 and B164). The Park Place outlet and Silver Beach Creek had slightly higher median temperatures, and Euclid, Millwheel, Park Place, Silver Beach Creeks had slightly lower median dissolved oxygen concentrations. This is a typical pattern for residential streams (Figures B163 and B166).

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by pH levels near 6.8–7.5, conductivities $\leq$150 μS, alkalinities $\leq$50 mg/L, total solids $\leq$100 mg/L, and total organic carbon concentrations $<$2 mg/L (Figures B167–B181 and Table 14). Sites that did not match this description included the residential streams (Park Place, Euclid, Millwheel, and Silver Beach Creeks) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$15 mg/L) and low turbidities ($\leq$10 NTU) except during periods of high precipitation and runoff (Figures B176–B184).

Ammonia concentrations were generally low except in the residential streams (Figures B185–B187). Ammonia 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 B188– B193). The relatively high nitrate and total nitrogen concentrations in Smith Creek may be 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 phosphorus usually indicate a near-by source such as an anaerobic wetland or a pollution source. In the Lake Whatcom tributaries, total phosphorus concentrations were usually much higher than soluble phosphate concentrations (Figures B194–B199). Total phosphorus and soluble phosphate concentrations were usually highest in the residential streams.

High coliform counts are an indicator of residential pollution (Figures B200–B202), and many of the Lake Whatcom tributaries exceeded the WAC 173–201A coliform surface water standards, based on the monthly data collected in 2004–2006 (Matthews, et al., 2007). The current biannual monitoring program does not provide enough data to assess whether sites fail to meet the WAC 173–201A standards; however, many sites had counts that exceeded 100 cfu/100 mL at least once, and one site (Park Place) exceeded 100 cfu/100 mL in both samples (Table 12).

The metals concentrations were within expected ranges, and most were near or below detection levels (Table 13). Chromium, copper, iron, and zinc were often detectable, and were usually higher in residential tributaries, but all were within normal ranges for surface waters in the watershed.

Site	Date	Alk (mg/L)	Cond (μS/cm)	DO (mg/L)	pH	Temp (C)	Turb (NTU)	TSS (mg/L)	TS (mg/L)
Anderson	Feb 10, 2009	21.4	67.4	11.74	6.84	4.4	1.84	<2	49.7
	Jul 15, 2009	24.2	70.7	8.52	6.70	12.6	1.20	<2	57.9
Austin	Feb 10, 2009	16.6	69.1	12.81	7.32	3.4	1.60	<2	51.8
	Jul 15, 2009	31.8	114.8	9.41	7.37	12.7	0.43	<26	77.6
Blue Canyon	Feb 10, 2009	138.2	306.0	13.15	8.17	3.7	1.55	<2	188.6
	Jul 15, 2009	145.9	292.0	10.08	8.19	12.8	0.74	<2	177.6
Brannian	Feb 10, 2009	8.6	41.6	12.15	6.74	3.6	1.00	<2	32.8
	Jul 15, 2009	18.2	52.2	7.31	6.66	13.5	0.50	<2	46.6
Carpenter	Feb 10, 2009	27.0	88.5	12.88	7.36	3.2	1.49	<2	75.4
	Jul 15, 2009	44.5	116.8	7.98	7.41	16.2	0.83	<2	92.3
Euclid	Feb 10, 2009	33.2	114.0.	12.04	7.17	3.6	1.85	<2	76.3
	Jul 15, 2009	53.9	145.7	6.88	6.99	13.8	1.44	<2	98.8
Millwheel	Feb 10, 2009	37.3	116.5	11.97	7.23	3.4	10.2	3.17	95.4
	Jul 15, 2009	NA	NA	NA	NA	NA	NA	NA	NA
Olsen	Feb 10, 2009	19.8	63.8	13.27	7.29	2.4	10.90	11.9	64.8
	Jul 15, 2009	42.1	112	8.94	7.59	15.3	0.56	<2	83.2
Park Place	Feb 10, 2009	94.4	246.0	11.44	7.62	5.2	3.3	<2	155.6
	Jul 15, 2009	126.5	274.0	7.32	7.55	17.4	2.05	<2	178.6
Silver Beach	Feb 10, 2009	66.2	176.6	12.68	7.70	3.4	4.58	<2	118.4
	Jul 15, 2009	NA	305.0	8.70	7.97	15.0	2.36	14.00	208.0
Smith	Feb 10, 2009	14.1	52.7	13.64	7.07	2.3	1.30	<2	42.0
	Jul 15, 2009	30.2	82.1	9.34	7.29	13.9	0.45	<2	62.3
Whatcom	Feb 10, 2009	19.4	61.8	12.01	7.21	4.4	1.31	<2	40.6
	Jul 15, 2009	21.4	61.9	8.34	7.66	20.5	2.00	<2	115.6

Table 11: Lake Whatcom tributary data: alkalinity, conductivity, dissolved oxygen, temperature, turbidity, pH, total solids and total suspended solids.

Site	Date	NH3 (μg-N/L)	NO3 (μg-N/L)	TN (μg-N/L)	SRP (μg-P/L)	TP (μg-P/L)	FC (cfu/100 mL)
Anderson	Feb 10, 2009	34.6	666.5	854.2	6.7	17.6	14
	Jul 15, 2009	12.6	576.4	785.9	5.2	23.9	140
Austin	Feb 10, 2009	$<$10	591.7	692.7	7.0	14.5	5
	Jul 15, 2009	$<$10	296.8	419.0	7.6	11.7	160
Blue Canyon	Feb 10, 2009	$<$10	934.8	302.0	$<$5	10.7	$<$1
	Jul 15, 2009	$<$10	174.5	235.2	6.0	14.3	70
Brannian	Feb 10, 2009	$<$10	263.9	1064.4	11.1	12.4	2
	Jul 15, 2009	$<$10	219.2	382.0	$<$5	8.5	70
Carpenter	Feb 10, 2009	$<$10	922.0	1091.3	15.9	15.9	68
	Jul 15, 2009	16.2	506.3	693.9	11.1	21.9	770
Euclid	Feb 10, 2009	26.8	624.2	806.4	23.2	14.8	41
	Jul 15, 2009	34.6	153.7	332.5	5.9	19.0	60
Millwheel	Feb 10, 2009	16.6	757.4	1032.5	11.4	30.0	52
	Jul 15, 2009	NA	NA	NA	NA	NA	NA
Olsen	Feb 10, 2009	$<$10	761.1	870.4	9.8	19.4	1
	Jul 15, 2009	10.9	407.8	555.4	9.2	14.7	470
ParkPlace	Feb 10, 2009	36.5	879.8	1177.2	17.4	29.5	37
	Jul 15, 2009	98.7	125.4	543.1	17.5	57.2	430
Silver Beach	Feb 10, 2009	$<$10	603.2	878.3	13.8	26.9	140
	Jul 15, 2009	$<$10	542.0	829.4	16.3	33.7	600
Smith	Feb 10, 2009	$<$10	968.7	1058.8	11.1	13.0	$<$1
	Jul 15, 2009	$<$10	549.2	702.9	6.3	8.2	43
Whatcom	Feb 10, 2009	$<$10	357.7	486.2	$<$5	8.7	13
	Jul 15, 2009	10.1	74.5	367.9	$<$5	13.3	58

Table 12: Lake Whatcom tributary data: ammonia, nitrate/nitrite, total nitrogen, soluble phosphate, total phosphorus, and fecal coliforms.

	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 10, 2009	<0.01	<0.0005	0.002	<0.001	0.265	<0.0001	<0.005	<0.001	<0.001
Austin	Feb 10, 2009	<0.01	<0.0005	0.003	0.003	0.158	<0.0001	<0.005	<0.001	<0.001
Blue Canyon	Feb 10, 2009	<0.01	<0.0005	0.005	0.001	0.061	<0.0001	<0.005	<0.001	<0.001
Brannian	Feb 10, 2009	<0.01	<0.0005	0.002	<0.001	0.141	<0.0001	<0.005	<0.001	<0.001
Carpenter	Feb 10, 2009	<0.01	<0.0005	0.003	<0.001	0.109	<0.0001	<0.005	<0.001	<0.001
Euclid	Feb 10, 2009	<0.01	<0.0005	<0.001	0.001	0.153	<0.0001	<0.005	<0.001	<0.001
Millwheel	Feb 10, 2009	<0.01	<0.0005	0.004	<0.001	0.718	<0.0001	<0.005	<0.001	0.002
Olsen	Feb 10, 2009	<0.01	<0.0005	<0.001	0.004	0.619	<0.0001	<0.005	<0.001	<0.001
Park Place	Feb 10, 2009	<0.01	<0.0005	0.004	0.003	0.375	<0.0001	<0.005	<0.001	0.002
Silver Beach	Feb 10, 2009	<0.01	<0.0005	0.003	0.002	0.464	<0.0001	<0.005	<0.001	0.001
Smith	Feb 10, 2009	<0.01	<0.0005	0.002	<0.001	0.060	<0.0001	<0.005	<0.001	<0.001
Whatcom	Feb 10, 2009	<0.01	<0.0005	0.002	<0.001	0.066	<0.0001	<0.005	<0.001	<0.001
Anderson	July 15, 2009	<0.01	<0.0005	0.002	0.002	0.502	<0.0001	<0.005	<0.001	0.002
Austin	July 15, 2009	<0.01	<0.0005	<0.001	<0.001	0.129	<0.0001	<0.005	0.003	<0.001
Blue Canyon	July 15, 2009	<0.01	<0.0005	<0.001	<0.001	0.036	<0.0001	<0.005	<0.001	0.002
Brannian	July 15, 2009	<0.01	<0.0005	<0.001	<0.001	0.306	<0.0001	<0.005	0.004	0.002
Carpenter	July 15, 2009	<0.01	<0.0005	<0.001	0.002	0.102	<0.0001	<0.005	0.002	0.003
Euclid	July 15, 2009	<0.01	<0.0005	0.002	<0.001	0.517	<0.0001	<0.005	0.004	0.017
Millwheel	July 15, 2009	NA	NA	NA	NA	NA	NA	NA	NA	NA
Olsen	July 15, 2009	<0.01	<0.0005	<0.001	0.001	0.078	<0.0001	<0.005	0.002	<0.001
Park Place	July 15, 2009	<0.01	<0.0005	0.003	0.007	0.626	<0.0001	<0.005	<0.001	0.005
Silver Beach	July 15, 2009	<0.01	<0.0005	0.002	0.004	0.342	<0.0001	<0.005	<0.001	0.002
Smith	July 15, 2009	<0.01	<0.0005	<0.001	<0.001	0.018	<0.0001	<0.005	0.002	<0.001
Whatcom	July 15, 2009	<0.01	<0.0005	<0.001	<0.001	0.126	<0.0001	<0.005	0.022	0.002

Table 13: 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 included in in the online data files (http://www.ac.wwu.edu/∼iws).

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Anderson	Feb 10, 2009	170†	Jul 15, 2009	9.3
Austin (lower)	Feb 10, 2009	3.9	Jul 15, 2009	6.9
Blue Canyon	Feb 10, 2009	170†	Jul 15, 2009	17.0
Brannian	Feb 10, 2009	8.9	Jul 15, 2009	3.0
Carpenter	Feb 10, 2009	6.1	Jul 15, 2009	5.4
Euclid	Feb 10, 2009	7.3	Jul 15, 2009	23.0
Millwheel	Feb 10, 2009	7.0	Jul 15, 2009	NA
Olsen	Feb 10, 2009	5.7	Jul 15, 2009	6.4
Park Place	Feb 10, 2009	14.0	Jul 15, 2009	9.2
Silver Beach	Feb 10, 2009	180†	Jul 15, 2009	15.0
Smith	Feb 10, 2009	<1	Jul 15, 2009	4.5
Whatcom	Feb 10, 2009	2.8	Jul 15, 2009	3.4

†Atypical results; data verified in AmTest reports.

Table 14: Lake Whatcom tributary data: total organic carbon.

4 Lake Whatcom Hydrology

4.1 Hydrograph Data

Recording hydrographs are installed in Austin Creek and Smith Creek; the data are plotted in Figures 18–19 (pages 56–57). The location of each hydrograph is described in Appendix A.2. All hydrograph data, including data from previous years, are online at http://www.ac.wwu.edu/∼iws. Detailed field notes 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.

The historic hydrograph data were recorded at 30 minute intervals until the summer of 2003, when new recorders were installed at all sites. The new recorders log data at 15 minute intervals. The primary reason for changing the logging interval was to conform with USGS hydrograph data that are being collected at additional sites in the Lake Whatcom watershed. Figures 20–22 (pages 58–60) shows the rating curves for each hydrograph. New rating curves need to be generated whenever the creek channel is significantly altered due to storm runoff or construction activities. Starting dates for each rating curve are indicated in Figures 20–22. Rating curves for earlier water years are available from the Institute for Watershed Studies.

Severe storms during January 2009 caused damage to the Smith Creek gaging site, resulting in the loss of data from January 7 through April 27, 2009. Due to the amount of stream bed scouring that occurred this winter, the rating curves for both sites have been recalibrated. As a result, the WY2009 flow calculations are based on pre- and post-2009 rating equations. Figure 20 (page 58) shows the rating curves used for Austin Creek; Figures 21–22 (pages 59–60) show the curves for Smith Creek, which were further divided into low and high flow conditions.

4.2 Water Budget

A water balance was applied to Lake Whatcom to identify its 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 15, page 53). Inputs into the lake include direct precipitation, runoff (surface runoff + groundwater), and (usually) water diverted from the Middle Fork of the Nooksack River. The diversion structure was damaged during the winter storms, so no water was diverted from the Nooksack River in WY2009. Outputs include evaporation, Whatcom Creek, the Whatcom Falls Fish Hatchery, City of Bellingham, Puget Sound Energy Co-Generation Plant (PSE)[17], and the Lake Whatcom Water and Sewer District.[18] 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. A daily weighted average was calculated using a Python script that employed a spatial interpolation technique (inverse distance weighted) in ArcGIS to distribute rainfall from the 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 (Ferrari and Nuanes, 2001). 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 2008/2009 was 42.1 inches (5,712 mg). This is the lowest rainfall in the last 5 years, in part because lower than normal values were recorded at the North Shore gauge.

The lake received an average of 10.9 inches of rain (26% of the yearly total) in a 20 day period between December 24, 2008 and January 14, 2009. About 6.3 inches of this occurred between January 4 and 8, resulting in significant runoff to the lake and discharge in Whatcom Creek.

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 Ferrari and Nuanes (2001). The estimated yearly evaporation from the lake is 20.0 inches (2,723 MG), 75% of which occurred between May and September.

[17]Located at the Georgia Pacific site
[18]Formerly Water District #10

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-capacity data developed by Ferrari and Nuanes (2001). The rating curve accounts for changes in volume of the lake due to lake level changes. The median total lake volume in 2008/2009 was 252,433 MG. Figure 23 (page 61) 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 the 6.3 inch storm event. The last time the lake reached 315.0 feet was during the November 24, 1990 flood event in Whatcom County.

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. 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 Distributed Hydrology-Soils-Vegetation Model (DHSVM) was also used to simulate runoff into the lake. The DHSVM is a spatially distributed, physically based numerical model that was applied in earlier Lake Whatcom watershed studies (Matthews et al., 2007; Kelleher, 2006).

The daily water balance quantities were summed into 7-day totals, which were used to generate Figures 24–27 (pages 62–65). Figure 24 shows 7-day summed totals for inputs, outputs, and change in storage. All the inputs except runoff are shown in Figure 25; all outputs except Whatcom Creek are shown in Figure 26. Due to their much higher magnitude, runoff and Whatcom Creek data are included on Figure 27.

Yearly water balance totals are listed in Table 15 (page 53) along with data from four previous water years. The total volume of outputs in WY2009 were 13.6% 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 7.4 year residence time.[19] Tables 16 and 17 (pages 54–55) show the 2008/2009 total input and output volumes along with the corresponding monthly percentage of each total.

[19]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.

	WY2009 (9/30/08–10/1/09)	WY2008 (9/30/07–10/1/08)	WY2007 (9/30/06–10/1/07)	WY2006 (9/30/05–10/1/06)	WY2005 (9/30/04–10/1/05)
Inputs (MG)*					
Direct Precipitation	5,712 (17.7%)	6,006 (16.7%)	7,063 (18.2%)	6,783 (17.9%)	6,501 (16.2%)
Diversion	0 (0%)	4,902 (13.7%)	2,920 (7.5%)	4,155 (11.0%)	3,852 (9.6%)
Runoff	26,491 (82.3%)	24,989 (69.6%)	28,717 (74.2%)	26,879 (71.1%)	29,673 (74.1%)
Total	32,203 (100%)	35,896 (100%)	38,700 (100%)	37,817 (100%)	40,026 (100%)
Outputs (MG%)					
Whatcom Creek	26,598 (77.5%)	25,793 (76.1%)	30,359 (77.1%)	28,290 (74.8%)	30,899 (74.0%)
Hatchery	856 (2.5%)	931 (2.7%)	1,002 (2.5%)	1,253 (3.3%)	1,288 (3.1%)
Puget Sound Co-Gen (PSE%)	4 (0.01%)	240 (0.7%)	807 (2.0%)	960 (2.5%)	2,198 (5.3%)
City of Bellingham	3,886 (11.3%)	3,874 (11.4%)	4,145 (10.5%)	4,111 (10.9%)	4,111 (9.8%)
LW Water/Sewer Distr.	250 (0.7%)	237 (0.7%)	232 (0.6%)	242 (0.6%)	252 (0.6%)
Evaporation	2,723 (7.9%)	2,807 (8.3%)	2,831 (7.2%)	2,946 (7.8%)	2,990 (7.2%)
Total	34,317 (100%)	33,883 (100%)	39,376 (100%)	37,802 (100%)	41,738 (100%)
Net change in storage	-2,115	2,033	-520	15	-1,692
Median lake volume (MG)	252,433	253,003	252,759	252,287	252,856
Outflow percent of volume	13.6	13.4%	15.6%	15.0%	16.5%
Residence time (years)**	7.4	7.5	6.4	6.7	6.1

*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 15: Annual water balance quantities for the Lake Whatcom watershed, WY2005–WY2009.

	Input Percents*			
Month	Diver	Precip	Runoff	Total
Oct	0.00	6.16	0.87	0.87
Nov	0.00	18.86	12.76	12.76
Dec	0.00	10.84	9.93	9.93
Jan	0.00	18.51	41.52	41.52
Feb	0.00	5.67	3.79	3.79
Mar	0.00	10.94	9.60	9.60
Apr	0.00	5.53	11.28	11.28
May	0.00	12.79	9.95	9.95
Jun	0.00	1.09	1.23	1.23
Jul	0.00	2.23	0.76	0.76
Aug	0.00	2.07	-0.77	-0.77
Sep	0.00	5.32	-0.92	-0.92
	Input Volume (MG)			
Total	0.00	5,712	26,491	26,491

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

Table 16: Monthly input water balance quantities for the Lake Whatcom watershed, October 2008–September 2009.

	Output Percents						
Month	WC	Hatch	PSE	COB	WSD	Evap	Total
Oct	11.26	10.86	7.64	7.64	6.99	4.00	10.23
Nov	15.20	9.71	6.97	6.97	7.08	2.17	13.04
Dec	9.98	9.88	7.55	7.55	8.72	0.64	8.95
Jan	43.08	13.11	7.23	7.23	8.61	1.30	34.70
Feb	4.51	9.88	6.02	6.02	7.08	1.99	4.63
Mar	1.31	11.44	6.83	6.83	7.85	5.64	2.58
Apr	1.73	10.27	6.62	6.62	7.91	10.37	3.23
May	10.49	5.07	7.59	7.59	8.69	12.05	10.13
Jun	1.18	3.75	10.88	10.88	9.82	15.97	3.58
Jul	0.69	4.56	13.40	13.40	10.51	18.57	3.72
Aug	0.29	6.05	10.83	10.83	9.11	16.69	2.99
Sep	0.28	5.43	8.45	8.45	7.63	10.61	2.20
	Output Volume (MG)						
Total	26,598	856	3.9	3,886	250	2,723	3,4317

Table 17: Monthly output water balance quantities for the Lake Whatcom watershed, October 2008–September 2009.

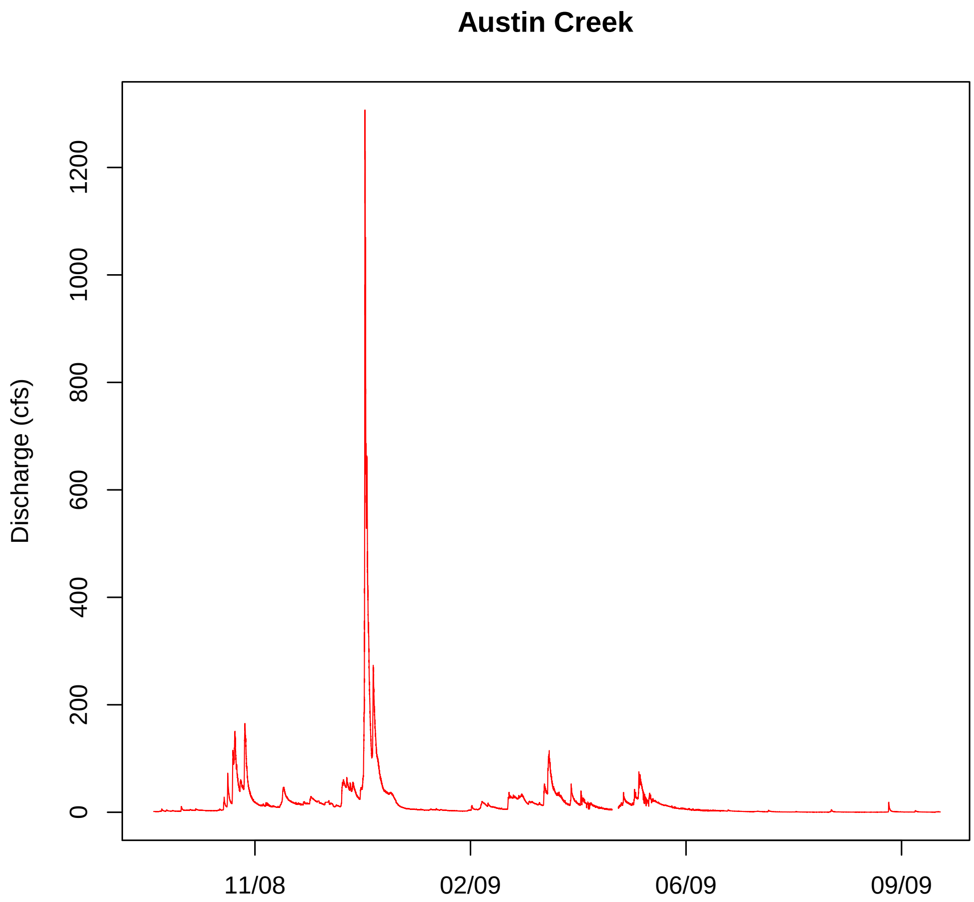


Figure 18: Austin Creek hydrograph, October 1, 2008–September 30, 2009. Data were recorded at 15 minute intervals.

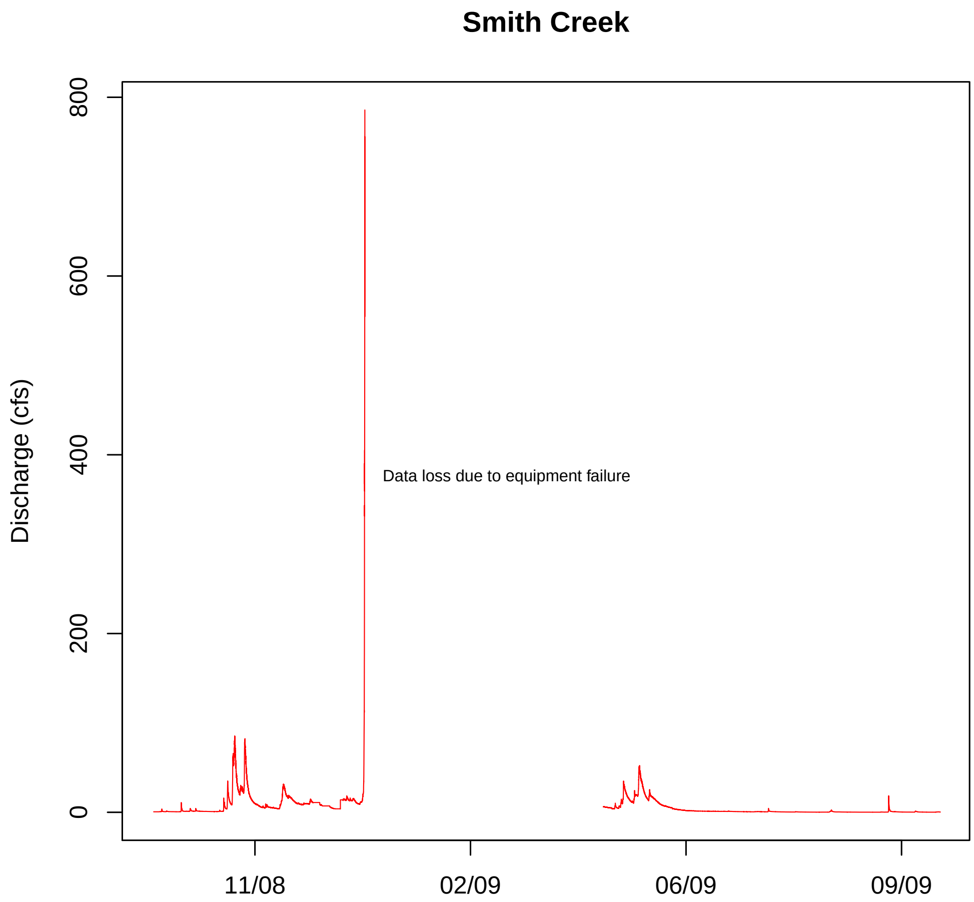
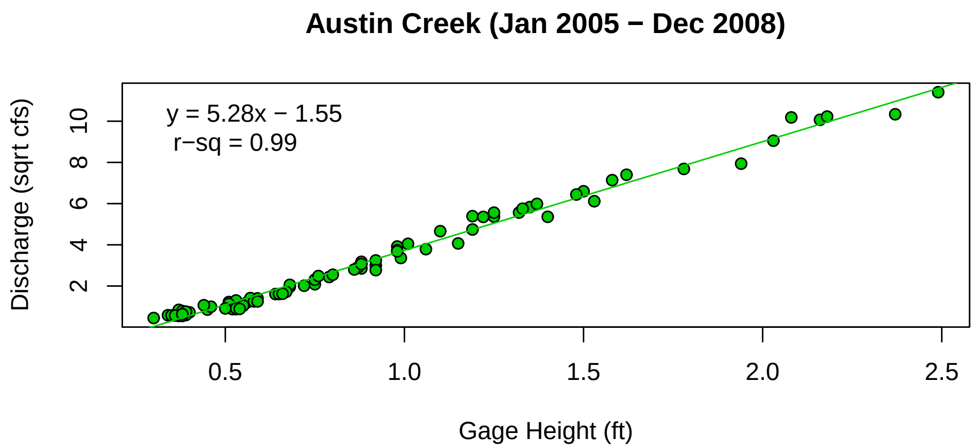


Figure 19: Smith Creek hydrograph, October 1, 2008–September 30, 2009. Data were recorded at 15 minute intervals.



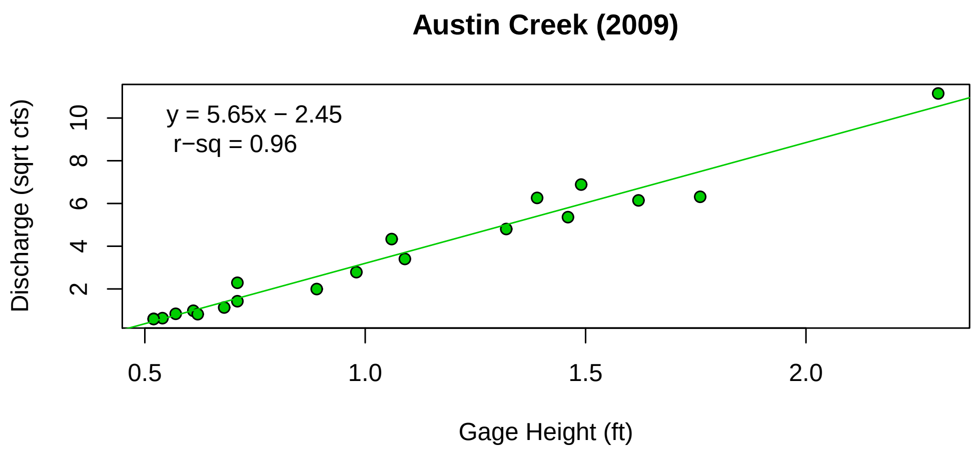


Figure 20: Austin Creek rating curves for 2005–2008 and new calibrations beginning in 2009. Regressions show the relationship between gauge height (x) and square root transformed discharge (y), beginning from the date listed on each figure. For earlier rating curves, contact the Institute for Watershed Studies.

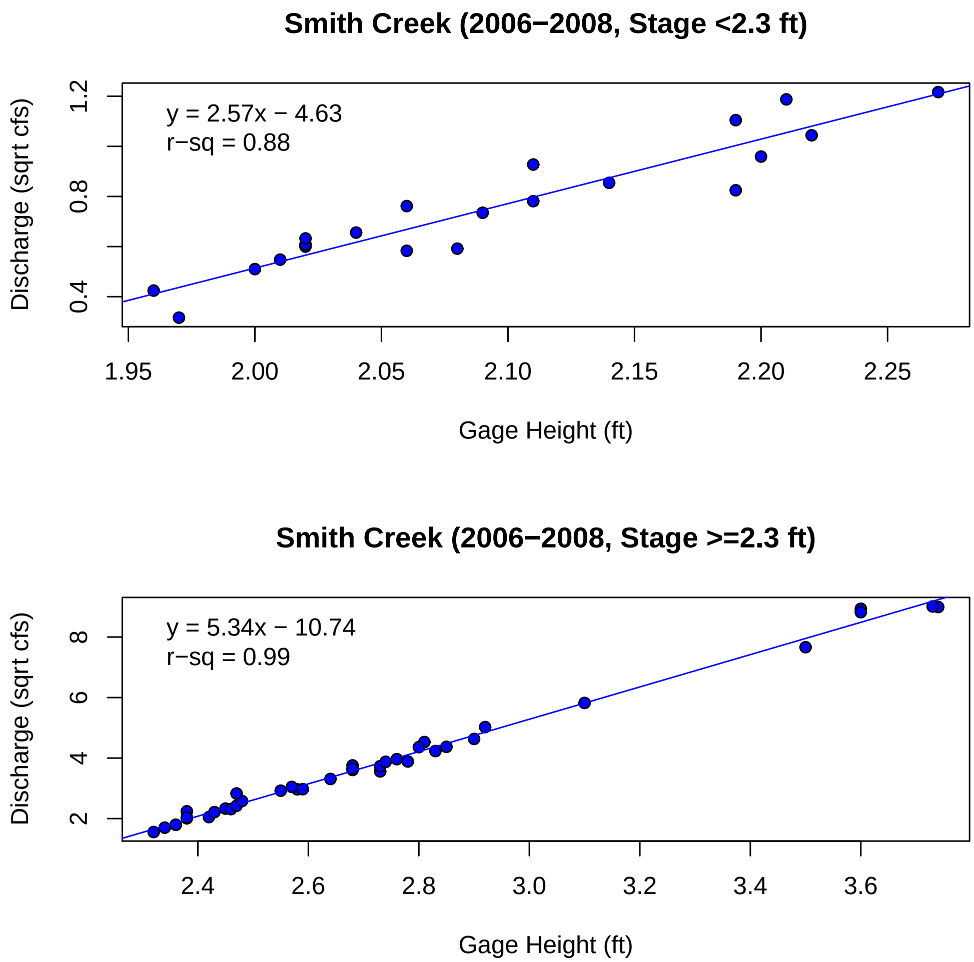


Figure 21: Smith Creek rating curves prior to the January 2009 storm event. Regressions show the relationship between gauge height (x) and square root transformed discharge (y), beginning from the date listed on each figure. For earlier rating curves, contact the Institute for Watershed Studies.

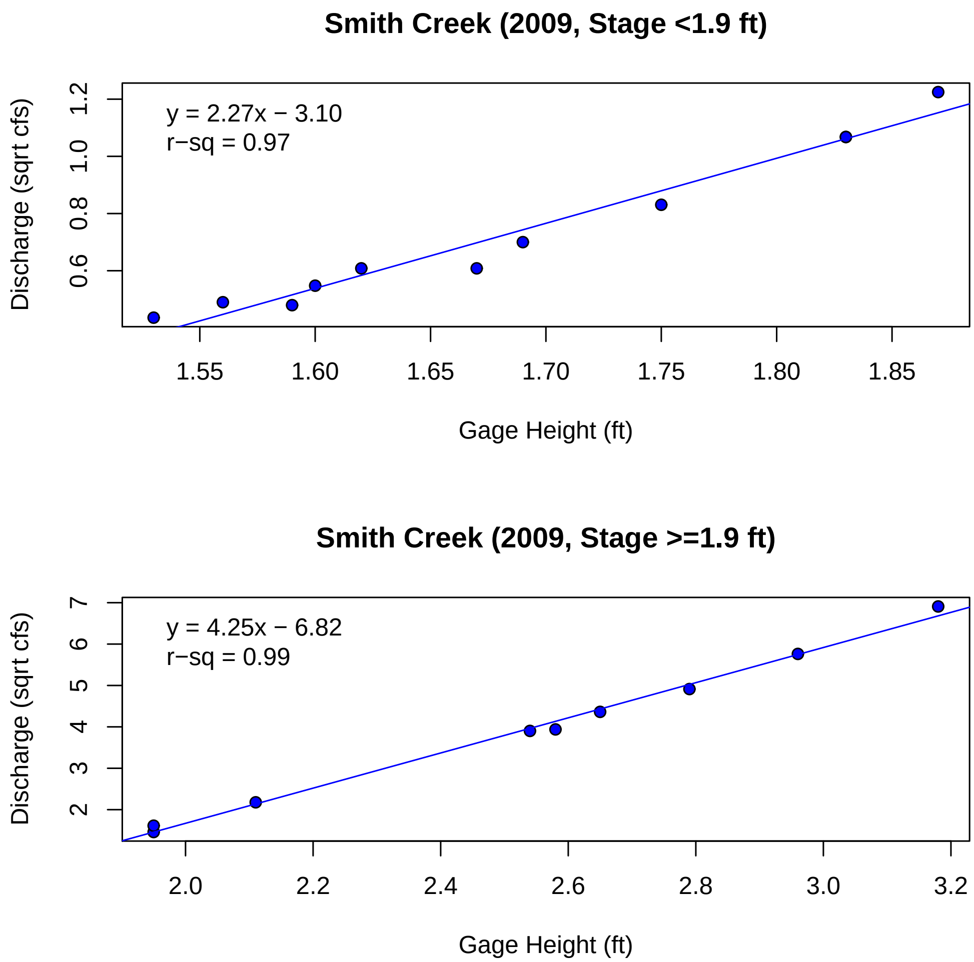


Figure 22: Smith Creek rating curves following the January 2009 storm event. Regressions show the relationship between gauge height (x) and square root transformed discharge (y), beginning from the date listed on each figure. For earlier rating curves, contact the Institute for Watershed Studies.

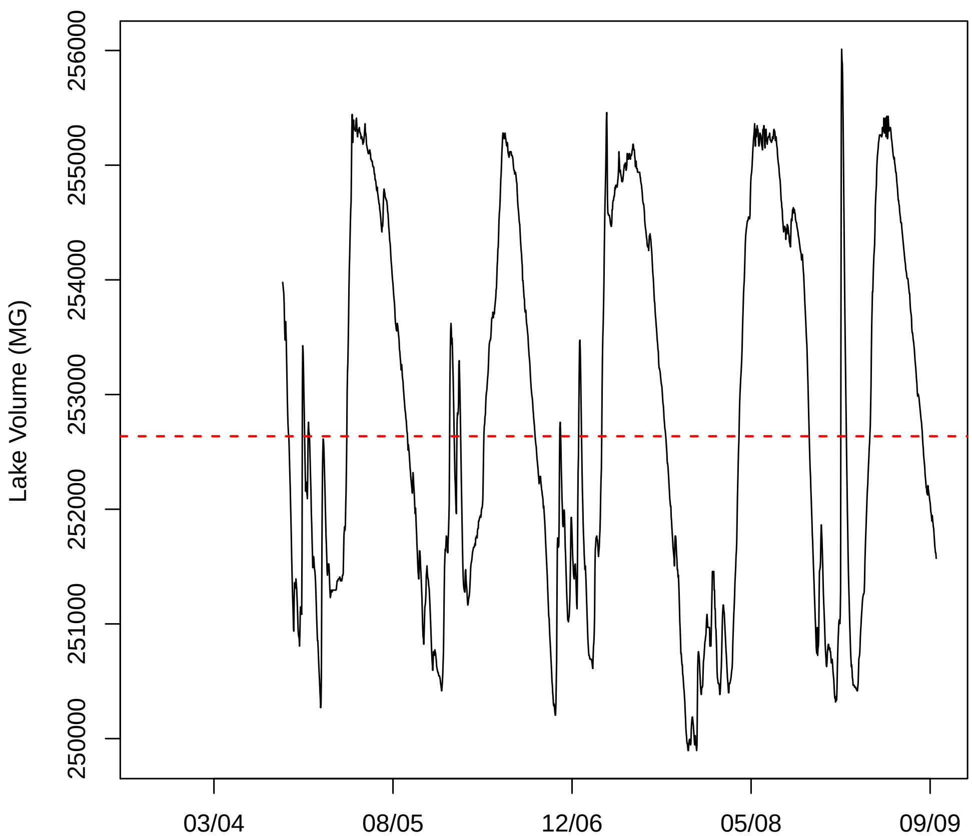


Figure 23: Comparison of Lake Whatcom daily lake volumes for WY2004–WY2009. Horizontal line represents median lake volume for the period plotted.

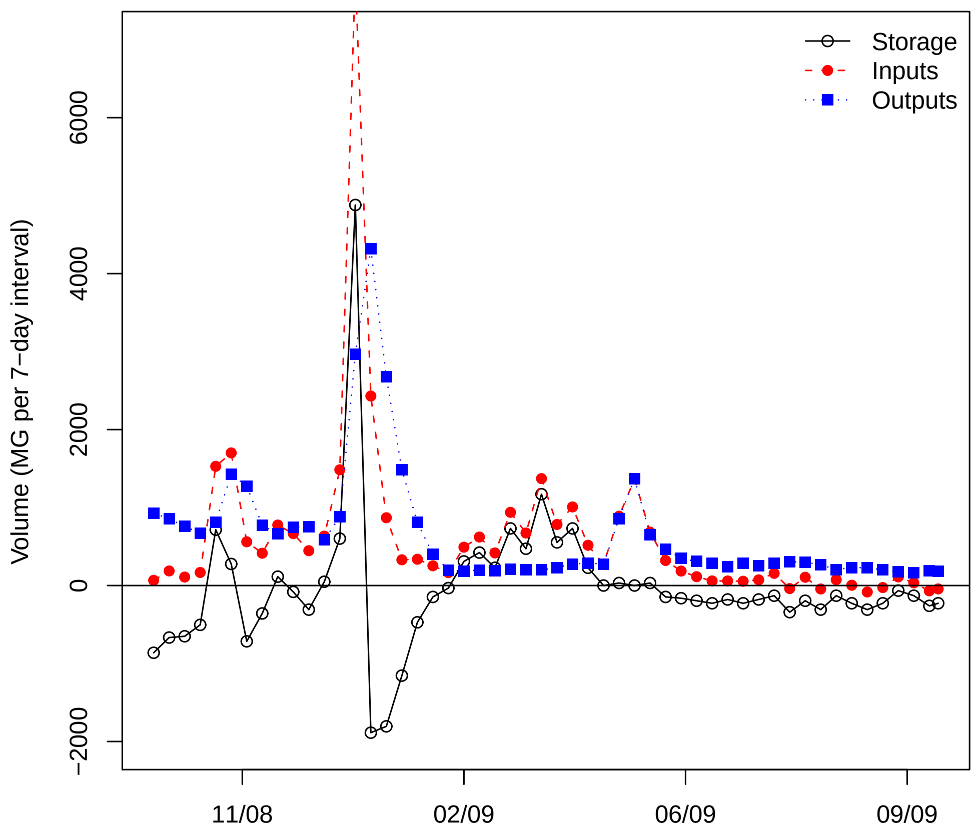


Figure 24: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2008–September 30, 2009.

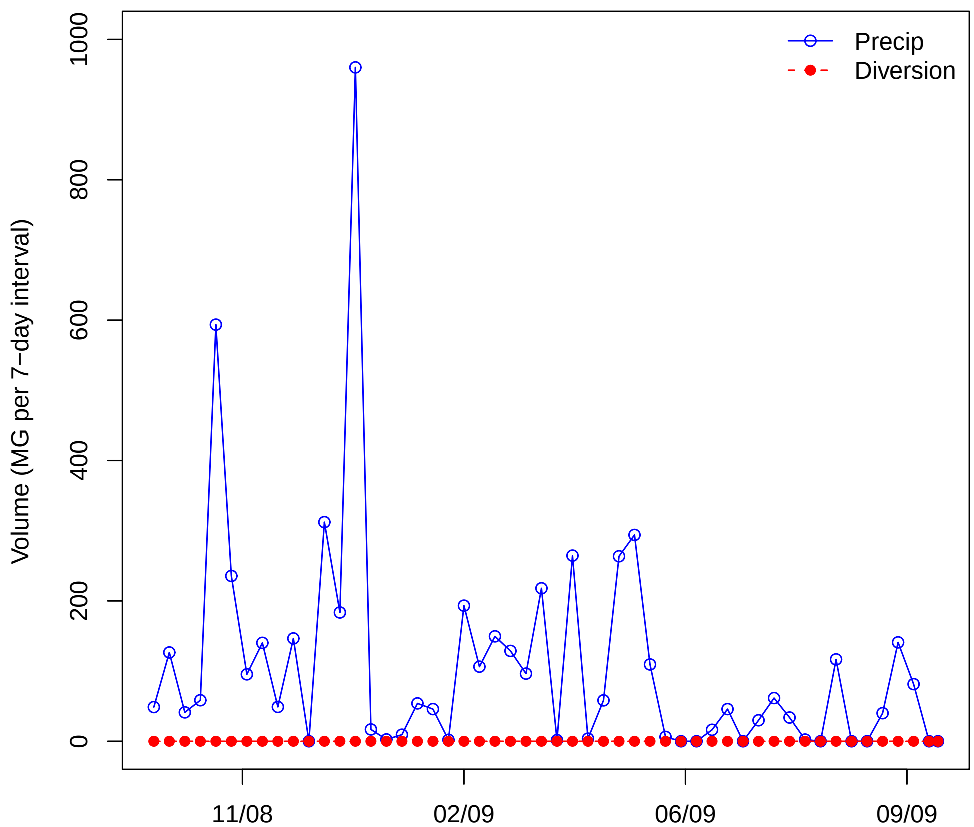


Figure 25: Lake Whatcom watershed direct hydrologic inputs, October 1, 2008–September 30, 2009. Runoff is included on Figure 27 as described on page 52.

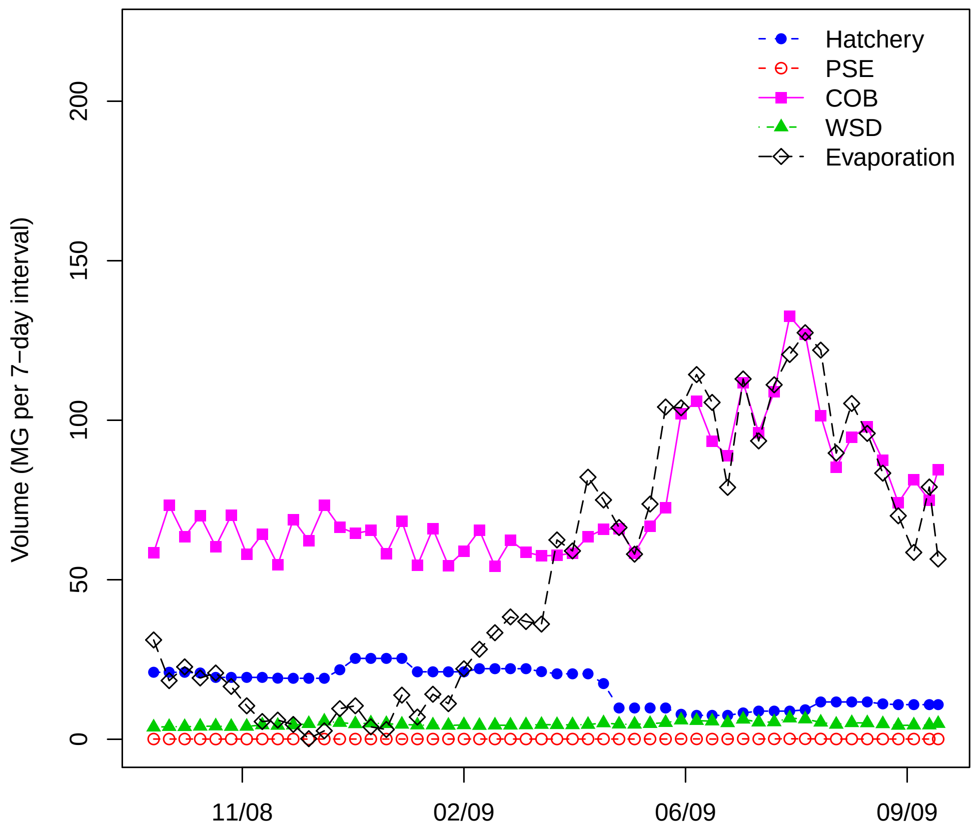


Figure 26: Lake Whatcom watershed hydrologic withdrawals, October 1, 2008–September 30, 2009. Whatcom Creek output is included on Figure 27 as described on page 52.

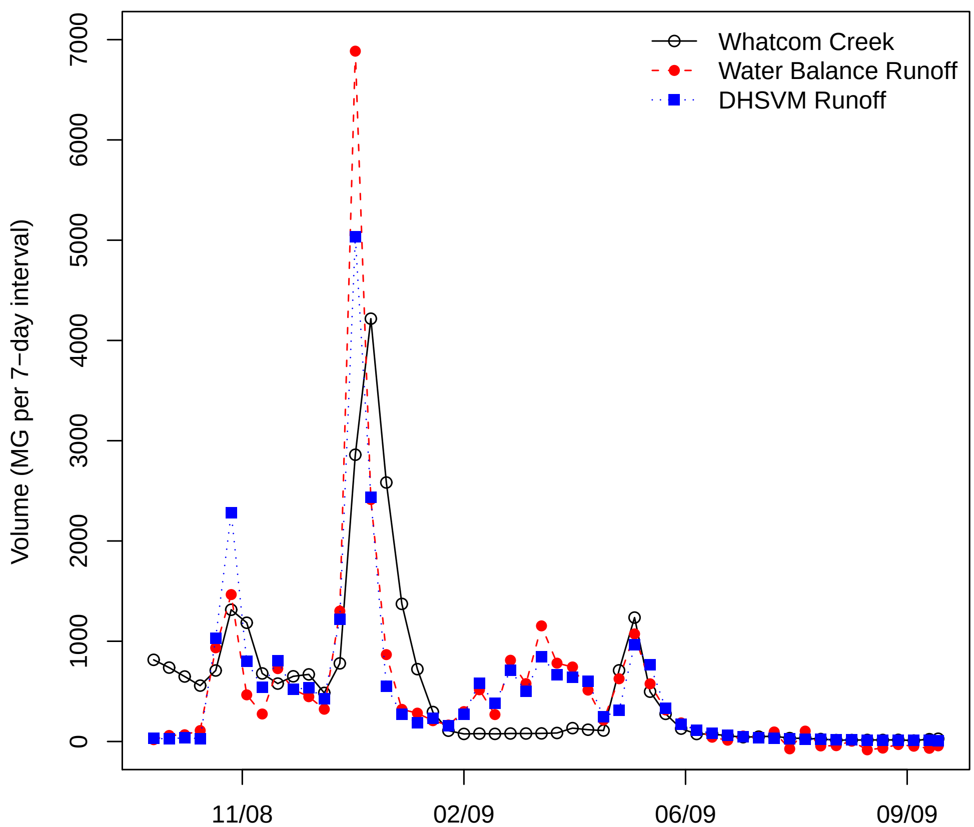


Figure 27: Summary of 7-day Whatcom Creek flows, water balance runoff estimates, and DHSVM runoff estimates, October 1, 2008–September 30, 2009.

5 Storm Water Treatment Monitoring

The objective of the storm water monitoring was to evaluate the storm water treatment efficiencies of representative treatment facilities in the Lake Whatcom watershed. To achieve this objective, IWS has monitored six different treatment sites, beginning in 1994:

Site	Description	Monitoring Dates
Alabama Hill	canister vault	2004–2008
Brentwood	series of wet ponds	1998–2004 and in 2007–2008
Park Place	series of wet ponds; converted to gravel filter with final wet cell in 2005	1994–2009
Parkstone	grass swale and wet pond	2004
Silvern	canister vault	2004
South Campus (outside watershed)	grass swales and rock/plant filter with	2001–2008

In mid-2009, the focus of our storm water program shifted from monitoring the sites listed above. We are currently working with the City to evaluate the effectiveness of a state-of-the art storm water treatment design installed along Northshore Drive. We are also collecting baseline storm event data from Silver Beach Creek, which will be used to evaluate the performance of an intensive watershed restoration and storm water treatment project that is proposed for the Silver Beach area. Results from the new monitoring efforts will be presented in the 2009/2010 annual report.

The 2009 monitoring results from Park Place are presented below; results from other sites have been reported in previous annual reports (see Section 6.2, beginning on page 76). For historical perspective, the locations of all 1994–2009 storm water monitoring sites are described in Appendix A.

5.1 Sampling Procedures - Park Place (2009)

Storm water samples were collected at the Park Place storm water treatment facility on January 27–29 (wet season, low flow) and March 17–18, 2009 (wet season, storm flow). During the January sampling period the weather was cold, with a slight amount of precipitation during sampling and snow prior to sampling. Ice developed on the open water cell of the facility; all storm water flow moved through the facility (none was diverted). During the March sampling period it was cold, with moderate precipitation until the afternoon of March 17, after which there was no precipitation to the end of the sample period. All storm water flow moved through the facility.

Rainfall totals (daily inches)	Bloedel/Donovan Gauge	Geneva Gauge
January 26, 2009	0.00	0.00
January 27, 2009	0.02	0.01
January 28, 2009	0.00	0.00
January 29, 2009	0.02	0.01
March 16, 2009	0.18	0.30
March 17, 2009	0.30	0.15
March 18, 2009	0.00	0.01

Composite samples were collected at inflow and outflow points using ISCO samplers provided by the City of Bellingham that collect water samples at 90 minute intervals over a 48 hour period. The composite samples were analyzed for total solids, total suspended solids, heavy metals (arsenic, cadmium, chromium, copper, iron, nickel, lead, and zinc), total organic carbon, total nitrogen, and total phosphorus. Multiple grab samples were collected during the sampling period at the inflow and outflow to measure bacteria (fecal coliforms), conductivity, dissolved oxygen, pH, and temperature, which are parameters that can’t be measured from composite samples. Bacteria samples were analyzed by the City of Bellingham; conductivity, dissolved oxygen, pH, and temperature were measured using the Hydrolab field meter.

5.2 Results and Discussion - Park Place (2009)

Tables 18–20 (pages 69–71) show the raw data and percent analyte reduction from the storm water treatment systems that were sampled during the current monitoring period. Percent reduction was calculated as follows, based on the approach described by Winer (2000) for *Event Mean Concentration Efficiency*:

$$\begin{aligned} \text{Reduction}(\%) &= \frac{\overline{x}_{\text{inlet}} - \overline{x}_{\text{outlet}}}{\overline{x}_{\text{inlet}}} \times 100 \\ \text{where :} & \\ \overline{x}_{\text{inlet}} &= \text{inlet avg. conc.} \\ \overline{x}_{\text{outlet}} &= \text{outlet avg. conc.} \end{aligned}$$

Two of the most important storm water contaminants relative to lake eutrophication are total suspended solids and total phosphorus reductions. As discussed on page 9, phosphorus is likely to limit algal growth in Lake Whatcom, and phosphorus often enters lakes physically or chemically bound to the surface of particles.

The Park Place treatment facility demonstrated excellent reduction of suspended solids in March (79%); the TSS concentrations in January were below detection at both the inlet and outlet (Table 18, page 69). Phosphorus removal was inconsistent (Table 18), and the historic data indicate that phosphorus removal efficiencies are not statistically different from zero (Table 21, page 72).

Fecal coliforms are a common pollutant in storm water runoff that are not directly linked to lake eutrophication, but are important as indicators of potential health threats. The Lake Whatcom TMDL will require coliform reduction in addition to phosphorus reduction. The Park Place sand filter provided excellent coliform reductions on both sampling dates (85-90%; Table 20, page 71).

Site	Date	TSS (mg/L)	TS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
Park Place inlet	Jan 27–29, 2009	<2	145.3	12.0	0.89	0.037
Park Place outlet	Jan 27–29, 2009	<2*	136.1	12.0	0.90	0.030
	Percent reduction :	0	6	0	-1	19
Park Place inlet	Mar 17–18, 2009	9.45	119.3	NA	0.98	0.388
Park Place outlet	Mar 17–18, 2009	<2*	110.3	NA	0.89	0.440
	Percent reduction:	79	8	NA	9	-13

*Value replaced with detection limit to calculate percent reduction.

Table 18: Composite samples from the Park Place storm water treatment site with average percent reductions between inlet and outlet for total suspended solids, total solids, total organic carbon, total nitrogen, and total phosphorus. Negative values represent an increase in concentration at the outlet.

Site	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
Park Place inlet	Jan 27–29, 2009	<0.01	<0.0005	0.002	0.003	0.750	0.0001	<0.005	0.001	0.008
Park Place outlet	Jan 27–29, 2009	<0.01	<0.0005	0.002	0.003	0.128	<0.0001	<0.005	0.001	0.001
	Percent reduction:	NA	NA	0	0	83	NA	NA	0	88
Park Place inlet	Mar 17–18, 2009	NA	NA	NA	NA	NA	NA	NA	NA	NA
Park Place outlet	Mar 17–18, 2009	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Percent reduction:	NA	NA	NA	NA	NA	NA	NA	NA	NA

*Value replaced with detection limit to calculate percent reduction.

Table 19: Composite samples from the Park Place storm water treatment site showing average percent reductions between inlet and outlet for total metals. Negative values represent an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)
Inlet	Jan 27, 2009 (A)	3.8	7.35	12.74	212.0	170
Inlet	Jan 28, 2009 (B)	4.2	7.43	12.37	215.0	84
Inlet	Jan 28, 2009 (C)	4.6	7.35	11.56	212.0	110
Inlet	Jan 29, 2009 (D)	4.7	7.41	12.00	216.0	220
Outlet	Jan 27, 2009 (A)	2.9	7.09	11.07	217.0	16
Outlet	Jan 28, 2009 (B)	3.5	7.16	10.64	213.0	10
Outlet	Jan 28, 2009 (C)	3.7	7.14	10.06	213.0	14
Outlet	Jan 29, 2009 (D)	4.3	7.14	10.46	213.0	16
	Percent reduction:	17	3	13	0	90
Inlet	Mar 17, 2009 (A)	5.2	7.10	11.58	137.4	660
Inlet	Mar 17, 2009 (B)	6.9	7.28	11.05	185.4	200
Inlet	Mar 18, 2009 (C)	6.2	7.40	11.10	187.3	250
Inlet	Mar 18, 2009 (D)	7.1	7.35	11.18	184.7	250
Outlet	Mar 17, 2009 (A)	4.9	7.09	10.53	155.5	110
Outlet	Mar 17, 2009 (B)	6.5	7.11	9.98 1	66.0 4	8
Outlet	Mar 18, 2009 (C)	5.9	7.08	9.47 1	83.3 2	8
	Percent reduction:	8	3	13	1	85

Table 20: Grab samples from the Park Place storm water treatment site with average percent reductions between inlet and outlet samples. Sample collection times were sequential; negative values indicate an increase in concentration at the outlet.

Total Suspended Solids

Site	Min.	Max.	Mean	95% CI
Alabama (n=9)	-1	69	35	18–52**
Brentwood (n=20)	-174	77	-31	-66 – 5 (ns)
Park Place (n=39)	-239	89	17	-1 – 36 (ns)
South Campus (n=21)	0	94	70	60 – 80***

Total Phosphorus

Site	Min.	Max.	Mean	95% CI
Alabama (n=9)	-46	27	-1	-15 – 17 (ns)
Brentwood (n=21)	-400	56	-7	-51 – 37 (ns)
Park Place (n=31)	-350	70	-14	-34 – 6 (ns)
South Campus (n=21)	10	75	51	44 – 59***

*sig. at $p \leq 0.05$ **sig. at $p \leq 0.01$ ***sig. at $p \leq 0.001$

Table 21: Summary of TSS and TP reductions at Alabama (2004–2008), Brentwood (1998–2008), Park Place (1994–2009), and South Campus (2001–2008) storm water treatment sites. Only the Park Place treatment system was monitored in 2009; the other sites are included to provide perspective. Statistical significance was based on a one-sample t-test of whether the mean percent reduction was significantly different from zero.

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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.ac.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, 2007/2008 Final Report, March 19, 2009. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2006/2007 Final Report, April 2, 2008. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2005/2006 Final Report, April 11, 2007. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2004/2005 Final Report, March 30, 2006. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2003/2004 Final Report, March 15, 2005. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2002/2003 Final Report, April 5, 2004. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2001/2002 Final Report, April 21, 2003. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2000/2001 Final Report, March 15, 2002. Report to the City of Bellingham, WA.

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Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1997/98 Final Report, April 12, 1999. Report to the City of Bellingham, WA.

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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–A4 (pages 83–86) show the locations of the current monitoring sites and Table A1 (page 82) 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[20] is mounted in the stilling well on the east side of

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

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 the 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.

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 the 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 **Alabama Hill storm water treatment vault** is located on the east side of a 3-way intersection of Alabama St., Electric Ave., and North Shore Dr. The vault drains directly into Lake Whatcom.

The **Brentwood wet pond** is located at the southwest corner of the intersection between Britton Rd. and Barkley Blvd. The facility treats residential runoff from north of Barkley Blvd. and west of Britton Rd. Treated water flows from the facility into an underground drain that flows directly into Lake Whatcom, bypassing the Park Place storm water treatment system.

The **Park Place sand filter** is located on Park Place, south of North Shore Dr. and east of the intersection with Britton Rd. The facility treats residential runoff from south of Barkley Blvd. and west of Britton Rd. Treated water flows from the facility flows directly into Lake Whatcom. This site was formerly the Park Place wet pond, but was renamed following the 2006 retrofit.

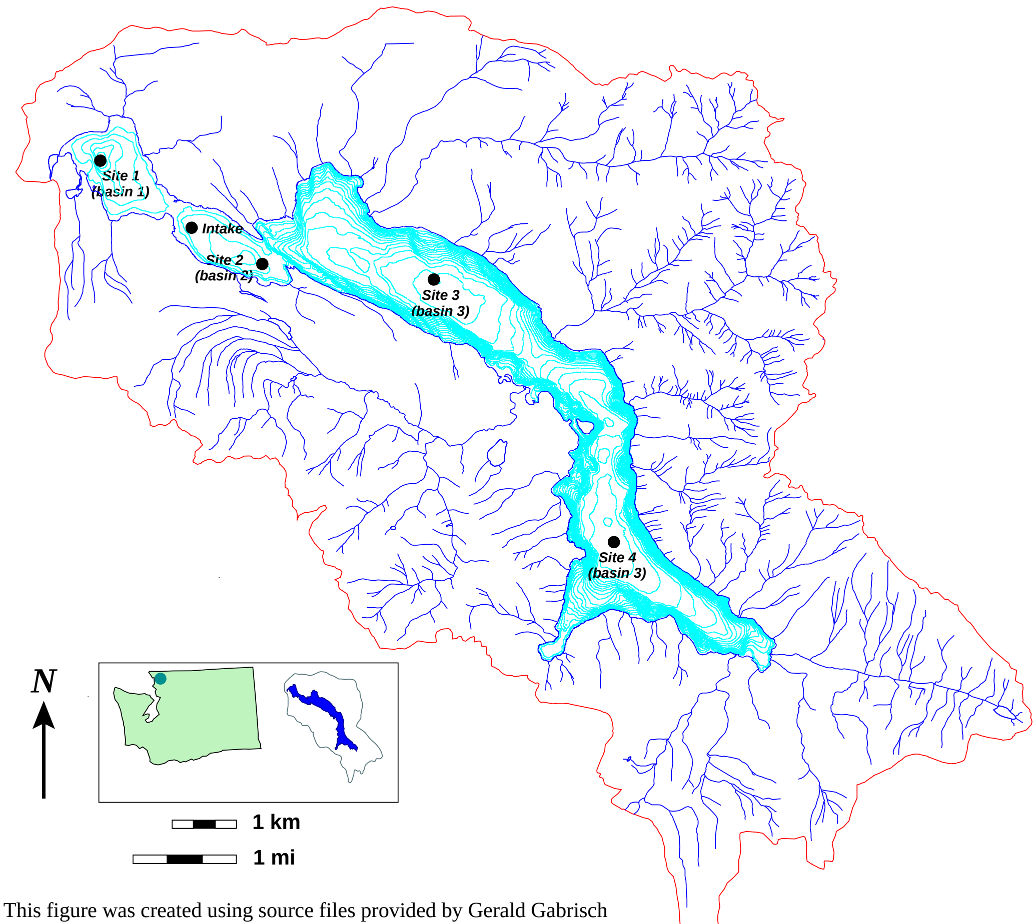
The **South Campus storm water treatment facility** is located south of the intersection between Bill McDonald Pky. and South College Dr, and treats runoff from the southern portion of Western Washington University. The runoff flows into a large underground concrete settling vault located on the northwest corner of the intersection, then flows into a series of grass swales and gravel beds planted with aquatic vegetation. This facility is outside the Lake Whatcom watershed.

Lake Sites	Latitude	Longitude
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	Longitude
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

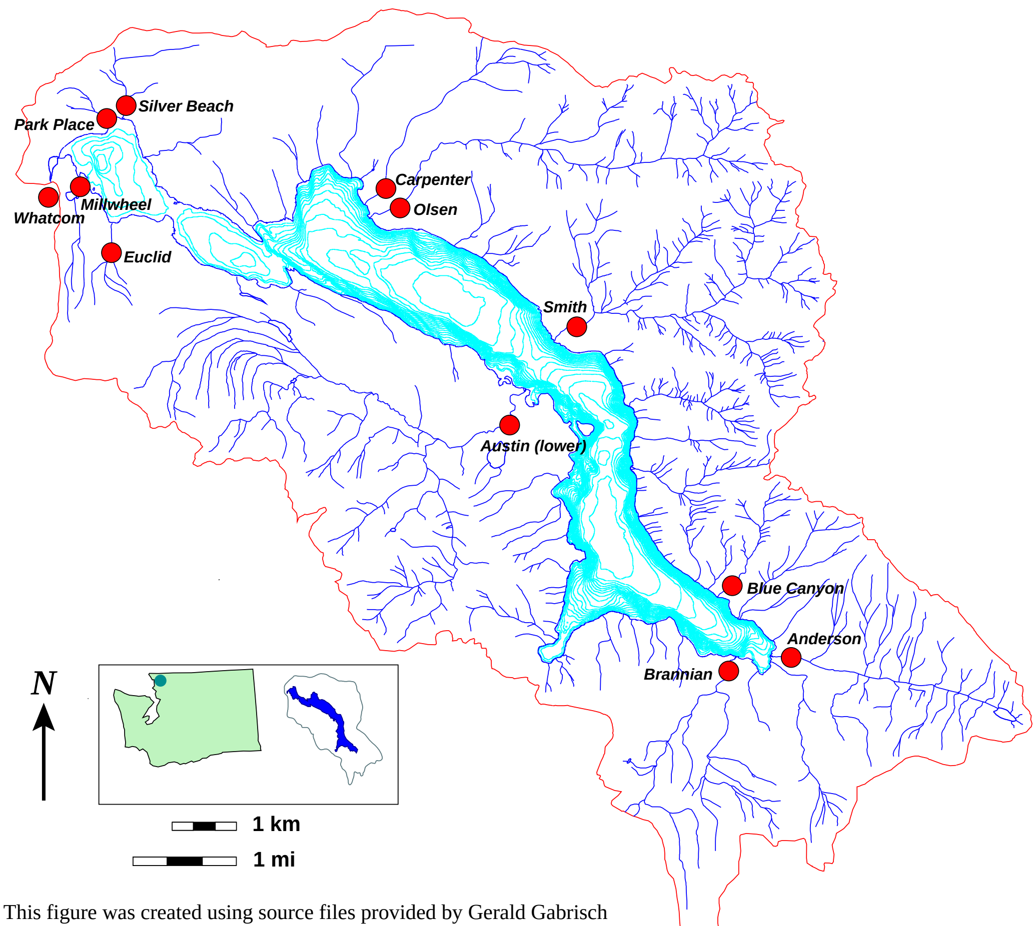
Storm Water Sites	Latitude	Longitude
Alabama Hill	48.76289	122.42060
Brentwood	48.76904	122.40945
Park Place	48.76904	122.40945
South Campus	48.72615	122.48847

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



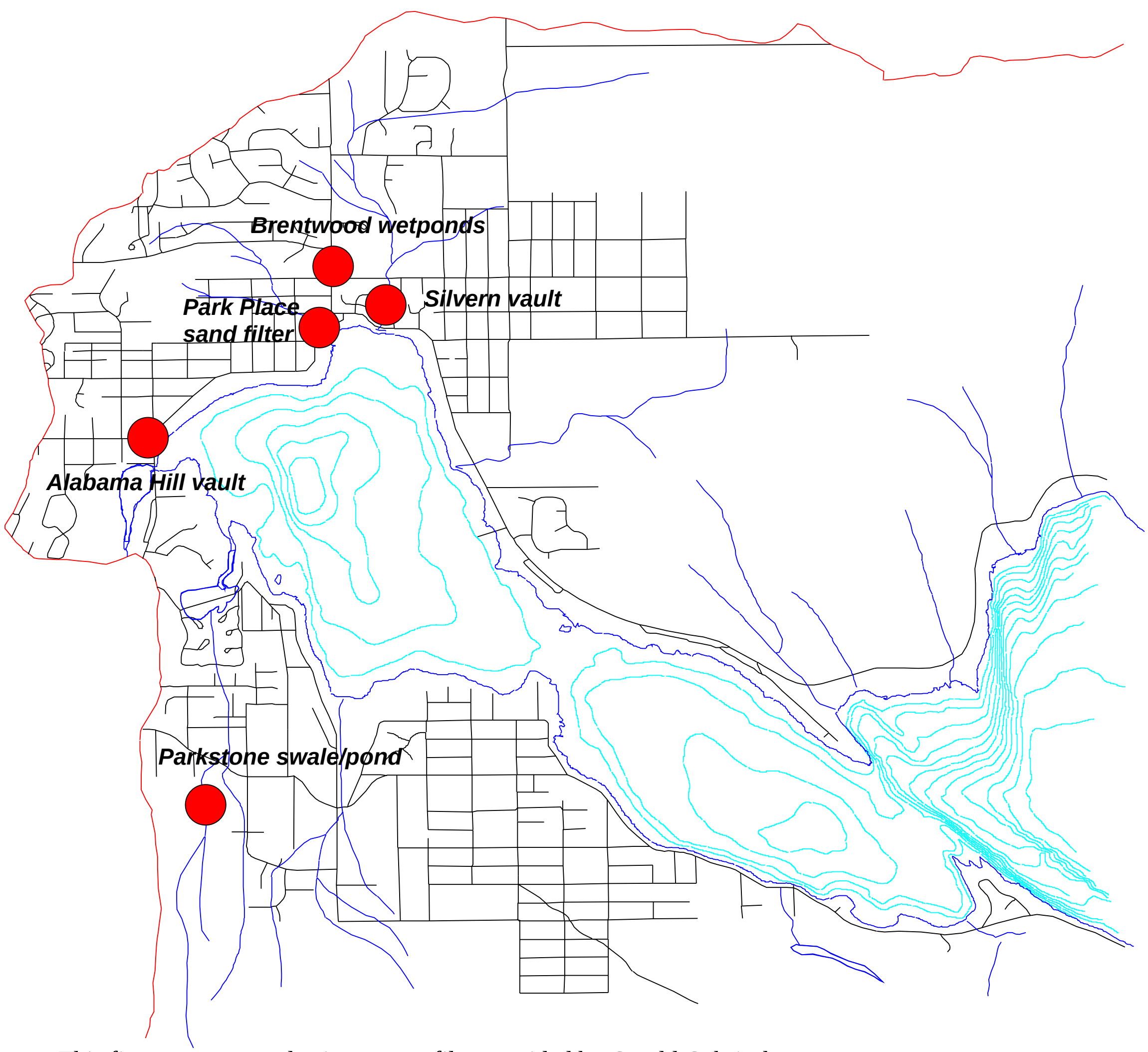
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

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 creek 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: Locations of the Alabama Hill vault, Brentwood wet ponds, Park Place sand filter, Parkstone swale/pond, and the Silvern vault. Only the Park Place sand filter was sampled in 2008/2009

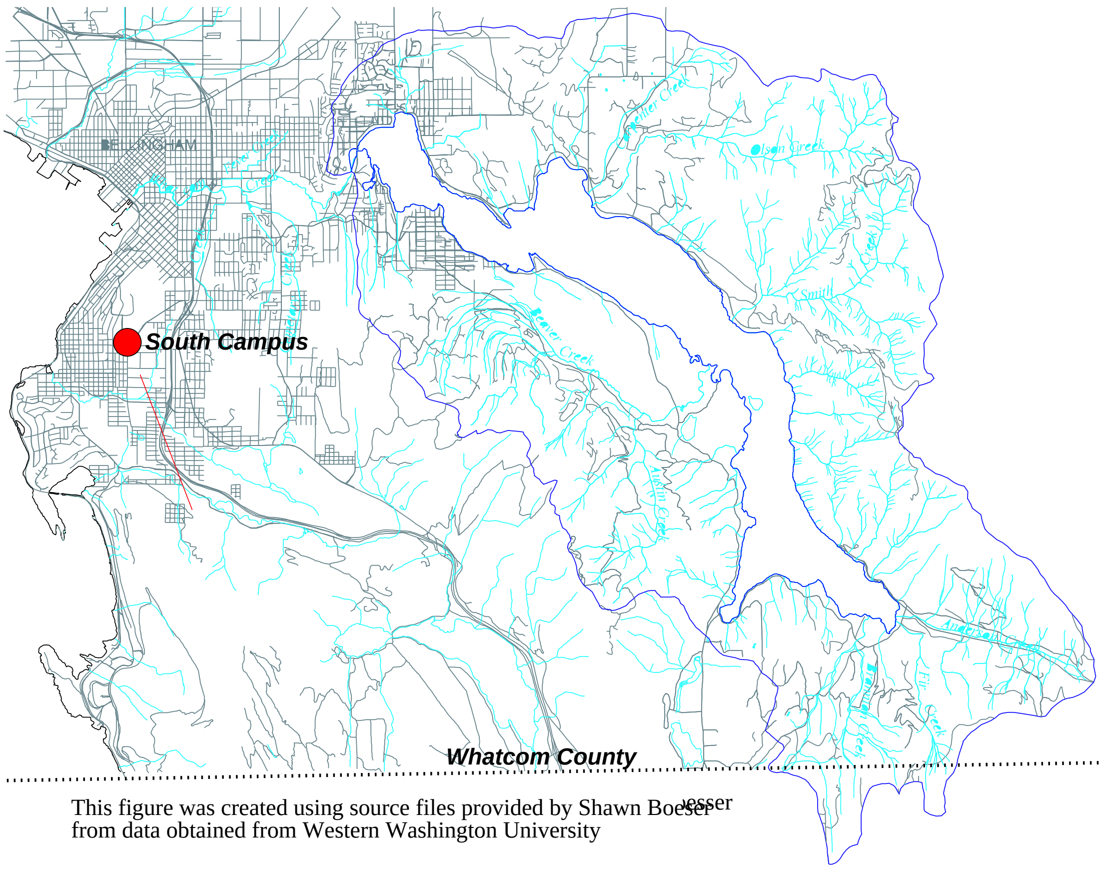


Figure A4: Location of the South Campus storm water treatment facility. This site was not sampled in 2009.

Figure A5: Photograph of the Alabama Hill vault, May 2006. This site was not sampled in 2008/2009.

Figure A6: Photograph of the Brentwood wet pond, July 2004. This site was not sampled in 2008/2009.

Figure A7: Photograph of the original Park Place storm water treatment system prior to retrofit (March 2005).

Figure A8: Photograph of the Park Place storm water treatment system in May 2006, after an extensive retrofit where two of the sites wet cells were filled with sand. This site was sampled in 2008/2009.

Figure A9: Photograph of the Parkstone wet pond and swale, November 2003. This site was not sampled in 2008/2009.

Figure A10: Photograph of the Silvern storm water treatment vault, May 2004. This site was not sampled in 2008/2009.

Figure A11: Photograph of the South Campus storm water treatment facility, January 2005. This site was not sampled in 2008/2009.

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 16).

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 16). 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 162–166, 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. Refer to Matthews, et al. (2005) for a discussion of historic trends in Lake Whatcom.

B.1 Monthly Hydrolab Profiles

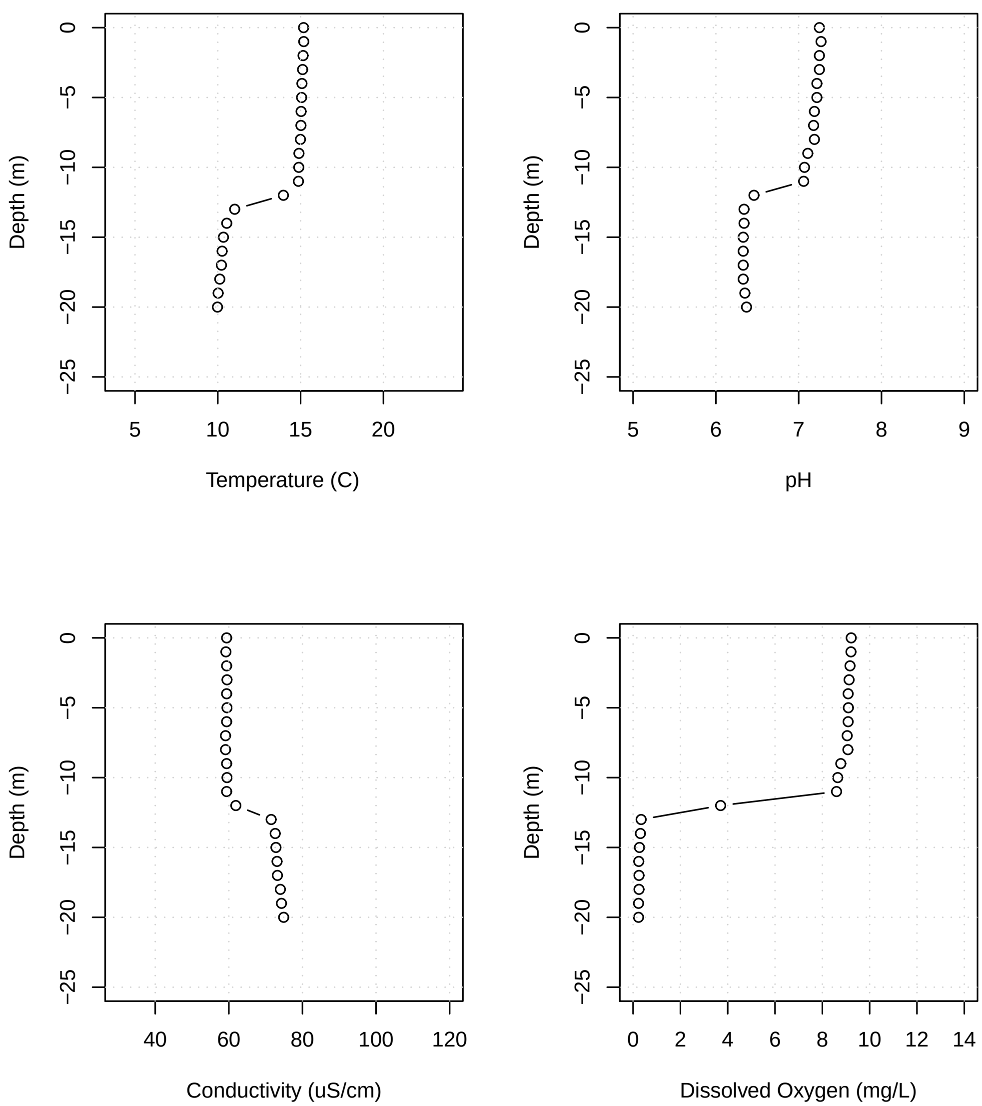


Figure B1: Lake Whatcom Hydrolab profile for Site 1, October 9, 2008.

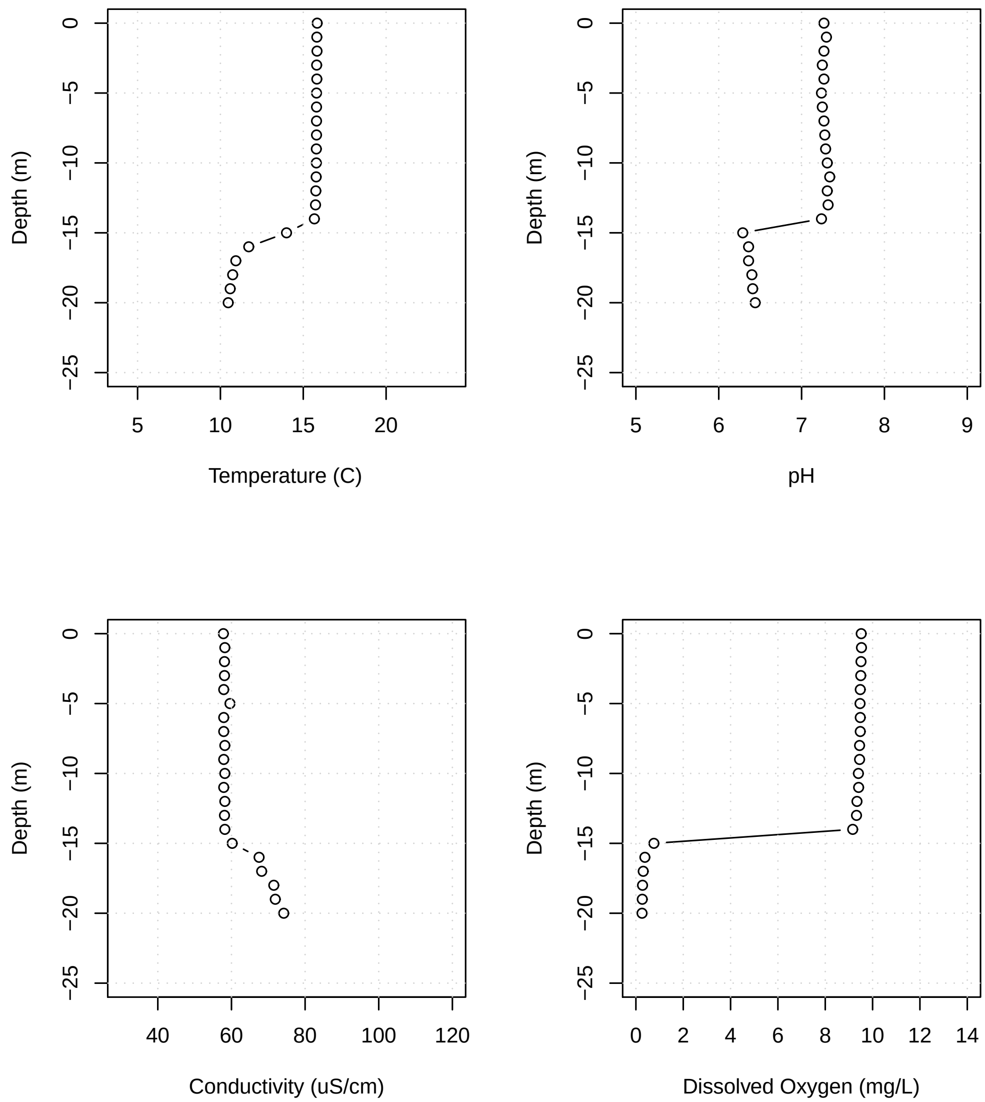


Figure B2: Lake Whatcom Hydrolab profile for Site 2, October 9, 2008.

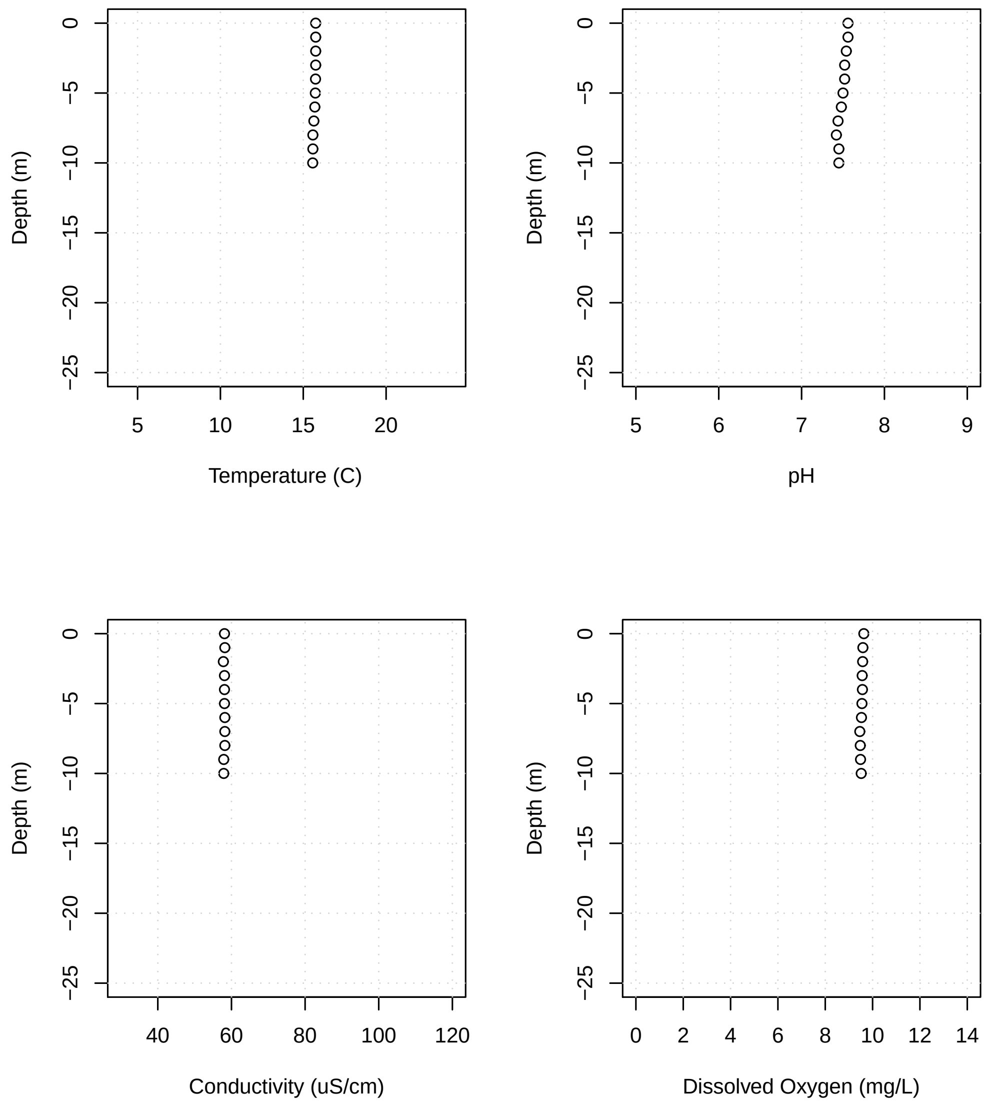


Figure B3: Lake Whatcom Hydrolab profile for the Intake, October 9, 2008.

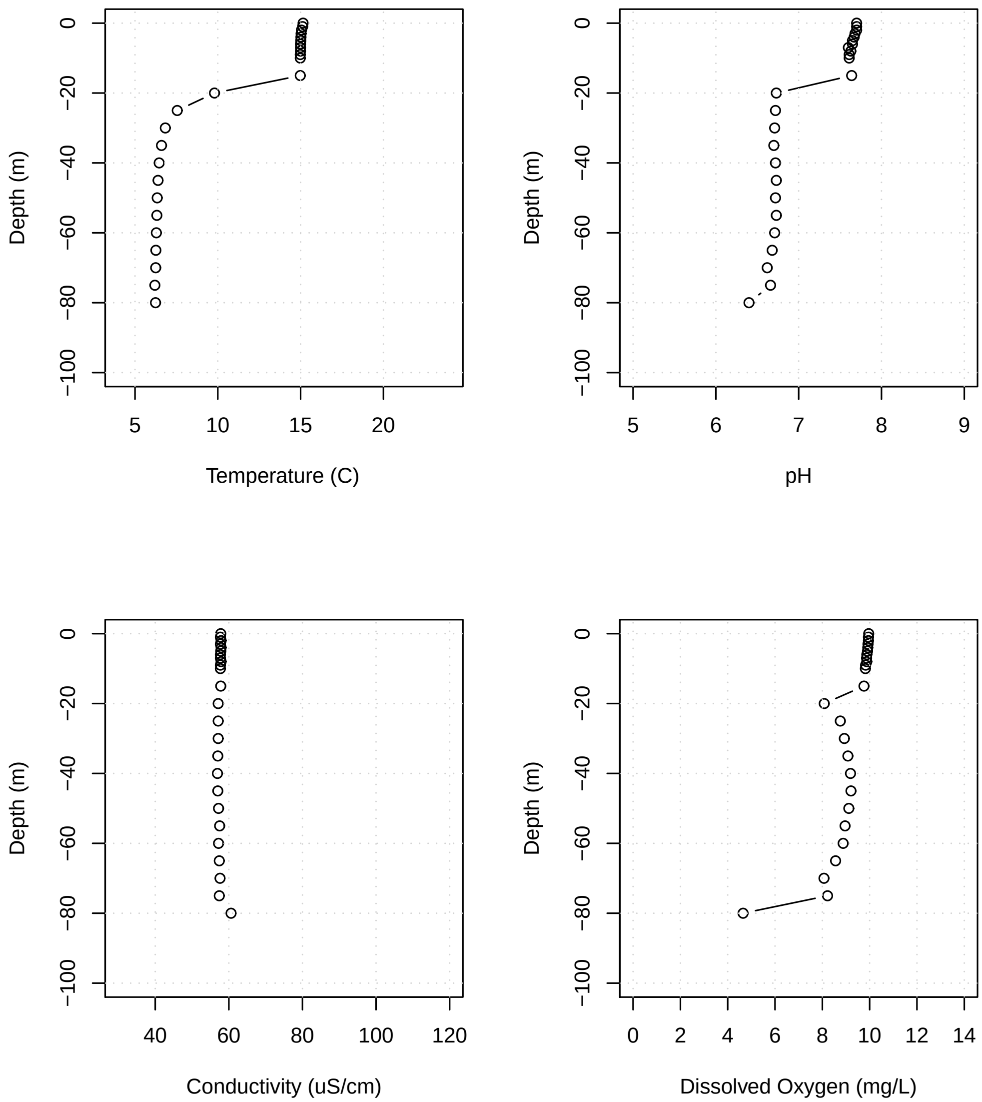


Figure B4: Lake Whatcom Hydrolab profile for Site 3, October 14, 2008.

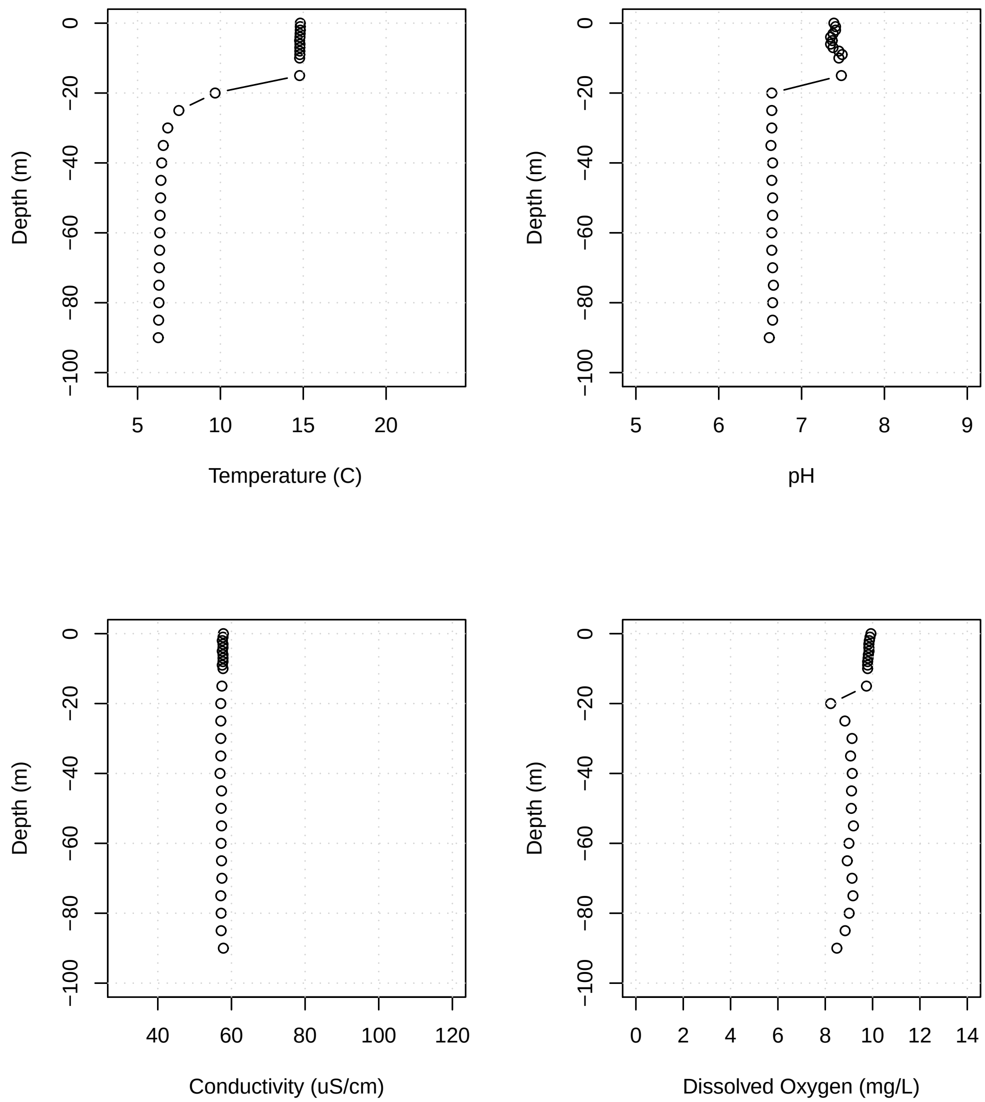


Figure B5: Lake Whatcom Hydrolab profile for Site 4, October 14, 2008.

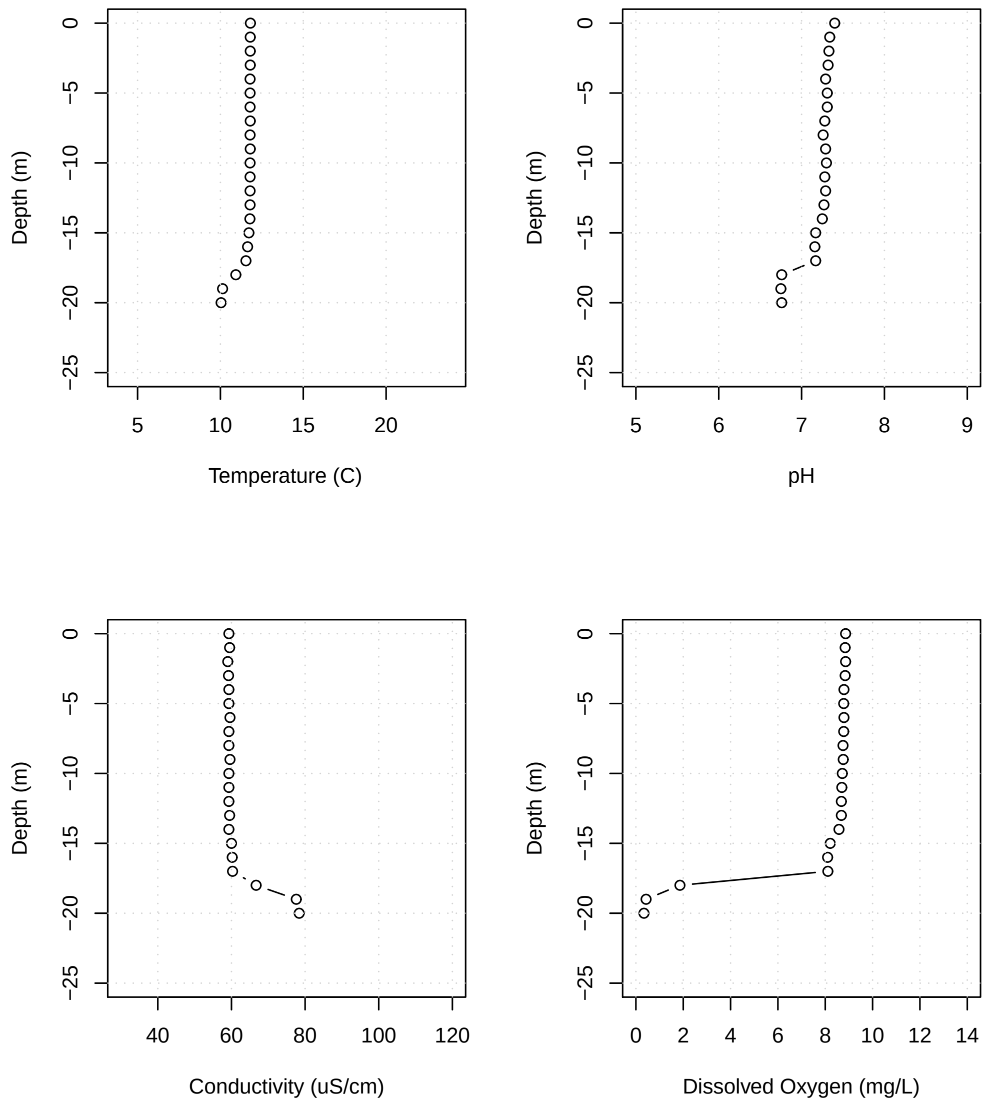


Figure B6: Lake Whatcom Hydrolab profile for Site 1, November 4, 2008.

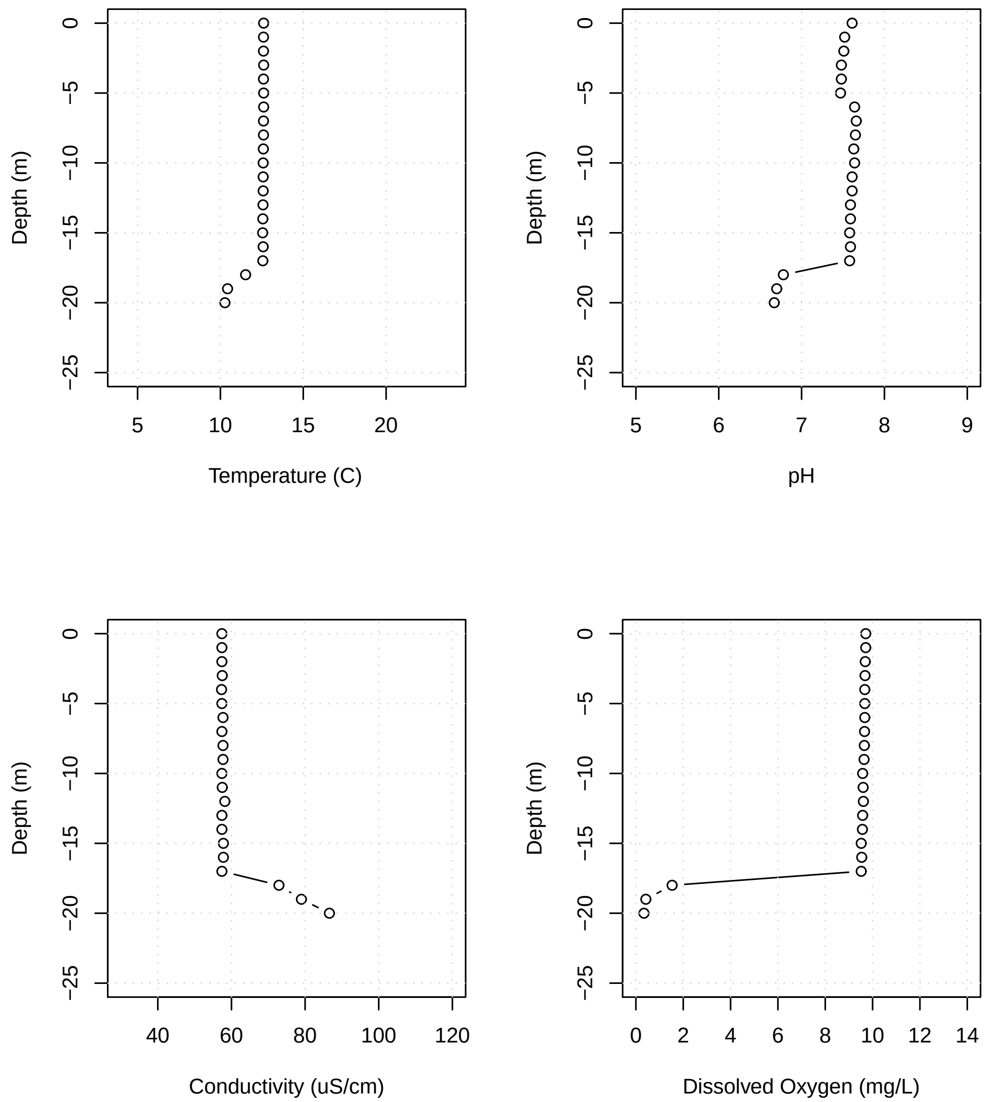


Figure B7: Lake Whatcom Hydrolab profile for Site 2, November 4, 2008.

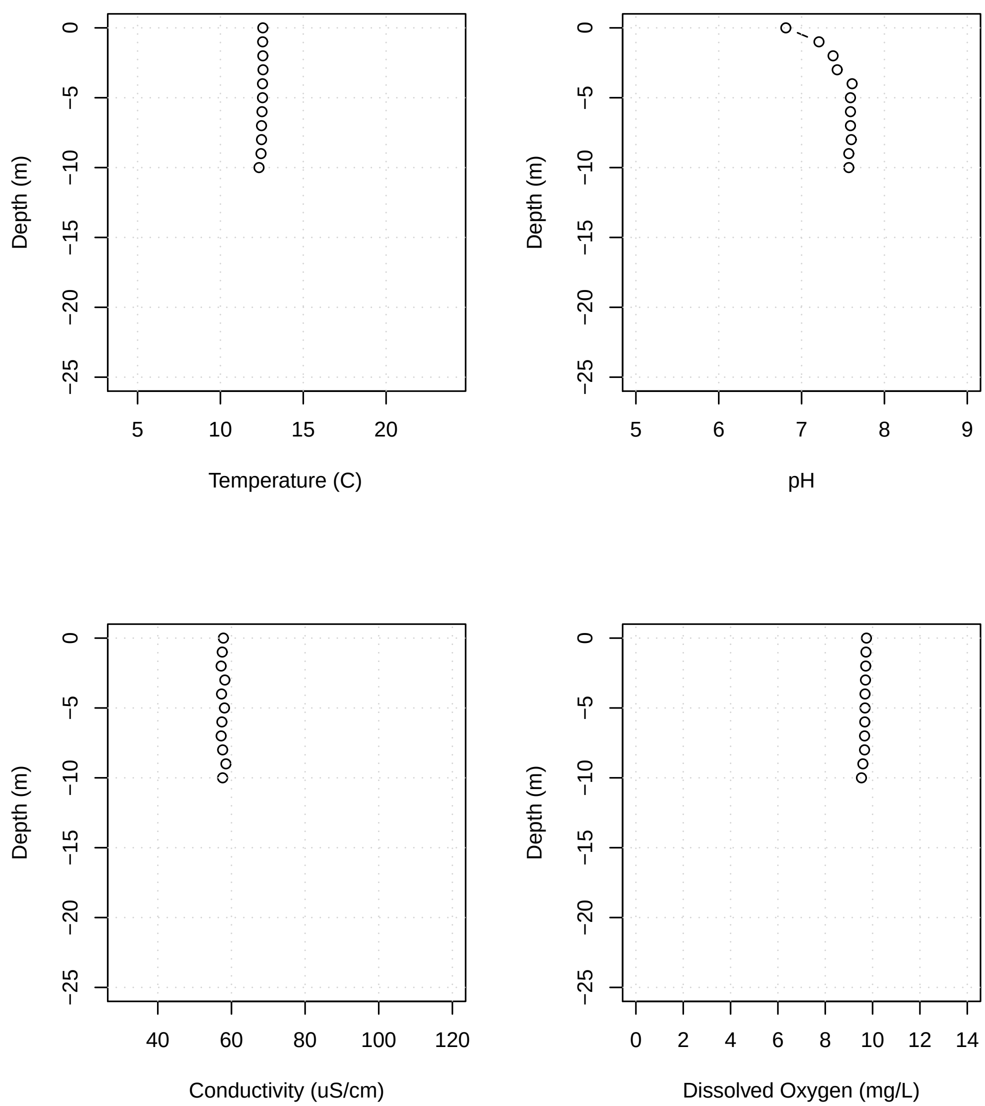


Figure B8: Lake Whatcom Hydrolab profile for the Intake, November 4, 2008. The cause of the pH drift is unknown.

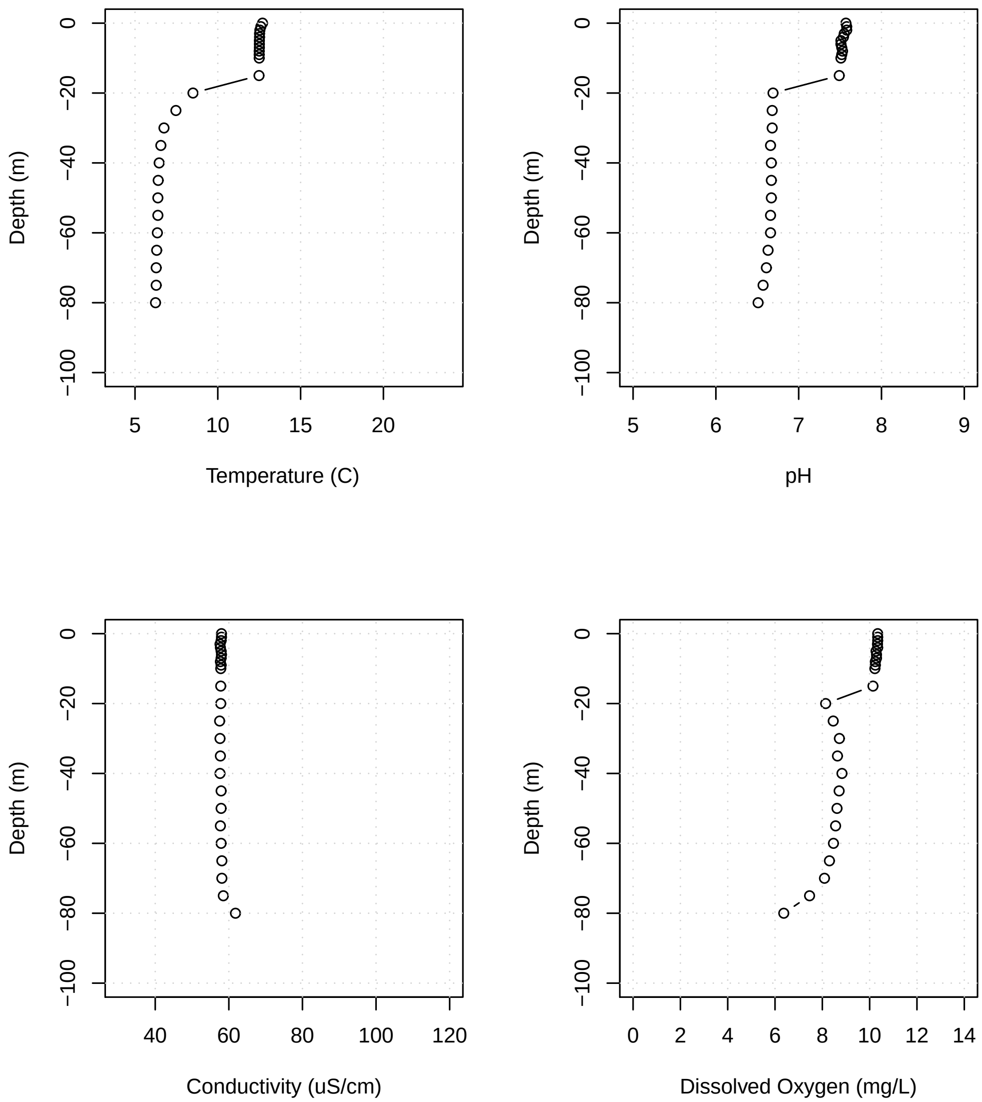


Figure B9: Lake Whatcom Hydrolab profile for Site 3, November 5, 2008.

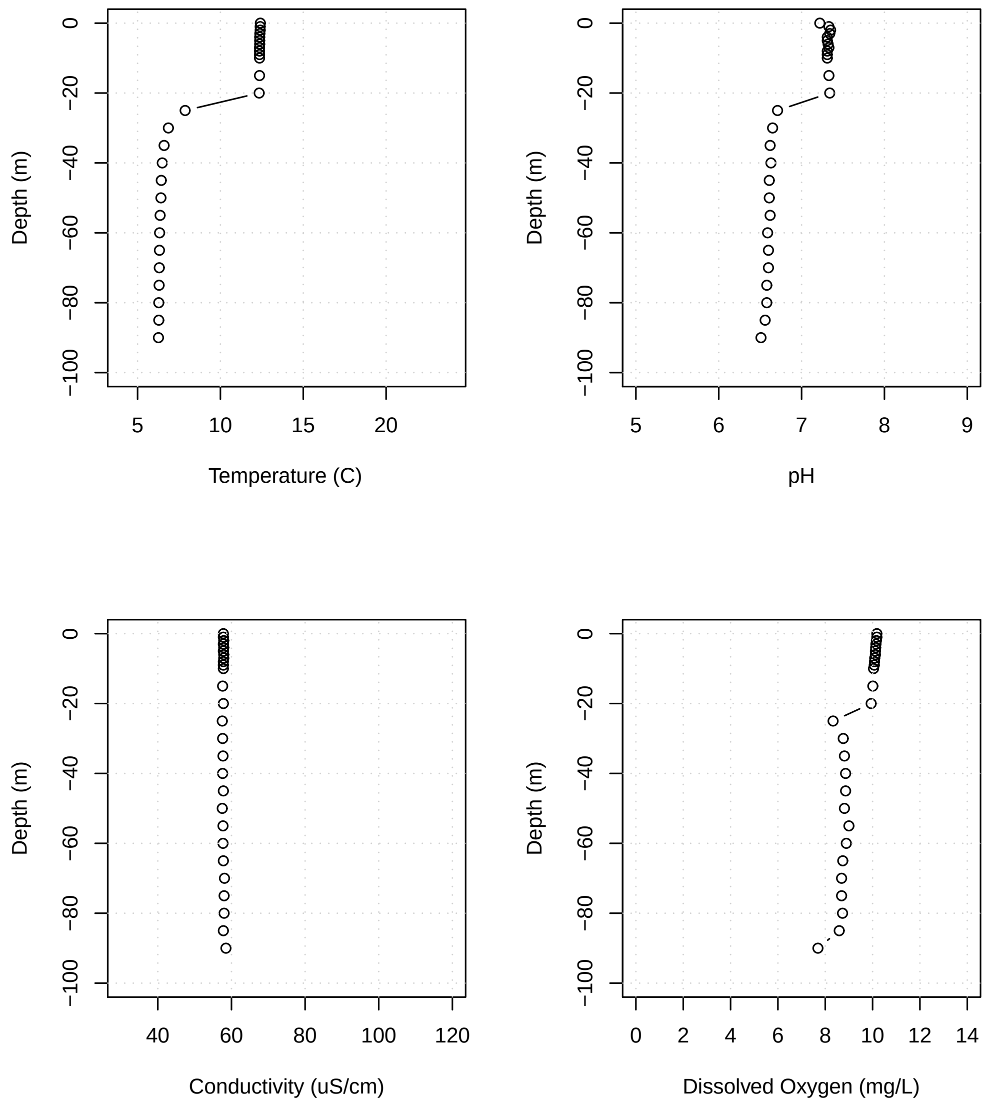


Figure B10: Lake Whatcom Hydrolab profile for Site 4, November 5, 2008.

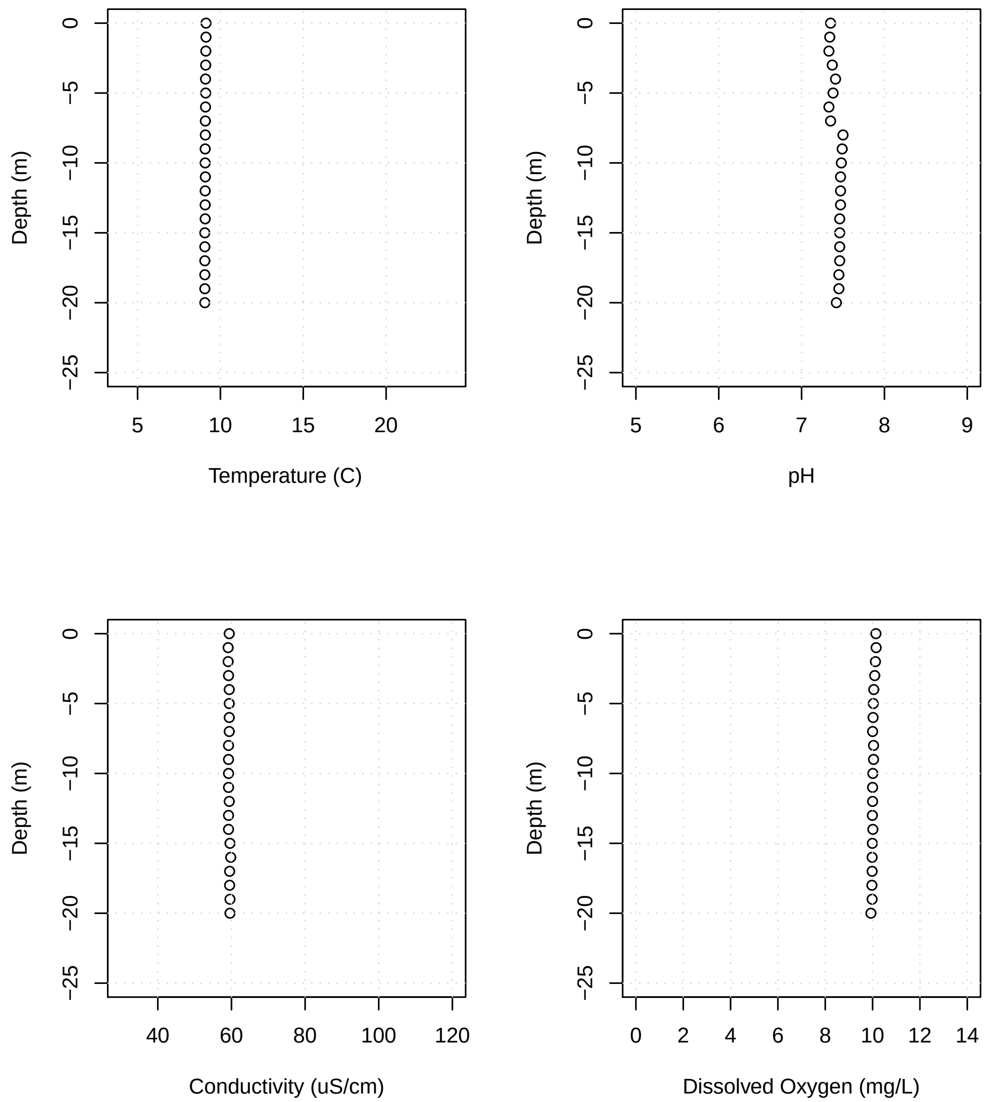


Figure B11: Lake Whatcom Hydrolab profile for Site 1, December 4, 2008.

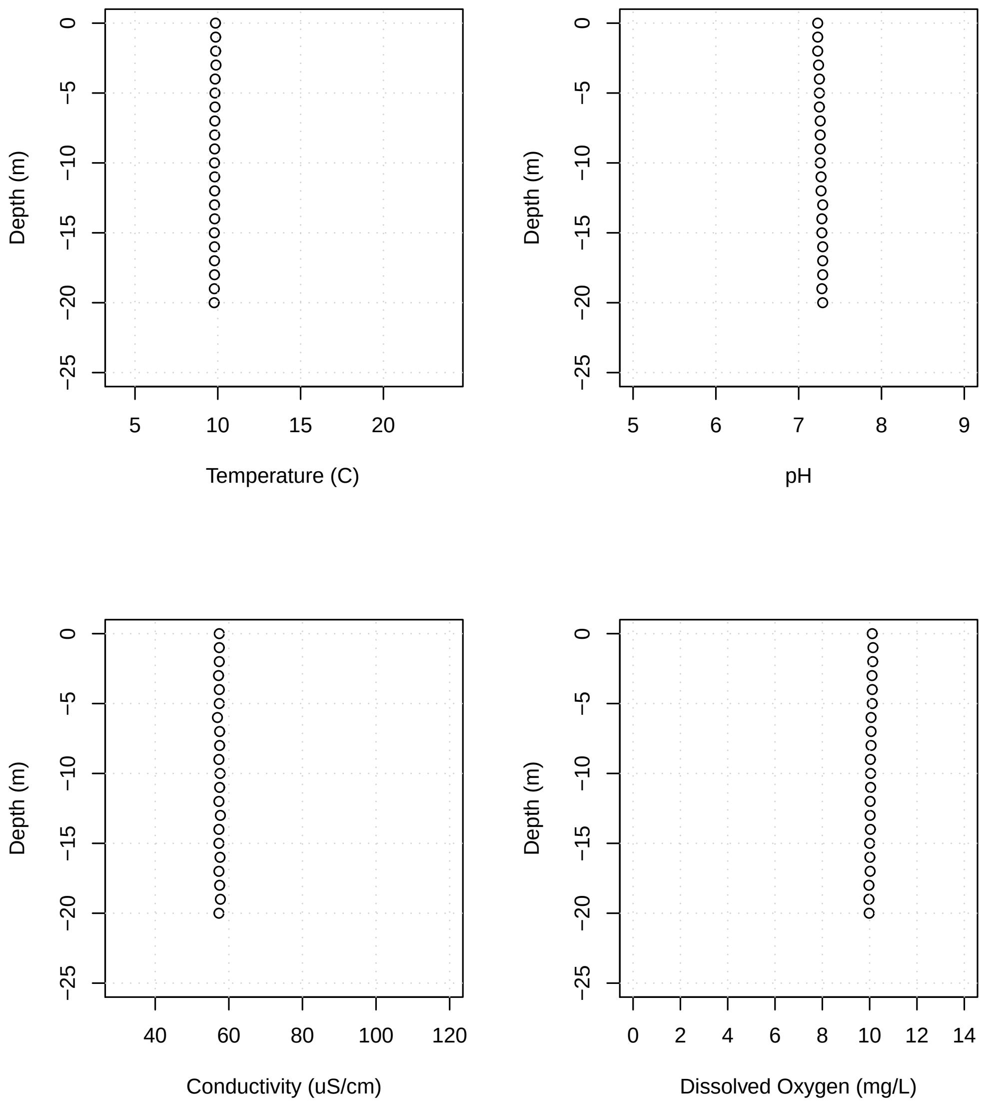


Figure B12: Lake Whatcom Hydrolab profile for Site 2, December 4, 2008.

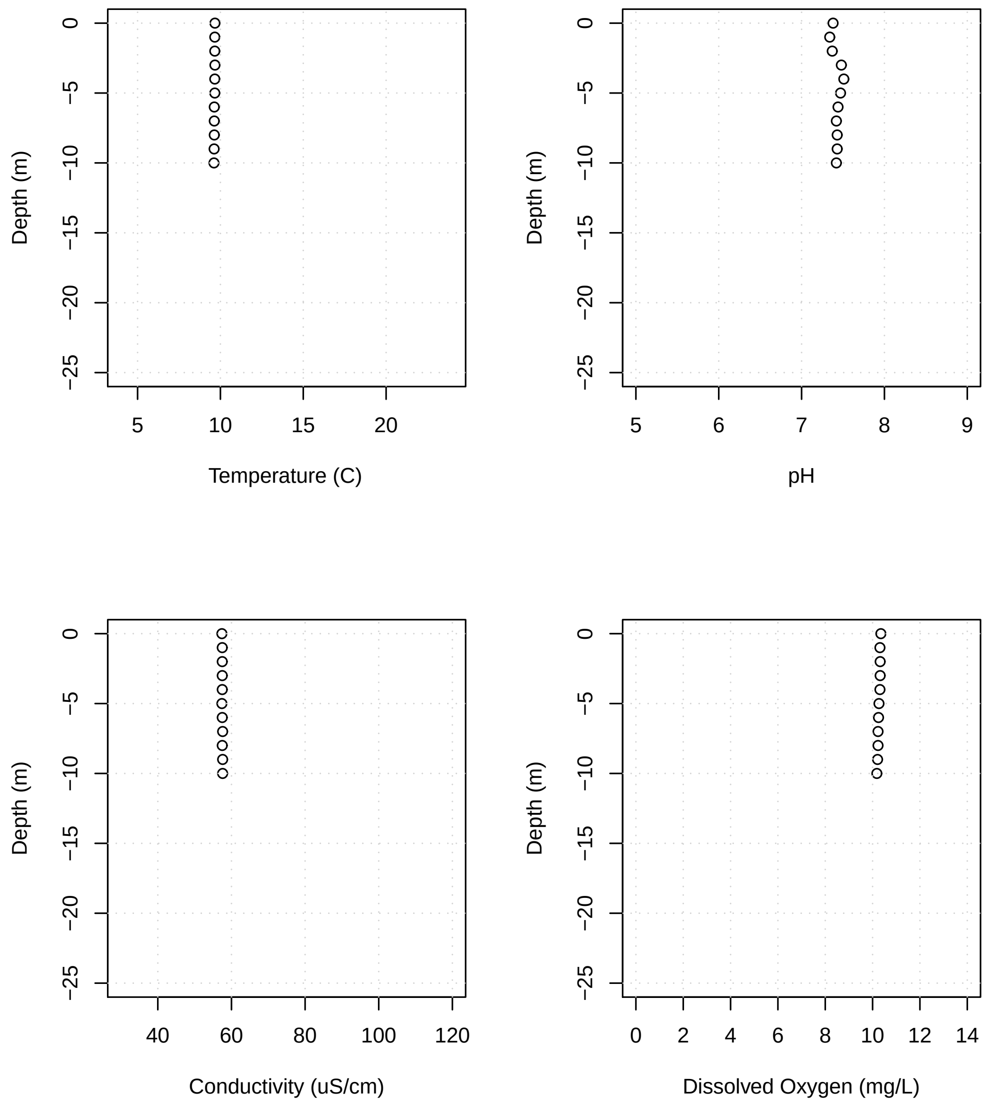


Figure B13: Lake Whatcom Hydrolab profile for the Intake, December 4, 2008.

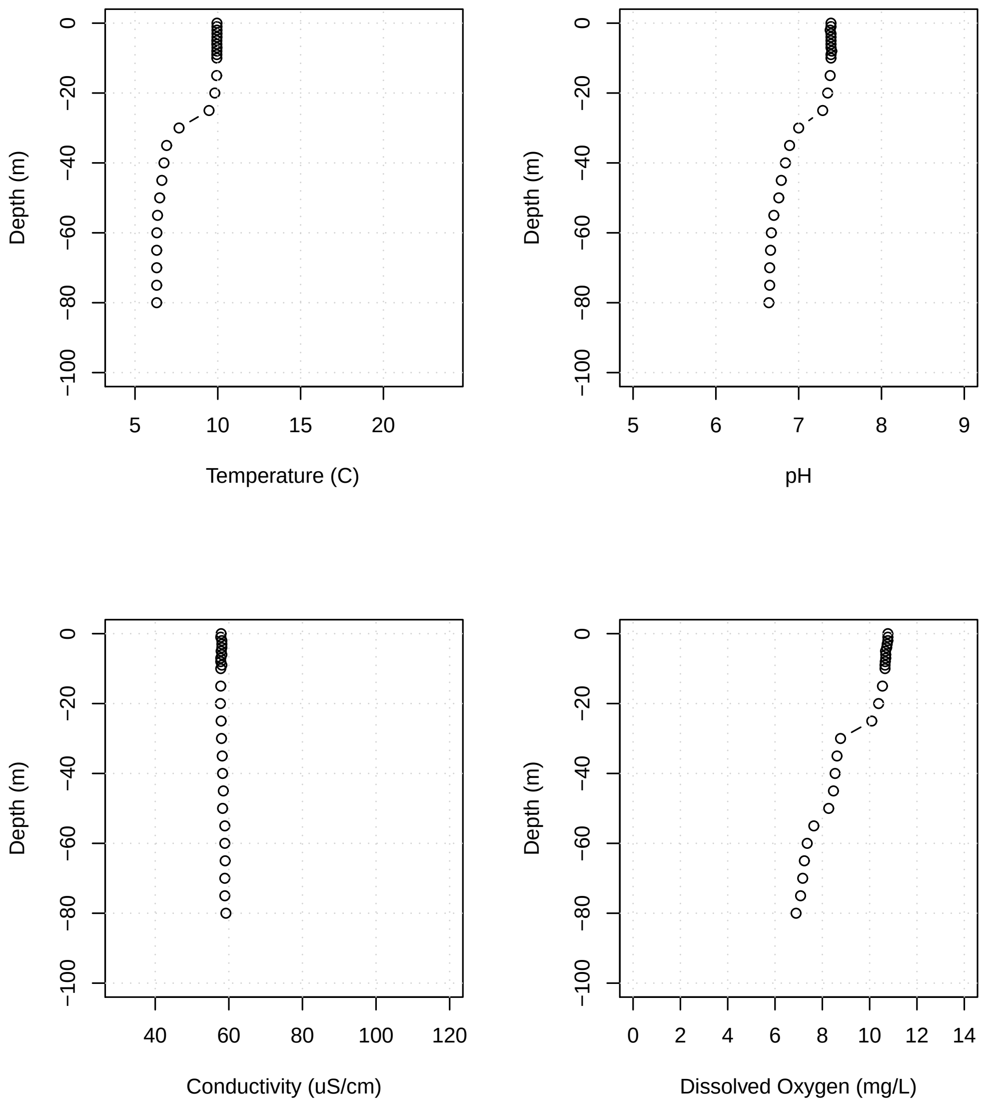


Figure B14: Lake Whatcom Hydrolab profile for Site 3, December 2, 2008.

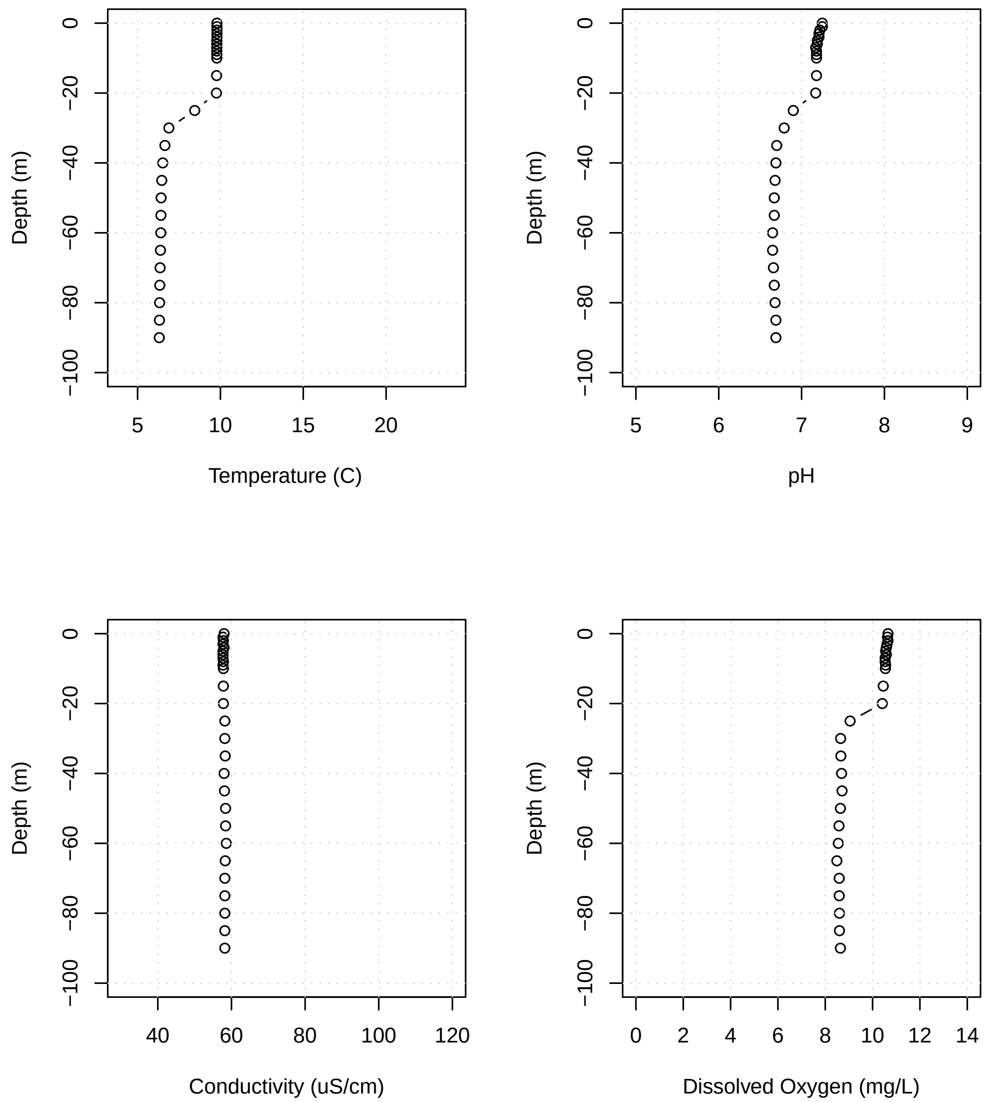


Figure B15: Lake Whatcom Hydrolab profile for Site 4, December 2, 2008.

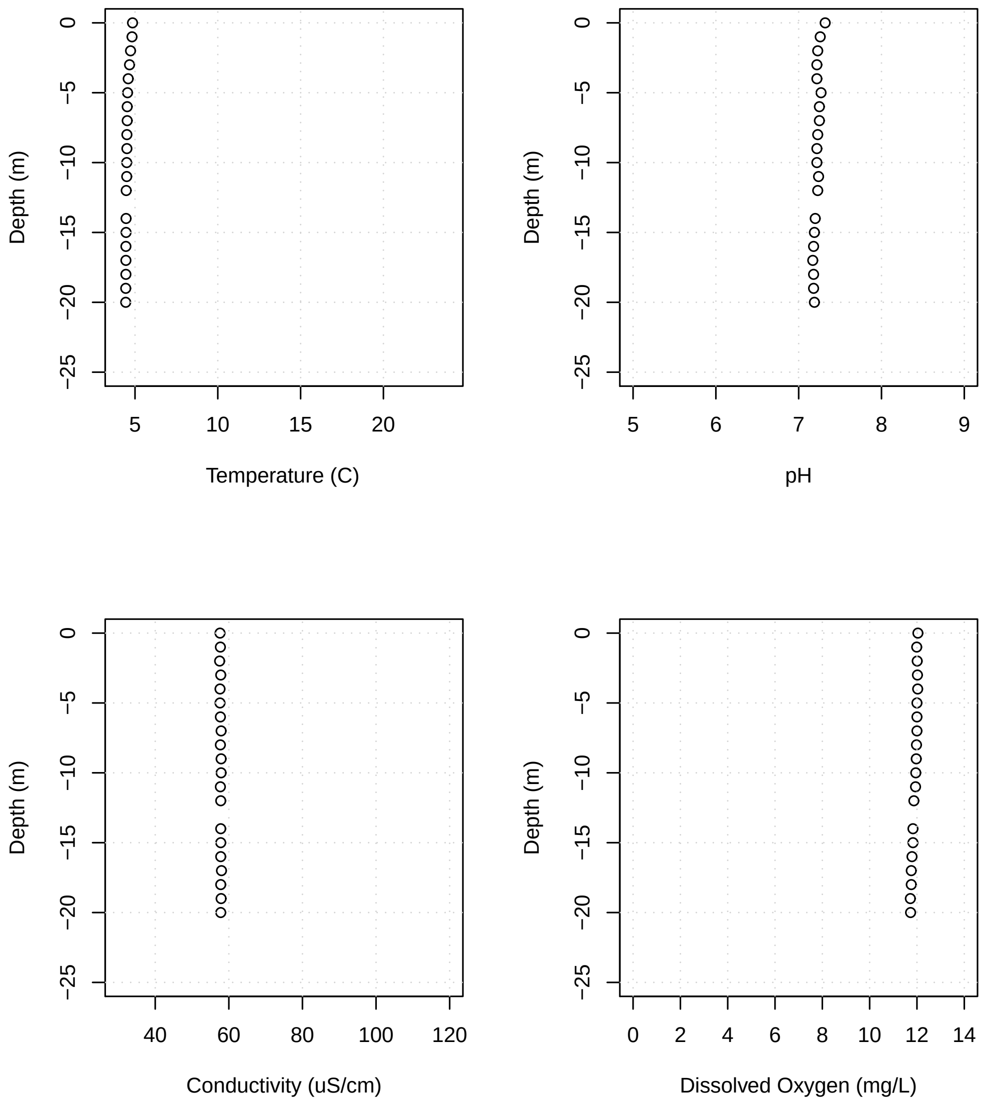


Figure B16: Lake Whatcom Hydrolab profile for Site 1, February 5, 2009. Data from 13 meters are missing due to instrument error.

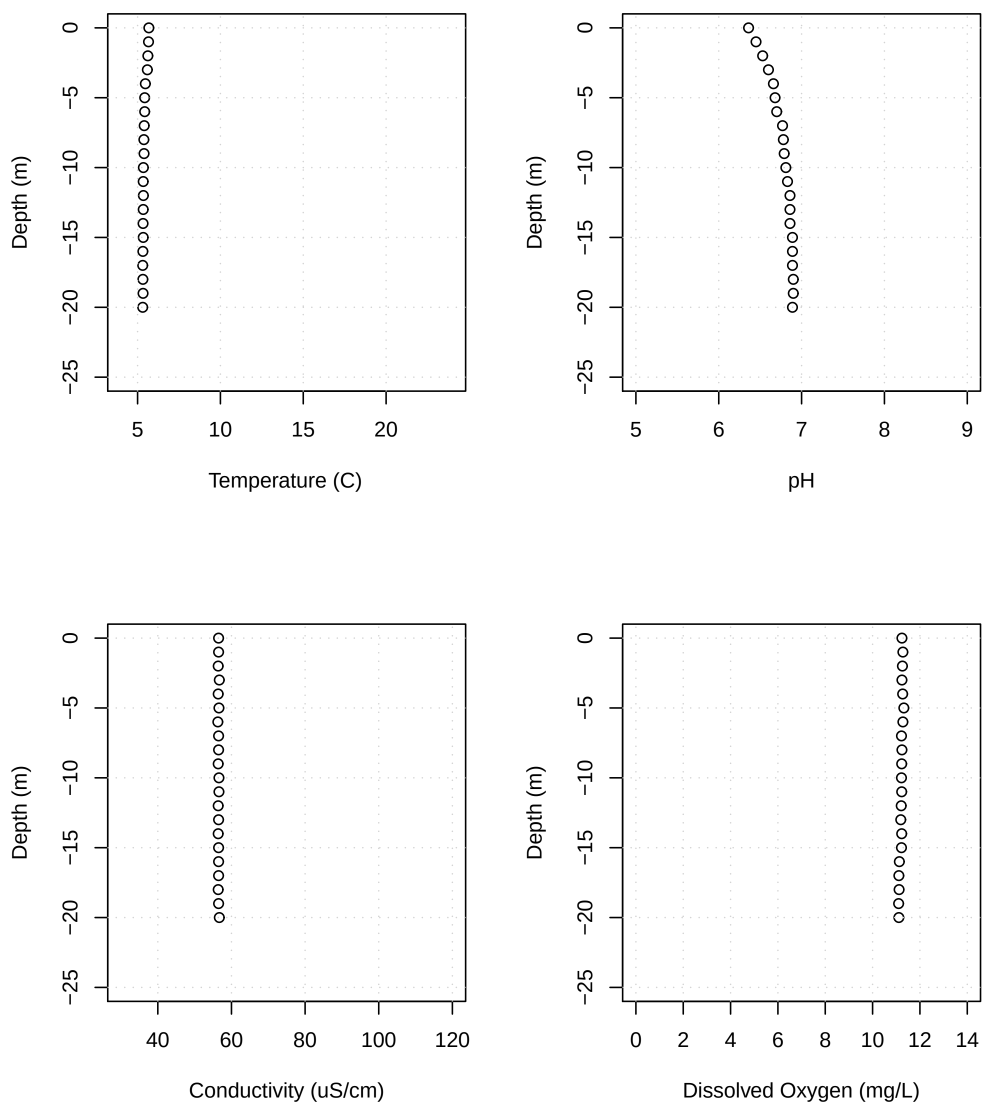


Figure B17: Lake Whatcom Hydrolab profile for Site 2, February 5, 2009. The cause of the pH drift is unknown.

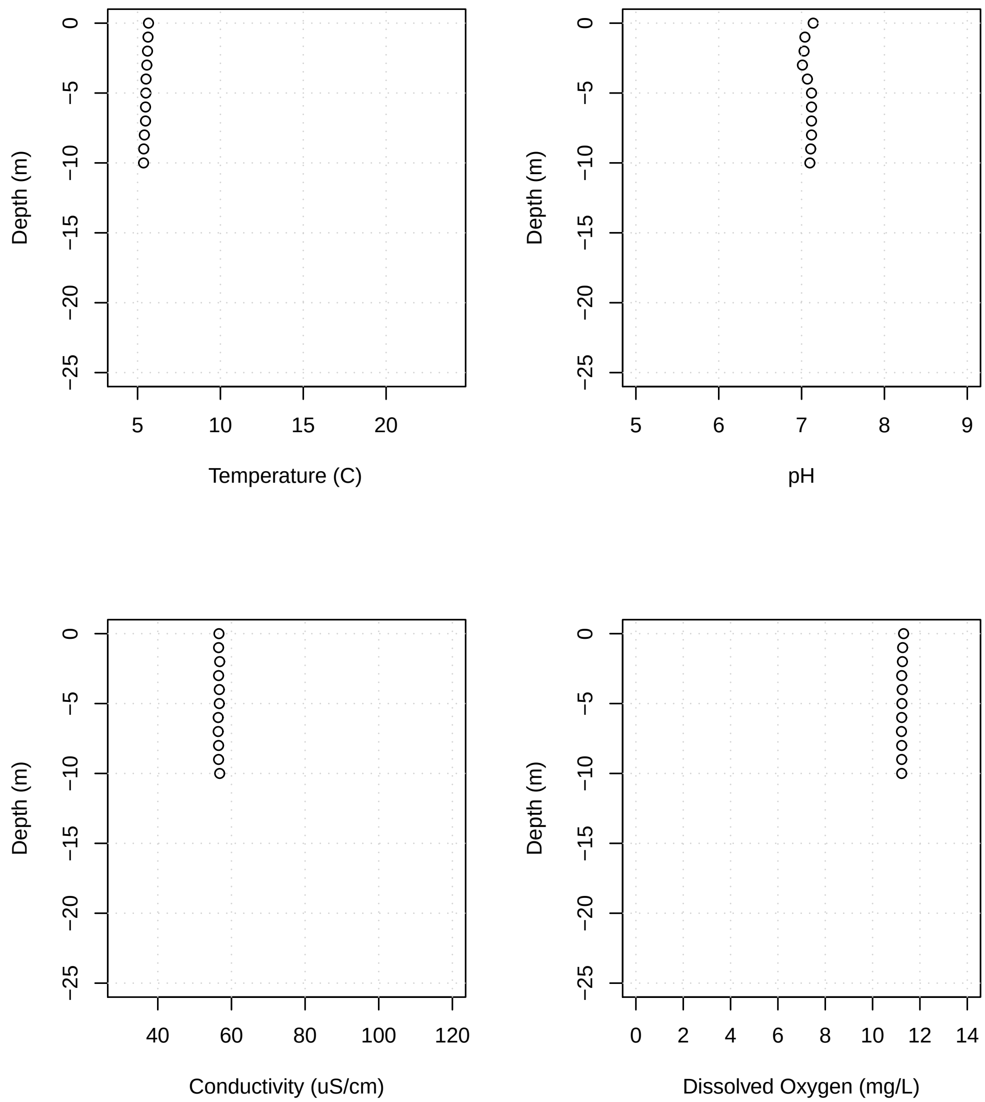


Figure B18: Lake Whatcom Hydrolab profile for the Intake, February 5, 2009.

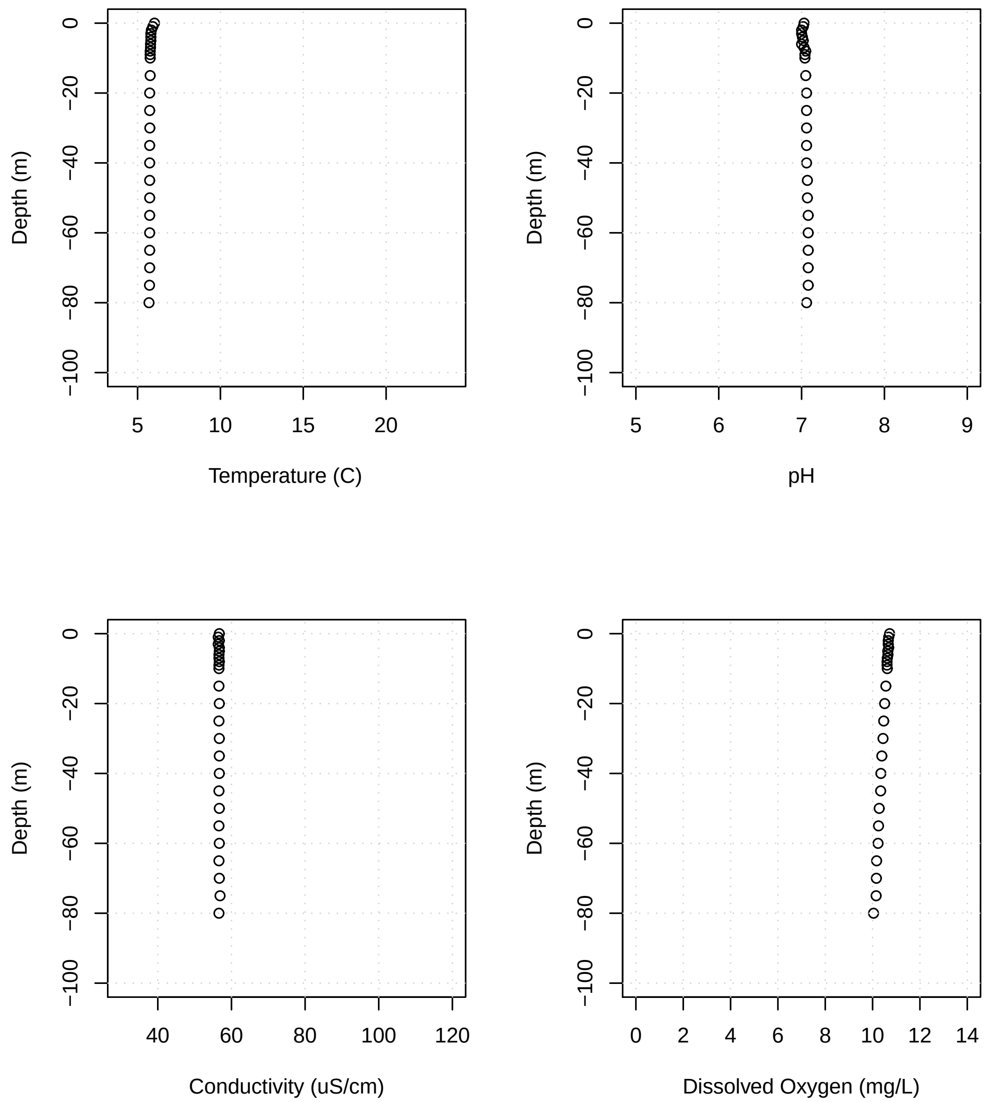


Figure B19: Lake Whatcom Hydrolab profile for Site 3, February 3, 2009.

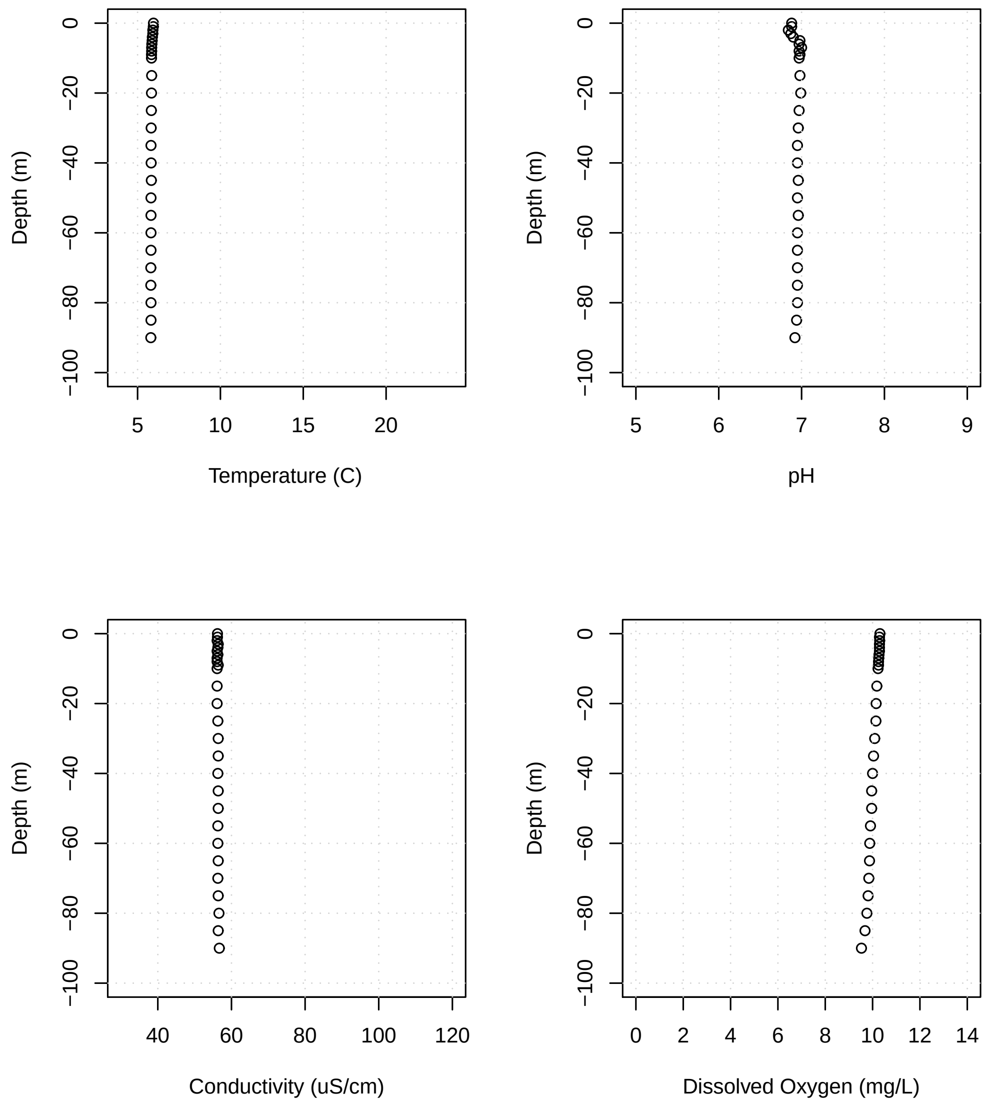


Figure B20: Lake Whatcom Hydrolab profile for Site 4, February 3, 2009.

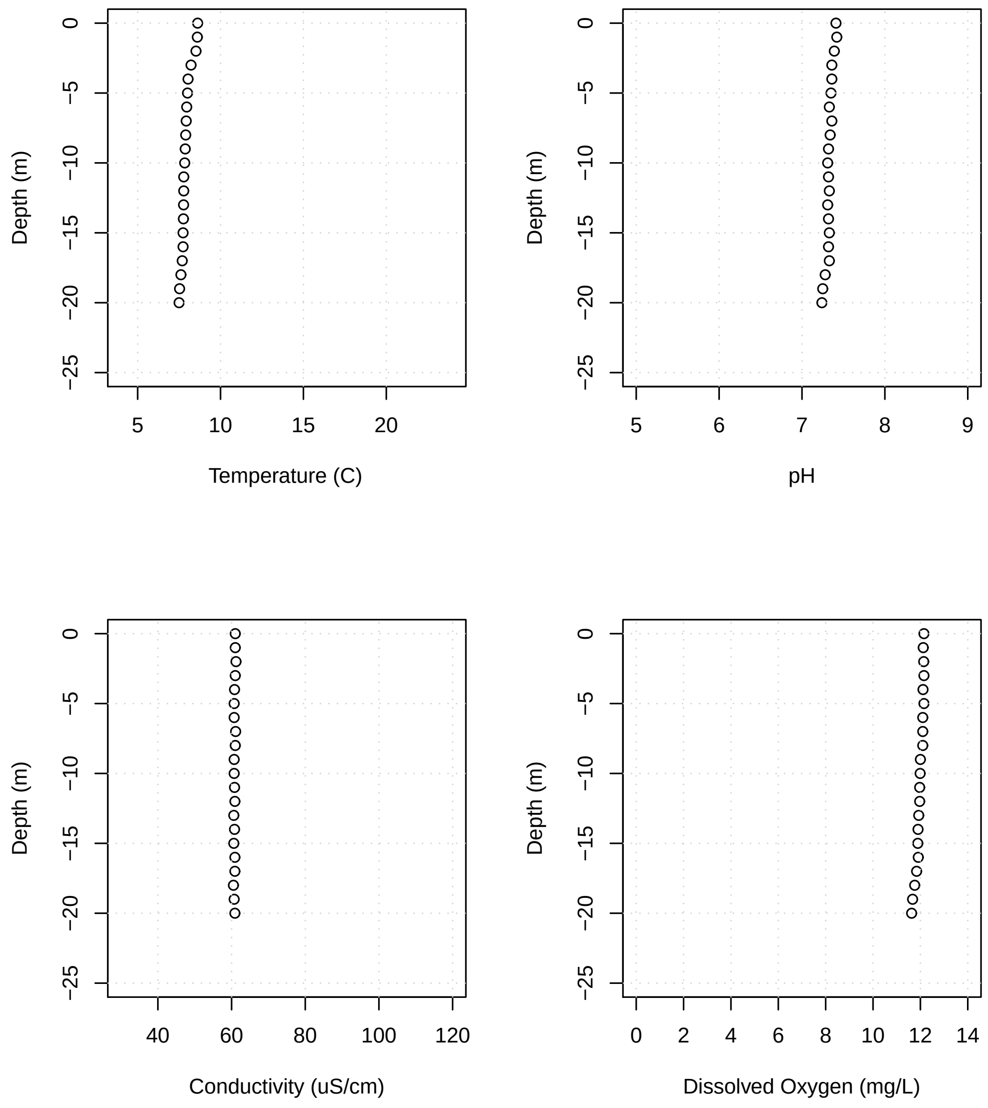


Figure B21: Lake Whatcom Hydrolab profile for Site 1, April 14, 2009.

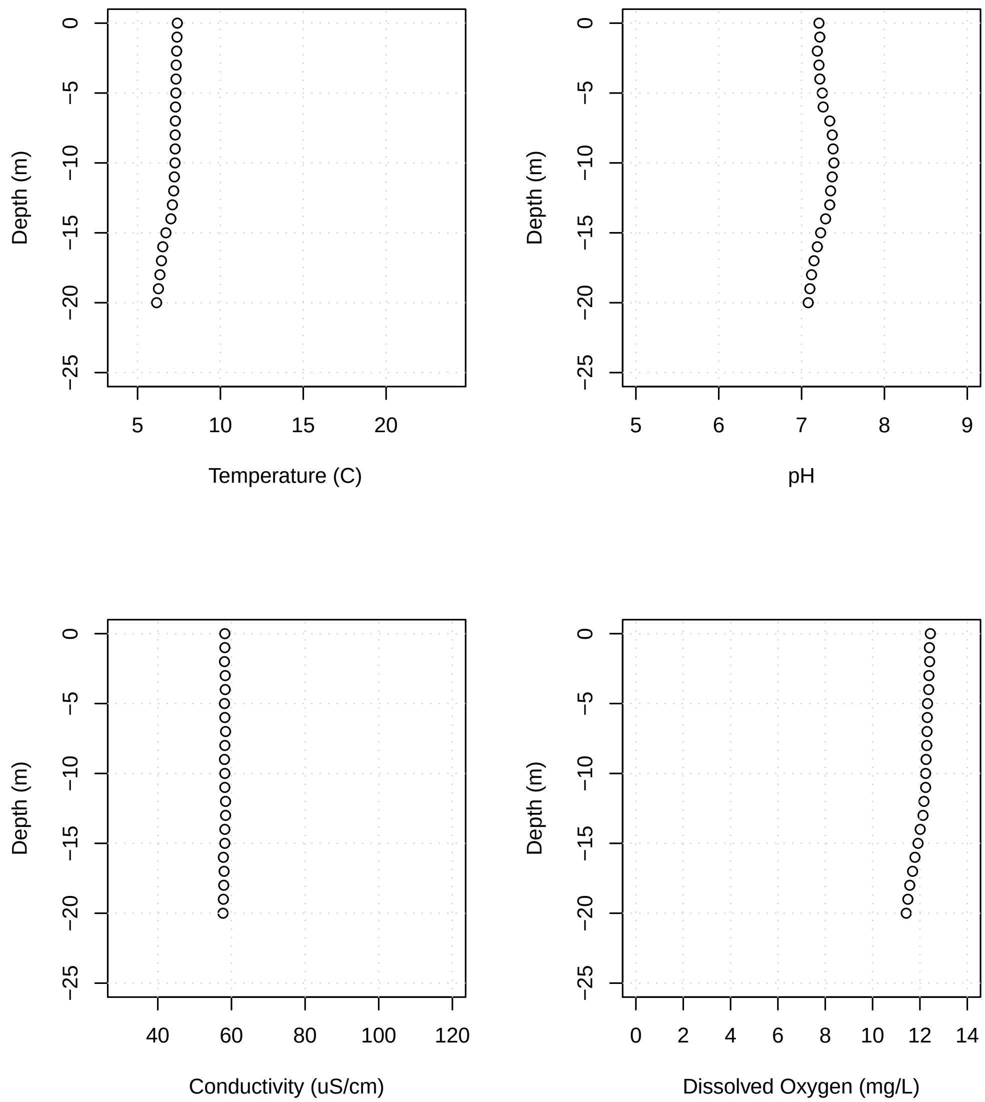


Figure B22: Lake Whatcom Hydrolab profile for Site 2, April 14, 2009.

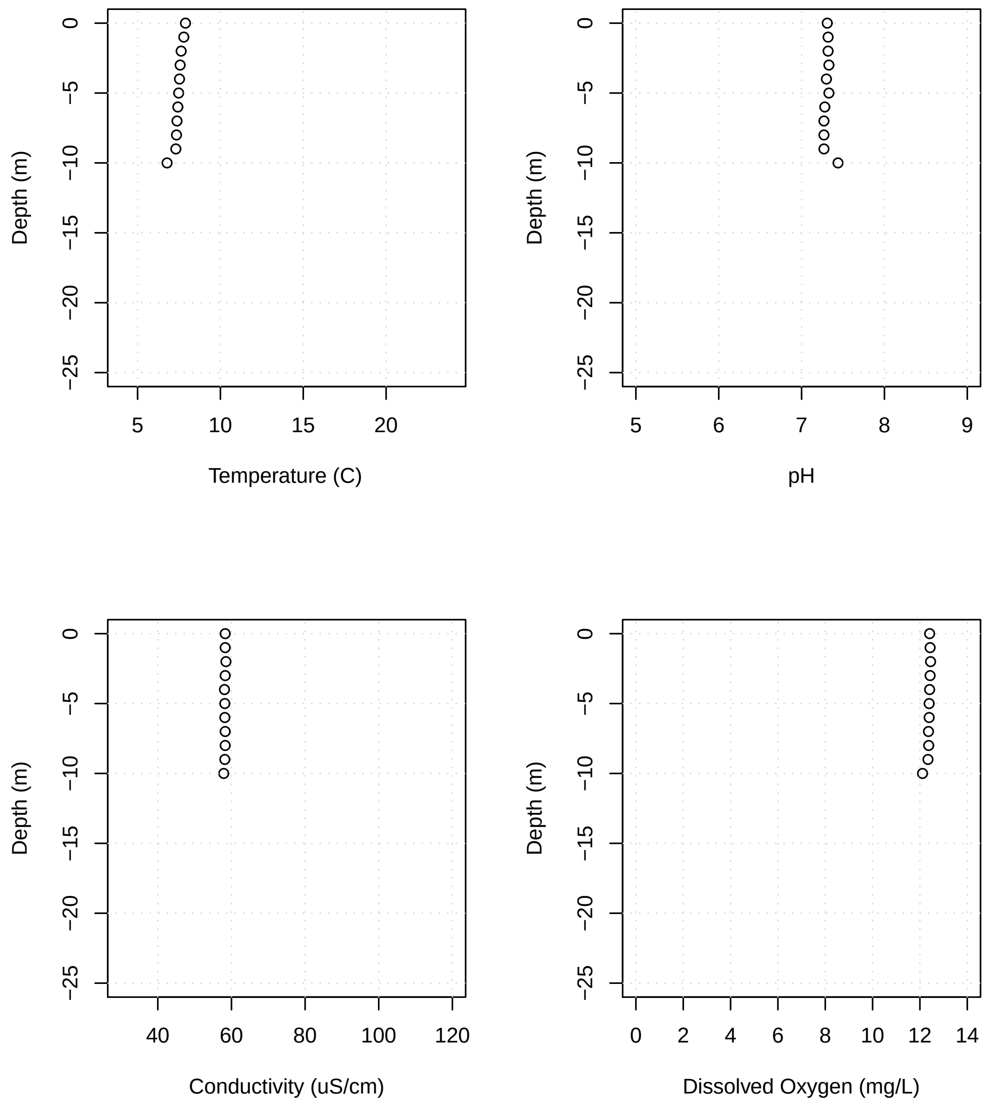


Figure B23: Lake Whatcom Hydrolab profile for the Intake, April 14, 2009.

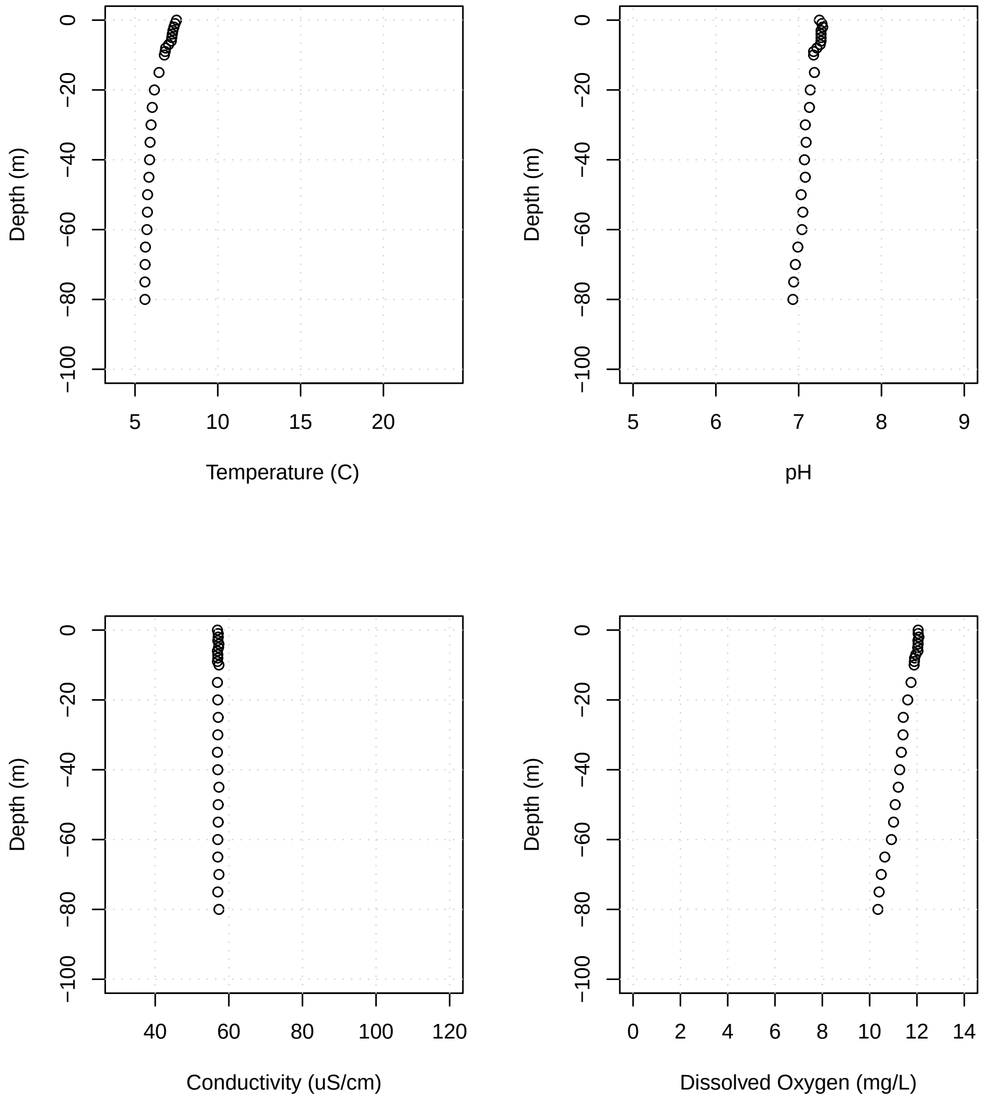


Figure B24: Lake Whatcom Hydrolab profile for Site 3, April 9, 2009.

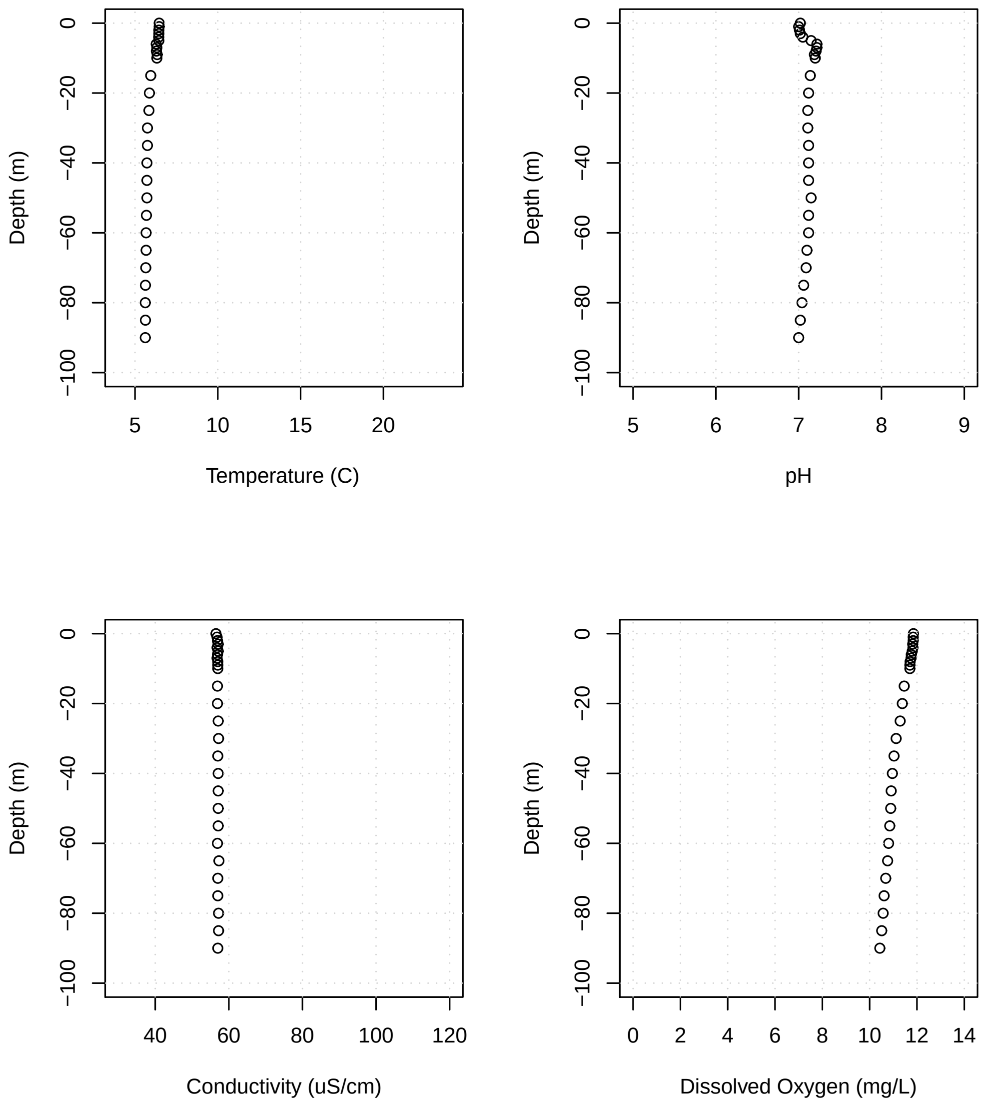


Figure B25: Lake Whatcom Hydrolab profile for Site 4, April 9, 2009.

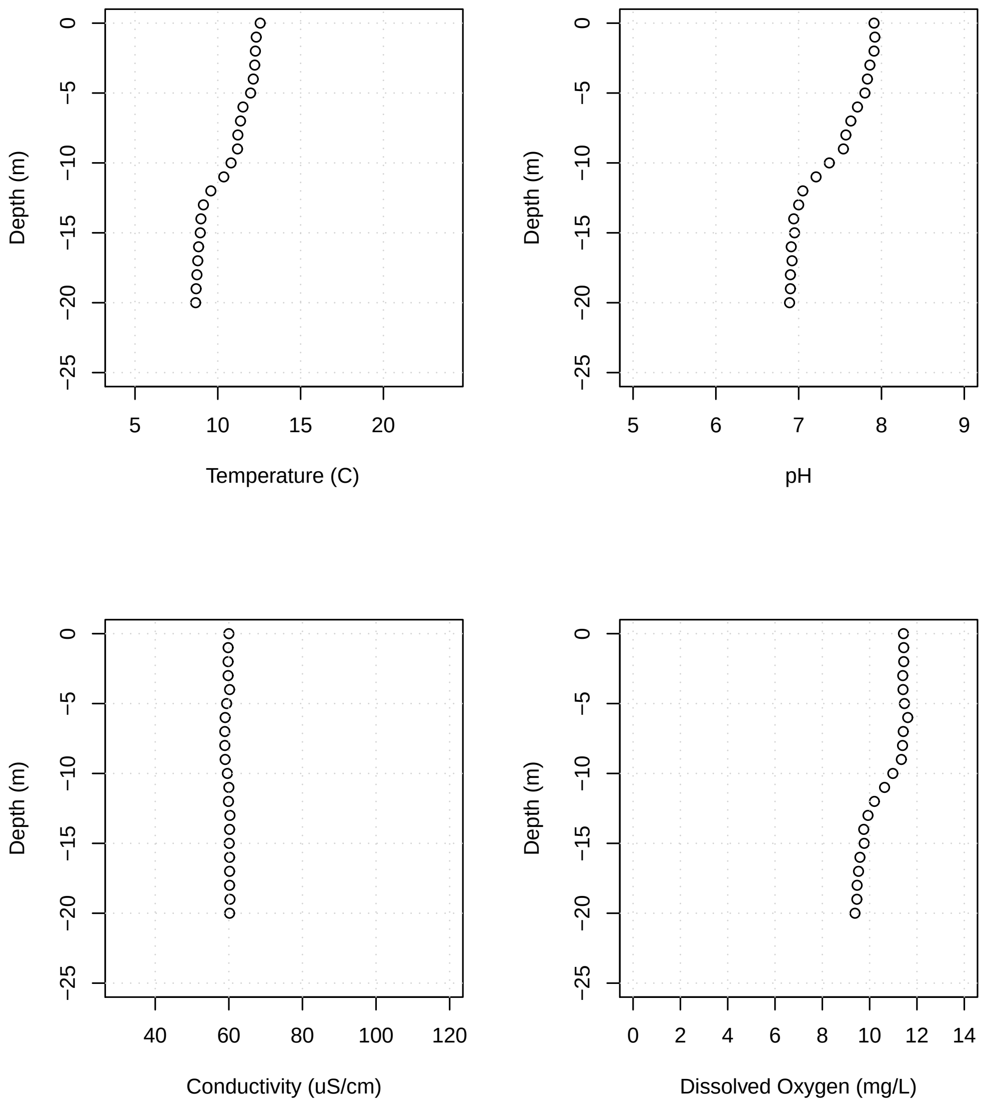


Figure B26: Lake Whatcom Hydrolab profile for Site 1, May 14, 2009.

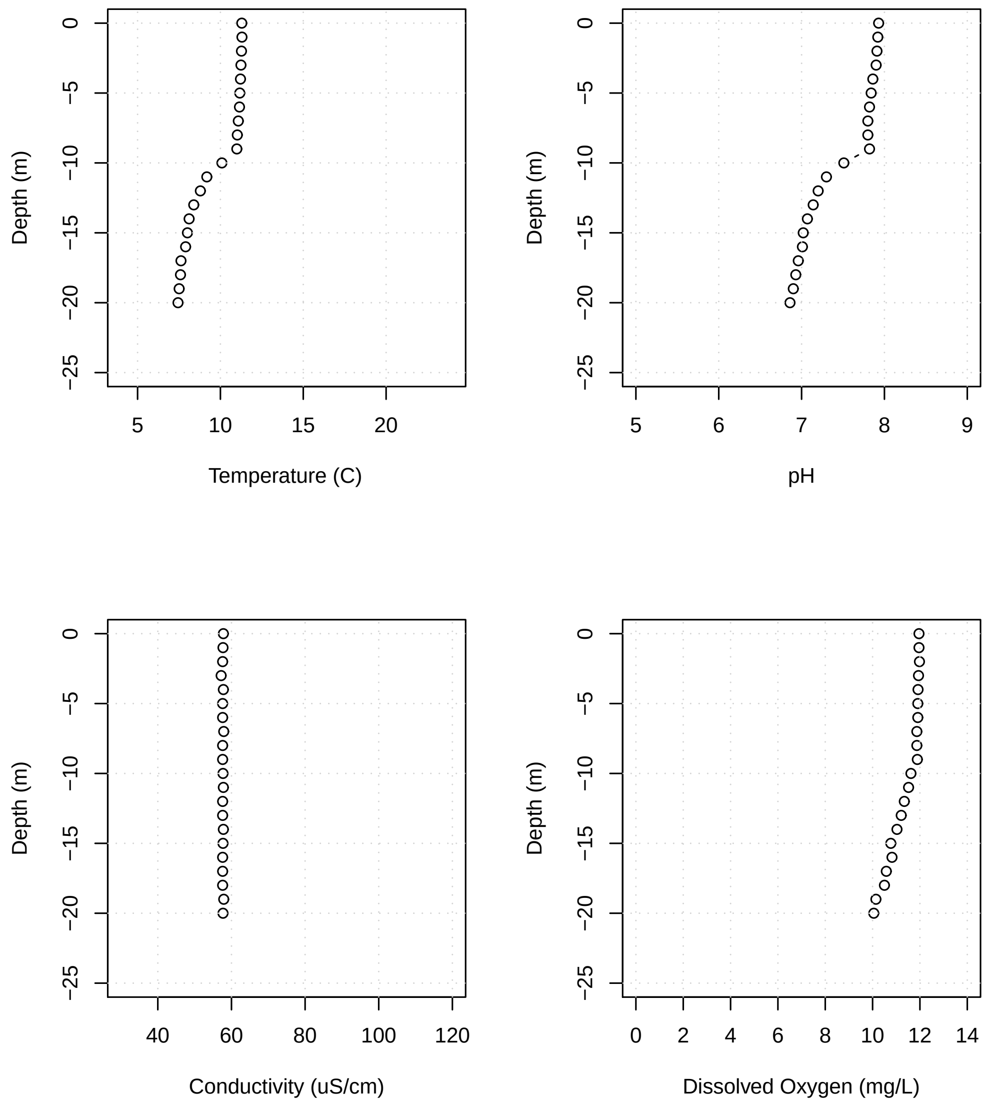


Figure B27: Lake Whatcom Hydrolab profile for Site 2, May 14, 2009.

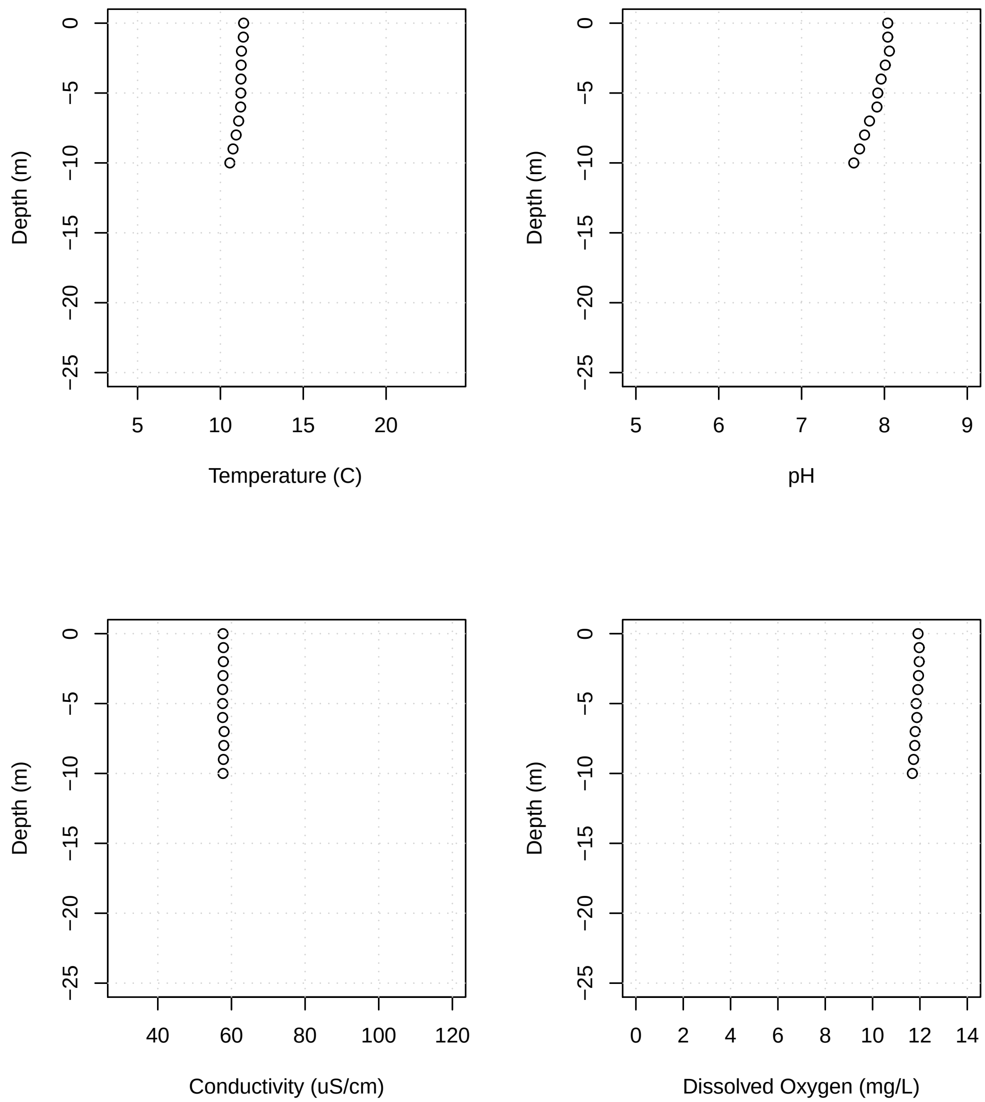


Figure B28: Lake Whatcom Hydrolab profile for the Intake, May 14, 2009.

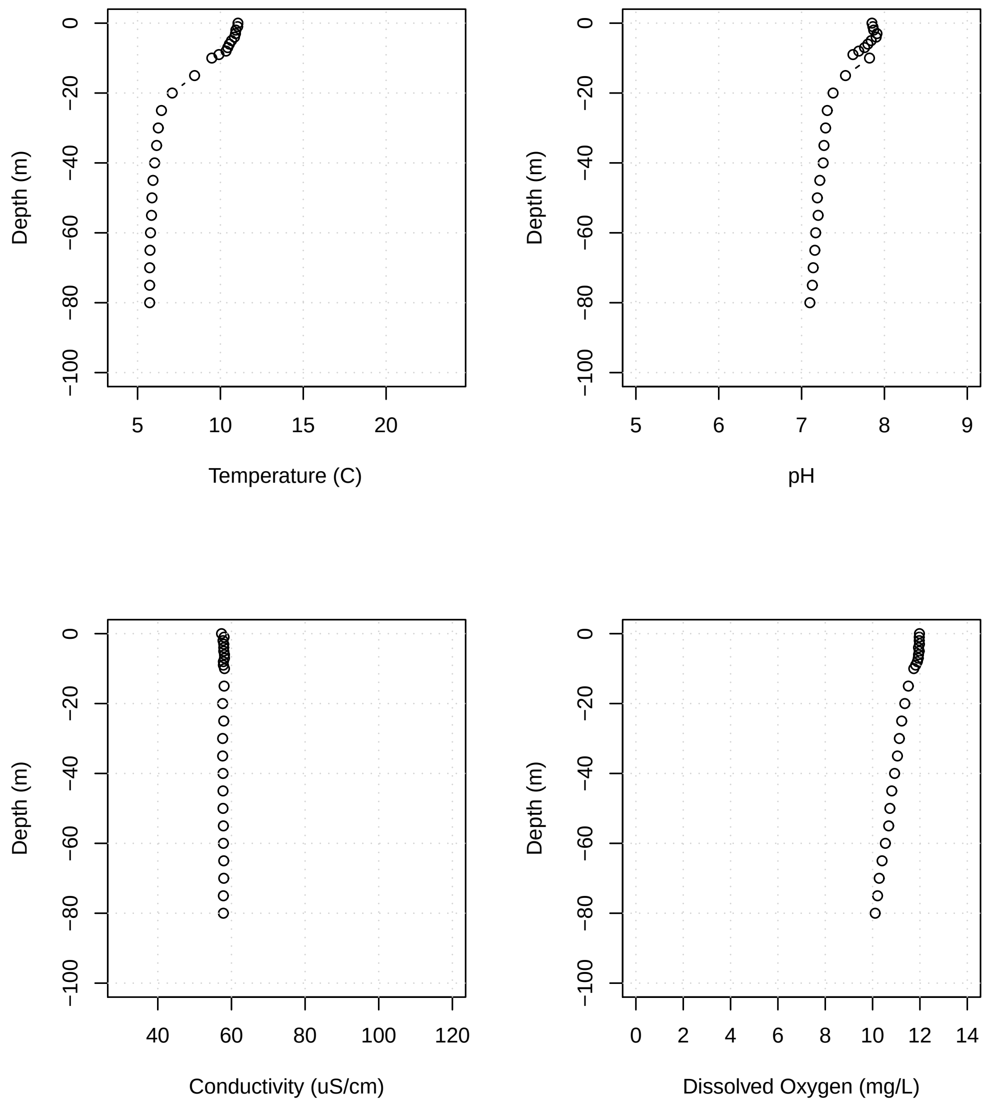


Figure B29: Lake Whatcom Hydrolab profile for Site 3, May 12, 2009.

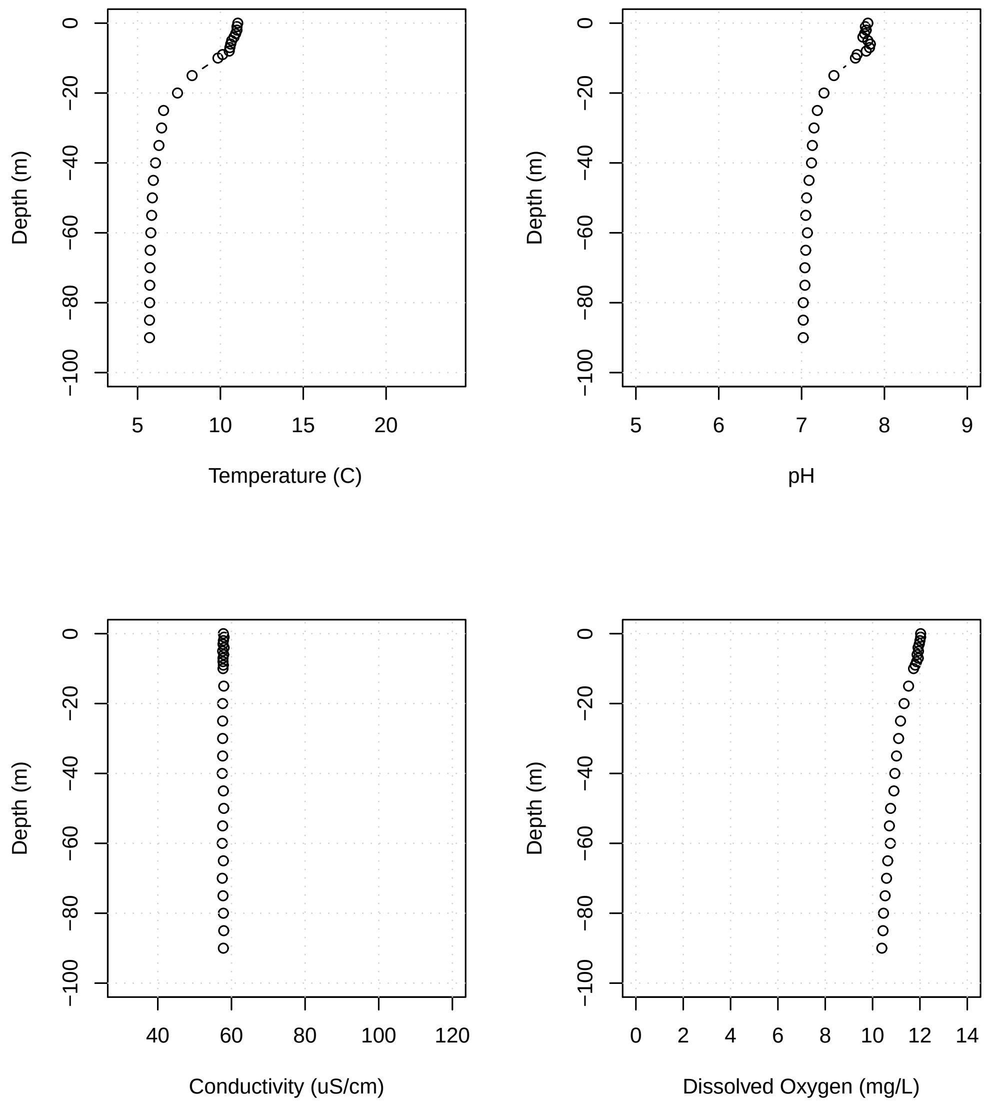


Figure B30: Lake Whatcom Hydrolab profile for Site 4, May 12, 2009.

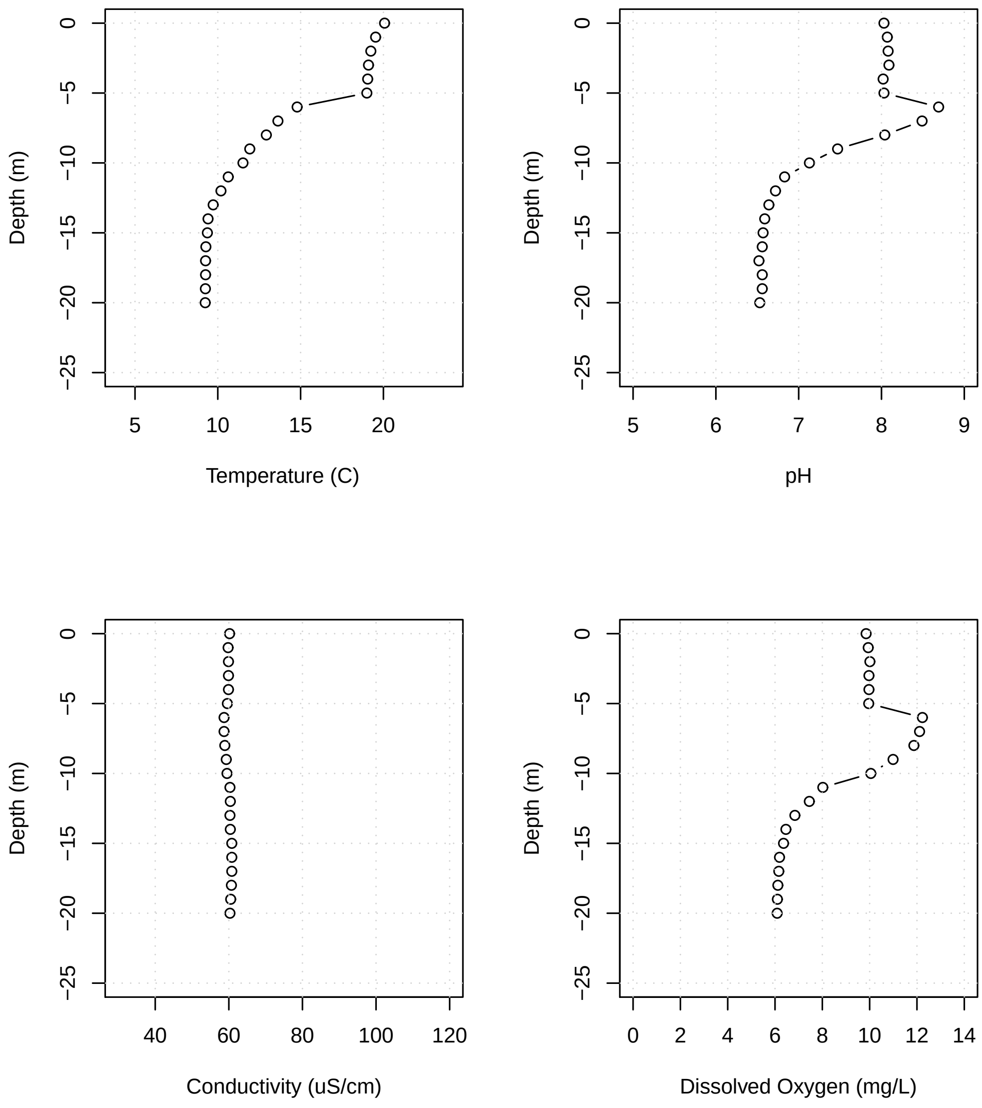


Figure B31: Lake Whatcom Hydrolab profile for Site 1, June 11, 2009.

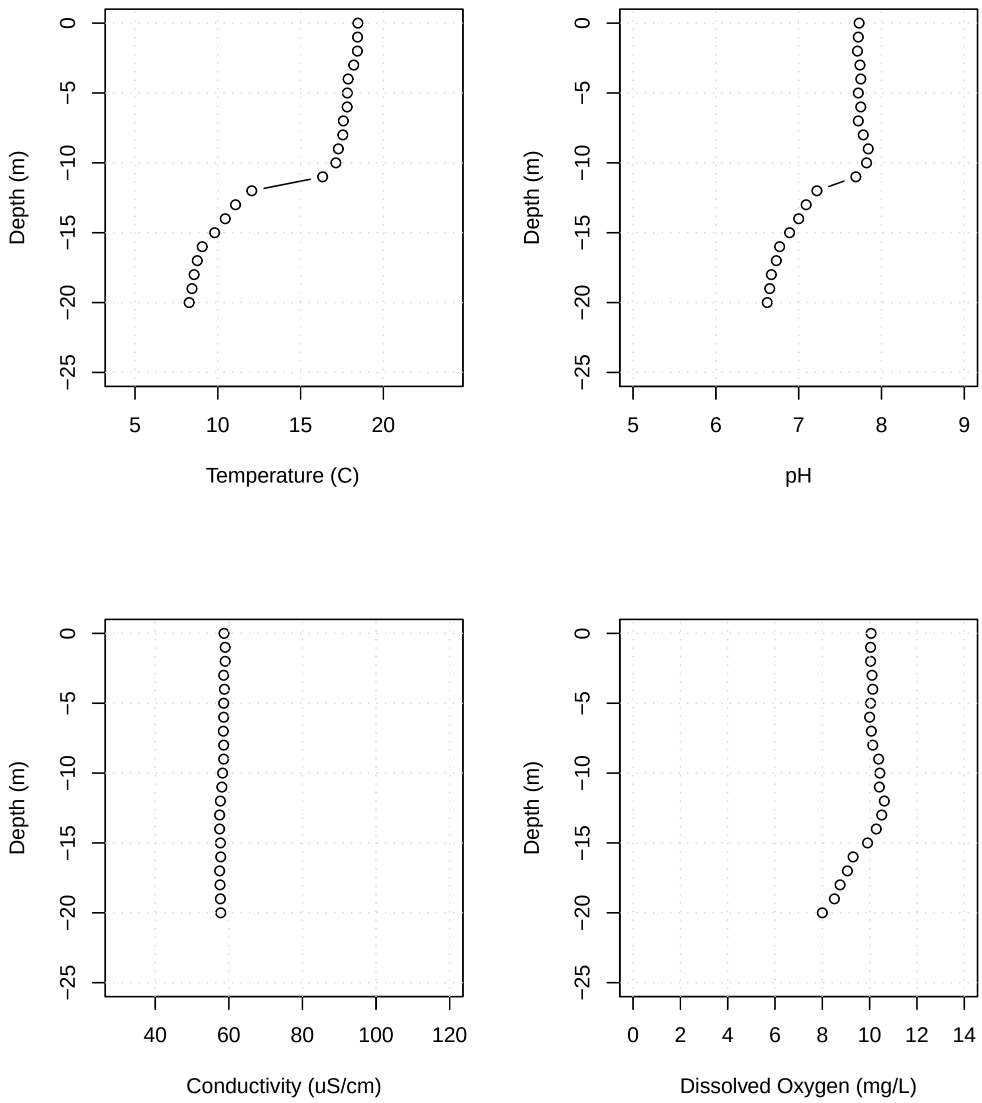


Figure B32: Lake Whatcom Hydrolab profile for Site 2, June 11, 2009.

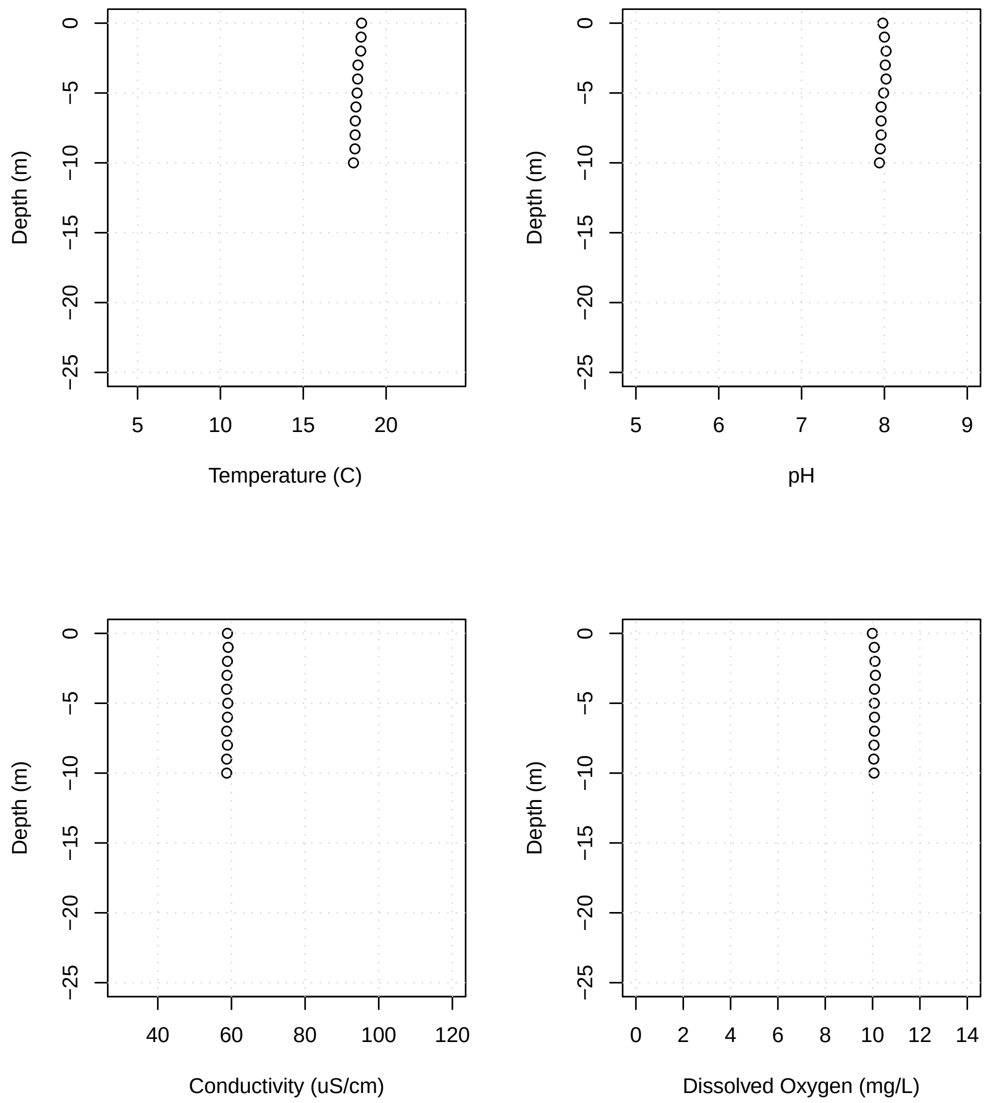


Figure B33: Lake Whatcom Hydrolab profile for the Intake, June 11, 2009.

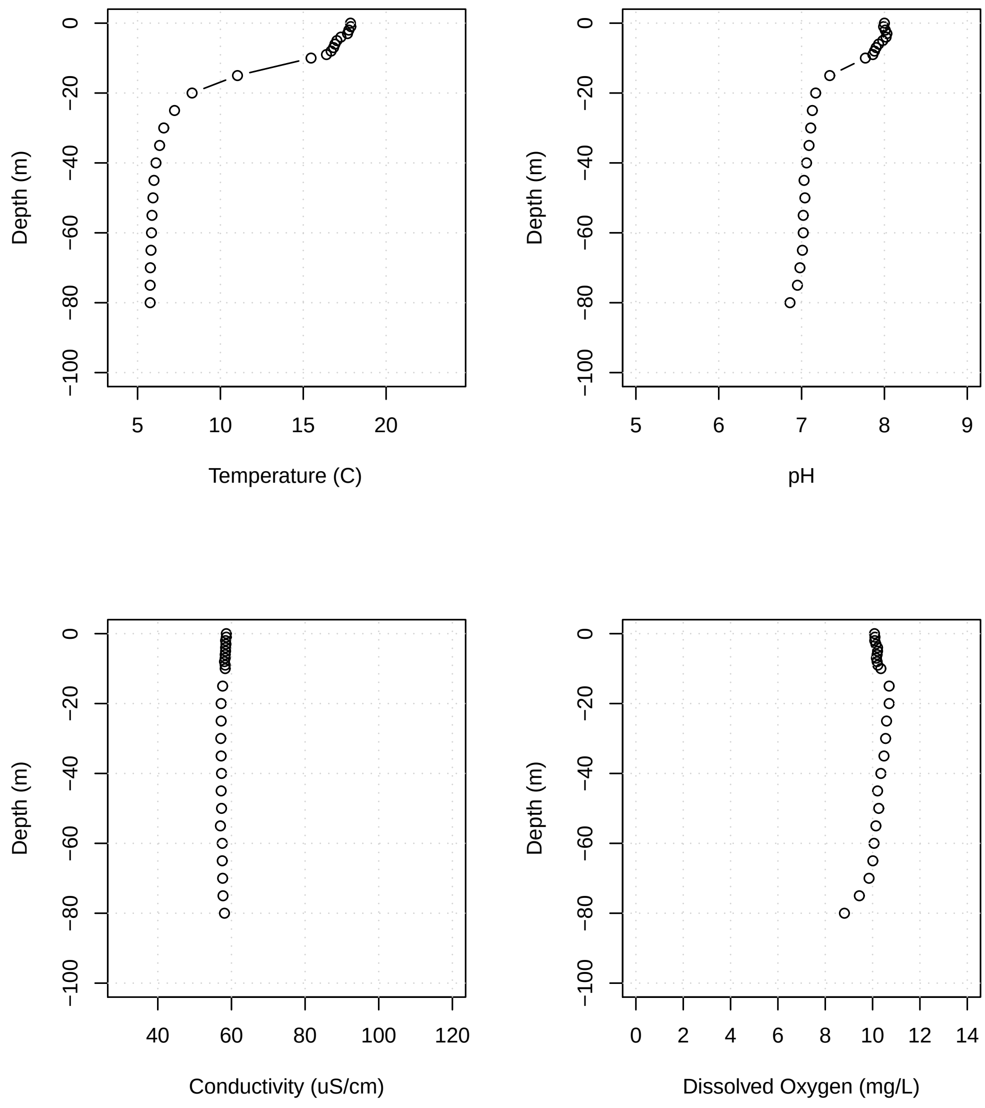


Figure B34: Lake Whatcom Hydrolab profile for Site 3, June 9, 2009.

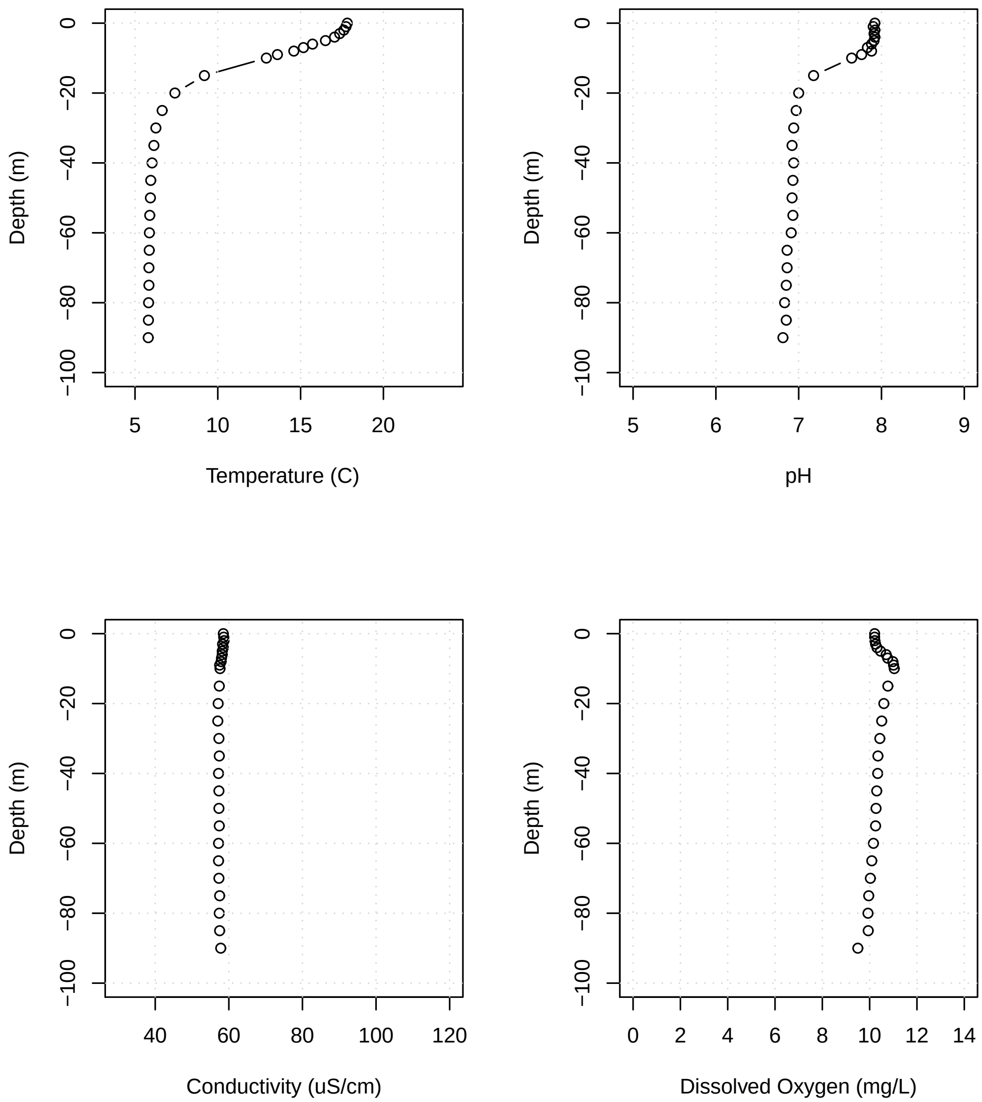


Figure B35: Lake Whatcom Hydrolab profile for Site 4, June 9, 2009.

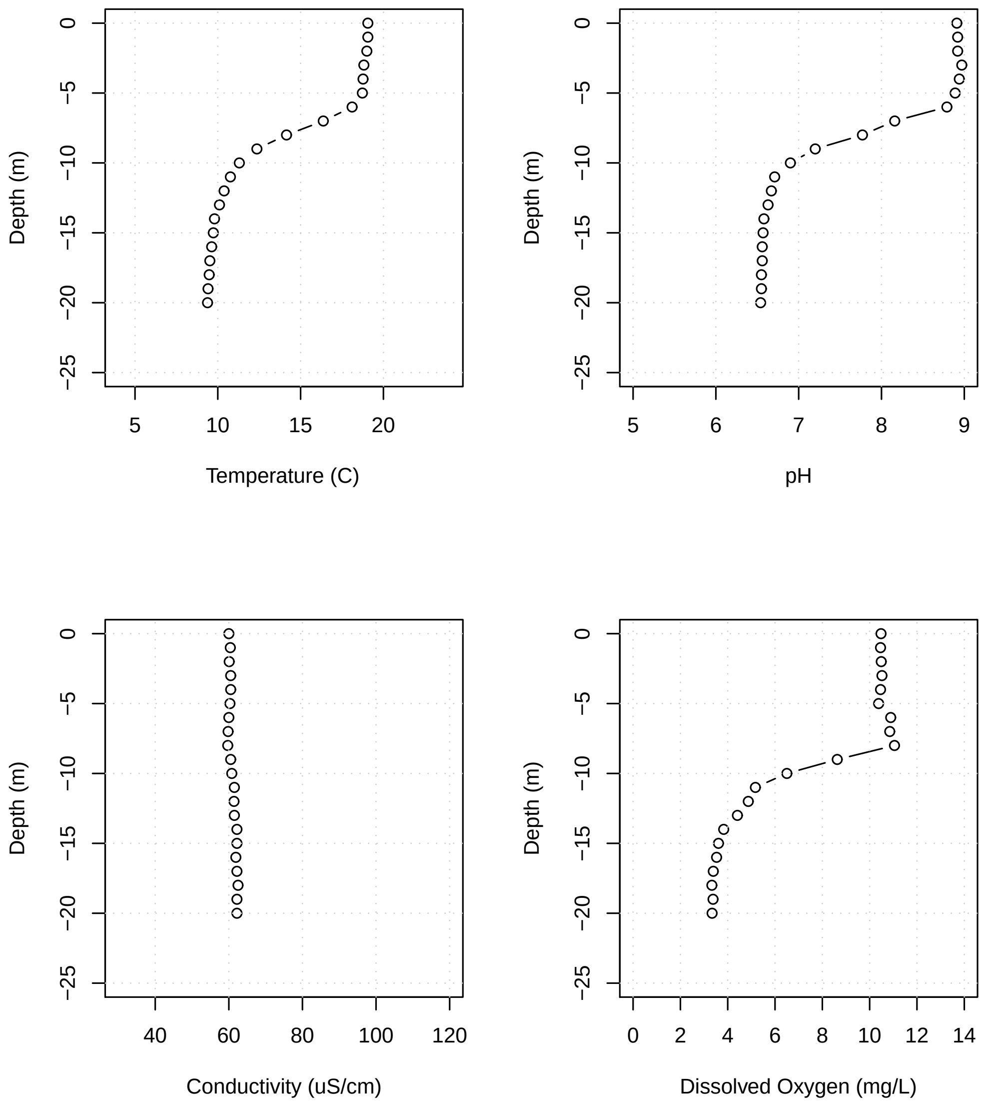


Figure B36: Lake Whatcom Hydrolab profile for Site 1, July 9, 2009.

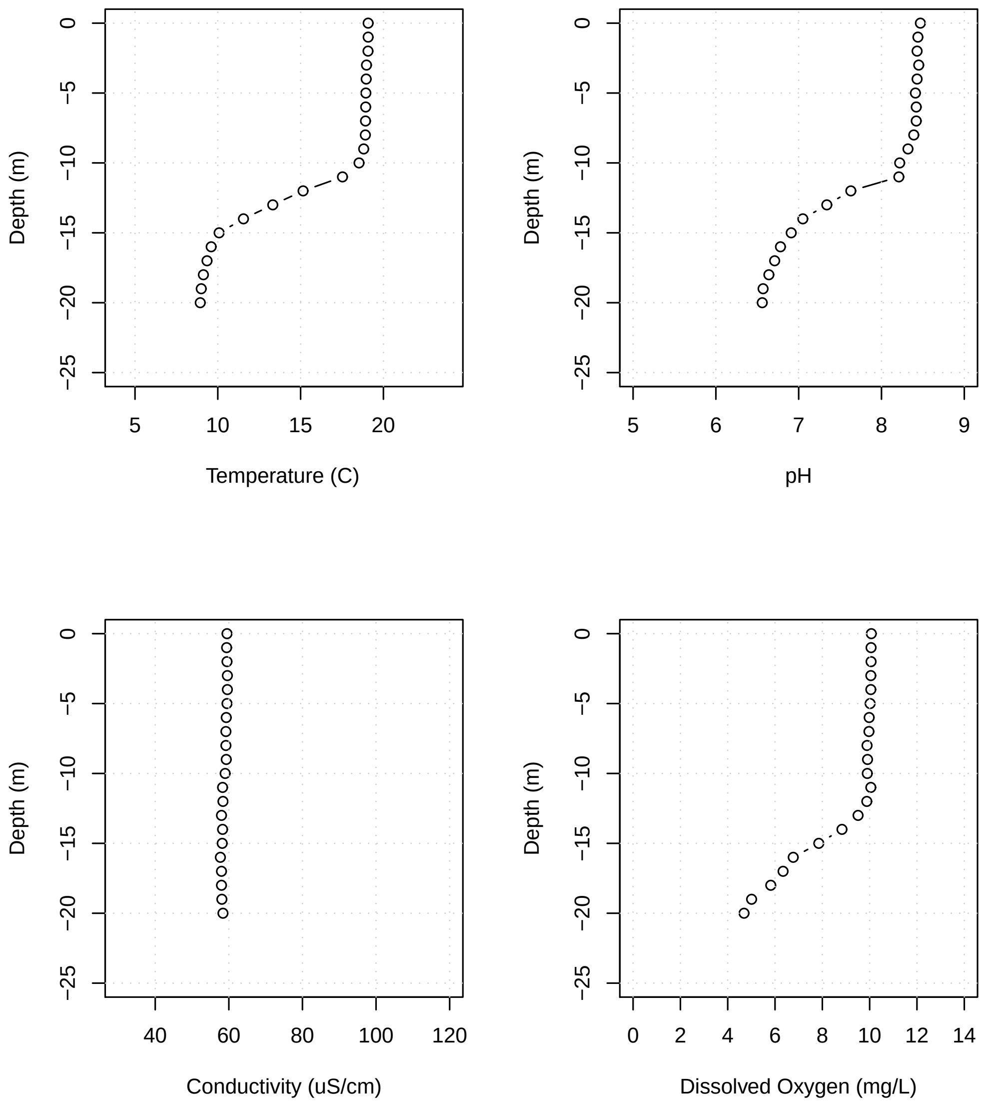


Figure B37: Lake Whatcom Hydrolab profile for Site 2, July 9, 2009.

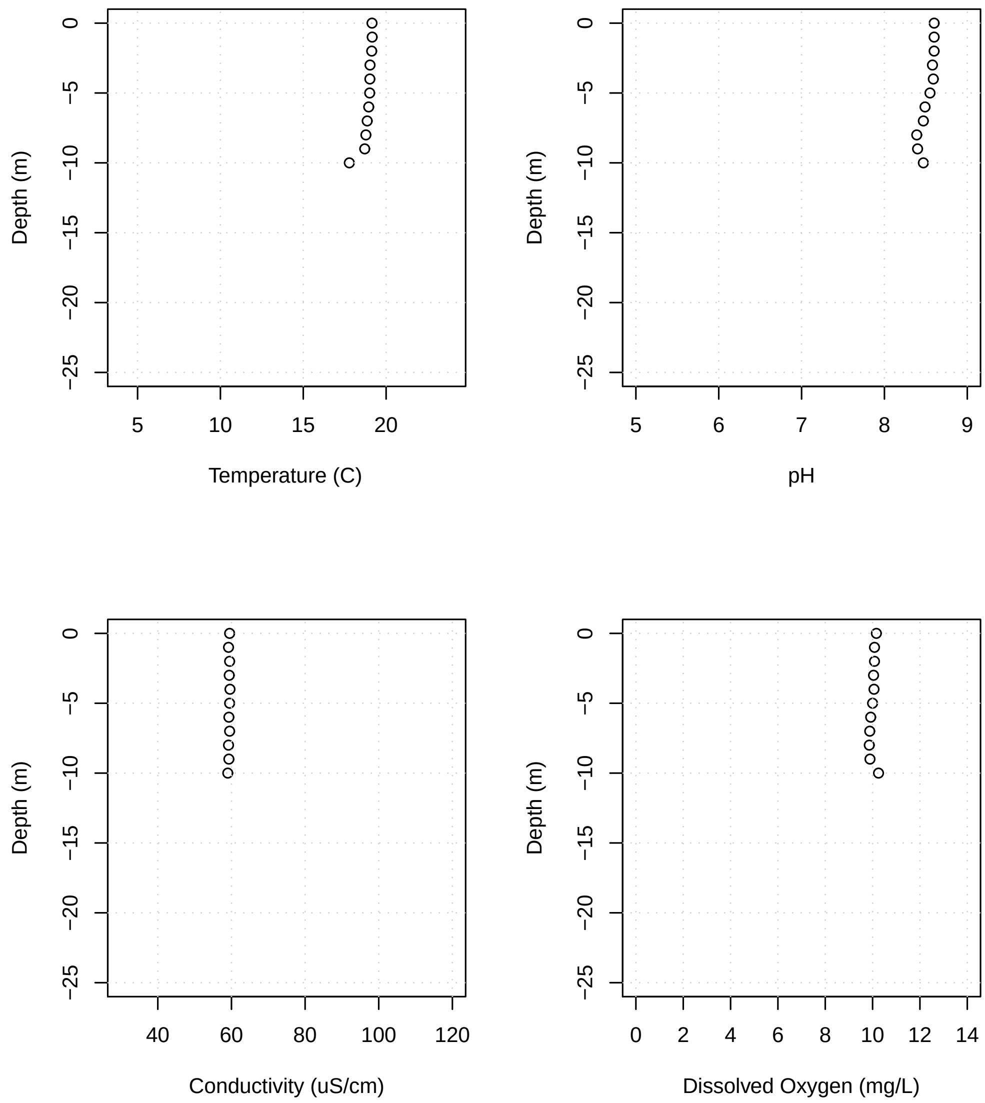


Figure B38: Lake Whatcom Hydrolab profile for the Intake, July 9, 2009.

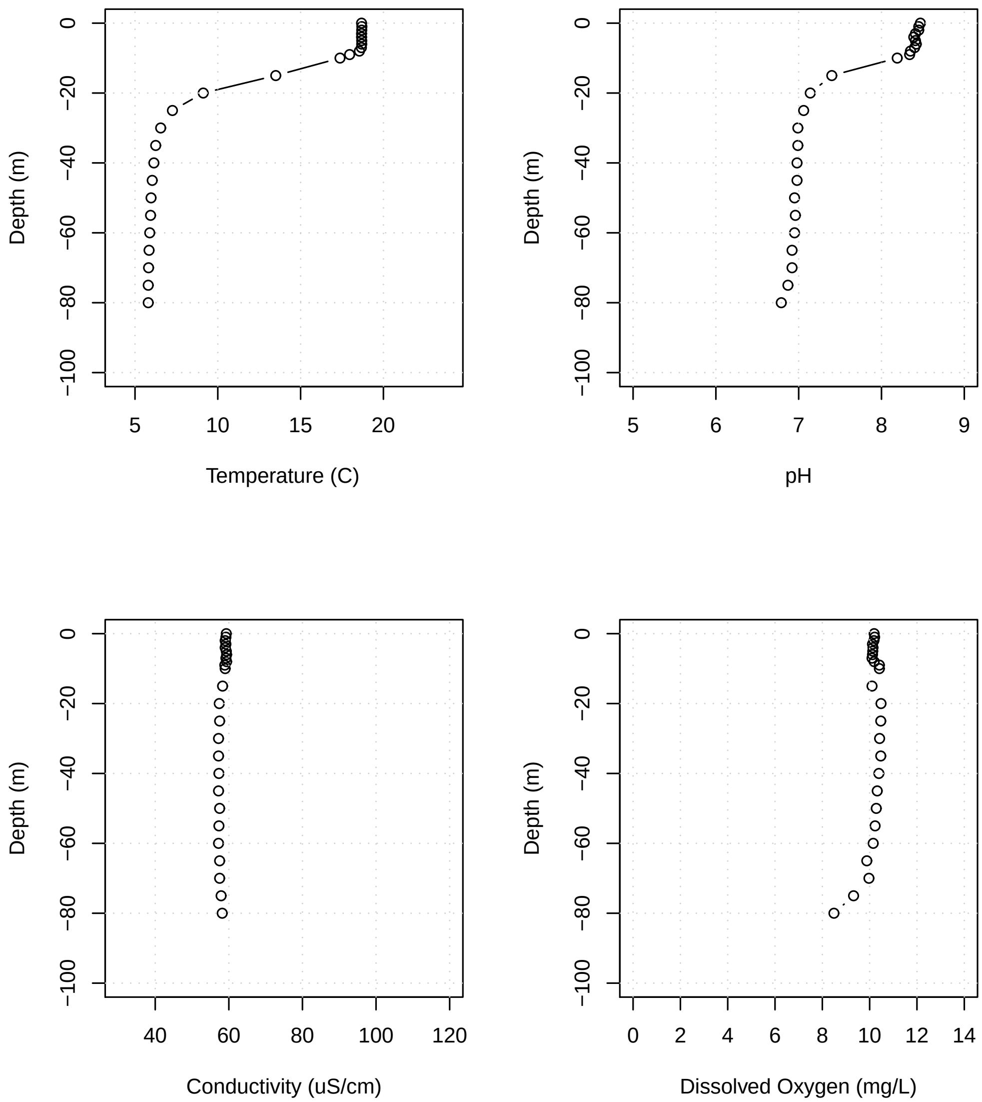


Figure B39: Lake Whatcom Hydrolab profile for Site 3, July 7, 2009.

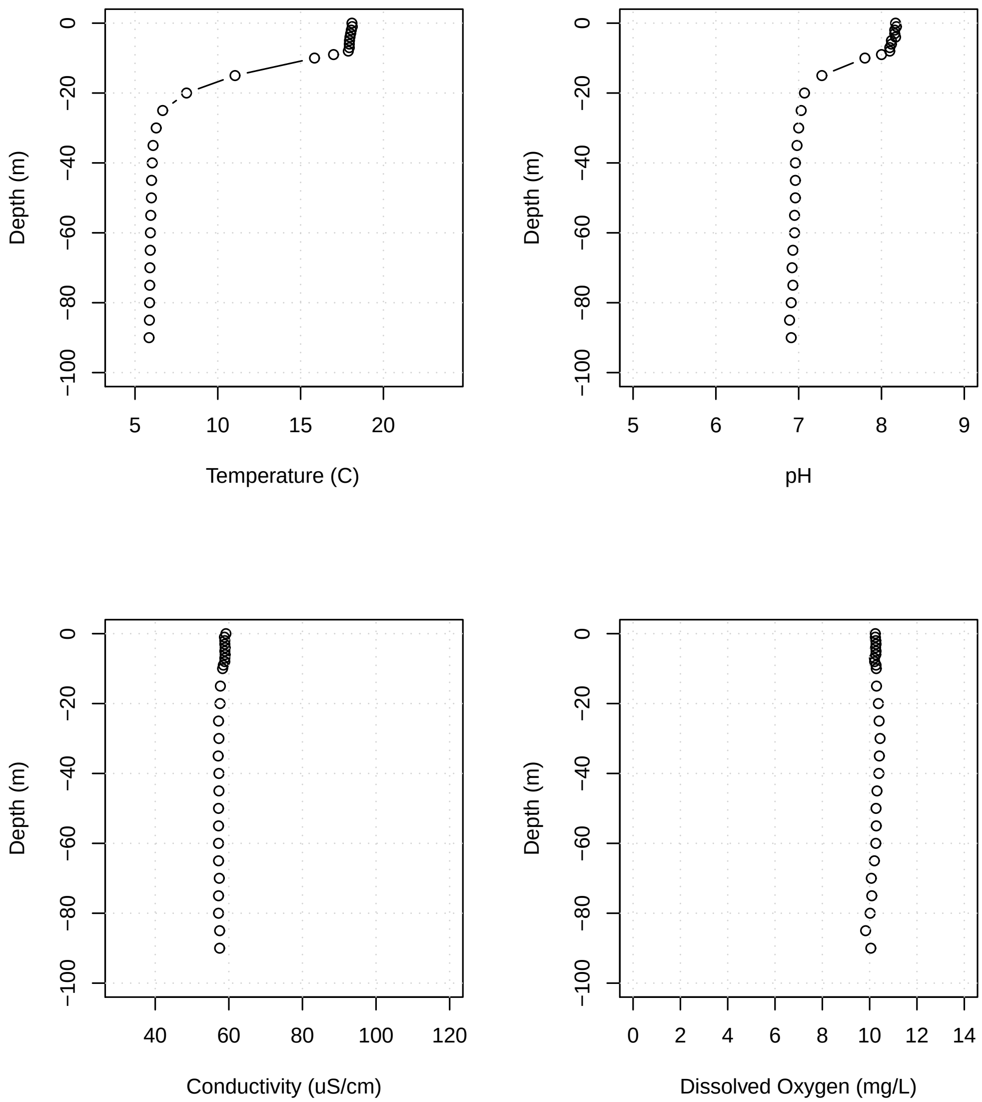


Figure B40: Lake Whatcom Hydrolab profile for Site 4, July 7, 2009.

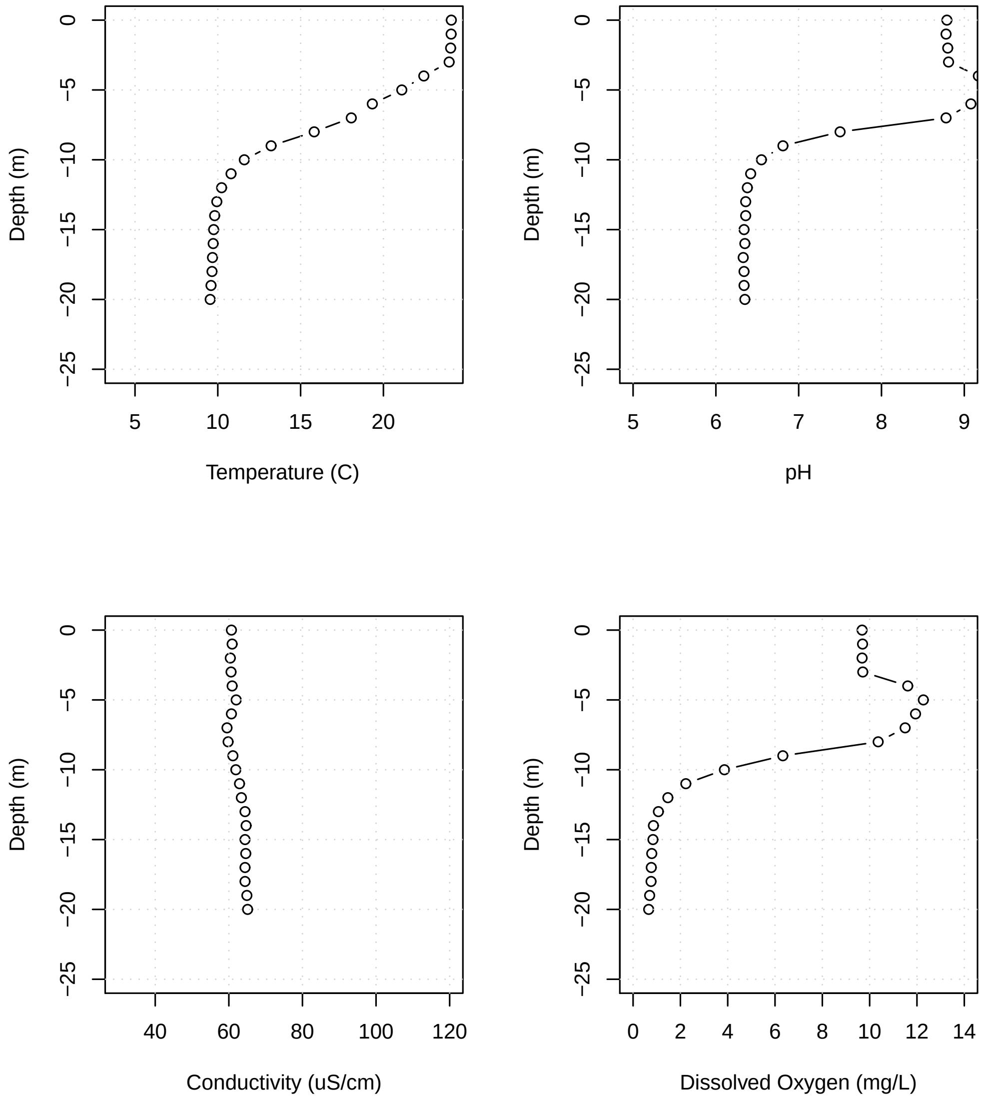


Figure B41: Lake Whatcom Hydrolab profile for Site 1, August 4, 2009.

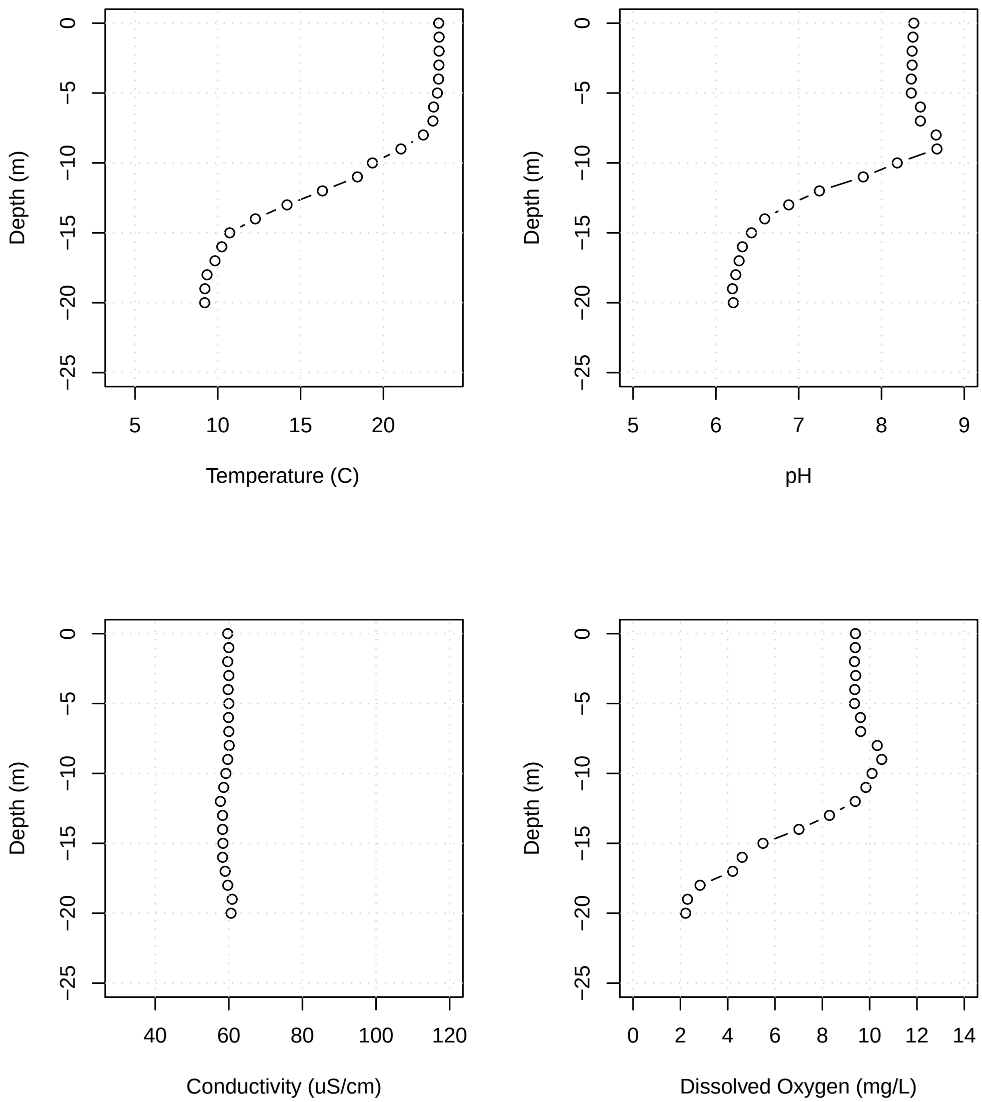


Figure B42: Lake Whatcom Hydrolab profile for Site 2, August 4, 2009.

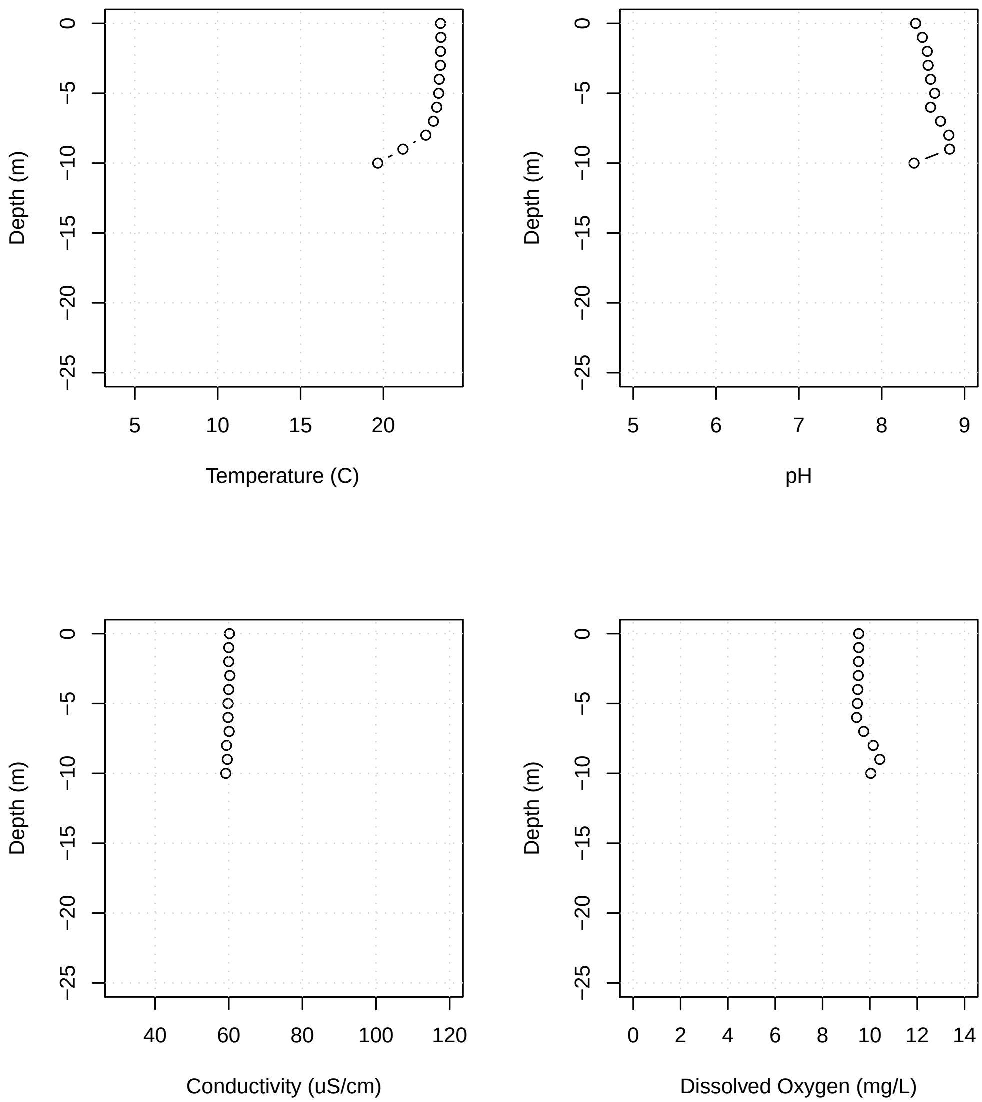


Figure B43: Lake Whatcom Hydrolab profile for the Intake, August 4, 2009.

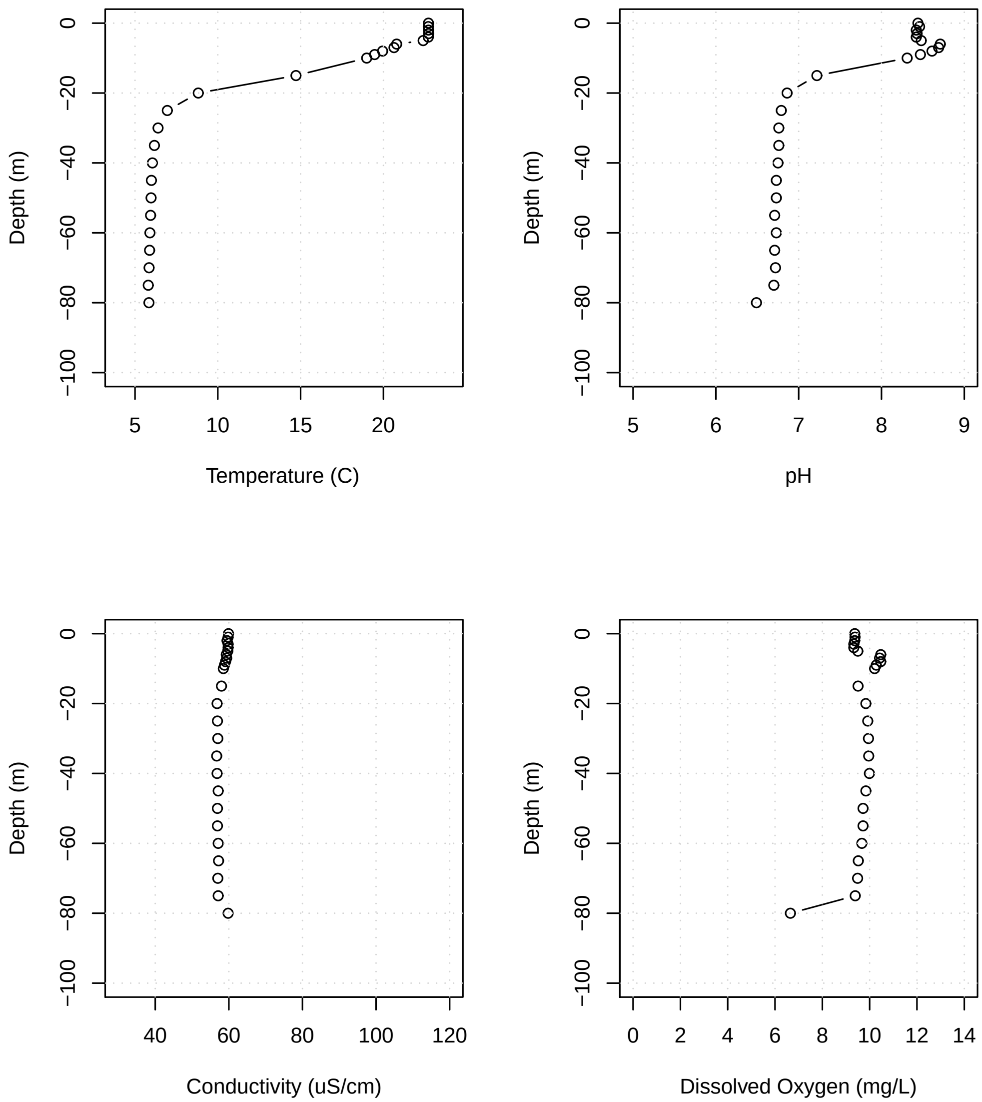


Figure B44: Lake Whatcom Hydrolab profile for Site 3, August 5, 2009.

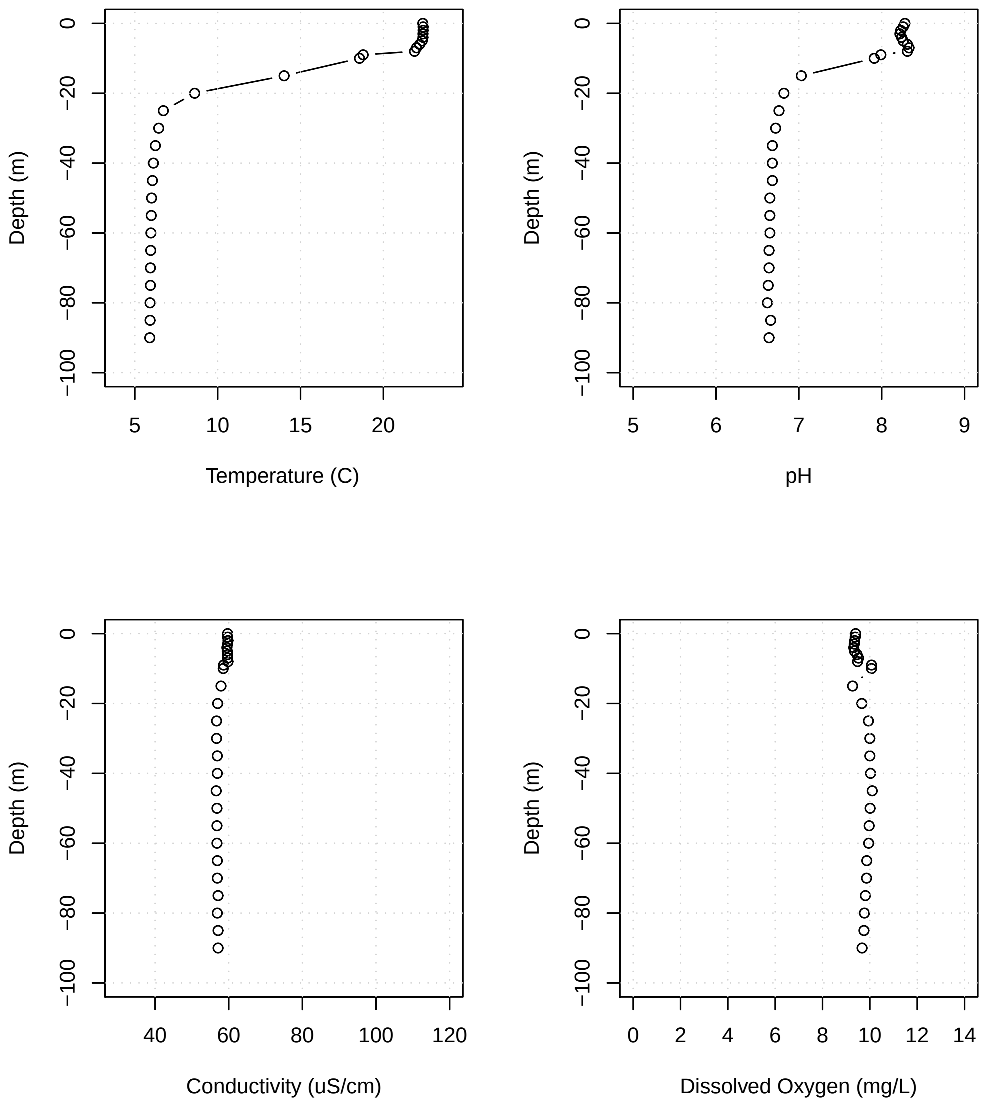


Figure B45: Lake Whatcom Hydrolab profile for Site 4, August 5, 2009.

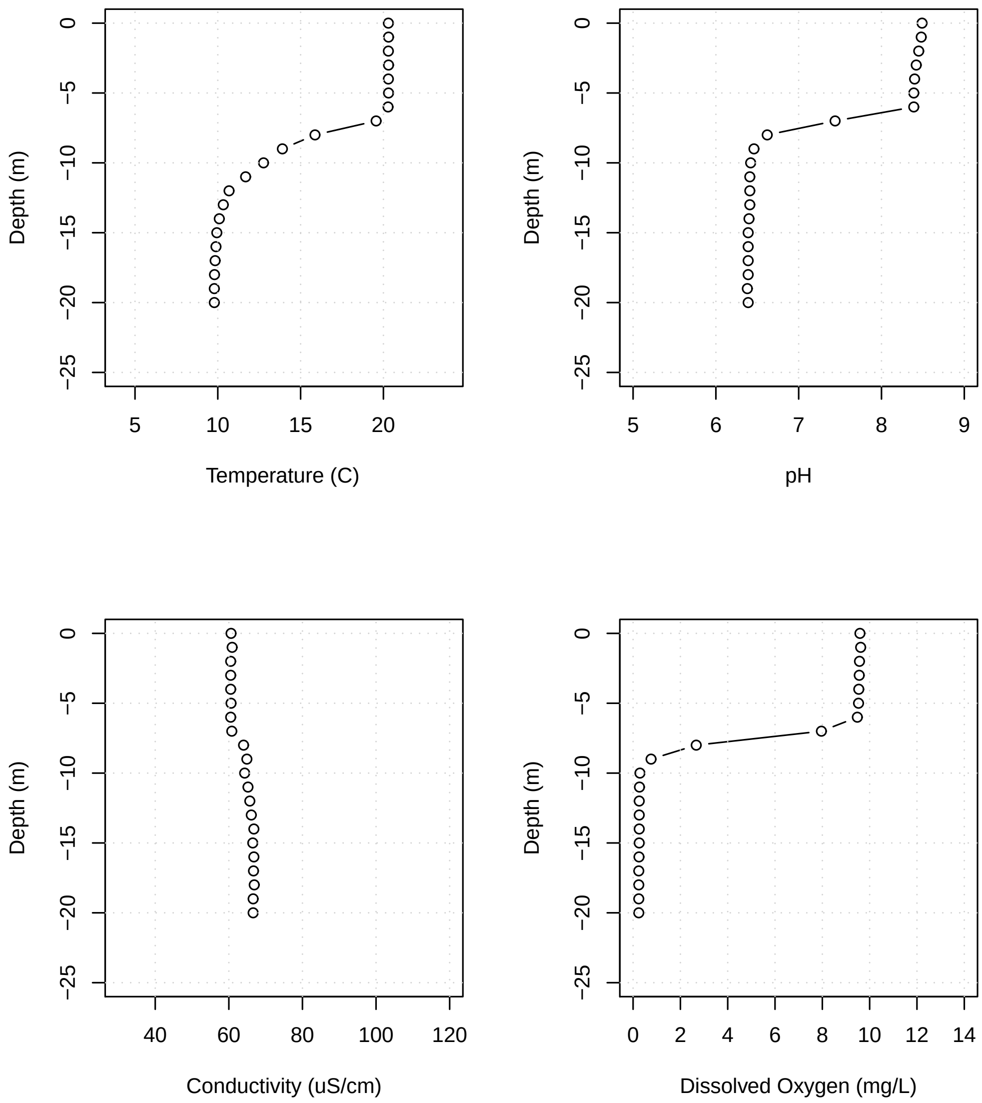


Figure B46: Lake Whatcom Hydrolab profile for Site 1, September 3, 2009.

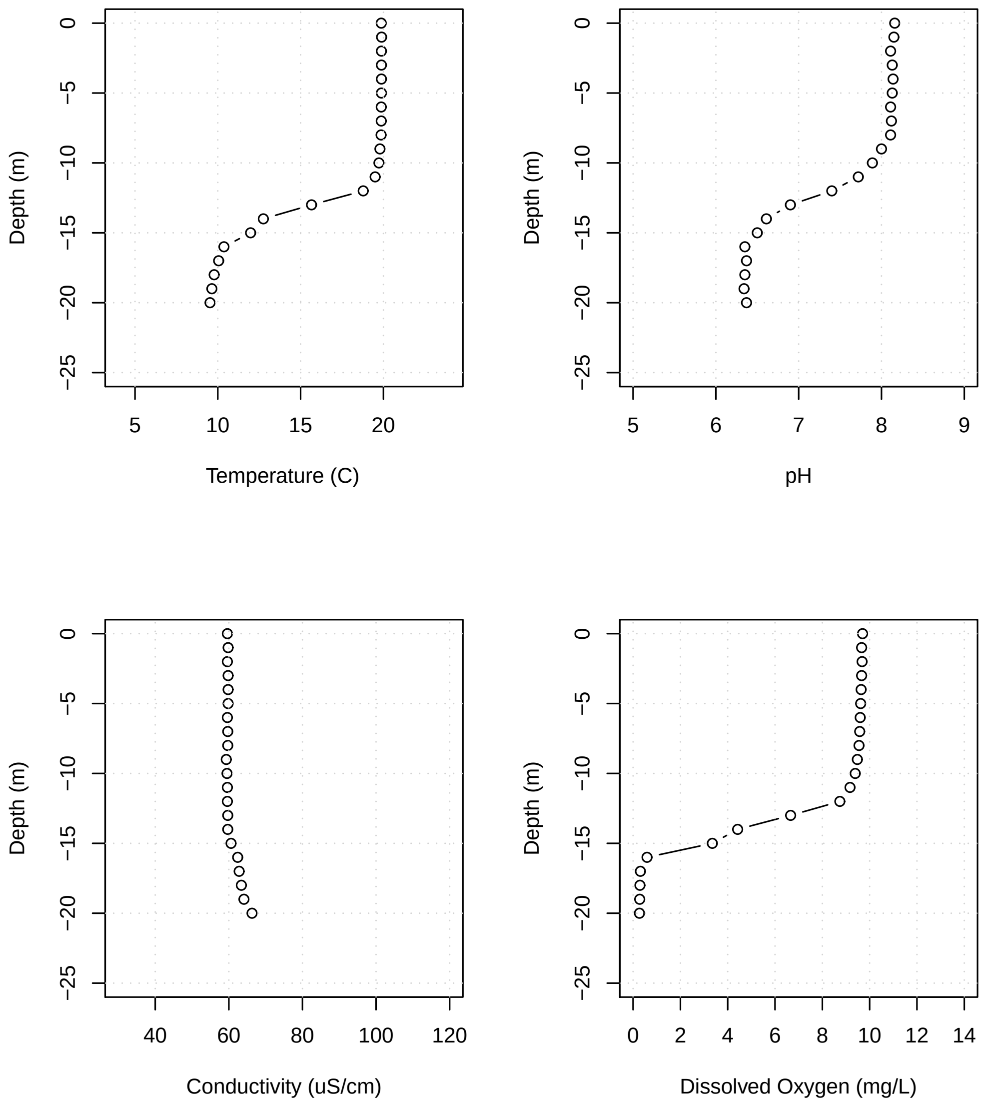


Figure B47: Lake Whatcom Hydrolab profile for Site 2, September 3, 2009.

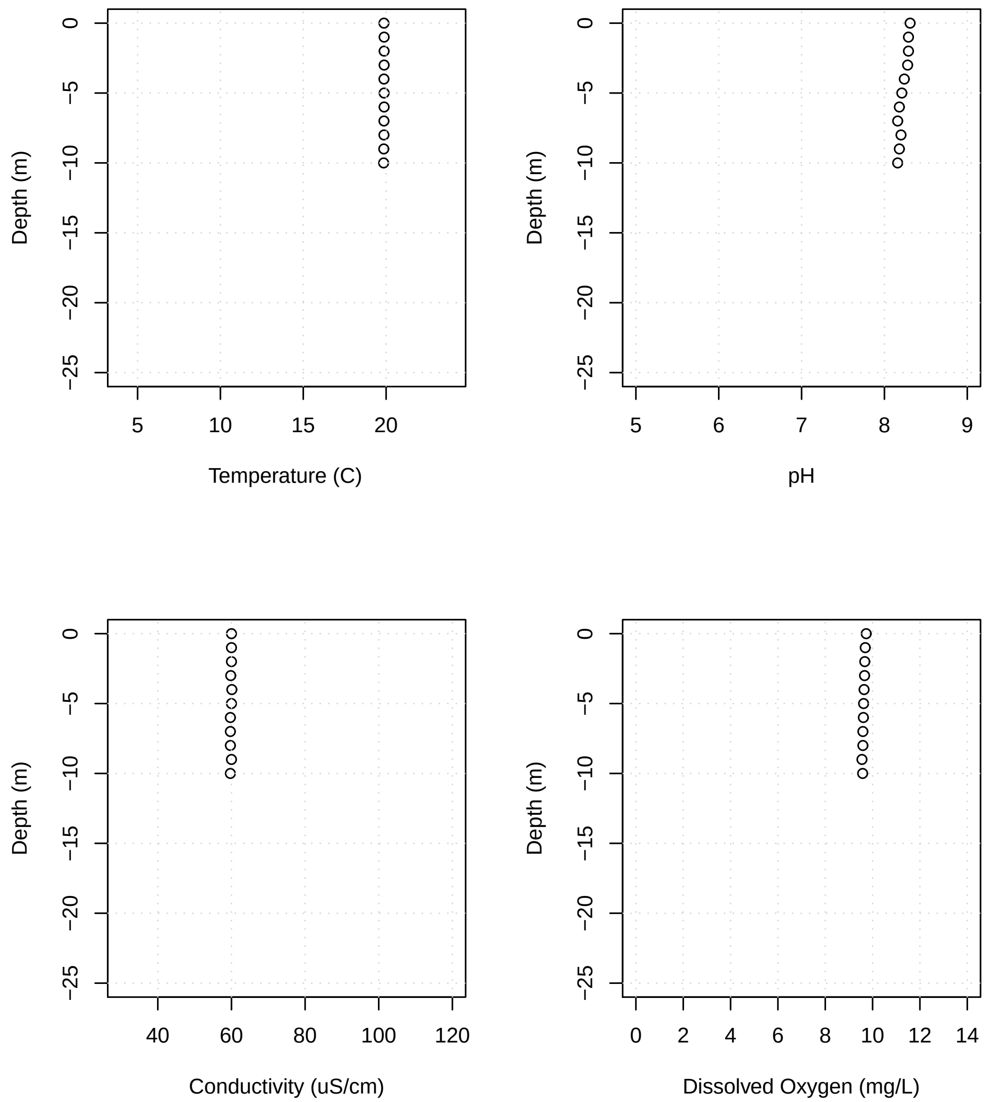


Figure B48: Lake Whatcom Hydrolab profile for the Intake, September 3, 2009.

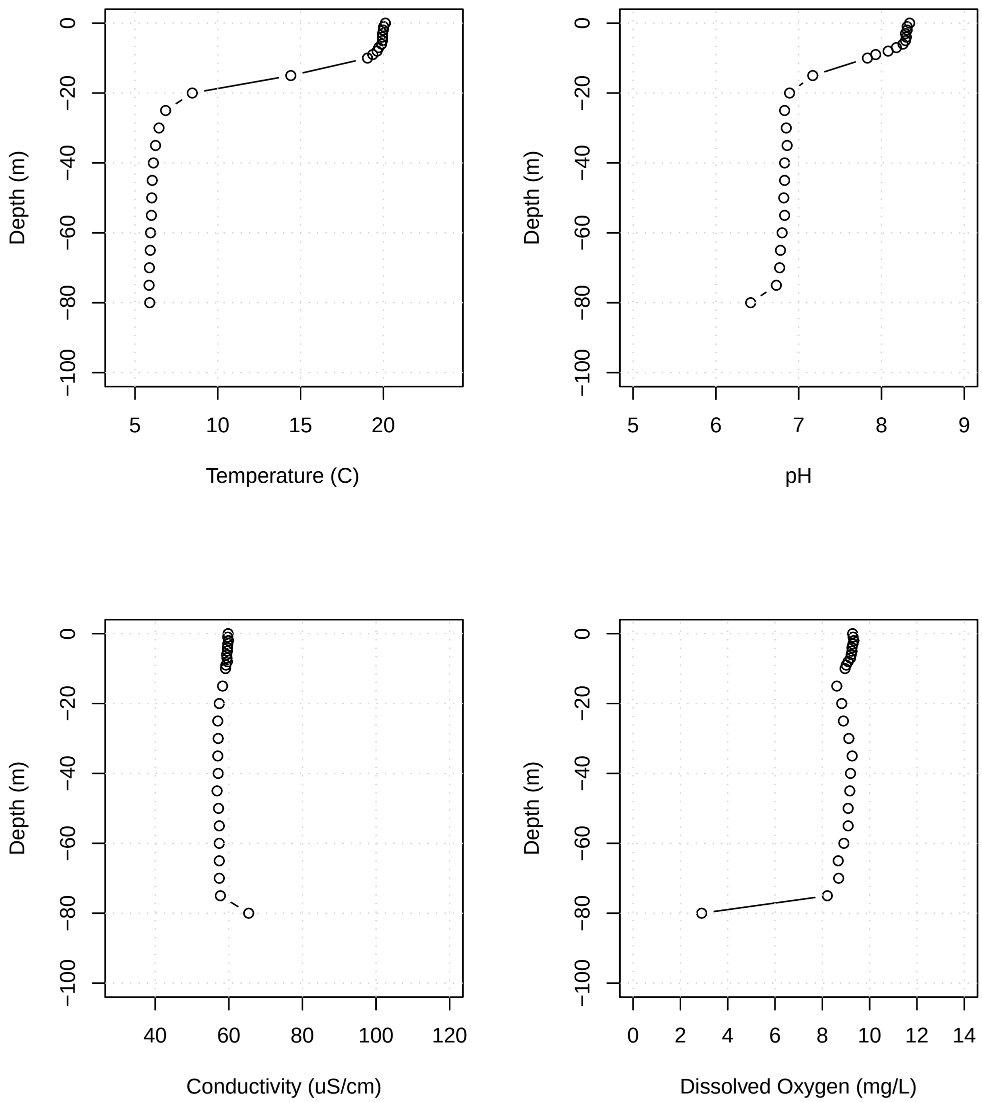


Figure B49: Lake Whatcom Hydrolab profile for Site 3, September 1, 2009.

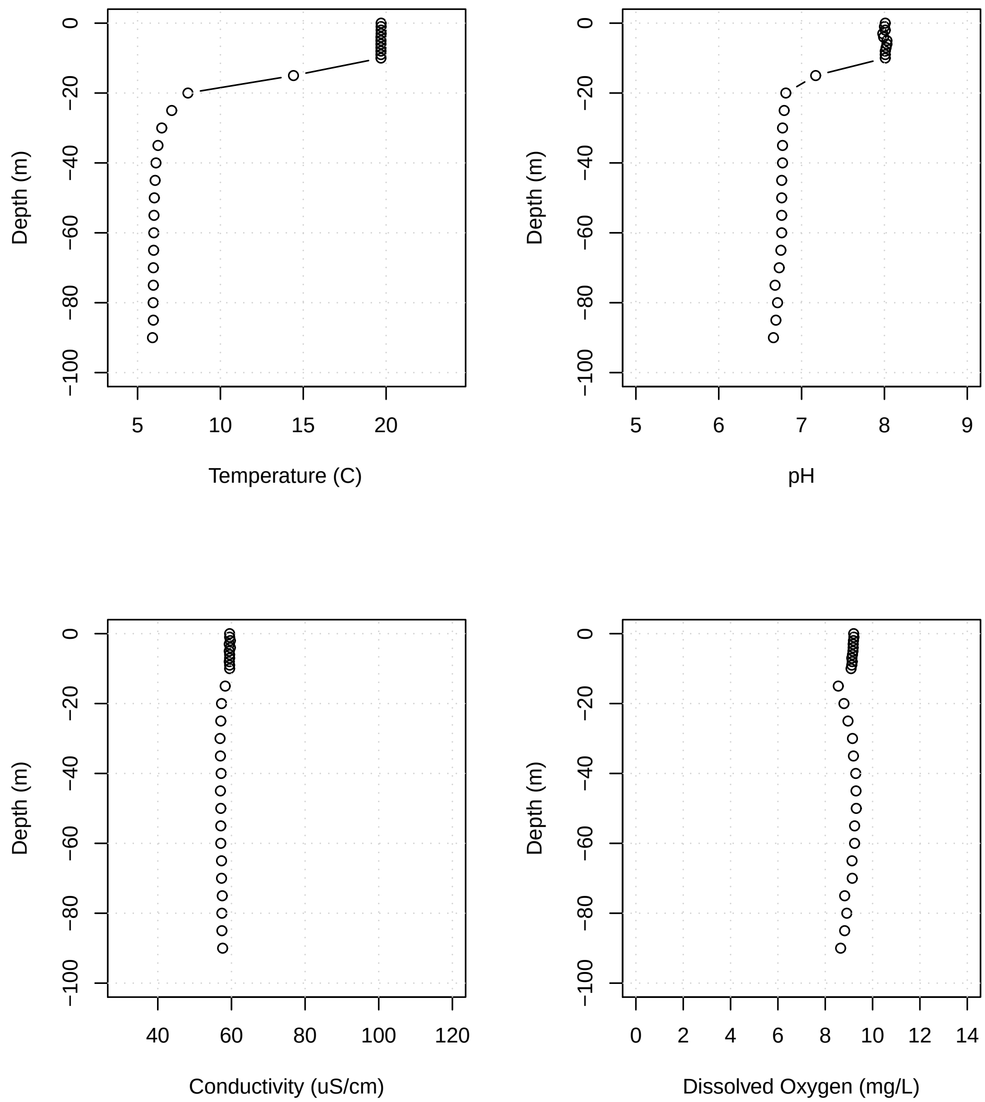


Figure B50: Lake Whatcom Hydrolab profile for Site 4, September 1, 2009.

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

Lake Whatcom temperature data for Site 1, February 1988 through December 2009.

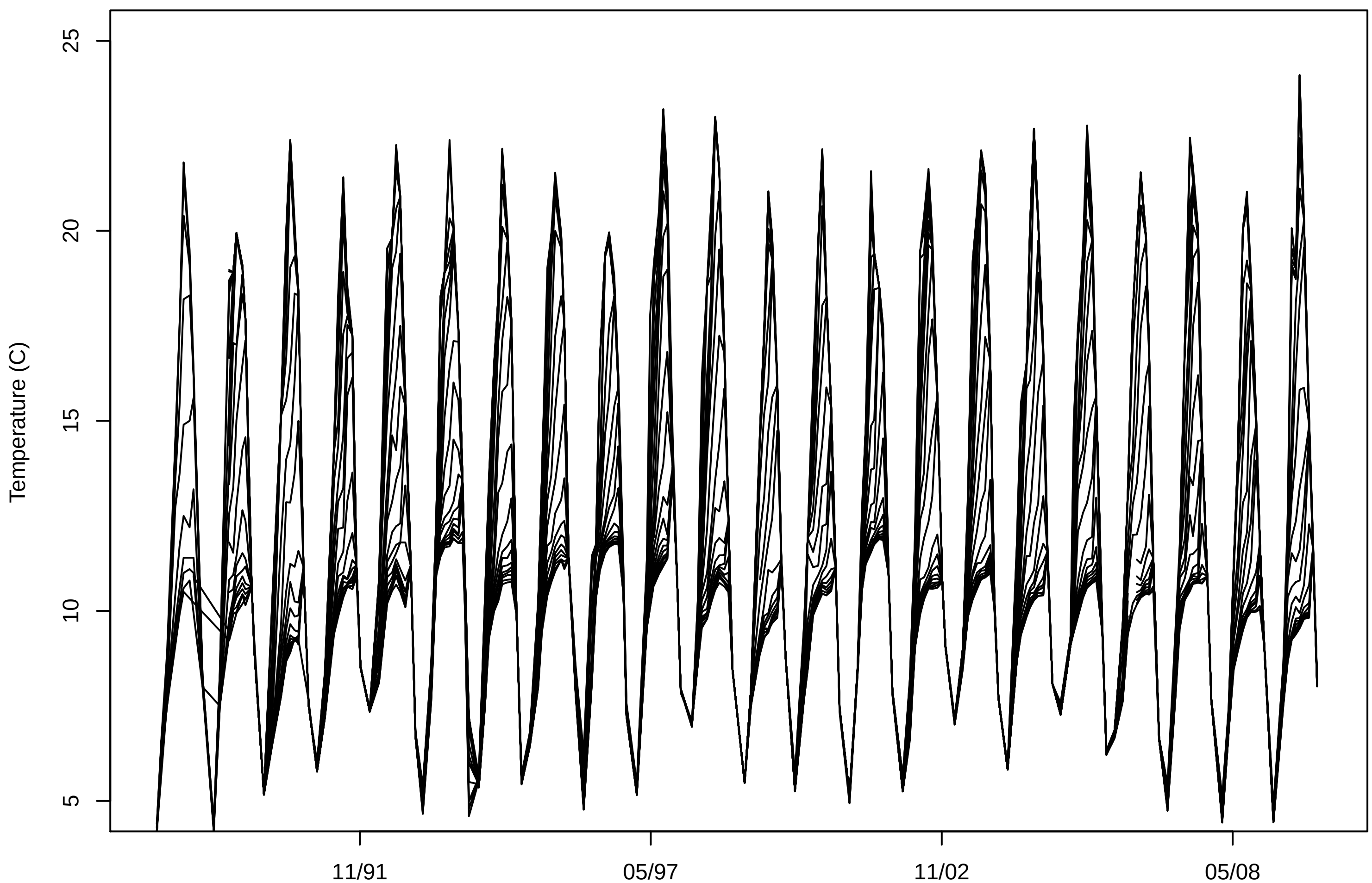


Figure B51: Lake Whatcom historic temperature data for Site 1.

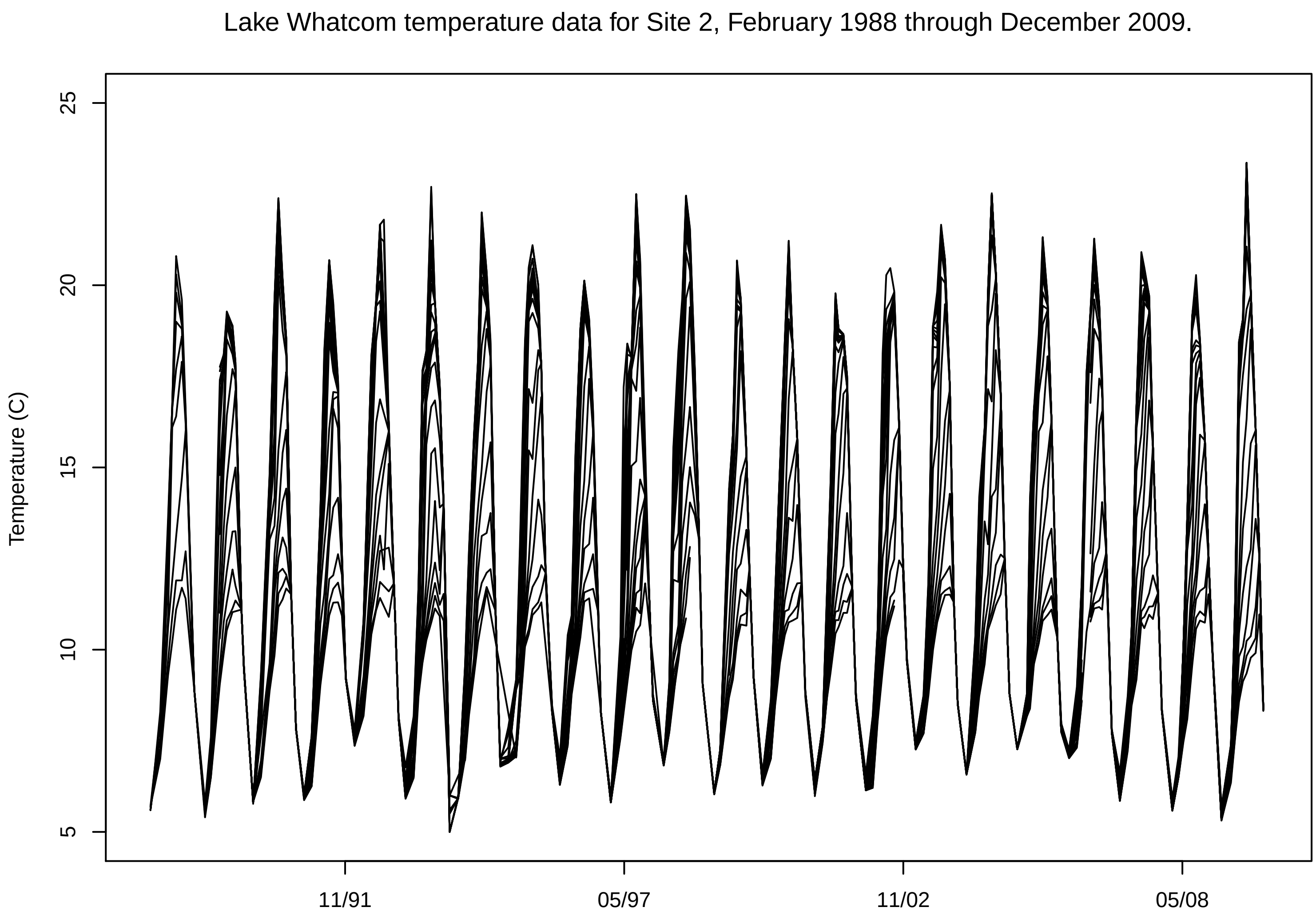


Figure B52: Lake Whatcom historic temperature data for Site 2.

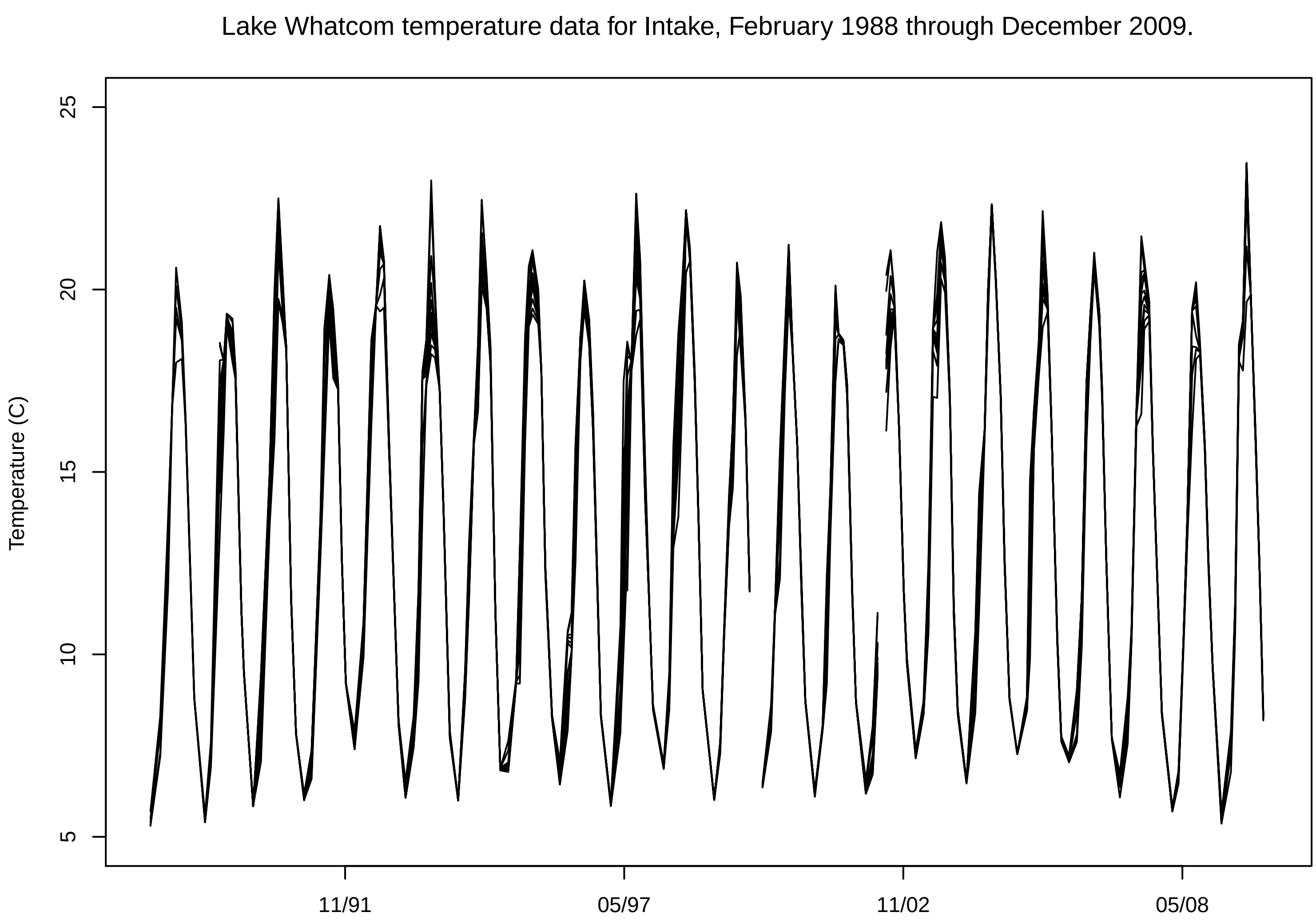


Figure B53: Lake Whatcom historic temperature data for the Intake.

Lake Whatcom temperature data for Site 3, February 1988 through December 2009.

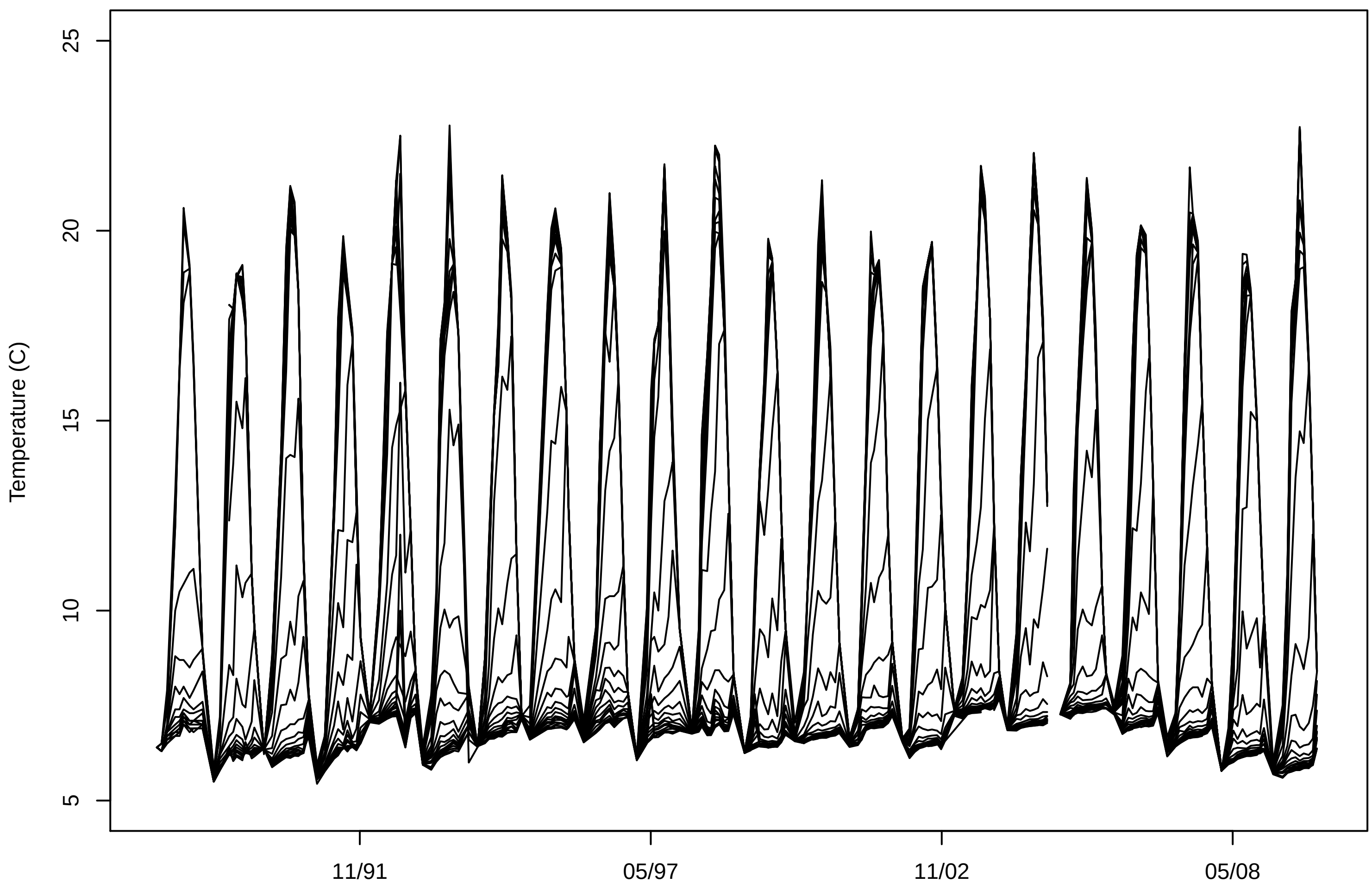


Figure B54: Lake Whatcom historic temperature data for Site 3.

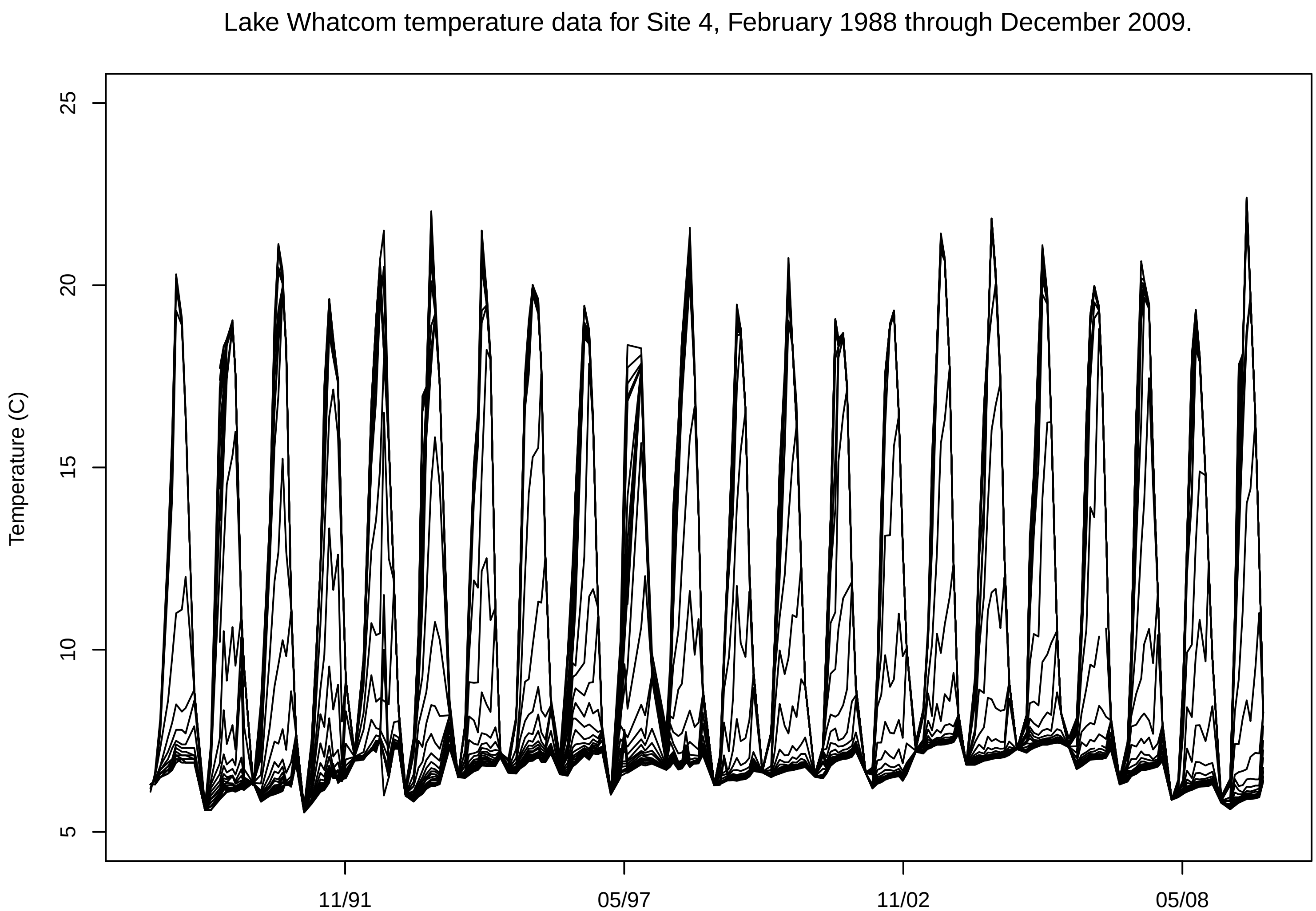


Figure B55: Lake Whatcom historic temperature data for Site 4.

Lake Whatcom dissolved oxygen data for Site 1, February 1988 through December 2009.

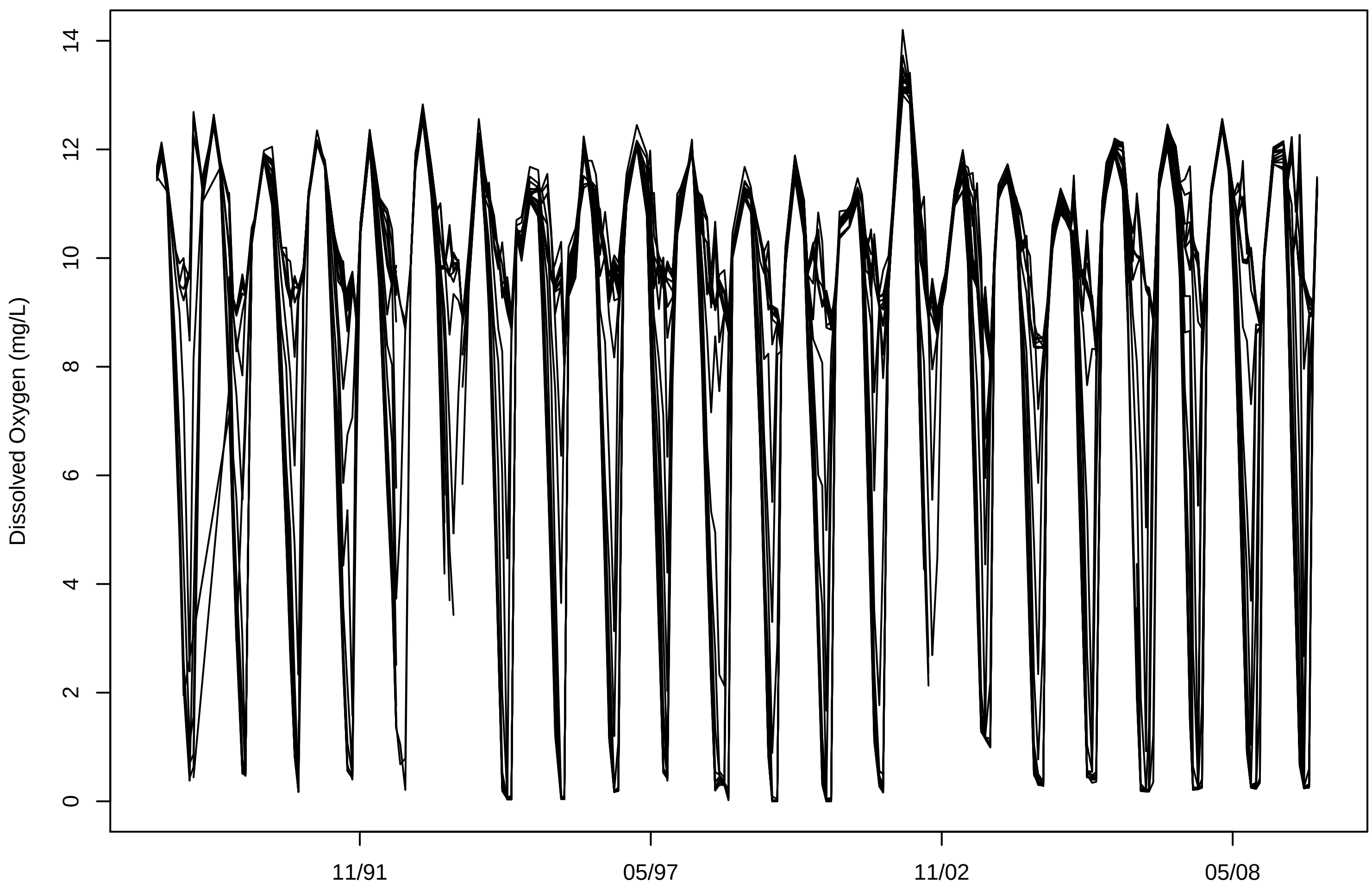


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

Lake Whatcom dissolved oxygen data for Site 2, February 1988 through December 2009.

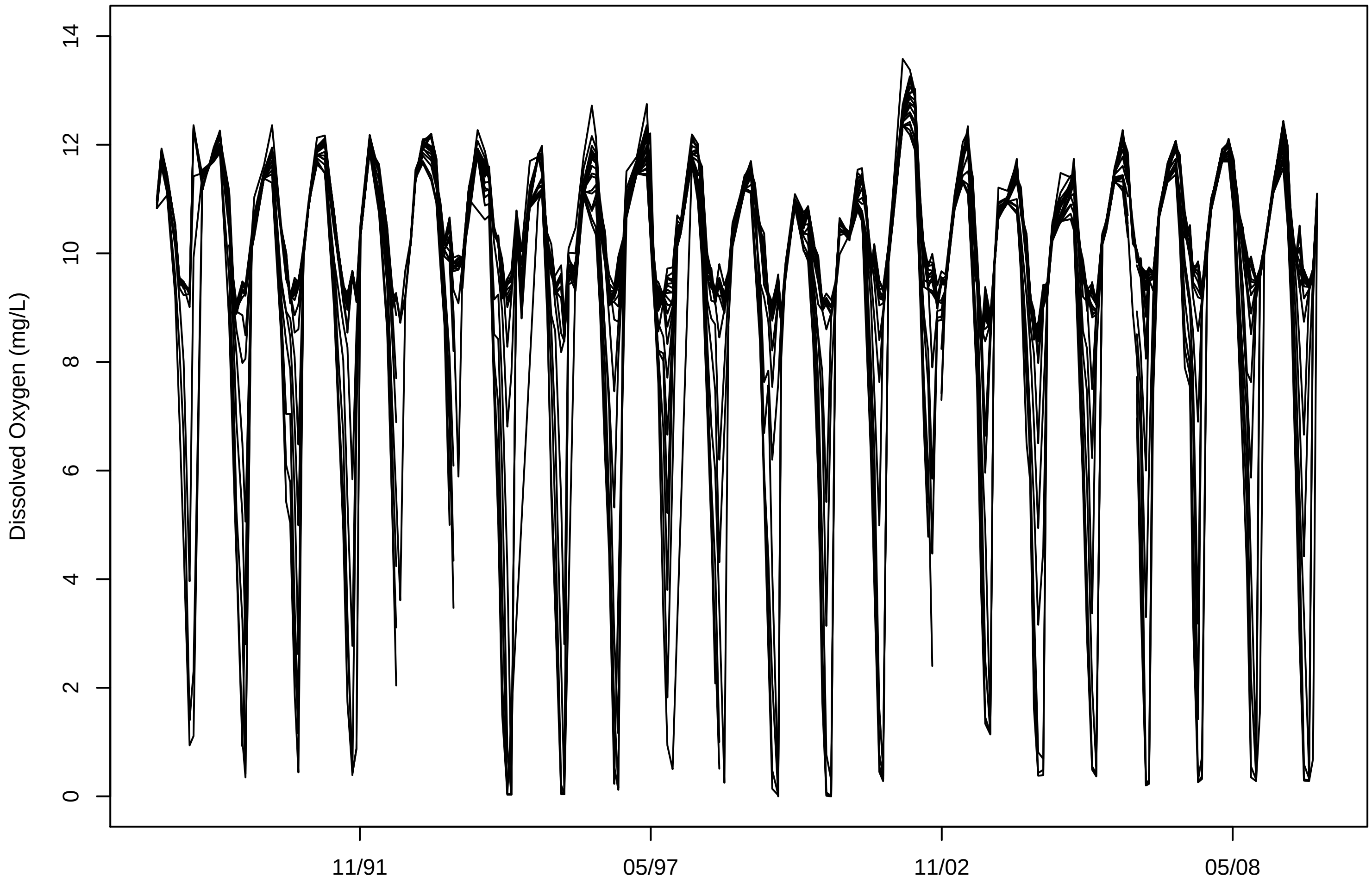


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

Lake Whatcom dissolved oxygen data for Intake, February 1988 through December 2009.

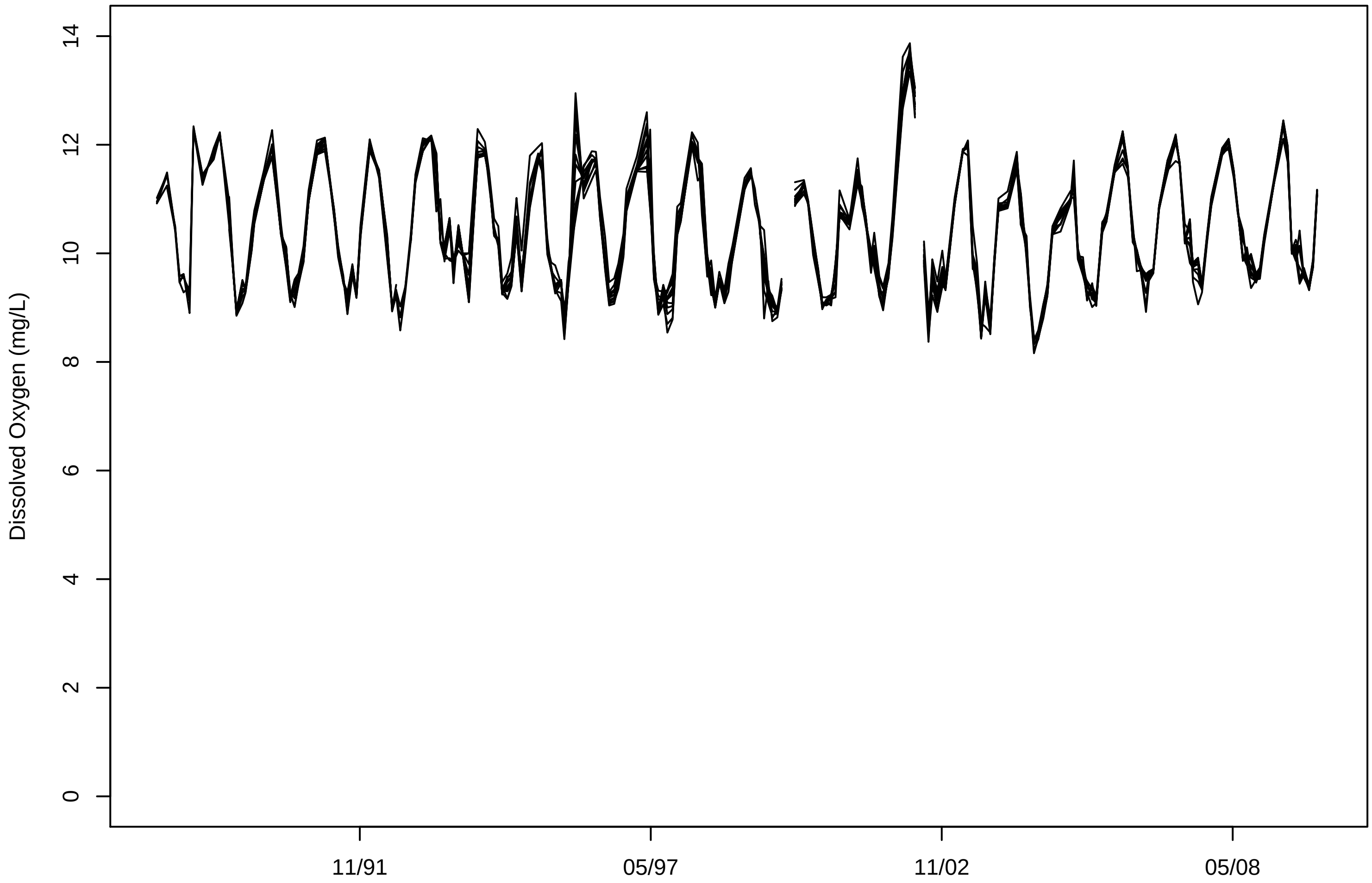


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake.

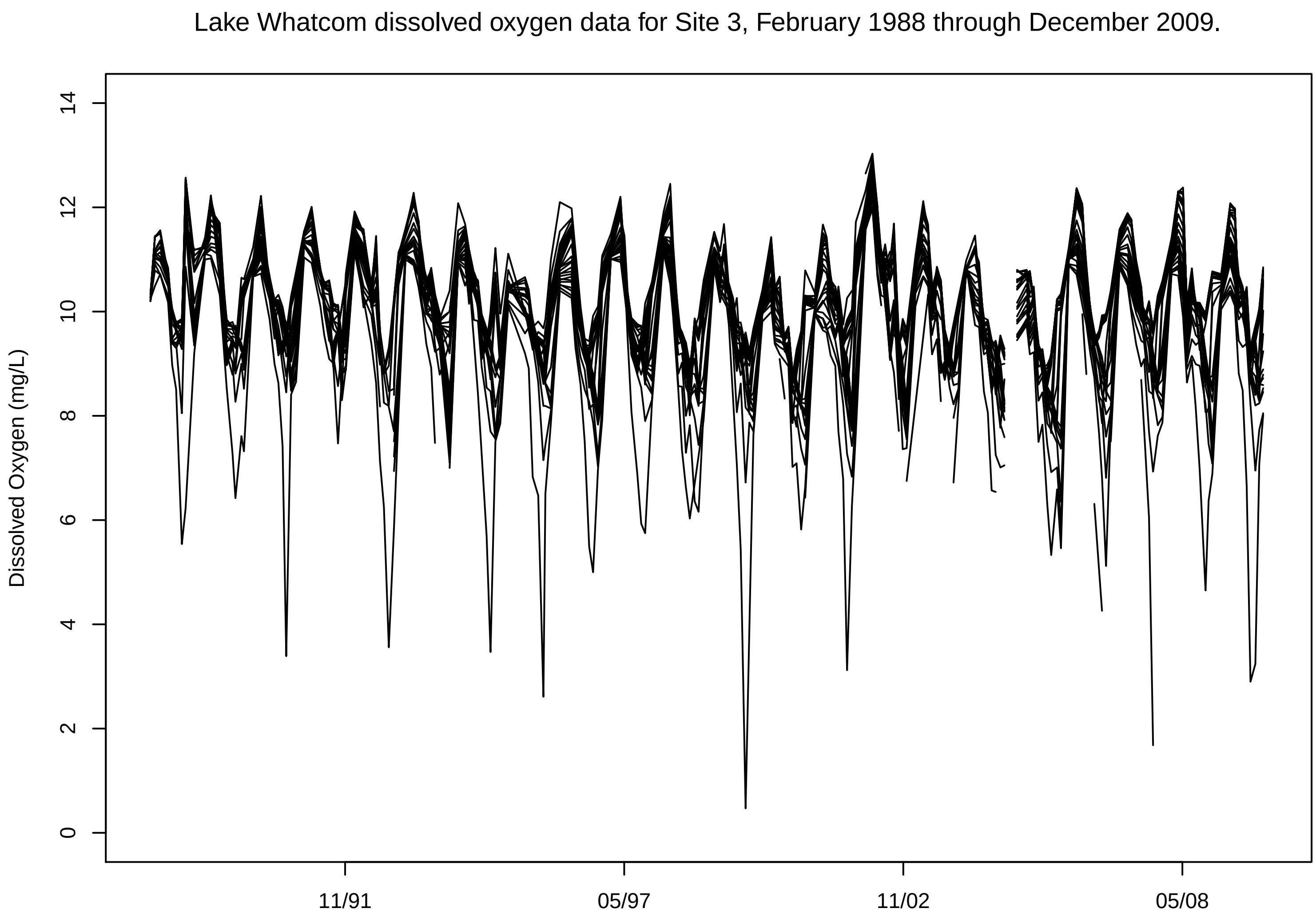


Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.

Lake Whatcom dissolved oxygen data for Site 4, February 1988 through December 2009.

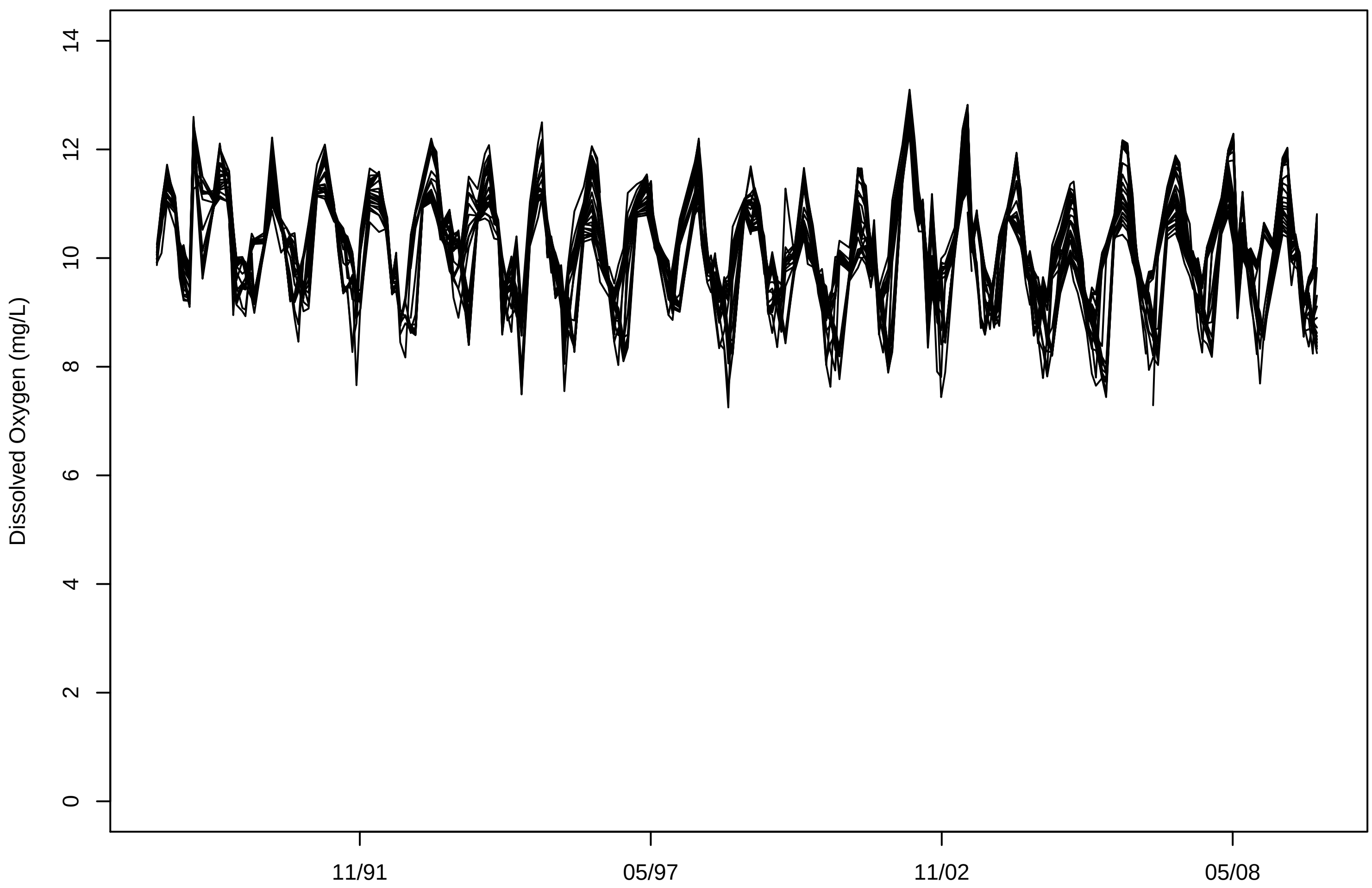


Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

Lake Whatcom pH data for Site 1, February 1988 through December 2009.

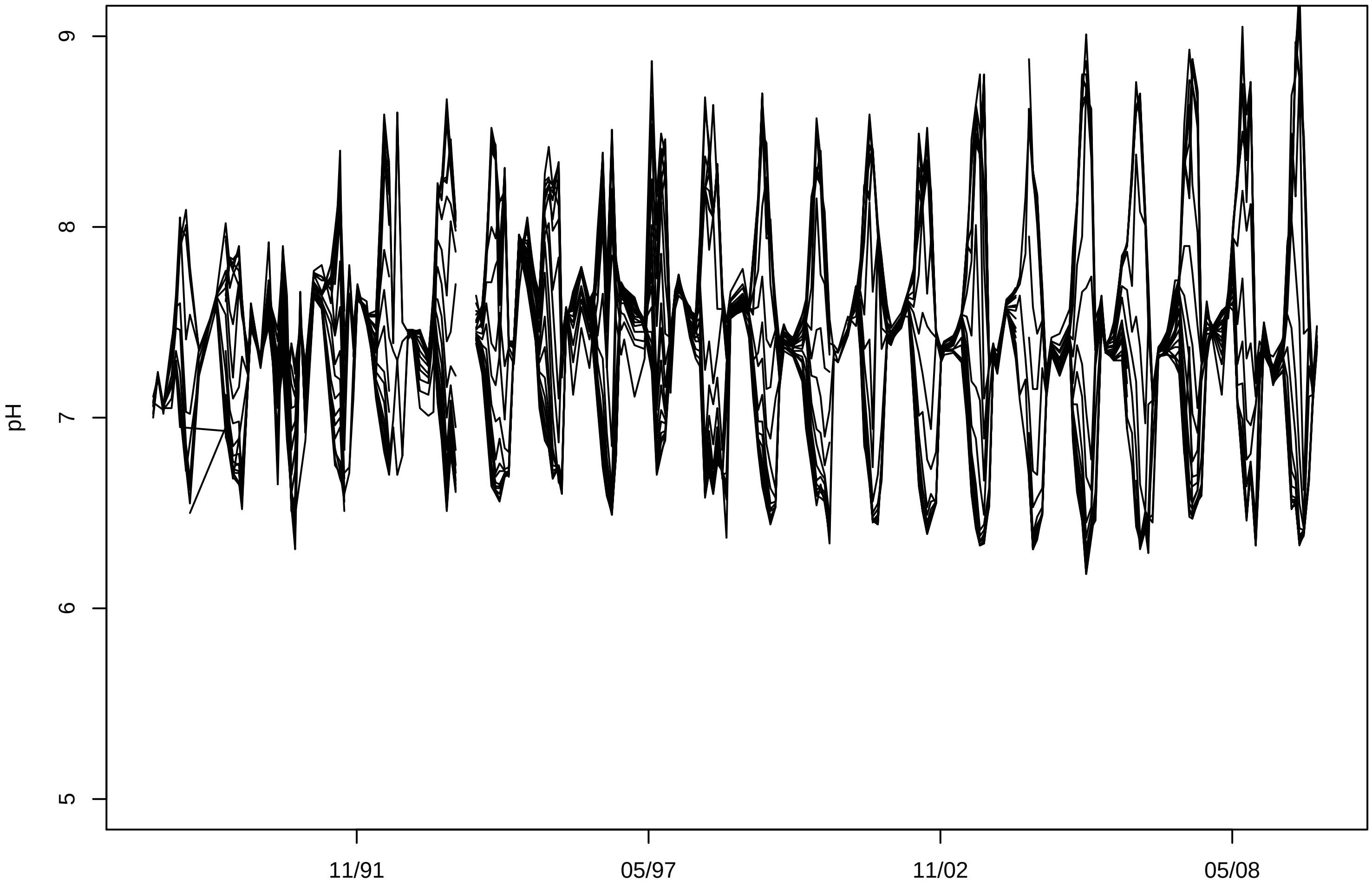


Figure B61: Lake Whatcom historic pH data for Site 1.

Lake Whatcom pH data for Site 2, February 1988 through December 2009.

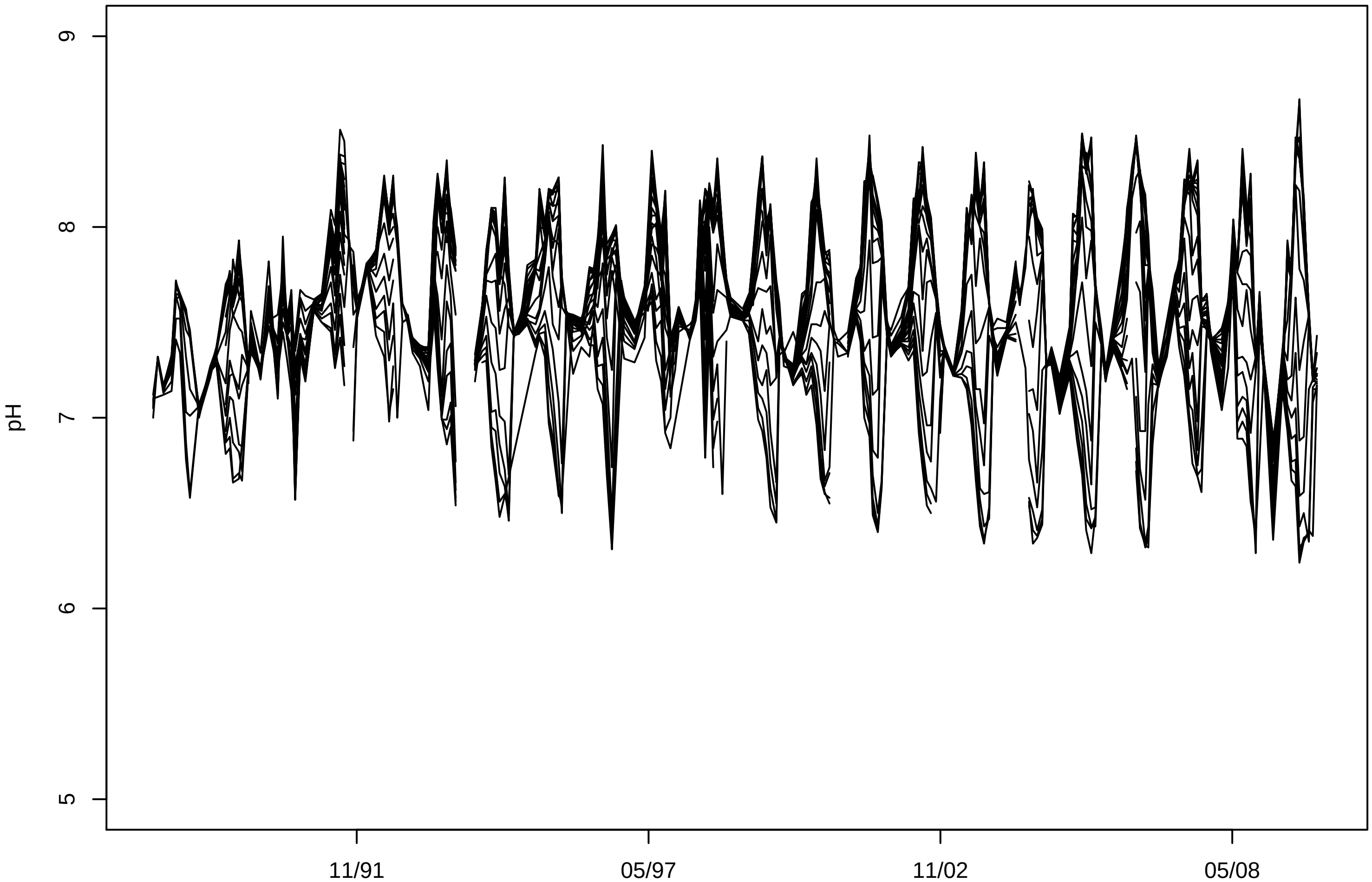


Figure B62: Lake Whatcom historic pH data for Site 2.

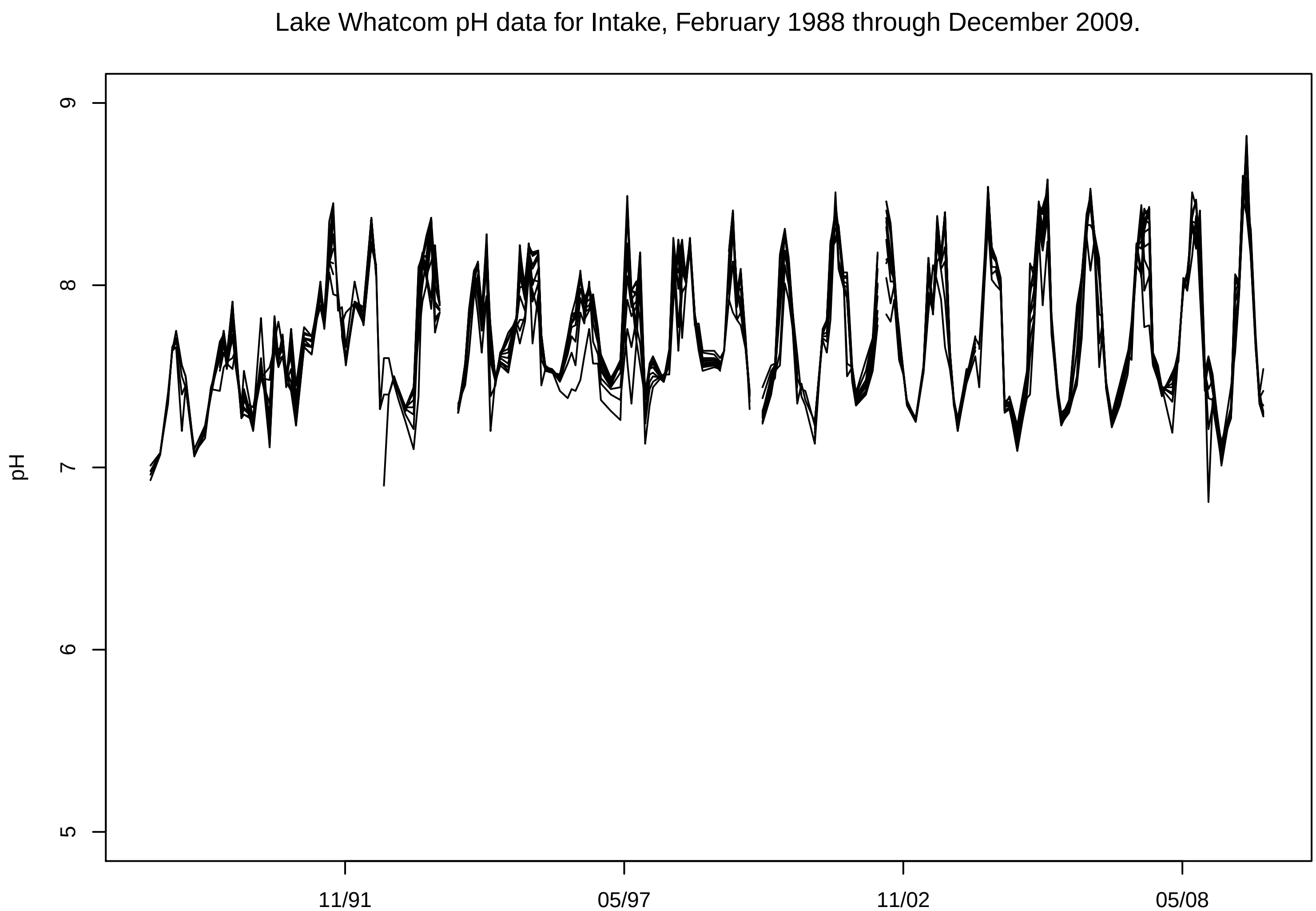


Figure B63: Lake Whatcom historic pH data for the Intake.

Lake Whatcom pH data for Site 3, February 1988 through December 2009.

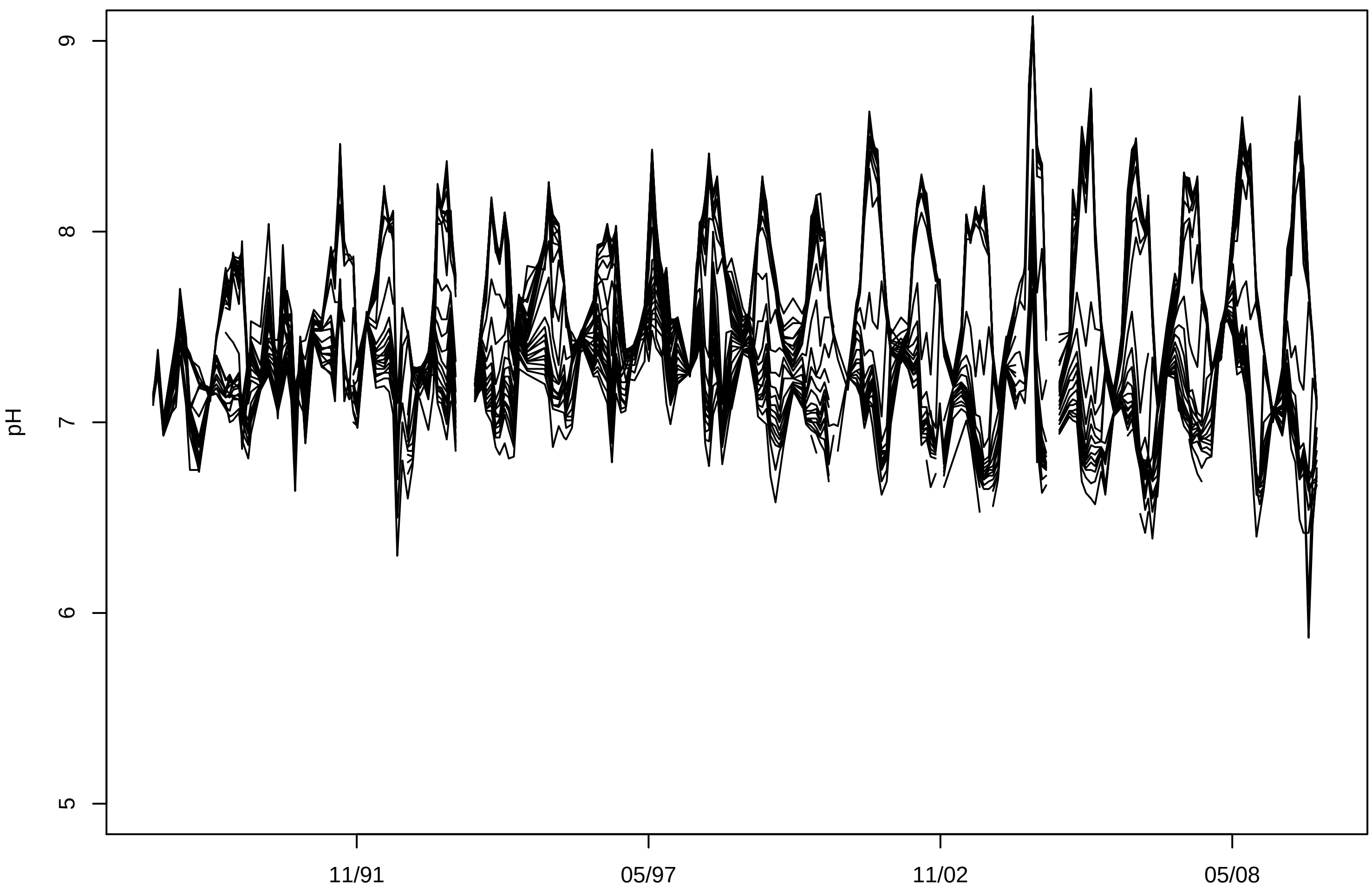


Figure B64: Lake Whatcom historic pH data for Site 3.

Lake Whatcom pH data for Site 4, February 1988 through December 2009.

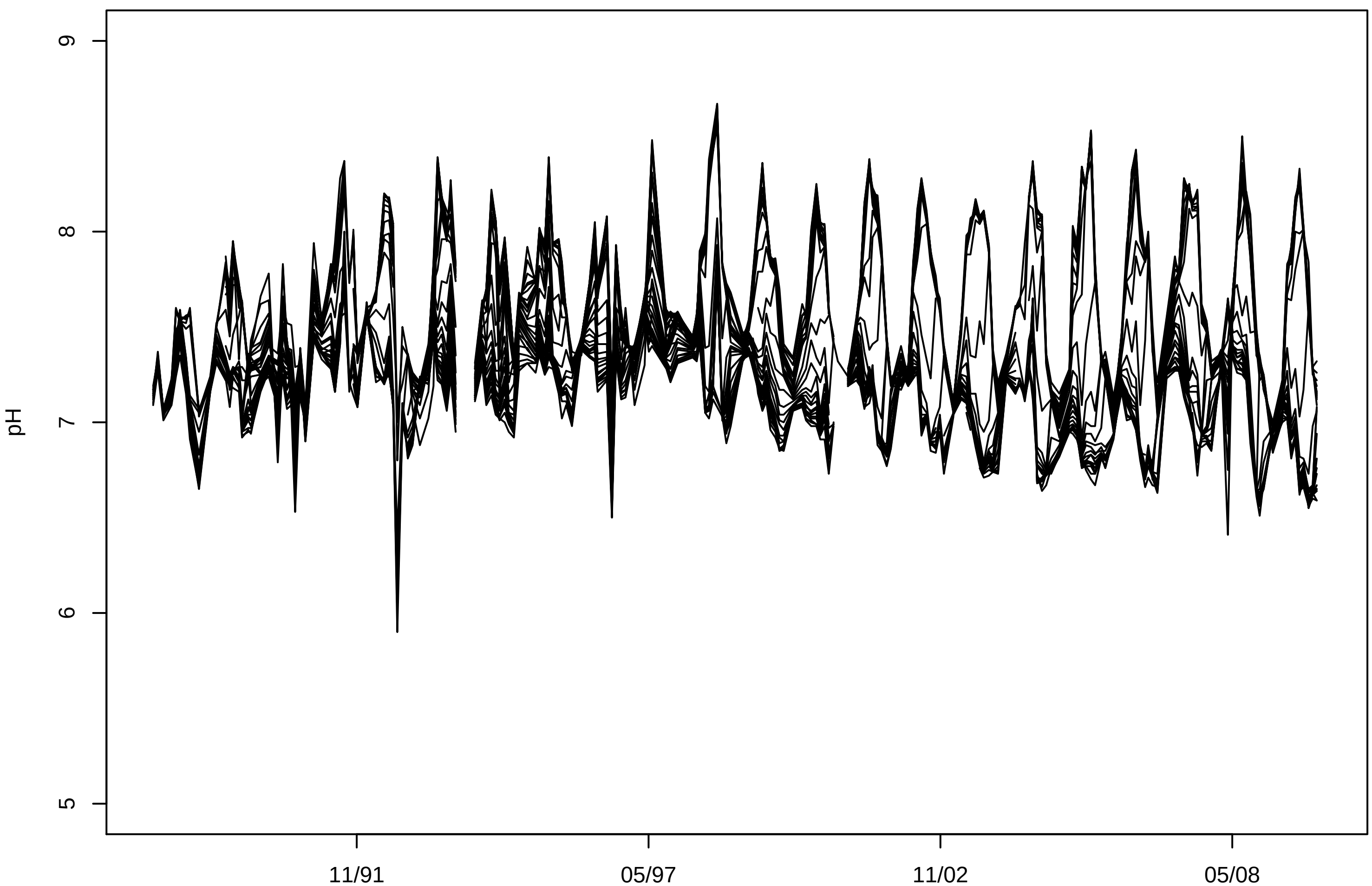


Figure B65: Lake Whatcom historic pH data for Site 4.

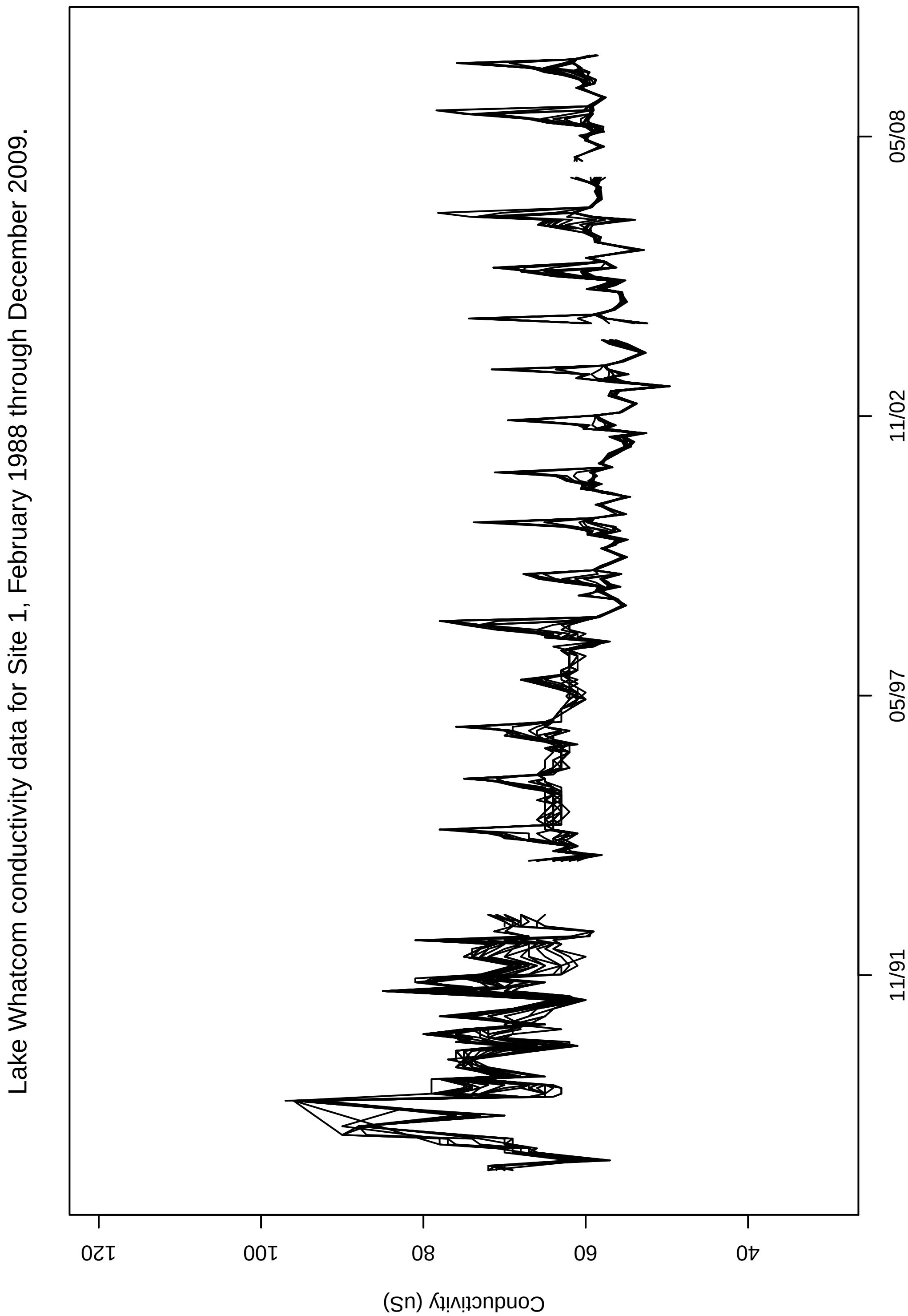


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

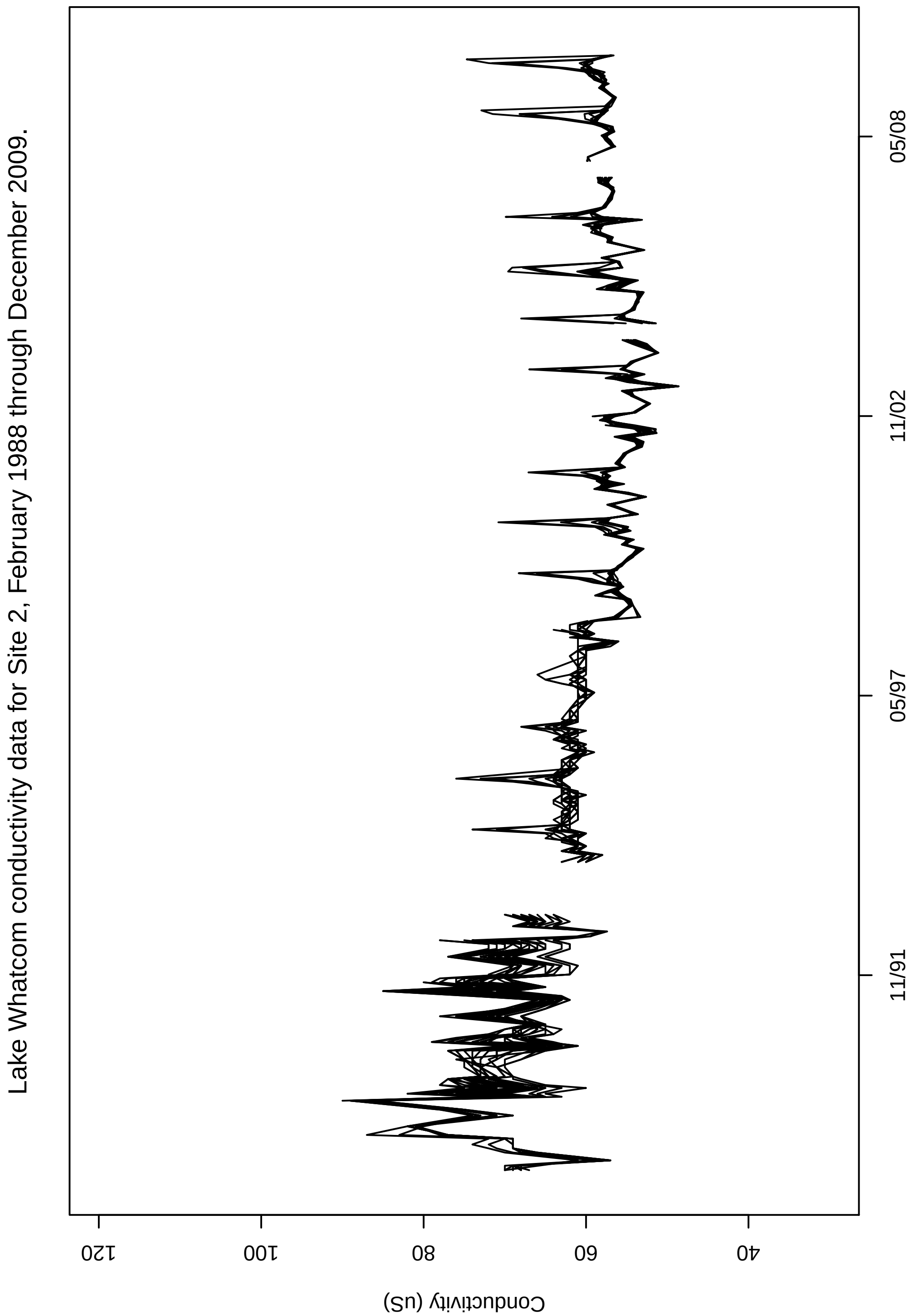


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

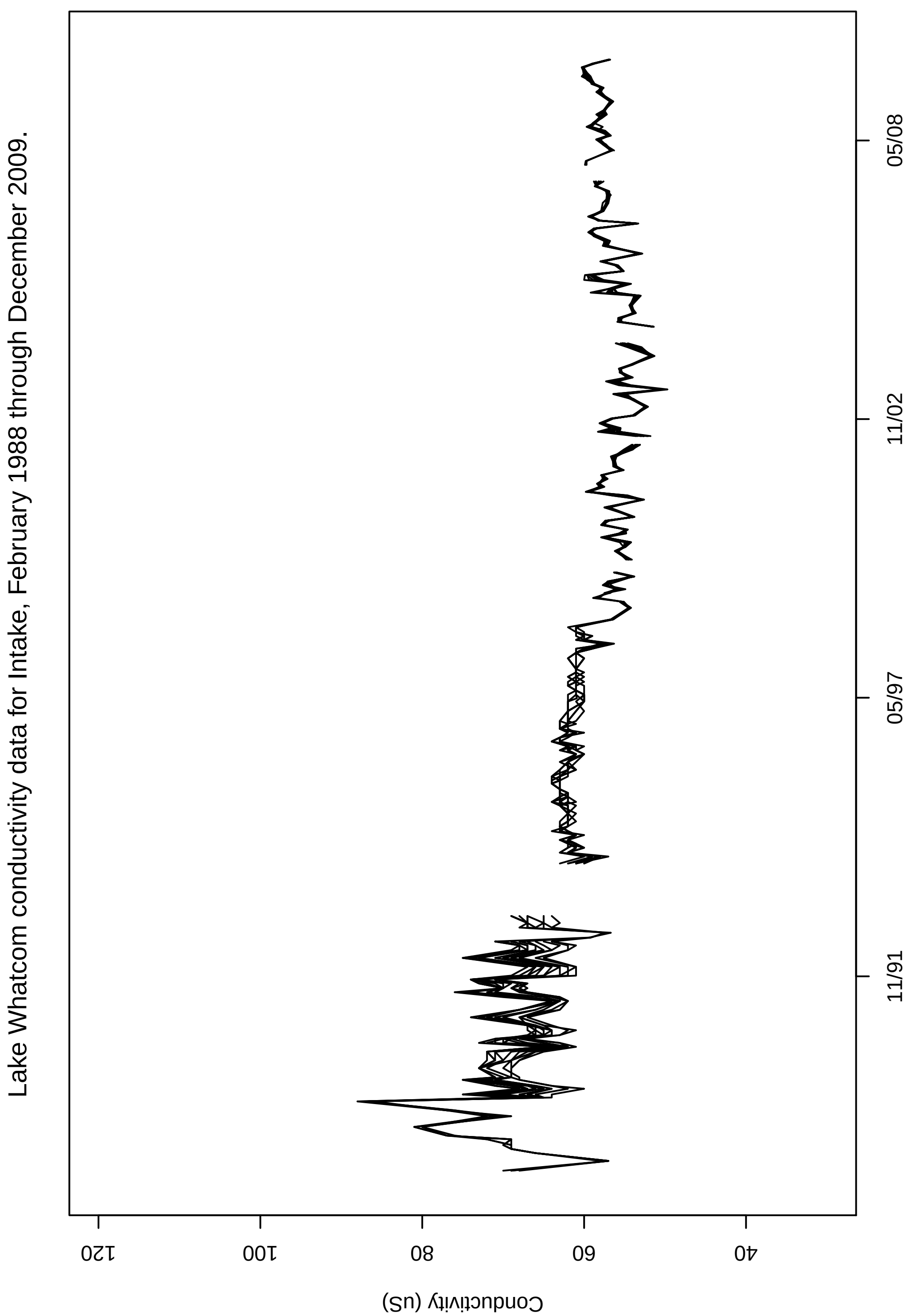


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

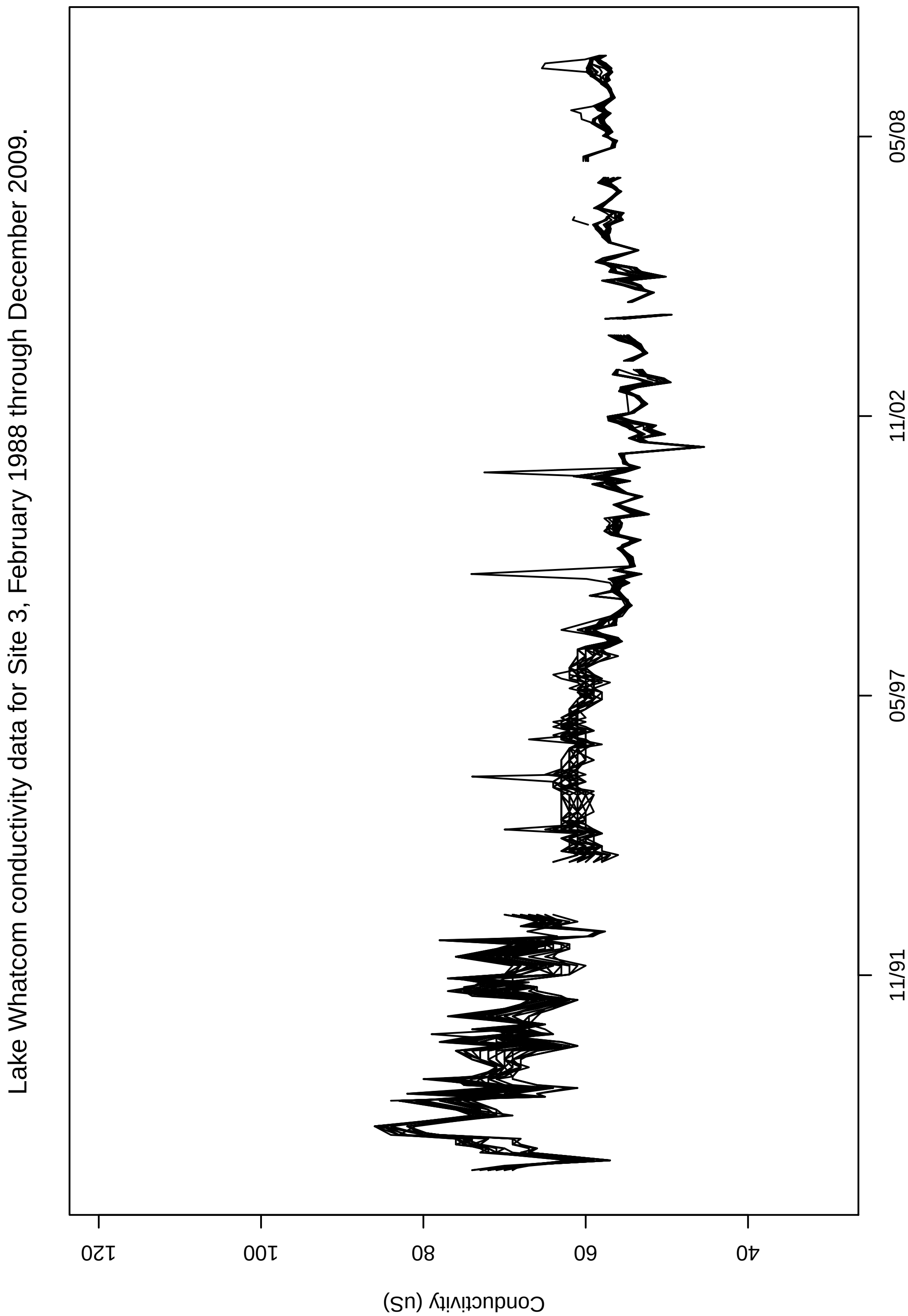


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

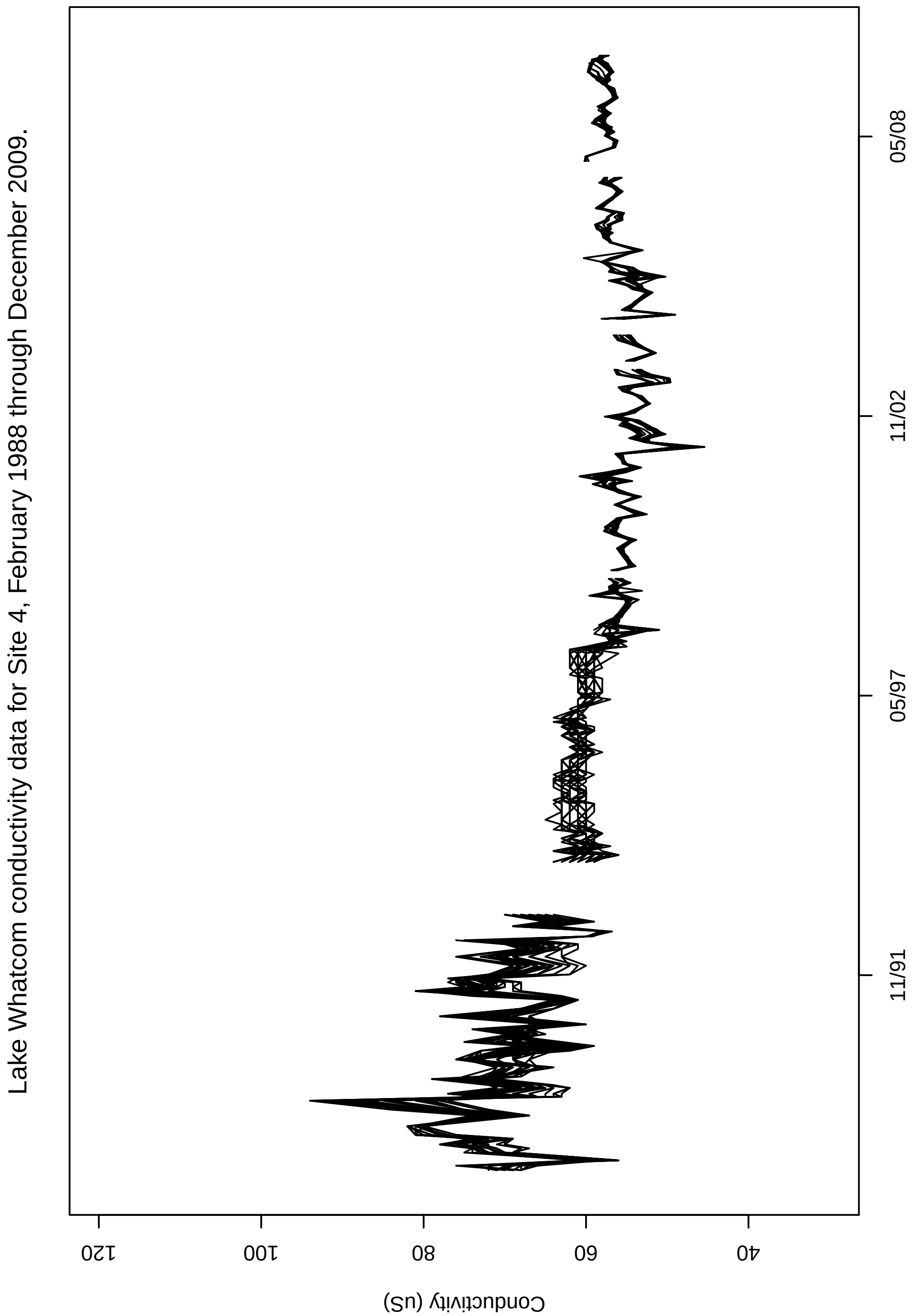


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

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

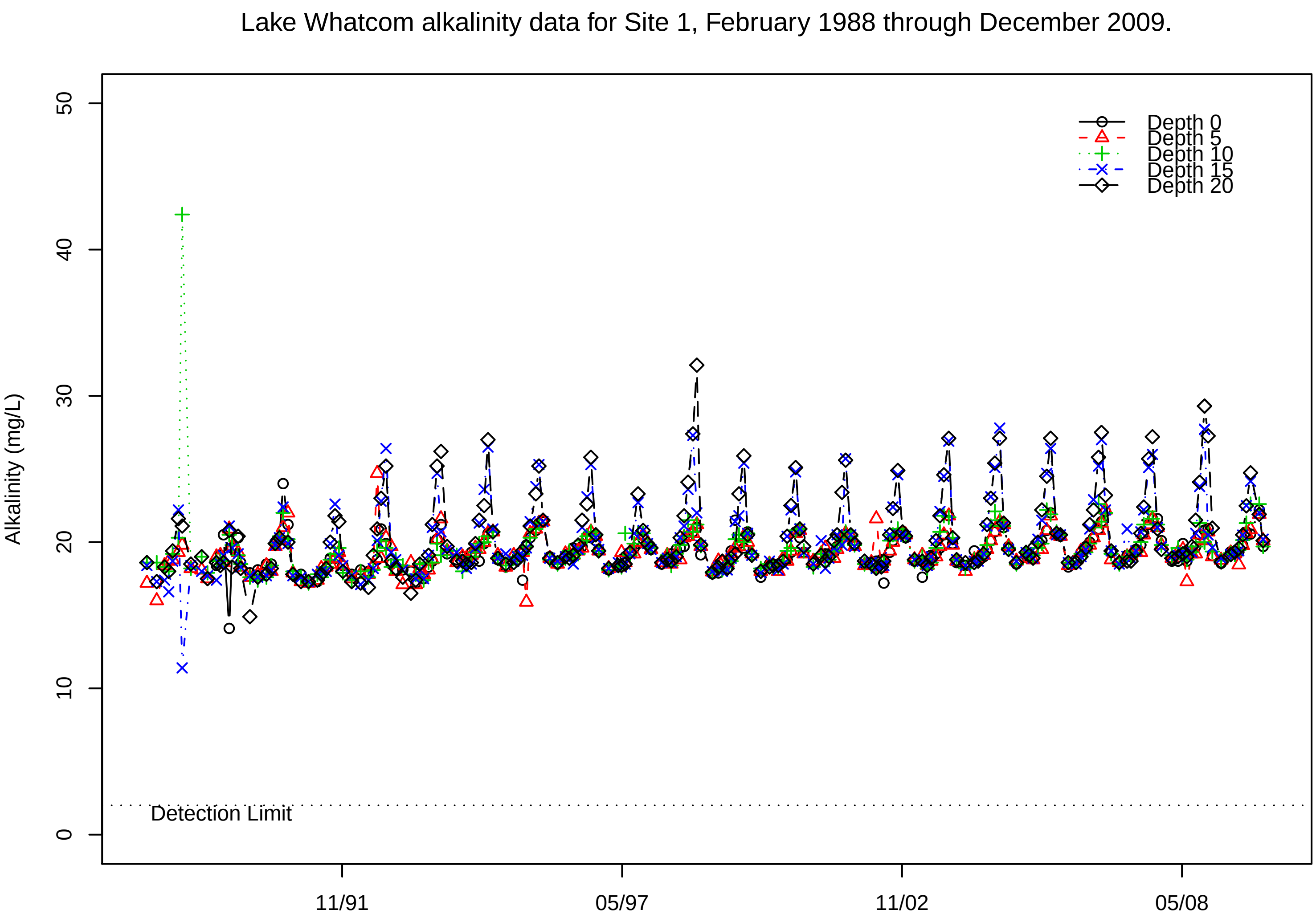


Figure B71: Lake Whatcom alkalinity data for Site 1.

Lake Whatcom alkalinity data for Site 2, February 1988 through December 2009.

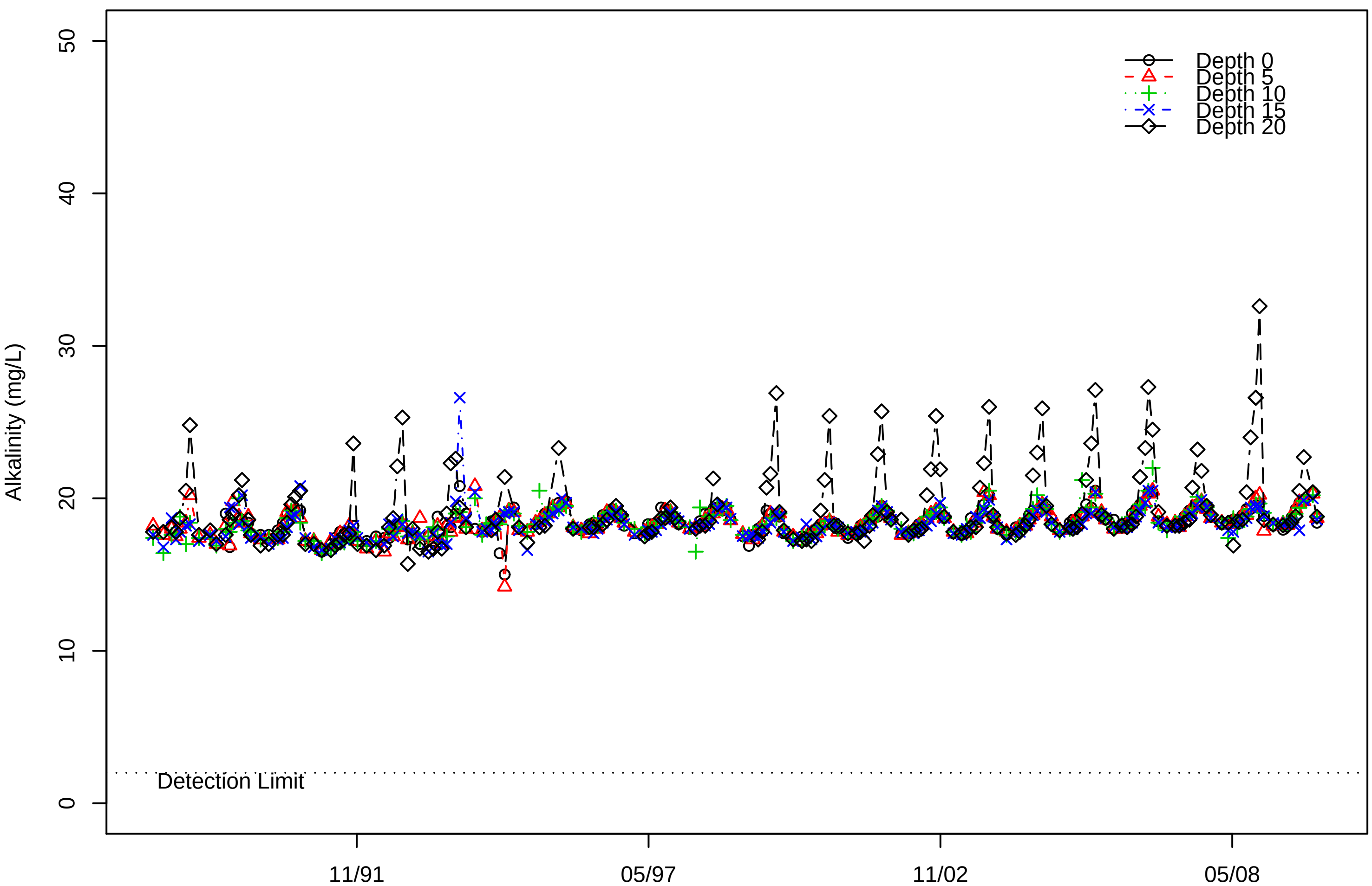


Figure B72: Lake Whatcom alkalinity data for Site 2.

Lake Whatcom alkalinity data for Intake, February 1988 through December 2009.

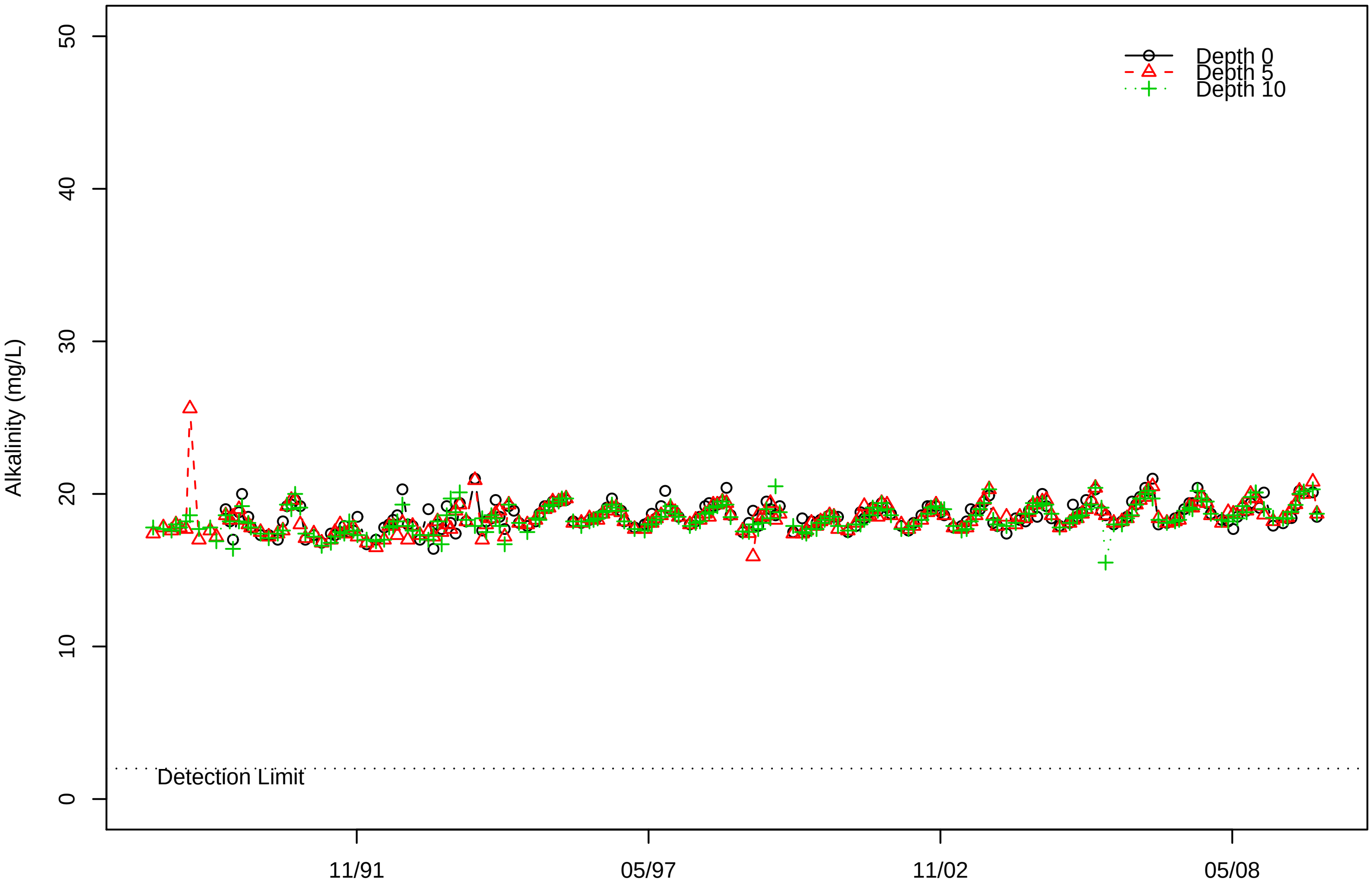


Figure B73: Lake Whatcom alkalinity data for the Intake site.

Lake Whatcom alkalinity data for Site 3, February 1988 through December 2009.

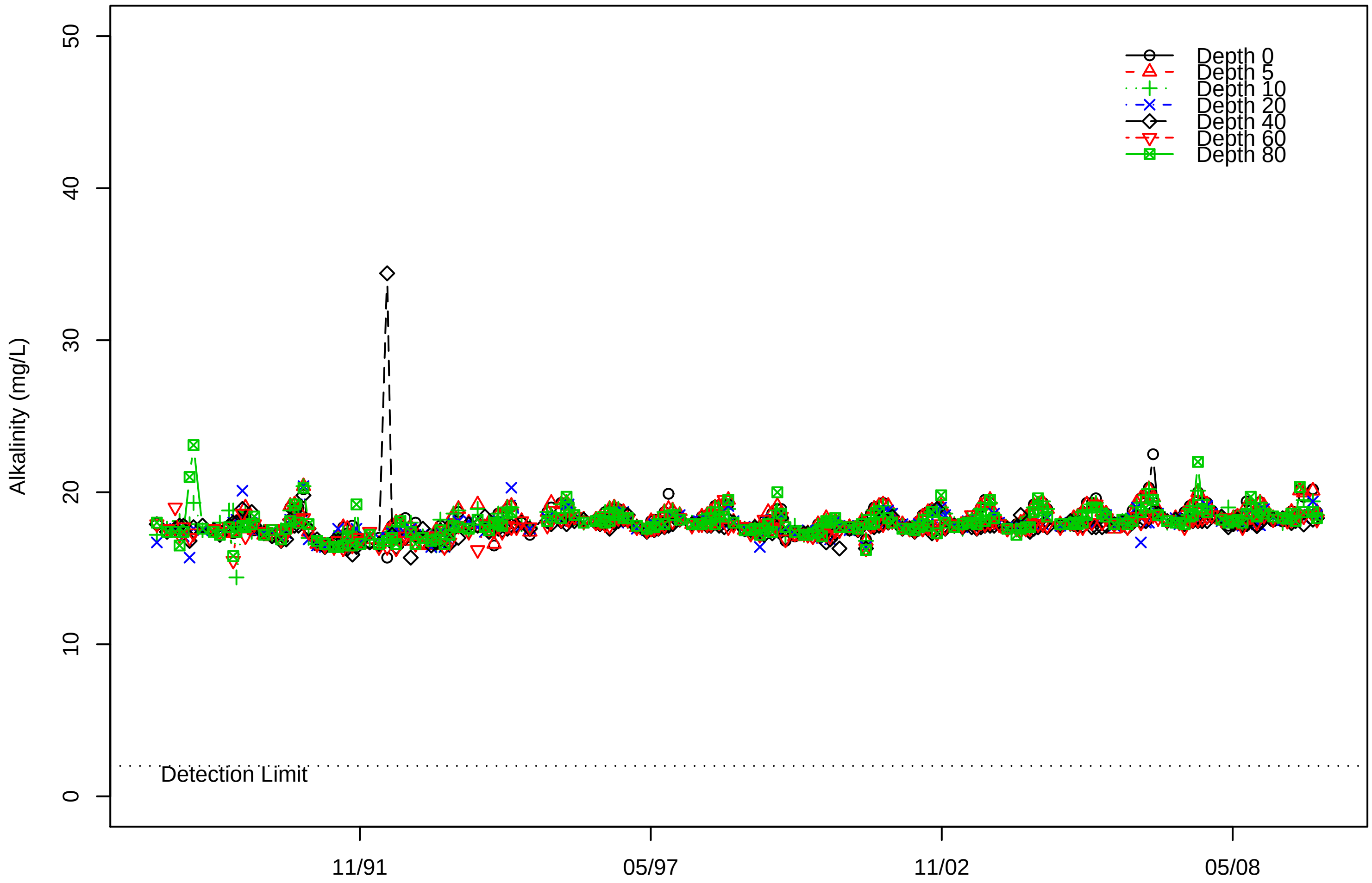


Figure B74: Lake Whatcom alkalinity data for Site 3.

Lake Whatcom alkalinity data for Site 4, February 1988 through December 2009.

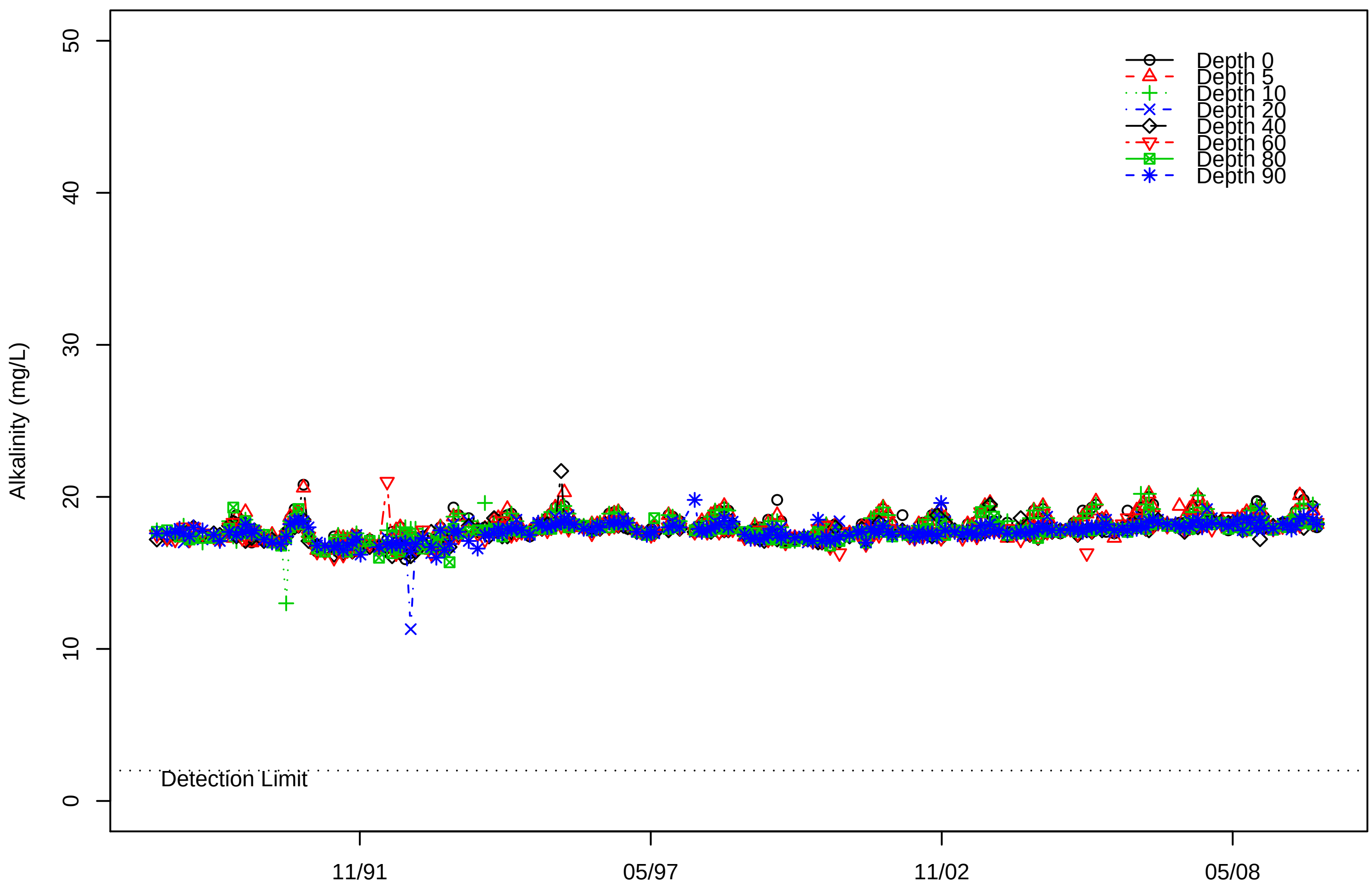


Figure B75: Lake Whatcom alkalinity data for Site 4.

Lake Whatcom turbidity data for Site 1, February 1988 through December 2009.

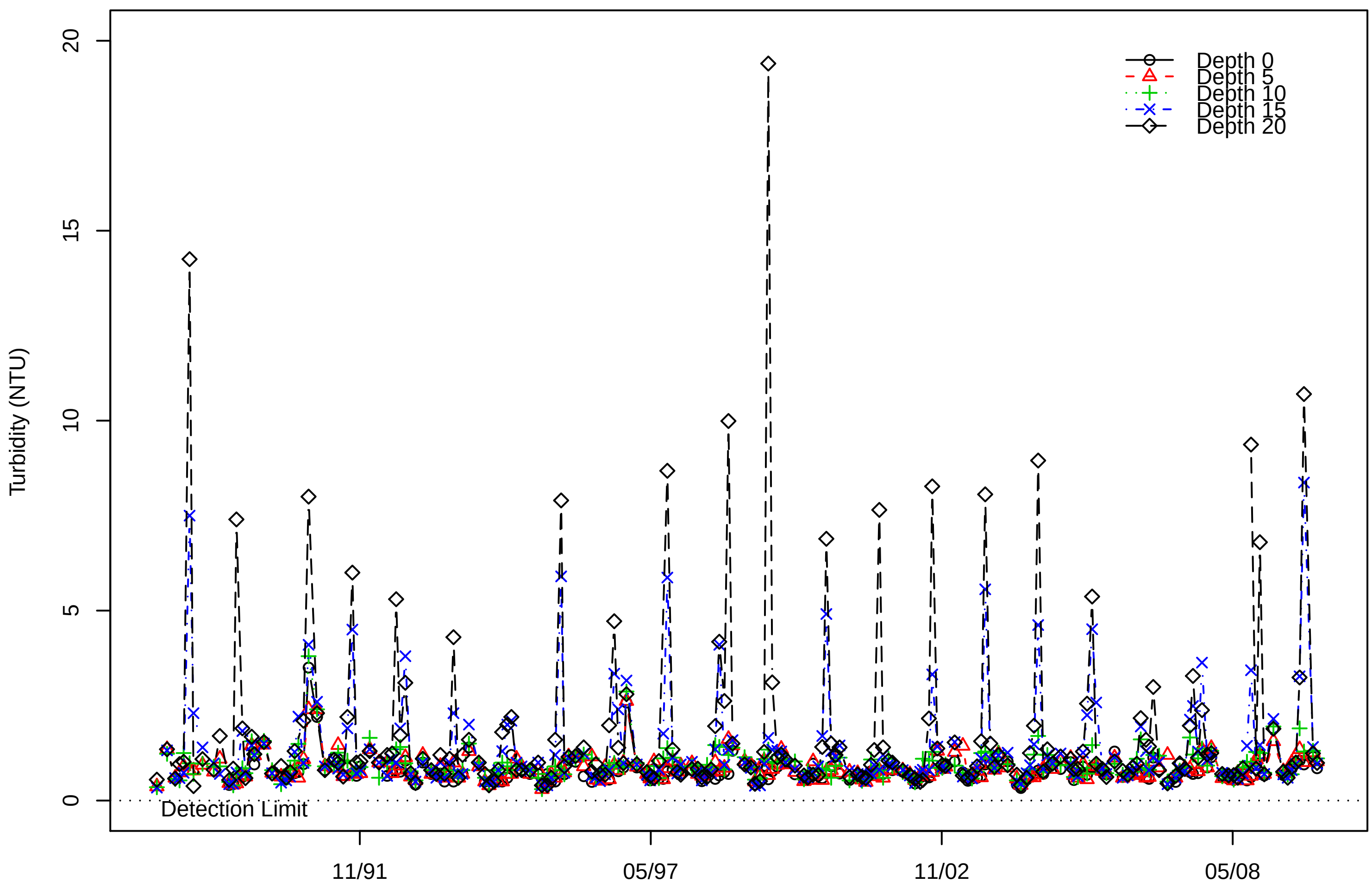
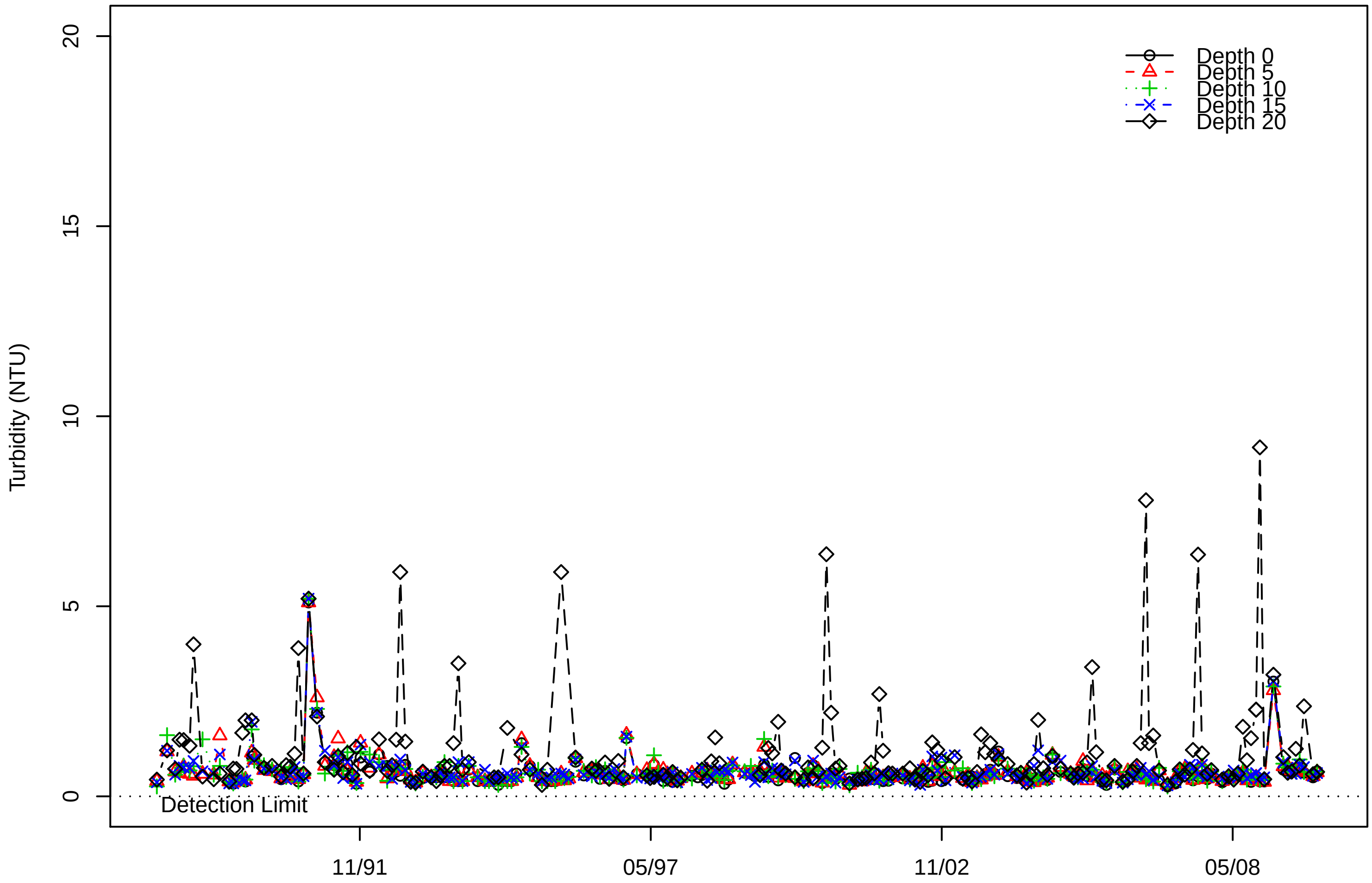


Figure B76: Lake Whatcom turbidity data for Site 1.

Figure B77: Lake Whatcom turbidity data for Site 2.

Lake Whatcom turbidity data for Site 2, February 1988 through December 2009.



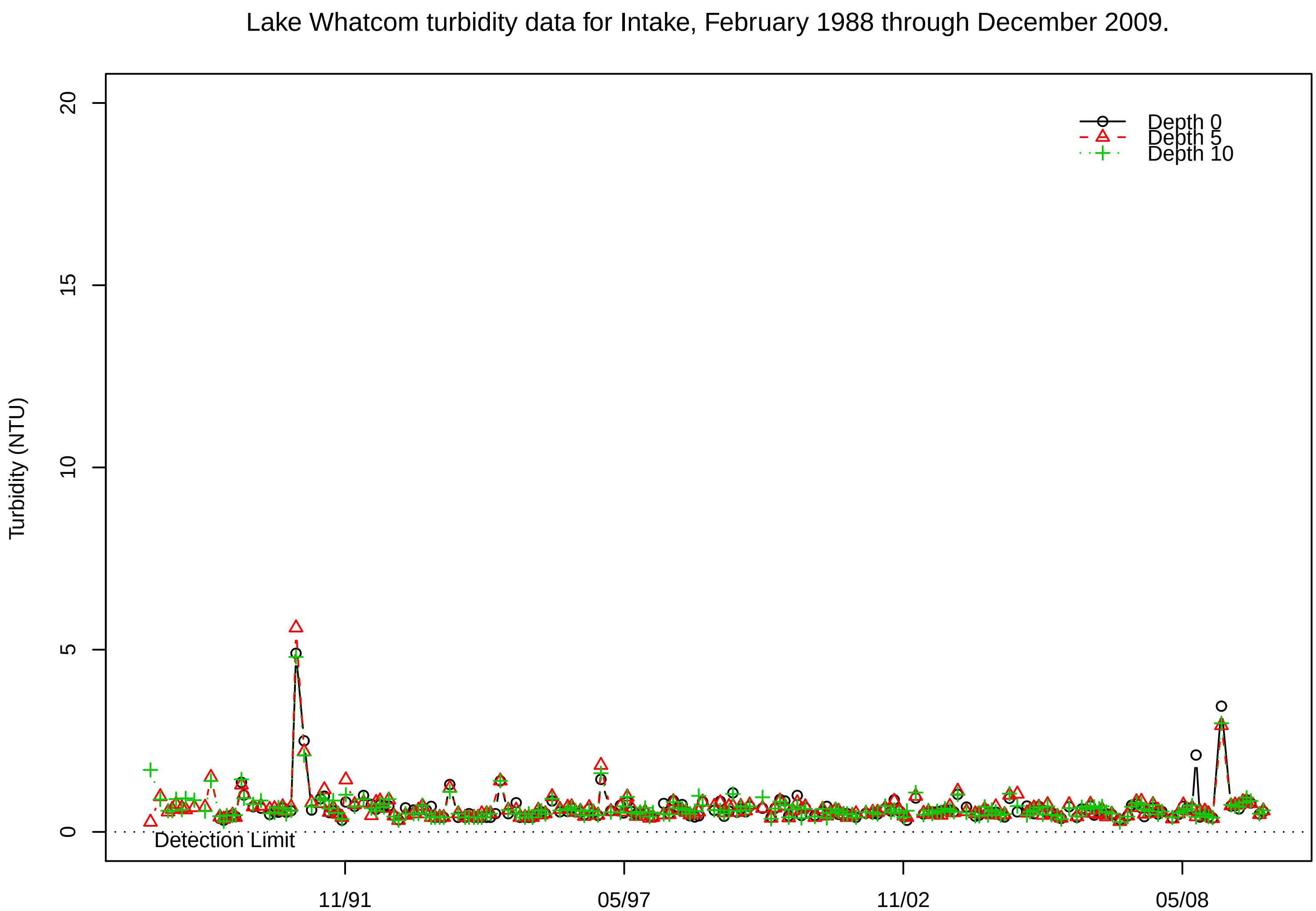


Figure B78: Lake Whatcom turbidity data for the Intake site.

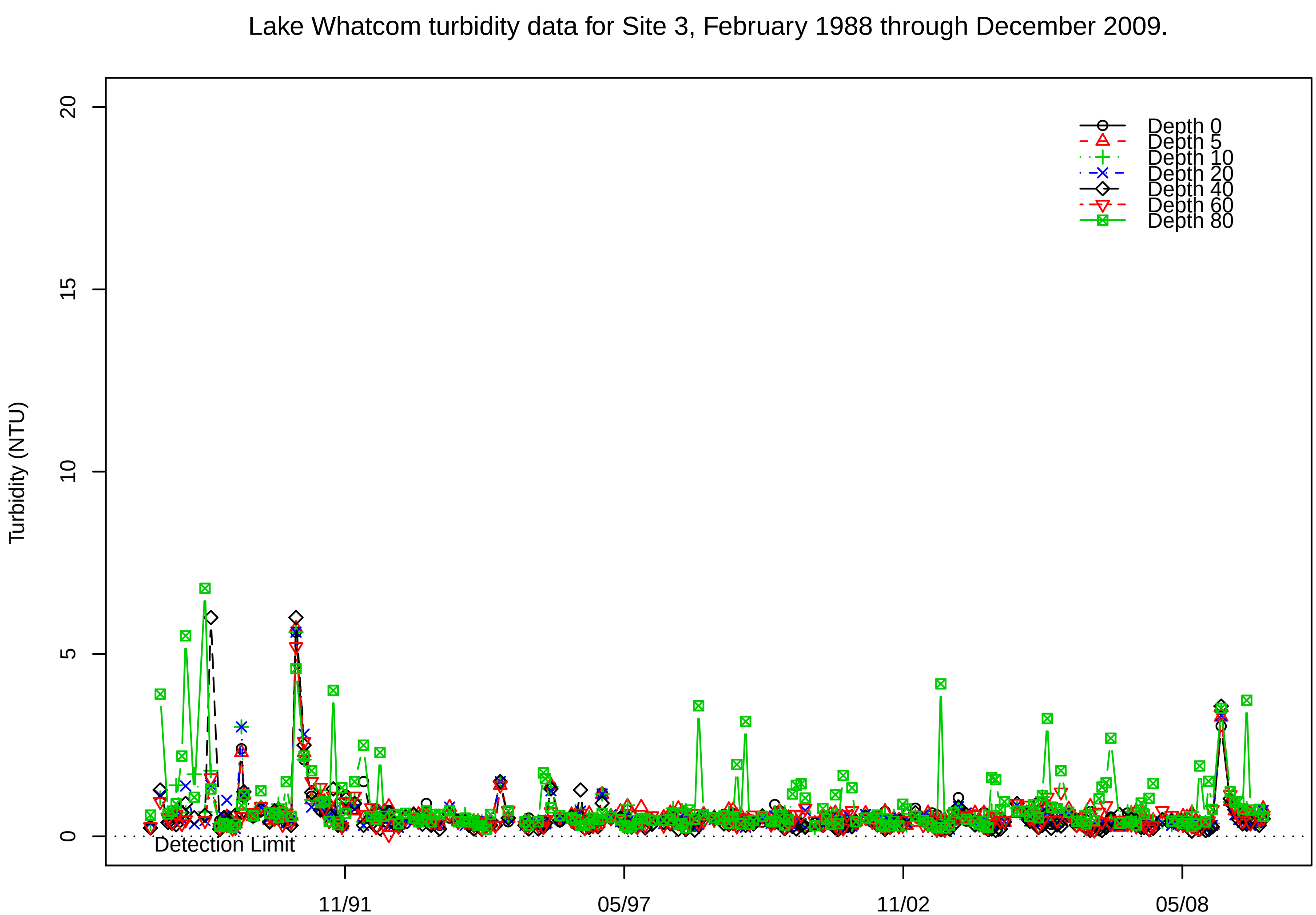


Figure B79: Lake Whatcom turbidity data for Site 3.

Lake Whatcom turbidity data for Site 4, February 1988 through December 2009.

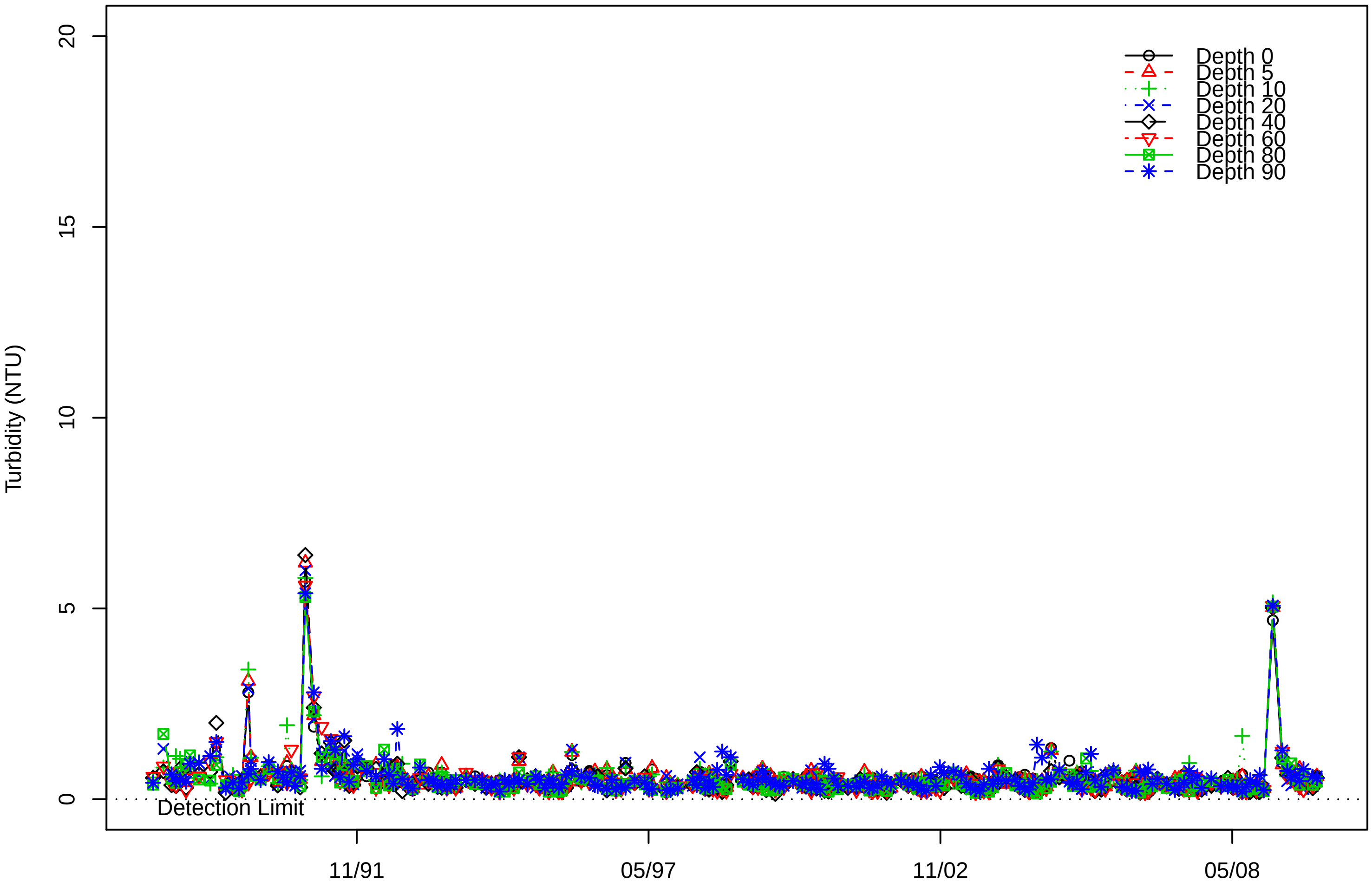


Figure B80: Lake Whatcom turbidity data for Site 4.

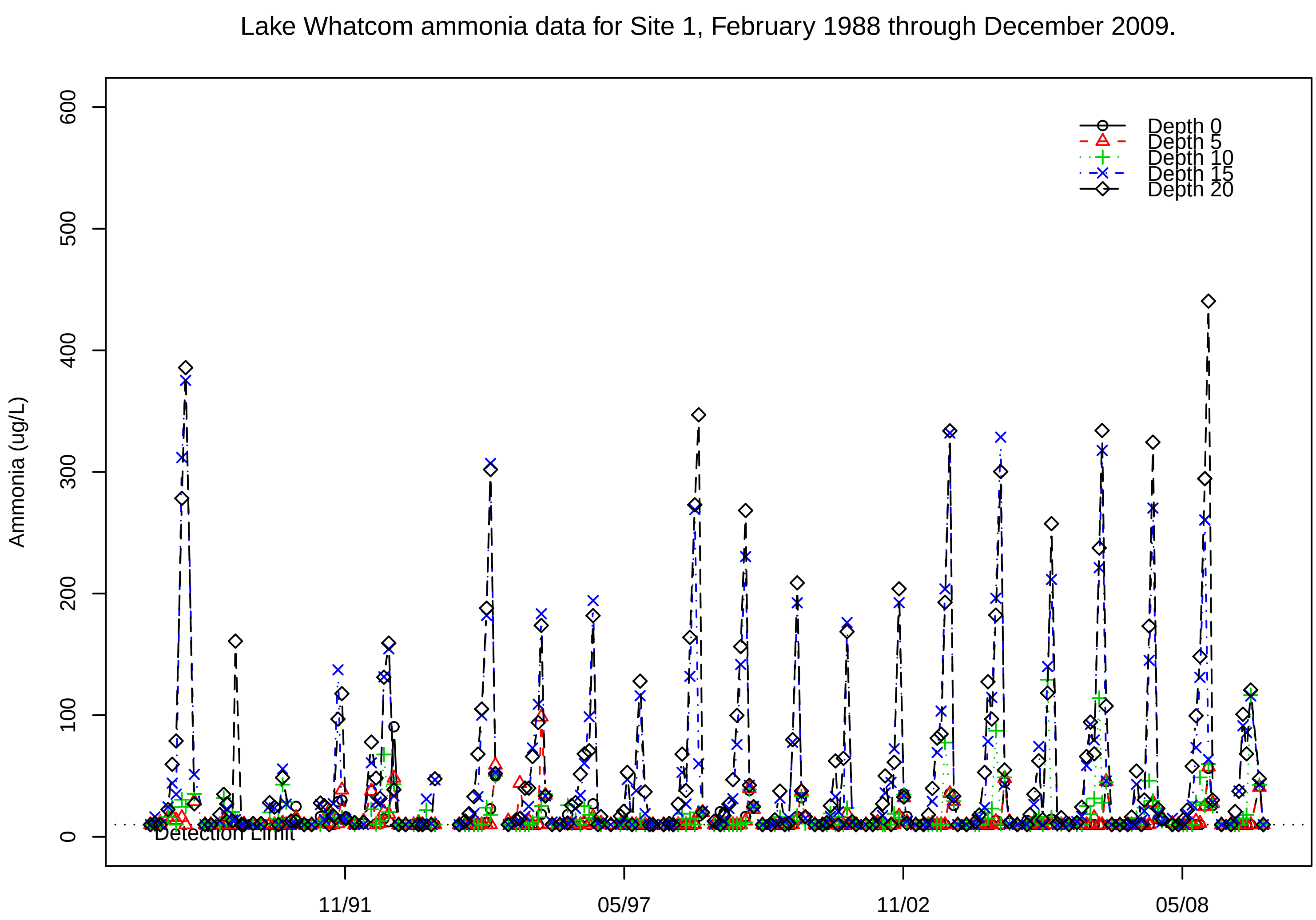


Figure B81: Lake Whatcom ammonia data for Site 1.

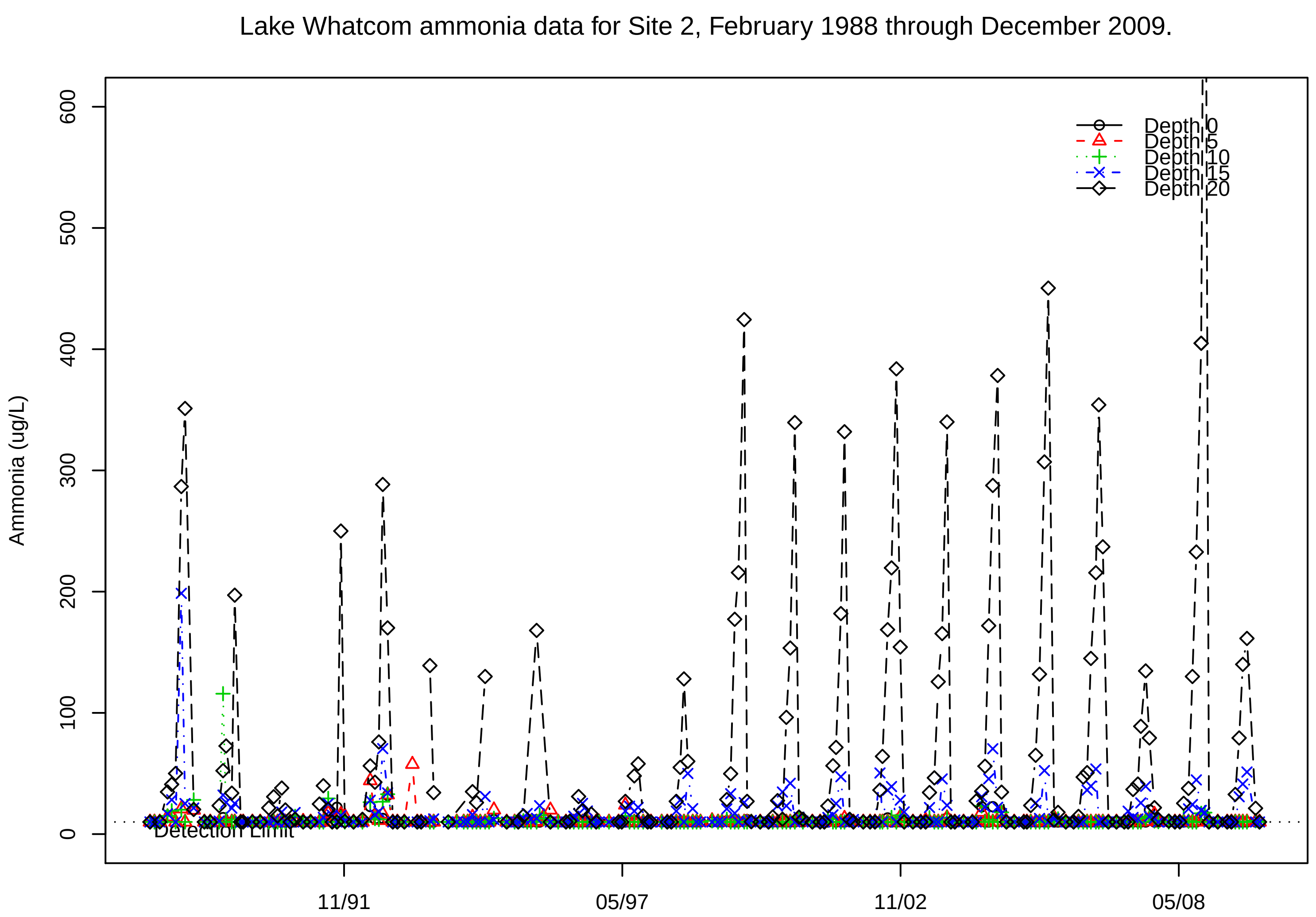


Figure B82: Lake Whatcom ammonia data for Site 2.

Lake Whatcom ammonia data for Intake, February 1988 through December 2009.

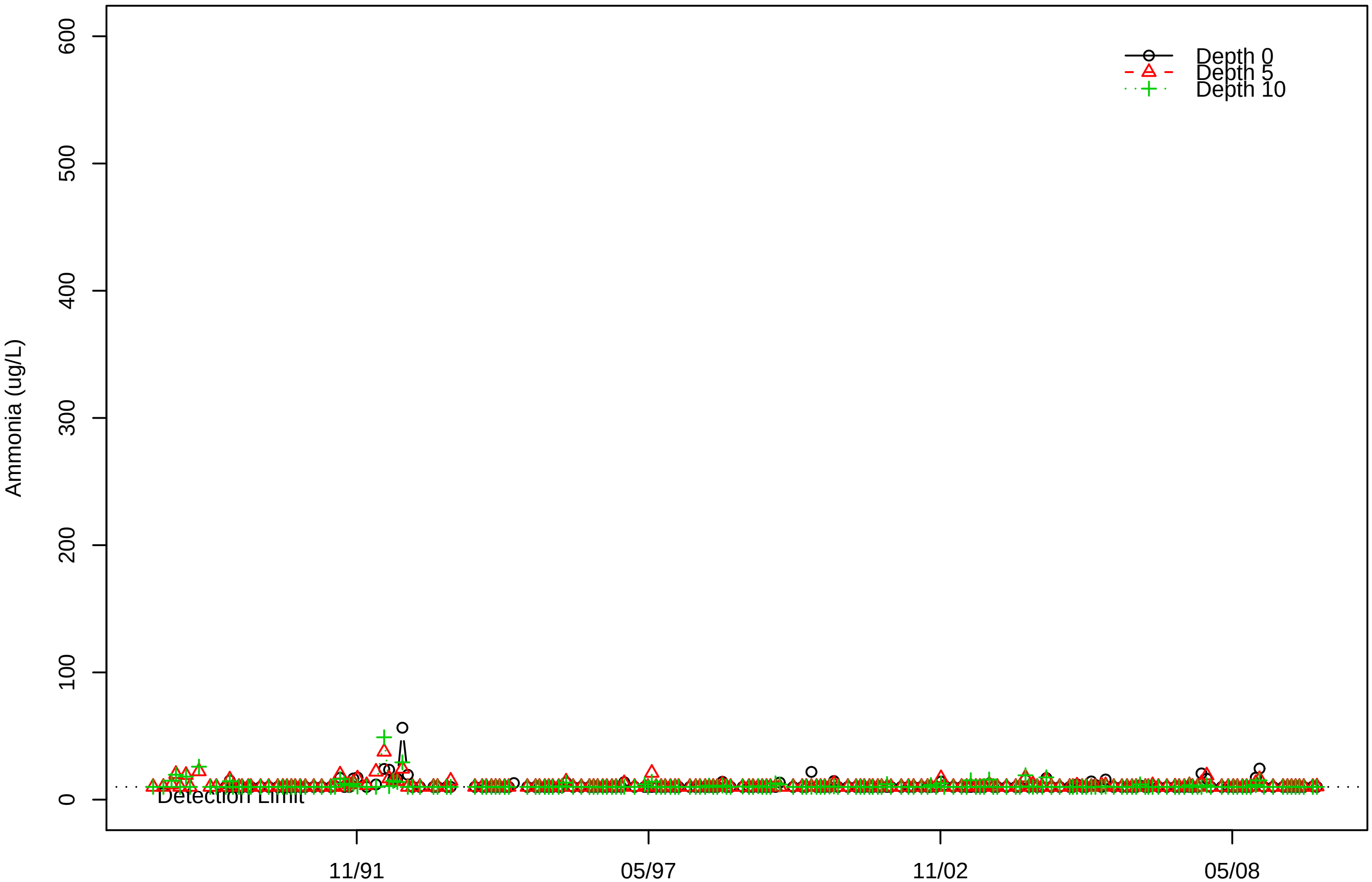


Figure B83: Lake Whatcom ammonia data for the Intake site.

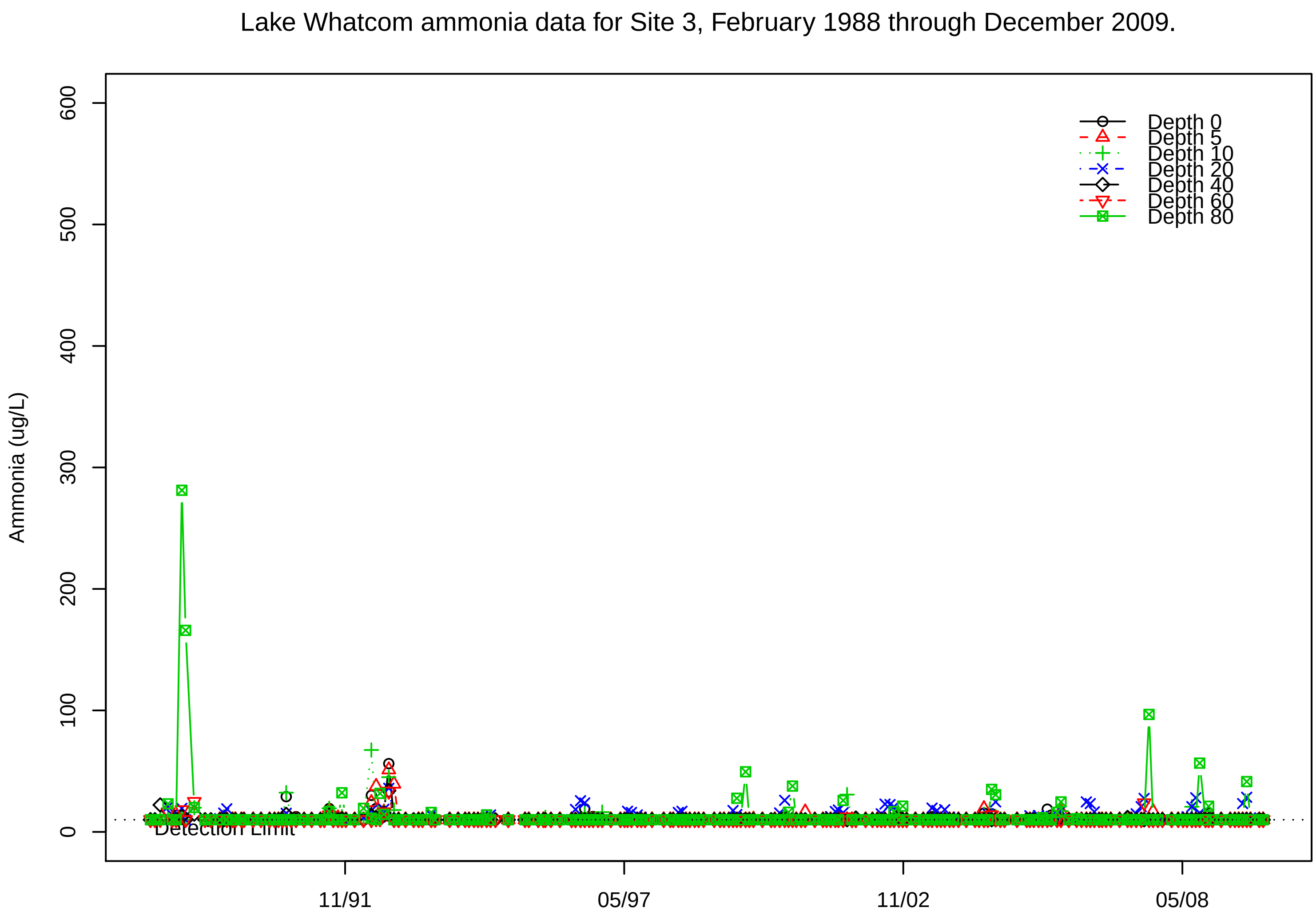


Figure B84: Lake Whatcom ammonia data for Site 3.

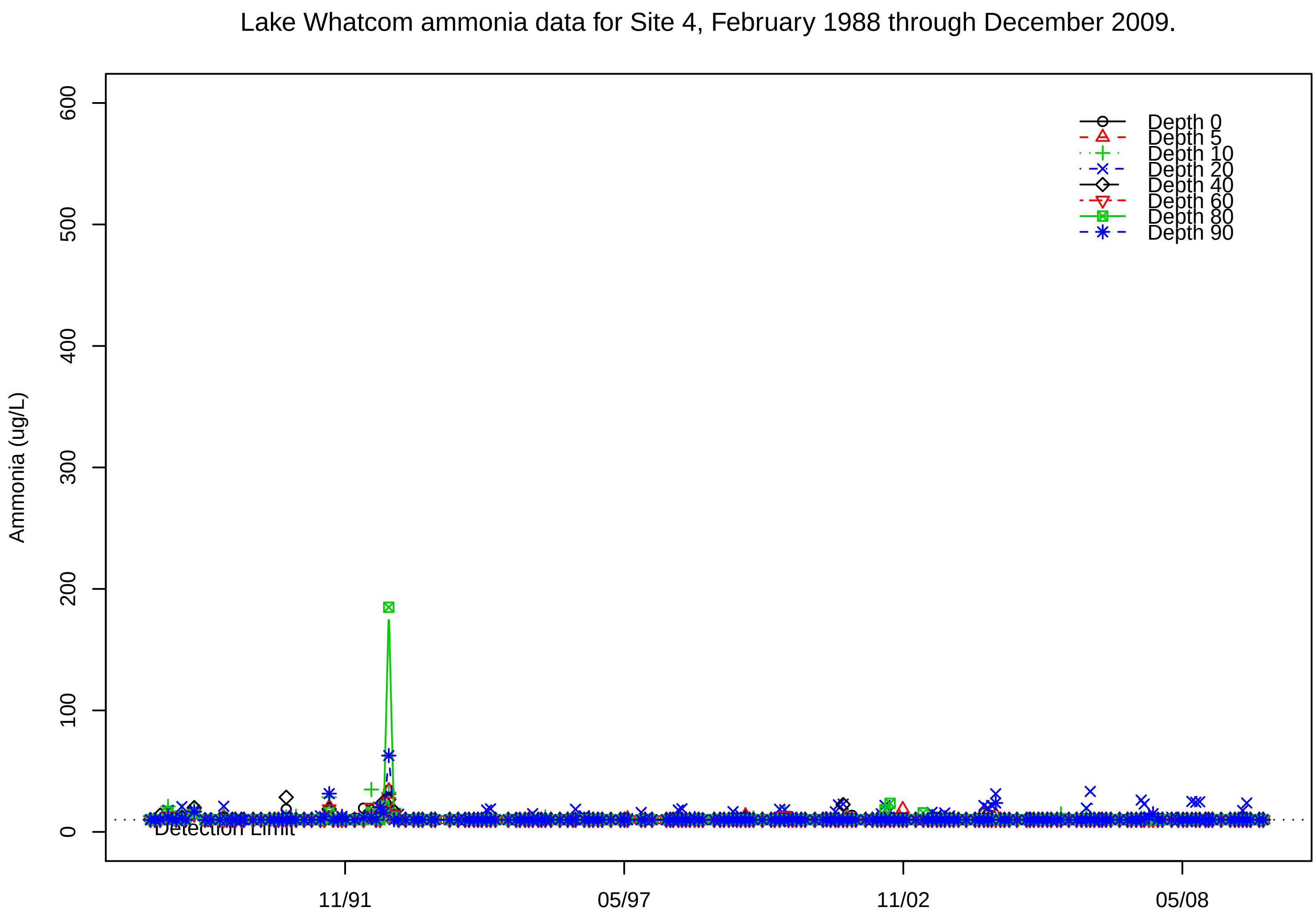


Figure B85: Lake Whatcom ammonia data for Site 4.

Lake Whatcom nitrate/nitrite data for Site 1, February 1988 through December 2009.

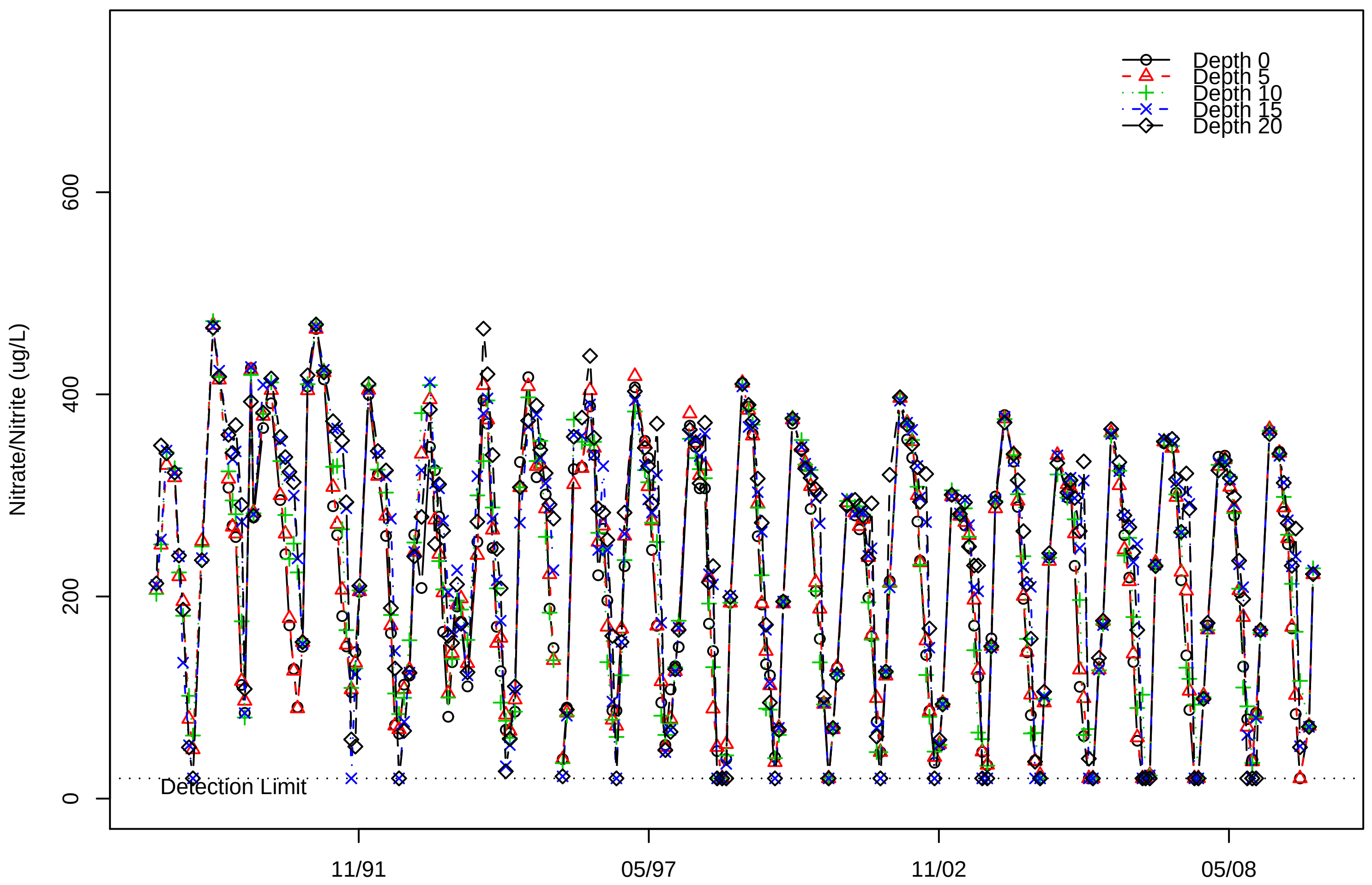


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.

Lake Whatcom nitrate/nitrite data for Site 2, February 1988 through December 2009.

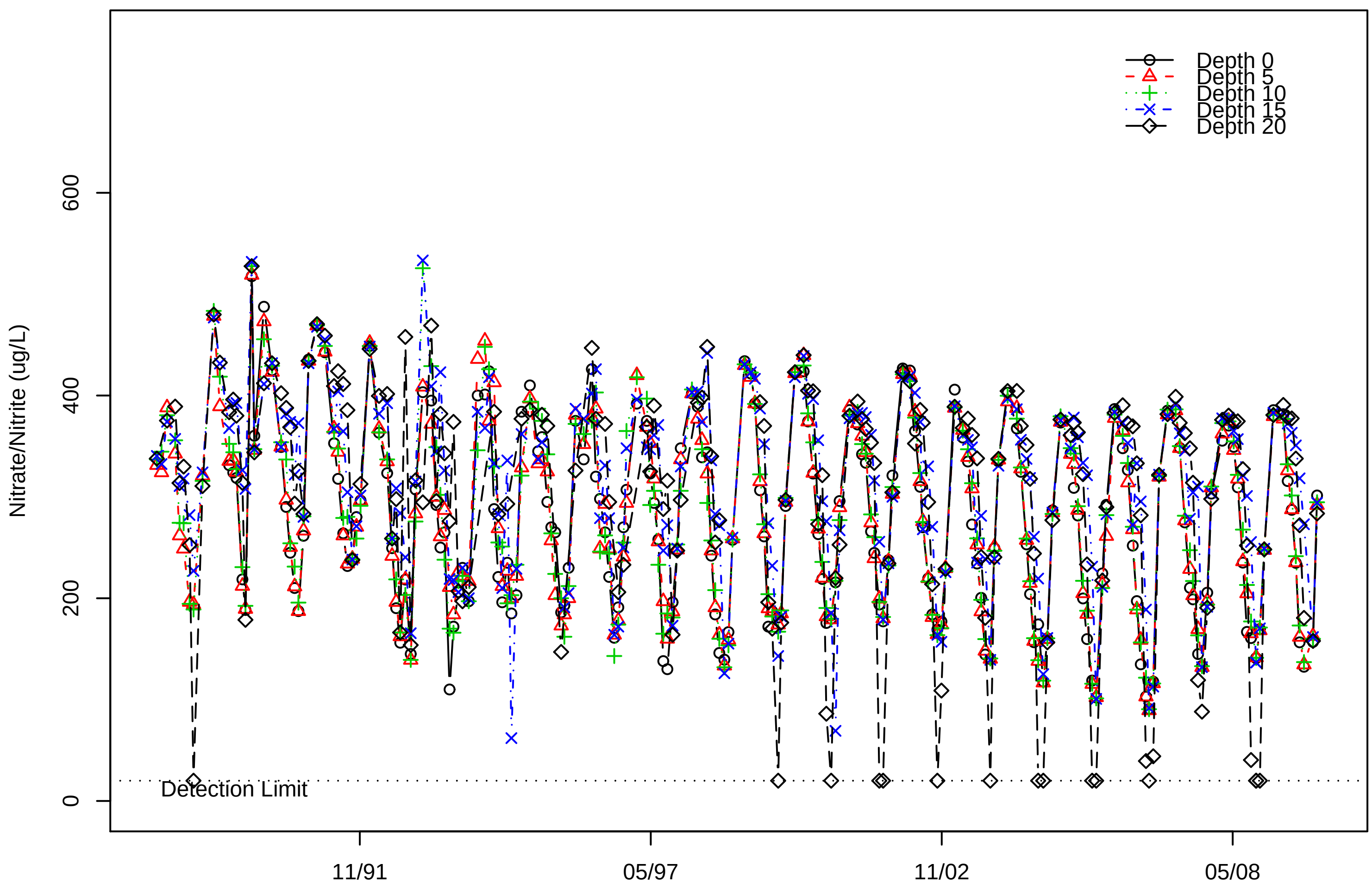


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

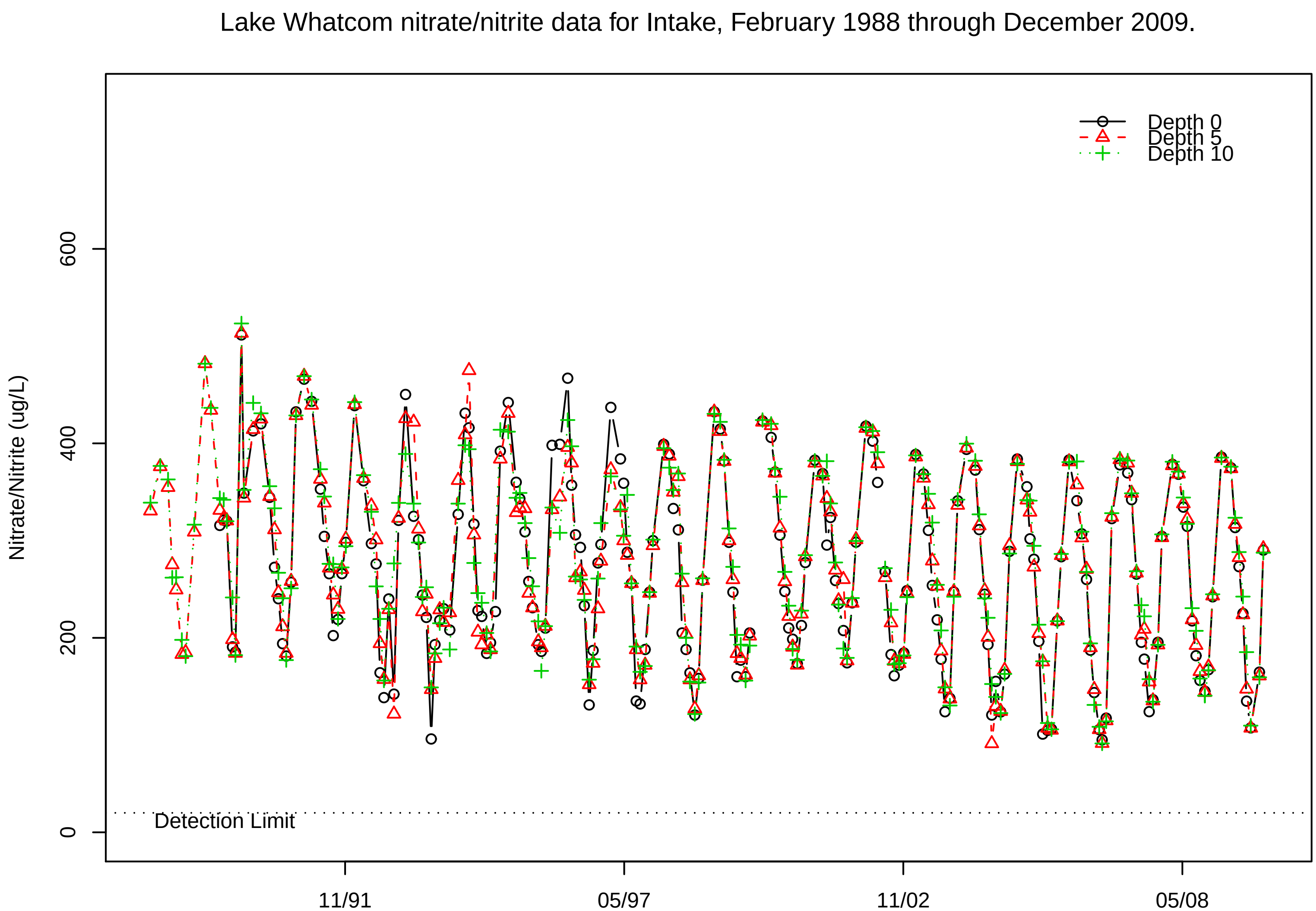


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

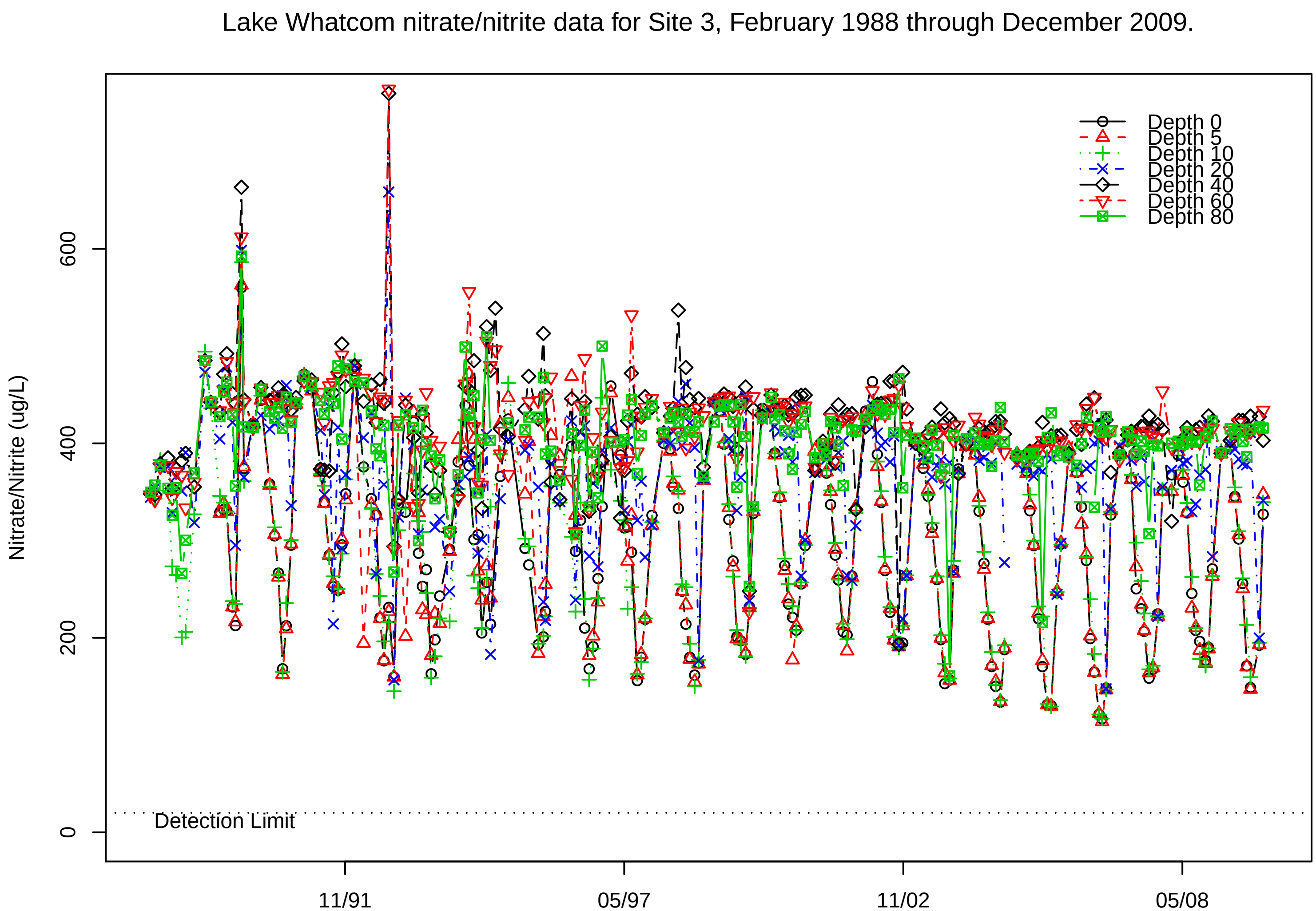


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

Lake Whatcom nitrate/nitrite data for Site 4, February 1988 through December 2009.

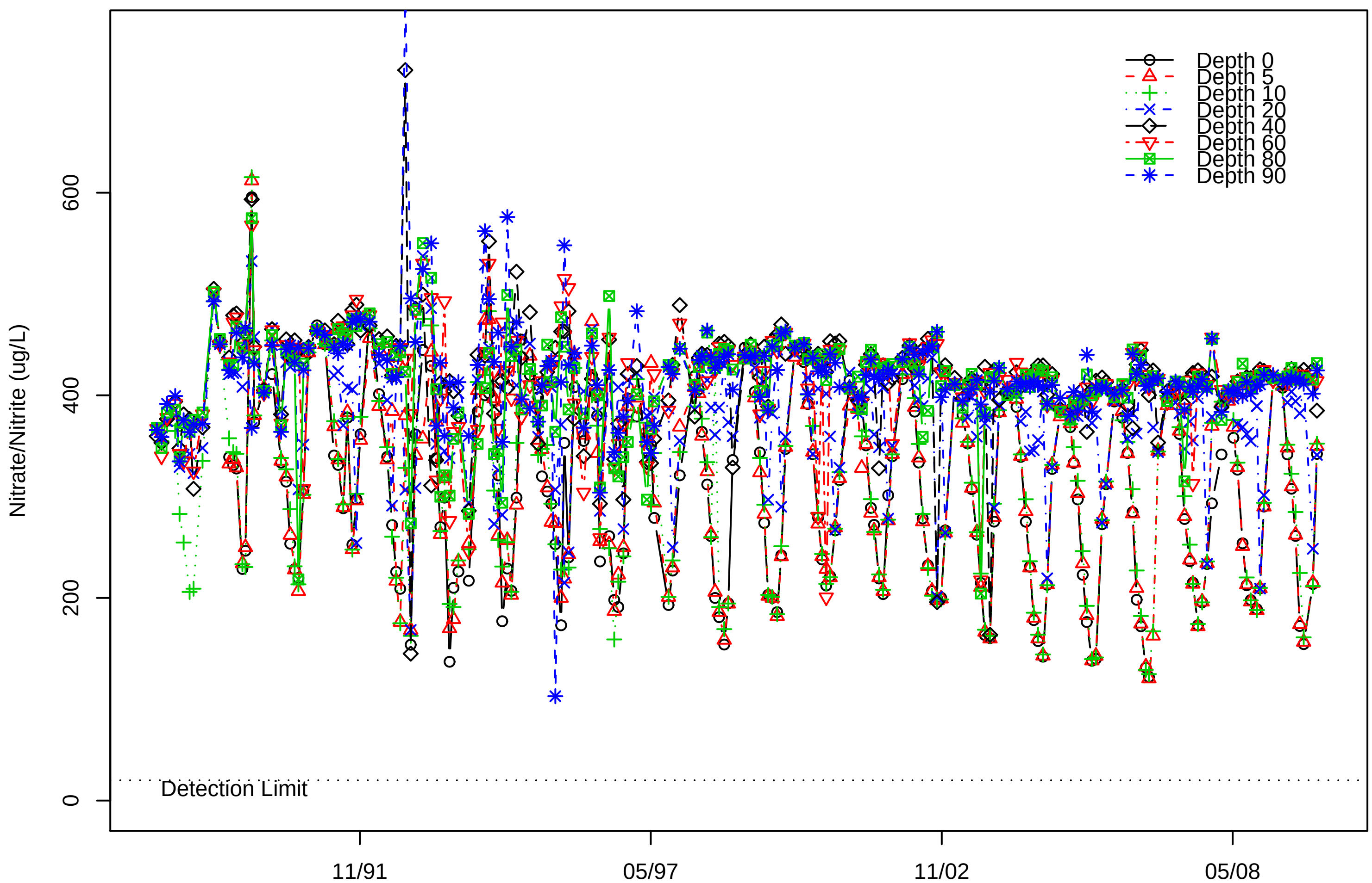


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4.

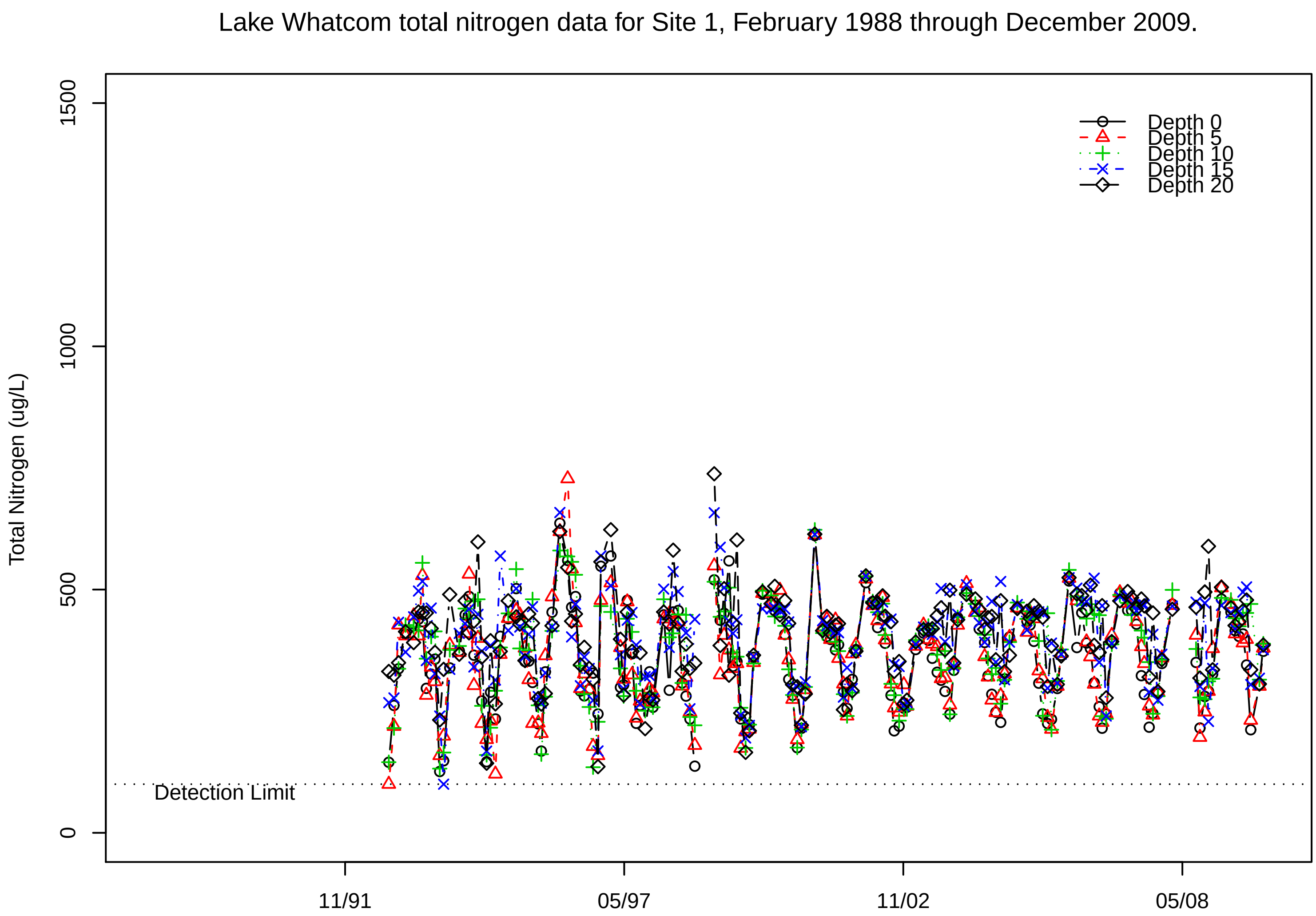


Figure B91: Lake Whatcom total nitrogen data for Site 1.

Lake Whatcom total nitrogen data for Site 2, February 1988 through December 2009.

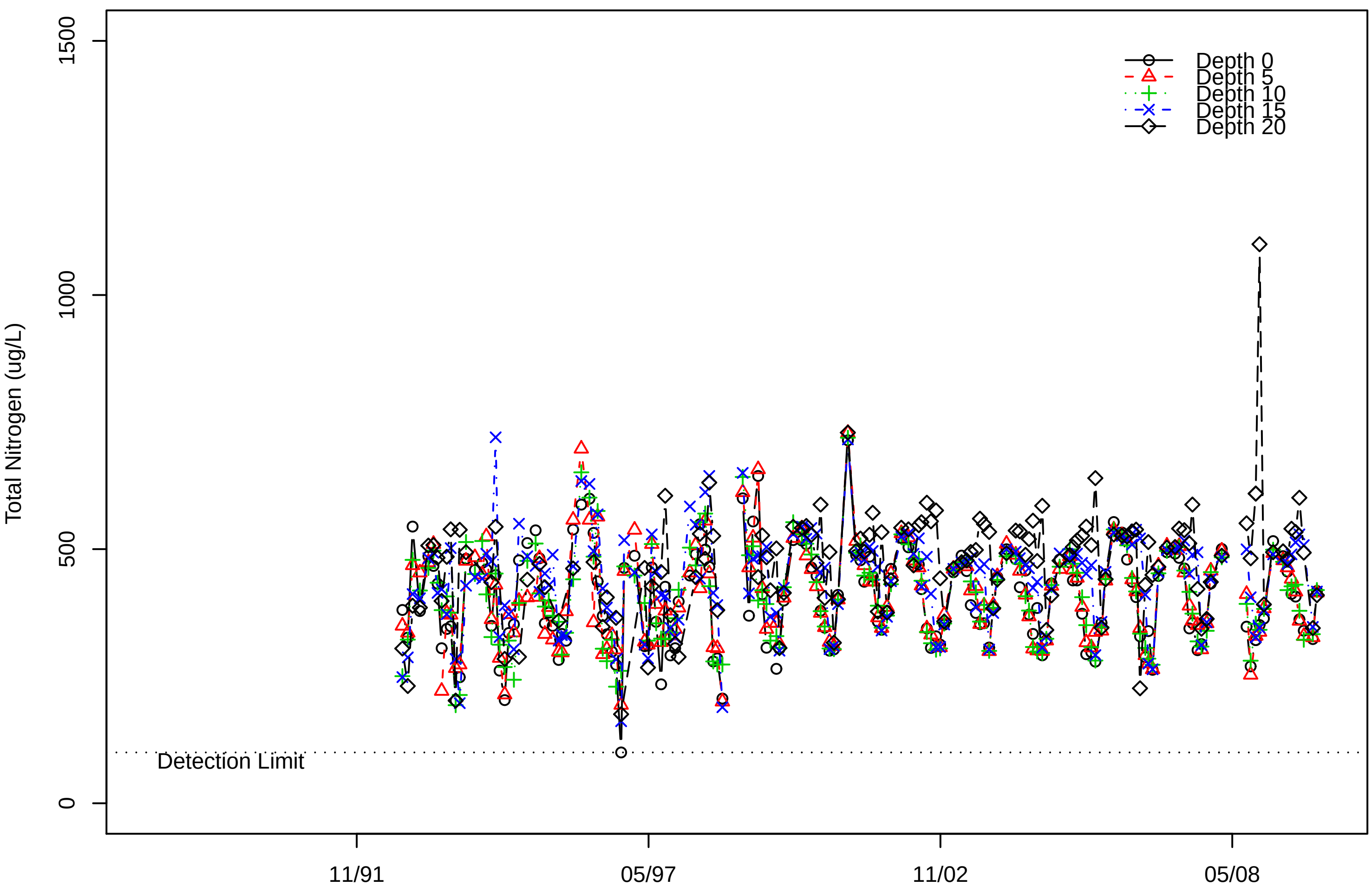


Figure B92: Lake Whatcom total nitrogen data for Site 2.

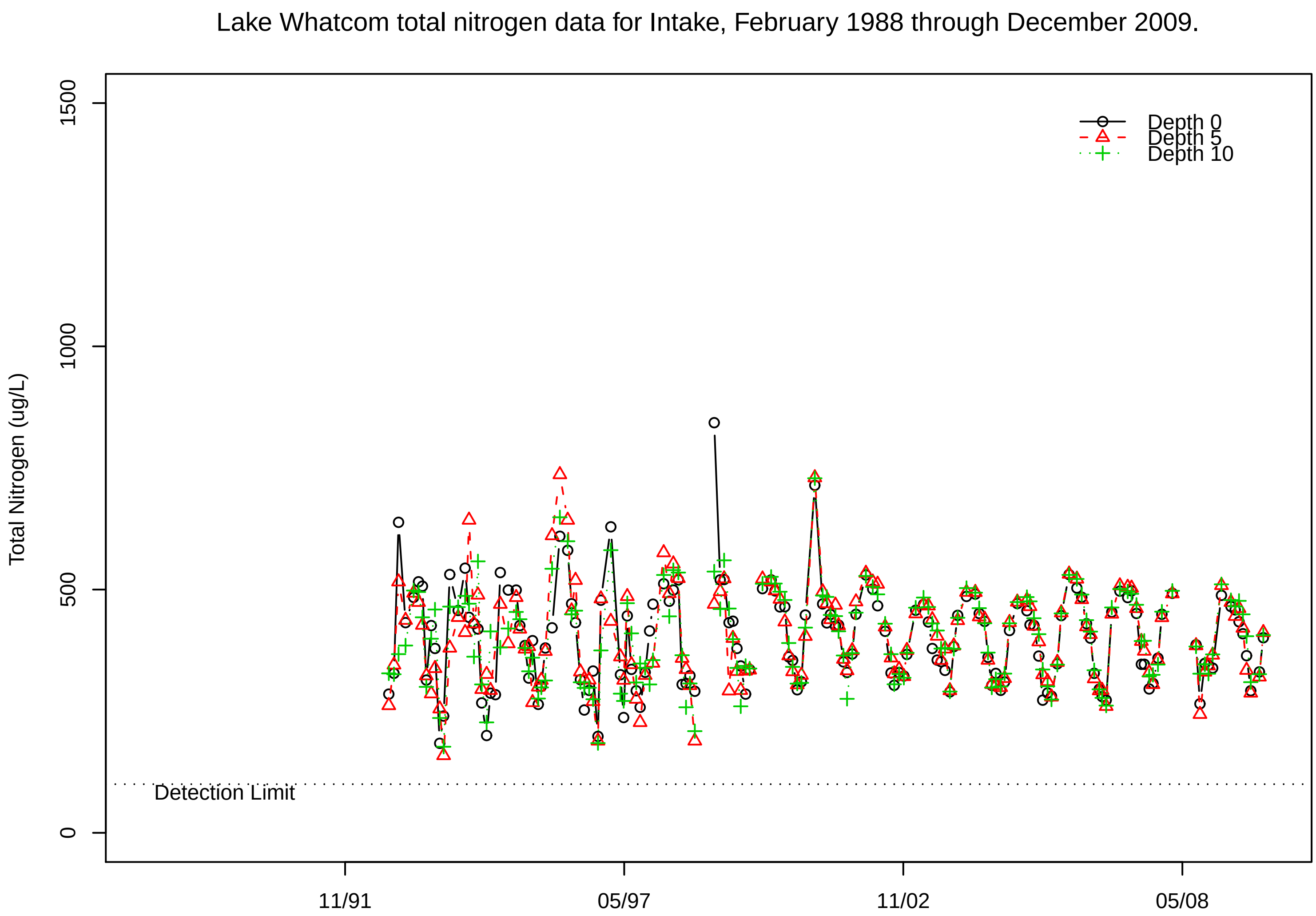


Figure B93: Lake Whatcom total nitrogen data for the Intake site.

Lake Whatcom total nitrogen data for Site 3, February 1988 through December 2009.

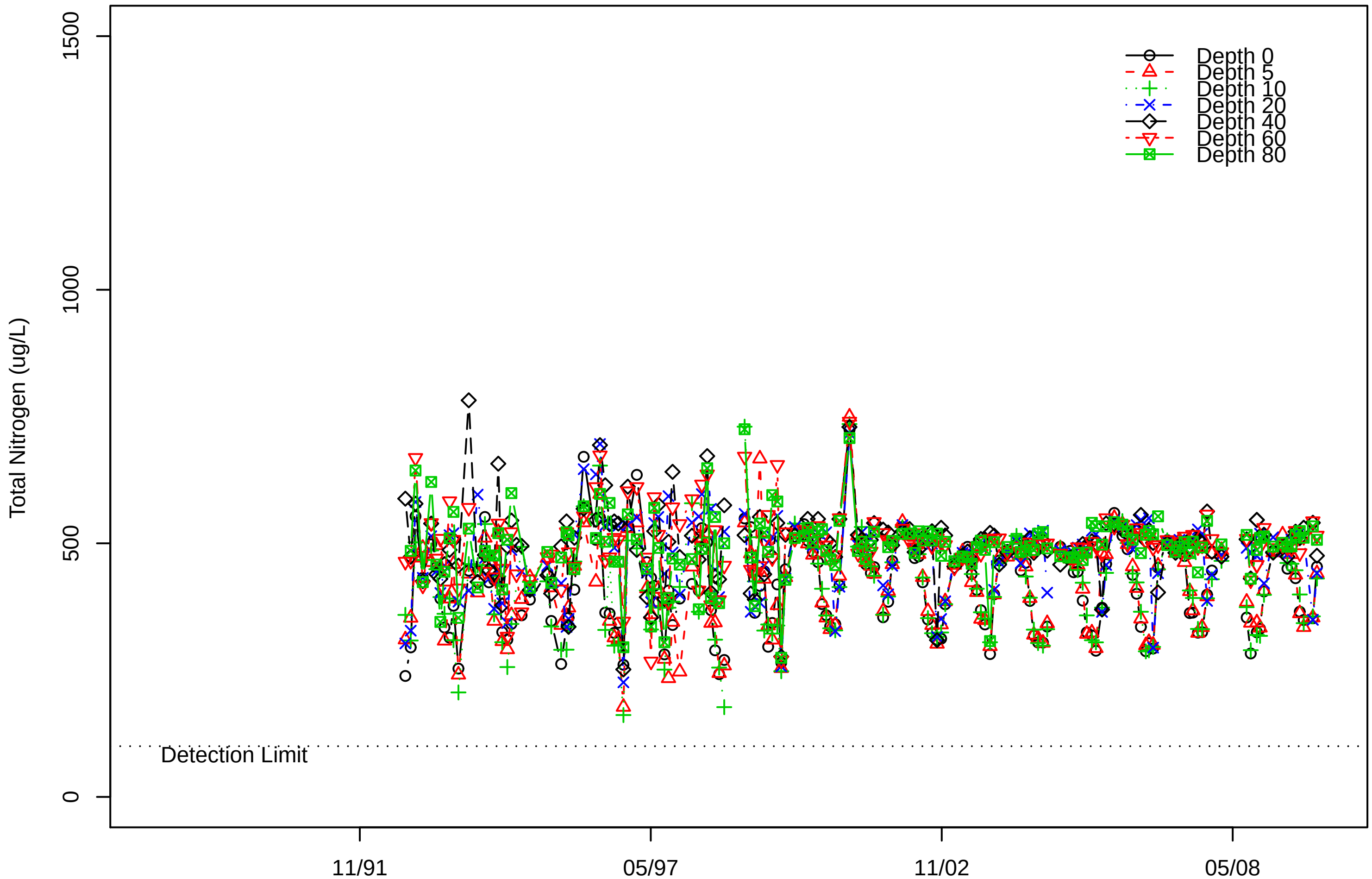


Figure B94: Lake Whatcom total nitrogen data for Site 3.

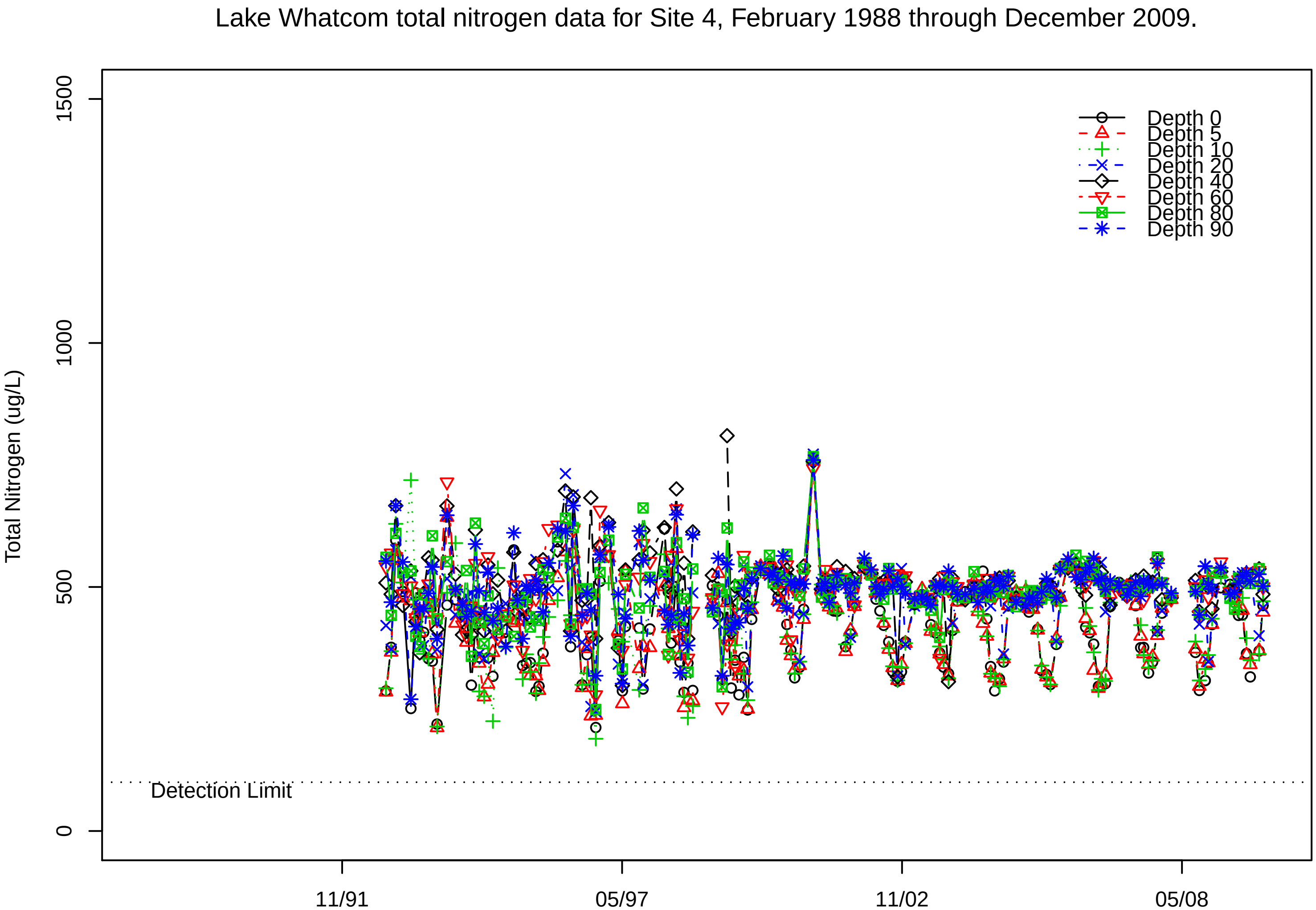


Figure B95: Lake Whatcom total nitrogen data for Site 4.

Lake Whatcom soluble reactive phosphate data for Site 1, February 1988 through December 2009.

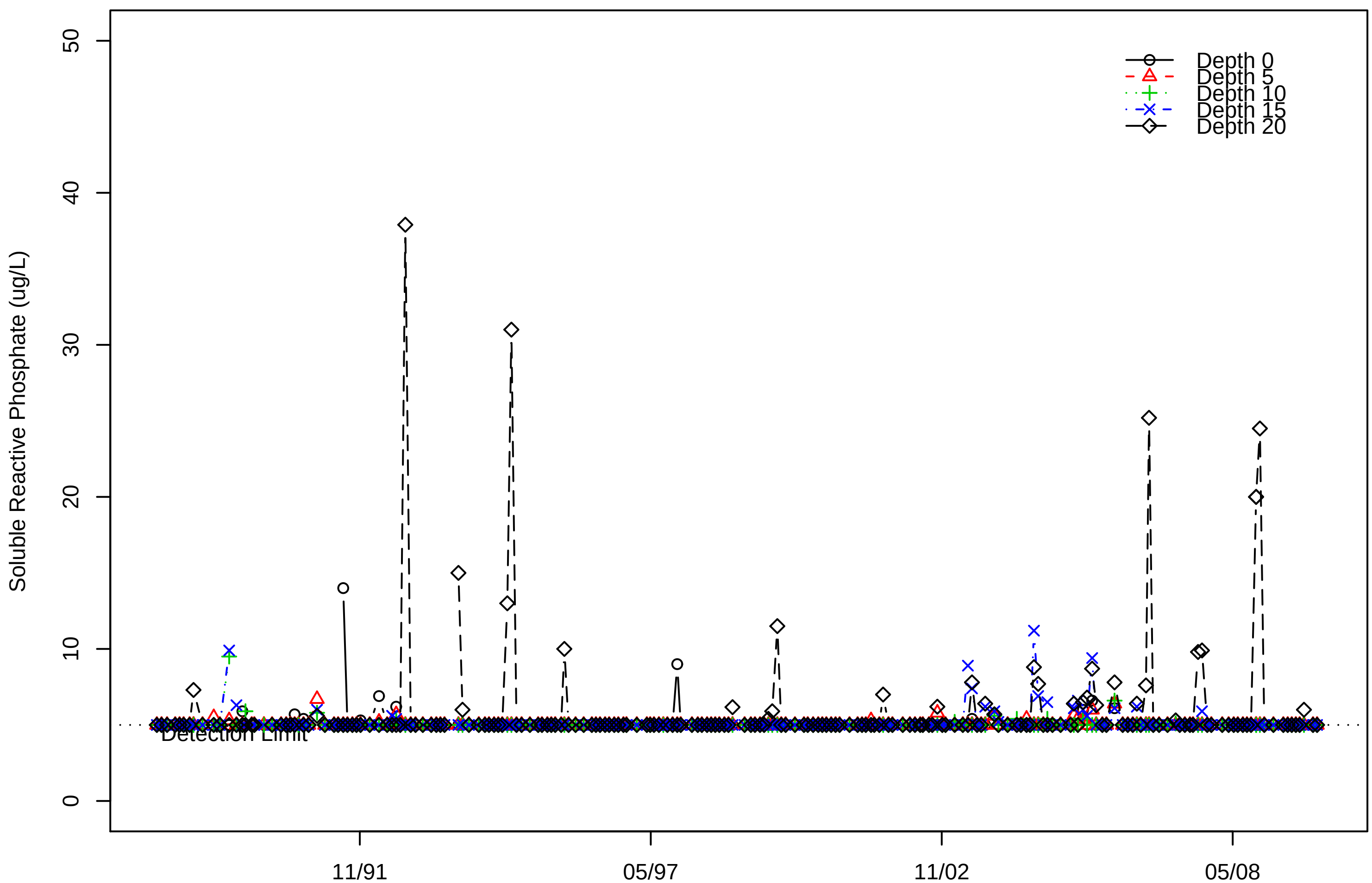


Figure B96: Lake Whatcom soluble phosphate data for Site 1.

Lake Whatcom soluble reactive phosphate data for Site 2, February 1988 through December 2009.

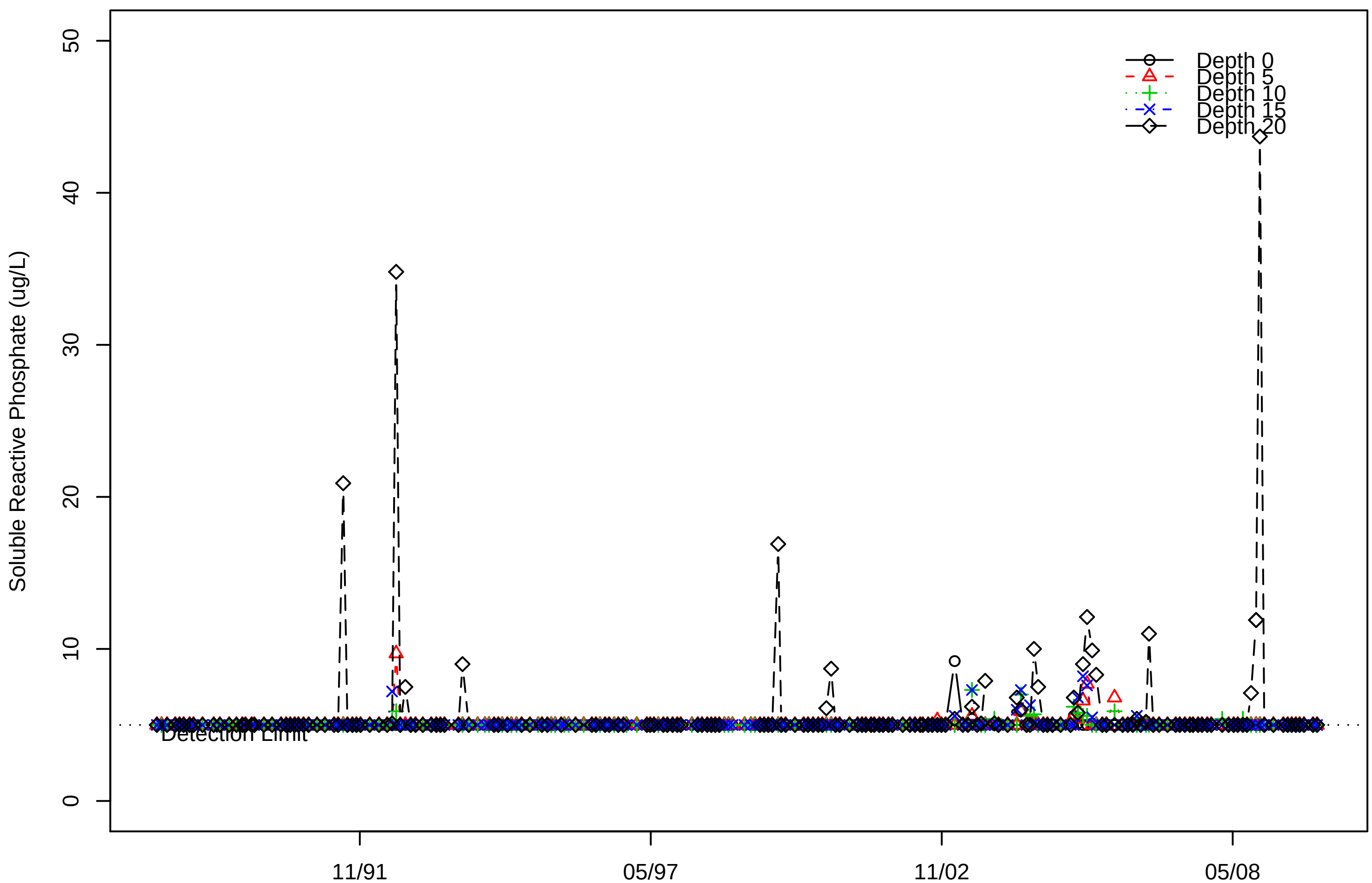


Figure B97: Lake Whatcom soluble phosphate data for Site 2.

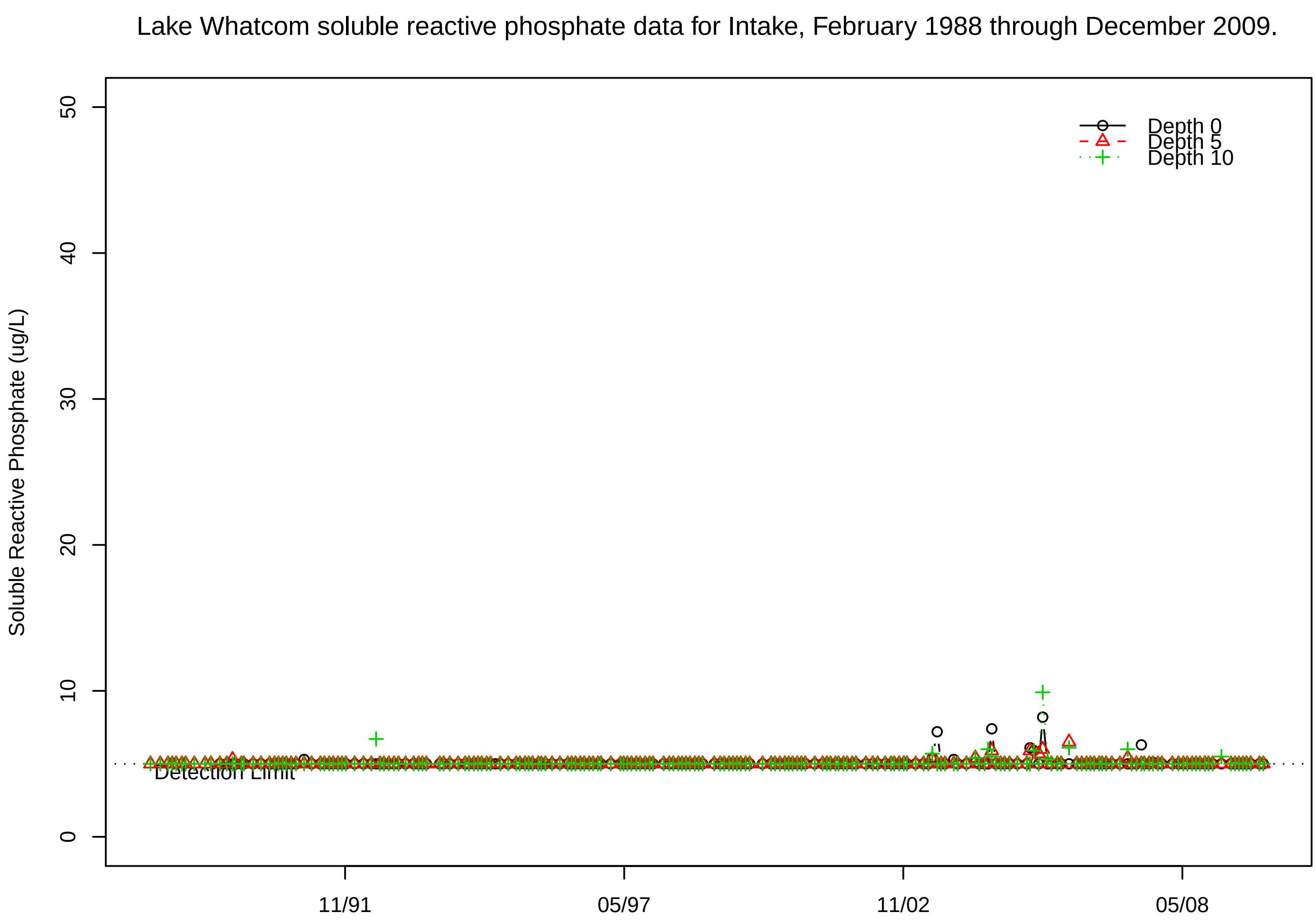


Figure B98: Lake Whatcom soluble reactive phosphate data for the Intake site.

Lake Whatcom soluble reactive phosphate data for Site 3, February 1988 through December 2009.

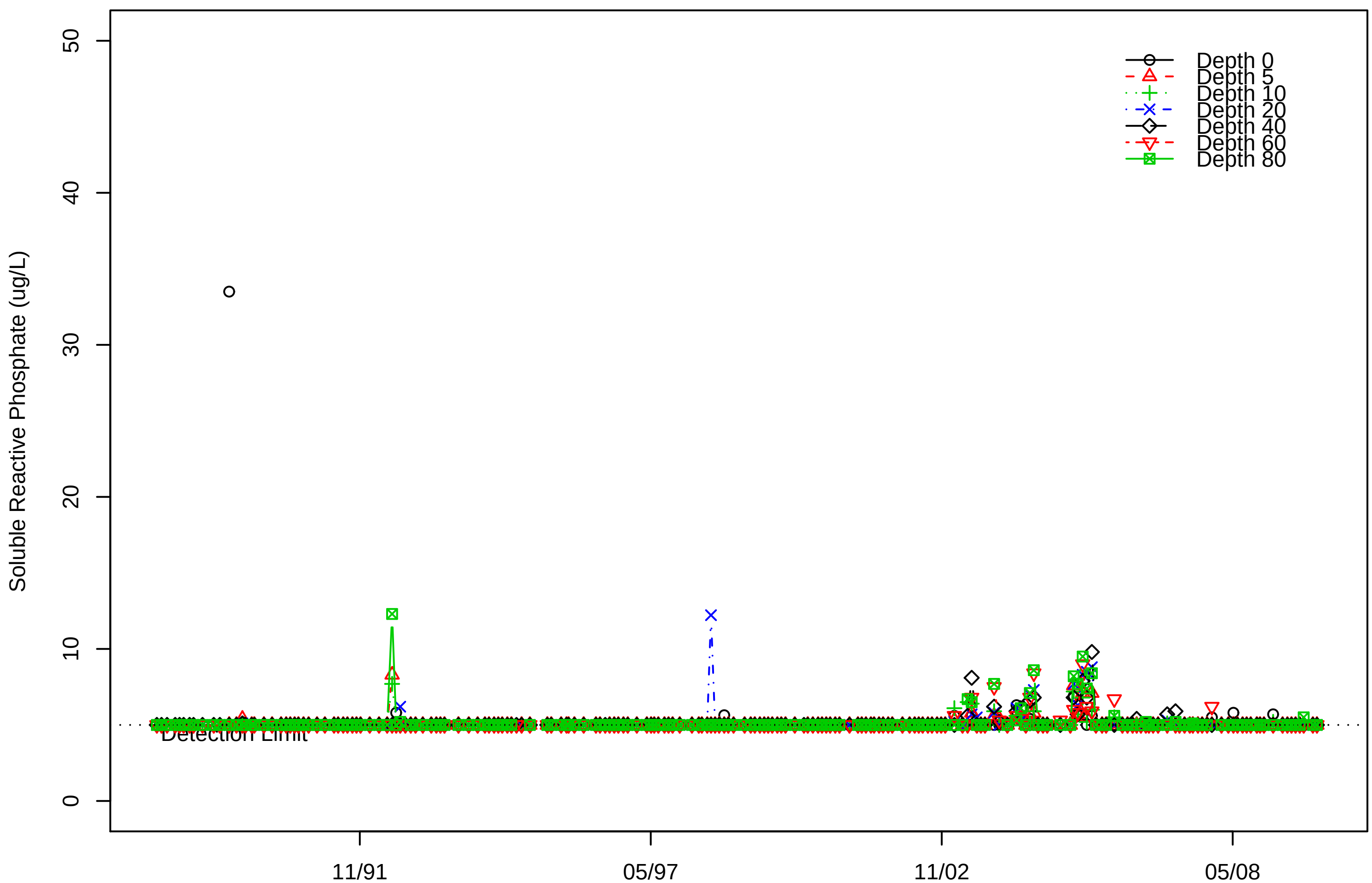


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

Lake Whatcom soluble reactive phosphate data for Site 4, February 1988 through December 2009.

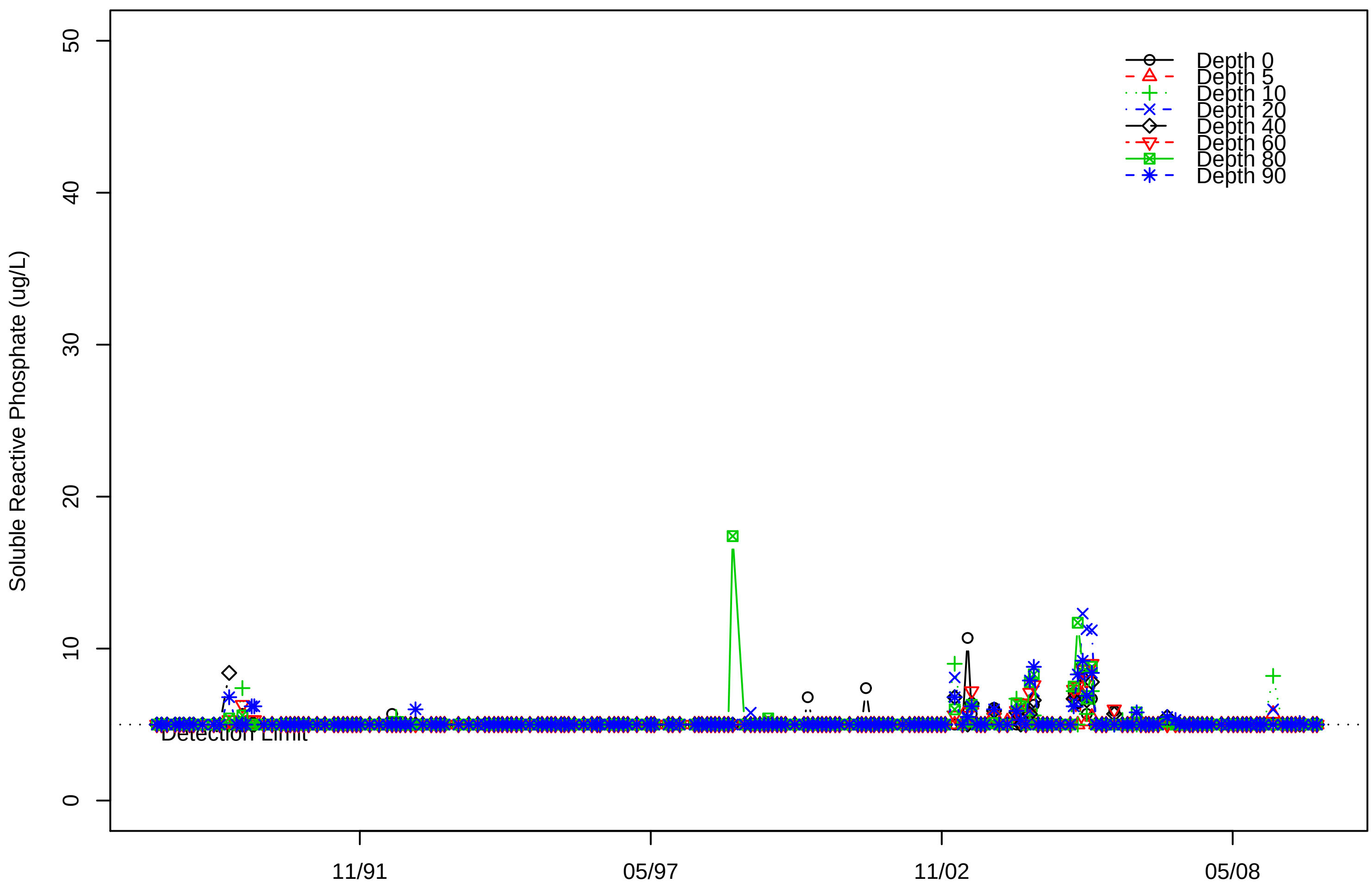


Figure B100: Lake Whatcom soluble phosphate data for Site 4.

Lake Whatcom total phosphorus data for Site 1, February 1988 through December 2009.

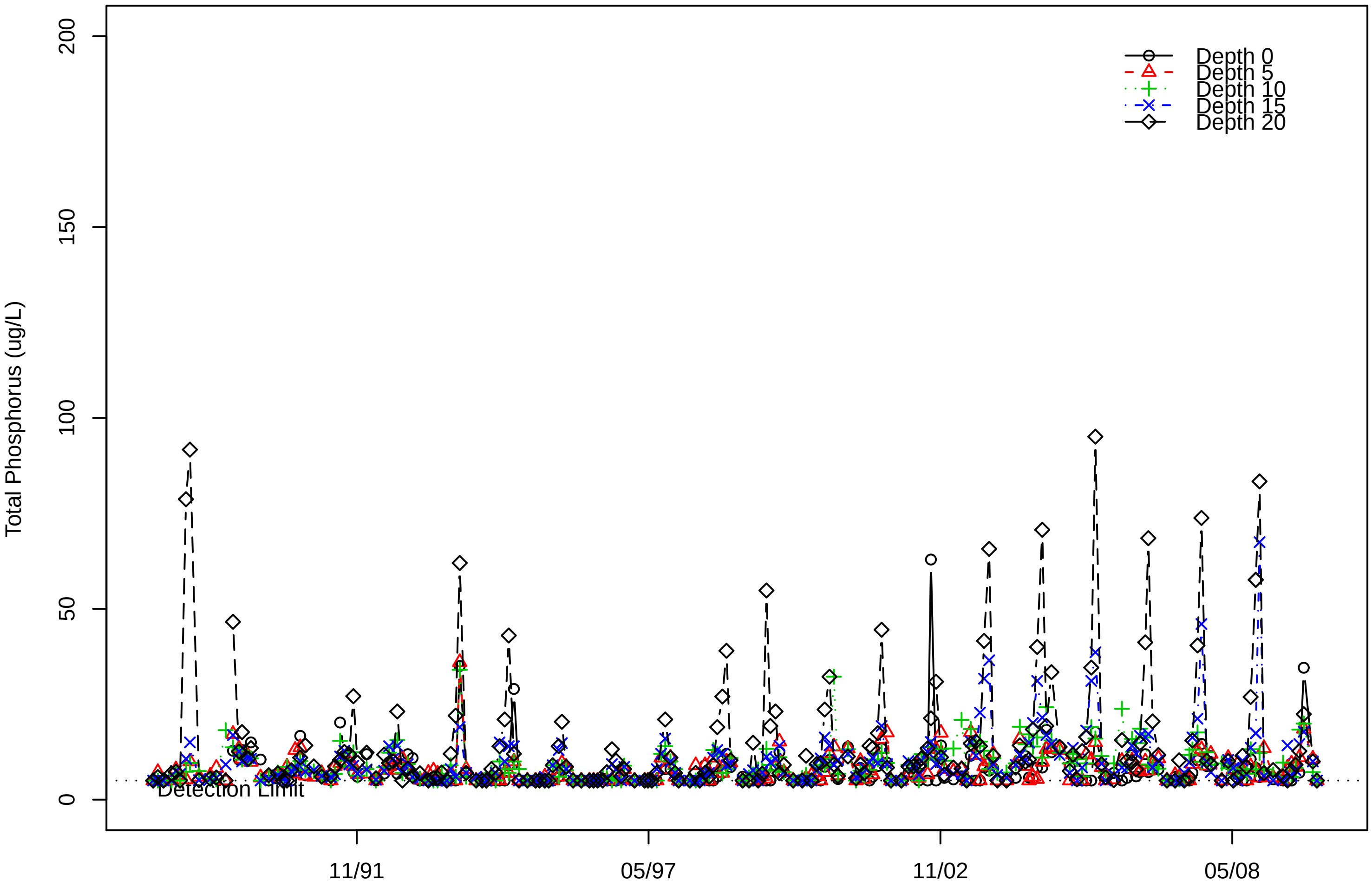


Figure B101: Lake Whatcom total phosphorus data for Site 1.

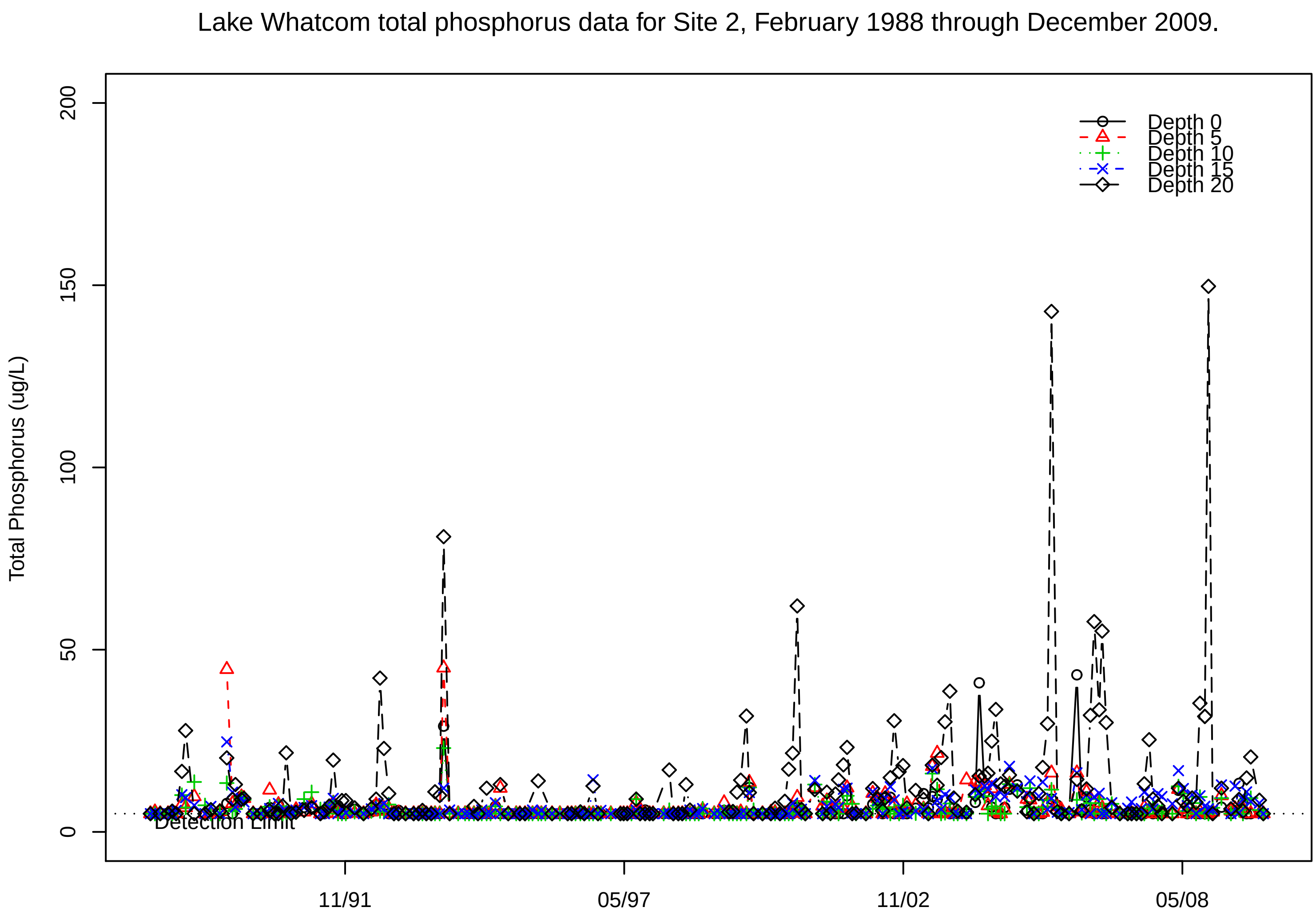


Figure B102: Lake Whatcom total phosphorus data for Site 2.

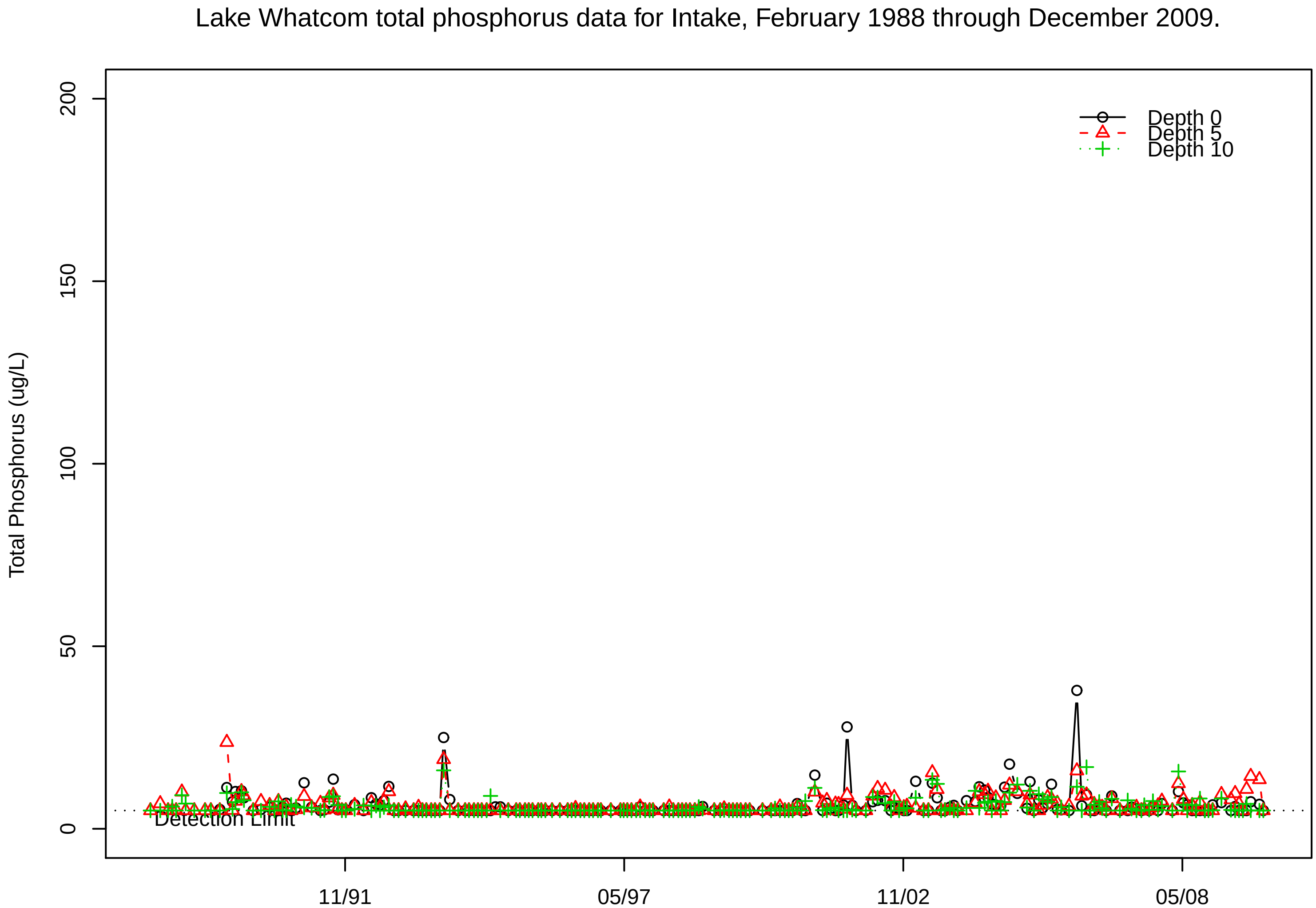


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

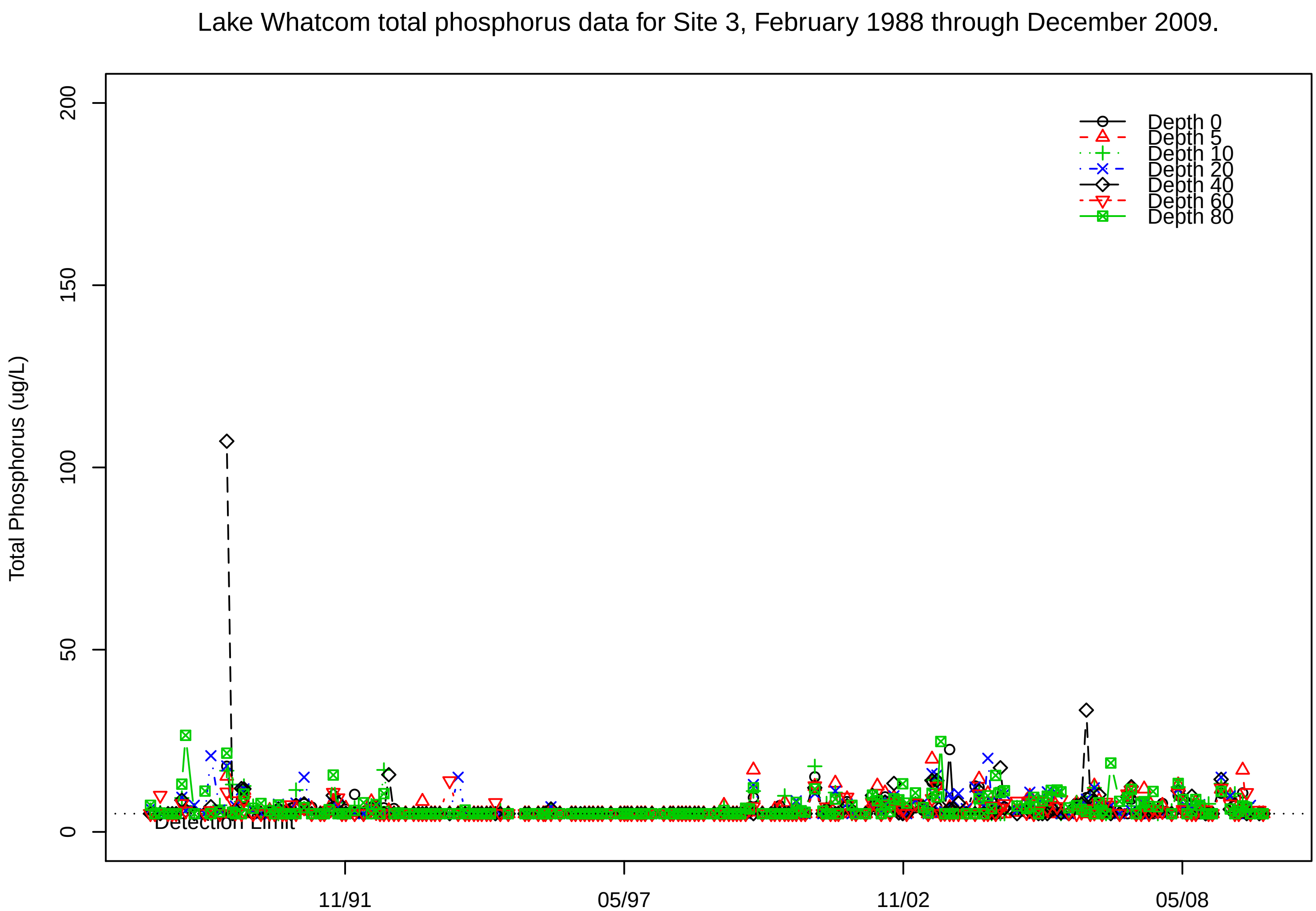


Figure B104: Lake Whatcom total phosphorus data for Site 3.

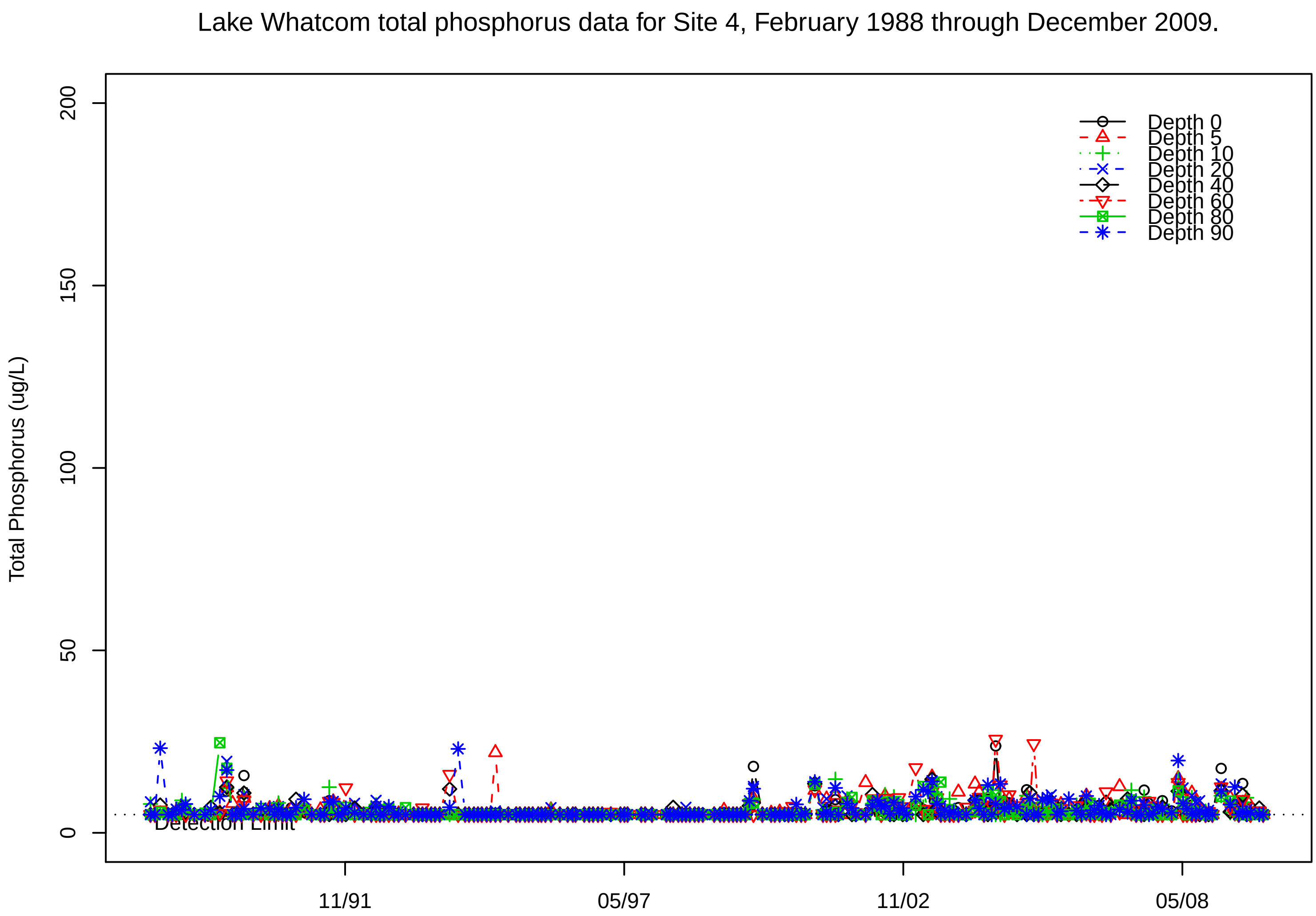


Figure B105: Lake Whatcom total phosphorus data for Site 4.

Lake Whatcom chlorophyll a data for Site 1, February 1988 through December 2009.

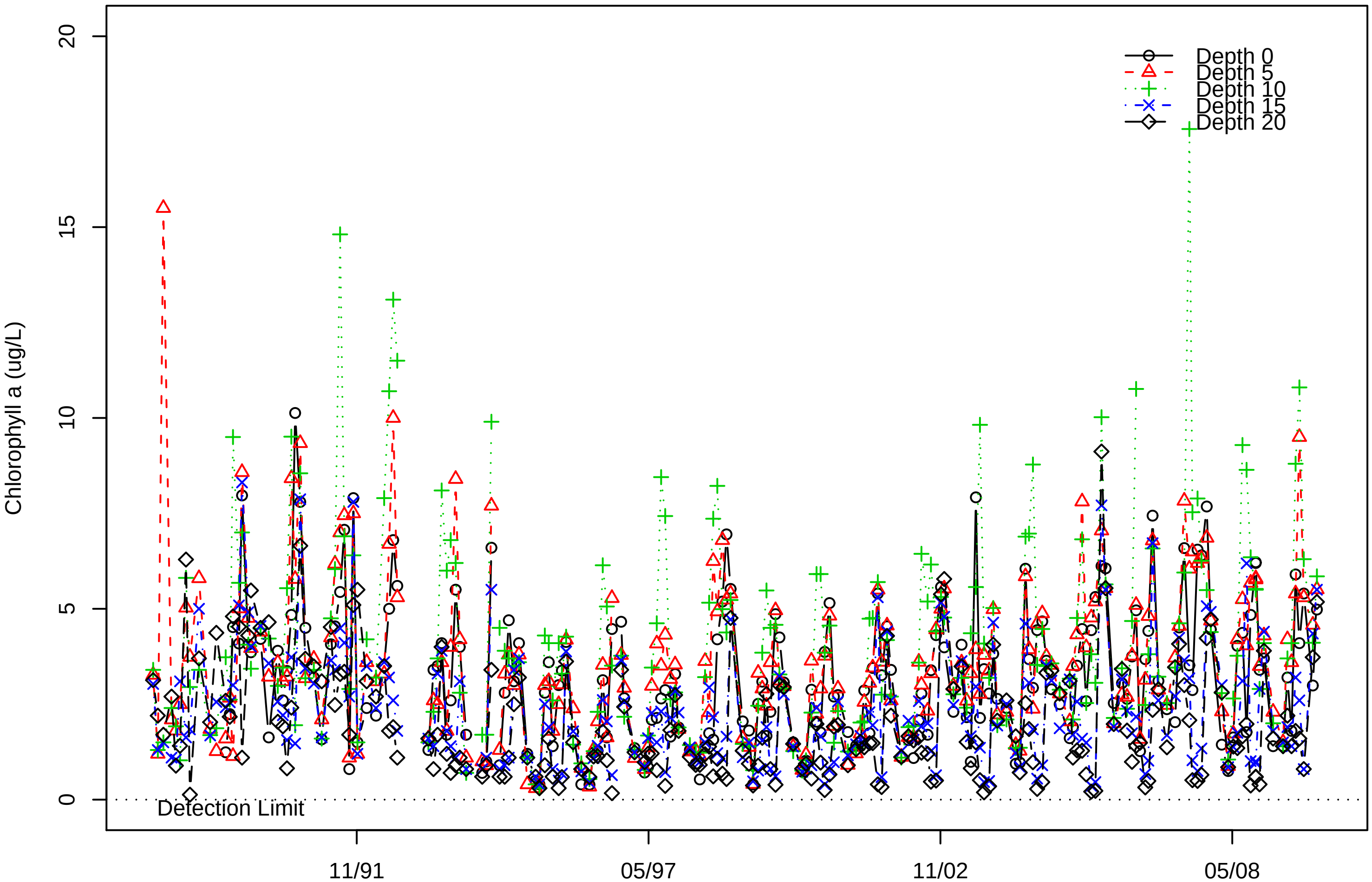


Figure B106: Lake Whatcom chlorophyll data for Site 1.

Lake Whatcom chlorophyll a data for Site 2, February 1988 through December 2009.

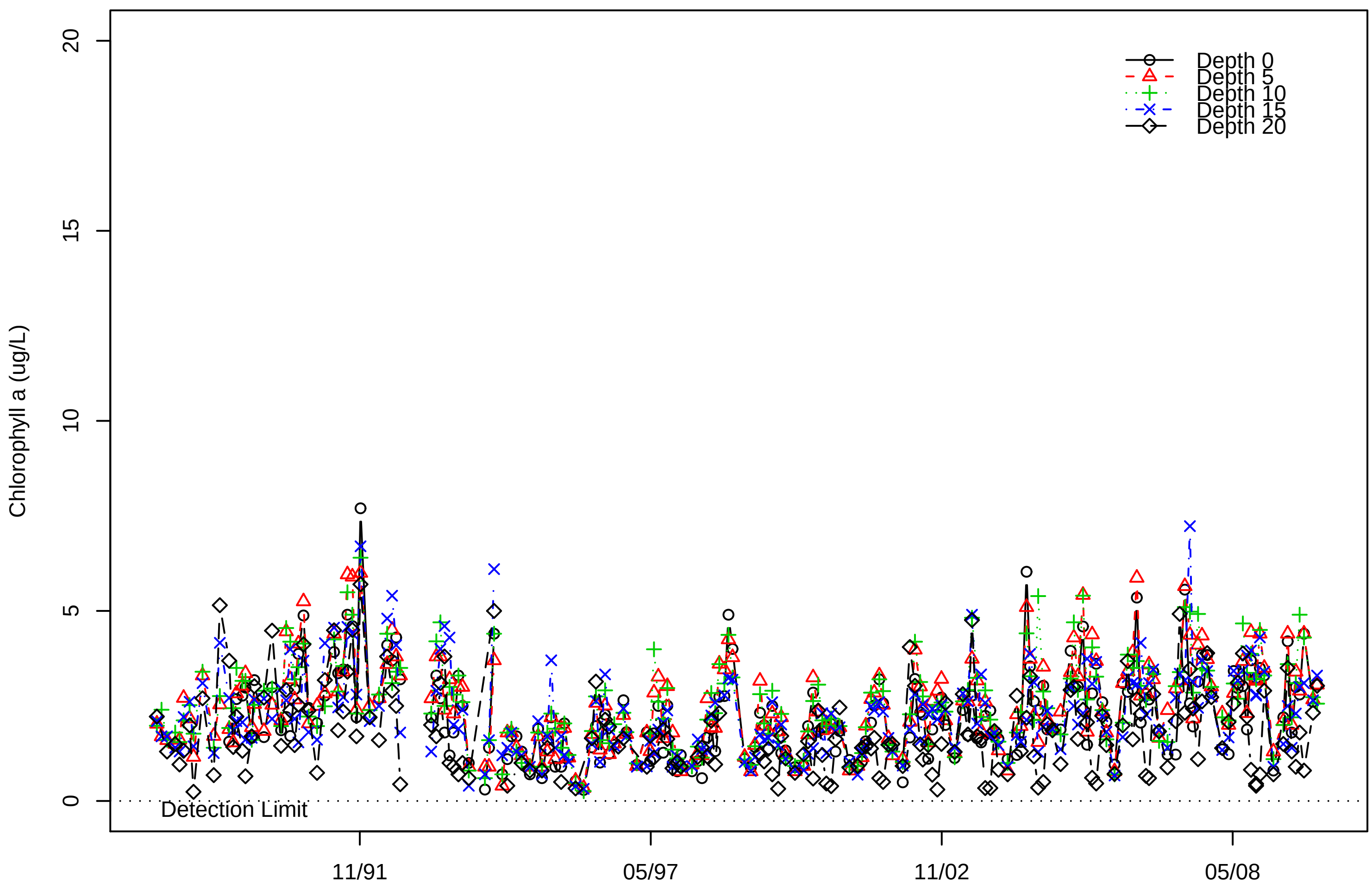


Figure B107: Lake Whatcom chlorophyll data for Site 2.

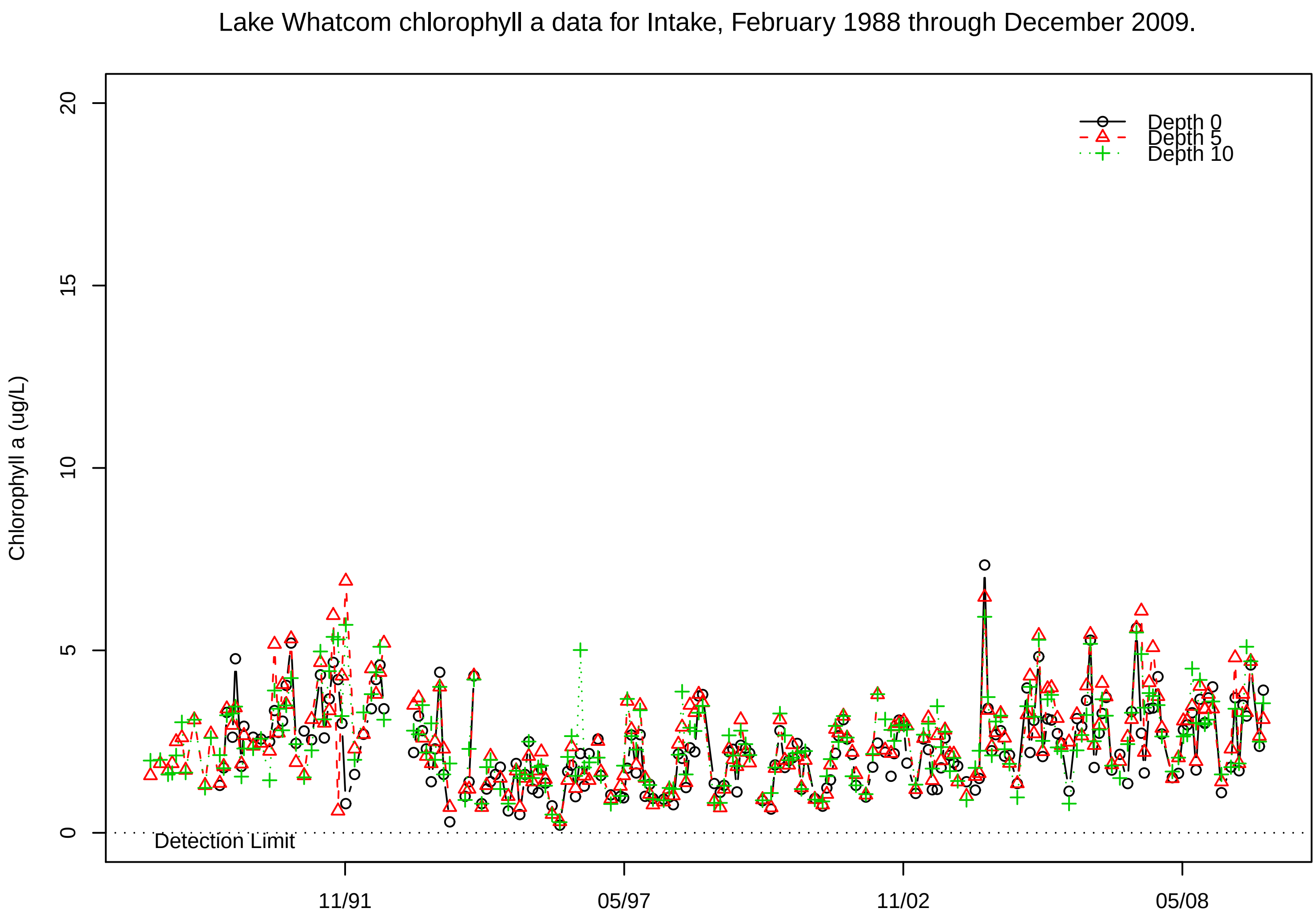


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

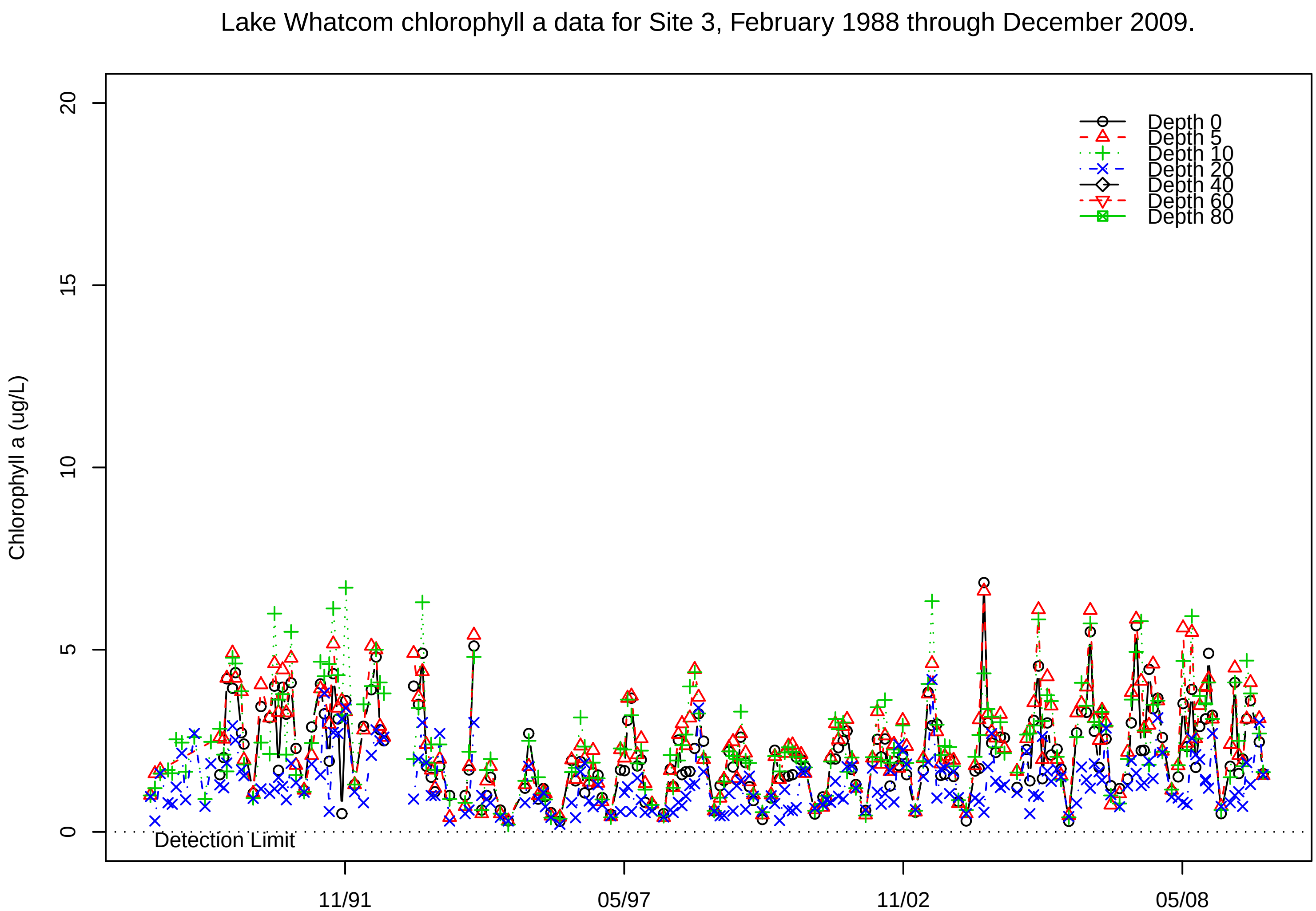


Figure B109: Lake Whatcom chlorophyll data for Site 3.

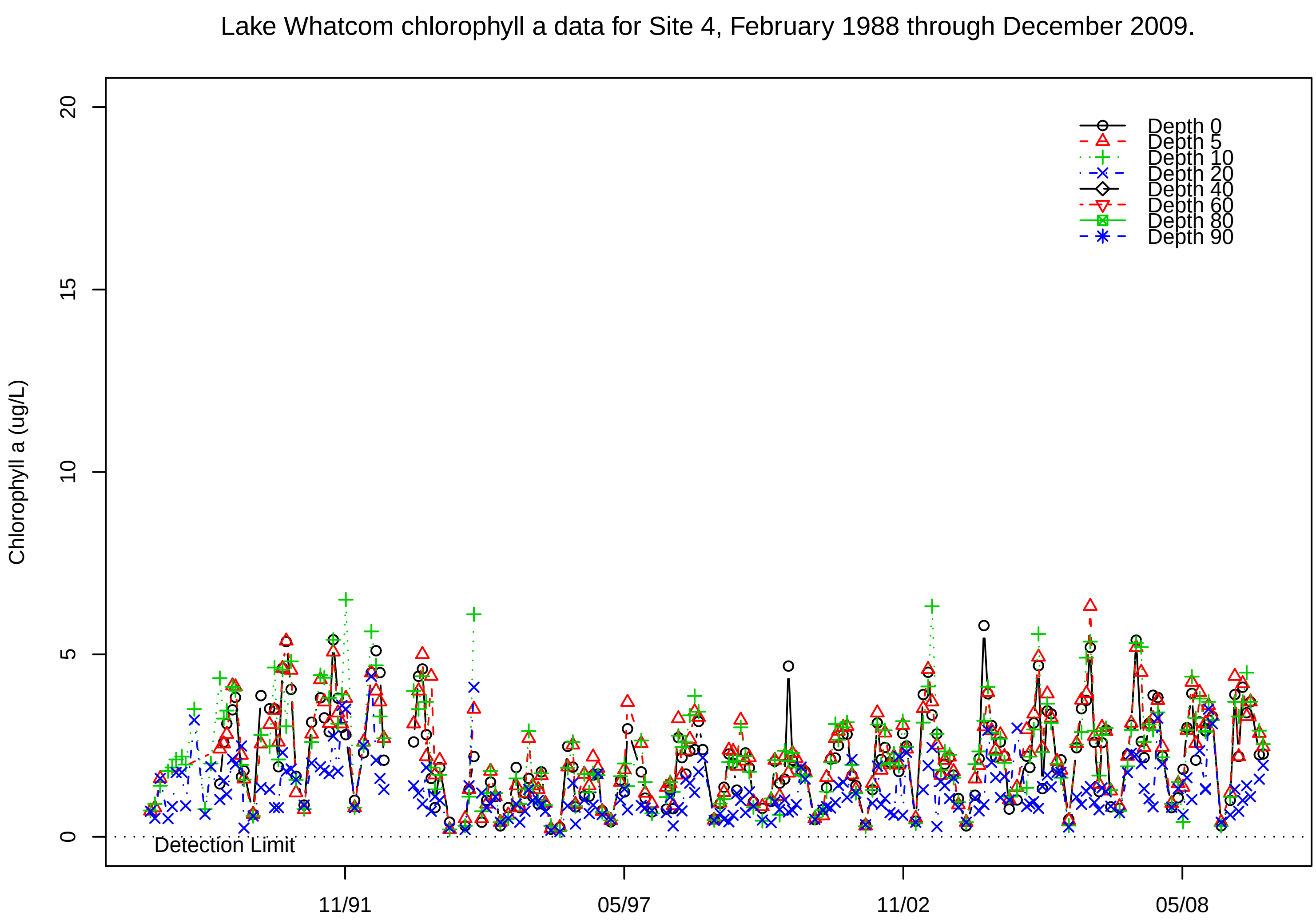


Figure B110: Lake Whatcom chlorophyll data for Site 4.

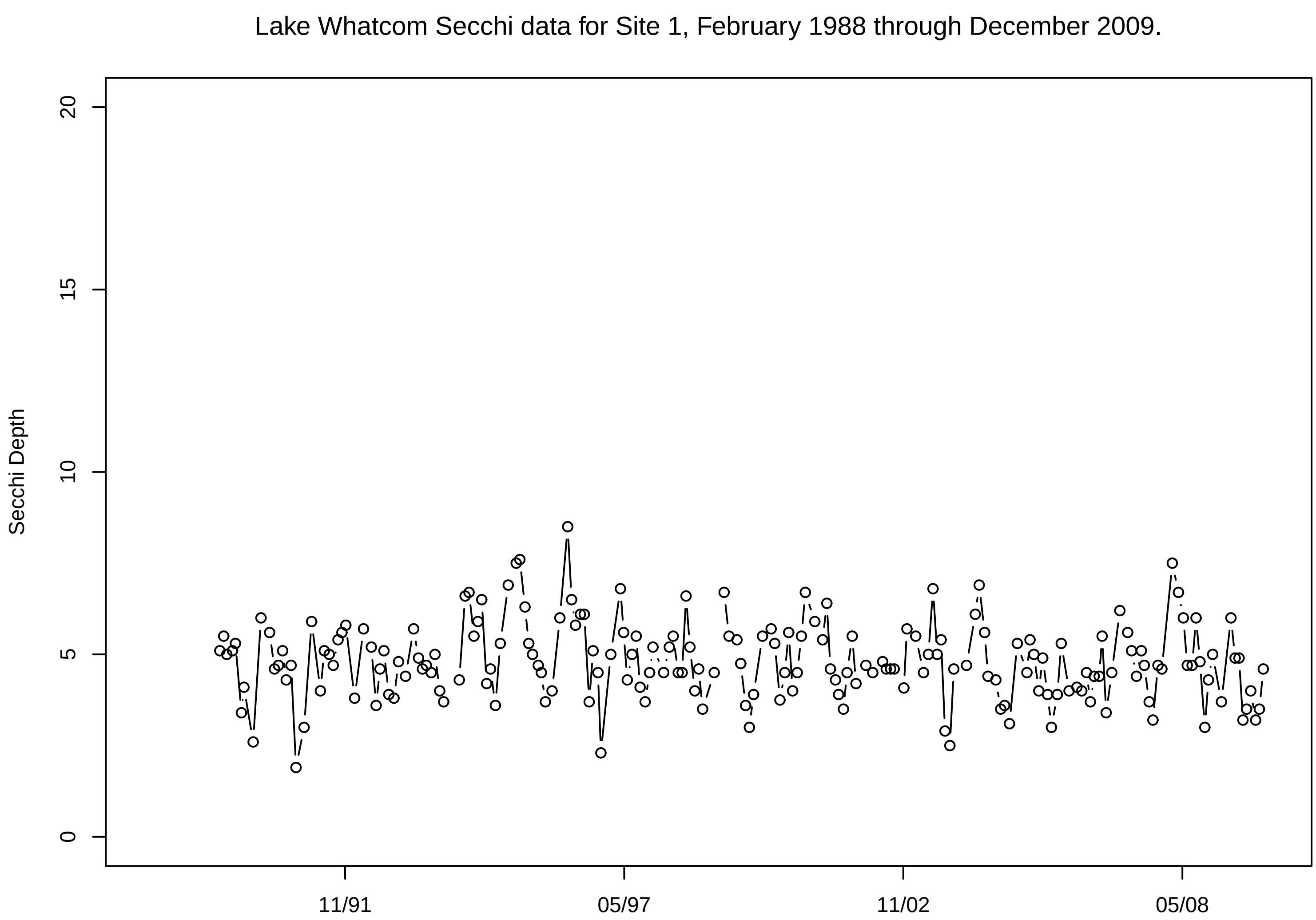


Figure B111: Lake Whatcom Secchi depths for Site 1.

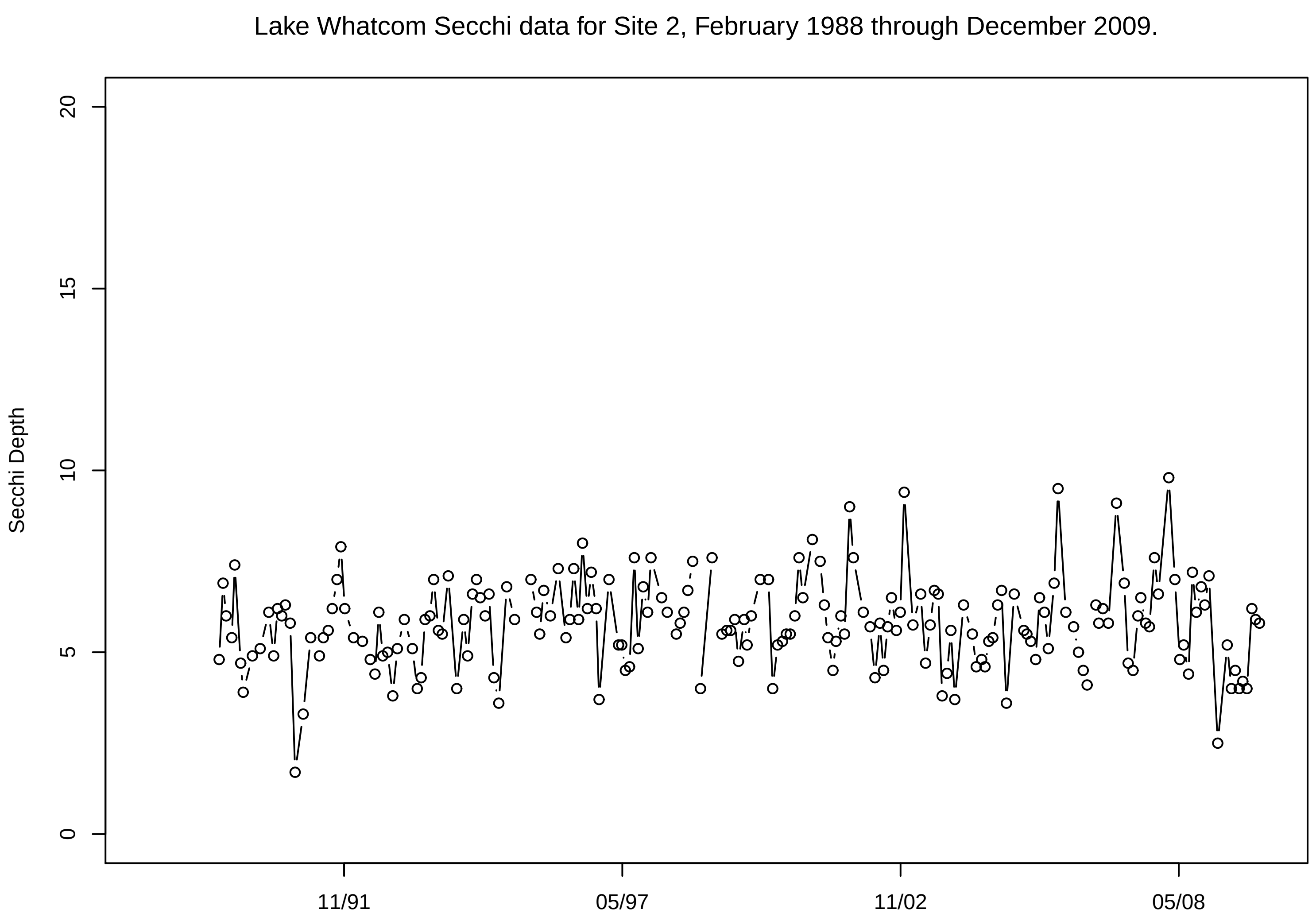


Figure B112: Lake Whatcom Secchi depths for Site 2.

Lake Whatcom Secchi data for Intake, February 1988 through December 2009.

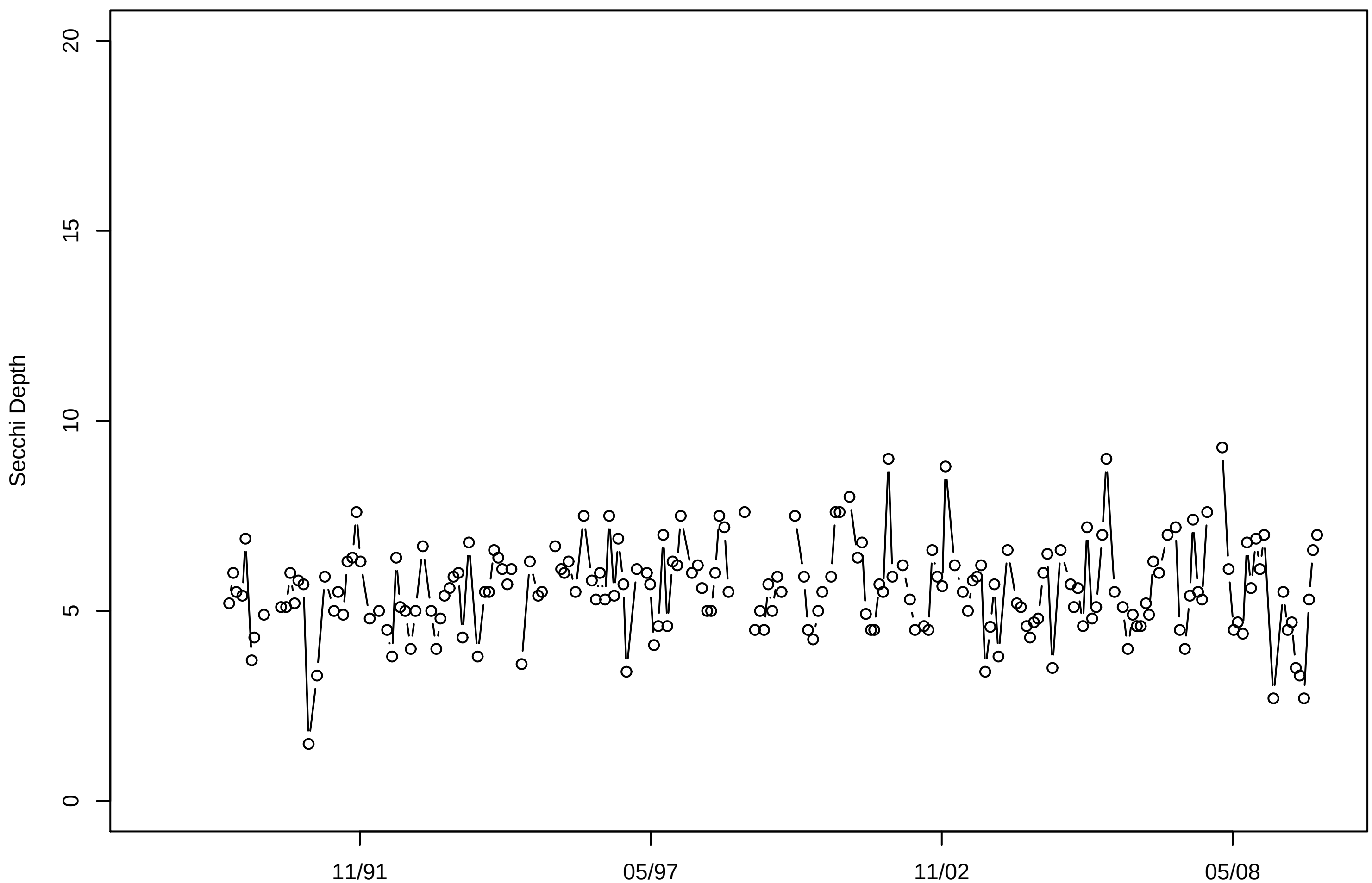


Figure B113: Lake Whatcom Secchi depths for the Intake site.

Lake Whatcom Secchi data for Site 3, February 1988 through December 2009.

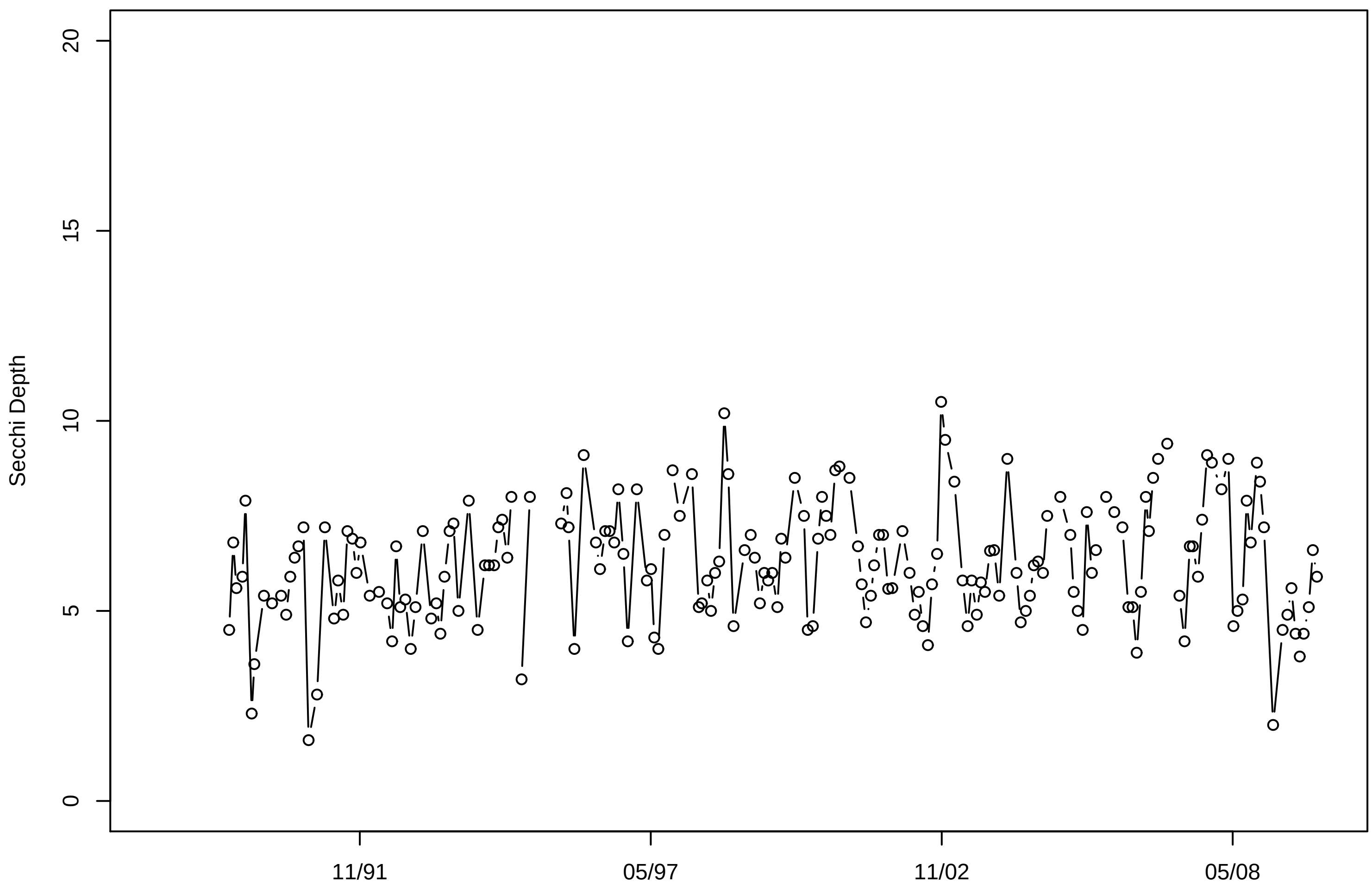


Figure B114: Lake Whatcom Secchi depths for Site 3.

Lake Whatcom Secchi data for Site 4, February 1988 through December 2009.

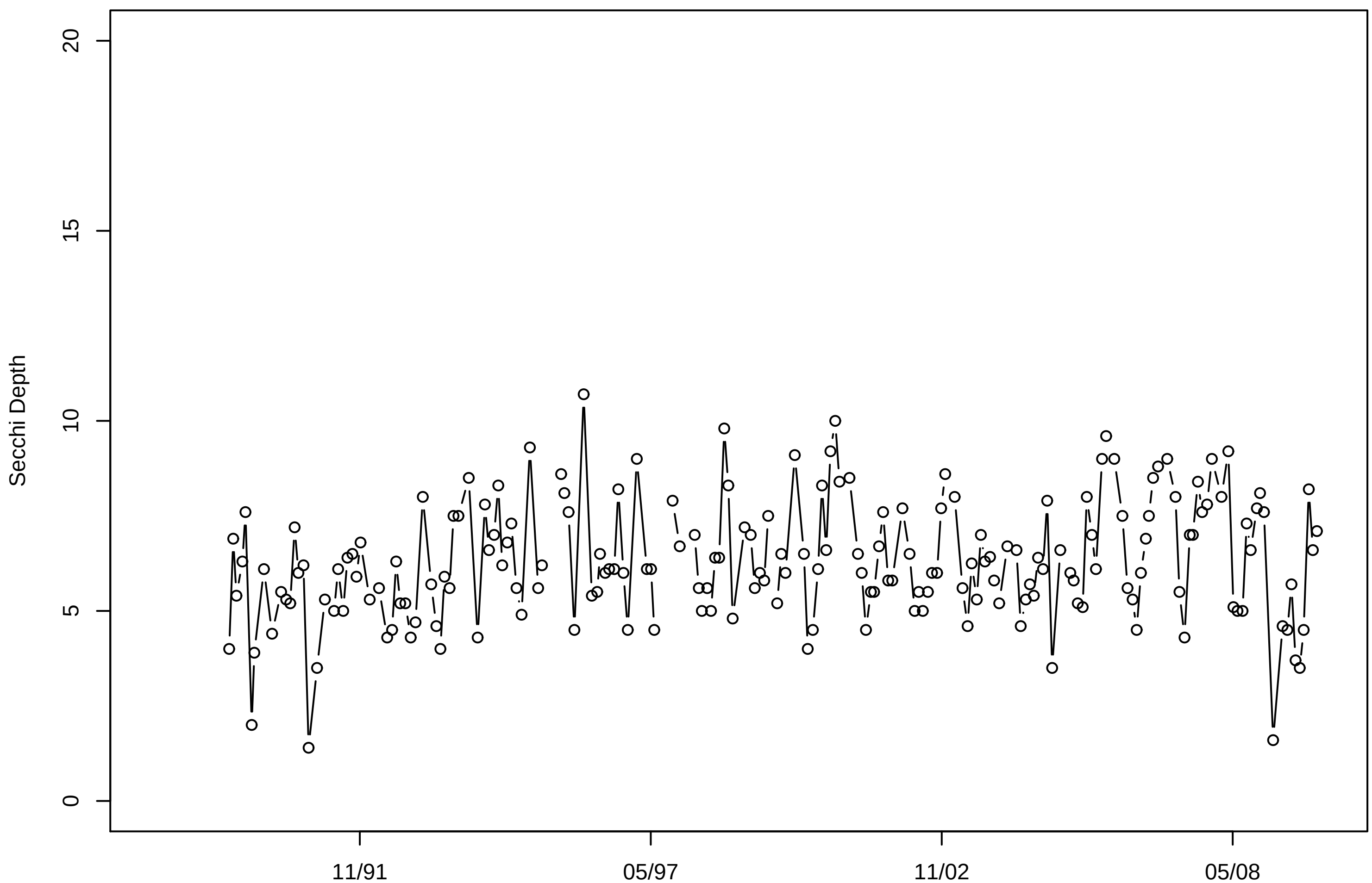


Figure B115: Lake Whatcom Secchi depths for Site 4.

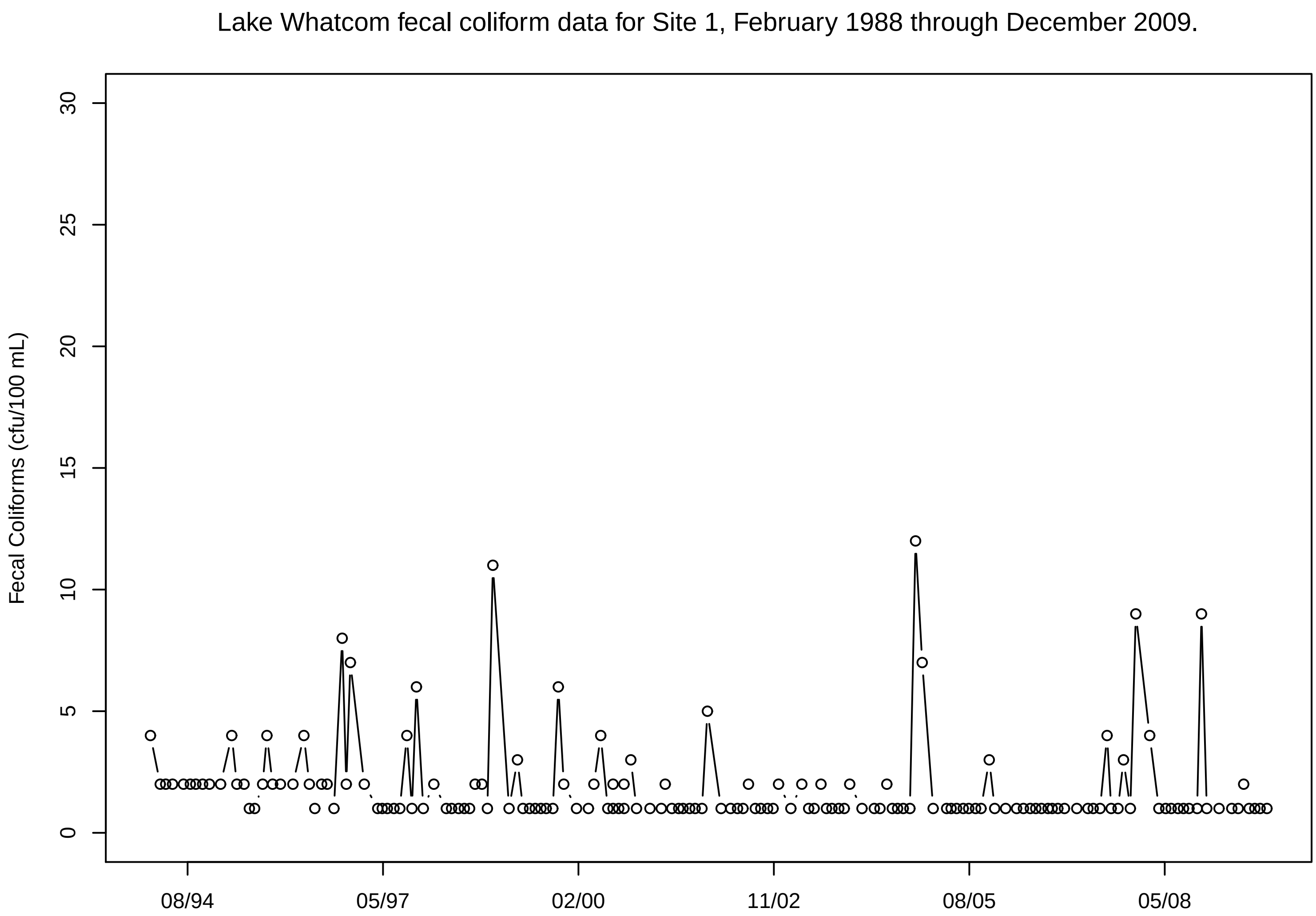


Figure B116: Lake Whatcom fecal coliform data for Site 1.

Lake Whatcom fecal coliform data for Site 2, February 1988 through December 2009.

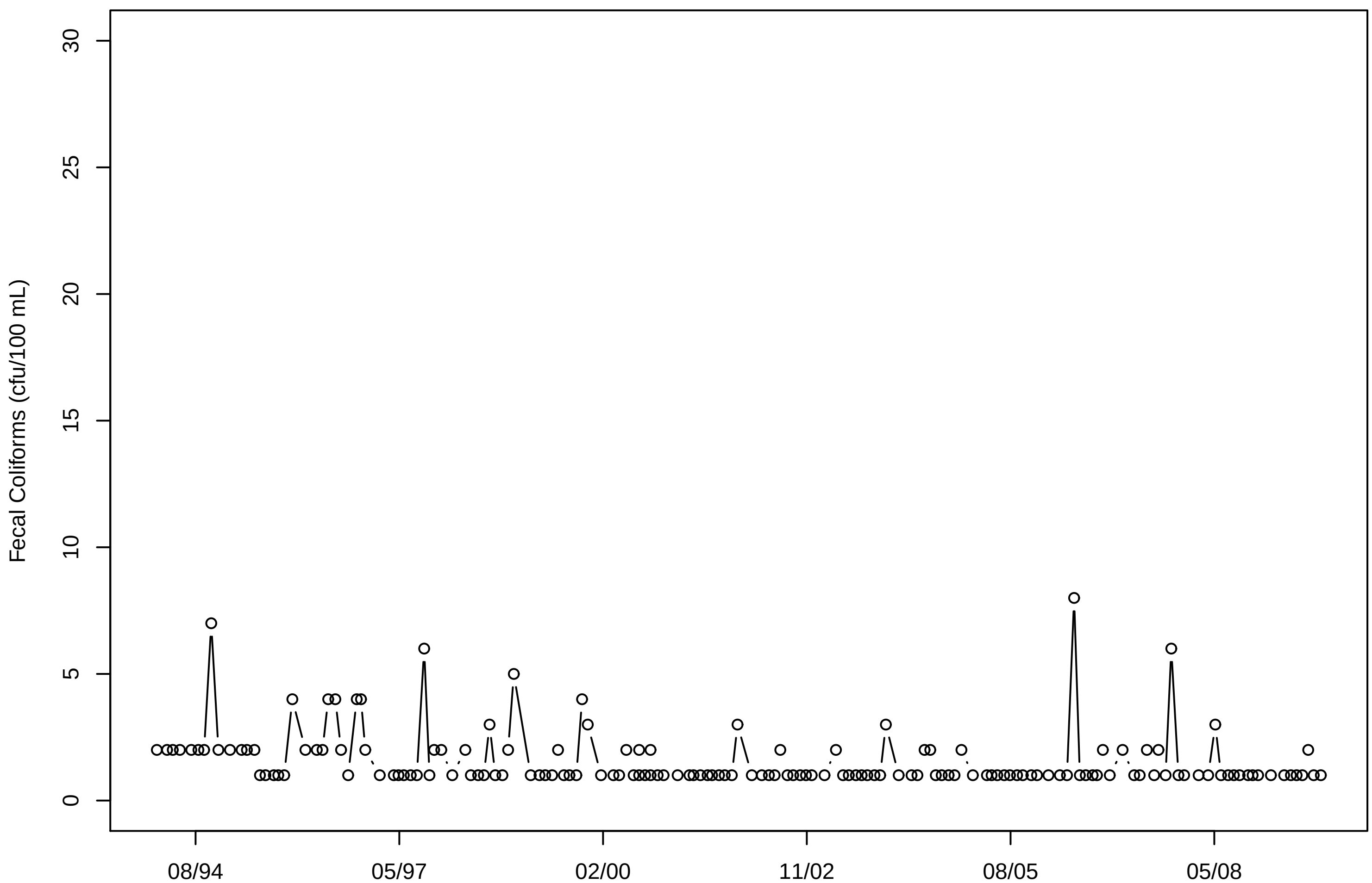


Figure B117: Lake Whatcom fecal coliform data for Site 2.

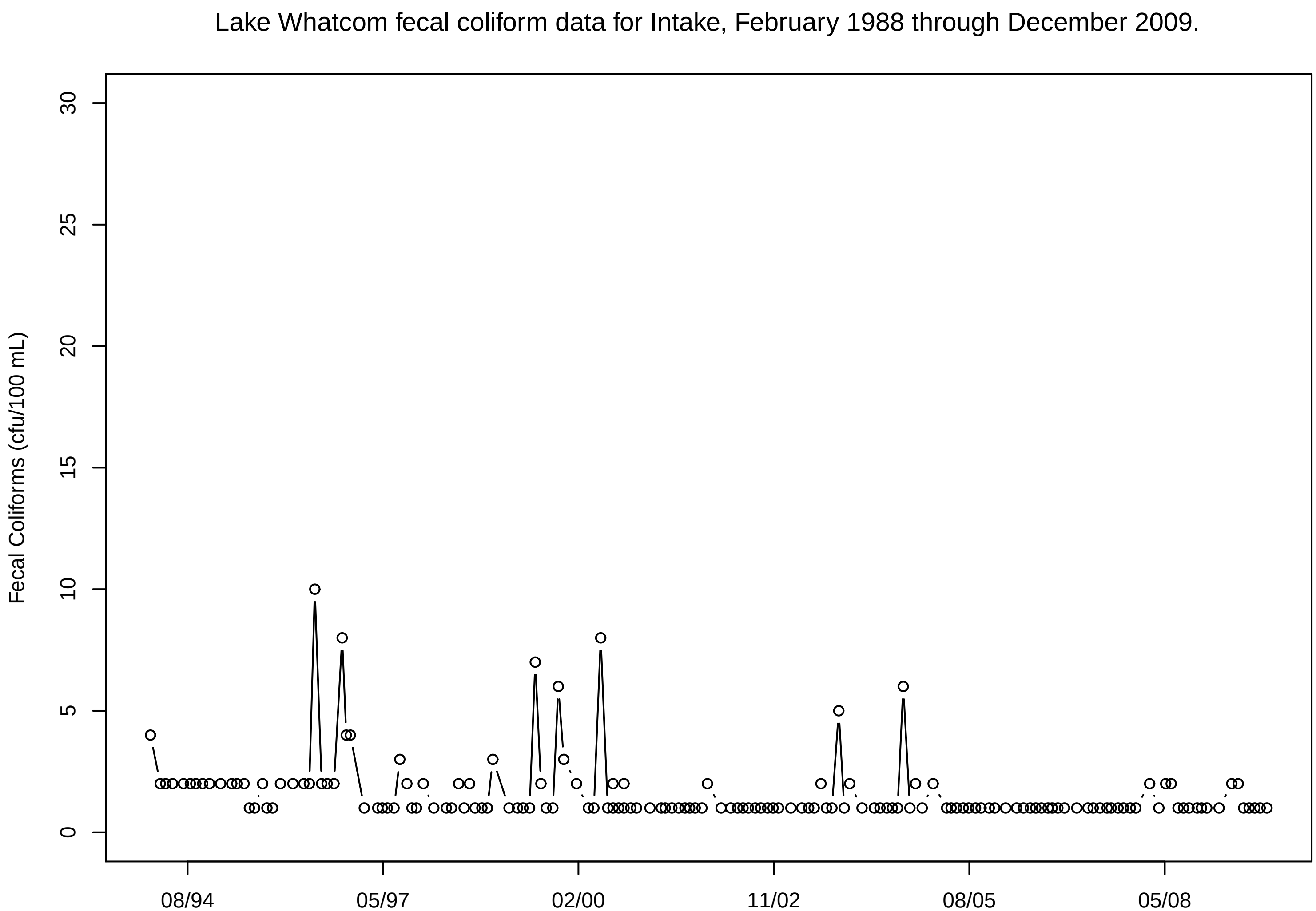


Figure B118: Lake Whatcom fecal coliform data for the Intake site.

Lake Whatcom fecal coliform data for Site 3, February 1988 through December 2009.

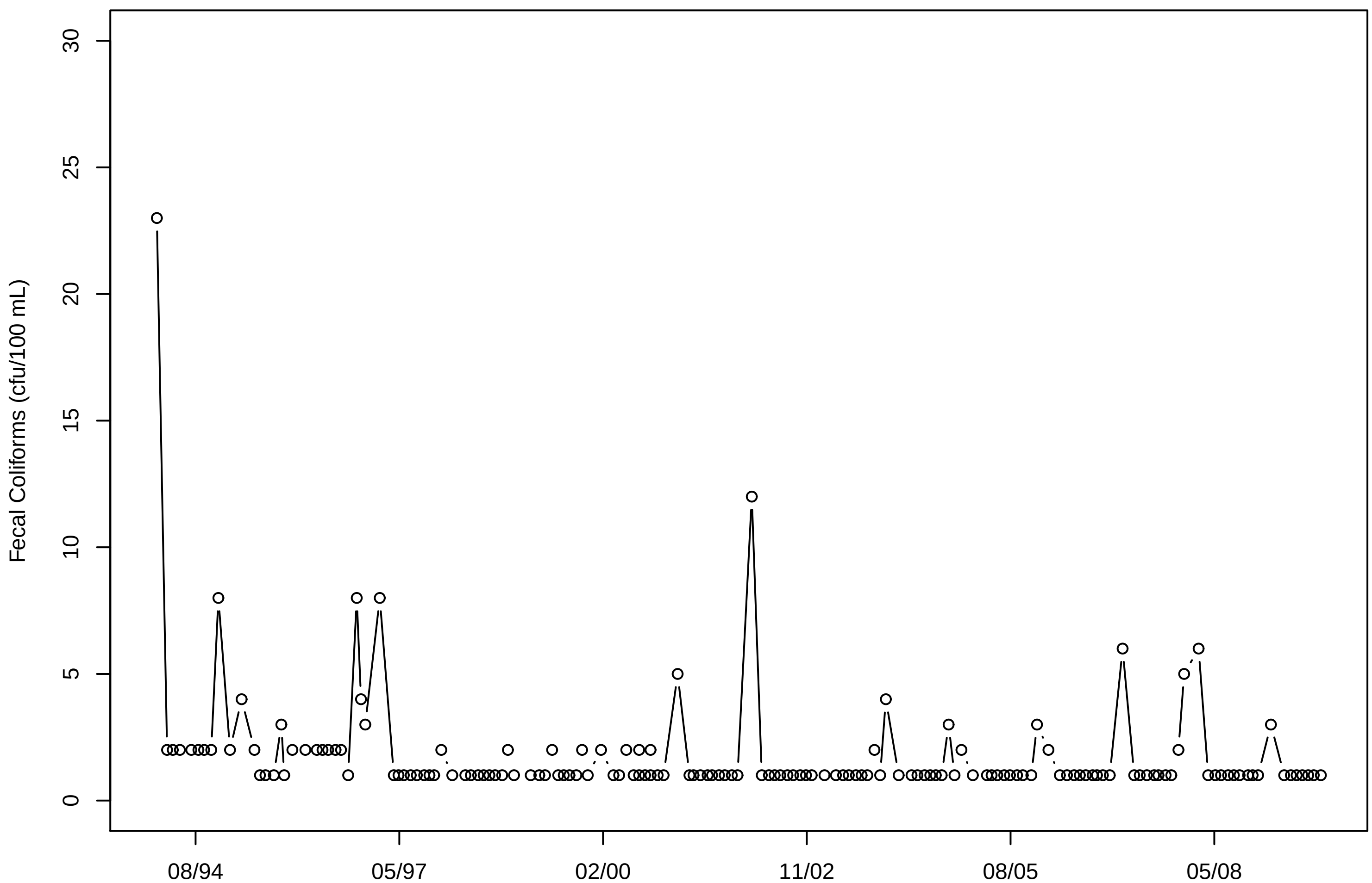


Figure B119: Lake Whatcom fecal coliform data for Site 3.

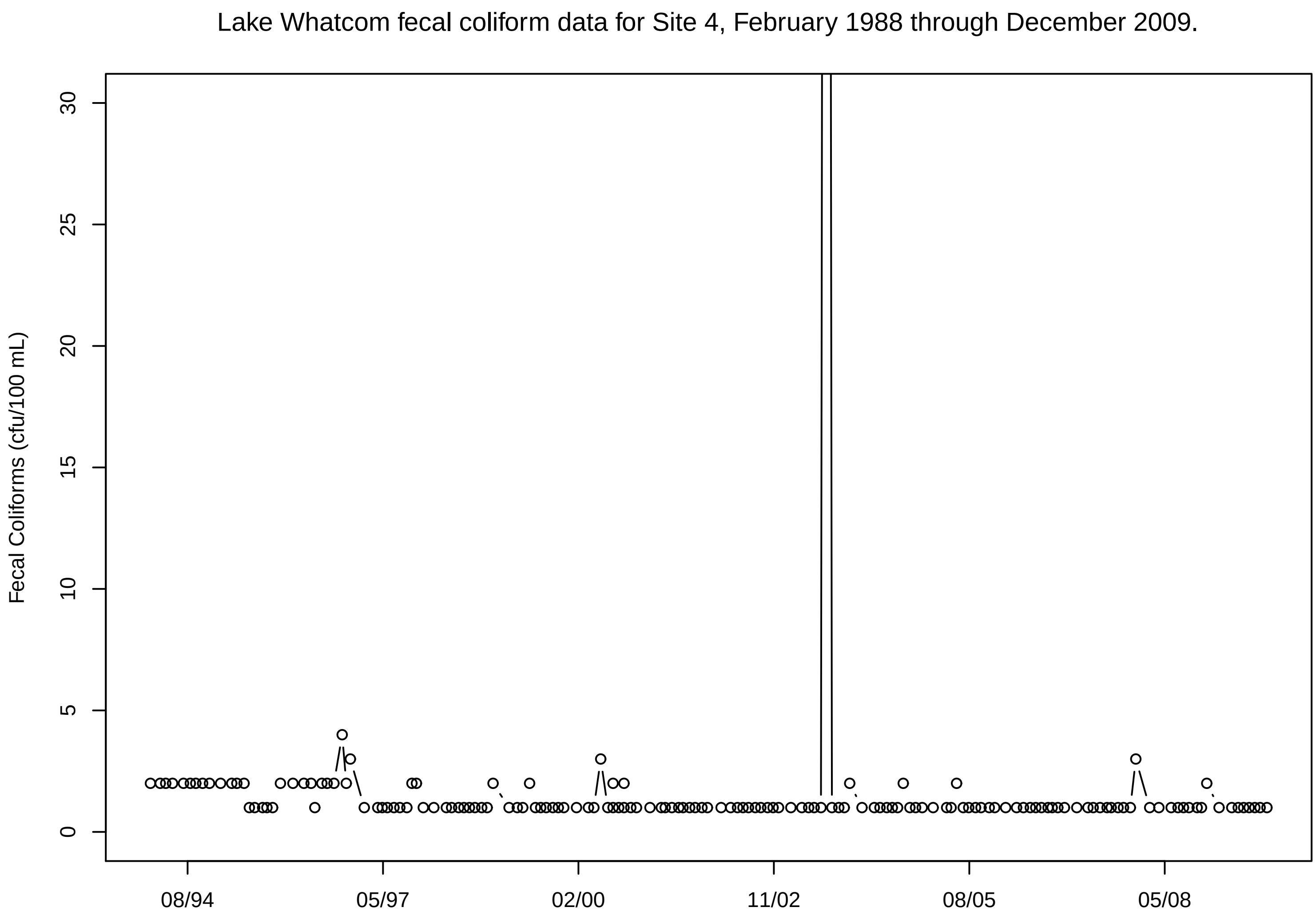


Figure B120: Lake Whatcom fecal coliform data for Site 4.

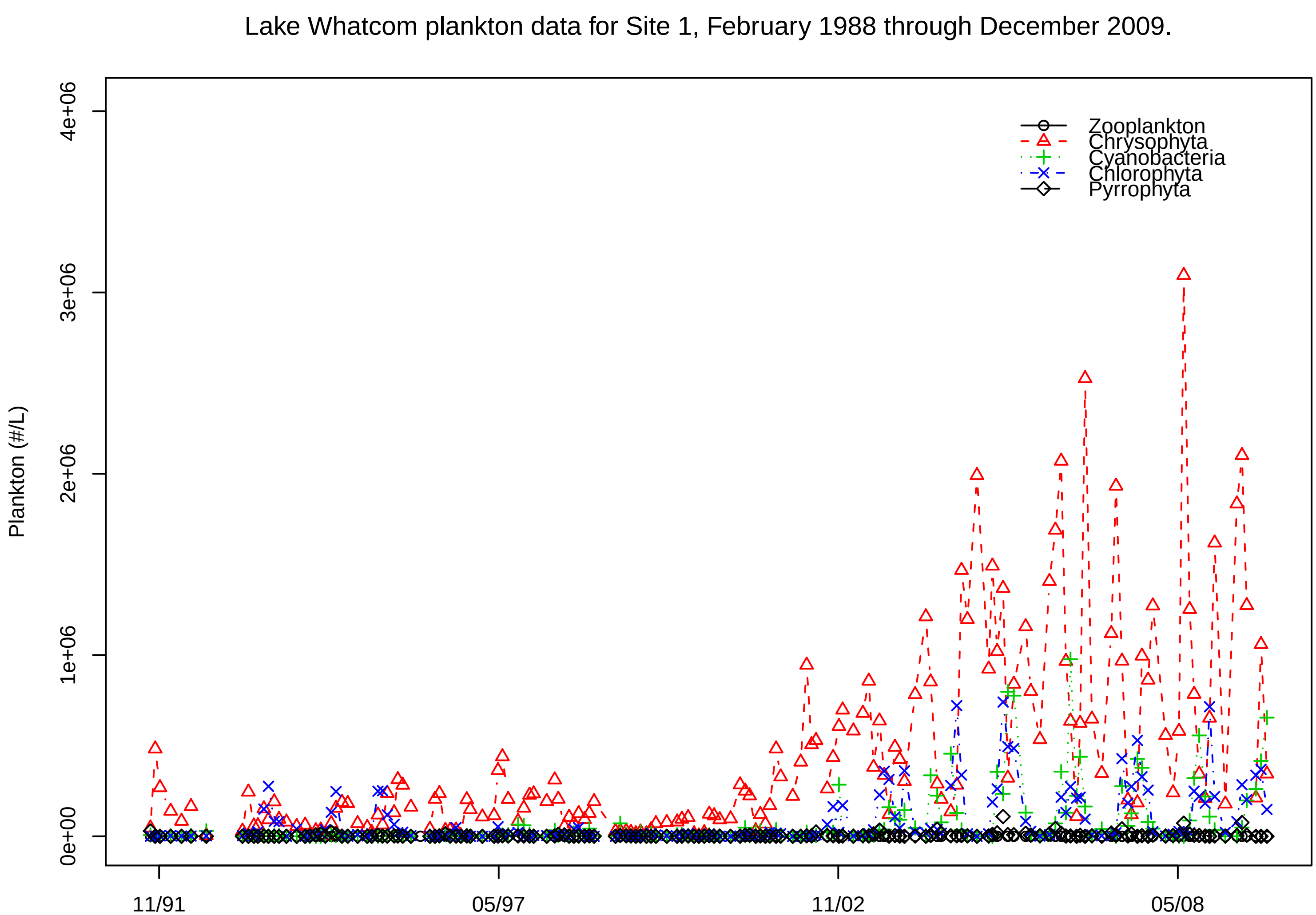


Figure B121: Lake Whatcom plankton data for Site 1.

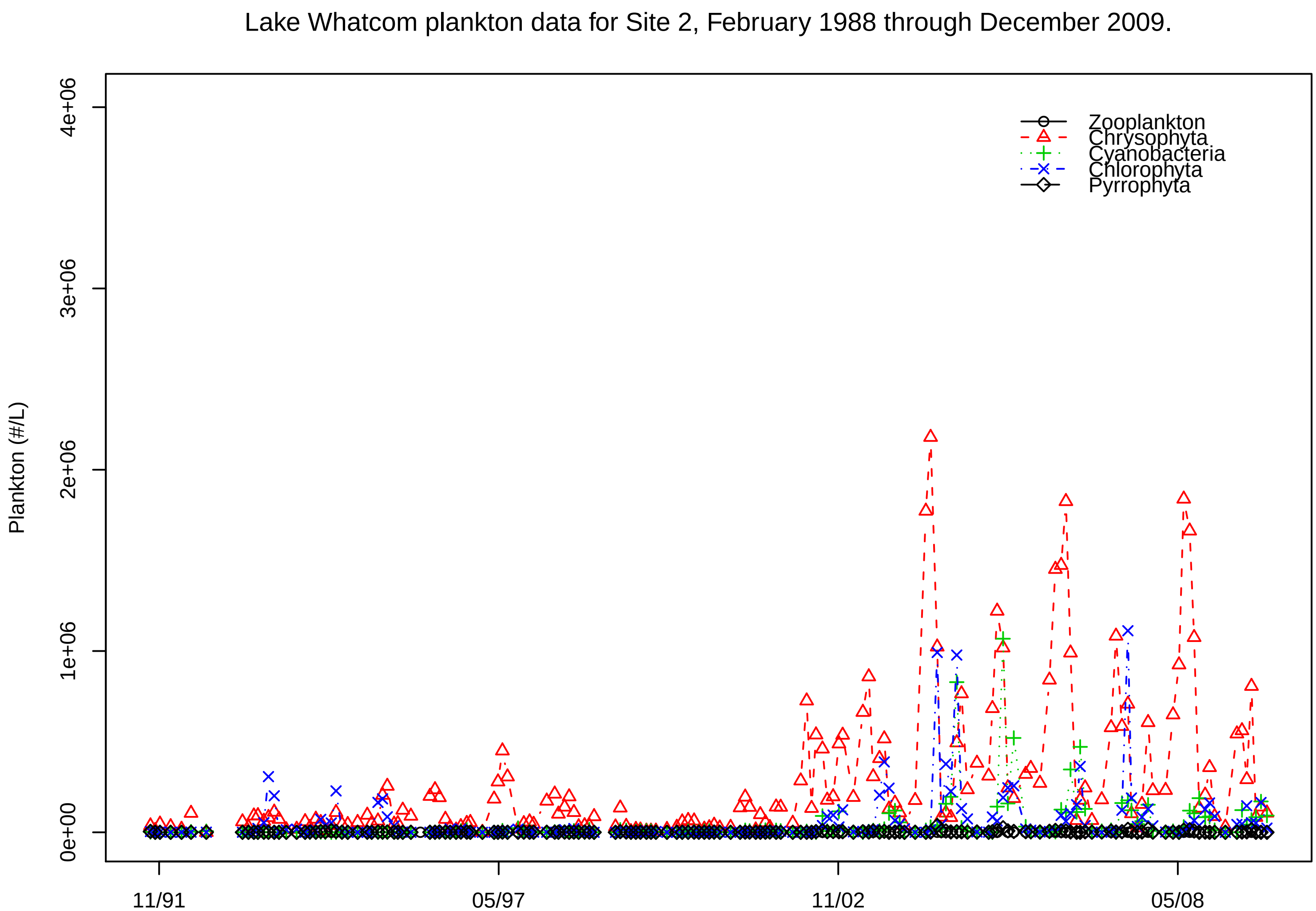


Figure B122: Lake Whatcom plankton data for Site 2.

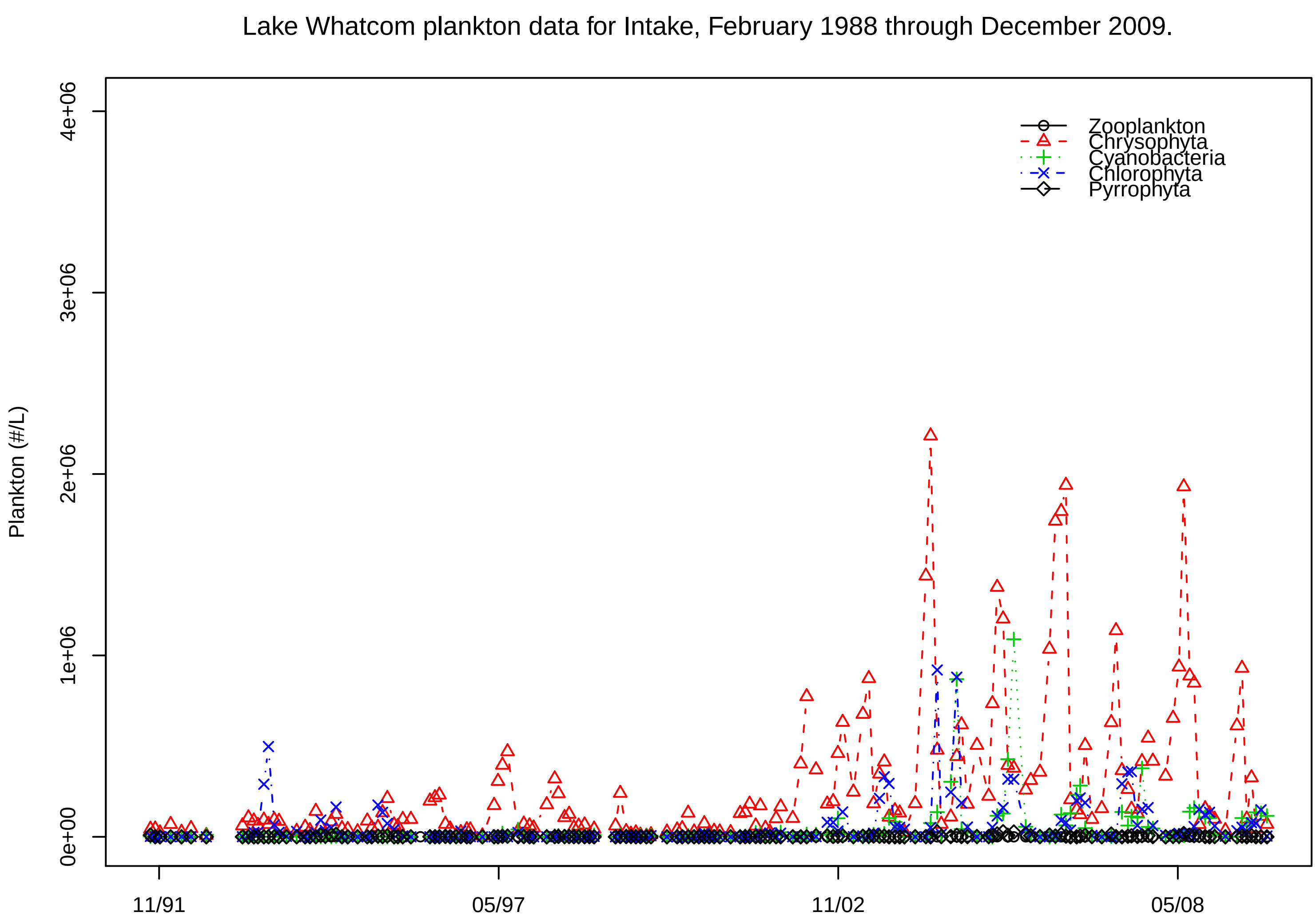


Figure B123: Lake Whatcom plankton data for the Intake Site.

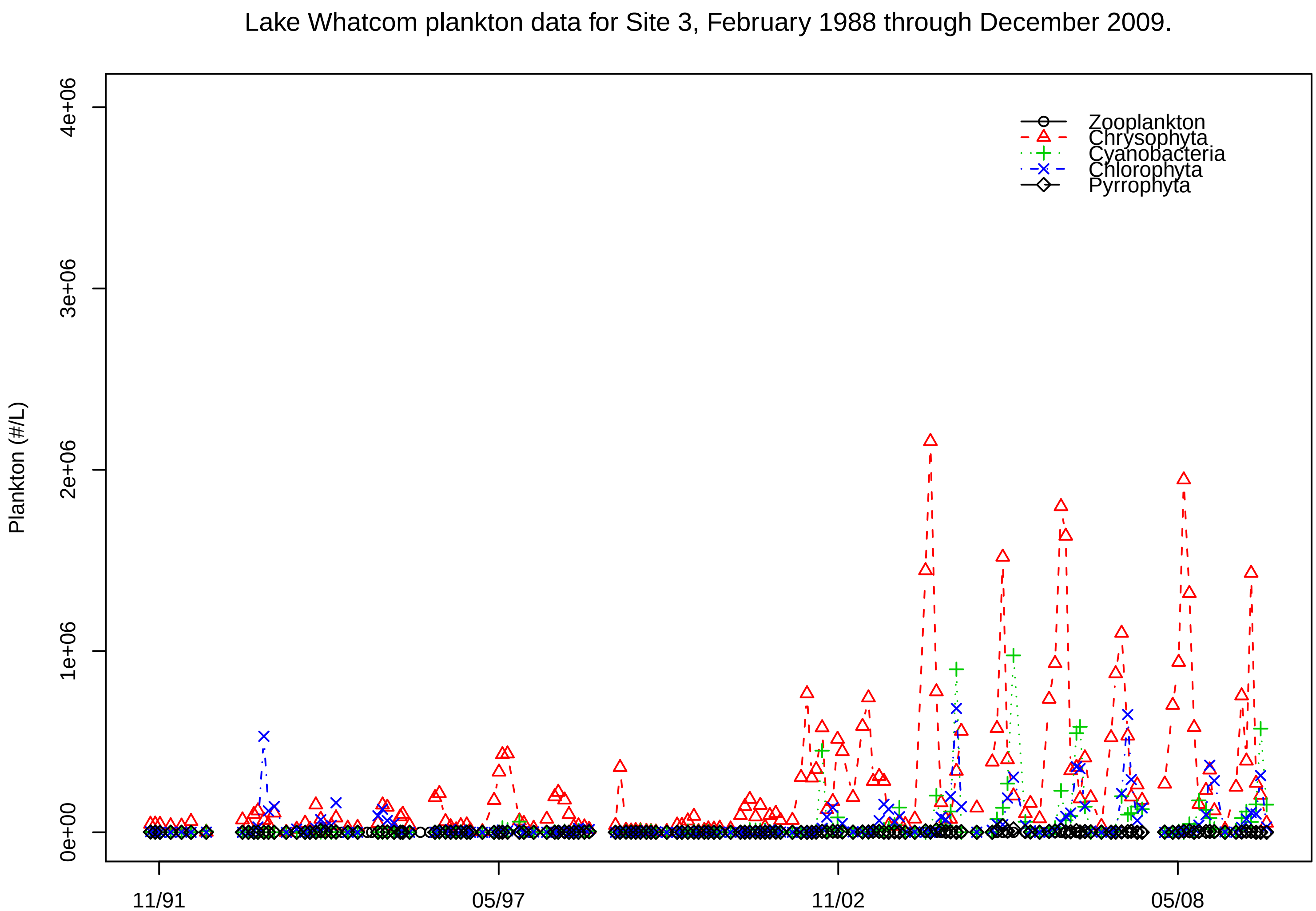


Figure B124: Lake Whatcom plankton data for Site 3.

Lake Whatcom plankton data for Site 4, February 1988 through December 2009.

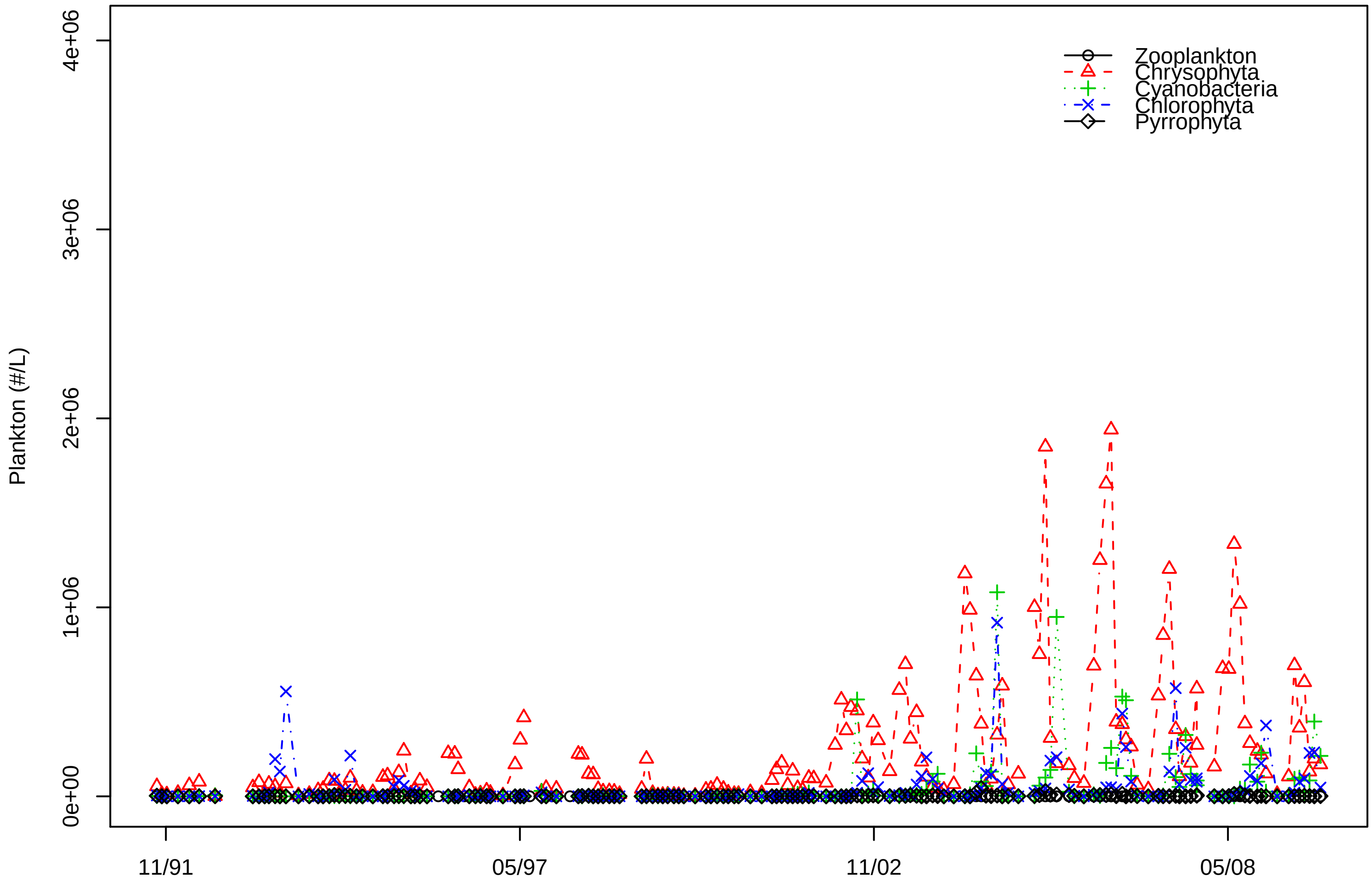


Figure B125: Lake Whatcom plankton data for Site 4.

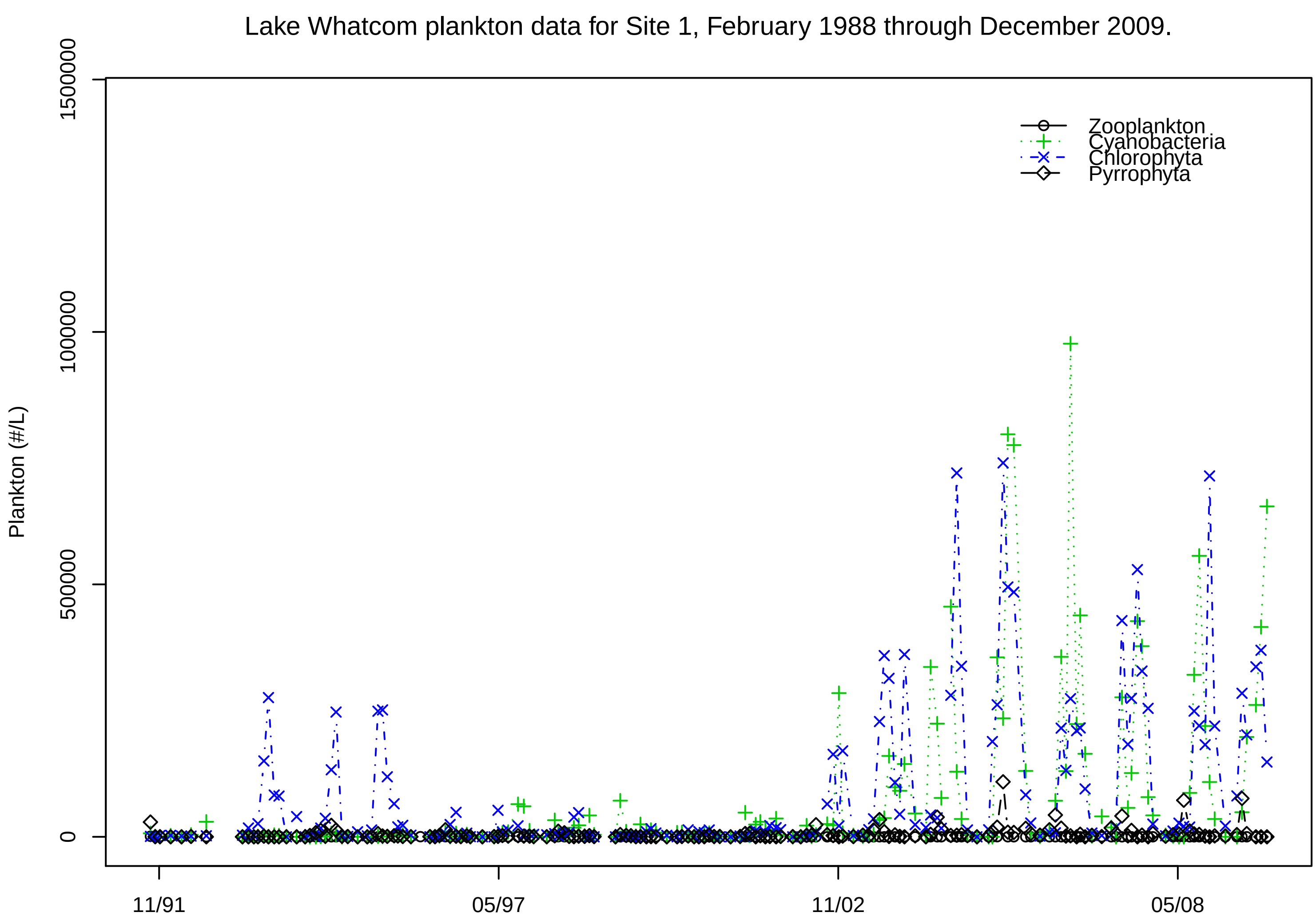


Figure B126: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

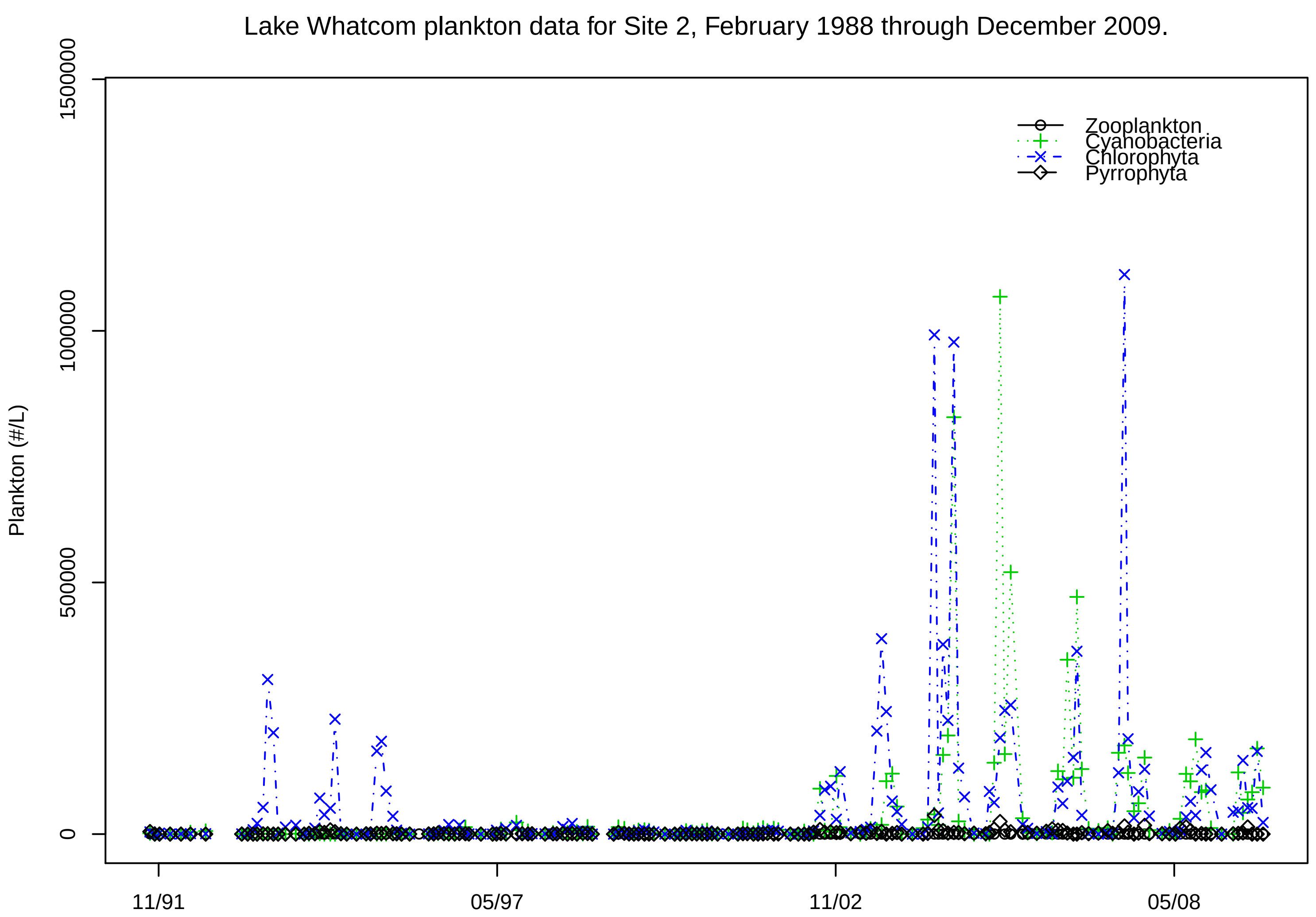


Figure B127: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

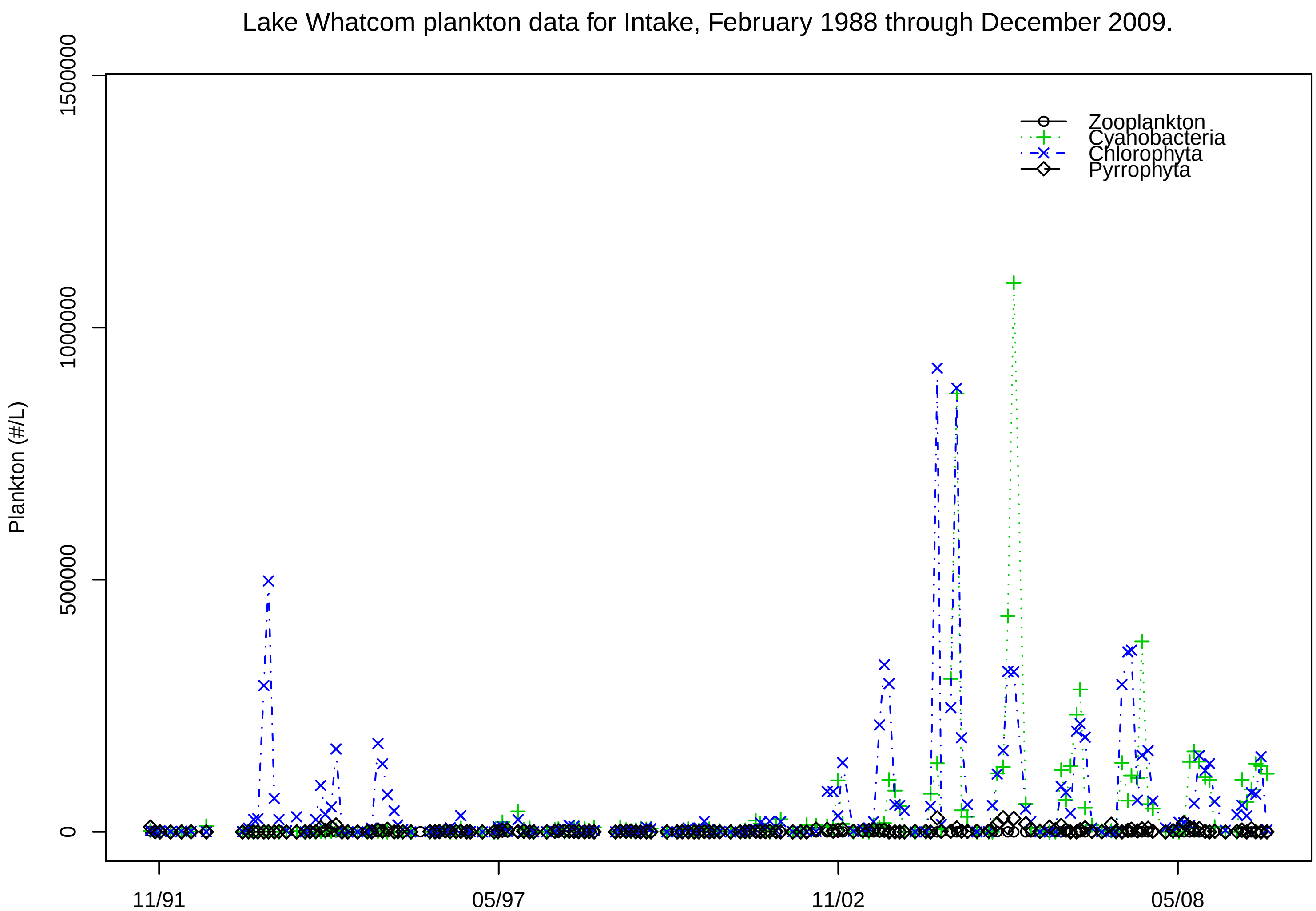


Figure B128: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

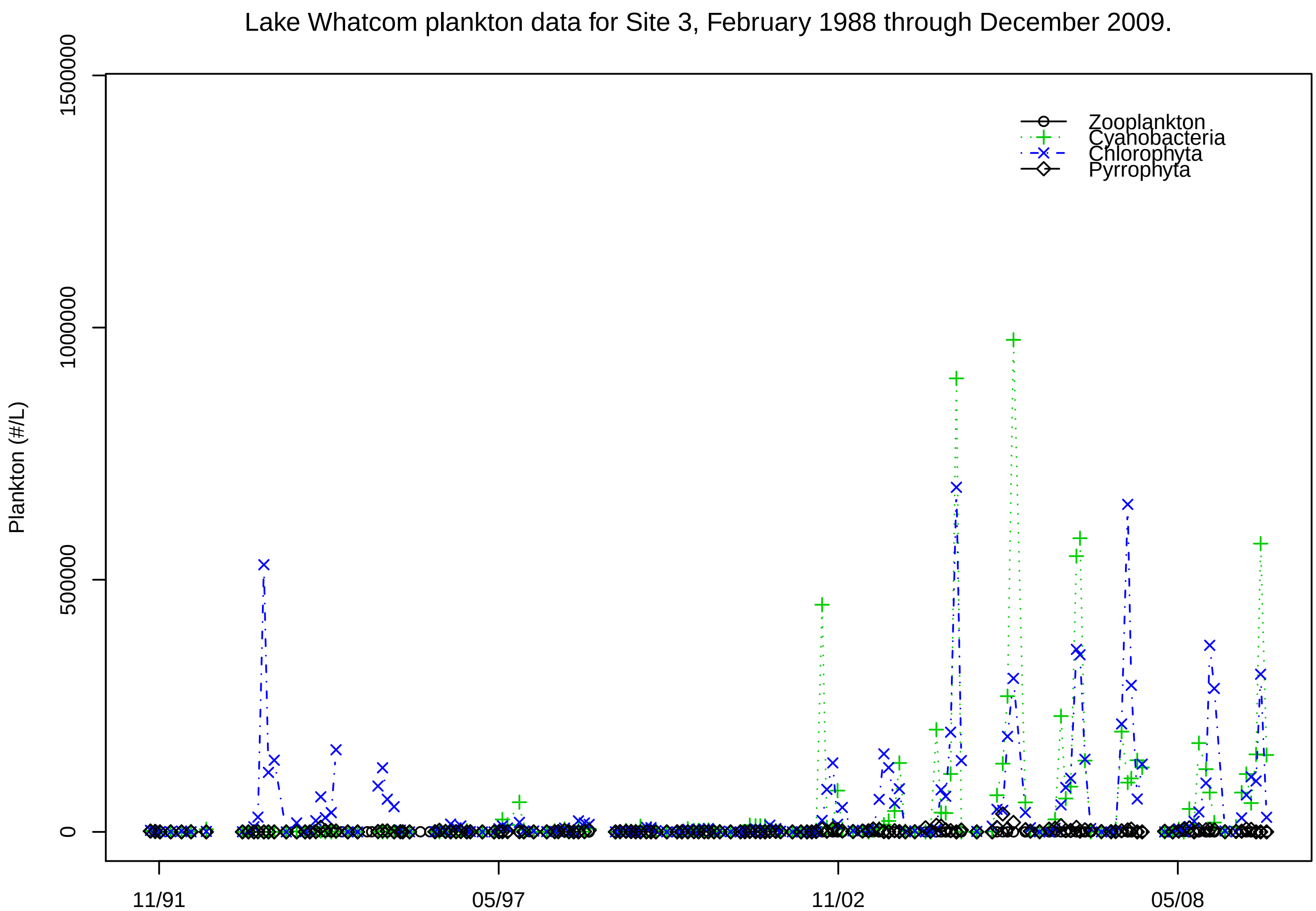


Figure B129: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

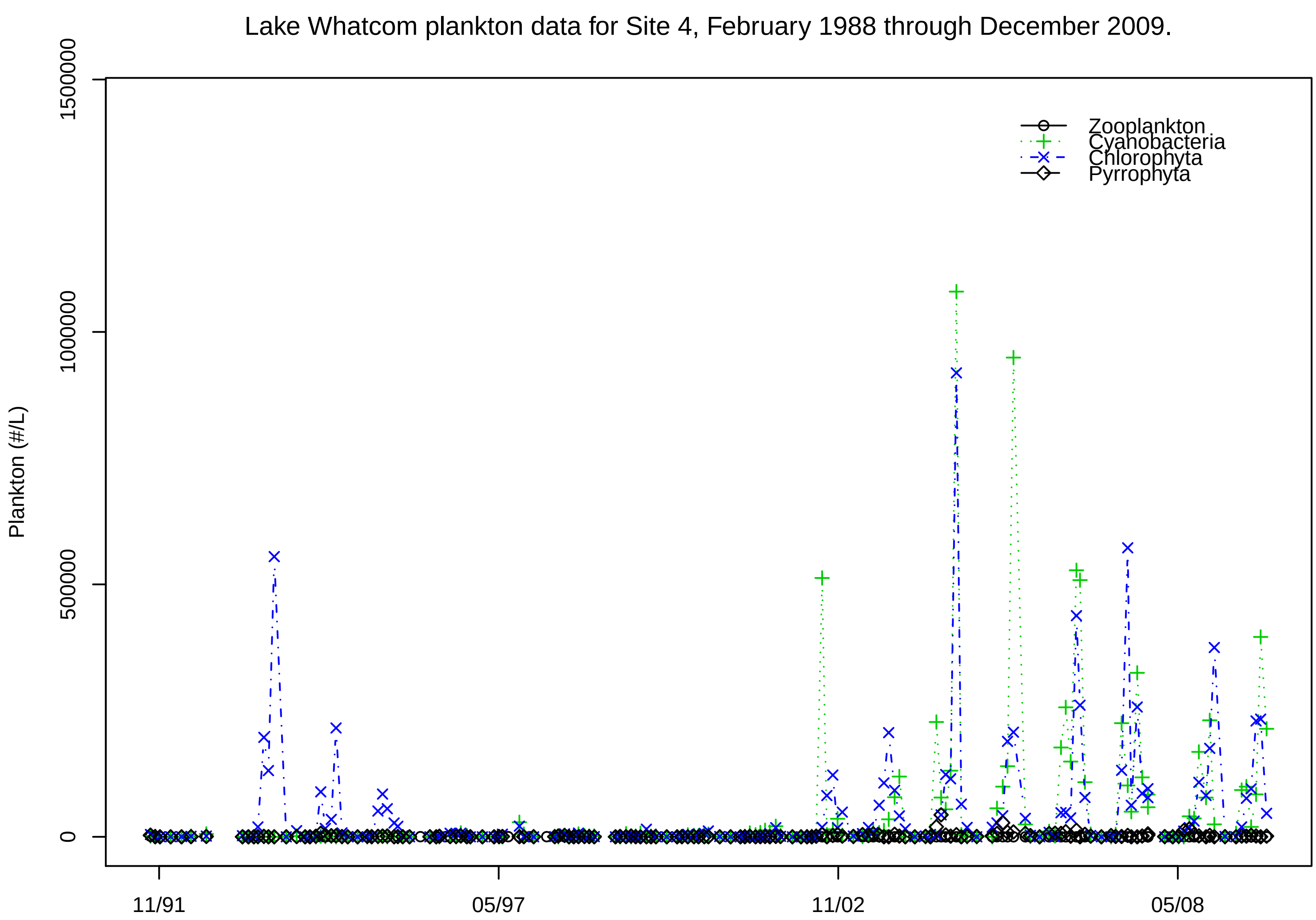


Figure B130: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

B.4 Lake Whatcom Algae Photographs

The following images show the different types of algae collected in basin 2 of Lake Whatcom during August 2009. Most of the photographs show specimens collected from Lake Whatcom. In a few cases, high resolution images were not available for specimens from Lake Whatcom, so representative images were included from a different site. Additional low-resolution images were included in the 2006/2007 annual report for Lake Whatcom taxa identified by the Academy of Natural Sciences of Philadelphia (Matthews, et al., 2008).

Figure B131: **Chlorophyta:** *Ankistrodesmus falcatus*, Cranberry Lake, September 1, 2008 (no image from Lake Whatcom).

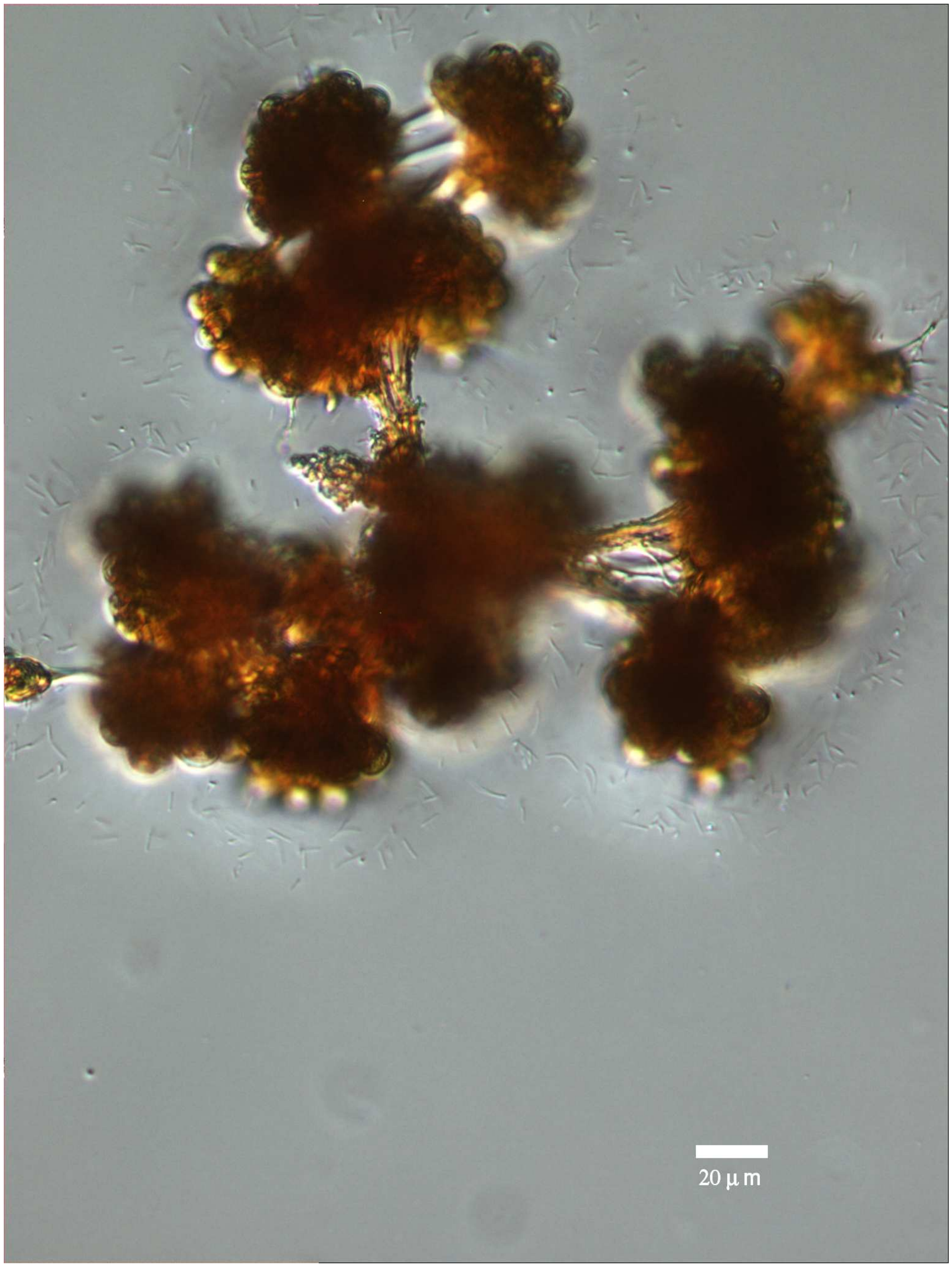


Figure B132: **Chlorophyta:** *Botryococcus*, Lake Whatcom, September 17, 2009.

Figure B133: **Chlorophyta:** *Closterium* species, Mirror Lake, August 11, 2009 (no image from Lake Whatcom).

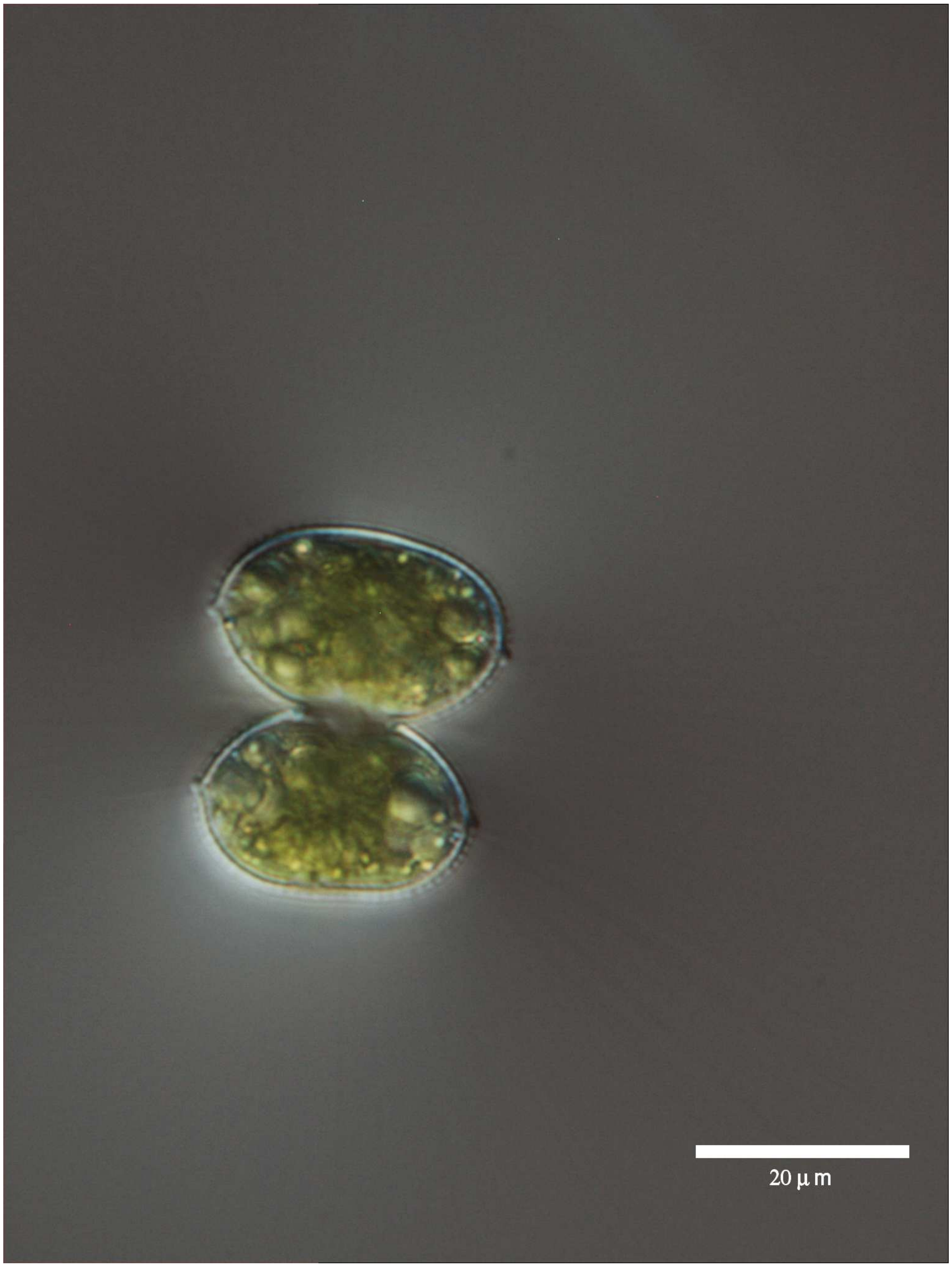


Figure B134: **Chlorophyta:** *Cosmarium*, Lake Whatcom, September 17, 2009.

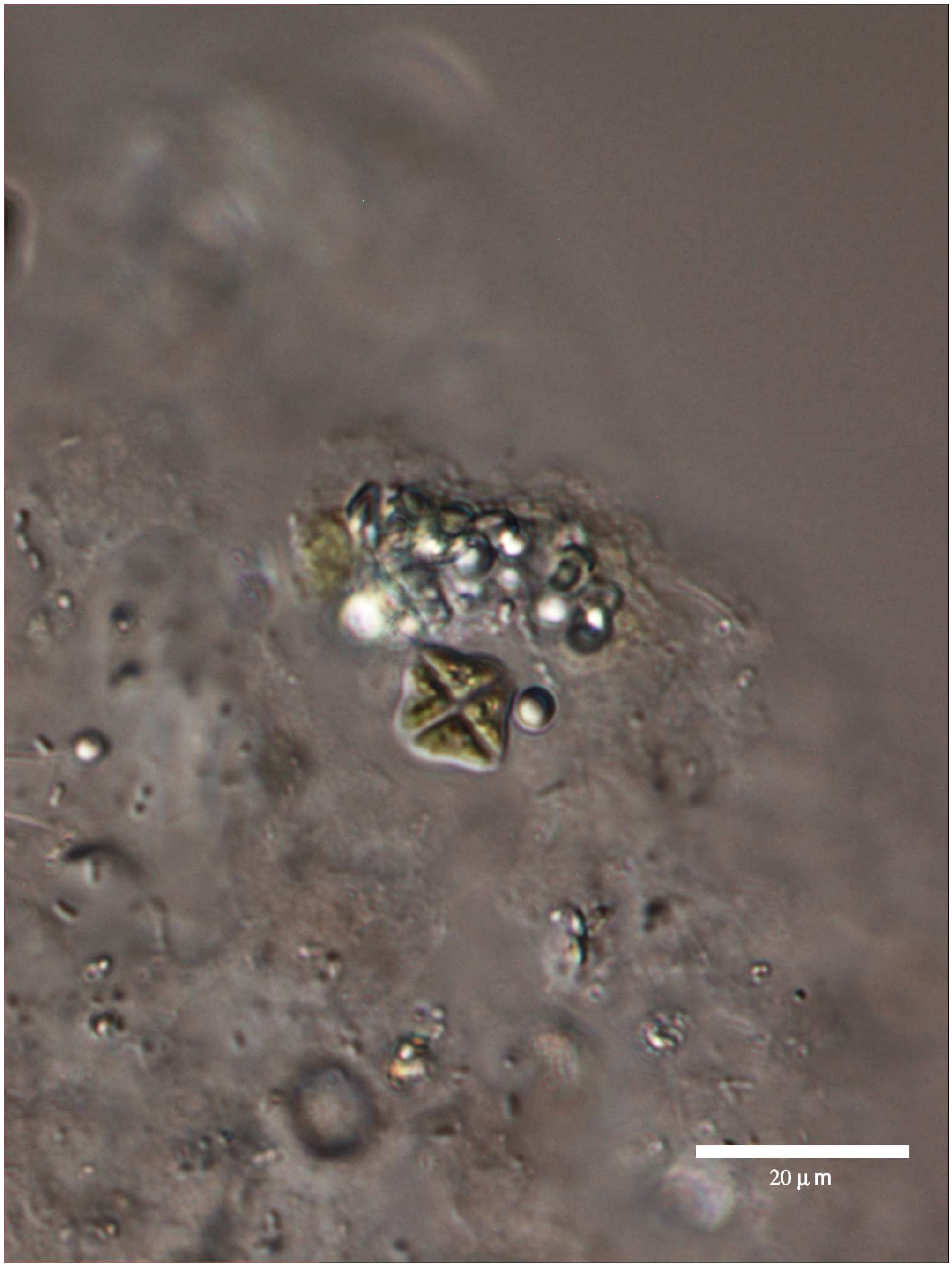


Figure B135: **Chlorophyta:** *Crucigenia*, Lake Whatcom, July 31, 2009.

Figure B136: **Chlorophyta:** *Elakatothrix gelatinosa*, Lake Louise, May 27, 2009 (no image from Lake Whatcom).

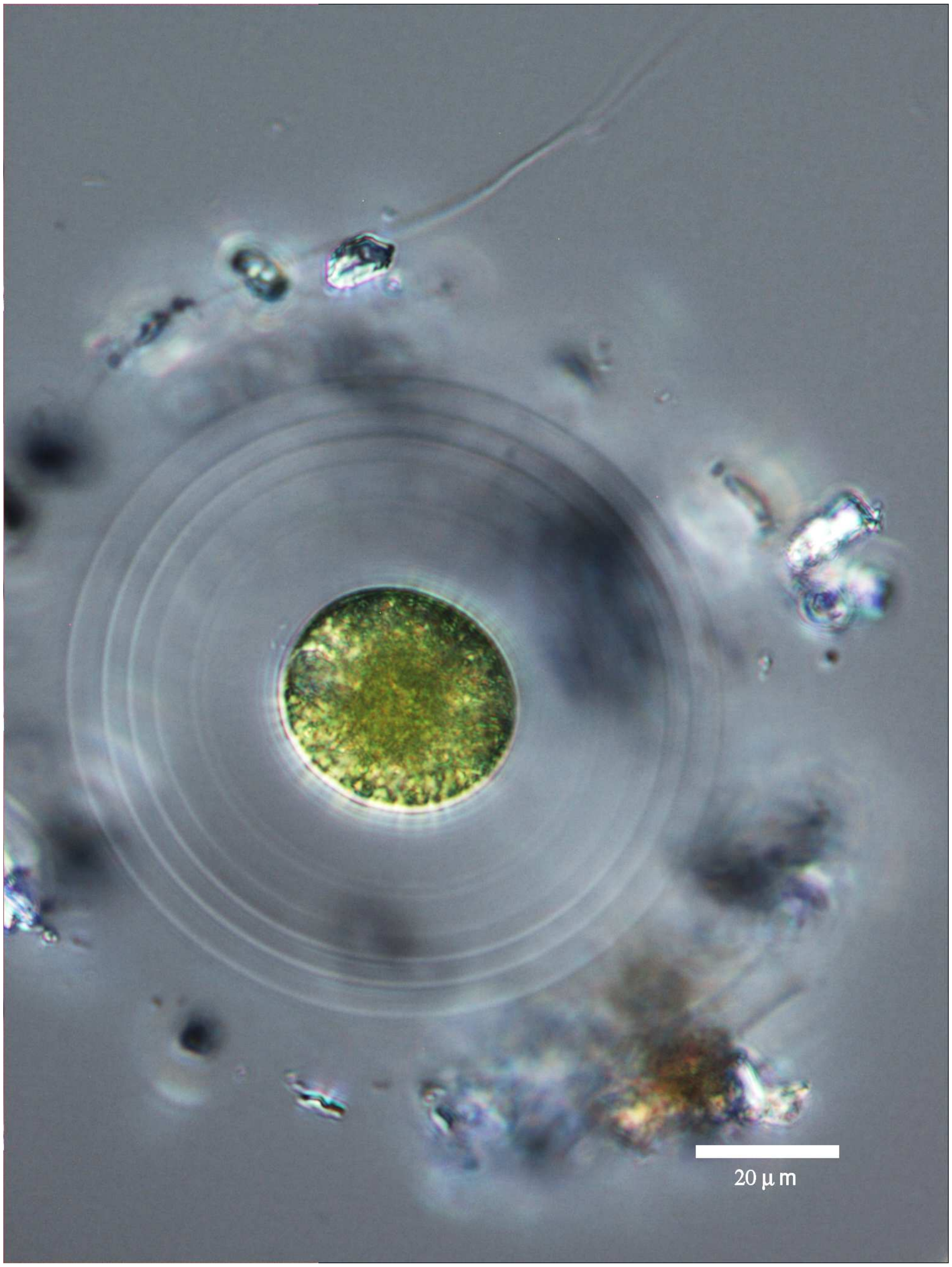


Figure B137: **Chlorophyta:** *Gloeocystis*, Ross Lake, June 1, 2009 (no image from Lake Whatcom).

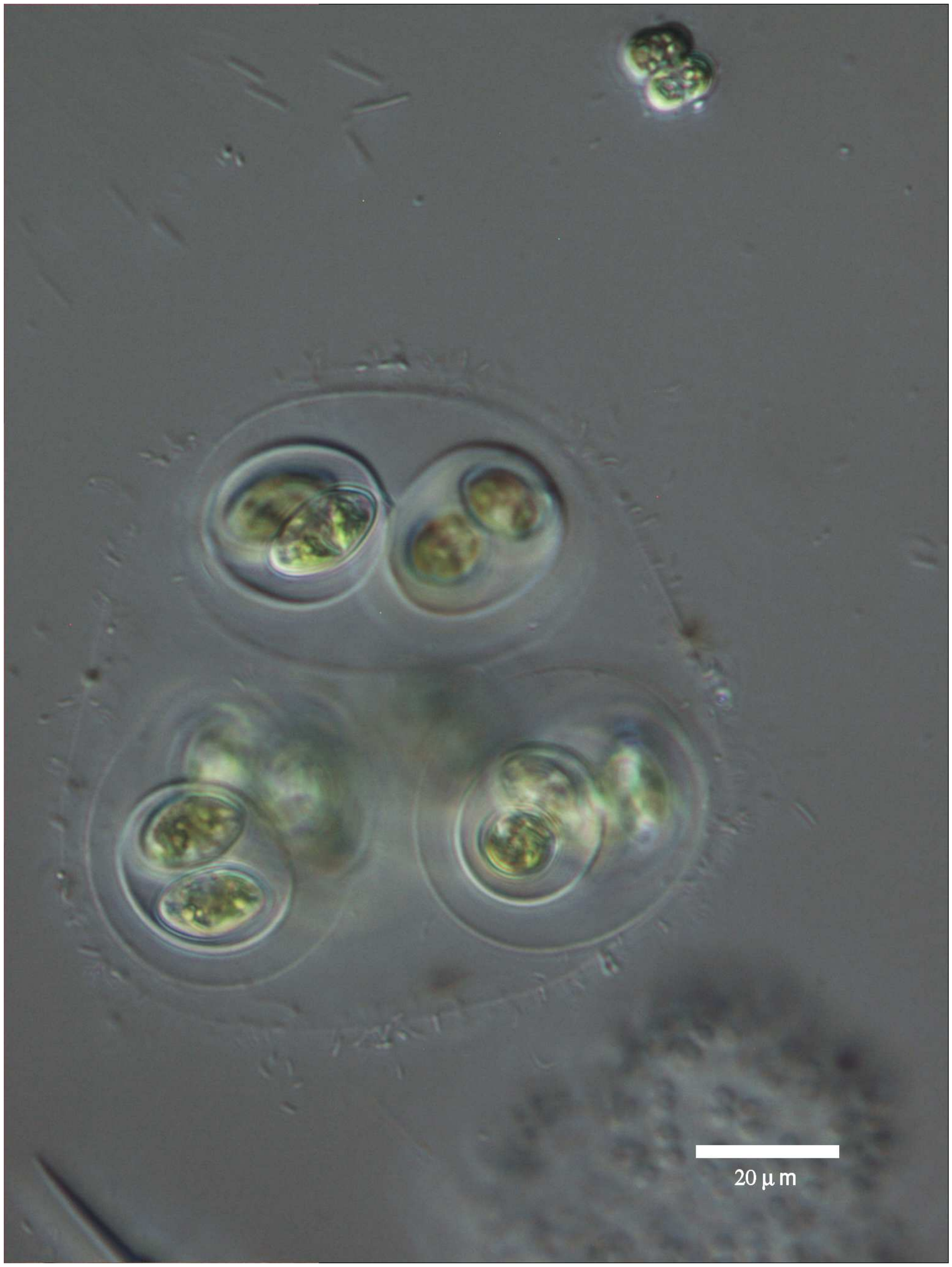


Figure B138: **Chlorophyta:** *Oocystis*, Lake Whatcom, September 17, 2009.

Figure B139: **Chlorophyta:** *Pediastrum*, Wiser Lake, August 19, 2009 (no image from Lake Whatcom).

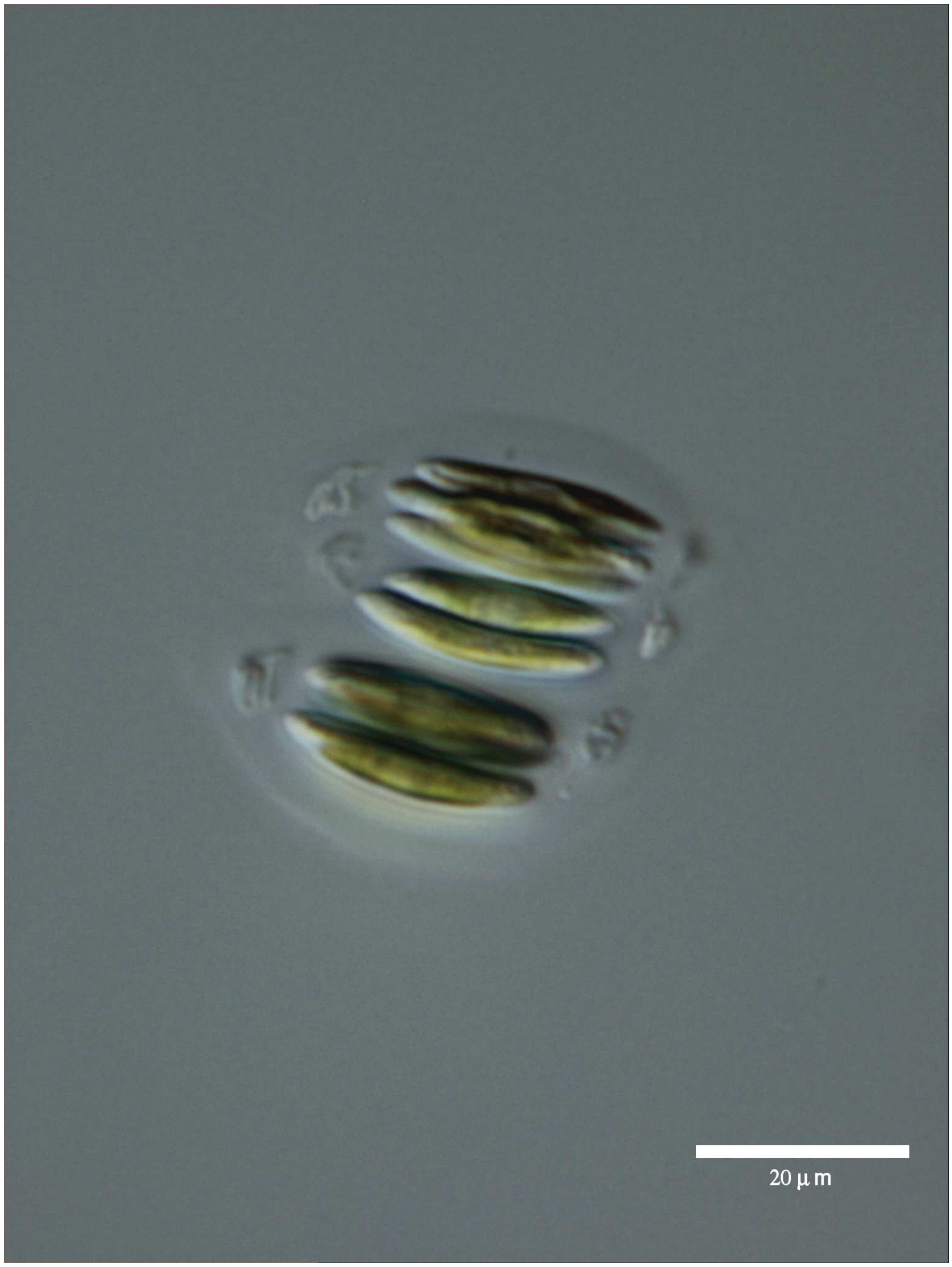


Figure B140: **Chlorophyta:** *Quadrigula closteroides*, Lake Padden, October 21, 2009 (no image from Lake Whatcom).

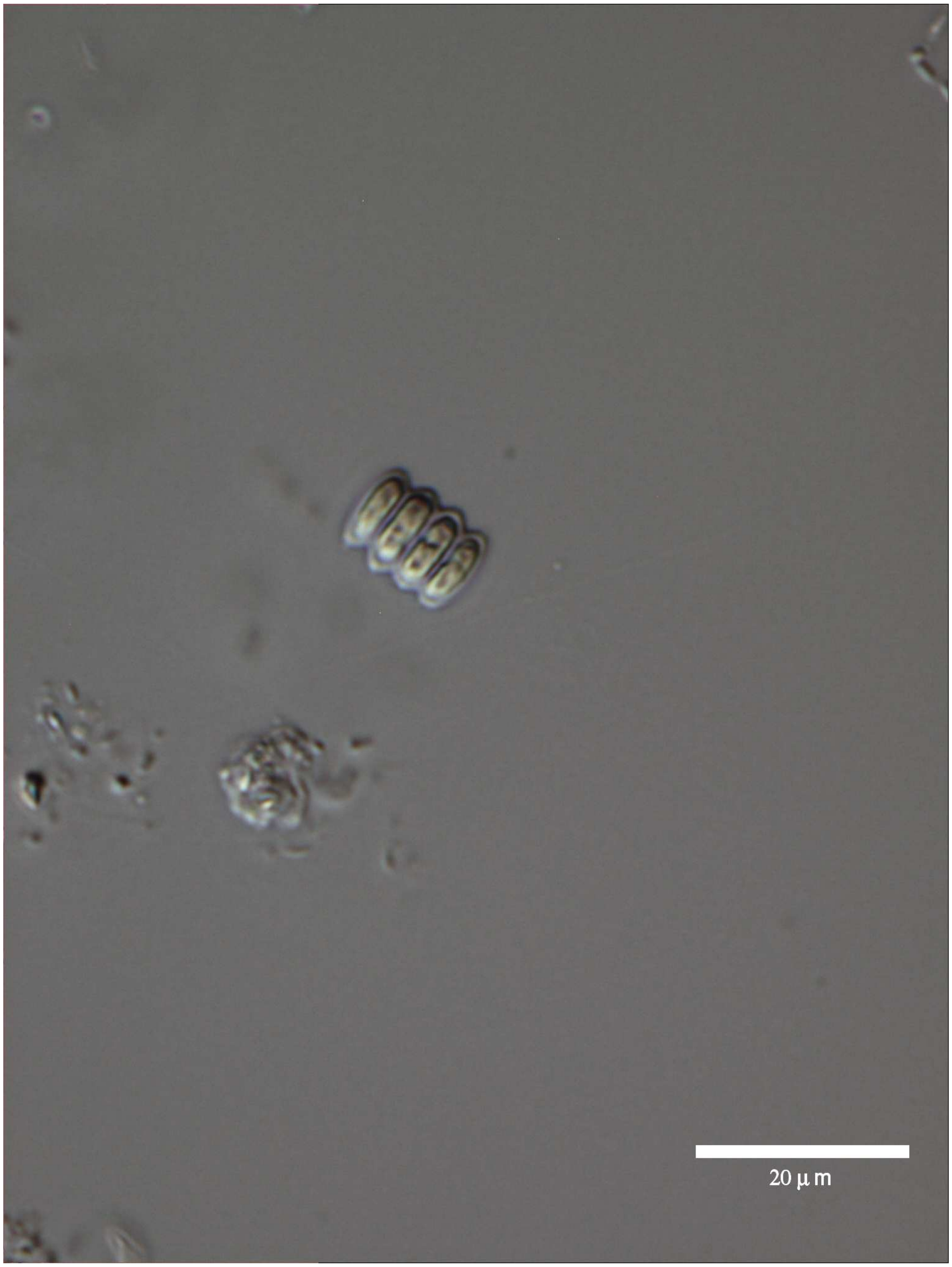


Figure B141: **Chlorophyta:** *Scenedesmus*, Lake Whatcom, July 31, 2009.

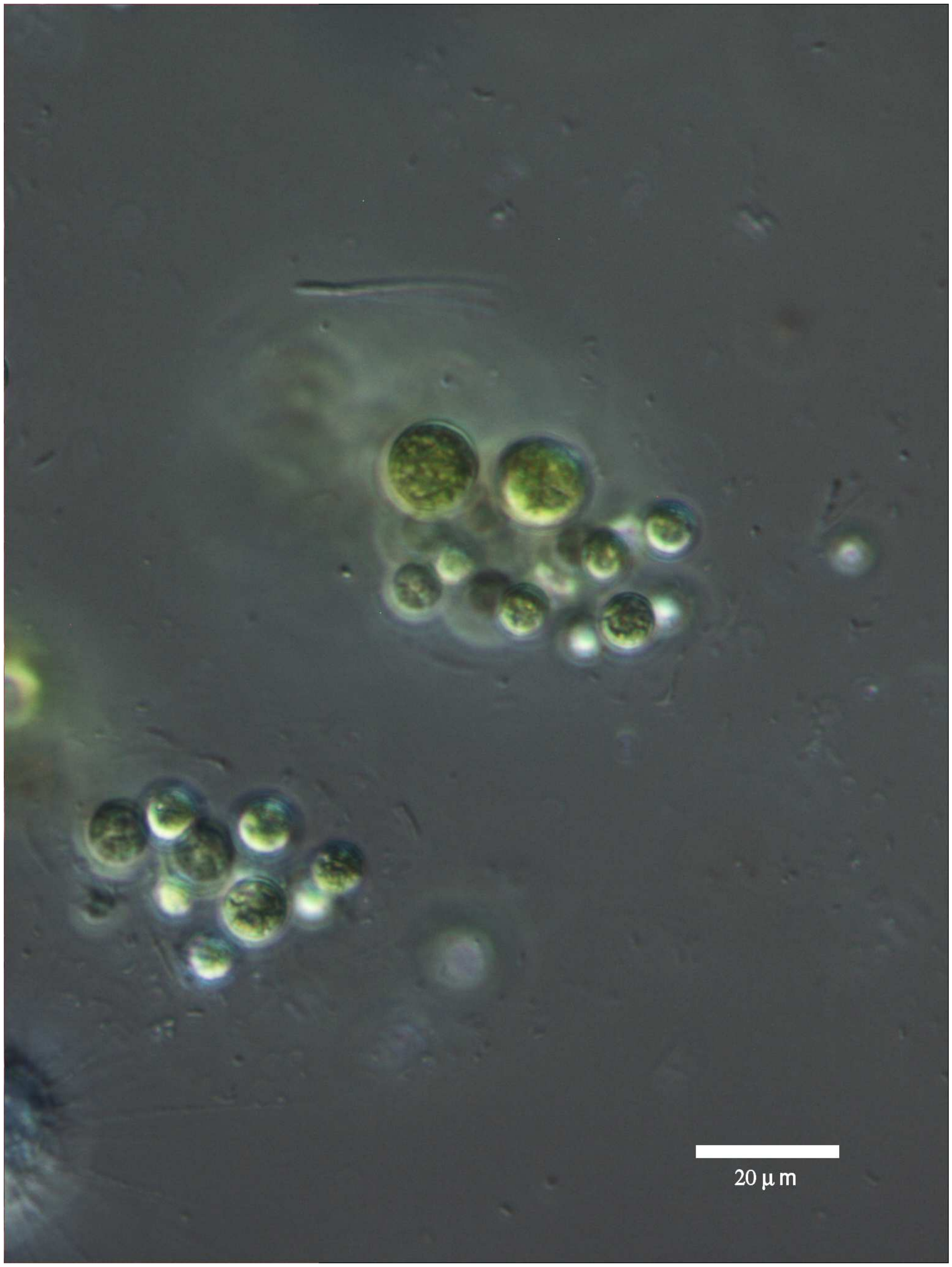


Figure B142: **Chlorophyta:** *Sphaerocystis schroeteri*, Lake Whatcom, September 17, 2009.

Figure B143: **Cyanobacteria:** *Aphanocapsa* (with *Aphanothece*, and *Snowella*), Lake Whatcom, September 17, 2009.

Figure B144: **Cyanobacteria:** *Aphanothece*, Lake Whatcom, September 17, 2009.

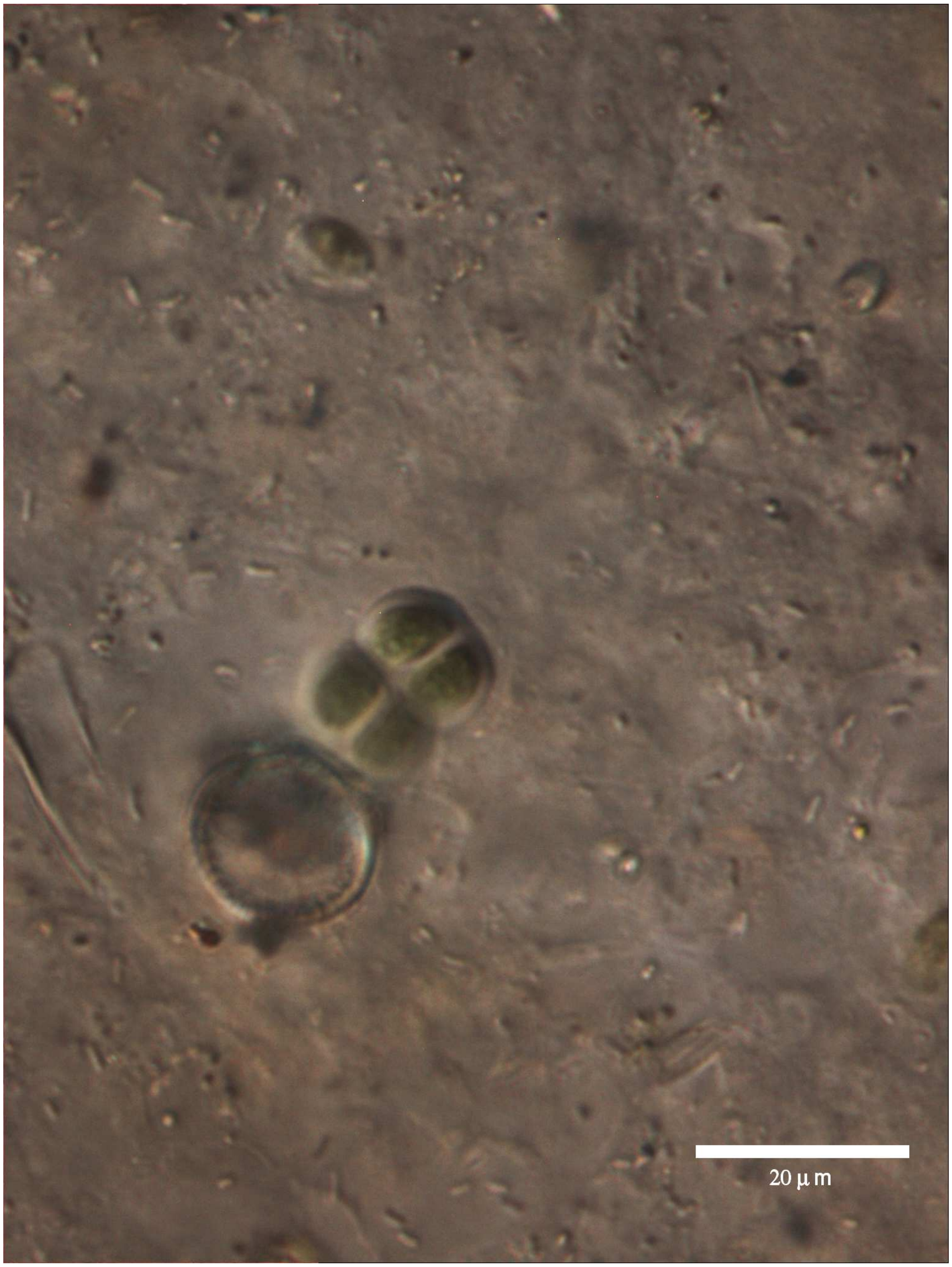


Figure B145: **Cyanobacteria:** *Chroococcus turgida* (embedded in *Aphanocapsa*/*Aphanothece* matrix), Lake Whatcom, July 31, 2009.

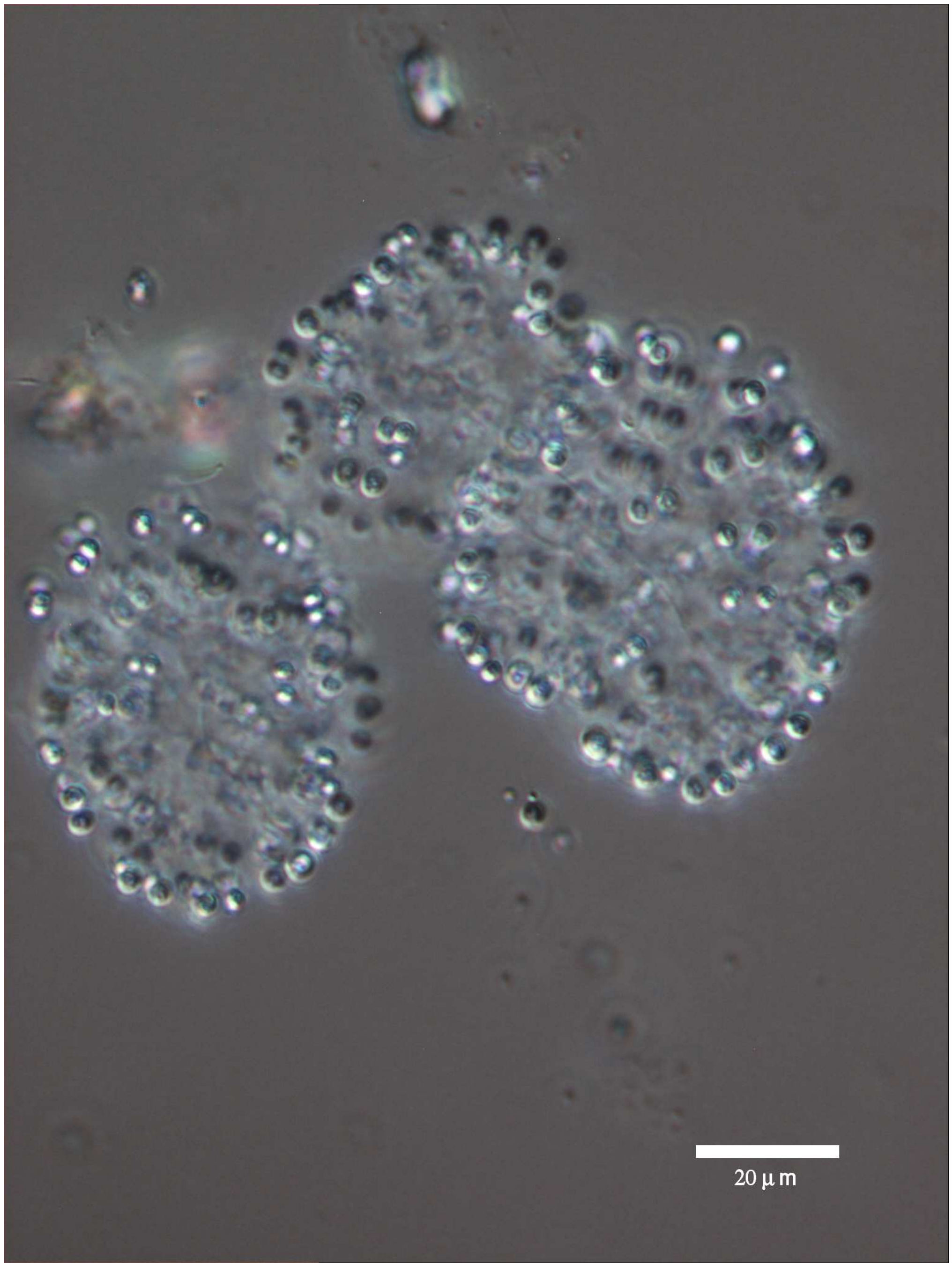


Figure B146: **Cyanobacteria:** *Snowella lacustris*, Lake Whatcom, September 11, 2009.

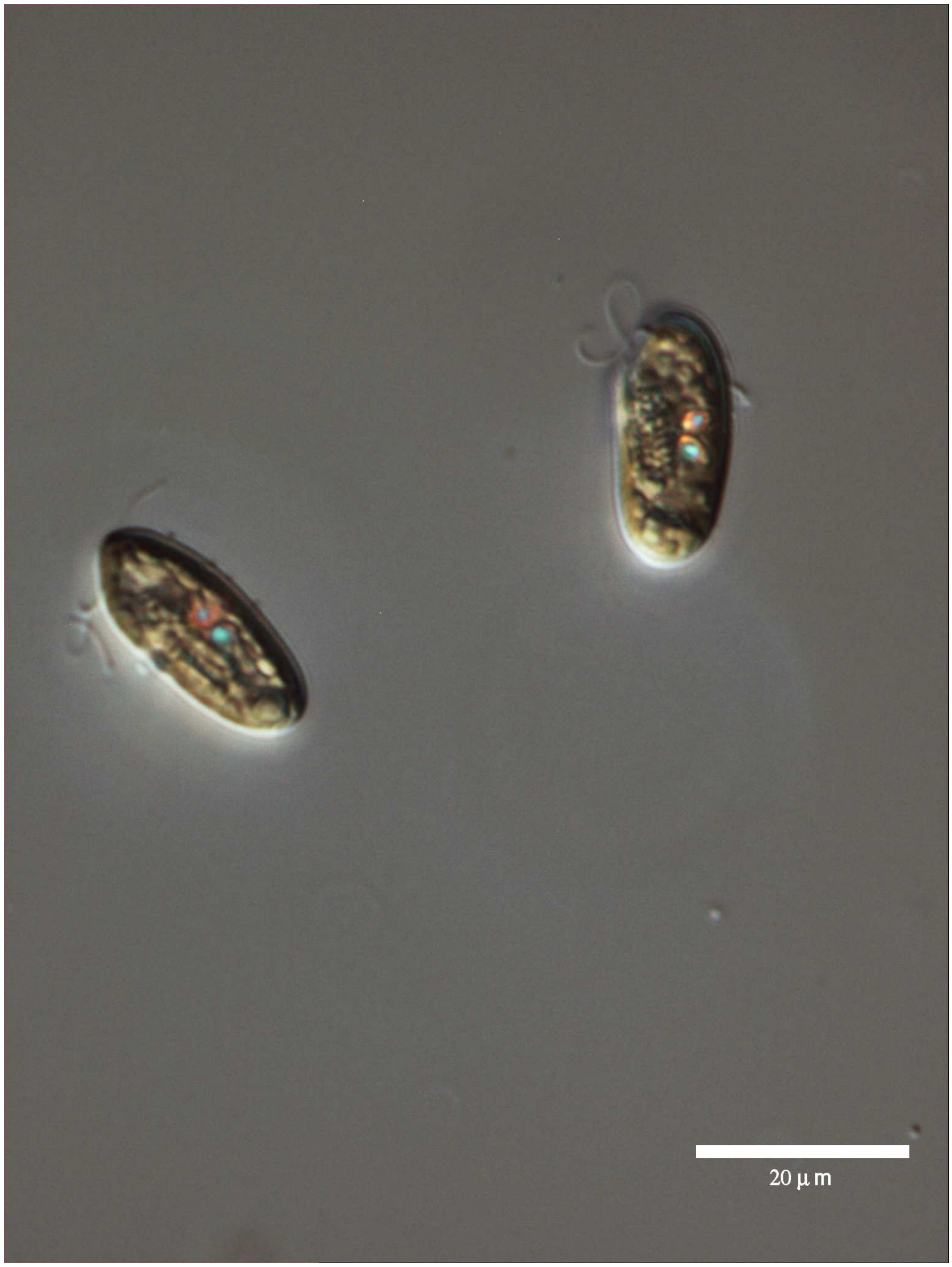


Figure B147: **Cryptophyta:** *Cryptomonas*, Lake Whatcom, September 17, 2009.

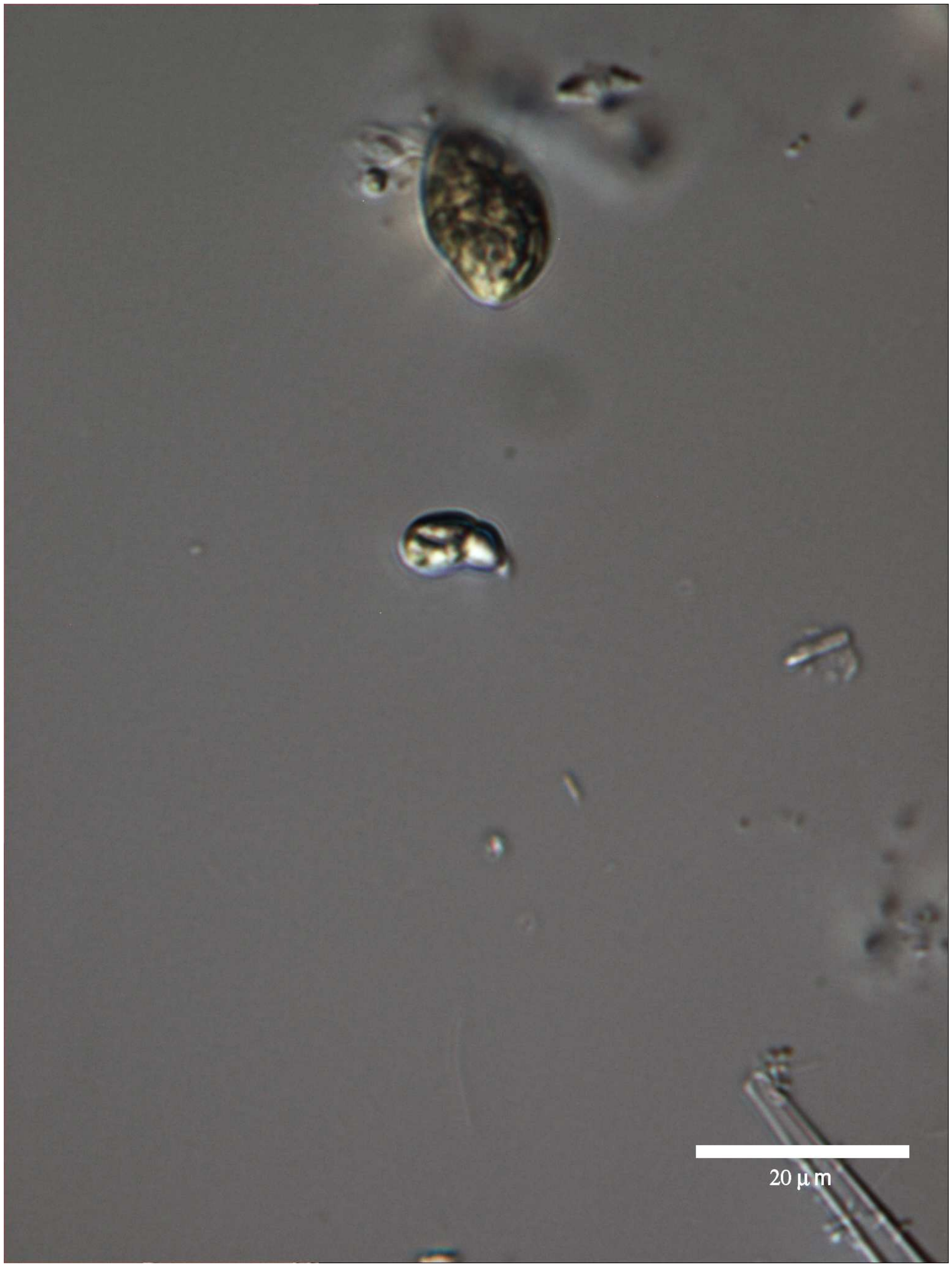


Figure B148: **Cryptophyta:** *Komma caudata* (Geitler) Hill (or *Rhodomonas* or *Chroomonas*). This tiny cryptomonad is very common in local lakes and was present in all of the Lake Whatcom samples collected in August 2009. The taxonomy of small cryptomonads is difficult and poorly described so the identification is uncertain.

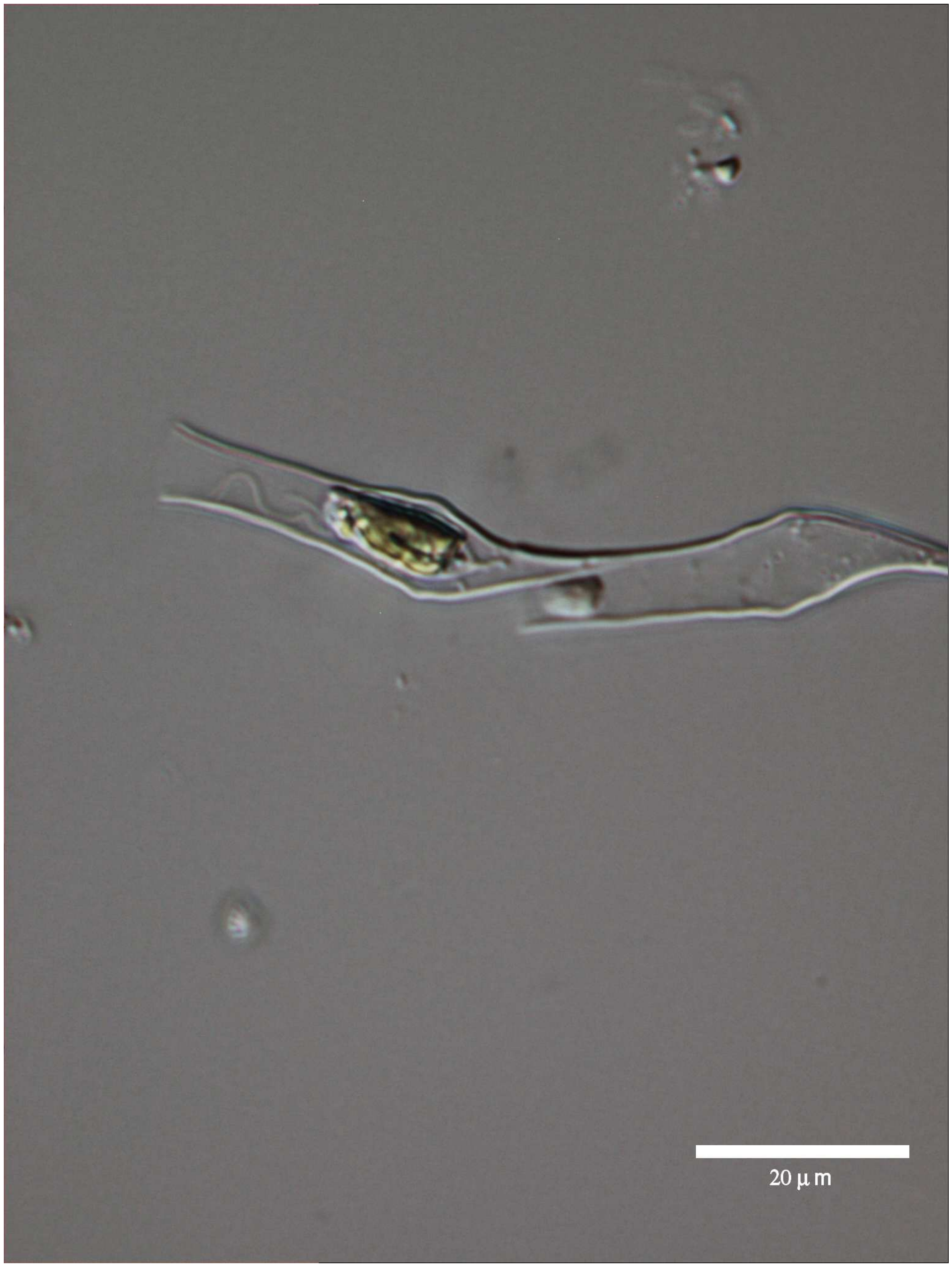


Figure B149: **Chrysophyta:** *Dinobryon*, Lake Whatcom, July 31, 2009.

Figure B150: **Chrysophyta:** *Mallomonas*, Clear Lake, August 23, 2007 (no image from Lake Whatcom).

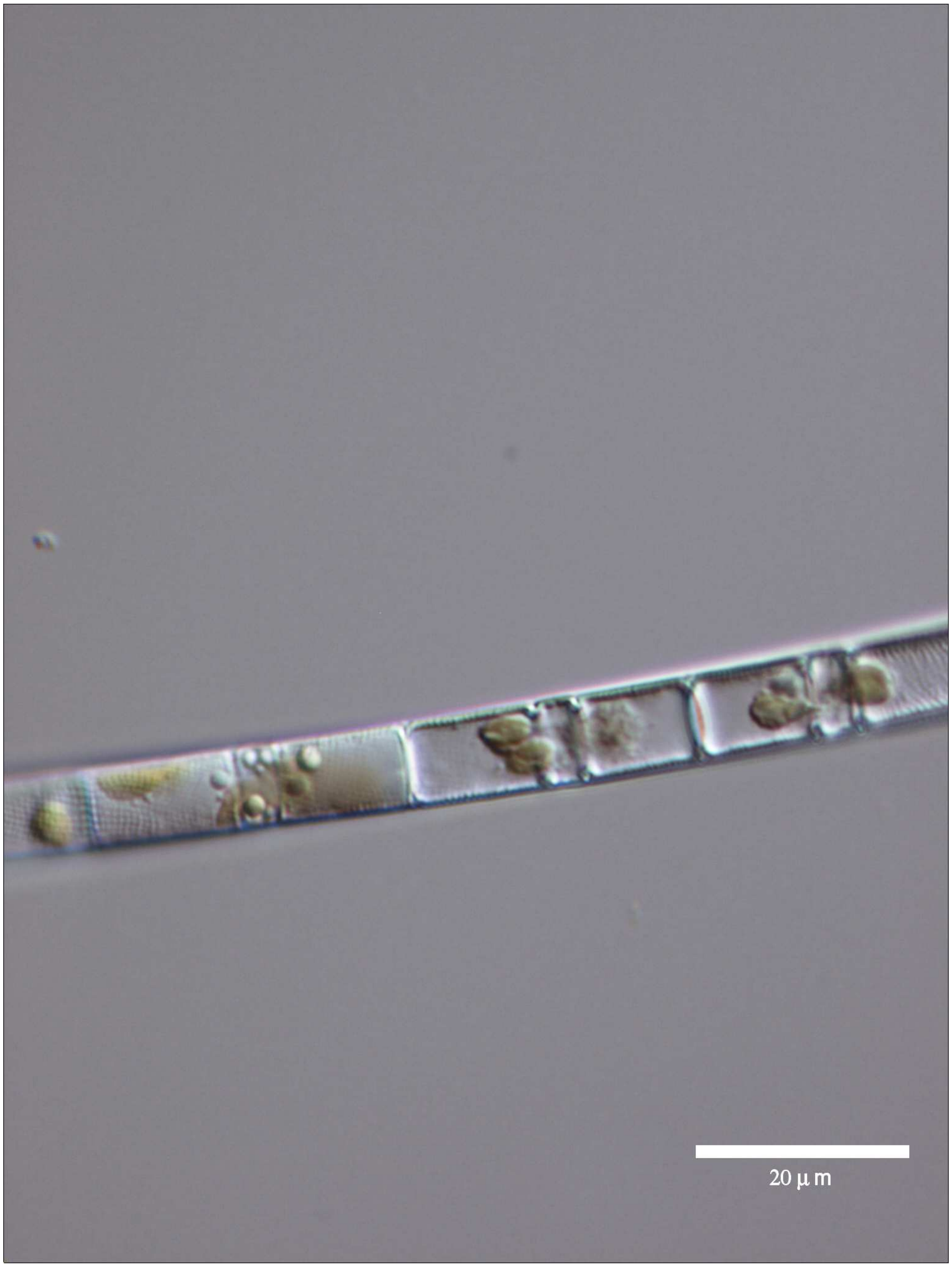


Figure B151: **Chrysophyta (diatoms):** *Aulacoseira*, Lake Whatcom, April 4, 2007.

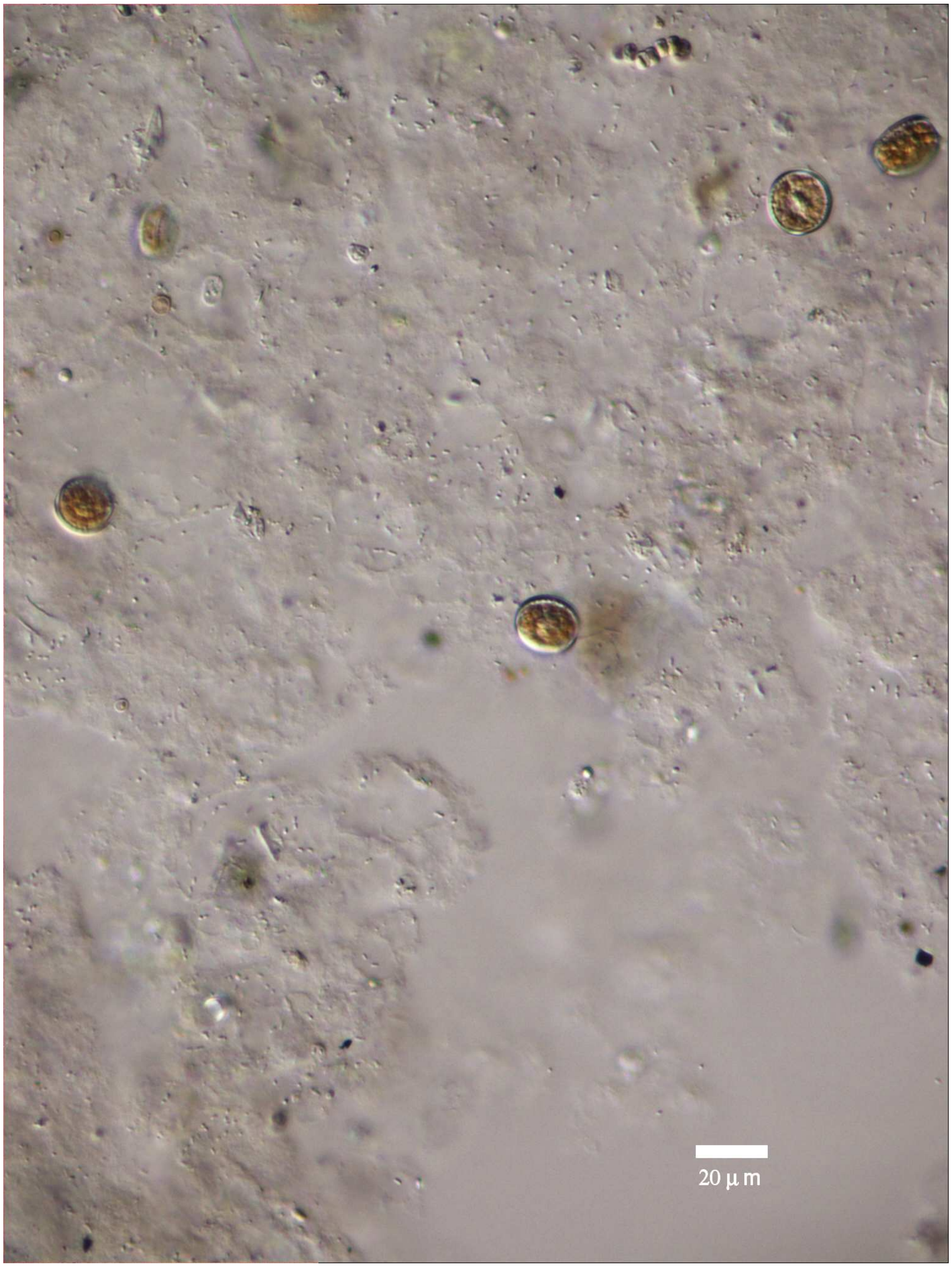


Figure B152: **Chrysophyta (diatoms):** *Cyclotella* (embedded in *Aphanocapsa*/*Aphanothece* matrix), Lake Whatcom, July 31, 2009.

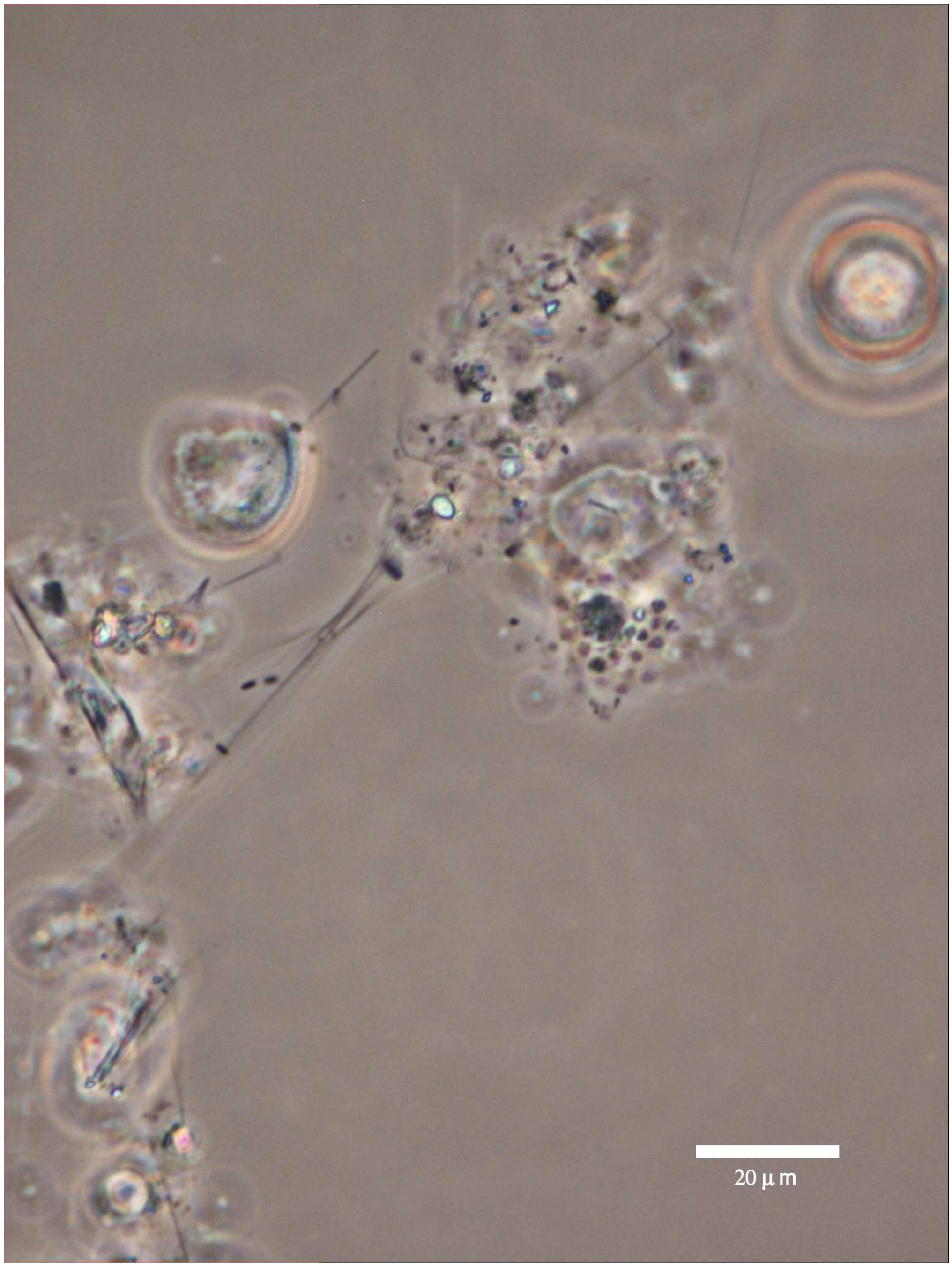


Figure B153: **Chrysophyta (diatoms):** *Cyclotella* fibers, Lake Whatcom, July 31, 2009.

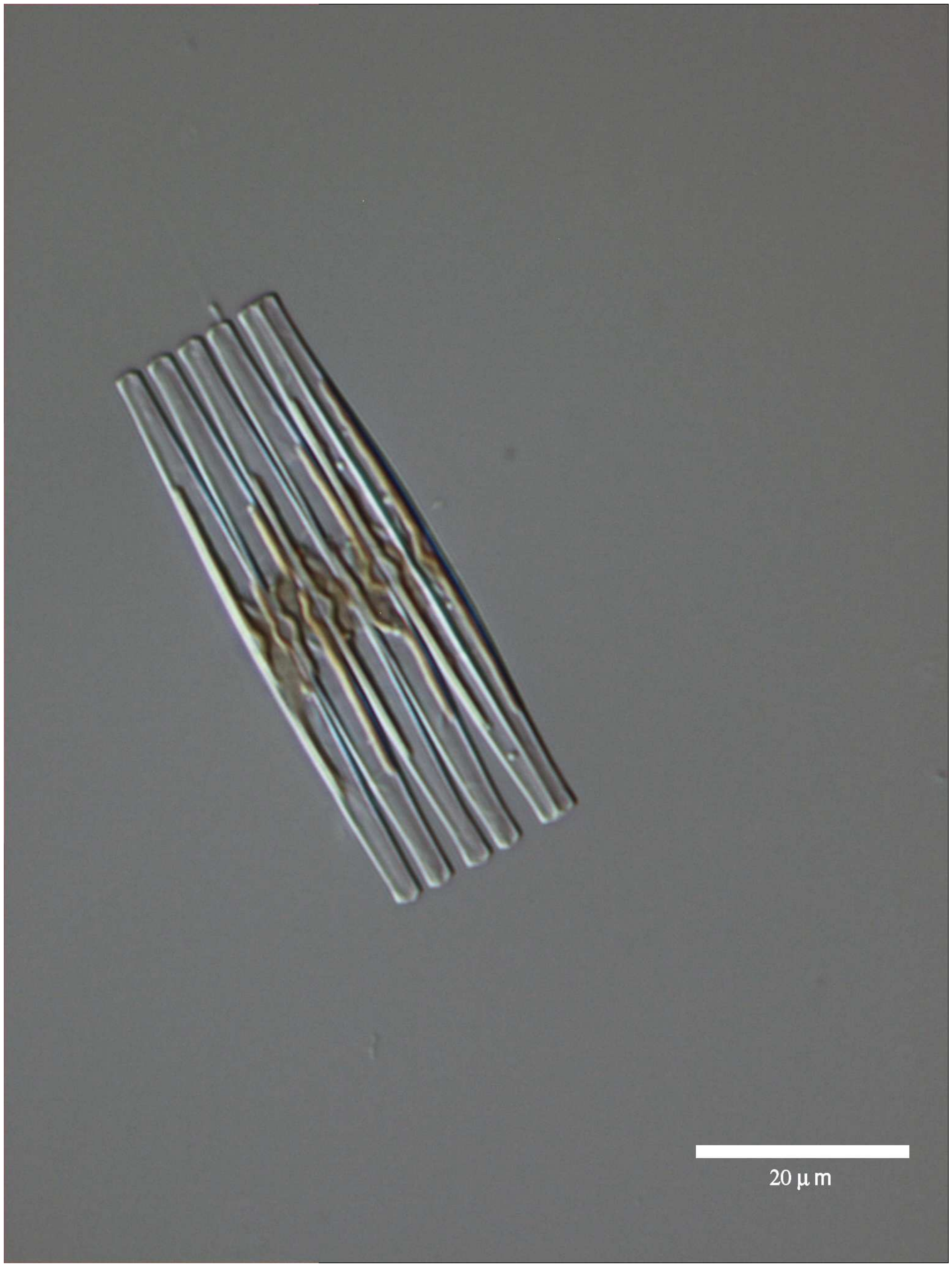


Figure B154: **Chrysophyta (diatoms):** *Fragilaria*, Lake Whatcom, July 31, 2009.

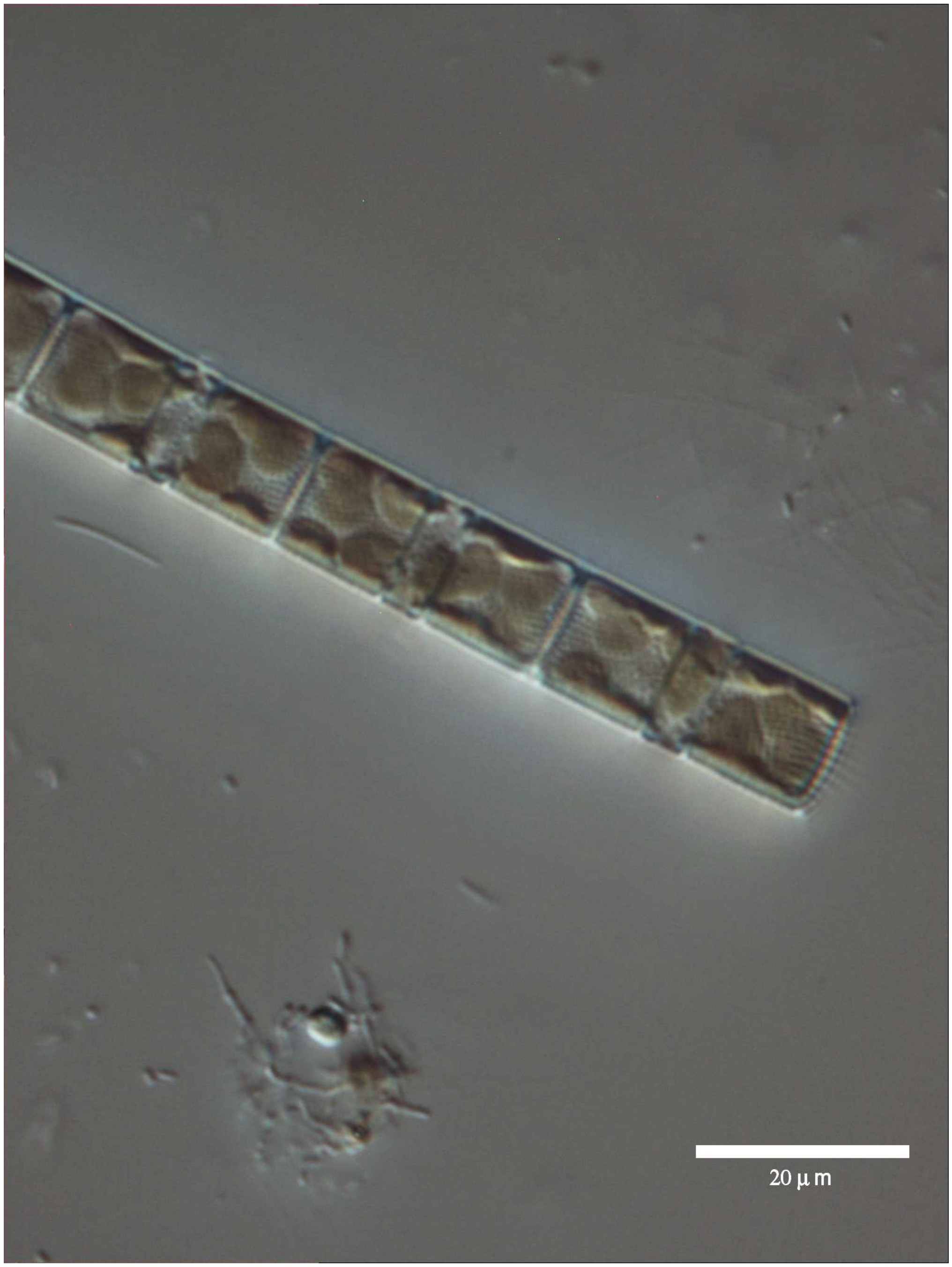


Figure B155: **Chrysophyta (diatoms):** *Melosira*, Lake Whatcom, September 17, 2009.

Figure B156: **Chrysophyta (diatoms):** *Synedra*, Lake Whatcom, September 17, 2009.

Figure B157: **Chrysophyta (diatoms):** *Thalassiosira pseudonana*, Lake Whatcom, July 31, 2009.

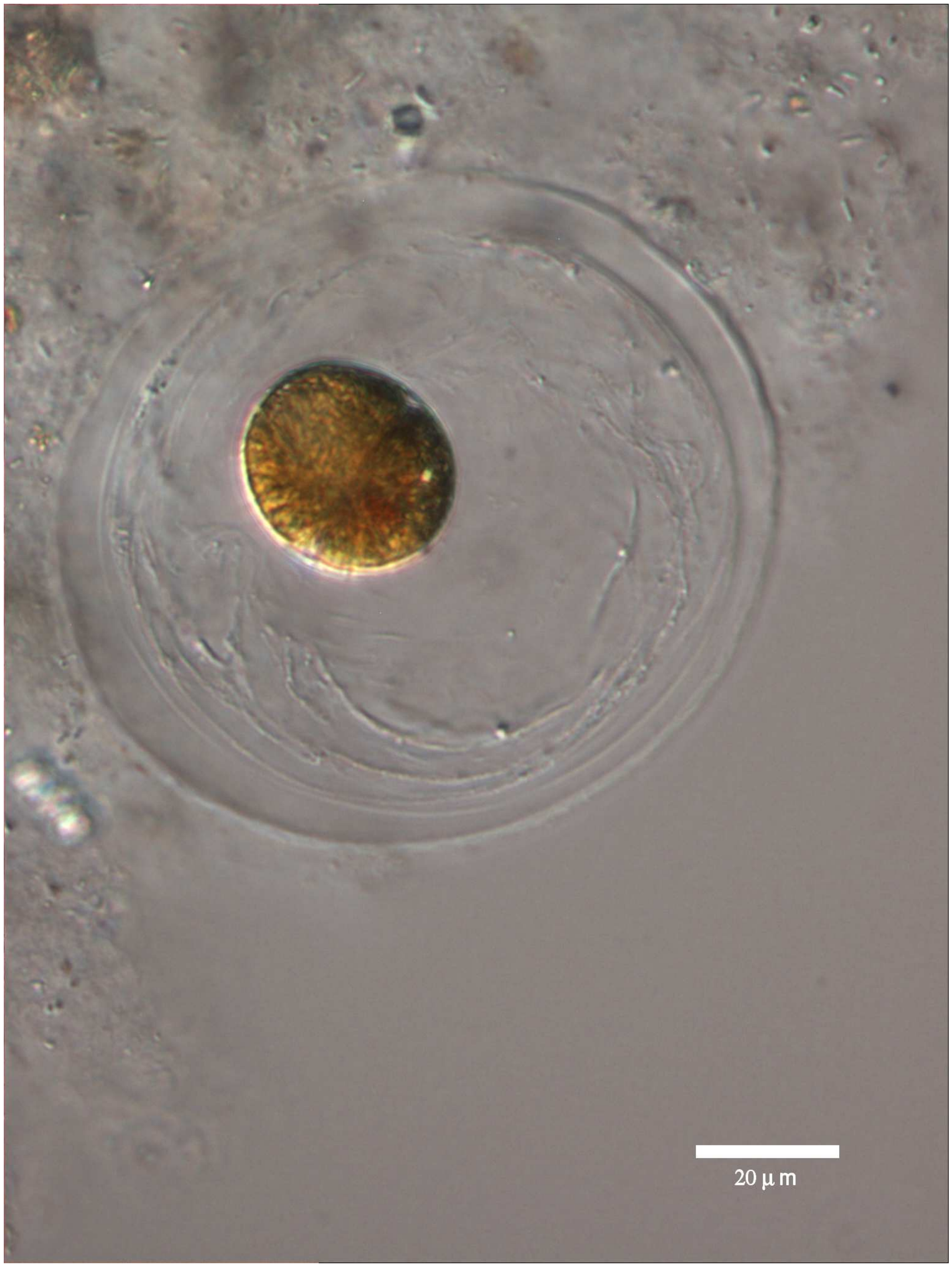


Figure B158: **Dinoflagellates:** *Gymnodinium* (encysted), Lake Whatcom, July 31, 2009.

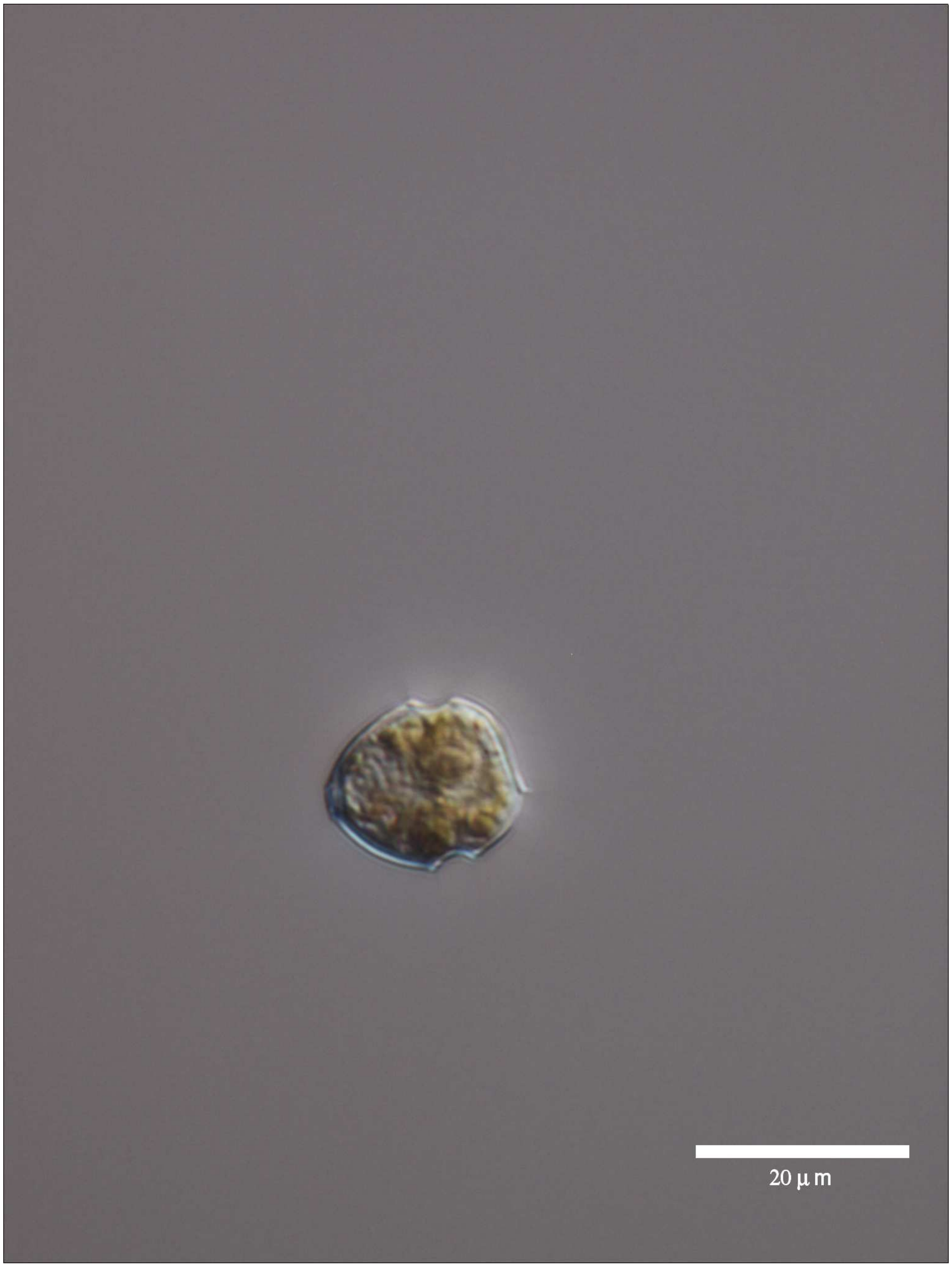


Figure B159: **Dinoflagellates:** *Peridinium umbonatum*, Lake Cavanaugh, August 23, 2007 (no image from Lake Whatcom).

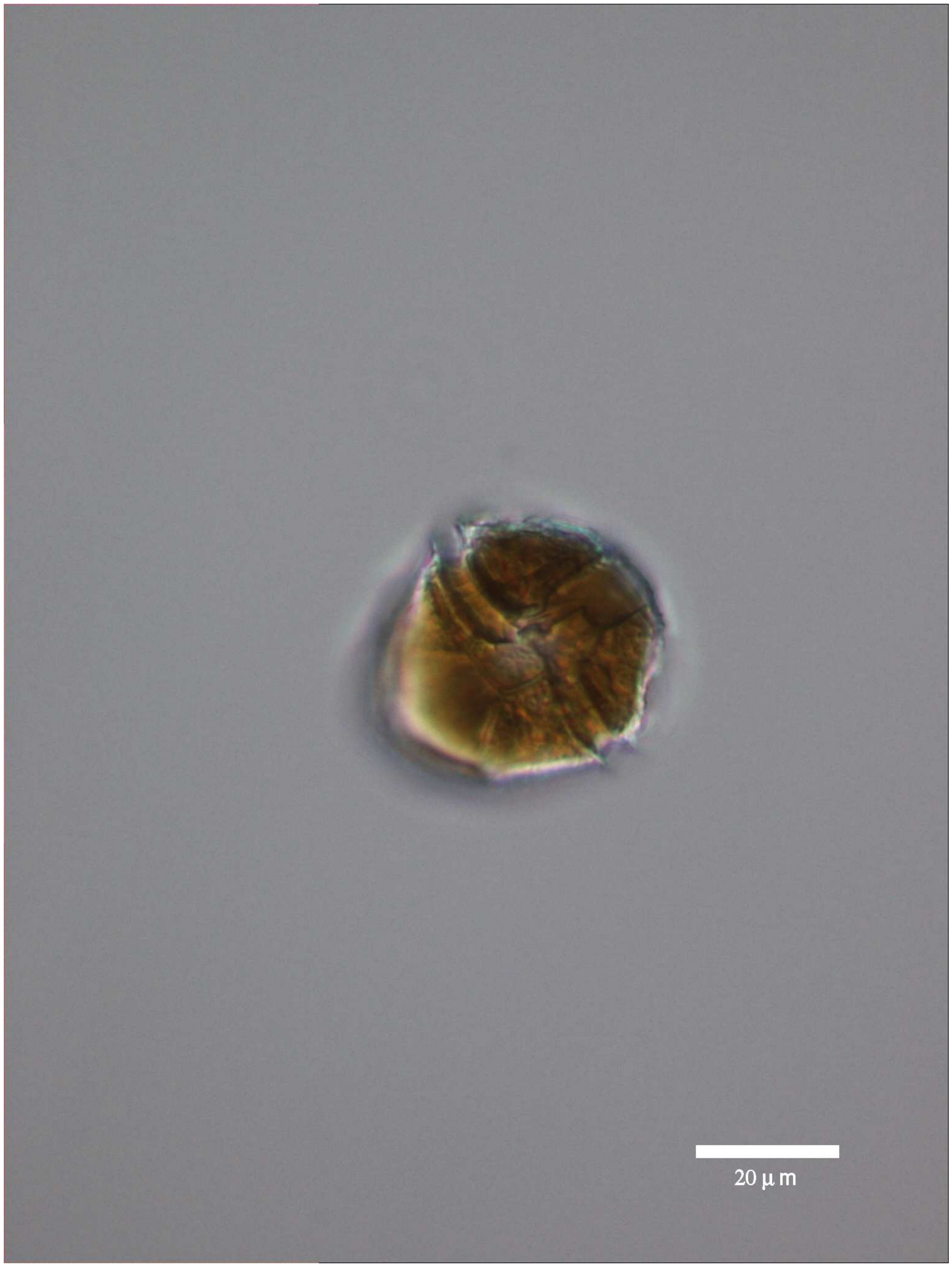


Figure B160: **Dinoflagellates:** *Peridinium*, Lake Whatcom, August 4, 2009.

B.5 Lake Whatcom Tributary Data (2004-present)

The figures in this appendix include the monthly baseline data collected from October 2004 through September 2006 and the biannual 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 from 2004–2006 have been omitted to provide more informative plotting scales; all original data, including outliers, are available online at http://www.ac.wwu.edu/∼iws.

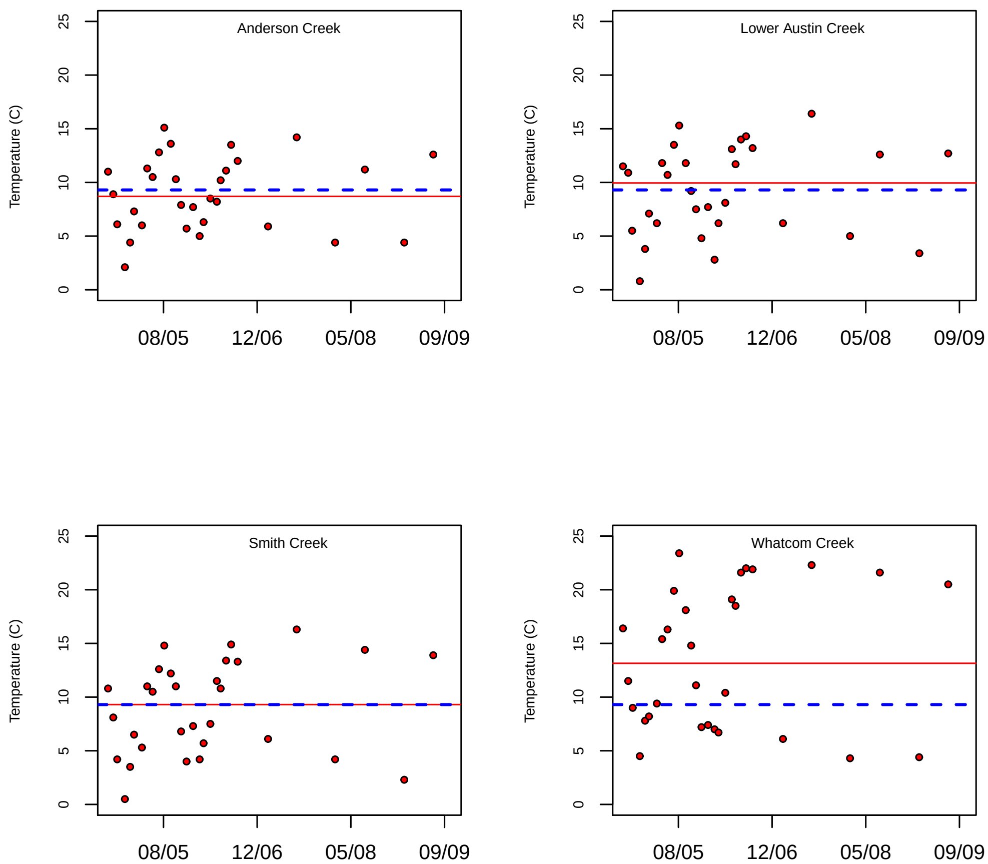


Figure B161: Temperature data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

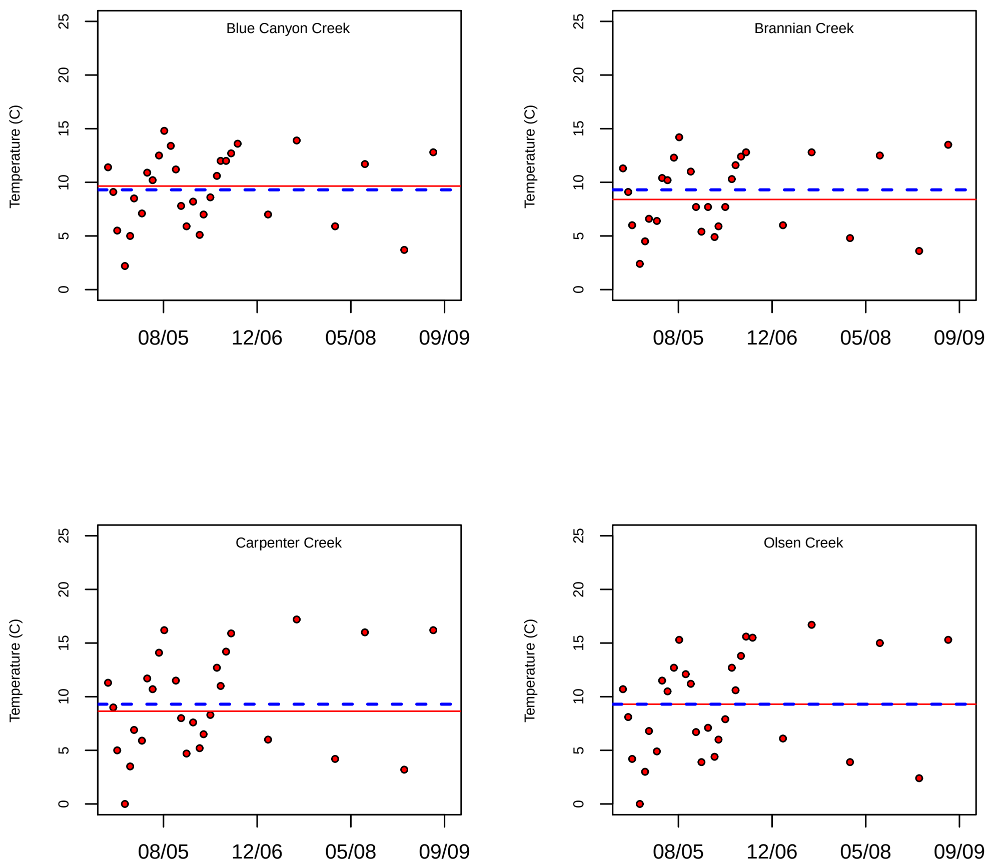


Figure B162: Temperature data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

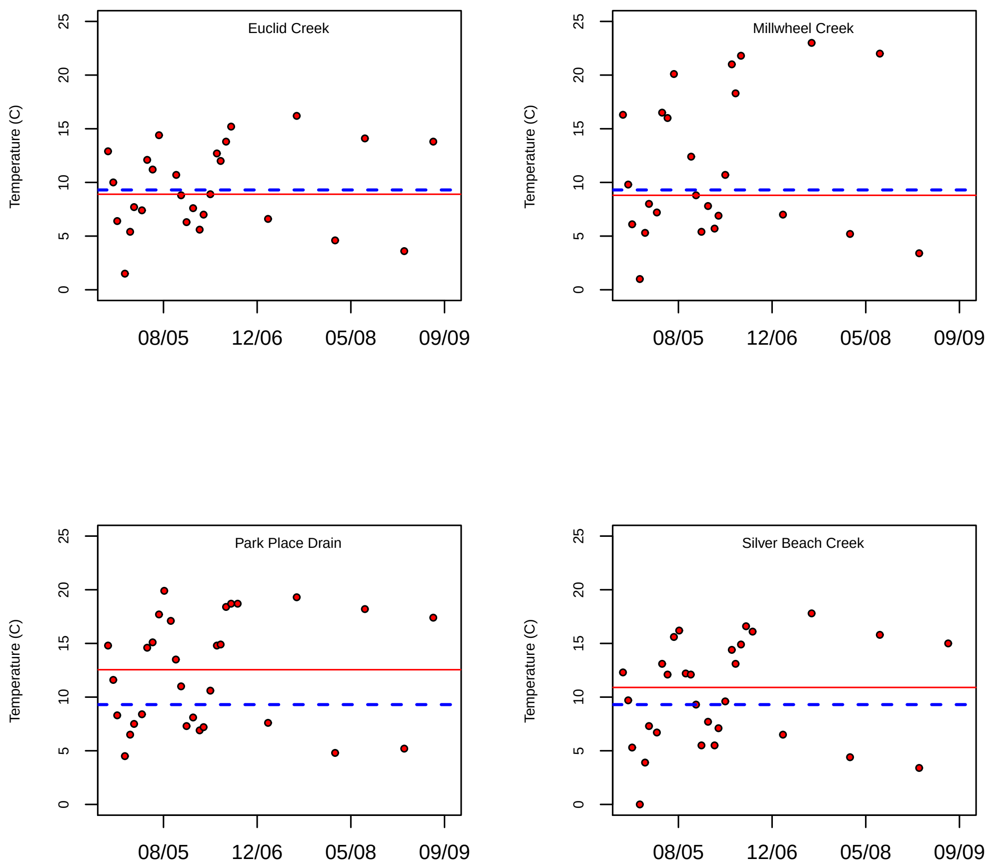


Figure B163: Temperature data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

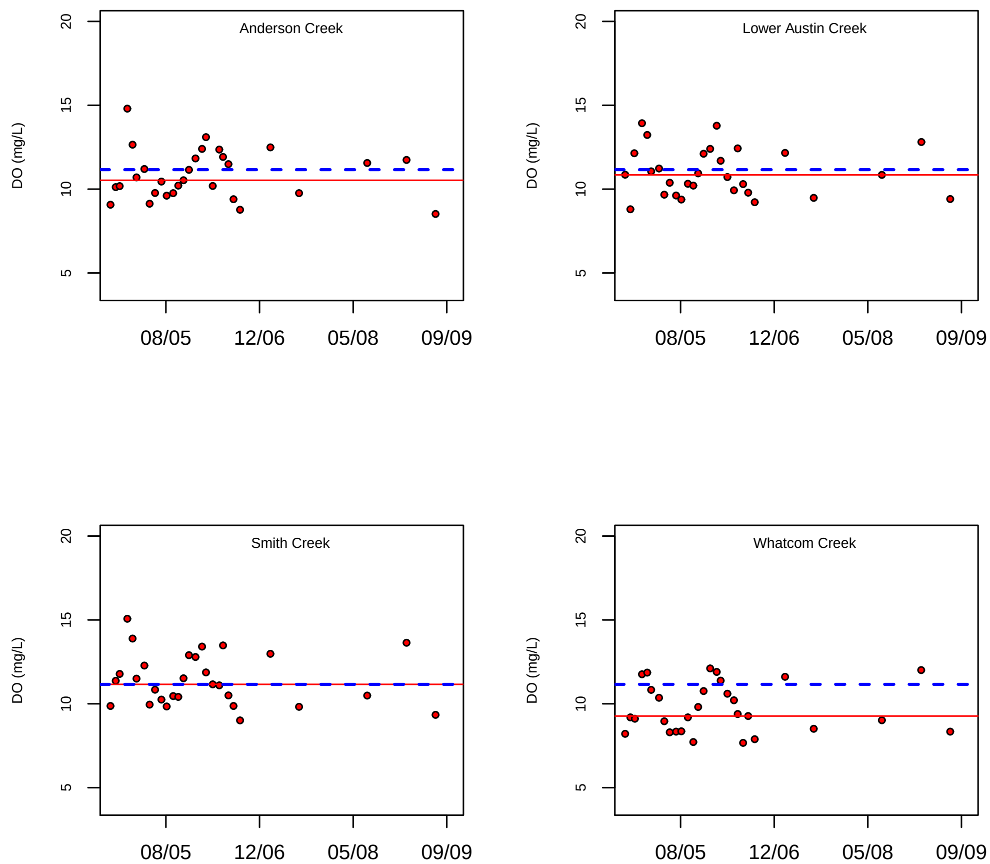


Figure B164: Dissolved oxygen data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

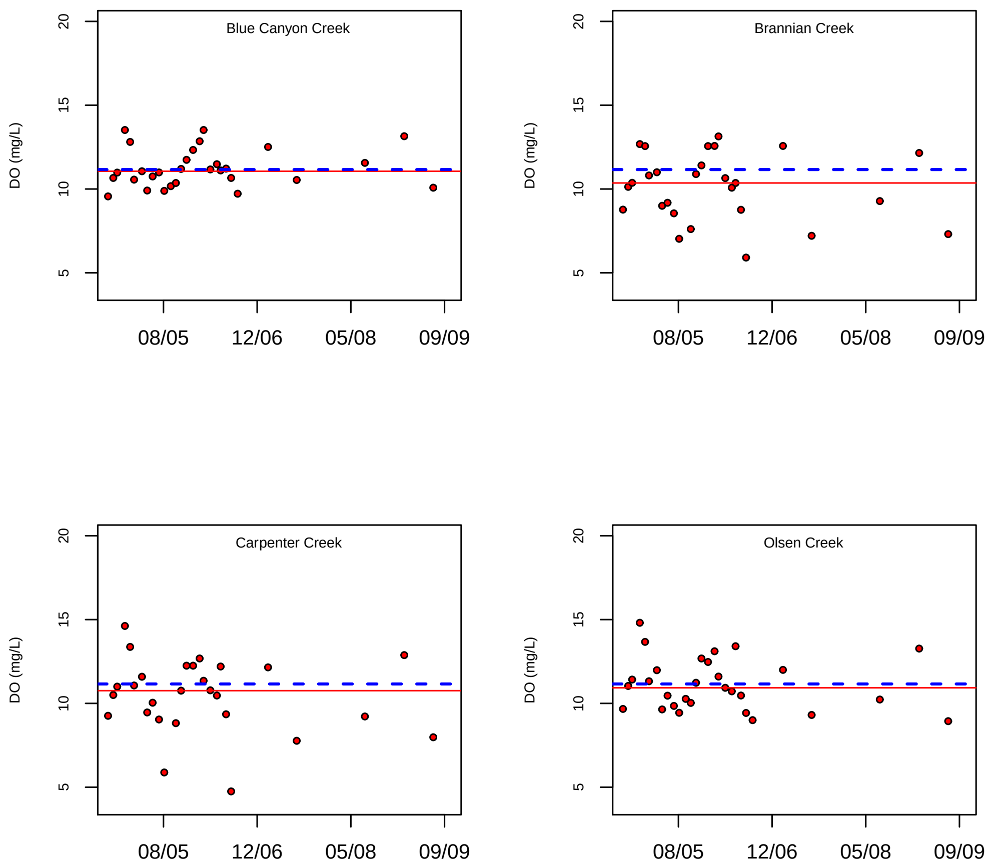


Figure B165: Dissolved oxygen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

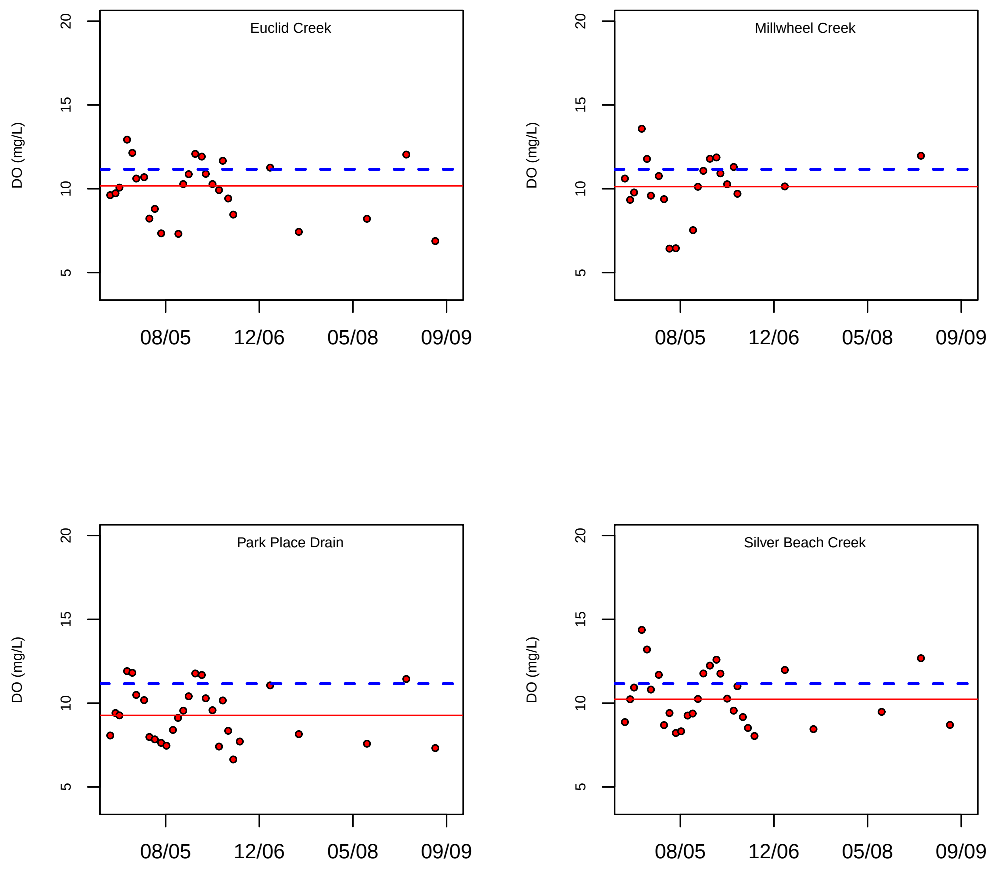


Figure B166: Dissolved oxygen data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

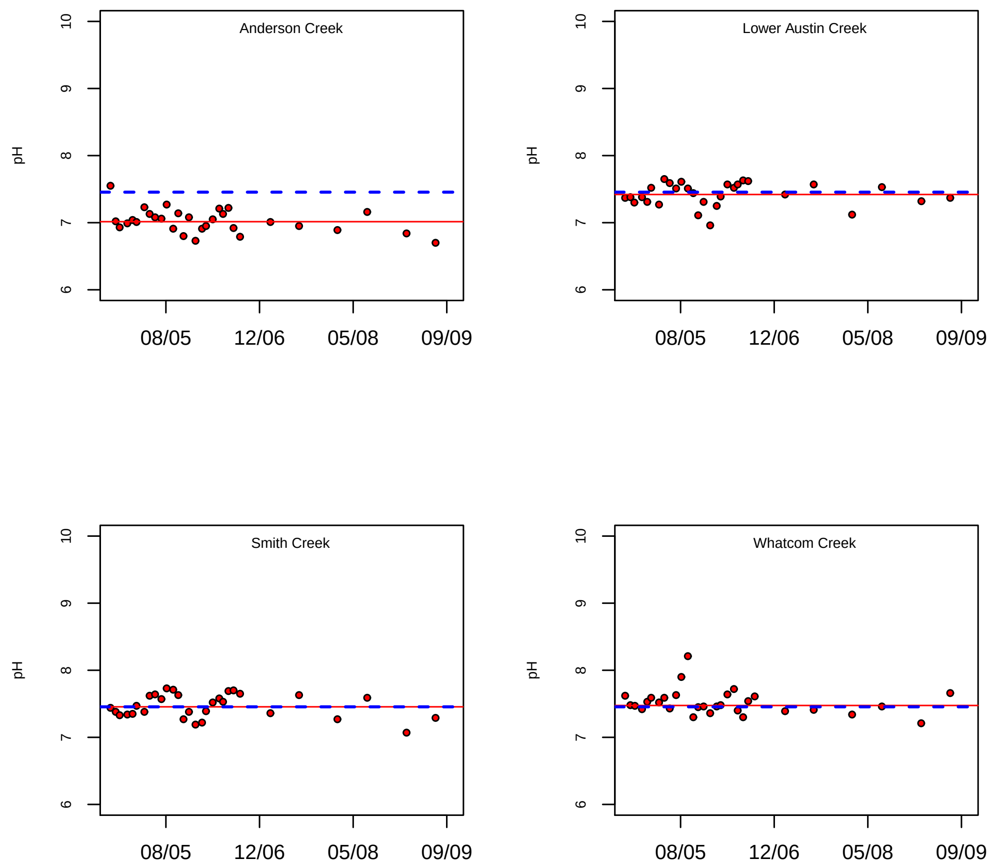


Figure B167: Tributary pH data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

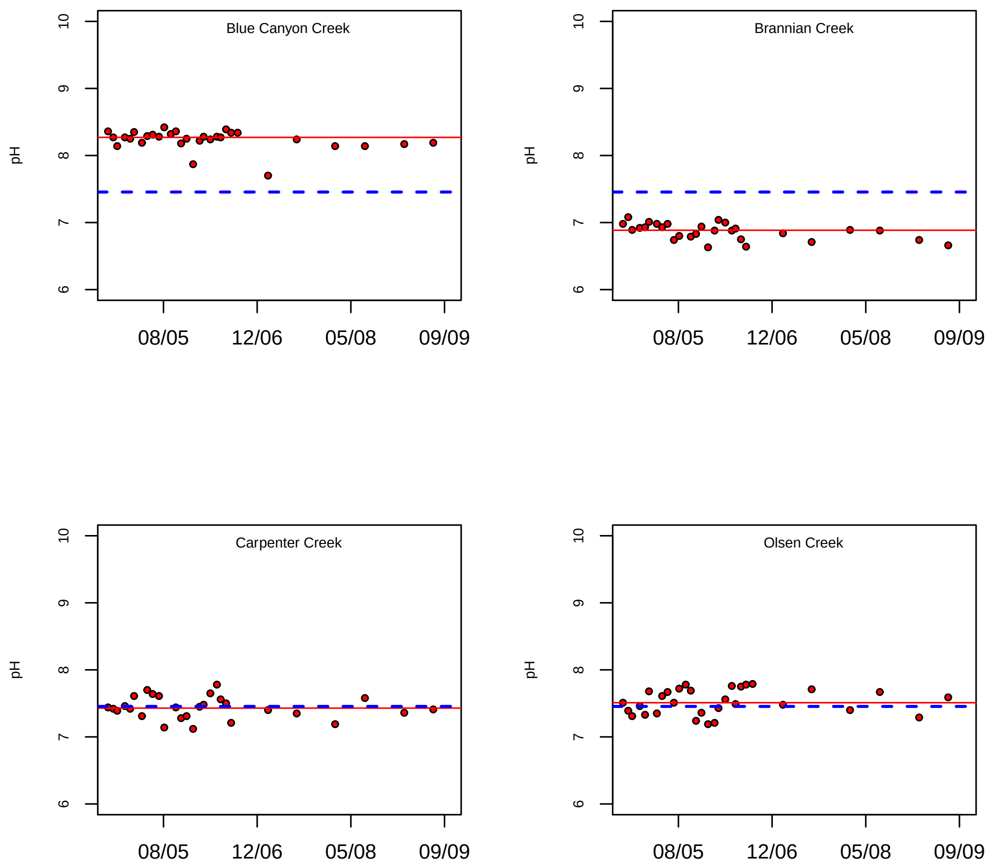


Figure B168: Tributary pH data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

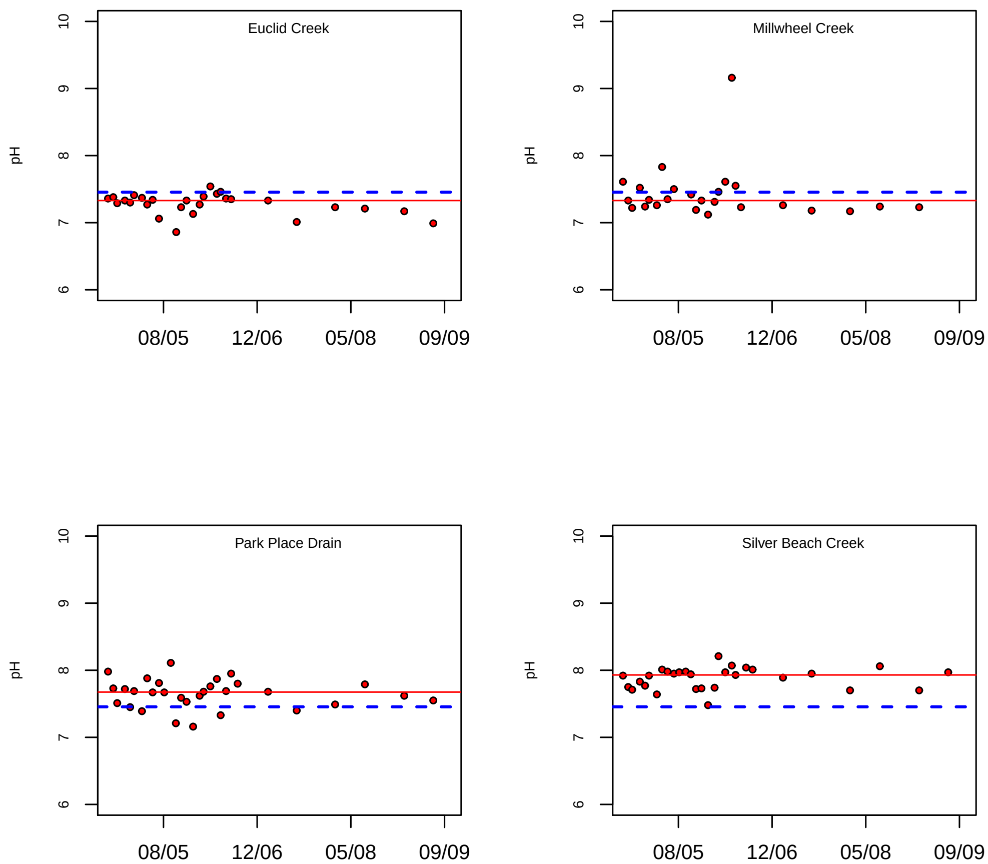


Figure B169: Tributary pH data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

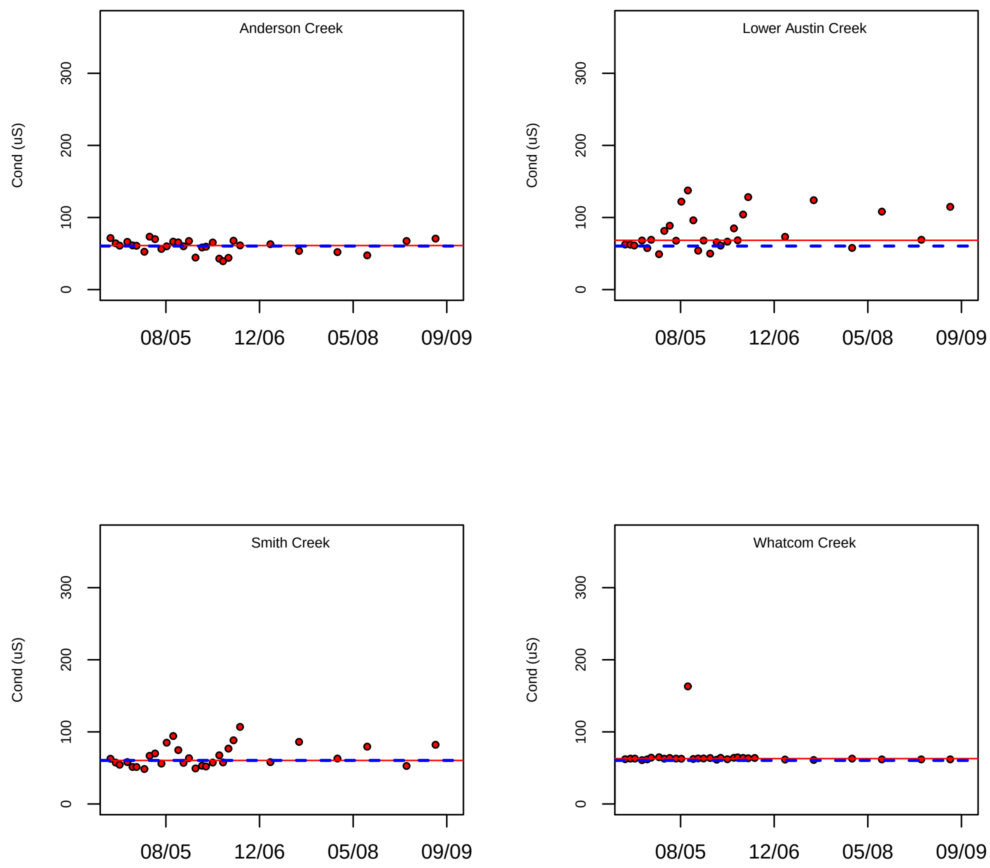


Figure B170: Conductivity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

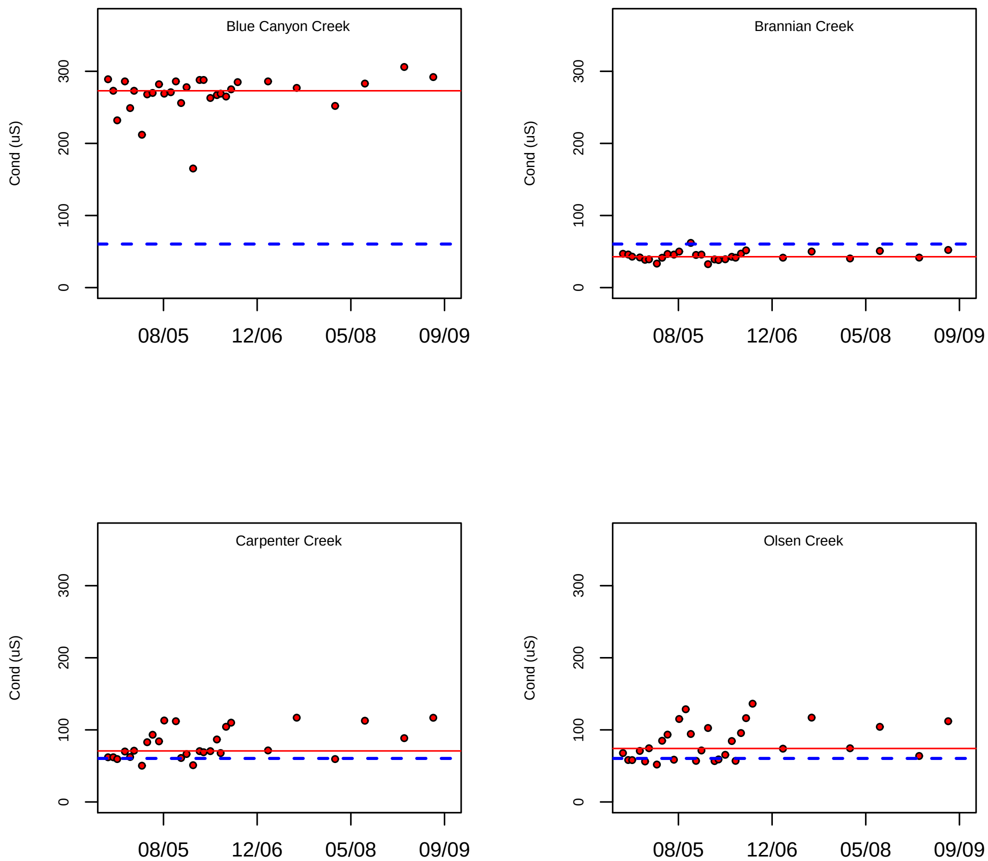


Figure B171: Conductivity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

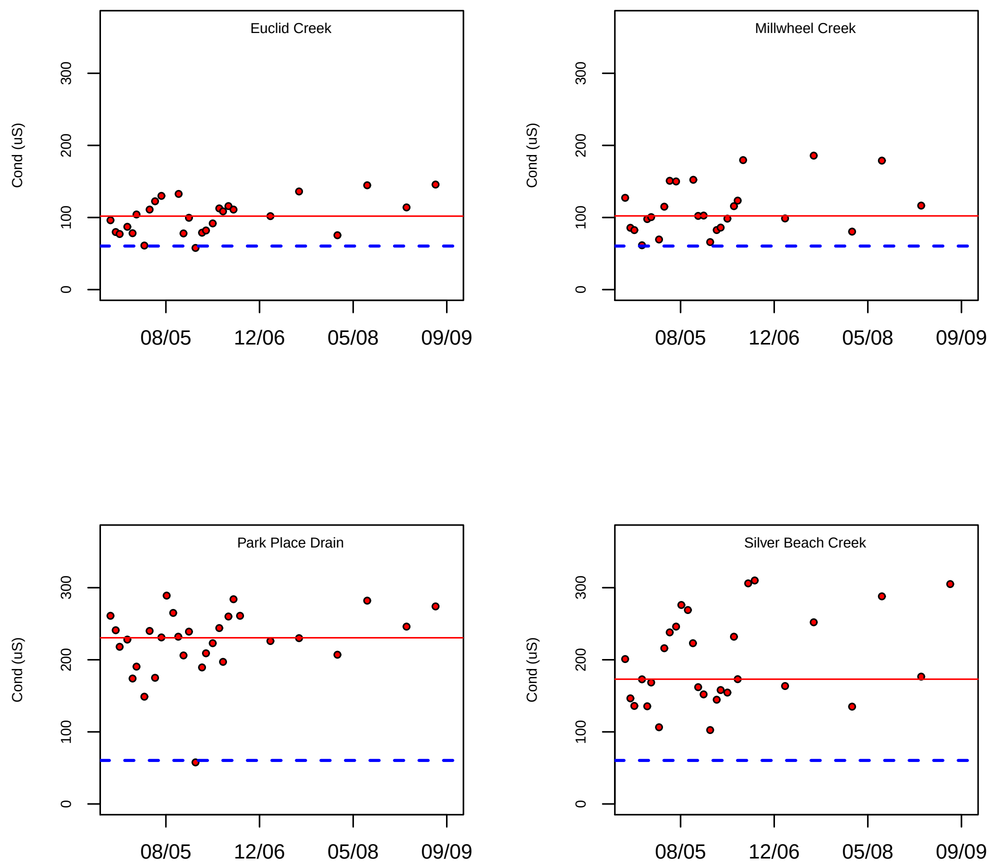


Figure B172: Conductivity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

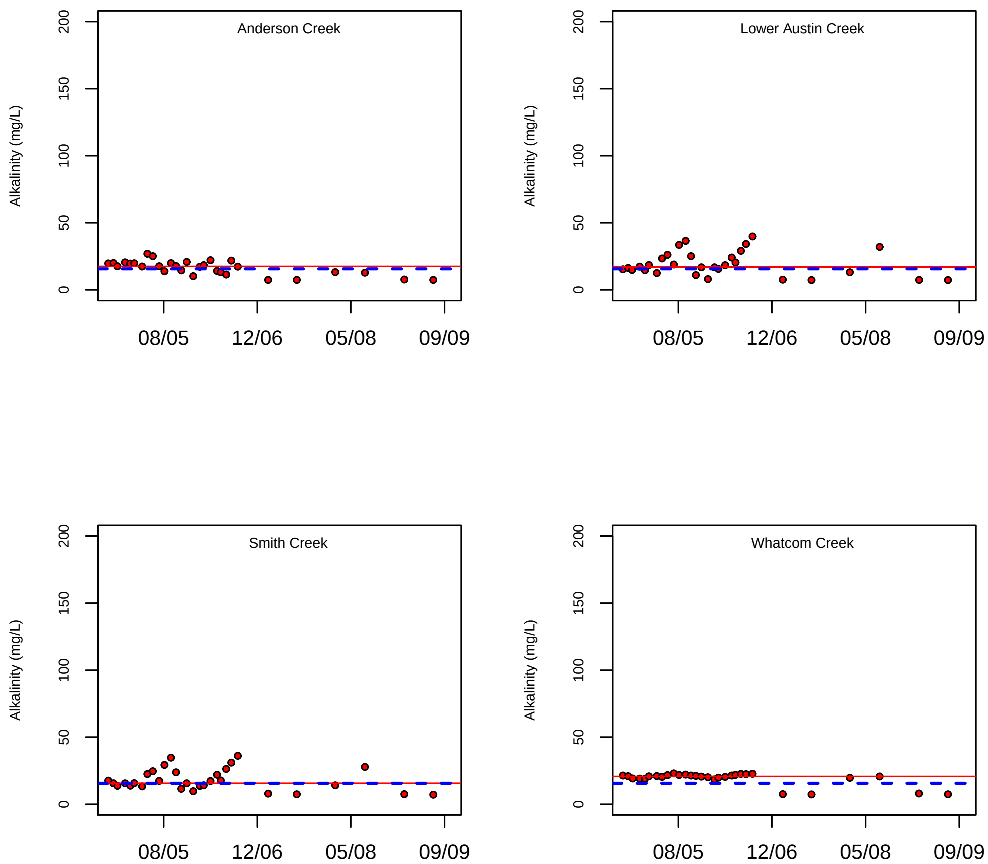


Figure B173: Alkalinity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

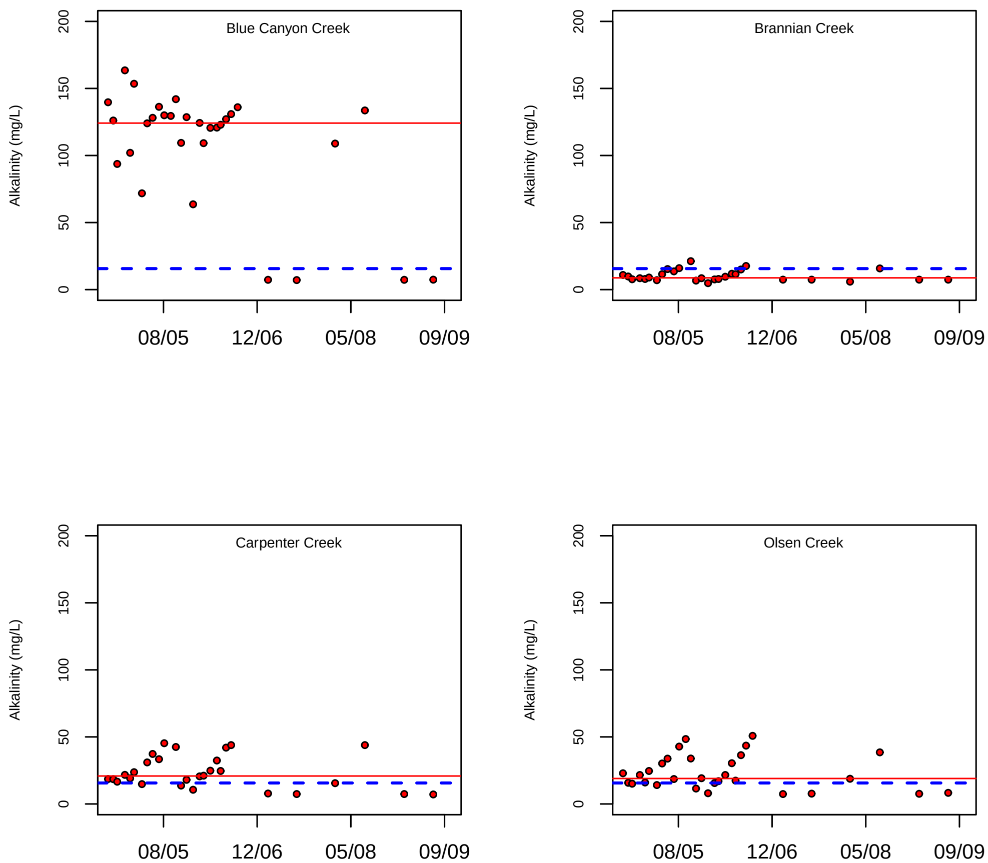


Figure B174: Alkalinity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

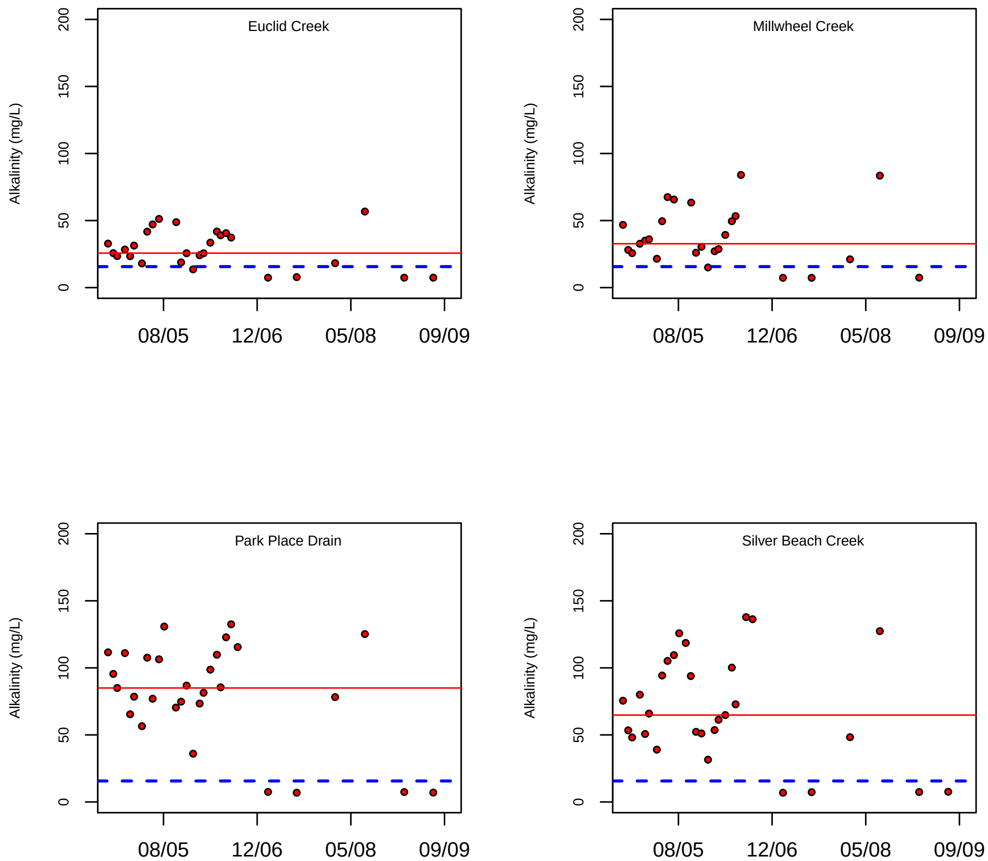


Figure B175: Alkalinity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

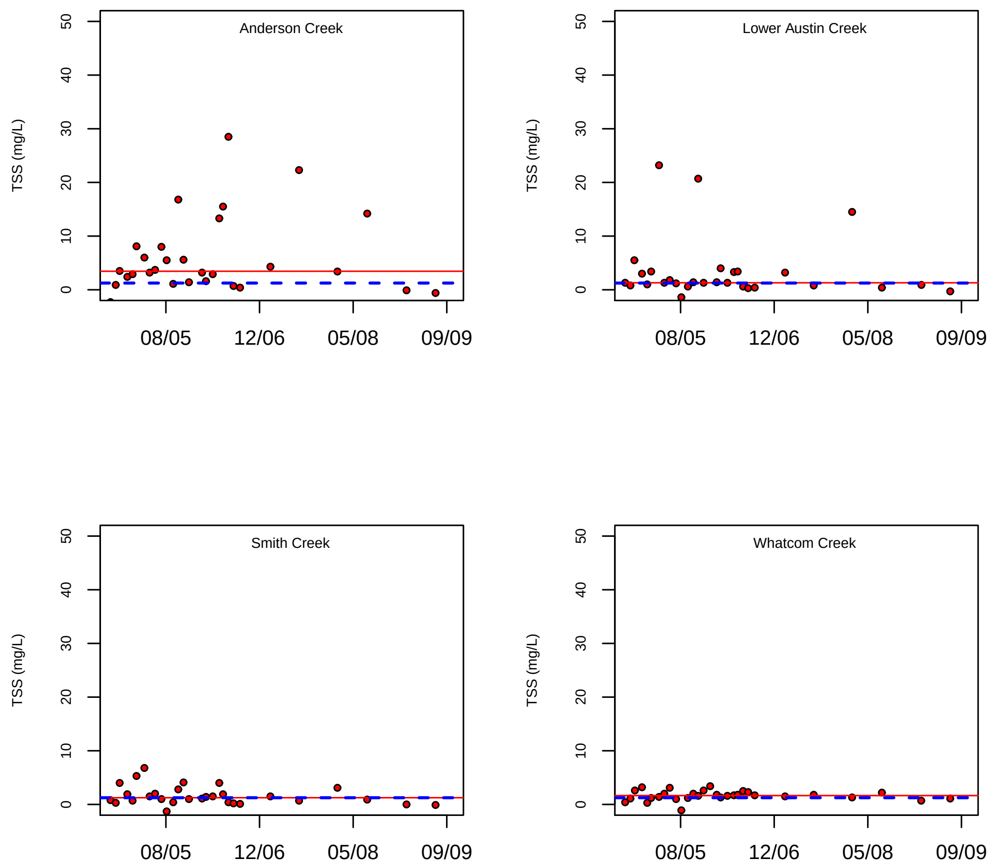


Figure B176: Total suspended solids data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

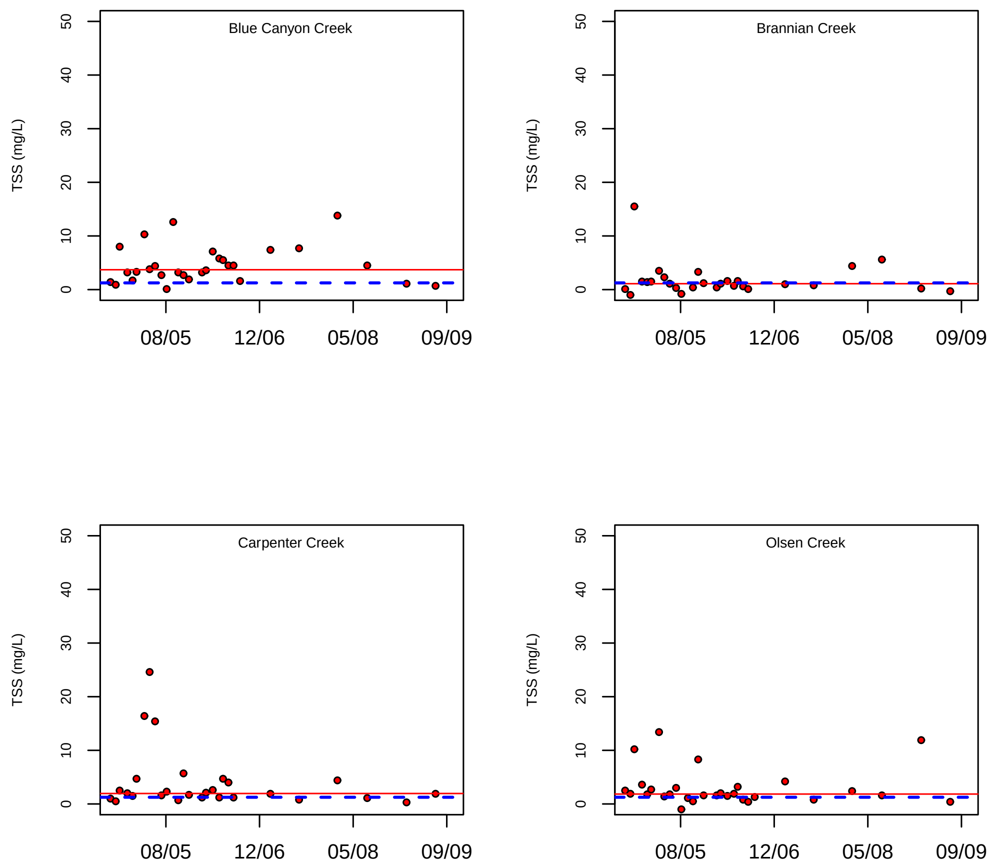


Figure B177: Total suspended solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

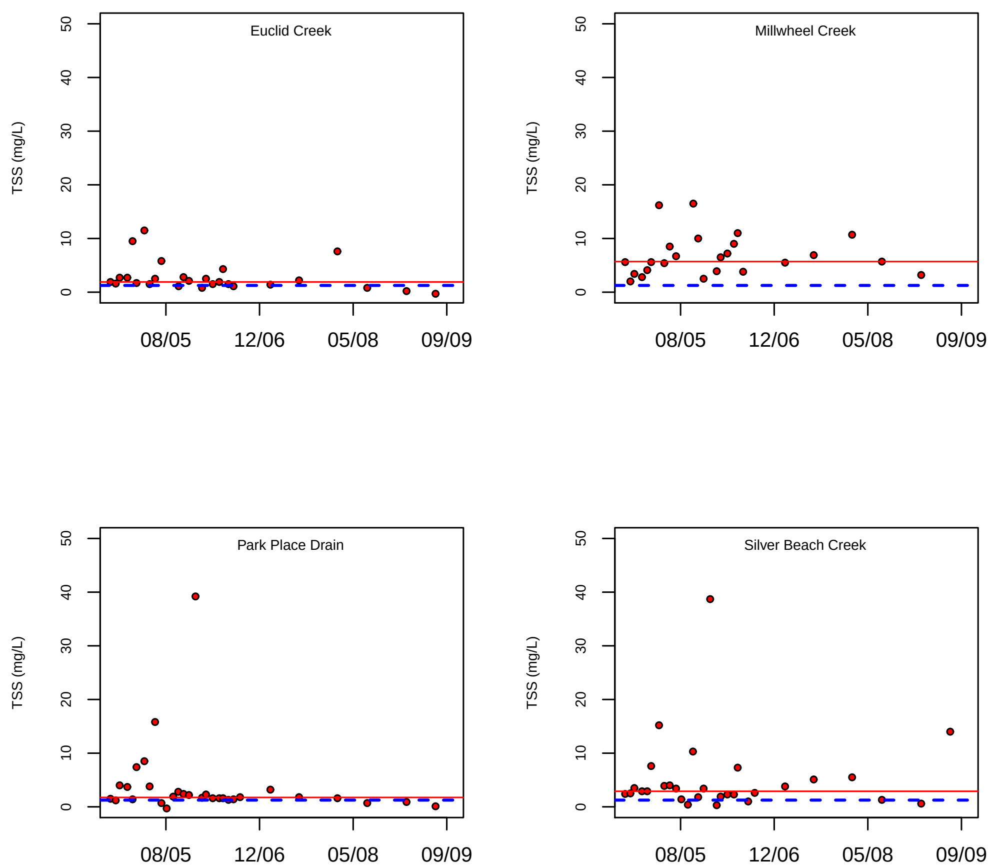


Figure B178: Total suspended solids data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

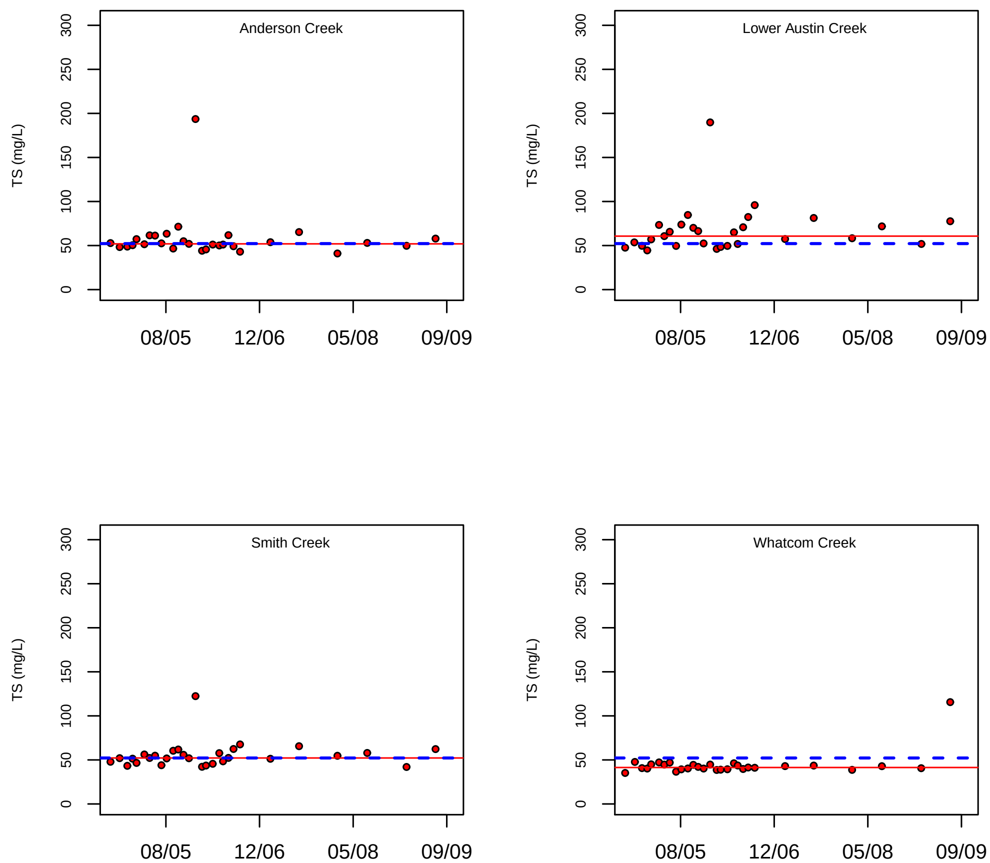


Figure B179: Total solids data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

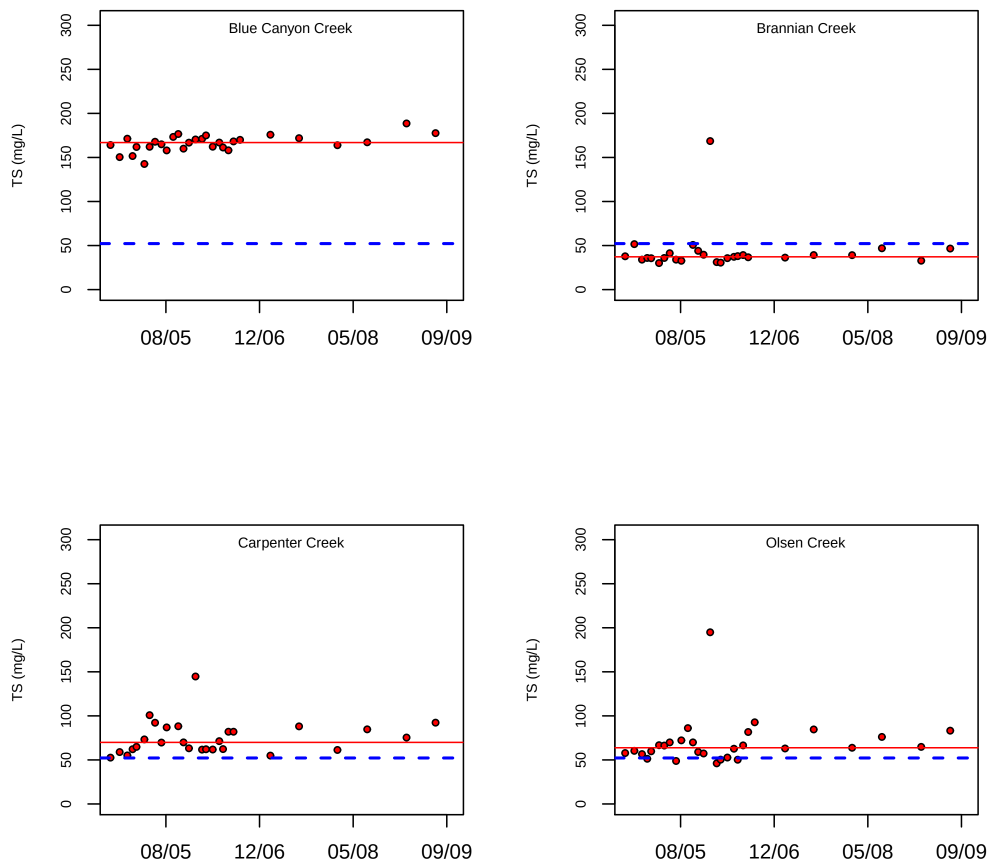


Figure B180: Total solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

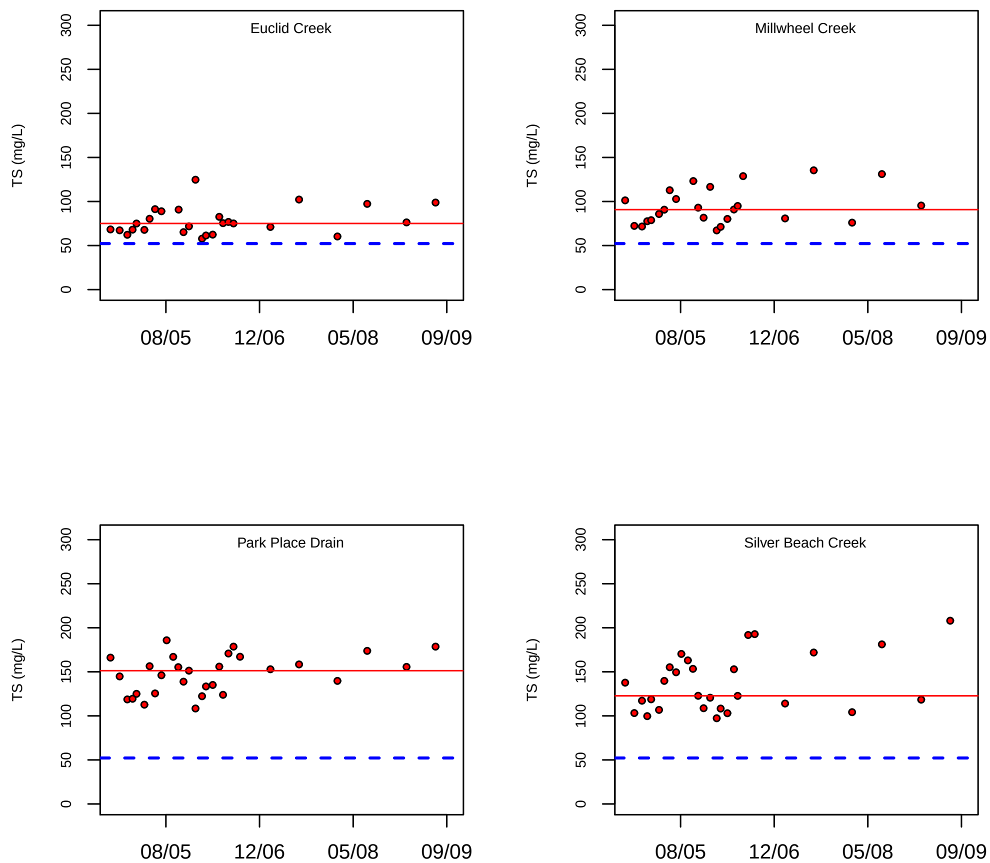


Figure B181: Total solids data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

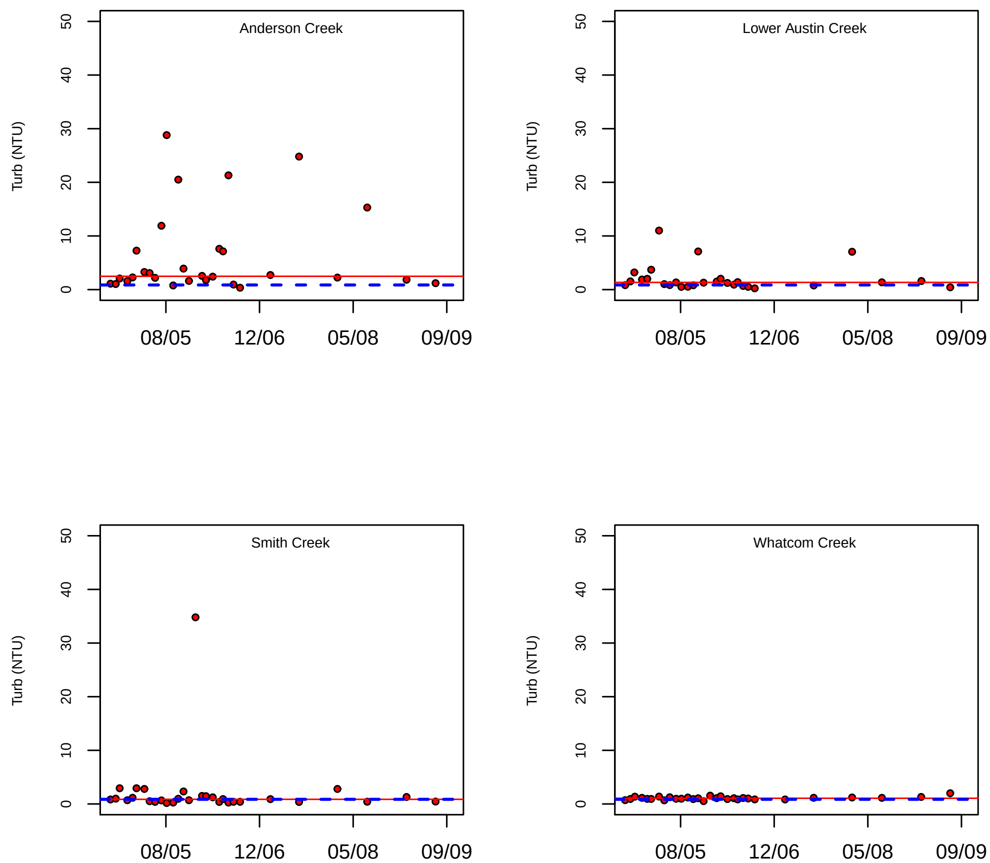


Figure B182: Turbidity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

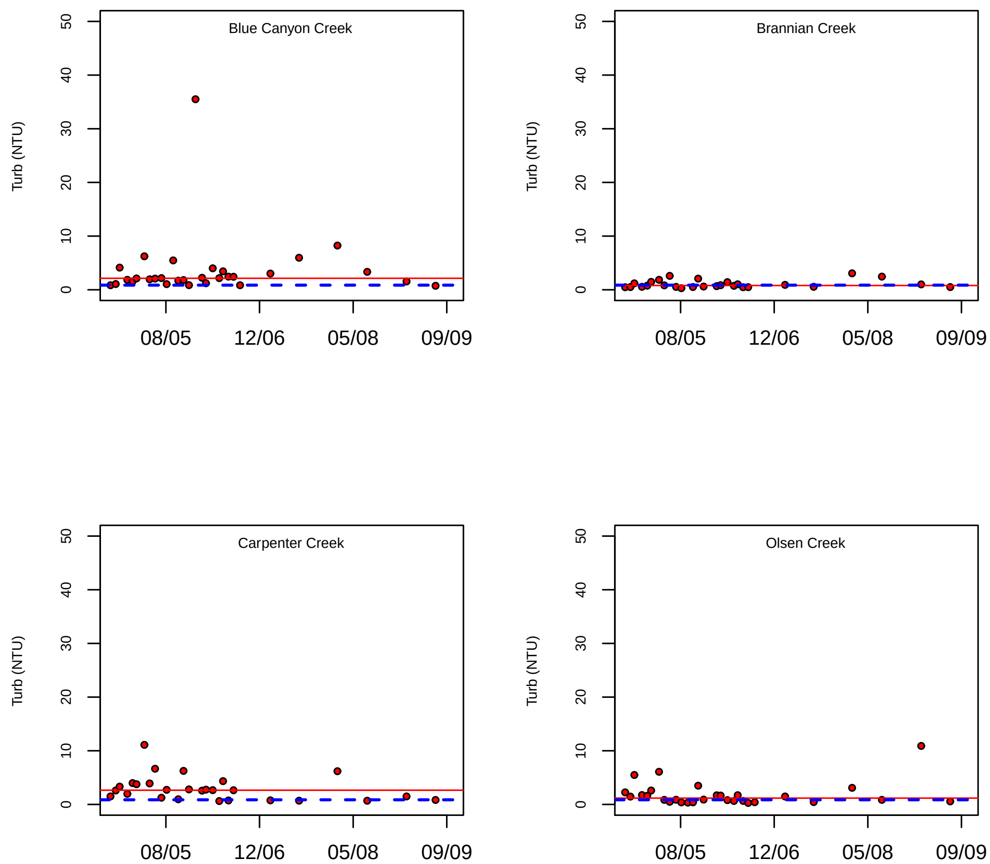


Figure B183: Turbidity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

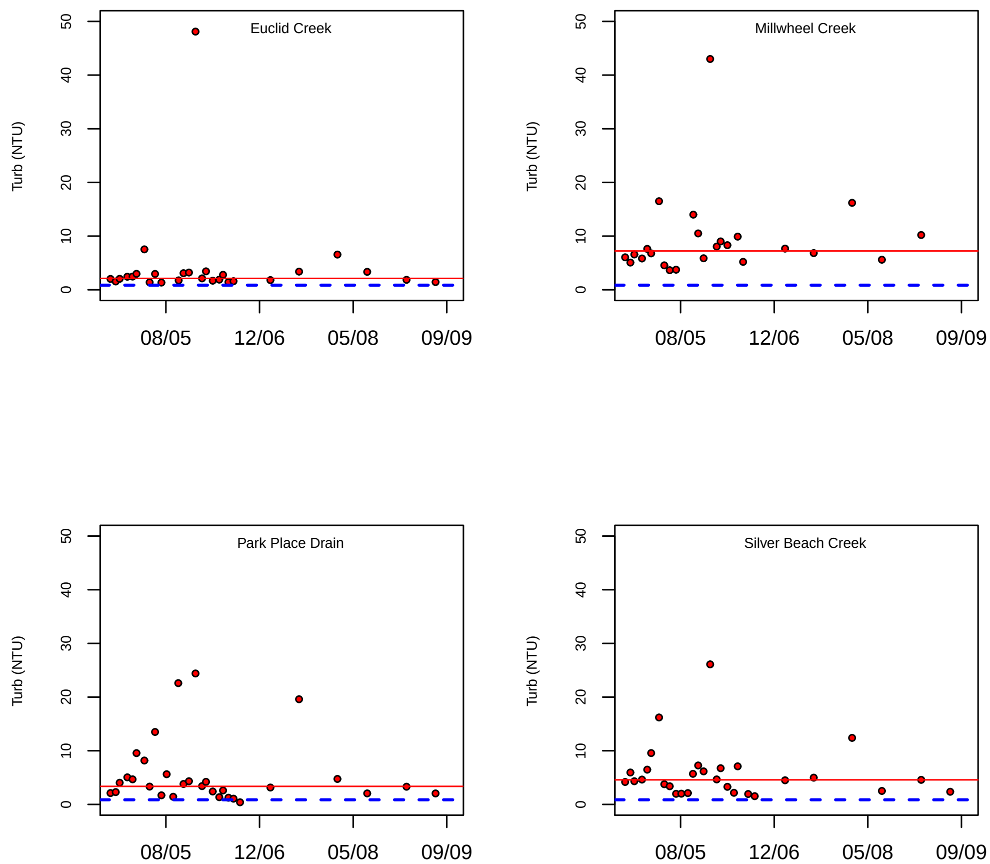


Figure B184: Turbidity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

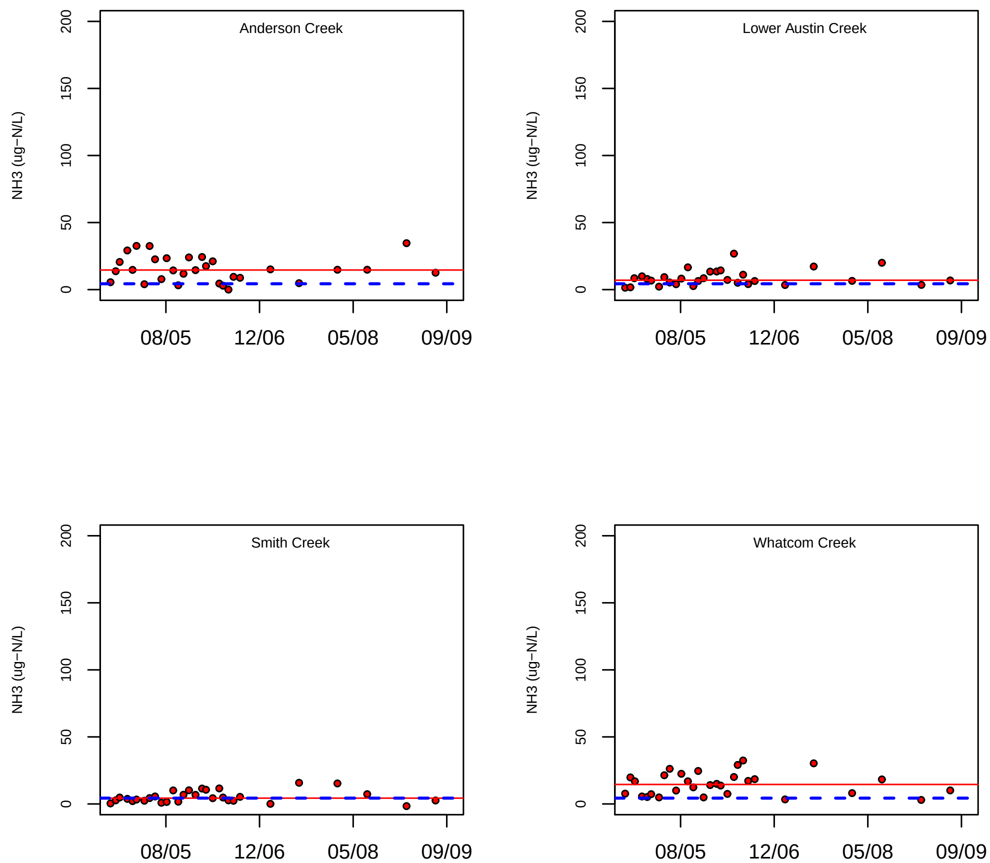


Figure B185: Ammonia data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

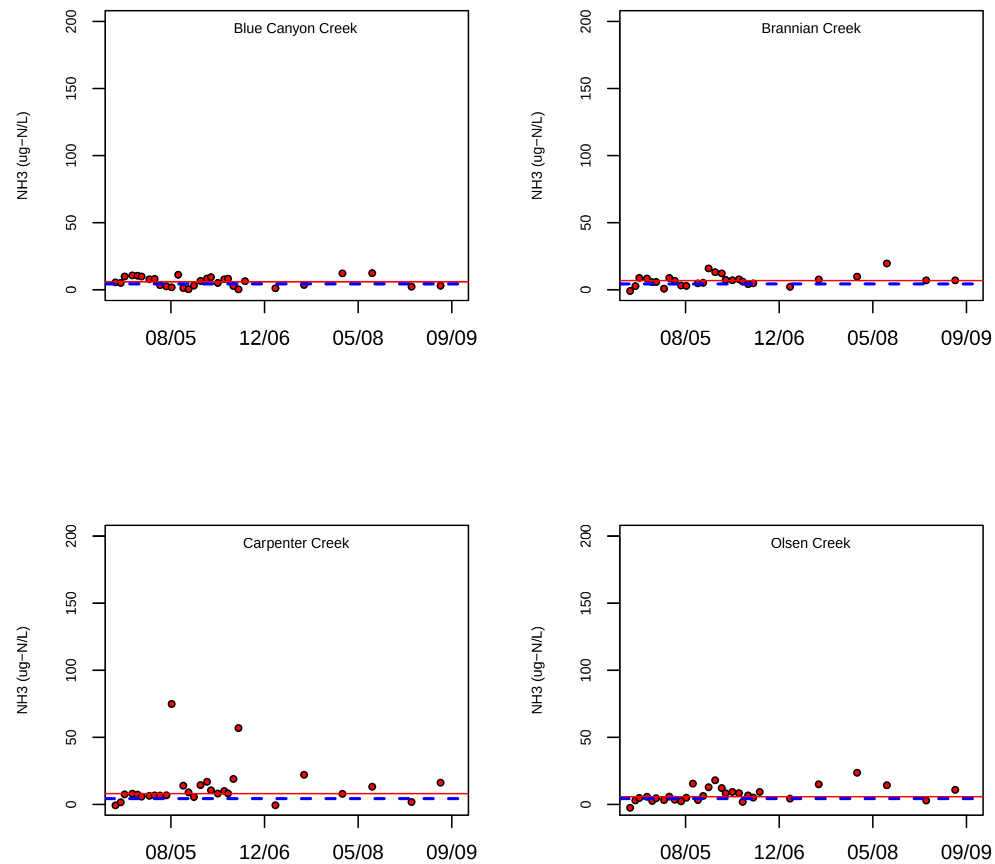


Figure B186: Ammonia data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

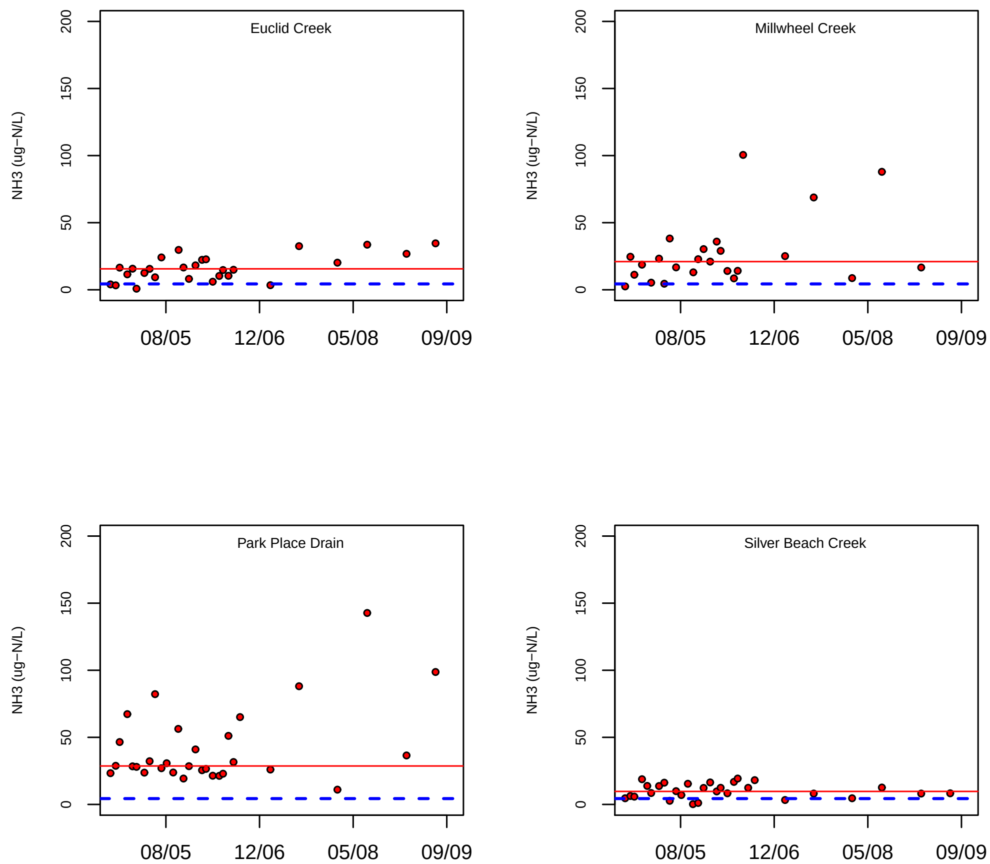


Figure B187: Ammonia data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

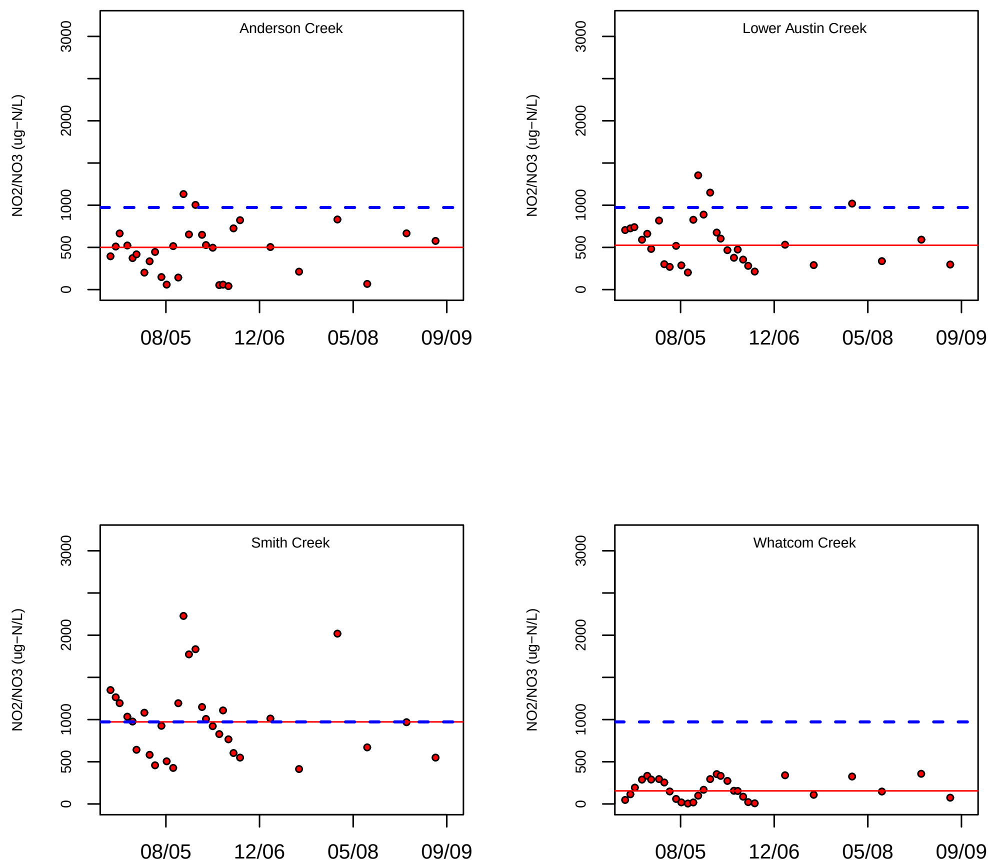


Figure B188: Nitrate/nitrite data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

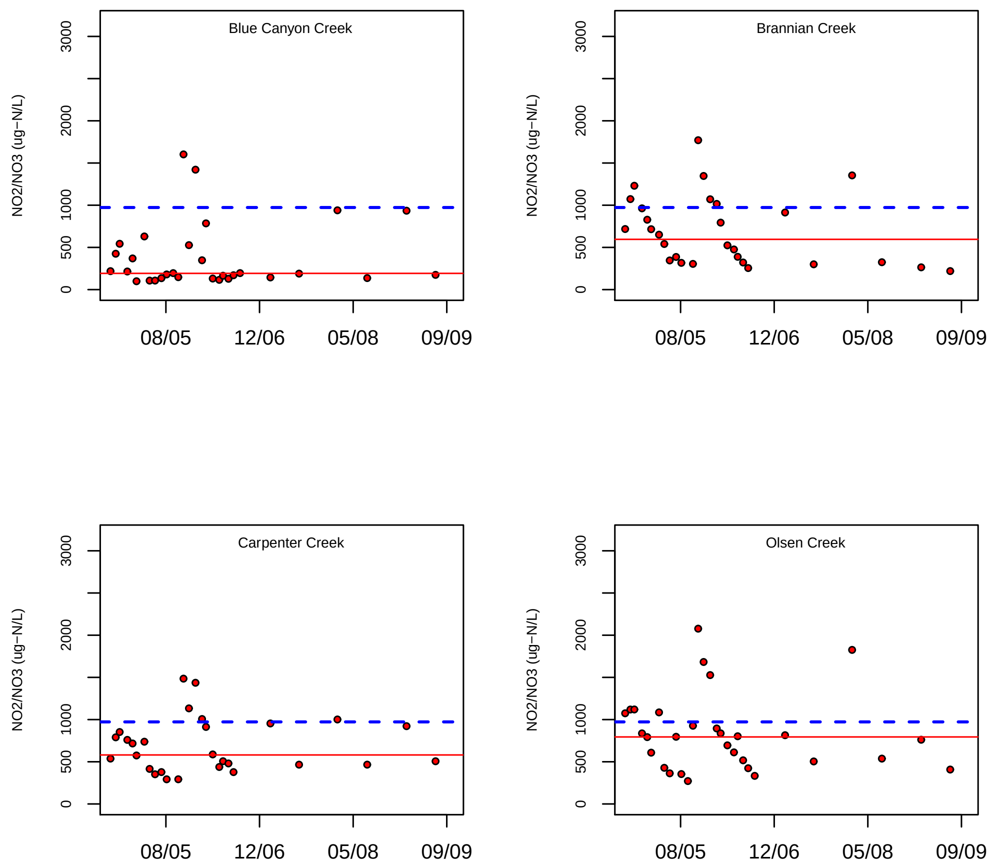


Figure B189: Nitrate/nitrite data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

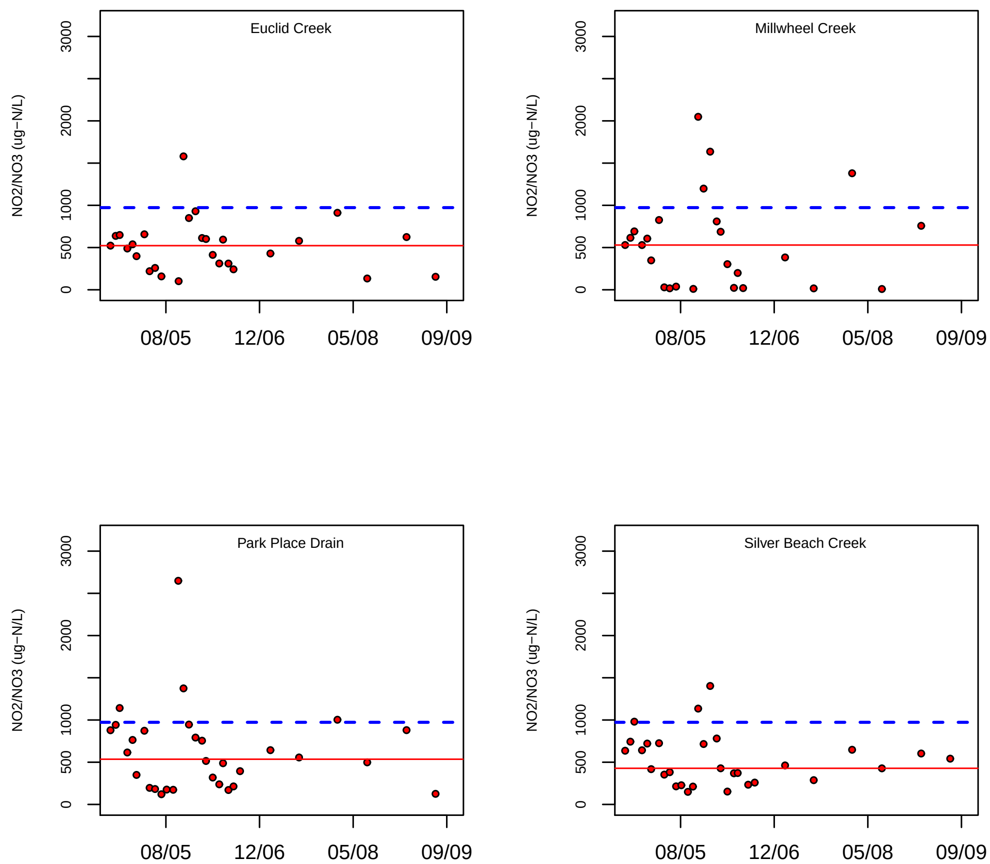


Figure B190: Nitrate/nitrite data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

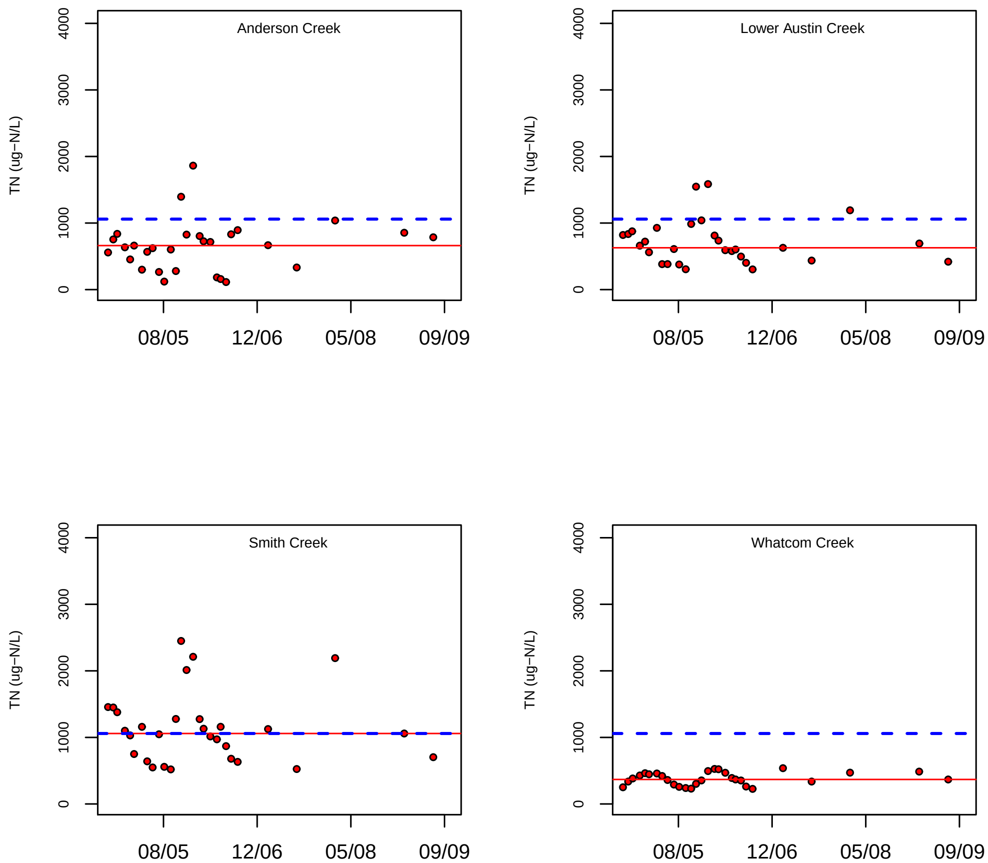


Figure B191: Total nitrogen data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

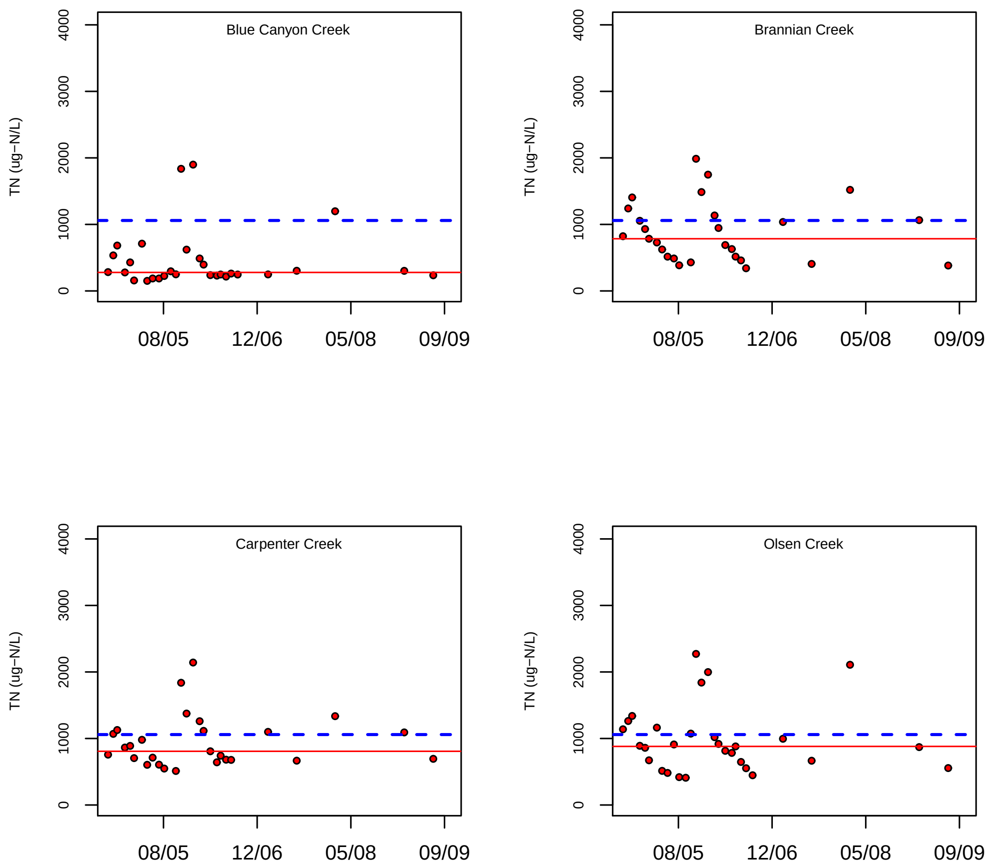


Figure B192: Total nitrogen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

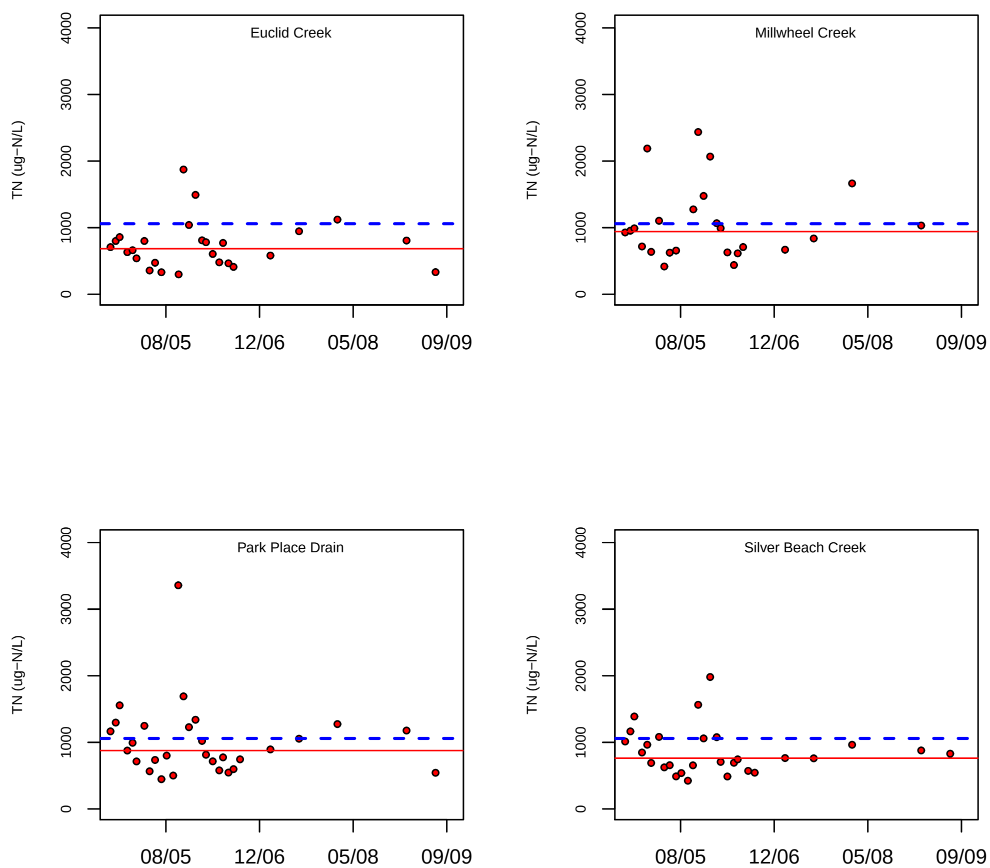


Figure B193: Total nitrogen data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

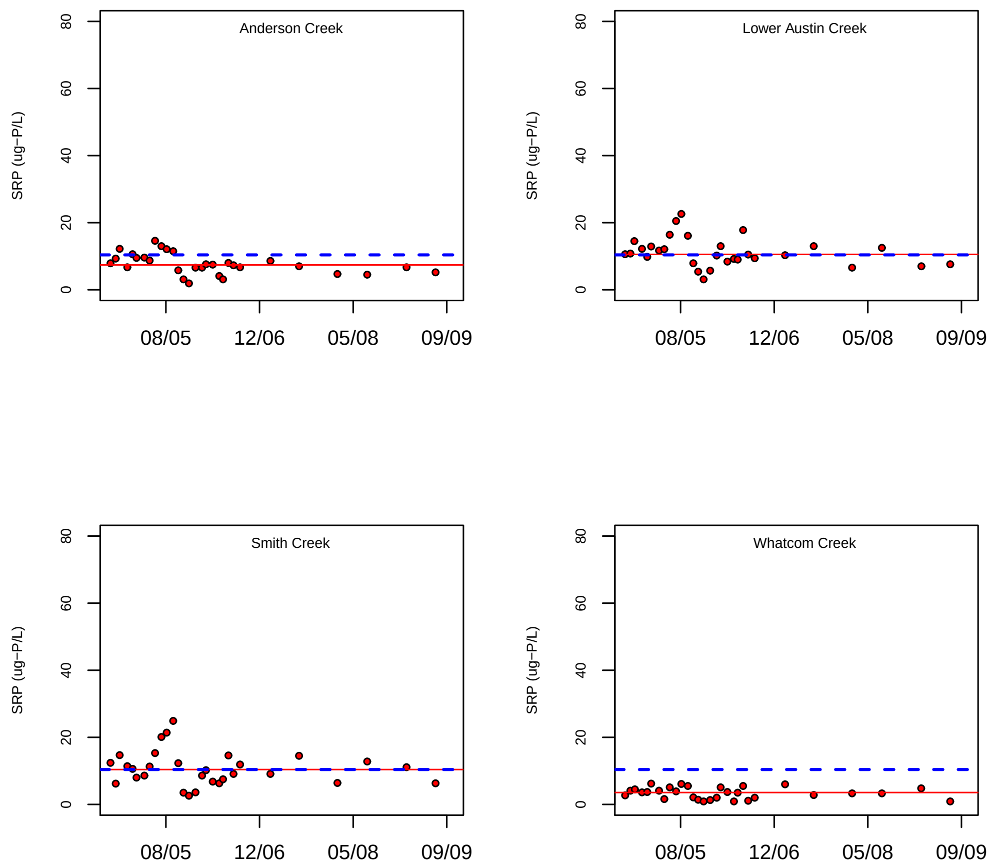


Figure B194: Soluble phosphate data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

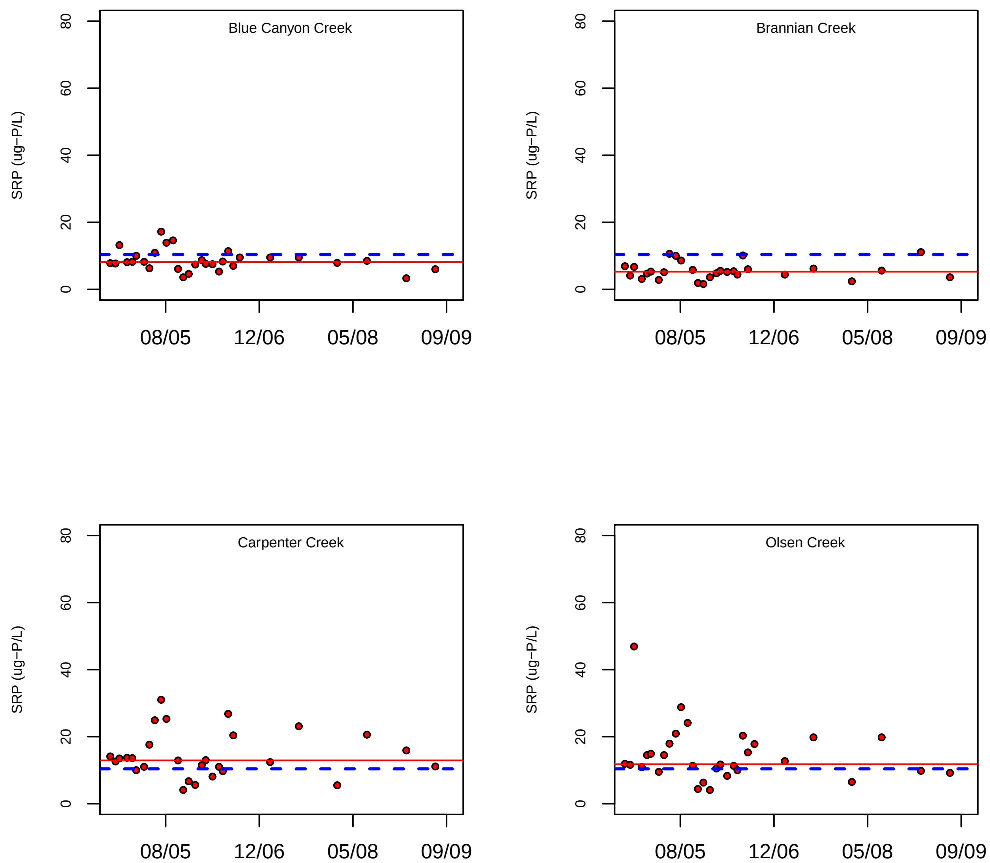


Figure B195: Soluble phosphate data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

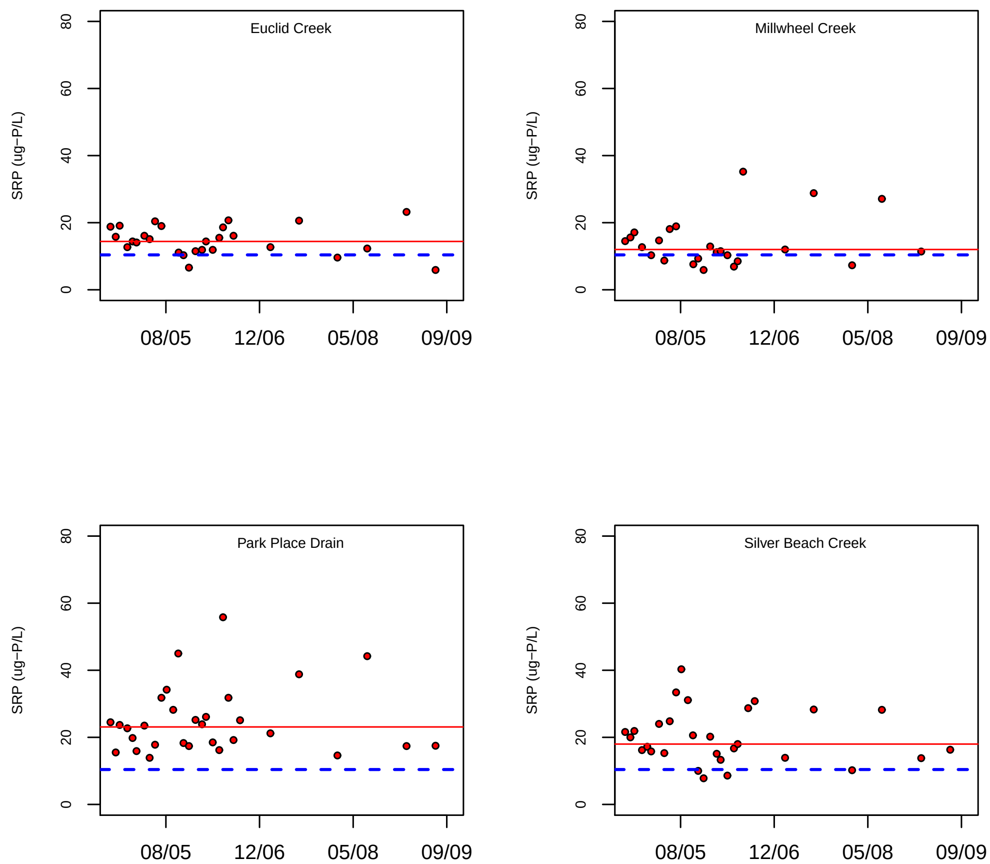


Figure B196: Soluble phosphate data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

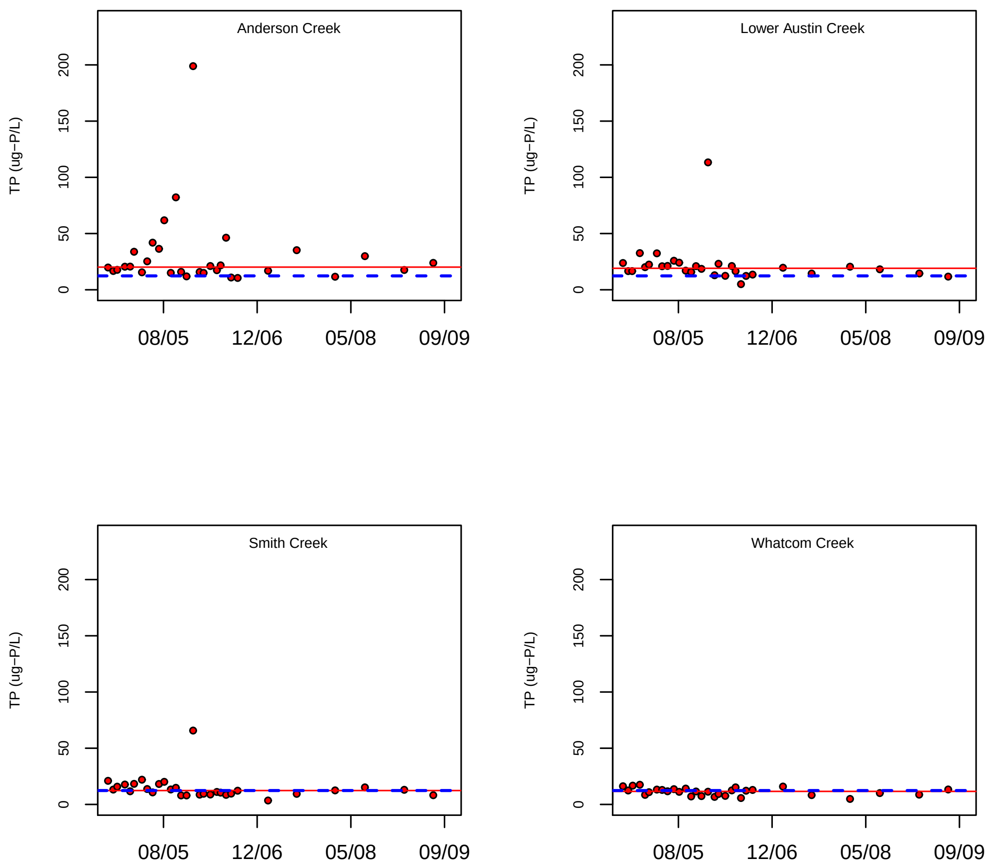


Figure B197: Total phosphorus data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

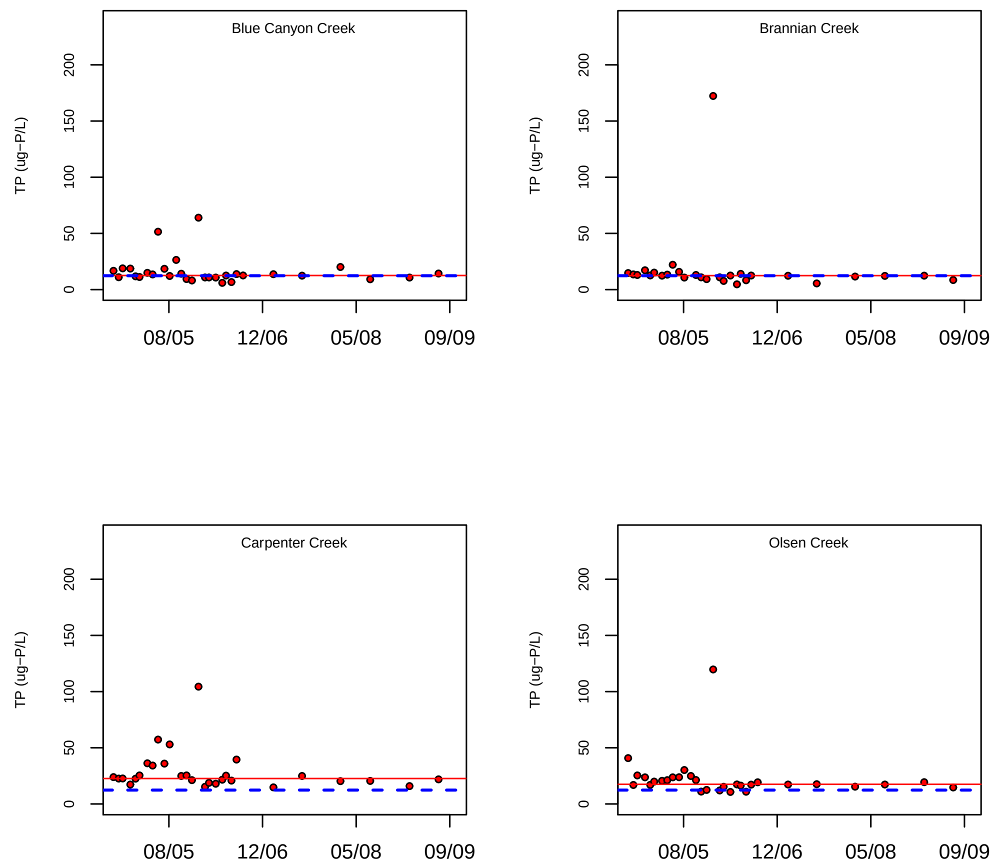


Figure B198: Total phosphorus data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

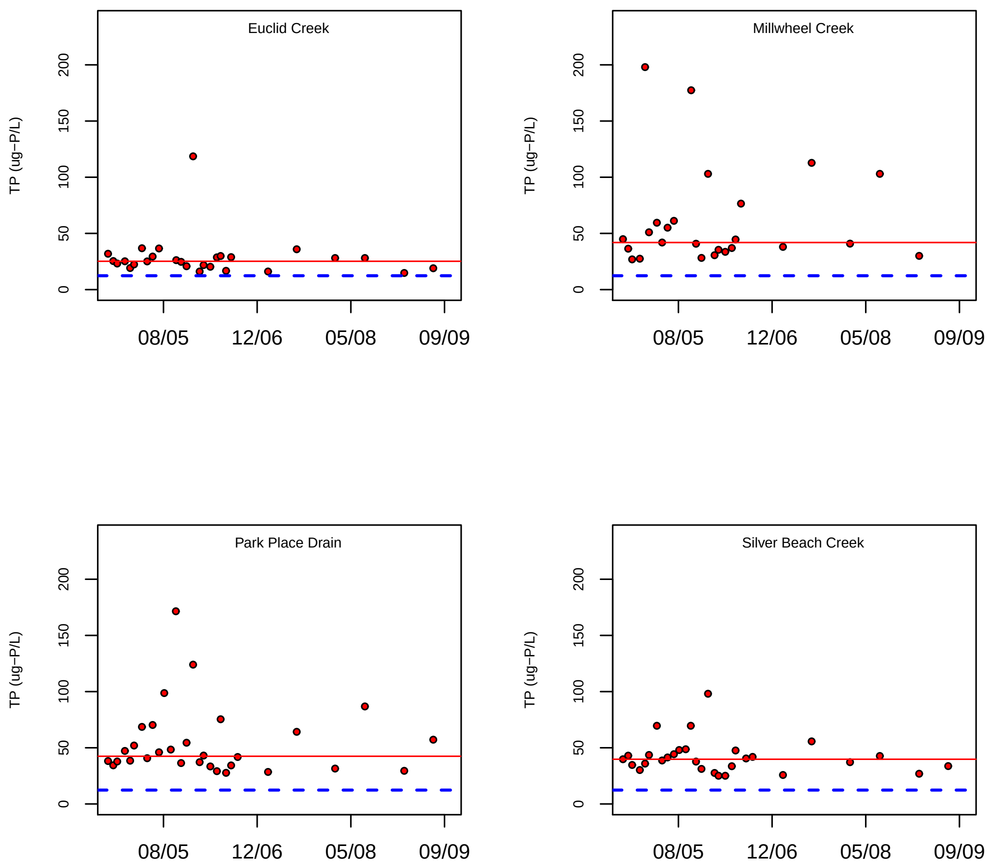


Figure B199: Total phosphorus data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

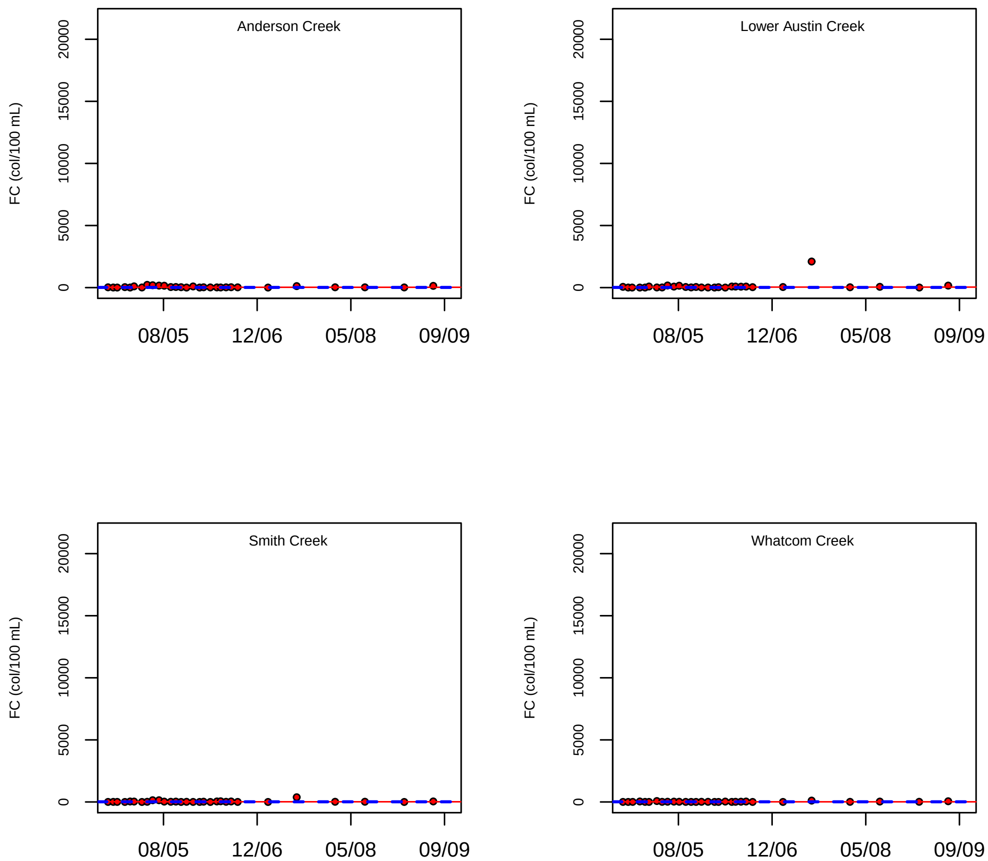


Figure B200: Fecal coliform data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

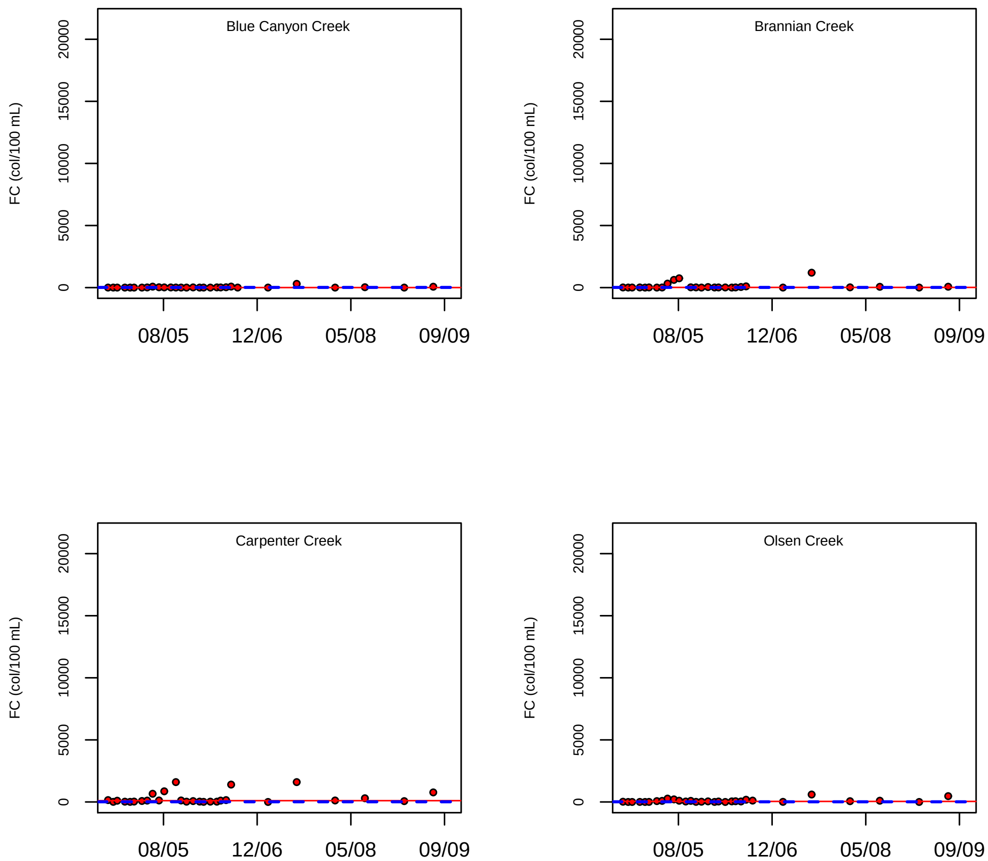


Figure B201: Fecal coliform data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

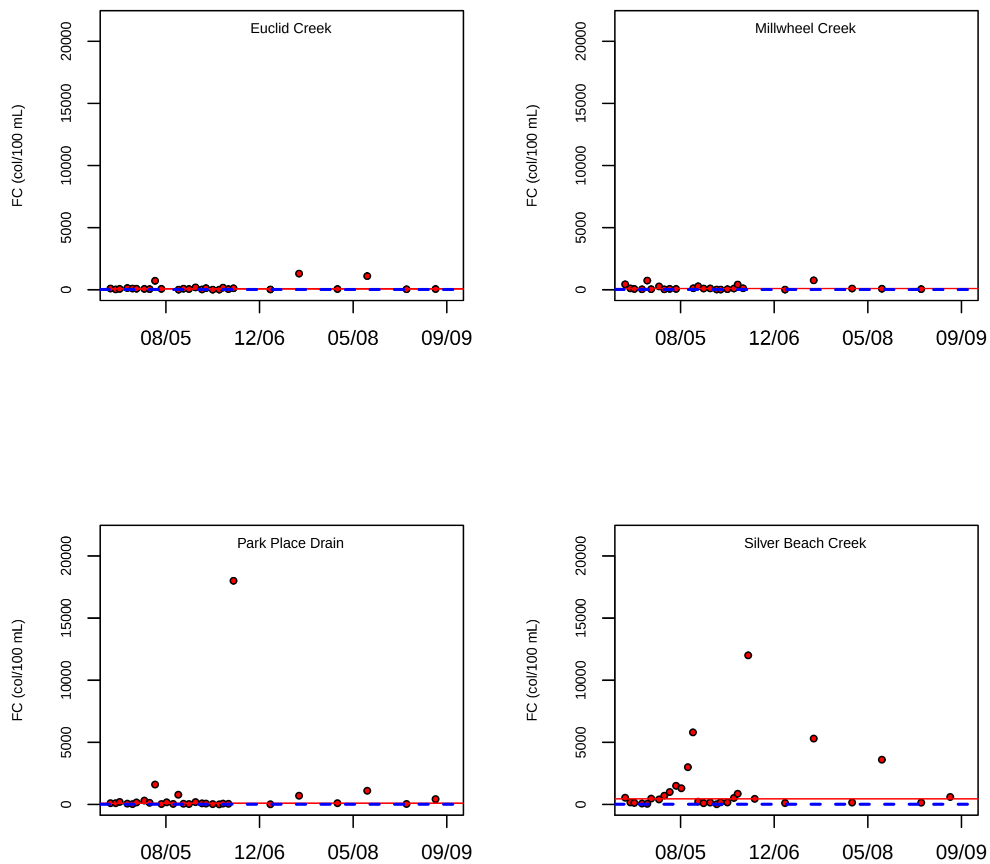


Figure B202: Fecal coliform data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

C Quality Control

C.1 Performance Evaluation Reports

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 16). Single-blind quality control tests were conducted as part of the IWS laboratory certification process (Tables C1–C2). All results from the single-blind tests were within acceptance limits.

	Reported Value†	True Value†	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	465	468	421–516	accept
Total alkalinity (mg/L as $CaCO_3$)	40.0	38.9	33.1–45.5	accept
Ammonia nitrogen, manual (mg-N/L)	10.1	10.0	7.40–12.5	accept
Ammonia nitrogen, autoanalysis (mg-N/L)	10.3	10.0	7.40–12.5	accept
Nitrate nitrogen, autoanalysis (mg-N/L)	7.29	7.42	6.04–8.63	accept
Nitrite nitrogen, autoanalysis (mg-N/L)	1.42	1.38	1.13–1.62	accept
Orthophosphate, manual (mg-P/L)	0.680	0.690	0.506–0.889	accept
Orthophosphate, autoanalysis (mg-P/L)	0.670	0.690	0.506–0.889	accept
Total phosphorus, manual (mg-P/L)	8.48	8.05	6.65–9.52	accept
Total phosphorus, autoanalysis (mg-P/L)	8.17	8.05	6.65–9.52	accept
pH	6.28	6.30	6.10–6.50	accept
Solids, non-filterable (mg/L)	44.3	49.5	38.3–56.7	accept
Solids, total (mg/L)	555	550	495–605	accept
Turbidity (NTU)	9.50	9.40	7.94–10.6	accept

Table C1: Single-blind quality control results, WP–142 (11/14/2008).

	Reported Value†	True Value†	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	350	349	310–387	accept
Total alkalinity (mg/L as $CaCO_3$)	44.3	43.6	37.4–50.4	accept
Ammonia nitrogen, manual (mg-N/L)	17.7	16.3	12.2–20.2	accept
Ammonia nitrogen, autoanalysis (mg-N/L)	14.7	16.3	12.2–20.2	accept
Nitrate nitrogen, autoanalysis (mg-N/L)	13.4	13.3	10.8–15.5	accept
Nitrite nitrogen, autoanalysis (mg-N/L)	0.827	0.834	0.658–1.00	accept
Orthophosphate, manual (mg-P/L)	1.80	1.81	1.45–2.19	accept
Orthophosphate, autoanalysis (mg-P/L)	1.76	1.81	1.45–2.19	accept
Total phosphorus, manual (mg-P/L)	1.42	1.50	1.18–1.87	accept
Total phosphorus, autoanalysis (mg-P/L)	1.42	1.50	1.18–1.87	accept
pH	9.29	9.20	9.00–9.40	accept
Solids, non-filterable (mg/L)	74.8	89.6	73.7–99.3	accept
Solids, total (mg/L)	na	na	na	na
Turbidity (NTU)	9.85	10.2	8.64–11.5	accept

Table C2: Single-blind quality control results, WP–148 (5/22/2009).

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 (ammonia, 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.[21]

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 2008 (upper examples in Figures C1–C26, pages 306–331), and used to evaluate data from October 2008 through September 2009 (lower examples in Figures C1–C26).

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

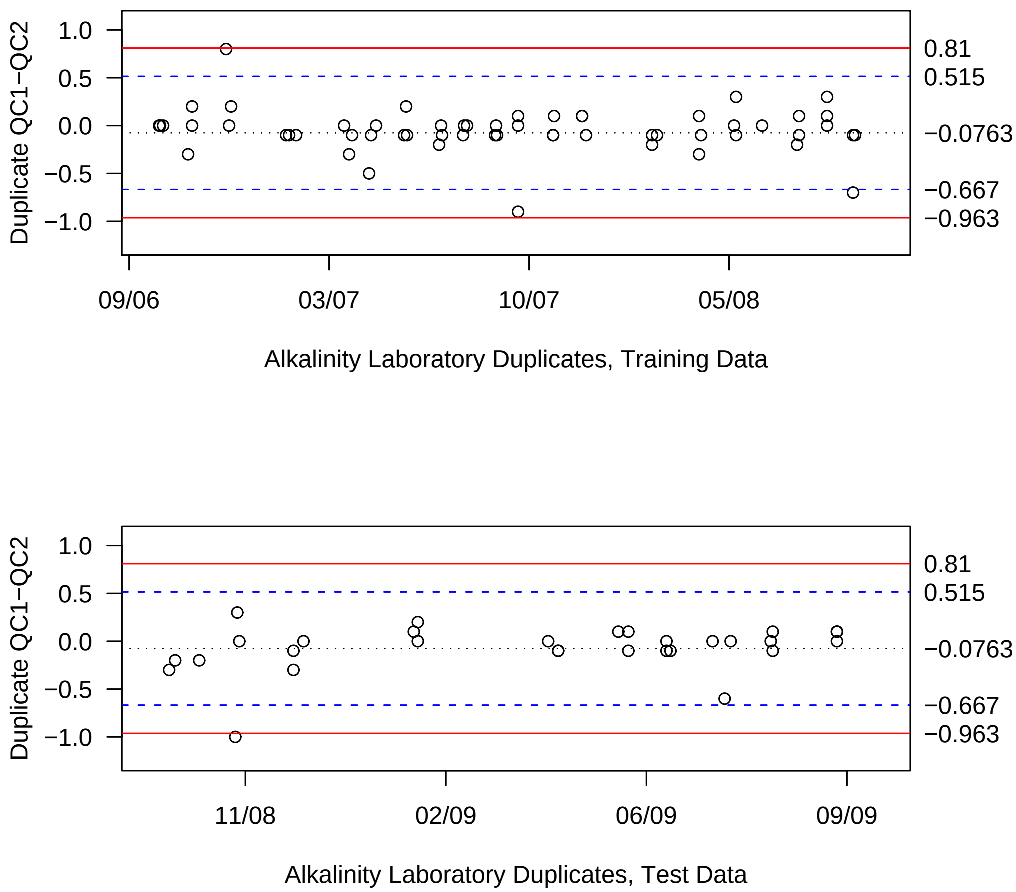
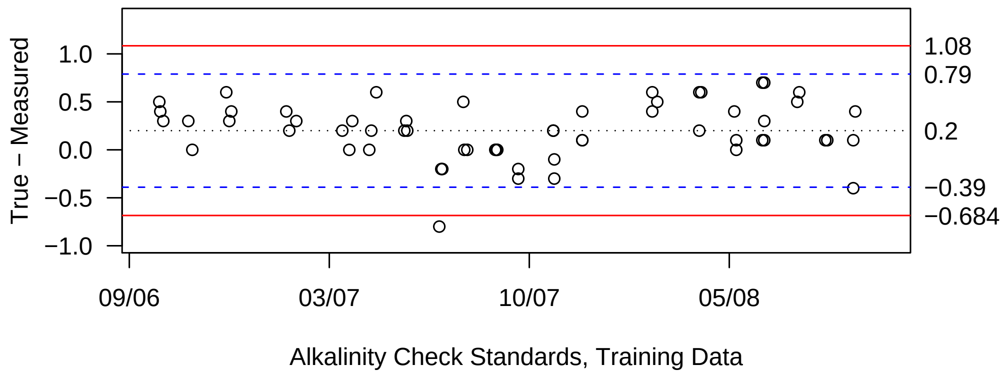


Figure C1: Alkalinity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



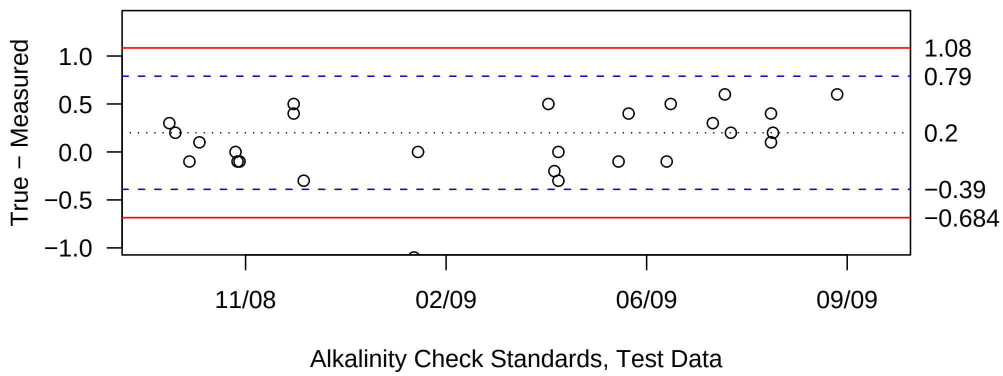
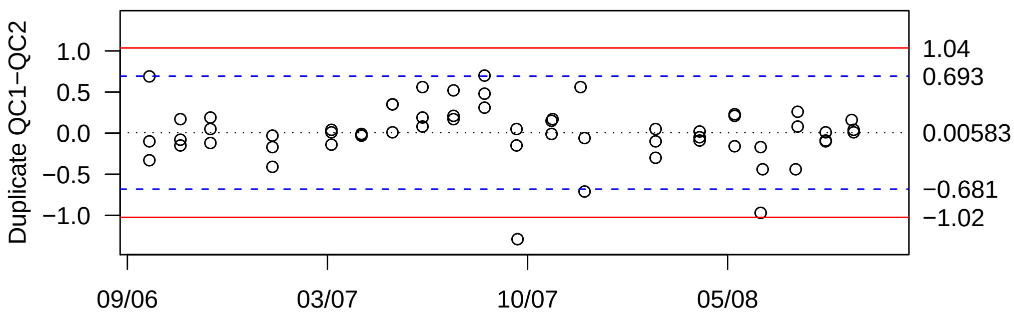
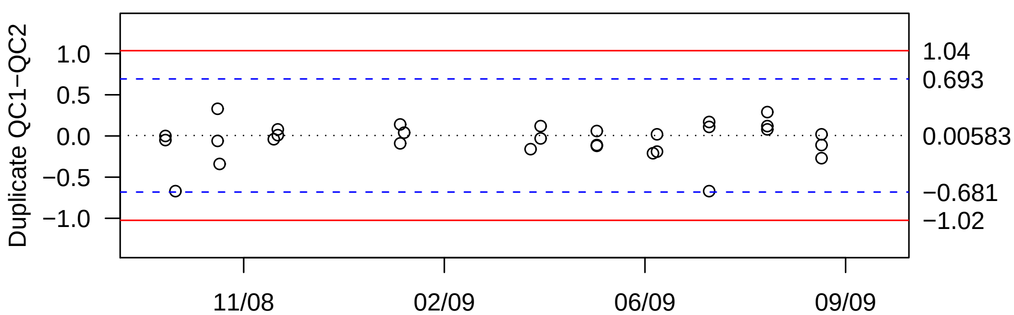


Figure C2: Alkalinity check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

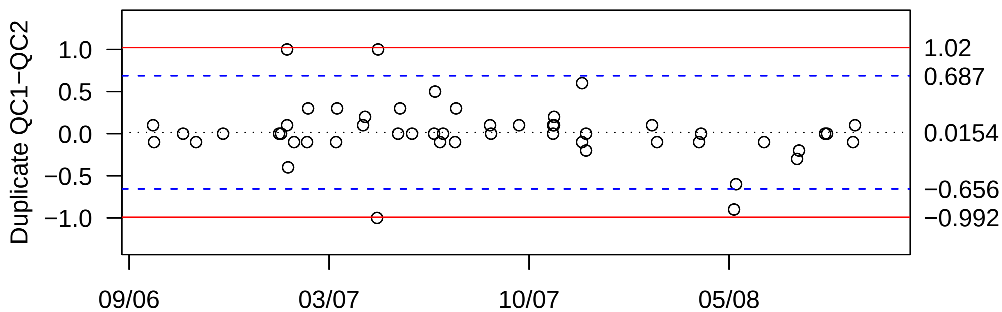


Chlorophyll Laboratory Duplicates, Training Data

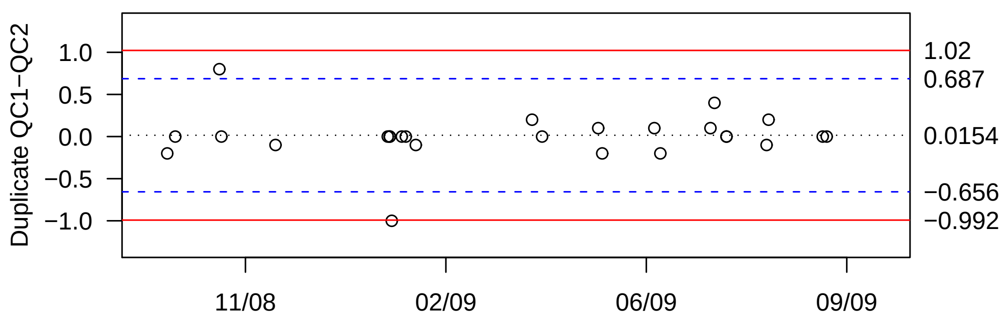


Chlorophyll Laboratory Duplicates, Test Data

Figure C3: Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program (lake samples only; no samples collected for storm water or tributary monitoring). 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.

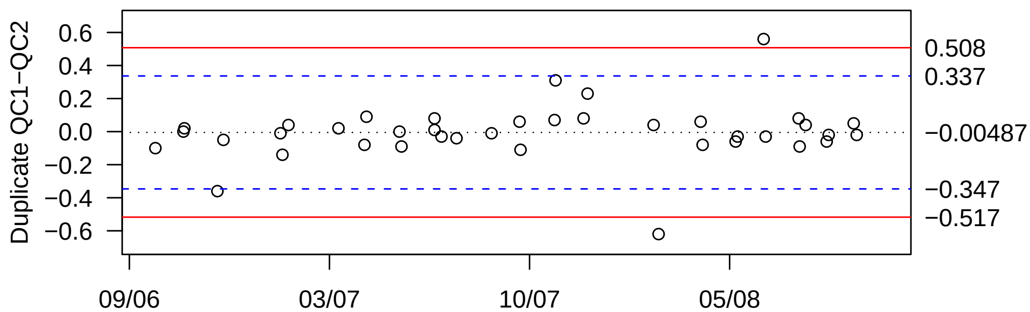


Conductivity Laboratory Duplicates, Training Data

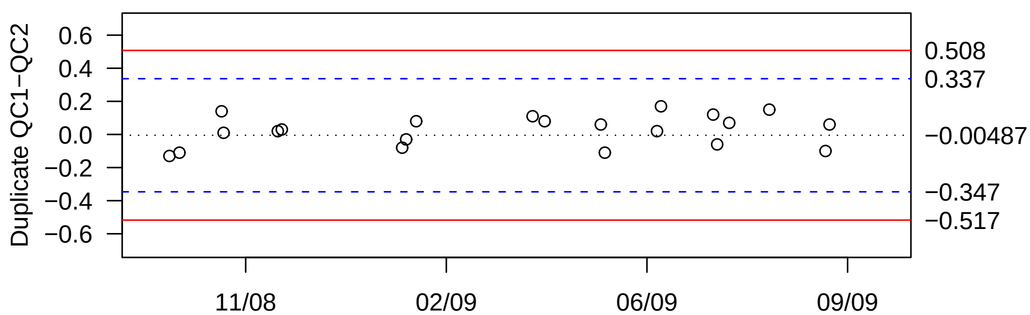


Conductivity Laboratory Duplicates, Test Data

Figure C4: 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.

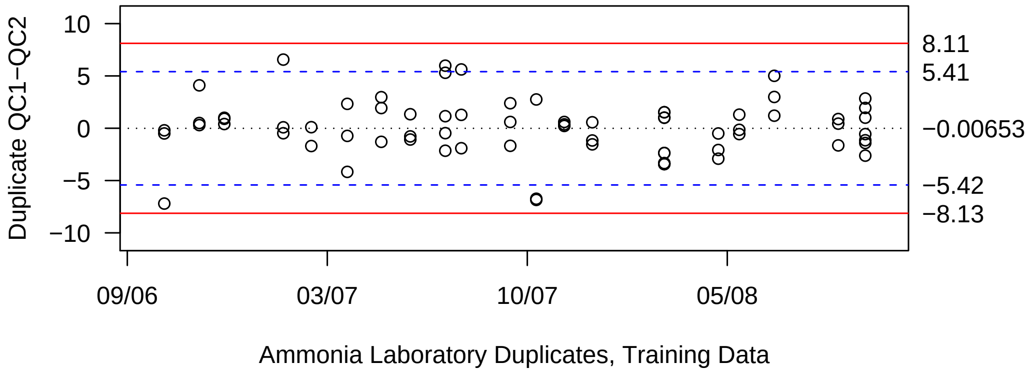


Dissolved Oxygen Laboratory Duplicates, Training Data



Dissolved Oxygen Laboratory Duplicates, Test Data

Figure C5: 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.



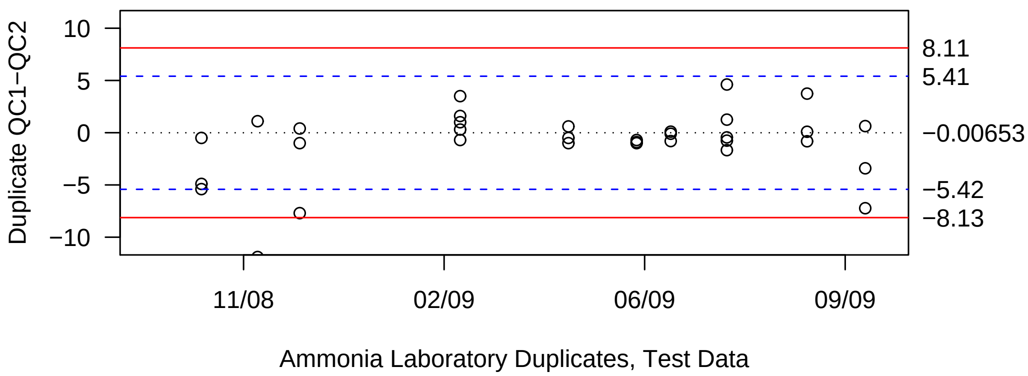
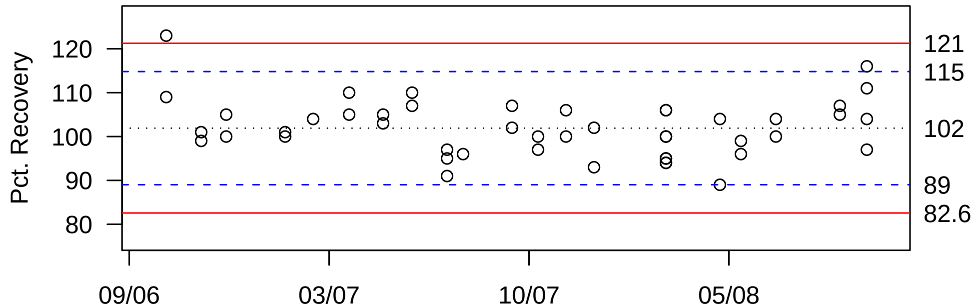
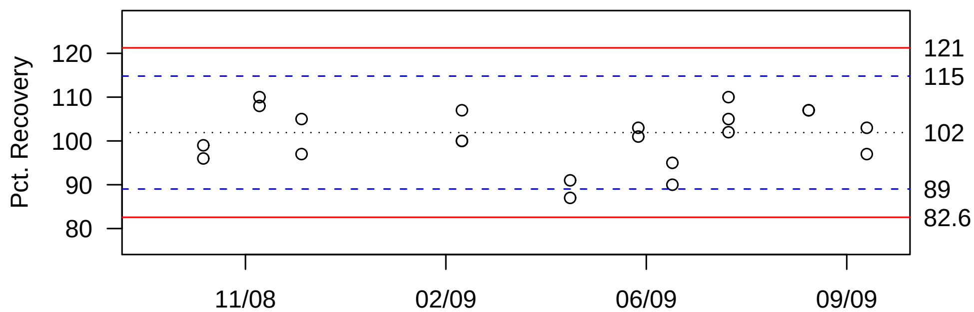


Figure C6: Ammonia laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

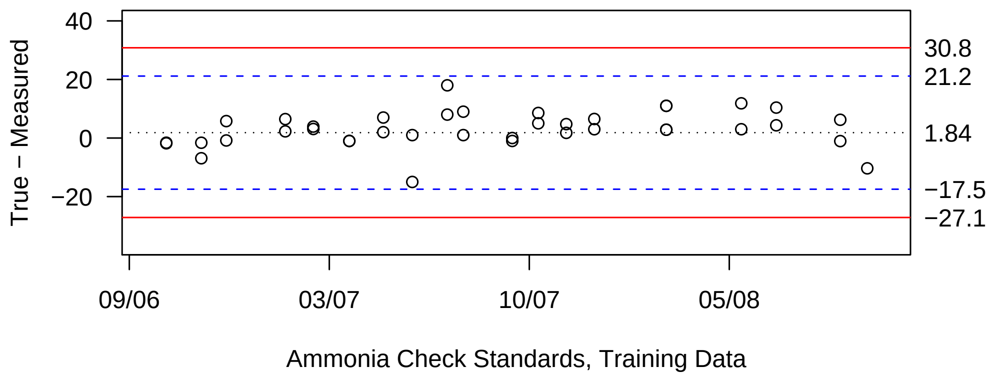


Ammonia Spike Recoveries, Training Data



Ammonia Spike Recoveries, Test Data

Figure C7: Ammonia 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



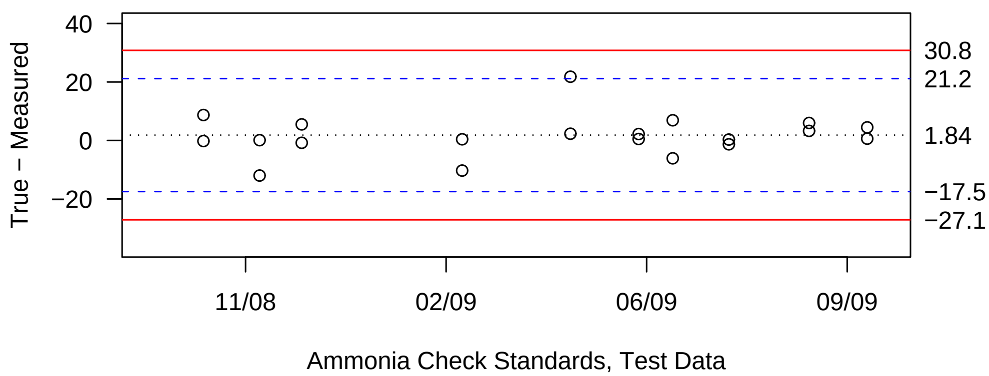
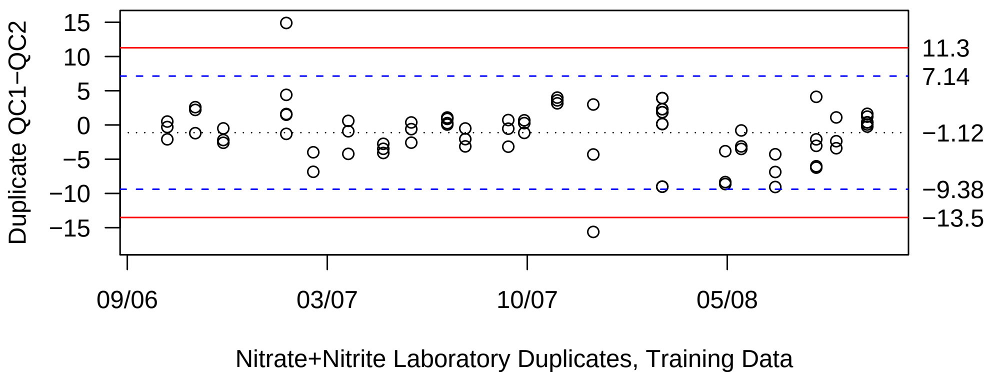


Figure C8: Ammonia check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



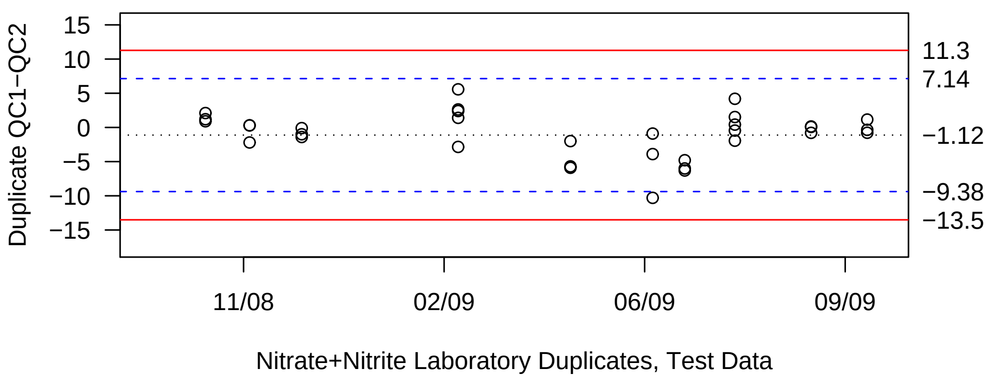
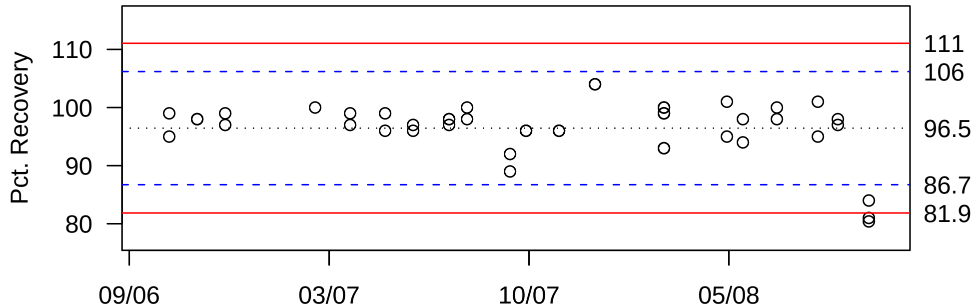
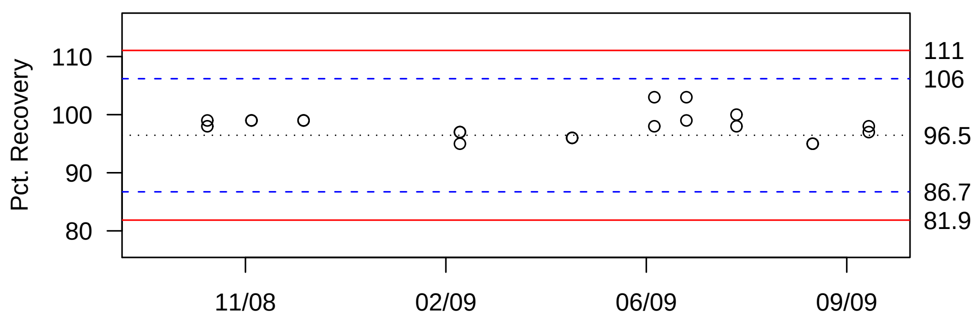


Figure C9: Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

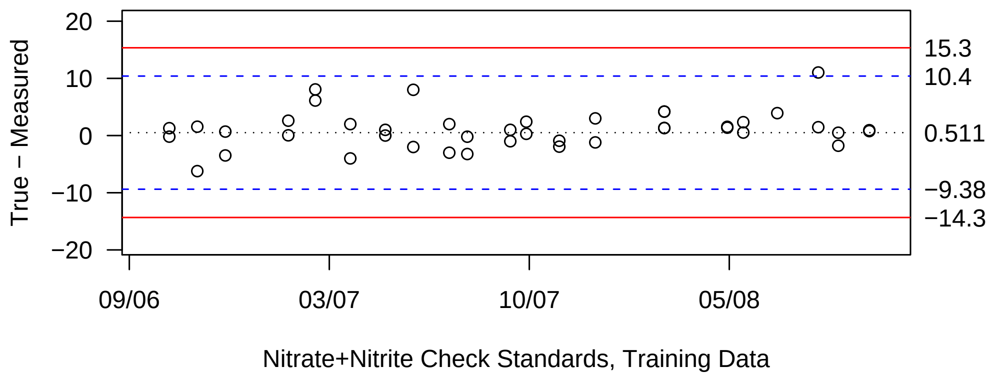


Nitrate+Nitrite Spike Recoveries, Training Data



Nitrate+Nitrite Spike Recoveries, Test Data

Figure C10: 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.



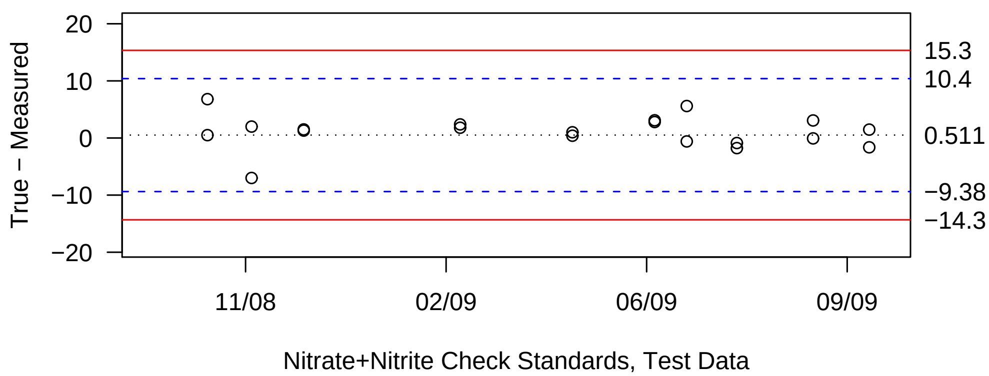
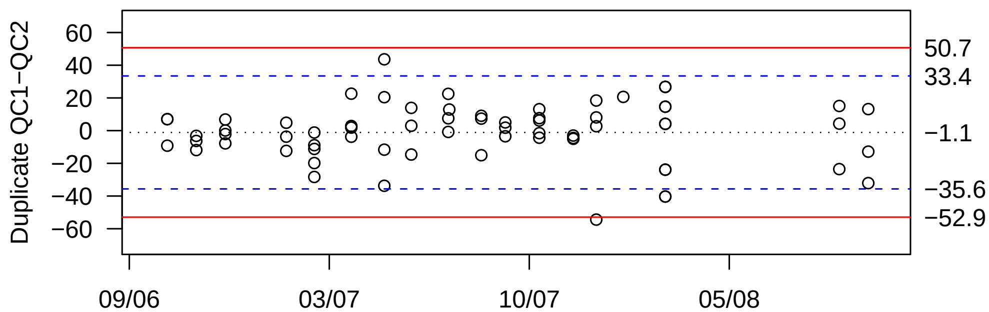
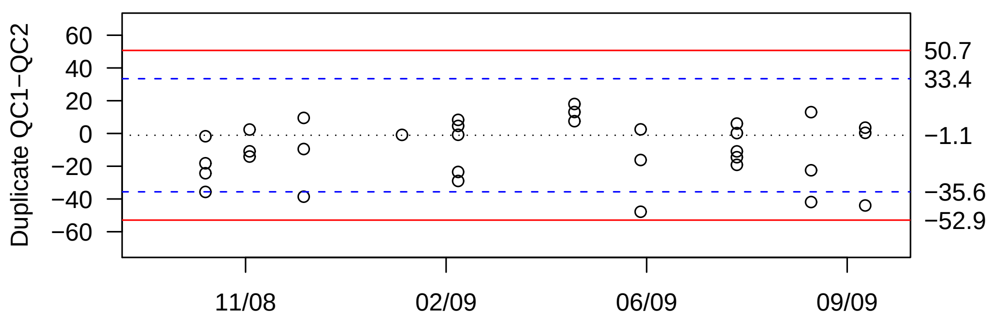


Figure C11: Nitrate/nitrite check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

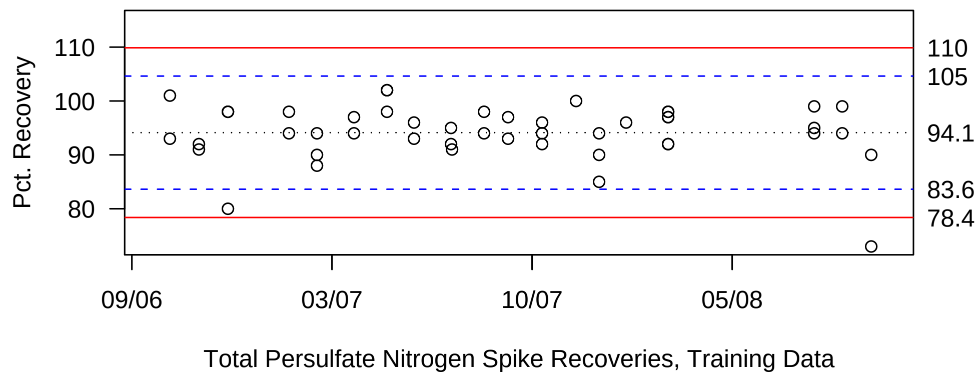


Total Persulfate Nitrogen Laboratory Duplicates, Training Data



Total Persulfate Nitrogen Laboratory Duplicates, Test Data

Figure C12: 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.



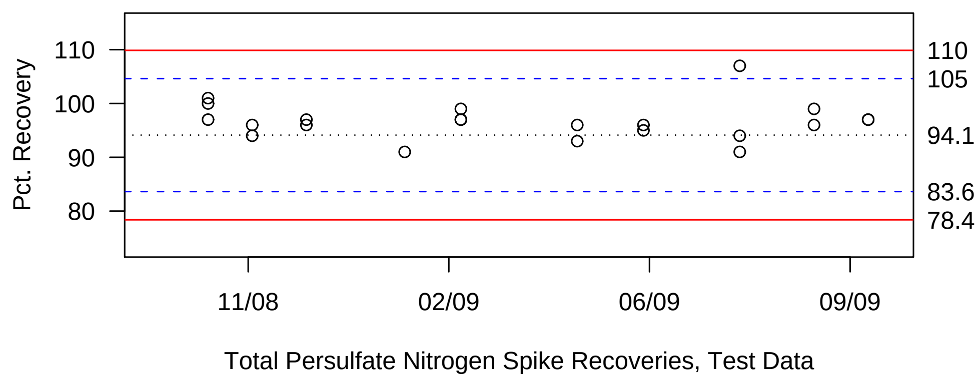
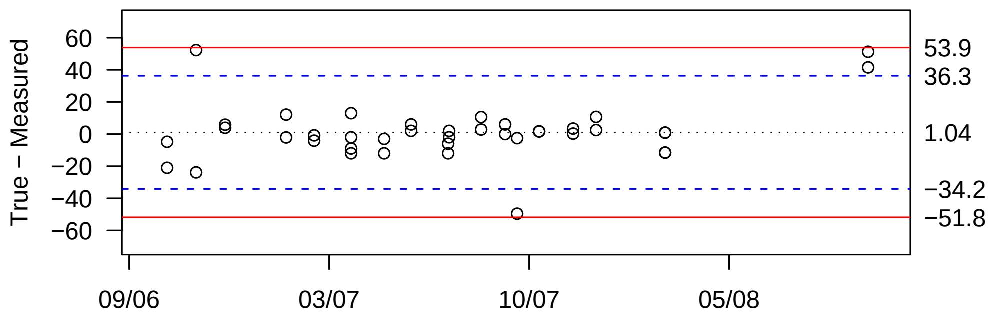
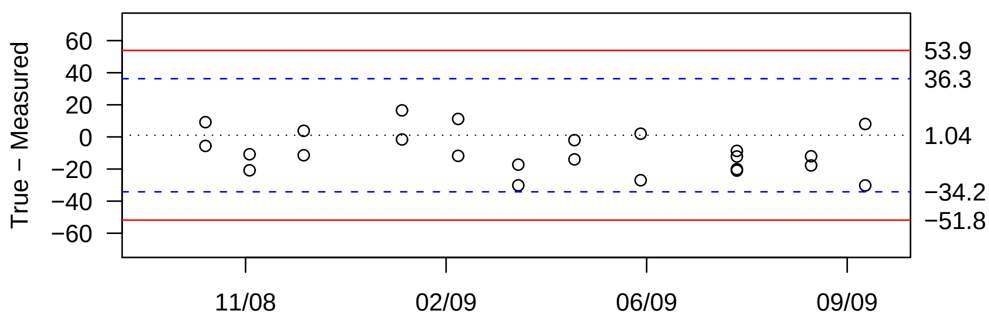


Figure C13: Total nitrogen matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

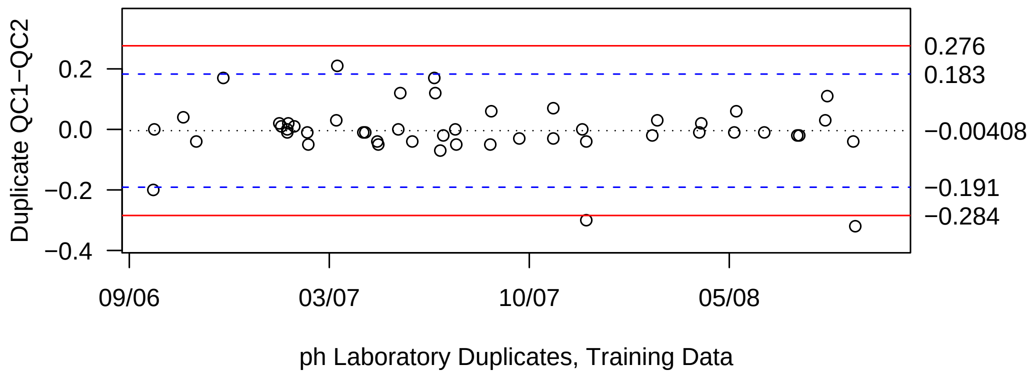


Total Persulfate Nitrogen Check Standards, Training Data



Total Persulfate Nitrogen Check Standards, Test Data

Figure C14: Total nitrogen 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.



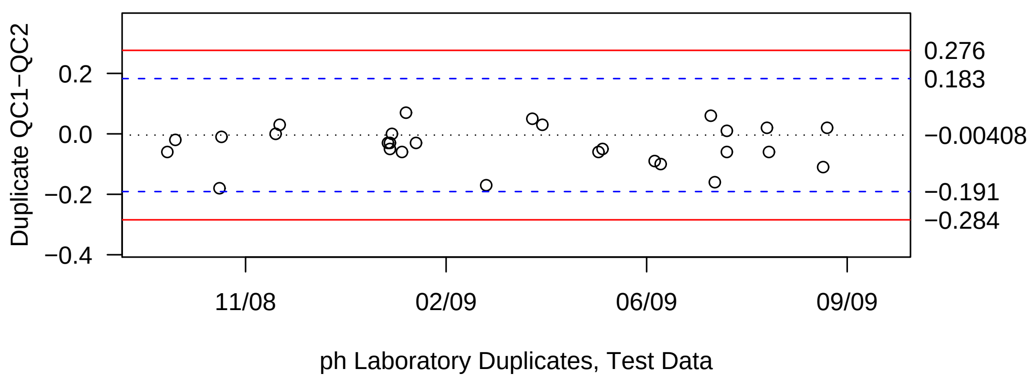
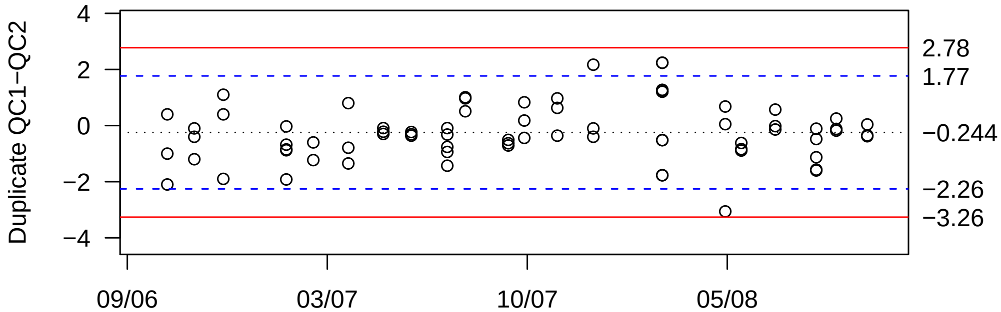
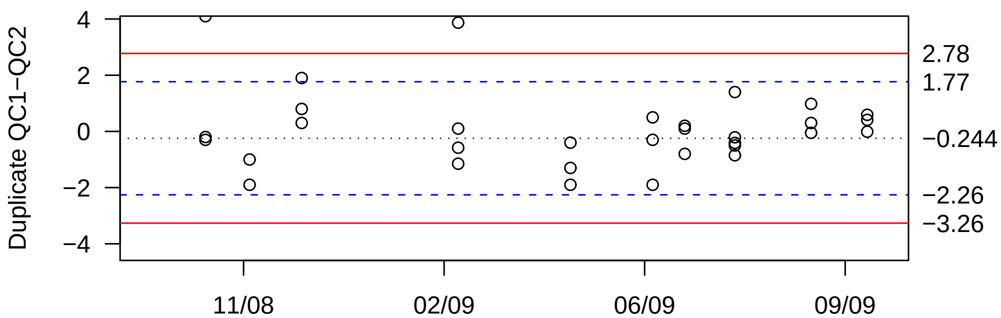


Figure C15: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

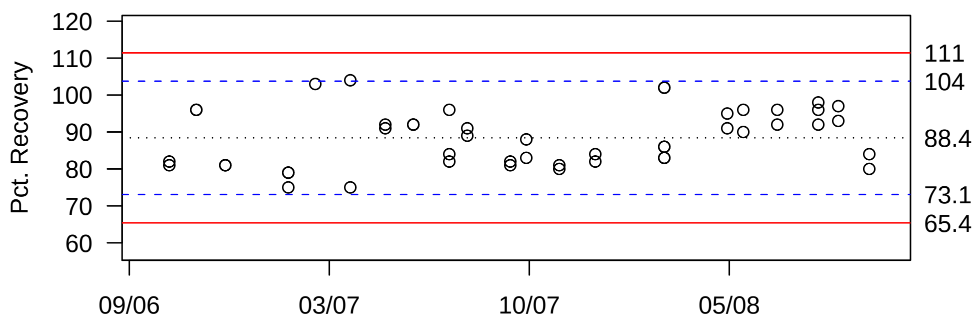


Soluble Phosphate Laboratory Duplicates, Training Data

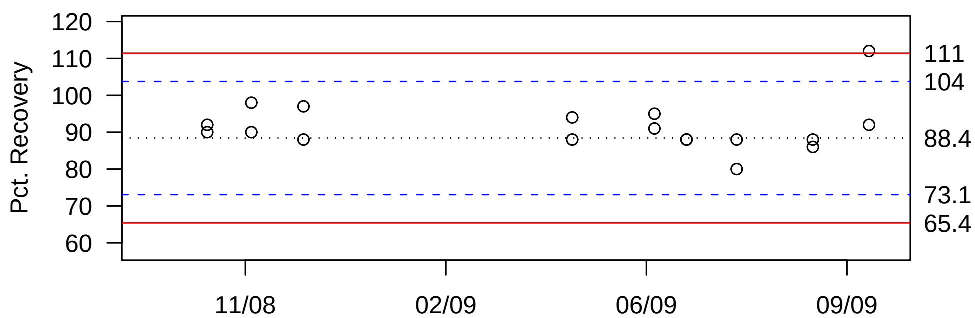


Soluble Phosphate Laboratory Duplicates, Test Data

Figure C16: 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.

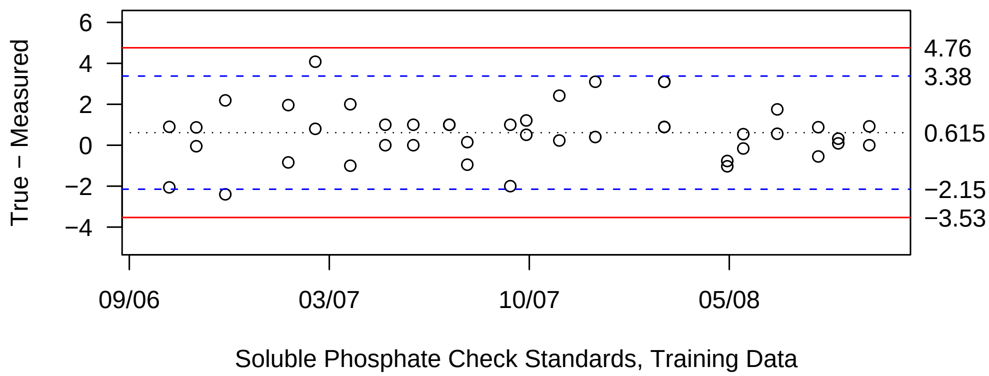


Soluble Phosphate Spike Recoveries, Training Data



Soluble Phosphate Spike Recoveries, Test Data

Figure C17: 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.



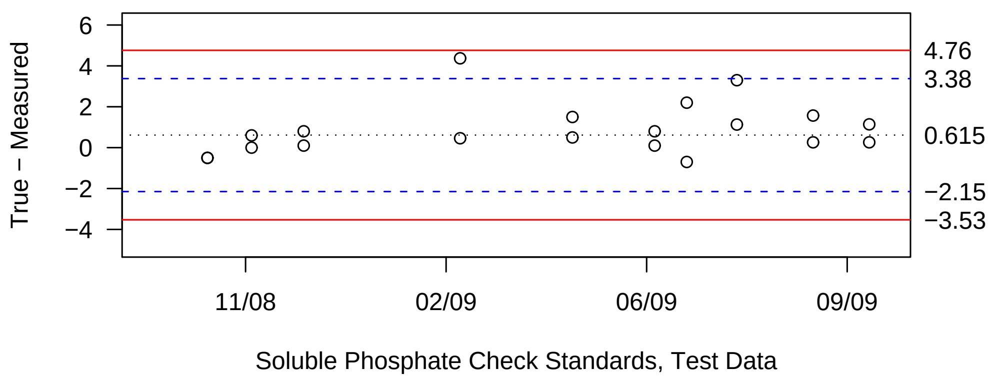
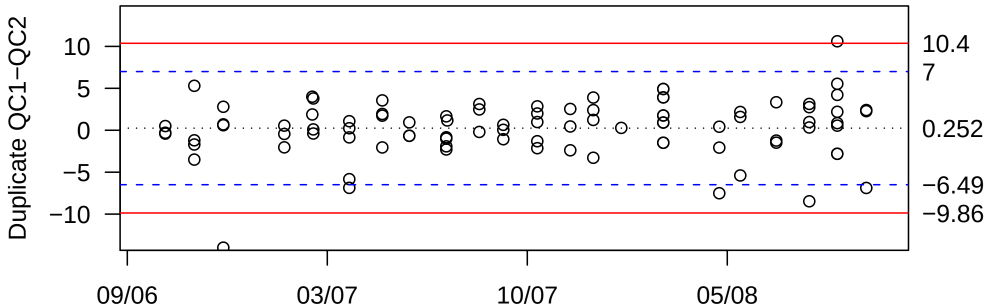
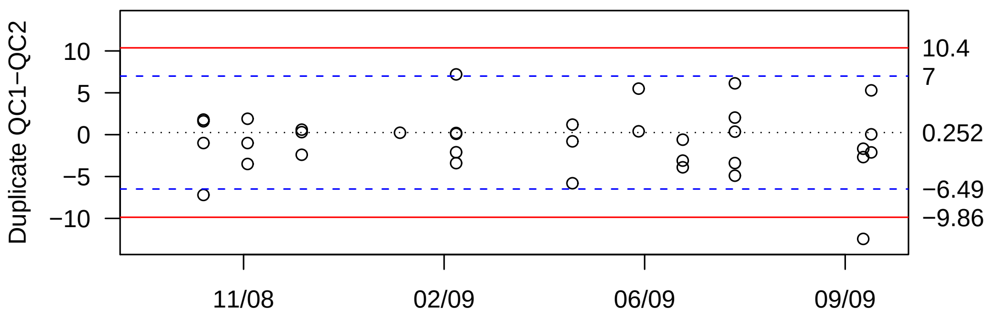


Figure C18: Soluble reactive phosphate check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

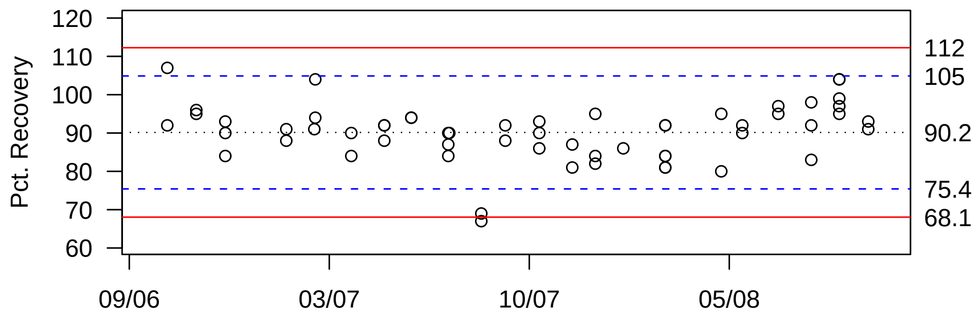


Total Phosphorus Laboratory Duplicates, Training Data

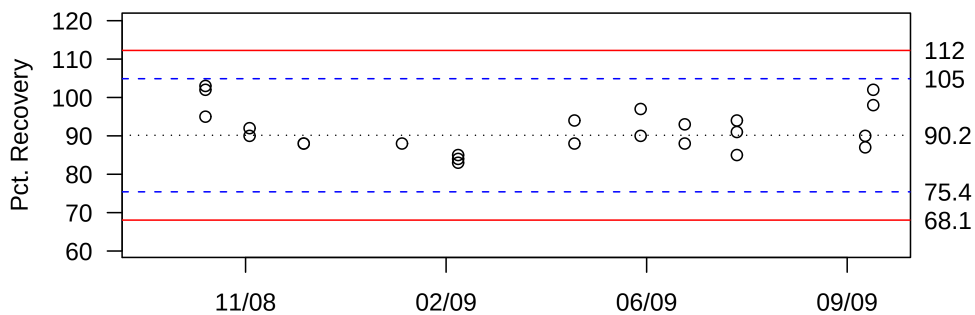


Total Phosphorus Laboratory Duplicates, Test Data

Figure C19: 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.

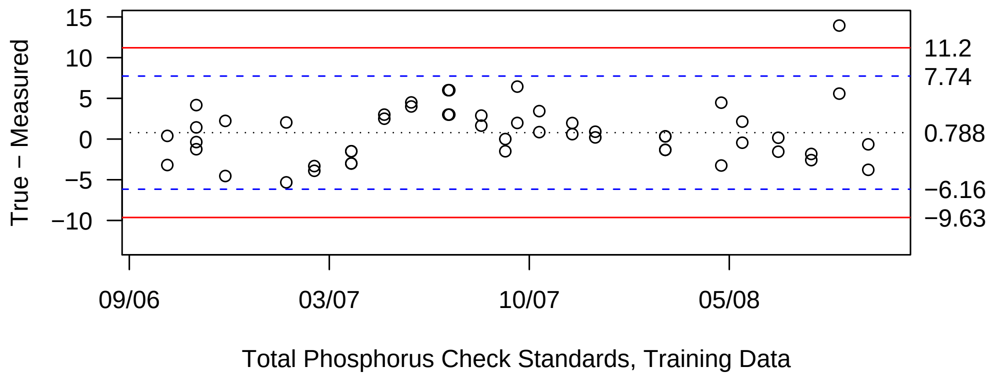


Total Phosphorus Spike Recoveries, Training Data



Total Phosphorus Spike Recoveries, Test Data

Figure C20: 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.



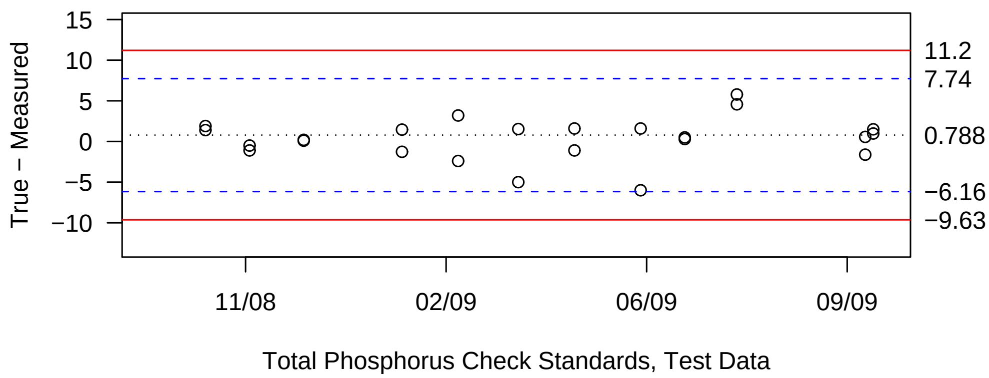
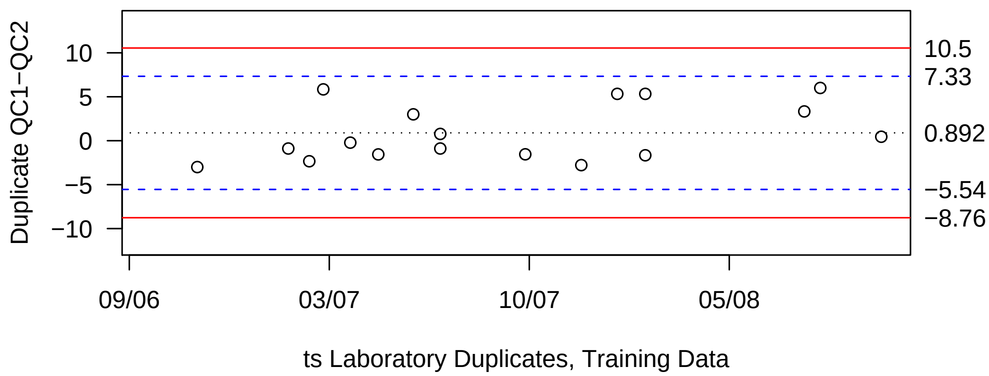


Figure C21: Total phosphorus check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



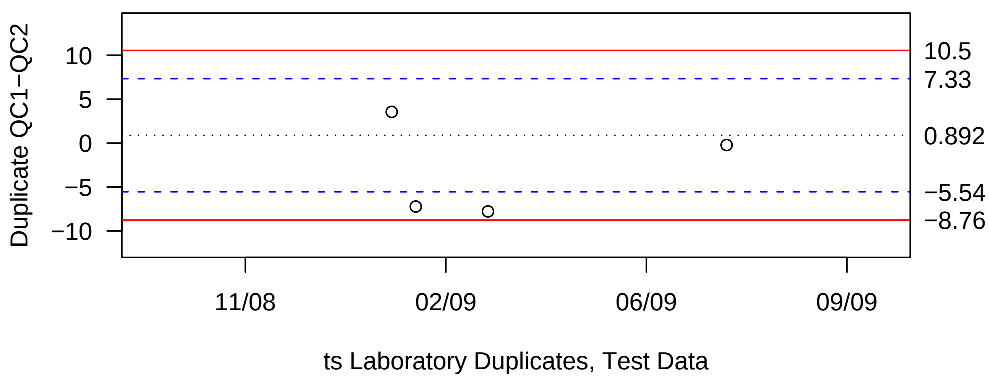
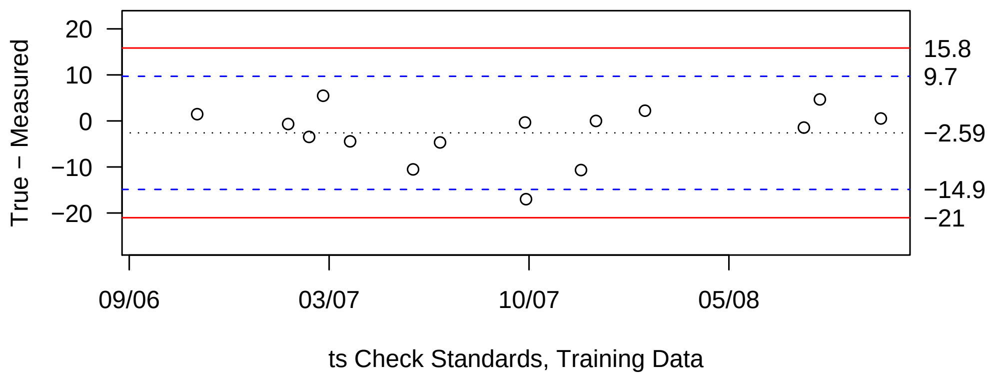


Figure C22: Total solids laboratory duplicates for the Lake Whatcom monitoring program (storm water and tributary samples only; no samples collected for lake monitoring). Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



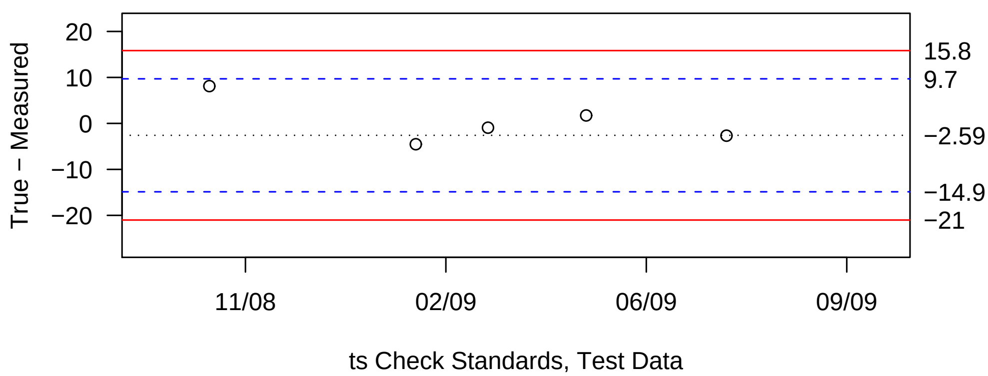
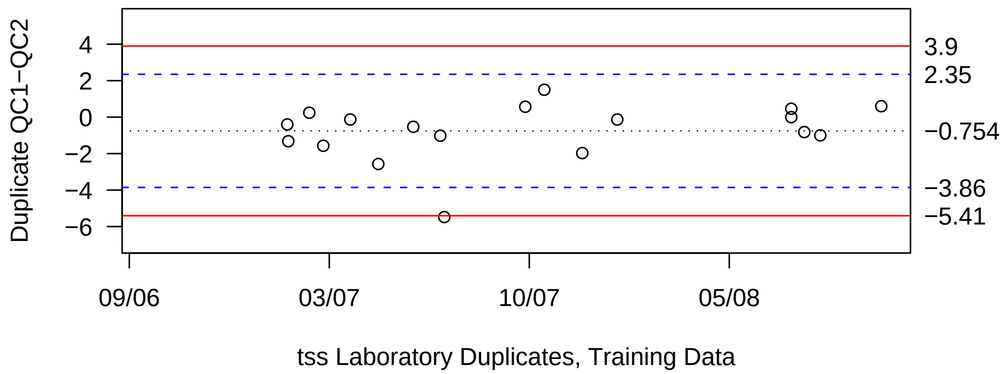


Figure C23: Total solids check standards for the Lake Whatcom monitoring program (storm water and tributary samples only; no samples collected for lake monitoring). Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



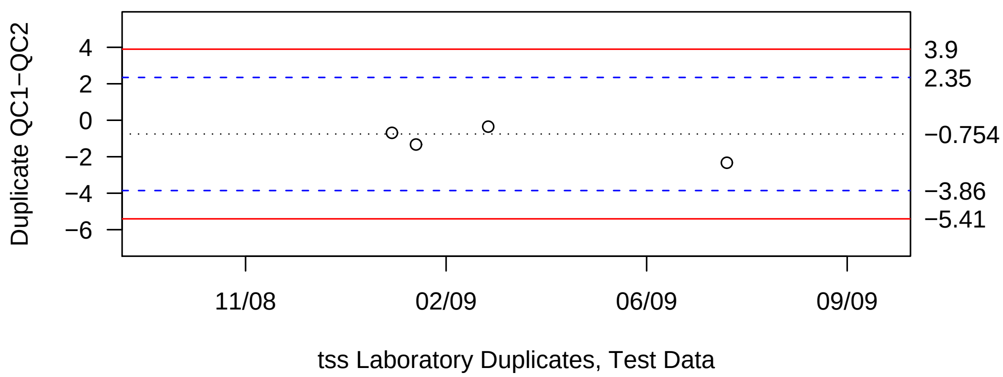
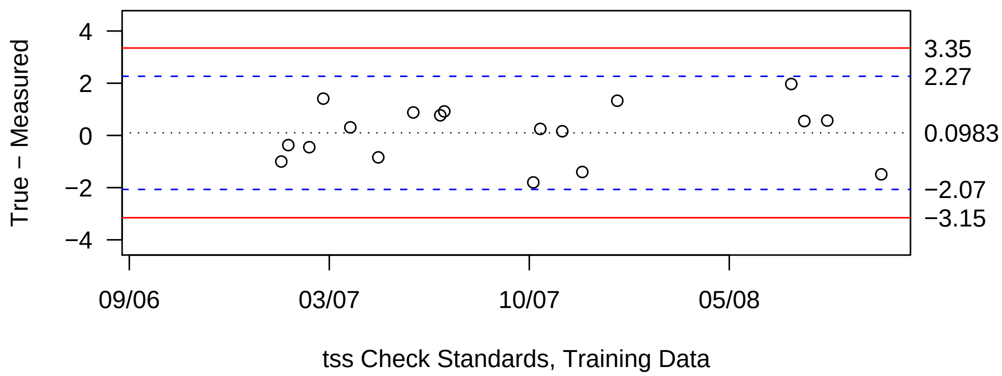


Figure C24: Total suspended solids laboratory duplicates for the Lake Whatcom monitoring program (storm water and tributary samples only; no samples collected for lake monitoring). Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



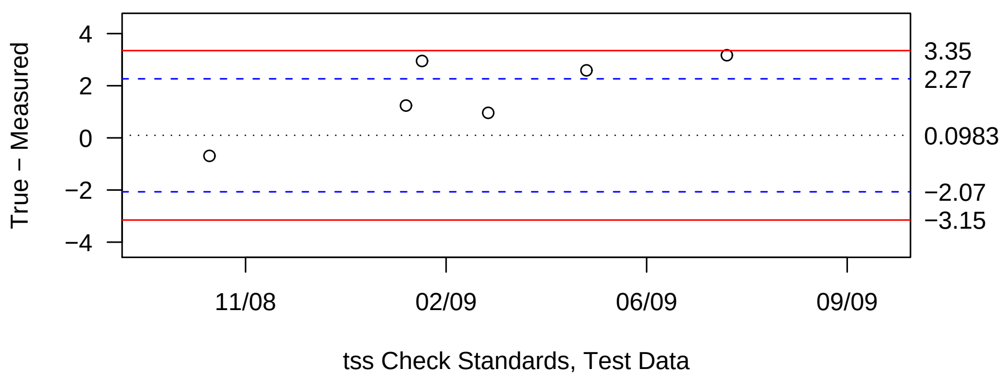
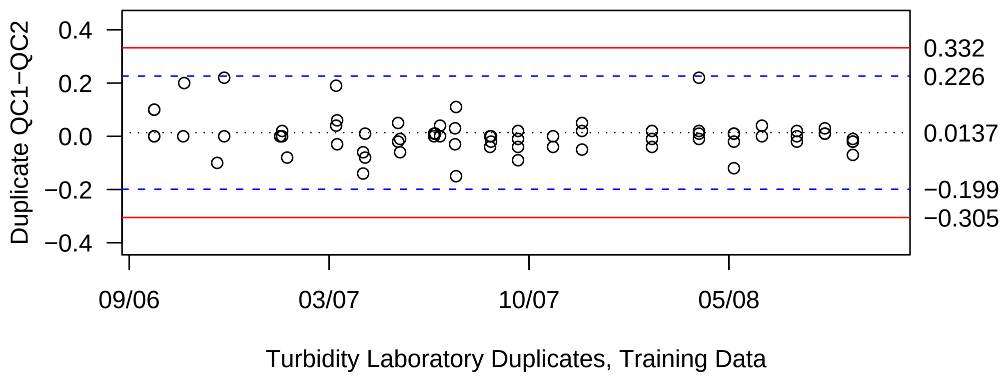


Figure C25: Total suspended solids check standards for the Lake Whatcom monitoring program (storm water and tributary samples only; no samples collected for lake monitoring). Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



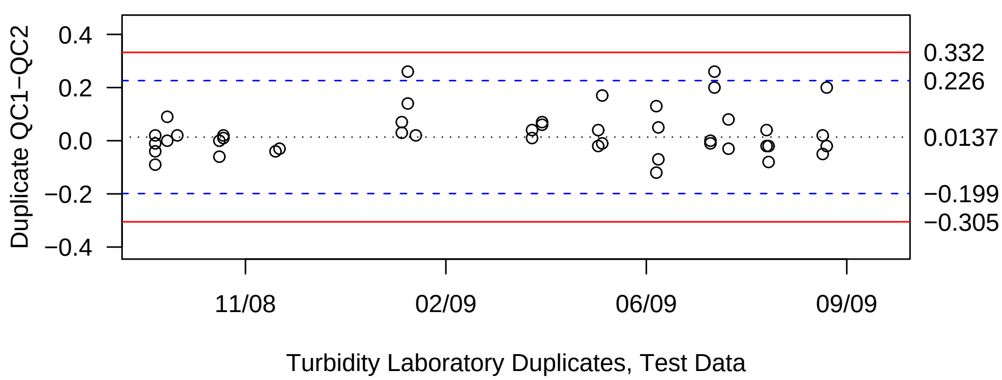


Figure C26: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

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 C27–C36, pages 333–342). 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:

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

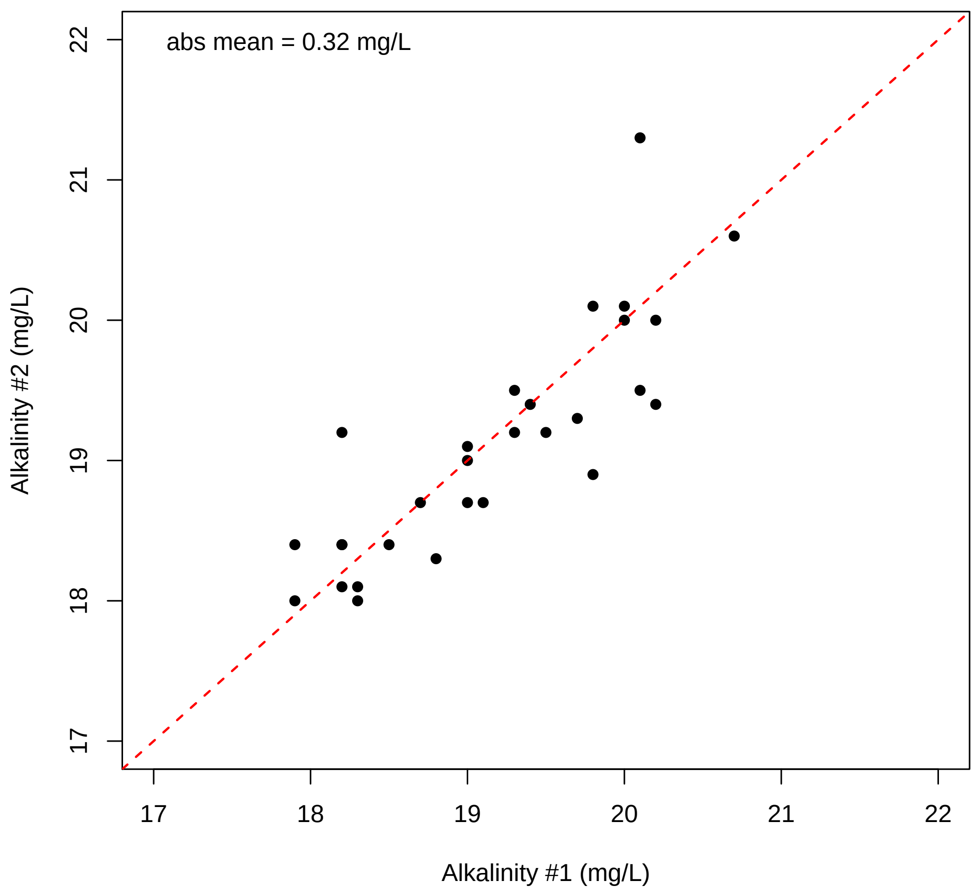


Figure C27: Alkalinity field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

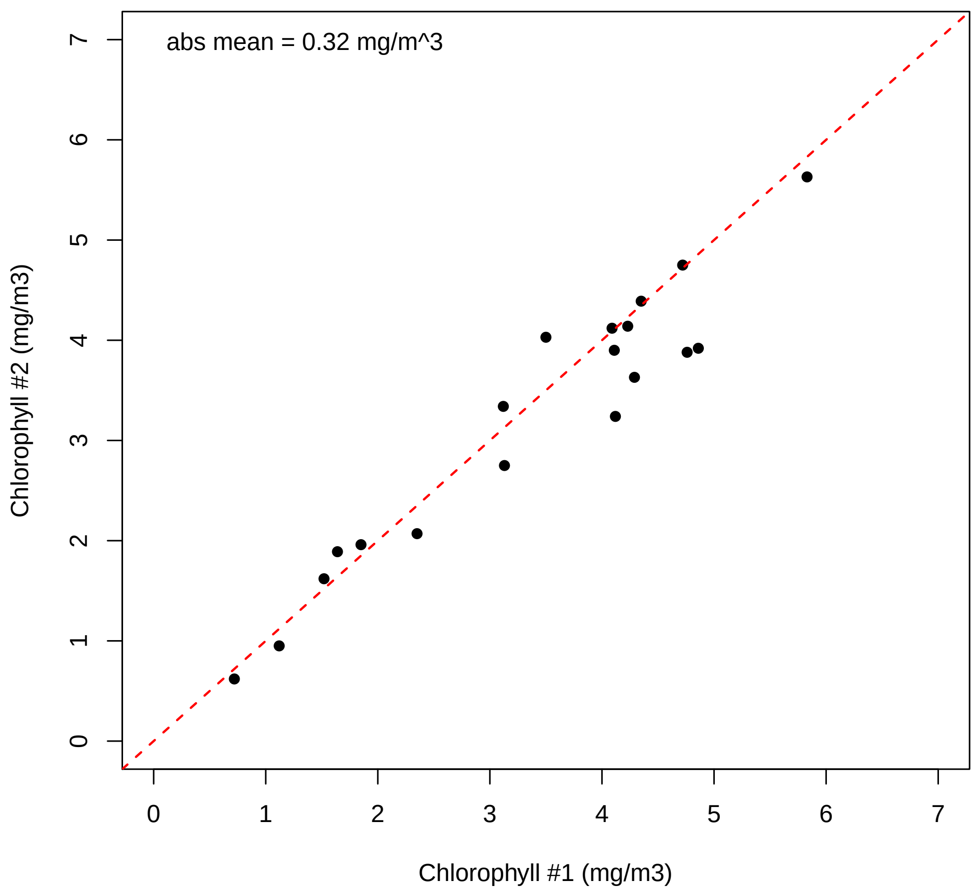


Figure C28: Chlorophyll field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

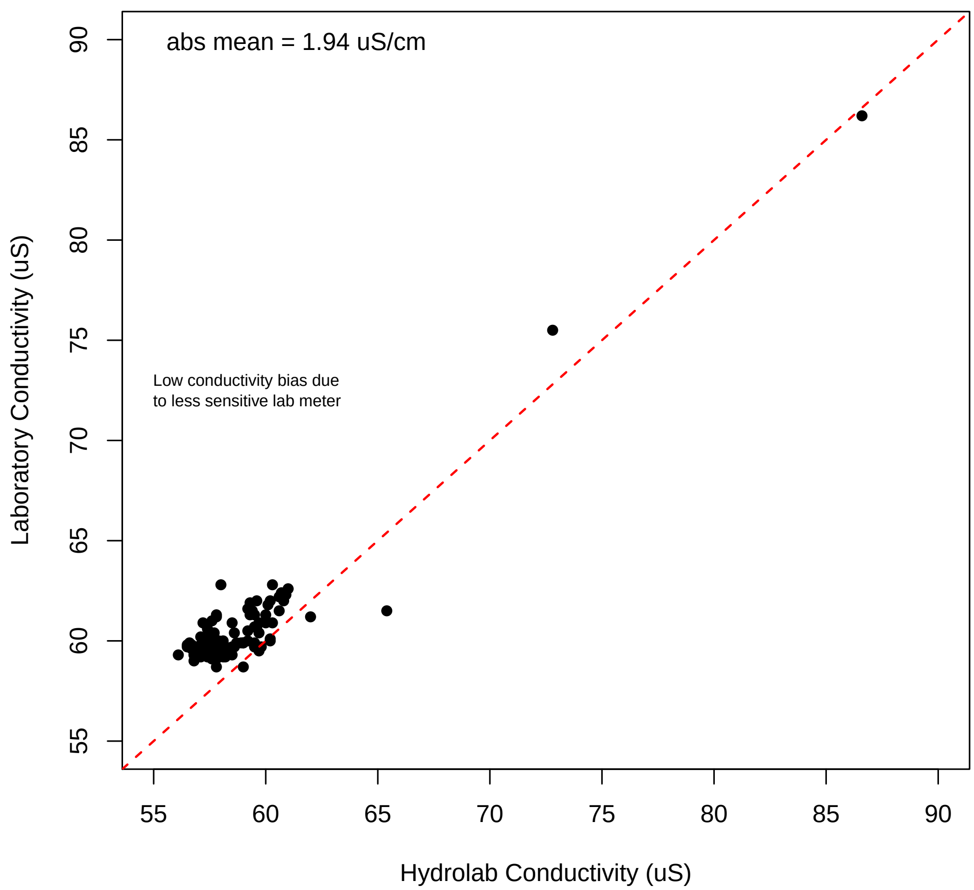


Figure C29: Conductivity field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

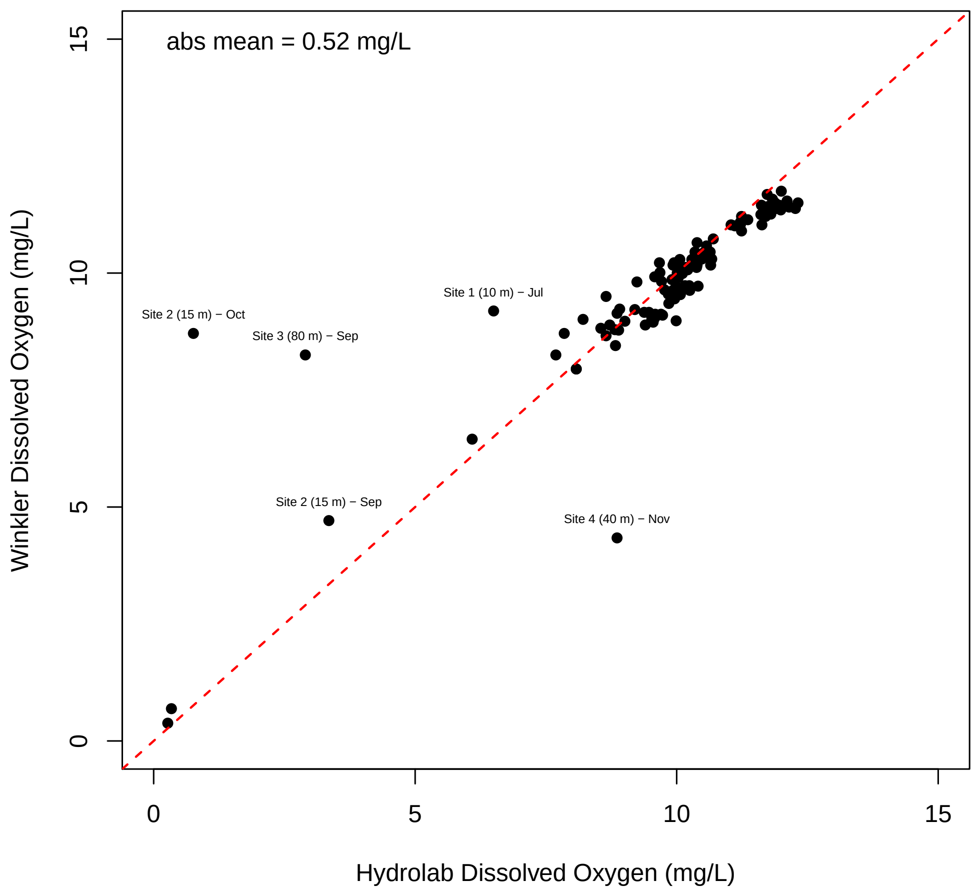


Figure C30: Dissolved oxygen field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. Most outliers were collected when the lake was stratified at depths were extreme oxygen gradients were present. These differences illustrate the variation between samples collected at true depth (Hydrolab) and depth measured using a marked line (Winkler), which is slightly shallower than true depth.

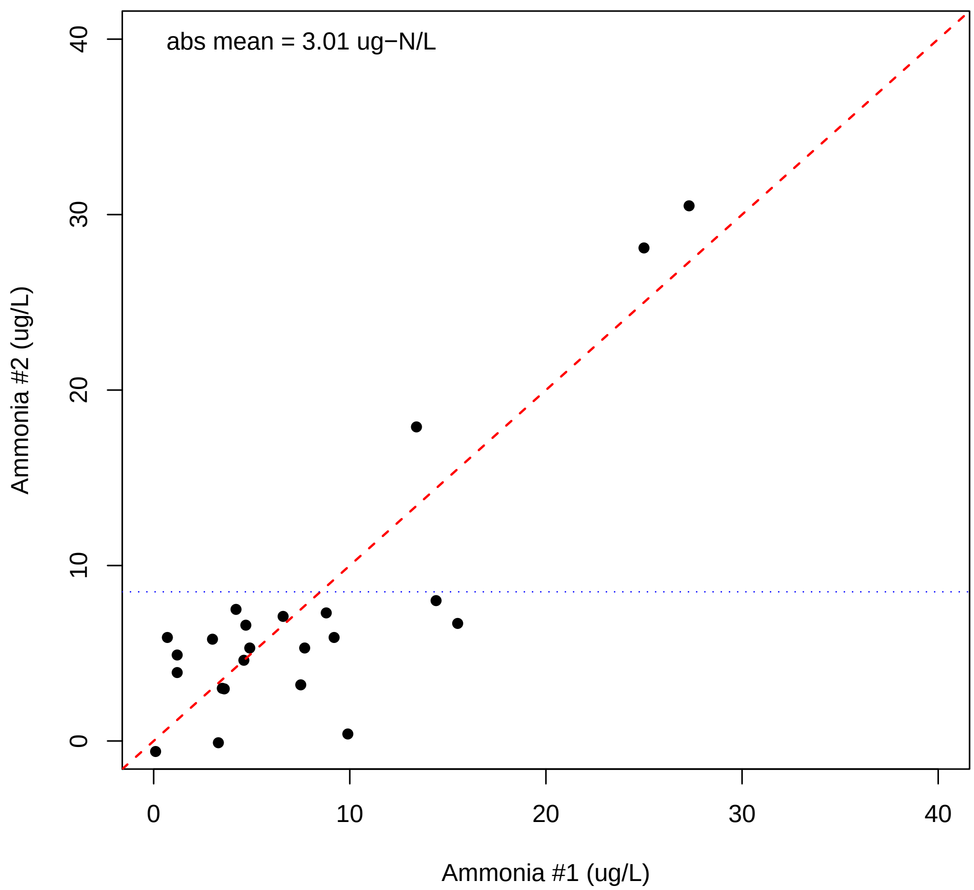


Figure C31: Ammonia field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

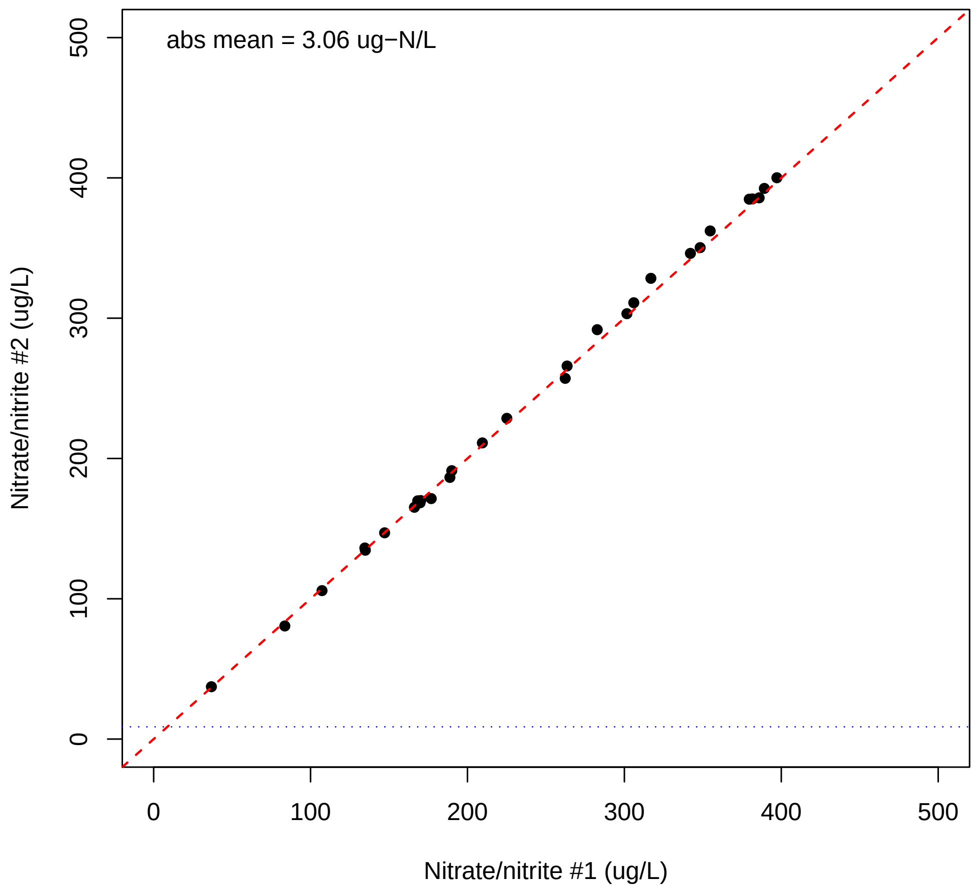


Figure C32: Nitrate/nitrite field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

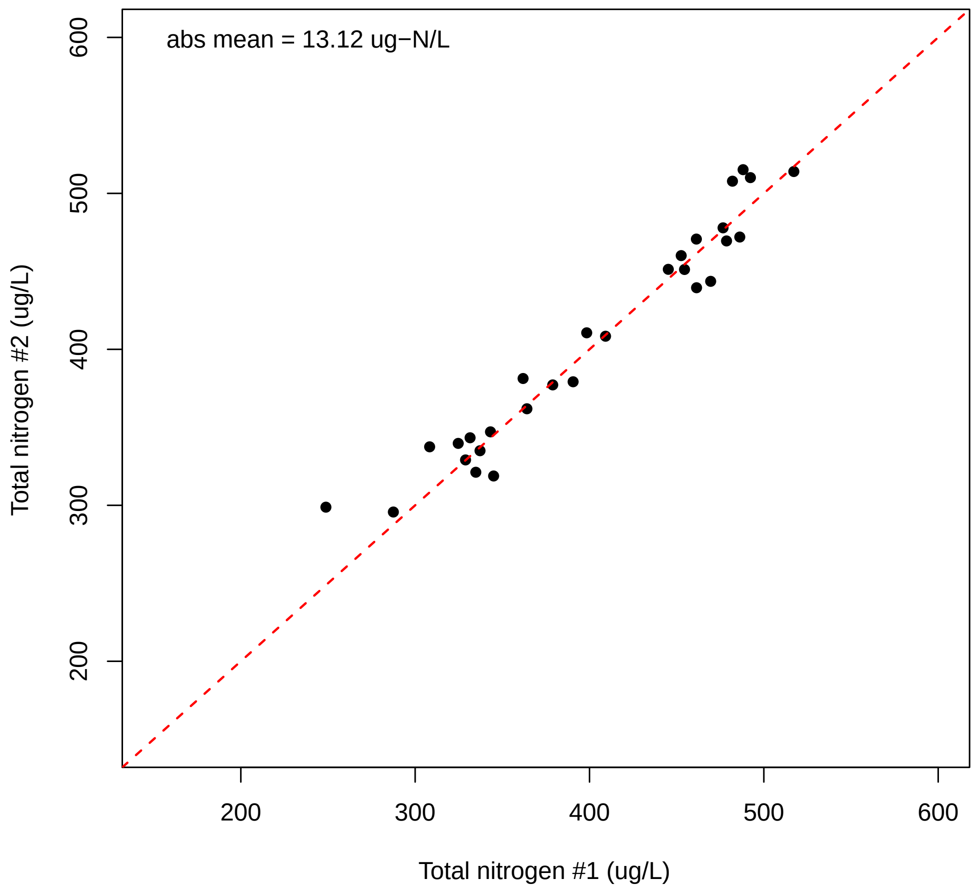


Figure C33: Total nitrogen field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

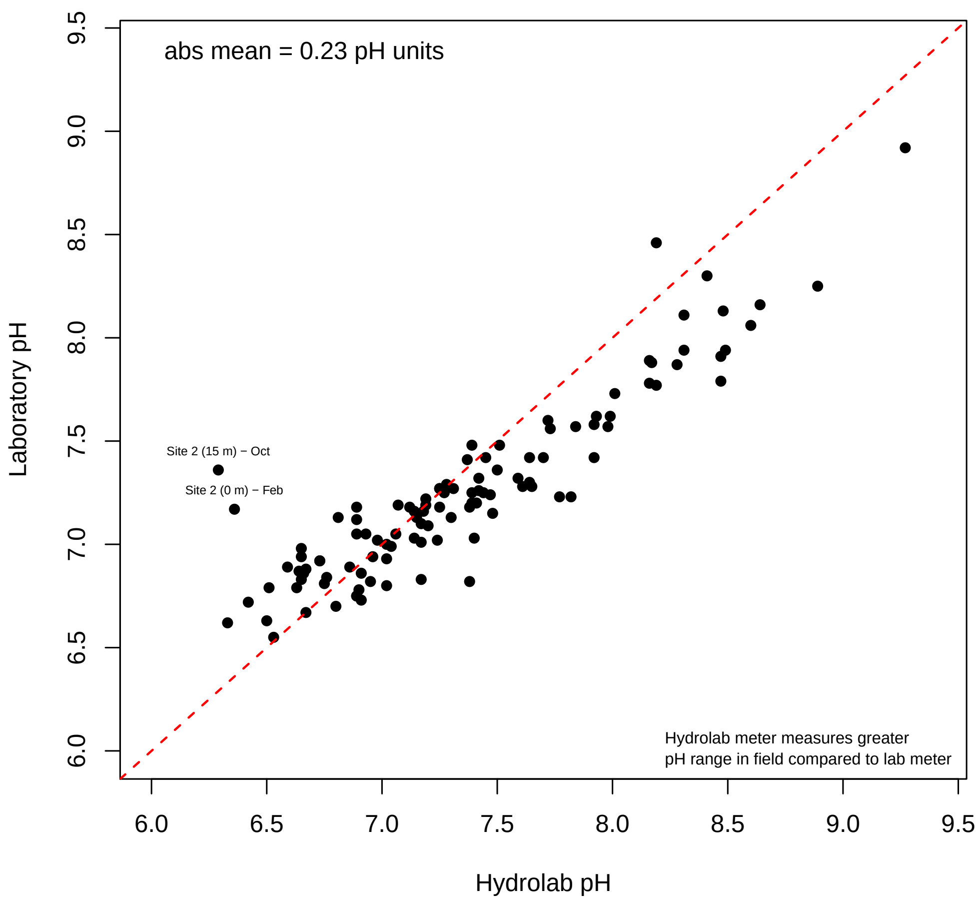


Figure C34: Field duplicates for pH from the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The results show a slight systematic bias due to changes in dissolved CO_2 and associated inorganic carbon ions between field and laboratory samples. One outlier was collected during late summer when extreme pH gradients were present; the second outlier was collected at the surface in April and represents sampling error.

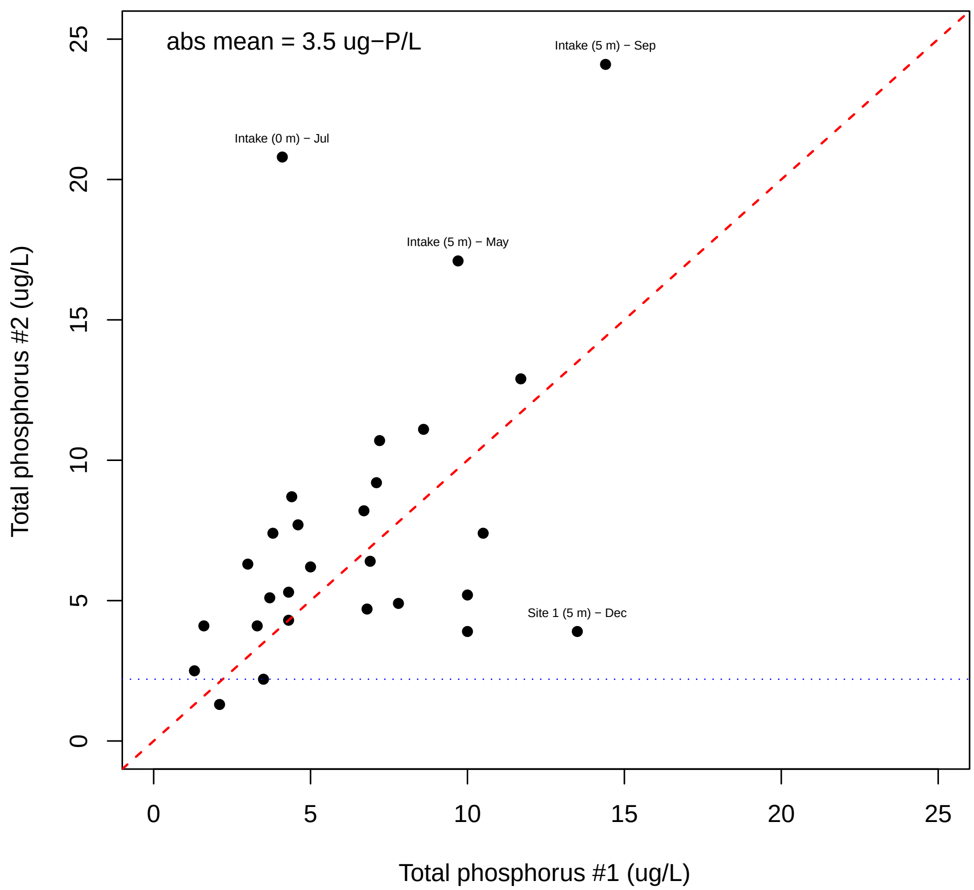


Figure C35: Total phosphorus field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

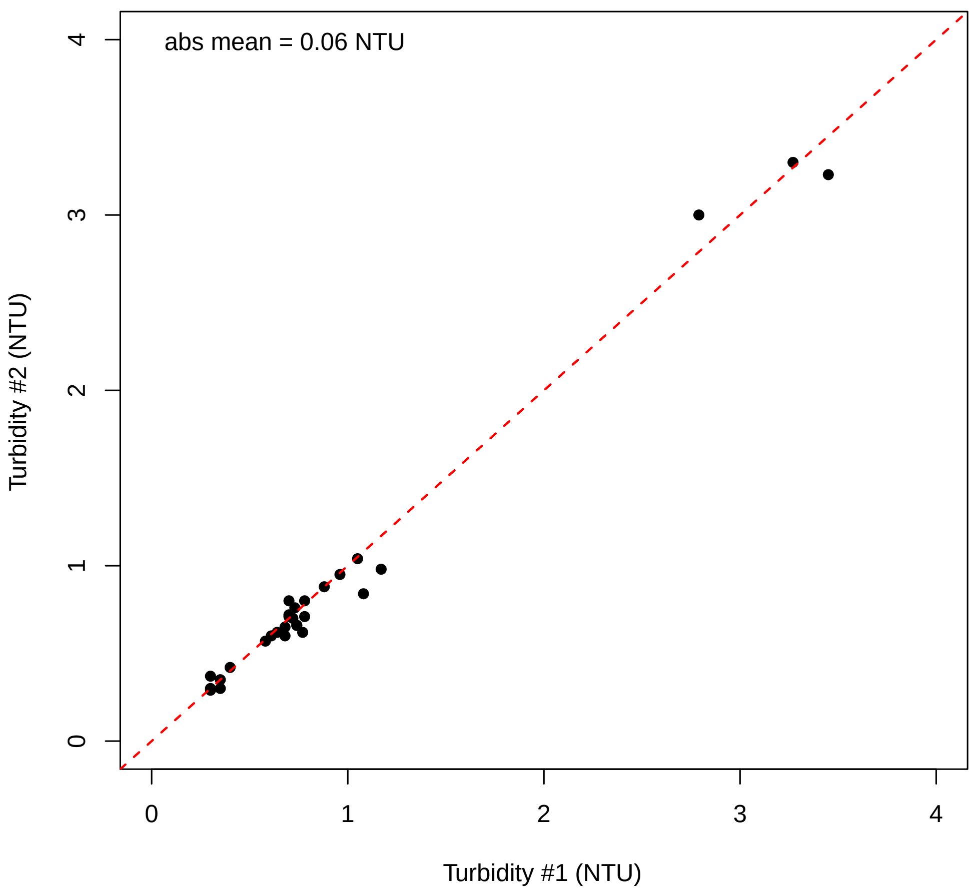


Figure C36: Turbidity field duplicates for the 2008/2009 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

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 MARCH 9, 2010
************************************************************
The historic Lake Whatcom data are available in electronic
format at the IWS website (http://www.ac.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
```

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, mg/m3).

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
WY2001.csv
WY2002.csv
WY2003.csv
WY2004_rev.csv (revised Anderson Creek data)
WY2005.csv
WY2006.csv
WY2007.csv
WY2008.csv
WY2009.csv
```

The WY1998-WY2001 hydrograph data files contain the following variables: month, day, year, hour, min, sec, ander.g (anderson gage height, ft), ander.cfs (anderson discharge, cfs), austin.g (austin gage height, ft), austin.cfs (austin discharge, cfs), smith.g (smith gage height, ft), smith.cfs (smith 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:
****

comps.csv
grab.csv

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 (2004-2009)
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 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.

```
*************************************************************
* 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 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.

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* ROUTINE DATA VERIFICATION PROCESS
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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.