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Lake Whatcom Monitoring Project 2009/2010 Report

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2009/2010 Final Report

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Executive Summary

- This report describes the results from the 2009/2010 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 110.

- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The water temperatures were slightly warmer than usual in February and April 2010, but unusually cool in May, June, and September. The lake was weakly stratified in June; stable stratification was present at Sites 1–4 by early July.

- 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 2010 hypolimnetic oxygen concentrations dropped rapidly, and by August the oxygen levels were <2 mg/L at all depths below 11 meters.

- There continues to be a significant trend developing in the pH data. The maximum pH values are increasing slightly over time, which is probably due the increasing levels of photosynthesis in the epilimnion.

- 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. The patterns continue to be somewhat variable, but it does not appear that the upward trends have stabilized.

- Algal blooms developed during the summer of 2010 that were associated with poor water filtration rates at the City's water treatment facility. The dominant algae associated with this bloom were *Aphanocapsa* and *Aphanothece* (nontoxic Cyanobacteria).

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

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

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

- Beginning in January 2010, the tributaries were sampled monthly to collect baseline data. Most of the tributaries had relatively low concentrations of total and dissolved solids, low alkalinities and conductivities, and low levels of nitrate and 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 WY2010[1] included surface and subsurface runoff (73.5%), direct precipitation (23.7%), and water diverted from the Middle Fork of the Nooksack River (2.8%). Outputs included Whatcom Creek (75.4%), the City of Bellingham (11.9%), evaporation (8.8%), the Whatcom Falls

[1] Water Year 2010 covers the period from October 1, 2009 through September 30, 2010

Hatchery (3.0%), the Lake Whatcom Water and Sewer District (0.8%)[2], and the Puget Sound Energy Co-Generation (0.2%)[3].

- The storm water monitoring objectives changed in 2009 to focus on collecting baseline storm event data from Silver Beach Creek and evaluating the effectiveness of the North Shore Drive overlay. Storm runoff in Silver Beach Creek contained elevated levels of total suspended solids and phosphorus that were significantly correlated with flow rates. The North Shore Drive overlay was difficult to evaluate because it was not designed to infiltrate all runoff in that portion of the watershed. Flowing water was visible in the drains associated with the overlay, but the presence or absence of flowing water did not appear to be directly related to local precipitation.

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

1 Introduction

This report is part of an on-going series of annual reports and special project reports that document the Lake Whatcom monitoring program over time. Many of the reports are available online at http://www.wwu.edu/iws (follow links under Lake Studies to Lake Whatcom); older reports are available in the IWS library and through the City of Bellingham Public Works Department. A summary of the Lake Whatcom reports, including special project reports, is included in Section 6.2, beginning on page 110.

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

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

The major objectives of the 2009/2010 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.

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

Detailed site descriptions can be found in Appendix A. The historic lake data are plotted in Appendix B. The current quality control results can be found in Appendix C. The 2009/2010 monitoring data are available online at http://www.wwu.edu/iws as described in Appendix D (page 341). Table 1 (page 18) 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 117 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 6 & 8, November 3 & 4 and December 1 & 2, 2009; and February 4 & 9, April 13 & 15, May 4 & 6, June 1 & 3, July 6 & 8, August 3 & 5, and September 8 & 9, 2010. Each sampling event is a multi-day task; all samples were collected during daylight hours, typically between 10:00 am and 3:00 pm.

A DataSonde 5 and Surveyor 4 Hydrolab field meter was used to measure temperature, pH, dissolved oxygen, and conductivity. 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 18). Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.[5] 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.

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

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 19–23) summarize the current field measurements, ambient water quality, and coliform data. The raw data are available online at http://www.wwu.edu/iws as described in Appendix D (page 341). The monthly Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 123–172).

The 2009/2010 lake data are plotted with historic lake data in Figures B51–B130 (pages 174–254). 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 138–142) and the multi-year temperature profiles (Figures B51–B55, pages 174–178) show that the water column mixes during the fall, winter, and early spring. During this time, water temperatures, dissolved oxygen concentrations, pH levels, and conductivities are fairly uniform from the surface to the bottom of the lake, even at Site 4, which is over 300 ft (100 m) deep.

The summer Hydrolab profiles (e.g., Figures B46–B50, pages 168–172) show how the lake stratifies into a warm surface layer (*epilimnion*), and cool bottom layer (*hypolimnion*). The transition zone between the epilimnion and hypolimnion (the *metalimnion*), is a region of rapidly changing water temperature. When stratified, the profiles show distinct differences between surface and bottom temperatures.

Stratification develops gradually, and once stable, persists until fall or winter, depending on location in the lake. 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 but basin 3 (Sites 3–4) is often still stratified in November and early December. Complete destratification of basin 3 usually occurs in December or early January, so by February the temperatures are relatively uniform throughout the water column at all sites.

On November 4, 2009 the water column at Site 1 was completely mixed from the surface to the bottom (Figure B6, page 128), but Site 2 was still slightly stratified near the bottom (Figure B7, page 129). Basin 3 (Sites 3–4) was still stratified on November 3, 2009, but by December 1 the water column was only weakly stratified, so the basin probably turned over before the end of December. By February 2010 all sites were destratified and the water column was mixed from the surface to the bottom of the lake.

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

The surface water temperatures were slightly warmer than usual in February and April 2010, but unusually cool in May, June, and September (Figure 1, page 29). The lake was unstratified in April and weakly stratified by early May (Δ T $\leq 5°$ C; Figures B21–B30, pages 148–147). Sites 1–2 were still only weakly stratified in early June (Figures B31–B35, pages 153–157); all sites except the intake showed stable stratification by July.

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 163–164 and 179–180). 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 172 and 183). In contrast, there is rapid depletion of the hypolimnetic oxygen concentrations at Sites 1–2 (Figures B46–B47, and B56–B57, pages 168–169 and 179–180). 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.[6]

[6] 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 approximately 75%, 70%, and 17%, respectively (Mitchell, et al., 2010).

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).[7] 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 30–33), there were significant negative correlations between dissolved oxygen and time for all samples collected from the hypolimnion during July and August.[8]

Despite the cool spring and late stratification, the hypolimnetic oxygen levels dropped rapidly once the lake stratified. Between June and August the dissolved oxygen concentrations dropped from near saturation to near zero at all depths below 10 meters, losing 6–8 mg/L in 63 days. The fastest rate of decline occurred at 11 and 12 meters, where the oxygen levels dropped 8.3 and 8.2 mg/L, respectively, for an average loss of 0.13 mg/L per day.

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in August (e.g., Figure B41, page 163). This was caused by the accumulation of phytoplankton along the density gradient between the epilimnion and hypolimnion where light and nutrients are sufficient to support very high levels of photosynthesis. Chlorophyll concentrations within the metalimnetic oxygen peak may be 4-5 times higher than those measured near the surface of the lake (Matthews and DeLuna, 2008).

Site 3 developed an oxygen sag near the bottom during late summer and fall in 2009 and again in 2010 (Figures B4, page 126 from October 2009 and Figure B49, page 171 from September 2010). Sites 3 and 4 developed small oxygen sags near the thermocline (e.g., Figures B4 and B5, pages 126 and 127), which are caused by respiration of heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (Matthews and DeLuna, 2008).

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

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

2.3.3 Conductivity and pH

The Hydrolab pH and conductivity data followed trends that were, for the most part, typical for Lake Whatcom (Figures B61–B70, pages 184–193). 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 illustrated in Figure B41, page 163, which shows a metalimnetic oxygen peak from photosynthesis coincident with a metalimnetic pH peak.

There is a significant trend developing in the pH data. While the minimum pH values in the water column[9] have remained fairly constant over time (Figure 6, page 34), the maximum pH has increased significantly at all sites (Figure 7, page 35). This trend is most likely due to increasing algal densities in the epilimnion (see Section 2.3.6). Algal photosynthesis can cause a temporary increase in daytime pH by lowering the concentration of dissolved CO_2 in the water column. Carbon dioxide combines with water to form carbonic acid: $H_2O + CO_2 \leftrightarrow H_2CO_3$. Photosynthetic removal of CO_2 causes a temporary (daytime) reduction in carbonic acid. This phenomenon is cyclic; during the night, when algae are not photosynthesizing, the amount of dissolved CO_2 is replenished through equilibrium with the atmosphere. This photosynthesis effect is especially pronounced in poorly-buffered, low alkalinity water and in lakes or streams with dense populations of algae or other aquatic plants.

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 195–199). 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.

[9] The near-bottom pH values were excluded from this analysis because they are more affected by sediment chemistry than algal photosynthesis in the water column.

Turbidity values in the lake were usually low (1–3 NTU) except during late summer in samples from the bottom of the lake. The high turbidity levels during this time are an indication of increasing turbulence in the lower hypolimnion as the lake begins to destratify. The highest turbidity peaks were measured at Sites 1–2 (Figures B76–B80, pages 200–204).

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 205–229) 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.[10]

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.[11] Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 210–214), particularly at Site 1, where the epilimnetic nitrate concentrations often drop below 20 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)[12] have

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

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

[12] 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.

been declining over time (Figure 8, page 36). Low epilimnetic DIN concentrations favor the growth of Cyanobacteria because many types of cyanobacteia can use dissolved N_2 gas as a nitrogen source.

Hypolimnetic nitrate concentrations dropped below 20 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 2008–2010, 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.

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 24; Figures B81 & B82, pages 205 & 206). 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 206). The highest ammonia concentration measured since 1988 was collected at Site 2 in November 2008 (976 μg-N/L); the second highest ammonia concentration was measured at Site 2 in October 2010 (511 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 208–209). 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 220–224 and B101–B105, pages 225–229). 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 9, page 37). The epilimnetic phosphorus levels have increased significantly at Sites 1, 2, and 4 (Figure 9, page 37); however, the pattern is quite erratic, reflecting the complicated nature of phosphorus movement in the water column. It is important to note that low water column phosphorus concentrations do not always match up with low algal densities, and may instead indicate rapid and efficient cycling of phosphorus among the lake biota.

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 24).[13] 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.

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 230–234). 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 245–254). 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 235–239) 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).

[13] 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).

The median near-surface summer chlorophyll concentrations were higher in 2010 compared to 2009 (Figure 10, page 38), but the algae counts (all sites combined) were about the same (Figures 11–12, pages 39–40). This discrepancy between chlorophyll and algae counts reflects the difference between numerical density and biomass. Chlorophyll is a direct measure of algal biomass and is best used to evaluate trophic changes in the lake (e.g., is the lake becoming more biologically productive?). Algal counts are a numerical way to look for trends within the same type of algae (e.g., are the numbers of Cyanobacteria increasing?). The relationship between chlorophyll and cell density is complex. The amount of chlorophyll in an algal cell is influenced by the physiological age and condition of the cell, light intensity, nutrient availability, and many other factors. In addition, while most types of algae are counted by individual cells, a few types must be counted by colonies because the cells are too difficult to see. Even if the amount of chlorophyll was constant in each cell, it would take many tiny cells to equal the chlorophyll biomass in one large colony.

One of the eutrophication trends in Lake Whatcom has been a fairly steady increase in the numbers of Cyanobacteria at all sites. This trend is best viewed using a $\log_{10}$ plot (Figure 12, page 40), which shows the counts increasing from 1994 through 2004 or 2005. During the past five years the counts have been more or less consistent, going up or down slightly depending on the site and year.

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

Beginning in December 2009, IWS started collecting supplemental monthly plankton samples from 10 meters at Site 2 and the Intake and from the City's raw water gatehouse. Our goal was to generate detailed information about the algae responsible for filter clogging events using samples collected at the gatehouse and at depths close to the water withdrawal depth in basin 2. The supplemental algal counts were identified to a much lower taxonomic level than our regular algal counts using a settling chamber method (Hamilton, et al., 2001) that captures tiny individual algal cells ($<20\ \mu$m diameter) that can pass through our regular plankton net. Because of the different concentration methods and sampling depths, the settled algae counts are not directly comparable to the historic algal counts collected using a plankton net (Figures B121–B130, pages 245–254), but the general taxonomic patterns will be similar.

Dense, sticky colonies of *Aphanocapsa* and *Aphanothece* were exceeding abundant in the settled samples, comprising nearly 85% of the total cell count (Tables 10–11, pages 27–28 and Figure 13, page 41). The densities of *Aphanocapsa* and *Aphanothece* increased during the summer, coinciding with a decrease in the City's water production rate (Figure 14, page 42).[14]

The third most abundant group of algae in the samples was *Cyclotella* and *Thalassiosira*, which were combined for this report because they have similar filter-clogging features (Figure 15, page 43). Both taxa 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. Although these taxa were moderately common in the settled samples, especially during the late summer when *Aphanocapsa* and *Aphanothece* were abundant, their density was not as useful for predicting poor water production rates (Figure 16, page 44).

Total algae counts from the gatehouse, Intake (10 m), and Site 2 (10 m) were used to predict water production rates using simple linear regression (Figure 17, page 45). All three regressions were statistically significant, with adjusted r^2 values of 0.640–0.719. Because most of the cells in the settled samples were *Aphanocapsa* and *Aphanothece*, similar regressions could be built using just those taxa. The advantage to using a smaller subset of algae is that future sampling efforts could focus on those two taxa, saving a considerable amount of analysis time. The

[14]Water production data were reported in units of "unit filter run volume" (UFRV), which is the product of the filtration rate (gal/min), filter run length (min), and filter surface area (ft^2). Good water production rates are usually $\geq$5000 (P. Wendling and B. Evans, City of Bellingham Public Works Department, personal communications.).

best regression between water production rates and *Aphanocapsa+Aphanothece* was created using data from the Intake, resulting in an adjusted r^2 value of 0.694 (Figure 18, page 46).

We will continue counting settled samples during 2011 to help evaluate factors affecting the City's water production rates. In particular, we will try to confirm whether *Aphanocapsa* and *Aphanothece* densities, or other water quality factors, can be used to predict when water production rates are likely to decline.

2.3.7 Coliform bacteria

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

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

All of the mid-basin (Sites 1–4) and Intake values for fecal coliforms were less than 10 cfu[15]/100 mL (Figures B116–B120, pages 240–244) 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.

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

2.3.8 Metals

The metals data for Lake Whatcom are included in Table 8 (page 25). 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.

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 26). 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 19, page 47). 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 20, page 48).[16]

As illustrated in Figure 21 (page 49), 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	–	–	$\pm$ 0.6 mg/L
cond	Conductivity	APHA (2005) #2510; SOP-LW-19	–	–	$\pm$ 1.2 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
tss	T. suspended solids	APHA (2005) #2540 D; SOP-IWS-22	2 mg/L	0.7 mg/L	$\pm$ 2.8 mg/L
turb	Turbidity	APHA (2005) #2130; SOP-IWS-11	–	–	$\pm$ 0.2 NTU
nh3	Ammonia (auto)	APHA (2005) #4500-NH_3 H; SOP-IWS-19	10 μg-N/L	6.5 μg-N/L	$\pm$ 5.1 μg-N/L
no3	Nitrite/nitrate (auto)	APHA (2005) #4500-NO_3 I; SOP-IWS-19	20 μg-N/L	4.1 μg-N/L	$\pm$ 4.1 μg-N/L
tn	T. nitrogen (auto)	APHA (2005) #4500-N C; SOP-IWS-19	100 μg-N/L	20.3 μg-N/L	$\pm$ 26.9 μg-N/L
srp	Sol. phosphate (auto)	APHA (2005) #4500-P G; SOP-IWS-19	5 μg-P/L	1.4 μg-P/L	$\pm$ 1.8 μg-P/L
tp	T. phosphorus (auto)	APHA (2005) #4500-P H; SOP-IWS-19	5 μg-P/L	5.4 μg-P/L	$\pm$ 6.0 μg-P/L
IWS plankton analyses:					
chl	Chlorophyll	APHA (2005) #10200 H; SOP-IWS-16	–	–	$\pm$ 0.1 μg/L
chlo	Chlorophyta	Lind (1985), Schindler trap	–	–	–
cyan	Cyanobacteria	Lind (1985), Schindler trap	–	–	–
chry	Chrysophyta	Lind (1985), Schindler trap	–	–	–
pyrr	Pyrrophyta	Lind (1985), Schindler trap	–	–	–
City coliform analyses:					
fc	Fecal coliform	APHA (2005) #9222 D		1 cfu/100 mL	–
AmTest analyses:					
As	T. arsenic	EPA (1994) 200.7	–	0.01 mg/L	–
Cd	T. cadmium	EPA (1994) 200.7	–	0.0005 mg/L	–
Cr	T. chromium	EPA (1994) 200.7	–	0.001 mg/L	–
Cu	T. copper	EPA (1994) 200.7	–	0.001 mg/L	–
Fe	T. iron	EPA (1994) 200.7	–	0.005 mg/L	–
Pb	T. lead	EPA (1979) 239.2	–	0.001 mg/L	–
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.	N
Alkalinity (mg/L $CaCO_3$)	18.6	20.1	20.8	27.2	50
Conductivity (μS/cm)	57.6	60.2	61.3	75.9	210
Dissolved oxygen (mg/L)	0.2	9.8	8.4	12.1	210
pH	6.3	7.4	7.3	8.8	210
Temperature (°C)	6.6	11.5	11.7	22.1	210
Turbidity (NTU)	$<$2	$<$2	$<$2	9.9	50
Nitrogen - ammonium (μg-N/L)	$<$10	$<$10	30.7	271.3	50
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	196.1	166.0	313.5	50
Nitrogen - total (μg-N/L)	193.9	380.5	361.2	460.3	50
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	10.5	50
Phosphorus - total (μg-P/L)	$<$5	8.8	9.8	52.0	50
Chlorophyll (μg/L)	0.3	3.8	4.1	12.7	50
Secchi depth (m)	2.9	4.4	4.2	5.5	10
Coliforms - fecal (cfu/100 mL)‡	$<$1	1	1	6	10

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

Table 2: Summary of Site 1 ambient water quality data, Oct. 2009 – Sept. 2010.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	18.0	19.0	19.2	20.8	30
Conductivity (μS/cm)	56.8	58.1	58.2	60.3	110
Dissolved oxygen (mg/L)	9.2	10.9	10.7	12.3	110
pH	7.2	7.8	7.7	8.3	110
Temperature (°C)	6.8	12.7	13.2	21.7	110
Turbidity (NTU)	<2	<2	<2	<2	30
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	13.3	30
Nitrogen - nitrate/nitrite (μg-N/L)	100.9	254.3	231.4	355.8	30
Nitrogen - total (μg-N/L)	239.4	388.8	369.9	480.9	30
Phosphorus - soluble (μg-P/L)	<5	<5	<5	11.0	30
Phosphorus - total (μg-P/L)	<5	<5	<5	13.5	30
Chlorophyll (μg/L)	2.0	3.4	3.5	5.9	30
Secchi depth (m)	4.3	5.4	5.5	7.0	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	1	10

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

Table 3: Summary of Intake ambient water quality data, Oct. 2009– Sept. 2010.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	18.1	19.0	19.5	26.2	50
Conductivity (μS/cm)	56.6	57.9	58.9	79.4	210
Dissolved oxygen (mg/L)	0.3	10.4	9.4	12.3	210
pH	6.3	7.3	7.4	8.3	210
Temperature (°C)	6.7	11.0	11.9	21.5	210
Turbidity (NTU)	$<$2	$<$2	$<$2	3.5	50
Nitrogen - ammonium (μg-N/L)	$<$10	$<$10	22.7	363.9	50
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	259.9	235.6	362.1	50
Nitrogen - total (μg-N/L)	239.3	417.9	399.3	524.8	50
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	8.5	50
Phosphorus - total (μg-P/L)§	$<$5	7.1	8.0	49.9	49
Chlorophyll (μg/L)	0.6	3.0	3.2	5.4	50
Secchi depth (m)	4.4	5.6	5.5	6.2	10
Coliforms - fecal (cfu/100 mL)‡	$<$1	1	1	1	10

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).
§One sample lost due to analytical error.

Table 4: Summary of Site 2 ambient water quality data, Oct. 2009 – Sept. 2010.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	17.4	18.4	18.6	20.3	70
Conductivity (μS/cm)	56.1	57.6	57.8	65.0	250
Dissolved oxygen (mg/L)	3.2	10.0	10.0	11.9	250
pH	6.4	7.2	7.3	8.4	250
Temperature (°C)	5.9	7.5	9.8	20.6	250
Turbidity (NTU)	<2	<2	<2	<2	70
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	15.7	70
Nitrogen - nitrate/nitrite (μg-N/L)	128.6	364.6	326.5	434.0	70
Nitrogen - total (μg-N/L)	268.2	451.3	433.9	544.0	70
Phosphorus - soluble (μg-P/L)	<5	<5	<5	5.6	70
Phosphorus - total (μg-P/L)	<5	<5	<5	22.3	70
Chlorophyll (μg/L)	1.2	2.6	2.9	5.8	50
Secchi depth (m)	4.1	5.0	5.3	6.6	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	3	10

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

Table 5: Summary of Site 3 ambient water quality data, Oct. 2009 – Sept. 2010.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	17.8	18.4	18.6	20.3	80
Conductivity (μS/cm)	55.7	57.5	57.6	59.6	270
Dissolved oxygen (mg/L)	8.2	9.9	10.1	12.0	270
pH	6.4	7.1	7.2	8.2	270
Temperature (°C)	5.9	7.4	9.5	20.4	270
Turbidity (NTU)	<2	<2	<2	<2	80
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	17.0	80
Nitrogen - nitrate/nitrite (μg-N/L)	132.7	378.6	337.8	431.8	80
Nitrogen - total (μg-N/L)	282.9	461.5	444.9	537.7	80
Phosphorus - soluble (μg-P/L)	<5	<5	<5	11.4	80
Phosphorus - total (μg-P/L)	<5	5.2	<5	24.7	80
Chlorophyll (μg/L)	1.2	2.7	2.9	5.6	50
Secchi depth (m)	4.3	6.6	6.6	8.3	10
Coliforms - fecal (cfu/100 mL)[‡]	<1	1	1	3	10

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

Table 6: Summary of Site 4 ambient water quality data, Oct. 2009 – Sept. 2010.

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

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

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

	Depth (m)	Date	T. As (mg/L)	T. Cd (mg/L)	T. Cr (mg/L)	T. Cu (mg/L)	T. Fe (mg/L)	T. Hg (mg/L)	T. Ni (mg/L)	T. Pb (mg/L)	T. Zn (mg/L)
Site 1	0	Feb 9, 2010	<0.01	<0.0005	<0.001	<0.001	0.019	0.0001	<0.005	<0.001	<0.001
Site 1	20	Feb 9, 2010	<0.01	<0.0005	<0.001	<0.001	0.027	0.0003	<0.005	<0.001	<0.001
Intake	0	Feb 9, 2010	<0.01	<0.0005	<0.001	<0.001	0.014	<0.0001	<0.005	<0.001	<0.001
Intake	10	Feb 9, 2010	<0.01	<0.0005	<0.001	0.001	0.015	<0.0001	<0.005	<0.001	<0.001
Site 2	0	Feb 9, 2010	<0.01	<0.0005	<0.001	<0.001	0.017	<0.0001	<0.005	<0.001	<0.001
Site 2	20	Feb 9, 2010	<0.01	<0.0005	<0.001	<0.001	0.016	<0.0001	<0.005	<0.001	<0.001
Site 3	0	Feb 4, 2010	<0.01	<0.0005	<0.001	0.002	0.019	<0.0001	<0.005	0.001	<0.001
Site 3	80	Feb 4, 2010	<0.01	<0.0005	<0.001	<0.001	0.028	0.0001	<0.005	<0.001	<0.001
Site 4	0	Feb 4, 2010	<0.01	<0.0005	<0.001	<0.001	0.017	<0.0001	<0.005	<0.001	<0.001
Site 4	90	Feb 4, 2010	<0.01	<0.0005	<0.001	0.002	0.025	0.0002	<0.005	<0.001	<0.001
Site 1	0	Aug 5, 2010	<0.01	<0.0005	<0.001	0.002	0.014	<0.0001	<0.005	<0.001	0.002
Site 1	20	Aug 5, 2010	<0.01	<0.0005	<0.001	0.001	0.850	<0.0001	<0.005	<0.001	0.004
Intake	0	Aug 5, 2010	<0.01	<0.0005	<0.001	<0.001	0.017	<0.0001	<0.005	<0.001	0.002
Intake	10	Aug 5, 2010	<0.01	<0.0005	<0.001	<0.001	0.009	<0.0001	<0.005	<0.001	0.003
Site 2	0	Aug 5, 2010	<0.01	0.0006	<0.001	0.001	0.010	<0.0001	<0.005	<0.001	0.003
Site 2	20	Aug 5, 2010	<0.01	<0.0005	<0.001	<0.001	0.222	<0.0001	<0.005	<0.001	0.006
Site 3	0	Aug 3, 2010	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0001	<0.005	<0.001	0.002
Site 3	80	Aug 3, 2010	<0.01	<0.0005	<0.001	<0.001	0.016	<0.0001	<0.005	<0.001	0.004
Site 4	0	Aug 3, 2010	<0.01	<0.0005	0.001	<0.001	0.015	<0.0001	<0.005	<0.001	0.005
Site 4	90	Aug 3, 2010	<0.01	<0.0005	<0.001	<0.001	0.010	<0.0001	<0.005	<0.001	0.004

Table 8: Lake Whatcom 2009/2010 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.wwu.edu/iws).

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 9, 2010	0	3.3	Aug 5, 2010	0	2.4
	Feb 9, 2010	20	4.9	Aug 5, 2010	20	2.5
Intake	Feb 9, 2010	0	1.4	Aug 5, 2010	0	2.6
	Feb 9, 2010	10	4.6	Aug 5, 2010	10	8.0
Site 2	Feb 9, 2010	0	3.4	Aug 5, 2010	0	2.9
	Feb 9, 2010	20	2.3	Aug 5, 2010	15	5.2
Site 3	Feb 4, 2009	0	4.6	Aug 5, 2010	0	1.5
	Feb 4, 2009	80	3.0	Aug 5, 2010	80	1.9
Site 4	Feb 4, 2009	0	6.0	Aug 5, 2010	0	<1
	Feb 4, 2009	90	3.9	Aug 5, 2010	90	2.6

Table 9: Lake Whatcom 2009/2010 total organic carbon data.

Taxa	Pct. of Total Count	Pct. of Total Count w/o Aphanocapsa
Cyanobacteria (bluegreen algae)		
Anabaena Bory de Saint-Vincent & Bornet & Flahault	0.1	0.8
Aphanocapsa Nägeli and *Aphanothece* Nägeli	84.8	NA
Chroomonas Hansgirg and *Eucapsis* Clements & Shantz	<0.1	<0.1
Merismopedia Meyen	<0.1	0.3
Microcystis Lemmermann	0.7	4.7
Pseudanabaena Lauterborn	0.4	2.5
Rhabdoderma Schmidle & Lauterborn	<0.1	<0.1
Snowella lacustris (Chodat) Komárek & Hinkák	5.4	35.4
Woronichinia naegeliana (Unger) Elekin	0.2	1.2
Chrysophyta (golden algae)		
Bitrichia chodatii (Reverdin) Chodat	<0.1	0.1
Dinobryon bavaricum Imhof	0.2	1.1
Dinobryon divergens Imhof	0.3	2.1
Dinobryon sertularia Ehrenberg	0.1	0.4
Epipyxis Ehrenberg	<0.1	0.1
Mallomonas Perty	<0.1	0.1
Ochromonas Vysotskii [Wissotsky] and *Chrysochromulina* Lackey	<0.1	<0.1
Stichogloea Chodat	<0.1	0.1
Stylochrysalis F. Stein	<0.1	<0.1
Chrysophyta (diatoms)		
Asterionella formosa Hassall	0.6	3.9
Aulacoseira Thwaites	0.3	2.1
Cyclotella (Kützing) Brébisson and *Thalassiosira* Cleve	1.8	11.7
Fragilaria Lyngbye	0.2	1.3
Melosira C. Agardh	<0.1	<0.1
Stephanodiscus Ehrenberg	<0.1	0.2
Synedra Ehrenberg	0.4	2.9
Tabellaria fenistrata (Lyngbye) Kützing	1.1	7.1
Urosolenia longiseta (O. Zacharias) Edlund & Stoermer	0.2	1.4
diatoms, misc	0.1	0.9

Table 10: Relative abundances of Cyanobacteria (bluegreen bacteria) and Chrysophyta (golden algae and diatoms) collected at the gatehouse, Intake (10 m), and Site 2 (10 m) between December 2009 and November 2010.

Taxa	Pct. of Total Count	Pct. of Total Count w/o Aphanocapsa
Chlorophyta (green algae)		
Ankistrodesmus Corda	<0.1	<0.1
Asterococcus Scherffel and *Planktosphaeria* G. M. Smith	<0.1	0.1
Botryococcus Kützing	0.1	0.6
Chlamydomonas Ehrenberg	<0.1	0.1
Chlorella M. Beijerinck	<0.1	<0.1
Crucigenia tetrapedia (Kirchner) Kuntze	0.1	0.6
desmids (misc.)	<0.1	0.1
Dictyosphaerium pulchellum H. C. Woods	<0.1	0.2
Elakatothrix gelatinosa Wille	0.1	0.4
Gloeotila Kützing	<0.1	<0.1
Monoraphidium Komárková-Legnerová	<0.1	<0.1
Oocystis Nägeli & A. Braun	0.1	0.4
Pediastrum Meyen	0.1	0.4
Quadrigula Printz	<0.1	0.2
Scenedesmus Meyen	0.7	4.4
Sphaerocystis schroeteri Chodat	0.1	0.3
Tetraedron minimum (A. Braun) Hansgirg	<0.1	0.1
Tetraspora lacustris Lemmermann	0.1	0.7
desmids (misc.)	<0.1	0.1
Pyrrhophyta (dinoflagellates		
Gymnodinium Stein	<0.1	0.1
Peridinium Ehrenberg	<0.1	0.1
Peridinium umbonatum F. Stein	<0.1	0.2
Euglenophyta (euglenoids)		
Trachelomonas Ehrenberg	<0.1	<0.1
Cryptophyta (cryptomonads)		
Cryptomonas Ehrenberg	0.3	2.0
Komma D. R. A. Hill and *Chroomonas* Hansgirg	1.3	8.3

Table 11: Relative abundances of Chlorophyta (green algae) and miscellaneous other types of algae collected at the gatehouse, Intake (10 m), and Site 2 (10 m) between December 2009 and November 2010.

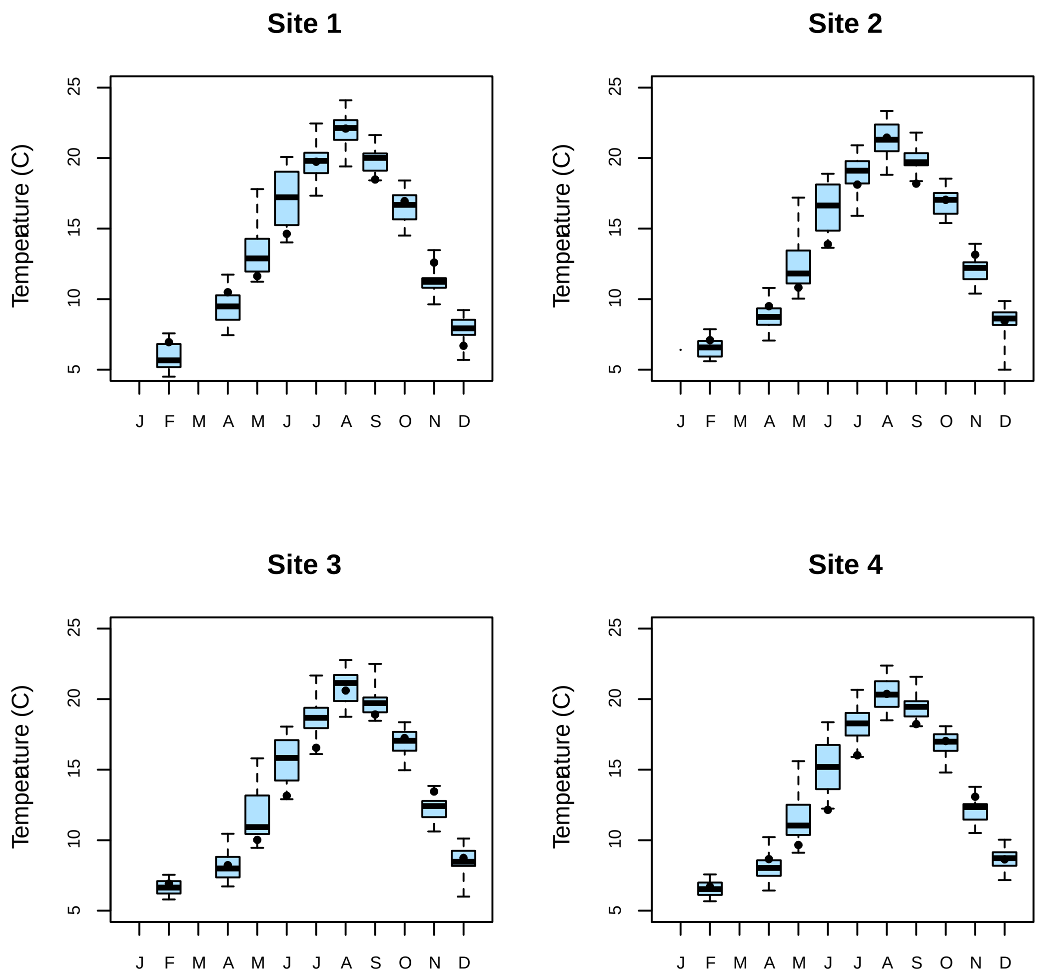


Figure 1: Boxplots showing 1988–2009 surface water temperatures (depth <1 m, all sites and years) with monthly 2010 data (●). Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

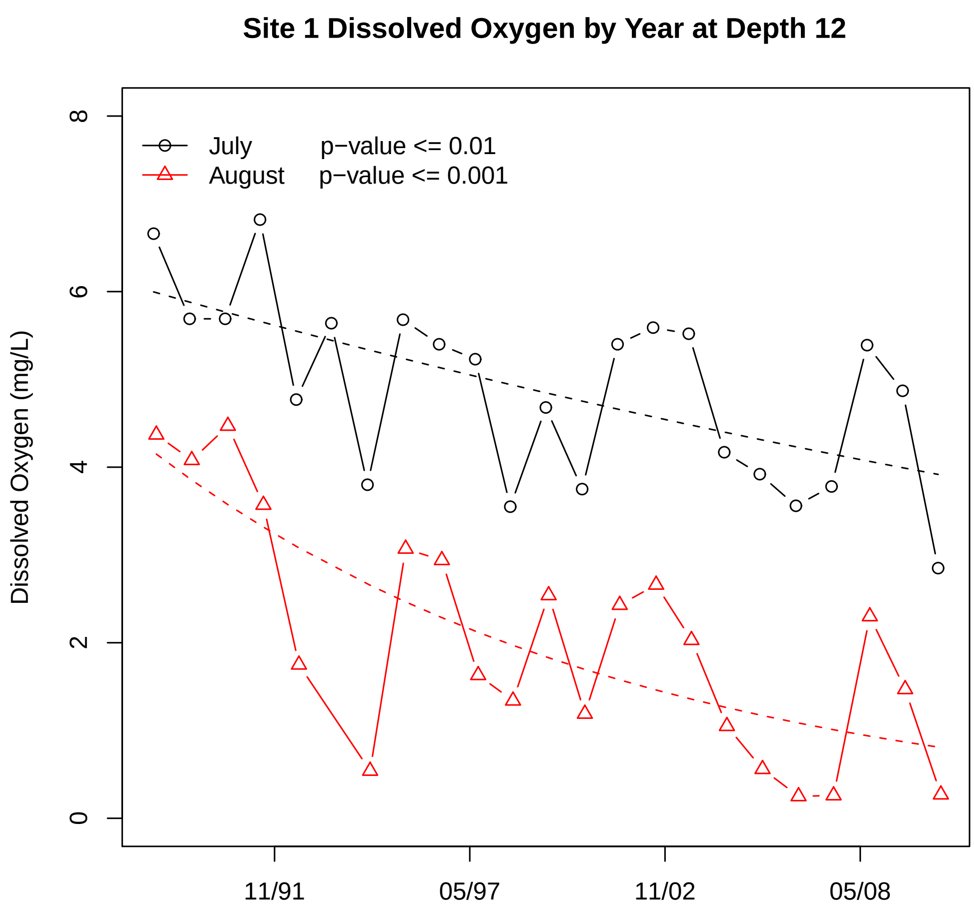


Figure 2: Nonlinear relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

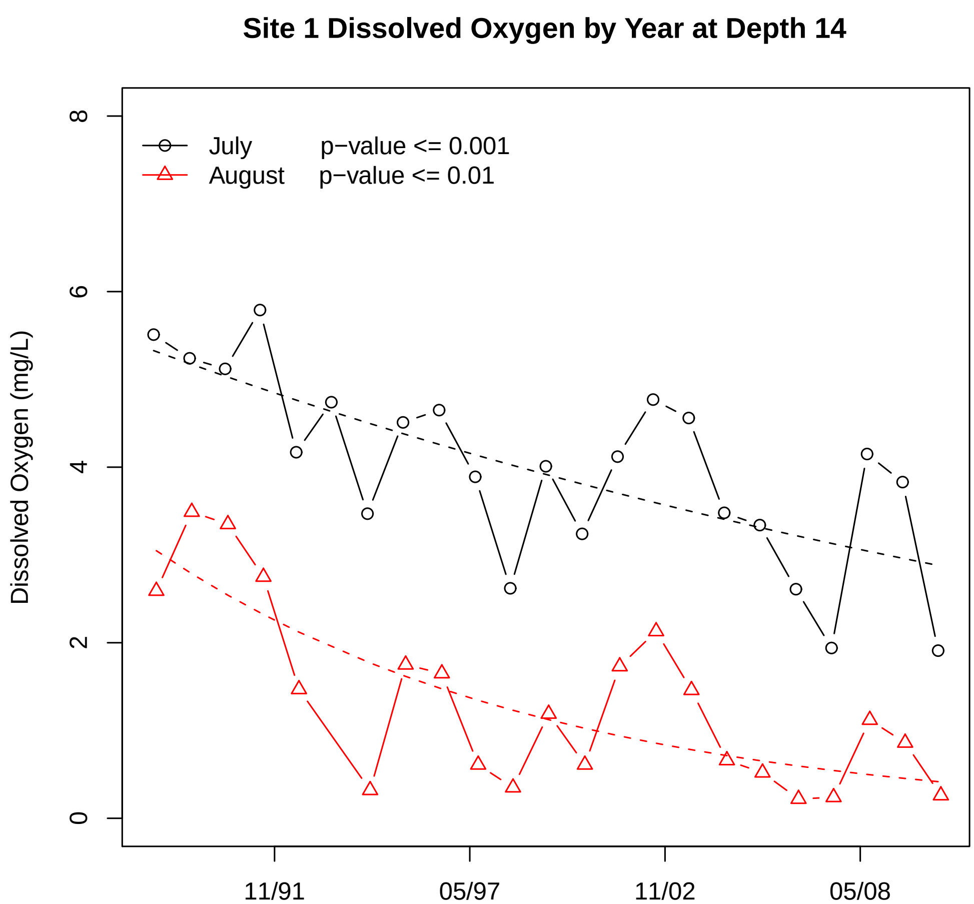


Figure 3: Nonlinear relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

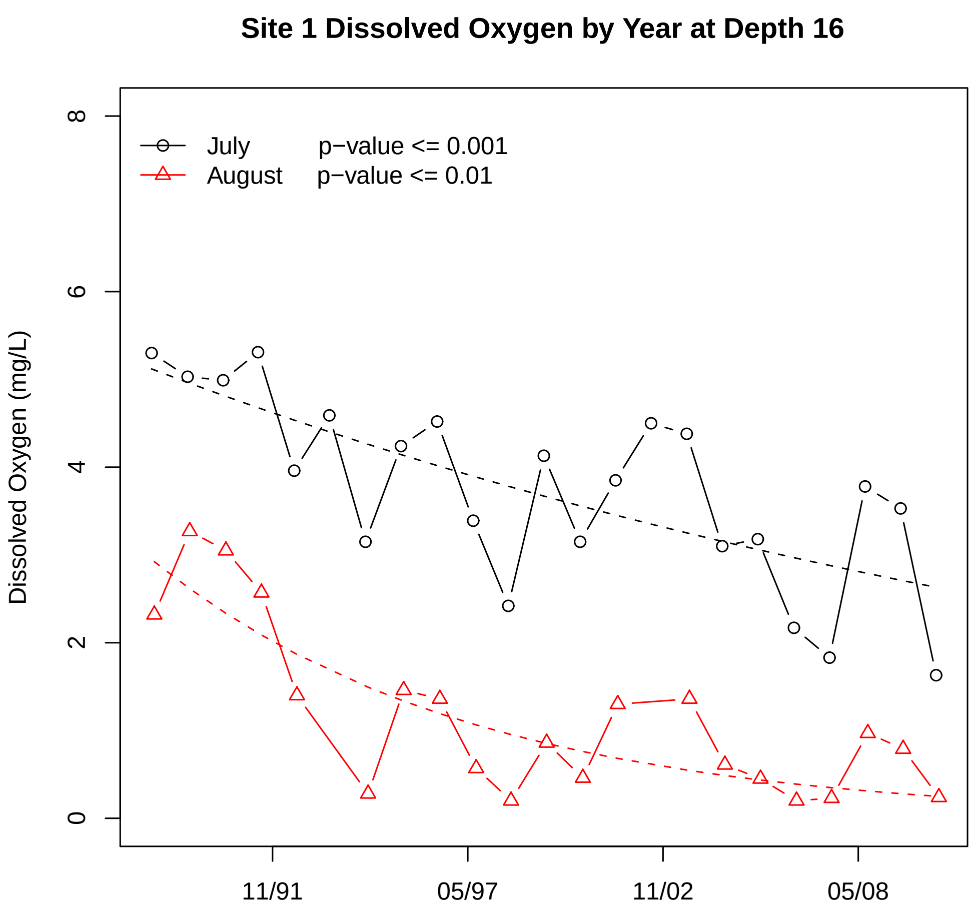


Figure 4: Nonlinear relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

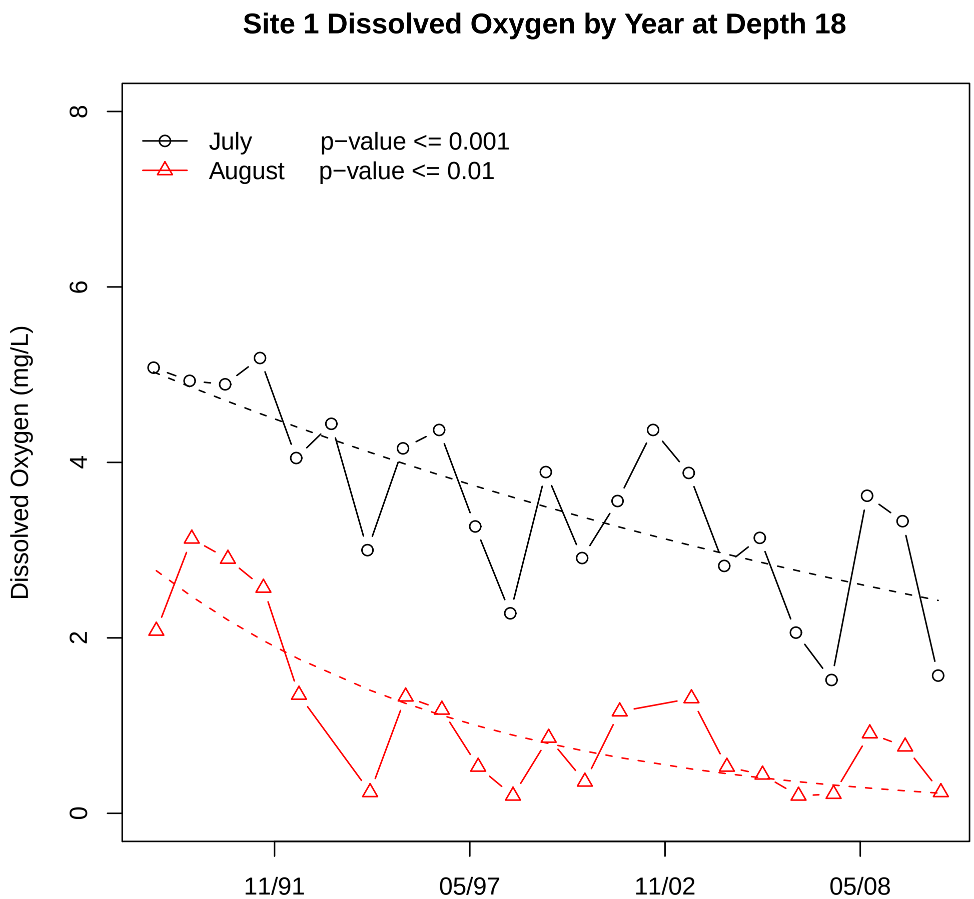


Figure 5: Nonlinear relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

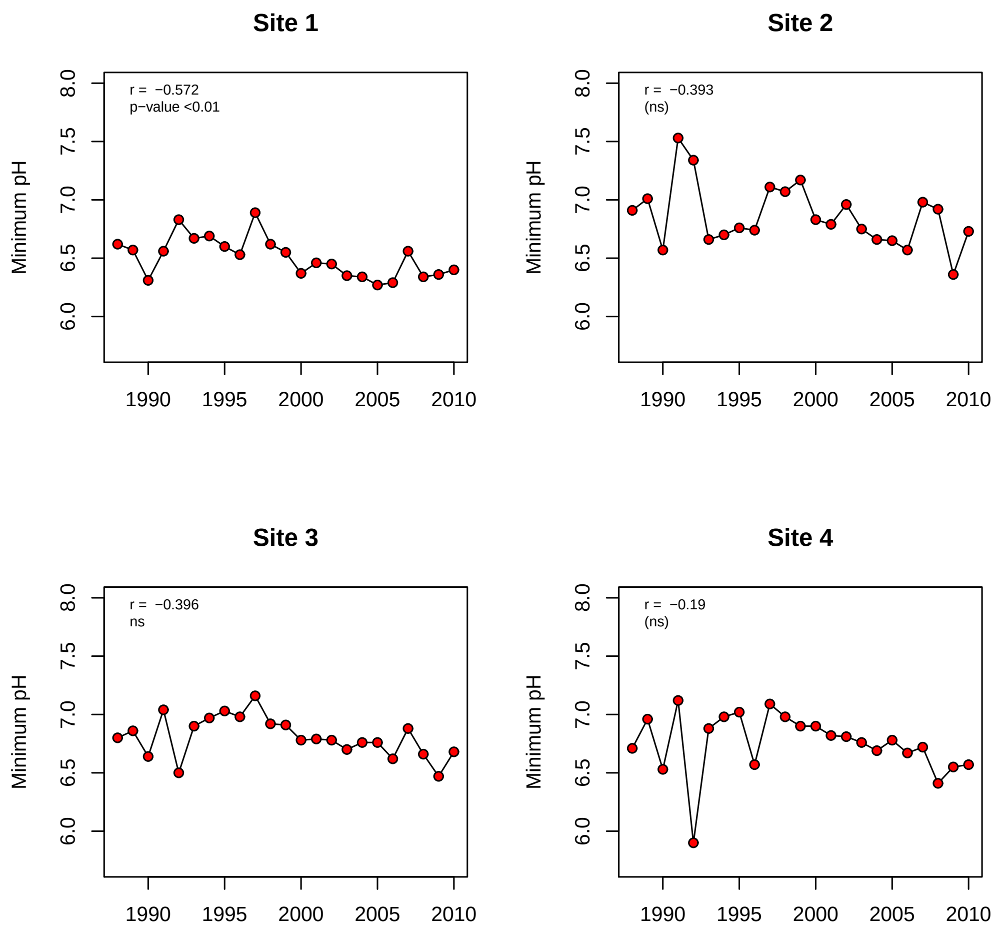


Figure 6: Correlation between minimum annual pH and year (Sites 1–2 depths <15 m; Sites 3–4 depths <65 m). Pearson's r correlations were used because the data were approximately monotonic-linear; only Site 1 correlation was significant.

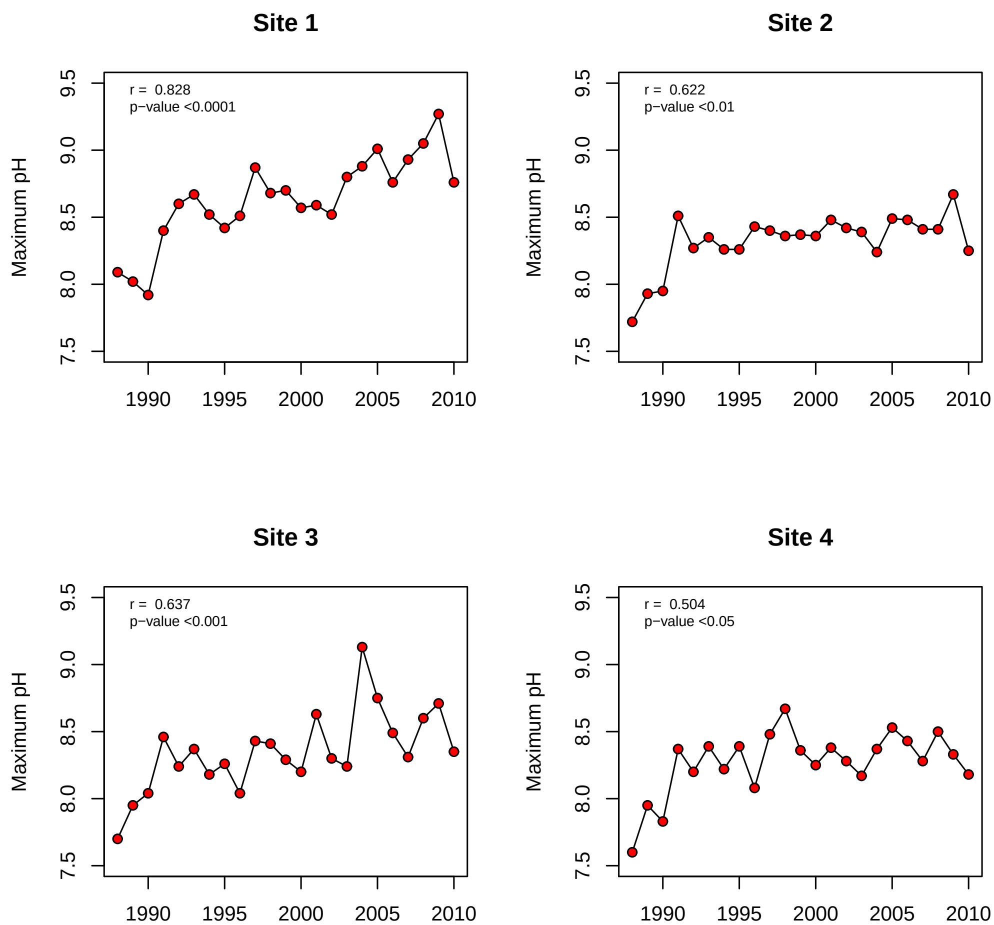


Figure 7: Correlation between maximum annual pH and year (Sites 1–2 depths <15 m; Sites 3–4 depths <65 m). Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

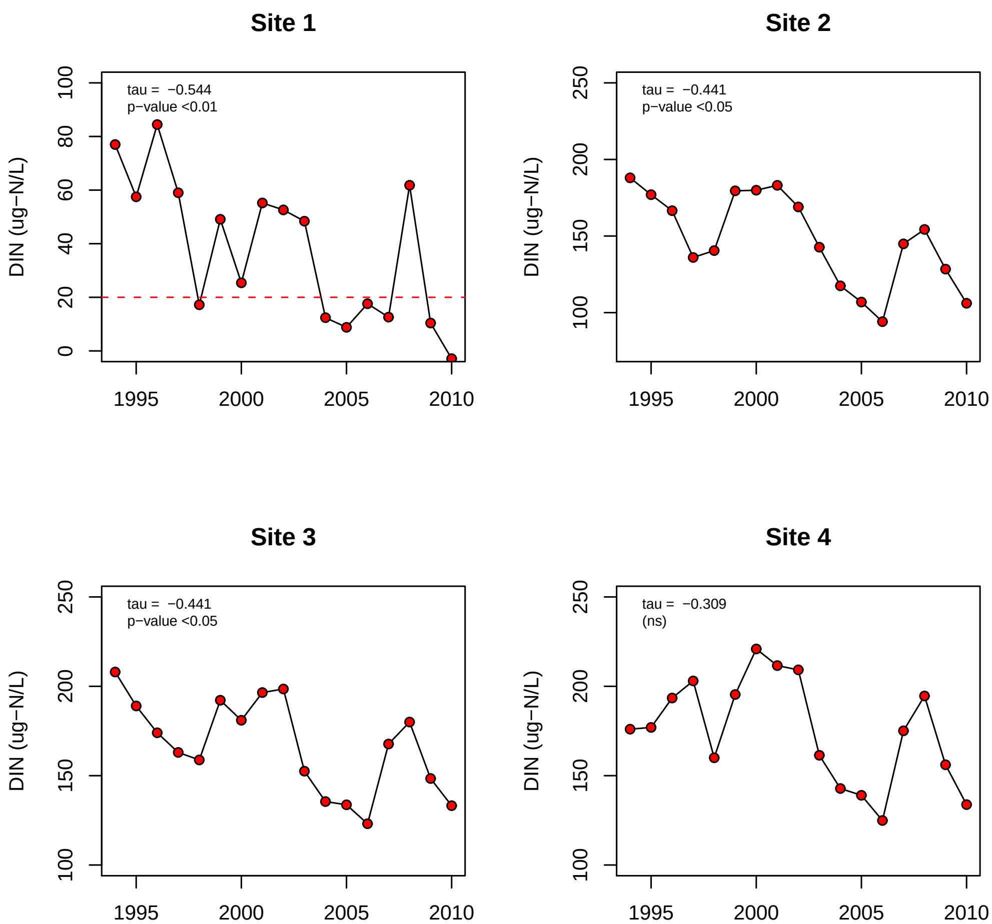


Figure 8: Minimum summer, near-surface dissolved inorganic nitrogen concentrations (1994–2010, June-Oct, depths $\leq$5 m). Uncensored (raw) data were used to illustrate that minimum values are dropping below analytical detection limits (dashed red line). Kendall's τ correlations were used because the data were not monotonic-linear; correlations were significant at Sites 1–3.

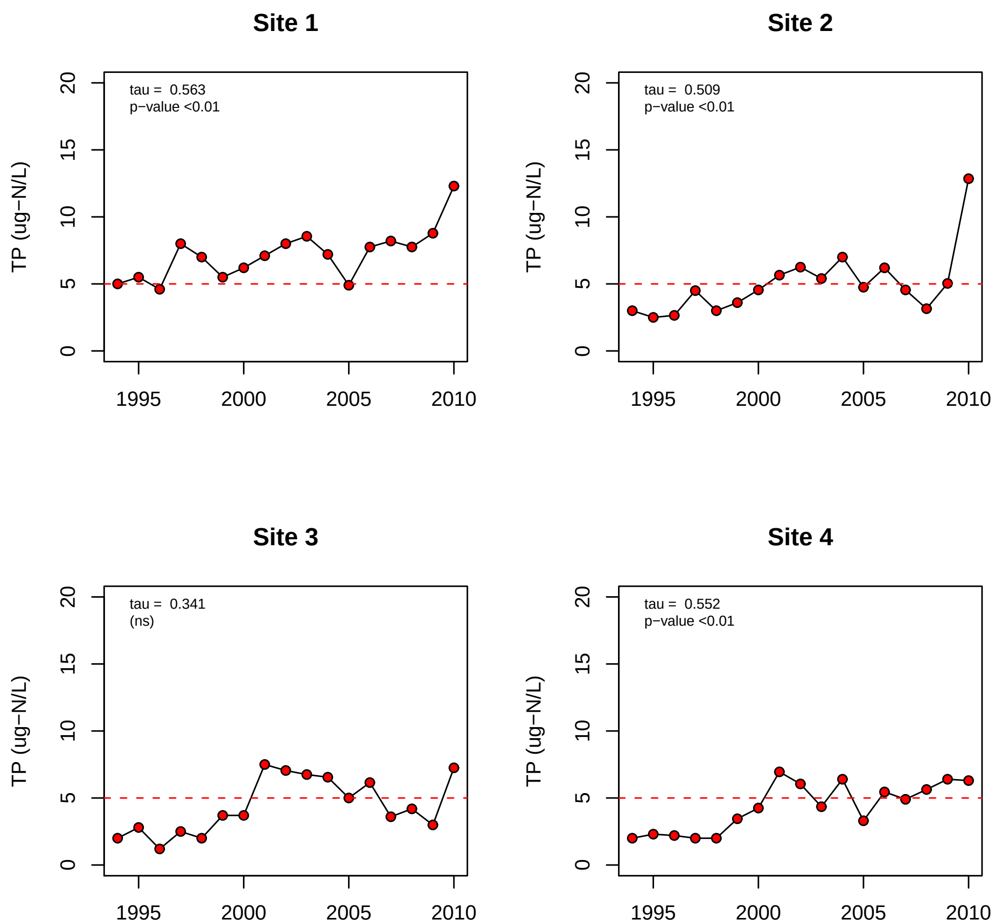


Figure 9: Median summer, near-surface total phosphorus concentrations (1994–2010, June-Oct, depths ≤5 m). Uncensored (raw) data were used to illustrate that median values are increasingly above analytical detection limits (dashed red line). Kendall's τ correlations were used because the data were not monotonic-linear; correlations were significant at Sites 1, 2, and 4.

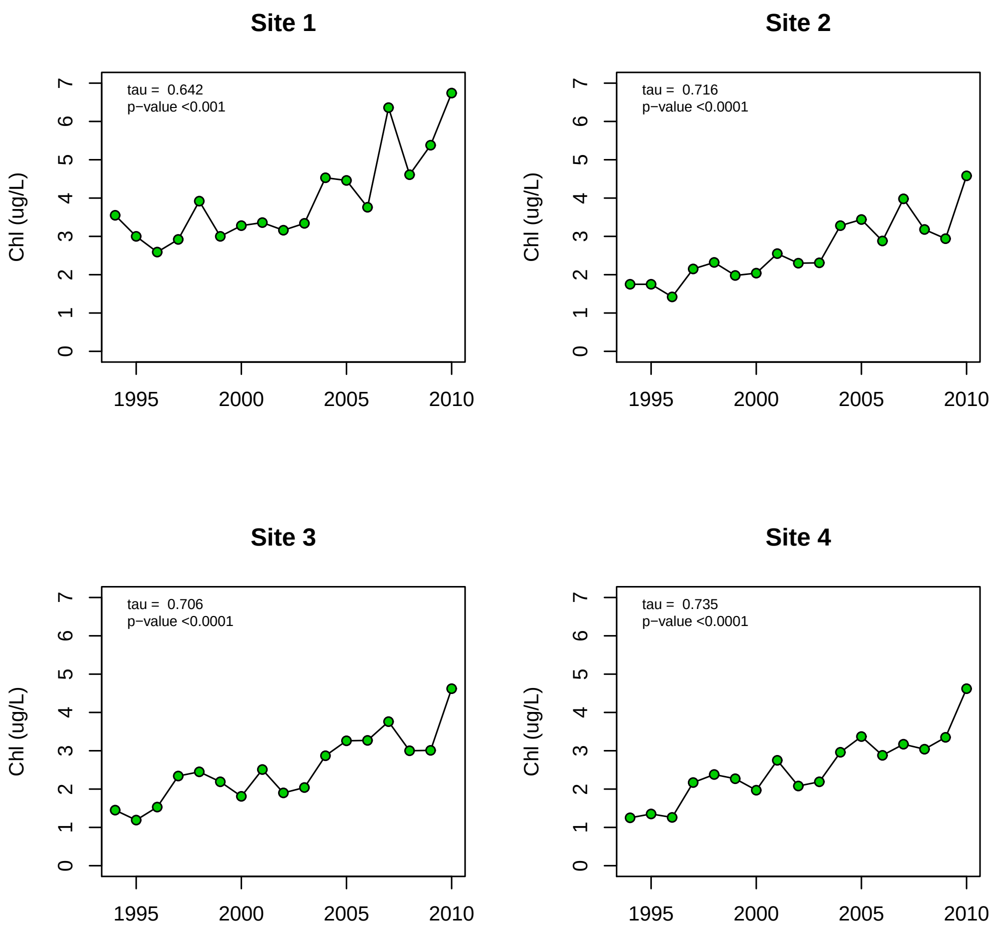


Figure 10: Median summer near-surface chlorophyll concentrations (1994–2010, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

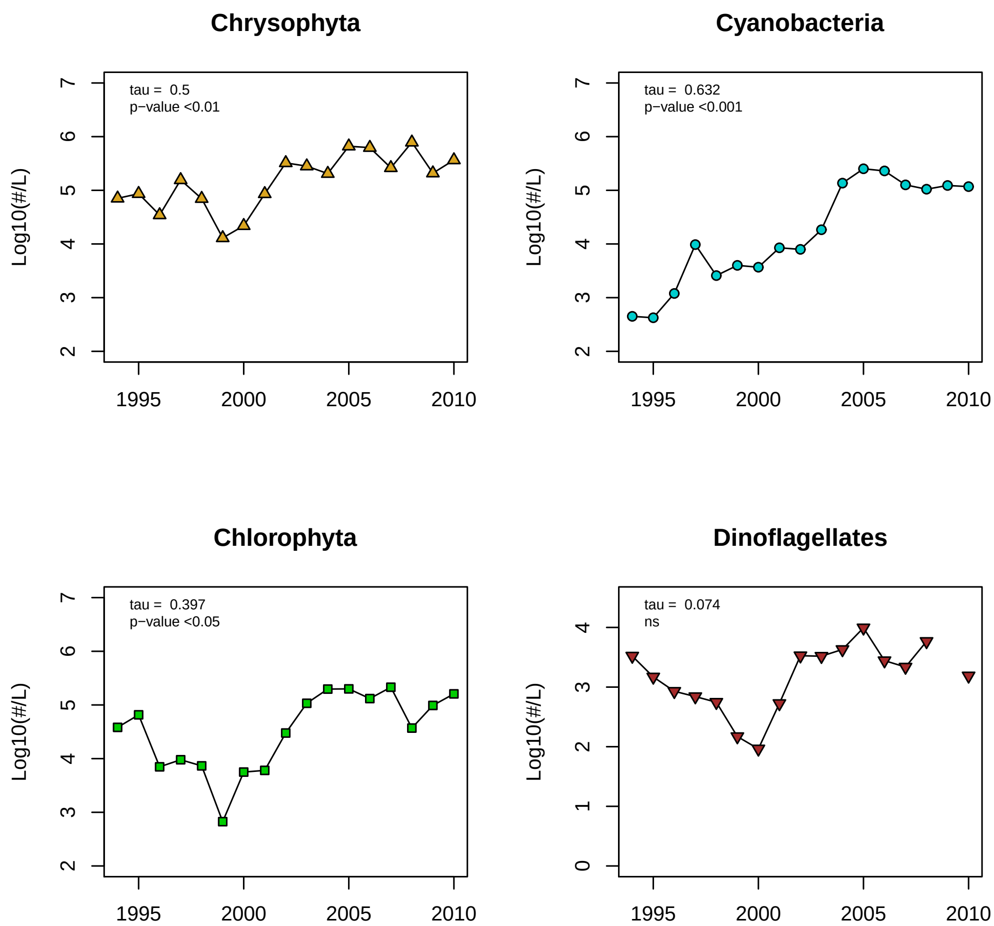


Figure 11: Log_{10} plots of median summer, near-surface algae counts (1994-2010, June-October, all sites and depths). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations except Dinoflagellates were significant.

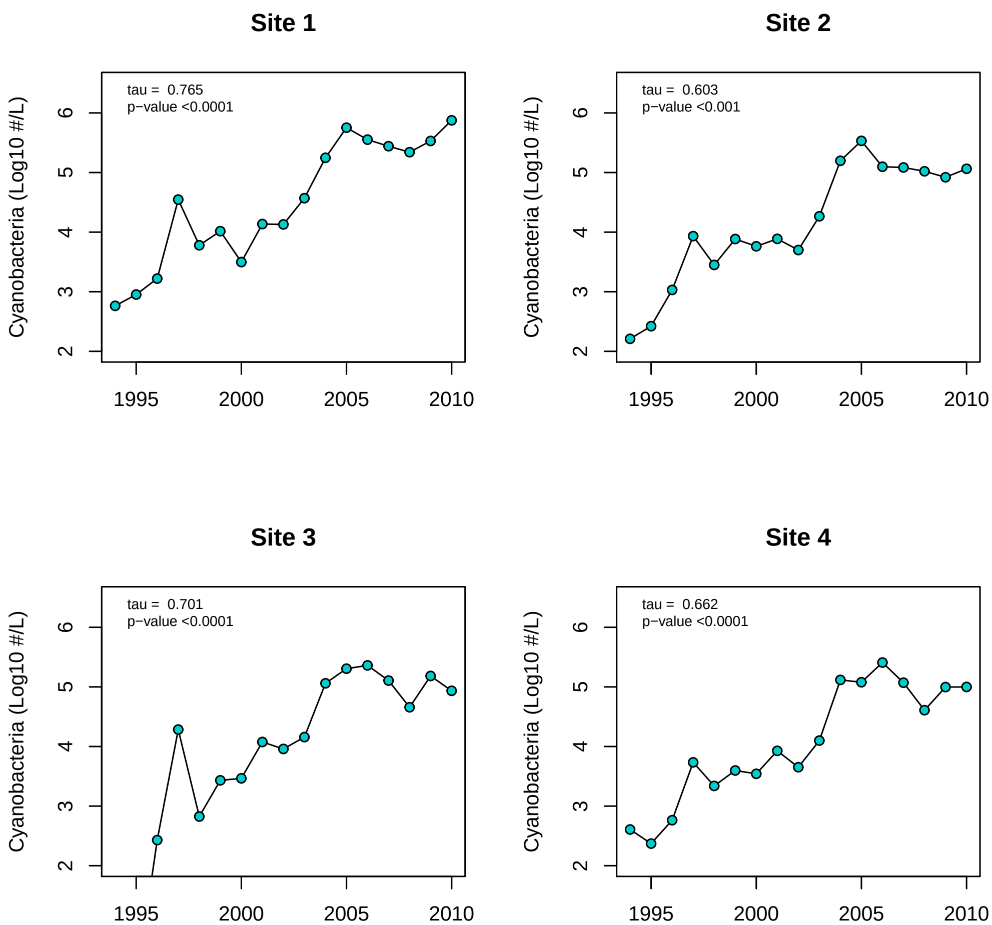


Figure 12: Log_{10} plots of median summer, near-surface Cyanobacteria counts (1994–2010, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

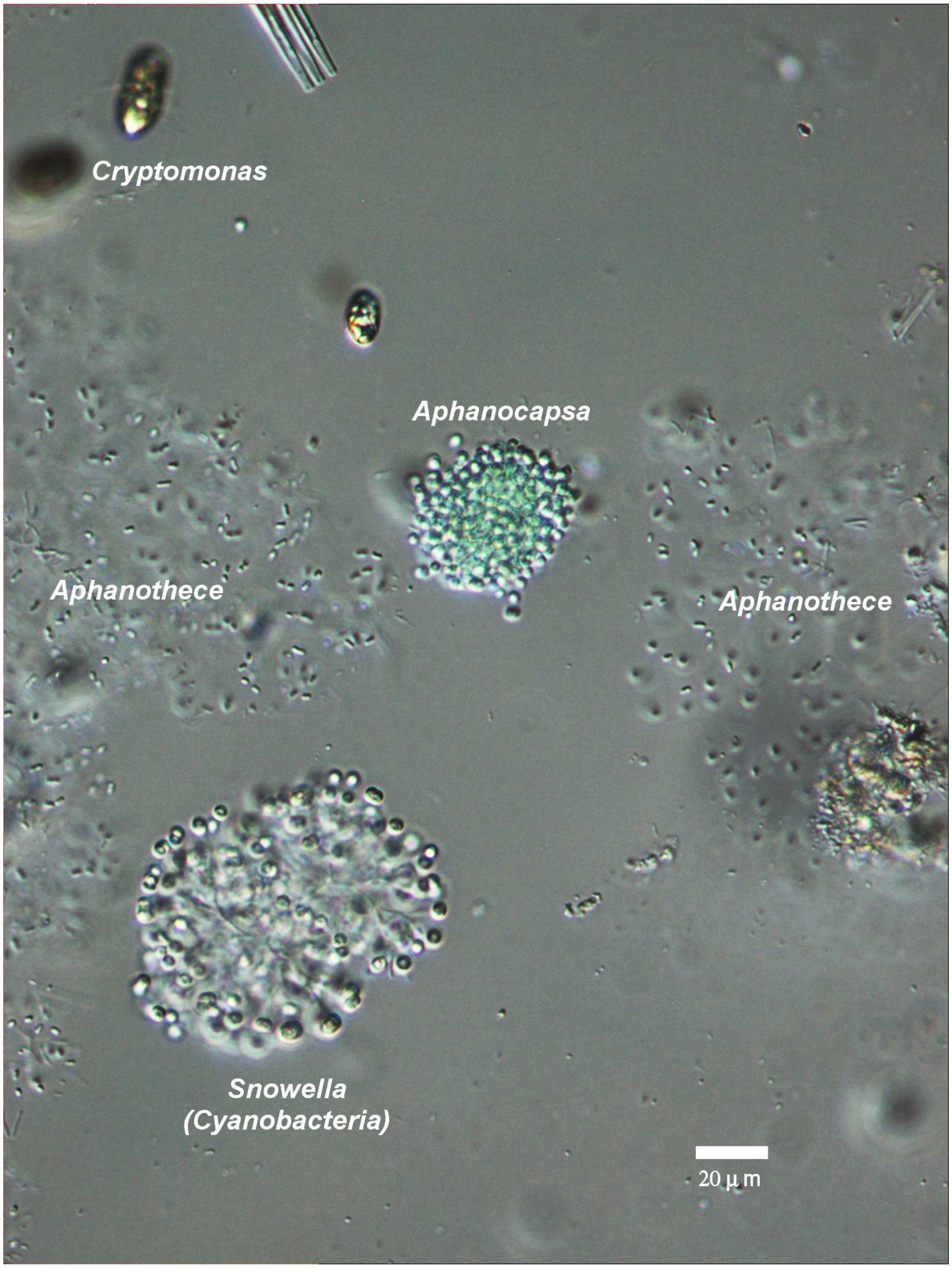


Figure 13: Lake Whatcom *Aphanocapsa* and *Aphanothece* colonies. Several other common Lake Whatcom algae taxa are also shown, including *Snowella* and *Cryptomonas*. See Tables 10–11 (pages 27–28) for a list of algae found in the lake.

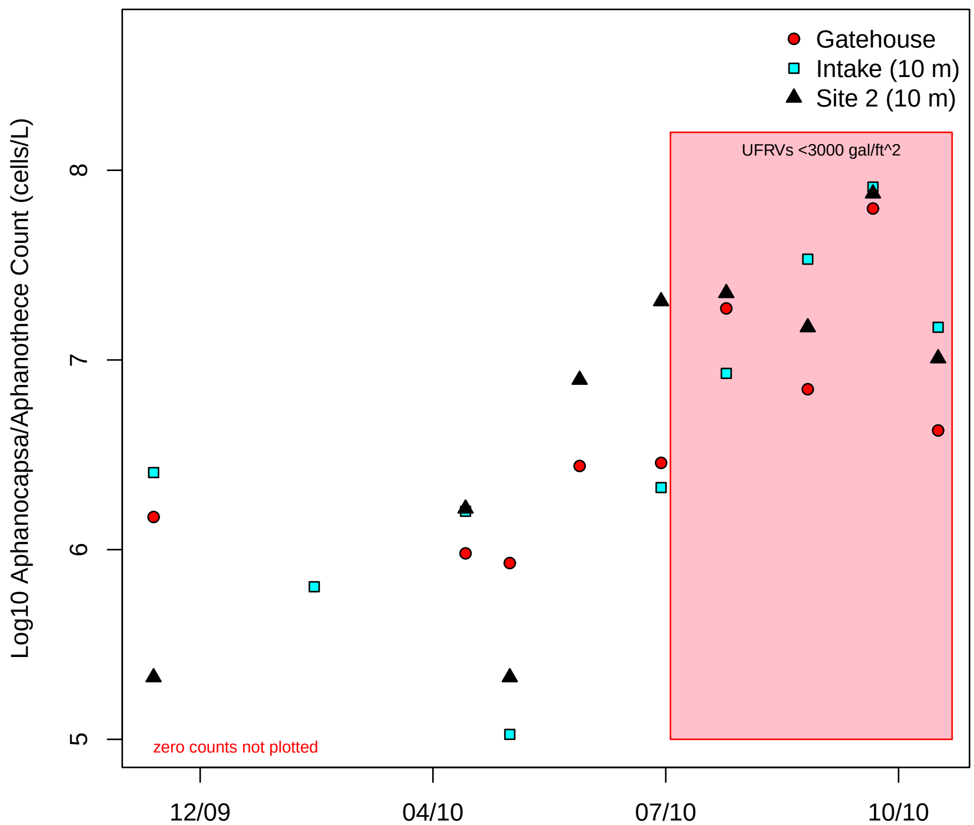


Figure 14: Log_{10} plots of *Aphanocapsa* and *Aphanothece* at the gatehouse, Intake, and Site 2, December 2009–November 2010. The shaded rectangle shows the period of very poor water filtration (see discussion on page 13).

Figure 15: *Cyclotella* cell showing extracellular fibers. See Tables 10–11 (pages 27–28) for a list of algae found in the lake.

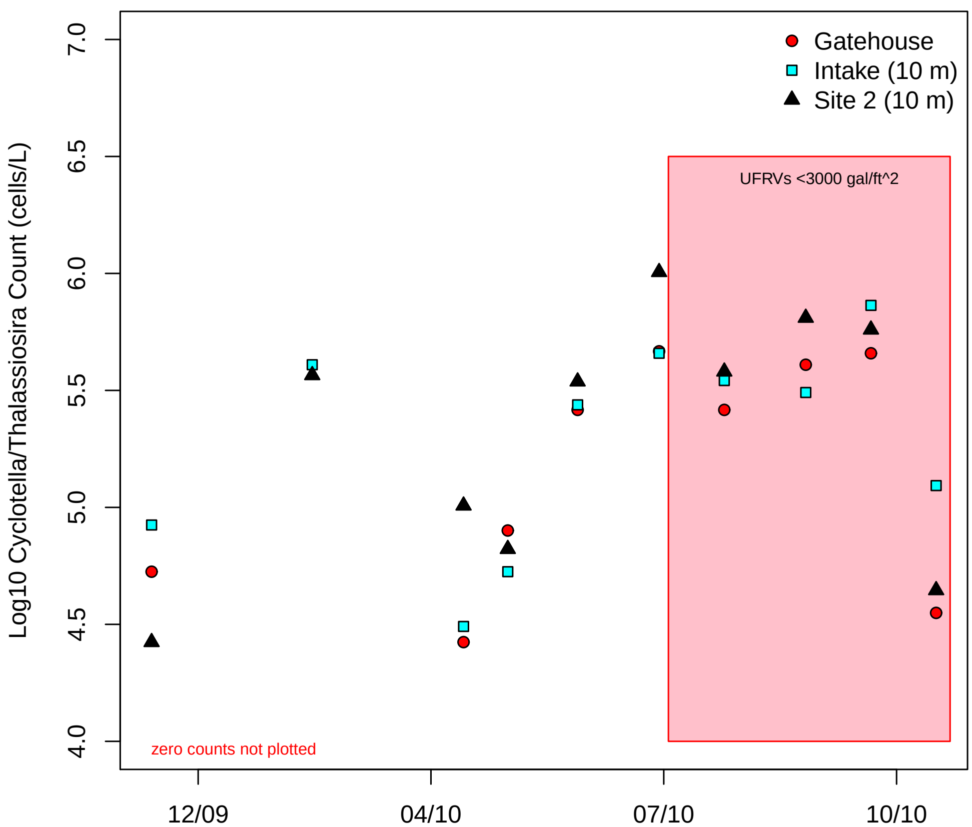


Figure 16: Log_{10} plots of *Cyclotella* and *Thalassiosira* at the gatehouse, Intake, and Site 2, December 2009–November 2010. The shaded rectangle shows the period of very poor water filtration (see discussion on page 13).

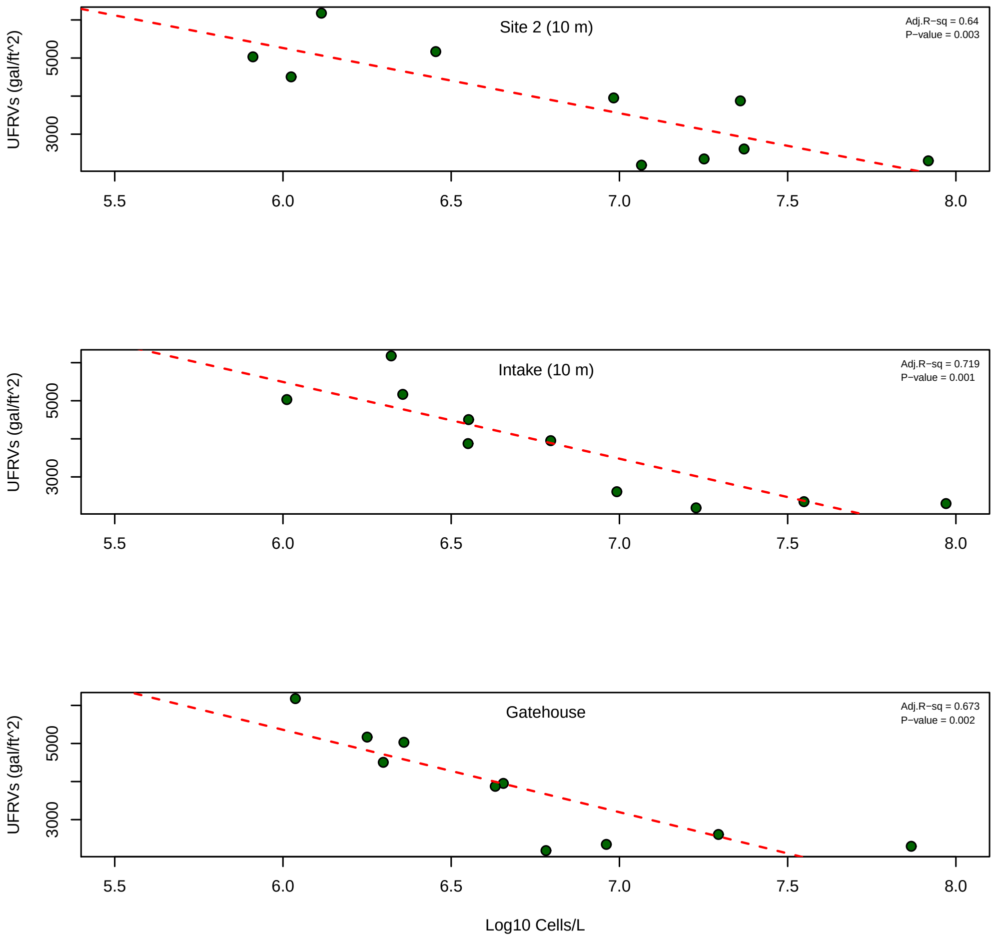


Figure 17: Regression of water production rates (UFRVs) as a function of total algae counts at the gatehouse, Intake (10 m), and Site 2 (10 m), December 2009–November 2010.

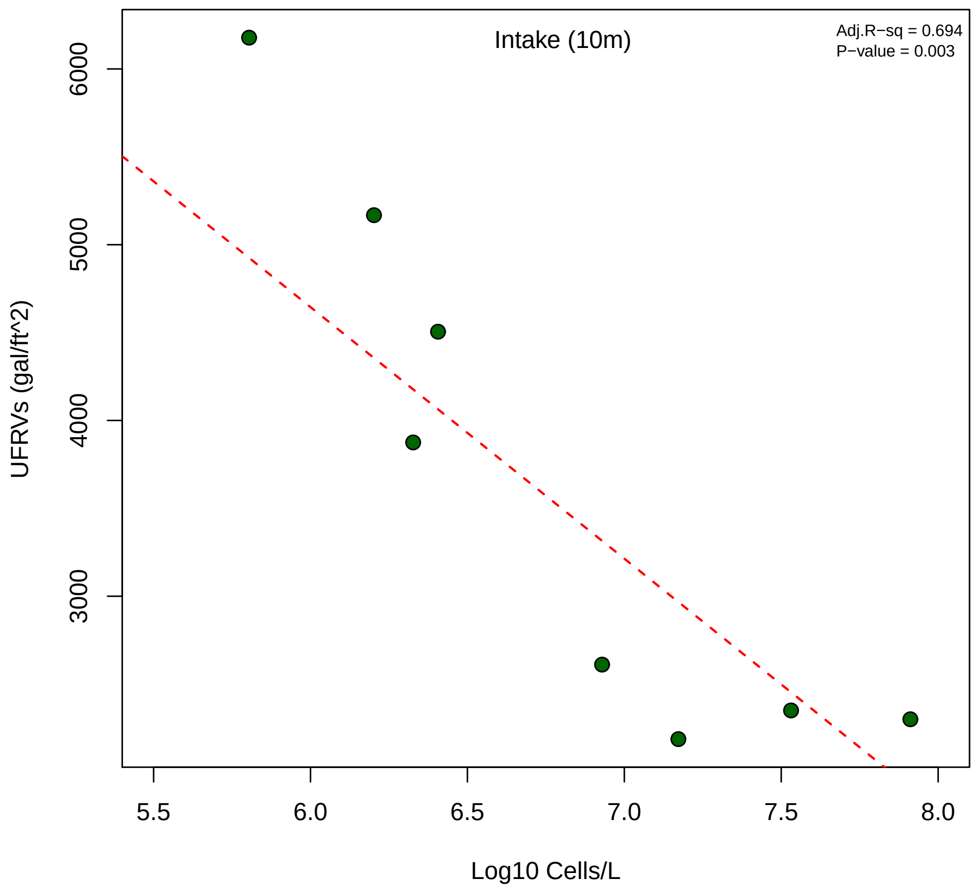


Figure 18: Regression of water production rates (UFRVs) as a function of *Aphanocapsa* and *Aphanothece* counts at the Intake (10 m), December 2009–November 2010.

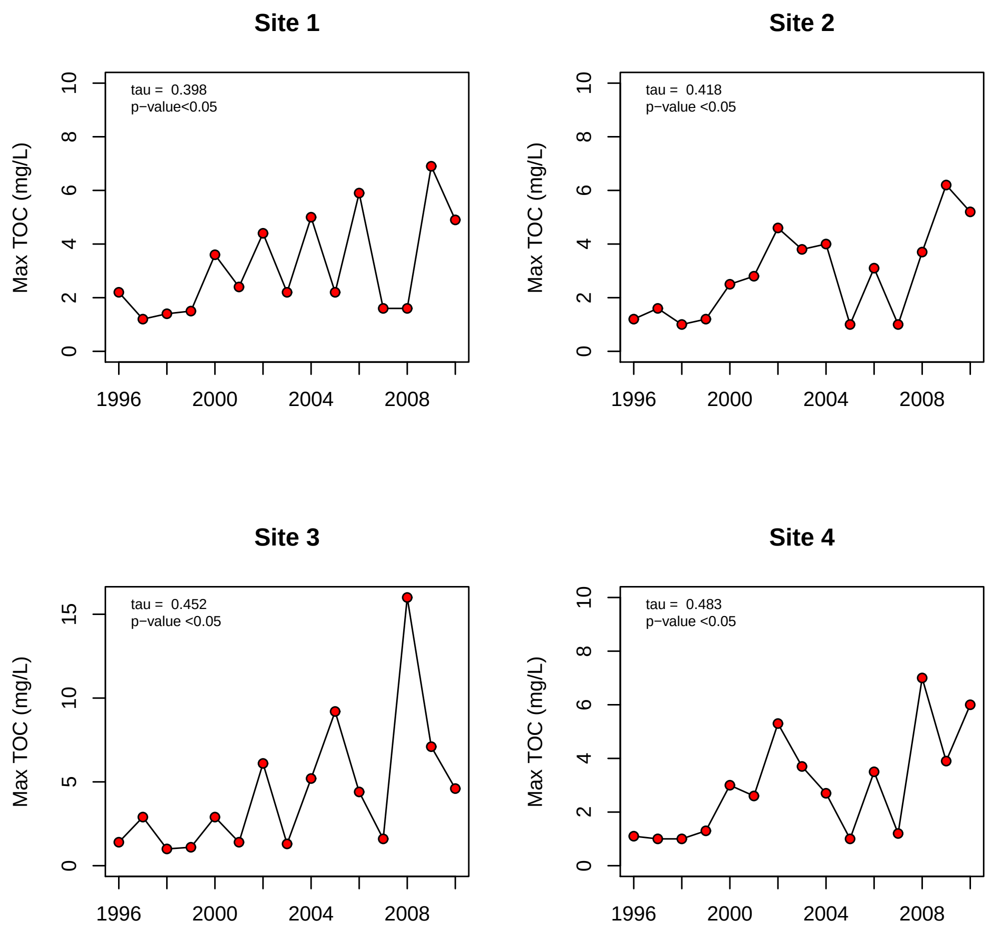


Figure 19: Maximum annual total organic carbon concentrations at Sites 1–4. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

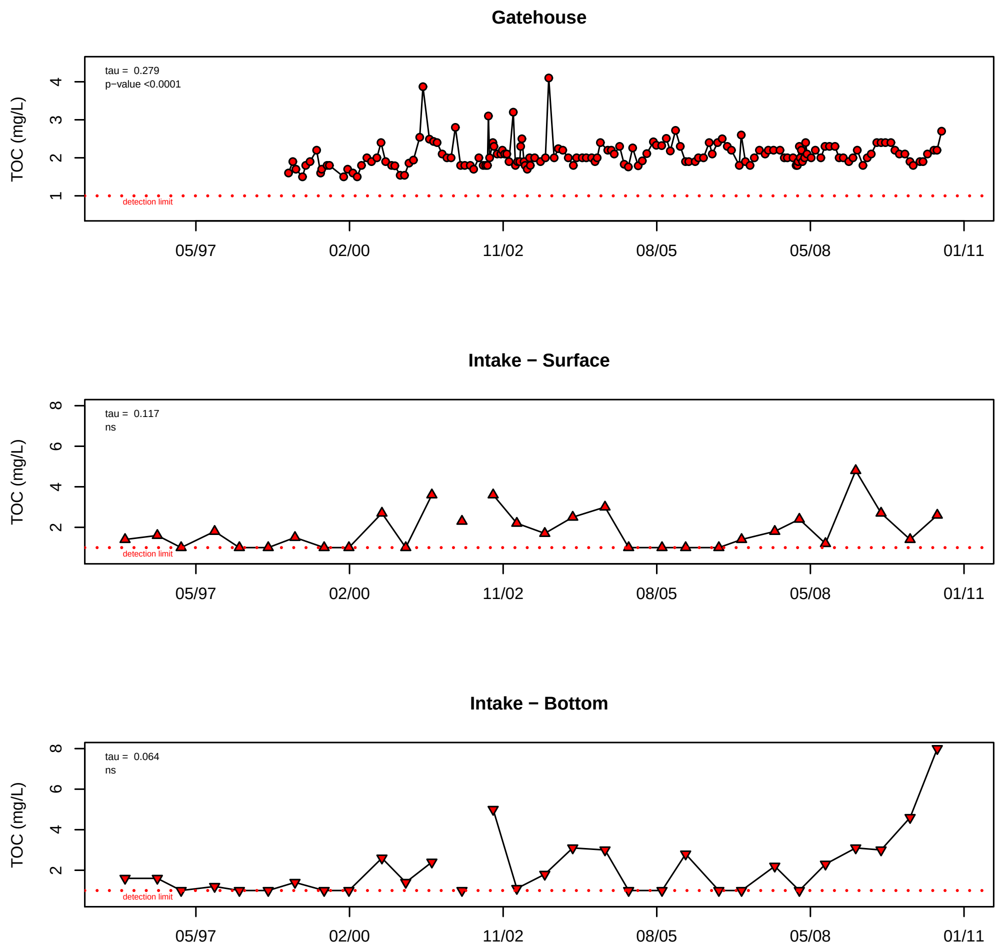


Figure 20: Total organic carbon concentrations at the Intake (off-shore, surface and bottom) and gatehouse. Gatehouse data were provided by the City of Bellingham Public Works Department. Kendall's τ correlations were used because the data were not monotonic-linear; only the gatehouse correlation was significant.

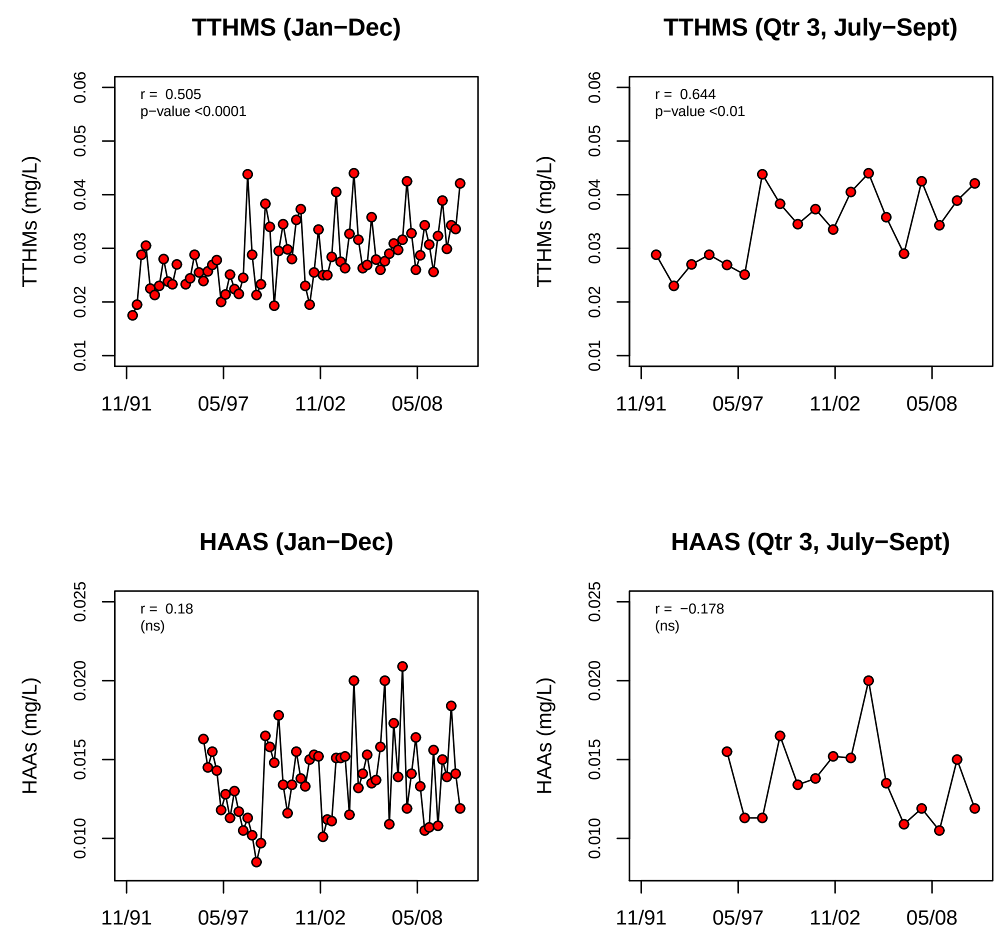


Figure 21: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2010. Data were provided by the City of Bellingham Public Works Department. Kendall's τ correlations were used because the data were not monotonic-linear; correlations 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. The level of effort was reduced from 2007–2009, with samples collected twice each year. Beginning in January 2010, monthly sampling was reinitiated, and is scheduled to continue through 2012.

3.1 Site Descriptions

Samples were collected from Anderson, Austin, Blue Canyon, Brannian, Carpenter, Euclid, Mill Wheel, Olsen, Silver Beach, Smith, and Whatcom Creeks and the Park Place drain. The sampling locations for these sites are described in Appendix A.2 and shown on Figure A2, page 118.

3.2 Field Sampling and Analytical Methods

The tributaries were sampled on January 12, February 16, March 9, April 6, May 11, June 8, July 13, August 10, September 14, and October 12, 2010.

The analytical procedures for sampling the tributaries are summarized in Table 1 (page 18). 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. Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.[17] All other analyses were done by WWU.

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

3.3 Results and Discussion

The monthly data are summarized in Tables 12–23 (pages 54–65) and the biannual metals and total organic carbon data are listed in Tables 24–25 (pages 66–67). Historic data from 2004 through the current monitoring period are plotted in Appendix B.4 (Figures B131–B169, pages 256–294). These figures include a dashed (blue) horizontal line that shows the median value for Smith Creek and a solid (red) horizontal line that shows the median value for each creek. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted.

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

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by pH levels near 6.5–7.5, conductivities $\leq$150 μS, and alkalinities $\leq$50 mg/L (Figures B137–B145). Sites that did not match this description included the residential tributaries (Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$15 mg/L) and low turbidities ($\leq$10 NTU) except during periods of high precipitation and runoff (Figures B146–B151).

Ammonia concentrations were generally low ($\leq$10 μg-N/L) except in the residential streams (Figures B152–B154). 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 B155– B160). The relatively high nitrate and total nitrogen concentrations in Smith Creek is probably due to the presence of nitrogen-fixing alders (*Alnus rubra*) in the riparian zone upstream from the sampling site. High nitrate and total nitrogen concentrations are not necessarily an indication of water pollution, and low nitrate concentrations actually favor the growth of nuisance Cyanobacteria. The exceptionally low concentrations in Whatcom Creek reflect algal uptake of nitrogen in the lake.

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

Total phosphorus concentrations were higher than soluble phosphate concentrations (Figures B161–B166). The median 2010 concentrations were $\leq$30 μg-P/L at all sites except Millwheel and Silver Beach Creeks and the Park Place drain. As with soluble phosphate, nearly all sites have had occasional high total phosphorus peaks, and high concentrations were common in samples from residential sites.

High coliform counts are an indicator of residential pollution (Figures B167–B169), and although most of the sites have low geometric mean counts in 2010, five of the sites exceeded the WAC 173–201A coliform surface water standards. Carpenter, Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain all had geometric means >50 cfu/100 mL and 50–80% of the samples exceeded 100 cfu/100 mL.

The total organic carbon concentrations were between 5–15 mg/L. Unlike 2009, there were no extremely high total organic carbon concentrations in the winter samples from February 2010 (see Matthews, et al., 2010). The 2010 winter samples were, however, slightly higher at most sites compared to July.

The metals concentrations were within expected ranges, and most were at or below detection levels (Table 24). Chromium, copper, iron, lead, and zinc were often detectable, but were within normal ranges for surface waters in the watershed.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	11.9	16.8	16.4	20.0	10
Conductivity (μS/cm)‡	49.7	57.1	56.7	61.3	10
Dissolved oxygen (mg/L)	9.5	10.9	11.1	12.5	10
pH	6.4	7.1	7.0	7.2	10
Temperature (°C)	5.1	9.9	9.7	13.6	10
Total suspended solids (mg/L)	<2	4.8	8.8	20.9	10
Turbidity (NTU)	<2	4.2	9.9	33.2	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	20.4	10
Nitrogen - nitrate/nitrite (μg-N/L)	41.4	354.5	307.3	578.4	10
Nitrogen - total (μg-N/L)	<100	471.4	450.7	812.0	9
Phosphorus - soluble (μg-P/L)	<5	6.9	6.8	10.1	10
Phosphorus - total (μg-P/L)	12.0	24.0	30.2	62.0	10
Coliforms - fecal (cfu/100 mL)§	<1	28	13	56	10
(Percent of samples >100 cfu/100 mL = 0)					

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

Table 12: Summary of Anderson Creek water quality data, Jan-Oct. 2010. The May total nitrogen result is missing due to analysis error.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	12.4	18.7	19.9	32.9	10
Conductivity (μS/cm)[‡]	49.8	63.4	71.5	119.3	9
Dissolved oxygen (mg/L)	9.3	11.3	11.2	13.5	10
pH	6.7	7.4	7.3	7.7	9
Temperature (°C)	3.8	9.3	9.6	14.1	10
Total suspended solids (mg/L)	<2	<2	3.7	14.1	10
Turbidity (NTU)	<2	<2	2.3	8.4	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	<10	10
Nitrogen - nitrate/nitrite (μg-N/L)	226.8	517.0	489.0	984.5	10
Nitrogen - total (μg-N/L)	283.9	627.2	602.9	1124.4	10
Phosphorus - soluble (μg-P/L)	5.5	8.5	9.1	13.4	10
Phosphorus - total (μg-P/L)	5.4	15.1	14.9	24.5	10
Coliforms - fecal (cfu/100 mL)[§]	<1	45	25	140	10
(Percent of samples $>$100 cfu/100 mL = 10)					

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

Table 13: Summary of Austin Creek water quality data, Jan-Oct. 2010. The October conductivity and pH results are missing due to analysis error.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	103.5	136.0	134.7	157.9	10
Conductivity (μS/cm)‡	243.0	286.5	284.4	310.0	10
Dissolved oxygen (mg/L)	9.9	11.4	11.5	13.0	10
pH	7.9	8.2	8.2	8.4	10
Temperature (°C)	5.0	9.9	9.9	13.3	10
Total suspended solids (mg/L)	<2	3.2	3.4	5.6	10
Turbidity (NTU)	<2	2.1	2.1	4.0	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	<10	10
Nitrogen - nitrate/nitrite (μg-N/L)	121.0	286.0	356.6	962.6	10
Nitrogen - total (μg-N/L)	148.4	363.1	425.4	1137.9	10
Phosphorus - soluble (μg-P/L)	<5	9.3	8.9	11.4	10
Phosphorus - total (μg-P/L)	<5	13.8	13.3	24.5	10
Coliforms - fecal (cfu/100 mL)§	<1	5	5	75	10
(Percent of samples $>$100 cfu/100 mL = 0)					

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

Table 14: Summary of Blue Canyon Creek water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	6.9	10.3	12.1	20.8	10
Conductivity (μS/cm)[‡]	36.0	38.0	42.6	57.9	10
Dissolved oxygen (mg/L)	7.3	10.9	10.4	12.7	10
pH	6.5	6.9	6.8	7.1	10
Temperature (°C)	5.0	9.7	9.8	13.7	10
Total suspended solids (mg/L)	<2	<2	2.4	9.5	10
Turbidity (NTU)	<2	<2	<2	6.4	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	<10	10
Nitrogen - nitrate/nitrite (μg-N/L)	134.6	494.7	421.1	749.3	10
Nitrogen - total (μg-N/L)	236.0	613.3	542.4	803.9	10
Phosphorus - soluble (μg-P/L)	<5	<5	<5	6.2	10
Phosphorus - total (μg-P/L)	<5	12.3	11.8	22.3	10
Coliforms - fecal (cfu/100 mL)[§]	1	15	12	49	10
(Percent of samples $>$100 cfu/100 mL = 0)					

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

Table 15: Summary of Brannian Creek water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	12.0	23.6	27.6	47.0	10
Conductivity (μS/cm)[‡]	51.1	69.2	78.1	115.1	10
Dissolved oxygen (mg/L)	7.9	10.6	10.5	12.4	10
pH	6.7	7.5	7.4	7.7	10
Temperature (°C)	5.2	11.5	10.8	15.9	10
Total suspended solids (mg/L)	<2	2.1	3.8	13.8	10
Turbidity (NTU)	<2	2.4	3.5	10.7	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	<10	10
Nitrogen - nitrate/nitrite (μg-N/L)	304.9	556.0	564.0	1001.9	10
Nitrogen - total (μg-N/L)	418.1	709.2	746.1	1134.2	10
Phosphorus - soluble (μg-P/L)	<5	10.3	11.7	20.6	10
Phosphorus - total (μg-P/L)	9.2	19.4	19.6	29.3	10
Coliforms - fecal (cfu/100 mL)[§]	24	87	107	1800	10
(Percent of samples $>$100 cfu/100 mL = 50)					

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

Table 16: Summary of Carpenter Creek water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	19.5	33.8	40.1	58.3	10
Conductivity (μS/cm)[‡]	71.1	91.6	106.2	146.4	10
Dissolved oxygen (mg/L)	7.5	10.4	10.1	12.4	10
pH	6.8	7.4	7.3	7.5	10
Temperature (°C)	5.4	10.7	10.5	14.4	10
Total suspended solids (mg/L)	<2	2.9	4.0	13.1	10
Turbidity (NTU)	<2	3.1	3.8	9.7	10
Nitrogen - ammonium (μg-N/L)	<10	11.7	12.6	23.6	10
Nitrogen - nitrate/nitrite (μg-N/L)	143.5	398.3	400.2	716.0	10
Nitrogen - total (μg-N/L)	276.7	557.2	575.8	907.0	10
Phosphorus - soluble (μg-P/L)	7.9	13.3	12.8	15.6	10
Phosphorus - total (μg-P/L)	16.1	25.8	24.8	32.9	10
Coliforms - fecal (cfu/100 mL)[§]	14	205	142	450	10
(Percent of samples $>$100 cfu/100 mL = 80)					

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

Table 17: Summary of Euclid Creek water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	23.1	34.3	37.9	59.7	8
Conductivity (μS/cm)‡	77.7	90.8	98.7	140.0	8
Dissolved oxygen (mg/L)	7.3	10.8	10.6	12.5	8
pH	6.7	7.4	7.4	8.0	8
Temperature (°C)	5.4	10.8	11.3	17.5	8
Total suspended solids (mg/L)	3.6	5.8	9.2	27.6	8
Turbidity (NTU)	6.0	9.5	10.5	24.1	8
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	13.6	8
Nitrogen - nitrate/nitrite (μg-N/L)	<20	465.4	428.1	900.2	8
Nitrogen - total (μg-N/L)	506.0	969.0	1015.1	1968.7	8
Phosphorus - soluble (μg-P/L)	7.1	9.9	9.7	11.8	8
Phosphorus - total (μg-P/L)	28.6	37.2	67.7	217.2	8
Coliforms - fecal (cfu/100 mL)§	40	185	224	2500	8
(Percent of samples >100 cfu/100 mL = 75)					

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

Table 18: Summary of Millwheel Creek water quality data, Jan-Oct. 2010. Millwheel Creek had negligible flow on July 13 and August 10, 2010; no water quality samples were collected on these dates.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	11.4	20.1	22.4	42.6	10
Conductivity (μS/cm)[‡]	47.5	62.1	69.4	115.8	10
Dissolved oxygen (mg/L)	9.5	11.0	11.1	12.7	10
pH	6.8	7.4	7.4	7.8	10
Temperature (°C)	5.0	10.4	10.1	14.6	10
Total suspended solids (mg/L)	<2	2.5	8.0	49.2	10
Turbidity (NTU)	<2	<2	5.0	31.6	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	<10	10
Nitrogen - nitrate/nitrite (μg-N/L)	475.1	834.5	828.6	1462.3	10
Nitrogen - total (μg-N/L)	522.0	932.2	920.5	1563.8	10
Phosphorus - soluble (μg-P/L)	6.6	10.3	11.0	18.4	10
Phosphorus - total (μg-P/L)	9.4	14.5	15.4	22.7	10
Coliforms - fecal (cfu/100 mL)[§]	1	4	7	160	10
(Percent of samples $>$100 cfu/100 mL = 10)					

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

Table 19: Summary of Olsen Creek water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	26.8	89.0	84.7	120.2	10
Conductivity (μS/cm)[‡]	159.5	215.0	213.5	272.0	10
Dissolved oxygen (mg/L)	7.1	9.1	9.1	11.4	10
pH	7.0	7.5	7.5	7.8	10
Temperature (°C)	7.2	13.8	13.2	19.1	10
Total suspended solids (mg/L)	<2	<2	2.6	5.1	10
Turbidity (NTU)	<2	3.8	4.3	8.7	10
Nitrogen - ammonium (μg-N/L)	<10	30.6	45.0	111.6	10
Nitrogen - nitrate/nitrite (μg-N/L)	186.5	496.7	540.7	998.8	10
Nitrogen - total (μg-N/L)	568.0	783.0	826.4	1204.5	10
Phosphorus - soluble (μg-P/L)	13.9	23.0	23.8	33.9	10
Phosphorus - total (μg-P/L)	28.3	38.7	43.5	68.4	10
Coliforms - fecal (cfu/100 mL)[§]	29	145	126	440	10
(Percent of samples $>$100 cfu/100 mL = 80)					

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

Table 20: Summary of Park Place drain water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	36.0	75.3	79.4	127.4	10
Conductivity (μS/cm)‡	106.9	178.1	192.1	291.0	10
Dissolved oxygen (mg/L)	8.4	10.0	10.3	12.4	10
pH	7.2	7.9	7.9	8.3	10
Temperature (°C)	5.7	12.8	11.6	15.2	10
Total suspended solids (mg/L)	<2	2.8	4.2	8.2	10
Turbidity (NTU)	<2	3.8	5.0	11.1	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	12.2	10
Nitrogen - nitrate/nitrite (μg-N/L)	293.8	419.2	467.0	830.1	10
Nitrogen - total (μg-N/L)	548.0	691.1	743.7	1140.1	10
Phosphorus - soluble (μg-P/L)	11.3	17.5	19.0	29.8	10
Phosphorus - total (μg-P/L)	20.0	31.6	31.5	40.9	10
Coliforms - fecal (cfu/100 mL)§	49	165	213	1000	10
(Percent of samples >100 cfu/100 mL = 80)					

†Uncensored arithmetic means except coliforms(geometric mean);
§Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 21: Summary of Silver Beach Creek water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean[†]	Max.	N
Alkalinity (mg/L $CaCO_3$)	11.8	17.2	18.6	29.9	10
Conductivity (μS/cm)[‡]	46.1	55.8	59.8	85.7	10
Dissolved oxygen (mg/L)	9.3	11.3	11.3	12.9	10
pH	6.8	7.3	7.3	7.6	10
Temperature (°C)	4.5	10.1	9.9	14.7	10
Total suspended solids (mg/L)	<2	<2	2.0	5.6	10
Turbidity (NTU)	<2	<2	<2	2.7	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	10.2	10
Nitrogen - nitrate/nitrite (μg-N/L)	351.7	809.5	810.4	1516.2	10
Nitrogen - total (μg-N/L)	378.9	910.5	893.0	1646.6	10
Phosphorus - soluble (μg-P/L)	<5	8.0	8.9	15.1	10
Phosphorus - total (μg-P/L)	5.2	11.5	13.4	32.4	10
Coliforms - fecal (cfu/100 mL)[§]	1	6	7	180	10
(Percent of samples $>$100 cfu/100 mL = 10)					

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

Table 22: Summary of Smith Creek water quality data, Jan-Oct. 2010.

Variable	Min.	Med.	Mean†	Max.	N
Alkalinity (mg/L $CaCO_3$)	20.6	21.5	22.3	25.9	10
Conductivity (μS/cm)‡	60.3	62.5	65.1	73.6	10
Dissolved oxygen (mg/L)	8.1	10.0	10.0	12.1	10
pH	7.1	7.4	7.4	7.7	10
Temperature (°C)	7.0	15.5	14.1	20.8	10
Total suspended solids (mg/L)	<2	<2	2.0	4.4	10
Turbidity (NTU)	<2	<2	<2	<2	10
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	13.8	10
Nitrogen - nitrate/nitrite (μg-N/L)	<20	164.0	148.6	317.0	10
Nitrogen - total (μg-N/L)	215.9	359.3	340.0	447.7	10
Phosphorus - soluble (μg-P/L)	<5	<5	<5	<5	10
Phosphorus - total (μg-P/L)	<5	11.3	10.6	18.0	10
Coliforms - fecal (cfu/100 mL)§	1	10	8	68	10
(Percent of samples $>$100 cfu/100 mL = 0)					

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

Table 23: Summary of Whatcom Creek water quality data, Jan-Oct. 2010.

	Date	T. As (mg/L)	T. Cd (mg/L)	T. Cr (mg/L)	T. Cu (mg/L)	T. Fe (mg/L)	T. Hg (mg/L)	T. Ni (mg/L)	T. Pb (mg/L)	T. Zn (mg/L)
Anderson	Feb 16, 2010	<0.01	<0.0005	<0.001	0.002	0.432	<0.01	<0.005	<0.001	0.001
Austin (lower)	Feb 16, 2010	<0.01	<0.0005	0.001	0.002	0.510	<0.01	<0.005	<0.001	0.003
Blue Canyon	Feb 16, 2010	<0.01	<0.0005	<0.001	<0.001	0.096	<0.01	<0.005	<0.001	0.005
Brannian	Feb 16, 2010	<0.01	<0.0005	0.001	0.001	0.317	<0.01	<0.005	<0.001	0.003
Carpenter	Feb 16, 2010	<0.01	<0.0005	0.001	0.002	0.370	<0.01	<0.005	<0.001	<0.001
Euclid	Feb 16, 2010	<0.01	<0.0005	<0.001	0.001	0.315	<0.01	<0.005	<0.001	0.002
Millwheel	Feb 16, 2010	<0.01	<0.0005	0.001	0.002	0.633	<0.01	<0.005	<0.001	0.007
Olsen	Feb 16, 2010	<0.01	<0.0005	0.001	0.002	0.385	<0.01	<0.005	<0.001	<0.001
Park Place	Feb 16, 2010	<0.01	<0.0005	<0.001	0.003	0.470	<0.01	<0.005	<0.001	0.011
Silver Beach	Feb 16, 2010	<0.01	<0.0005	<0.001	0.002	0.597	<0.01	<0.005	<0.001	0.002
Smith	Feb 16, 2010	<0.01	<0.0005	<0.001	<0.001	0.093	<0.01	<0.005	<0.001	<0.001
Whatcom	Feb 16, 2010	<0.01	<0.0005	<0.001	<0.001	0.162	<0.01	<0.005	<0.001	0.002
Anderson	Jul 13, 2010	<0.01	<0.0005	0.001	0.002	0.361	<0.0001	<0.005	0.001	0.003
Austin (lower)	Jul 13, 2010	<0.01	<0.0005	<0.001	0.001	0.190	<0.0001	<0.005	0.001	0.003
Blue Canyon	Jul 13, 2010	<0.01	<0.0005	0.002	<0.001	0.088	<0.0001	<0.005	0.001	0.006
Brannian	Jul 13, 2010	<0.01	<0.0005	<0.001	0.001	0.433	<0.0001	<0.005	0.002	0.004
Carpenter	Jul 13, 2010	<0.01	<0.0005	<0.001	0.002	0.160	<0.0001	<0.005	0.001	0.003
Euclid	Jul 13, 2010	<0.01	<0.0005	<0.001	0.002	0.450	<0.0001	<0.005	<0.001	0.003
Millwheel† Jul 13, 2010	NA	NA	NA	NA	NA	NA	NA	NA	NA	
Olsen	Jul 13, 2010	<0.01	<0.0005	0.001	0.002	0.064	<0.0001	<0.005	0.001	0.003
Park Place	Jul 13, 2010	<0.01	<0.0005	<0.001	0.003	0.580	<0.0001	<0.005	0.001	0.005
Silver Beach	Jul 13, 2010	<0.01	<0.0005	<0.001	0.002	0.209	<0.0001	<0.005	0.001	0.004
Smith	Jul 13, 2010	<0.01	<0.0005	0.001	0.002	0.018	<0.0001	<0.005	0.001	0.003
Whatcom	Jul 13, 2010	<0.01	<0.0005	0.002	0.002	0.070	<0.0001	<0.005	0.001	0.004

†Insufficient flow to sample.

Table 24: 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.wwu.edu/iws). This parameter is sampled twice each year.

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Anderson	Feb 16, 2010	9.7	Jul 13, 2010	2.4
Austin (lower)	Feb 16, 2010	14.0	Jul 13, 2010	7.1
Blue Canyon	Feb 16, 2010	14.0	Jul 13, 2010	11.0
Brannian	Feb 16, 2010	4.6	Jul 13, 2010	4.5
Carpenter	Feb 16, 2010	7.5	Jul 13, 2010	4.8
Euclid	Feb 16, 2010	7.5	Jul 13, 2010	3.0
Millwheel	Feb 16, 2010	6.4	Jul 13, 2010	NA†
Olsen	Feb 16, 2010	7.6	Jul 13, 2010	3.0
Park Place	Feb 16, 2010	13.0	Jul 13, 2010	9.5
Silver Beach	Feb 16, 2010	13.0	Jul 13, 2010	8.3
Smith	Feb 16, 2010	4.5	Jul 13, 2010	2.8
Whatcom	Feb 16, 2010	5.1	Jul 13, 2010	8.0

†Insufficient flow to sample.

Table 25: Lake Whatcom tributary data: total organic carbon. This parameter is sampled twice each year.

4 Lake Whatcom Hydrology

4.1 Hydrograph Data

Recording hydrographs are installed in Austin Creek and Smith Creek; the data are plotted in Figures 22–23 (pages 75–76). The location of each hydrograph is described in Appendix A.2. All hydrograph data, including data from previous years, are online at http://www.wwu.edu/iws. Detailed field notes 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 24–25 (pages 77–78) 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. The rating curves in Figures 24–25 were used for the current water year; rating curves for earlier water years are available from the Institute for Watershed Studies.

4.2 Water Budget

A water balance was applied to Lake Whatcom to identify major water inputs and outputs and to examine runoff and storage. The traditional method of estimating a water balance was employed, where inputs - outputs = change in storage (Table 26, page 72). Inputs into the lake include direct precipitation, runoff (surface runoff + groundwater), and water diverted from the Middle Fork of the Nooksack River. Outputs include evaporation, Whatcom Creek, the Whatcom Falls Fish Hatchery, City of Bellingham, Puget Sound Energy Co-Generation Plant [18], and the Lake Whatcom Water and Sewer District.[19] 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.

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

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 (Mitchell et al., 2010). The rating curve accounts for changes in surface area of the lake due to lake level changes. The average annual direct rainfall to the lake for the water year 2009/2010 was 54.6 inches (7,350 MG). This is the highest yearly rainfall recorded in the last 5 years.

Daily diversion volumes were estimated using a hydrograph separation technique based on hourly discharge data from the Anderson Creek USGS stream gauge (USGS 12201950). Fifteen minute provisional data were acquired from the USGS and processed into hourly data. The hourly data were compared to the outfall valve log-sheet provided by the City of Bellingham. The log-sheet documents the dates and times that the diversion was operating and the valve opening percent. These dates and times were located on the hydrograph. A baseflow was manually estimated and removed from the hydrograph. The remaining volume was used to estimate a daily volume discharging to the lake from the diversion. Approximately 860 MG were diverted into the lake between June and September.

Daily lake evaporation was estimated using a model based on the Penman method (Dingman, 1994). The Penman method is theoretically based model that estimates free-water evaporation using both energy-balance and mass transfer concepts. The method requires daily average incident solar radiation, air temperature, dew point temperature, and wind speed. Hourly data from the North Shore weather station in the watershed were used to estimate daily averages. The daily evaporation depths (inches) predicted by the model were converted to volumes (MG) via a rating curve generated from the lake level-area data developed by Mitchell et al. (2010). The estimated yearly evaporation from the lake is 19.2 inches (2,592 MG), 88% of which occurred between April and September.

Daily change in storage was determined by subtracting each day's lake level by the subsequent day's level. This resulted in negative values when the lake level was decreasing and positive values when the lake level was increasing. The change in storage magnitudes are sensitive to the accuracy of the lake level measurements; small lake level changes correspond to large lake volumes. The daily net change in lake level (inches) was converted to a volume (MG) via a rating curve generated from the lake level-volume data developed by Mitchell et al. (2010). The rating curve accounts for changes in volume of the lake due to lake level changes. The median total lake volume in 2009/2010 was 252,074 MG. Figure 26 (page 79) shows daily lake-volume values for the past five years. There was a spike in lake volume when the lake rose from a level of 312.0 feet on January 4, to 315.0 feet on January 9, 2009 due to a 6.3 inch storm event. 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 and diversion volumes. Negative values of runoff estimated from the water budget are likely due to noise in the change in storage estimates or may represent a loss of lake water to deep aquifer systems. The 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 27–30 (pages 80–83). Figure 27 shows 7-day summed totals for inputs, outputs, and change in storage. All the inputs except runoff are shown in Figure 28; all outputs except Whatcom Creek are shown in Figure 29. Due to their much higher magnitude, runoff and Whatcom Creek data are included on Figure 30.

Yearly water balance totals are listed in Table 26 (page 72) along with data from four previous water years. The total volume of outputs in WY2010 were 11.7% 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 8.5 year residence time.[20] Tables 27 and 28 (pages 73–74) show the 2009/2010 total input and output volumes along with the corresponding monthly percentage of each total.

[20]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.

	WY2010 (9/30/09–10/1/10)	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)
Inputs (MG)*					
Direct Precipitation	7,350 (23.7%)	5,712 (17.7%)	6,006 (16.7%)	7,063 (18.2%)	6,783 (17.9%)
Diversion	860 (2.8%)	0 (0%)	4,902 (13.7%)	2,920 (7.5%)	4,155 (11.0%)
Runoff	22,762 (73.5%)	26,491 (82.3%)	24,989 (69.6%)	28,717 (74.2%)	26,879 (71.1%)
Total	30,973 (100%)	32,203 (100%)	35,896 (100%)	38,700 (100%)	37,817 (100%)
Outputs (MG%)					
Whatcom Creek	22,311 (75.4%)	26,598 (77.5%)	25,793 (76.1%)	30,359 (77.1%)	28,290 (74.8%)
Hatchery	875 (3.0%)	856 (2.5%)	931 (2.7%)	1,002 (2.5%)	1,253 (3.3%)
Puget Sound Co-Gen	51 (0.2%)	4 (0.01%)	240 (0.7%)	807 (2.0%)	960 (2.5%)
City of Bellingham	3,522 (11.9%)	3,886 (11.3%)	3,874 (11.4%)	4,145 (10.5%)	4,111 (10.9%)
LW Water/Sewer Distr.	239 (0.8%)	250 (0.7%)	237 (0.7%)	232 (0.6%)	242 (0.6%)
Evaporation	2,592 (8.8%)	2,723 (7.9%)	2,807 (8.3%)	2,831 (7.2%)	2,946 (7.8%)
Total	29,589 (100%)	34,317 (100%)	33,883 (100%)	39,376 (100%)	37,802 (100%)
Net change in storage	1,384	-2,115	2,033	-520	15
Median lake volume (MG)	252,074	252,433	253,003	252,759	252,287
Outflow percent of volume	11.7%	13.6	13.4%	15.6%	15.0%
Residence time (years)**	8.5	7.4	7.5	6.4	6.7

*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 26: Annual water balance quantities for the Lake Whatcom watershed, WY2006–WY2010.

	Input Percents*			
Month	Diversion	Precipitation	Runoff	Total
Oct	0.00	15.59	3.16	0.87
Nov	0.00	20.54	28.81	12.76
Dec	0.00	4.18	5.20	9.93
Jan	0.00	12.11	18.20	41.52
Feb	0.00	5.76	4.54	3.79
Mar	0.61	8.48	9.10	9.60
Apr	0.00	7.90	9.17	11.28
May	0.00	8.67	12.14	9.95
Jun	14.71	4.33	7.07	1.23
Jul	20.01	0.22	0.67	0.76
Aug	33.68	1.89	-2.08	-0.77
Sep	30.98	10.33	4.03	-0.92
	Input Volume (MG)			
Total	860	7,350	22,762	26,491

*Runoff = surface runoff + groundwater;

Table 27: Monthly input water balance quantities for the Lake Whatcom watershed, October 2009–September 2010.

Month	WC	Hatch	PSE	COB	WSD	Evap	Total
	Output Percents†						
Oct	6.90	5.76	9.75	8.17	8.27	3.57	6.74
Nov	30.36	5.85	4.29	7.44	8.67	0.40	24.06
Dec	12.91	8.78	14.63	7.07	9.79	0.33	10.97
Jan	21.37	9.72	1.84	7.04	8.93	0.25	17.33
Feb	2.35	8.84	1.90	6.88	6.96	1.77	3.07
Mar	0.86	10.34	0.90	6.96	7.62	5.20	2.30
Apr	0.83	6.68	6.81	7.04	7.42	10.41	2.65
May	10.13	4.99	4.47	8.12	7.74	13.64	10.02
Jun	9.24	7.30	0.33	7.96	7.38	15.91	9.58
Jul	2.00	10.80	12.74	12.74	10.13	23.95	5.55
Aug	1.26	10.66	29.72	12.19	9.60	17.03	4.34
Sep	1.78	10.28	12.62	8.41	7.49	7.54	3.39
	Output Volume (MG)						
Total	22,311	875	51	3,522	239	2,592	29,589

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

Table 28: Monthly output water balance quantities for the Lake Whatcom watershed, October 2009–September 2010.

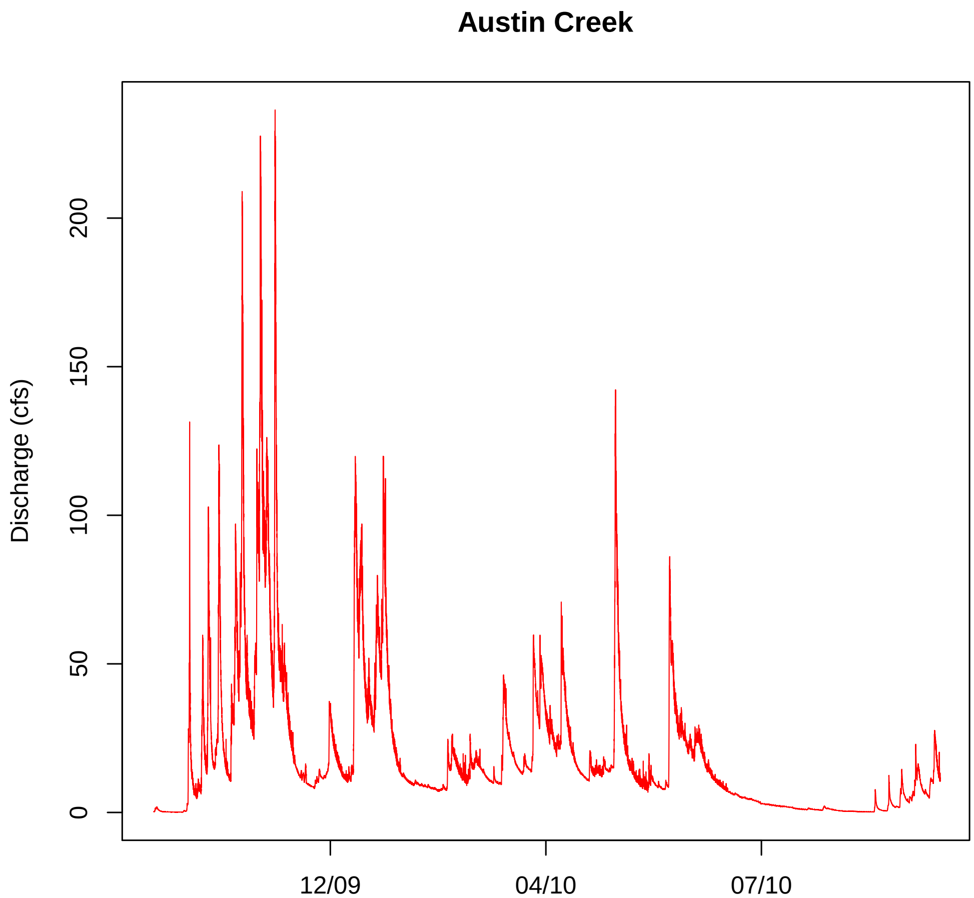


Figure 22: Austin Creek hydrograph, October 1, 2009–September 30, 2010. Data were recorded at 15 minute intervals.

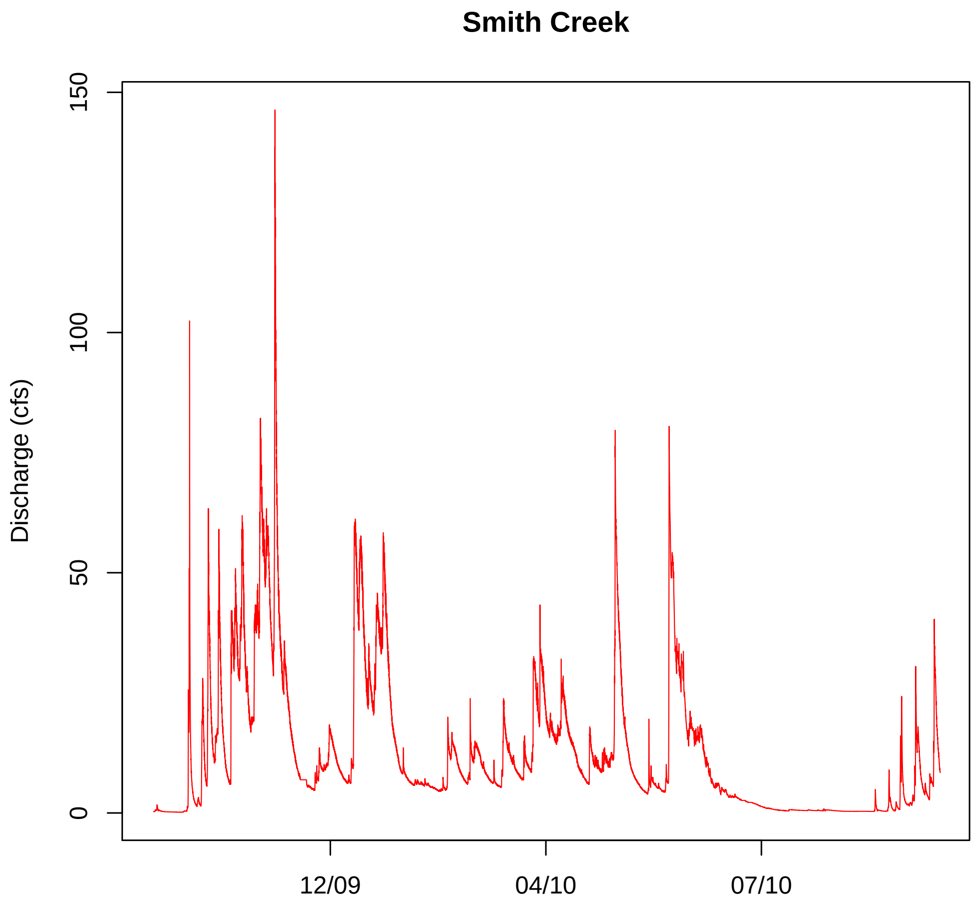


Figure 23: Smith Creek hydrograph, October 1, 2009–September 30, 2010. Data were recorded at 15 minute intervals.

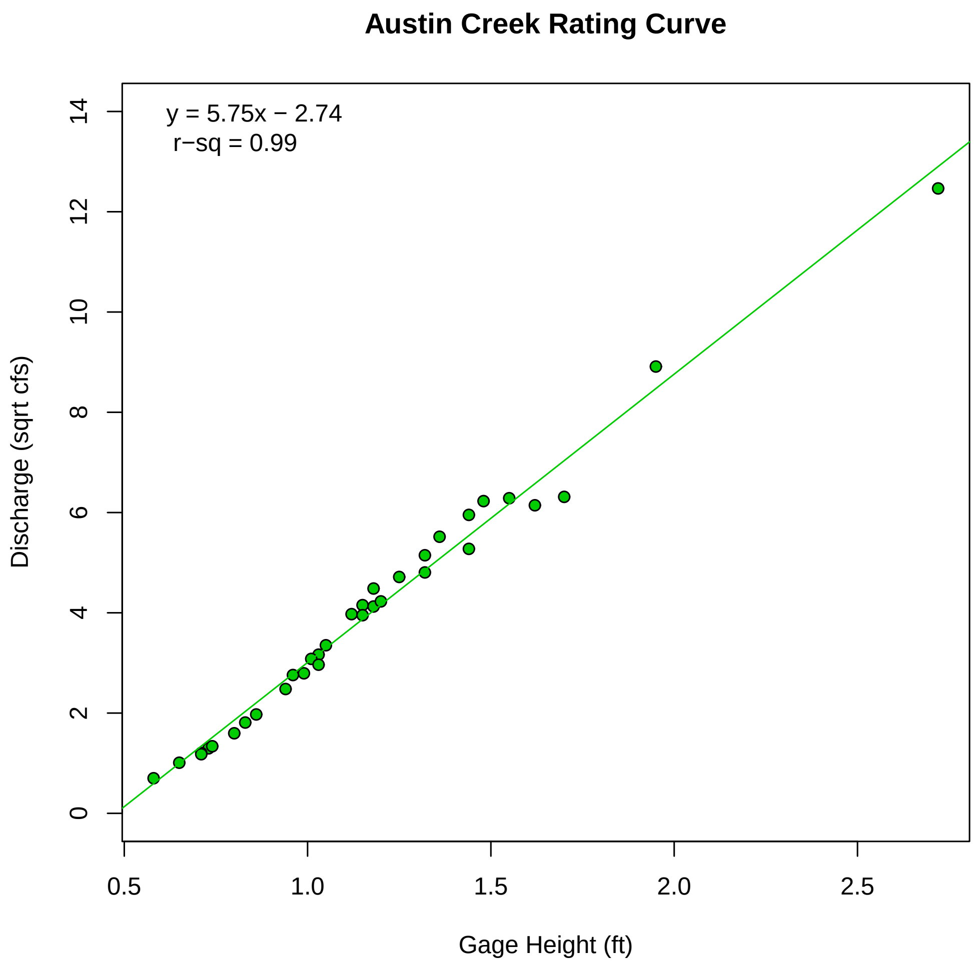


Figure 24: Austin Creek rating curve. Regressions show the relationship between gauge height (x) and square root transformed discharge (y) for WY2010. For earlier rating curves, contact the Institute for Watershed Studies.

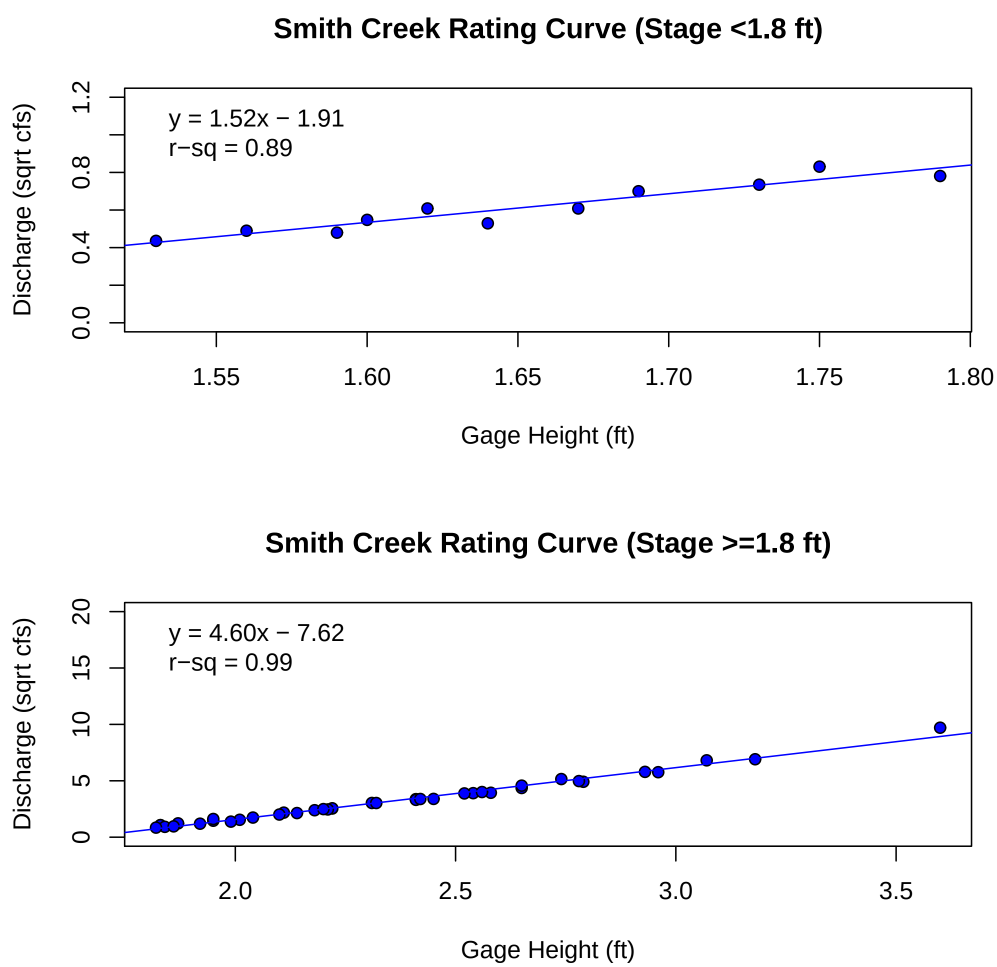


Figure 25: Smith Creek rating curves for low flows (stage $<$1.8 ft) and moderate and high flows (stage $\geq$1.8 ft). Regressions show the relationship between gauge height (x) and square root transformed discharge (y) for WY2010. For earlier rating curves, contact the Institute for Watershed Studies.

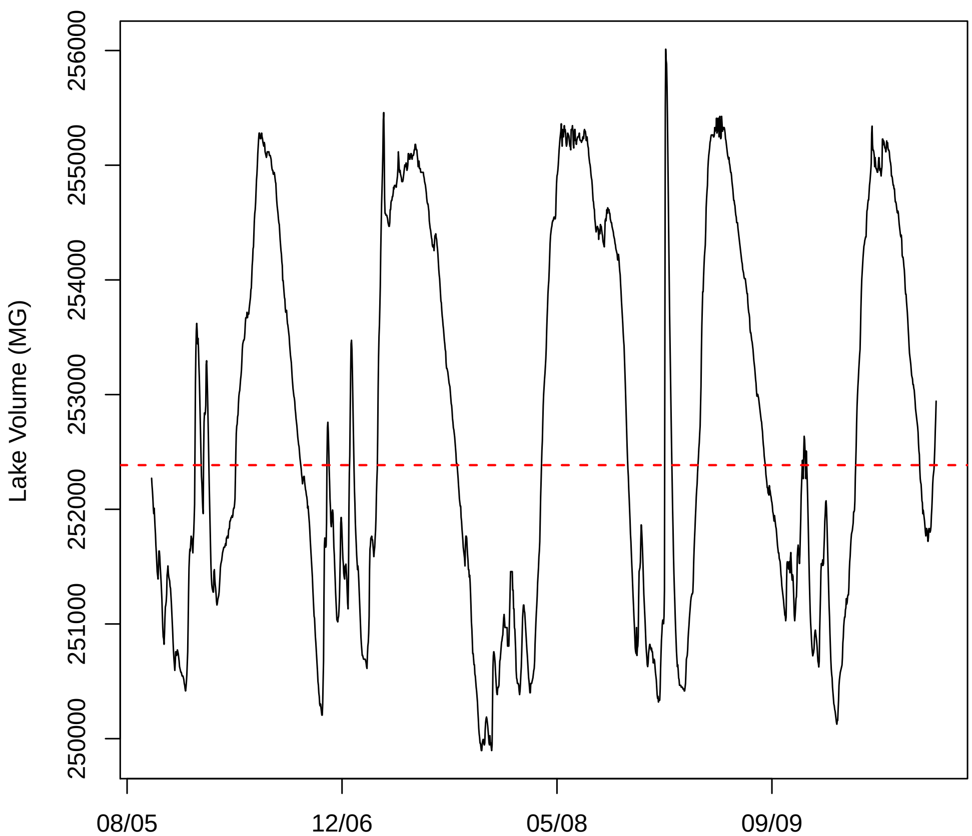


Figure 26: Comparison of Lake Whatcom daily lake volumes for WY2006–WY2010. Horizontal line represents median lake volume for the period plotted.

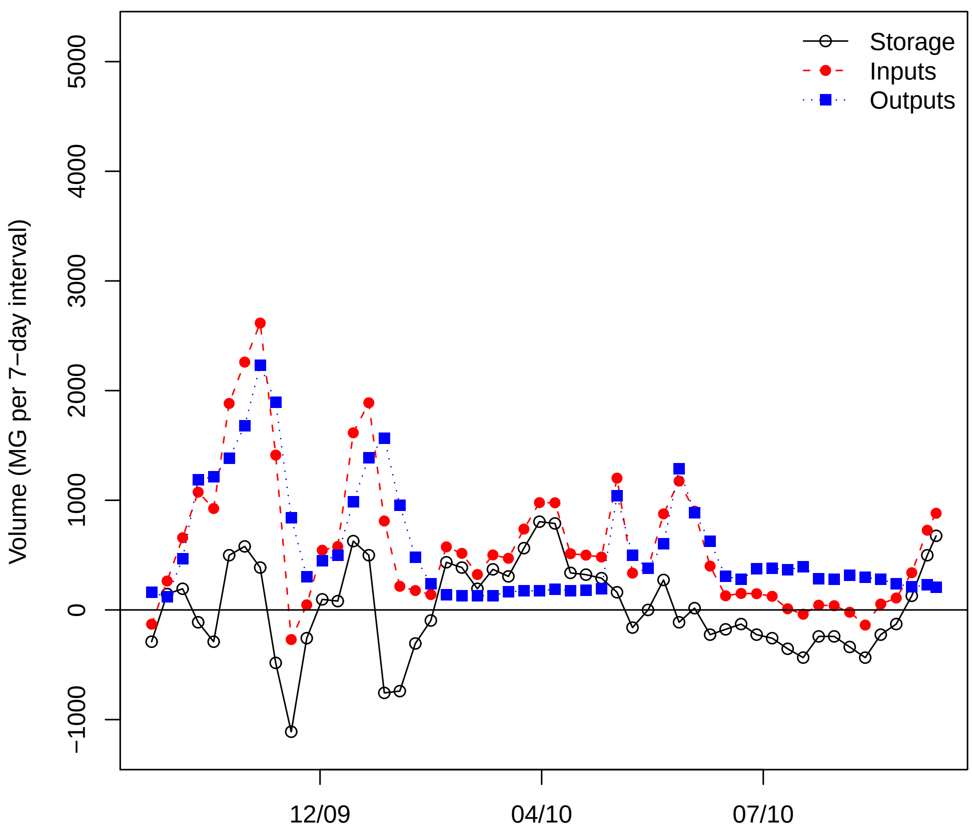


Figure 27: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2009–September 30, 2010.

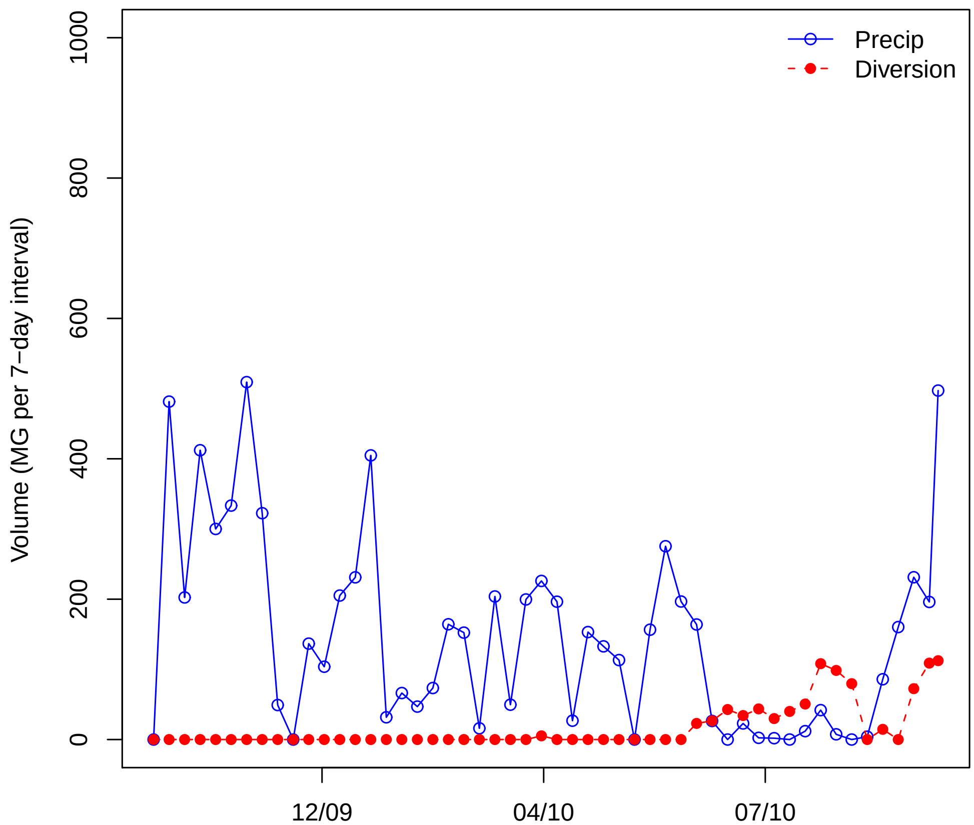


Figure 28: Lake Whatcom watershed direct hydrologic inputs, October 1, 2009–September 30, 2010. Runoff is included on Figure 30 as described in Section 4.2.

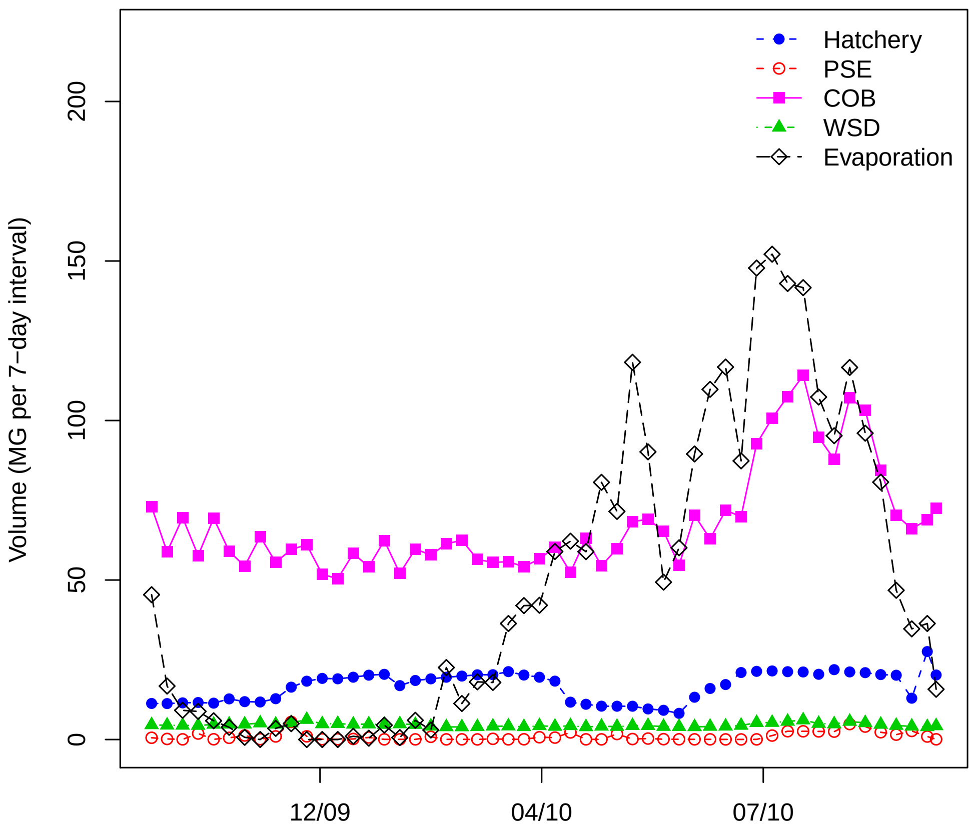


Figure 29: Lake Whatcom watershed hydrologic withdrawals, October 1, 2009–September 30, 2010. Whatcom Creek output is included on Figure 30 as described in Section 4.2.

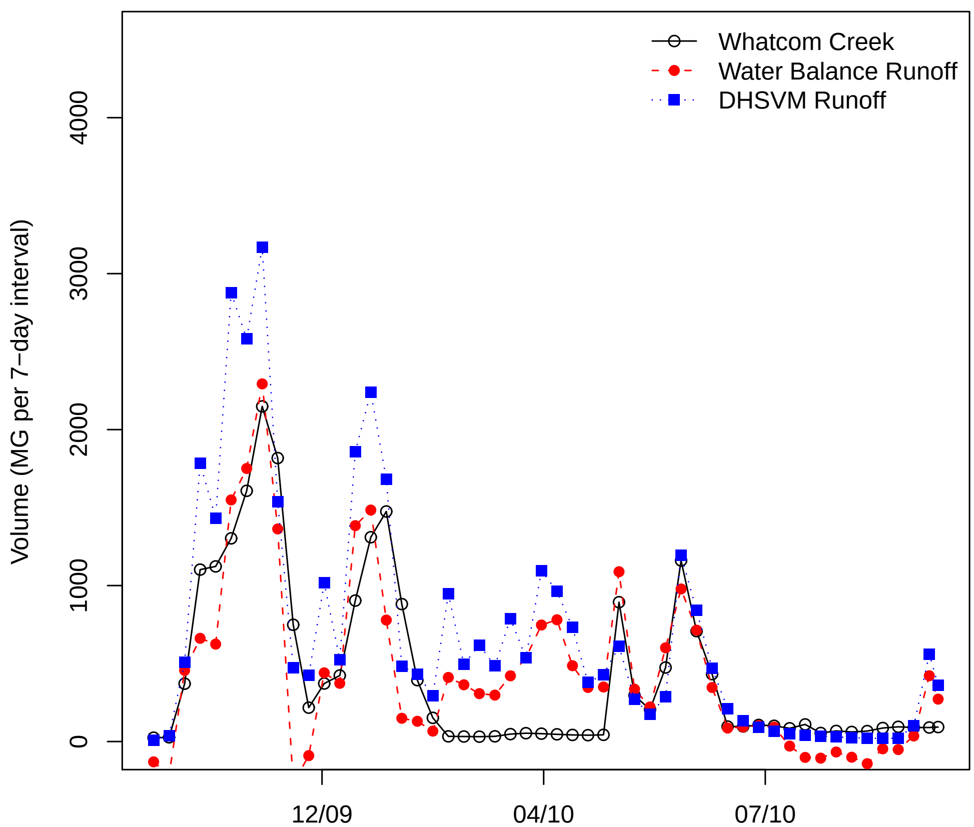


Figure 30: Summary of 7-day Whatcom Creek flows, water balance runoff estimates, and DHSVM runoff estimates, October 1, 2009–September 30, 2010.

5 Storm Water Monitoring

Beginning in 2009 the storm water program focused on collecting baseline storm event data from Silver Beach Creek and evaluating the effectiveness of a state-of-the art storm water treatment design installed along North Shore Drive. The current monitoring results are presented below; results from other storm water treatment sites in the Lake Whatcom watershed have been reported in previous annual reports (see Section 6.2, beginning on page 110).

5.1 Silver Beach Creek

Flow-paced discrete samples were collected at the USGS gauging site near the mouth of Silver Beach Creek (Figure A3, page 119) using an ISCO sampler provided by the City of Bellingham. The goal was to collect data from storms that produced $\geq$1 cm of precipitation in 24 hours, with the sample period covering both the rising and falling leg of the hydrograph. The water samples were analyzed to measure total suspended solids, total phosphorus, soluble phosphate, total nitrogen, and nitrate/nitrite as described in Table 1 (page 18).

A total of ten storm events were sampled from September through December 2009 (Table 29, page 88). Due to the unpredictable nature of storm events and the need to calibrate the ISCO for this site, some of the sampling periods did not meet the sampling goals described above. Six of the storm events met the precipitation goal ($\geq$1 cm in 24 hr). Two additional storms were designated "marginal" in Table 29 because they fell slightly short of the precipitation goal but had good hydrograph profiles. Of the remaining two events, one was the first storm we sampled (Event #1) and did not produce useful flow data. The remaining event (Event #3) occurred shortly after a period of rain, but although there was flow through the ISCO, there was no measurable precipitation at the nearby gauge. For this report, we will discuss the eight events designated as qualifying or marginal in Table 29, omitting results from Event #1 and Event #3.

Most storm events showed an increase in total suspended solids and phosphorus related to stream flow (Figures 31–36, pages 89–94). This relationship was particularly clear for large, high flow storm events (e.g., Events #5 and #8). Flow was not the only factor affecting sediment and phosphorus transport, however, because some moderately high flow events had low sediment and phosphorus concentrations (e.g., Event #9). Nitrogen concentrations seemed more or less unaffected by small storms, but were diluted by precipitation during large storms (Figures 37–40, pages 95–98). A notable exception to this occurred during Event #8, where the total nitrogen concentrations increased with storm flow.

Despite the variability between storm events, total suspended solids and total phosphorus were highly correlated with flow rates (Figures 41–42, pages 99–100). In addition, total and soluble phosphorus concentrations were highly correlated with total suspended solids concentrations (Figure 43, page 101). These correlations were anticipated, and simply illustrate how storm flow transports sediments and phosphorus into residential streams.

5.2 North Shore Drive

The North Shore overlay was installed by the City of Bellingham along North Shore Drive between Dakin Street and Poplar Drive as a measure to reduce direct storm water runoff into Lake Whatcom by infiltrating a portion of storm water flow from the overlay area. The main features of the overlay are porous concrete bicycle lanes on both sides of North Shore Drive and sections of porous concrete sidewalk (Figure 44, page 102). To facilitate infiltration, the porous concrete is installed over 18 inches of sand and 12 inches of crushed rock.

The overlay was installed atop a pre-existing storm drain system, and as such is a hybrid system. During rainfall events that generate runoff, the major portion of runoff is conveyed by the conventional storm drain system. That portion of runoff generated directly from North Shore Drive that is bordered by the porous concrete bicycle lanes is infiltrated, as well as any precipitation falling directly onto the porous concrete sidewalk areas.

In consultation with the City, we selected the area between Dakin Street and East Connecticut Street to study the effectiveness of the overlay for treating runoff. This portion of the overlay is accessible and represents typical overlay conditions. In addition, it has a system collection catch basin located at the corner of Dakin Street and North Shore Drive (Figure 45, page 103). The overlay is designed to facilitate infiltration, so our goal was to determine when there was flowing water present in the drain, and, if possible, relate this information to precipitation events.

During April 2010, instrumentation was installed in the catch basin to determine if there was any flow in excess of infiltration. The instrumentation package was an electro-optical sensor coupled to a data logger that would record if any water was flowing out of the pipe. The sensor was not designed to determine quantity of flow but merely presence/absence of flowing water. Precipitation data were collected from a tipping bucket rain gauge placed in the Park Place Storm Water Treatment facility. Additional precipitation data were obtained from the rain gauge operated by the City at Bloedel/Donovan.

There were three logger "events" indicating flow in the drain during the sample period from April 1 to April 23, 2010 (Figure 46, page 104). These were compared to both the Park Place precipitation data and precipitation data from a City of Bellingham operated rain gauge at Bloedel Donovan park. The event signals were inconclusive; two events were recorded concurrent with precipitation and one event was logged on a day following precipitation, but several substantial rainfall events generated no event signal.

Beginning in September 2010, we changed our approach and started making periodic visual observations of the catch basin. Again, the goal was to determine whether there was flow in the main drain of the system and under what conditions. As with the logger events, there was no consistent relationship between observations of flow in the drain and precipitation at the site (Figure 47, page 105).

As mentioned earlier, the North Shore Drive overlay is not designed to collect and treat all storm water runoff from the area, but to infiltrate runoff from the road, bike lane and sidewalk surfaces. As a result, direct storm water runoff from this portion of the Lake Whatcom watershed may be reduced, but will not be completely eliminated.

Runoff in the North Shore Drive drainage network was sampled on October 23 and October 26, concurrent with Silver Beach Creek Events 4 and 5 (Table 29). These samples represent runoff that has not been treated by sand filtration. The total phosphorus concentrations in the drainage network ranged from 26.2–184.2 μg-P/L (median = 115 μg-P/L), which is typical for residential runoff. Because there is still some flow in the North Shore Drive drainage network, it will be important to characterize any effect of sand filtration and estimate the amount of phosphorus that reaches the lake. This is beyond the scope of the IWS monitoring project.

Event	Sampling Period	Event Duration (hr)	Total Precip (cm)	Qualify?
1	19:45 Sept 28 to 23:30 Sept 29	3.8	0.03	No
2	10:00 Oct 1 to 11:00 Oct 2	19.4	0.48	marginal
3	16:30 Oct 12 to 3:30 Oct 13	10.8	0.00	No
4	17:30 Oct 22 to 10:45 Oct 24	35.2	2.49	Yes
5	9:00 Oct 25 to 14:15 Oct 27	46.1	3.76	Yes
6	11:00 Nov 5 to 17:45 Nov 7	48.9	2.74	Yes
7	8:00 Nov 9 to 18:45 Nov 12	75.8	3.45	Yes
8	6:00 Nov 16 to 9:00 Nov 18	38.9	5.26	Yes
9	0:00 Nov 19 to 8:00 Nov 20	26.2	2.18	Yes
10	14:30 Dec 14 to 16:30 Dec 22	186.8	2.97	marginal

Table 29: Summary of Silver Beach Creek storm events and precipitation totals at the Bloedel/Donovan precipitation gauge, September–December, 2009. Precipitation data were provided by the City of Bellingham.

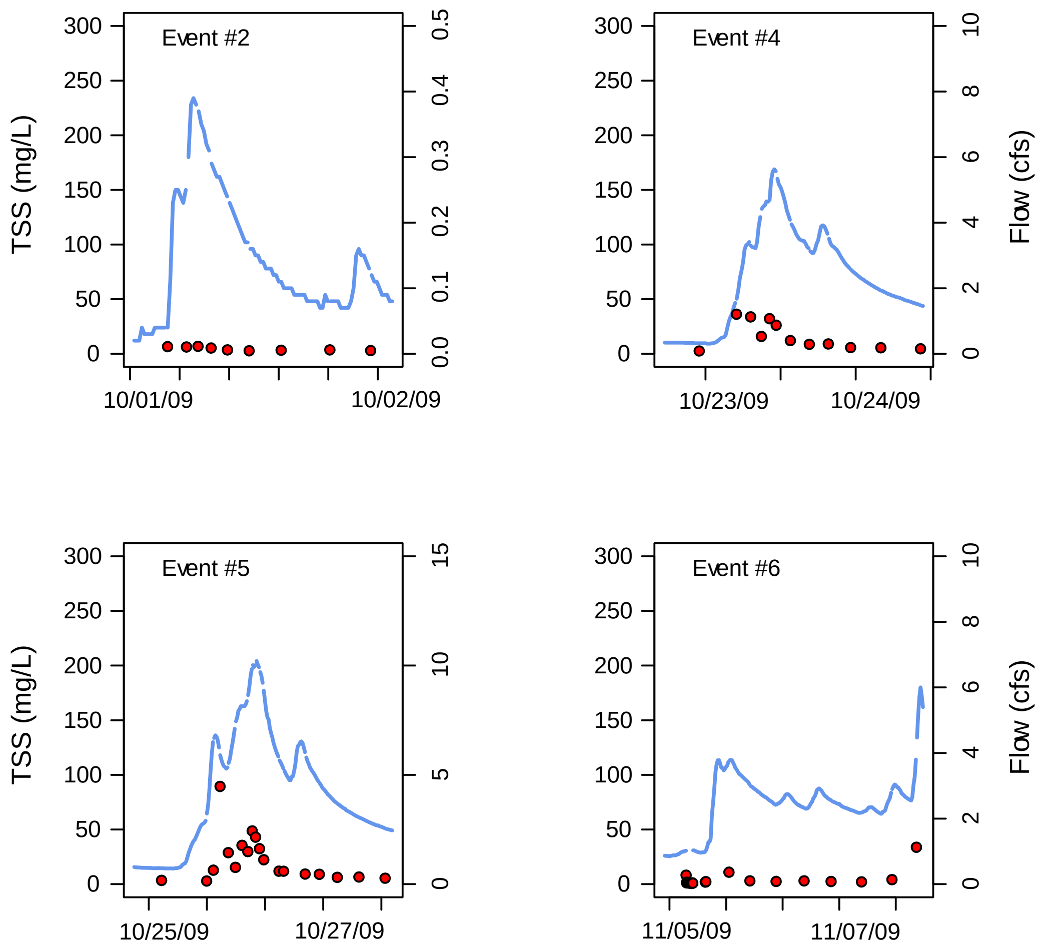


Figure 31: Silver Beach Creek storm water monitoring results for Events 2, 4, 5, and 6: total suspended solids (●) vs. flow (—).

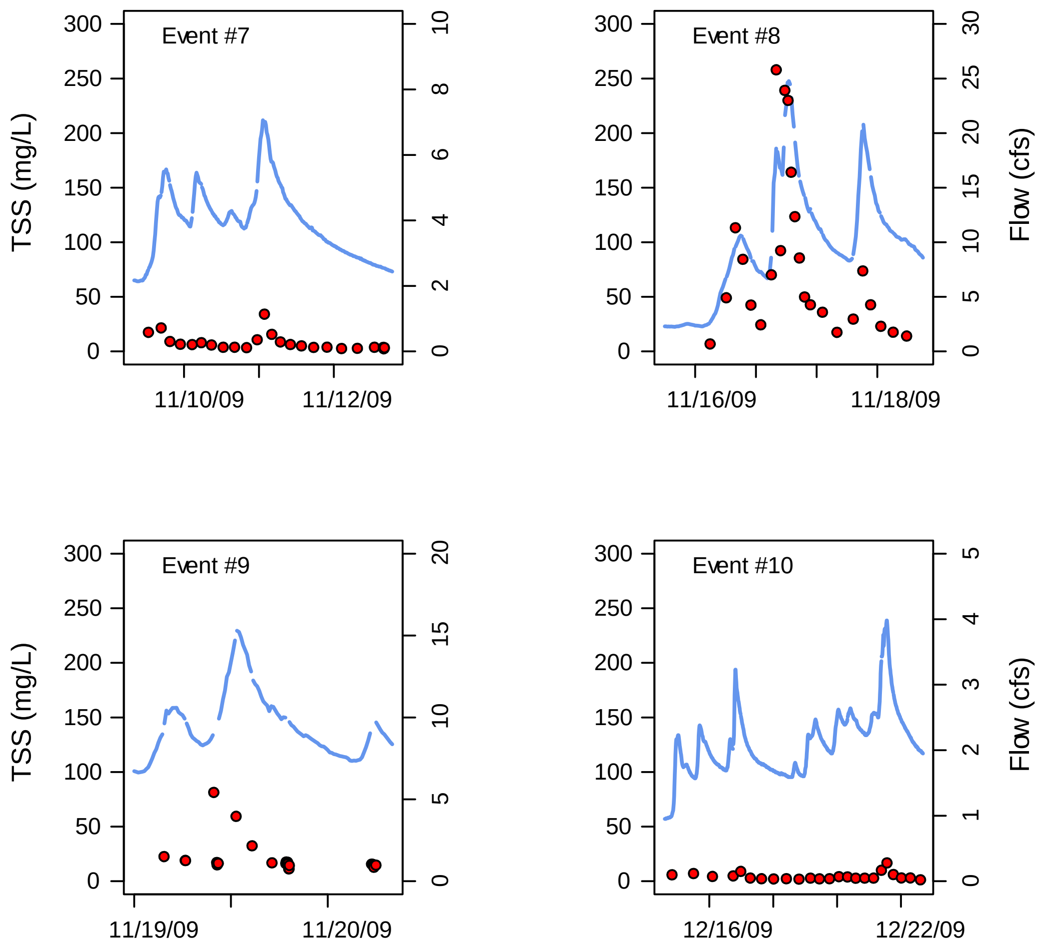


Figure 32: Silver Beach Creek storm water monitoring results for Events 7, 8, 9, and 10: total suspended solids (•) vs. flow (—).

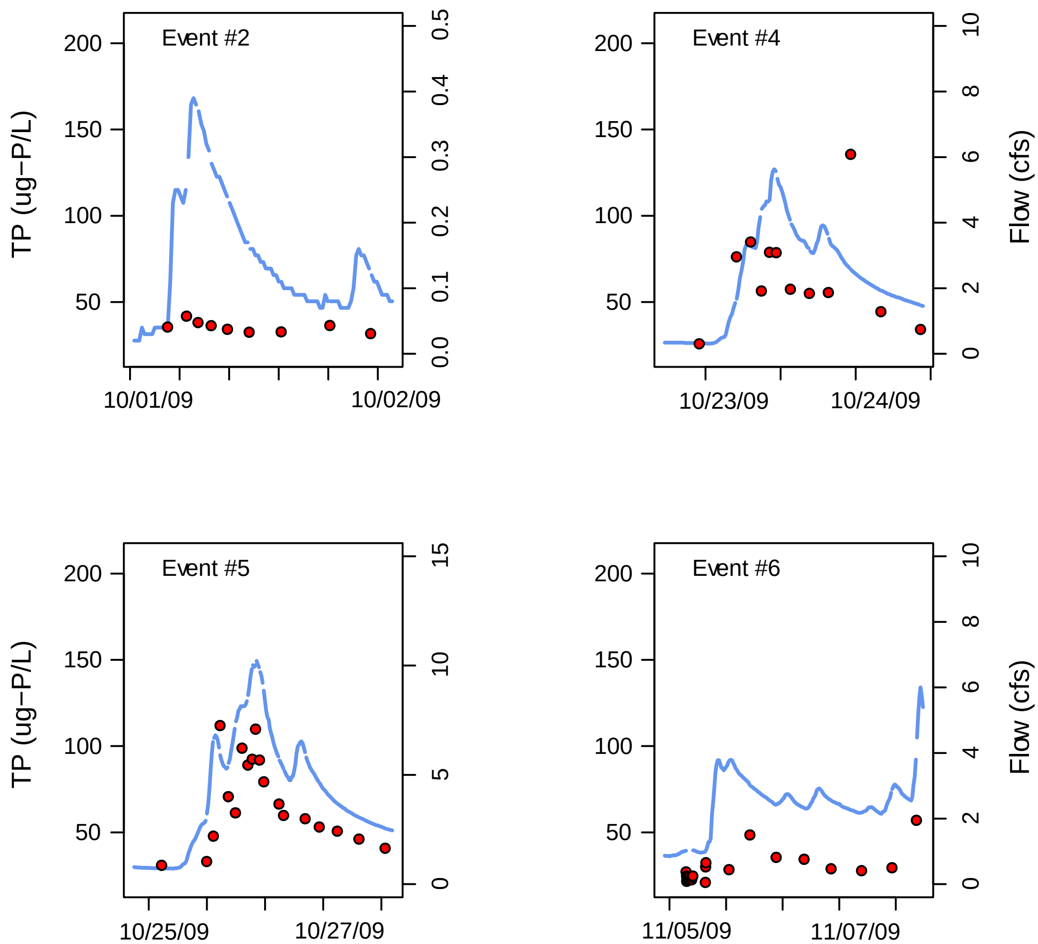


Figure 33: Silver Beach Creek storm water monitoring results for Events 2, 4, 5, and 6: total phosphorus (•) vs. flow (—).

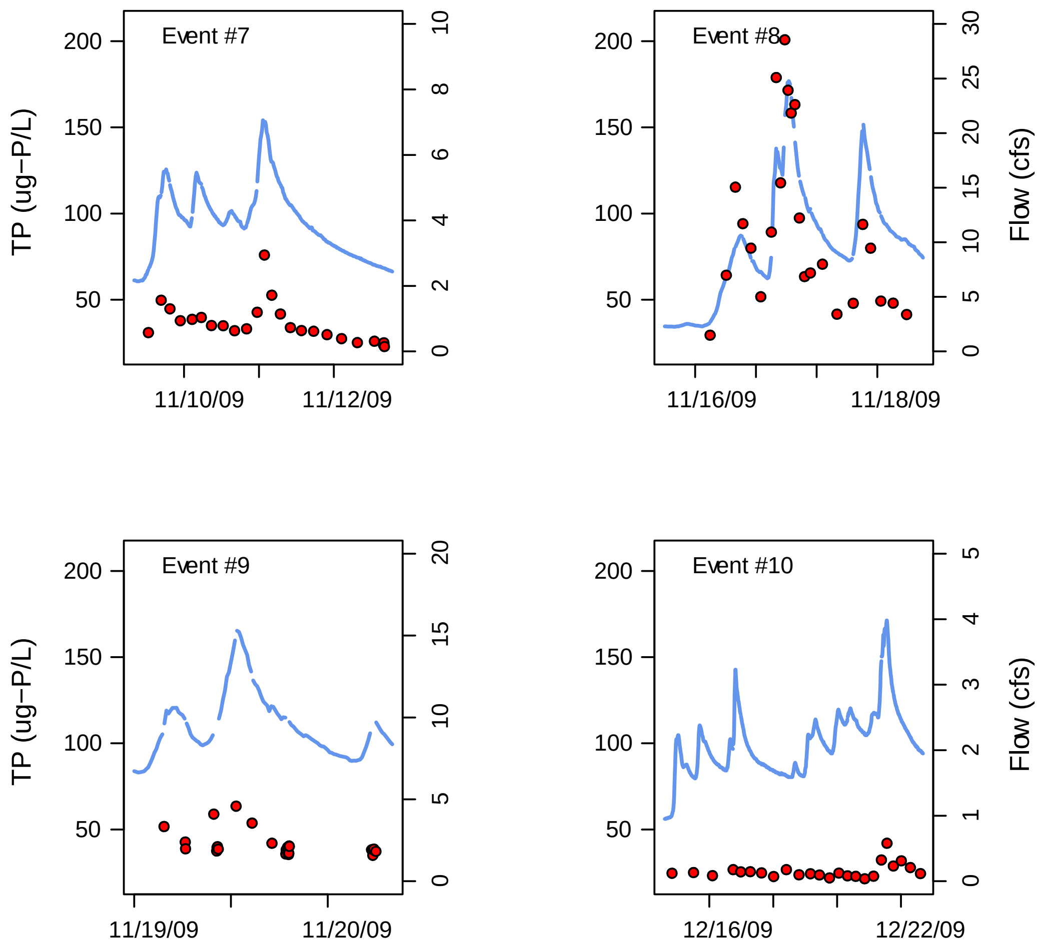


Figure 34: Silver Beach Creek storm water monitoring results for Events 7, 8, 9, and 10: total phosphorus (•) vs. flow (—).

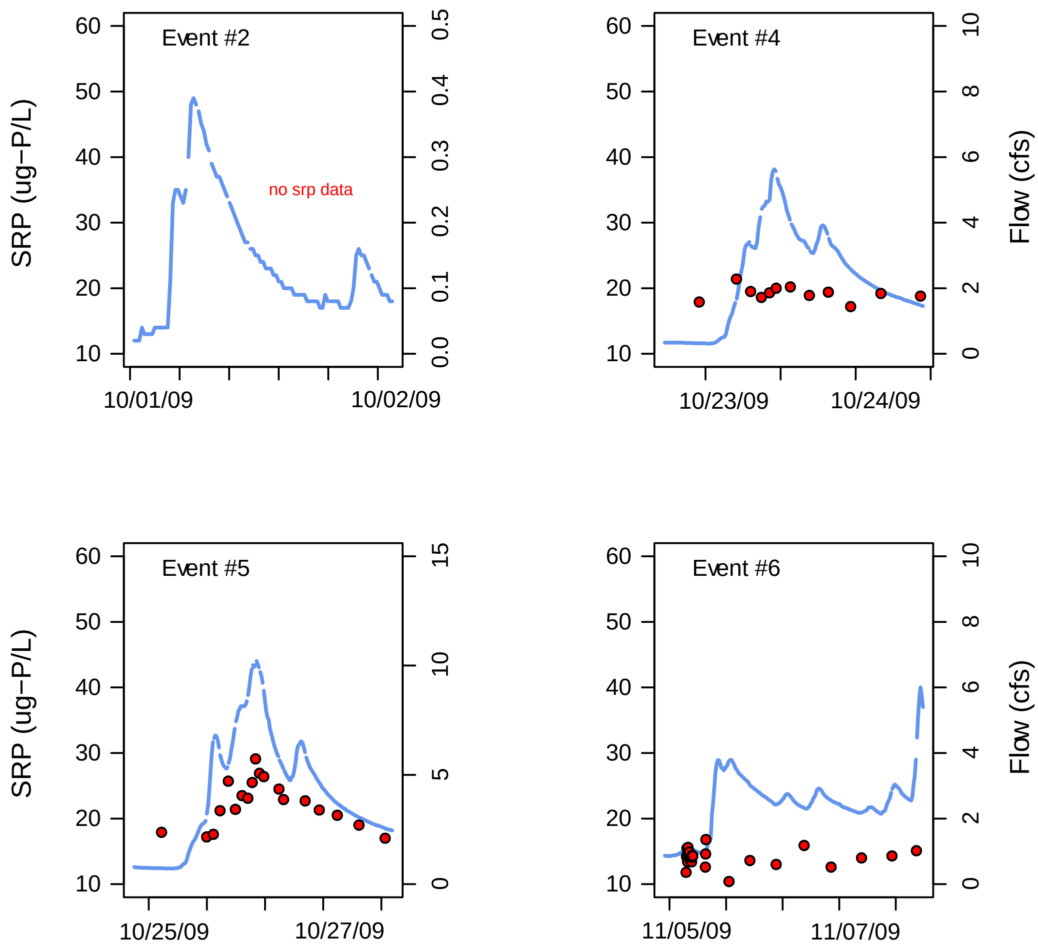


Figure 35: Silver Beach Creek storm water monitoring results for Events 2, 4, 5, and 6: soluble phosphate (•) vs. flow (—).

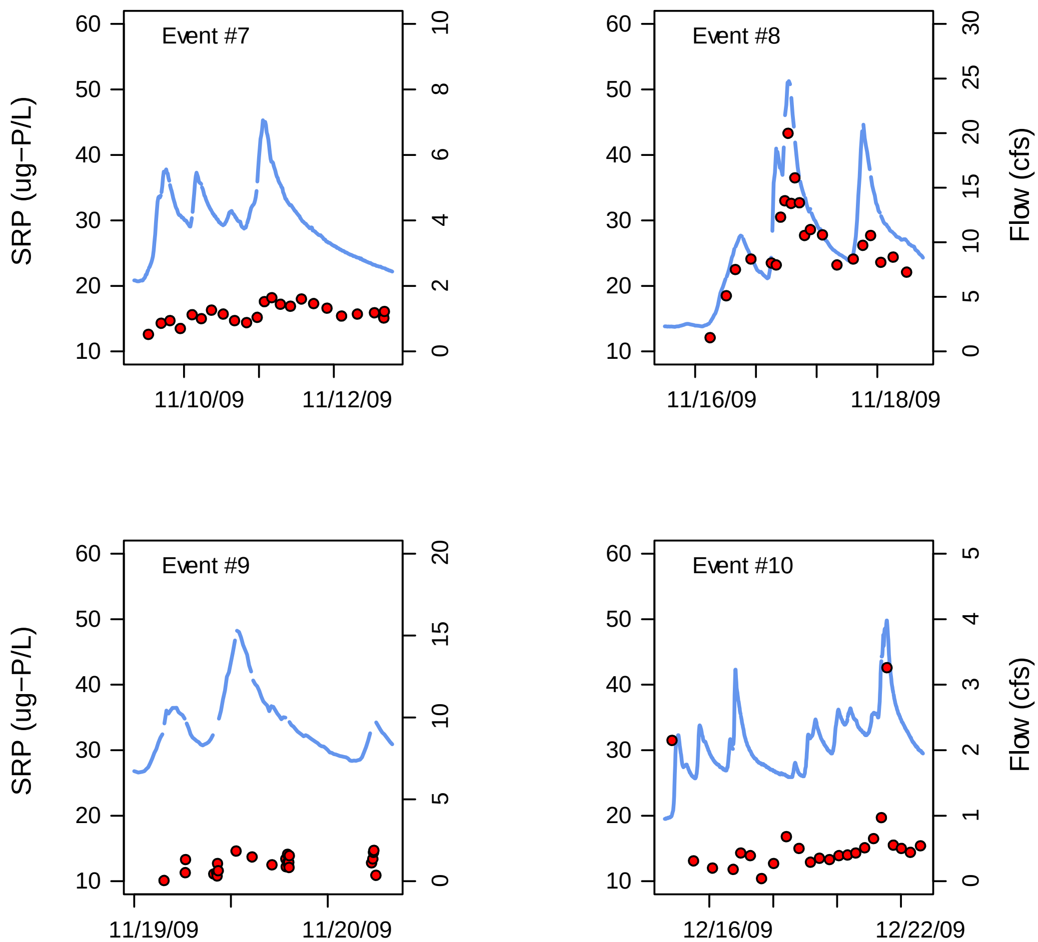


Figure 36: Silver Beach Creek storm water monitoring results for Events 7, 8, 9, and 10: soluble phosphate (•) vs. flow (—).

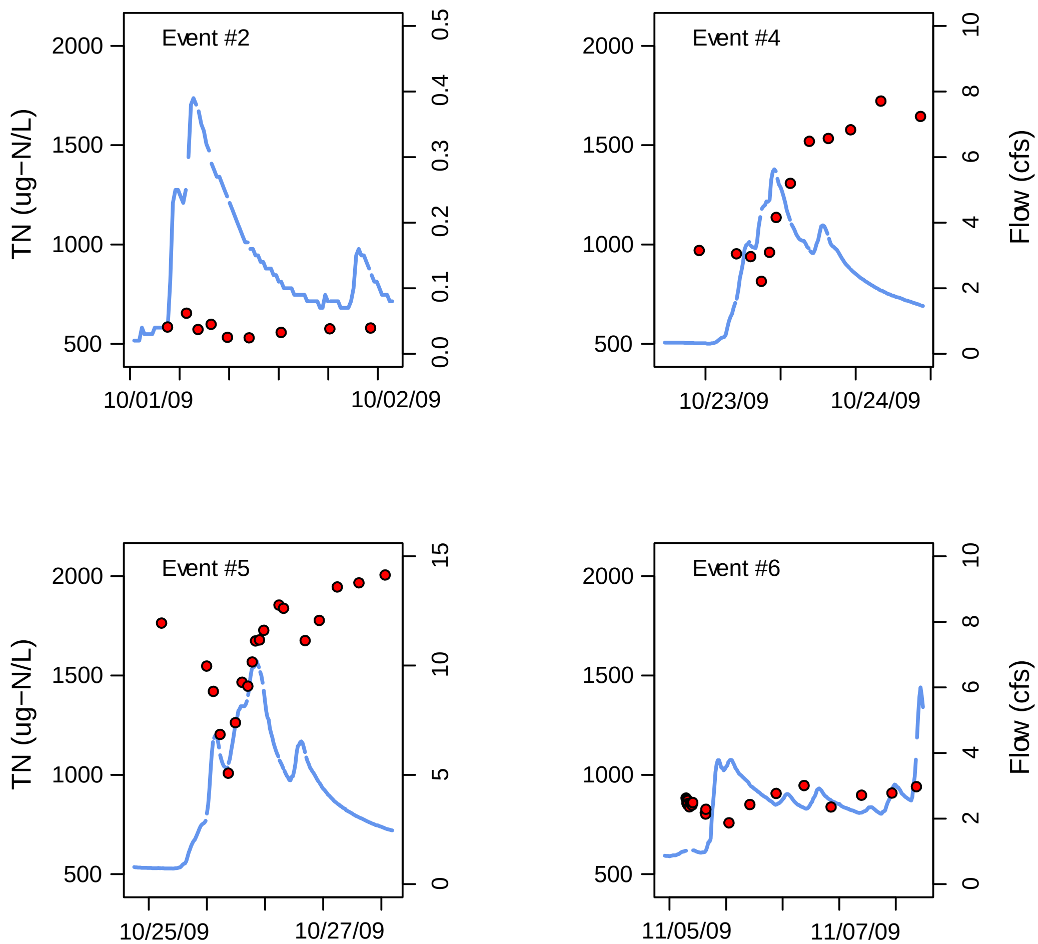


Figure 37: Silver Beach Creek storm water monitoring results for Events 2, 4, 5, and 6: total nitrogen (●) vs. flow (—).

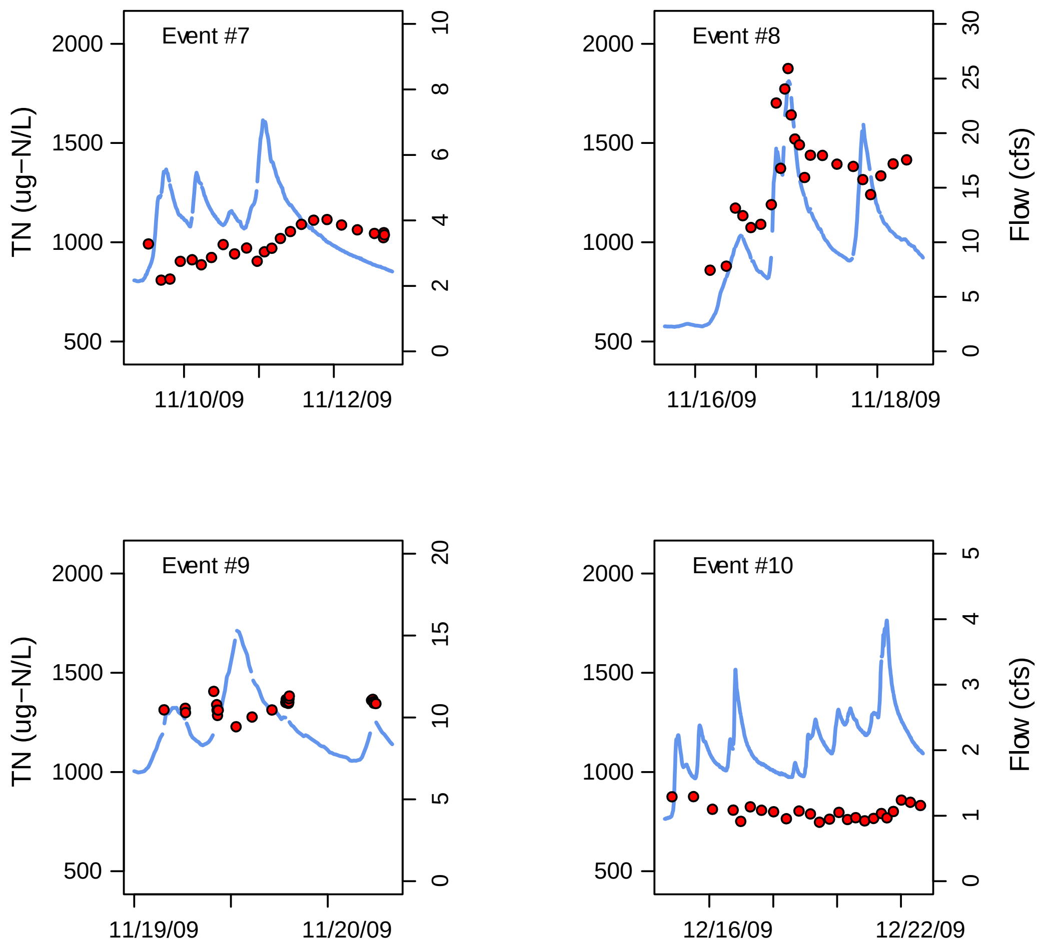


Figure 38: Silver Beach Creek storm water monitoring results for Events 7, 8, 9, and 10: total nitrogen (•) vs. flow (—).

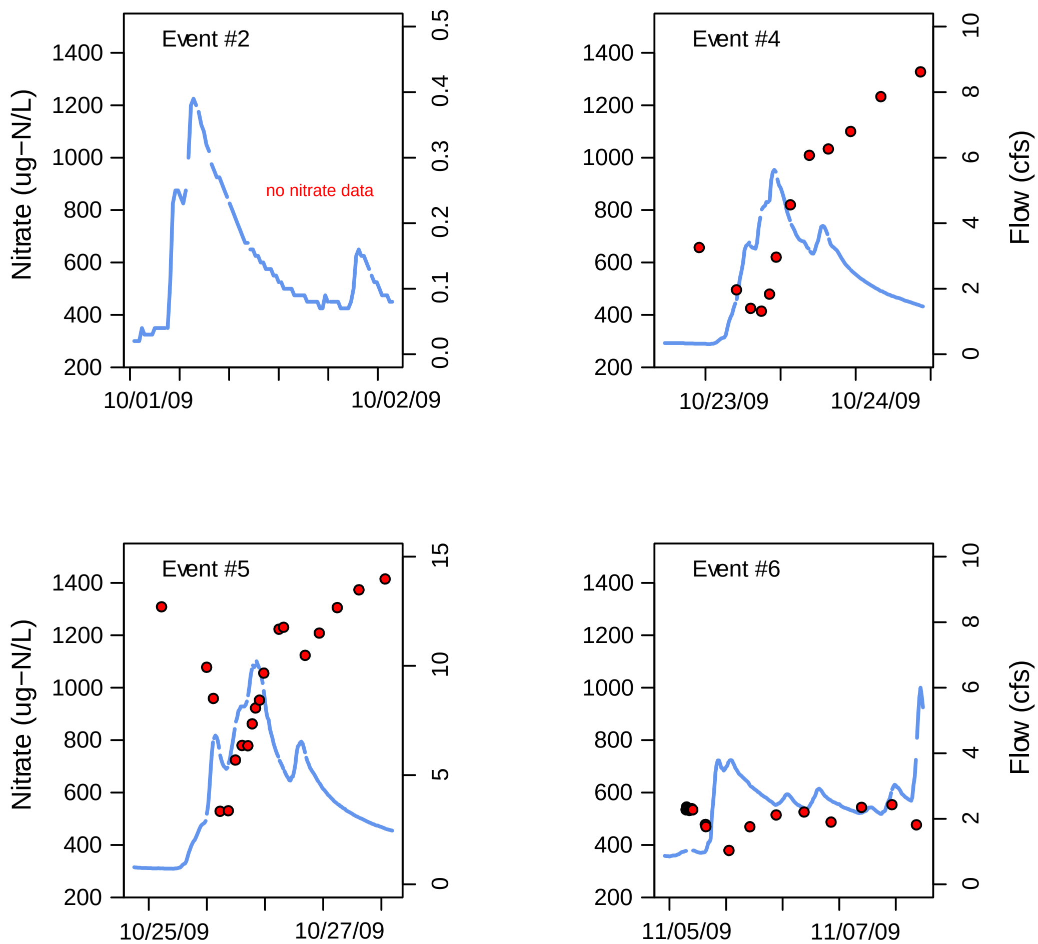


Figure 39: Silver Beach Creek storm water monitoring results for Events 2, 4, 5, and 6: nitrate/nitrite (•) vs. flow (—).

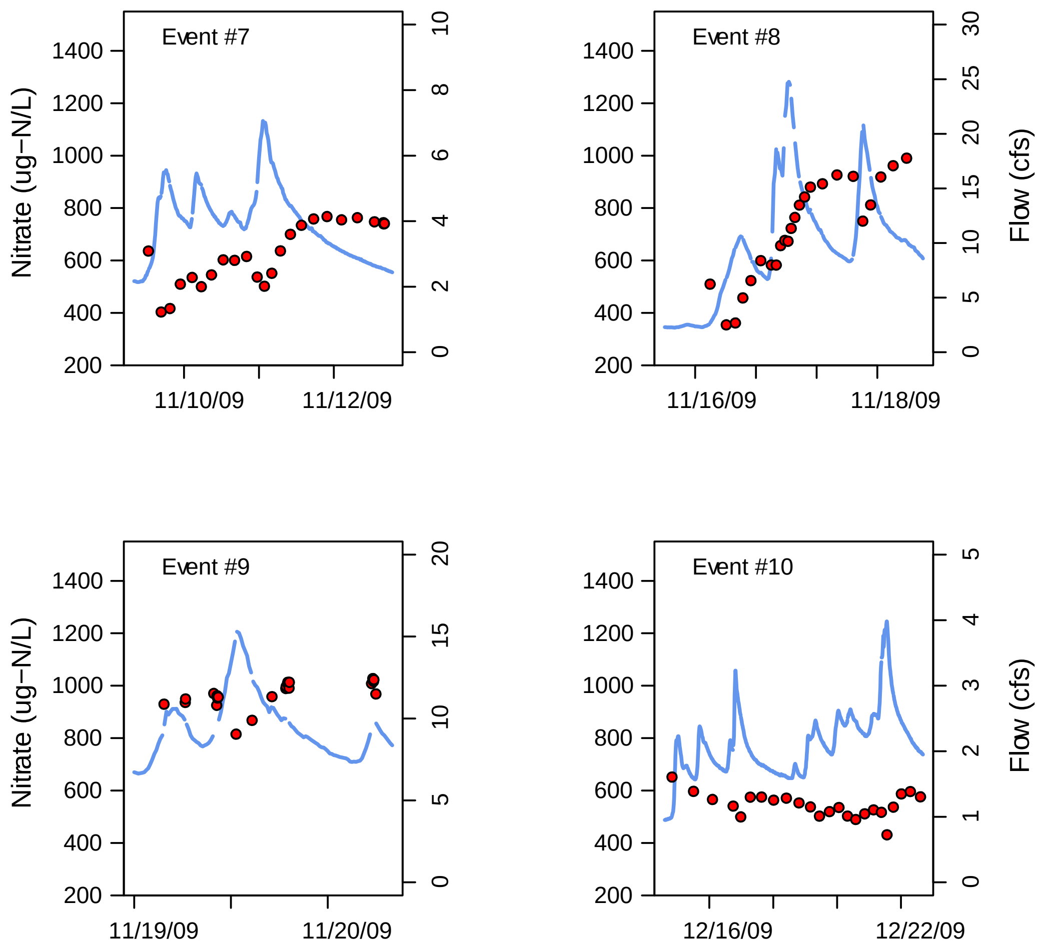


Figure 40: Silver Beach Creek storm water monitoring results for Events 7, 8, 9, and 10: nitrate/nitrite (•) vs. flow (—).

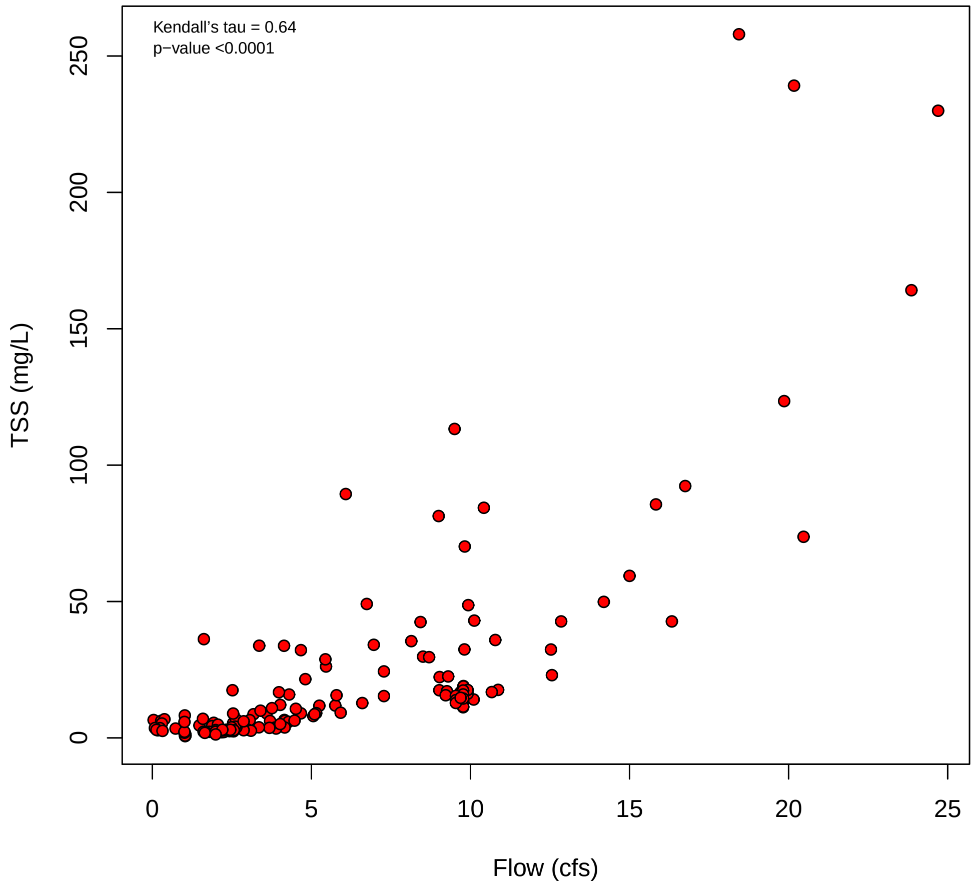


Figure 41: Correlation between flow rates and total suspended solids in Silver Beach Creek (Events 2 and 4–10). Flow rates were measured at 15 minute intervals that rarely matched sample collection times; coincident flows were estimated by averaging adjacent flows. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

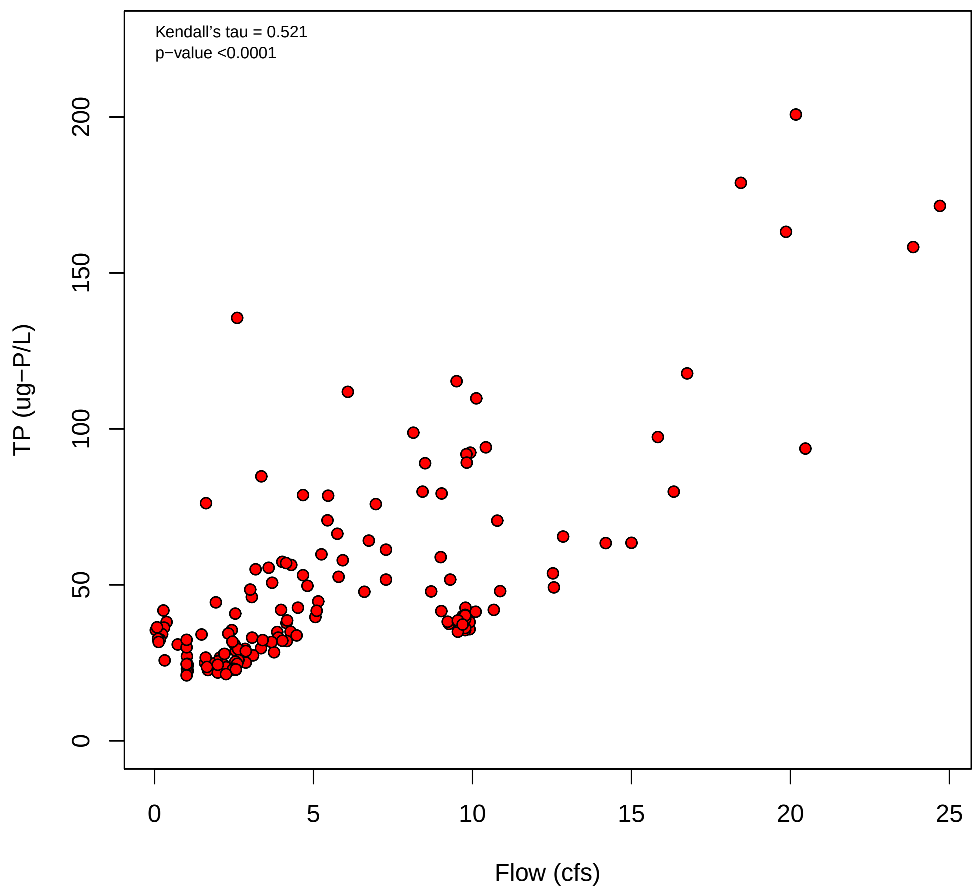


Figure 42: Correlation between flow rates and total phosphorus in Silver Beach Creek (Events 2 and 4–10). Flow rates were measured at 15 minute intervals that rarely matched sample collection times; coincident flows were estimated by averaging adjacent flows. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

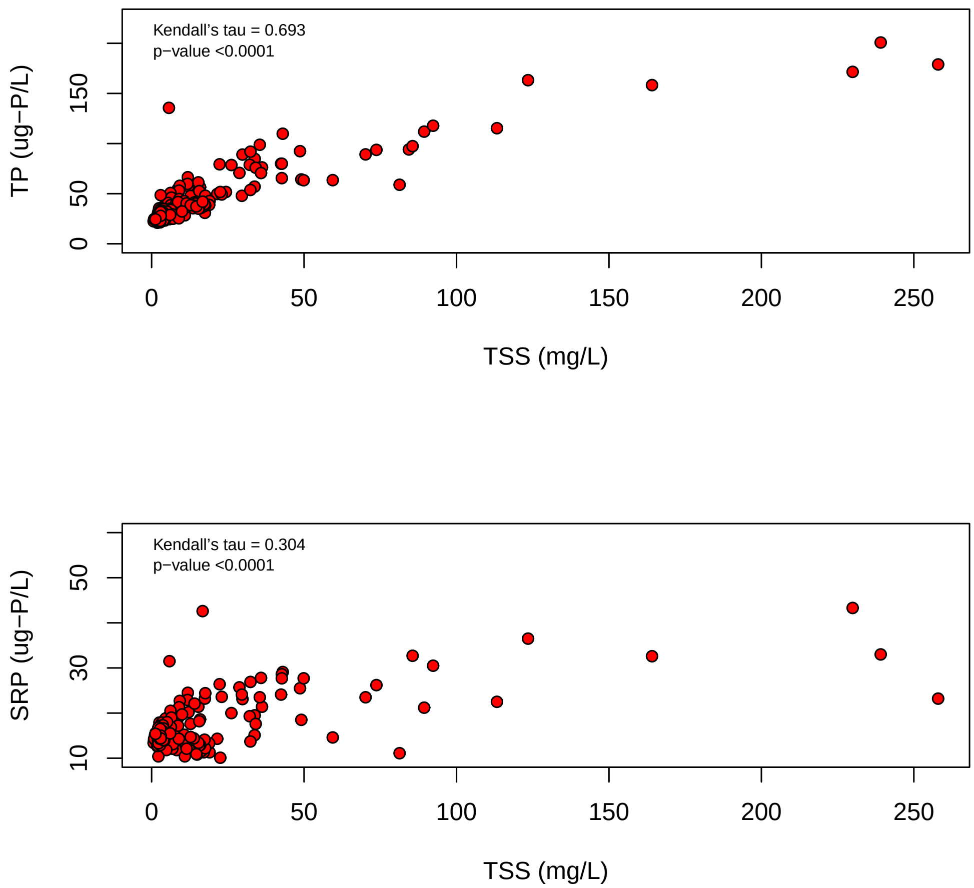
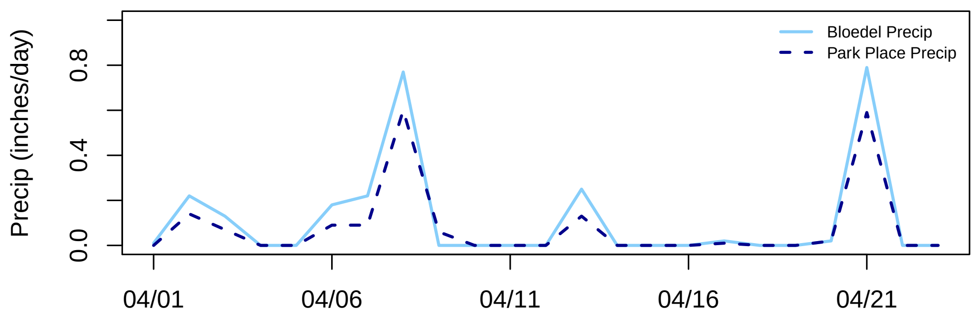


Figure 43: Correlations between flow rates and total phosphorus, soluble phosphate, total nitrogen, and nitrate/nitrite in Silver Beach Creek (Events 2 and 4–10). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

Figure 44: North Shore Drive overlay showing porous concrete bicycle lanes and sidewalk.

Figure 45: Catch basin access for North Shore Drive overlay.



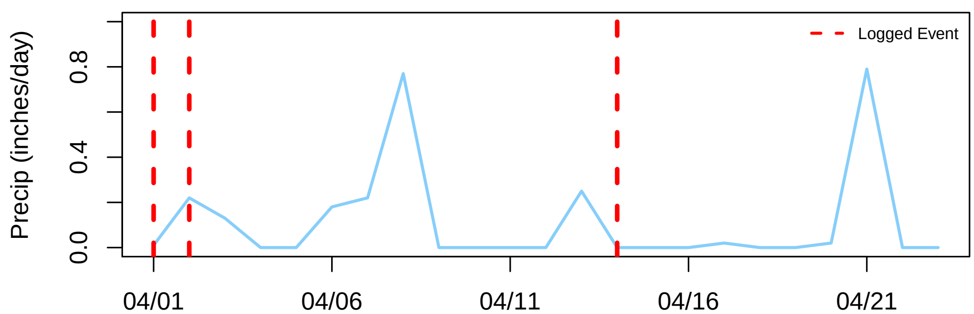
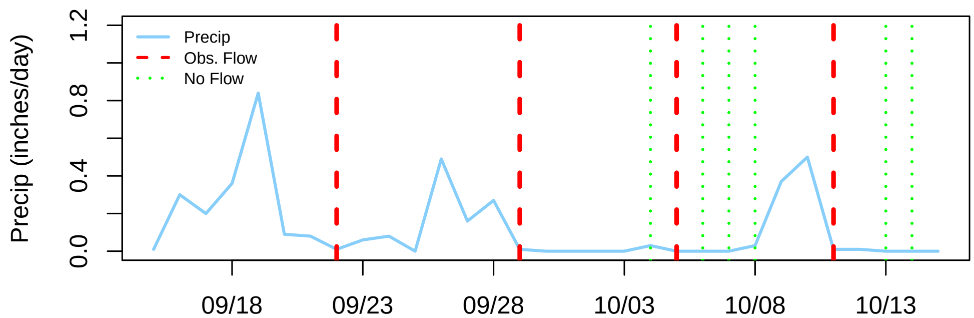


Figure 46: Flow events recorded for the North Shore Drive overlay based on electronic flow detection in the catch basin. The upper figure shows the similarity between precipitation measured at the two gauging sites. The vertical lines in the lower figure show when flowing water was detected in the system.



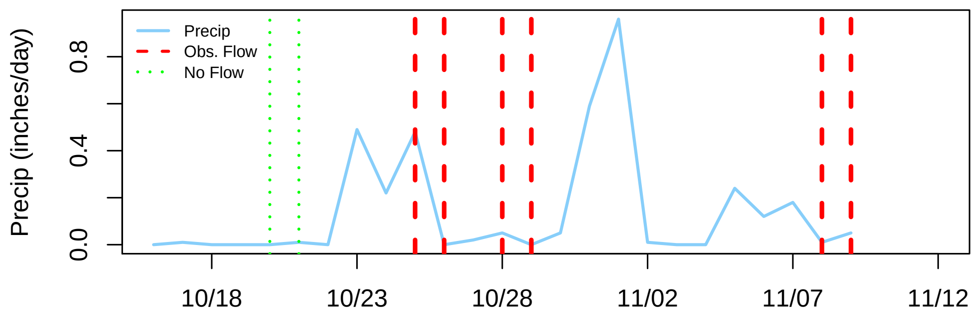


Figure 47: Flow events recorded for the North Shore Drive overlay based on visual examination of the catch basin. The red vertical lines show when flowing water was observed in the system; the green vertical lines show when the system was inspected and no flowing water was observed.

6 References and Related Reports

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6.2 Related Reports

The following is a list of annual reports and special project reports produced by the Institute for Watershed Studies since 1987 as part of the Lake Whatcom monitoring program sponsored by the City of Bellingham and Western Washington University. Many of the reports are available online at http://www.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, 2009/2010 Final Report, March 1, 2011. Report to the City of Bellingham, WA.

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

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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.

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

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

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

A Site Descriptions

Figures A1–A3 (pages 117–119) show the locations of the current monitoring sites and Table A1 (page 116) 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[21] is mounted in the stilling well on the east side of

[21] 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 that cross the road. This site can be difficult to locate and may be dry or have minimal flow during drought conditions; contact IWS for detailed information about the site location.

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

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

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

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

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

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

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

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

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

A.3 Storm Water Monitoring Sites

The storm water monitoring program was revised in 2009/2010 to focus on collecting baseline data at the Silver Beach Creek outlet and the North Shore Drive overlay. For information about other storm water sites that have been monitored by IWS, refer to the annual reports listed in Section 6.2 (page 110).

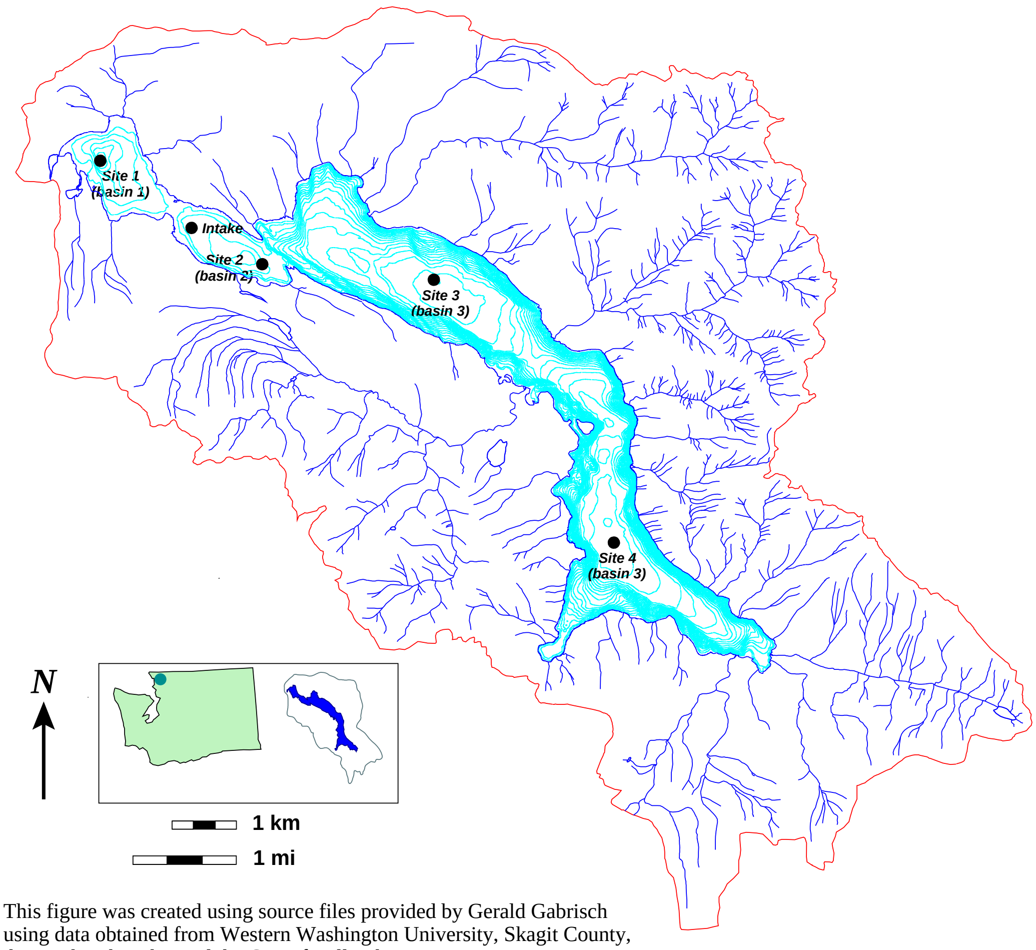
Silver Beach storm runoff samples were collected at the USGS gauging site behind the house at 3007 Maynard Place and approximately 150 m upstream from the culvert at North Shore Dr.

North Shore Drive storm flow observations were made by accessing the manhole on the northeast corner of the intersection of Dakin St. and North Shore Dr.

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

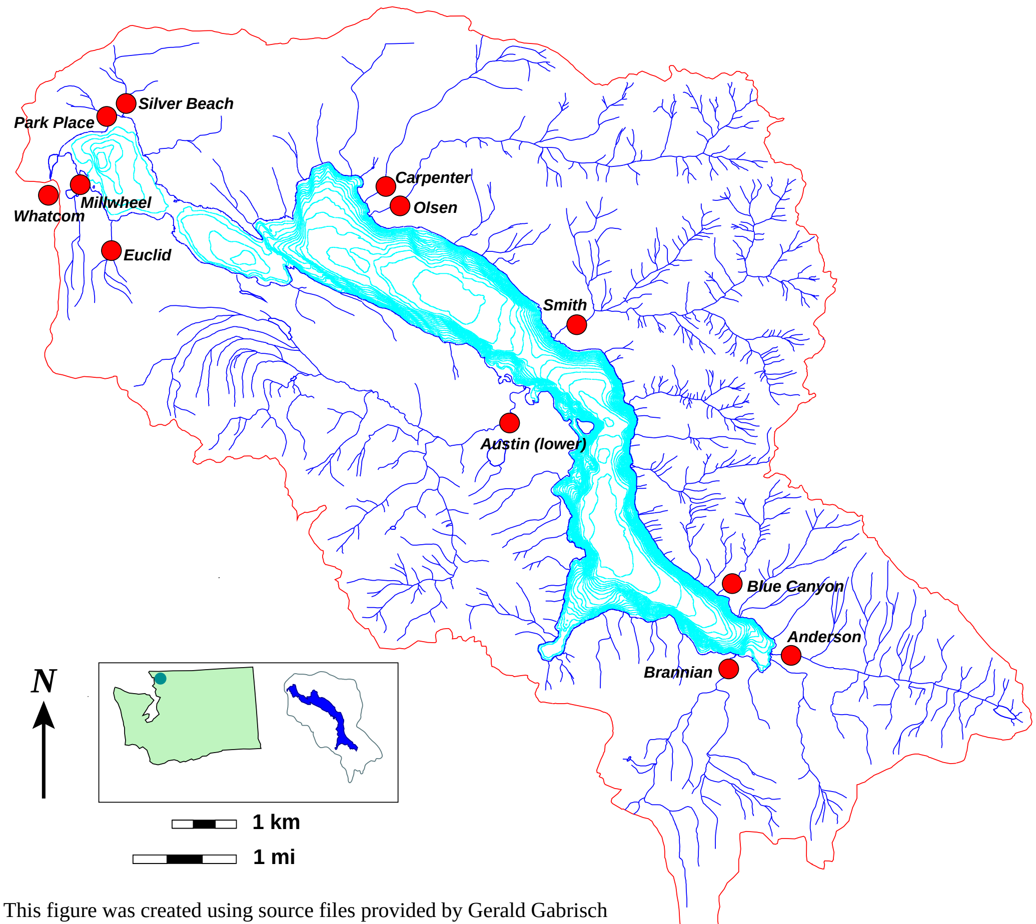
Creek Sites	Latitude	Longitude
Anderson	48.67335	122.26751
Austin (lower)	48.71312	122.33076
Blue Canyon	48.68532	122.28295
Brannian	48.66910	122.27949
Carpenter	48.75432	122.35449
Euclid	48.74844	122.41005
Millwheel	48.75507	122.41635
Olsen	48.75129	122.35353
Park Place	48.76894	122.40915
Silver Beach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

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



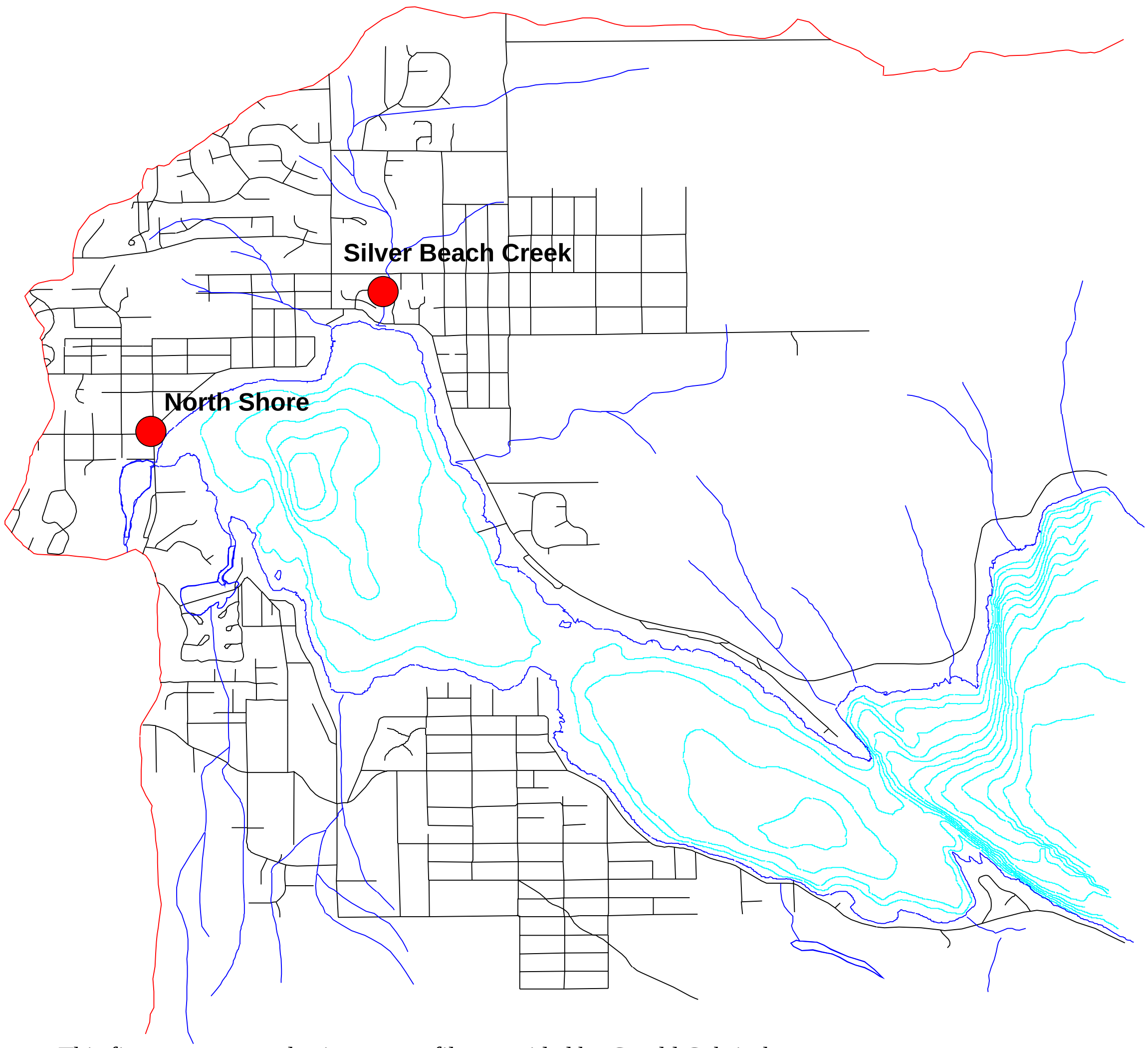
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A1: Lake Whatcom lake sampling sites.



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

Figure A2: Lake Whatcom tributary sampling sites.



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

Figure A3: Silver Beach Creek and North Shore Drive storm water sites.

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 18).

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 18). 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 189–193, which show the effect of using increasingly sensitive conductivity probes). These changes generally result in a reduction in analytical variability, and sometimes result in lower detection limits.

B.1 Monthly Hydrolab Profiles

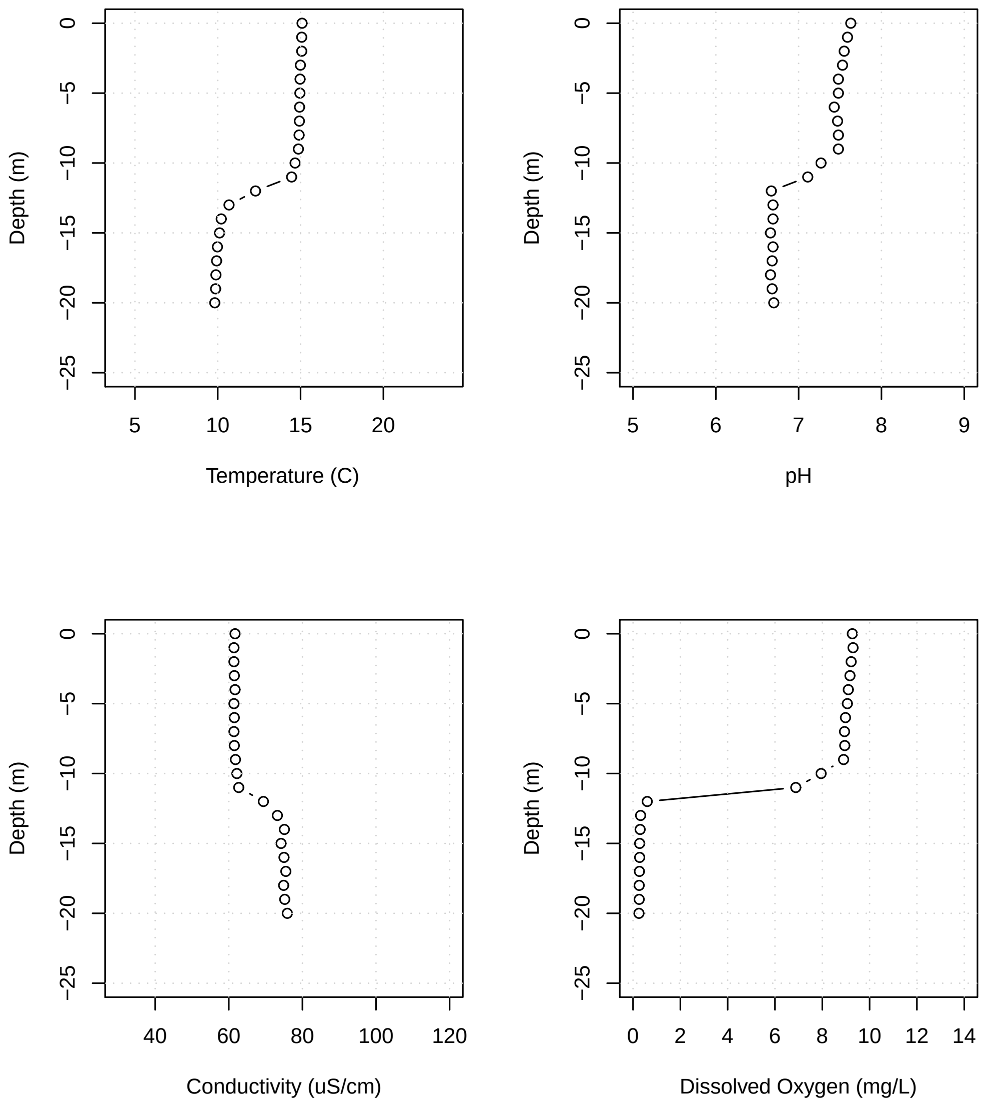


Figure B1: Lake Whatcom Hydrolab profile for Site 1, October 8, 2009.

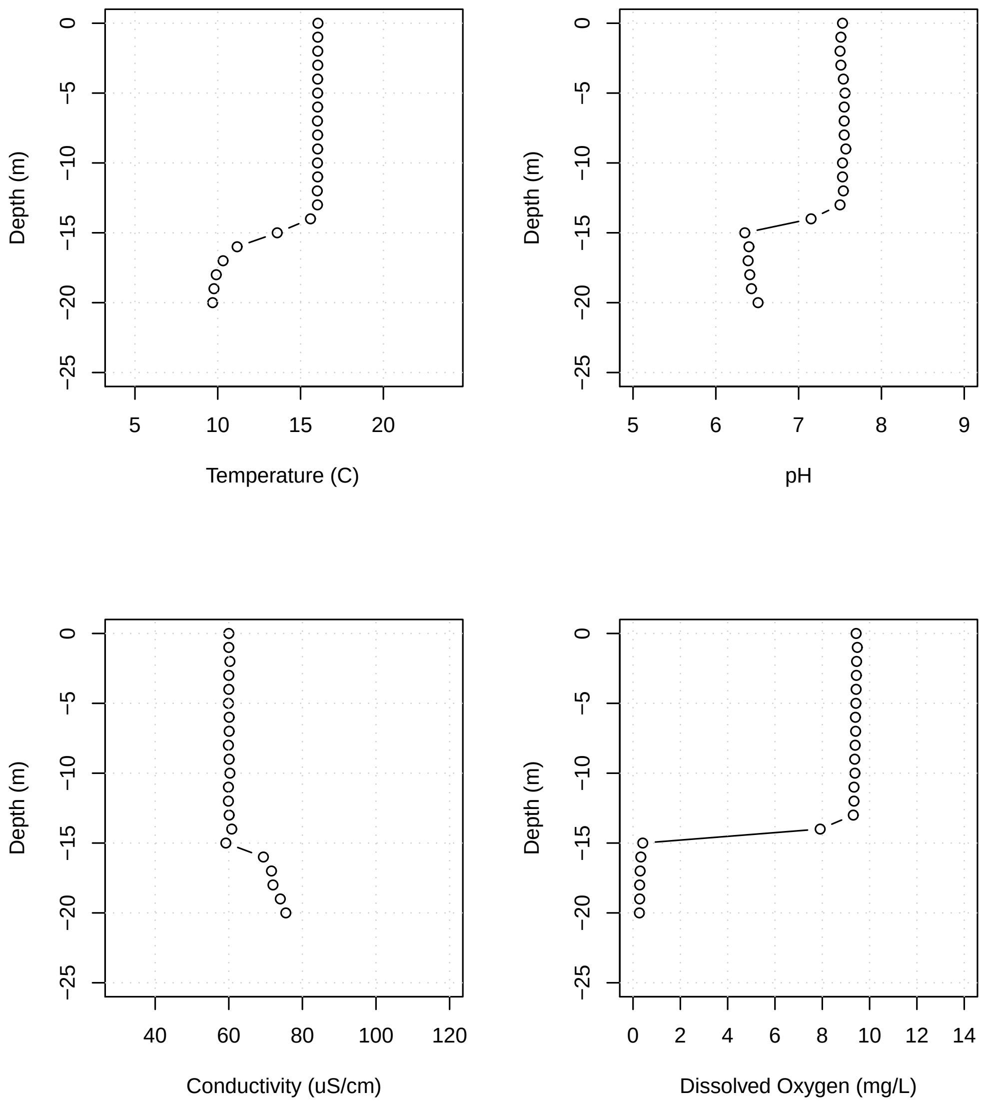


Figure B2: Lake Whatcom Hydrolab profile for Site 2, October 8, 2009.

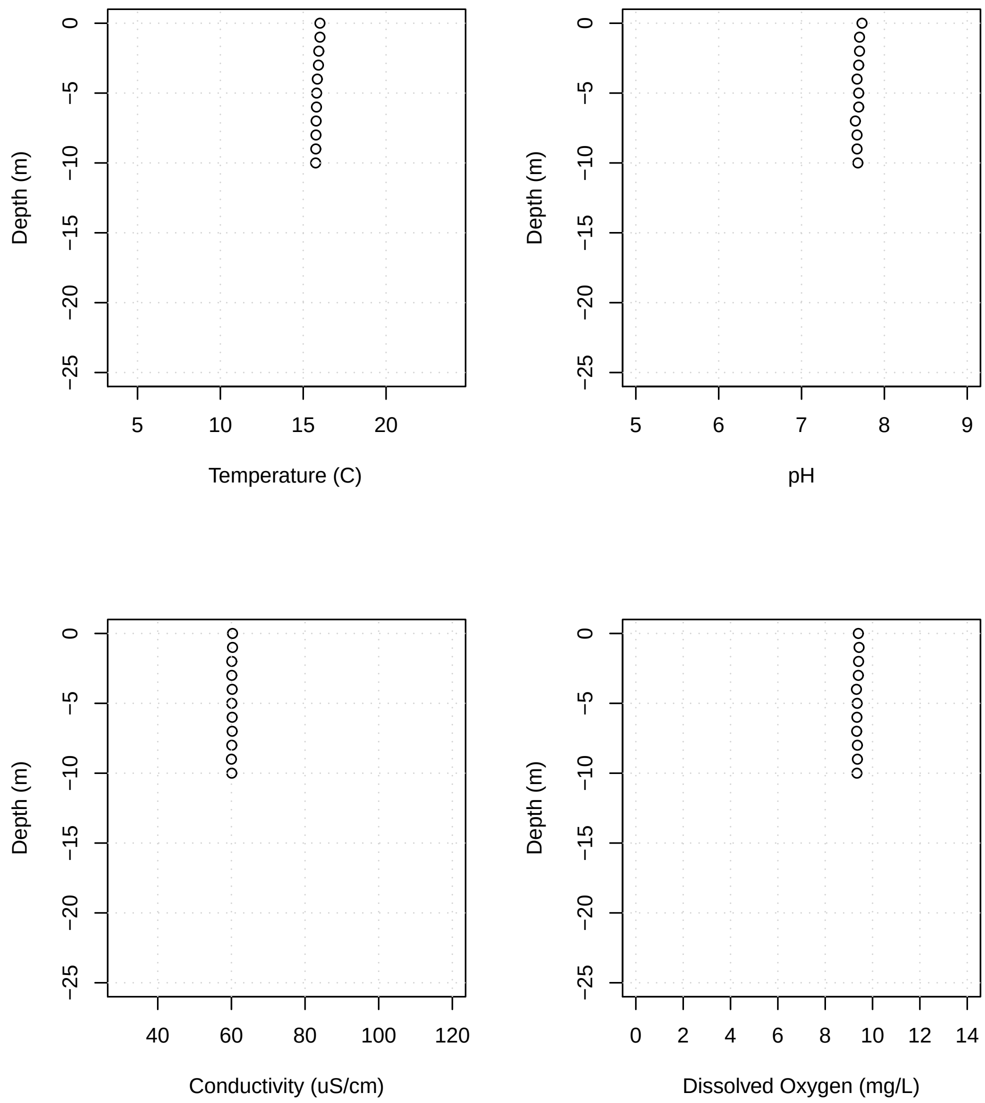


Figure B3: Lake Whatcom Hydrolab profile for the Intake, October 8, 2009.

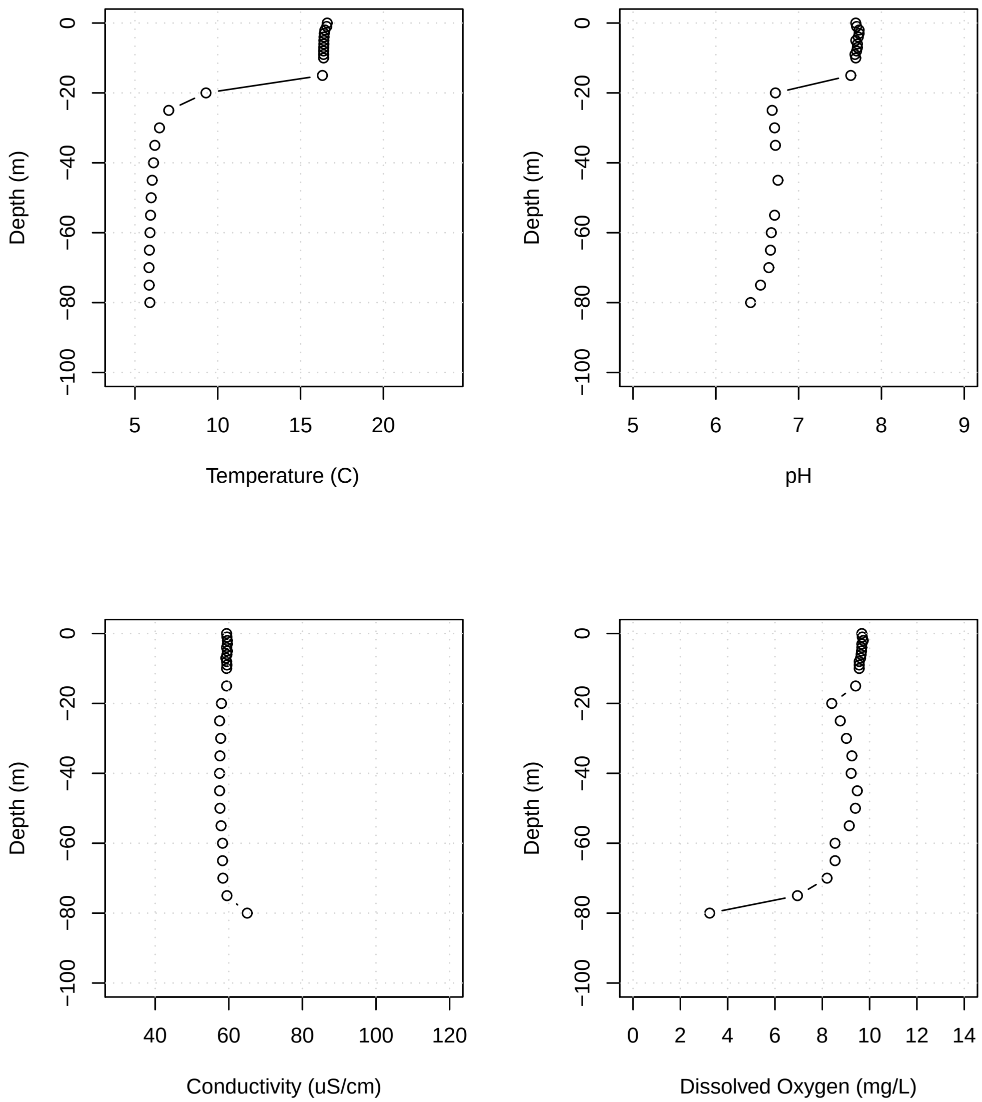


Figure B4: Lake Whatcom Hydrolab profile for Site 3, October 6, 2009. The pH values from 40m and 50 m are missing due to instrumentation error.

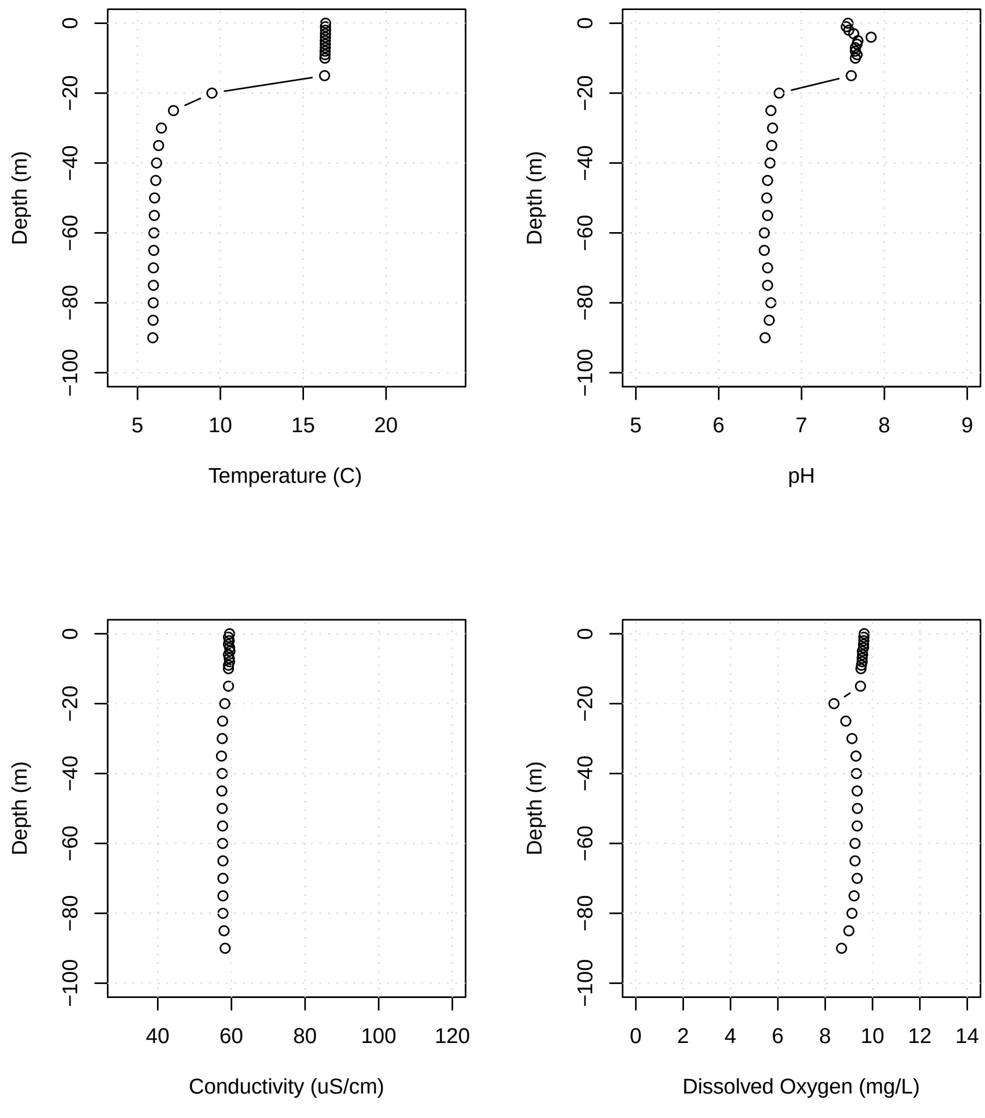


Figure B5: Lake Whatcom Hydrolab profile for Site 4, October 6, 2009.

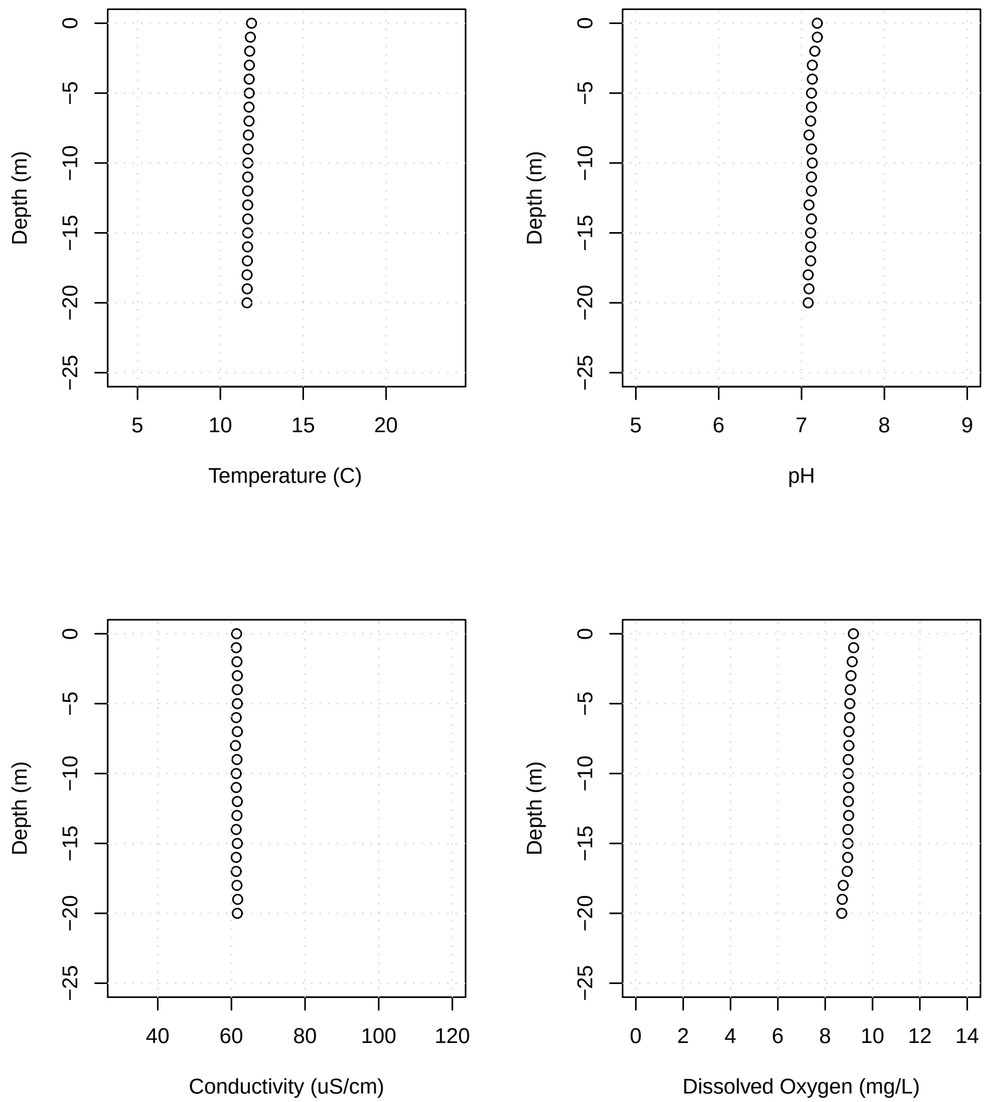


Figure B6: Lake Whatcom Hydrolab profile for Site 1, November 4, 2009.

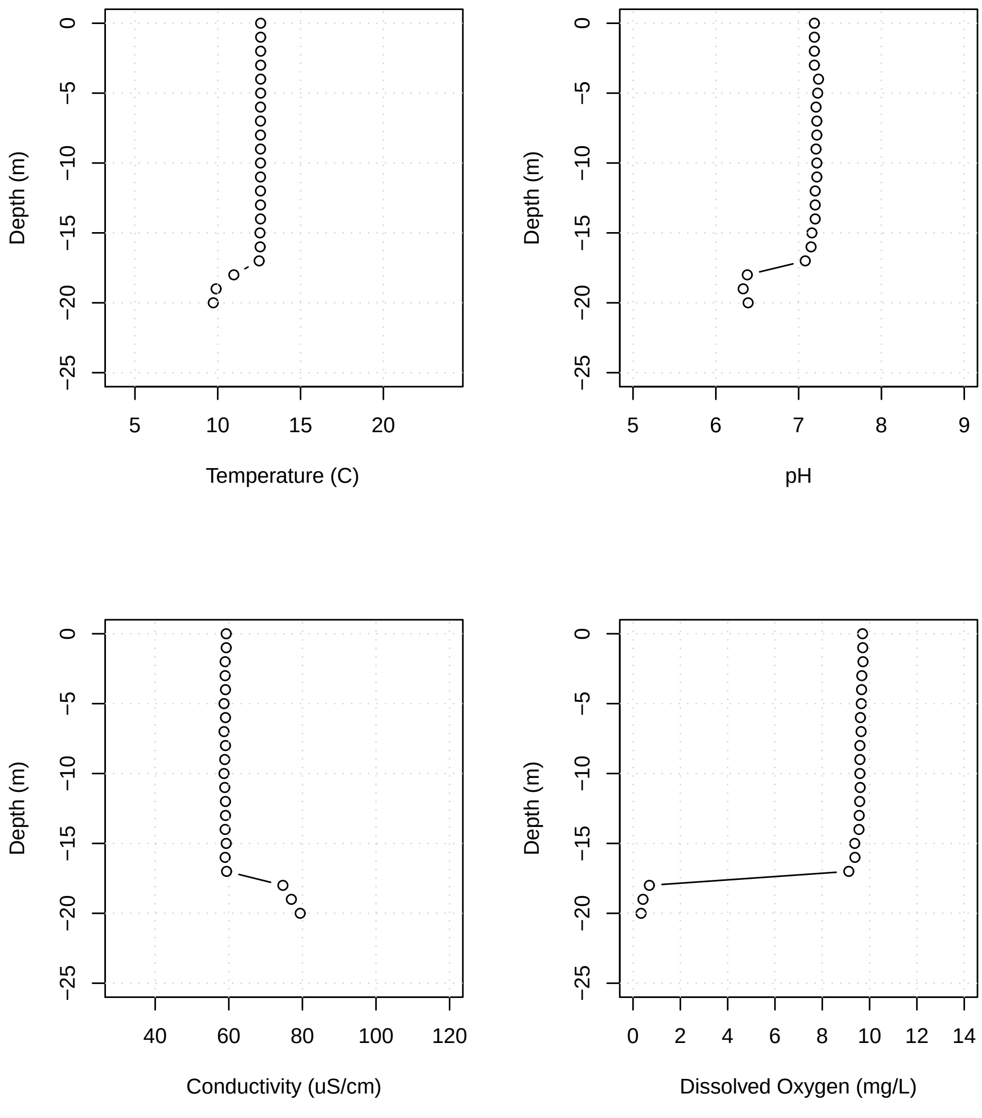


Figure B7: Lake Whatcom Hydrolab profile for Site 2, November 4, 2009.

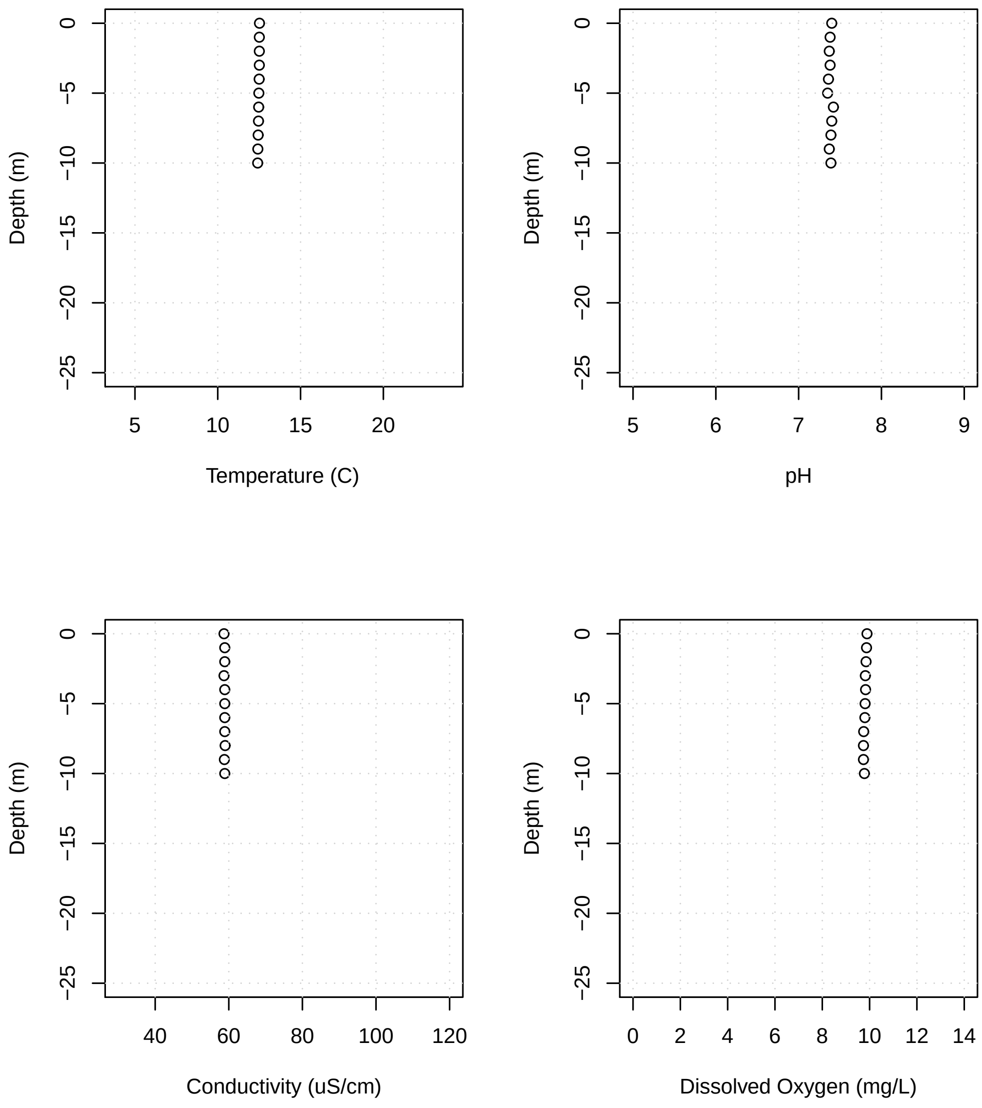


Figure B8: Lake Whatcom Hydrolab profile for the Intake, November 4, 2009.

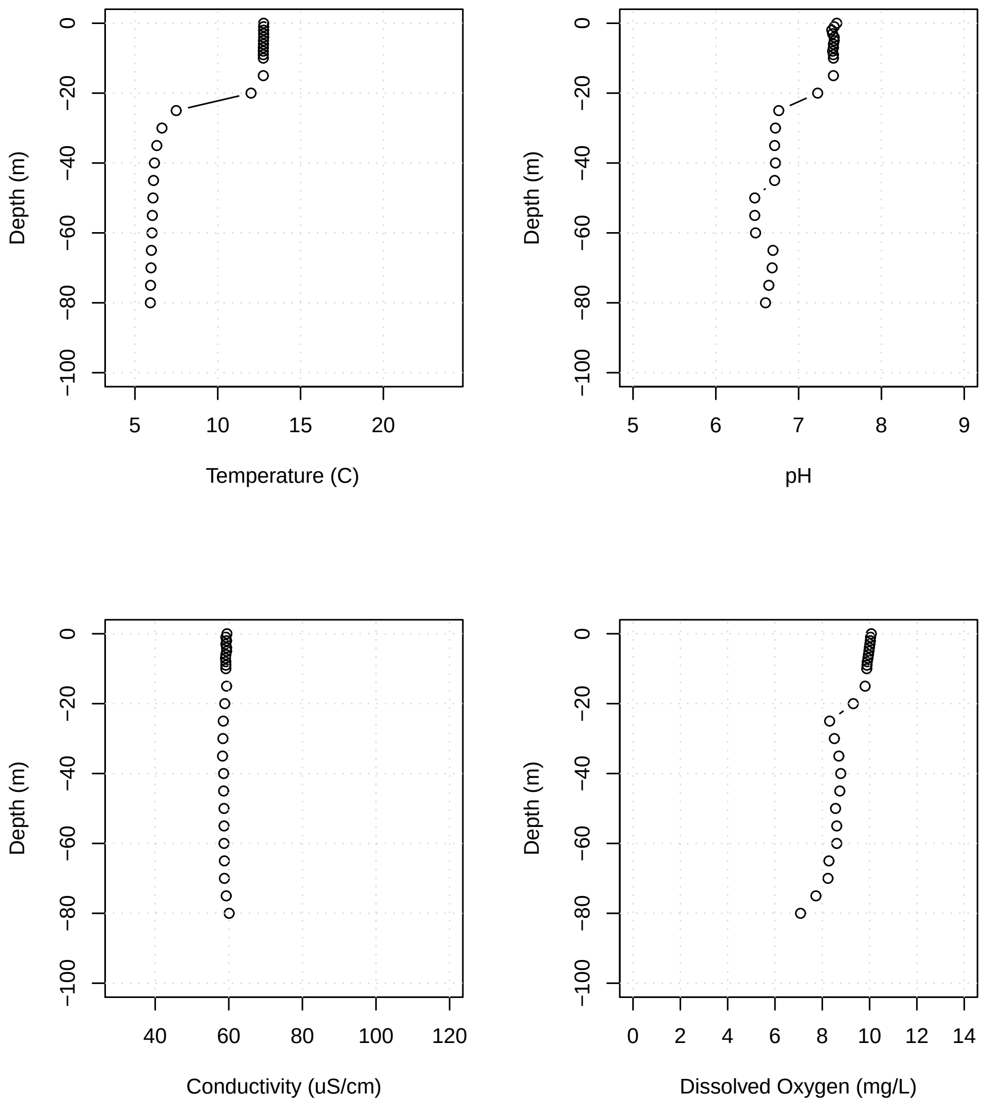


Figure B9: Lake Whatcom Hydrolab profile for Site 3, November 3, 2009.

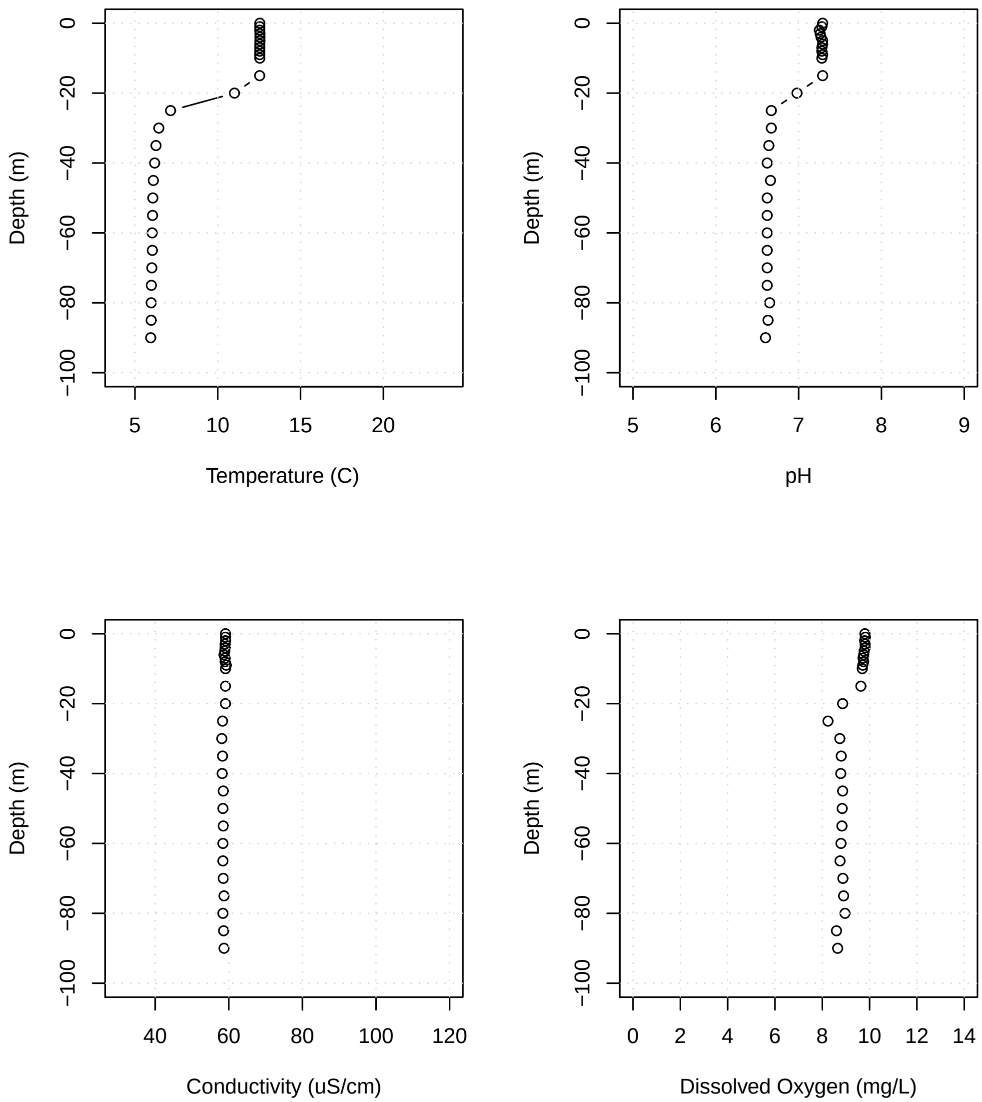


Figure B10: Lake Whatcom Hydrolab profile for Site 4, November 3, 2009.

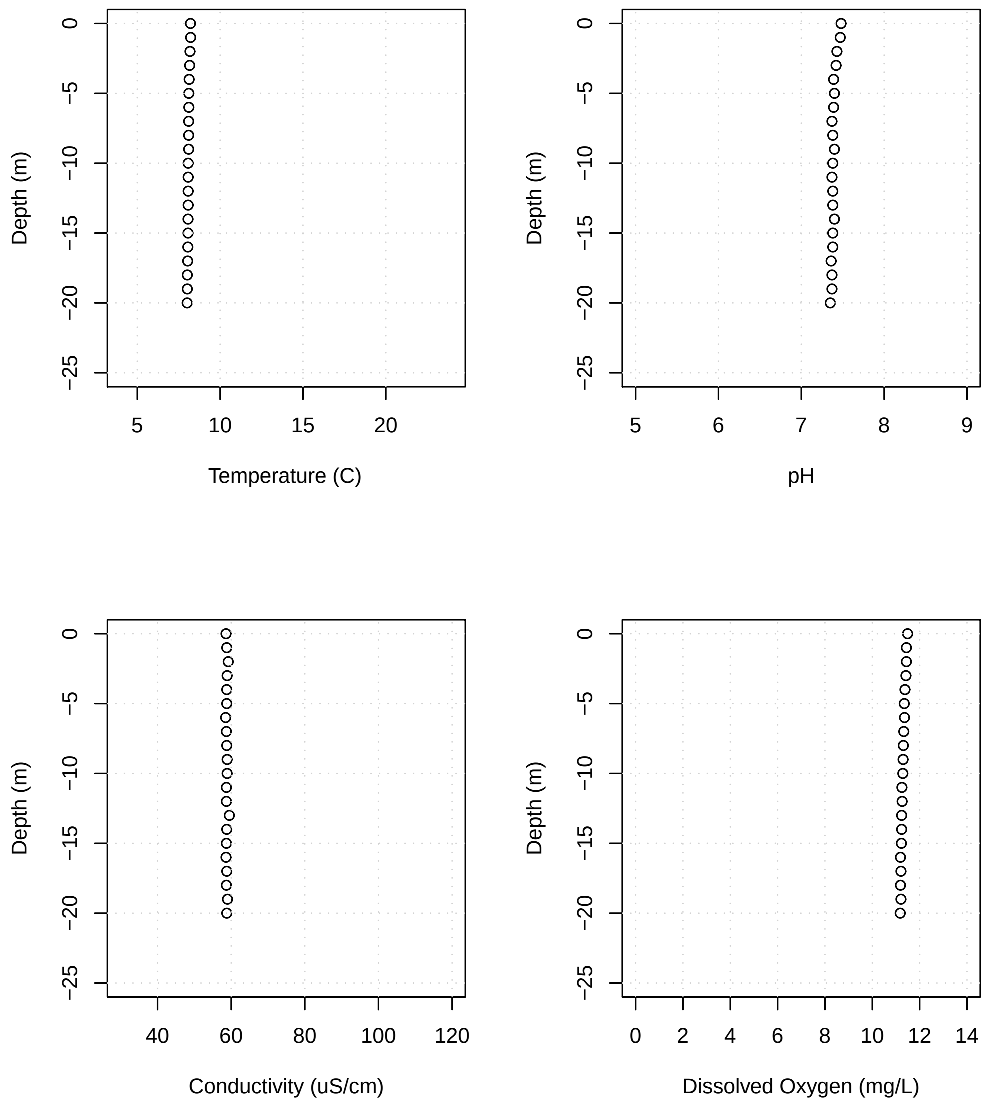


Figure B11: Lake Whatcom Hydrolab profile for Site 1, December 2, 2009.

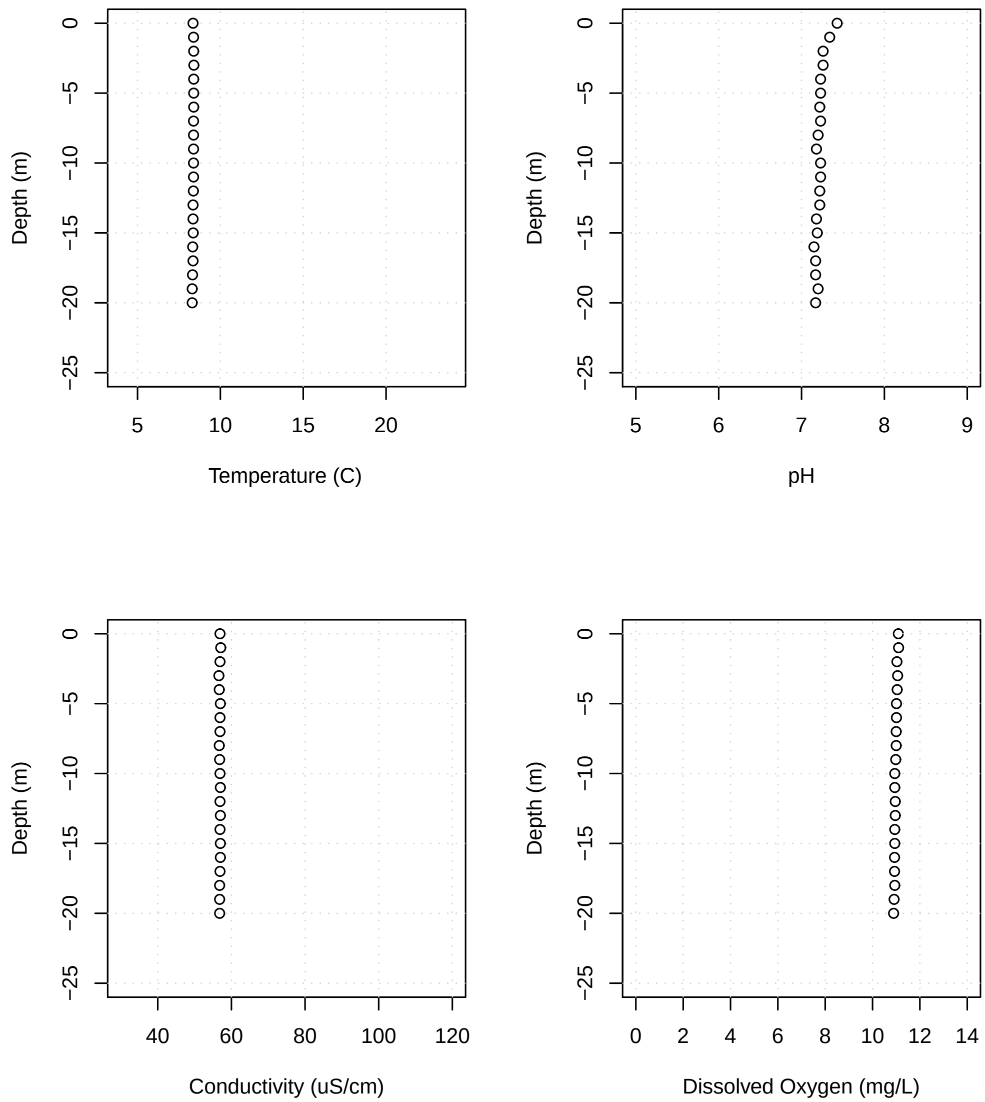


Figure B12: Lake Whatcom Hydrolab profile for Site 2, December 2, 2009.

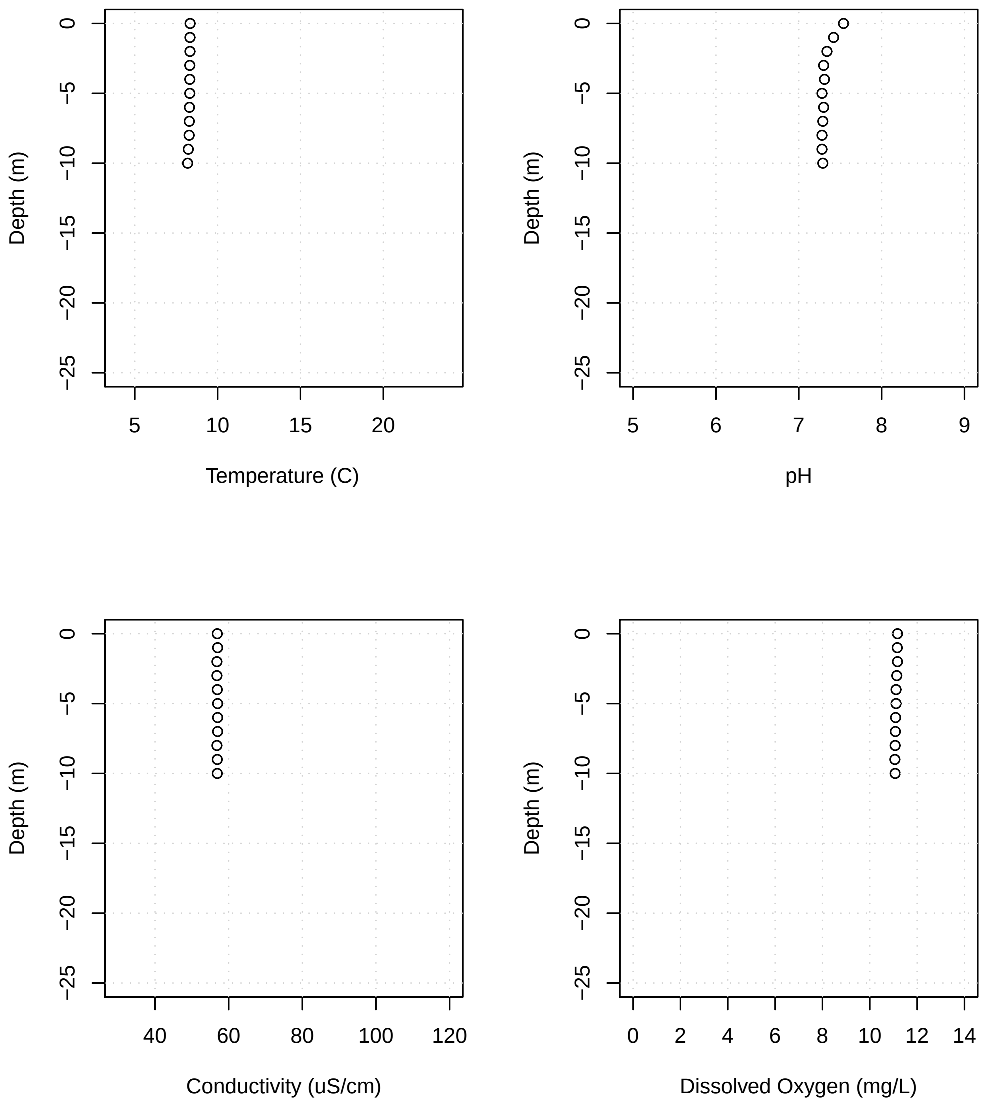


Figure B13: Lake Whatcom Hydrolab profile for the Intake, December 2, 2009.

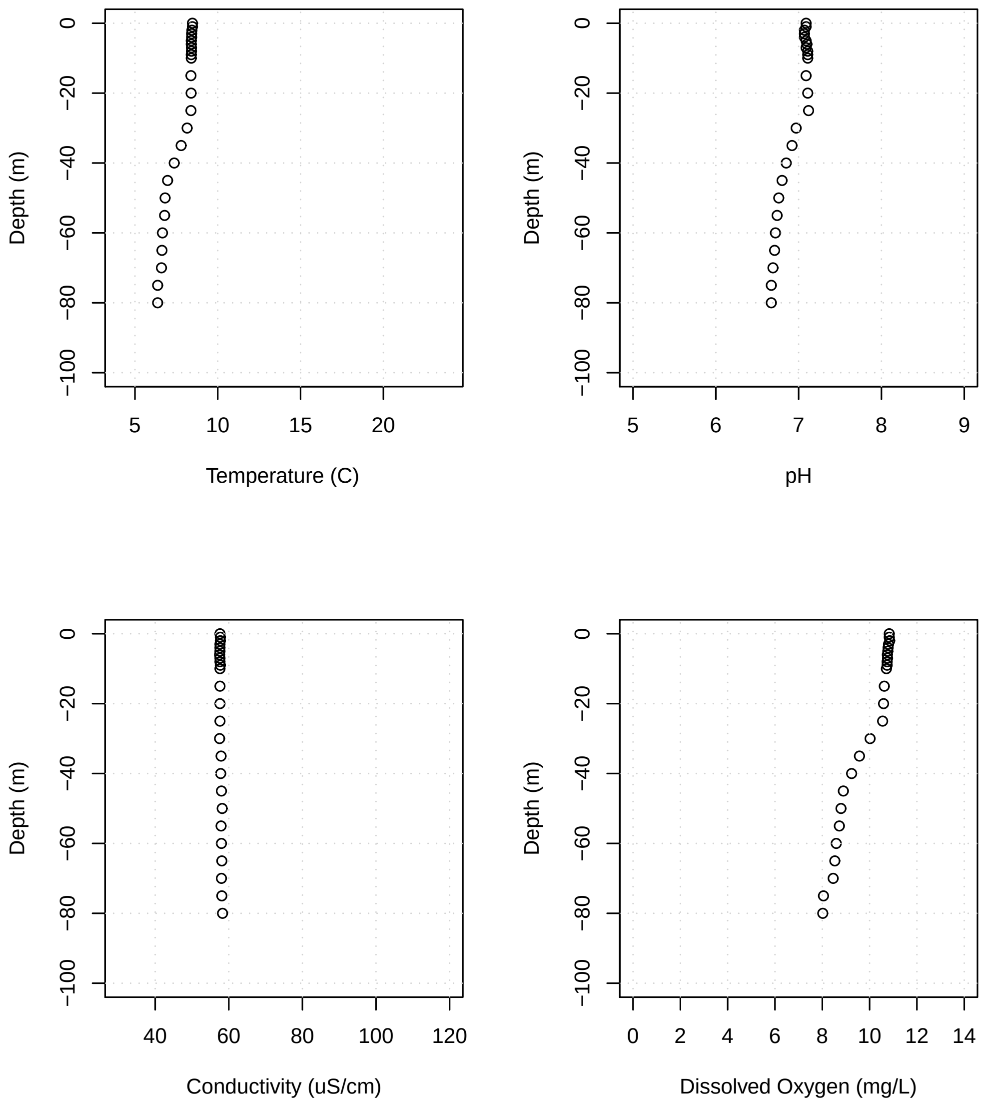


Figure B14: Lake Whatcom Hydrolab profile for Site 3, December 1, 2009.

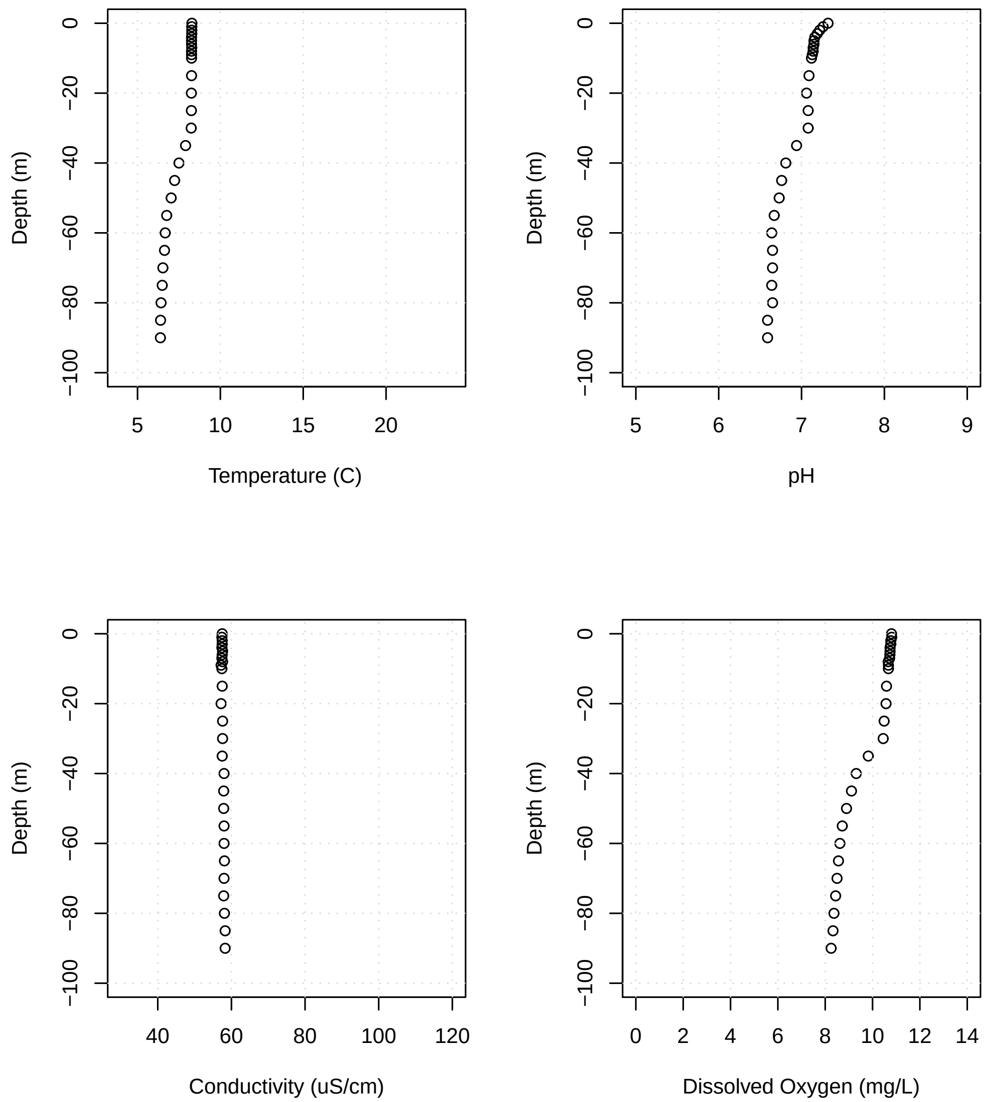


Figure B15: Lake Whatcom Hydrolab profile for Site 4, December 1, 2009.

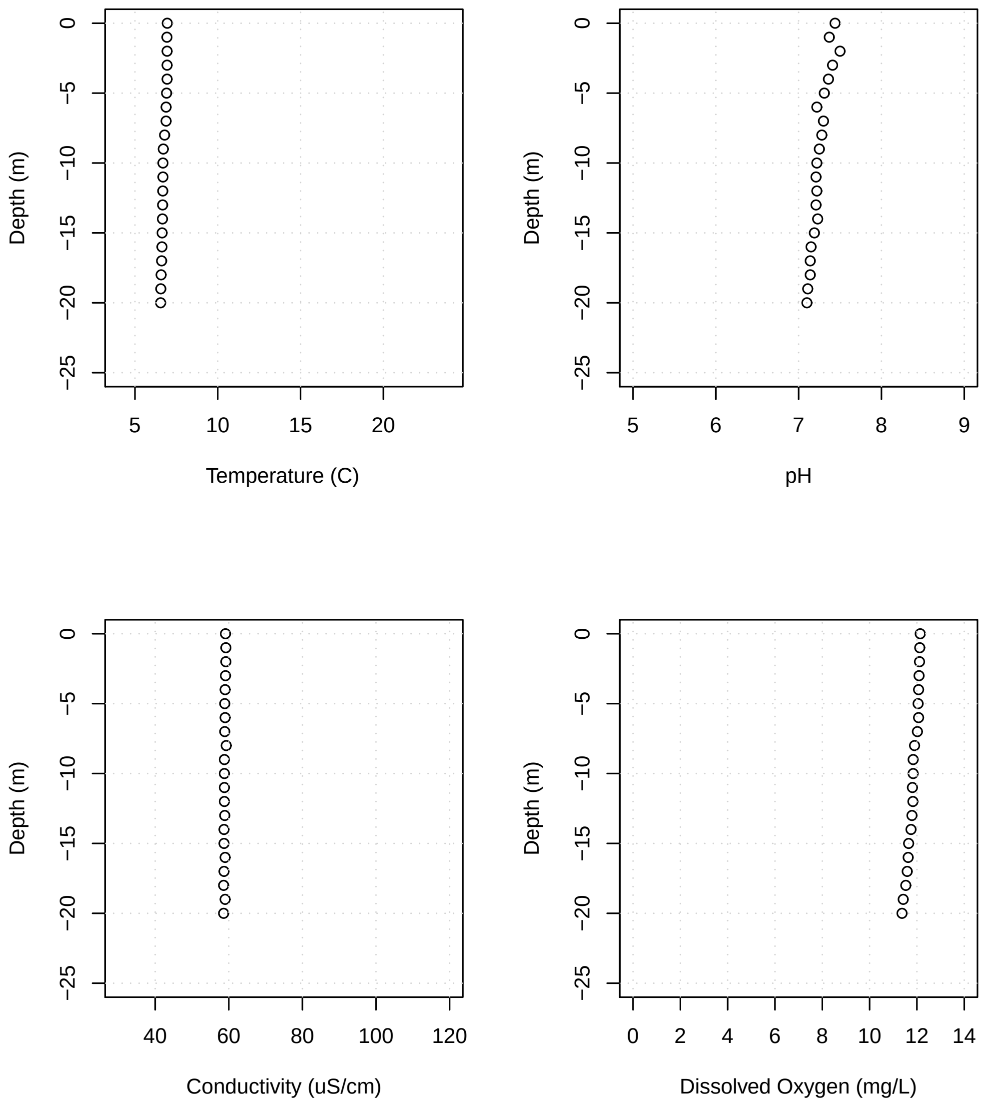


Figure B16: Lake Whatcom Hydrolab profile for Site 1, February 9, 2010.

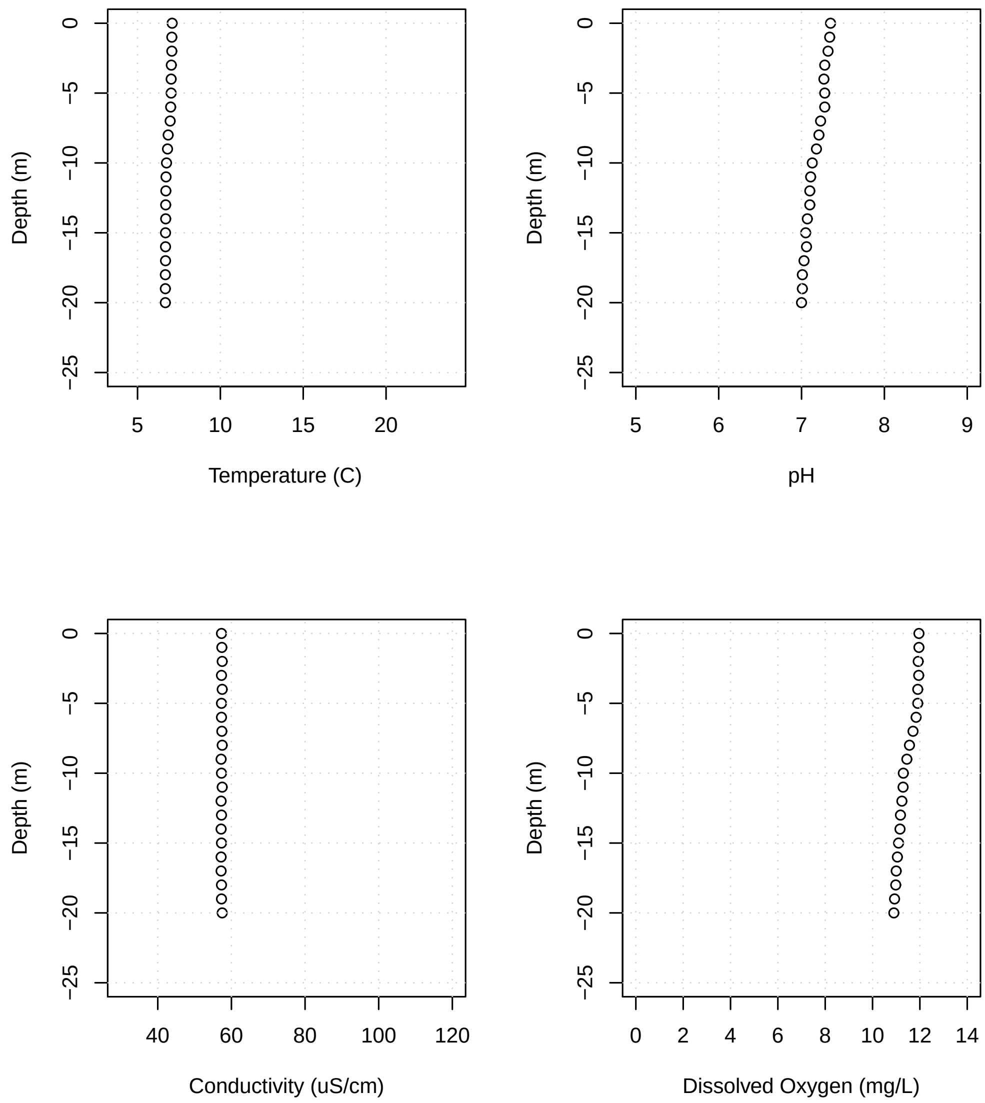


Figure B17: Lake Whatcom Hydrolab profile for Site 2, February 9, 2010.

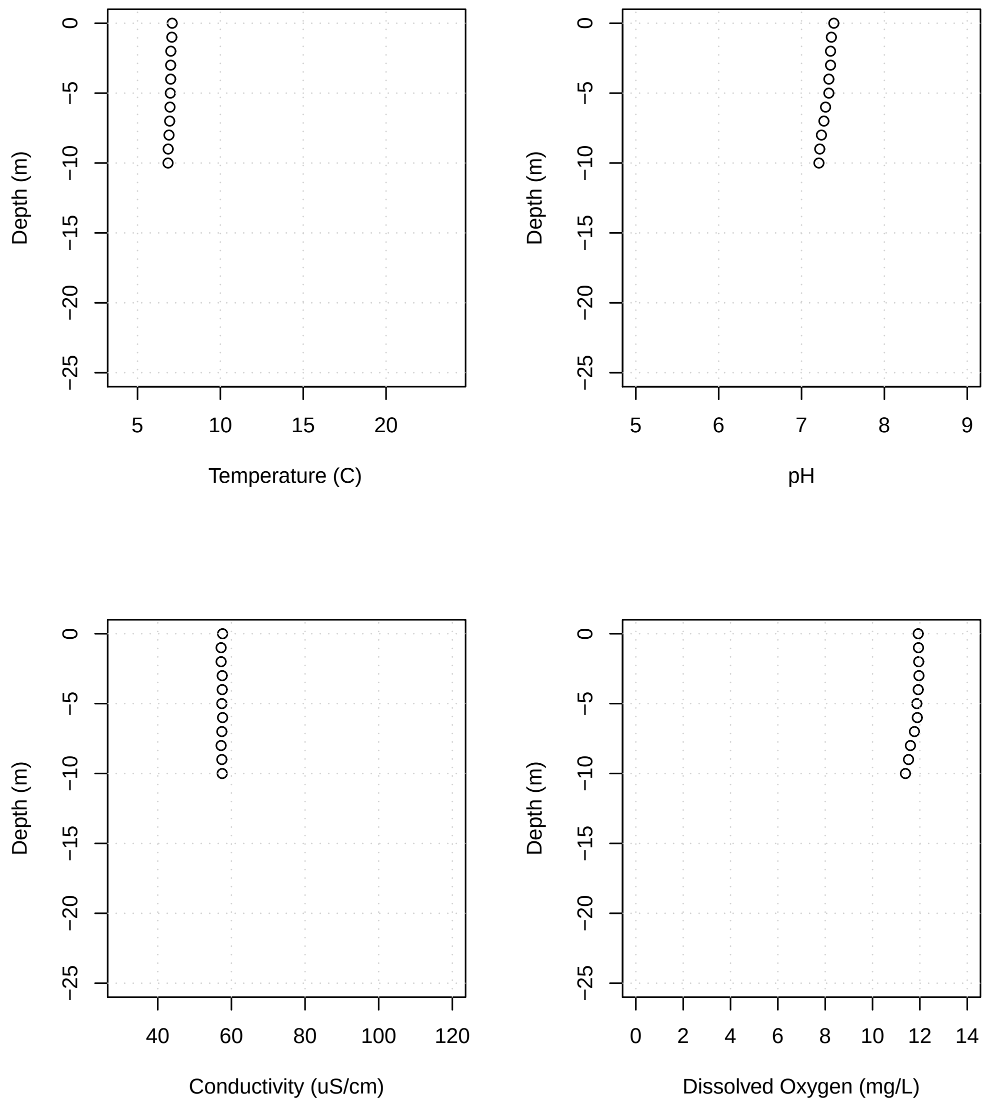


Figure B18: Lake Whatcom Hydrolab profile for the Intake, February 9, 2010.

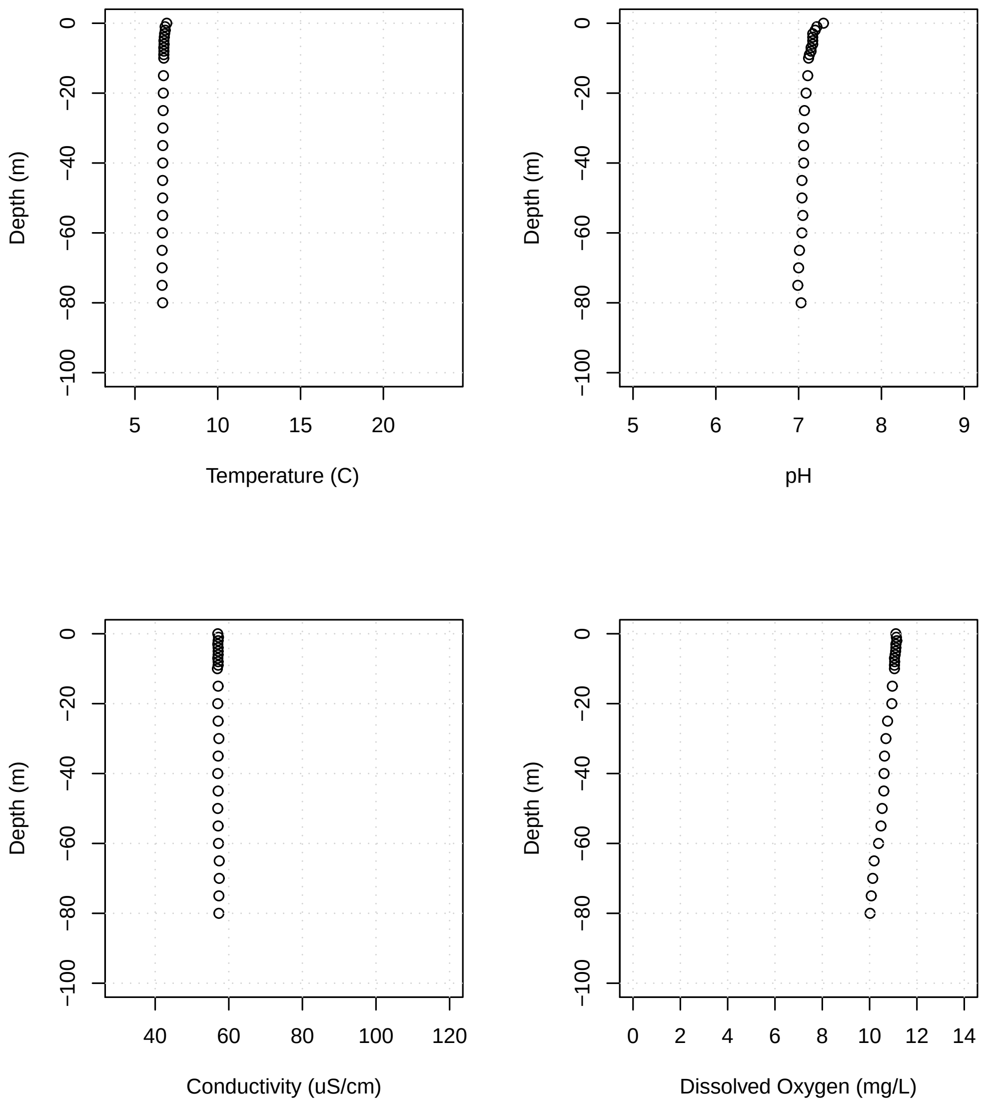


Figure B19: Lake Whatcom Hydrolab profile for Site 3, February 4, 2010.

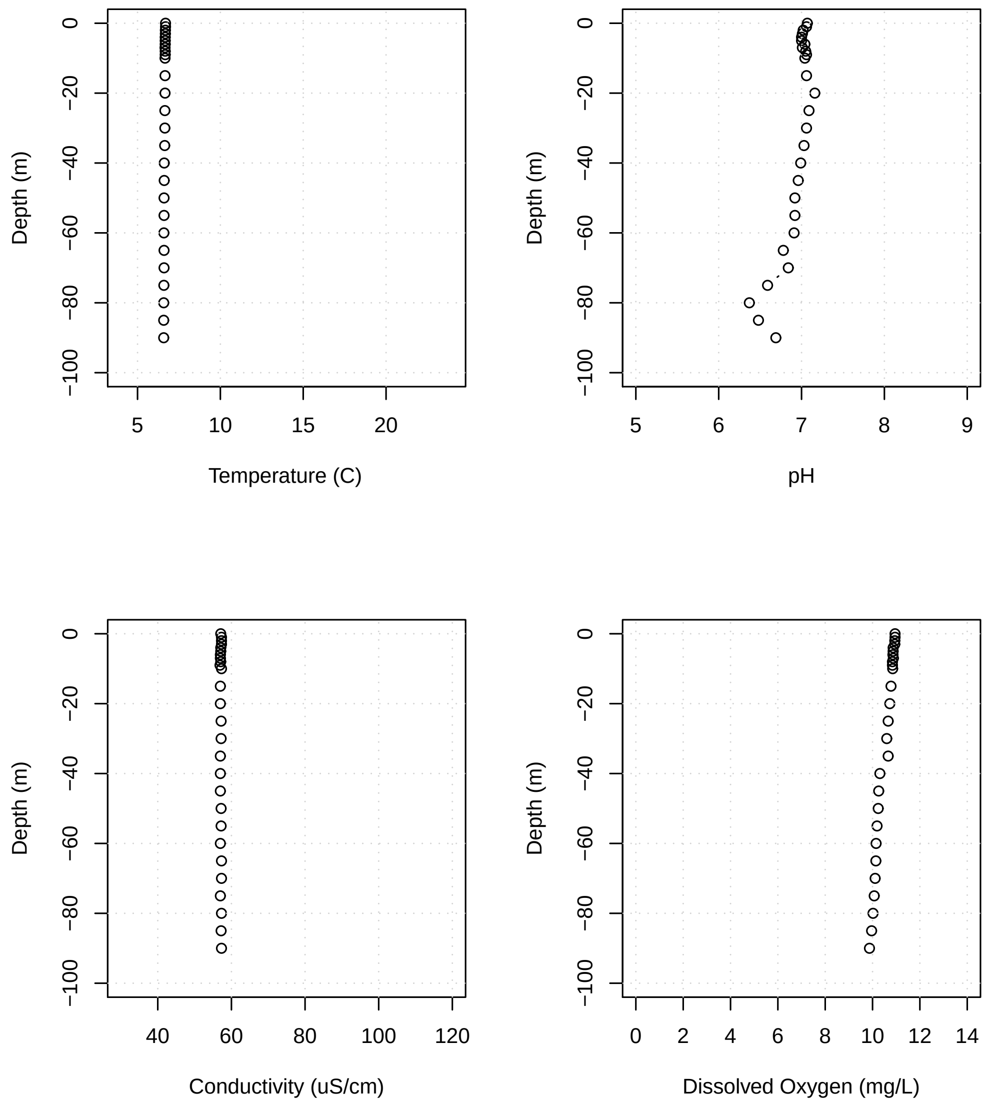


Figure B20: Lake Whatcom Hydrolab profile for Site 4, February 4, 2010.

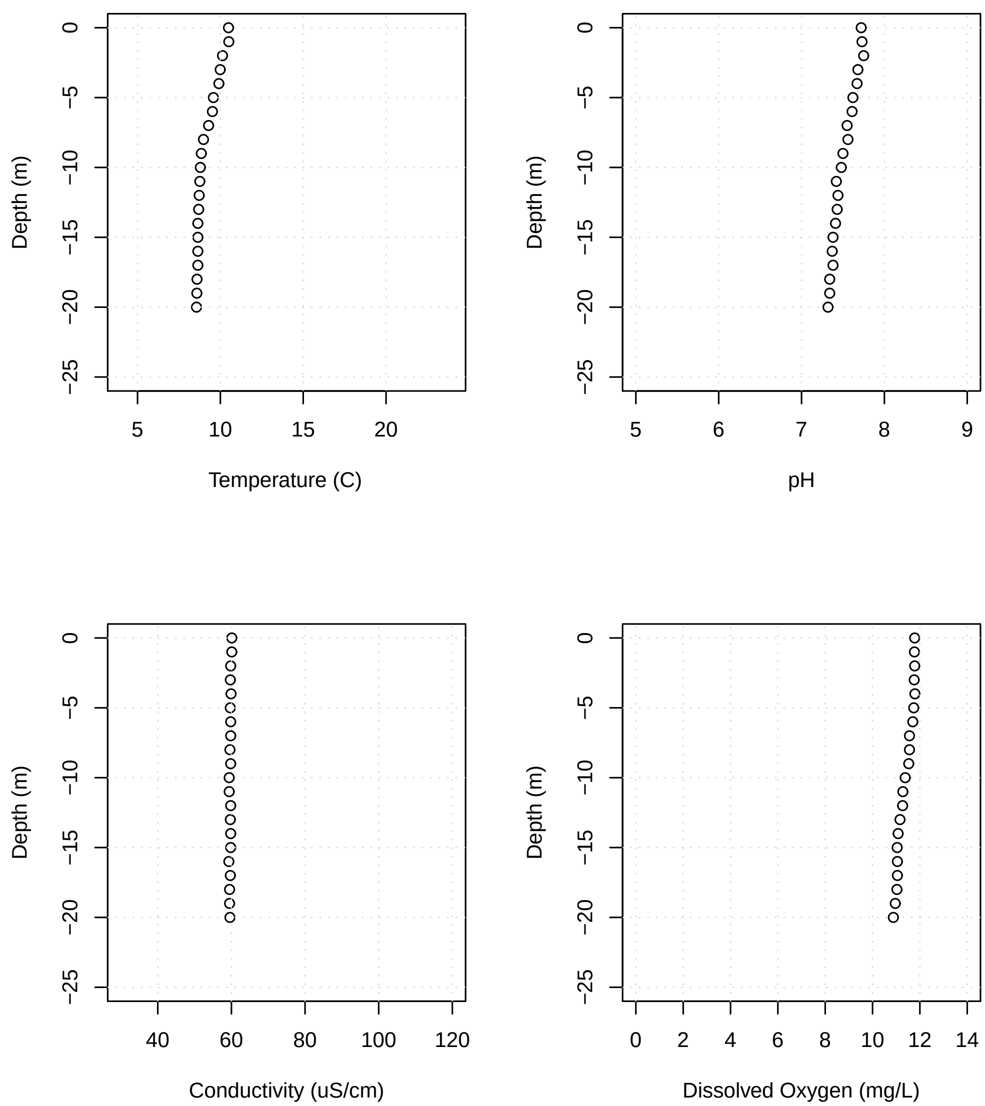


Figure B21: Lake Whatcom Hydrolab profile for Site 1, April 15, 2010.

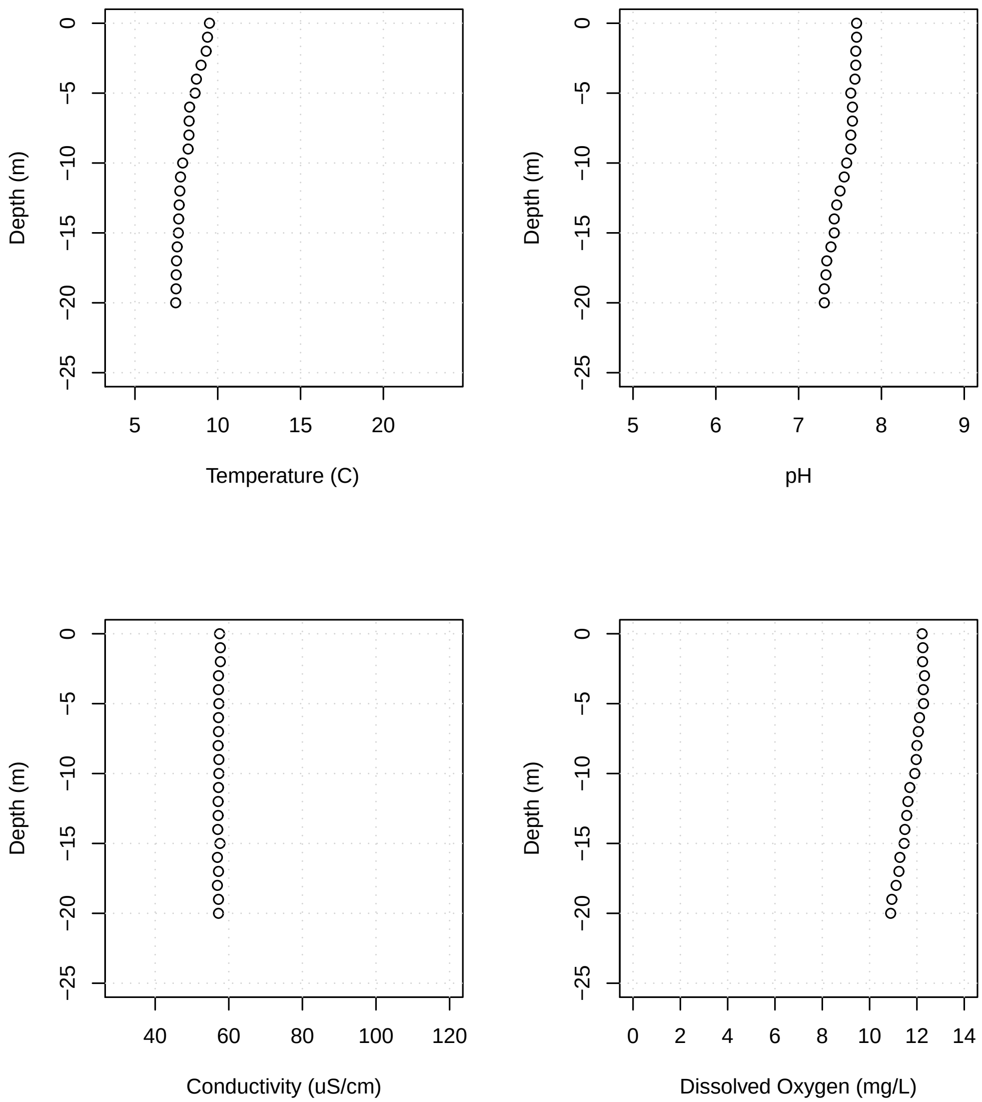


Figure B22: Lake Whatcom Hydrolab profile for Site 2, April 15, 2010.

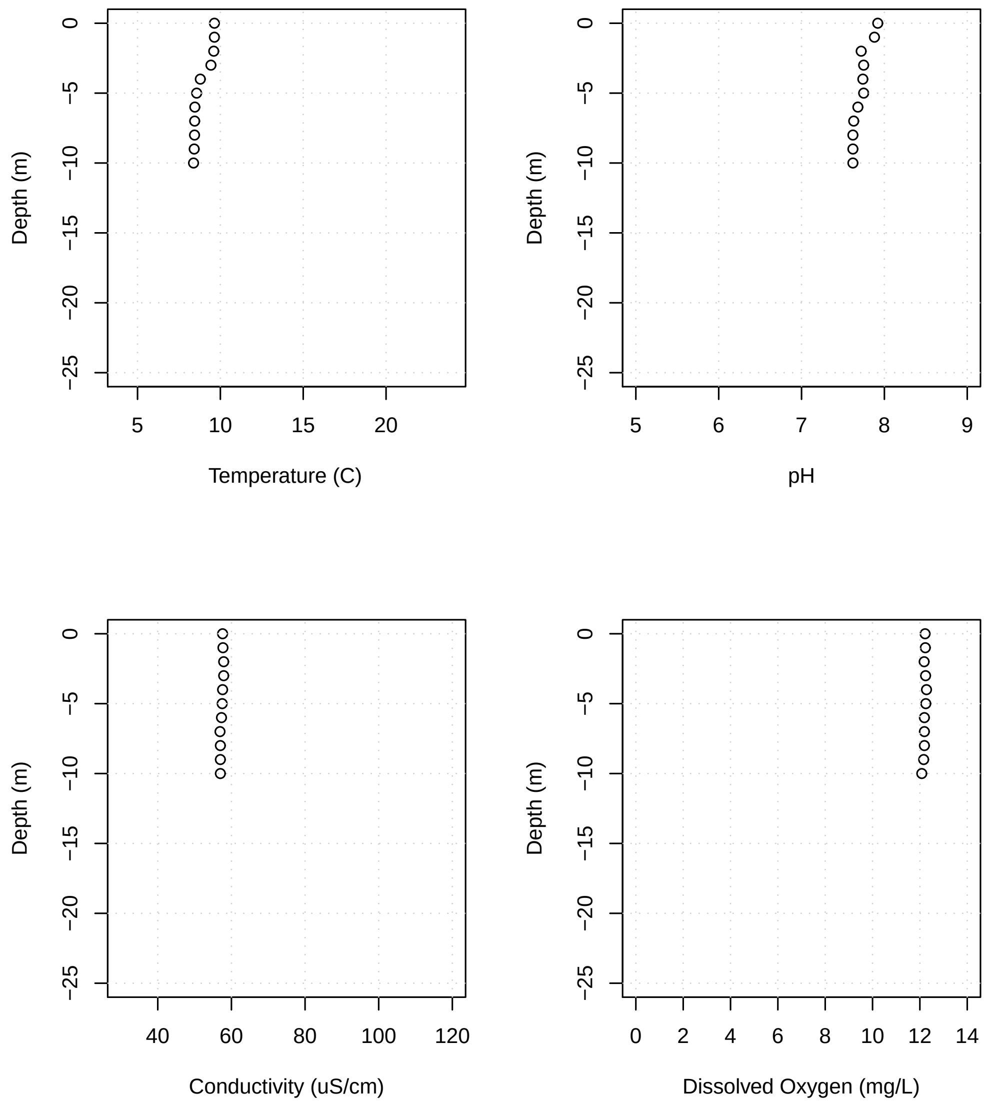


Figure B23: Lake Whatcom Hydrolab profile for the Intake, April 15, 2010.

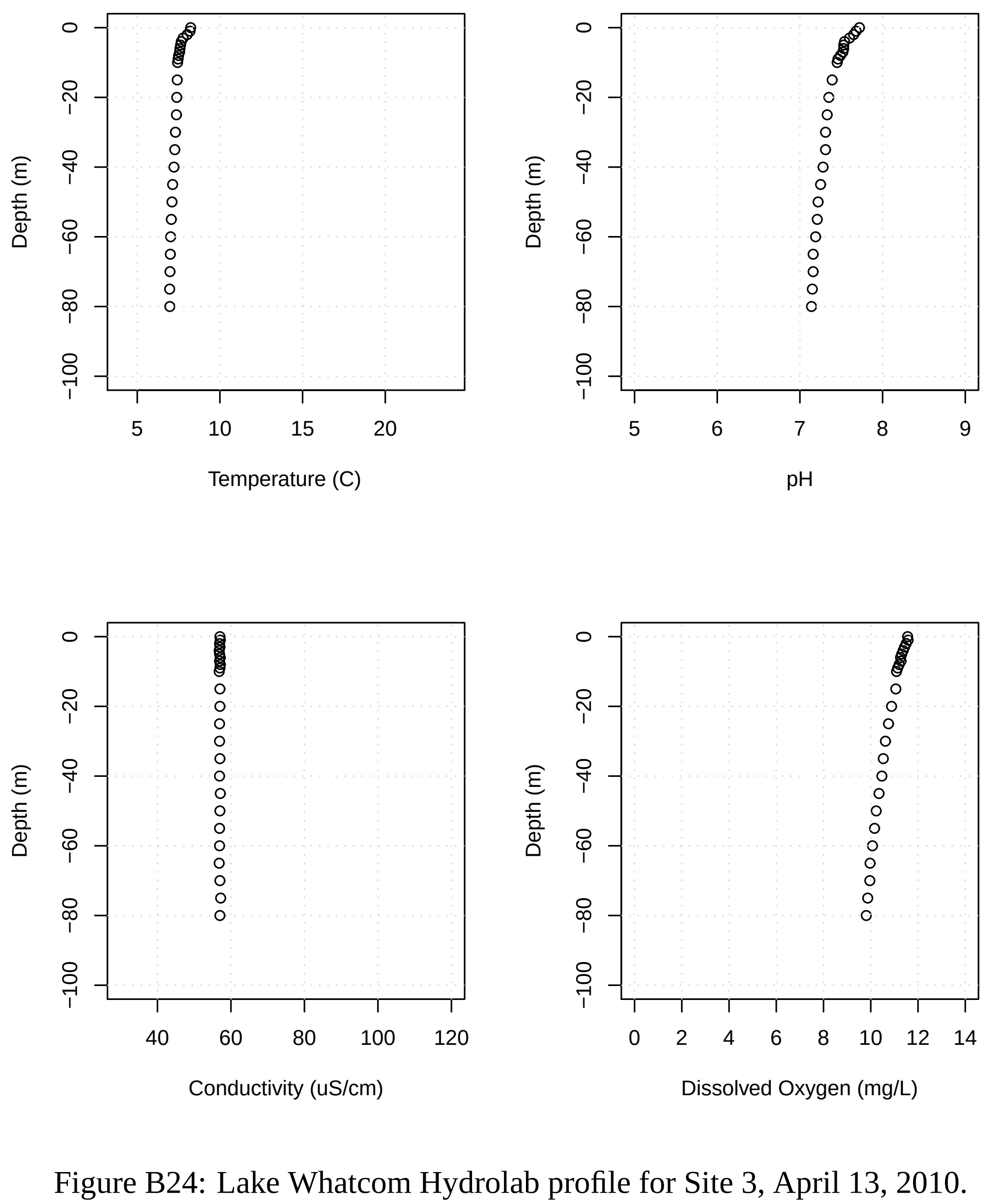


Figure B24: Lake Whatcom Hydrolab profile for Site 3, April 13, 2010.

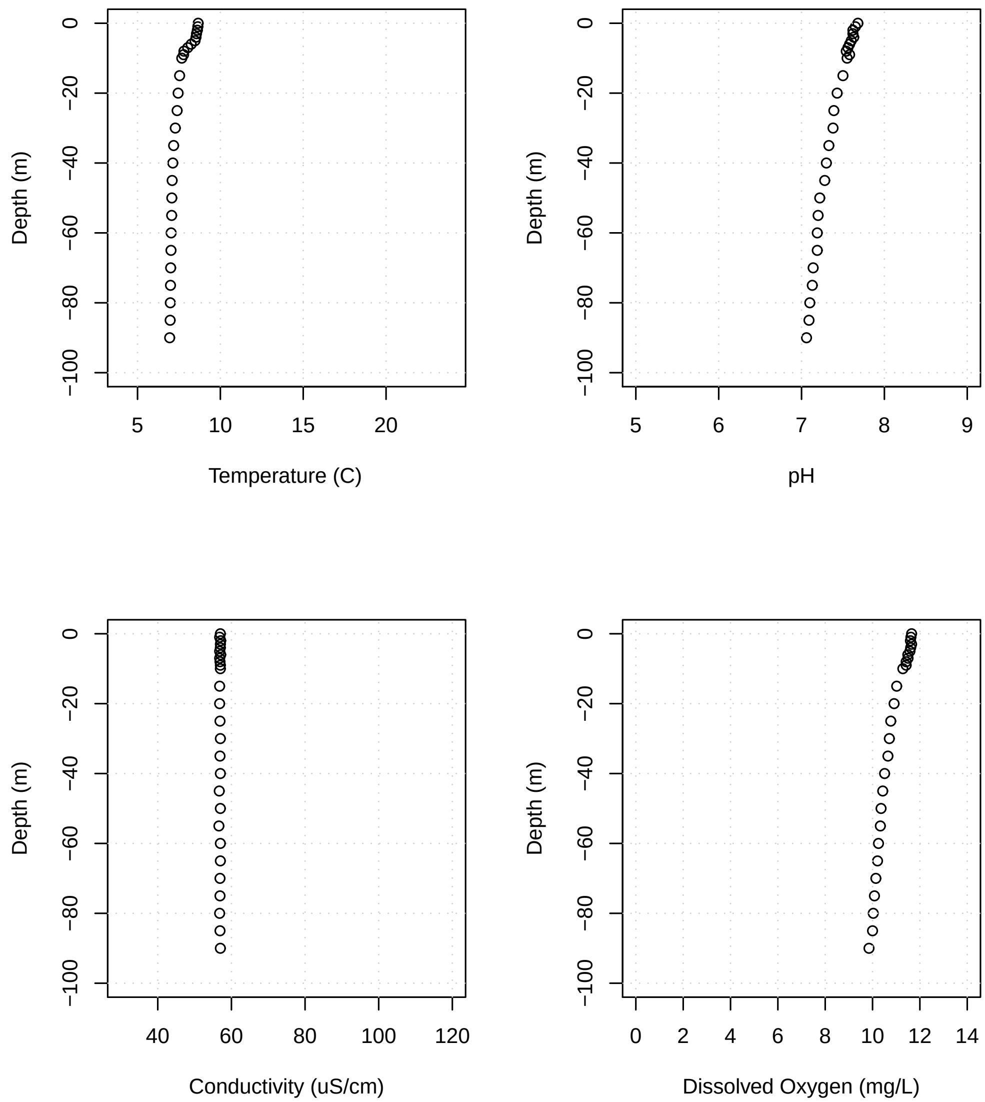


Figure B25: Lake Whatcom Hydrolab profile for Site 4, April 13, 2010.

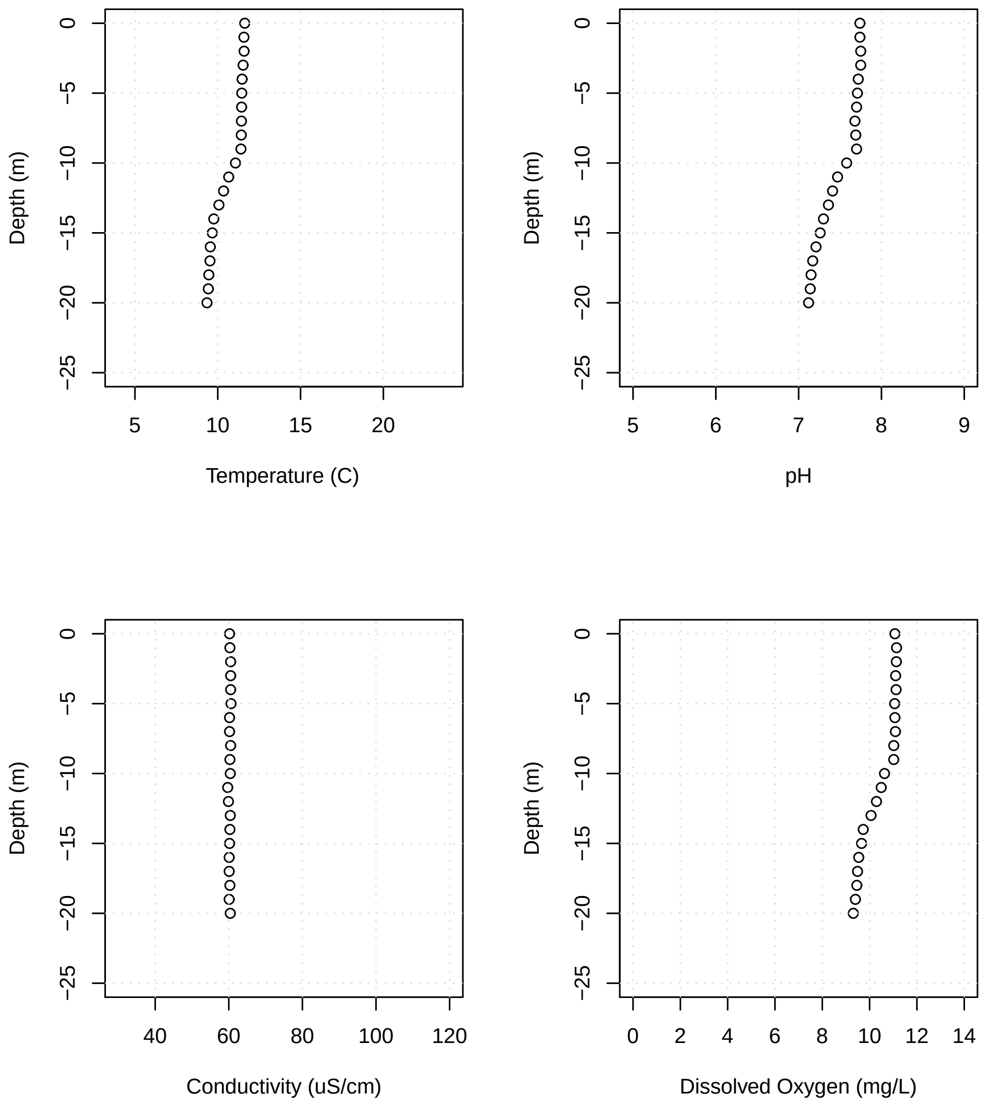


Figure B26: Lake Whatcom Hydrolab profile for Site 1, May 4, 2010.

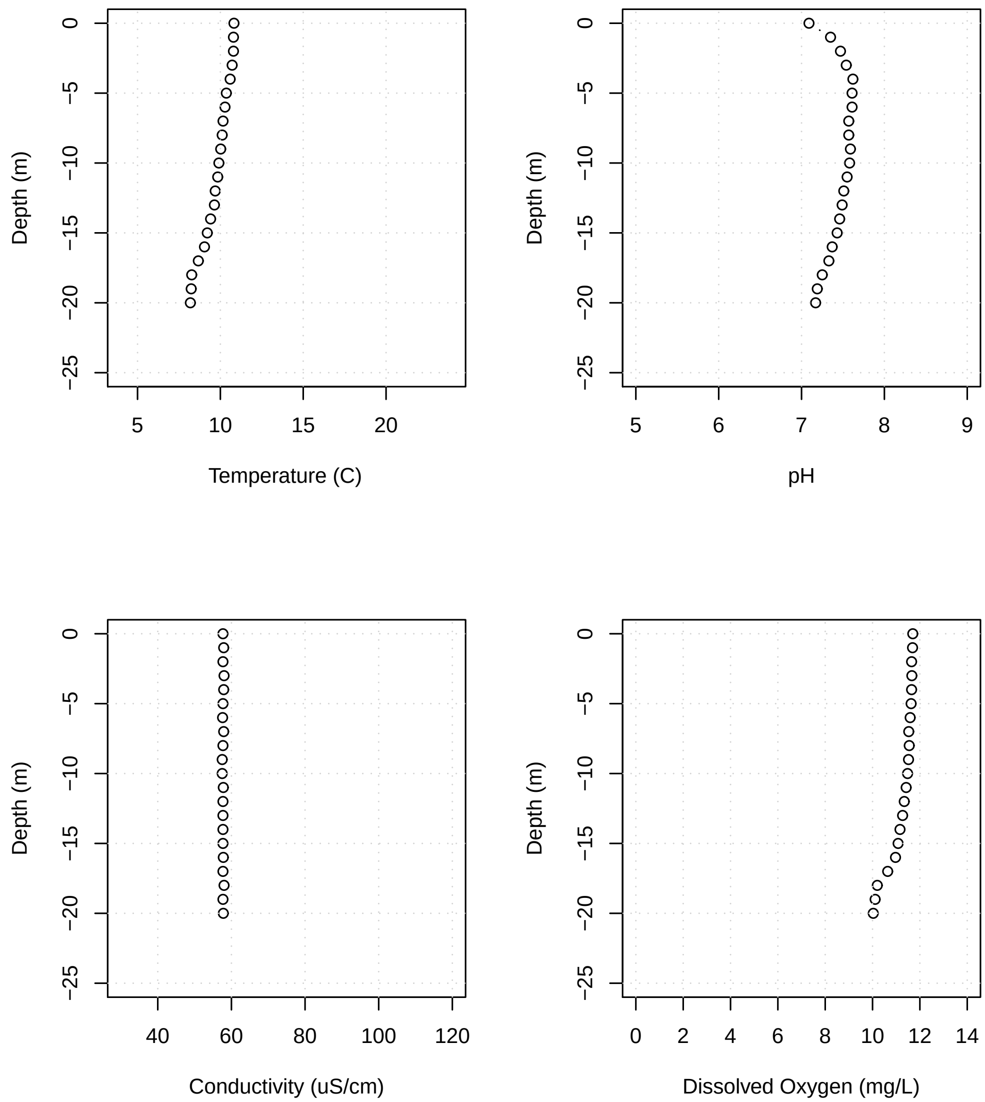


Figure B27: Lake Whatcom Hydrolab profile for Site 2, May 4, 2010.

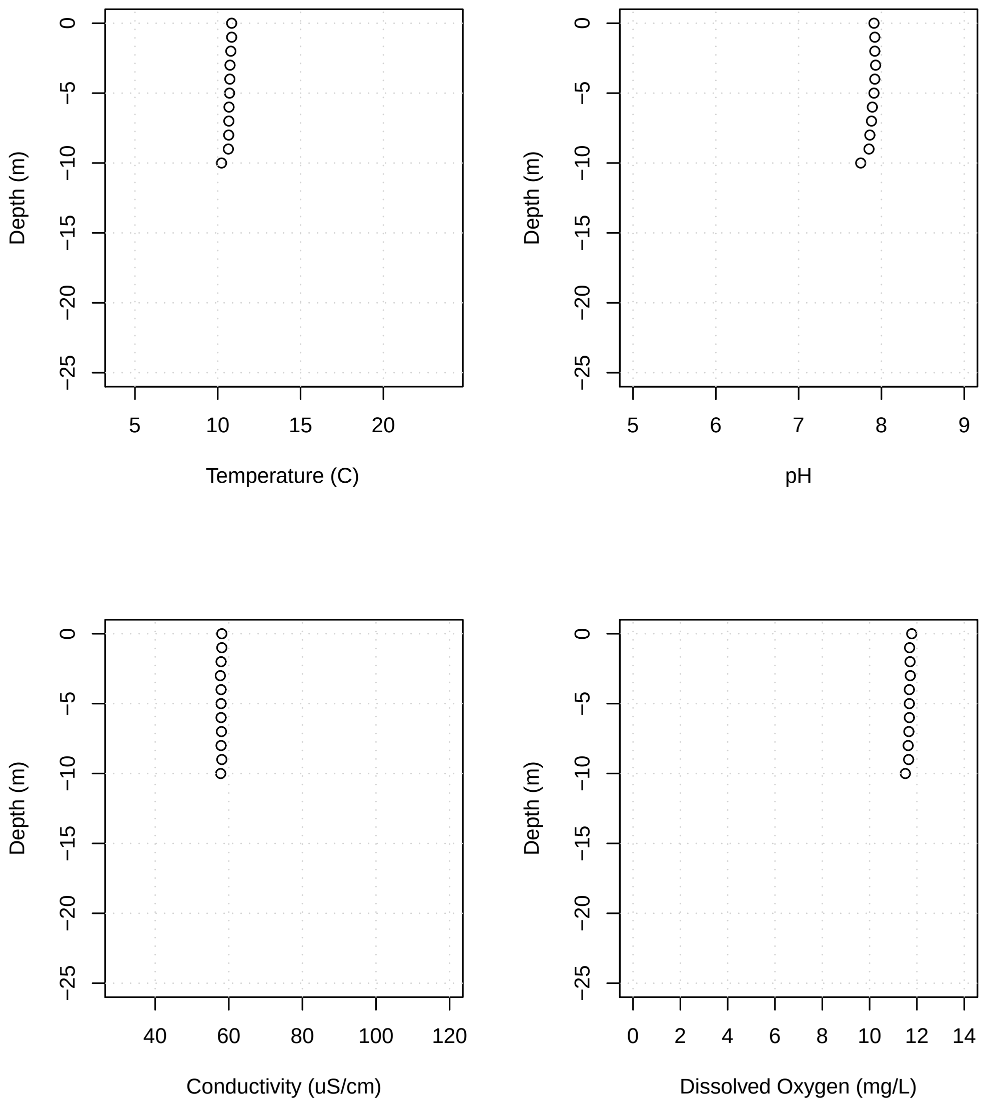


Figure B28: Lake Whatcom Hydrolab profile for the Intake, May 4, 2010.

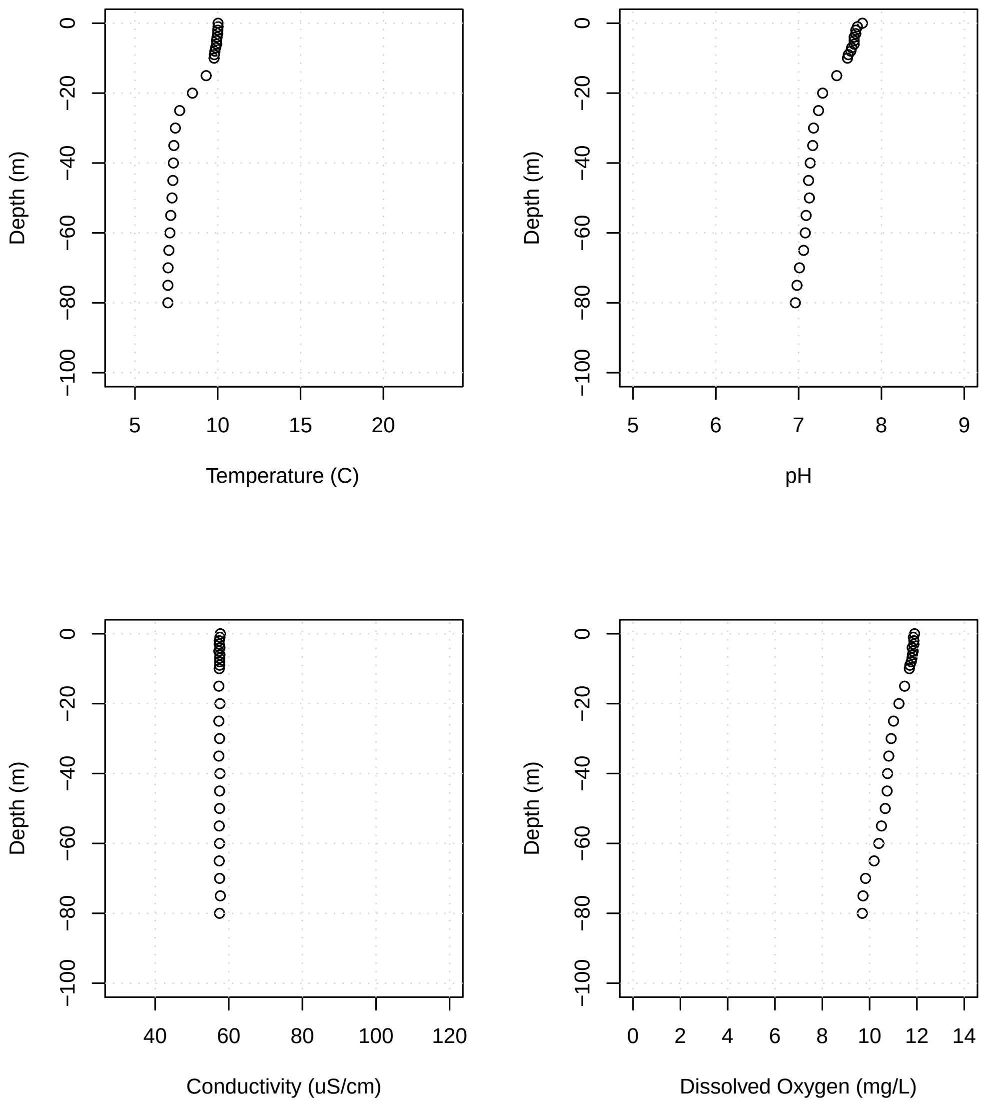


Figure B29: Lake Whatcom Hydrolab profile for Site 3, May 6, 2010.

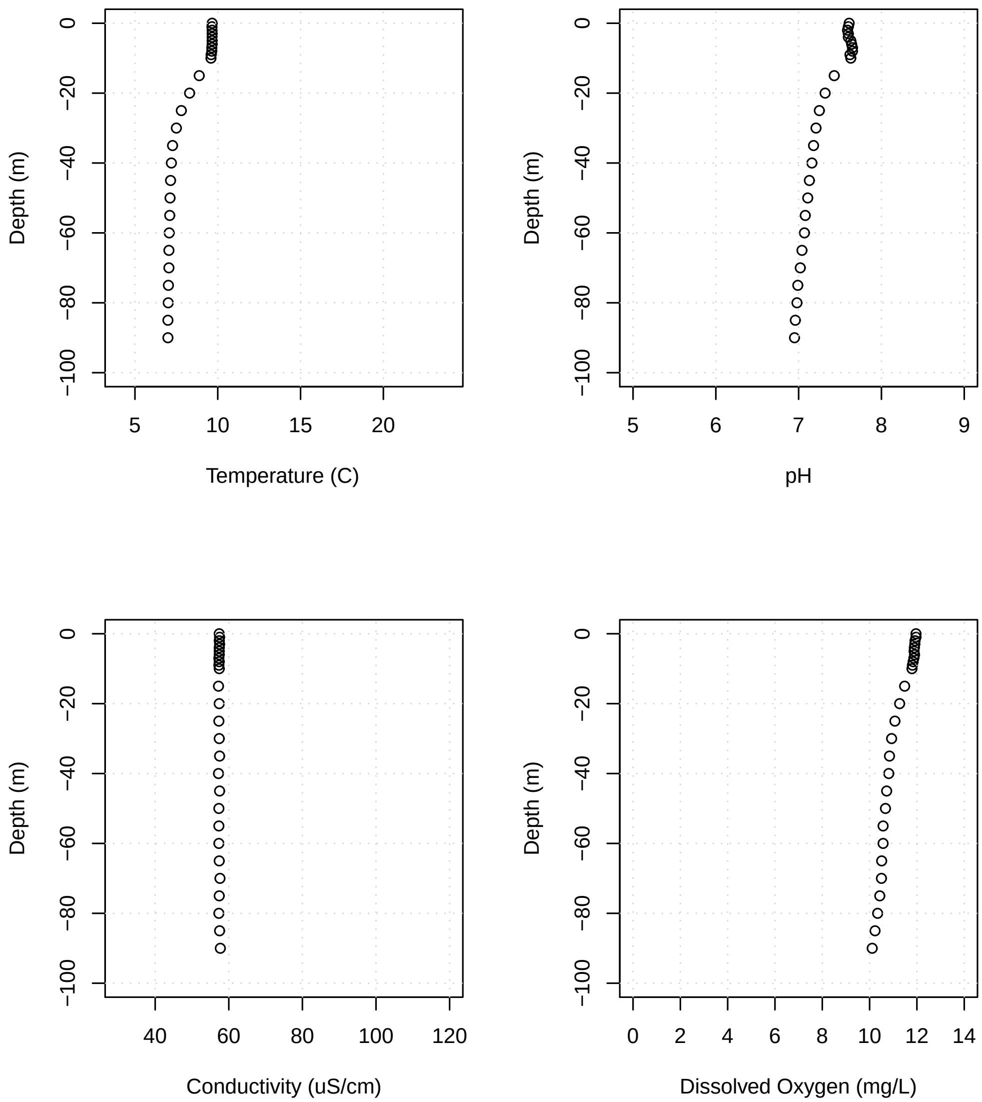


Figure B30: Lake Whatcom Hydrolab profile for Site 4, May 6, 2010.

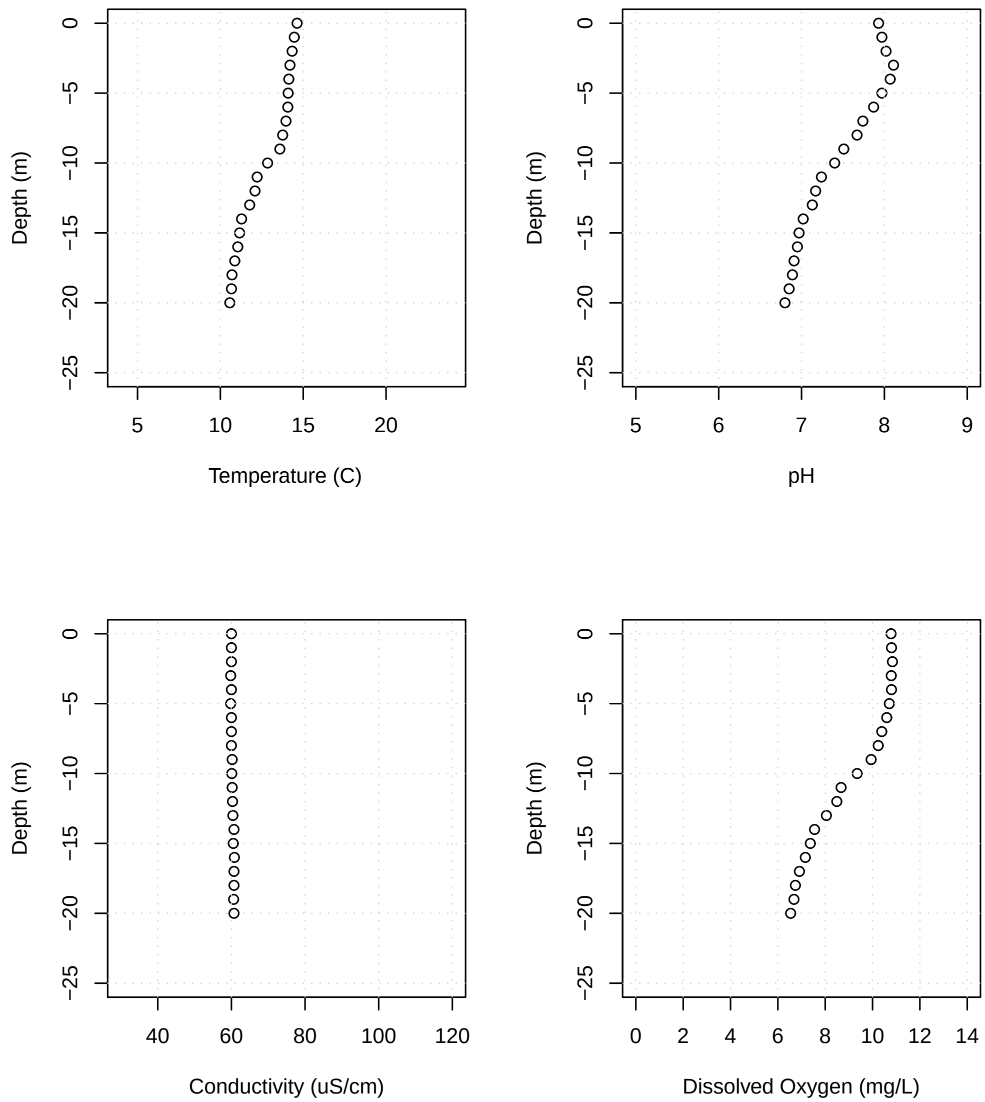


Figure B31: Lake Whatcom Hydrolab profile for Site 1, June 3, 2010.

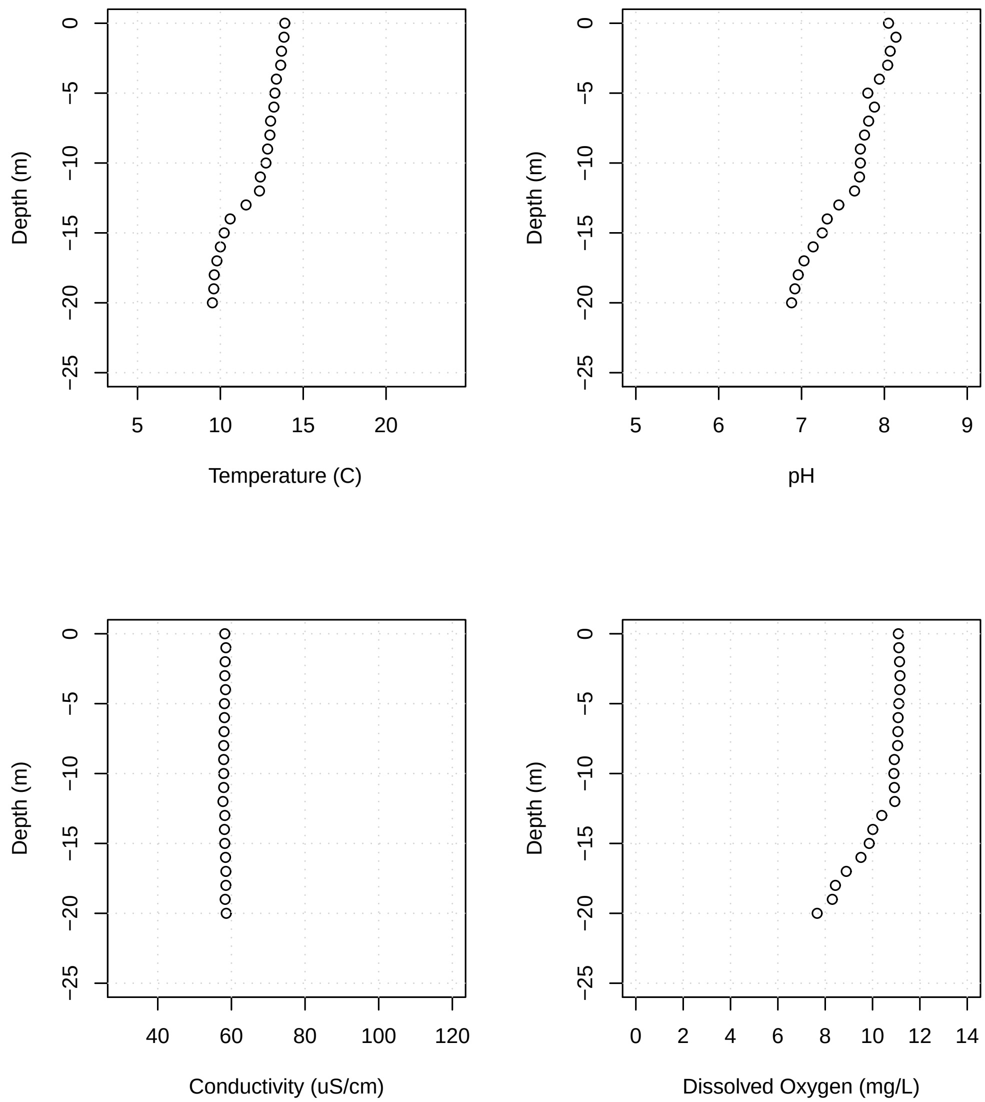


Figure B32: Lake Whatcom Hydrolab profile for Site 2, June 3, 2010.

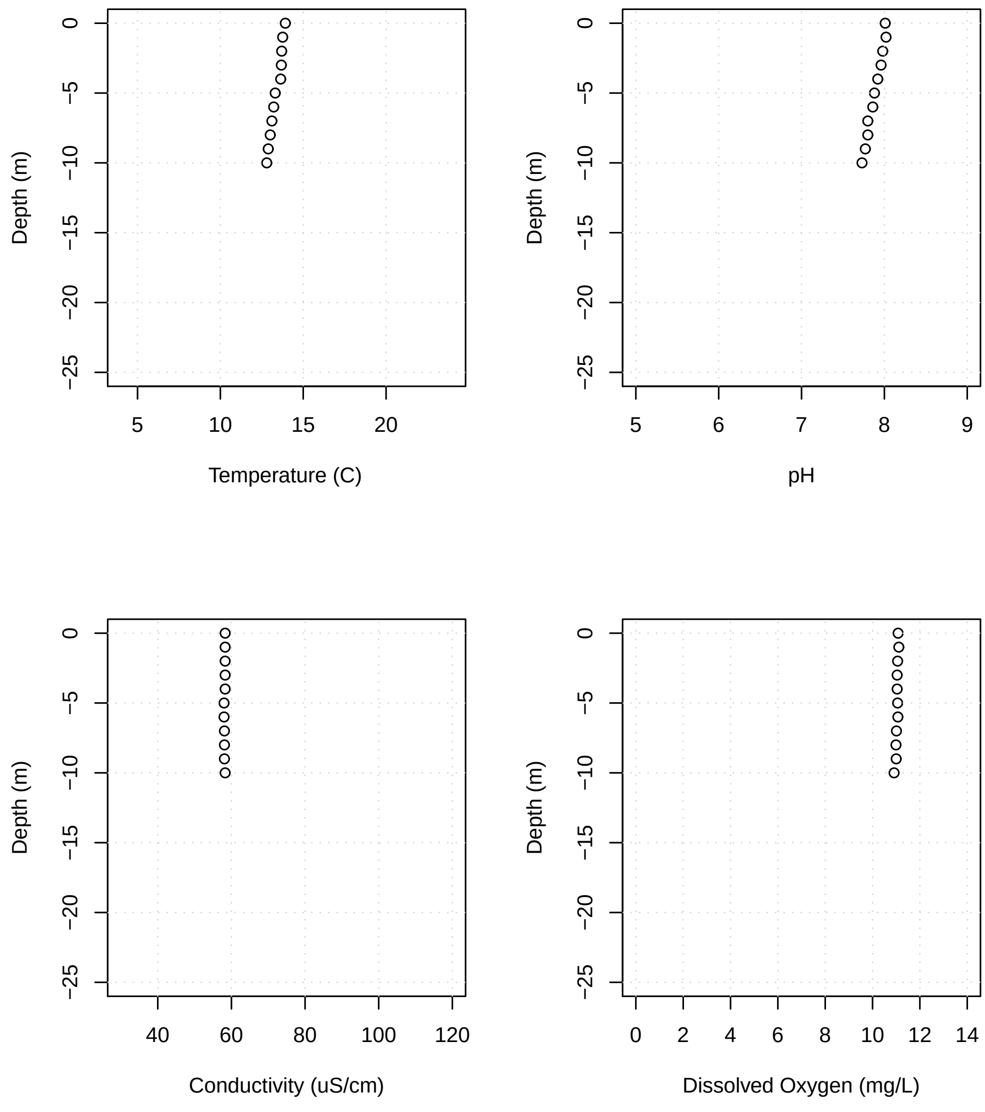


Figure B33: Lake Whatcom Hydrolab profile for the Intake, June 3, 2010.

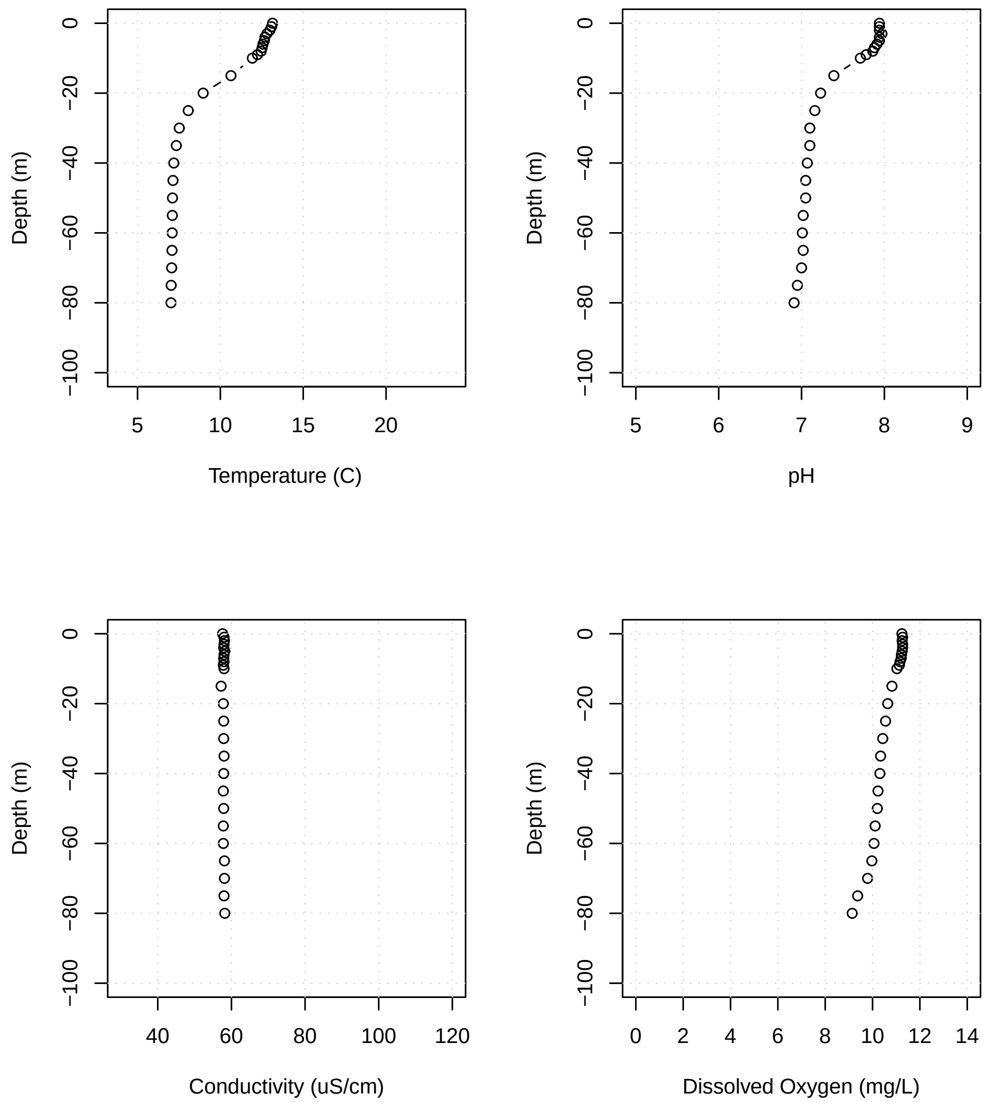


Figure B34: Lake Whatcom Hydrolab profile for Site 3, June 1, 2010.

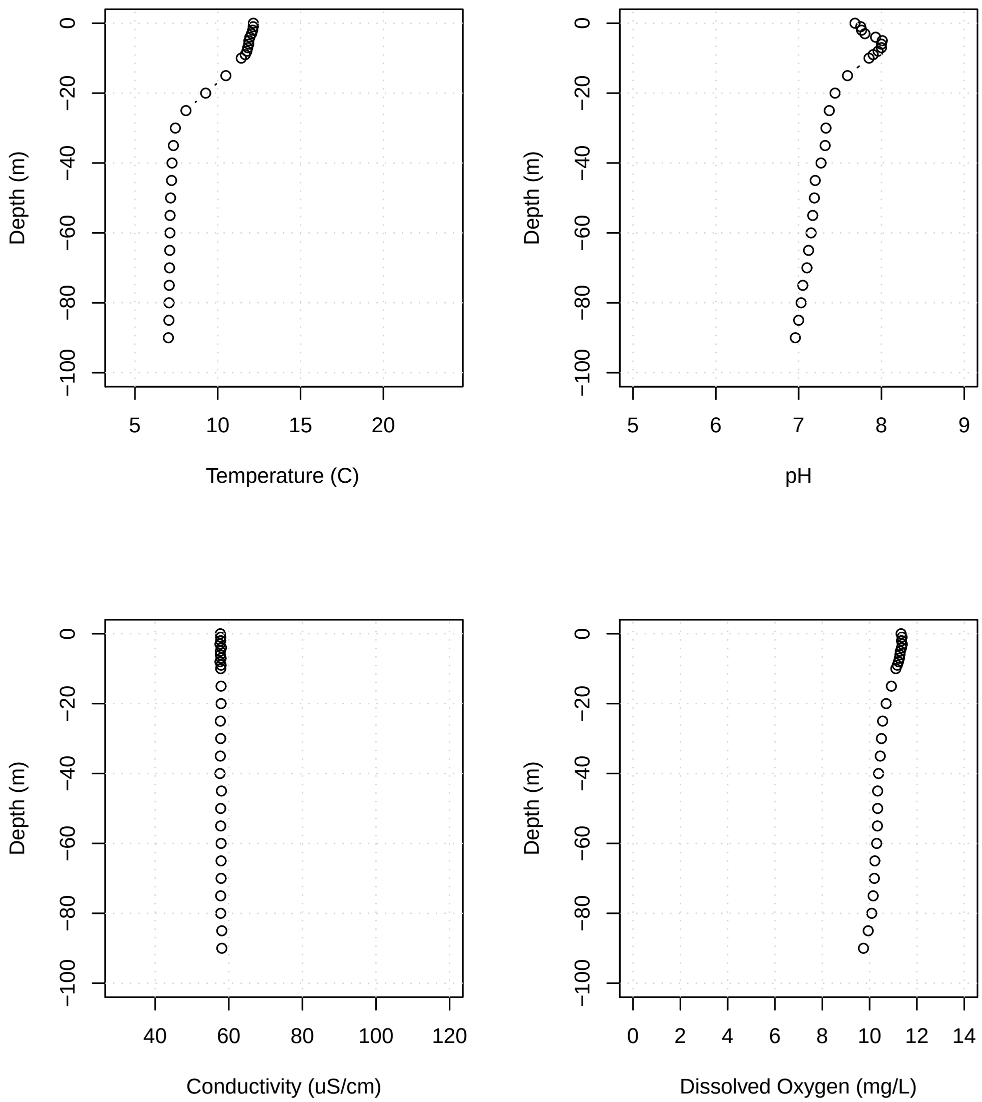


Figure B35: Lake Whatcom Hydrolab profile for Site 4, June 1, 2010.

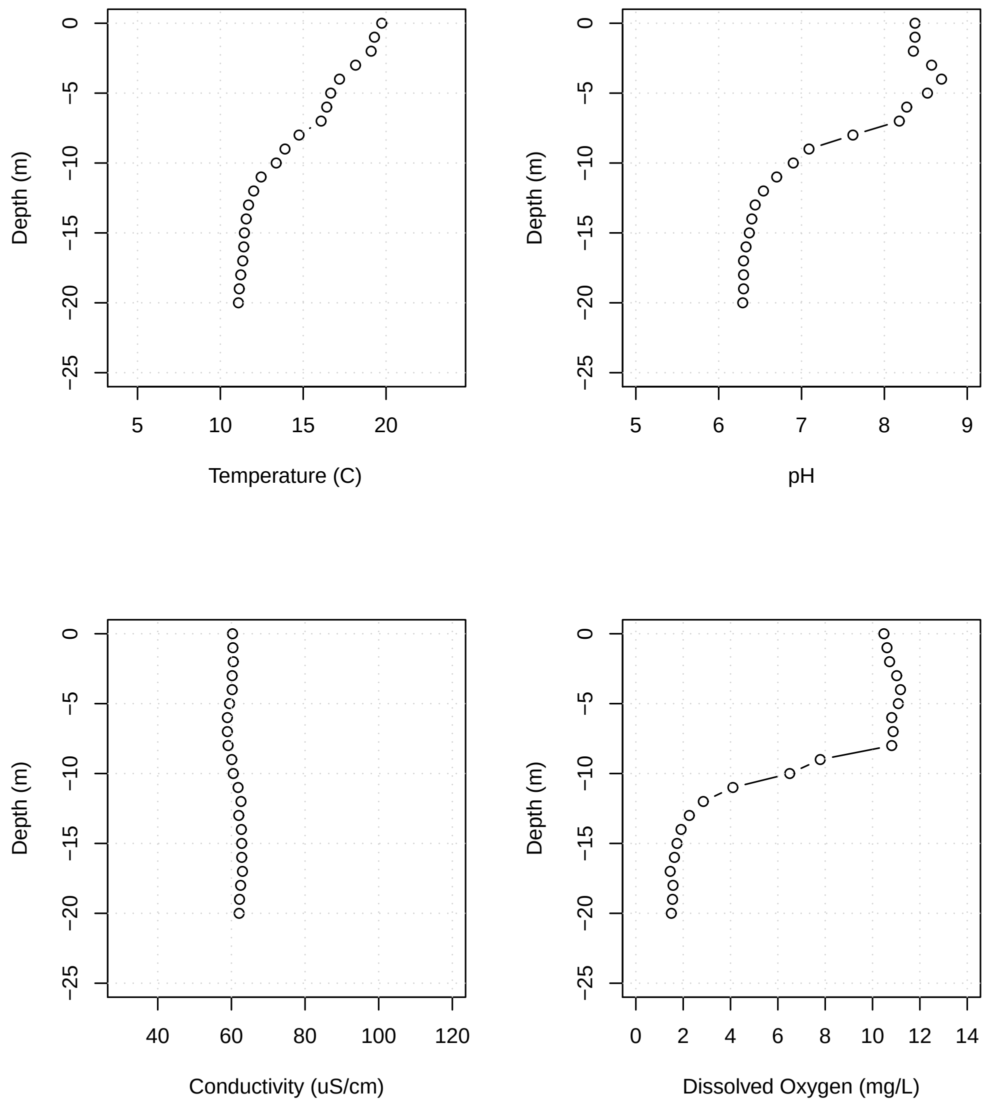


Figure B36: Lake Whatcom Hydrolab profile for Site 1, July 8, 2010.

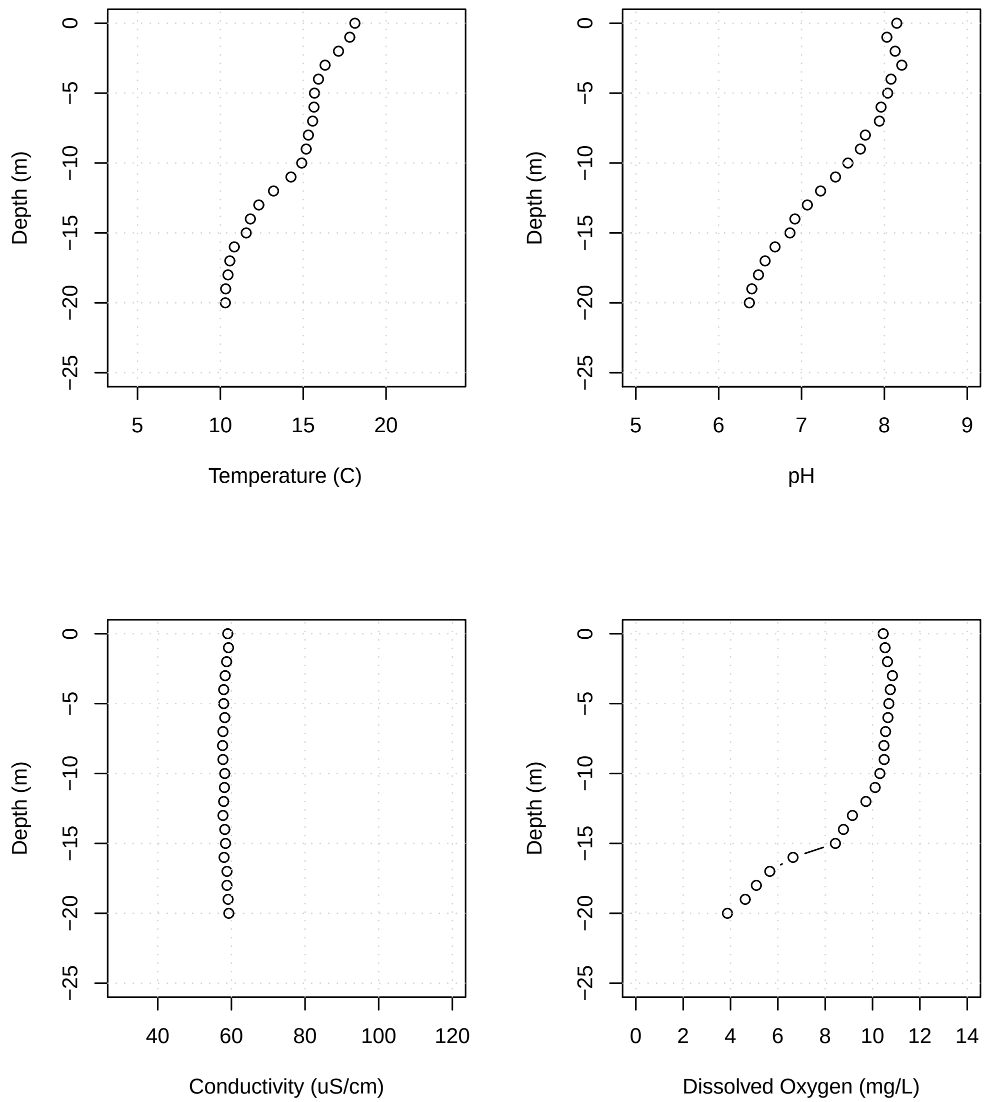


Figure B37: Lake Whatcom Hydrolab profile for Site 2, July 8, 2010.

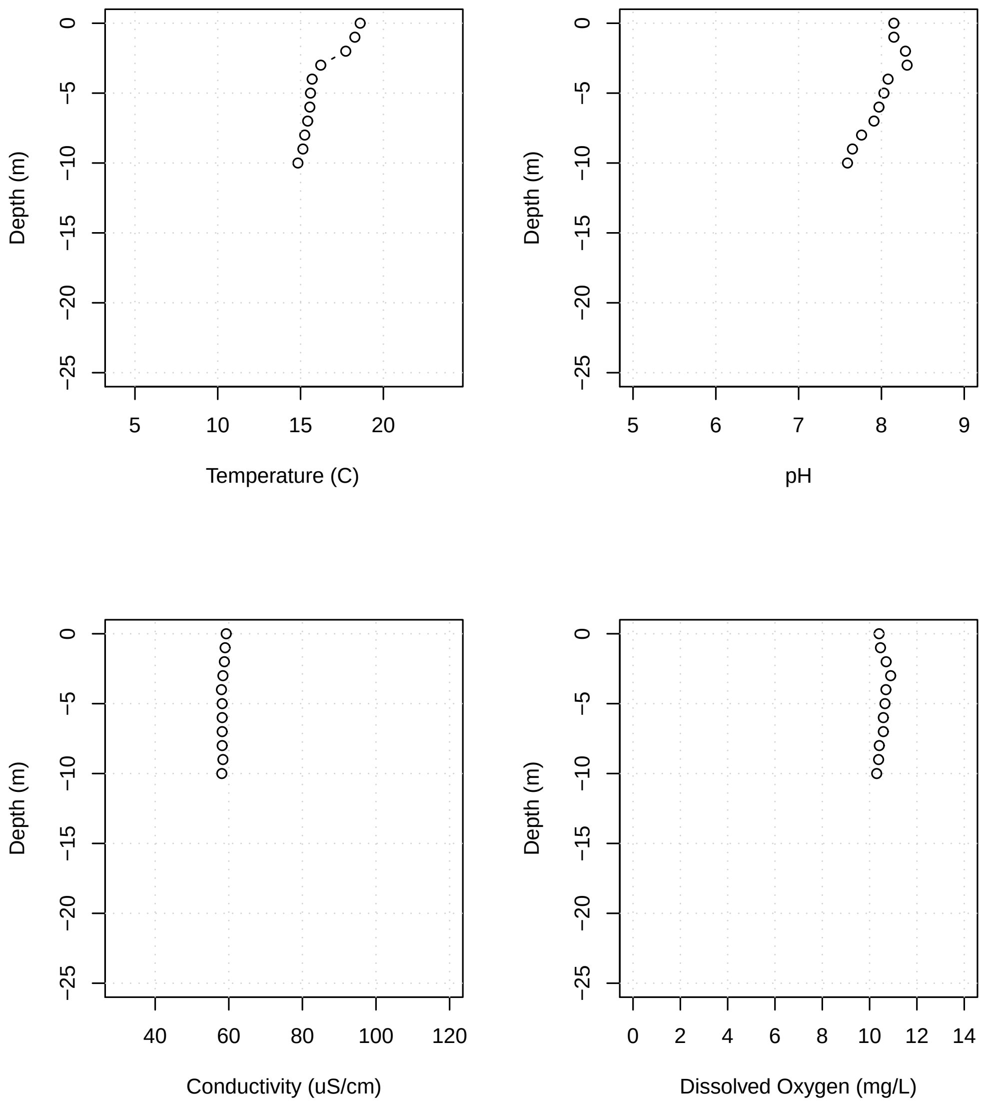


Figure B38: Lake Whatcom Hydrolab profile for the Intake, July 8, 2010.

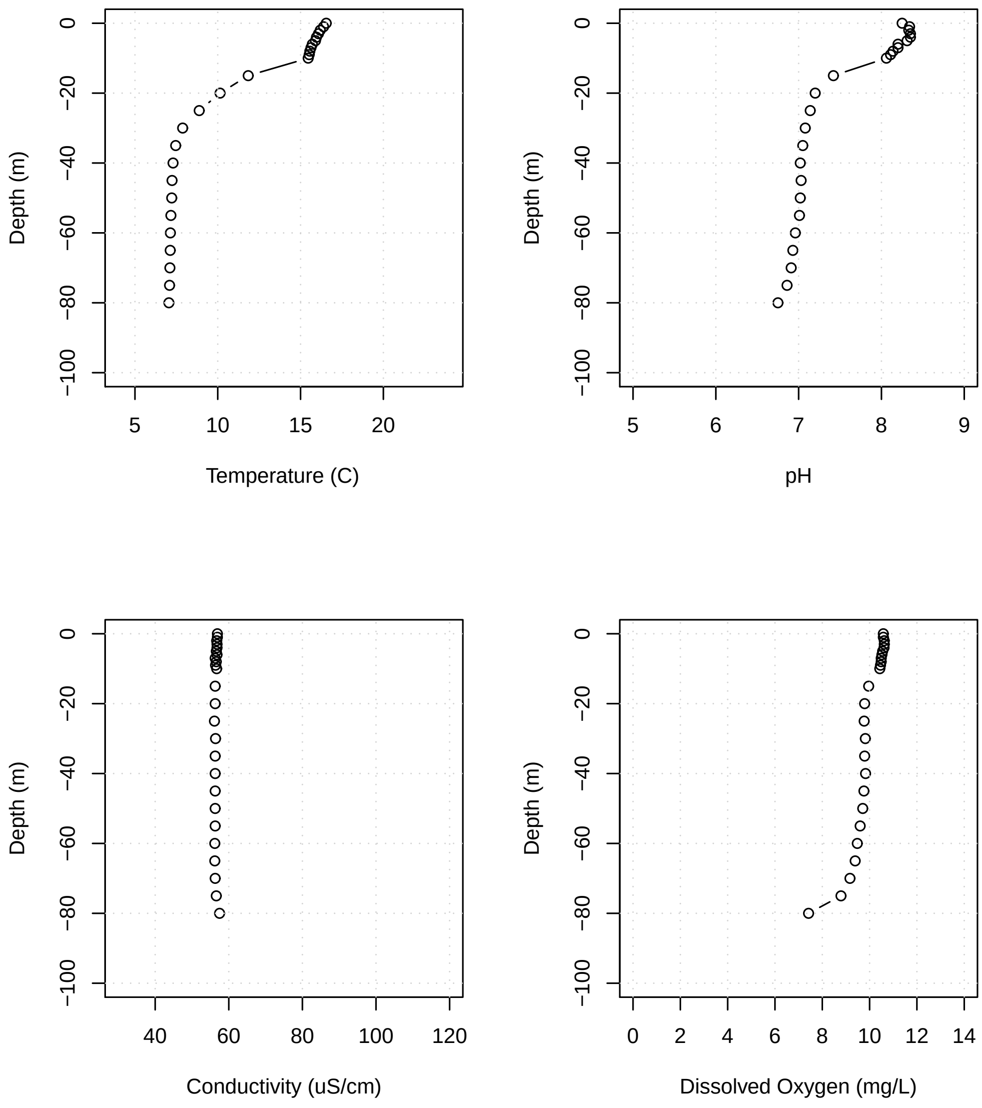


Figure B39: Lake Whatcom Hydrolab profile for Site 3, July 6, 2010.

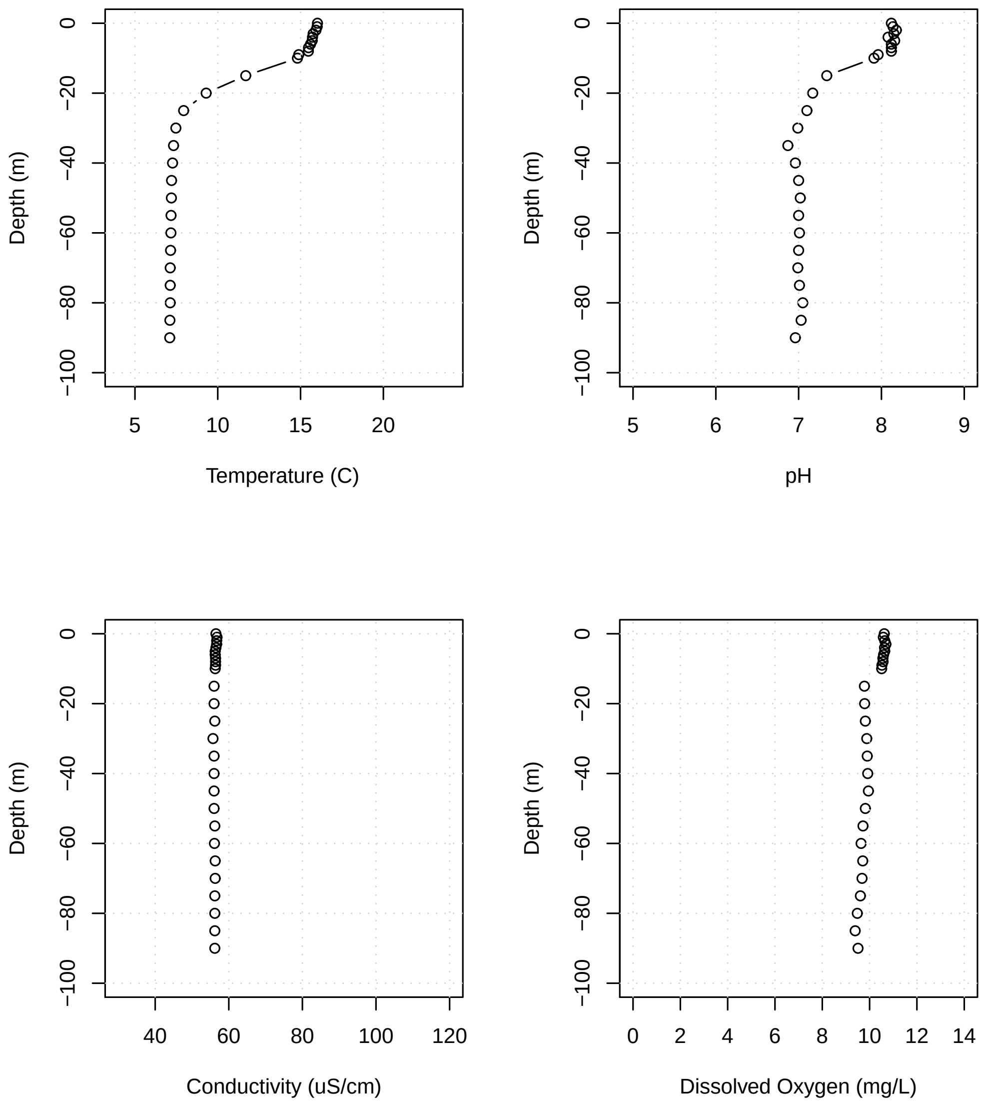


Figure B40: Lake Whatcom Hydrolab profile for Site 4, July 6, 2010.

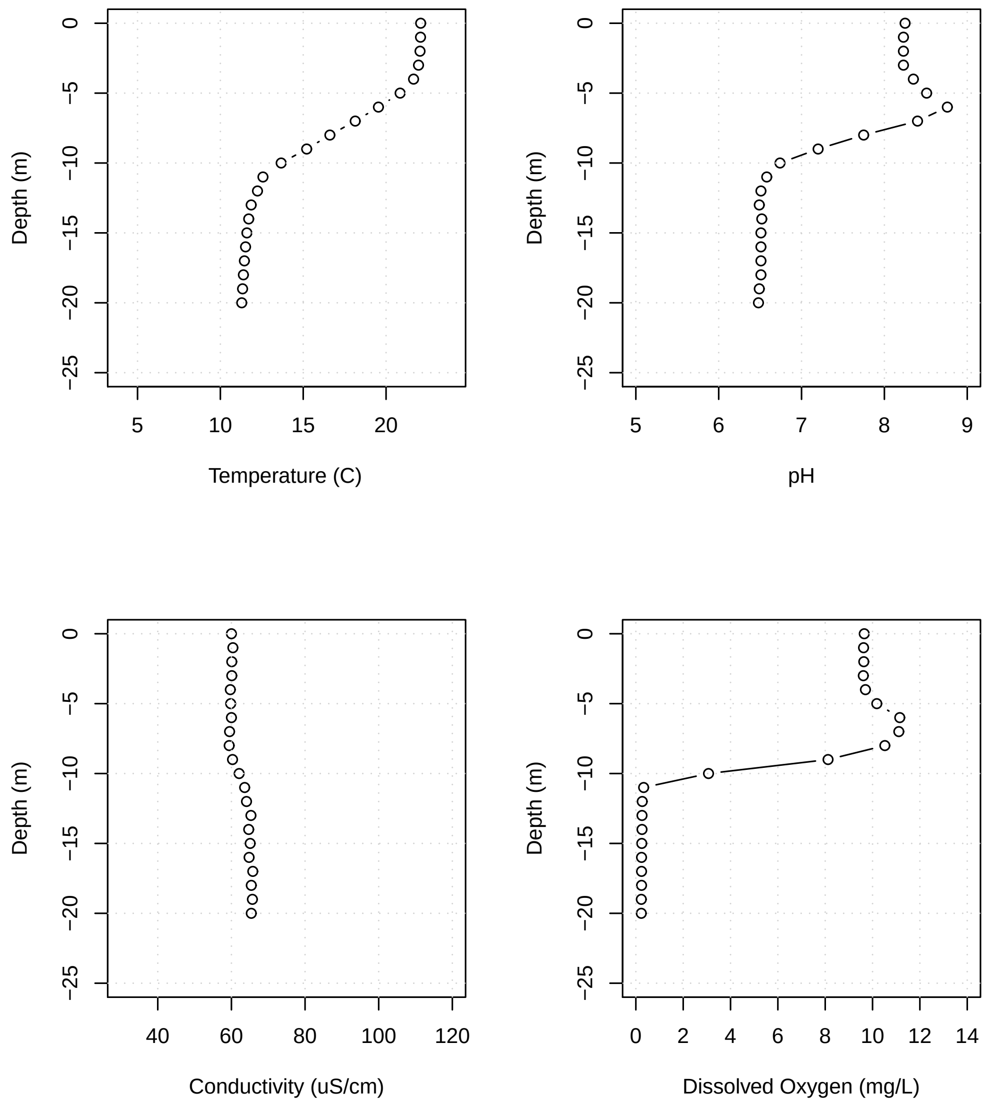


Figure B41: Lake Whatcom Hydrolab profile for Site 1, August 5, 2010.

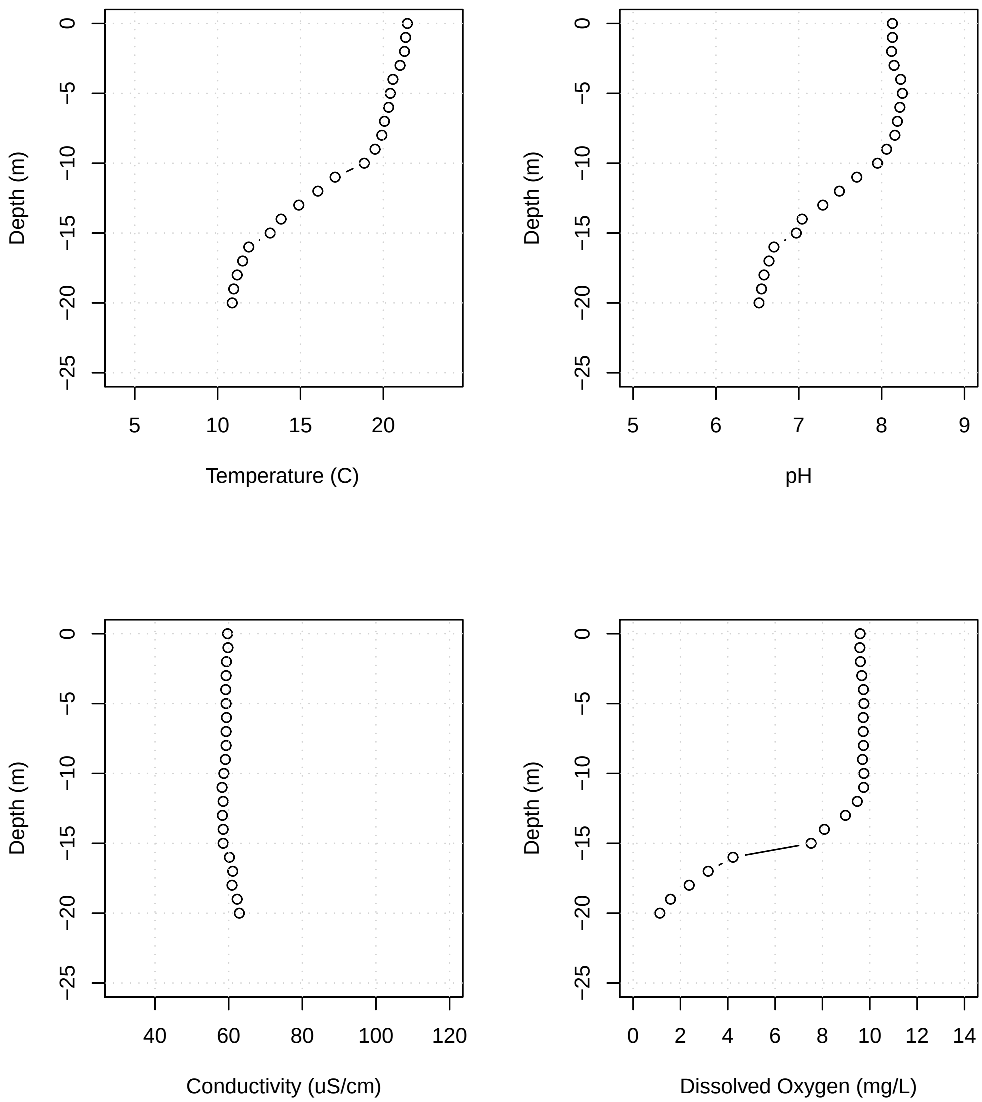


Figure B42: Lake Whatcom Hydrolab profile for Site 2, August 5, 2010.

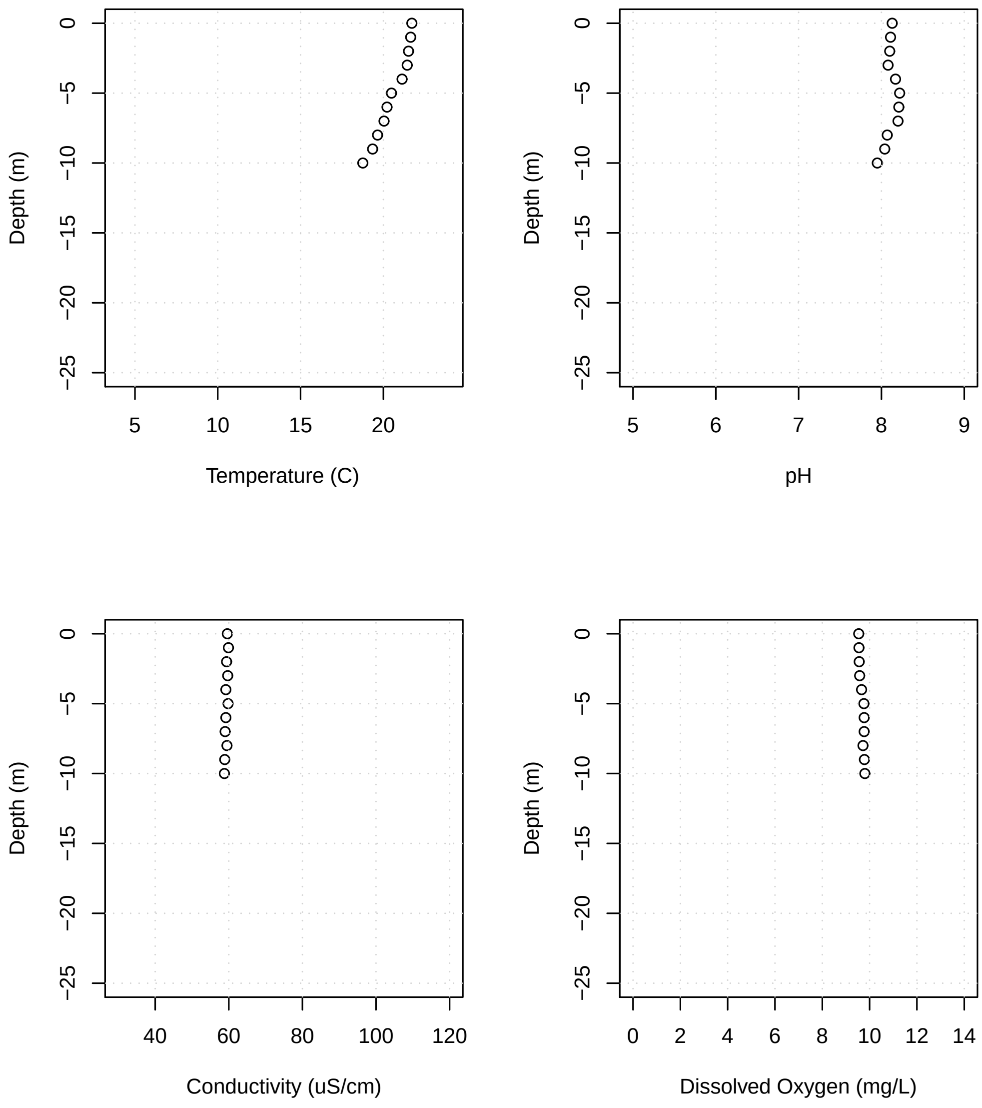


Figure B43: Lake Whatcom Hydrolab profile for the Intake, August 5, 2010.

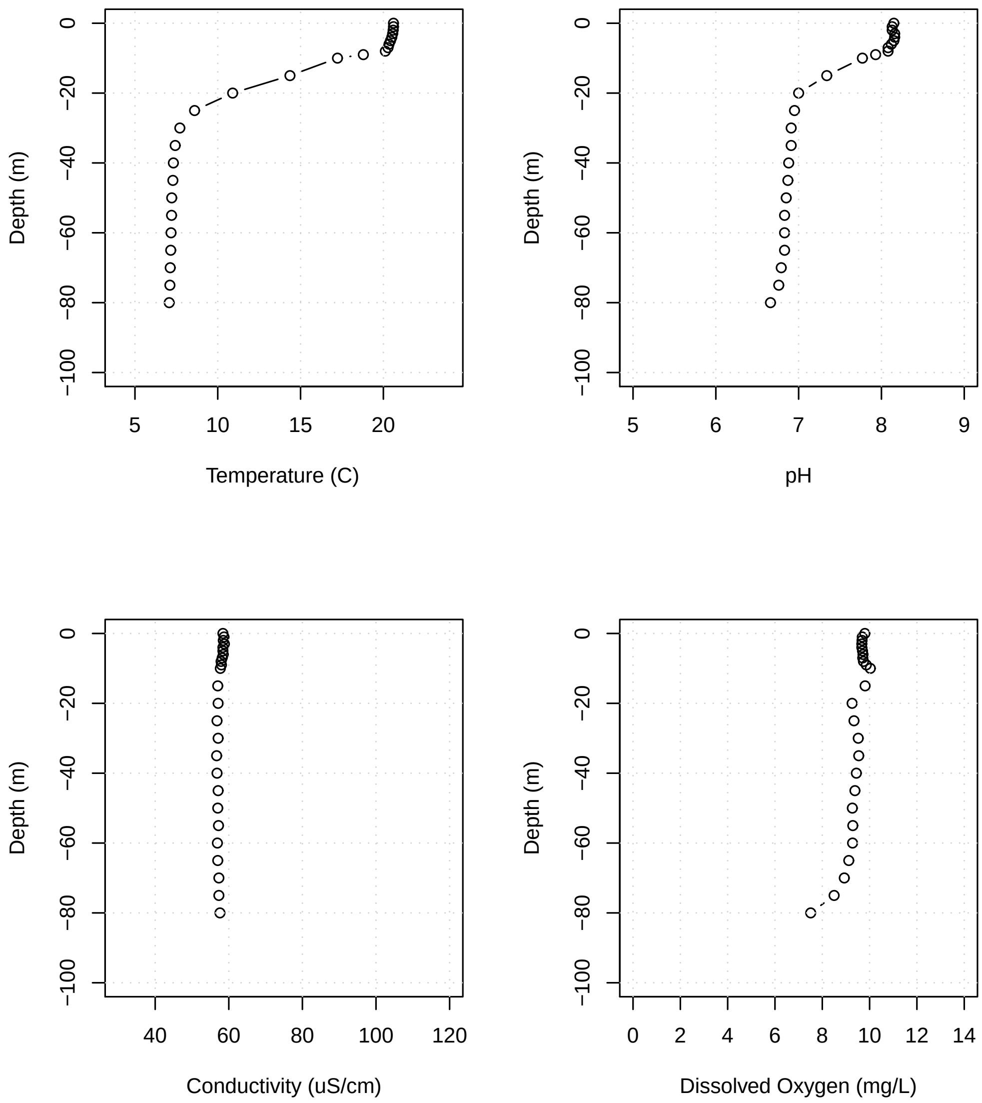


Figure B44: Lake Whatcom Hydrolab profile for Site 3, August 3, 2010.

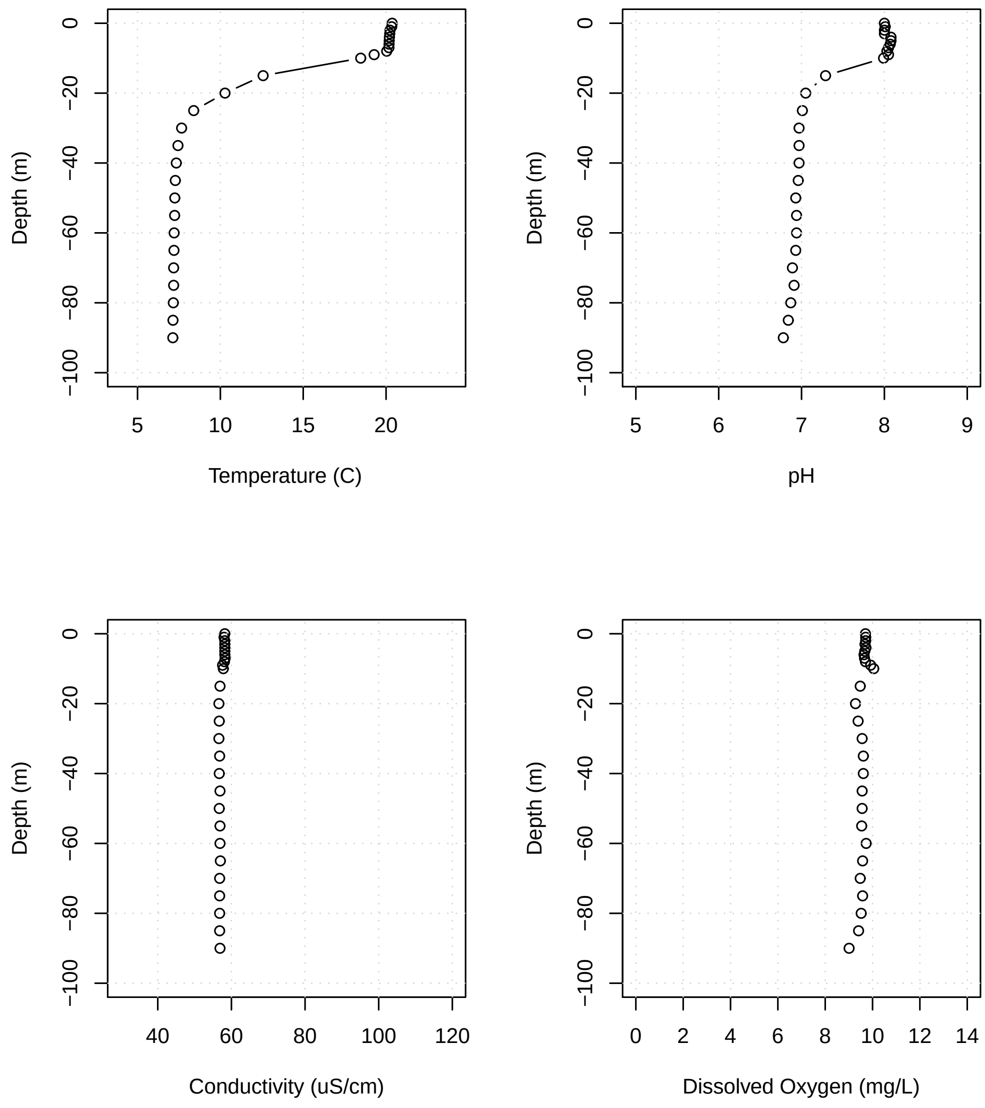


Figure B45: Lake Whatcom Hydrolab profile for Site 4, August 3, 2010.

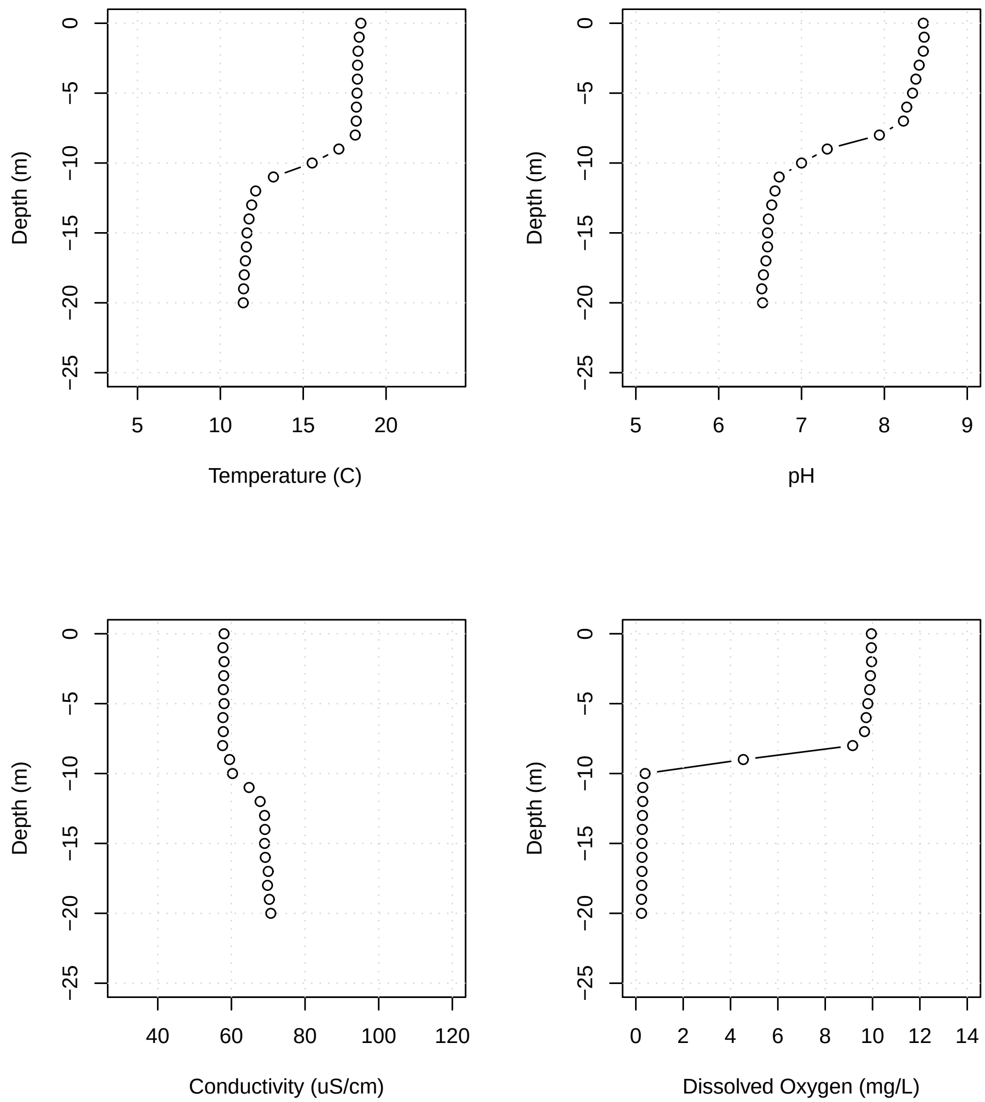


Figure B46: Lake Whatcom Hydrolab profile for Site 1, September 9, 2010.

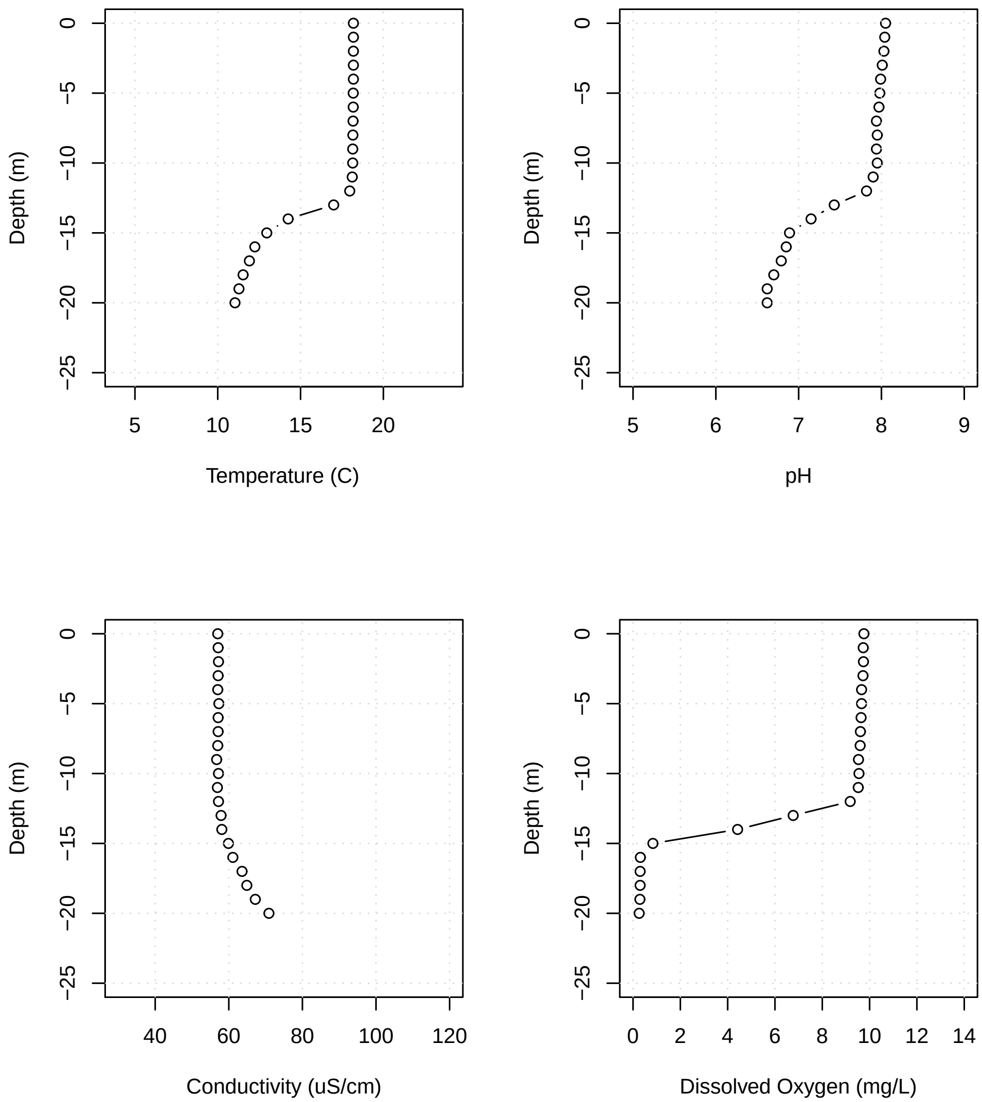


Figure B47: Lake Whatcom Hydrolab profile for Site 2, September 9, 2010.

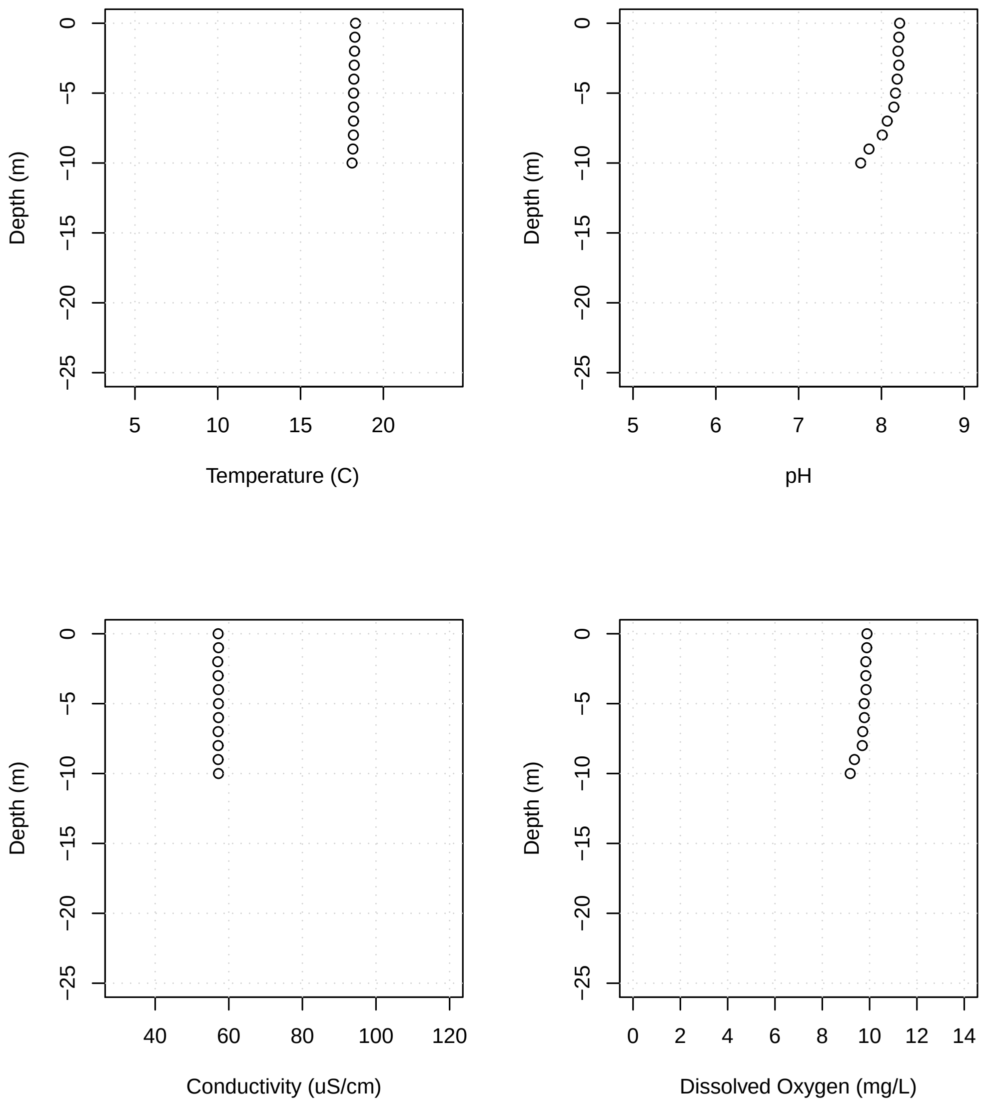


Figure B48: Lake Whatcom Hydrolab profile for the Intake, September 9, 2010.

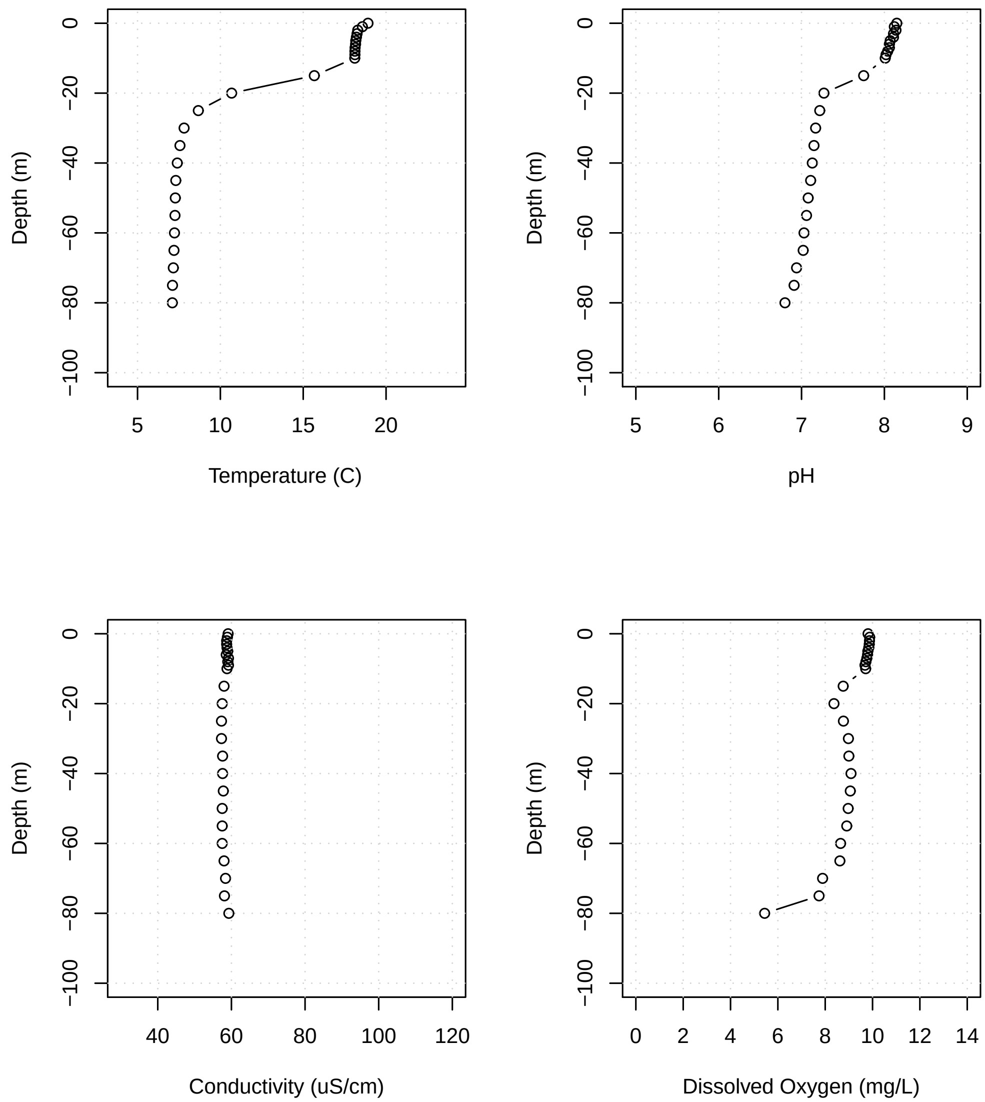


Figure B49: Lake Whatcom Hydrolab profile for Site 3, September 8, 2010.

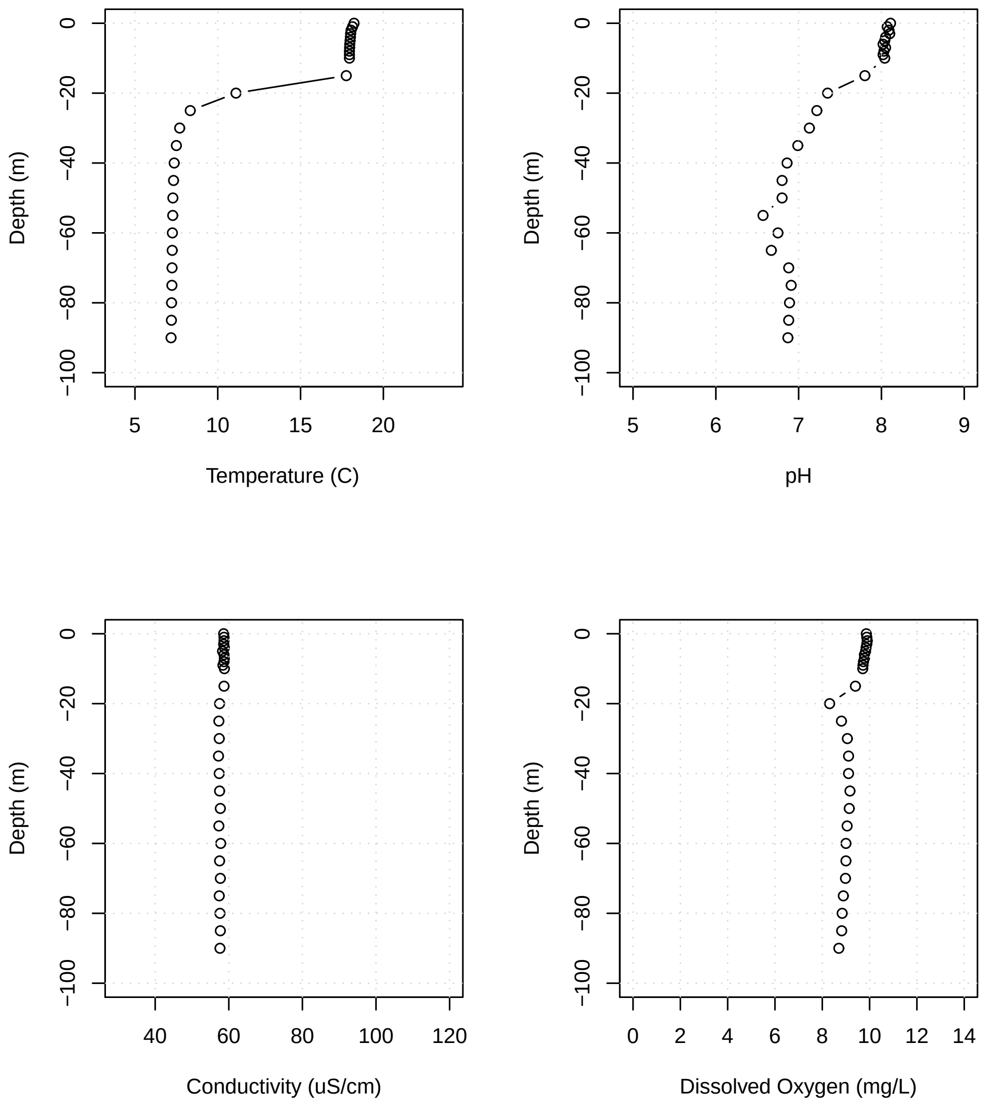


Figure B50: Lake Whatcom Hydrolab profile for Site 4, September 8, 2010.

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

Lake Whatcom temperature data for Site 1, February 1988 through December 2010.

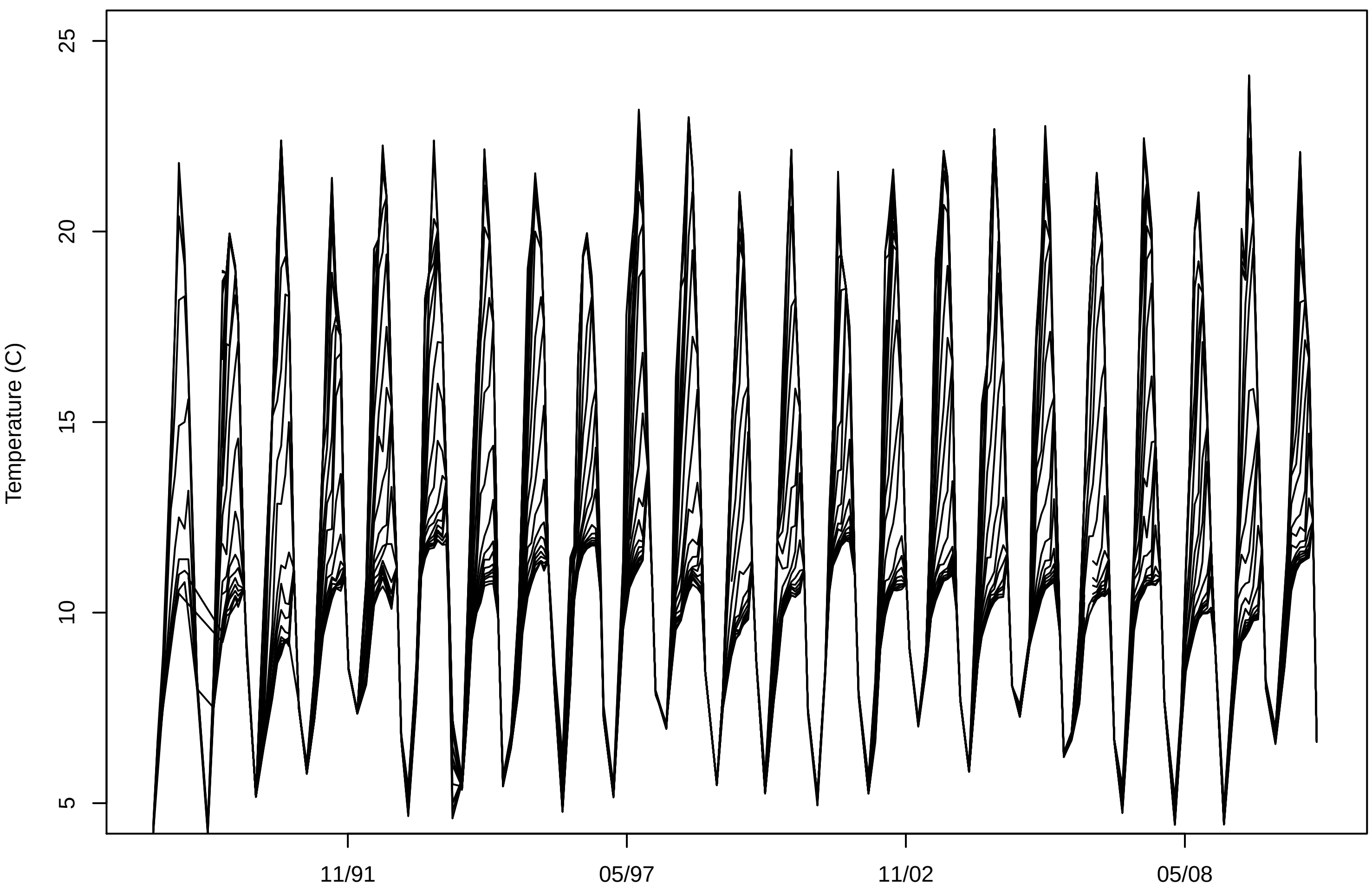


Figure B51: Lake Whatcom historic temperature data for Site 1.

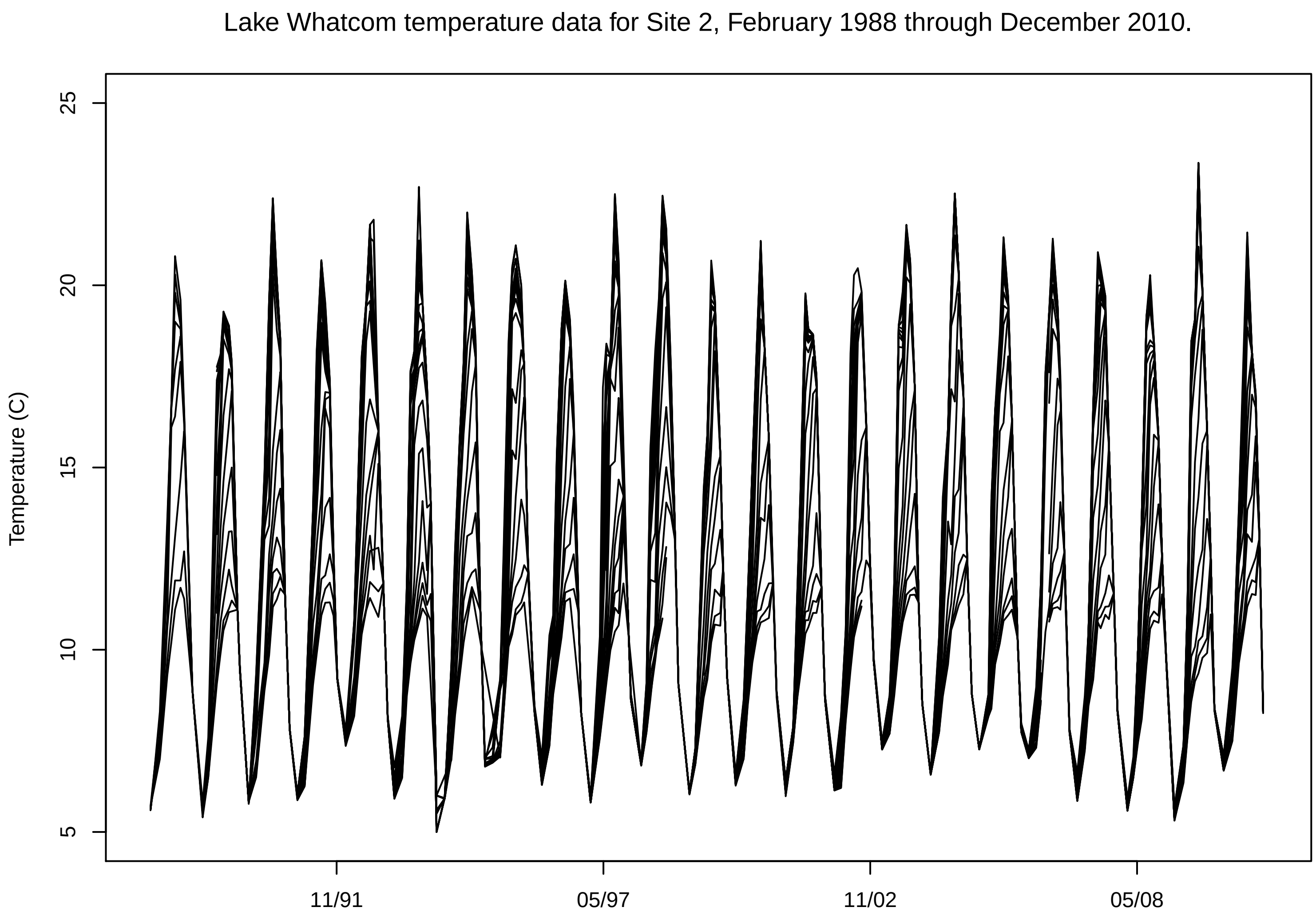


Figure B52: Lake Whatcom historic temperature data for Site 2.

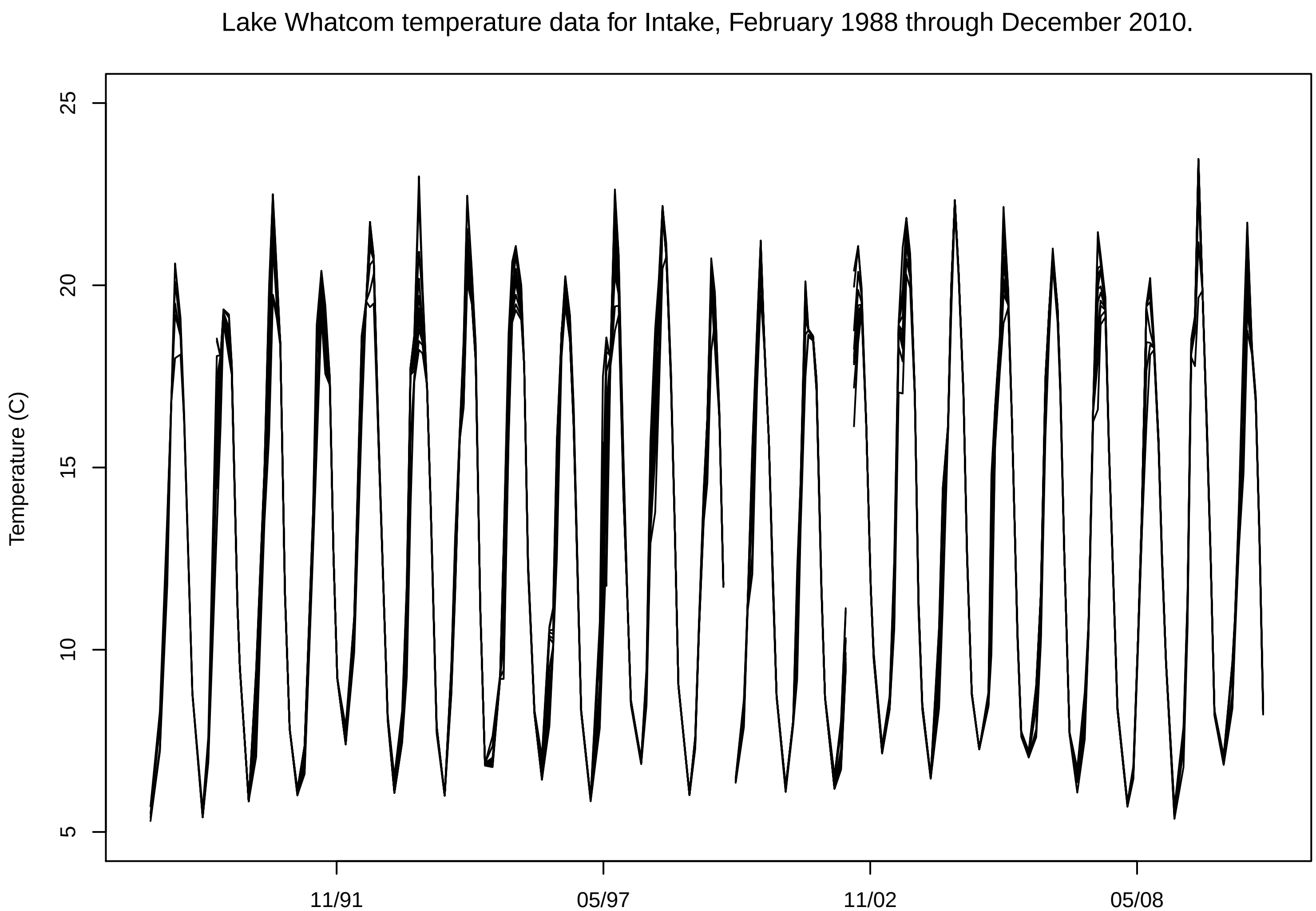


Figure B53: Lake Whatcom historic temperature data for the Intake.

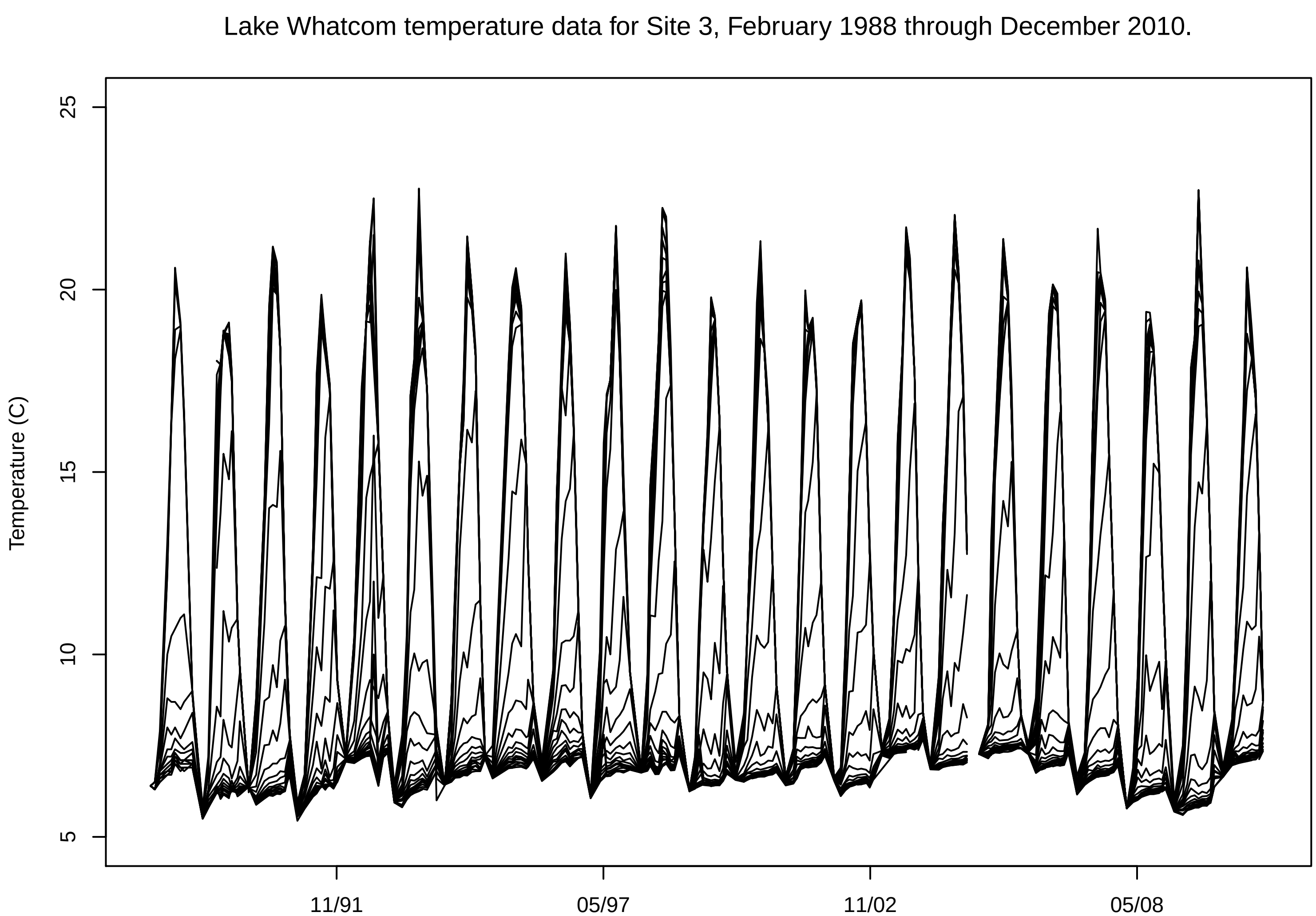


Figure B54: Lake Whatcom historic temperature data for Site 3.

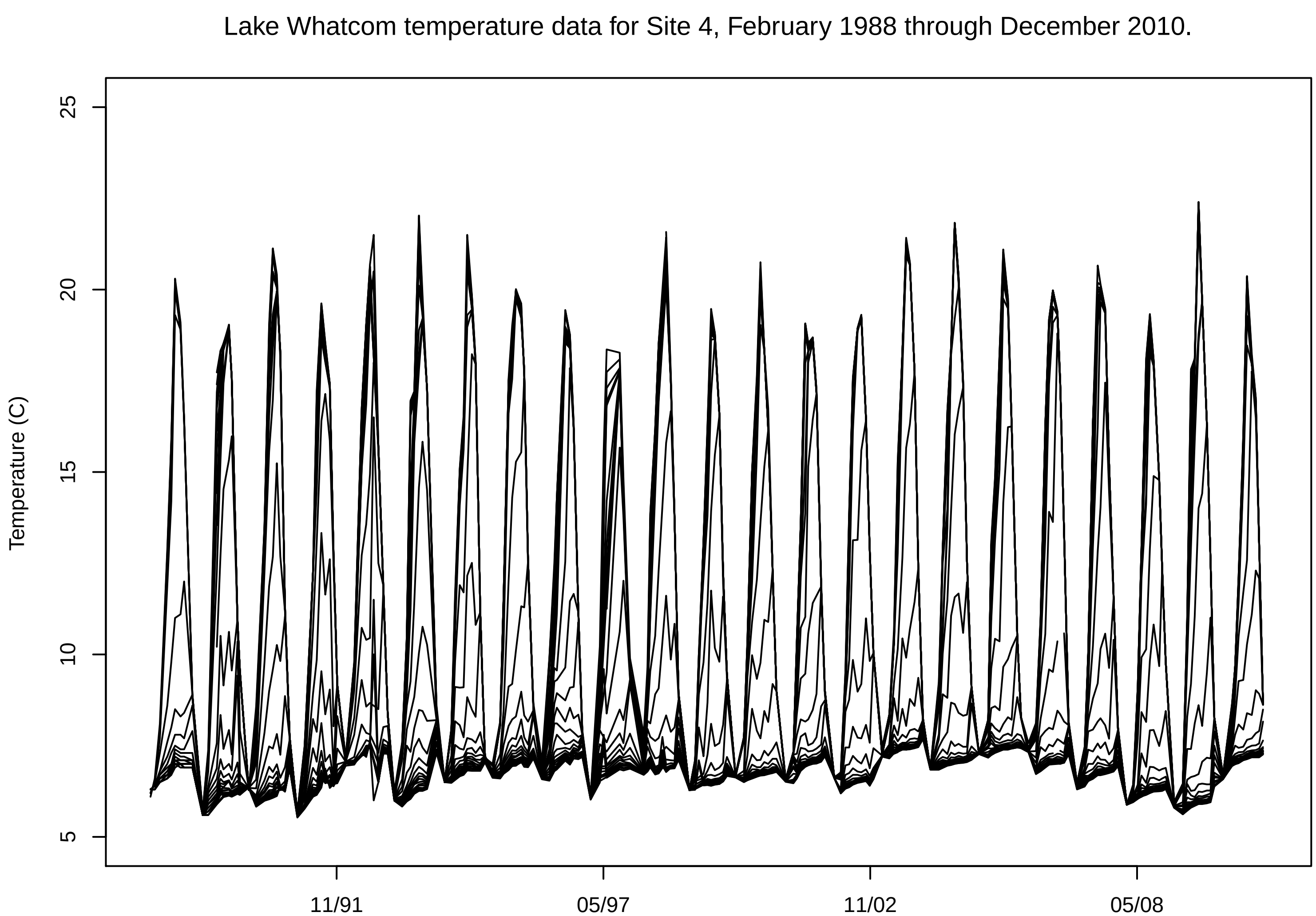


Figure B55: Lake Whatcom historic temperature data for Site 4.

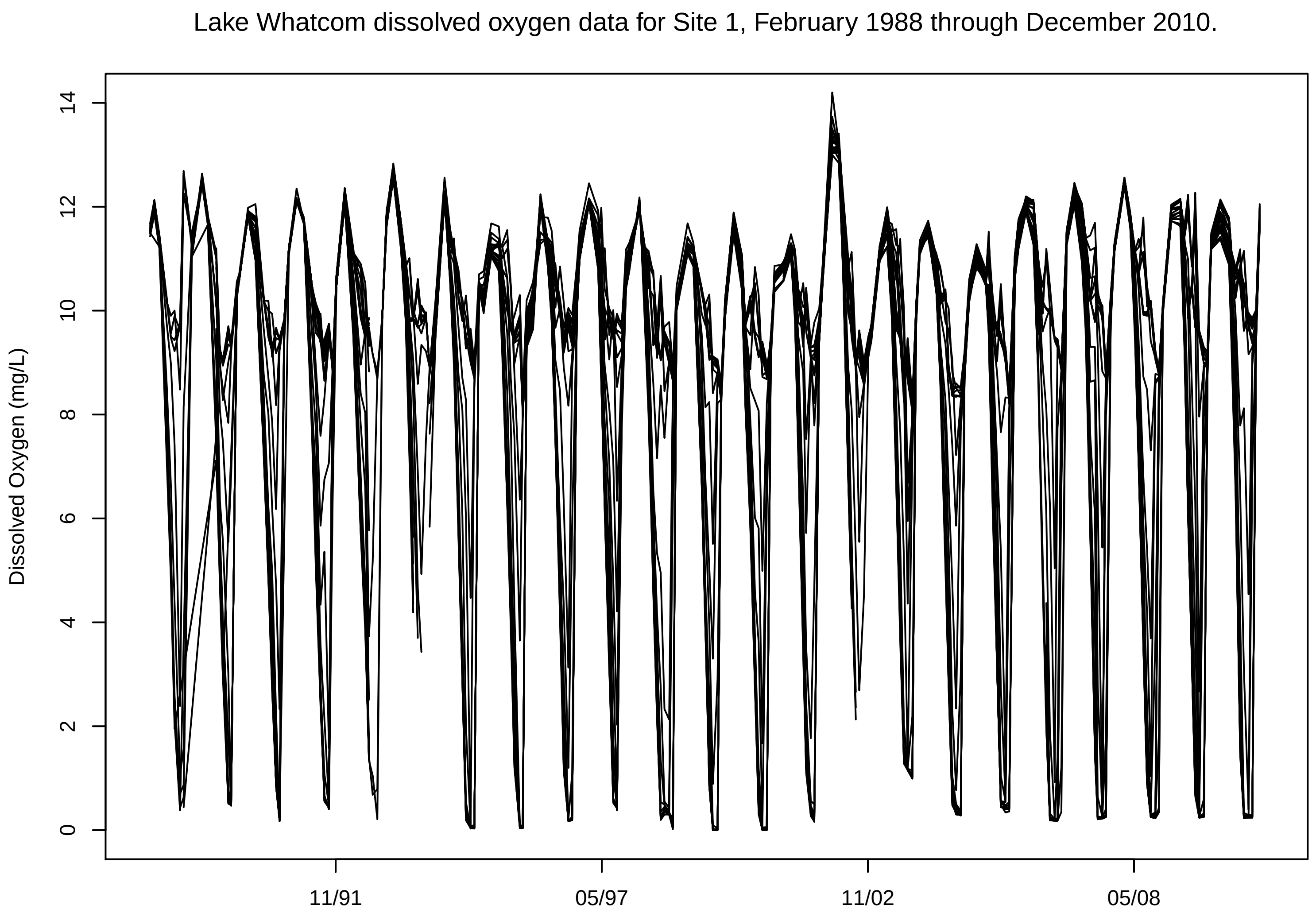


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

Lake Whatcom dissolved oxygen data for Site 2, February 1988 through December 2010.

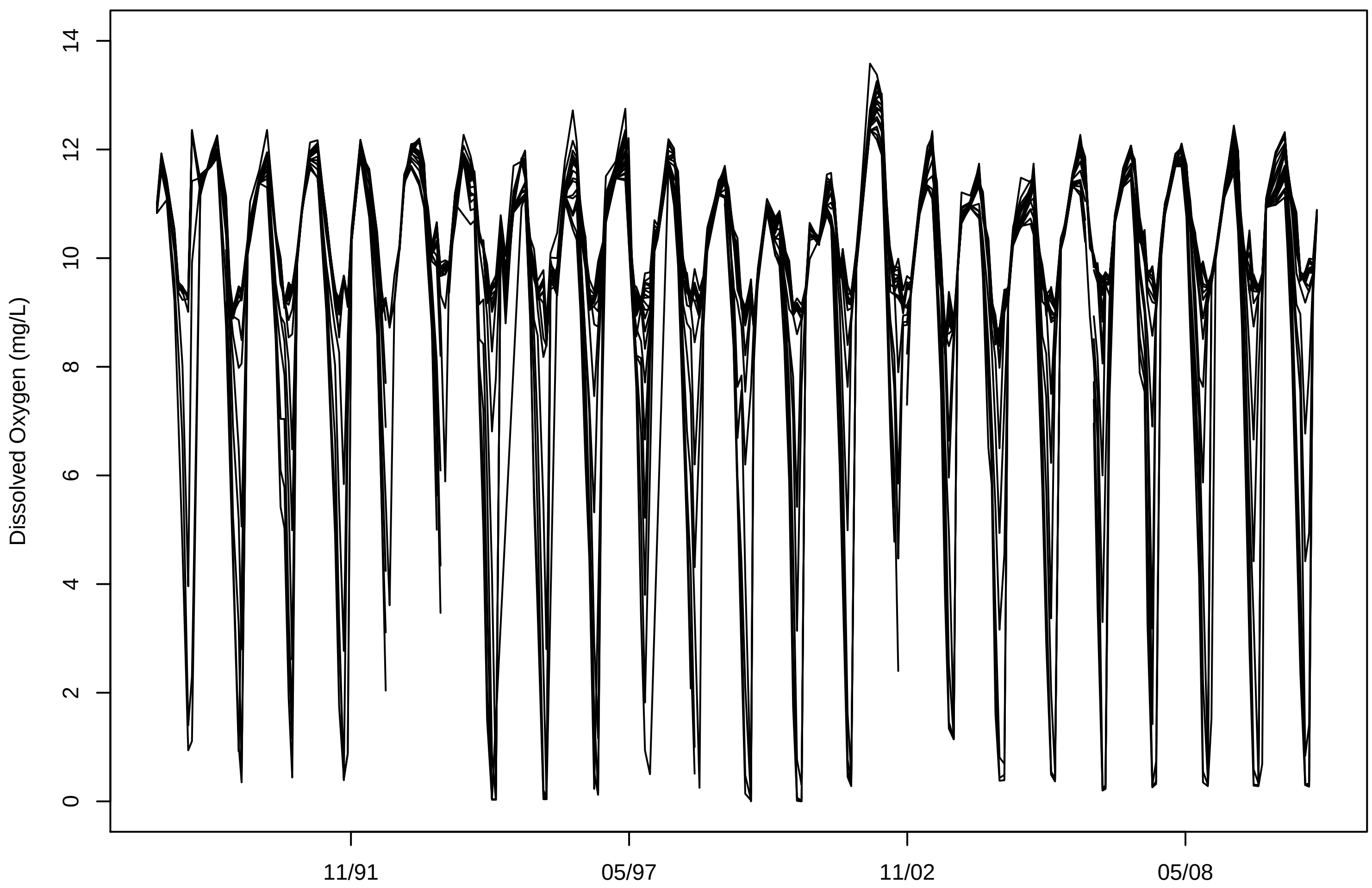


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

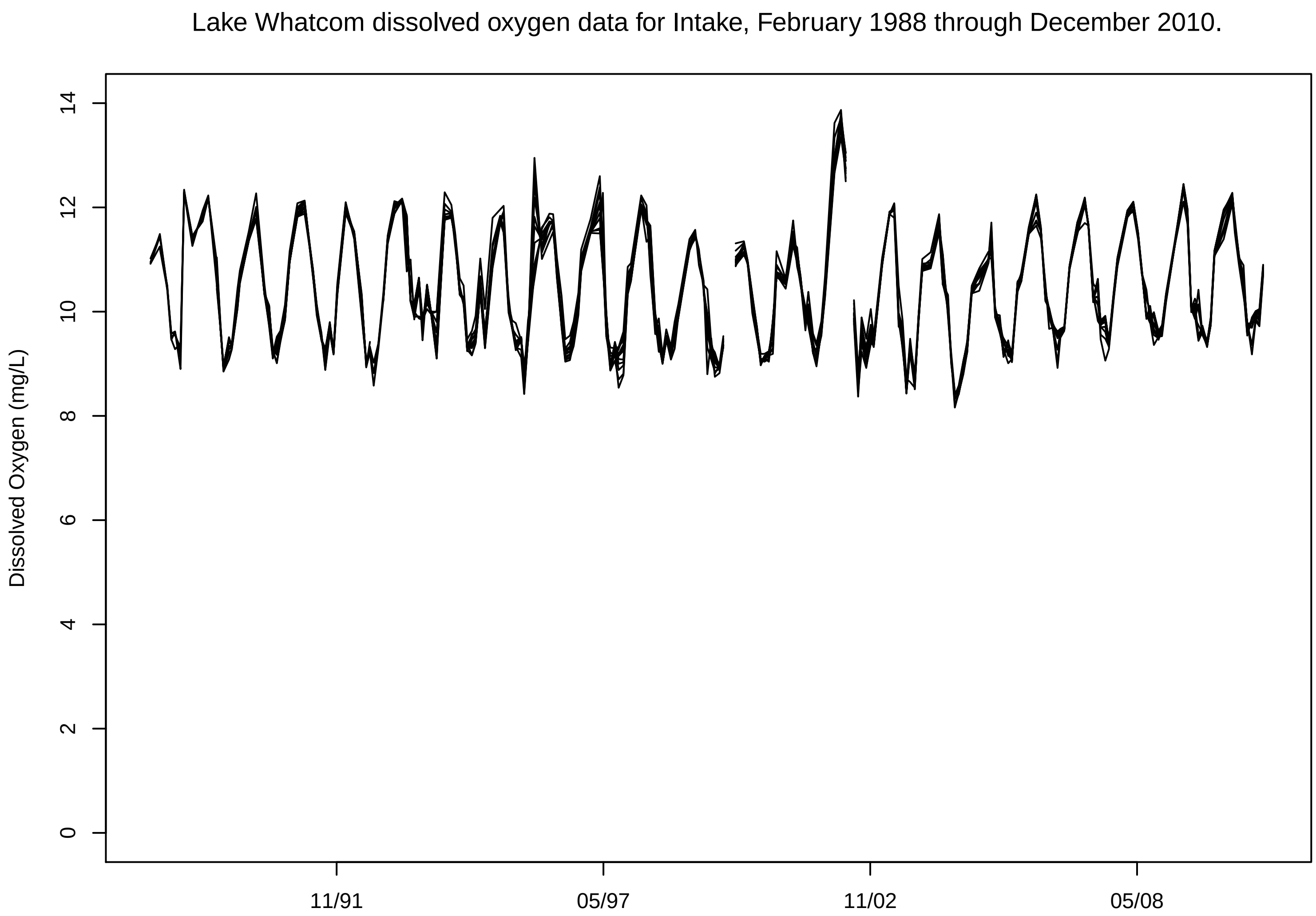


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake.

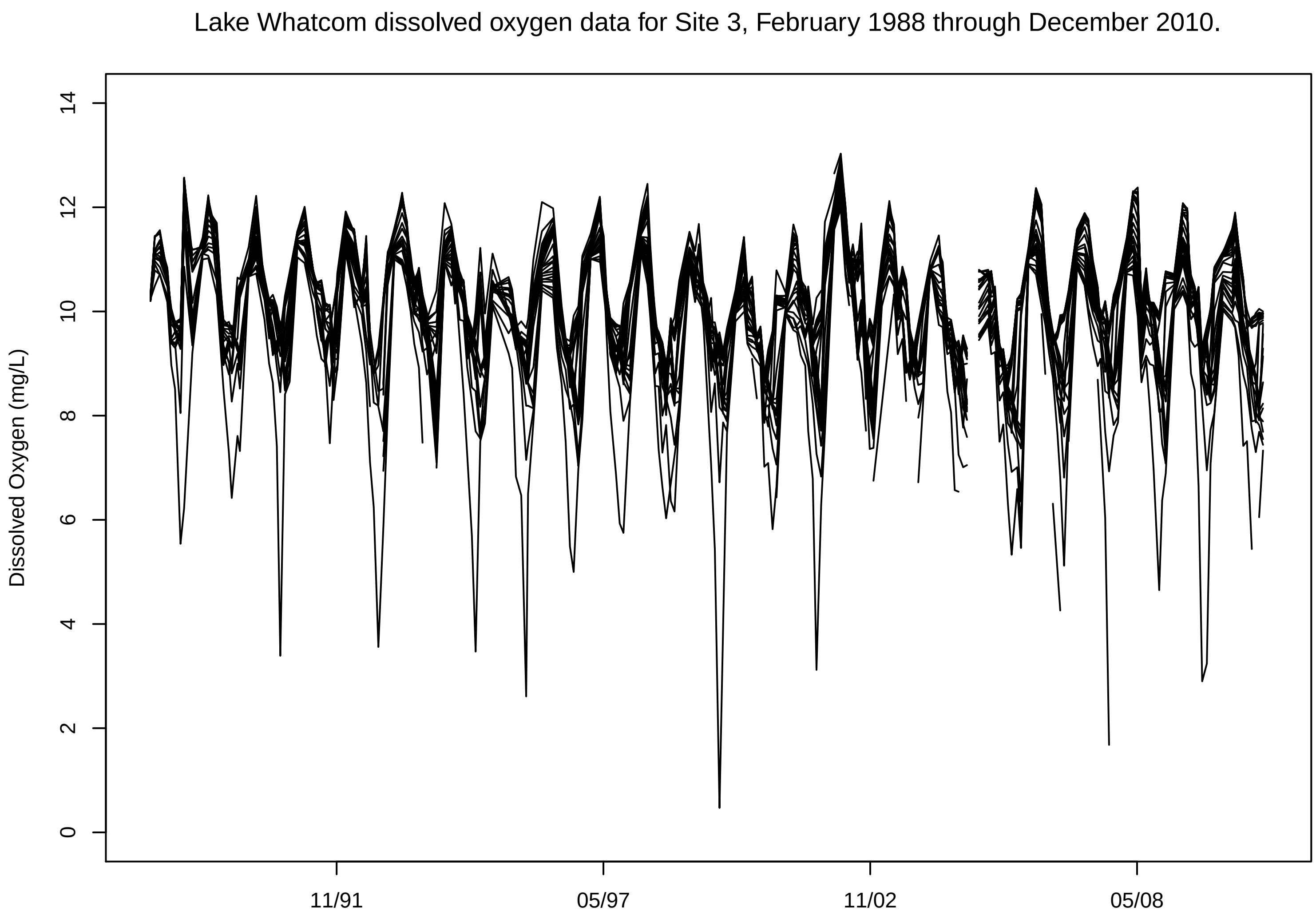


Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.

Lake Whatcom dissolved oxygen data for Site 4, February 1988 through December 2010.

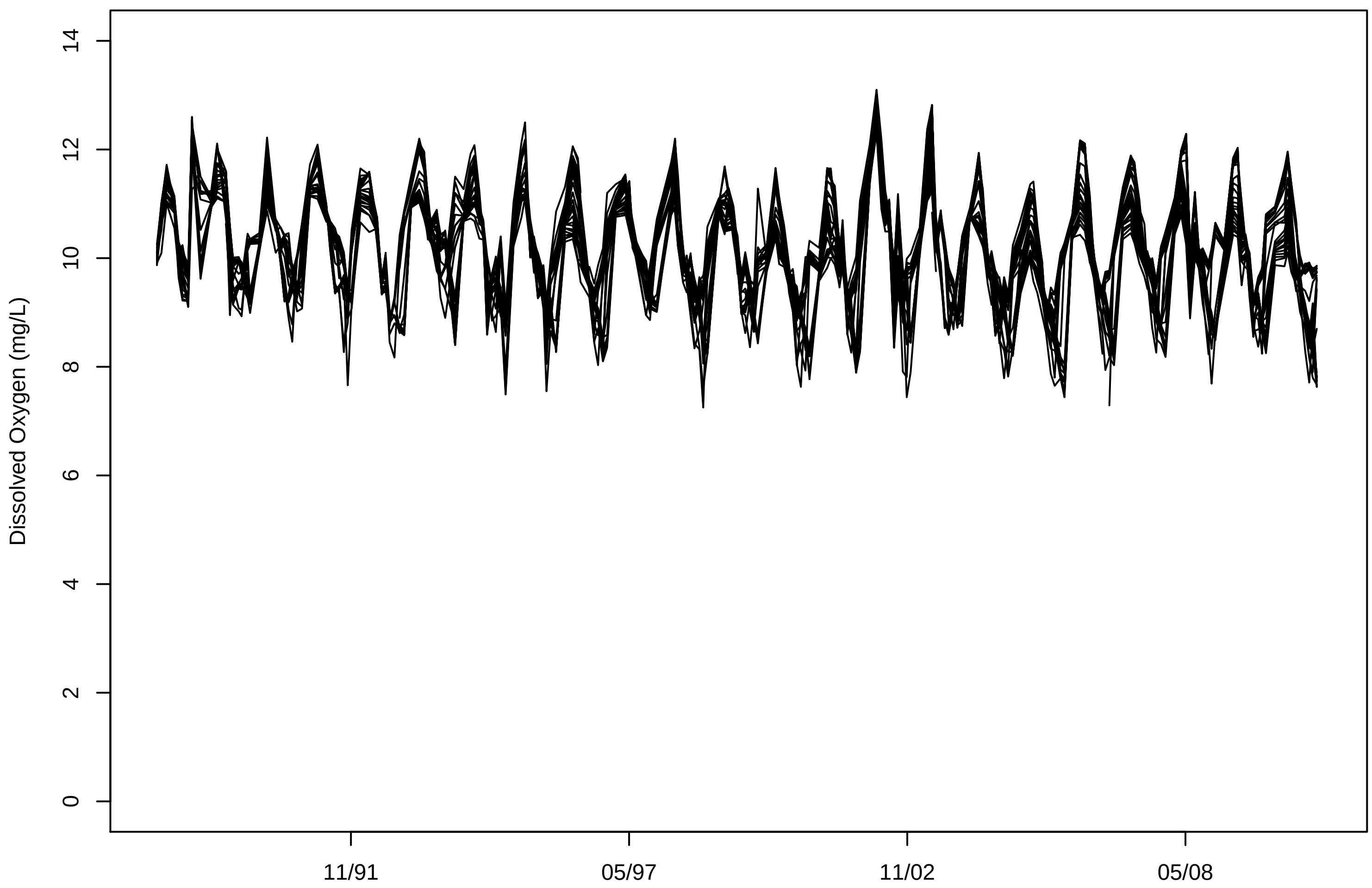


Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

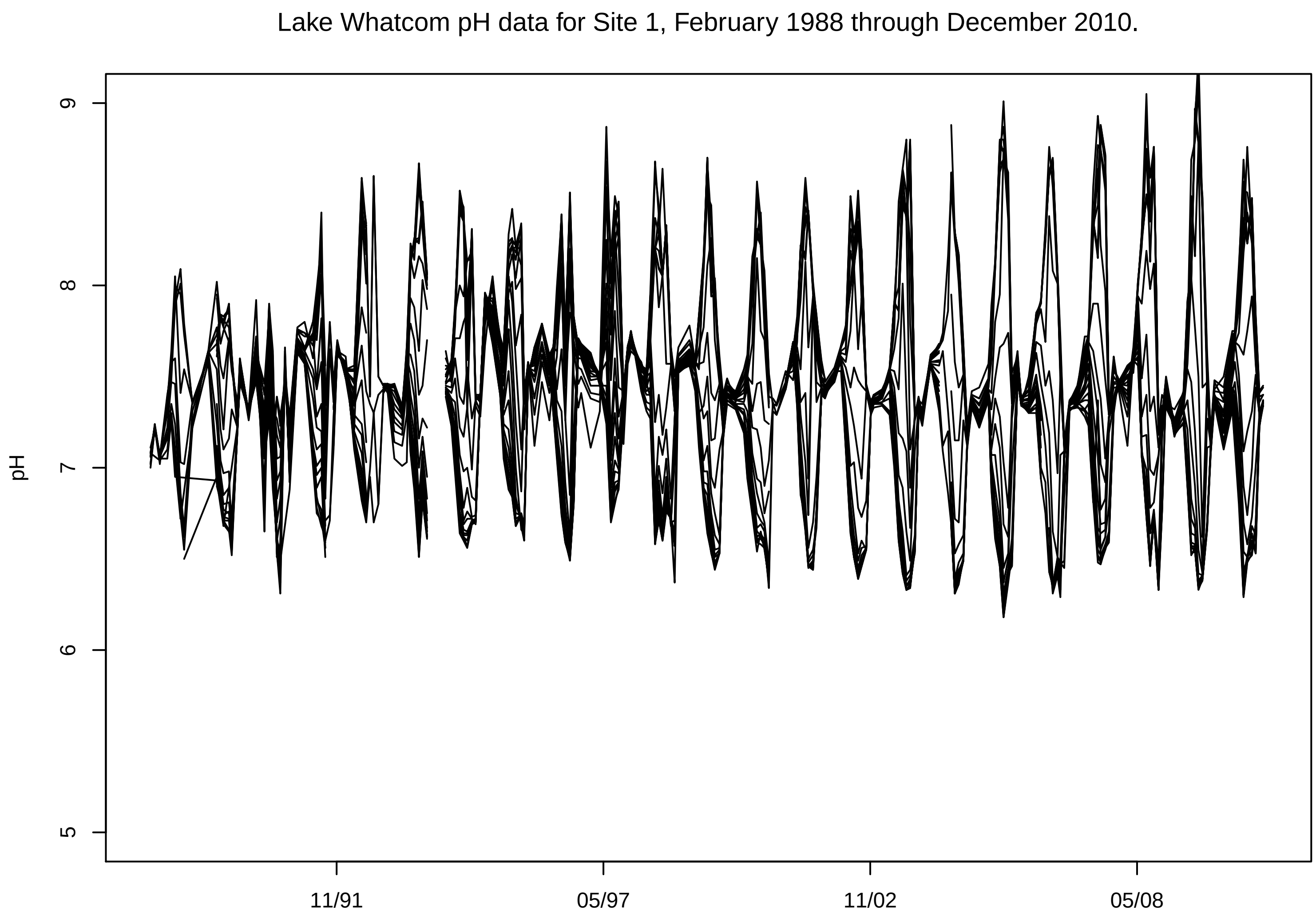


Figure B61: Lake Whatcom historic pH data for Site 1.

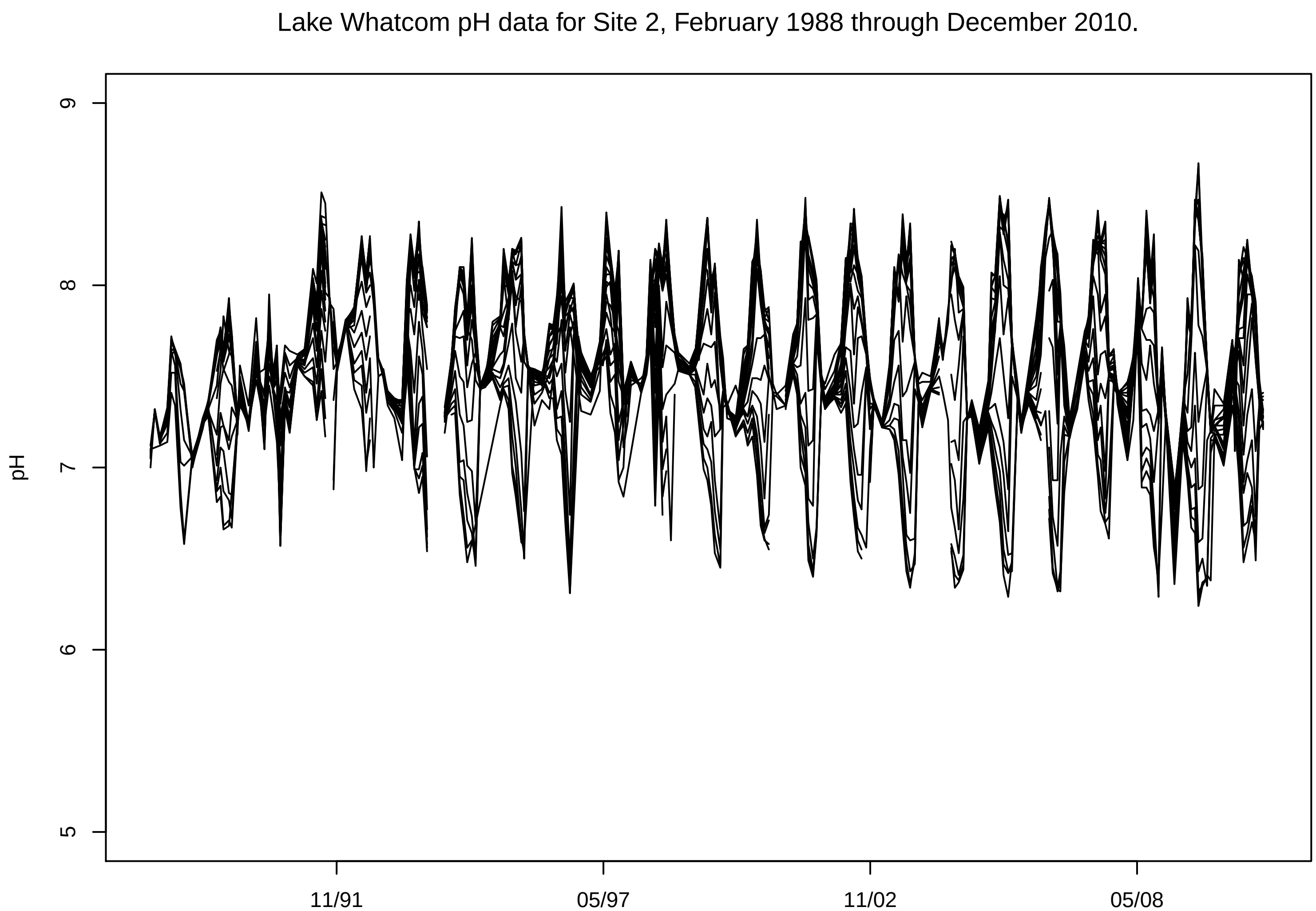


Figure B62: Lake Whatcom historic pH data for Site 2.

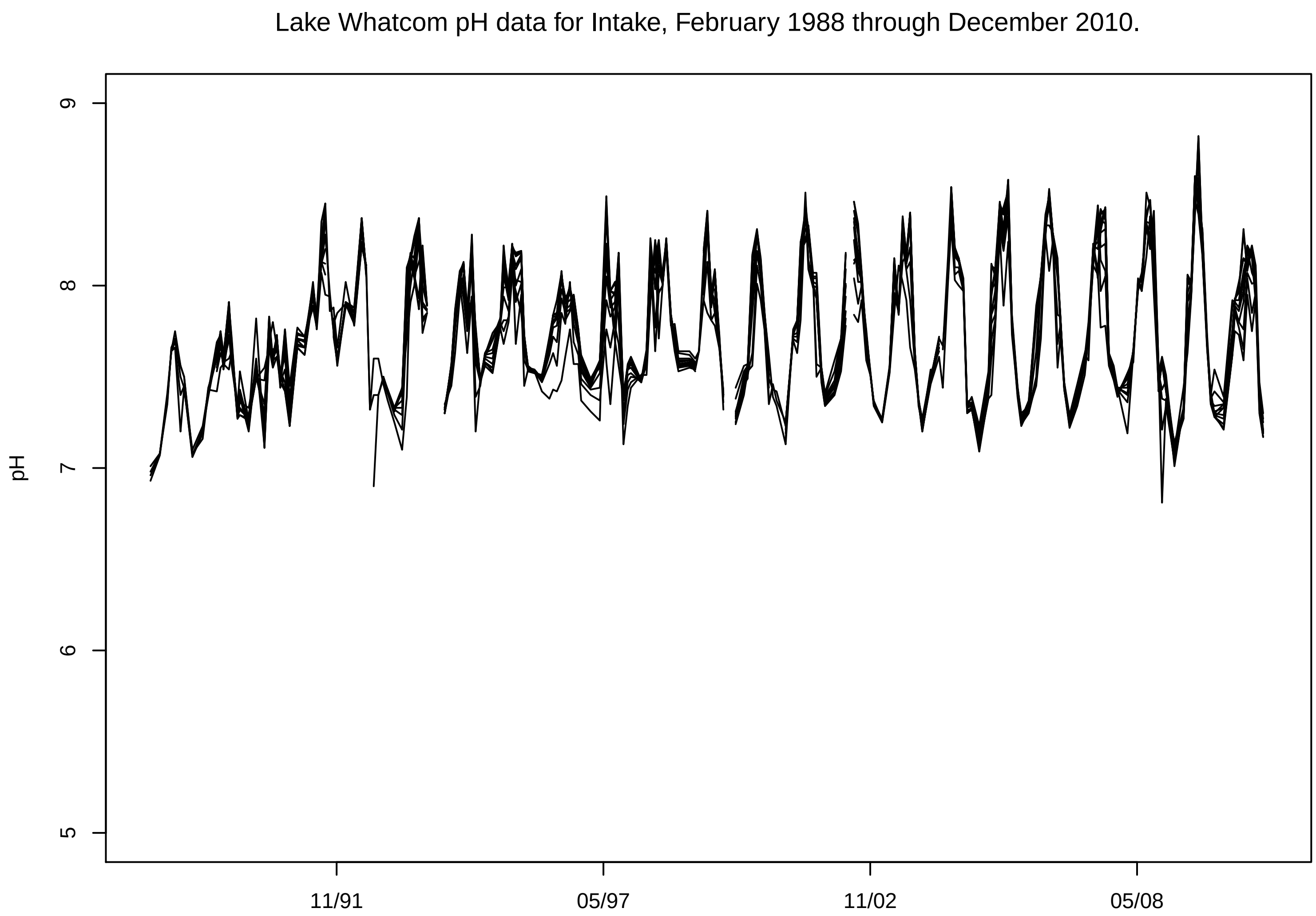


Figure B63: Lake Whatcom historic pH data for the Intake.

Lake Whatcom pH data for Site 3, February 1988 through December 2010.

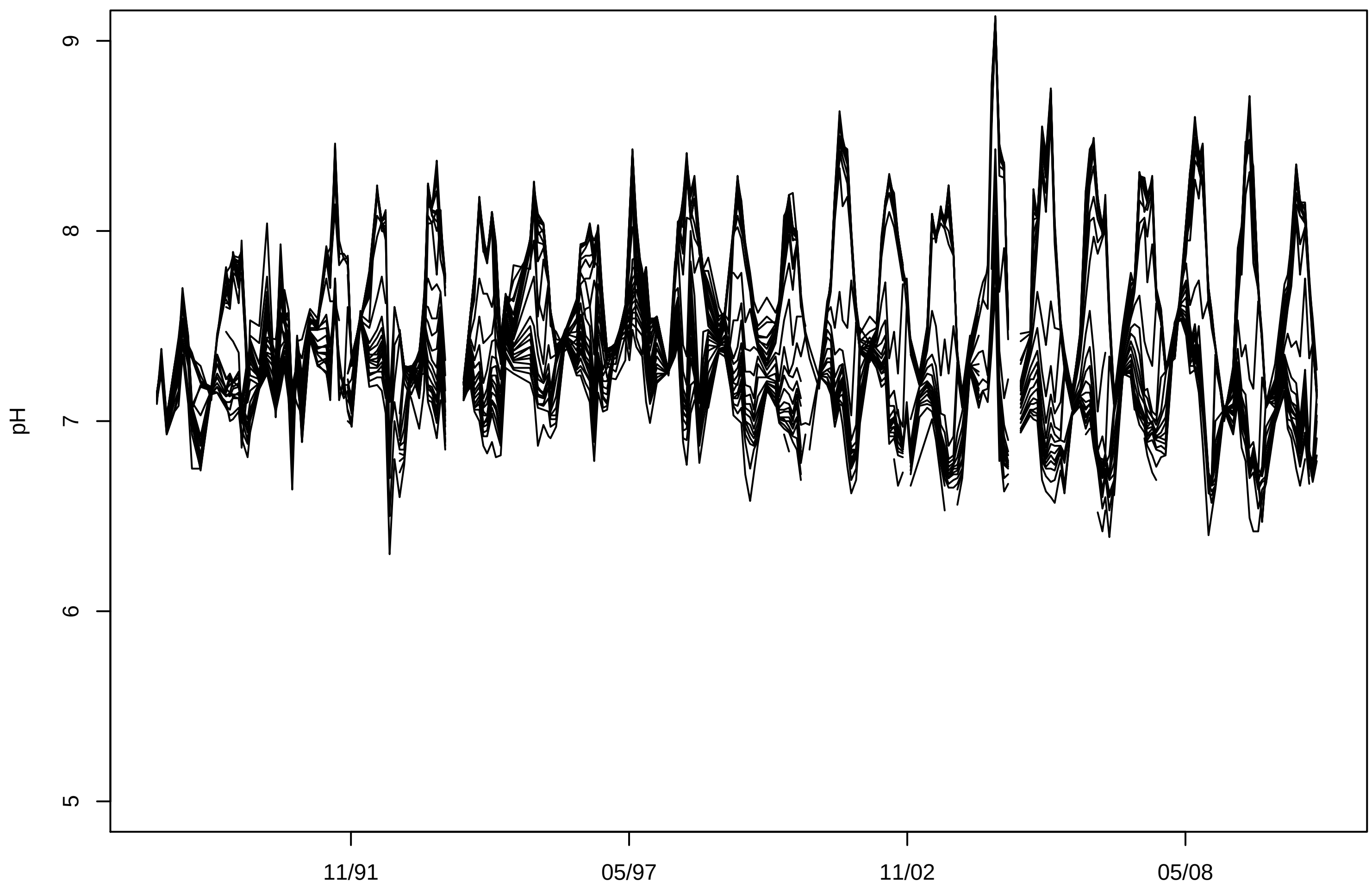


Figure B64: Lake Whatcom historic pH data for Site 3.

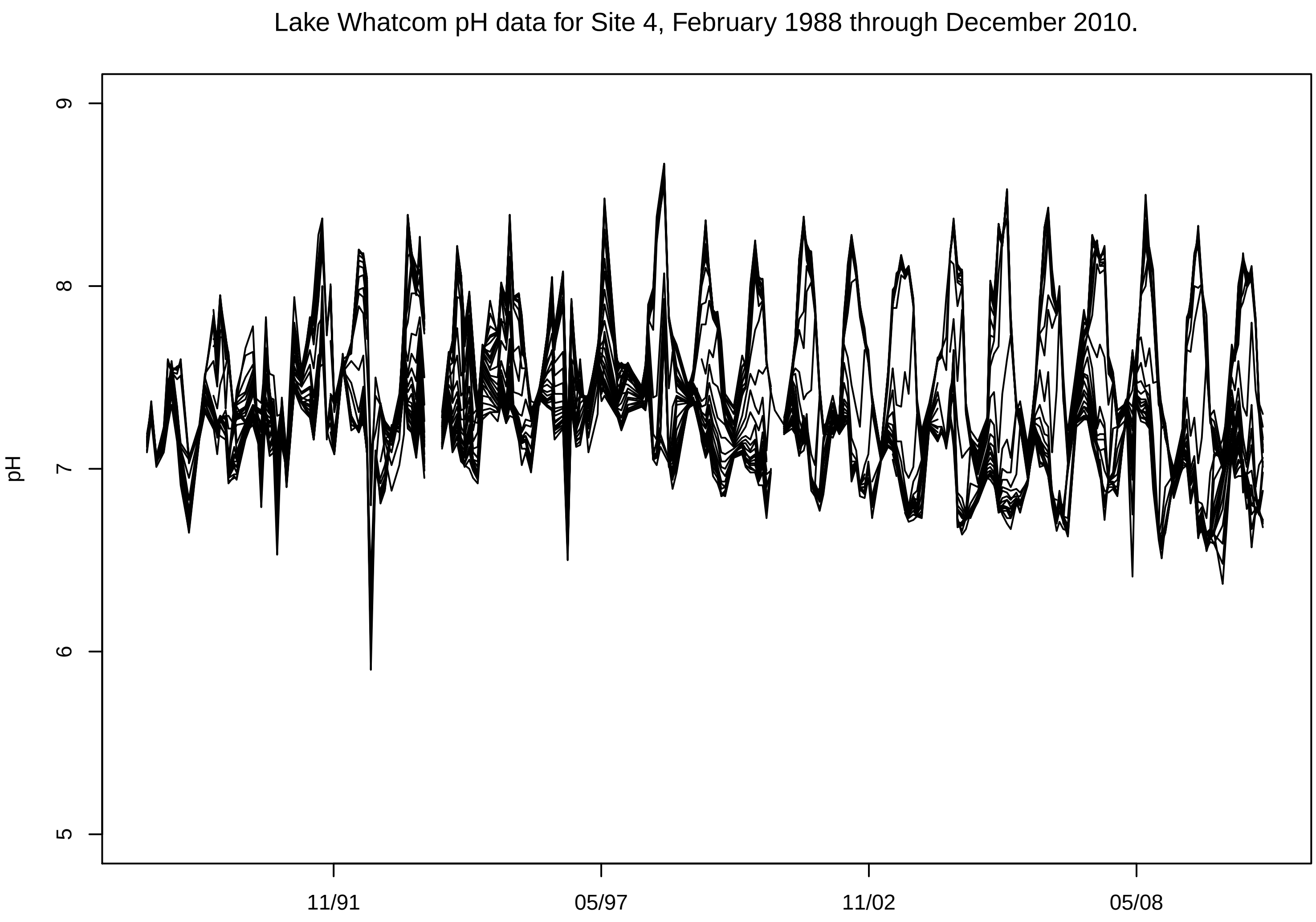


Figure B65: Lake Whatcom historic pH data for Site 4.

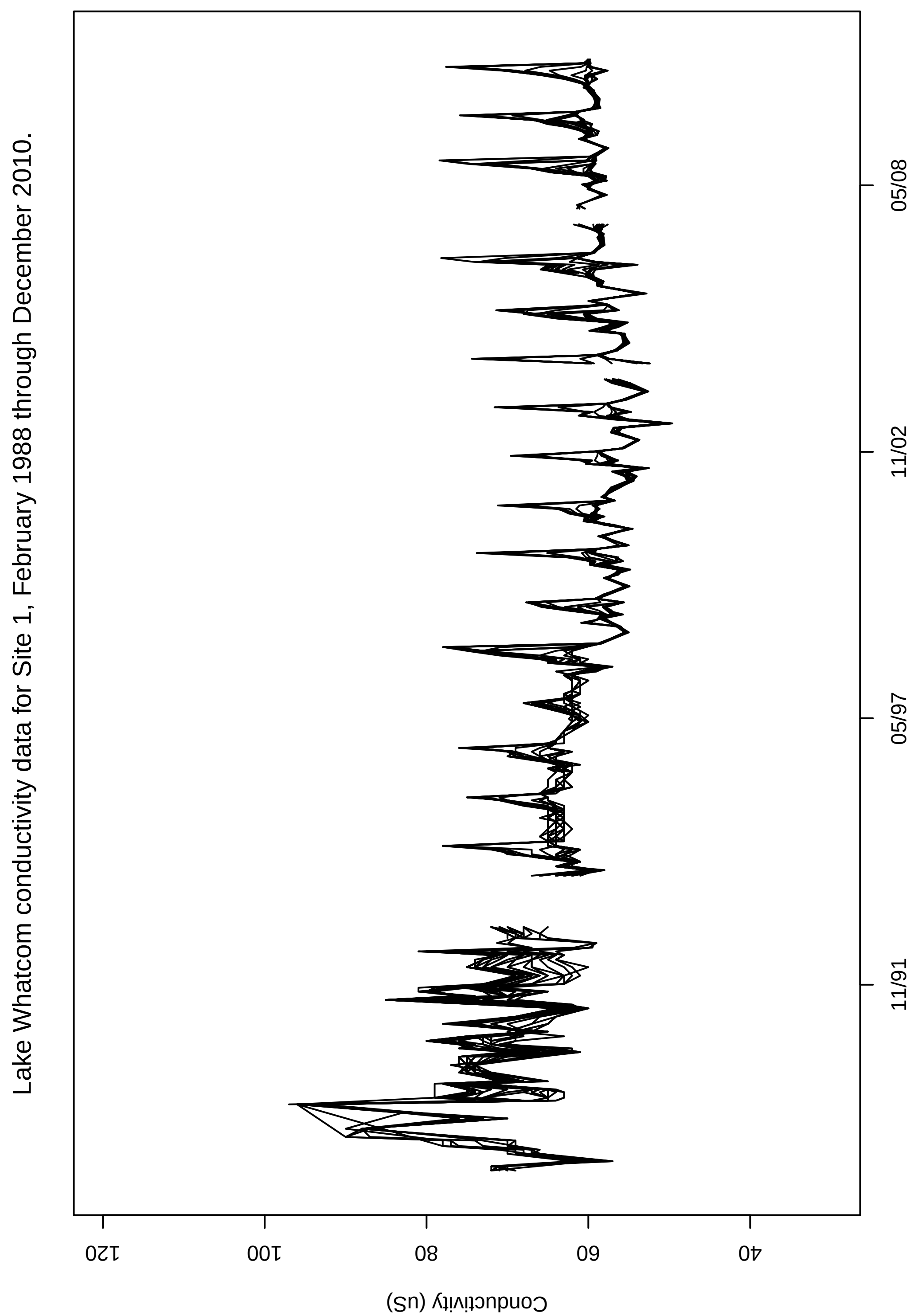


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

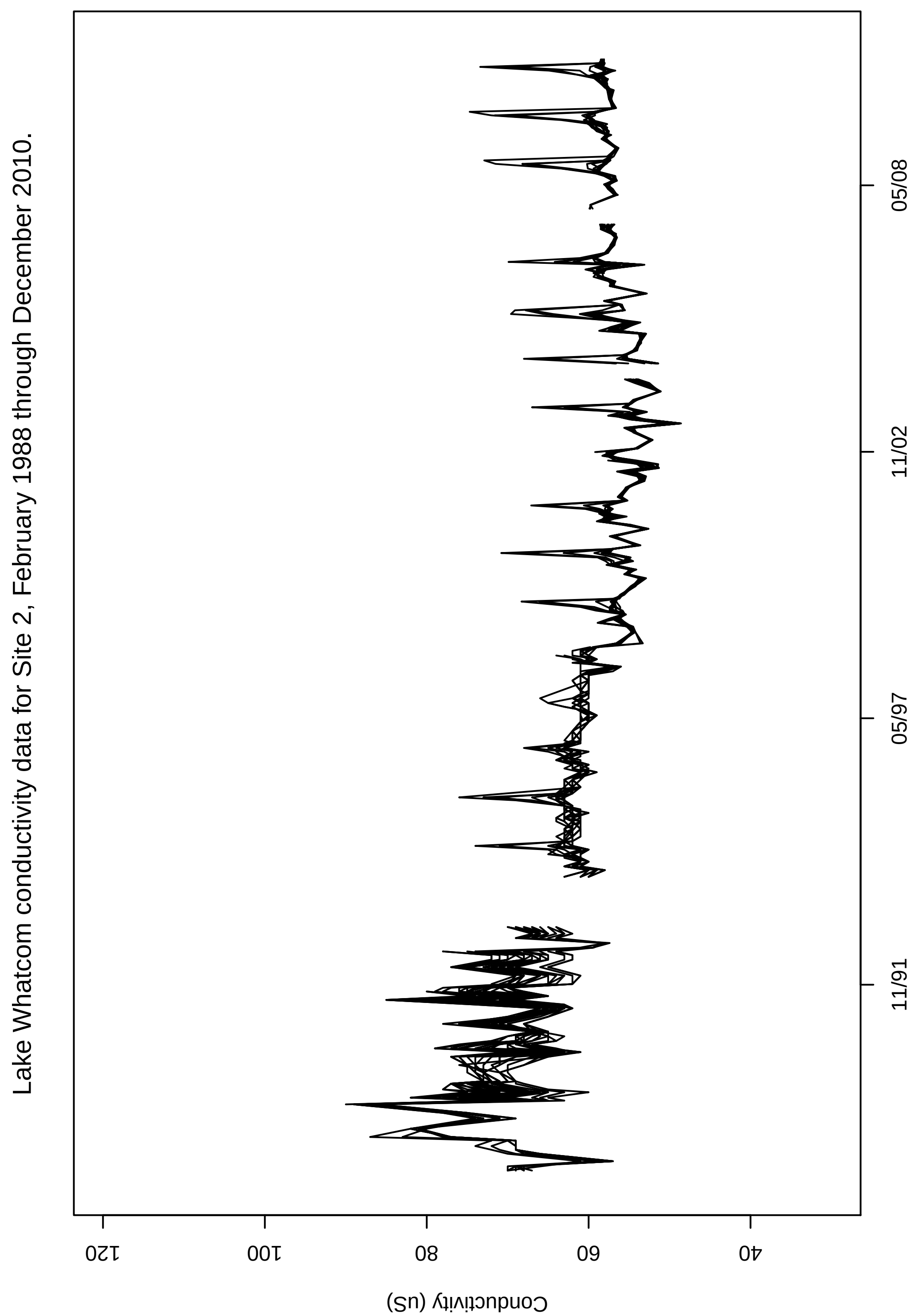


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

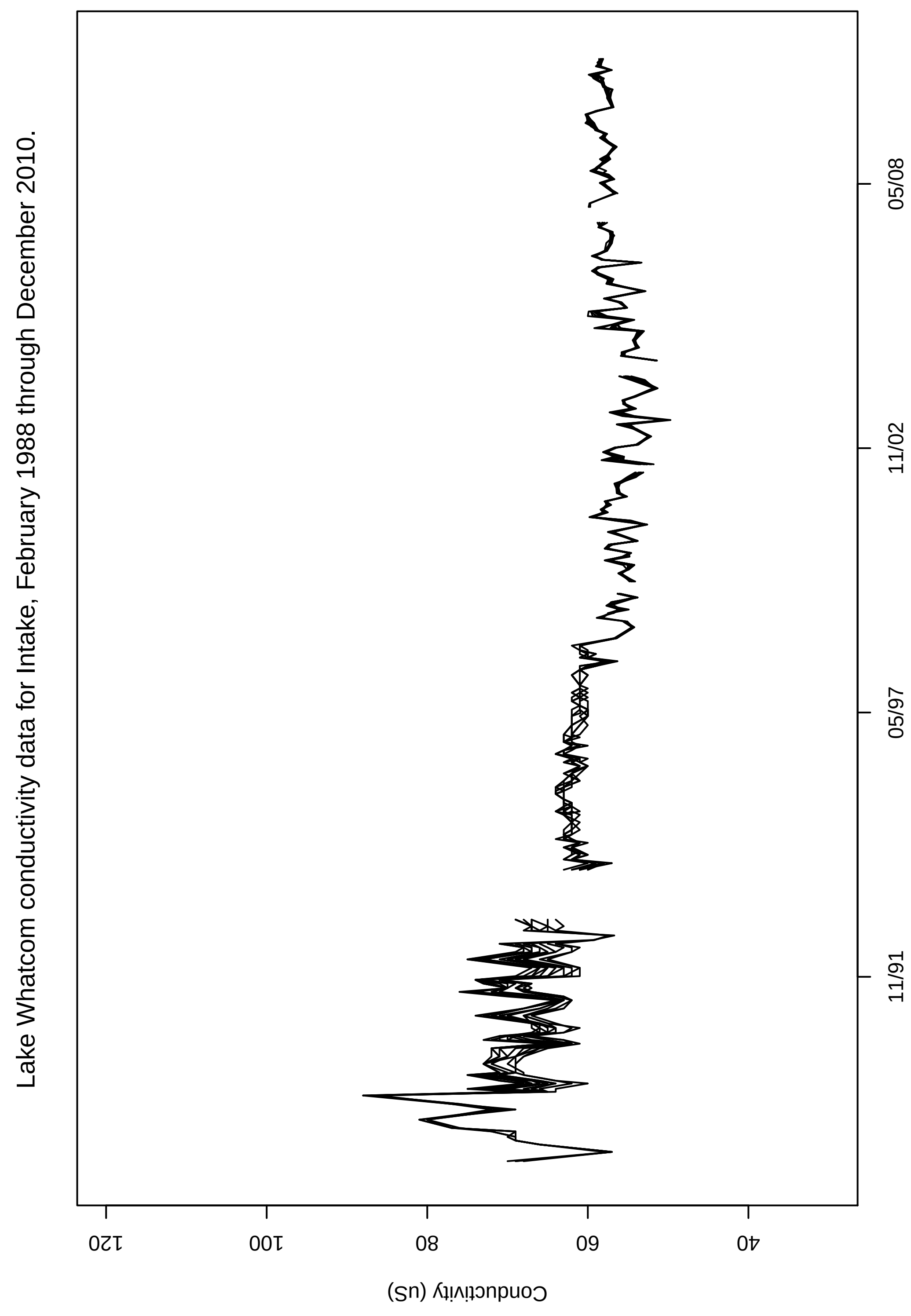


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

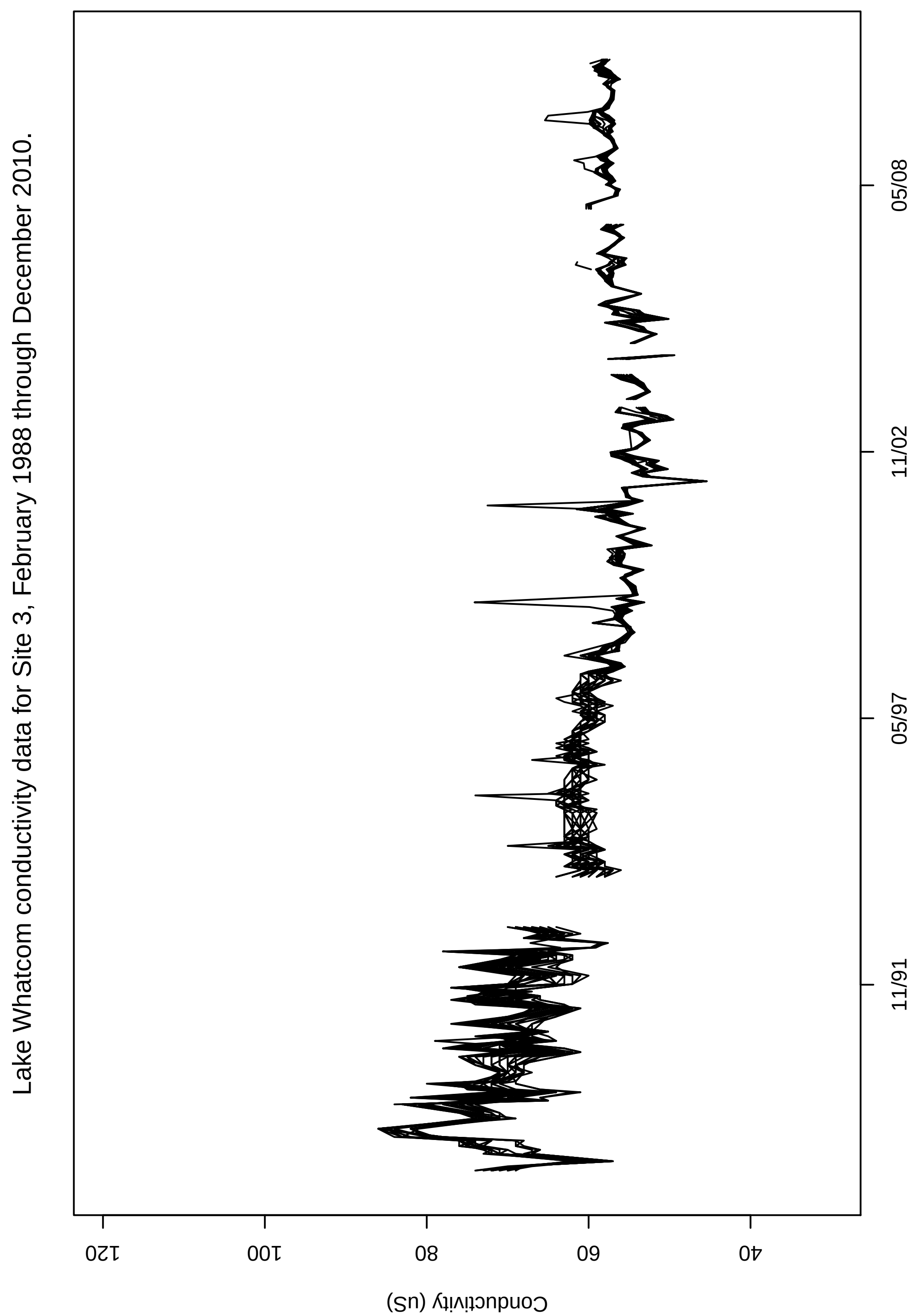


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

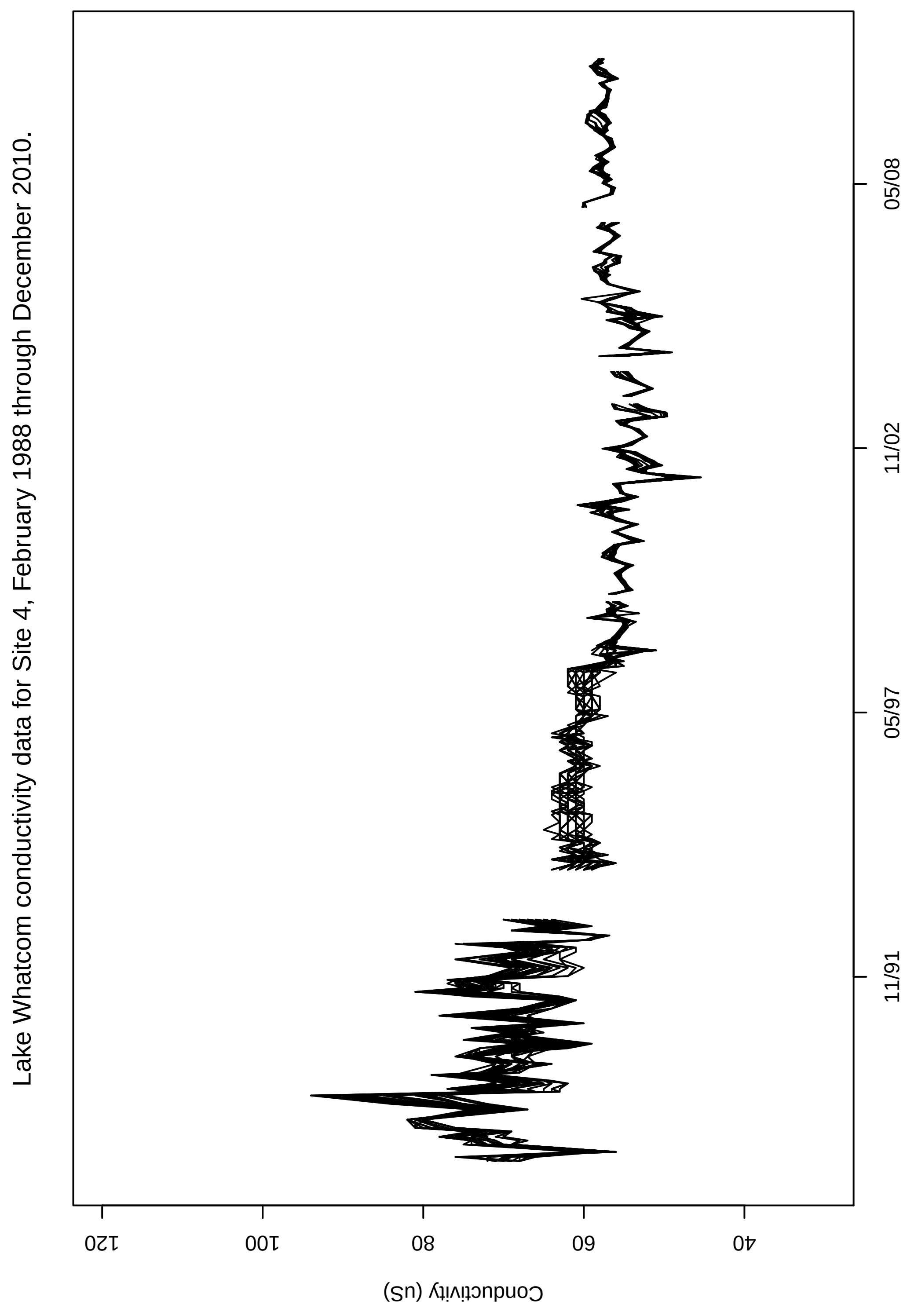


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

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

Lake Whatcom alkalinity data for Site 1, February 1988 through December 2010.

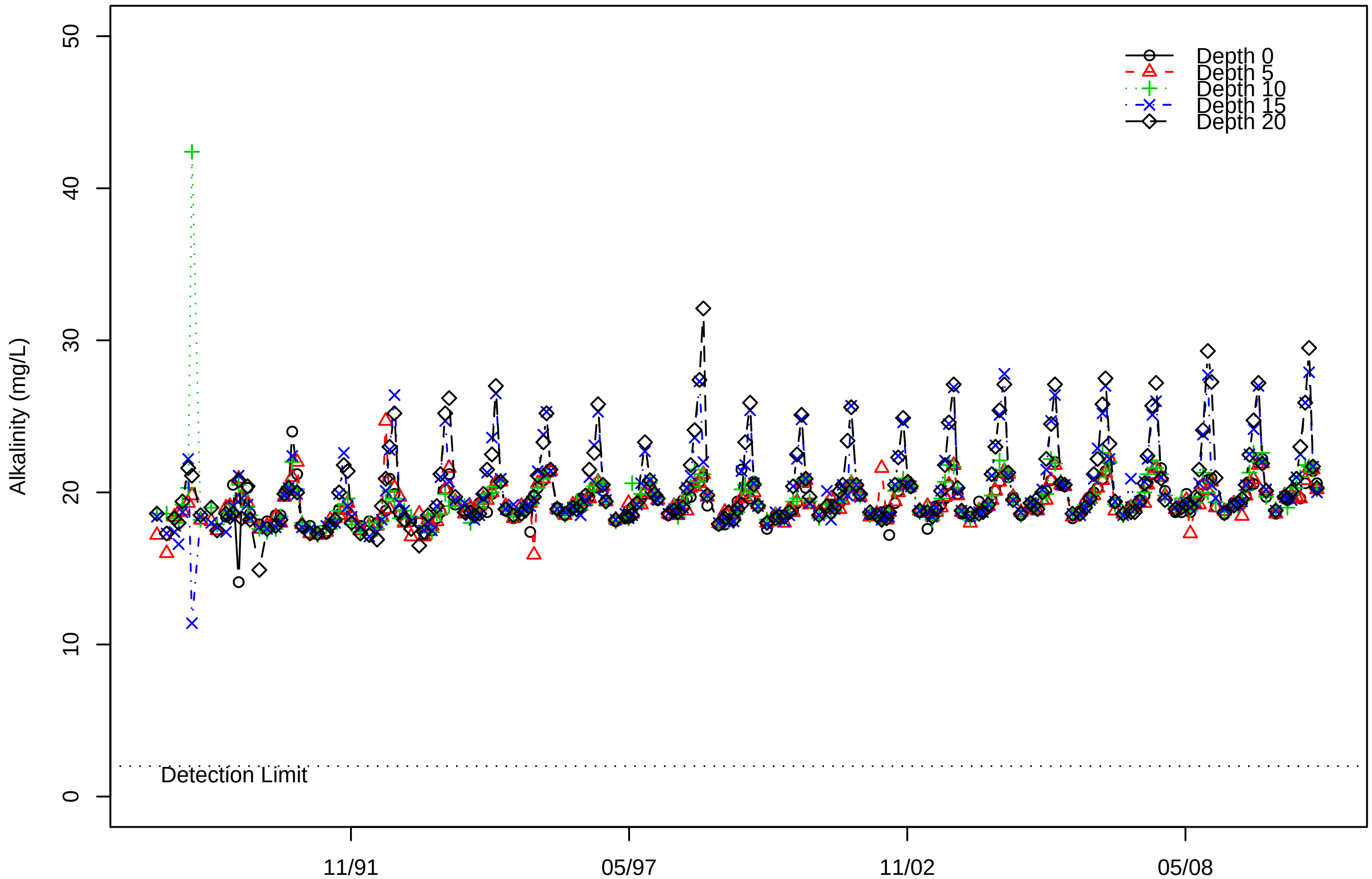


Figure B71: Lake Whatcom alkalinity data for Site 1.

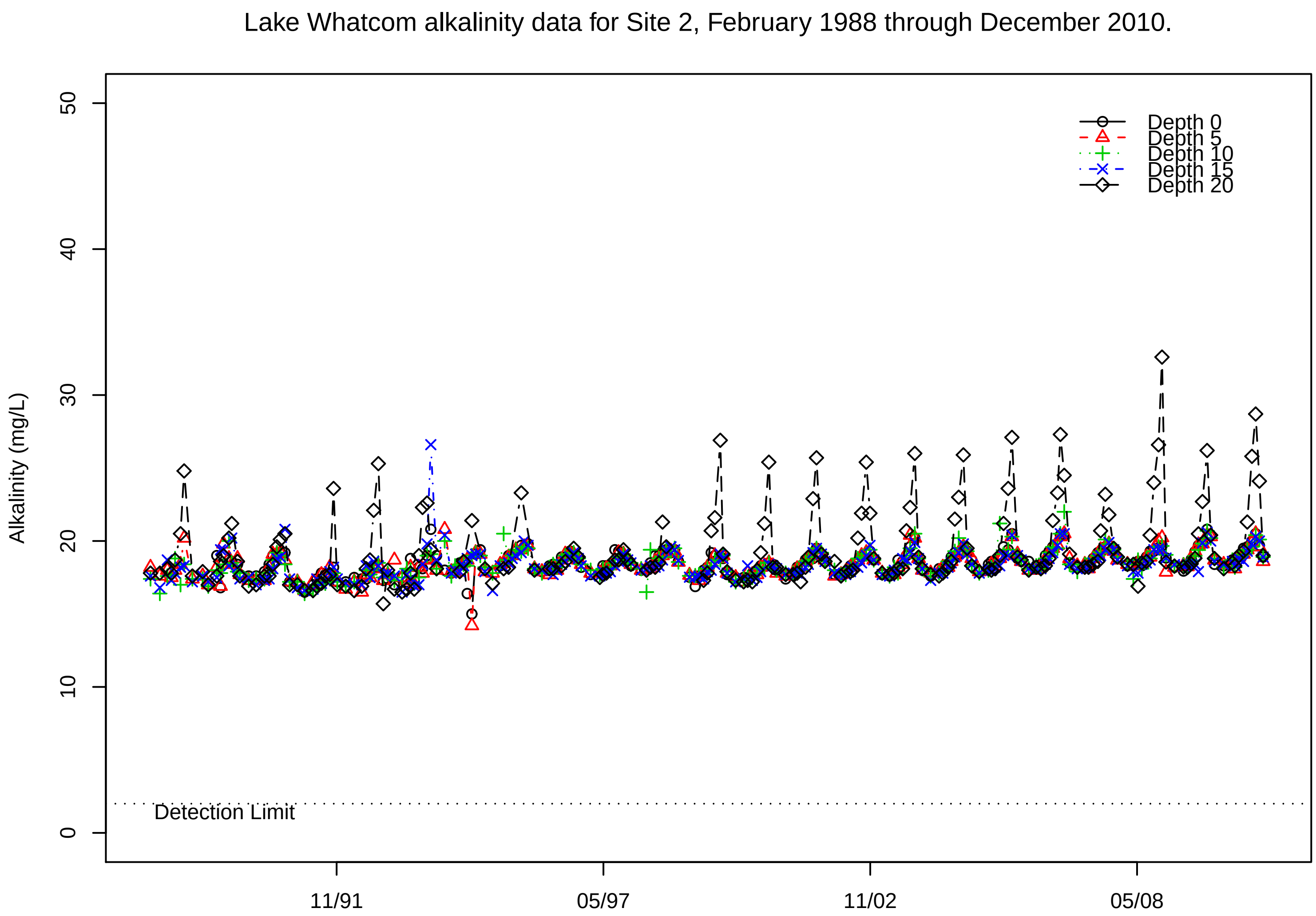


Figure B72: Lake Whatcom alkalinity data for Site 2.

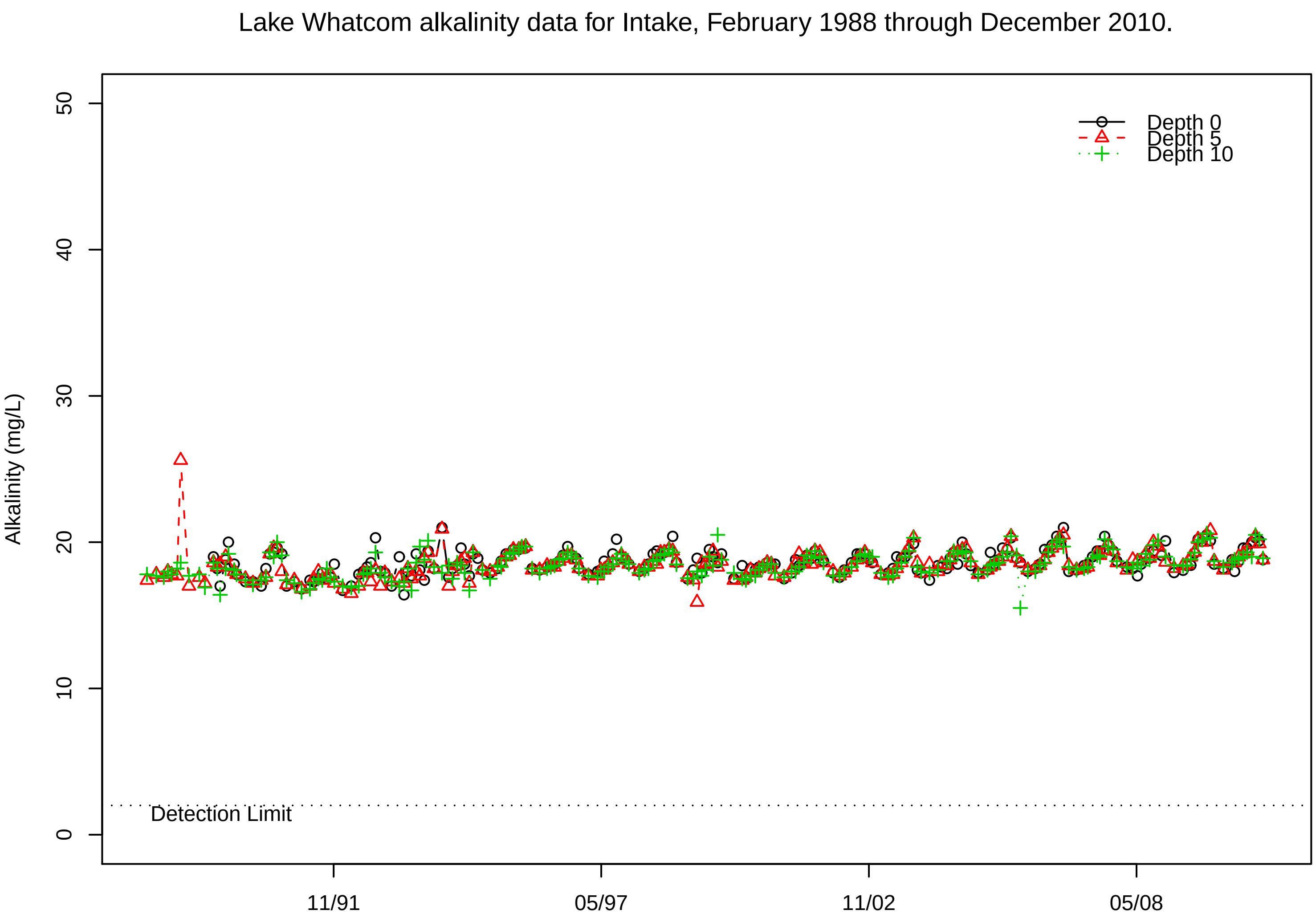


Figure B73: Lake Whatcom alkalinity data for the Intake site.

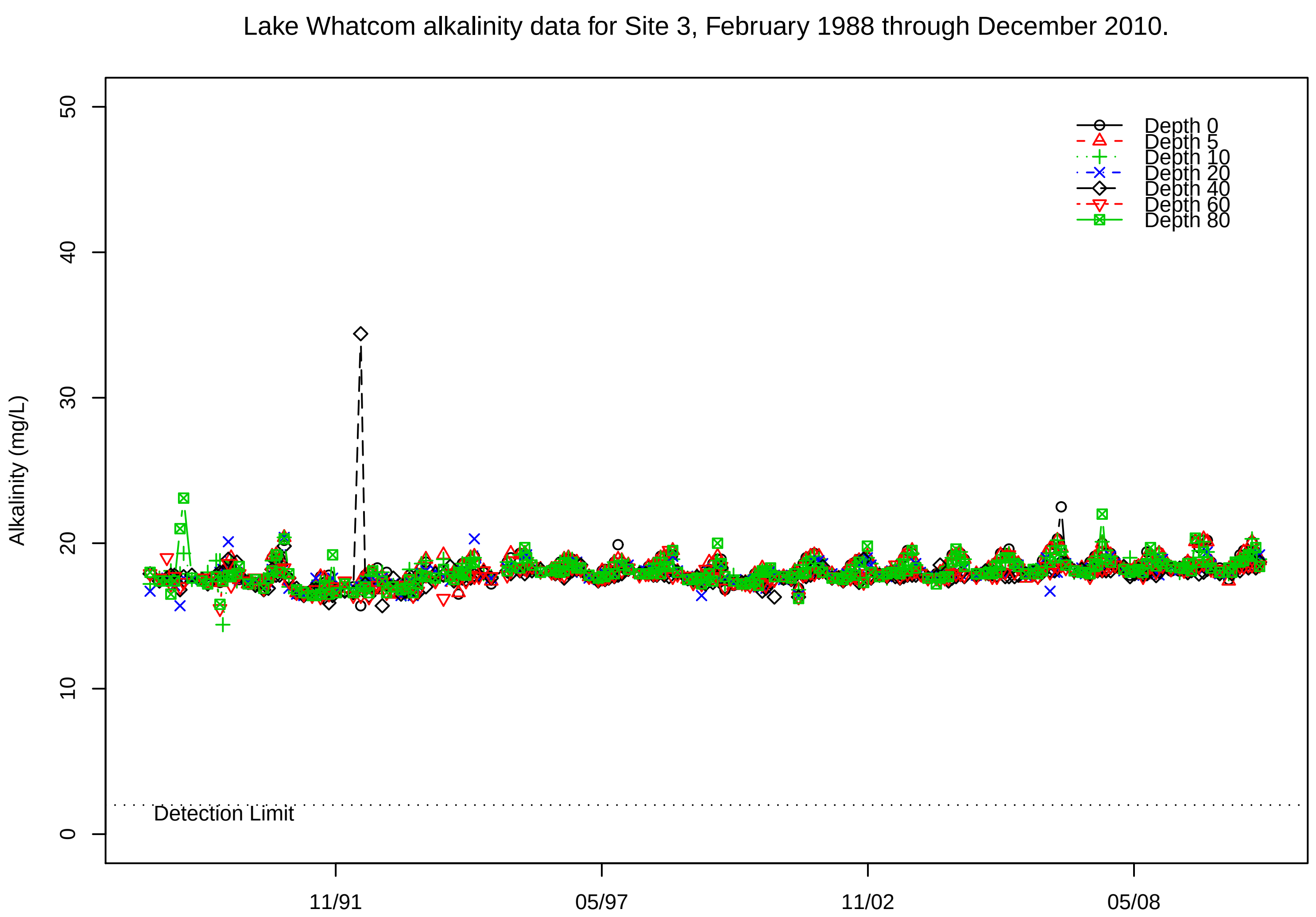


Figure B74: Lake Whatcom alkalinity data for Site 3.

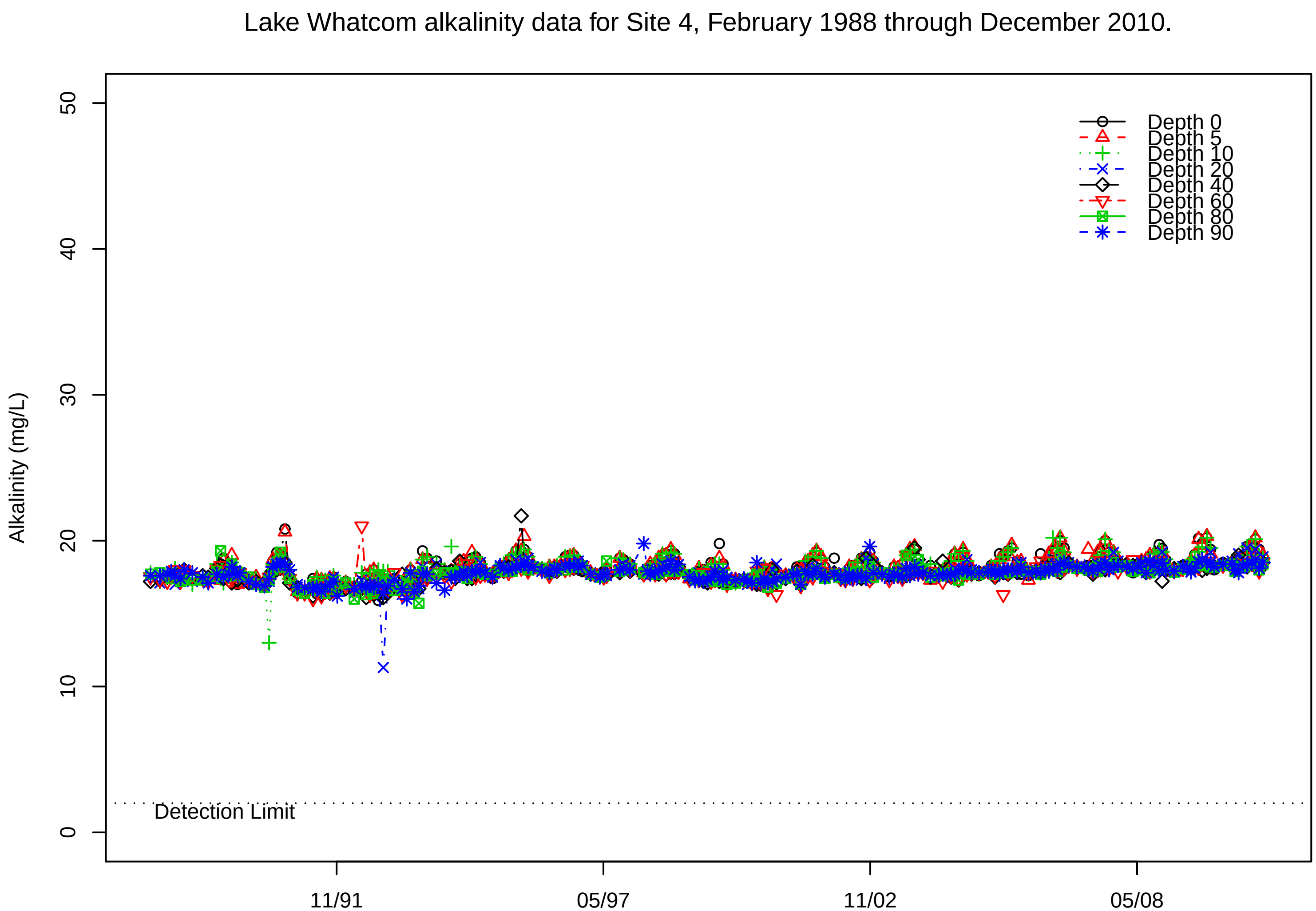


Figure B75: Lake Whatcom alkalinity data for Site 4.

Lake Whatcom turbidity data for Site 1, February 1988 through December 2010.

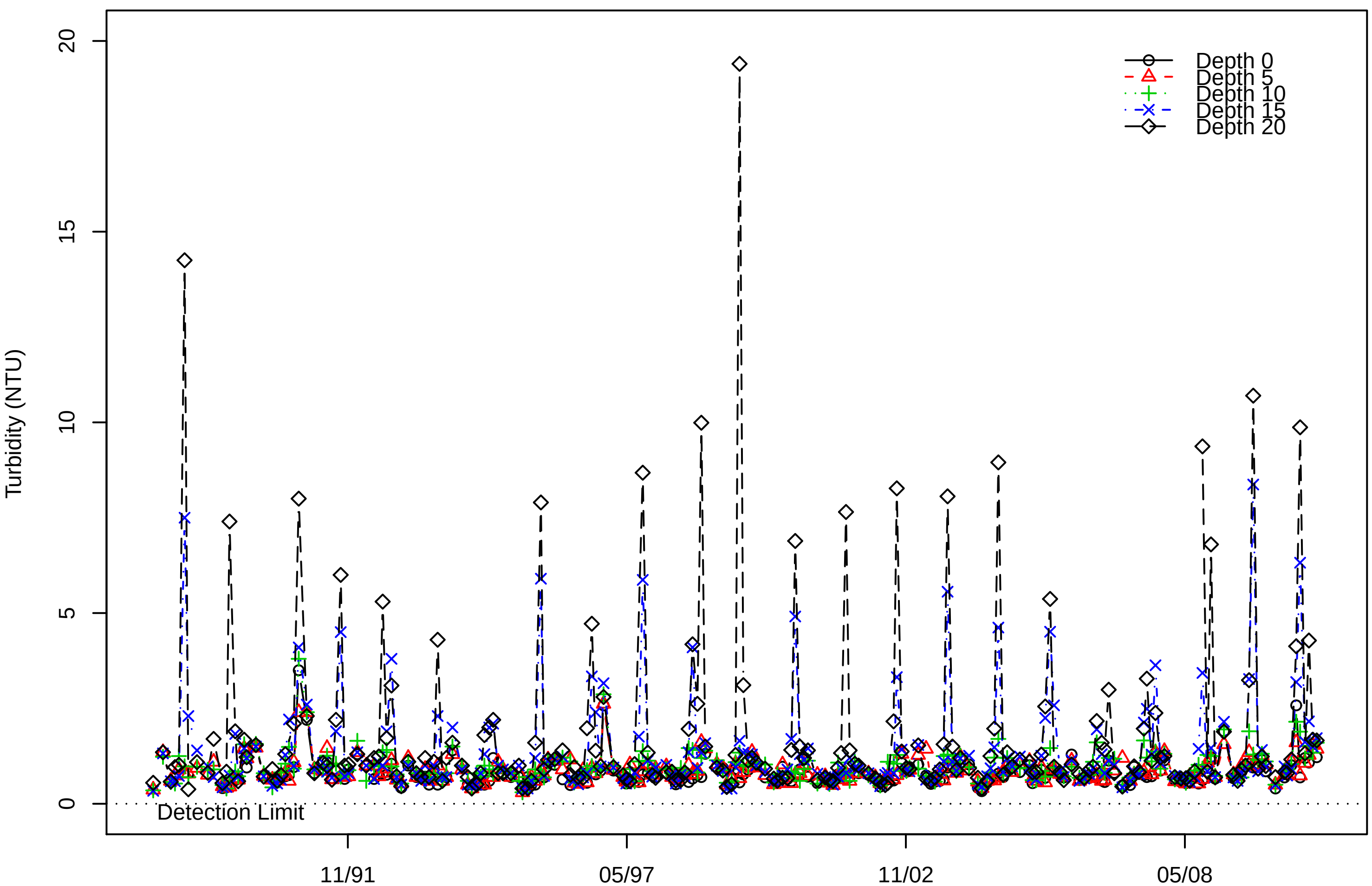


Figure B76: Lake Whatcom turbidity data for Site 1.

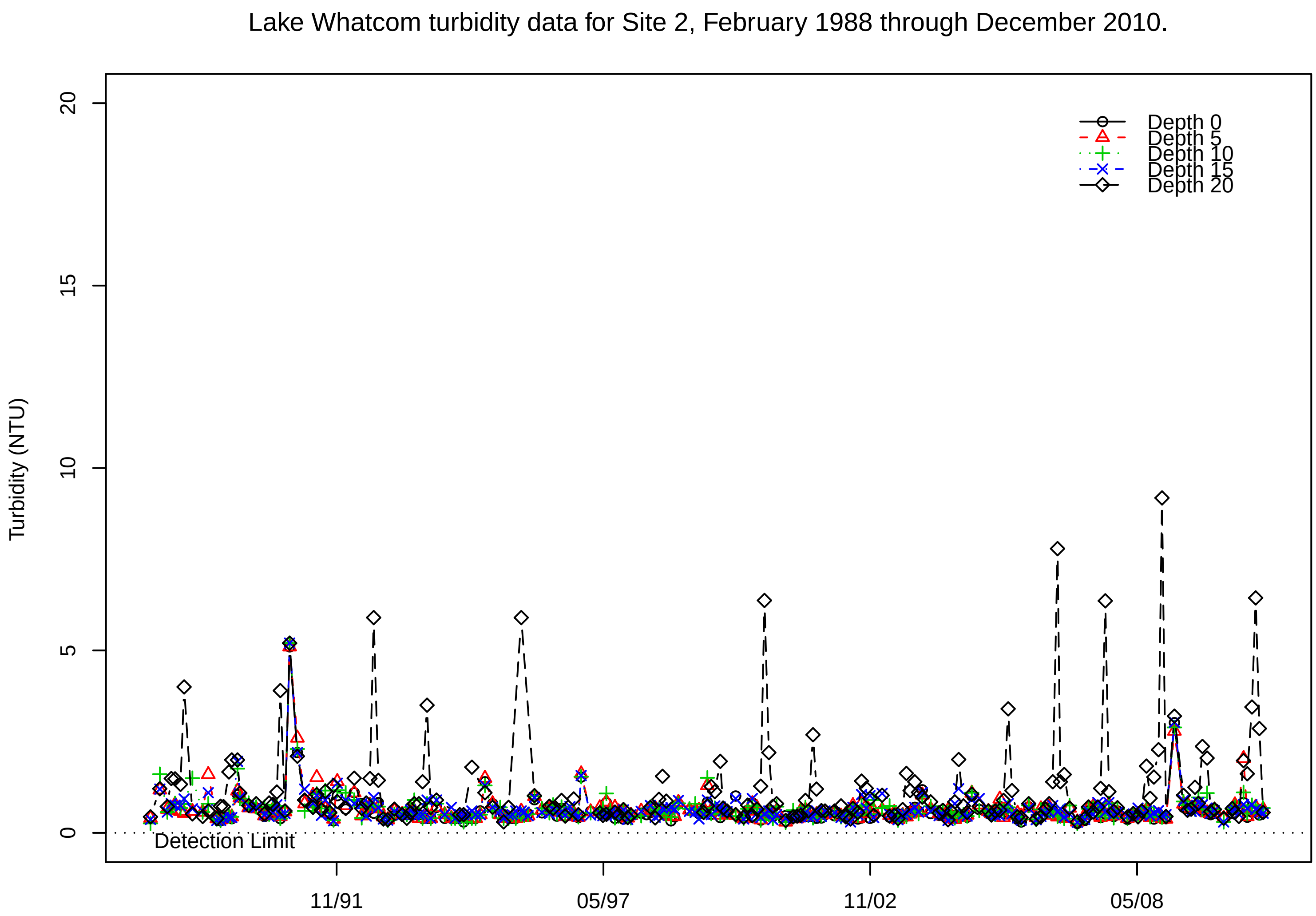


Figure B77: Lake Whatcom turbidity data for Site 2.

Lake Whatcom turbidity data for Intake, February 1988 through December 2010.

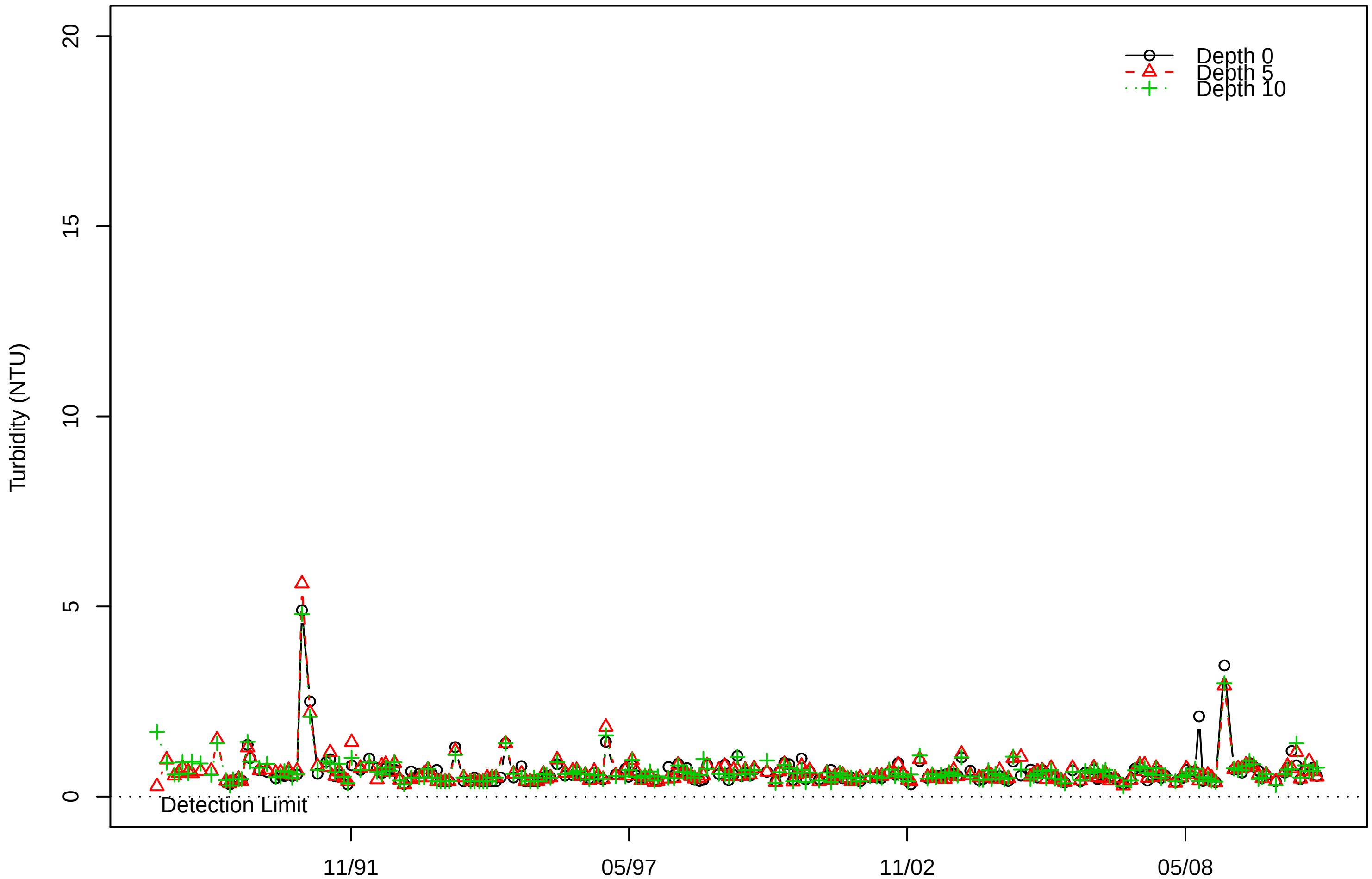


Figure B78: Lake Whatcom turbidity data for the Intake site.

Lake Whatcom turbidity data for Site 3, February 1988 through December 2010.

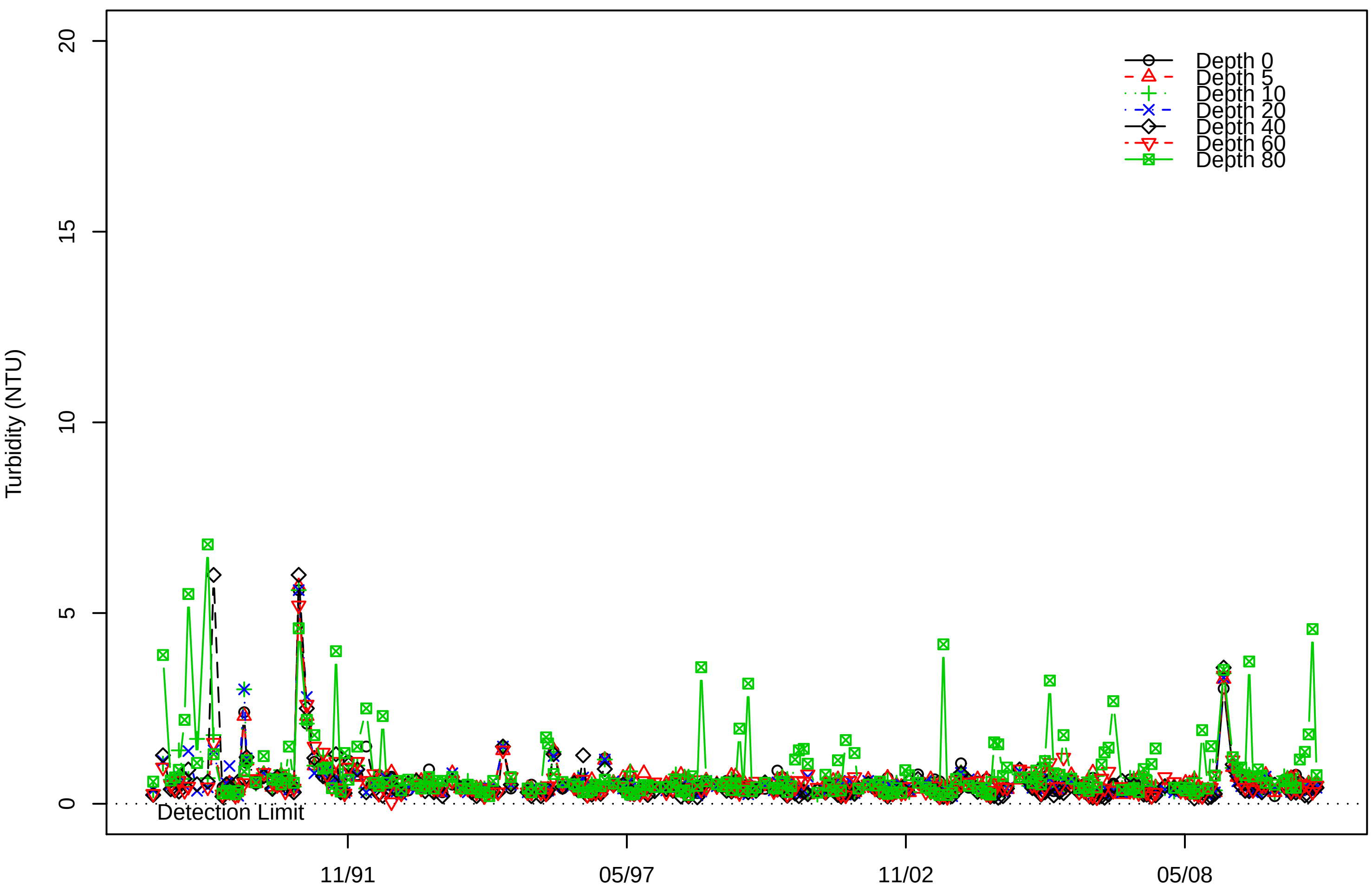


Figure B79: Lake Whatcom turbidity data for Site 3.

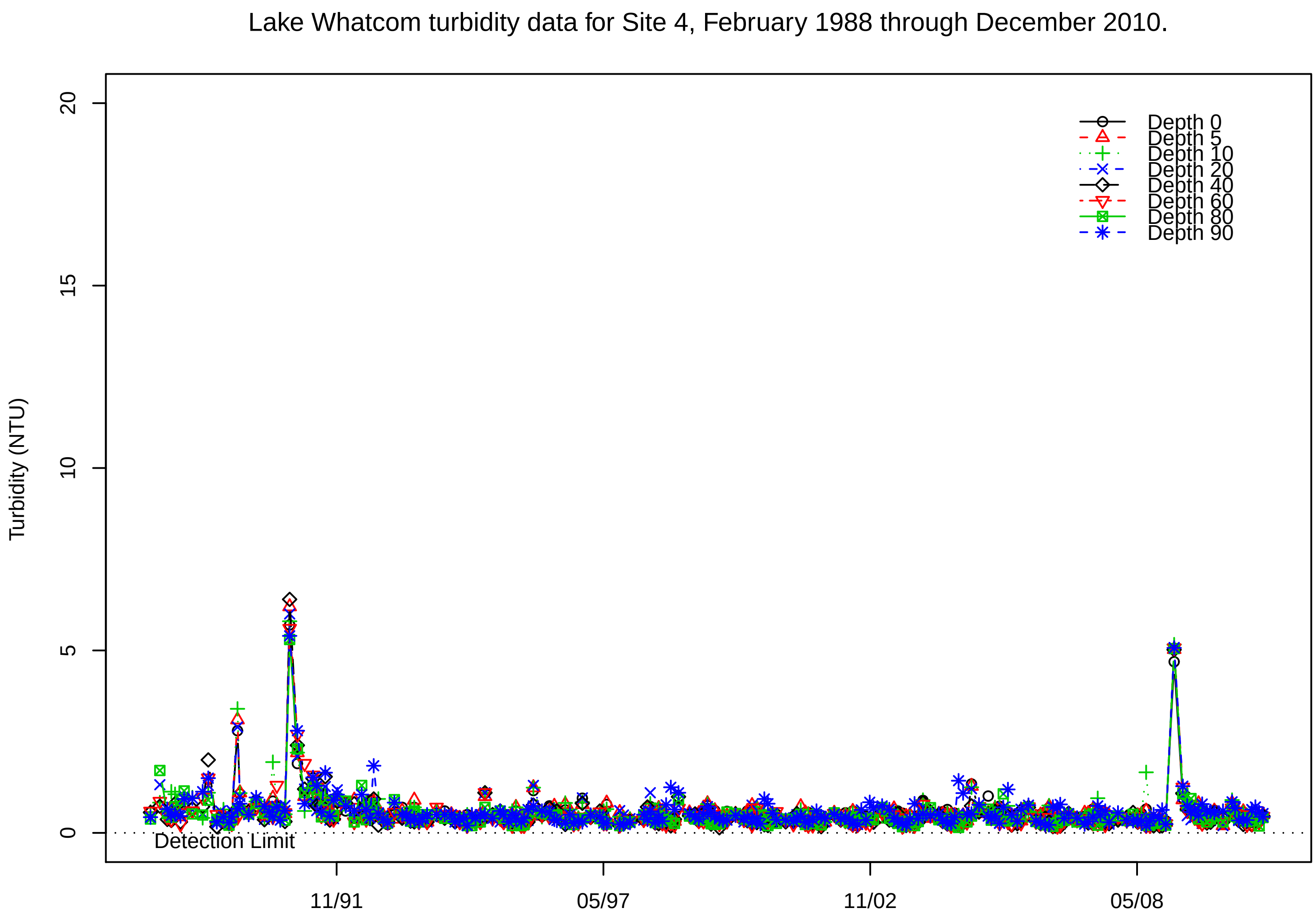


Figure B80: Lake Whatcom turbidity data for Site 4.

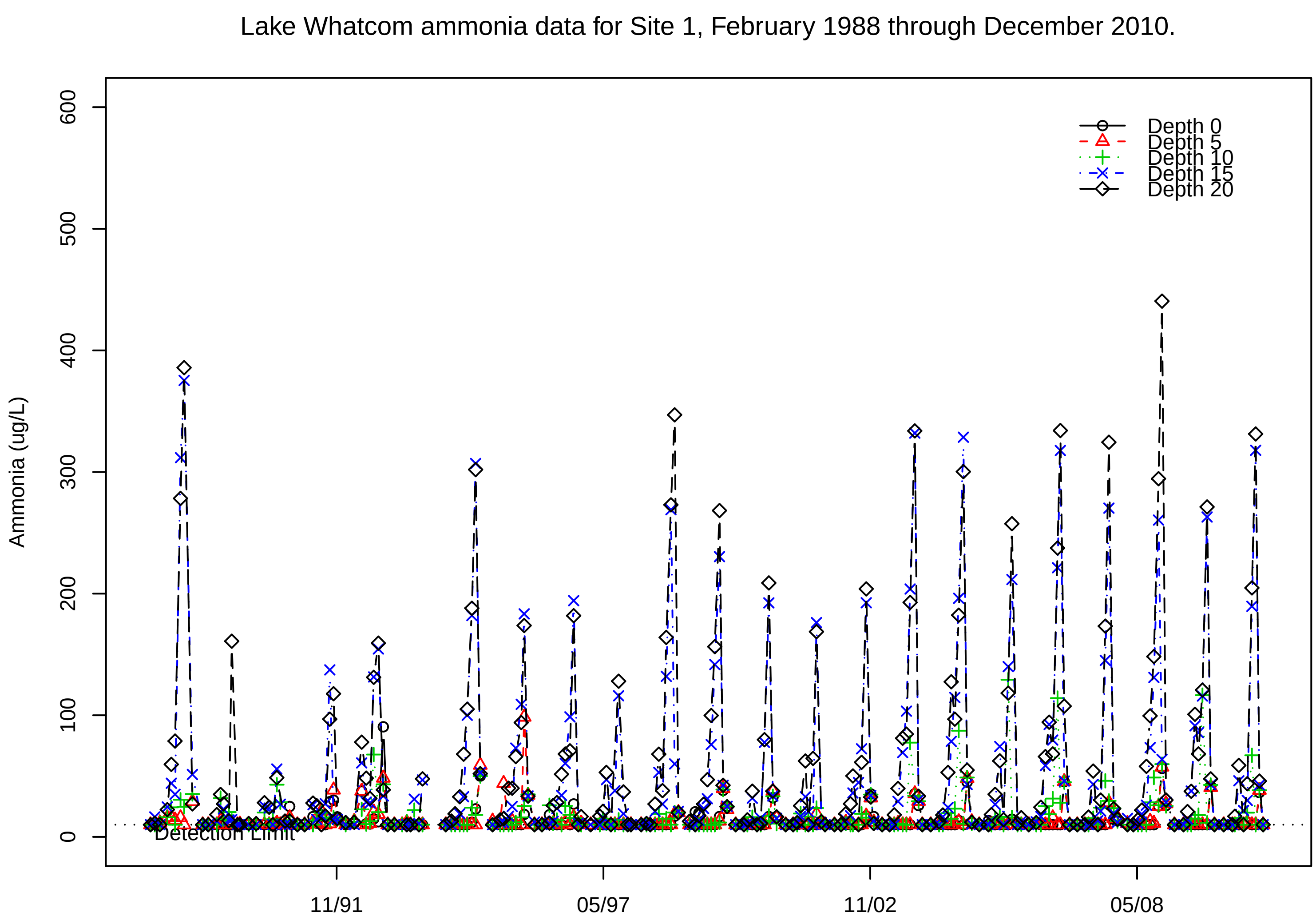
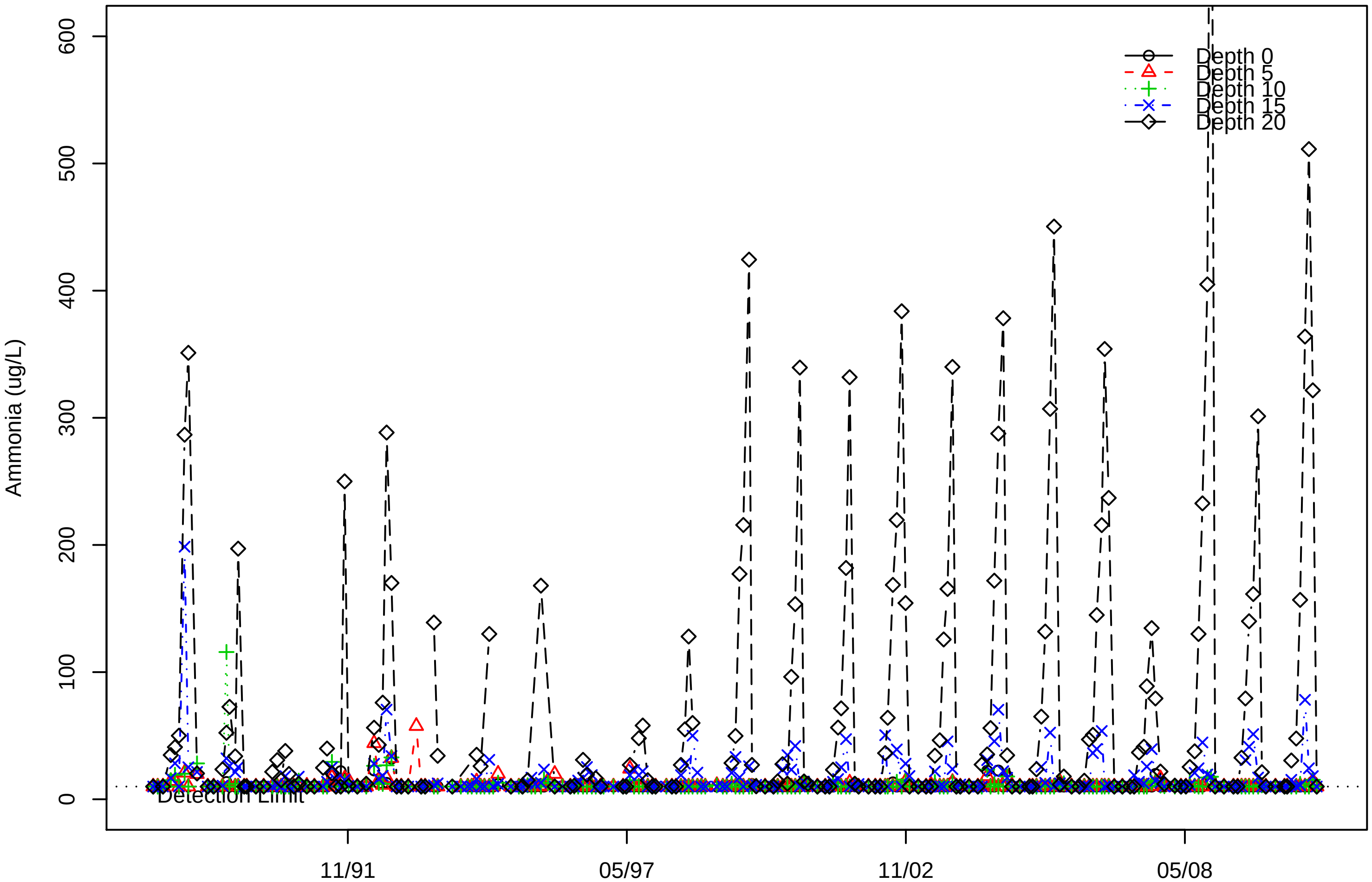


Figure B81: Lake Whatcom ammonia data for Site 1.

Figure B82: Lake Whatcom ammonia data for Site 2.

Lake Whatcom ammonia data for Site 2, February 1988 through December 2010.



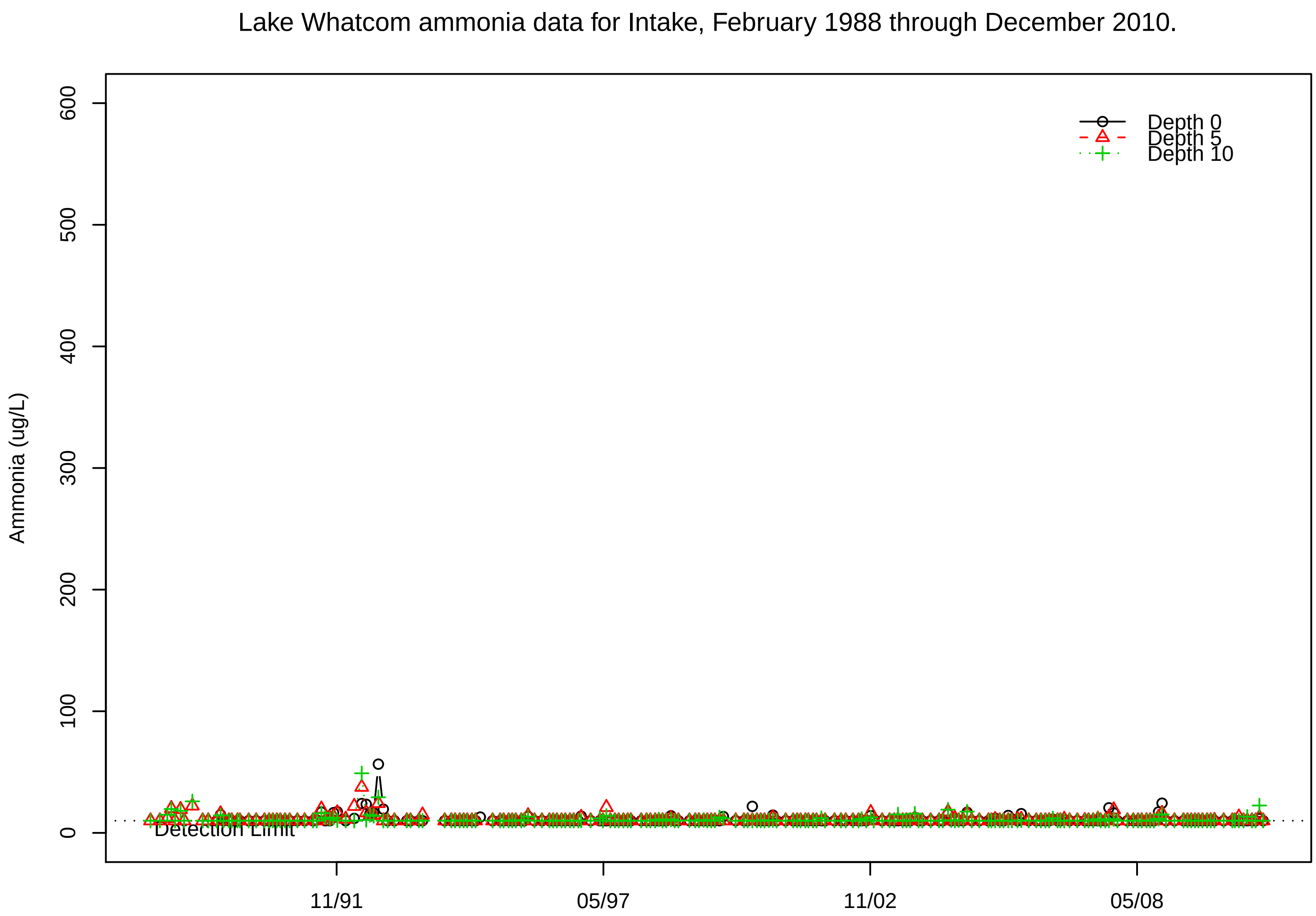


Figure B83: Lake Whatcom ammonia data for the Intake site.

Lake Whatcom ammonia data for Site 3, February 1988 through December 2010.

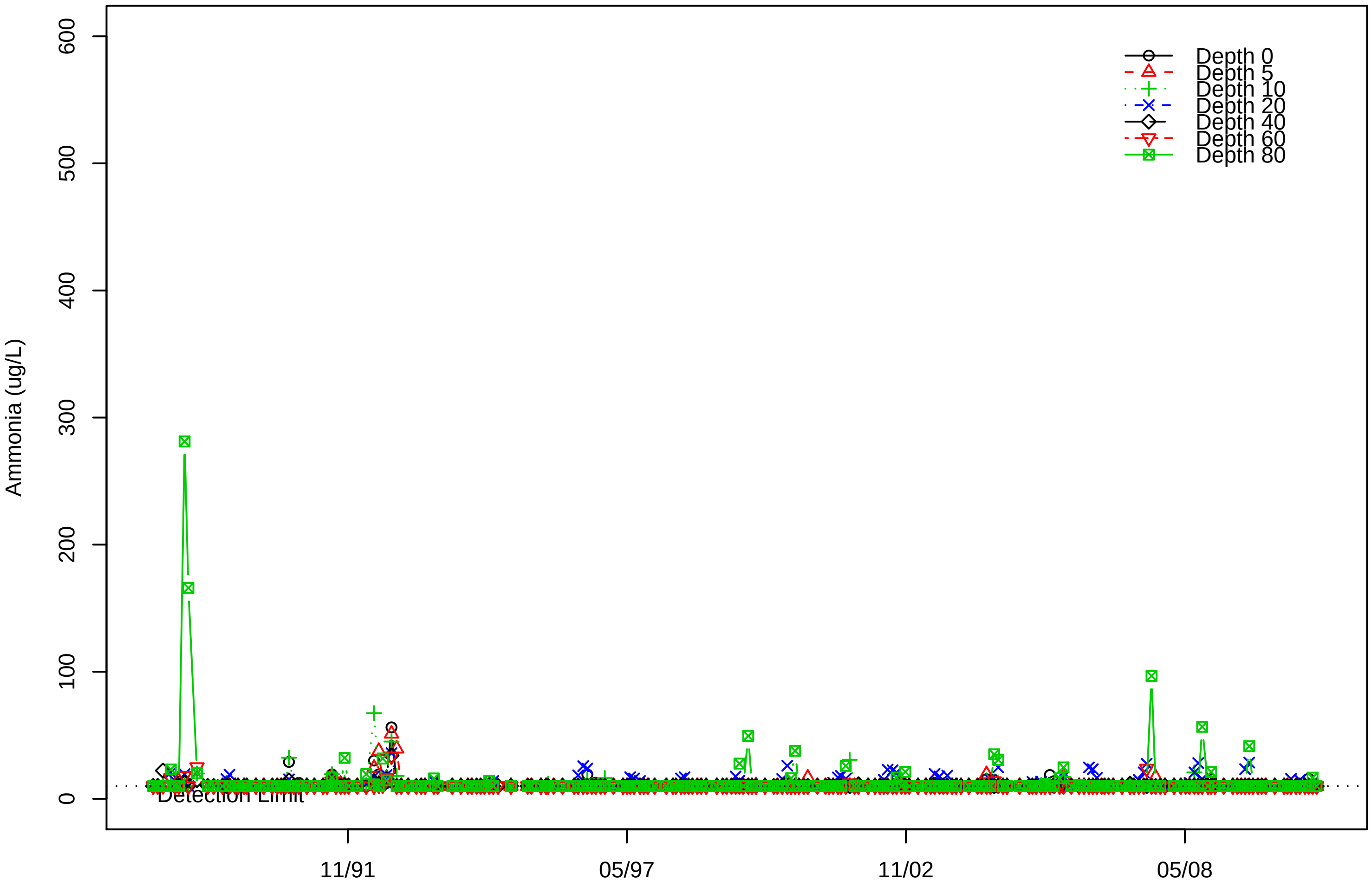
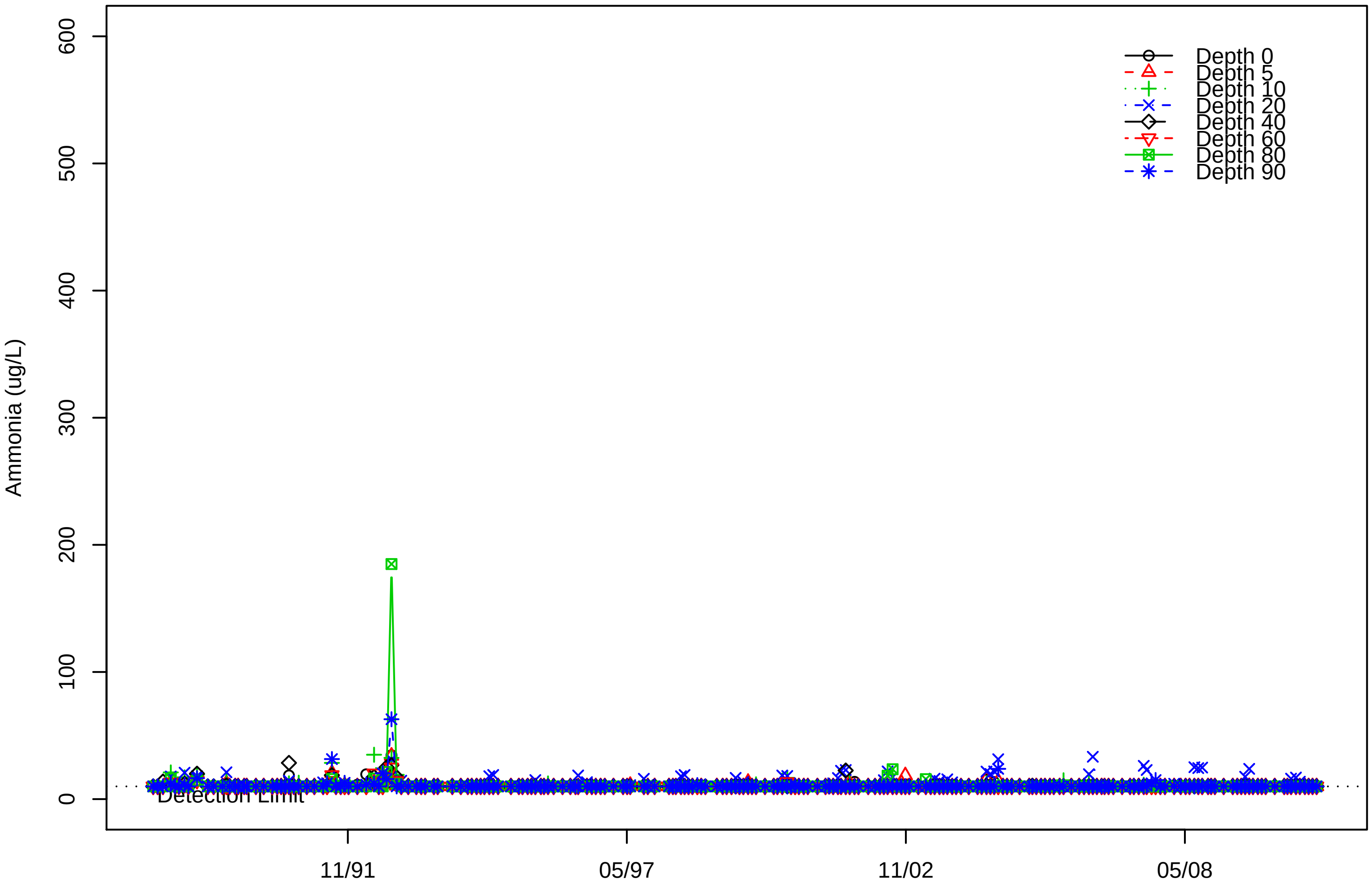


Figure B84: Lake Whatcom ammonia data for Site 3.

Figure B85: Lake Whatcom ammonia data for Site 4.

Lake Whatcom ammonia data for Site 4, February 1988 through December 2010.



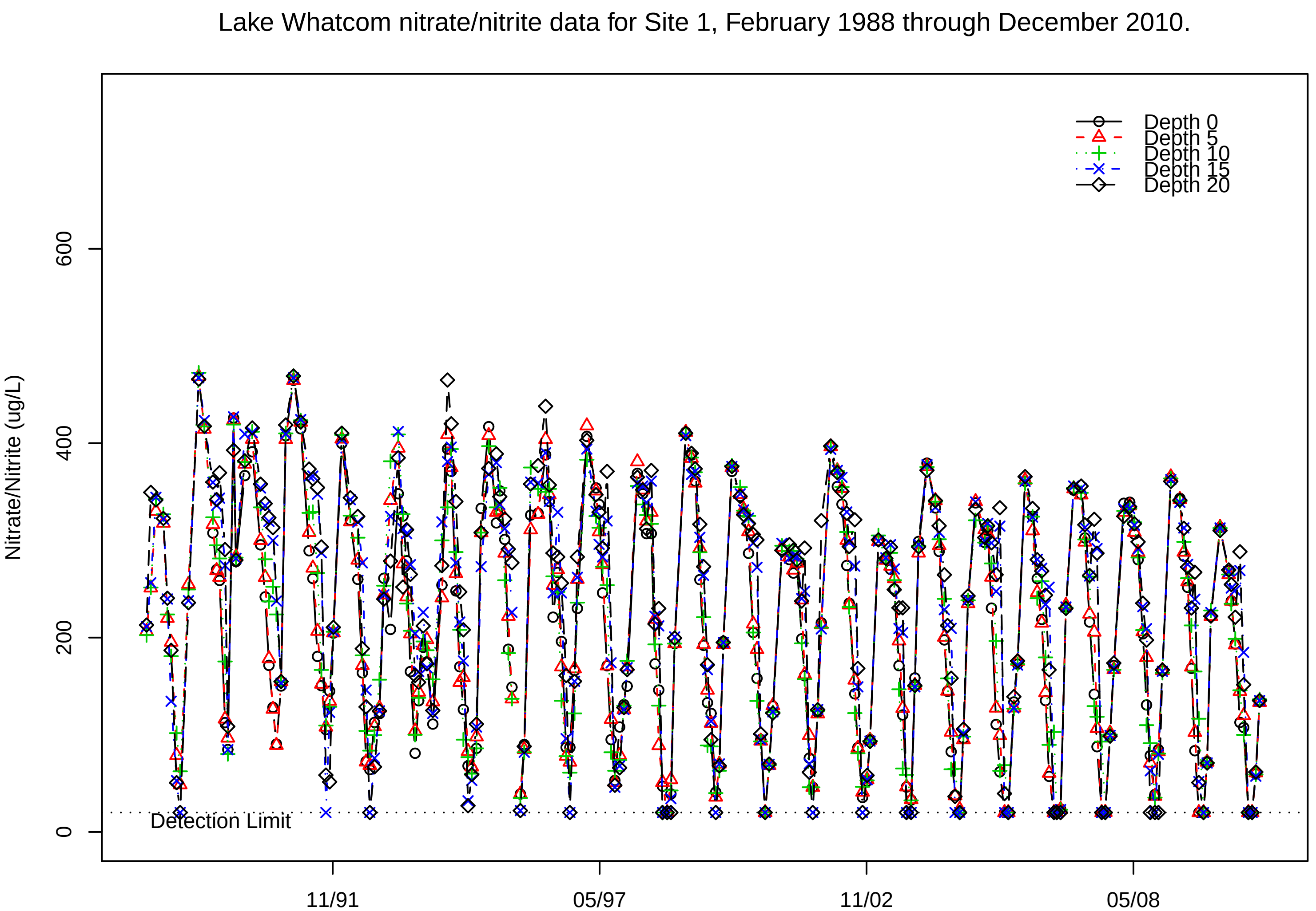


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.

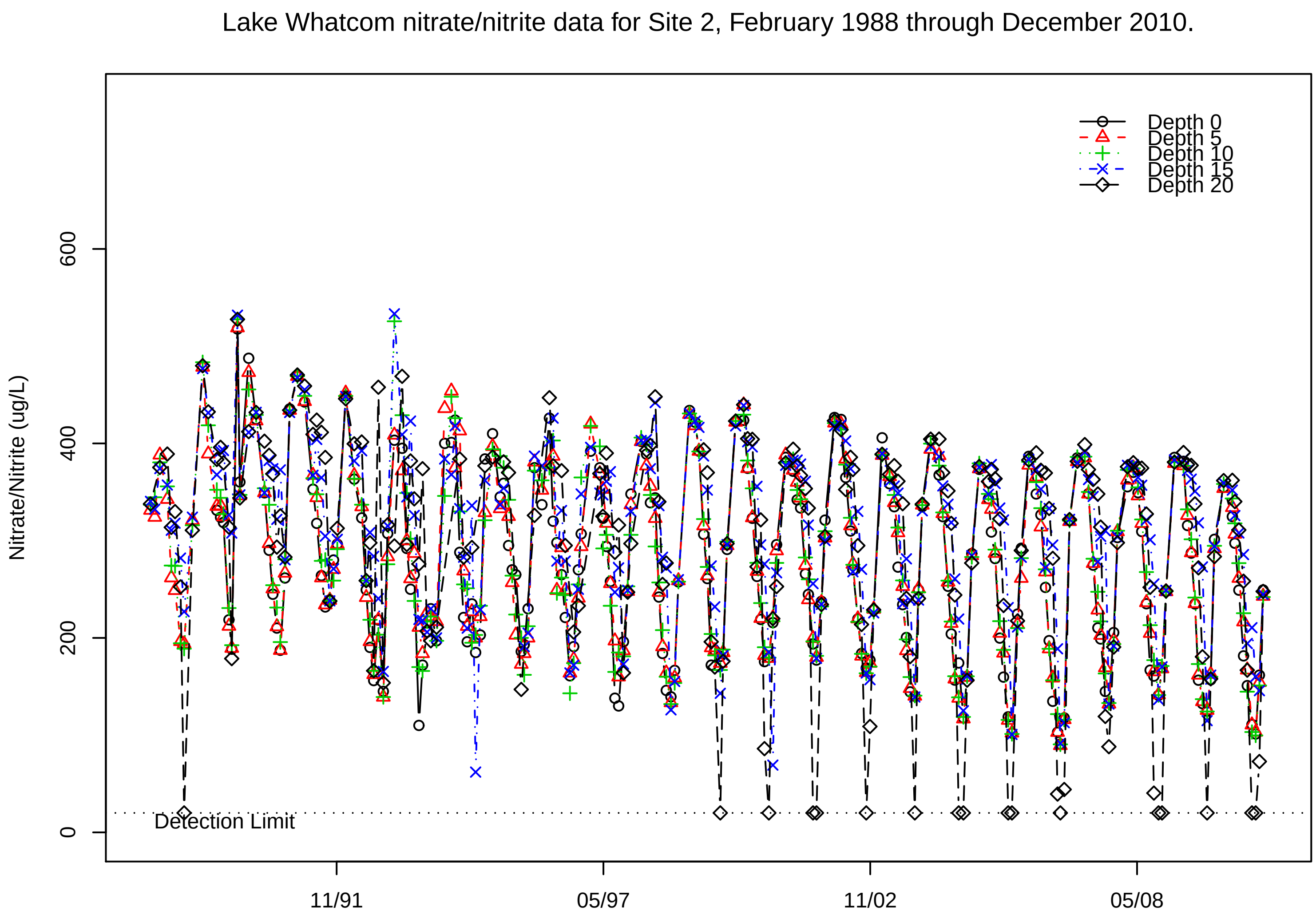


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

Lake Whatcom nitrate/nitrite data for Intake, February 1988 through December 2010.

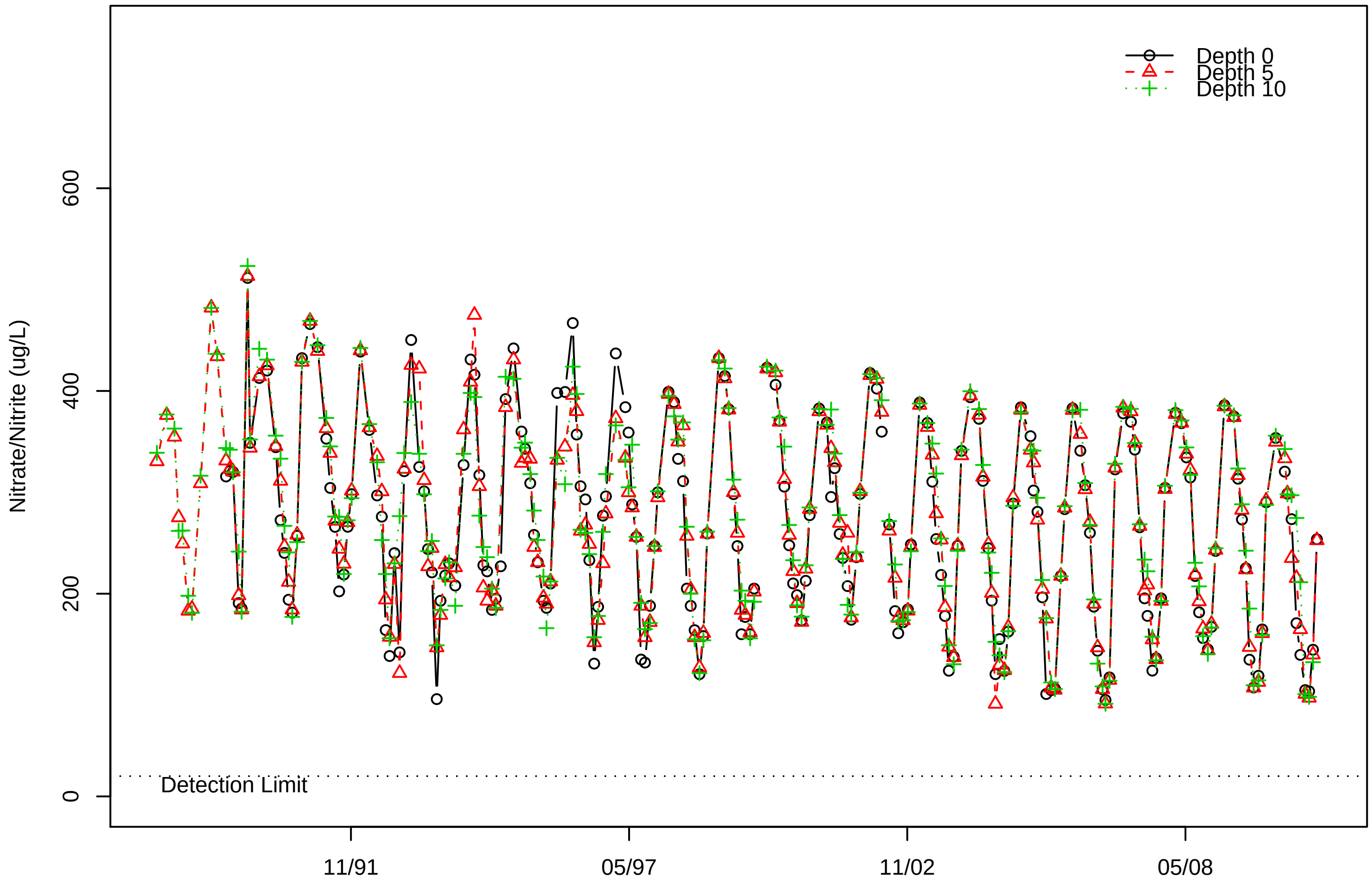


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

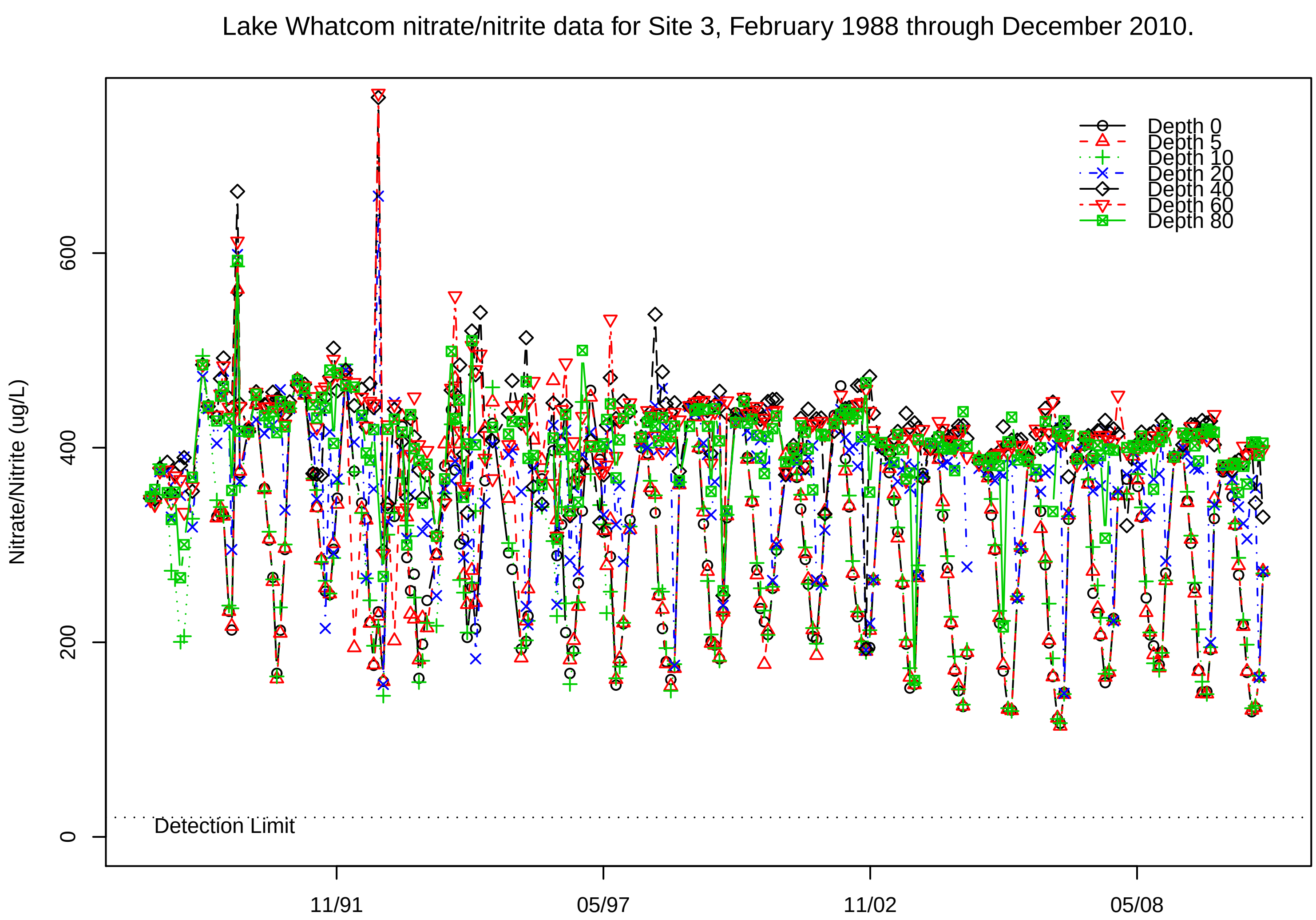
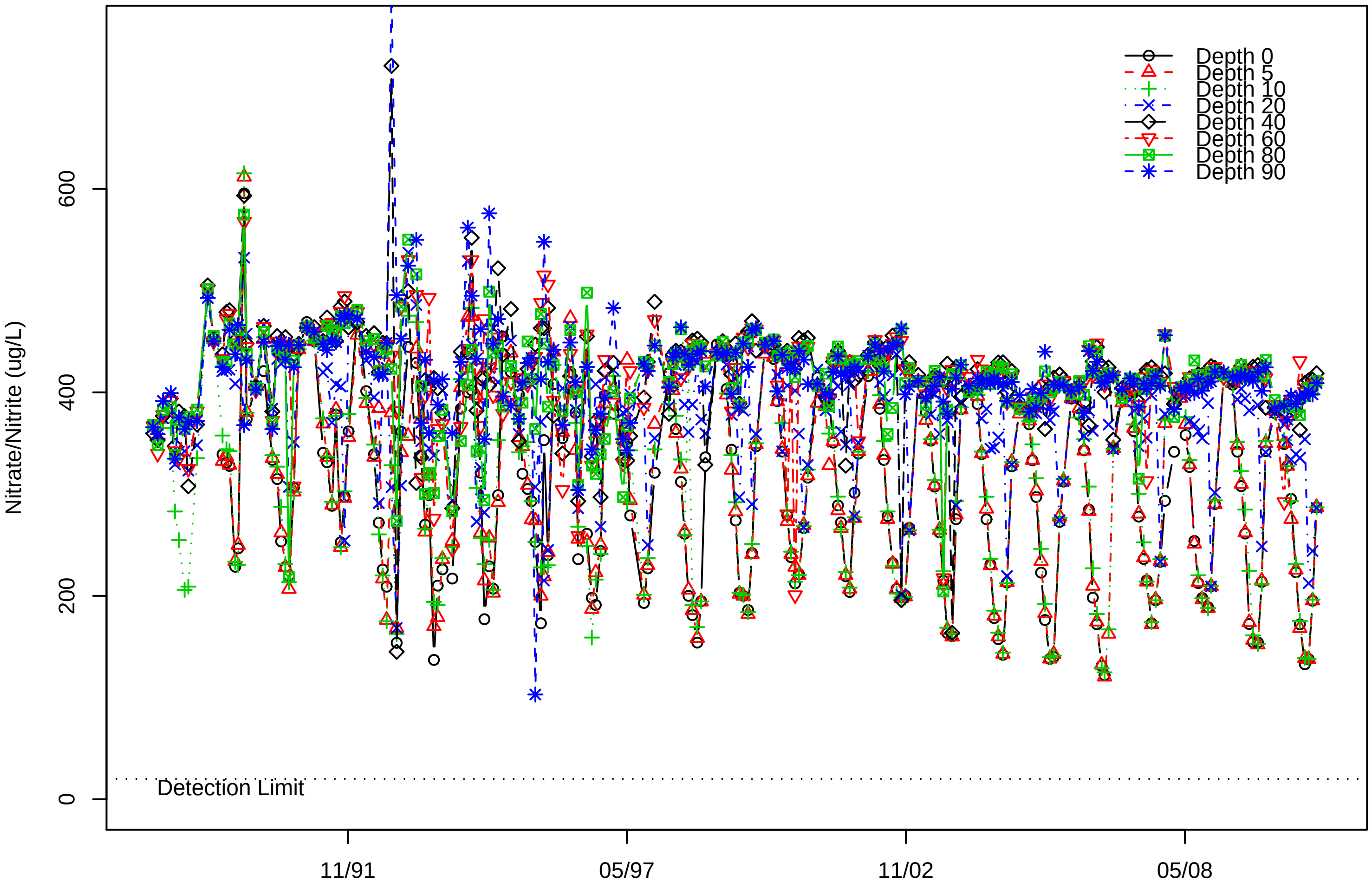


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

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

Lake Whatcom nitrate/nitrite data for Site 4, February 1988 through December 2010.



Lake Whatcom total nitrogen data for Site 1, February 1988 through December 2010.

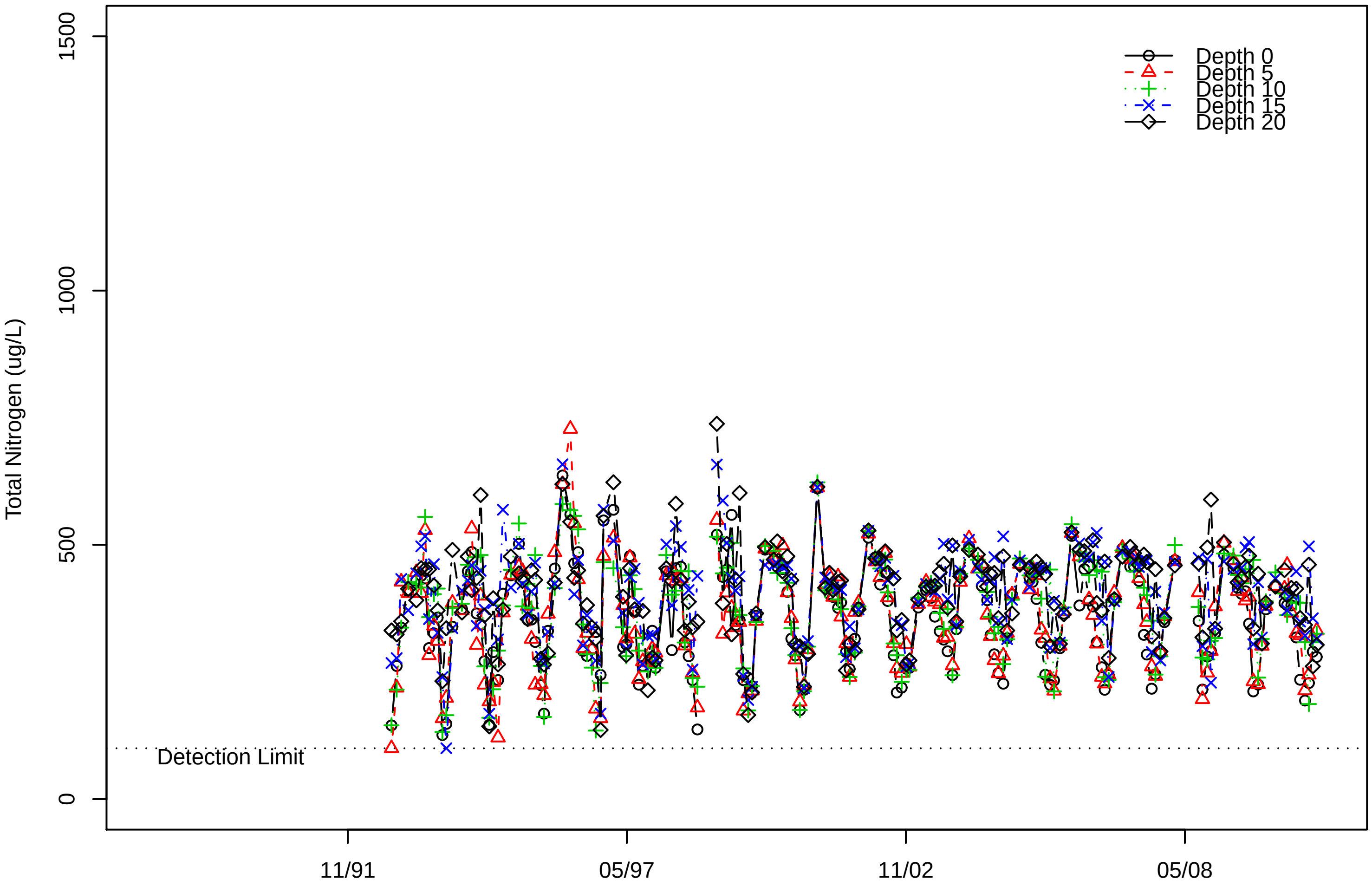


Figure B91: Lake Whatcom total nitrogen data for Site 1.

Lake Whatcom total nitrogen data for Site 2, February 1988 through December 2010.

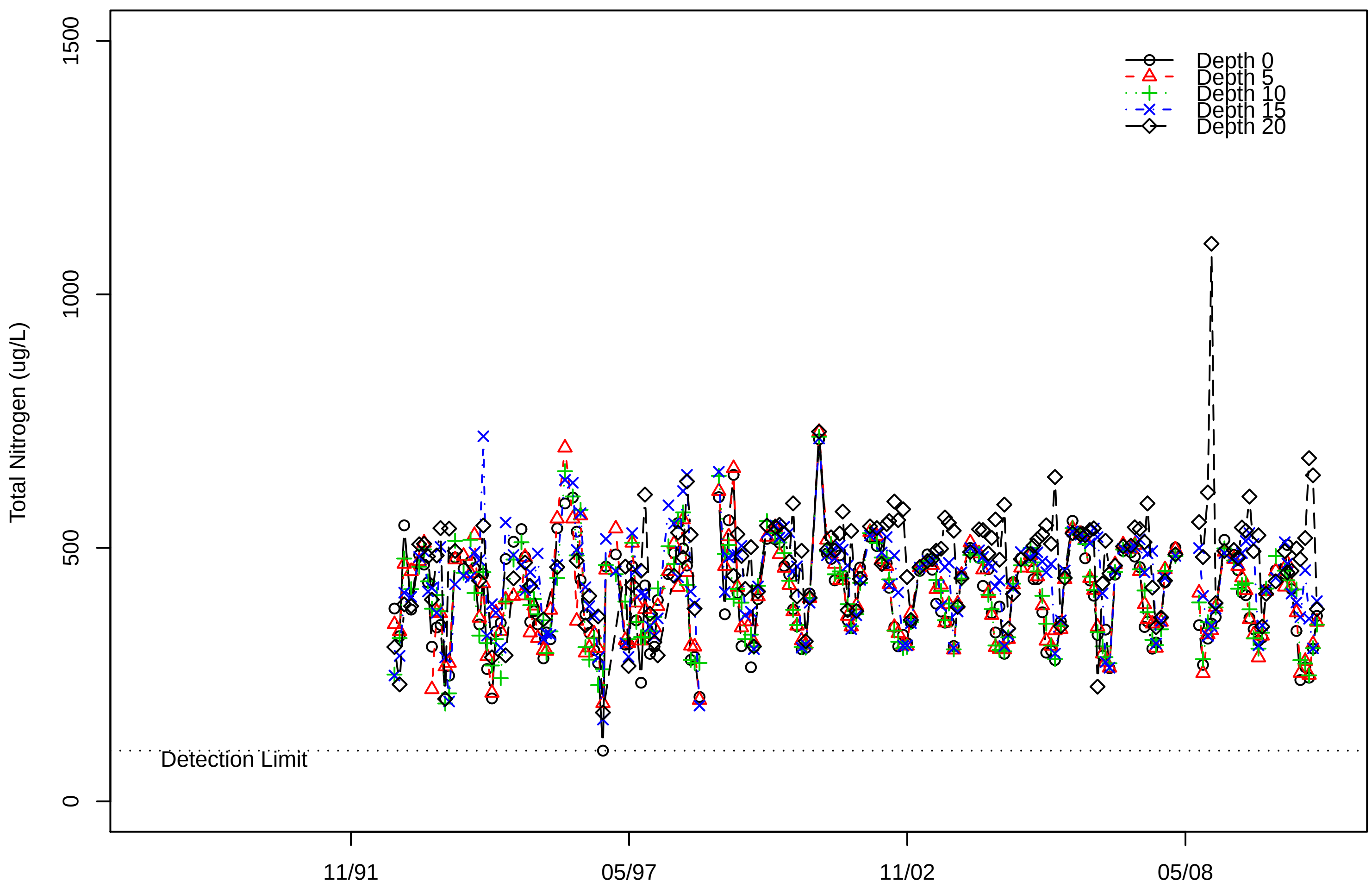


Figure B92: Lake Whatcom total nitrogen data for Site 2.

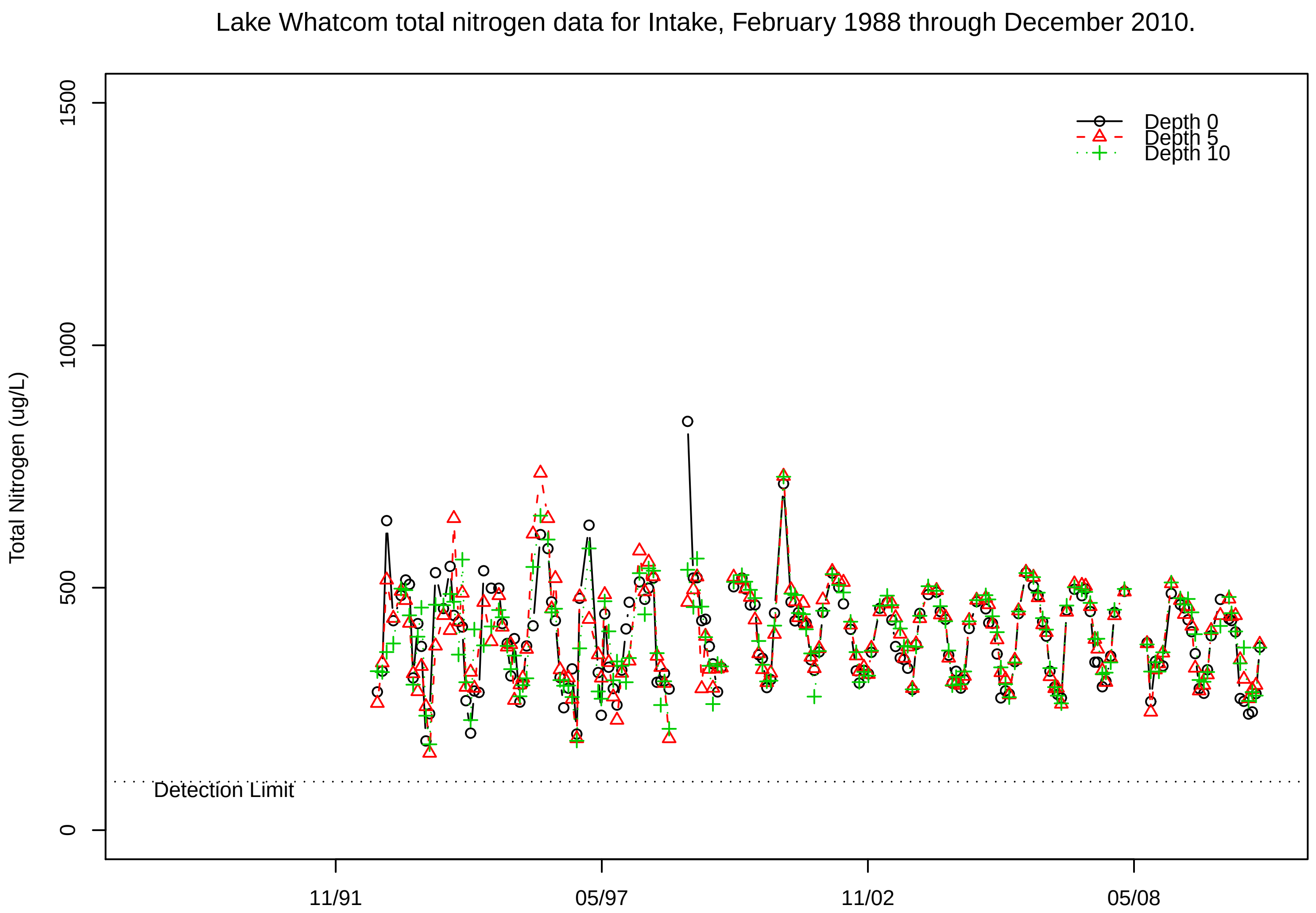


Figure B93: Lake Whatcom total nitrogen data for the Intake site.

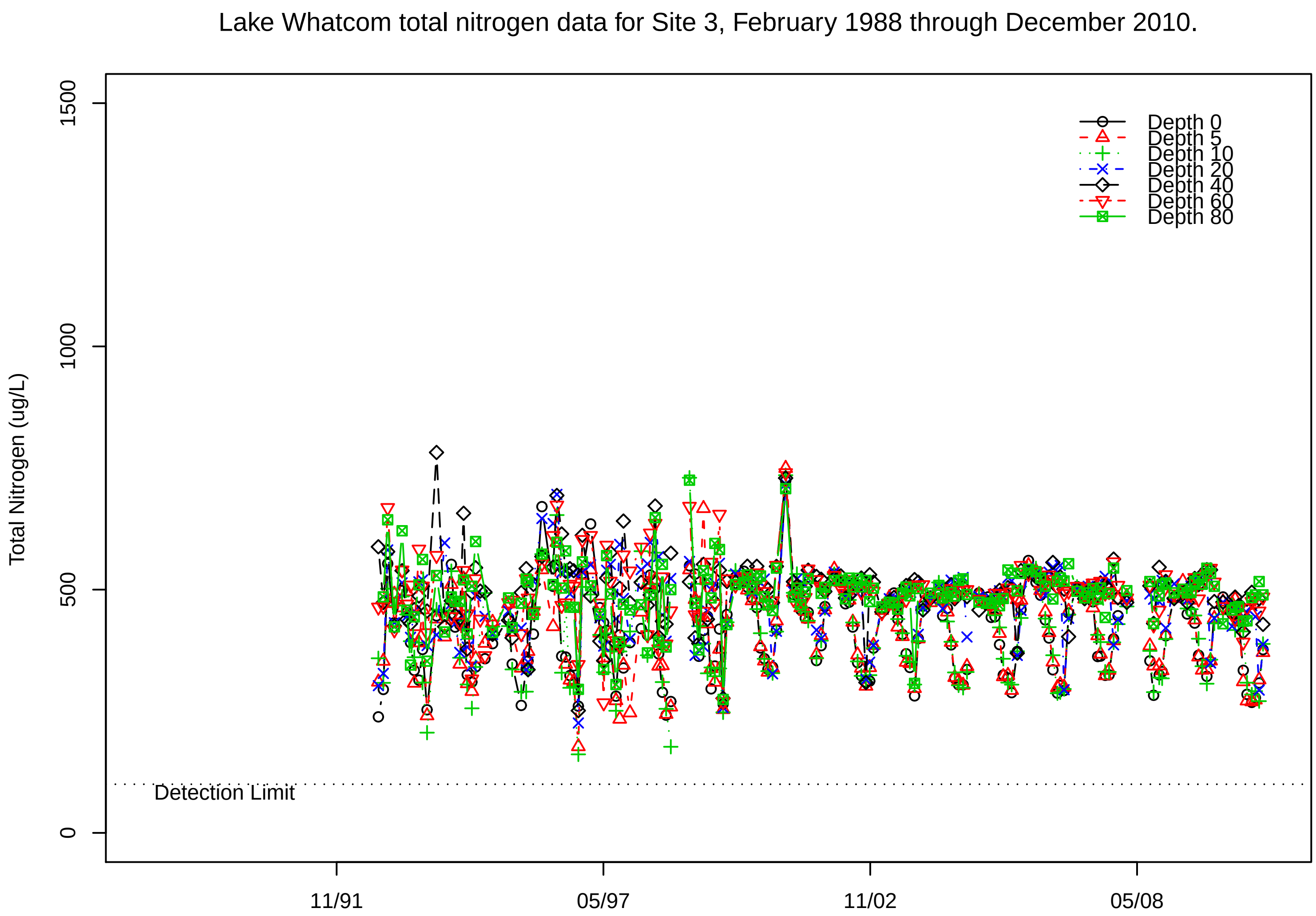


Figure B94: Lake Whatcom total nitrogen data for Site 3.

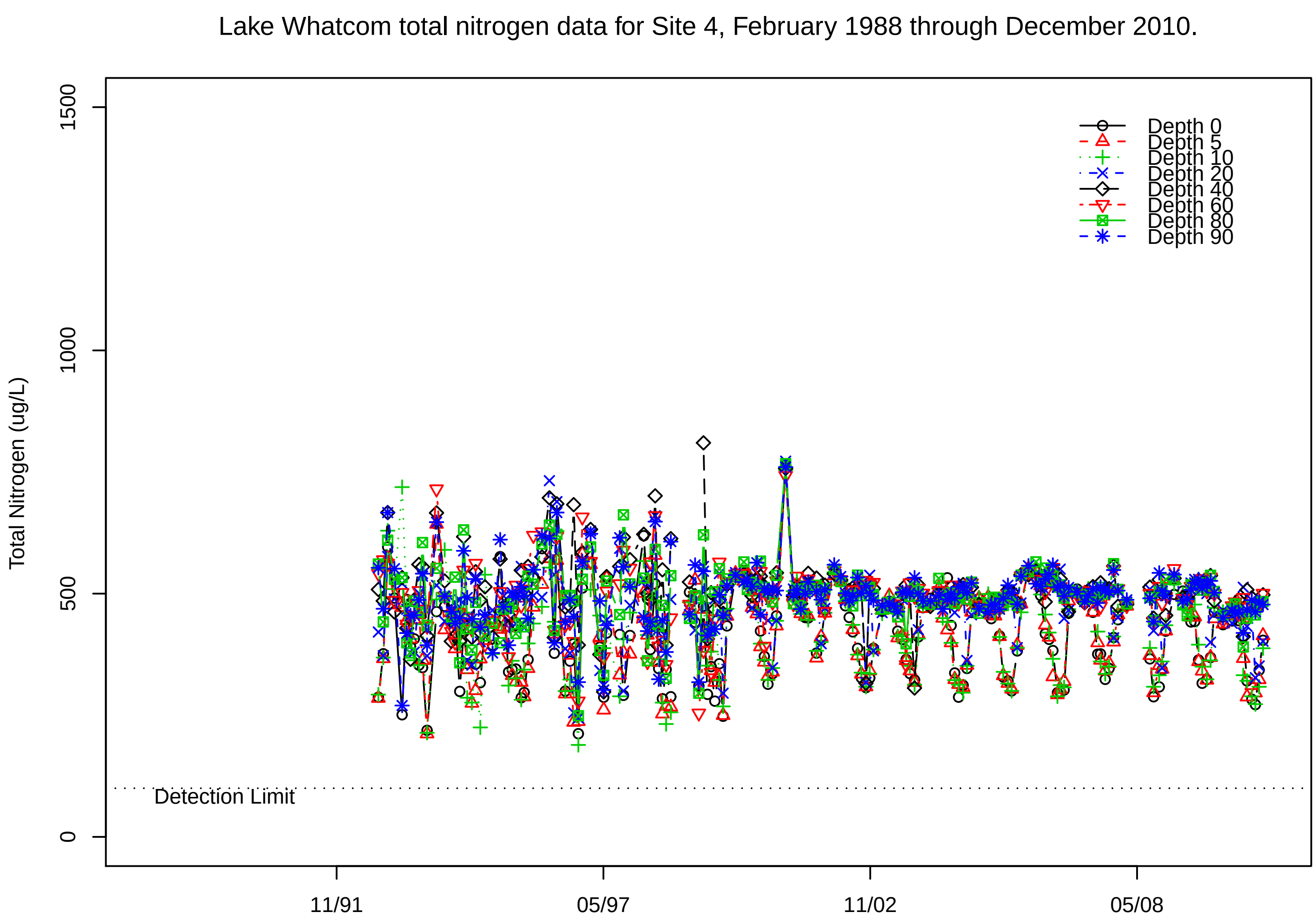


Figure B95: Lake Whatcom total nitrogen data for Site 4.

Lake Whatcom soluble reactive phosphate data for Site 1, February 1988 through December 2010.

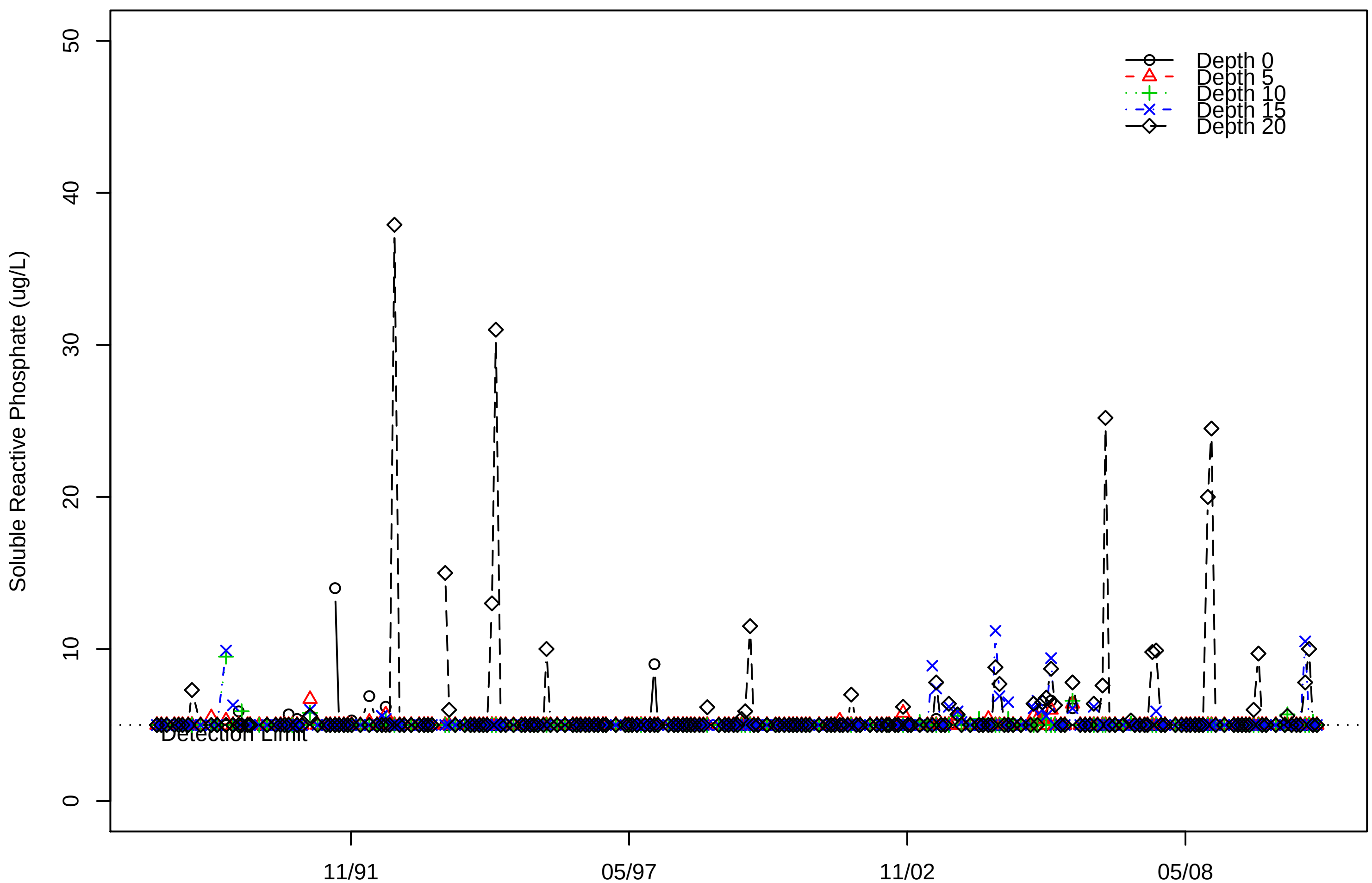


Figure B96: Lake Whatcom soluble phosphate data for Site 1.

Lake Whatcom soluble reactive phosphate data for Site 2, February 1988 through December 2010.

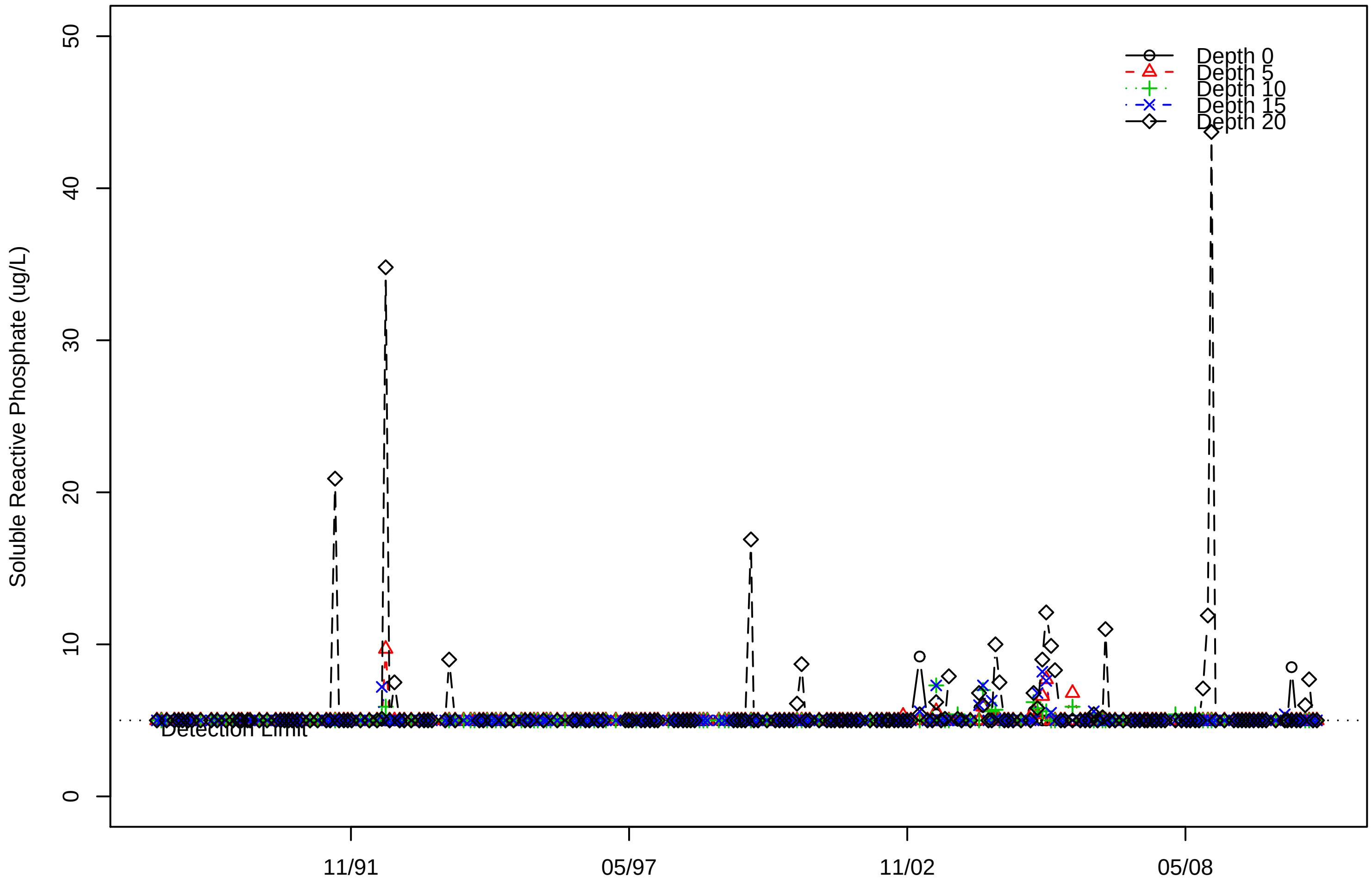


Figure B97: Lake Whatcom soluble phosphate data for Site 2.

Lake Whatcom soluble reactive phosphate data for Intake, February 1988 through December 2010.

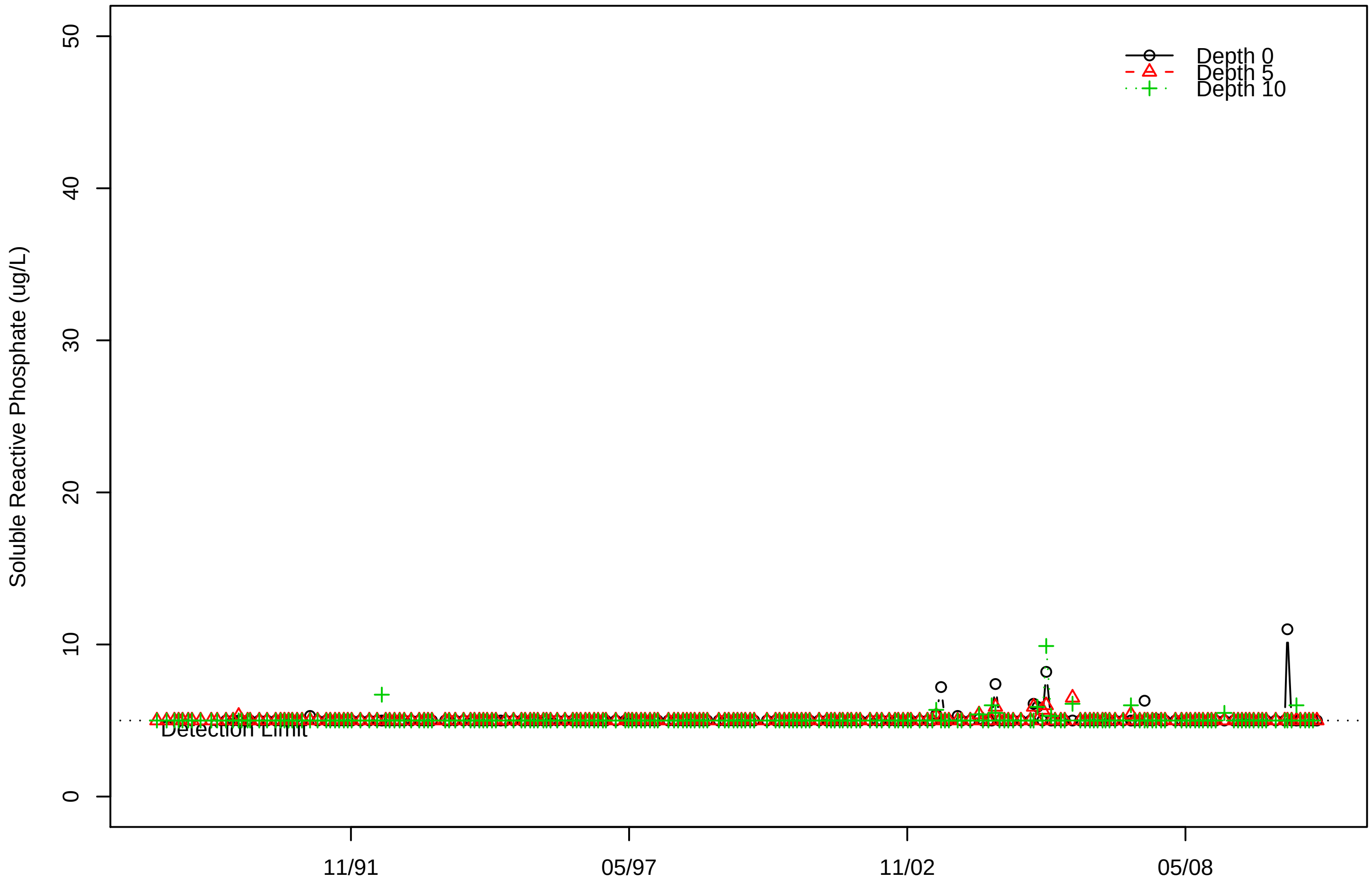


Figure B98: Lake Whatcom soluble reactive phosphate data for the Intake site.

Lake Whatcom soluble reactive phosphate data for Site 3, February 1988 through December 2010.

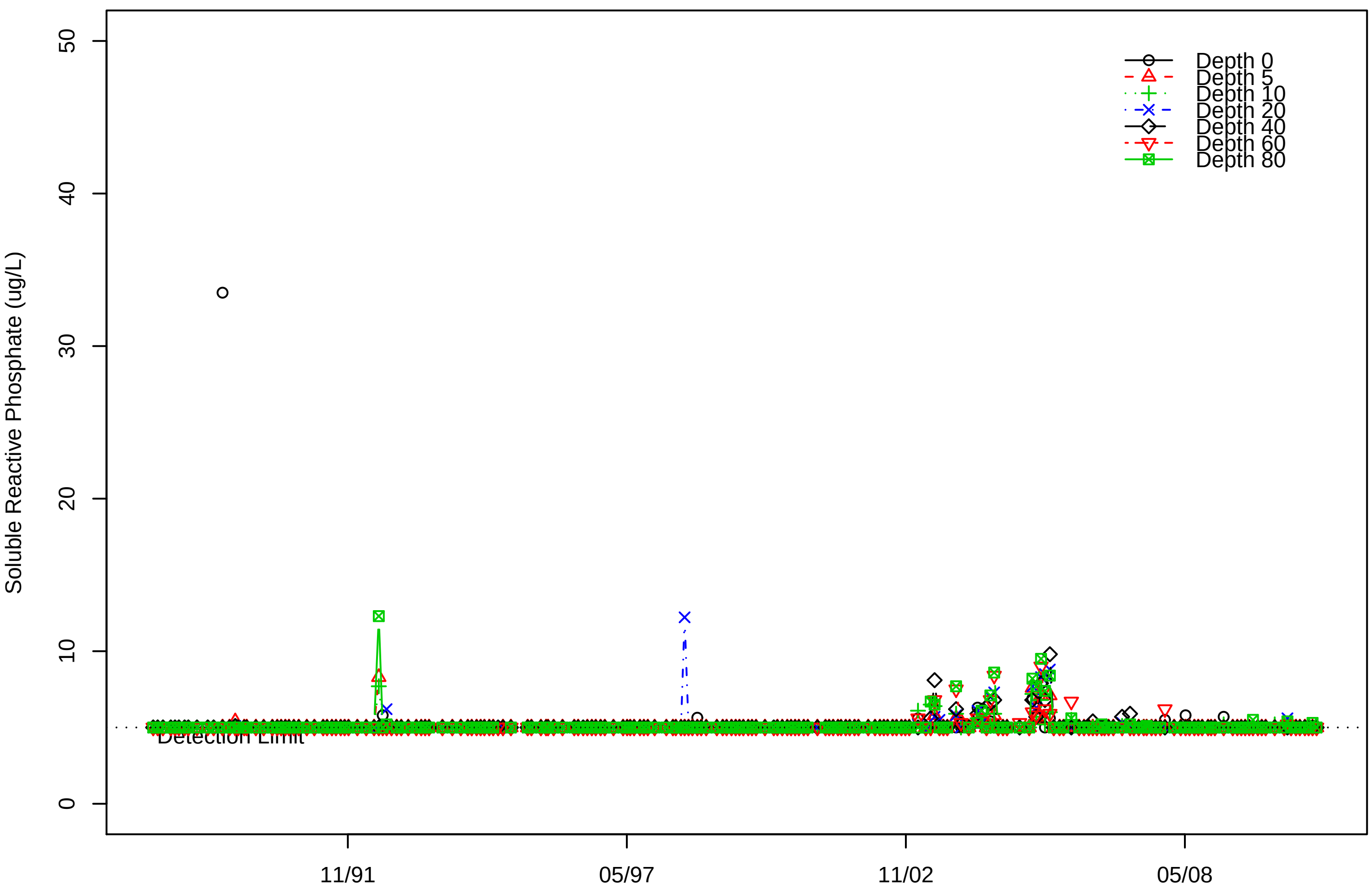


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

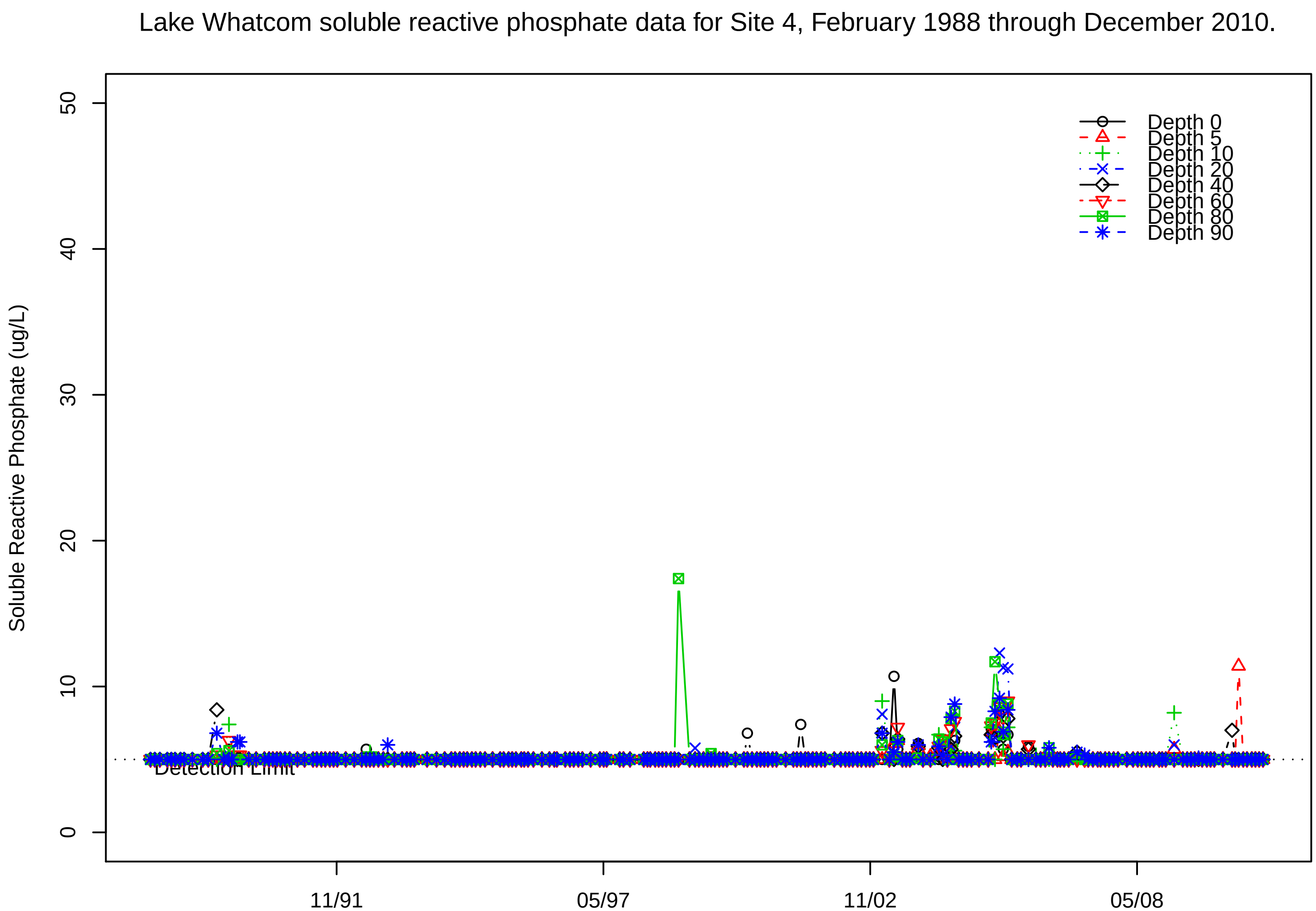


Figure B100: Lake Whatcom soluble reactive phosphate data for Site 4.

Lake Whatcom total phosphorus data for Site 1, February 1988 through December 2010.

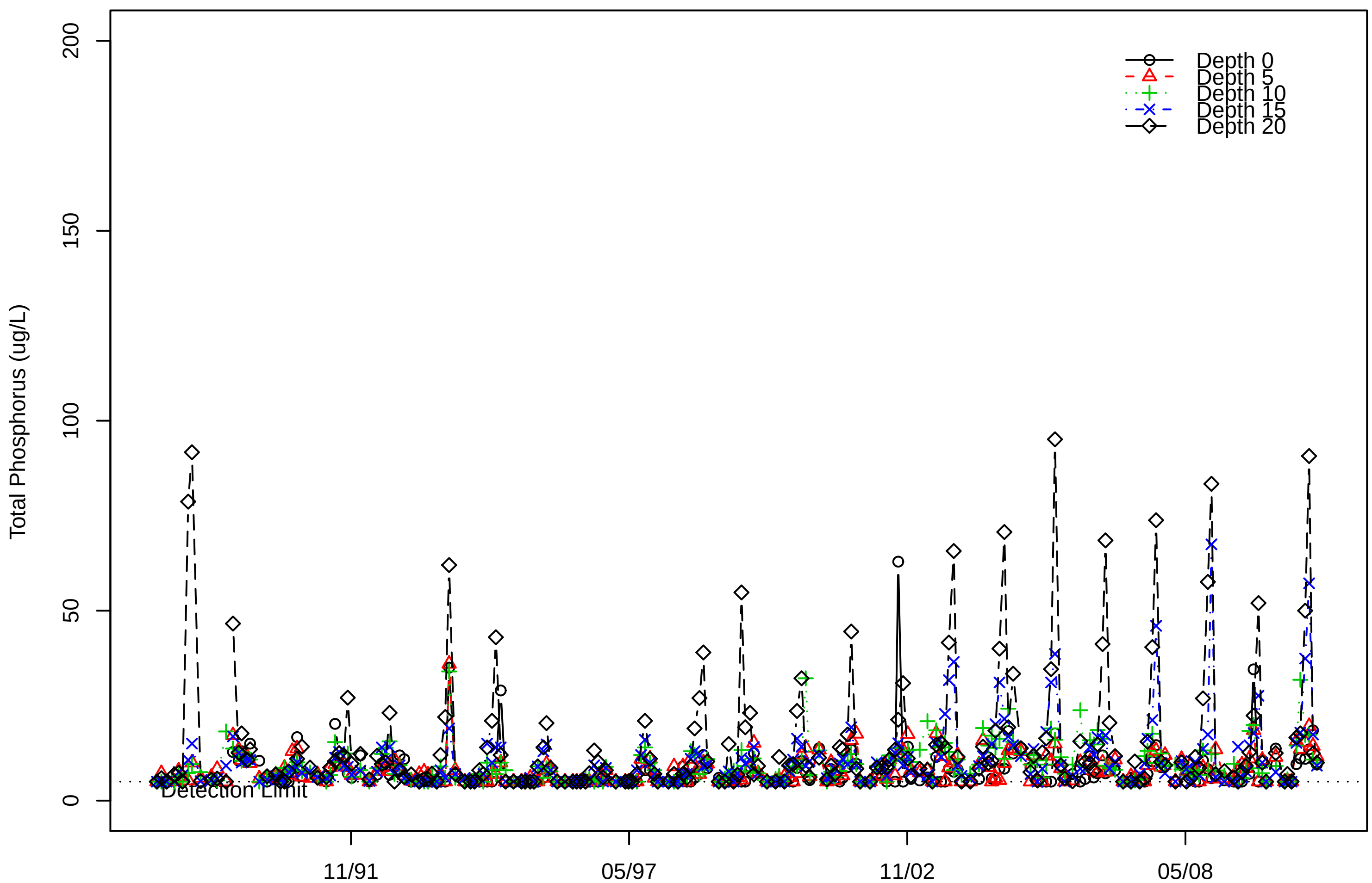


Figure B101: Lake Whatcom total phosphorus data for Site 1.

Lake Whatcom total phosphorus data for Site 2, February 1988 through December 2010.

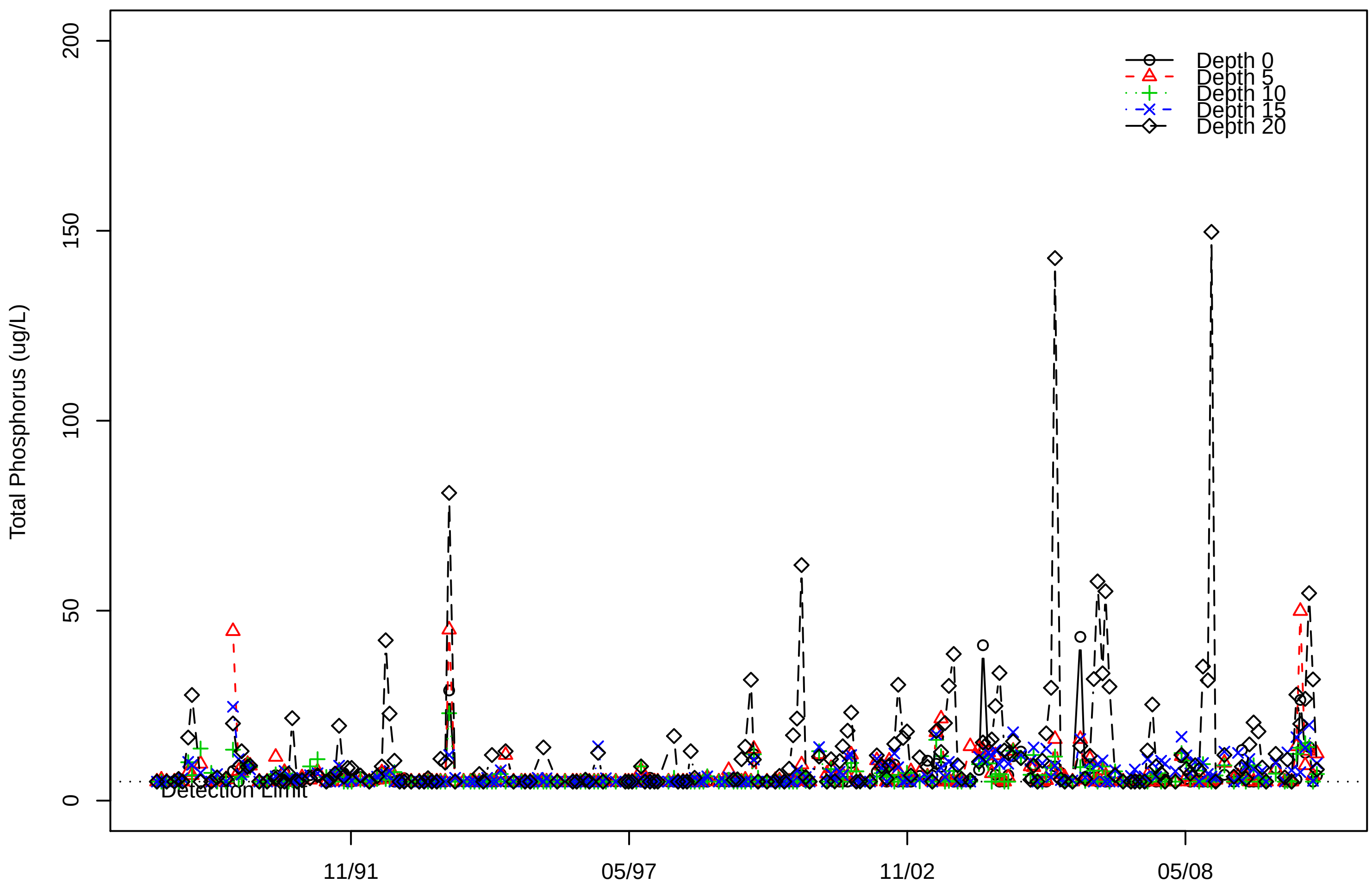


Figure B102: Lake Whatcom total phosphorus data for Site 2.

Lake Whatcom total phosphorus data for Intake, February 1988 through December 2010.

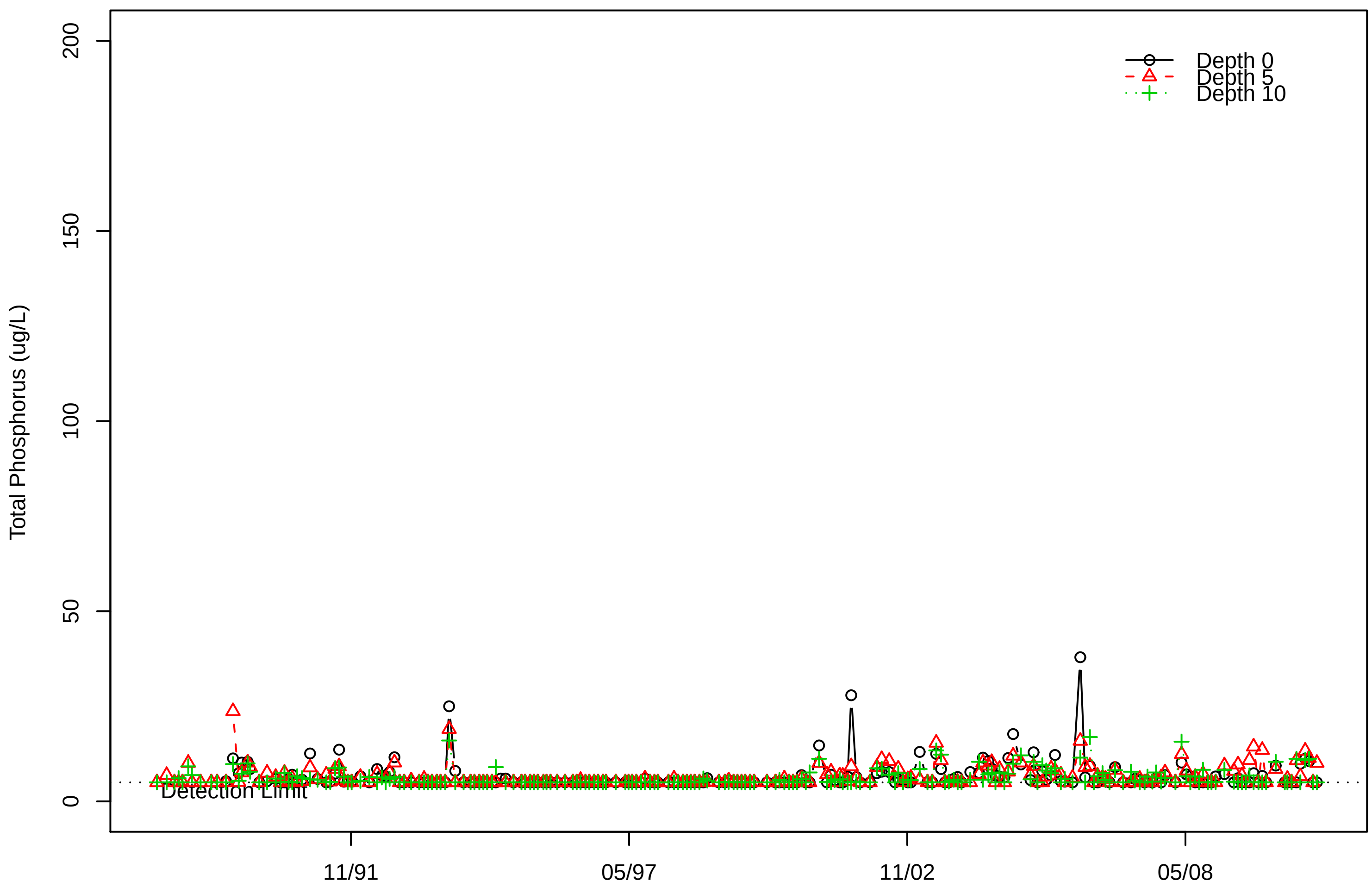


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

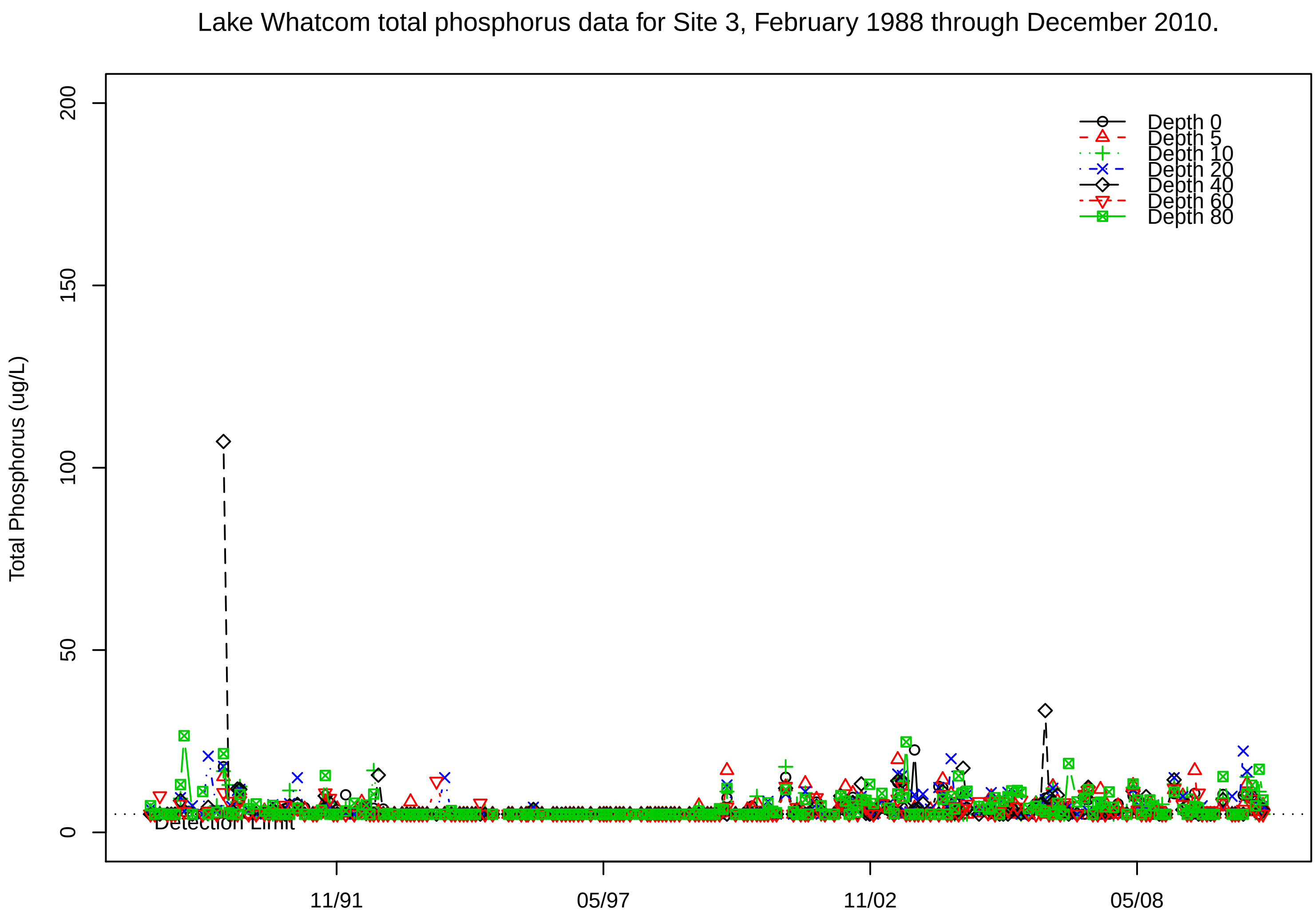


Figure B104: Lake Whatcom total phosphorus data for Site 3.

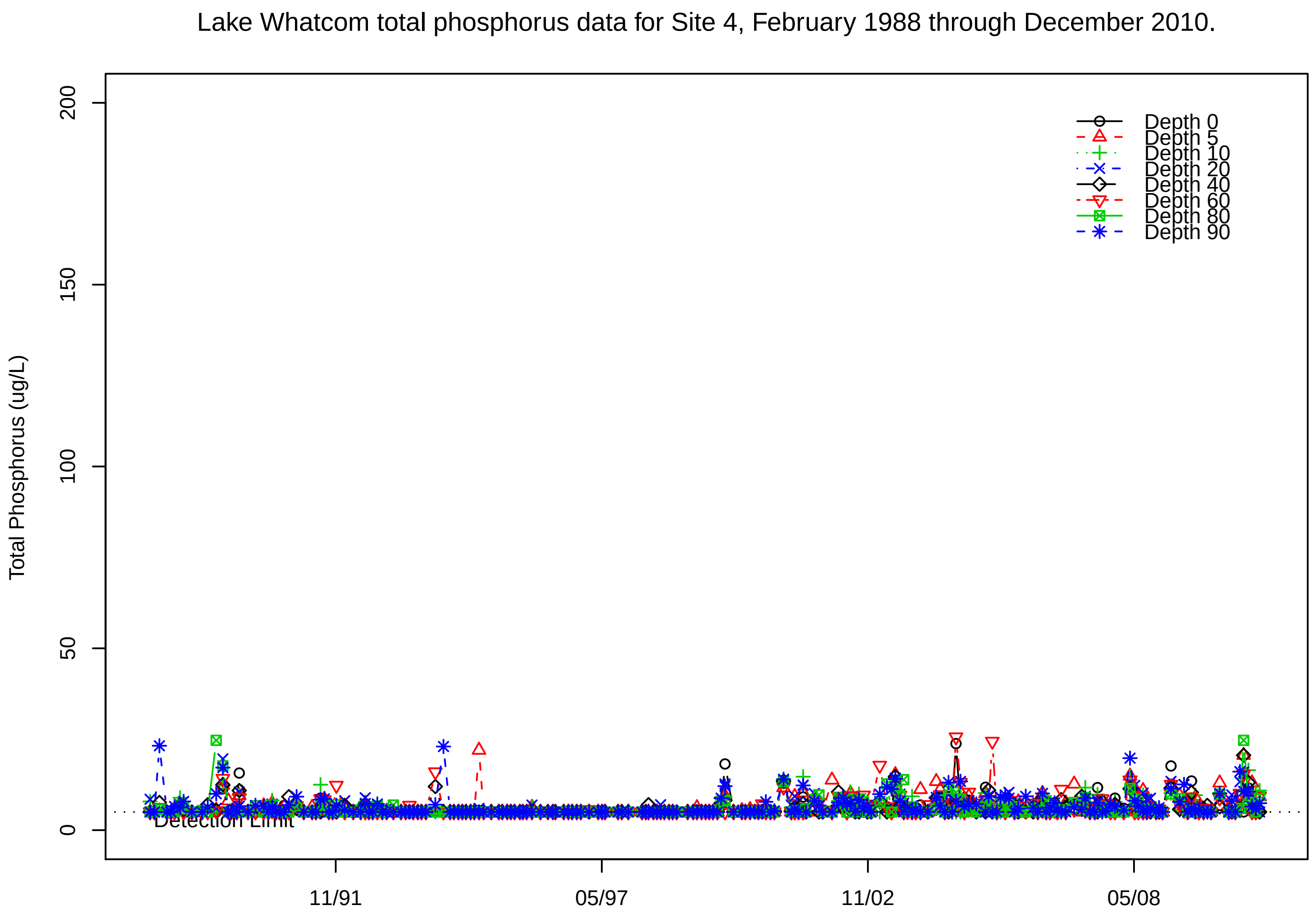


Figure B105: Lake Whatcom total phosphorus data for Site 4.

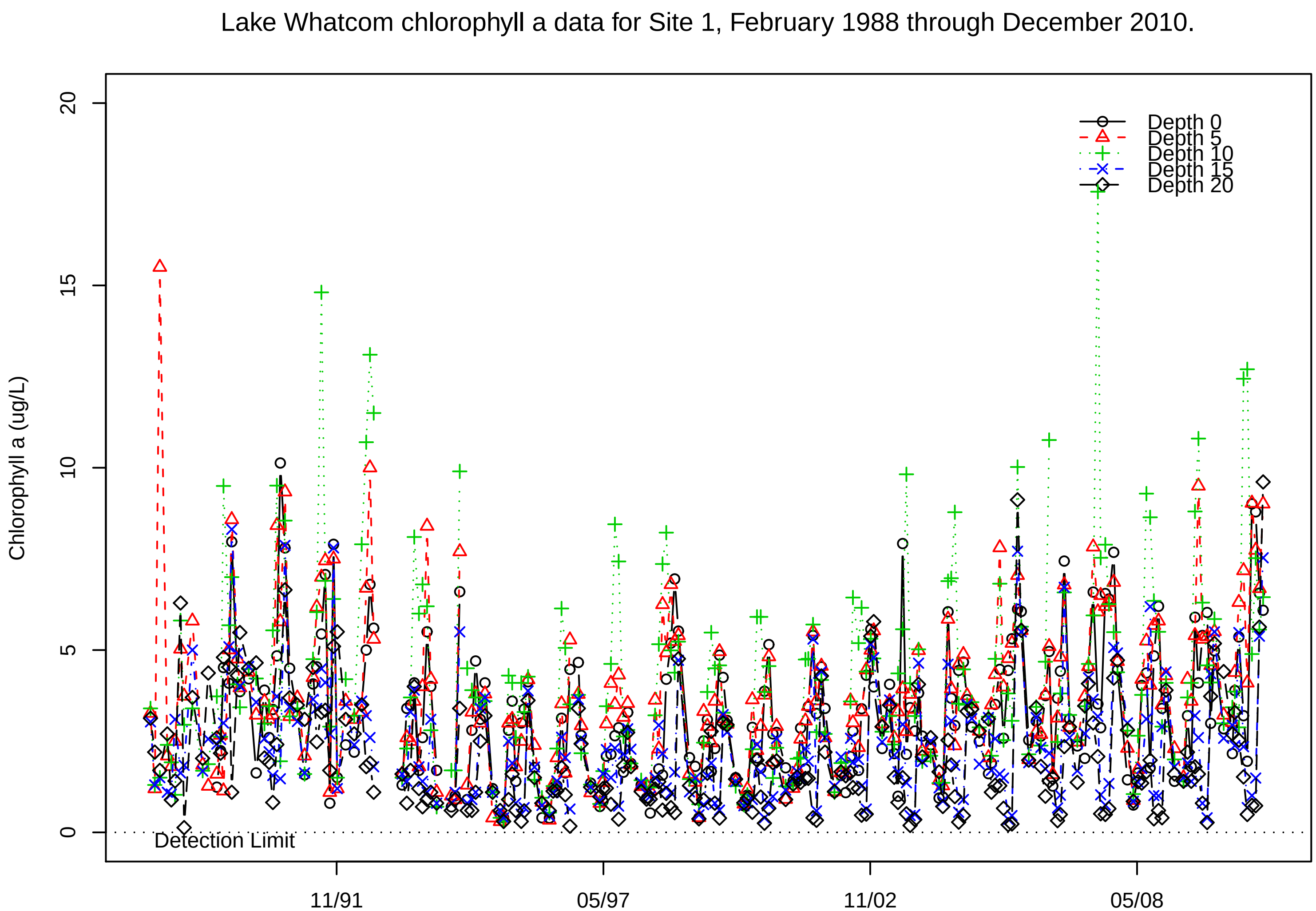


Figure B106: Lake Whatcom chlorophyll data for Site 1.

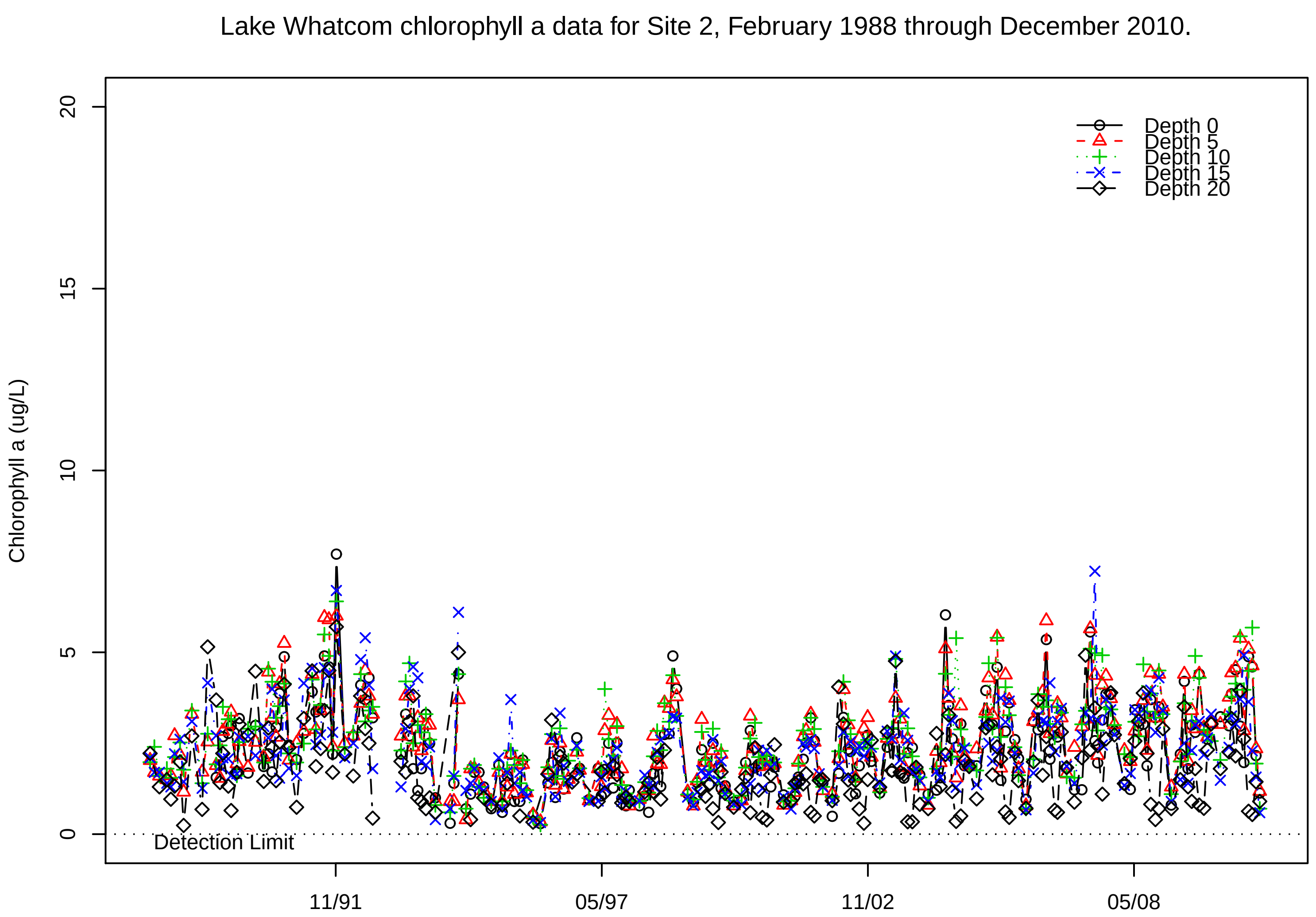


Figure B107: Lake Whatcom chlorophyll data for Site 2.

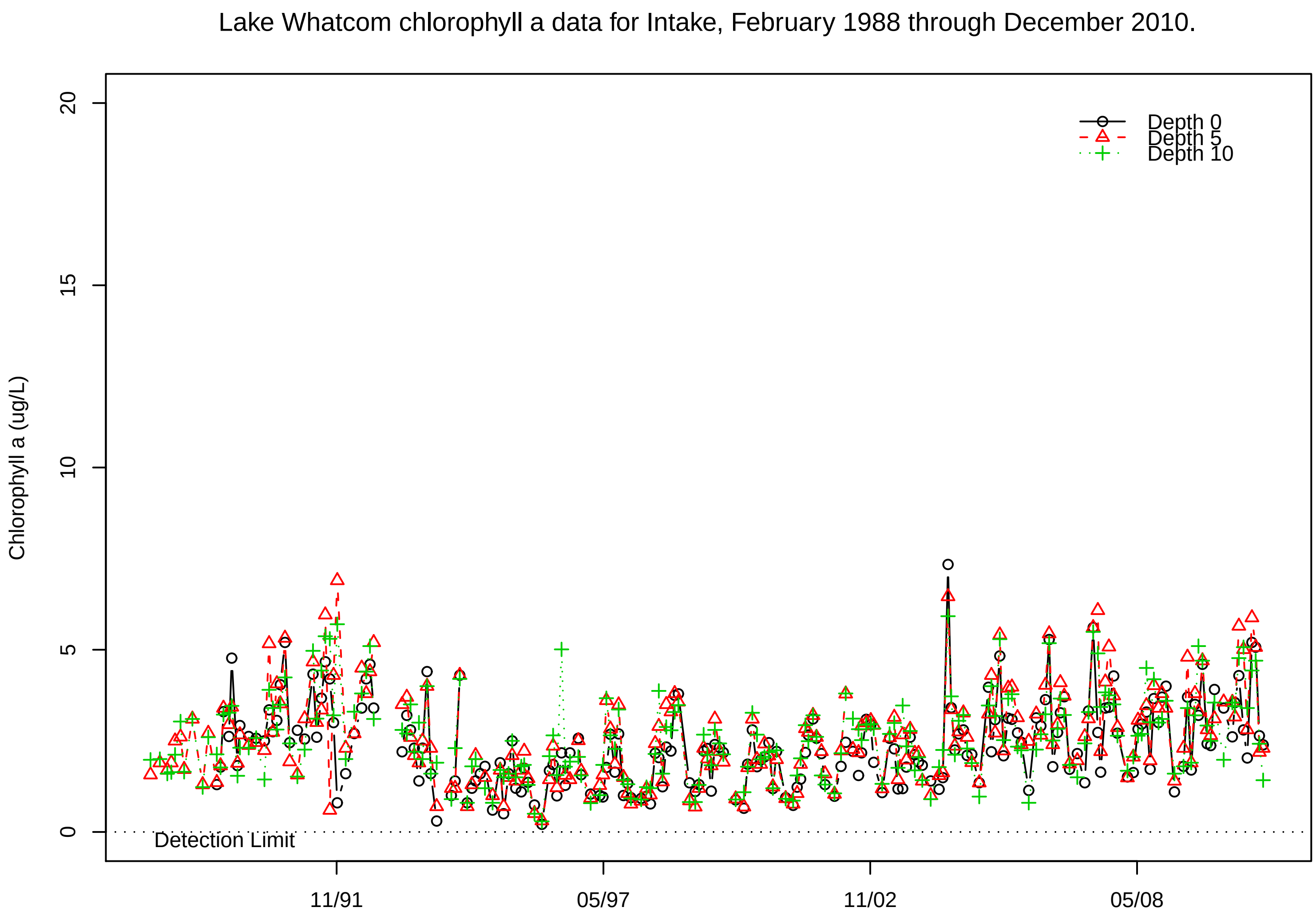


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

Lake Whatcom chlorophyll a data for Site 3, February 1988 through December 2010.

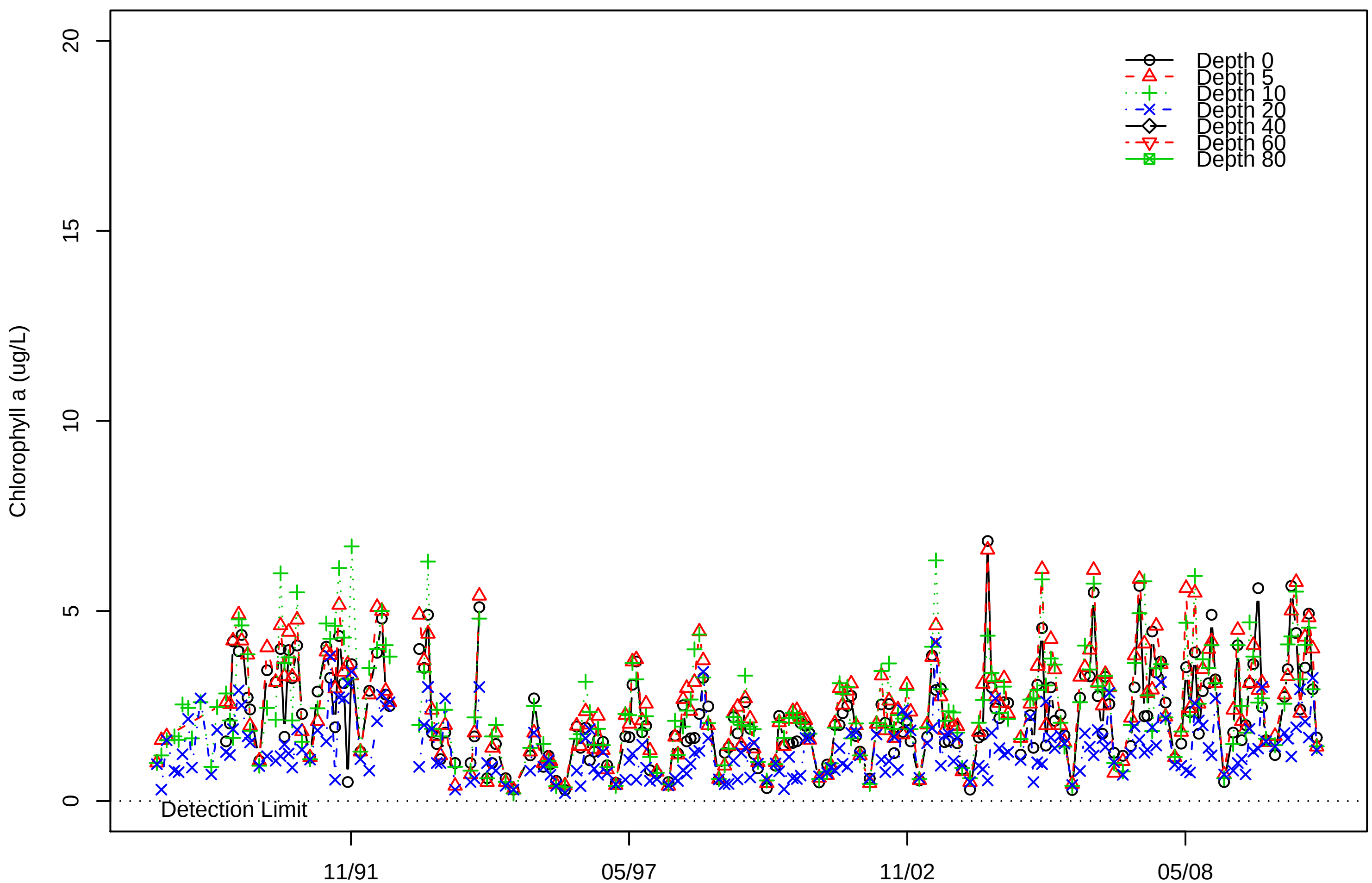


Figure B109: Lake Whatcom chlorophyll data for Site 3.

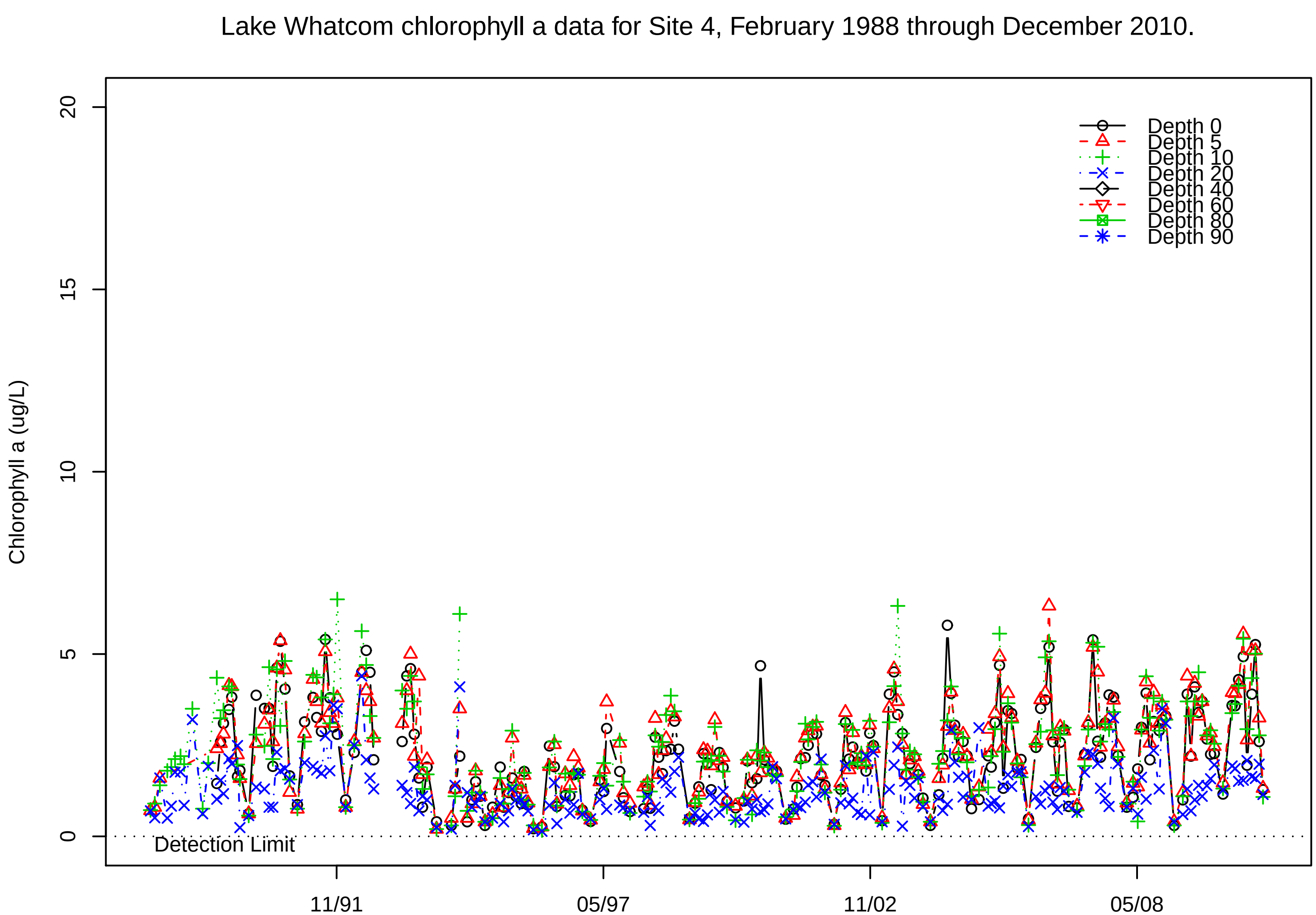


Figure B110: Lake Whatcom chlorophyll data for Site 4.

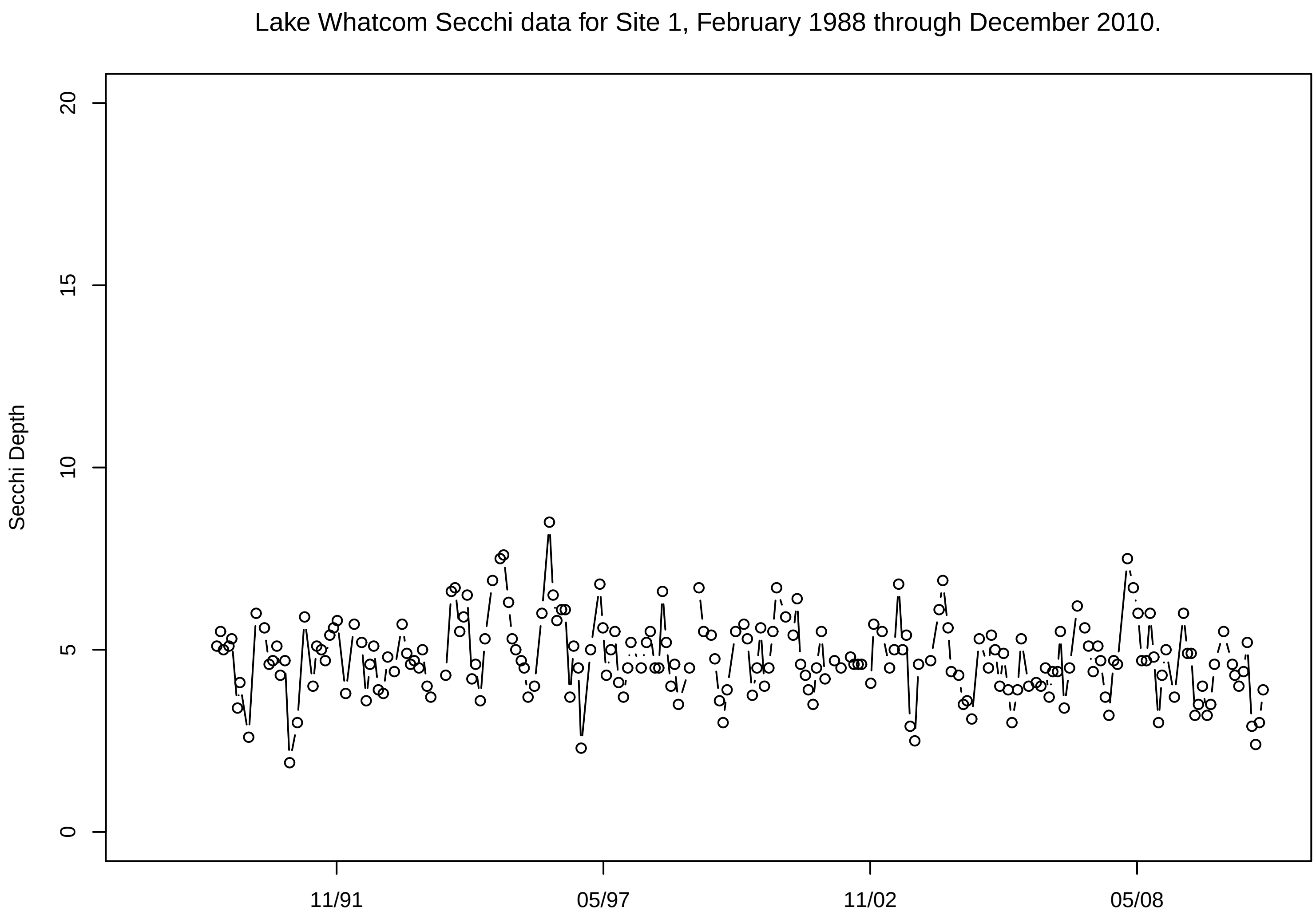


Figure B111: Lake Whatcom Secchi depths for Site 1.

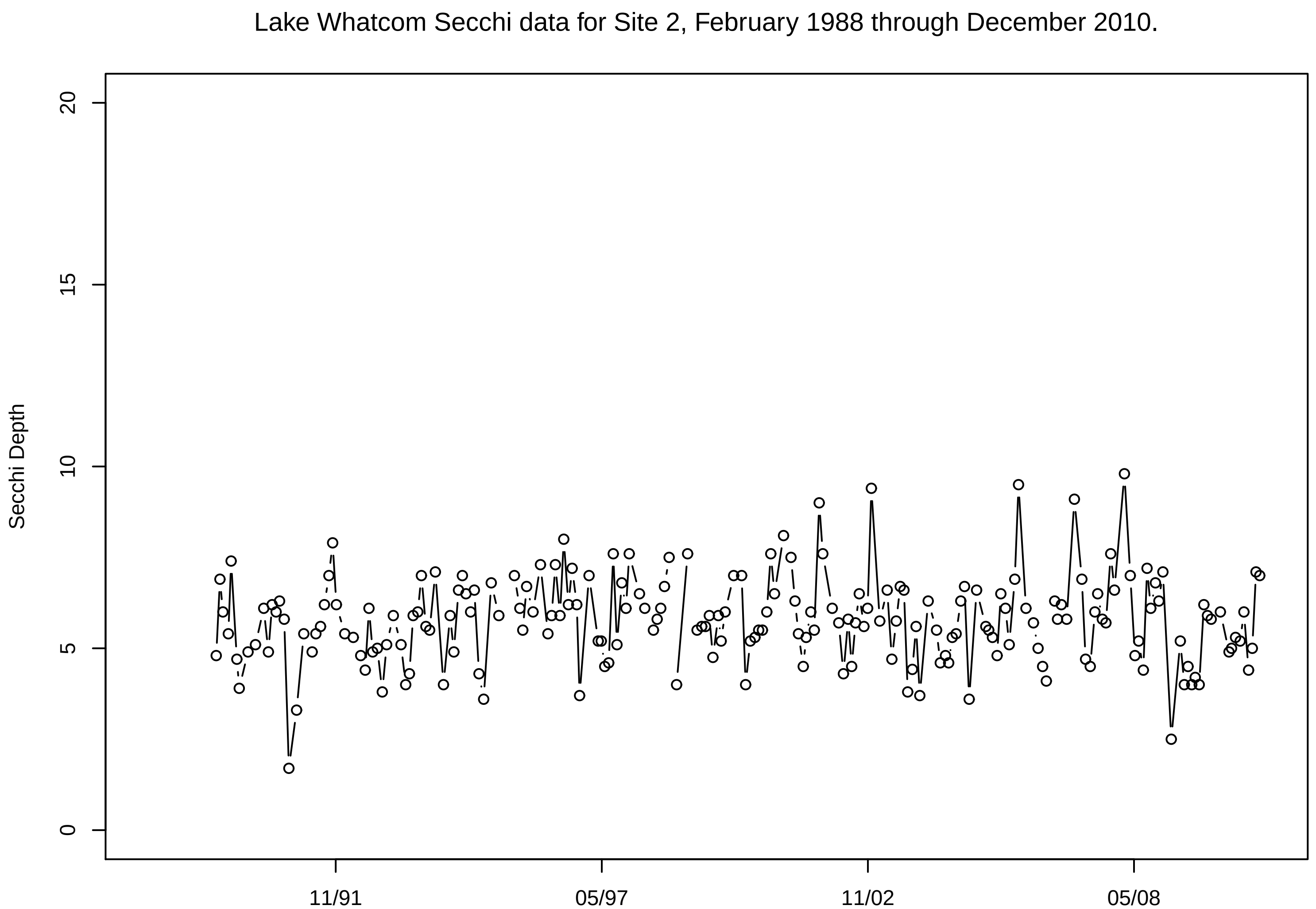


Figure B112: Lake Whatcom Secchi depths for Site 2.

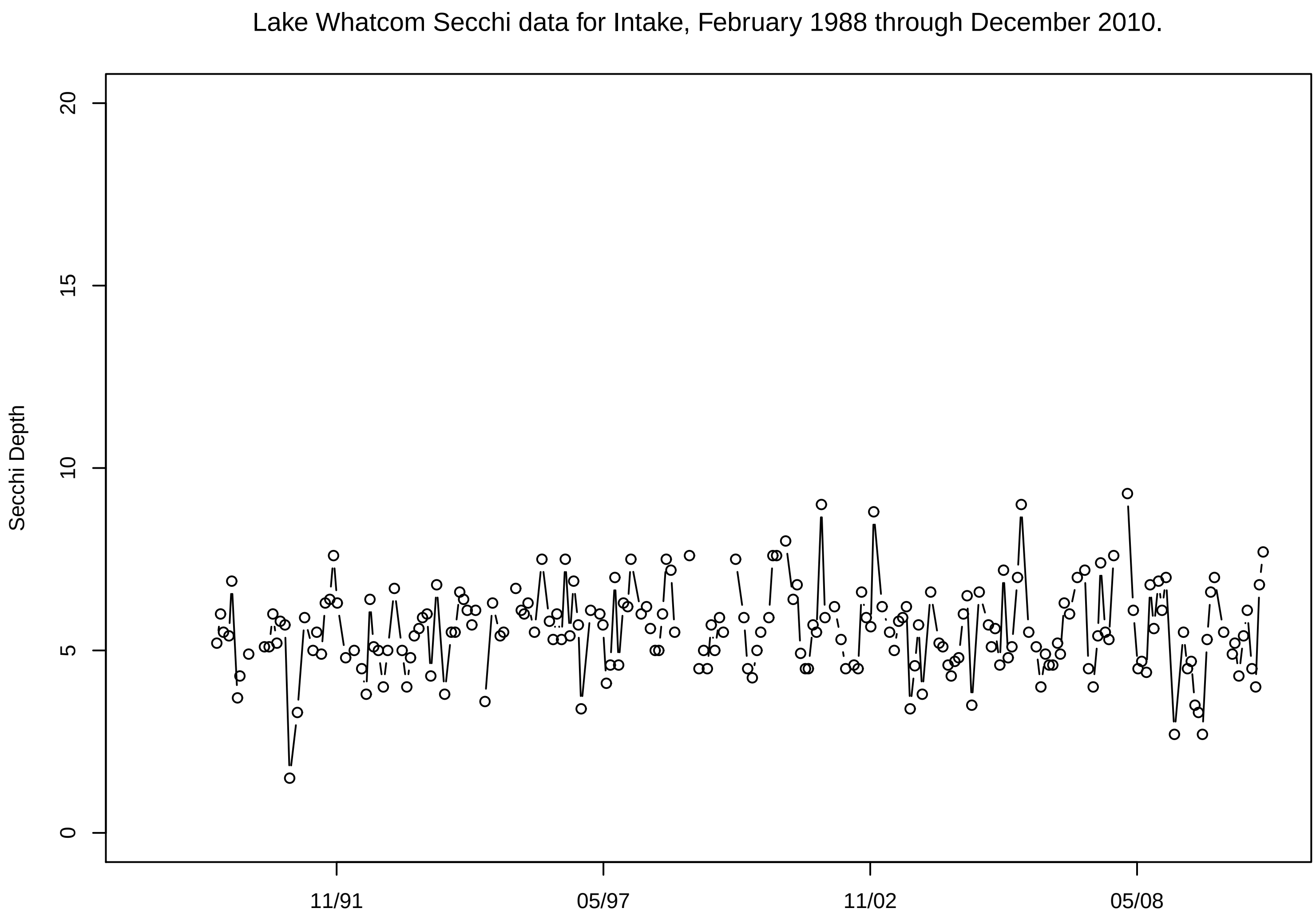


Figure B113: Lake Whatcom Secchi depths for the Intake site.

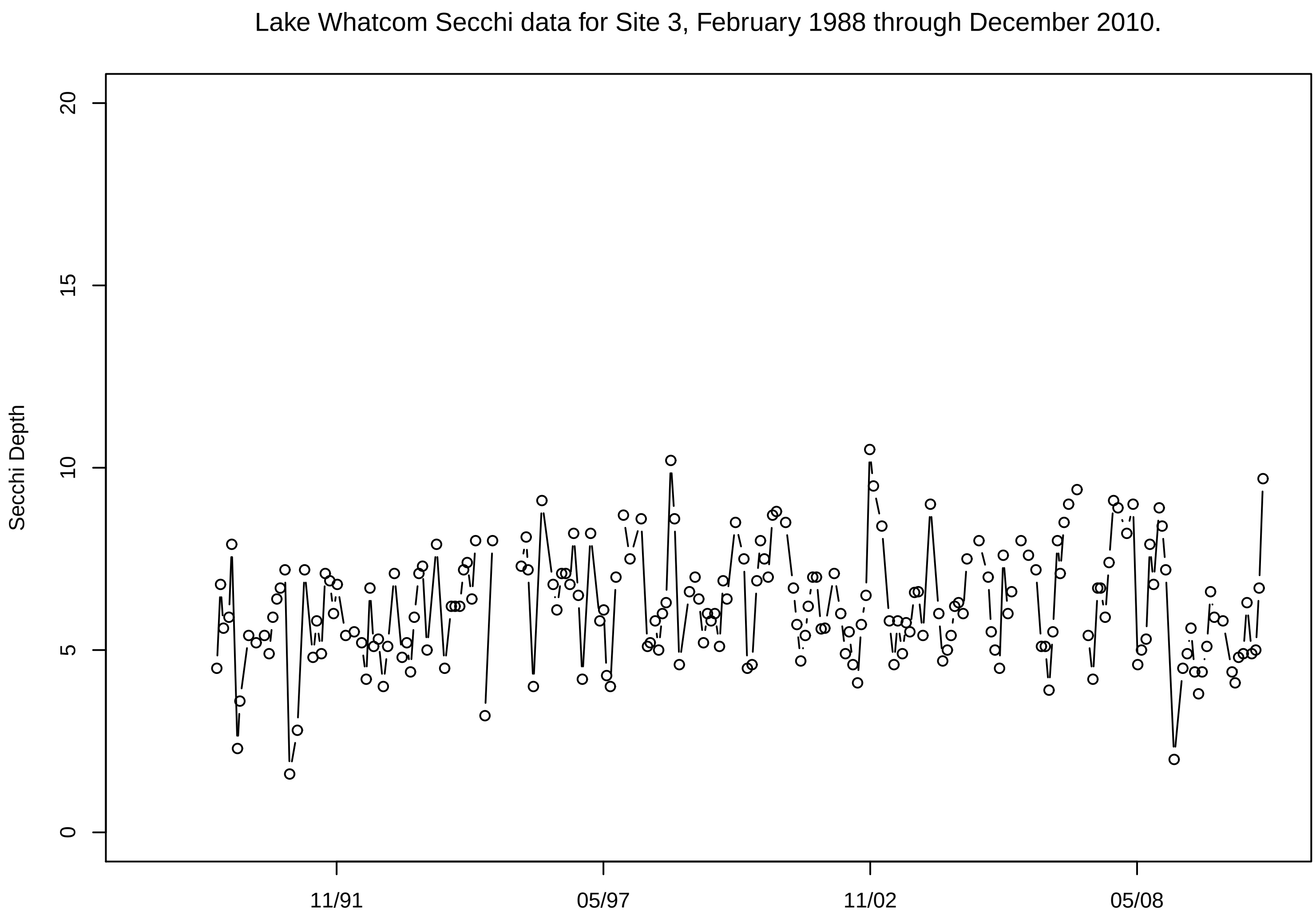


Figure B114: Lake Whatcom Secchi depths for Site 3.

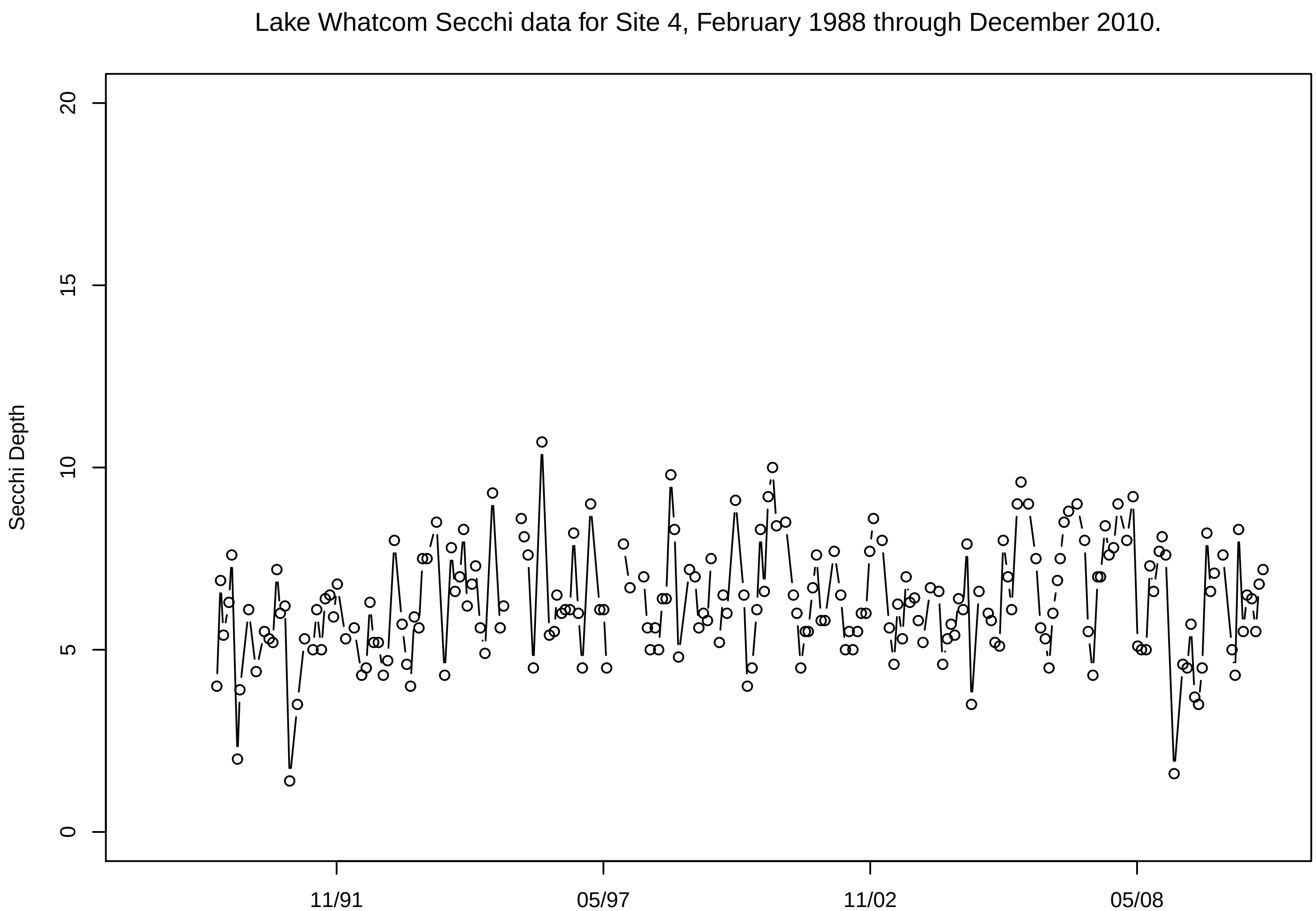


Figure B115: Lake Whatcom Secchi depths for Site 4.

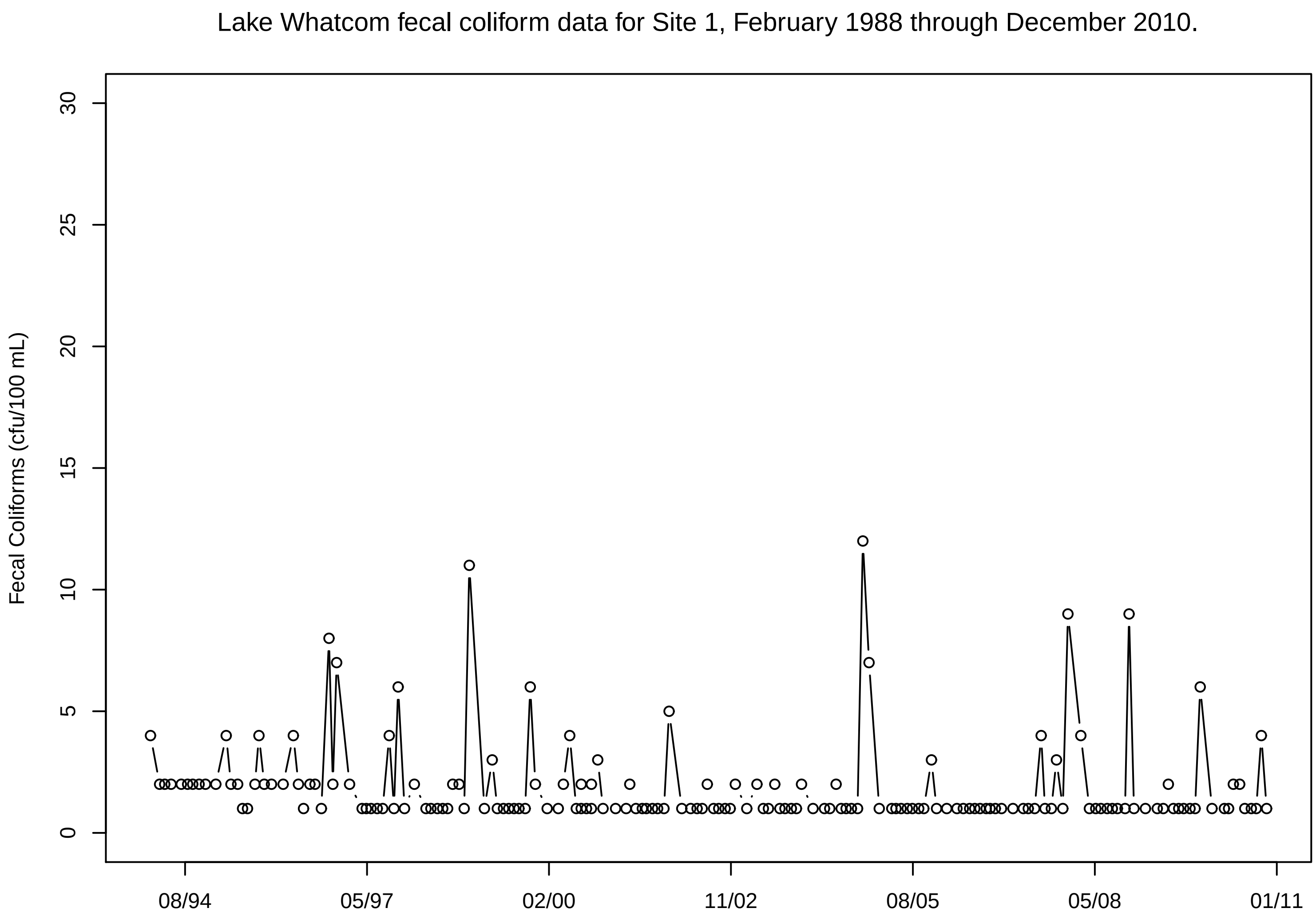


Figure B116: Lake Whatcom fecal coliform data for Site 1.

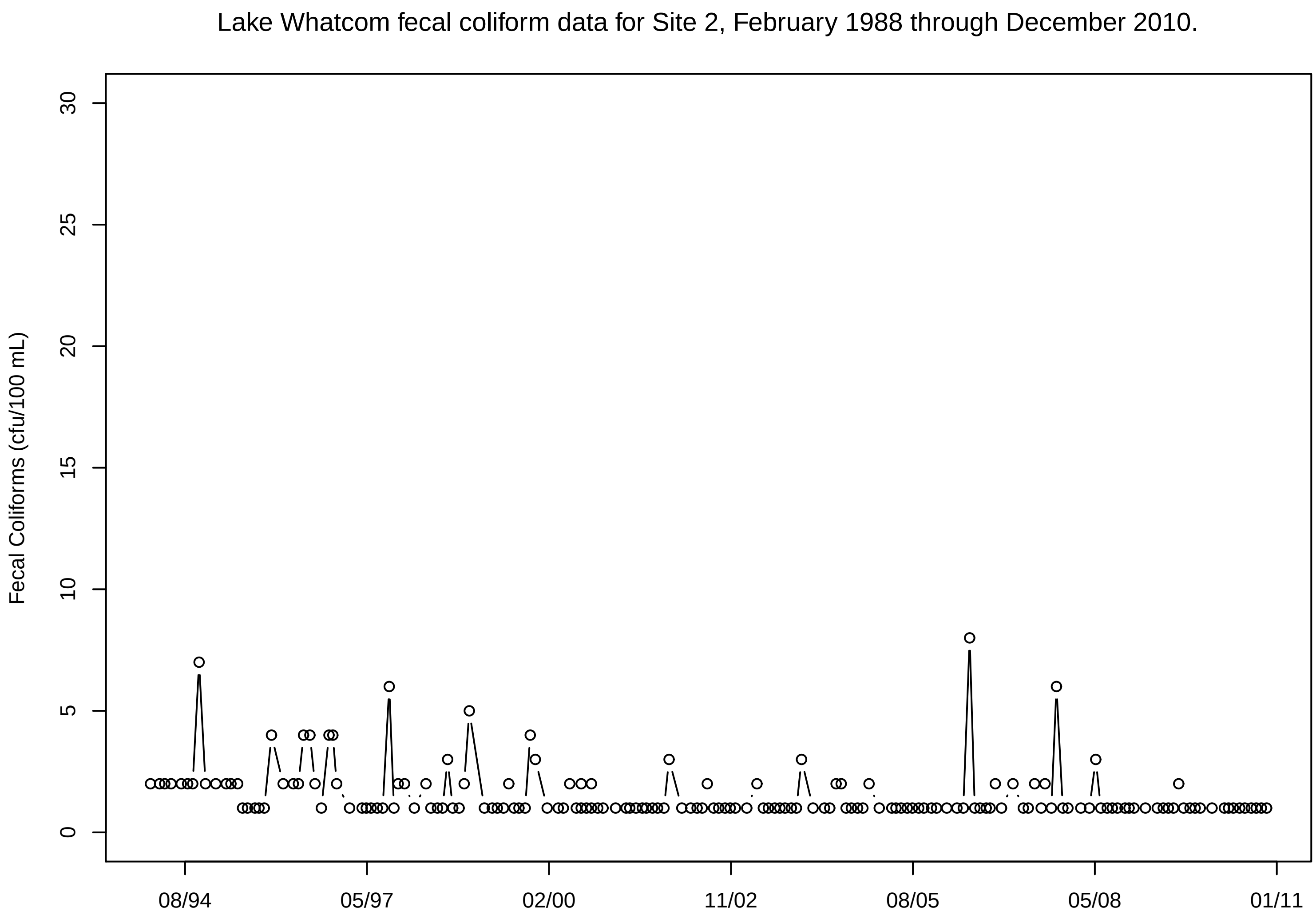


Figure B117: Lake Whatcom fecal coliform data for Site 2.

Lake Whatcom fecal coliform data for Intake, February 1988 through December 2010.

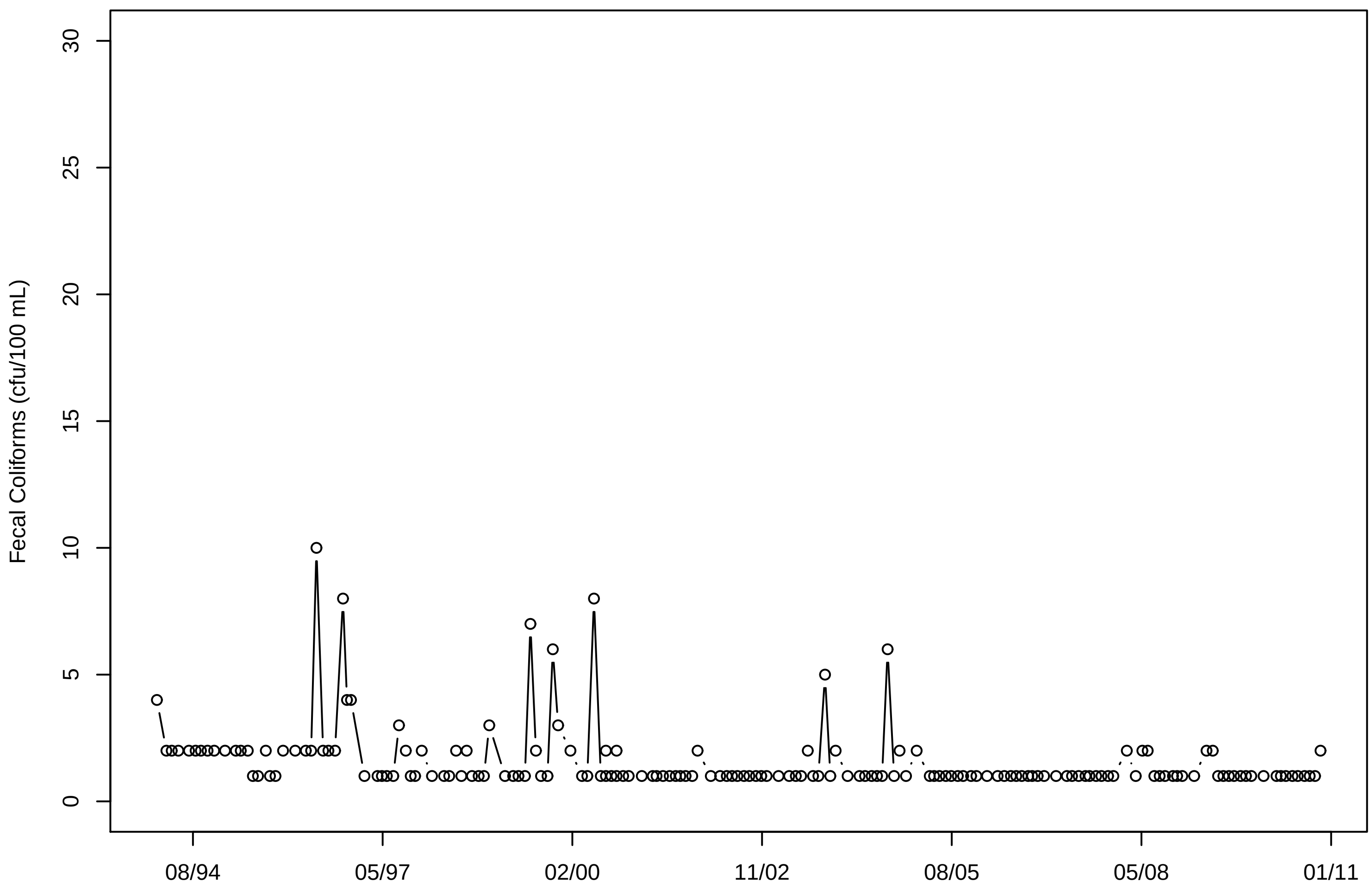


Figure B118: Lake Whatcom fecal coliform data for the Intake site.

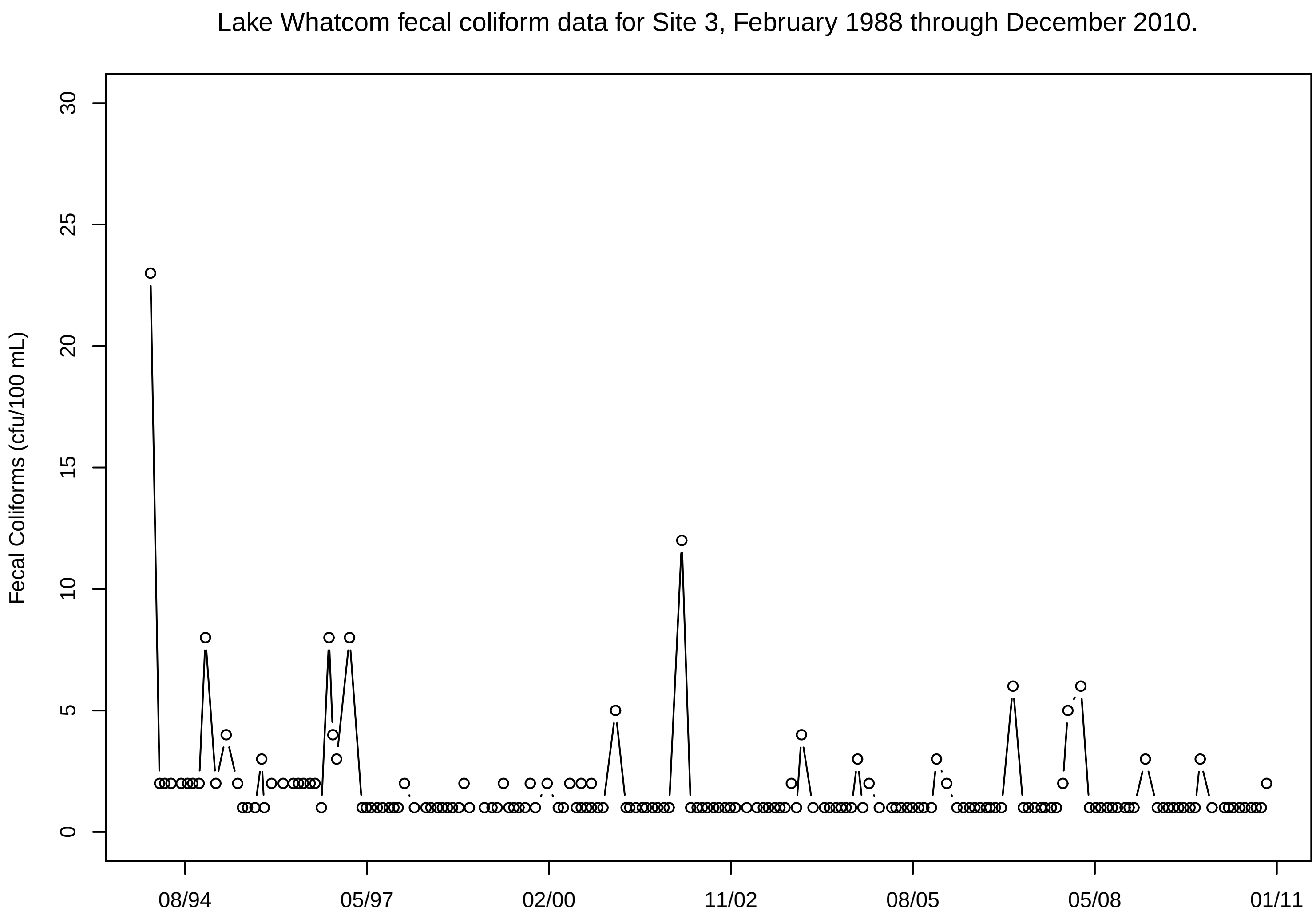


Figure B119: Lake Whatcom fecal coliform data for Site 3.

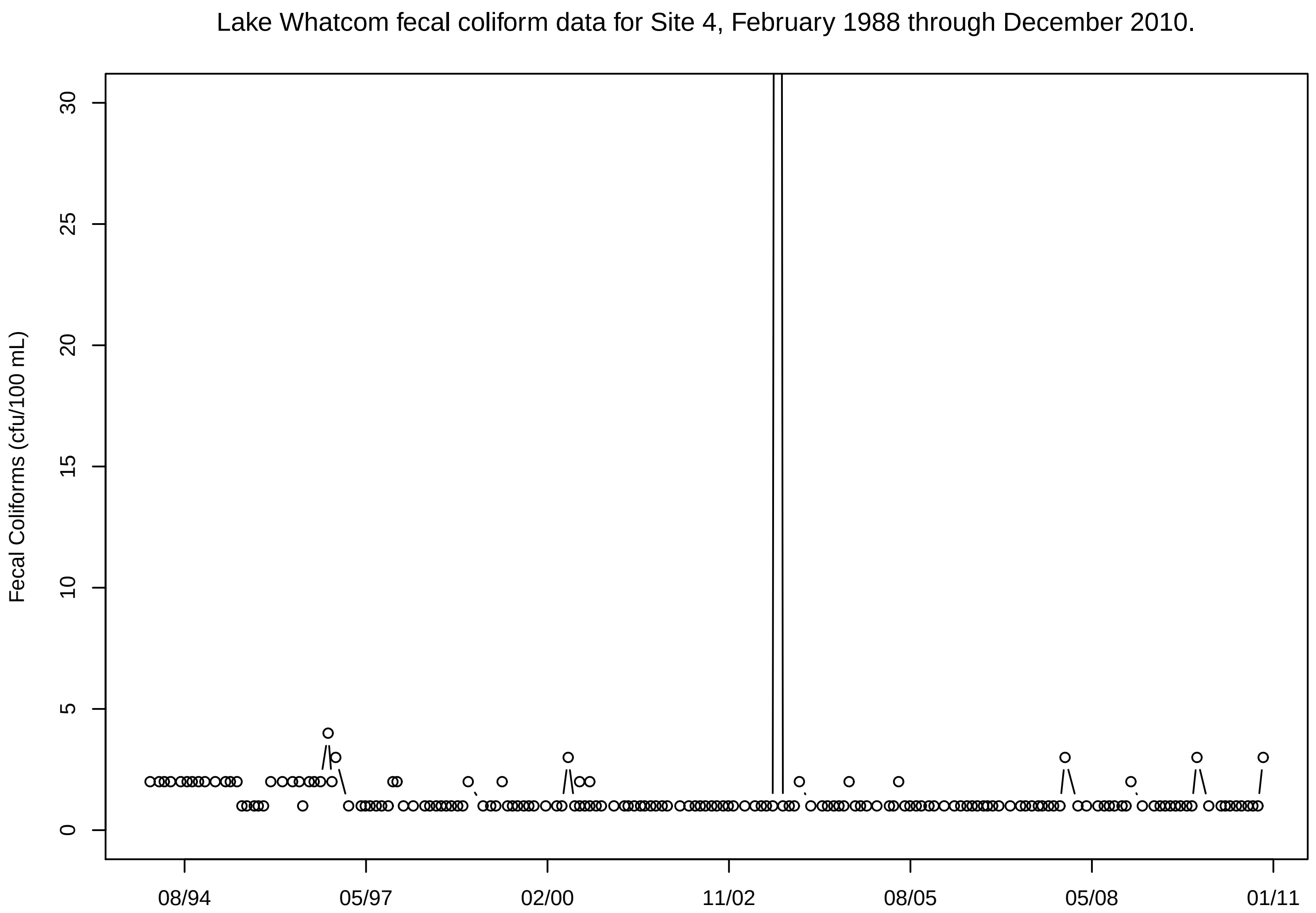


Figure B120: Lake Whatcom fecal coliform data for Site 4.

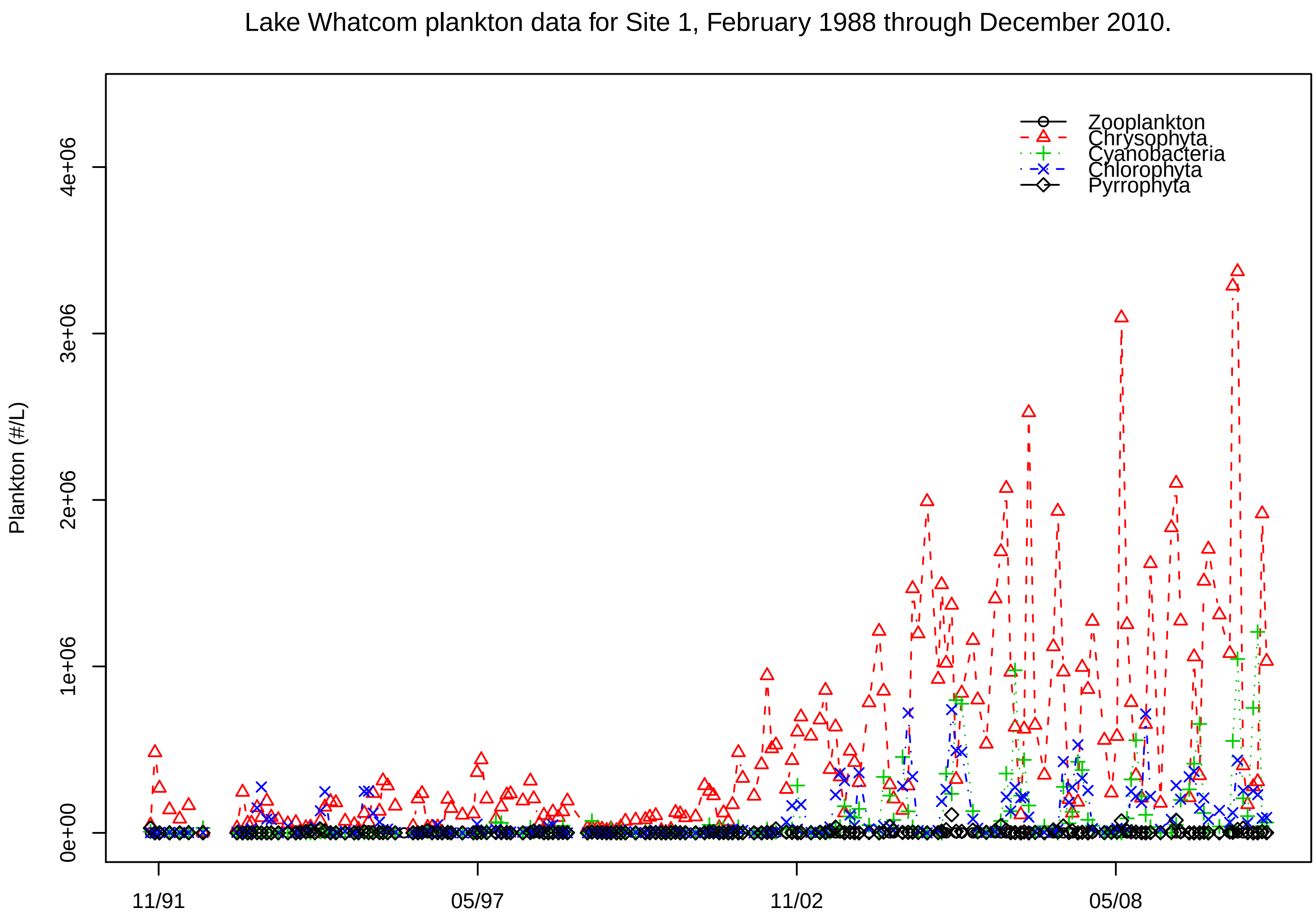


Figure B121: Lake Whatcom plankton data for Site 1.

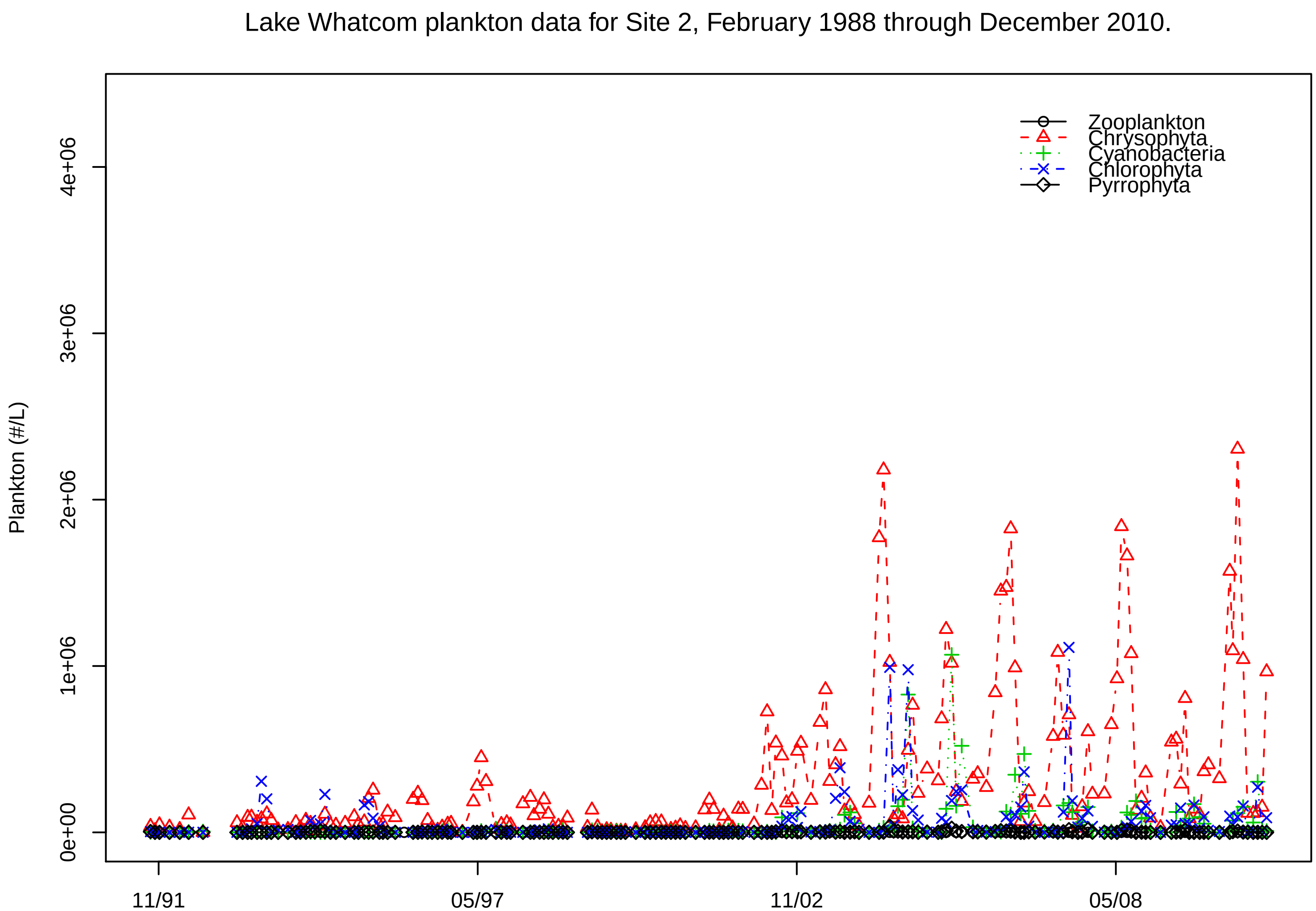


Figure B122: Lake Whatcom plankton data for Site 2.

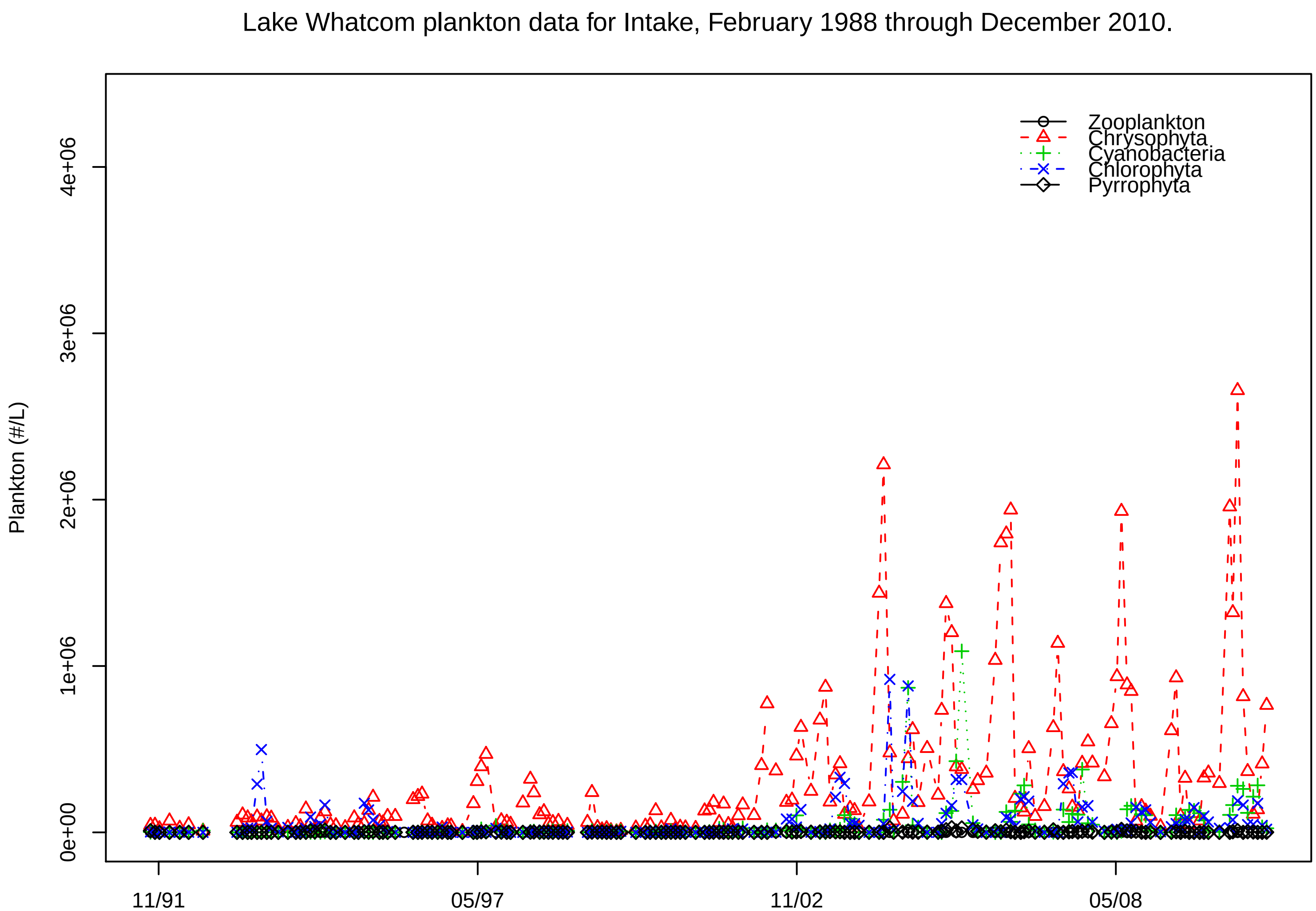


Figure B123: Lake Whatcom plankton data for the Intake Site.

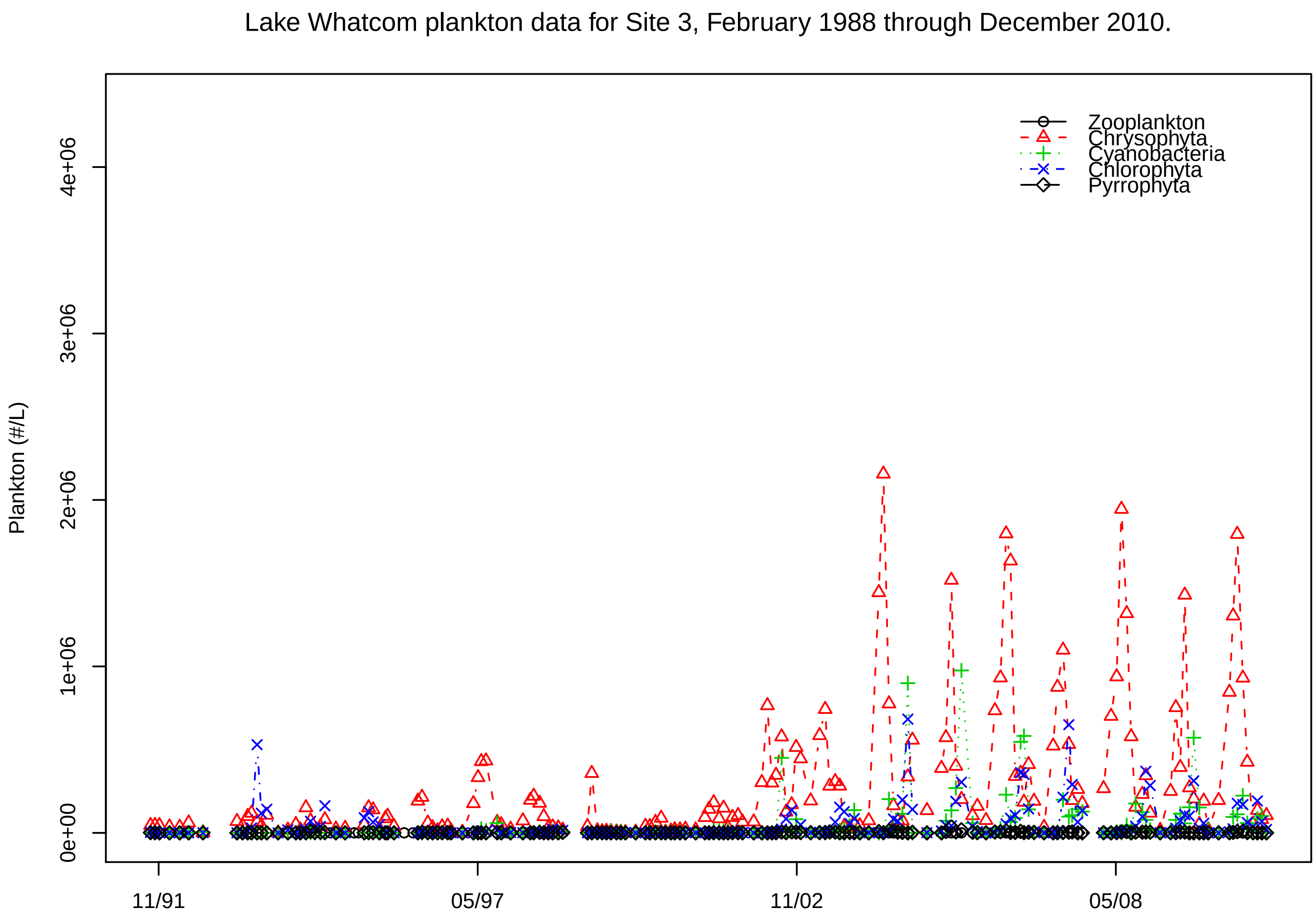


Figure B124: Lake Whatcom plankton data for Site 3.

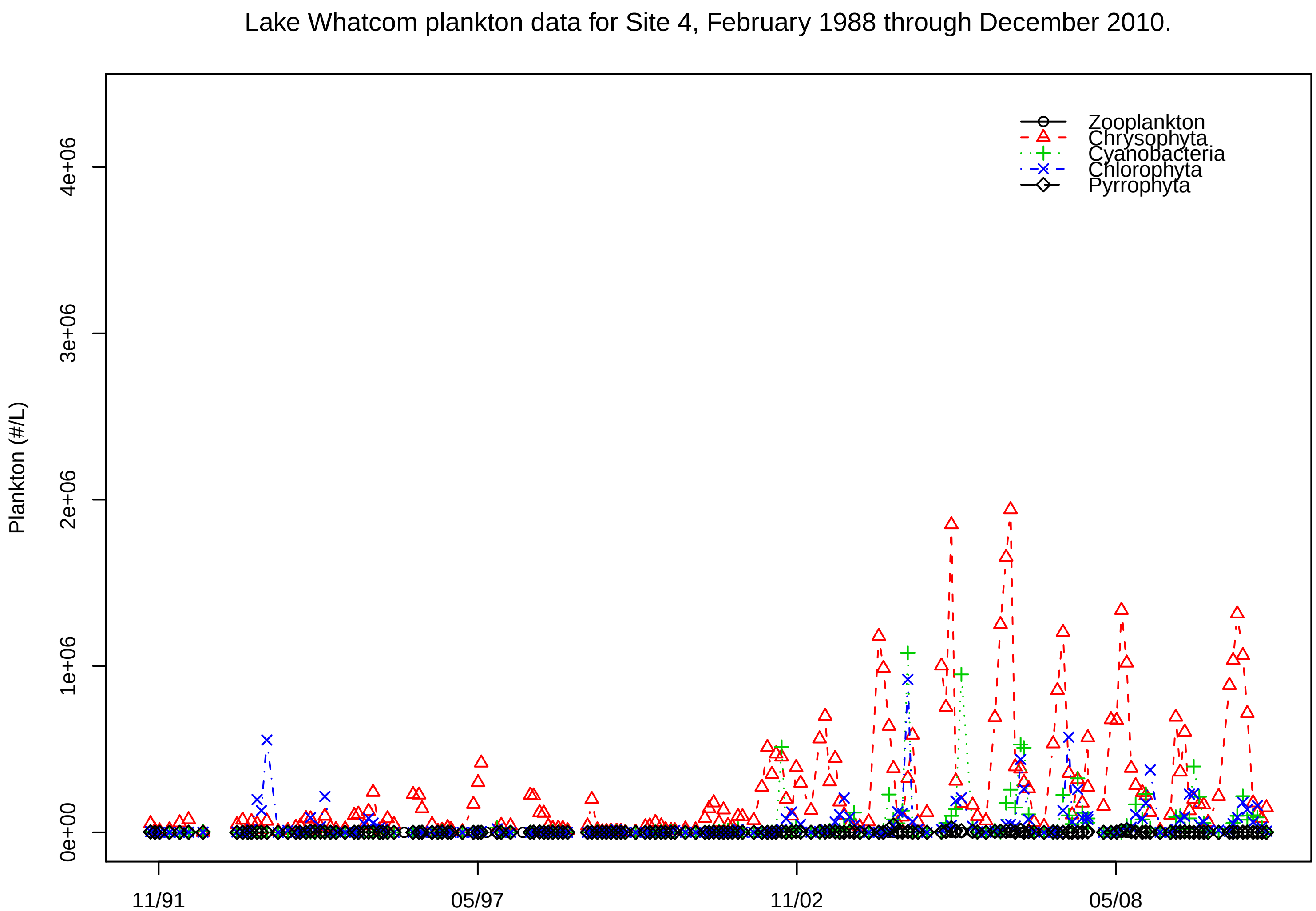


Figure B125: Lake Whatcom plankton data for Site 4.

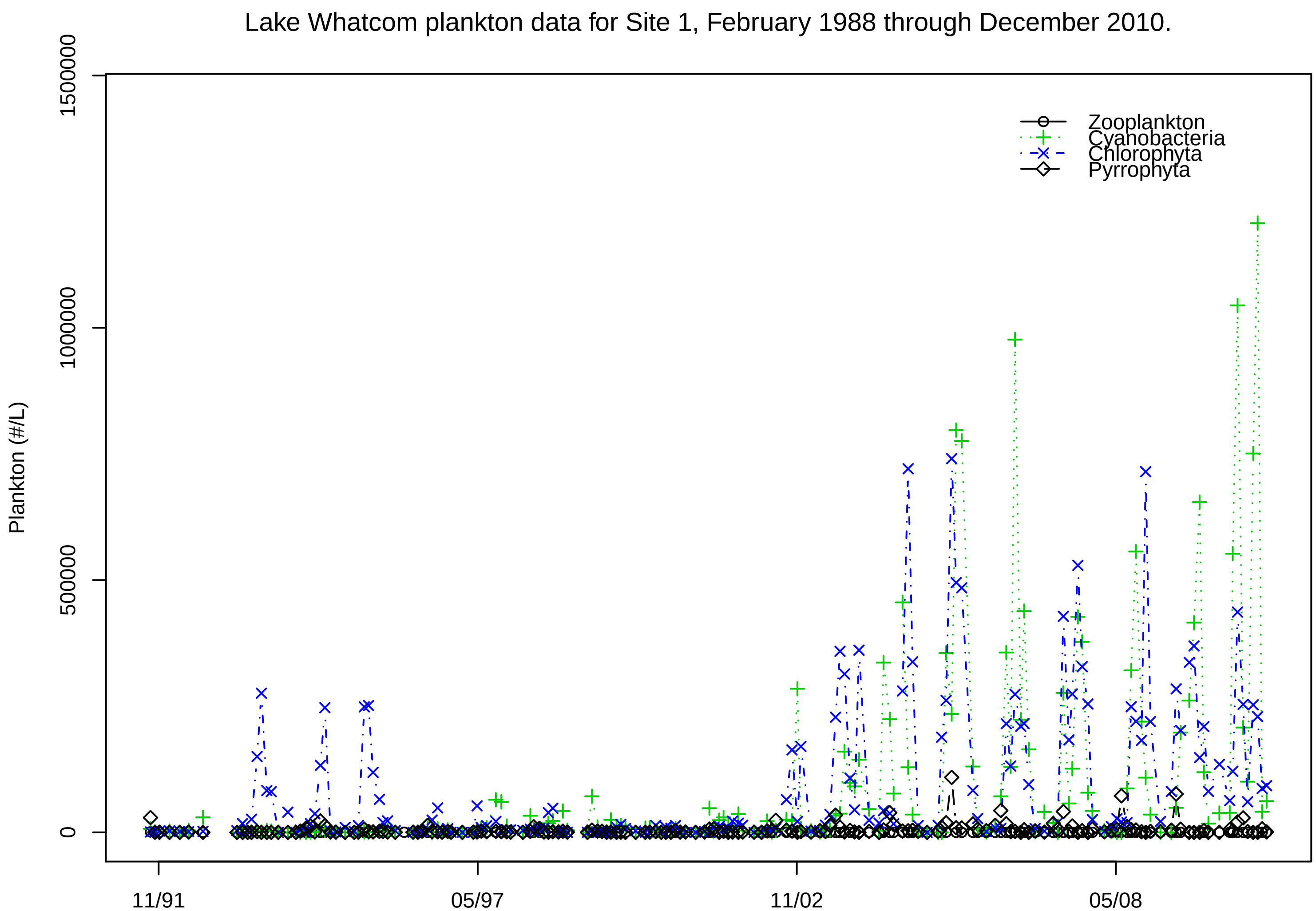


Figure B126: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

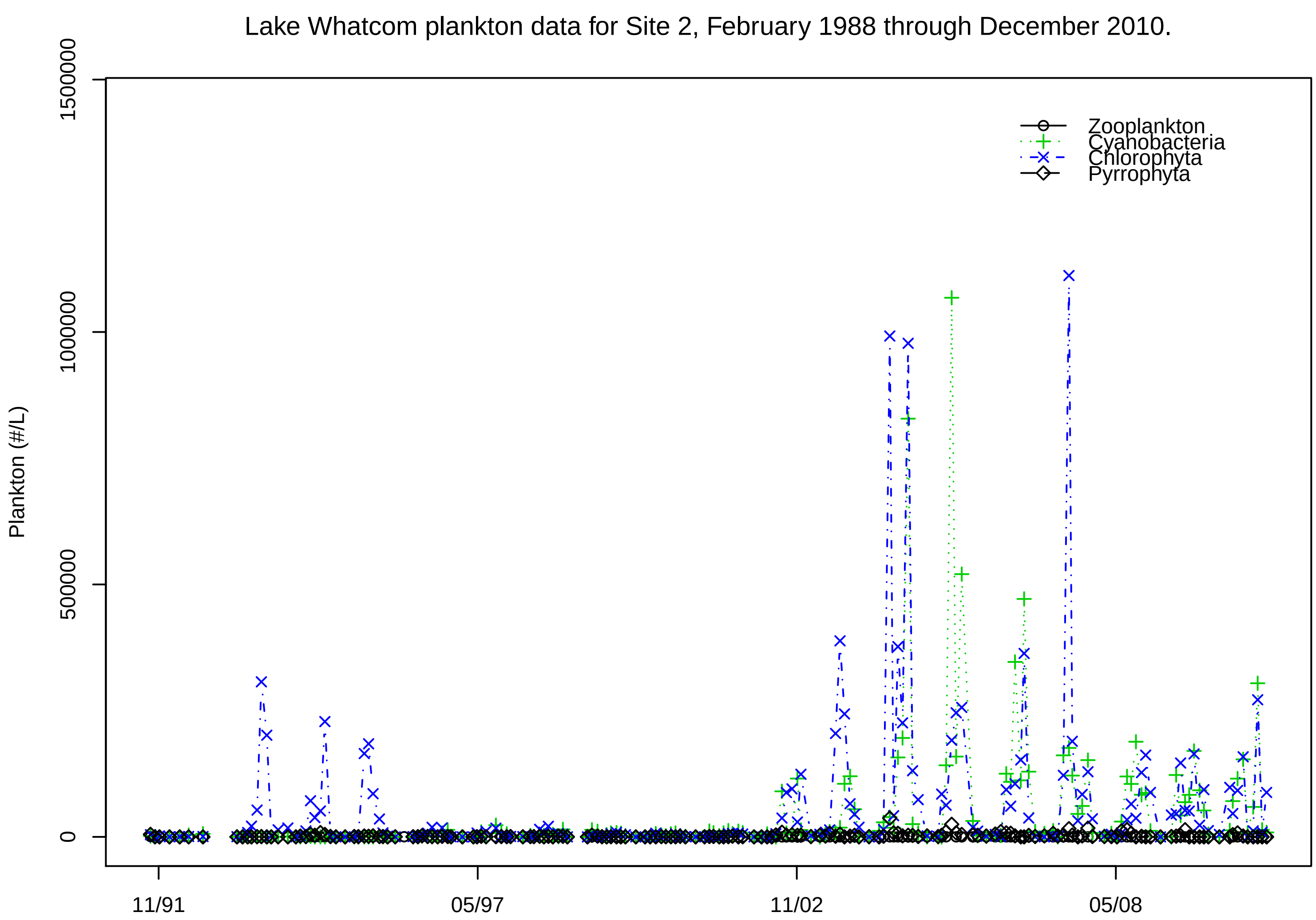


Figure B127: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

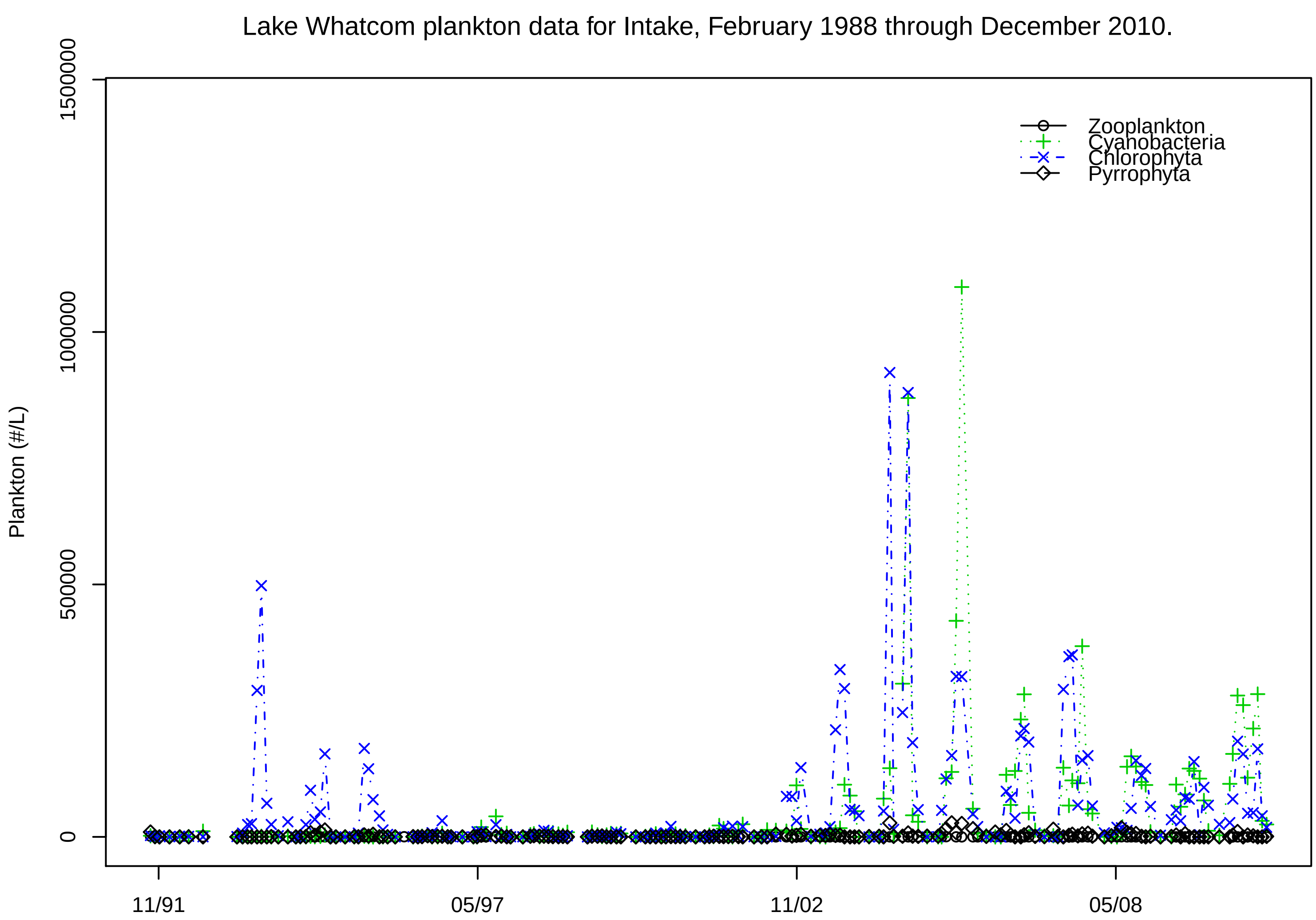


Figure B128: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

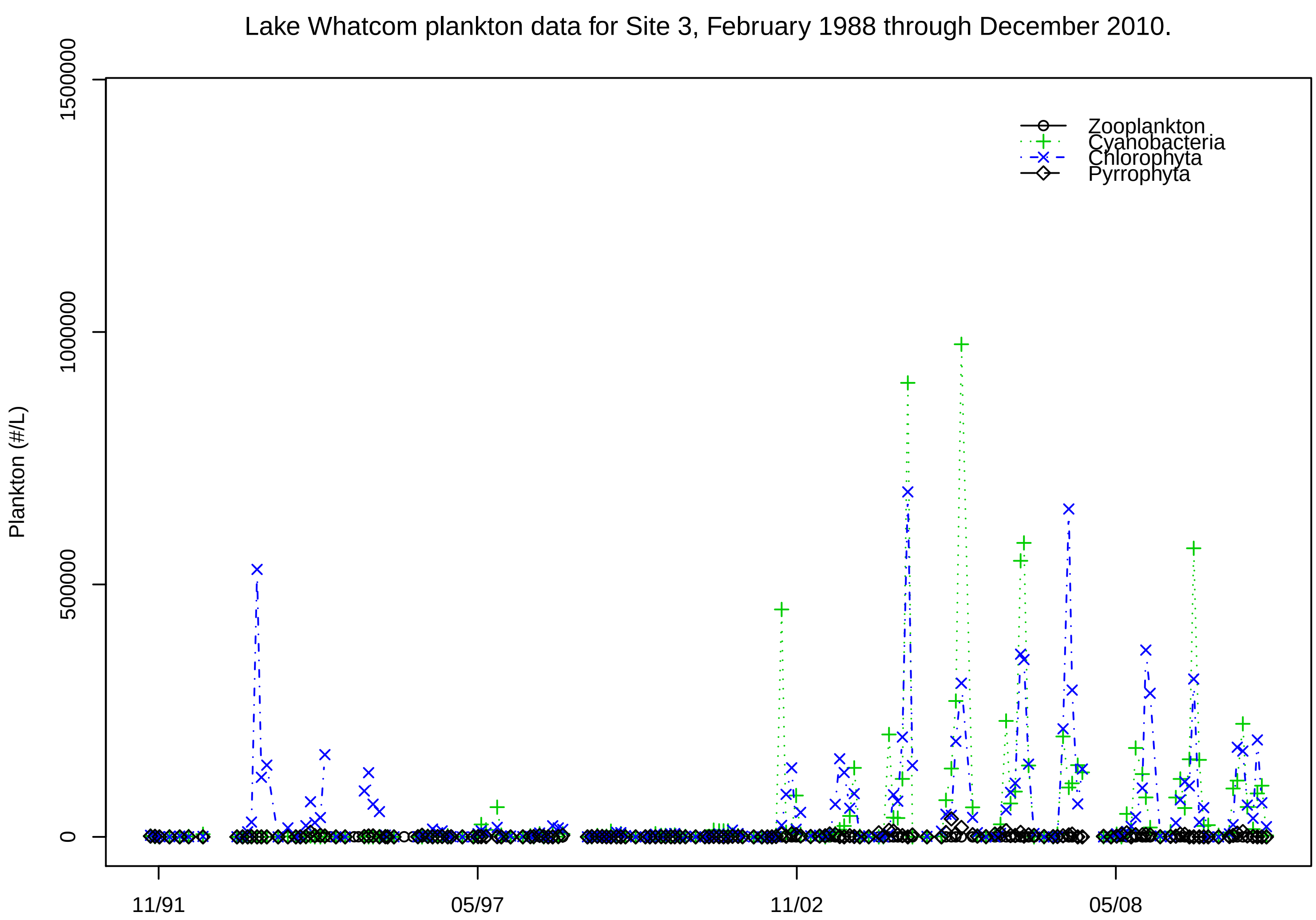


Figure B129: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

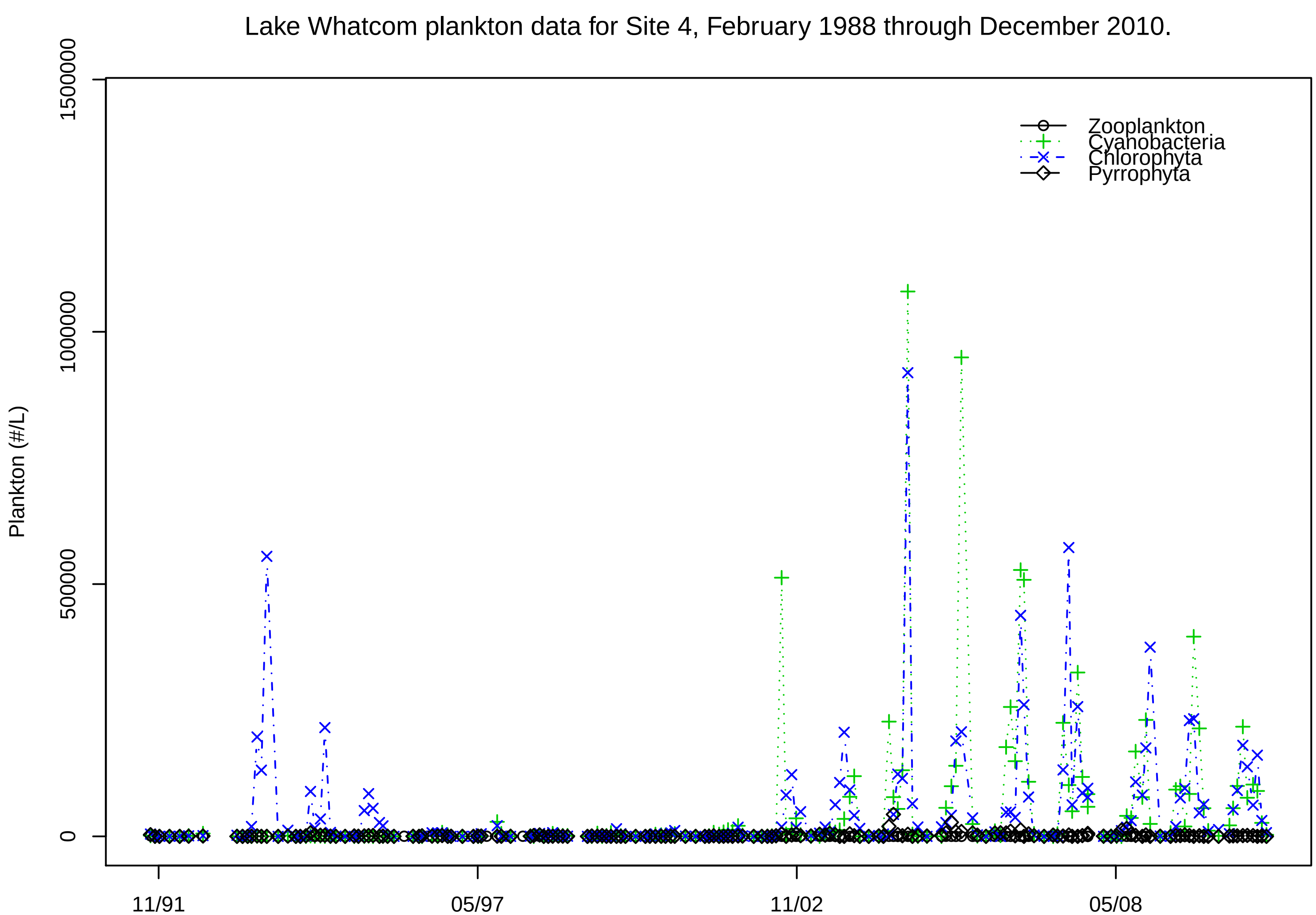


Figure B130: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

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

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

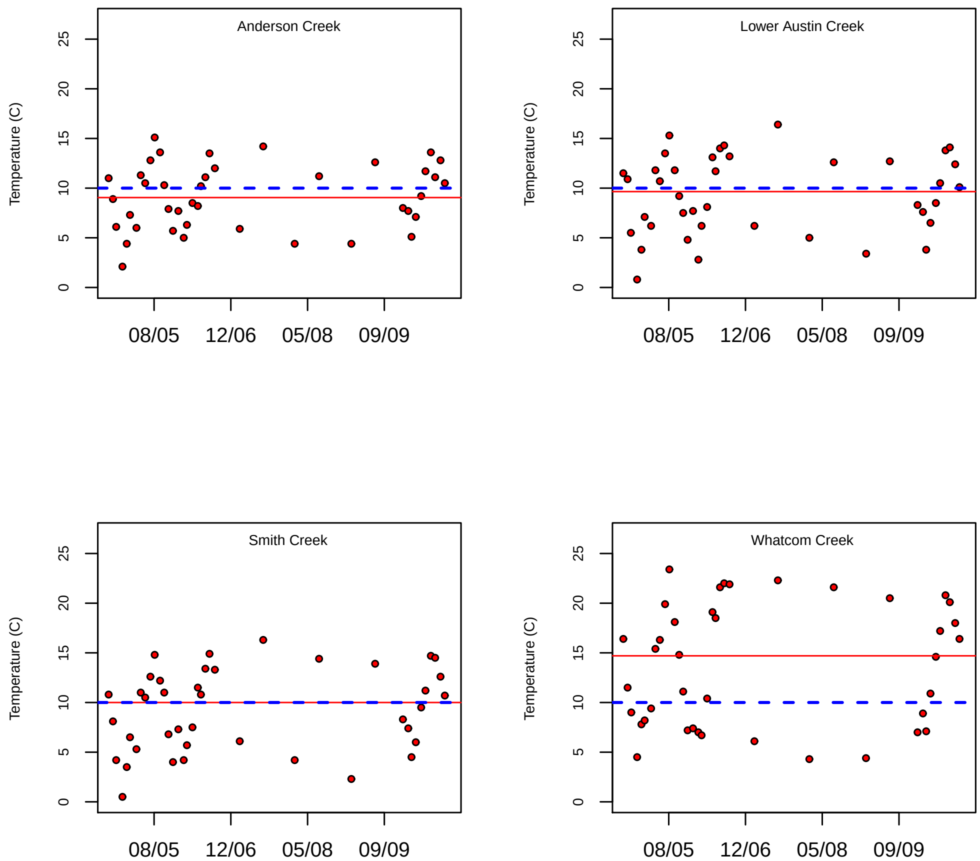


Figure B131: Temperature data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

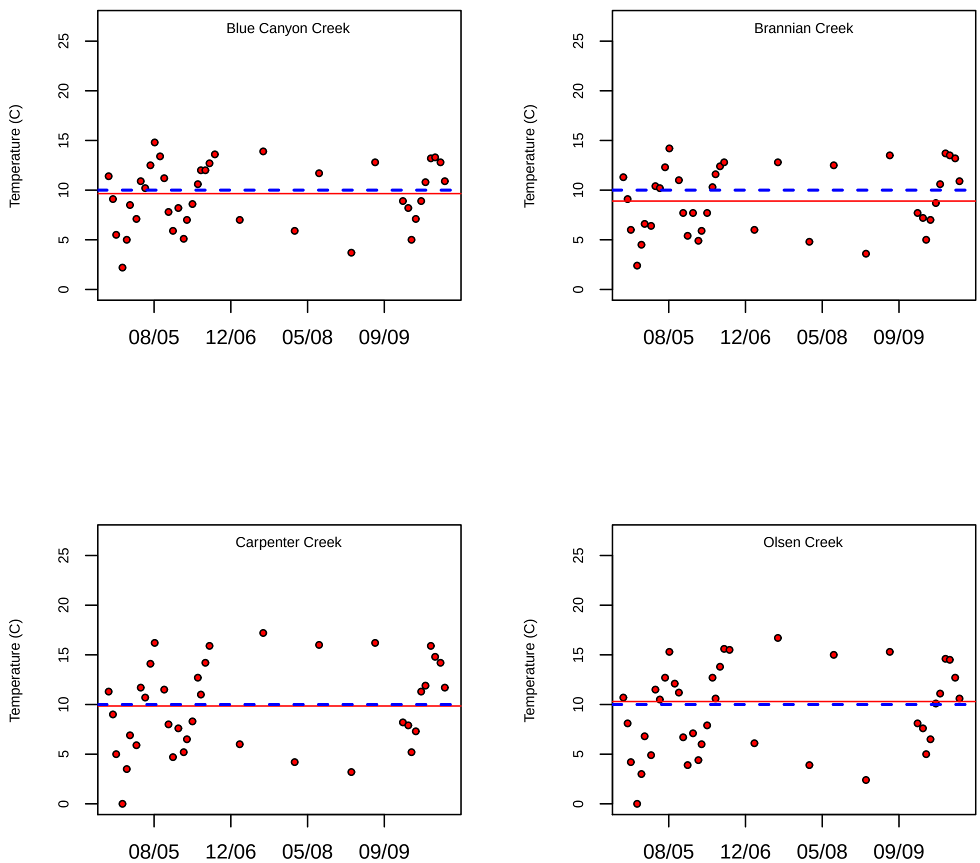


Figure B132: Temperature data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

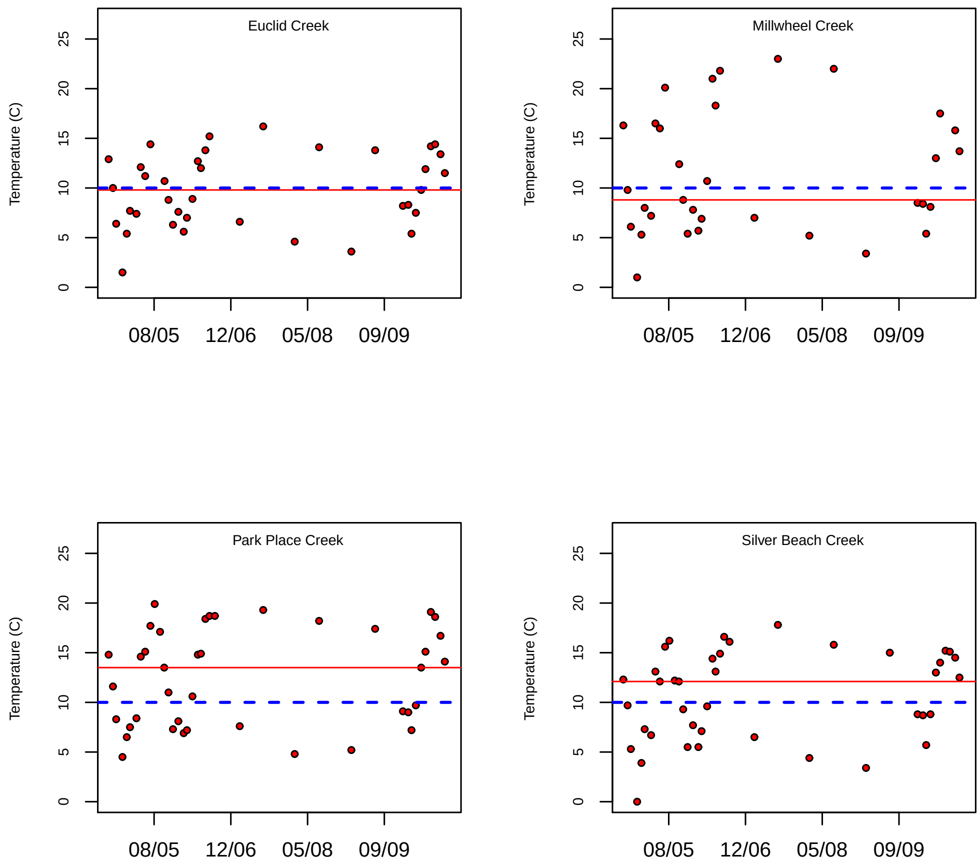


Figure B133: Temperature data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

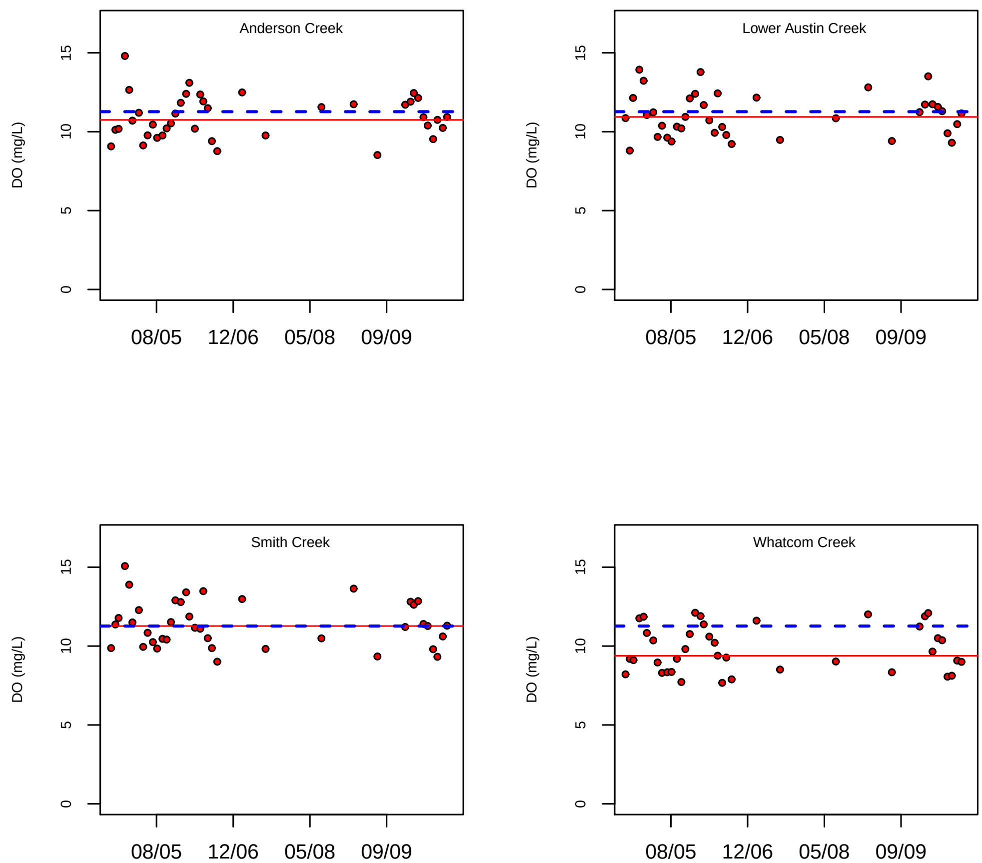


Figure B134: Dissolved oxygen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

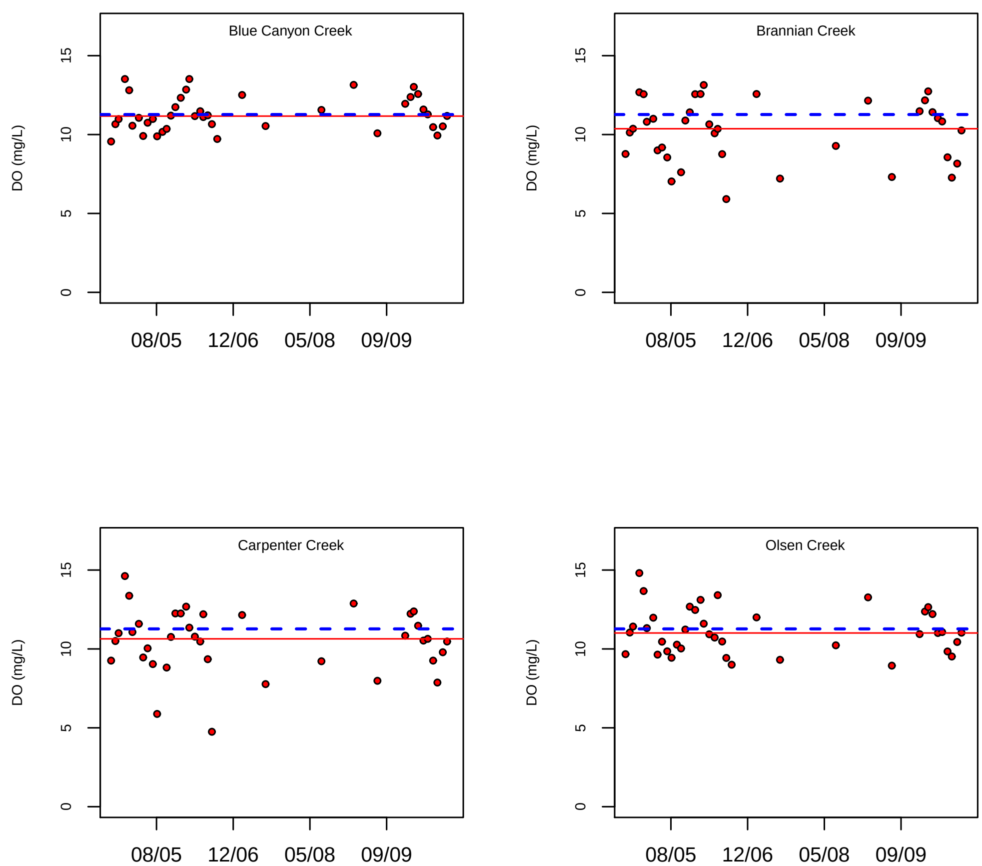


Figure B135: Dissolved oxygen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

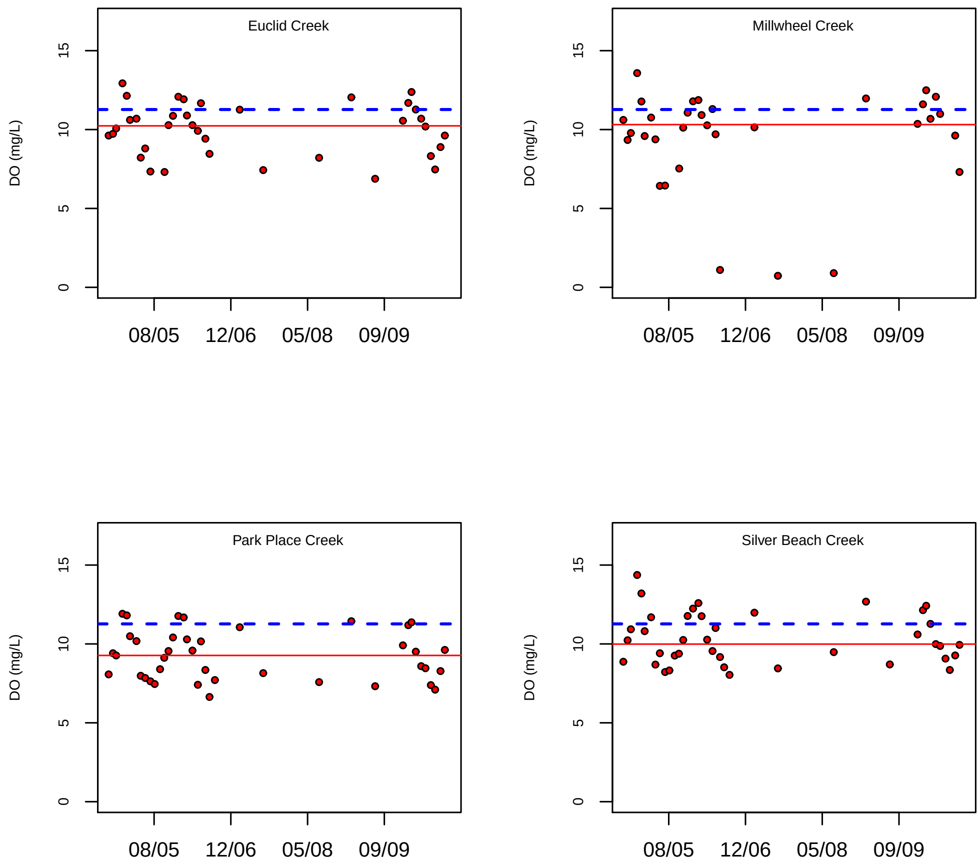


Figure B136: Dissolved oxygen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

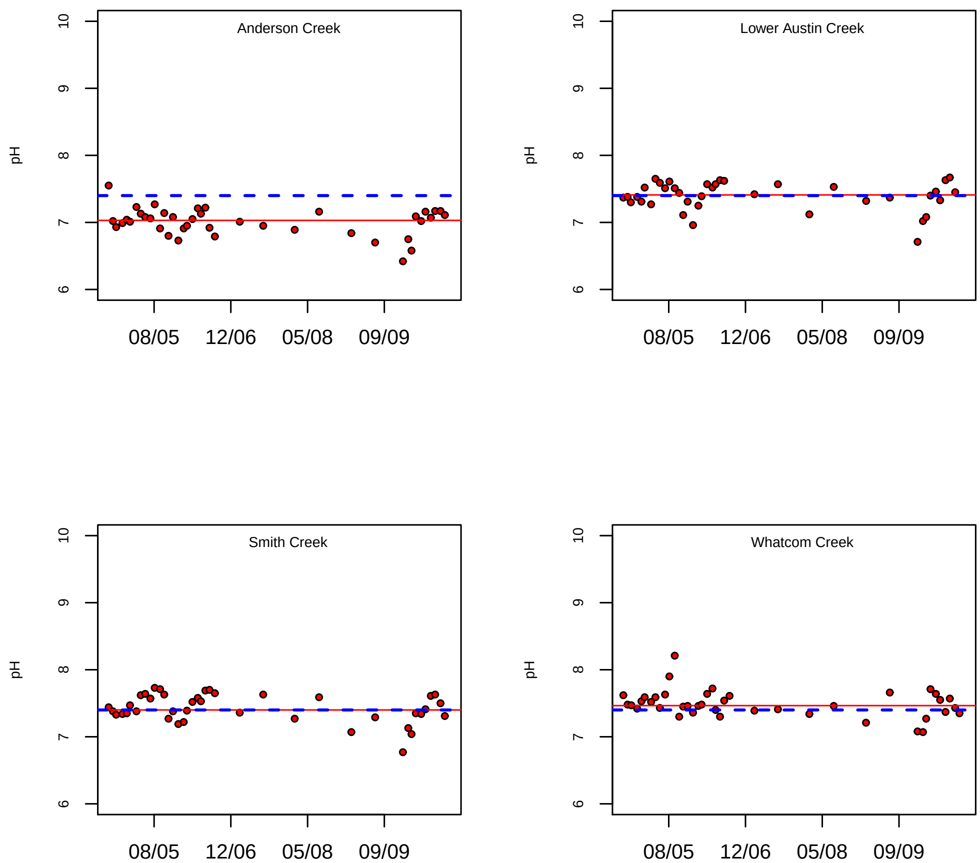


Figure B137: Tributary pH data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

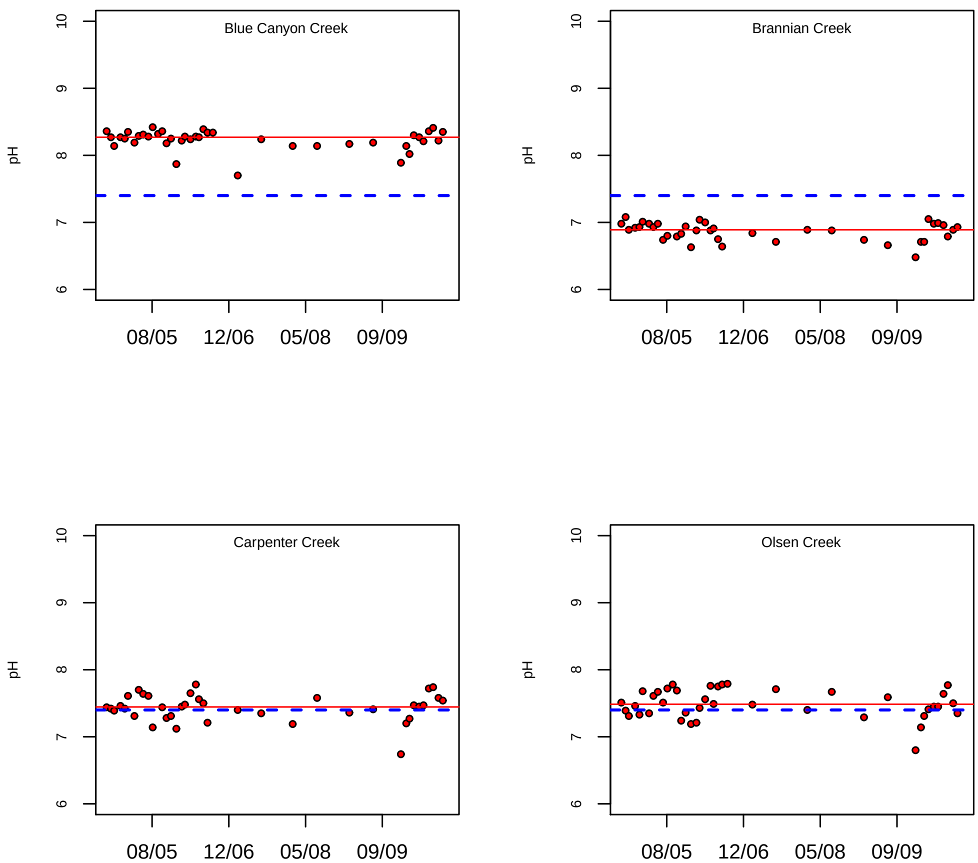


Figure B138: Tributary pH data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

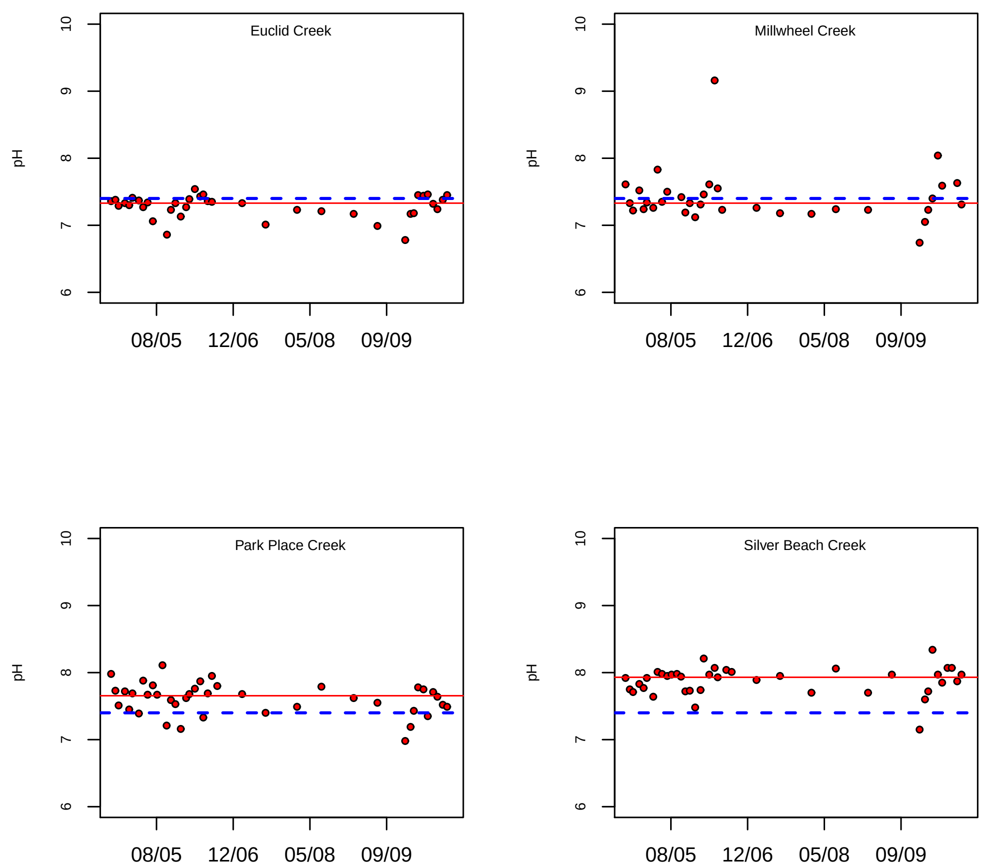


Figure B139: Tributary pH data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

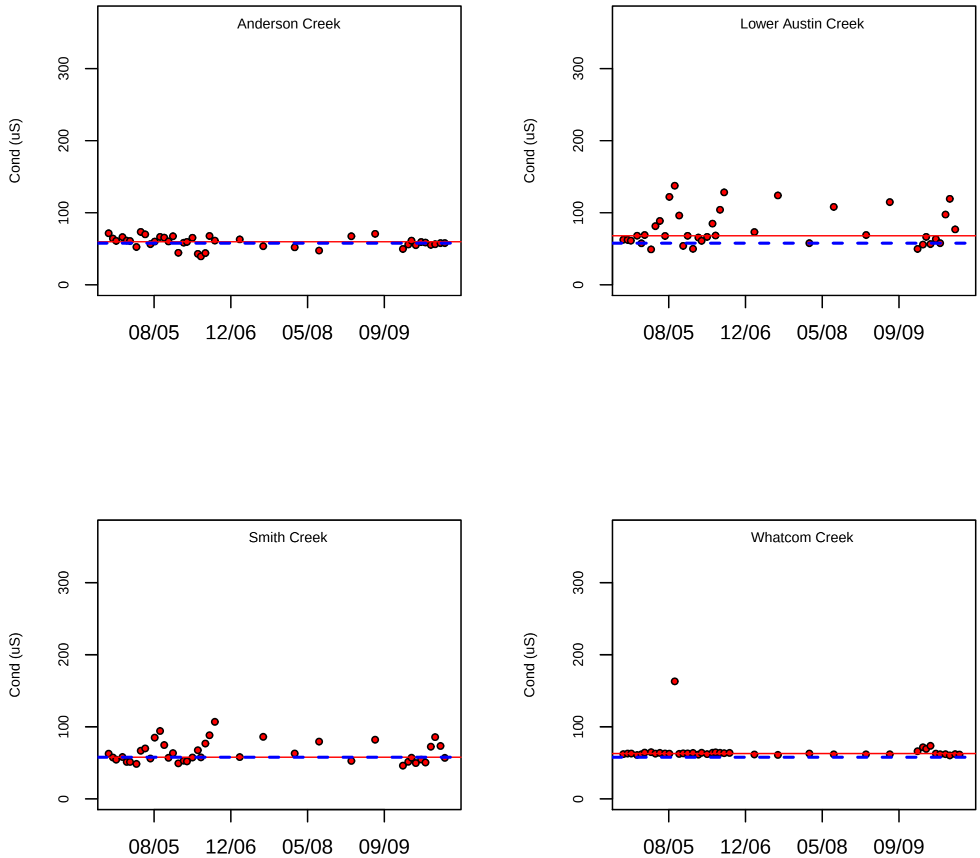


Figure B140: Conductivity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

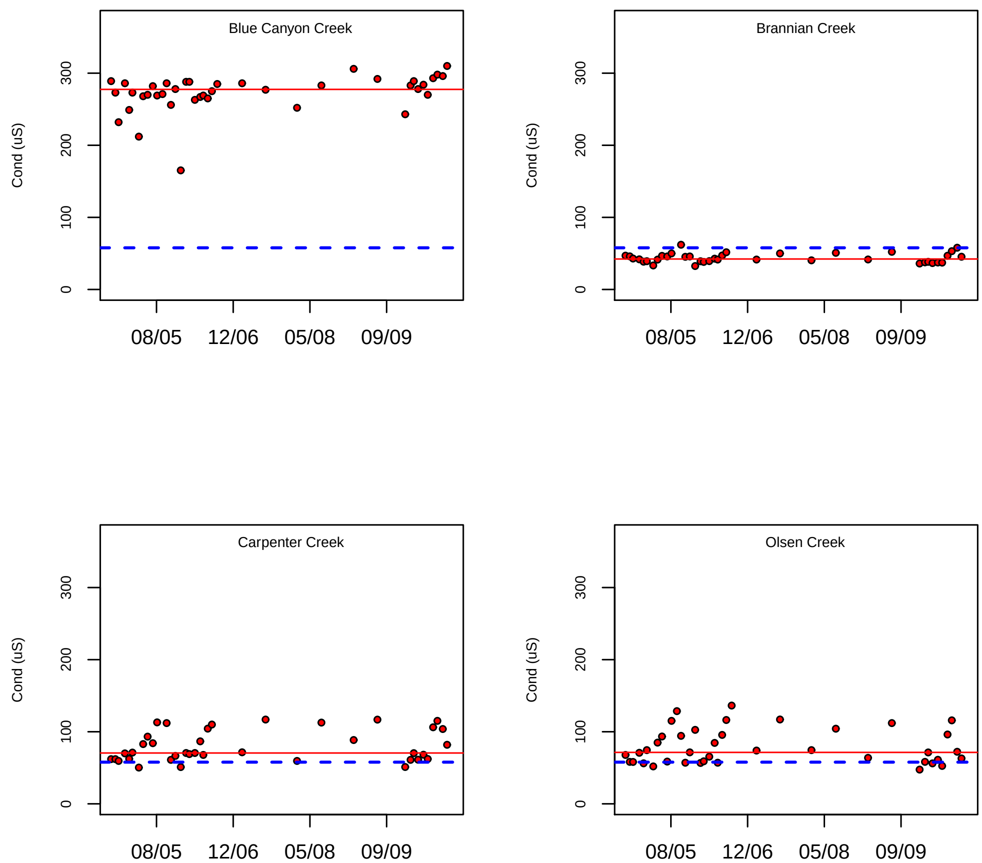


Figure B141: Conductivity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

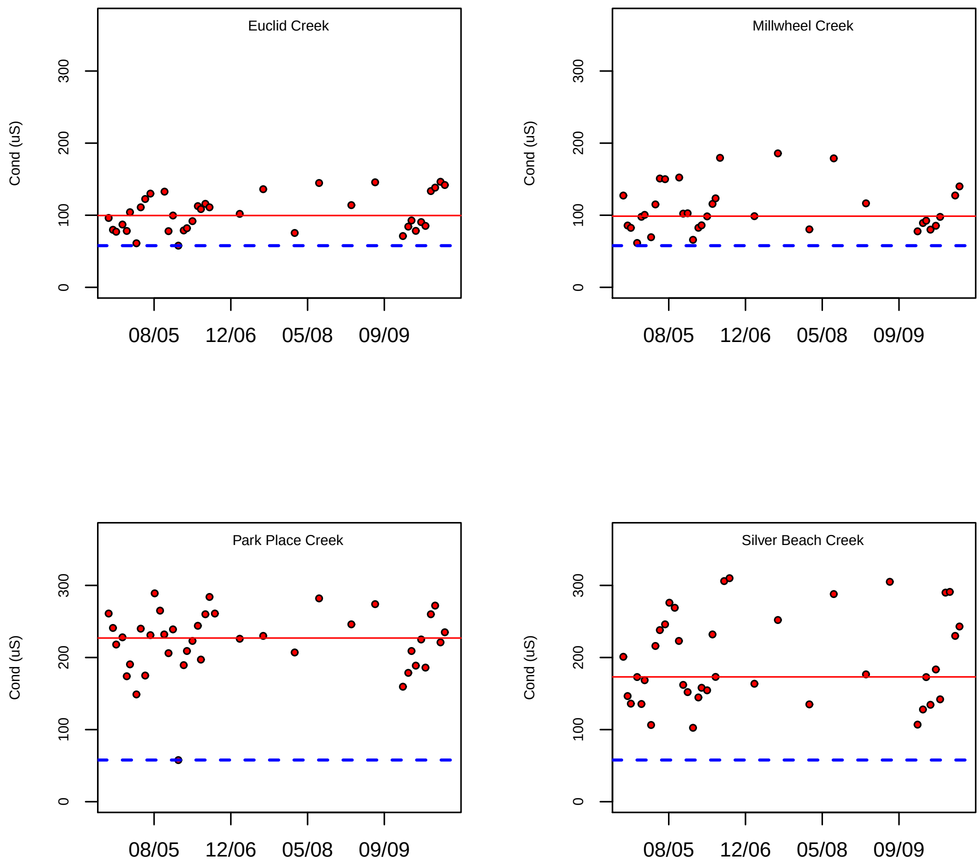


Figure B142: Conductivity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

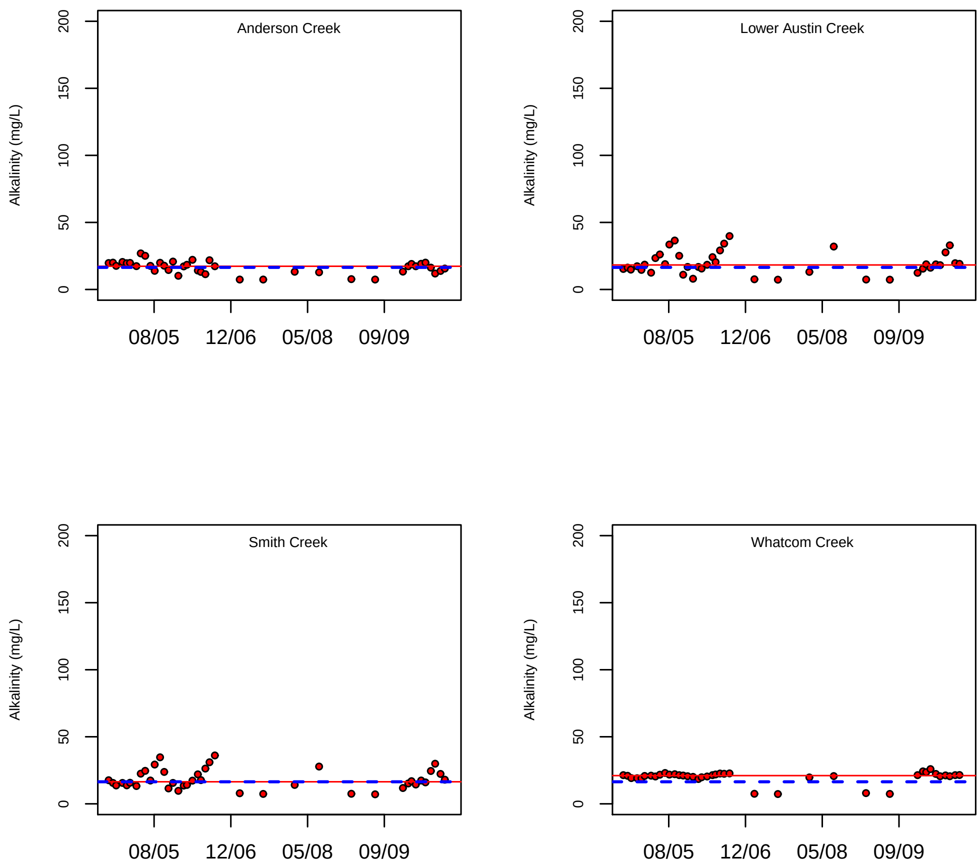


Figure B143: Alkalinity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

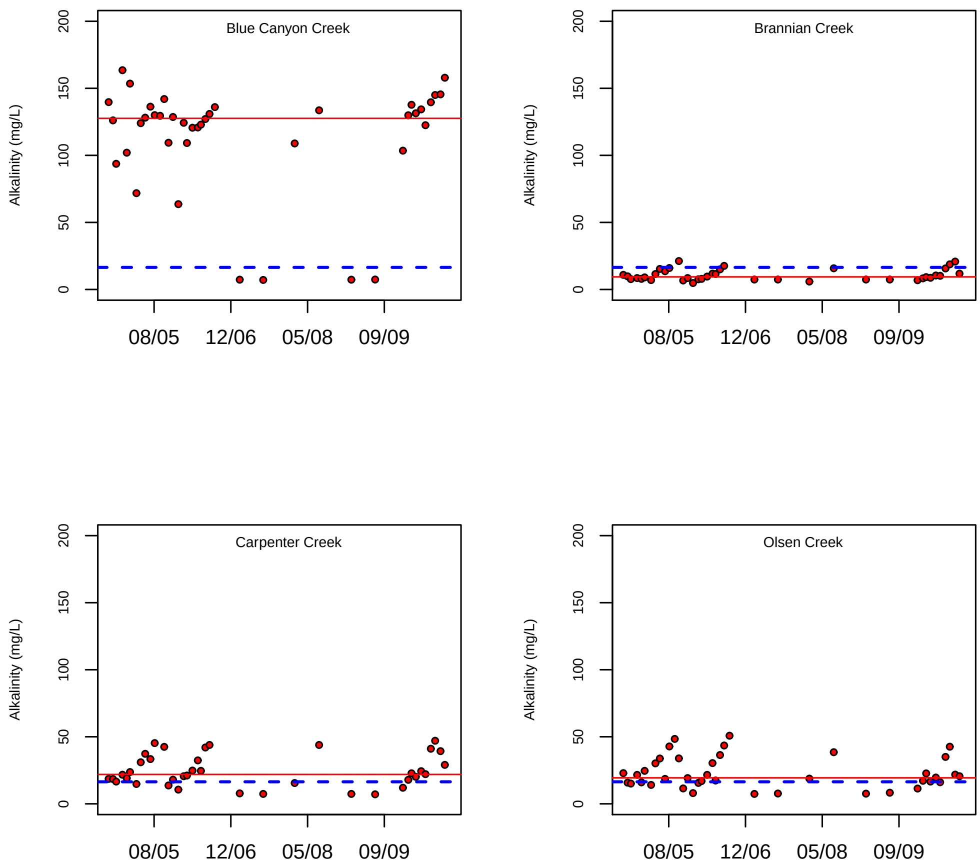


Figure B144: Alkalinity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

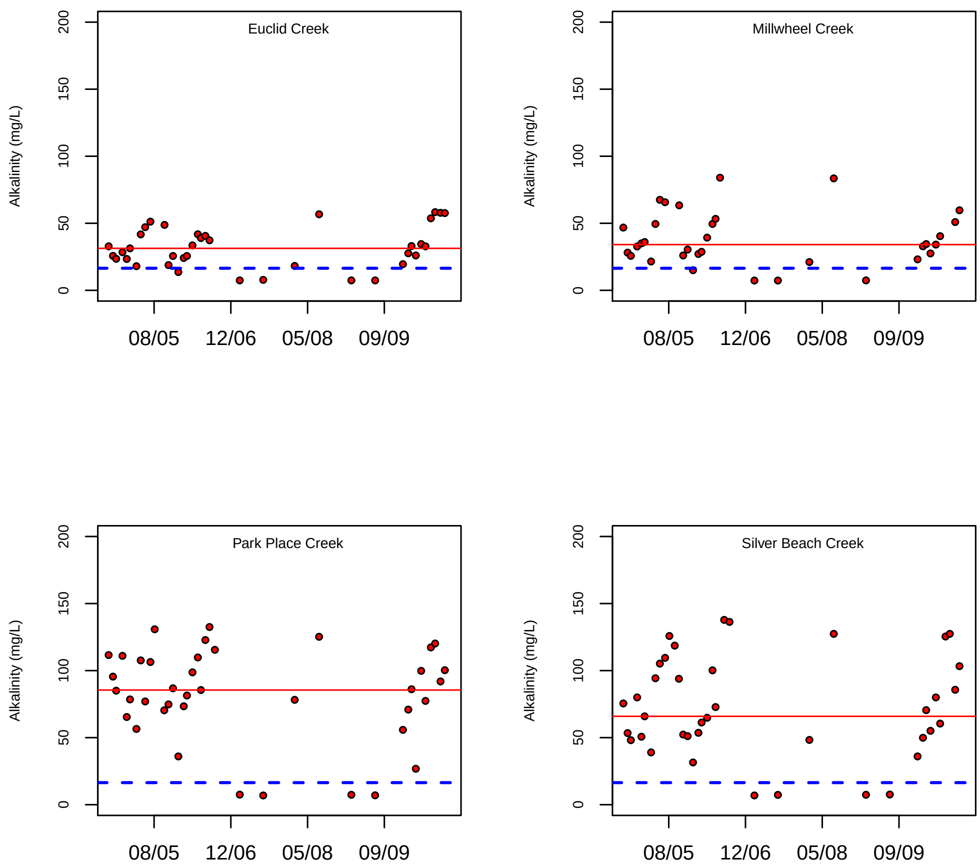


Figure B145: Alkalinity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

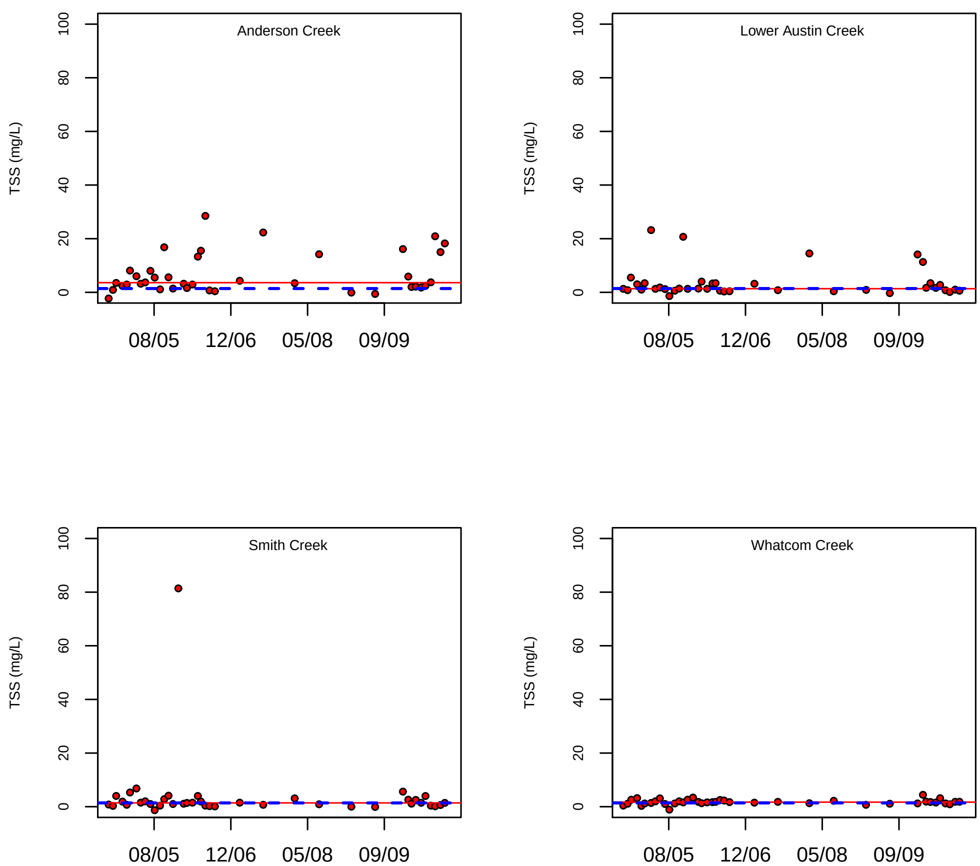


Figure B146: Total suspended solids data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

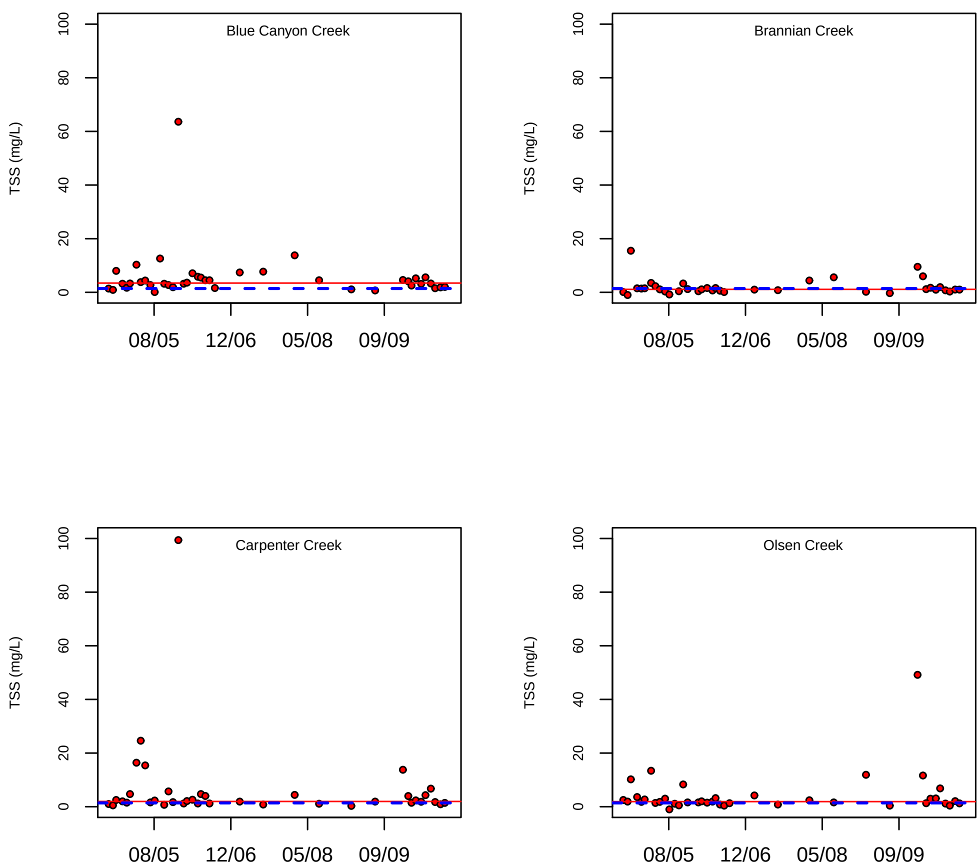


Figure B147: Total suspended solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

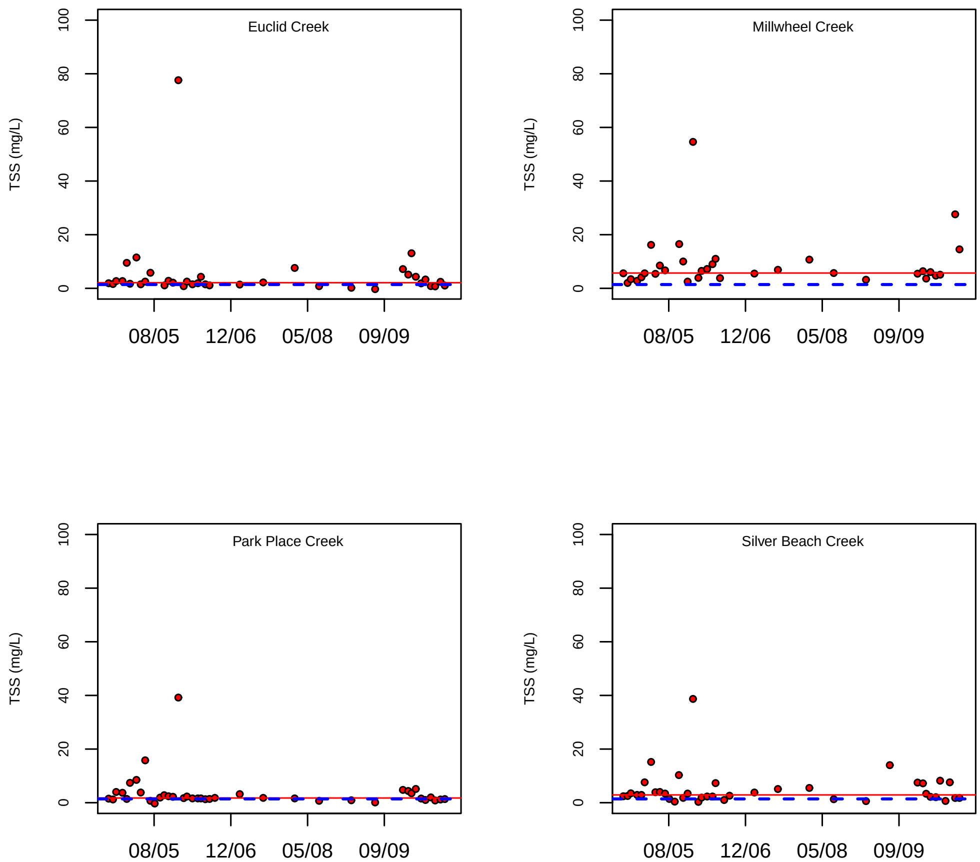


Figure B148: Total suspended solids data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

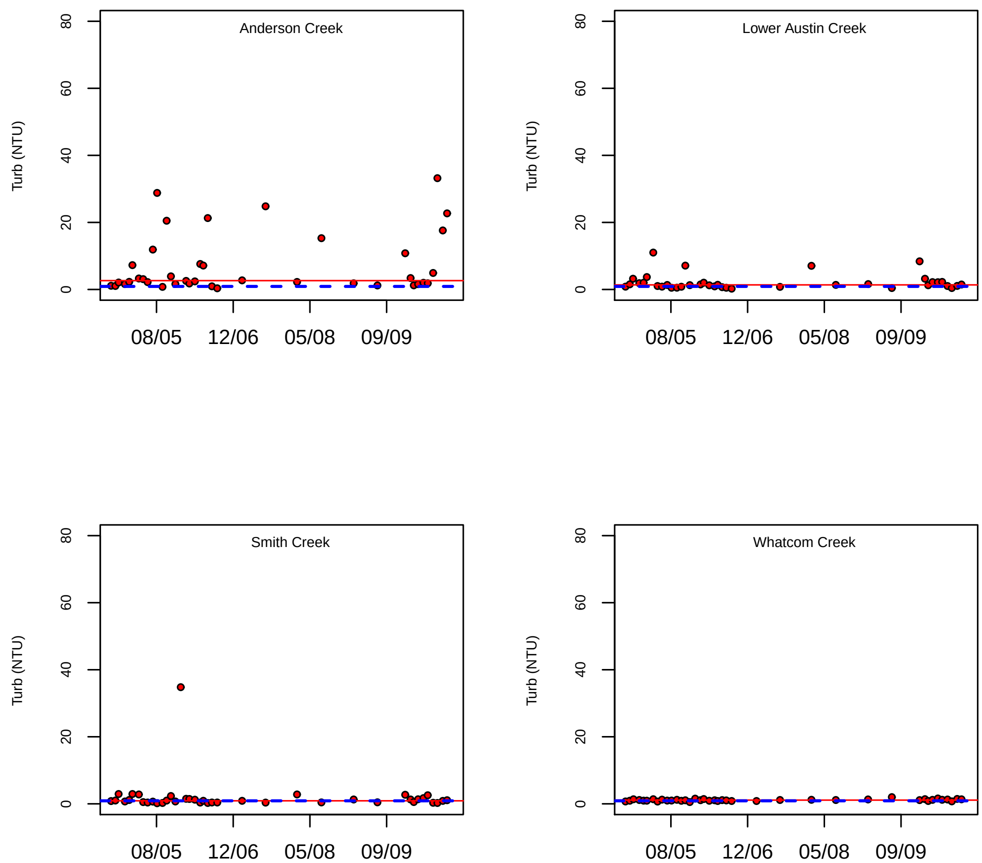


Figure B149: Turbidity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

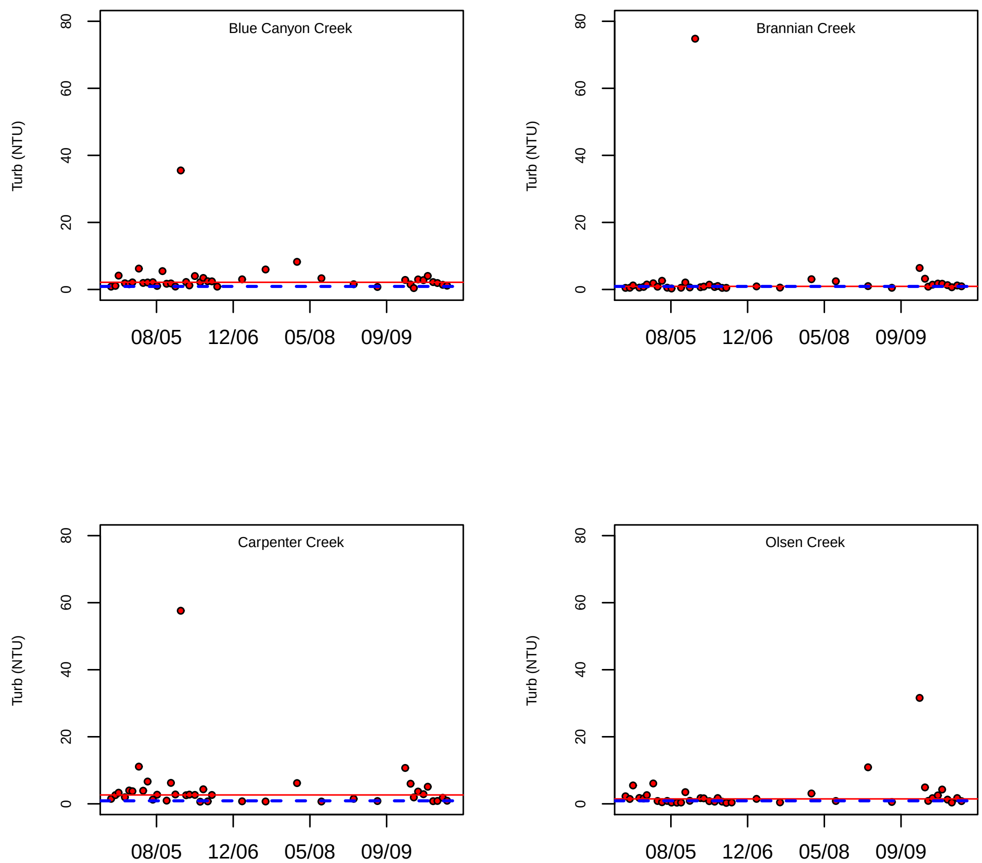


Figure B150: Turbidity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

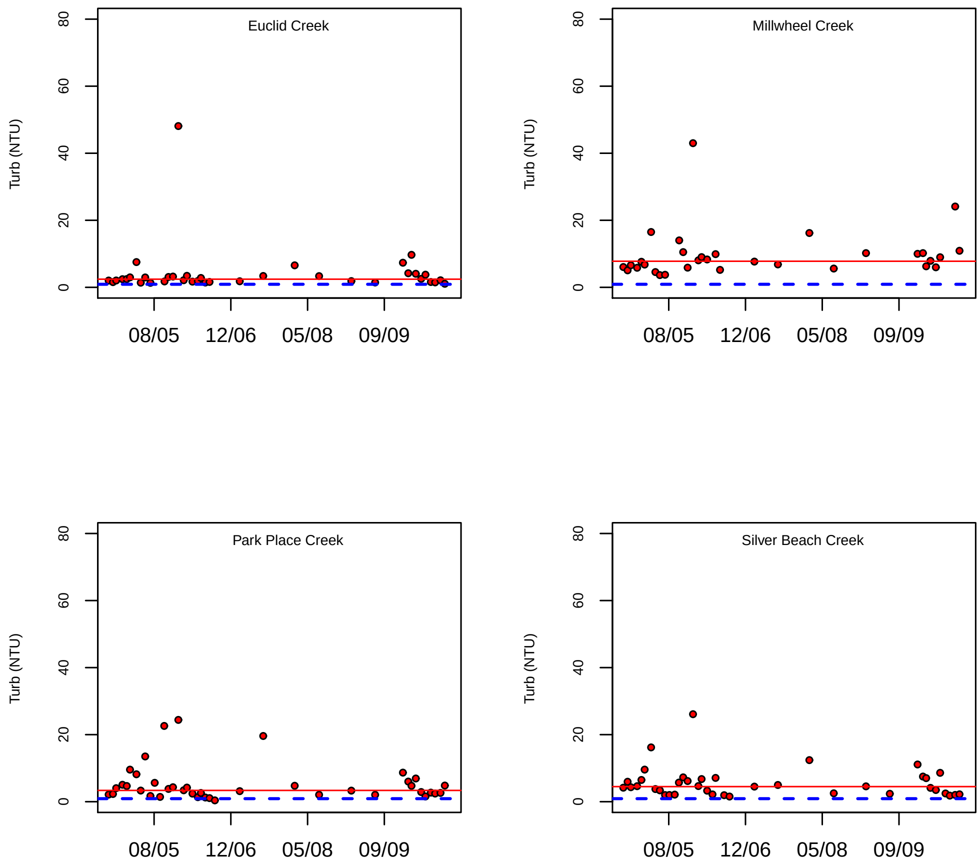


Figure B151: Turbidity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

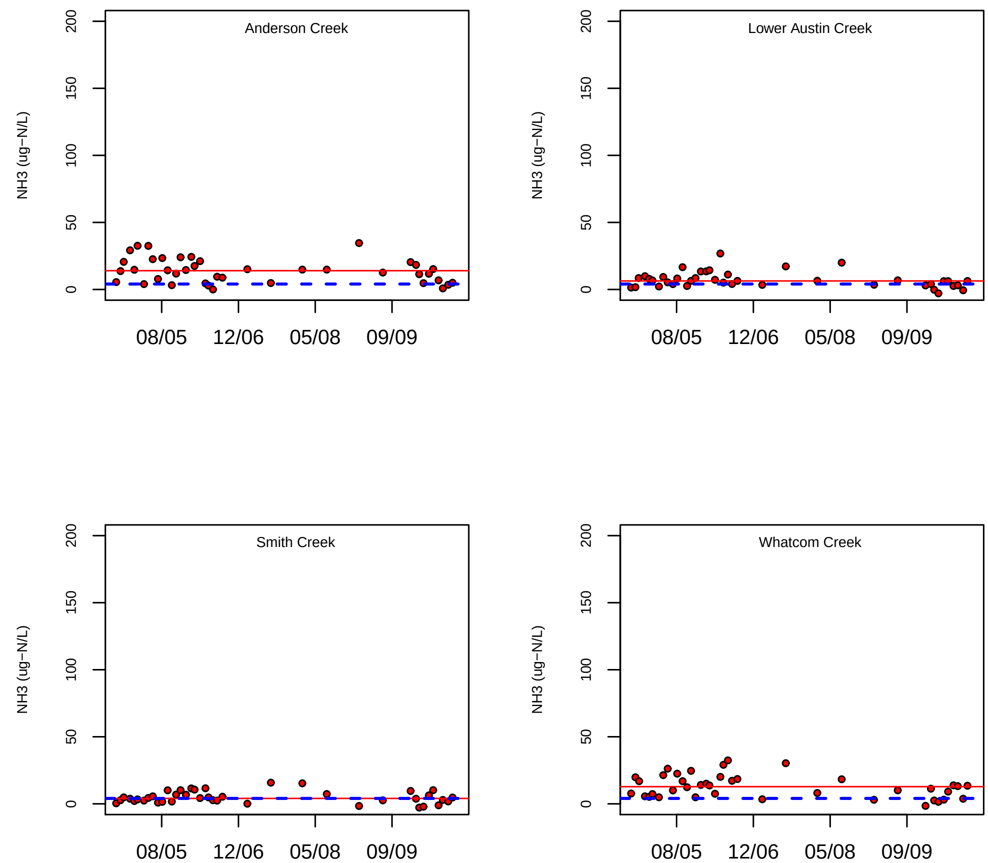


Figure B152: Ammonia data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

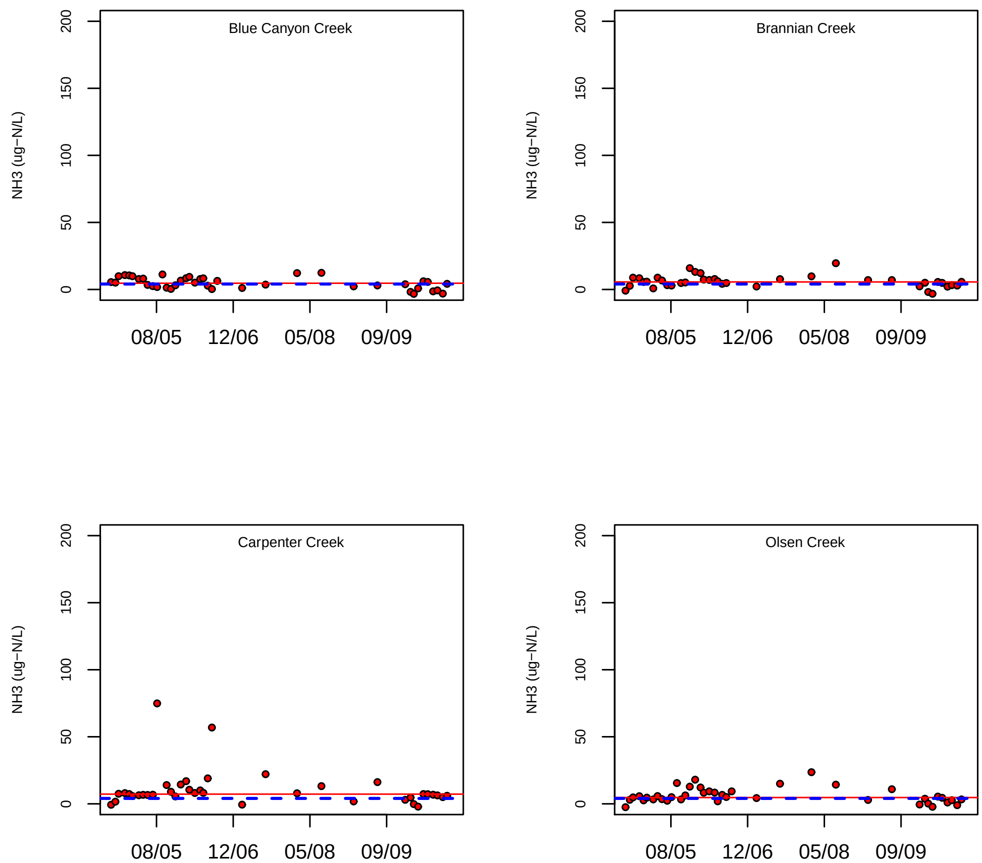


Figure B153: Ammonia data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

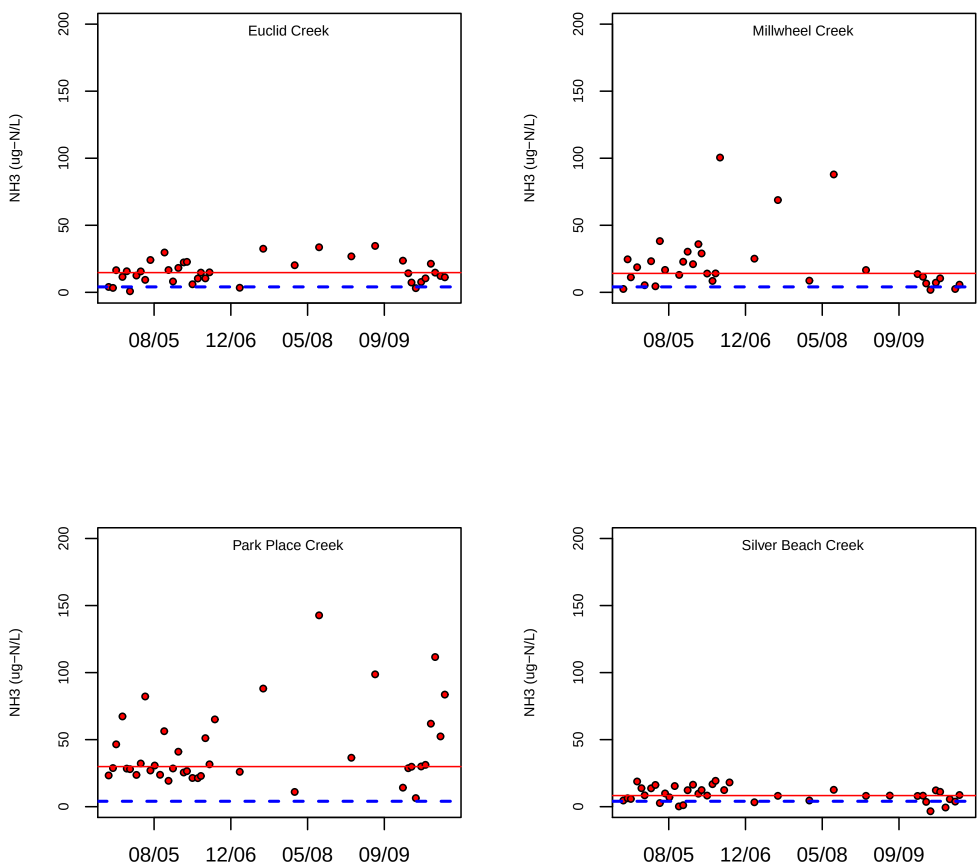


Figure B154: Ammonia data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

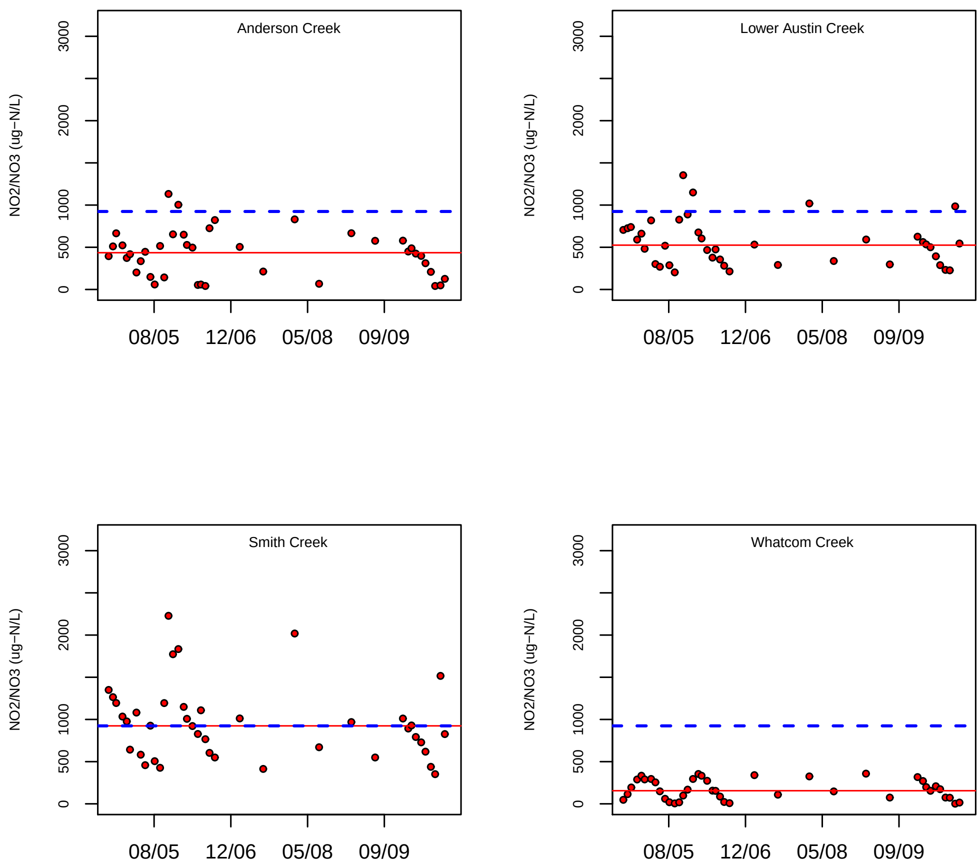


Figure B155: Nitrate/nitrite data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

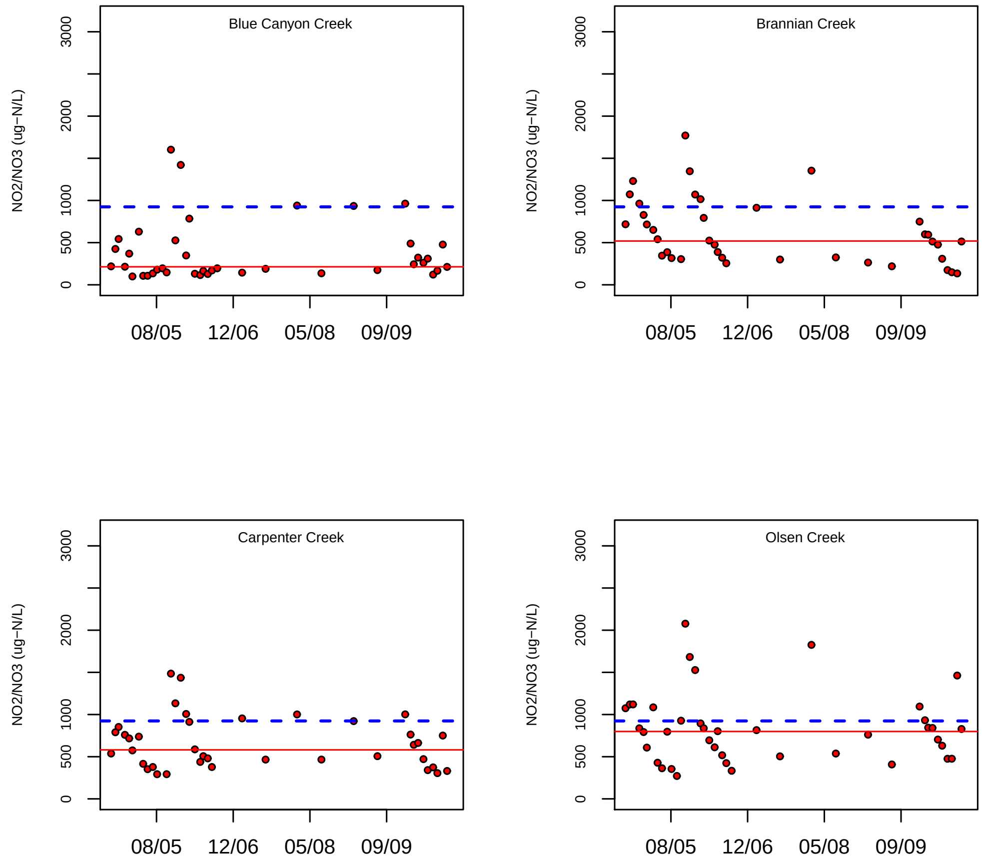


Figure B156: Nitrate/nitrite data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

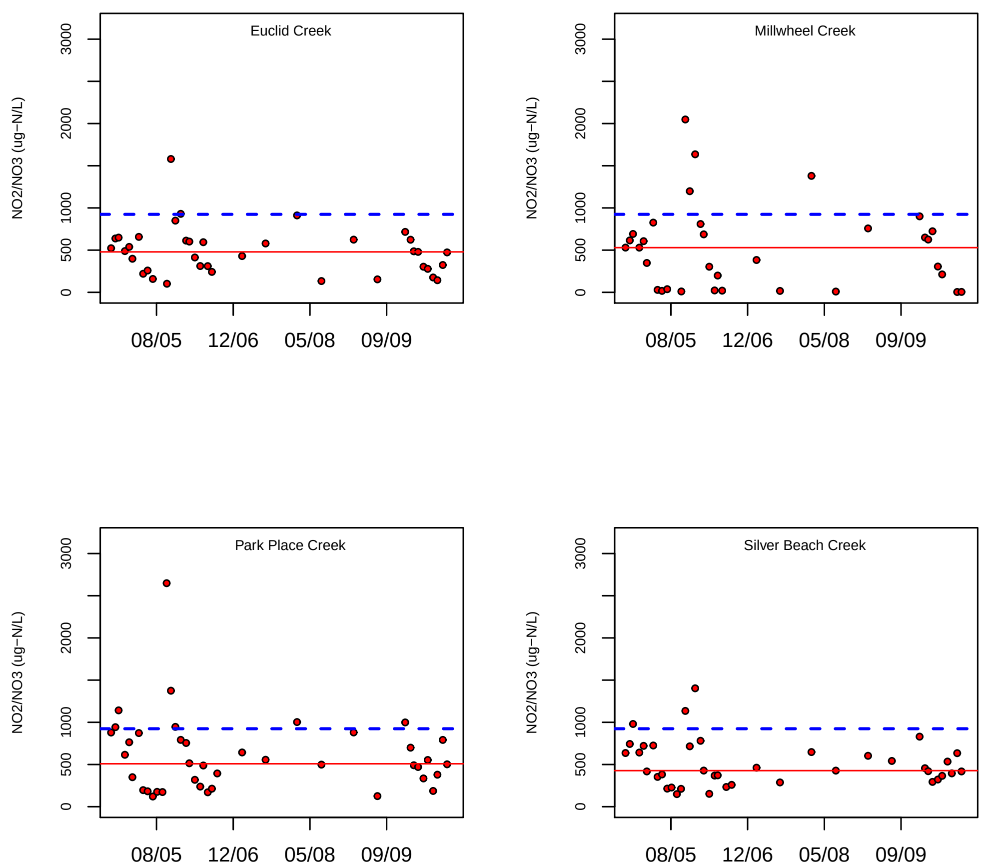


Figure B157: Nitrate/nitrite data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

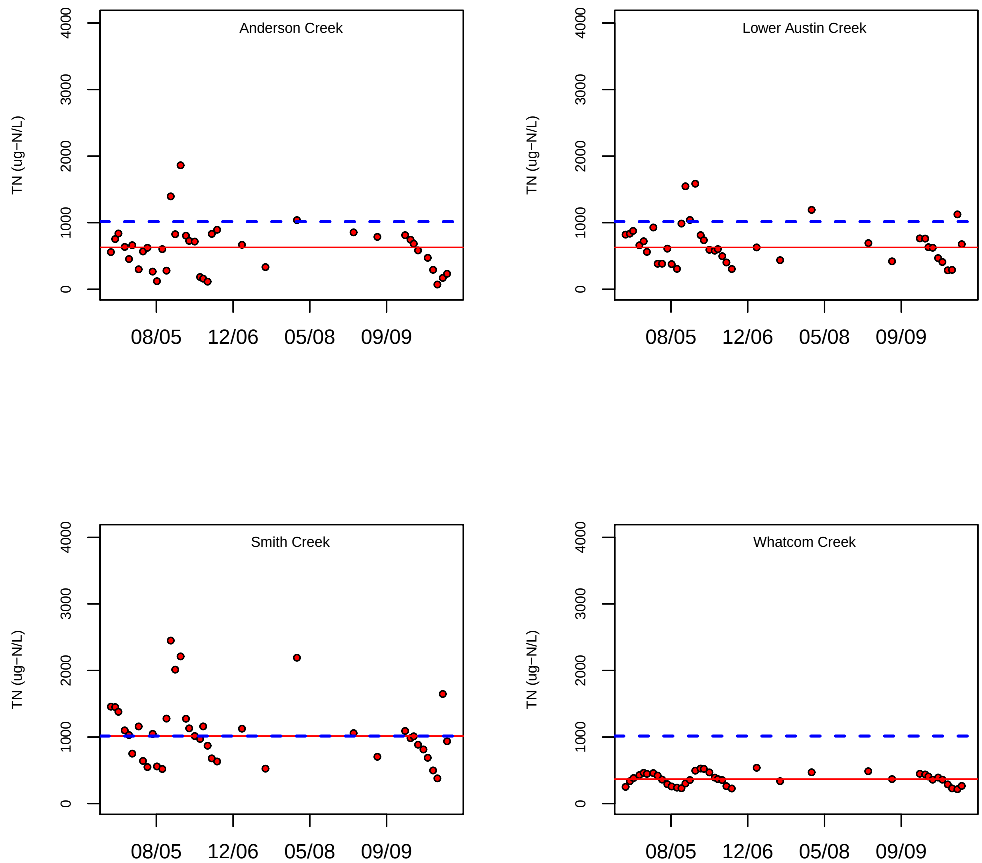


Figure B158: Total nitrogen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

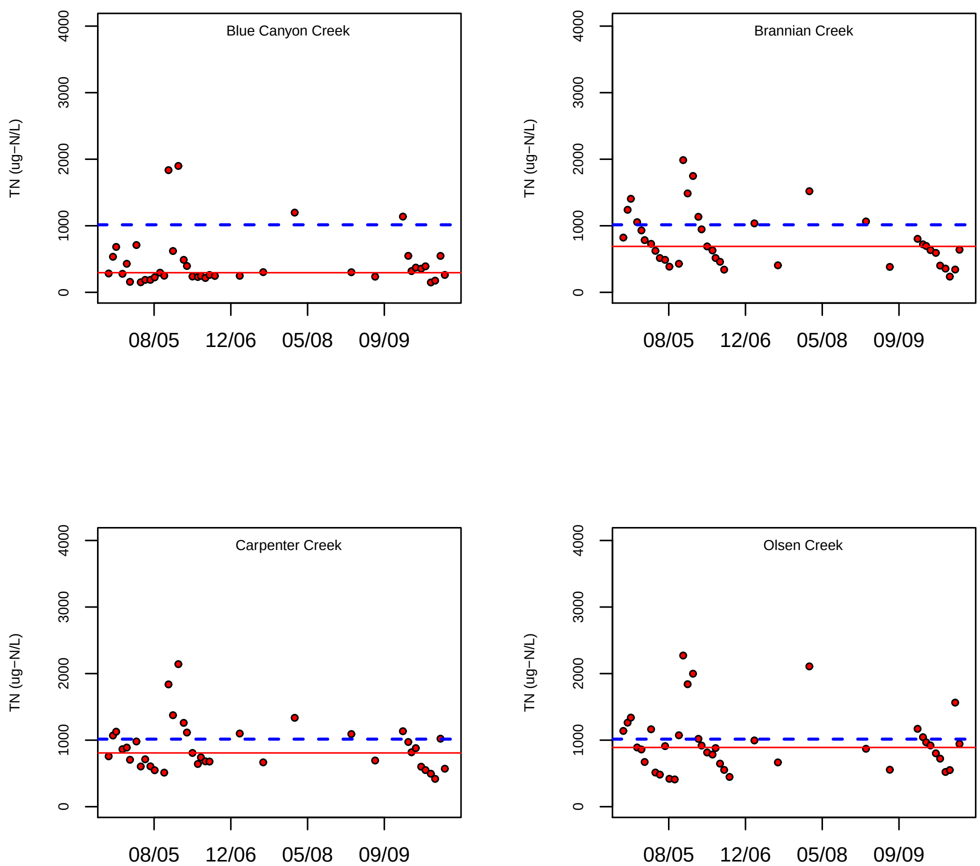


Figure B159: Total nitrogen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

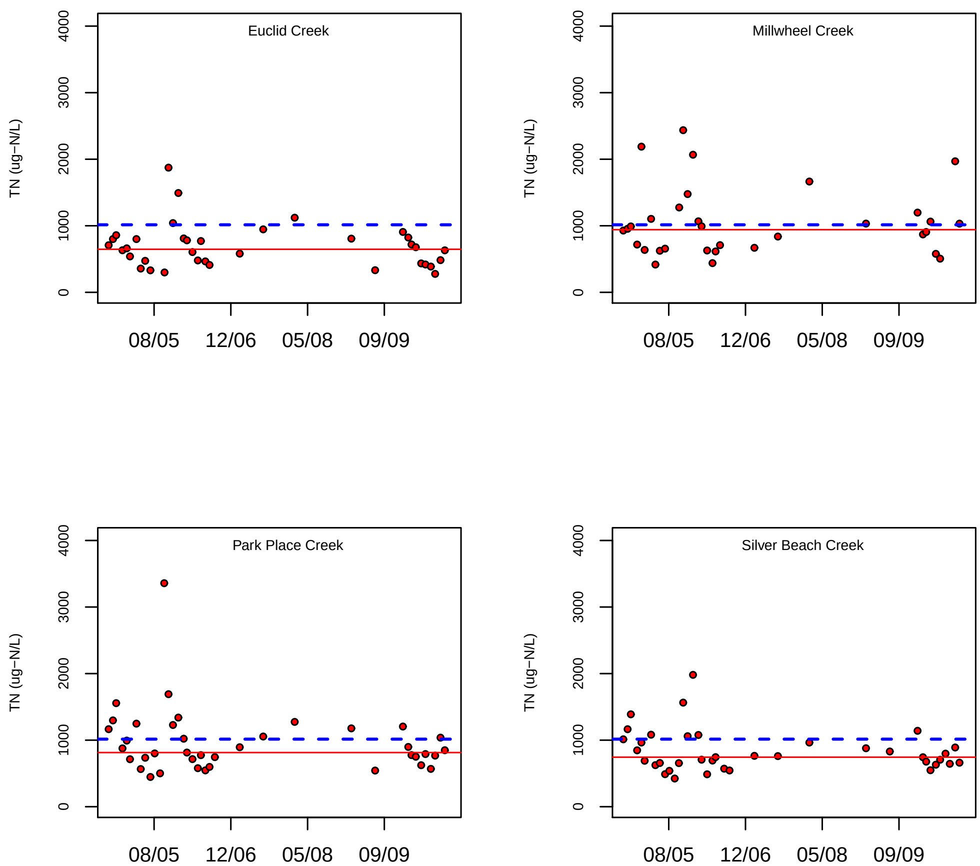


Figure B160: Total nitrogen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

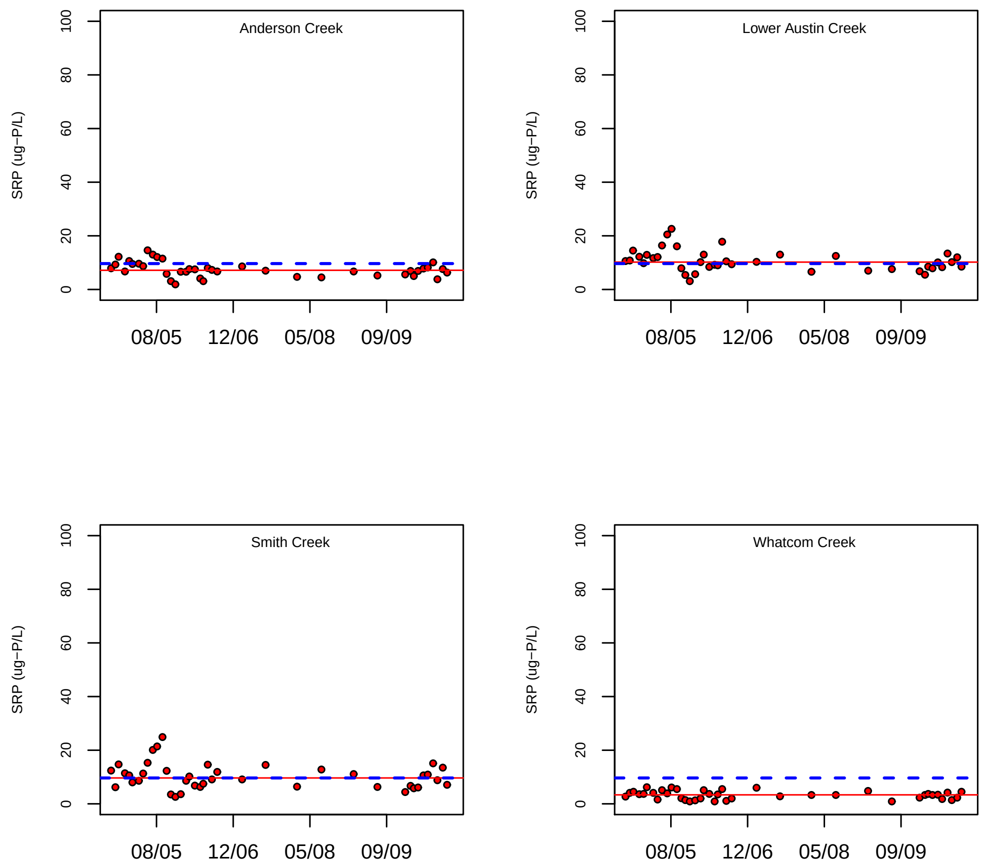


Figure B161: Soluble phosphate data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

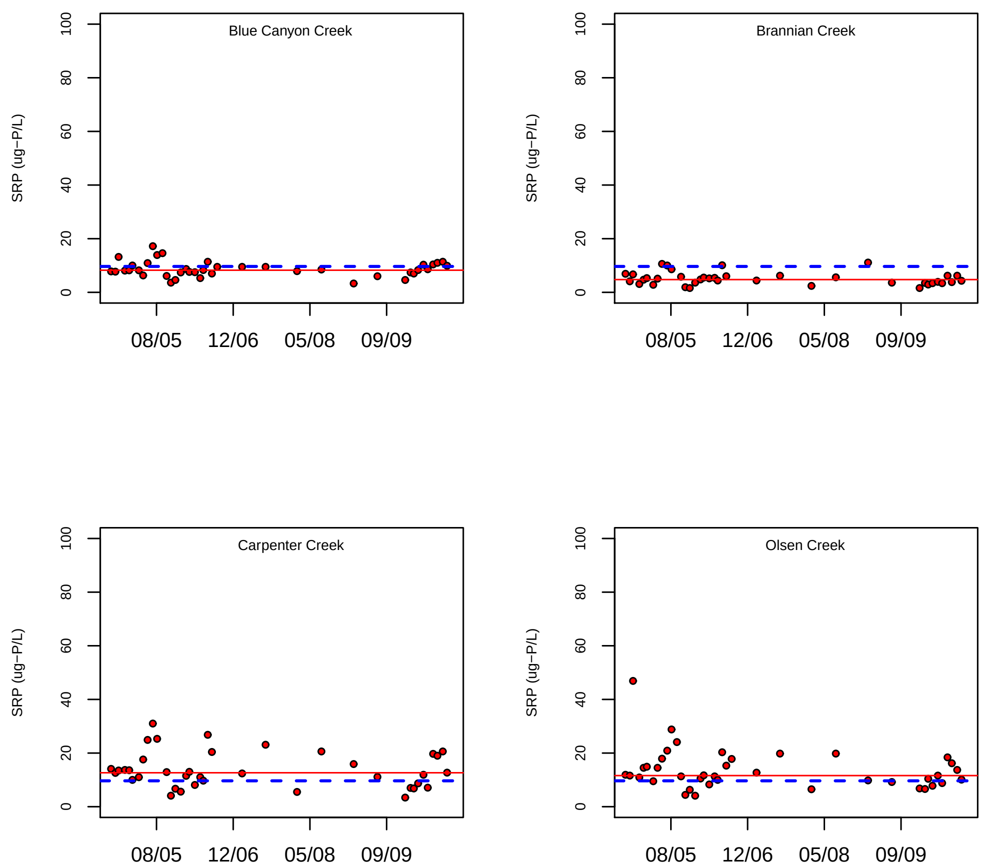


Figure B162: Soluble phosphate data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

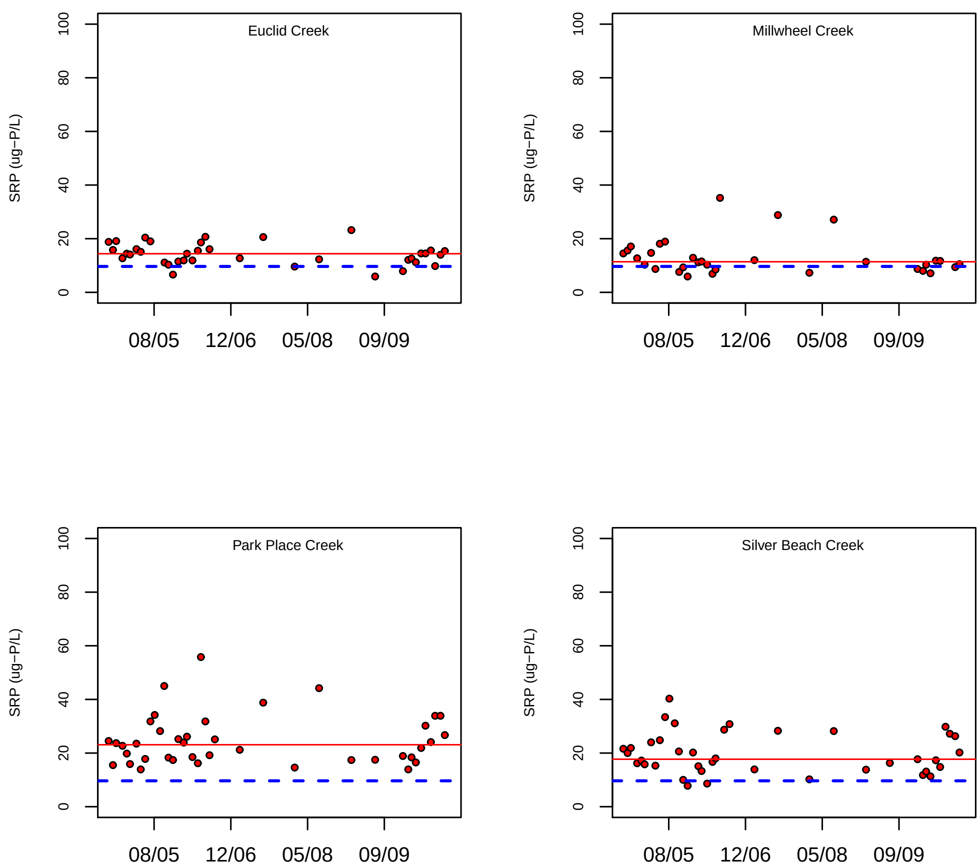


Figure B163: Soluble phosphate data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

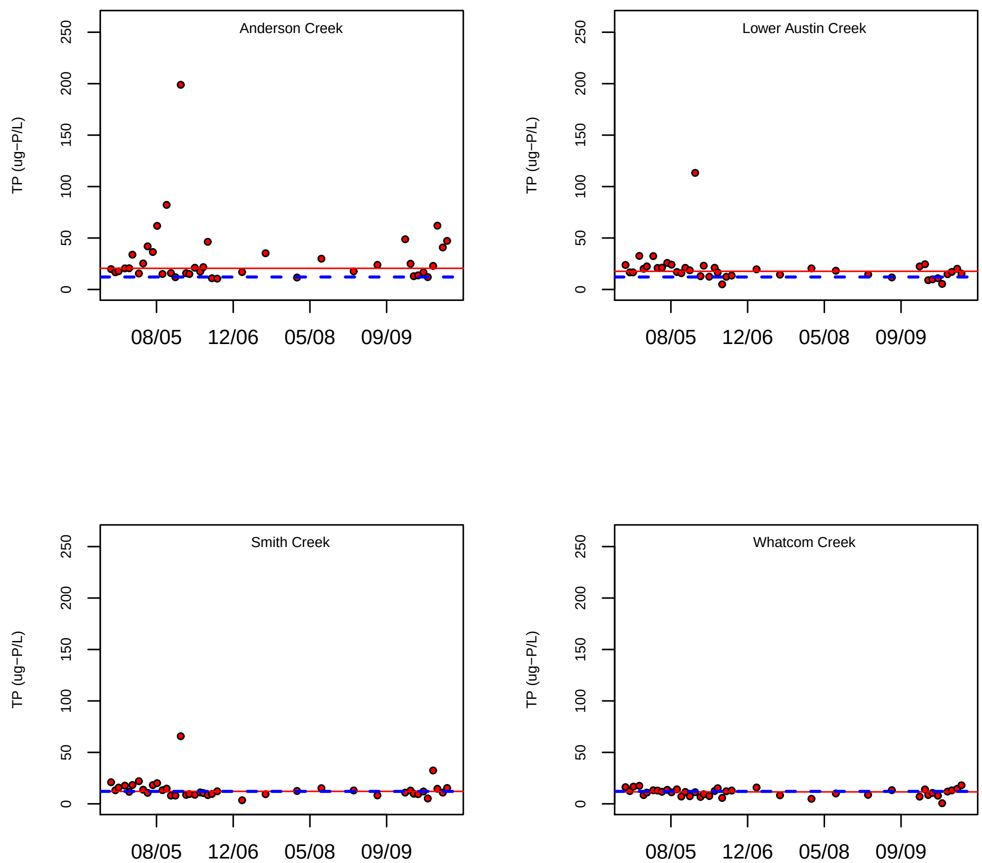


Figure B164: Total phosphorus data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

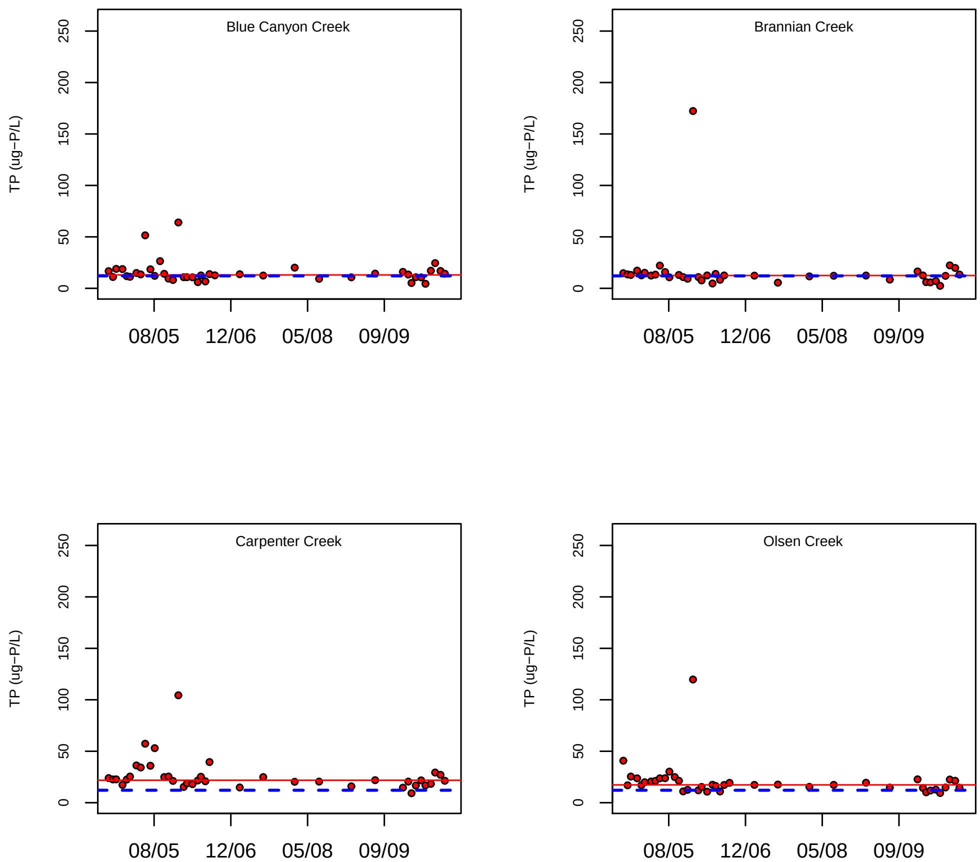


Figure B165: Total phosphorus data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

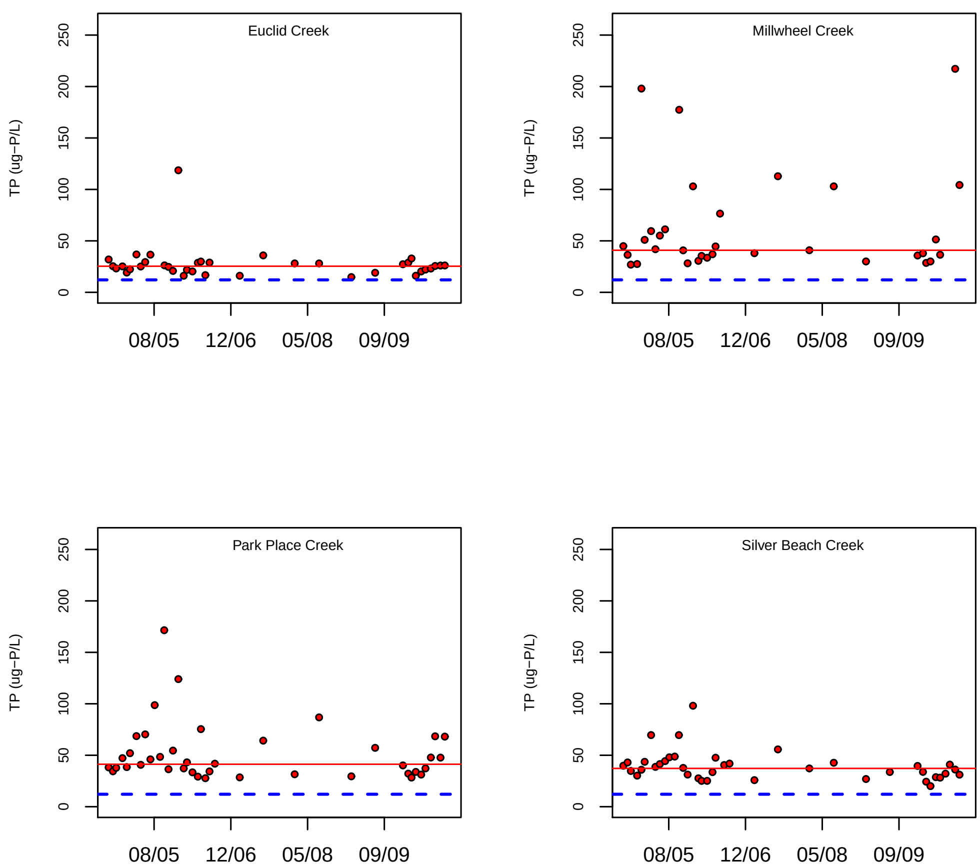


Figure B166: Total phosphorus data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

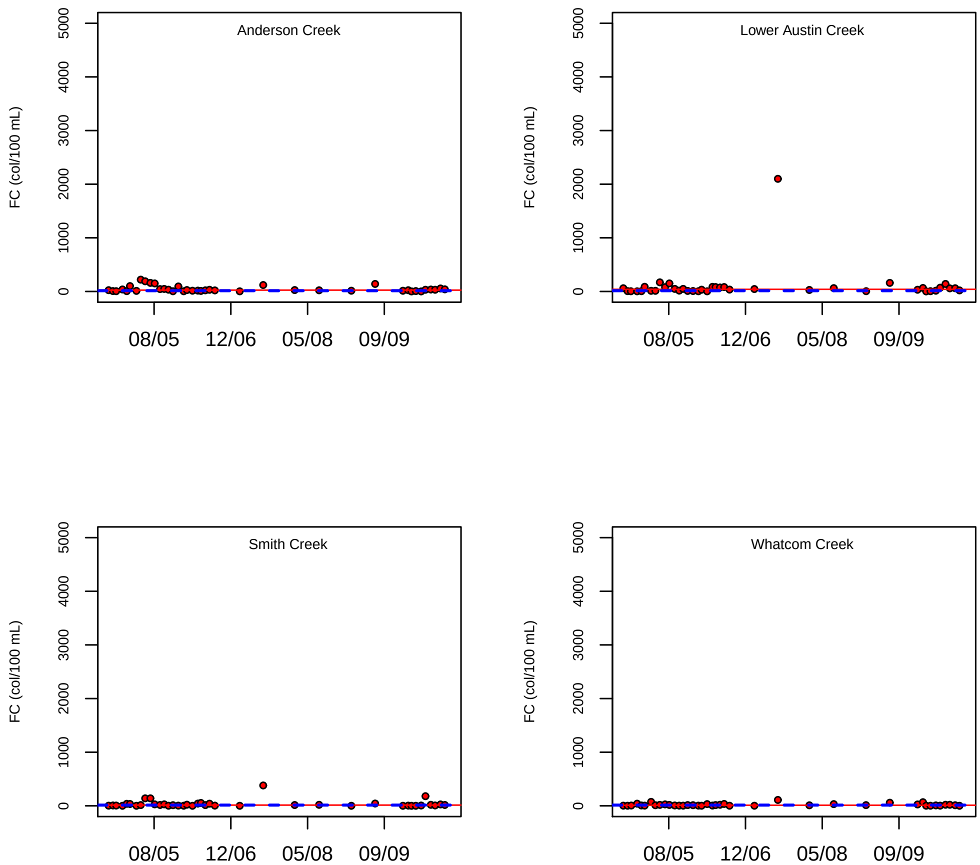


Figure B167: Fecal coliform data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

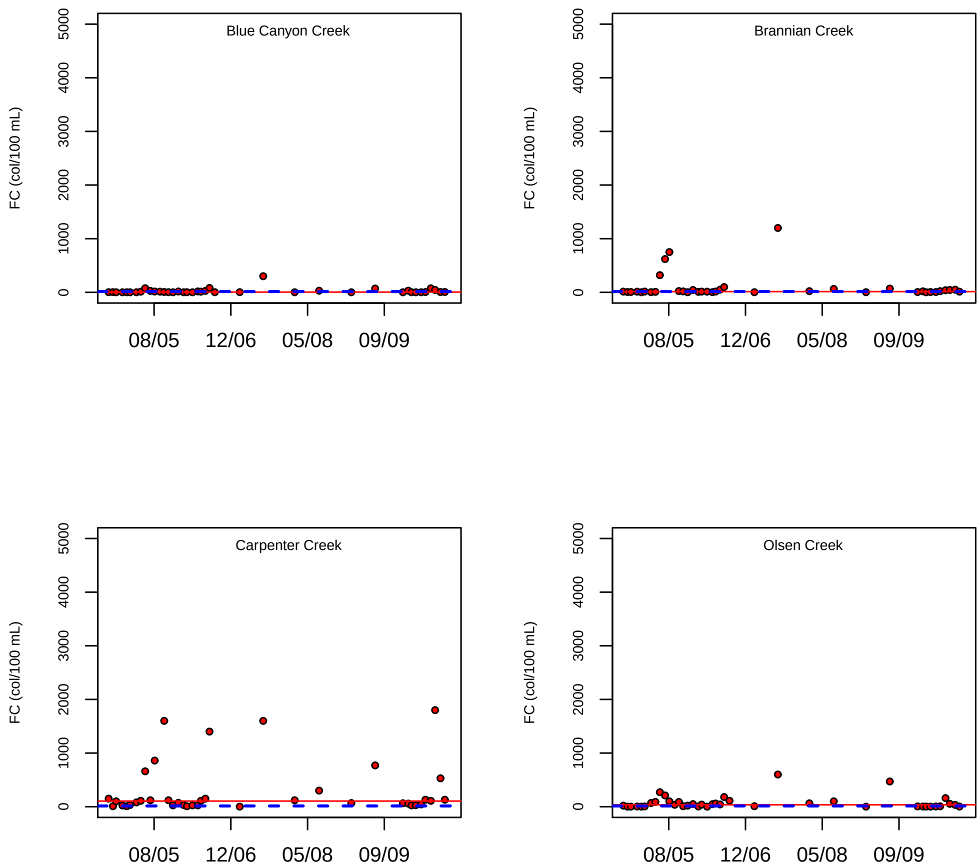


Figure B168: Fecal coliform data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

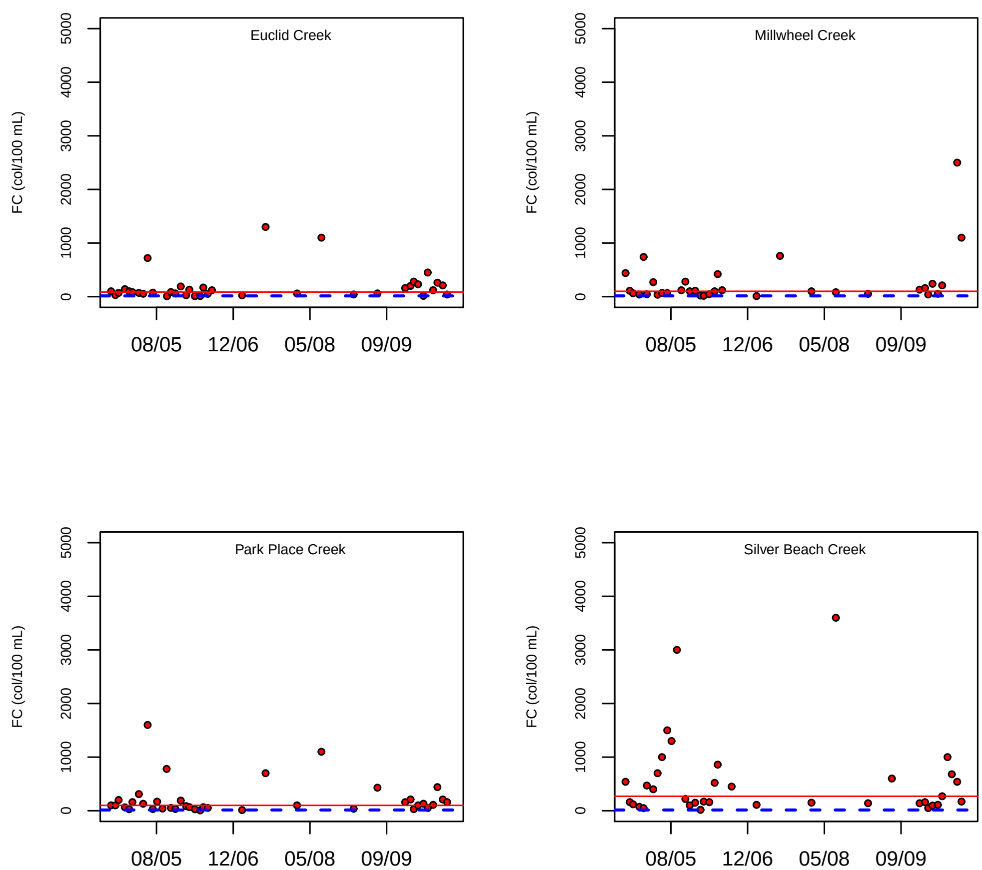


Figure B169: Fecal coliform data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

C Quality Control

C.1 Performance Evaluation 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 18). 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)	438	436	391–481	accept
Total alkalinity (mg/L as $CaCO_3$)	76.2	77.3	68.1–85.6	accept
Ammonia nitrogen, manual (mg-N/L)	11.1	11.0	8.15–13.7	accept
Ammonia nitrogen, autoanalysis (mg-N/L)	10.2	11.0	8.15–13.7	accept
Nitrate nitrogen, autoanalysis (mg-N/L)	21.2	21.4	17.4–24.9	accept
Nitrite nitrogen, autoanalysis (mg-N/L)	2.75	2.70	2.29–3.11	accept
Orthophosphate, manual (mg-P/L)	2.81	2.74	2.23–3.27	accept
Orthophosphate, autoanalysis (mg-P/L)	2.79	2.74	2.23–3.27	accept
Total phosphorus, manual (mg-P/L)	2.12	2.28	1.83–2.78	accept
Total phosphorus, autoanalysis (mg-P/L)	2.18	2.28	1.83–2.78	accept
pH	6.49	6.50	6.30–6.70	accept
Solids, non-filterable (mg/L)	24.8	28.3	19.6–34.2	accept
Turbidity (NTU)	4.85	4.85	3.98–5.66	accept

Table C1: Single-blind quality control results, WP–154 (10/20/2009).

	Reported Value†	True Value†	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	375	370	330–410	accept
Total alkalinity (mg/L as $CaCO_3$)	62.5	63.0	55.1–70.6	accept
Ammonia nitrogen, manual (mg-N/L)	9.11	9.16	6.77–11.5	accept
Ammonia nitrogen, autoanalysis (mg-N/L)	10.6	9.16	6.77–11.5	accept
Nitrate nitrogen, autoanalysis (mg-N/L)	6.96	6.95	5.66–8.09	accept
Nitrite nitrogen, autoanalysis (mg-N/L)	0.750	0.740	0.576–0.896	accept
Orthophosphate, manual (mg-P/L)	1.28	1.24	0.969–1.53	accept
Orthophosphate, autoanalysis (mg-P/L)	1.25	1.24	0.969–1.53	accept
Total phosphorus, manual (mg-P/L)	3.48	3.60	2.96–4.32	accept
Total phosphorus, autoanalysis (mg-P/L)	3.74	3.60	2.93–4.32	accept
pH	6.89	6.90	6.70–7.10	accept
Solids, non-filterable (mg/L)	38.0	42.1	31.8–48.8	accept
Turbidity (NTU)	13.4	14.3	12.2–16.0	accept

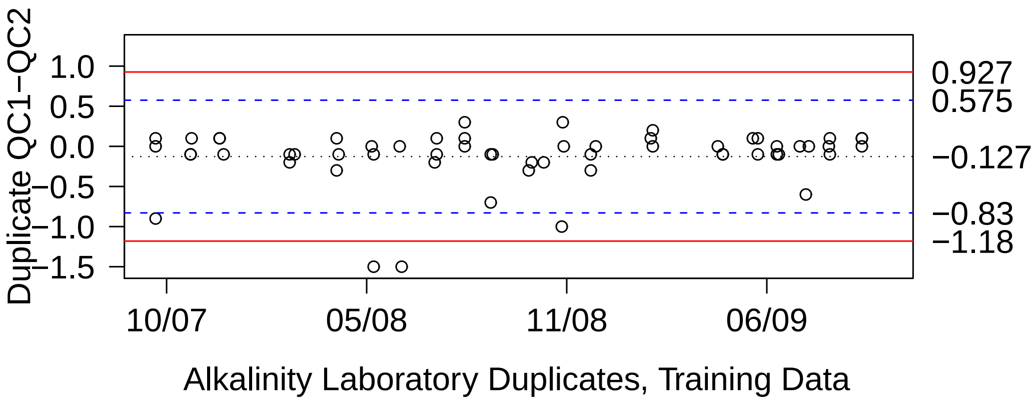
Table C2: Single-blind quality control results, WP–160 (3/3/2010).

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.[22]

The quality control results for laboratory duplicates, matrix spikes, and check standards are plotted in control charts. Upper and lower acceptance limits (± 2 std. dev. from mean pair difference) and upper and lower warning limits (± 3 std. dev. from mean pair difference) were developed using data from September 2006 through September 2009 (upper examples in Figures C1–C24, pages 299–322), and used to evaluate data from October 2009 through September 2010 (lower examples in Figures C1–C24).

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



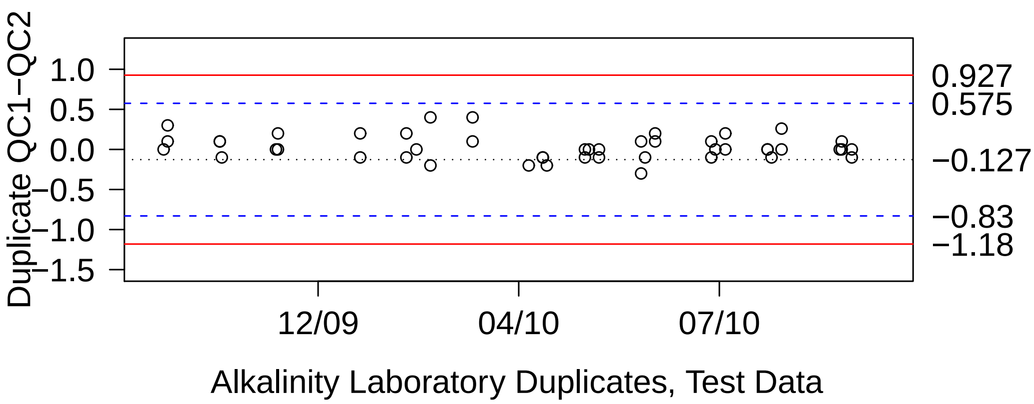
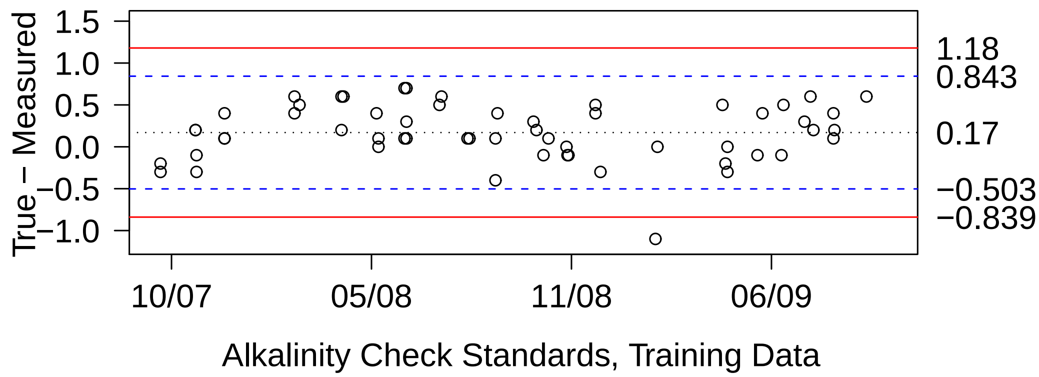


Figure C1: Alkalinity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



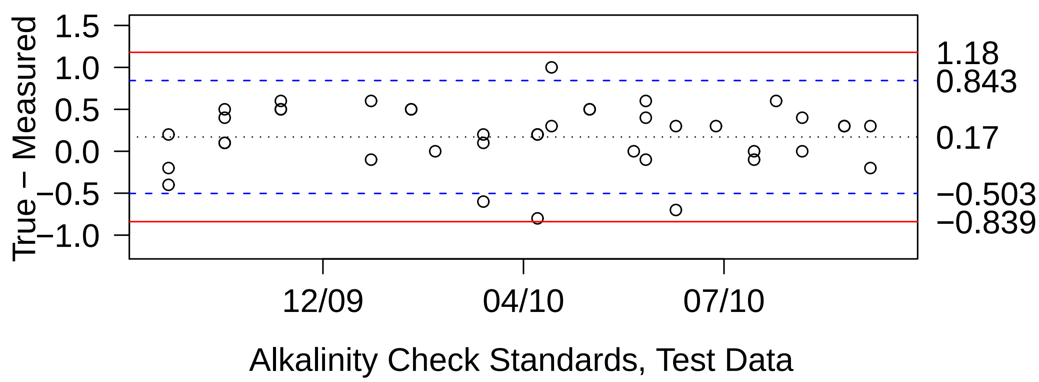


Figure C2: Alkalinity check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

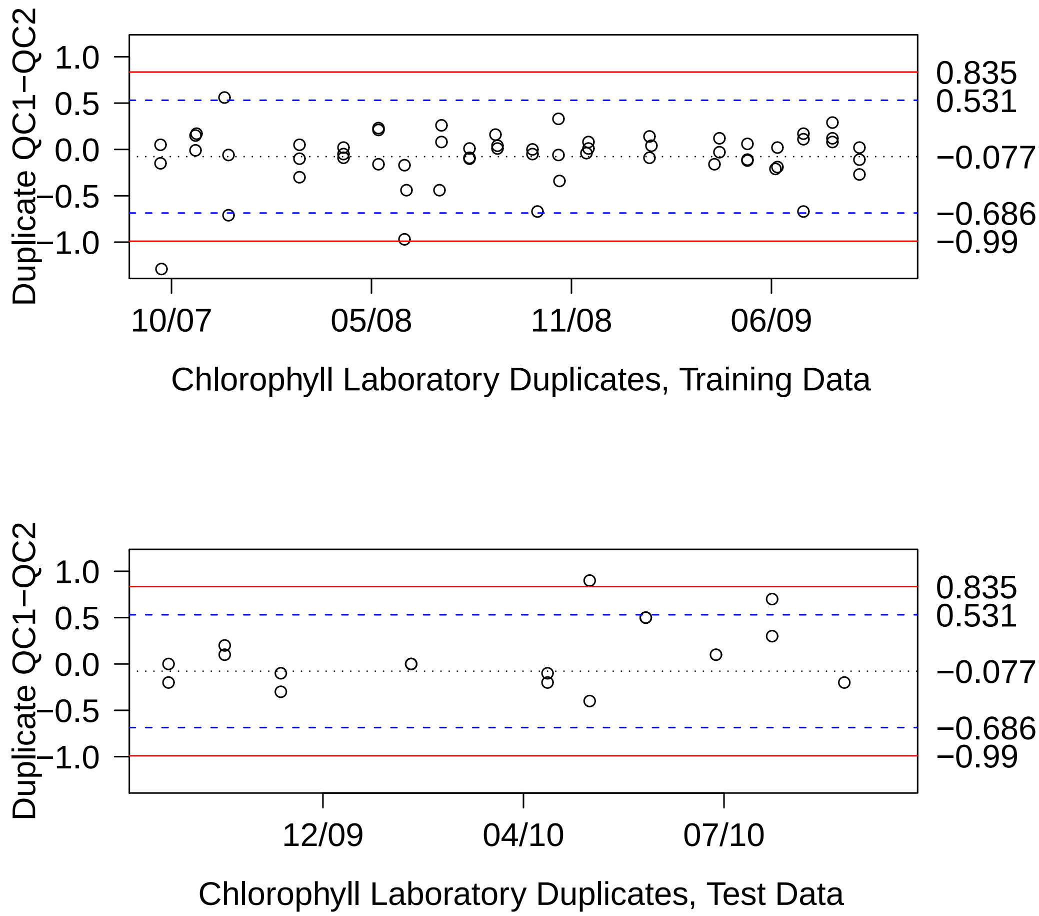
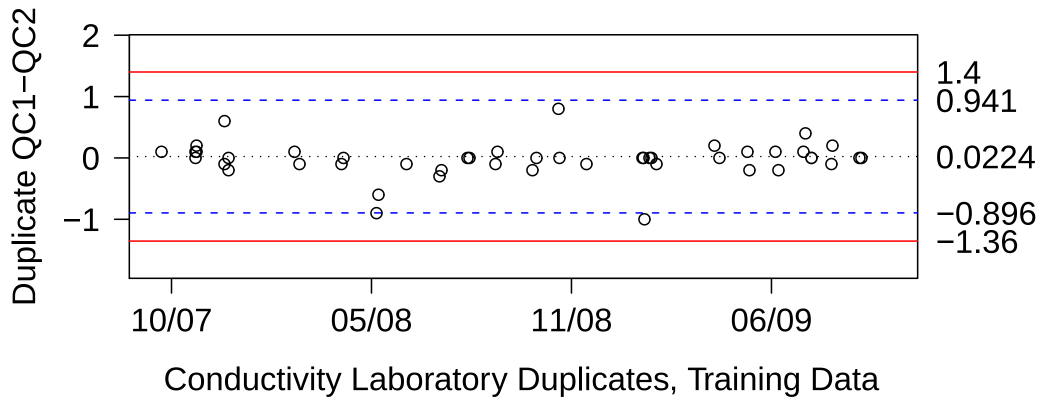


Figure C3: Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program (lake samples). Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



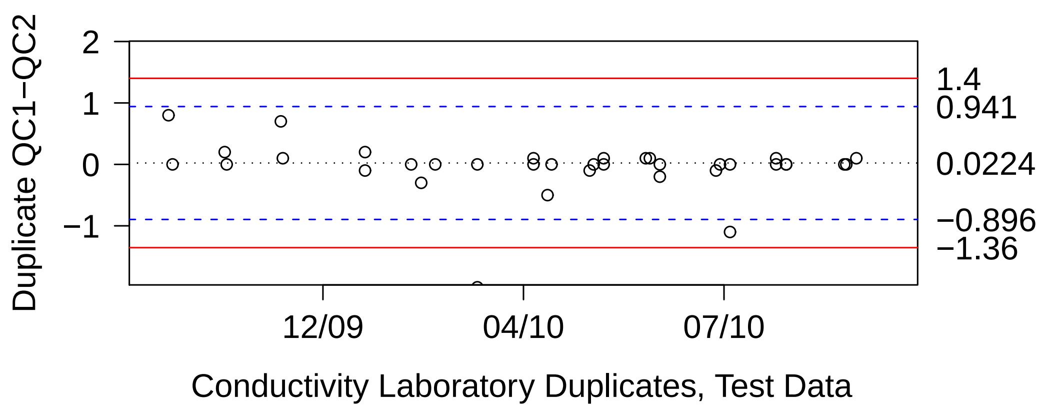
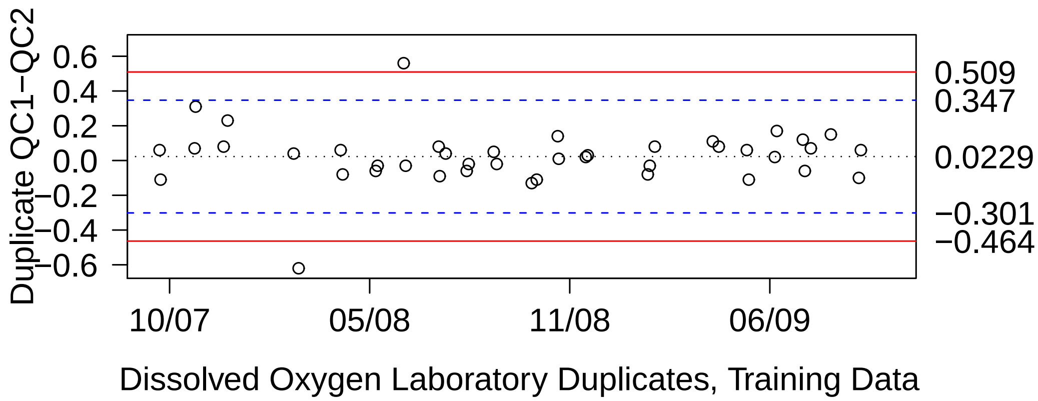


Figure C4: Conductivity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



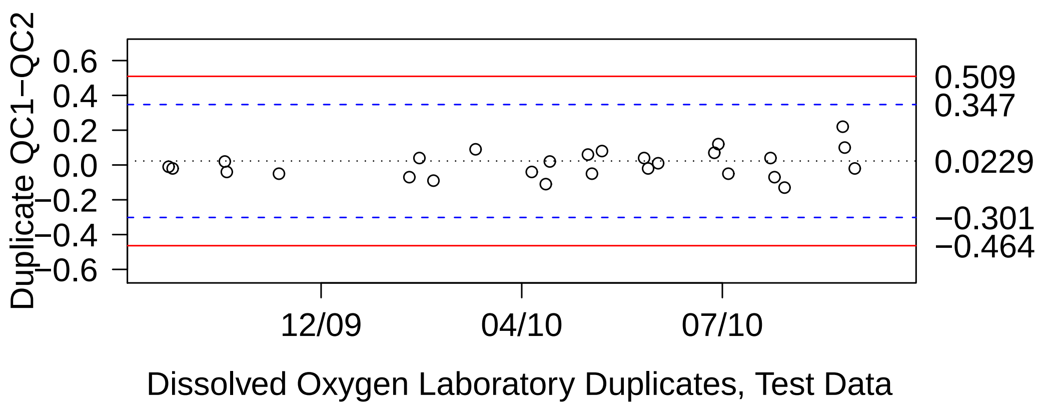
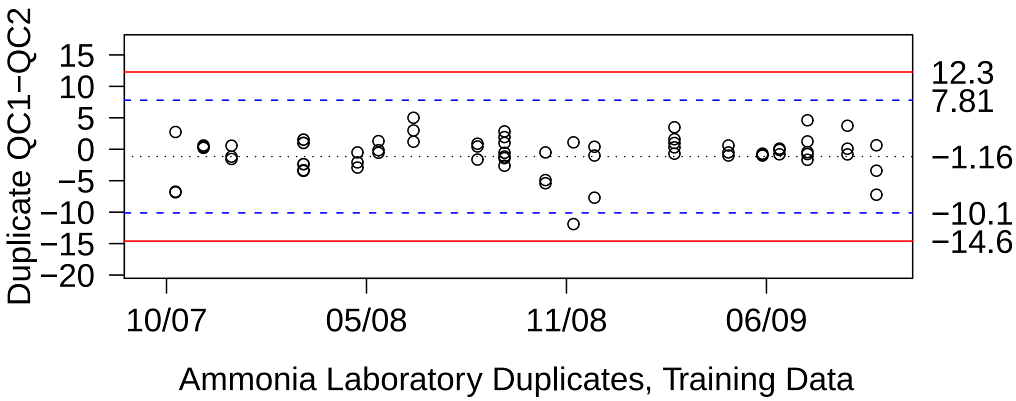


Figure C5: Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



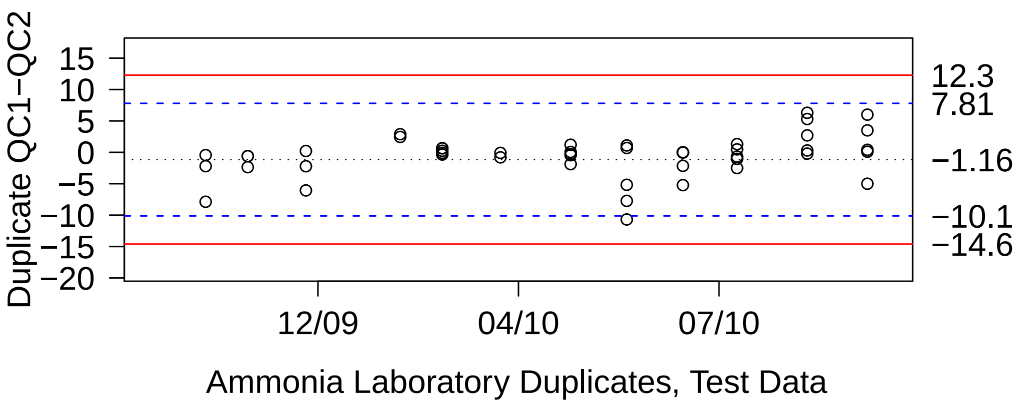
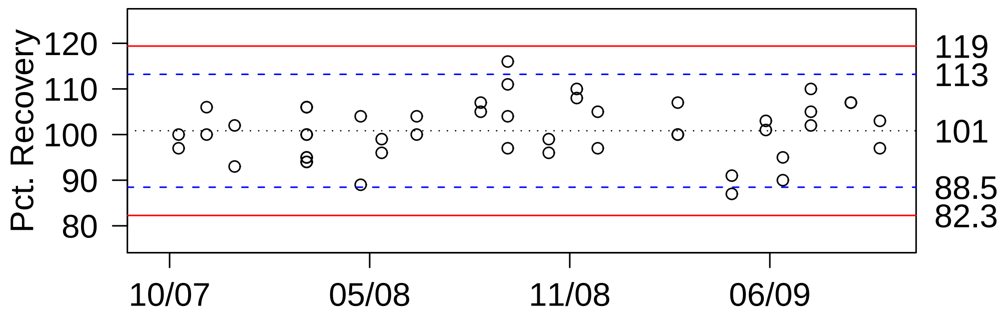
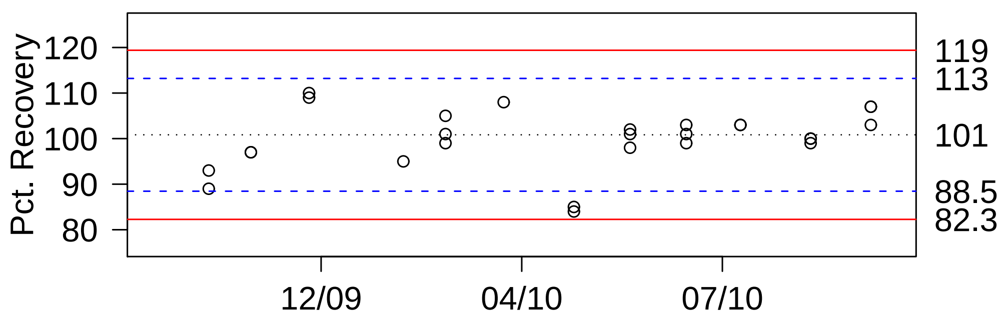


Figure C6: Ammonia laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



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

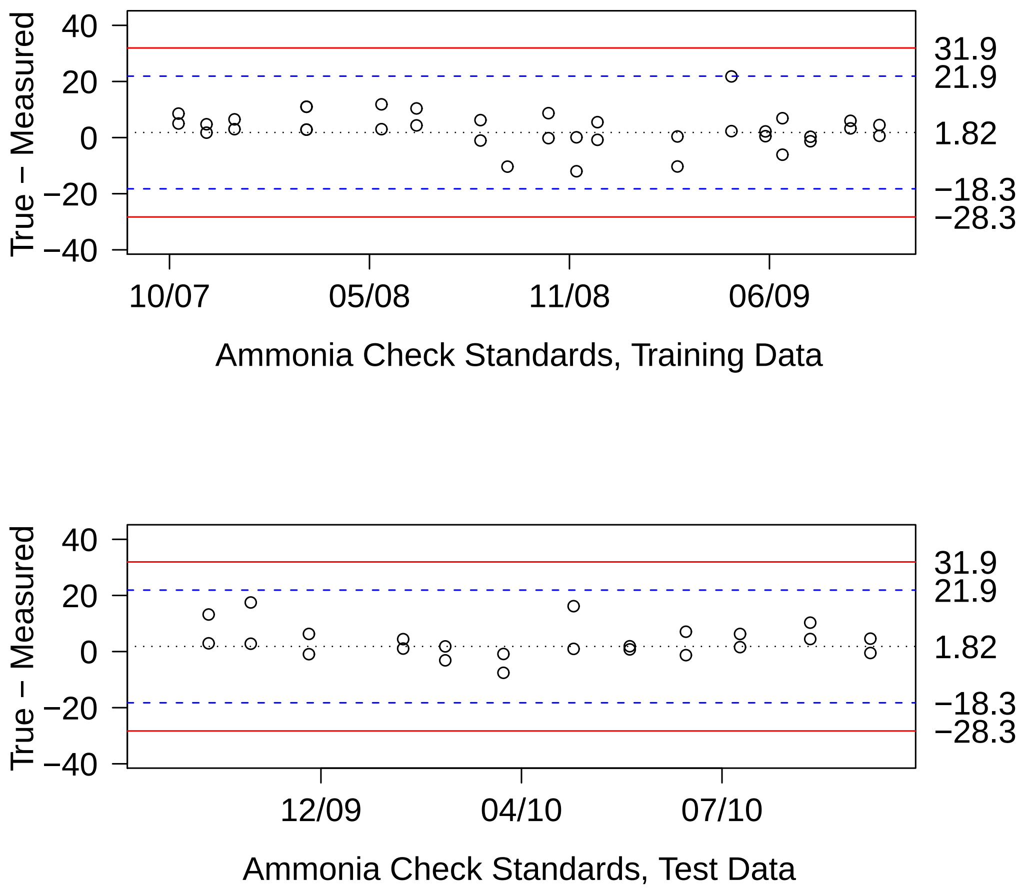
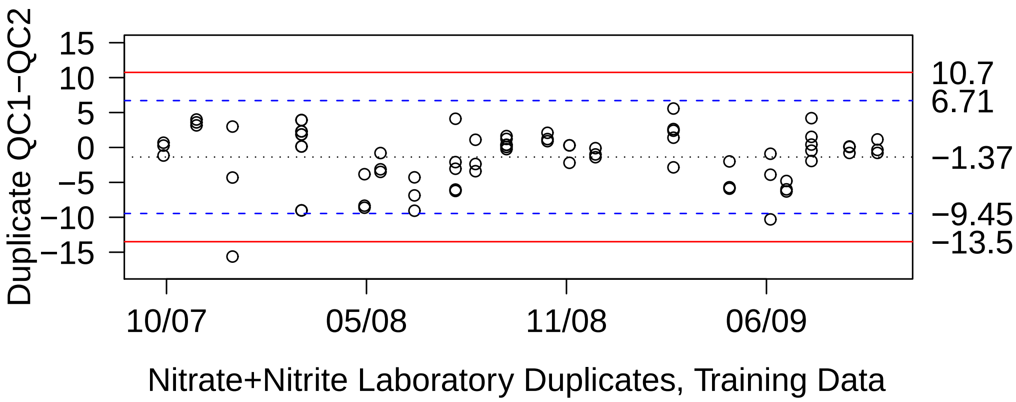


Figure C8: Ammonia check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



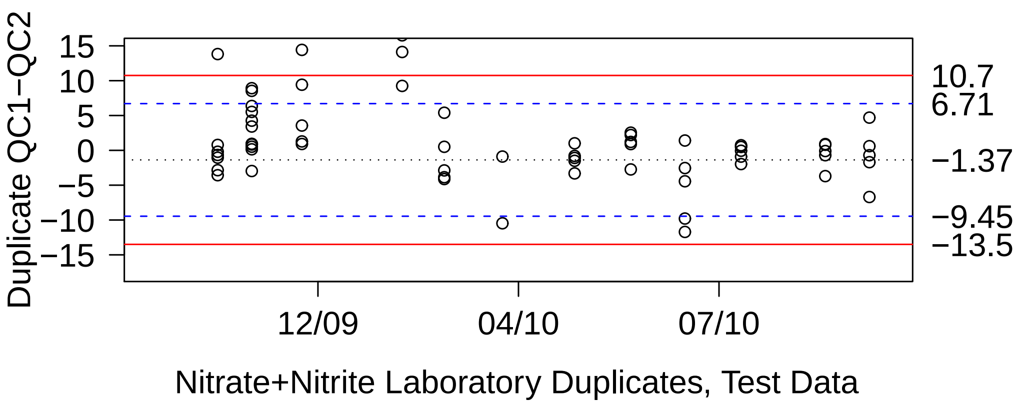
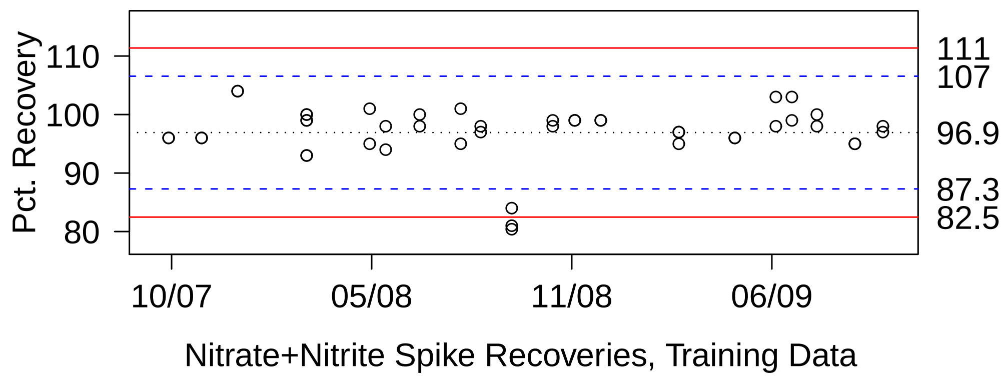


Figure C9: Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data. Increased variability was noted in February 2009; instrument repaired in March 2009.



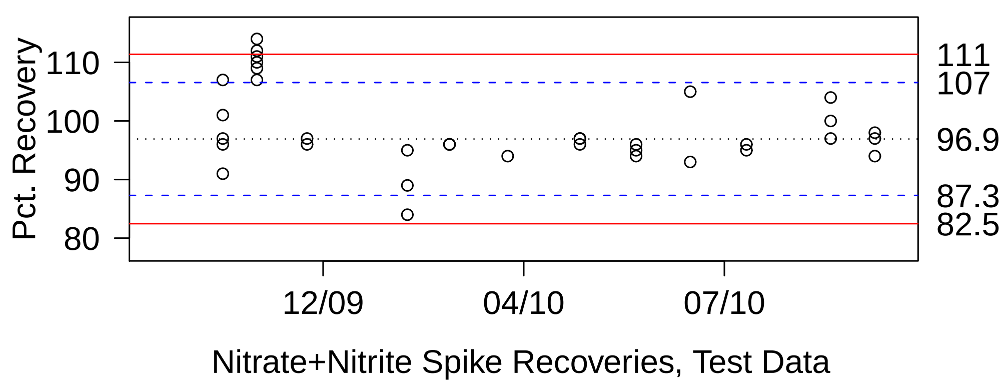


Figure C10: Nitrate/nitrite matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

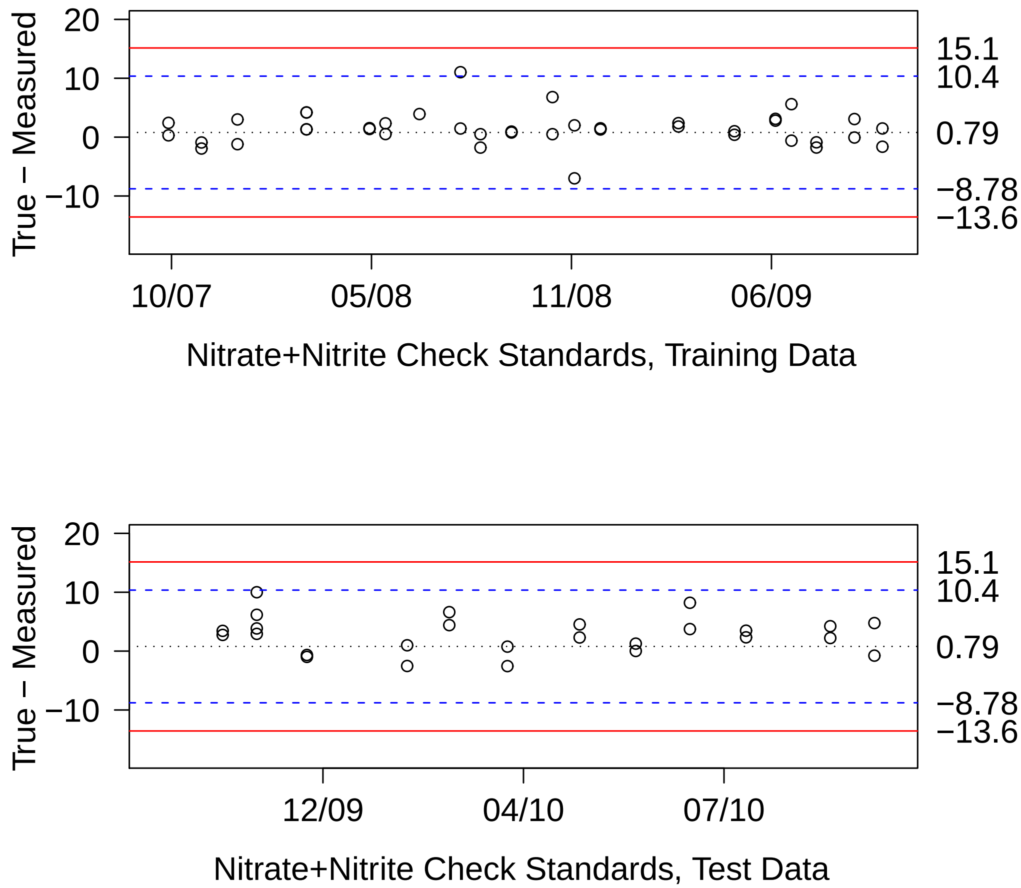
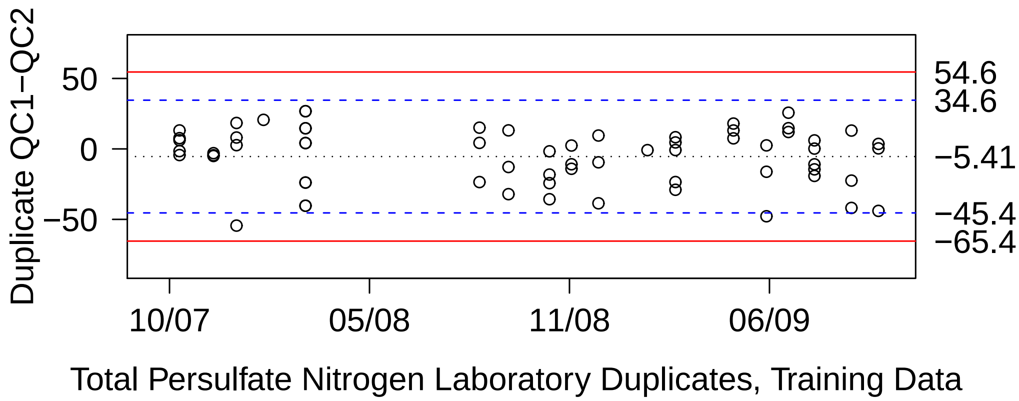


Figure C11: Nitrate/nitrite check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



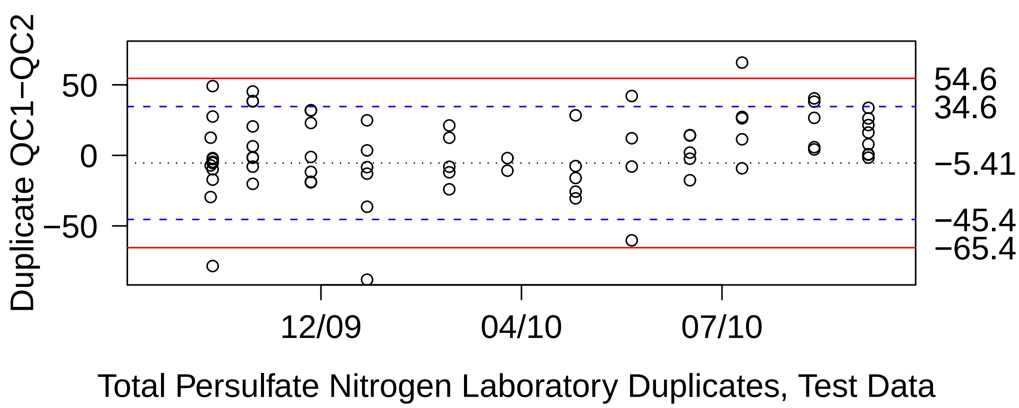
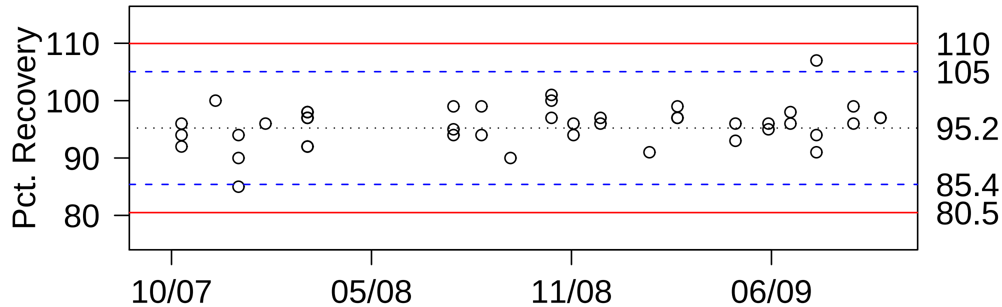
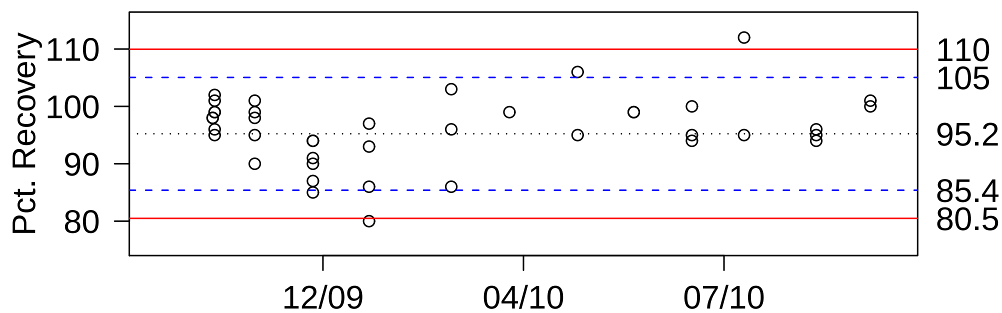


Figure C12: Total nitrogen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

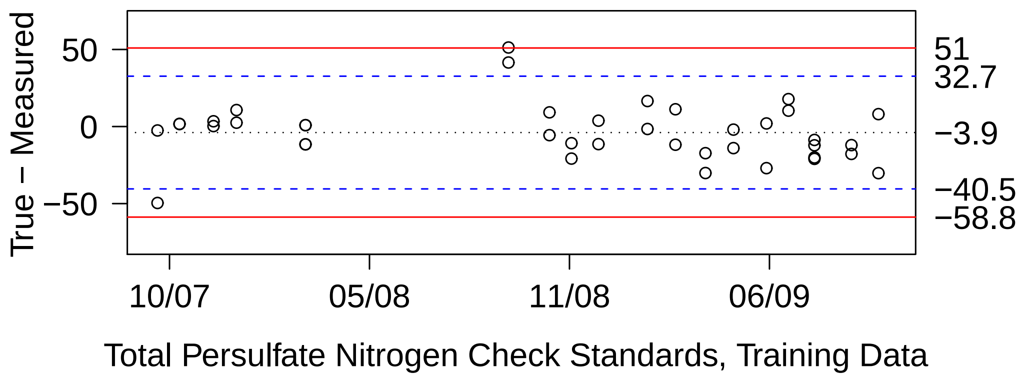


Total Persulfate Nitrogen Spike Recoveries, Training Data



Total Persulfate Nitrogen Spike Recoveries, Test 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.



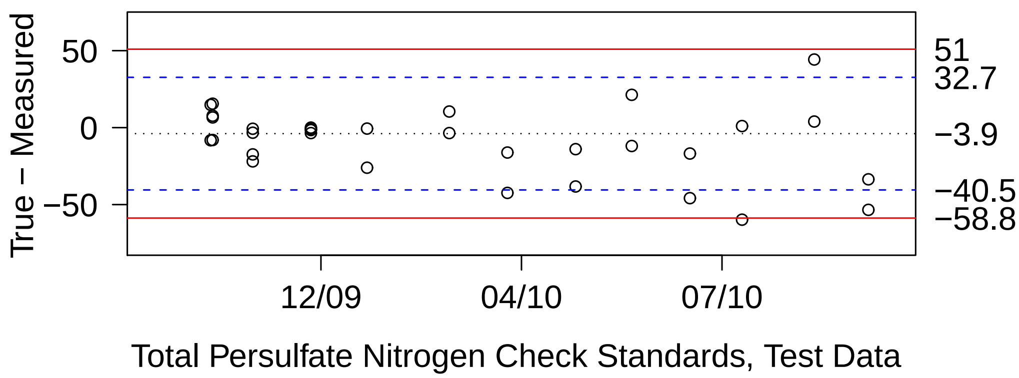
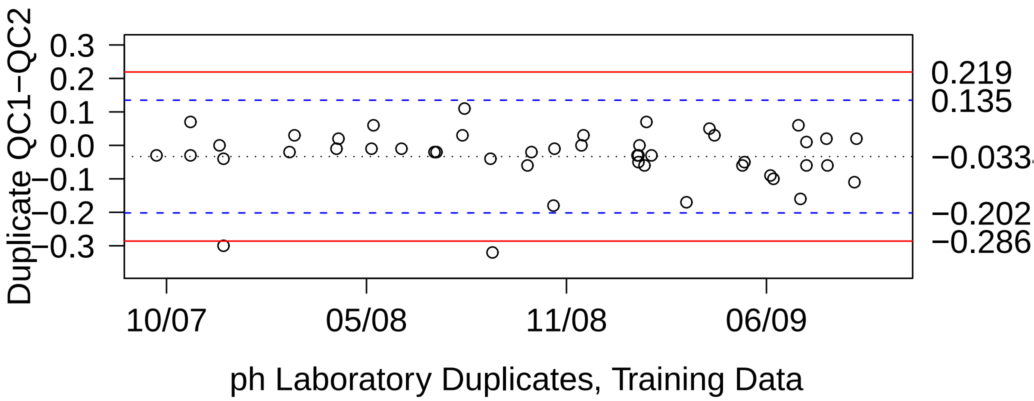


Figure C14: Total nitrogen check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



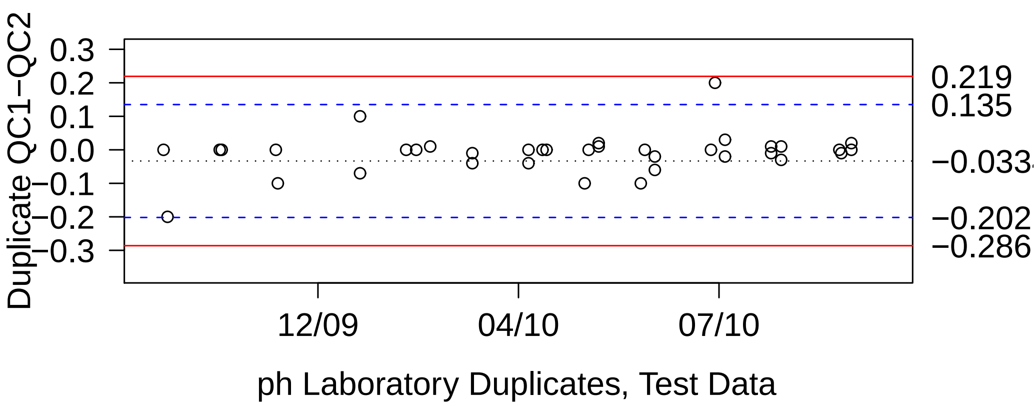
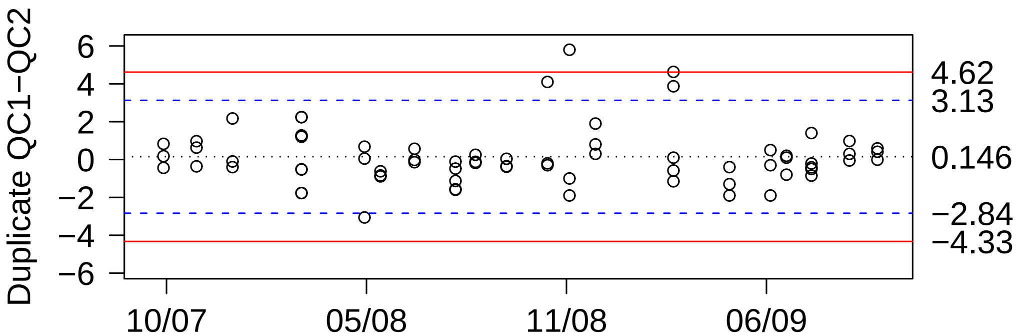
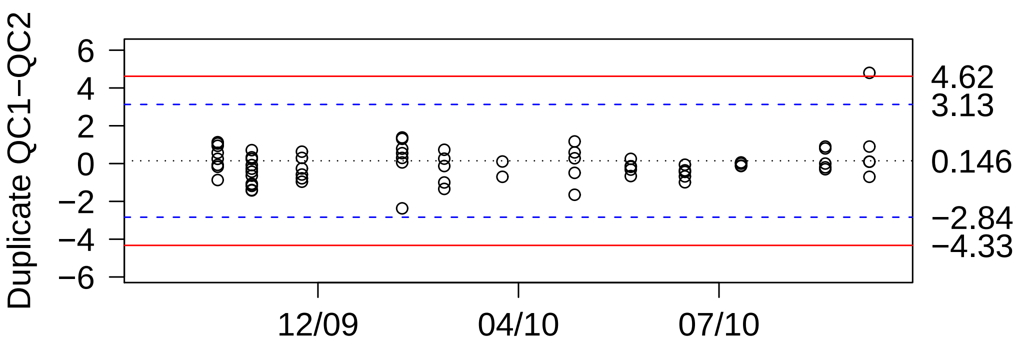


Figure C15: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

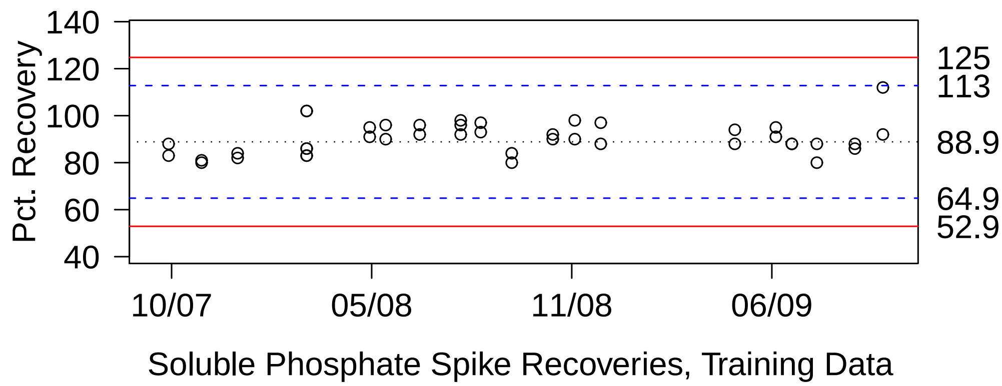


Soluble Phosphate Laboratory Duplicates, Training Data



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.



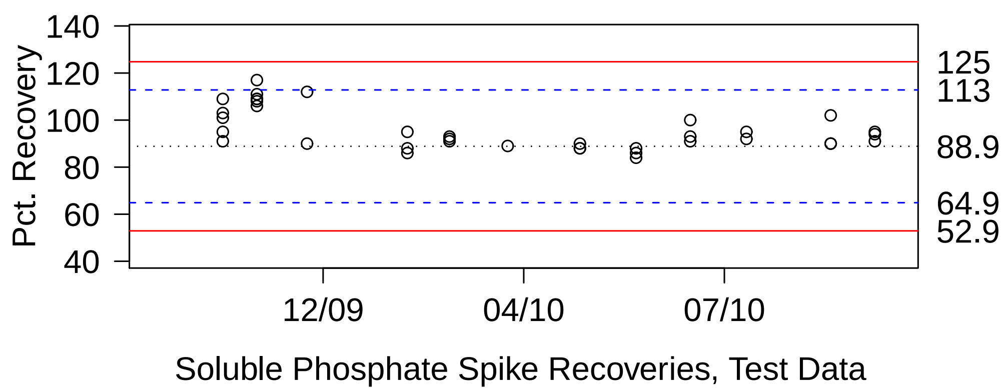
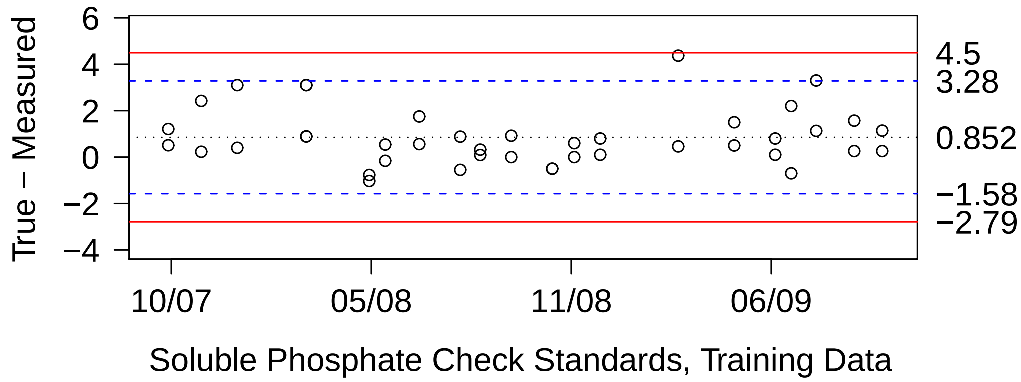


Figure C17: Soluble reactive phosphate matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



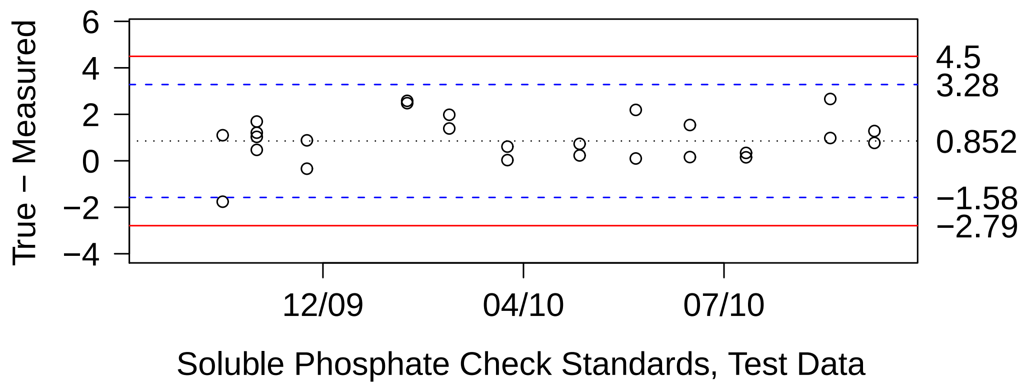
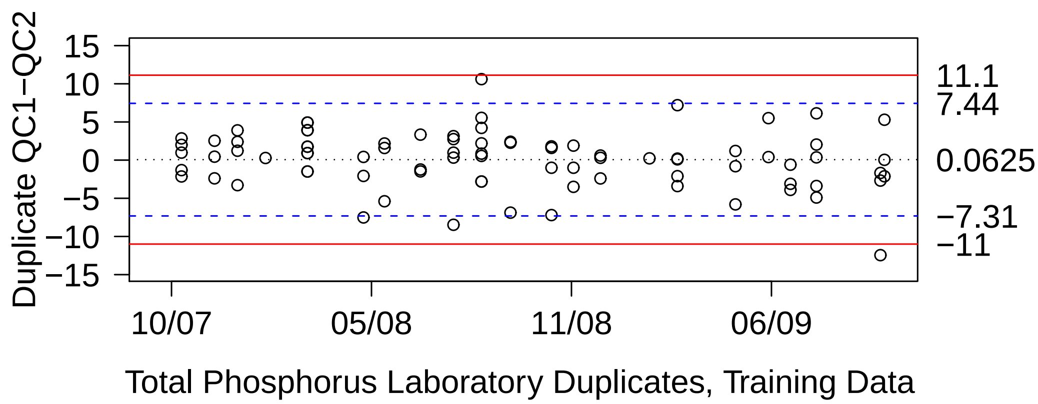


Figure C18: Soluble reactive phosphate check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



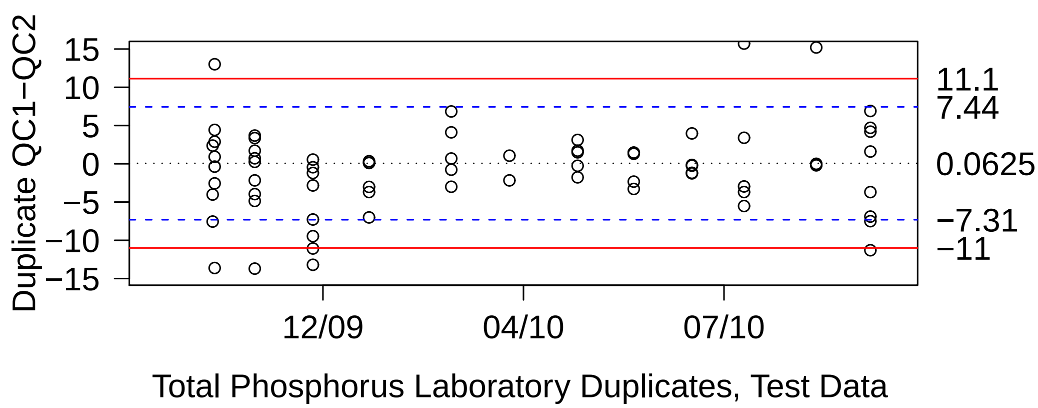
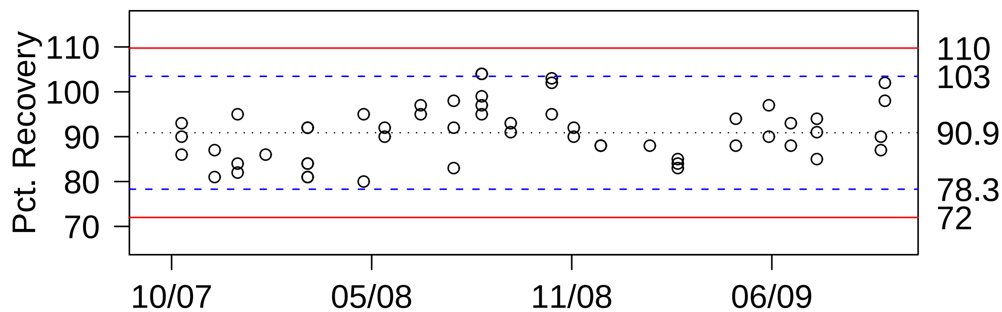
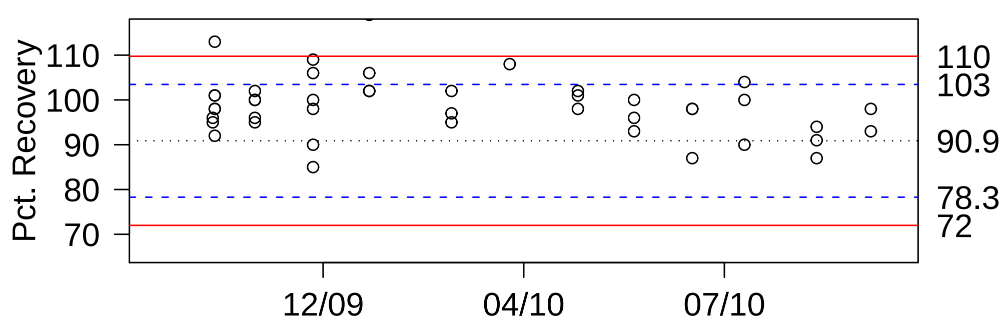


Figure C19: Total phosphorus laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data. Slight increase in variability may be due to insufficient persulfate concentration; method revised to increase concentration.

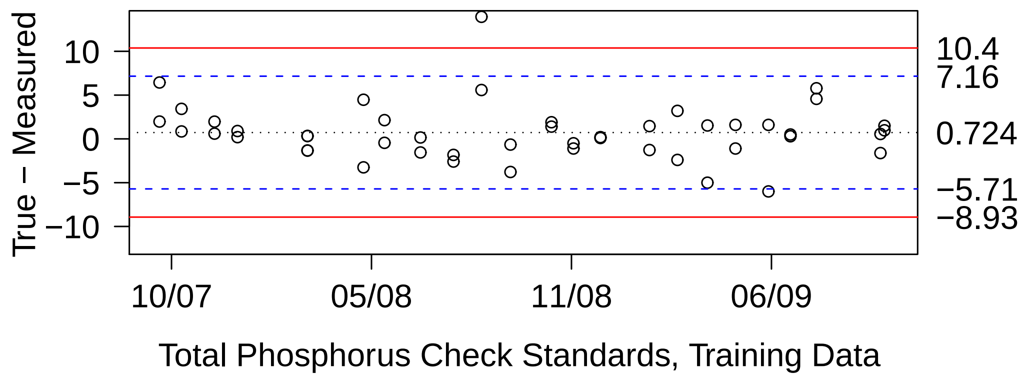


Total Phosphorus Spike Recoveries, Training Data



Total Phosphorus Spike Recoveries, Test Data

Figure 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.



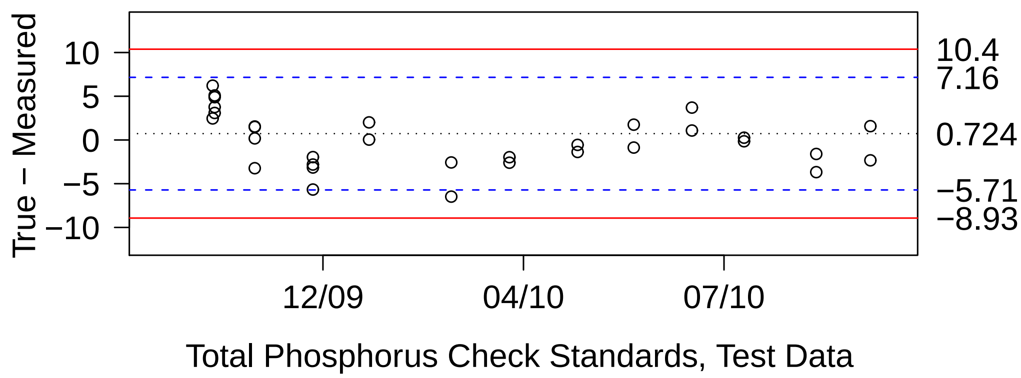
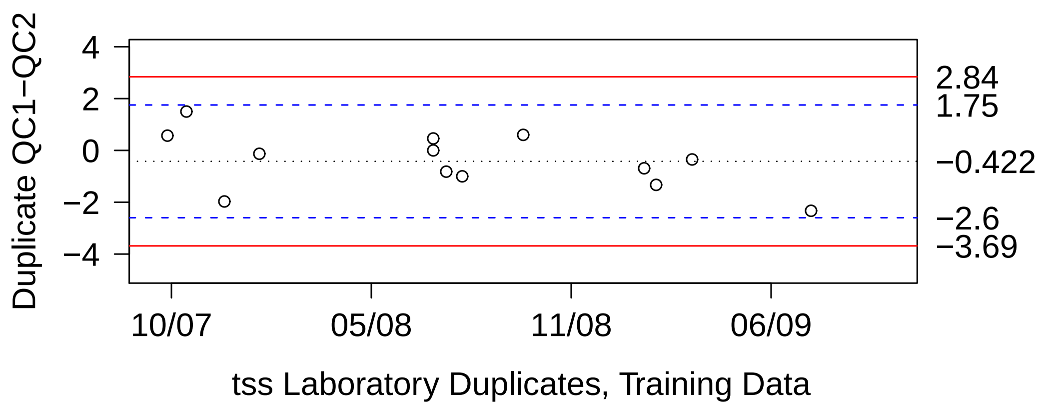


Figure C21: Total phosphorus check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



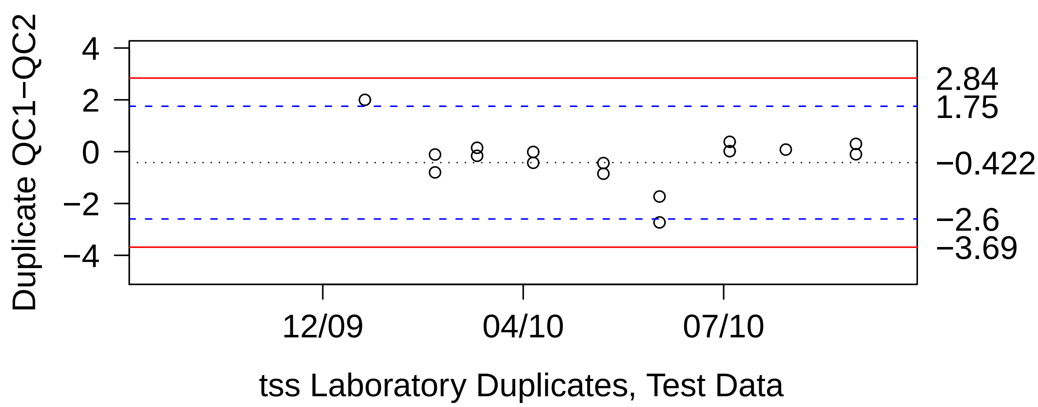
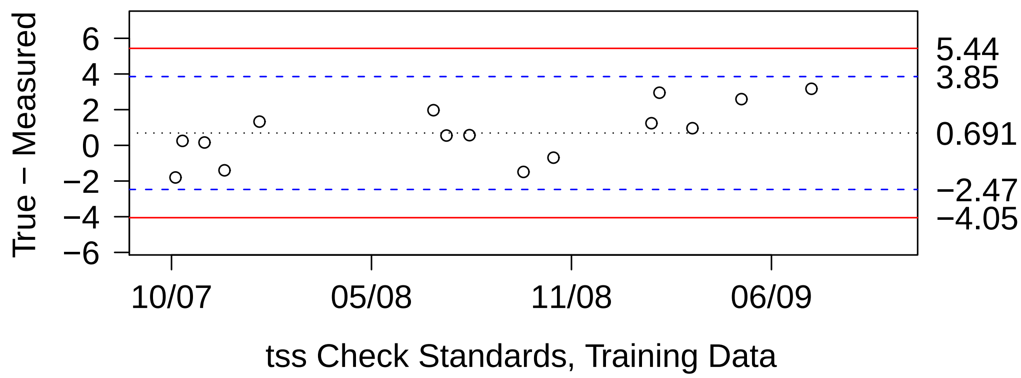


Figure C22: Total suspended solids laboratory duplicates for the Lake Whatcom monitoring program (creek and storm water samples). Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



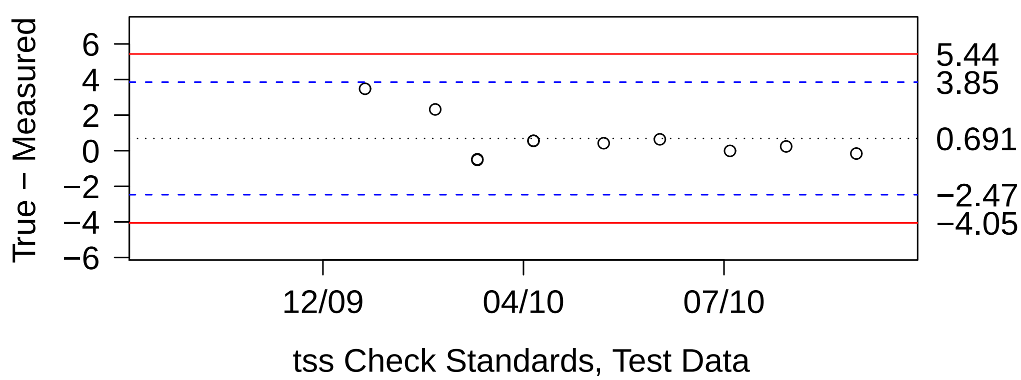
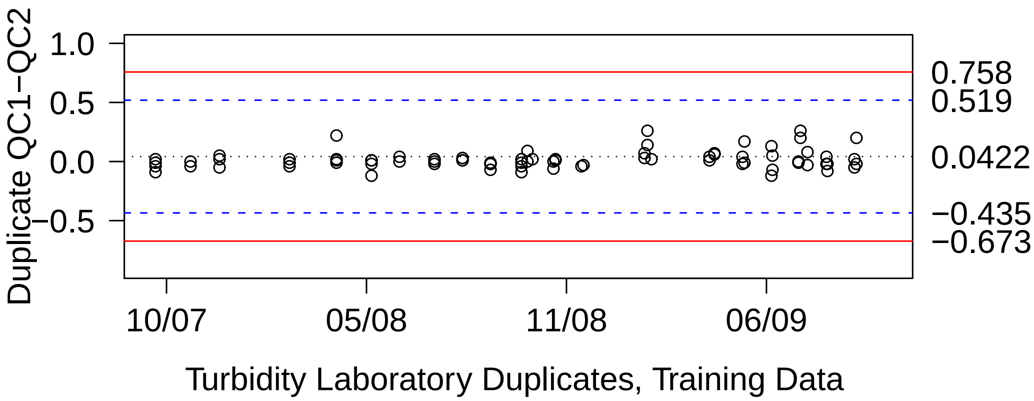


Figure C23: Total suspended solids check standards for the Lake Whatcom monitoring program (creek and storm water samples). Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



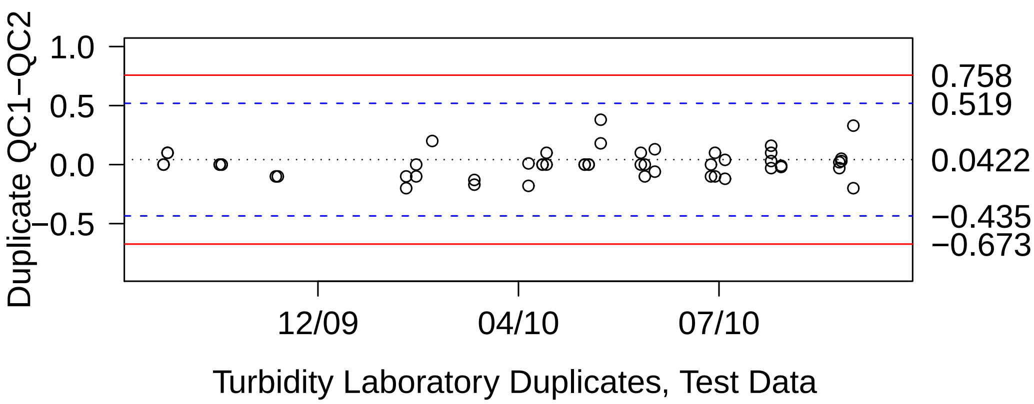


Figure C24: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

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 C25–C41, pages 324–340). 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:

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

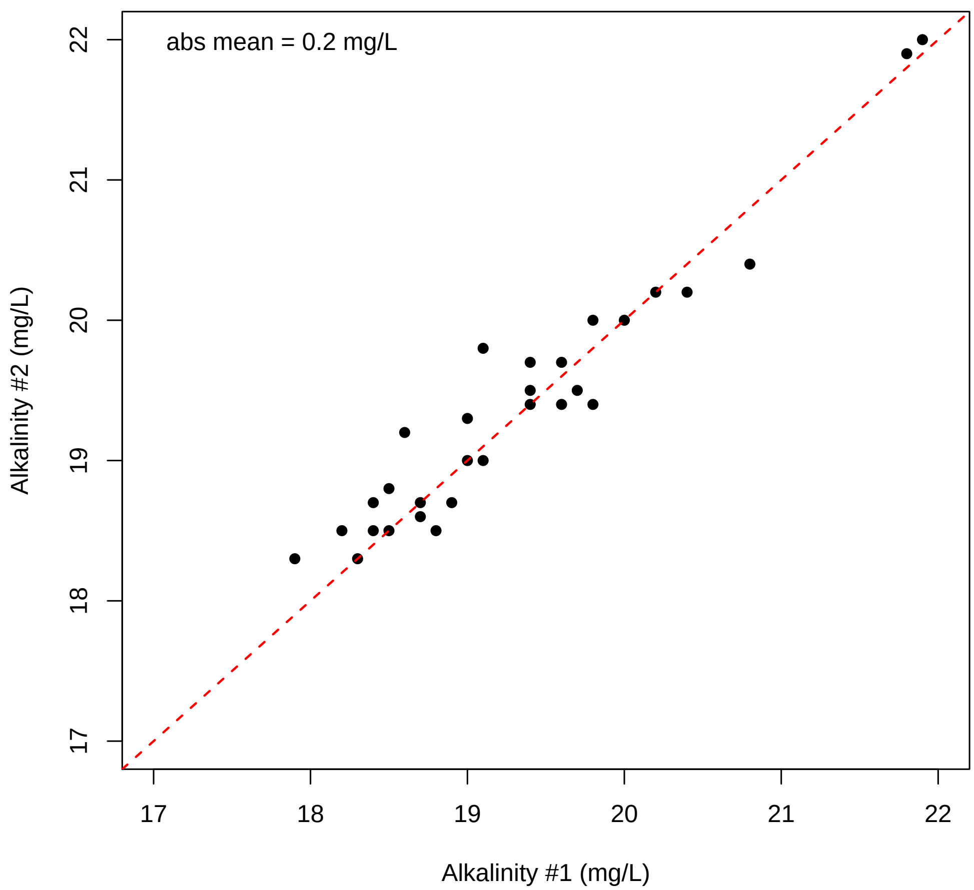


Figure C25: Alkalinity field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

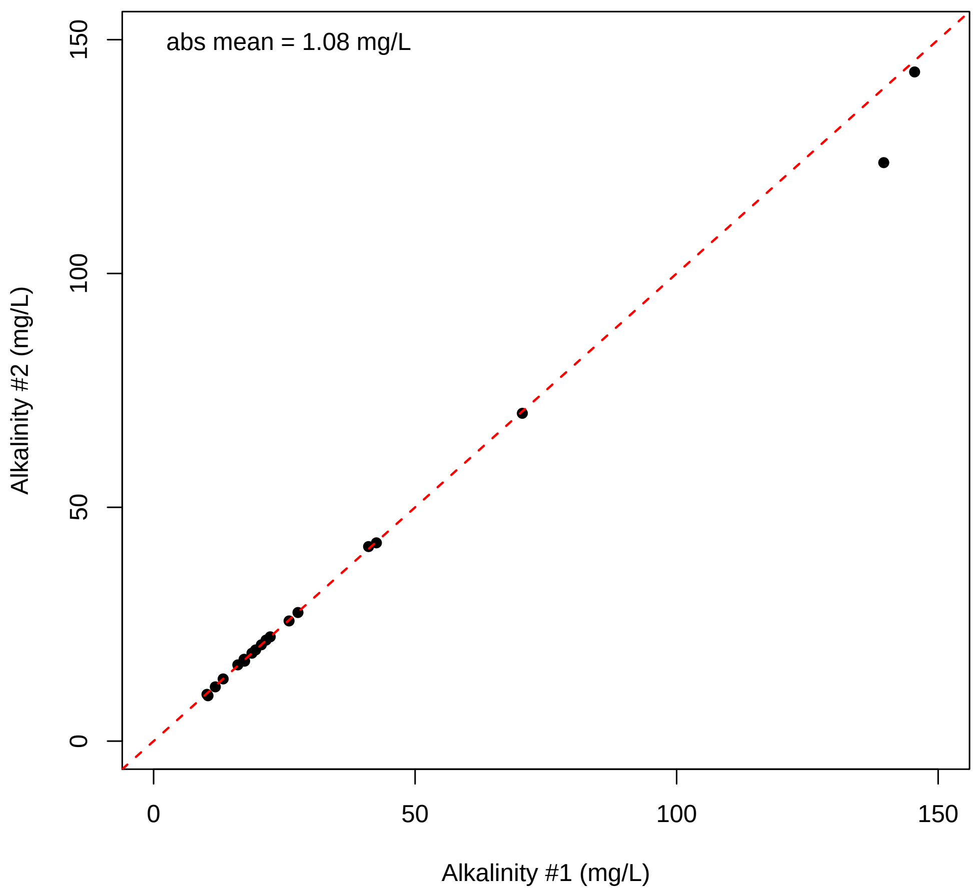


Figure C26: Alkalinity field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship.

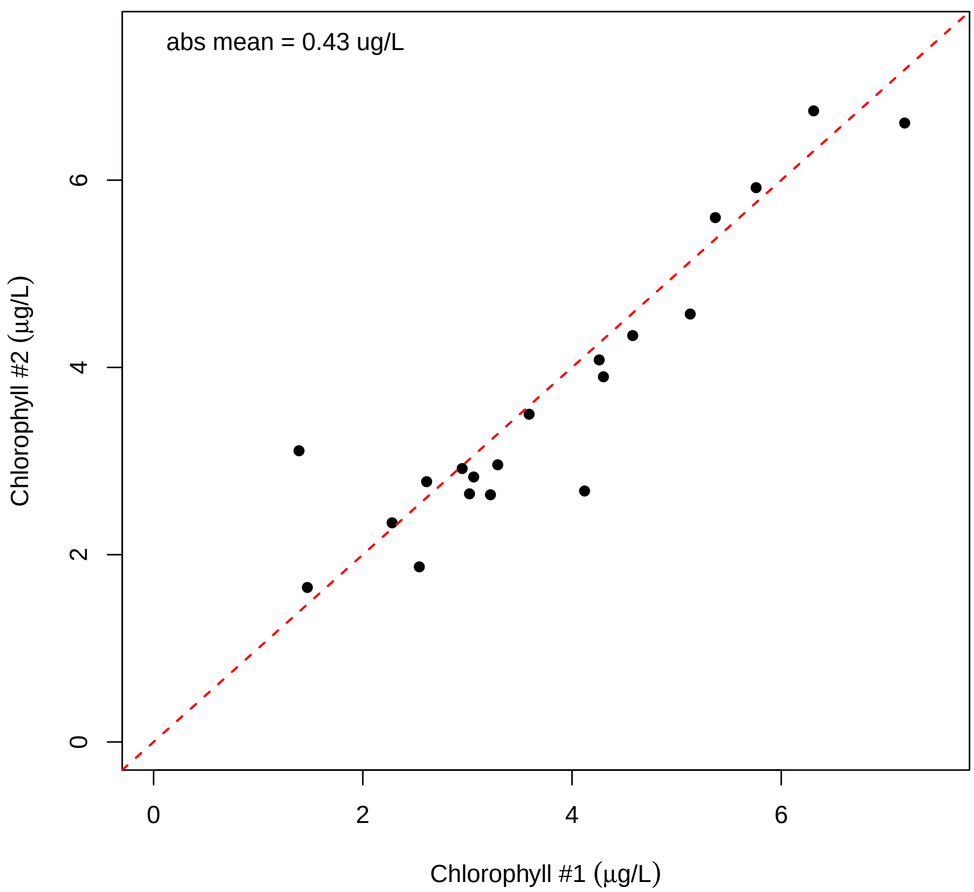


Figure C27: Chlorophyll field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

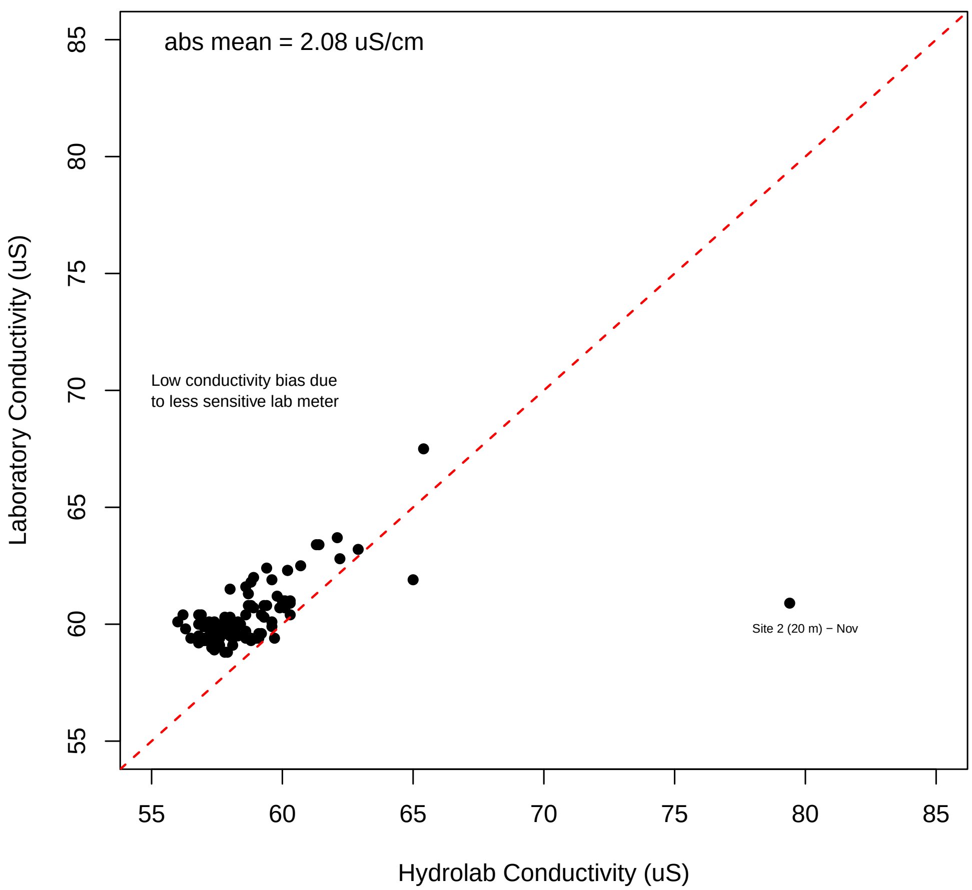


Figure C28: Conductivity field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

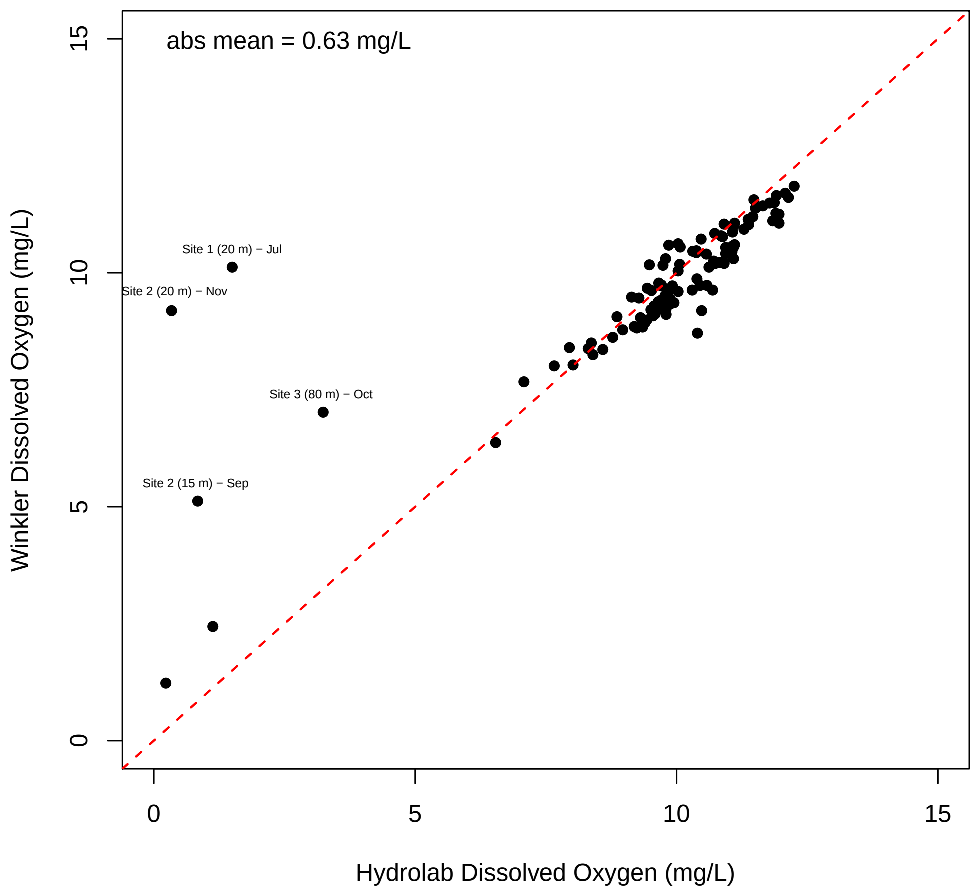


Figure C29: Dissolved oxygen field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. Most outliers were collected when the lake was stratified at depths were extreme oxygen gradients were present. These differences illustrate the variation between samples collected at true depth (Hydrolab) and depth measured using a marked line (Winkler), which is slightly shallower than true depth.

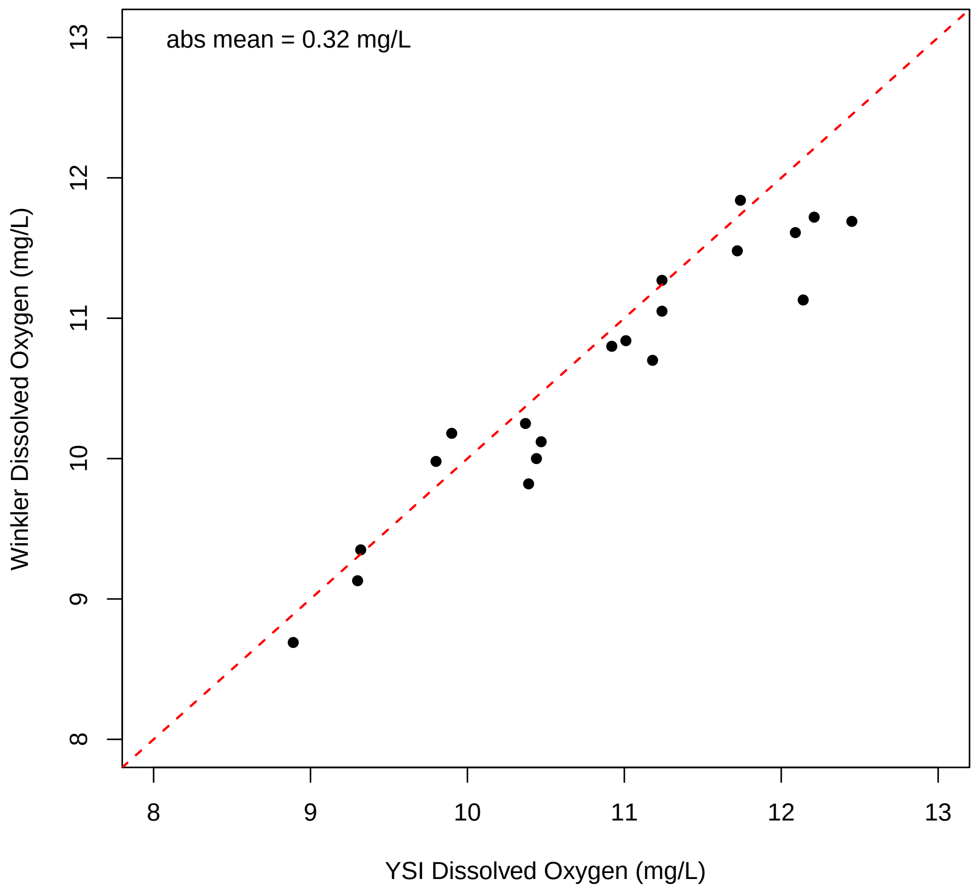


Figure C30: Dissolved oxygen field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship.

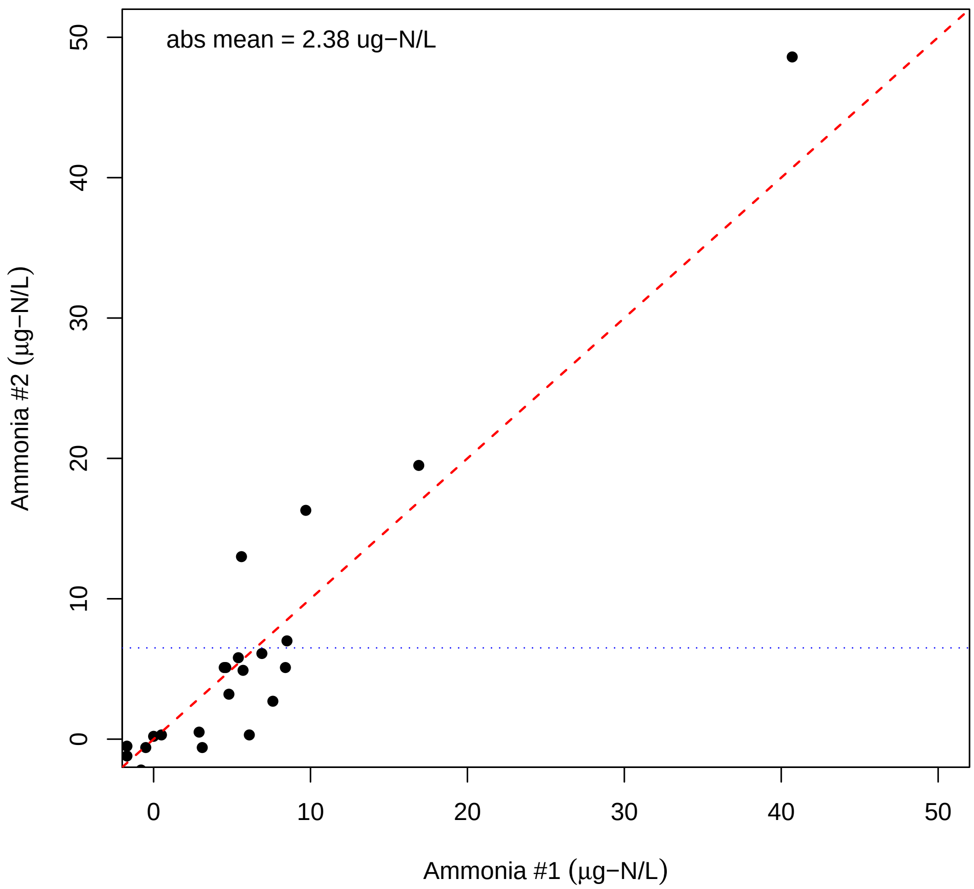


Figure C31: Ammonia field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

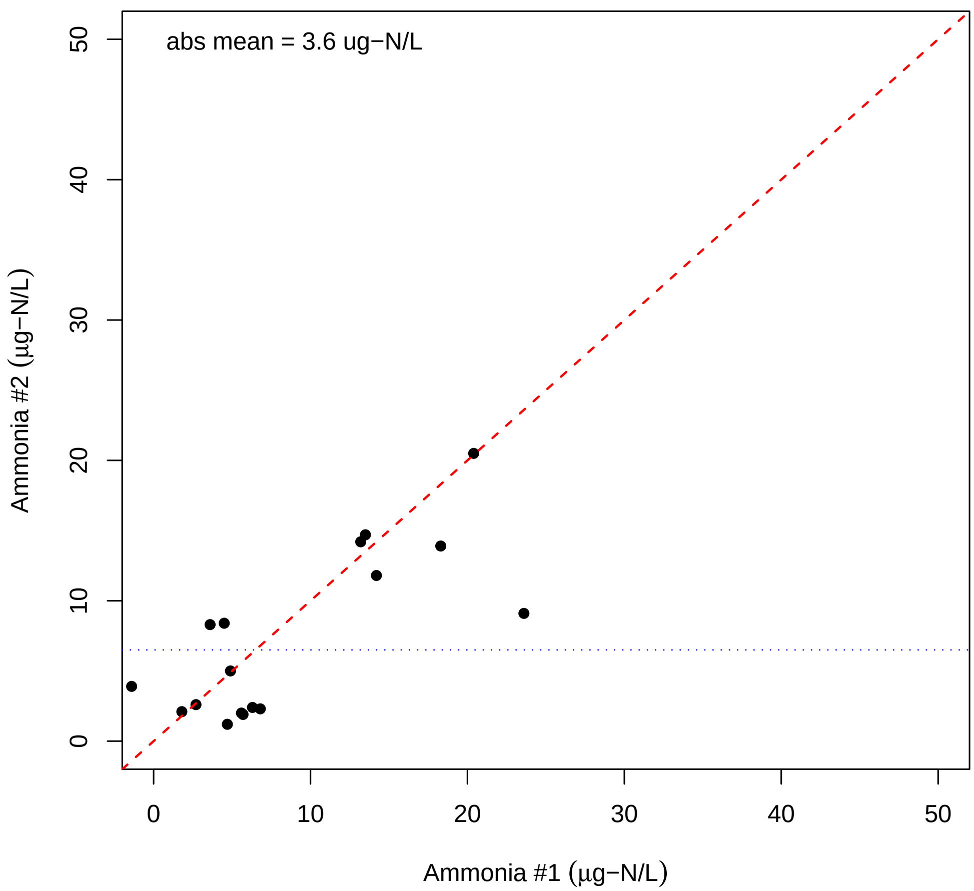


Figure C32: Ammonia field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

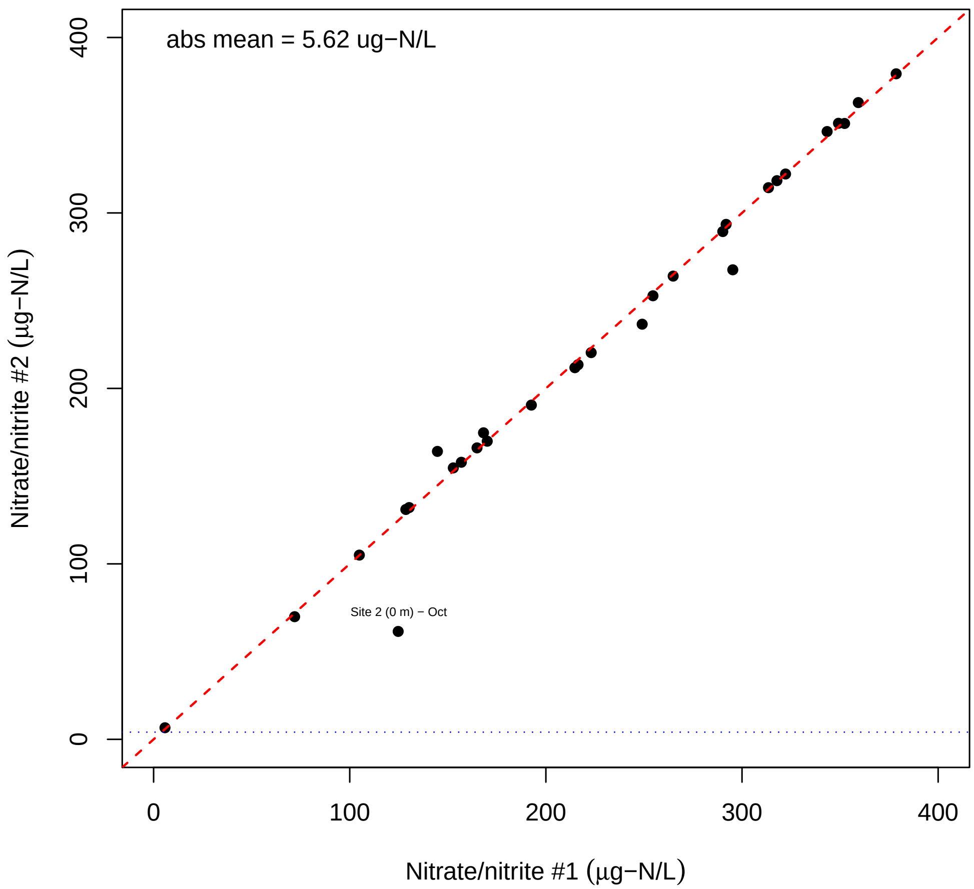


Figure C33: Nitrate/nitrite field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

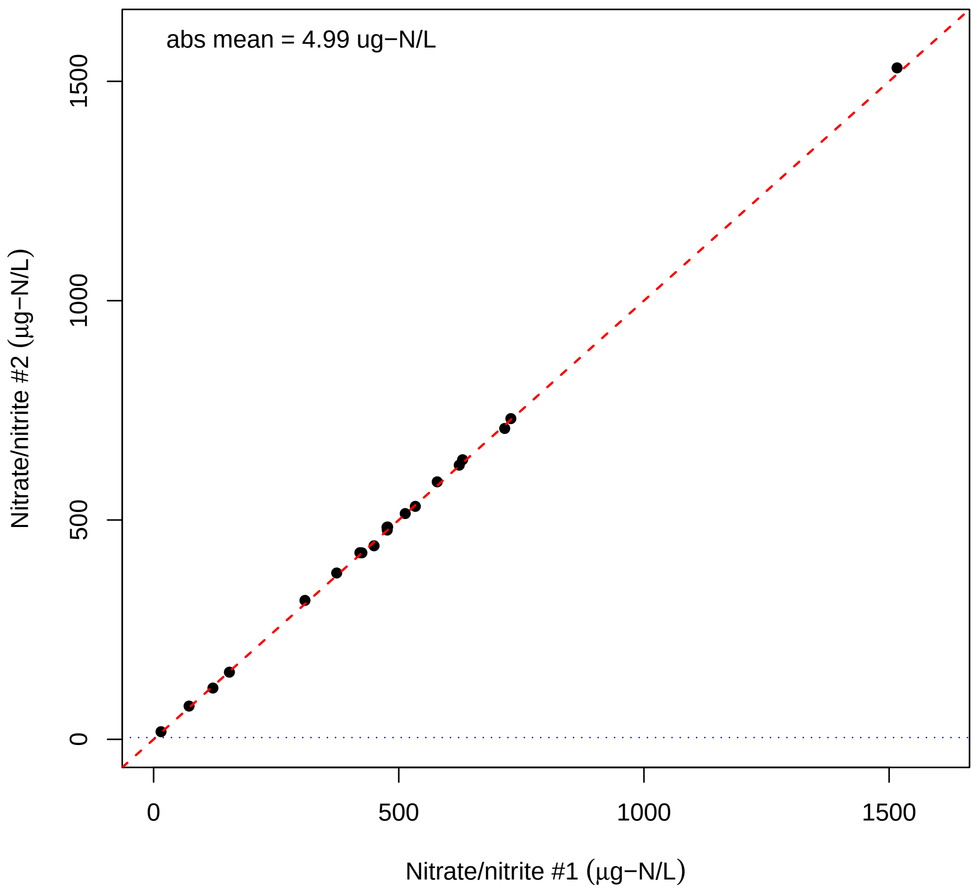


Figure C34: Nitrate/nitrite field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

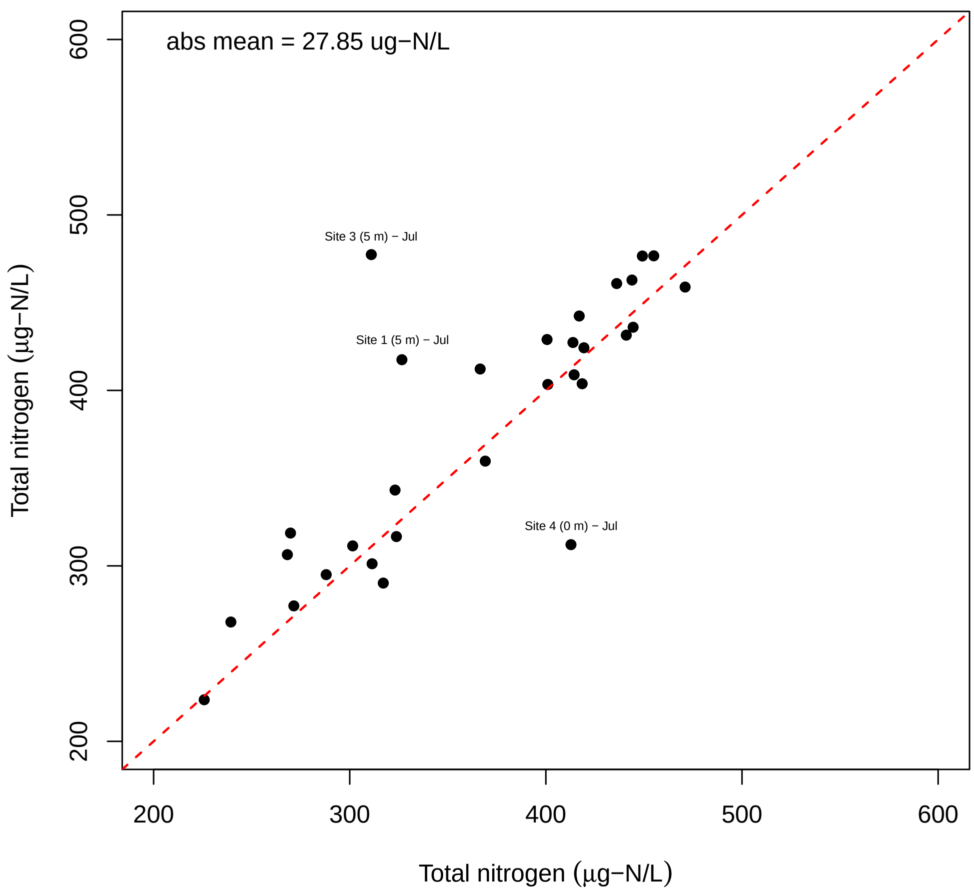


Figure C35: Total nitrogen field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

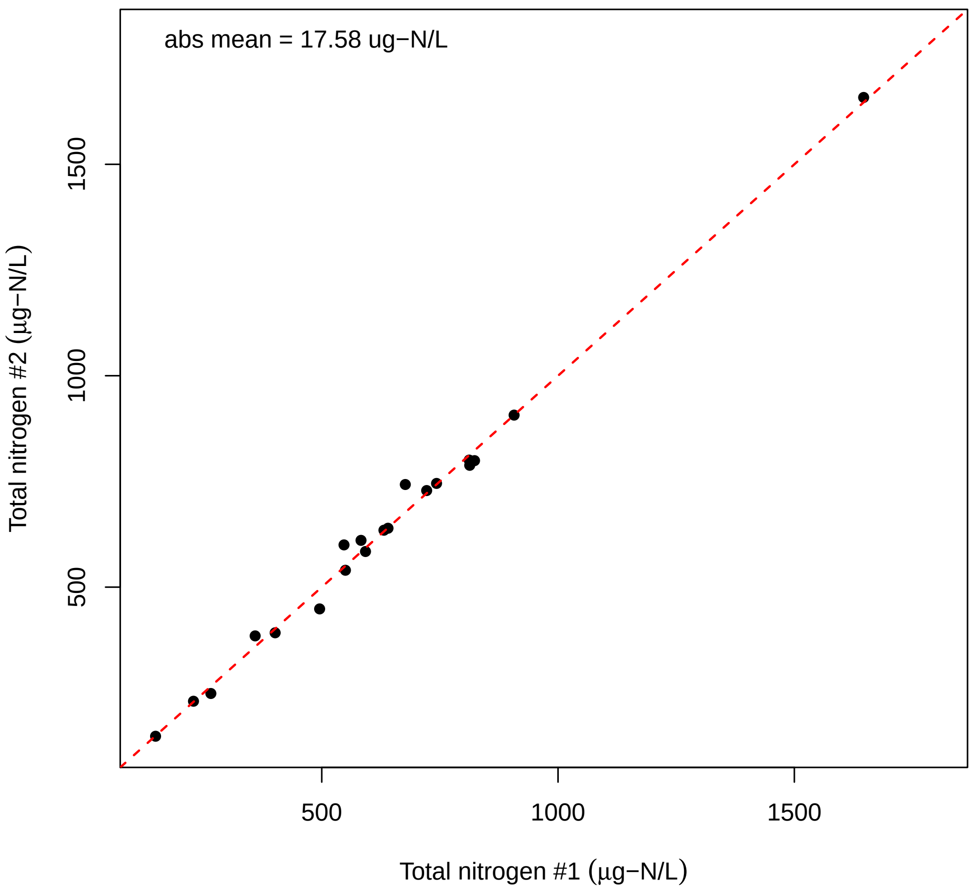


Figure C36: Total nitrogen field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

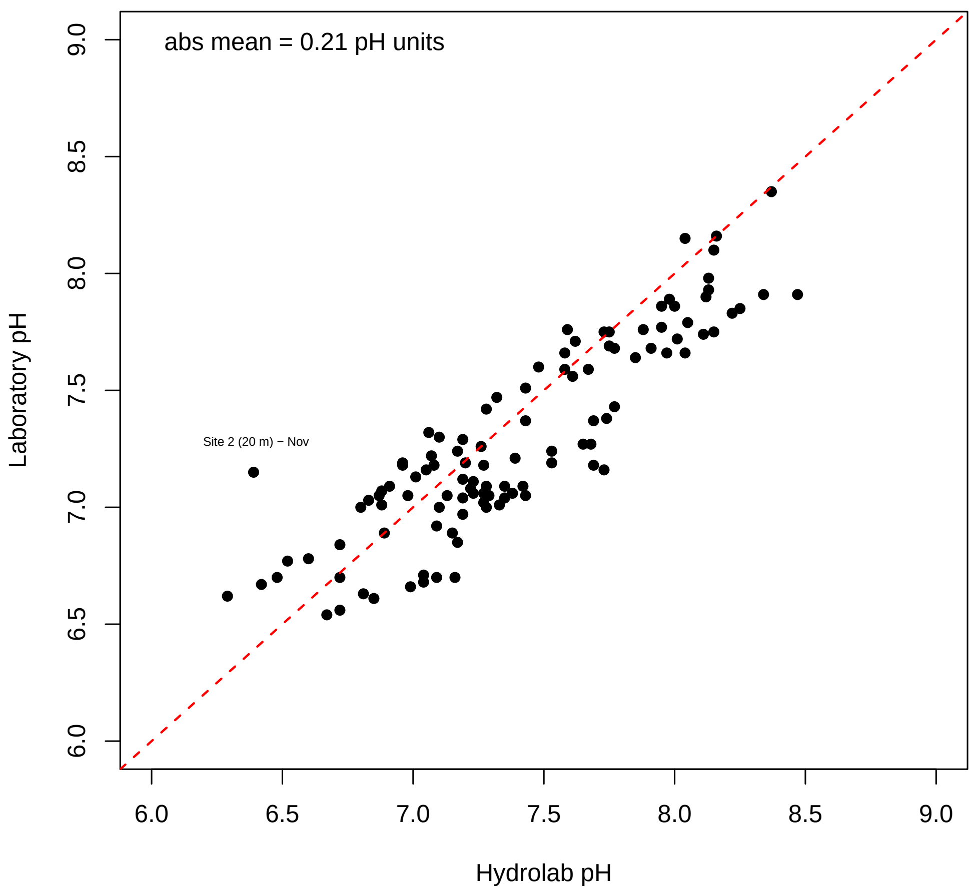


Figure C37: Field duplicates for pH from the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

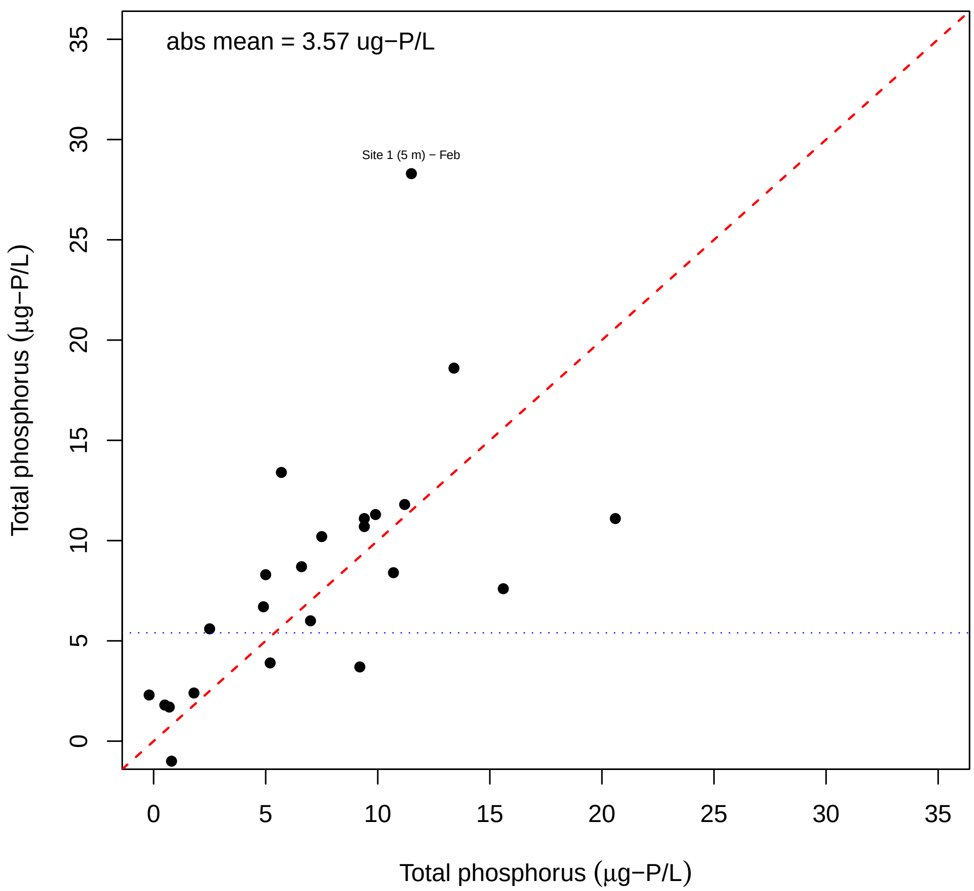


Figure C38: Total phosphorus field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

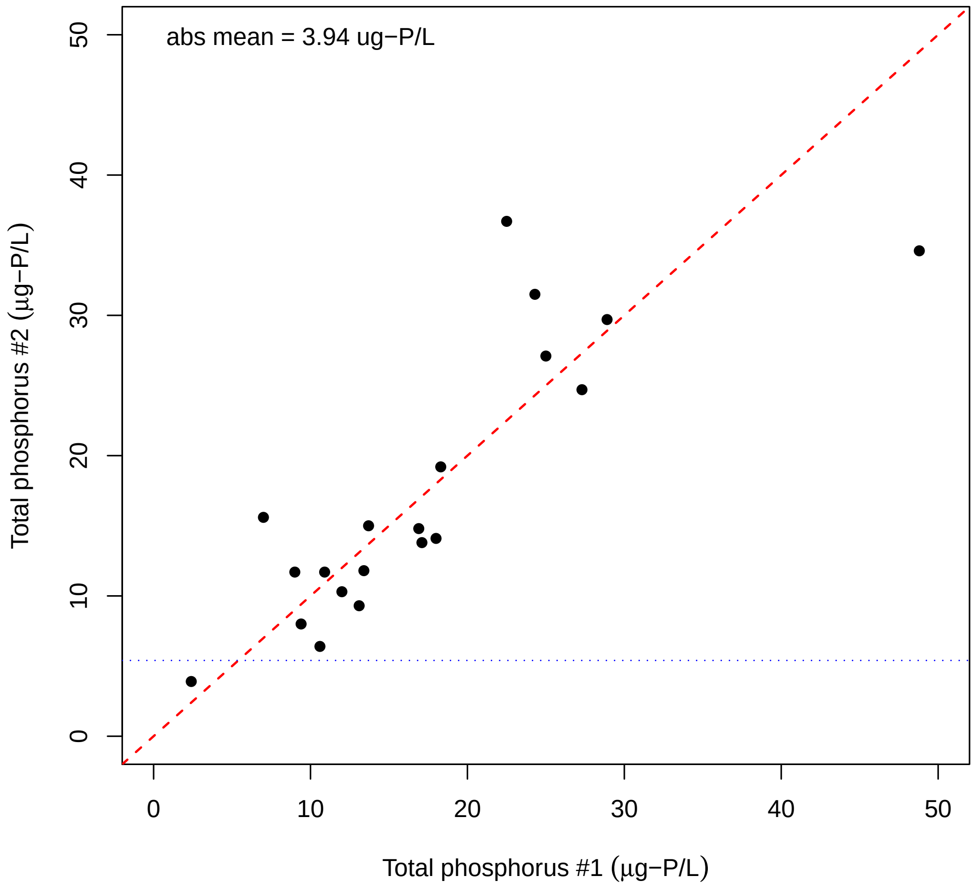


Figure C39: Total phosphorus field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

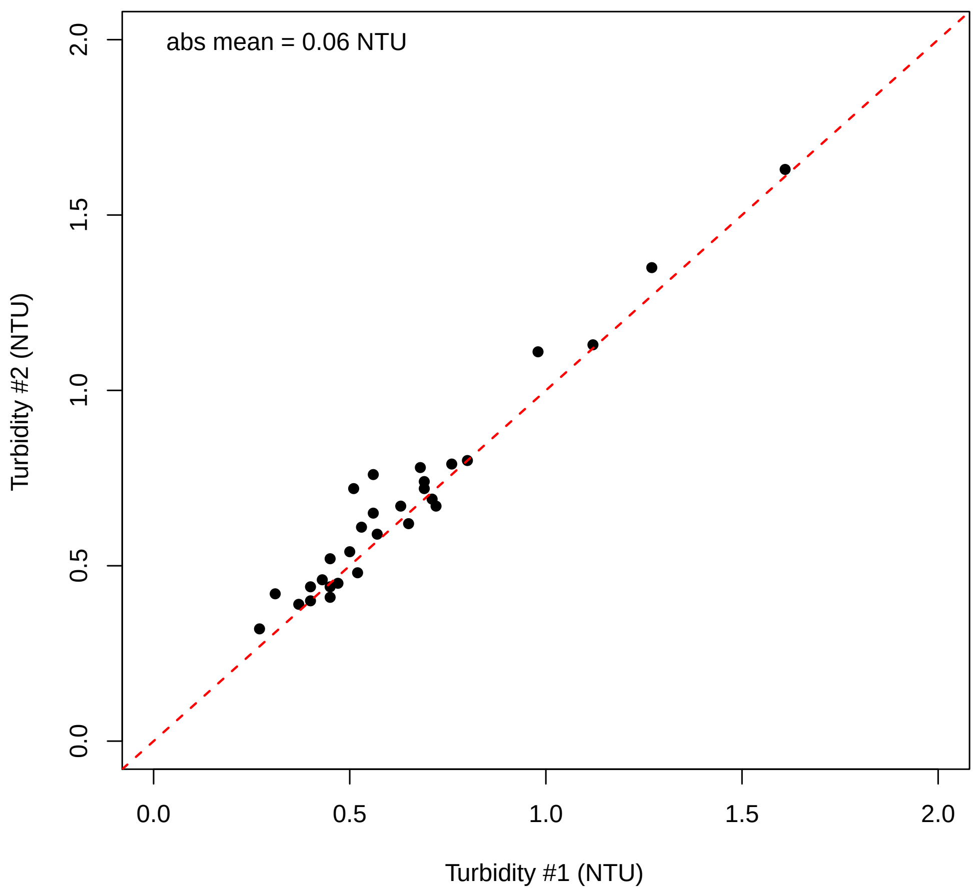


Figure C40: Turbidity field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

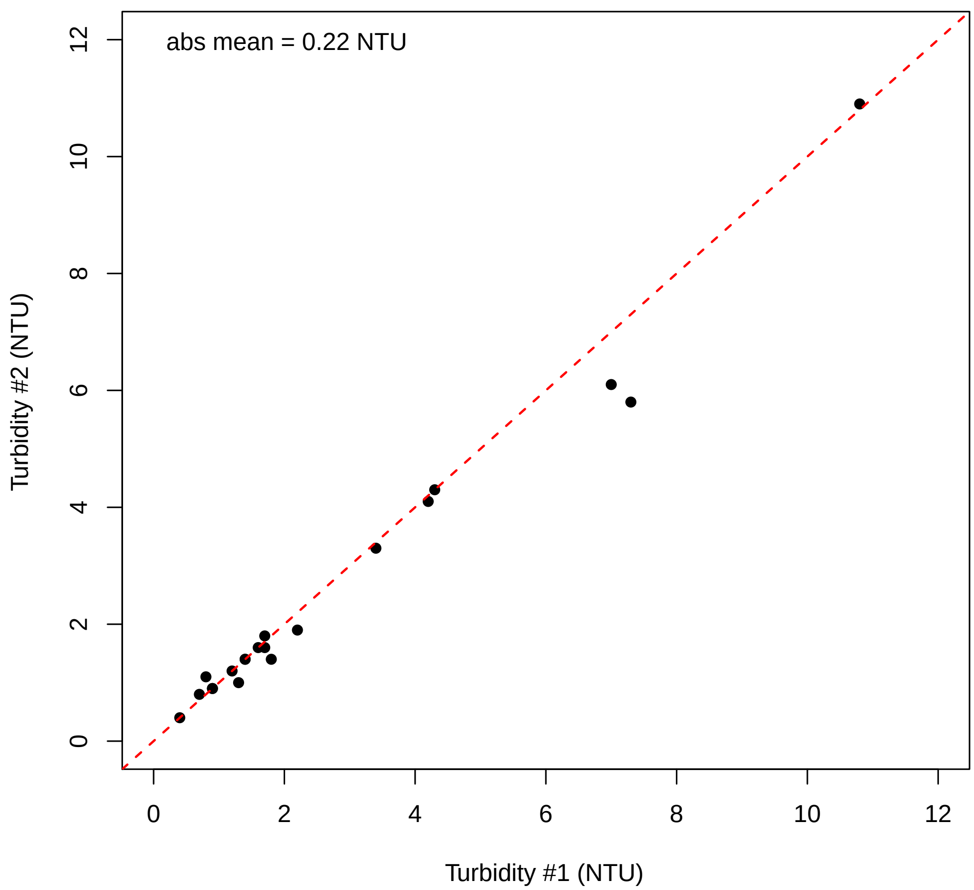


Figure C41: Turbidity field duplicates for the 2009/2010 Lake Whatcom Monitoring Project (creek samples). Diagonal reference line shows a 1:1 relationship.

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 FEBRUARY 2, 2011
**************************************************************
The historic Lake Whatcom data are available in electronic format at the IWS
website (http://www.wwu.edu/iws), with the exception of the coliform data,
which are available from the City of Bellingham Public Works Department.

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

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

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

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

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

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

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

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

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

```
*************************************************************
* HYDROGRAPH DATA FILES:
*************************************************************
WY1998.csv
WY1999.csv
WY2000.csv
WY2001.csv
WY2002.csv
WY2003.csv
WY2004_rev.csv (revised Anderson Creek data)
WY2005.csv
WY2006.csv
WY2007.csv
WY2008.csv
WY2009.csv
WY2010.csv
```

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

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

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

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

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

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

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

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

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

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

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

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

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*************************************************************
* SITE CODES (ALL DATA FILES - INCLUDES DISCONTINUED SITES)
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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)
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    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
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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.