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Lake Whatcom Monitoring Project 2007/2008 Report

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2007/2008 Final Report

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Executive Summary

- This report describes the results from the 2007/2008 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 78.

- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The spring of 2008 was colder than usual and the lake was only weakly stratified by the first week of May. Stable stratification was present at Sites 1–4 by early June. Although the onset of stratification was late, stratification persisted until mid-November at Sites 1–2. As a result, many of the indicators of low oxygen that are normally measured in October did not appear until November.

- 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. The July and August oxygen levels were not as low as usual in 2008, probably because of the cold, cloudy spring and delayed stratification.

- Nitrate depletion was evident at all sites in the photosynthetic zone during the summer, but the depletion was not as pronounced as in previous years. This was probably due to the cold, cloudy spring and delayed stratification.

- Anaerobic conditions in the hypolimnion at Sites 1 and 2 resulted in elevated concentrations of ammonia, nitrate, and hydrogen sulfide by the end of the summer. Despite the cold spring and late stratification, by October, the hypolimnetic ammonia concentrations were very high at Sites 1–2. Because the lake did not destratify until mid-November, the ammonia concentration at the bottom of Site 2 was the highest value measured since 1988 (976 μg-N/L).

- The summer near-surface total phosphorus and chlorophyll concentrations were about the same or slightly lower in 2008 compared to 2007. The cyanobacteria counts declined slightly in 2008 while the chrysophyte counts increased.

- The concentrations of trihalomethanes in Bellingham's treated drinking water were not as high in 2008 as in 2007, which was consistent with the chlorophyll data from Site 2.

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

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

- Tributaries were sampled in February and July 2008 to collect baseline data from locations that were sampled monthly in 2004–2006. Most of the tributaries had relatively low concentrations of total and dissolved solids, low alkalinities and conductivities, and low levels of nitrate and ammonia. Residential streams had higher concentrations of total and dissolved solids, higher alkalinities and conductivities, higher coliform counts, and higher nutrient concentrations.

- A water balance was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage. The major inputs into the lake during WY2008[1] included surface and subsurface runoff (69.6%), direct precipitation (16.7%), and water diverted from the Middle Fork of the Nooksack River (13.7%). Outputs included Whatcom Creek (76.1%), the City of Bellingham (11.4%), evaporation (8.3%), the Whatcom Falls Hatchery (2.7%), Puget Sound Energy Co-Generation (0.7%)[2], and the Lake Whatcom Water and Sewer District (0.7%).[3]

[1] Water Year 2008 covers the period from October 1, 2007 through September 30, 2008
[2] This facility currently operates at the former Georgia Pacific site.
[3] Formerly Water District #10

- Four storm water treatment systems were monitored in 2007/2008: the Park Place sand filter[4]; the Alabama Hill underground storm water treatment vault; the Brentwood wet ponds; and the South Campus storm water treatment facility, which is outside the Lake Whatcom watershed, but is used as a reference site.

- Most of the storm water treatment systems removed suspended solids from the runoff, with percent reductions ranging from 0–80%. Solids reductions were low when inlet concentrations were low; conversely, total suspended solids reductions ranged from 42–80% when the inlet concentration was $>$2.5 mg/L. The Park Place system was retrofitted in 2006, adding a series of sand filters. The site had moderate suspended solids removal efficiencies (10–57%) and excellent coliform removals (63–100%), but no improvement in phosphorus removal.

- Phosphorus removal efficiencies were low or inconsistent for most sites inside the watershed (-365–58%). The South Campus system continued to provided consistent phosphorus reduction (27–65%). The Alabama Hill vault provided 0–25% phosphorus reduction, which was similar to the 8–18% phosphorus reductions measured in 2007. The City has placed an emphasis on maintenance and regular cleaning at this site, which may be contributing to the modest, but consistent phosphorus removal.

[4]Formerly the Park Place wet ponds

1 Introduction

This report is part of an on-going series of annual reports and special project reports that document the Lake Whatcom monitoring program over time. Many of the reports are available online at http://www.ac.wwu.edu/∼iws (follow links under Lake Studies to Lake Whatcom); older reports are available in the IWS library and through the City of Bellingham Public Works Department. A summary of the Lake Whatcom reports, including special project reports, is included in Section 6.2, beginning on page 78.

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom also serve as a water source for the Puget Sound Energy Co-Generation Plant, which is located at the former Georgia-Pacific Corporation site on Bellingham Bay[5] The lake and parts of the watershed provide recreational opportunities, as well as providing important habitats for fish and wildlife. The lake is used as a storage reservoir to buffer peak storm water flows in Whatcom Creek. Much of the watershed is zoned for forestry and is managed by state or private timber companies. Because of its esthetic 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 2007/2008 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.

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

Detailed site descriptions can be found in Appendix A. The historic lake data are plotted in Appendix B. The current quality control results can be found in Appendix C. The 2007/2008 monitoring data are available online at http://www.ac.wwu.edu/∼iws as described in Appendix D (page 309). Table 1 (page 15) 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 85 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 3 & 4, November 7 & 8 and December 6 & 10, 2007; and February 14 & 19, April 1 & 3, May 6 & 8, June 3 & 5, July 8 & 10, August 5 & 7, and September 2 & 4, 2008. Each sampling event is a multi-day task; all samples were collected during daylight hours, typically between 10:00 am and 3:00 pm.

A Surveyor IVa Hydrolab was used to measure temperature, pH, dissolved oxygen, and conductivity. All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory, and were analyzed as described in Table 1 (page 15). Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.[6] Plankton samples were placed in a cooler and returned to the laboratory unpreserved. The plankton sample volumes were measured in the laboratory and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant.

2.3 Results and Discussion

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

Tables 2–6 (pages 16–20) summarize the current field measurements, ambient water quality, and coliform data. The raw data are available online at http://www.ac.wwu.edu/∼iws as described in Appendix D (page 309). The monthly Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 96–145).

The 2007/2008 lake data are plotted with historic lake data in Figures B51–B130 (pages 147–227). These figures are scaled to plot the full range of Lake Whatcom water quality data including minimum, maximum, and outlier values, and do not provide the best illustration of trends that occur in the lake. Separate tables and figures are provided to show trends and illustrate specific patterns in the data.

2.3.1 Water temperature

The mid-winter Hydrolab profiles (e.g., Figures B16–B20, pages 111–115) and the multi-year temperature profiles (Figures B51–B55, pages 147–151) show that the water column mixes during the fall, winter, and early spring. During this time, water temperatures, dissolved oxygen concentrations, pH levels, and conductivities are fairly uniform from the surface to the bottom of the lake, even at Site 4, which is over 300 ft (100 m) deep.

[6] AmTest, 14603 N.E. 87th St., Redmond, WA, 98052.

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

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

In Lake Whatcom, all sites except the Intake are usually stratified by June. (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.

Destratification occurs abruptly in basins 1 and 2, and more gradually in basin 3. The lake cools as the weather becomes colder and days shortens. Basins 1 and 2 (Sites 1–2) usually destratify by the end of October; basin 3 (Sites 3–4) is often still stratified in November or early December. Complete destratification probably occurs in late December or early January in basin 3. By February the temperatures are relatively uniform throughout the water column.

Although destratification is relatively abrupt, the mixing process is not instantaneous. When the lake first begins to mix, water column temperatures can be uniform from the surface to the bottom, but the rate of water circulation may not have been sufficient to replenish hypolimnetic oxygen concentrations (see November 2006 Hydrolab profiles from Sites 1–2, Figures B6 and B7; Matthews, et al., 2008).

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; 23.2° C on August 13, 1997). 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 2008 surface water temperatures were colder than usual (Table 7 and Figure 1, pages 21 and 28); May, June, and July 2008 were the coldest surface water temperatures measured since 1988. The lake was unstratified in April, and only weakly stratified by the first week in May (Δ T $< 5^\circ$ C; Figures B21–B30, pages 116–125). Stable stratification was present at Sites 1–4 by early June (Figures B31–B35, pages 126–130).

2.3.2 Dissolved oxygen

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

As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures B41–B42 and B56–B57, pages 136–137 and 152–153). Hypolimnetic oxygen depletion only becomes apparent after stratification, when the lower waters of the basin are isolated from the lake's surface and biological respiration consumes the oxygen dissolved in the water. Biological respiration usually increases when there is an abundant supply of nutrients. In basin 3, which has comparatively low concentrations of essential nutrients such as phosphorus, biological respiration has little influence on hypolimnetic oxygen concentrations (e.g., Figures B50 and B60, pages 145 and 156). In contrast, Site 1 shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures B46 and B56, pages 141 and 152).

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.

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

To illustrate this trend we fitted the July and August data using an exponential function (see discussion by Matthews, et al., 2004). As indicated in Figures 2–5 (pages 29–32), there were significant negative correlations between dissolved oxygen and time for all samples collected from the hypolimnion during July and August.[8] The 2008 data are somewhat atypical, showing relatively high July and August hypolimnetic oxygen levels. This was probably caused by the extremely cold, cloudy spring, which delayed stratification until June. Once stratified, however, the hypolimnetic oxygen concentrations dropped rapidly. By the first week in September the oxygen levels were $<$1 mg/L at all depths below 11 meters.

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in June and July (e.g., Figures B31 and B36, pages 126 and 131). 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 (e.g., Figures B4 and B49, pages 99 and 144). Sites 3 and 4 developed small oxygen sags near the thermocline (e.g., Figures B4 and B5, pages 99 and 100), which are caused by respiration of heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (Matthews and DeLuna, 2008).

2.3.3 Conductivity and pH

The Hydrolab pH and conductivity data followed trends that were typical for Lake Whatcom, with only small differences between sites and depths (Figures B61–B70, pages 157–166). Surface pH values increased during the summer due to photosynthetic activity. Hypolimnetic pH values decreased and conductivity values increased due to decomposition and the release of dissolved compounds from the sediments. A significant long-term trend was apparent in the conductivity data. This trend is the result of changing to increasingly sensitive equipment during the

[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 $\pm$1, the stronger the correlation. The significance is measured using the p-value; significant correlations have p-values $<$0.05. Monotonic linear correlations were measured using Pearson's r; monotonic nonlinear (e.g., exponential) correlations were measured using Kendall's τ.

past two decades, resulting in lower values over time, and does not indicate any actual change in the conductivity in the lake (Matthews, et al., 2004).

2.3.4 Alkalinity and turbidity

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures B71–B75, pages 168–172). During the summer the alkalinity values at the bottom of Sites 1–2, and occasionally Site 3, increased due to decomposition and the release of dissolved compounds in the lower waters.

The turbidity values were mostly less than 1–2 NTU except during late summer in samples from the lower depths at Sites 1–2, and occasionally Site 3 (Figures B76–B80, pages 173–177). The high turbidity levels near the bottom are an indication of increasing turbulence in the lower hypolimnion as the lake begins to destratify. The influence of surface runoff from storms can also elevate lake turbidity levels, but the peaks are usually small compared to the summer hypolimnetic peaks. The effects of storm runoff can be seen in December 1990 and February 1991, when sediment entered the lake during several major storms and caused elevated turbidity levels throughout the water column, especially in basin 3 (Figures B76–B80, pages 173–177).

The late summer turbidity peaks at Site 1 were unusually low during 2006 and 2007, but returned to typical levels in 2008 (Figure B76, page 173). These transient peaks are associated with turbulence in the lowest portion of the hypolimnion as the lake begins to destratify. They do not persist long in the water column, and are easily missed by sampling at the wrong time of year or higher in the hypolimnion.

2.3.5 Nitrogen and phosphorus

Figures B81–B105 (pages 178–202) show the nitrogen and phosphorus data for Lake Whatcom. Nitrogen and phosphorus are important nutrients that influence the amount and type of microbiota (e.g., algae) that grow in the lake. In Lake Whatcom, most algae use inorganic nitrogen in the form of nitrate for growth. Under some conditions, ammonia or dissolved nitrogen gas can be used.[9]

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

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 183–187), particularly at Sites 1–2, where the epilimnetic nitrate concentrations often drop below 50–100 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)[10] have been declining over time (Figure 6, page 33). Sites 2–4 had higher summer near-surface DIN concentrations in 2007 and 2008, and Site 1 had higher near-surface DIN in 2008. It is too early to tell whether this represents an improvement in the lake's water quality, especially since 2007 and 2008 both had cold cloudy springs that resulted in late stratification. The DIN trend is consistent with near-surface phosphorus and chlorophyll data (see discussion on pages 9 and 11), however, so it is possible that we are seeing stabilization of the lake's algal populations.

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 in 2008, 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 less nitrate reduction. The onset of stratification was also late in 2008, but the lake destratified later in 2008 (mid-November) compared to 2007 (mid-October), so despite similar late stratifications, 2008 had a longer period of anoxia.

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 8, page 22; Figures B81 & B82, pages 178 & 179). Elevated hypolimnetic ammonia concentrations have been common at both

[10]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.

sites throughout the monitoring period, but beginning in 1999 the concentrations increased noticeably at Site 2 (Figure B82, page 179). The highest ammonia concentration measured since 1988 was collected in November 2008 at Site 2 - 20 meters (976 μg-N/L). The high ammonia concentration at Site 2 contributed to the unusually high total nitrogen peak (Figure B92, page 189).

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

Although the Lake Whatcom microbiota require nitrogen, phosphorus is usually what limits microbial growth (Bittner, 1993; Liang, 1994; Matthews, et al., 2002a; McDonald, 1994). Soluble forms of phosphorus (e.g., soluble phosphate) are easily taken up by 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. 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 and microbiota.

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.

Total phosphorus and soluble phosphate concentrations were usually low except in the hypolimnion at Sites 1 and 2 just prior to destratification (Figures B96–B100, pages 193–197 and B101–B105, pages 198–202). There were extremely high hypolimnetic phosphorus concentrations measured at Sites 1–2 in October and November 2008 (Figures B96–B97 and B101–B102, pages 193–194 and 198–199), which was consistent with the pattern described for ammonia.

Epilimnetic total phosphorus concentrations are usually lower than late-summer hypolimnetic peaks, but the levels of epilimnetic total phosphorus have been increasing throughout the lake (Figure 7, page 34). Prior to 2000, the median epilimnetic phosphorus concentrations were below analytical detection levels[11] at Sites 3 and 4, and usually below detection at Site 2. Since 2000, most of the medians have been above detection. There is some indication that the summer, near-surface phosphorus concentrations have stabilized (Figure 7), but since 2007 and 2008 were relatively cool years, with late stratification, it is too early to tell whether the pattern reflects improvement in the water quality.

Site 2 hypolimnetic ammonia, phosphorus, and hydrogen sulfide: Since 1999, Site 2 has usually had higher concentrations of ammonia, total phosphorus, and hydrogen sulfide than Site 1 (Table 8, page 22). These compounds are all by-products of anoxia. In 2007, the concentrations of these compounds dropped, especially at Site 2, seemingly in response to the short period of lake stratification (Matthews, et al., 2008). Hypolimnetic oxygen depletion does not occur as fast at Site 2 as at Site 1, so late stratification should have a more effect on anoxia at Site 2. In 2007 the lake stratified late and destratified early. As a result, the hypolimnion was anoxic for no more than 2 months, which may not have been long enough to develop high concentrations of hydrogen sulfide, ammonia, or phosphorus, especially at Site 2. In 2008, stratification was again late, but the period of stratification persisted until mid-November. There was a substantial accumulation of ammonia, phosphorus, and hydrogen sulfide at both sites, with Site 2 again having higher concentrations. The lake was still stratified in early November, and the ammonia concentration at Site 2 exceeded all previously measured concentrations.

2.3.6 Chlorophyll, plankton, and Secchi depth

Site 1 continued to have the highest chlorophyll concentrations of all the sites (Figures B106–B110, pages 203–207). Peak chlorophyll concentrations were usually collected at 0–15 m, while samples from 20 m had relatively low chlorophyll concentrations. Twenty meters is near the lower limit of the photic zone, so the light levels are not optimal for algal growth at this depth.

[11] Analytical detection limits vary slightly from year to year. Historically, the detection limits were about 5 μg-P/L; currently, the total phosphorus detection level is 4.1 μg-P/L.

The Lake Whatcom plankton counts were usually dominated by Chrysophyta, consisting primarily of diatoms, *Dinobryon*, and *Mallomonas* (Figures B121–B130, pages 218–227). Substantial blooms of bluegreen bacteria (Cyanobacteria) and green algae (Chlorophyta) were also measured at all sites during summer and late fall. Previous analyses of algal biomass in Lake Whatcom indicated that although Chrysophyta dominate the numerical plankton counts, Cyanobacteria and Chlorophyta often dominate the plankton biomass, particularly in late summer and early fall (Ashurst, 2003; Matthews, et al., 2002b).

Secchi depths (Figures B111–B115, pages 208–212) showed no clear seasonal pattern because transparency in Lake Whatcom is affected by particulates from storm events and the Nooksack River diversion as well as algal blooms

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

The 2008 median near-surface summer chlorophyll concentrations were slightly lower at all sites (Figure 8, page 35), which was consistent with the patterns described for DIN and phosphorus. Most of the algal counts were also lower in 2008, with the notable exception of the Chrysophyta (Figures 9–11, pages 36–38). This discrepancy between lower chlorophyll concentrations and higher Chrysophyta counts reflects the difference between algal biomass (chlorophyll) and numerical counts. Algae come in different sizes. Most of the Chrysophyta are counted as individual cells, while many of the Cyanobacteria and Chlorophyta are counted by colonies because the individual cells are very tiny. Colonies of Cyanobacteria and Chlorophyta contain much more algal biomass than individual Chrysophyta cells, so increased numbers of Chrysophyta may not corresponds with an increase in chlorophyll, especially if there are fewer Cyanobacteria or Chlorophyta. Numerical counts are best used to look for trends within the same type of algae (e.g., are the numbers of Cyanobacteria increasing?) and algal biomass is best used to evaluate changing trophic status (e.g., is the lake becoming more biologically productive?).

One of the eutrophication trends in Lake Whatcom has been a fairly steady increase in the numbers of Cyanobacteria at all sites (Figures 10 and 11, pages 37 and 38). For the past 3–4 years, however, the numbers of Cyanobacteria has stabilized or dropped slightly. This pattern is best viewed using a $\log_{10}$ plot of the counts (Figure 11), which shows the counts increasing from 1994 through 2004 or 2005, depending on site, then flattening or decreasing from 2004/2005 through 2008. It is too early to tell whether this represents an improvement in the lake's water quality, especially given the extremely high ammonia and phosphorus concentrations in the hypolimnion at Site 2. Still, when combined with the other indicators (less DIN depletion; lower summer, near-surface phosphorus and chlorophyll), the changes are encouraging.

Lake Whatcom algal taxonomy: Plankton counts are included as part of the long-term lake monitoring project, but the counts are done using broad taxonomic groups (e.g., Cyanobacteria, Chlorophyta, etc.). Although there have been several graduate and undergraduate projects that involved identifying and quantifying algae in Lake Whatcom, there has not yet been a systematic attempt to describe the algal taxonomic diversity of the lake. Last year we sent algal samples collected on April 3, 2007 to the Academy of Natural Sciences of Philadelphia[12] for taxonomic identification. Because the 2007 samples were collected in early spring, the plankton were dominated by Chrysophyta (diatoms) and Chlorophyta; Cyanobacteria were poorly represented. We collected additional samples on October 14, 2008 and sent them to Aquatic Analysts[13], who were contracted in 2002 and 2003 by the Department of Ecology to count and identify Lake Whatcom phytoplankton. The results from the April and October plankton samples are summarized in Tables 9–11 (pages 23–25).

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:

[12] 1900 Benjamin Franklin Parkway, Philadelphia, PA, 19103
[13] Jim Sweet, Aquatic Analysts, 22 Acme Rd., While Salmon, WA 98672

> *Fecal coliform organisms 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[14]/100 mL (Figures B116–B120, pages 213–217) and passed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

Coliform samples collected offshore from the Bloedel-Donovan swimming area had slightly higher counts than at Site 1 (mid-basin). None of the Bloedel-Donovan counts exceeded 100 cfu/100 mL, and with a geometric mean of 3.6, the Bloedel-Donovan site passed both parts of the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

2.3.8 Metals

The metals data for Lake Whatcom are included in Table 12 (page 26). 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 concentrations were measured in September at the bottom of Sites 1 and 2. These elevated iron concentrations were the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water. Chromium and copper were detected in many of the samples, but at levels close to detection limits and typical for Lake Whatcom.

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

2.3.9 Total organic carbon and disinfection by-products

Total organic carbon concentrations, along with plankton and chlorophyll data, are used to help assess the likelihood of developing potentially harmful disinfection by-products through the reaction of chlorine with organic compounds during the drinking water treatment process. Algae excrete dissolved organic carbon into water, which, along with other decaying organic material, can react with chlorine to form disinfection by-products, predominately chloroform and other trihalomethanes (THMs). As algal densities increase, we expect to see an increase in THMs. The major concern with THMs is their potential carcinogenicity. It can be difficult and expensive to remove THMs from drinking water (Viessman & Hammer, 1985).

Most of the 2007/2008 total organic carbon concentrations at the Intake were low ($\leq$2.5 mg/L; Table 13, page 27). Two high concentrations were reported in the February samples: 16.0 mg/L at Site 3 (bottom) and 7.0 mg/L at Site 4 (surface). These values were confirmed in the AmTest data report, but the results are atypical and may represent sample contamination. The long-term data suggest that the total organic carbon concentrations may be increasing over time, particularly at the gatehouse (Figure 12, page 39).[15]

As illustrated in Figure 13 (page 40), THMs have been increasing in Bellingham's treated drinking water, particularly during the late summer/fall (third quarter = September). The third quarter THMs were not as high in 2008 as in 2007, matching the Site 2 chlorophyll concentrations, which were not as high in 2008 as in 2007.

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.

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

Abbrev.	Parameter	Method	Historic DL†	2007/2008 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	–	–	$\pm$ 0.8 μS/cm
do	Dissolved oxygen	APHA (2005) #4500-O.C.; SOP-IWS-12	–	–	$\pm$ 0.1 mg/L
ph	pH-lab	APHA (2005) #4500-H^+; SOP-IWS-8	–	–	$\pm$ 0.03 pH unit
ts	T. solids	APHA (2005) #2540 B; SOP-IWS-22	2 mg/L	15.2 mg/L	$\pm$ 11.3 mg/L
tss	T. suspended solids	APHA (2005) #2540 D; SOP-IWS-22	2 mg/L	4.3 mg/L	$\pm$ 2.2 mg/L
turb	Turbidity	APHA (2005) #2130; SOP-IWS-11	–	–	$\pm$ 0.2 NTUs
nh3	Ammonia (auto)	APHA (2005) #4500-NH_3 H; SOP-IWS-19	10 μg-N/L	7.2 μg-N/L	$\pm$ 5.5 μg-N/L
no3	Nitrite/nitrate (auto)	APHA (2005) #4500-NO_3 I; SOP-IWS-19	20 μg-N/L	9.0 μg-N/L	$\pm$ 4.0 μg-N/L
tn	T. nitrogen (auto)	APHA (2005) #4500-N C; SOP-IWS-19	100 μg-N/L	14.4 μg-N/L	$\pm$ 18.1 μg-N/L
srp	Sol. phosphate (auto)	APHA (2005) #4500-P G; SOP-IWS-19	5 μg-P/L	1.1 μg-P/L	$\pm$ 1.9 μg-P/L
tp	T. phosphorus (auto)	APHA (2005) #4500-P H; SOP-IWS-19	5 μg-P/L	4.1 μg-P/L	$\pm$ 4.8 μg-P/L
IWS plankton analyses:					
chl	Chlorophyll	APHA (2005) #10200 H; SOP-IWS-16	–	–	$\pm$ 0.1 mg/m^3
chlo	Chlorophyta	Lind (1985), Schindler trap	–	–	–
cyan	Cyanophyta	Lind (1985), Schindler trap	–	–	–
chry	Chrysophyta	Lind (1985), Schindler trap	–	–	–
pyrr	Pyrrophyta	Lind (1985), Schindler trap	–	–	–
City coliform analyses:					
fc	Fecal coliform	APHA (2005) #9222 D		1 cfu/100 mL	–
AmTest analyses:					
As	T. arsenic	EPA (1994) 200.7	–	0.01 mg/L	–
Cd	T. cadmium	EPA (1994) 200.7	–	0.0005 mg/L	–
Cr	T. chromium	EPA (1994) 200.7	–	0.001 mg/L	–
Cu	T. copper	EPA (1994) 200.7	–	0.001 mg/L	–
Fe	T. iron	EPA (1994) 200.7	–	0.005 mg/L	–
Pb	T. lead	EPA (1979) 239.2	–	0.001 mg/L	–
Hg	T. mercury	EPA (1994) 245.1	–	0.0001 mg/L	–
Ni	T. nickel	EPA (1994) 200.7	–	0.005 mg/L	–
Zn	T. zinc	EPA (1994) 200.7	–	0.001 mg/L	–
TOC	T. organic carbon	EPA (1979) 415.1	–	1.0 mg/L	–

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

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

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.3	19.7	20.2	27.2	1.8	50
Conductivity (μS/cm)‡	57.7	59.8	60.1	67.1	2.2	157
Dissolved oxygen (mg/L)	0.3	10.1	8.9	12.6	3.6	210
pH	6.5	7.5	7.5	9.1	0.6	210
Temperature (°)	4.4	10.2	10.7	21.0	4.1	210
Turbidity (NTU)	0.5	0.7	1.2	9.4	1.4	49
Nitrogen - ammonium (μg-N/L)	$<$10	13.1	34.0	324.5	62.3	50
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	205.0	199.6	339.3	112.7	50
Nitrogen - total (μg-N/L)	196.5	353.0	351.4	499.4	88.8	30
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	9.9	1.5	50
Phosphorus - total (μg-P/L)	$<$5	8.9	10.6	73.8	11.4	50
Chlorophyll (mg/m^3)	0.4	3.4	3.6	9.3	2.3	50
Secchi depth (m)	3.2	4.8	5.3	7.5	1.2	10
Coliforms - fecal (cfu100 mL)§	$<$1	1	2	9	NA	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Conductivity data are incomplete from Oct-Dec 2007.
§Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 2: Summary of Site 1 ambient water quality data, Oct. 2007 – Sept. 2008.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.7	18.8	18.9	20.0	0.6	29
Conductivity (μS/cm)[‡]	56.3	58.1	58.0	59.9	1.0	83
Dissolved oxygen (mg/L)	9.3	10.6	10.7	12.1	0.9	110
pH	7.2	7.8	7.9	8.5	0.4	110
Temperature (°)	5.7	12.3	12.8	20.2	4.9	110
Turbidity (NTU)	0.4	0.6	0.6	2.1	0.3	30
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	20.6	4.6	30
Nitrogen - nitrate/nitrite (μg-N/L)	134.3	266.9	261.5	381.1	87.2	30
Nitrogen - total (μg-N/L)	243.7	371.0	378.6	497.5	78.2	18
Phosphorus - soluble (μg-P/L)	<5	<5	<5	5.1	1.1	30
Phosphorus - total (μg-P/L)	<5	6.3	5.7	15.7	3.7	30
Chlorophyll (mg/m^3)	1.5	3.0	3.0	5.1	.9	30
Secchi depth (m)	4.4	5.6	6.0	9.3	1.6	9
Coliforms - fecal (cfu/100 mL)[§]	<1	1	1	2	NA	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Conductivity data are incomplete from Oct-Dec 2007.
[§]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3: Summary of Intake ambient water quality data, Oct. 2007 – Sept. 2008.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	16.9	18.8	19.0	24.0	1.1	50
Conductivity (μS/cm)[‡]	56.4	57.6	58.0	66.2	1.6	157
Dissolved oxygen (mg/L)	0.3	10.3	9.8	12.1	2.6	210
pH	6.5	7.5	7.5	8.4	0.4	210
Temperature (°)	5.6	10.8	11.4	20.3	4.3	210
Turbidity (NTU)	0.4	0.5	0.6	1.8	0.3	50
Nitrogen - ammonium (μg-N/L)	<10	<10	18.9	232.7	37.4	50
Nitrogen - nitrate/nitrite (μg-N/L)	40.4	303.6	272.8	380.2	93.0	50
Nitrogen - total (μg-N/L)	252.8	398.8	397.2	550.8	81.7	30
Phosphorus - soluble (μg-P/L)	<5	<5	<5	7.1	1.3	50
Phosphorus - total (μg-P/L)	<5	6.0	6.8	35.3	5.8	50
Chlorophyll (mg/m^3)	0.8	3.1	3.0	4.7	.9	50
Secchi depth (m)	4.4	6.4	6.4	9.8	1.6	10
Coliforms - fecal (cfu/100 mL)[§]	<1	1	1	6	NA	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Conductivity data are incomplete from Oct-Dec 2007.
[§]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 4: Summary of Site 2 ambient water quality data, Oct. 2007 – Sept. 2008.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.7	18.3	18.5	19.7	0.5	68
Conductivity (μS/cm)‡	56.1	57.5	57.6	61.0	1.1	188
Dissolved oxygen (mg/L)	1.7	10.2	10.2	12.4	1.2	248
pH	6.7	7.5	7.6	8.6	0.5	248
Temperature (°)	5.8	7.0	9.4	19.4	4.3	248
Turbidity (NTU)	0.1	0.4	0.4	1.9	0.3	62
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	56.6	7.8	69
Nitrogen - nitrate/nitrite (μg-N/L)	167.8	372.9	344.0	453.8	80.6	69
Nitrogen - total (μg-N/L)	282.8	473.7	444.0	562.8	72.8	41
Phosphorus - soluble (μg-P/L)	<5	<5	<5	6.2	1.2	69
Phosphorus - total (μg-P/L)	<5	5.8	6.2	13.3	2.9	69
Chlorophyll (mg/m^3)	0.8	2.6	2.7	5.9	1.3	50
Secchi depth (m)	4.6	7.7	7.2	9.1	1.7	10
Coliforms - fecal (cfu/100 mL)§	<1	1	2	6	NA	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Conductivity data are incomplete from Oct-Dec 2007.
§Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 5: Summary of Site 3 ambient water quality data, Oct. 2007 – Sept. 2008.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.8	18.2	18.4	19.3	0.4	80
Conductivity (μS/cm)‡	56.1	57.4	57.5	60.2	1.0	205
Dissolved oxygen (mg/L)	8.2	10.2	10.2	12.3	0.9	270
pH	6.4	7.4	7.4	8.5	0.4	270
Temperature (°)	5.9	6.9	9.0	19.3	4.1	270
Turbidity (NTU)	0.2	0.4	0.4	1.7	0.2	72
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	25.1	4.8	80
Nitrogen - nitrate/nitrite (μg-N/L)	195.6	397.0	361.7	457.2	76.1	78
Nitrogen - total (μg-N/L)	288.0	475.0	454.7	561.6	67.6	48
Phosphorus - soluble (μg-P/L)	<5	<5	<5	<5	1.0	78
Phosphorus - total (μg-P/L)	<5	6.0	6.7	19.8	3.4	80
Chlorophyll (mg/m^3)	0.4	2.5	2.4	4.4	1.1	48
Secchi depth (m)	5.0	7.5	7.1	9.2	1.6	10
Coliforms - fecal (cfu/100 mL)§	<1	1	1	3	NA	9

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Conductivity data are incomplete from Oct-Dec 2007.
§Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 6: Summary of Site 4 ambient water quality data, Oct. 2006 – Sept. 2007.

		Feb	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Site 1	1988–2007 med	5.7	9.6	13.1	17.2	19.8	22.1	20.0	16.9	11.2	7.8
	1988–2007 min	4.5	7.9	11.7	14.4	17.3	19.4	18.4	14.5	9.6	5.7
	2008	5.1†	7.4‡	11.2‡	14.0‡	20.0	21.0†	18.8†	15.2†	11.8	9.2
Site 2	1988–2007 med	6.6	8.8	11.9	16.6	19.0	21.3	19.7	17.1	11.8	8.6
	1988–2007 min	5.6	7.3	10.5	13.8	15.9	18.8	18.4	15.4	10.4	5.0
	2008	5.9†	7.1‡	10.0‡	13.6‡	19.1	20.3†	18.5†	15.8†	12.6	9.9
Site 3	1988–2007 med	6.7	8.2	11.0	15.8	18.6	21.1	19.7	17.2	12.4	8.4
	1988–2007 min	5.8	6.7	9.6	12.9	16.1	18.8	18.5	15.0	10.6	6.0
	2008	5.8†	6.9†	9.5‡	13.3†	19.4	19.4†	18.5†	15.2†	12.7	10.0
Site 4	1988–2007 med	6.6	8.1	11.0	15.2	18.3	20.3	19.4	17.2	12.3	8.7
	1988–2007 min	5.7	6.8	9.5	12.2	15.9	18.5	18.3	14.8	10.5	7.2
	2008	5.9†	6.4‡	9.1‡	13.0†	18.1†	19.3†	18.1†	14.8†	12.4	9.8

†Colder than 1988–2007 median surface temperature.
‡Coldest surface temperature in 1988–2008 monitoring period.

Table 7: Comparison between 2008 surface water temperatures and median historic (1988–2007) surface water temperatures.

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

†Samples analyzed by Edge Analytical.

Table 8: October hypolimnetic ammonia and hydrogen sulfide concentrations at Sites 1 and 2, 1999–2008. The H_2S samples were analyzed in the field using a HACH test kit until 2005, when duplicate samples were analyzed by Edge Analytical, Bellingham, WA. After 2005, samples were analyzed by Edge Analytical.

	Site 1	Site 2	Intake	Site 3	Site 4
Chrysophyta - Diatoms					
Achnanthes minutissima	⋆	⋆	-	-	⋆
Achnanthidium sp.	-	-	-	○	○
Actinocyclus normanii	○	○	○	○	-
Asterionella formosa	○	○	●	○	○
Aulacoseira ambigua	○	○	○	○	○
Cocconeis sp.	-	-	○	○	-
Cyclotella bodanica	○	○	○	○	○
Cyclotella comta	⋆	⋆	⋆	⋆	⋆
Cyclotella kutzingiana	⋆	⋆	⋆	-	⋆
Cyclotella meneghiniana	○	○	○	○	○
Cyclotella ocellata	⋆	⋆	⋆	⋆	⋆
Cyclotella stelligera	⋆	⋆	⋆	⋆	⋆
Cyclotella sp.	○	○	○	○	○
Cymbella affinis	-	○	○	○	○
Cymbella naviculiformis	-	⋆	-	-	-
Diploneis sp.	○	-	○	○	-
Encyonema sp.	○	-	-	○	-
Fragilaria capucina	-		○	-	-
Fragilaria construens venter	-	-	⋆	-	-
Fragilaria crotonensis	○	○	●	●	○
Fragilaria sp.	-	-	○	○	-
Melosira ambigua	-	-	⋆	-	-
Nitzschia capitellata	⋆	-	-	-	-
Nitzschia sigmoidea	-	-	○	-	-
Nitzschia sp.	⋆	-	-	-	-
Stephanodiscus hantzschii	⋆	-	-	-	-
Stephanodiscus minutulus	○	○	○	○	-
Stephanodiscus niagarae	○	○	○	○	○
Stephanodiscus sp.	○	○	○	○	○
Synedra radians	⋆	⋆	⋆	⋆	⋆
Synedra rumpens	-	-	⋆	-	-
Synedra sp.	○	○	○	○	○
Thalassiosira pseudonana	○	○	○	○	○

Table 9: Diatoms in Lake Whatcom water samples collected on April 3, 2007 and October 14, 2008. Presence (April = ○; October = ⋆; both = ●) or absence (-) is indicated for each site. Taxonomic identifications were provided by the Academy of Natural Sciences of Philadelphia (April) or Aquatic Analysts (October).

	Site 1	Site 2	Intake	Site 3	Site 4
Other Chrysophyta					
Chromulina sp.	⋆	⋆	⋆	⋆	⋆
Dinobryon divergens	○	○	○	○	-
Dinobryon sertularia	-	-	⋆	-	⋆
Dinobryon sp.	-	-	○	-	-
Mallomonas sp.	●	○	○	●	⋆
Cyanobacteria					
Anabaena flos-aquae	-	-	-	⋆	-
Aphanocapsa sp.	-	○	○	○	○
Aphanothece sp.	⋆	-	●	●	○
Chroococcus minimus	⋆	-	-	-	⋆
Microcystis aeruginosa	⋆	-	-	-	-
Pseudanabaena sp.	○	-	○	-	○

Table 10: Non-diatom chrysophytes and cyanobacteria in Lake Whatcom water samples collected on April 3, 2007 and October 14, 2008. Presence (April = ○; October = ⋆; both = ●) or absence (-) is indicated for each site. Taxonomic identifications were provided by the Academy of Natural Sciences of Philadelphia (April) or Aquatic Analysts (October).

	Site 1	Site 2	Intake	Site 3	Site 4
Chlorophyta					
Ankistrodesmus falcatus	-	-	⋆	⋆	○
Ankistrodesmus sp.	-	○	○	○	○
Botryococcus braunii	-	-	-	○	-
Chlamydomonas sp.	⋆	⋆	⋆	⋆	⋆
Cosmarium sp.	-	-	-	-	⋆
Crucigenia quadrata	○	-	○	○	○
Crucigenia tetrapedia	●	○	○	○	○
Desmidium	-	-	⋆	⋆	-
Dictyosphaerium ehrenbergianum	-	-	⋆	-	-
Elakatothrix gelatinosa	-	○	○	-	-
Eudorina elegans	○	-	-	-	-
Mougeotia sp.	-	-	○	-	-
Oocystis lacustris	-	-	-	-	⋆
Oocystis parva	○	-	○	○	○
Oocystis sp.	-	○	-	-	○
Quadrigula lacustris	-	-	○	-	-
Quadrigula sp.	○	-	○	-	-
Scenedesmus ecornis	○	○	○	○	○
Scenedesmus quadricauda	⋆	⋆	⋆	⋆	⋆
Scenedesmus sp.	○	○	○	○	○
Sphaerocystis schroeteri	⋆	-	⋆	-	-
Tetraedron caudatum	-	-	○	-	-
Tetraedron minimum	○	○	●	○	○
Euglenophyta					
Euglena sp.	-	-	○	-	-
Cryptophyta					
Cryptomonas erosa	⋆	⋆	⋆	⋆	⋆
Cryptomonas ovata	○	○	○	○	○
Cryptomonas sp.	○	-	-	○	○
Rhodomonas minuta	⋆	⋆	⋆	⋆	⋆
Pyrrophyta					
Ceratium hirudinella	○	-	-	-	-
Glenodinium sp.	⋆	-	-	⋆	⋆
Peridinium willei	○	○	○	○	○

Table 11: Non-chrysophyte algae in Lake Whatcom water samples collected on April 3, 2007 and October 14, 2008. Presence (April = ○; October = ⋆; both = ●) or absence (-) is indicated for each site. Taxonomic identifications were provided by the Academy of Natural Sciences of Philadelphia (April) or Aquatic Analysts (October).

	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 19, 2008	<0.01	<0.0005	<0.001	0.002	0.094	<0.0001	<0.005	<0.001	0.003
Site 1	20	Feb 19, 2008	<0.01	<0.0005	0.003	0.002	0.025	<0.0001	<0.005	<0.001	<0.001
Intake	0	Feb 19, 2008	<0.01	<0.0005	<0.001	<0.001	0.015	<0.0001	<0.005	<0.001	<0.001
Intake	10	Feb 19, 2008	<0.01	<0.0005	0.002	<0.001	0.013	<0.0001	<0.005	<0.001	<0.001
Site 2	0	Feb 19, 2008	<0.01	<0.0005	<0.001	<0.001	0.013	<0.0001	<0.005	<0.001	<0.001
Site 2	20	Feb 19, 2008	<0.01	<0.0005	0.001	<0.001	0.013	<0.0001	<0.005	<0.001	<0.001
Site 3	0	Feb 14, 2008	<0.01	<0.0005	0.001	<0.001	0.016	<0.0001	<0.005	<0.001	<0.001
Site 3	80	Feb 14, 2008	<0.01	<0.0005	0.002	<0.001	0.016	<0.0001	<0.005	<0.001	<0.001
Site 4	0	Feb 14, 2008	<0.01	<0.0005	<0.001	<0.001	0.026	<0.0001	<0.005	<0.001	<0.001
Site 4	90	Feb 14, 2008	<0.01	<0.0005	0.002	<0.001	0.022	<0.0001	<0.005	<0.001	<0.001
Site 1	0	Aug 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.019	<0.0001	<0.005	<0.001	0.001
Site 1	20	Aug 7, 2008	<0.01	<0.0005	<0.001	0.002	0.289	<0.0001	<0.005	<0.001	0.009
Intake	0	Aug 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.013	<0.0001	<0.005	<0.001	0.004
Intake	10	Aug 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.011	<0.0001	<0.005	<0.001	<0.001
Site 2	0	Aug 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.016	<0.0001	<0.005	<0.001	0.001
Site 2	20	Aug 7, 2008	<0.01	<0.0005	<0.001	0.001	0.157	<0.0001	<0.005	<0.001	0.002
Site 3	0	Aug 5, 2008	<0.01	<0.0005	<0.001	<0.001	0.013	<0.0001	<0.005	<0.001	0.003
Site 3	80	Aug 5, 2008	<0.01	<0.0005	<0.001	<0.001	0.019	<0.0001	<0.005	<0.001	0.002
Site 4	0	Aug 5, 2008	<0.01	<0.0005	<0.001	<0.001	0.008	<0.0001	<0.005	<0.001	0.003
Site 4	90	Aug 5, 2008	<0.01	<0.0005	<0.001	<0.001	0.011	<0.0001	<0.005	<0.001	<0.001

Table 12: Lake Whatcom 2007/2008 total metals data. Only the metals specified in the monitoring plan are included in this table; the results for 24 additional metals are included in the online data files (http://www.ac.wwu.edu∼iws).

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 19, 2008	0	<1	Aug 7, 2008	0	1.6
	Feb 19, 2008	20	<1	Aug 7, 2008	20	1.5
Intake	Feb 19, 2008	0	2.4	Aug 7, 2008	0	1.2
	Feb 19, 2008	10	<1	Aug 7, 2008	10	2.3
Site 2	Feb 19, 2008	0	3.7	Aug 7, 2008	0	1.1
	Feb 19, 2008	20	<1	Aug 7, 2008	15	1.9
Site 3	Feb 14, 2008	0	<1	Aug 5, 2008	0	2.4
	Feb 14, 2008	80	16.0[†]	Aug 5, 2008	80	2.3
Site 4	Feb 14, 2008	0	7.0[†]	Aug 5, 2008	0	<1
	Feb 14, 2008	90	<1	Aug 5, 2008	90	1.9

[†]Atypical results; data verified in AmTest reports (http://www.ac.wwu.edu/∼iws).

Table 13: Lake Whatcom 2007/2008 total organic carbon data.

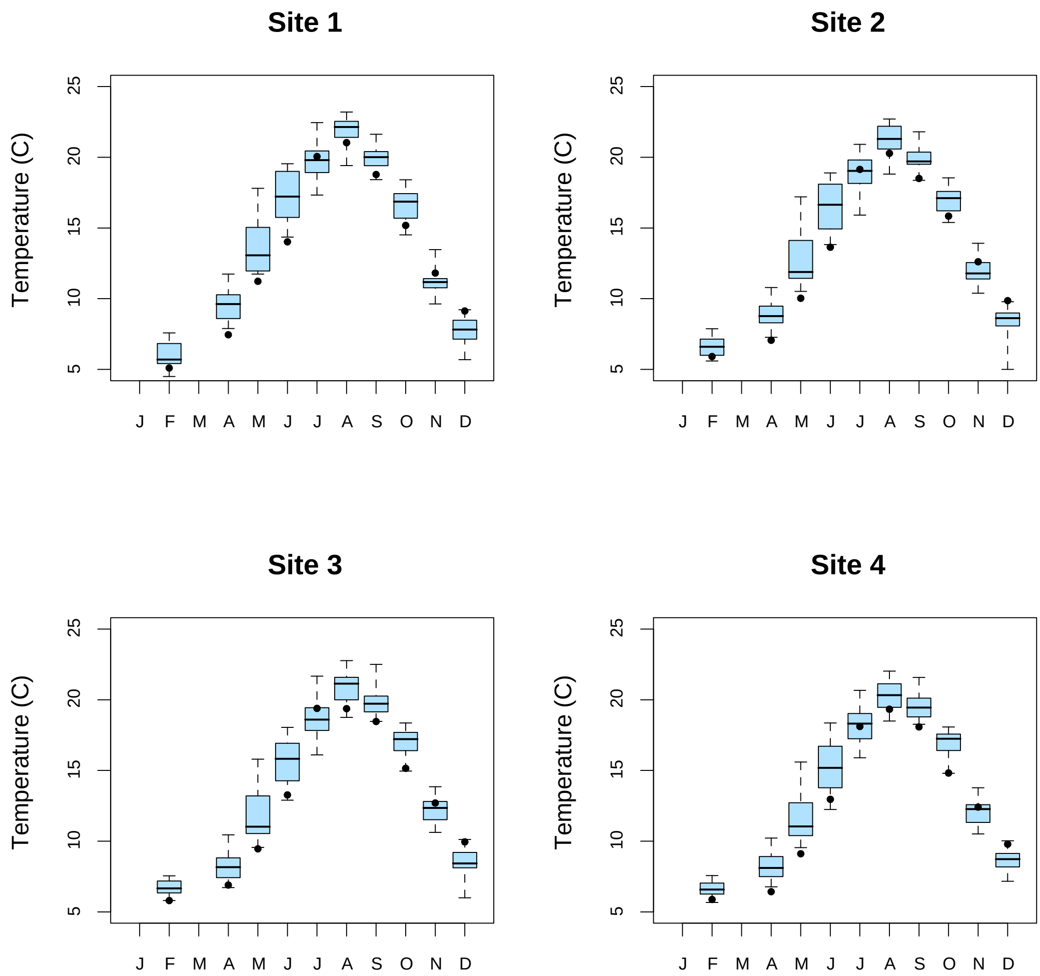

Figure 1: Boxplots showing 1988–2007 surface water temperatures (depth <1 m, all sites and years) with monthly 2008 data (●). Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

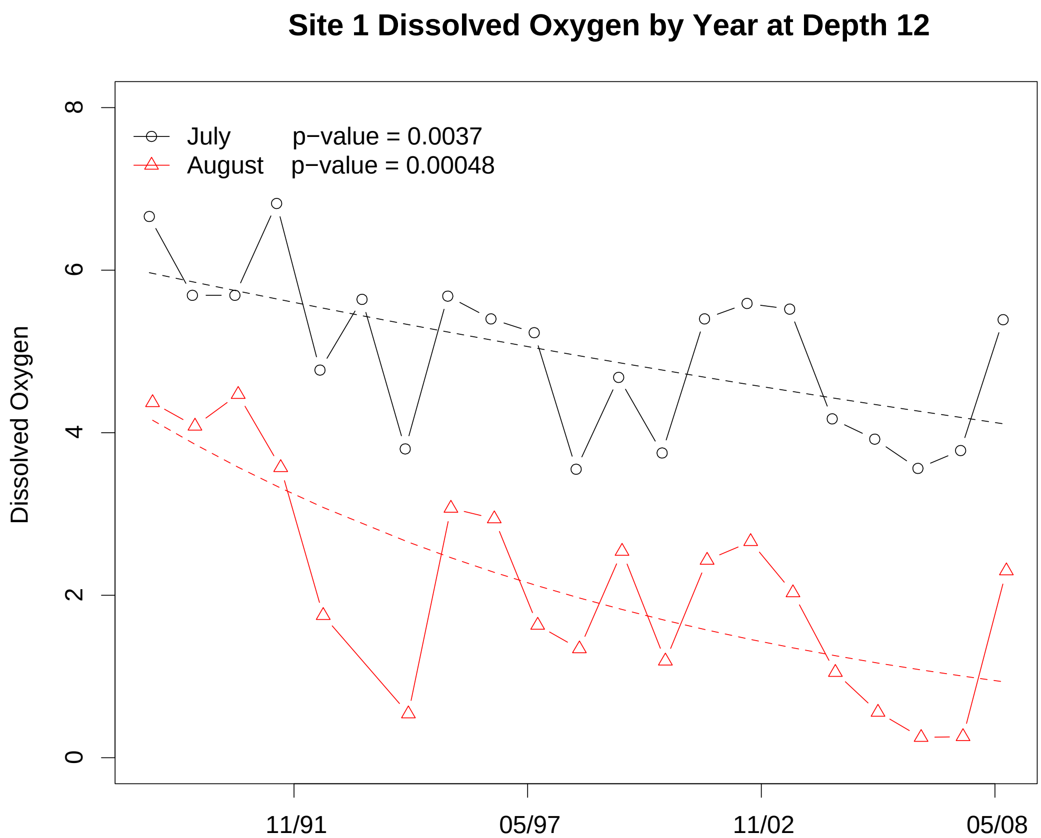

Figure 2: Nonlinear relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

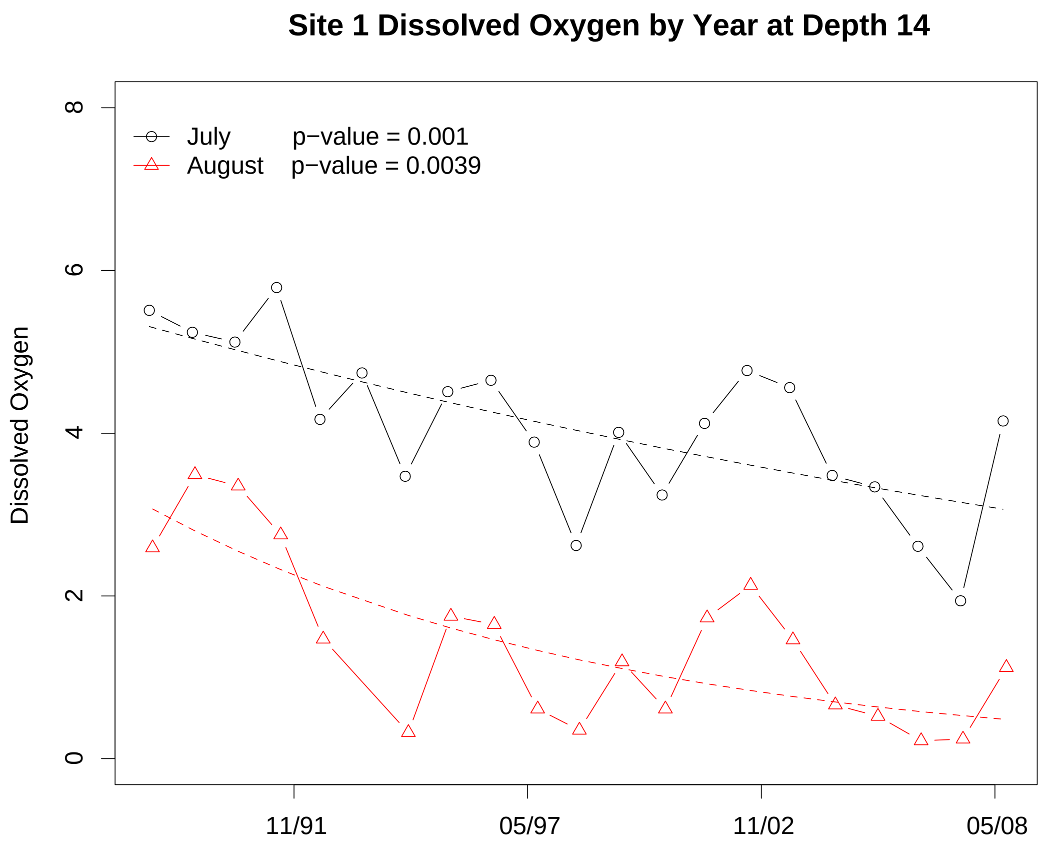

Figure 3: Nonlinear relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

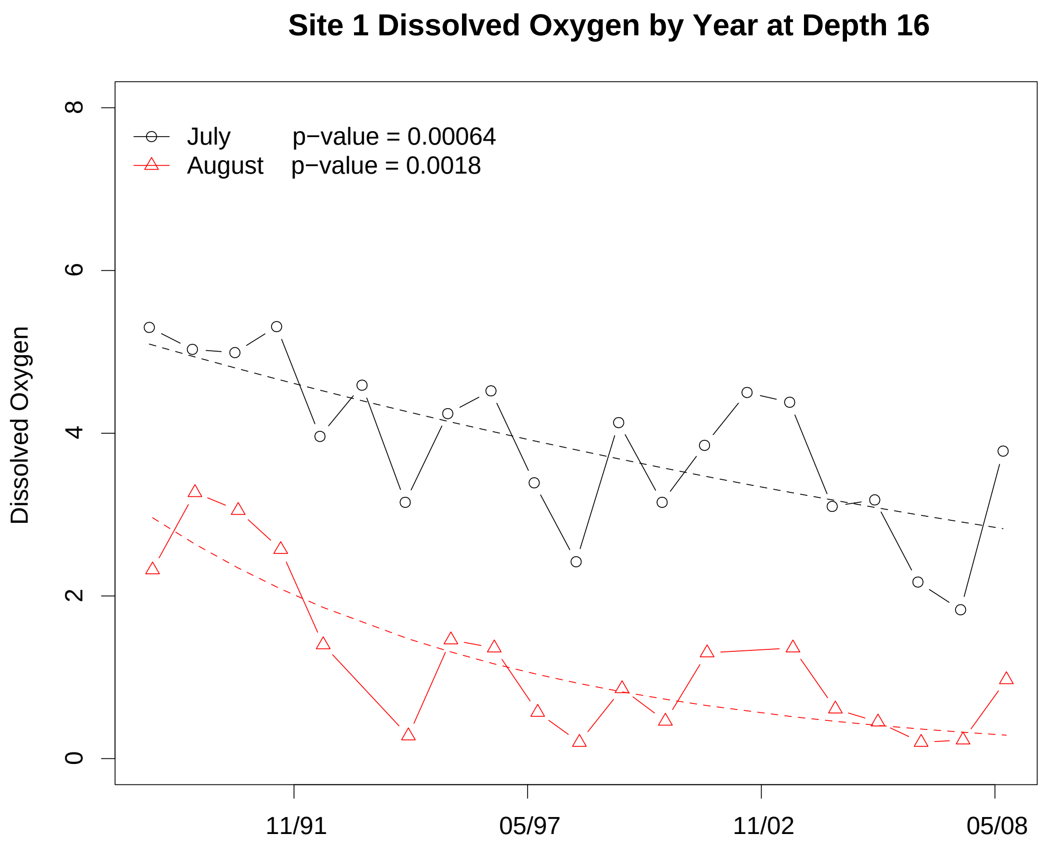

Figure 4: Nonlinear relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

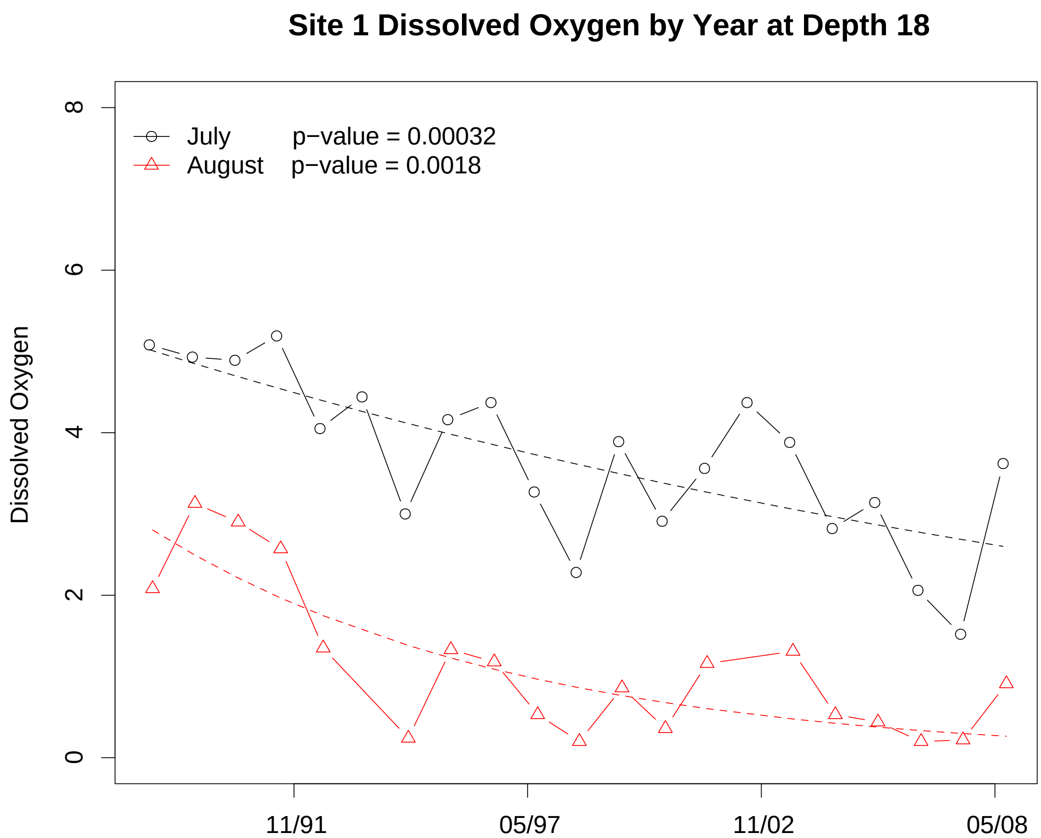

Figure 5: Nonlinear relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

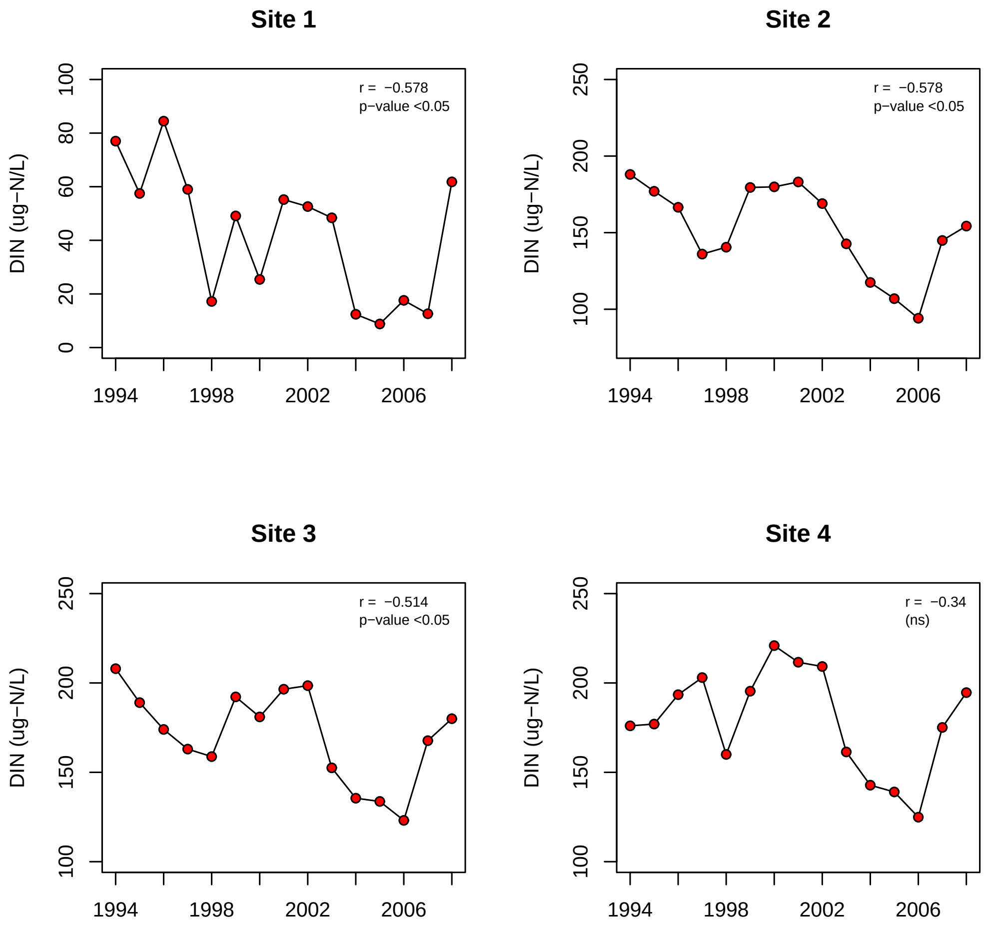

Figure 6: Minimum summer, near-surface dissolved inorganic nitrogen concentrations (1994–2008, June-Oct, depths $\leq$5 m). Pearson's r correlations were used because the data were approximately monotonic-linear; correlations were significant at Sites 1–3.

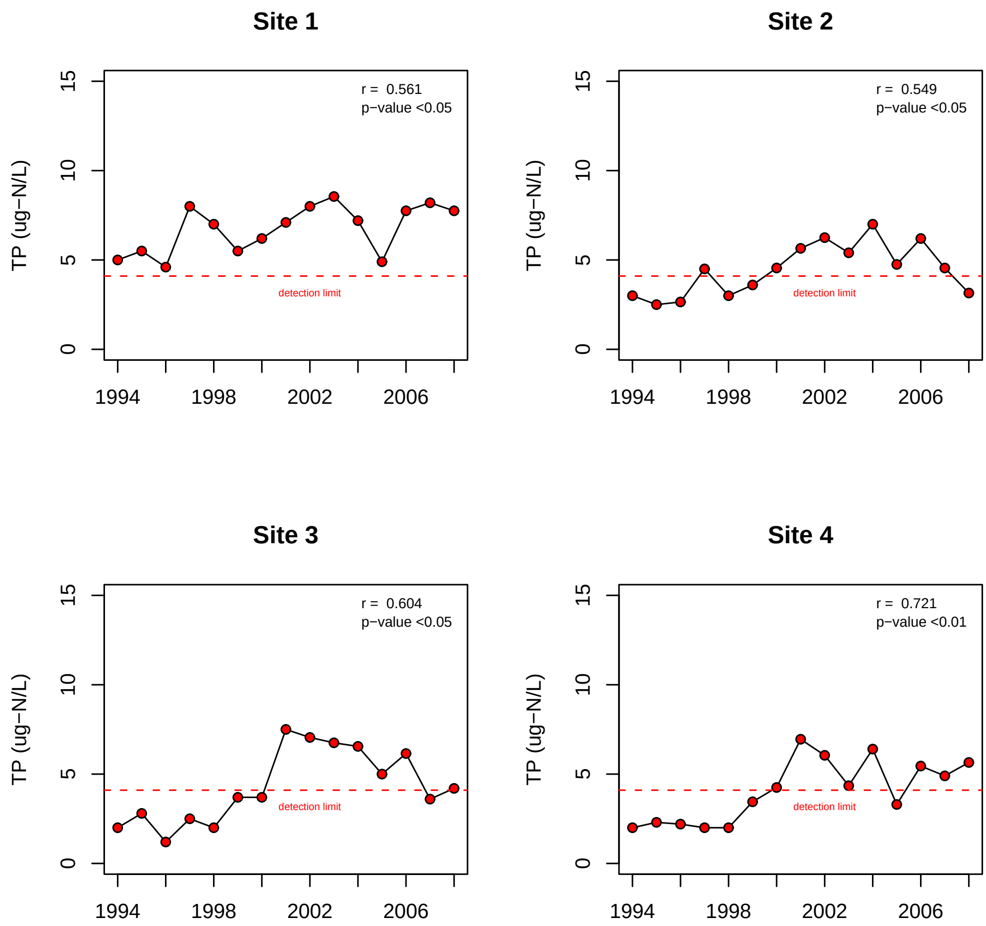

Figure 7: Median summer, near-surface total phosphorus concentrations (1994–2008, June-Oct, depths ≤5 m). Uncensored (raw) data were used to illustrate that median values are increasingly above analytical detection limits (Table 1). Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

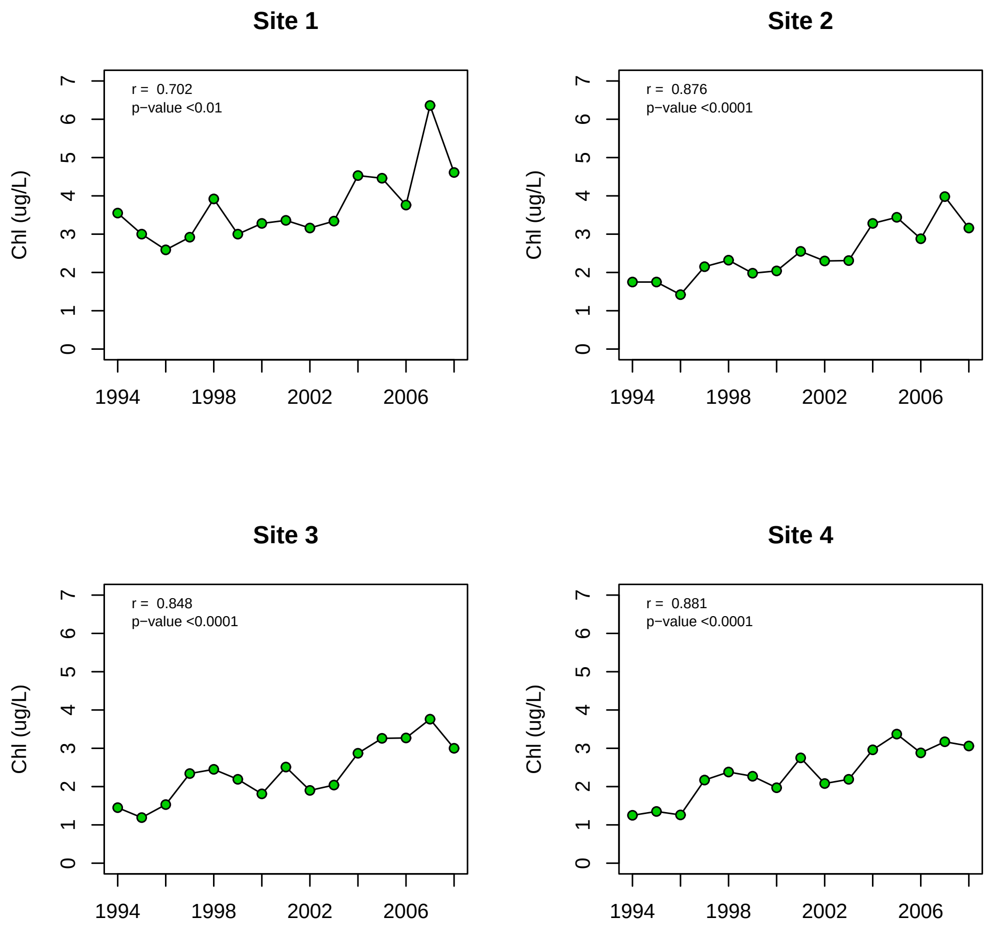

Figure 8: Median summer near-surface chlorophyll concentrations (1994–2008, June-October, depths $\leq$5 m). Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

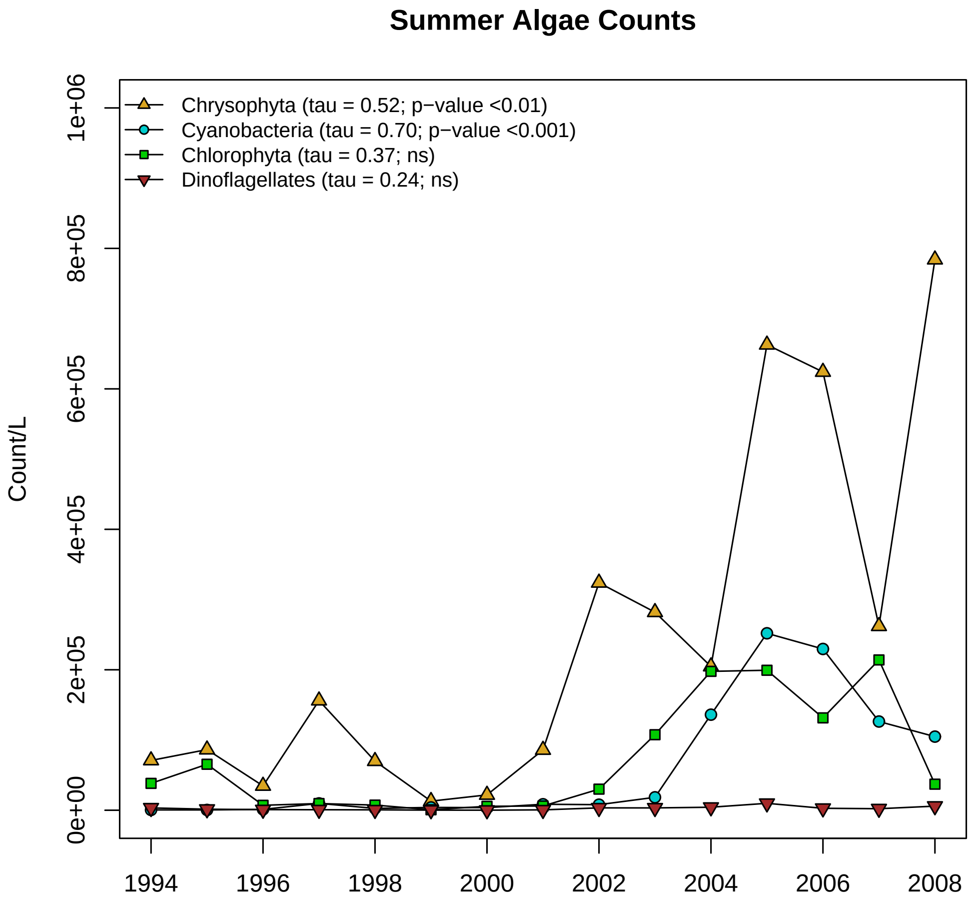

Figure 9: Median summer, near-surface algae counts (1994-2007, June-October, all sites and depths). Kendall's τ correlations were used because the data were not monotonic-linear; correlations for Chrysophyta and Cyanobacteria were significant.

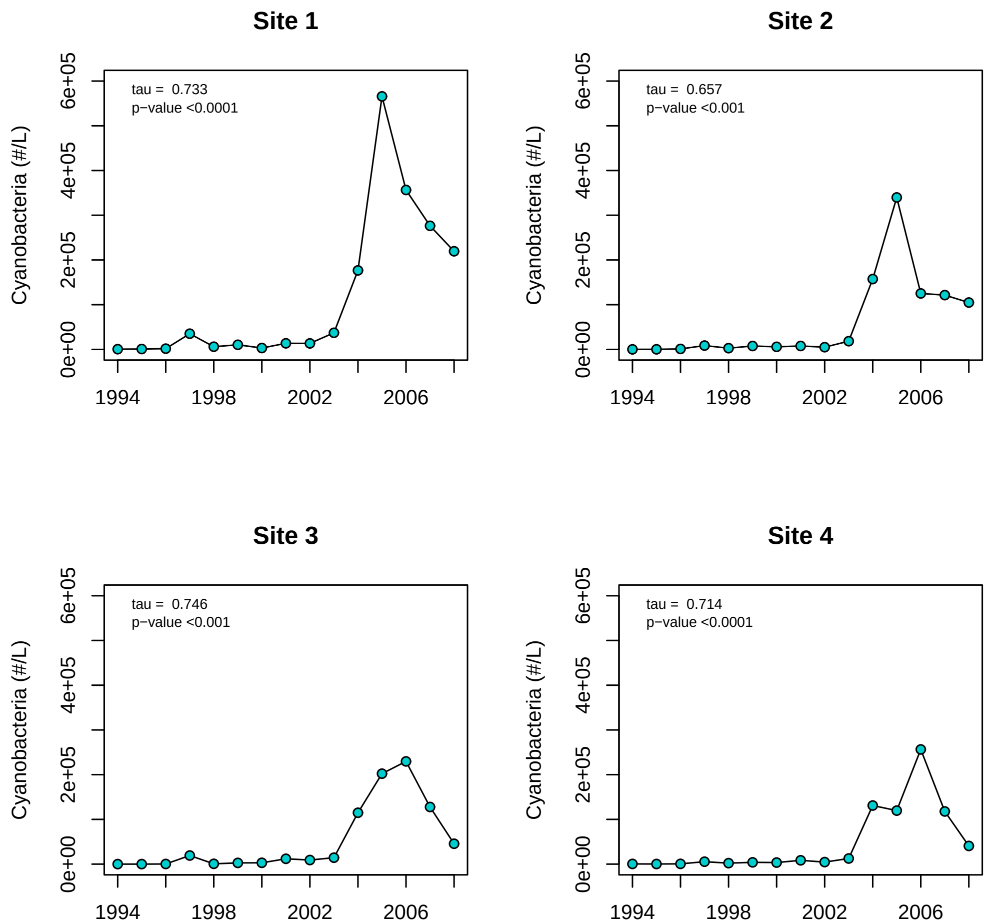

Figure 10: Median summer, near-surface cyanobacteria counts (1994–2008, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

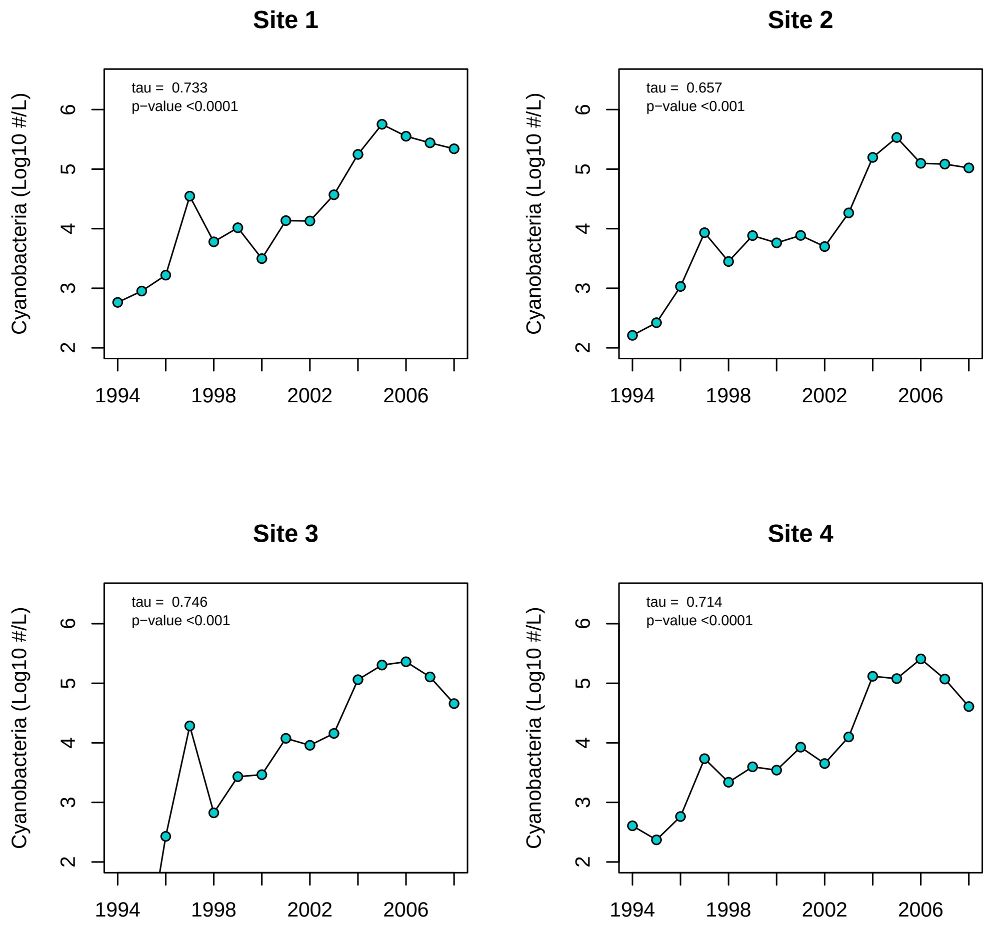

Figure 11: Log_{10} plots of median summer, near-surface cyanobacteria counts (1994–2008, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant. The correlation results in this figure are identical to Figure 10 because Kendall's τ is based on ranks.

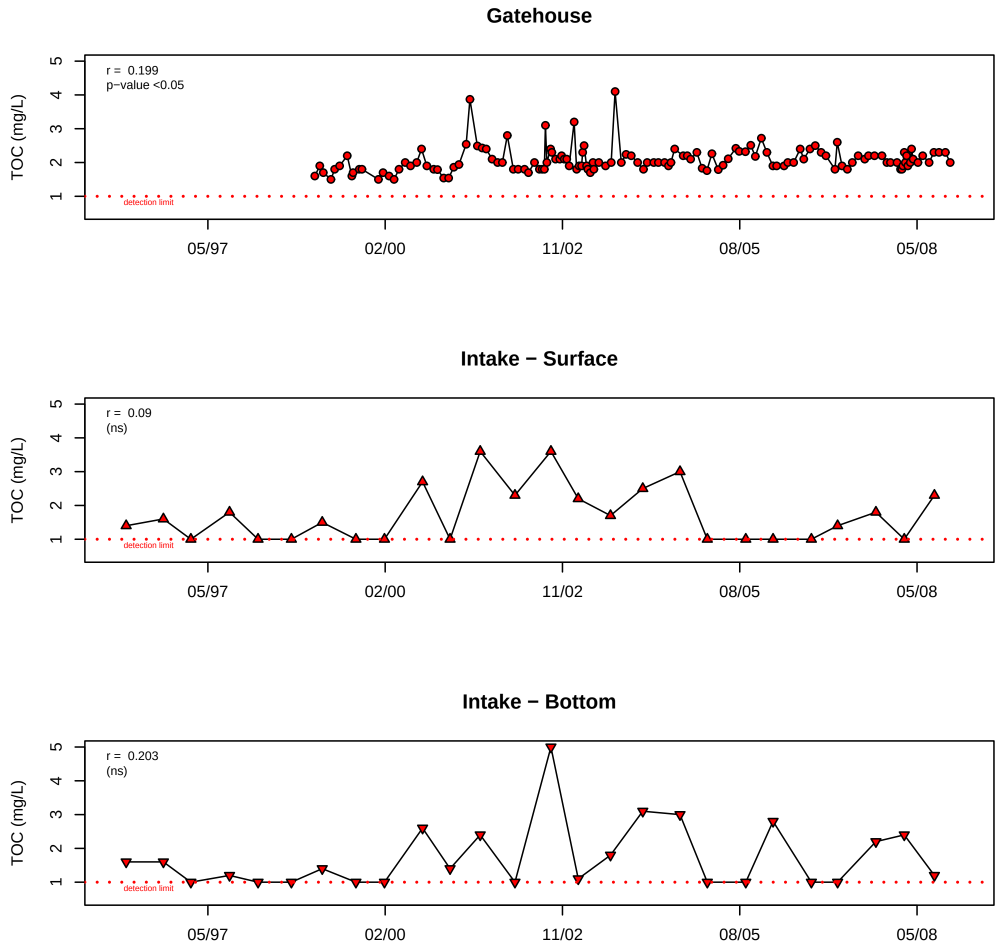

Figure 12: Total organic carbon concentrations at the Intake (off-shore, surface and bottom) and from the gatehouse. Gatehouse data were provided by the City of Bellingham Public Works Department. Pearson's r correlations were used because the data were approximately monotonic-linear; only the gatehouse correlation was significant.

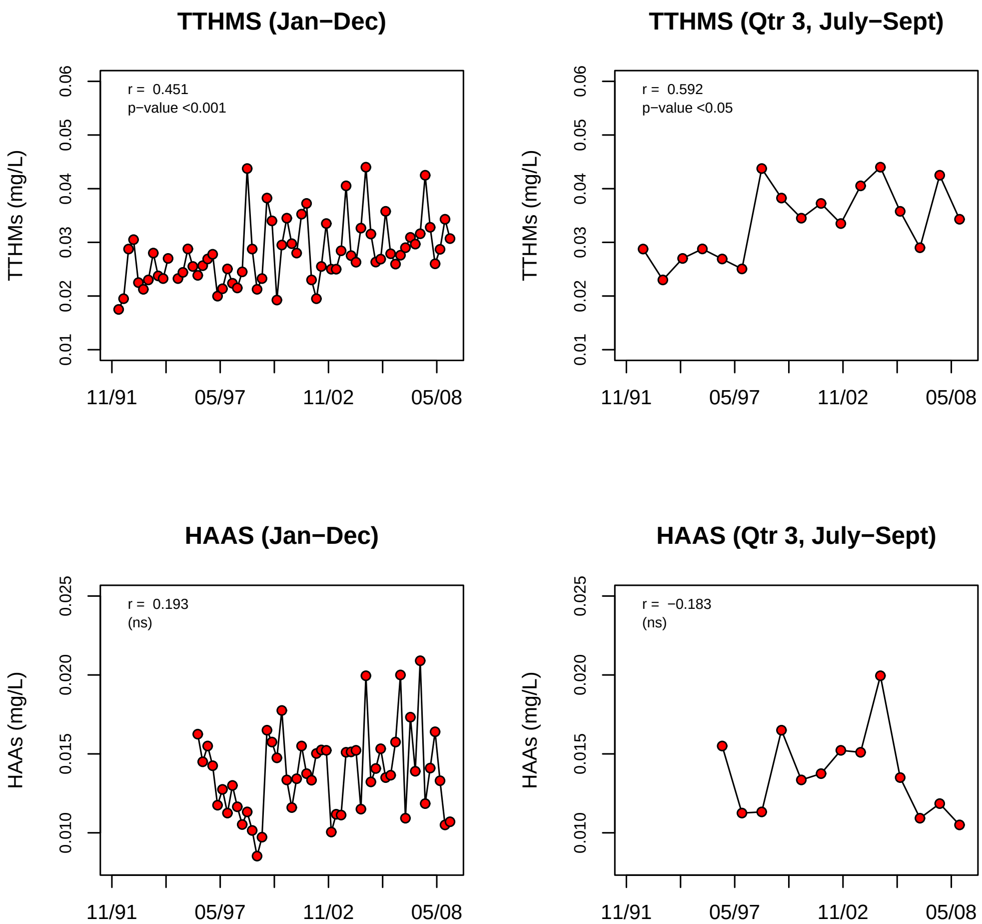

Figure 13: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2008. Data were provided by the City of Bellingham Public Works Department. Pearson's r correlations were used because the data were approximately monotonic-linear; correlations for Jan-Dec THMs and Qtr 3 THMs were significant.

3 Tributary Monitoring

The major objective for the tributary monitoring was to provide baseline data for the major tributaries that flow into Lake Whatcom. Whatcom Creek was also sampled to provide baseline data for the lake's outlet. Monthly baseline data were collected from 2004–2006. This level of effort was reduced in 2007, and tributary data are now collected twice each year.

3.1 Site Descriptions

Twelve sites were sampled twice during 2008 (February and September) to provide baseline tributary data in the Lake Whatcom watershed (Figure A2, page 86). Samples were collected from Anderson, Austin, Blue Canyon, Brannian, Carpenter, Euclid, Mill Wheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. The sampling locations for these sites are described in Appendix A.2.

3.2 Field Sampling and Analytical Methods

The analytical procedures for sampling the tributaries are summarized in Table 1 (page 15). All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory. Once in the laboratory the handling procedures that were relevant for each analysis were followed (see Table 1). The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. All other analyses were done by WWU personnel.

3.3 Results and Discussion

The current data are listed in Tables 14–17 (pages 44–47) and plotted in Appendix B.4 (Figures B131–B172, pages 229–269). The plots in Appendix B.4 also include the monthly data collected from October 2004-September 2006 data to show the typical ranges for each site. These figures include a dashed (blue) horizontal line that shows the median value for Smith Creek and a solid (red) horizontal line that shows the median value for each creek. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted.

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

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by pH levels near 6.8–7.5, conductivities $\leq$150 μS, alkalinities $\leq$50 mg/L, total solids $\leq$100 mg/L, and total organic carbon concentrations $<$2 mg/L (Figures B137–B151 and Table 17). Sites that did not match this description included the residential streams (Park Place, Euclid, Millwheel, and Silver Beach Creeks) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$15 mg/L) and low turbidities ($\leq$10 NTU) except during periods of high precipitation and runoff (Figures B146–B154).

Ammonia concentrations were elevated in several residential streams (Park Place and Millwheel; Figures B155–B157). 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 B158– B163). The relatively high nitrate and total nitrogen concentrations in Smith Creek may be due to the presence of nitrogen-fixing alders (*Alnus rubra*) in the riparian zone upstream from the sampling site. High nitrate and total nitrogen concentrations are not necessarily an indication of water pollution, and low nitrate concentrations actually favor the growth of nuisance Cyanobacteria. The exceptionally low concentrations in Whatcom Creek reflect algal uptake of nitrogen in the lake.

Soluble inorganic phosphate is quickly removed from surface water by biota, so high concentrations of soluble phosphorus usually indicate a near-by source such as an anaerobic wetland or a pollution source. In the Lake Whatcom tributaries, total phosphorus concentrations were usually much higher than soluble phosphate concentrations (Figures B164–B169). Total phosphorus and soluble phosphate concentrations were usually highest in the residential streams.

High coliform counts are an indicator of residential pollution (Figures B170–B172), and many of the Lake Whatcom tributaries exceeded the WAC 173–201A coliform surface water standards, based on the monthly data collected in 2004–2006 (Matthews, et al., 2007). The current biannual monitoring program does not provide enough data to assess whether sites fail to meet the WAC 173–201A standards; however, many sites had counts that exceeded 100 cfu/100 mL at least once, and three sites (Carpenter, Park Place, and Silver Beach) exceeded 100 cfu/100 mL in both samples (Table 15).

The metals concentrations were within expected ranges, and most were near or below detection levels (Table 16). Copper, iron, and zinc were often detectable, and were usually higher in residential tributaries, but all were within normal ranges for surface waters in the watershed.

Site	Date	Alk (mg/L)	Cond (μS/cm)	DO (mg/L)	pH	Temp (C)	Turb (NTU)	TS (mg/L)	TSS (mg/L)
Anderson	Feb 7, 2008	13.2	52.0	NA	6.89	4.4	2.24	41.0	3.4
	Jul 15, 2008	12.8	47.5	11.56	7.16	11.2	15.3	53.0	14.2
Austin	Feb 7, 2008	13.1	57.8	NA	7.12	5.0	7.05	58.3	14.5
	Jul 15, 2008	32.0	108.1	10.85	7.53	12.6	1.36	71.8	<2
Blue Canyon	Feb 7, 2008	108.9	252.0	NA	8.14	5.9	8.24	163.9	13.8
	Jul 15, 2008	133.6	283.0	11.56	8.14	11.7	3.34	167.2	4.5
Brannian	Feb 7, 2008	5.9	40.4	NA	6.89	4.8	3.06	39.1	4.4
	Jul 15, 2008	15.8	50.8	9.28	6.88	12.5	2.45	46.9	5.6
Carpenter	Feb 7, 2008	15.5	59.5	NA	7.19	4.2	6.19	61.3	4.4
	Jul 15, 2008	43.9	112.7	9.22	7.58	16.0	0.69	84.7	<2
Euclid	Feb 7, 2008	18.2	75.4	NA	7.23	4.6	6.56	60.3	7.6
	Jul 15, 2008	56.7	144.7	8.21	7.21	14.1	3.34	97.3	<2
Millwheel	Feb 7, 2008	21.1	80.4	NA	7.17	5.2	16.20	76.0	10.7
	Jul 15, 2008	83.5	178.9	0.9	7.24	22.0	5.60	131.1	5.7
Olsen	Feb 7, 2008	18.8	74.5	NA	7.4	3.9	3.09	63.8	2.4
	Jul 15, 2008	38.5	104.2	10.23	7.67	15.0	0.85	76.1	<2
Park Place	Feb 7, 2008	78.2	207.0	NA	7.49	4.8	4.75	139.7	<2
	Jul 15, 2008	125.2	282.0	7.58	7.79	18.2	2.06	173.8	<2
Silver Beach	Feb 7, 2008	48.3	135.0	NA	7.7	4.4	12.40	104.2	5.5
	Jul 15, 2008	127.4	288.0	9.48	8.06	15.8	2.51	181.2	<2
Smith	Feb 7, 2008	14.1	63.0	NA	7.27	4.2	2.80	54.7	3.1
	Jul 15, 2008	27.8	79.5	10.49	7.59	14.4	0.42	57.9	<2
Whatcom	Feb 7, 2008	19.7	62.9	NA	7.34	4.3	1.21	38.7	<2
	Jul 15, 2008	20.7	61.8	9.02	7.46	21.6	1.14	42.9	2.2

Table 14: Lake Whatcom tributary data: alkalinity, conductivity, dissolved oxygen, temperature, turbidity, pH, total solids and total suspended solids.

Site	Date	NH3 (μg-N/L)	NO3 (μg-N/L)	TN (μg-N/L)	SRP (μg-P/L)	TP (μg-P/L)	FC (cfu/100 mL)
Anderson	Feb 7, 2008	14.8	830.7	1038.1	<5	11.6	26
	Jul 15, 2008	14.8	67.1	NA	<5	29.9	22
Austin	Feb 7, 2008	<10	1018.9	1191.6	6.6	20.5	28
	Jul 15, 2008	20.0	337.3	NA	12.5	18.2	62
Blue Canyon	Feb 7, 2008	12.2	939.5	1197.7	7.9	20.1	1
	Jul 15, 2008	12.4	136.6	NA	8.5	9.2	30
Brannian	Feb 7, 2008	<10	1353.5	1519.3	<5	11.6	21
	Jul 15, 2008	19.6	324.4	NA	5.6	12.2	63
Carpenter	Feb 7, 2008	<10	1001.2	1335.4	5.5	20.3	120
	Jul 15, 2008	13.2	466.0	NA	20.6	20.5	300
Euclid	Feb 7, 2008	20.2	911.4	1121.3	9.6	28.1	59
	Jul 15, 2008	33.6	133.6	NA	12.3	28.1	1100
Millwheel	Feb 7, 2008	<10	1379.9	1664.4	7.3	40.9	100
	Jul 15, 2008	87.9	<20	NA	27.1	103.0	83
Olsen	Feb 7, 2008	23.6	1825.9	2108.1	6.5	15.4	63
	Jul 15, 2008	14.3	537.4	NA	19.8	17.3	100
Park Place	Feb 7, 2008	11.0	1003.0	1274.0	14.6	31.5	100
	Jul 15, 2008	142.7	498.4	NA	44.2	86.8	1100
Silver Beach	Feb 7, 2008	<10	647.5	963.7	10.2	37.2	150
	Jul 15, 2008	12.6	427.6	NA	28.2	42.7	3600
Smith	Feb 7, 2008	15.3	2018.4	2191.5	6.4	12.5	15
	Jul 15, 2008	<10	670.6	NA	12.8	15.2	19
Whatcom	Feb 7, 2008	<10	325.0	470.4	<5	<5	10
	Jul 15, 2008	18.3	147.2	NA	<5	10.1	32

Table 15: Lake Whatcom tributary data: ammonia, nitrate/nitrite, total nitrogen, soluble phosphate, total phosphorus, and fecal coliforms.

	Date	T. As (mg/L)	T. Cd (mg/L)	T. Cr (mg/L)	T. Cu (mg/L)	T. Fe (mg/L)	T. Hg (mg/L)	T. Ni (mg/L)	T. Pb (mg/L)	T. Zn (mg/L)
Anderson	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.220	<0.0001	<0.005	<0.001	0.002
Austin (lower)	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.685	<0.0001	<0.005	<0.001	0.006
Blue Canyon	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.680	<0.0001	<0.005	0.002	<0.001
Brannian	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.285	<0.0001	<0.005	0.002	<0.001
Carpenter	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.456	<0.0001	<0.005	0.001	0.001
Euclid	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.450	<0.0001	<0.005	0.001	<0.001
Millwheel	Feb 7, 2008	<0.01	<0.0005	<0.001	0.004	0.984	<0.0001	<0.005	0.001	0.006
Olsen	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.195	<0.0001	<0.005	<0.001	<0.001
Park Place	Feb 7, 2008	<0.01	<0.0005	<0.001	0.002	0.426	<0.0001	<0.005	<0.001	0.004
Silver Beach	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.885	<0.0001	<0.005	<0.001	<0.001
Smith	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.175	<0.0001	<0.005	0.001	<0.001
Whatcom	Feb 7, 2008	<0.01	<0.0005	<0.001	<0.001	0.039	<0.0001	<0.005	0.001	<0.001
Anderson	Jul 15, 2008	<0.01	<0.0005	0.002	0.003	0.719	<0.0001	<0.005	<0.001	0.002
Austin (lower)	Jul 15, 2008	<0.01	<0.0005	<0.001	<0.001	0.362	<0.0001	<0.005	<0.001	0.002
Blue Canyon	Jul 15, 2008	<0.01	<0.0005	<0.001	<0.001	0.218	<0.0001	<0.005	<0.001	0.001
Brannian	Jul 15, 2008	<0.01	<0.0005	0.002	0.002	0.972	<0.0001	<0.005	<0.001	0.003
Carpenter	Jul 15, 2008	<0.01	<0.0005	<0.001	<0.001	0.108	<0.0001	<0.005	<0.001	<0.001
Euclid	Jul 15, 2008	<0.01	<0.0005	<0.001	0.004	0.968	<0.0001	<0.005	<0.001	0.004
Millwheel	Jul 15, 2008	<0.01	<0.0005	<0.001	0.003	2.200	<0.0001	<0.005	<0.001	0.003
Olsen	Jul 15, 2008	<0.01	<0.0005	<0.001	0.003	0.068	<0.0001	<0.005	<0.001	<0.001
Park Place	Jul 15, 2008	<0.01	<0.0005	<0.001	0.005	0.483	<0.0001	<0.005	<0.001	0.008
Silver Beach	Jul 15, 2008	<0.01	<0.0005	0.002	0.003	0.272	<0.0001	<0.005	<0.001	0.001
Smith	Jul 15, 2008	<0.01	<0.0005	<0.001	<0.001	0.045	<0.0001	<0.005	<0.001	0.002
Whatcom	Jul 15, 2008	<0.01	<0.0005	<0.001	<0.001	0.069	<0.0001	<0.005	<0.001	0.001

Table 16: Lake Whatcom tributary data: total metals. Only the metals specified in the monitoring plan are included in this table; the results for 24 additional metals are included in in the online data files (http://www.ac.wwu.edu/∼iws).

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Anderson	Feb 7, 2008	<1	Jul 15, 2008	<1
Austin (lower)	Feb 7, 2008	<1	Jul 15, 2008	<1
Blue Canyon	Feb 7, 2008	1.4	Jul 15, 2008	<1
Brannian	Feb 7, 2008	<1	Jul 15, 2008	<1
Carpenter	Feb 7, 2008	1.1	Jul 15, 2008	<1
Euclid	Feb 7, 2008	4.0	Jul 15, 2008	1.7
Millwheel	Feb 7, 2008	2.8	Jul 15, 2008	11.0
Olsen	Feb 7, 2008	4.1	Jul 15, 2008	1.4
Park Place	Feb 7, 2008	2.4	Jul 15, 2008	13.0
Silver Beach	Feb 7, 2008	1.5	Jul 15, 2008	19.0
Smith	Feb 7, 2008	<1	Jul 15, 2008	<1
Whatcom	Feb 7, 2008	1.2	Jul 15, 2008	1.0

Table 17: Lake Whatcom tributary data: total organic carbon.

4 Lake Whatcom Hydrology

4.1 Hydrograph Data

Recording hydrographs are installed in Austin and Smith Creeks; the data are plotted in Figures 14–15 (pages 54–55). The location of each hydrograph is described in Appendix A.2. All hydrograph data, including data from previous years, are online at http://www.ac.wwu.edu/∼iws. Detailed field notes for each water year are available from the Institute for Watershed Studies. All results are reported as Pacific Standard Time, without Daylight Saving Time adjustment.

The historic hydrograph data were recorded at 30 minute intervals until 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. Figure 16 (page 56) shows the rating curves for each hydrograph. New rating curves need to be generated whenever the creek channel is significantly altered due to storm runoff or construction activities. Starting dates for each rating curve are indicated in Figure 16. 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 its major water inputs and outputs and to examine runoff and storage. The traditional method of estimating a water balance was employed, where inputs - outputs = change in storage (Table 18, page 51). Inputs into the lake include direct precipitation, water diverted from the Middle Fork of the Nooksack River (diversion), runoff (surface runoff + groundwater). Outputs include evaporation, Whatcom Creek, the Whatcom Falls Fish Hatchery, City of Bellingham, Puget Sound Energy Co-Generation Plant (PSE)[16], and the Lake Whatcom Water and Sewer District.[17] 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.

[16] Located at the Georgia Pacific site
[17] 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, Smith Creek, and Brannian Creek gauges. A daily weighted average was calculated using a 10 meter raster of the lake, the four point values, and a kriging, spatial interpolation technique in ArcGIS. The average direct-precipitation depth (inches) for a given day was converted to volume in millions of gallons (MG) via a rating curve generated from the lake level-area data (Ferrari and Nuanes, 2001). The rating curve accounts for changes in surface area of the lake due to lake level changes. The average annual direct rainfall to the lake for the water year 2007/2008 was 44.3 inches (6006 MG), the lowest rainfall in the last 5 years.

Diversion volumes from the Middle Fork of the Nooksack River were estimated by separating the modeled natural discharge in Anderson Creek from the discharge recorded by the USGS at the mouth of Anderson Creek (USGS station number 12201950). The Distributed Hydrology-Soils-Vegetation Model (DHSVM) was used to simulate the natural flow in Anderson Creek. 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). Outfall data recorded by the City of Bellingham at the diversion dam on the Middle Fork were used to validate the timing and magnitudes of the flow volumes estimated from the hydrograph separation technique.

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 Smith Creek weather station in the watershed were used to estimate daily averages. The daily evaporation depths (inches) predicted by the model were converted to volumes (MG) via a rating curve generated from the lake level-area data developed by Ferrari and Nuanes (2001). The estimated yearly evaporation from the lake for the water year 2007/2008 was 20.5 inches (2807 MG), most of which occurred between May 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-capacity data developed by Ferrari and Nuanes (2001). The rating curve accounts for changes in volume of the lake due to lake level changes. The median total lake volume in 2007/2008 was 253,003 MG. Figure 17 (page 57) shows daily lake-volume values for the past five years. Although the rainfall was the lowest during the past 5 years, the median lake volume was the highest.

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 magnitudes.

The daily water balance quantities were summed into 7-day totals, which were used to generate Figures 18–21 (pages 58–61). Figure 18 shows 7-day summed totals for inputs, outputs, and change in storage. All the inputs except runoff are shown in Figure 19; all outputs except Whatcom Creek are shown in Figure 20. Due to their much higher magnitude, runoff and Whatcom Creek data are included on Figure 21.

Yearly water balance totals are listed in Table 18 (page 51) along with the yearly total values for the four previous water years. The total volume of outputs correspond to 13.4% of the median total volume of the lake. Under the assumption that the lake is completely mixed and flow is steady state (inputs = outputs), this would correspond to a 7.5 year residence time, with residence times for the past 5 years ranging from 6.1–7.5 years.[18] Tables 19 and 20 (pages 52–53) show the 2007/2008 total input and output volumes along with the corresponding monthly percentage of each total.

The DHSVM was also used to simulate surface-water runoff into the lake (Figure 21). 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.

[18] 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.

	WY2008 (9/30/07–10/1/08)	WY2007 (9/30/06–10/1/07)	WY2006 (9/30/05–10/1/06)	WY2005 (9/30/04–10/1/05)	WY2004 (9/30/03–10/1/04)
Inputs (MG)					
Direct Precipitation	6,006 (16.7)	7,063 (18.2)	6,783 (17.9)	6,501 (16.2)	7,612 (18.6)
Diversion	4,902 (13.7)	2,920 (7.5)	4,155 (11.0)	3,852 (9.6)	5,095 (12.4)
Runoff*	24,989 (69.6)	28,717 (74.2)	26,879 (71.1)	29,673 (74.1)	28,288 (69.0)
Total	35,896 (100)	38,700 (100)	37,817 (100)	40,026 (100)	40,995 (100)
Outputs (MG)					
Whatcom Creek	25,793 (76.1)	30,359 (77.1)	28,290 (74.8)	30,899 (74.0)	26,948 (71.2)
Hatchery	931 (2.7)	1,002 (2.5)	1,253 (3.3)	1,288 (3.1)	1,278 (3.4)
Puget Sound Co-Gen (PSE)	240 (0.7)	807 (2.0)	960 (2.5)	2,198 (5.3)	2,053 (5.4)
City of Bellingham	3,874 (11.4)	4,145 (10.5)	4,111 (10.9)	4,111 (9.8)	4,449 (11.8)
LW Water/Sewer Distr.	237 (0.7)	232 (0.6)	242 (0.6)	252 (0.6)	204 (0.5)
Evaporation	2,807 (8.3)	2,831 (7.2)	2,946 (7.8)	2,990 (7.2)	2,924 (7.7)
Total	33,883 (100)	39,376 (100)	37,802 (100)	41,738 (100)	37,855 (100)
Net change in storage	2,033	-520	15	-1,692	3,139
Median lake volume (MG)	253,003	252,759	252,287	252,856	252,970
Outflow percent of volume	13.4%	15.6%	15.0%	16.5%	15.0%
Residence time (years)**	7.5	6.4	6.7	6.1	6.7

*Runoff = surface runoff + groundwater

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

Table 18: Annual water balance quantities for the Lake Whatcom watershed, WY2004–WY2008.

	Input Percents			
Month	Diver	Precip	Runoff*	Total
Oct	10.99	12.08	4.03	6.33
Nov	6.10	8.51	4.84	5.63
Dec	1.49	16.35	16.58	14.48
Jan	2.44	10.26	16.24	13.36
Feb	0.08	7.80	15.08	11.81
Mar	2.49	12.43	13.02	11.48
Apr	4.69	5.50	10.21	8.67
May	22.12	5.62	8.74	10.05
Jun	28.14	7.57	7.58	10.39
Jul	14.55	1.89	0.48	2.64
Aug	6.91	11.03	2.24	4.35
Sep	0.00	0.95	0.95	0.82
	Input Volume (MG)			
Total	4,902	6,006	24,989	35,896

*Runoff = surface runoff + groundwater

Table 19: Monthly input water balance quantities for the Lake Whatcom watershed, October 2007–September 2008.

	Output Percents						
Month	WC	Hatch	PSE	COB	WSD	Evap	Total
Oct	12.15	9.98	20.82	7.90	8.60	5.32	11.07
Nov	6.86	9.35	14.72	7.27	8.20	2.52	6.68
Dec	13.97	10.00	29.90	7.13	8.40	1.68	12.14
Jan	18.90	10.57	11.42	7.53	8.06	1.34	15.78
Feb	14.82	9.79	15.80	6.90	7.37	3.02	12.76
Mar	3.61	10.42	4.73	7.43	7.77	6.17	4.48
Apr	2.56	5.62	0.19	7.30	7.37	9.27	3.76
May	10.10	2.70	0.09	7.85	7.85	11.71	9.69
Jun	10.91	6.42	0.07	8.77	8.76	14.66	10.76
Jul	2.39	3.82	1.12	12.65	10.43	21.64	5.24
Aug	1.86	10.59	0.74	10.72	9.06	13.55	4.13
Sep	1.87	10.74	0.40	8.55	8.13	9.12	3.51
	Output Volume (MG)						
Total	25,793	931	240	3,874	237	2,807	33,883

Table 20: Monthly output water balance quantities for the Lake Whatcom watershed, October 2007–September 2008.

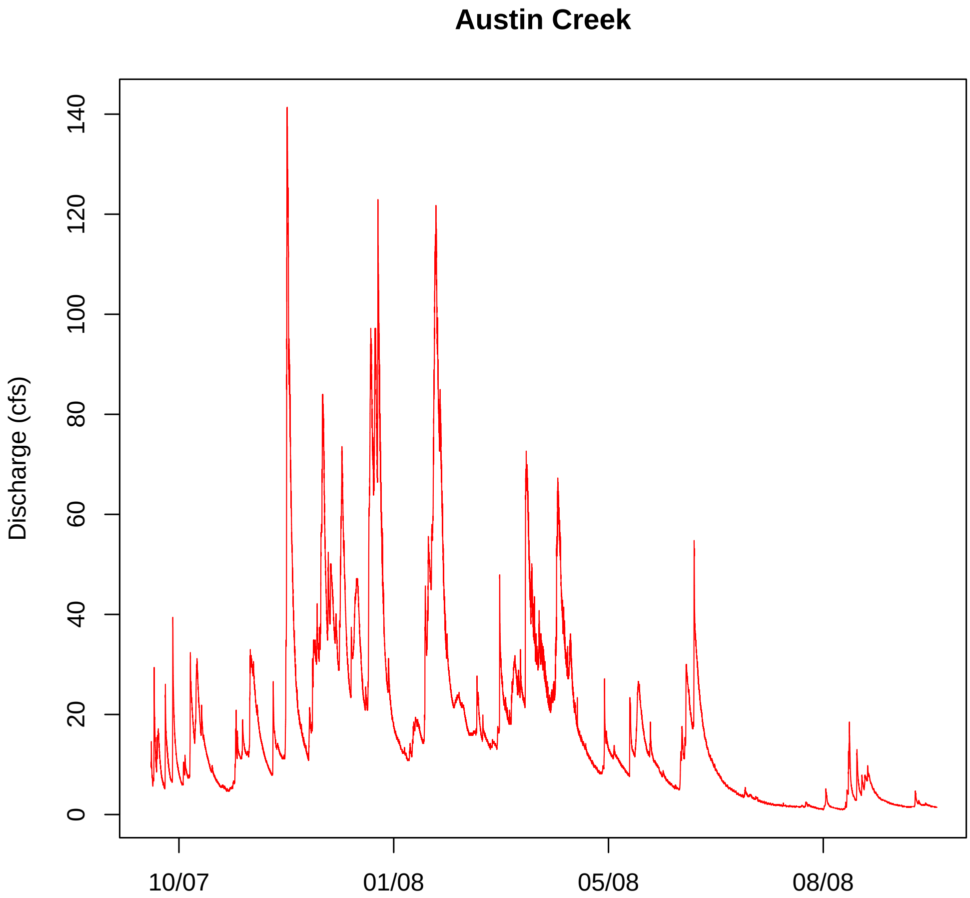

Figure 14: Austin Creek hydrograph, October 1, 2007–September 30, 2008. Data were recorded at 15 minute intervals.

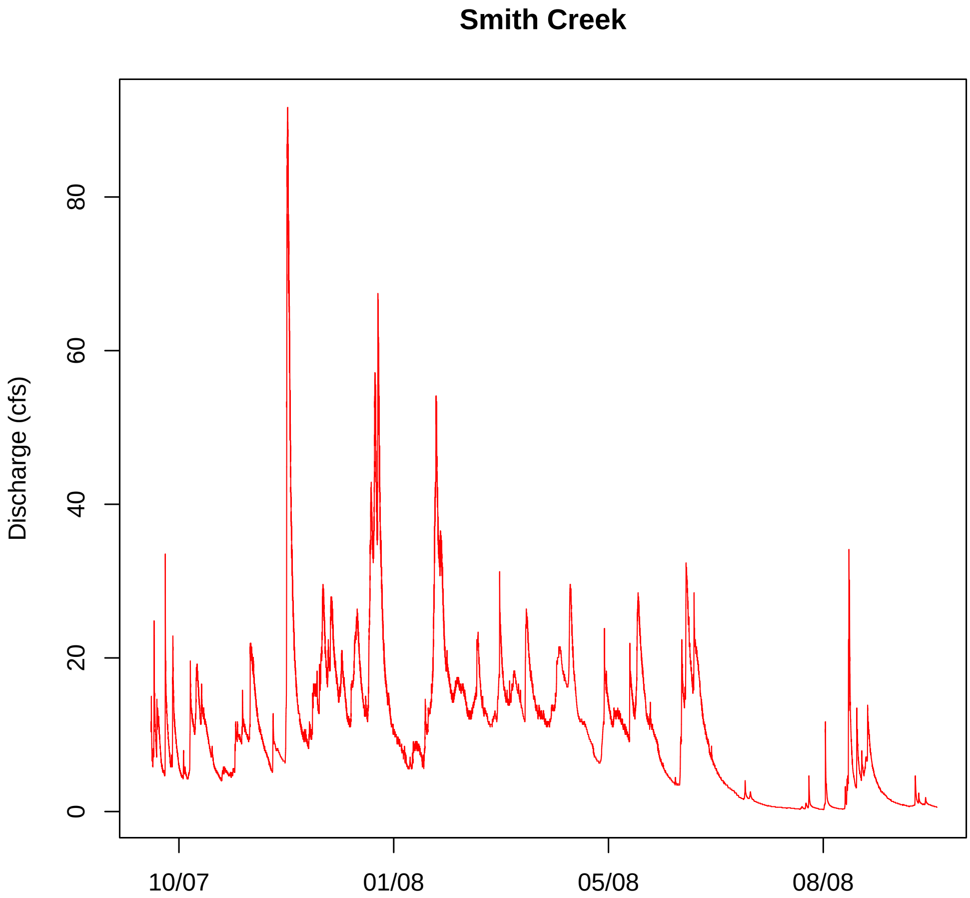

Figure 15: Smith Creek hydrograph, October 1, 2007–September 30, 2008. Data were recorded at 15 minute intervals.

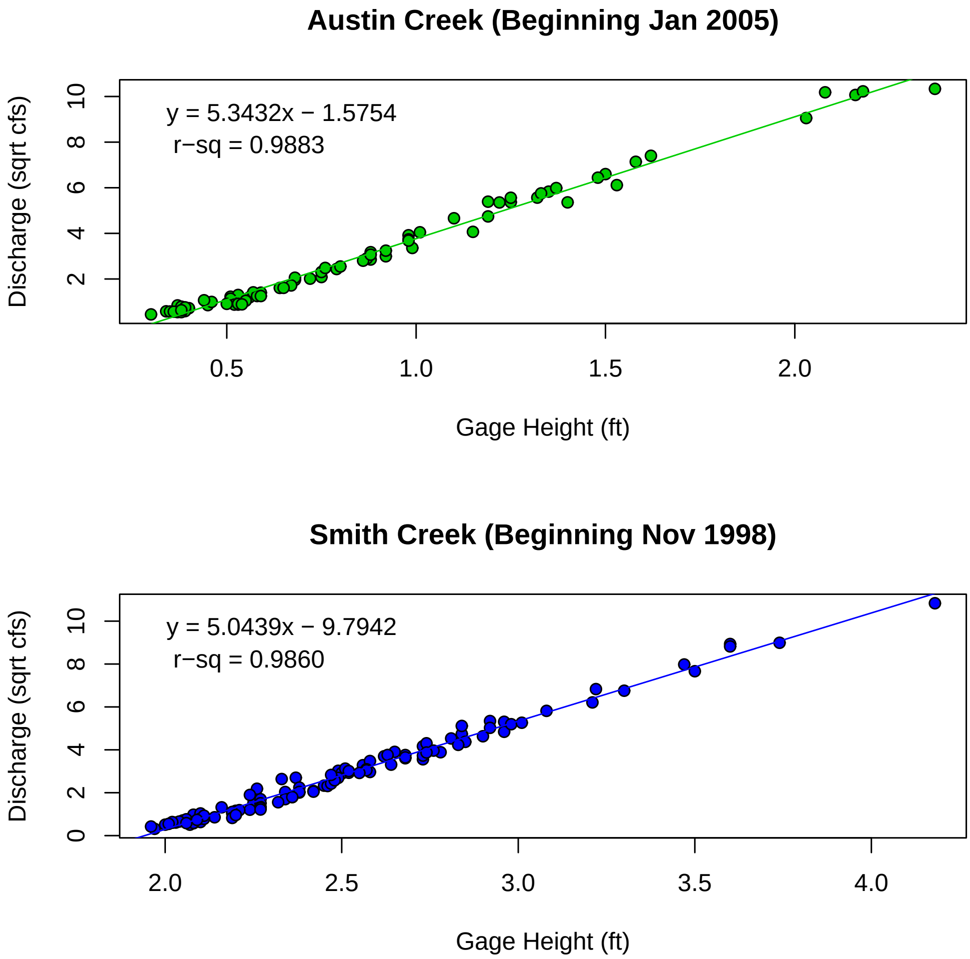

Figure 16: Austin Creek and Smith Creek rating curves. Regressions show the relationship between gauge height (x) and square root transformed discharge (y), beginning from the date listed on each figure. For earlier rating curves, contact the Institute for Watershed Studies.

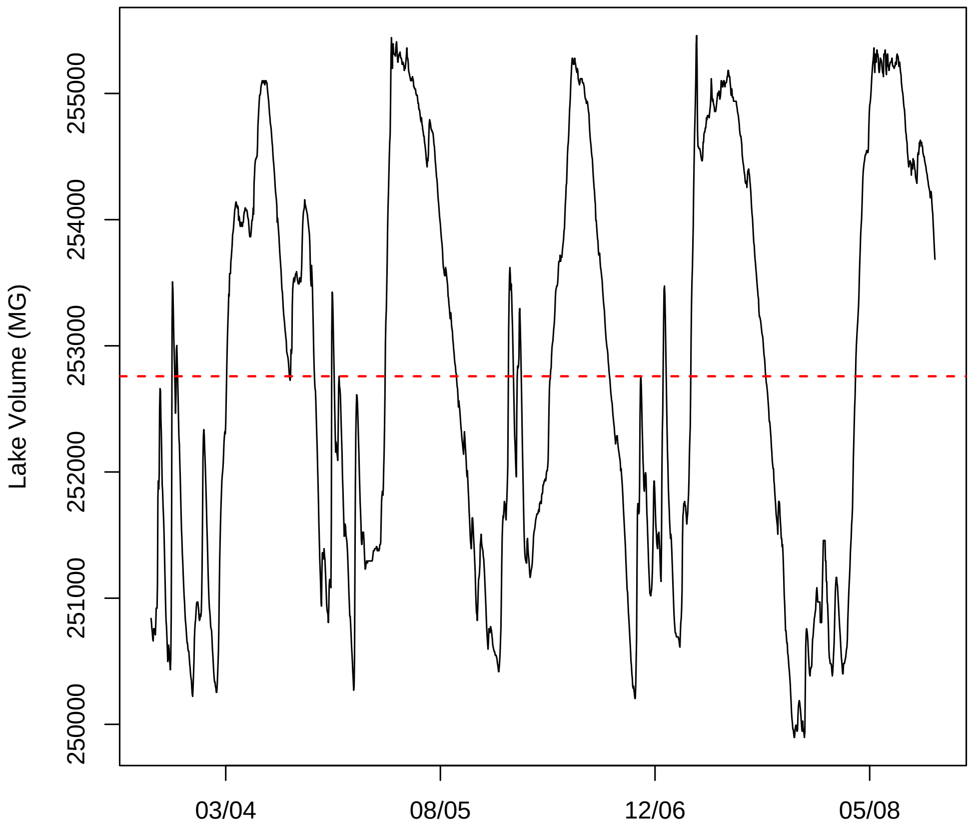

Figure 17: Comparison of Lake Whatcom daily lake volumes for 2003–2008. Horizontal line represents median lake volume for the period plotted.

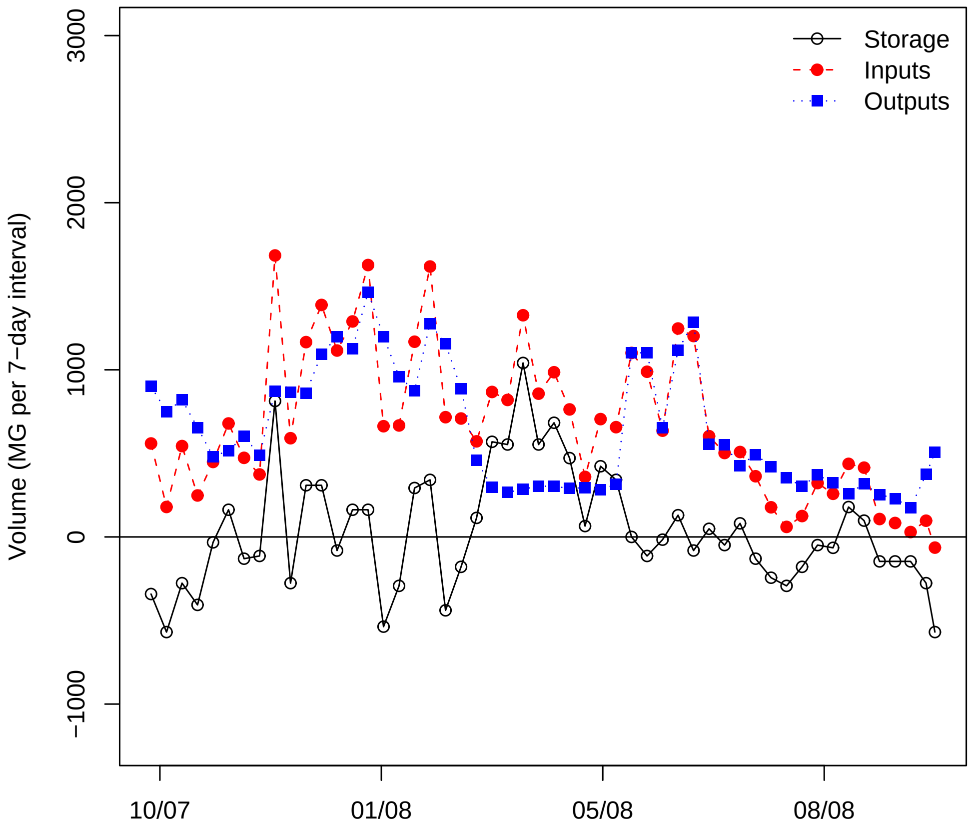

Figure 18: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2007–September 30, 2008.

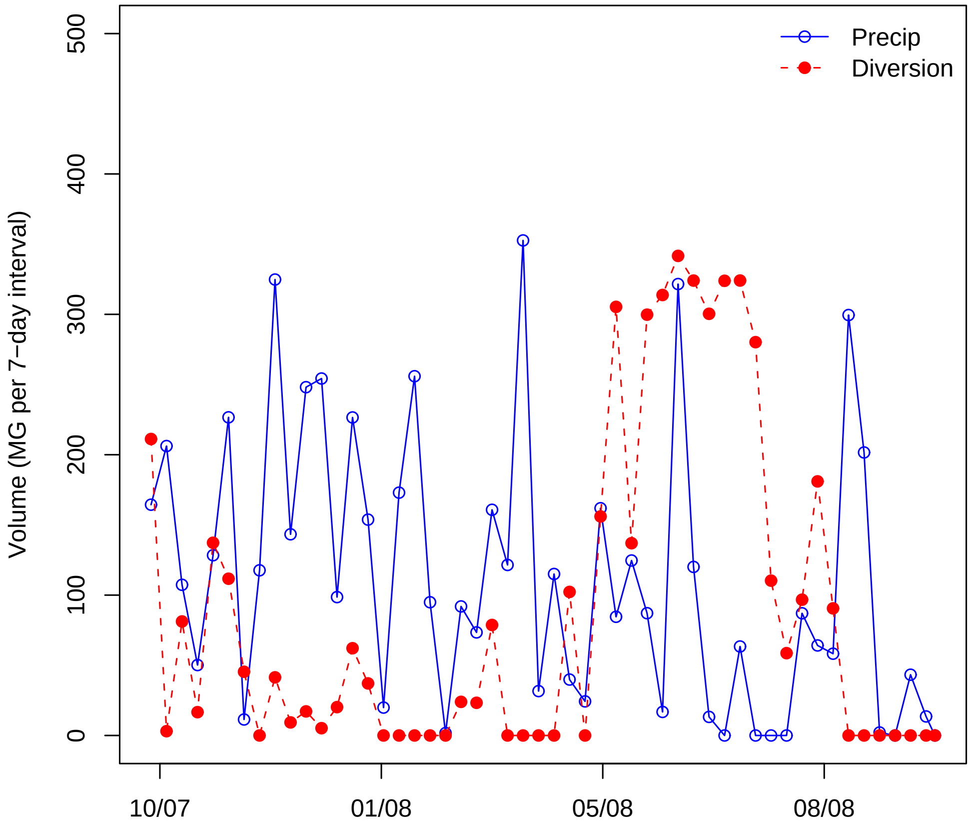

Figure 19: Lake Whatcom watershed direct hydrologic inputs, October 1, 2007–September 30, 2008. Runoff is included on Figure 21 as described on page 50.

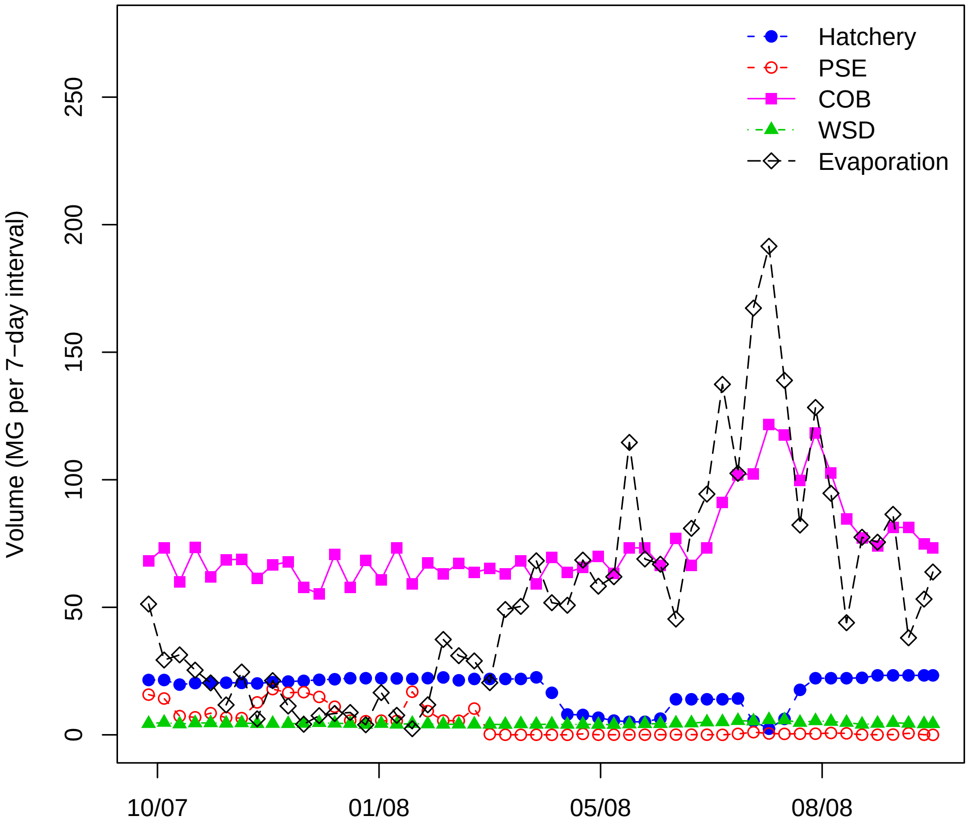

Figure 20: Lake Whatcom watershed hydrologic withdrawals, October 1, 2007–September 30, 2008. Whatcom Creek output is included on Figure 21 as described on page 50.

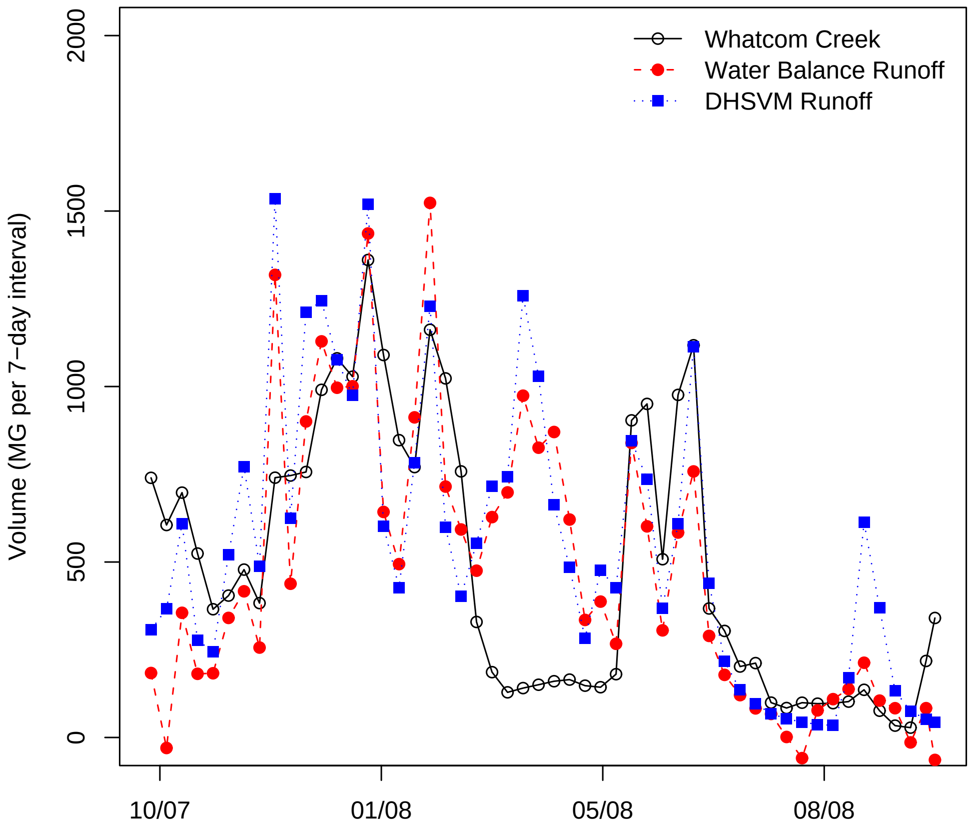

Figure 21: Summary of 7-day Whatcom Creek flows, water balance runoff estimates, and DHSVM runoff estimates, October 1, 2007–September 30, 2008.

5 Storm Water Treatment Monitoring

The objective of the storm water monitoring was to evaluate the storm water treatment efficiencies of representative treatment facilities in the Lake Whatcom watershed. During the 2007/2008 monitoring period, samples were collected from the Park Place sand filter[19], the Brentwood wet ponds, the Alabama Hill vault, and the South Campus storm water treatment facility.[20] The locations of the current monitoring sites are described in Appendix A; photographs of the sites are included in Figures A5–A9 (pages 89–93).

5.1 Sampling Procedures

Storm water samples were collected on the following dates, which were selected to cover a range of weather conditions including wet weather nominal and high flows and dry weather nominal flows:

Alabama Vault	Oct 8, 2007: Wet conditions/moderate to heavy flow Dec 4–5, 2007: Wet conditions/moderate to heavy flow
Park Place	Oct 8, 2007: Wet conditions/low flow; heavy precip. 72 hrs prior to sampling Dec 3, 2007: Wet conditions/high flow; heavy precip. and snow prior to sampling Sept 29, 2008: Dry conditions/low flow; no precip. within 72 hrs of sampling (construction related street washing on N. Shore Dr. may have flowed into Park Place)
Brentwood	Oct 8, 2007: Wet conditions/low flow; heavy precip. 72 hrs prior to sampling Sept 29, 2008: Dry conditions/low flow; no precip. within 72 hrs of sampling
S. Campus	Oct 16, 2007: Wet conditions/low flow Jan 8, 2008: Wet conditions/high flow Jul 29, 2008: Dry conditions/low flow. Construction on campus have have introduced solids into treatment site

Where possible, composite samples were collected at inflow and outflow points using ISCO samplers provided by the City of Bellingham that collect water samples at 90 minute intervals over a 48 hour period. The composite samples were

[19]formerly the Park Place wet ponds

[20]The South Campus storm water treatment facility is a state-of-the-art combination of grass swales and rock/plant filters. Although outside the Lake Whatcom watershed, it is included to provide information about the effectiveness of this type of treatment system.

analyzed for total solids, total suspended solids, heavy metals (arsenic, cadmium, chromium, copper, iron, nickel, lead, and zinc), total organic carbon, total nitrogen, and total phosphorus. Multiple grab samples were collected during the sampling period at the inflow(s) and outflow(s) at each site to measure bacteria (fecal coliforms), conductivity, dissolved oxygen, pH, and temperature, which are parameters that can't be measured from composite samples. Bacteria samples were analyzed by the City of Bellingham; conductivity, dissolved oxygen, pH, and temperature were measured using the Hydrolab field meter.

Due to flow and design constraints, 48-hr composite sampling is not feasible in the Alabama Hill vault. In order to obtain data from this site, multiple grab samples were collected over 24–48 hrs to measure total solids, total suspended solids, total nitrogen, and total phosphorus in addition to the parameters normally collected from grab samples. Although composite sampling is preferred, comparisons between composite sampling and multiple grab sampling show reasonably similar results (see discussion by Matthews, et al., 2008).

5.2 Results and Discussion

The Park Place wet pond has been monitored since 1994 and annual water quality data are summarized by Matthews, et al. (2001). Monitoring at the South Campus facility began in 2001 and monitoring at the Alabama Hill vault began in 2004. The Brentwood wet ponds were sampled from 1998–2004 and in 2007–2008. Additional storm water treatment sites that have been monitored in the past include the Parkstone swale/wet pond (2004) and the Silvern vault (2004).

Tables 21–26 (pages 66–71) show the raw data and percent analyte reduction from the storm water treatment systems that were sampled during the current monitoring period. Percent reduction was calculated as follows, based on the approach described by Winer (2000) for *Event Mean Concentration Efficiency*:

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

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

All sites with detectable levels of TSS provided at least some removal of suspended solids. Overall, the removal efficiencies ranging from 0–80% (Tables 21 and 23, pages 66 and 68), but when inlet concentrations were $\geq$2.5 mg/L, TSS reductions were higher, ranging from 42–80%. The best TSS reductions were measured at the South Campus rock/plant filter (51–80%).

Phosphorus removal was less consistent, ranging from -365 (phosphorus export) at Park Place to 65% reduction at the South Campus site (Tables 21 and 23). As with TSS, the South Campus site demonstrated consistent phosphorus removal on all sampling dates (27–65%), which was similar to past data collected at this site (Figure 23 and Table 27). The other sites had inconsistent TP reductions, and reduction efficiencies did not appear to be related to inlet concentrations. The Park Place sand filter had the worst performance, exporting phosphorus on all sampling dates. Brentwood was inconsistent, exporting phosphorus during the October sampling event and removing a substantial amount of phosphorus (58%) during the September sampling event.

Fecal coliforms are a common pollutant in storm water runoff that are not directly linked to lake eutrophication, but are nevertheless important as an indicator of potential health threats. The Lake Whatcom TMDL will require coliform reduction in addition to phosphorus reduction, and it is encouraging to note that the Park Place sand/gravel filter provided excellent coliform reductions on all sampling dates (63–100%; Table 25, page 70).

Alabama Hill vault: The Alabama Hill vault is an underground canister system that can be filled with special materials designed to remove specific pollutants from surface runoff (Figure A5, page 89). Due to flow and design constraints, flow composite sampling is not feasible. Instead, we collect multiple grab samples within 24–48 hr storm events when flow in the system is sufficient to ensure accurate sampling. Paired composite data and multiple grab data collected during the same storm event have produced very similar results (Matthews, et al., 2008), indicating that multiple grab sampling is a feasible surrogate for composite sampling when composite sampling is not possible.

In 2008 the Alabama Hill vault produced small, but consistent reductions for total phosphorus (10–25%; Table 23), which is similar to the 8–18% TP removals measured in 2007 (Matthews, et al., 2008). The City has placed an emphasis on maintenance and regular cleaning at this site, which may be contributing to the modest, but consistent phosphorus removals.[21]

[21]Information provided by the City of Bellingham Public Works Department.

Site	Date	TSS (mg/L)	TS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
Brentwood inlet	Oct 8–10, 2007	<2*	163.3	<1	1.09	0.024
Brentwood outlet	Oct 8–10, 2007	2.00	118.9	<1	0.35	0.027
	Percent reduction:	0	27	NA	68	-12
Brentwood inlet	Sep 29–30, 2008	8.47	194.0	1.4	1.22	0.036
Brentwood outlet	Sep 29–30, 2008	<2*	135.6	1.7	0.27	0.015
	Percent reduction:	76	30	-21	78	58
Park Place inlet	Oct 8–10, 2007	2.22	118.7	<1	0.72	0.060
Park Place outlet	Oct 8–10, 2007	<2*	115.3	<1	0.63	0.082
	Percent reduction :	10	3	NA	12	-37
Park Place inlet	Dec 3–5, 2007	4.64	132.2	1.6	1.76	0.050
Park Place outlet	Dec 3–5, 2007	<2*	121.1	<1*	1.38	0.059
	Percent reduction:	57	8	38	4	-18
Park Place inlet	Sep 29–30, 2008	2.33	154.2	<1	1.00	0.057
Park Place outlet	Sep 29–30, 2008	2.00	157.3	<1	0.72	0.265
	Percent reduction:	14	4	NA	28	-365
S.Campus inlet	Oct 16–18, 2007	56.70	277.4	<1	0.89	0.122
S. Campus outletE	Oct 16–18, 2007	6.98	194.9	<1	0.31	0.043
S.Campus outletW	Oct 16–18, 2007	15.60	194.4	<1	0.31	0.042
	Percent reduction:	80	30	NA	65	65
S.Campus inlet	Jan 8–10, 2008	63.00	224.3	<1	0.78	0.083
S. Campus outletE	Jan 8–10, 2008	10.99	177.8	<1	0.54	0.040
S.Campus outletW	Jan 8–10, 2008	21.88	184.4	<1	0.63	0.046
	Percent reduction:	74	19	NA	25	48
S.Campus inlet	Jul 29–31, 2008	4.27	252.5	14.0	1.07	0.068
S. Campus outletE	Jul 29–31, 2008	2.17	287.3	5.6	0.45	0.072
S.Campus outletW	Jul 29–31, 2008	<2*	255.8	6.7	0.42	0.027
	Percent reduction:	51	-8	56	59	27

*Value replaced with detection limit to calculate percent reduction.

Table 21: Composite samples from the Brentwood, Park Place, and South Campus storm water treatment sites with average percent reductions between inlet and outlet for total suspended solids, total solids, total organic carbon, total nitrogen, and total phosphorus. Negative values represent an increase in concentration at the outlet.

Site	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
Brentwood inlet	Oct 8–10, 2007	<0.01	<0.0005	0.001	<0.001	0.568	<0.0001	0.007	<0.001*	0.022
Brentwood outlet	Oct 8–10, 2007	<0.01	<0.0005	<0.001*	<0.001	0.347	<0.0001	<0.005*	0.001	<0.001*
	Percent reduction:	NA	NA	0	NA	39	NA	29	0	95
Brentwood inlet	Sep 29–30, 2008	<0.01	<0.0005	<0.001*	0.002	0.163	<0.0001	<0.005	<0.001	0.006
Brentwood outlet	Sep 29–30, 2008	<0.01	<0.0005	0.001	0.002	1.290	<0.0001	<0.005	<0.001	0.011
	Percent reduction:	NA	NA	0	0	-691	NA	NA	NA	-83
Park Place inlet	Oct 8–10, 2007	<0.01	<0.0005	0.003	0.005	0.595	<0.0001	<0.005	<0.001*	0.014
Park Place outlet	Oct 8–10, 2007	<0.01	<0.0005	<0.001*	<0.001*	0.675	<0.0001	<0.005	0.004	0.009
	Percent reduction:	NA	NA	67	80	-13	NA	NA	-300	36
Park Place inlet	Dec 3–5, 2007	<0.01	<0.0005	<0.001	0.005	0.650	<0.0001	<0.005	<0.001	0.025
Park Place outlet	Dec 3–5, 2007	<0.01	<0.0005	<0.001	0.004	0.243	<0.0001	<0.005	<0.001*	0.003
	Percent reduction:	NA	NA	NA	20	63	NA	NA	NA	88
Park Place inlet	Sep 29–30, 2008	<0.01	<0.0005	<0.001	0.005	1.230	<0.0001	<0.005	<0.001	0.014
Park Place outlet	Sep 29–30, 2008	<0.01	<0.0005	<0.001	0.002	2.550	<0.0001	<0.005	<0.001	0.012
	Percent reduction:	NA	NA	NA	60	-107	NA	NA	NA	14
S.Campus inlet	Oct 16–18, 2007	<0.01	<0.0005	0.001	0.004	3.710	<0.0001	<0.005	0.003	0.016
S. Campus outletE	Oct 16–18, 2007	<0.01	<0.0005	<0.001*	0.001	0.342	<0.0001	<0.005	0.001	0.002
S.Campus outletW	Oct 16–18, 2007	<0.01	<0.0005	0.001	0.001	0.543	<0.0001*	<0.005	0.001	0.002
	Percent reduction:	NA	NA	0	75	88	NA	NA	67	88
S.Campus inlet	Jan 8–10, 2008	<0.01	<0.0005	0.005	0.008	3.480	<0.0001	<0.005	0.002	0.026
S. Campus outletE	Jan 8–10, 2008	<0.01	<0.0005	0.002	0.004	0.638	<0.0001	<0.005	<0.001	0.027
S.Campus outletW	Jan 8–10, 2008	<0.01	<0.0005	0.002	0.006	1.020	<0.0001	<0.005	<0.001	0.036
	Percent reduction:	NA	NA	60	38	76	NA	NA	NA	-21
S.Campus inlet	Jul 29–31, 2008	<0.01	<0.0005	<0.001	0.002	2.040	<0.0001	<0.005	<0.001	0.003
S. Campus outletE	Jul 29–31, 2008	<0.01	<0.0005	<0.001	<0.001	0.645	<0.0001	<0.005	<0.001	0.004
S.Campus outletW	Jul 29–31, 2008	<0.01	<0.0005	<0.001	<0.001	0.064	<0.0001	<0.005	<0.001	0.001
	Percent reduction:	NA	NA	NA	NA	83	NA	NA	NA	17

*Value replaced with detection limit to calculate percent reduction.

Table 22: Composite samples from the Brentwood, Park Place, and South Campus storm water treatment sites with average percent reductions between inlet and outlet for total metals. Negative values represent an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)
Inlet	Oct 29, 2007 (A)	10.1	7.30	10.7	76.1	NA
Outlet	Oct 29, 2007 (A)	10.0	7.20	9.8	78.6	NA
	Percent reduction:	1	1	8	-3	NA
Inlet	Dec 4, 2007 (A)	9.6	7.34	10.6	163.0	130
Inlet	Dec 4, 2007 (B)	9.4	7.42	10.5	220.0	140
Inlet	Dec 5, 2007 (C)	8.9	7.45	11.2	238.0	110
Outlet	Dec 4, 2007 (A)	9.5	7.34	10.5	158.4	300
Outlet	Dec 4, 2007 (B)	9.9	7.36	9.8	217.0	50
Outlet	Dec 5, 2007 (C)	8.8	7.40	10.3	236.0	44
	Percent reduction:	-1	0	5	2	-4

Site	Date	TSS (mg/L)	TN (mg/L)	TP (mg-N/L)
Inlet	Oct 29, 2007 (A)	37.4	1.19	0.153
Outlet	Oct 29, 2007 (A)	18.7	1.07	0.114
	Percent reduction:	50	10	25
Inlet	Dec 4, 2007 (A)	47.8	2.56	0.215
Inlet	Dec 4, 2007 (B)	6.1	3.22	0.144
Inlet	Dec 5, 2007 (C)	4.7	2.77	0.098
Outlet	Dec 4, 2007 (A)	26.5	2.36	0.171
Outlet	Dec 4, 2007 (B)	4.1	3.27	0.141
Outlet	Dec 5, 2007 (C)	3.1	2.71	0.097
	Percent reduction:	42	2	10

Table 23: Alabama vault grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential, beginning with A; up to five samples were collected within 48 hr if flow was sufficient to ensure accurate sampling of inflow and outflow. Negative values indicate an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)
Inlet	Oct 8, 2007 (A)	16.0	7.10	8.06	246.0	37
Inlet	Oct 9, 2007 (B)	16.0	7.13	8.07	256.0	23
Inlet	Oct 9, 2007 (C)	16.2	7.10	8.35	258.0	12
Inlet	Oct 10, 2007 (D)	15.4	6.73	6.82	214.0	500
Outlet	Oct 8, 2007 (A)	10.5	7.25	6.81	187.9	22
Outlet	Oct 9, 2007 (B)	10.5	7.31	7.51	185.0	20
Outlet	Oct 9, 2007 (C)	11.3	7.32	7.80	184.9	5
Outlet	Oct 10, 2007 (D)	11.8	7.25	7.18	183.7	85
	Percent reduction:	31	-4	6	24	77
Inlet	Sep 29, 2008 (A)	17.2	7.23	7.78	286.0	1
Inlet	Sep 29, 2008 (B)	17.7	7.22	7.68	288.0	<1*
Inlet	Sep 30, 2008 (C)	17.1	7.30	7.74	293.0	3
Inlet	Sep 30, 2008 (D)	17.8	7.28	7.79	291.0	4
Outlet	Sep 29, 2008 (A)	12.6	7.18	5.71	210.0	59
Outlet	Sep 29, 2008 (B)	14.1	7.19	5.84	213.0	35
Outlet	Sep 30, 2008 (C)	12.7	7.14	5.54	213.0	56
Outlet	Sep 30, 2008 (D)	13.8	7.20	5.91	213.0	34
	Percent reduction:	24	1	26	27	-1944

*Value replaced with detection limit to calculate percent reduction.

Table 24: Brentwood wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential; negative values indicate an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)
Inlet	Oct 8, 2007 (A)	13.2	7.63	9.27	176.2	560
Inlet	Oct 9, 2007 (B)	13.2	7.51	9.42	174.0	660
Inlet	Oct 9, 2007 (C)	13.7	7.54	9.52	171.7	620
Inlet	Oct 10, 2007 (D)	13.7	7.39	9.00	149.8	880
Outlet	Oct 8, 2007 (A)	12.8	6.96	4.76	164.2	8
Outlet	Oct 9, 2007 (B)	12.9	6.92	3.80	169.0	5
Outlet	Oct 9, 2007 (C)	12.9	6.91	3.21	172.1	4
Outlet	Oct 10, 2007 (D)	13.0	6.83	2.72	178.6	4
	Percent reduction:	4	8	61	-2	99
Inlet	Dec 3, 2007 (A)	9.5	7.15	10.30	166.6	340
Inlet	Dec 4, 2007 (B)	9.7	7.16	10.75	173.5	200
Inlet	Dec 4, 2007 (C)	10.0	7.28	10.40	188.6	100
Inlet	Dec 5, 2007 (D)	9.3	7.30	11.58	199.2	70
Outlet	Dec 3, 2007 (A)	8.4	7.08	9.12	145.5	180
Outlet	Dec 4, 2007 (B)	9.5	7.05	8.37	163.4	46
Outlet	Dec 4, 2007 (C)	9.8	7.07	8.08	171.6	20
Outlet	Dec 5, 2007 (D)	9.2	7.11	8.92	193.3	20
	Percent reduction:	4	2	20	7	63
Inlet	Sep 29, 2008 (A)	15.6	7.51	8.03	232.0	5000
Inlet	Sep 29, 2008 (B)	16.2	7.50	7.70	233.0	4400
Inlet	Sep 30, 2008 (C)	15.7	7.43	7.65	239.0	16000
Inlet	Sep 30, 2008 (D)	15.9	7.38	7.71	207.0	17000
Outlet	Sep 29, 2008 (A)	15.2	6.74	0.34	239.0	3
Outlet	Sep 29, 2008 (B)	15.3	6.78	0.27	240.0	13
Outlet	Sep 30, 2008 (C)	15.1	6.72	0.33	241.0	1
Outlet	Sep 30, 2008 (D)	15.2	6.73	0.24	240.0	1
	Percent reduction:	4	10	96	-5	100

Table 25: Park Place sand/gravel filter grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential; negative values indicate an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)
Inlet	Oct 16, 2007 (A)	13.7	7.34	8.42	230.0	710
Inlet	Oct 16, 2007 (B)	13.9	7.37	7.53	336.0	160
Inlet	Oct 17, 2007 (C)	13.2	7.41	7.67	373.0	70
Inlet	Oct 17, 2007 (D)	13.8	7.46	7.25	409.0	300
Outlet-E	Oct 16, 2007 (A)	12.1	7.36	4.17	287.0	920
Outlet-E	Oct 16, 2007 (B)	12.2	7.33	2.67	330.0	330
Outlet-E	Oct 17, 2007 (C)	11.4	7.46	3.02	299.0	230
Outlet-E	Oct 17, 2007 (D)	11.7	7.42	1.90	313.0	100
Outlet-W	Oct 16, 2007 (A)	12.8	7.51	3.96	271.0	81
Outlet-W	Oct 16, 2007 (B)	12.8	7.44	1.32	300.0	6
Outlet-W	Oct 17, 2007 (C)	12.0	7.53	1.59	283.0	10
Outlet-W	Oct 17, 2007 (D)	12.0	7.48	0.80	314.0	<2*
	Percent reduction:	11	-1	69	11	32
Inlet	Jan 8, 2008 (A)	9.3	7.23	10.40	262.0	NA
Inlet	Jan 9, 2008 (B)	9.1	7.46	9.45	327.0	20
Inlet	Jan 9, 2008 (C)	9.4	7.53	9.47	364.0	13
Inlet	Jan 10, 2008 (D)	7.1	7.81	10.84	153.0	160
Outlet-E	Jan 8, 2008 (A)	7.4	7.42	7.35	294.0	NA
Outlet-E	Jan 9, 2008 (B)	7.1	7.50	6.21	301.0	40
Outlet-E	Jan 9, 2008 (C)	7.3	7.52	5.48	317.0	5
Outlet-E	Jan 10, 2008 (D)	6.8	7.66	9.14	193.0	240
Outlet-W	Jan 8, 2008 (A)	7.3	7.57	8.50	292.0	NA
Outlet-W	Jan 9, 2008 (B)	7.3	7.59	6.20	296.0	24
Outlet-W	Jan 9, 2008 (C)	7.4	7.67	5.76	326.0	4
Outlet-W	Jan 10, 2008 (D)	7.1	7.84	10.07	169.0	280
	Percent reduction:	17	-1	27	1	-54
Inlet	Jul 30, 2008 (A)	16.4	7.38	8.08	383.0	35
Inlet	Jul 30, 2008 (B)	16.5	7.44	7.58	400.0	8
Inlet	Jul 31, 2008 (C)	15.9	7.28	7.92	396.0	7
Inlet	Jul 31, 2008 (D)	15.9	7.36	7.85	404.0	5
Outlet-E	Jul 30, 2008 (A)	14.2	7.24	0.81	465.0	7
Outlet-E	Jul 30, 2008 (B)	14.1	7.22	0.25	464.0	12
Outlet-E	Jul 31, 2008 (C)	13.9	7.24	0.20	470.0	40
Outlet-E	Jul 31, 2008 (D)	13.9	7.20	0.23	468.0	71
Outlet-W	Jul 30, 2008 (A)	14.9	7.33	2.59	414.0	69
Outlet-W	Jul 30, 2008 (B)	15.1	7.32	7.15	412.0	39
Outlet-W	Jul 31, 2008 (C)	14.7	7.31	1.95	416.0	61
Outlet-W	Jul 31, 2008 (D)	14.6	7.24	1.93	409.0	61
	Percent reduction:	11	1	76	-11	-227

*Value replaced with detection limit to calculate percent reduction.

Table 26: South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential; negative values indicate an increase in concentration at the outlet.

Total Suspended Solids

Site	Min.	Max.	Mean	95% CI
Alabama (n=9)	-1	69	35	18–52**
Brentwood (n=20)	-174	77	-31	-66 – 5 (ns)
Park Place (n=37)	-239	89	16	-3 – 36 (ns)
South Campus (n=21)	0	94	70	60 – 80***

Total Phosphorus

Site	Min.	Max.	Mean	95% CI
Alabama (n=9)	-46	27	-1	-15 – 17 (ns)
Brentwood (n=21)	-400	56	-7	-51 – 37 (ns)
Park Place (n=39)	-350	70	-14	-36 – 7 (ns)
South Campus (n=21)	10	75	51	44 – 59***

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

Table 27: Overall TSS and TP reductions at Alabama (2004–2008), Brentwood (1998–2008), Park Place (1994–2008), and South Campus (2001–2008) storm water treatment sites. Statistical significance was tested using a one sample t-test to determine whether the mean percent reduction was significantly different from zero.

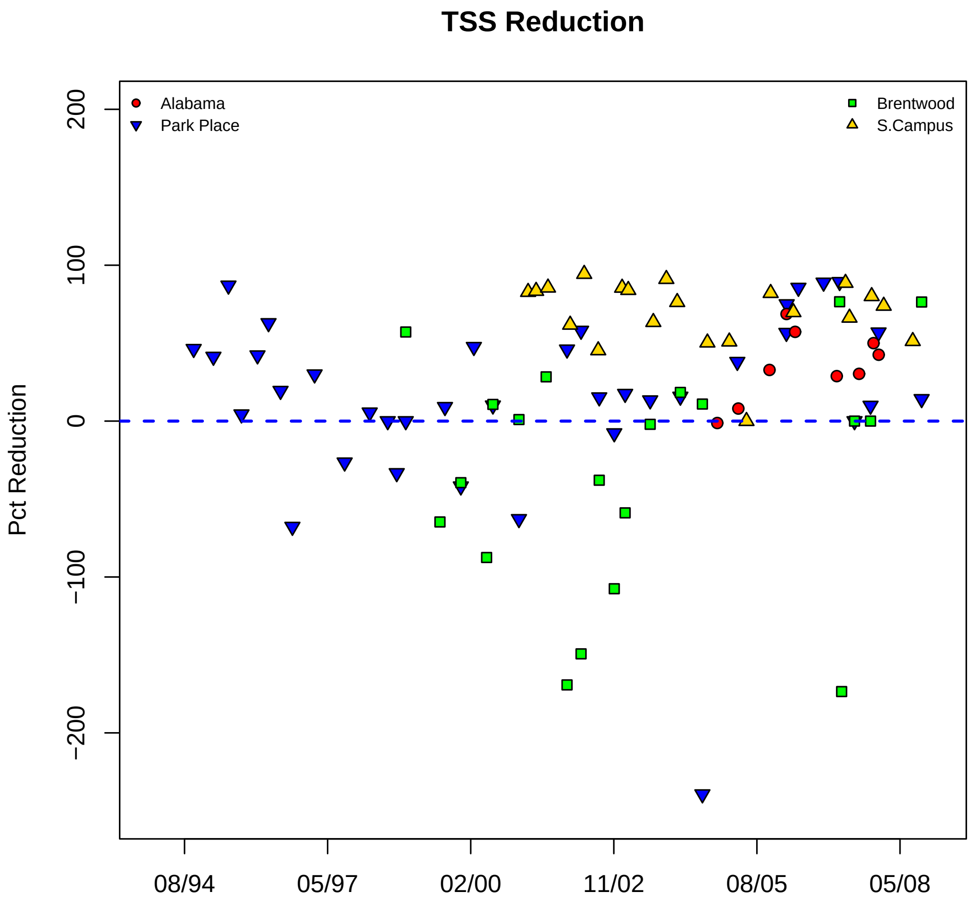

Figure 22: Percent reduction of total suspended solids concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites. Negative values indicate higher concentrations at the outlet compared to the inlet.

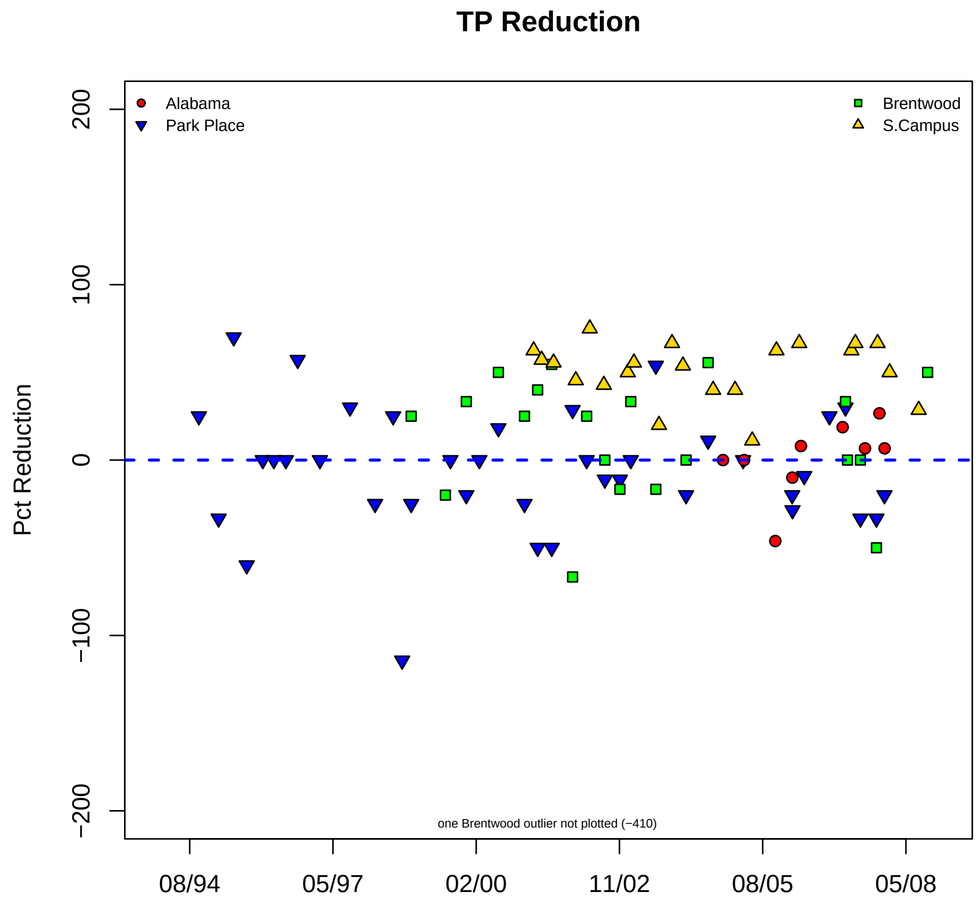

Figure 23: Percent reduction of total phosphorus concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites. Negative values indicate higher concentrations at the outlet compared to the inlet.

6 References and Related Reports

6.1 References

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Matthews, R. A., M. Hilles, J. Vandersypen, R. J. Mitchell, and G. B. Matthews. 2007. Lake Whatcom Monitoring Project 2005–2006 Final Report. Final Report prepared for the City of Bellingham Public Works Department, April, 2007, Bellingham, WA.

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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.

6.2.1 Annual monitoring reports

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

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

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

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

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

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

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

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

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

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

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

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

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

6.2.2 Other Lake Whatcom reports

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

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

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

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

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

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

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

A Site Descriptions

Figures A1–A4 (pages 85–88) show the locations of the current monitoring sites and Table A1 (page 84) 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[22] is mounted in the stilling well on the east side of

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

Anderson Creek, directly adjacent to the bridge over Anderson Creek (South Bay Rd.), approximately 0.5 km from the mouth of the creek.

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

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

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

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

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

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

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

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

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

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

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

A.3 Storm Water Monitoring Sites

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

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

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

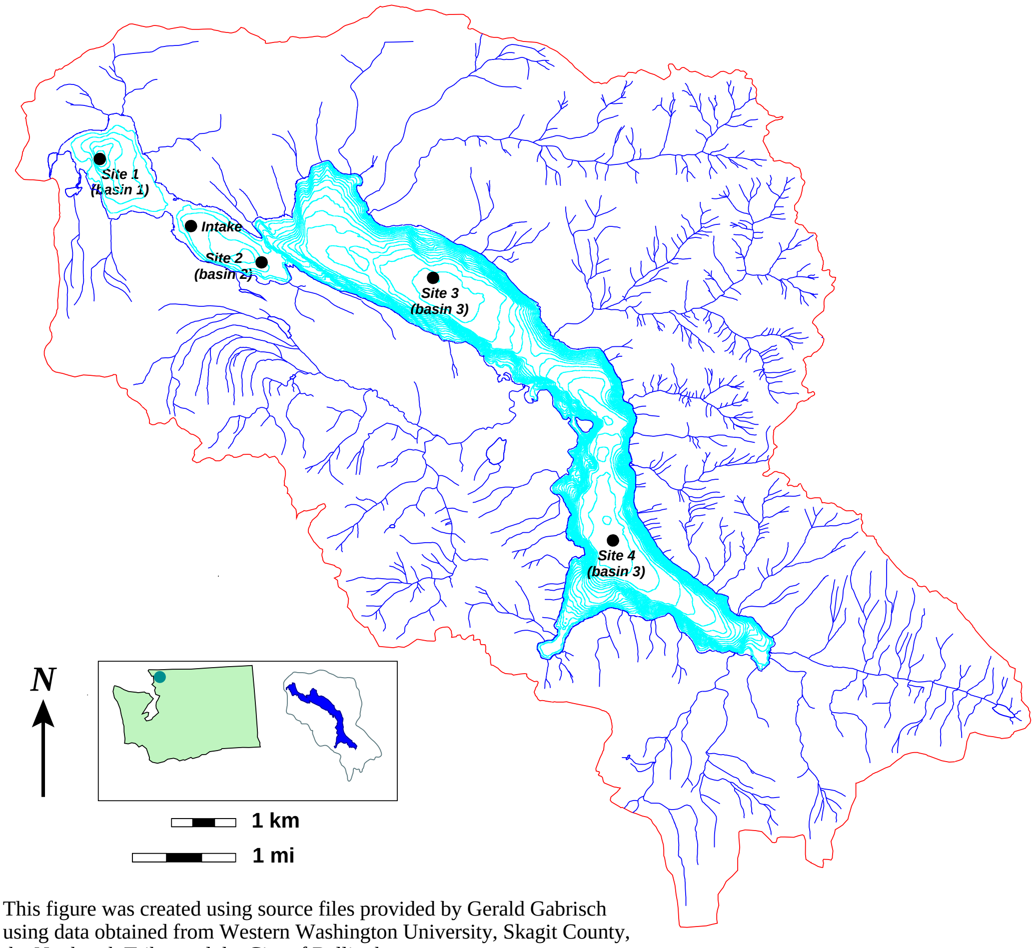
The **South Campus storm water treatment facility** is located south of the intersection between Bill McDonald Pky. and South College Dr, and treats runoff from the southern portion of Western Washington University. The runoff flows into a large underground concrete settling vault located on the northwest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

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

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

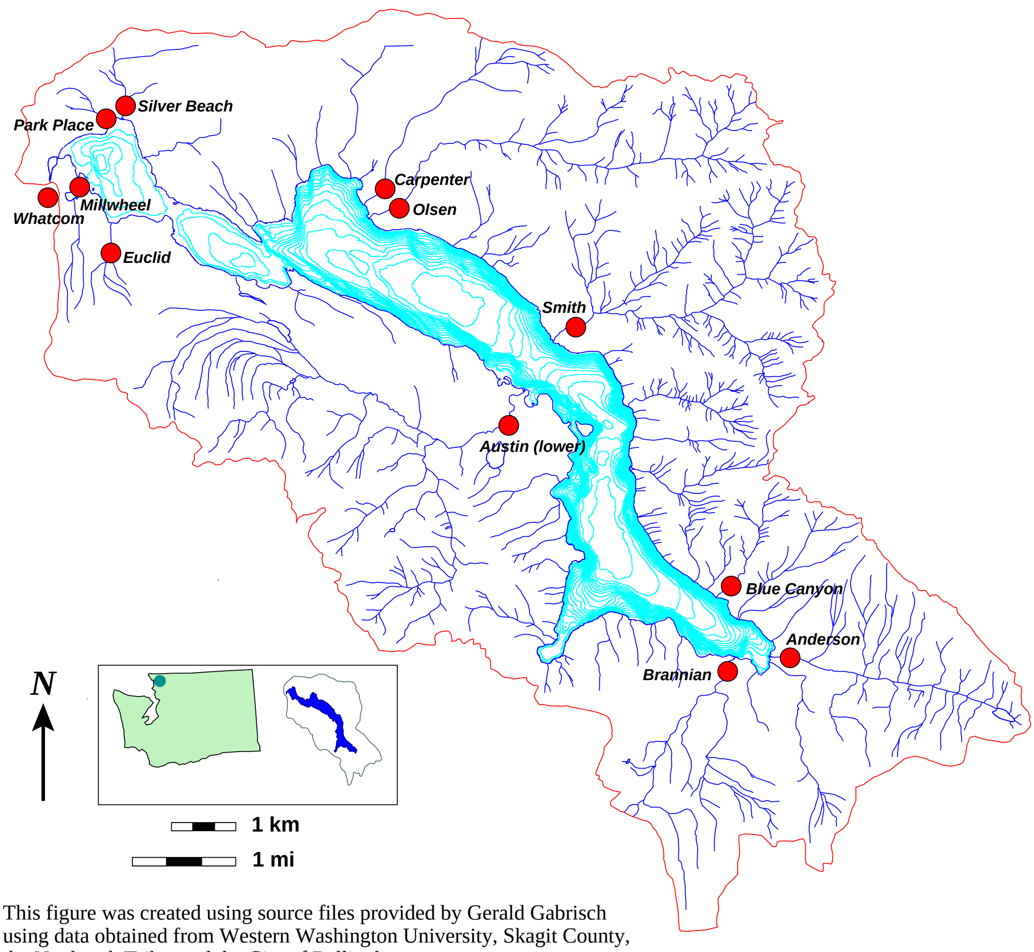
Storm Water Sites	Latitude	Longitude
Alabama Hill	48.76289	122.42060
Brentwood	48.76904	122.40945
Park Place	48.76904	122.40945
South Campus	48.72615	122.48847

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



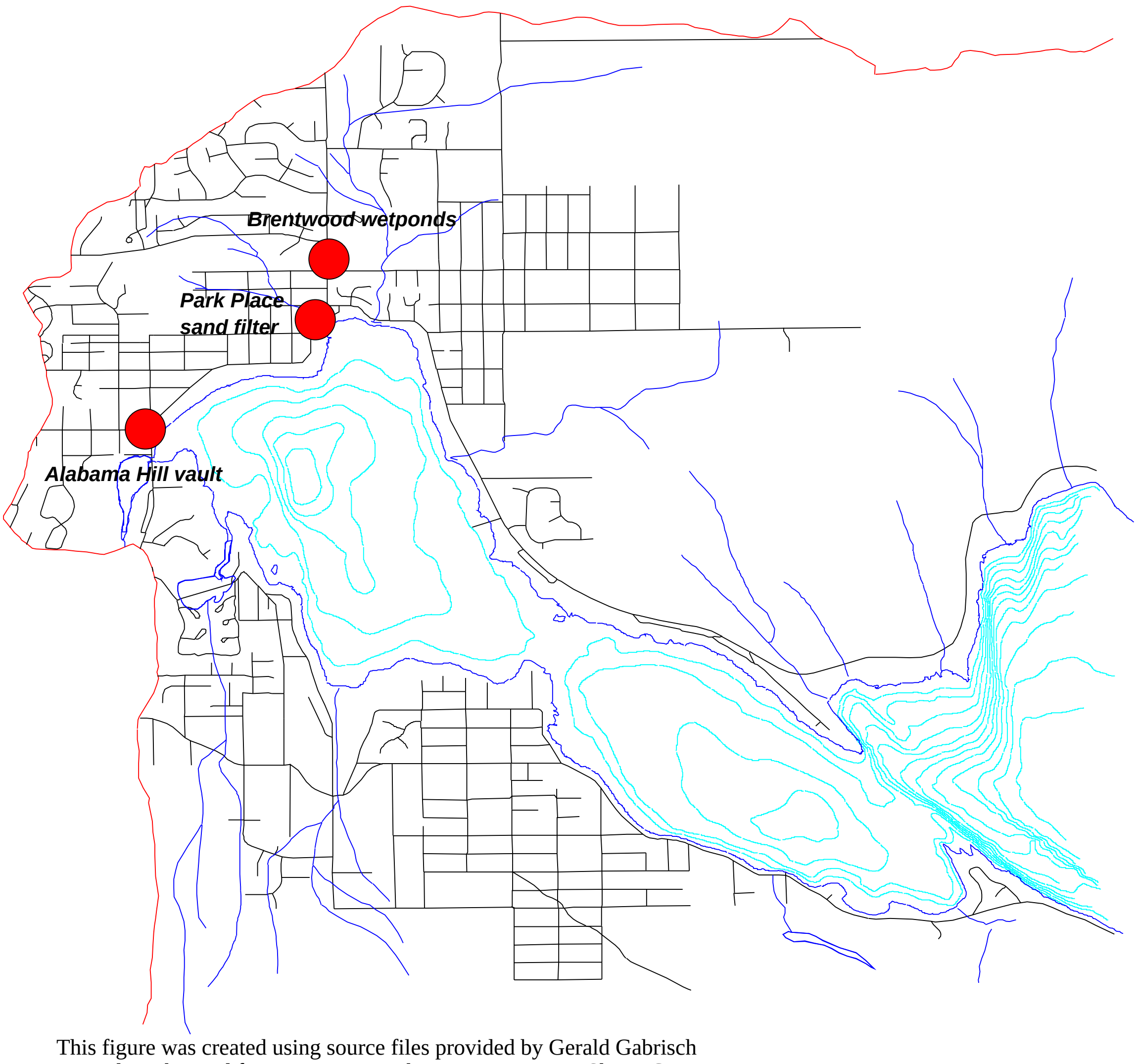
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A1: Lake Whatcom lake sampling sites.



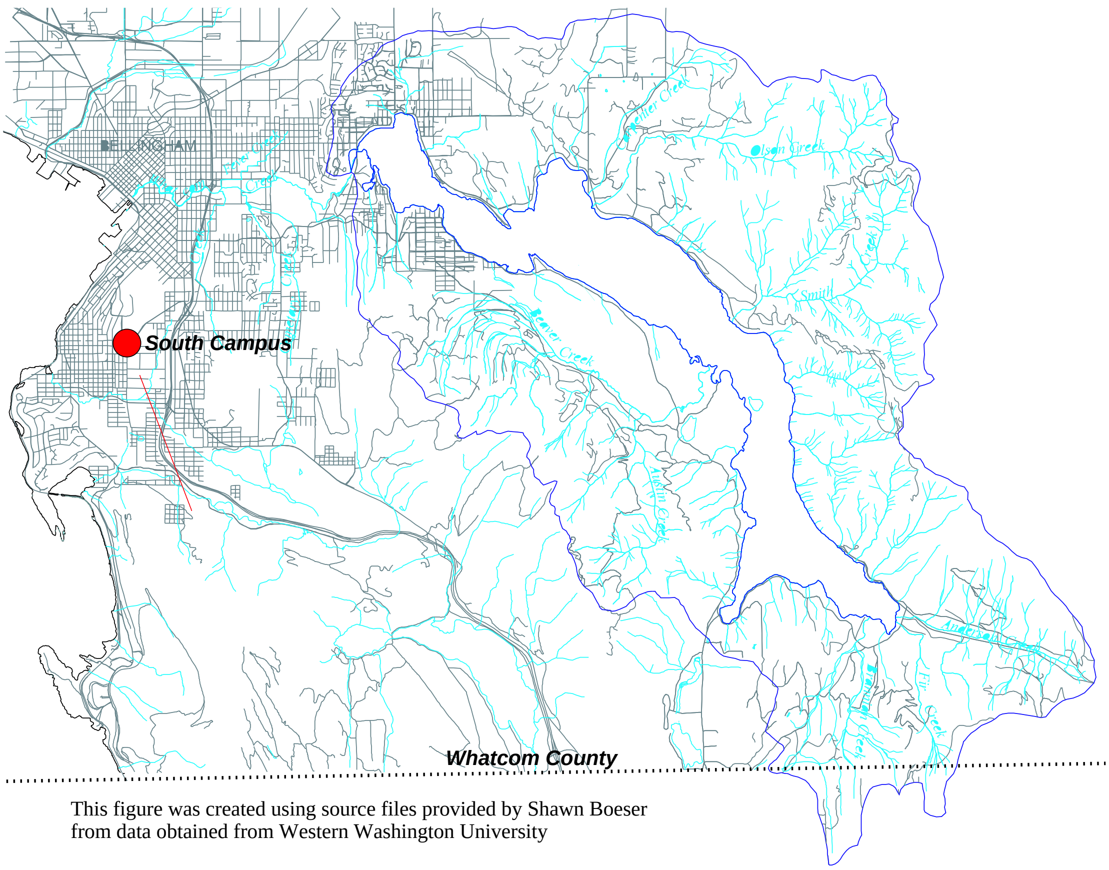
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A2: Lake Whatcom creek sampling sites.



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

Figure A3: Locations of the Park Place sand filter, Brentwood wet pond, and the Alabama Hill vault.



This figure was created using source files provided by Shawn Boeser
from data obtained from Western Washington University

Figure A4: Location of the South Campus storm water treatment facility.

Figure A5: Photograph of the Alabama Hill vault, May 2006.

Figure A6: Photograph of the Brentwood wet pond, July 2004.

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

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

Figure A9: Photograph of the South Campus storm water treatment facility, January 2005.

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 15).

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 15). 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 in order to allow comparisons between all years.

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

Because of the length of the data record, many of the figures reflect trends related to improvements in analytical techniques over time, and introduction of increasingly sensitive field equipment (see, for example, Figures B66–B70, pages 162–166, which show the effect of using increasingly sensitive conductivity probes). These changes generally result in a reduction in analytical variability, and sometimes result in lower detection limits. Refer to Matthews, et al. (2005) for a discussion of historic trends in Lake Whatcom.

B.1 Monthly Hydrolab Profiles

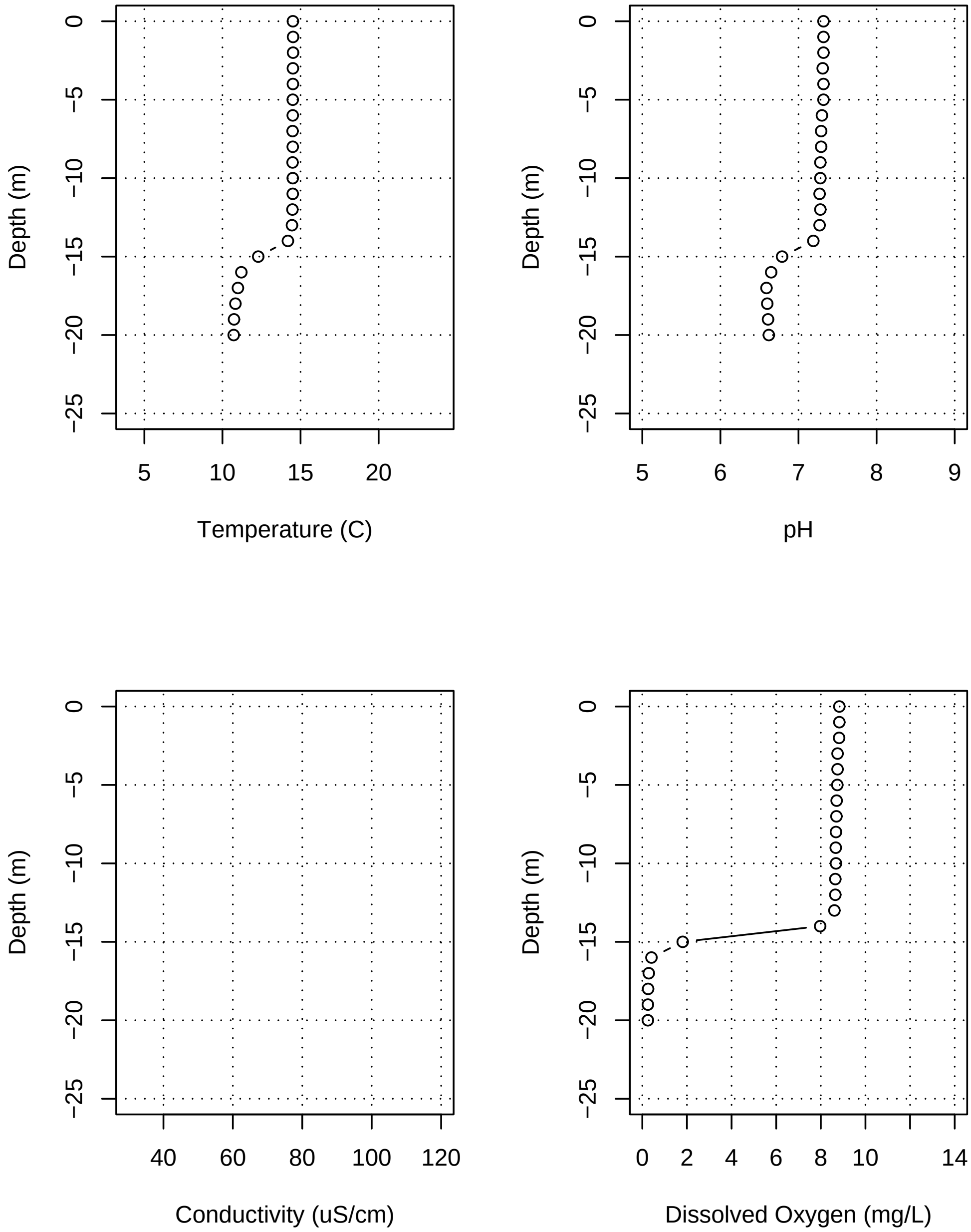


Figure B1: Lake Whatcom Hydrolab profile for Site 1, October 3, 2007. Conductivity data are not available due to equipment malfunction.

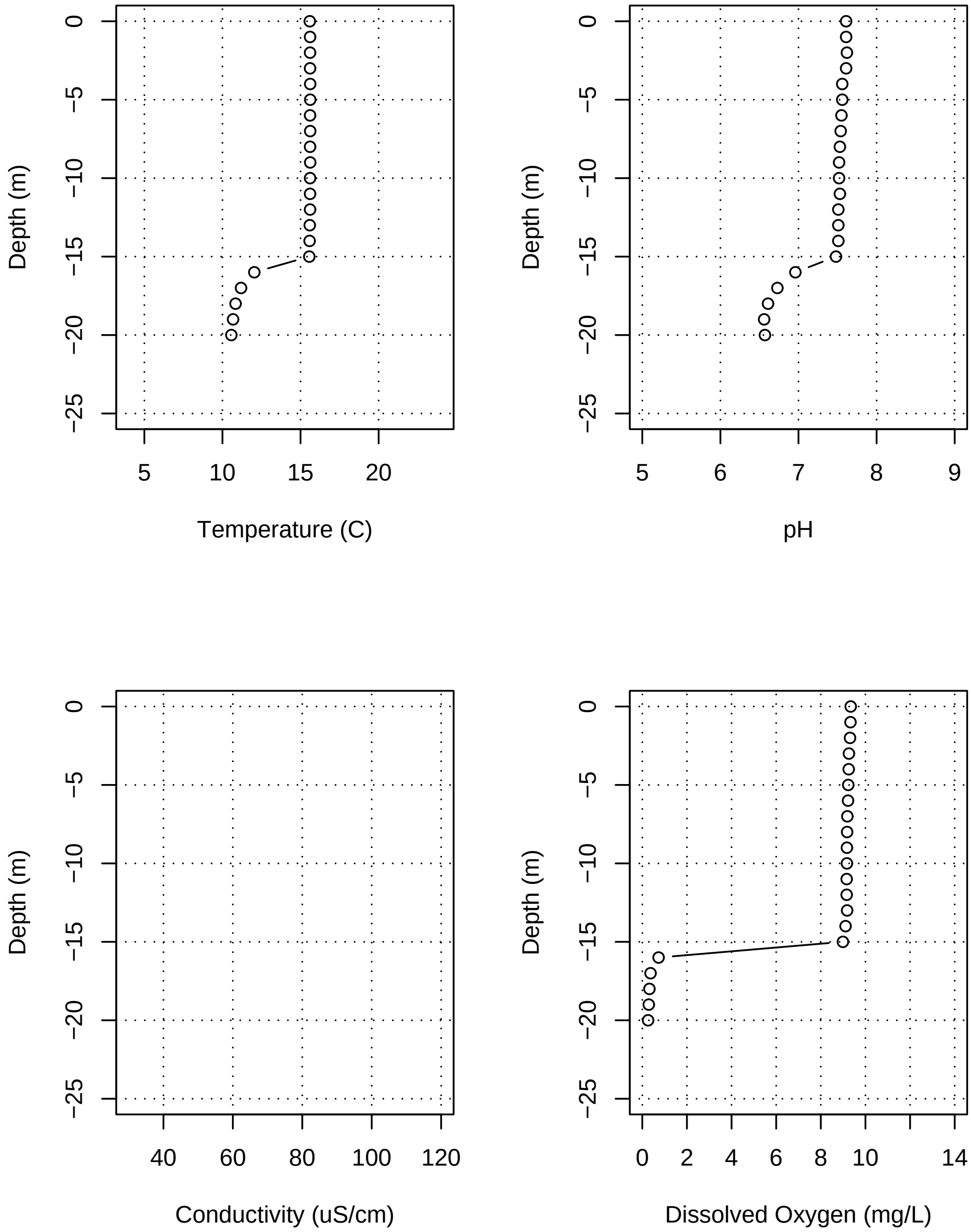


Figure B2: Lake Whatcom Hydrolab profile for Site 2, October 3, 2007. Conductivity data are not available due to equipment malfunction.

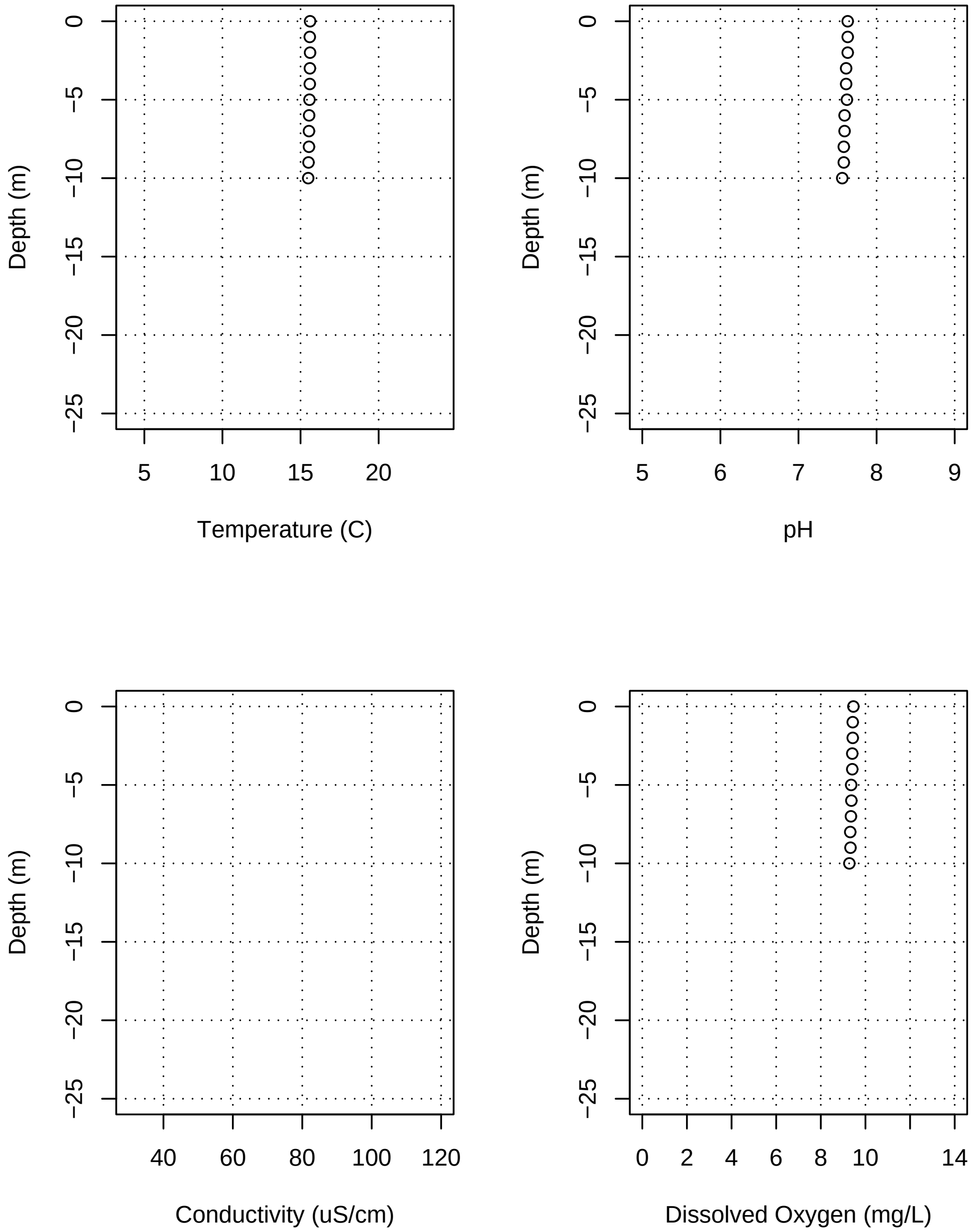


Figure B3: Lake Whatcom Hydrolab profile for the Intake, October 3, 2007. Conductivity data are not available due to equipment malfunction.

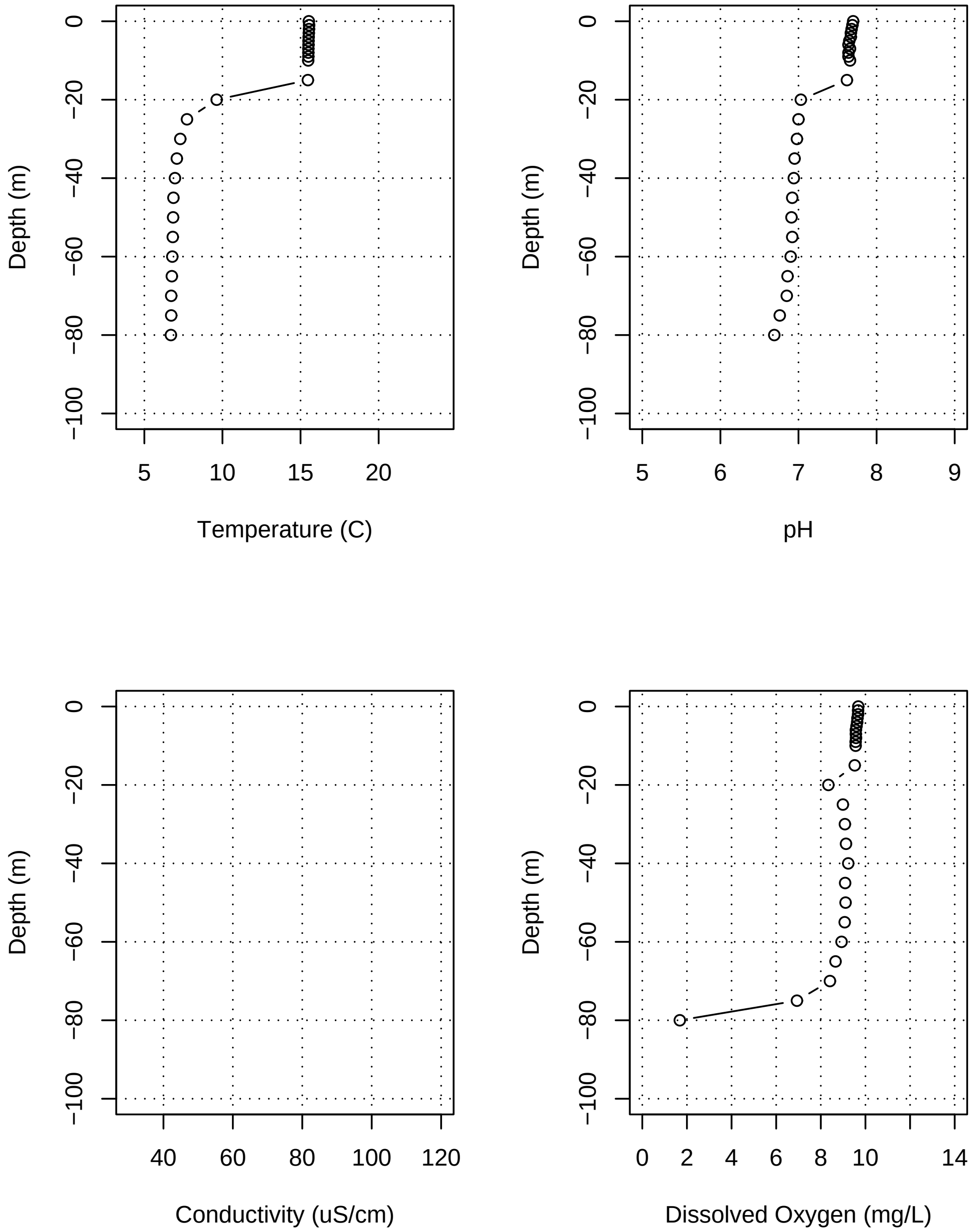


Figure B4: Lake Whatcom Hydrolab profile for Site 3, October 4, 2007. Conductivity data are not available due to equipment malfunction.

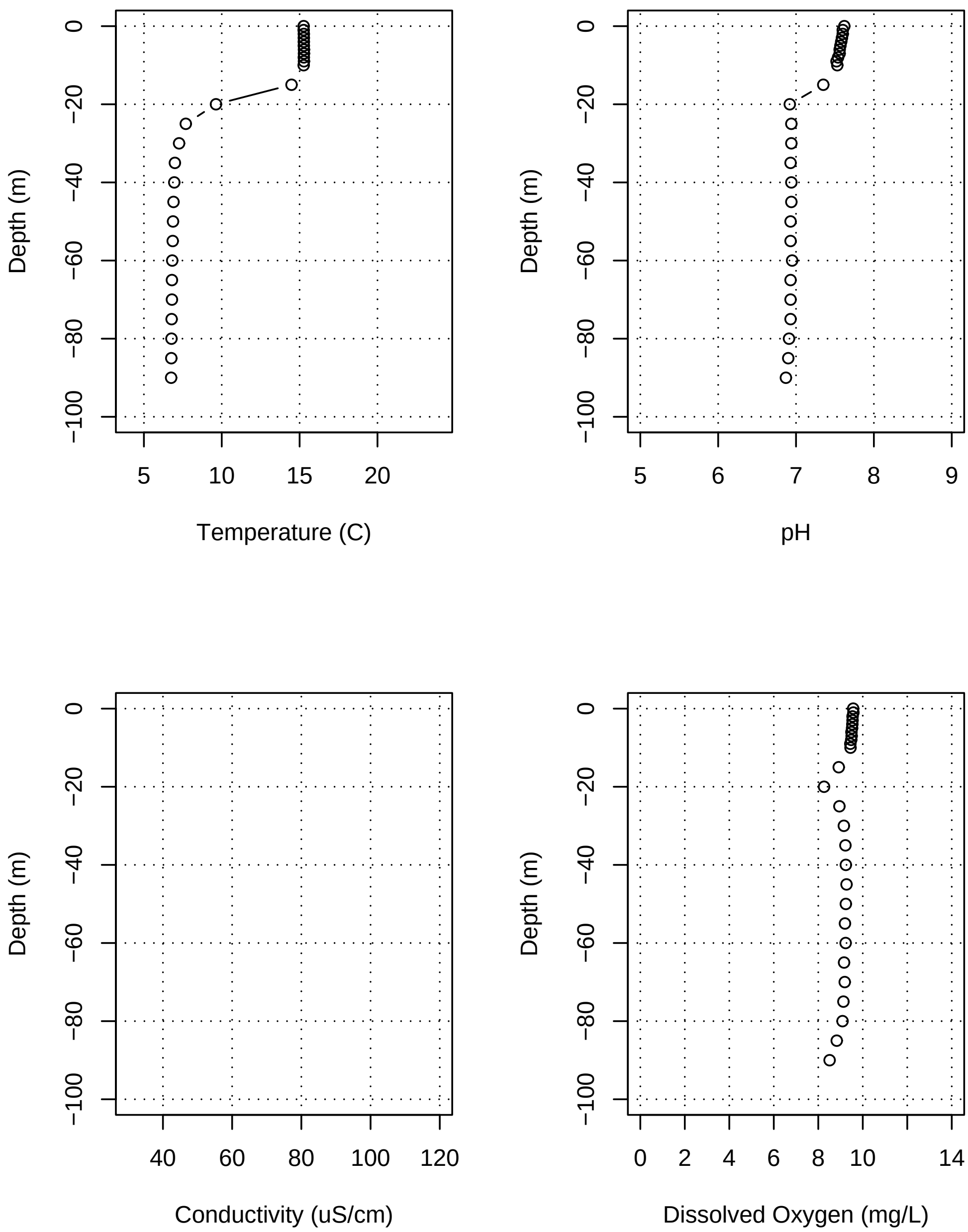


Figure B5: Lake Whatcom Hydrolab profile for Site 4, October 4, 2007. Conductivity data are not available due to equipment malfunction.

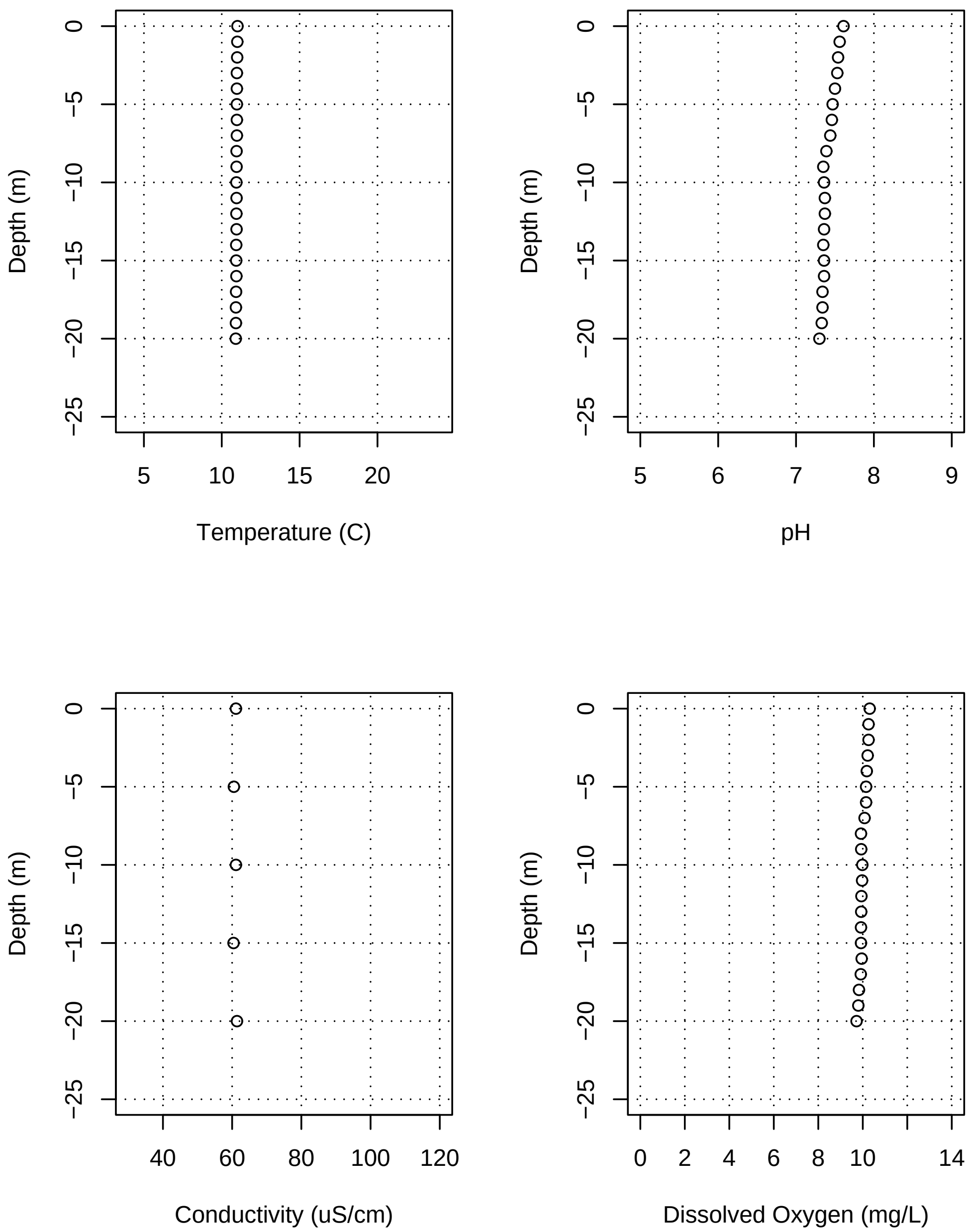


Figure B6: Lake Whatcom Hydrolab profile for Site 1, November 8, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

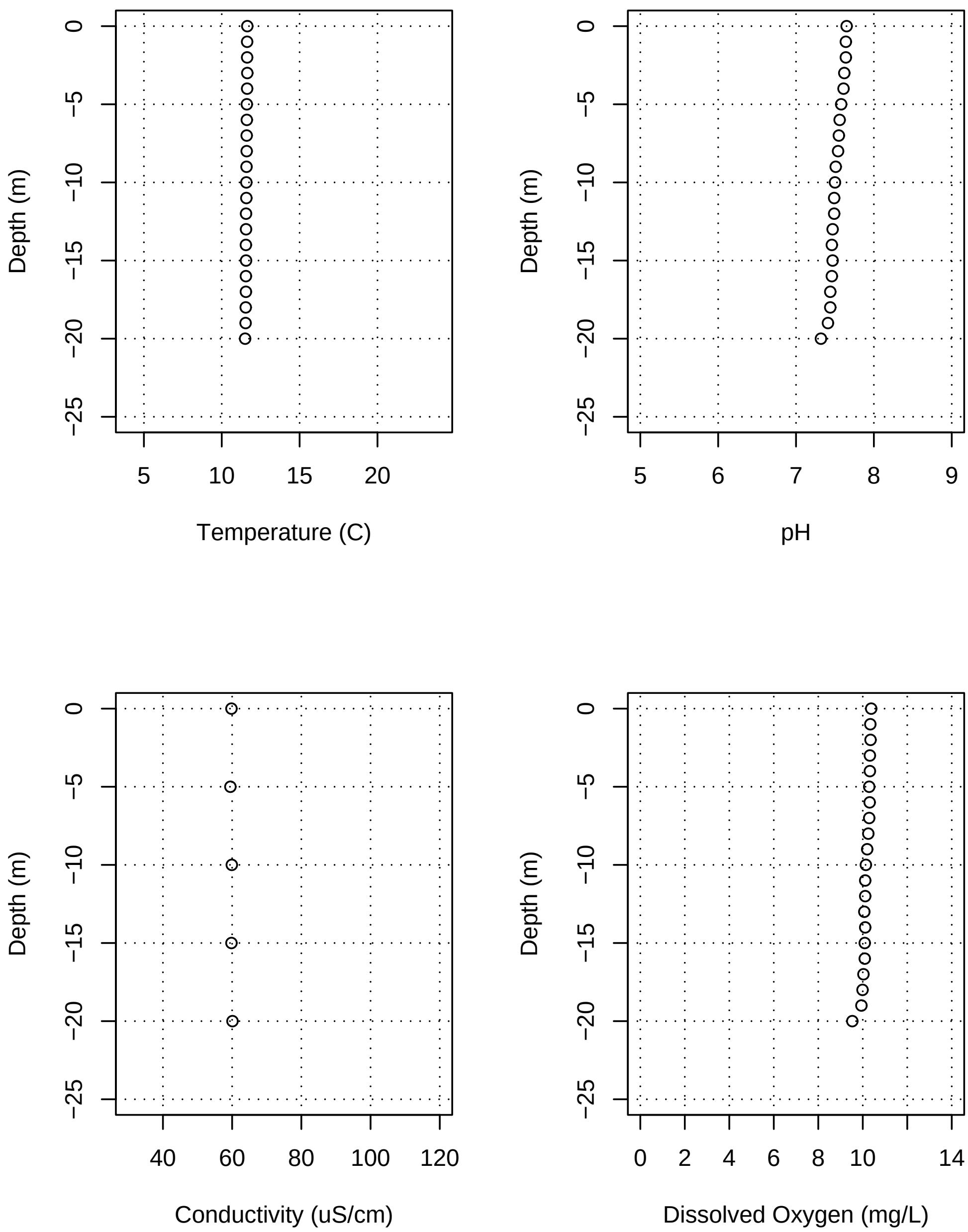


Figure B7: Lake Whatcom Hydrolab profile for Site 2, November 8, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

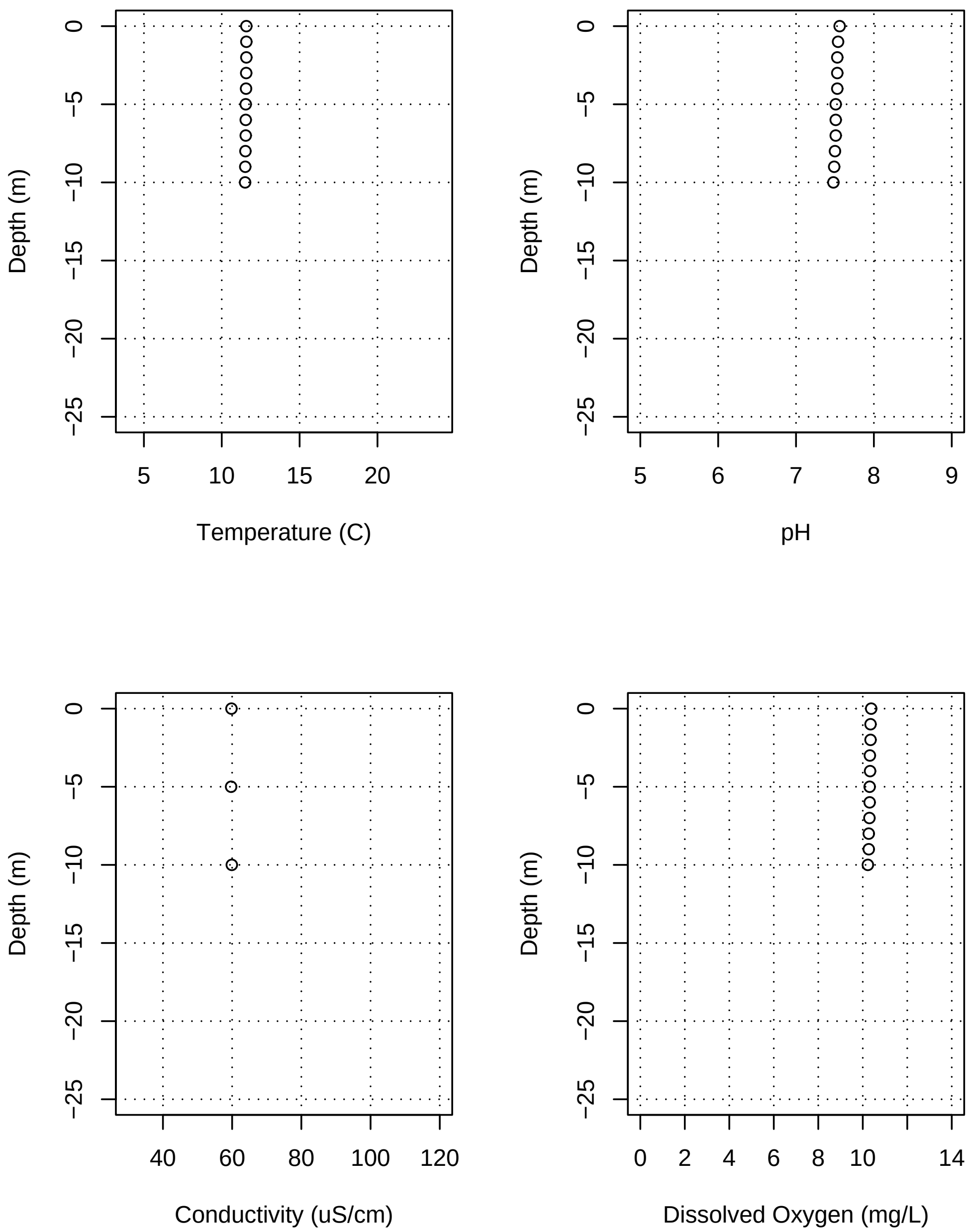


Figure B8: Lake Whatcom Hydrolab profile for the Intake, November 8, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

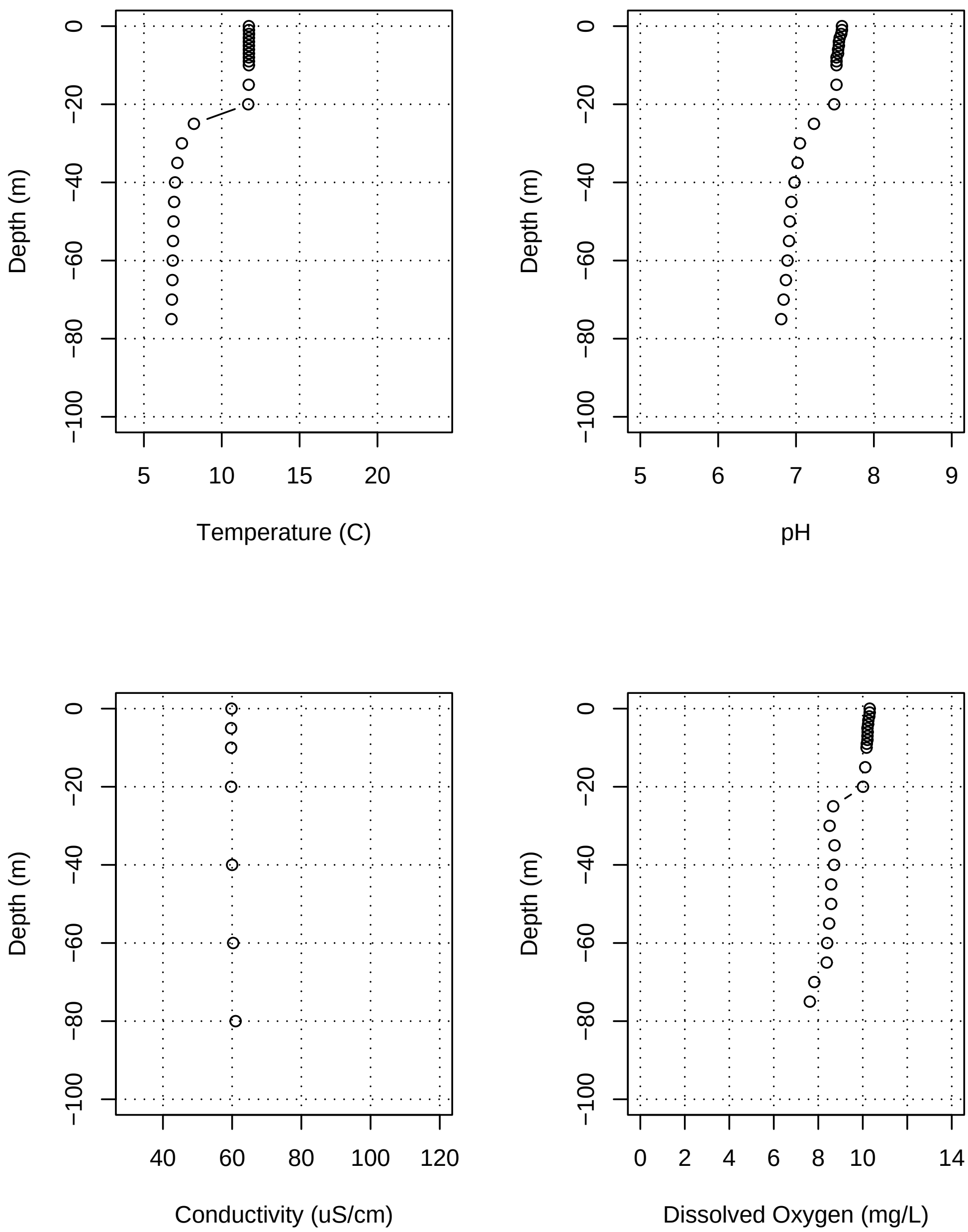


Figure B9: Lake Whatcom Hydrolab profile for Site 3, November 7, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

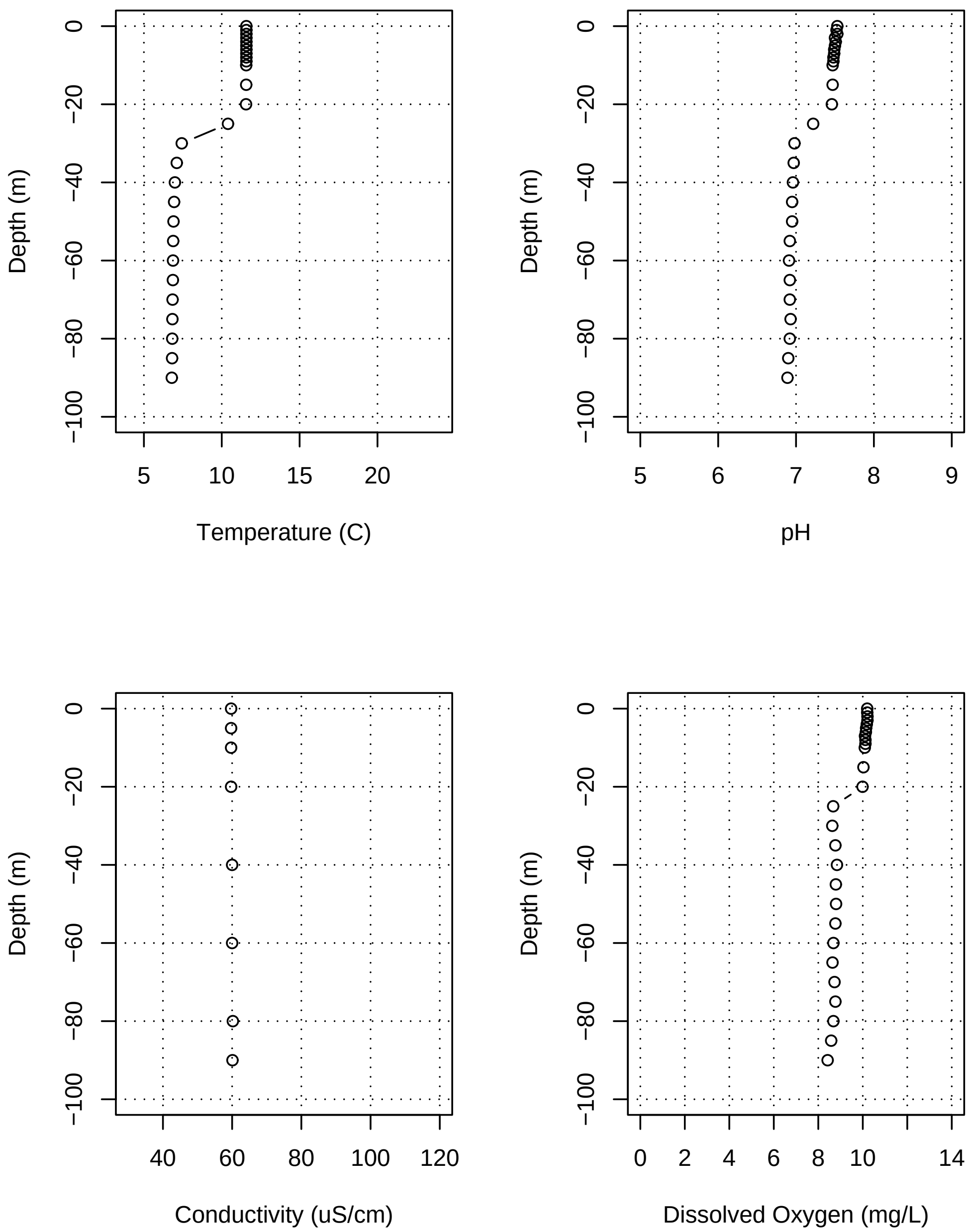


Figure B10: Lake Whatcom Hydrolab profile for Site 4, November 7, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

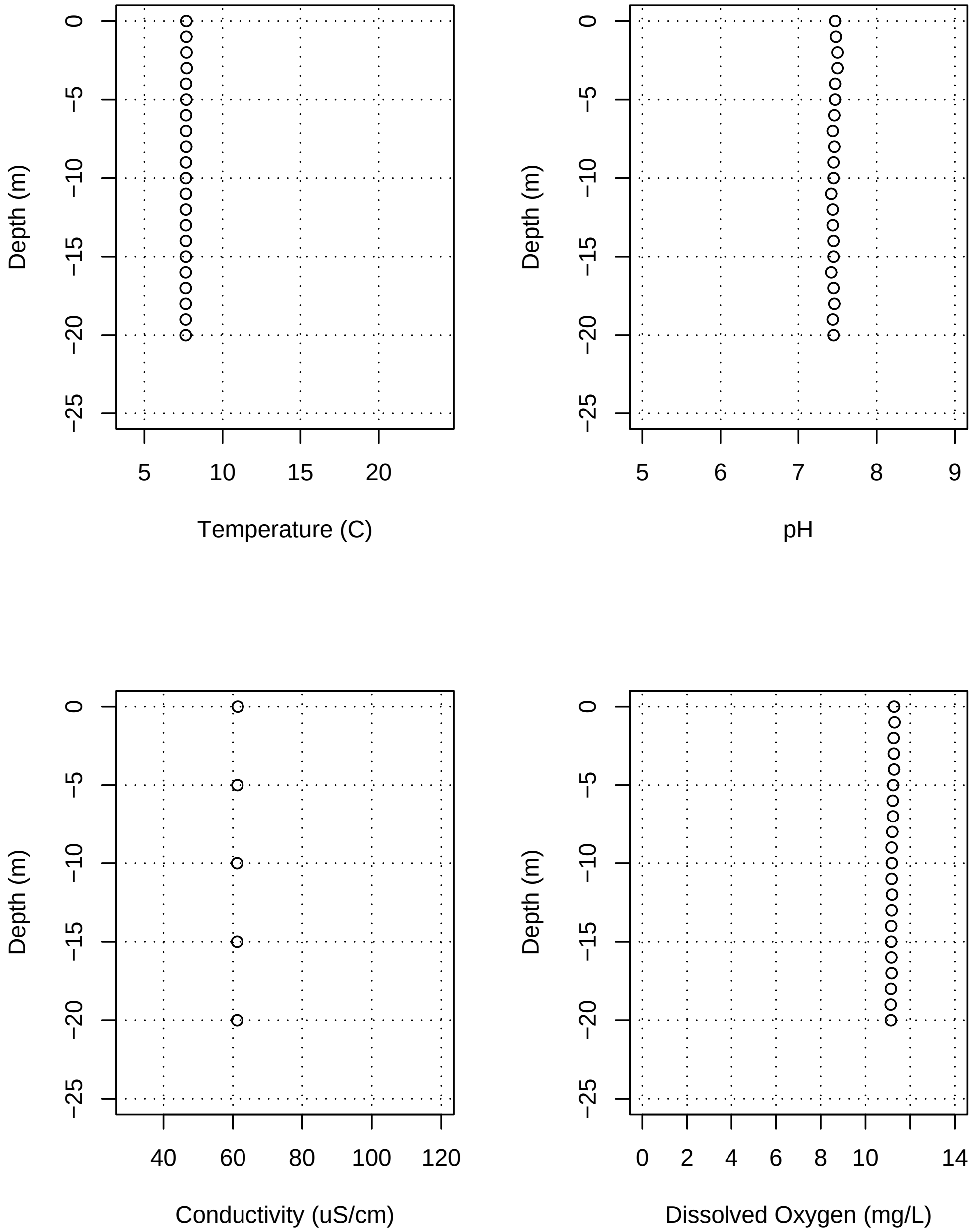


Figure B11: Lake Whatcom Hydrolab profile for Site 1, December 6, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

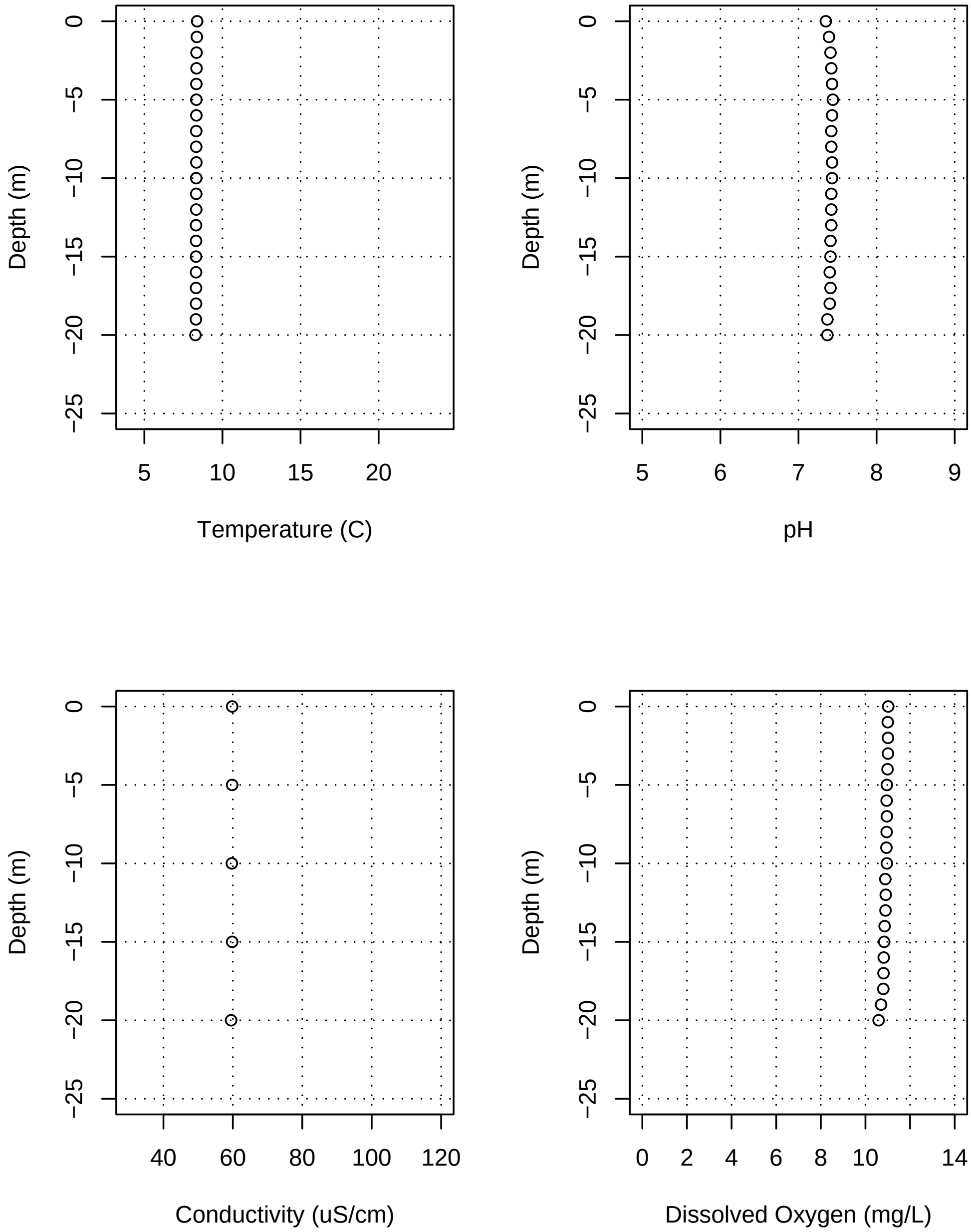


Figure B12: Lake Whatcom Hydrolab profile for Site 2, December 6, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

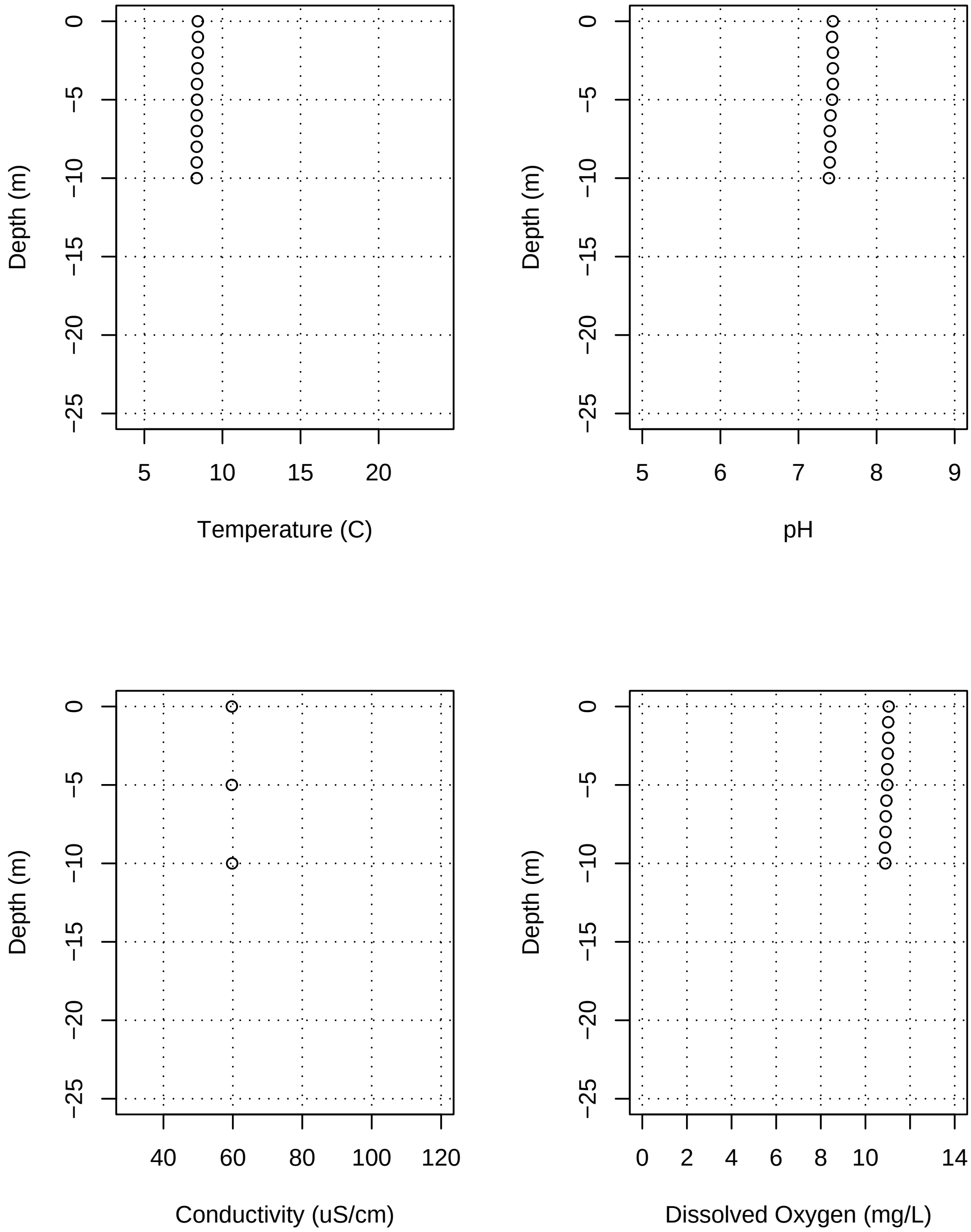


Figure B13: Lake Whatcom Hydrolab profile for the Intake, December 6, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

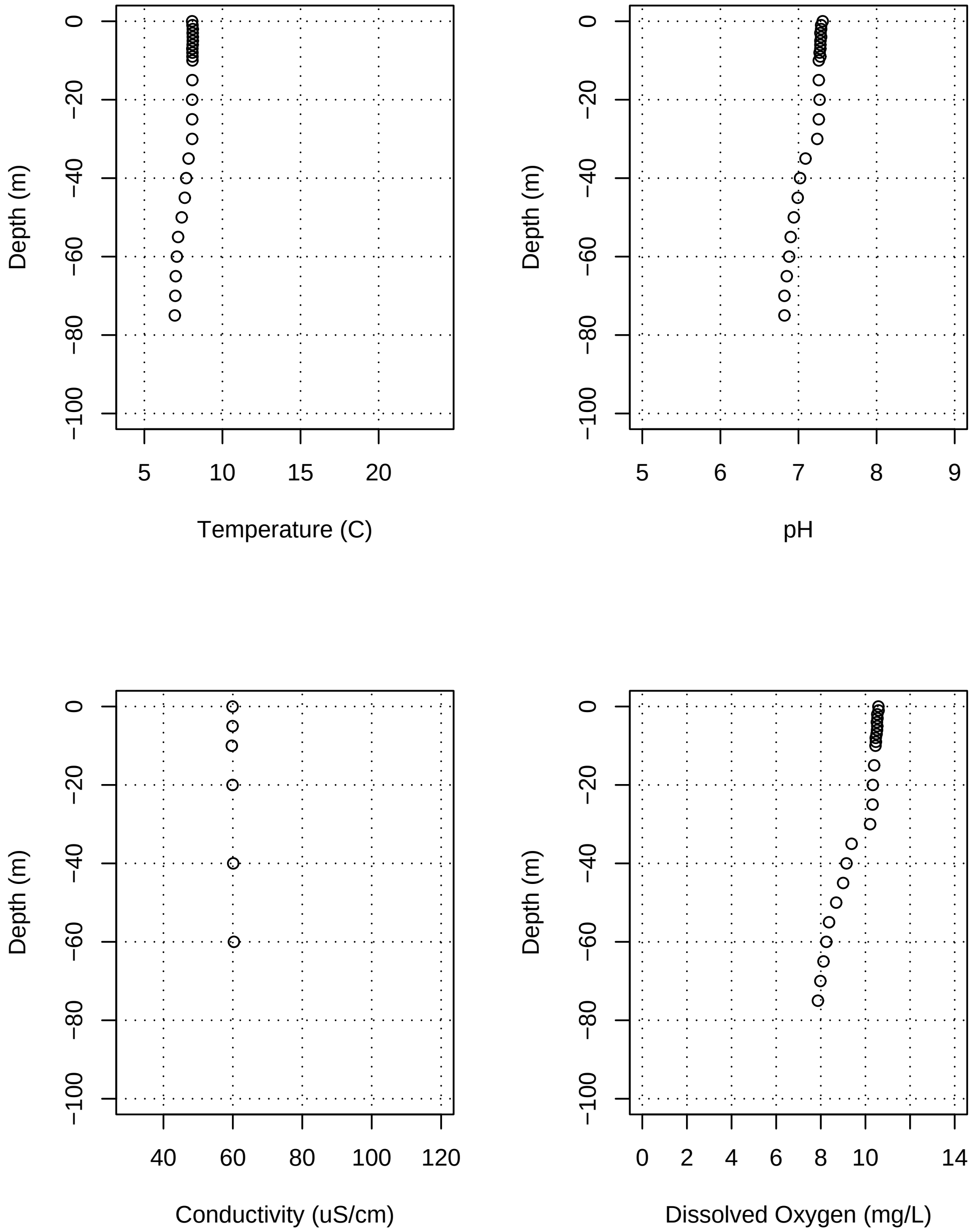


Figure B14: Lake Whatcom Hydrolab profile for Site 3, December 10, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

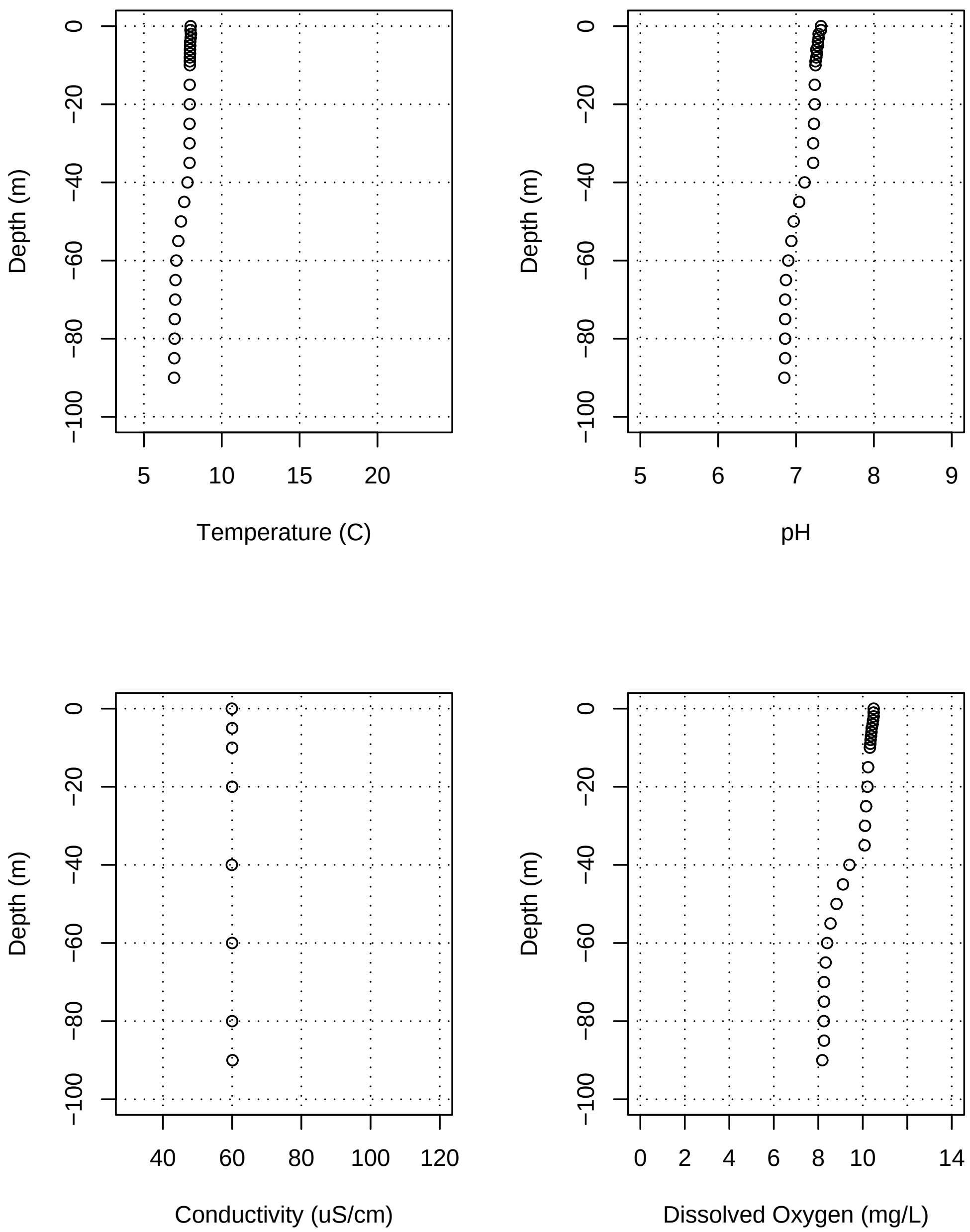


Figure B15: Lake Whatcom Hydrolab profile for Site 4, December 10, 2007. Field conductivity are not available due to equipment malfunction; laboratory conductivity data were collected at the depths indicated.

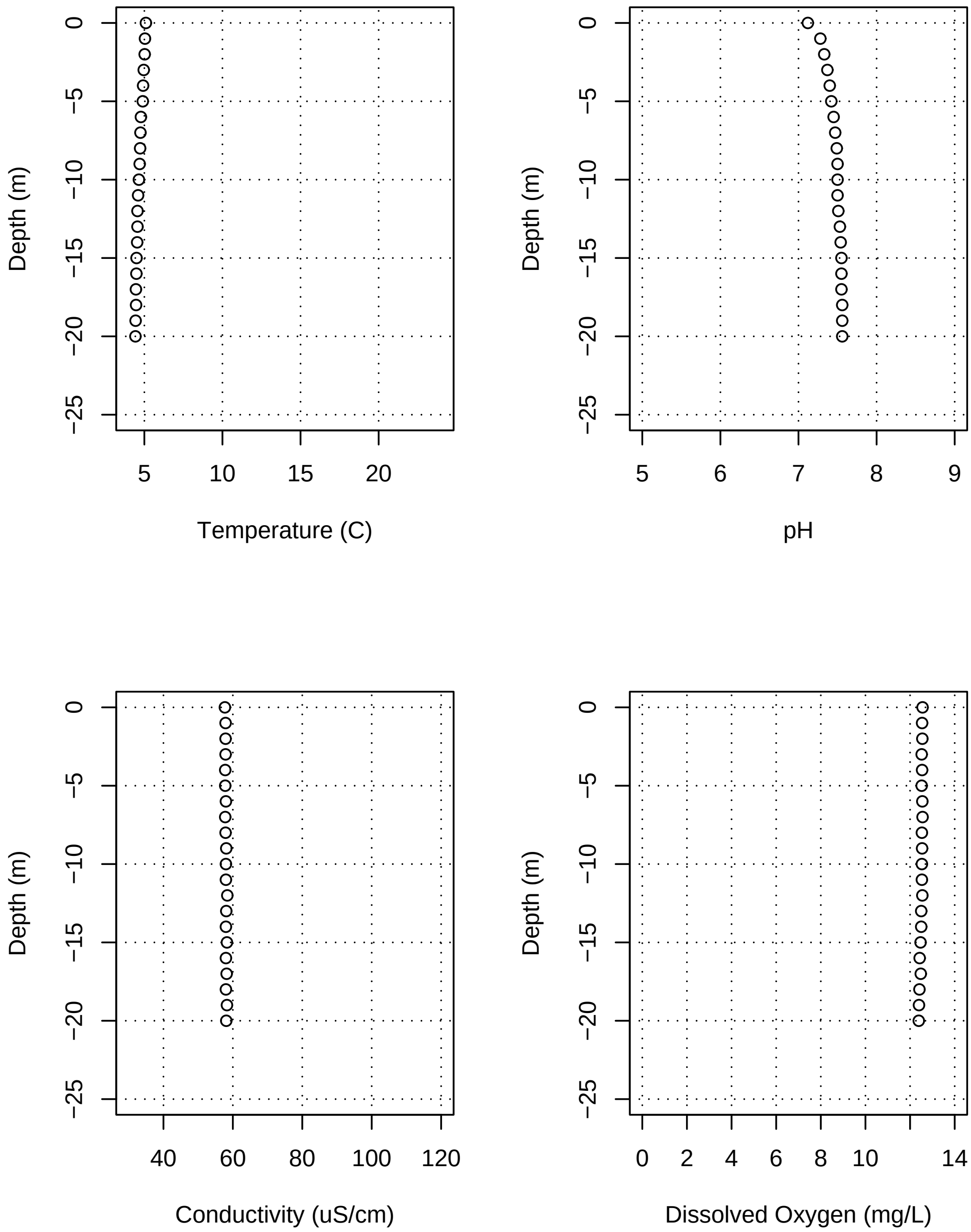


Figure B16: Lake Whatcom Hydrolab profile for Site 1, February 19, 2008.

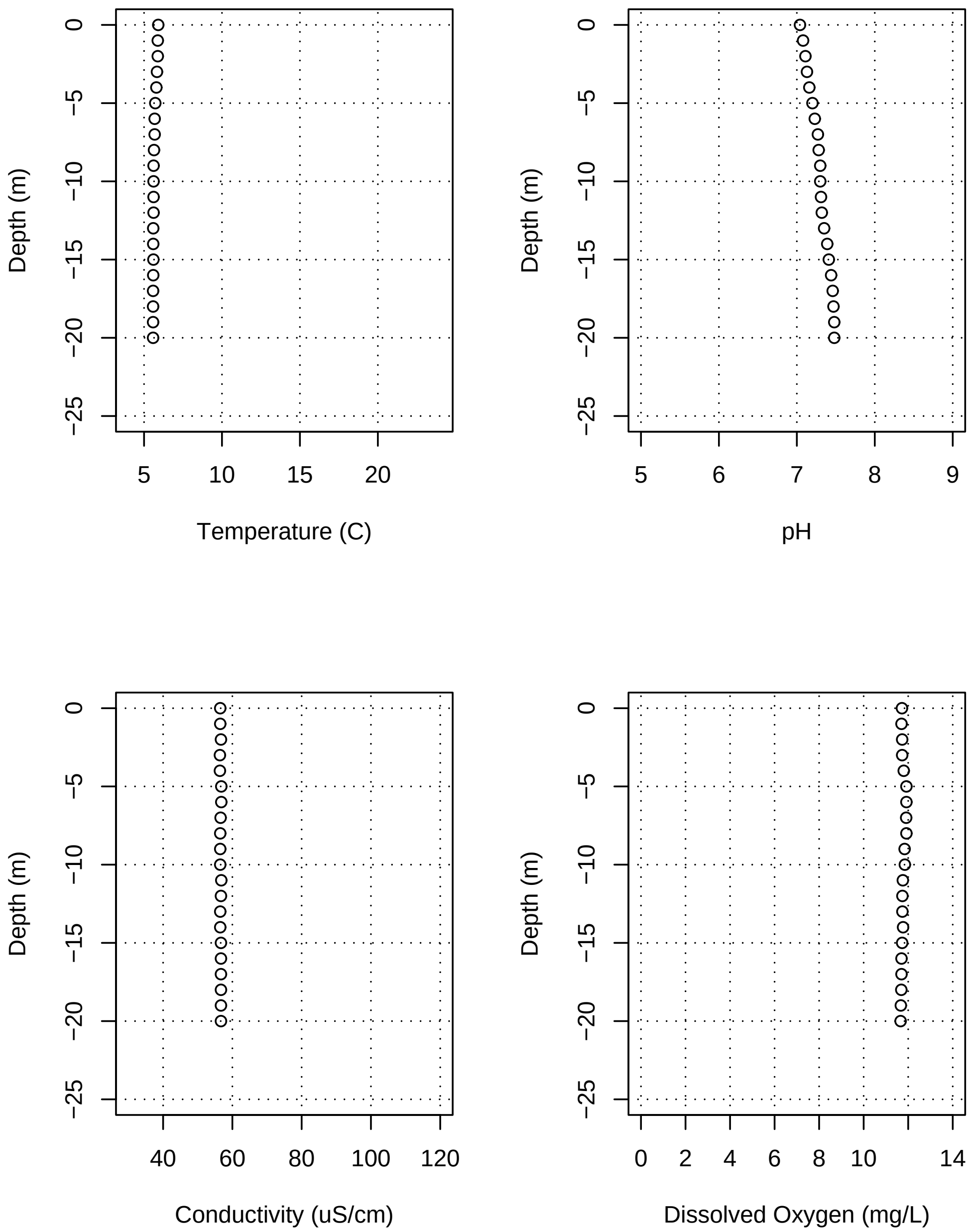


Figure B17: Lake Whatcom Hydrolab profile for Site 2, February 19, 2008.

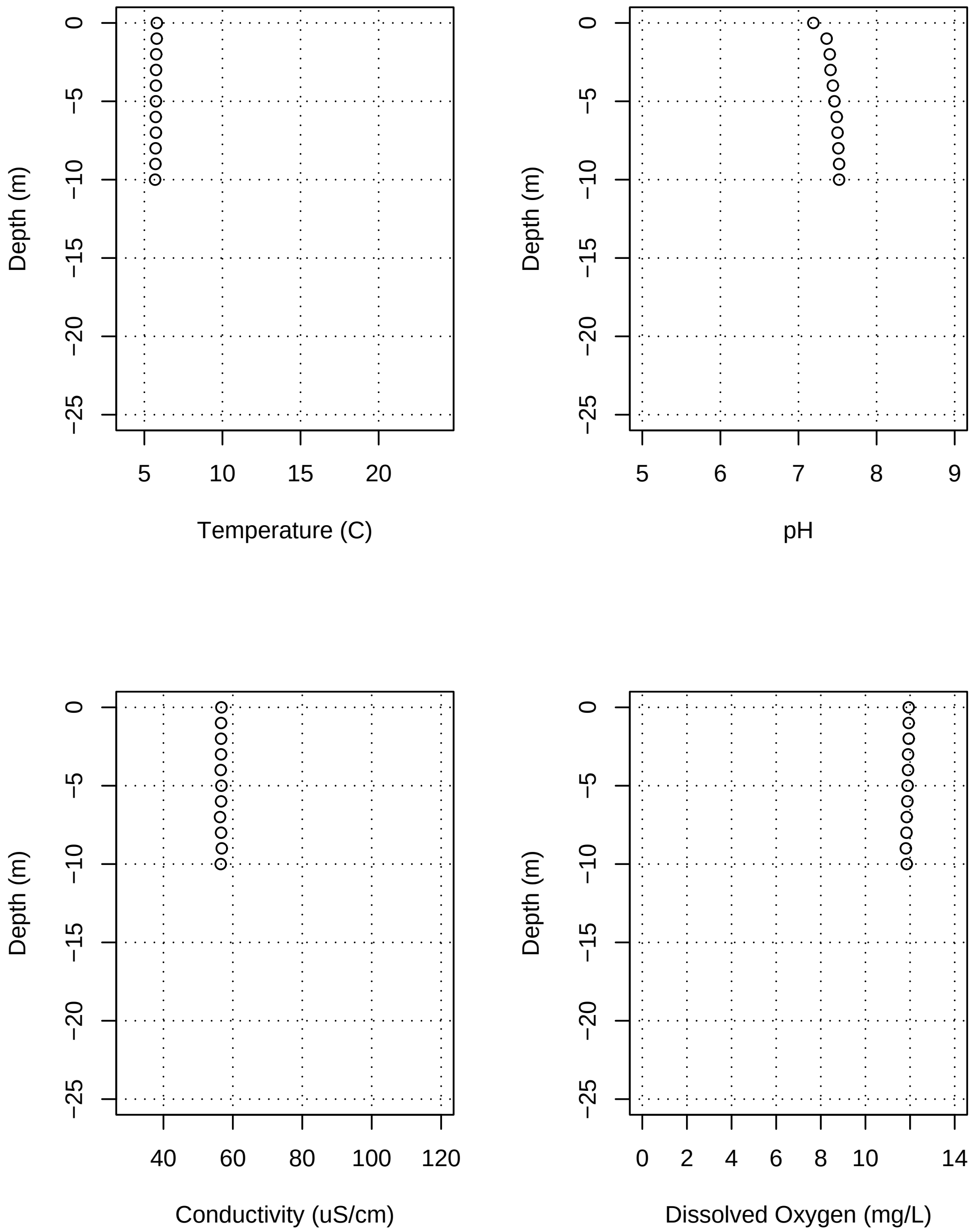


Figure B18: Lake Whatcom Hydrolab profile for the Intake, February 19, 2008.

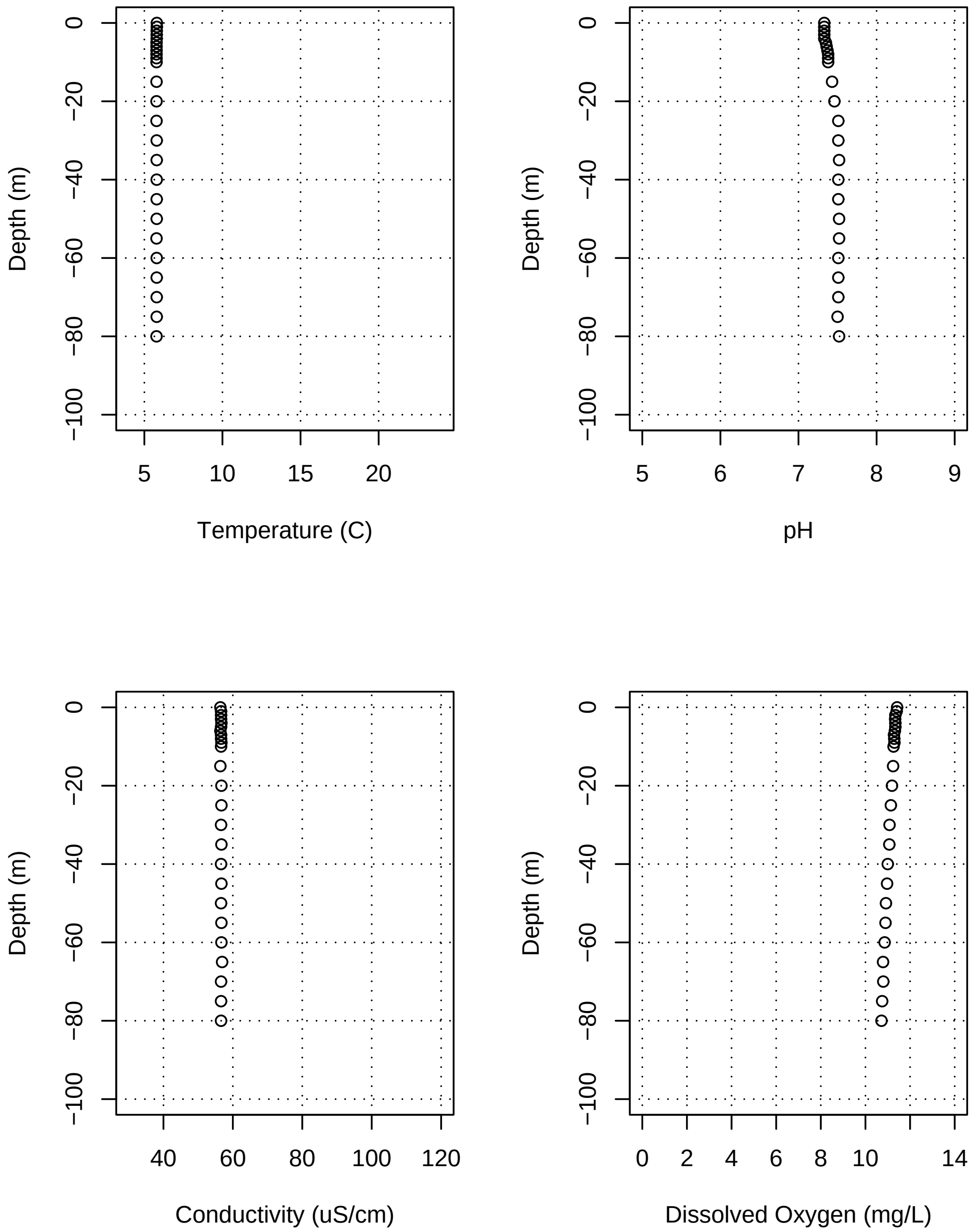


Figure B19: Lake Whatcom Hydrolab profile for Site 3, February 14, 2008.

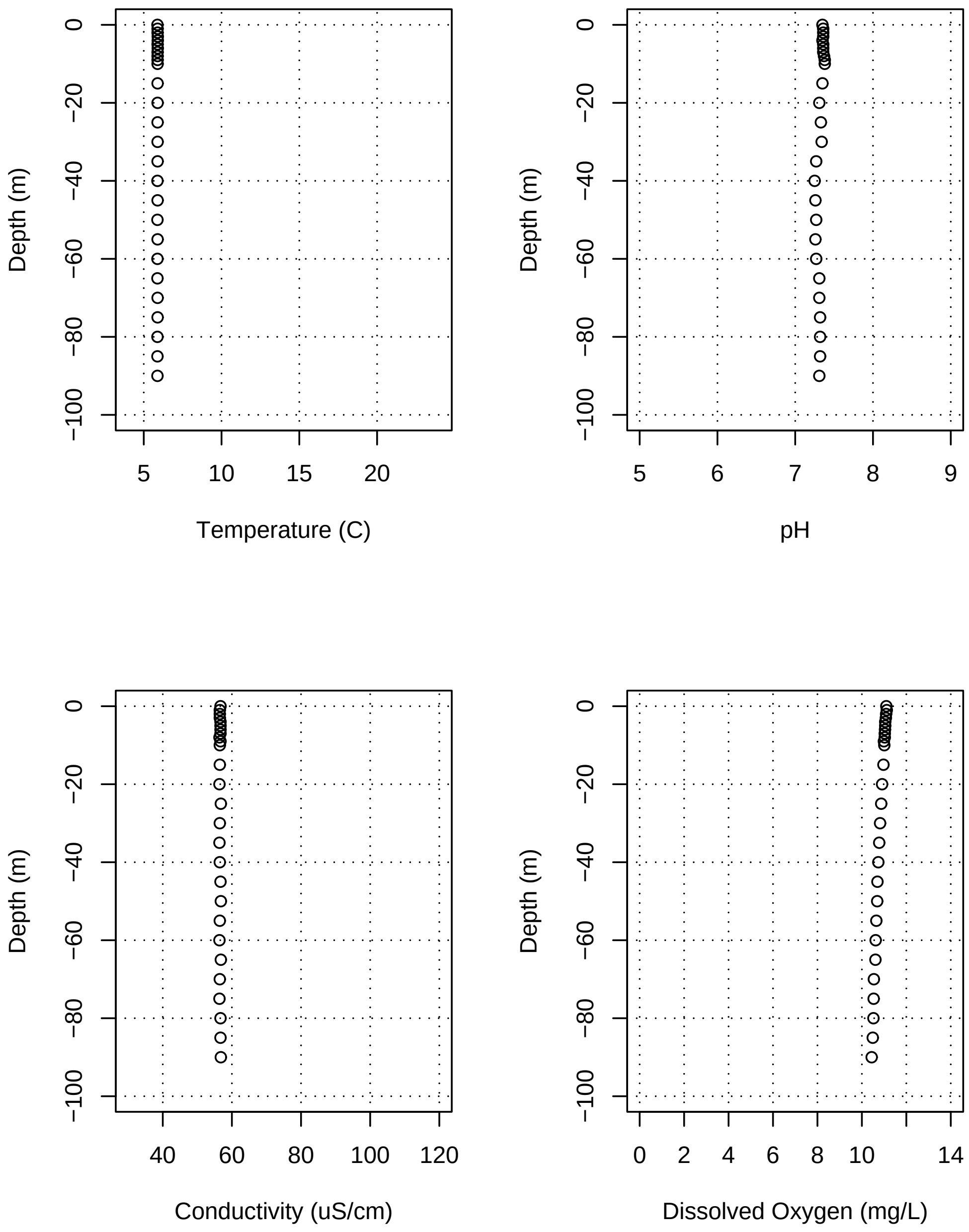


Figure B20: Lake Whatcom Hydrolab profile for Site 4, February 14, 2008.

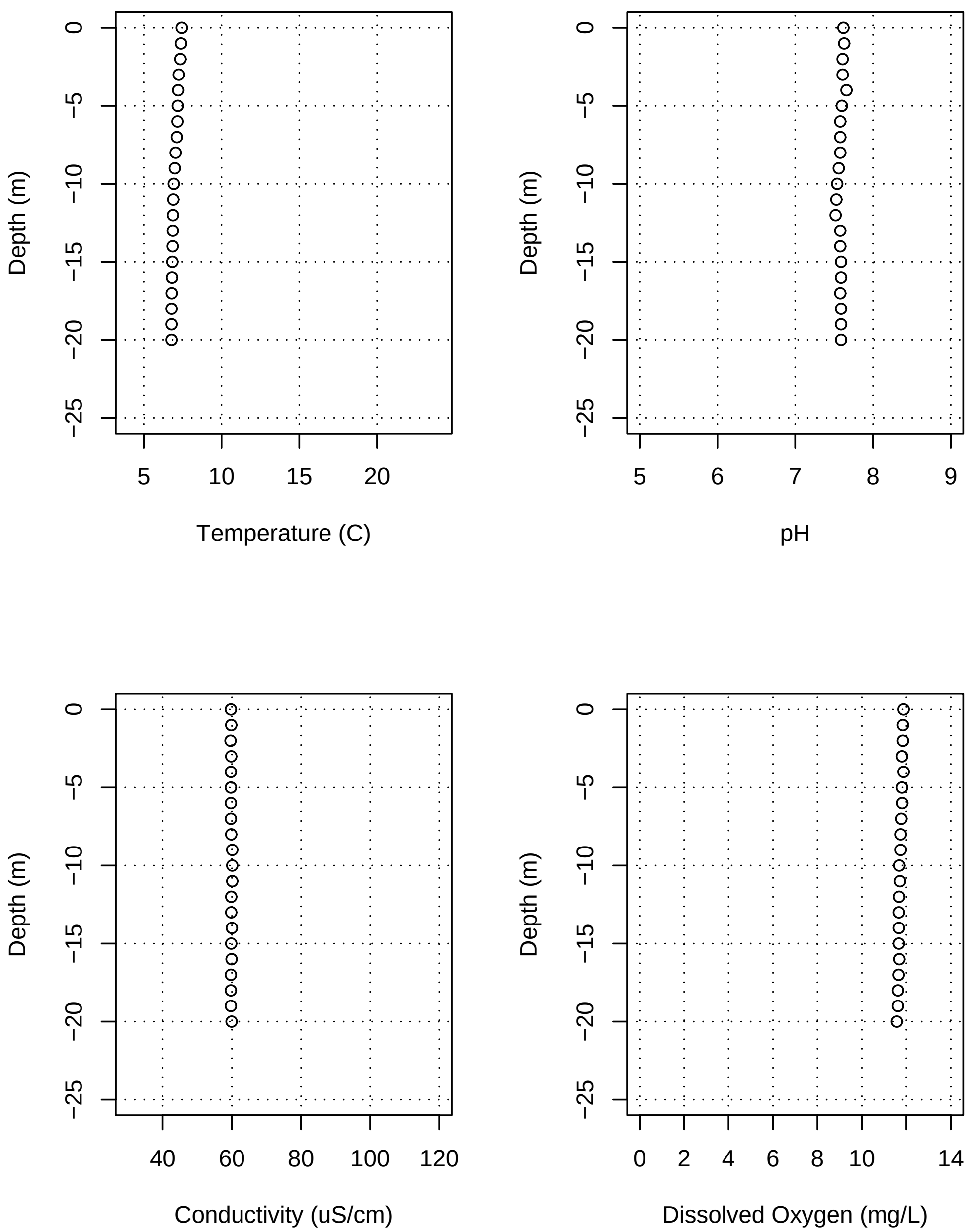


Figure B21: Lake Whatcom Hydrolab profile for Site 1, April 3, 2008.

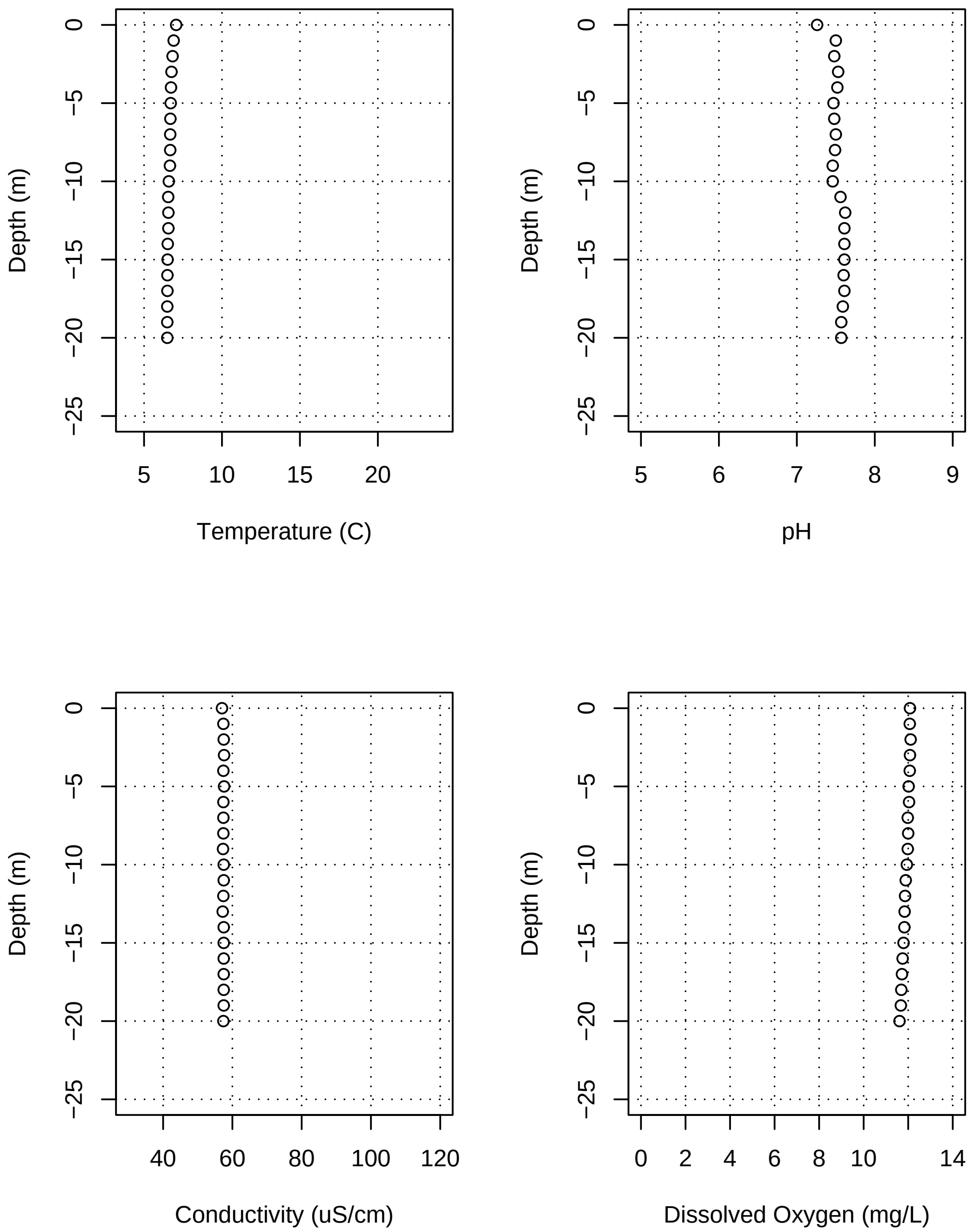


Figure B22: Lake Whatcom Hydrolab profile for Site 2, April 3, 2008.

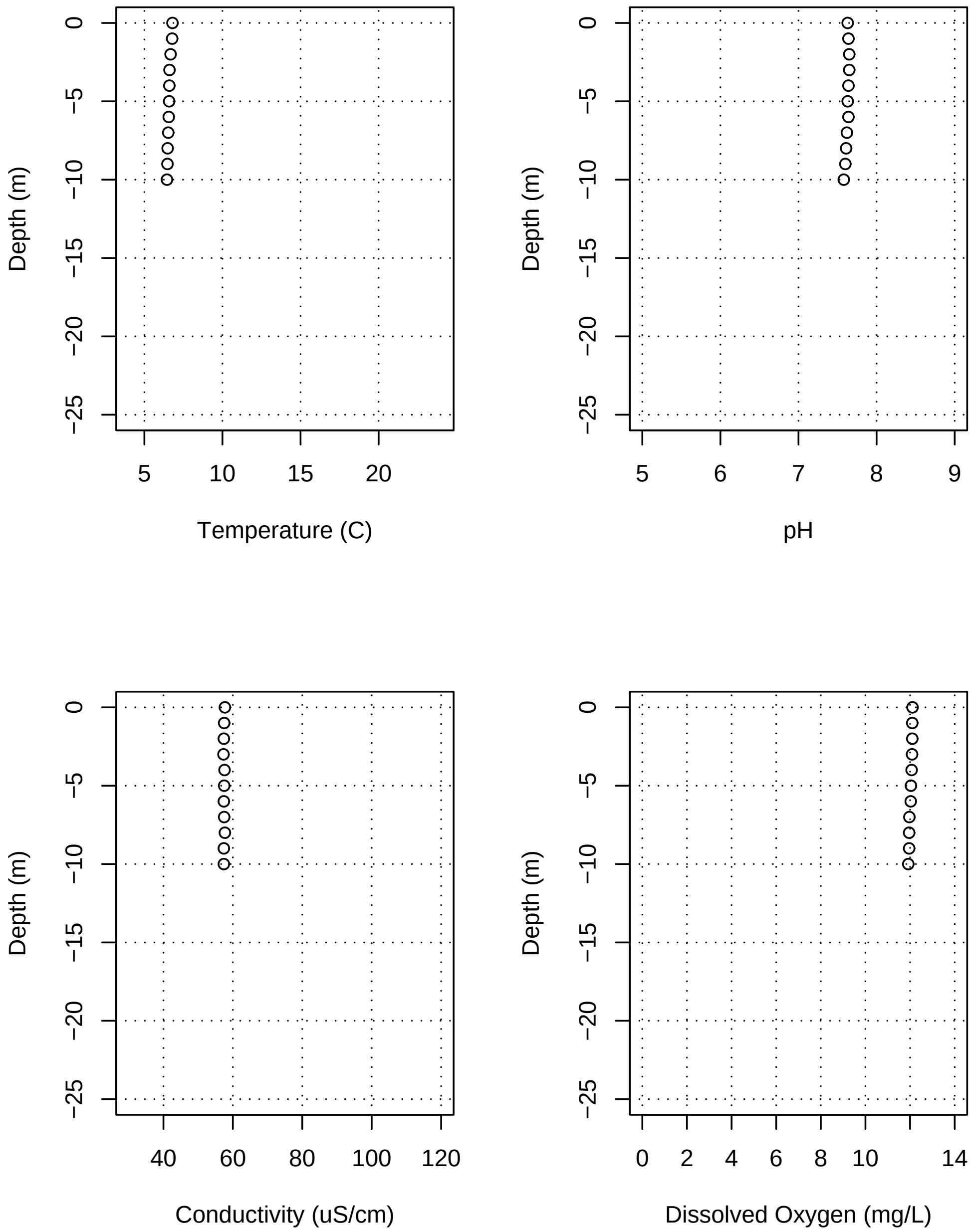


Figure B23: Lake Whatcom Hydrolab profile for the Intake, April 3, 2008.

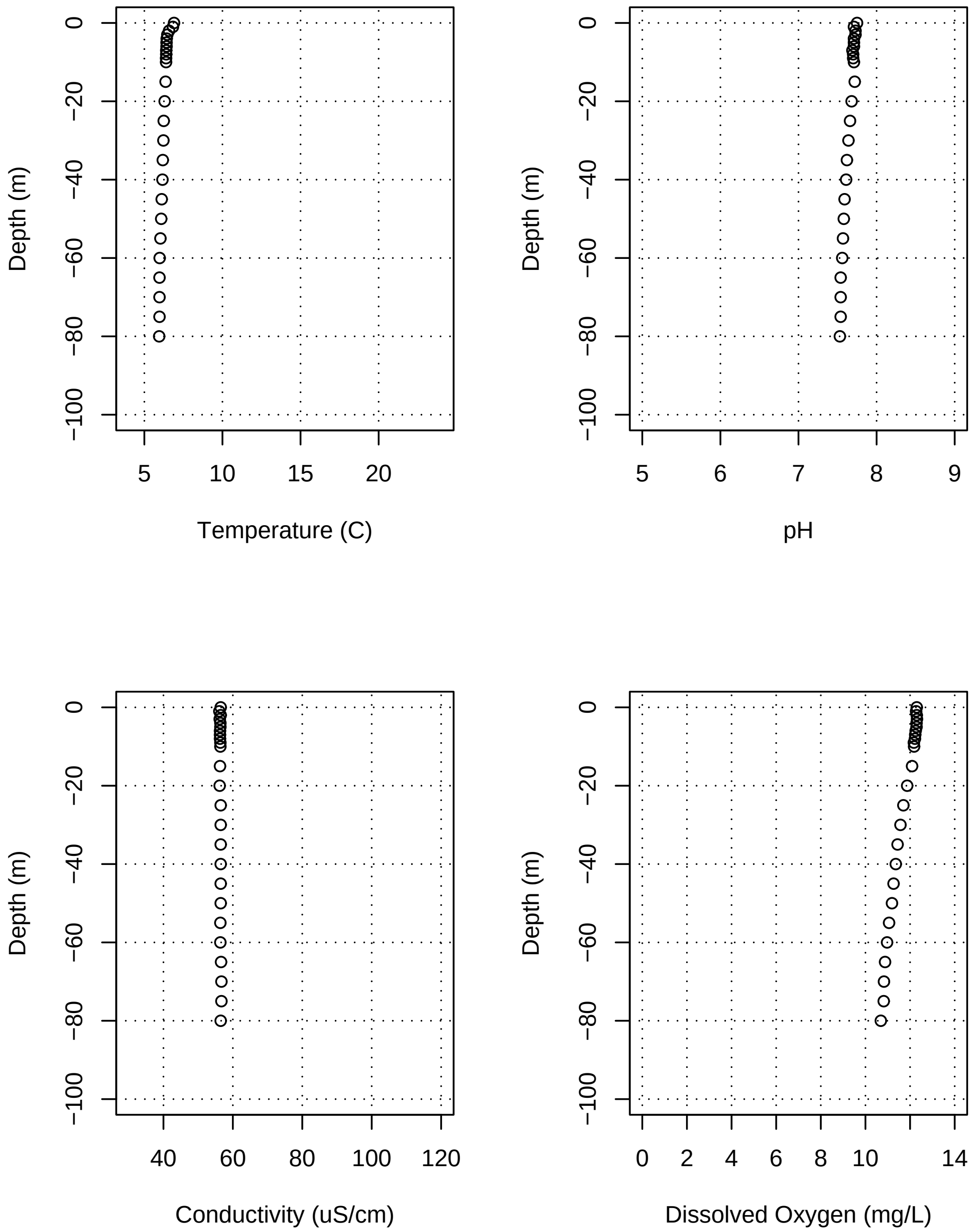


Figure B24: Lake Whatcom Hydrolab profile for Site 3, April 1, 2008.

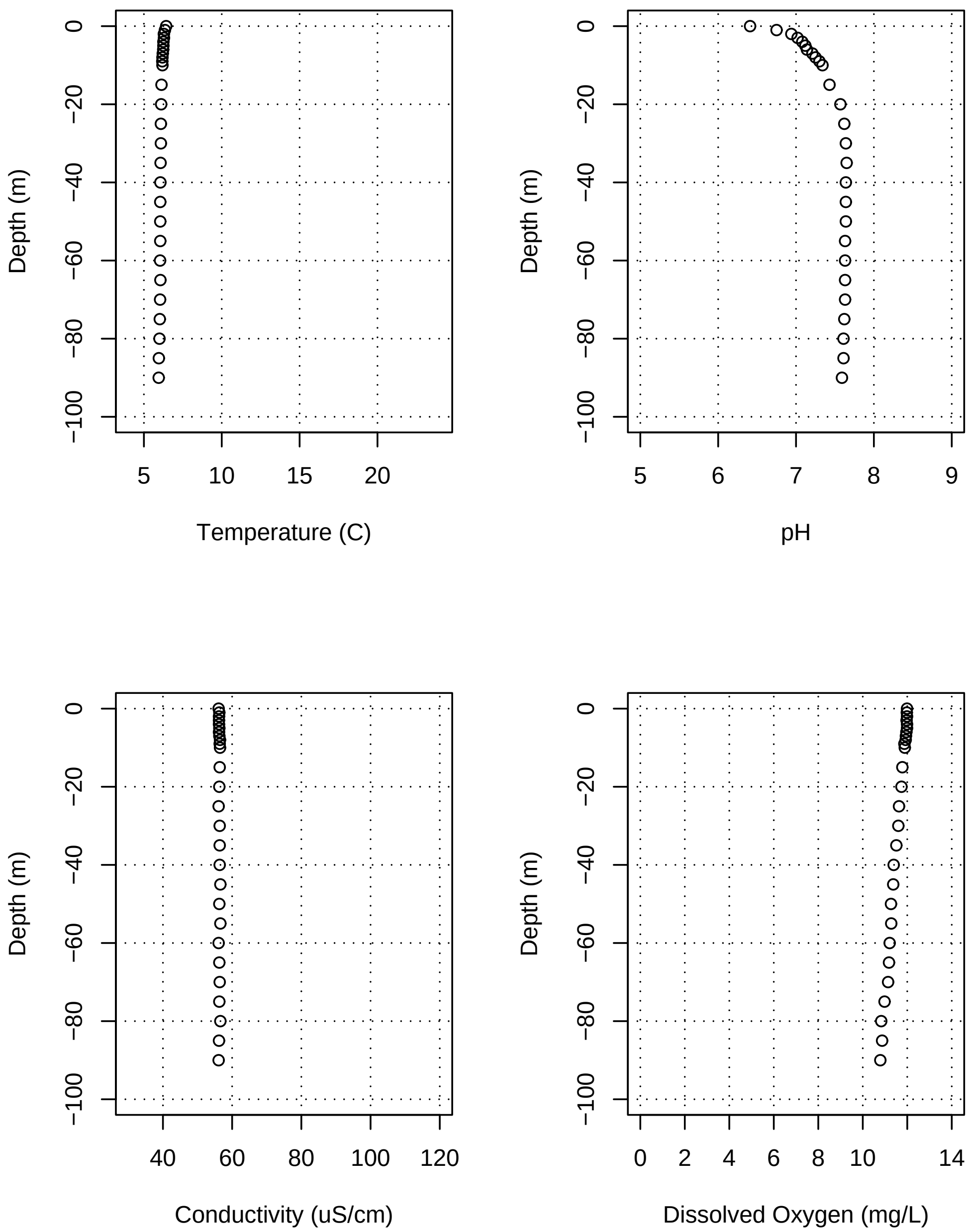


Figure B25: Lake Whatcom Hydrolab profile for Site 4, April 1, 2008. The cause of the near-surface pH drift is unknown, but the values were verified.

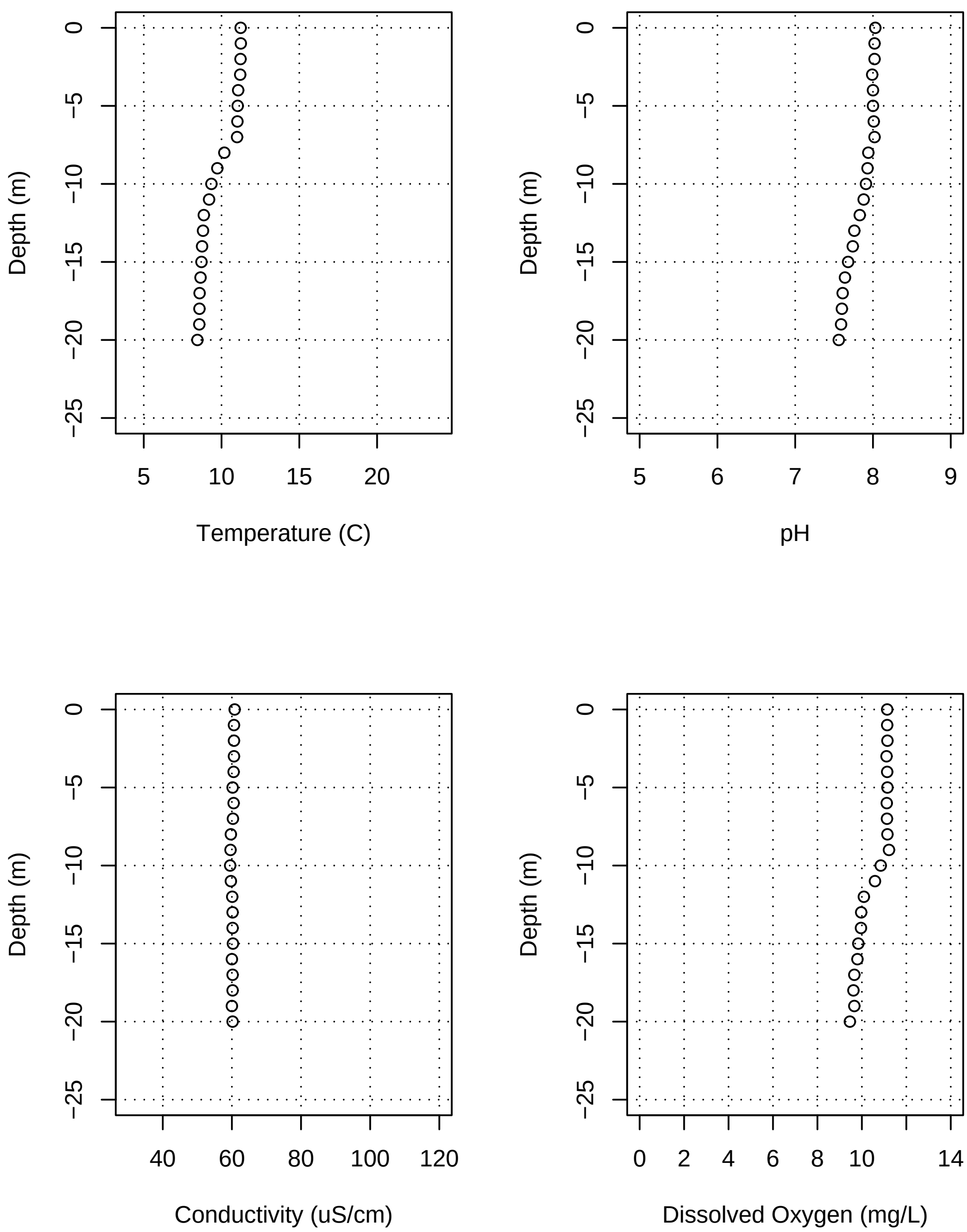


Figure B26: Lake Whatcom Hydrolab profile for Site 1, May 8, 2008.

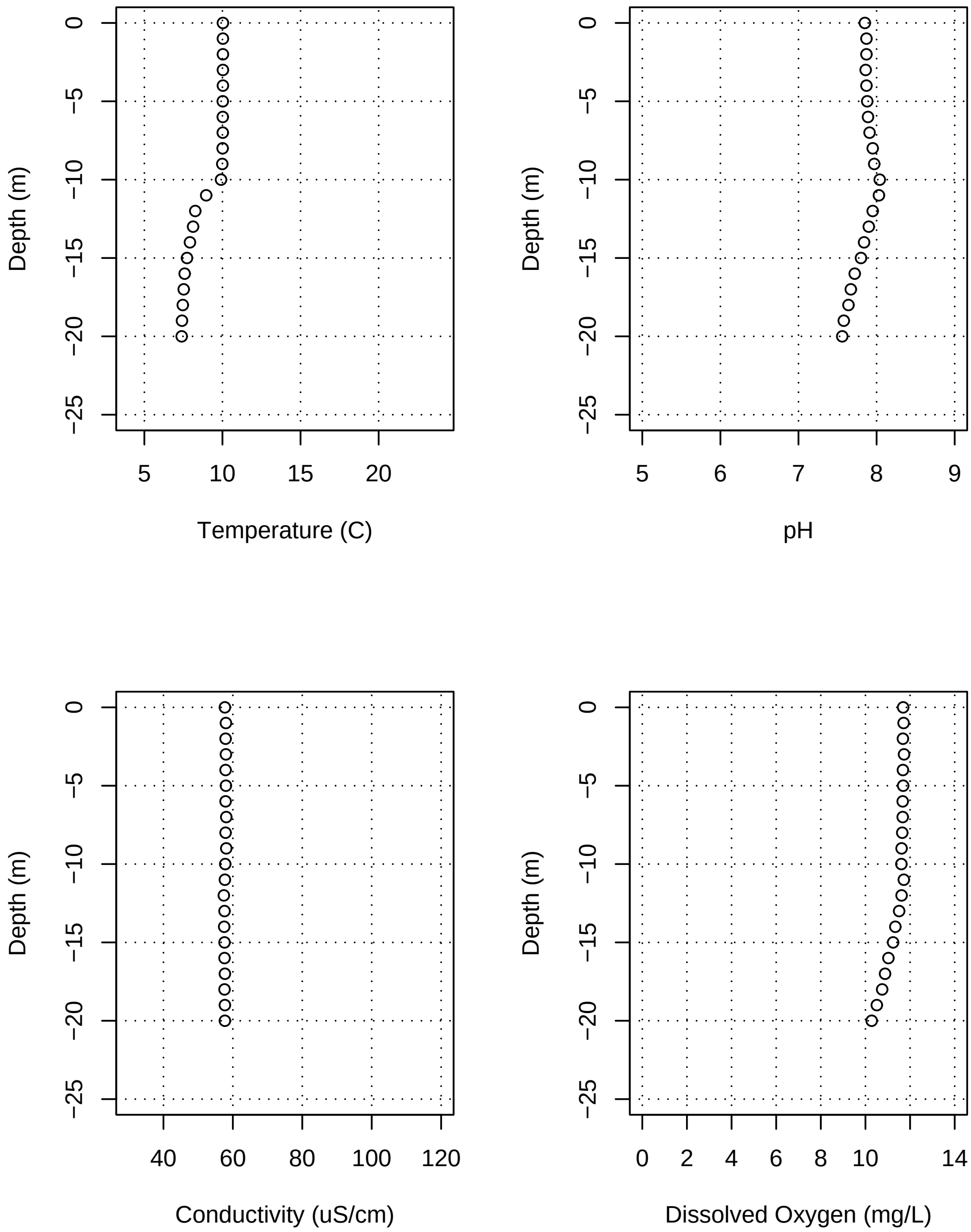


Figure B27: Lake Whatcom Hydrolab profile for Site 2, May 8, 2008.

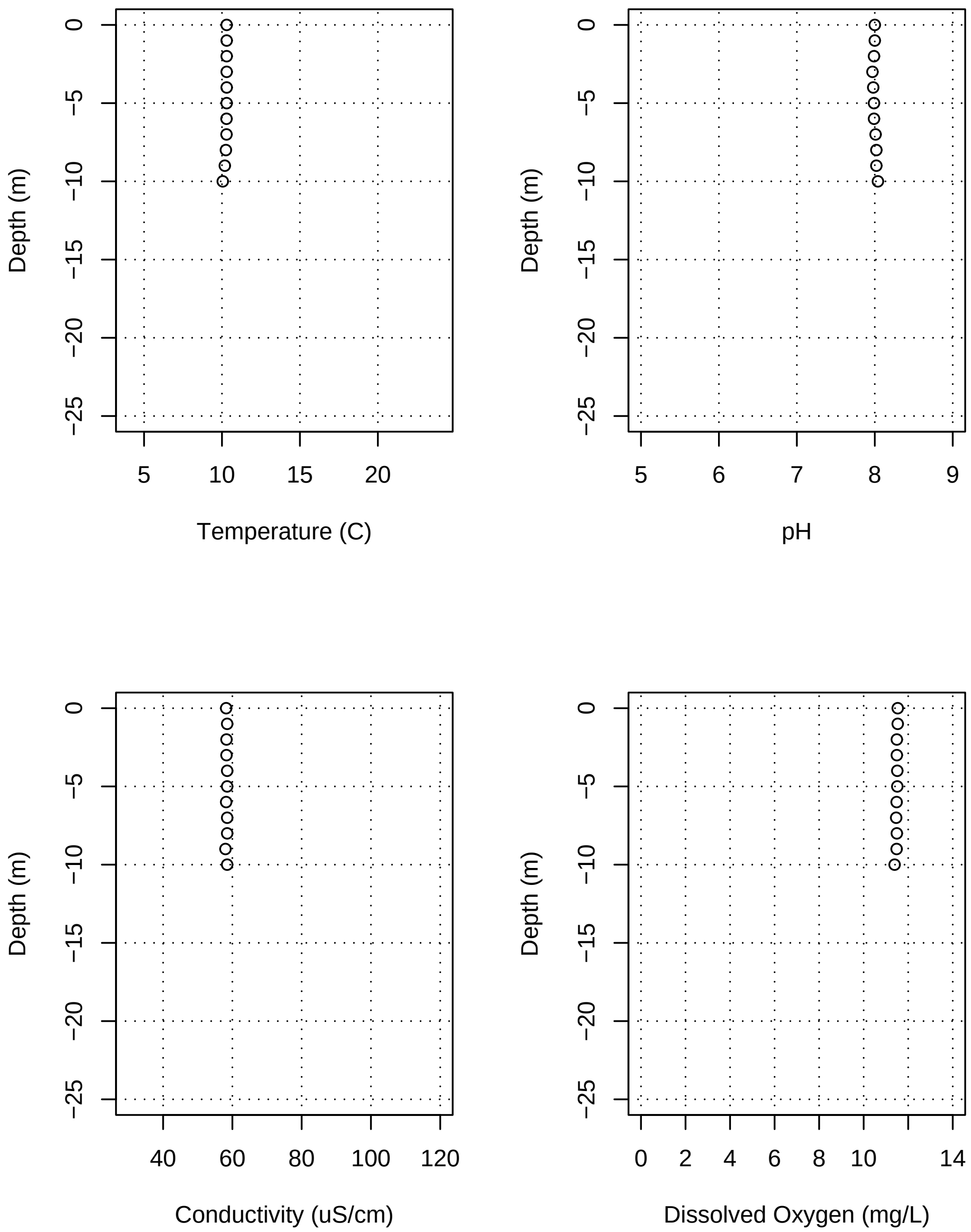


Figure B28: Lake Whatcom Hydrolab profile for the Intake, May 8, 2008.

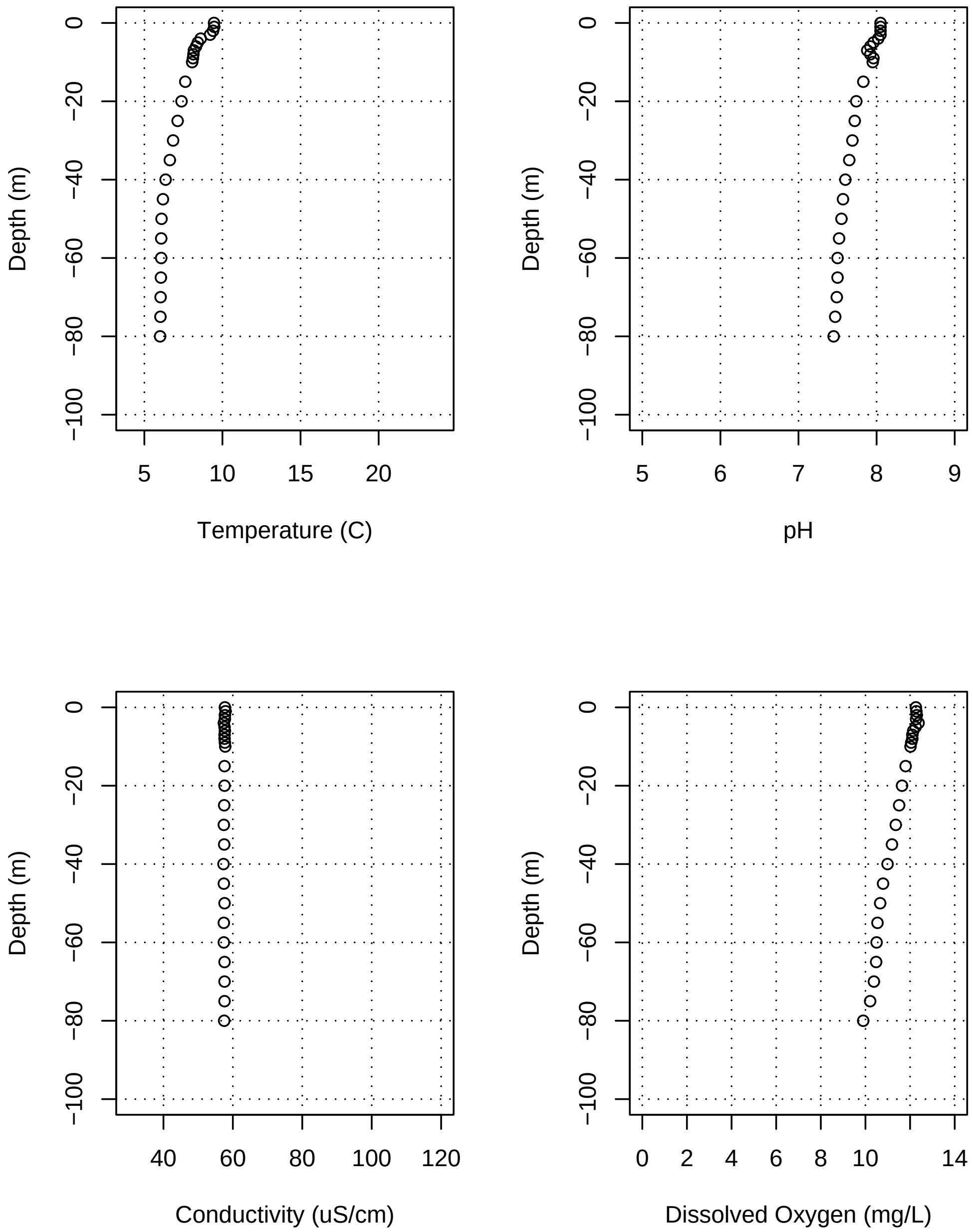


Figure B29: Lake Whatcom Hydrolab profile for Site 3, May 6, 2008.

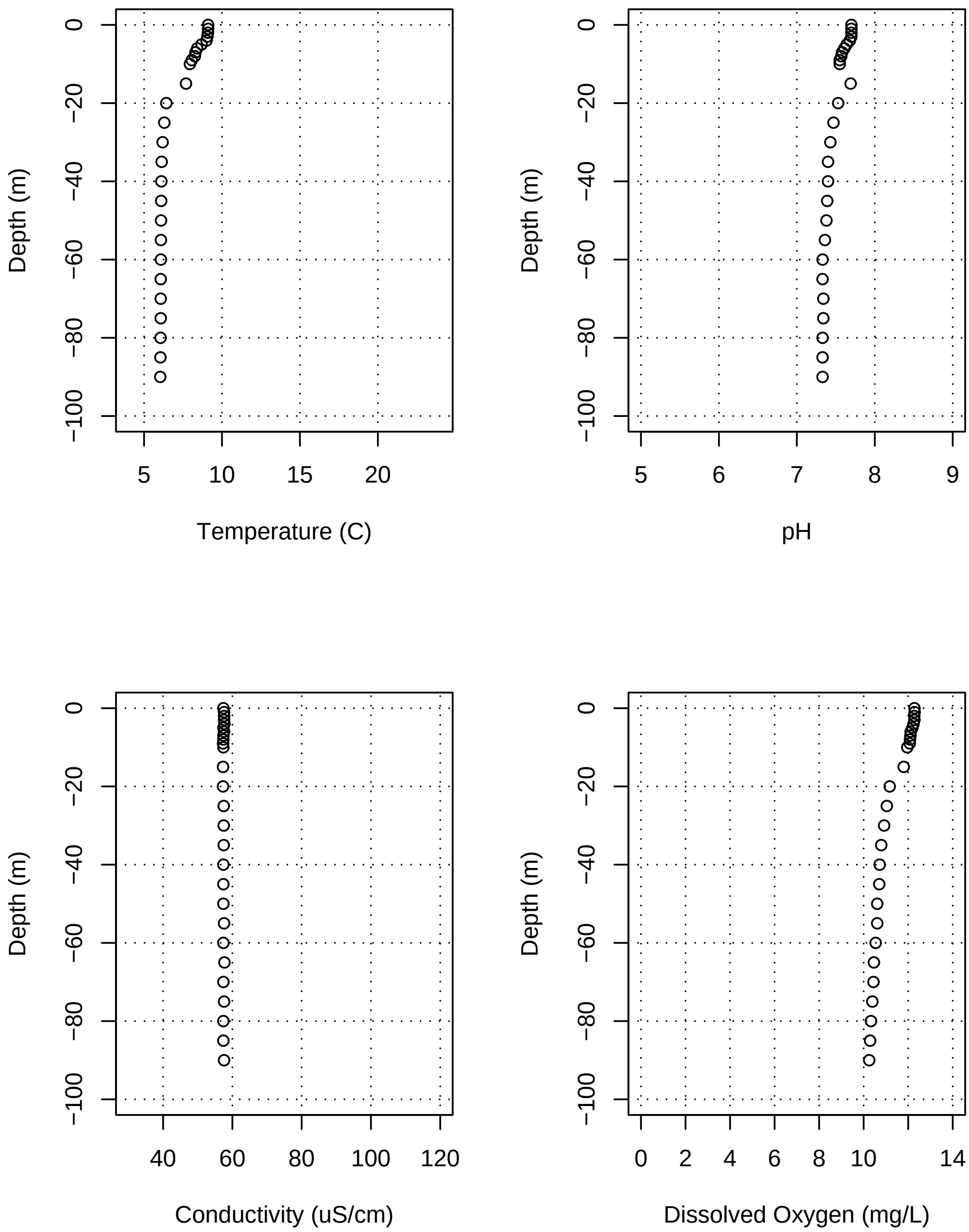


Figure B30: Lake Whatcom Hydrolab profile for Site 4, May 6, 2008.

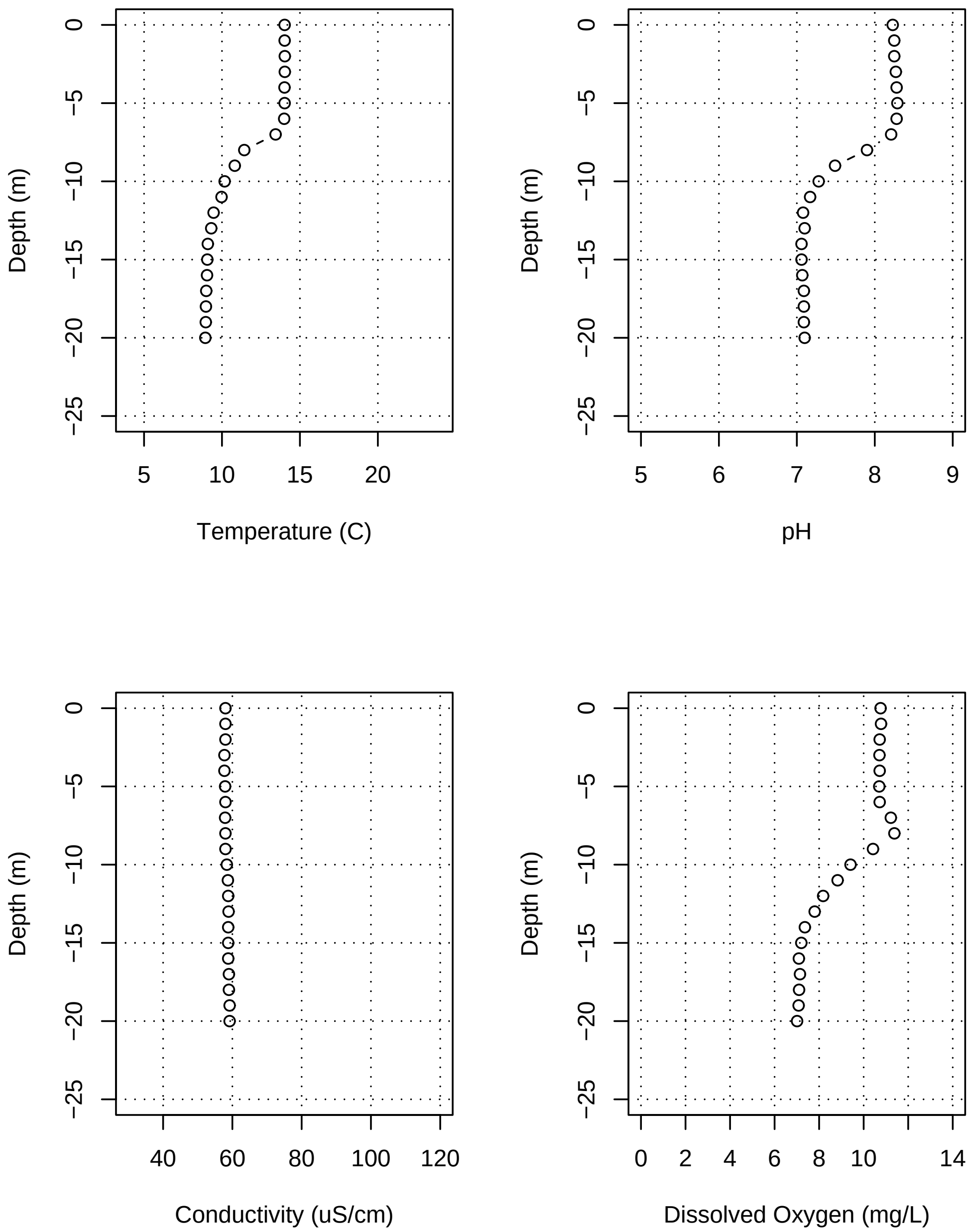


Figure B31: Lake Whatcom Hydrolab profile for Site 1, June 5, 2008.

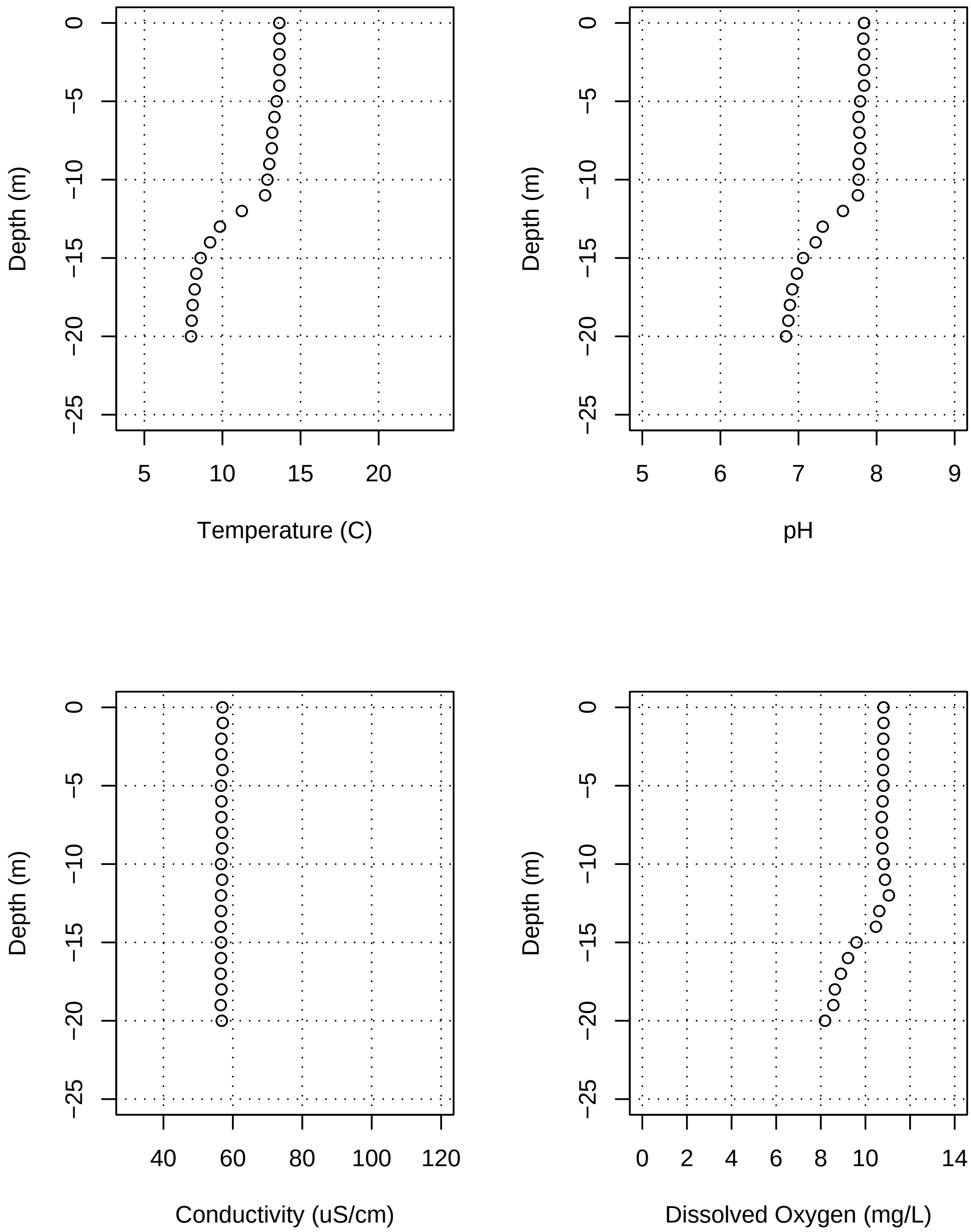


Figure B32: Lake Whatcom Hydrolab profile for Site 2, June 5, 2008.

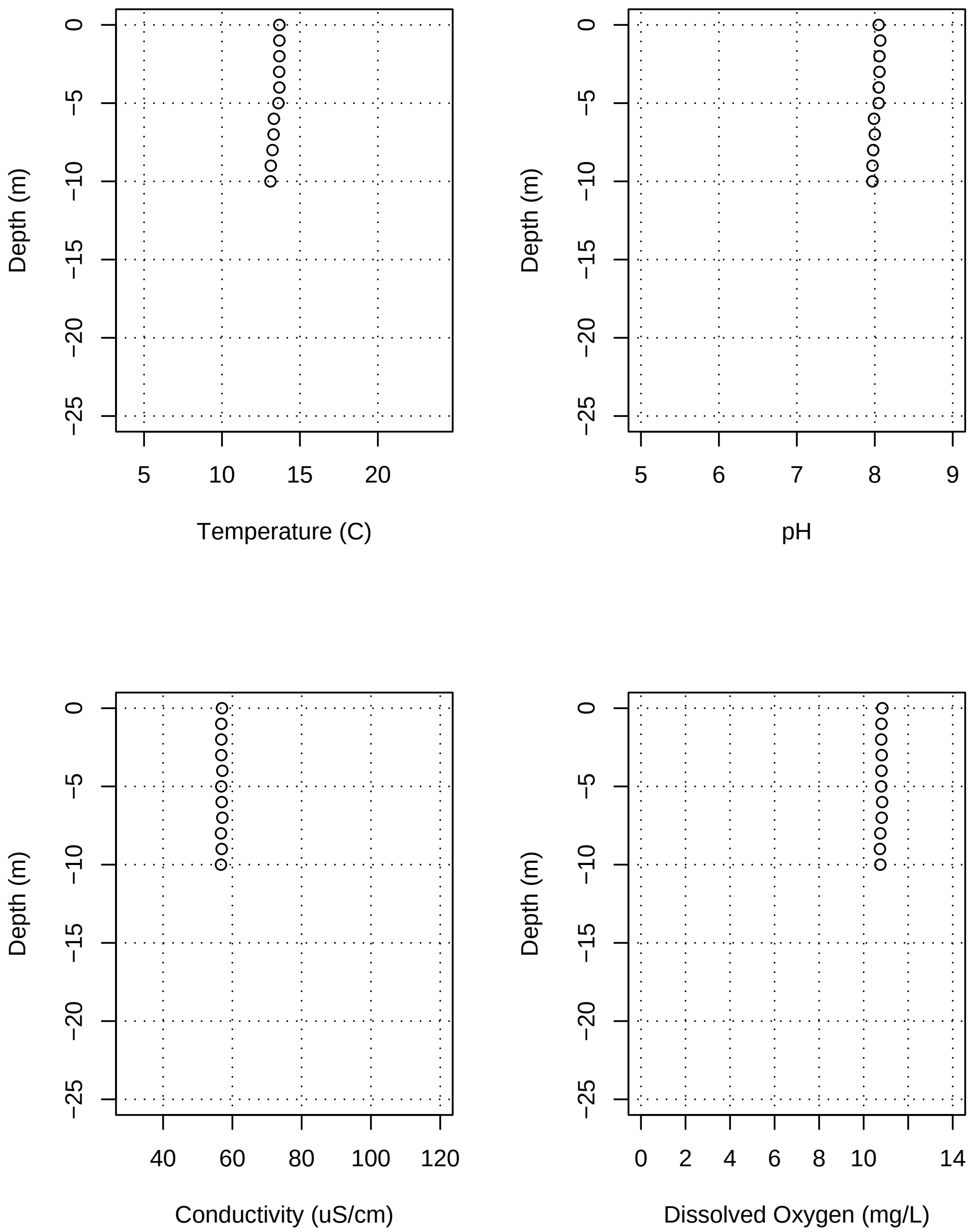


Figure B33: Lake Whatcom Hydrolab profile for the Intake, June 5, 2008.

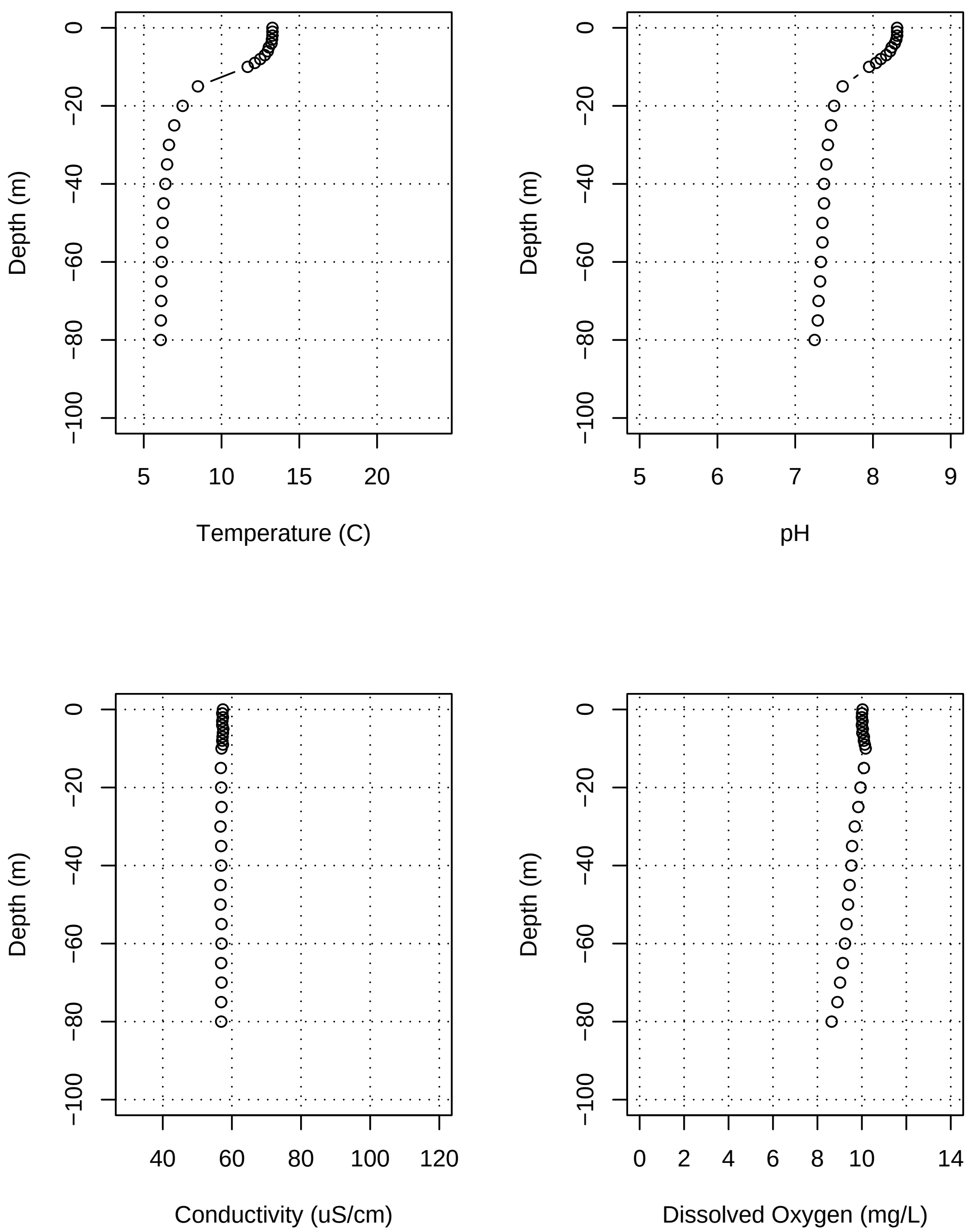


Figure B34: Lake Whatcom Hydrolab profile for Site 3, June 3, 2008.

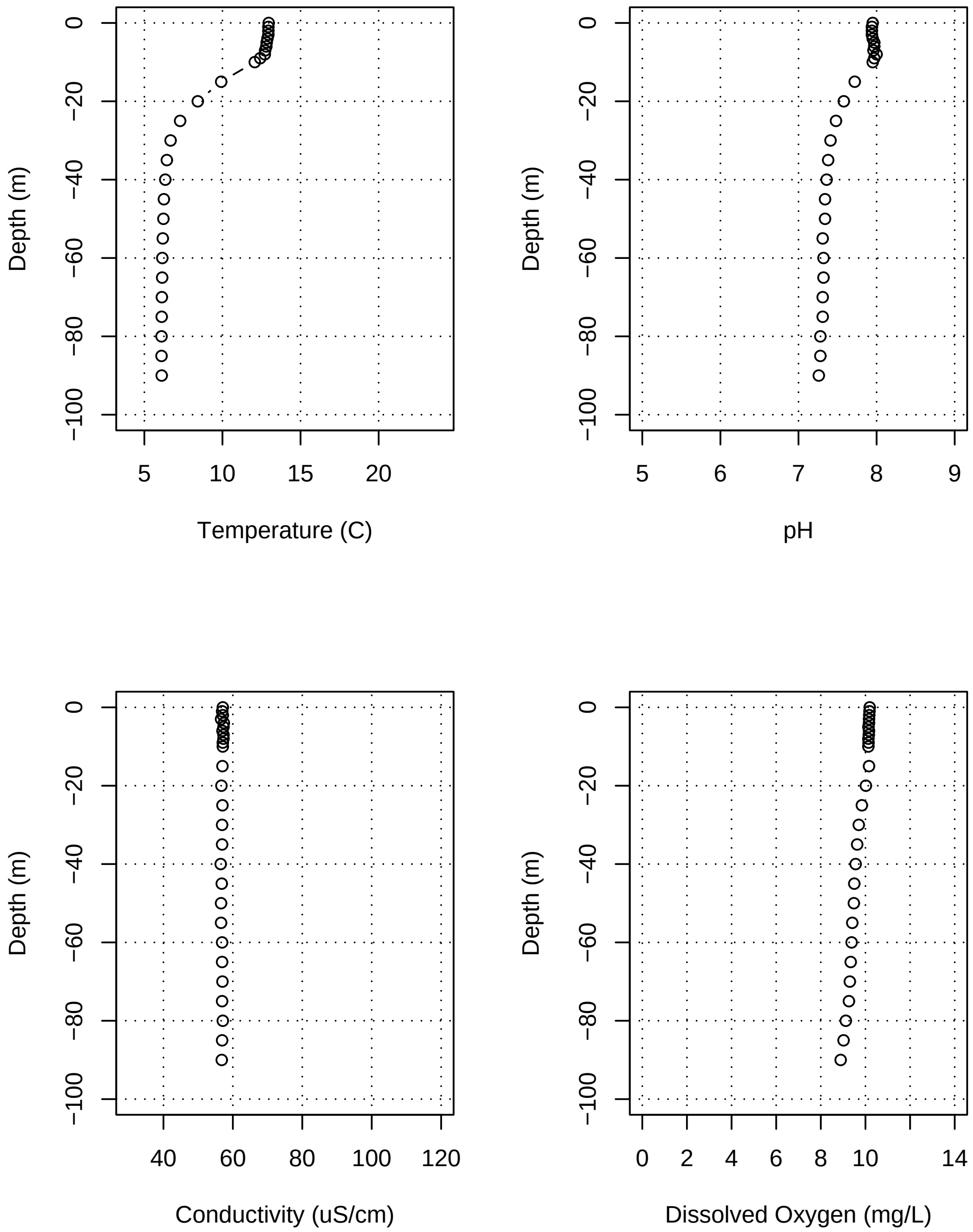


Figure B35: Lake Whatcom Hydrolab profile for Site 4, June 3, 2008.

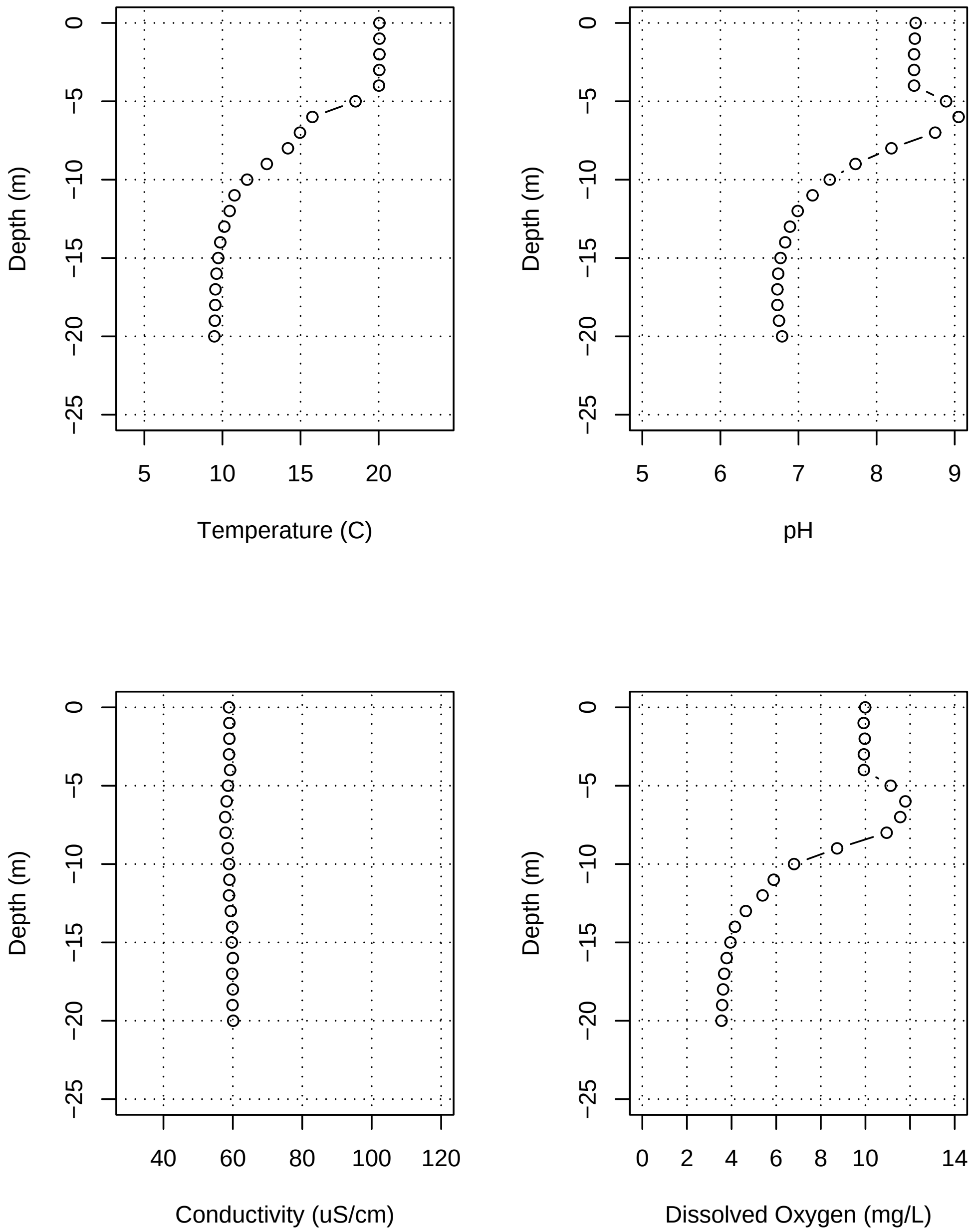


Figure B36: Lake Whatcom Hydrolab profile for Site 1, July 10, 2008.

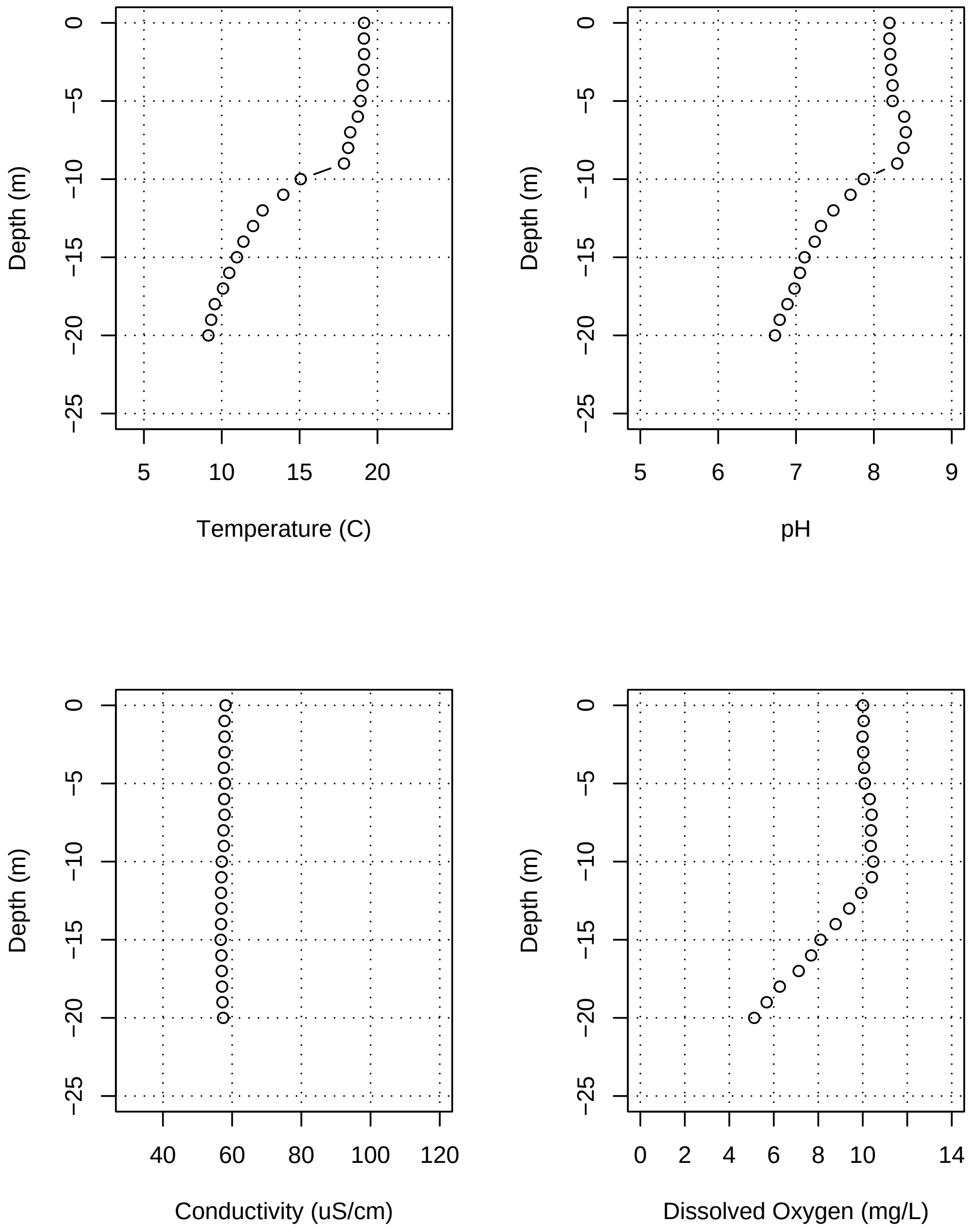


Figure B37: Lake Whatcom Hydrolab profile for Site 2, July 10, 2008.

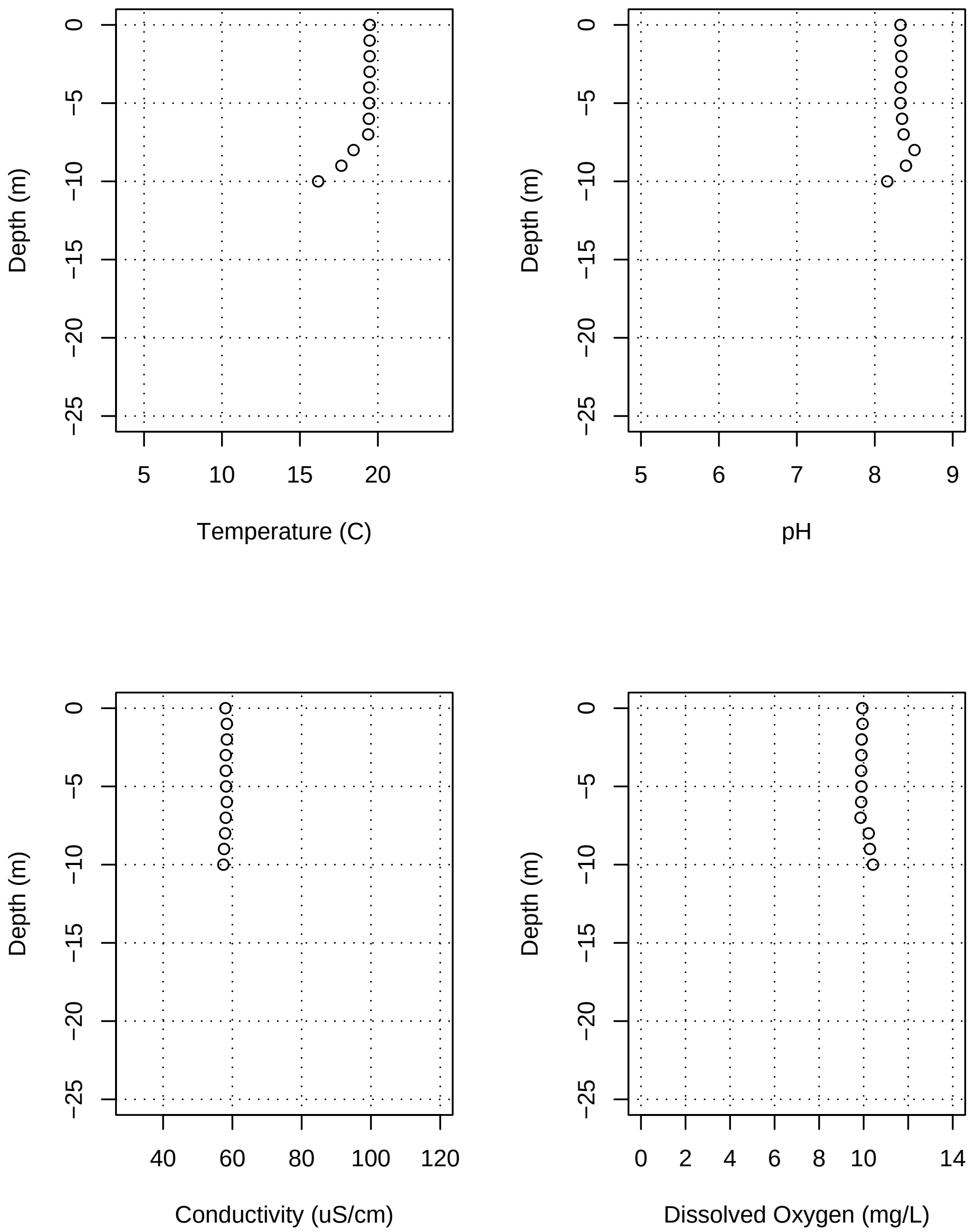


Figure B38: Lake Whatcom Hydrolab profile for the Intake, July 10, 2008.

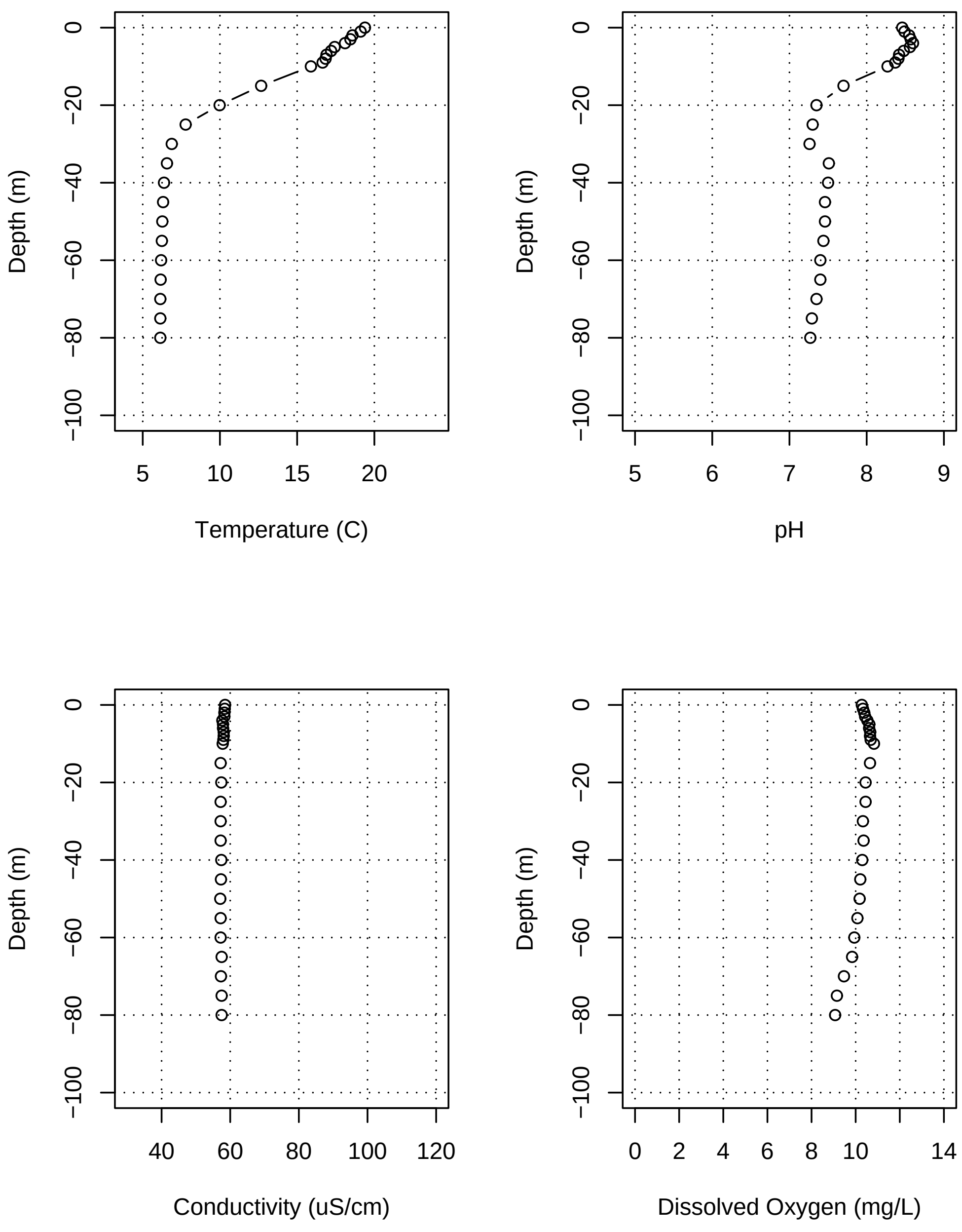


Figure B39: Lake Whatcom Hydrolab profile for Site 3, July 8, 2008.

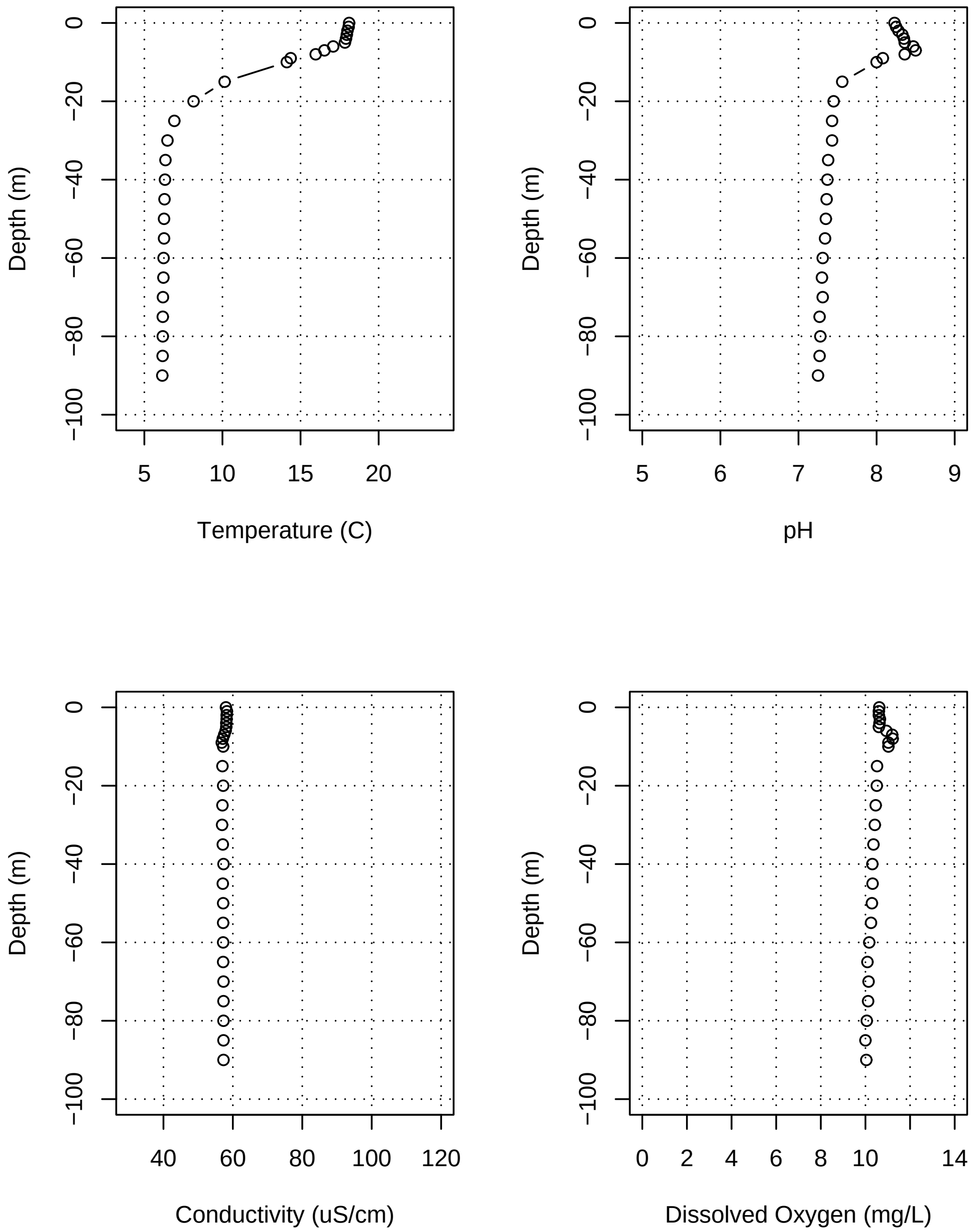


Figure B40: Lake Whatcom Hydrolab profile for Site 4, July 8, 2008.

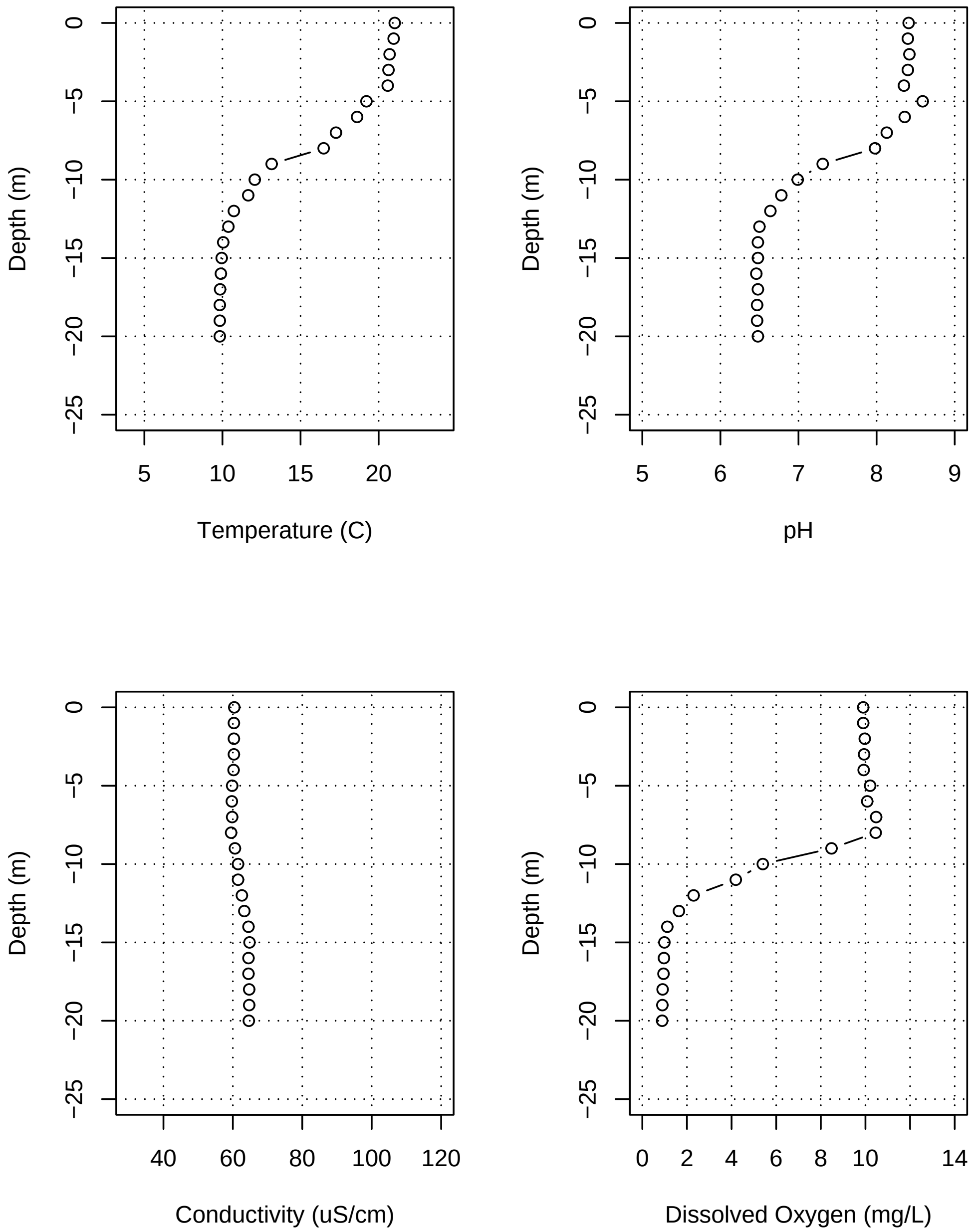


Figure B41: Lake Whatcom Hydrolab profile for Site 1, August 7, 2008.

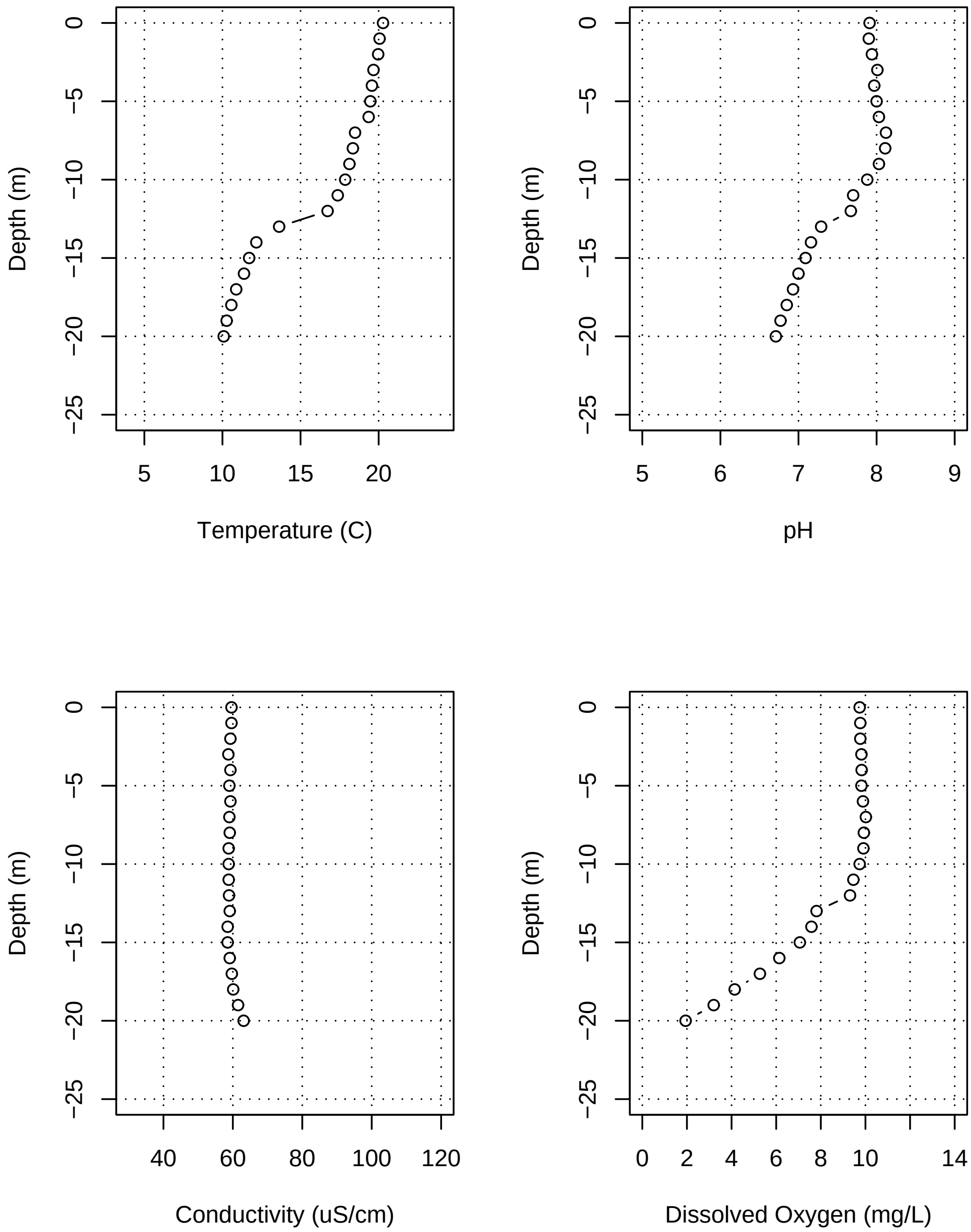


Figure B42: Lake Whatcom Hydrolab profile for Site 2, August 7, 2008.

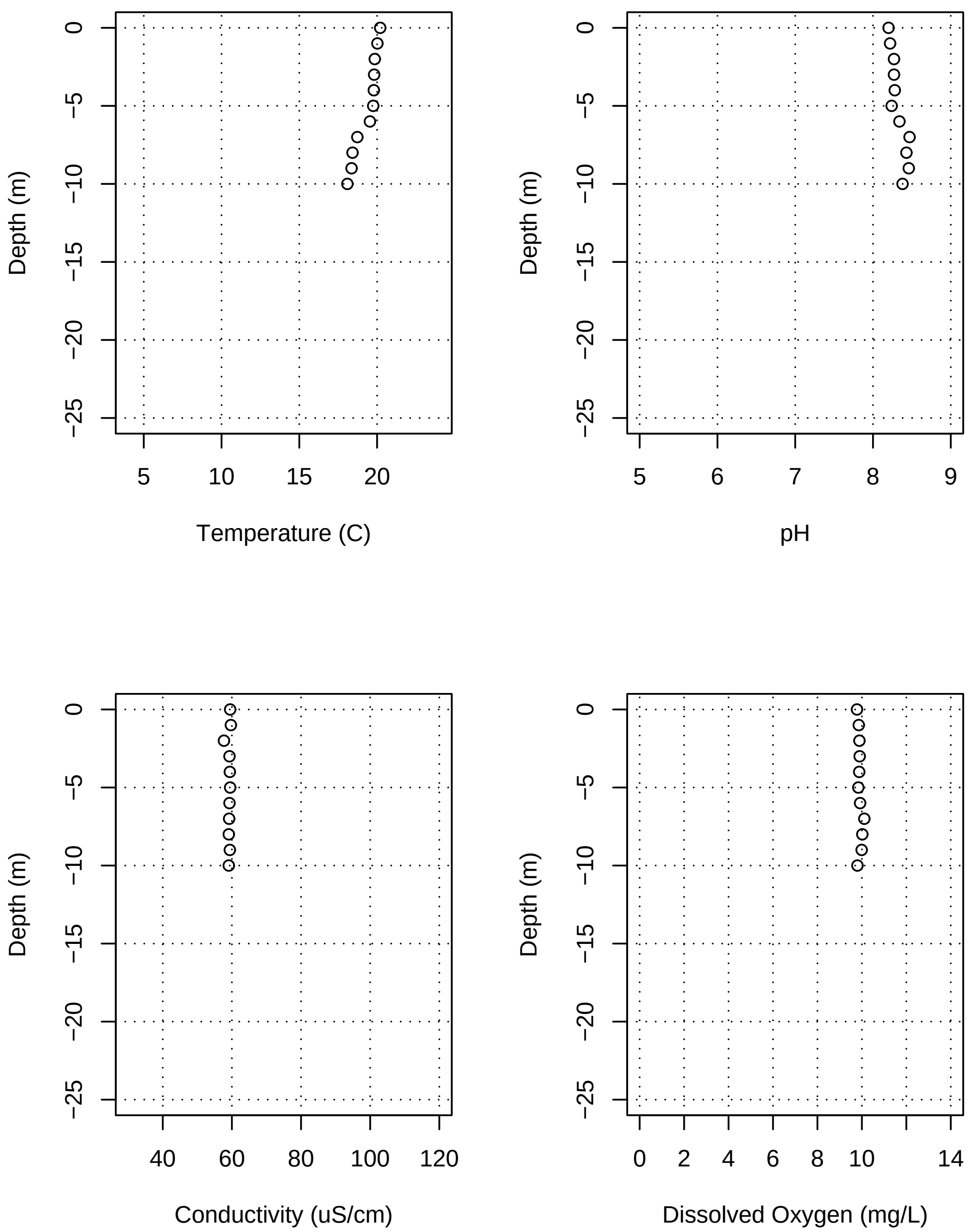


Figure B43: Lake Whatcom Hydrolab profile for the Intake, August 7, 2008.

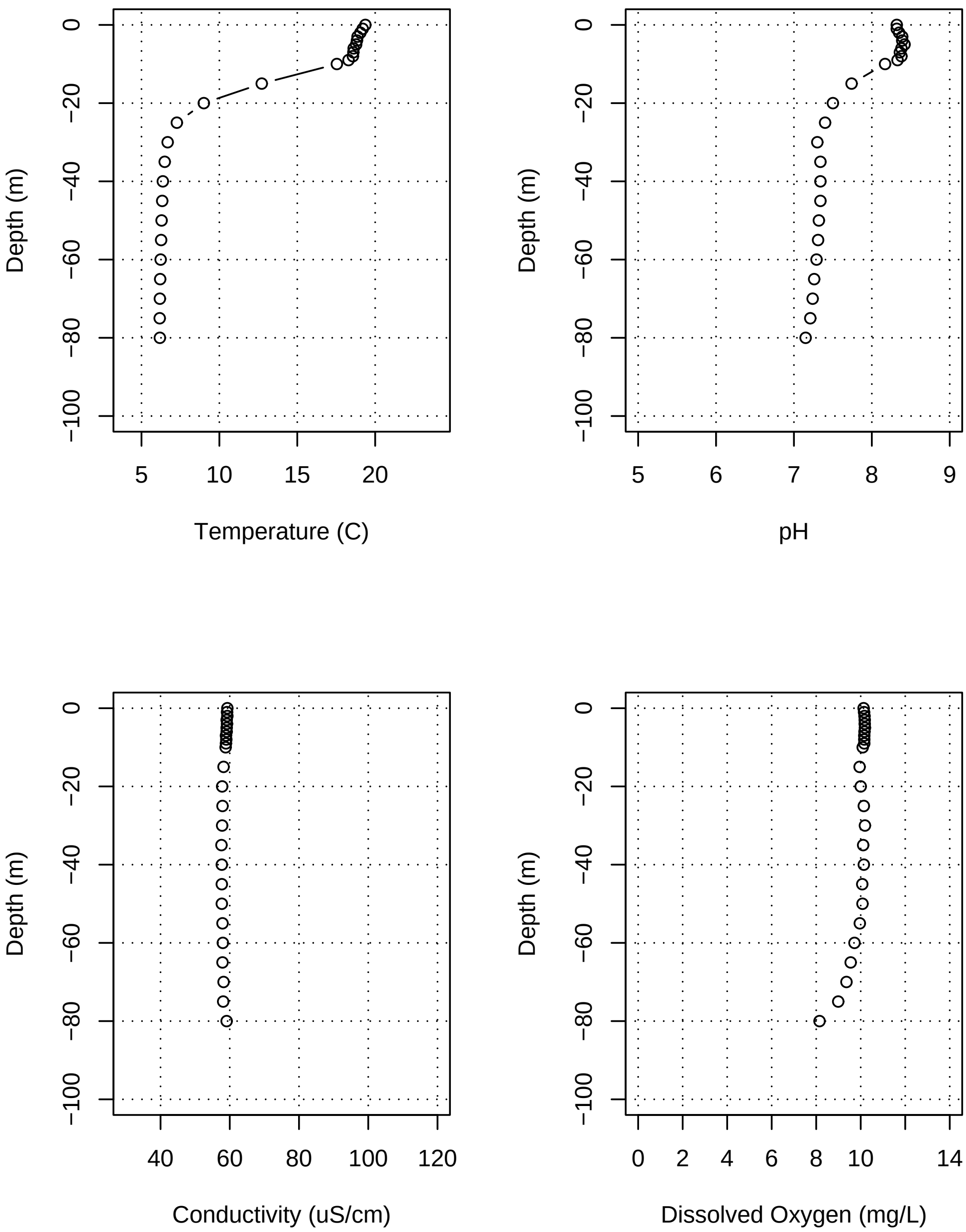


Figure B44: Lake Whatcom Hydrolab profile for Site 3, August 5, 2008.

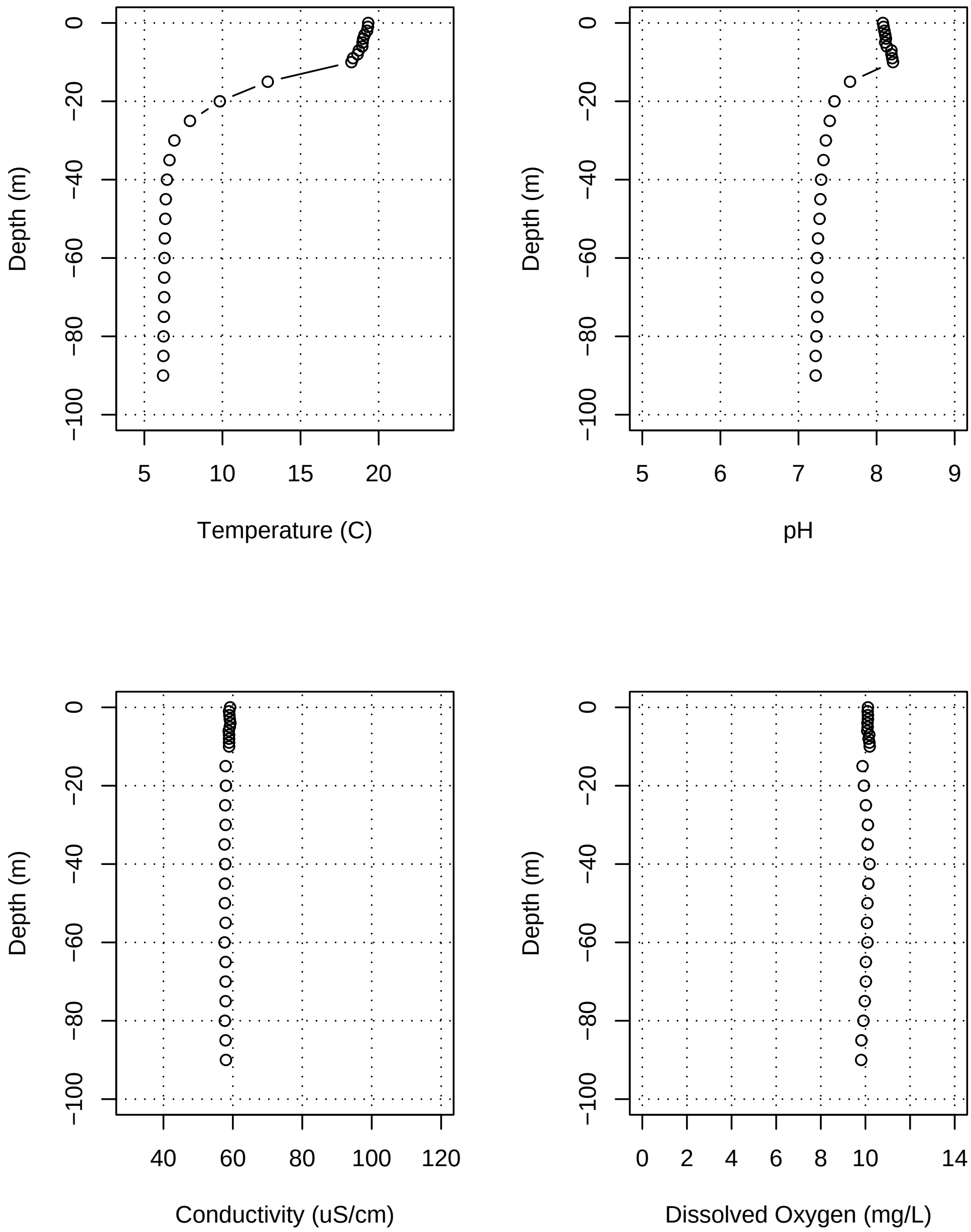


Figure B45: Lake Whatcom Hydrolab profile for Site 4, August 5, 2008.

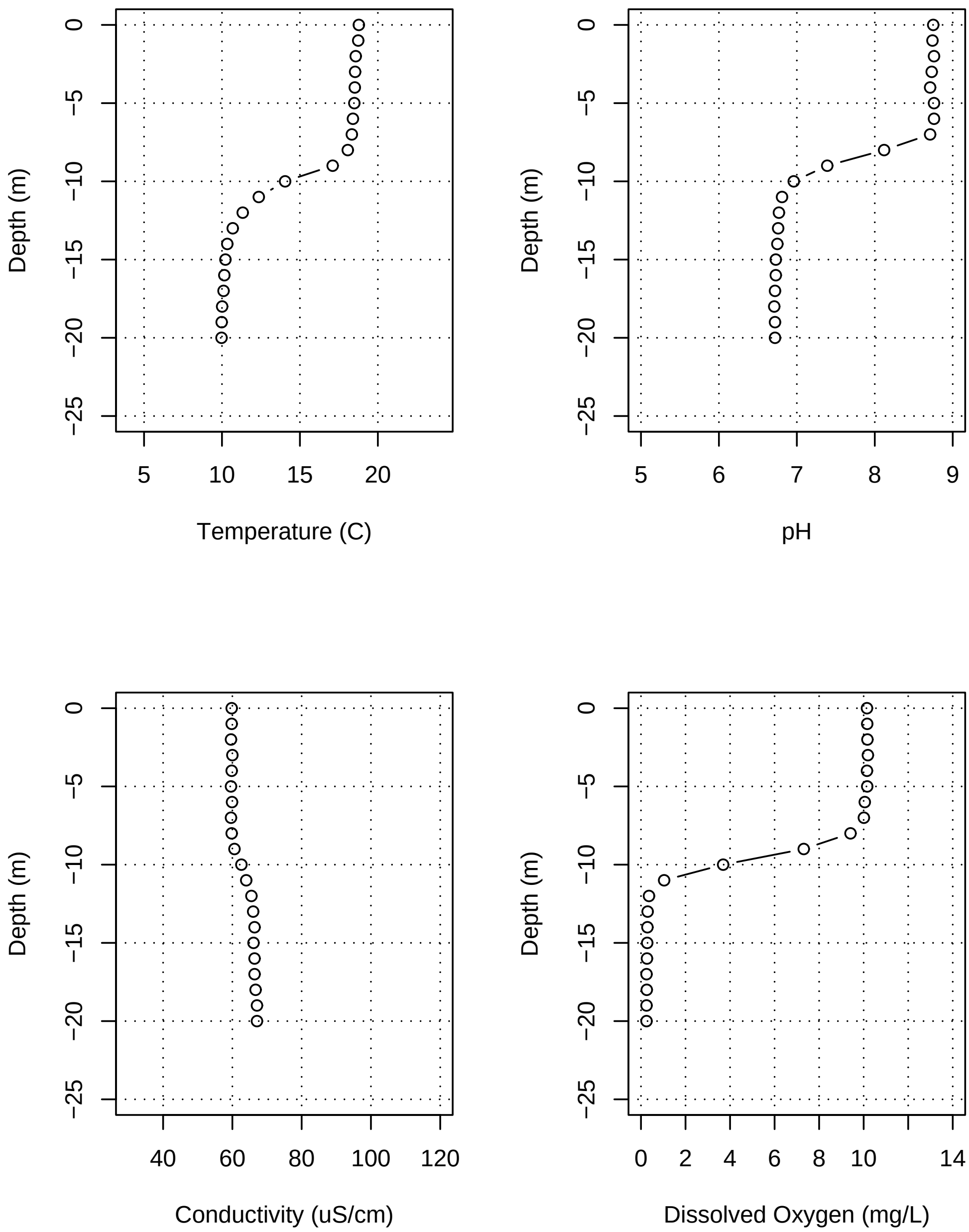


Figure B46: Lake Whatcom Hydrolab profile for Site 1, September 4, 2008.

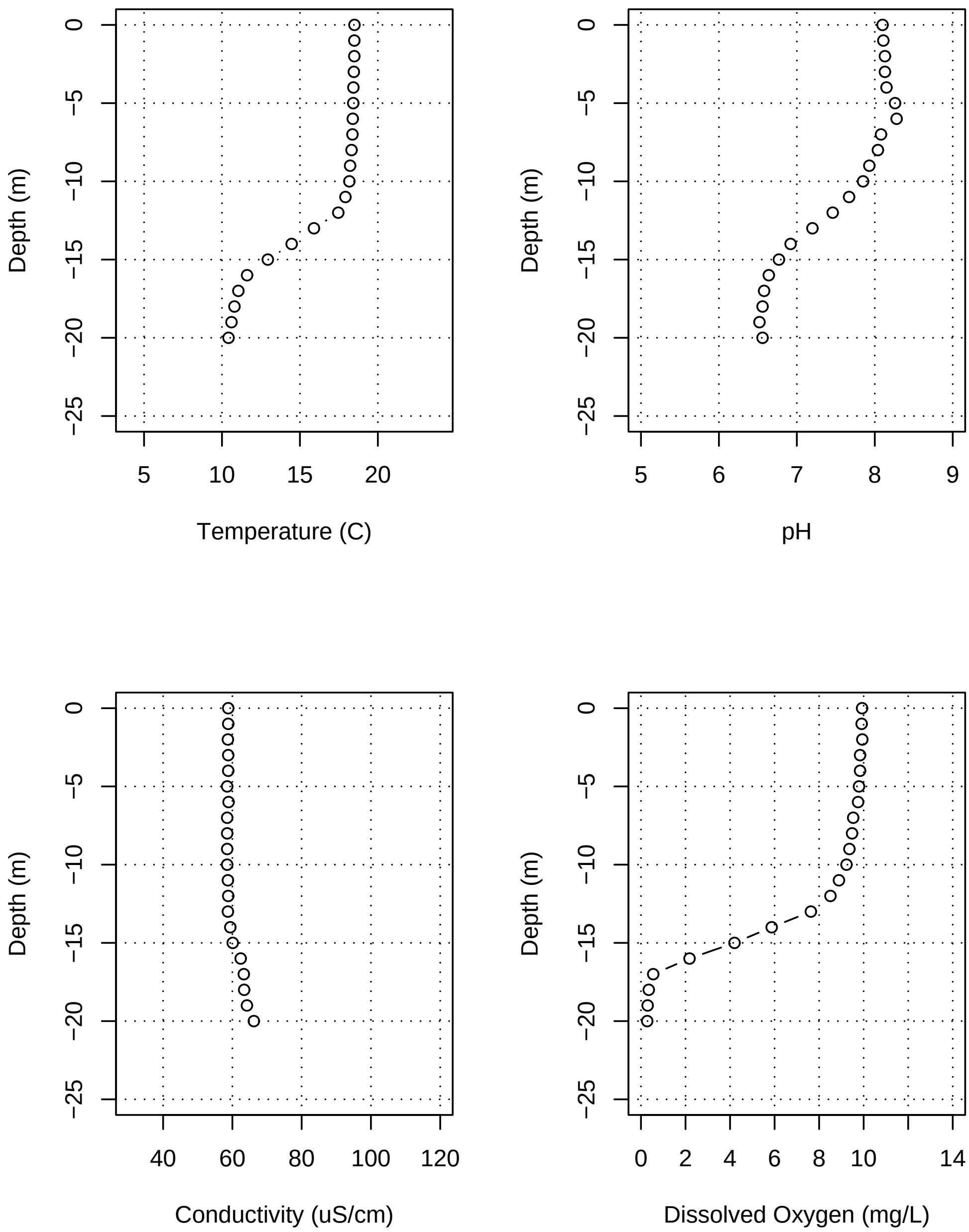


Figure B47: Lake Whatcom Hydrolab profile for Site 2, September 4, 2008.

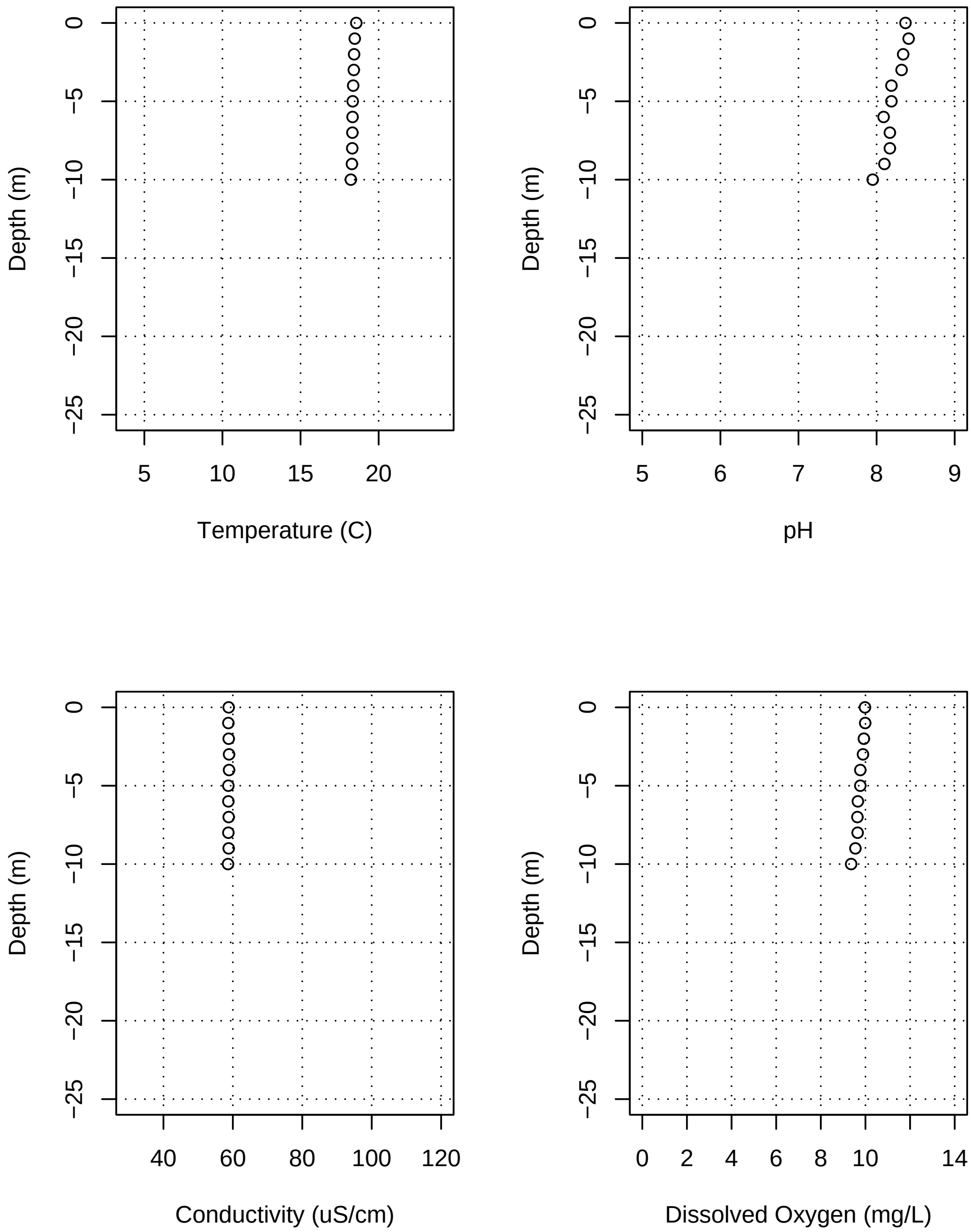


Figure B48: Lake Whatcom Hydrolab profile for the Intake, September 4, 2008.

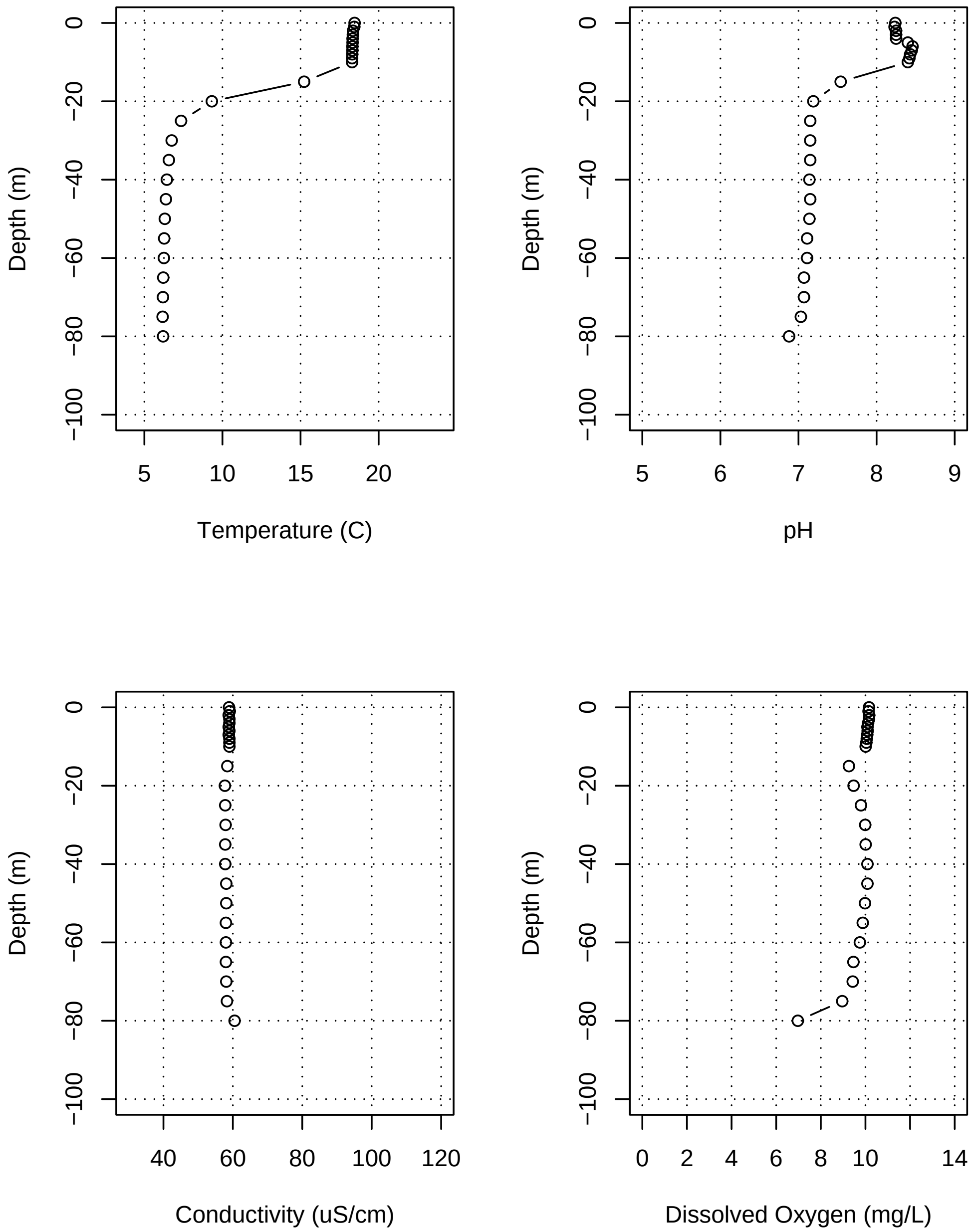


Figure B49: Lake Whatcom Hydrolab profile for Site 3, September 2, 2008.

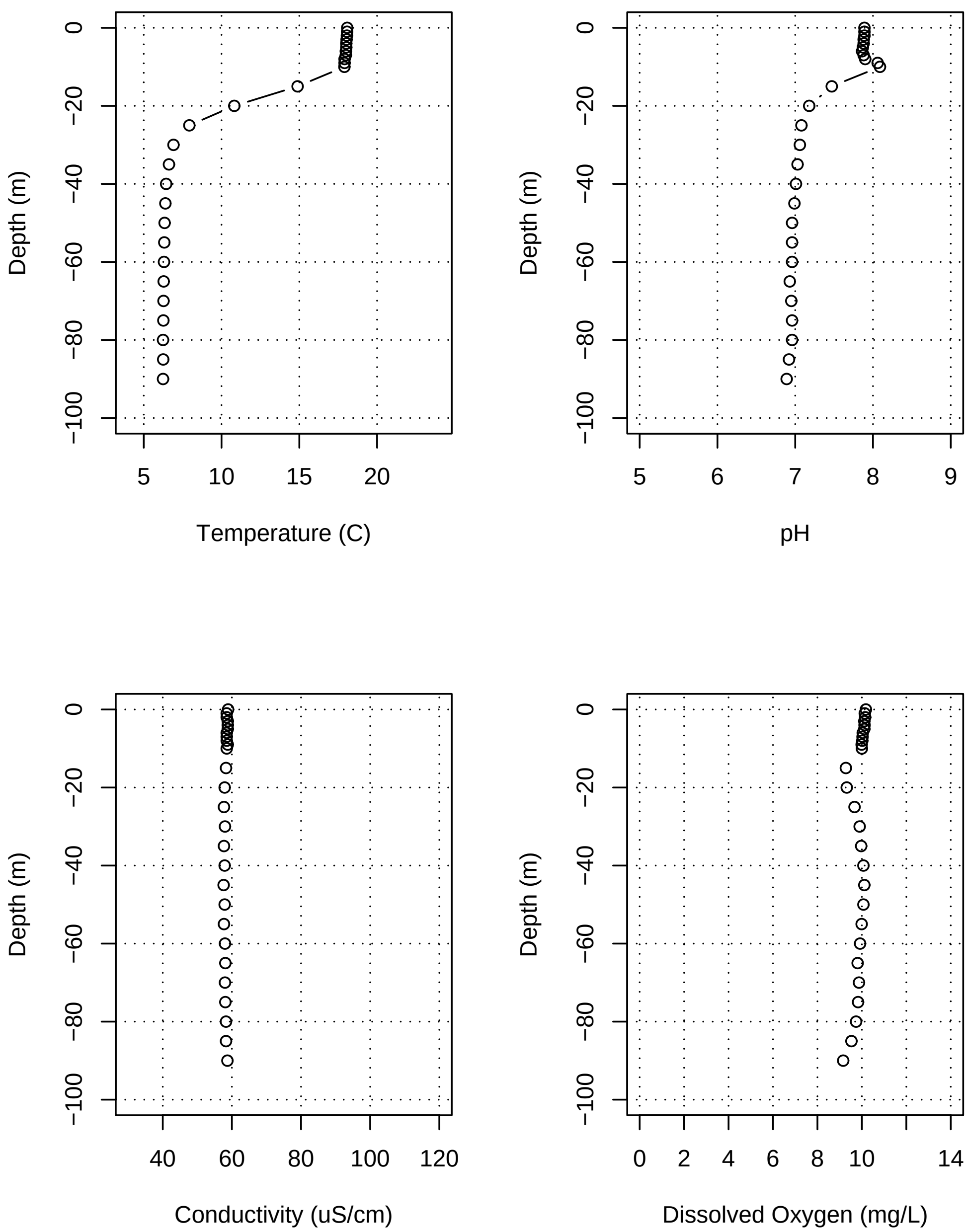


Figure B50: Lake Whatcom Hydrolab profile for Site 4, September 2, 2008.

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

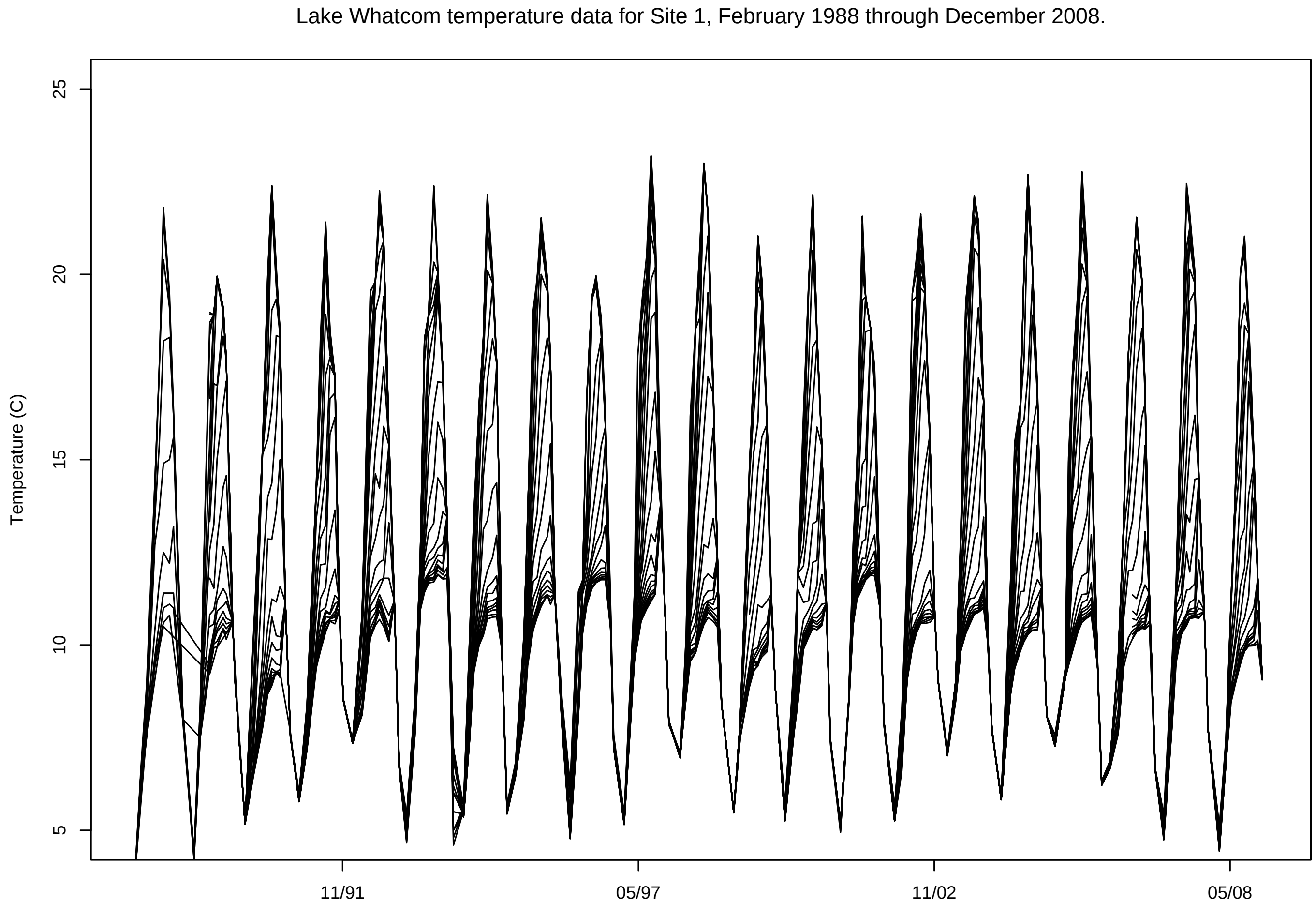


Figure B51: Lake Whatcom historic temperature data for Site 1.

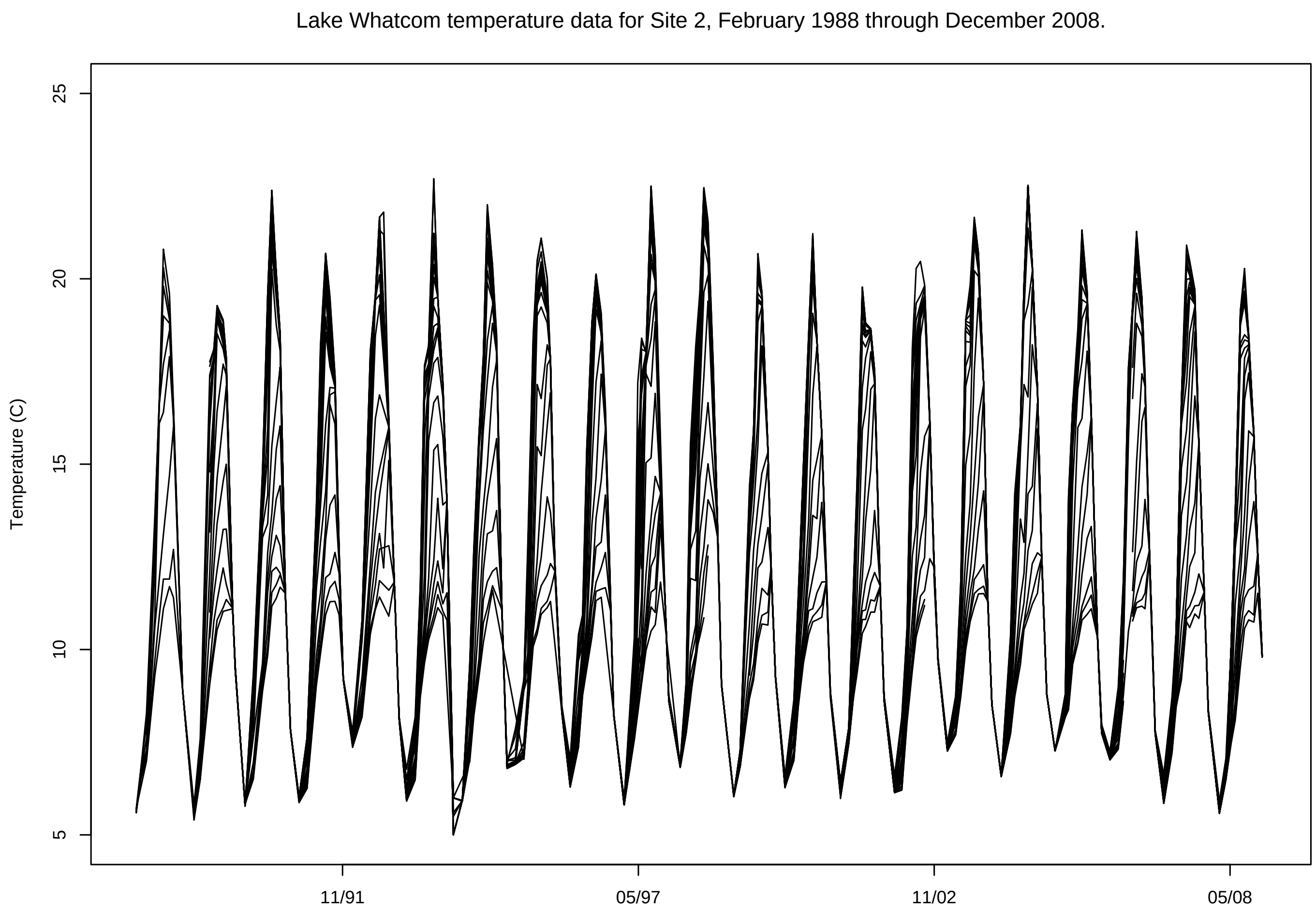


Figure B52: Lake Whatcom historic temperature data for Site 2.

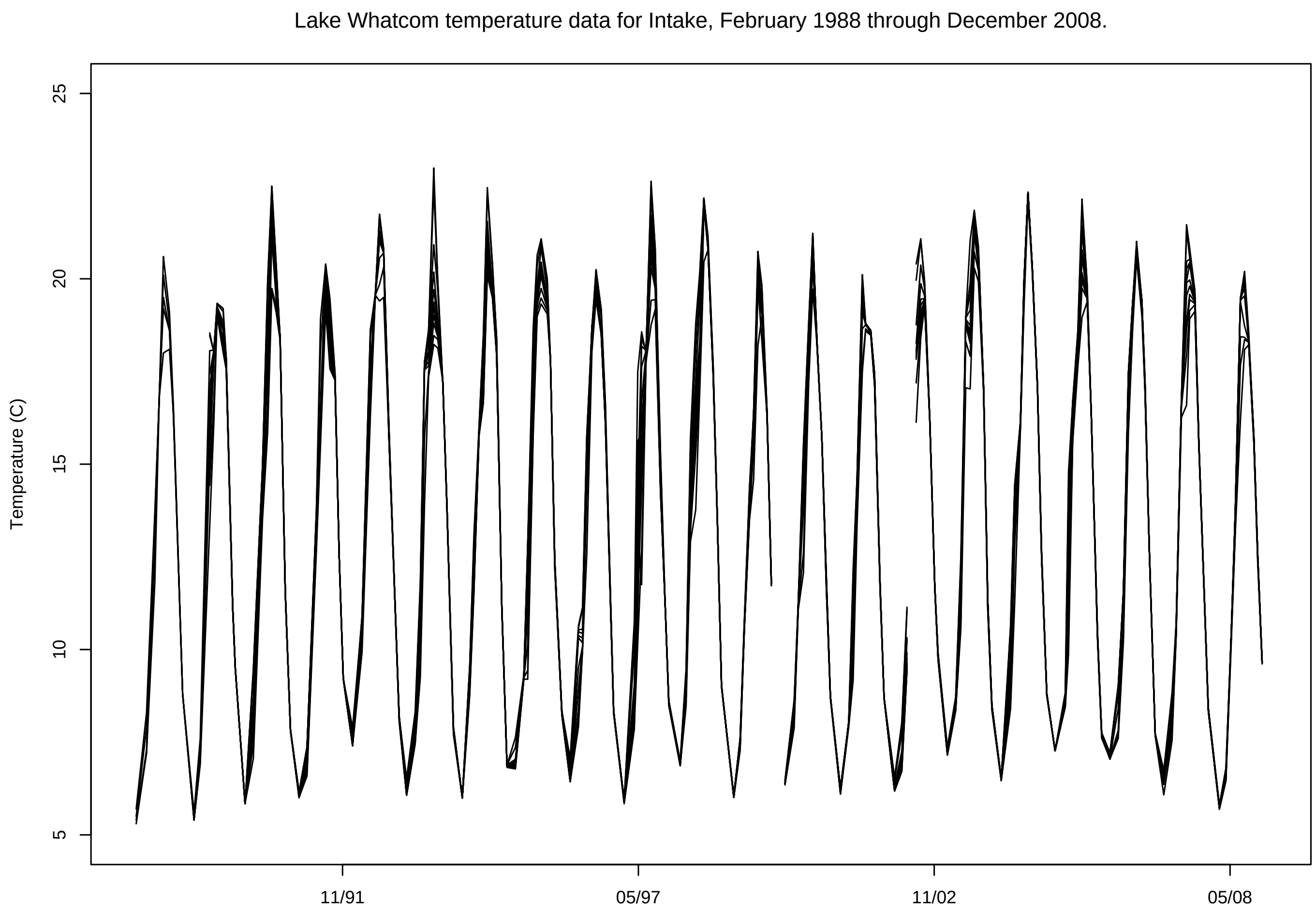


Figure B53: Lake Whatcom historic temperature data for the Intake.

Lake Whatcom temperature data for Site 3, February 1988 through December 2008.

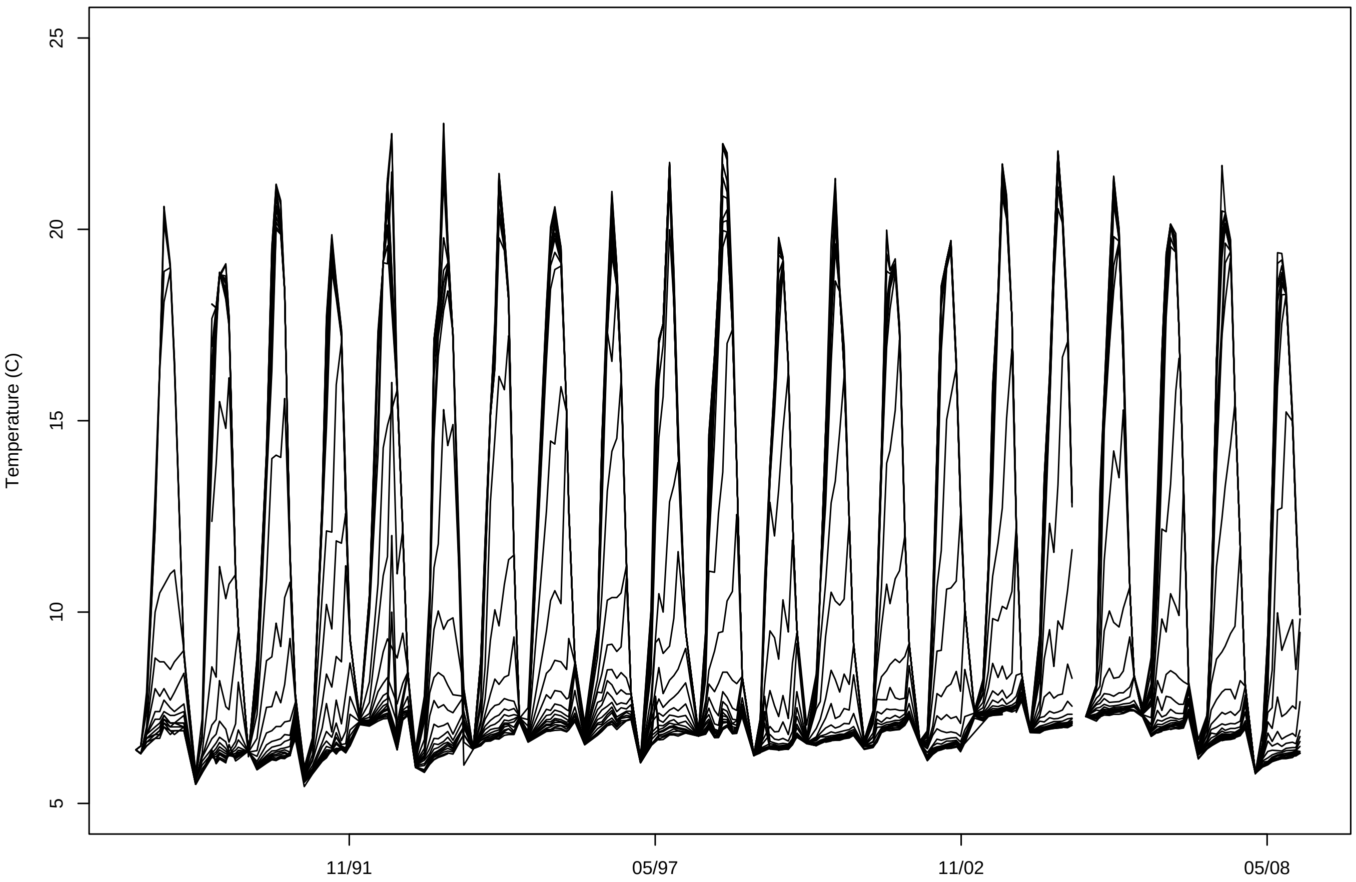


Figure B54: Lake Whatcom historic temperature data for Site 3.

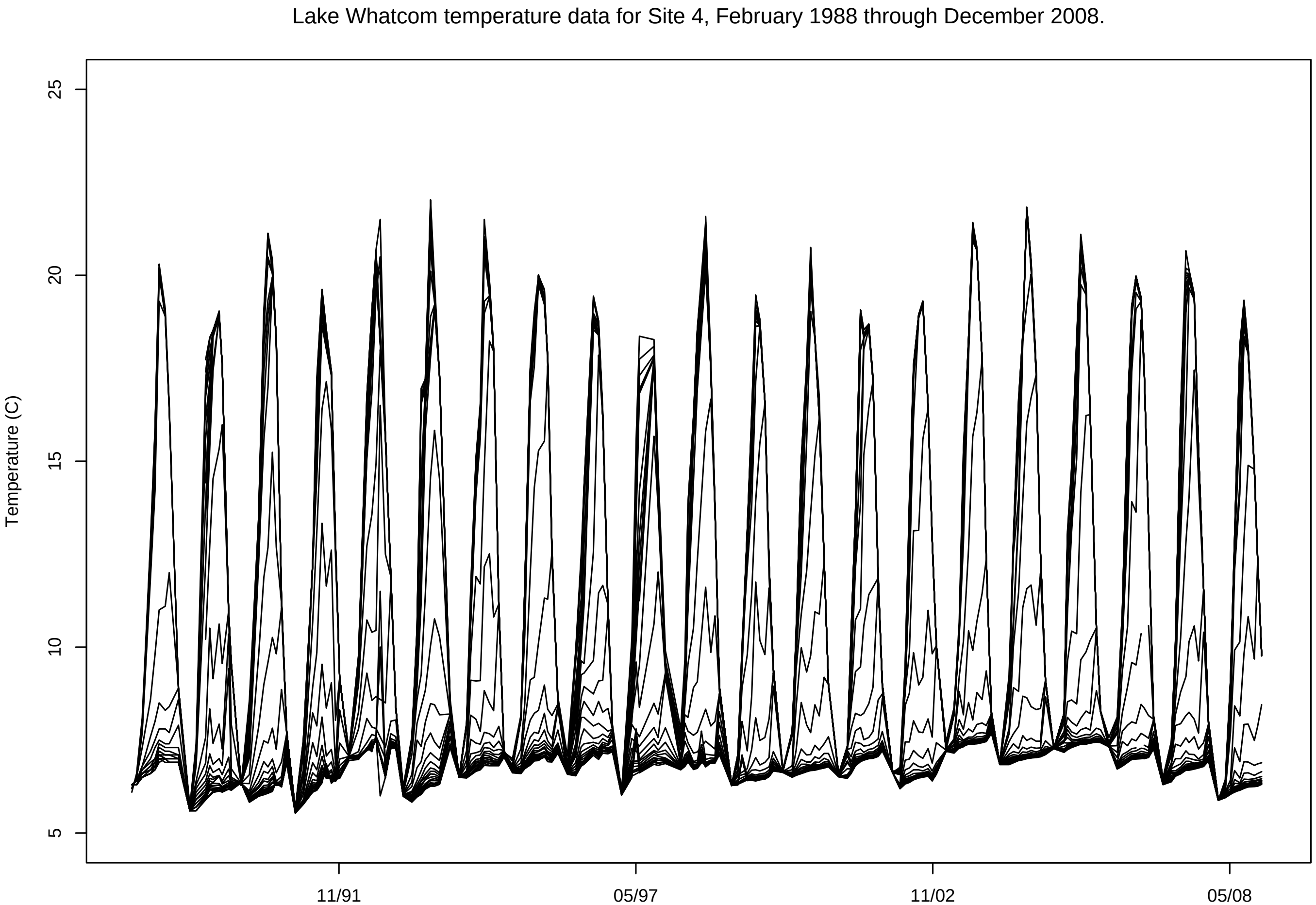


Figure B55: Lake Whatcom historic temperature data for Site 4.

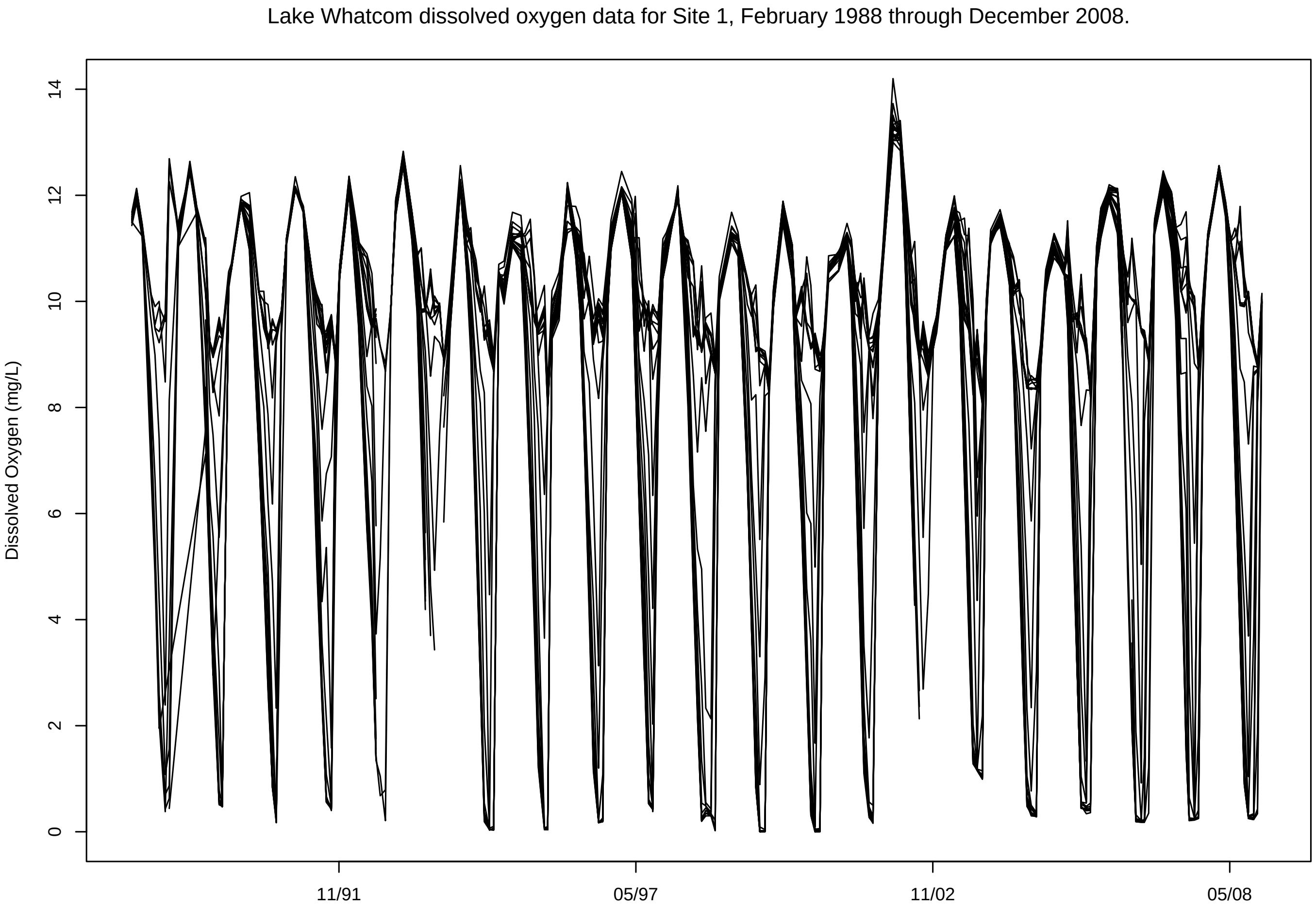


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

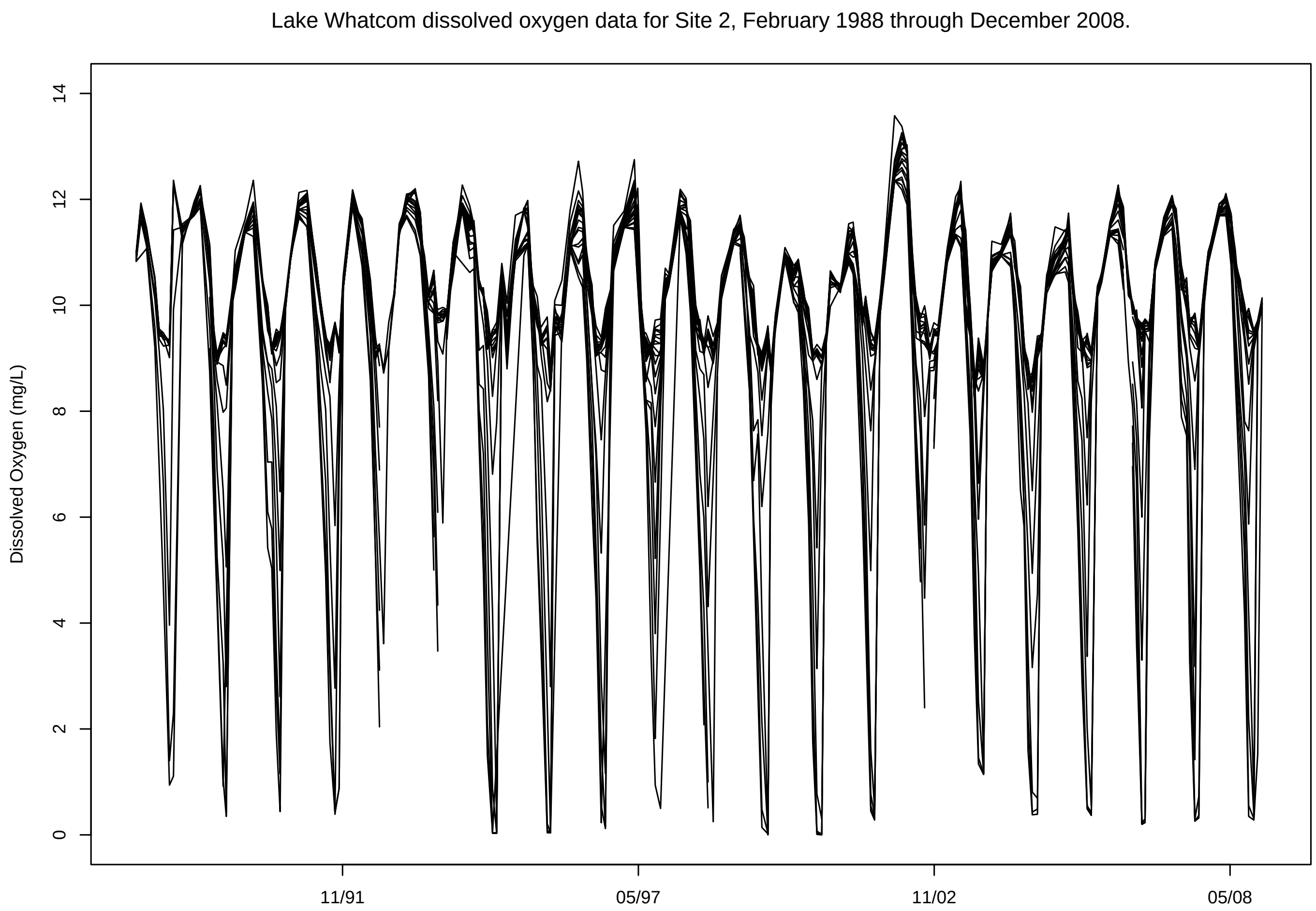


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

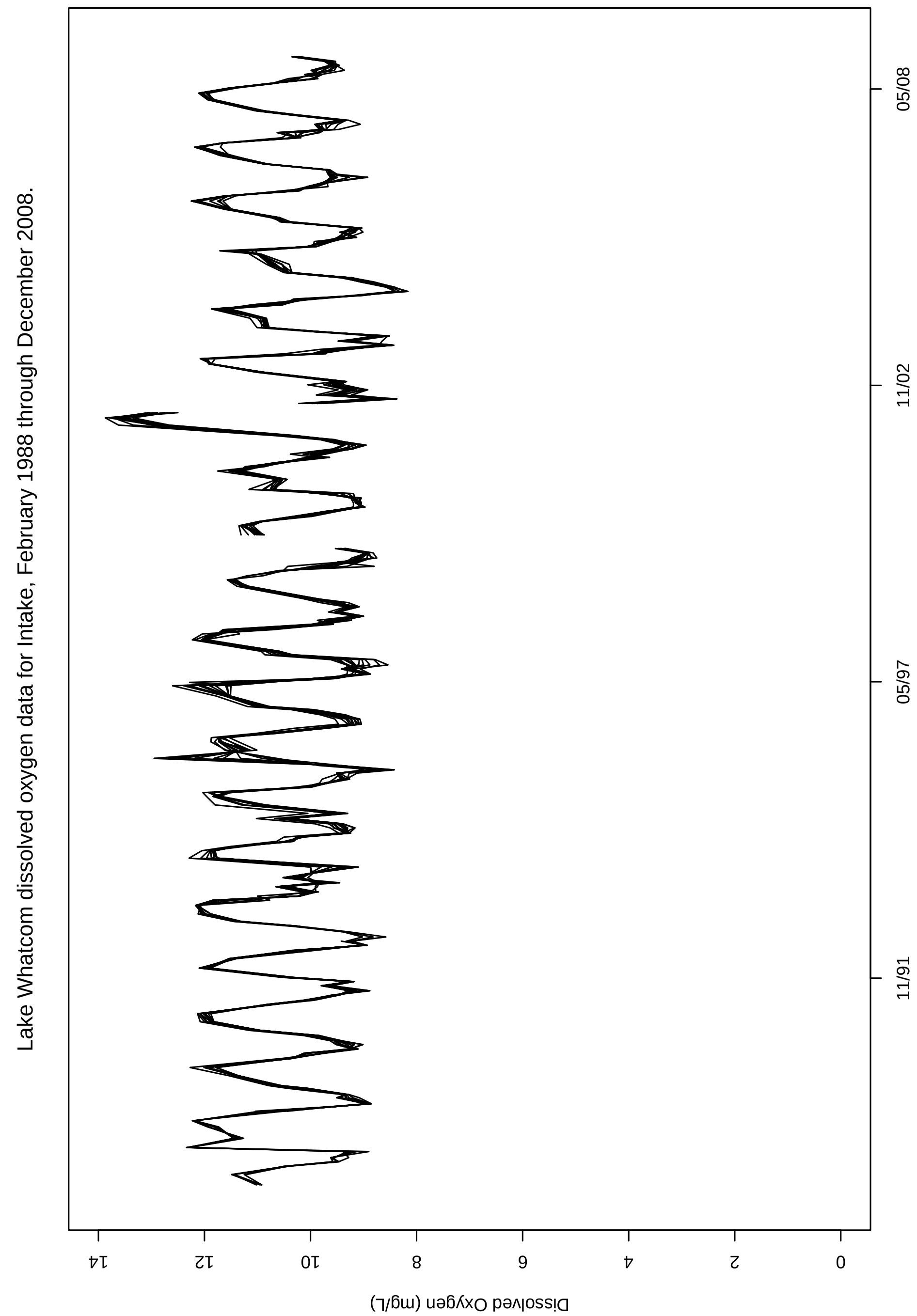


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake.

Lake Whatcom dissolved oxygen data for Site 3, February 1988 through December 2008.

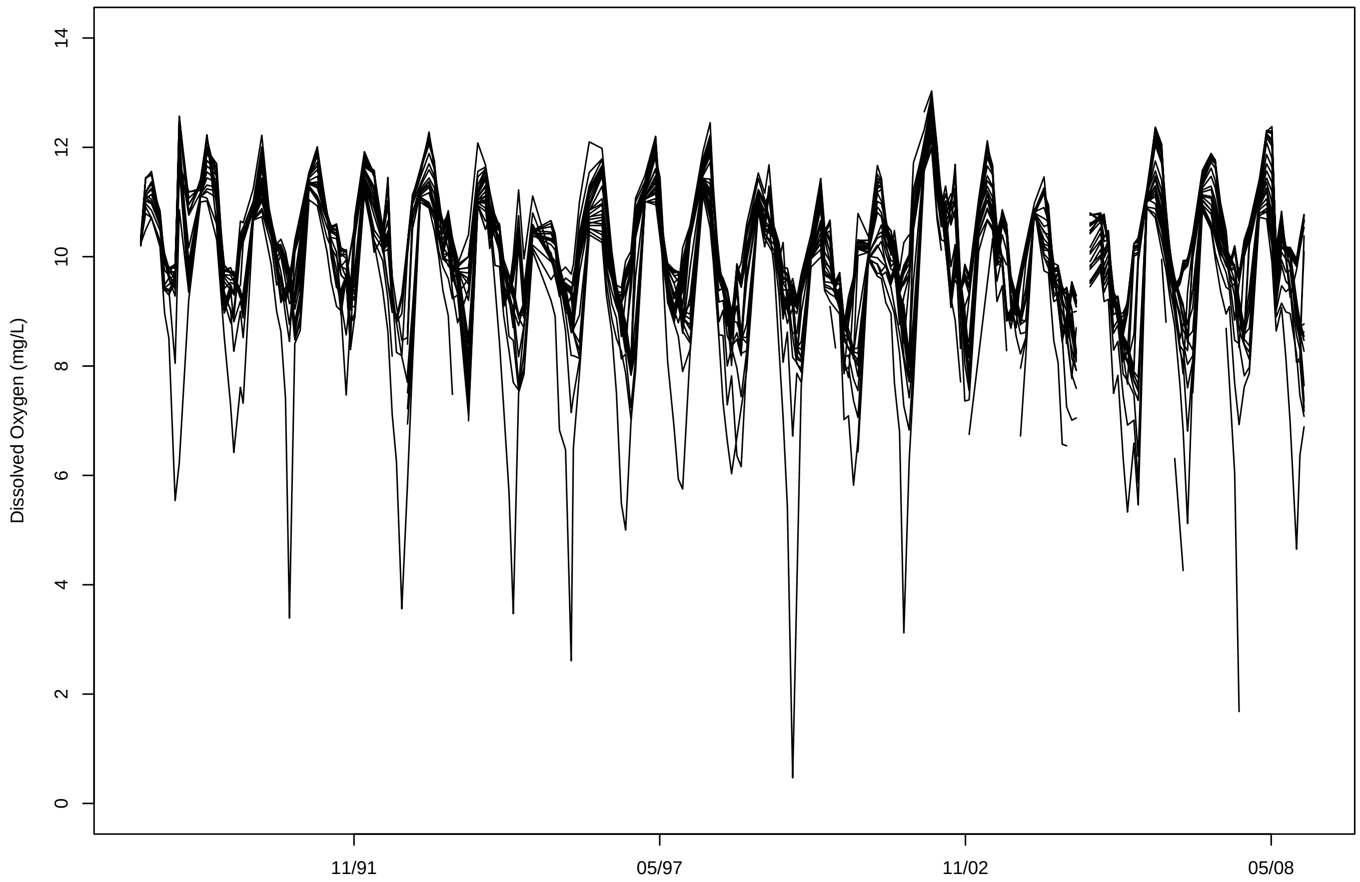


Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.

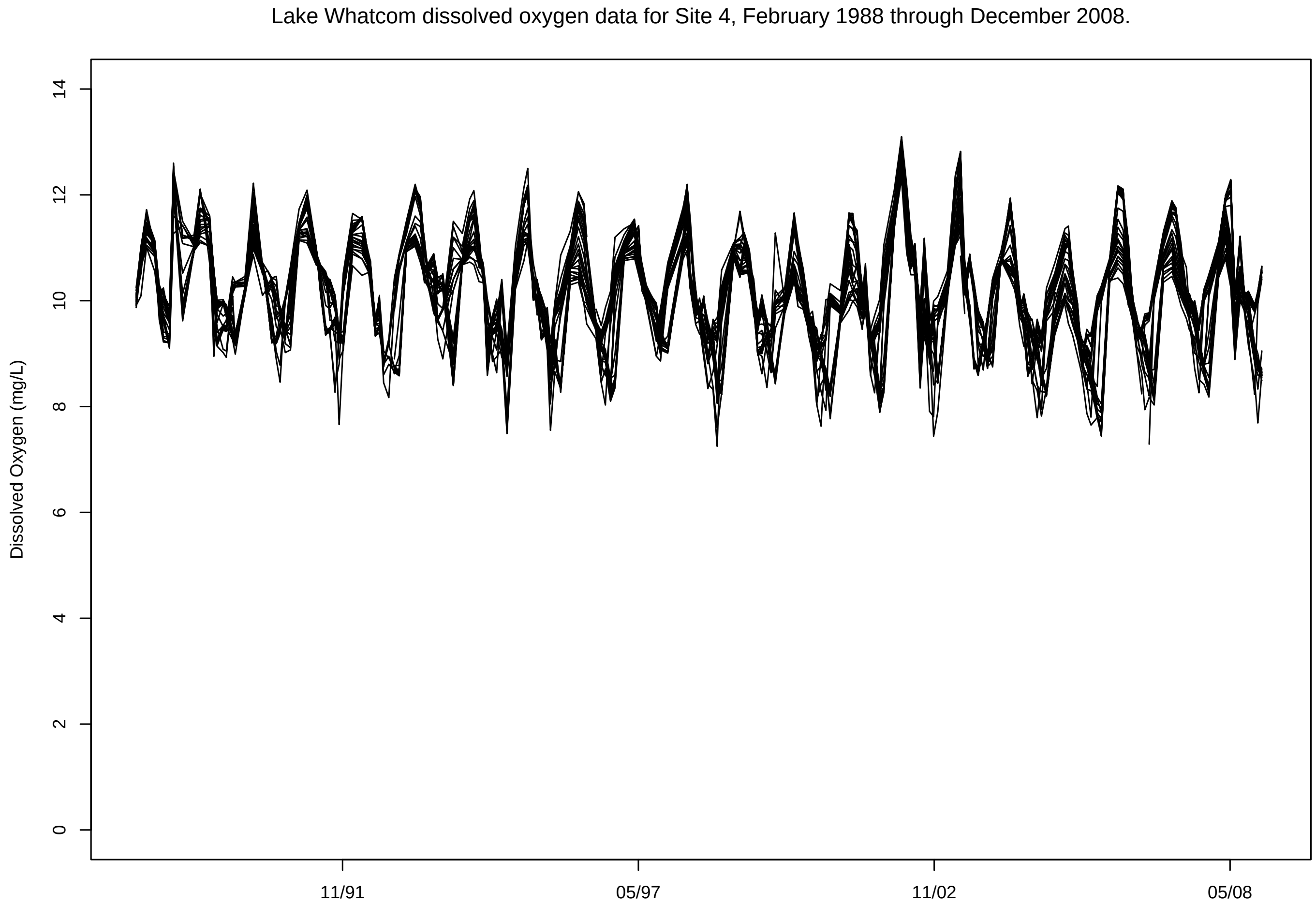


Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

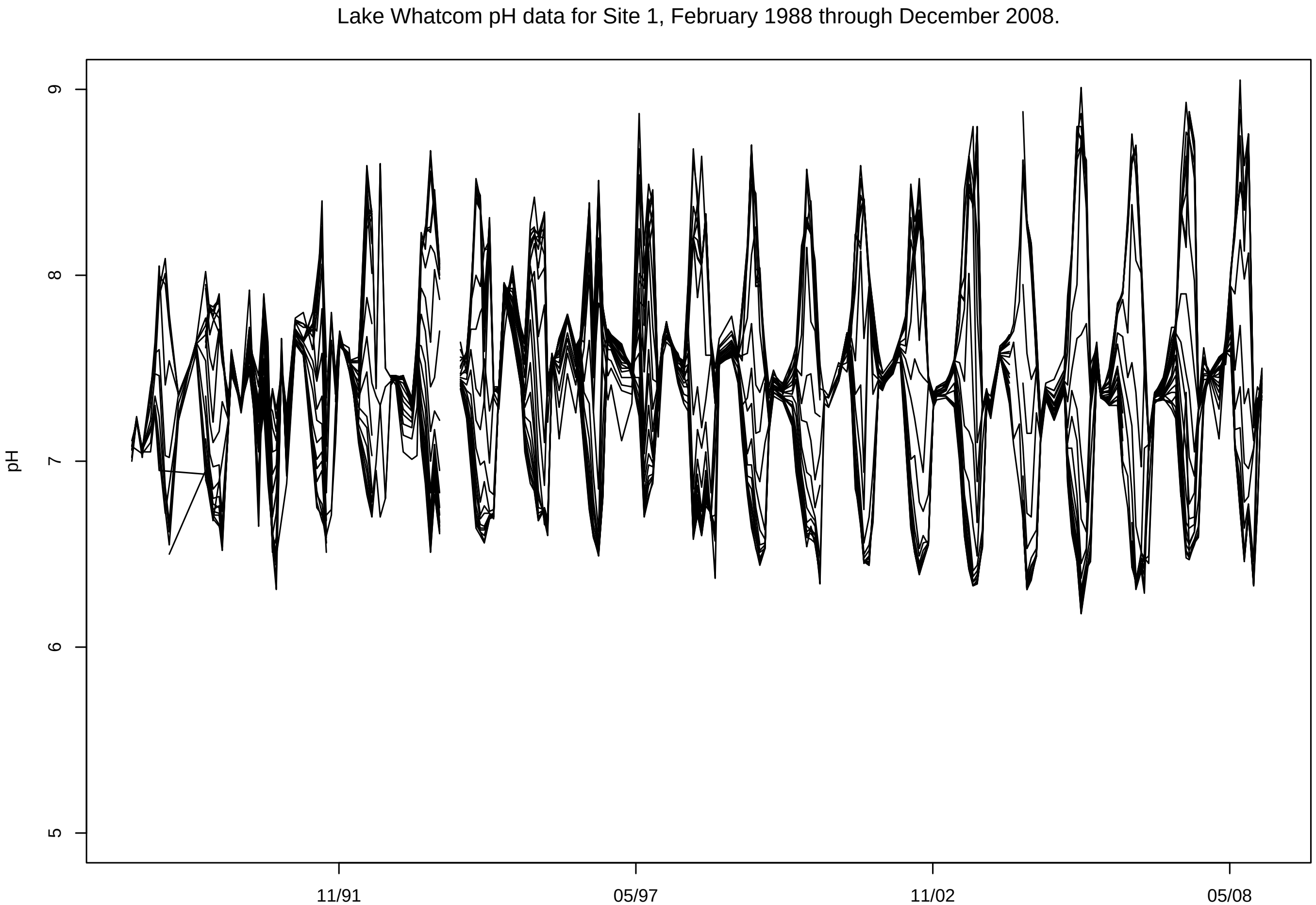


Figure B61: Lake Whatcom historic pH data for Site 1.

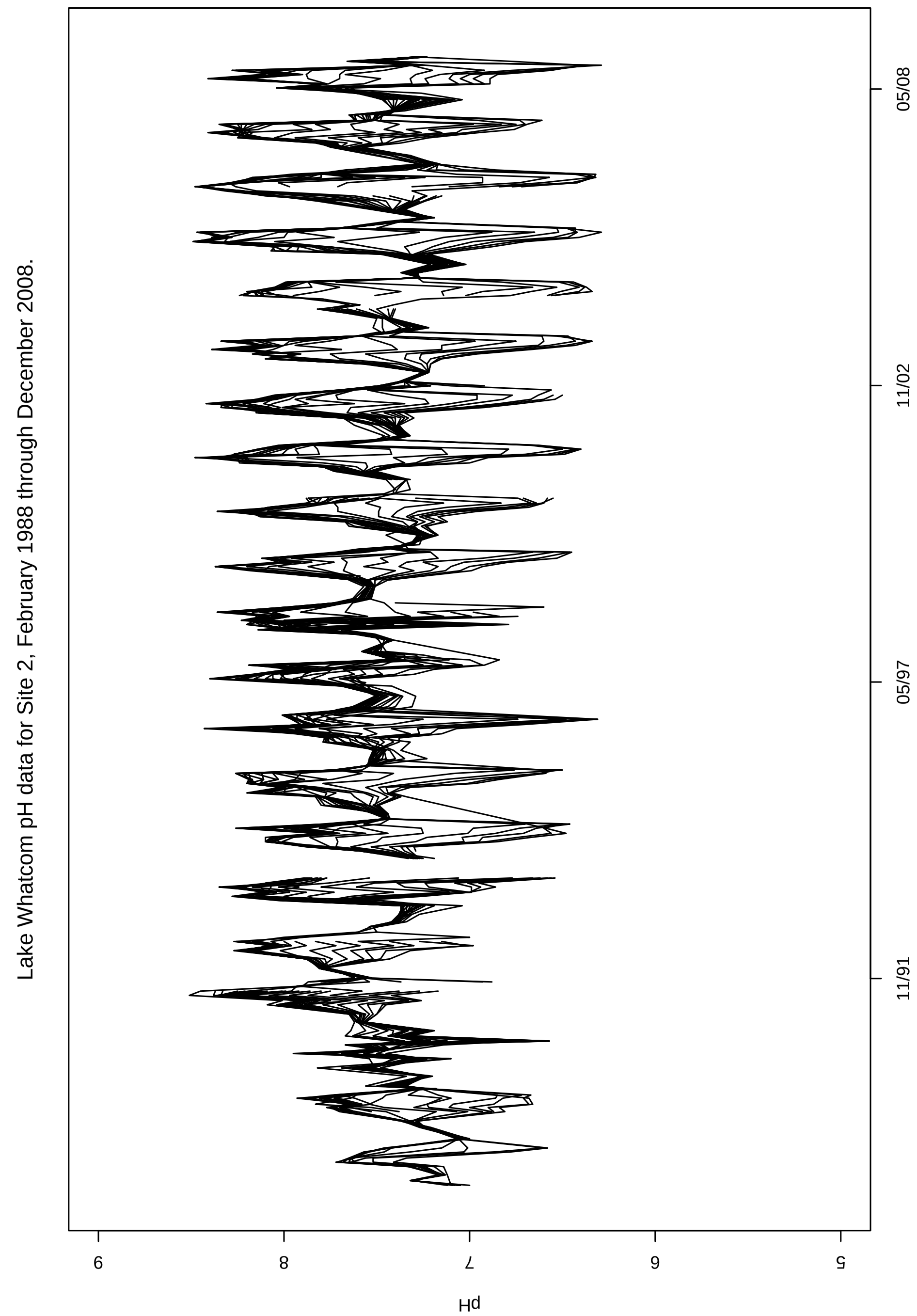


Figure B62: Lake Whatcom historic pH data for Site 2.

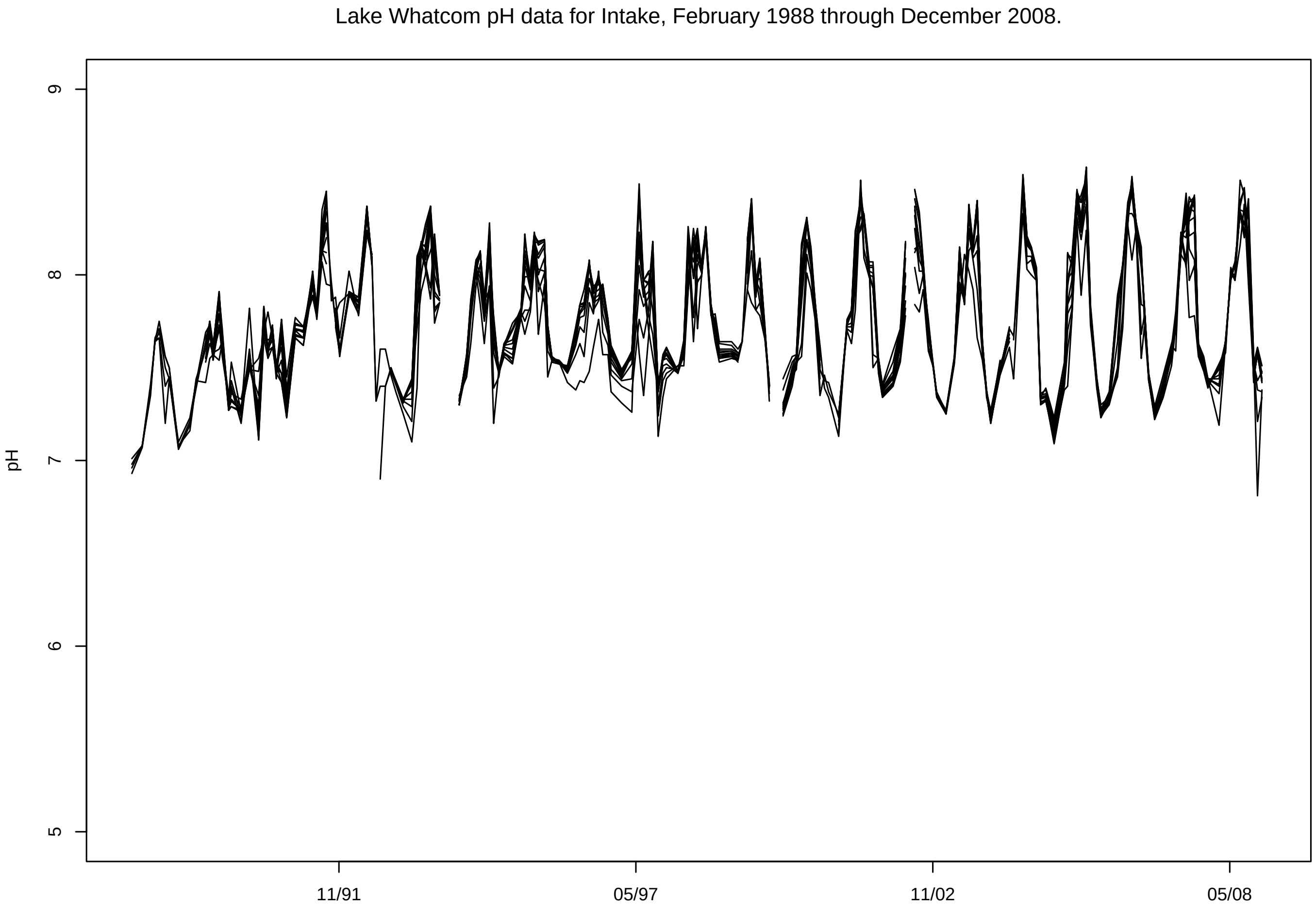


Figure B63: Lake Whatcom historic pH data for the Intake.

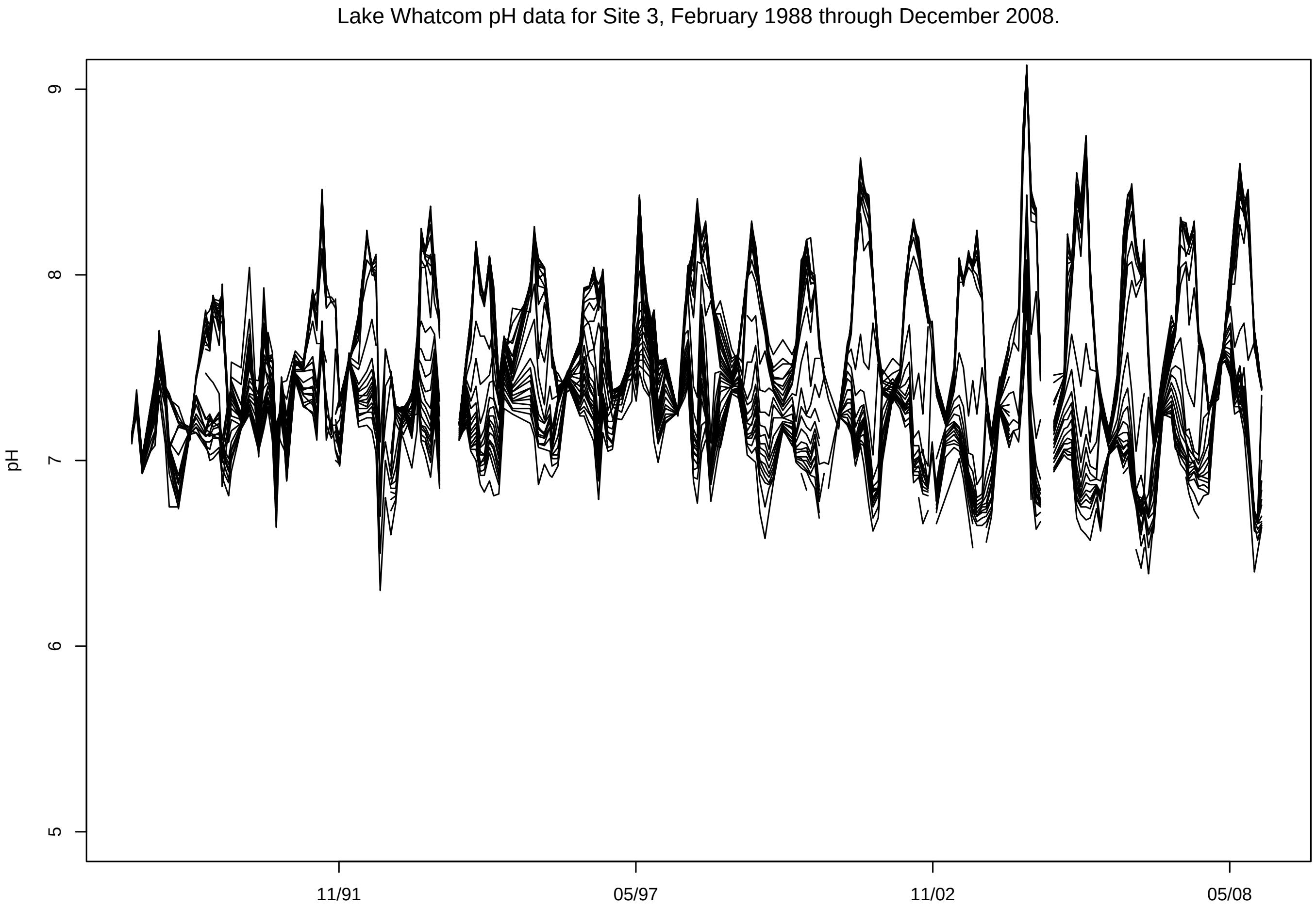


Figure B64: Lake Whatcom historic pH data for Site 3.

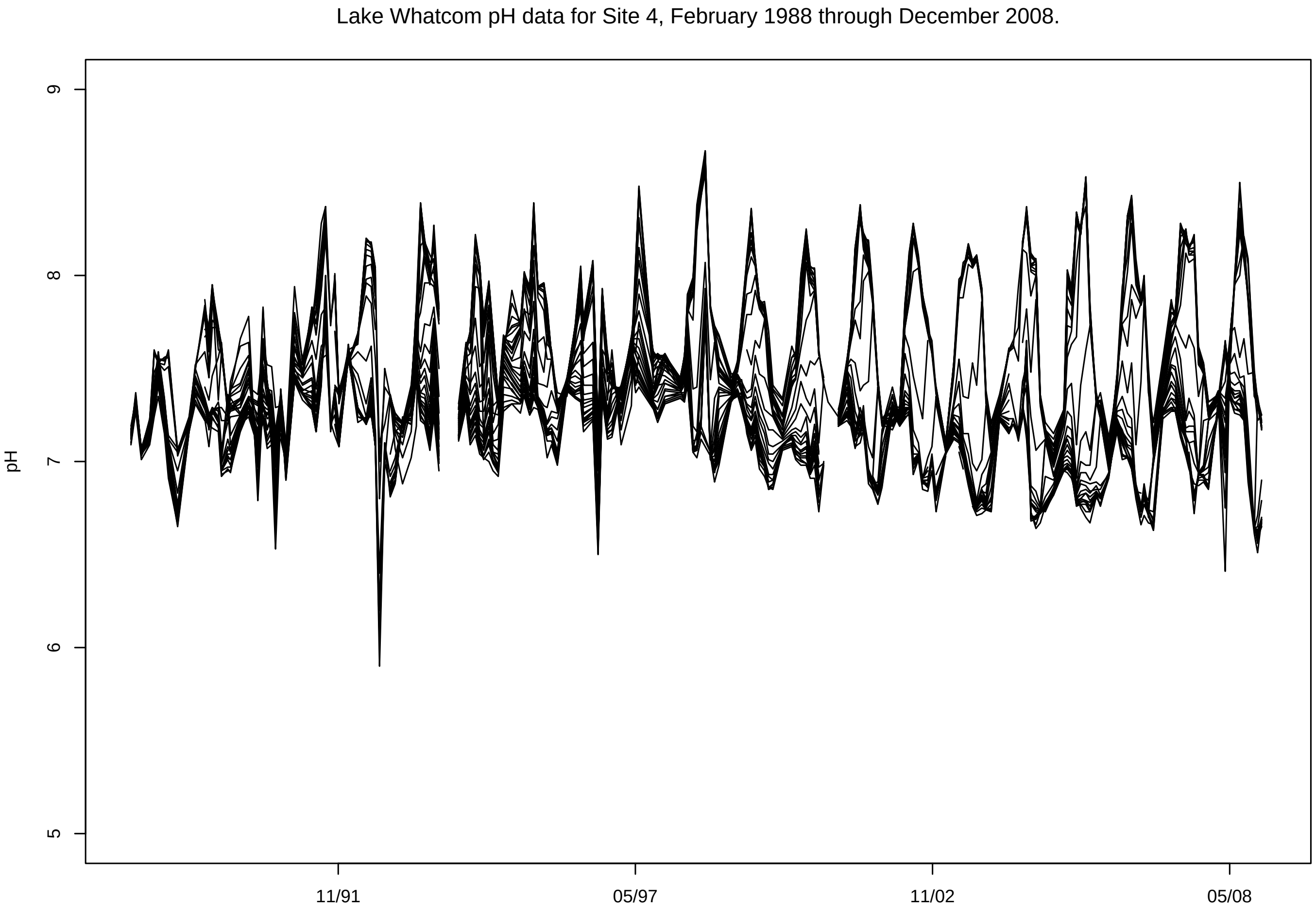


Figure B65: Lake Whatcom historic pH data for Site 4.

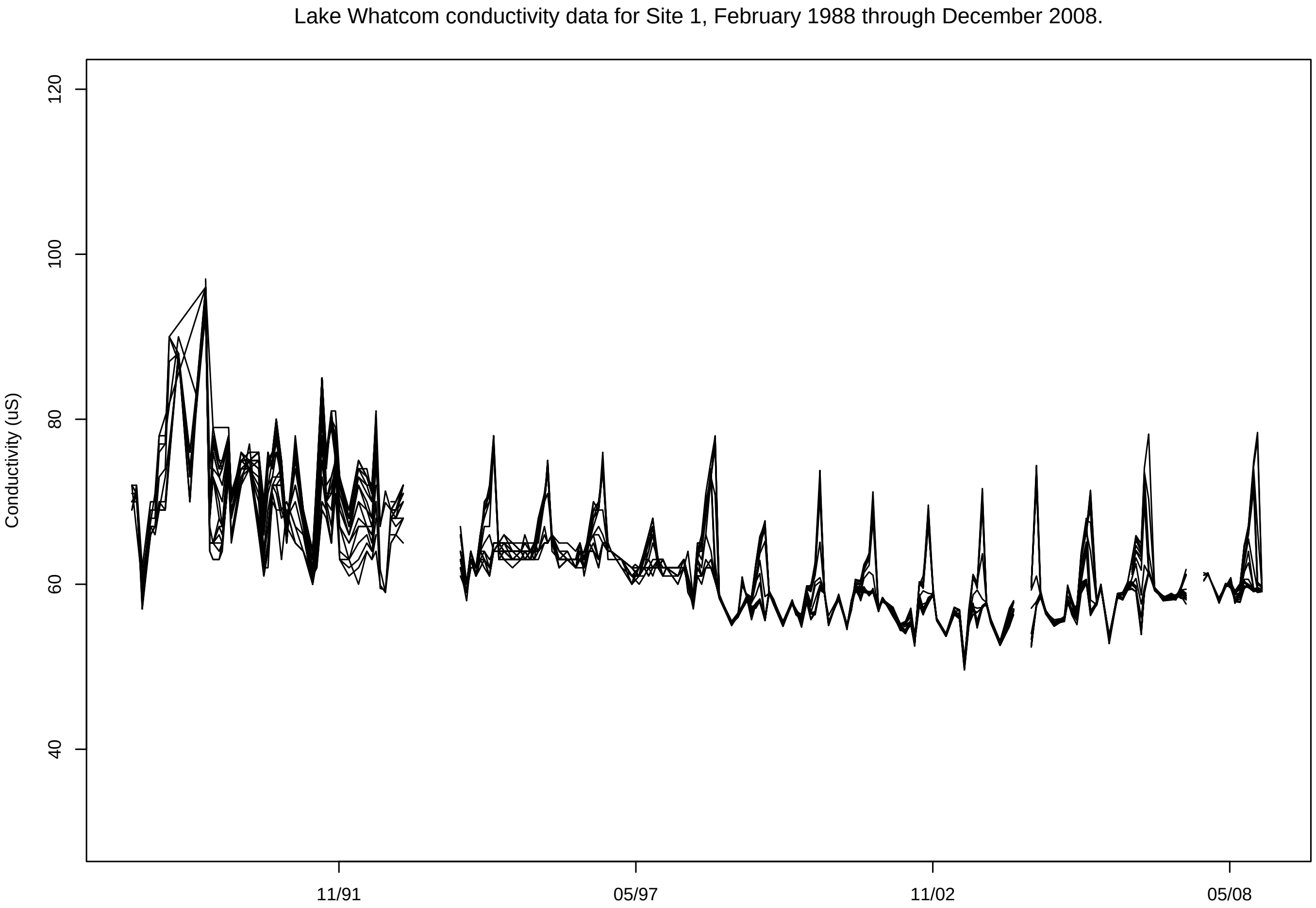


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

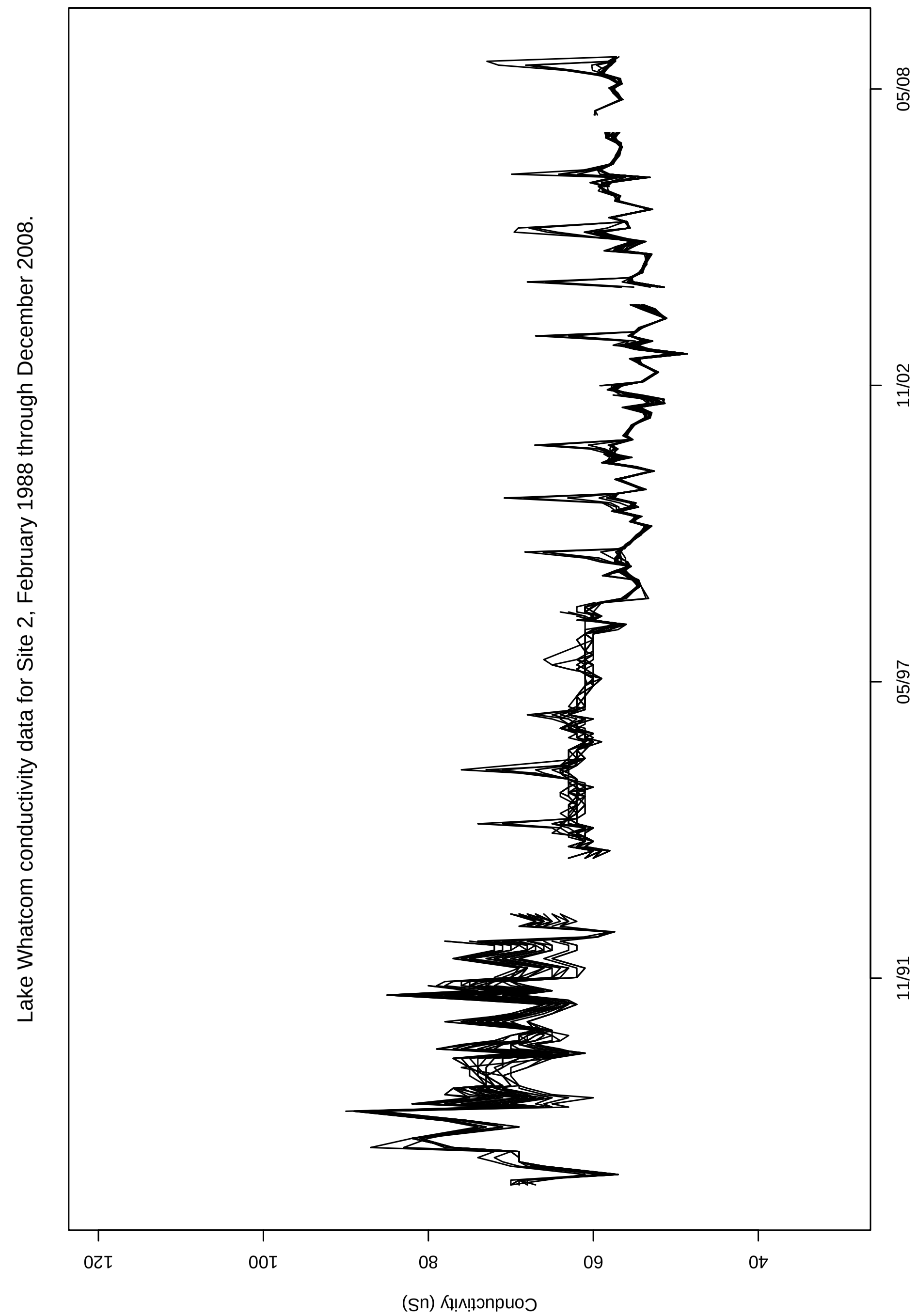


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

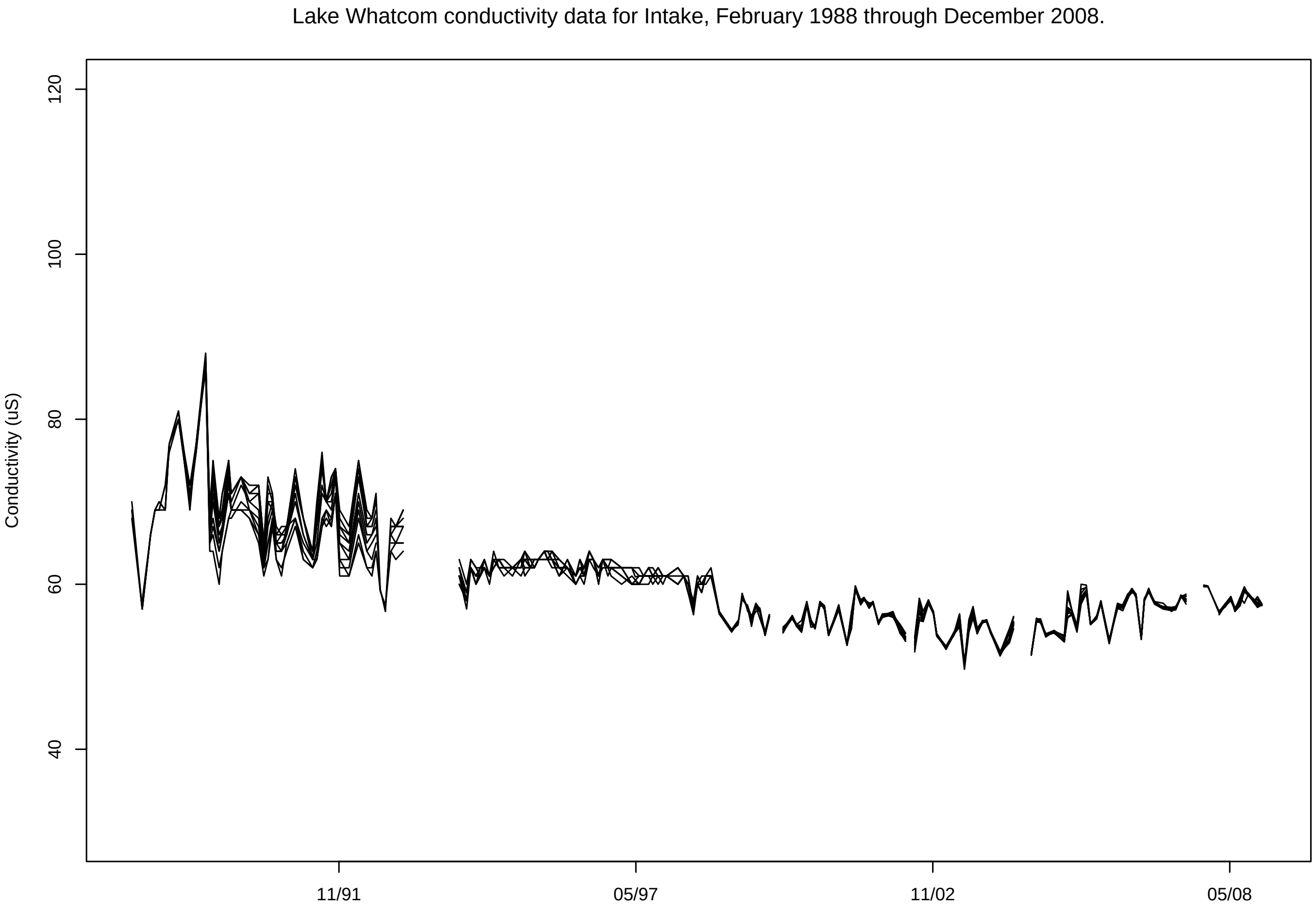


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

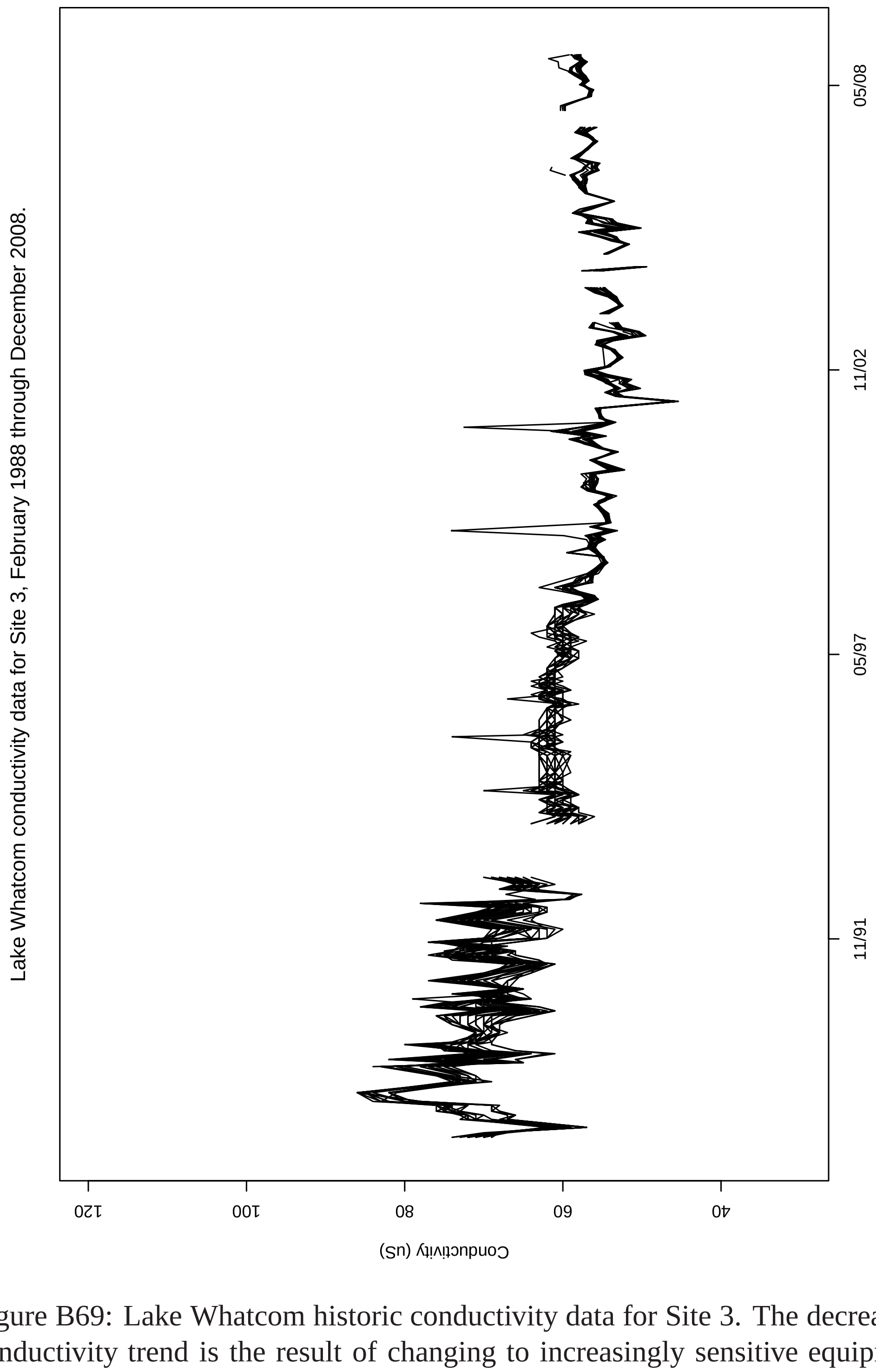


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

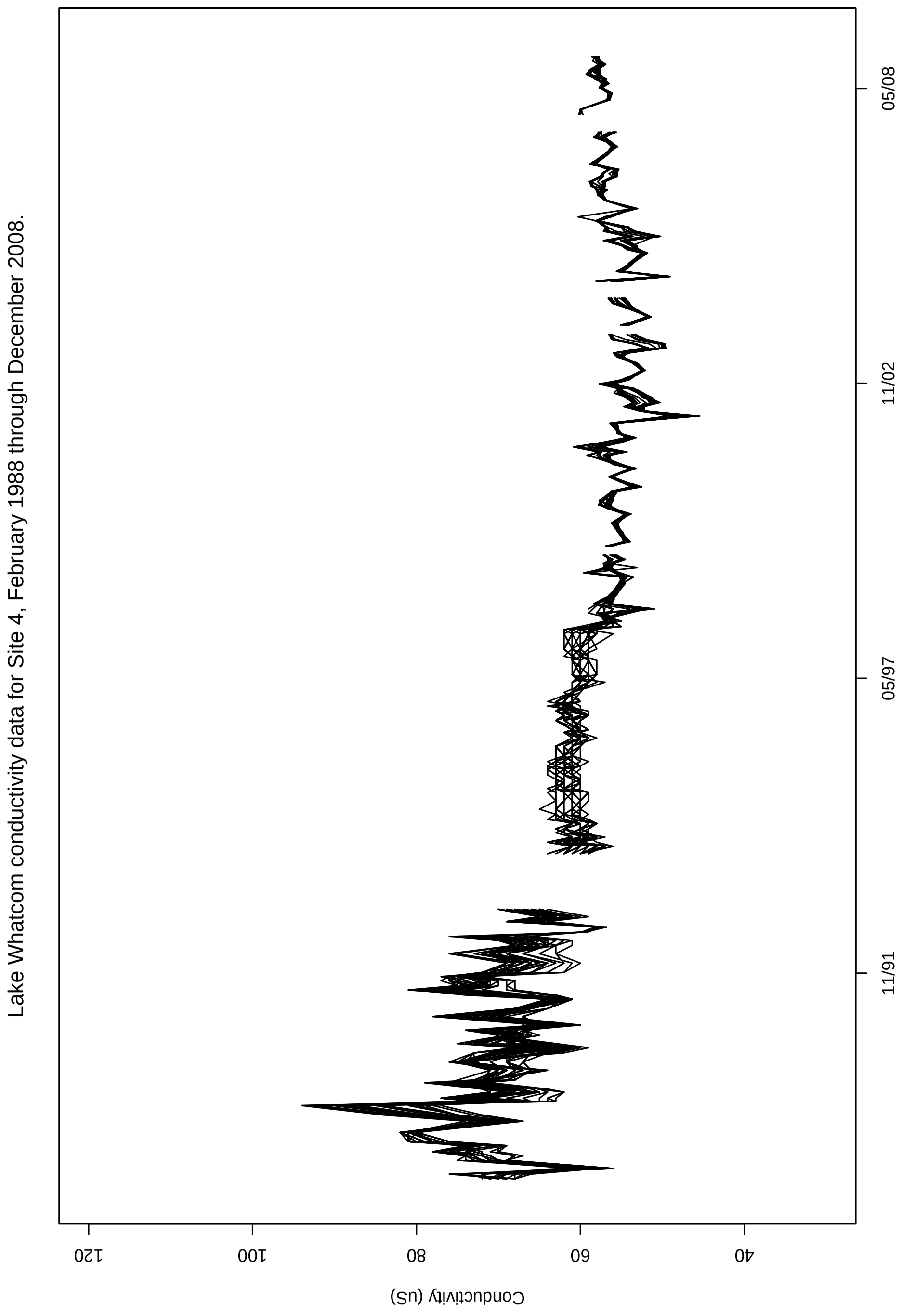


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

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

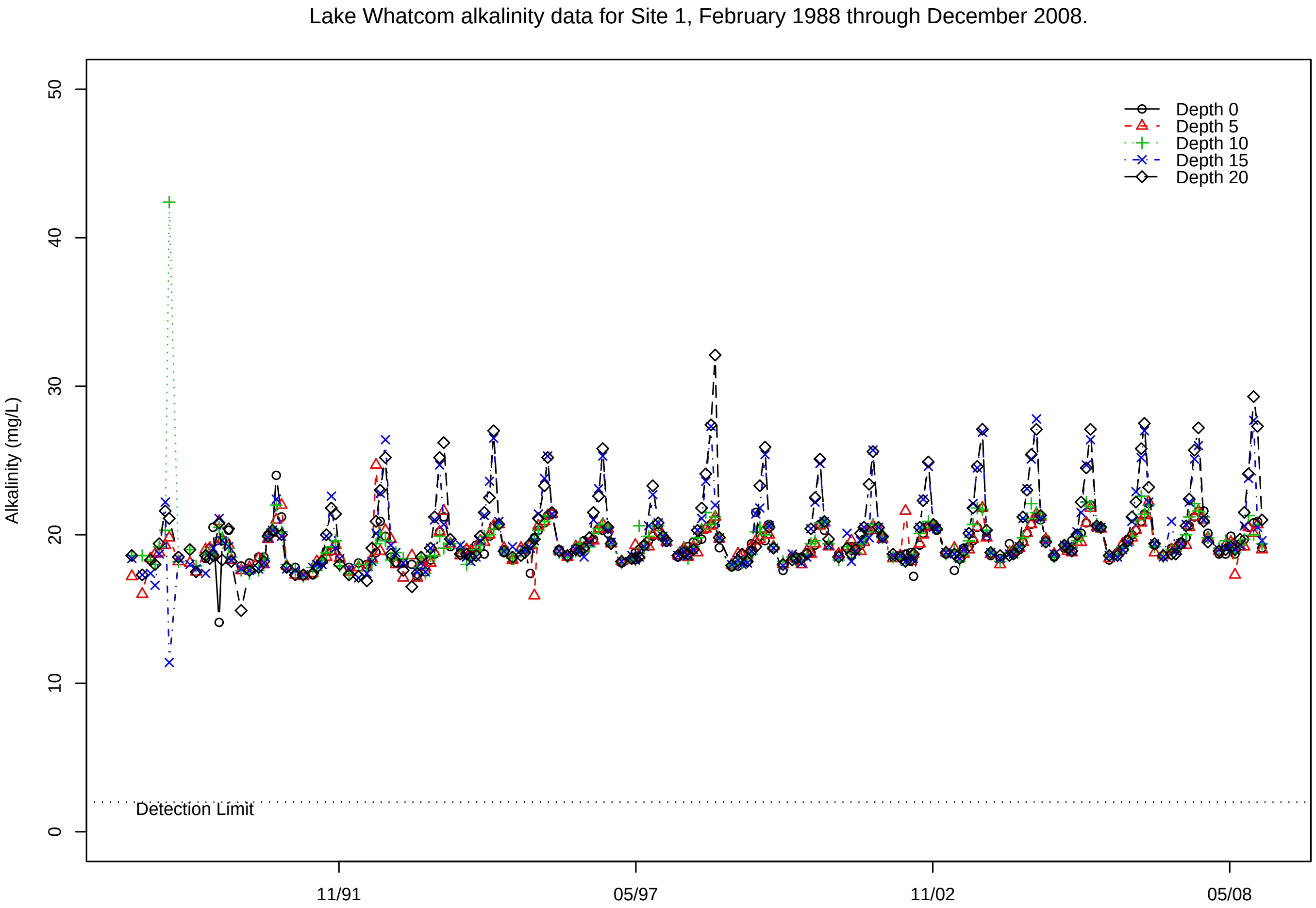


Figure B71: Lake Whatcom alkalinity data for Site 1.

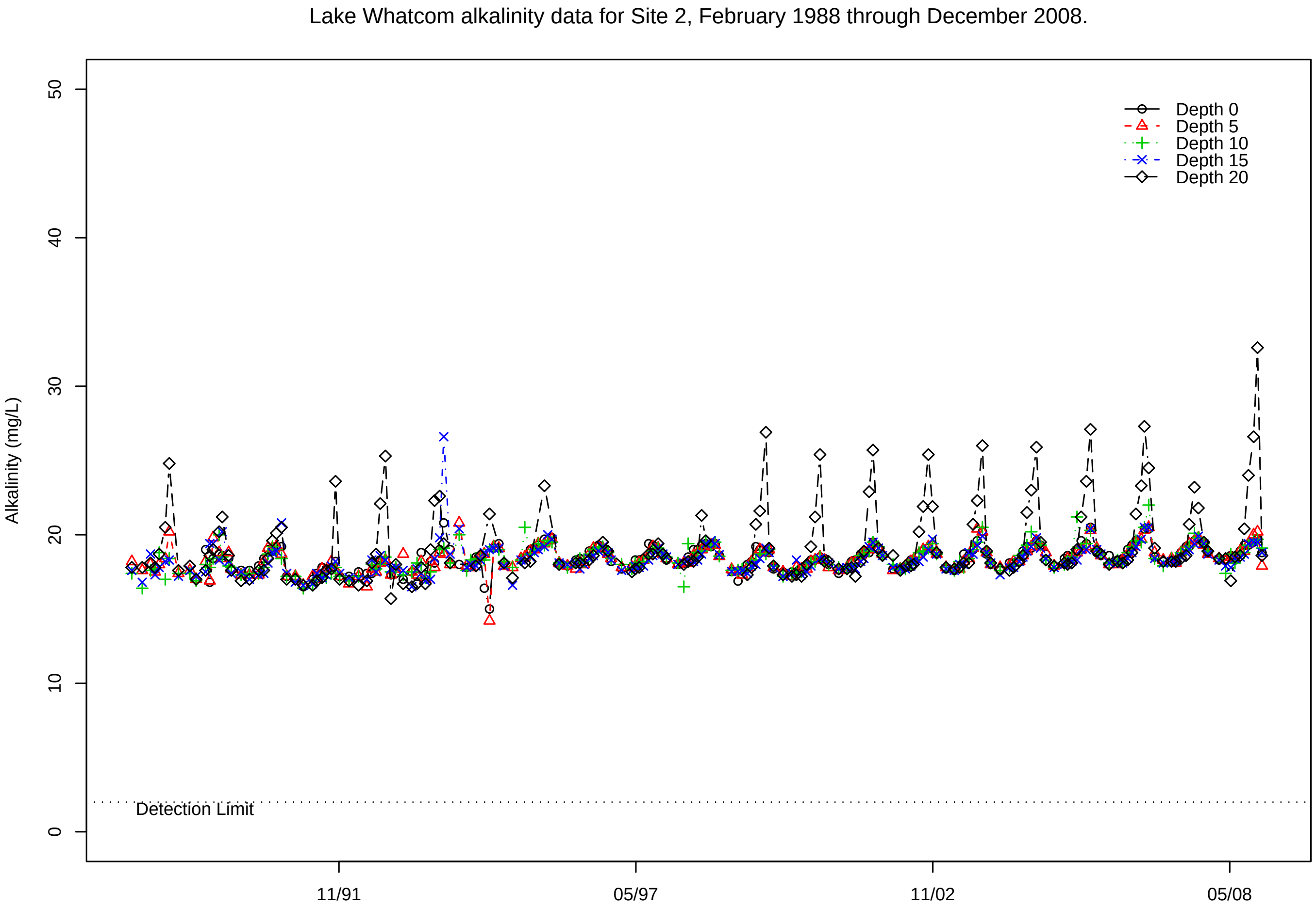


Figure B72: Lake Whatcom alkalinity data for Site 2.

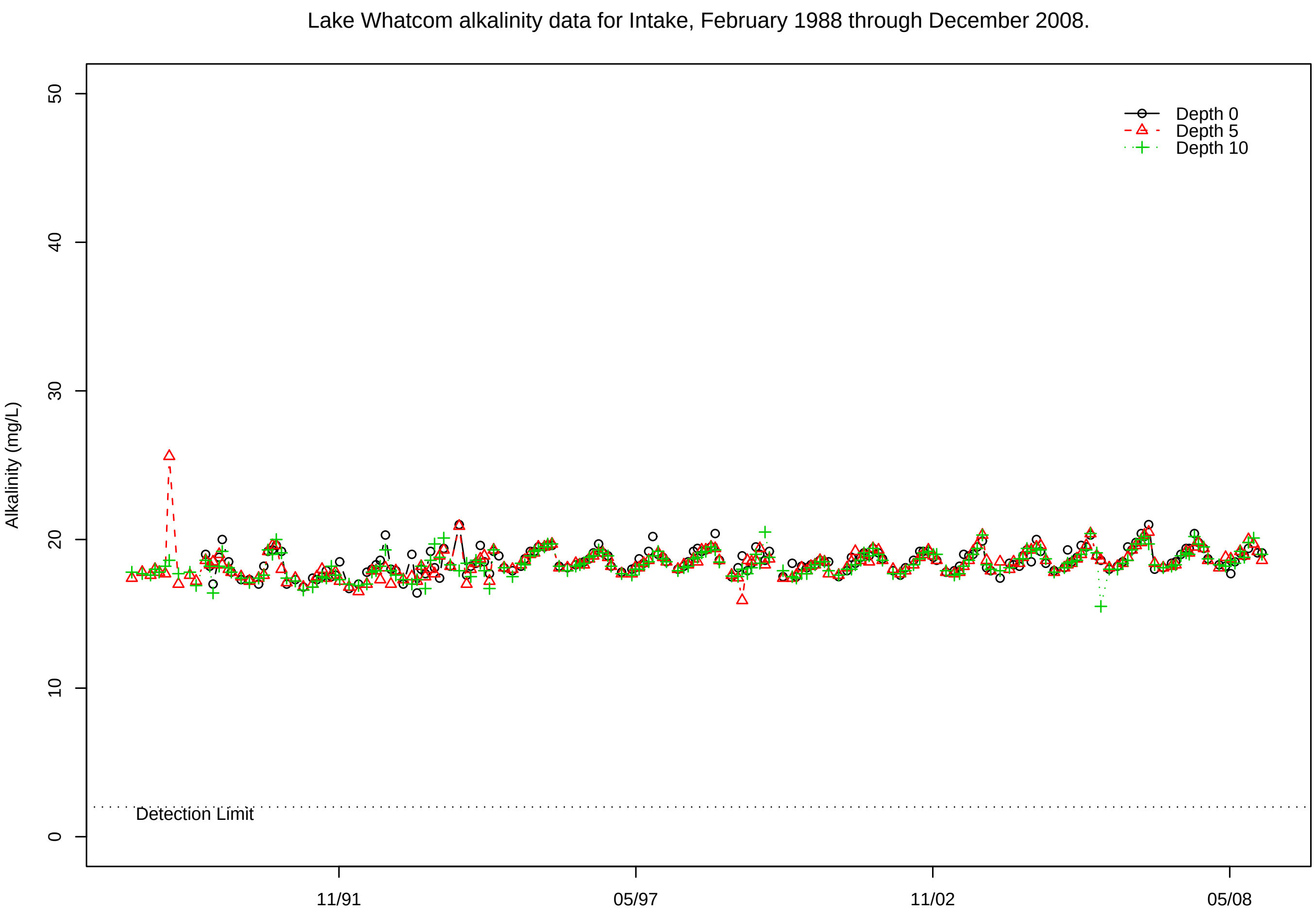


Figure B73: Lake Whatcom alkalinity data for the Intake site.

Lake Whatcom alkalinity data for Site 3, February 1988 through December 2008.

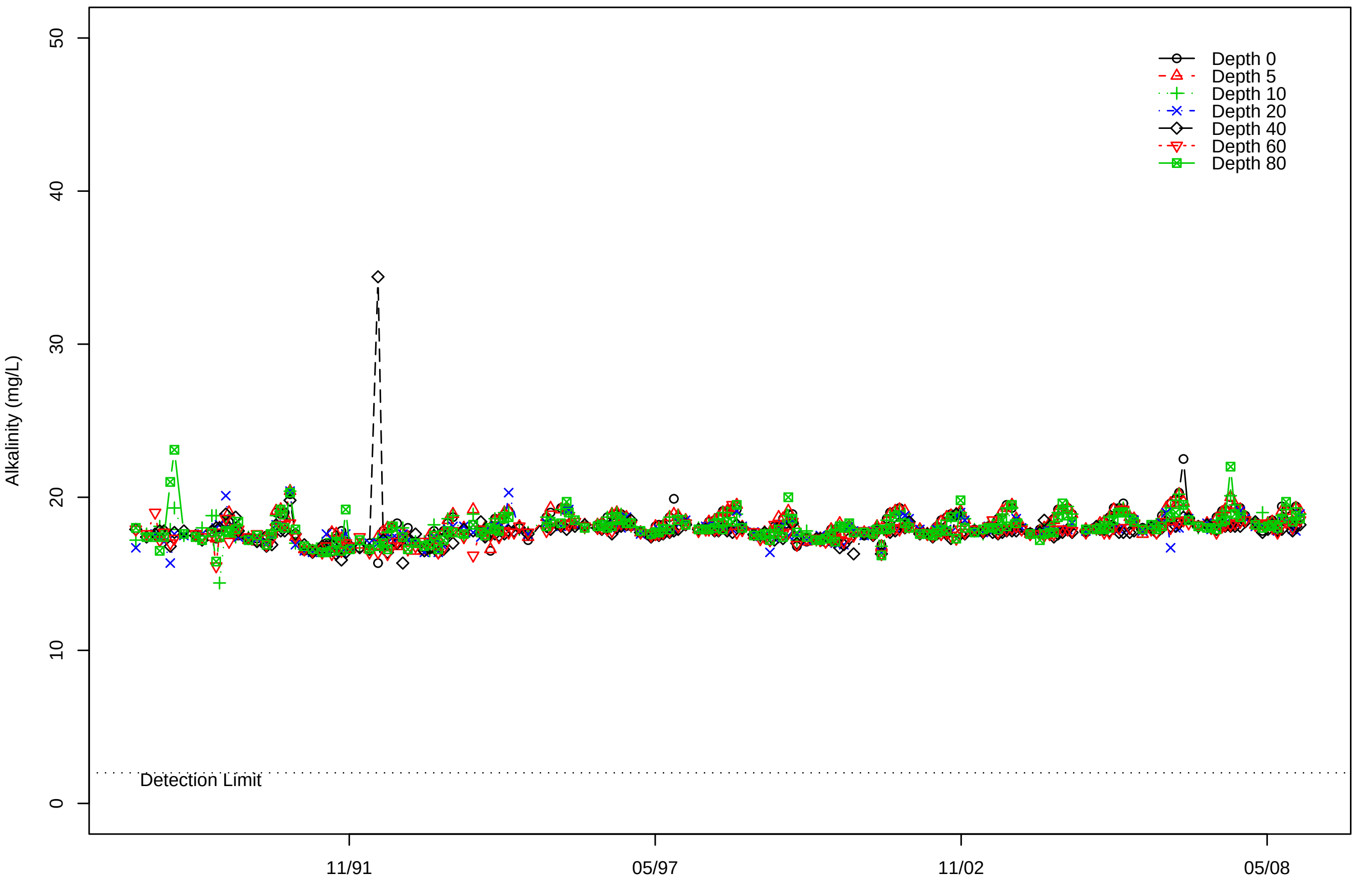


Figure B74: Lake Whatcom alkalinity data for Site 3.

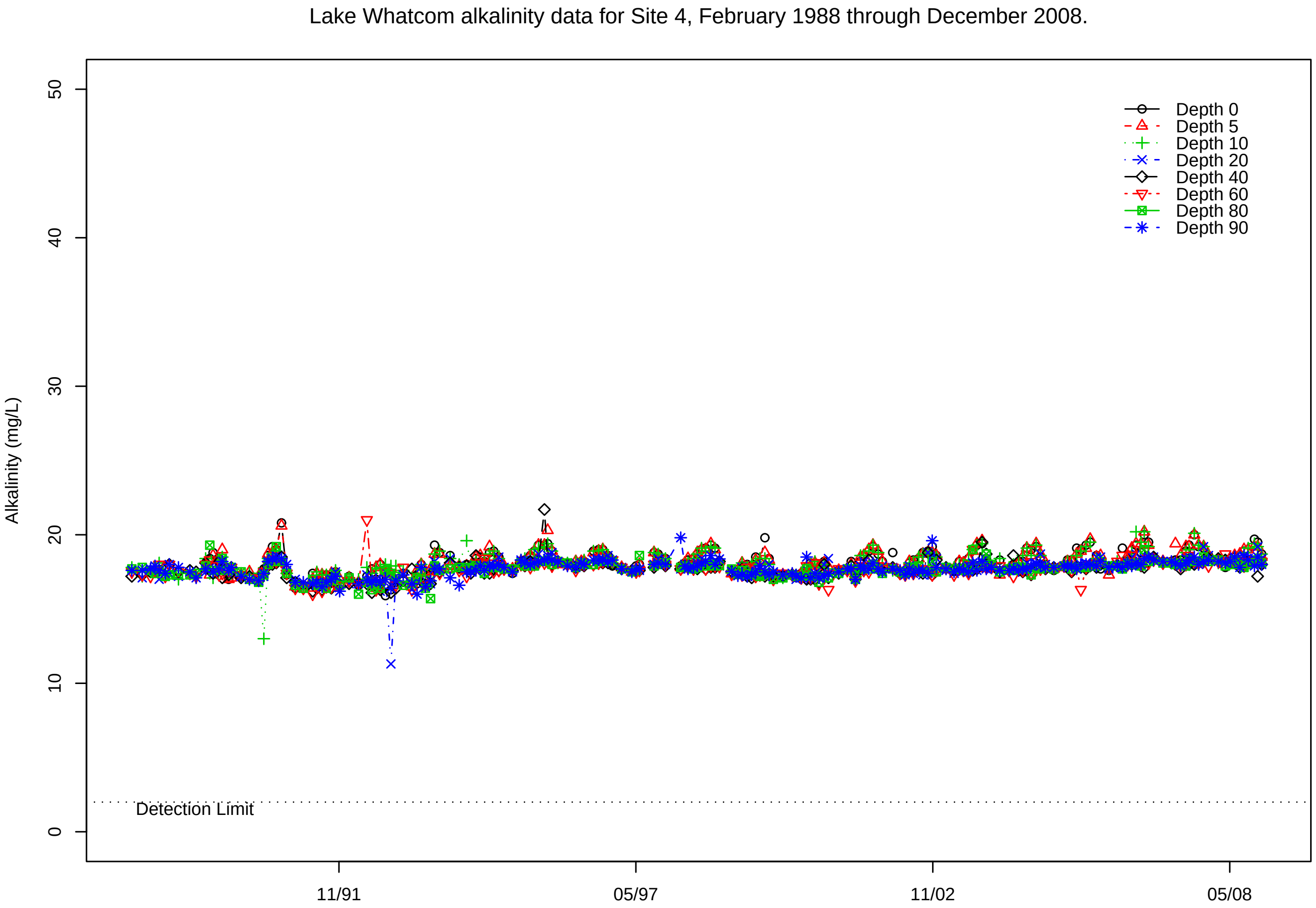


Figure B75: Lake Whatcom alkalinity data for Site 4.

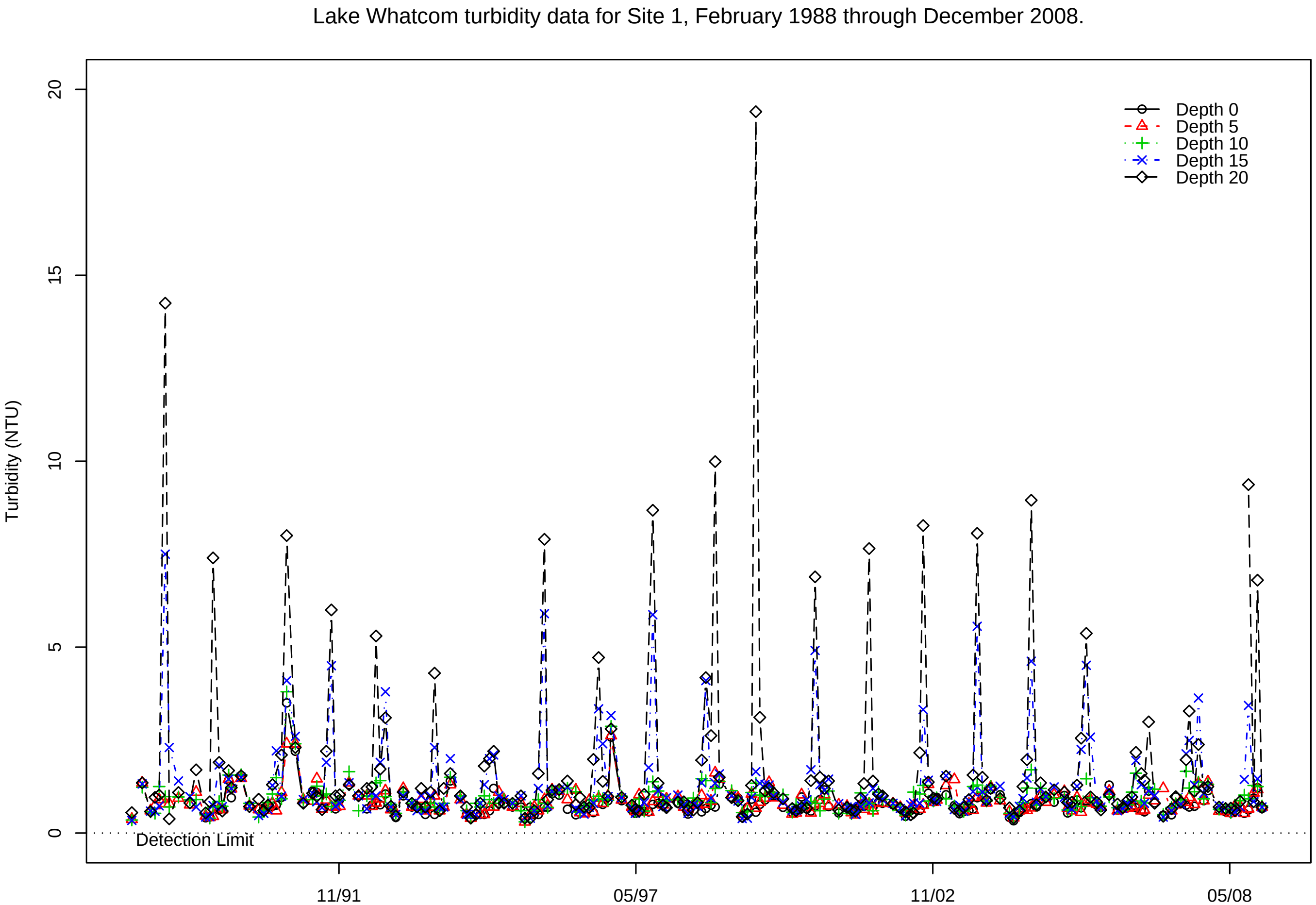


Figure B76: Lake Whatcom turbidity data for Site 1.

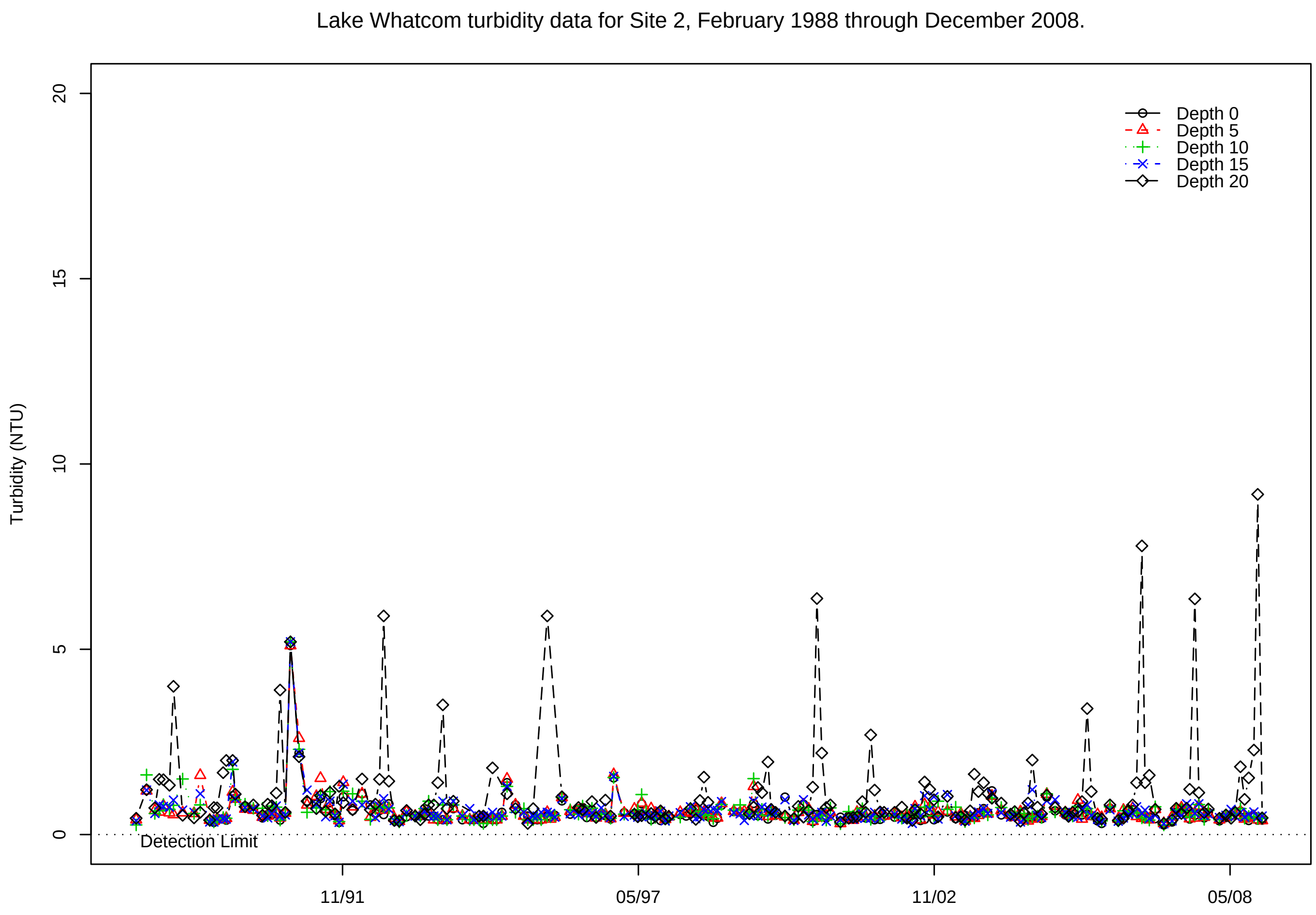


Figure B77: Lake Whatcom turbidity data for Site 2.

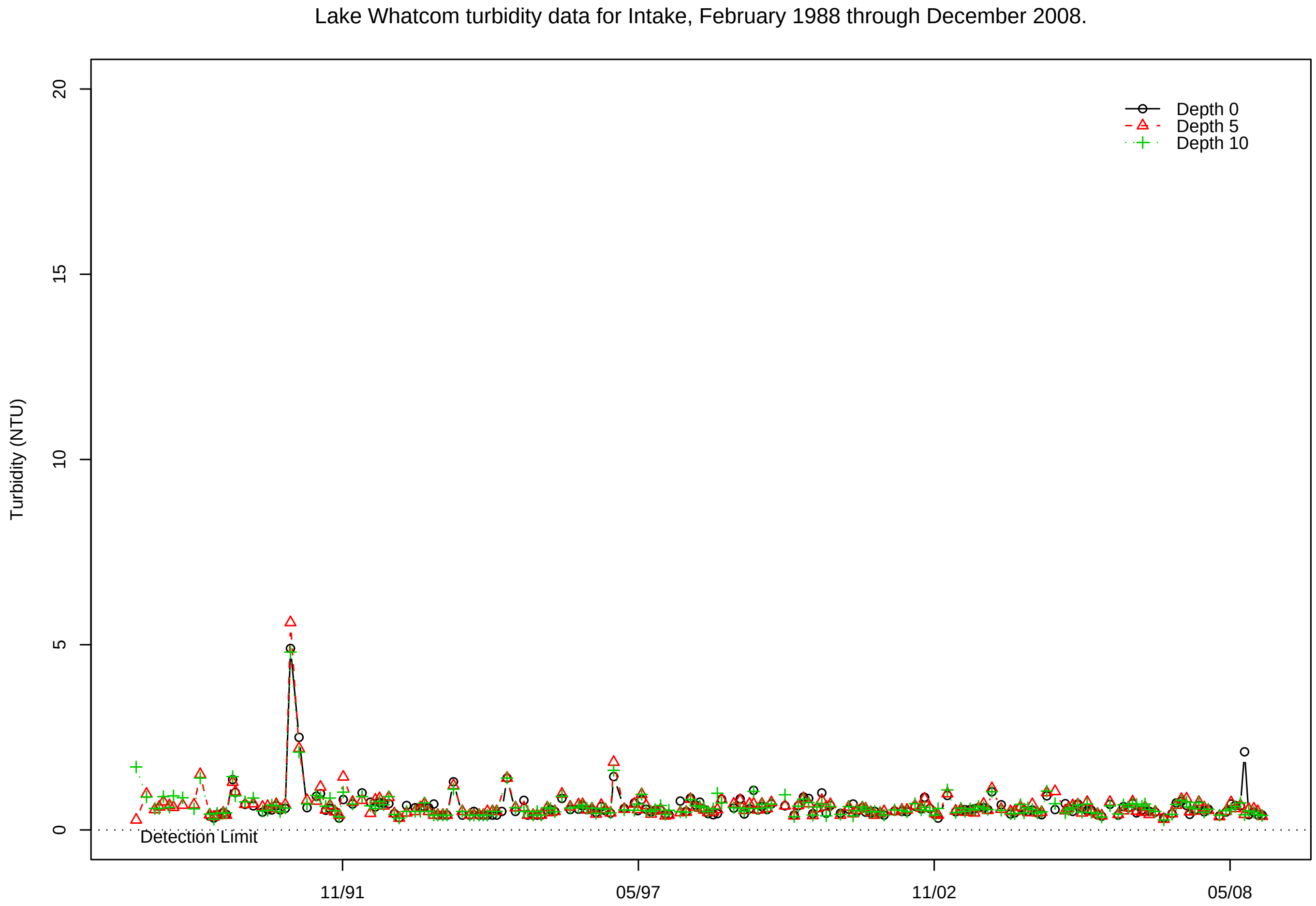


Figure B78: Lake Whatcom turbidity data for the Intake site.

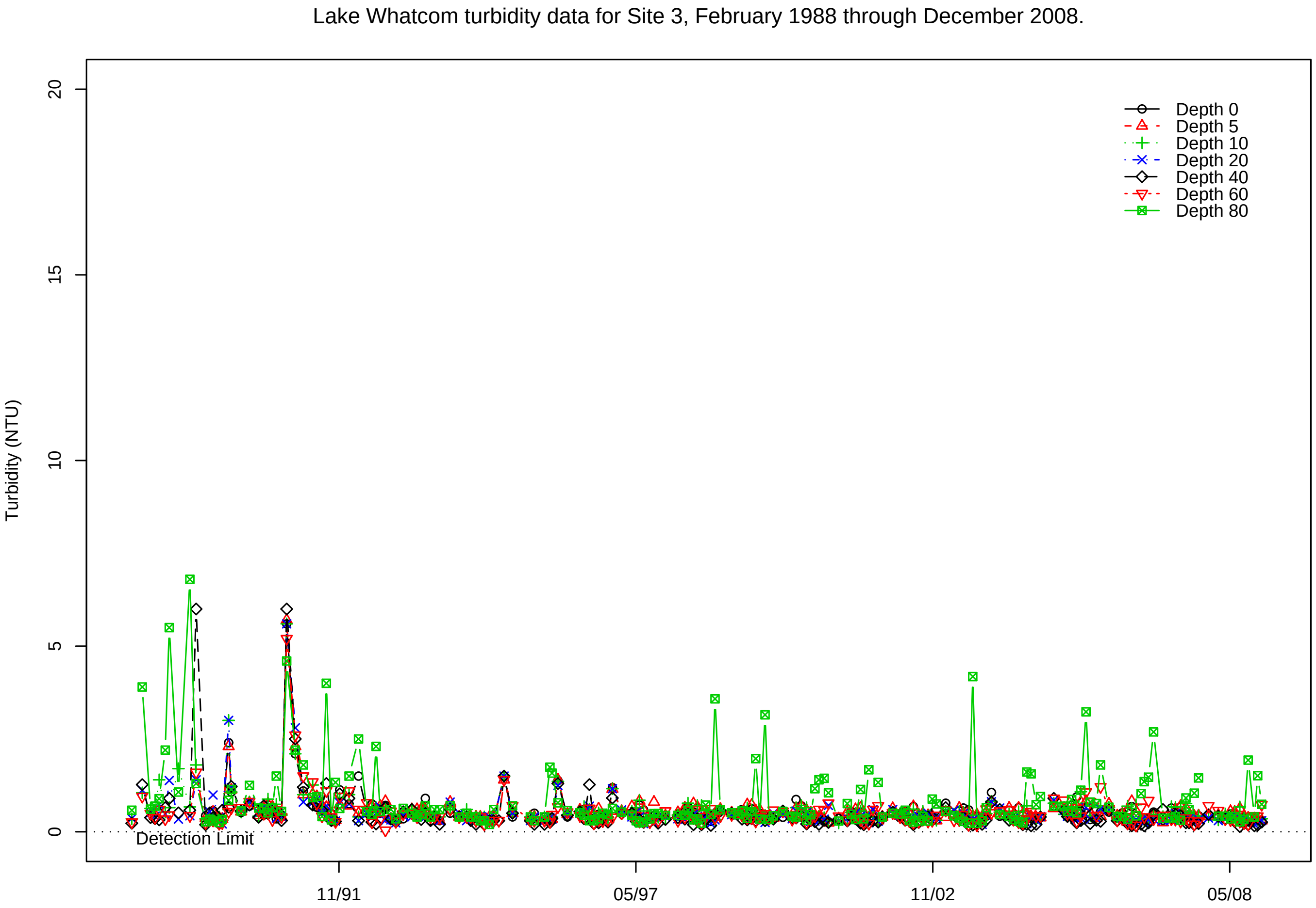


Figure B79: Lake Whatcom turbidity data for Site 3.

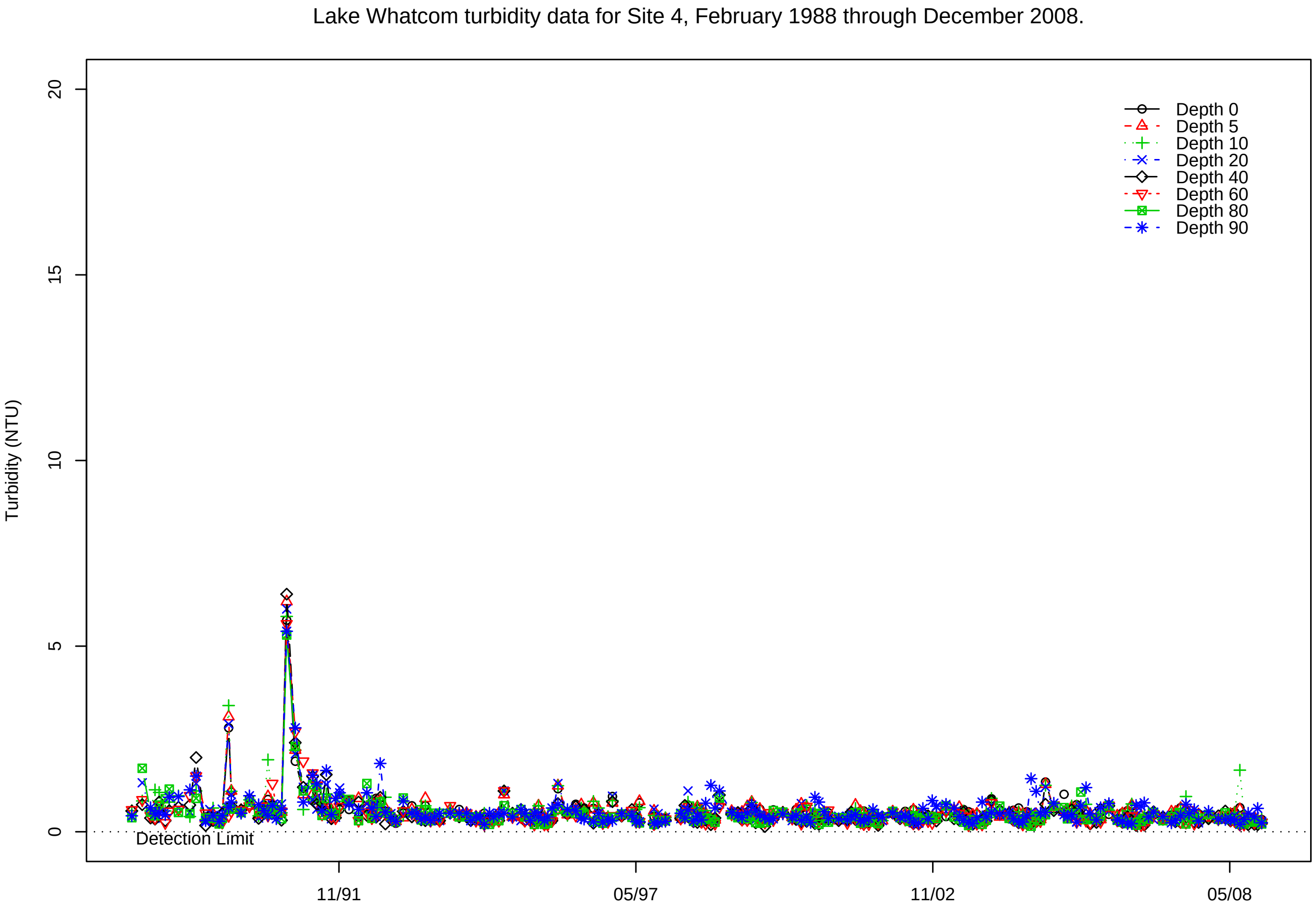


Figure B80: Lake Whatcom turbidity data for Site 4.

Lake Whatcom ammonia data for Site 1, February 1988 through December 2008.

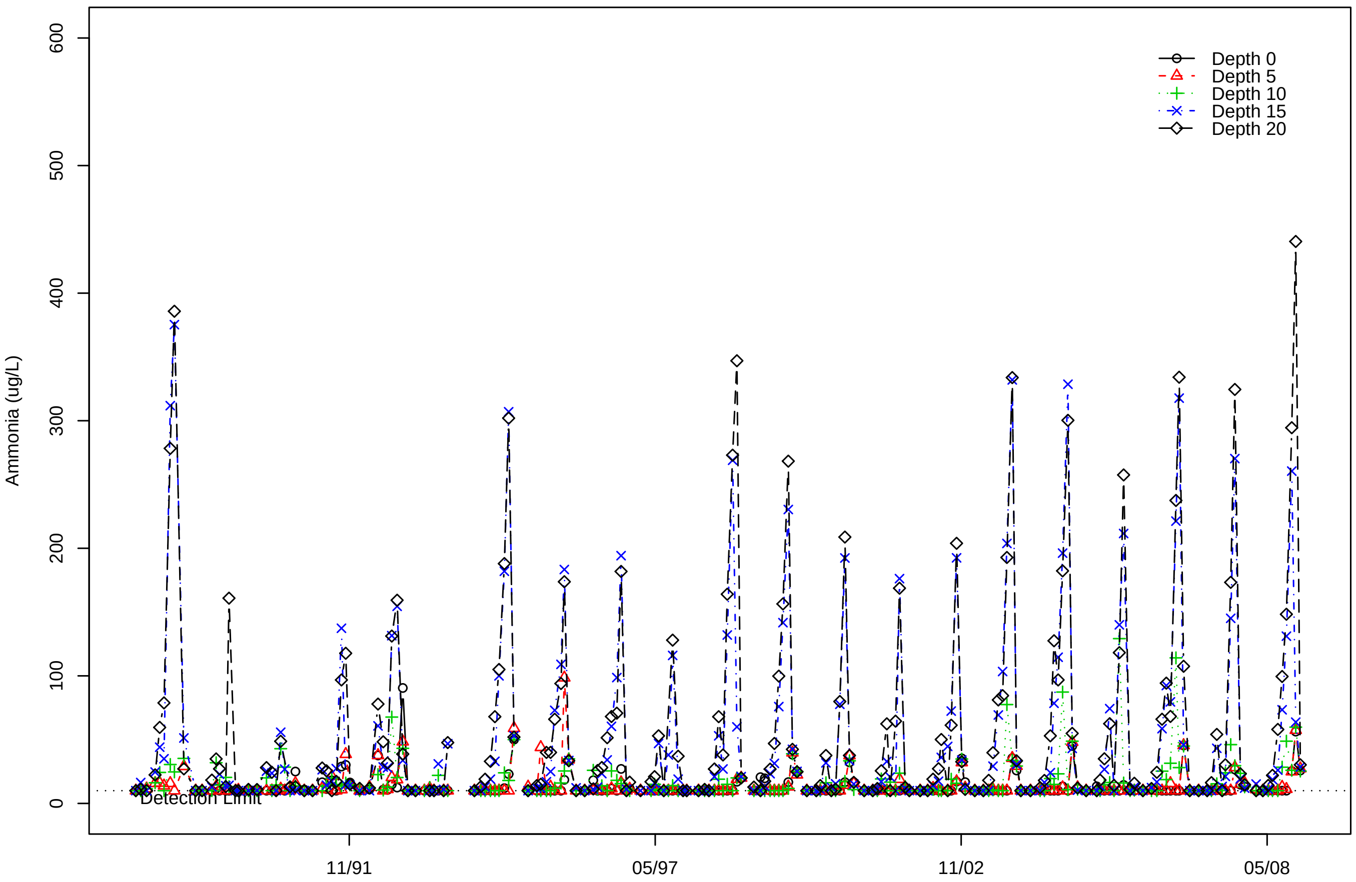


Figure B81: Lake Whatcom ammonia data for Site 1.

Lake Whatcom ammonia data for Site 2, February 1988 through December 2008.

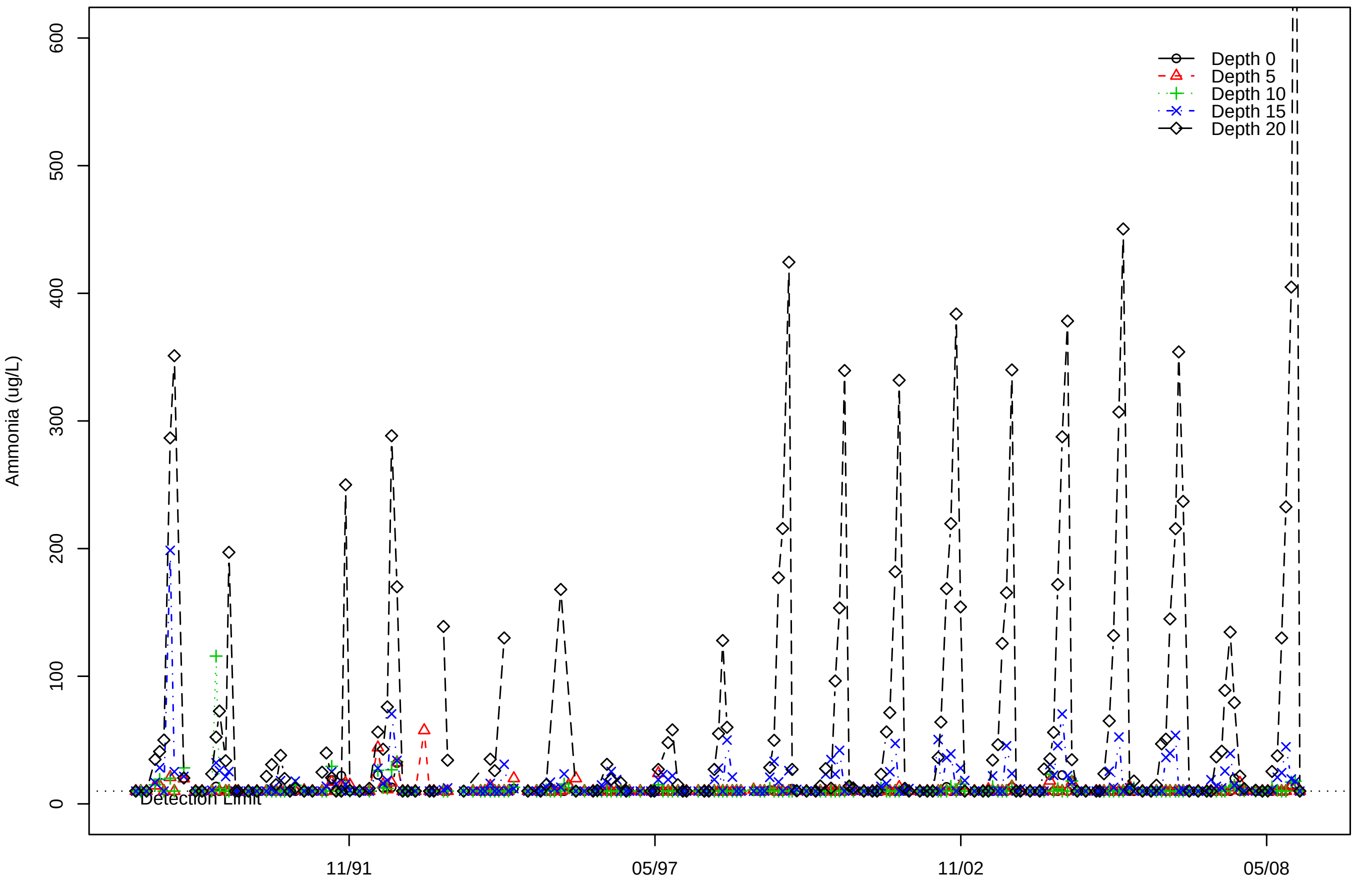


Figure B82: Lake Whatcom ammonia data for Site 2.

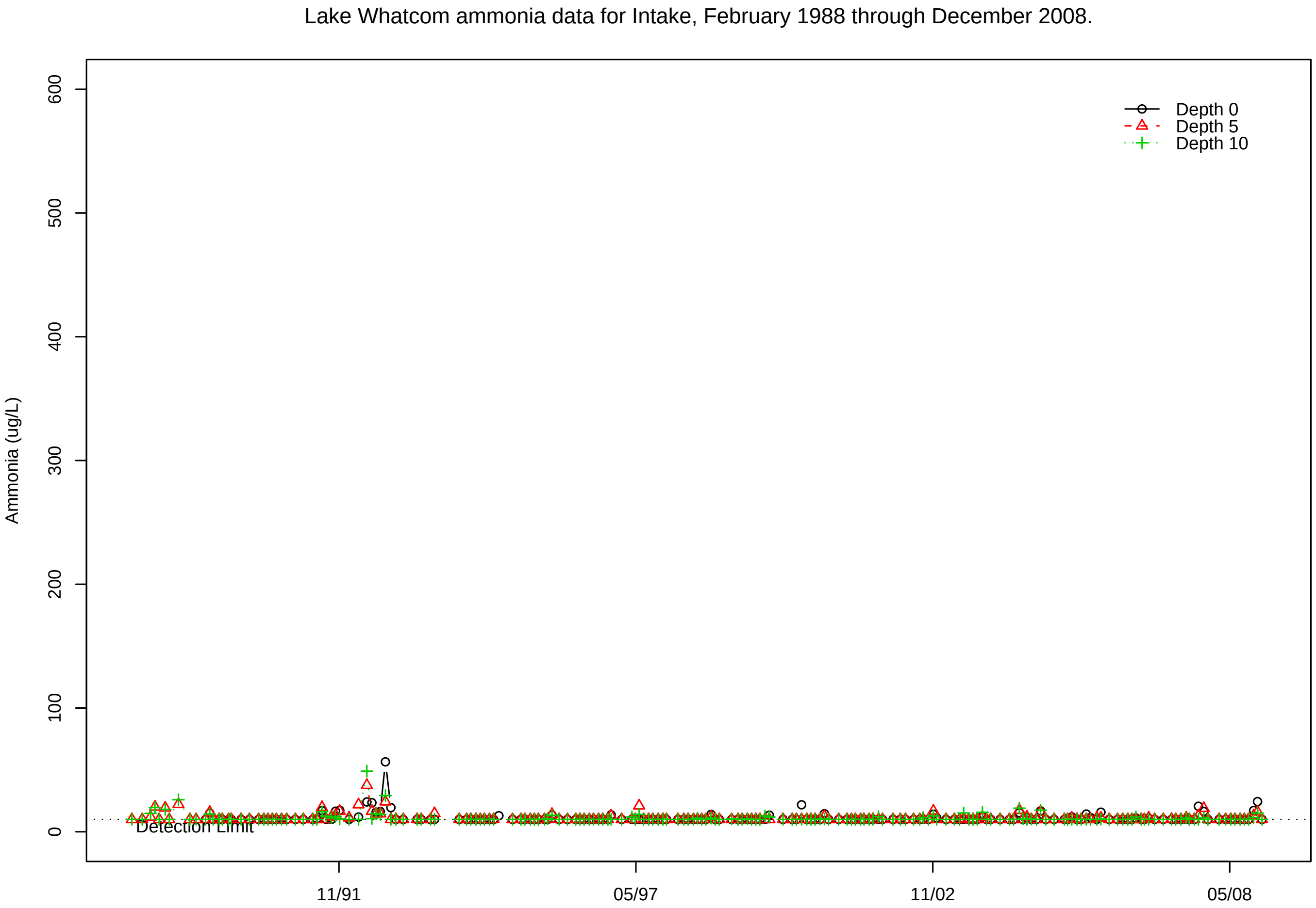


Figure B83: Lake Whatcom ammonia data for the Intake site.

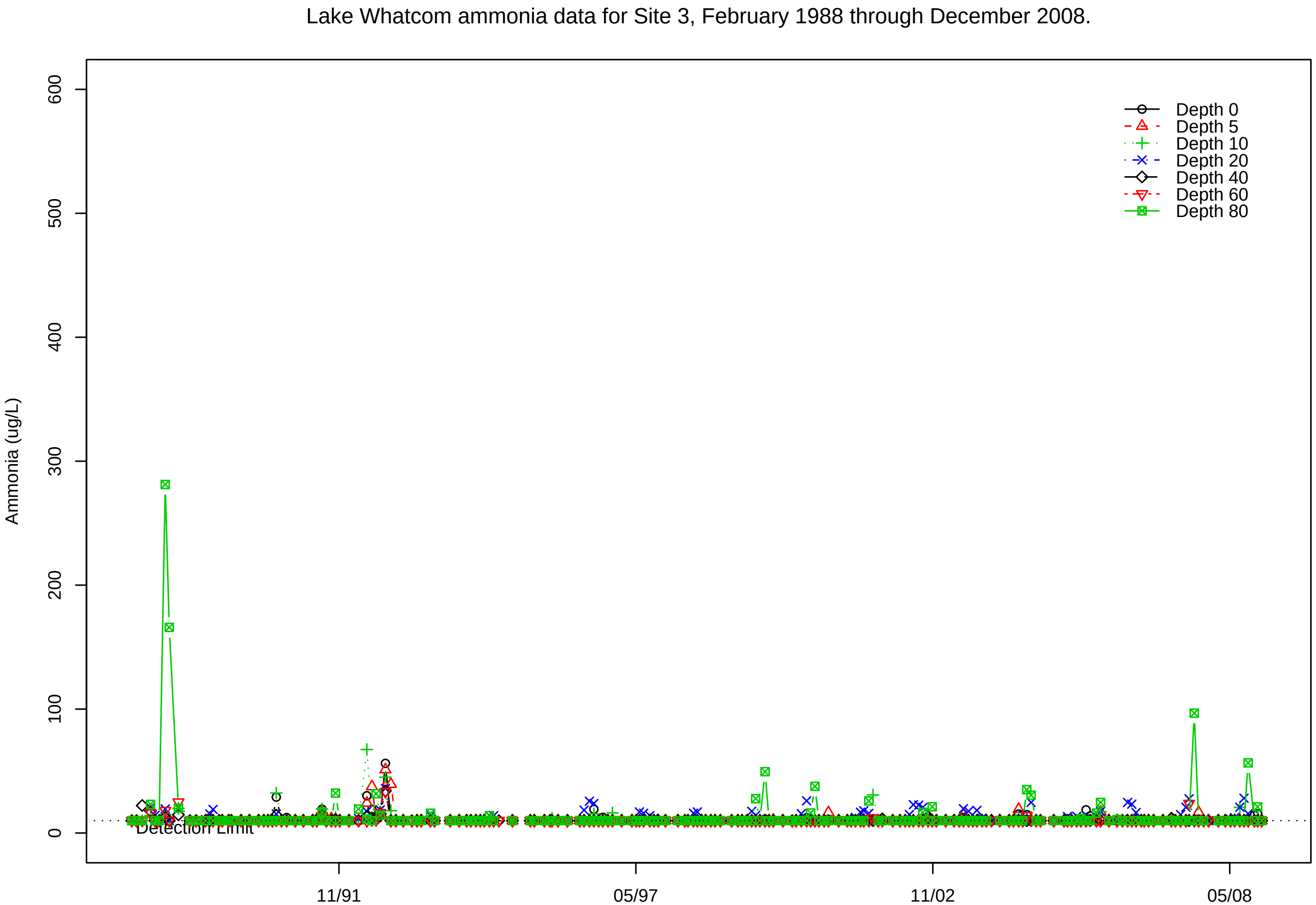


Figure B84: Lake Whatcom ammonia data for Site 3.

Lake Whatcom ammonia data for Site 4, February 1988 through December 2008.

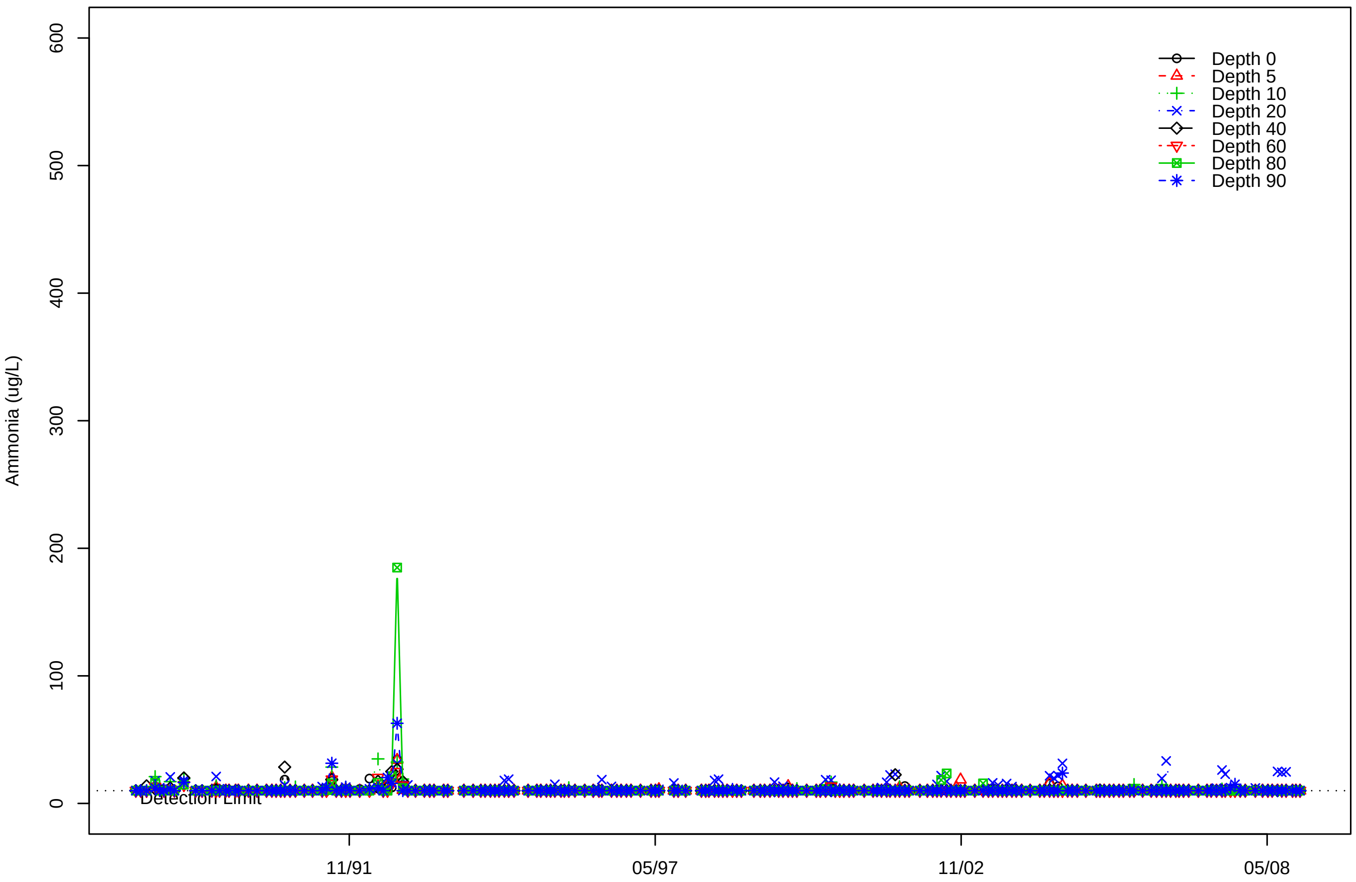


Figure B85: Lake Whatcom ammonia data for Site 4.

Lake Whatcom nitrate/nitrite data for Site 1, February 1988 through December 2008.

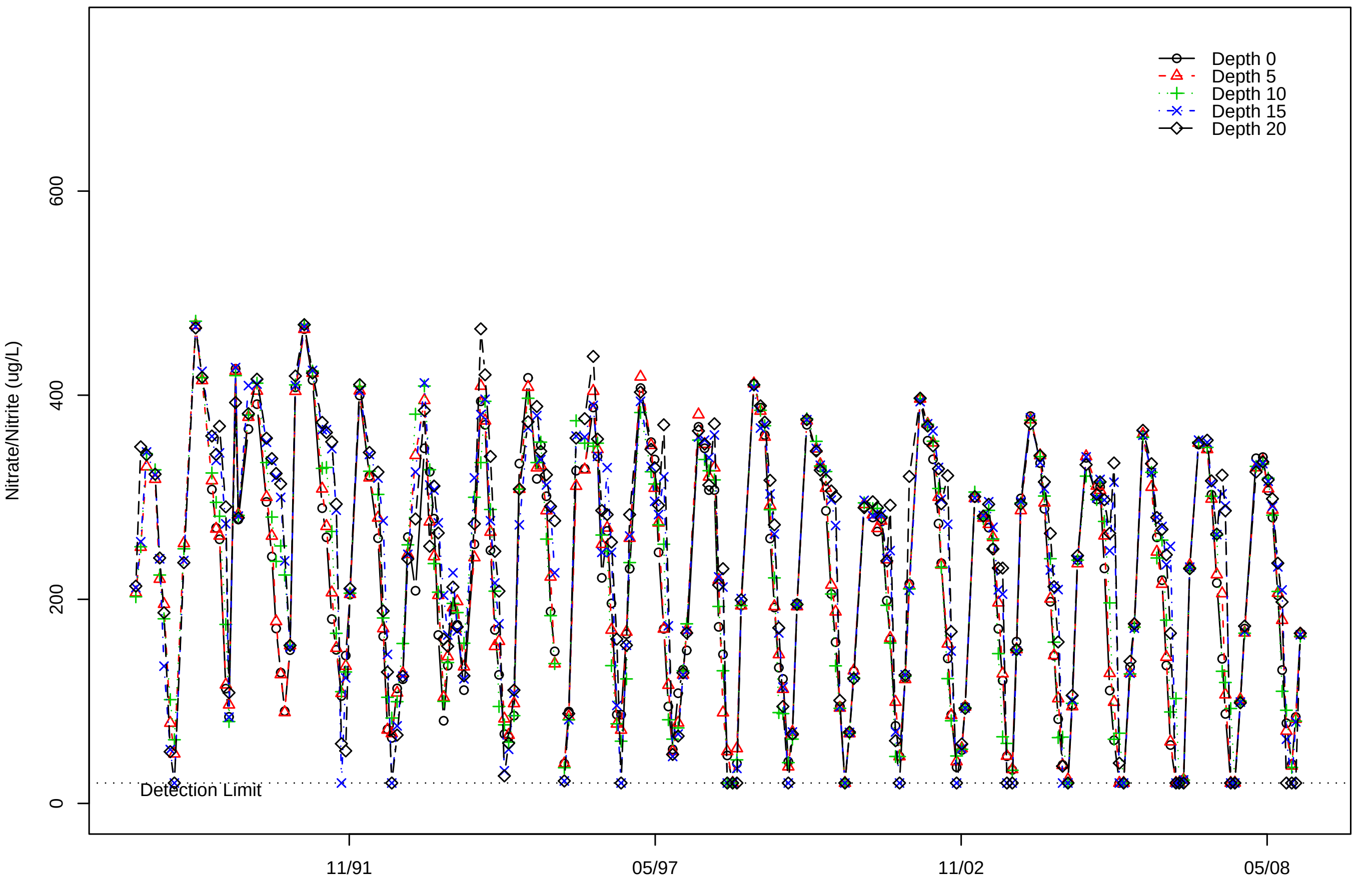


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.

Lake Whatcom nitrate/nitrite data for Site 2, February 1988 through December 2008.

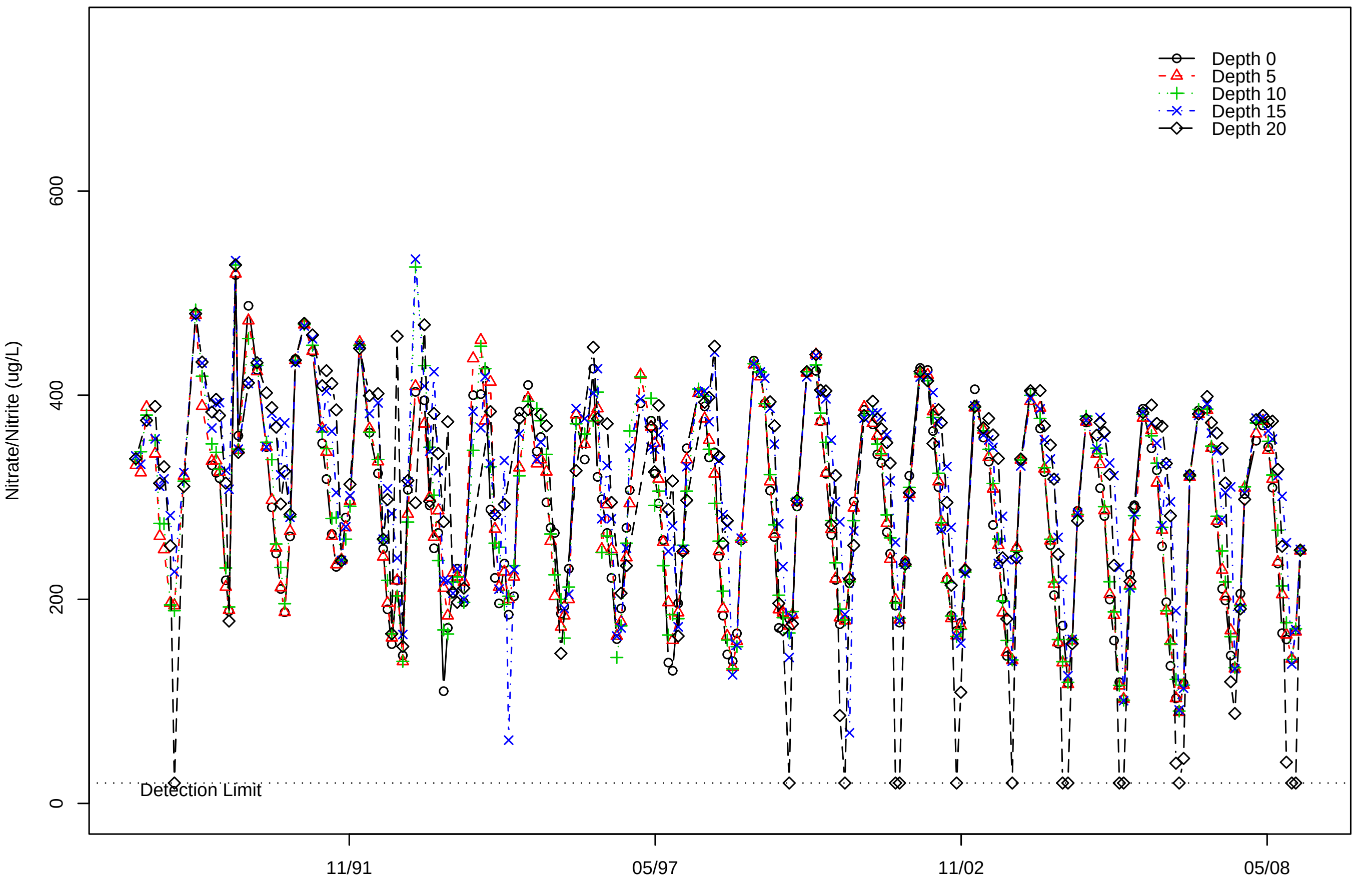


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

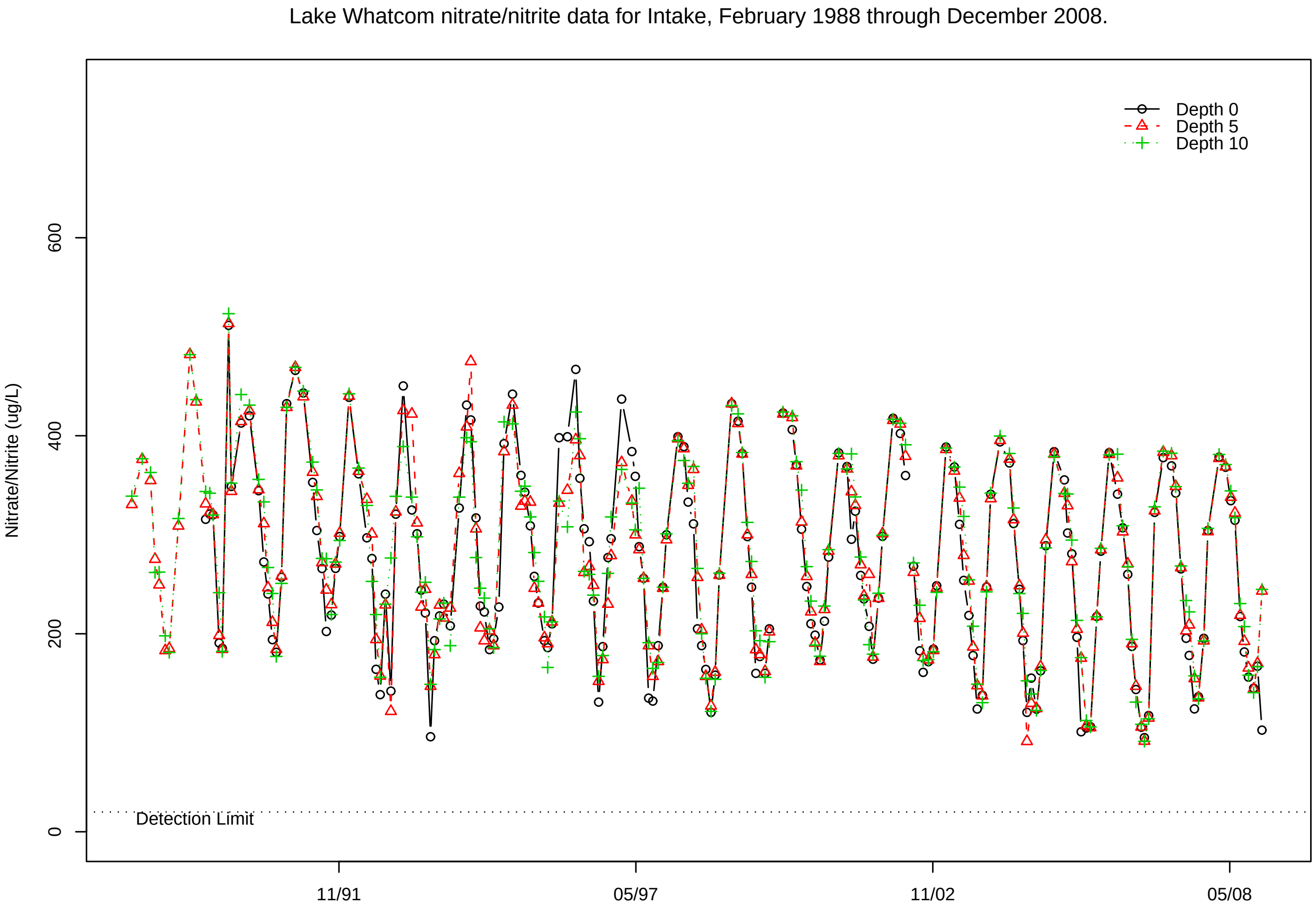


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

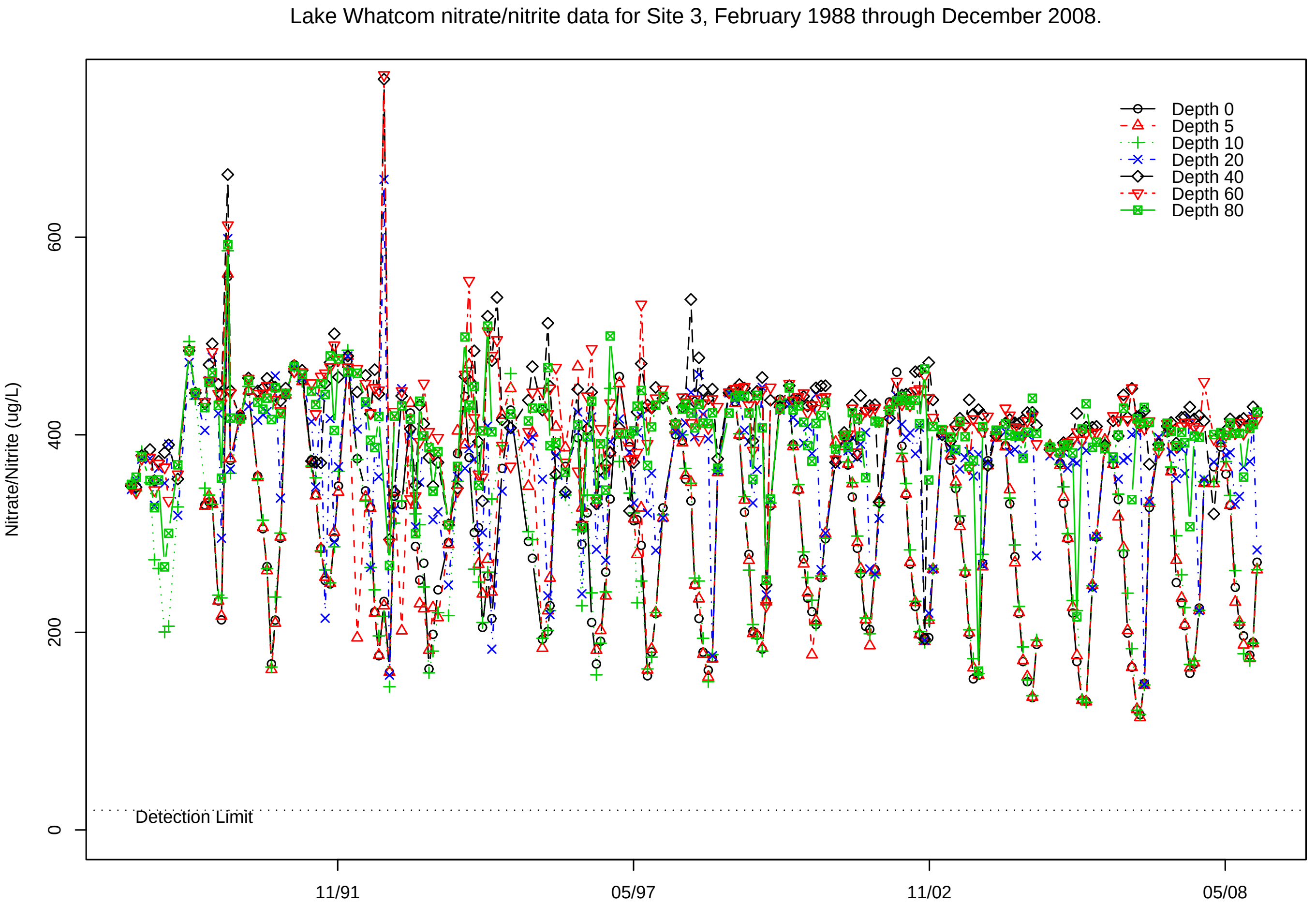


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

Lake Whatcom nitrate/nitrite data for Site 4, February 1988 through December 2008.

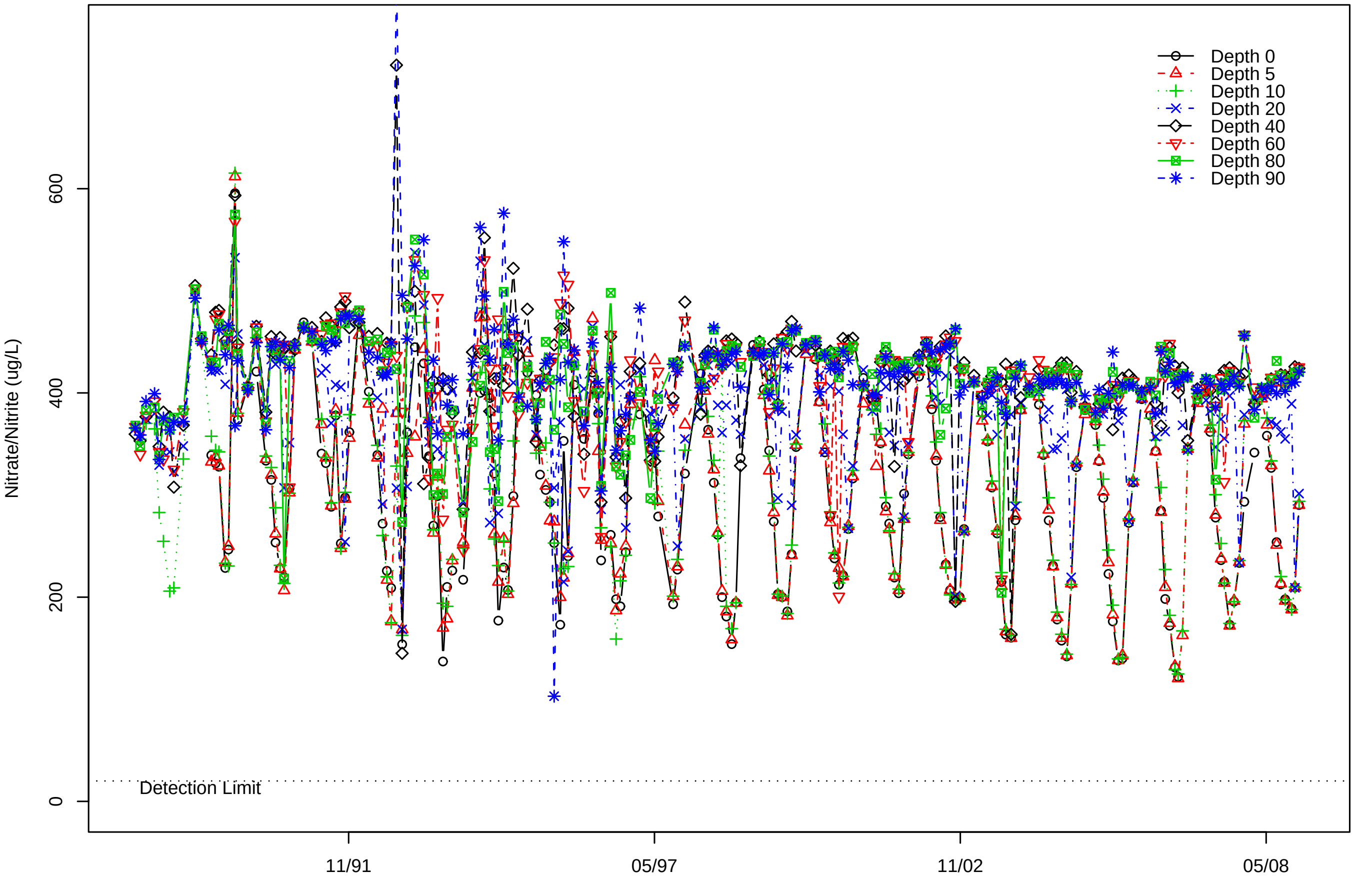


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4.

Lake Whatcom total nitrogen data for Site 1, February 1988 through December 2008.

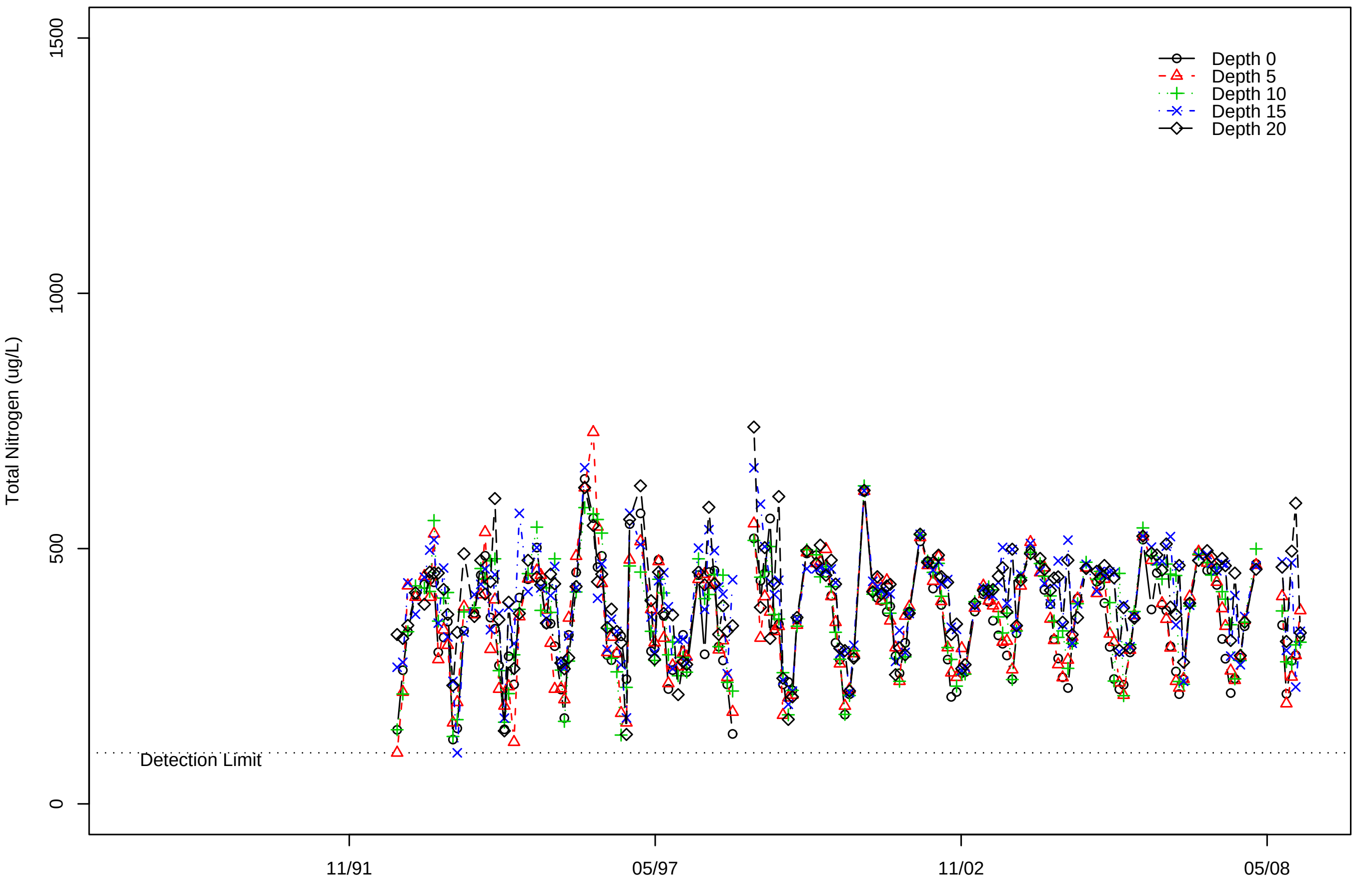


Figure B91: Lake Whatcom total nitrogen data for Site 1.

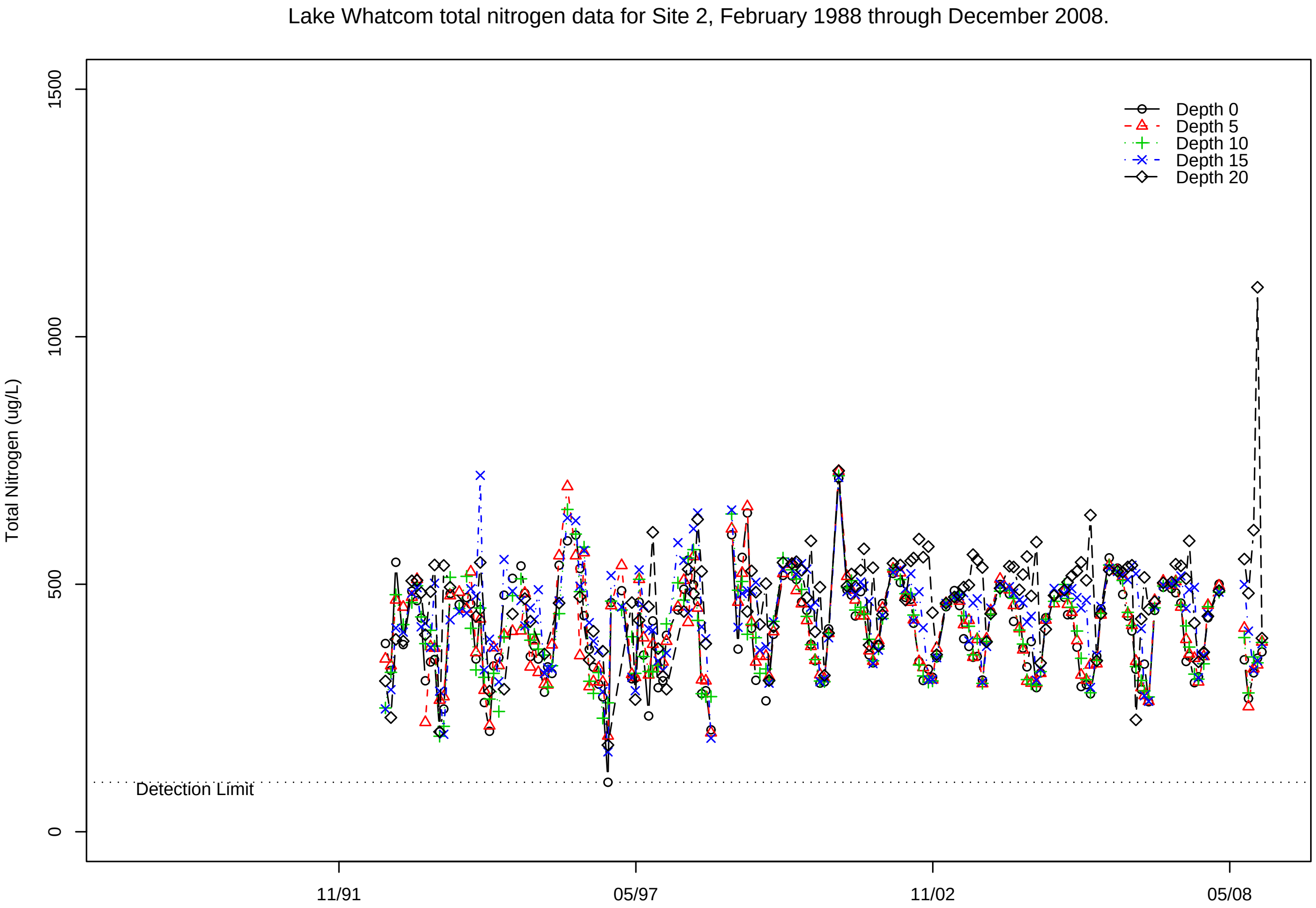


Figure B92: Lake Whatcom total nitrogen data for Site 2.

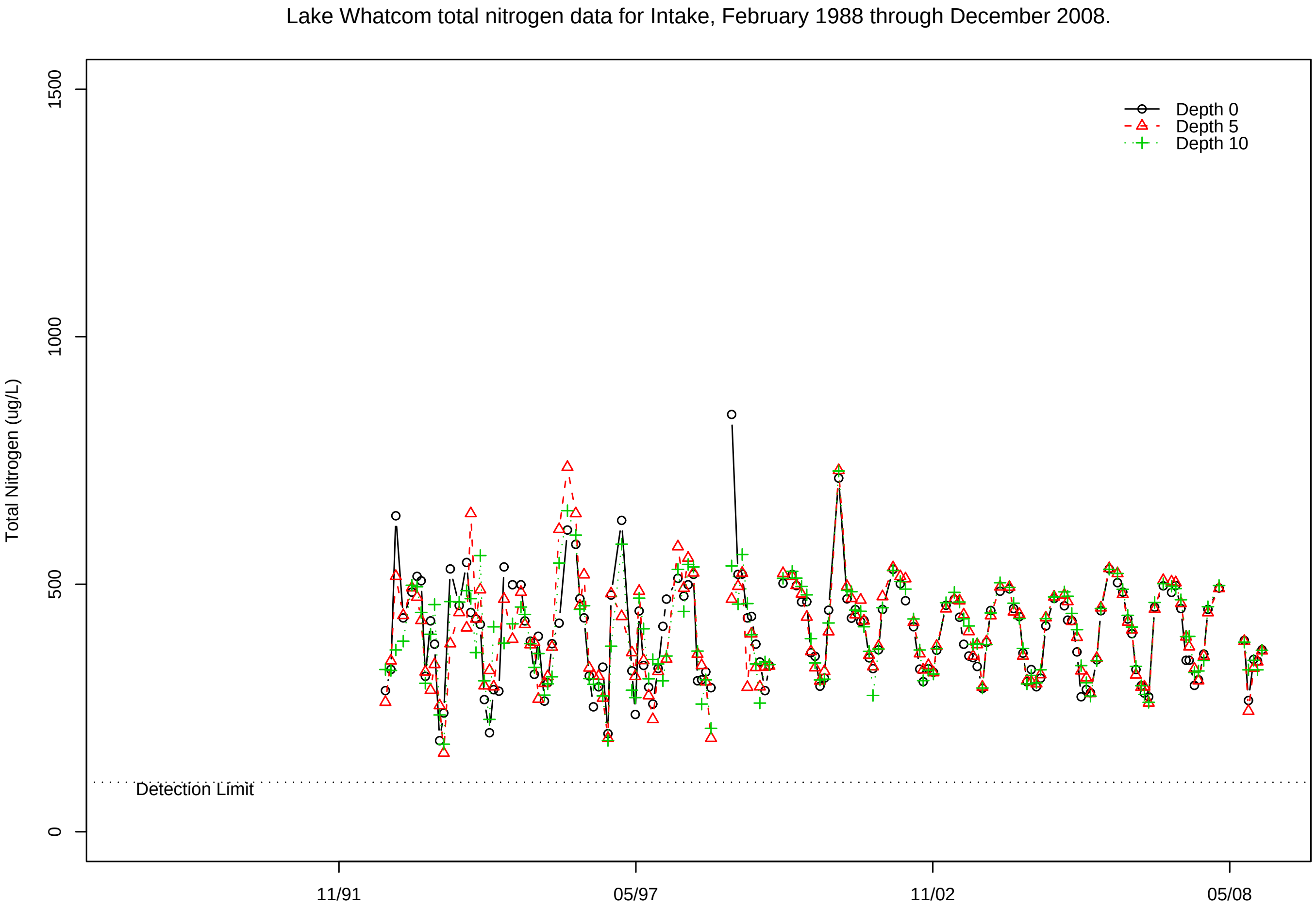


Figure B93: Lake Whatcom total nitrogen data for the Intake site.

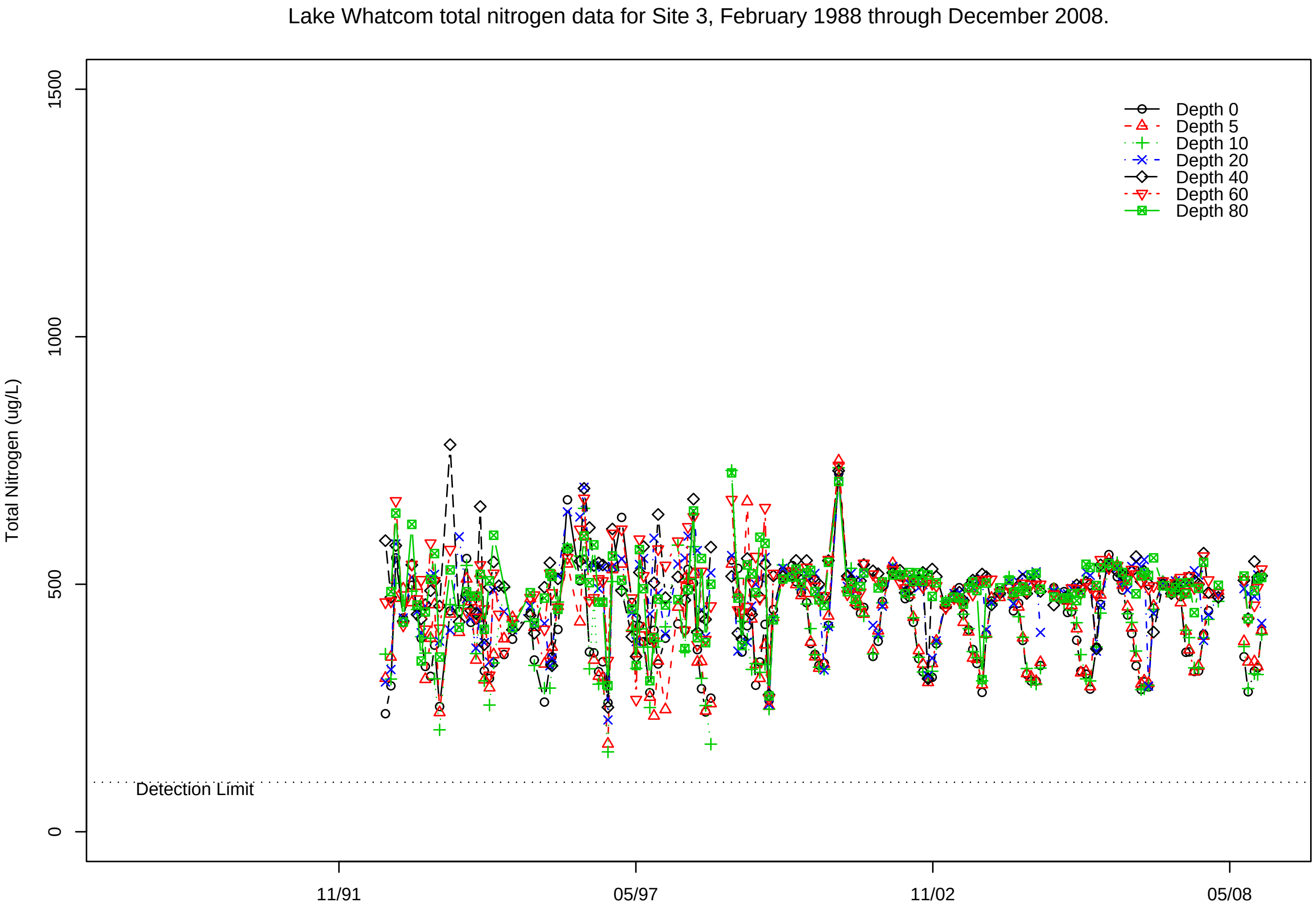


Figure B94: Lake Whatcom total nitrogen data for Site 3.

Lake Whatcom total nitrogen data for Site 4, February 1988 through December 2008.

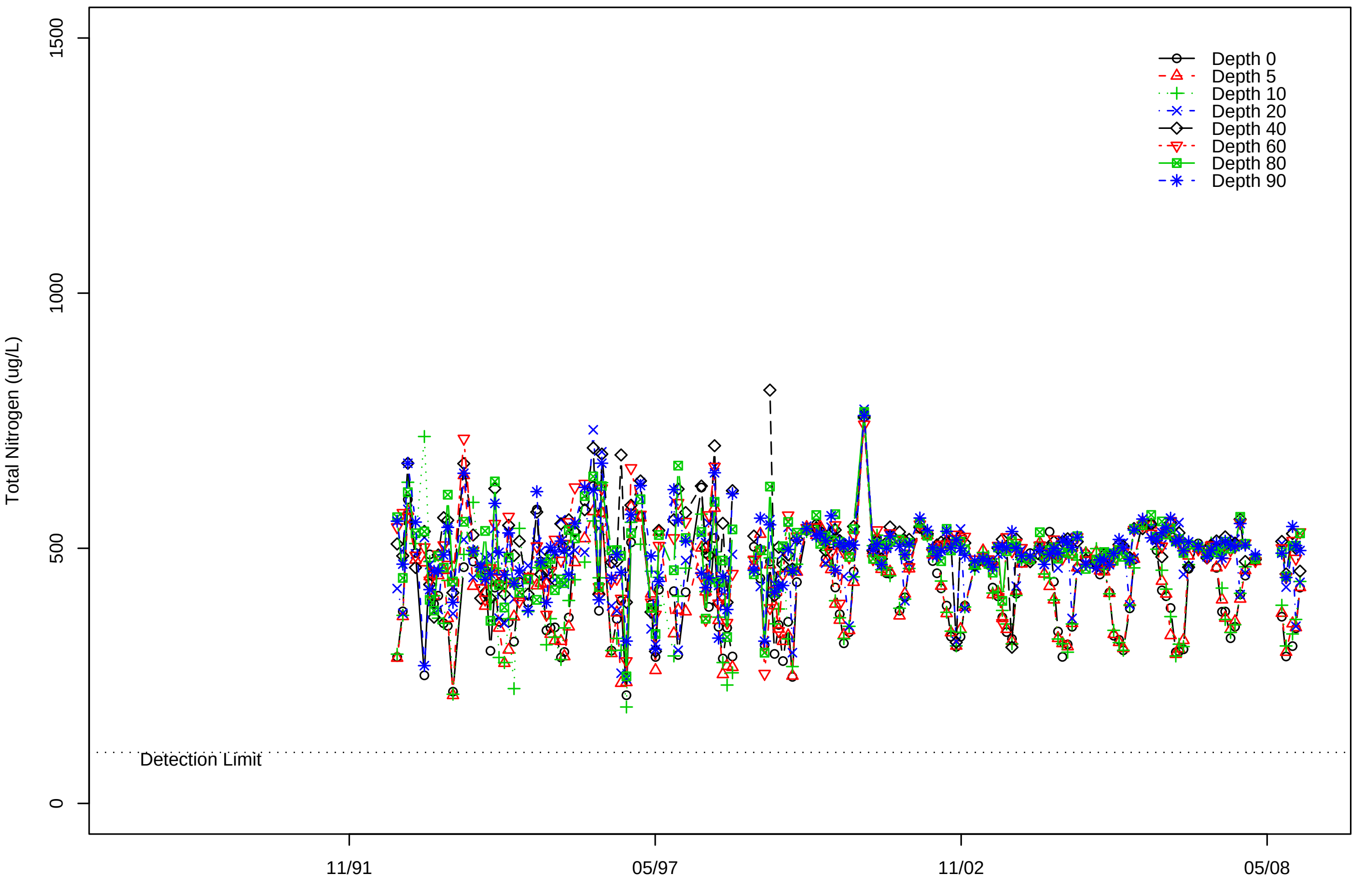


Figure B95: Lake Whatcom total nitrogen data for Site 4.

Lake Whatcom soluble reactive phosphate data for Site 1, February 1988 through December 2008.

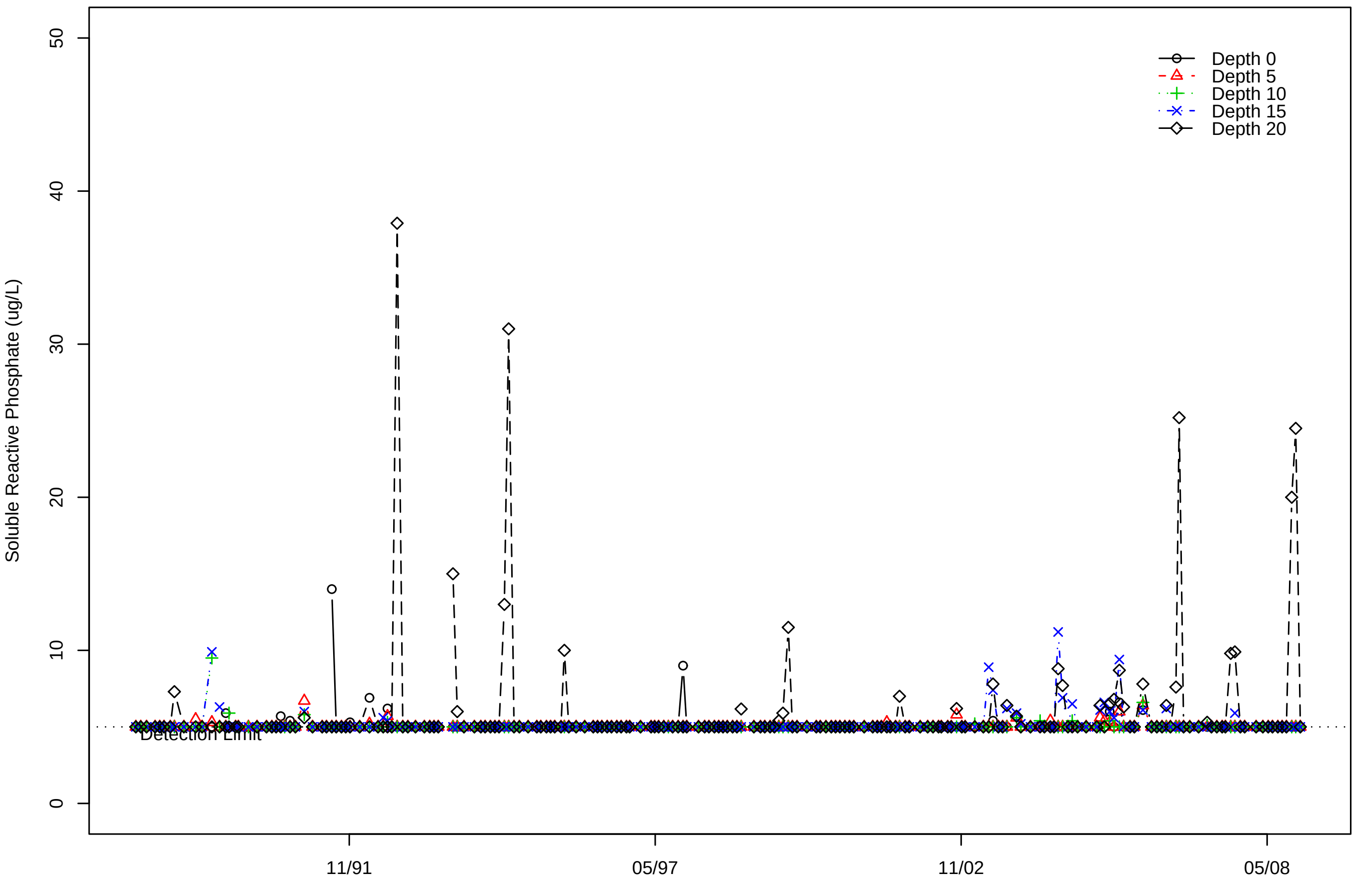


Figure B96: Lake Whatcom soluble phosphate data for Site 1.

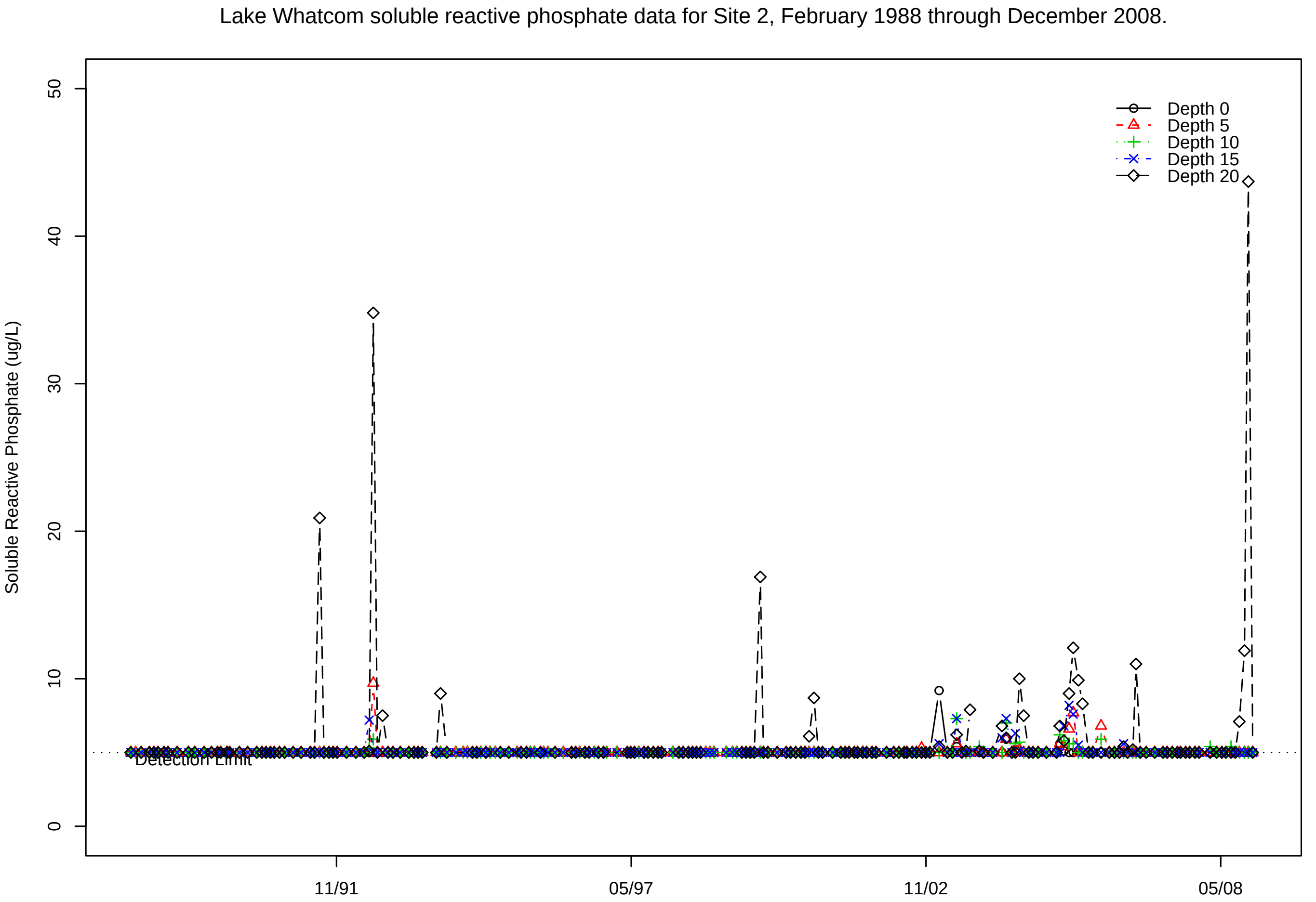


Figure B97: Lake Whatcom soluble phosphate data for Site 2.

Lake Whatcom soluble reactive phosphate data for Intake, February 1988 through December 2008.

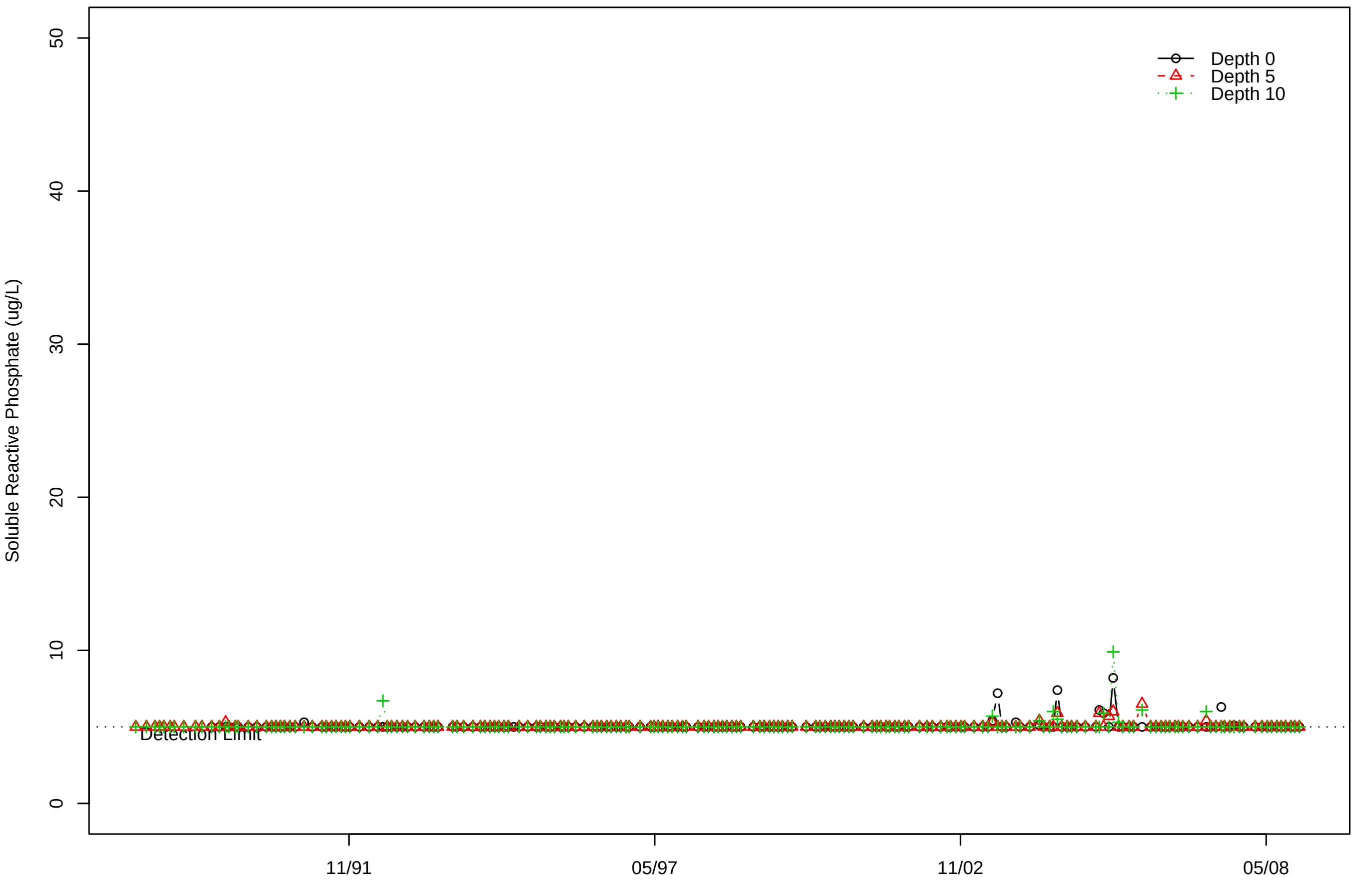


Figure B98: Lake Whatcom soluble phosphate data for the Intake site.

Lake Whatcom soluble reactive phosphate data for Site 3, February 1988 through December 2008.

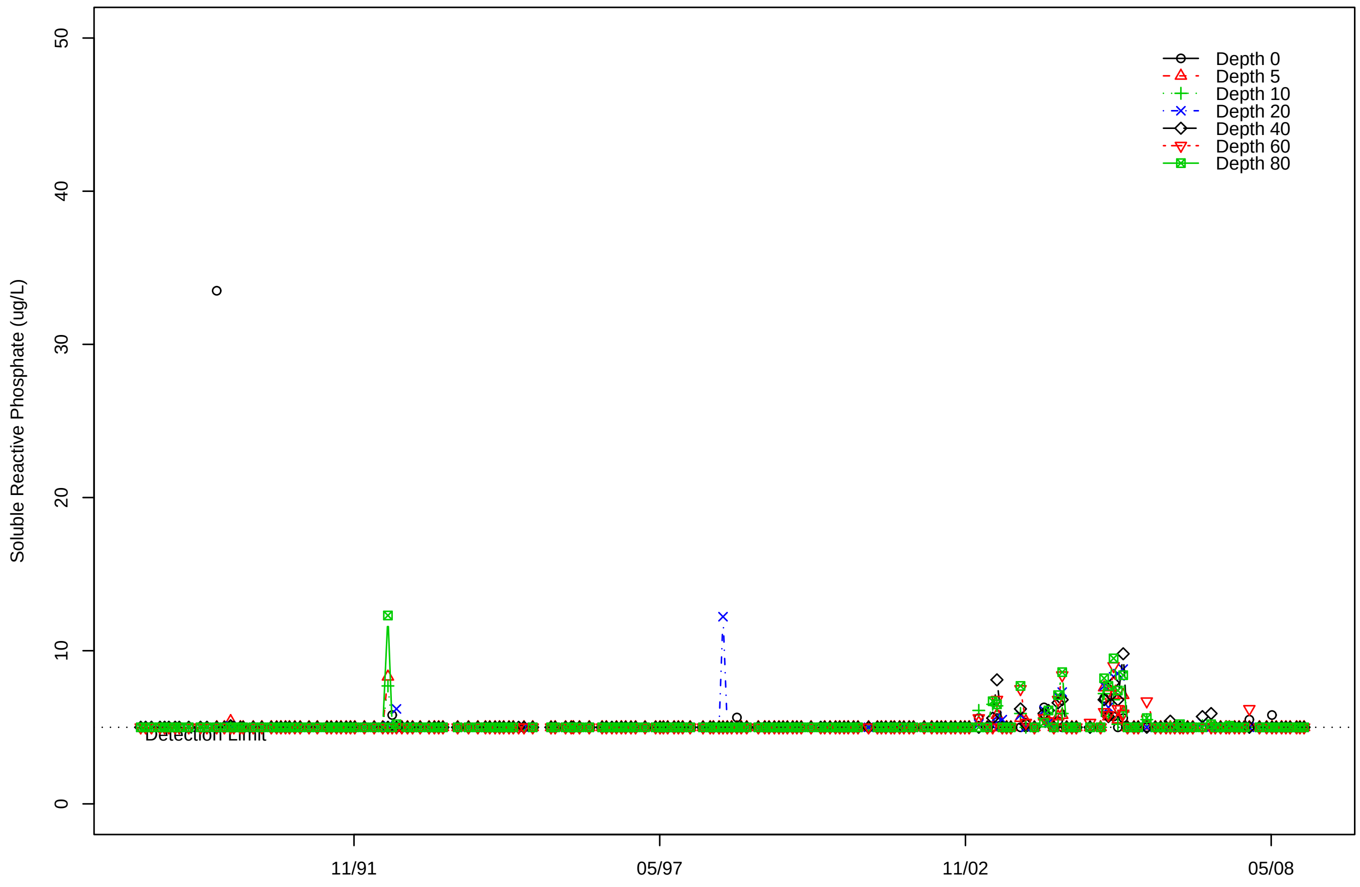


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

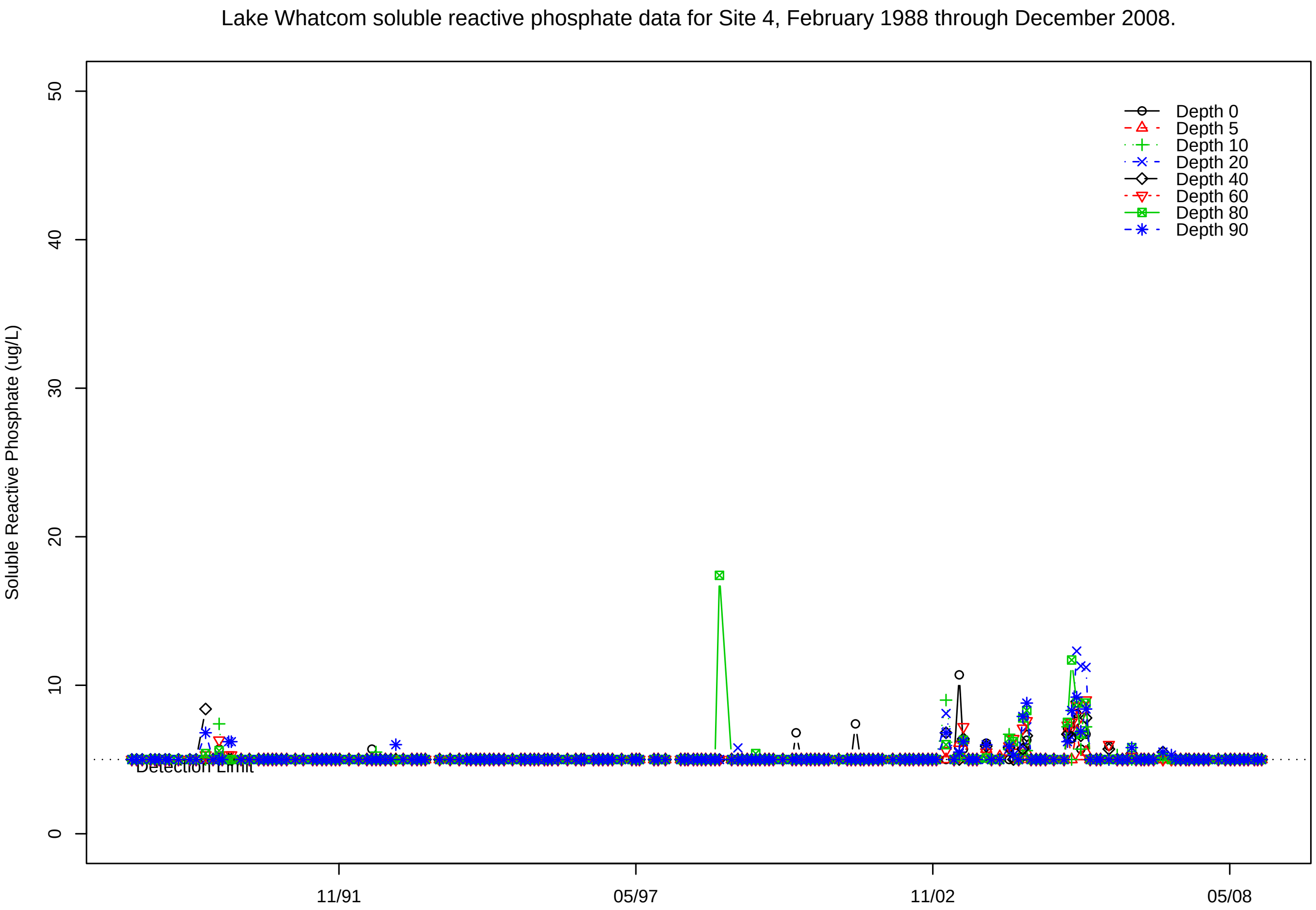


Figure B100: Lake Whatcom soluble phosphate data for Site 4.

Lake Whatcom total phosphorus data for Site 1, February 1988 through December 2008.

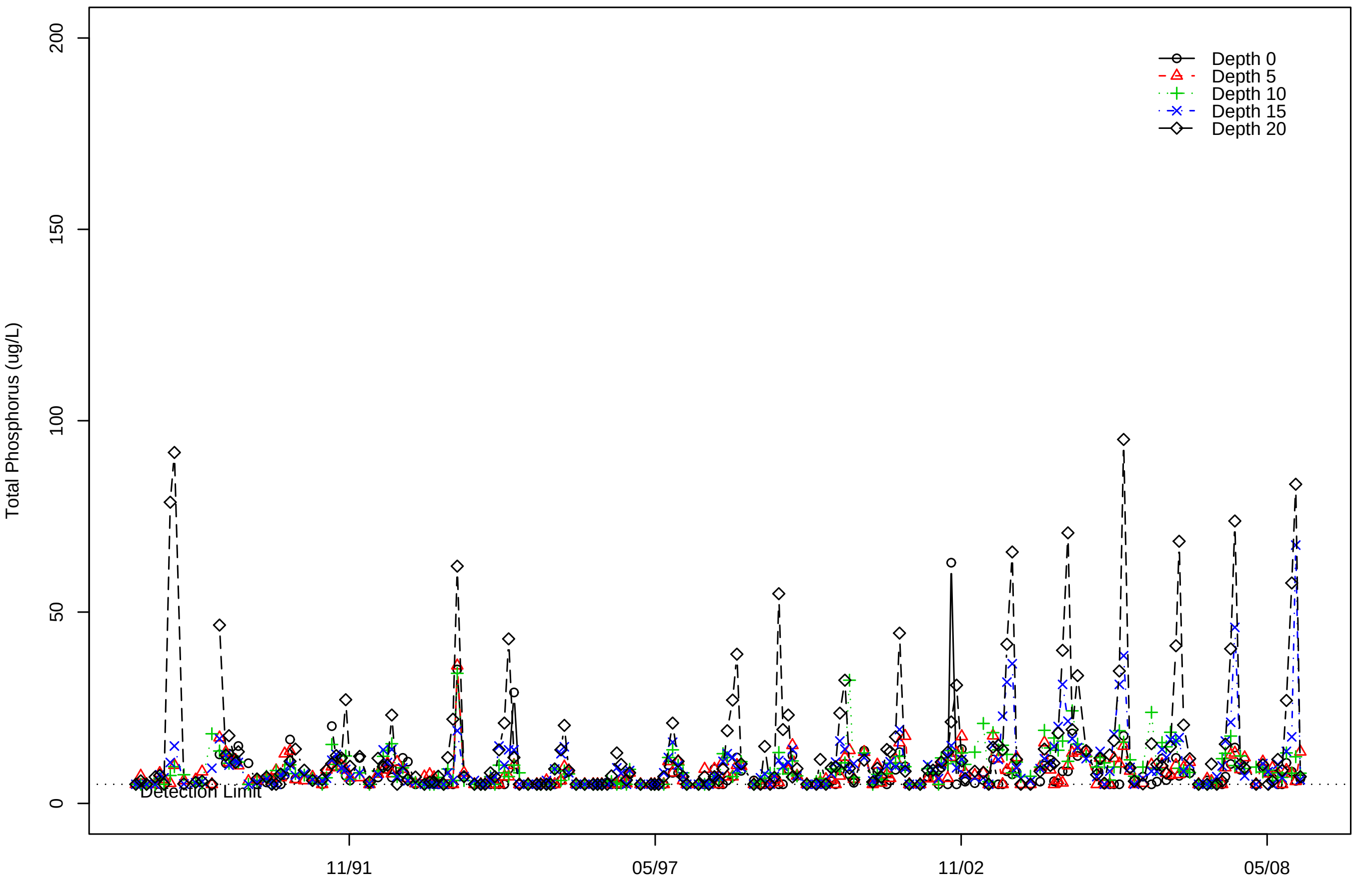


Figure B101: Lake Whatcom total phosphorus data for Site 1.

Lake Whatcom total phosphorus data for Site 2, February 1988 through December 2008.

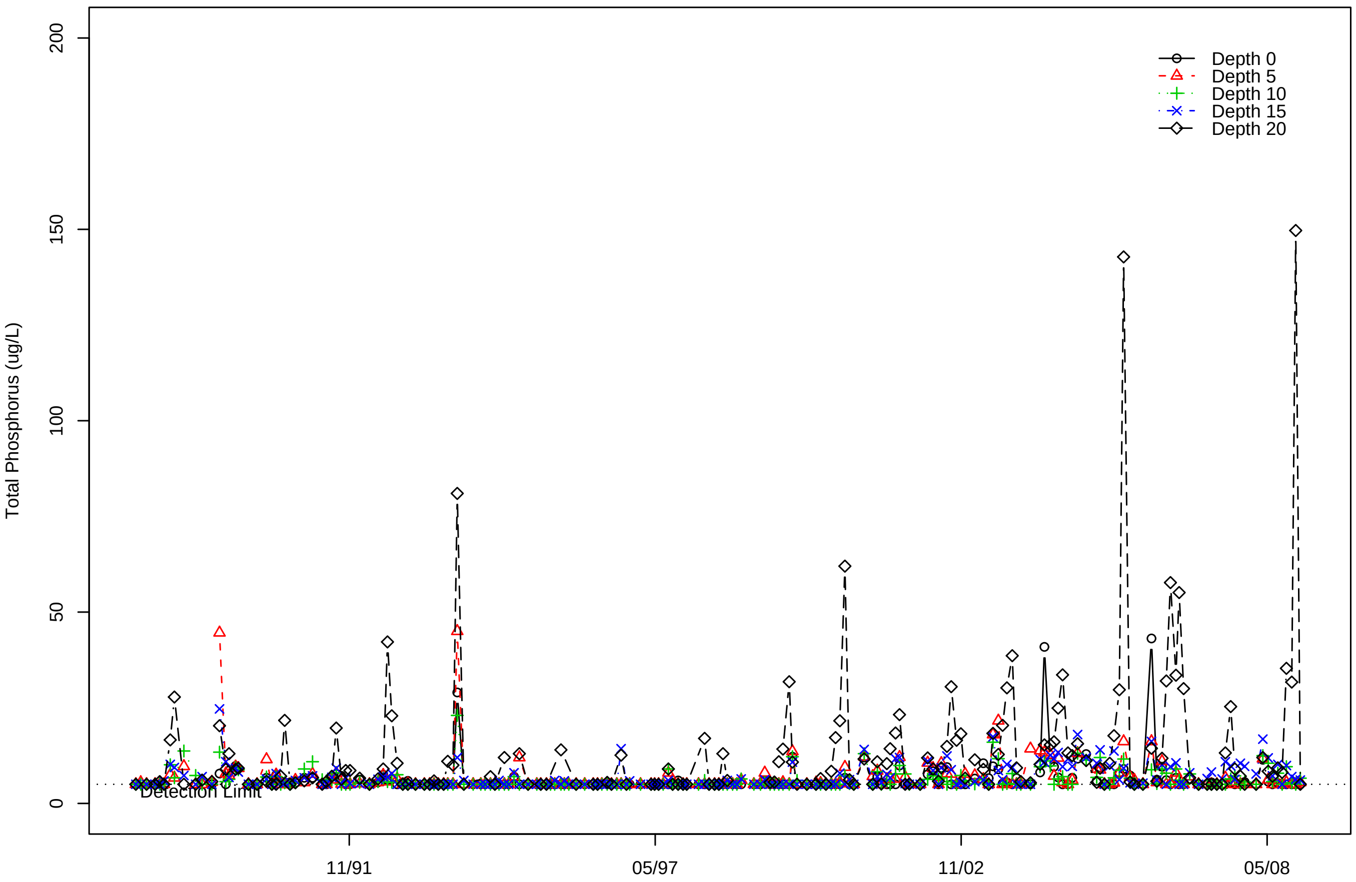


Figure B102: Lake Whatcom total phosphorus data for Site 2.

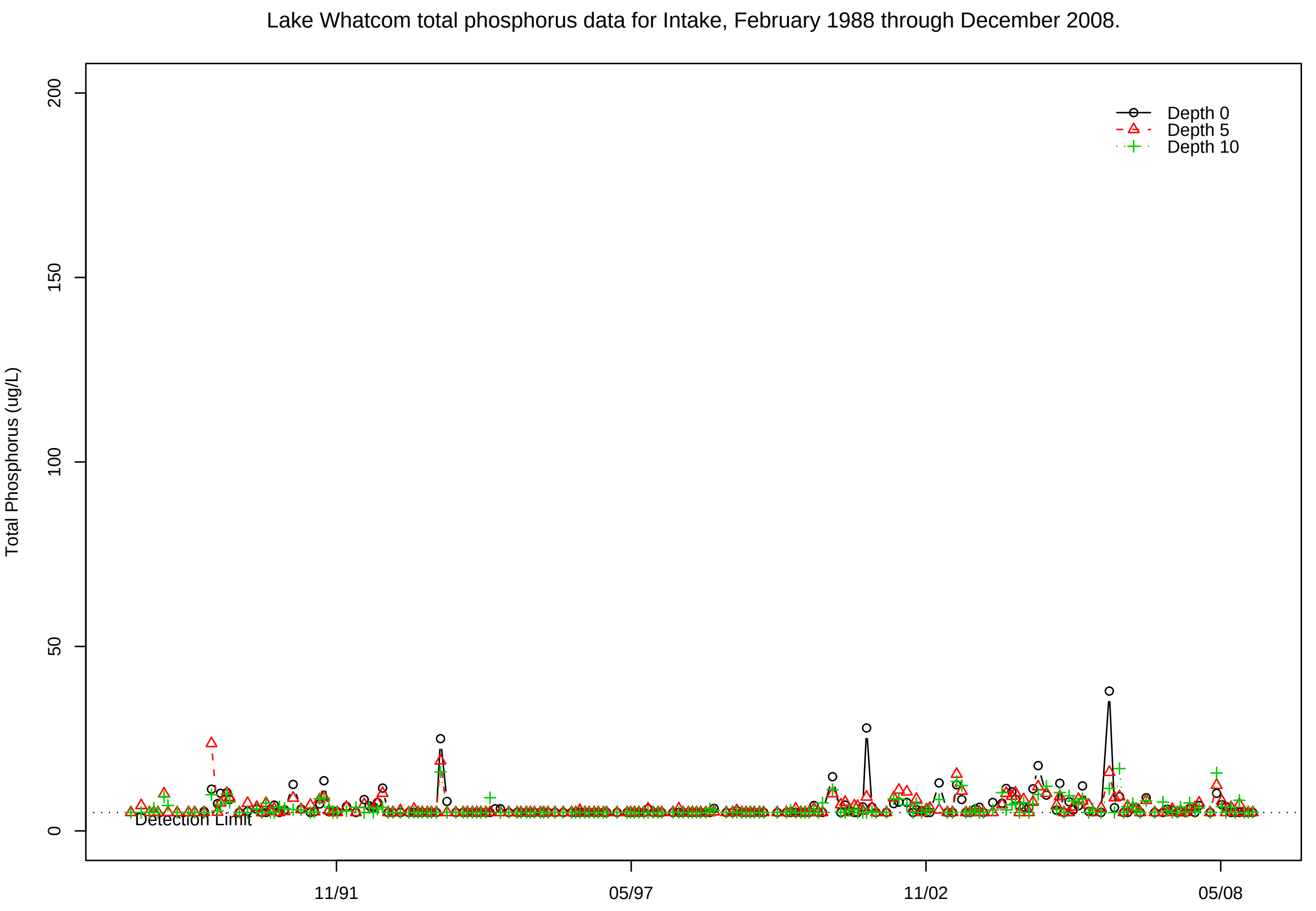


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

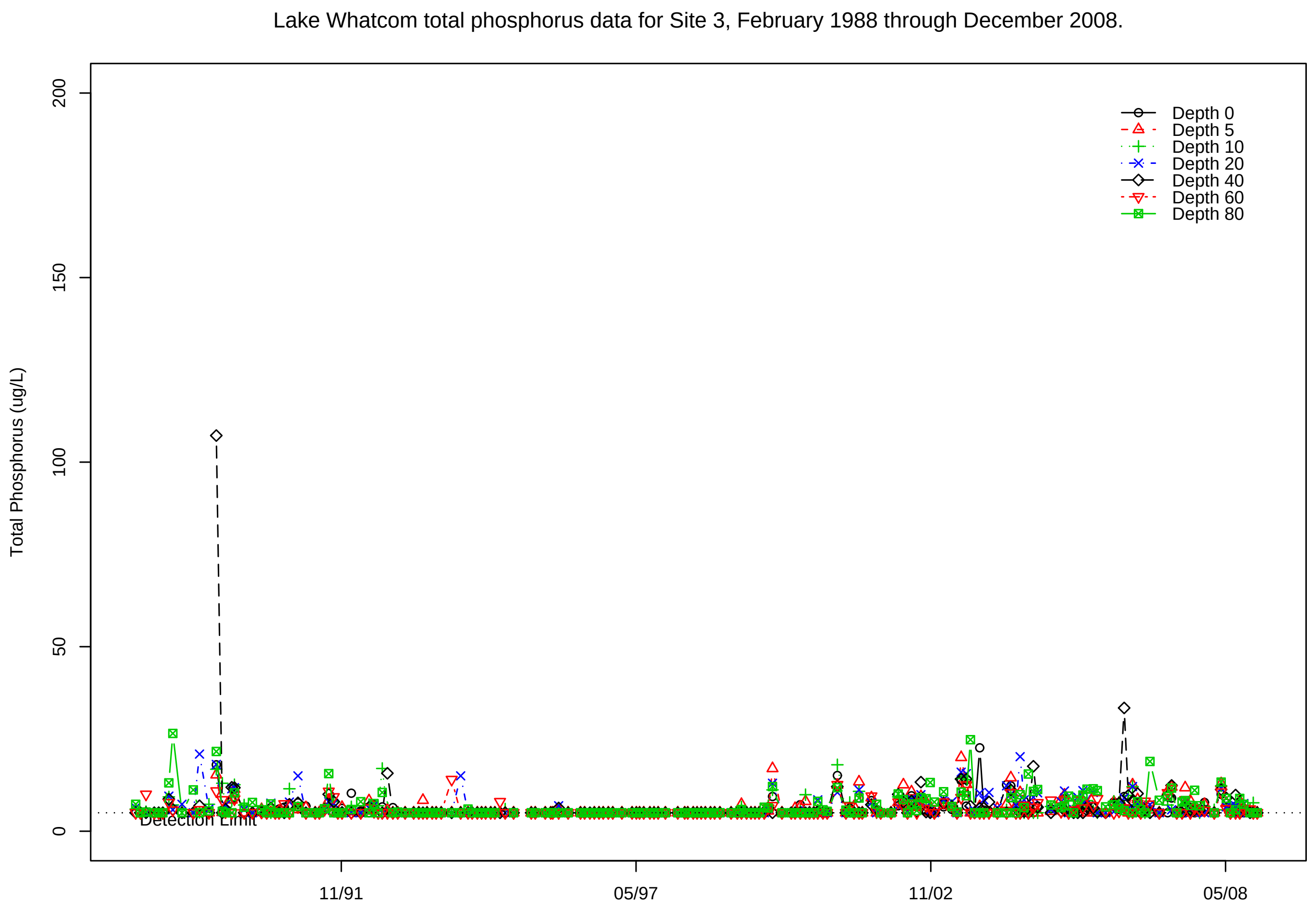


Figure B104: Lake Whatcom total phosphorus data for Site 3.

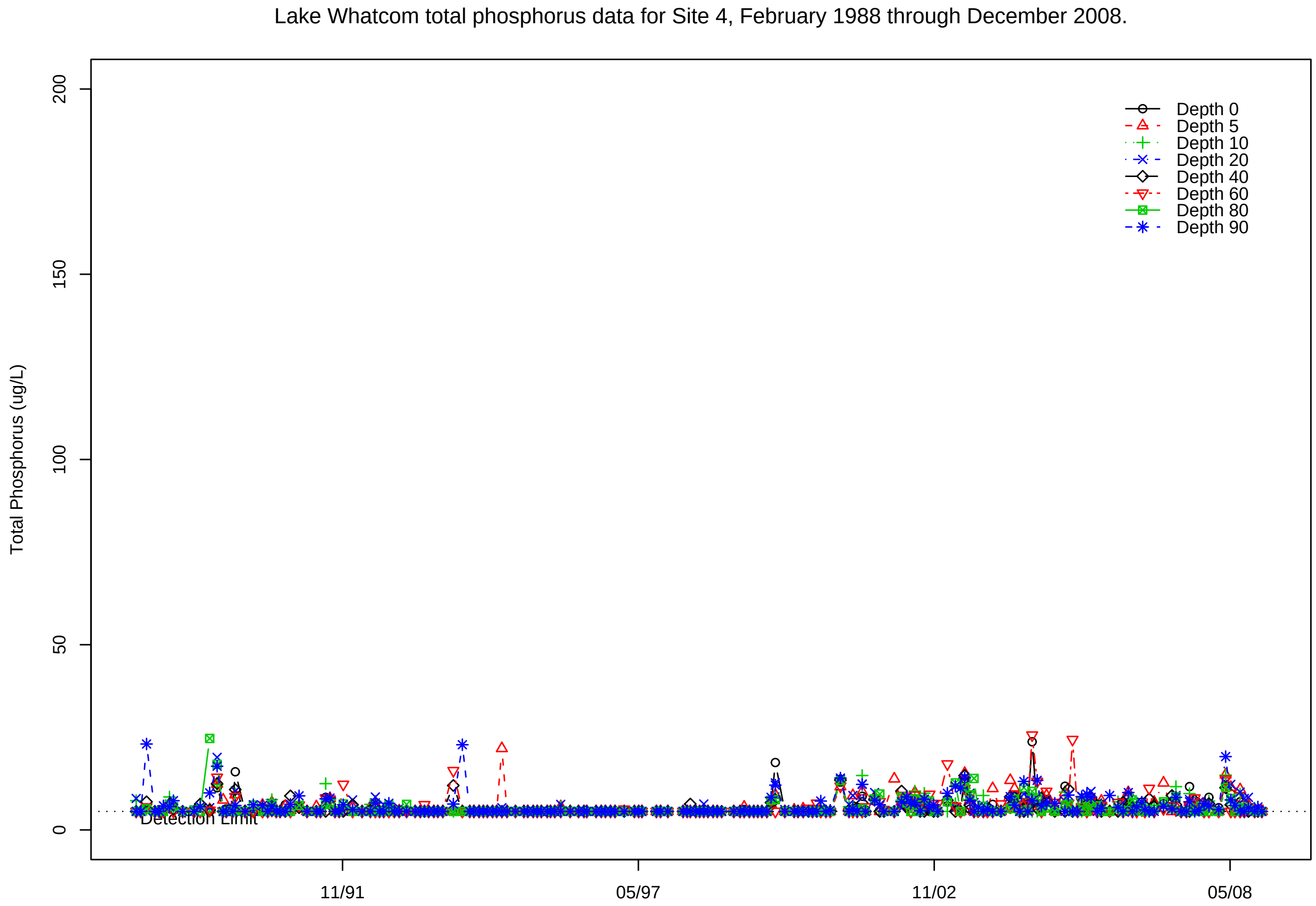


Figure B105: Lake Whatcom total phosphorus data for Site 4.

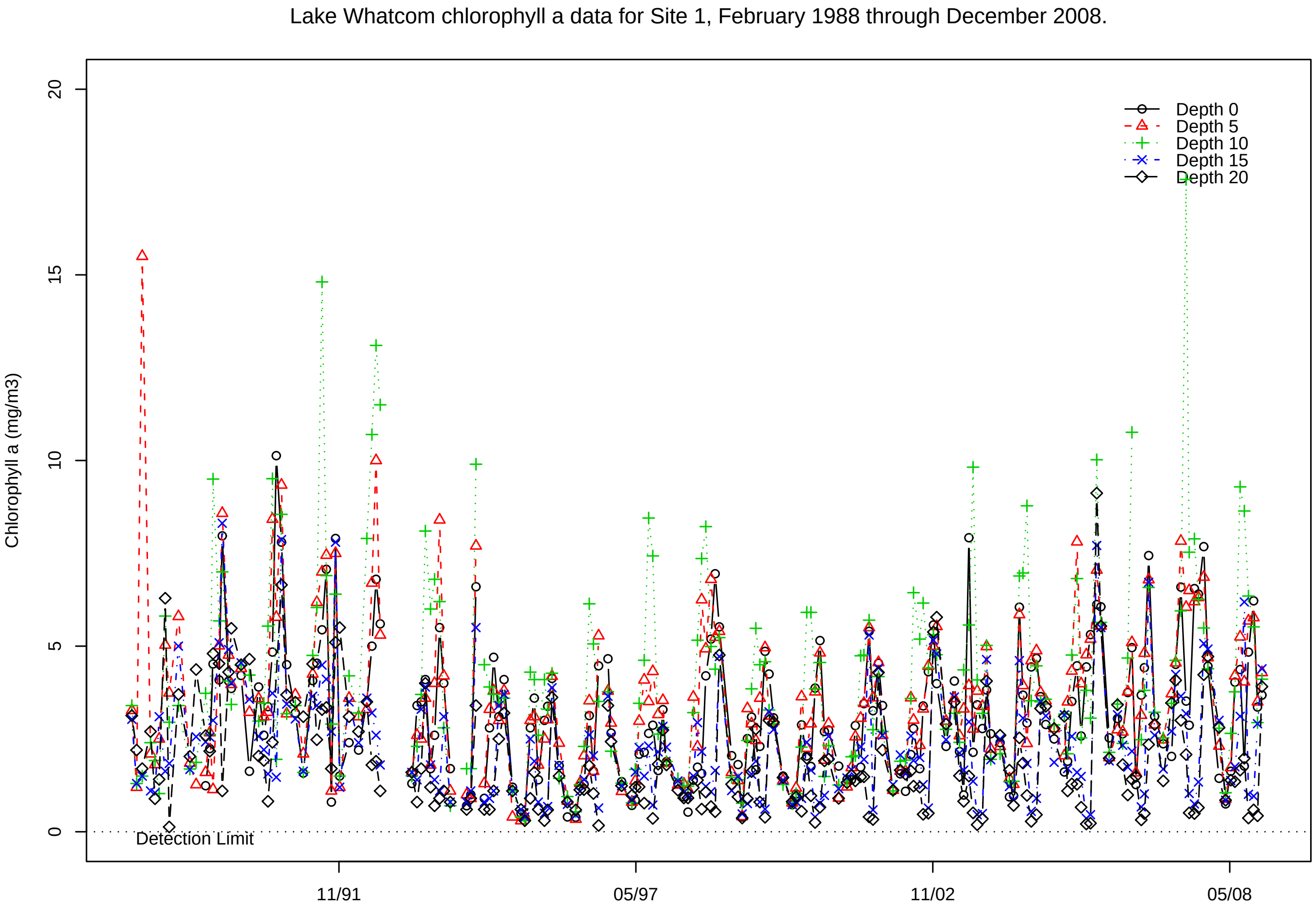


Figure B106: Lake Whatcom chlorophyll data for Site 1.

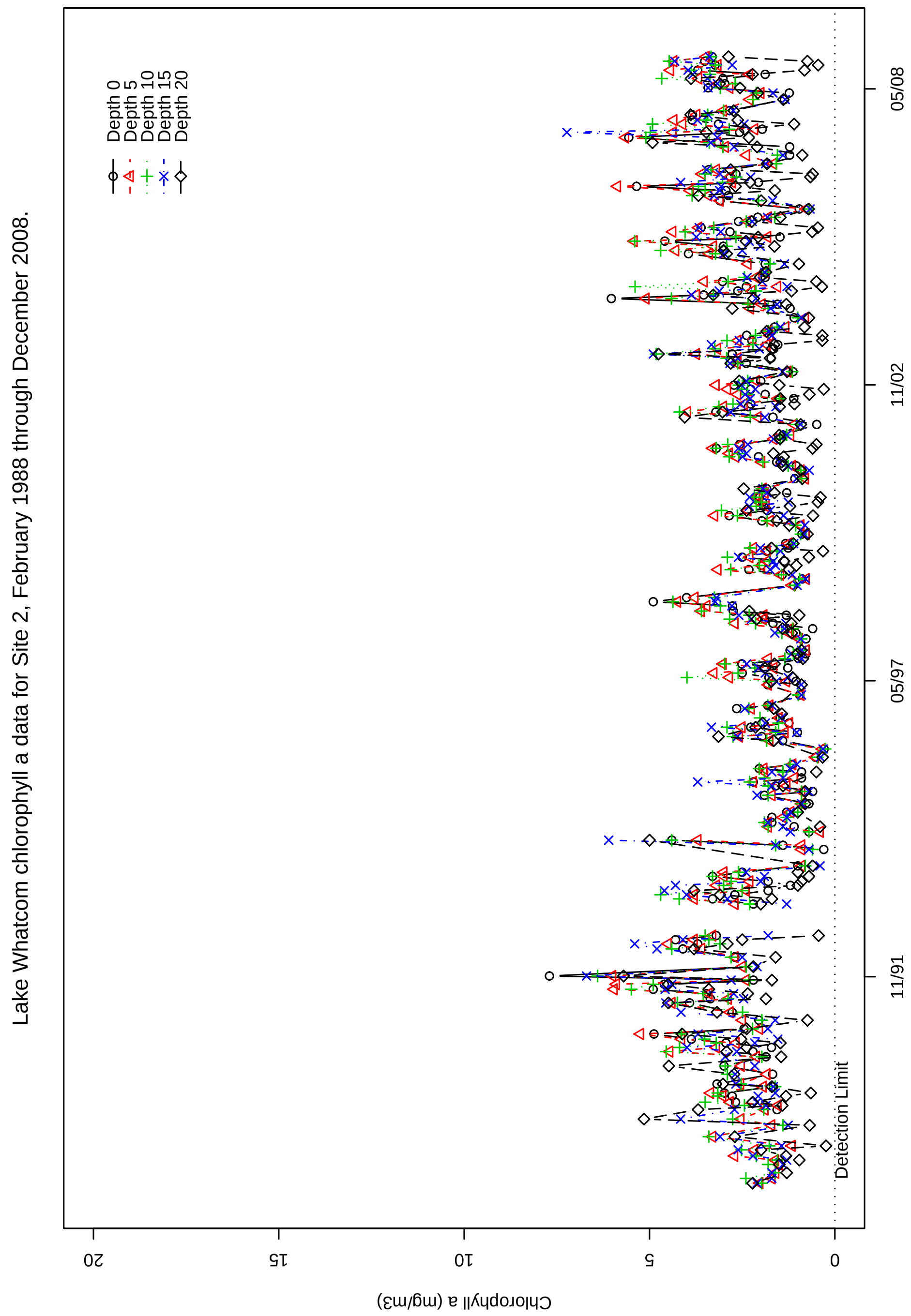


Figure B107: Lake Whatcom chlorophyll data for Site 2.

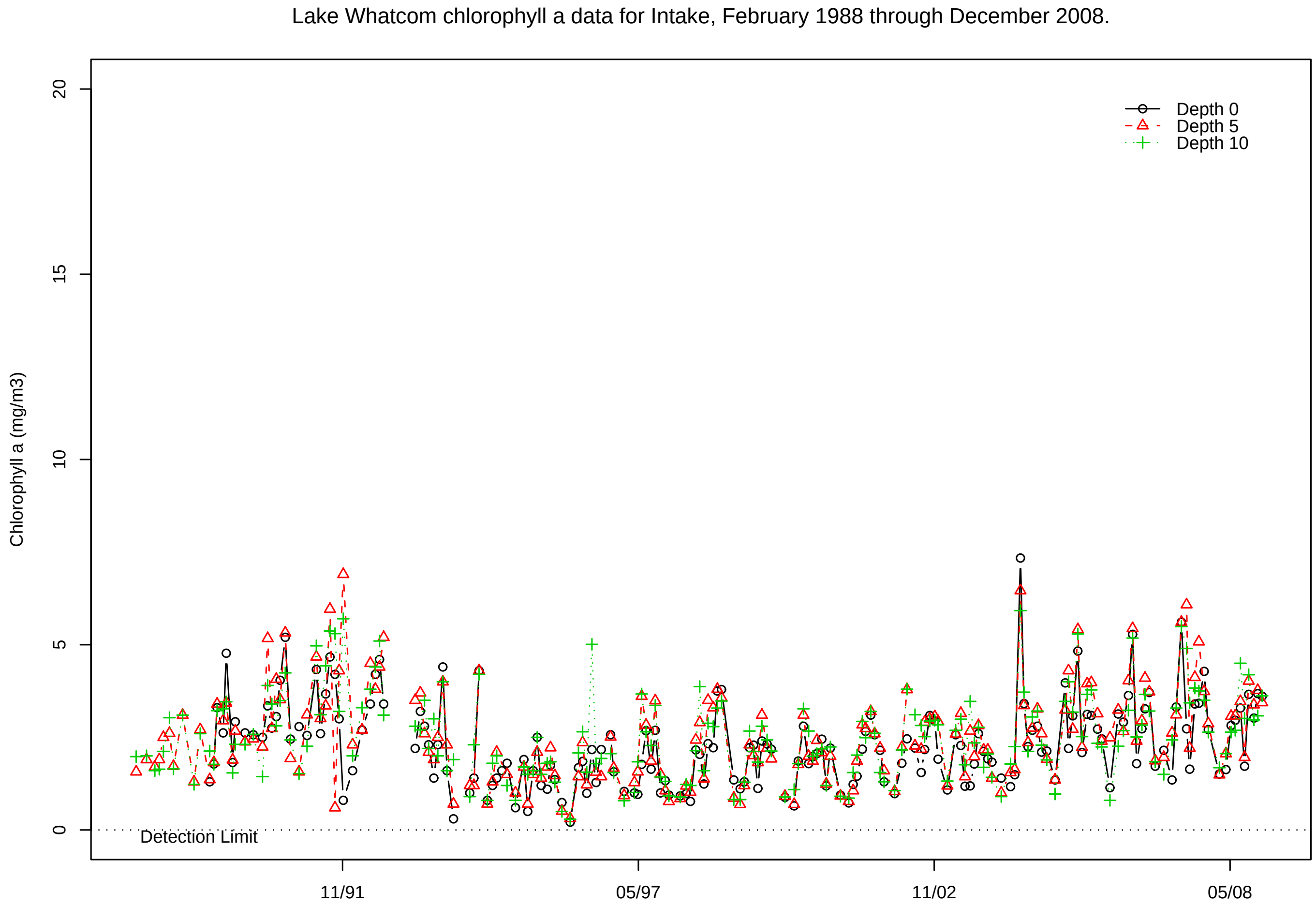


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

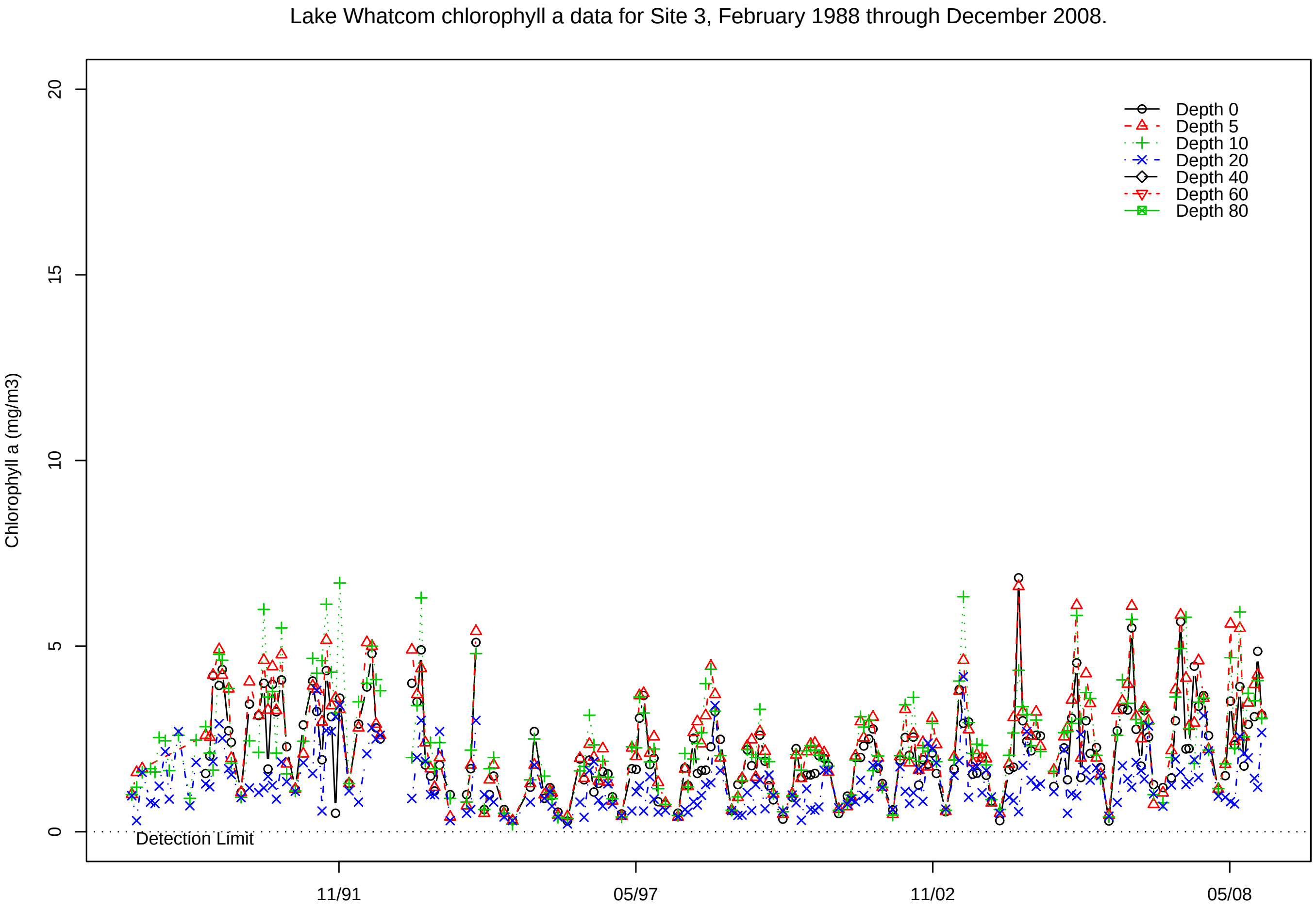


Figure B109: Lake Whatcom chlorophyll data for Site 3.

Lake Whatcom chlorophyll a data for Site 4, February 1988 through December 2008.

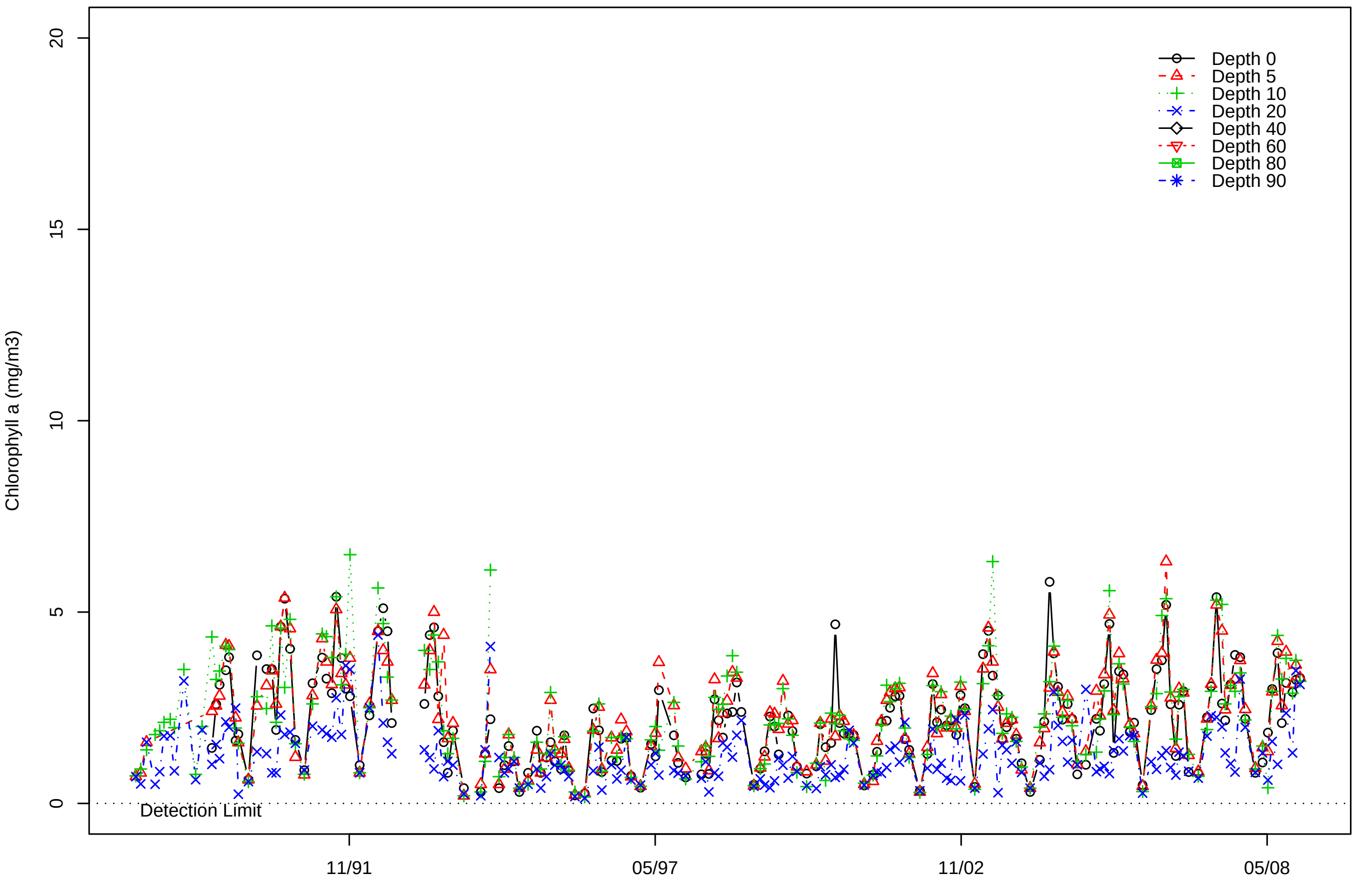


Figure B110: Lake Whatcom chlorophyll data for Site 4.

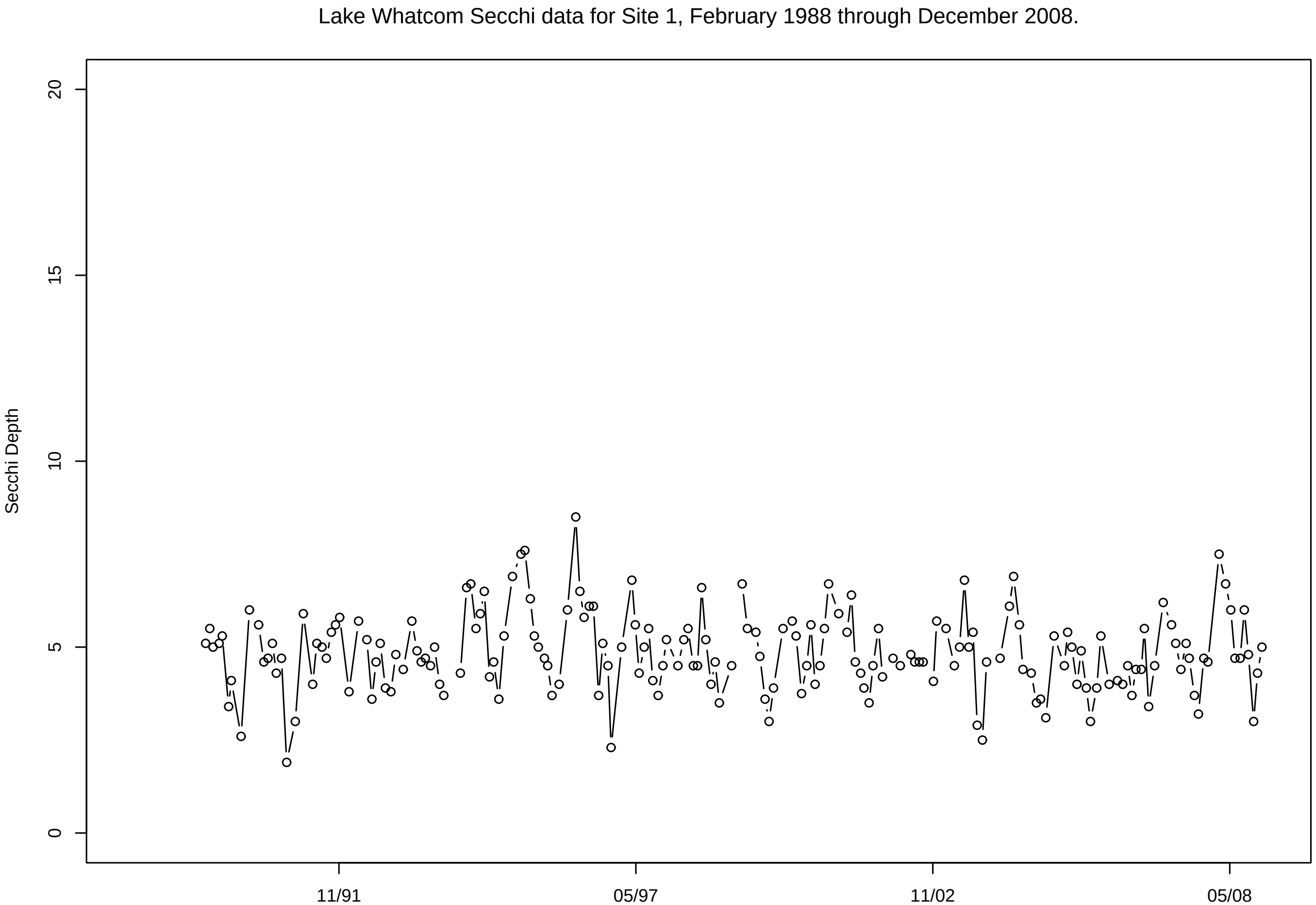


Figure B111: Lake Whatcom Secchi depths for Site 1.

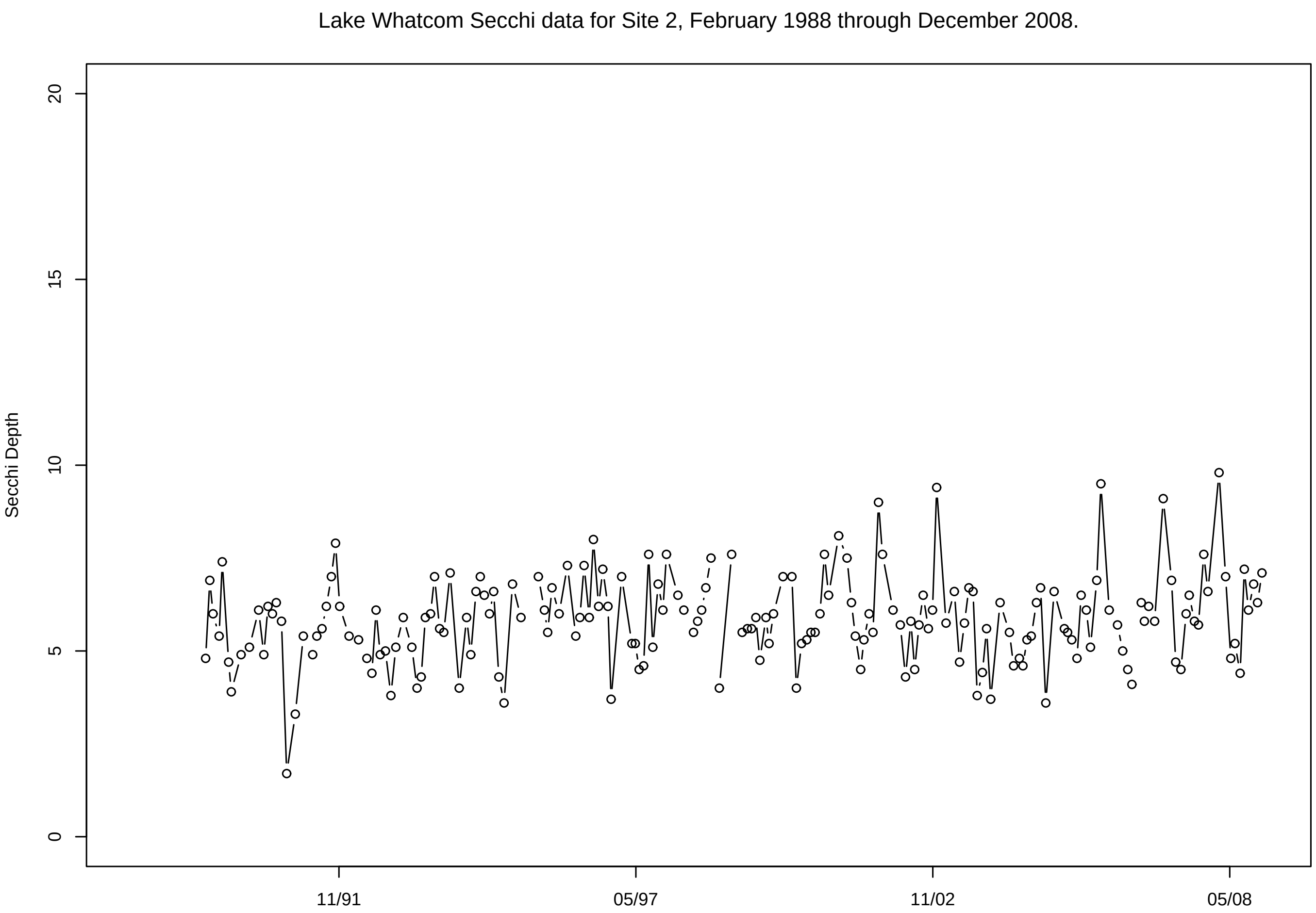


Figure B112: Lake Whatcom Secchi depths for Site 2.

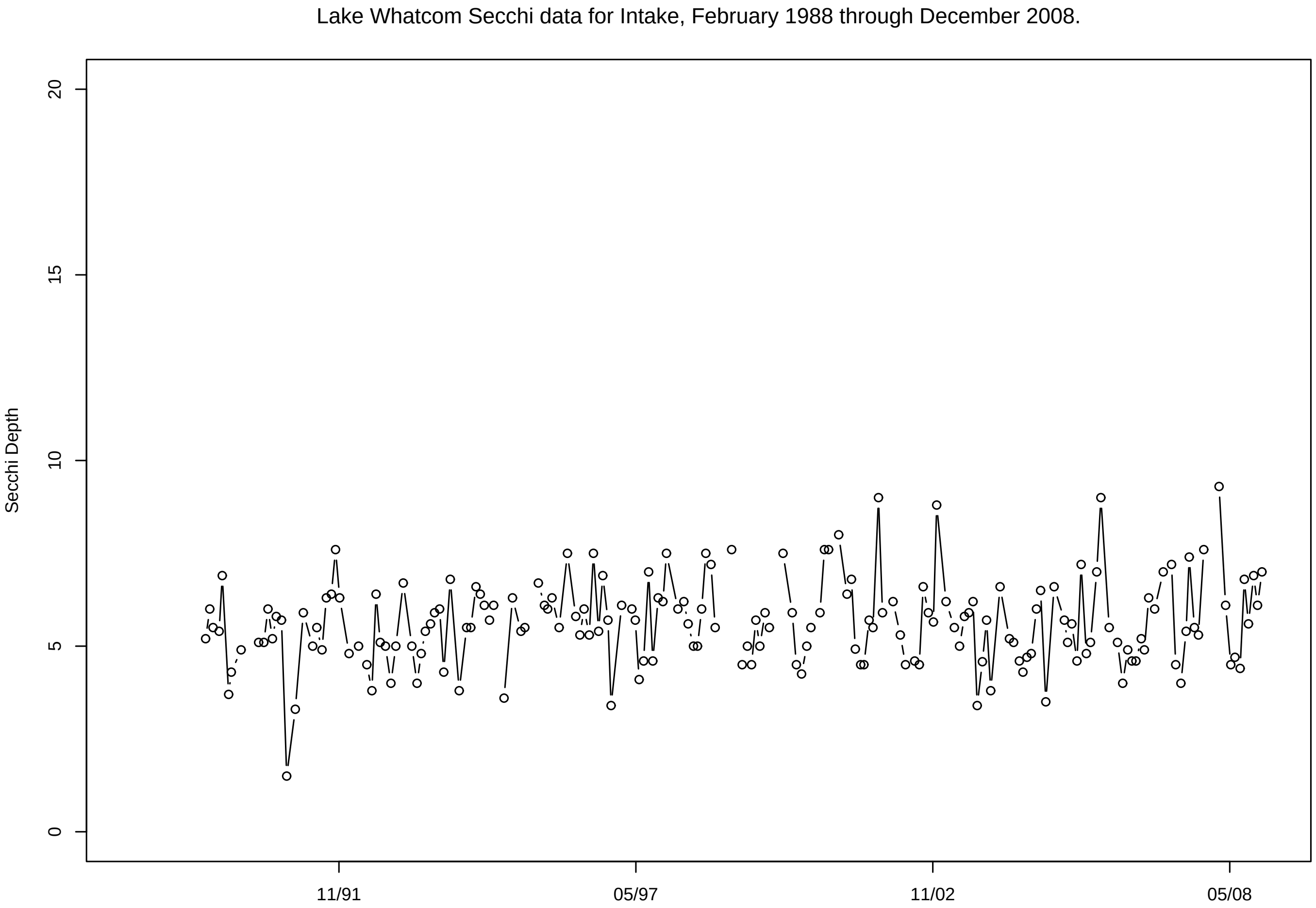


Figure B113: Lake Whatcom Secchi depths for the Intake site.

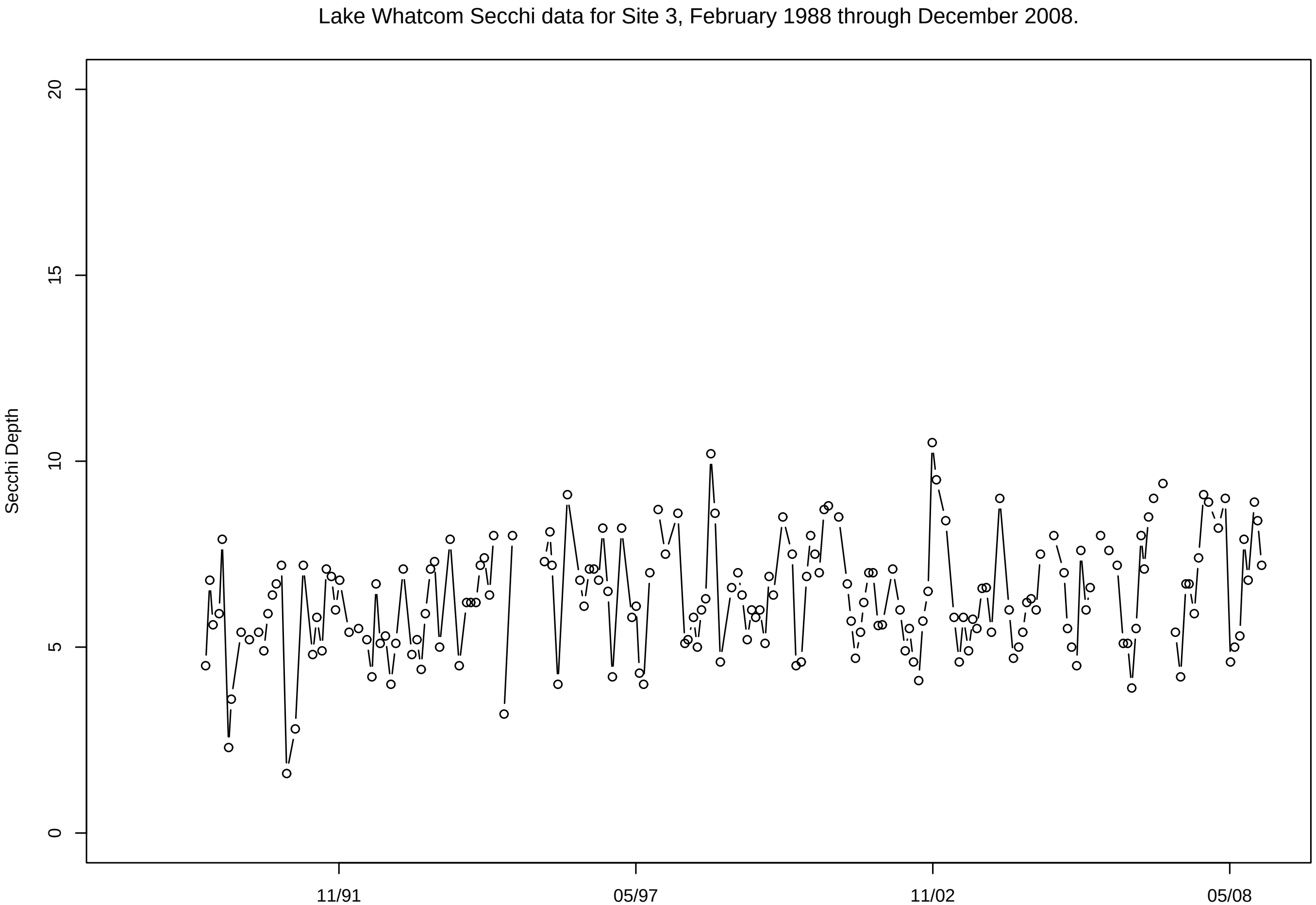


Figure B114: Lake Whatcom Secchi depths for Site 3.

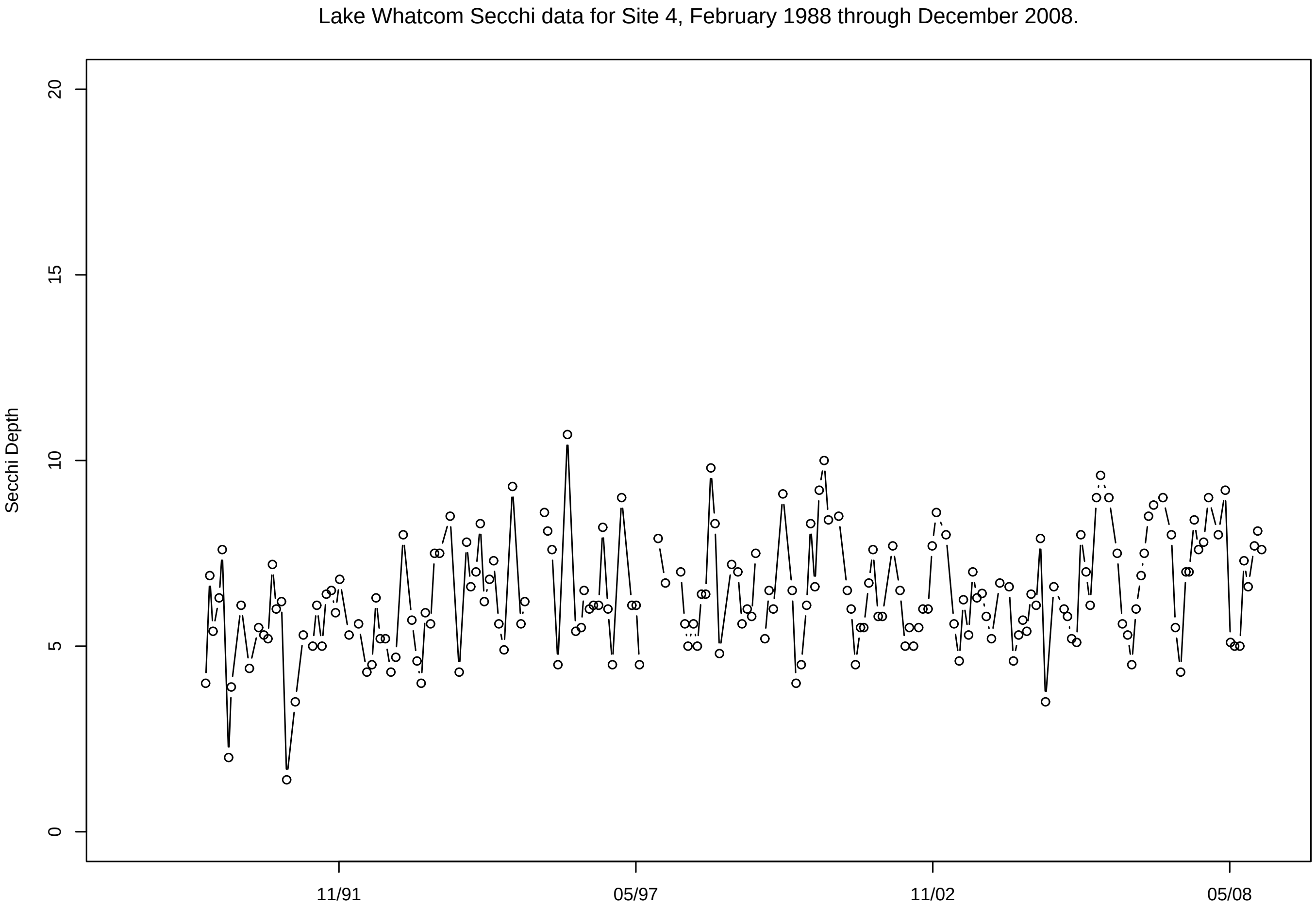


Figure B115: Lake Whatcom Secchi depths for Site 4.

Lake Whatcom fecal coliform data for Site 1, February 1988 through December 2008.

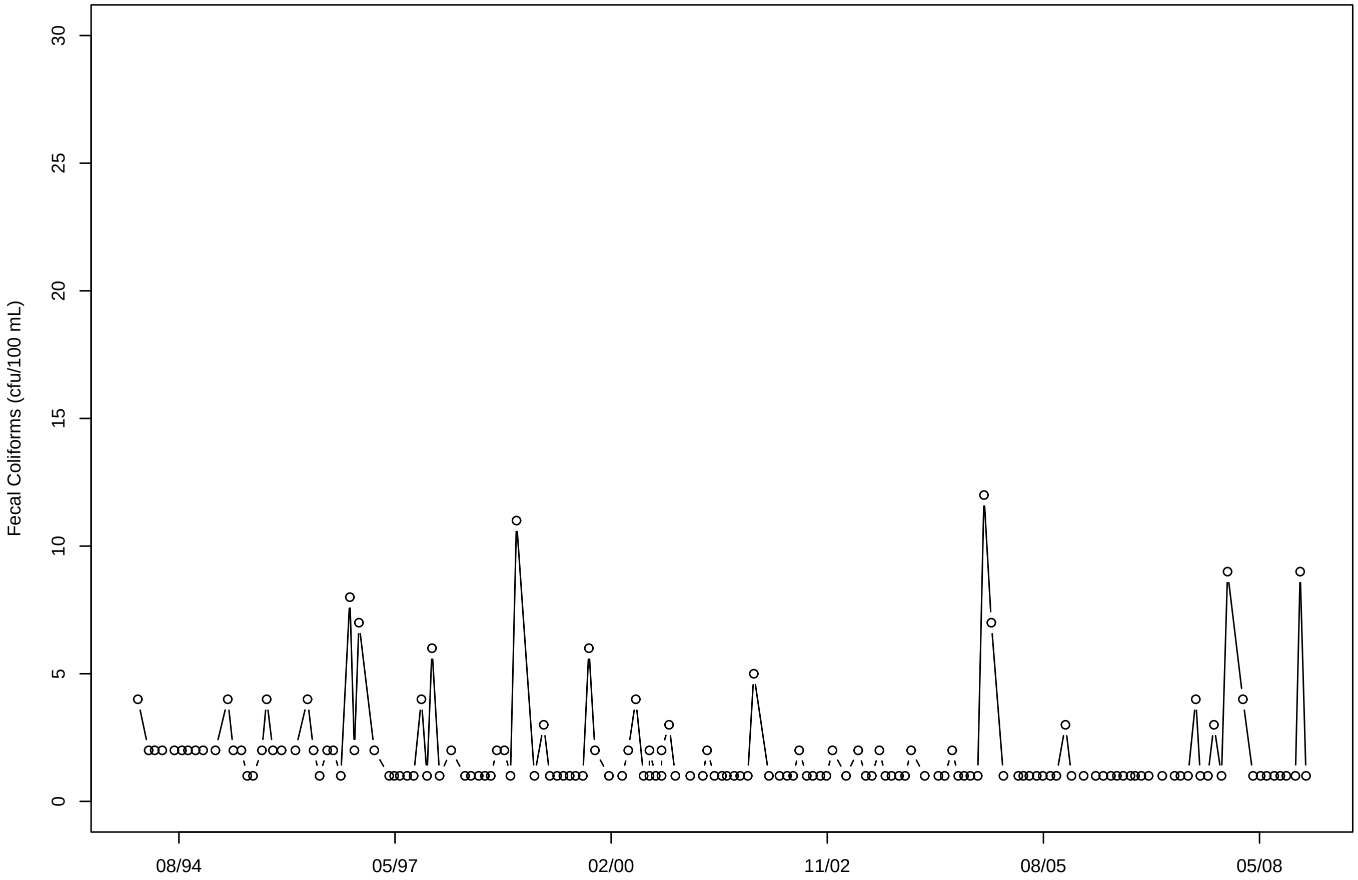


Figure B116: Lake Whatcom fecal coliform data for Site 1.

Lake Whatcom fecal coliform data for Site 2, February 1988 through December 2008.

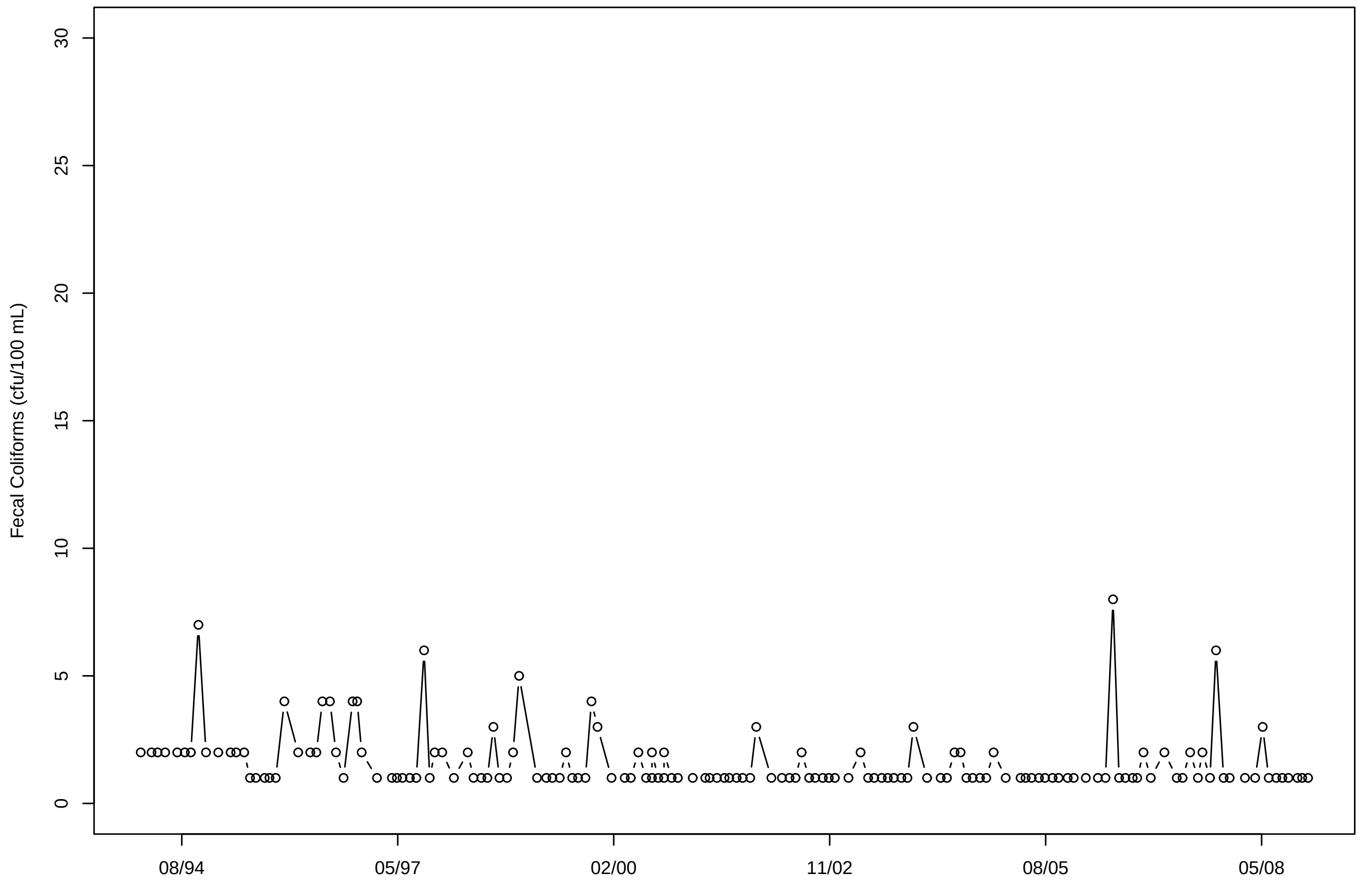


Figure B117: Lake Whatcom fecal coliform data for Site 2.

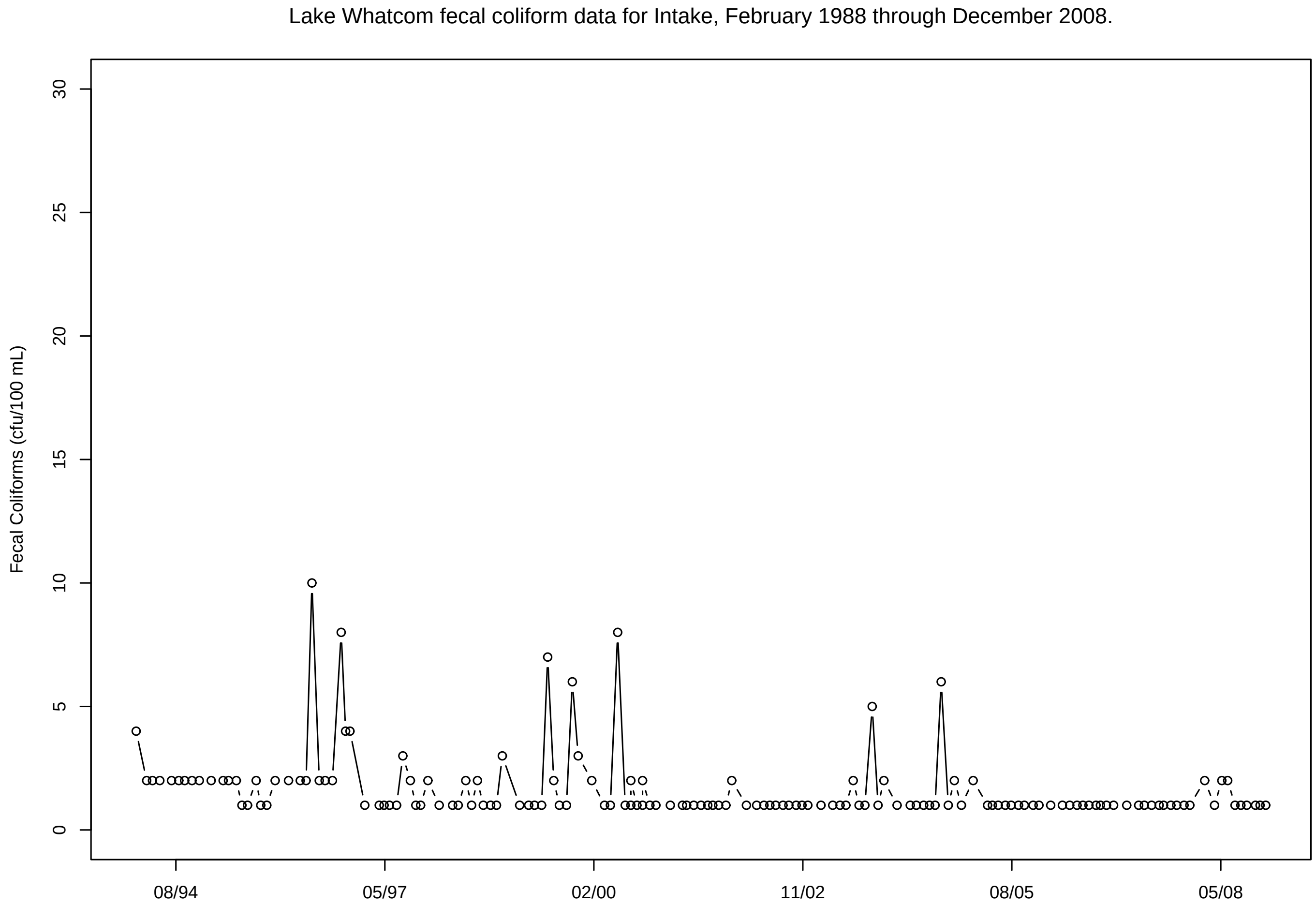


Figure B118: Lake Whatcom fecal coliform data for the Intake site.

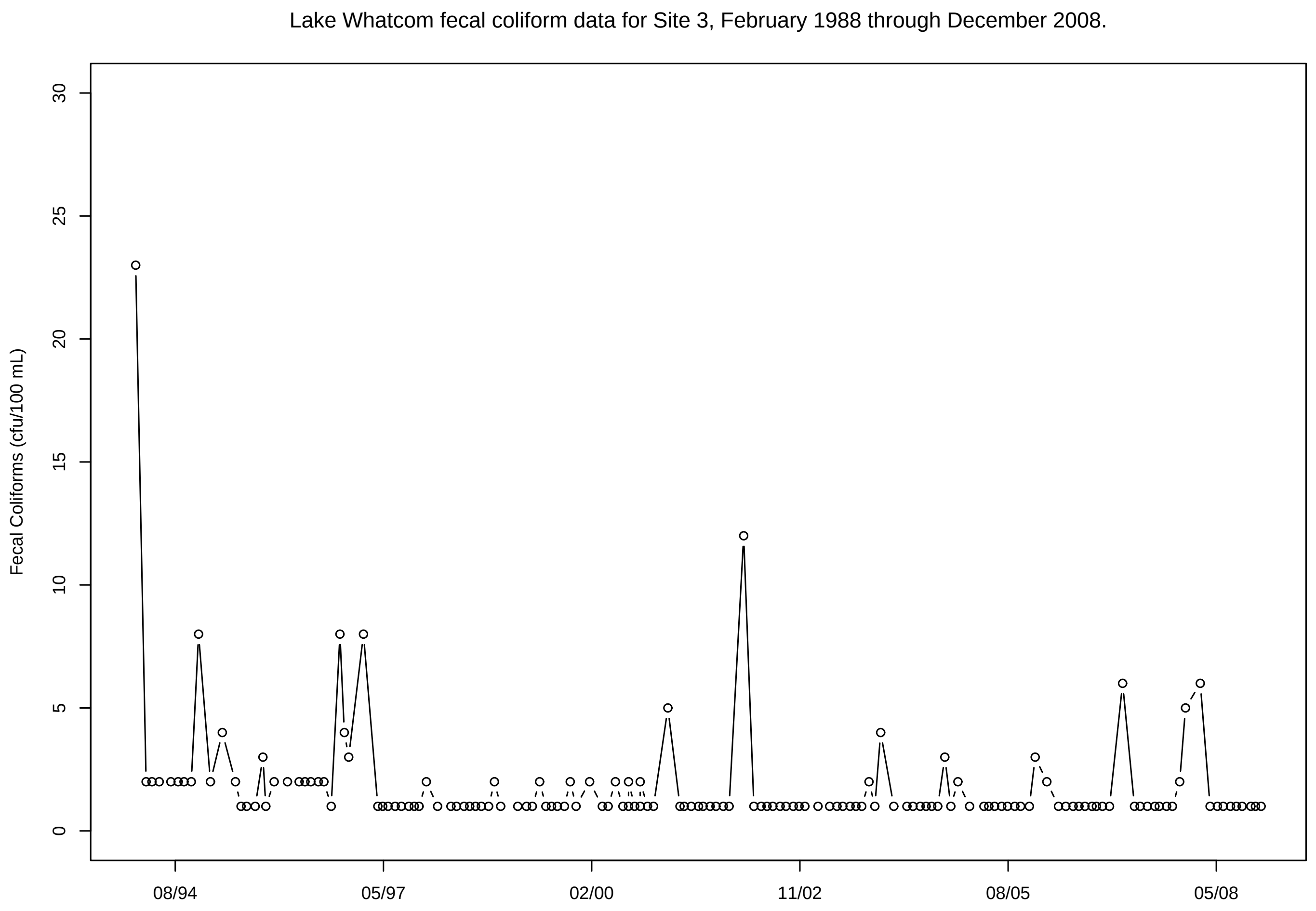


Figure B119: Lake Whatcom fecal coliform data for Site 3.

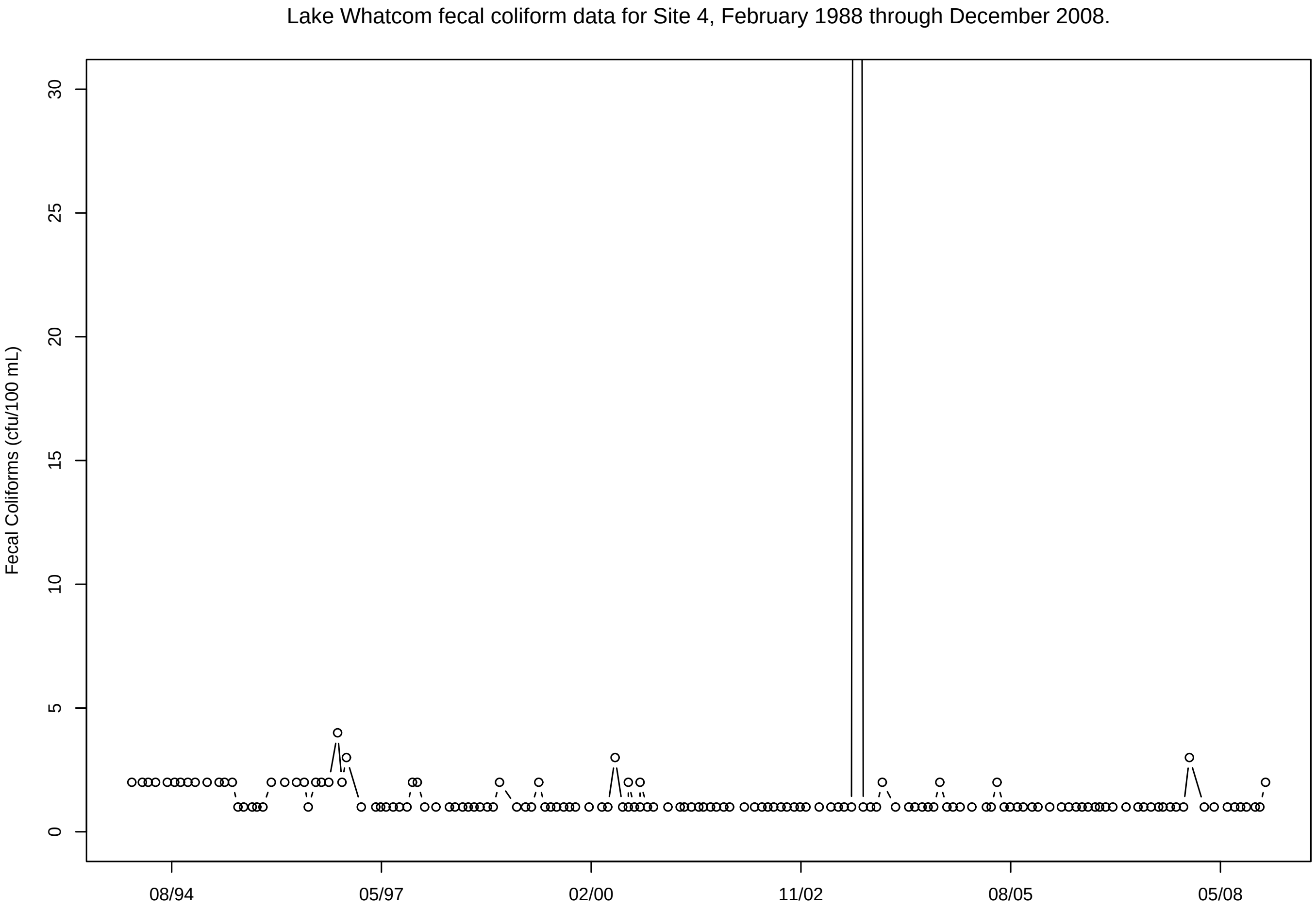


Figure B120: Lake Whatcom fecal coliform data for Site 4.

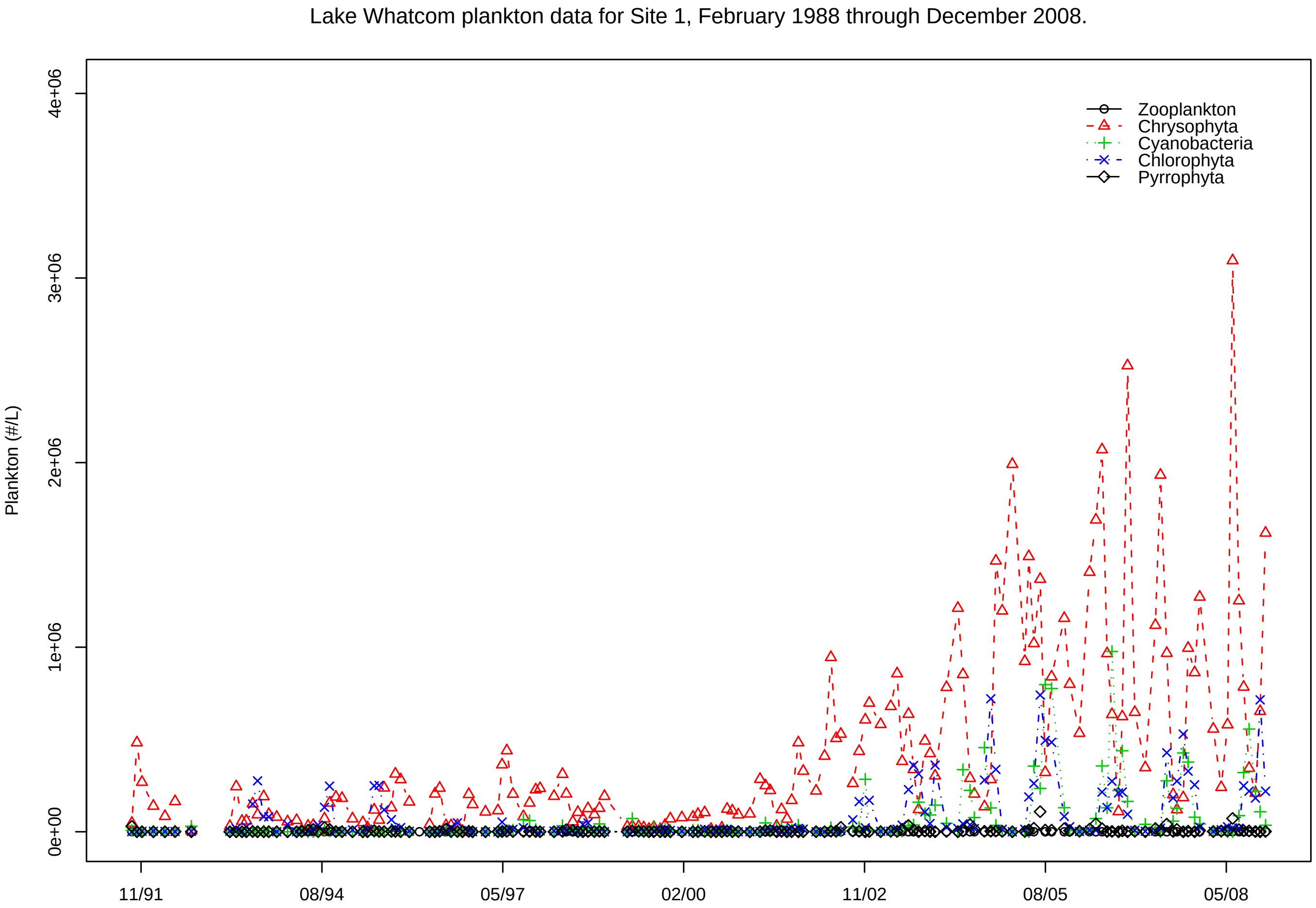


Figure B121: Lake Whatcom plankton data for Site 1.

Lake Whatcom plankton data for Site 2, February 1988 through December 2008.

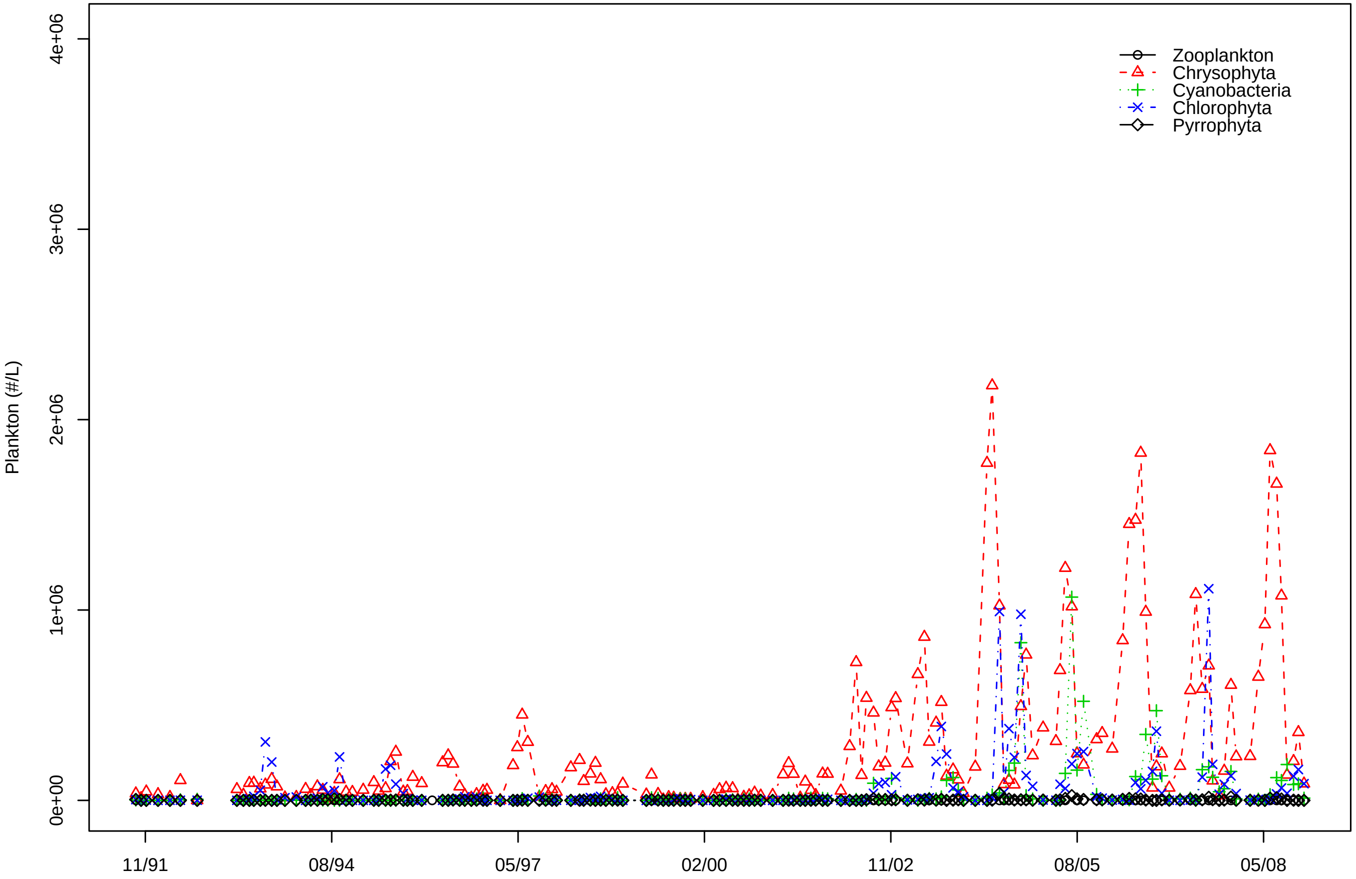


Figure B122: Lake Whatcom plankton data for Site 2.

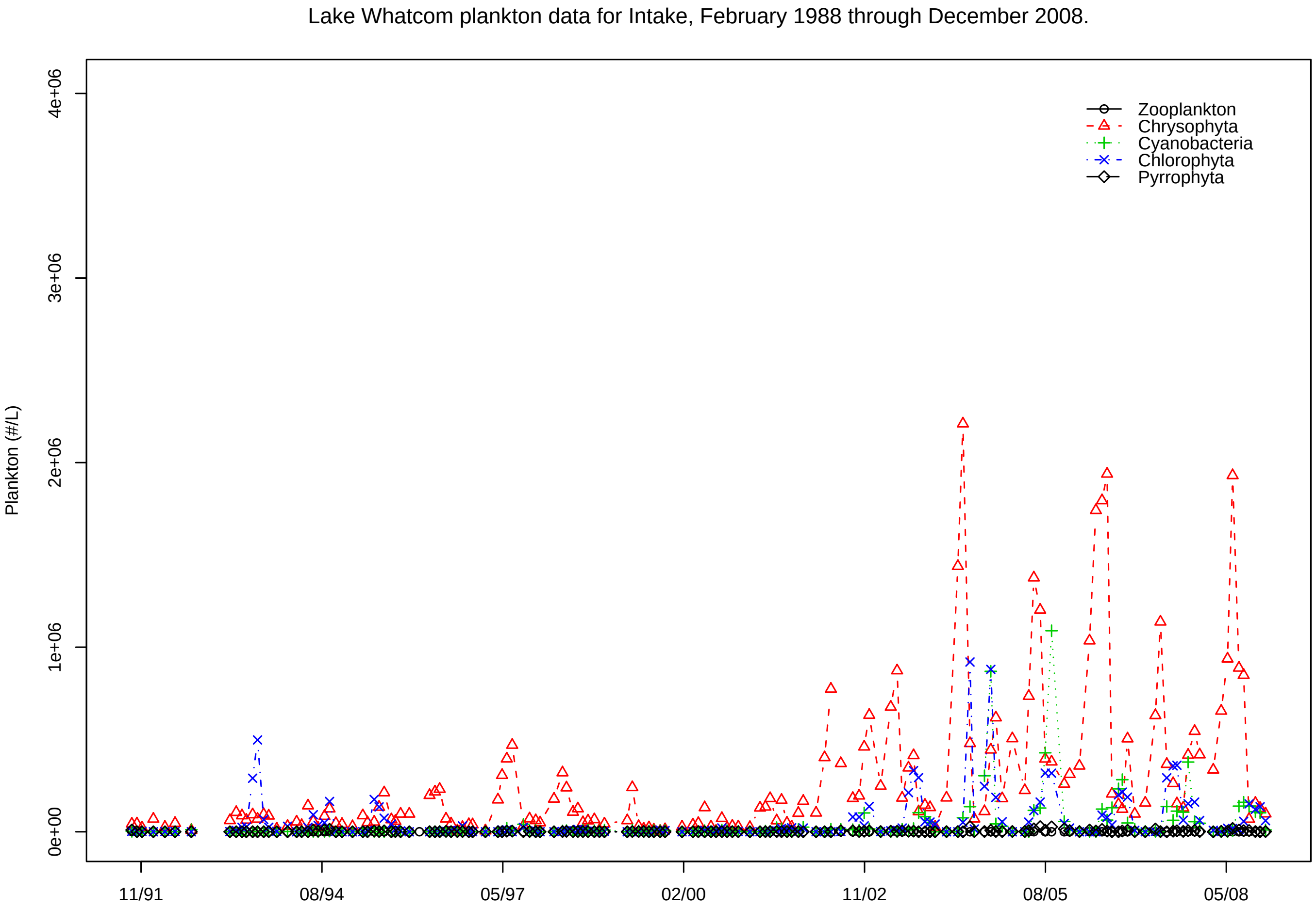


Figure B123: Lake Whatcom plankton data for the Intake Site.

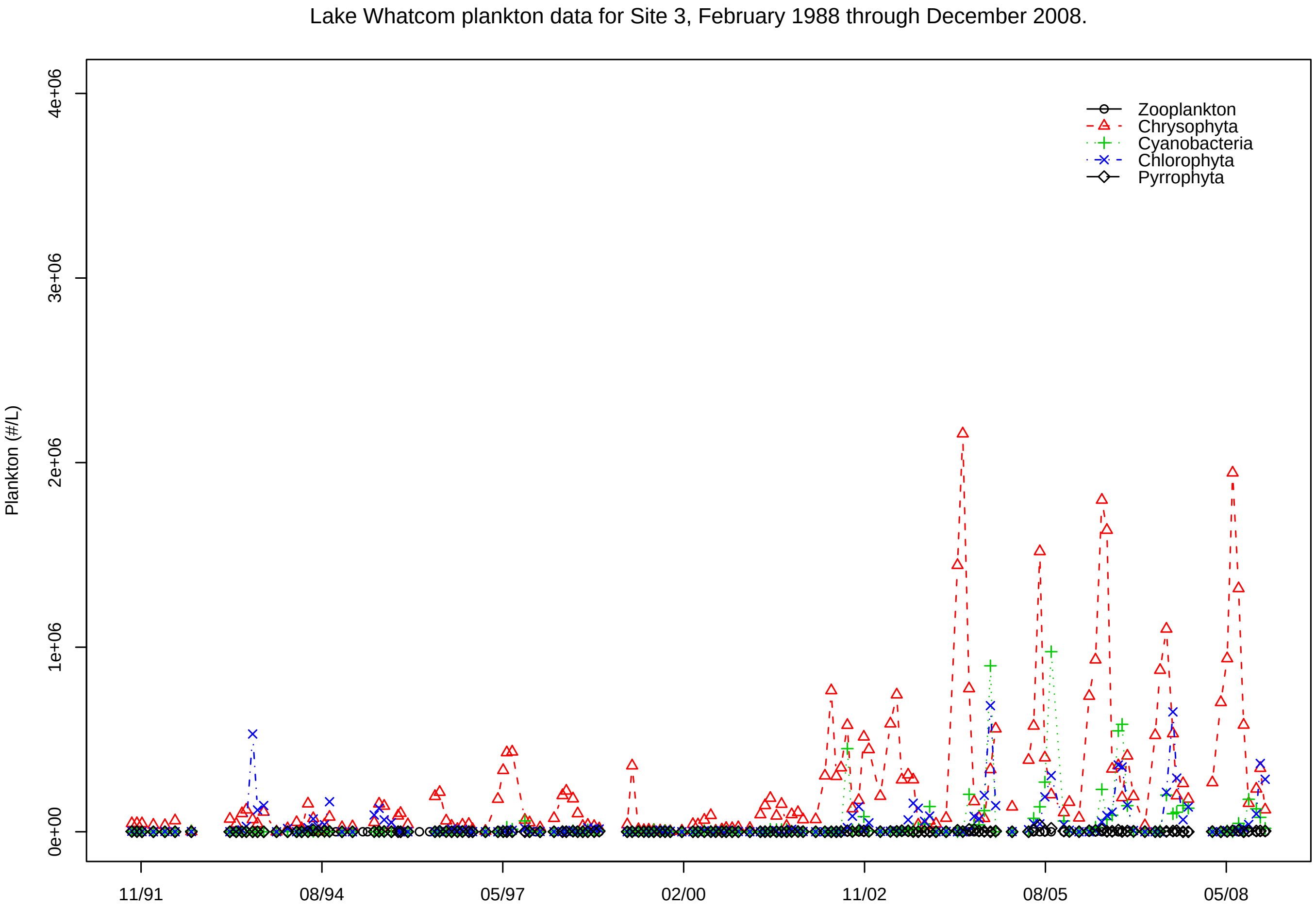


Figure B124: Lake Whatcom plankton data for Site 3.

Lake Whatcom plankton data for Site 4, February 1988 through December 2008.

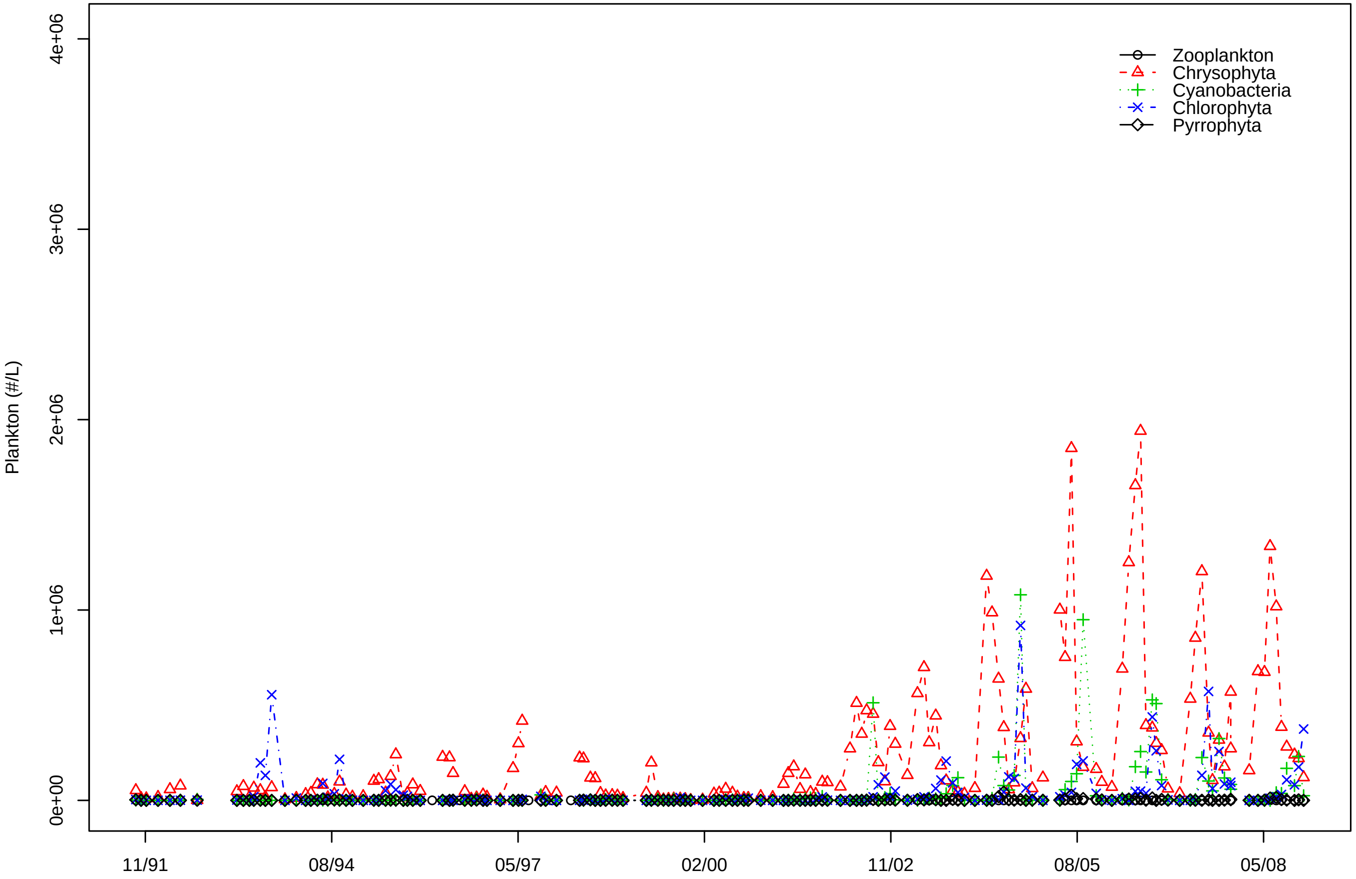


Figure B125: Lake Whatcom plankton data for Site 4.

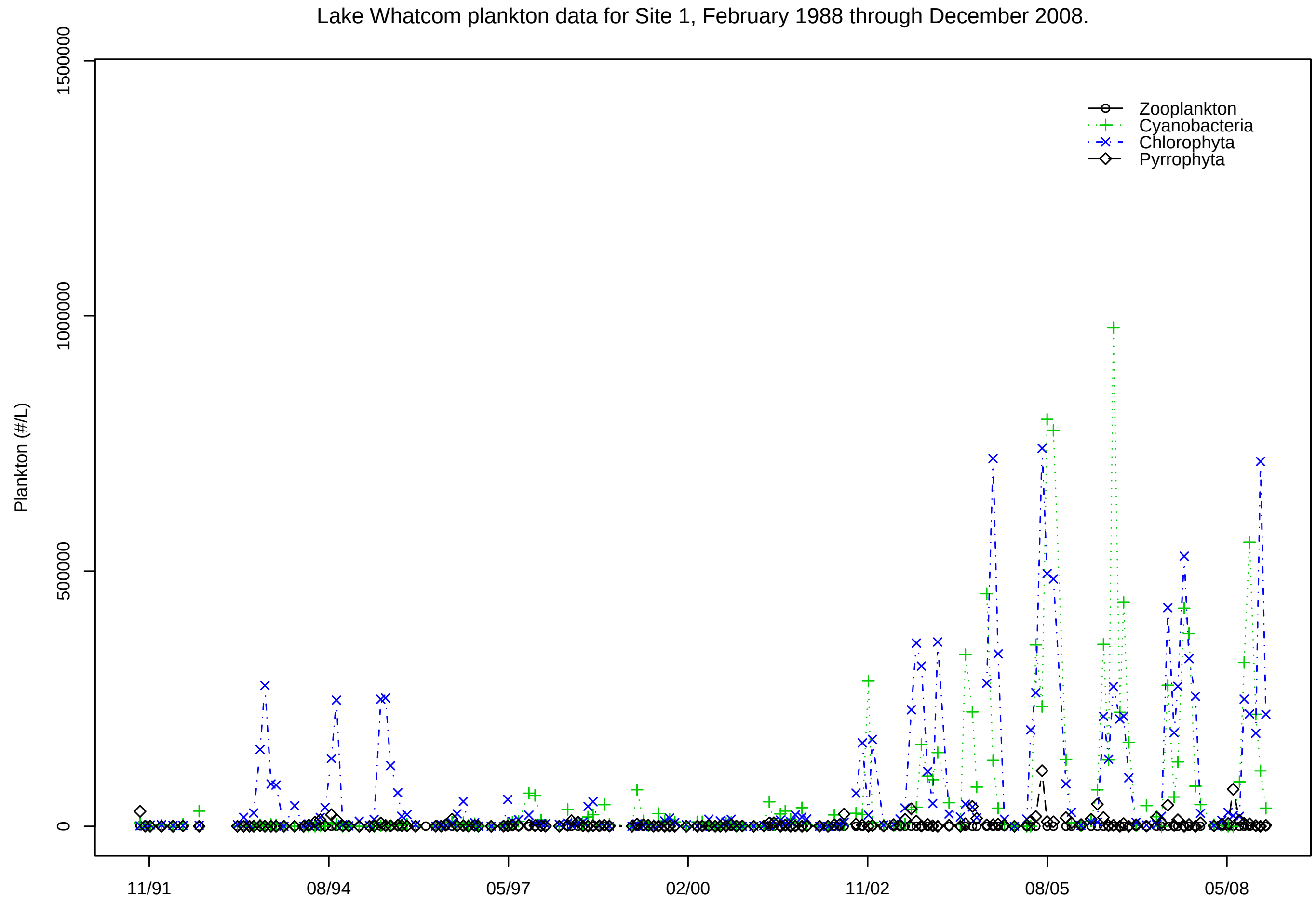


Figure B126: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

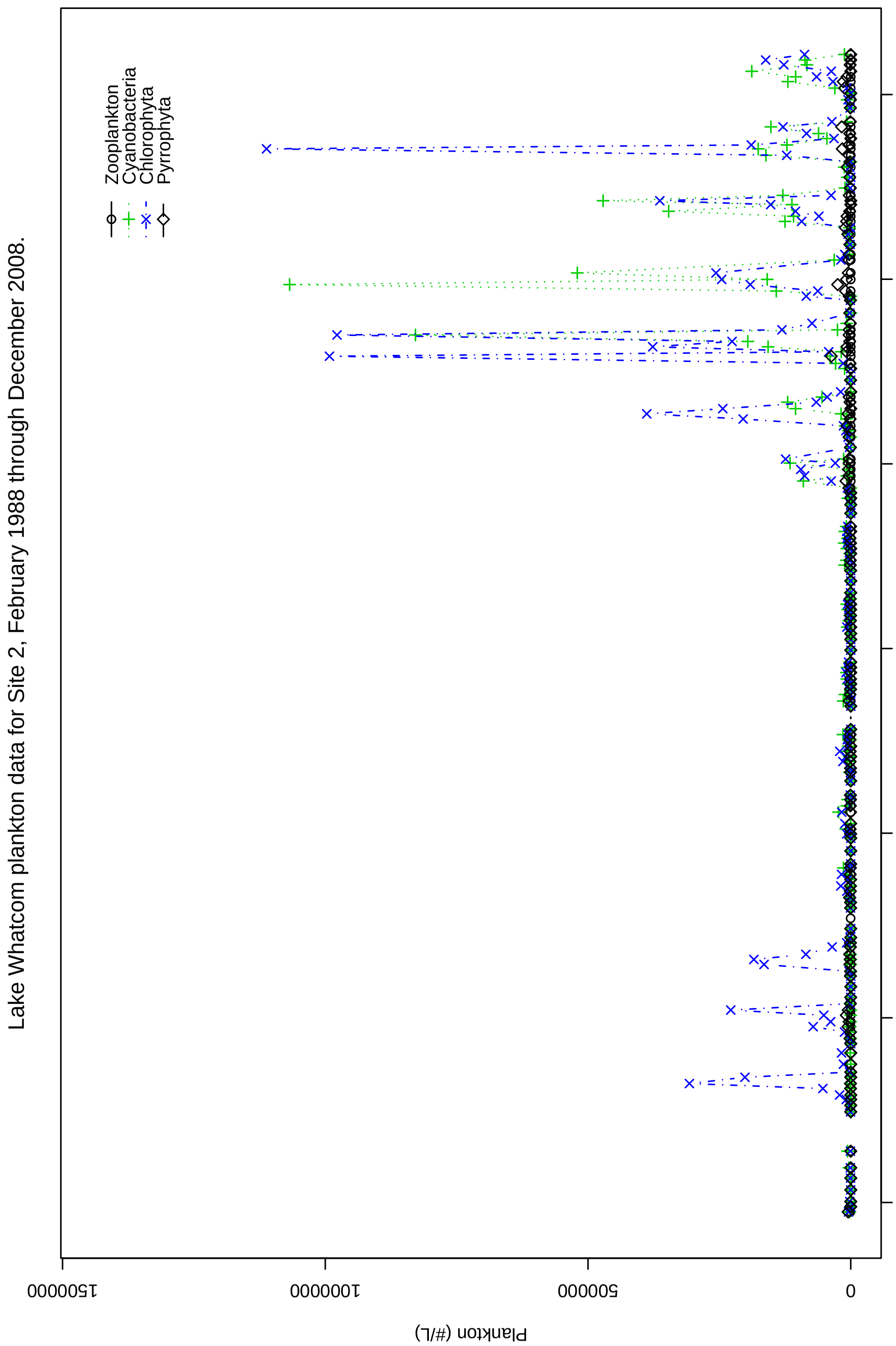


Figure B127: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

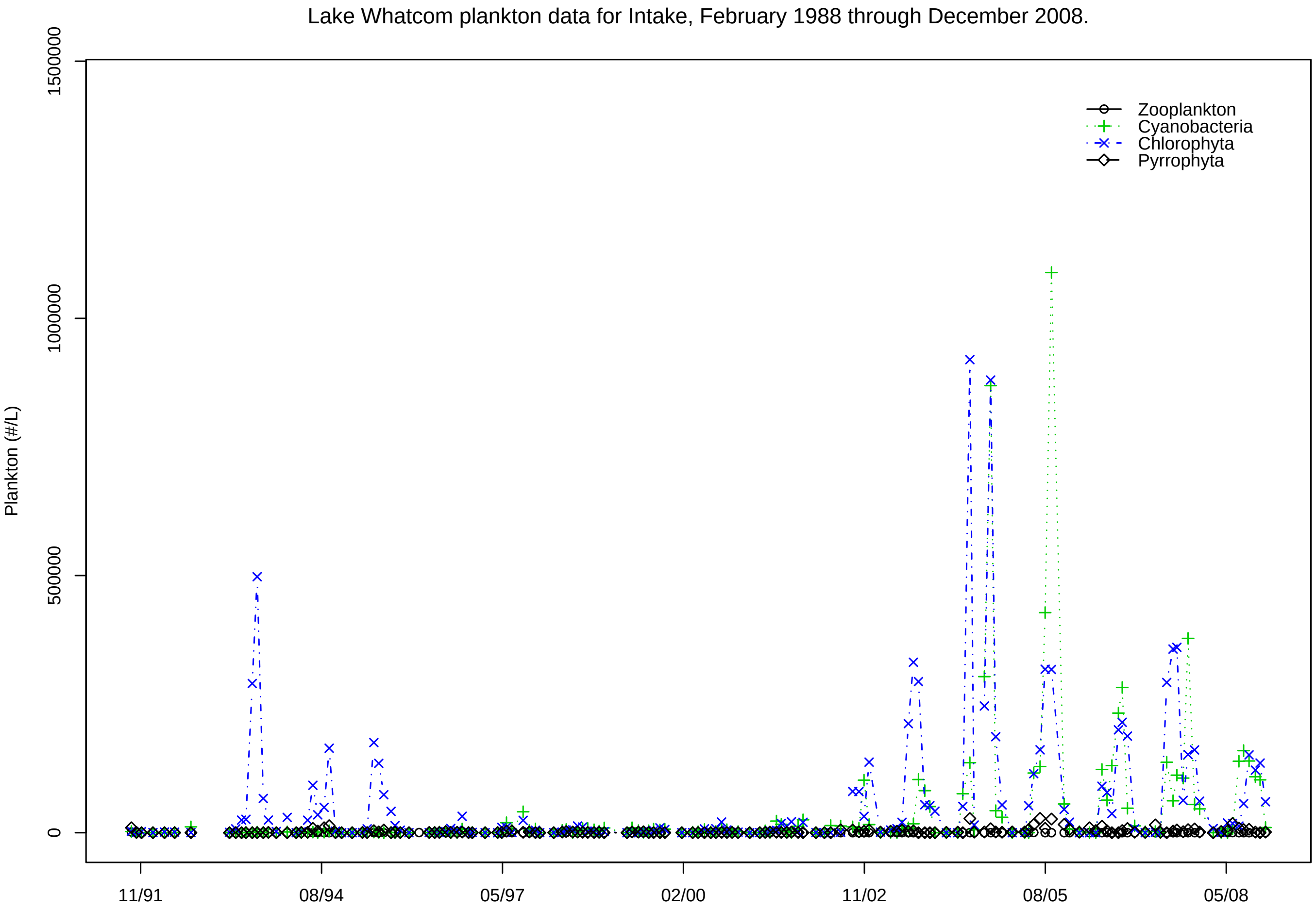


Figure B128: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

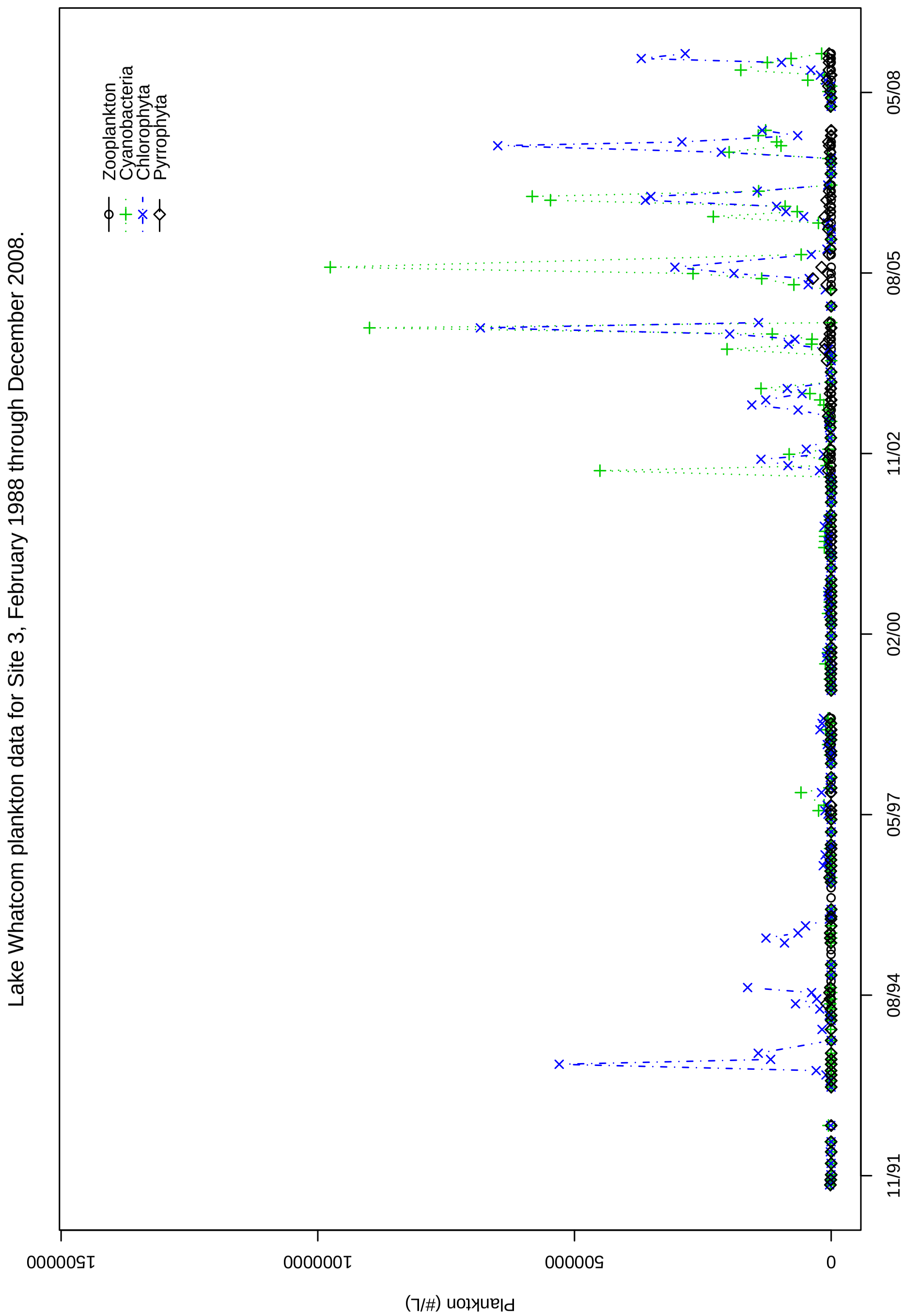


Figure B129: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

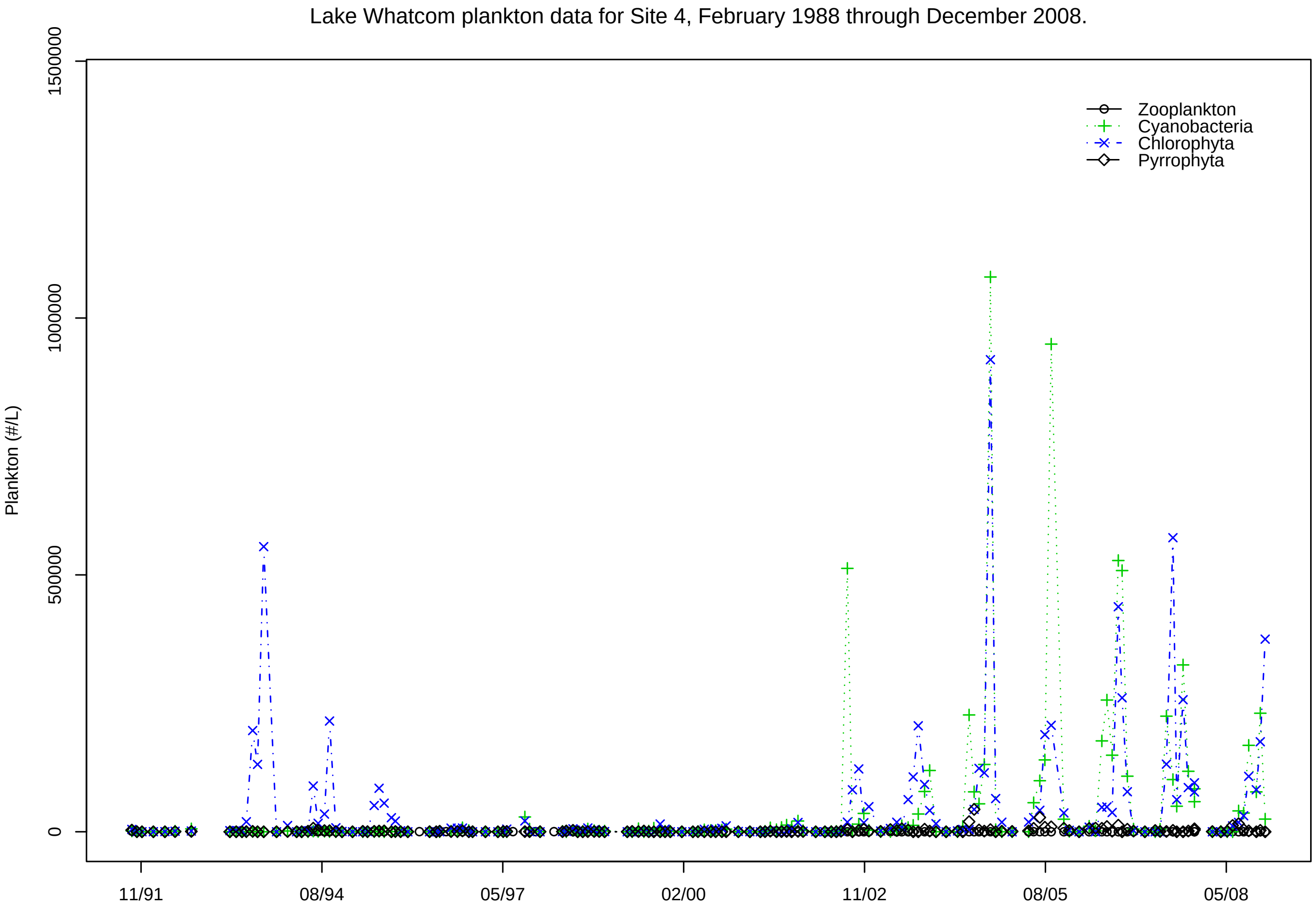


Figure B130: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

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

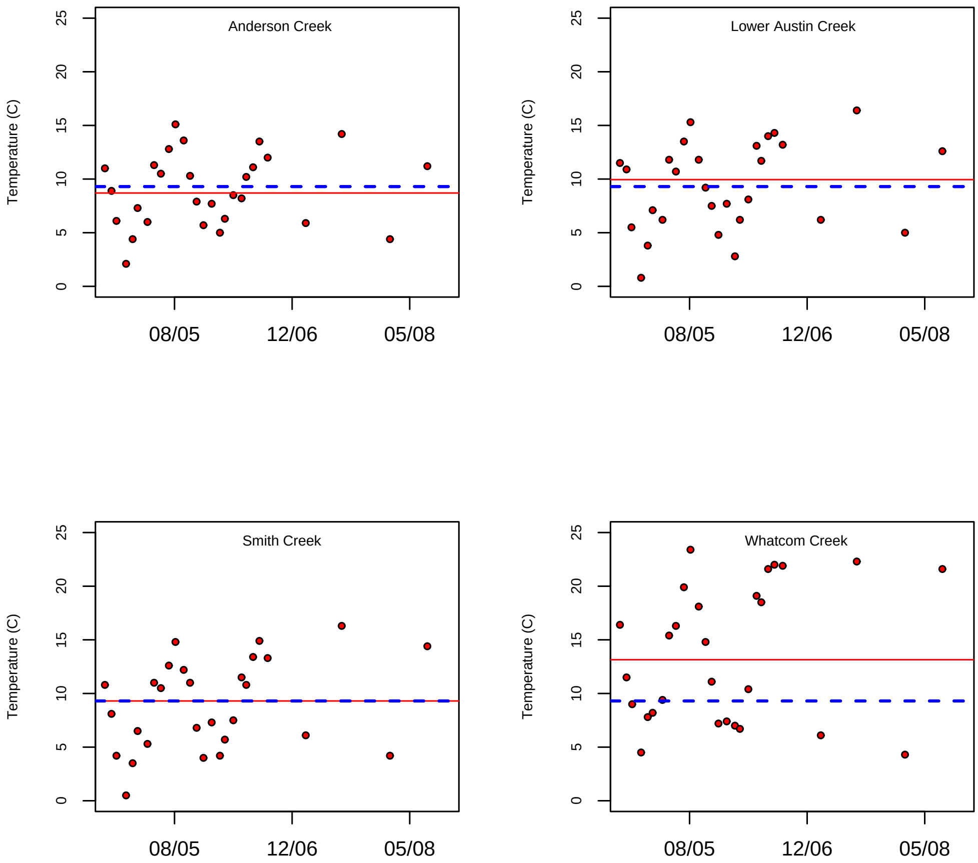


Figure B131: Temperature data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

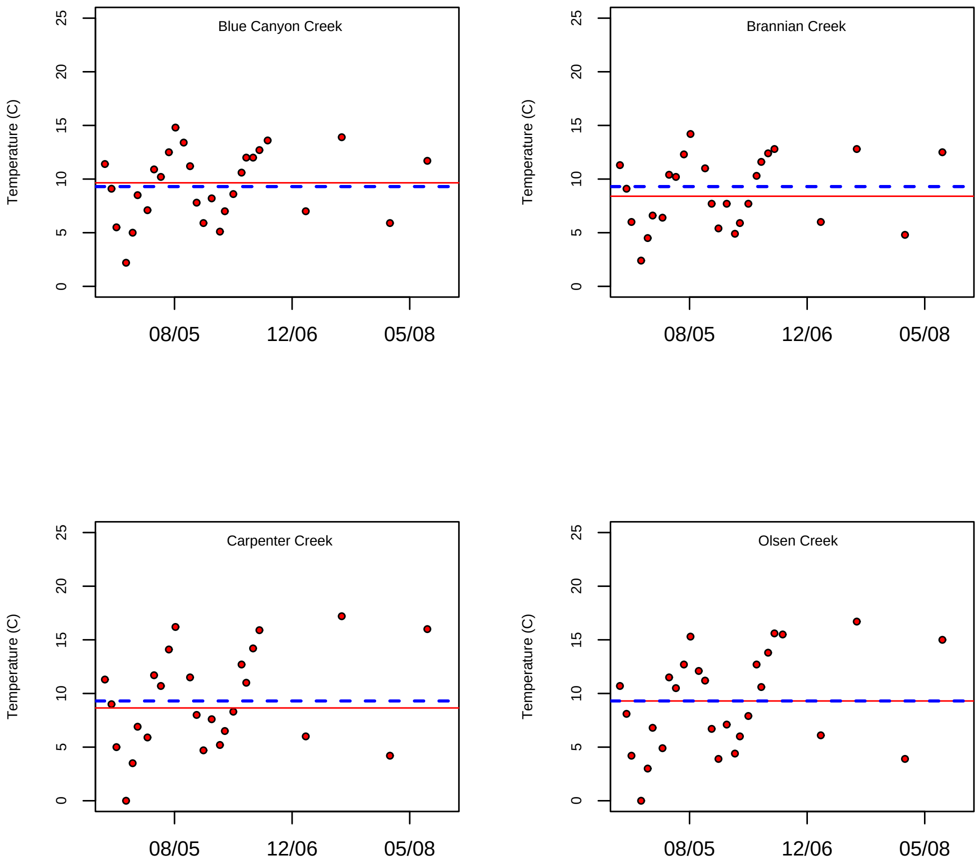


Figure B132: Temperature data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

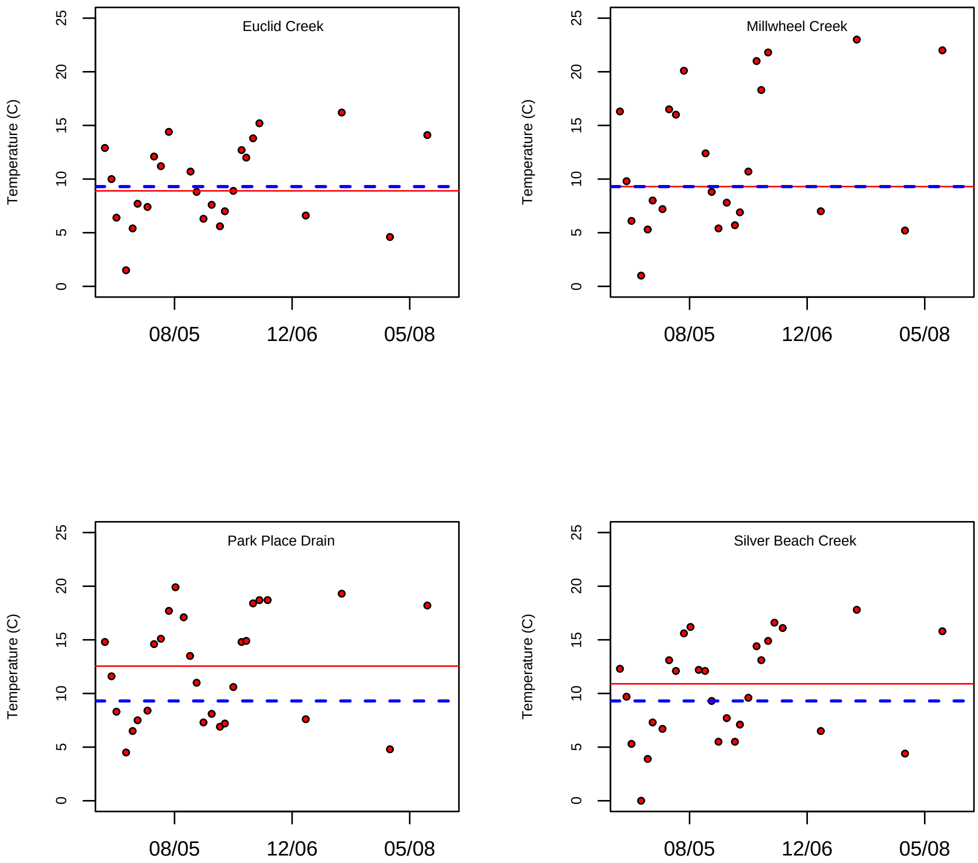


Figure B133: Temperature data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

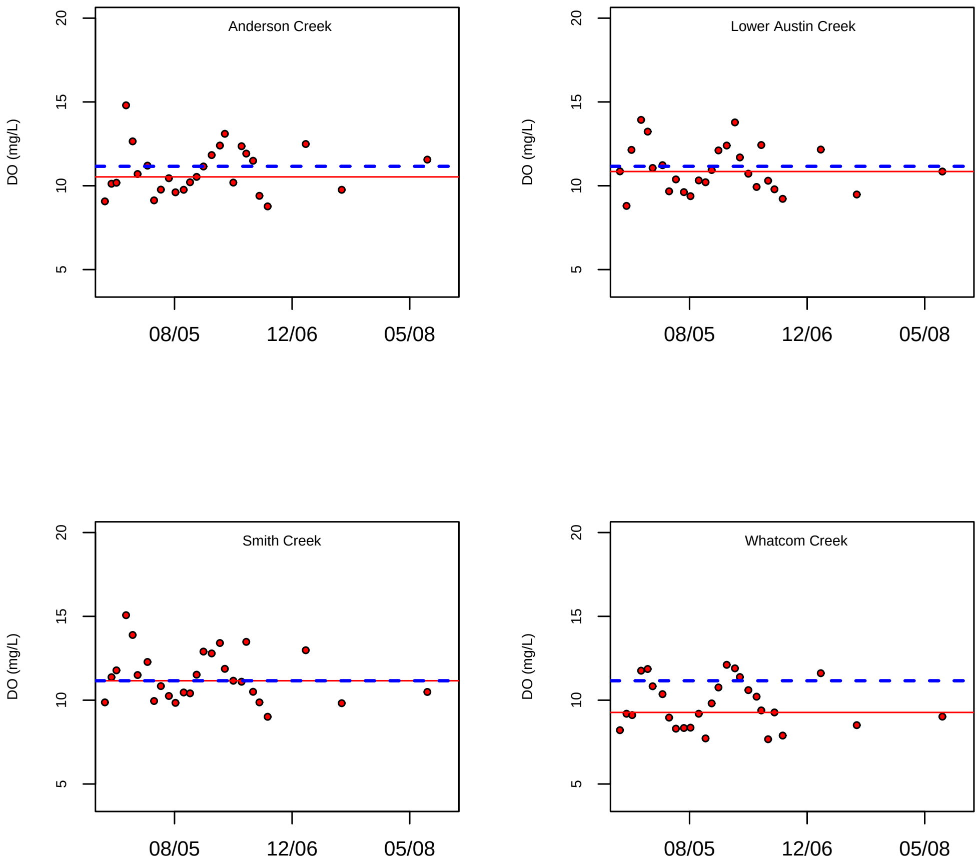


Figure B134: Dissolved oxygen data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

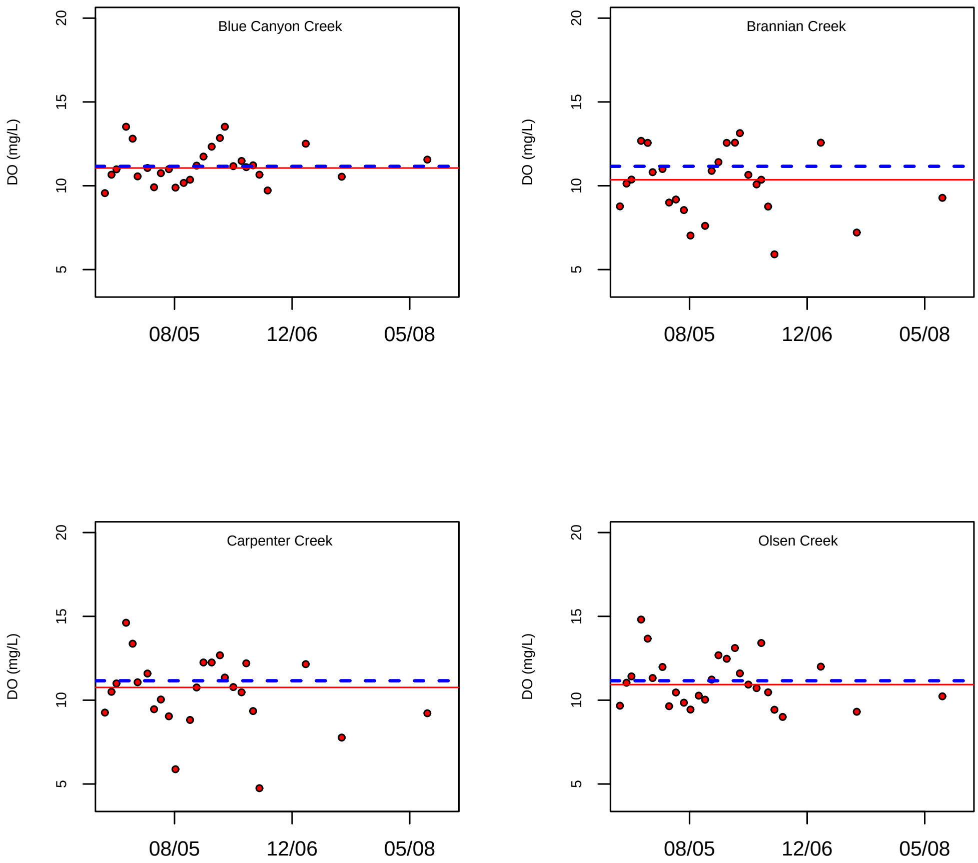


Figure B135: Dissolved oxygen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

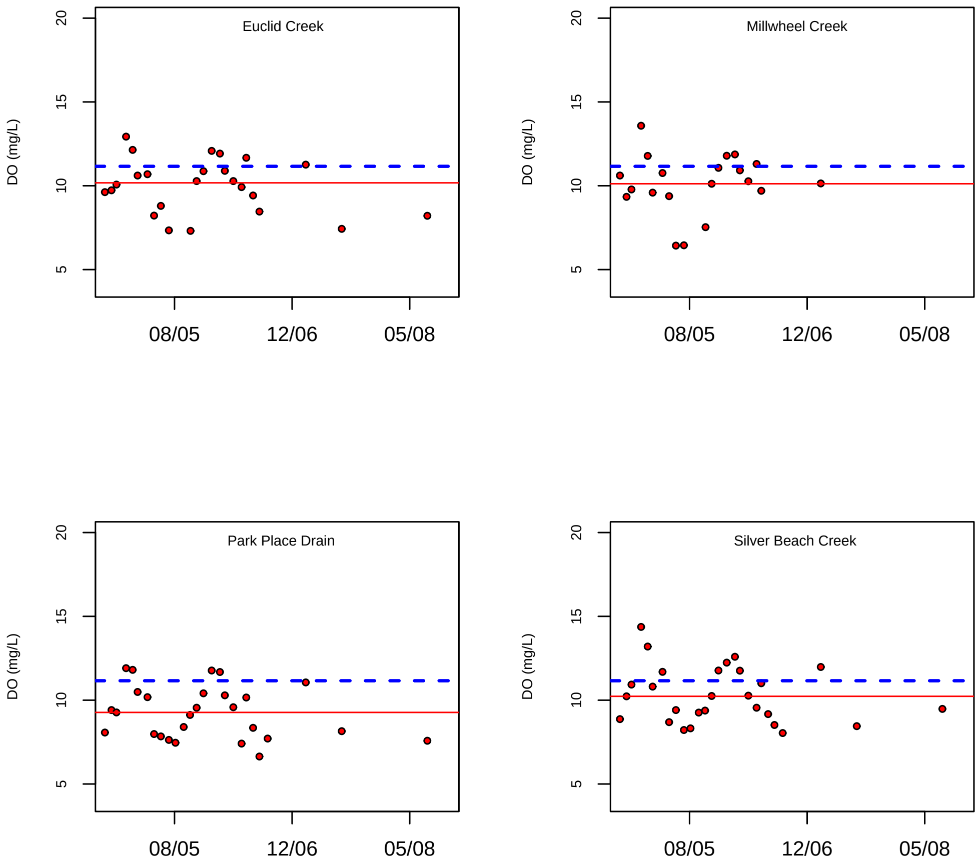


Figure B136: Dissolved oxygen data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

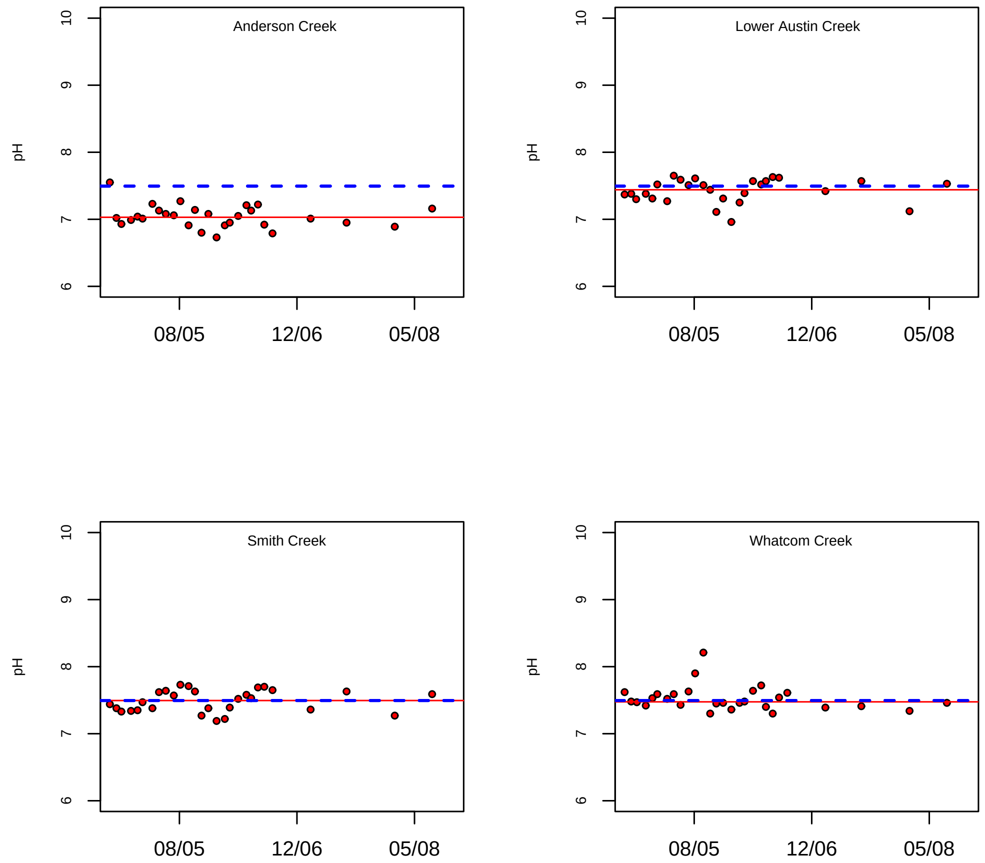


Figure B137: Tributary pH data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

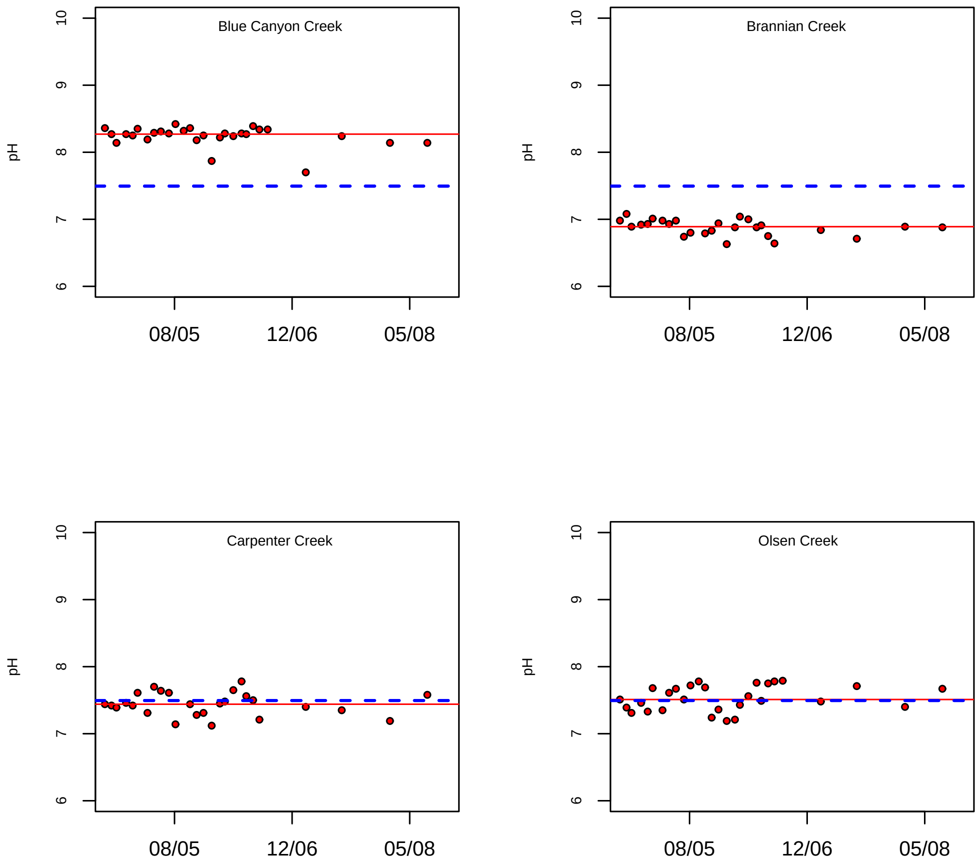


Figure B138: Tributary pH data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

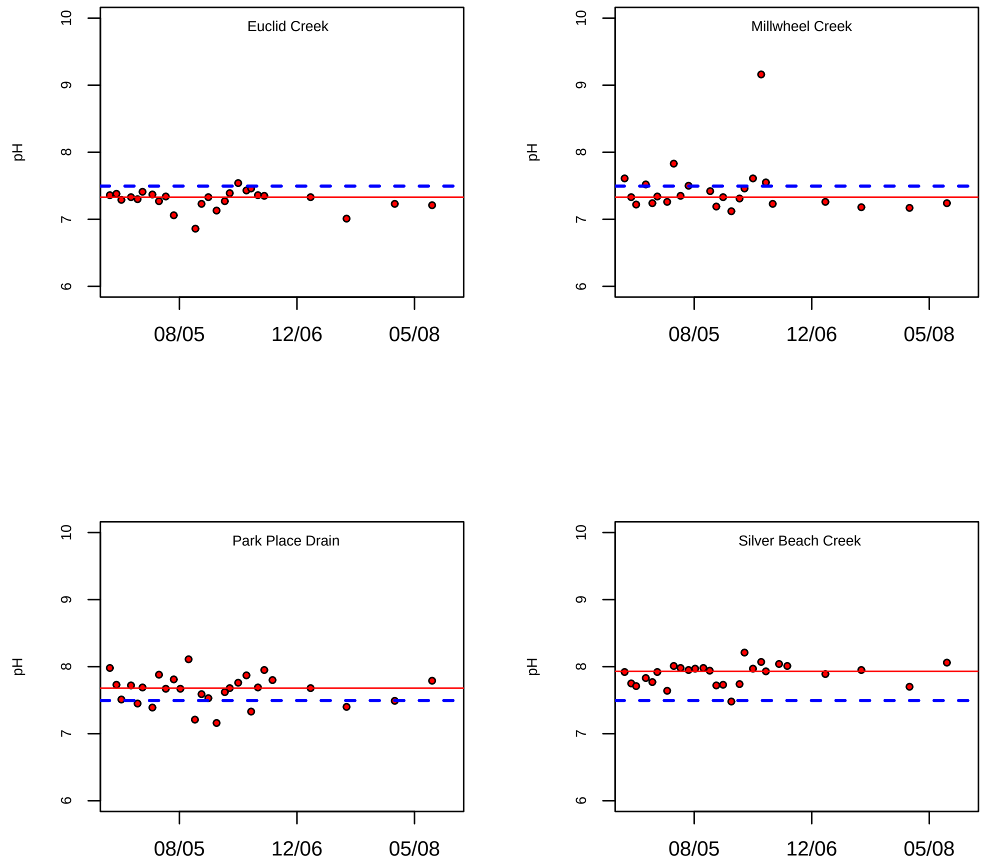


Figure B139: Tributary pH data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

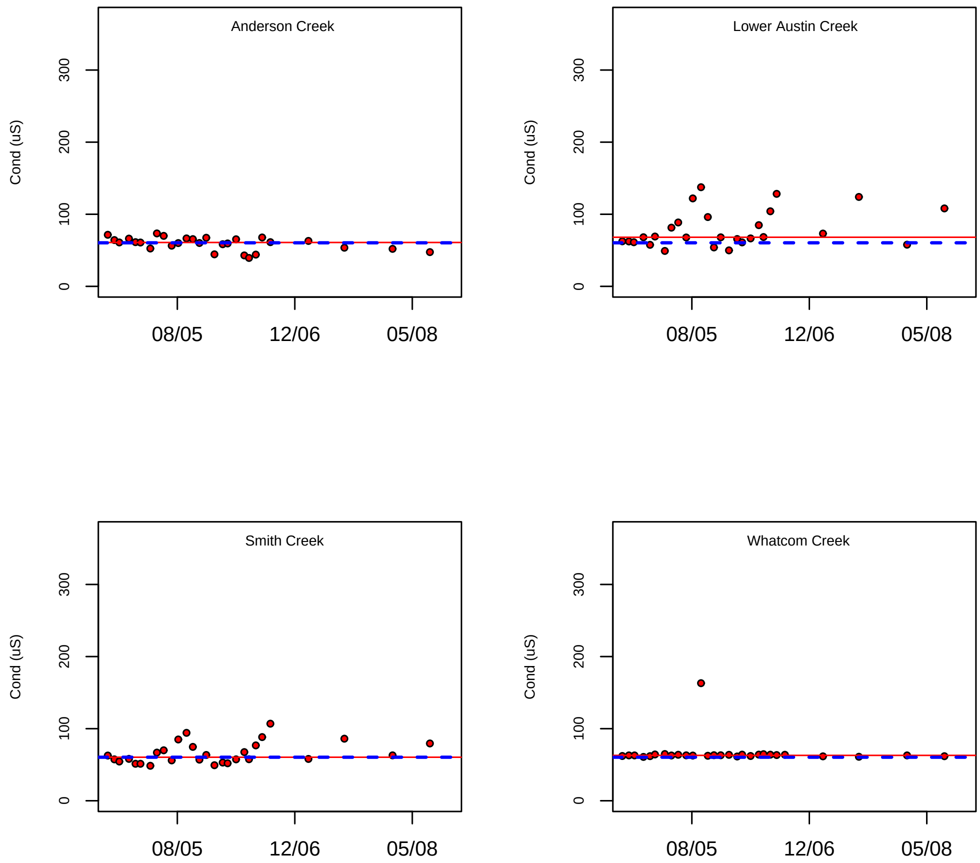


Figure B140: Conductivity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

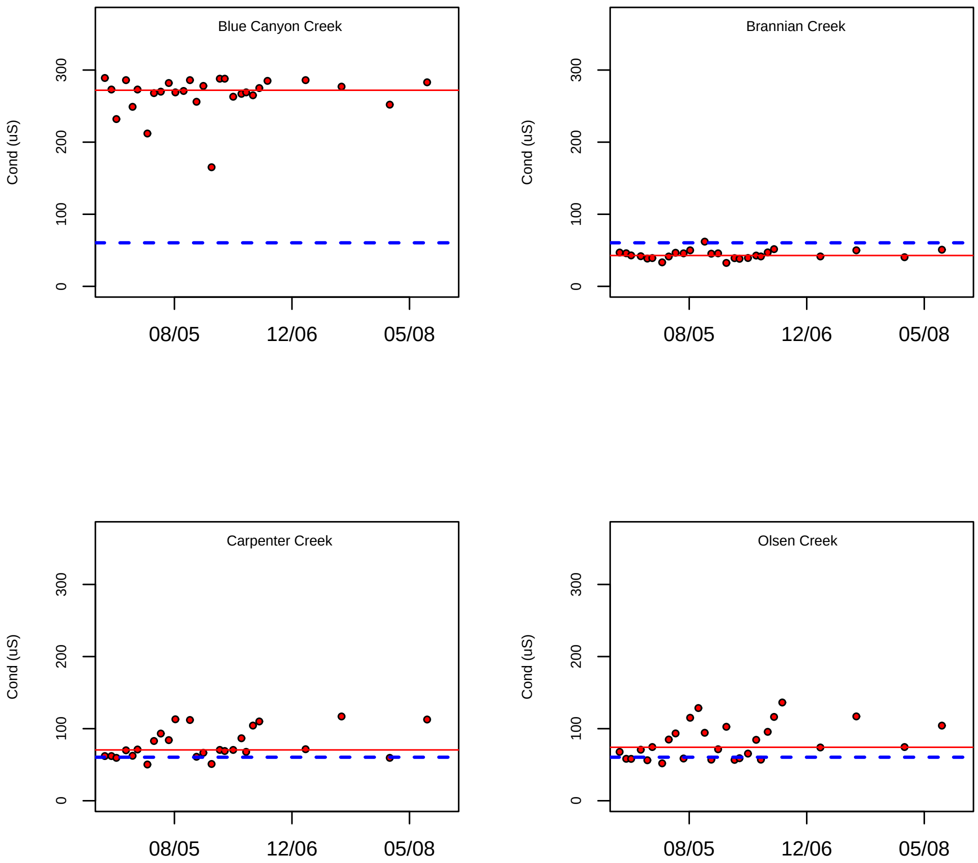


Figure B141: Conductivity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

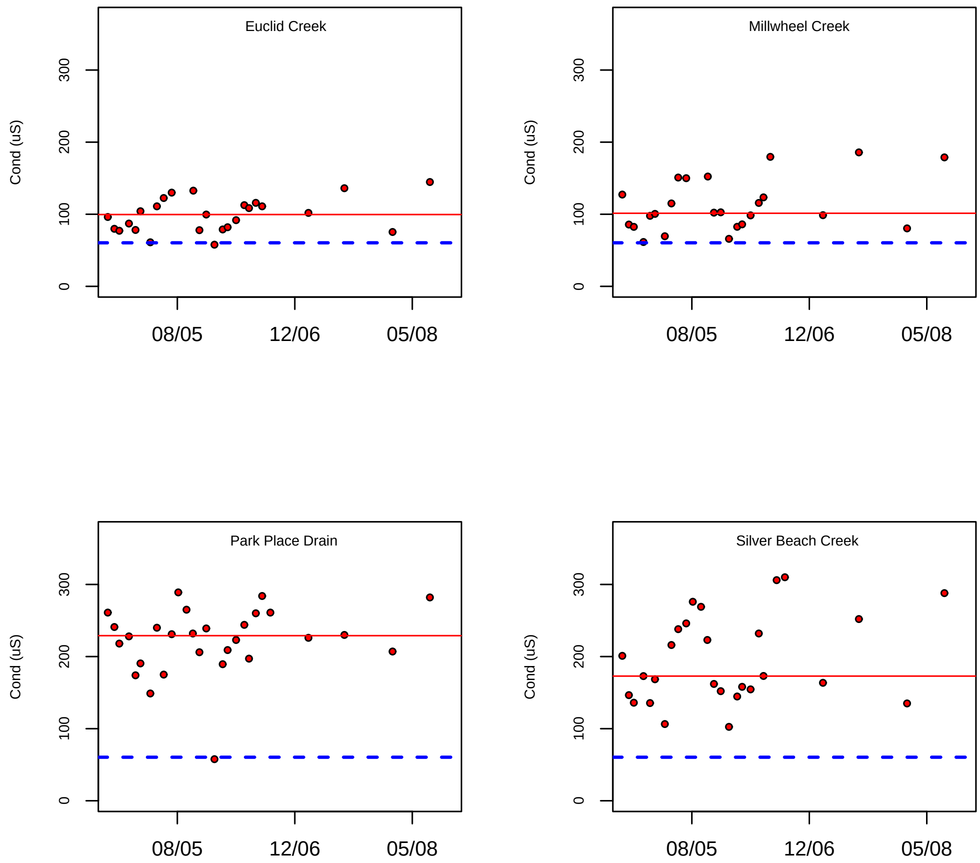


Figure B142: Conductivity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

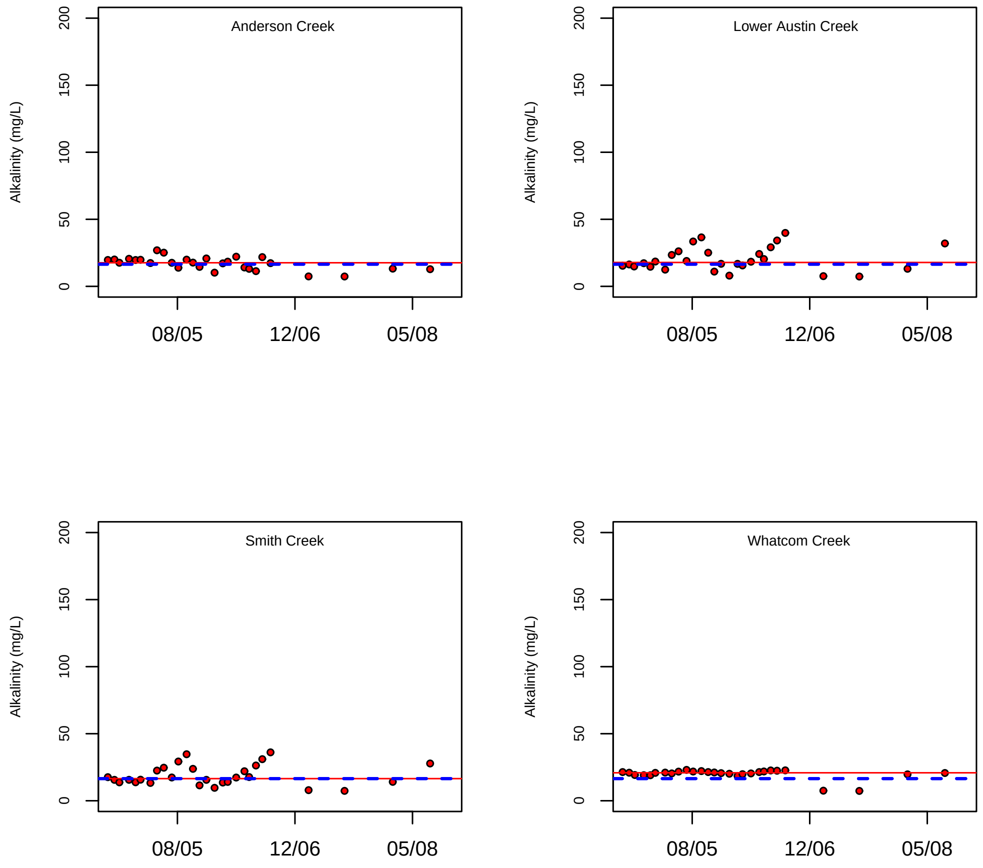


Figure B143: Alkalinity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

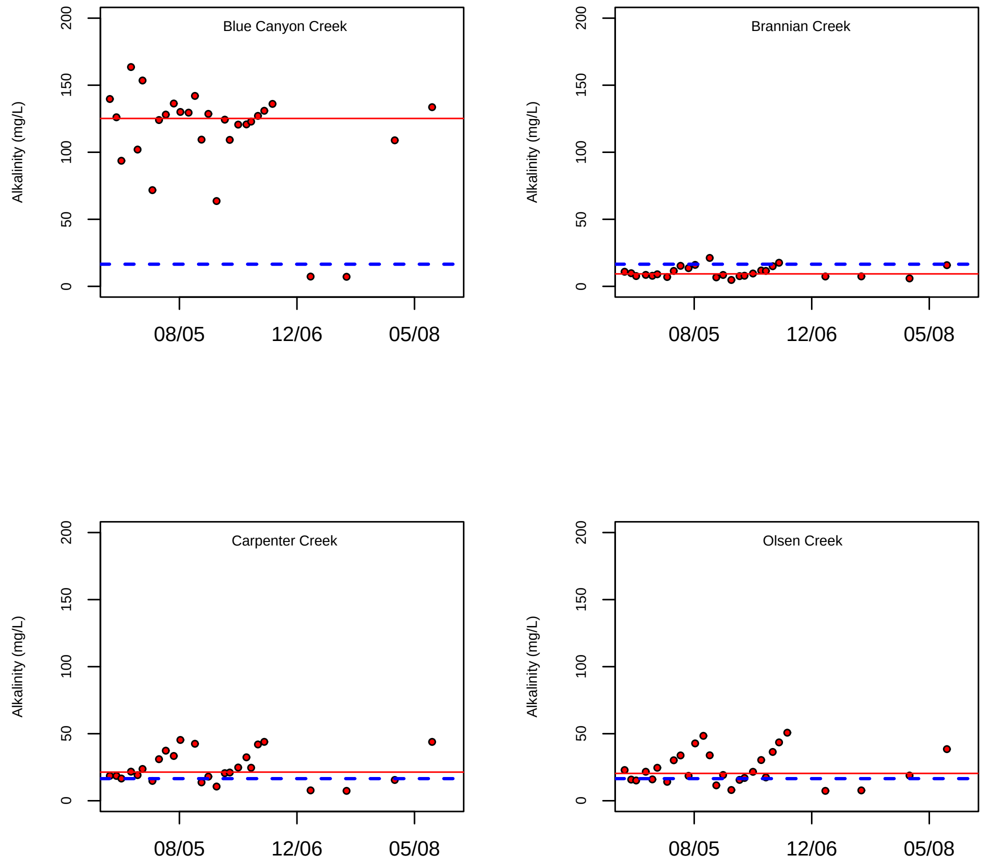


Figure B144: Alkalinity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

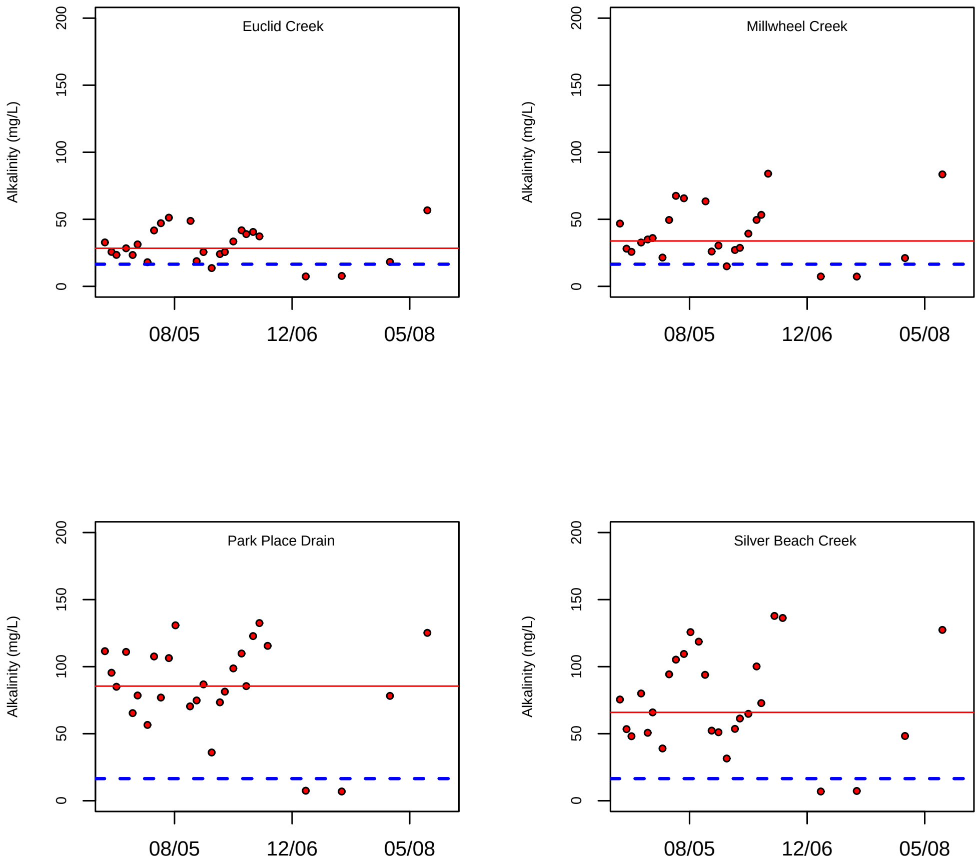


Figure B145: Alkalinity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

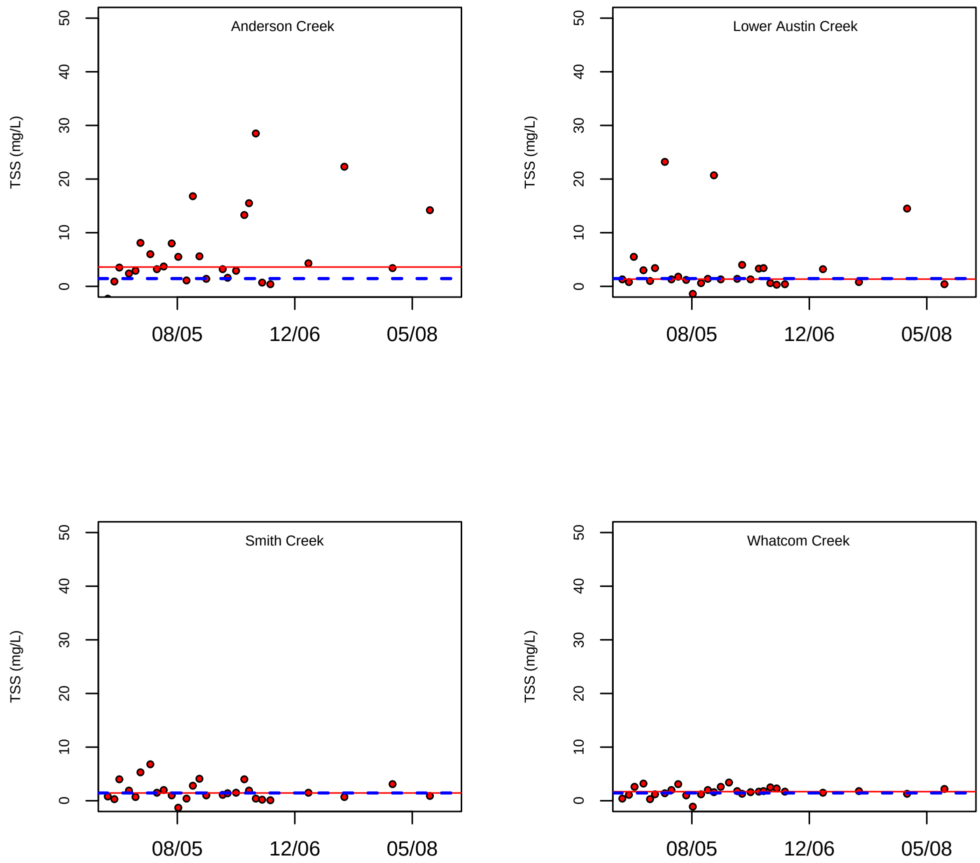


Figure B146: Total suspended solids data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

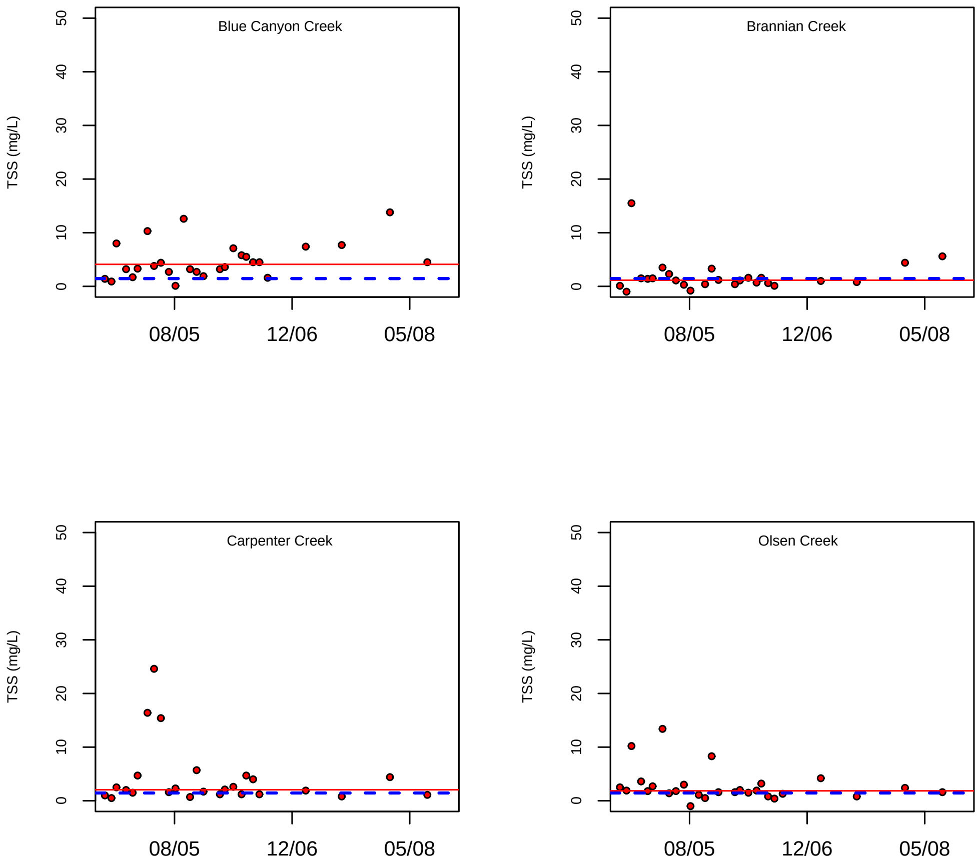


Figure B147: Total suspended solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

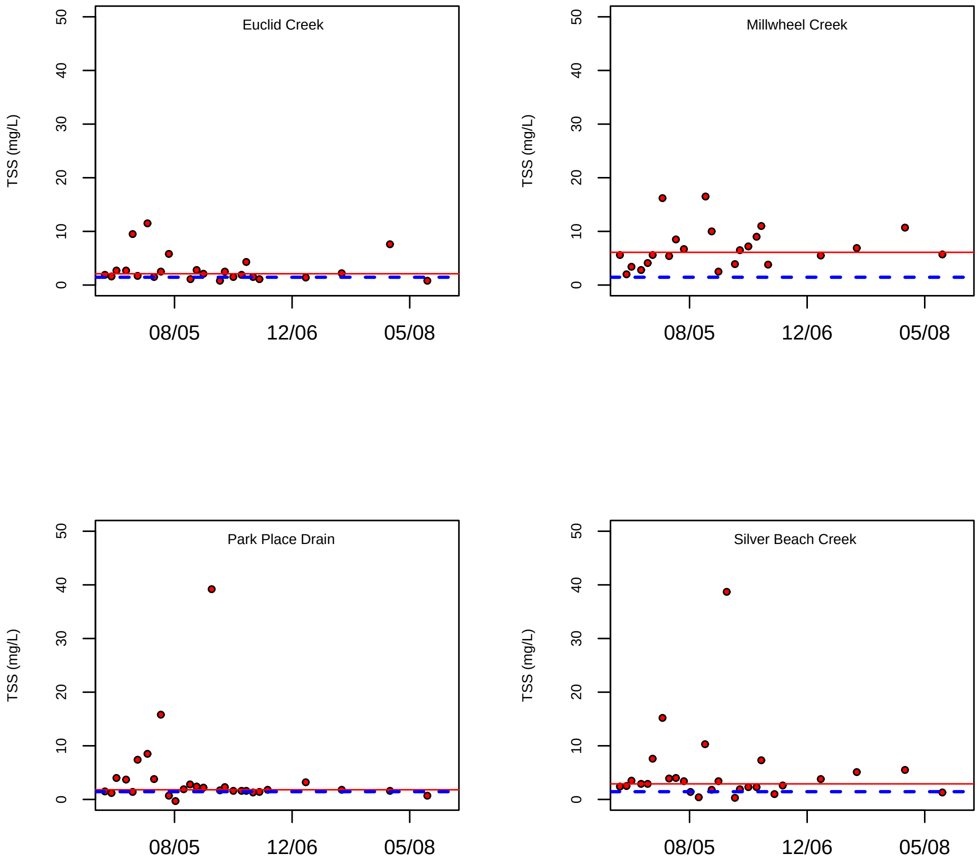


Figure B148: Total suspended solids data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

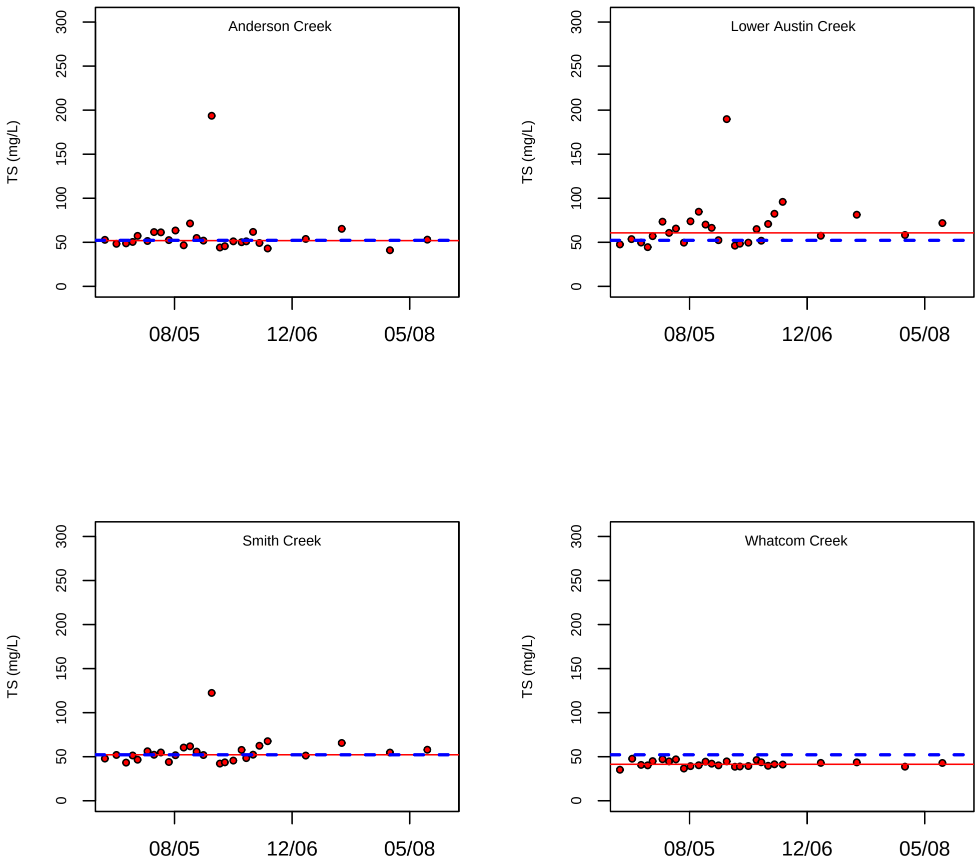


Figure B149: Total solids data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

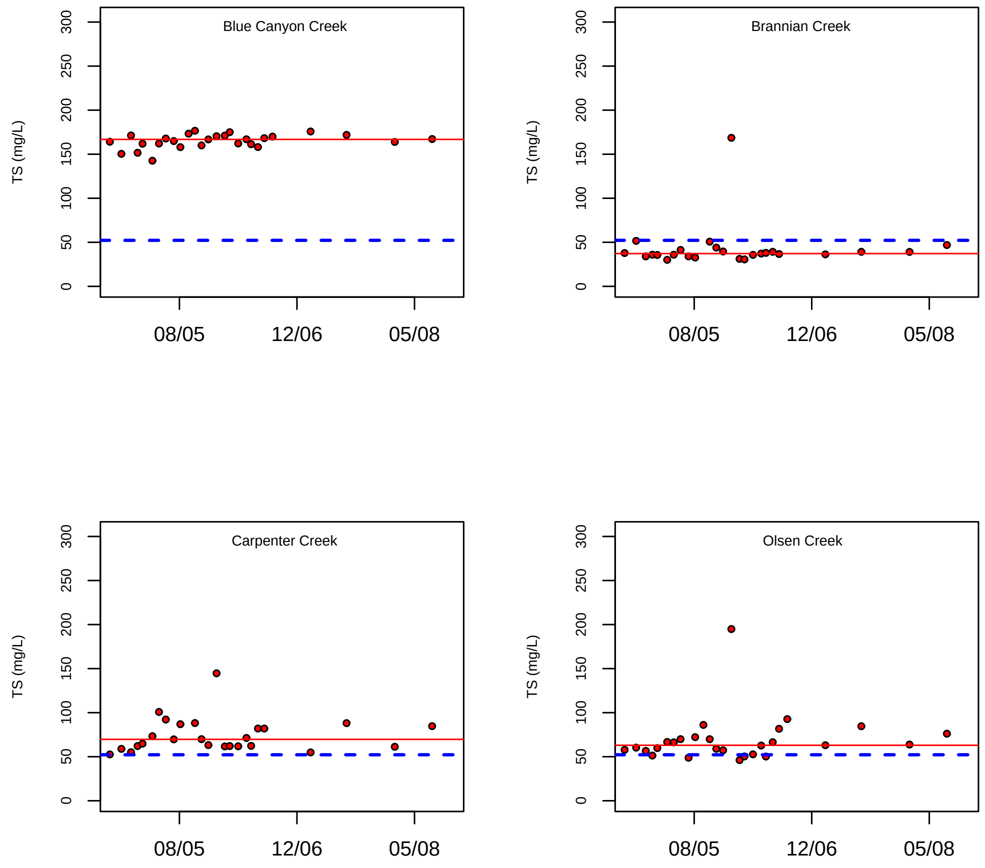


Figure B150: Total solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

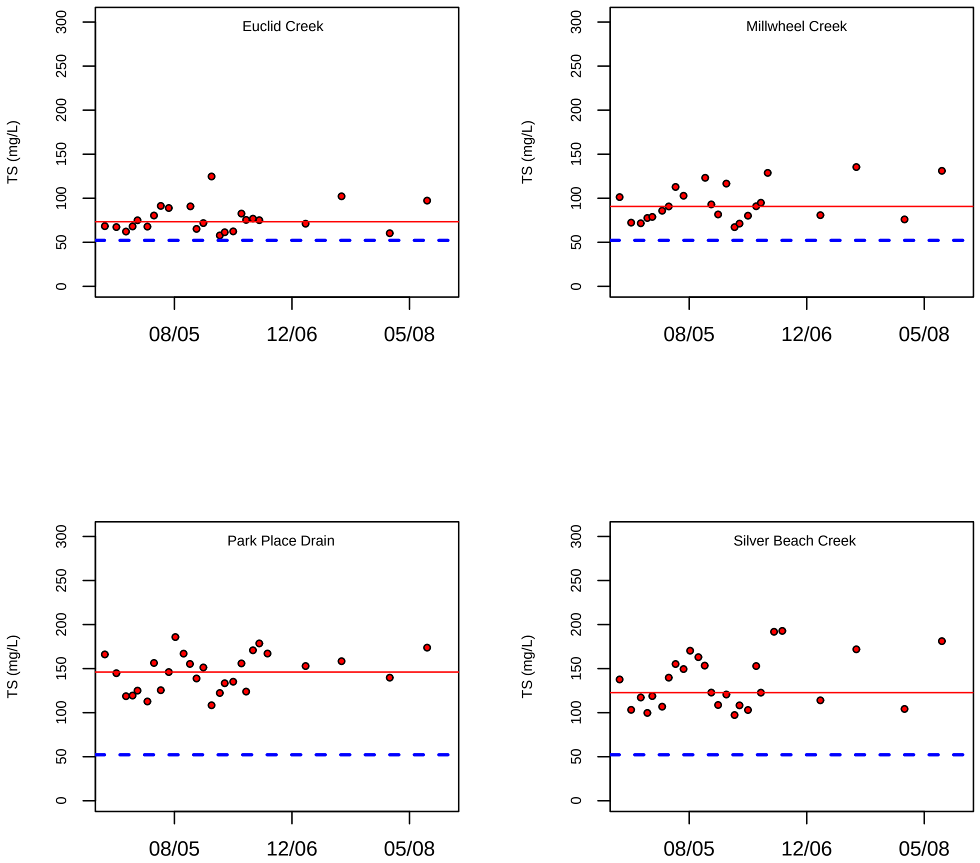


Figure B151: Total solids data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

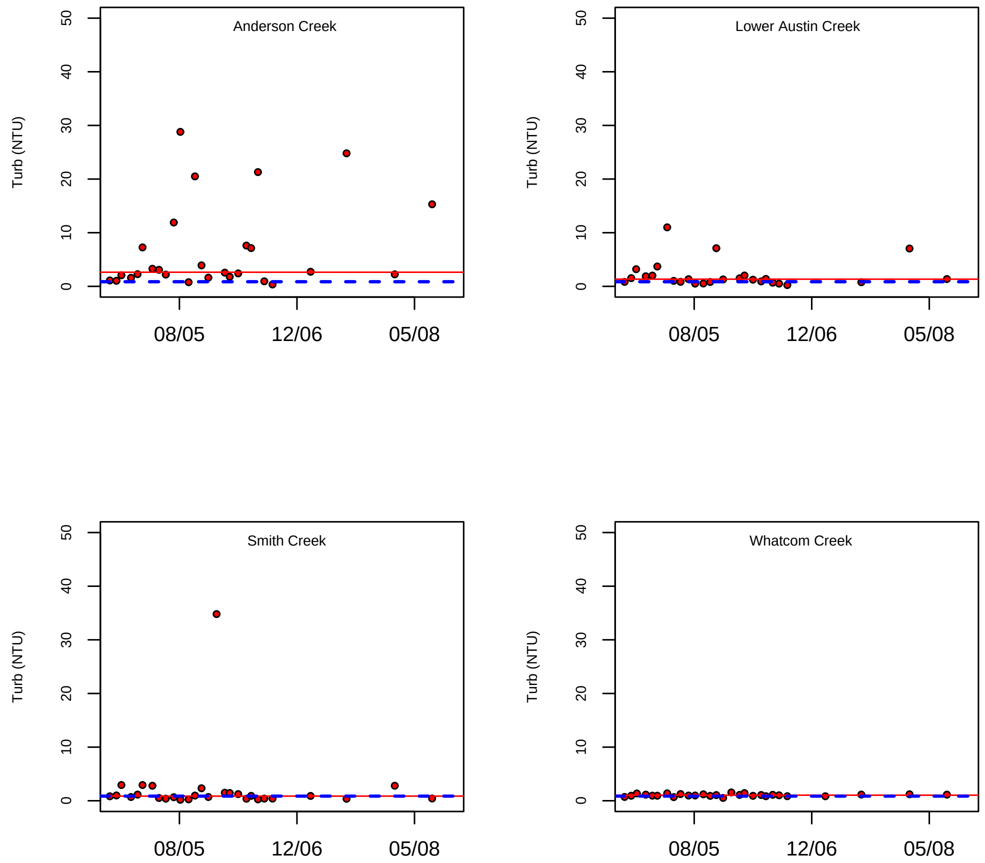


Figure B152: Turbidity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

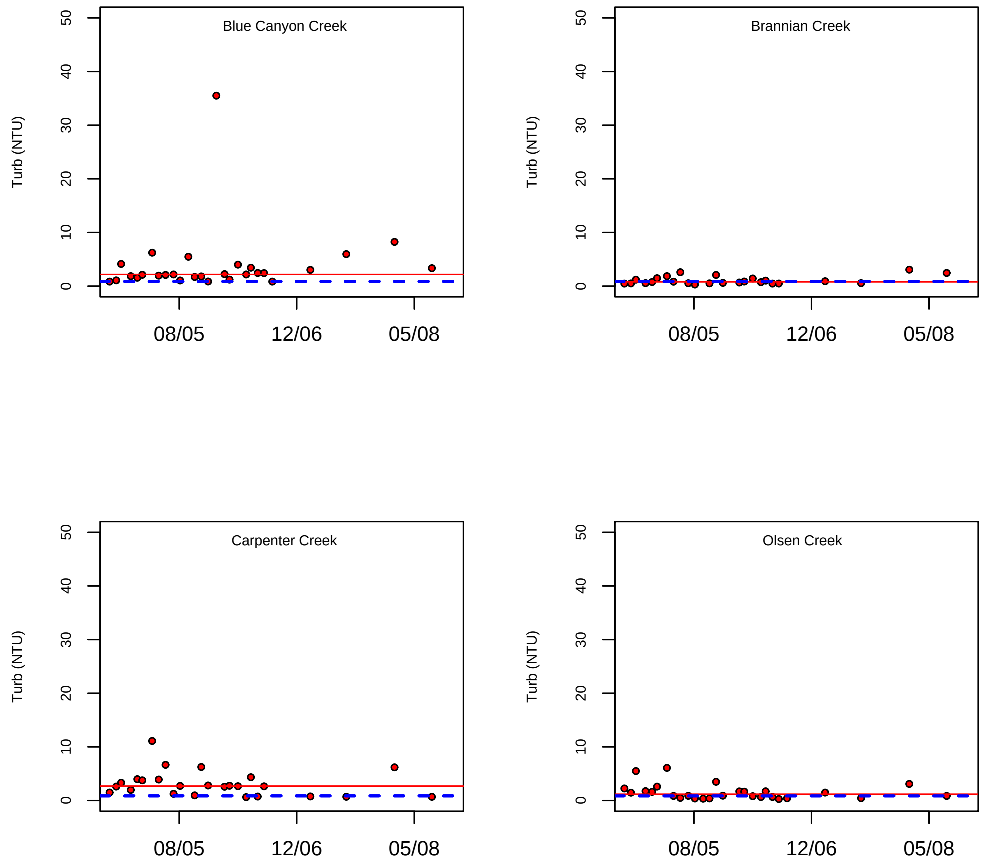


Figure B153: Turbidity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

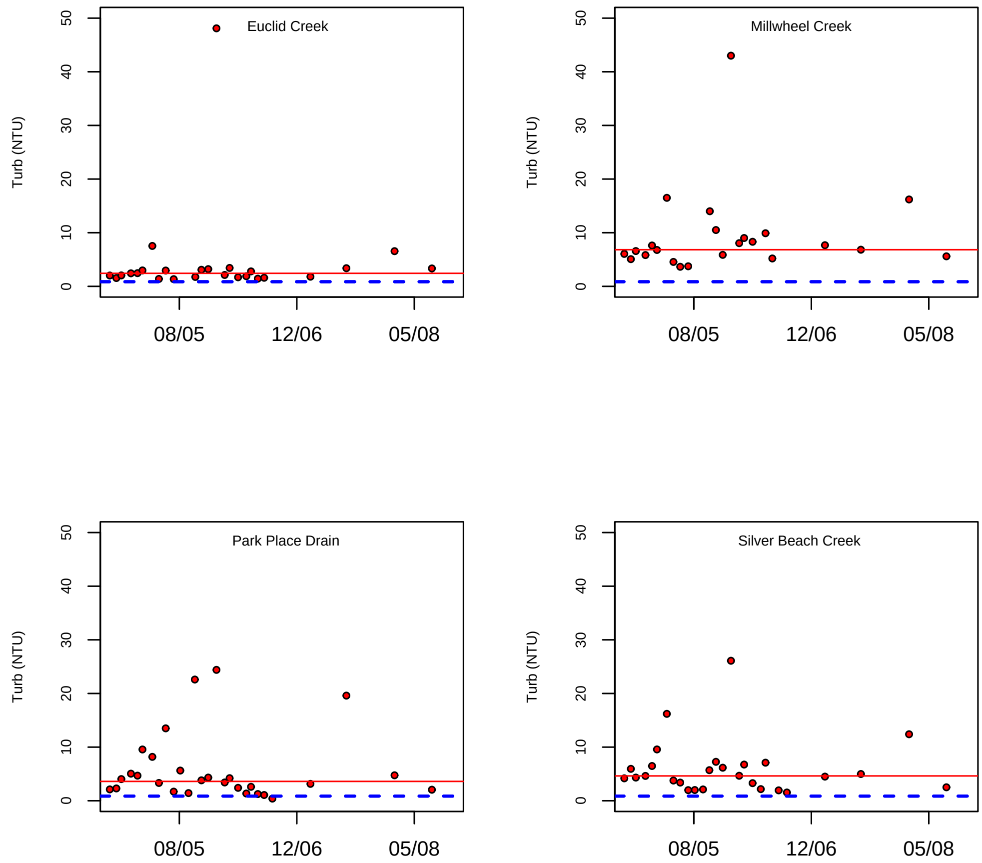


Figure B154: Turbidity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

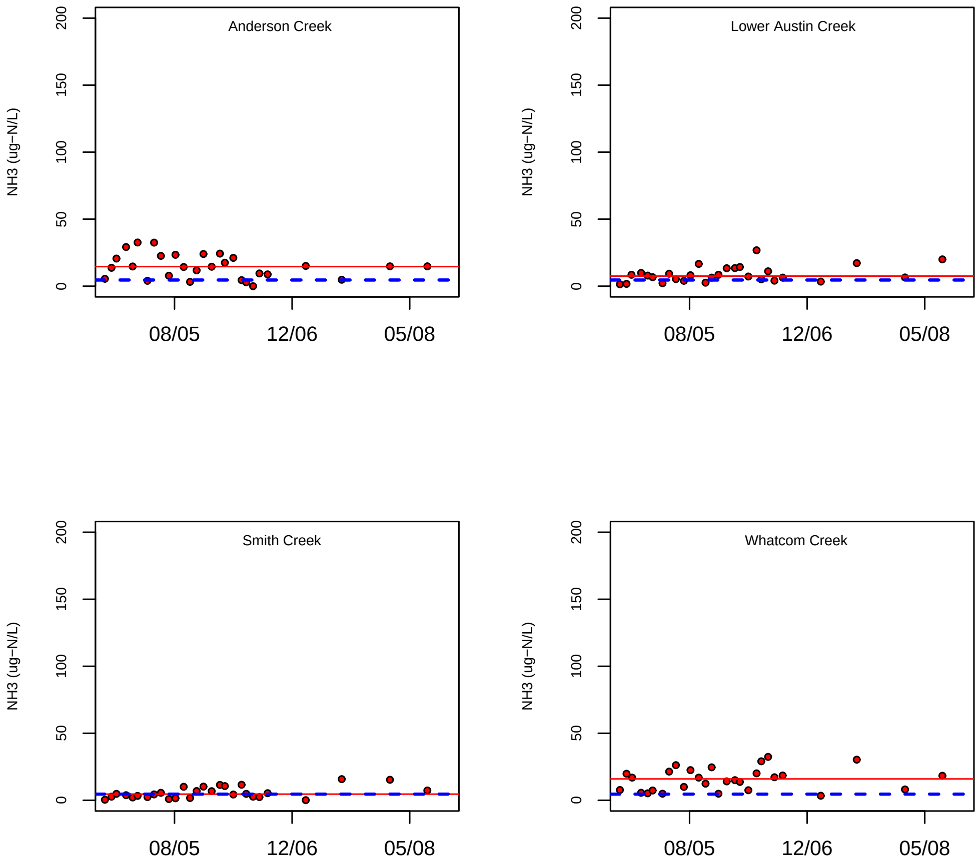


Figure B155: Ammonia data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

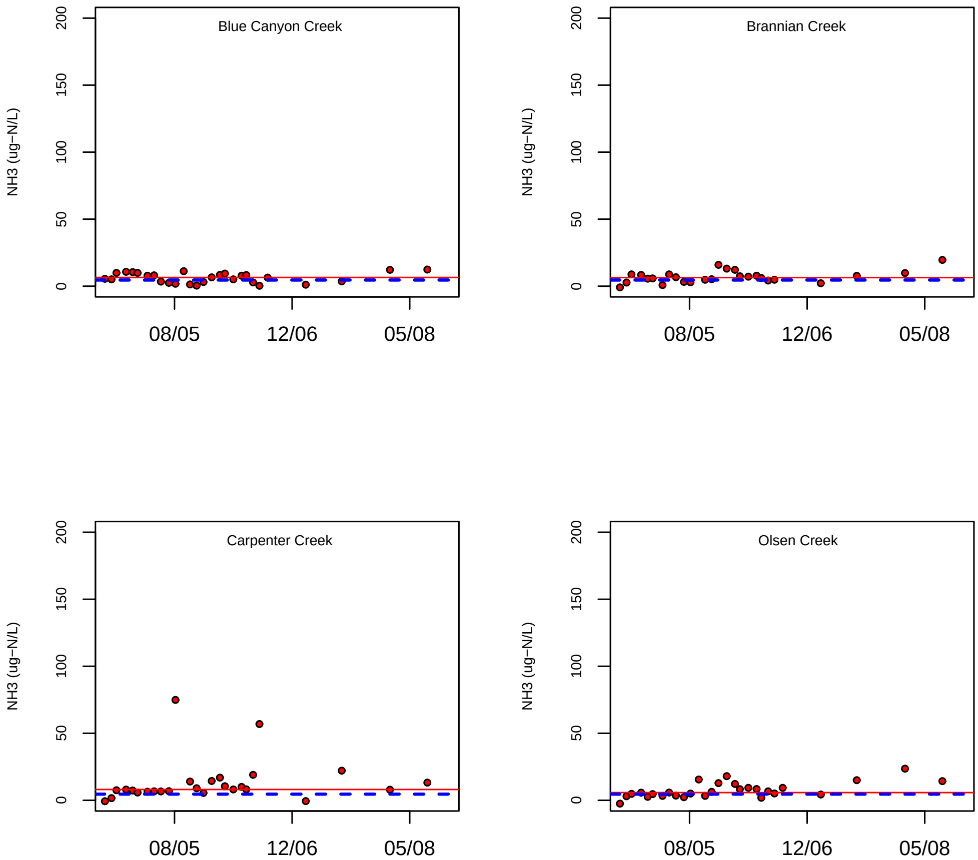


Figure B156: Ammonia data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

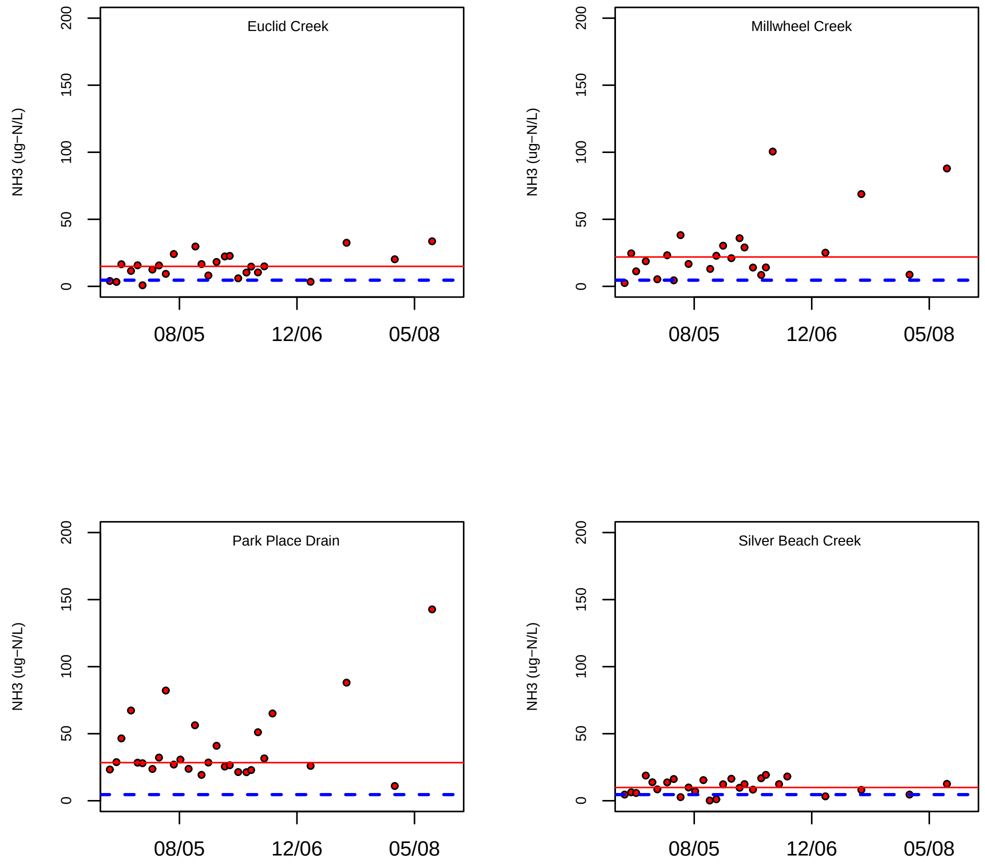


Figure B157: Ammonia data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

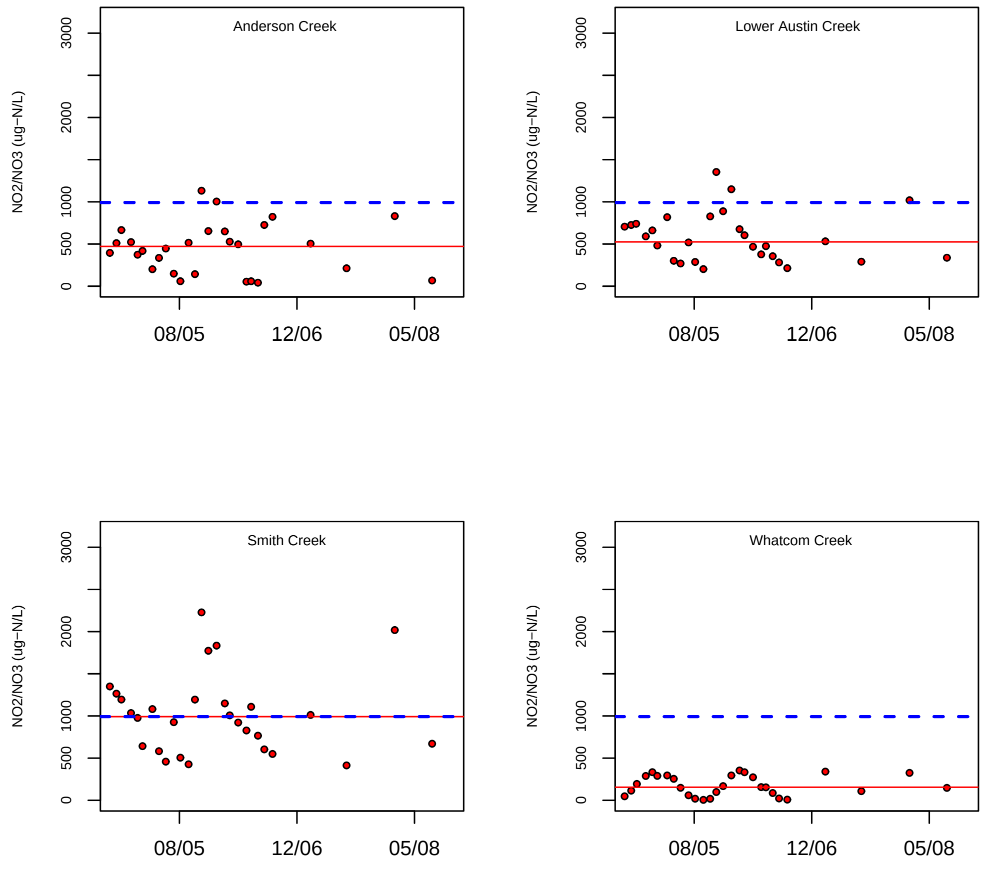


Figure B158: Nitrate/nitrite data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

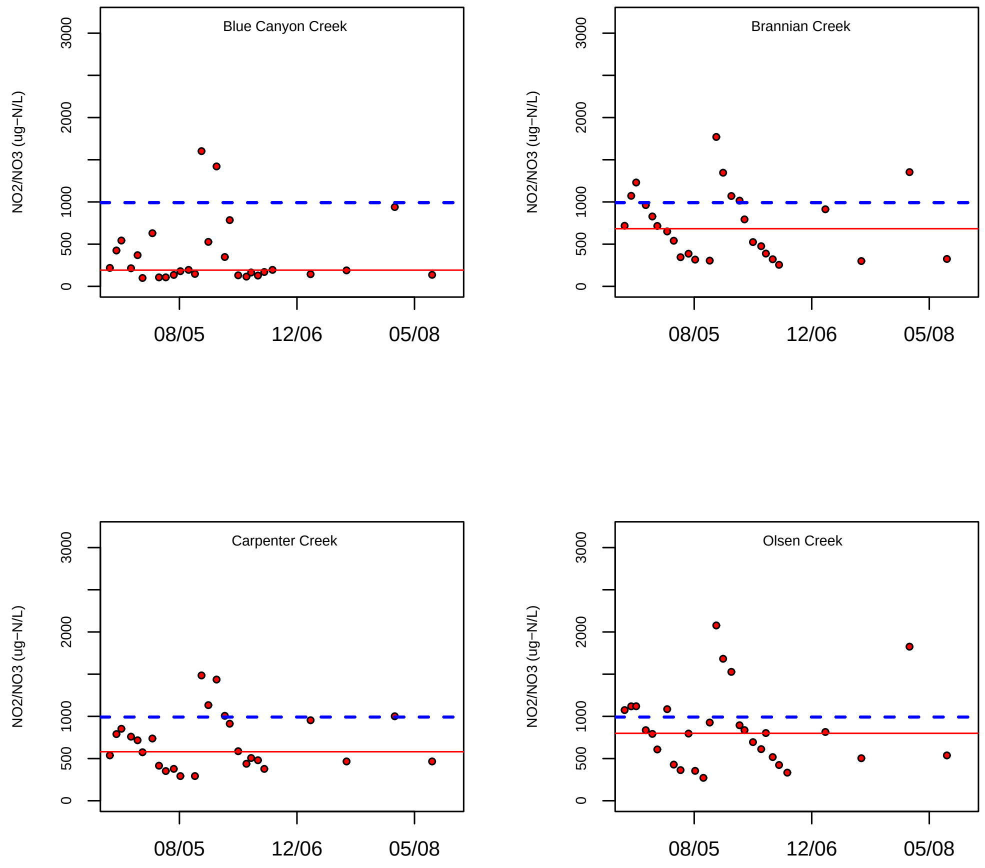


Figure B159: Nitrate/nitrite data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

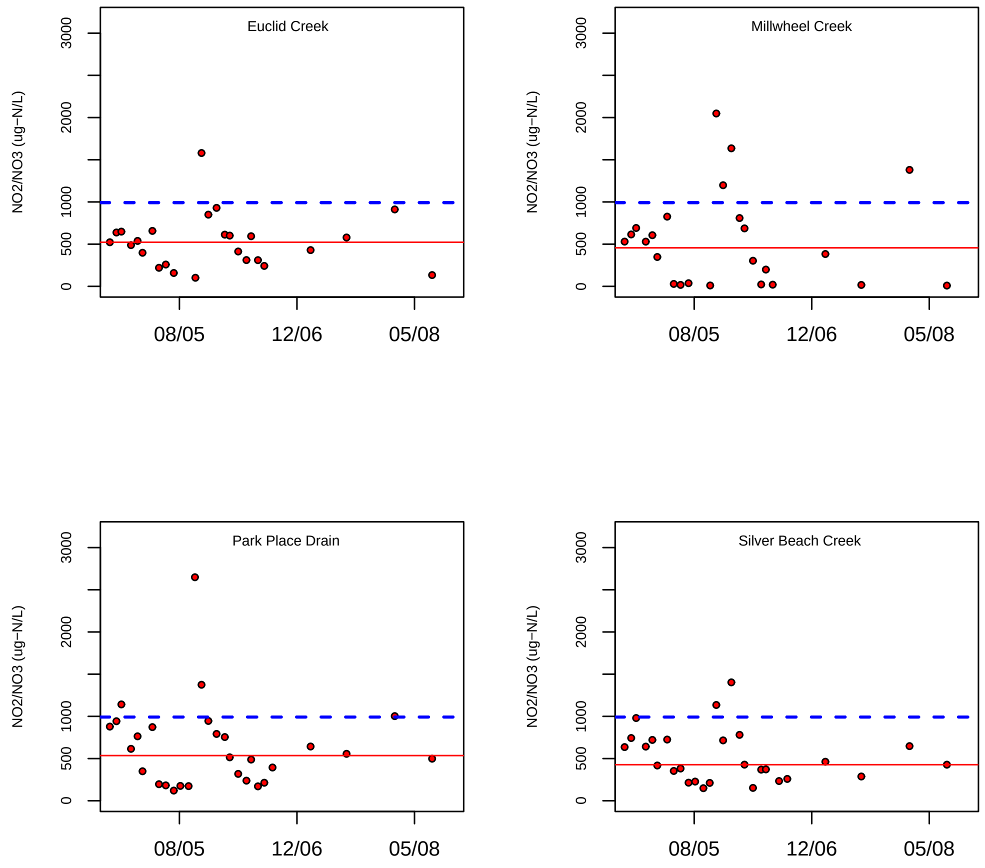


Figure B160: Nitrate/nitrite data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

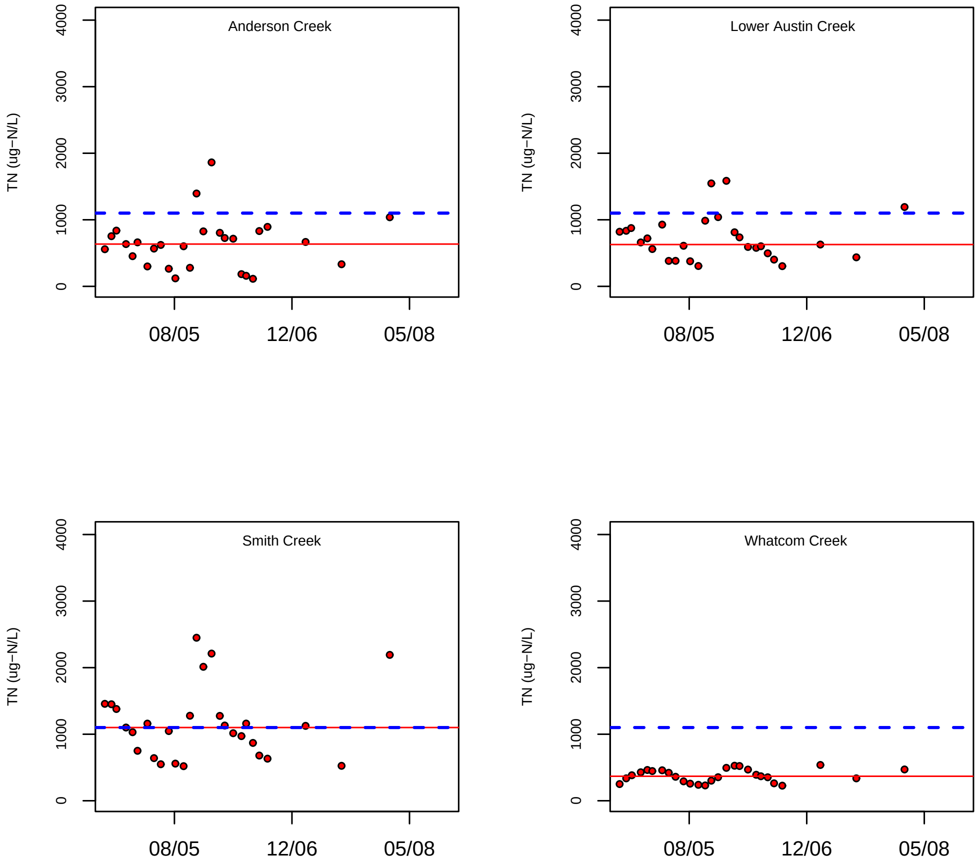


Figure B161: Total nitrogen data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each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

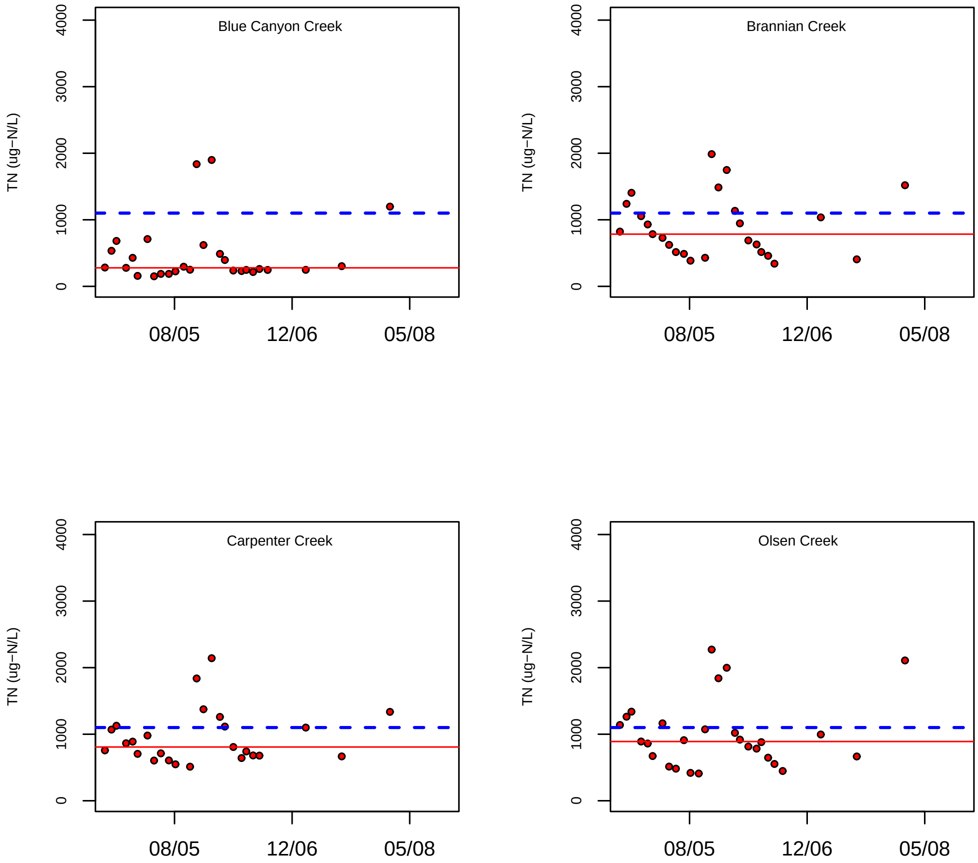


Figure B162: Total nitrogen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value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

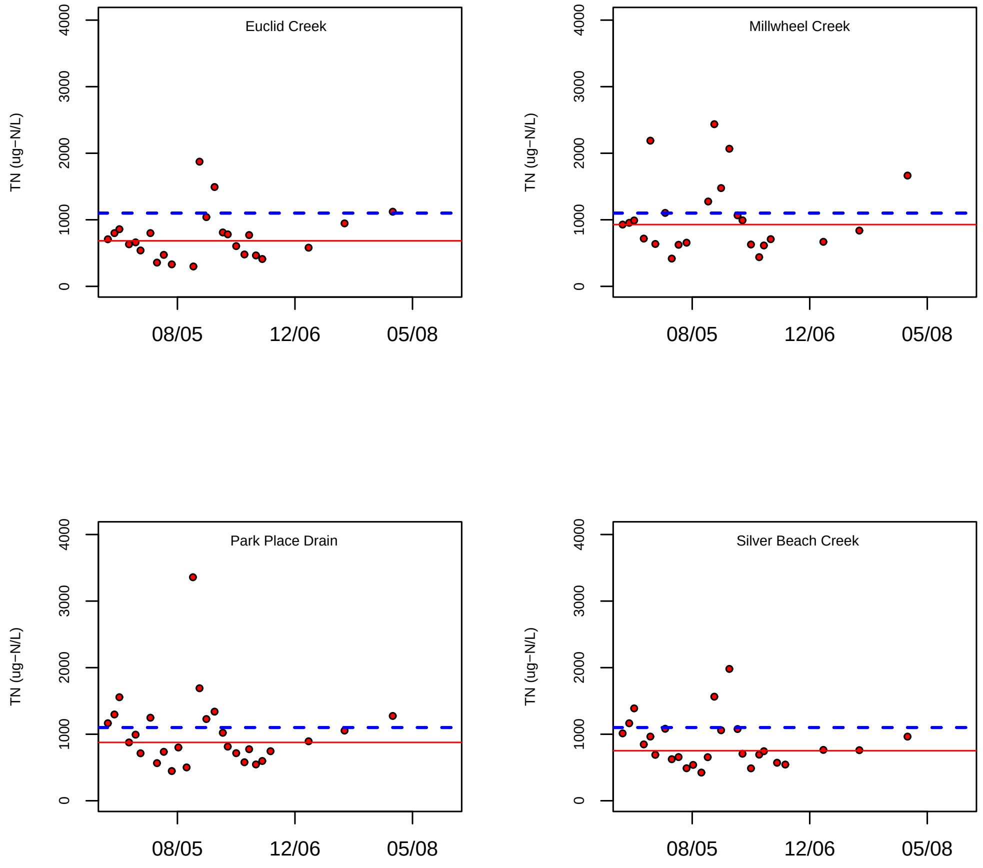


Figure B163: Total nitrogen data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value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

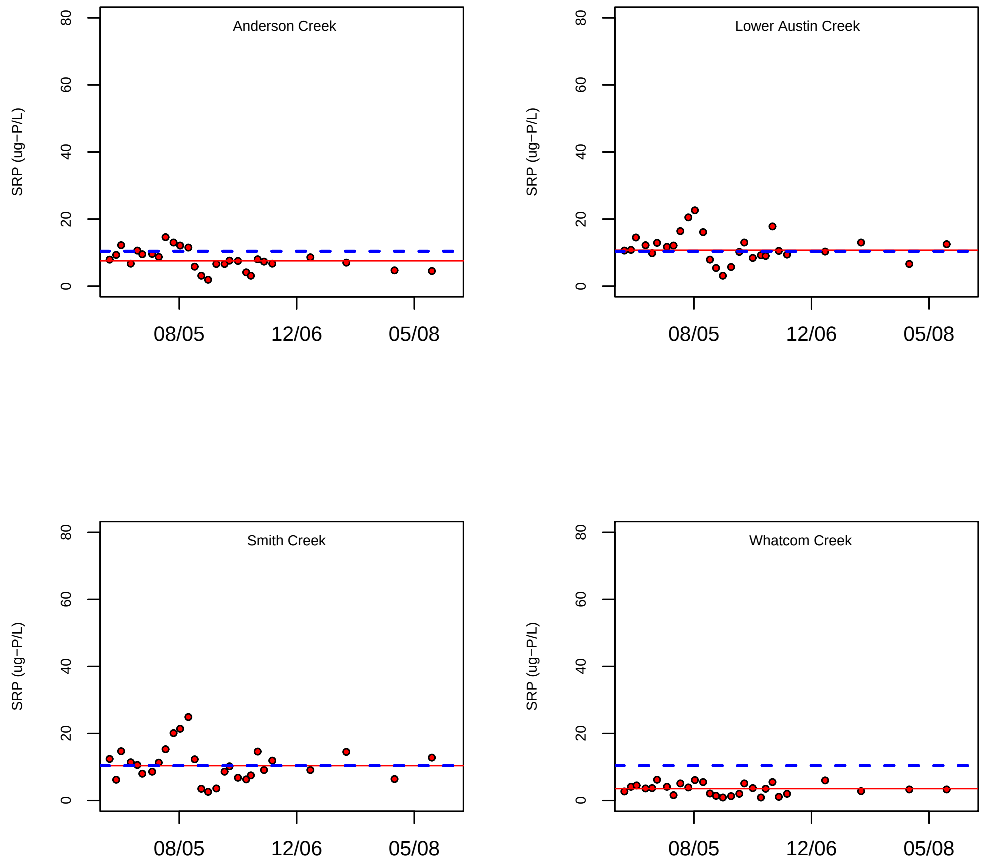


Figure B164: Soluble phosphate data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for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

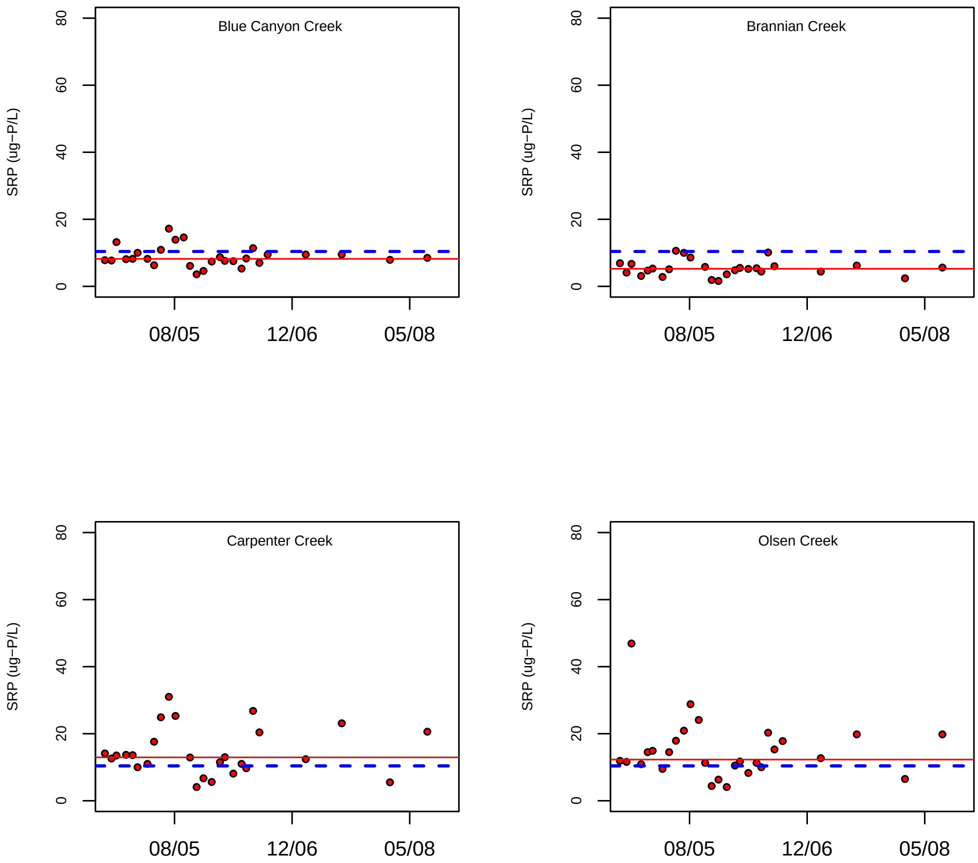


Figure B165: Soluble phosphate data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value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

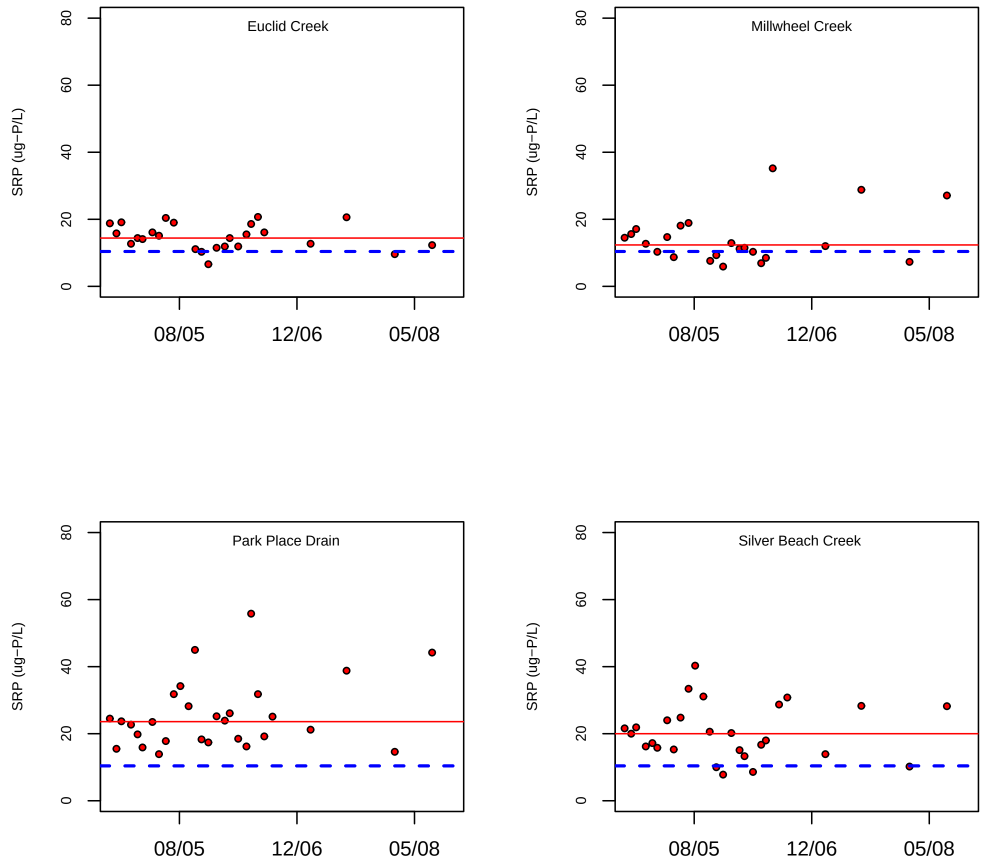


Figure B166: Soluble phosphate data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median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

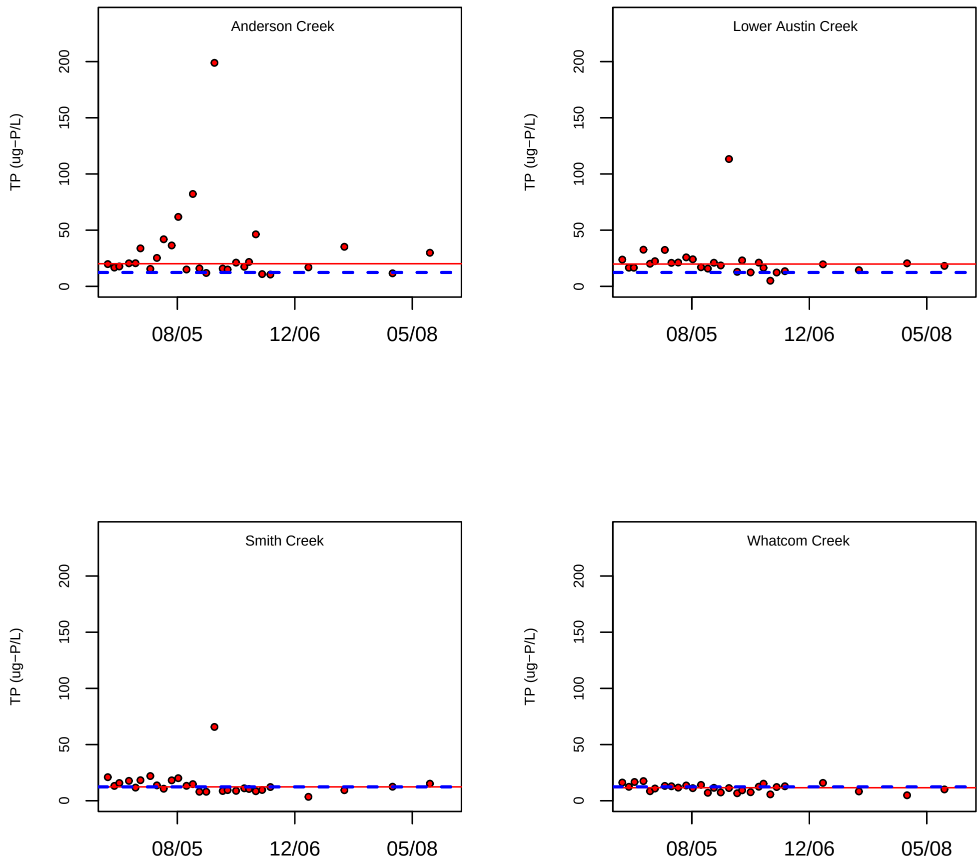


Figure B167: Total phosphorus data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each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

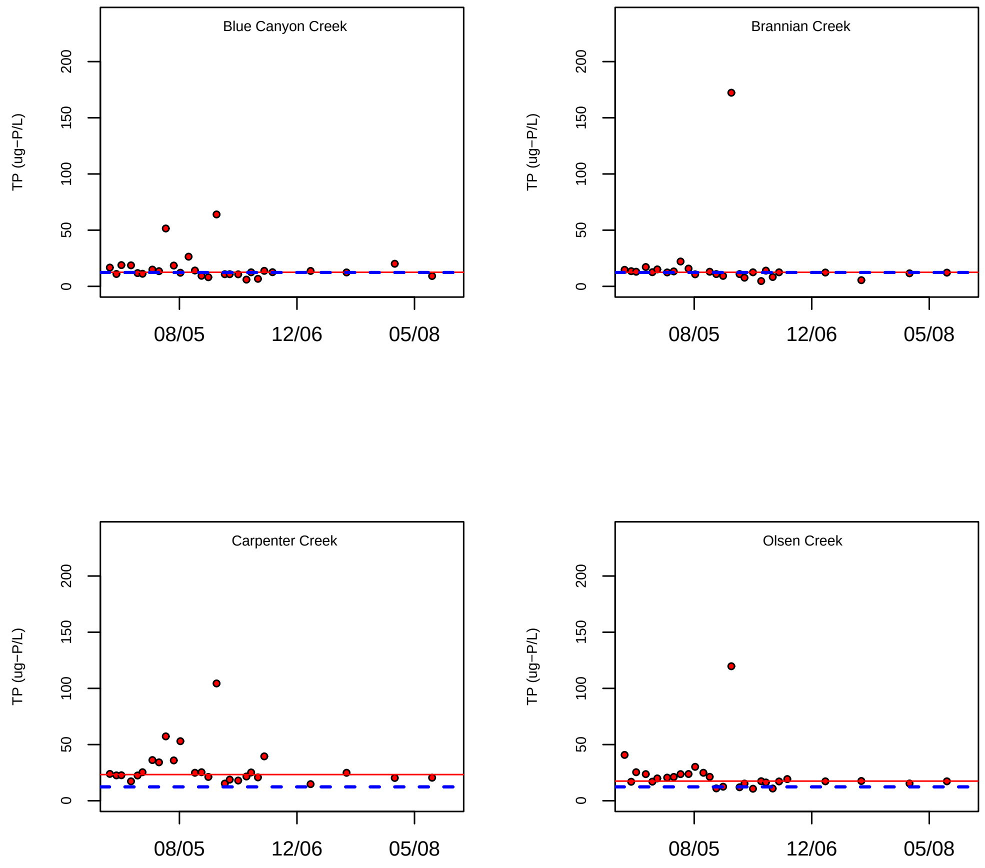


Figure B168: Total phosphorus data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value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

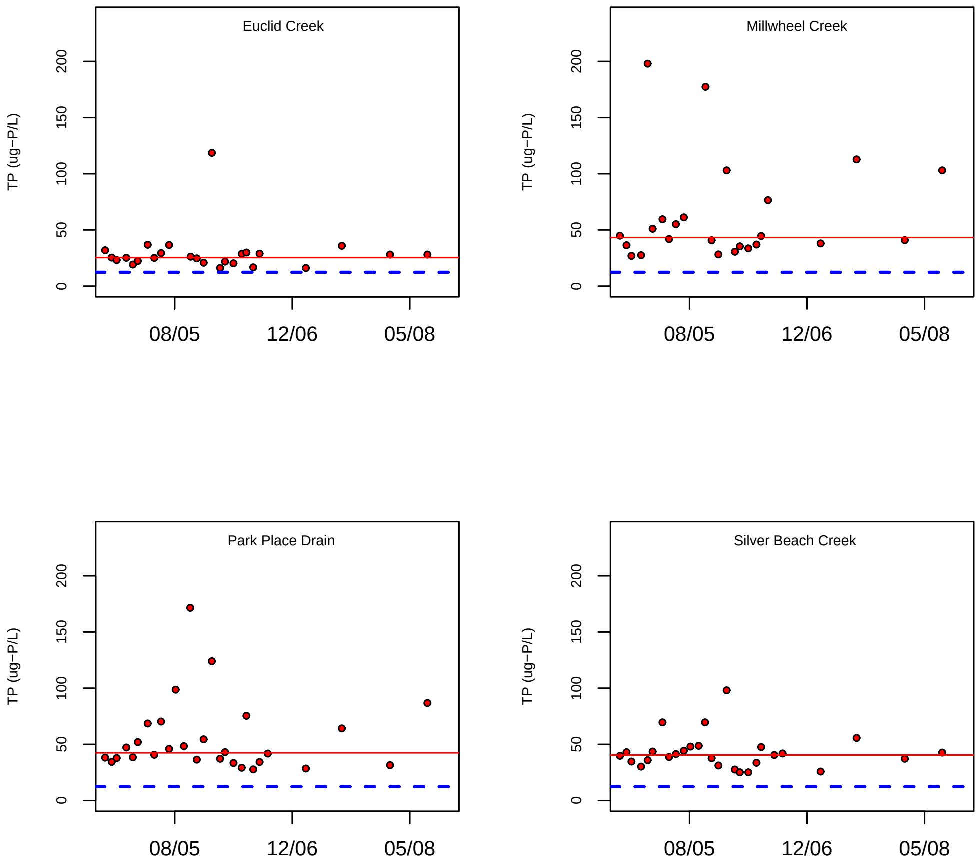


Figure B169: Total phosphorus data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median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

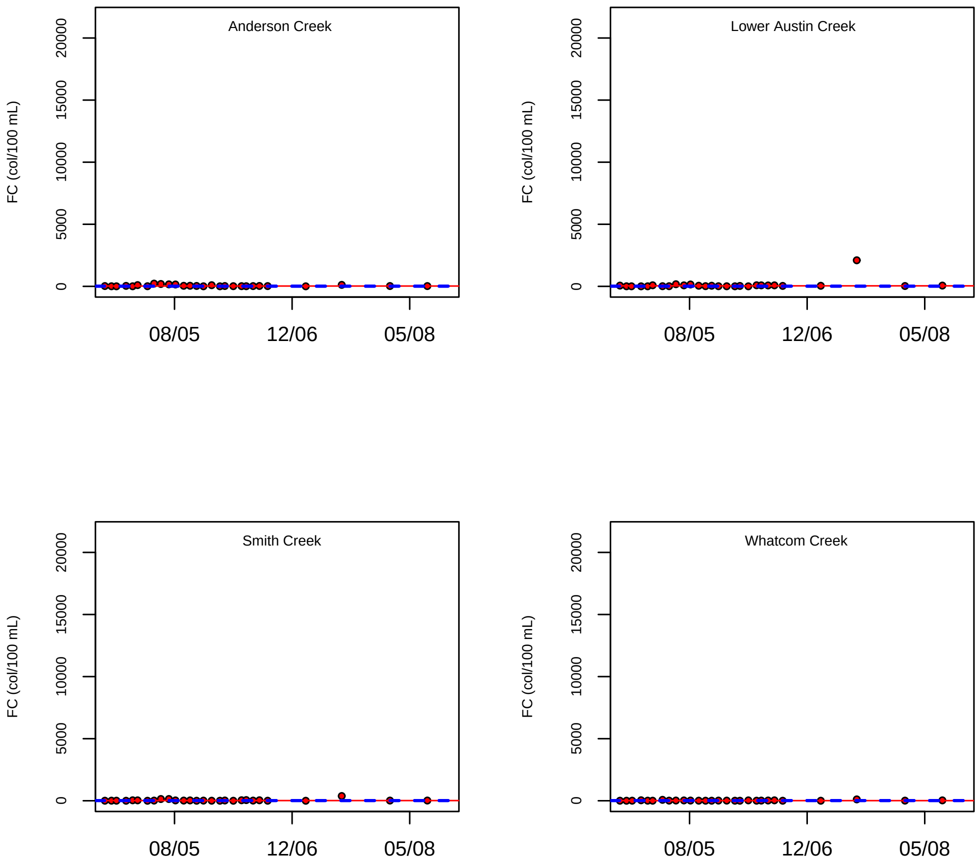


Figure B170: Fecal coliform data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each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

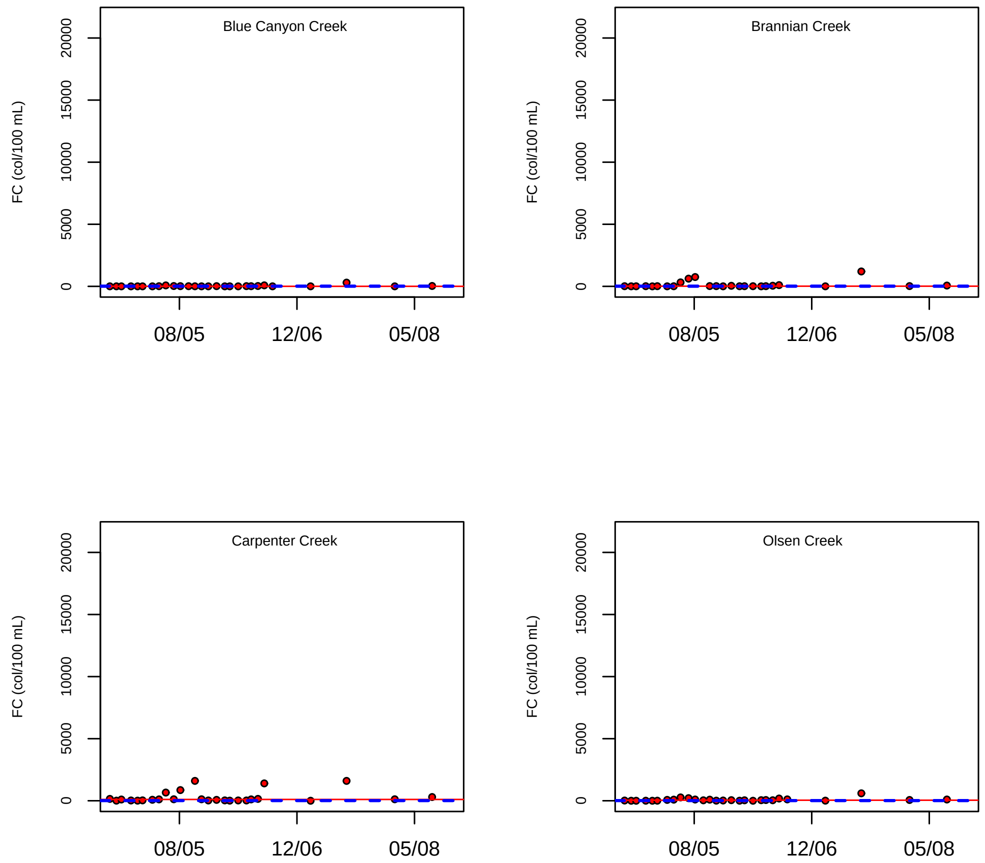


Figure B171: Fecal coliform data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value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

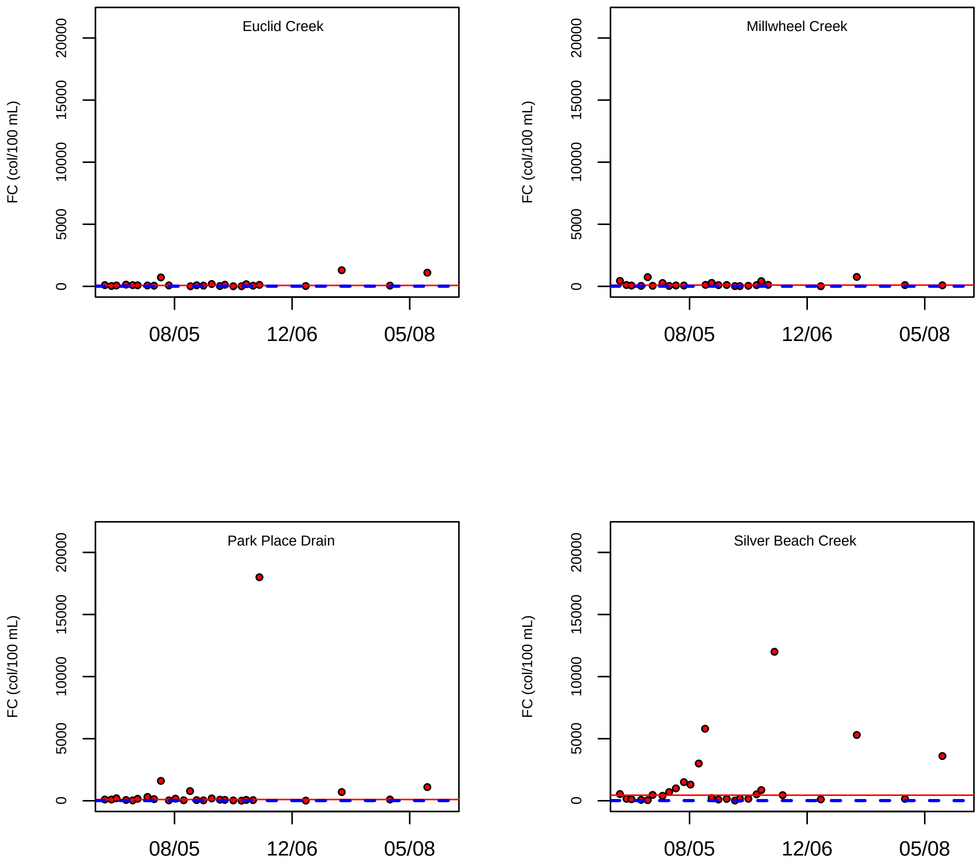


Figure B172: Fecal coliform data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value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

C Quality Control

C.1 Performance Evaluation Reports

In order to maintain a high degree of accuracy and confidence in the water quality data all personnel associated with this project were trained according to standard operating procedures for the methods listed in Table 1 (page 15). 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 except pH (WP–130) and turbidity (WP–136). Both analyses were repeated and the results were within acceptance limits.

	Reported Value[†]	True Value[†]	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	349	355	317–394	accept
Total alkalinity (mg/L as $CaCO_3$)	103	105	93.3–116	accept
Ammonia nitrogen, manual (mg-N/L)	18.8	18.7	14.0–23.1	accept
Ammonia nitrogen, autoanalysis (mg-N/L)	20.0	18.7	14.0–23.1	accept
Nitrate nitrogen, autoanalysis (mg-N/L)	21.9	22.2	18.1–25.8	accept
Nitrite nitrogen, autoanalysis (mg-N/L)	2.29	2.30	1.94–2.66	accept
Orthophosphate, manual (mg-P/L)	5.28	5.28	4.37–6.23	accept
Orthophosphate, autoanalysis (mg-P/L)	5.14	5.28	4.37–6.23	accept
Total phosphorus, manual (mg-P/L)	7.82	7.92	6.54–9.36	accept
Total phosphorus, autoanalysis (mg-P/L)	8.60	7.92	6.54–9.36	accept
pH	8.23	8.60	8.40–8.80	repeat
(WP–133, pH only)	9.93	9.90	9.70–10.1	accept
Solids, non-filterable (mg/L)	39.8	39.9	29.9–46.5	accept
Solids, total (mg/L)	301	275	236–311	accept
Turbidity (NTU)	7.14	6.72	5.61–7.71	accept

Table C1: Single-blind quality control results, WP–130 (11/16/2007).

	Reported Value†	True Value†	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	412	411	368–455	accept
Total alkalinity (mg/L as $CaCO_3$)	79.4	80.2	70.7–88.6	accept
Ammonia nitrogen, manual (mg-N/L)	1.09	1.06	0.659–1.59	accept
Ammonia nitrogen, autoanalysis (mg-N/L)	1.31	1.06	0.659–1.59	accept
Nitrate nitrogen, autoanalysis (mg-N/L)	2.25	2.21	1.79–2.59	accept
Nitrite nitrogen, autoanalysis (mg-N/L)	2.34	2.39	2.02–2.76	accept
Orthophosphate, manual (mg-P/L)	3.68	3.71	3.05–4.40	accept
Orthophosphate, autoanalysis (mg-P/L)	3.65	3.71	3.05–4.40	accept
Total phosphorus, manual (mg-P/L)	2.25	2.42	1.95–2.94	accept
Total phosphorus, autoanalysis (mg-P/L)	2.22	2.42	1.95–2.94	accept
pH	6.90	6.90	6.70–7.10	repeat
Solids, non-filterable (mg/L)	51.8	56.2	44.2–63.8	accept
Solids, total (mg/L)	320	312	271–349	accept
Turbidity (NTU)	15.9	14.0	11.9–15.7	repeat
(WP–138, turbidity only)	11.9	12.0	10.2–13.5	accept

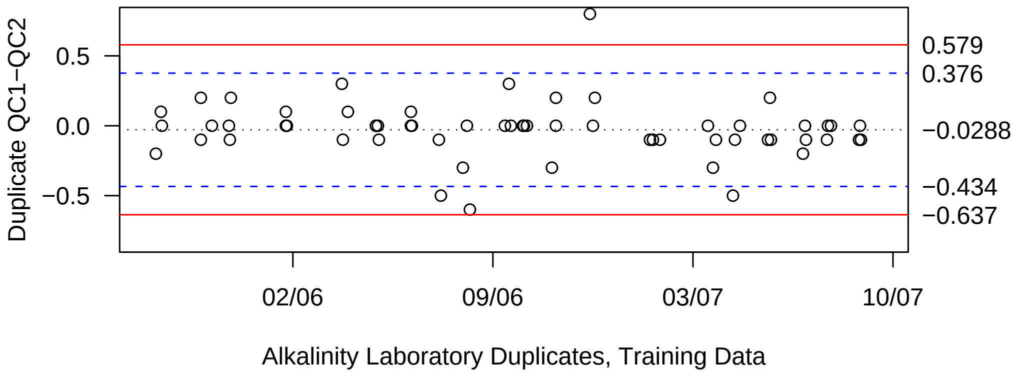
Table C2: Single-blind quality control results, WP–136 (5/16/2008).

C.2 Laboratory Duplicates, Spikes, and Check Standards

Ten percent of all 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.[23]

The quality control results for laboratory duplicates, matrix spikes, and check standards are plotted in control charge. 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 2005 through September 2007 (upper examples in Figures C1–C23, pages 275–297), and used to evaluate data from October 2007 through September 2008 (lower examples in Figures C1–C23).

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



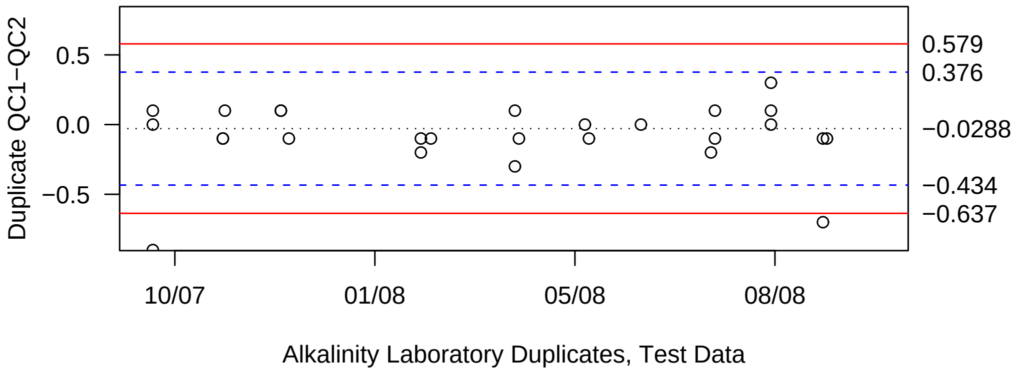
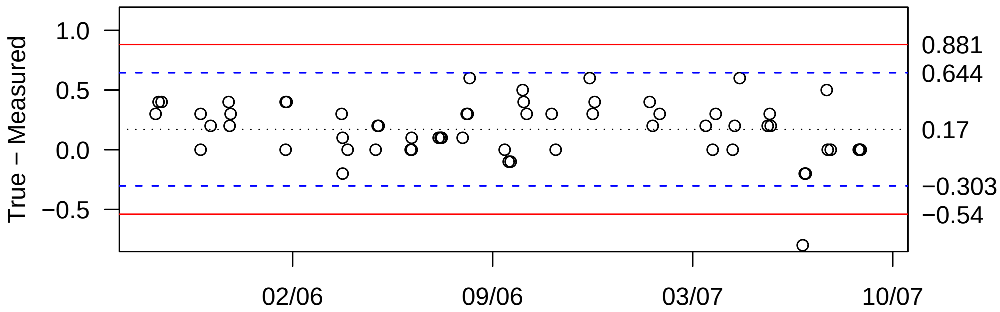
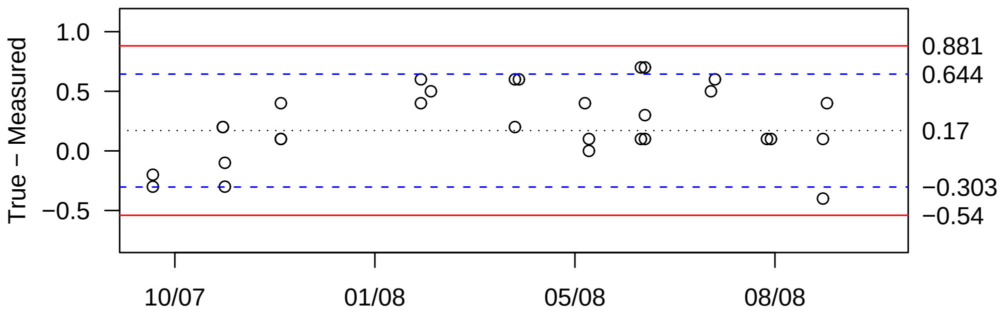


Figure C1: Alkalinity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

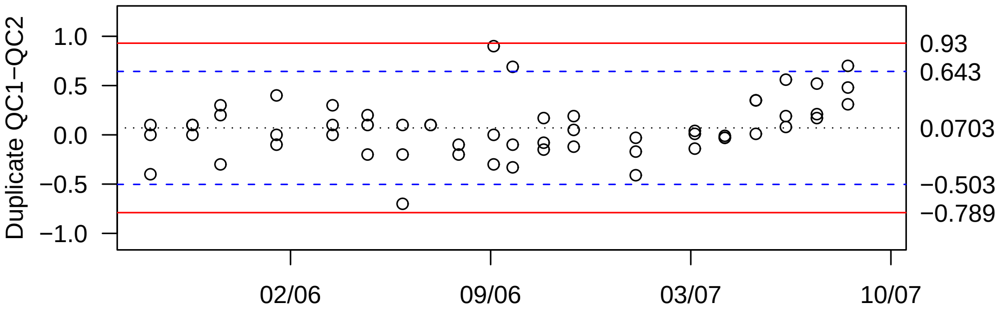


Alkalinity Check Standards, Training Data

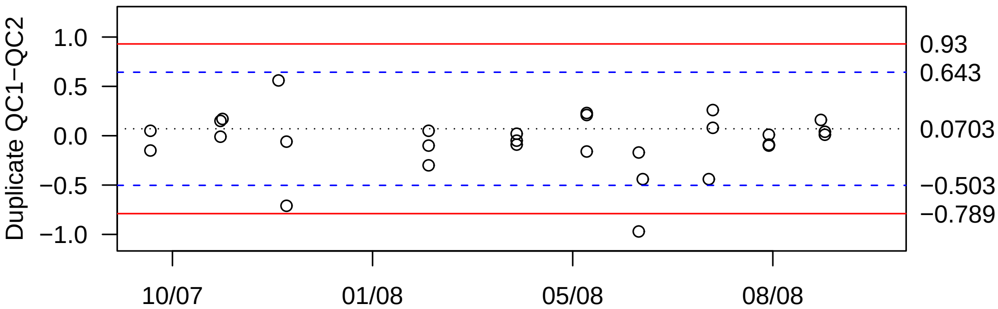


Alkalinity Check Standards, Test Data

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 preceeding two years of lab duplicate data.

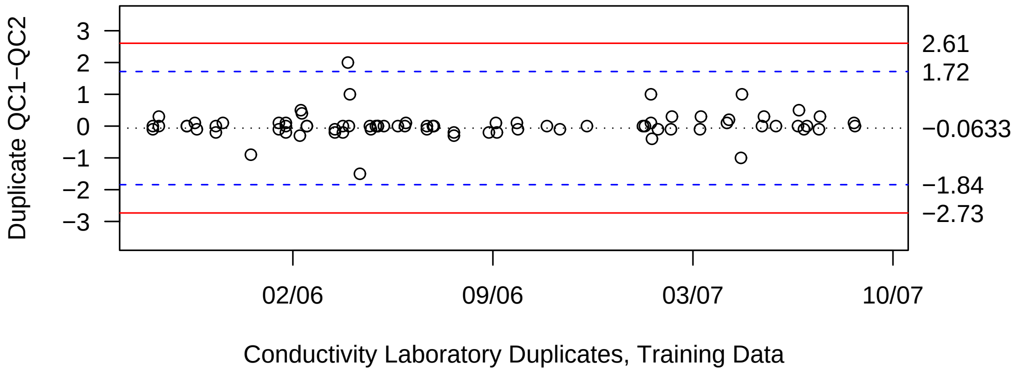


Chlorophyll Laboratory Duplicates, Training Data



Chlorophyll Laboratory Duplicates, Test Data

Figure C3: Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program. 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 preceeding two years of lab duplicate data.



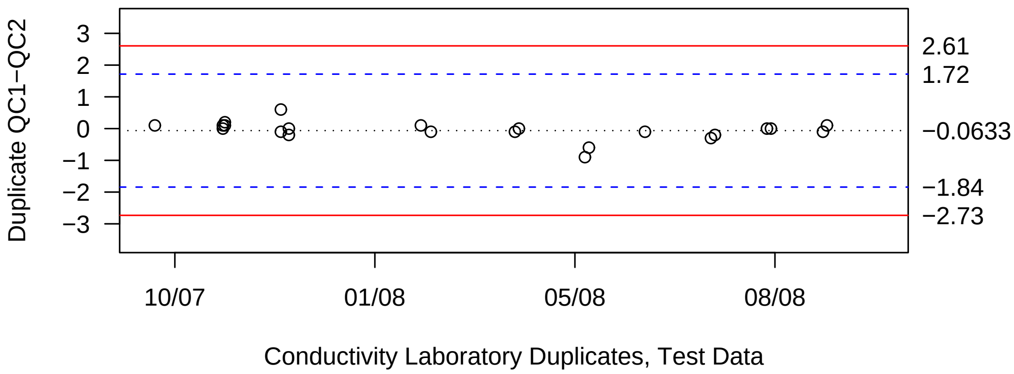
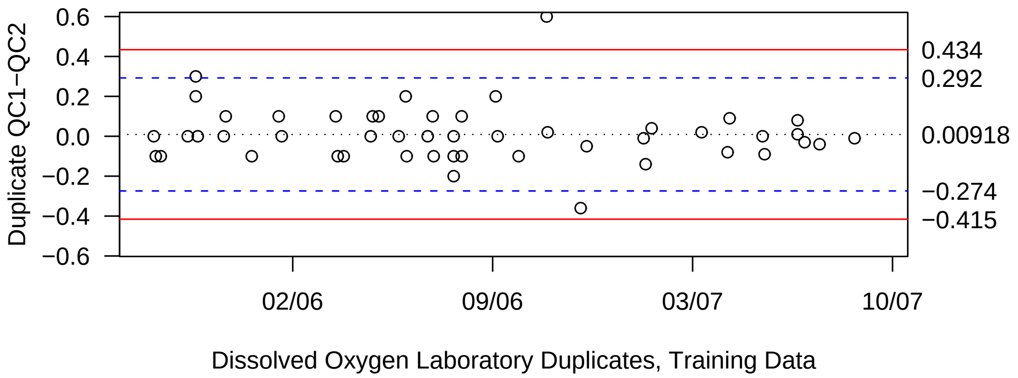


Figure C4: Conductivity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



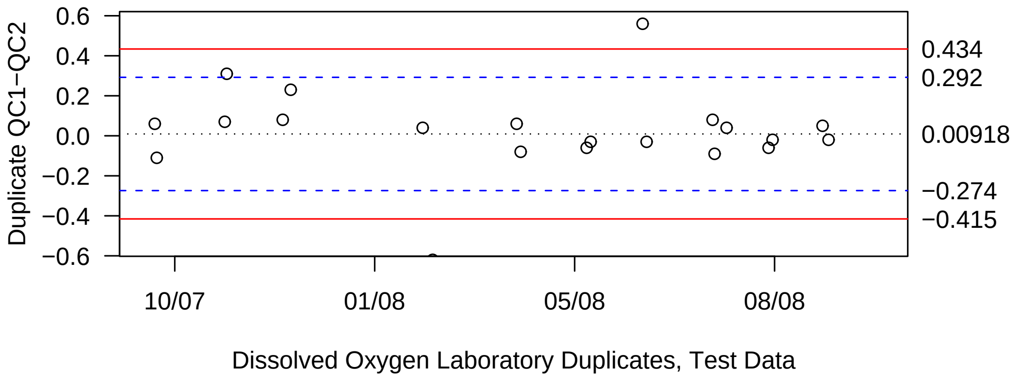
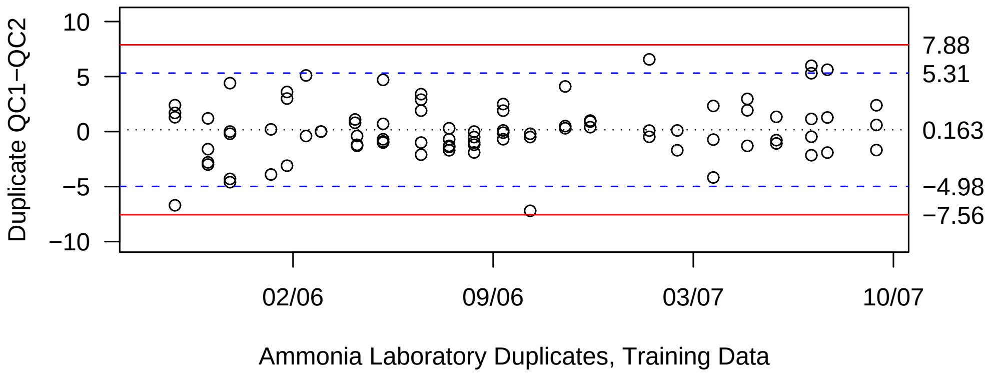


Figure C5: Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



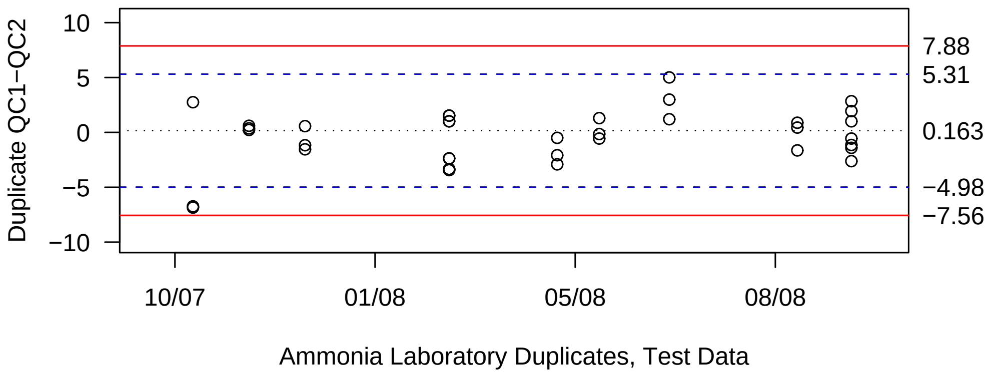
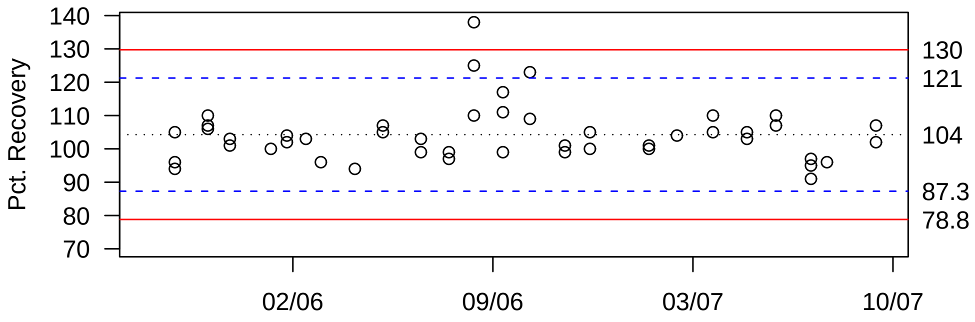
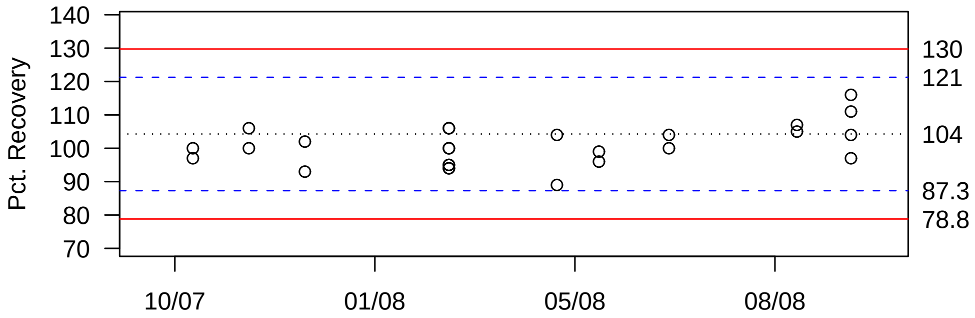


Figure C6: Ammonia laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

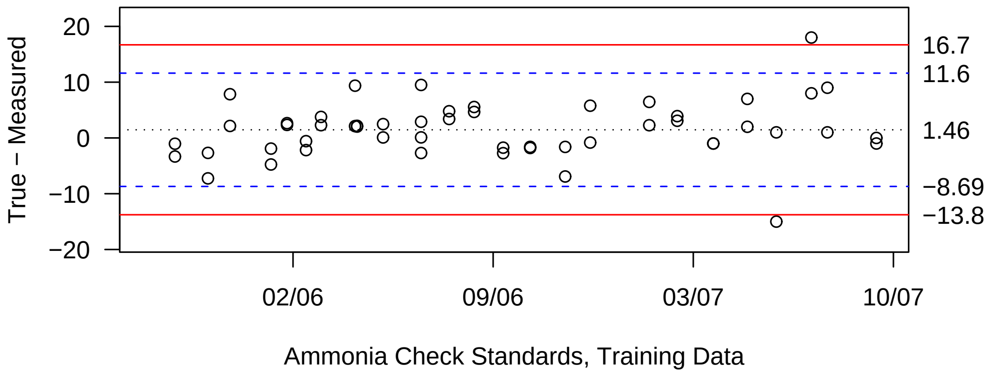


Ammonia Spike Recoveries, Training Data



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 preceeding two years of lab duplicate data. Although the training



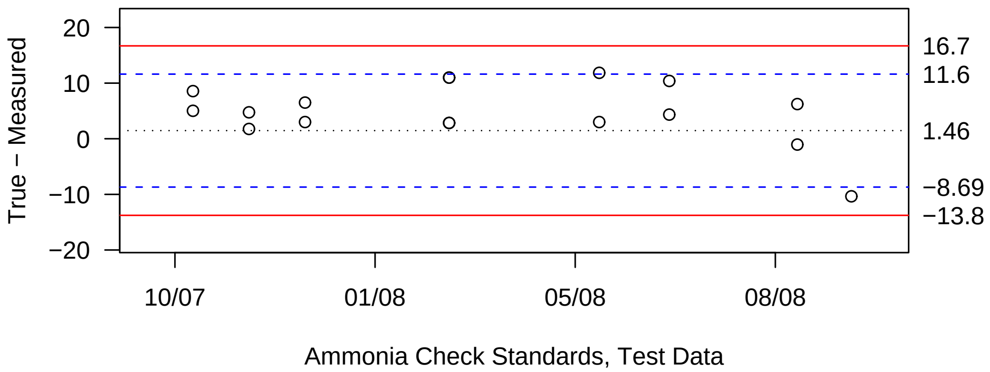
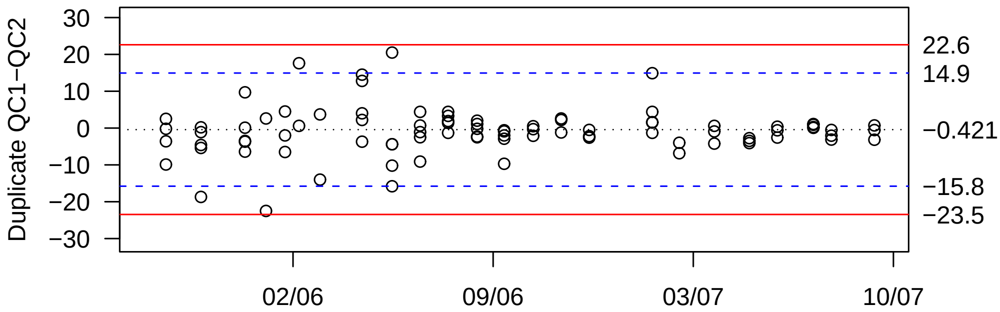
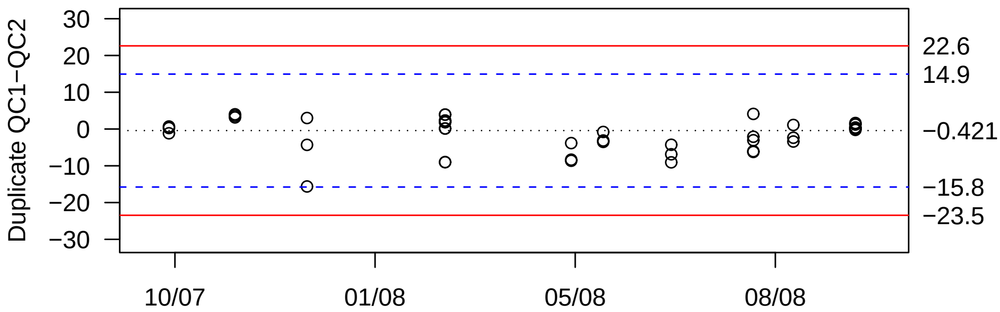


Figure C8: Ammonia check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

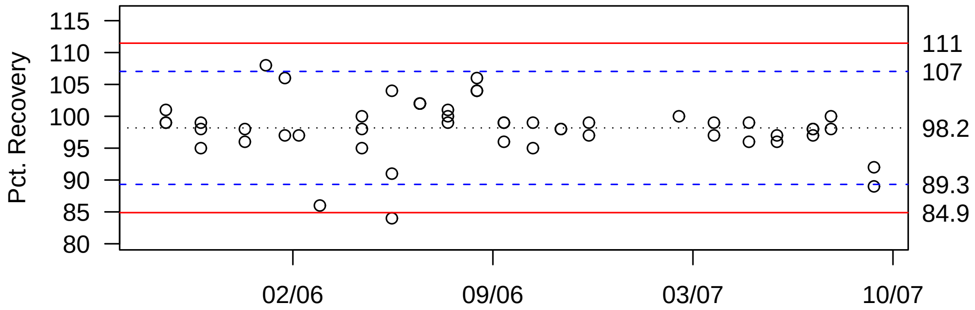


Nitrate+Nitrite Laboratory Duplicates, Training Data

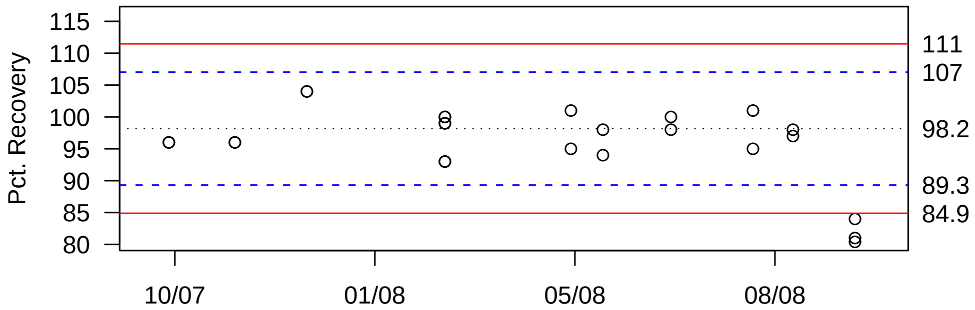


Nitrate+Nitrite Laboratory Duplicates, Test Data

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 preceeding two years of lab duplicate data.

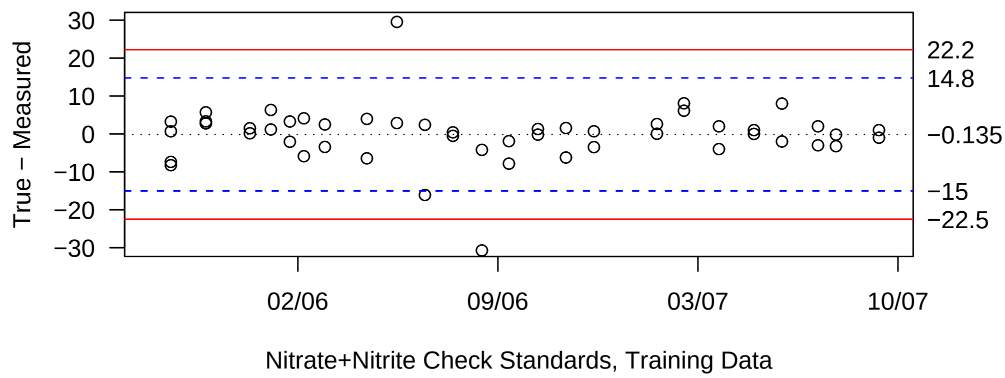


Nitrate+Nitrite Spike Recoveries, Training Data



Nitrate+Nitrite Spike Recoveries, Test Data

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



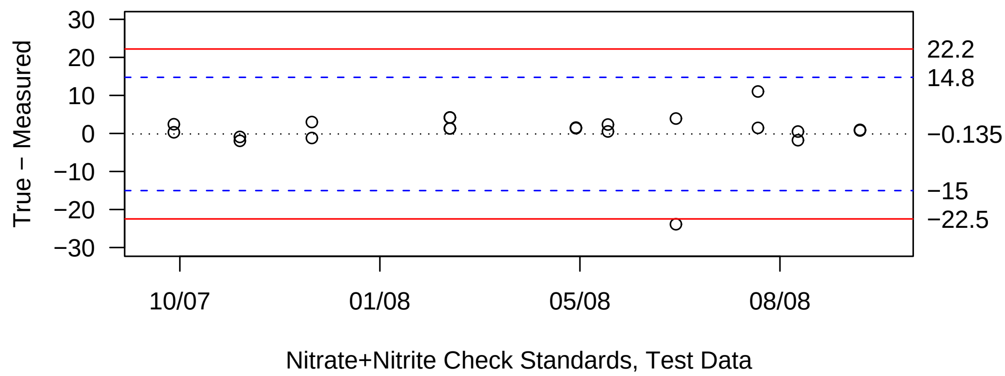
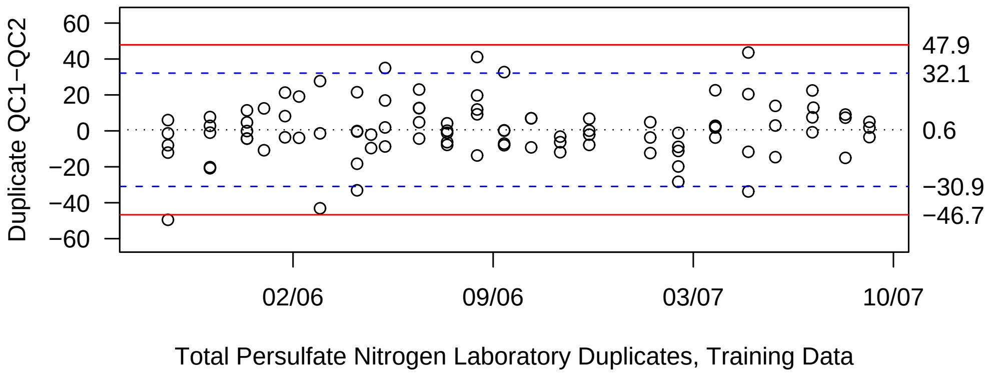


Figure C11: Nitrate/nitrite check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



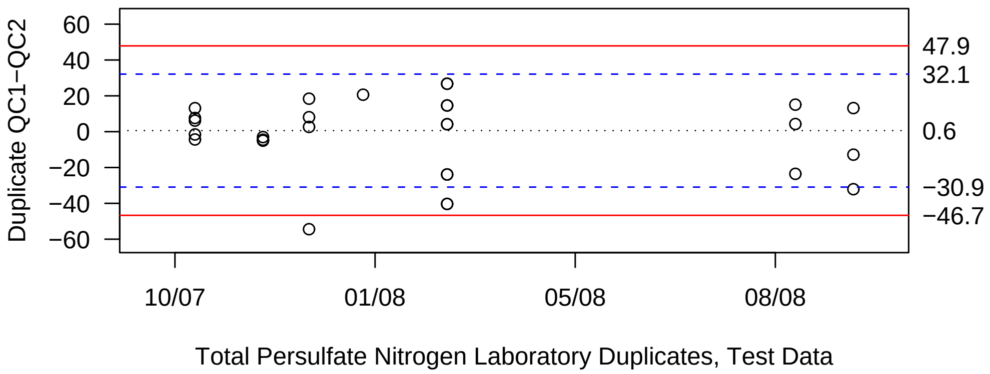
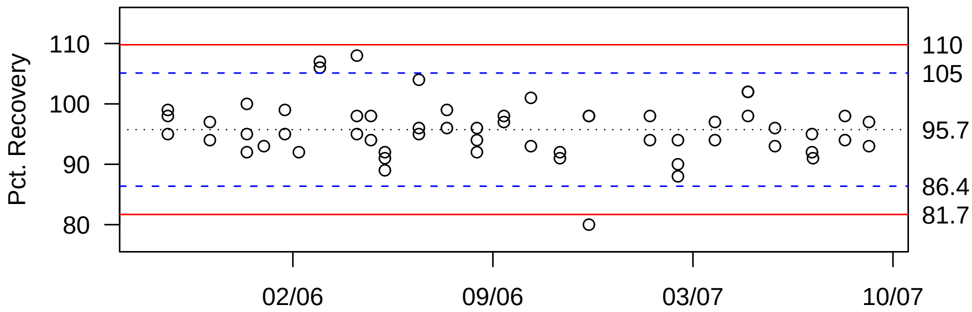
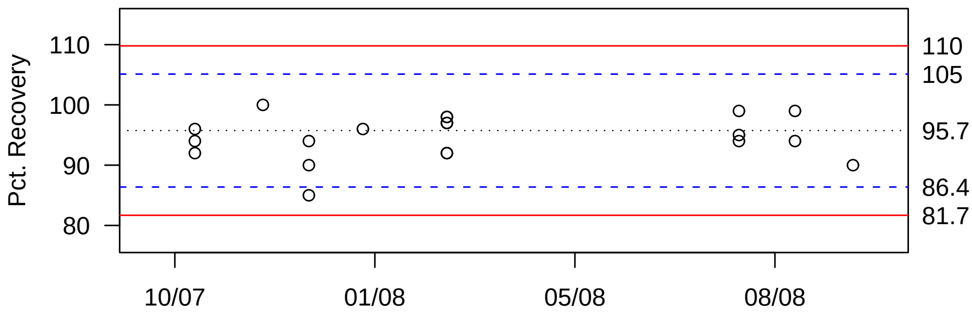


Figure C12: Total nitrogen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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

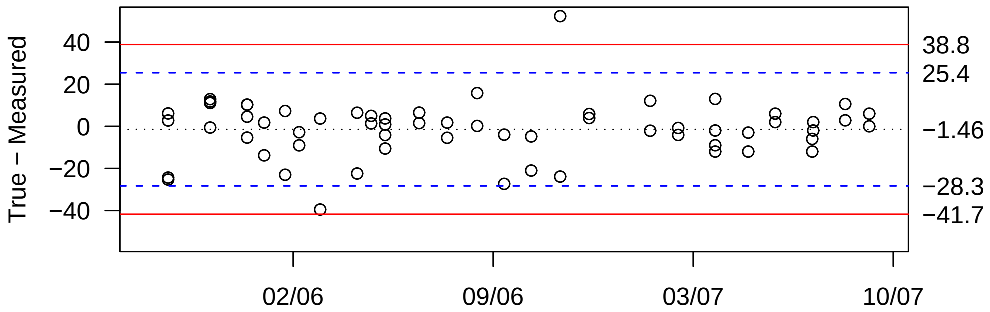


Total Persulfate Nitrogen Spike Recoveries, Training Data

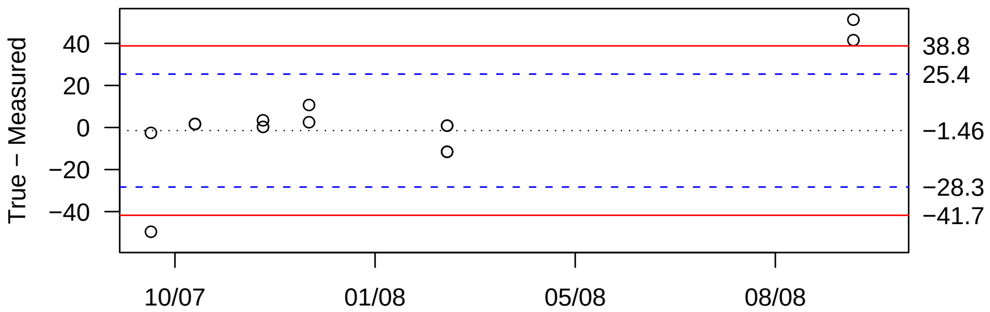


Total Persulfate Nitrogen Spike Recoveries, Test Data

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 preceeding two years of lab duplicate data.

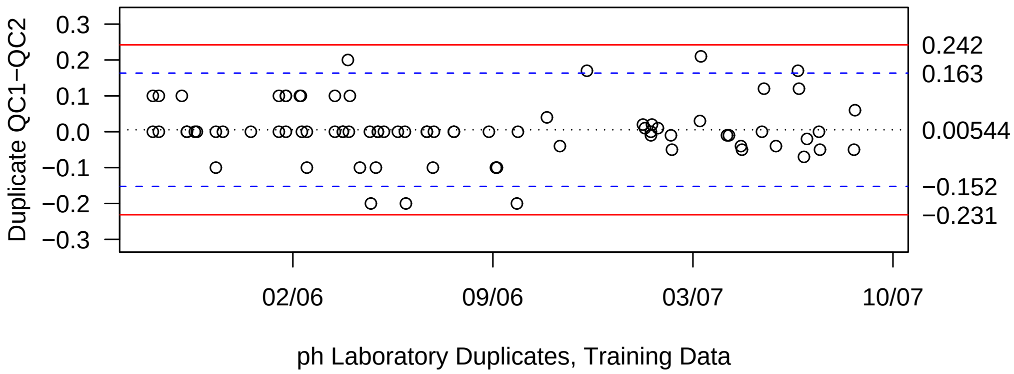


Total Persulfate Nitrogen Check Standards, Training Data



Total Persulfate Nitrogen Check Standards, Test Data

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



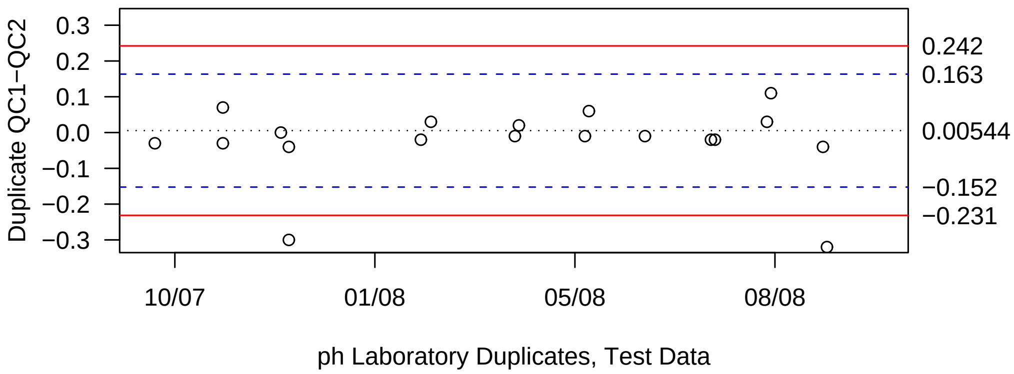
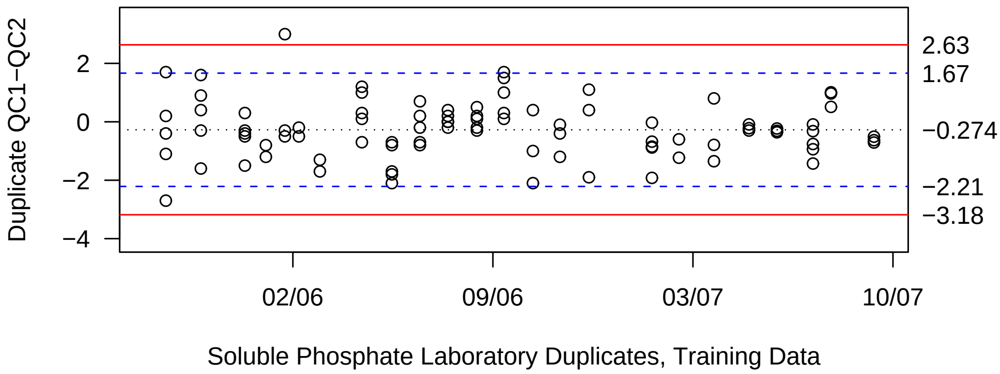


Figure C15: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



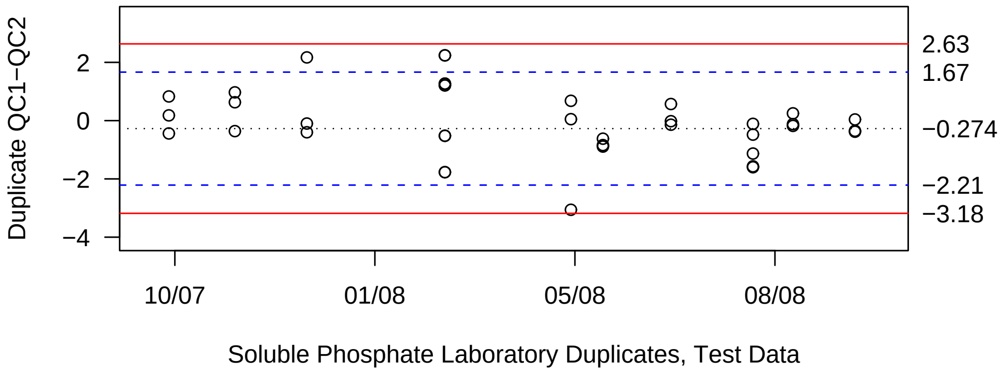
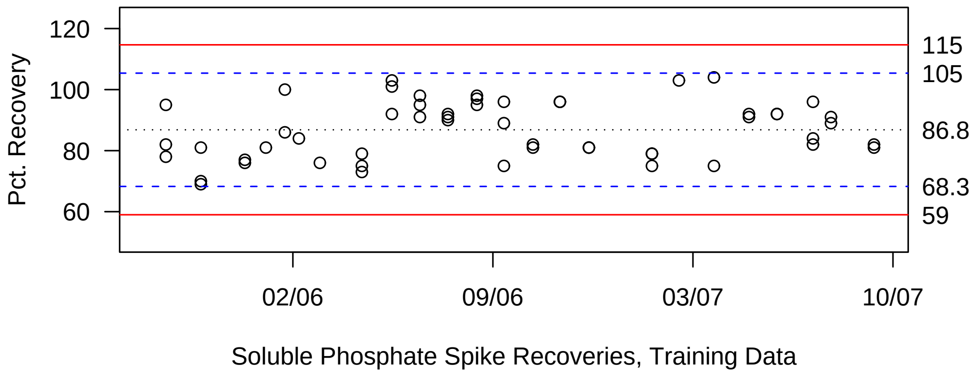


Figure C16: Soluble reactive phosphate laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



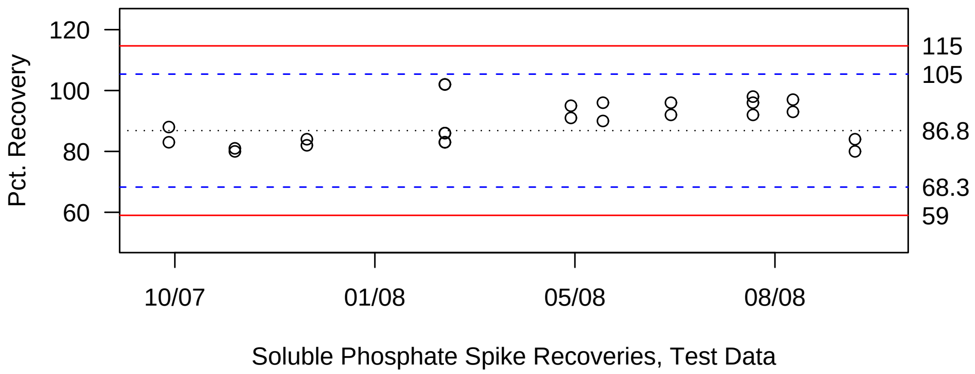
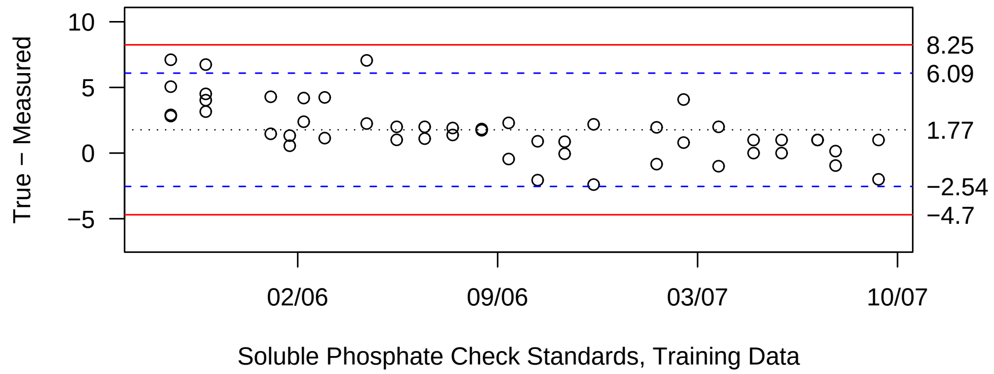


Figure C17: Soluble reactive phosphate matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



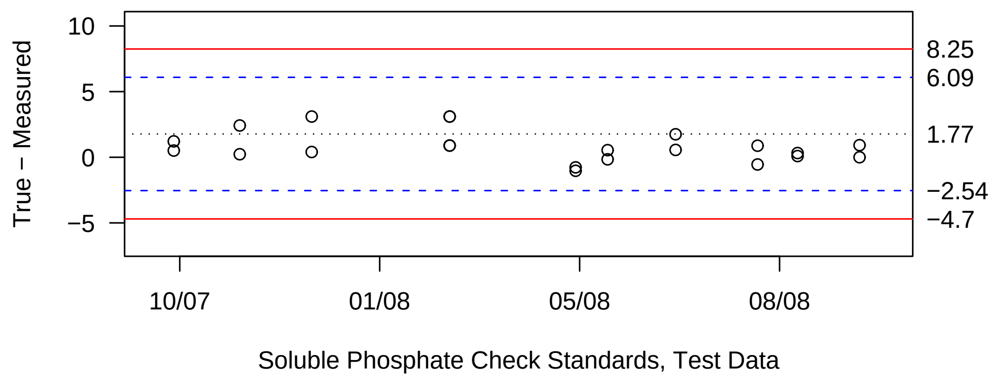
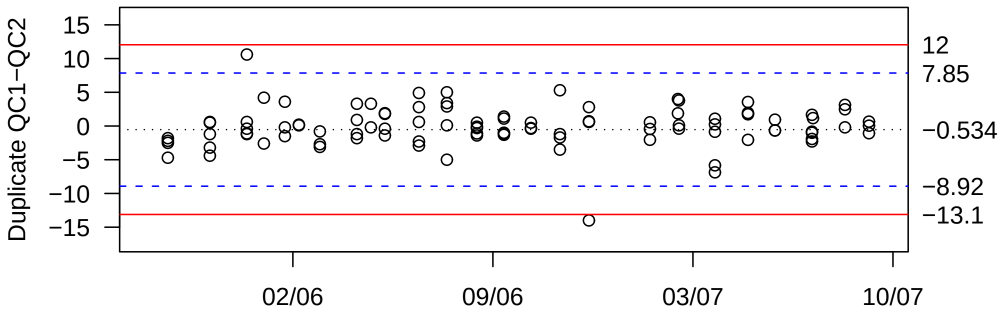
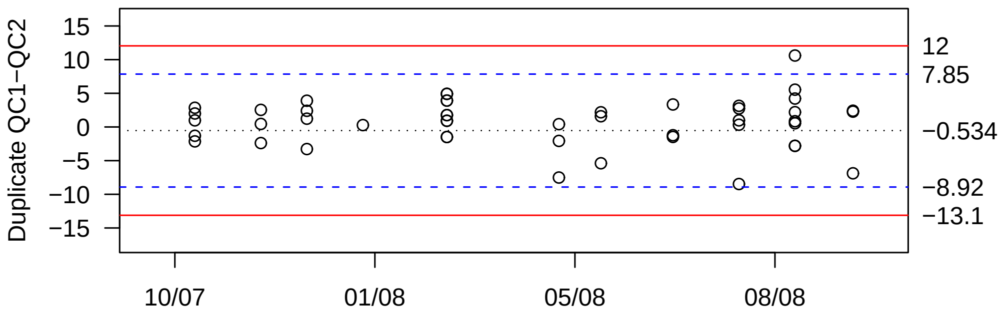


Figure C18: Soluble reactive phosphate check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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

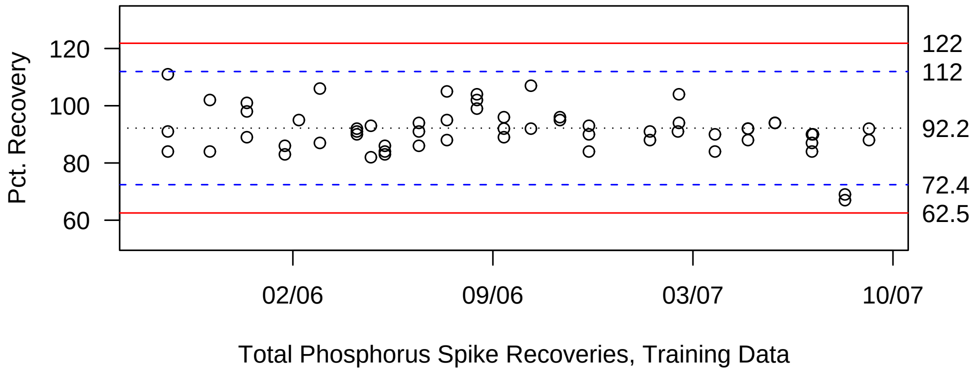


Total Phosphorus Laboratory Duplicates, Training Data



Total Phosphorus Laboratory Duplicates, Test Data

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



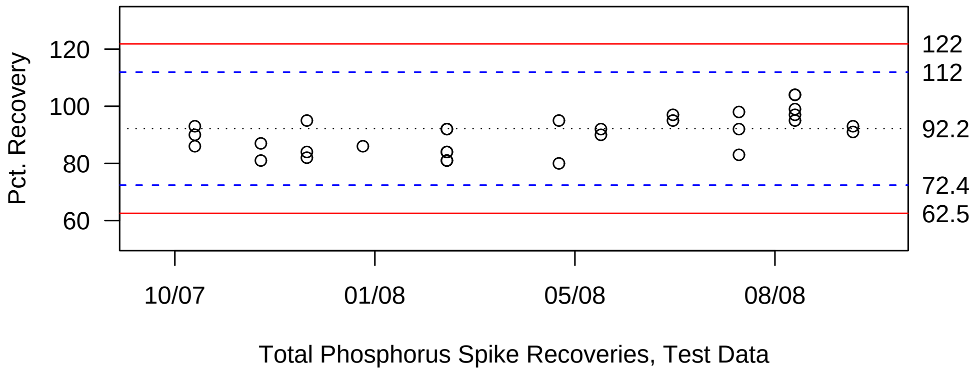
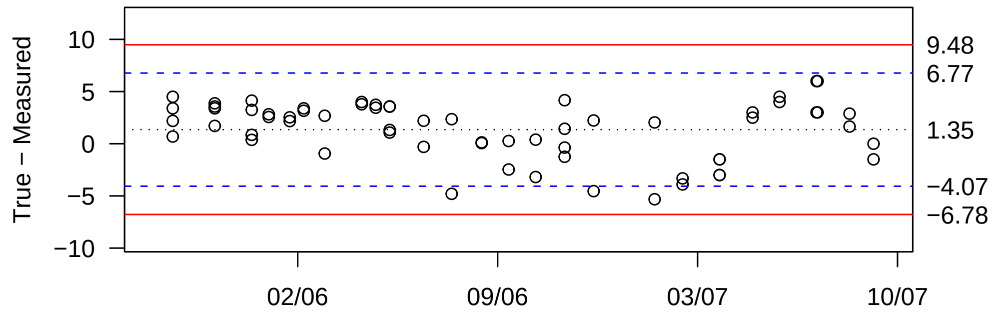
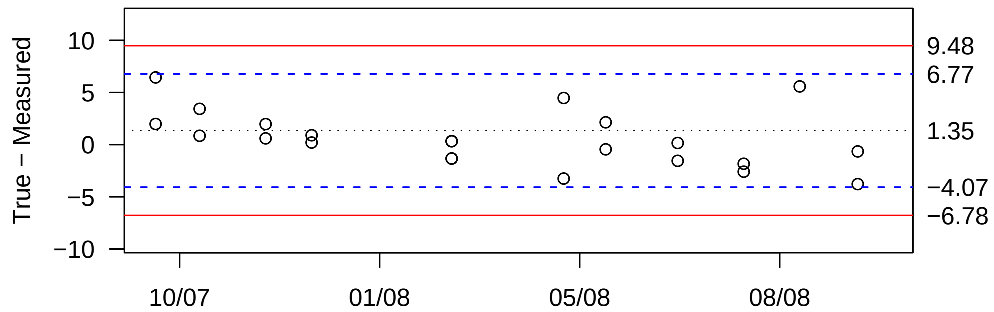


Figure C20: Total phosphorus matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

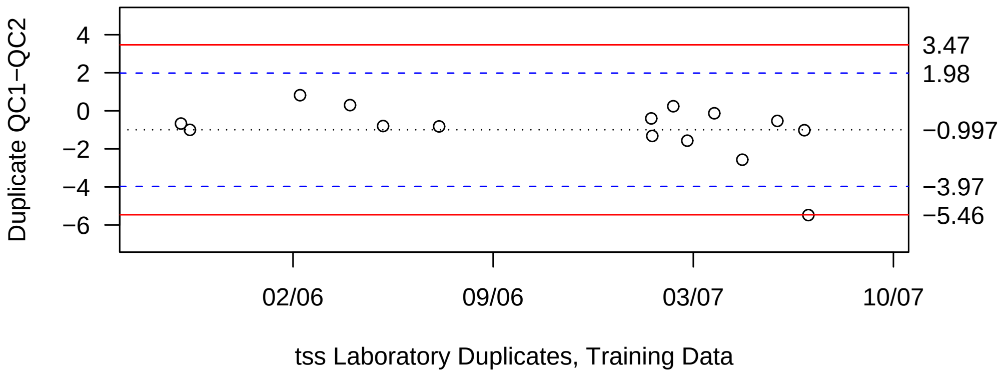


Total Phosphorus Check Standards, Training Data



Total Phosphorus Check Standards, Test 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 preceeding two years of lab duplicate data.



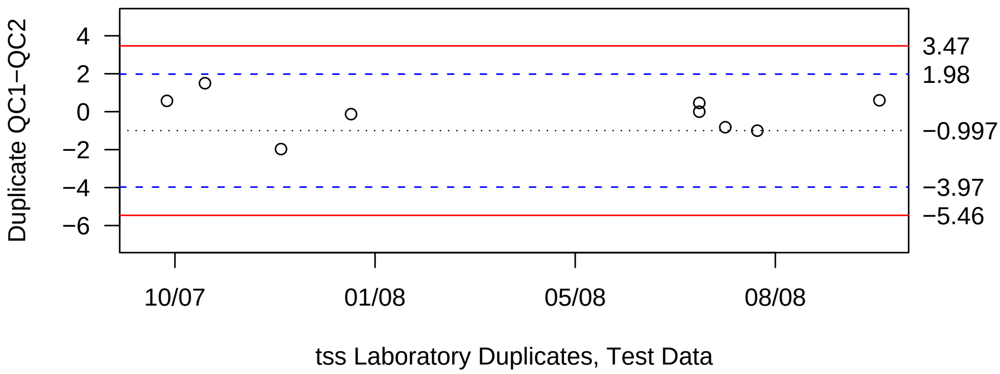
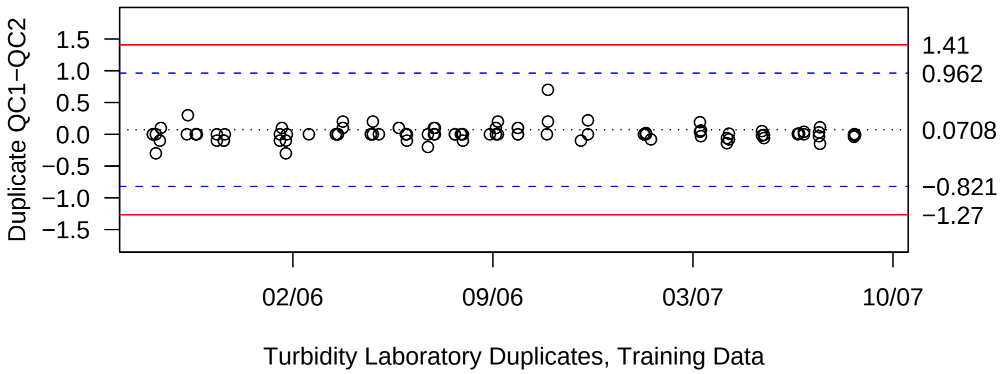


Figure C22: Total suspended solids laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



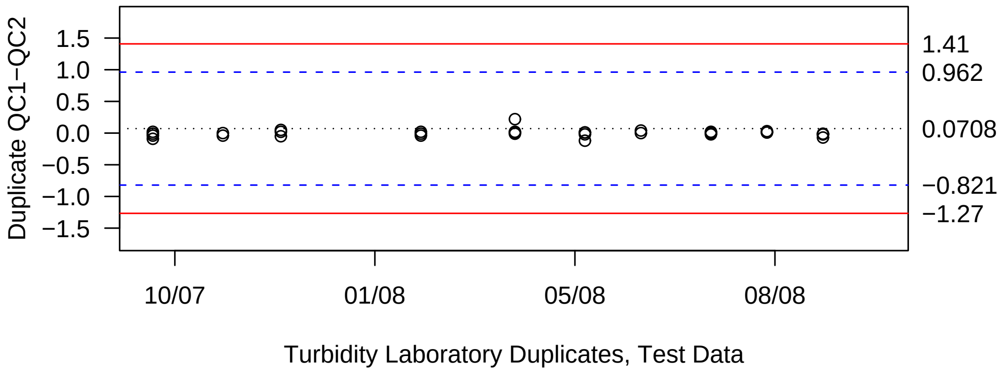


Figure C23: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

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 C24–C33, pages 299–308). 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:

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

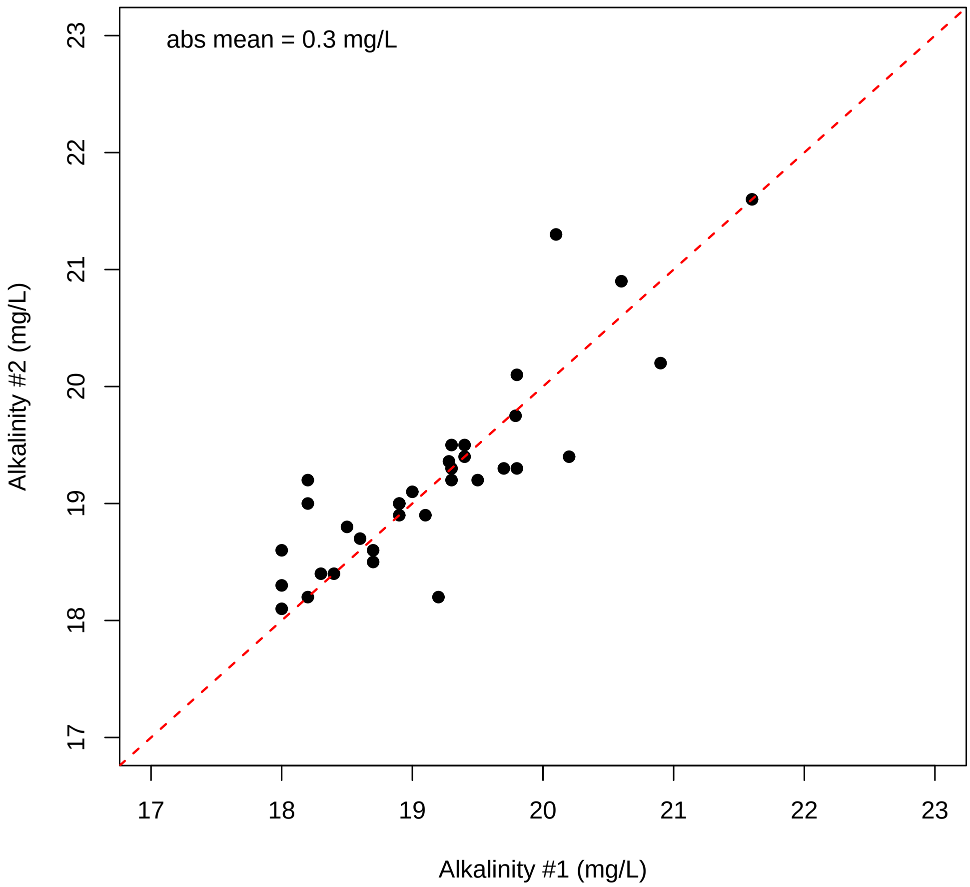


Figure C24: Alkalinity field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

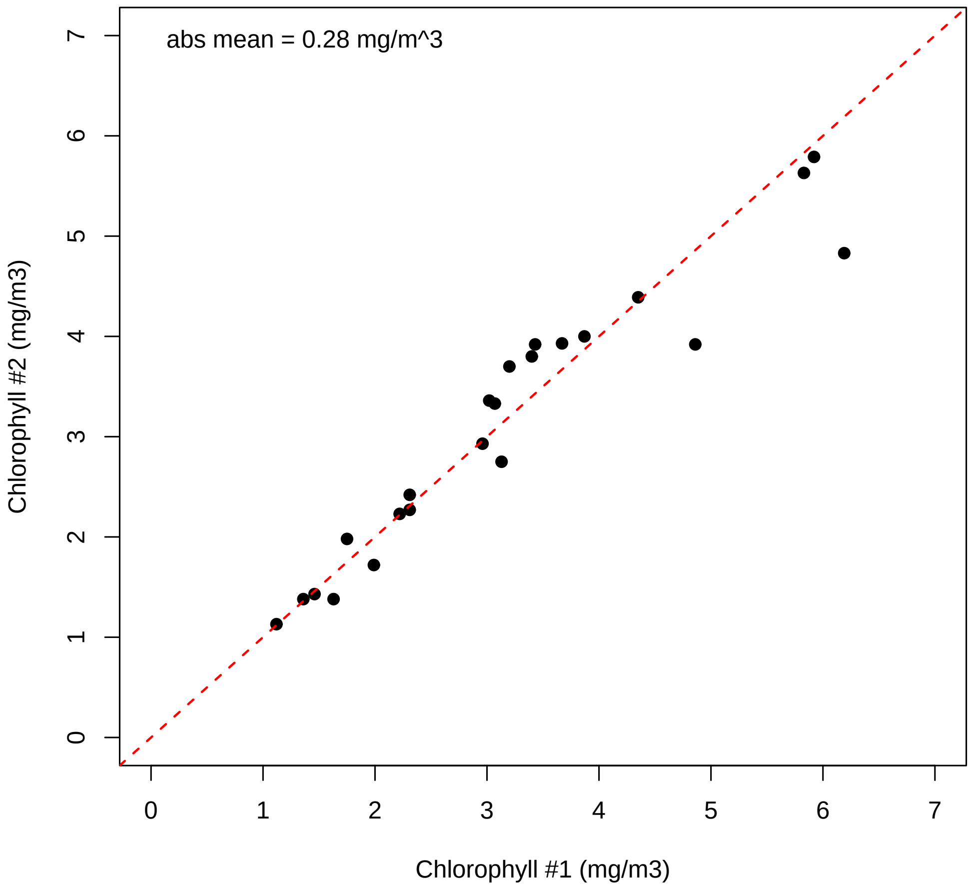


Figure C25: Chlorophyll field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

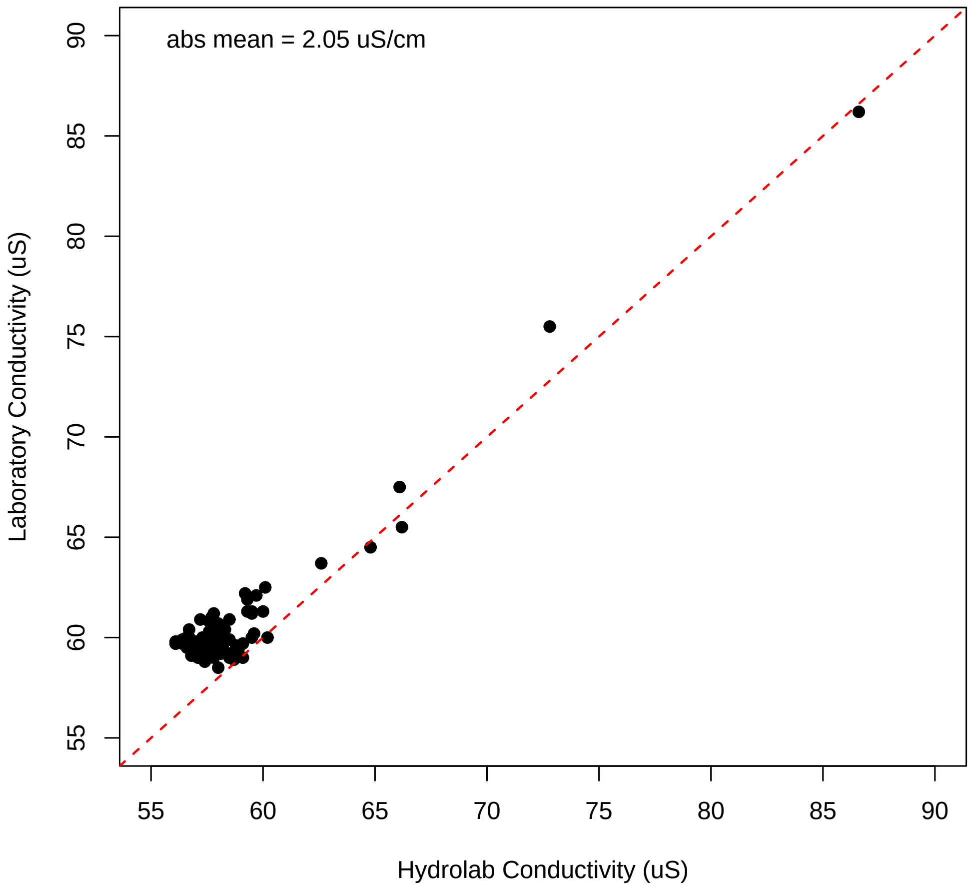


Figure C26: Conductivity field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

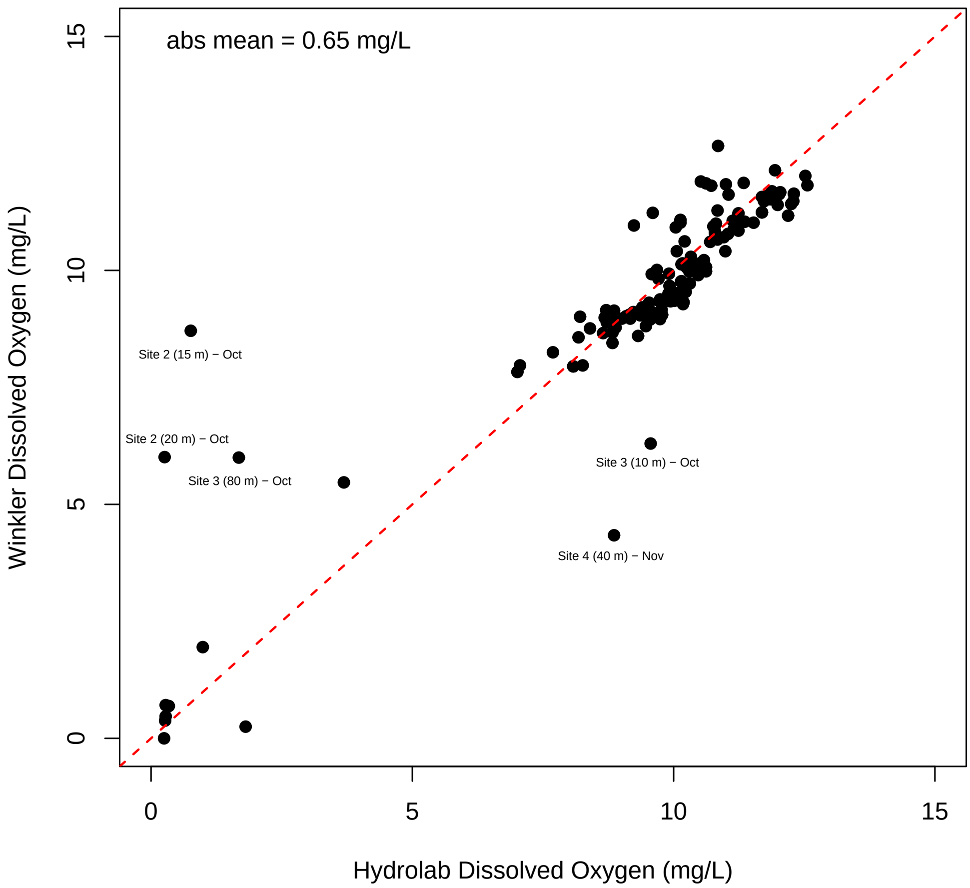


Figure C27: Dissolved oxygen field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. Most outliers were collected just prior to destratification at depths were extreme oxygen gradients were present. These differences illustrate the variation between samples collected at true depth (Hydrolab) and depth measured using a marked line (Winkler), which is slightly shallower than true depth.

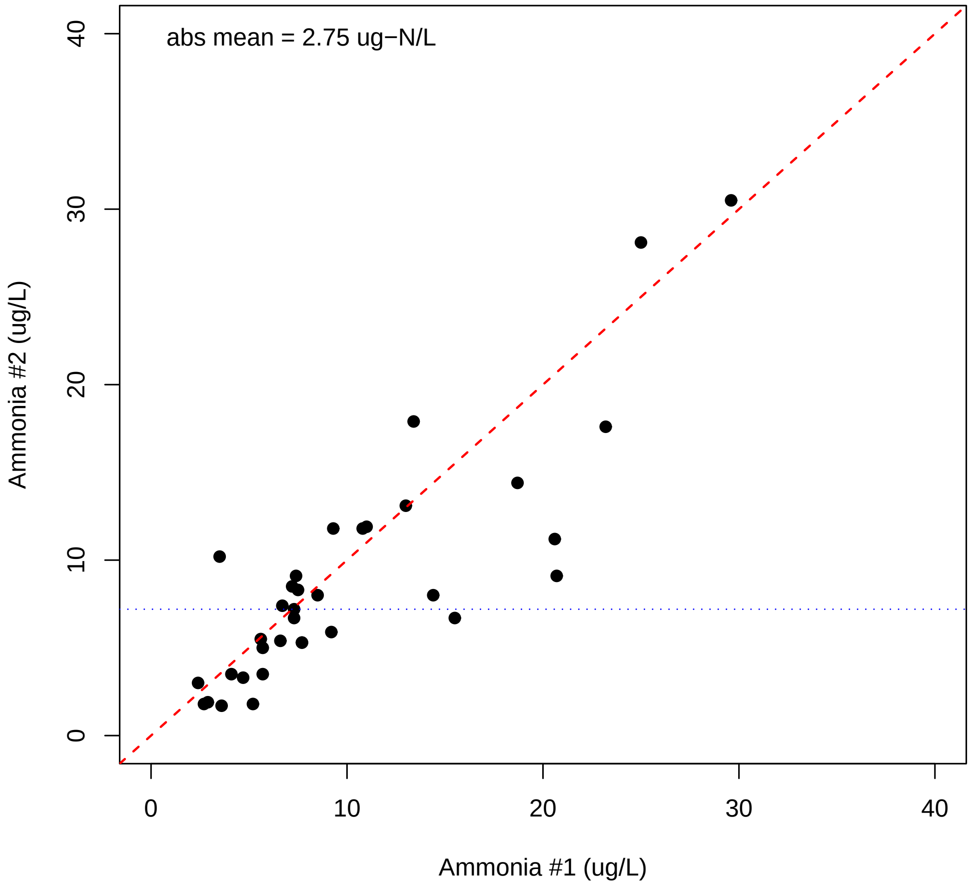


Figure C28: Ammonia field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

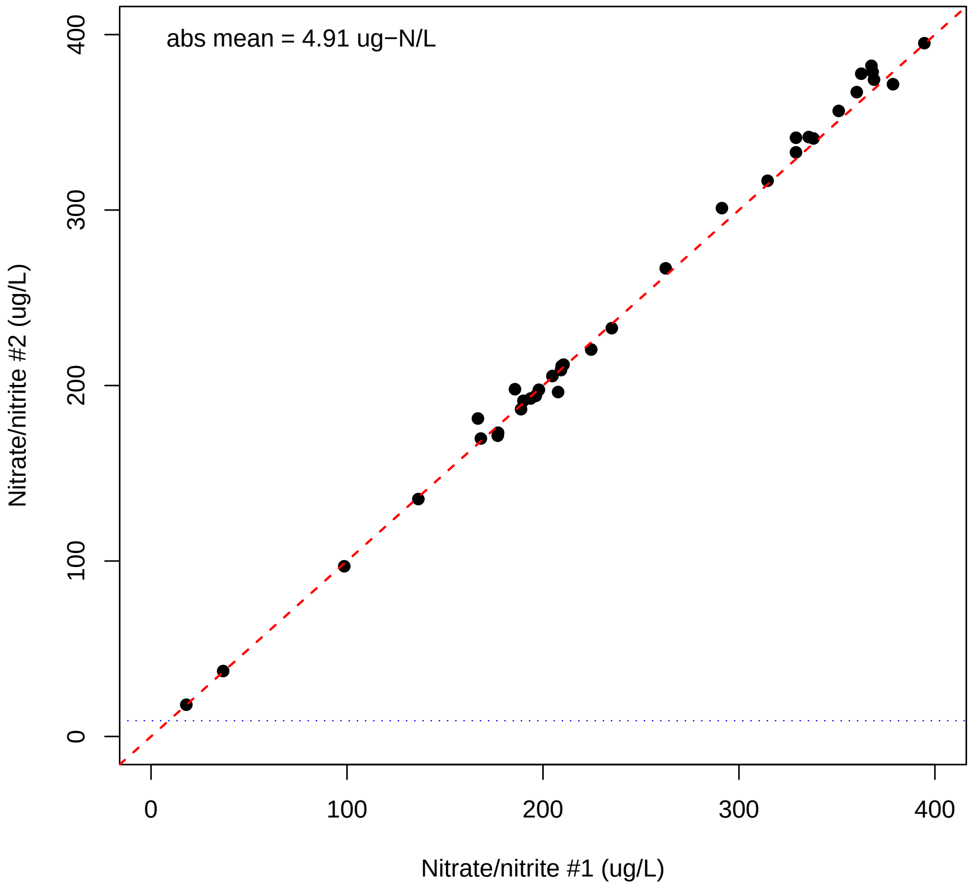


Figure C29: Nitrate/nitrite field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

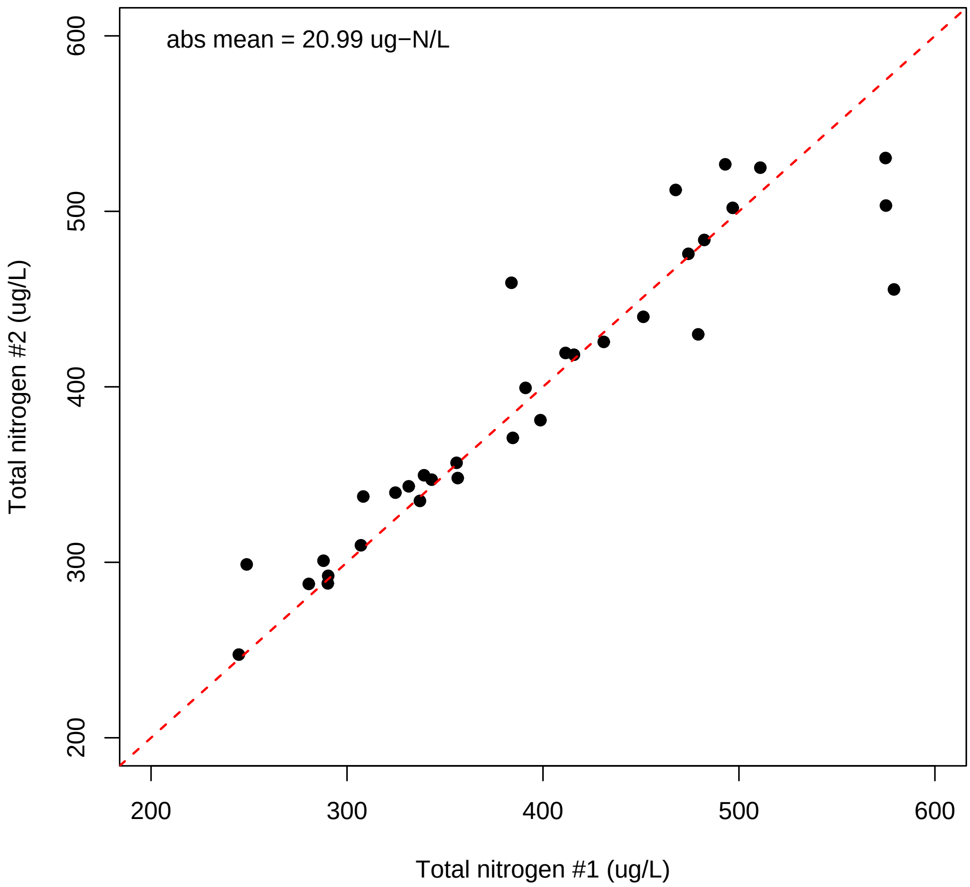


Figure C30: Total nitrogen field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

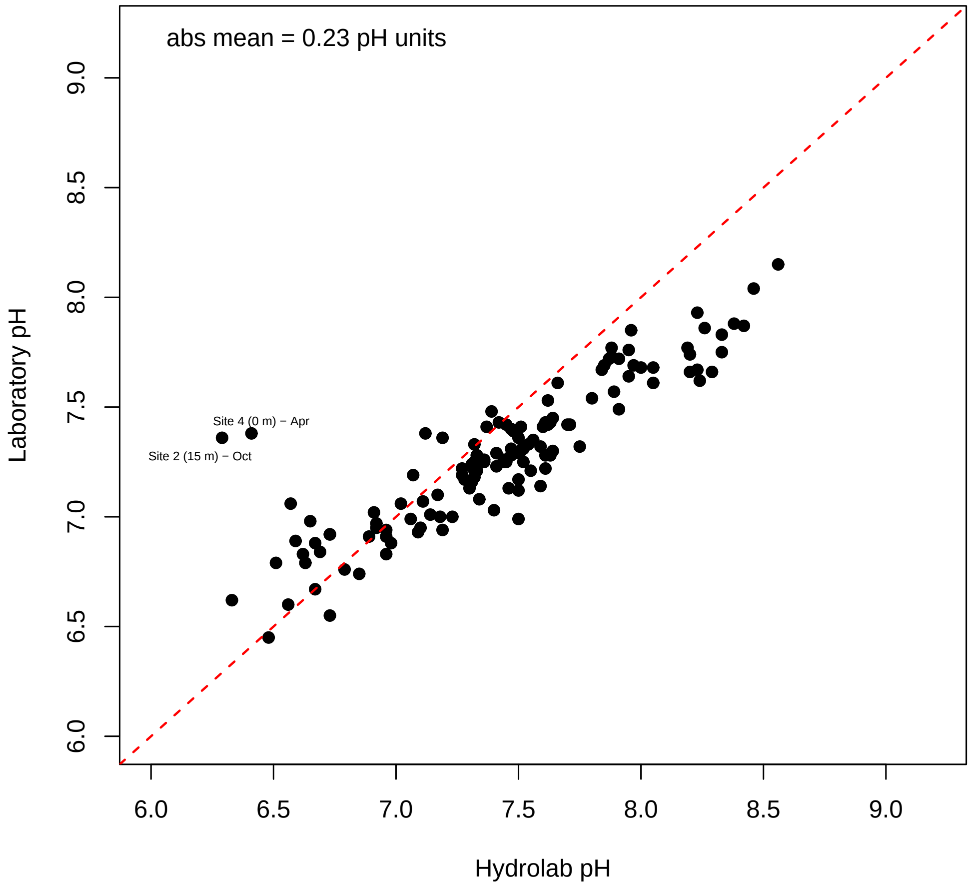


Figure C31: Field duplicates for pH from the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The results show a slight systematic bias due to changes in dissolved CO_2 and associated inorganic carbon ions between field and laboratory samples. One outlier was collected during late summer when extreme pH gradients were present; the second outlier was collected at the surface in April and represents sampling error.

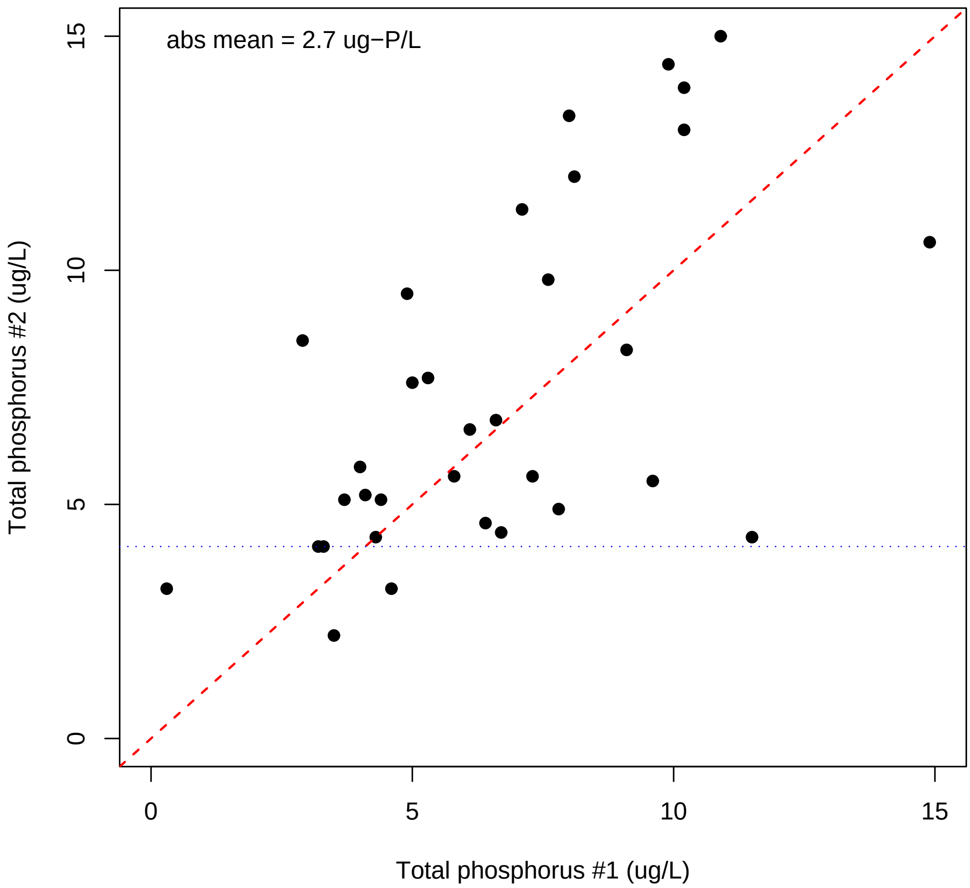


Figure C32: Total phosphorus field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

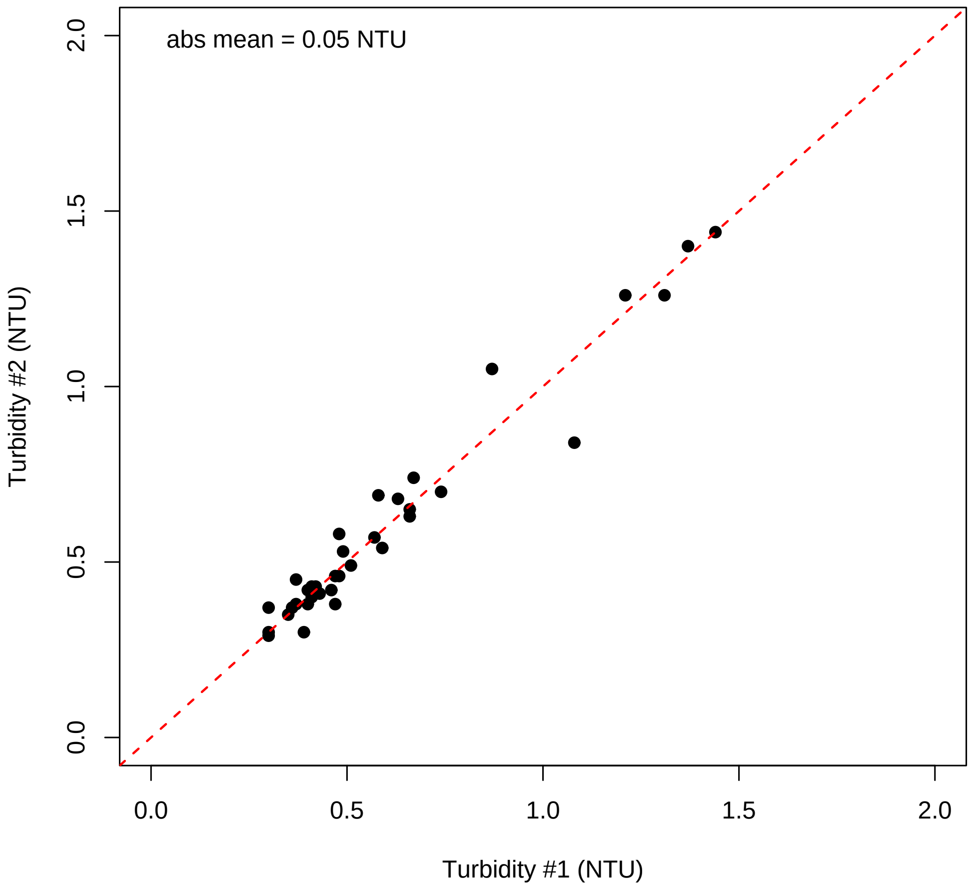


Figure C33: Turbidity field duplicates for the 2007/2008 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

D Lake Whatcom Online Data

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

```
**************************************************************
* README FILE - LAKE WHATCOM ONLINE DATA
* THIS FILE WAS UPDATED MARCH 19, 2009
**************************************************************

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

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

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

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

```
************************************************************
* LAKE DATA FILES:
************************************************************
Hydrolab data        Water quality        Plankton
1988_hl.csv          1988_wq.csv          plankton.csv
1989_hl.csv          1989_wq.csv
1990_hl.csv          1990_wq.csv
1991_hl.csv          1991_wq.csv          Metals/TOC
1992_hl.csv          1992_wq.csv          lakemetalstoc.csv
1993_hl.csv          1993_wq.csv
1994_hl.csv          1994_wq.csv
1995_hl.csv          1995_wq.csv
1996_hl.csv          1996_wq.csv
1997_hl.csv          1997_wq.csv
1998_hl.csv          1998_wq.csv
1999_hl.csv          1999_wq.csv
2000_hl.csv          2000_wq.csv
2001_hl.csv          2001_wq.csv
2002_hl.csv          2002_wq.csv
2003_hl.csv          2003_wq.csv
2004_hl.csv          2004_wq.csv
2005_hl.csv          2005_wq.csv
2006_hl.csv          2006_wq.csv
2007_hl.csv          2007_wq.csv
2008_hl.csv          2008_wq.csv
```

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

The water quality data files contain the following variables: site, depth (sample collection depth, m), month, day, year, alk (alkalinity, mg/L as CaCO3), turb (turbidity. NTU), nh3 (ammonium, ug-N/L), tn (total persulfate nitrogen, ug-N/L), nos (nitrate/ nitrite, ug-N/L), srp (soluble reactive phosphate, ug-P/L), tp (total persulfate phosphorus, ug-P/L), chl (chlorophyll, mg/m3).

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

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

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

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

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

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

```
***********************************************************
* STORM WATER DATA FILES:
***********************************************************
comps.csv
grab.csv
```

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

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

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

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

```
*************************************************************
* TRIBUTARY DATA FILES:
*************************************************************
creeks.csv (2004-2008)
creekwalk.csv (Nov 20, 2004)
48h.csv (2004-2006)
nonstd_discharge.csv (2004-2007)
```

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

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

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

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

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

    AlabamaVault inlet     = Alabama canister vault inlet
    AlabamaVault outlet    = Alabama canister vault outlet
    Brentwood inlet        = Brentwood wet pond inlet
    Brentwood outlet       = Brentwood wet pond outlet
    ParkPlace cell1        =  Park Place wet pond cell 1
    ParkPlace cell2        = Park Place wet pond cell 2
    ParkPlace cell3        = Park Place wet pond cell 3
    ParkPlace inlet        = Park Place wet pond inlet
    ParkPlace outlet       = Park Place wet pond outlet
    Parkstone_swale inlet  = Parkstone grass swale inlet
    Parkstone_swale outlet = Parkstone grass swale outlet
    Parkstone_pond inlet   = Parkstone wet pond inlet
    Parkstone_pond outlet  = Parkstone wet pond outlet
```

```
    SouthCampus inlet      = South Campus storm water facility inlet
    SouthCampus outletE    = South Campus storm water facility east outlet
    SouthCampus outletW    = South Campus storm water facility west outlet
    Sylvan inlet           = Sylvan storm drain inlet
    Sylvan outlet          = Sylvan storm drain outlet
    Wetland outlet         = Grace Lane wetland

    CW1 = Smith Creek (see alternate code below)
    CW2 = Silver Beach Creek (see alternate code below)
    CW3 = Park Place drain (see alternate code below)
    CW4 = Blue Canyon Creek (see alternate code below)
    CW5 = Anderson Creek (see alternate code below)
    CW6 = Wildwood Creek (discontinued in 2004)
    CW7 = Austin Creek (see alternate code below)

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

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

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

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

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

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

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

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

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