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Lake Whatcom Monitoring Project 2006/2007 Report

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Executive Summary

- This report describes the results from the 2006/2007 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 Anderson, 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 100.

- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The lake was weakly stratified by the first week in May, with stable stratification present by the first week in June.

- The levels of hypolimnetic oxygen have declined over time at Site 1, causing the lake to be listed by the Department of Ecology on the 1998 303D list of impaired waterbodies in the State of Washington.

- Nitrate depletion was evident at all sites in the photosynthetic zone during the summer. Epilimnetic nitrate concentrations fell below 20 μg-N/L at Site 1, creating an environment favorable for cyanobacteria (bluegreen algae).

- Anaerobic conditions in the hypolimnion at Site 1 resulted in elevated concentrations of ammonia, nitrate, and hydrogen sulfide by the end of the summer. Although Site 2 had similar increases, the concentrations were lower than in 2006. The difference may relate to an unusually short period of lake stratification due to cold weather in May and October.

- The 2007 summer near-surface total phosphorus concentrations were slightly lower at most sites compared to 2006. Similarly, cyanobacteria and Chrysophyta algae counts were lower at most sites. The 2007 chlorophyll concentrations and Chlorophyta algae counts, however, were higher than in 2006.

- The concentrations of trihalomethanes in Bellingham's treated drinking water increased in 2007 despite changes in water treatment chemicals that resulted in a short term reduction of the trihalomethanes in 2006. This increase is consistent with the increasing chlorophyll concentrations in 2007.

- 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 near the dock 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.

- Zinc and iron were detected at all sites in the lake, but were within normal ranges for the lake. Other metals were occasionally detected, but the concentrations were near the limits of detection.

- A diurnal study was conducted beginning at dawn and ending after sunset to measure temperature, dissolved oxygen, pH, and conductivity at two hour intervals from the surface to bottom at Site 1. The results help quantify the amount of change that occurs in the water column throughout the day.

- Tributaries were sampled in February and September 2007 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, and higher nutrient concentrations.

- The relationship between turbidity and total phosphorus was examined in the 2004–2007 tributary data using regression analysis of the raw and $\log_{10}$-transformed data. Although there were significant regressions for most sites, the linear models were heavily influenced by outliers, and most regressions had a high degree of uncertainty.

- 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 WY2007[1] included surface and subsurface runoff (74.2%), direct precipitation (18.2%), and water diverted from the Middle Fork of the Nooksack River (7.5%). Outputs included Whatcom Creek (77.1%), the

[1]Water Year 2007 covers the period from October 1, 2006 through September 30, 2007

City of Bellingham (10.5%), Georgia Pacific (2.0%), evaporation (7.2%), the Whatcom Falls Hatchery (2.5%), and the Lake Whatcom Water and Sewer District (0.6%).[2]

- Four storm water treatment systems were monitored in 2006/2007: the Park Place sand filter[3]; 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 29–89%. The Park Place system was retrofitted in 2006, adding a series of sand filters, and this site had very high suspended solids removal efficiencies in 2007 (85–89%). Phosphorus removal efficiencies were low and inconsistent for sites inside the watershed (-38–33%); only the South Campus system provided consistent phosphorus removal (67% in 2007).

[2]Formerly Water District #10
[3]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 100.

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom has also served as a water source for the Georgia-Pacific Corporation mill[4], which, prior to 2001, was the largest user of Lake Whatcom water. The lake and parts of the watershed provide recreational opportunities, as well as providing important habitats for fish and wildlife. The lake is used as a storage reservoir to buffer peak storm water flows in Whatcom Creek. Much of the watershed is zoned for forestry and is managed by state or private timber companies. Because of its aesthetic appeal, much of the watershed is highly valued for residential development.

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

The major objectives of the 2006/2007 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 Anderson, Austin, and Smith Creeks; and update the hydrologic model for Lake Whatcom.

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

Detailed site descriptions can be found in Appendix A. The historic lake data are plotted in Appendix B. The current quality control results can be found in Appendix C. The 2006/2007 monitoring data are printed in Appendix D in hardcopy versions of this report and are available online at http://www.ac.wwu.edu/∼iws. Table D1 on page 371 (at the beginning of Appendix D) 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 107 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 1 & 2 and December 5 & 12, 2006; and February 6 & 8, April 4 & 5, May 1 & 3, June 5 & 7, July 11 & 12, August 1 & 2, and September 5 & 6, 2007. Each sampling event is a multi-day task; all samples were collected during daylight hours, typically between 10:00 am and 3:00 pm.

A Surveyor IVa Hydrolab was used to measure temperature, pH, dissolved oxygen, and conductivity. All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory, and were analyzed as described in Table 1 (page 16). Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.[5] Plankton samples were placed in a cooler and returned to the laboratory unpreserved. The plankton sample volumes were measured in the laboratory and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant.

2.3 Results and Discussion

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

Tables 2–6 (pages 17–21) summarize the current field measurements, ambient water quality, and coliform data. The raw data are included in Appendix D and are available online at http://www.ac.wwu.edu/∼iws. The monthly Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 118–167).

The 2006/2007 lake data are plotted with historic lake data in Figures B51–B130 (pages 169–249). 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 133–137) and the multi-year temperature profiles (Figures B51–B55, pages 169–173) 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.

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

The summer Hydrolab profiles (e.g., Figures B46–B50, pages 163–167) 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, which is too shallow to develop a stable stratification, are usually stratified by June. 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. Typically, this occurs in all three basins by early June.

Destratification occurs abruptly in basins 1 and 2, and more gradually in basin 3. The lake cools as the weather becomes colder and day length shortens. Basins 1 and 2 (Sites 1–2) destratify by the end of October, while 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, so that when we collect winter samples in February, the temperatures are relatively uniform throughout the water column.

Although destratification is relatively abrupt, the process of mixing the lake from surface to bottom is not instantaneous. In November, the water column temperatures at Sites 1 and 2 were nearly uniform, but the dissolved oxygen, pH, and conductivity profiles indicated that the water column was not completely mixed (Figures B6–B7, pages 123–124). By December, Sites 1 and 2 showed the typical, mixed water column, with nearly uniform temperature, pH, conductivity, and dissolved oxygen at all depths (Figures B11–B12, pages 128–129).

The historic water temperature data indicate that the annual median[6] temperatures in basin 3 are cooler than basins 1 and 2, and the two shallow basins experi-

[6]The median is the center of a data set; half the data are above the median and half are below.

ence 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.

Most of the 2007 surface water temperatures were close to median values for the lake. May and October were unusually cold compared to historic data, and July was unusually warm (Figure 1, page 28). The lake was weakly stratified by the first week in May (Δ T $< 5°$ C), with stable stratification present at Sites 1–4 by early June (Figures B26–B35, pages 143–152).

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 nutrients (phosphorus and nitrogen) from the sediments; increased rates of algal production due to release of nutrients; 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 158–159 and 174–175). Hypolimnetic oxygen depletion only becomes apparent after stratification, at which time the lower waters of the basin are isolated from the lake's surface and biological respiration consumes the oxygen dissolved in the water. Biological productivity and respiration are increased when there is an abundant supply of nutrients, as well as by other environmental factors such as warm water temperatures. In basin 3, which has comparatively low concentrations of essential nutrients such as phosphorus, biological respiration has less influence on hypolimnetic oxygen concentrations (e.g., Figures B50 and B60, pages 167 and 178). In contrast, Site 1 shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures B46 and B56, pages 163 and 174).

The levels of hypolimnetic oxygen have declined over time at Site 1, causing the lake to be listed by the Department of Ecology as an "impaired" waterbody (Pelletier, 1998).[7] The increasing rate of oxygen loss is most apparent during July and August, after the lake develops a stable thermal stratification, but before oxygen levels drops near zero.

To illustrate this trend we fitted the July and August data using an exponential function (see discussion by Matthews, et al., 2004). As indicated in Figures 2–5 (pages 29–32), there were significant negative correlations between dissolved oxygen and time for all samples collected from the hypolimnion during July and August.[8] For the past two years, the hypolimnion has become nearly anaerobic at depths greater than 12 meters by August, so the trend line for August is beginning to flatten.

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in June and July (e.g., Figure B31, page 148). This was caused by the accumulation of phytoplankton along the density gradient between the epilimnion and hypolimnion in basin 1, 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).

Sites 3–4 developed small oxygen sags near the bottom during during late summer or fall (e.g., Figure B4, page 121). Both sites occasionally had small oxygen sags near the thermocline (e.g., Figure B4), which was 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–

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

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

B70, pages 179–188). Surface pH values increased during the summer due to photosynthetic activity and hypolimnetic pH values decreased 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 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 190–194). During the summer the alkalinity and conductivity values at the bottom of Sites 1–2 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 195–199). 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 winter storms on turbidity can be seen in the samples from December 1996. At that time, the water column was thoroughly mixed at Sites 1 and 2, so higher turbidities were measured at all depths. Basin 3, however, was still stratified below 40-50 m so higher turbidities were measured only in the epilimnion.

The turbidity patterns at Site 1 have been slightly atypical for the past two years (Figure B76, page 195). Historically, there were large peaks in turbidity just prior to destratification in samples from 20 meters. In 2006 and 2007, however, the peaks at 20 meters were less pronounced, despite relatively high turbidity values at other depths in the water column. It is possible that we missed the short intervals of time in 2006 and 2007 when these peaks occurred, or there may be a new turbidity pattern developing at Site 1.

2.3.5 Nitrogen and phosphorus

Figures B81–B105 (pages 200–224) 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]

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 205–209), particularly at Site 1, where the epilimnetic nitrate concentrations often fall below 20 μg-N/L by the end of the summer. Epilimnetic nitrogen depletion is an indirect measure of phytoplankton productivity, and because algal densities are increasing throughout the lake, epilimnetic dissolved inorganic nitrogen concentrations (DIN)[10] may be dropping over time (Figure 6, page 33). As discussed earlier, the summer of 2007 appeared to have a relatively short period of stratification, and the 2007 DIN results were atypical at Sites 2-4, so the DIN pattern is not yet clearly established. Coincident with low DIN concentrations, late summer is when we usually find the highest densities of nitrogen-fixing Cyanobacteria (also known as bluegreen bacteria or bluegreen algae).

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 in 2006 (and from 1999–2005), but not in 2007.

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 concentrations were measured just prior to destratification in the hypolimnion at Sites 1 and 2 (Figures B81 & B82, pages 200 & 201). Elevated hypolimnetic ammonia concentrations have been common at both sites throughout the monitoring period, but beginning in 1999 the concentrations increased noticeably at Site 2 (Table 7, page 22). In 2007, however, the hydrogen sulfide and ammonia levels

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

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

were considerably lower at Site 2 compared to Site 1 (see discussion on page 9).

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 203–204). 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 215–219 and B101–B105, pages 220–224). 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.

[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 3.9 μg-P/L.

Site 2 hypolimnetic nitrogen and phosphorus: Many of the Site 2 hypolimnetic by-products of anoxia, including ammonia and total phosphorus, were lower in 2007 compared to 2005 and 2006. The reason for these atypical results is not clear; however, the length of lake stratification may be a factor. May 2007 was unusually cool, and the lake stratified relatively late. Hypolimnetic oxygen depletion does not occur as fast at Site 2 as at Site 1, and the hypolimnion at Site 2 still contained 2–4 mg/L of oxygen during the first week of August. The Site 2 hypolimnion was anoxic in September, but October was unusually cold, and Site 2 was destratified by the first week in November 2007. 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.

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 225–229). 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.

The Lake Whatcom plankton counts were usually dominated by Chrysophyta, consisting primarily of diatoms, *Dinobryon*, and *Mallomonas* (Figures B121–B130, pages 240–249). 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 230–234) 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, 1983, for more about eutrophication and Matthews, et al., 2005, for a description of the chemical and biological indicators of eutrophication in Lake Whatcom).

The median near-surface summer chlorophyll concentrations increased at all sites (Figure 8, page 35), especially at Site 1. Conversely, algal numerical counts were lower in 2007 for all major groups except Chlorophyta (Figures 9–10, pages 36–37). This discrepancy between higher chlorophyll concentrations and lower algal counts reflects the difference between algal biomass (chlorophyll) and numerical counts. Algae come in different sizes. Most of the Chrysophyta are large enough to be counted as individual cells. 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. As a result, changes in numerical counts don't always correlate with changes in algal biomass. 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).

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. To begin this process, we sent algal samples collected on April 3, 2007 to the Academy of Natural Sciences of Philadelphia[12] for taxonomic identification. The Academy completed a taxonomic list (Tables 8–10, pages 23–25) and provided digital images for most taxa (Figures B131–B170, pages 251–290 in Appendix B.4). Because the samples were collected in early spring, the plankton were dominated by Chrysophyta (diatoms) and Chlorophyta; Cyanobacteria were poorly represented. We plan to collect additional samples during 2008 to add to the taxonomic list for Lake Whatcom.

[12] 1900 Benjamin Franklin Parkway, Philadelphia, PA, 19103

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 (online version available at http://www.ecy.wa.gov/biblio/wac173201a.html):

> *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[13]/100 mL (Figures B116–B120, pages 235–239) and passed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

Coliform samples collected near the dock 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 3.2, 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 11 (page 26). This table includes only the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); Appendix D.5 lists 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 newly detectable metals probably not represent increased metals concentrations in the lake.

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

Most of the metals concentrations were within normal concentration ranges for the lake. Iron and zinc were detectable at all sites during February and September. The highest iron concentrations, 1.590 mg/L and 1.160 mg/L, were measured in September at the bottom of Sites 1 and 2, respectively. The elevated iron concentrations at Sites 1 and 2 were the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water. Chromium, copper, lead, and mercury were detected in many of the samples, but at levels close to detection limits and typical for Lake Whatcom.

2.3.9 Total organic carbon and disinfection by-products

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

The 2006/2007 total organic carbon concentrations at the Intake were fairly low (Table 12, page 27). The long-term data, however, suggest that the concentrations may be increasing over time, particularly at the raw water gatehouse (Figure 11, page 38).[14]

As illustrated in Figure 12 (page 39), THMs have been increasing in Bellingham's treated drinking water, particularly during the fall (third quarter). To address this, the City used different treatment chemicals in 2006 to optimize removal of organic matter before the disinfection step in the drinking water treatment process. The additional treatment increased annual treatment costs by $10,000-12,000, and was initially encouraging because the THMs were lower in 2006.[15] Unfortunately, the 2007 THMs concentrations have resumed an upward trend.

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

Haloacetic acids (another important disinfection by-product) are not as closely linked to algal concentrations and chlorine dose (Sung, et al., 2000), and in previous reports, were not significantly correlated with time. The annual HAAs correlations are now marginally significant, possibly because of the increasing sample size.[16] The third quarter HAAs were not significantly correlated with time.

2.3.10 Site 1 diurnal study

Diurnal studies measure lake patterns that fluctuate on a daily basis, such as algal migrations up and down the water column in response to light, or dissolved oxygen changes over a 24-hr period. This type of information helps provide a comparison for the changes we observe from month to month and year to year.

The Lake Whatcom diurnal study was designed to measure how much change was occurring in temperature, dissolved oxygen, pH, and conductivity at a single site (Site 1) within a single day (August 7, 2007). The study involved collecting Hydrolab temperature, oxygen, pH, and conductivity profiles every two hours, beginning at dawn (4:18 am) and ending just after sunset (8:49 pm).[17]

Diurnal temperatures (Figures 13–14, pages 40–41) were very consistent within the epilimnion (0–6 m) and hypolimnion (12–20 m). Epilimnetic temperatures cooled slowly during the day, probably because the weather was overcast and unusually cool. As expected, metalimnetic temperatures followed a depth gradient, becoming increasingly cooler near the bottom of the lake. The metalimnetic temperatures also oscillated over time at each depth. The Hydrolab measures true depth, so these oscillations were probably not caused by inaccurate depth measurements, but rather by internal waves in the metalimnion[18]

The diurnal oxygen levels were also very consistent within the epilimnion and hypolimnion. The metalimnion oxygen concentrations decreased with depth and oscillated over time (Figures 15–16, pages 42–43). The most striking difference was that the uppermost metalimnetic samples had oxygen levels resembling the epilimnion, while the lowermost metalimnetic samples resembled the hypolimnion.

[16]Correlation significance is a function of the correlation statistic and sample size; as the sample size increases, the critical value for determining statistical significance decreases.

[17]The times listed for the diurnal study were Pacific Standard Time, not adjusted for daylight savings time.

[18]For a more complete discussion of waves and water movement in lakes, see Wetzel, 1983.

The diurnal pH results were similar to temperature and oxygen results: epilimnion and hypolimnion pH readings were consistent, while metalimnion samples followed a depth gradient and oscillated with time (Figures 17–18, pages 44–45). The lowest metalimnetic pH values (11 m) were similar to hypolimnetic data.

The diurnal conductivity data did not follow the same patterns as temperature, oxygen, and pH. Instead, conductivities decreased throughout the day, with nearly the same amount of variation at all depths (Figures 19–20, pages 46–47). Epilimnetic conductivities started higher and ended lower than other depths (Figure 19), suggesting a possible link to algal photosynthesis. As algae photosynthesize, they take up inorganic carbon from the water column and convert it to carbohydrates. In “soft” water lakes like Lake Whatcom, inorganic carbon levels are often so low that photosynthetic uptake can be tracked during daylight hours. The inorganic carbon levels are replenished at night as dissolved carbon dioxide combines with water to form carbonic acid and bicarbonate, the dominant type of inorganic carbon in soft water lakes. Although conductivity is not directly linked to photosynthesis, it is a measure of the concentration of dissolved ions in water. In most soft water lakes, carbonic acid and bicarbonate constitute a substantial fraction of the dissolved ions, so photosynthetic removal of these inorganic carbon compounds could be reflected in decreasing daytime conductivities.

Parameter	Method	Historic DL†	2006/2007 MDL†	Sensitivity or Confidence limit
Conductivity-field	Hydrolab (1997), field meter	–	–	$\pm$ 2 μS/cm
Conductivity-lab	APHA (2005) #2510, low-level, SOP-LW-9	–	–	$\pm$ 0.8 μS/cm
Dissolved oxygen-field	Hydrolab (1997), field meter	–	–	$\pm$ 0.1 mg/L
Dissolved oxygen-lab	APHA (2005) #4500-O.C., Winkler, SOP-LW-12	–	–	$\pm$ 0.1 mg/L
pH-field	Hydrolab (1997), field meter	–	–	$\pm$ 0.1 pH unit
pH-lab	APHA (2005) #4500-H^+, low-ionic, SOP-LW-8	–	–	$\pm$ 0.03 pH unit
Temperature	Hydrolab (1997), field meter	–	–	$\pm$ 0.1° C
Alkalinity	APHA (2005) #2320, low level, SOP-IWS-15	–	–	$\pm$ 0.7 mg/L
Discharge	Rantz et al. (1982), rating curve, SOP-IWS-6	–	–	–
Secchi depth	Lind (1985)	–	–	$\pm$ 0.1 m
T. solids	APHA (2005) #2540 B, gravimetric, SOP-LW-22	–	5.8 mg/L	$\pm$ 7.7 mg/L
T. suspended solids	APHA (2005) #2540 D, gravimetric, SOP-LW-22	2 mg/L	2.6 mg/L	$\pm$ 1.5 mg/L
Turbidity	APHA (2005) #2130, nephelometric, SOP-LW-11	–	–	$\pm$ 0.2 NTUs
Ammonia (auto)	APHA (2005) #4500-NH_3 H., phenate, SOP-LW-19	10 μg-N/L	5.4 μg-N/L	$\pm$ 6.9 μg-N/L
Nitrite/nitrate (auto)	APHA (2005) #4500-NO_3 I., Cd reduction, SOP-IWS-19	20 μg-N/L	6.4 μg-N/L	$\pm$ 4.9 μg-N/L
T. nitrogen (auto)	APHA (2005) #4500-N C., persulfate digestion, SOP-IWS-19	100 μg-N/L	11.3 μg-N/L	$\pm$ 18.1 μg-N/L
Sol. phosphate (auto)	APHA (2005) #4500-P G., ascorbic acid, SOP-IWS-19	5 μg-P/L	1.8 μg-P/L	$\pm$ 3.1 μg-P/L
T. phosphorus (auto)	APHA (2005) #4500-P H., persulfate digestion, SOP-IWS-19	5 μg-P/L	3.9 μg-P/L	$\pm$ 5.9 μg-P/L
Chlorophyll	APHA (2005) #10200 H, acetone, SOP-IWS-16	–	–	$\pm$ 0.1 mg/m^3
Plankton	Lind (1985), Schindler trap	–	–	–
Fecal coliform (City)	APHA (2005) #9222 D, membrane filter	1 cfu/100 mL	–	–

† Historic detection limits (DL) are usually higher than current method detection limits (MDL). See Appendix D for additional information.

Table 1: Summary of IWS and City of Bellingham analytical methods.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	18.5	19.7	20.6	27.5	2.2	50
Conductivity (μS/cm)‡	57.6	59.0	60.2	78.2	3.7	166
Dissolved oxygen (mg/L)	0.2	10.1	8.3	12.5	4.3	208
pH	6.3	7.4	7.4	8.9	0.6	208
Temperature (°C)	4.7	10.8	11.4	22.5	4.5	208
Turbidity (NTU)	0.4	0.8	1.0	3.3	0.6	50
Nitrogen - ammonium (μg-N/L)	$<$10	$<$10	33.4	334.1	69.8	50
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	231.3	193.9	356.0	134.7	50
Nitrogen - total (μg-N/L)	215.0	431.7	394.2	496.0	94.4	50
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	25.2	3.5	50
Phosphorus - total (μg-P/L)	$<$5	7.8	10.0	68.5	10.7	50
Chlorophyll (mg/m^3)	0.5	3.5	4.1	17.6	2.9	50
Secchi depth (m)	3.4	4.9	4.8	6.2	0.9	10
Coliforms - fecal (cfu/100 mL)§	$<$1	1	1	4	1	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Conductivity data are not available for Aug-Sept 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. 2006 – Sept. 2007.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	18.0	19.0	19.1	21.0	0.9	29
Conductivity (μS/cm)[‡]	56.7	57.9	57.9	59.5	0.8	88
Dissolved oxygen (mg/L)	9.1	10.3	10.5	12.2	0.9	110
pH	7.2	7.8	7.8	8.4	0.4	110
Temperature (°C)	6.1	14.5	13.8	21.5	5.1	110
Turbidity (NTU)	0.3	0.5	0.6	0.8	0.2	30
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	11.3	4.4	30
Nitrogen - nitrate/nitrite (μg-N/L)	91.4	249.6	246.5	384.4	105.3	30
Nitrogen - total (μg-N/L)	260.2	422.3	402.4	508.0	89.4	30
Phosphorus - soluble (μg-P/L)	<5	<5	<5	6.3	1.6	30
Phosphorus - total (μg-P/L)	<5	5.1	<5	9.0	2.8	30
Chlorophyll (mg/m^3)	1.4	3.3	3.3	6.1	1.3	30
Secchi depth (m)	4.0	5.8	5.8	7.4	1.2	10
Coliforms - fecal (cfu/100 mL)[§]	<1	1	1	1	0	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Conductivity data are not available for Aug-Sept 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. 2006 – Sept. 2007.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.9	18.8	19.4	27.3	1.7	50
Conductivity (μS/cm)‡	56.5	57.6	58.4	89.9	3.7	167
Dissolved oxygen (mg/L)	0.2	10.0	9.4	12.1	2.9	209
pH	6.3	7.5	7.5	8.4	0.5	209
Temperature (°C)	5.8	11.0	12.2	20.9	4.6	209
Turbidity (NTU)	0.3	0.5	0.7	6.4	0.9	50
Nitrogen - ammonium (μg-N/L)	<10	<10	23.0	354.1	62.0	50
Nitrogen - nitrate/nitrite (μg-N/L)	<20	307.3	262.4	398.8	113.7	50
Nitrogen - total (μg-N/L)	262.6	459.9	432.0	587.7	89.9	50
Phosphorus - soluble (μg-P/L)	<5	<5	<5	11.0	1.7	50
Phosphorus - total (μg-P/L)	<5	<5	5.9	55.1	9.1	50
Chlorophyll (mg/m^3)	0.6	3.0	3.0	7.2	1.3	50
Secchi depth (m)	4.5	5.8	6.1	9.1	1.3	9
Coliforms - fecal (cfu/100 mL)§	<1	1	1	2	1	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Conductivity data are not available for Aug-Sept 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. 2006 – Sept. 2007.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.7	18.3	18.7	22.5	0.9	67
Conductivity (μS/cm)‡	55.3	56.8	56.9	61.4	1.0	197
Dissolved oxygen (mg/L)	4.3	10.1	10.1	11.9	1.2	247
pH	6.4	7.3	7.4	8.3	0.5	247
Temperature (°C)	6.2	7.4	10.2	21.7	4.8	247
Turbidity (NTU)	0.2	0.4	0.5	2.7	0.4	70
Nitrogen - ammonium (μg-N/L)	<10	<10	<10	96.7	12.7	70
Nitrogen - nitrate/nitrite (μg-N/L)	113.9	388	337.1	428.1	98.0	70
Nitrogen - total (μg-N/L)	289	491.3	457.9	553.3	73.8	70
Phosphorus - soluble (μg-P/L)	<5	<5	<5	5.9	1.3	70
Phosphorus - total (μg-P/L)	<5	5.6	5.4	18.9	3.9	70
Chlorophyll (mg/m^3)	0.7	2.6	2.5	5.8	1.3	50
Secchi depth (m)	4.2	6.9	7.0	9.4	1.8	8
Coliforms - fecal (cfu/100 mL)§	<1	1	1	6	2	10

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Conductivity data are not available for Aug-Sept 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. 2006 – Sept. 2007.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.7	18.2	18.5	20.2	0.6	79
Conductivity (μS/cm)[‡]	55.3	56.6	56.8	58.8	0.9	214
Dissolved oxygen (mg/L)	7.3	10.1	10.1	11.9	0.9	268
pH	6.6	7.3	7.4	8.3	0.5	268
Temperature (°C)	6.3	7.3	9.9	20.7	4.7	268
Turbidity (NTU)	0.2	0.4	0.4	1.0	0.1	80
Nitrogen - ammonium (μg-N/L)	$<$10	$<$10	$<$10	26.2	5.5	80
Nitrogen - nitrate/nitrite (μg-N/L)	120.5	397.1	352.7	424.7	86.5	79
Nitrogen - total (μg-N/L)	297.9	496.8	468.4	550.4	64.8	80
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	5.5	1.3	80
Phosphorus - total (μg-P/L)	$<$5	5.5	5.3	12.7	3.0	79
Chlorophyll (mg/m^3)	0.7	2.5	2.5	5.4	1.3	50
Secchi depth (m)	4.3	8.0	7.4	9.0	1.6	9
Coliforms - fecal (cfu/100 mL)[§]	$<$1	1	1	1	0	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Conductivity data are not available for Aug-Sept 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.

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

[†]Samples analyzed by Edge Analytical.

Table 7: October hypolimnetic ammonia and hydrogen sulfide concentrations at Sites 1 and 2, 1999–2007. 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.

	Code	Site 1	Site 2	Intake	Site 3	Site 4
Diatoms						
Achnanthidium sp. 1	1045	-	-	-	•	•
Actinocyclus normanii	86002	•	•	•	•	-
Asterionella formosa	9001	•	•	•	•	•
Aulacoseira ambigua	10008	•	•	•	•	•
Cocconeis sp. 1†	16990	-	-	•	•	-
Cyclotella bodanica	20002	•	•	•	•	•
Cyclotella meneghiniana	20007	•	•	•	•	•
Cyclotella sp. 1	20990	•	•	•	•	•
Cyclotella sp. 2	20991	•	•	•	-	•
Cymbella affinis	23073	-	•	•	•	•
Diploneis sp. 1	30990	•	-	•	•	-
Encyonema sp. 1	110039	•	-	-	•	-
Fragilaria capucina	34006	-		•	-	-
Fragilaria crotonensis	34017	•	•	•	•	•
Fragilaria sp. 1	34990	-	-	•	•	-
Nitzschia sigmoidea	48177	-	-	•	-	-
Stephanodiscus minutulus	64018	•	•	•	•	-
Stephanodiscus niagarae	64001	•	•	•	•	•
Stephanodiscus sp. 1	64990	•	-	-	•	•
Stephanodiscus sp. 2	64991	-	•	•	-	-
Synedra sp. 1	66990	•	•	•	•	•
Thalassiosira pseudonana	70007	•	•	•	•	•
Other Chrysophyta						
Dinobryon divergens	1110007	•	•	•	•	-
Dinobryon sp. 1	1110002	-	-	•	-	-
Mallomonas sp. 1	1145000	•	•	•	•	-

†No photograph available

Table 8: Diatoms and other Chrysophyta in Lake Whatcom water samples collected on April 3, 2007. Presence (•) or absence (-) is indicated for each site. Taxonomic identifications were provided by the Academy of Natural Sciences of Philadelphia. Images for most species are included in Appendix B.4.

	Code	Site 1	Site 2	Intake	Site 3	Site 4
Chlorophyta						
Ankistrodesmus falcatus†	261000	-	-	-	-	●
Ankistrodesmus sp. 1	261004	-	●	●	●	●
Botryococcus braunii	279000	-	-	-	●	-
Crucigenia quadrata	328000	●	-	●	●	●
Crucigenia tetrapedia	328002	●	●	●	●	●
Elakatothrix gelatinosa	367000	-	●	●	-	-
Eudorina elegans	380000	●	-	-	-	-
Mougeotia sp. 1†	44400	-	-	●	-	-
Oocystis parva	458006	●	-	●	●	●
Oocystis sp. 1	458004	-	●	-	-	●
Quadrigula lacustris	500000	-	-	●	-	-
Quadrigula sp. 1	500002	●	-	●	-	-
Scenedesmus ecornis	510002	●	●	●	●	●
Scenedesmus sp. 1	510030	●	●	●	●	●
Tetraedron caudatum†	553005	-	-	●	-	-
Tetraedron minimum	553002	●	●	●	●	●
Euglenophyta						
Euglena sp. 1†	970000	-	-	●	-	-
Cryptophyta						
Cryptomonas ovata	1265003	●	●	●	●	●
Cryptomonas sp. 1	1265002	●	-	-	●	●
Pyrrhophyta						
Ceratium hirudinella	1334000	●	-	-	-	-
Peridinium willei	1457013	●	●	●	●	●

†No photograph available

Table 9: Non-chrysophyte algae in Lake Whatcom water samples collected on April 3, 2007. Presence (●) or absence (-) is indicated for each site. Taxonomic identifications were provided by the Academy of Natural Sciences of Philadelphia. Images for most species are included in Appendix B.4.

	Code	Site 1	Site 2	Intake	Site 3	Site 4
Cyanobacteria						
Aphanocapsa sp. 1	807001	-	•	•	•	•
Aphanothece sp. 1†	808000	-	-	•	•	•
Pseudanabaena sp. 1	897003	•	-	•	-	•

†No photograph available

Table 10: Cyanobacteria in Lake Whatcom water samples collected on April 3, 2007. Presence (•) or absence (-) is indicated for each site. Taxonomic identification and species codes were provided by the Academy of Natural Sciences of Philadelphia. Images for most species are included in Appendix B.4. Samples were collected in early spring, so there were few Cyanobacteria present.

	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 8, 2007	<0.01	<0.0005	<0.001	<0.001	0.042	0.0001	<0.005	<0.001	0.002
Site 1	20	Feb 8, 2007	<0.01	<0.0005	0.001	<0.001	0.146	<0.0002	<0.005	<0.001	<0.001
Intake	0	Feb 8, 2007	<0.01	<0.0005	0.001	0.001	0.061	<0.0002	<0.005	<0.001	0.011
Intake	10	Feb 8, 2007	<0.01	<0.0005	<0.001	<0.001	0.024	<0.0002	<0.005	<0.001	<0.001
Site 2	0	Feb 8, 2007	<0.01	<0.0005	<0.001	<0.001	0.017	<0.0002	<0.005	<0.001	0.003
Site 2	20	Feb 8, 2007	<0.01	<0.0005	<0.001	<0.001	0.027	0.0001	<0.005	0.001	<0.001
Site 3	0	Feb 6, 2007	<0.01	<0.0005	0.001	<0.001	0.024	0.0001	<0.005	<0.001	0.006
Site 3	80	Feb 6, 2007	<0.01	<0.0005	0.003	0.002	0.030	0.0002	<0.005	0.001	<0.001
Site 4	0	Feb 6, 2007	<0.01	<0.0005	0.002	0.001	0.036	0.0001	<0.005	<0.001	0.001
Site 4	90	Feb 6, 2007	<0.01	<0.0005	<0.001	0.007	0.056	0.0001	<0.005	0.002	0.014
Site 1	0	Sept 12, 2007	<0.01	<0.0005	0.004	0.001	0.034	<0.0001	<0.005	<0.001	0.002
Site 1	20	Sept 12, 2007	<0.01	<0.0005	0.005	<0.001	1.590	<0.0001	<0.005	<0.001	<0.001
Intake	0	Sept 12, 2007	<0.01	<0.0005	0.003	0.002	0.025	<0.0001	<0.005	<0.001	0.006
Intake	10	Sept 12, 2007	<0.01	<0.0005	0.003	<0.001	0.041	<0.0001	<0.005	<0.001	0.002
Site 2	0	Sept 12, 2007	<0.01	<0.0005	0.003	0.003	0.019	<0.0001	<0.005	<0.001	0.006
Site 2	20	Sept 12, 2007	<0.01	<0.0005	<0.001	<0.001	1.160	<0.0001	<0.005	<0.001	0.002
Site 3	0	Sept 12, 2007	<0.01	<0.0005	0.003	<0.001	0.007	<0.0001	<0.005	<0.001	<0.001
Site 3	80	Sept 12, 2007	<0.01	<0.0005	0.003	<0.001	0.025	<0.0001	<0.005	<0.001	0.017
Site 4	0	Sept 12, 2007	<0.01	<0.0005	0.003	<0.001	0.008	<0.0001	<0.005	<0.001	0.002
Site 4	90	Sept 12, 2007	<0.01	<0.0005	0.003	<0.001	0.014	<0.0001	<0.005	<0.001	0.002

Table 11: Lake Whatcom 2006/2007 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 Appendix D.5.

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 8, 2007	0	1.6	Sept 12, 2007	0	<1
	Feb 8, 2007	20	<1	Sept 12, 2007	20	<1
Intake	Feb 8, 2007	0	1.4	Sept 12, 2007	0	1.8
	Feb 8, 2007	10	<1	Sept 12, 2007	10	2.2
Site 2	Feb 8, 2007	0	<1	Sept 12, 2007	0	<1
	Feb 8, 2007	20	<1	Sept 12, 2007	15	<1
Site 3	Feb 6, 2007	0	<1	Sept 12, 2007	0	1.5
	Feb 6, 2007	80	1.6	Sept 12, 2007	80	<1
Site 4	Feb 6, 2007	0	1.2	Sept 12, 2007	0	<1
	Feb 6, 2007	90	<1	Sept 12, 2007	90	<1

Table 12: Lake Whatcom 2006/2007 total organic carbon data.

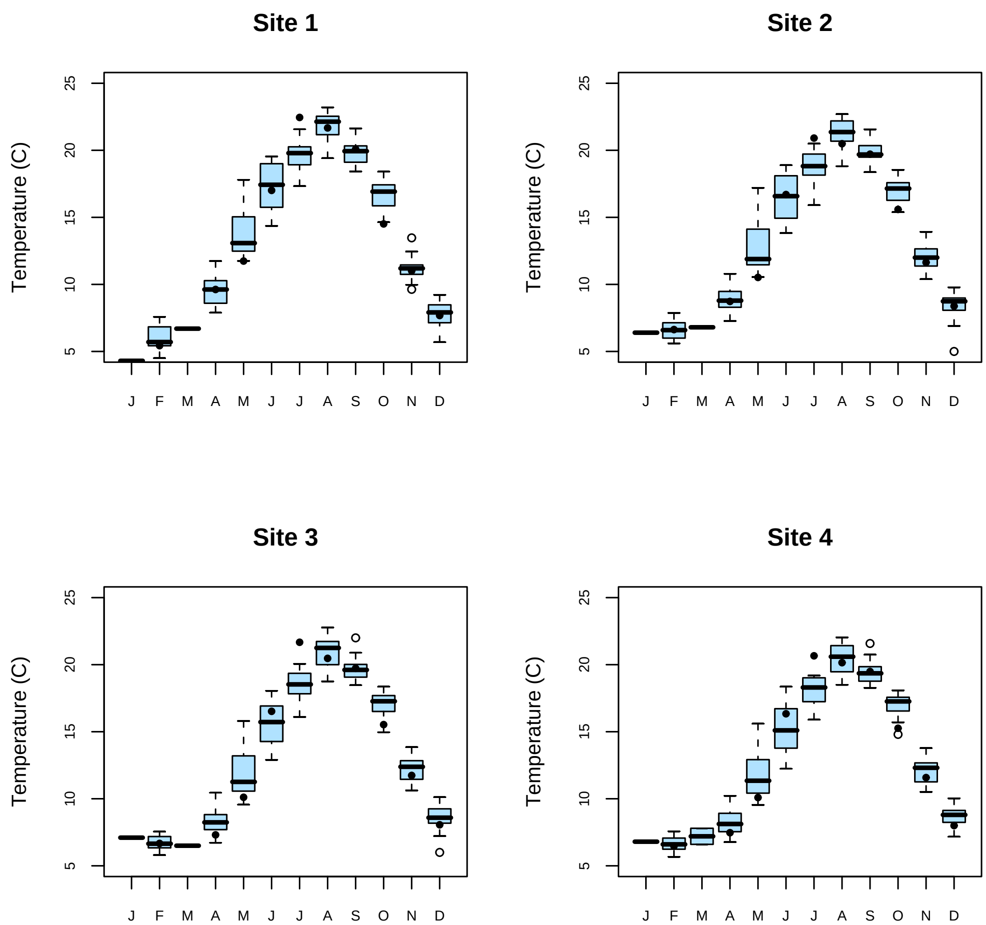

Figure 1: Boxplots showing 1988–2006 surface water temperatures (depth <1 m, all sites and years) with monthly 2007 data (●). Boxplots show medians and upper/lower quartiles; whiskers extend 1.5 × interquartile range or to maximum/minimum values; outliers lie outside 1.5 × IQR.

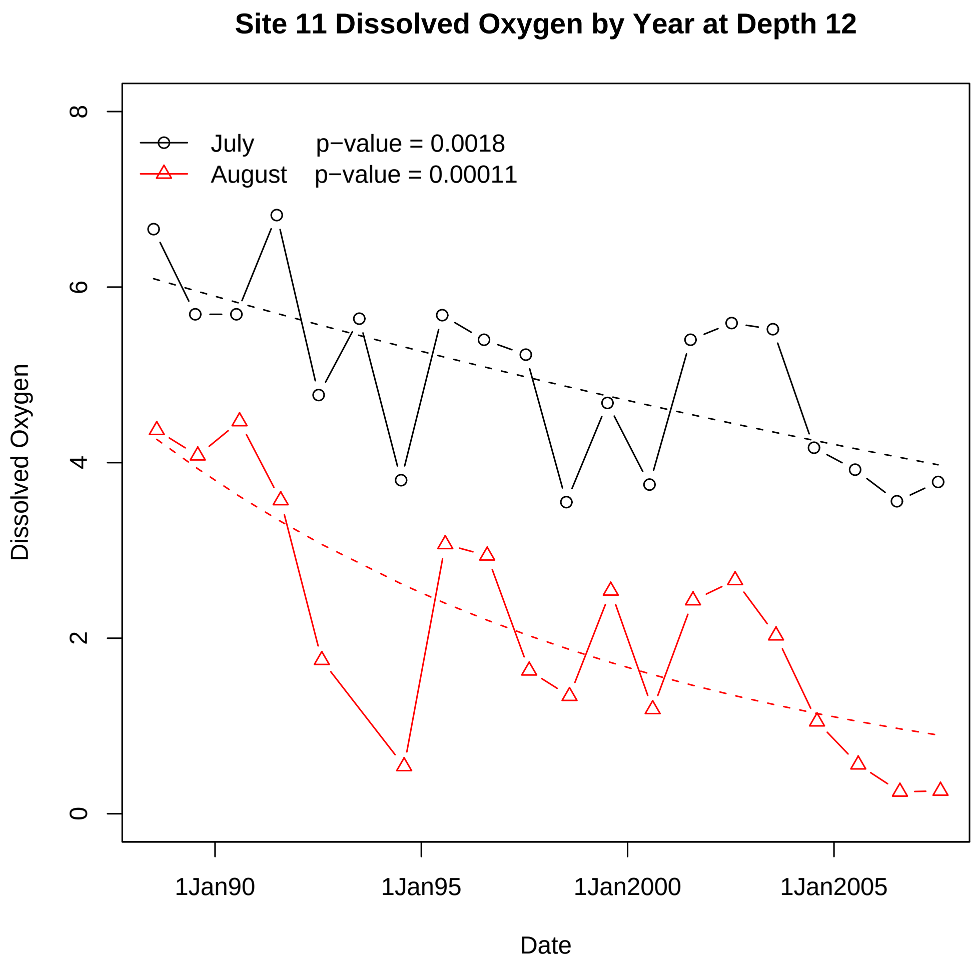

Figure 2: Nonlinear relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

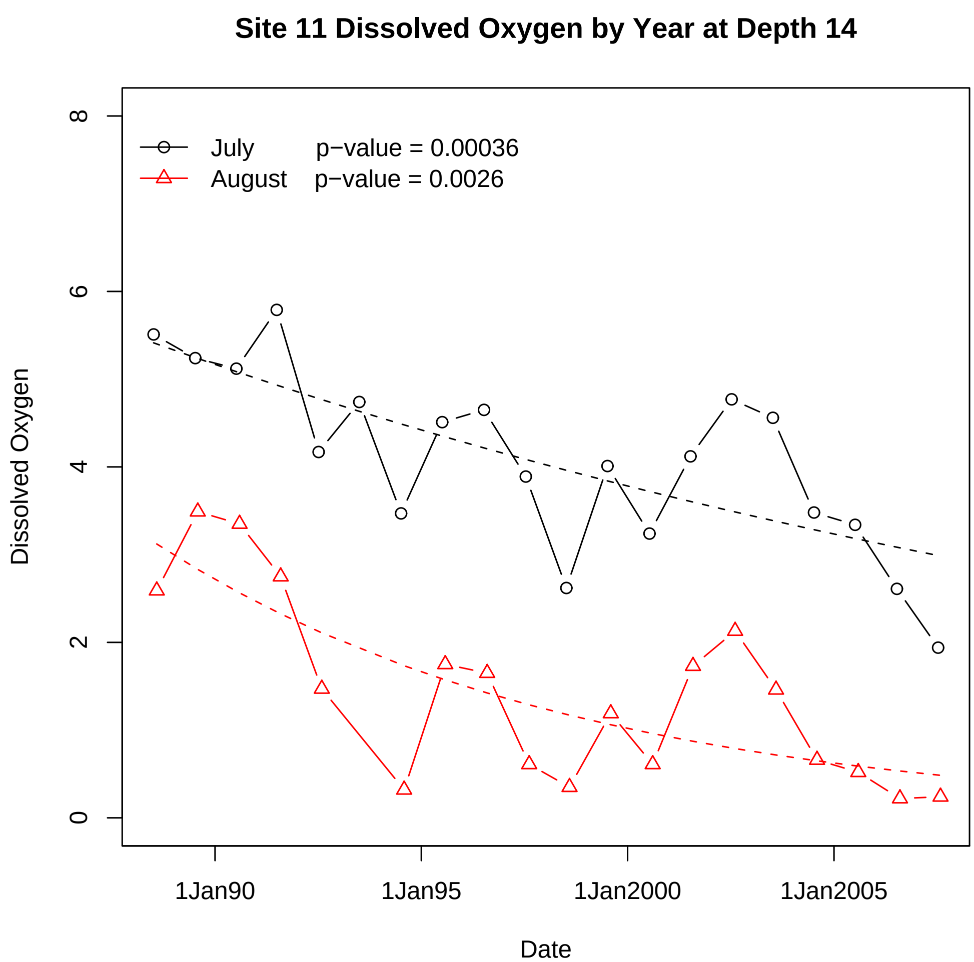

Figure 3: Nonlinear relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

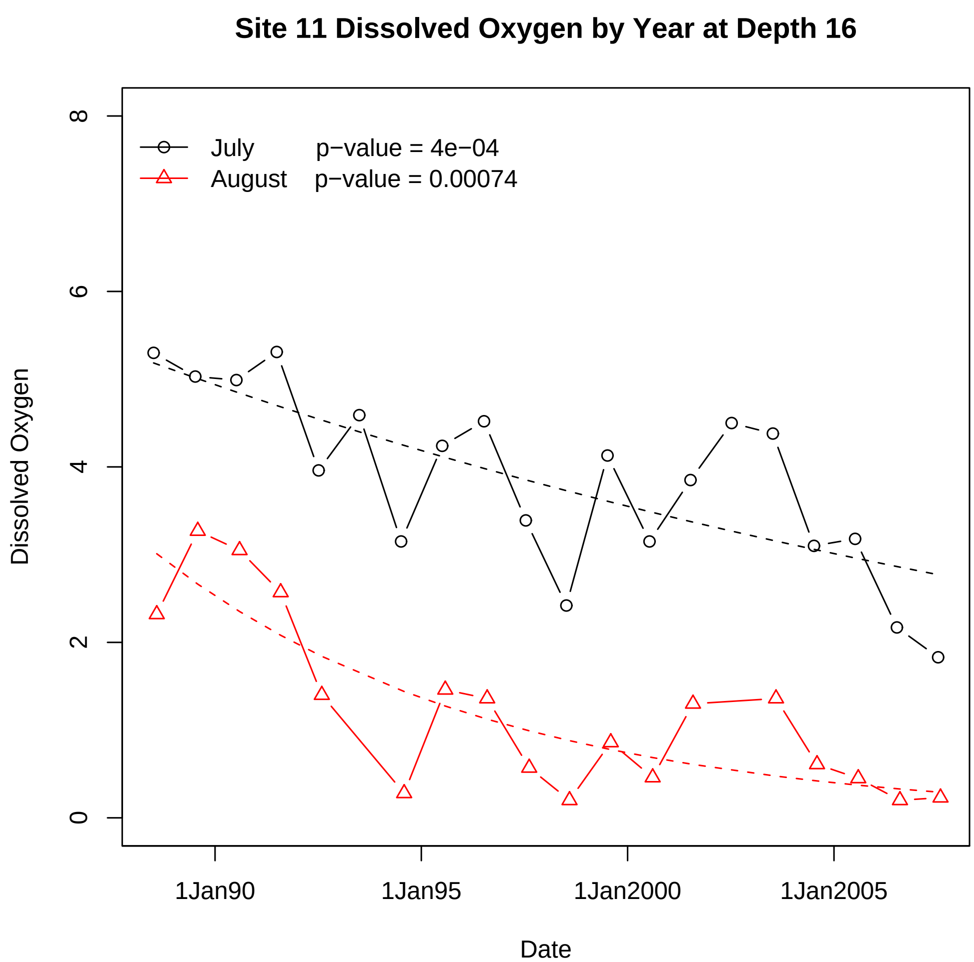

Figure 4: Nonlinear relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

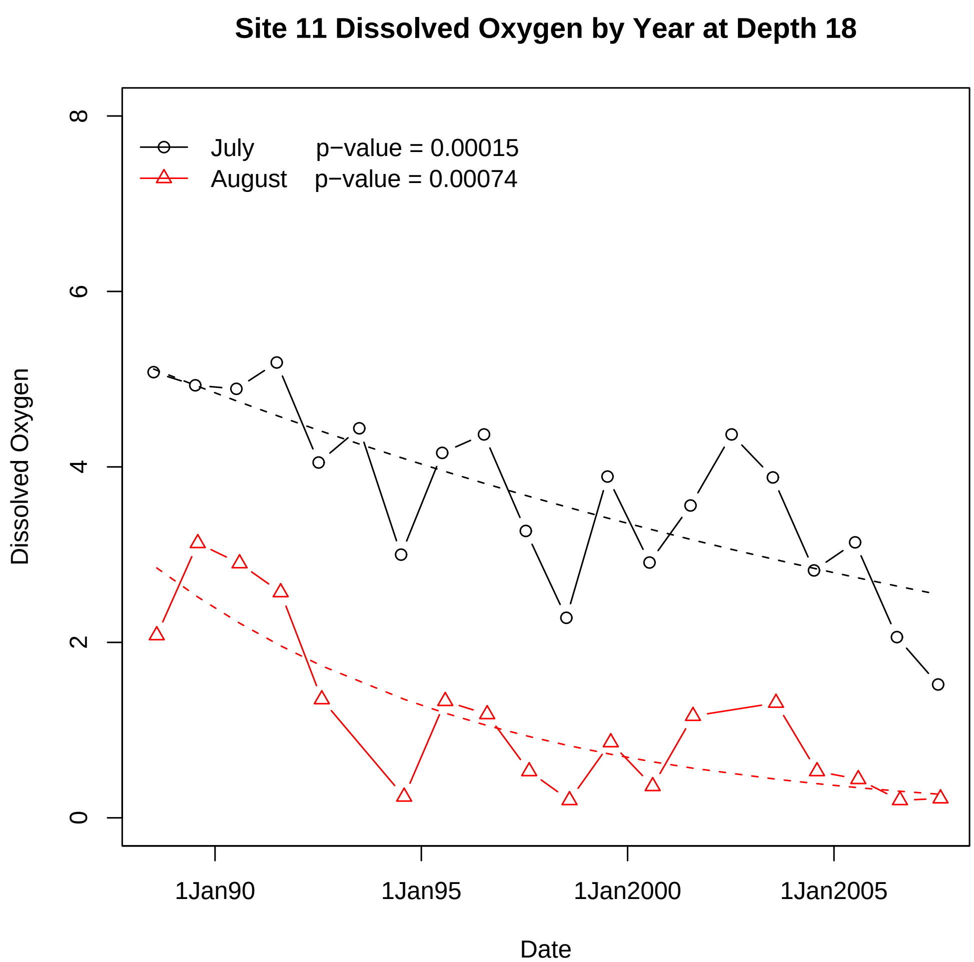

Figure 5: Nonlinear relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

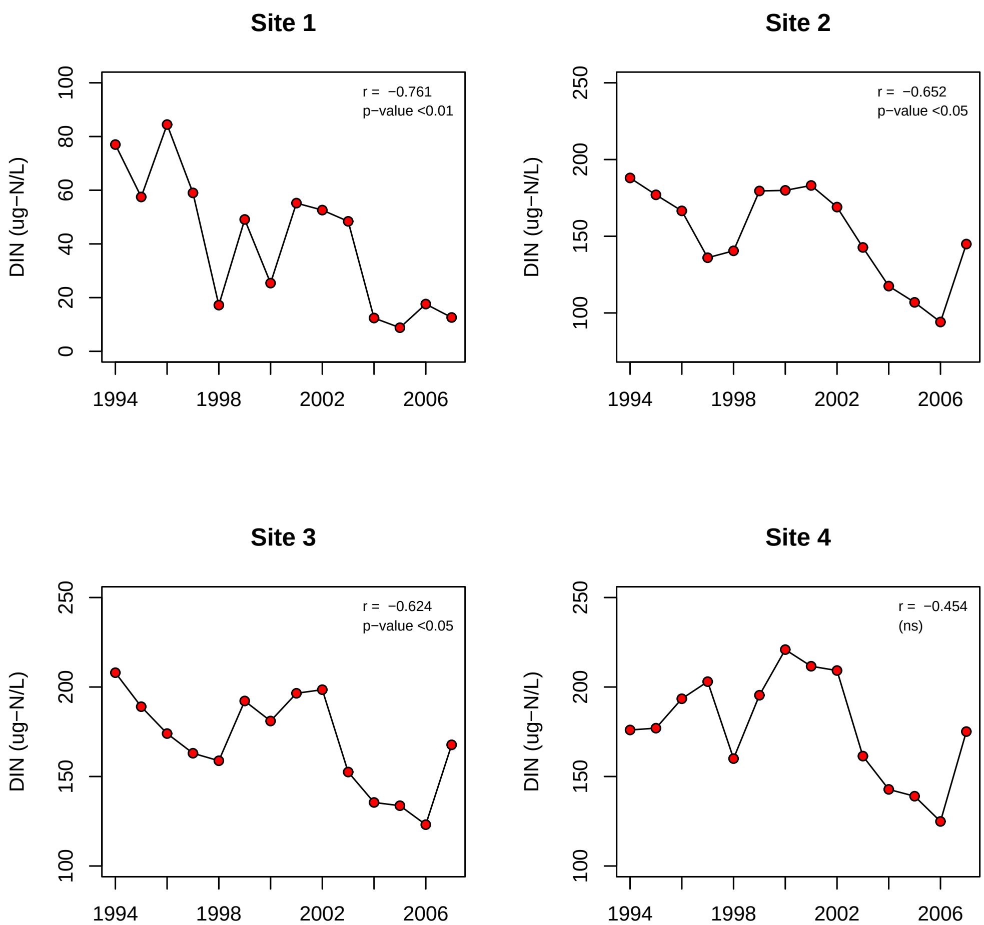

Figure 6: Minimum summer, near-surface dissolved inorganic nitrogen concentrations (1994–2007, June-Oct, depths $\leq$5 m). Pearson's r correlations were used because the data were approximately monotonic-linear; correlations were significant at Sites 1–3.

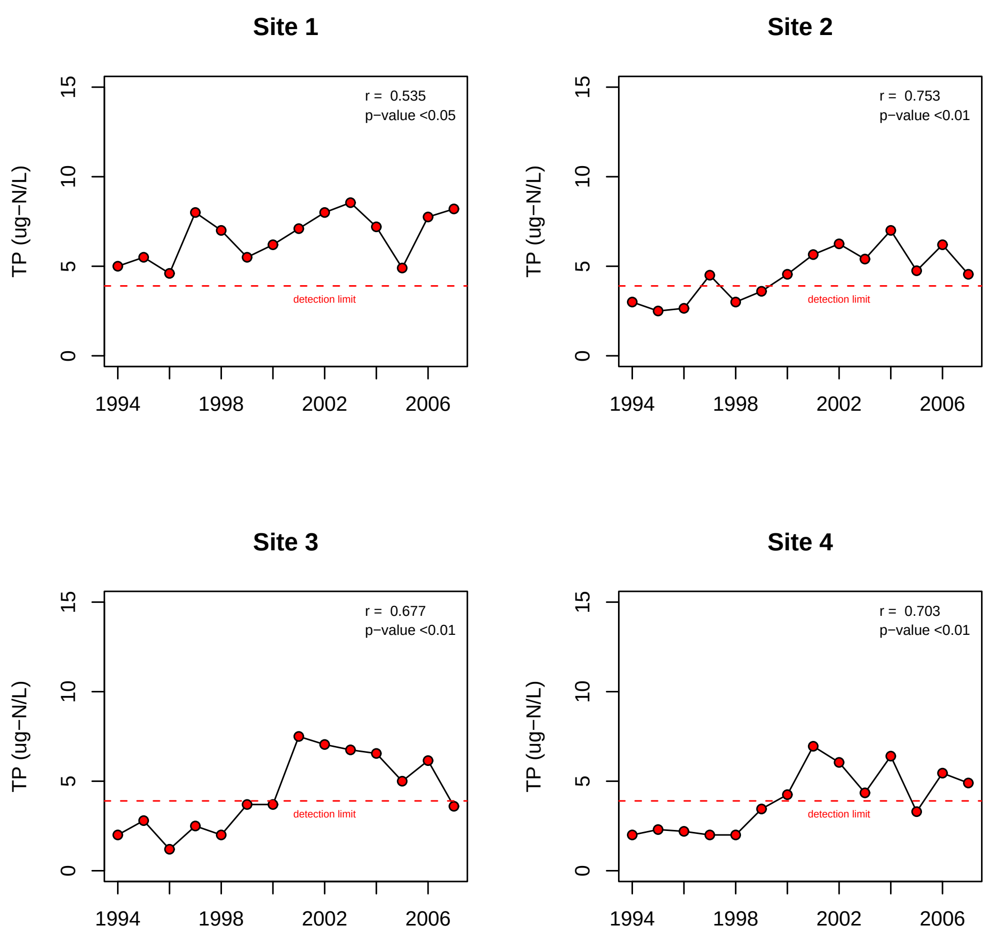

Figure 7: Median summer, near-surface total phosphorus concentrations (1994–2007, June-Oct, depths ≤5 m). Uncensored (raw) data were used to illustrate that median values are increasingly above analytical detection limits (3.9 μg-P/L; Table 1). Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

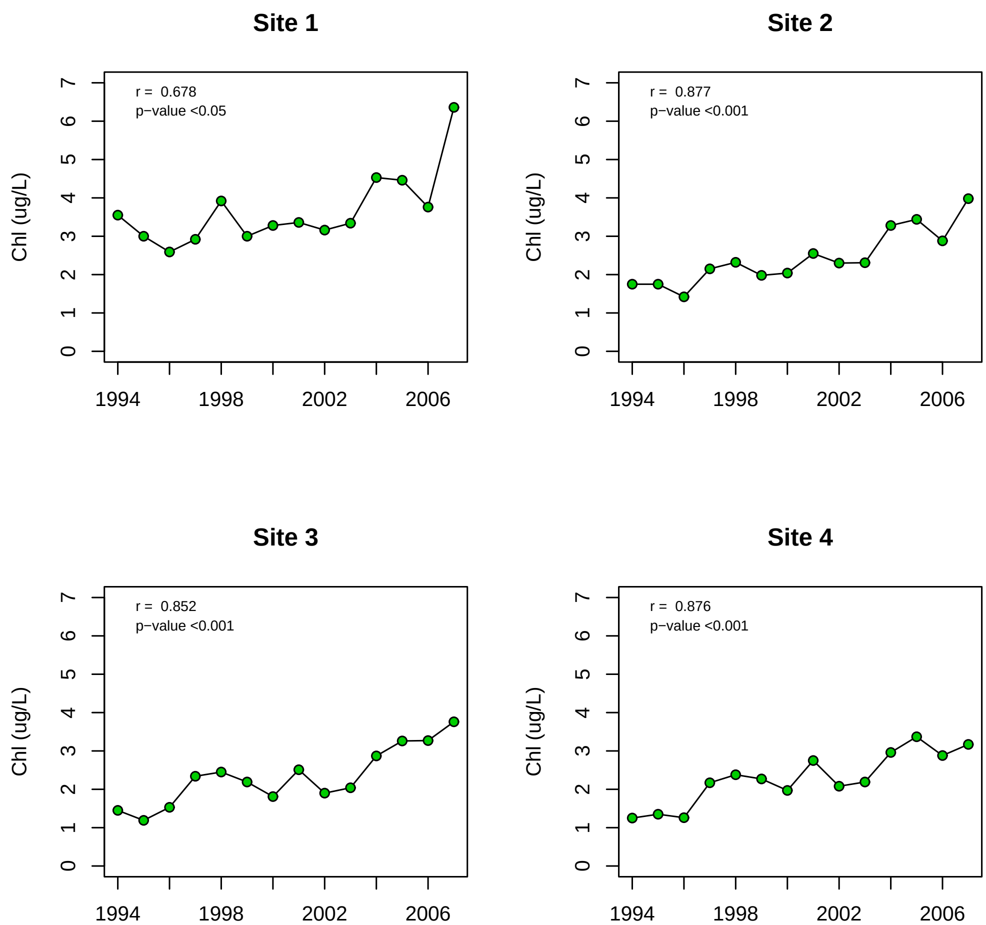

Figure 8: Median summer near-surface chlorophyll concentrations (1994–2007, June-October, depths $\leq$5 m). Pearson's r correlations were used because the data were approximately monotonic-linear; all correlations were significant.

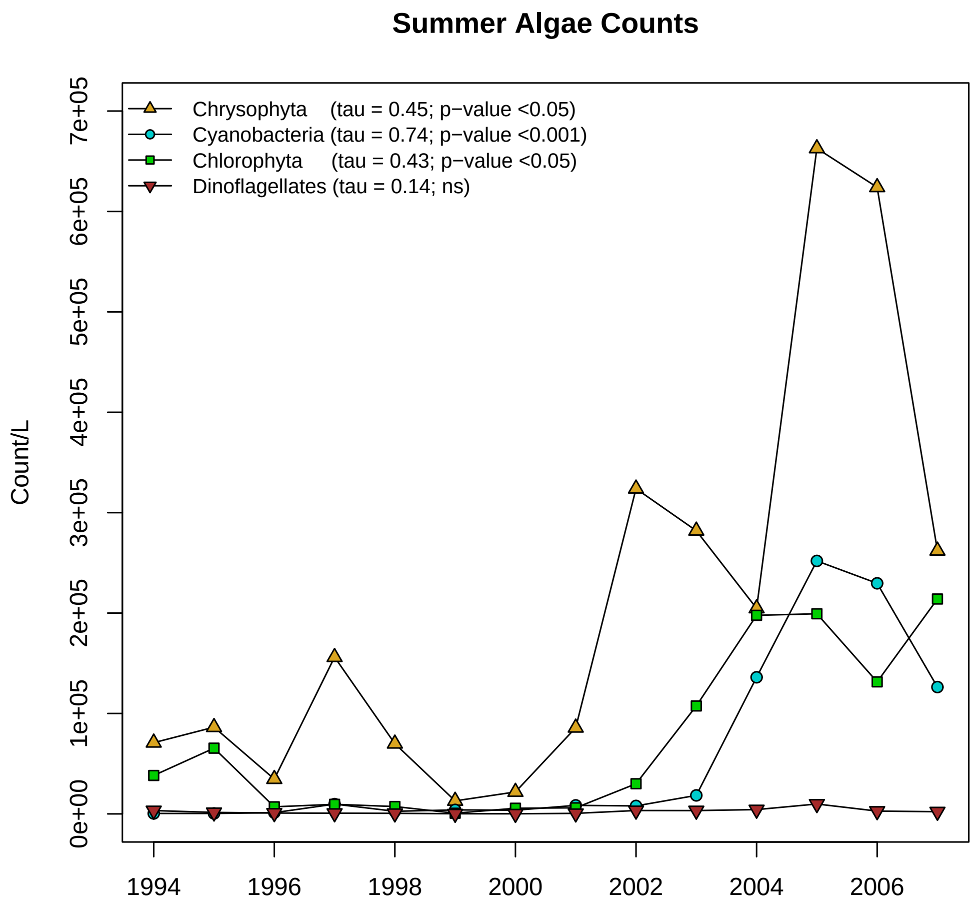

Figure 9: Median summer, near-surface algae counts (1994-2007, June-October, all sites and depths). Kendall's τ correlations were used because the data were not monotonic-linear; correlations for Chrysophyta, Chlorophyta, and Cyanobacteria were significant.

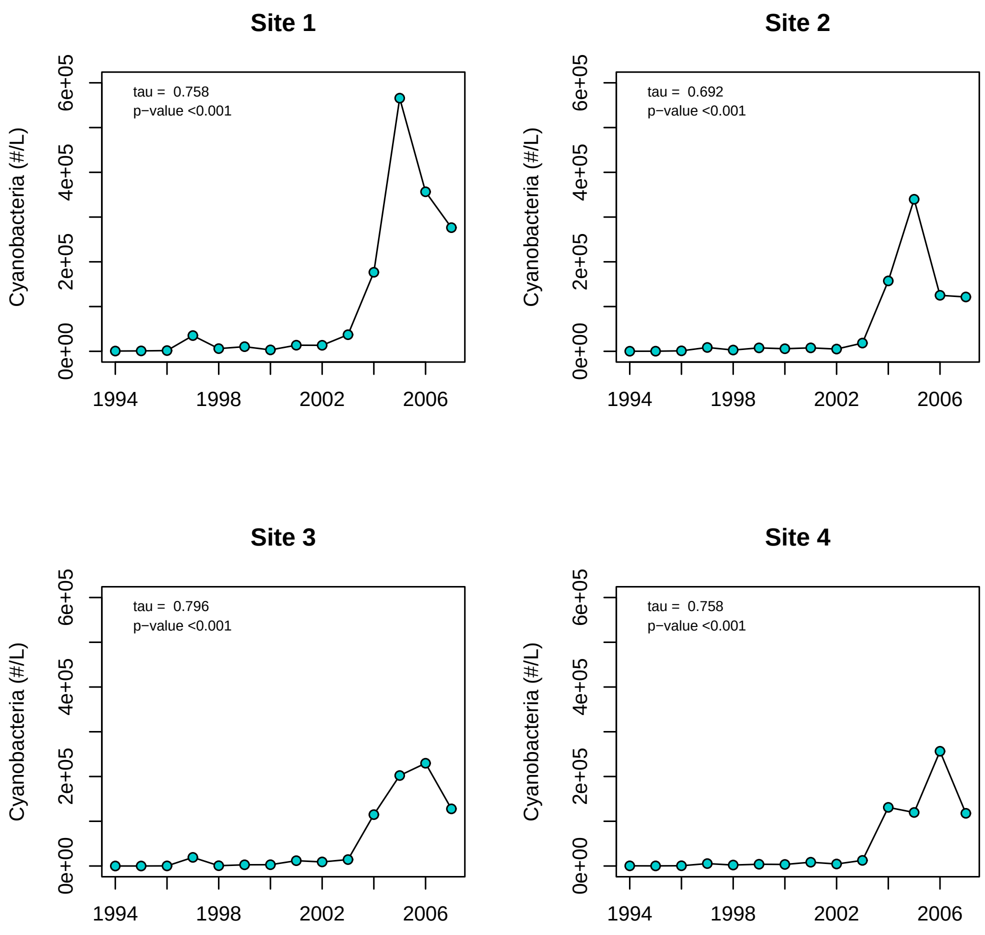

Figure 10: Median summer, near-surface cyanobacteria counts (1994–2007, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

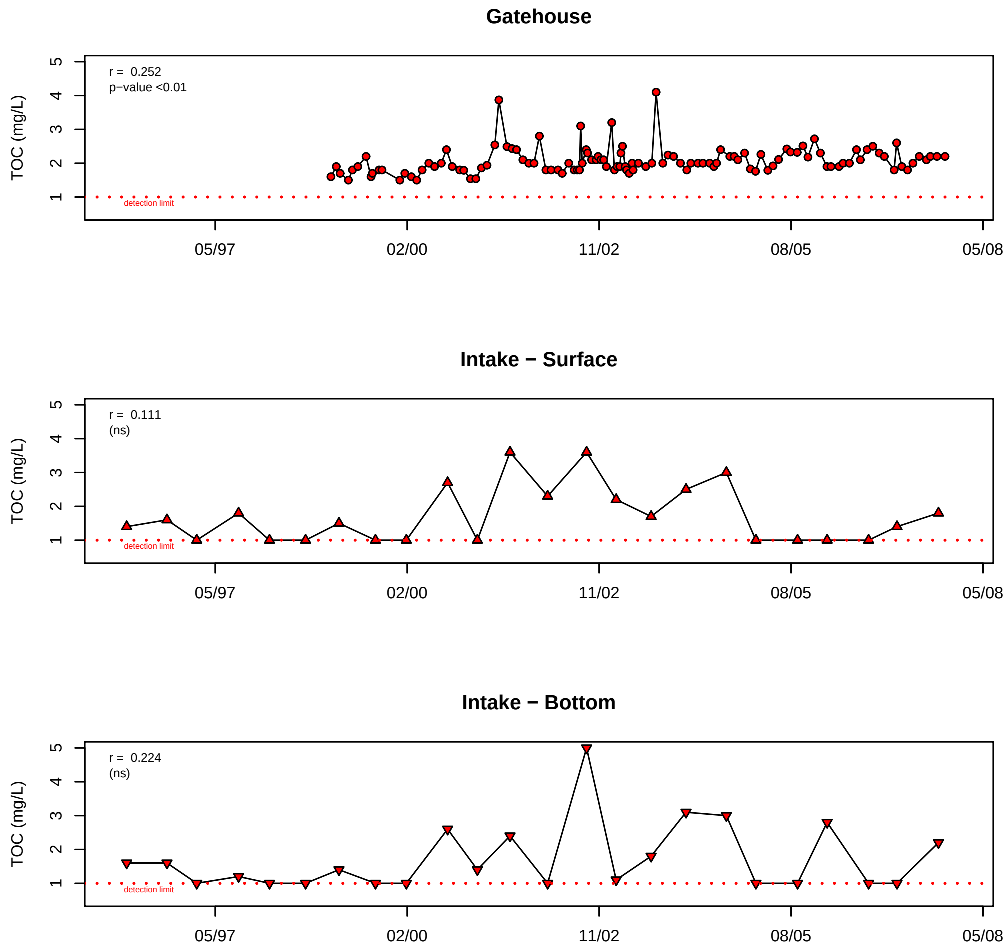

Figure 11: Total organic carbon concentrations at the Intake (off-shore, surface and bottom) and from the gatehouse. Gatehouse data were provided by the City of Bellingham Public Works Department. Pearson's r correlations were used because the data were approximately monotonic-linear; only the gatehouse correlation was significant.

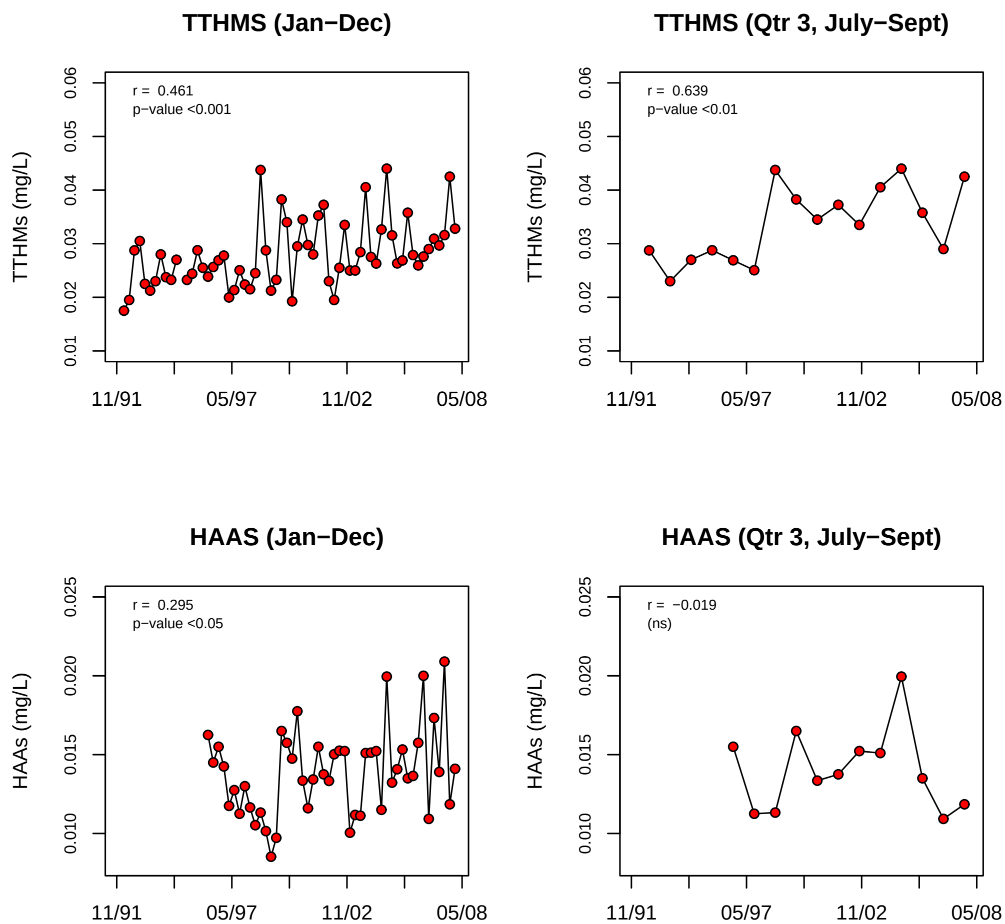

Figure 12: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2007. Data were provided by the City of Bellingham Public Works Department. Pearson's r correlations were used because the data were approximately monotonic-linear; correlations for Jan-Dec THMs, Qtr 3 THMs, and Jan-Dec HAAs were significant.

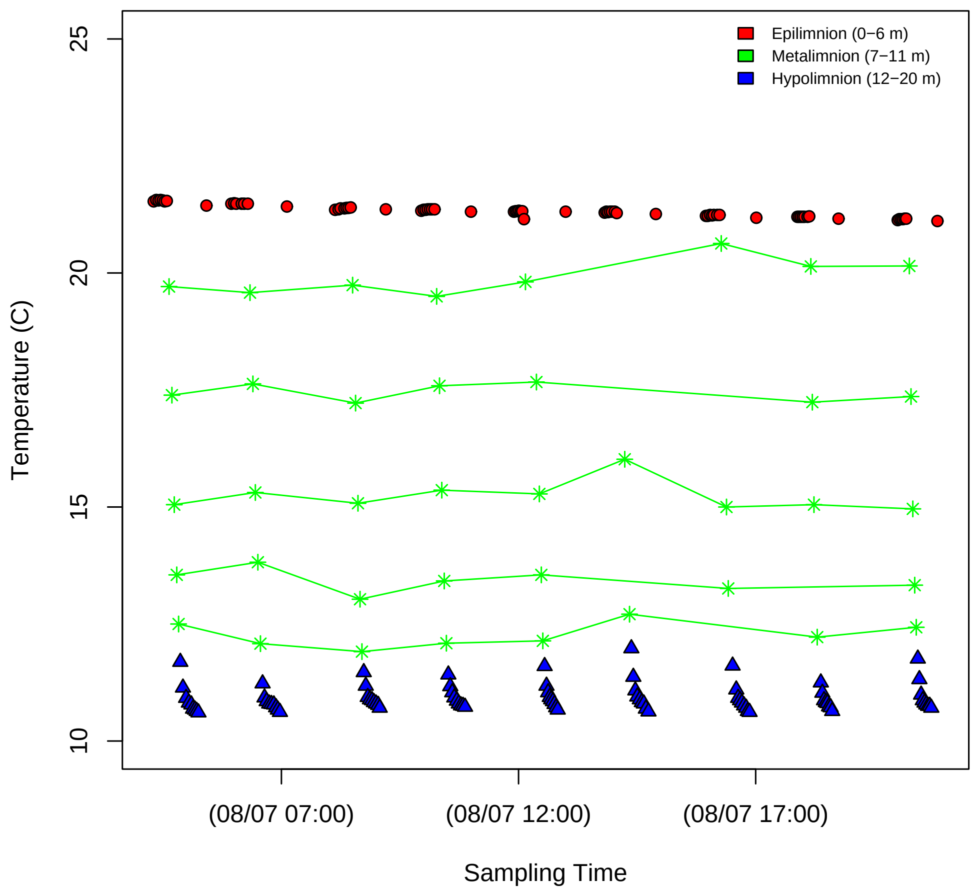

Figure 13: Site 1 diurnal water temperature patterns on August 7, 2007. Epilimnion, metalimnion, and hypolimnion categories were assigned based on temperature changes with depth; metalimnion data were plotted with lines joining data from the same depths (7–11 meters).

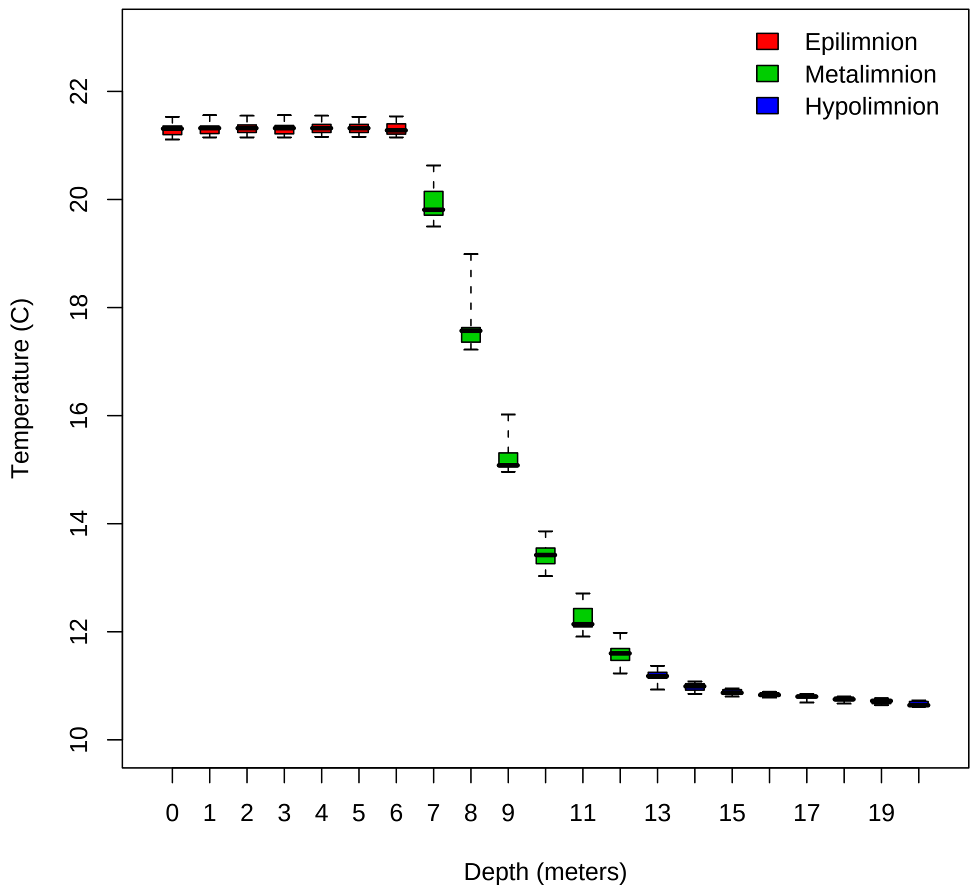

Figure 14: Boxplots showing Site 1 diurnal water temperature patterns on August 7, 2007. Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

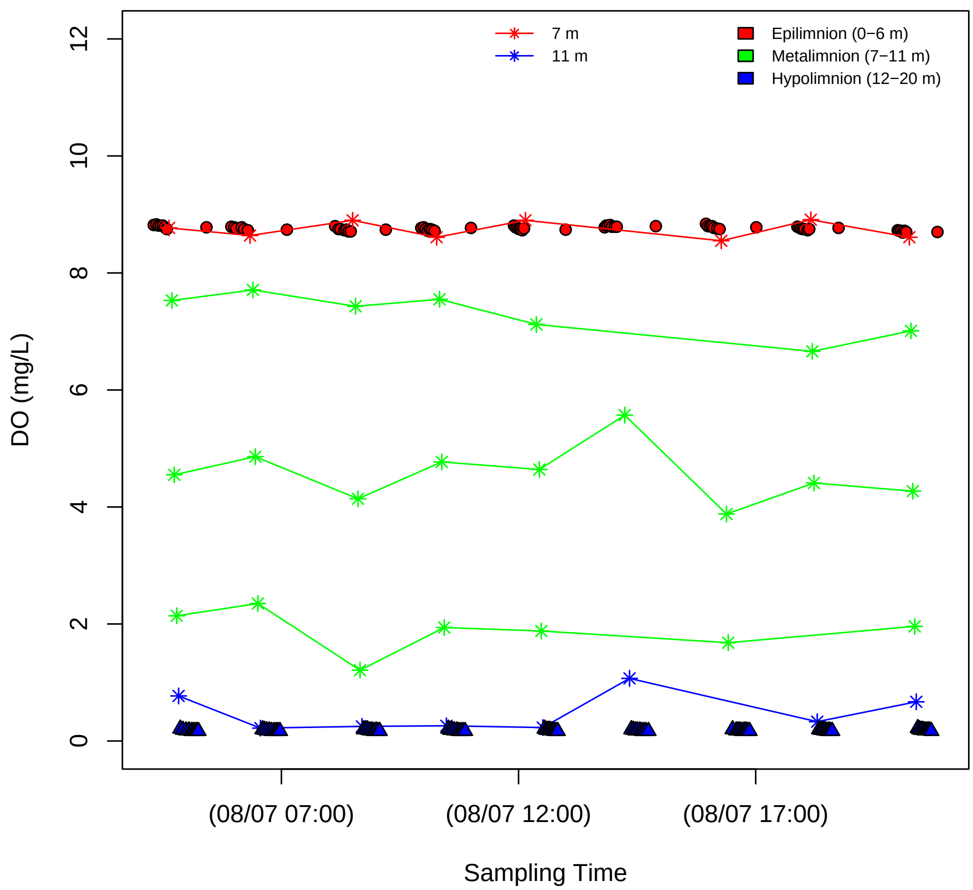

Figure 15: Site 1 diurnal dissolved oxygen patterns on August 7, 2007. Epilimnion, metalimnion, and hypolimnion categories were assigned based on water temperature; metalimnion data were plotted with lines joining data from the same depths (7–11 meters). Results from 7 and 11 meters resembled epilimnetic and hypolimnetic data and were shaded accordingly.

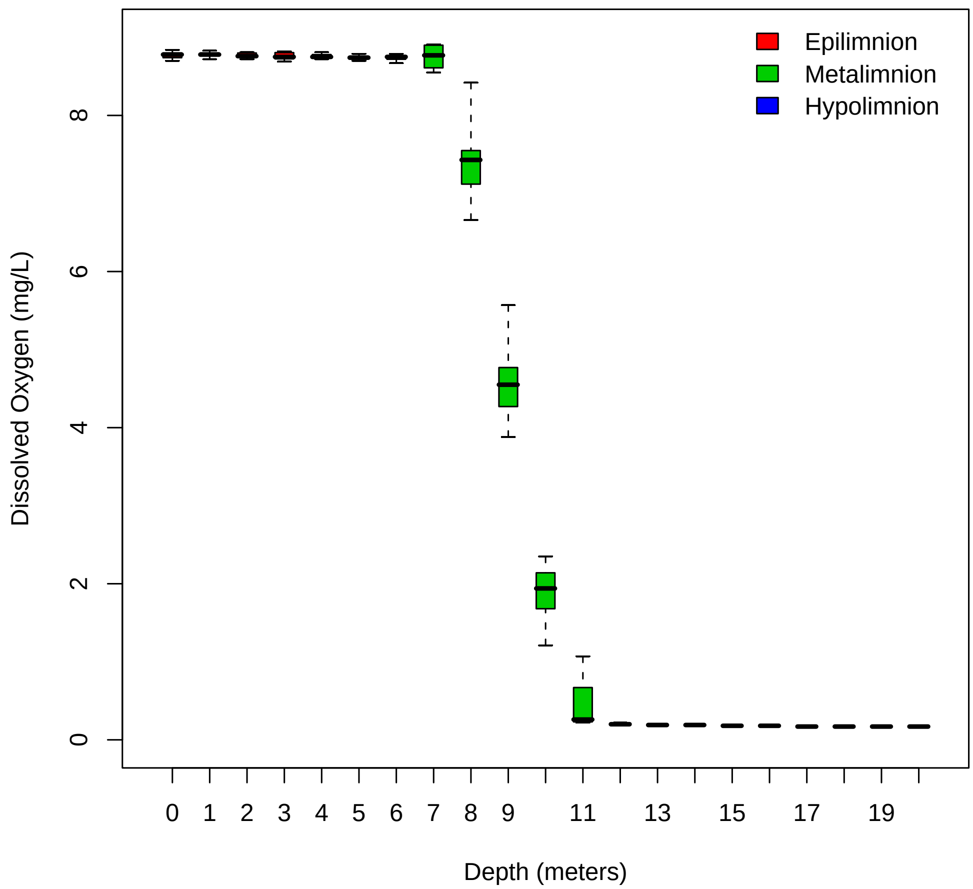

Figure 16: Boxplots showing Site 1 diurnal dissolved oxygen patterns on August 7, 2007. Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

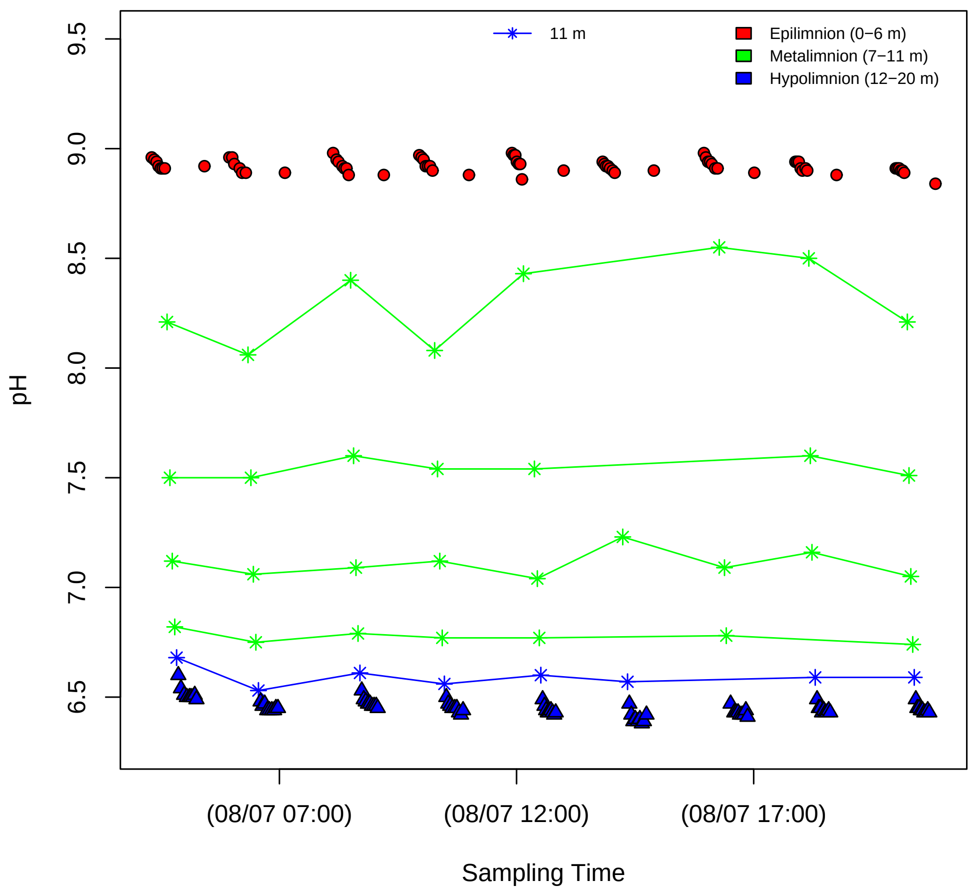

Figure 17: Site 1 diurnal pH patterns on August 7, 2007. Epilimnion, metalimnion, and hypolimnion categories were assigned based on temperature changes with depth; metalimnion data were plotted with lines joining data from the same depths (7–11 meters). Results from 11 meters resembled hypolimnetic data and were shaded accordingly.

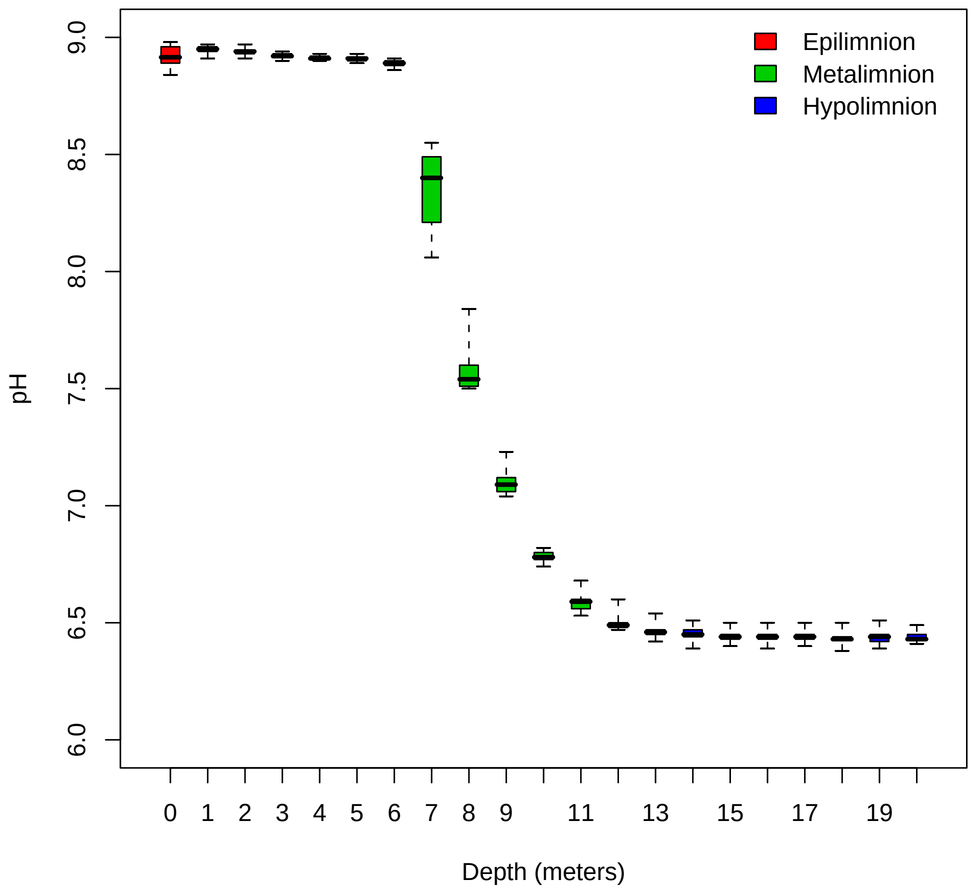

Figure 18: Boxplots showing Site 1 diurnal pH patterns on August 7, 2007. Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

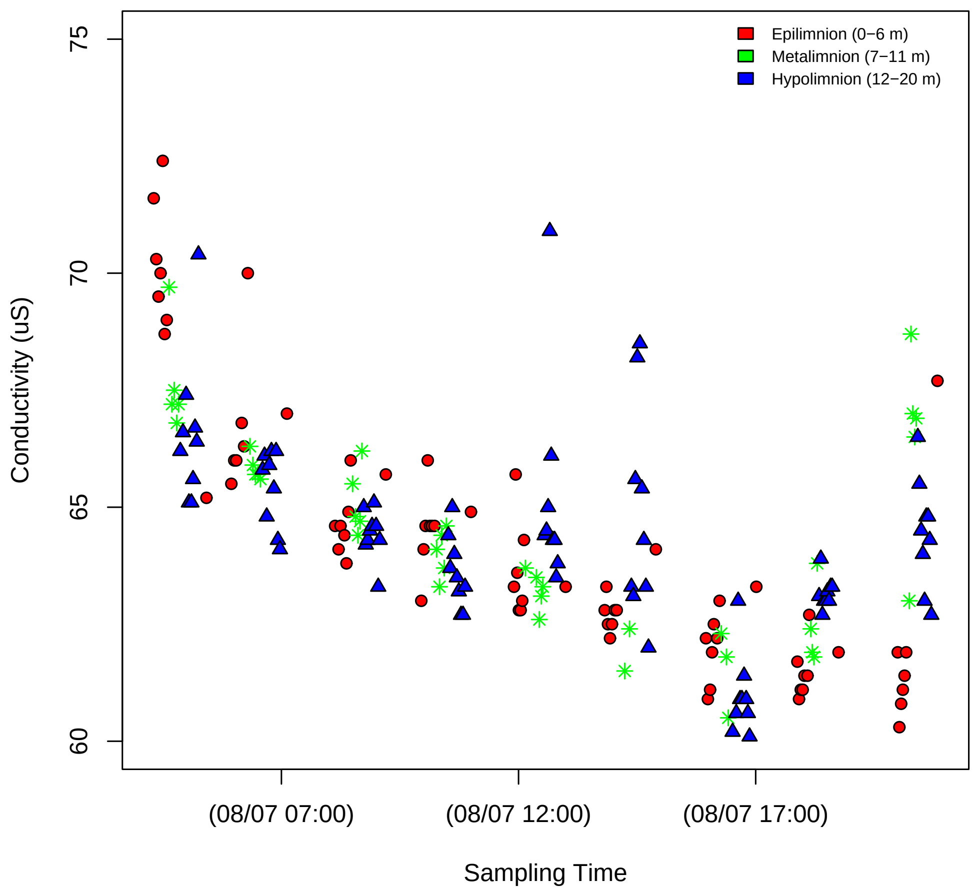

Figure 19: Site 1 diurnal conductivity patterns on August 7, 2007. Epilimnion, metalimnion, and hypolimnion categories were assigned based on temperature changes with depth.

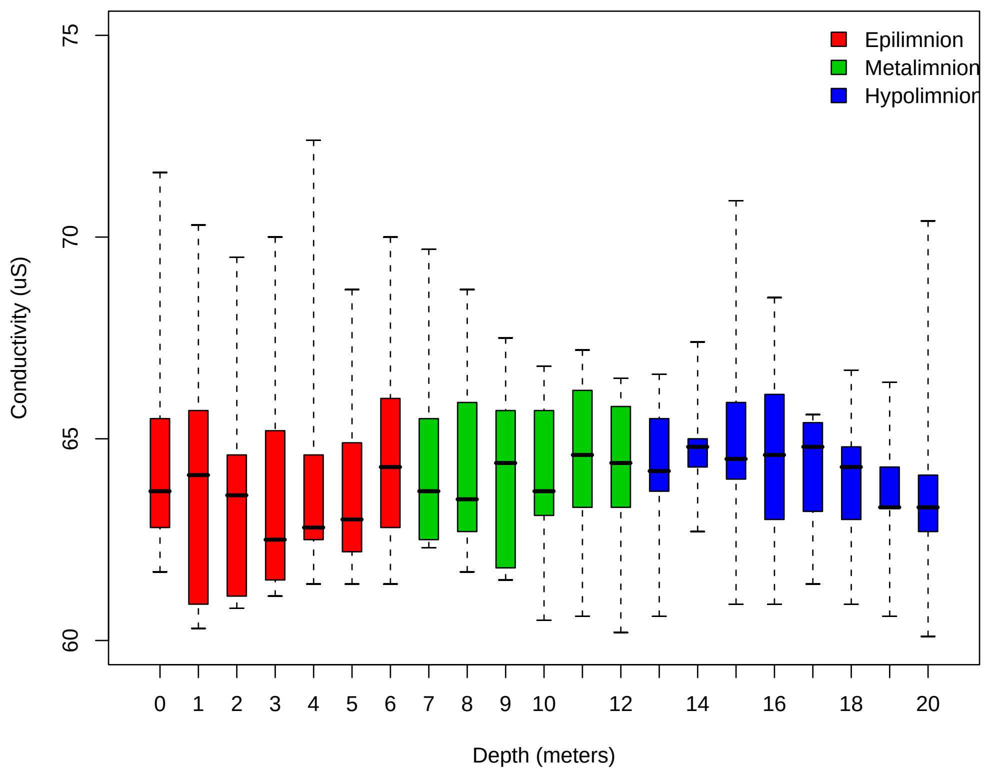

Figure 20: Boxplots showing Site 1 diurnal conductivity patterns on August 7, 2007. Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

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 2007 (February and September) to provide baseline tributary data in the Lake Whatcom watershed (Figure A2, page 108). 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 16). All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory. Once in the laboratory the handling procedures that were relevant for each analysis were followed (see Table 1). The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. All other analyses were done by WWU personnel. Discharge measurements were collected at Blue Canyon Creek; all other sites have USGS or IWS gauges that provide discharge data to the City.

3.3 Results and Discussion

3.3.1 Biannual monitoring

The current data are listed in Tables 13–16 (pages 52–55) and plotted in Appendix B.5 (Figures B171–B212, pages 292–332). The plots in Appendix B.5

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 B171–B176), 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 B171 and B174). The Park Place outlet and Silver Beach Creek had slightly lower median dissolved oxygen concentrations and slightly higher median temperatures, which is typical for residential streams (Figures B173 and B176).

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by pH levels near 7.0–7.5, conductivities $\leq$150 μS, alkalinities $\leq$50 mg/L, total solids $\leq$100 mg/L, and total organic carbon concentrations $<$1 mg/L (Figures B177–B191 and Table 16). Sites that did not match this description included the residential streams (e.g., Park Place outlet and Silver Beach Creek) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$10 mg/L) and low turbidities ($\leq$5 NTU) except for outliers that were usually related to precipitation events (Figures B186–B194).

Ammonia concentrations were elevated in several residential streams (Park Place, Millwheel, and Euclid Creeks), as well as in Anderson and Whatcom Creeks (Figures B195–B197). 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. The elevated ammonia at Park Place probably reflects residential pollution. In Whatcom Creek, it may be coming from basin 1. The ammonia source in Anderson Creek is unknown; there is a wetland, a small lake, and small “hobby farms” located upstream from our sampling site.

Most of the creeks had lower total nitrogen and nitrate/nitrate concentrations than Smith Creek (Figures B198– B203). 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 B204–B209). Total phosphorus and soluble phosphate concentrations were usually highest in the residential streams.

High coliform counts are an indicator of residential pollution (Figures B210–B212), 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, all sites had very high coliform counts in July 2007 ($>$100 cfu/100 mL). Only one site, Silver Beach Creek, had a high coliform count in February 2007 (110 cfu/100 mL).

The metals concentrations were within expected ranges, and most were near or below detection levels (Table 15). 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.

3.3.2 Relationship between turbidity and phosphorus

There is an important relationship between sediments and total phosphorus in surface runoff because phosphorus is often transported with sediments, either as particulate organic phosphorus (e.g., plant debris) or adsorbed onto the surface of fine particles. Because of this, it is theoretically possible to predict phosphorus concentrations by measuring runoff turbidity, which is a much simpler and faster analytical procedure than measuring phosphorus. Turbidity measurements can even be measured directly in the field using automated samplers.

To assess the relationship between turbidity and phosphorus in the Lake Whatcom watershed, we looked for significant regressions using the 2004–2006 monthly tributary data (Matthews, et al., 2007) and the tributary data collected in February and July, 2007. The data were censored to remove phosphorus values below analytical detection limits (TP <5 μ-P/L).[19] Only tributaries to Lake Whatcom that were monitored in 2007 were included in this analysis.[20] Whatcom Creek was not included because its water quality does not reflect surface runoff flowing into the lake.

When all tributary data were combined (Figure 21, page 56), the regression between total phosphorus and turbidity was statistically significant (p-value <0.001), but not very accurate (low R^2). A $\log_{10}$ transformation revealed that the untransformed regressions were biased by a few high values.[21] The low R^2 resulted in a high degree of uncertainty for estimates of total phosphorus. For example, given a turbidity of 20 NTU, the 95% confidence interval for predicting total phosphorus would be 14–90 μg-P/L for the untransformed linear model and 23–144 μg-P/L for the $\log_{10}$ transformed linear model (Figure 22, page 57).

There were significant regressions between total phosphorus and turbidity for most of the individual tributaries (Figures 23–32, pages 58–67); however, the untransformed regressions were heavily influenced by a few high x-y points (see, for example, the Anderson Creek results in Figure 23). The $\log_{10}$ transformed regressions provided better (less biased) models of the linear relationships at each site, but the transformed regressions had lower R^2 values.

The only sites that did not have significant regressions between turbidity and phosphorus were Millwheel Creek (Figure 28) and Silver Beach Creek (Figure 31 - log-scale). Both are residential sites, and Millwheel Creek has an upstream pond. Ponds trap sediment, making turbidity levels less predictable, and attract wildlife, making phosphorus transport less predictable.

[19]Censoring affected two samples: Smith Creek on February 14, 2007, and Brannian Creek on May 17, 2006. All other total phosphorus concentrations were above 5 μ-P/L.

[20]The 2004–2006 monitoring program included additional Austin Creek and Beaver Creek sites.

[21]Least-squares regression is heavily influenced by high values because the fit is determined by minimizing the squared distance from the fitted line.

Site	Date	Alk (mg/L)	Cond (μS/cm)	DO (mg/L)	pH	Temp (C)	Turb (NTU)	TS (mg/L)	TSS (mg/L)
Anderson	Feb 14, 2007	19.6	63.0	12.5	7.0	5.9	2.7	53.8	4.3
	Jul 17, 2007	15.4	53.6	9.8	7.0	14.2	24.8	65.3	22.3
Austin	Feb 14, 2007	18.7	73.2	12.2	7.4	6.2	NA	57.4	3.2
	Jul 17, 2007	34.3	124.0	9.5	7.6	16.4	0.8	81.3	<2
Blue Canyon	Feb 14, 2007	132.1	286.0	12.5	7.7	7.0	3.0	175.8	7.4
	Jul 17, 2007	134.6	277.0	10.5	8.2	13.9	6.0	171.9	7.7
Brannian	Feb 14, 2007	8.4	41.5	12.6	6.8	6.0	0.9	36.3	<2
	Jul 17, 2007	16.5	50.0	7.2	6.7	12.8	0.6	39.2	<2
Carpenter	Feb 14, 2007	21.3	71.5	12.2	7.4	6.0	0.8	54.9	<2
	Jul 17, 2007	46.0	116.9	7.8	7.4	17.2	0.7	88.1	<2
Euclid	Feb 14, 2007	32.4	101.9	11.3	7.3	6.6	1.8	71.1	<2
	Jul 17, 2007	49.3	136.1	7.4	7.0	16.2	3.4	102.2	2.2
Millwheel	Feb 14, 2007	34.3	98.7	10.1	7.3	7.0	7.7	80.8	5.5
	Jul 17, 2007	85.9	185.8	0.7	7.2	23.0	6.8	135.4	6.9
Olsen	Feb 14, 2007	22.1	73.9	12.0	7.5	6.1	1.5	63.0	4.2
	Jul 17, 2007	44.2	117.0	9.3	7.7	16.7	0.4	84.6	<2
Park Place	Feb 14, 2007	91.2	226.0	11.1	7.7	7.6	3.2	152.9	3.2
	Jul 17, 2007	99.7	230.0	8.2	7.4	19.3	19.6	158.4	<2
Silver Beach	Feb 14, 2007	61.6	163.6	12.0	7.9	6.5	4.5	114.0	3.8
	Jul 17, 2007	112.2	252.0	8.5	8.0	17.8	5.0	171.9	5.1
Smith	Feb 14, 2007	16.1	58.0	13.0	7.4	6.1	0.9	51.3	<2
	Jul 17, 2007	32.1	86.1	9.8	7.6	16.3	0.4	65.6	<2
Whatcom	Feb 14, 2007	18.9	61.6	11.6	7.4	6.1	0.8	43.0	<2
	Jul 17, 2007	20.6	61.0	8.5	7.4	22.3	1.2	43.6	<2

Table 13: 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 (cft/100 mL)
Anderson	Feb 14, 2007	15.1	504.3	667.1	8.6	16.9	3
	Jul 17, 2007	$<$10	212.2	332.0	7.0	35.2	120
Austin	Feb 14, 2007	$<$10	531.9	628.0	10.3	19.6	45
	Jul 17, 2007	17.2	290.2	436.2	13.0	14.4	2100
Blue Canyon	Feb 14, 2007	$<$10	144.0	247.9	9.5	13.7	3
	Jul 17, 2007	$<$10	189.3	303.3	9.5	12.4	300
Brannian	Feb 14, 2007	$<$10	913.3	1036.2	$<$5	12.3	2
	Jul 17, 2007	$<$10	299.6	405.8	6.2	5.5	1200
Carpenter	Feb 14, 2007	$<$10	954.1	1099.4	12.4	14.8	$<$1
	Jul 17, 2007	22.1	465.7	666.4	23.1	24.9	1600
Euclid	Feb 14, 2007	$<$10	429.4	581.2	12.7	16.1	24
	Jul 17, 2007	32.5	578.9	946.3	20.6	35.9	1300
Millwheel	Feb 14, 2007	25.1	383.1	669.1	12.0	38.0	10
	Jul 17, 2007	68.8	16.7	837.9	28.8	112.8	760
Olsen	Feb 14, 2007	$<$10	815.1	995.6	12.7	17.3	9
	Jul 17, 2007	15.0	504.0	665.4	19.8	17.6	600
Park Place	Feb 14, 2007	26.0	642.7	893.6	21.2	28.5	12
	Jul 17, 2007	88.1	556.0	1054.1	38.8	64.2	700
Silver Beach	Feb 14, 2007	$<$10	462.1	764.2	13.9	25.8	110
	Jul 17, 2007	$<$10	287.5	760.2	28.3	55.7	5300
Smith	Feb 14, 2007	$<$10	1012.0	1125.6	9.1	$<$5	1
	Jul 17, 2007	15.8	413.7	524.7	14.5	9.4	380
Whatcom	Feb 14, 2007	$<$10	340.0	537.7	6.0	15.9	2
	Jul 17, 2007	30.3	108.6	336.6	$<$5	8.3	110

Table 14: 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 14, 2007	<0.01	<0.0005	<0.001	<0.001	0.257	<0.0001	<0.005	<0.001	<0.001
Austin (lower)	Feb 14, 2007	<0.01	<0.0005	<0.001	0.002	0.157	<0.0001	<0.005	<0.001	0.002
Blue Canyon	Feb 14, 2007	<0.01	<0.0005	<0.001	0.001	0.204	<0.0001	<0.005	<0.001	<0.001
Brannian	Feb 14, 2007	<0.01	<0.0005	<0.001	<0.001	0.115	<0.0001	<0.005	<0.001	0.001
Carpenter	Feb 14, 2007	<0.01	<0.0005	0.001	<0.001	0.054	<0.0001	<0.005	<0.001	0.003
Euclid	Feb 14, 2007	<0.01	<0.0005	<0.001	0.002	0.106	<0.0001	<0.005	<0.001	0.002
Millwheel	Feb 14, 2007	<0.01	<0.0005	<0.001	0.002	0.616	<0.0001	<0.005	<0.001	0.002
Olsen	Feb 14, 2007	<0.01	<0.0005	<0.001	0.001	0.128	<0.0001	<0.005	<0.001	<0.001
Park Place	Feb 14, 2007	<0.01	<0.0005	<0.001	0.003	0.405	<0.0001	<0.005	<0.001	0.004
Silver Beach	Feb 14, 2007	<0.01	<0.0005	<0.001	<0.001	0.470	<0.0001	<0.005	<0.001	0.001
Smith	Feb 14, 2007	<0.01	<0.0005	<0.001	<0.001	0.536	<0.0001	<0.005	<0.001	<0.001
Whatcom	Feb 14, 2007	<0.01	<0.0005	<0.001	<0.001	0.027	<0.0001	<0.005	<0.001	<0.001
Anderson	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.959	<0.0001	<0.005	0.002	<0.001
Austin (lower)	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.255	<0.0001	<0.005	<0.001	<0.001
Blue Canyon	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.263	<0.0001	<0.005	<0.001	<0.001
Brannian	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.127	<0.0001	<0.005	<0.001	<0.001
Carpenter	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.164	<0.0001	<0.005	<0.001	<0.001
Euclid	July 17, 2007	<0.01	<0.0005	0.002	<0.001	0.366	<0.0001	<0.005	<0.001	<0.001
Millwheel	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	1.660	<0.0001	<0.005	<0.001	0.001
Olsen	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.062	<0.0001	<0.005	<0.001	<0.001
Park Place	July 17, 2007	<0.01	<0.0005	<0.001	0.002	0.546	<0.0001	<0.005	<0.001	<0.001
Silver Beach	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.500	<0.0001	<0.005	<0.001	<0.001
Smith	July 17, 2007	<0.01	<0.0005	0.002	<0.001	0.026	<0.0001	<0.005	<0.001	<0.001
Whatcom	July 17, 2007	<0.01	<0.0005	<0.001	<0.001	0.066	<0.0001	<0.005	<0.001	<0.001

Table 15: 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 Appendix D.5.

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Anderson	Feb 14, 2007	<1	July 17, 2007	<1
Austin (lower)	Feb 14, 2007	1.9	July 17, 2007	<1
Blue Canyon	Feb 14, 2007	3.8	July 17, 2007	<1
Brannian	Feb 14, 2007	<1	July 17, 2007	<1
Carpenter	Feb 14, 2007	<1	July 17, 2007	<1
Euclid	Feb 14, 2007	<1	July 17, 2007	1.4
Millwheel	Feb 14, 2007	1.2	July 17, 2007	<1
Olsen	Feb 14, 2007	1.4	July 17, 2007	<1
Park Place	Feb 14, 2007	<1	July 17, 2007	<1
Silver Beach	Feb 14, 2007	2.5	July 17, 2007	<1
Smith	Feb 14, 2007	<1	July 17, 2007	<1
Whatcom	Feb 14, 2007	3.0	July 17, 2007	<1

Table 16: Lake Whatcom tributary data: total organic carbon.

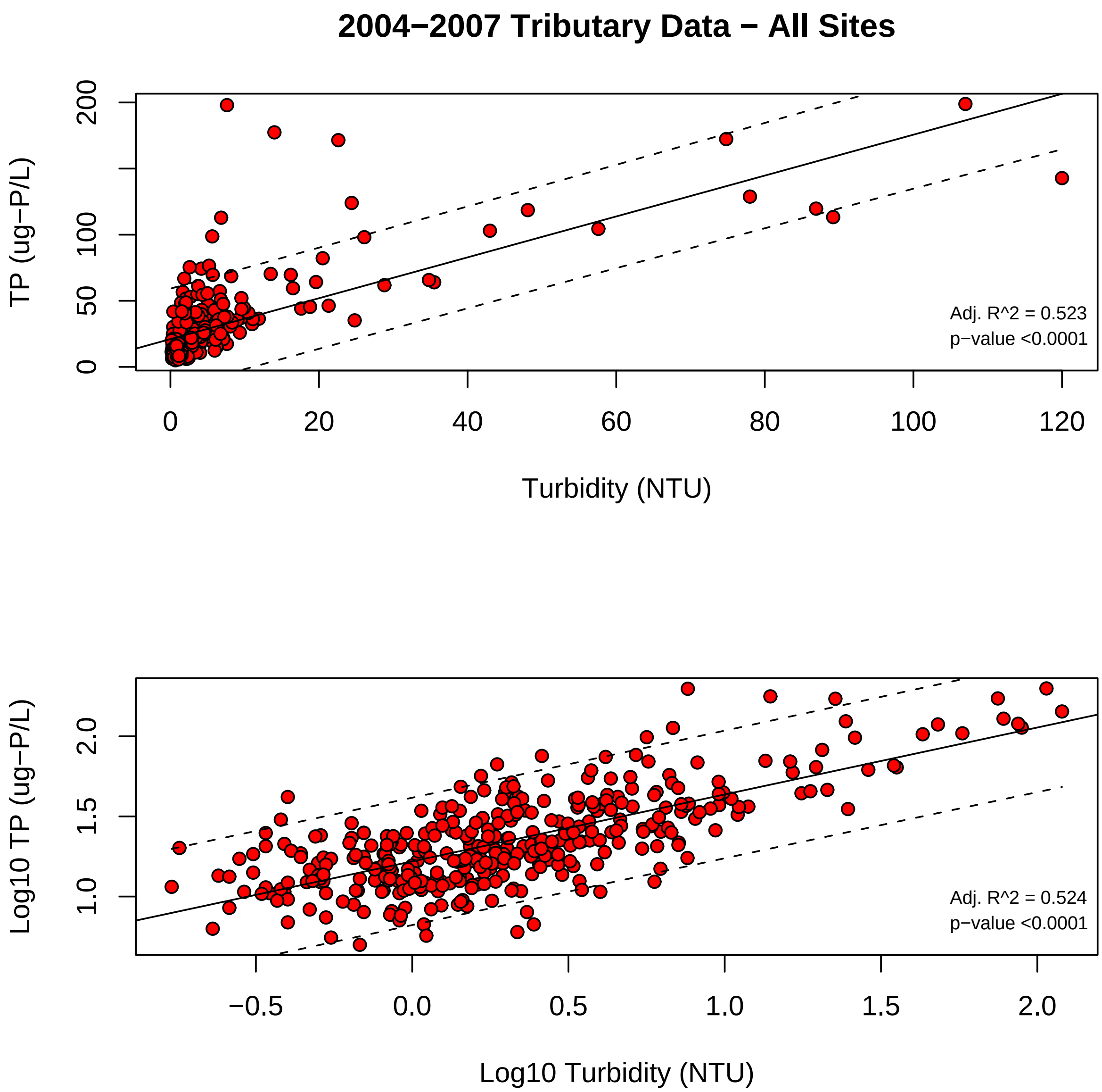

Figure 21: Linear regression between total phosphorus and turbidity for all currently monitored tributaries in the Lake Whatcom watershed (Anderson, lower Austin, Brannian, Carpenter, Euclid, Millwheel, Olsen, Park Place, Silver Beach, and Smith Creeks).

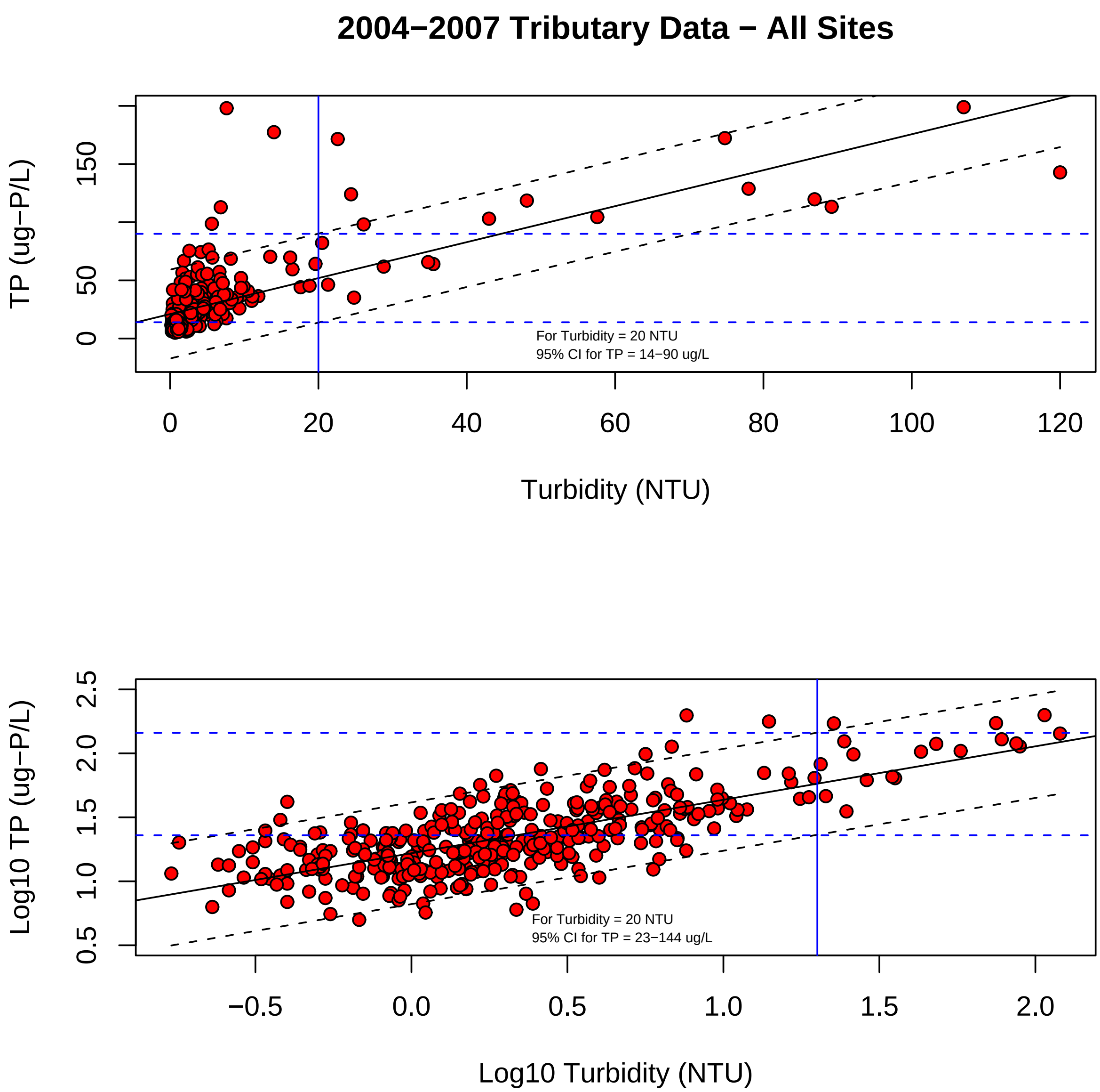

Figure 22: Linear regressions for untransformed and $\log_{10}$ transformed total phosphorus at all tributary sites showing 95% confidence intervals for turbidity = 20 NTU.

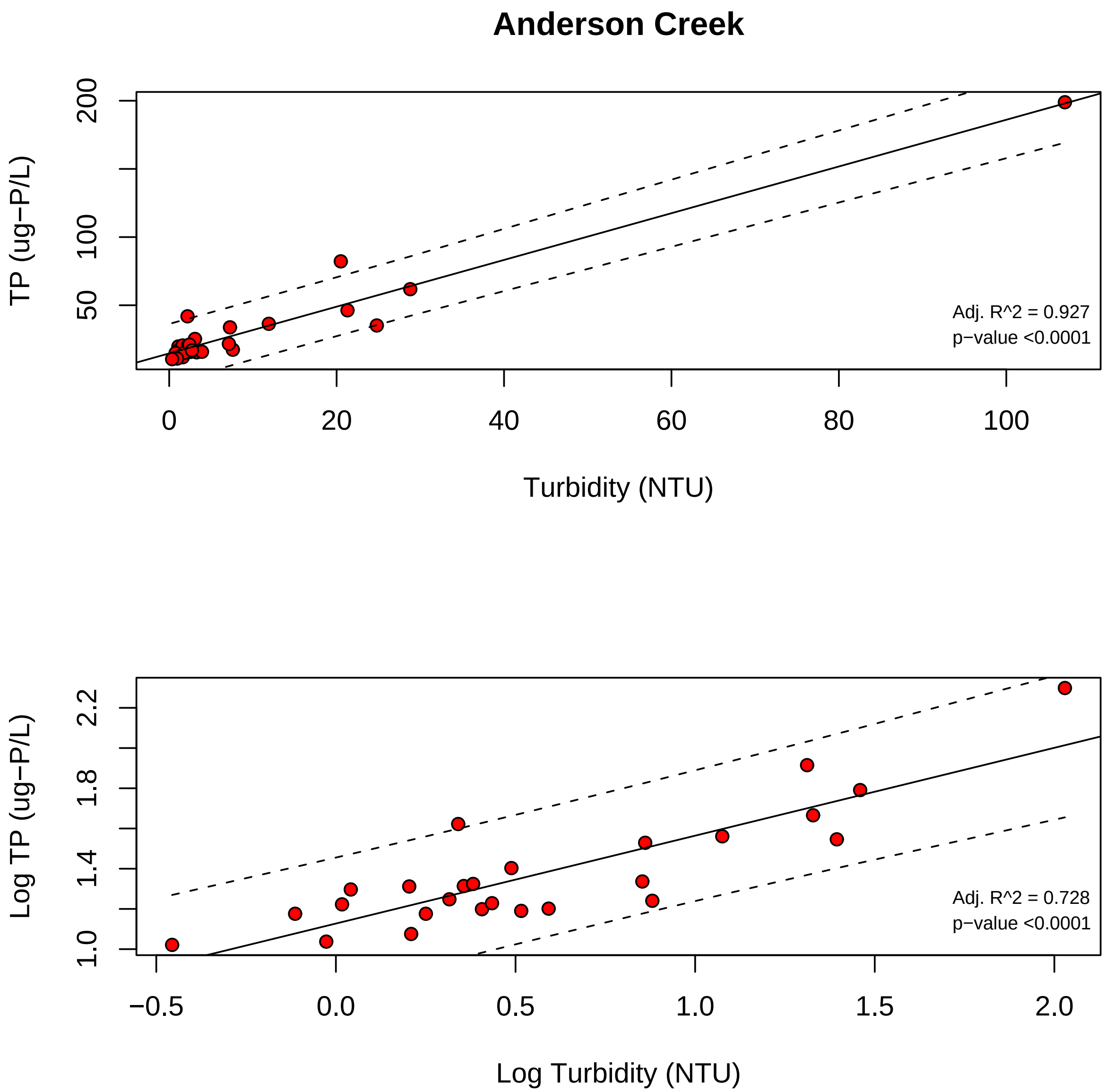

Figure 23: Regressions between total phosphorus and turbidity for Anderson Creek.

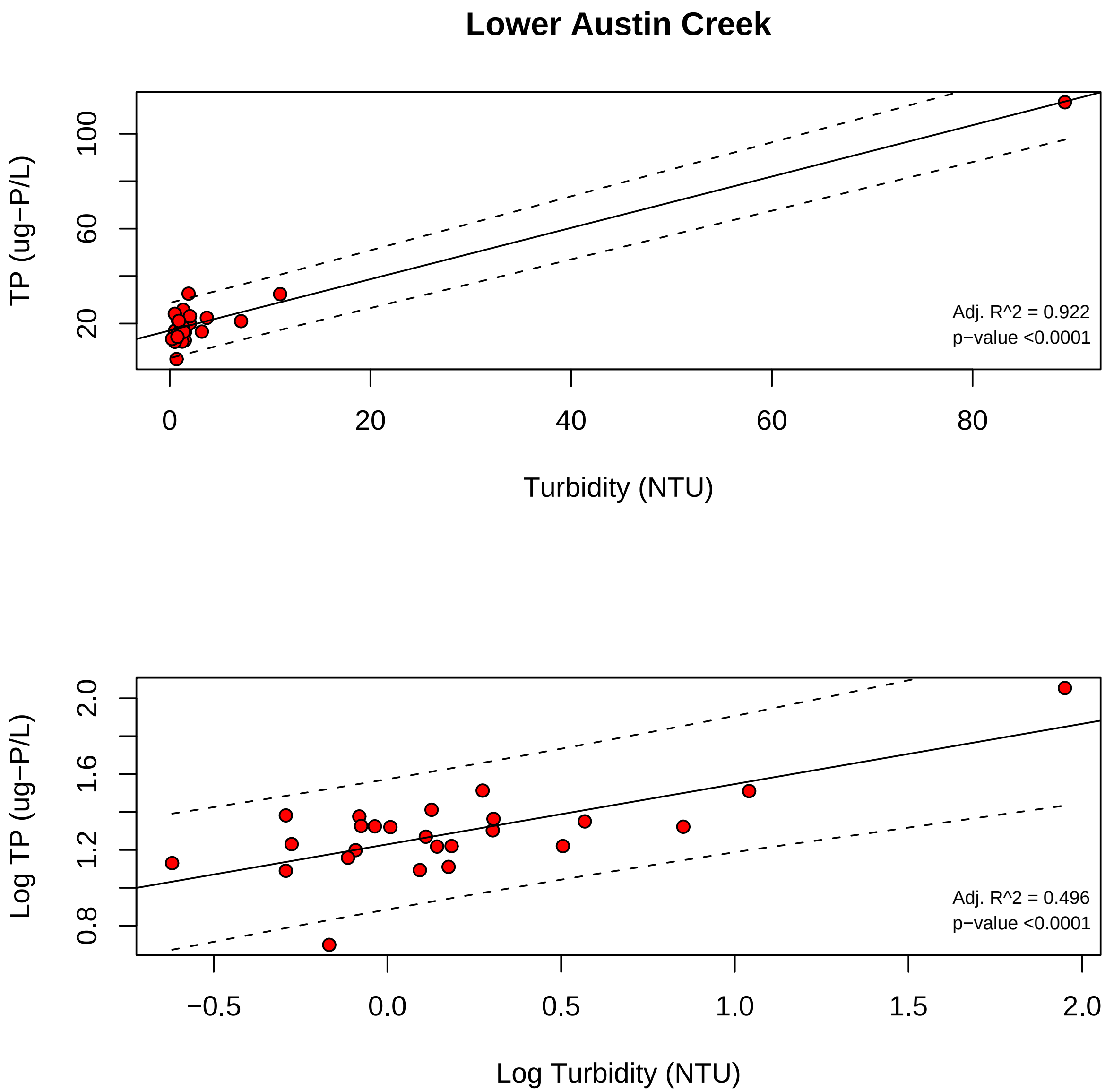

Figure 24: Regressions between total phosphorus and turbidity for Lower Austin Creek.

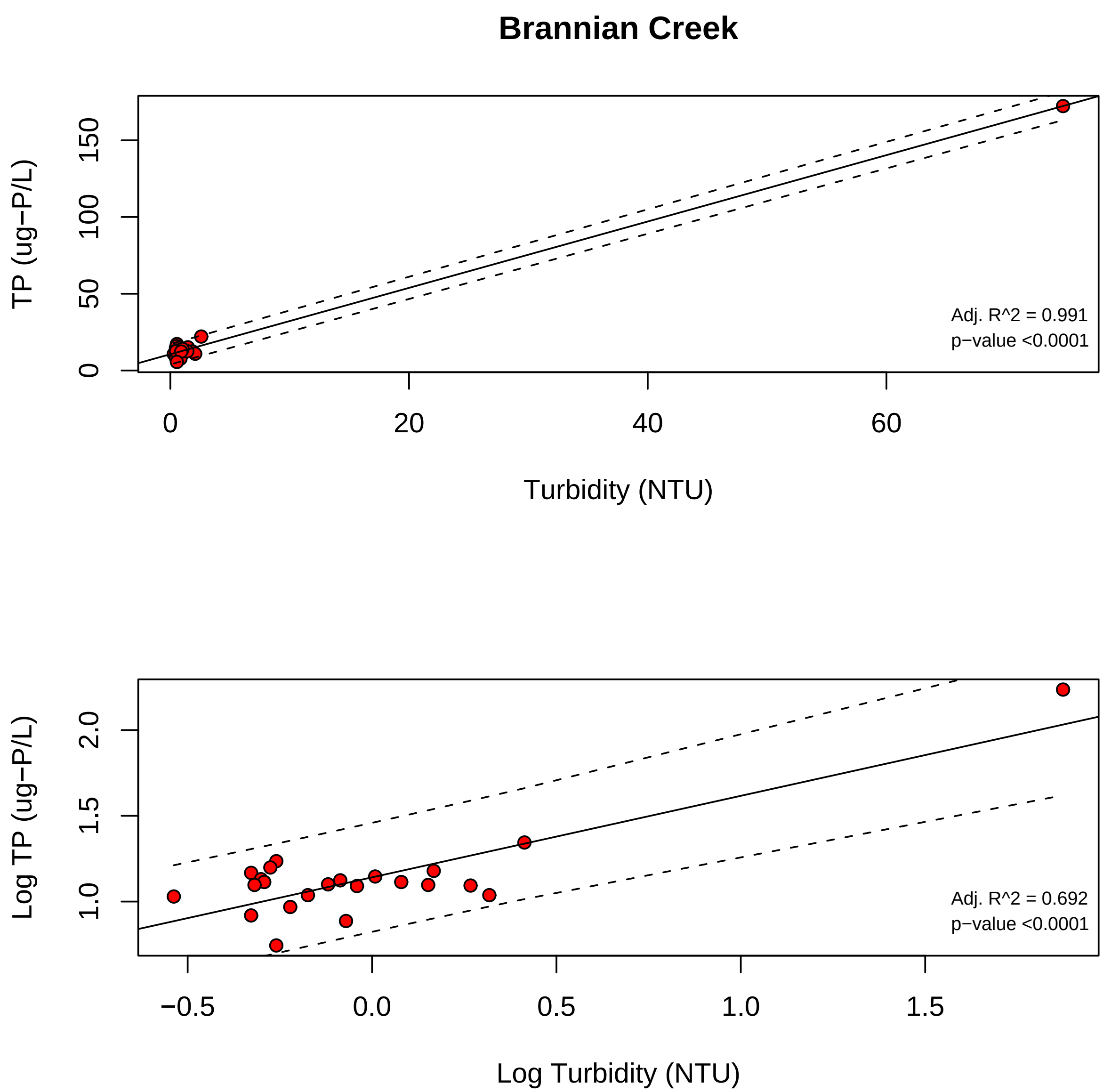

Figure 25: Regressions between total phosphorus and turbidity for Brannian Creek.

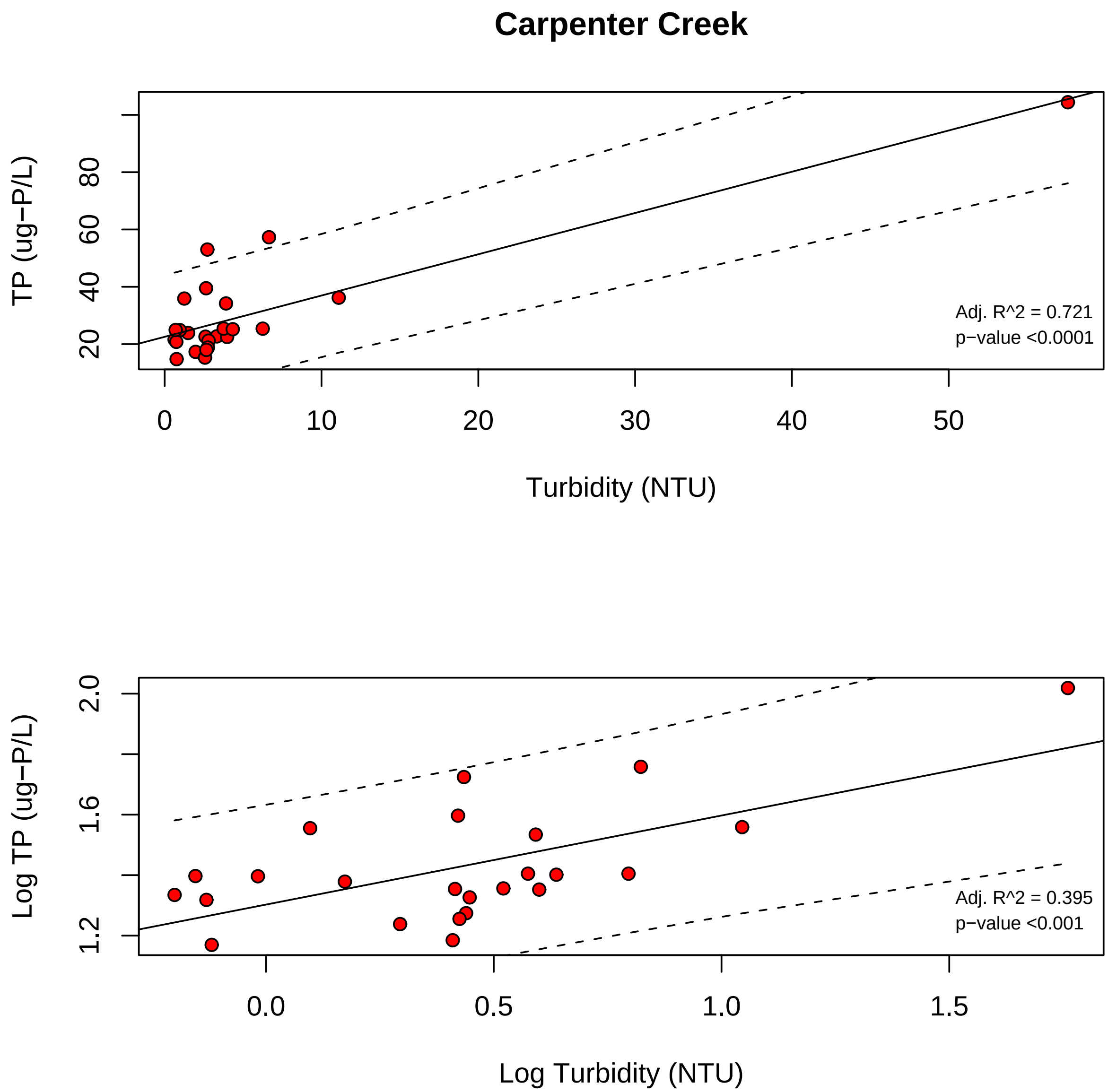

Figure 26: Regressions between total phosphorus and turbidity for Carpenter Creek.

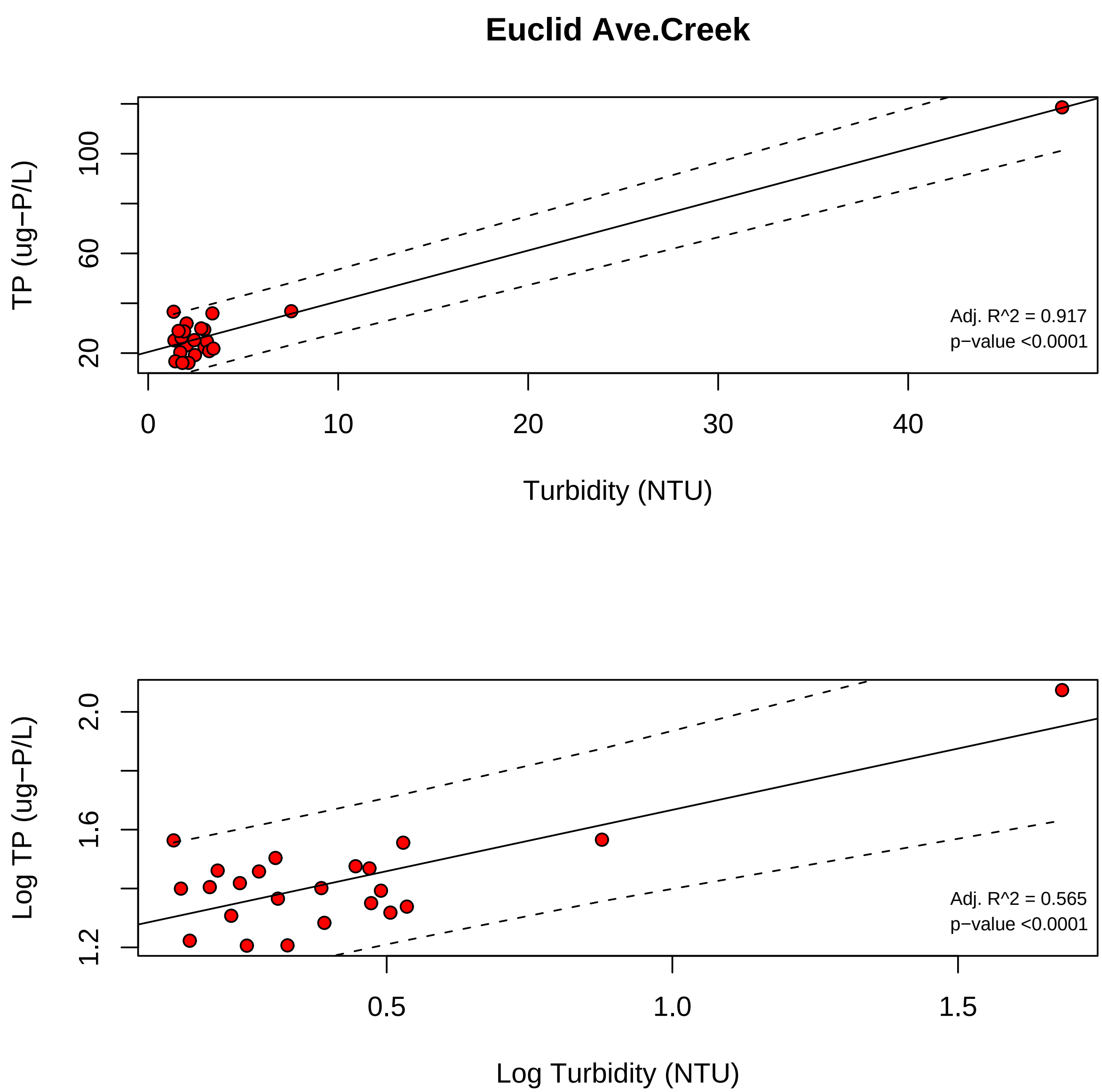

Figure 27: Regressions between total phosphorus and turbidity for Euclid Creek.

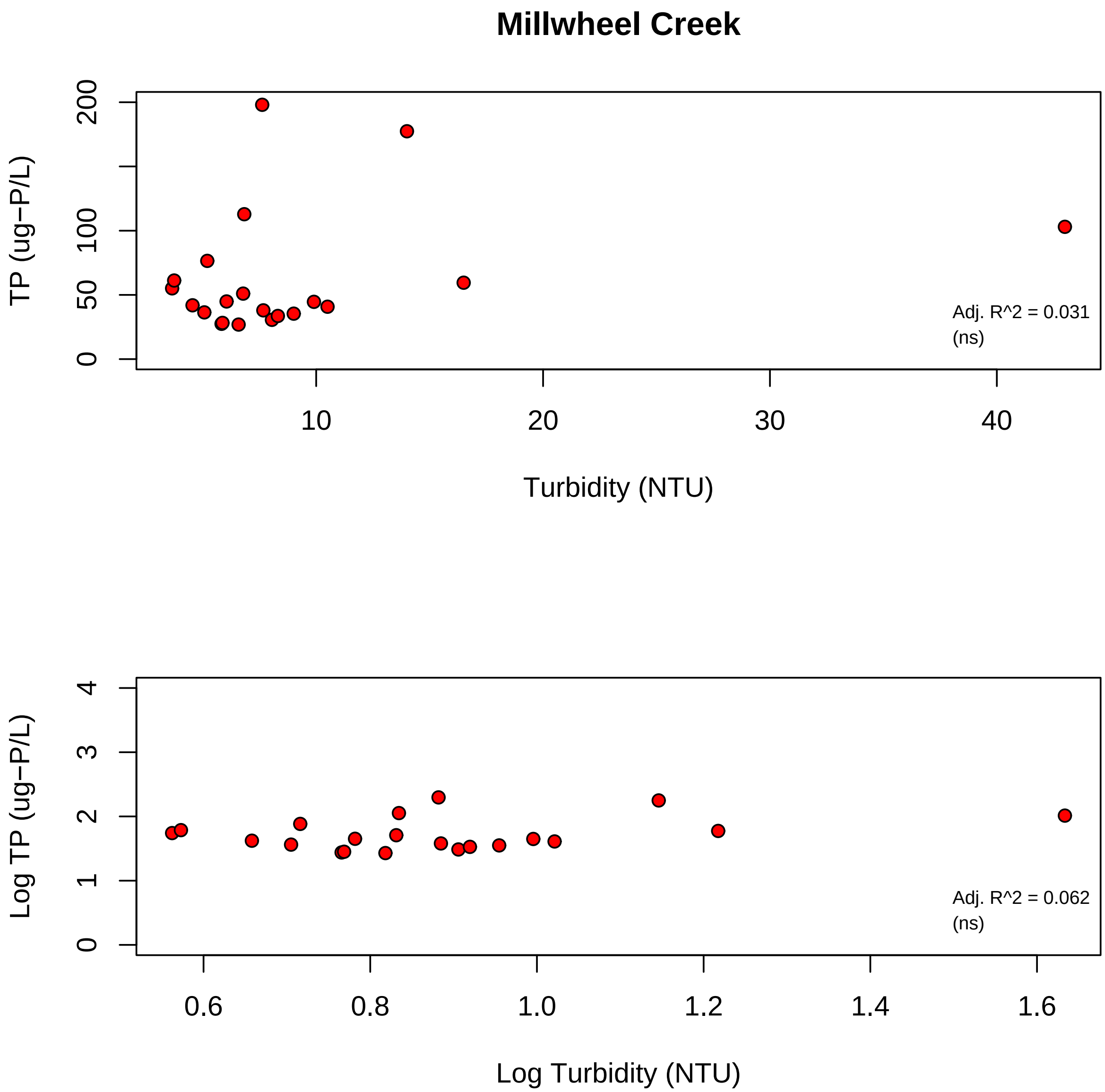

Figure 28: Regressions between total phosphorus and turbidity for Millwheel Creek.

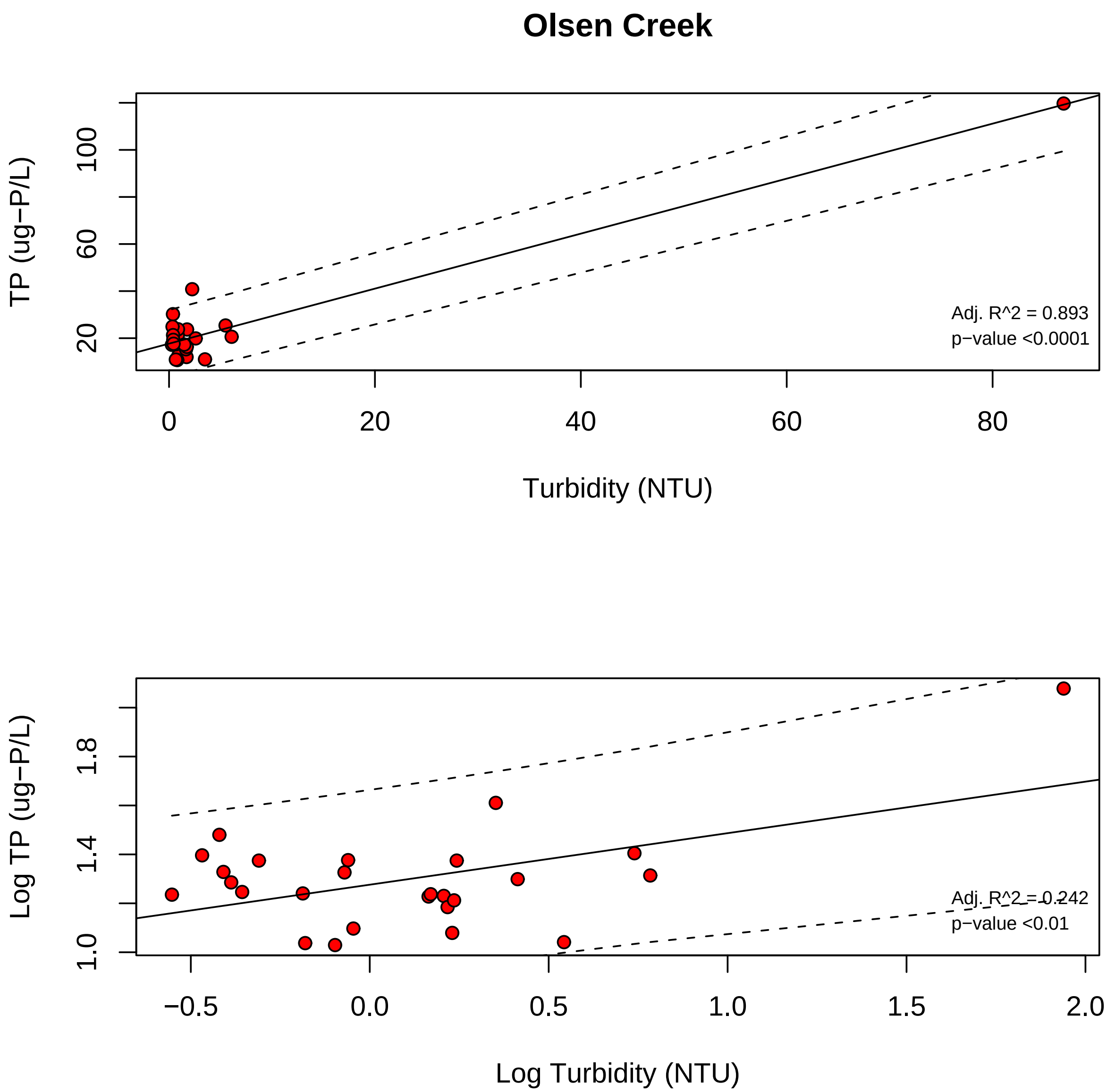

Figure 29: Regressions between total phosphorus and turbidity for Olsen Creek.

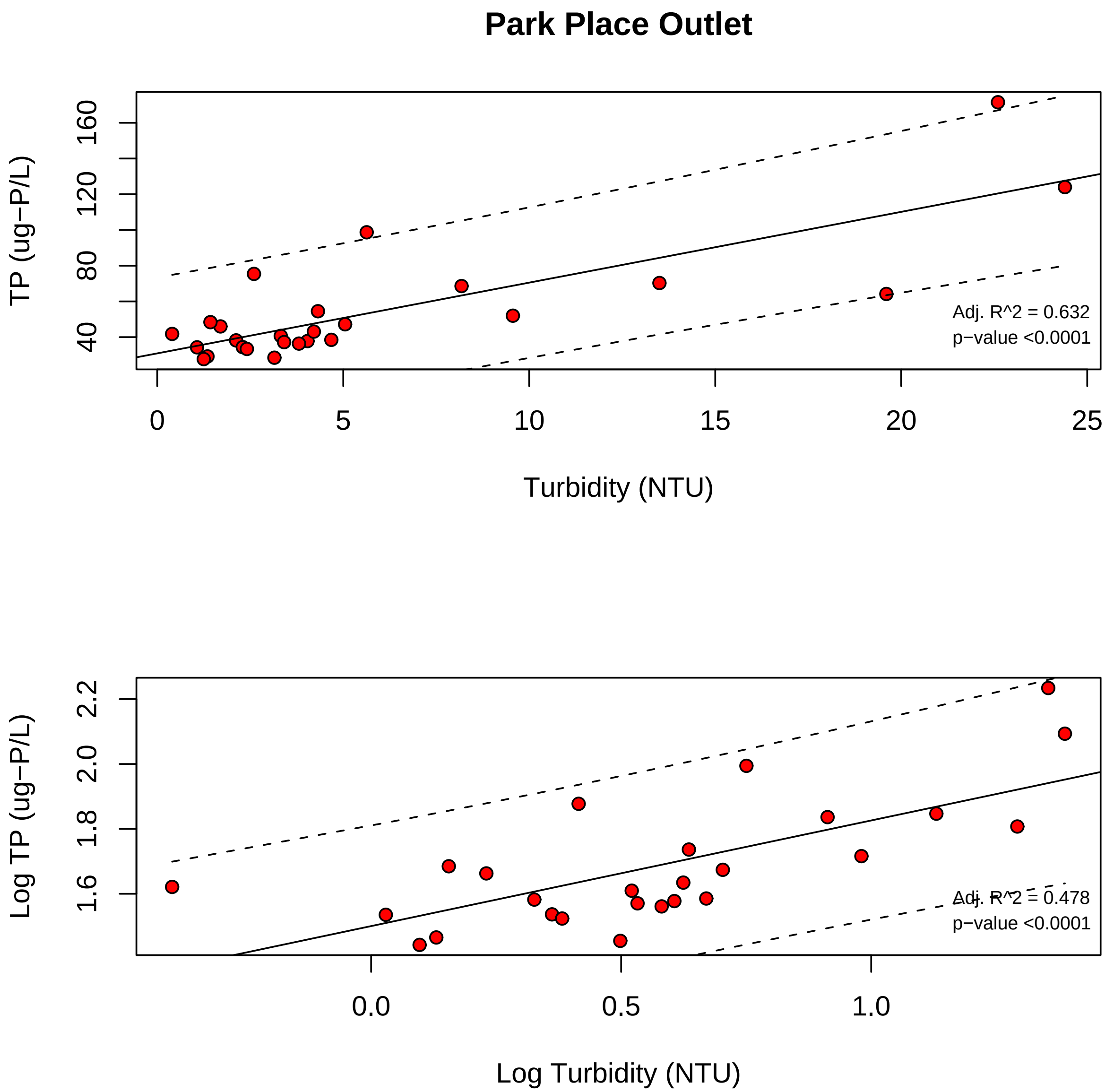

Figure 30: Regressions between total phosphorus and turbidity for the Park Place storm water treatment outlet.

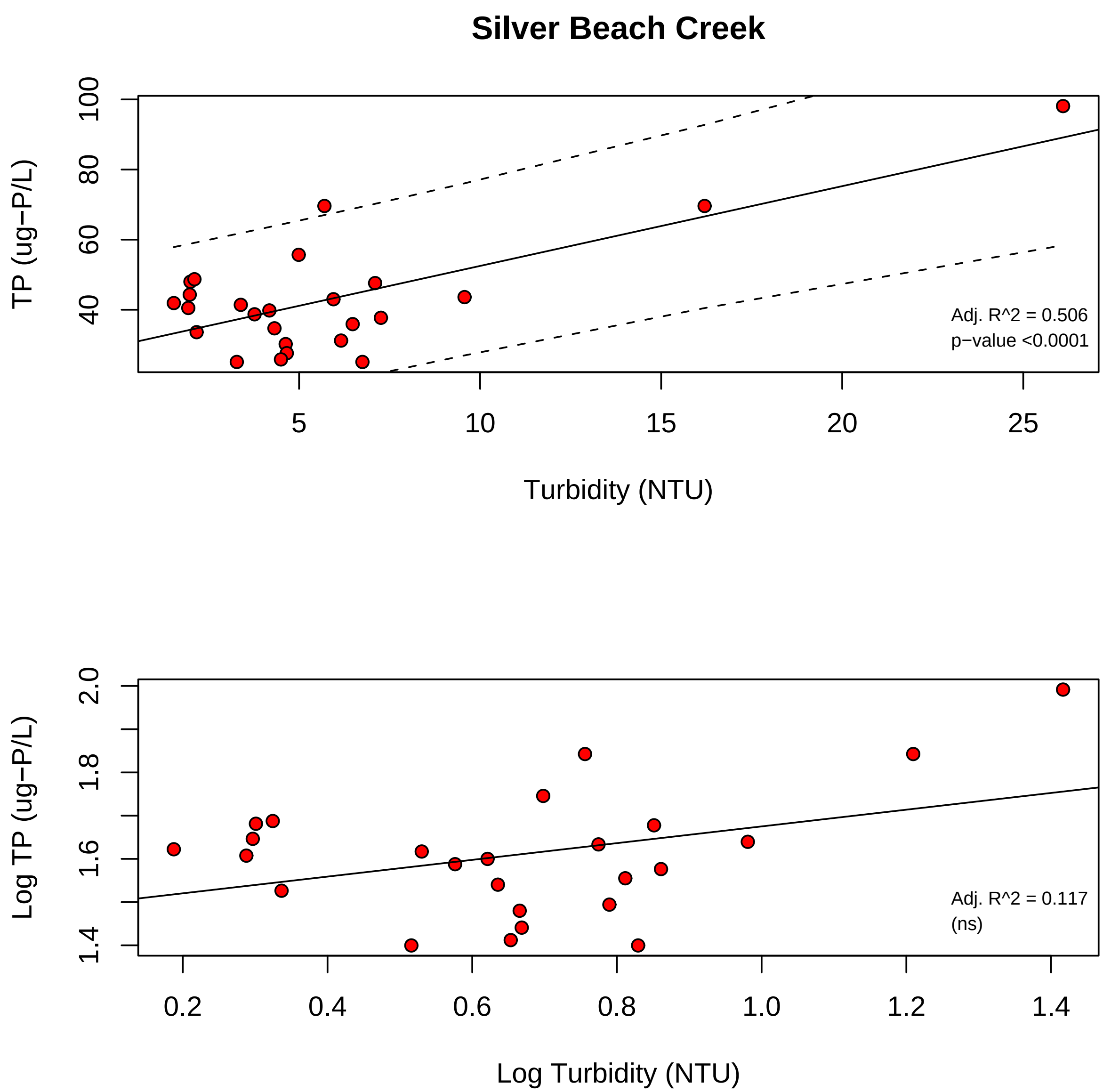

Figure 31: Regressions between total phosphorus and turbidity for Silver Beach Creek.

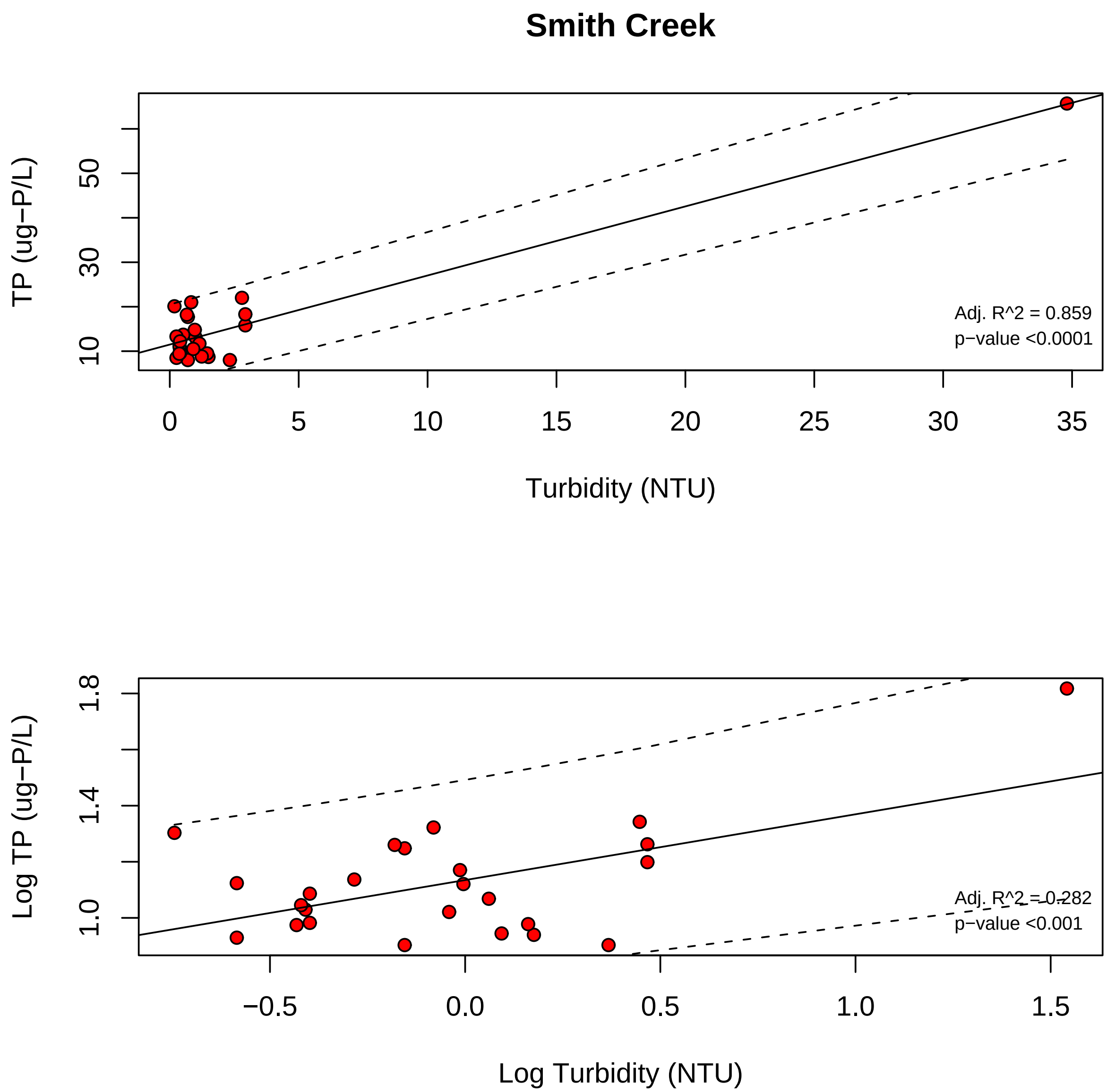

Figure 32: Regressions between total phosphorus and turbidity for Smith Creek.

4 Lake Whatcom Hydrology

4.1 Hydrograph Data

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks; the data are plotted in Figures 33–35 (pages 74–76). The location of each hydrograph is described in Appendix A.2. All hydrograph data, including data from previous years, are online at http://www.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 six additional sites in the Lake Whatcom watershed (Brannian, Carpenter, Euclid, Mill Wheel, Olsen, and Silver Beach Creeks). Figure 36 (page 77) 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 36. Rating curves for earlier water years are available from the Institute for Watershed Studies.

The City's hydrological monitoring equipment was stolen from the Anderson Creek site during the summer of 2007. As a result, the IWS records for Anderson Creek are incomplete in WY2007. Beginning in September 2007, the USGS was contracted to monitor Anderson Creek and post the data online at http://waterdata.usgs.gov/WA/nwis/current/?type=flow, so IWS no longer maintains this site.

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 (Table17, page 71). 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 Hatchery, City of Bellingham, Georgia Pacific, and the Lake Whatcom Water and Sewer District.[22] 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, and runoff. The diversion magnitudes used for the water balance were estimated, and have the lowest degree of precision.

Daily direct-precipitation magnitudes were estimated using the precipitation data recorded at the Bloedel Donovan, Geneva gatehouse, Smith Creek, and Brannian Creek gauges. This is the first year that data from the Bloedel Donovan gauge were used in the analysis. The Thiessen polygon method (Dingman, 1994) was used to estimate the daily direct-precipitation areal average over the lake by weighting the precipitation at each gauge by a respective lake-area percentage. The weighted areas were determined by the “Create Thiessen Polygons” tool 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 2006/2007 was 52.0 inches (7062 MG).

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 2006/2007 was 20.8 inches (2831 MG), most of which occurred between June 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 daily net change in lake level (inches) was converted to a volume (MG) via a rating

[22] Formerly Water District #10

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 2006/2007 was 252,759 MG. Figure 37 (page 78) shows daily lake-volume values for the past five years. The dramatic changes throughout the course of a year are due primarily to rainfall-runoff events and the Whatcom Creek discharges that are controlled by the COB.

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. Negative values of runoff are likely due to the change in storage estimates.

The daily water balance quantities were summed into 7-day totals, which were used to generate Figures 38–41 (pages 79–82). Figure 38 shows 7-day summed totals for inputs, outputs, and change in storage. All the inputs except runoff are shown in Figure 39; all outputs except Whatcom Creek are shown in Figure 40. Due to their much higher magnitude, runoff and Whatcom Creek data are included on Figure 41.

Yearly water balance totals are listed in Table 17 (page 71) along with the yearly total values for the four previous water years. The total volume of outputs correspond to 15.6% of the median total volume of the lake. Under the assumption that the lake is completely mixed and flow is steady state (inputs = outputs), this would correspond to a 6.4 year residence time, with residence times for the past 5 years ranging from 6.1–10.1 years.[23] Tables 18 and 19 (pages 72–73) show the 2006/2007 total input and output volumes along with the corresponding monthly percentage of each total.

The Distributed Hydrology-Soils-Vegetation Model (DHSVM) was use to simulate surface-water runoff into the lake (Figure 41). The DHSVM is a physically based numerical model developed at the University of Washington and Pacific Northwest National Laboratory (Wigmosta et al., 1994). The model was applied in earlier Lake Whatcom watershed studies (Matthews et al., 2007; Kelleher, 2006). The runoff estimated from the water budget and Whatcom Creek outflow are shown along with the runoff estimated using DHSVM in Figure 41.

[23] 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.

	WY2007 (9/30/06–10/1/07)	WY2006 (9/30/05–10/1/05)	WY2005 (9/30/04–10/1/05)	WY2004 (9/30/03–10/1/04)	WY2003 (9/30/02–10/1/03)
Inputs (MG)					
Direct Precipitation	7,063 (18.2%)	6,783 (17.9%)	6,501 (16.2%)	7,612 (18.6%)	4,859 (19.5%)
Diversion	2,920 (7.5%)	4,155 (11.0%)	3,852 (9.6%)	5,095 (12.4%)	4,442 (17.8%)
Runoff*	28,717 (74.2%)	26,879 (71.1%)	29,673 (74.1%)	28,288 (69.0%)	15,589 (62.6%)
Total	38,700 (100%)	37,817 (100%)	40,026 (100%)	40,955 (100%)	24,890 (100%)
Outputs (MG)					
Whatcom Creek	30,359 (77.1%)	28,290 (74.8%)	30,899 (74.0%)	26,948 (71.2%)	13,361 (53.5%)
Hatchery	1,002 (2.5%)	1,253 (3.3%)	1,288 (3.1%)	1,278 (3.4%)	1,124 (4.5%)
Georgia Pacific	807 (2.0%)	960 (2.5%)	2,198 (5.3%)	2,053 (5.4%)	2,988 (12.0%)
City of Bellingham	4,145 (10.5%)	4,111 (10.9%)	4,111 (9.8%)	4,449 (11.8%)	4,342 (17.4%)
LW Water/Sewer Distr.	232 (0.6%)	242 (0.6%)	252 (0.6%)	204 (0.5%)	136 (0.6%)
Evaporation	2,831 (7.2%)	2,946 (7.8%)	2,990 (7.2%)	2,924 (7.7%)	3,016 (12.1%)
Total	39,376 (100%)	37,802 (100%)	41,738 (100%)	37,855 (100%)	24,971 (100%)
Net change in storage	-520	15	-1,692	3,139	-81
Median lake volume (MG)	252,759	252,287	252,856	252,970	252,075
Outflow percent of volume	15.6%	15.0%	16.5%	15.0%	9.9%
Residence time (years)**	6.4	6.7	6.1	6.7	10.1

*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 17: Annual water balance quantities for the Lake Whatcom watershed, WY2003–WY2007.

Month	Input Percents			Total
	Diver	Precip	Runoff*	
Oct	0.94	3.40	-1.19	-0.19
Nov	8.04	26.18	18.07	18.79
Dec	5.31	11.42	18.24	16.02
Jan	0.00	14.26	25.78	21.73
Feb	9.15	8.06	10.42	9.89
Mar	11.92	13.25	18.07	16.73
Apr	7.34	6.53	6.56	6.61
May	23.54	3.19	3.49	4.95
Jun	17.30	3.83	1.39	3.04
Jul	13.61	3.07	1.28	2.53
Aug	1.75	2.11	-0.18	0.38
Sep	1.11	4.71	-1.92	-0.48
	Input Volume (MG)			
Total	2,920	7,063	28,717	38,700

*Runoff = surface runoff + groundwater

Table 18: Monthly input water balance quantities for the Lake Whatcom watershed, October 2006–September 2007.

Month	Output Percents						Total
	WC	Hatch	GP	COB	WSD	Evap	
Oct	3.58	8.72	6.98	7.70	7.68	5.13	4.35
Nov	17.66	6.29	10.30	7.06	7.75	3.15	15.00
Dec	20.62	6.49	11.07	7.27	8.27	1.52	17.21
Jan	26.98	6.49	10.81	6.95	8.51	1.83	22.10
Feb	8.28	6.82	7.19	6.38	7.47	3.82	7.70
Mar	9.74	7.89	7.78	6.99	7.34	6.72	9.13
Apr	4.68	7.63	7.98	6.74	7.40	10.45	5.47
May	3.22	7.70	5.61	8.11	7.93	12.29	4.58
Jun	1.78	11.85	5.65	8.61	8.54	12.52	3.65
Jul	1.53	11.41	6.44	13.22	10.27	18.05	4.35
Aug	0.85	7.24	10.72	12.34	10.11	15.25	3.51
Sep	1.09	11.46	9.47	8.63	8.73	9.26	2.95
	Output Volume (MG)						
Total	30,359	1,002	807	4,145	232	2,831	39,376

Table 19: Monthly output water balance quantities for the Lake Whatcom watershed, October 2006–September 2007.

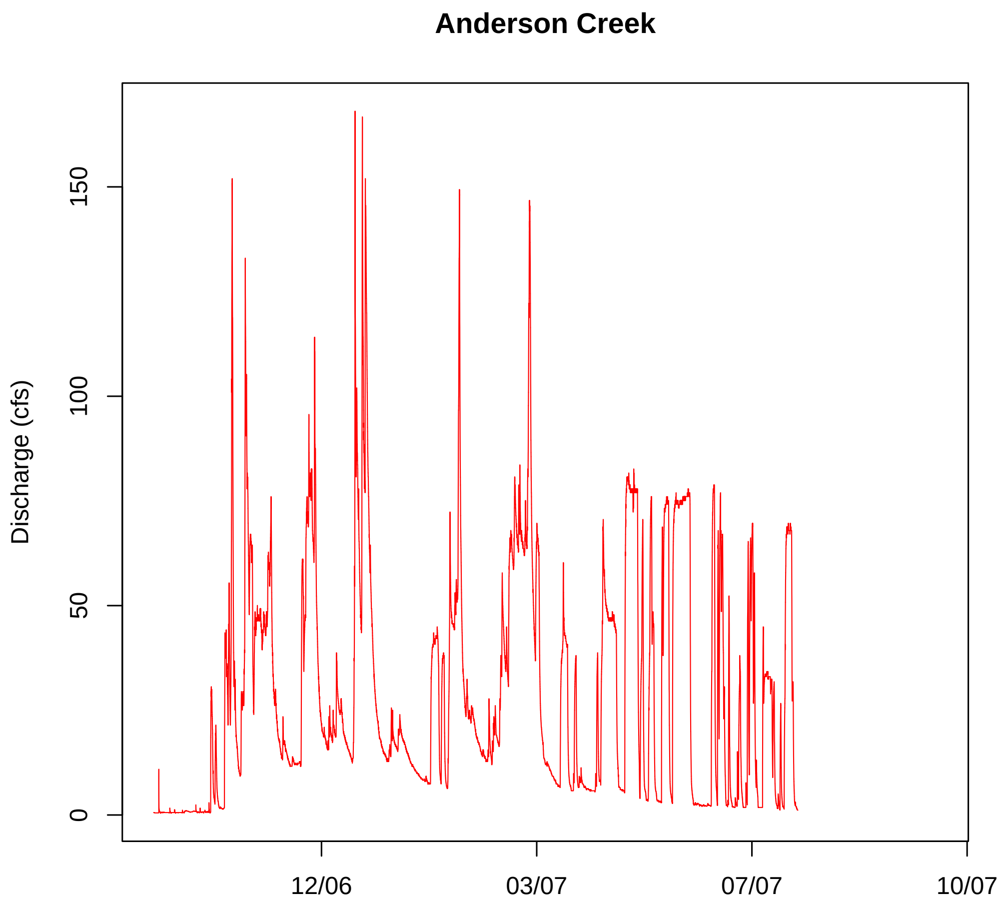

Figure 33: Anderson Creek hydrograph, October 1, 2006–September 30, 2007. Data were recorded at 15 minute intervals. Data are not available after July 27 due to equipment loss.

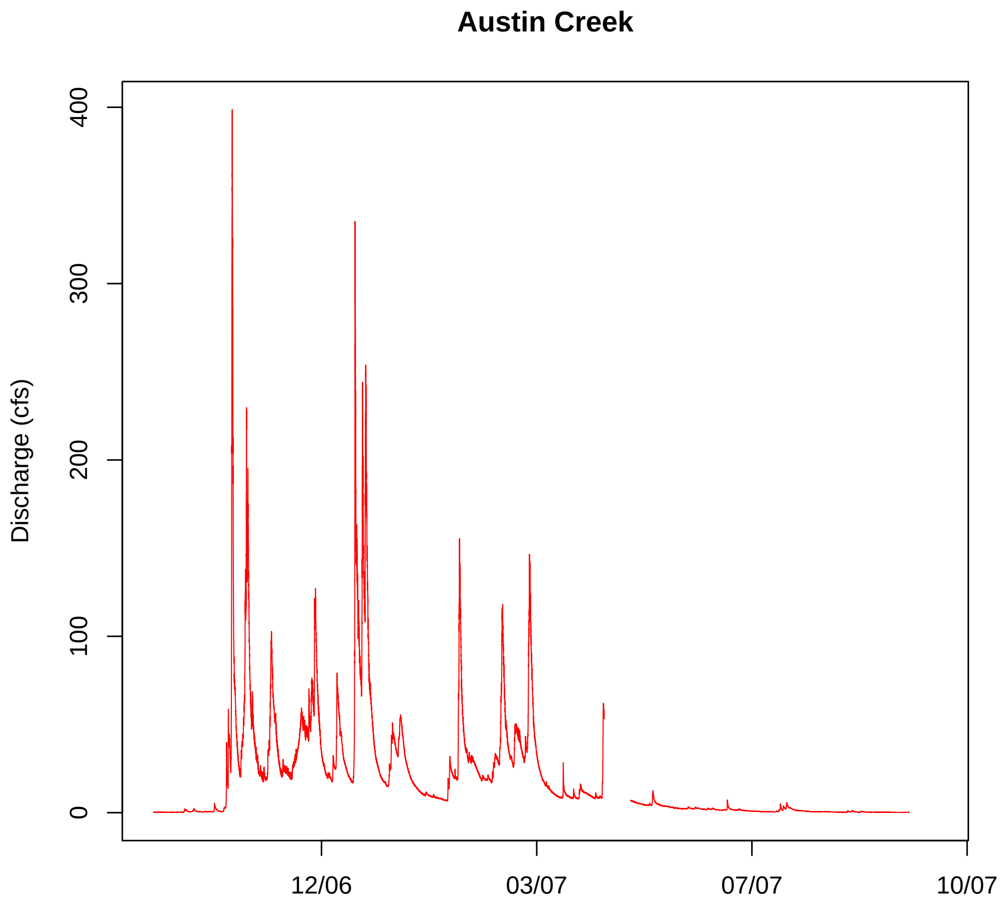

Figure 34: Austin Creek hydrograph, October 1, 2006–September 30, 2007. Data were recorded at 15 minute intervals.

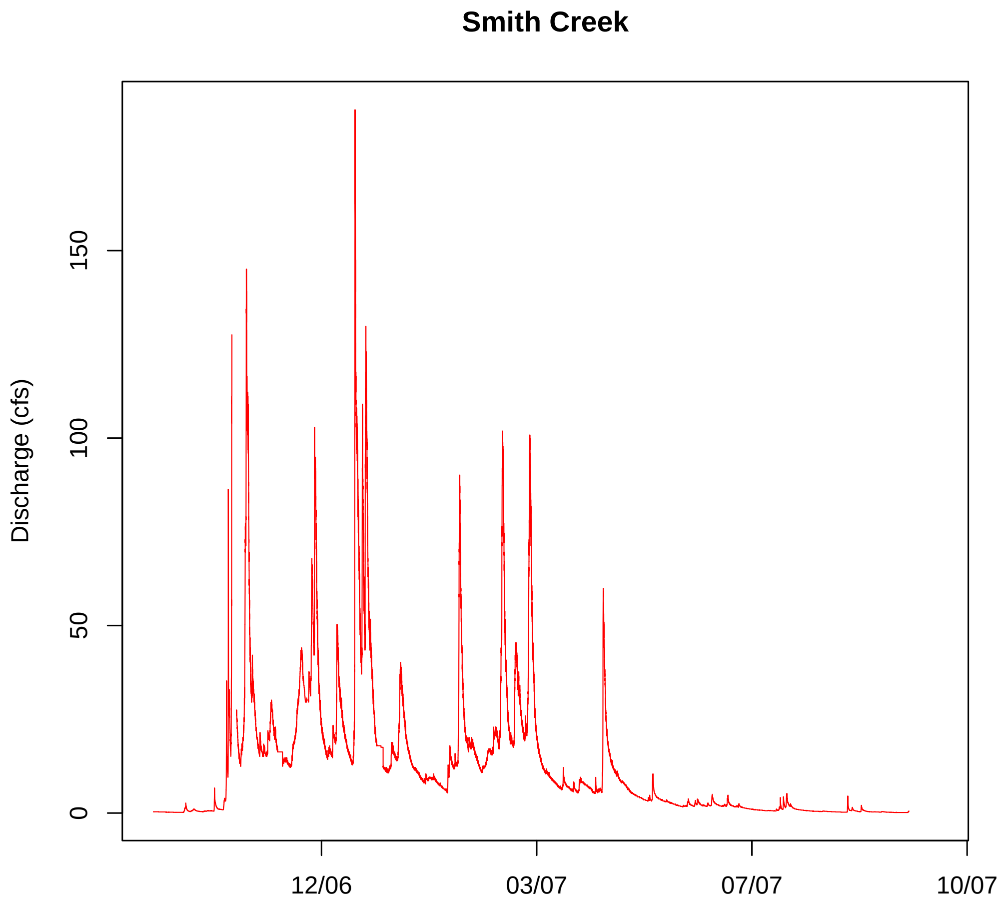

Figure 35: Smith Creek hydrograph, October 1, 2006–September 30, 2007. Data were recorded at 15 minute intervals.

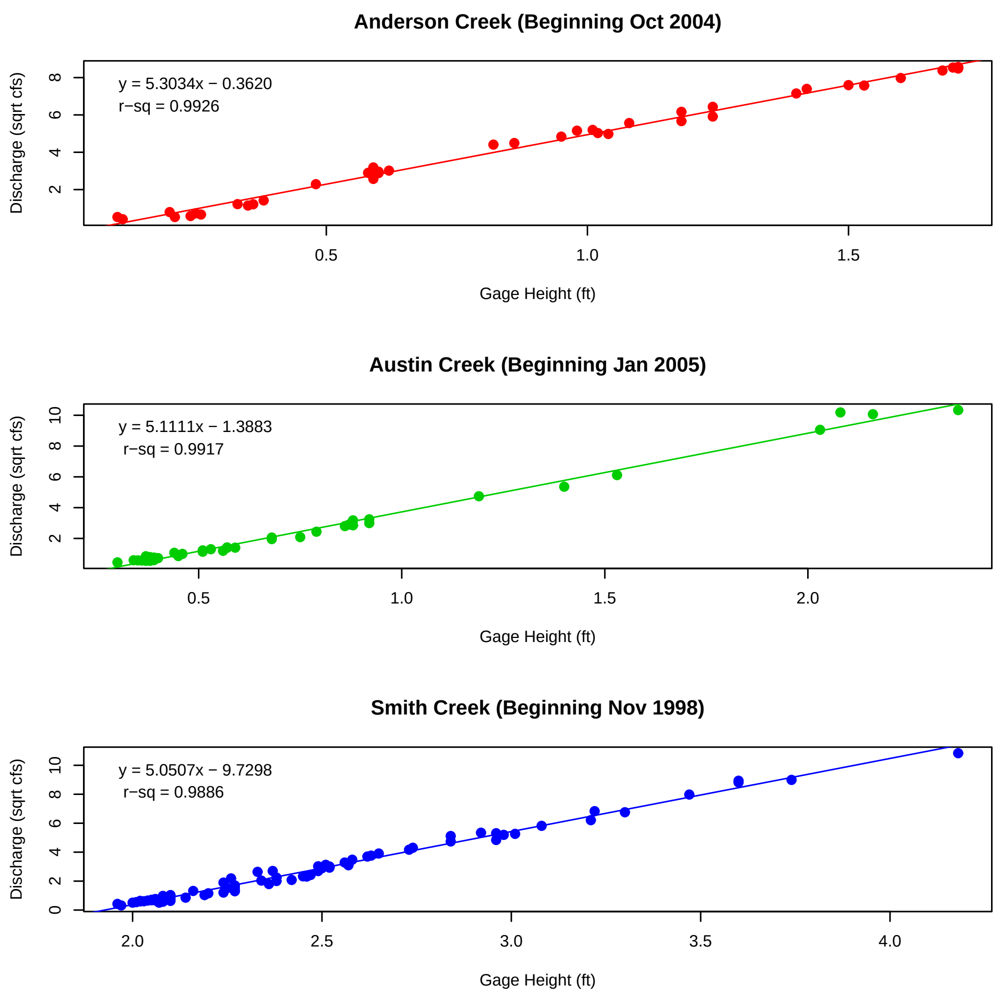

Figure 36: Anderson Creek, Austin Creek, and Smith Creek rating curves. Regressions show the relationship between gauge height (x) and square root transformed discharge (y), beginning from the date listed on each figure. For earlier rating curves, contact the Institute for Watershed Studies.

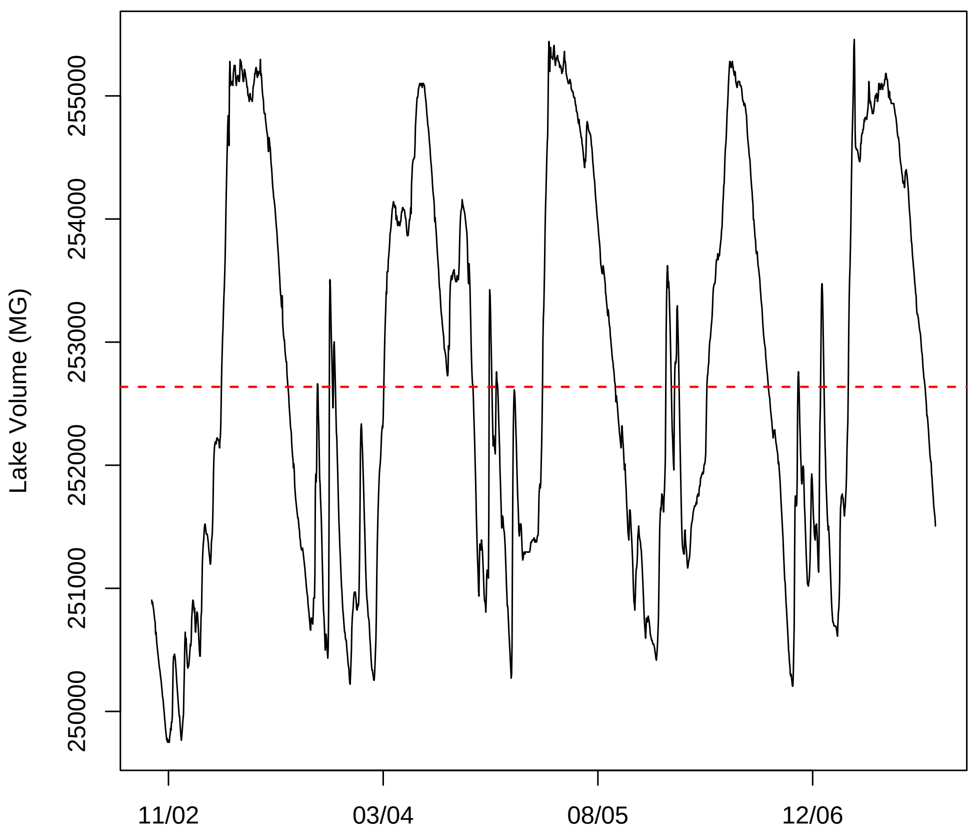

Figure 37: Comparison of Lake Whatcom daily lake volumes for 2002–2007. Horizontal line represents median lake volume for the period plotted.

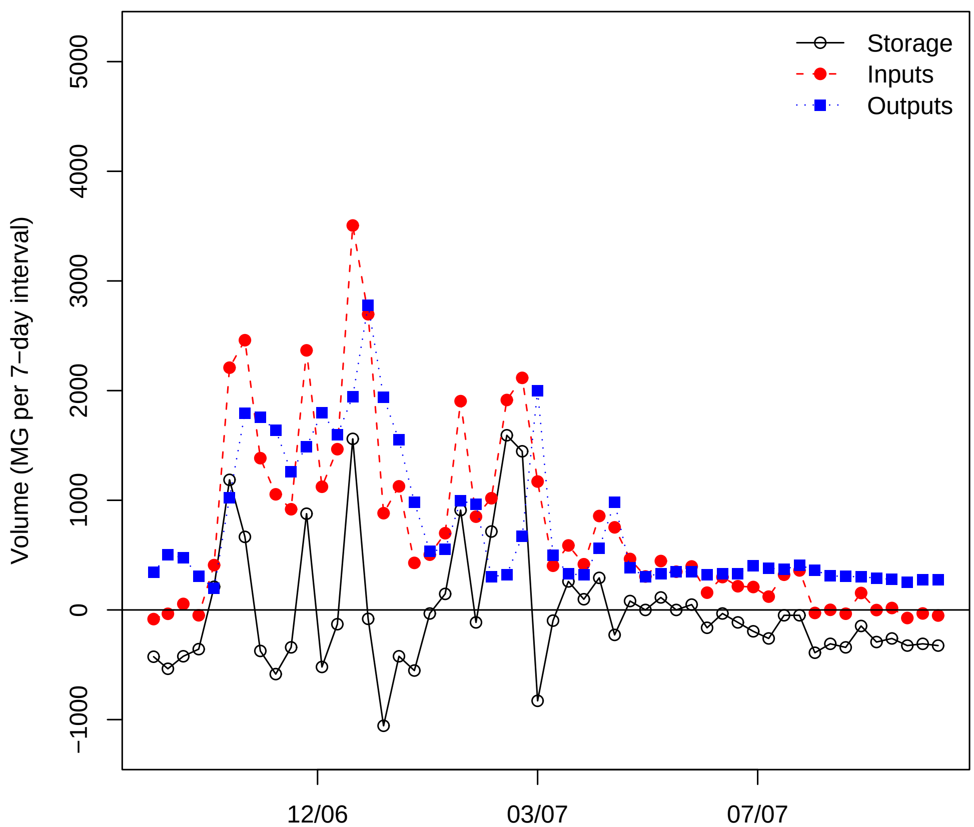

Figure 38: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2006–September 30, 2007.

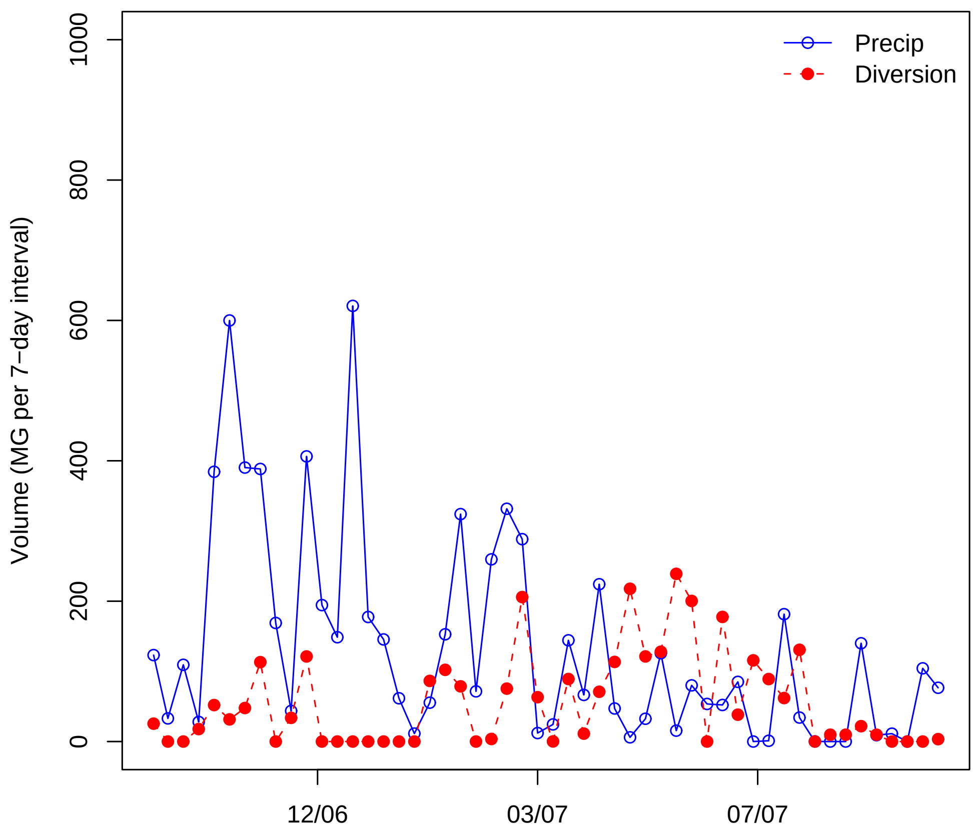

Figure 39: Lake Whatcom watershed direct hydrologic inputs, October 1, 2006–September 30, 2007. Runoff is included on Figure 41 as described on page 70.

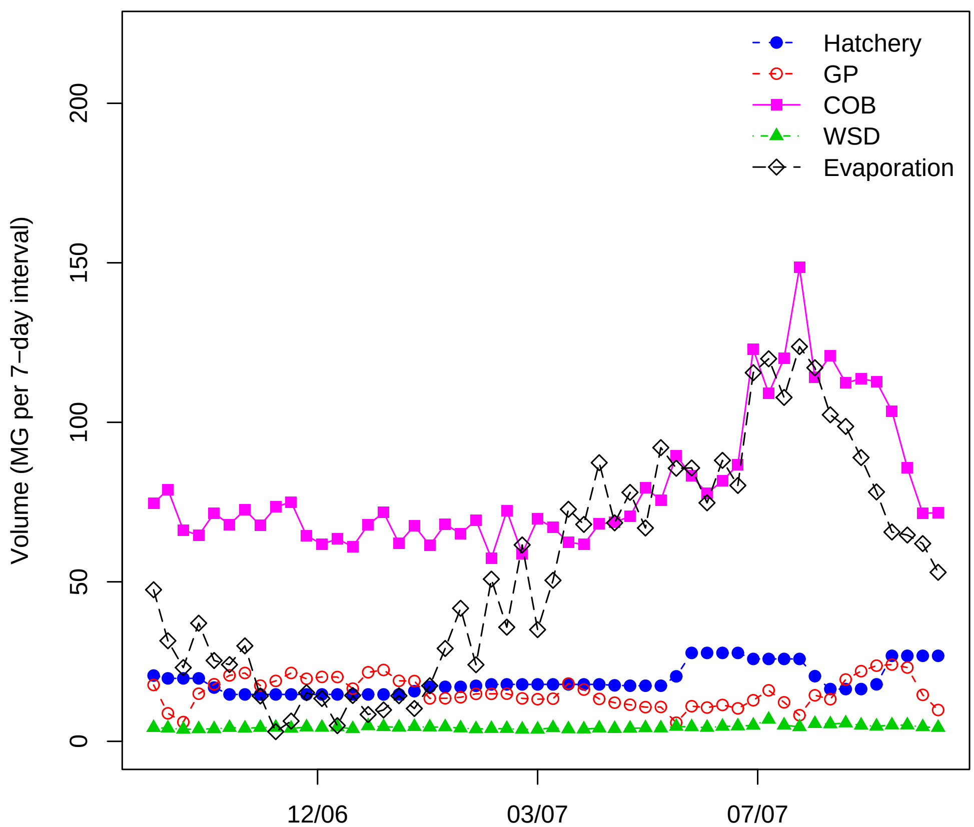

Figure 40: Lake Whatcom watershed hydrologic withdrawals, October 1, 2006–September 30, 2007. Whatcom Creek output is included on Figure 41 as described on page 70.

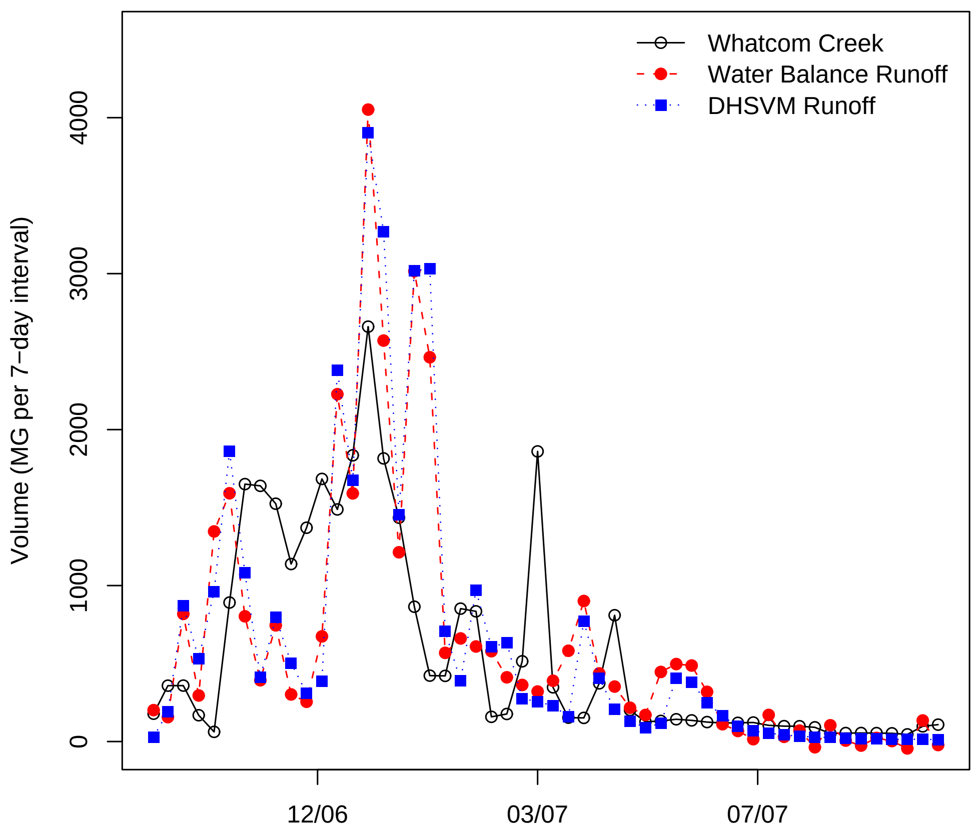

Figure 41: Summary of 7-day Whatcom Creek flows, water balance runoff estimates, and DHSVM runoff estimates, October 1, 2006–September 30, 2007.

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 2006/2007 monitoring period, samples were collected from the Park Place sand filter[24], the Brentwood wet ponds, the Alabama Hill vault, and the South Campus storm water treatment facility.[25] The locations of the current monitoring sites are described in Appendix A; photographs of the sites are included in Figures A5–A9 (pages 111–115).

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 Hill	Feb 14–15, 2007: Wet conditions; precip. prior to and during sampling Jul 20, 2007: Dry conditions; 0.45 in. precip during sampling
Park Place	Nov 14–16, 2006: Wet conditions/high flow; heavy precip. prior to and during sampling Mar 6–8, 2007: Wet conditions/high flow; heavy precip. prior to and during sampling Jun 18–20, 2007: Dry conditions/low flow; no precip. within 24 hrs of sampling
Brentwood	Mar 6–8, 2007: Wet conditions/high flow; heavy precip. prior to and during sampling Mar 20–21, 2007: Wet conditions/low flow; heavy precip. prior to sampling Jun 18–20, 2007: Dry conditions/low flow; no precip. within 24 hrs of sampling
S. Campus	Apr 16–18, 2007: Wet conditions/high flow; mod. precip. prior to and during sampling May 14–16, 2007: Wet conditions/low flow; no precip. within 48 hrs of sampling

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 analyzed for total solids, total suspended solids, heavy metals (arsenic, cadmium, chromium, copper, iron, nickel, lead, and zinc), total organic carbon, total ni-

[24] formerly the Park Place wet ponds

[25] 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.

trogen, 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 on page 85).

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. 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 20–25 (pages 87–92) 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.

During the current monitoring period, all sites with detectable levels of TSS provided at least some removal of suspended solids, with removal efficiencies ranging from 29–89% (Tables 20 and 22, pages 87 and 89). The best TSS removals were measured at the Park Place sand filter (85–89%) and the South Campus rock/plant filter (66–89%). Data from previous years shows that the South Campus facility consistently provides good TSS removal, but prior to its retrofit, Park Place had very mixed results (see long-term data in Figure 42 and Table 26). The installation of sand filters appears to have been very successful for reducing TSS.

Phosphorus removal was less consistent, ranging from -38 (phosphorus export) at the Park Place sand filter to 67% reduction at the South Campus site (Tables 20 and 22). As with TSS, the South Campus site demonstrated good TP reduction in 2007 (67%), with an average reduction of 52% for 2001–2007 (Figure 43 and Table 26). The other sites had low, inconsistent TP reductions (0–37%) or exported phosphorus (see Table 20, Park Place TP reduction for June 18–20 = -38%)

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 111). Due to flow and design constraints, 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 of the inlet and outlet.

Because the Alabama Hill vault is sampled differently, we wanted to assess the comparability between results generated using multiple grab sampling versus composite sampling. The Park Place sand filter provides the best location for comparative sampling, so in addition to the regular composite samples, we collected four sets of inlet/outlet grab samples during three different sampling events in 2006 (Table 27, page 94). The results were very similar for the multiple grab and composite data, both in terms of average inlet/outlet contaminant concentrations and the percent TSS and TP reductions. These results indicate that multiple grab sampling is a feasible surrogate for composite sampling, if composite sampling is not possible.

In 2007 the Alabama Hill vault produced small, but consistent reductions for total phosphorus (8–18%; Table 22). Although the past performance at this site rarely showed significant phosphorus reductions (Table 26, and Figure 43), the 2007 results are higher than the historic mean ($\overline{x} = -2\%$), and one of the values (18%) was slightly higher that the 95% confidence interval. The City has placed this site on a 2–3 month preventative maintenance and cleaning schedule, which should improve the performance of the system.[26] We will continue to monitor this site in 2008 to watch for improvements in phosphorus reduction.

[26]Alabama Hill vault maintenance schedule information was 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	Mar 6–8, 2007	8.53	144.6	<1	1.08	0.032
Brentwood outlet	Mar 6–8, 2007	5.47	106.7	<1	0.39	0.023
	Percent reduction:	36	26	NA	64	28
Brentwood inlet	Mar 20–22, 2007	<2	132.8	NA	1.42	0.021
Brentwood outlet	Mar 20–22, 2007	<2	93.2	NA	0.62	0.017
	Percent reduction:	NA	30	NA	56	19
Brentwood inlet	Jun 18–20, 2007	<2	172.6	<1	1.14	0.021
Brentwood outlet	Jun 18–20, 2007	<2	121.6	<1	0.50	0.021
	Percent reduction:	NA	30	NA	56	0
Park Place inlet	Nov 14–16, 2006	13.52	130.8	2.8	1.51	0.099
Park Place outlet	Nov 14–16, 2006	<2*	109.6	3.1	1.39	0.062
	Percent reduction :	85	16	-11	8	37
Park Place inlet	Mar 6–8, 2007	28.33	123.8	<1	0.84	0.099
Park Place outlet	Mar 6–8, 2007	3.04	99.4	<1	0.63	0.066
	Percent reduction:	89	20	NA	24	33
Park Place inlet	Jun 18–20, 2007	<2	121.0	<1	0.45	0.055
Park Place outlet	Jun 18–20, 2007	<2	116.3	<1	0.51	0.076
	Percent reduction:	NA	4	NA	-14	-38
S.Campus inlet	Apr 16–18, 2007	54.80	231.6	<1	0.84	0.082
S. Campus outletE	Apr 16–18, 2007	6.05	199.3	<1	0.36	0.026
S.Campus outletW	Apr 16–18, 2007	6.42	192.4	<1	0.40	0.018
	Percent reduction:	89	15	NA	55	67
S.Campus inlet	May 14–16, 2007	5.93	286.2	<1	0.84	0.060
S. Campus outletE	May 14–16, 2007	<2*	283.2	<1	0.23	0.022
S.Campus outletW	May 14–16, 2007	<2*	287.8	<1	0.25	0.018
	Percent reduction:	66	0	NA	71	67

*Value replaced with detection limit to calculate percent reduction.

Table 20: 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	Mar 6–8, 2007	<0.01	<0.0005	<0.001	<0.001	0.736	0.0001	<0.005	0.002	0.010
Brentwood outlet	Mar 6–8, 2007	<0.01	<0.0005	<0.001	0.005	0.353	0.0002	<0.005	0.002	0.006
	Percent reduction:	NA	NA	NA	-400	52	-100	NA	0	40
Brentwood inlet	Mar 20–22, 2007	NA	NA	NA	NA	NA	NA	NA	NA	NA
Brentwood outlet	Mar 20–22, 2007	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Percent reduction:	NA	NA	NA	NA	NA	NA	NA	NA	NA
Brentwood inlet	Jun 18–20, 2007	<0.01	<0.0005	<0.001*	<0.001*	0.453	<0.0001	<0.005	<0.001	<0.001*
Brentwood outlet	Jun 18–20, 2007	<0.01	<0.0005	0.002	0.005	0.548	<0.0001	<0.005	<0.001	0.002
	Percent reduction:	NA	NA	-100	-400	-21	NA	NA	NA	-100
Park Place inlet	Nov 14–16, 2006	<0.01	<0.0005	0.002	0.002	0.910	<0.0002	<0.005	0.002	0.024
Park Place outlet	Nov 14–16, 2006	<0.01	<0.0005	<0.001*	<0.001*	0.282	<0.0002	<0.005	<0.001*	0.002
	Percent reduction:	NA	NA	50	50	69	NA	NA	50	92
Park Place inlet	Mar 6–8, 2007	<0.01	<0.0005	<0.001	0.007	1.570	<0.0001	<0.005	0.004	0.045
Park Place outlet	Mar 6–8, 2007	<0.01	<0.0005	<0.001	0.003	0.322	<0.0001	<0.005	<0.001*	0.006
	Percent reduction:	NA	NA	NA	57	79	NA	NA	75	87
Park Place inlet	Jun 18–20, 2007	<0.01	<0.0005	0.003	<0.001	0.639	<0.0001	<0.005	<0.001	¡0.001
Park Place outlet	Jun 18–20, 2007	<0.01	<0.0005	0.003	<0.001	0.690	<0.0001	<0.005	<0.001	¡0.001
	Percent reduction:	NA	NA	0	NA	-8	NA	NA	NA	NA
S.Campus inlet	Apr 16–18, 2007	<0.01	<0.0005	<0.001	<0.001	2.180	0.0002	<0.005	0.004	0.025
S. Campus outletE	Apr 16–18, 2007	<0.01	<0.0005	<0.001	<0.001	0.258	0.0001	<0.005	0.002	0.005
S.Campus outletW	Apr 16–18, 2007	<0.01	<0.0005	<0.001	<0.001	0.241	<0.0001*	<0.005	0.001	0.012
	Percent reduction:	NA	NA	NA	NA	89	50	NA	63	66
S.Campus inlet	May 14–16, 2007	<0.01	<0.0005	0.004	<0.001*	1.980	<0.0001	<0.005	<0.001	0.012
S. Campus outletE	May 14–16, 2007	<0.01	<0.0005	<0.001*	0.007	0.005	<0.0001	<0.005	<0.001	0.013
S.Campus outletW	May 14–16, 2007	<0.01	<0.0005	0.001	0.002	0.021	<0.0001	<0.005	<0.001	0.018
	Percent reduction:	NA	NA	75	-350	99	NA	NA	NA	-29

*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 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	Feb 14, 2007 (A)	7.1	7.47	12.88	72.7	150
Inlet	Feb 15, 2007 (B)	7.9	7.49	10.49	101.3	88
Inlet	Feb 15, 2007 (C)	8.0	7.48	10.30	120.3	150
Inlet	Feb 15, 2007 (D)	8.0	7.57	10.35	159.3	95
Inlet	Feb 15, 2007 (E)	8.1	7.57	10.67	161.3	110
Outlet	Feb 14, 2007 (A)	7.0	7.42	12.42	72.8	91
Outlet	Feb 15, 2007 (B)	7.8	7.46	10.40	100.8	130
Outlet	Feb 15, 2007 (C)	7.9	7.39	9.94	108.7	68
Outlet	Feb 15, 2007 (D)	8.0	7.43	10.14	132.5	73
Outlet	Feb 15, 2007 (E)	8.0	7.47	10.53	164.4	100
	Percent reduction:	1	1	2	6	22
Inlet	Jul 20, 2007 (A)	20.0	7.26	7.40	67.3	NA
Inlet	Jul 20, 2007 (B)	19.5	7.29	7.77	64.7	NA
Inlet	Jul 20, 2007 (C)	19.0	7.26	7.94	57.9	NA
Inlet	Jul 20, 2007 (D)	19.0	7.30	7.83	65.1	NA
Outlet	Jul 20, 2007 (A)	20.0	7.11	7.23	77.0	NA
Outlet	Jul 20, 2007 (B)	19.6	7.20	7.59	68.0	NA
Outlet	Jul 20, 2007 (C)	19.2	7.17	7.87	61.6	NA
Outlet	Jul 20, 2007 (D)	19.0	7.19	7.65	63.2	NA
	Percent reduction:	0	2	2	-6	NA

Site	Date	TSS (mg/L)	TS (mg/L)	TN (mg/L)	TP (mg-N/L)	NO3 (mg-P/L)	SRP (mg/L)
Inlet	Feb 14, 2007 (A)	81.0	128.9	0.935	0.207	0.273	0.043
Inlet	Feb 15, 2007 (B)	52.7	118.3	1.034	0.161	0.484	0.050
Inlet	Feb 15, 2007 (C)	18.9	97.7	1.061	0.136	0.655	0.077
Inlet	Feb 15, 2007 (D)	8.8	105.9	1.310	0.127	0.952	0.090
Inlet	Feb 15, 2007 (E)	36.6	142.0	1.460	0.154	0.904	0.076
Outlet	Feb 14, 2007 (A)	82.2	130.6	0.984	0.219	0.291	0.039
Outlet	Feb 15, 2007 (B)	30.5	101.8	0.932	0.132	0.479	0.047
Outlet	Feb 15, 2007 (C)	8.3	74.7	0.892	0.092	0.579	0.052
Outlet	Feb 15, 2007 (D)	4.8	86.8	1.070	0.085	0.757	0.058
Outlet	Feb 15, 2007 (E)	15.1	125.6	1.370	0.112	0.977	0.066
	Percent reduction:	29	12	10	18	6	22
Inlet	Jul 20, 2007 (A)	30.3	NA	1.400	0.149	NA	NA
Inlet	Jul 20, 2007 (B)	18.0	NA	1.160	0.149	NA	NA
Inlet	Jul 20, 2007 (C)	26.0	NA	1.040	0.143	NA	NA
Inlet	Jul 20, 2007 (D)	15.4	NA	1.030	0.151	NA	NA
Outlet	Jul 20, 2007 (A)	20.7	NA	1.650	0.148	NA	NA
Outlet	Jul 20, 2007 (B)	16.2	NA	1.230	0.136	NA	NA
Outlet	Jul 20, 2007 (C)	17.0	NA	1.070	0.132	NA	NA
Outlet	Jul 20, 2007 (D)	8.6	NA	0.993	0.129	NA	NA
	Percent reduction:	30	NA	-7	8	NA	NA

Table 22: 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	Mar 6, 2007 (A)	8.8	6.94	10.15	257.0	1
Inlet	Mar 7, 2007 (B)	9.2	6.82	10.10	81.1	490
Inlet	Mar 7, 2007 (C)	9.0	6.86	9.02	203.0	120
Inlet	Mar 8, 2007 (D)	8.7	7.00	9.30	224.0	14
Outlet	Mar 6, 2007 (A)	6.2	7.35	10.90	159.8	1
Outlet	Mar 7, 2007 (B)	7.4	7.25	8.94	151.6	2
Outlet	Mar 7, 2007 (C)	7.8	7.39	10.07	158.7	2
Outlet	Mar 8, 2007 (D)	7.1	7.35	9.01	173.8	9
	Percent reduction:	20	-6	-1	16	98
Inlet	Mar 20, 2007 (A)	9.7	6.96	8.89	214.0	16
Inlet	Mar 21, 2007 (B)	9.3	6.92	9.75	223.0	6
Inlet	Mar 21, 2007 (C)	9.6	6.97	9.13	224.0	12
Inlet	Mar 22, 2007 (D)	9.4	6.97	8.84	226.0	NA
Outlet	Mar 20, 2007 (A)	9.6	7.20	9.00	135.5	3
Outlet	Mar 21, 2007 (B)	7.8	7.15	8.97	150.0	1
Outlet	Mar 21, 2007 (C)	9.0	7.19	9.16	150.5	$<$1*
Outlet	Mar 22, 2007 (D)	7.8	7.16	8.17	153.3	NA
	Percent reduction:	10	-3	4	34	85
Inlet	Jun 18, 2007 (A)	15.8	7.17	8.11	256.0	16
Inlet	Jun 19, 2007 (B)	15.7	7.19	8.15	263.0	2
Inlet	Jun 19, 2007 (C)	16.1	7.15	8.32	263.0	12
Inlet	Jun 20, 2007 (D)	15.9	7.20	7.62	264.0	12
Outlet	Jun 18, 2007 (A)	14.3	7.33	7.33	181.0	2
Outlet	Jun 19, 2007 (B)	13.8	7.35	7.12	181.0	12
Outlet	Jun 19, 2007 (C)	14.5	7.42	7.26	182.0	9
Outlet	Jun 20, 2007 (D)	15.6	7.41	6.67	185.0	5
	Percent reduction:	8	-3	12	30	33

*Value replaced with detection limit to calculate percent reduction.

Table 23: 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	Nov 14, 2006 (A)	9.1	7.44	10.79	175.9	69
Inlet	Nov 15, 2006 (B)	9.6	7.48	9.80	184.3	160
Inlet	Nov 16, 2006 (C)	8.9	7.43	10.45	180.8	120
Inlet	Nov 16, 2006 (D)	9.6	7.52	10.11	185.8	100
Outlet	Nov 14, 2006 (A)	9.0	7.05	8.19	165.1	17
Outlet	Nov 15, 2006 (B)	9.0	7.02	5.71	181.5	3
Outlet	Nov 16, 2006 (C)	8.9	6.97	7.37	173.6	37
Outlet	Nov 16, 2006 (D)	9.3	7.06	7.70	173.2	35
	Percent reduction:	3	6	30	5	80
Inlet	Mar 6, 2007 (A)	7.8	7.37	11.72	143.8	150
Inlet	Mar 7, 2007 (B)	8.6	7.32	10.53	101.2	130
Inlet	Mar 7, 2007 (C)	8.4	7.39	10.40	146.4	78
Inlet	Mar 8, 2007 (D)	7.6	7.18	10.36	114.0	250
Outlet	Mar 6, 2007 (A)	7.3	7.00	8.07	148.8	58
Outlet	Mar 7, 2007 (B)	8.4	7.09	8.64	123.3	40
Outlet	Mar 7, 2007 (C)	8.5	7.10	7.80	119.1	25
Outlet	Mar 8, 2007 (D)	7.3	7.13	8.37	136.0	52
	Percent reduction:	3	3	24	-4	71
Inlet	Jun 18, 2007 (A)	13.7	7.64	9.35	183.0	1200
Inlet	Jun 19, 2007 (B)	13.8	7.63	9.33	167.0	1100
Inlet	Jun 19, 2007 (C)	14.4	7.59	9.37	157.0	640
Inlet	Jun 20, 2007 (D)	14.3	7.61	8.61	160.0	280
Outlet	Jun 18, 2007 (A)	14.1	6.87	3.71	156.0	13
Outlet	Jun 19, 2007 (B)	14.4	6.86	2.35	168.0	3
Outlet	Jun 19, 2007 (C)	14.5	6.86	1.46	172.0	1
Outlet	Jun 20, 2007 (D)	14.3	6.85	0.20	186.0	$<$1*
	Percent reduction:	-2	10	79	-2	99

*Value replaced with detection limit to calculate percent reduction.

Table 24: 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	Apr 16, 2007 (A)	11.6	7.48	7.54	409.0	40
Inlet	Apr 17, 2007 (B)	10.1	7.69	9.40	195.0	1200
Inlet	Apr 17, 2007 (C)	11.3	7.89	9.14	191.0	400
Inlet	Apr 18, 2007 (D)	10.9	7.55	7.44	356.0	60
Outlet-E	Apr 16, 2007 (A)	10.6	7.38	3.28	407.0	18
Outlet-E	Apr 17, 2007 (B)	10.4	7.62	5.74	271.0	77
Outlet-E	Apr 17, 2007 (C)	11.9	7.67	5.80	263.0	120
Outlet-E	Apr 18, 2007 (D)	9.8	7.40	2.25	327.0	25
Outlet-W	Apr 16, 2007 (A)	10.2	7.41	2.44	416.0	10
Outlet-W	Apr 17, 2007 (B)	10.2	7.64	4.46	271.0	93
Outlet-W	Apr 17, 2007 (C)	11.3	7.71	5.23	251.0	86
Outlet-W	Apr 18, 2007 (D)	10.1	7.51	2.40	338.0	7
	Percent reduction:	4	1	53	-11	87
Inlet	May 14, 2007 (A)	13.8	7.39	7.33	464.0	5
Inlet	May 15, 2007 (B)	13.2	7.42	6.90	463.0	2
Inlet	May 15, 2007 (C)	13.4	7.44	6.85	471.0	10
Inlet	May 16, 2007 (D)	13.3	7.41	7.05	455.0	17
Outlet-E	May 14, 2007 (A)	11.9	7.26	0.55	465.0	<1*
Outlet-E	May 15, 2007 (B)	12.1	7.20	0.66	466.0	23
Outlet-E	May 15, 2007 (C)	11.8	7.27	0.41	467.0	9
Outlet-E	May 16, 2007 (D)	12.1	7.25	0.45	470.0	23
Outlet-W	May 14, 2007 (A)	11.7	7.29	0.82	466.0	<1*
Outlet-W	May 15, 2007 (B)	11.8	7.25	0.70	466.0	<1*
Outlet-W	May 15, 2007 (C)	11.6	7.31	0.75	466.0	1
Outlet-W	May 16, 2007 (D)	11.9	7.25	0.63	470.0	<1*
	Percent reduction:	12	2	91	-1	12

*Value replaced with detection limit to calculate percent reduction.

Table 25: 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=7)	-1	69	32	9 – 55**
Brentwood (n=18)	-174	77	-38	-75 – -1*
Park Place (n=34)	-239	89	15	-6 – 37 (ns)
South Campus (n=18)	0	94	70	59 – 82***

Total Phosphorus

Site	Min.	Max.	Mean	95% CI
Alabama (n=7)	-38	18	-2	-19 – 15 (ns)
Brentwood (n=19)	-410	58	-7	-57 – 42 (ns)
Park Place (n=36)	-129	70	-5	-17 – 7 (ns)
South Campus (n=18)	13	74	52	43 – 60***

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

Table 26: Overall TSS and TP reductions at Alabama (2004–2007), Brentwood (1998–2007), Park Place (1994–2007), and South Campus (2001–2007) 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.

		Feb/Mar		May		Nov	
Sample Type	Source	TSS	TP	TSS	TP	TSS	TP
48 hr composite	inlet	6.50	0.057	14.57	0.086	13.52	0.099
(90 min. intervals)	outlet	<2	0.062	2.77	0.105	<2	0.062
	Percent reduction:	69	-9	81	-22	85	37
Grab samples	inlet avg.	6.04	0.057	21.03	0.113	19.08	0.072
(n=4 in 48 hr)	outlet avg.	2.09	0.071	2.87	0.120	2.00	0.065
	Percent reduction:	65	-26	86	-6	90	10
Individual grab samples:							
Grab #1	inlet	5.67	0.052	55.10	0.192	3.33	0.044
Grab #2	inlet	2.50	0.040	8.40	0.089	62.62	0.151
Grab #3	inlet	3.50	0.090	11.00	0.089	6.23	0.049
Grab #4	inlet	2.37	0.045	9.63	0.083	7.12	0.045
Grab #1	outlet	2.37	0.06	5.00	0.172	<2	0.063
Grab #2	outlet	<2	0.06	<2	0.102	<2	0.058
Grab #3	outlet	<2	0.06	2.48	0.105	<2	0.068
Grab #4	outlet	<2	0.11	<2	0.099	<2	0.071

[†]Value replaced with detection limit to calculate percent reduction.

Table 27: Comparison between 48-hr composite samples and multiple grab samples (n=4 during 48 hr) collected February 27–March 1, May 22–24, and November 14–16, 2006 at the Park Place sand filter.

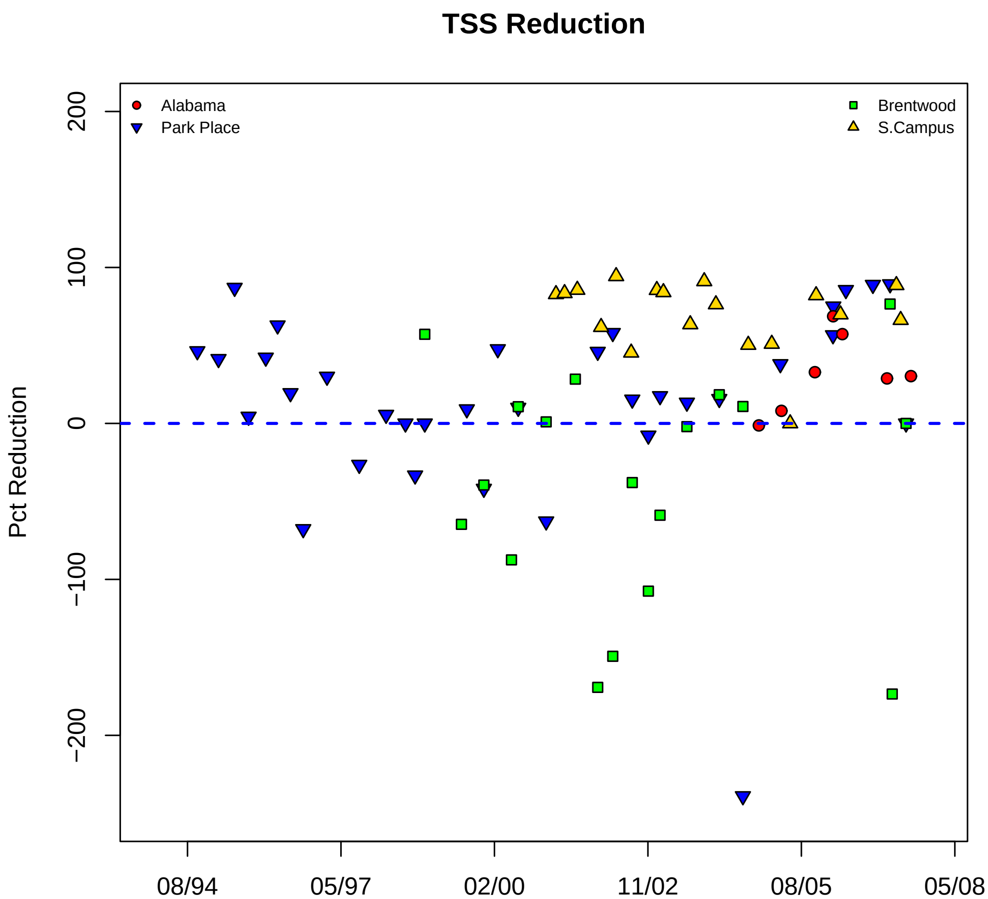

Figure 42: Percent reduction of total suspended solids concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites. Negative values indicate higher concentrations at the outlet compared to the inlet.

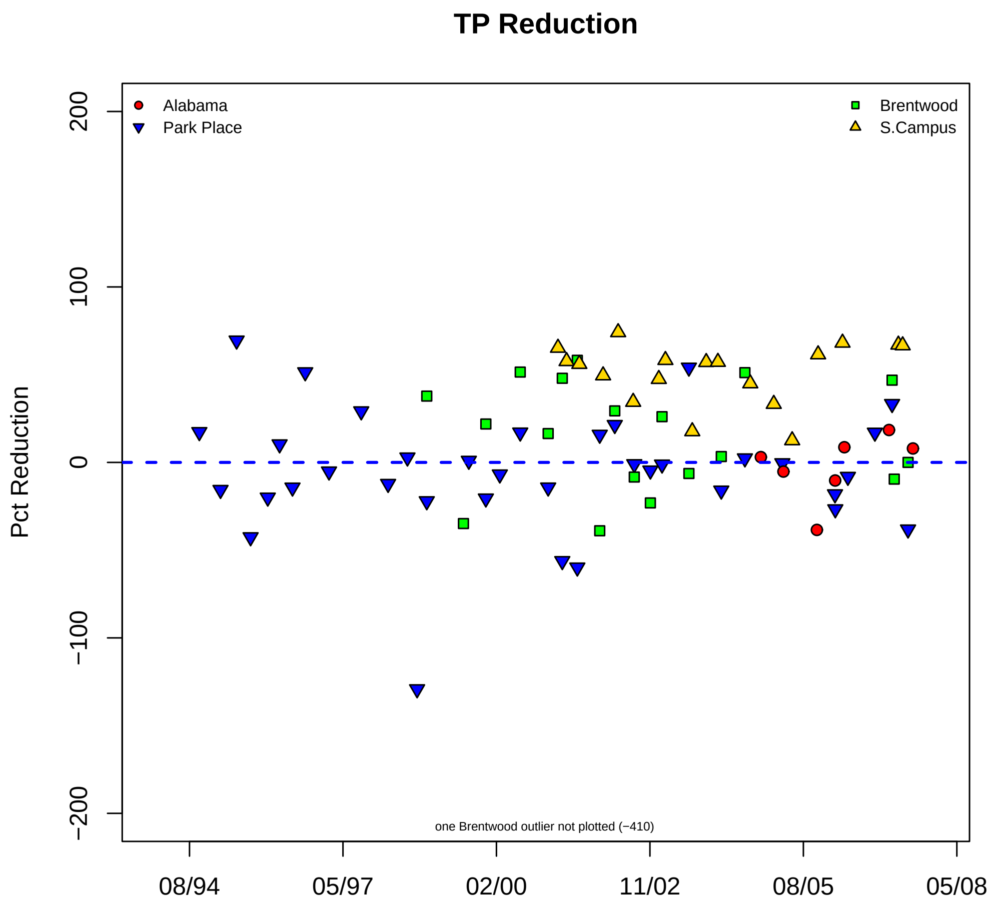

Figure 43: Percent reduction of total phosphorus concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites. Negative values indicate higher concentrations at the outlet compared to the inlet.

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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, 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.

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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, 1997/98 Final Report, April 12, 1999. Report to the City of Bellingham, WA.

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.

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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.

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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 107–110) show the locations of the current monitoring sites and Table A1 (page 106) 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[27] is mounted in the stilling well on the east side of

[27] 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.

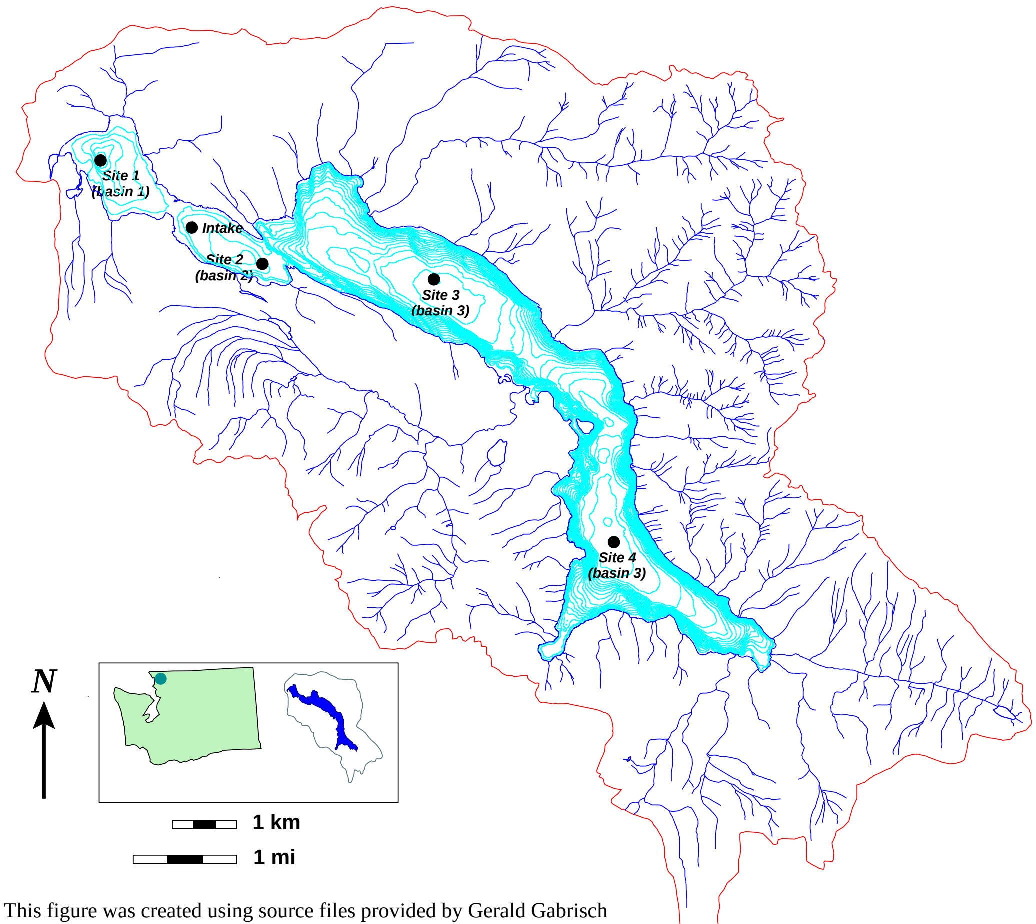
The **South Campus storm water treatment facility** is located south of the intersection between Bill McDonald Pky. and South College Dr, and treats runoff from the southern portion of Western Washington University. The runoff flows into a large underground concrete settling vault located on the northwest 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

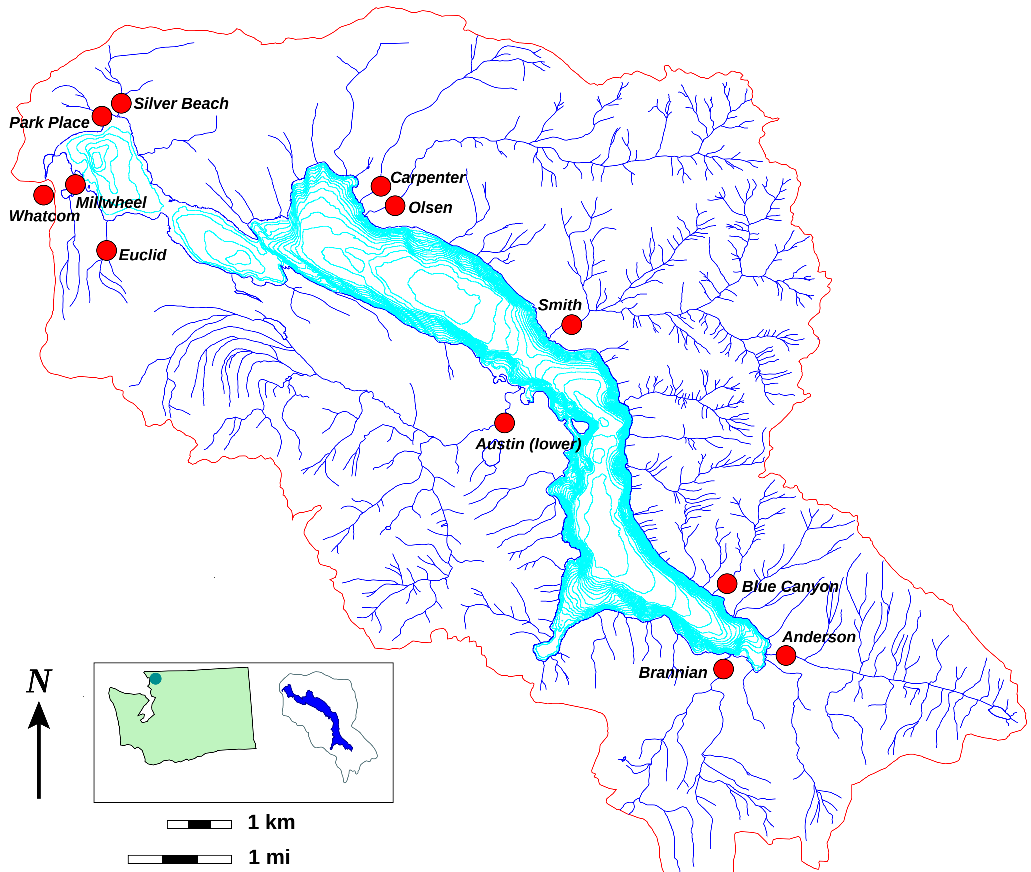
Storm Water Sites	Latitude	Longitude
Alabama Hill	no GPS data available	
Brentwood	no GPS data available	
Park Place	48.4608	122.2433
South Campus	no GPS data available	

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



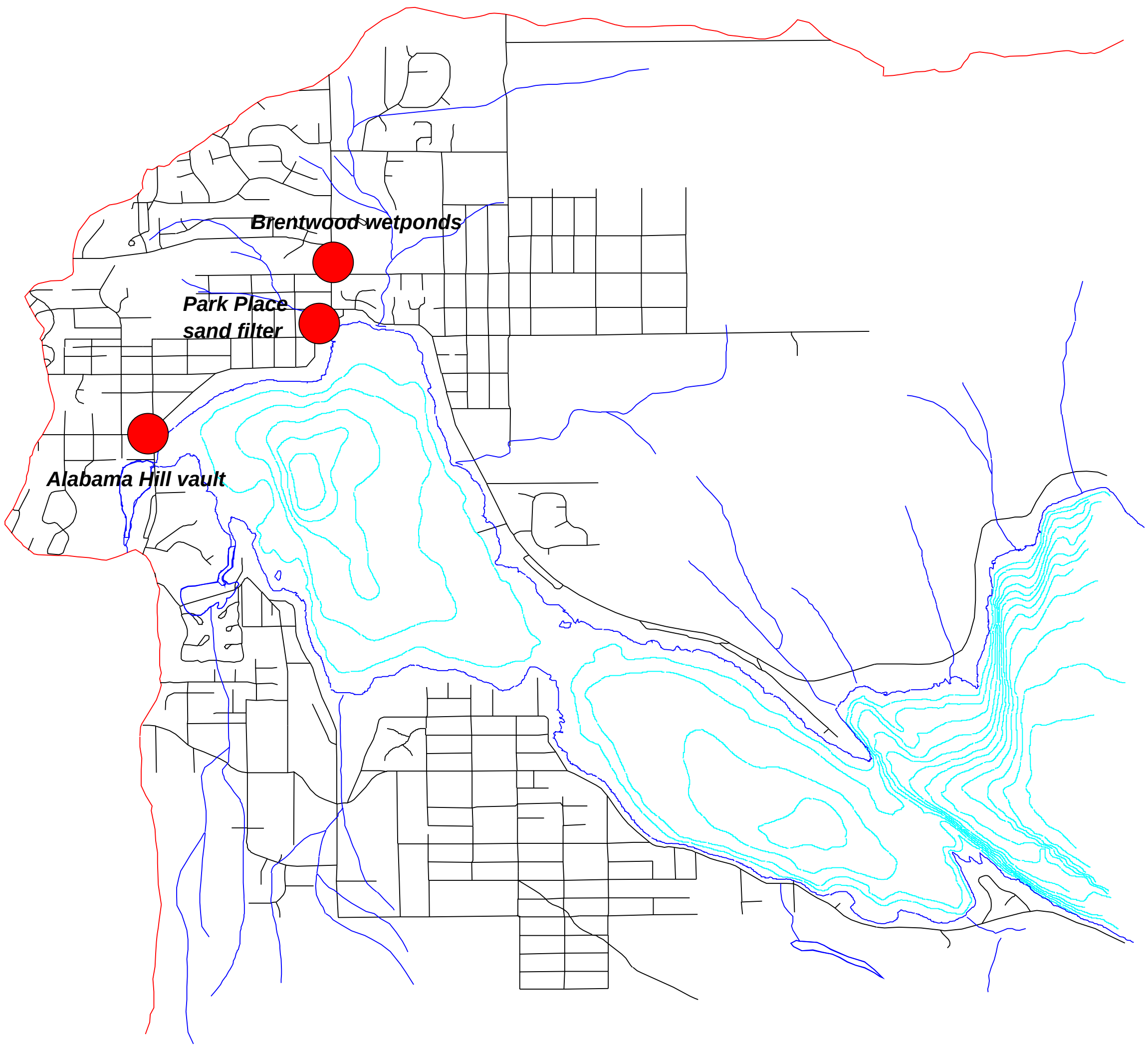
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A1: Lake Whatcom 2006/2007 lake sampling sites.



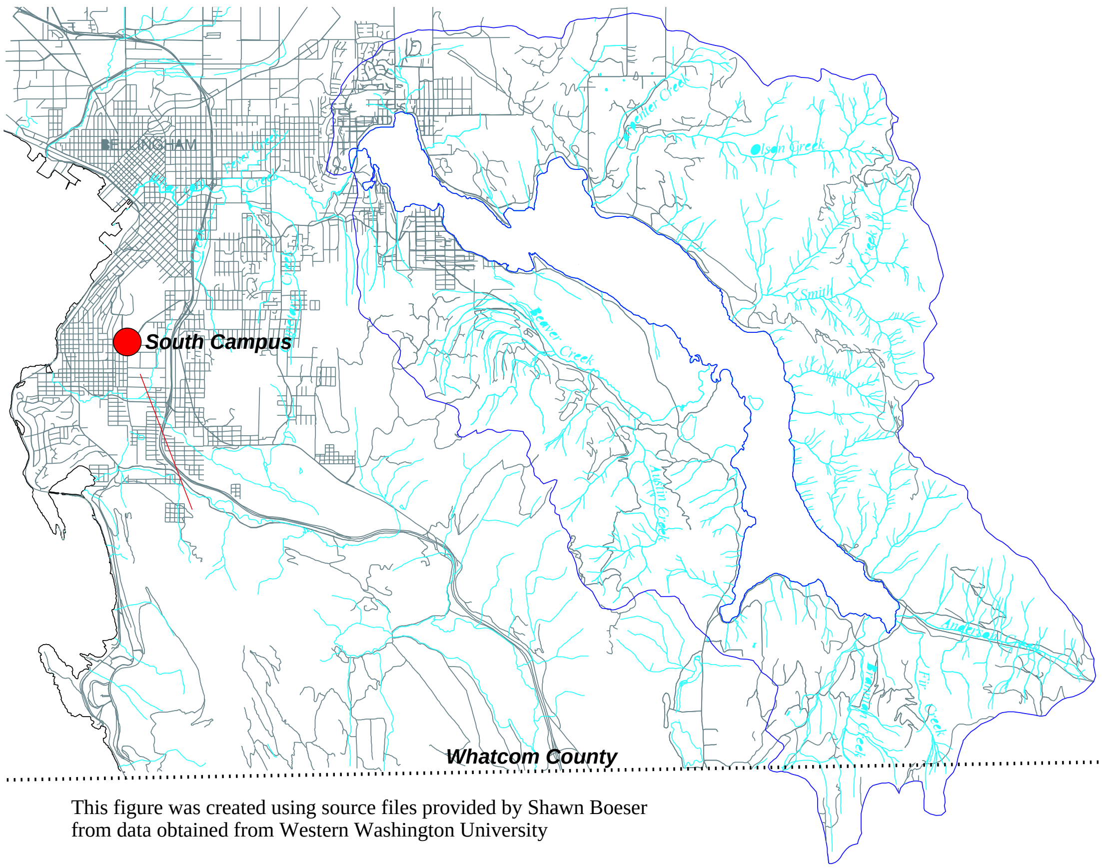
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A2: Lake Whatcom 2006/2007 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 D1. Table D1 includes abbreviations and detection limits for all analytes measured during the current year's monitoring program, as well as any other analyses included in the historic data posted online at http://www.ac.wwu.edu/∼iws.

The historic detection limits for each parameter were estimated based on recommended lower detection ranges (APHA, 1998; Hydrolab, 1997; Lind, 1985) instrument limitations, and analyst judgment on the lowest repeatable concentration for each test. Over time, some analytical techniques have improved so that current detection limits are lower than defined below (see current detection limits in Table 1, page 16). Because the Lake Whatcom data set includes long-term monitoring data, which 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 184–188, 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 (2006/2007)

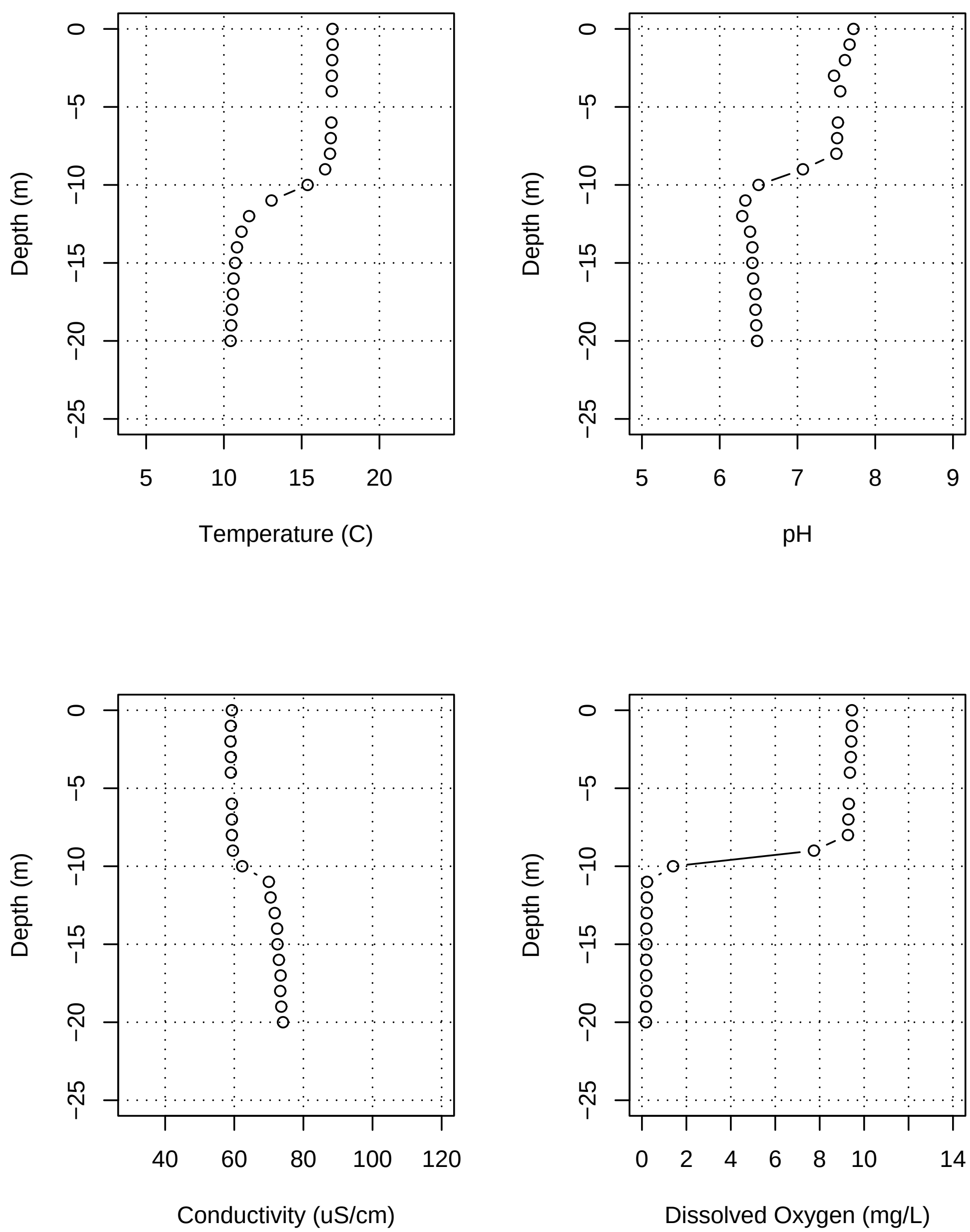


Figure B1: Lake Whatcom Hydrolab profile for Site 1, October 4, 2006.

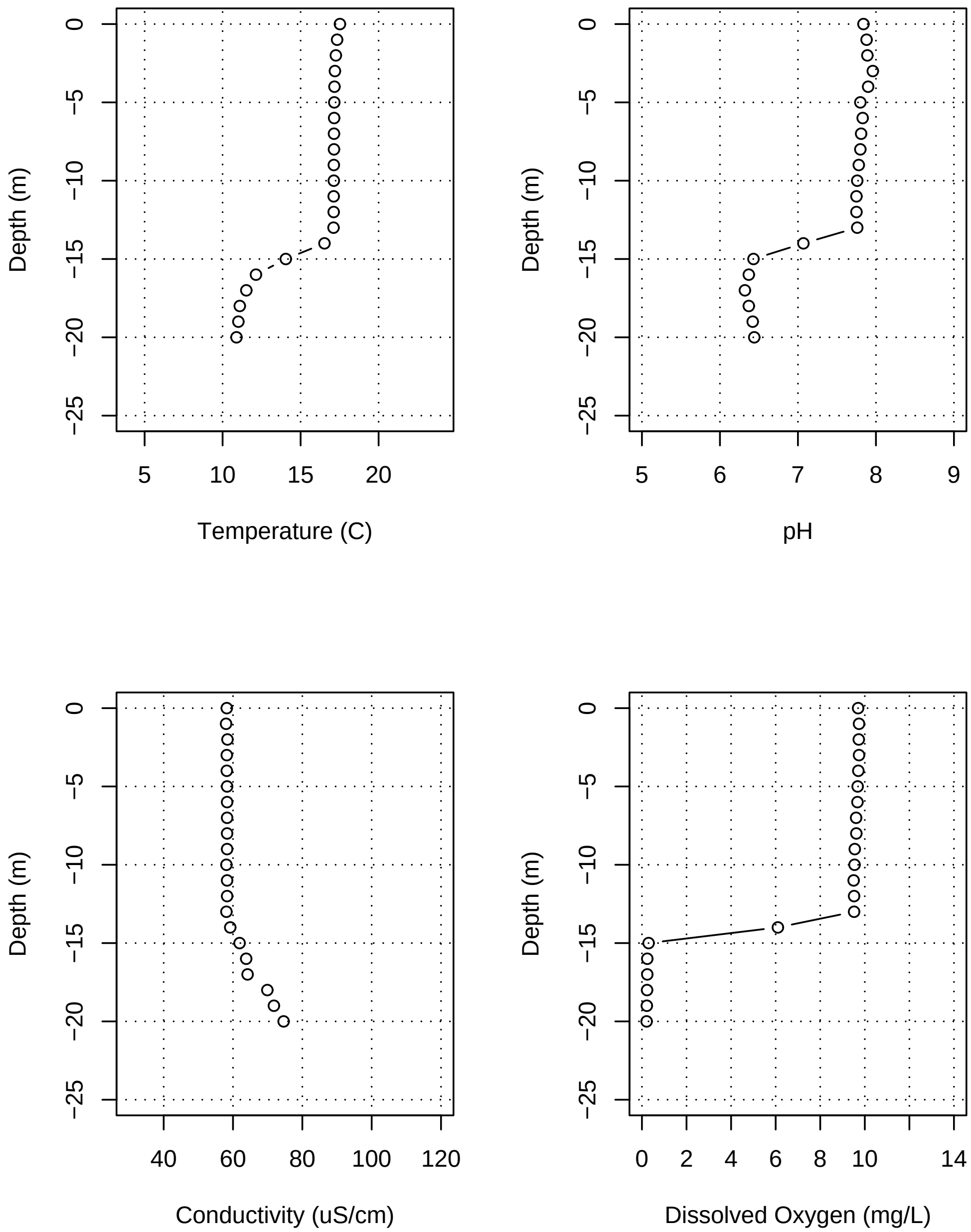


Figure B2: Lake Whatcom Hydrolab profile for Site 2, October 4, 2006.

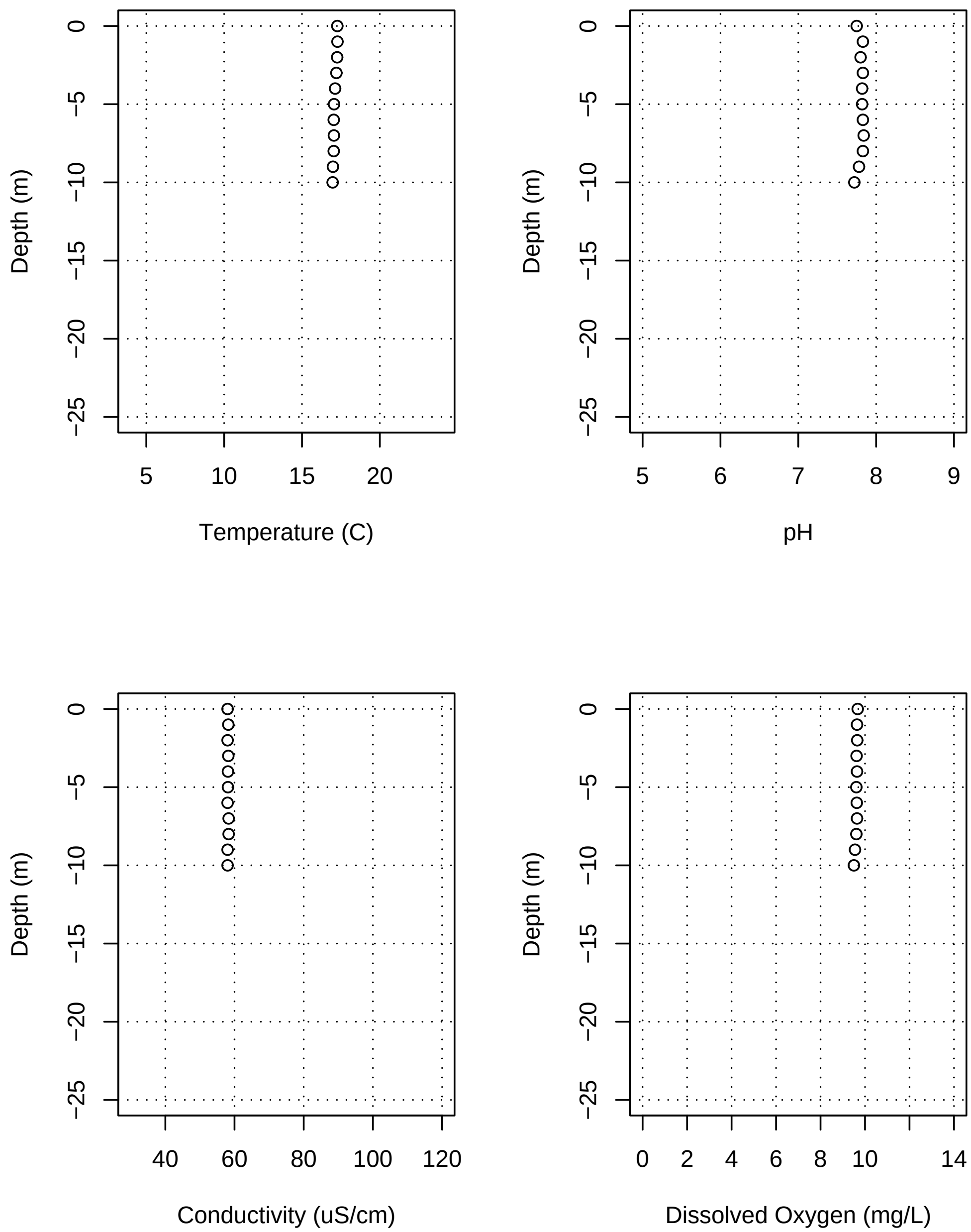


Figure B3: Lake Whatcom Hydrolab profile for the Intake, October 4, 2006.

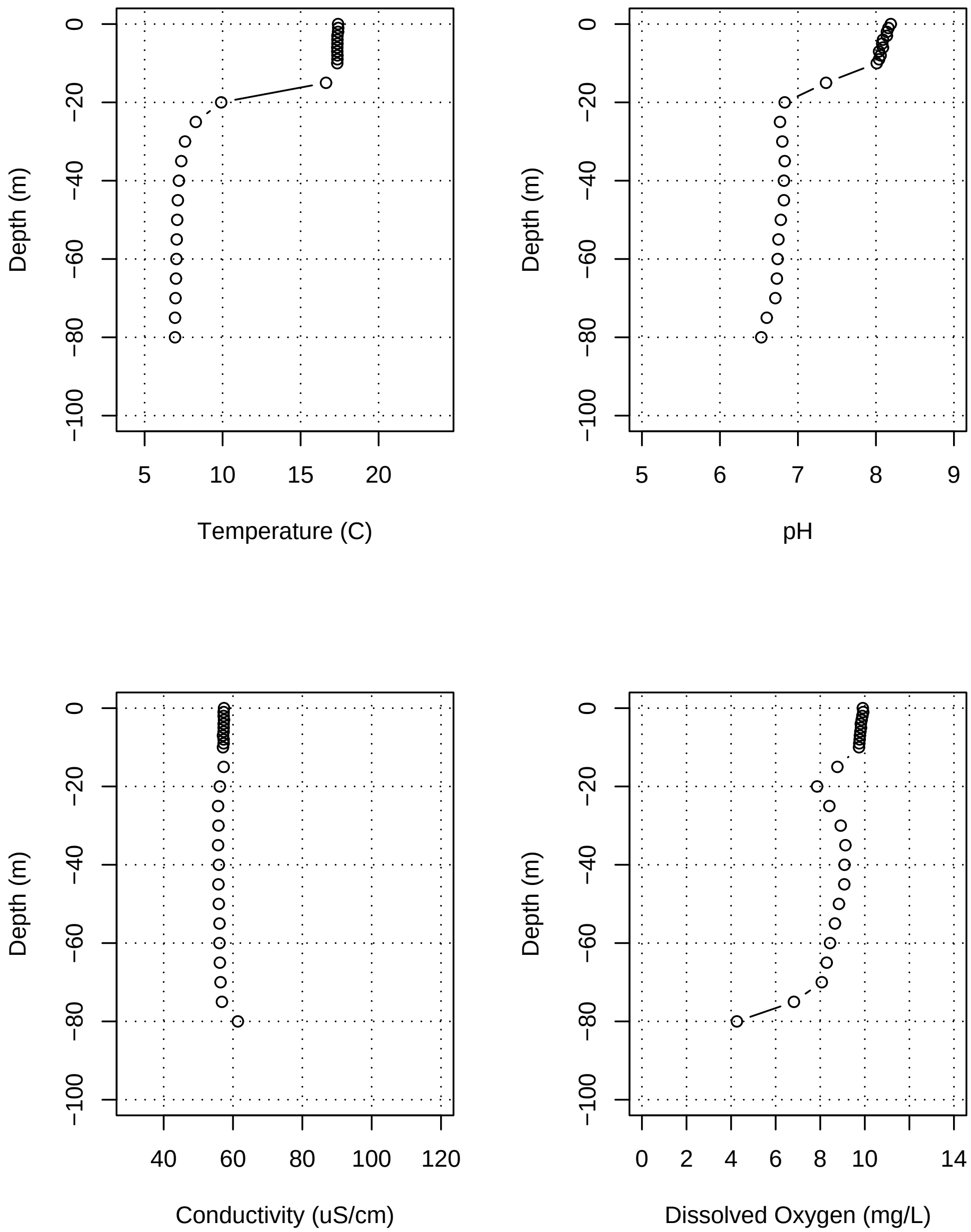


Figure B4: Lake Whatcom Hydrolab profile for Site 3, October 3, 2006.

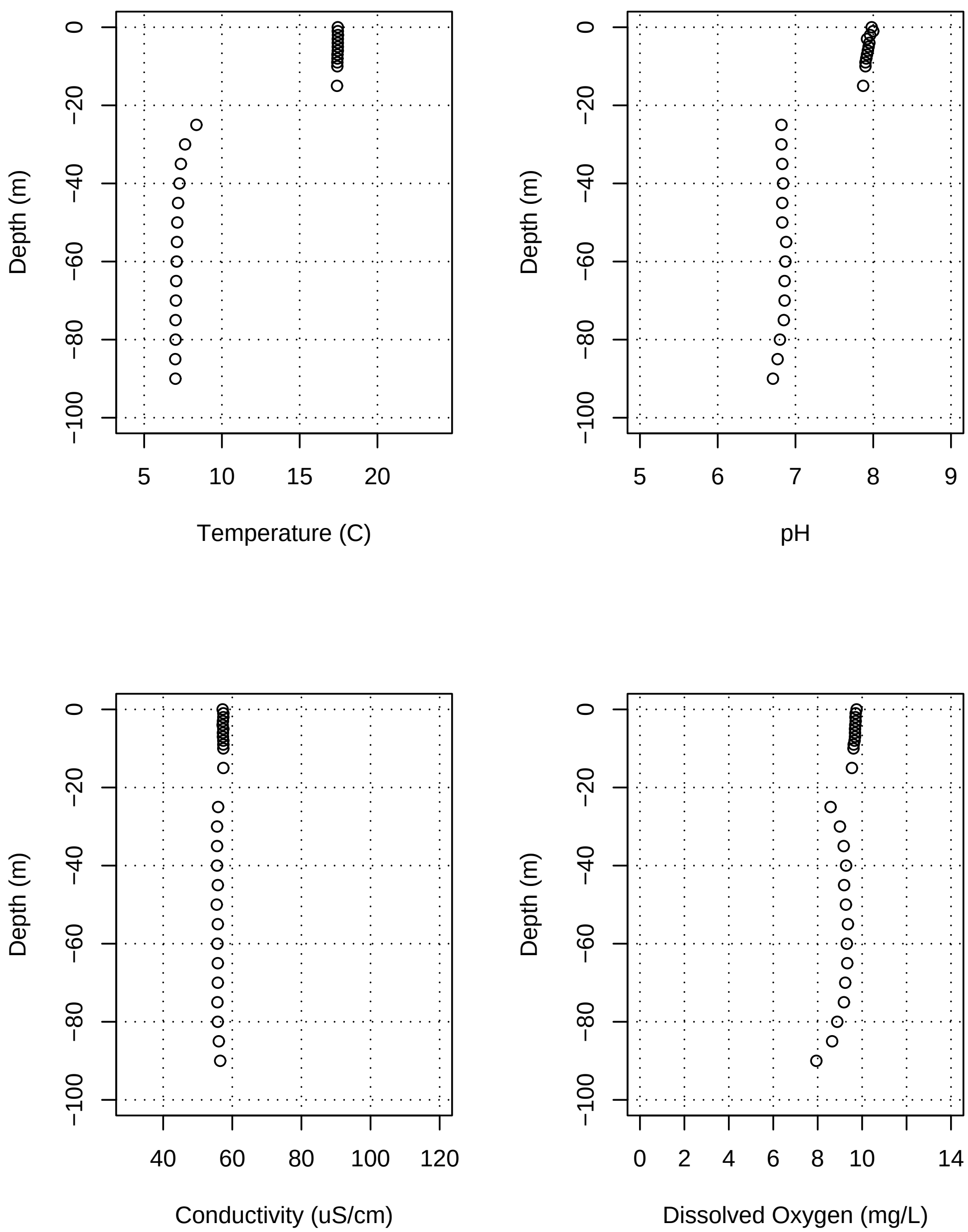


Figure B5: Lake Whatcom Hydrolab profile for Site 4, October 3, 2006. Data are not available at 20 m due to sampling error.

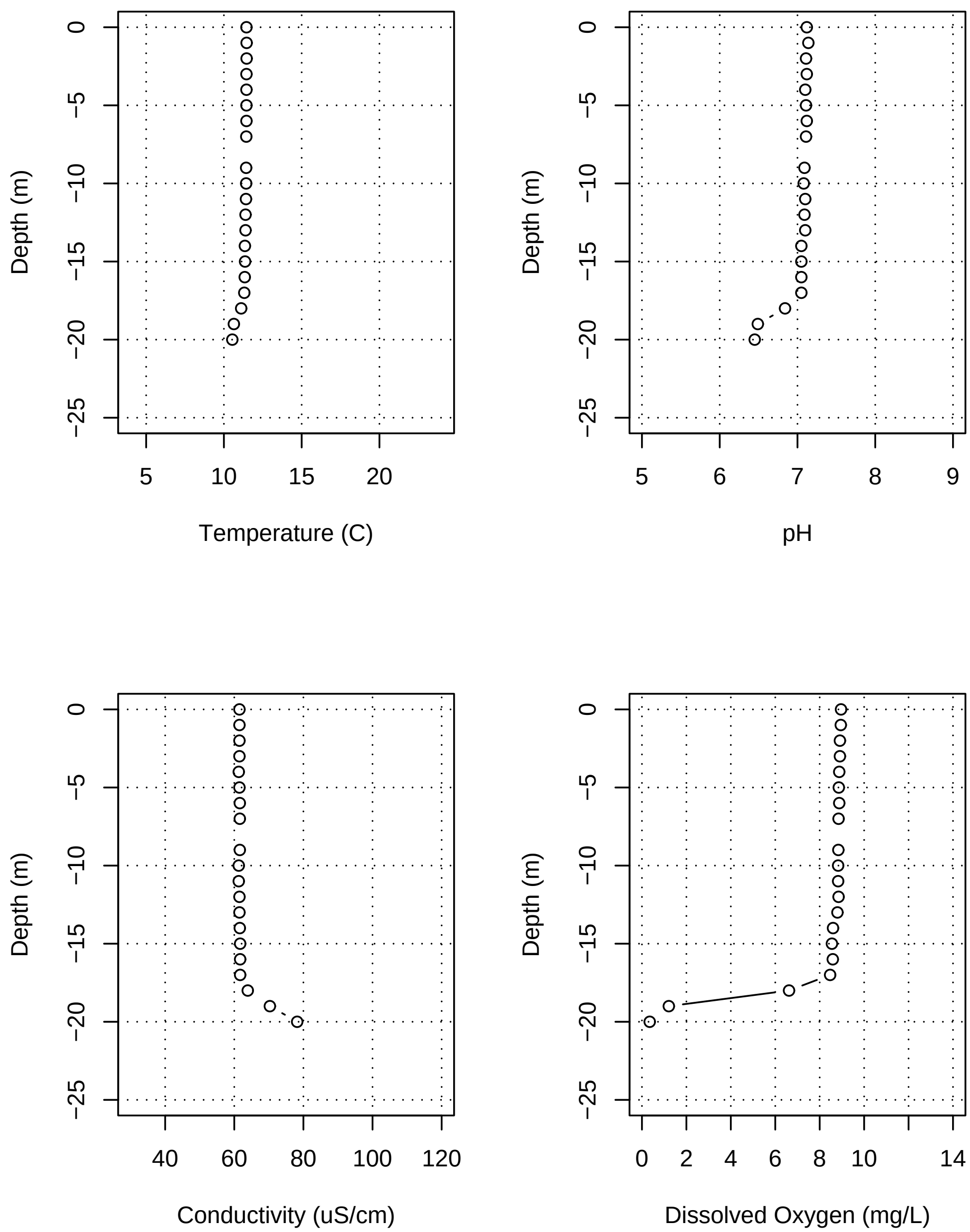


Figure B6: Lake Whatcom Hydrolab profile for Site 1, November 2, 2006. Data are not available at 8 m due to sampling error.

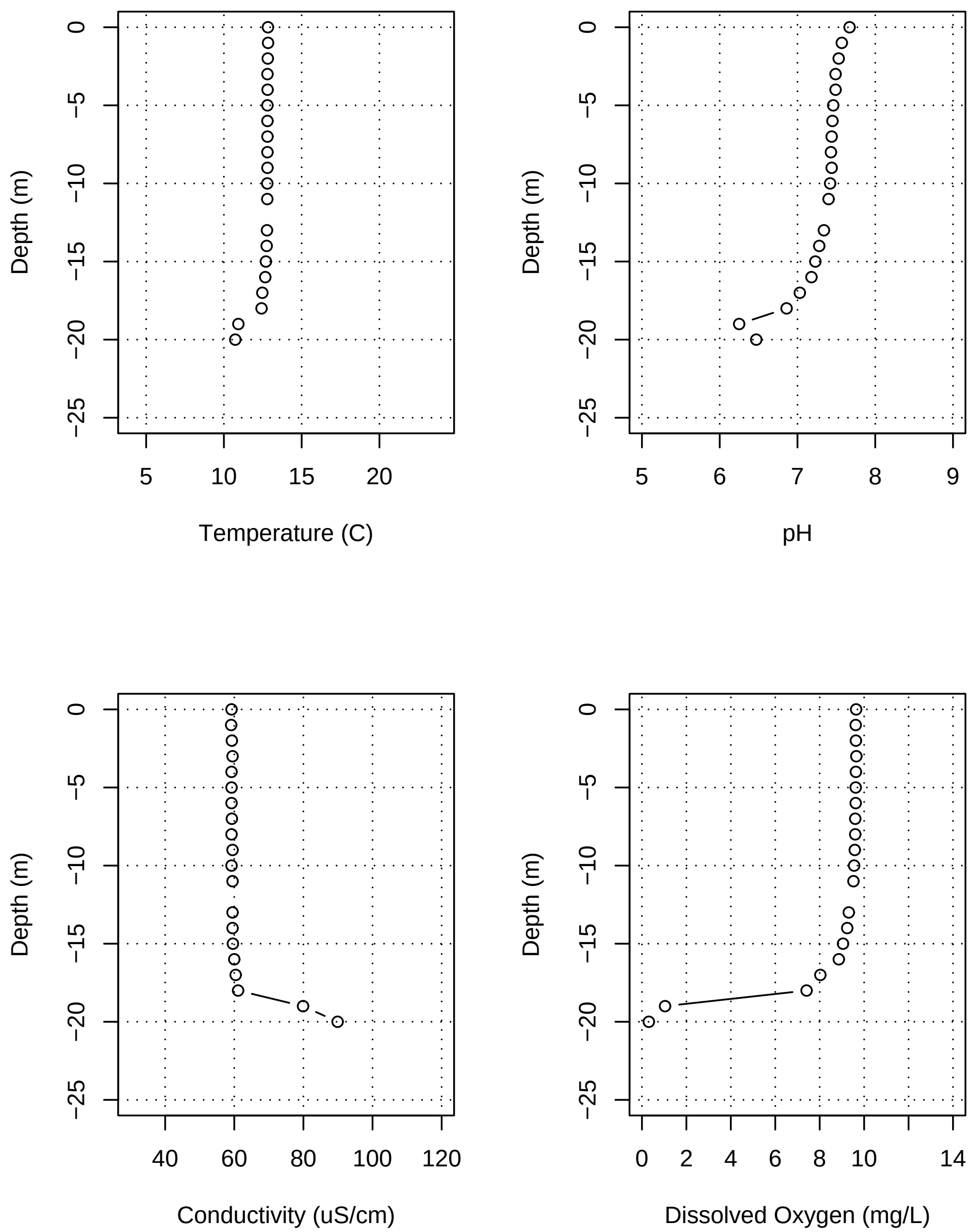


Figure B7: Lake Whatcom Hydrolab profile for Site 2, November 2, 2006. Data are not available at 12 m due to sampling error.

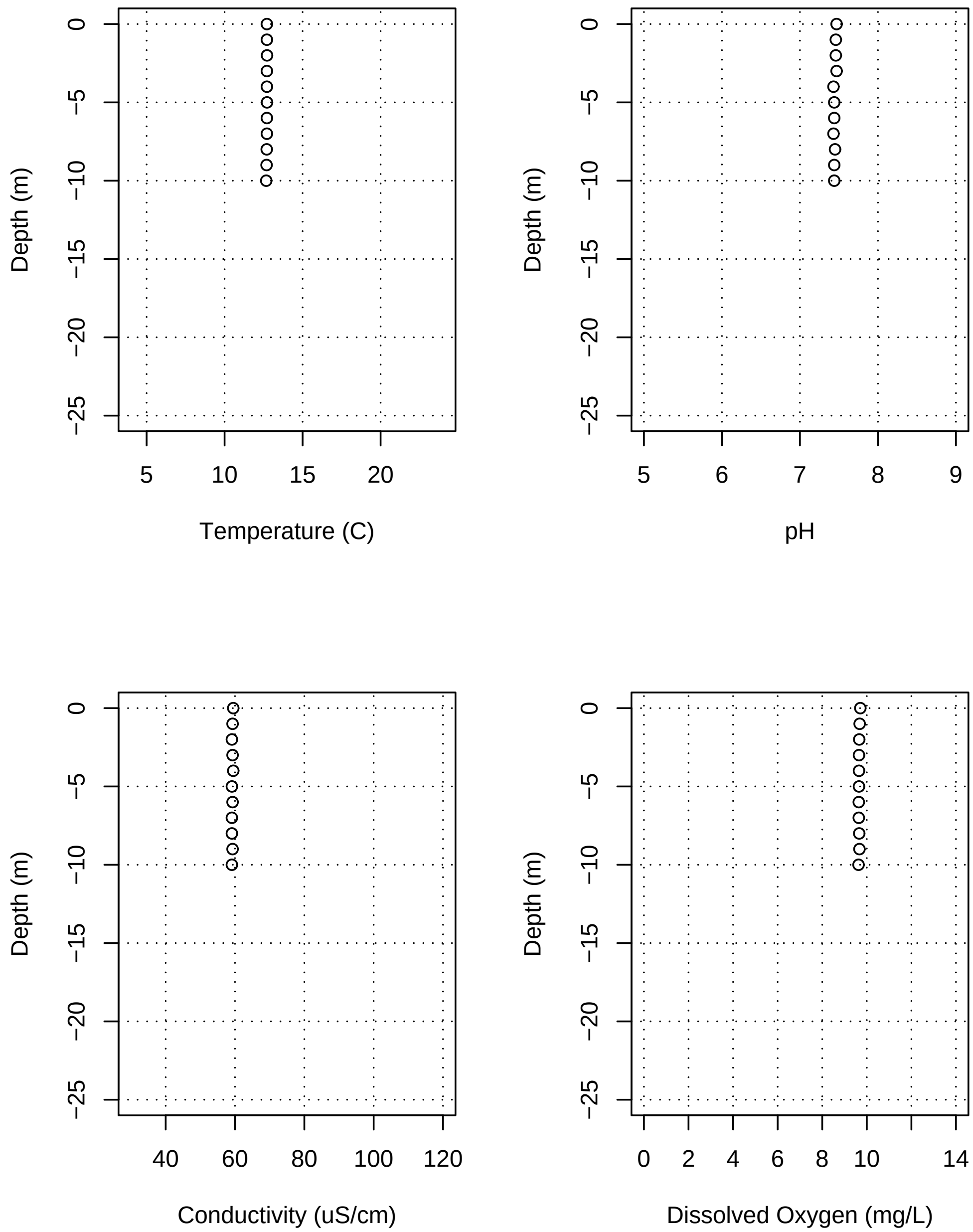


Figure B8: Lake Whatcom Hydrolab profile for the Intake, November 2, 2006.

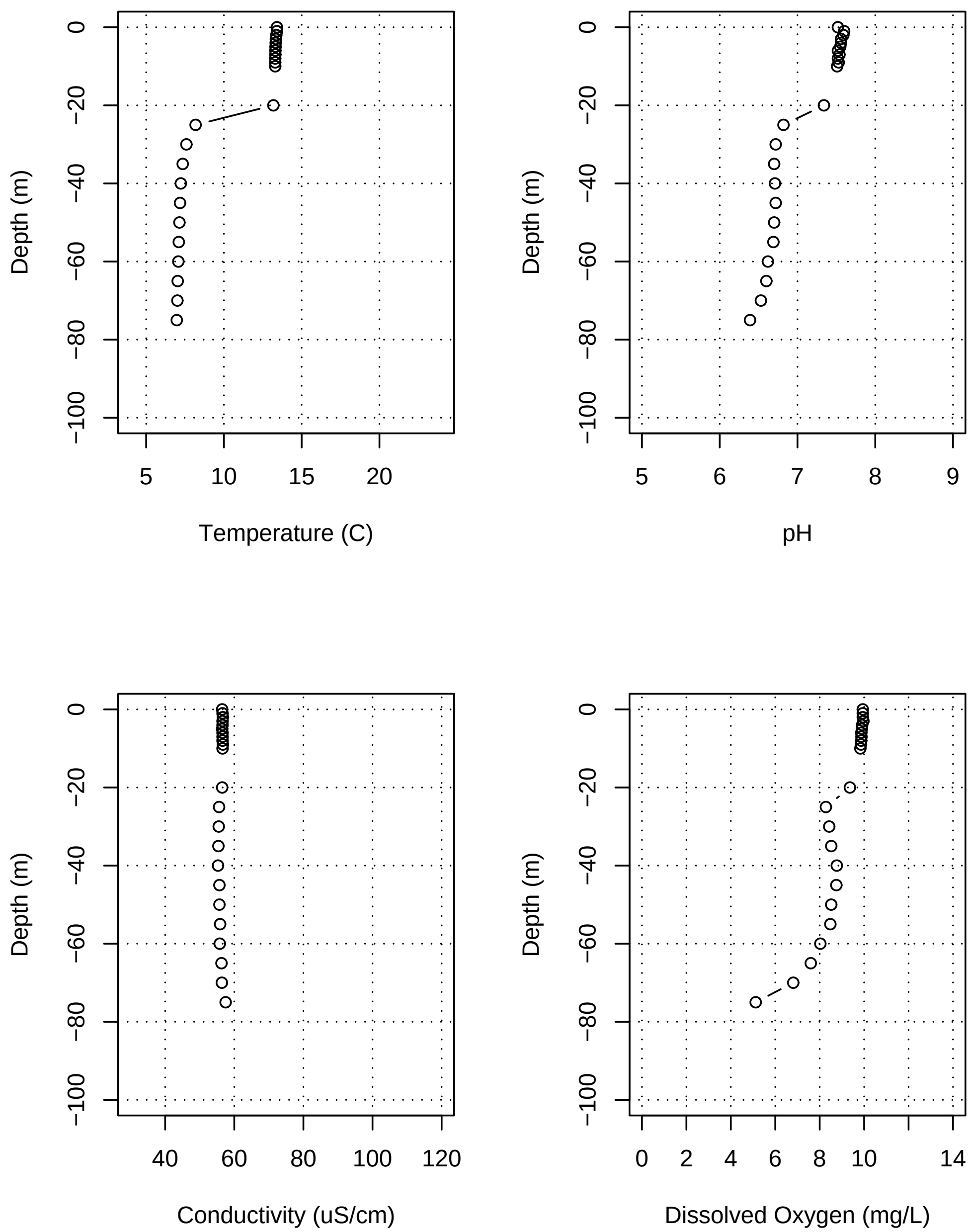


Figure B9: Lake Whatcom Hydrolab profile for Site 3, November 1, 2006. Data are not available at 15 m due to sampling error.

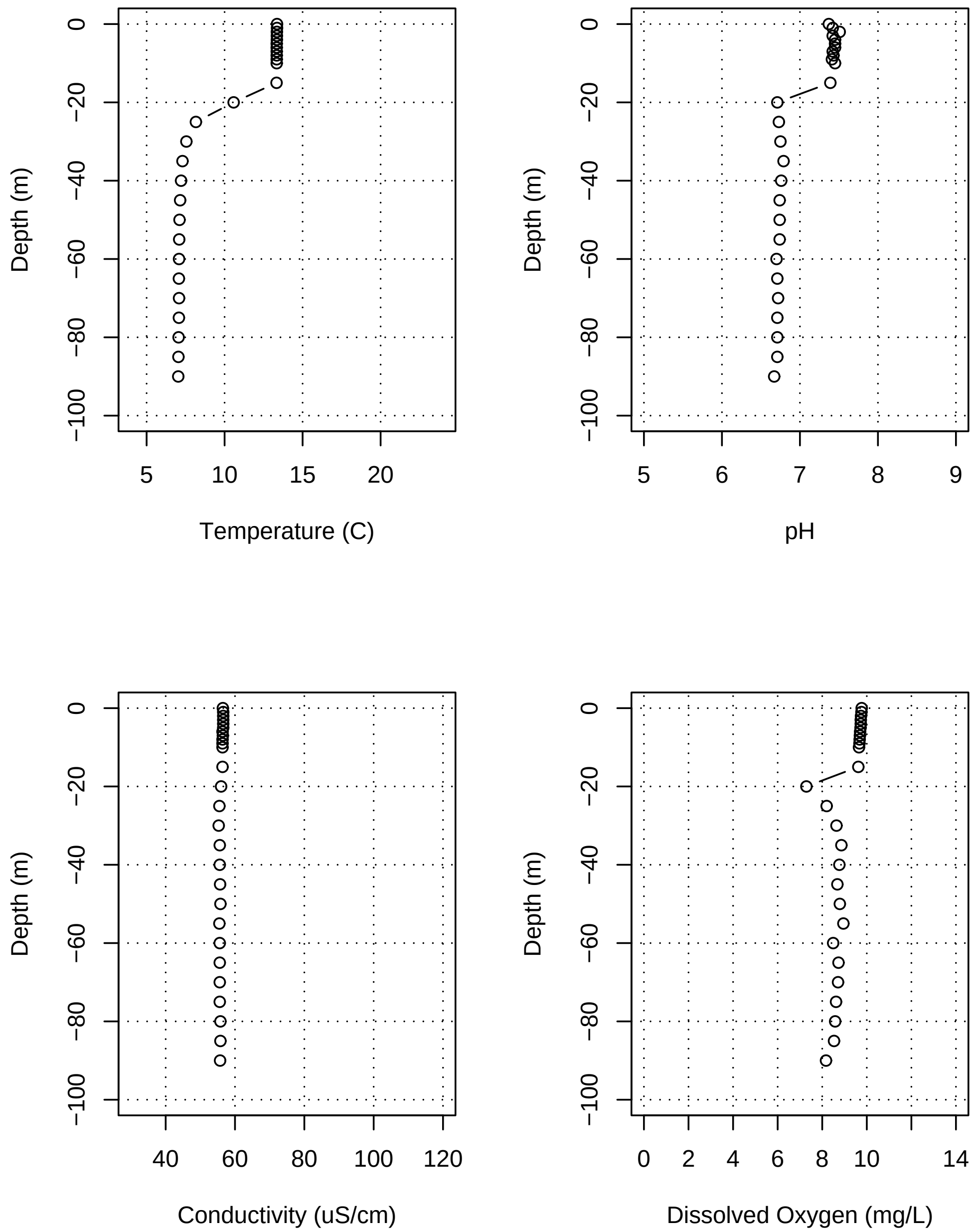


Figure B10: Lake Whatcom Hydrolab profile for Site 4, November 1, 2006.

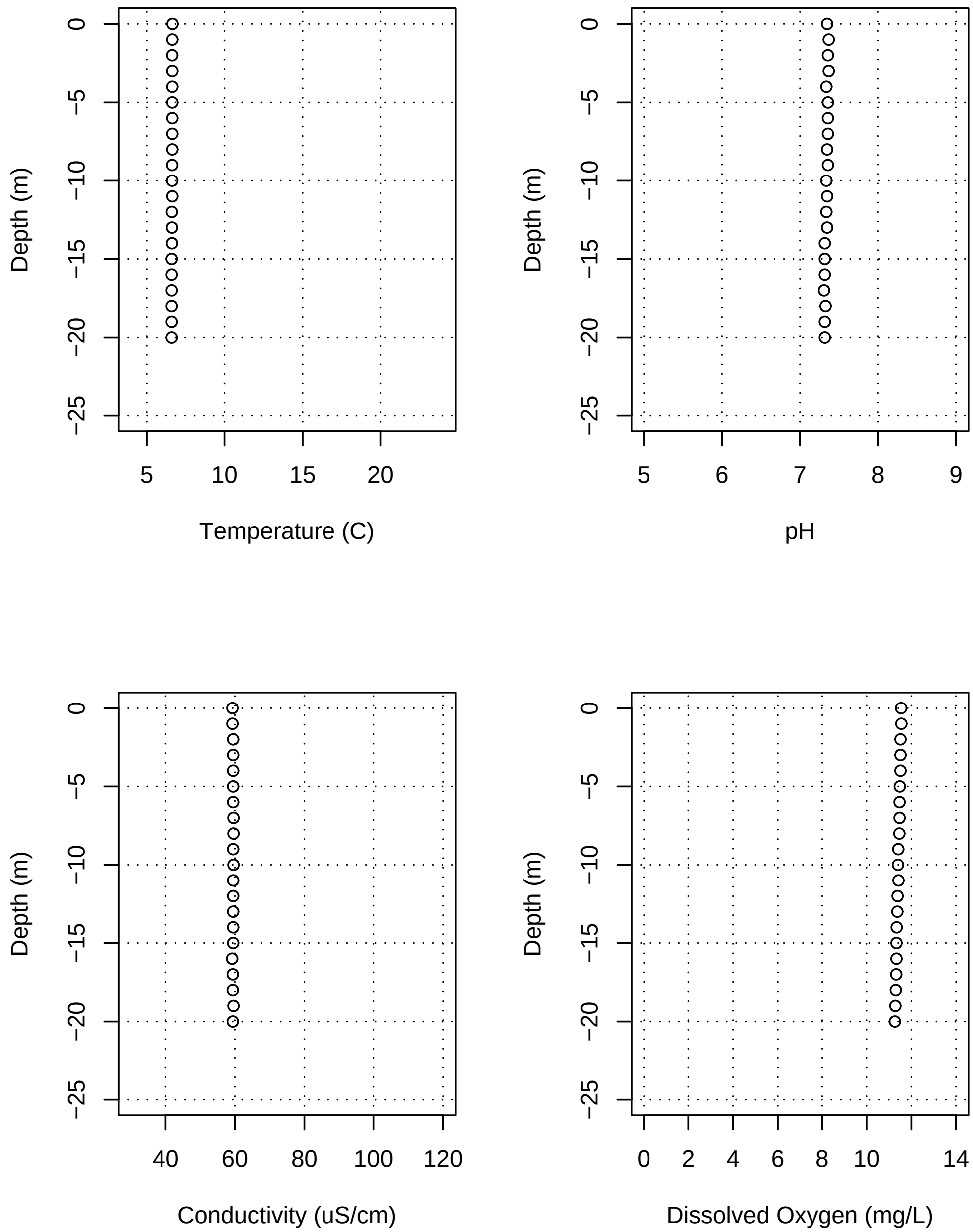


Figure B11: Lake Whatcom Hydrolab profile for Site 1, December 12, 2006.

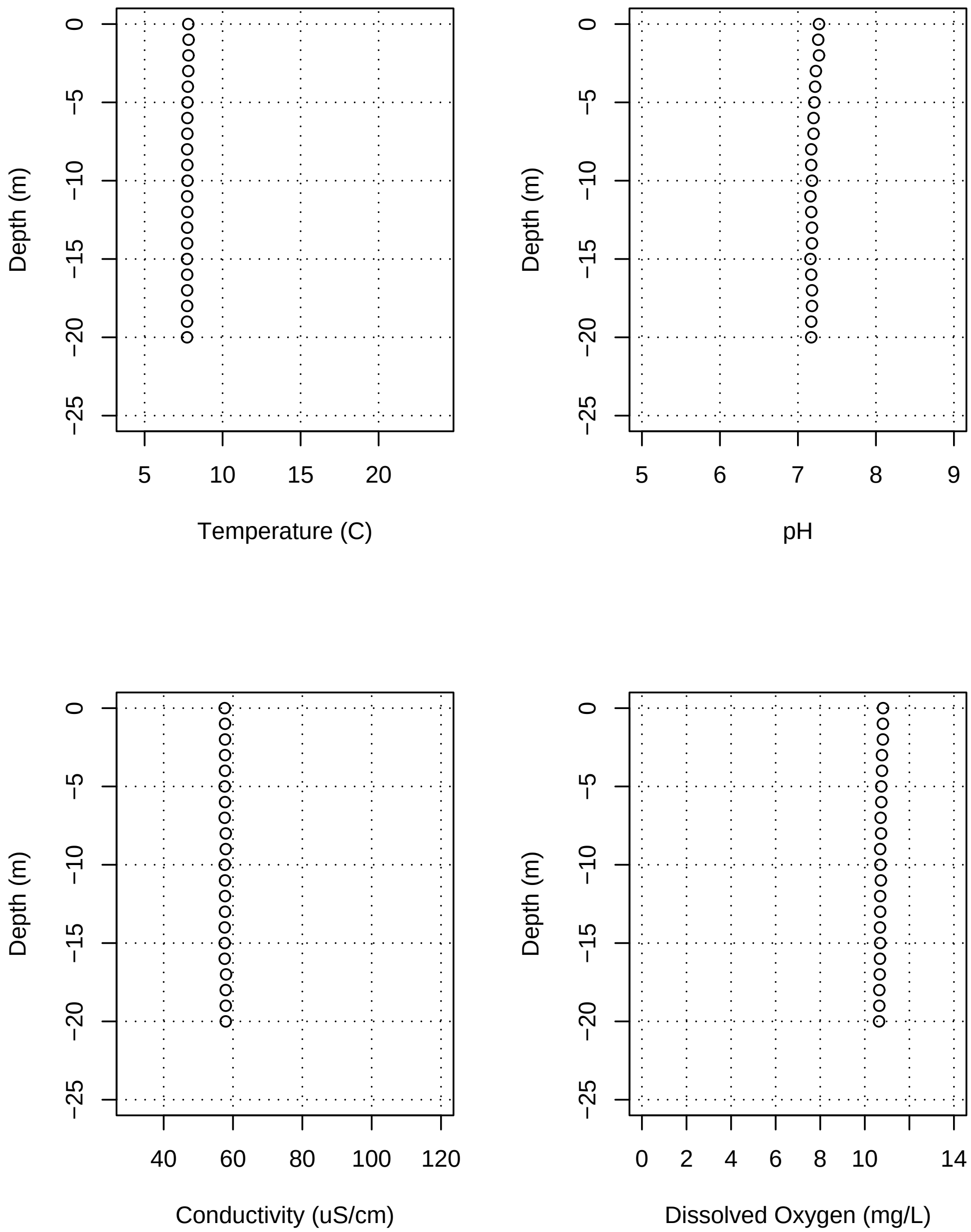


Figure B12: Lake Whatcom Hydrolab profile for Site 2, December 12, 2006.

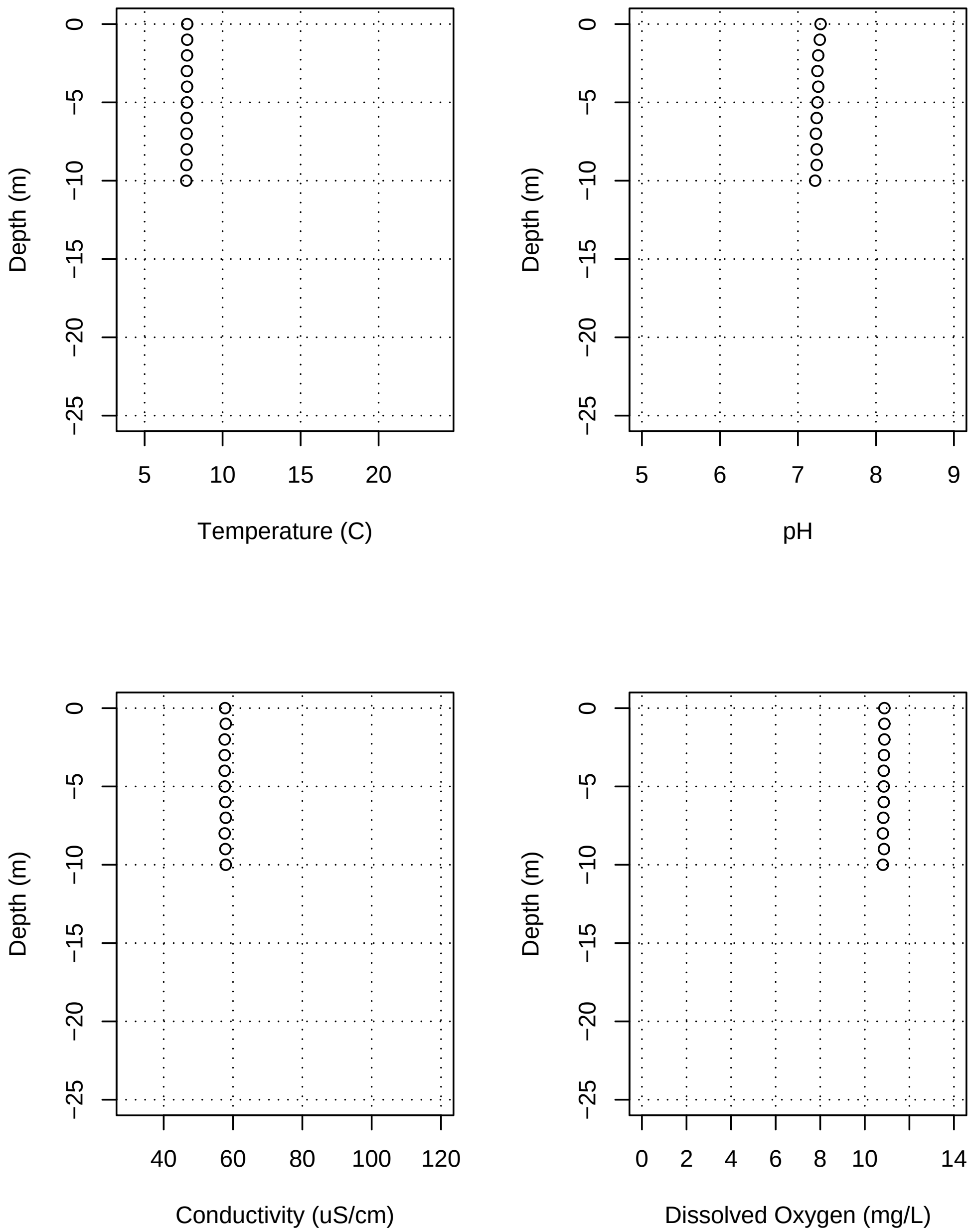


Figure B13: Lake Whatcom Hydrolab profile for the Intake, December 12, 2006.

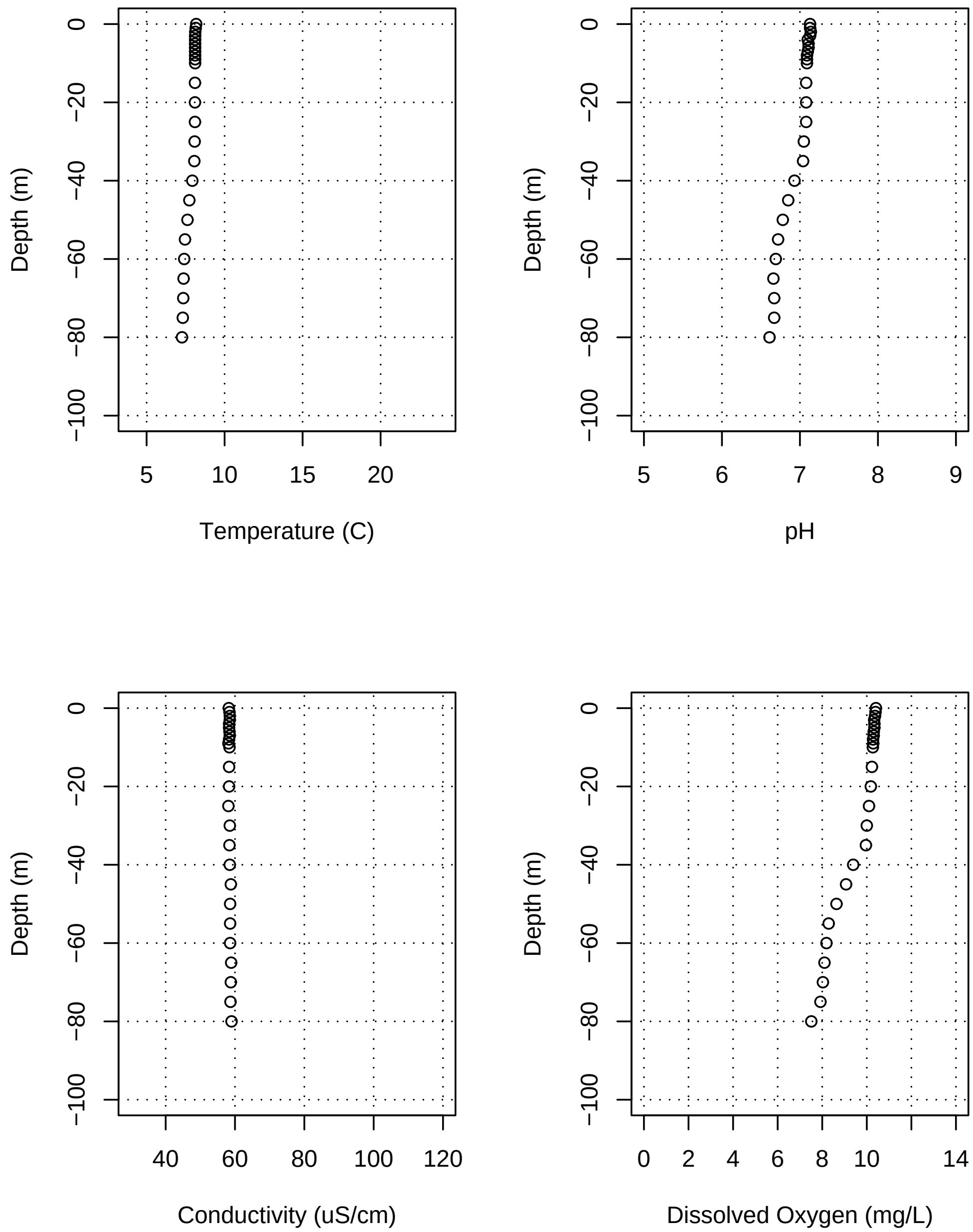


Figure B14: Lake Whatcom Hydrolab profile for Site 3, December 5, 2006.

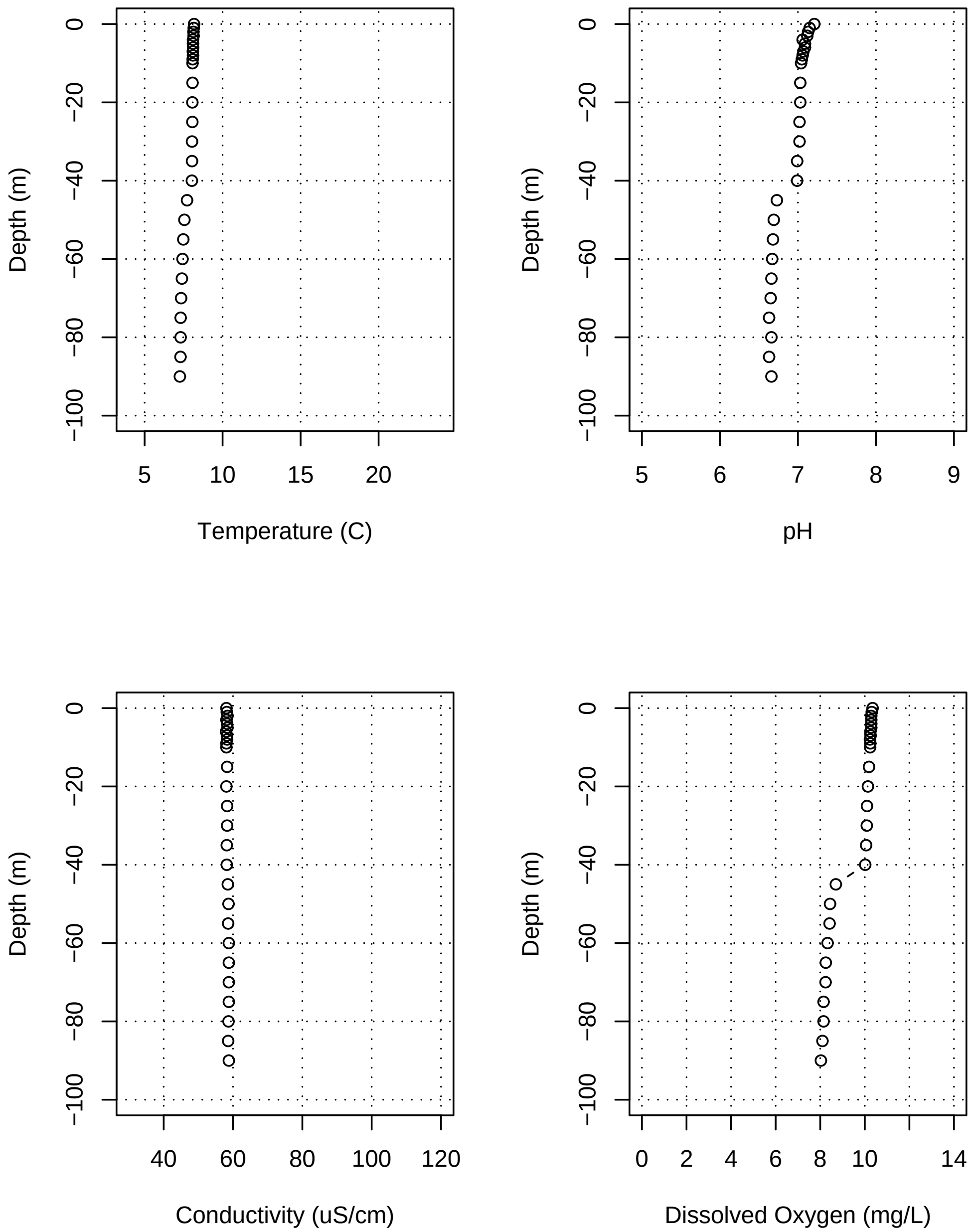


Figure B15: Lake Whatcom Hydrolab profile for Site 4, December 5, 2006.

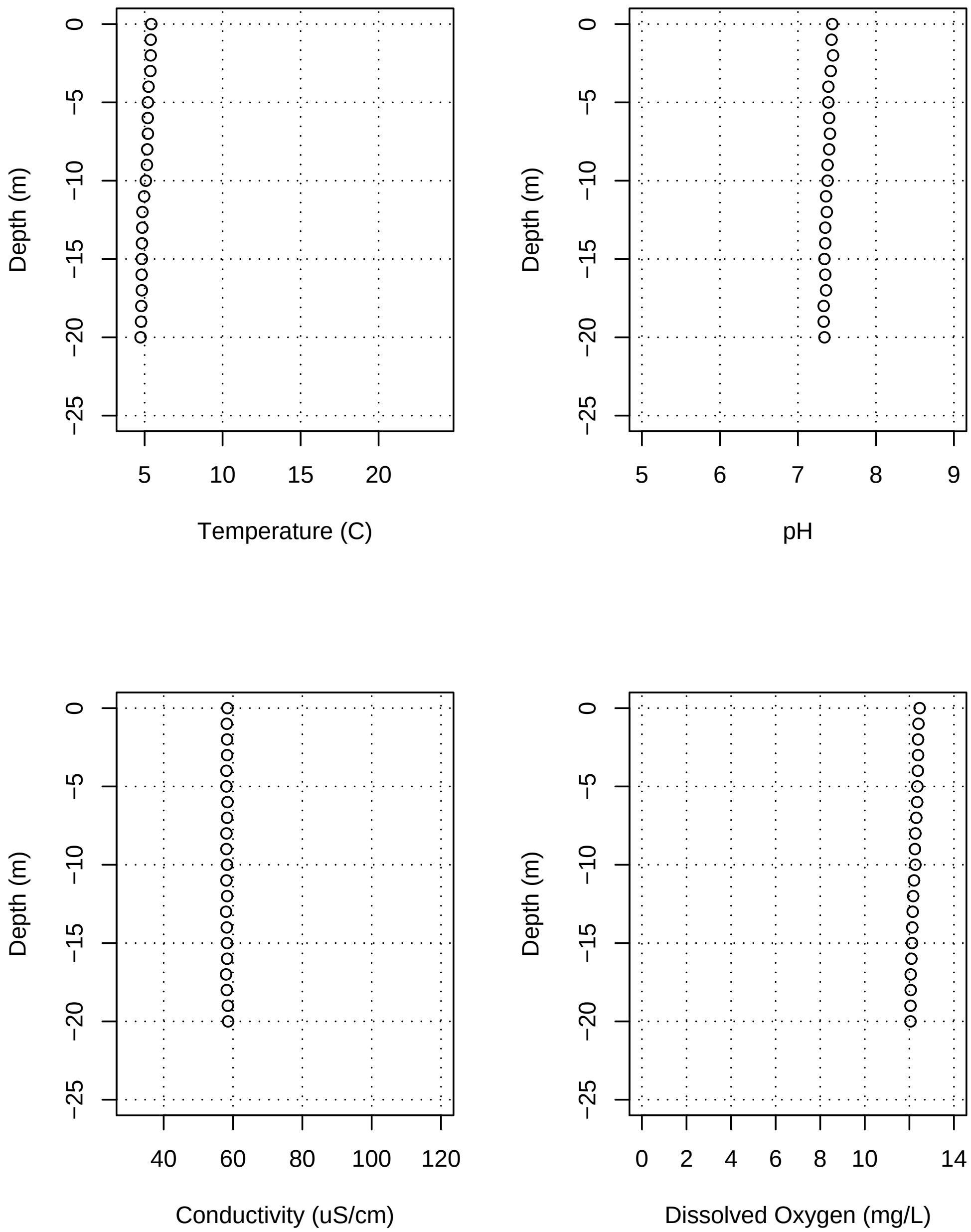


Figure B16: Lake Whatcom Hydrolab profile for Site 1, February 8, 2007.

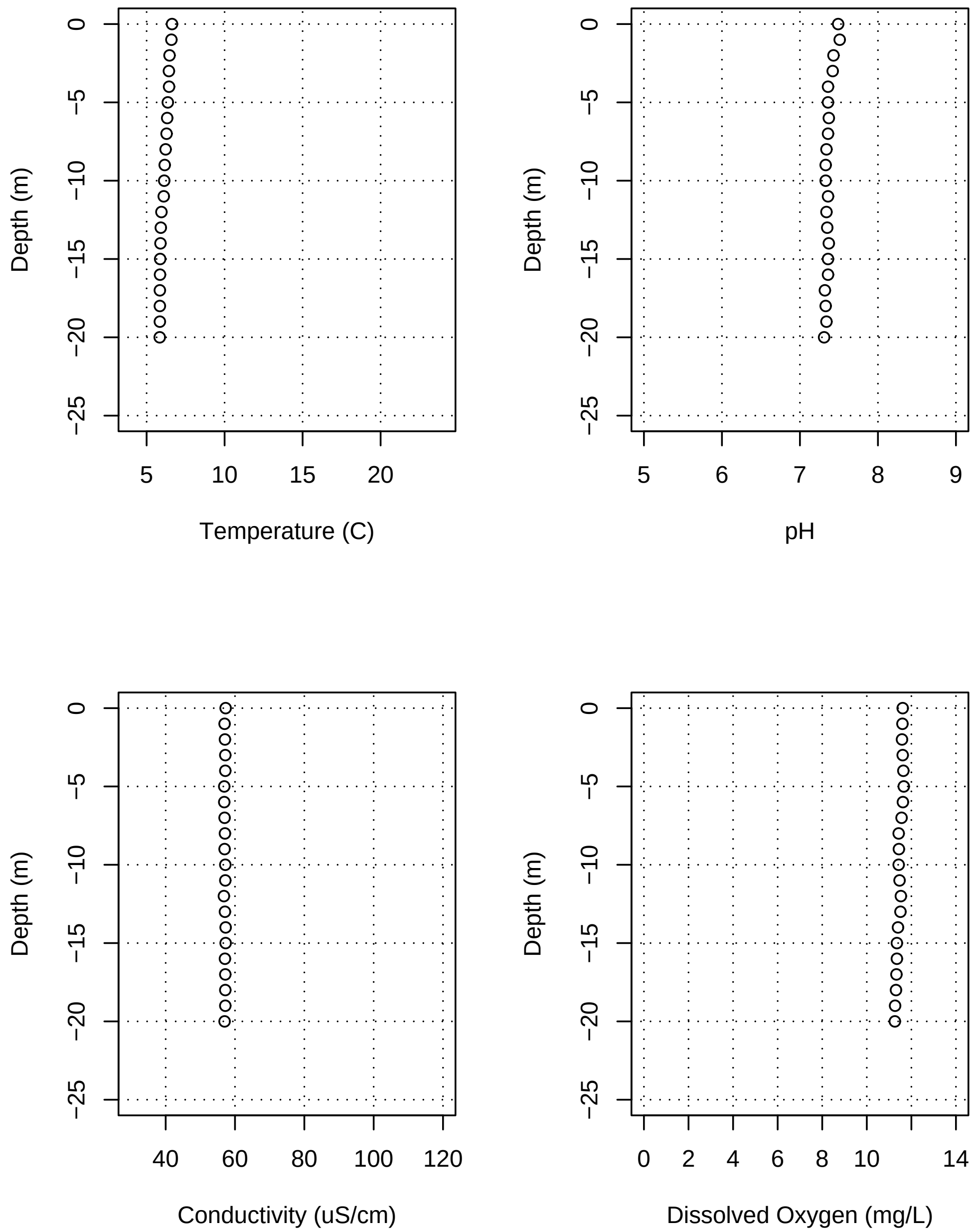


Figure B17: Lake Whatcom Hydrolab profile for Site 2, February 8, 2007.

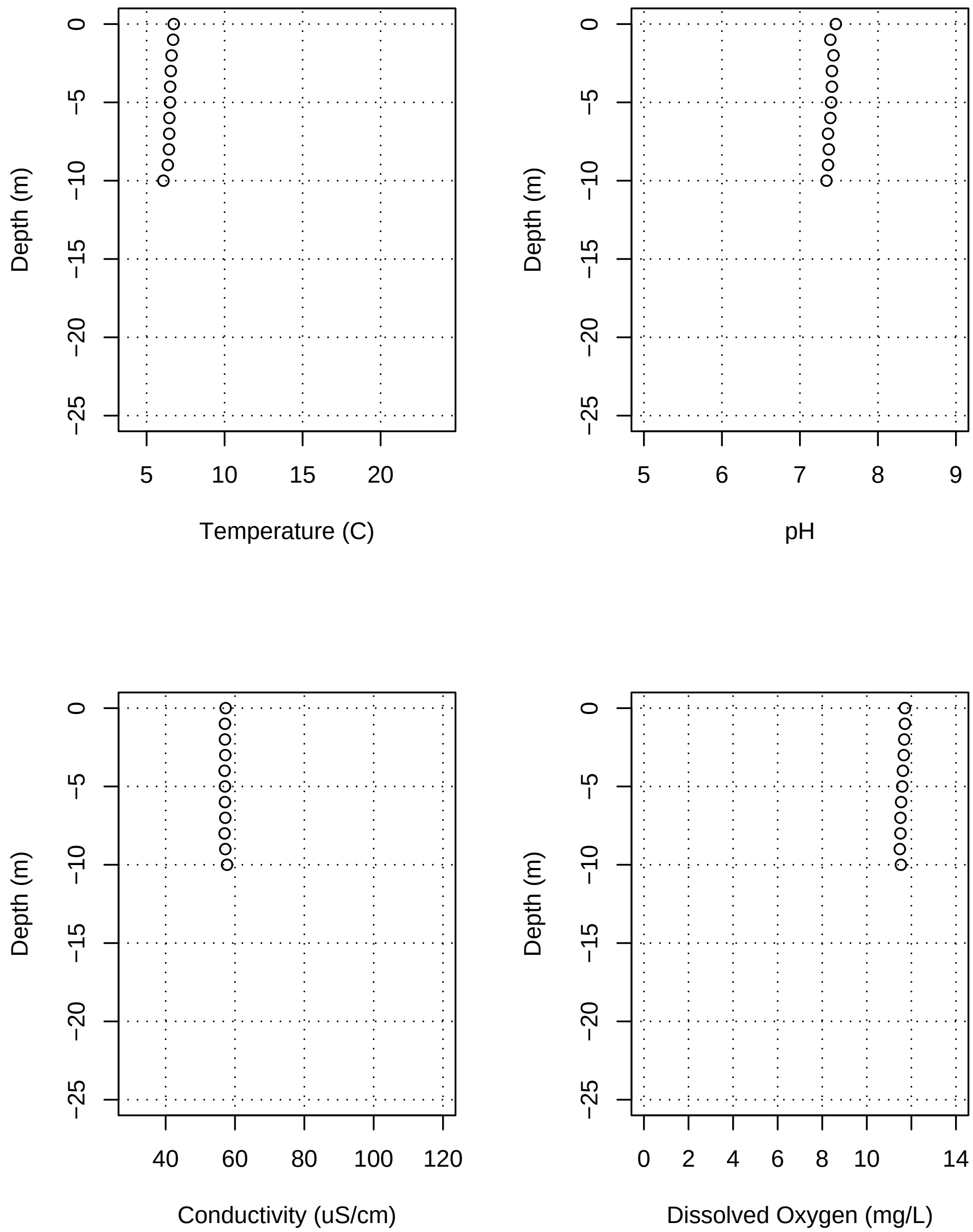


Figure B18: Lake Whatcom Hydrolab profile for the Intake, February 8, 2007.

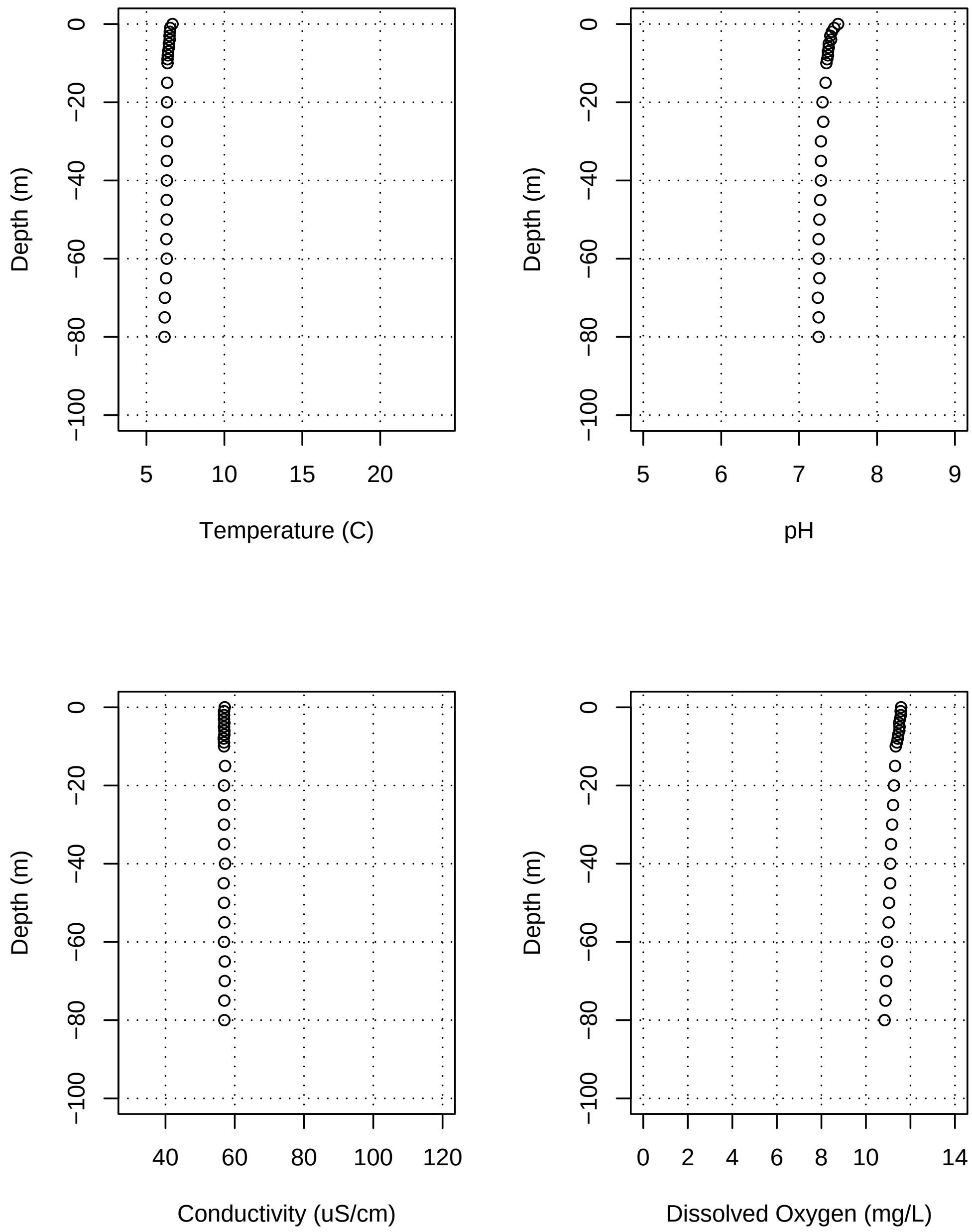


Figure B19: Lake Whatcom Hydrolab profile for Site 3, February 6, 2007.

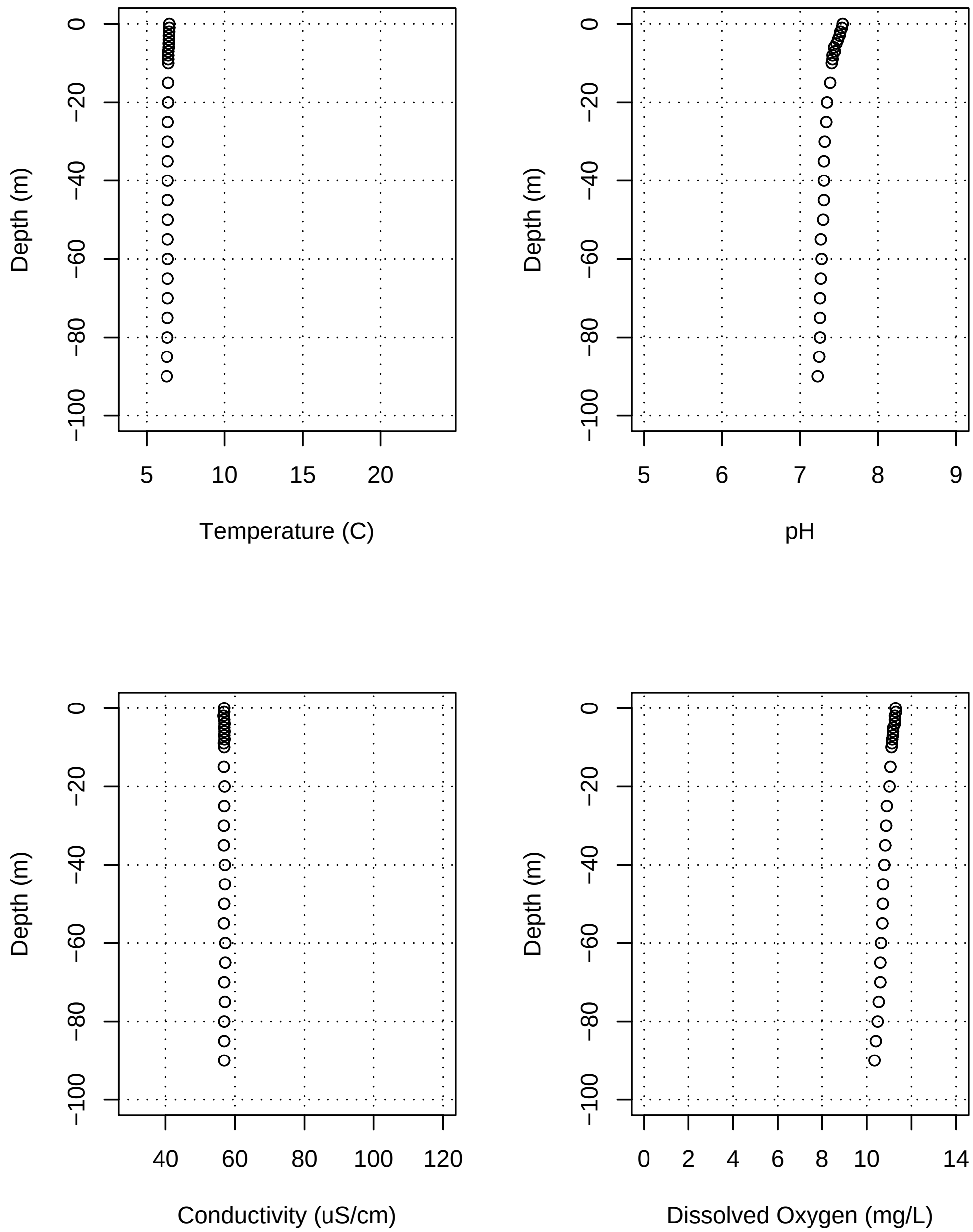


Figure B20: Lake Whatcom Hydrolab profile for Site 4, February 6, 2007.

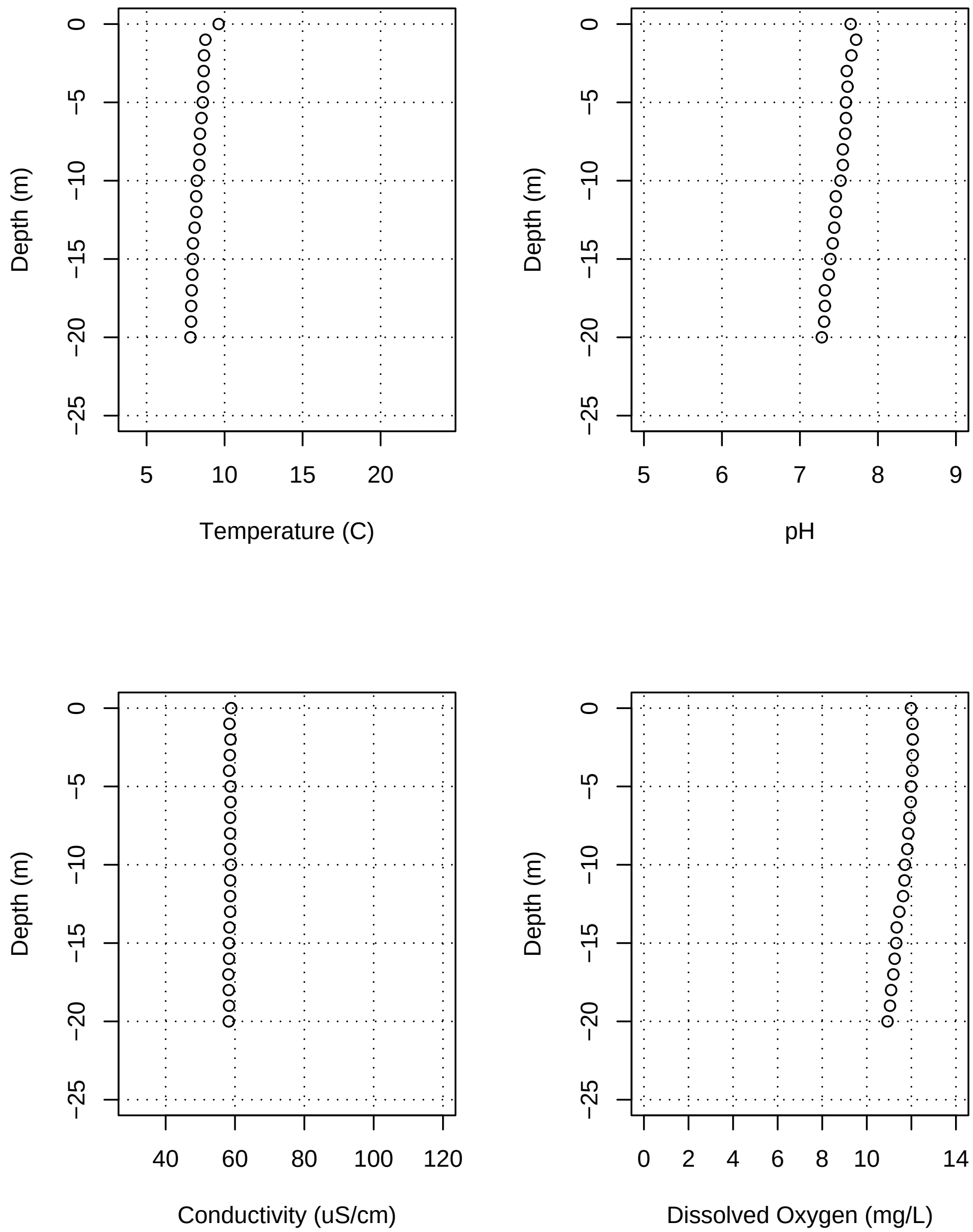


Figure B21: Lake Whatcom Hydrolab profile for Site 1, April 5, 2007.

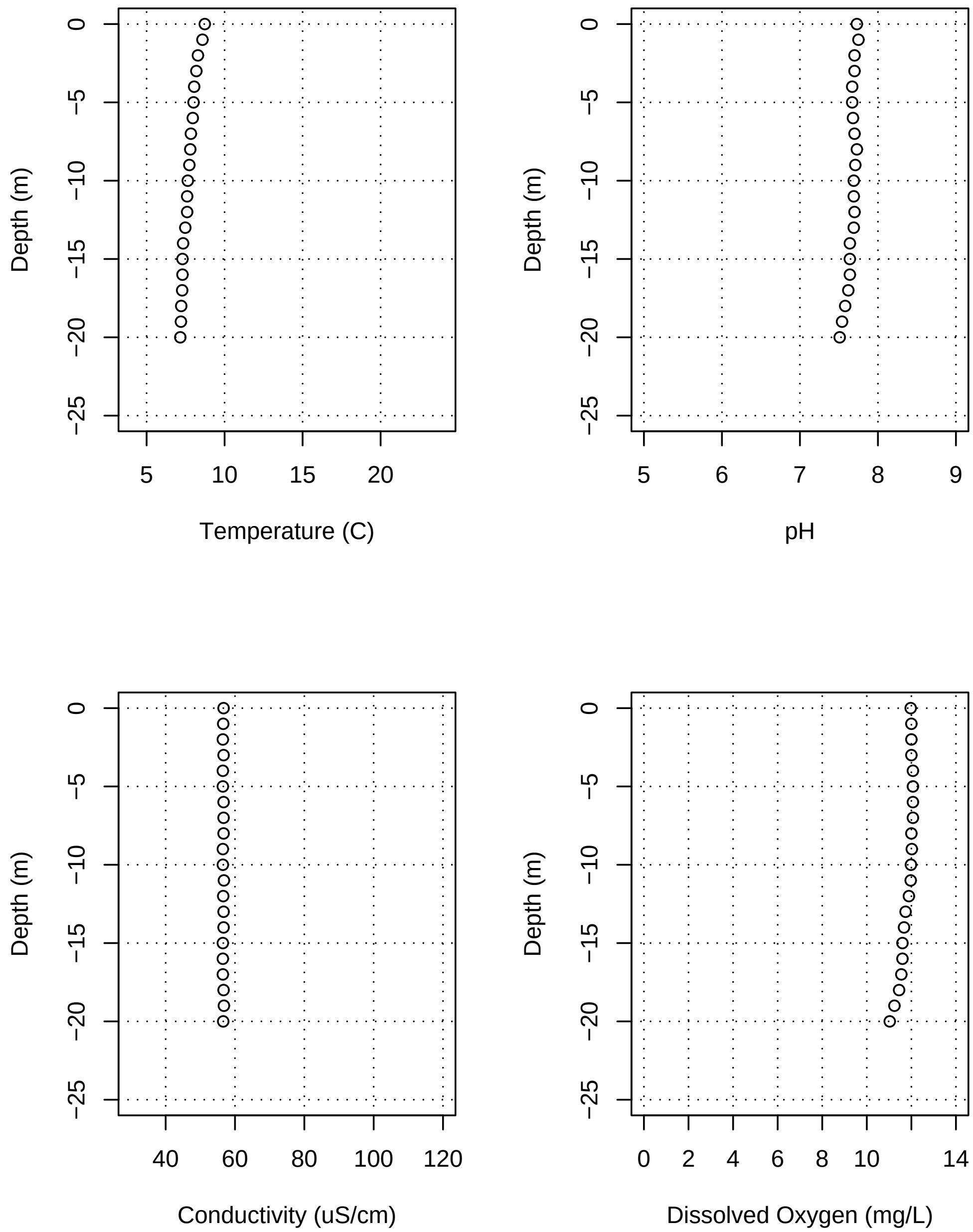


Figure B22: Lake Whatcom Hydrolab profile for Site 2, April 5, 2007.

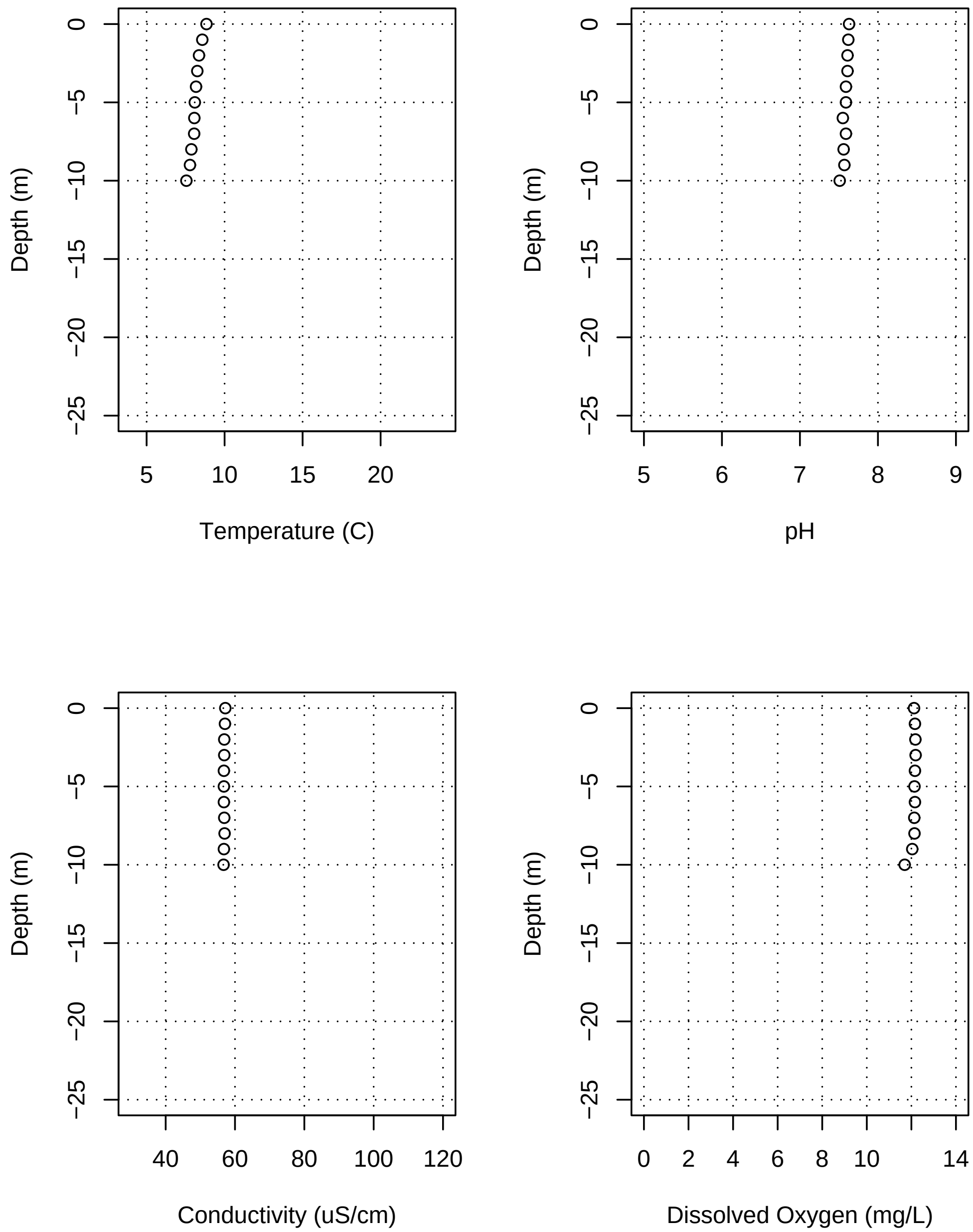


Figure B23: Lake Whatcom Hydrolab profile for the Intake, April 5, 2007.

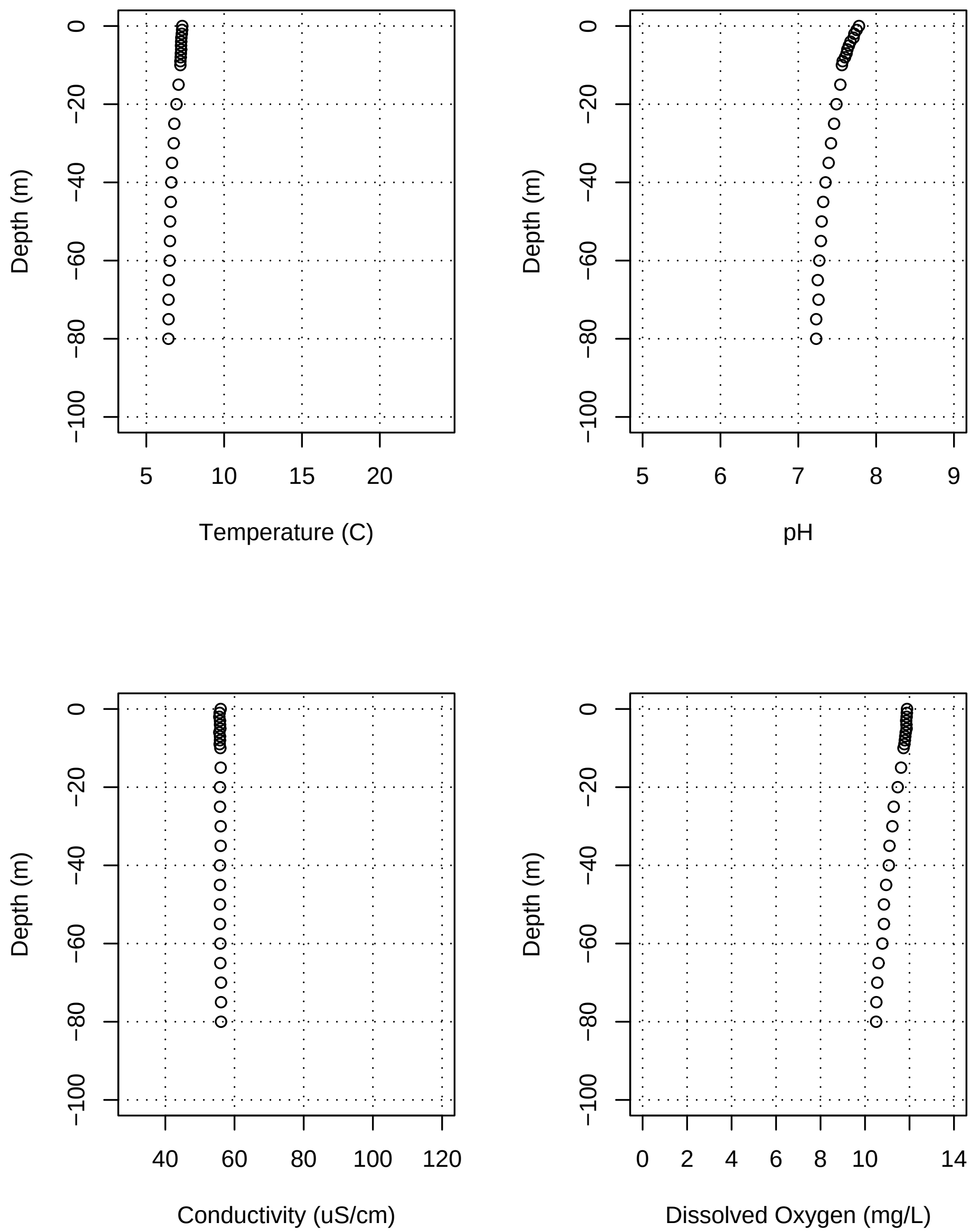


Figure B24: Lake Whatcom Hydrolab profile for Site 3, April 4, 2007.

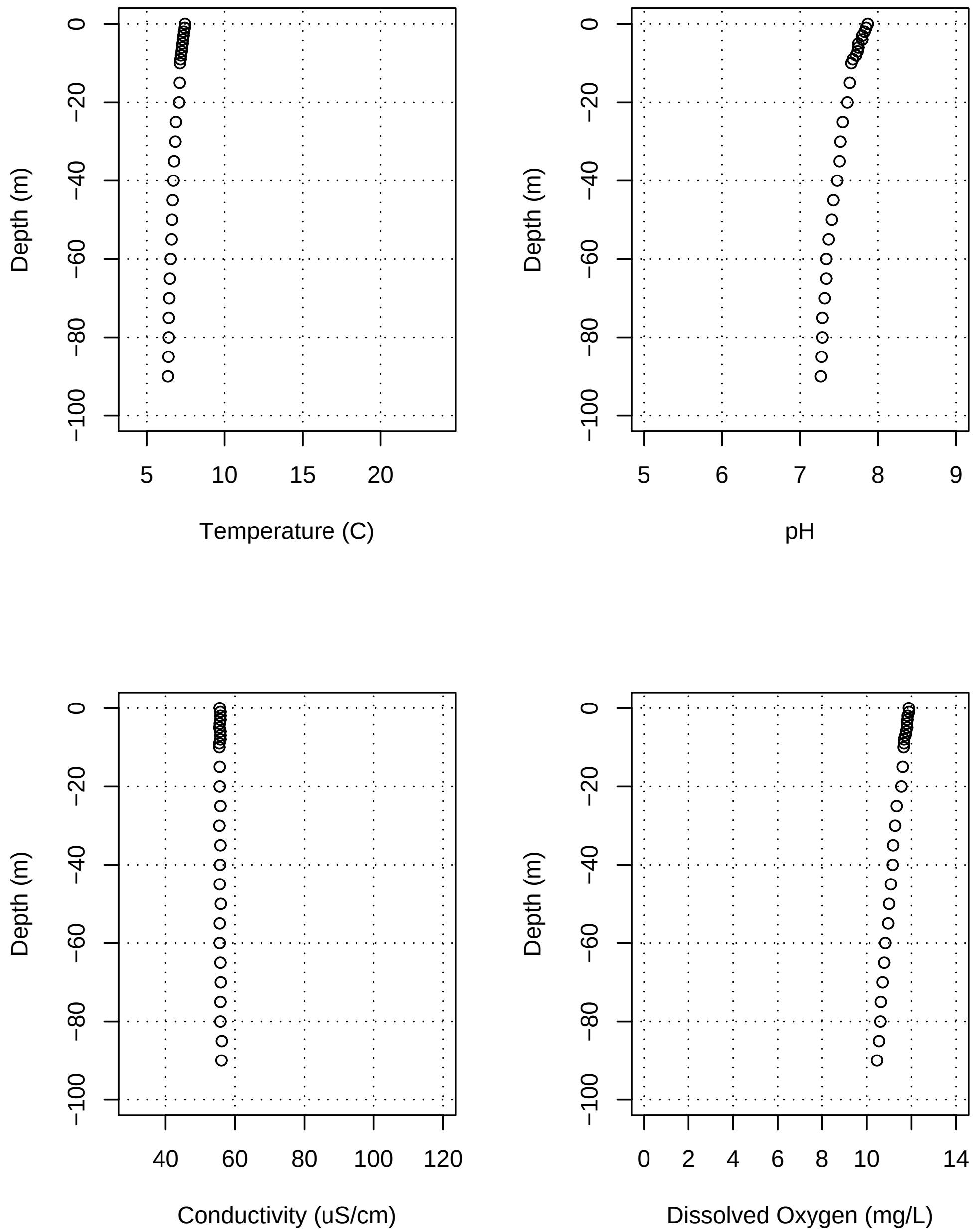


Figure B25: Lake Whatcom Hydrolab profile for Site 4, April 4, 2007.

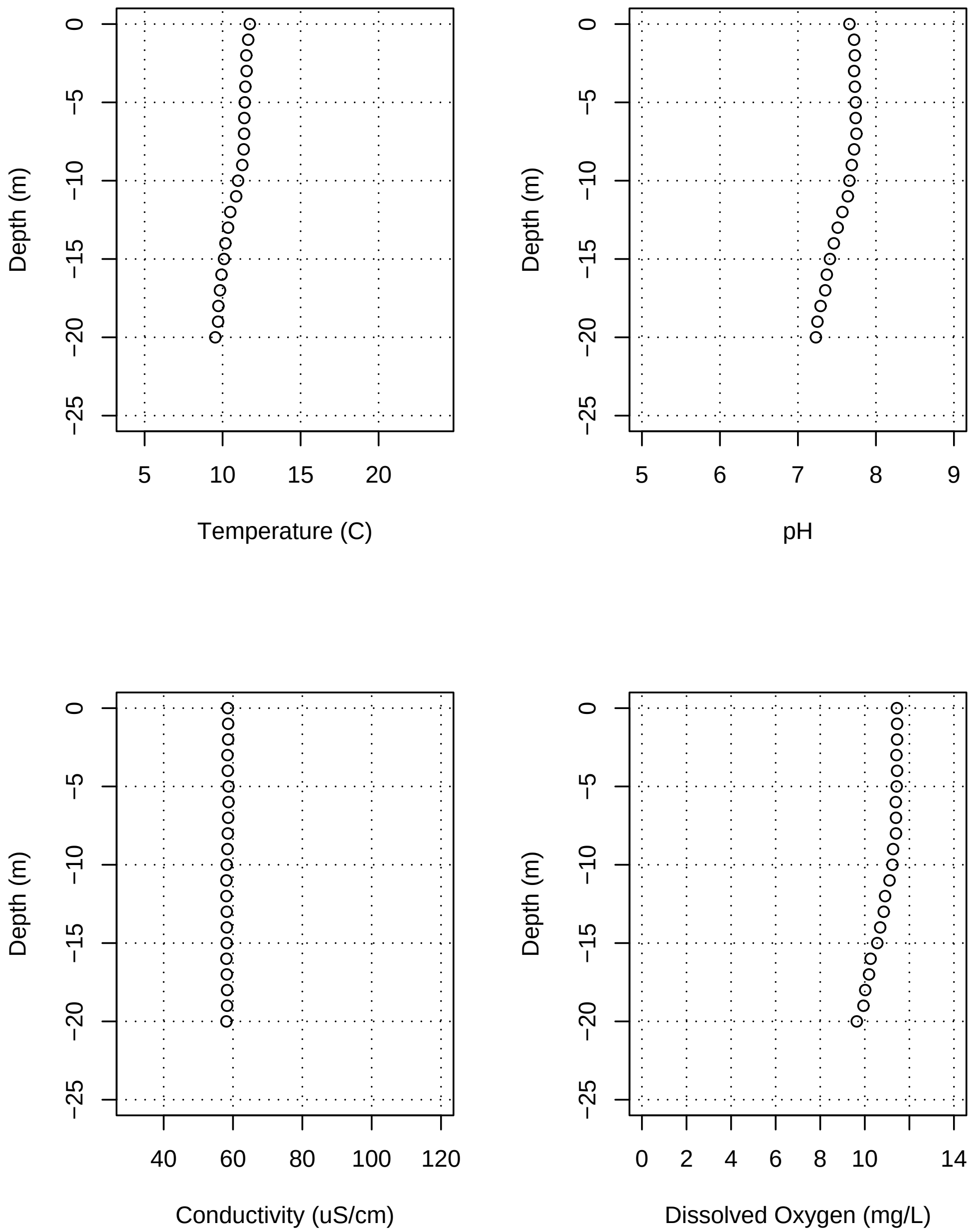


Figure B26: Lake Whatcom Hydrolab profile for Site 1, May 3, 2007.

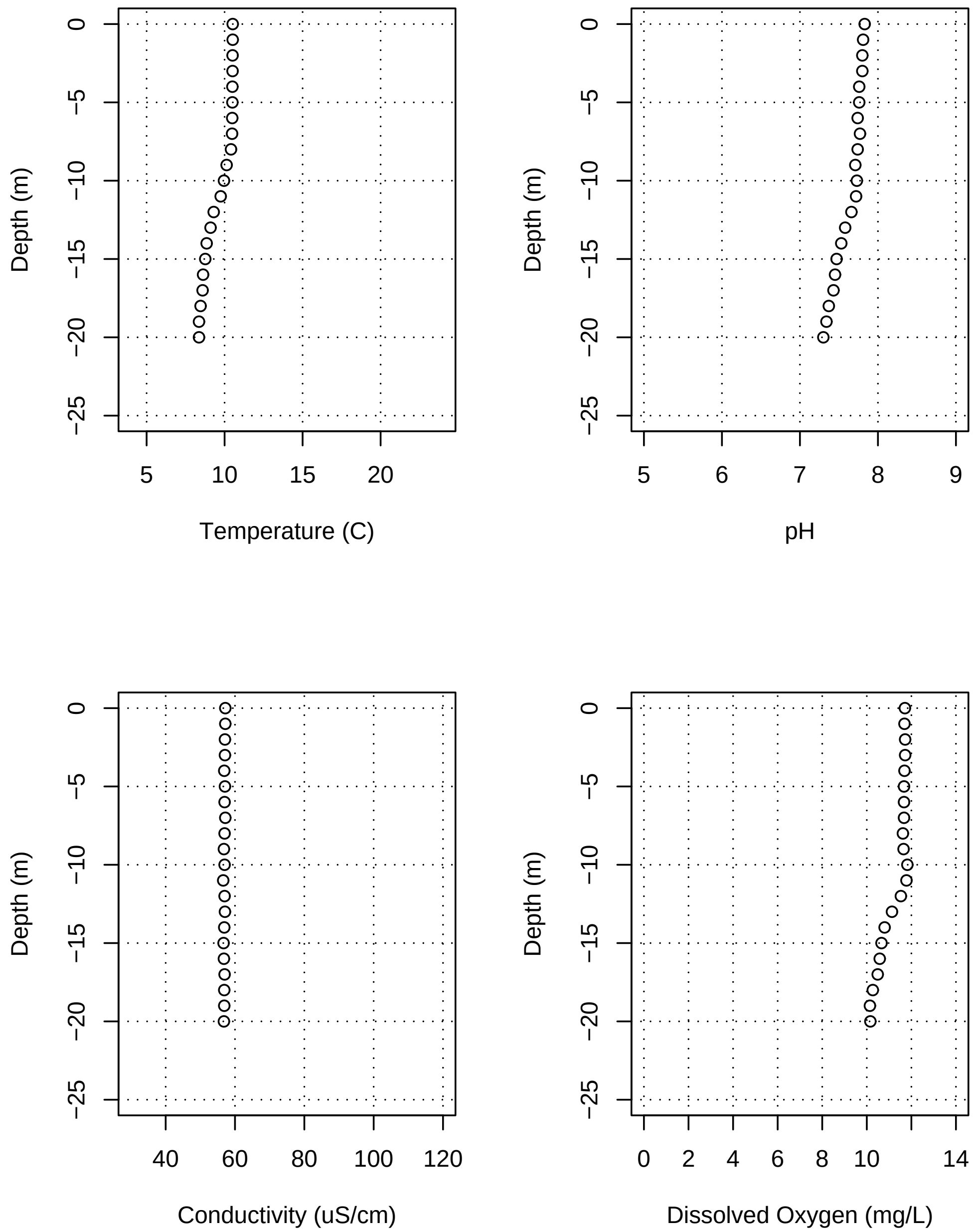


Figure B27: Lake Whatcom Hydrolab profile for Site 2, May 3, 2007.

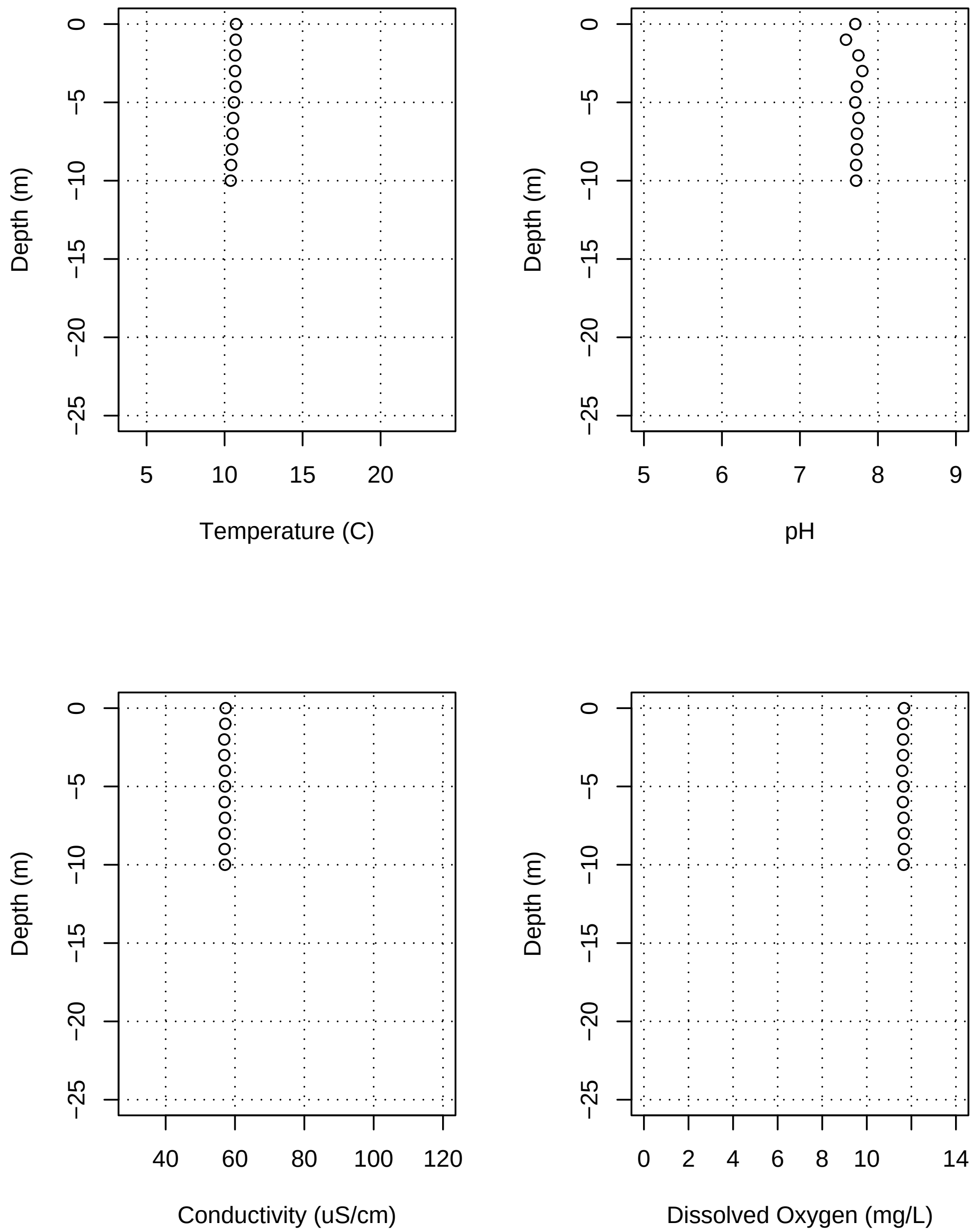


Figure B28: Lake Whatcom Hydrolab profile for the Intake, May 3, 2007.

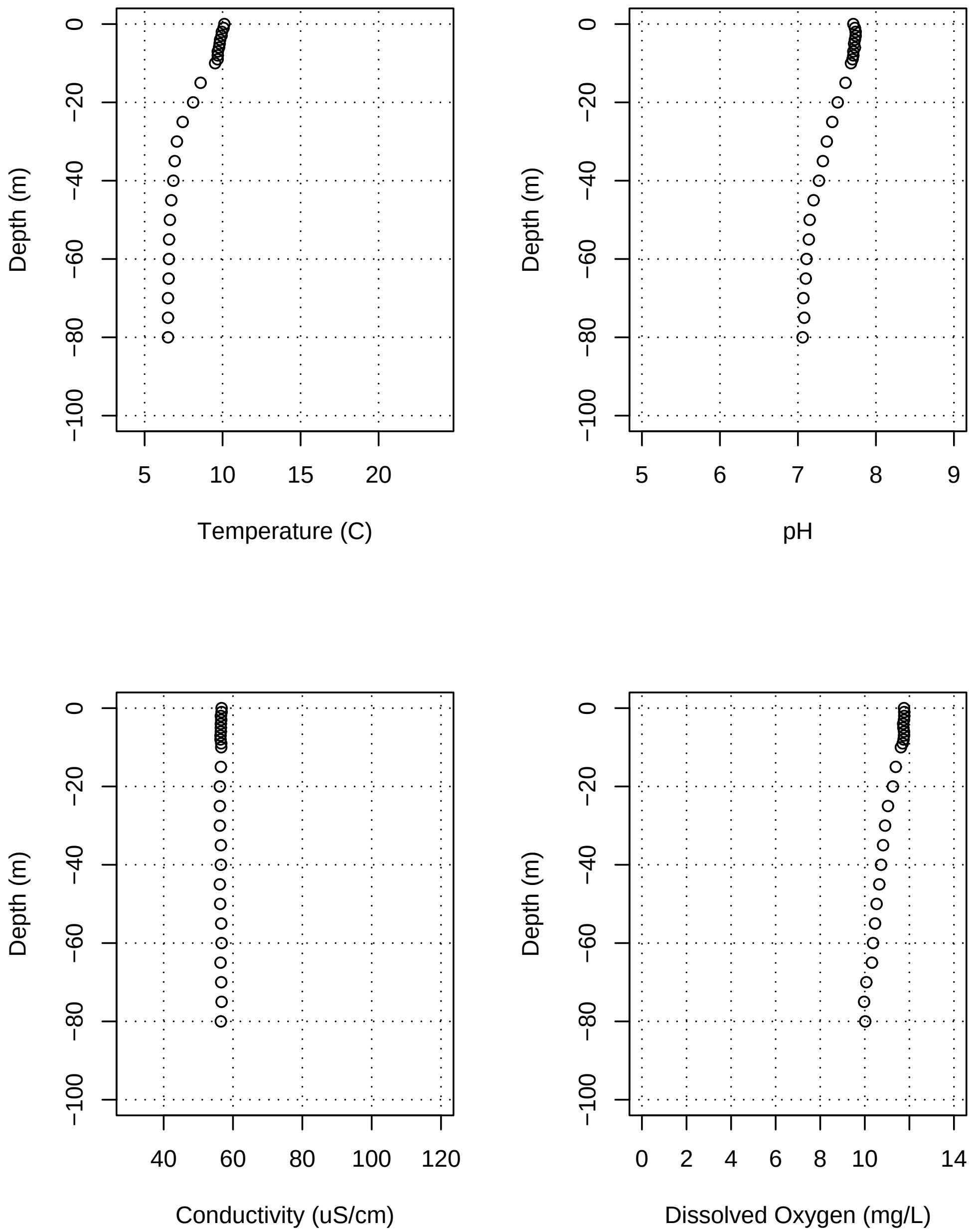


Figure B29: Lake Whatcom Hydrolab profile for Site 3, May 1, 2007.

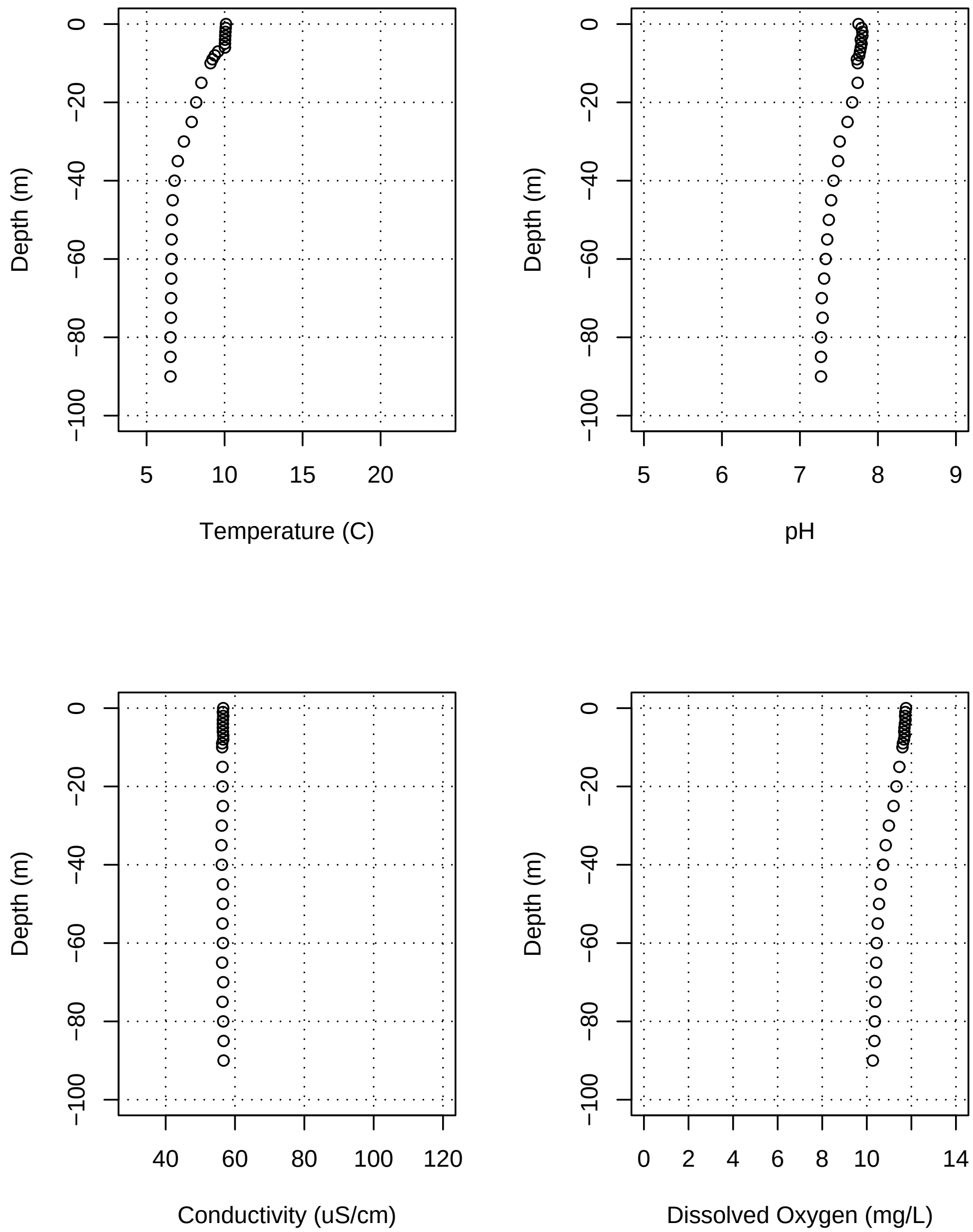


Figure B30: Lake Whatcom Hydrolab profile for Site 4, May 1, 2007.

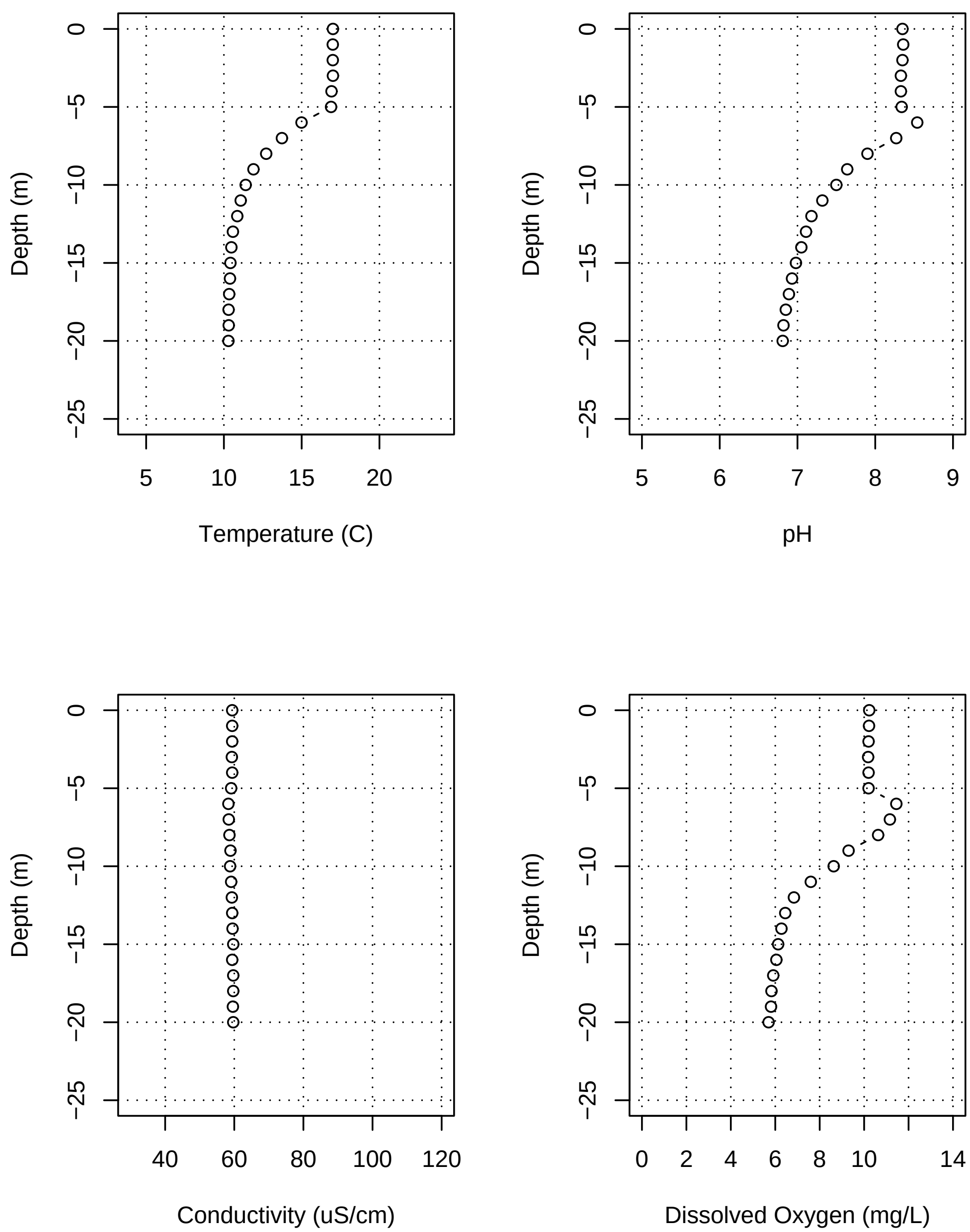


Figure B31: Lake Whatcom Hydrolab profile for Site 1, June 7, 2007.

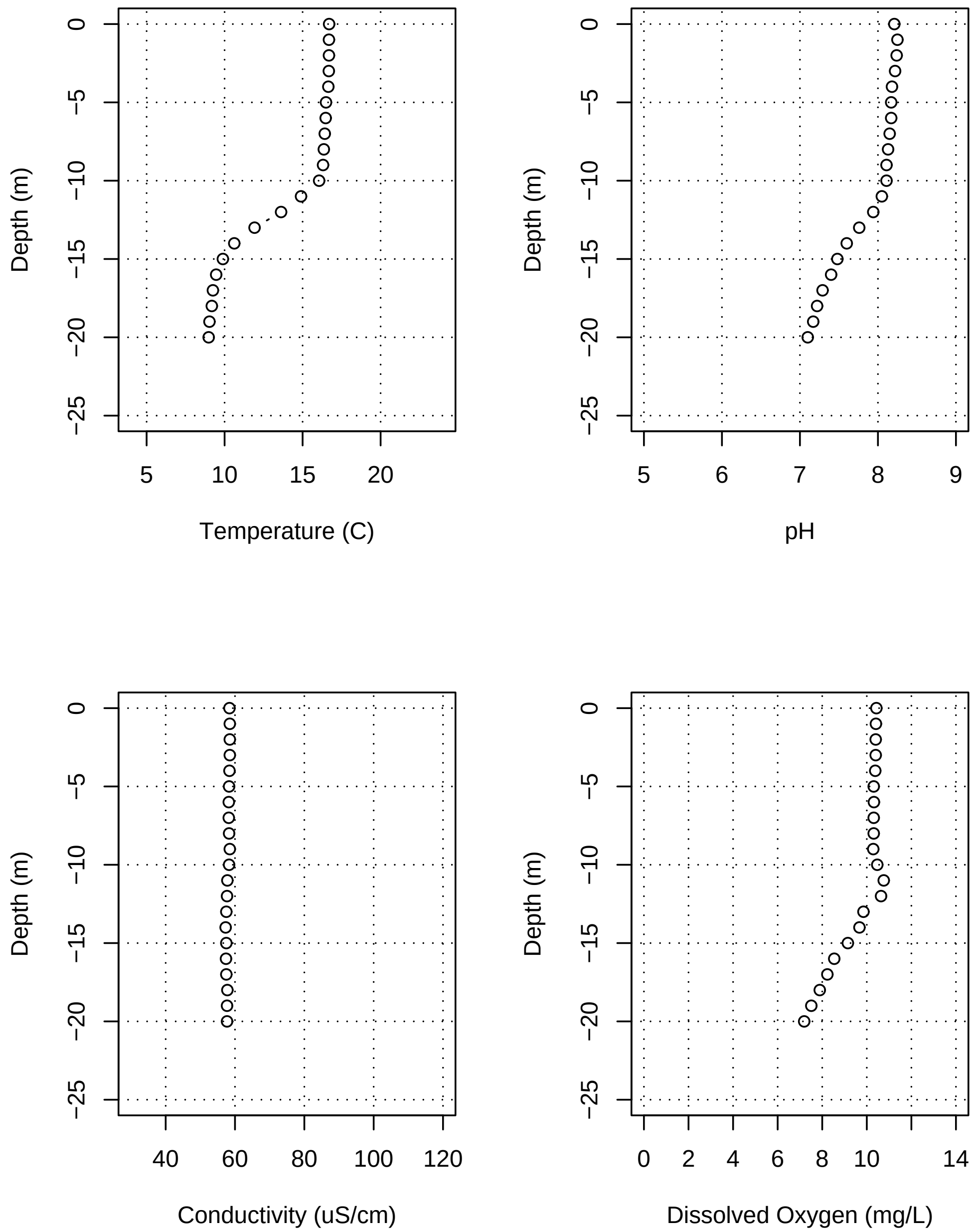


Figure B32: Lake Whatcom Hydrolab profile for Site 2, June 7, 2007.

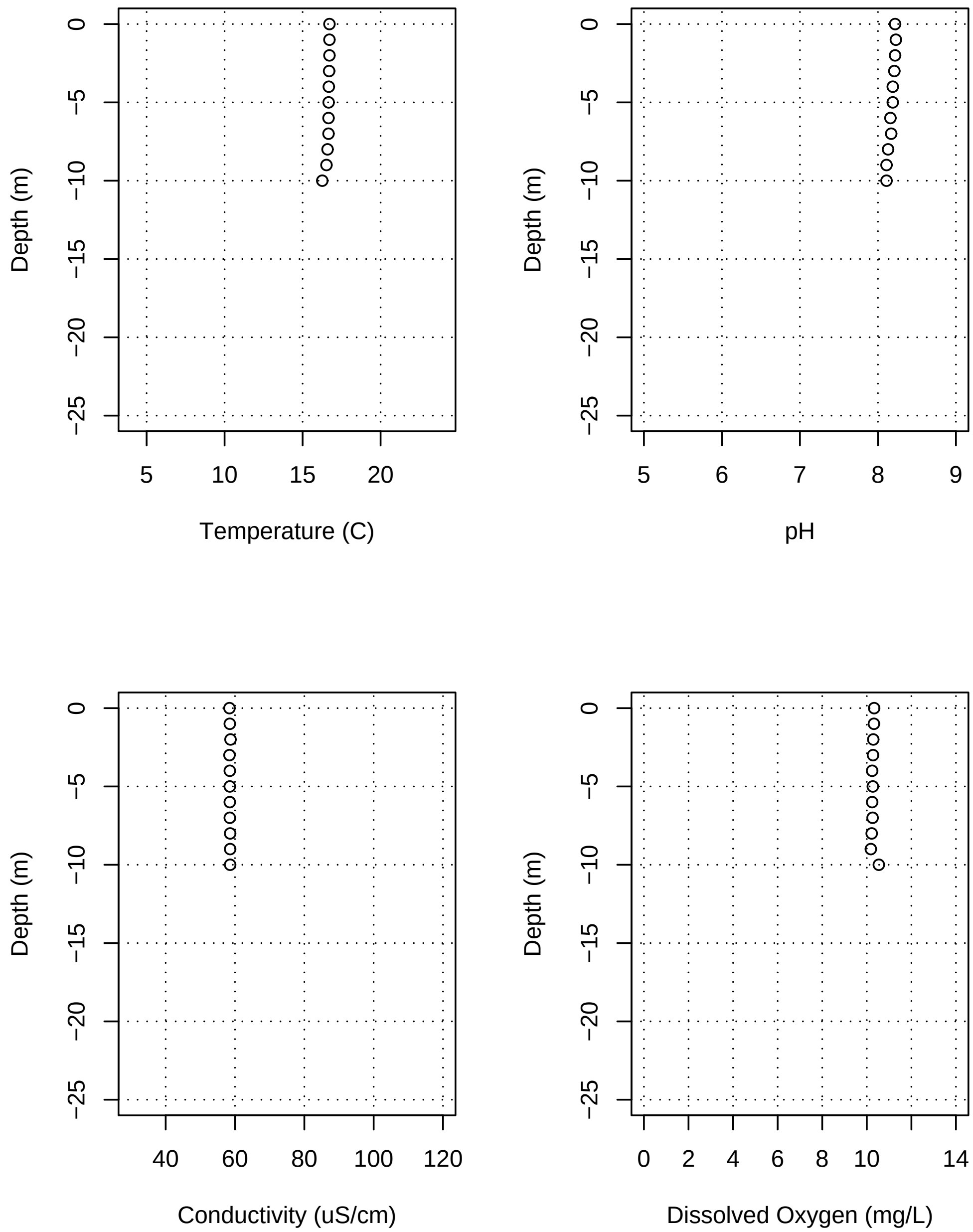


Figure B33: Lake Whatcom Hydrolab profile for the Intake, June 7, 2007.

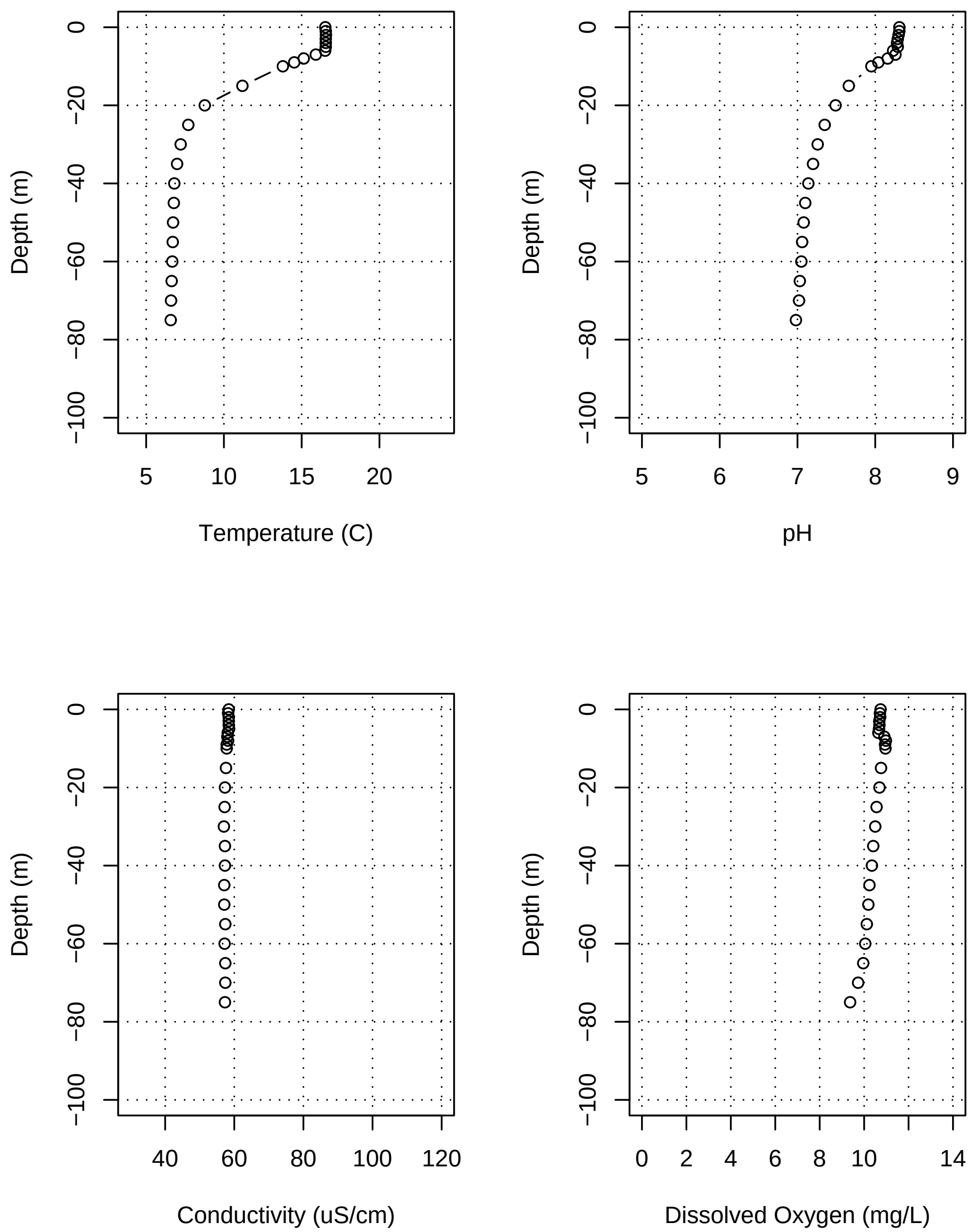


Figure B34: Lake Whatcom Hydrolab profile for Site 3, June 5, 2007. Data are not available at 65 m due to sampling error.

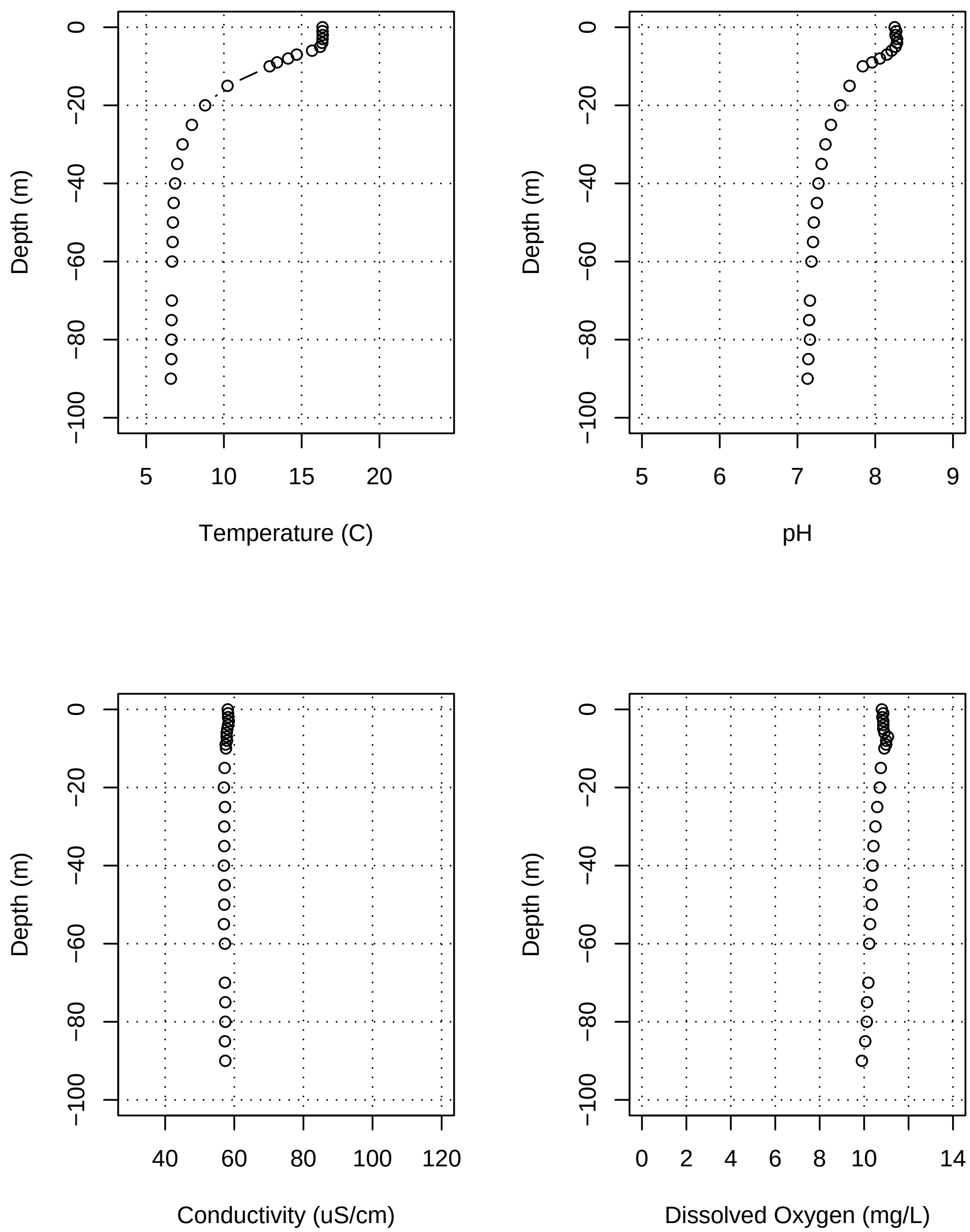


Figure B35: Lake Whatcom Hydrolab profile for Site 4, June 5, 2007. Data are not available at 65 m due to sampling error.

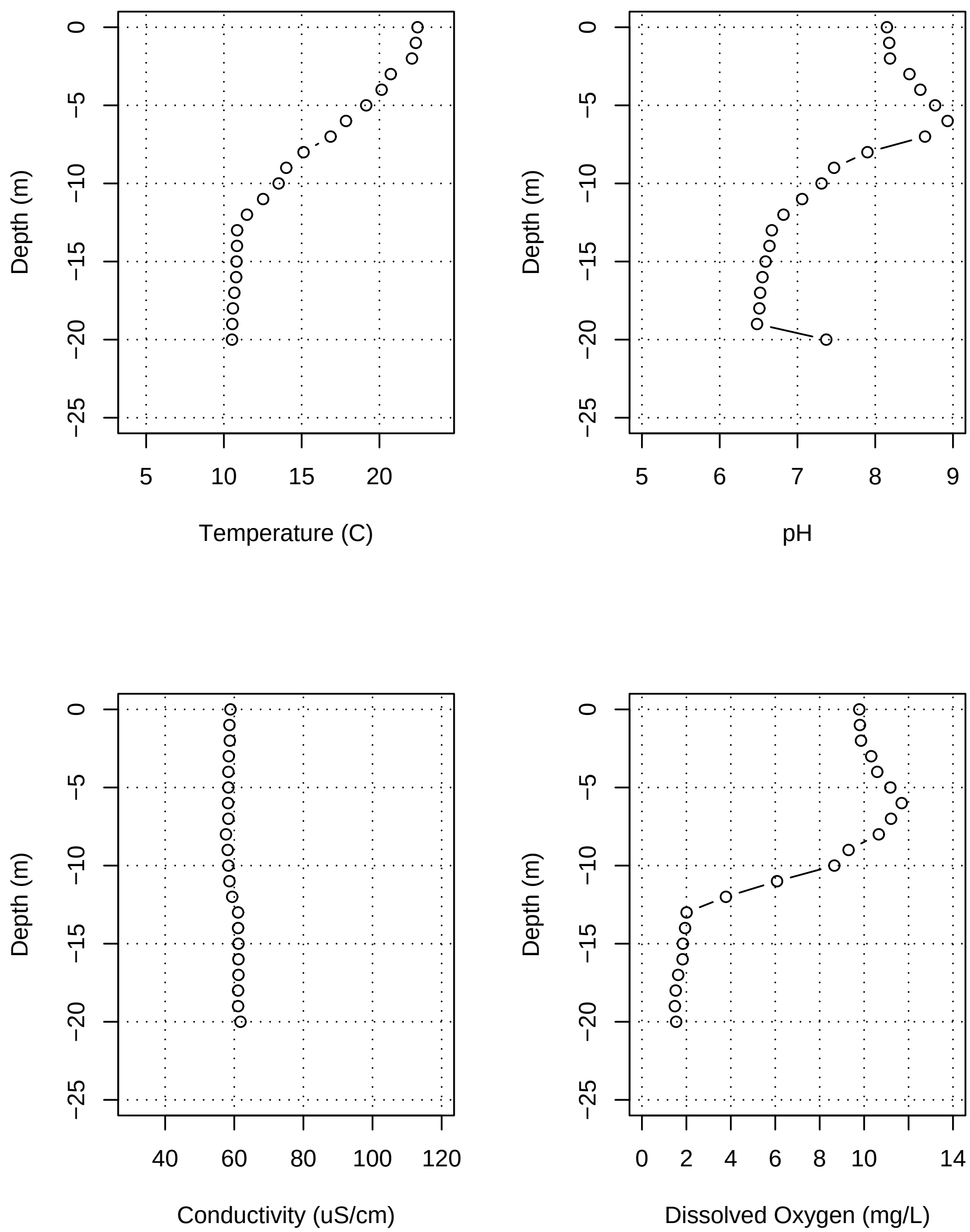


Figure B36: Lake Whatcom Hydrolab profile for Site 1, July 12, 2007. The high pH value measured at 20 meters has been verified; the cause of the unusual reading is not known, but could be from sediment contamination.

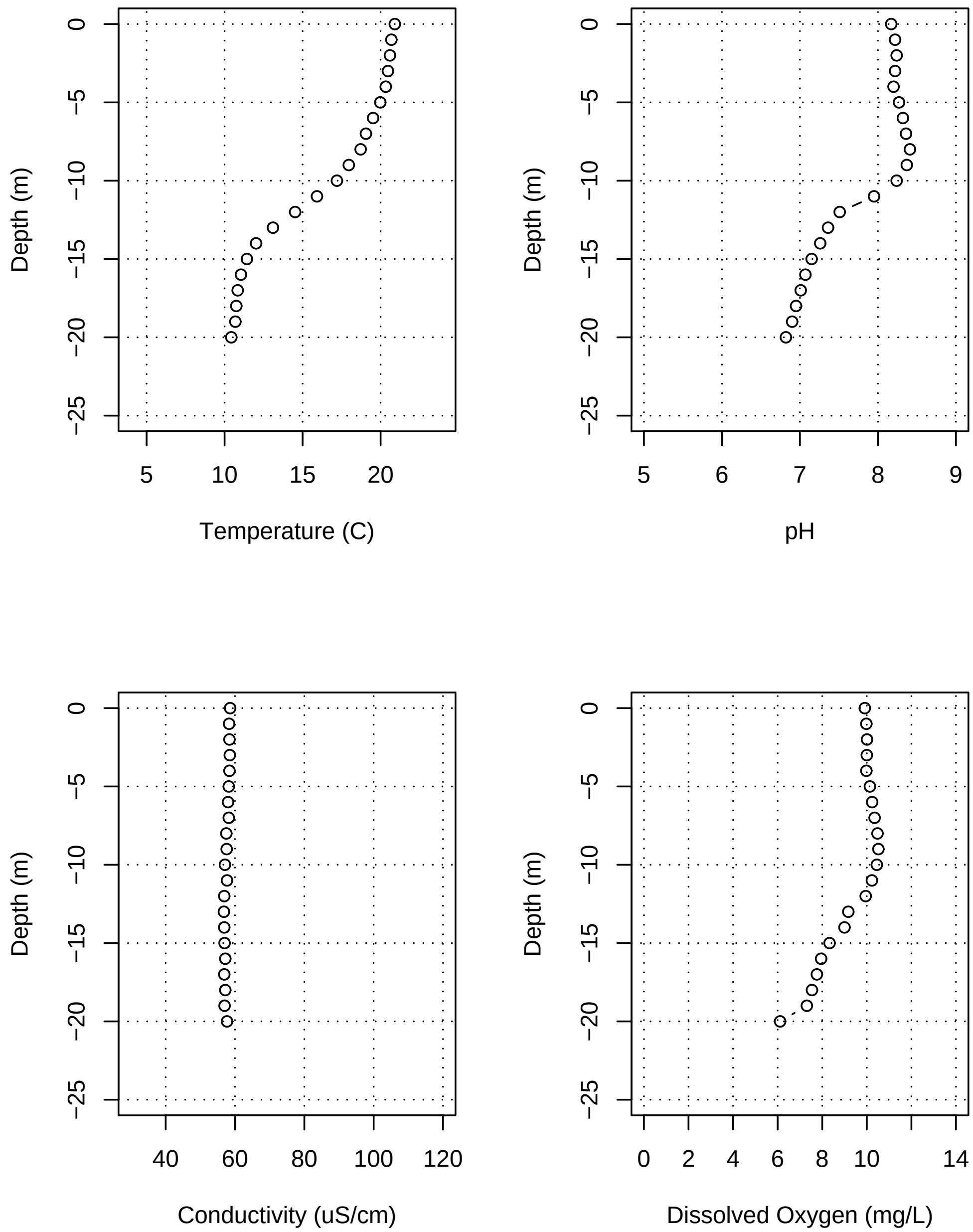


Figure B37: Lake Whatcom Hydrolab profile for Site 2, July 12, 2007.

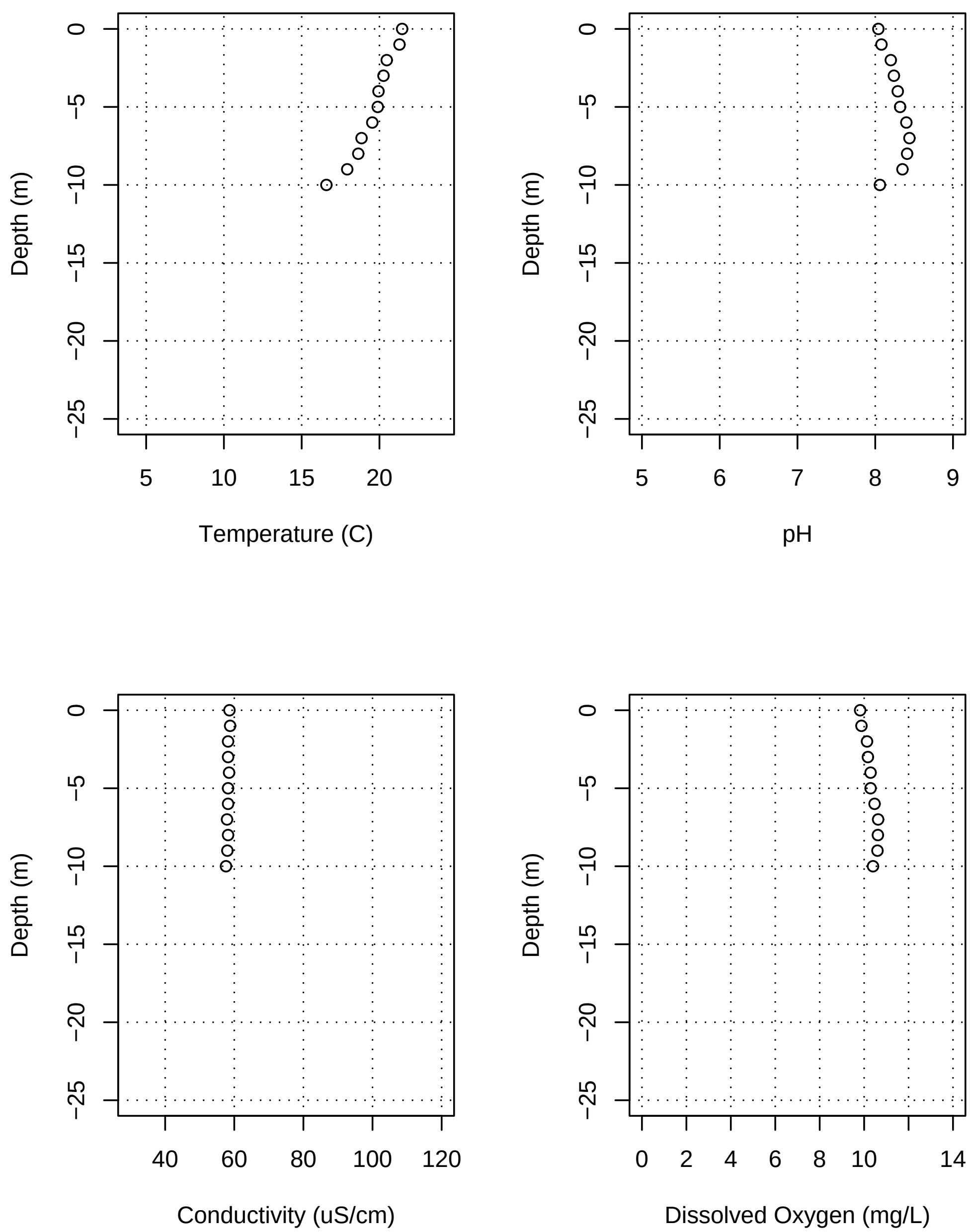


Figure B38: Lake Whatcom Hydrolab profile for the Intake, July 12, 2007.

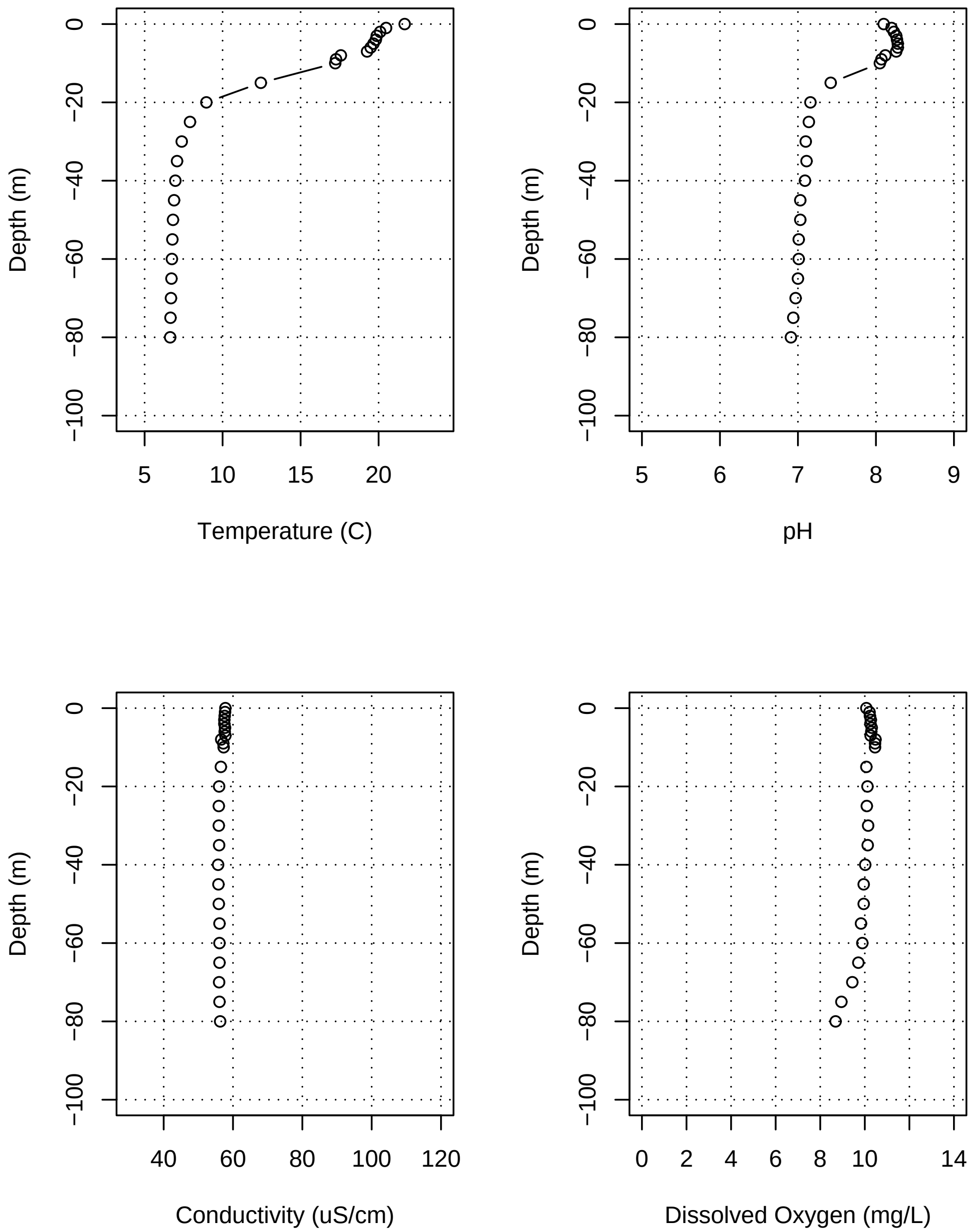


Figure B39: Lake Whatcom Hydrolab profile for Site 3, July 11, 2007.

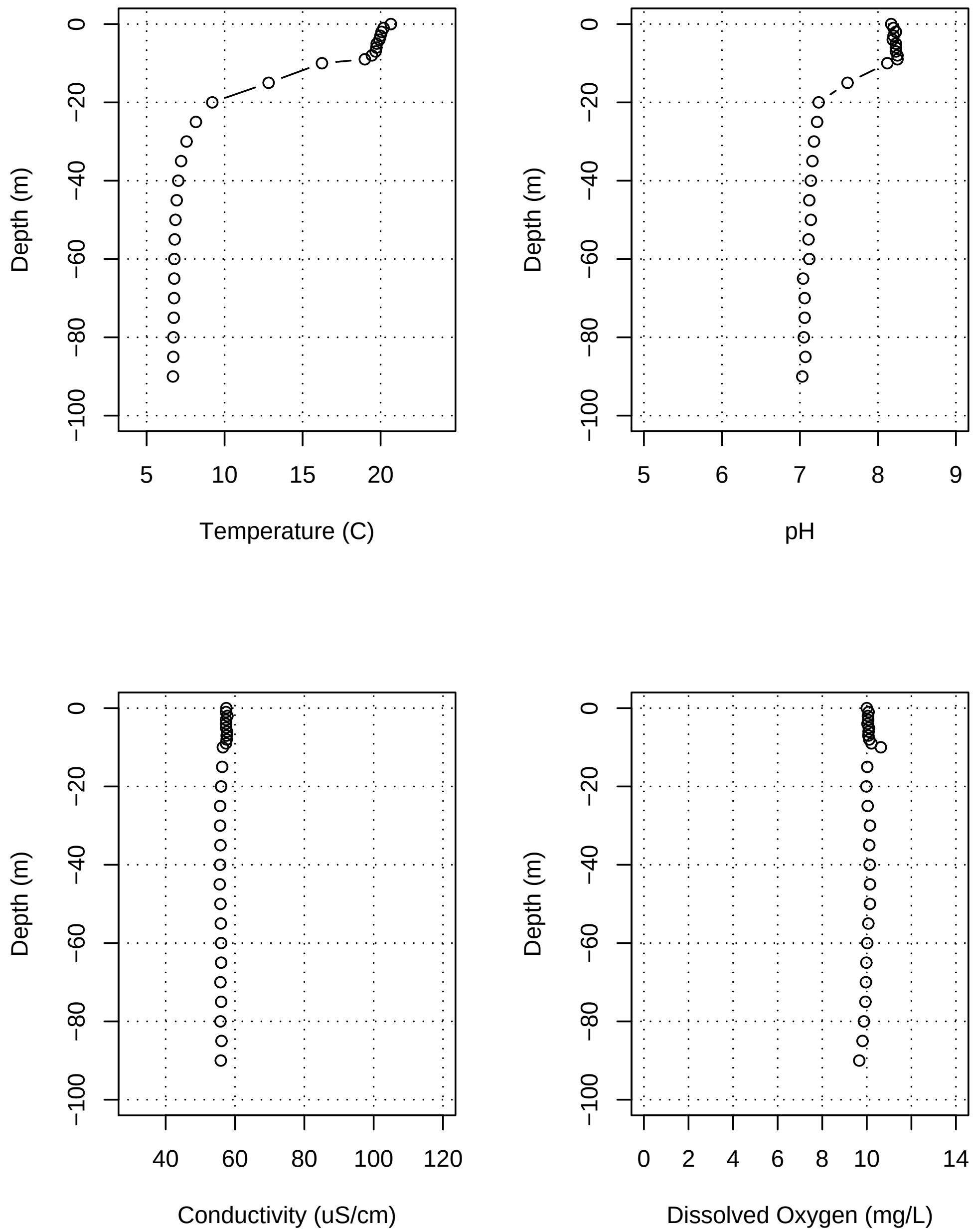


Figure B40: Lake Whatcom Hydrolab profile for Site 4, July 11, 2007.

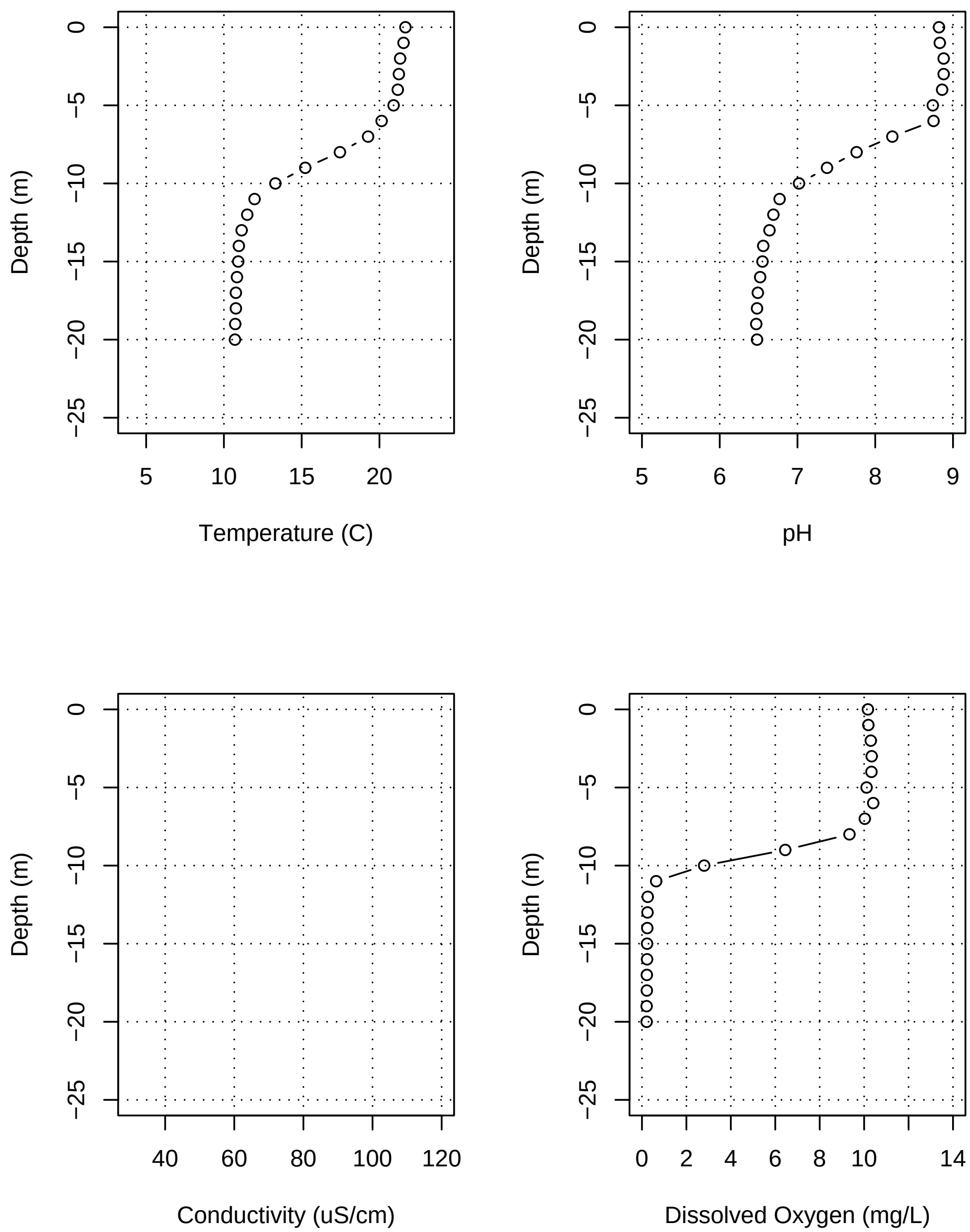


Figure B41: Lake Whatcom Hydrolab profile for Site 1, August 2, 2007. Conductivity data are missing due to equipment malfunction.

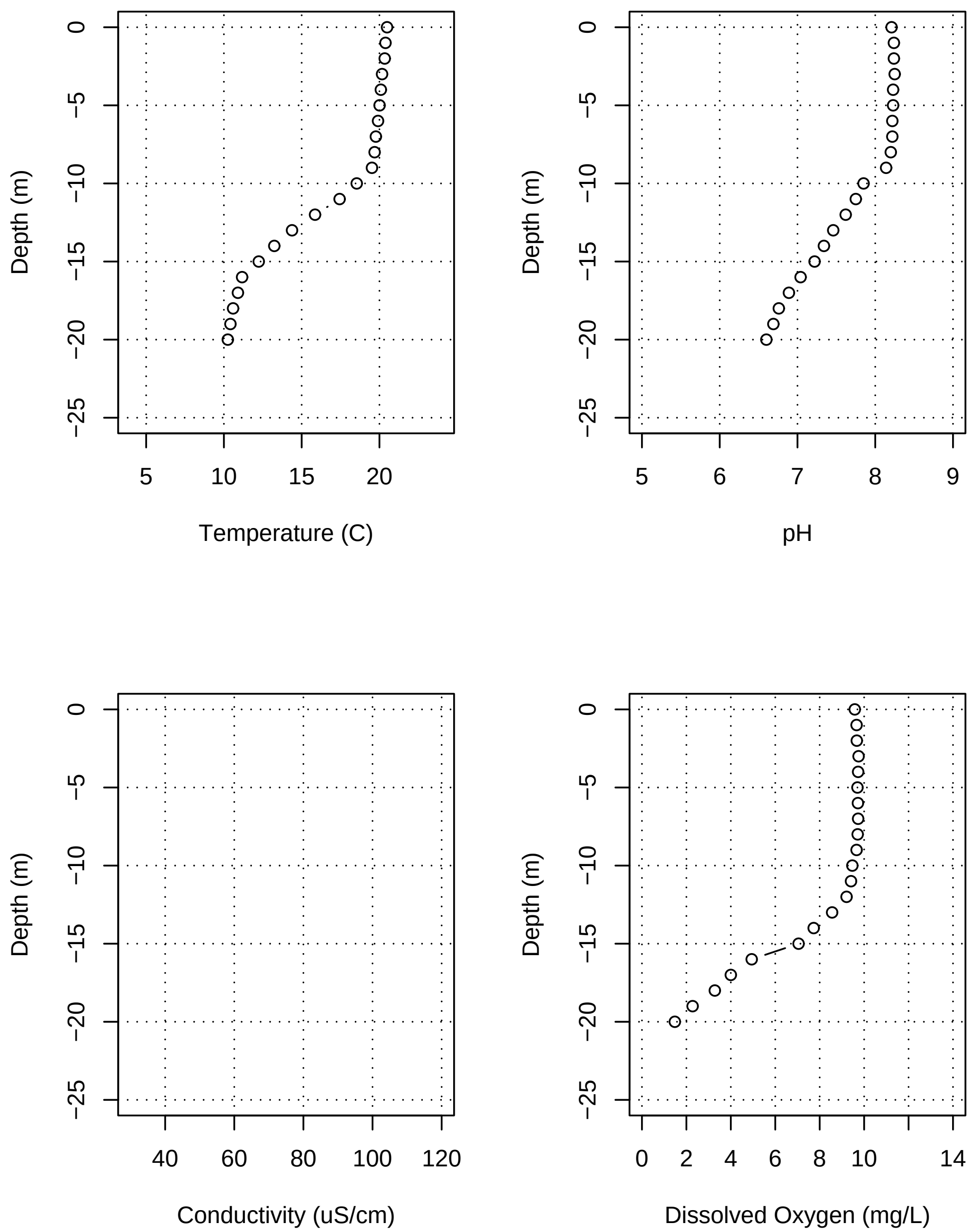


Figure B42: Lake Whatcom Hydrolab profile for Site 2, August 2, 2007. Conductivity data are missing due to equipment malfunction.

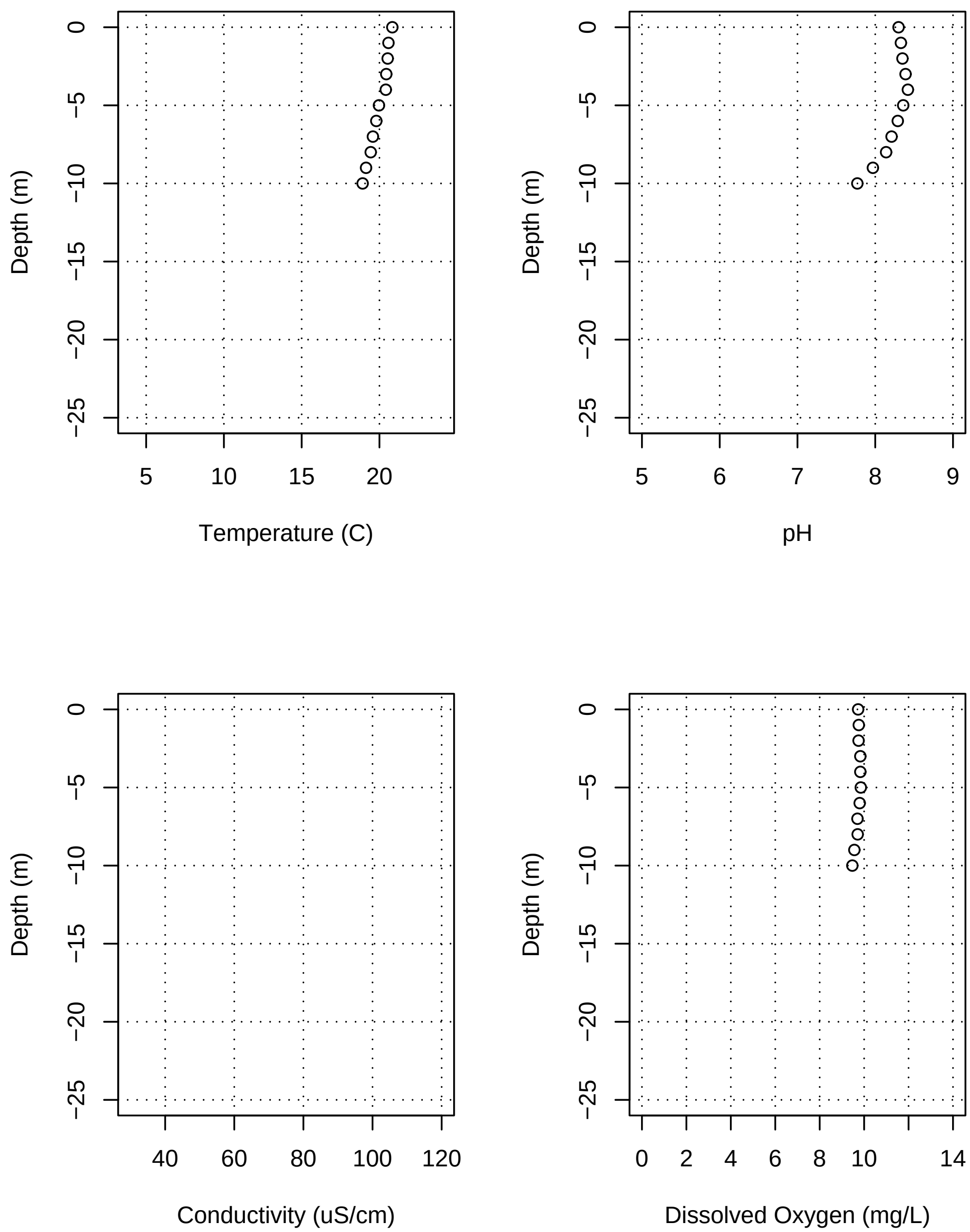


Figure B43: Lake Whatcom Hydrolab profile for the Intake, August 2, 2007. Conductivity data are missing due to equipment malfunction.

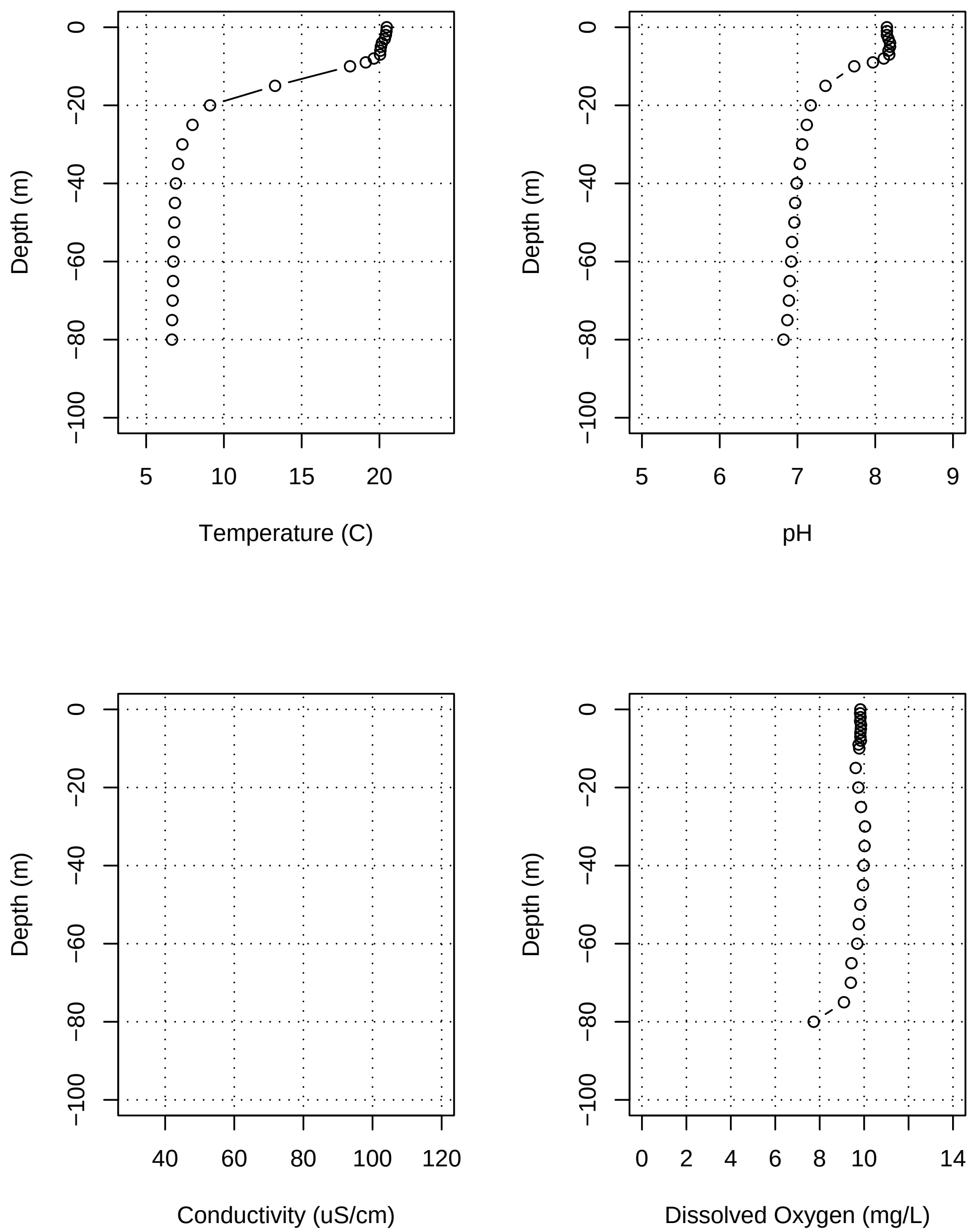


Figure B44: Lake Whatcom Hydrolab profile for Site 3, August 1, 2007. Conductivity data are missing due to equipment malfunction.

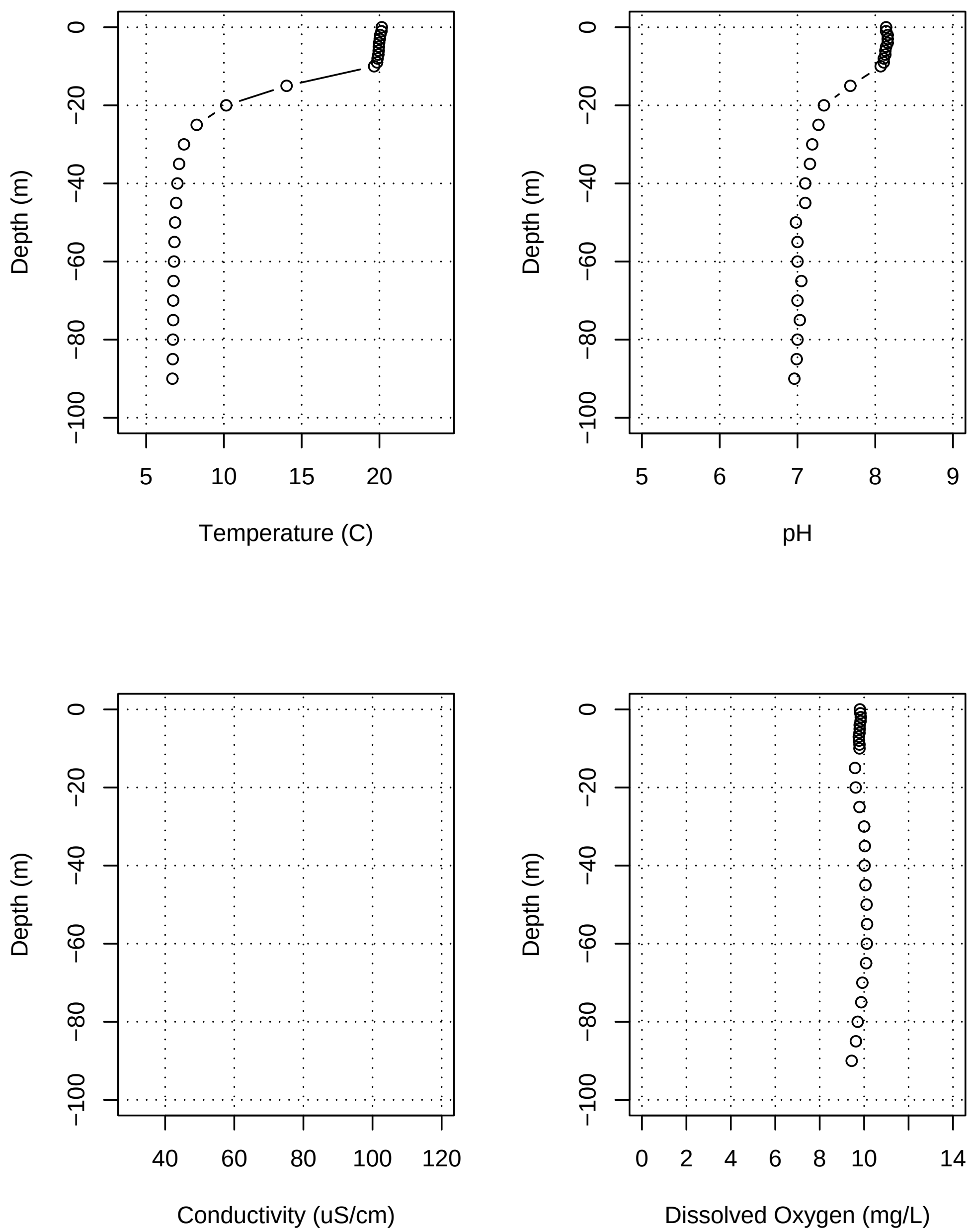


Figure B45: Lake Whatcom Hydrolab profile for Site 4, August 1, 2007. Conductivity data are missing due to equipment malfunction.

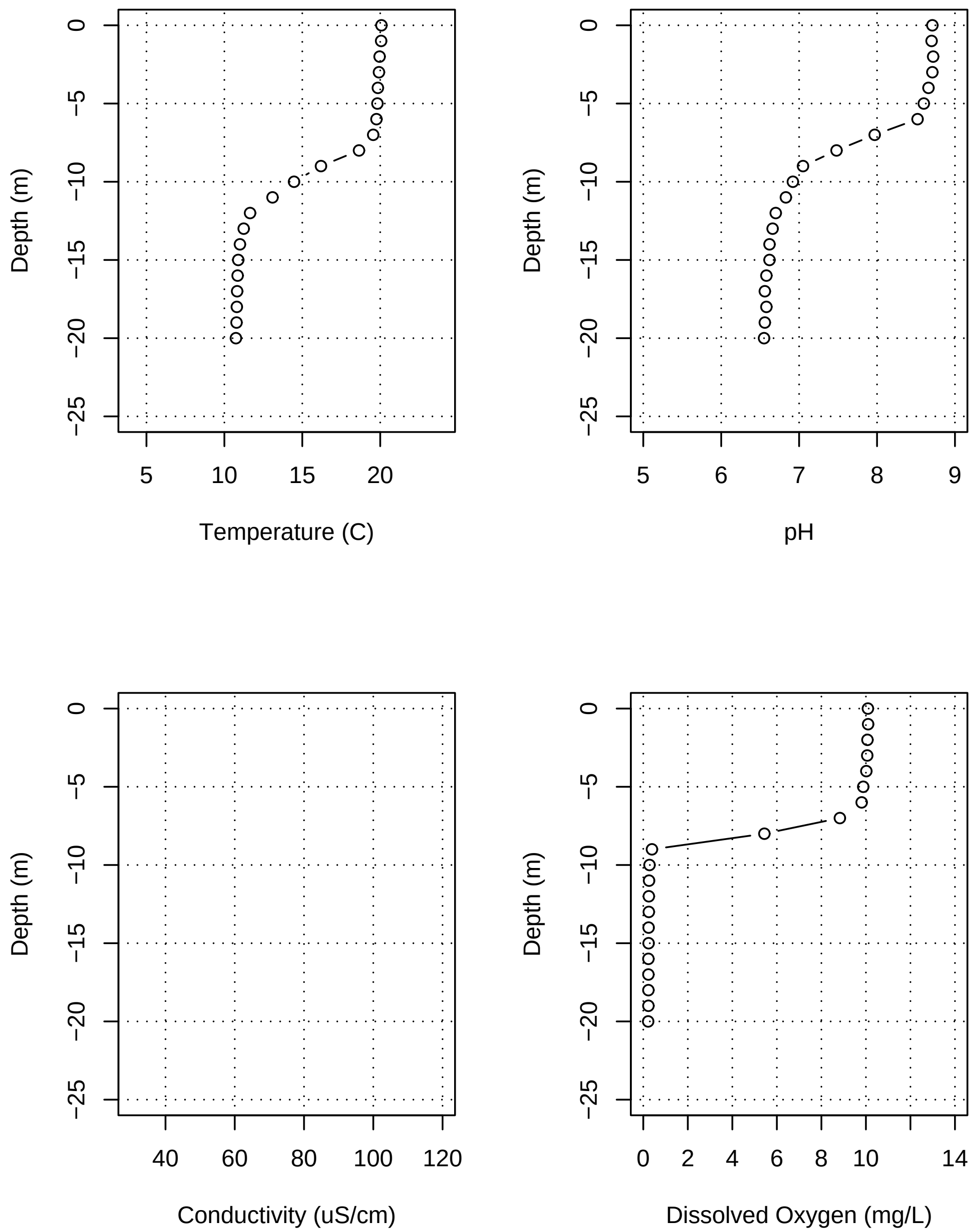


Figure B46: Lake Whatcom Hydrolab profile for Site 1, September 6, 2007. Conductivity data are missing due to equipment malfunction.

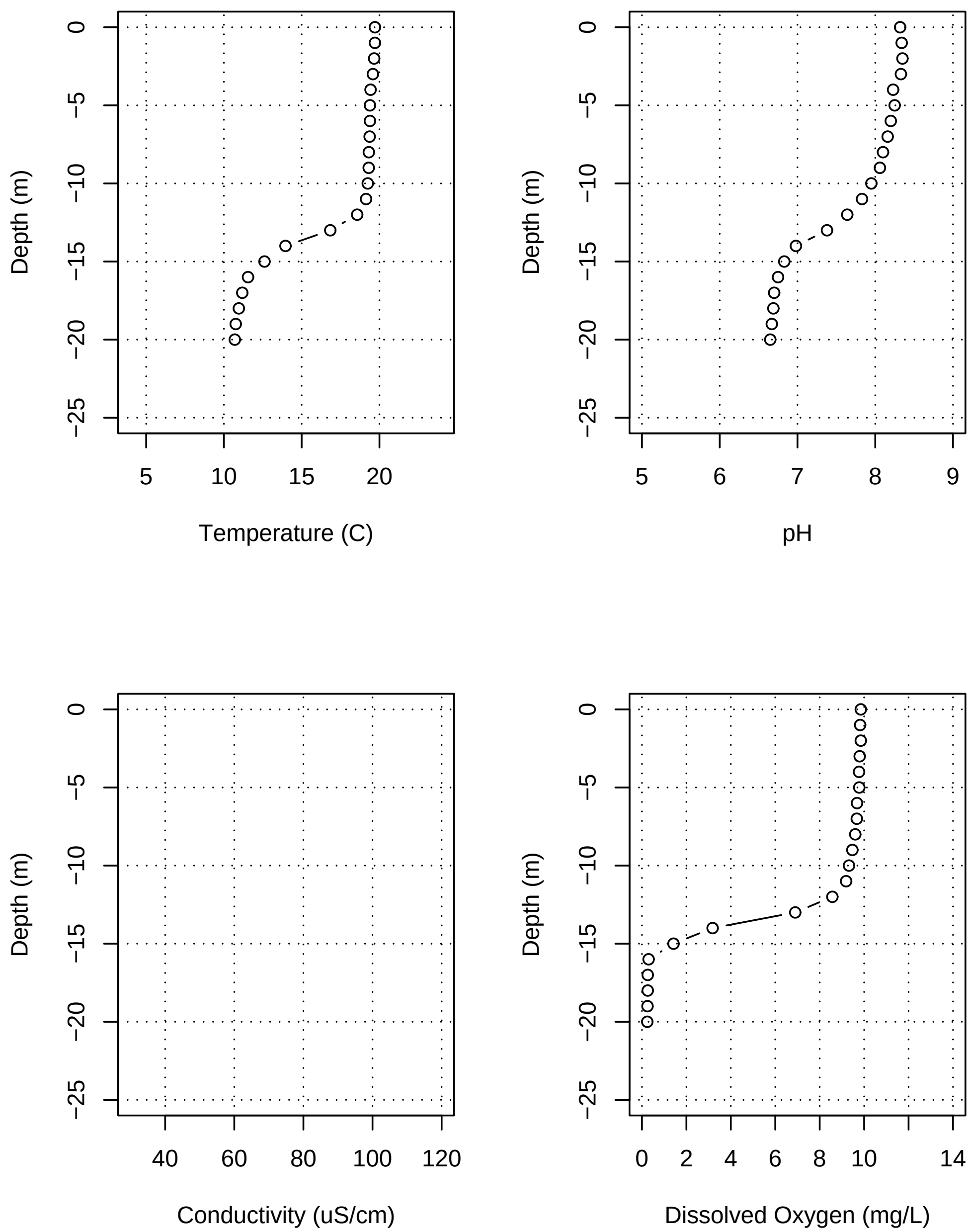


Figure B47: Lake Whatcom Hydrolab profile for Site 2, September 6, 2007. Conductivity data are missing due to equipment malfunction.

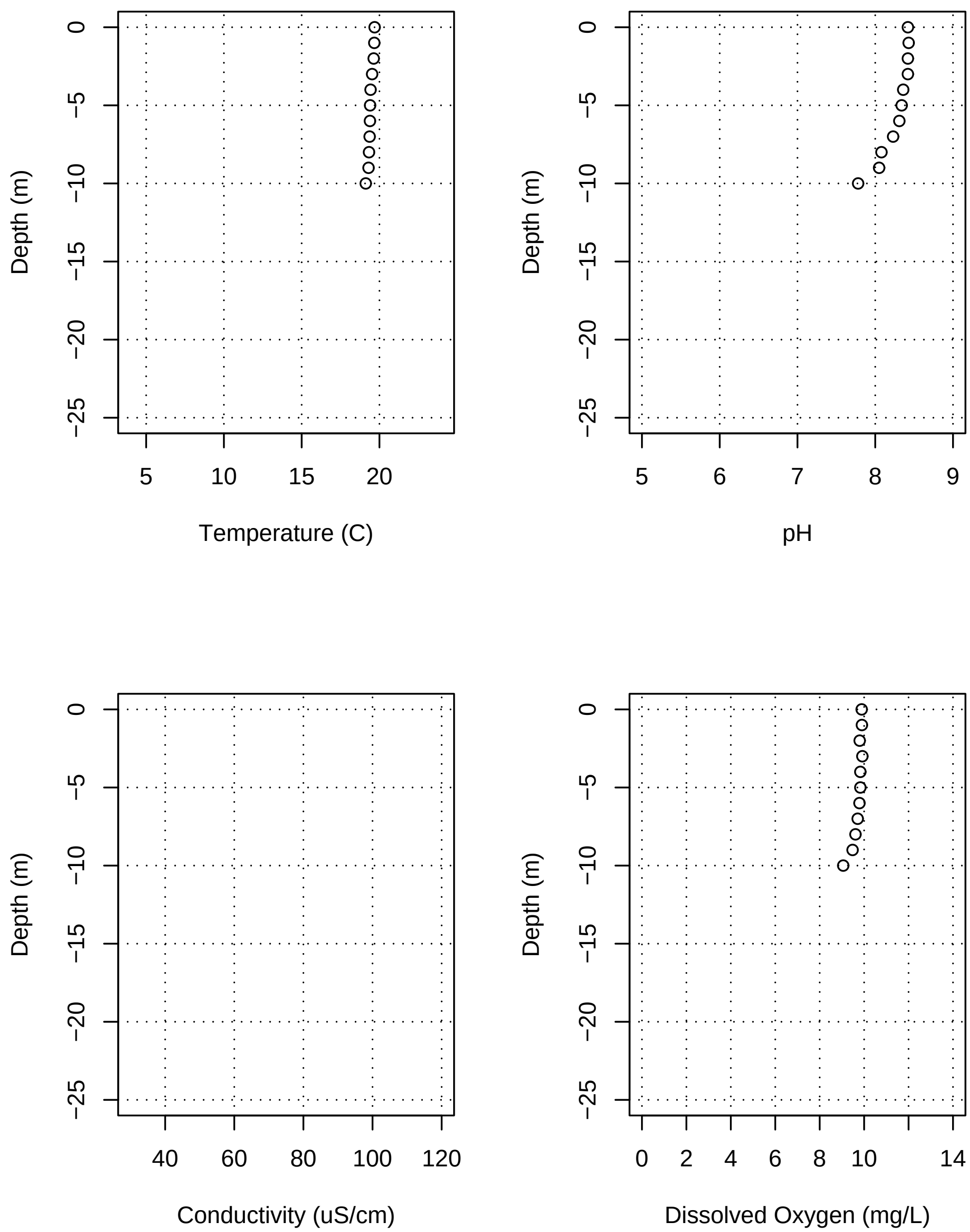


Figure B48: Lake Whatcom Hydrolab profile for the Intake, September 6, 2007. Conductivity data are missing due to equipment malfunction.

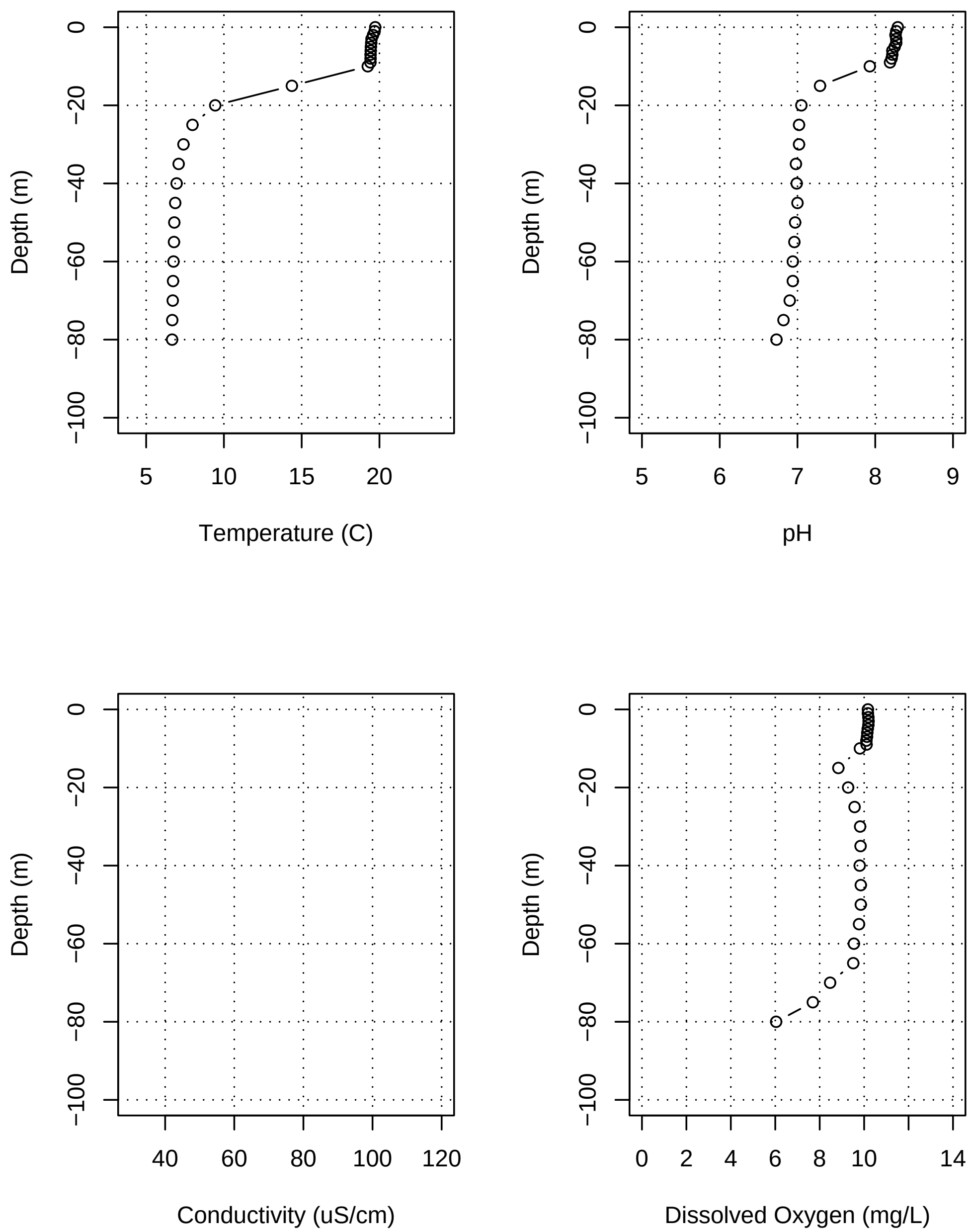


Figure B49: Lake Whatcom Hydrolab profile for Site 3, September 5, 2007. Conductivity data are missing due to equipment malfunction.

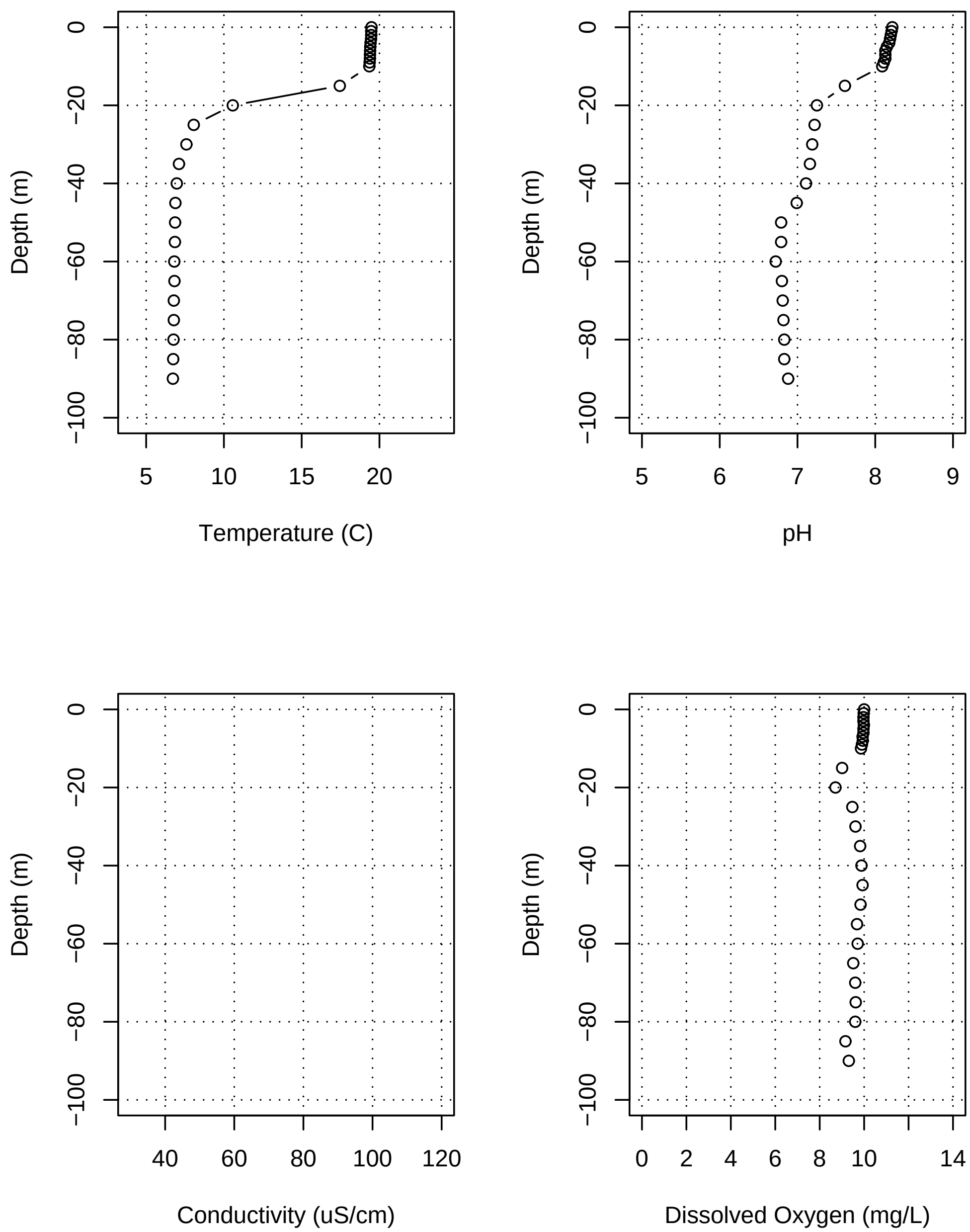


Figure B50: Lake Whatcom Hydrolab profile for Site 4, September 5, 2007. Conductivity data are missing due to equipment malfunction.

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

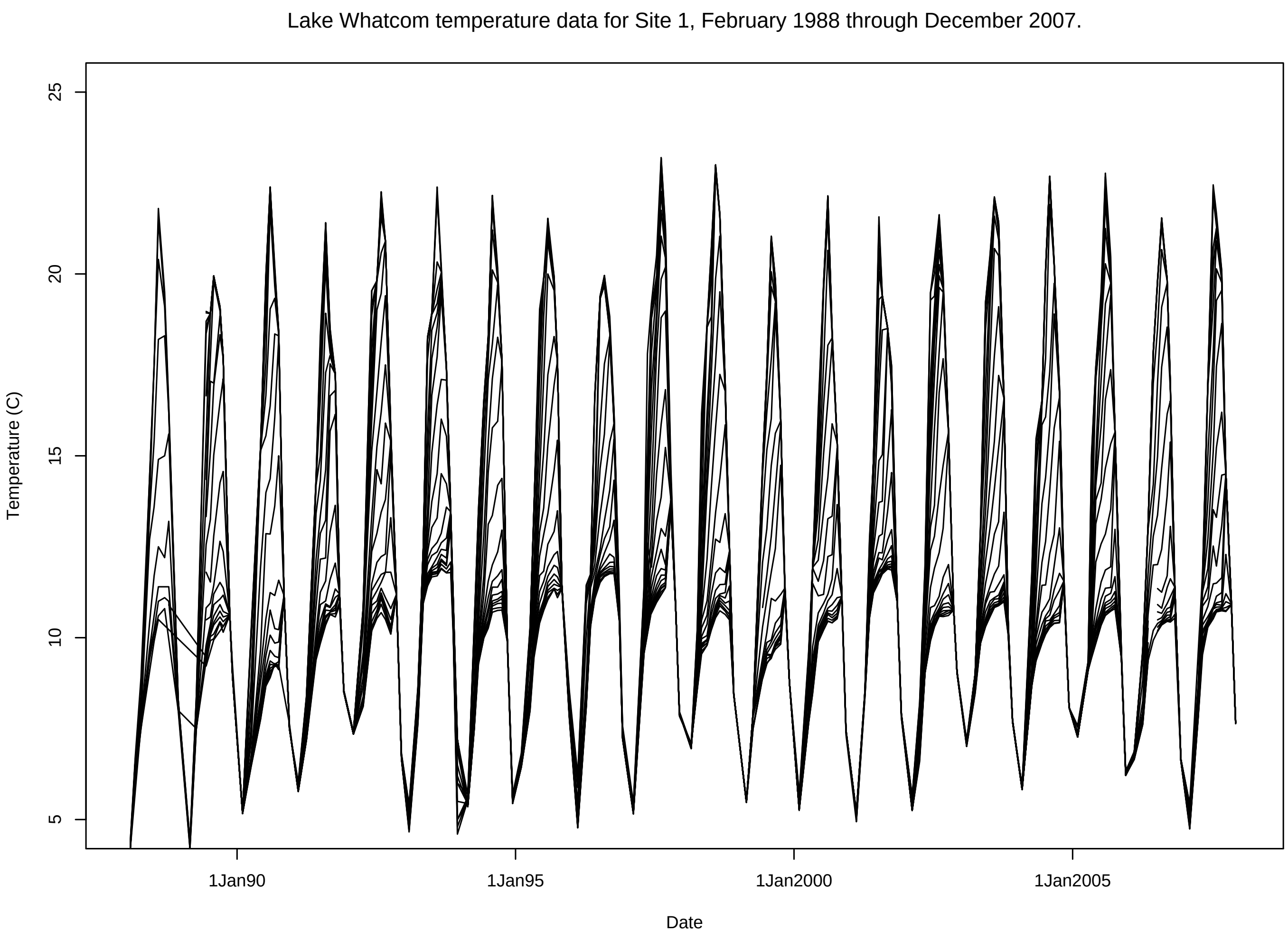


Figure B51: Lake Whatcom historic temperature data for Site 1.

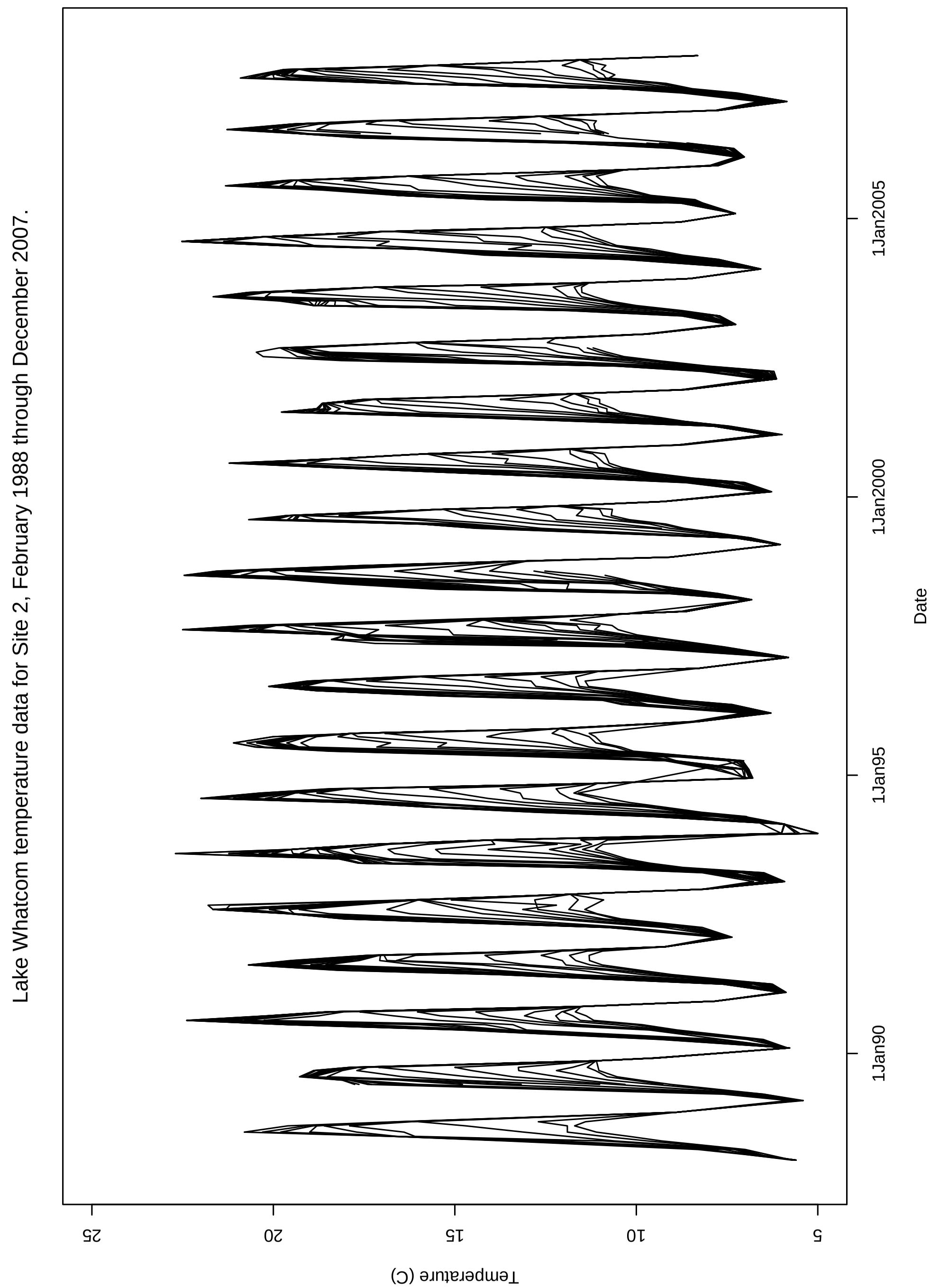


Figure B52: Lake Whatcom historic temperature data for Site 2.

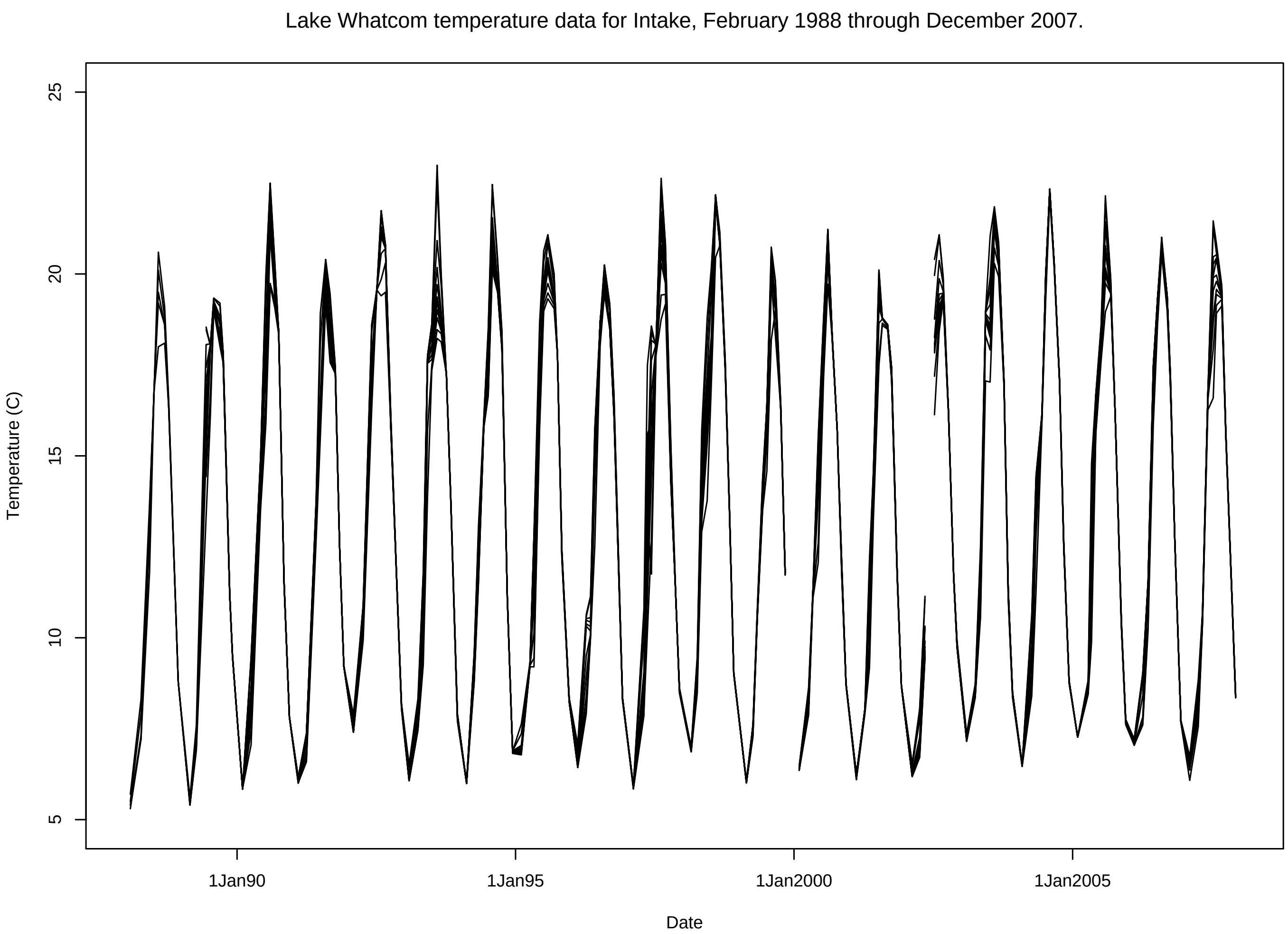


Figure B53: Lake Whatcom historic temperature data for the Intake.

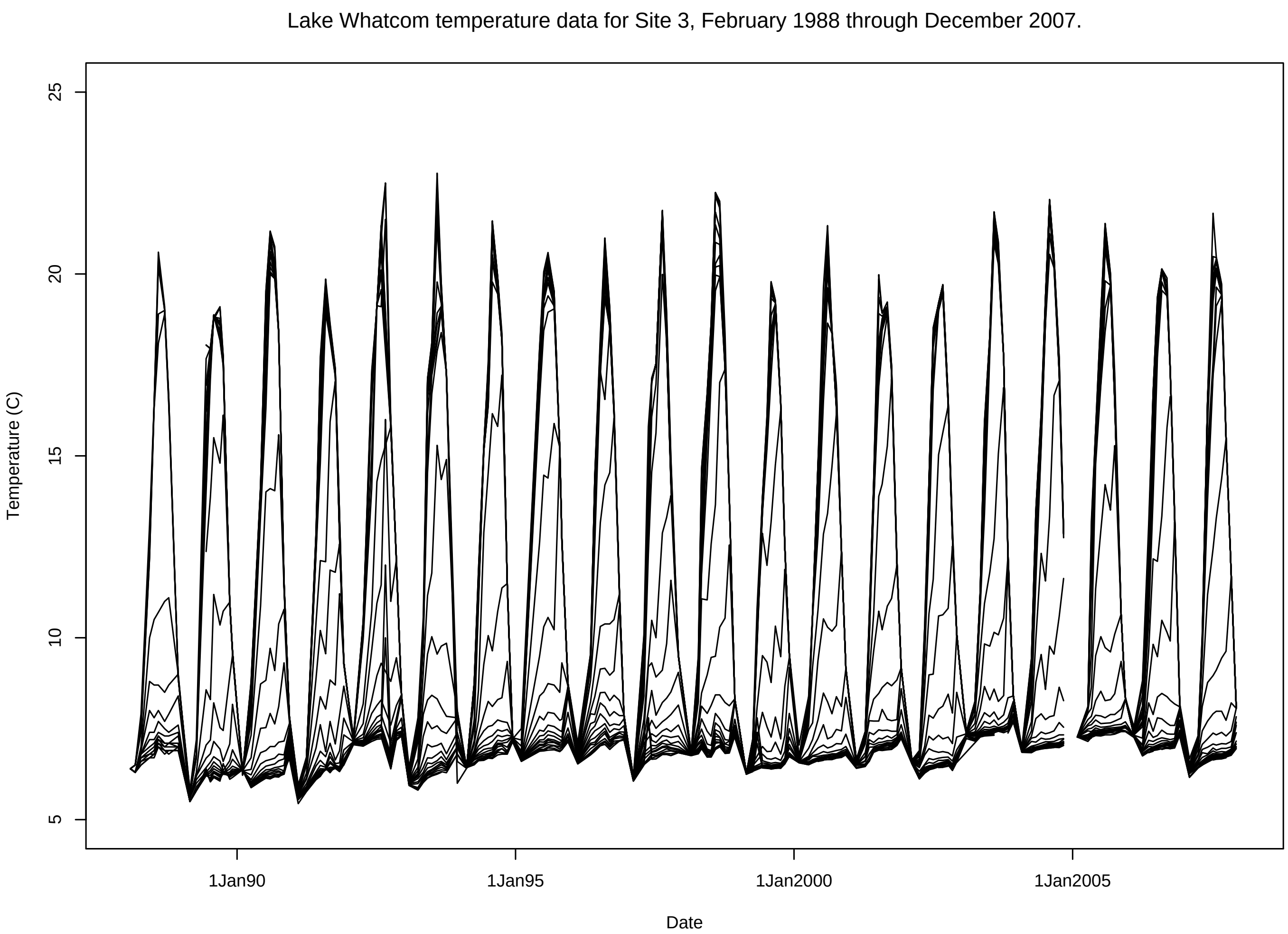


Figure B54: Lake Whatcom historic temperature data for Site 3.

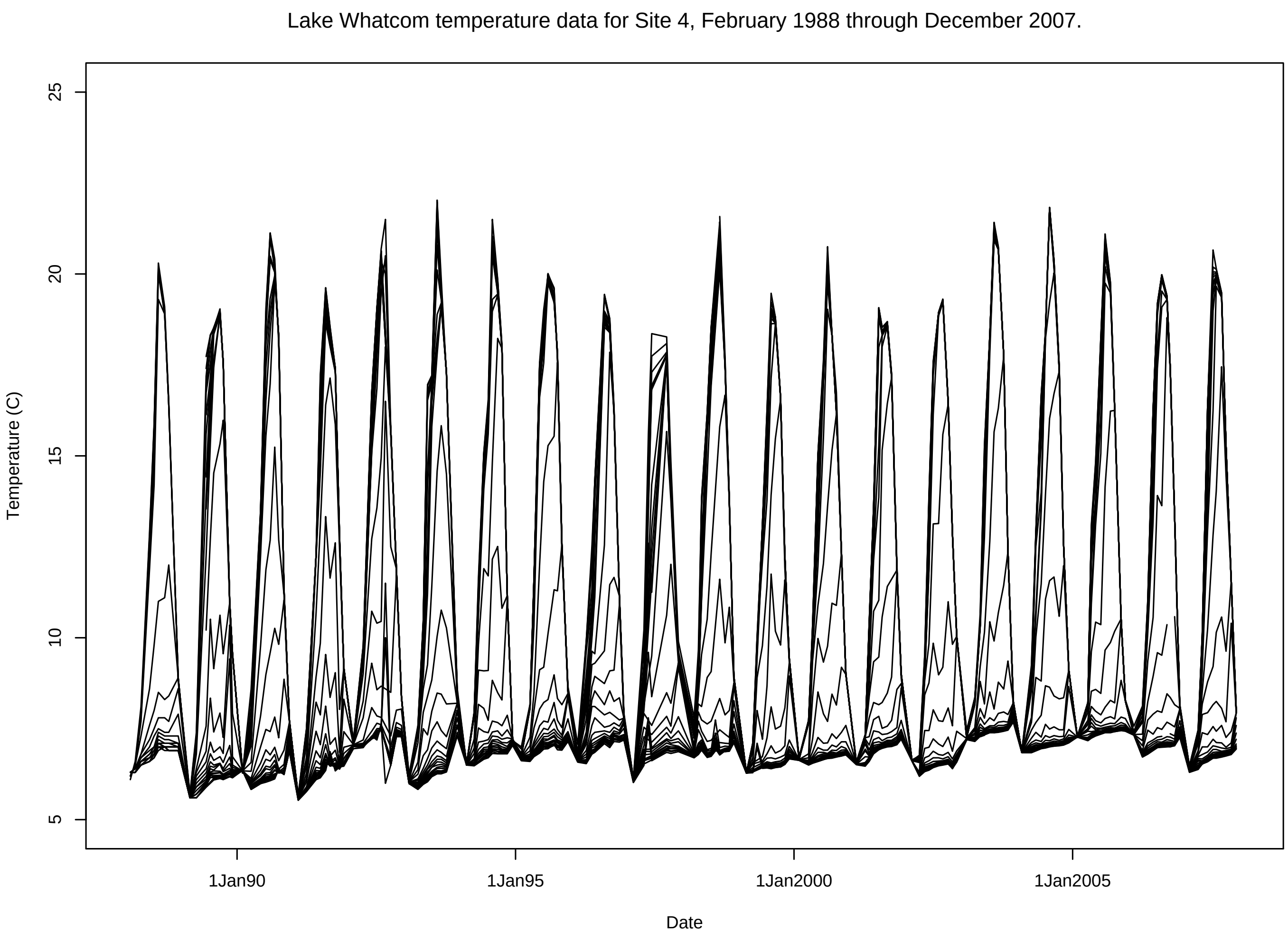


Figure B55: Lake Whatcom historic temperature data for Site 4.

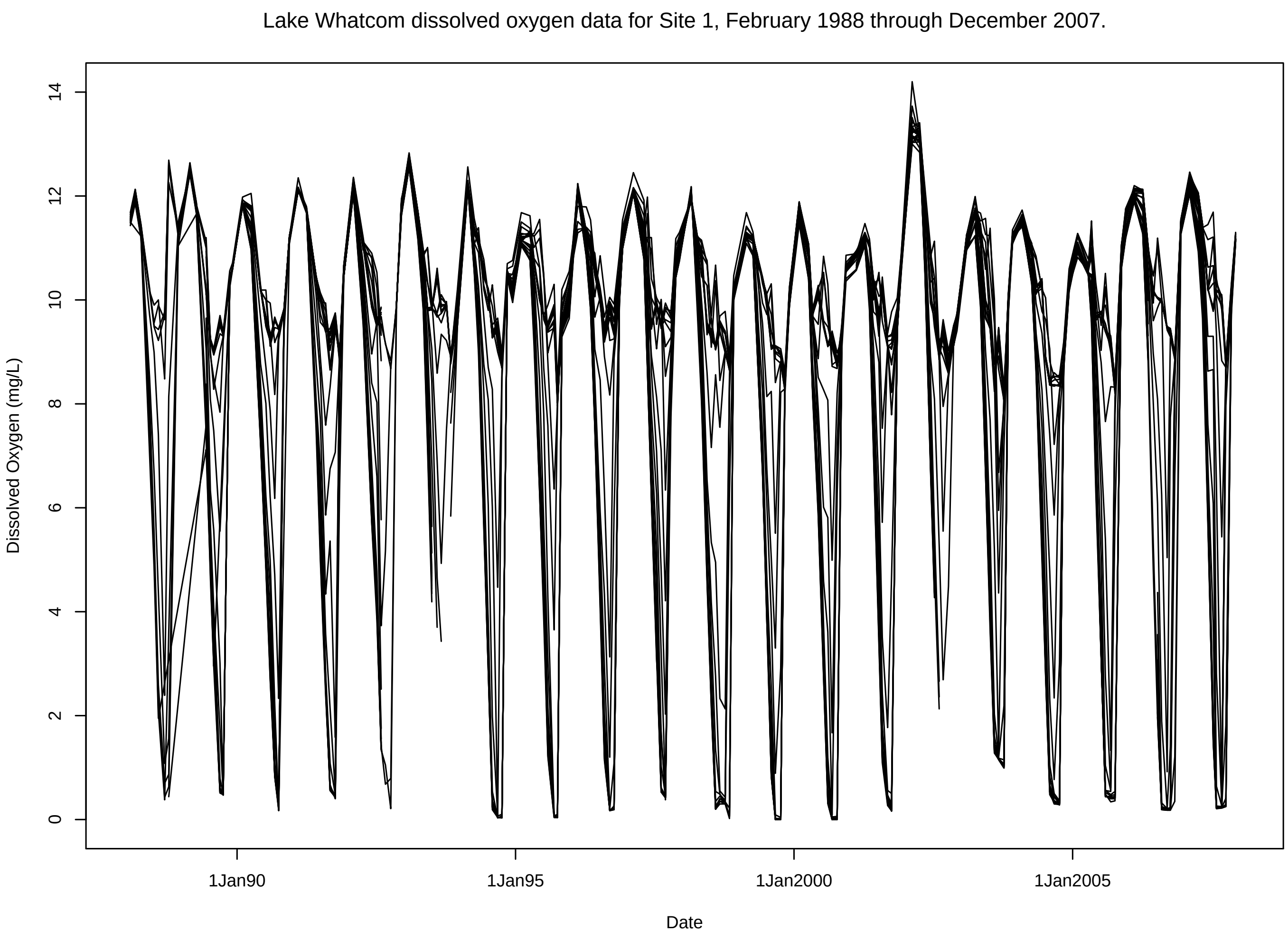


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

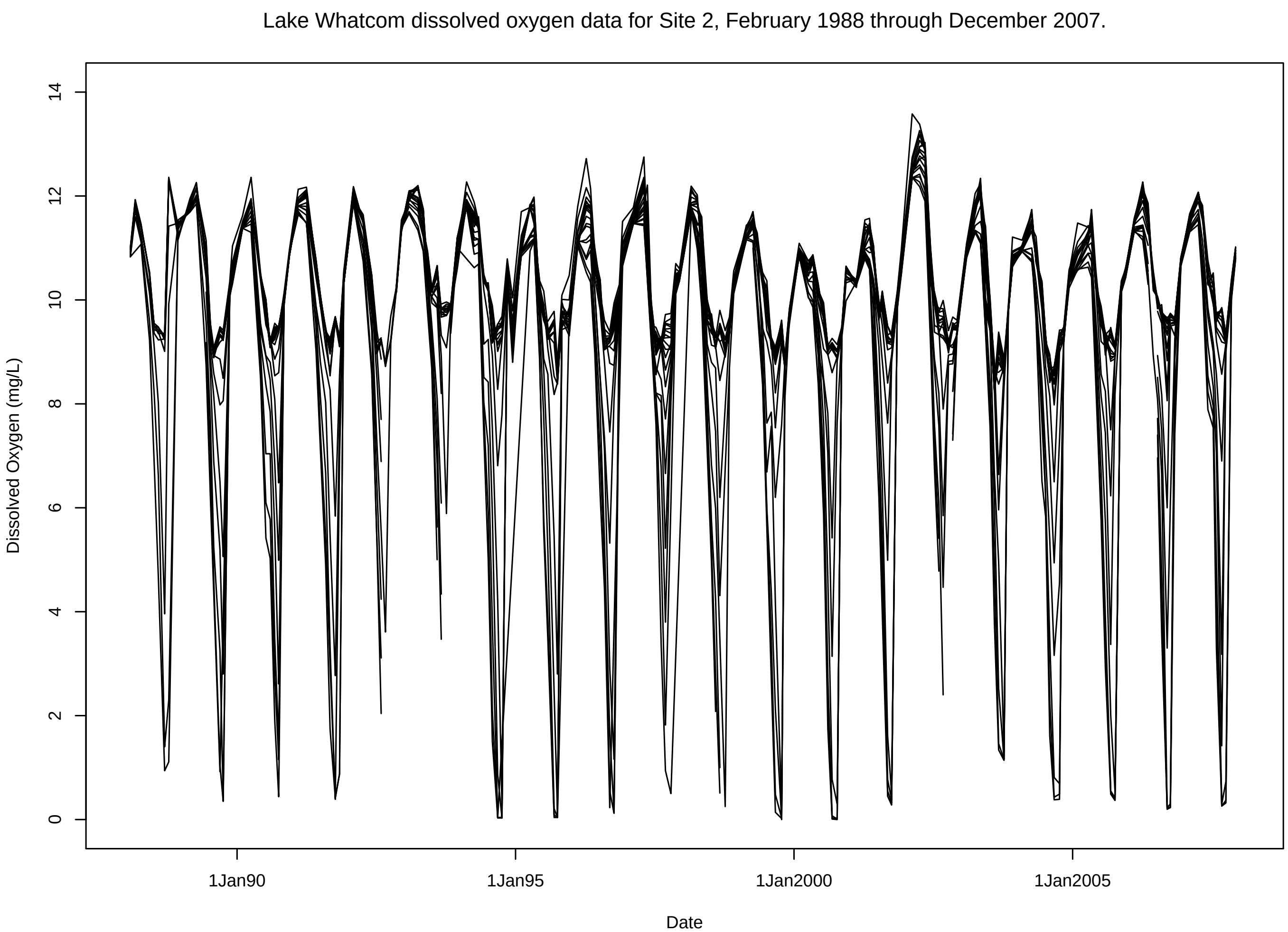


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

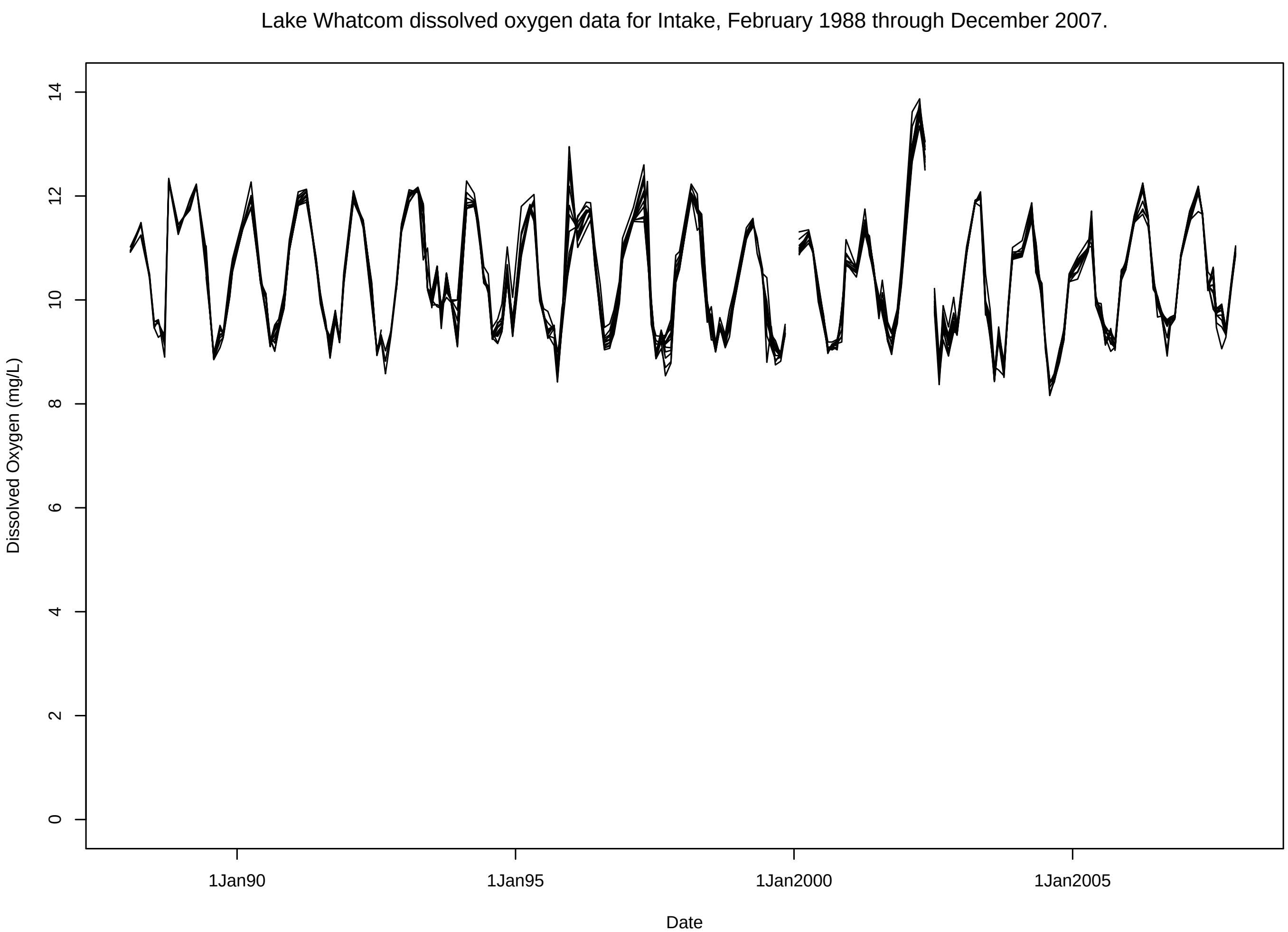


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake.

Lake Whatcom dissolved oxygen data for Site 3, February 1988 through December 2007.

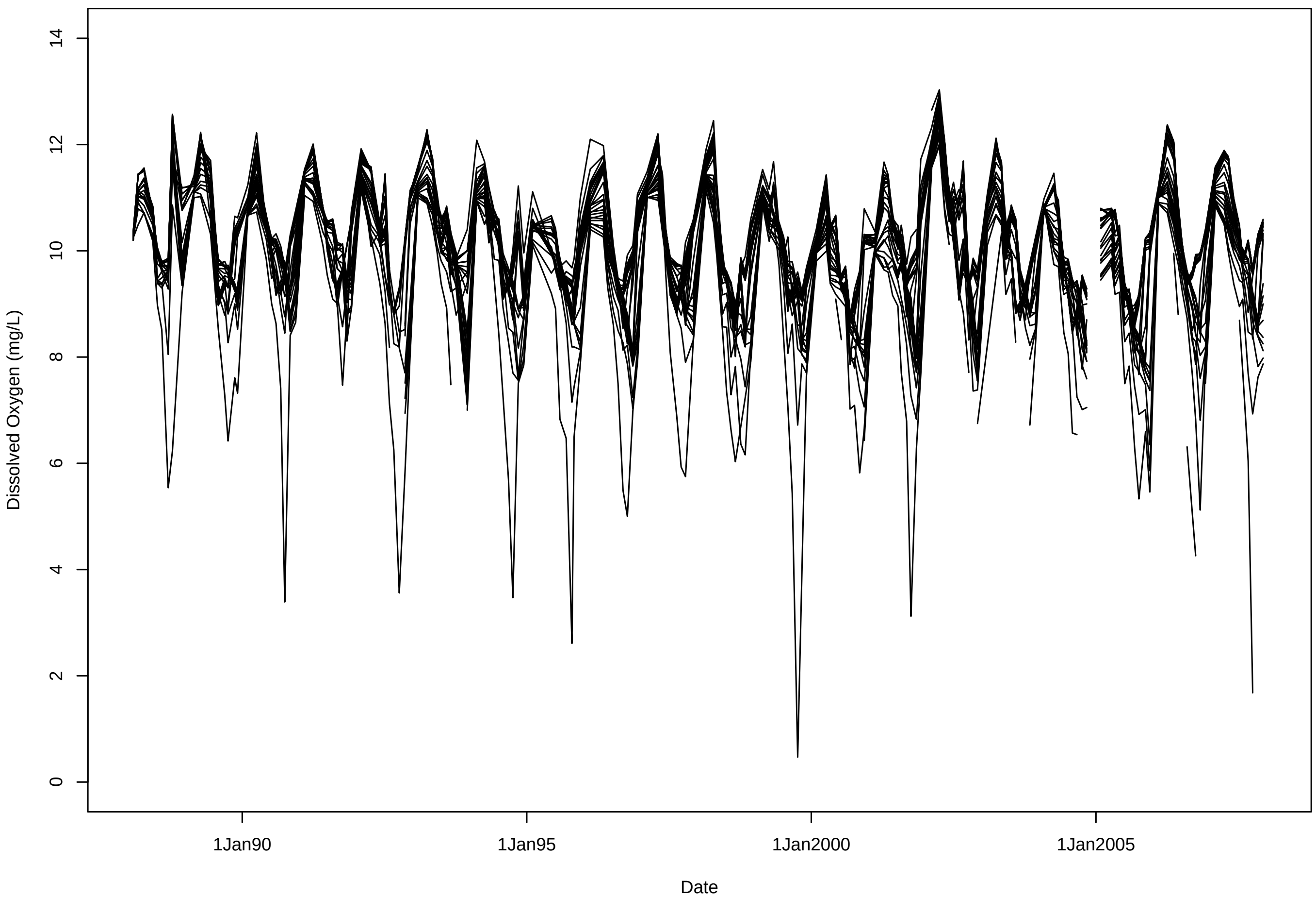


Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.

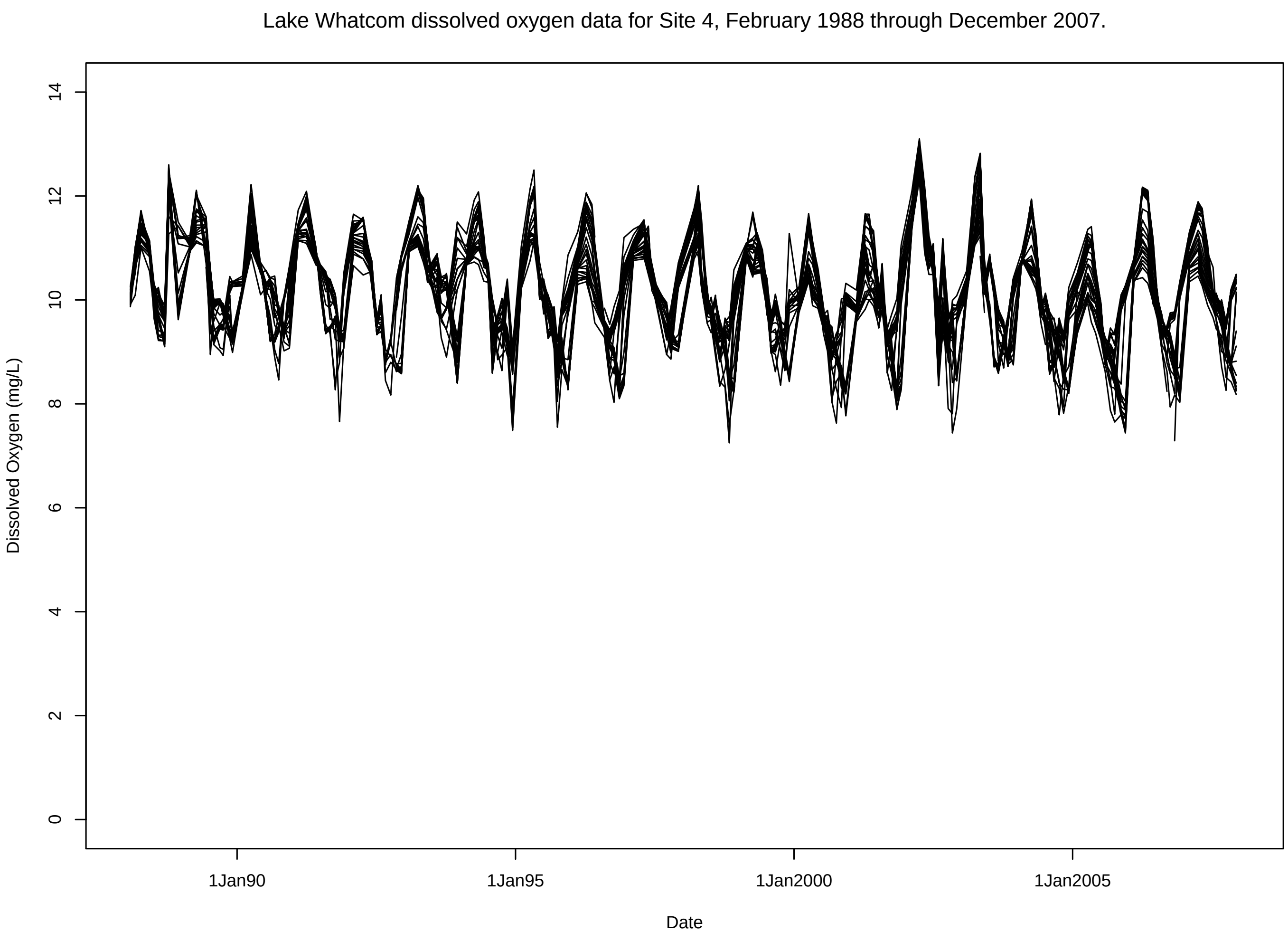


Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

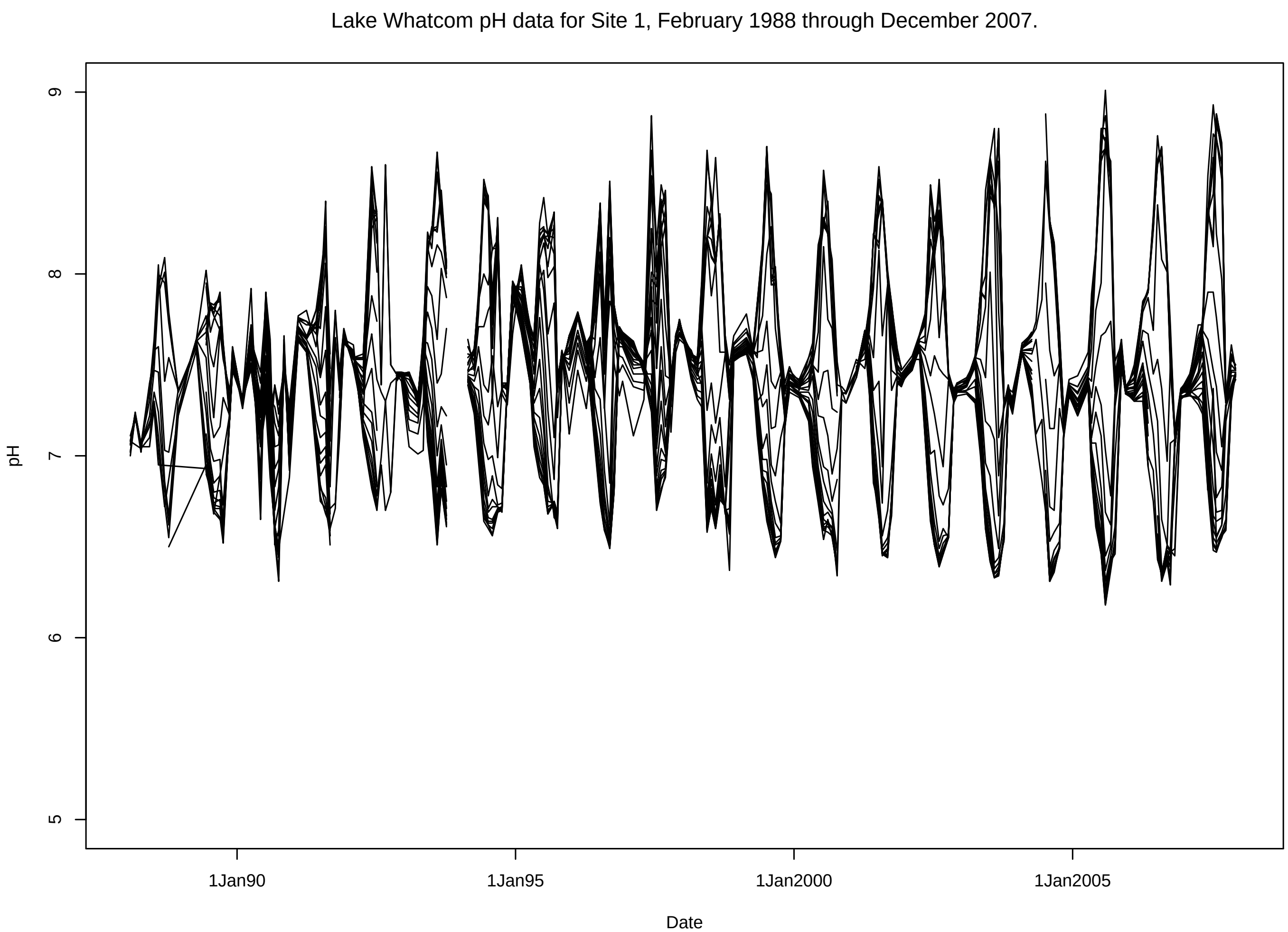


Figure B61: Lake Whatcom historic pH data for Site 1.

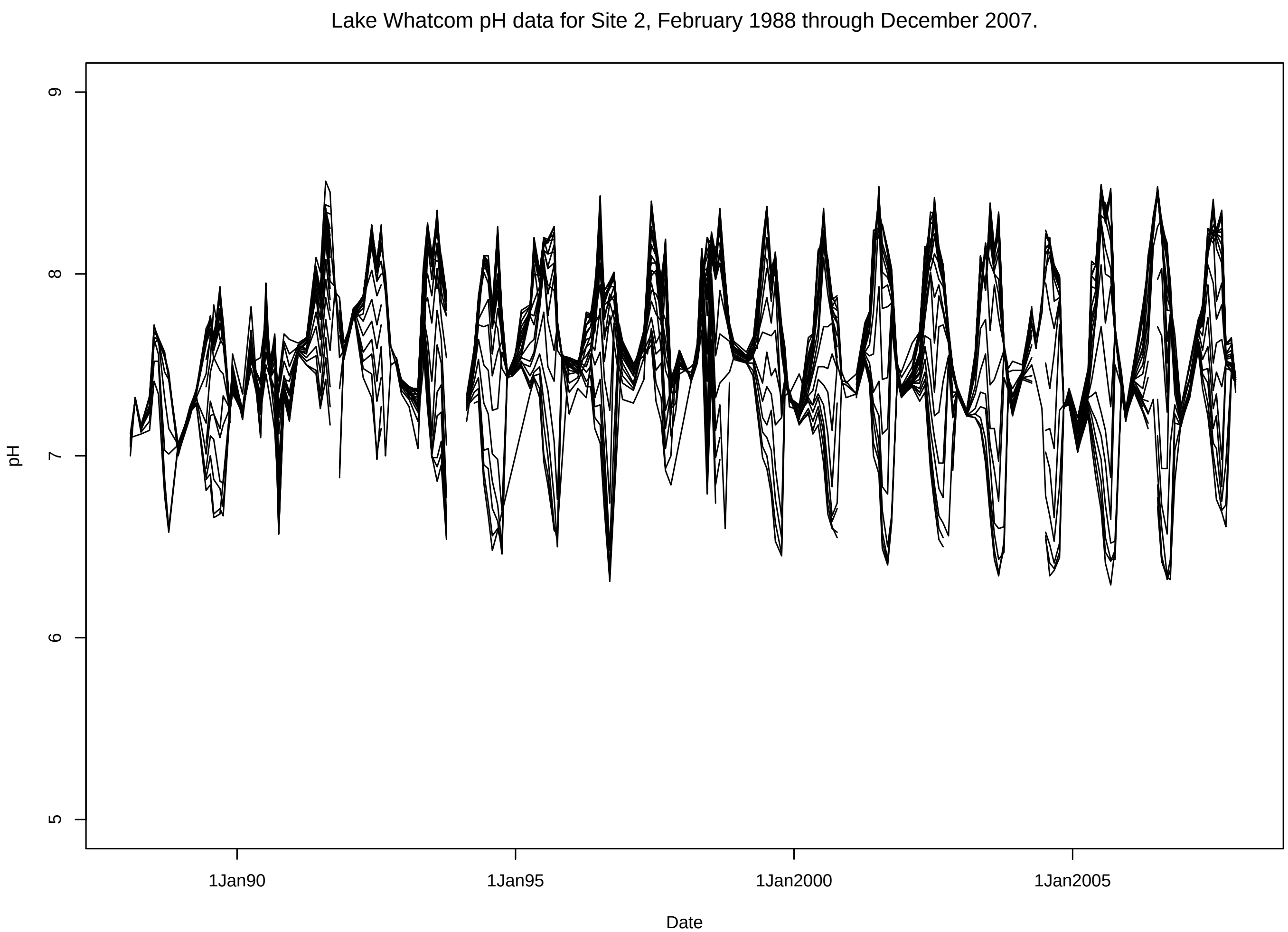


Figure B62: Lake Whatcom historic pH data for Site 2.

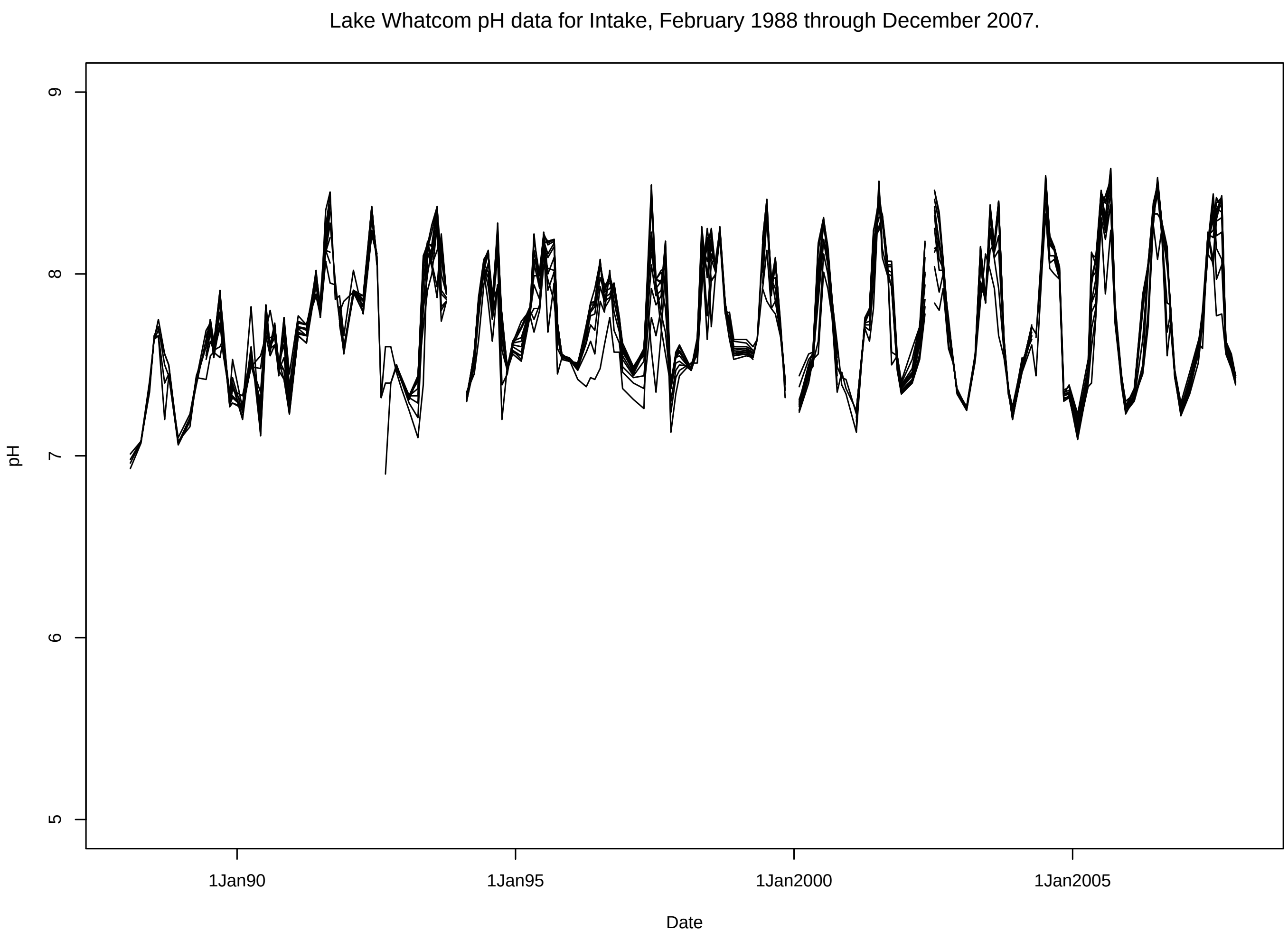


Figure B63: Lake Whatcom historic pH data for the Intake.

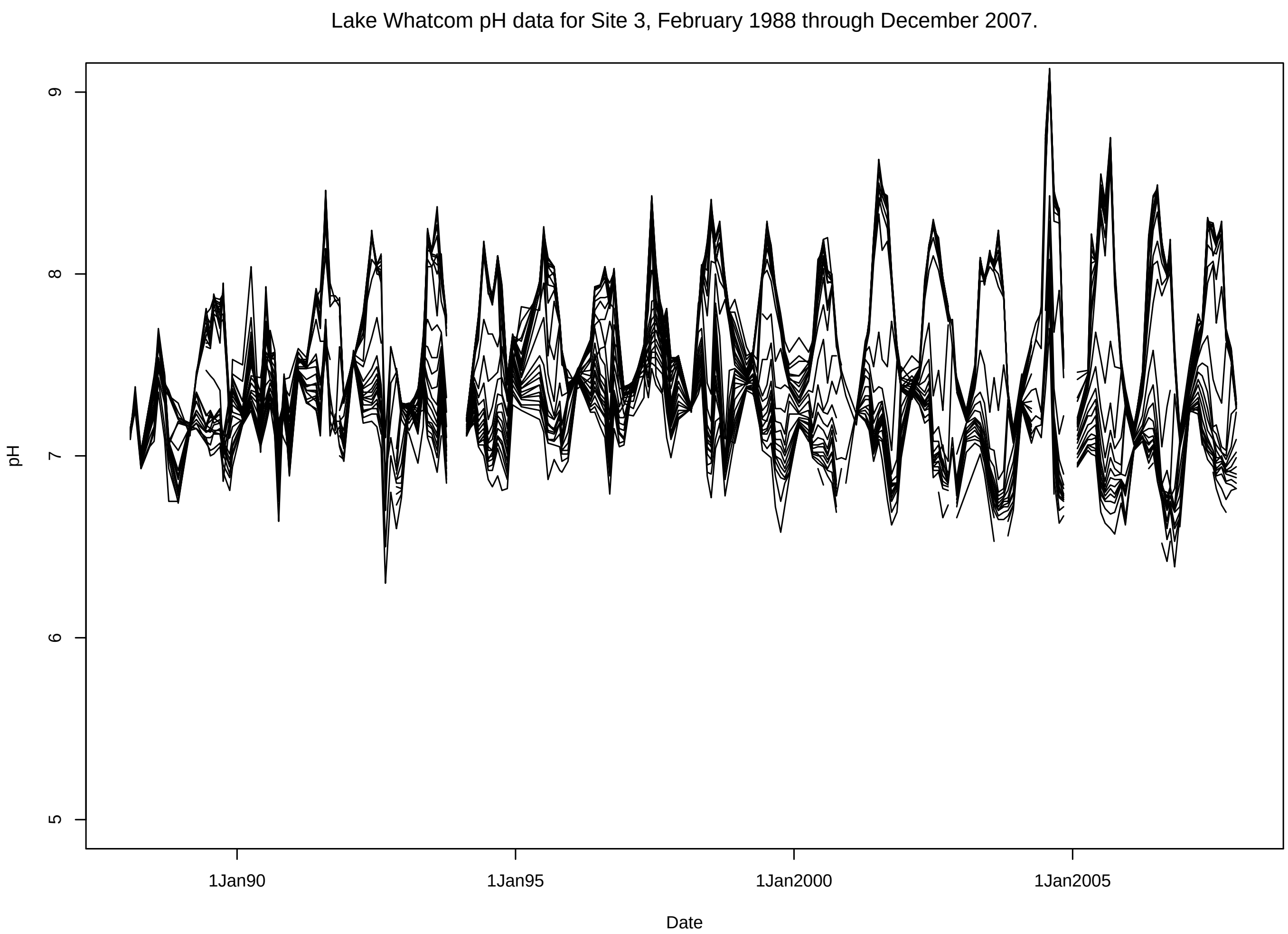


Figure B64: Lake Whatcom historic pH data for Site 3.

Lake Whatcom pH data for Site 4, February 1988 through December 2007.

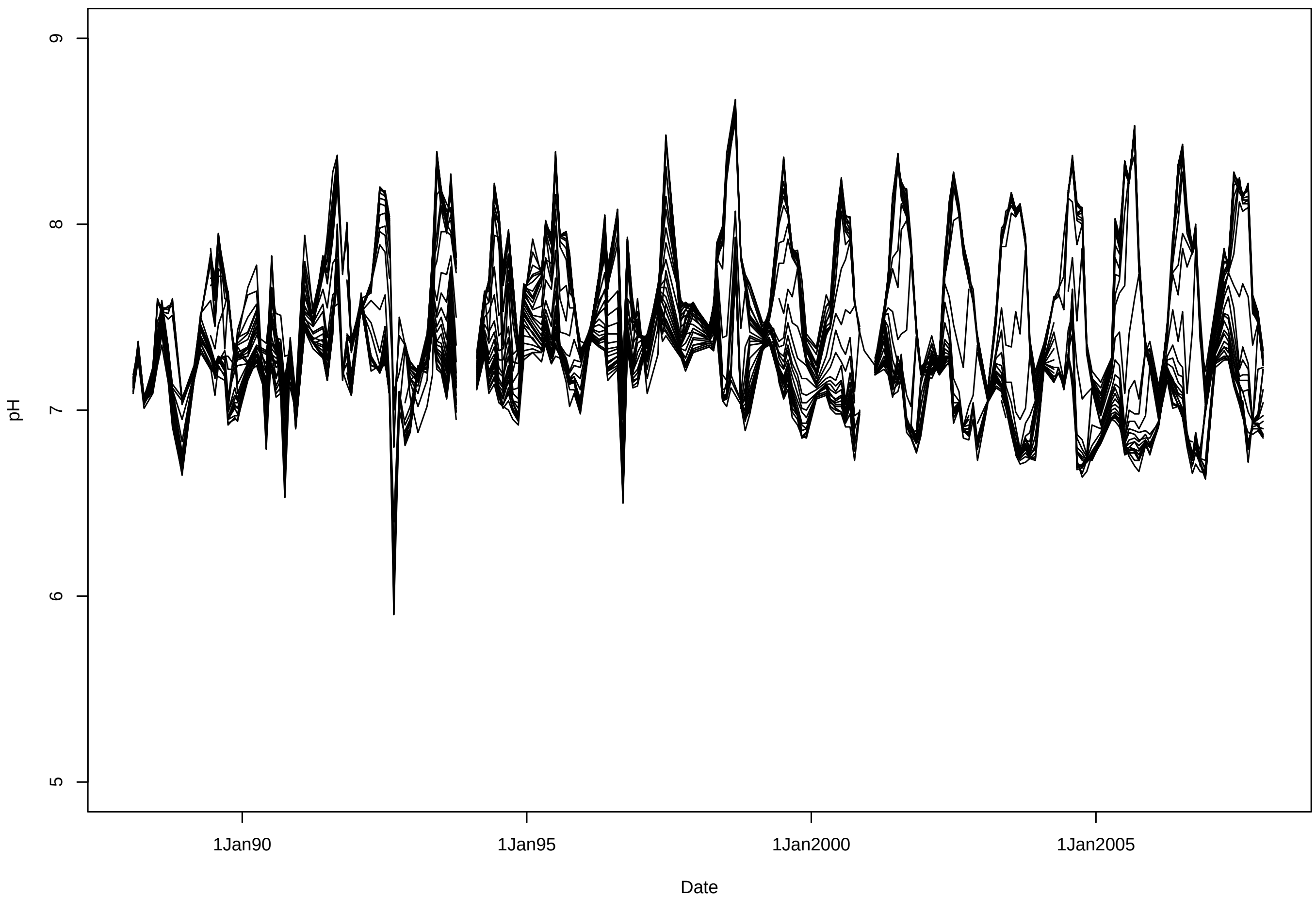


Figure B65: Lake Whatcom historic pH data for Site 4.

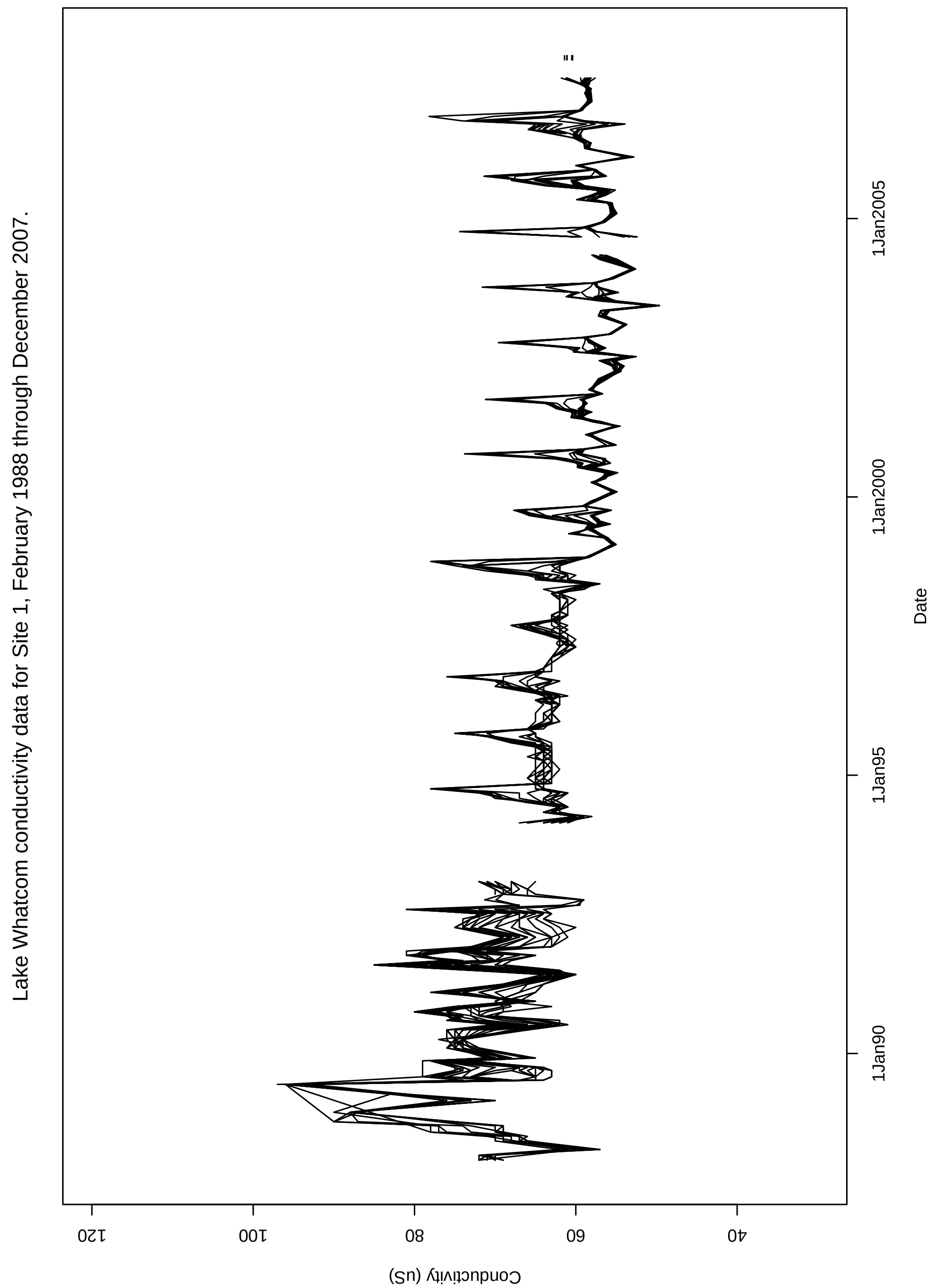


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

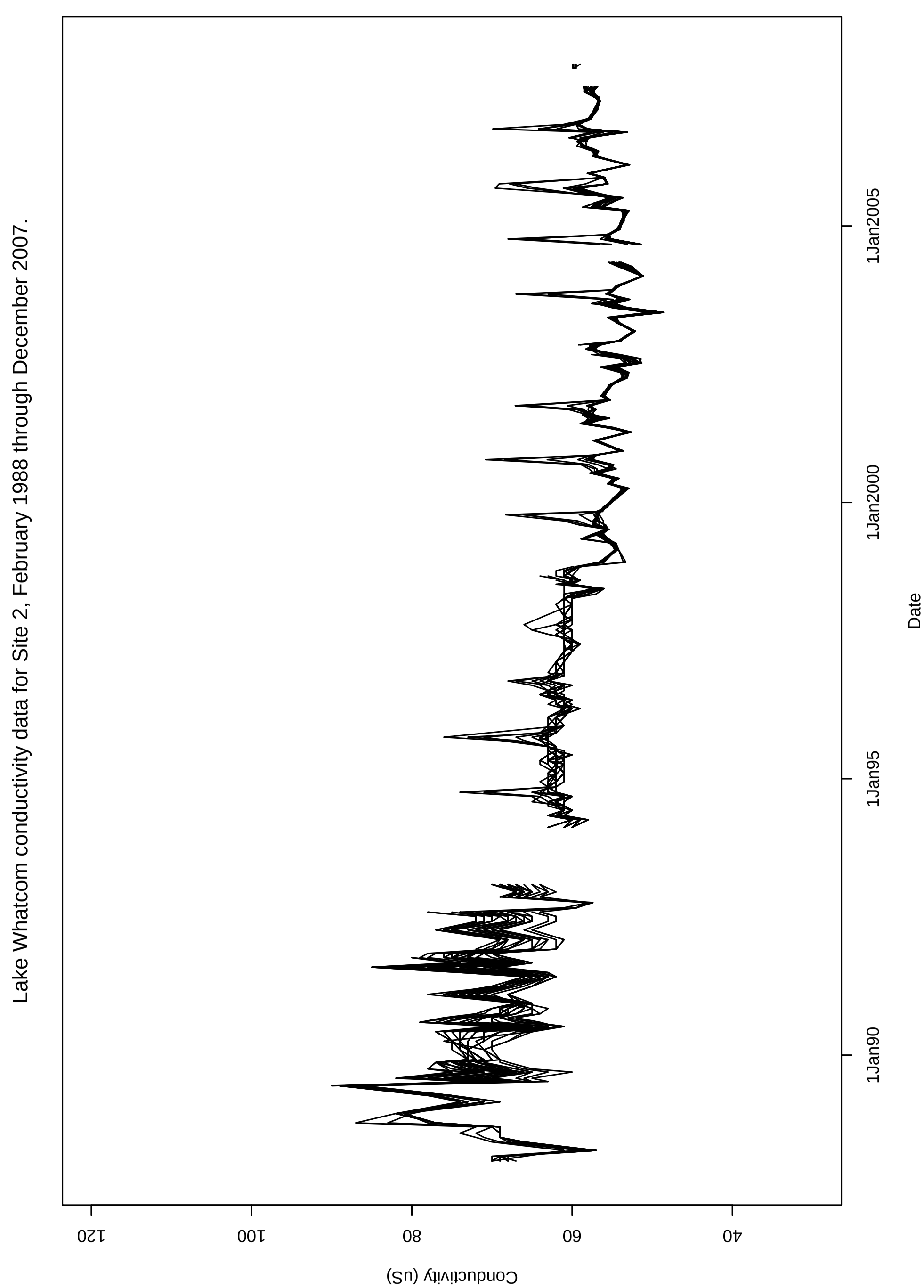


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

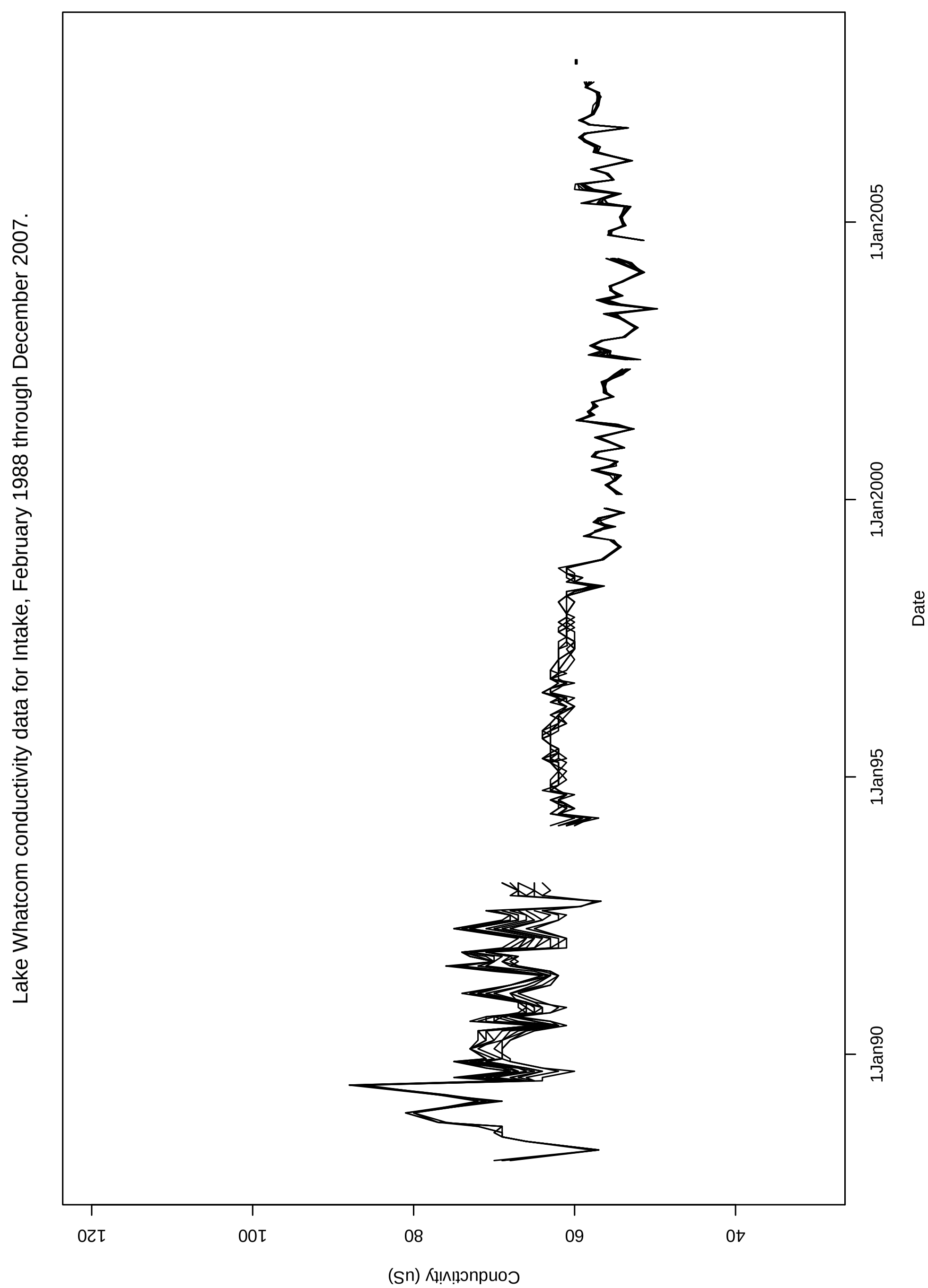


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

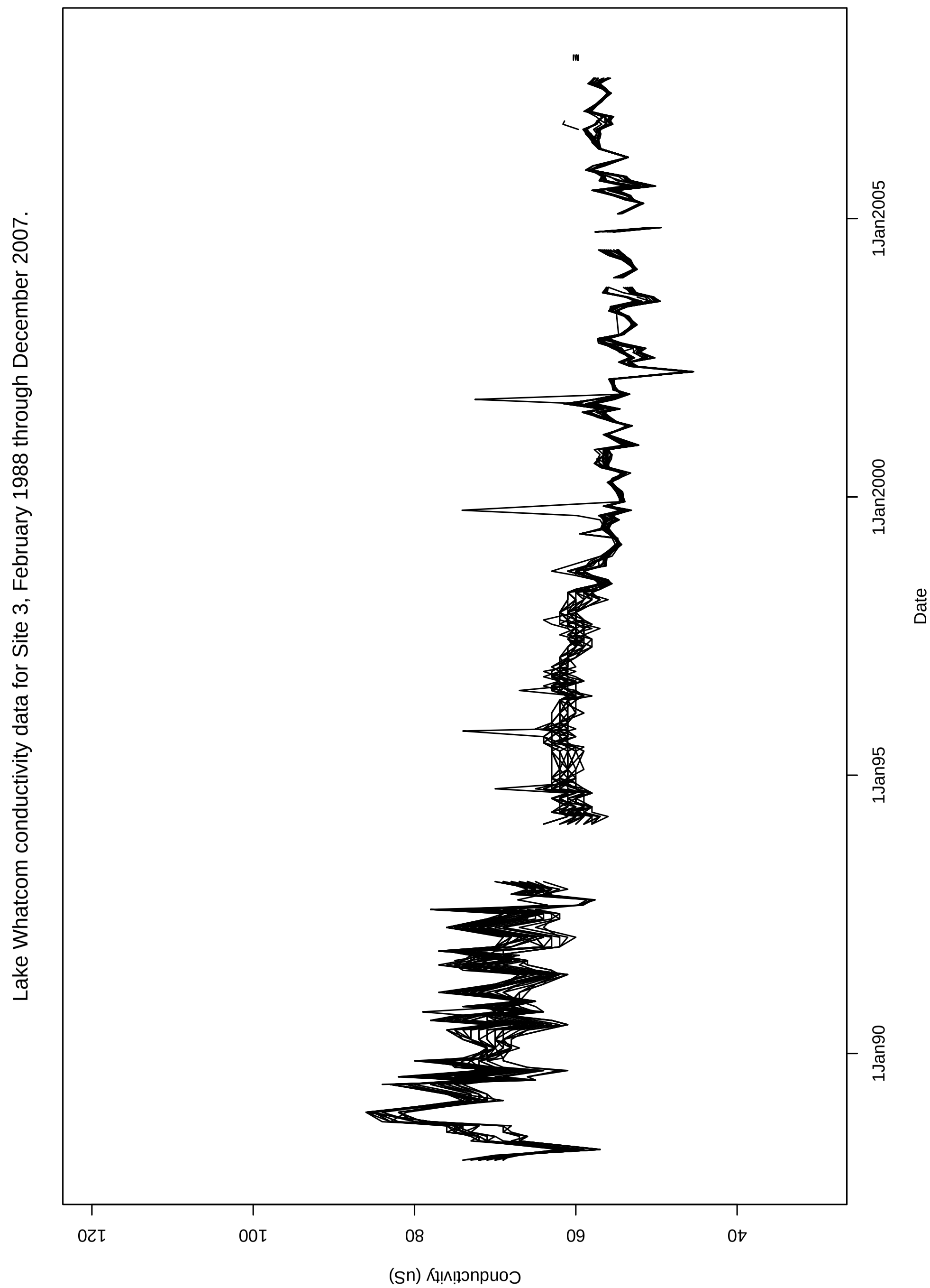


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

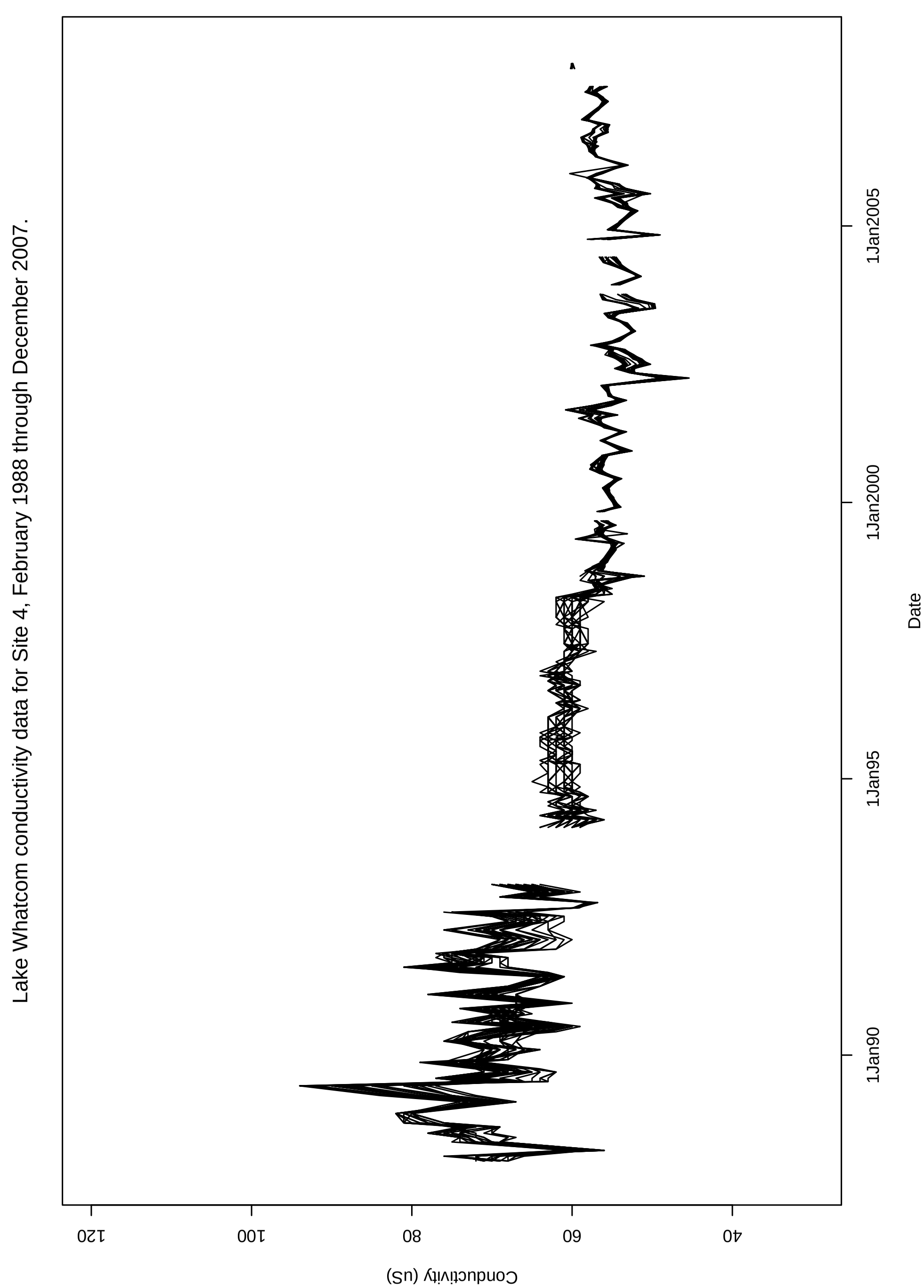


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

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

Lake Whatcom alkalinity data for Site 1, February 1988 through December 2007.

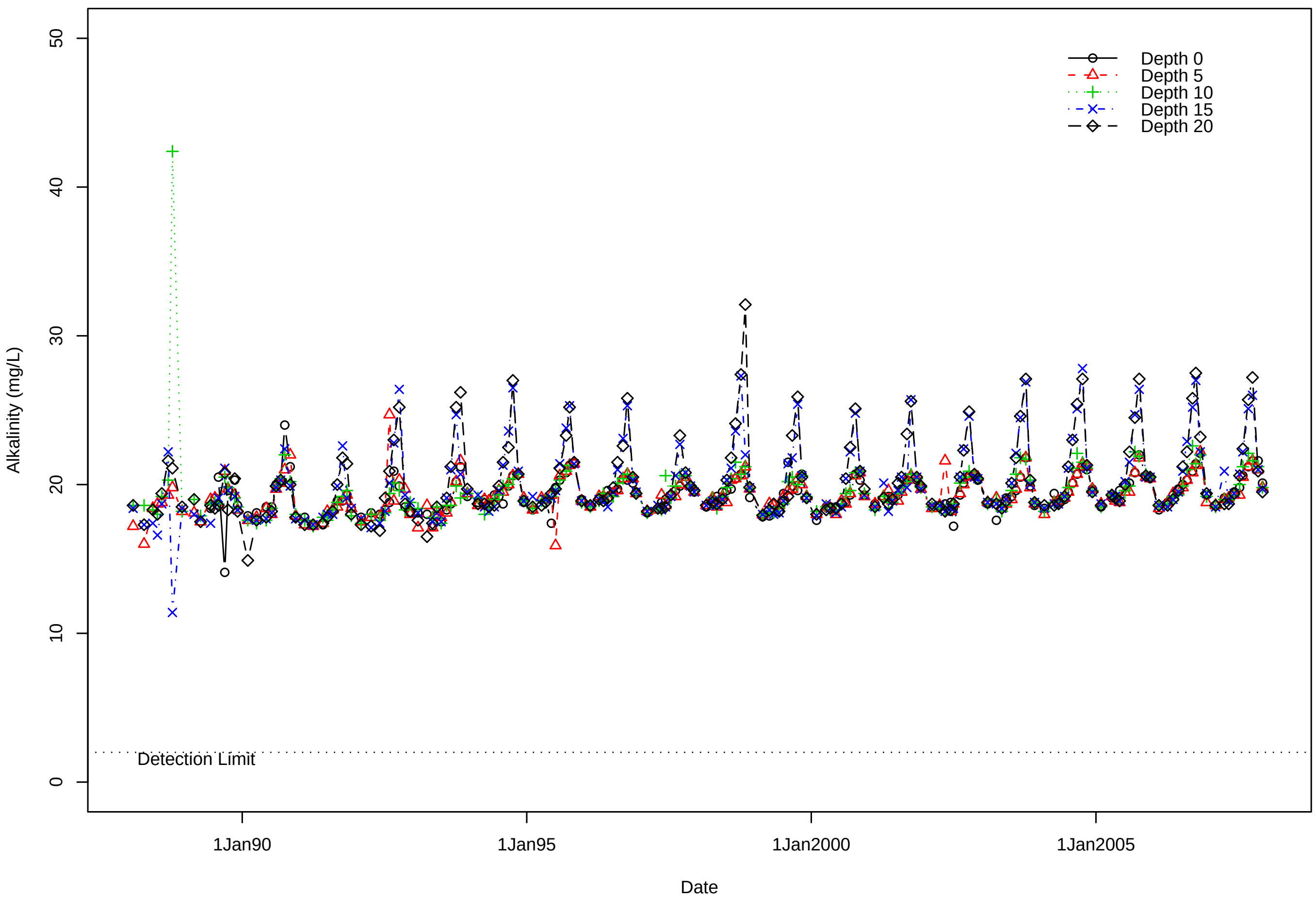


Figure B71: Lake Whatcom alkalinity data for Site 1.

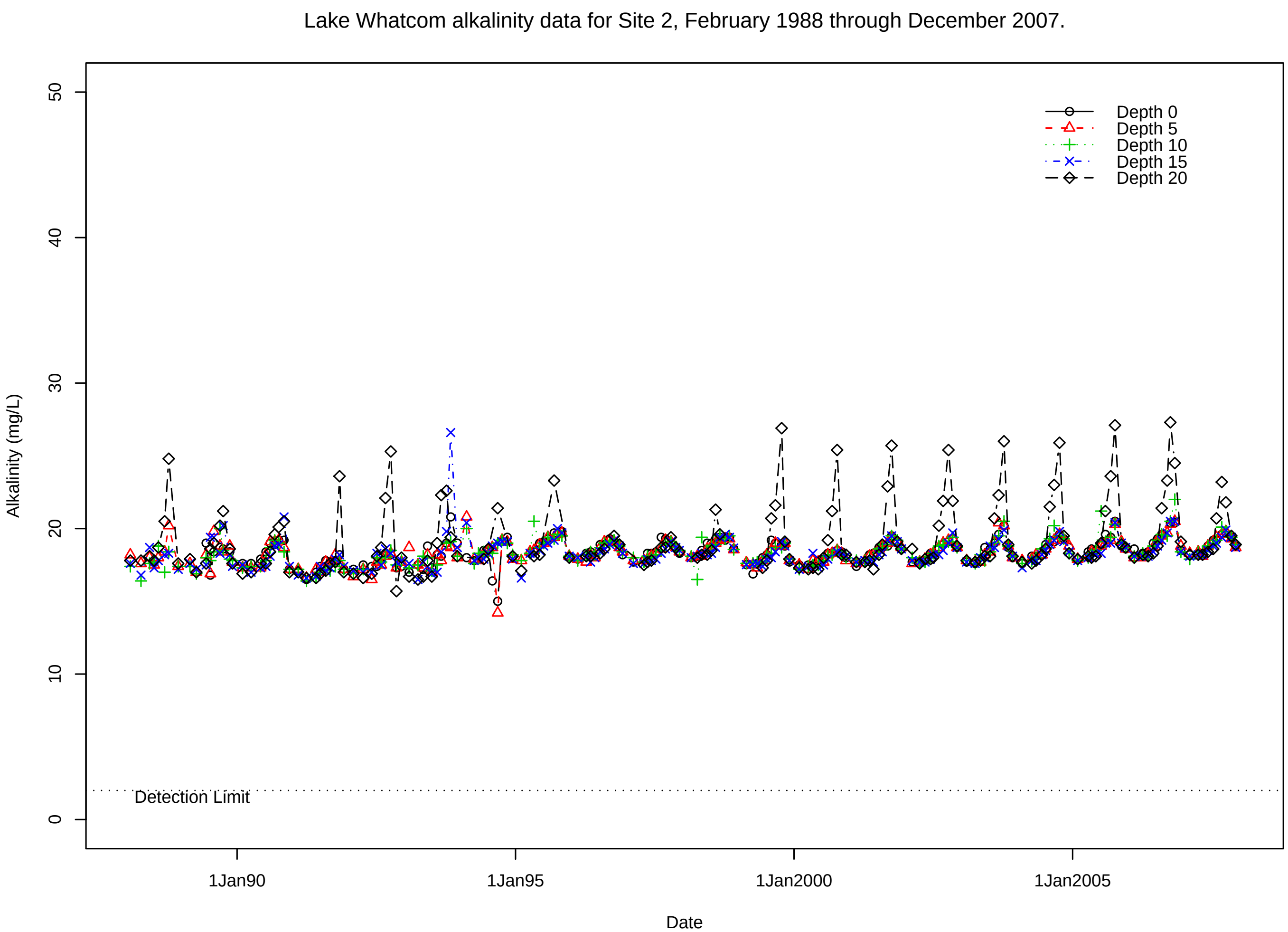


Figure B72: Lake Whatcom alkalinity data for Site 2.

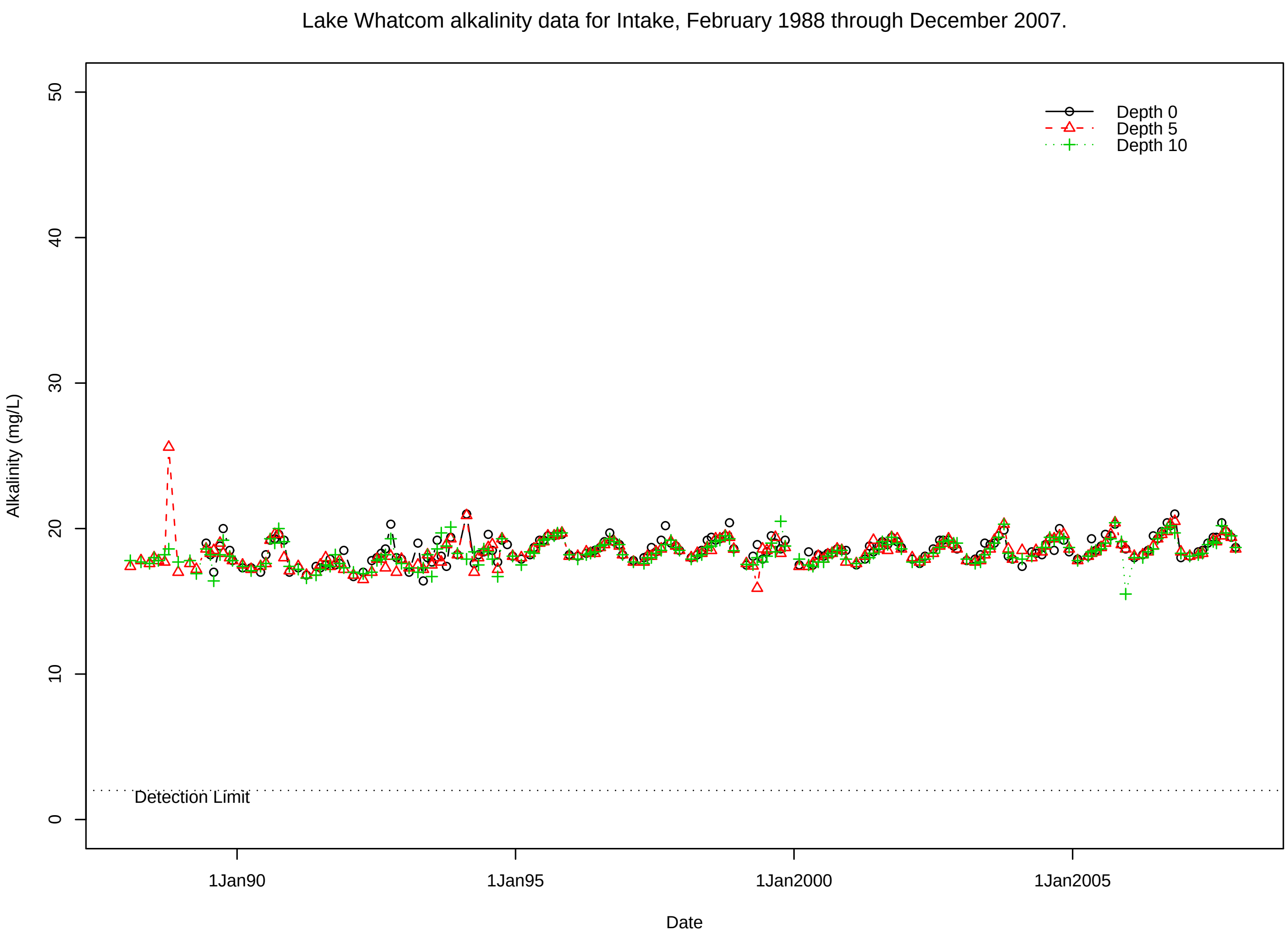


Figure B73: Lake Whatcom alkalinity data for the Intake site.

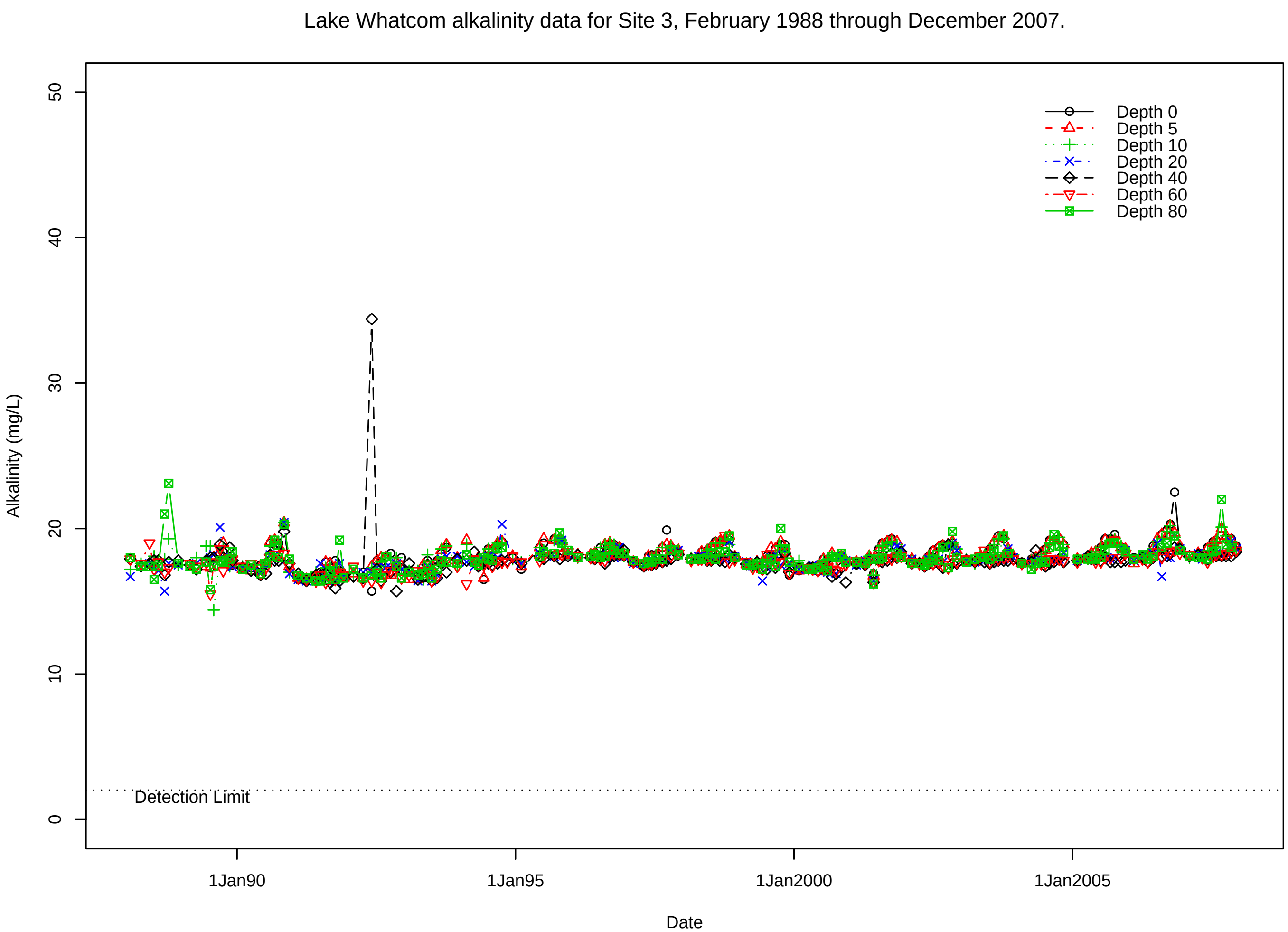


Figure B74: Lake Whatcom alkalinity data for Site 3.

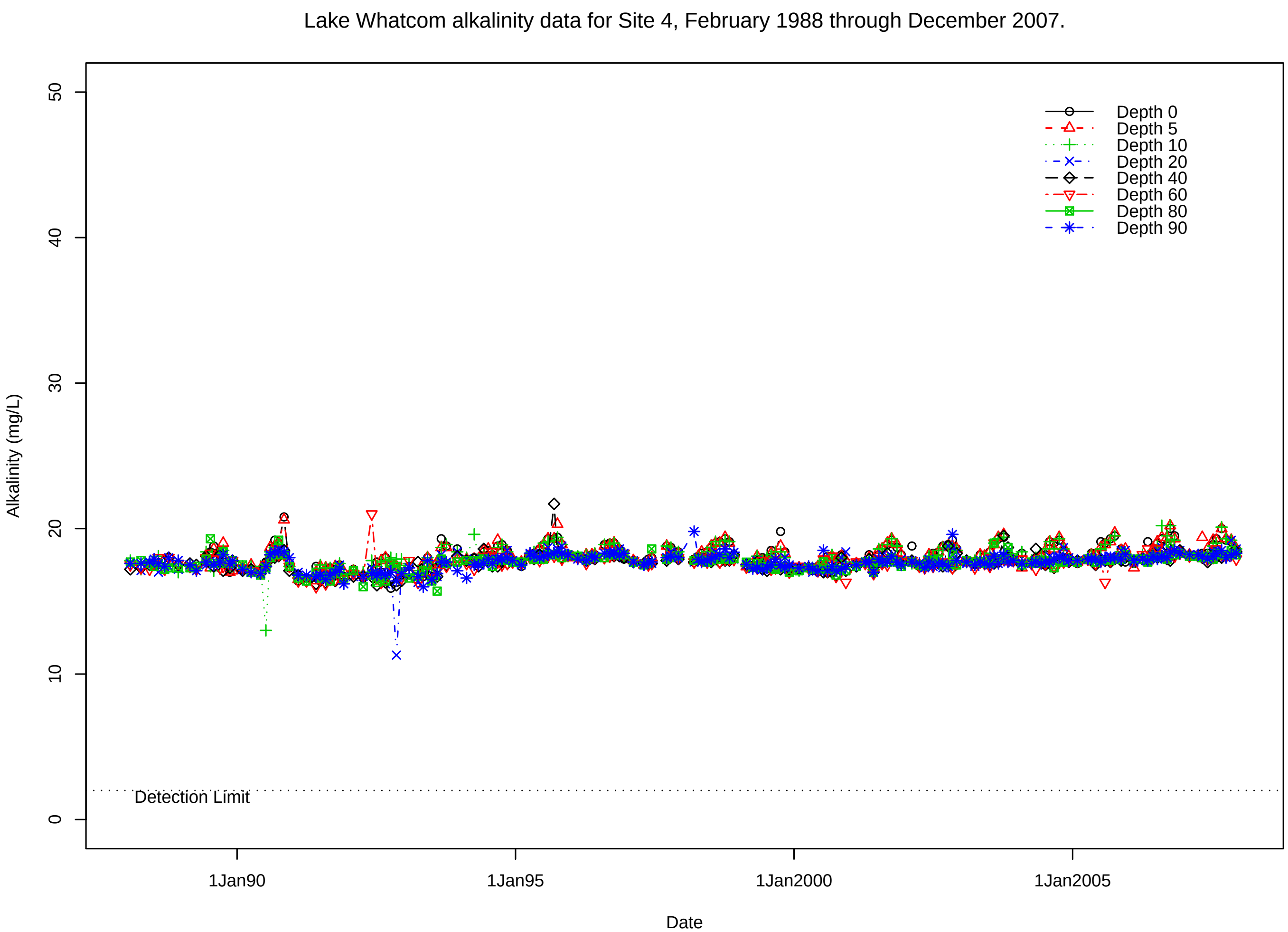


Figure B75: Lake Whatcom alkalinity data for Site 4.

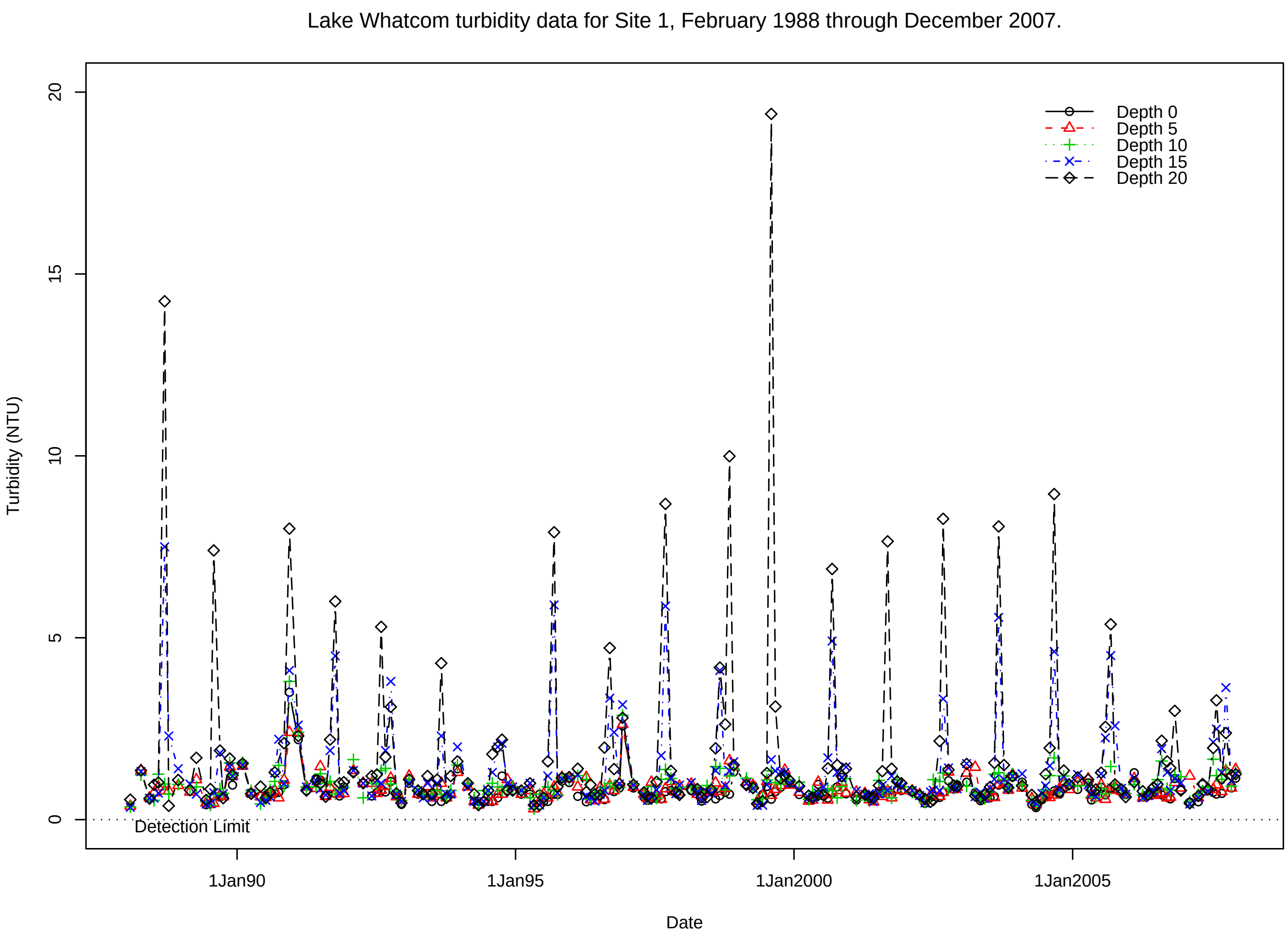


Figure B76: Lake Whatcom turbidity data for Site 1.

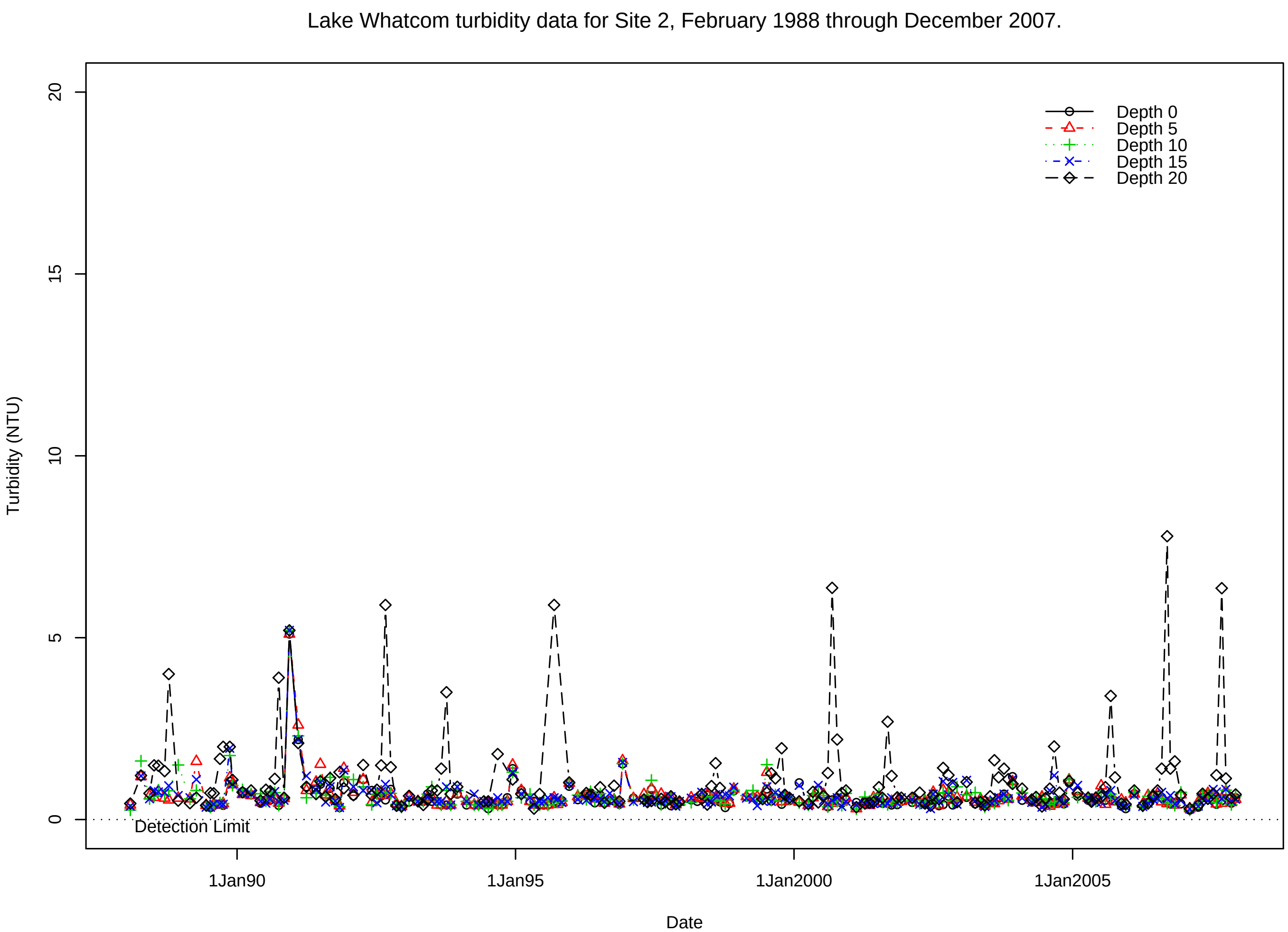


Figure B77: Lake Whatcom turbidity data for Site 2.

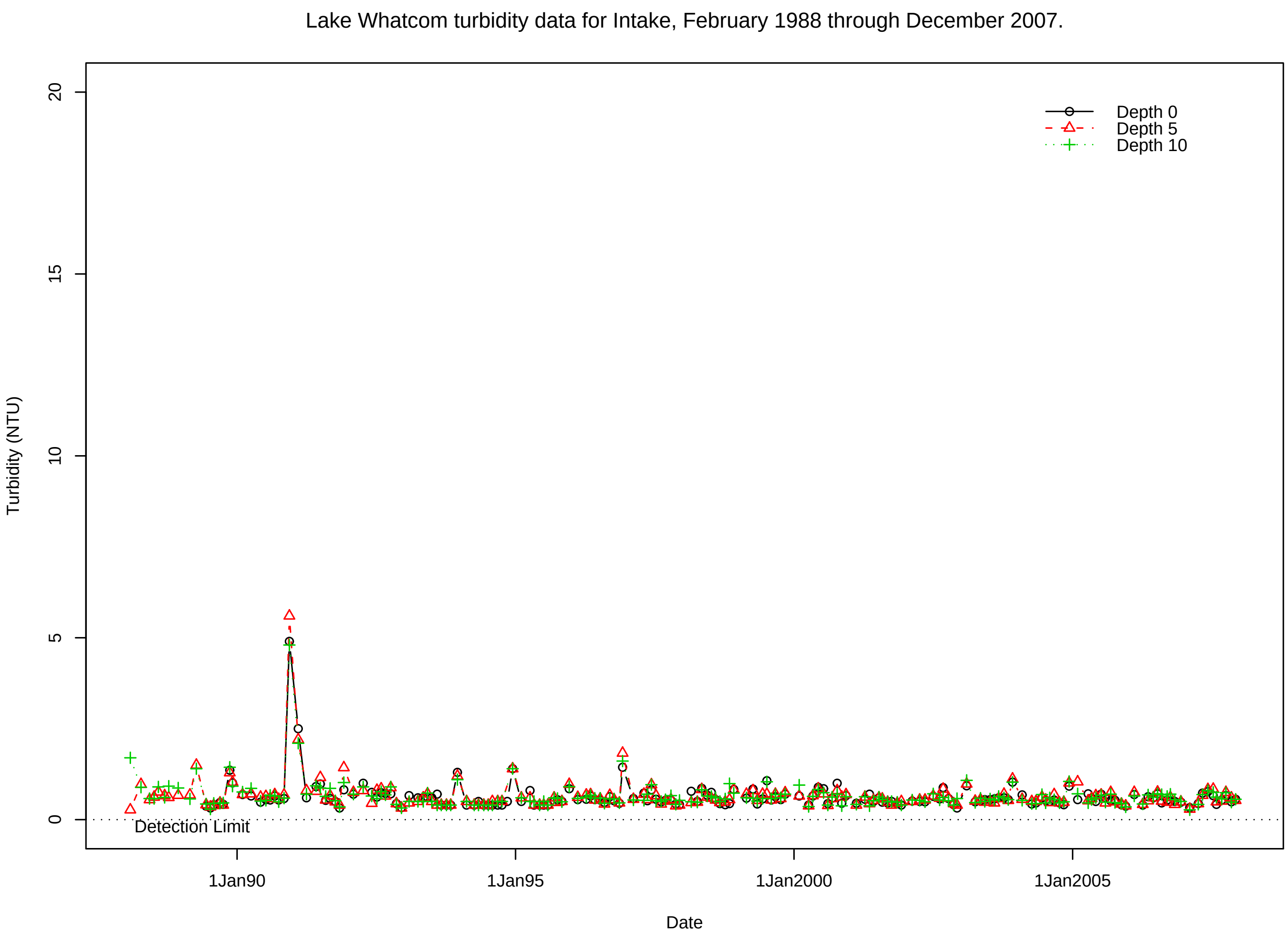
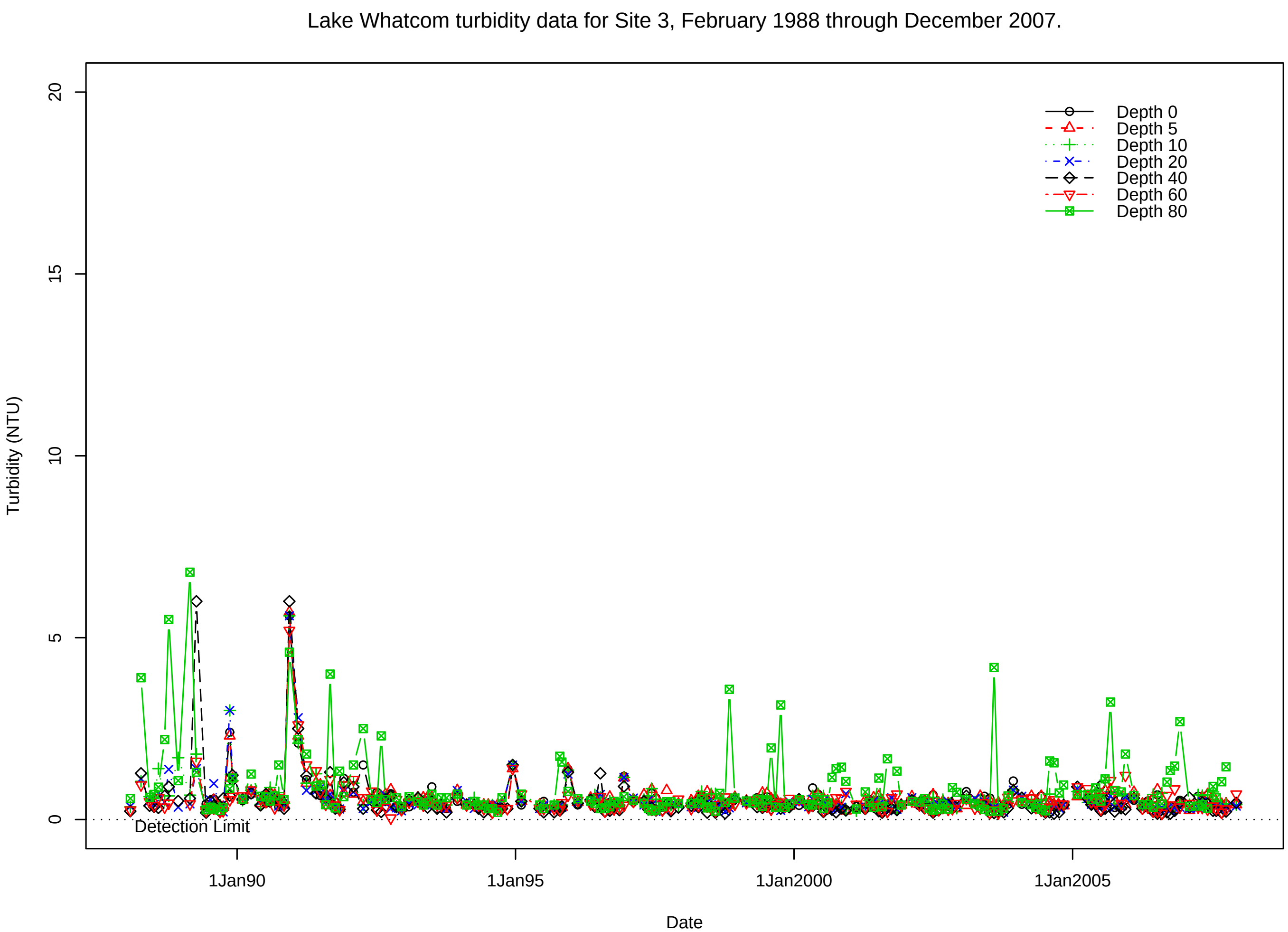


Figure B78: Lake Whatcom turbidity data for the Intake site.

Figure B79: Lake Whatcom turbidity data for Site 3.



Lake Whatcom turbidity data for Site 4, February 1988 through December 2007.

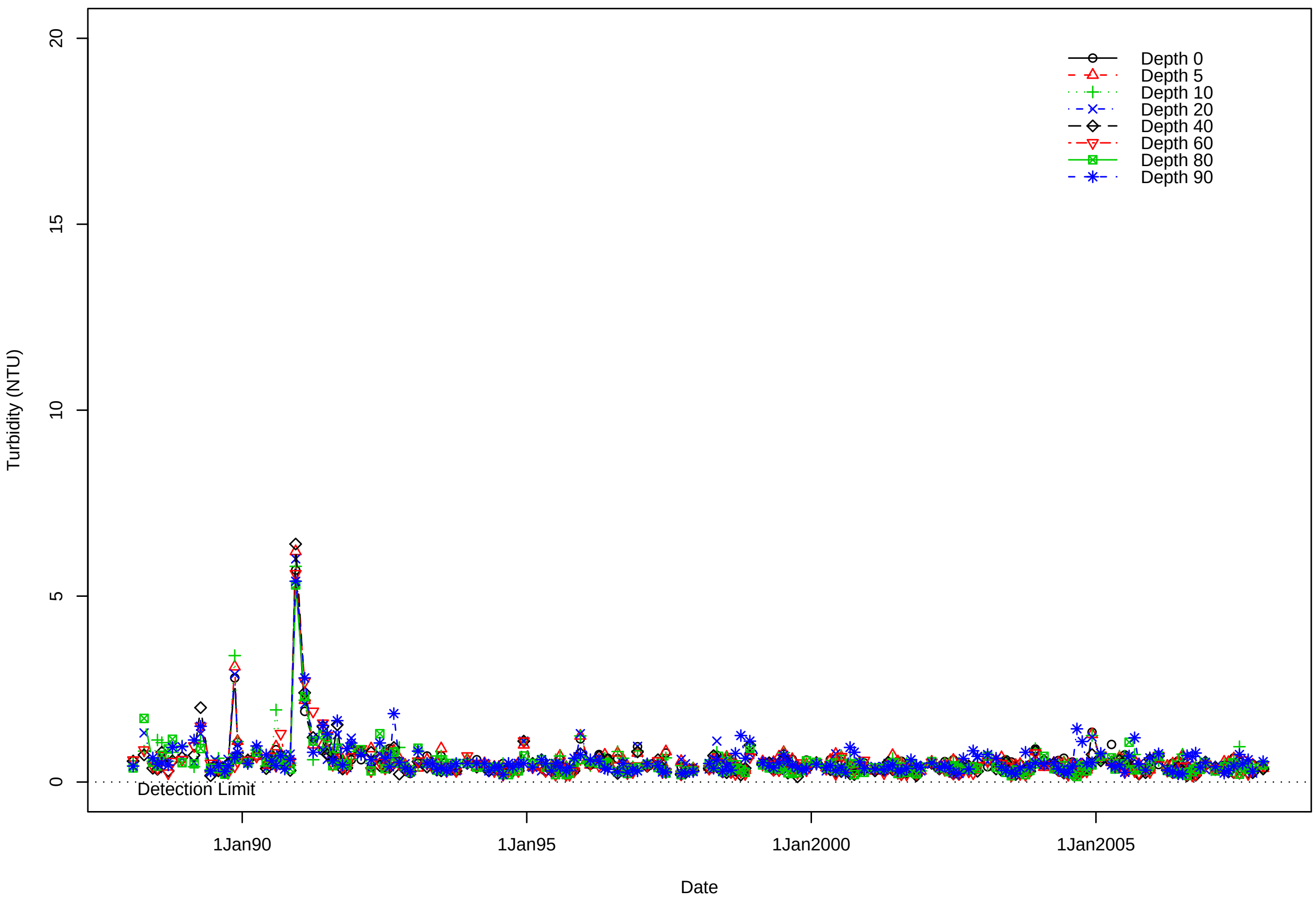


Figure B80: Lake Whatcom turbidity data for Site 4.

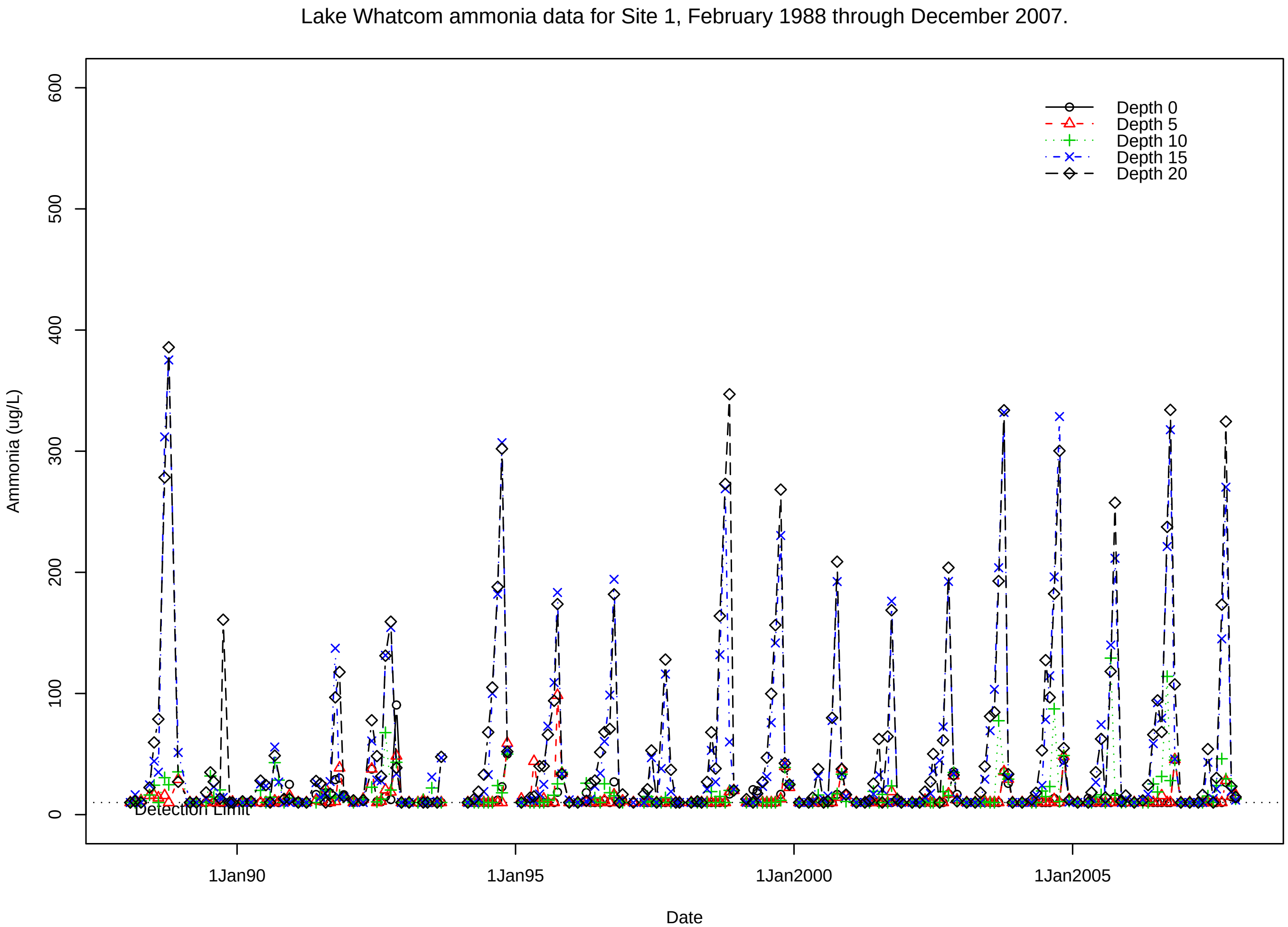


Figure B81: Lake Whatcom ammonia data for Site 1.

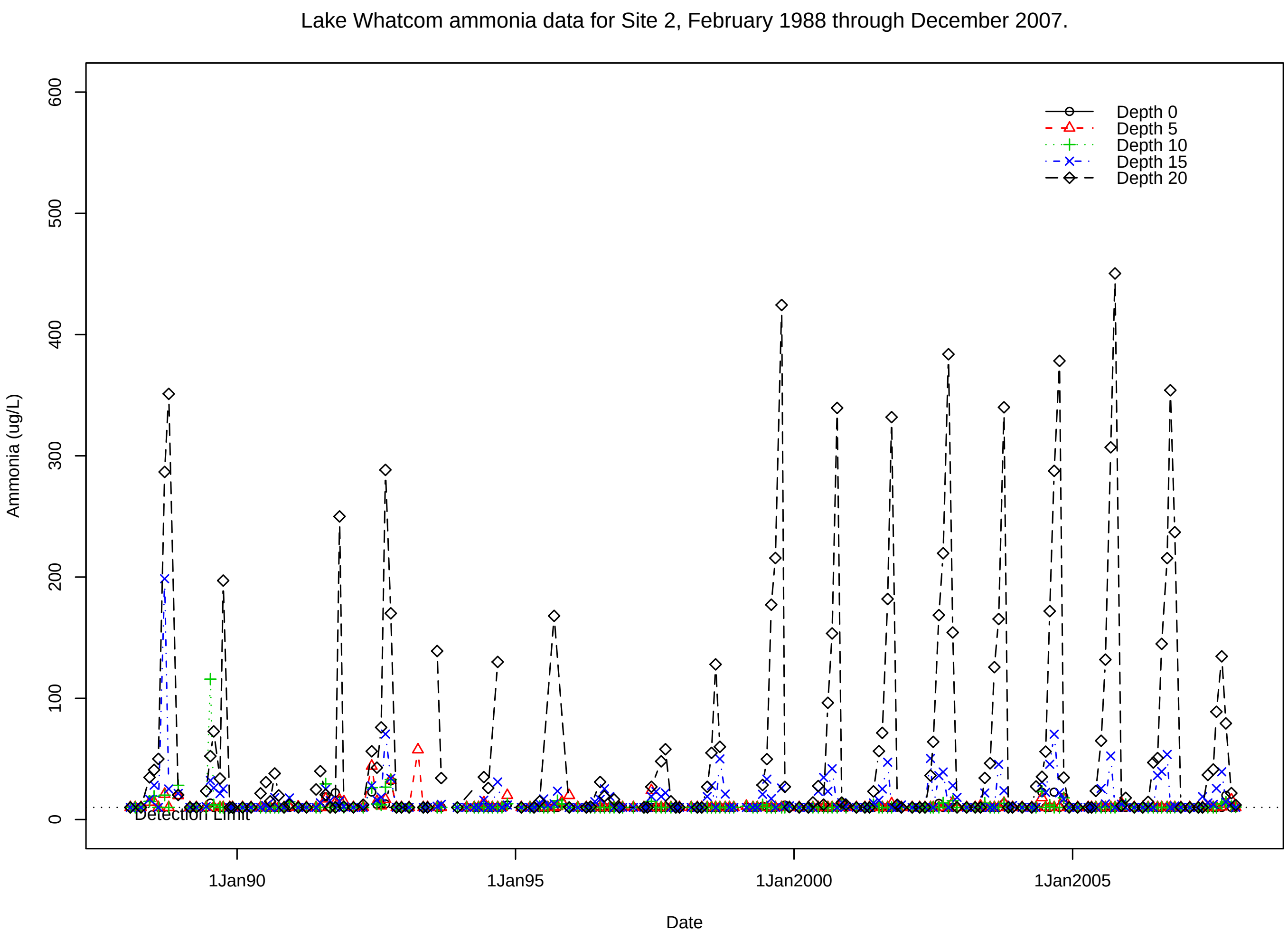


Figure B82: Lake Whatcom ammonia data for Site 2.

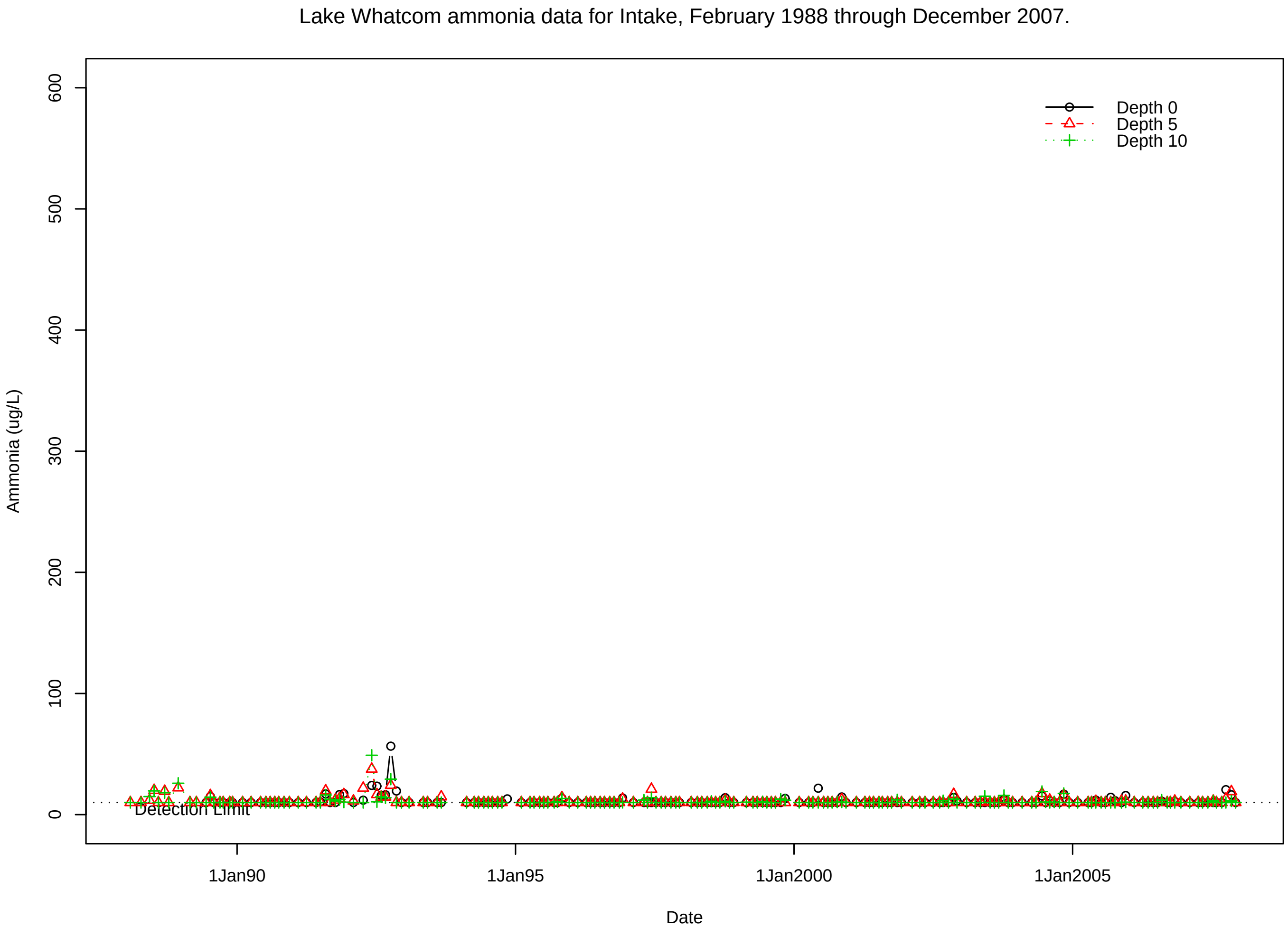


Figure B83: Lake Whatcom ammonia data for the Intake site.

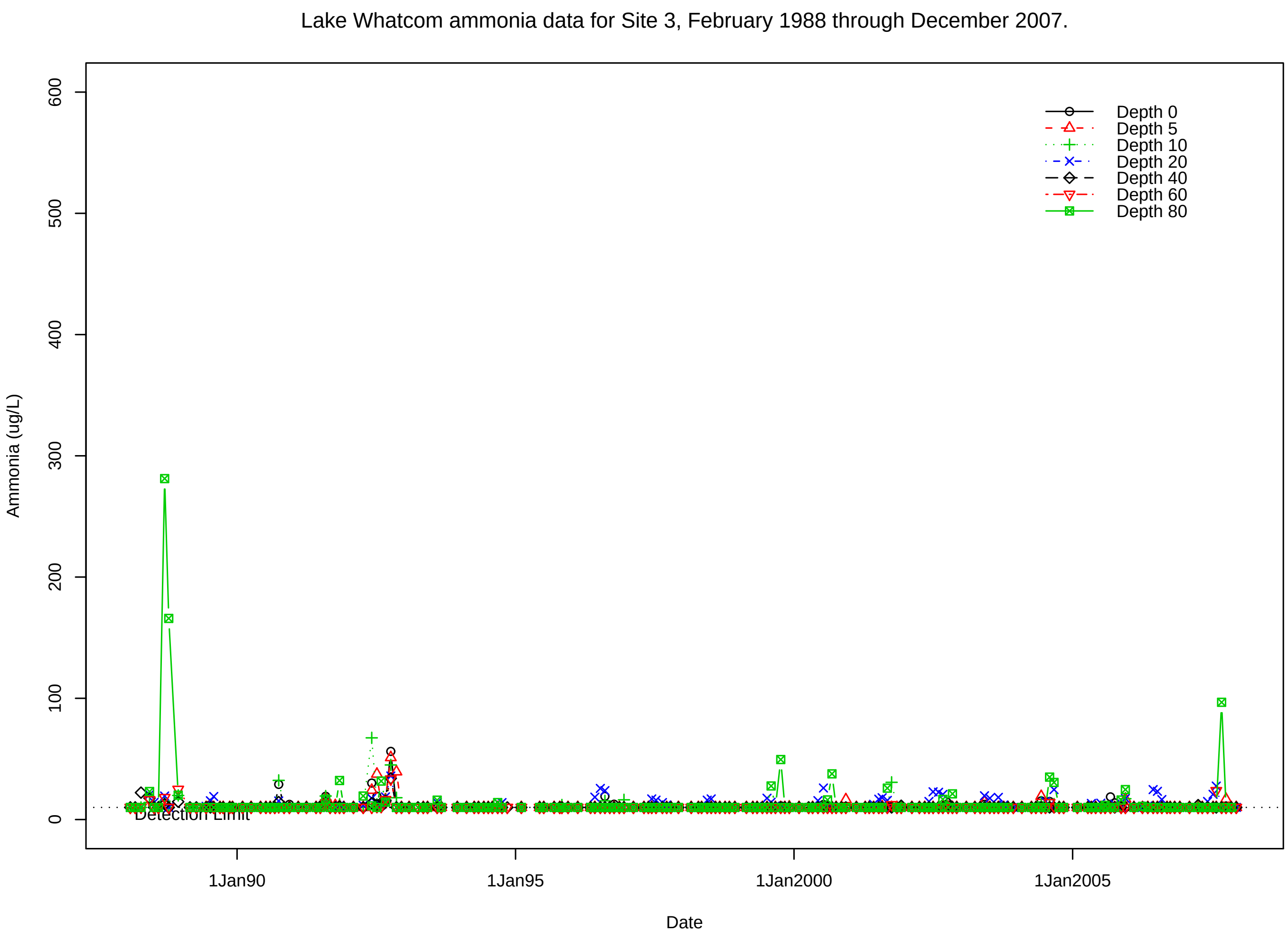


Figure B84: Lake Whatcom ammonia data for Site 3.

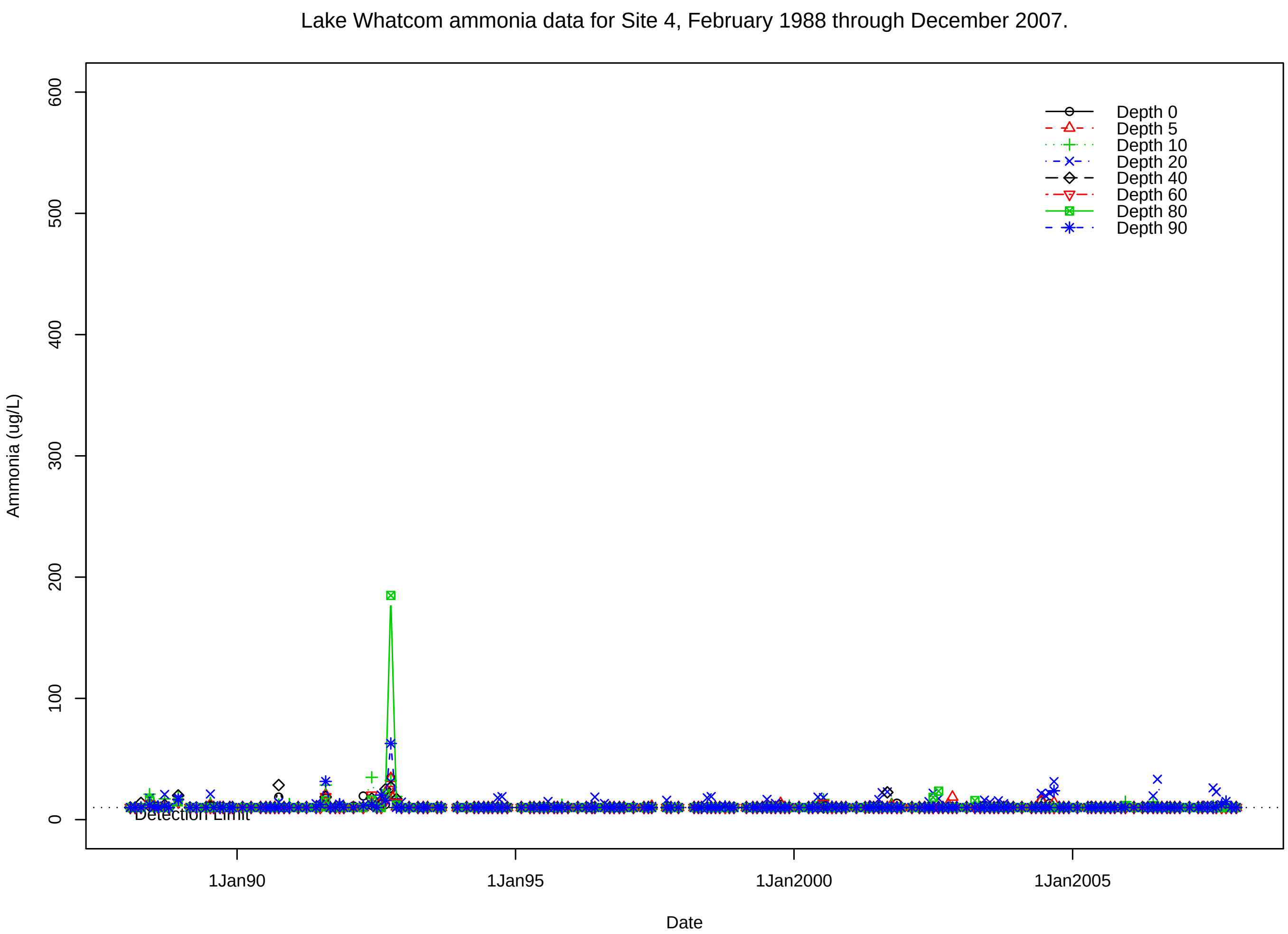


Figure B85: Lake Whatcom ammonia data for Site 4.

Lake Whatcom nitrate/nitrite data for Site 1, February 1988 through December 2007.

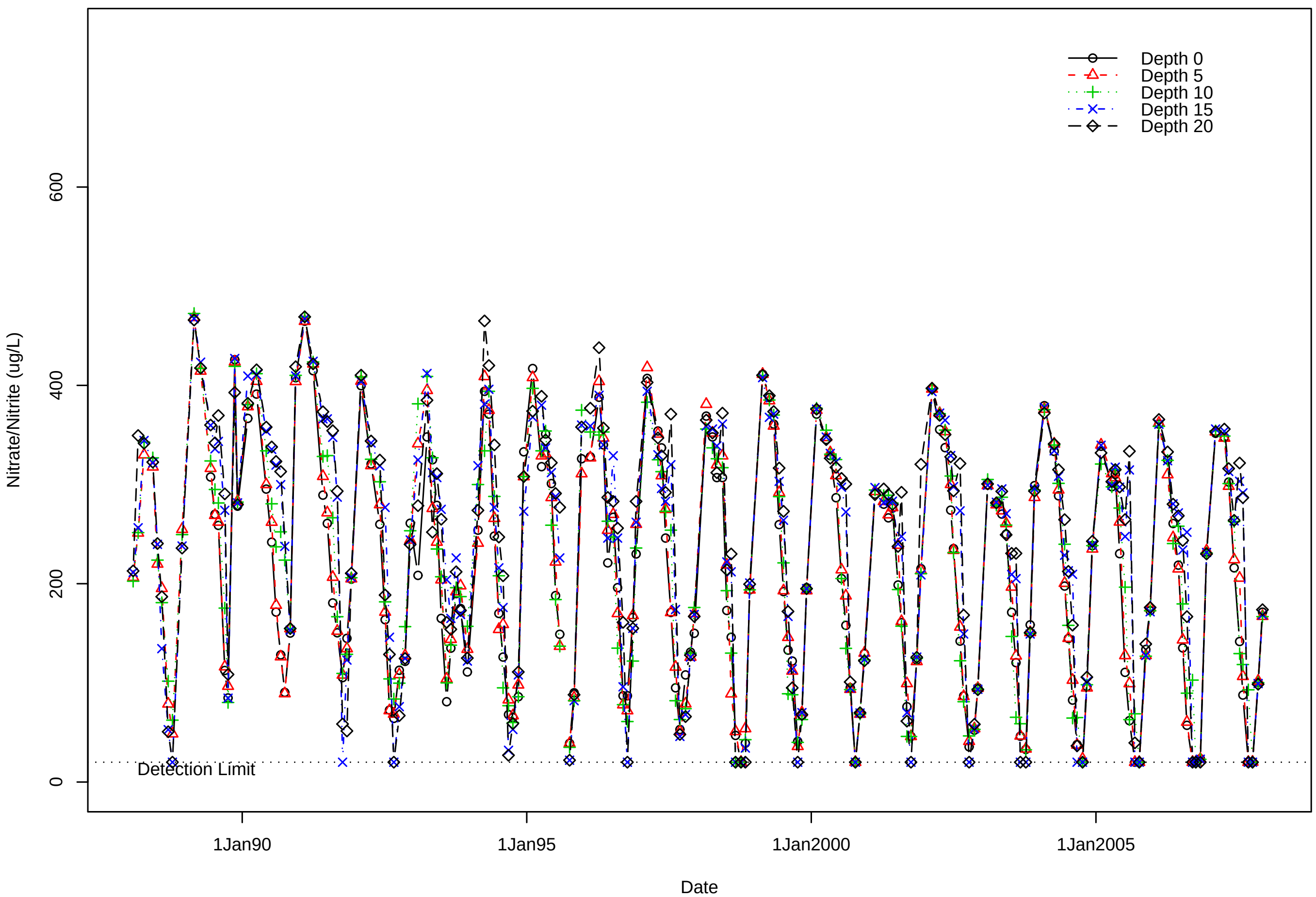


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.

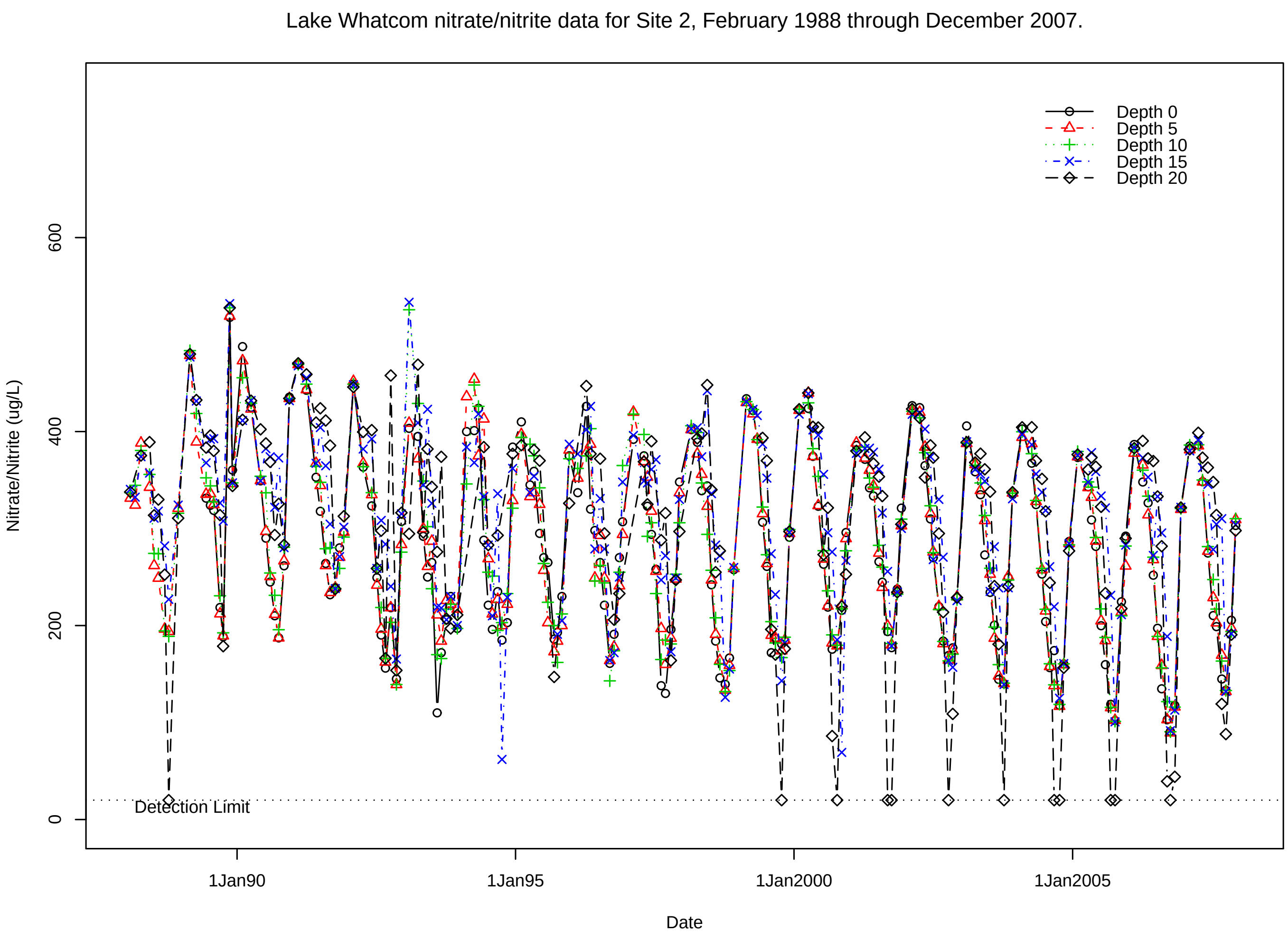


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

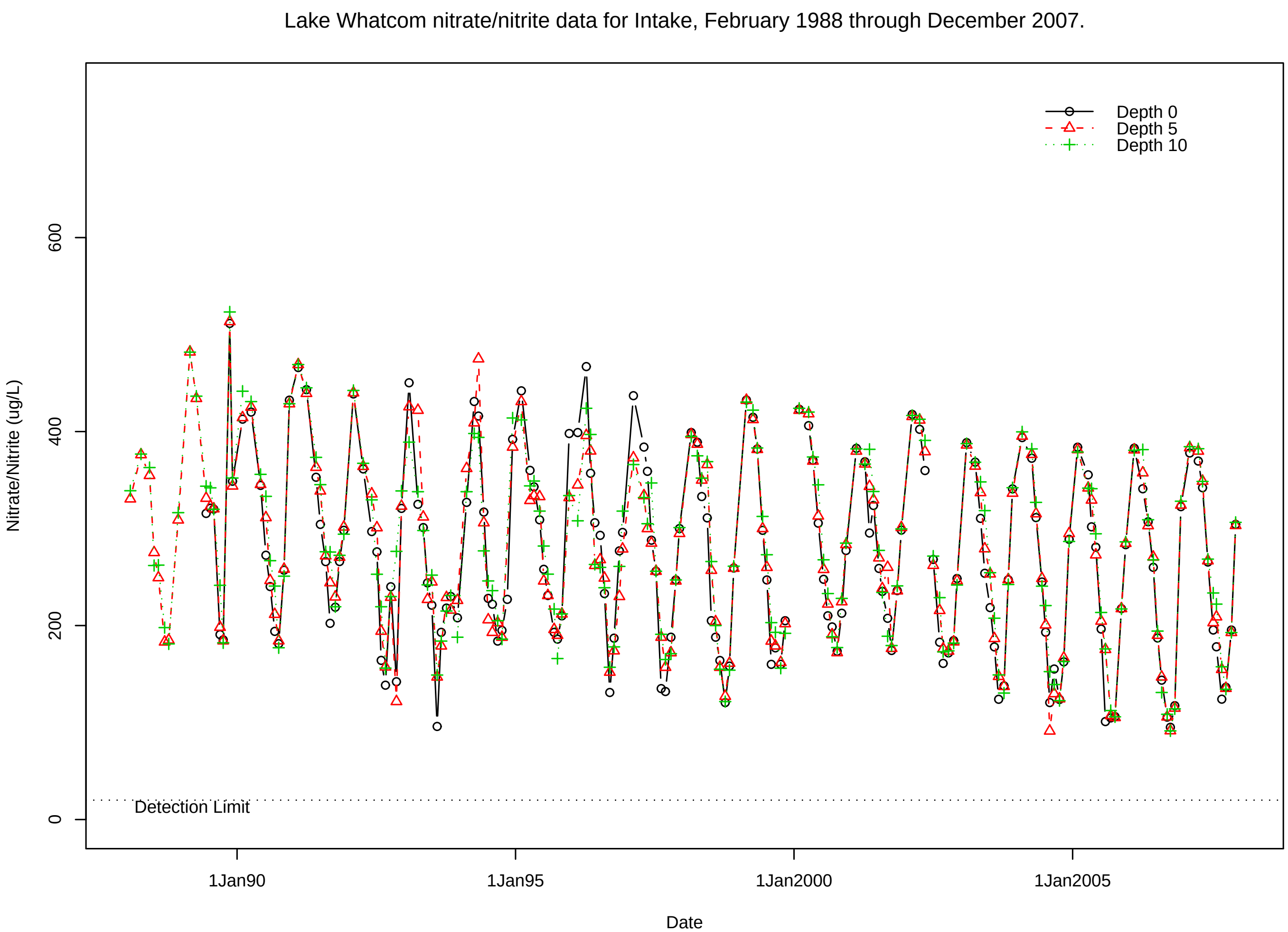


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

Lake Whatcom nitrate/nitrite data for Site 3, February 1988 through December 2007.

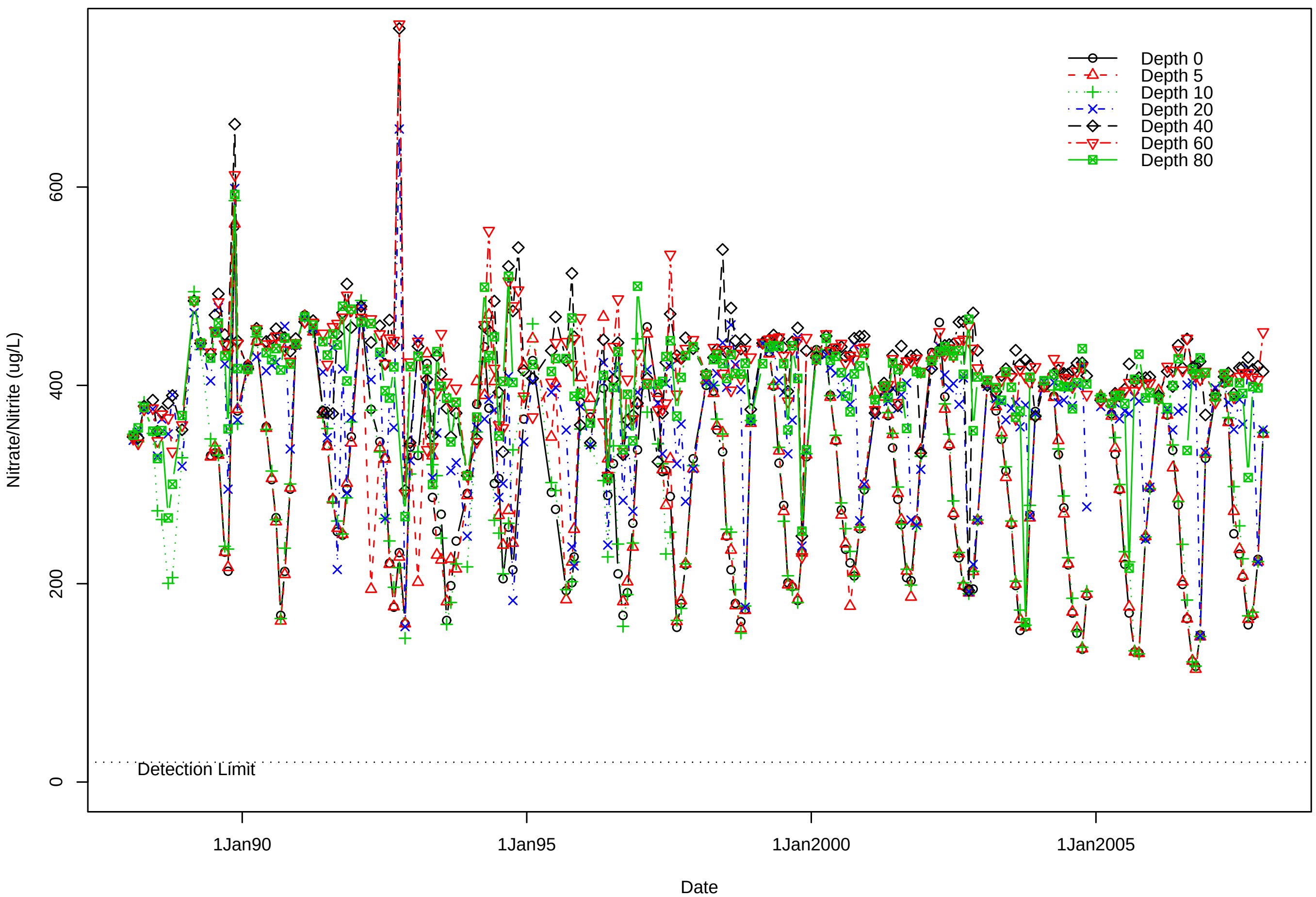


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

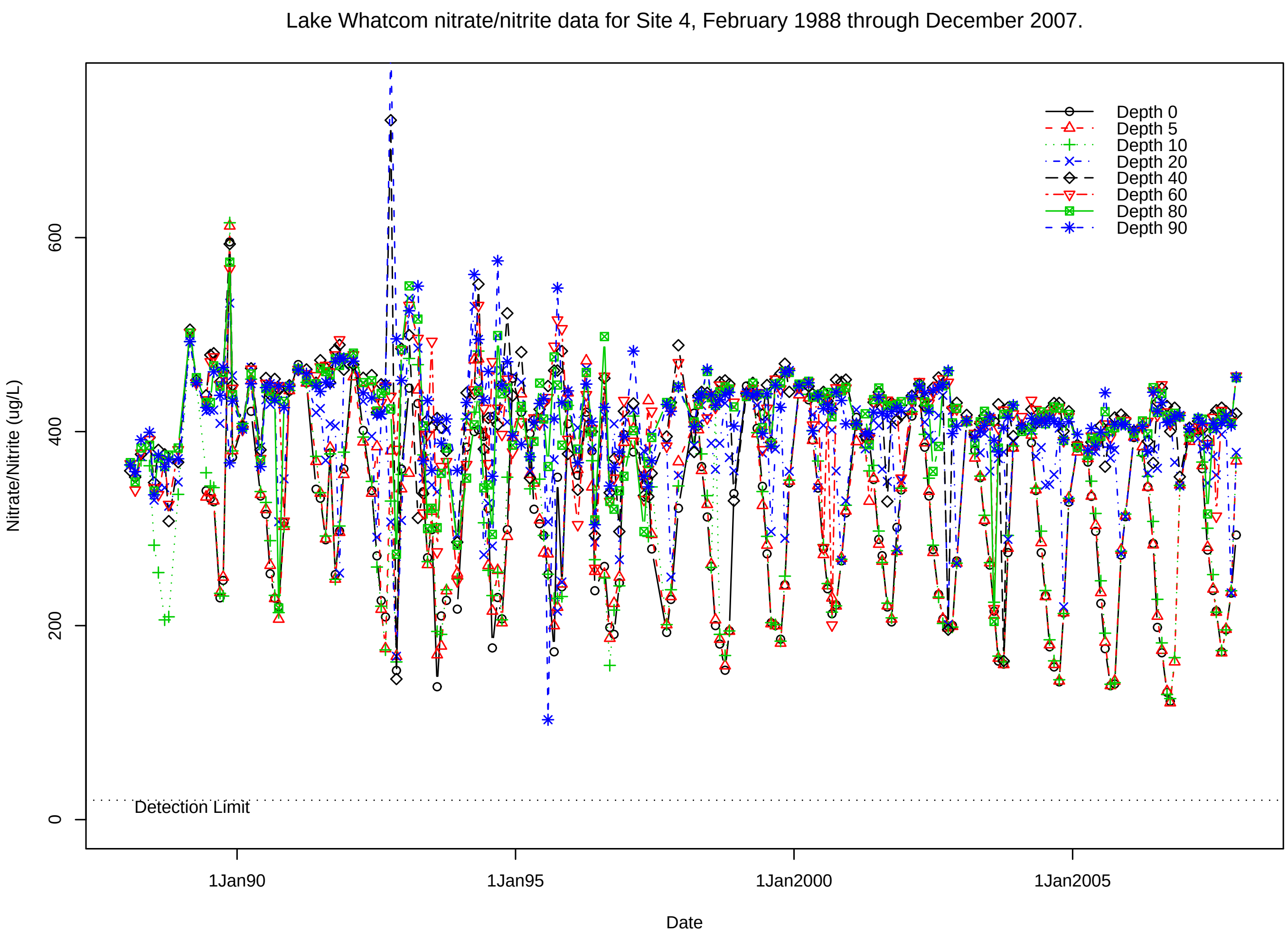


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4.

Lake Whatcom total nitrogen data for Site 1, February 1988 through December 2007.

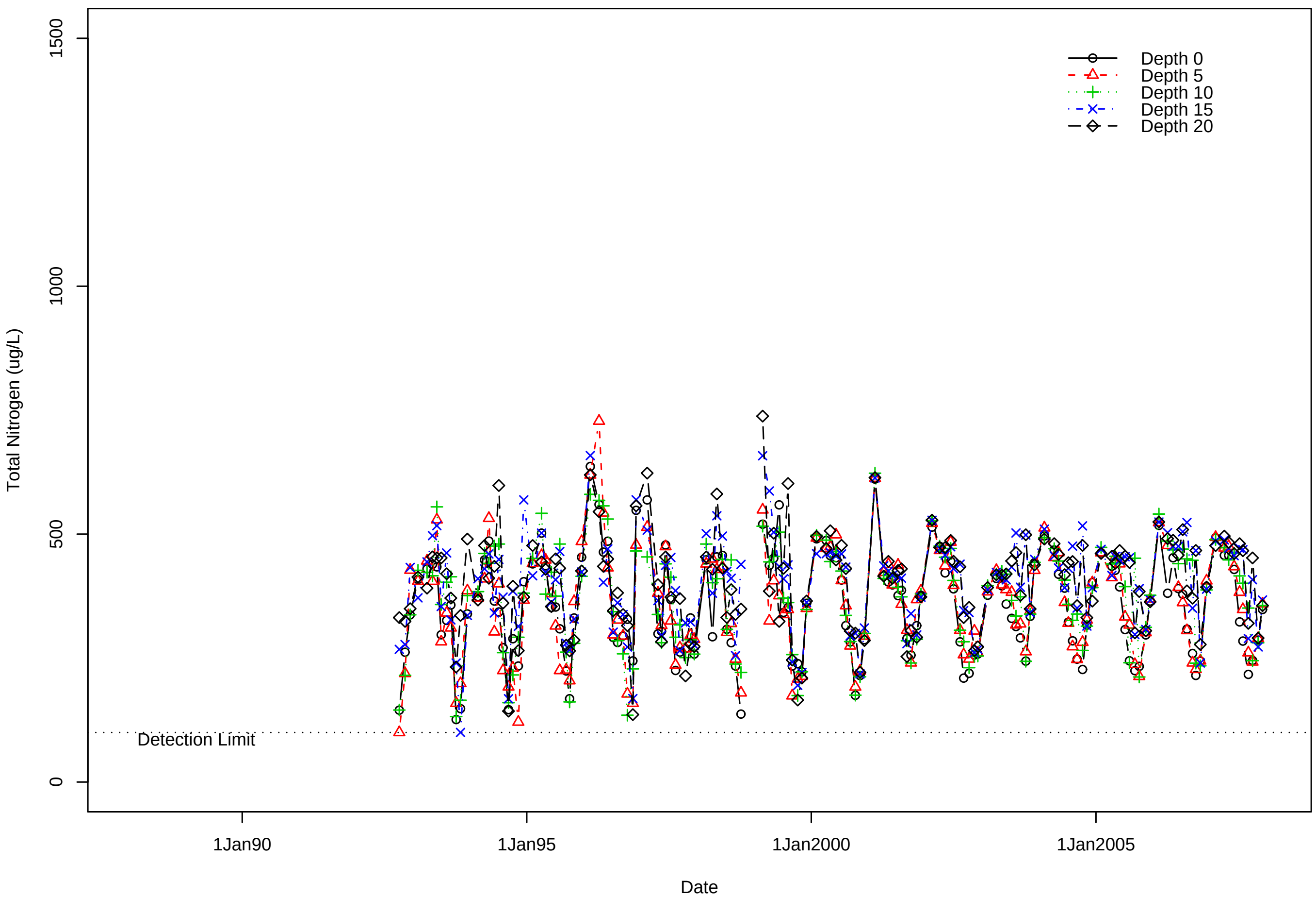


Figure B91: Lake Whatcom total nitrogen data for Site 1.

Lake Whatcom total nitrogen data for Site 2, February 1988 through December 2007.

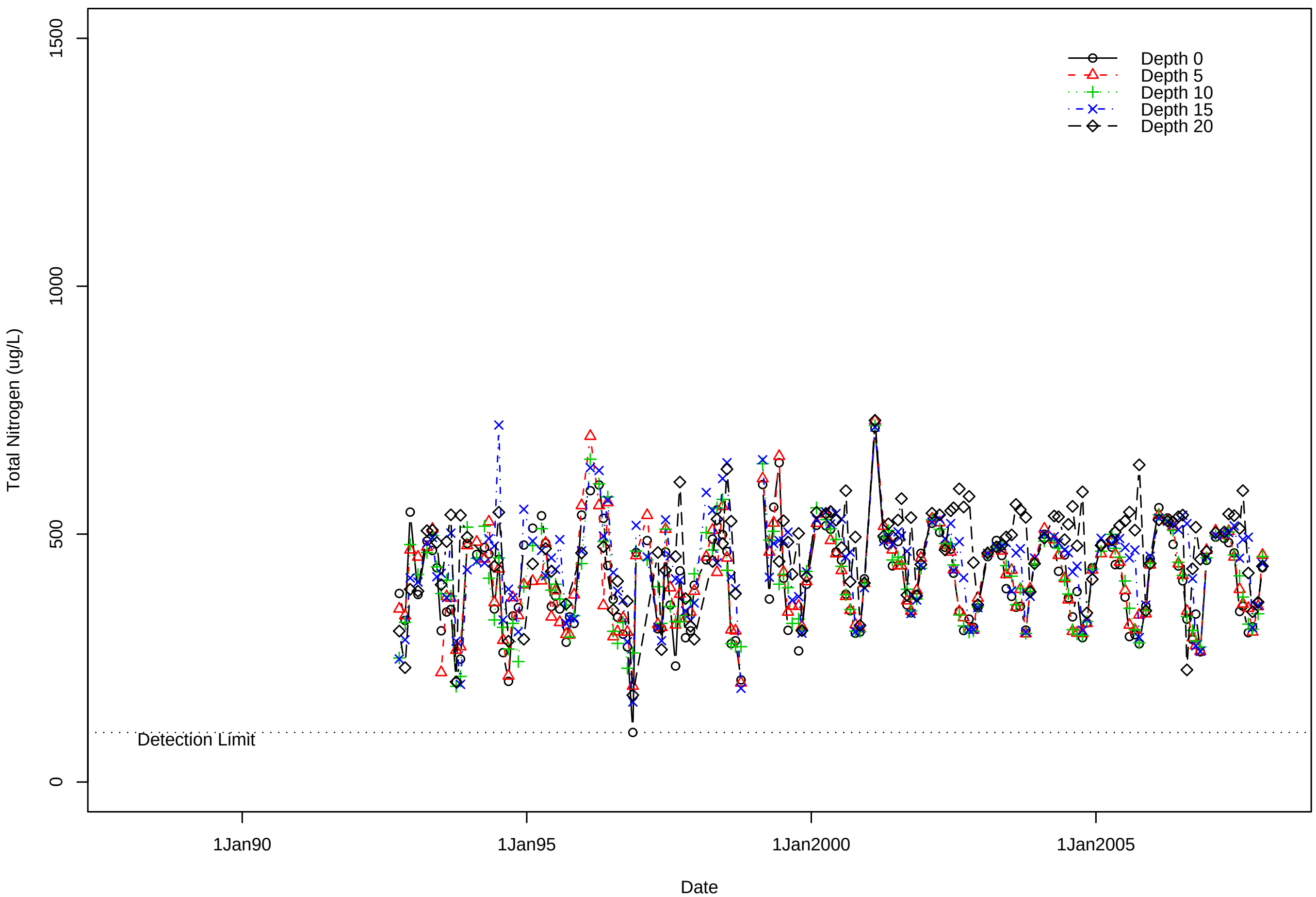


Figure B92: Lake Whatcom total nitrogen data for Site 2.

Lake Whatcom total nitrogen data for Intake, February 1988 through December 2007.

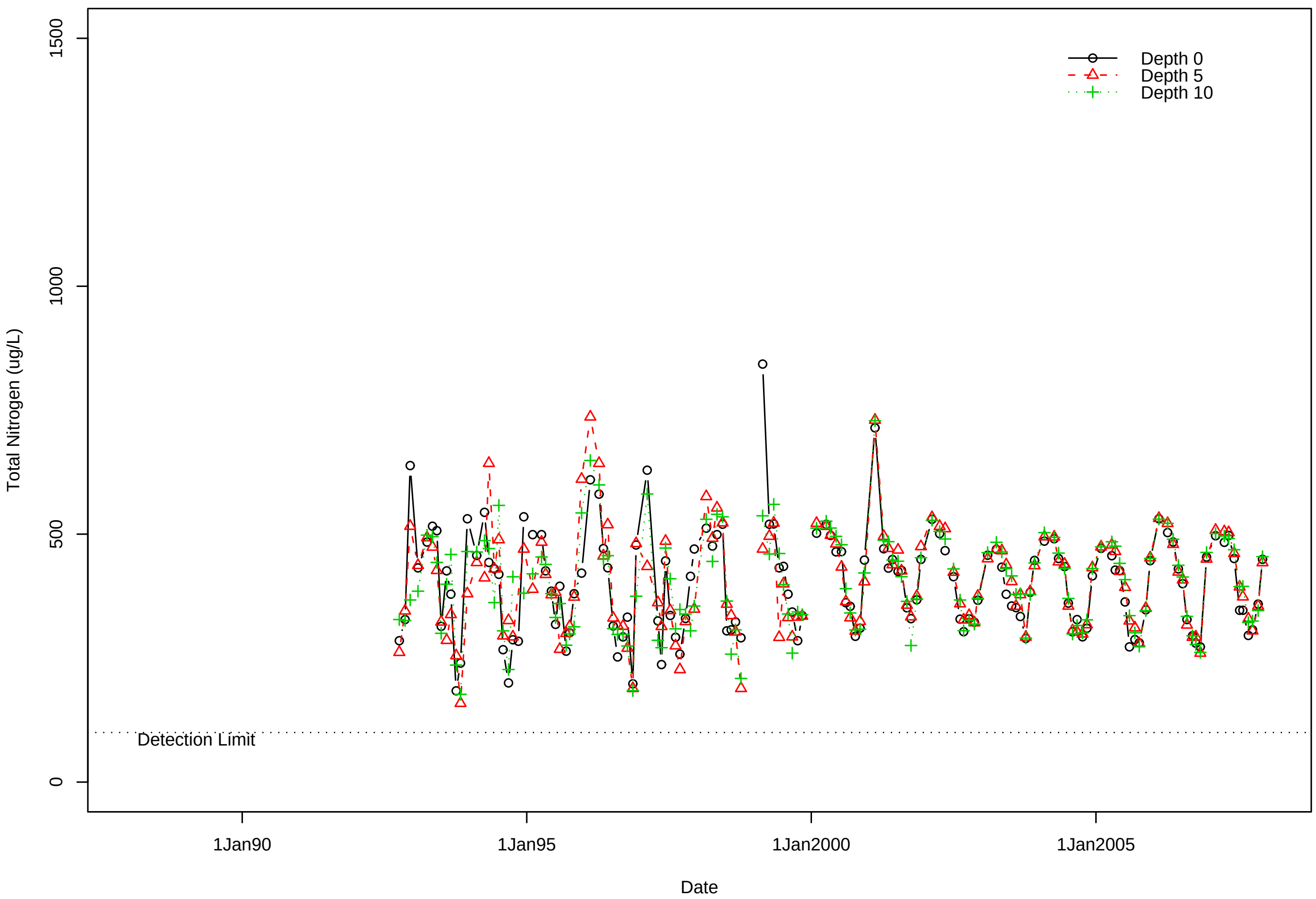


Figure B93: Lake Whatcom total nitrogen data for the Intake site.

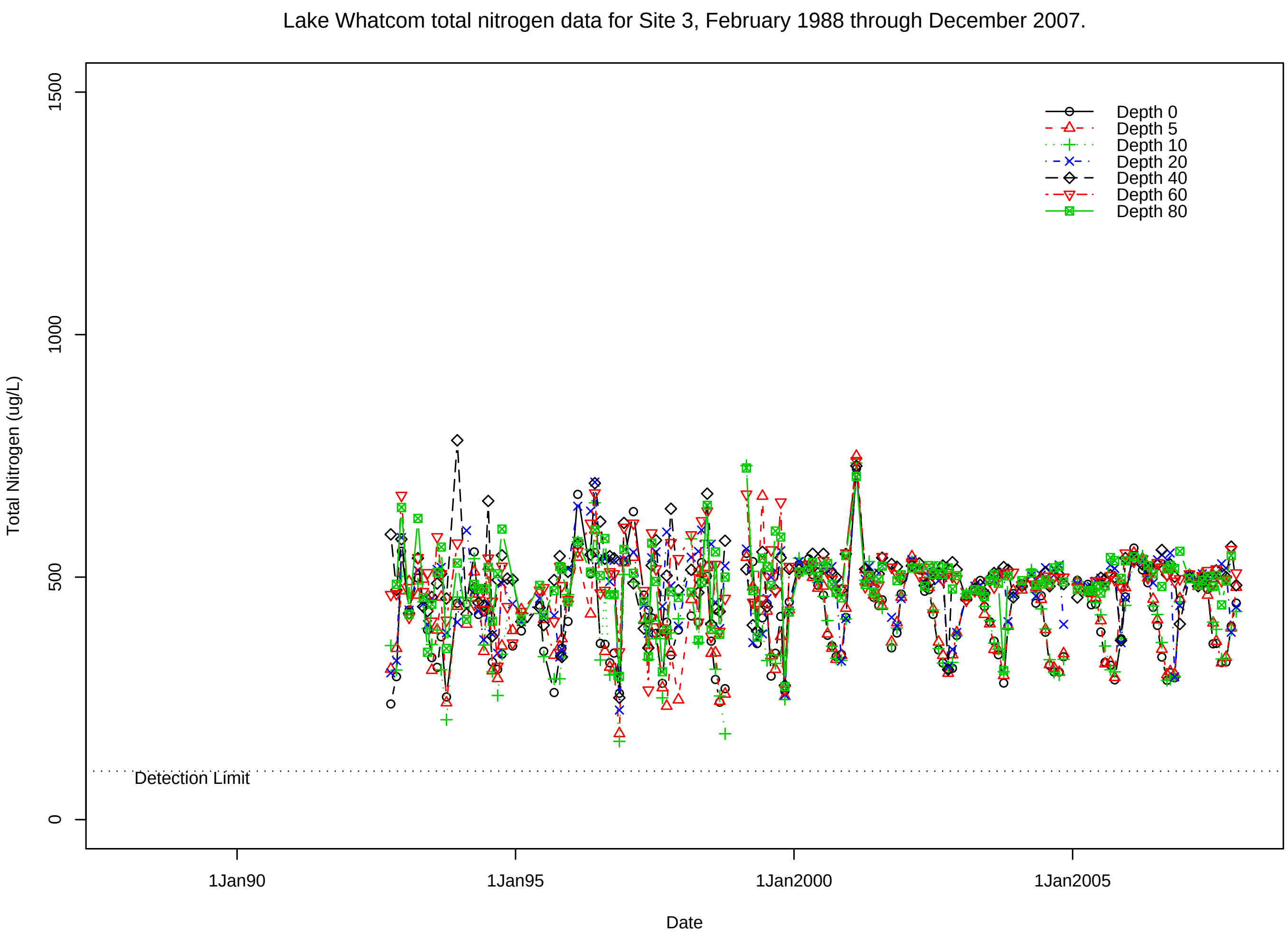
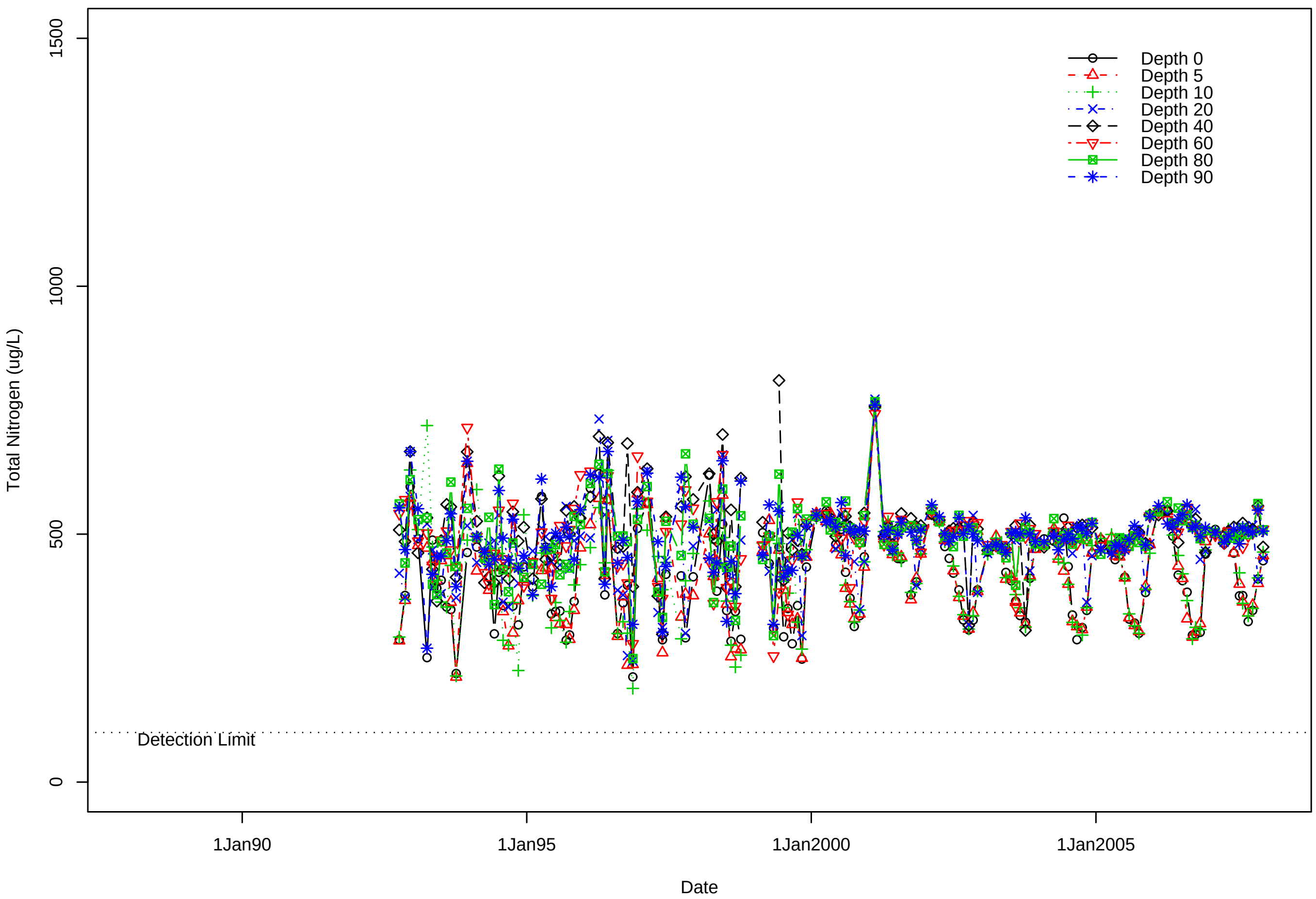


Figure B94: Lake Whatcom total nitrogen data for Site 3.

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

Lake Whatcom total nitrogen data for Site 4, February 1988 through December 2007.



Lake Whatcom soluble reactive phosphate data for Site 1, February 1988 through December 2007.

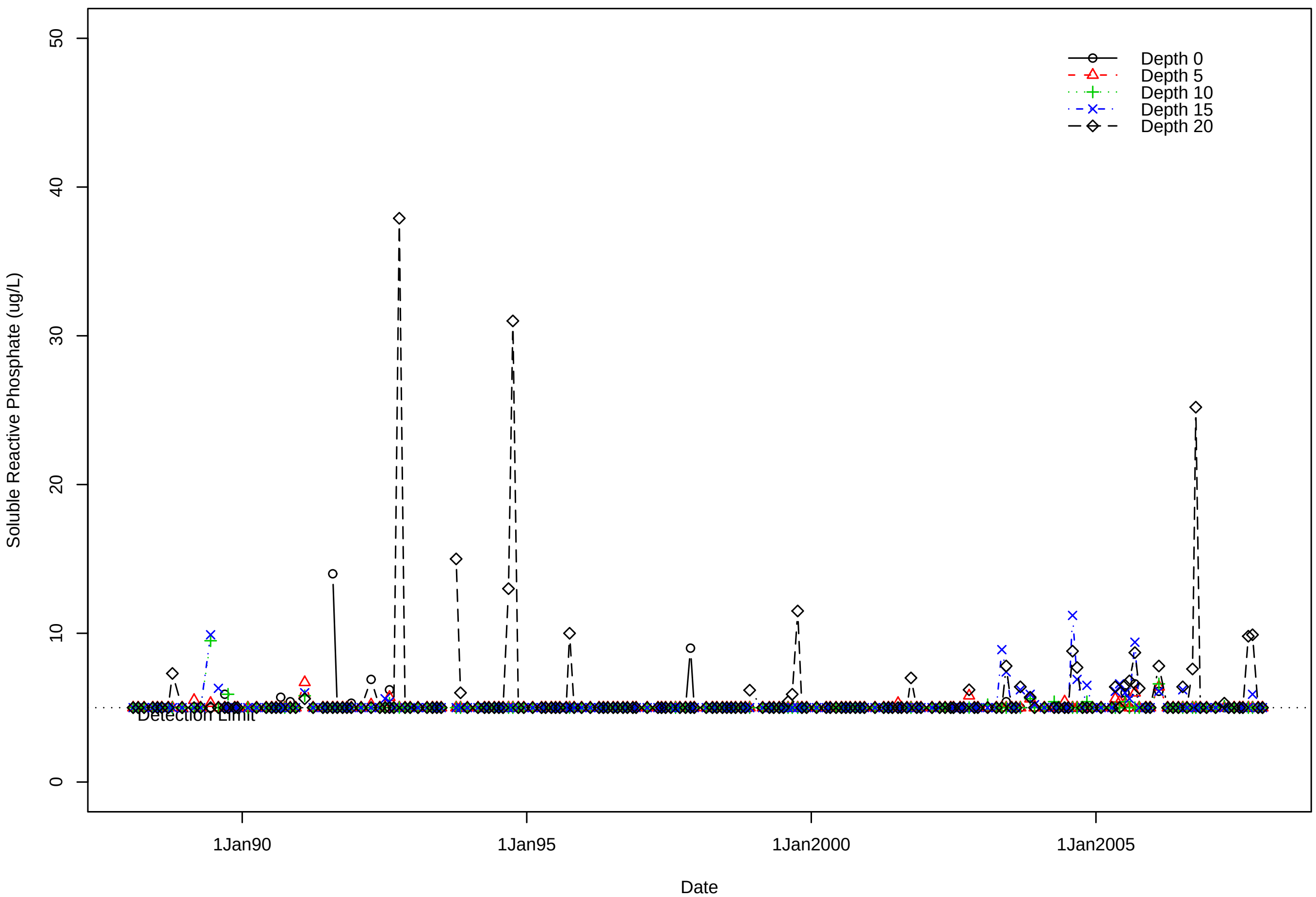


Figure B96: Lake Whatcom soluble phosphate data for Site 1.

Lake Whatcom soluble reactive phosphate data for Site 2, February 1988 through December 2007.

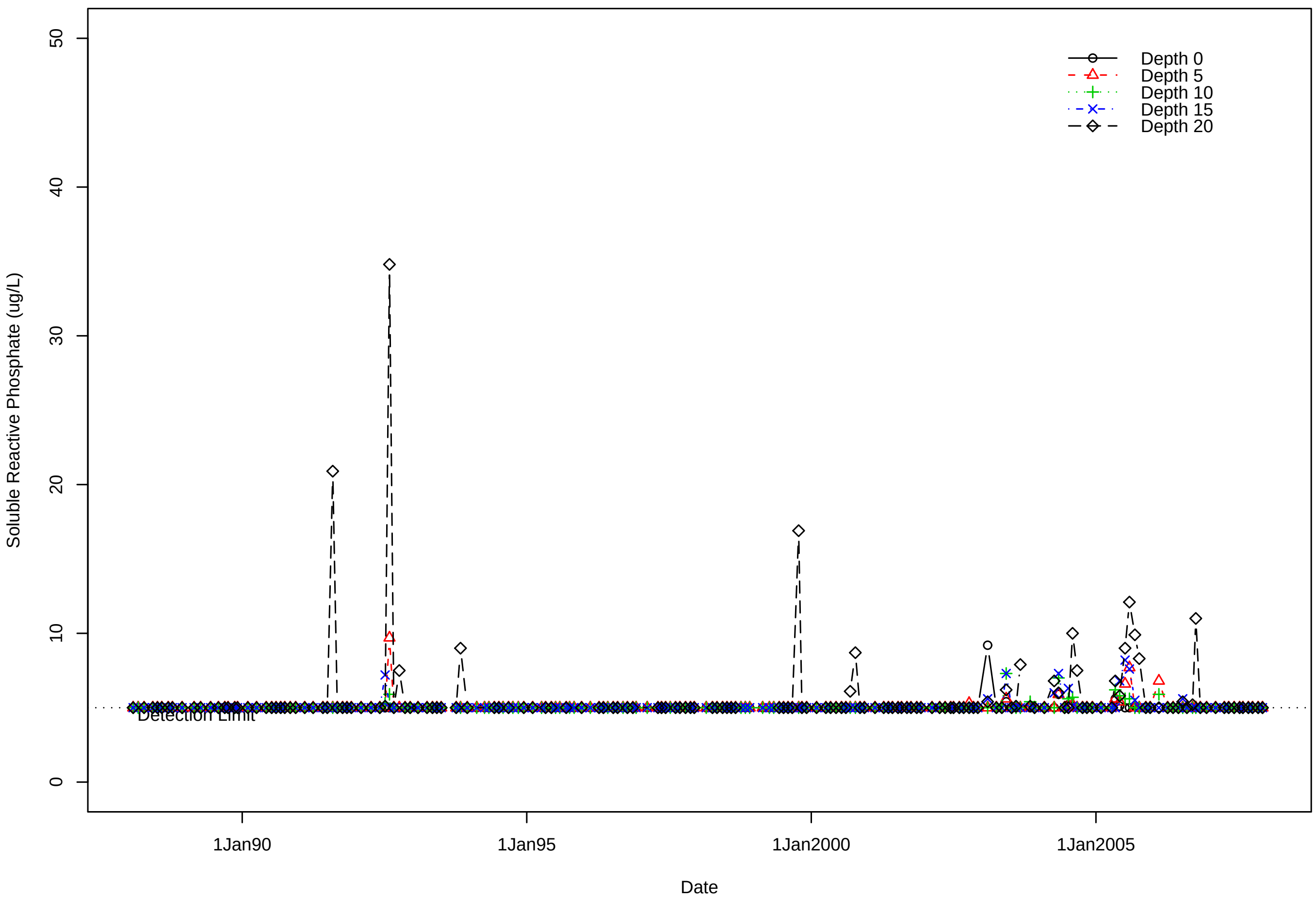


Figure B97: Lake Whatcom soluble phosphate data for Site 2.

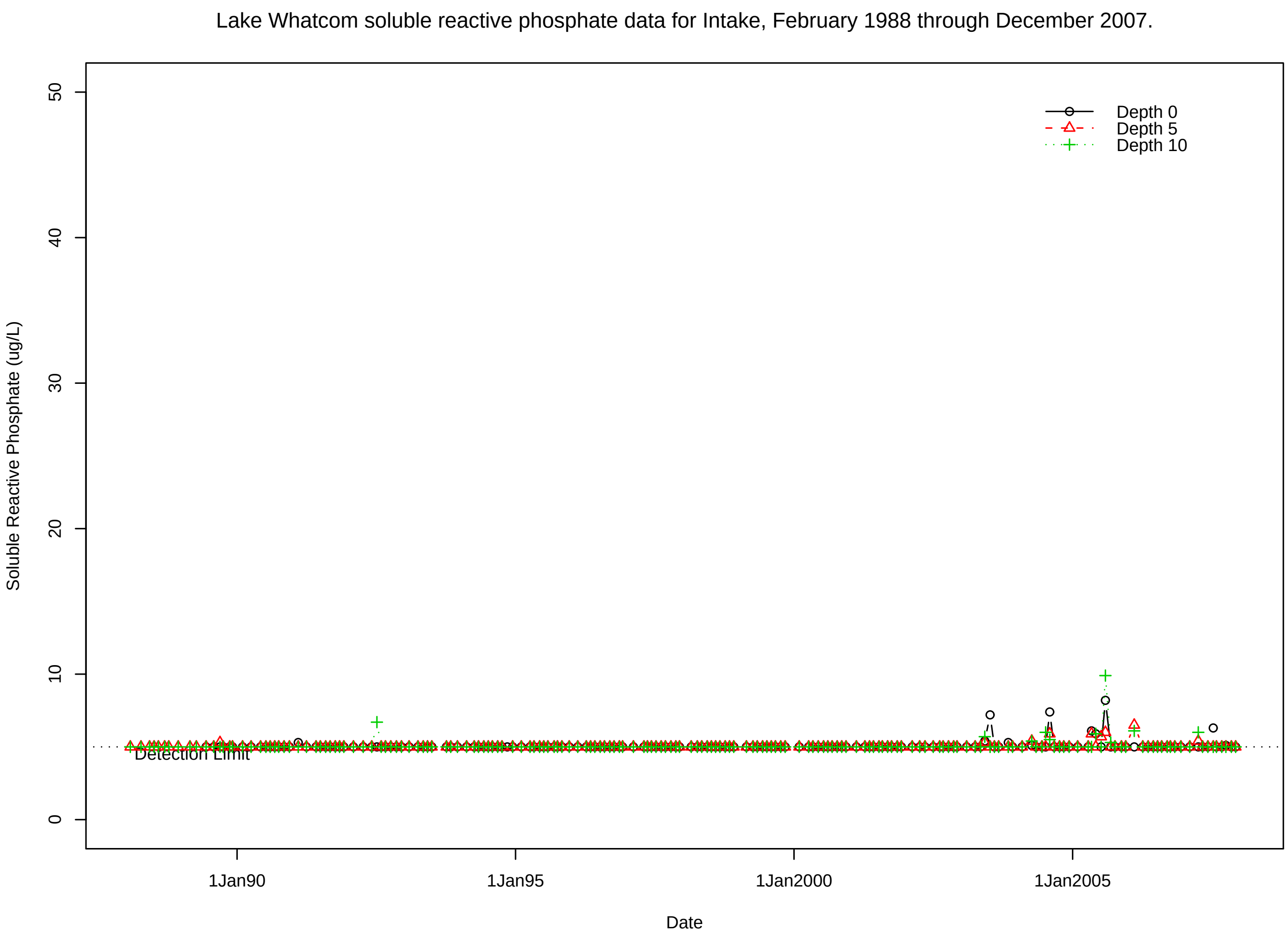


Figure B98: Lake Whatcom soluble phosphate data for the Intake site.

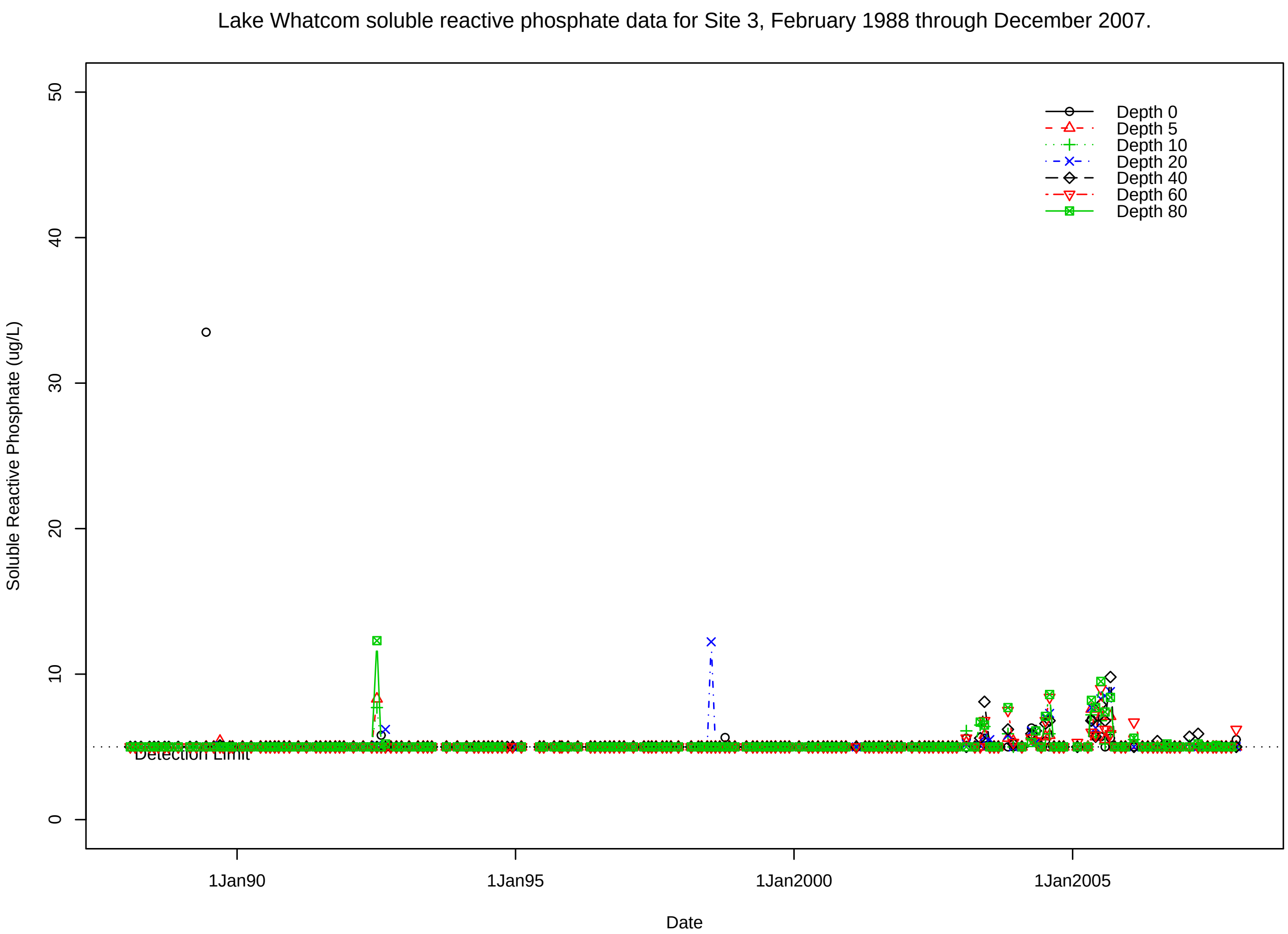


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

Lake Whatcom soluble reactive phosphate data for Site 4, February 1988 through December 2007.

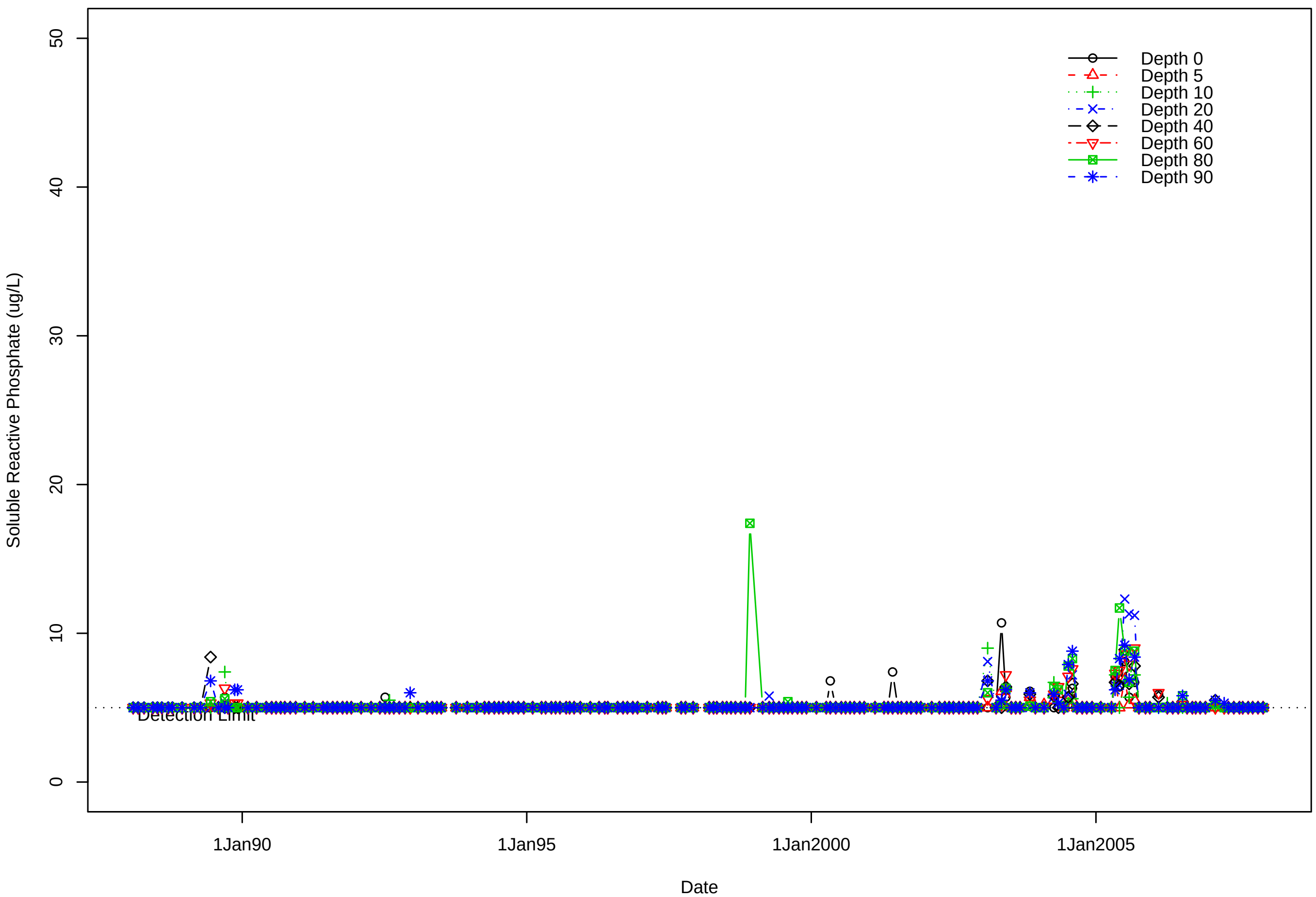


Figure B100: Lake Whatcom soluble phosphate data for Site 4.

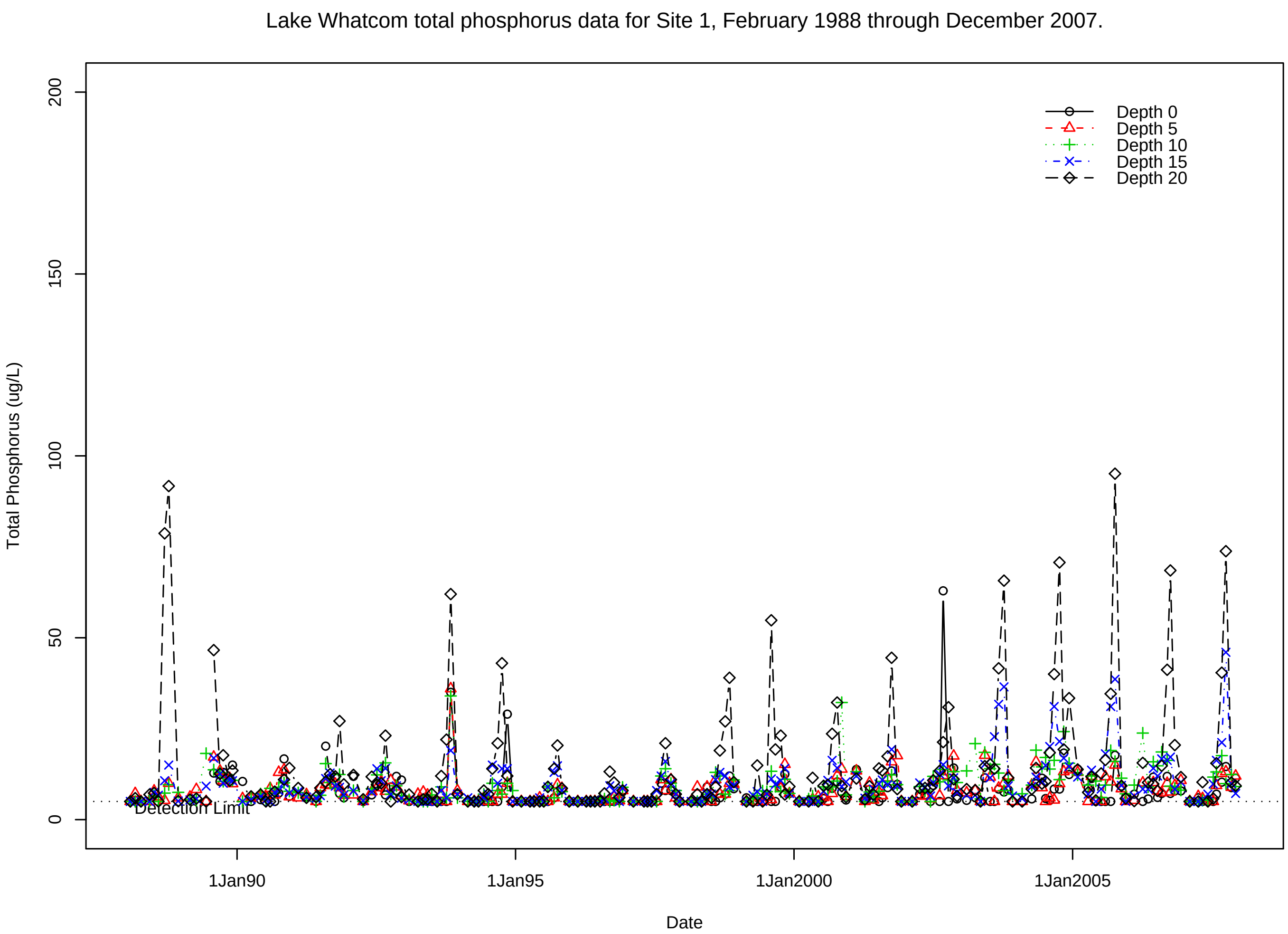


Figure B101: Lake Whatcom total phosphorus data for Site 1.

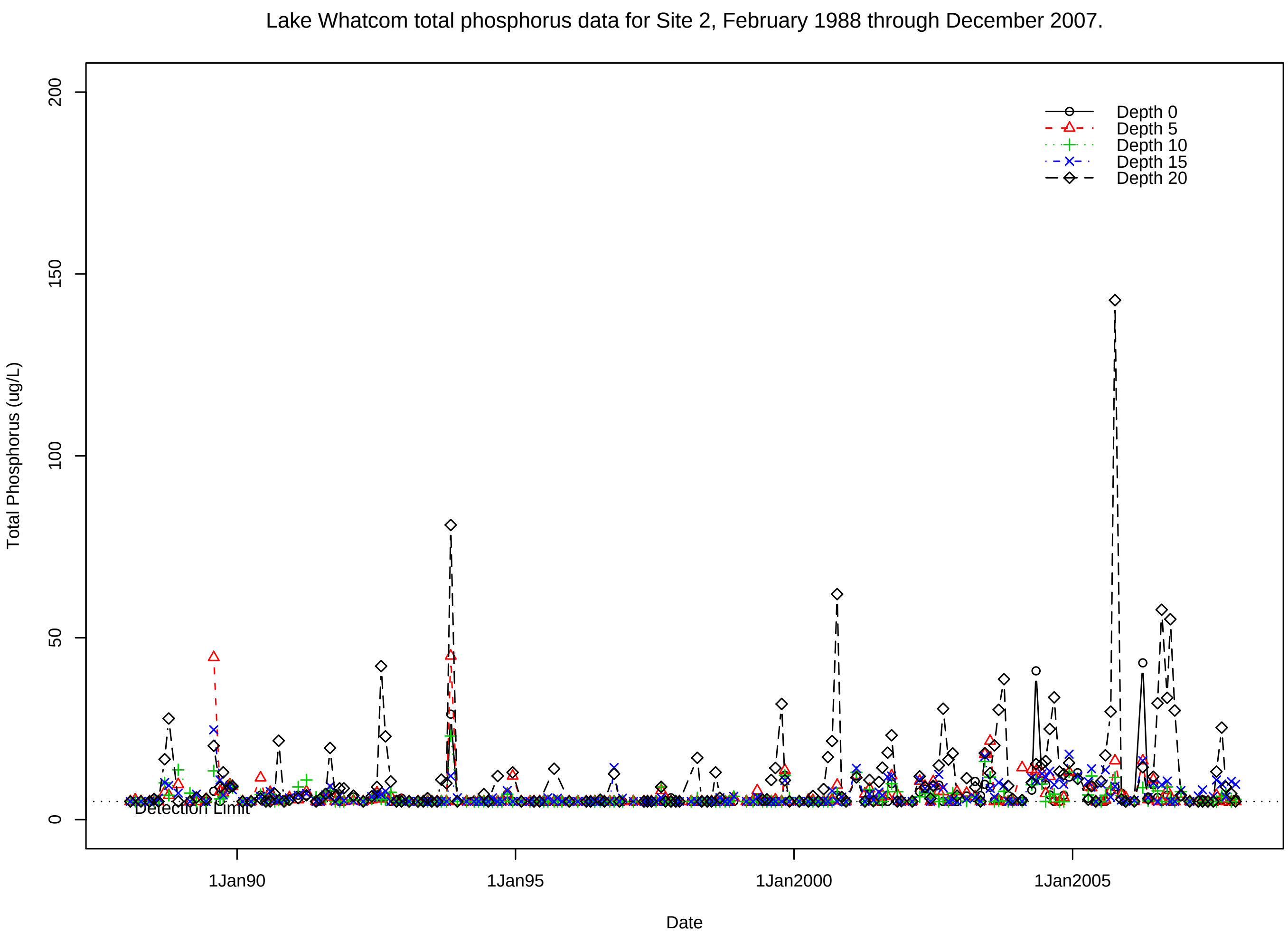


Figure B102: Lake Whatcom total phosphorus data for Site 2.

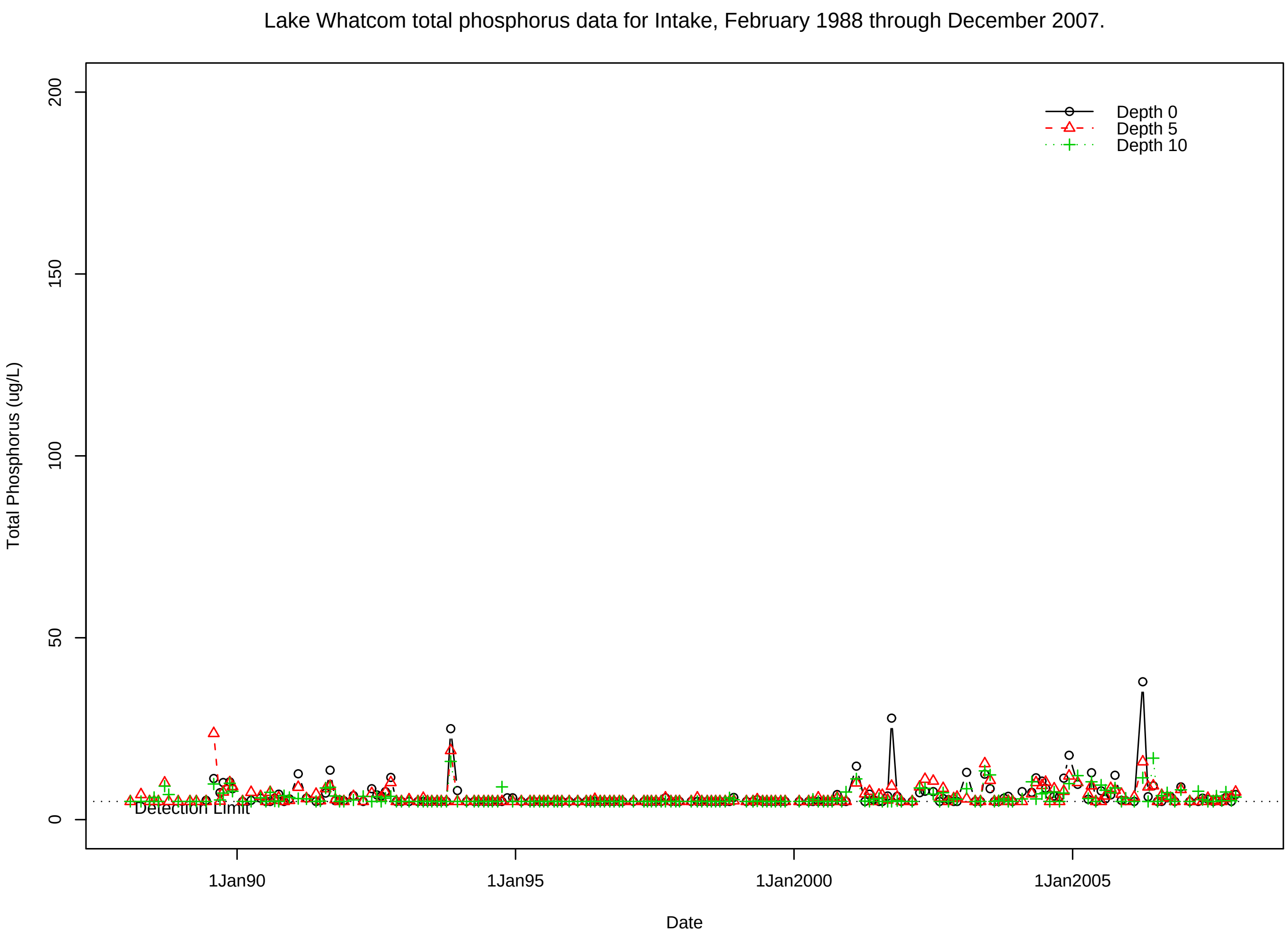


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

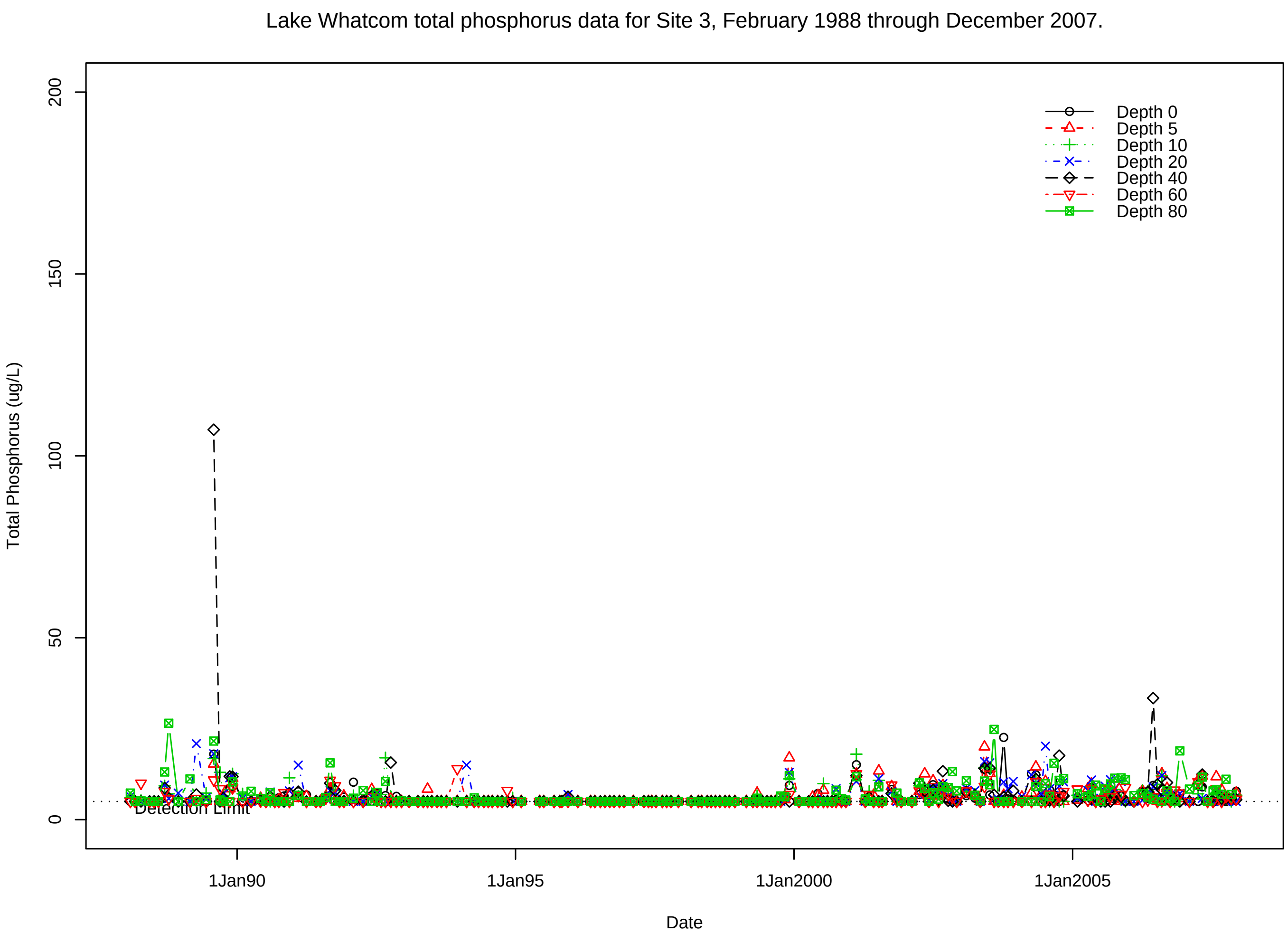


Figure B104: Lake Whatcom total phosphorus data for Site 3.

Lake Whatcom total phosphorus data for Site 4, February 1988 through December 2007.

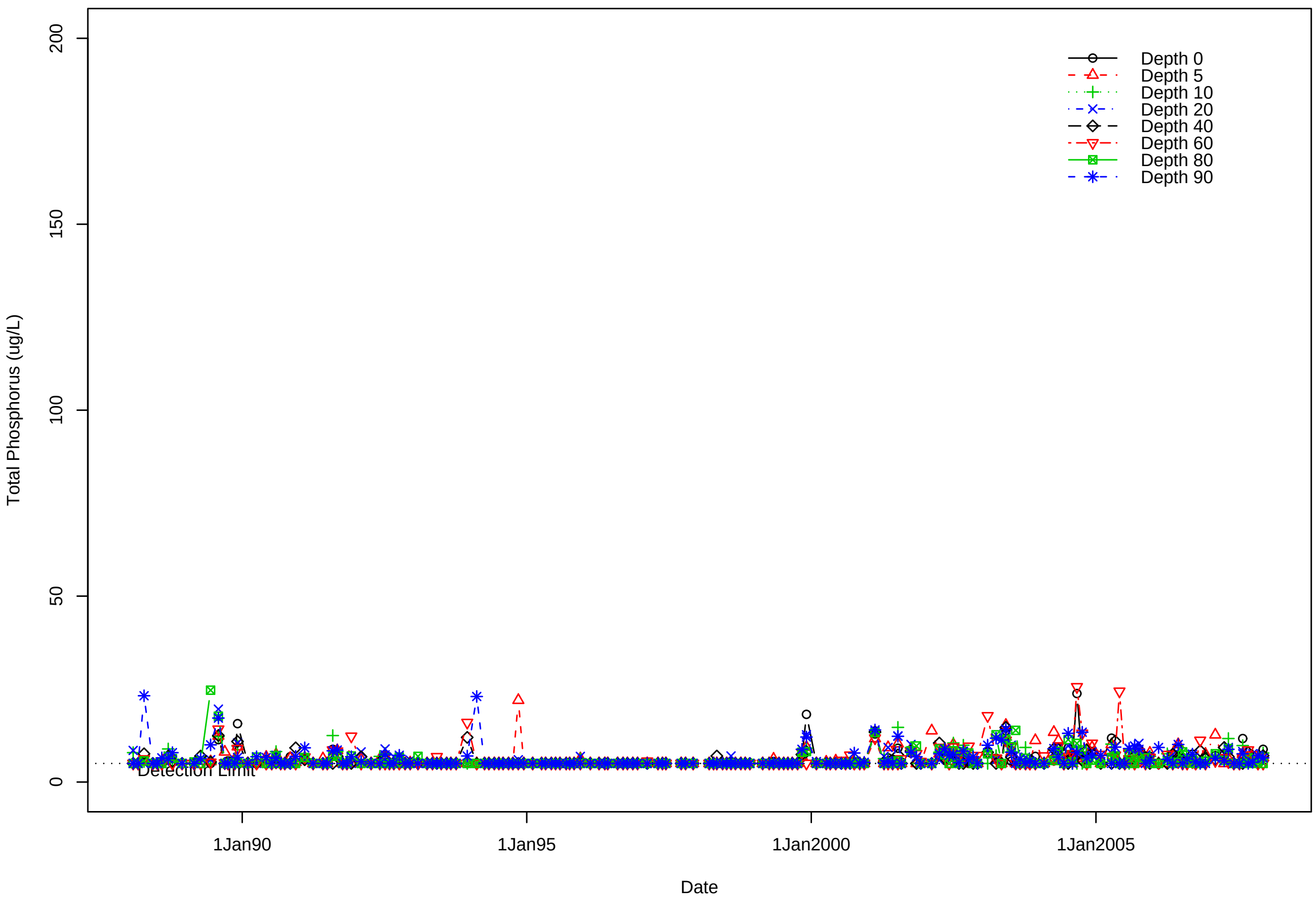


Figure B105: Lake Whatcom total phosphorus data for Site 4.

Lake Whatcom chlorophyll a data for Site 1, February 1988 through December 2007.

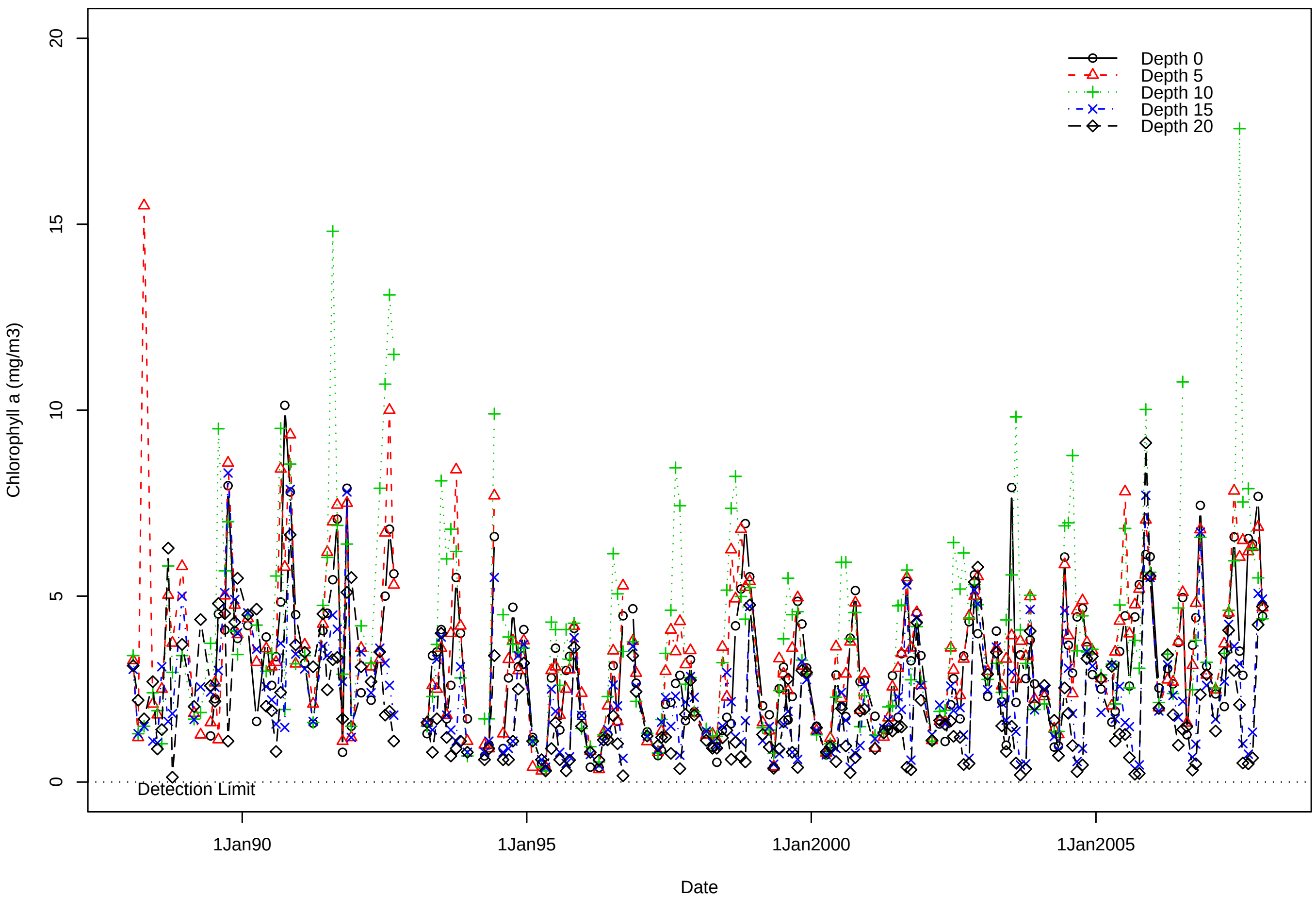


Figure B106: Lake Whatcom chlorophyll data for Site 1.

Lake Whatcom chlorophyll a data for Site 2, February 1988 through December 2007.

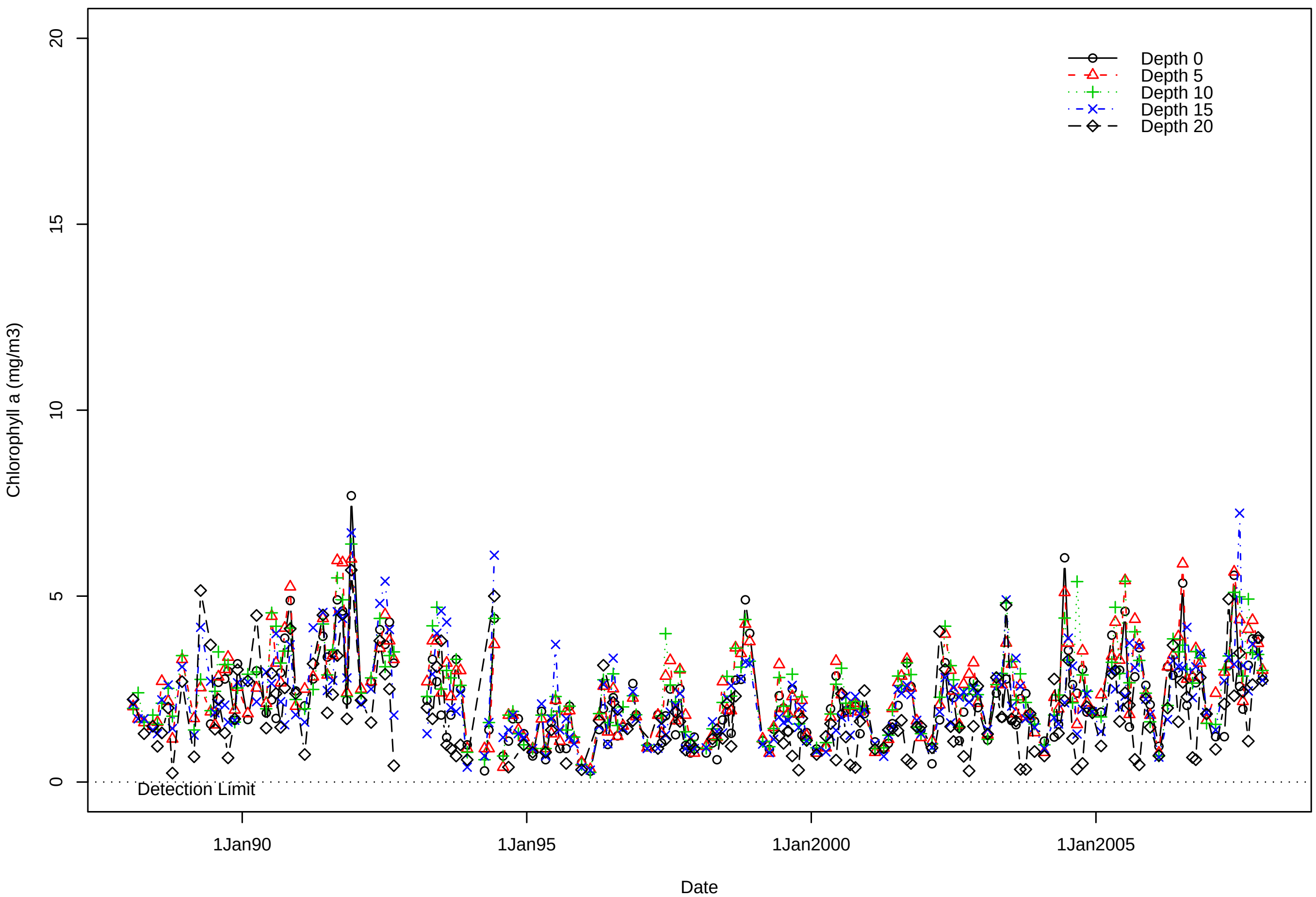


Figure B107: Lake Whatcom chlorophyll data for Site 2.

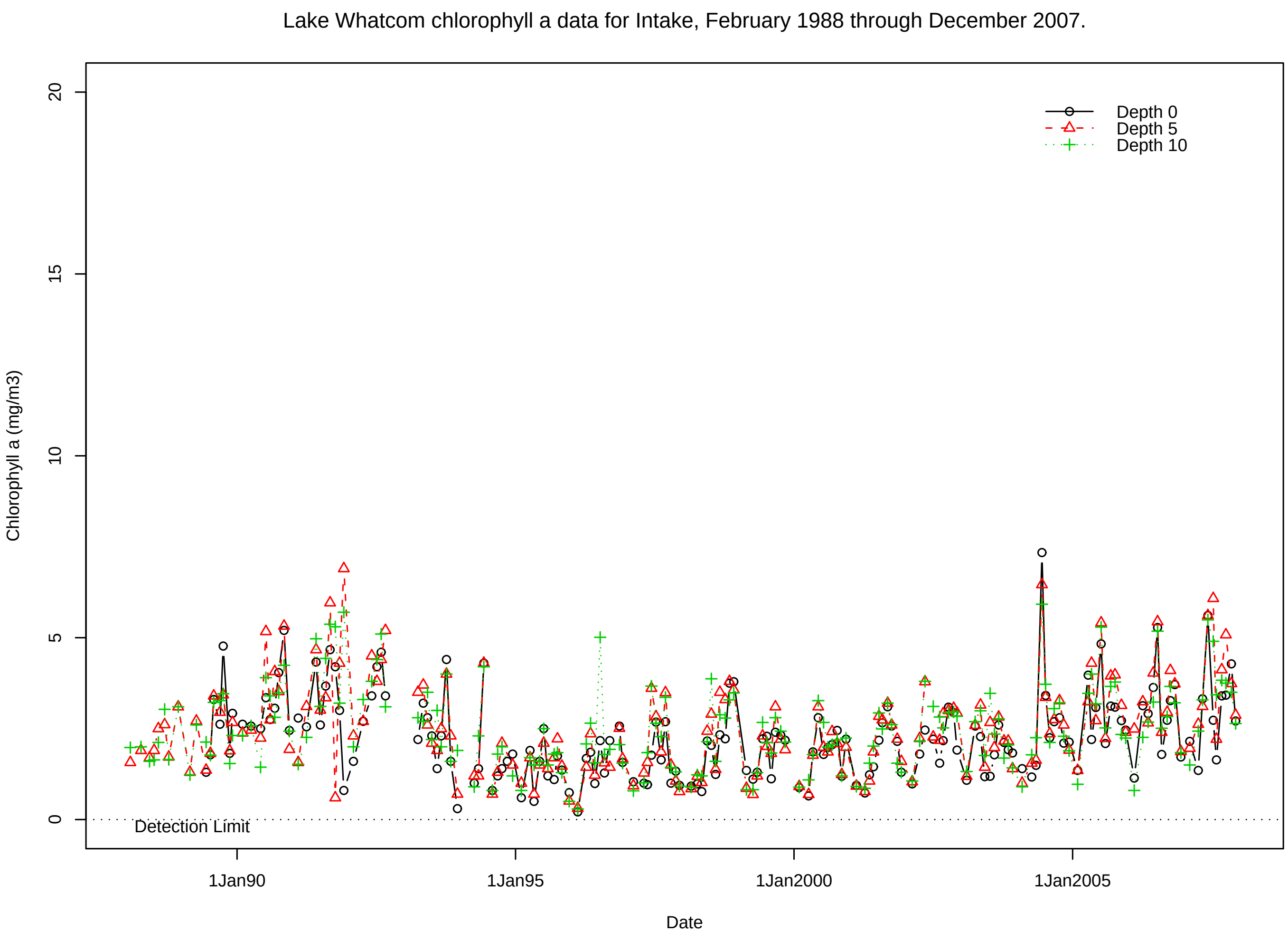


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

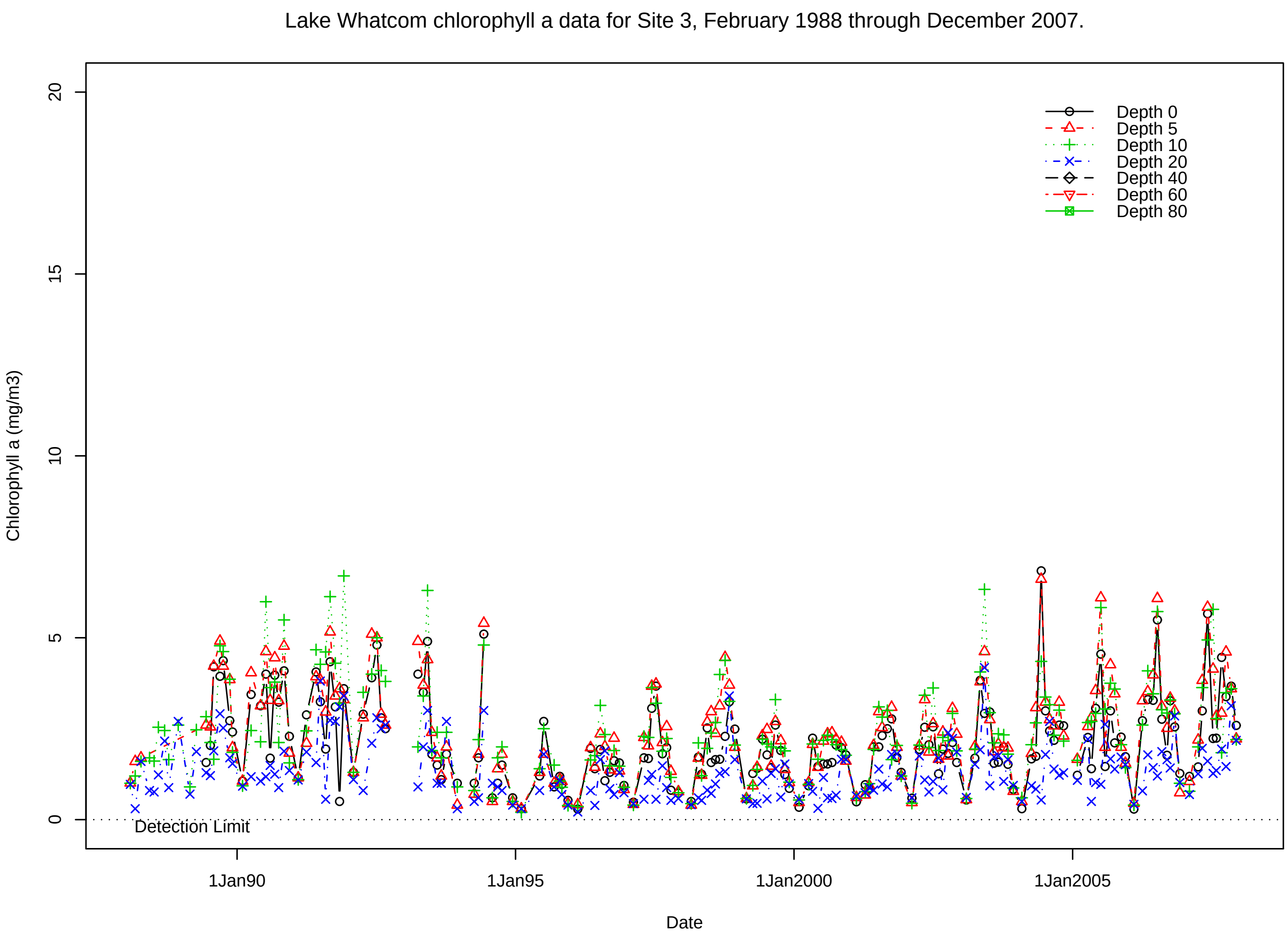


Figure B109: Lake Whatcom chlorophyll data for Site 3.

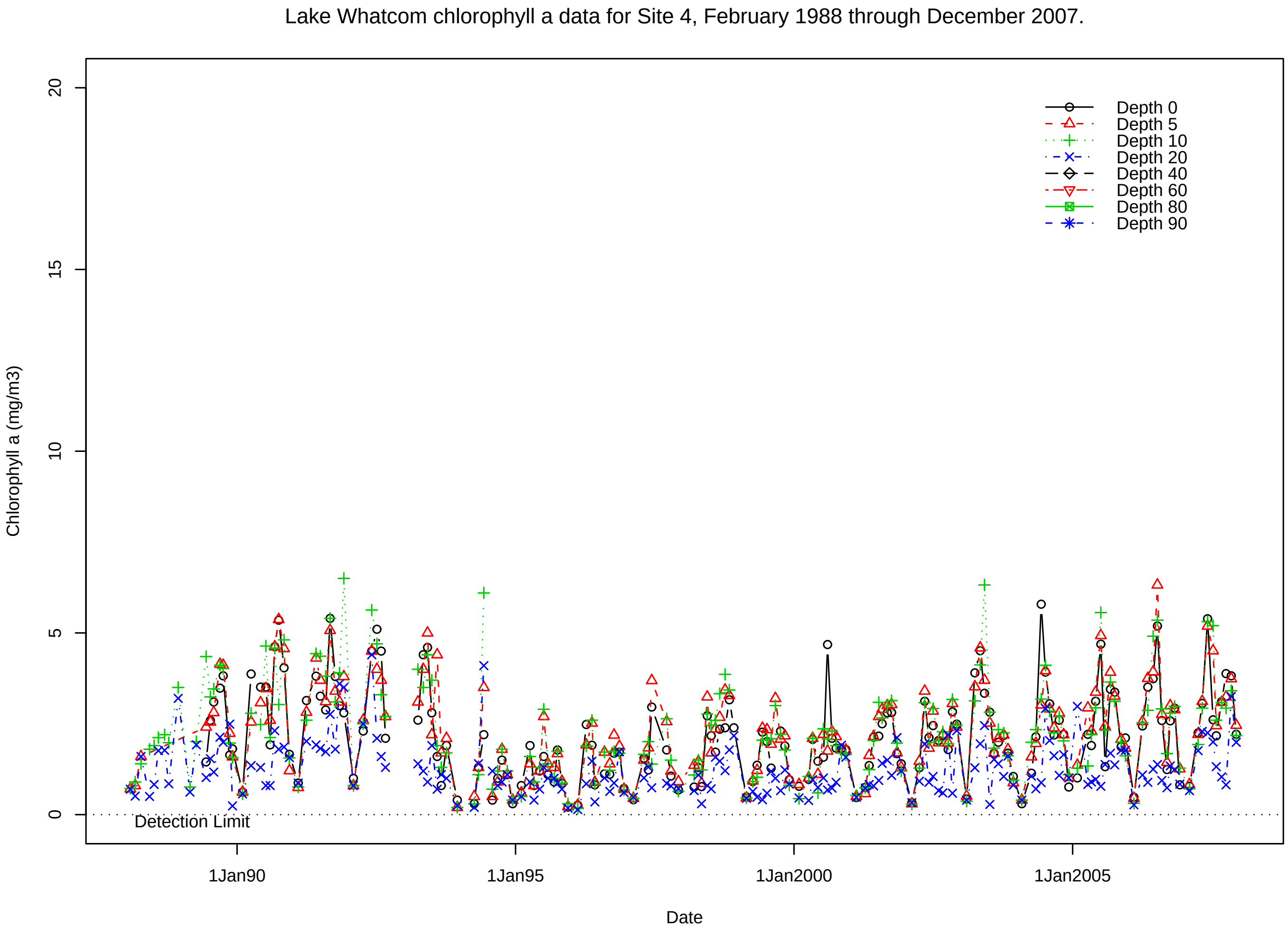


Figure B110: Lake Whatcom chlorophyll data for Site 4.

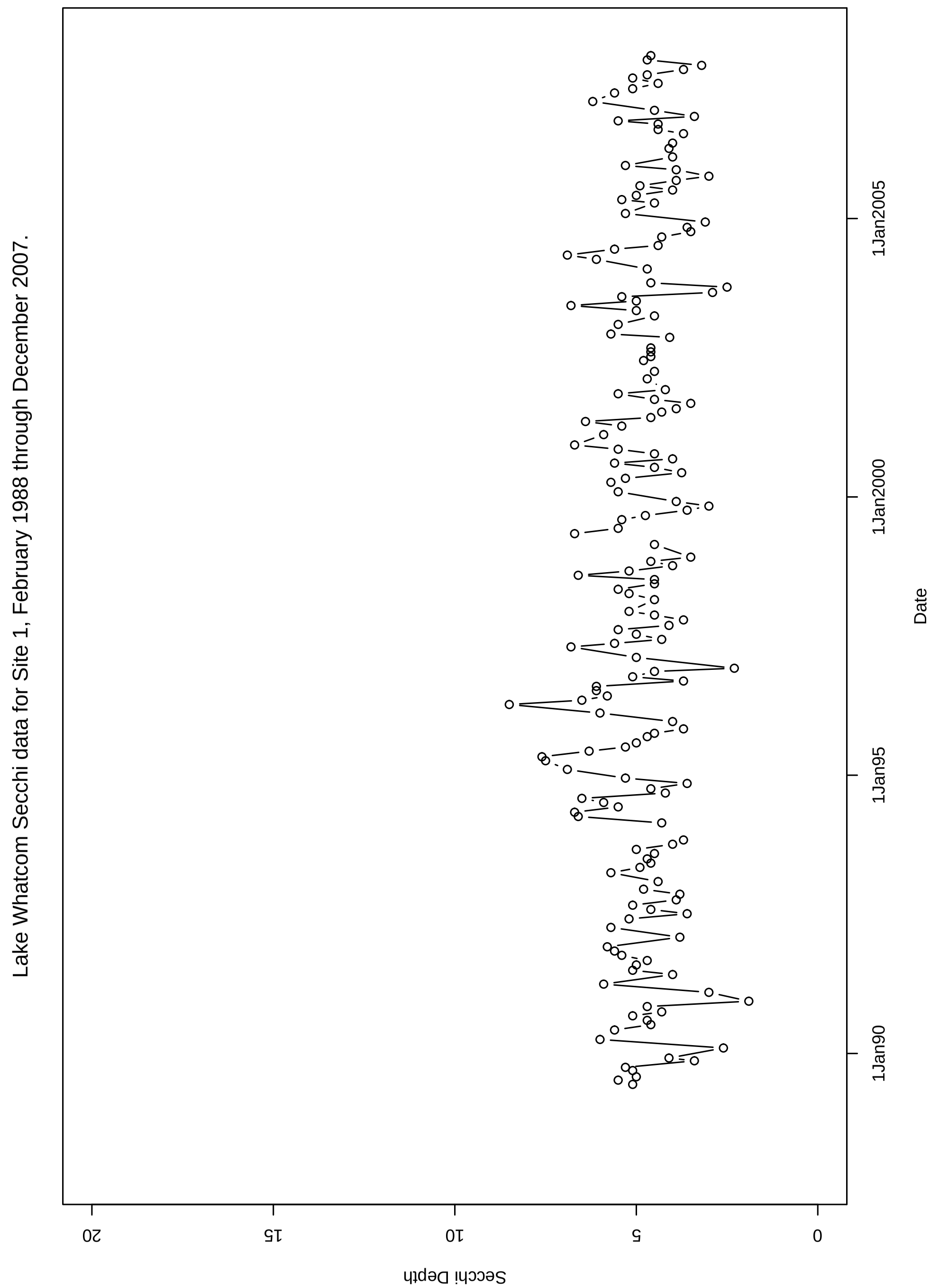
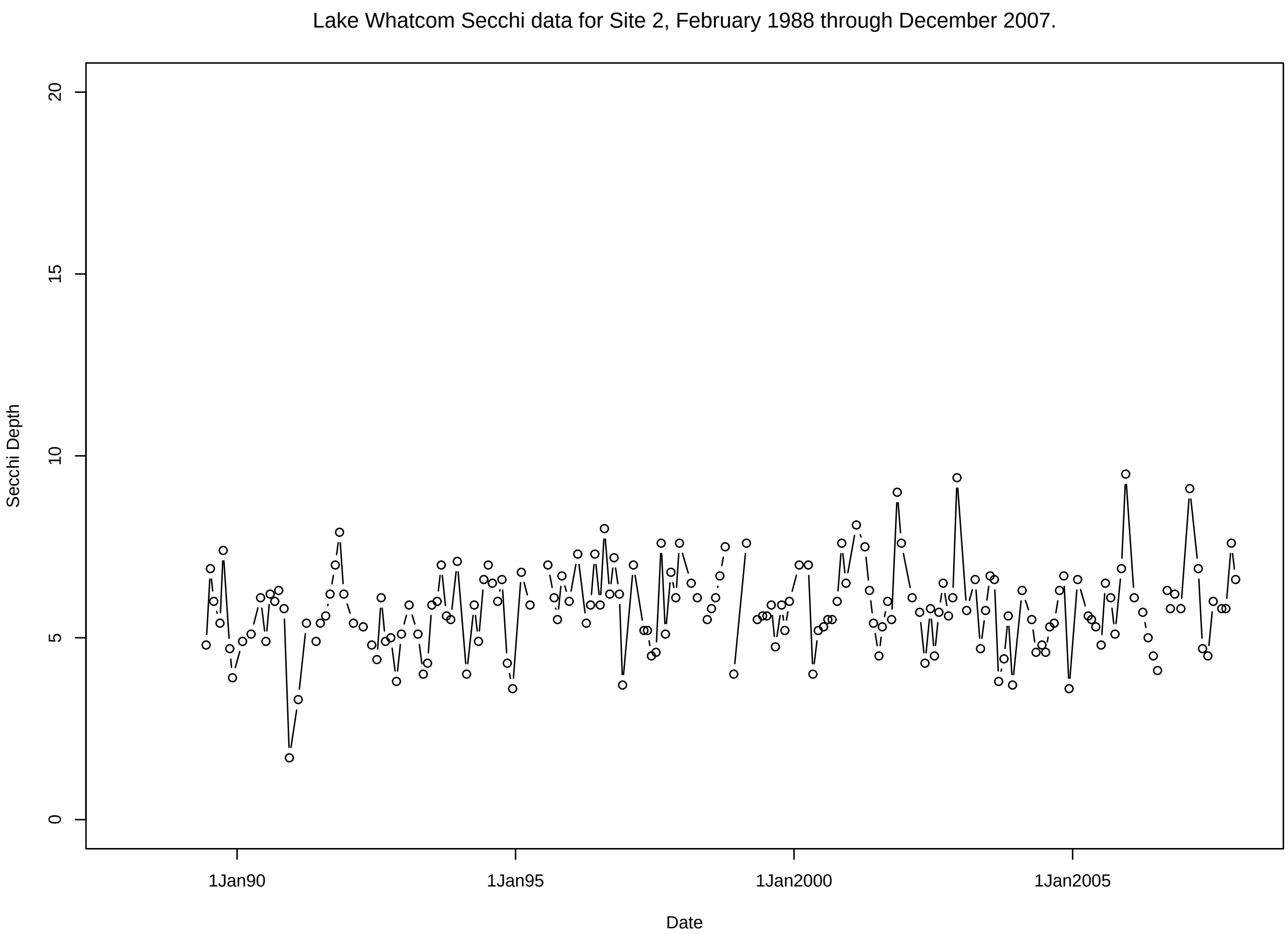


Figure B111: Lake Whatcom Secchi depths for Site 1.

Figure B112: Lake Whatcom Secchi depths for Site 2.



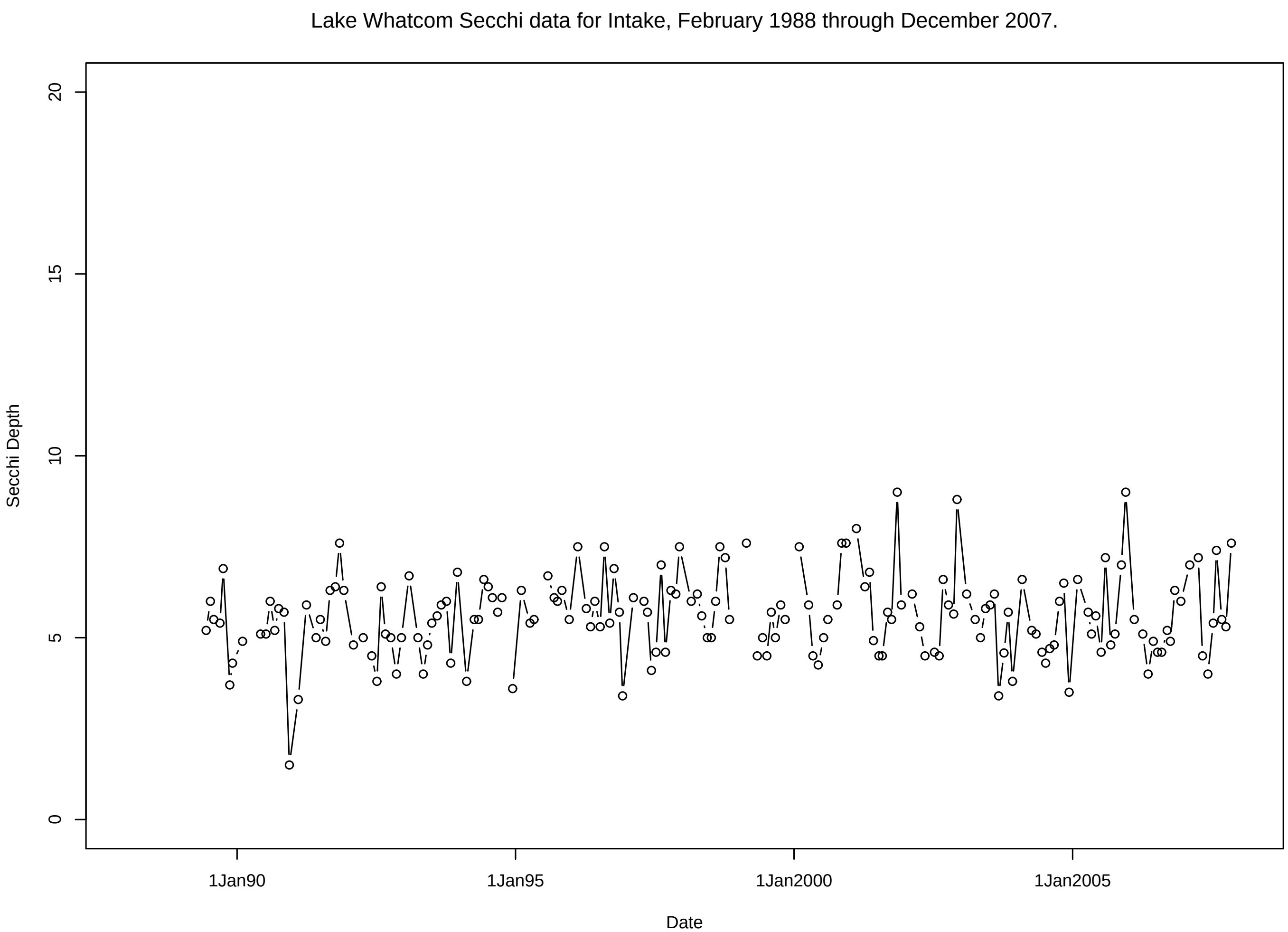


Figure B113: Lake Whatcom Secchi depths for the Intake site.

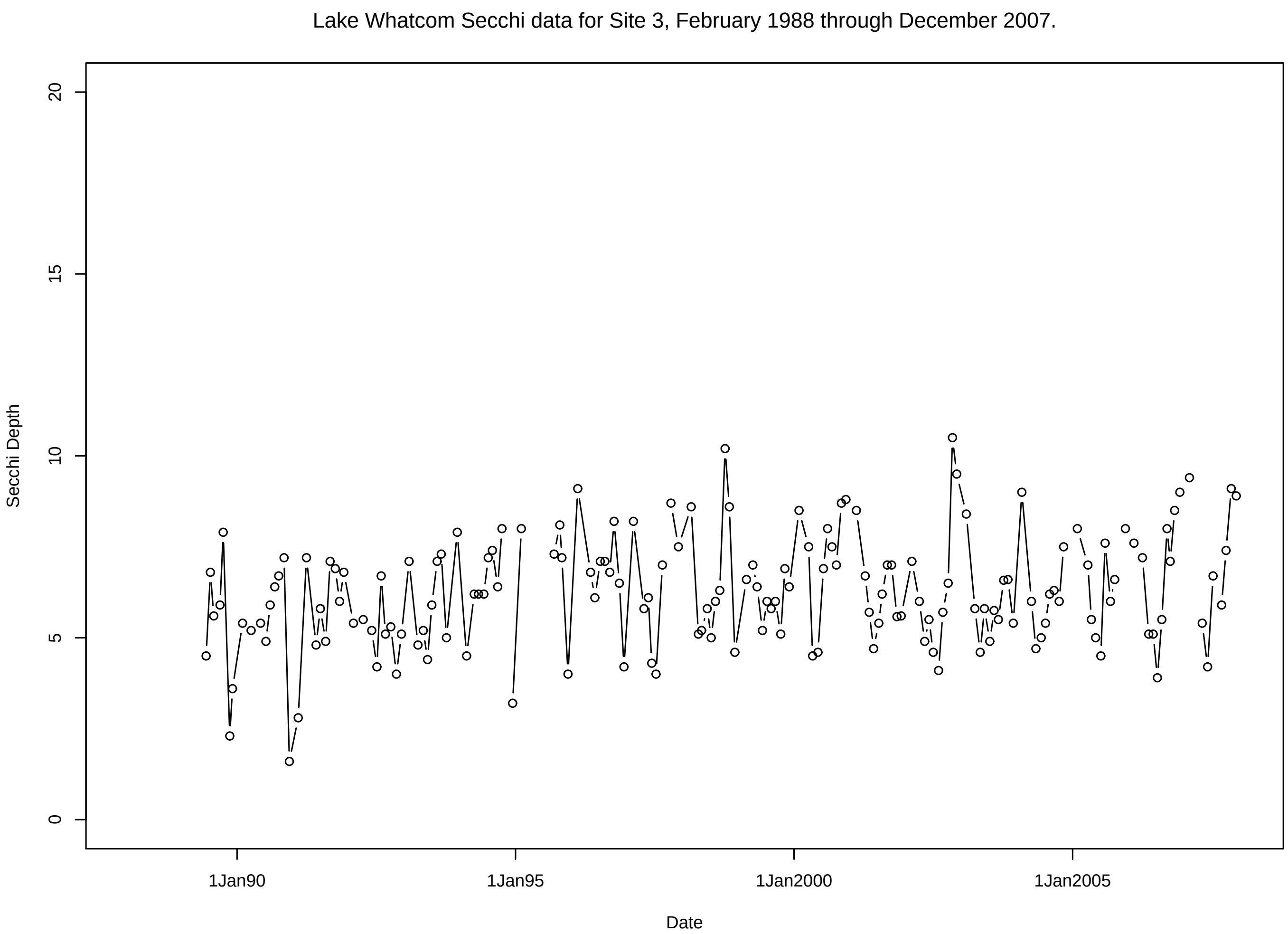


Figure B114: Lake Whatcom Secchi depths for Site 3.

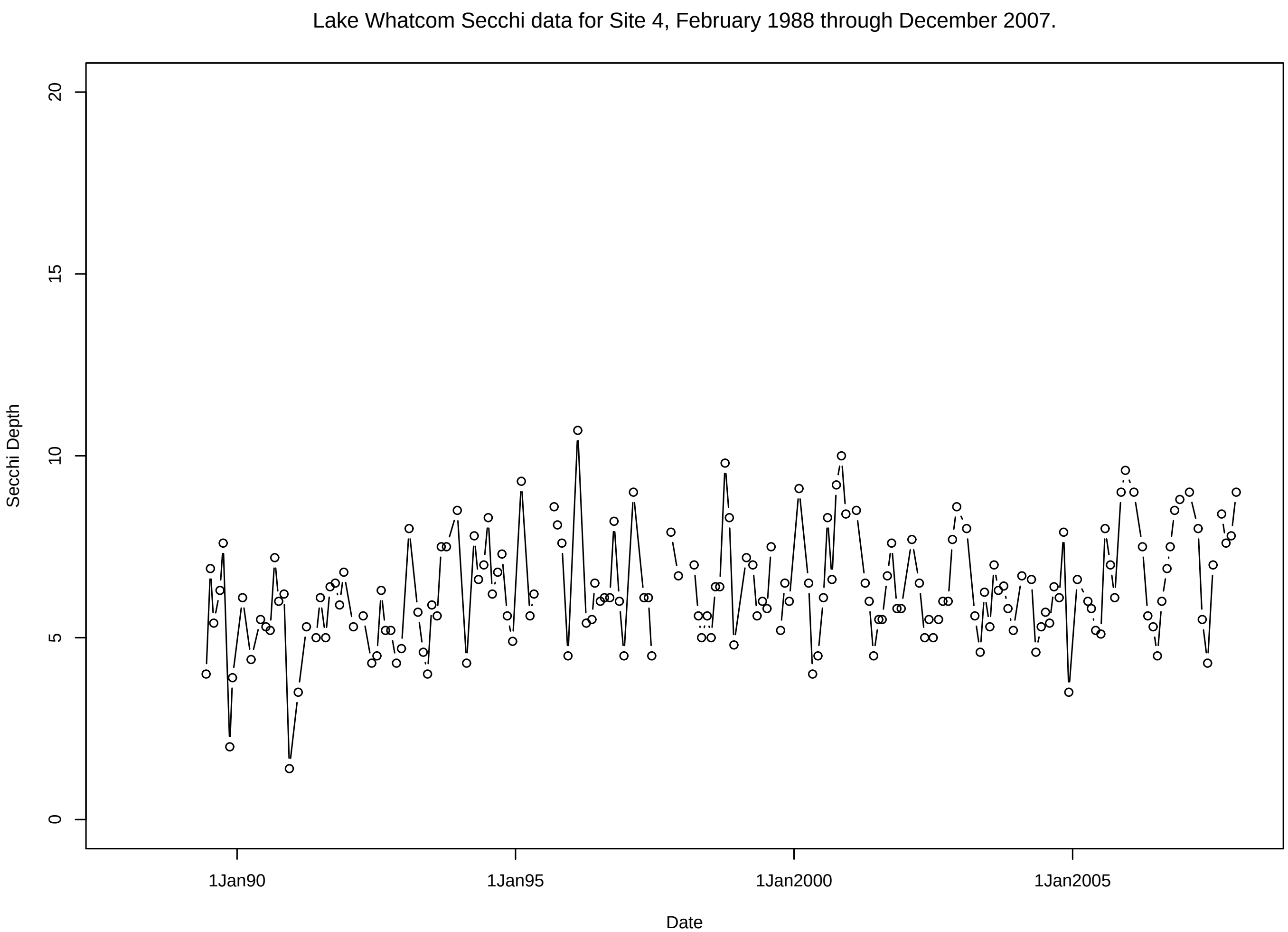


Figure B115: Lake Whatcom Secchi depths for Site 4.

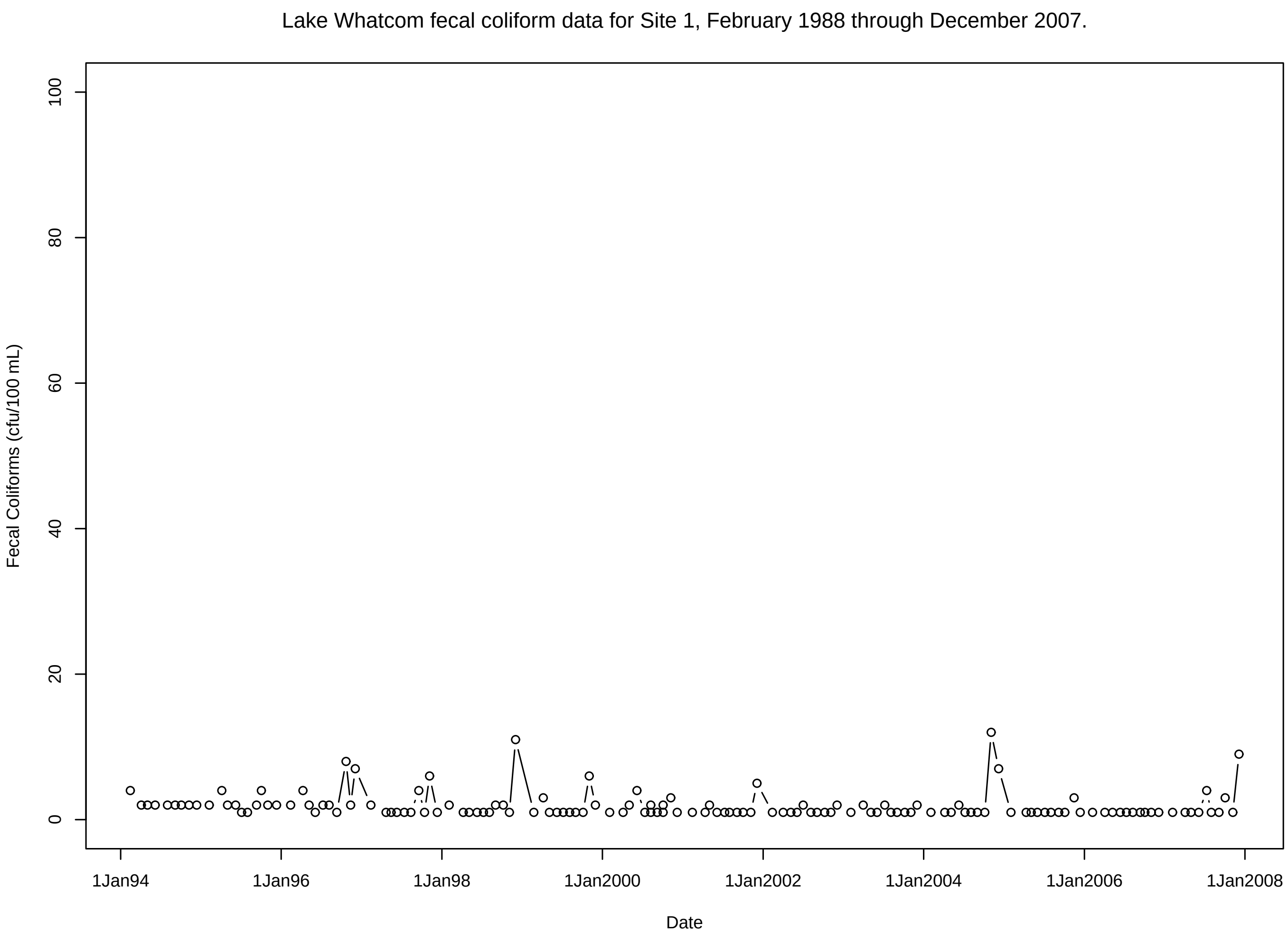


Figure B116: Lake Whatcom fecal coliform data for Site 1.

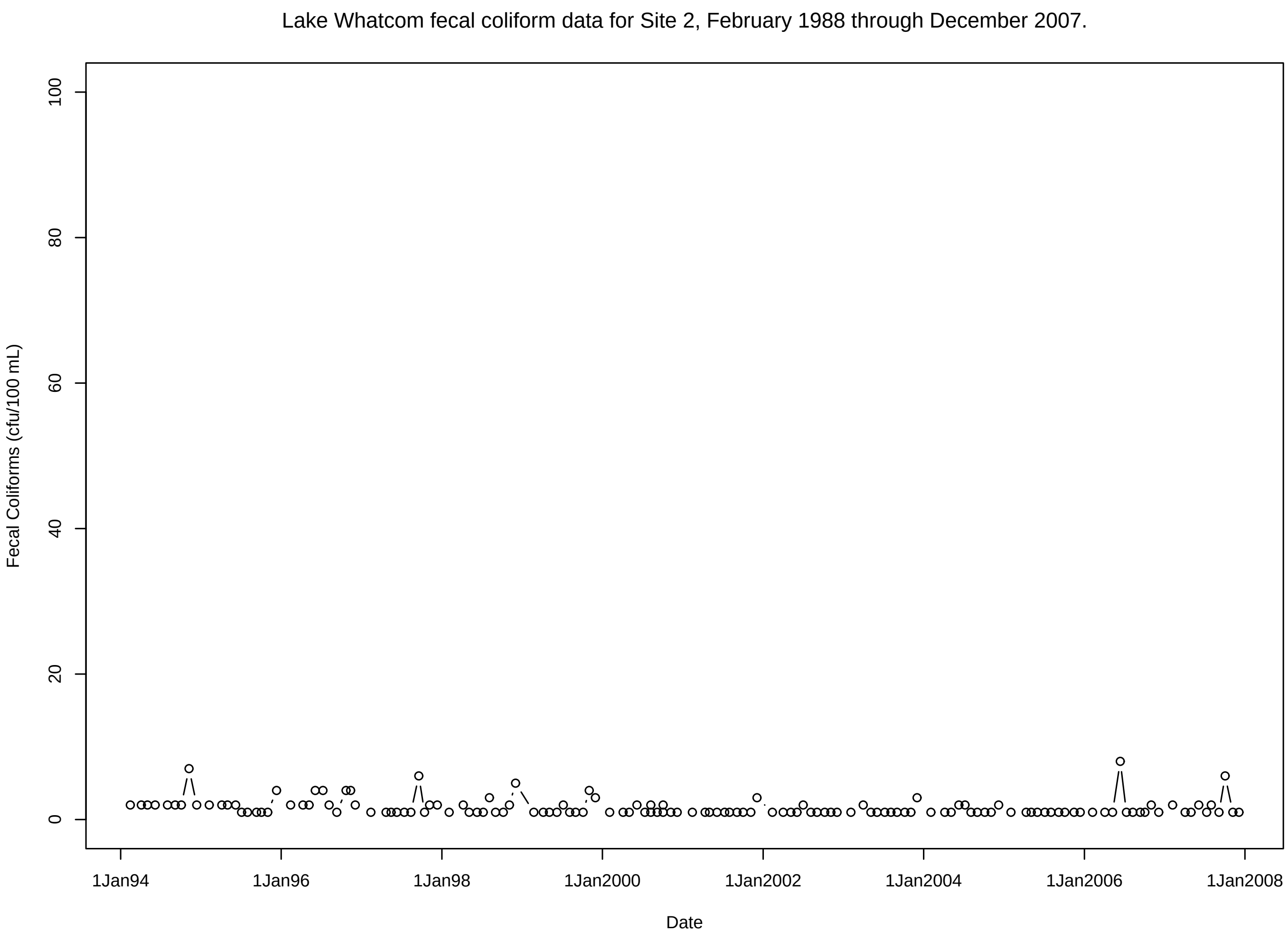


Figure B117: Lake Whatcom fecal coliform data for Site 2.

Lake Whatcom fecal coliform data for Intake, February 1988 through December 2007.

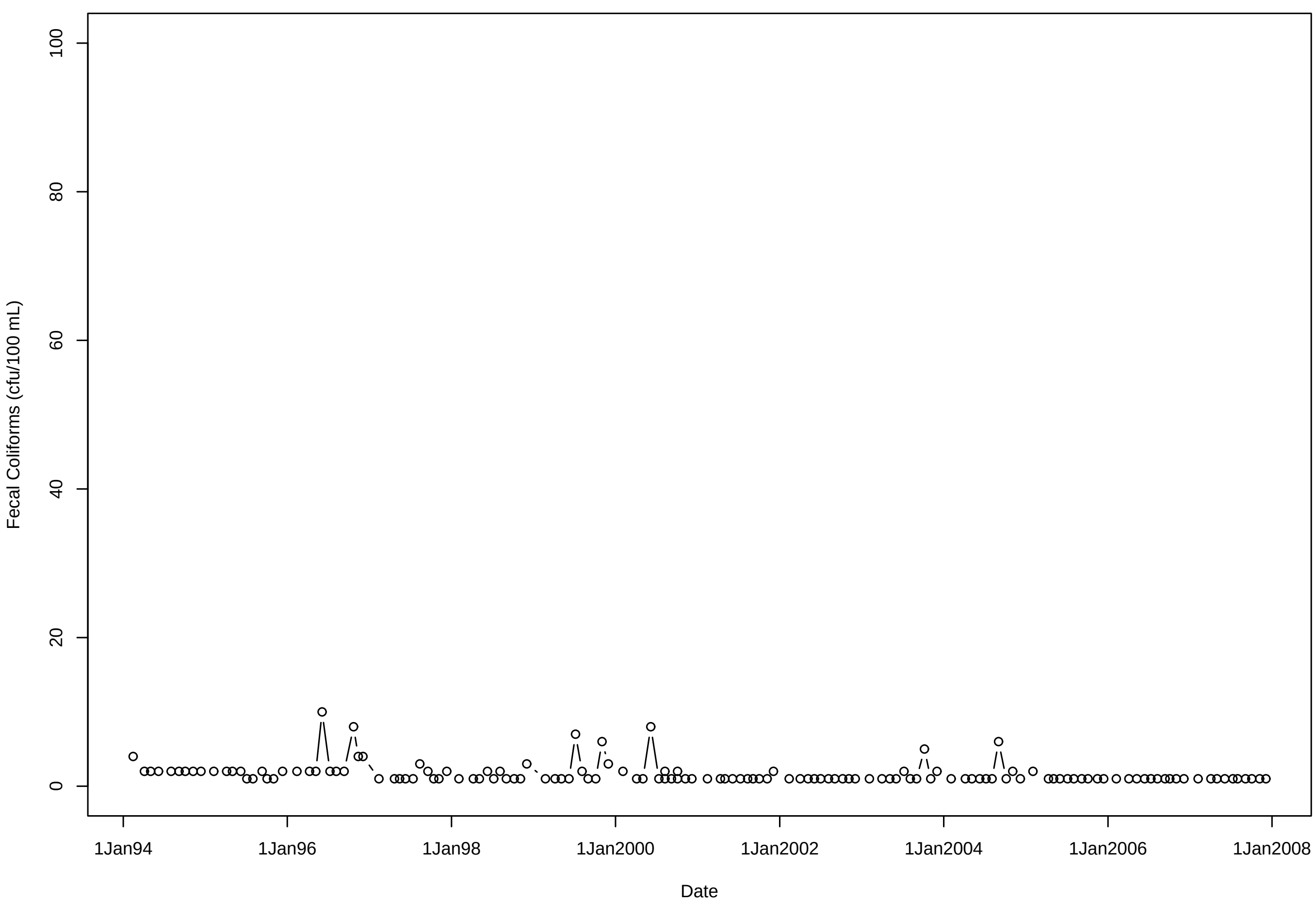


Figure B118: Lake Whatcom fecal coliform data for the Intake site.

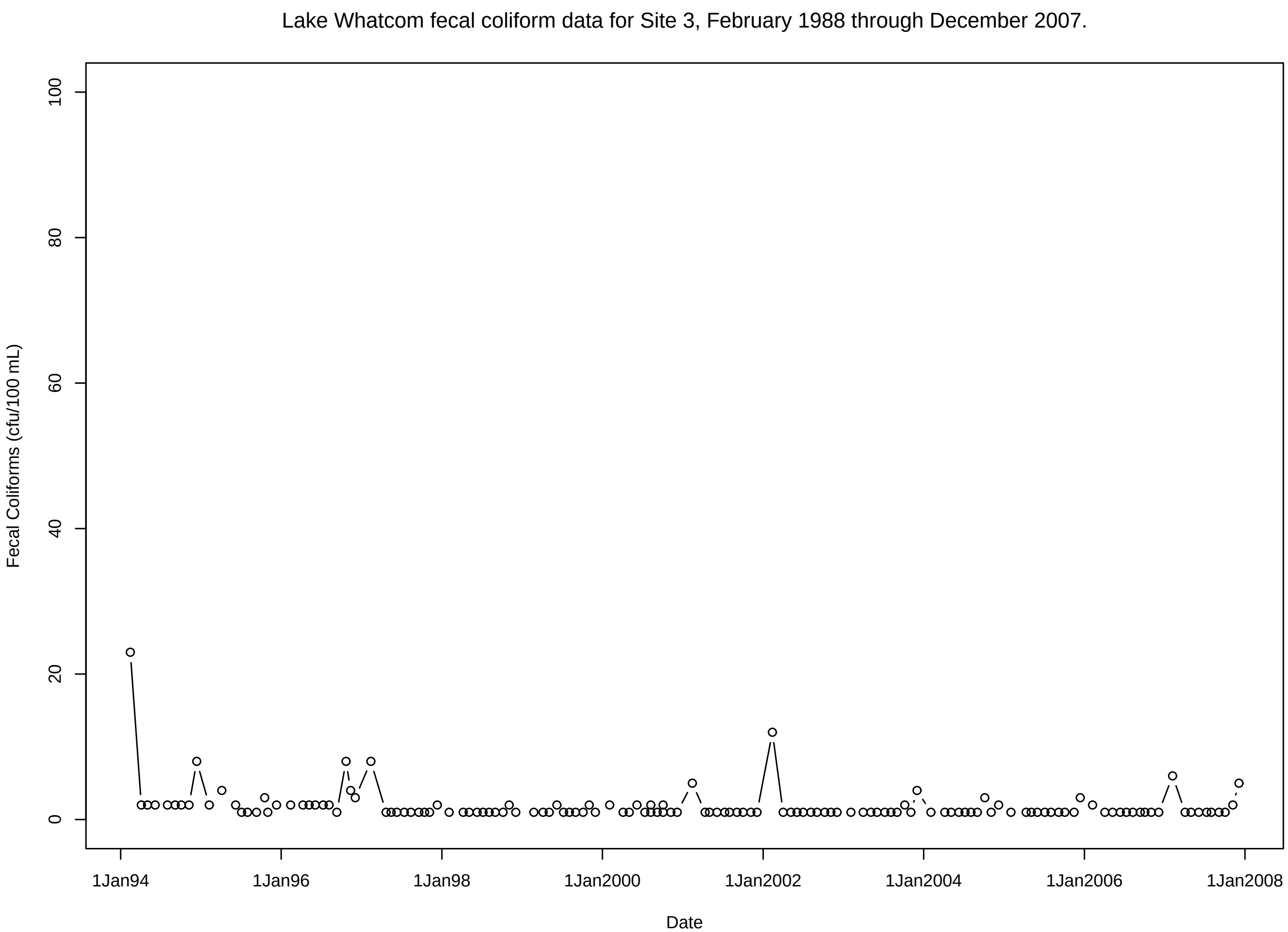


Figure B119: Lake Whatcom fecal coliform data for Site 3.

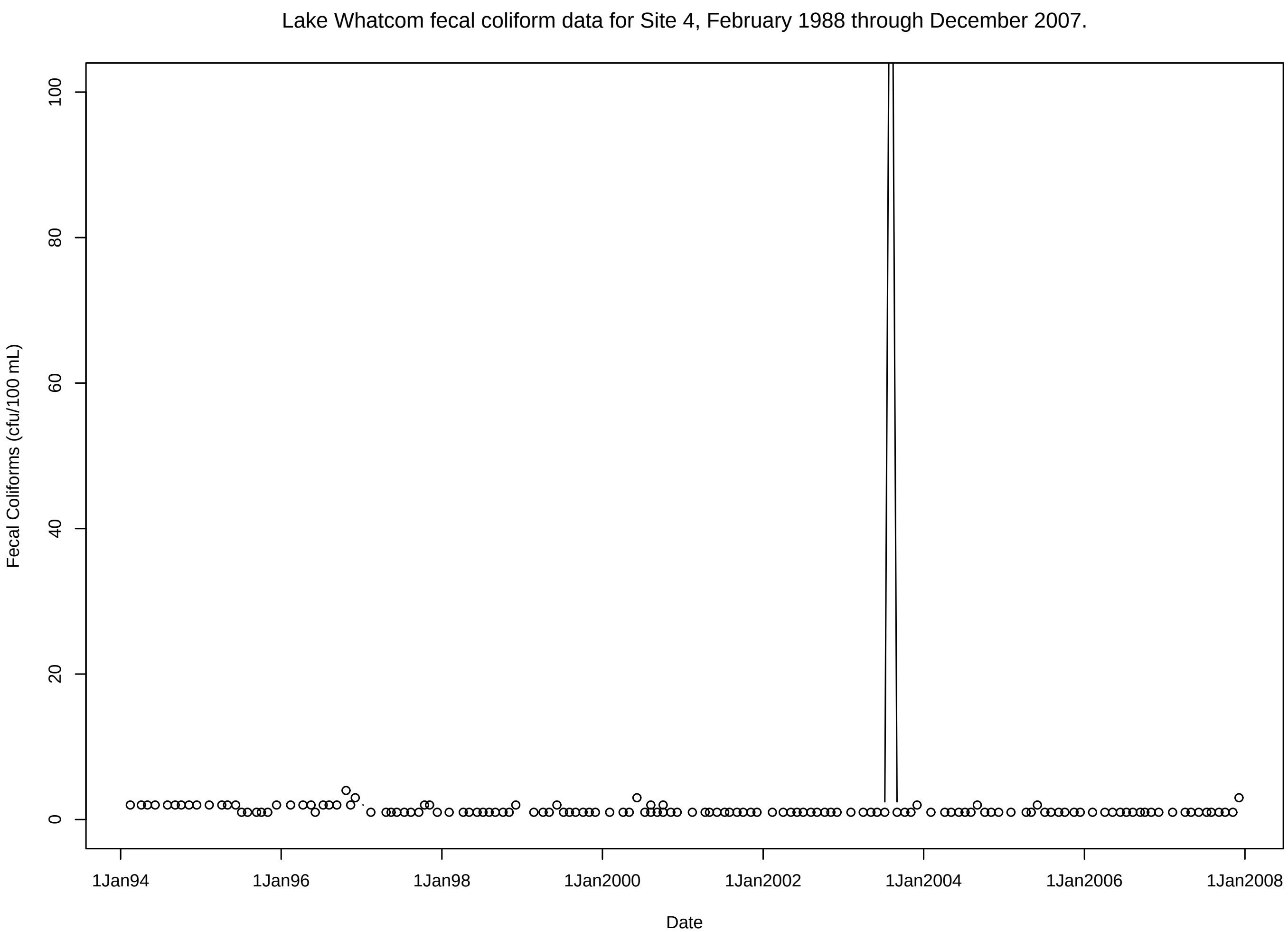


Figure B120: Lake Whatcom fecal coliform data for Site 4.

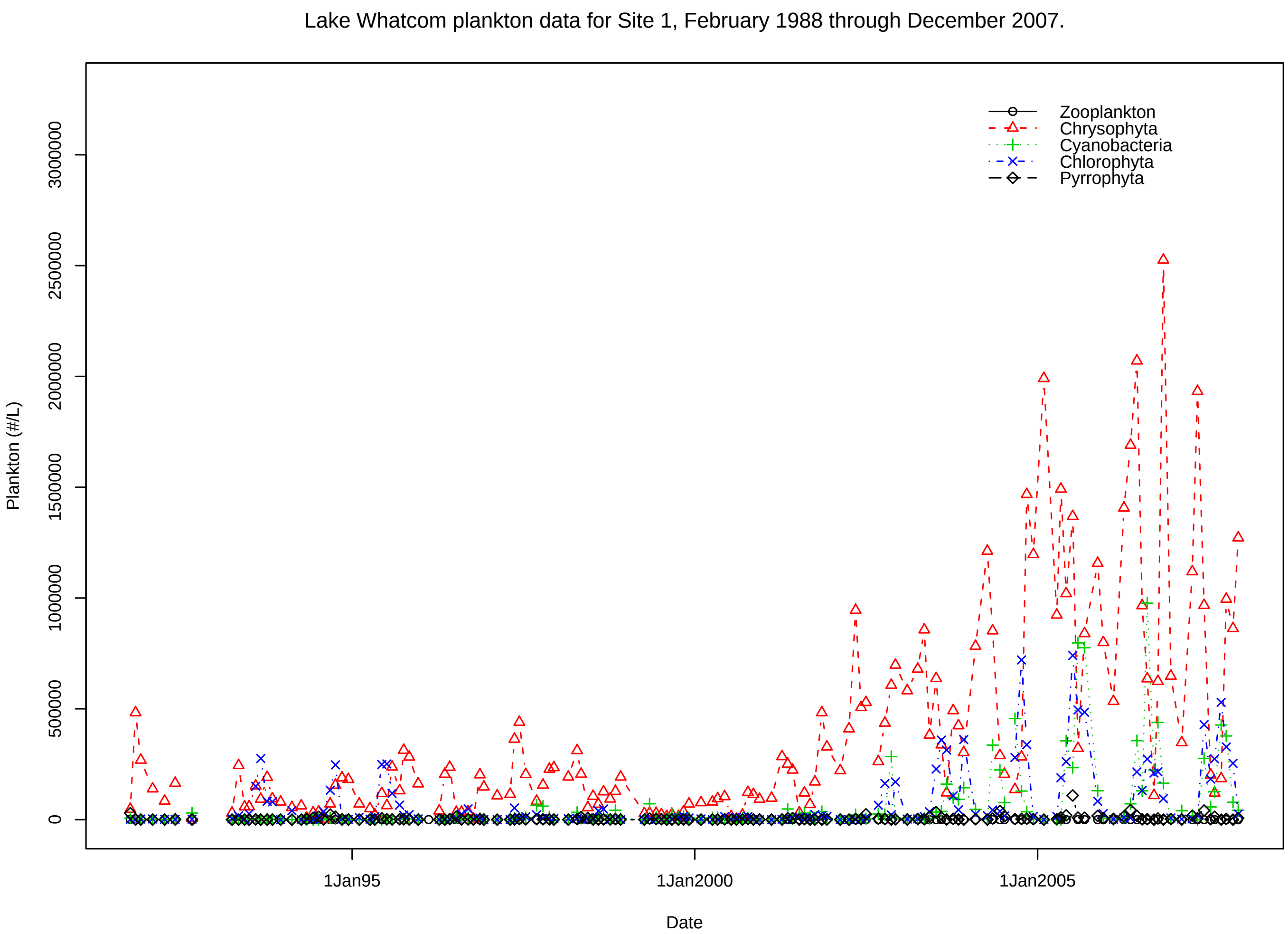


Figure B121: Lake Whatcom plankton data for Site 1.

Lake Whatcom plankton data for Site 2, February 1988 through December 2007.

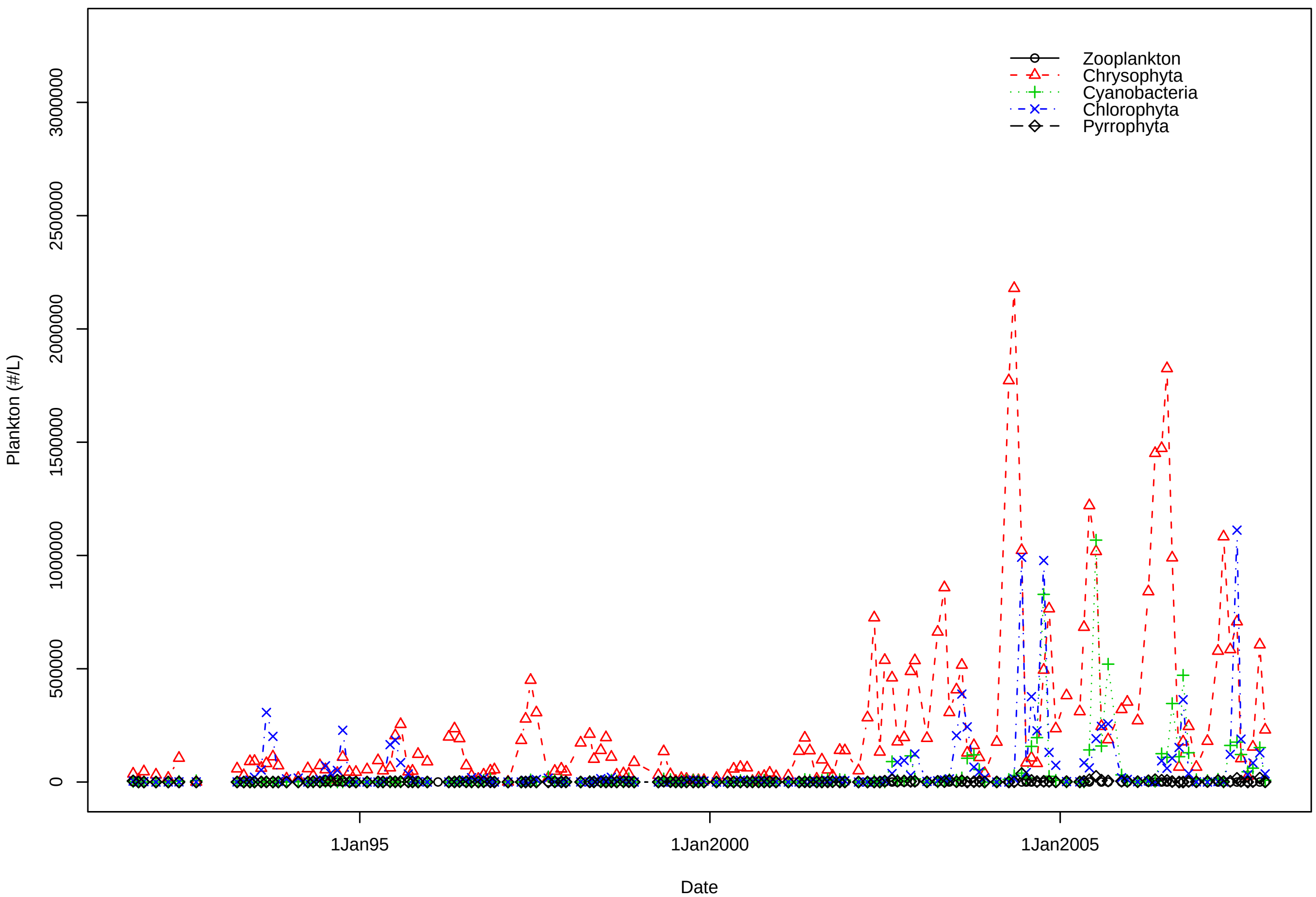


Figure B122: Lake Whatcom plankton data for Site 2.

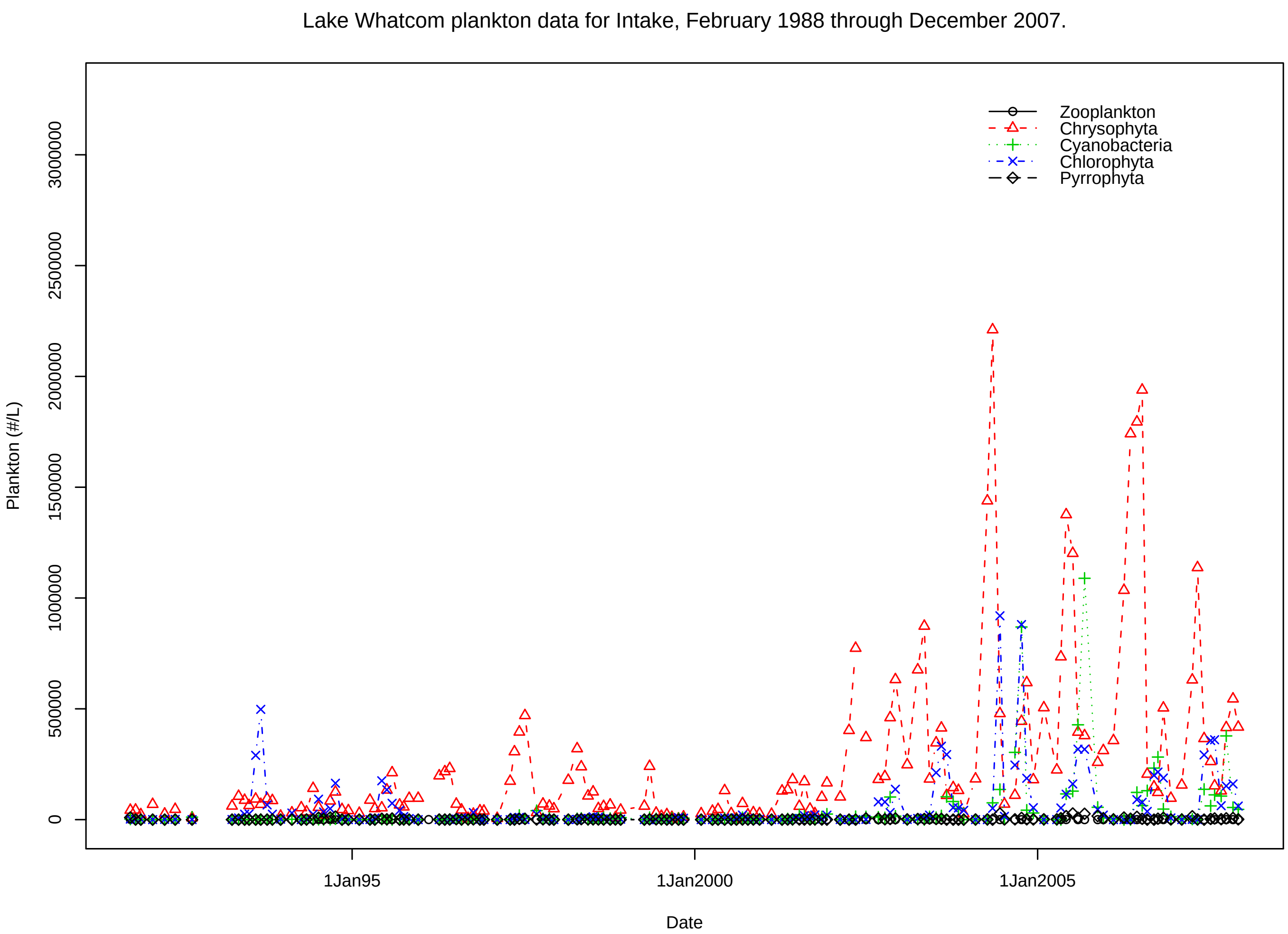


Figure B123: Lake Whatcom plankton data for the Intake Site.

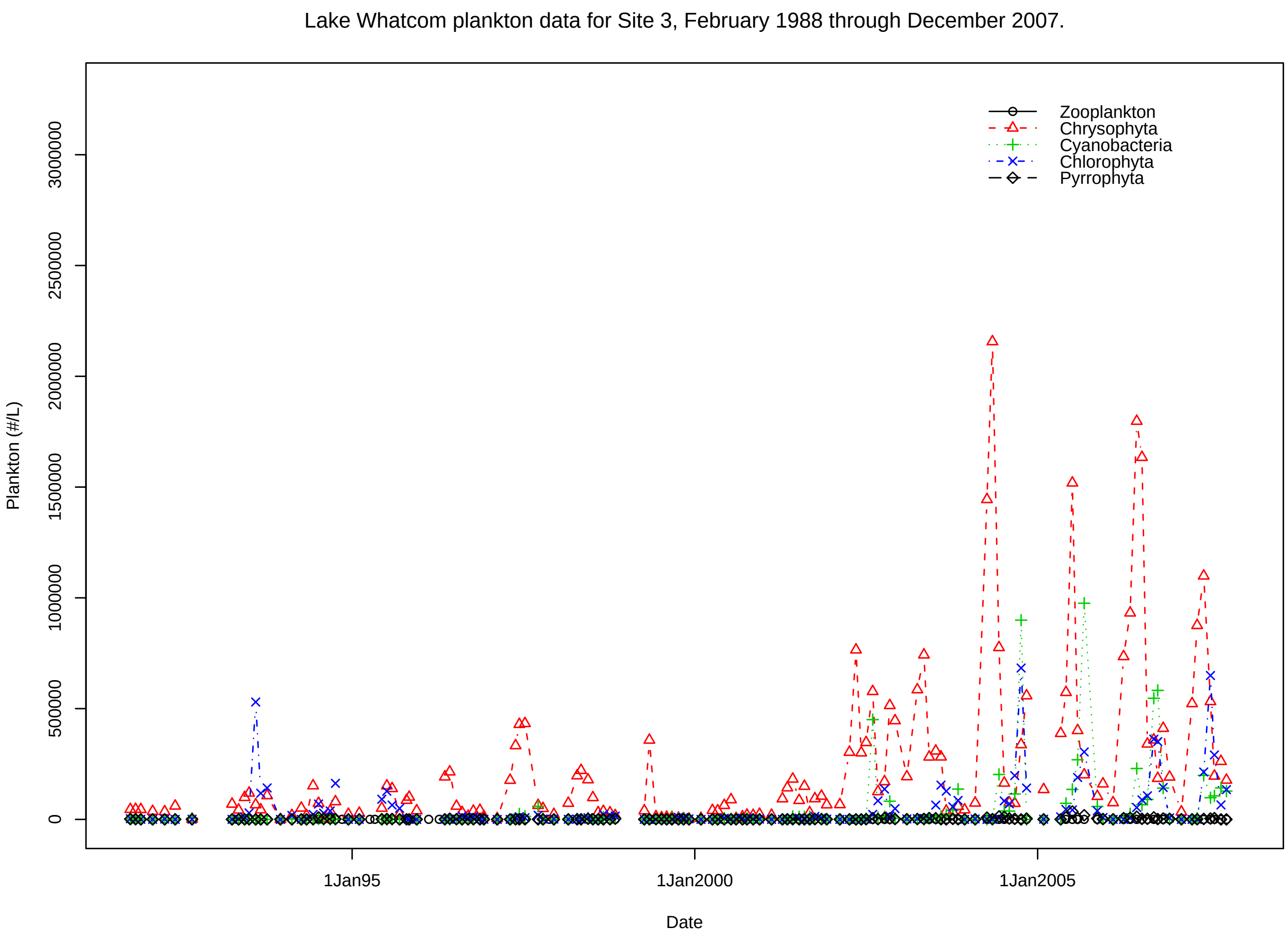


Figure B124: Lake Whatcom plankton data for Site 3.

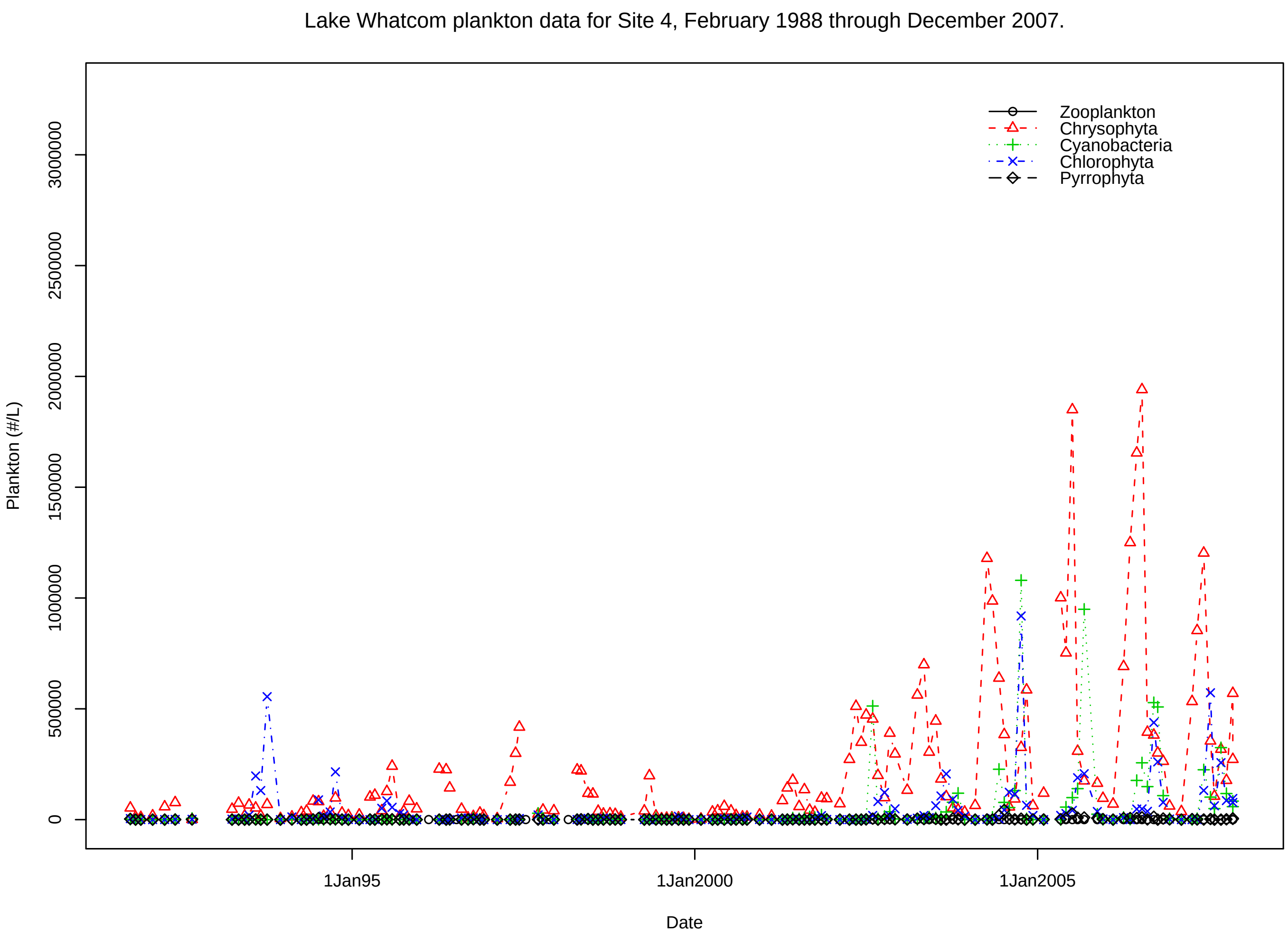


Figure B125: Lake Whatcom plankton data for Site 4.

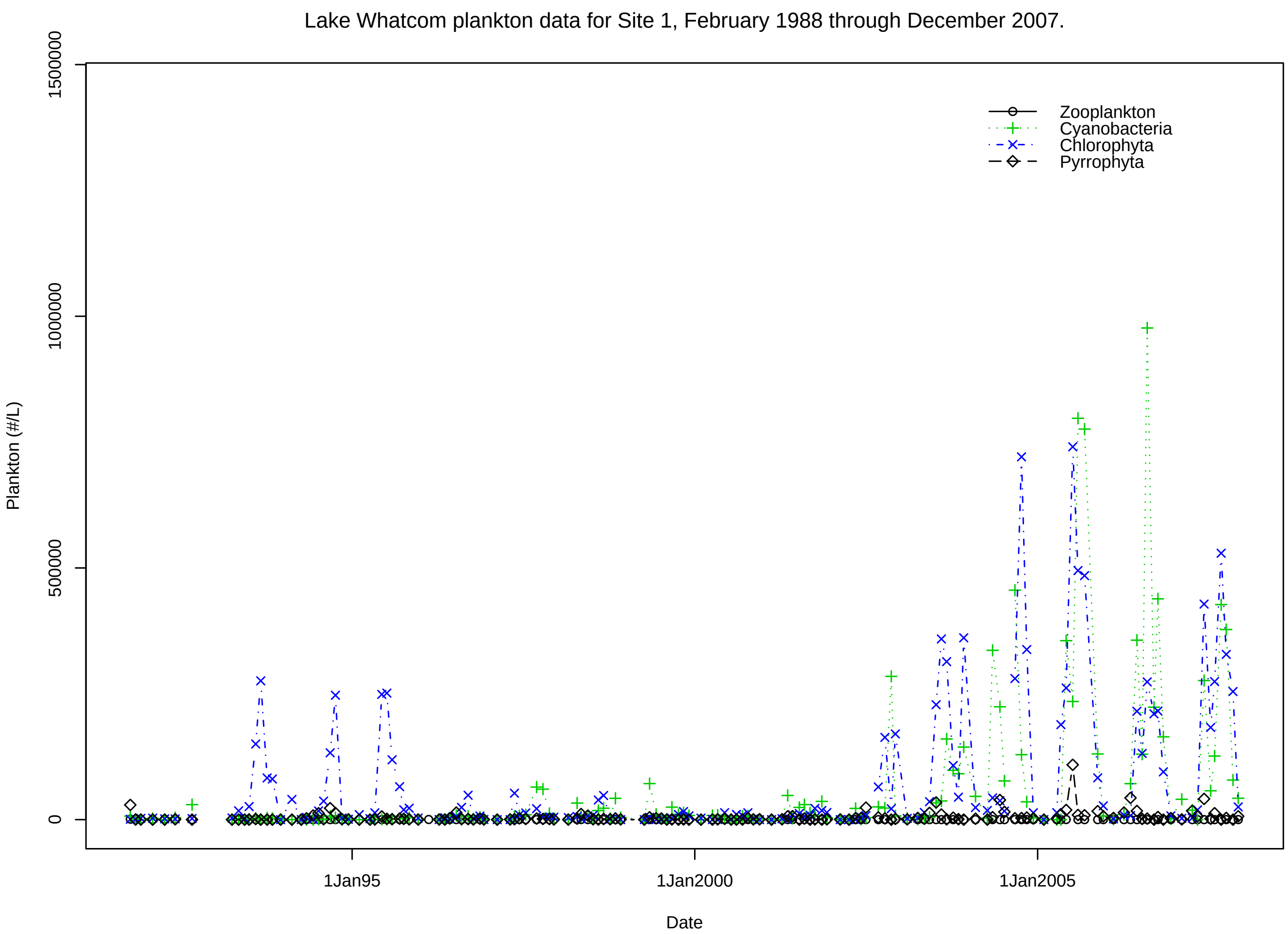


Figure B126: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

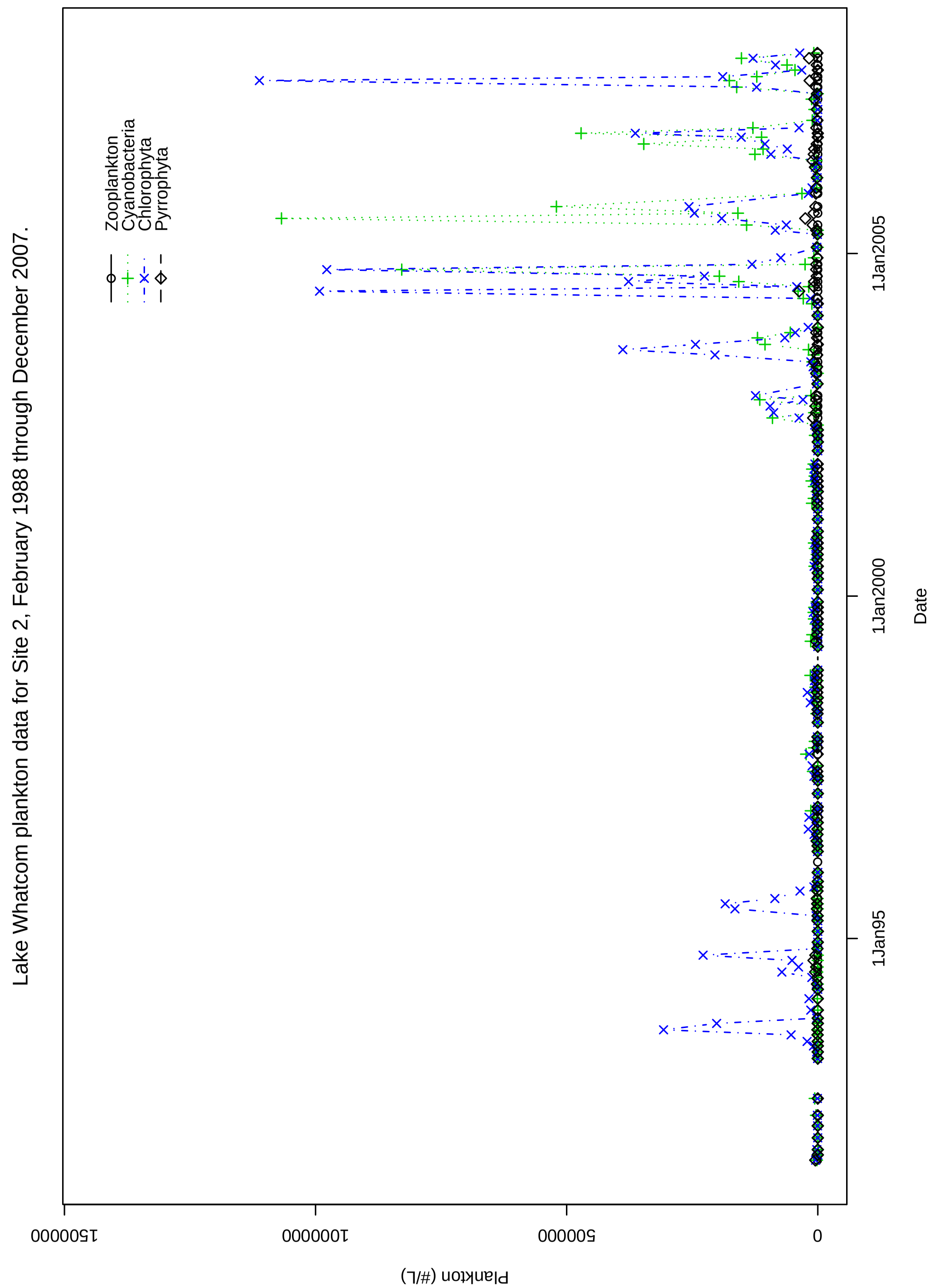


Figure B127: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

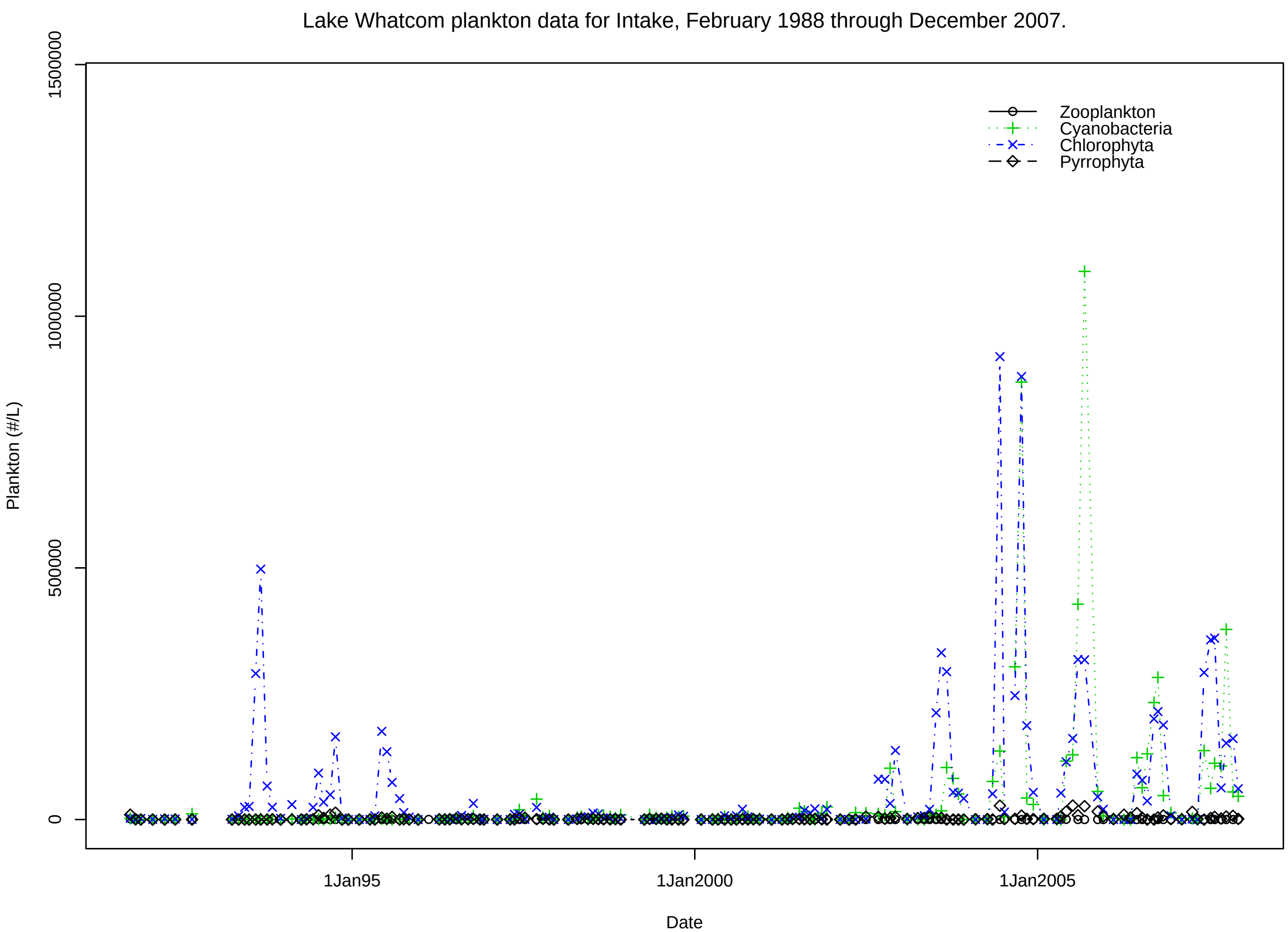


Figure B128: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

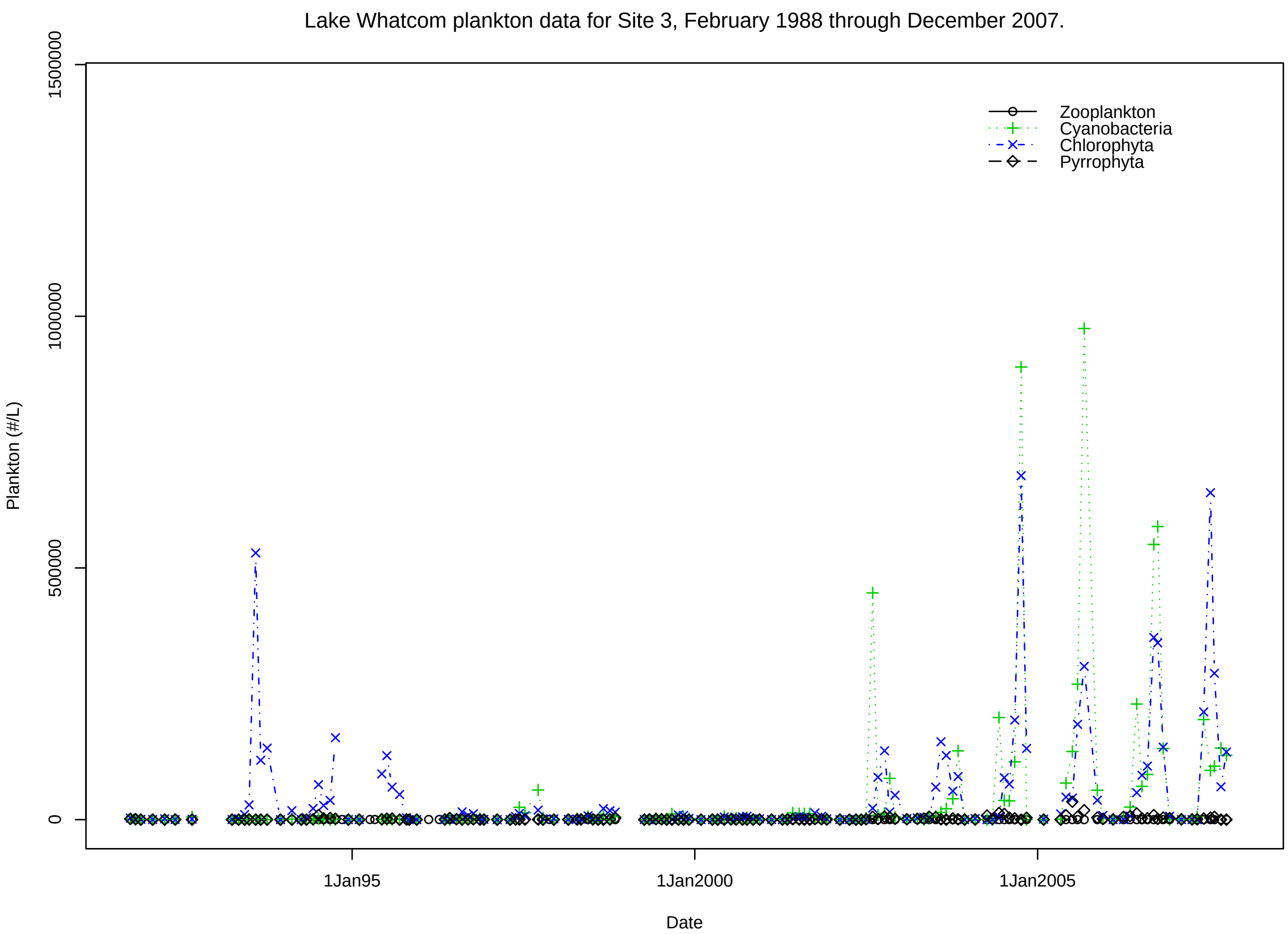


Figure B129: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

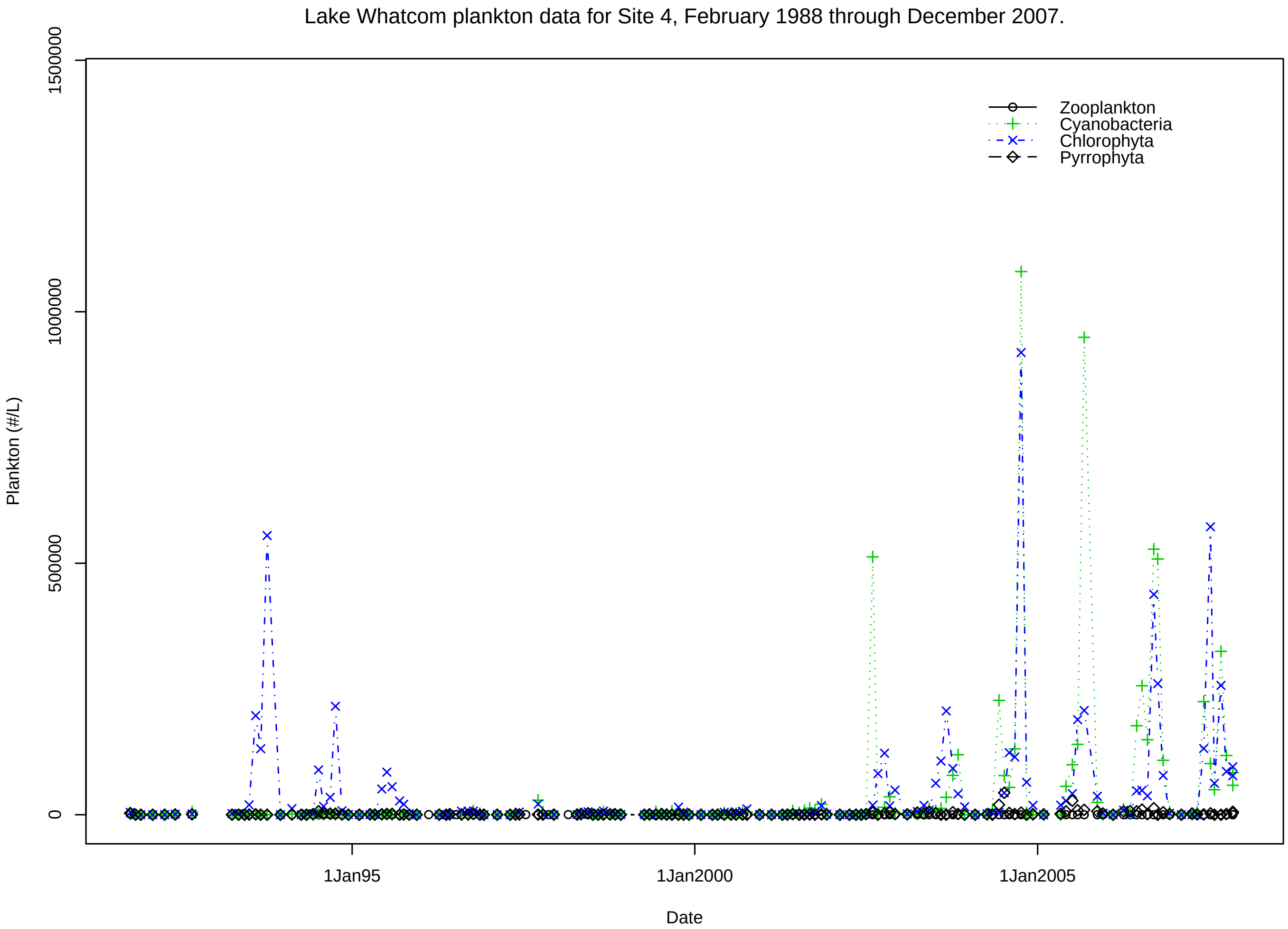


Figure B130: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

B.4 Images of Lake Whatcom Algae

Figure B131: CHRYSOPHYTA - diatom: *Achnanthidium* sp. 1 (ANSP #1045).

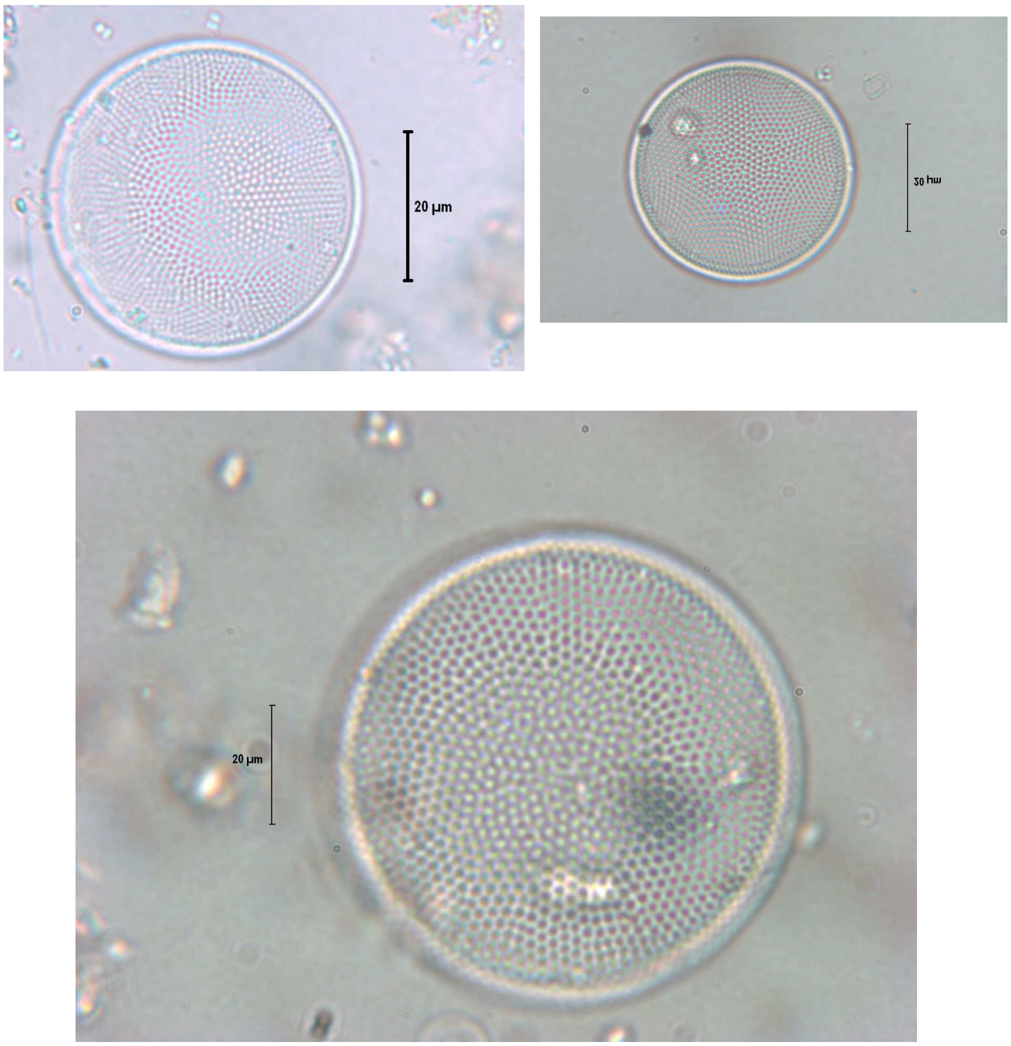


Figure B132: CHRYSOPHYTA - diatom: *Actinocyclus normanii* (Gregory) Hustedt (ANSP #86002).

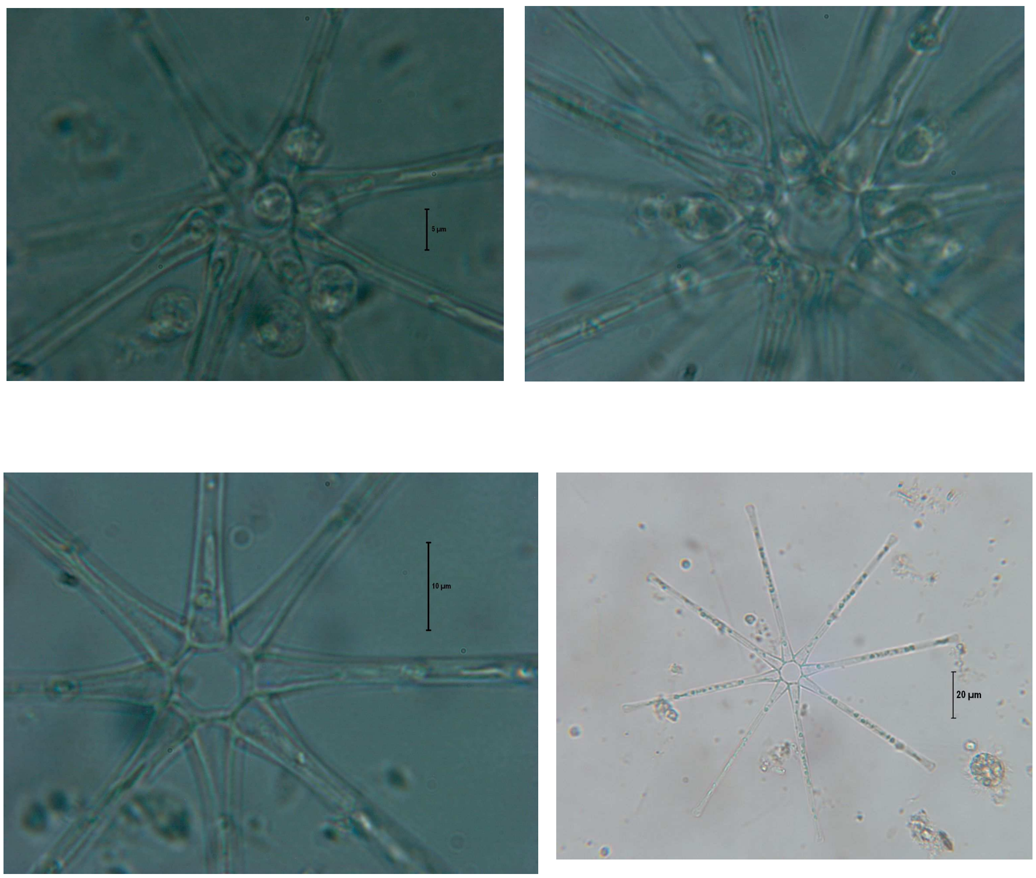


Figure B133: CHRYSOPHYTA - diatom: *Asterionella formosa* Hassal (ANSP #9001).

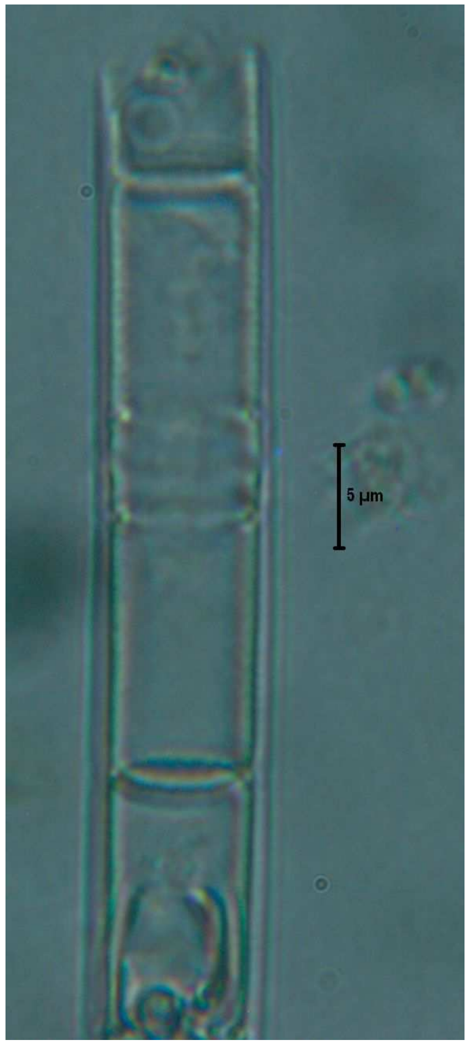


Figure B134: CHRYSOPHYTA - diatom: *Aulacoseira ambigua* (Grunow) Simonsen (ANSP #10008).

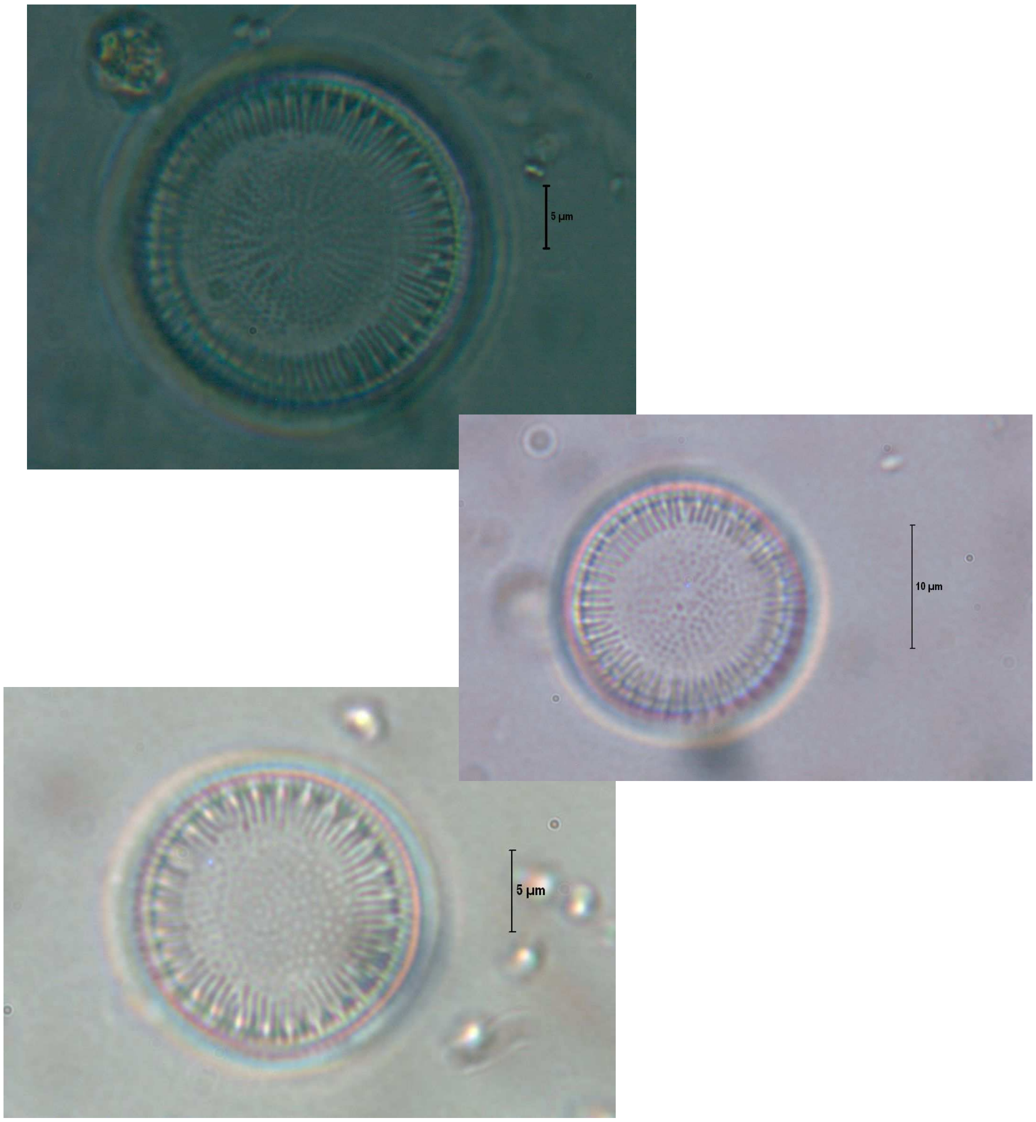


Figure B135: CHRYSOPHYTA - diatom: *Cyclotella bodanica* Grunow (ANSP #20002).

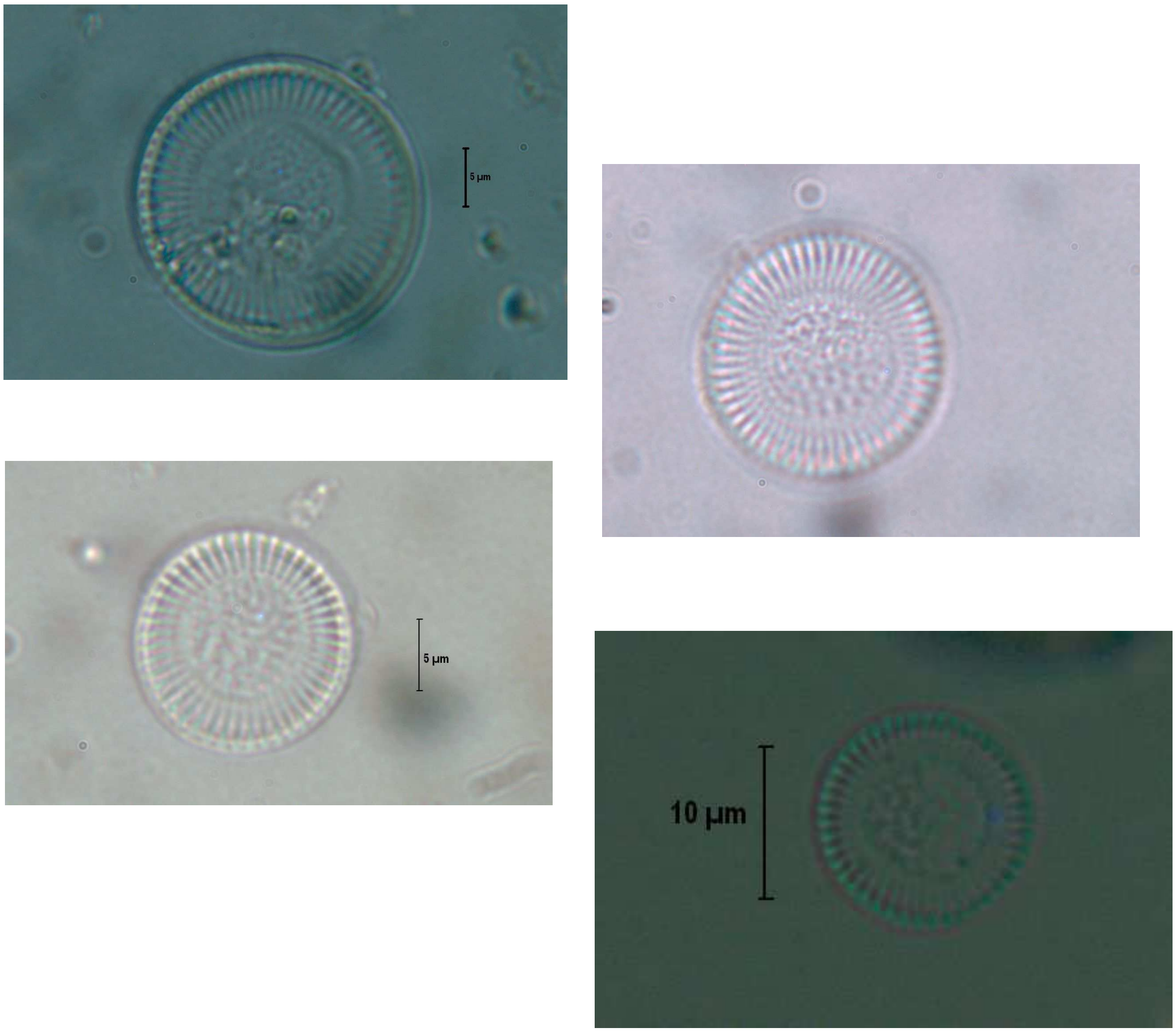


Figure B136: CHRYSOPHYTA - diatom: *Cyclotella meneghiniana* Kützing (ANSP #20007).

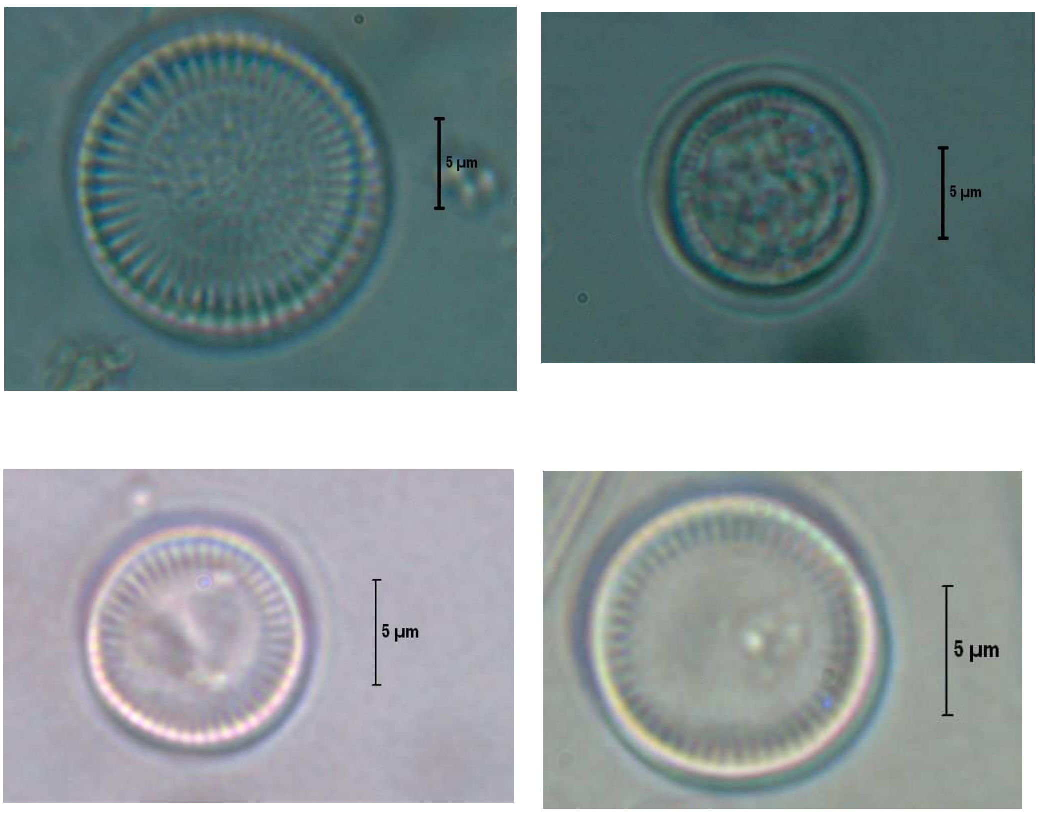


Figure B137: CHRYSOPHYTA - diatom: *Cyclotella* spp. (ANSP #20990 and 20991).

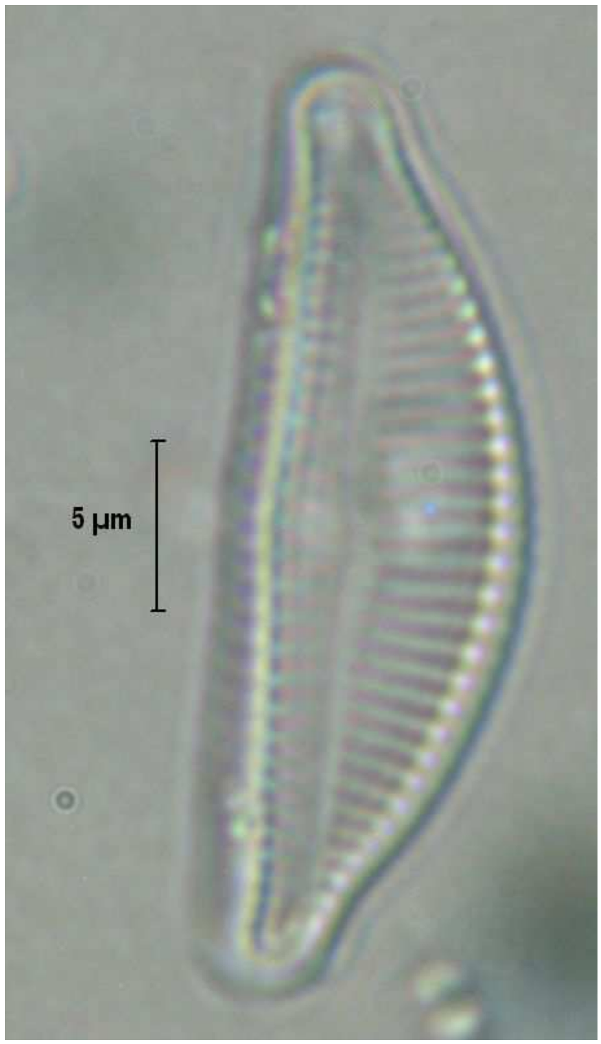


Figure B138: CHRYSOPHYTA - diatom: *Cymbella affinis* Kützing (ANSP #23073).

Figure B139: CHRYSOPHYTA - diatom: *Diploneis* sp. 1 (ANSP #30990).

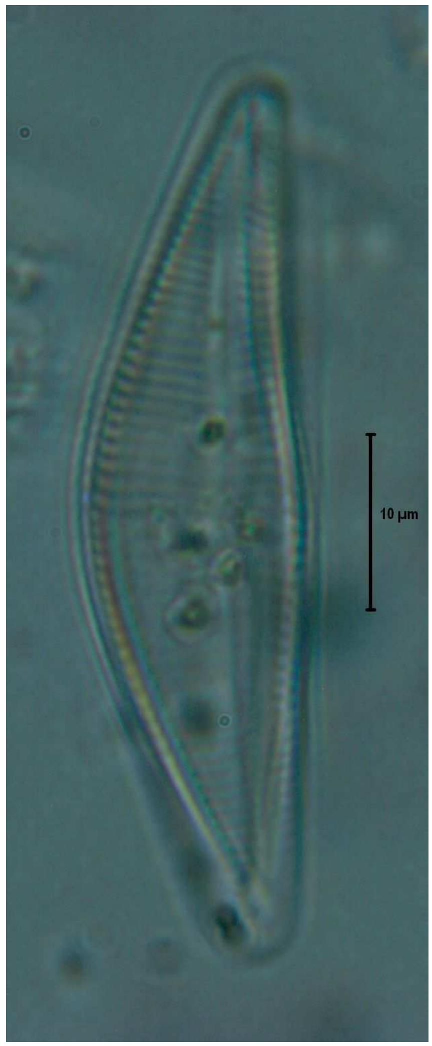


Figure B140: CHRYSOPHYTA - diatom: *Encyonema* sp. 1 (ANSP #110039).

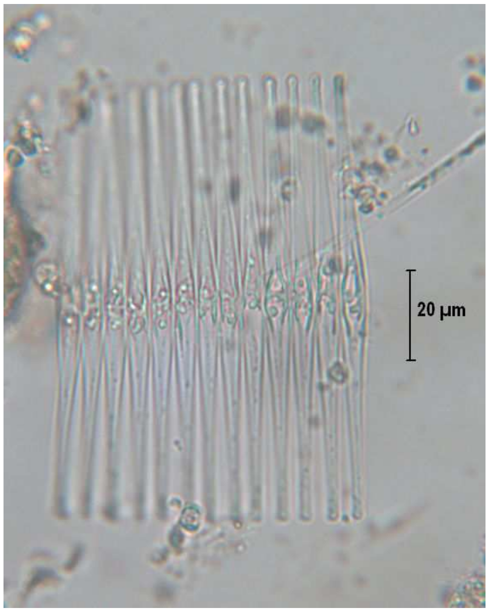


Figure B141: CHRYSOPHYTA - diatom: *Fragilaria crotonensis* Kitton (ANSP #34017).

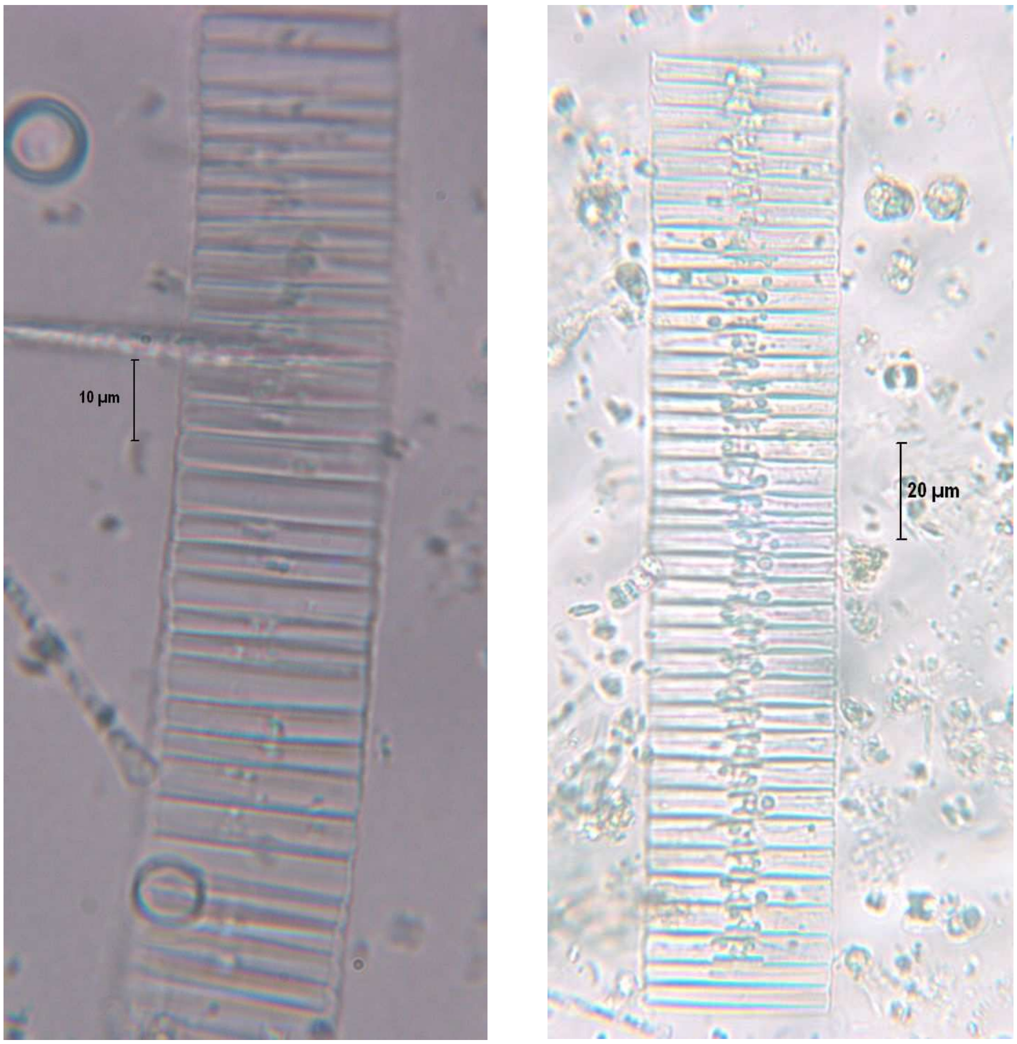


Figure B142: CHRYSOPHYTA - diatom: *Fragilaria* sp. 1 (ANSP #34990) or *Fragilaria capucina* Desmaziéres (ANSP #34006).

Figure B143: CHRYSOPHYTA - diatom: *Nitzschia sigmoidea* (Nitzsch) Ehrenberg (ANSP #48177).

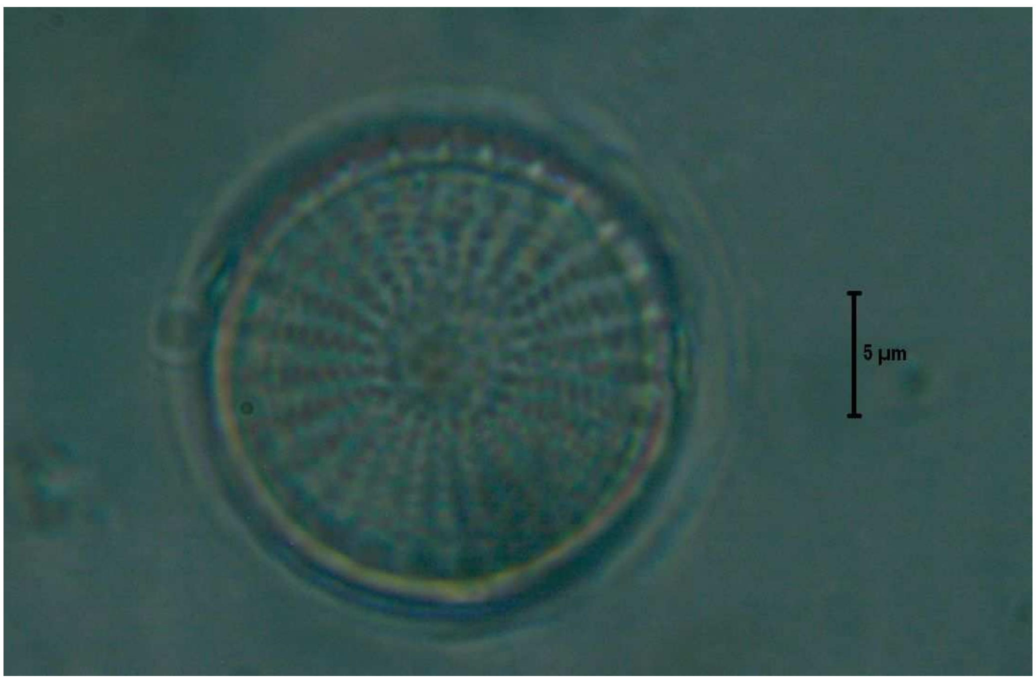


Figure B144: CHRYSOPHYTA - diatom: *Stephanodiscus minutulus* (Kützing) Cleve et Möller (ANSP #64018).

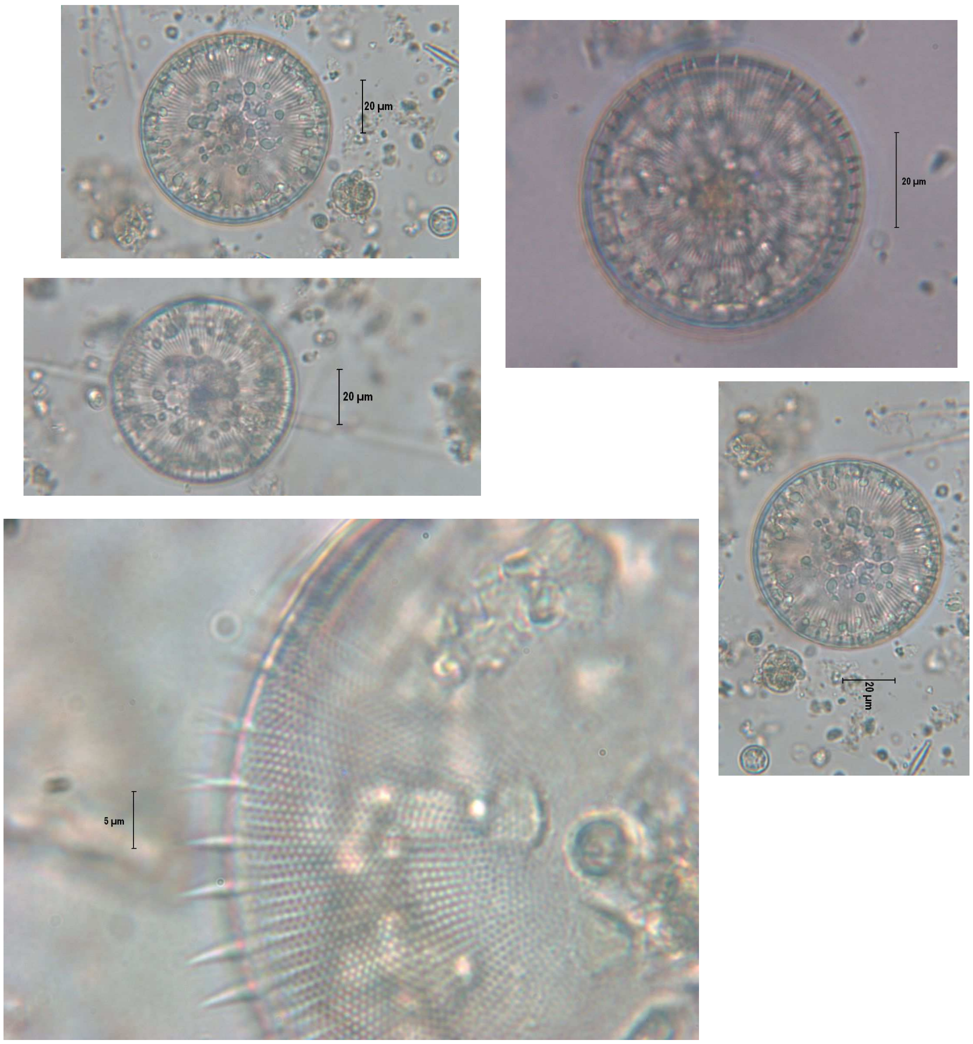


Figure B145: CHRYSOPHYTA - diatom: *Stephanodiscus niagarae* Ehrenberg (ANSP #64001), valve view.

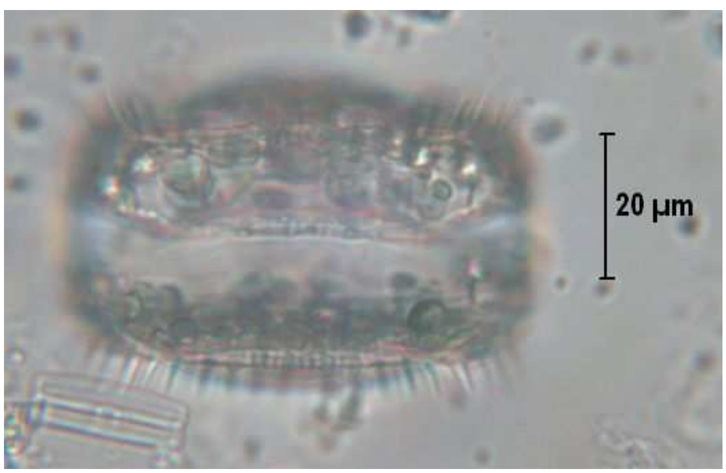


Figure B146: CHRYSOPHYTA - diatom: *Stephanodiscus niagarae* Ehrenberg (ANSP #64001), girdle view.

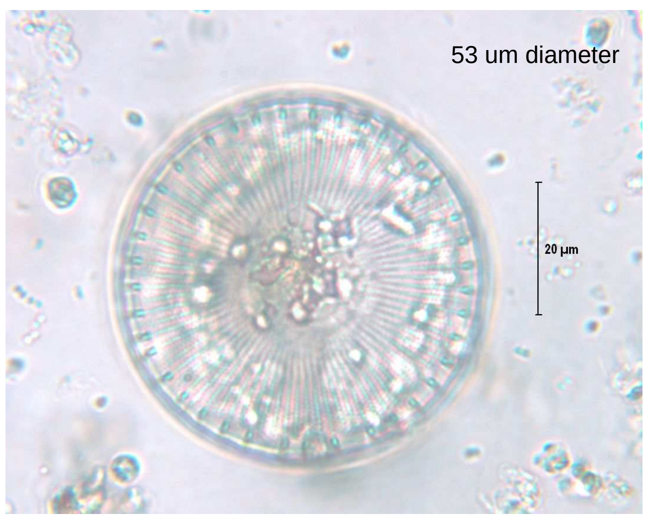


Figure B147: CHRYSOPHYTA - diatom: *Stephanodiscus* spp. (ANSP #64990 and 64991).

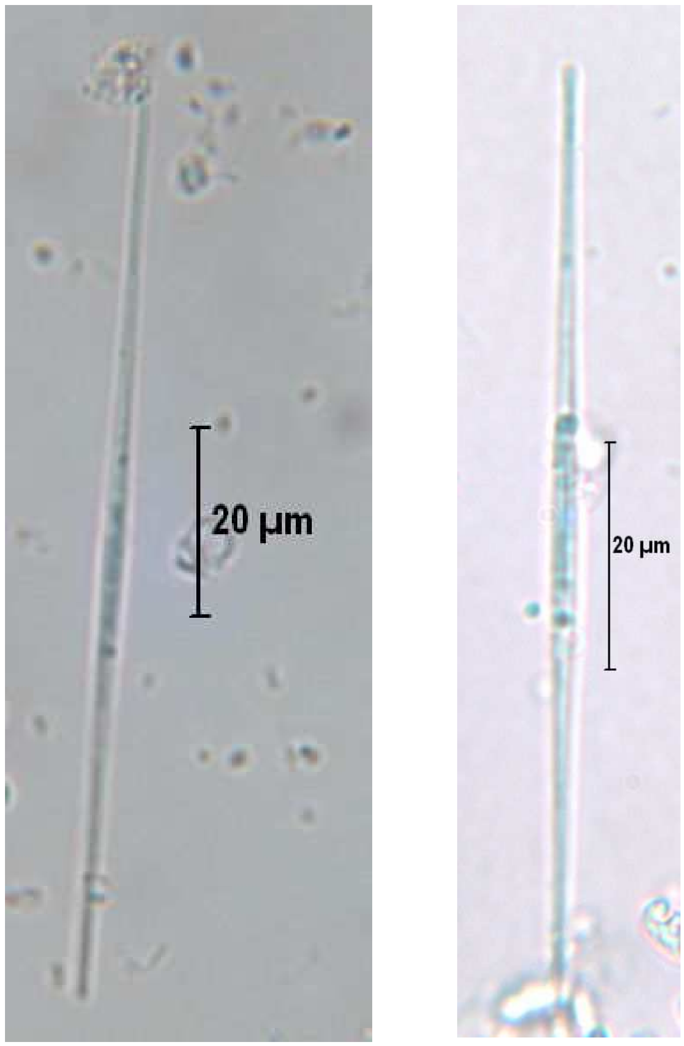


Figure B148: CHRYSOPHYTA - diatom: *Synedra* sp. 1 (ANSP #66990).

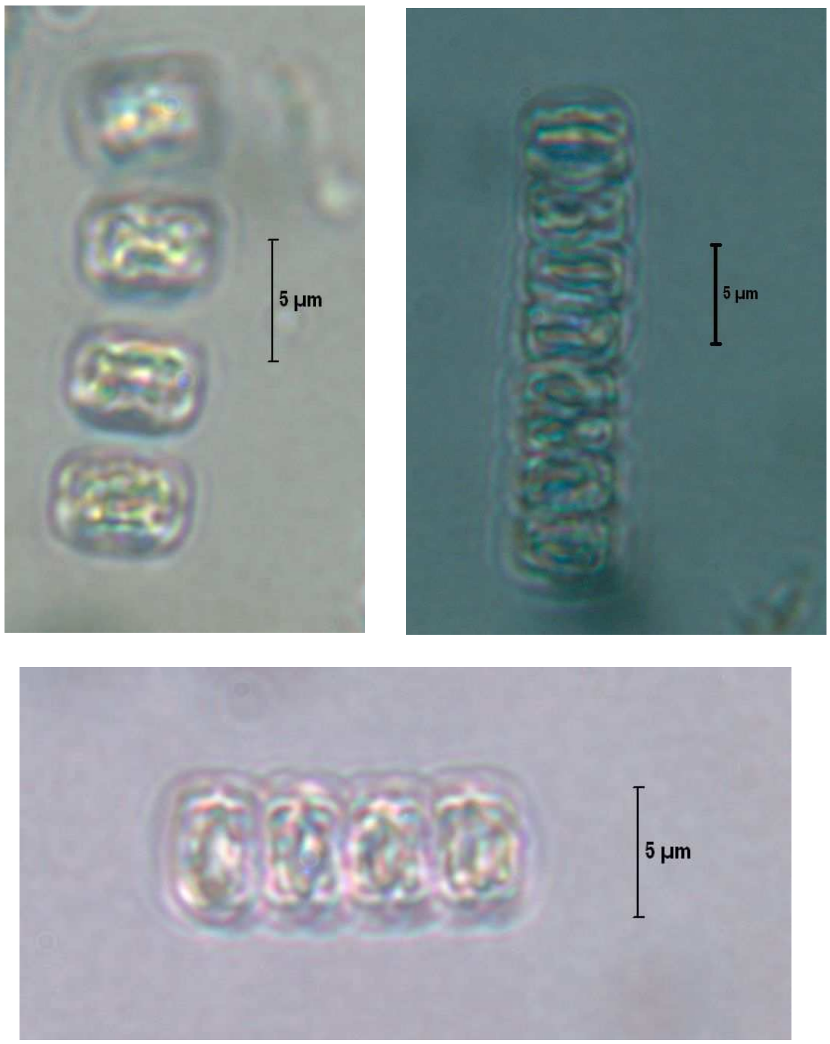


Figure B149: CHRYSOPHYTA - diatom: *Thalassiosira pseudonana* Hasle et Heimdal (ANSP #70007).

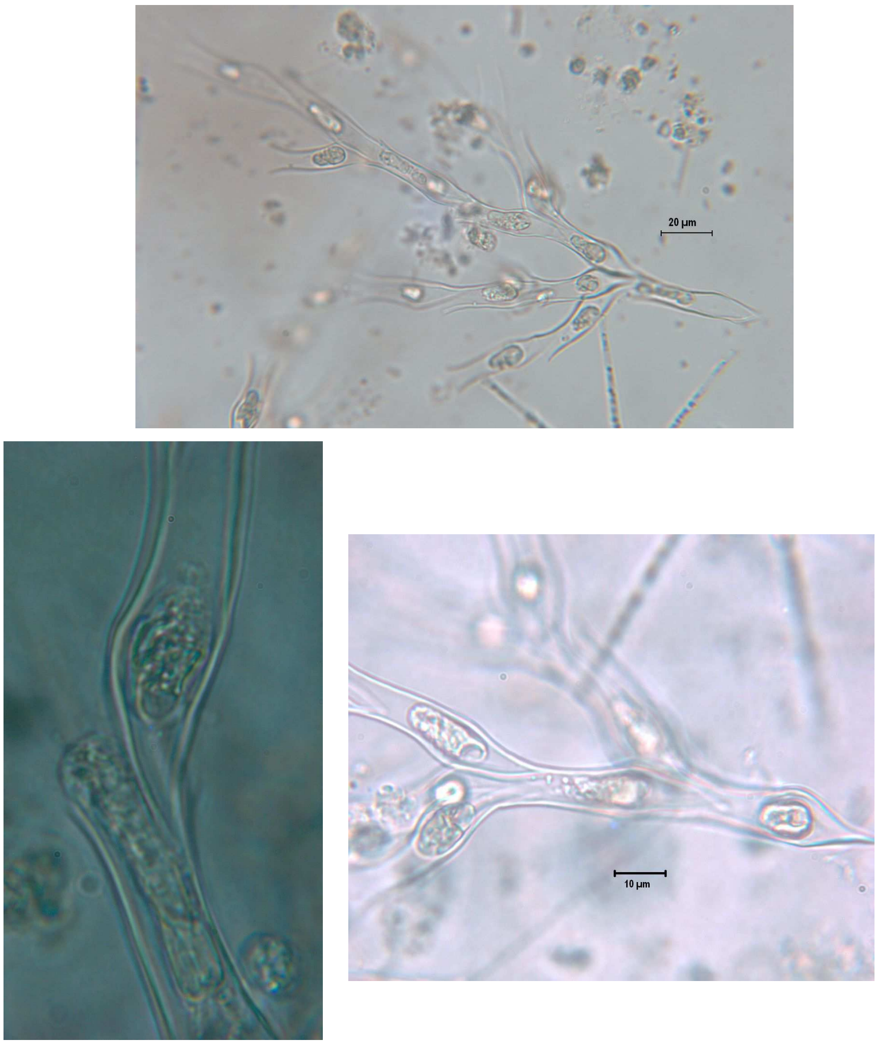


Figure B150: CHRYSOPHYTA: *Dinobryon divergens* Imhof (ANSP #1110007).

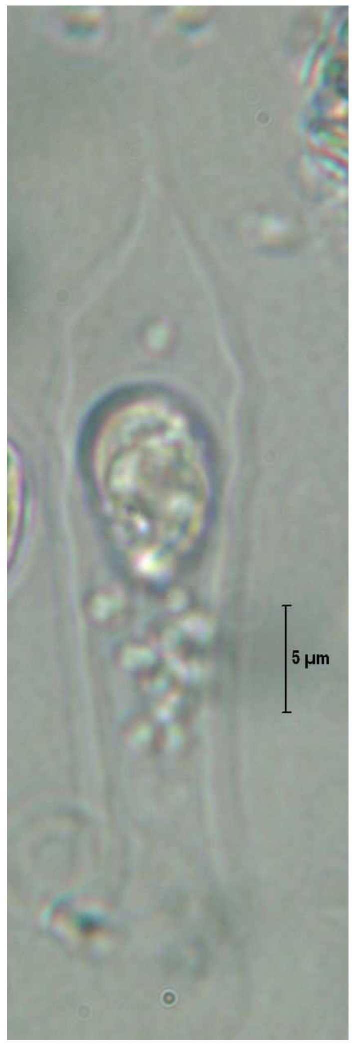


Figure B151: CHRYSOPHYTA: *Dinobryon* sp. 1 (ANSP #1110002).

Figure B152: CHRYSOPHYTA: *Mallomonas* spp. (ANSP #1145000). These appear to be two species, but ANSP assigned the same number to both images.

Figure B153: CHLOROPHYTA: *Ankistrodesmus* sp. 1 (ANSP #261004).

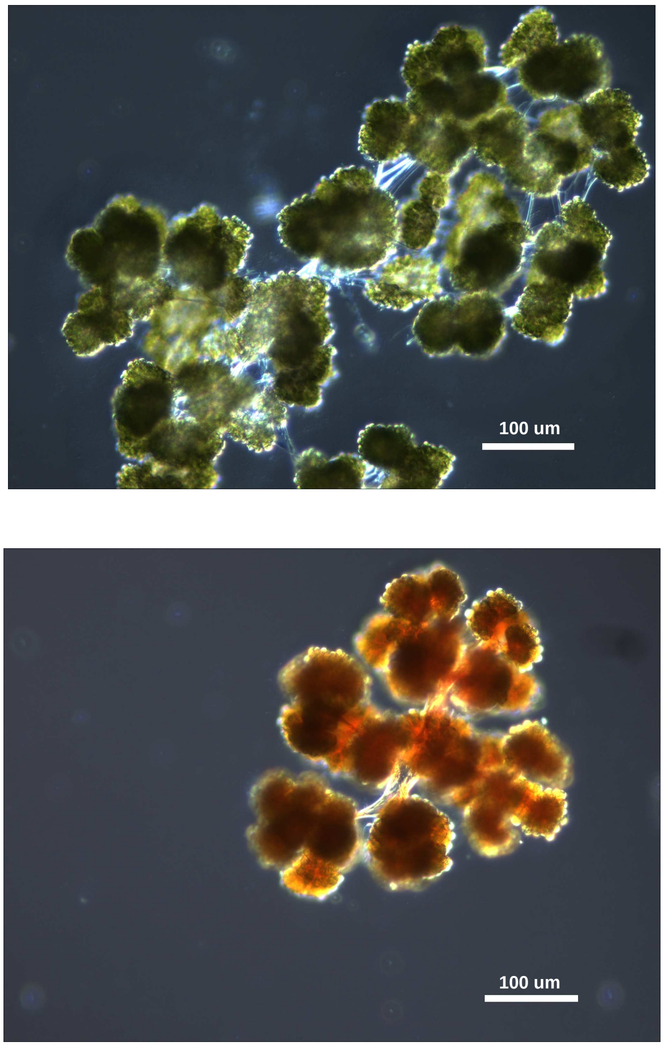


Figure B154: CHLOROPHYTA: *Botryococcus braunii* Kützing (ANSP #279000). Image is from the IWS digital image library; no ANSP image is available.

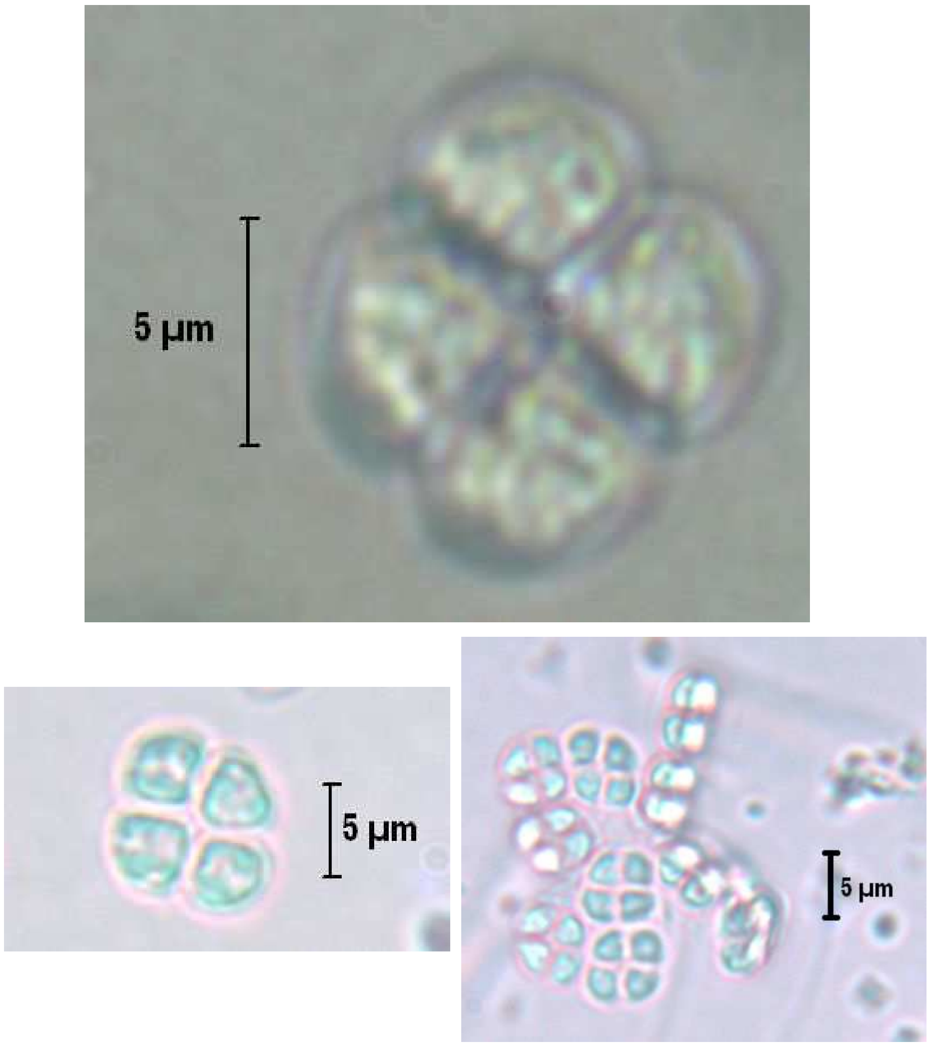


Figure B155: CHLOROPHYTA: *Crucigenia quadrata* Morren (ANSP #328000).

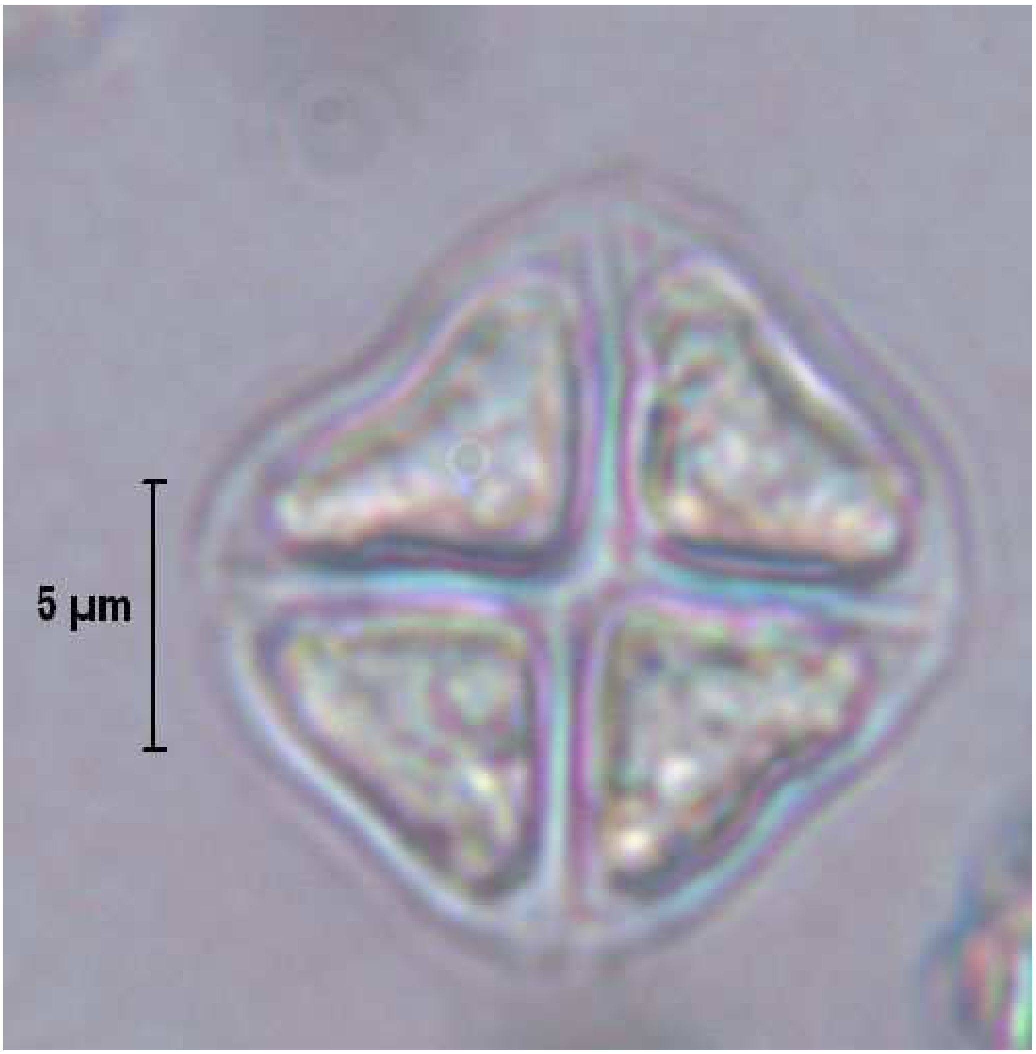


Figure B156: CHLOROPHYTA: *Crucigenia tetrapedia* (Kirchner) West et West (ANSP #328002).

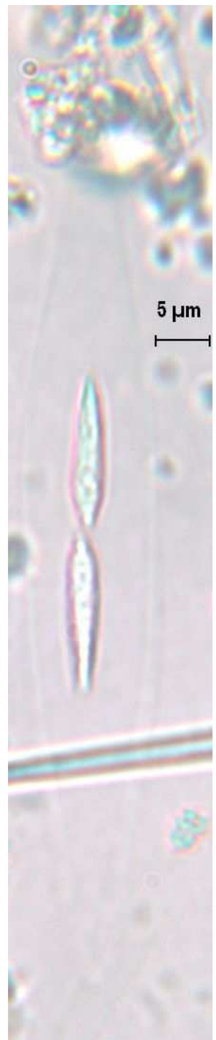


Figure B157: CHLOROPHYTA: *Elakatothrix gelatinosa* Wille (ANSP #367000).

Figure B158: CHLOROPHYTA: *Eudorina elegans* Ehrenberg (ANSP #380000).

Figure B159: CHLOROPHYTA: *Oocystis parva* West et West (ANSP #458006).

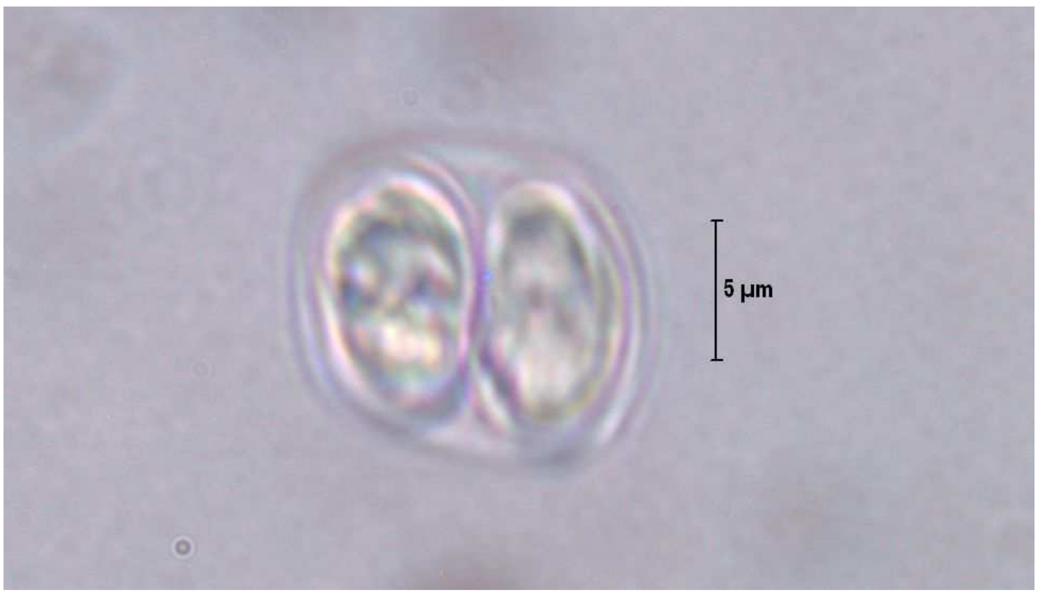


Figure B160: CHLOROPHYTA: *Oocystis* sp. 1 (ANSP #458004).

Figure B161: CHLOROPHYTA: *Quadrigula lacustris* (Tanner-Fullman) Smith (ANSP #500000) or *Quadrigula* sp. (ANSP #500002).

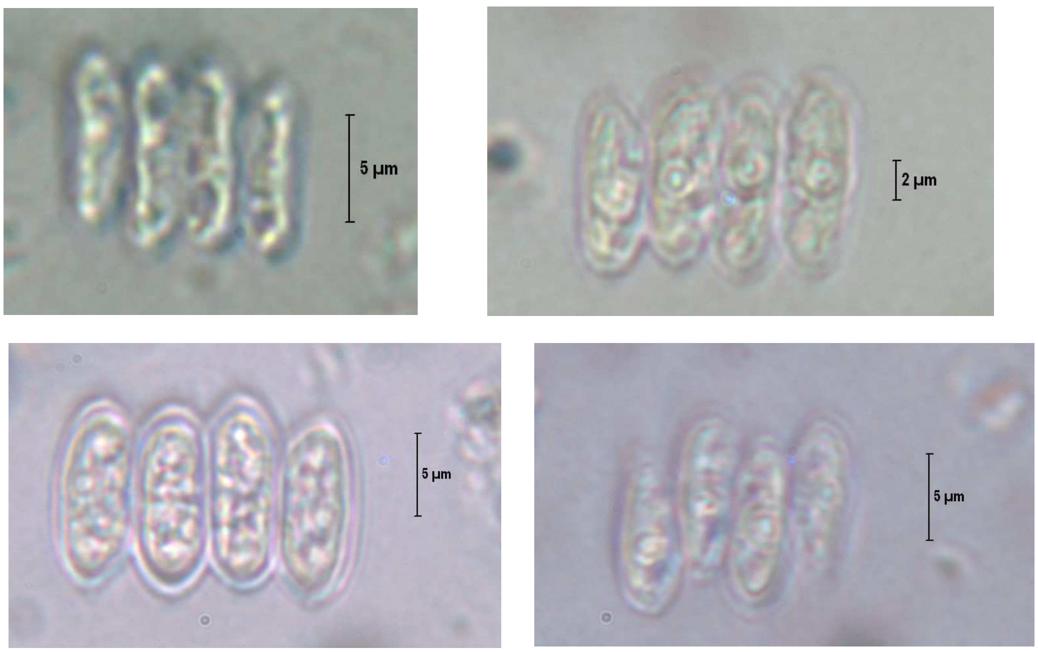


Figure B162: CHLOROPHYTA: *Scenedesmus ecornis* (Ralfs) Chodat (ANSP #510002).

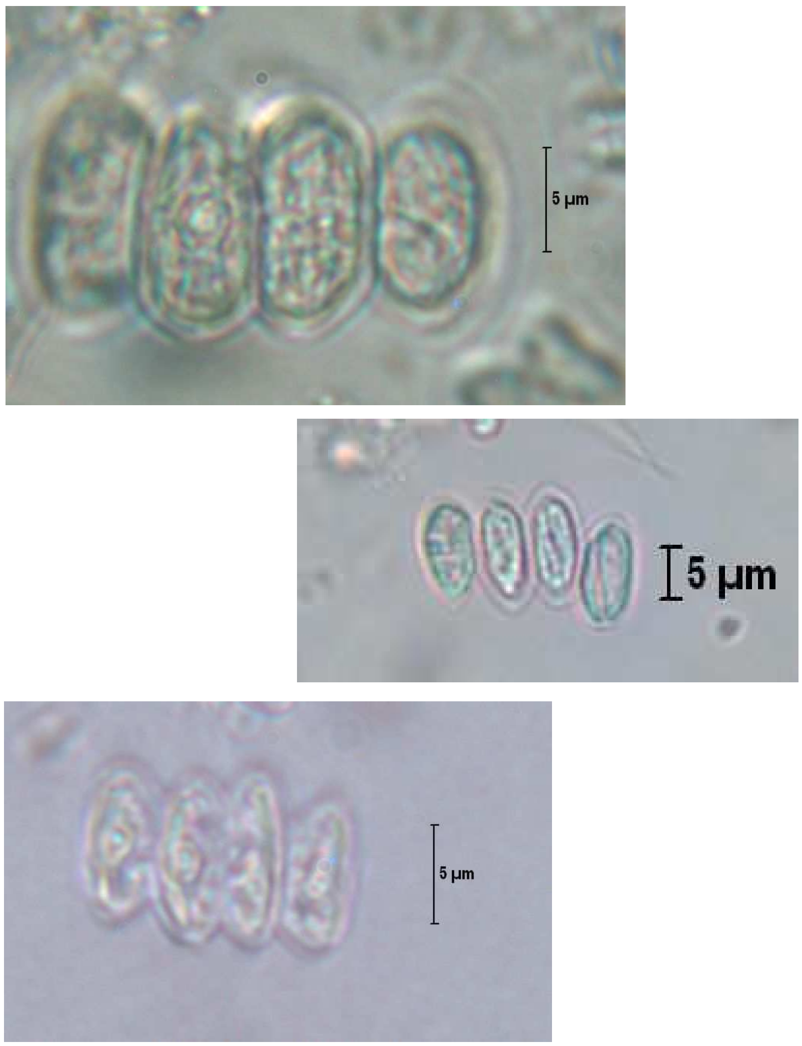
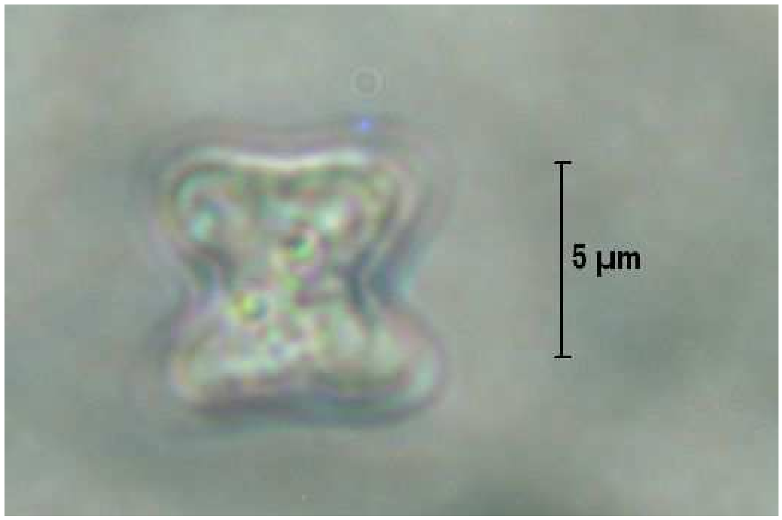


Figure B163: CHLOROPHYTA: *Scenedesmus* sp. 1 (ANSP #510030).



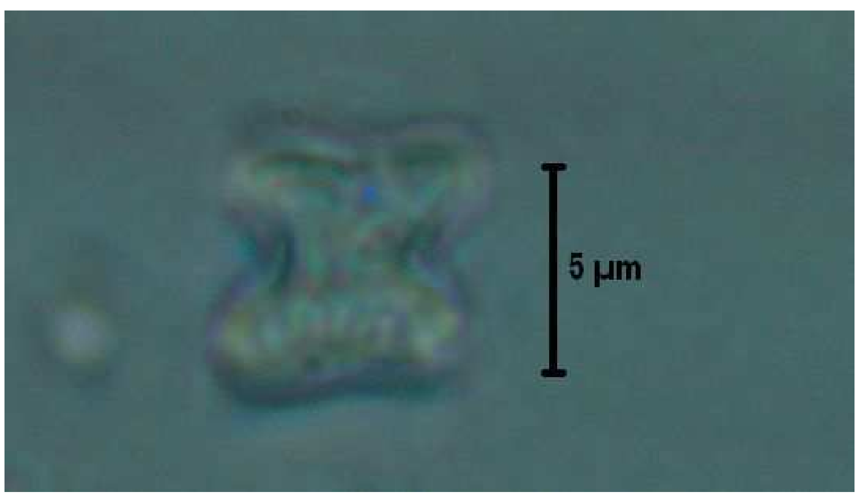


Figure B164: CHLOROPHYTA: *Tetraedron minimum* (Braun) Hansgirg (ANSP #553002).

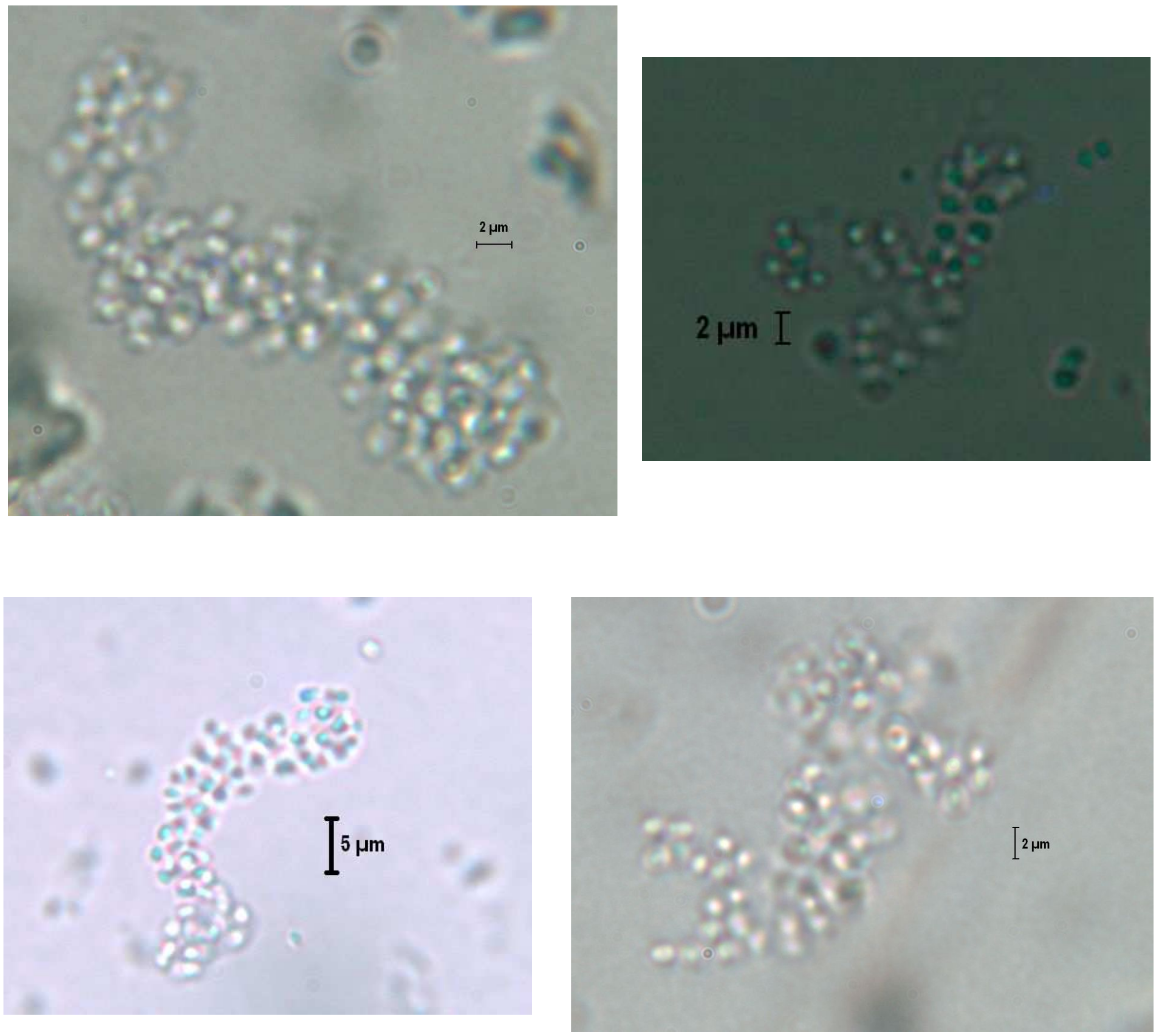


Figure B165: CYANOBACTERIA: *Aphanocapsa* sp. 1 (ANSP #807001).

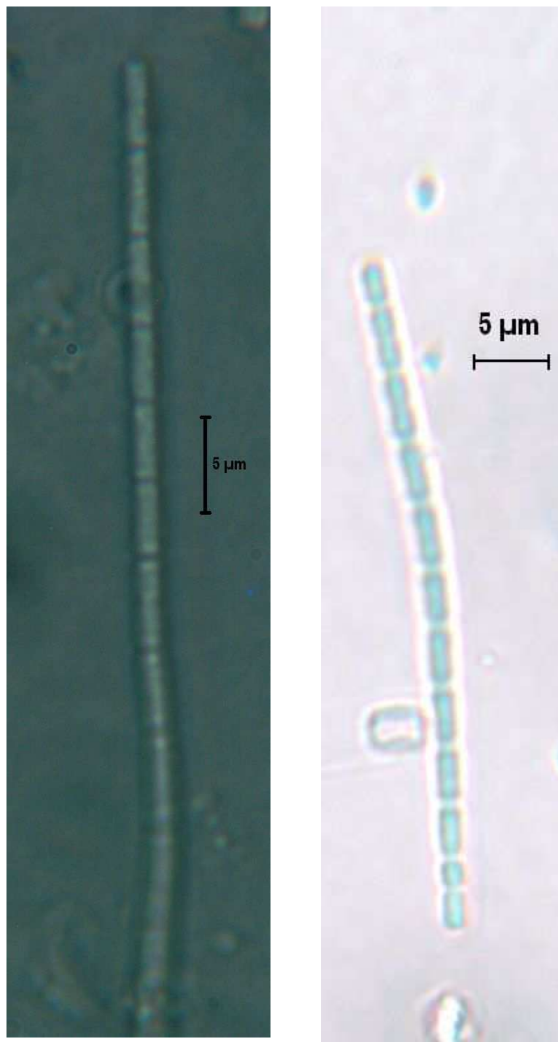


Figure B166: CYANOBACTERIA: *Pseudanabaena* sp. 1 (ANSP #897003).

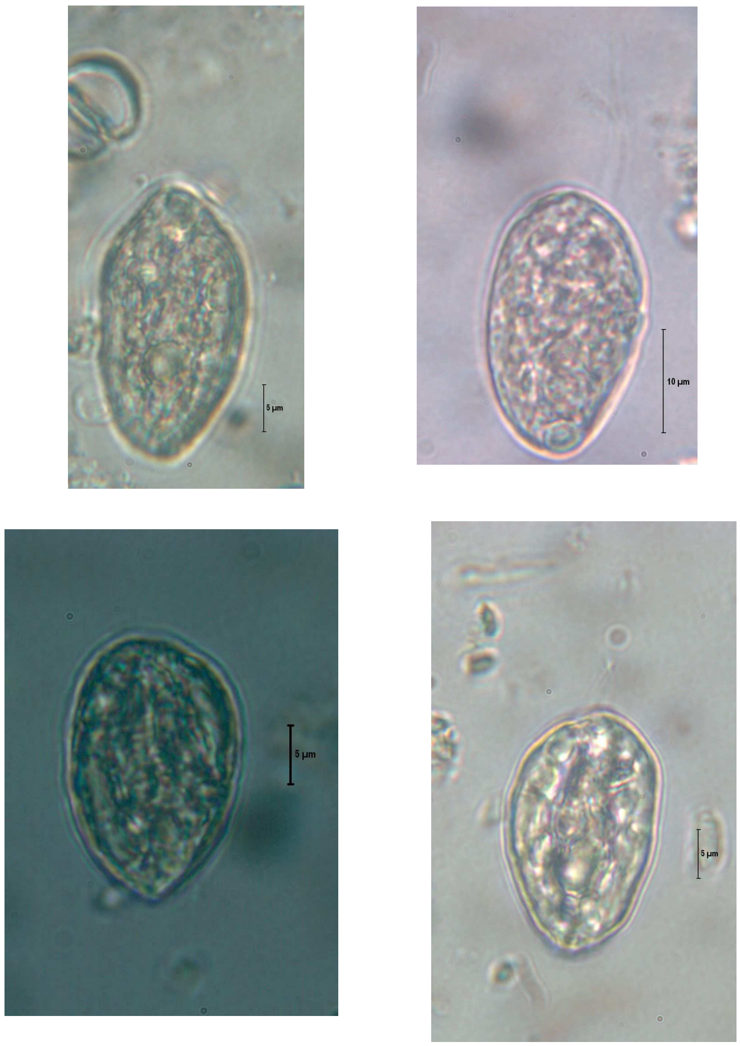


Figure B167: CRYPTOPHYTA: *Cryptomonas ovata* Ehrenberg (ANSP #1265003).

Figure B168: CRYPTOPHYTA: *Cryptomonas* sp. 1 (ANSP #1265002).

Figure B169: PYRRHOPHYTA: *Ceratium hirudinella* (Möller) Dujardin (ANSP #1334000). Image is from the IWS digital image library; no ANSP image is available.

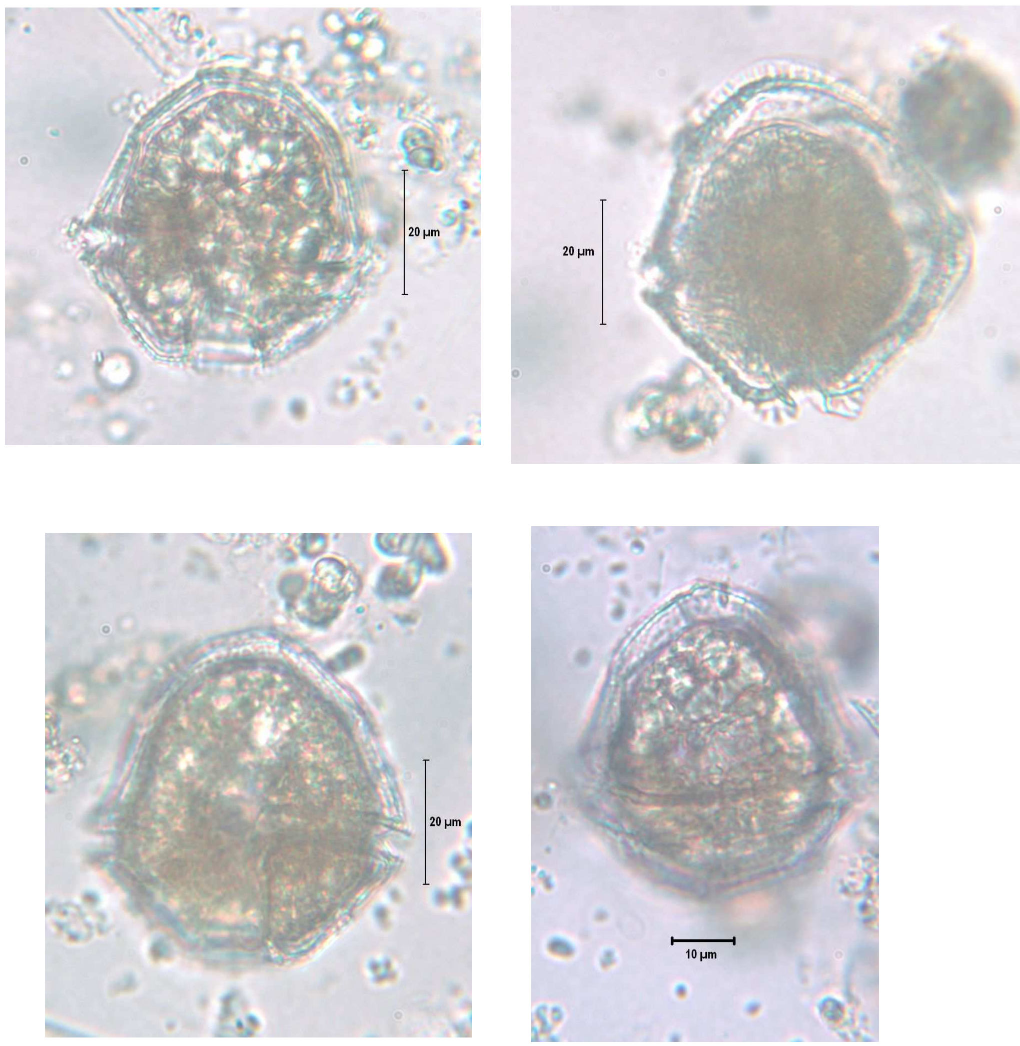


Figure B170: PYRRHOPHYTA: *Peridinium willei* Huitfeld-Kaas (ANSP #1457013).

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

The figures in this appendix include the monthly baseline data collected from October 4004 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.

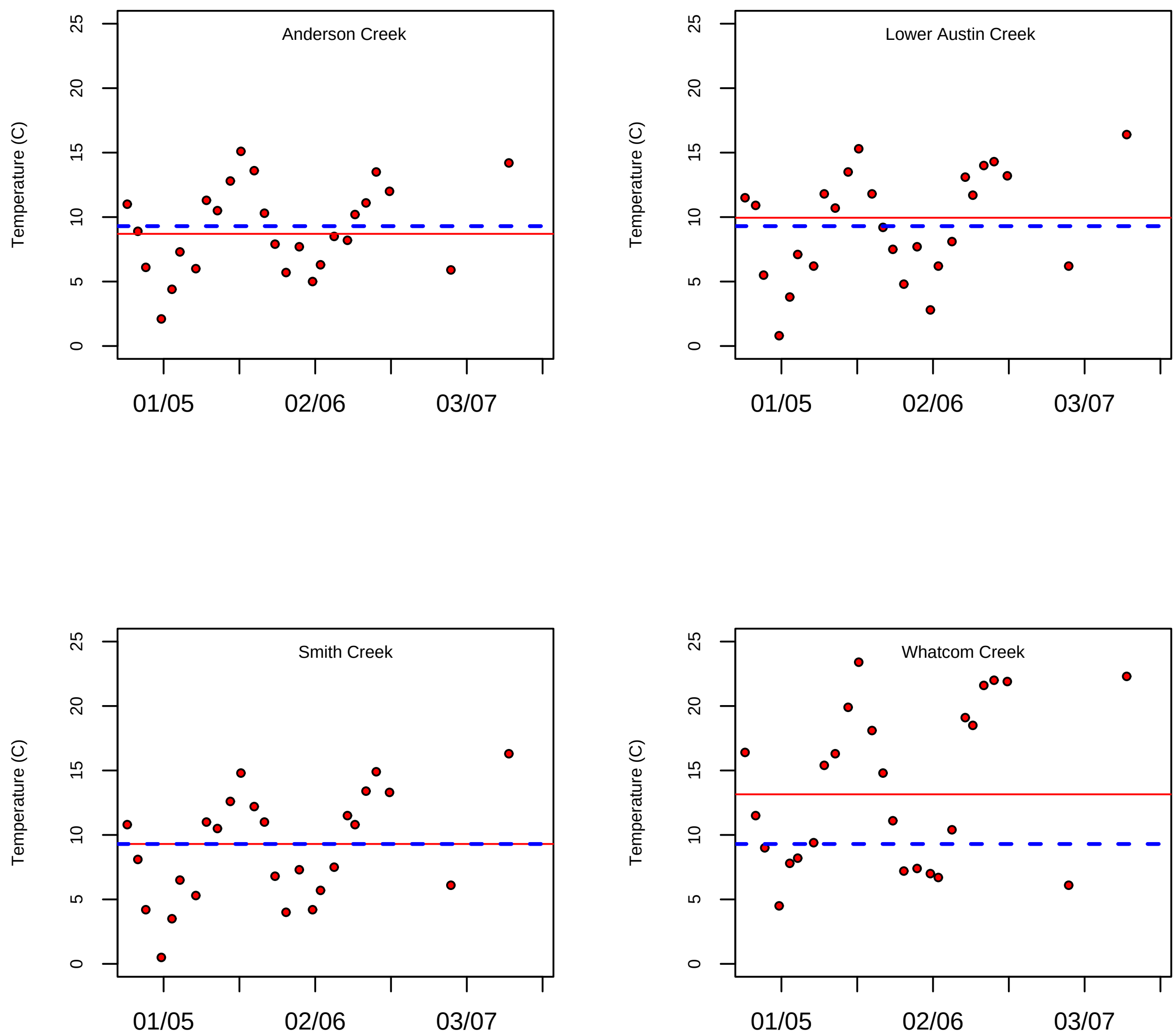


Figure B171: Temperature data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

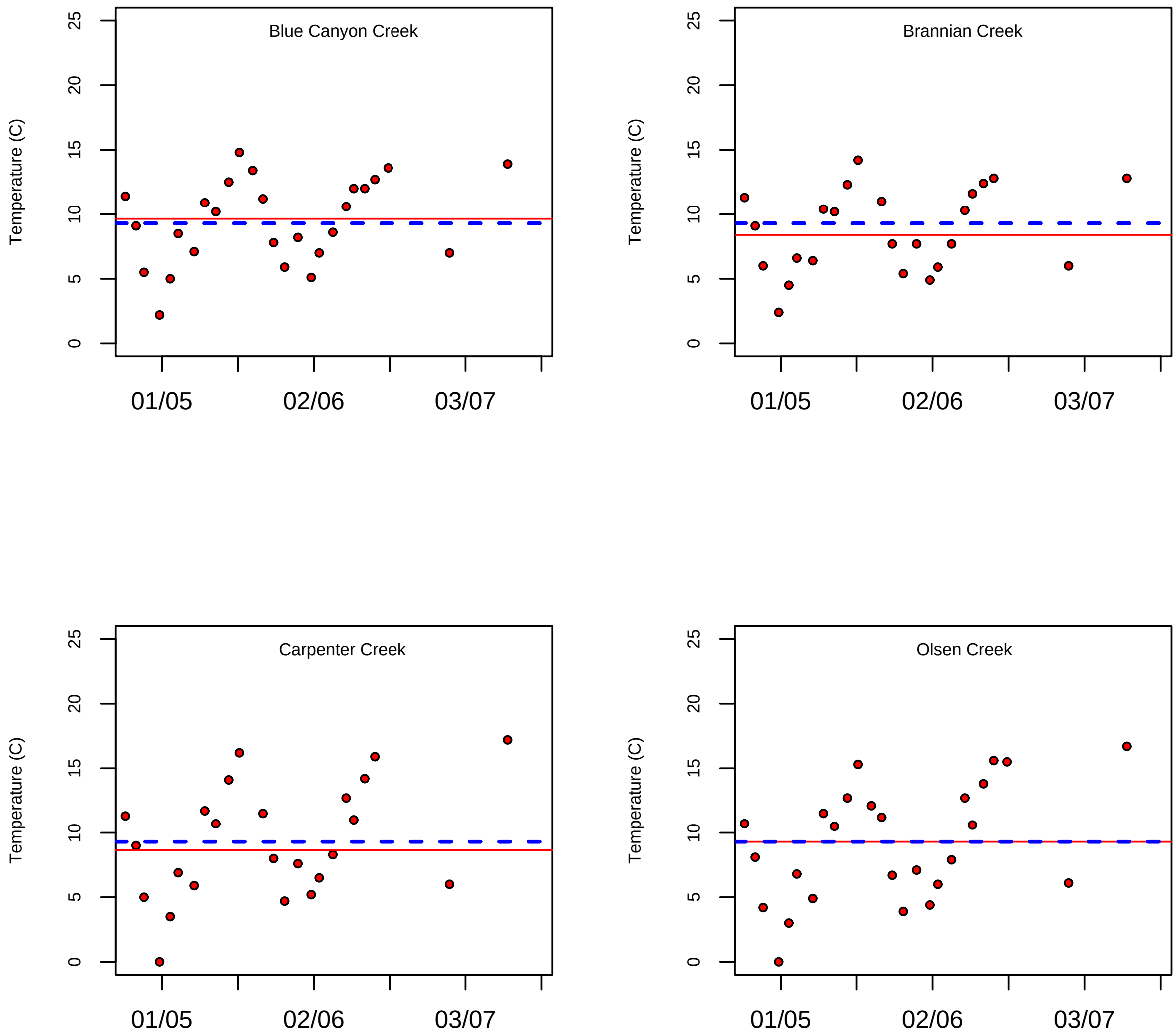


Figure B172: Temperature data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

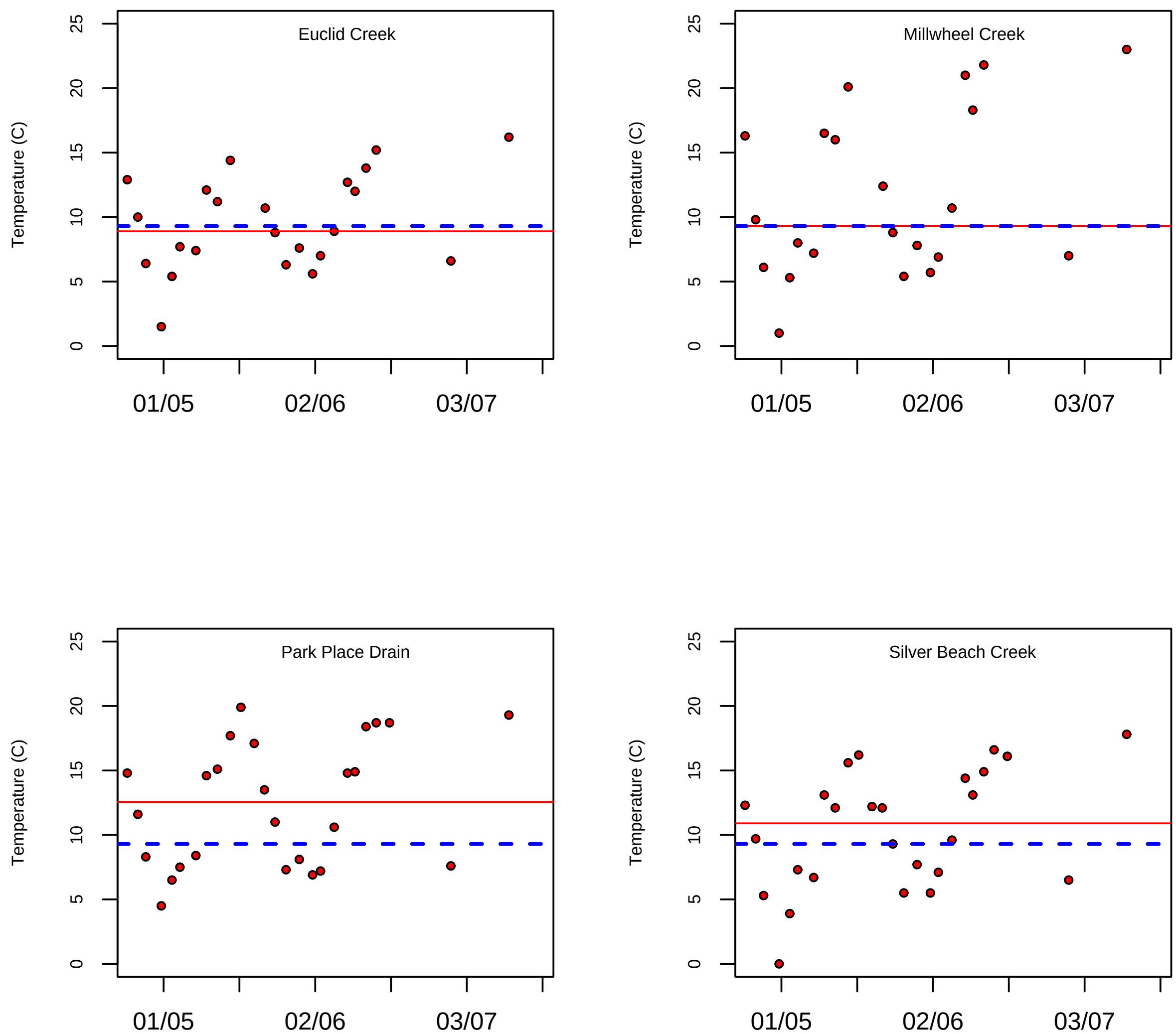


Figure B173: Temperature data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

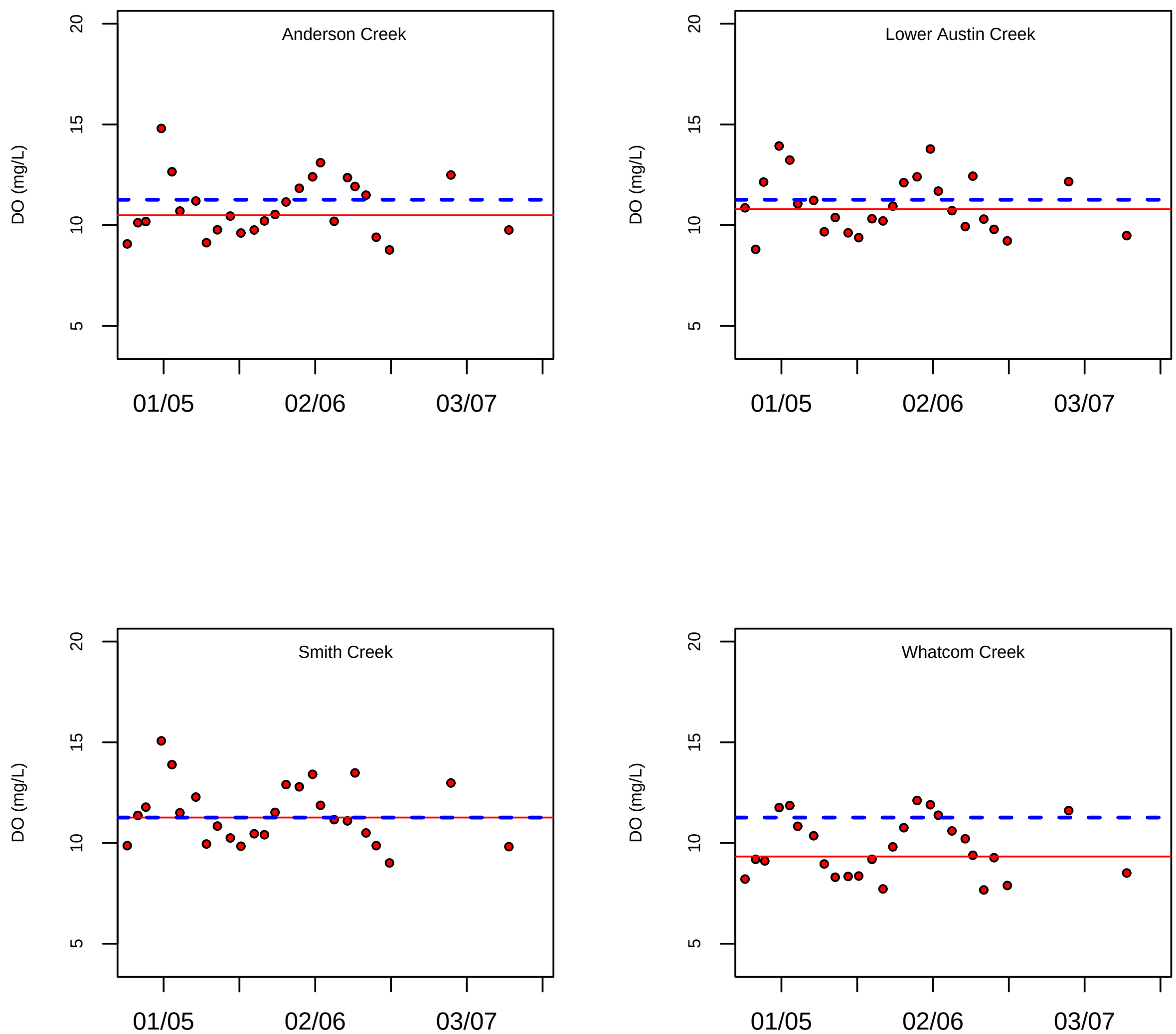


Figure B174: Dissolved oxygen data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

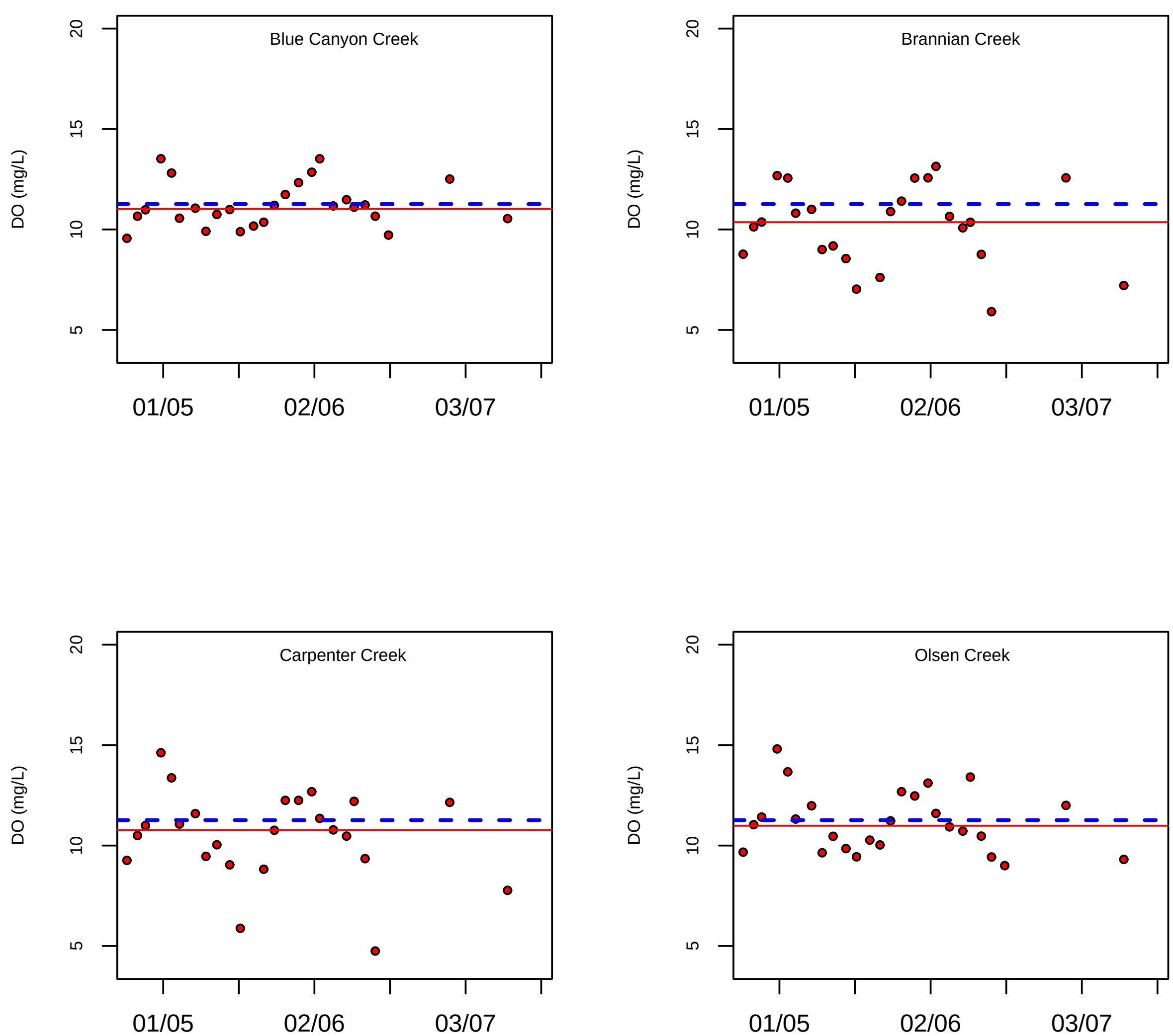


Figure B175: Dissolved oxygen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

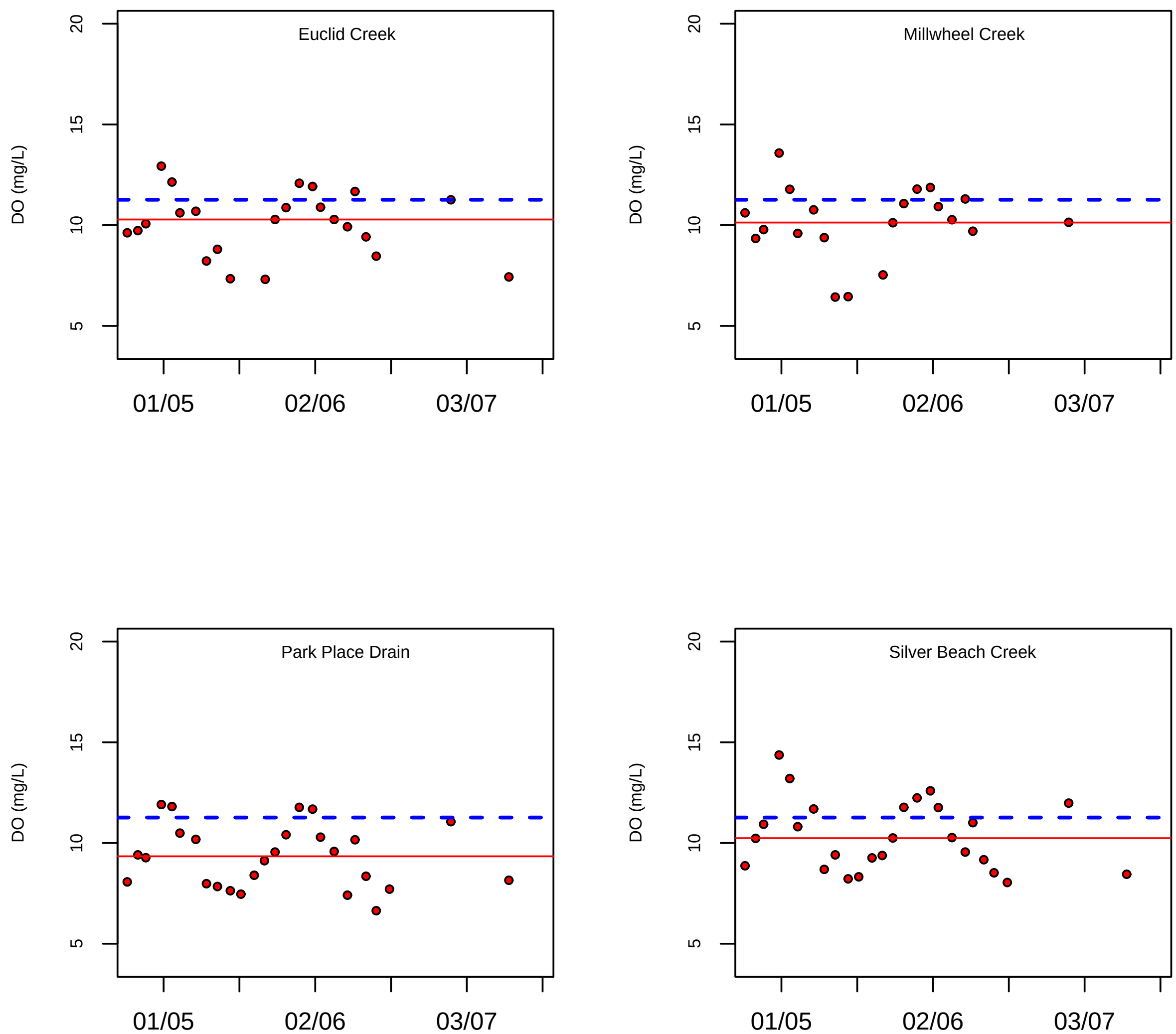


Figure B176: Dissolved oxygen data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

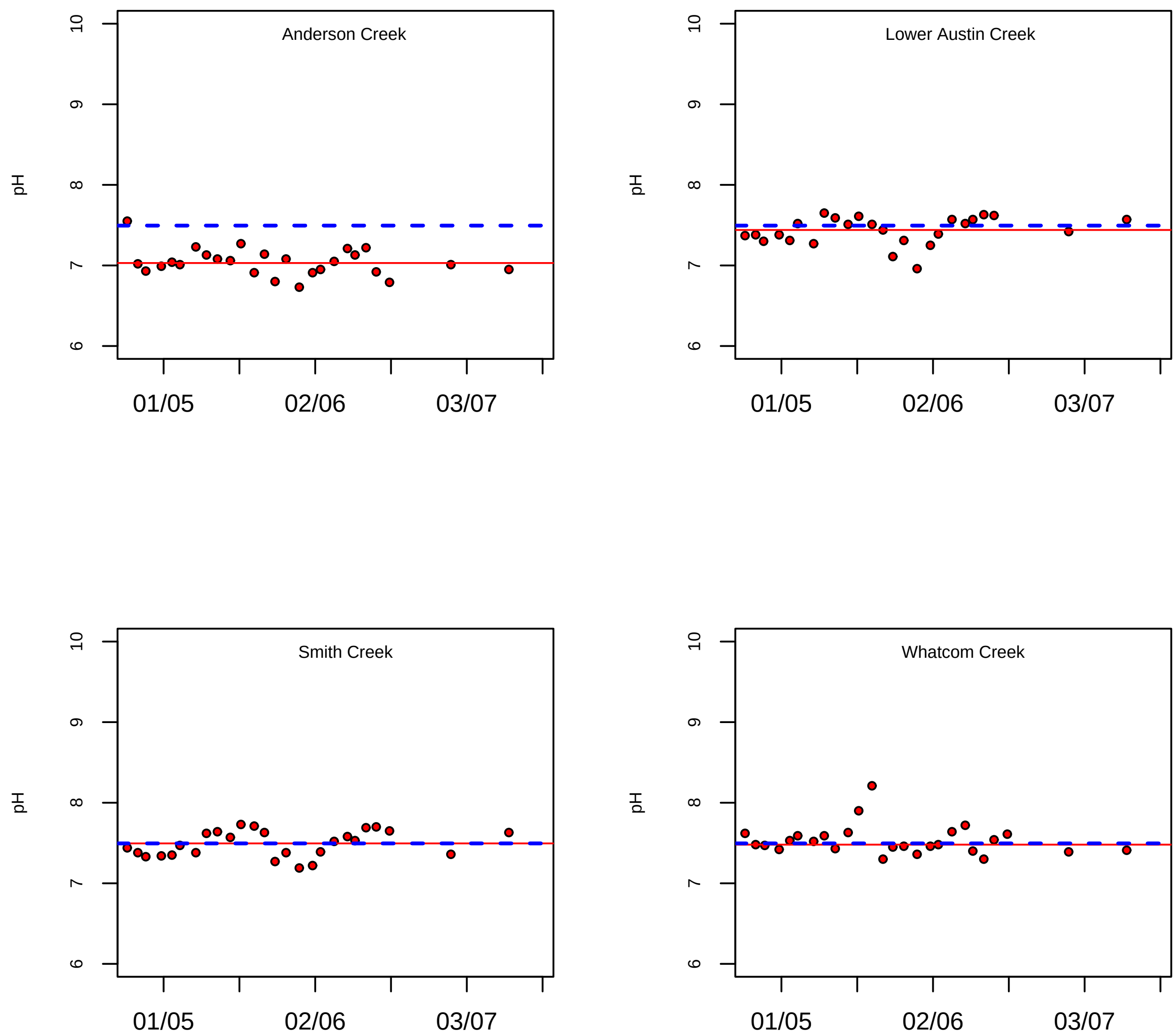


Figure B177: Tributary pH data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

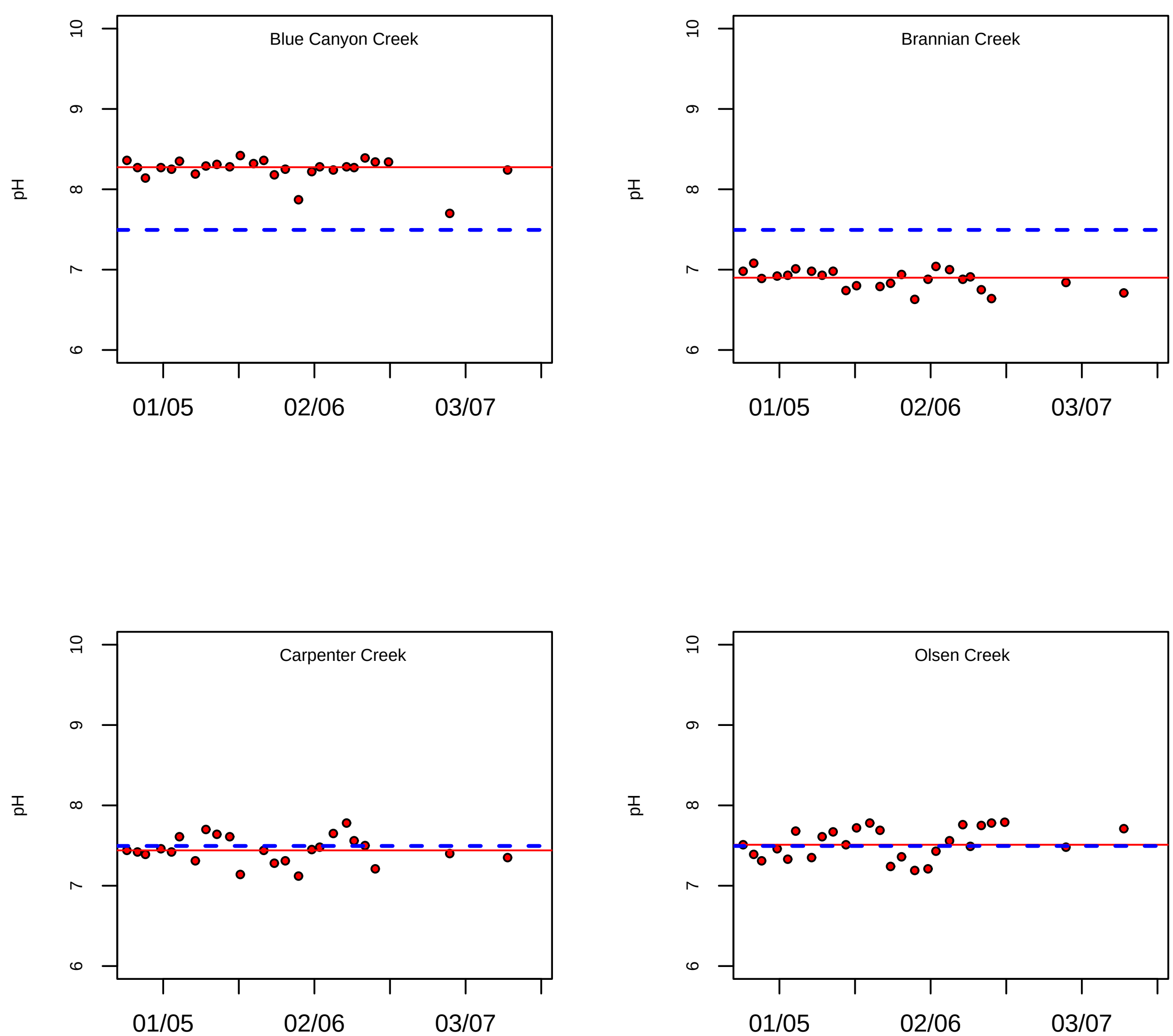


Figure B178: Tributary pH data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

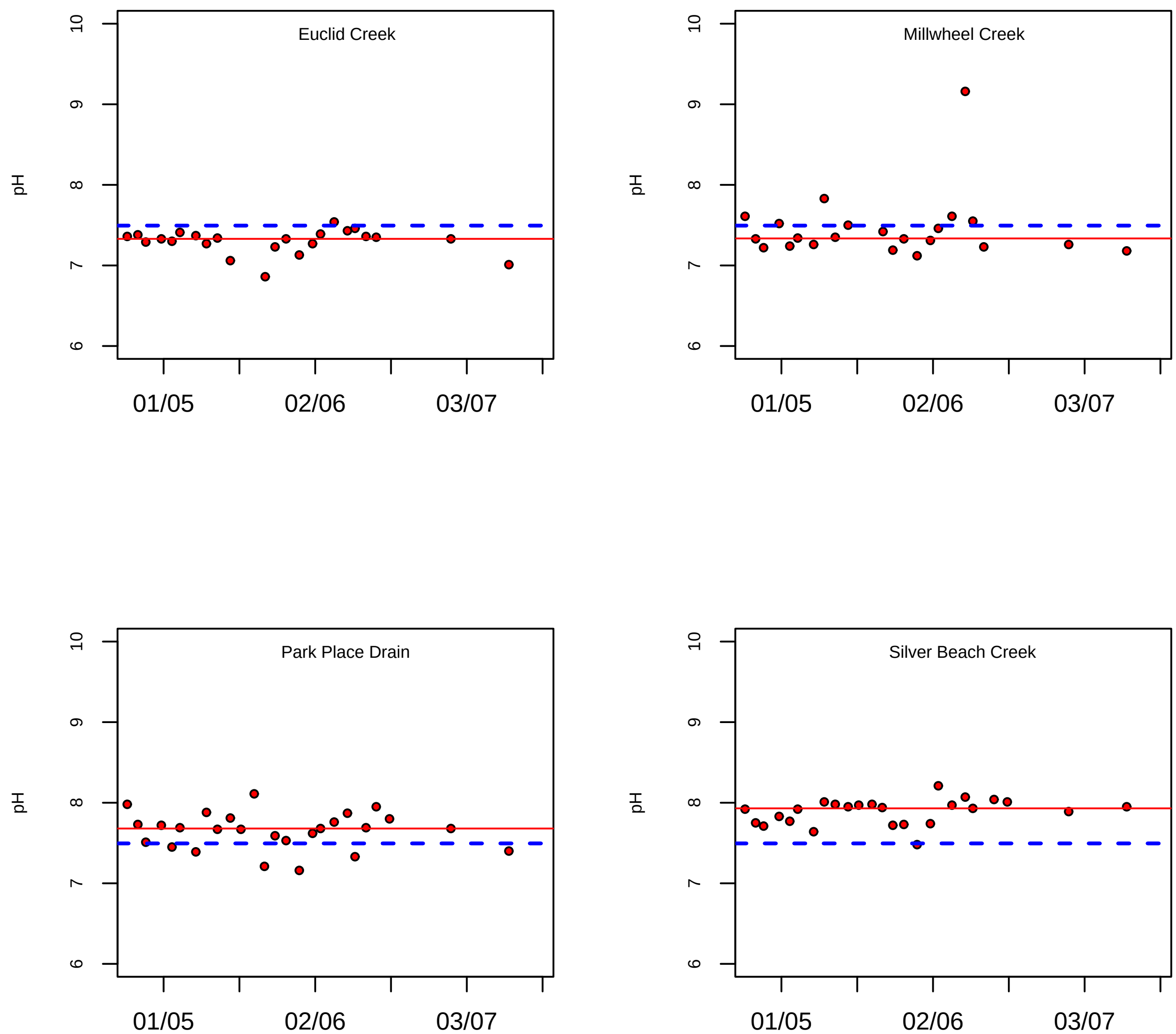


Figure B179: Tributary pH data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

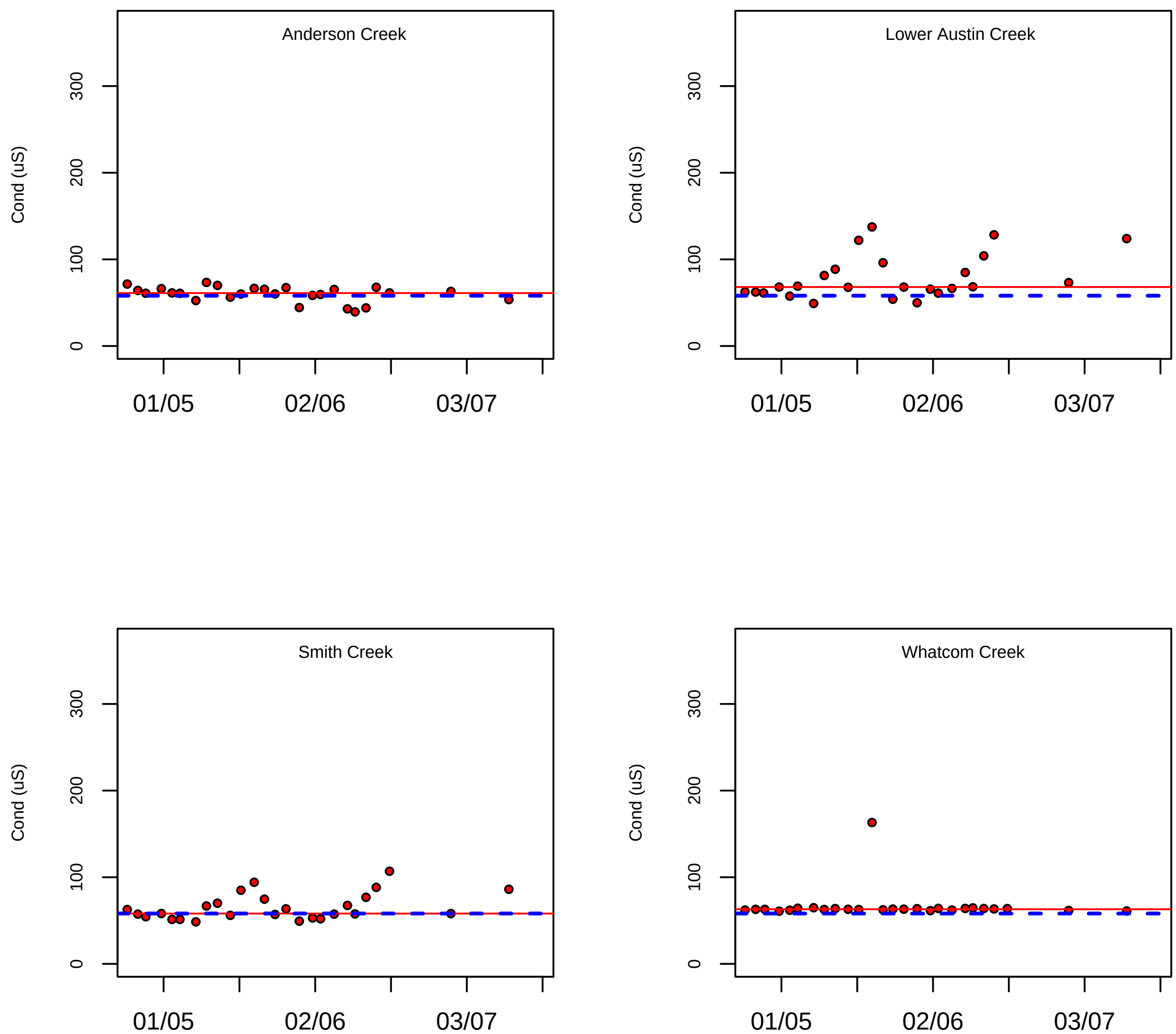


Figure B180: Conductivity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

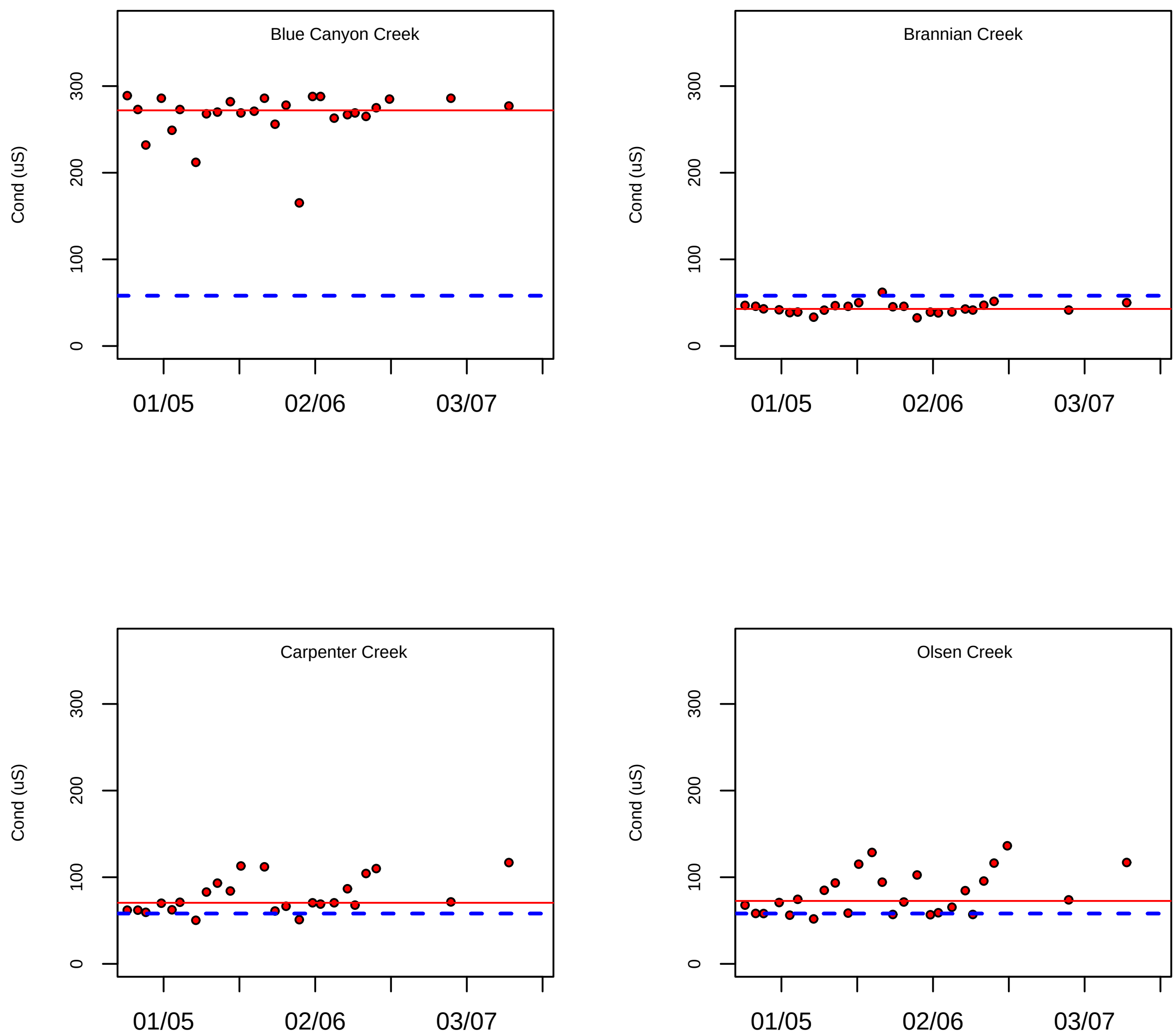


Figure B181: Conductivity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

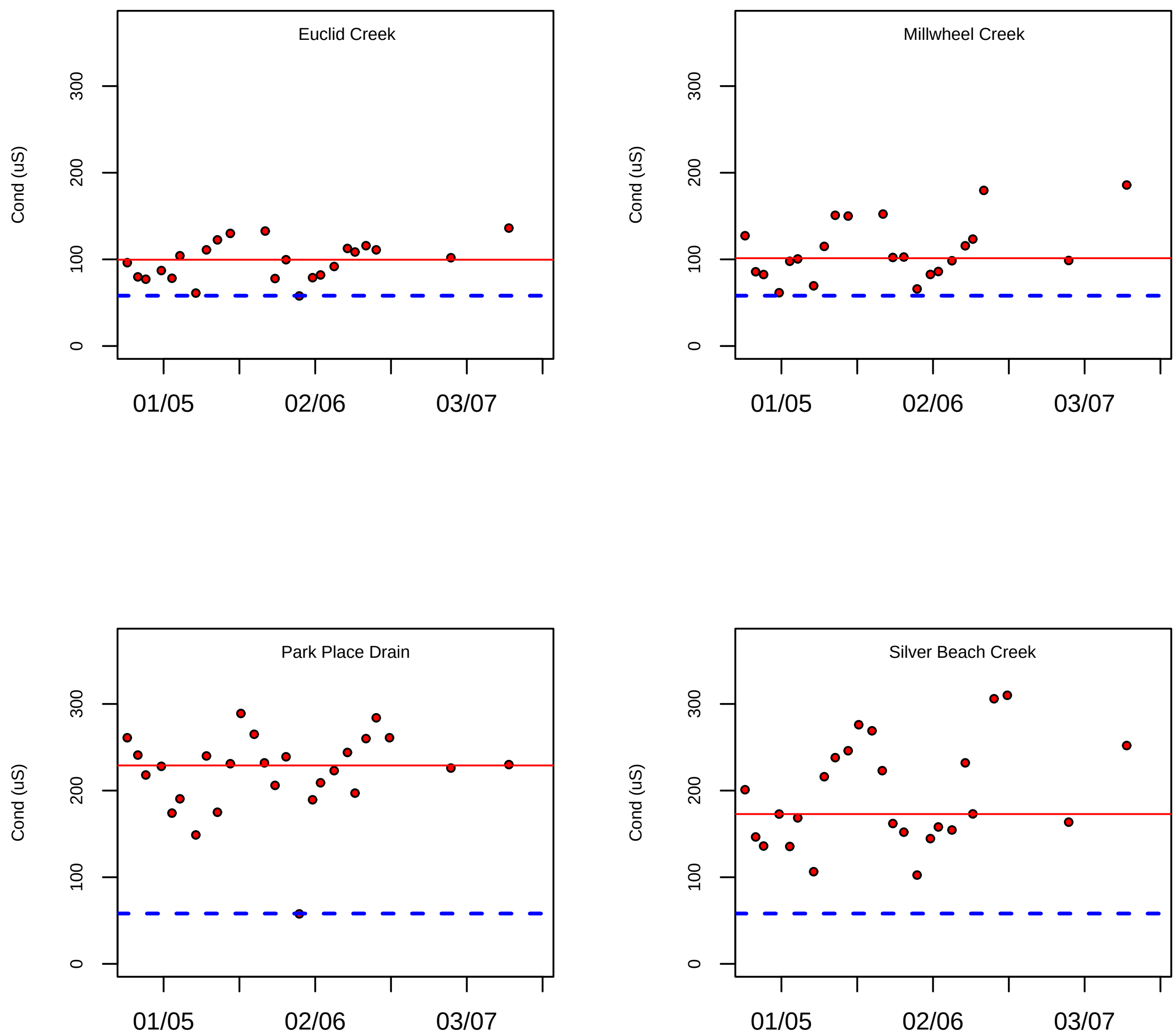


Figure B182: Conductivity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

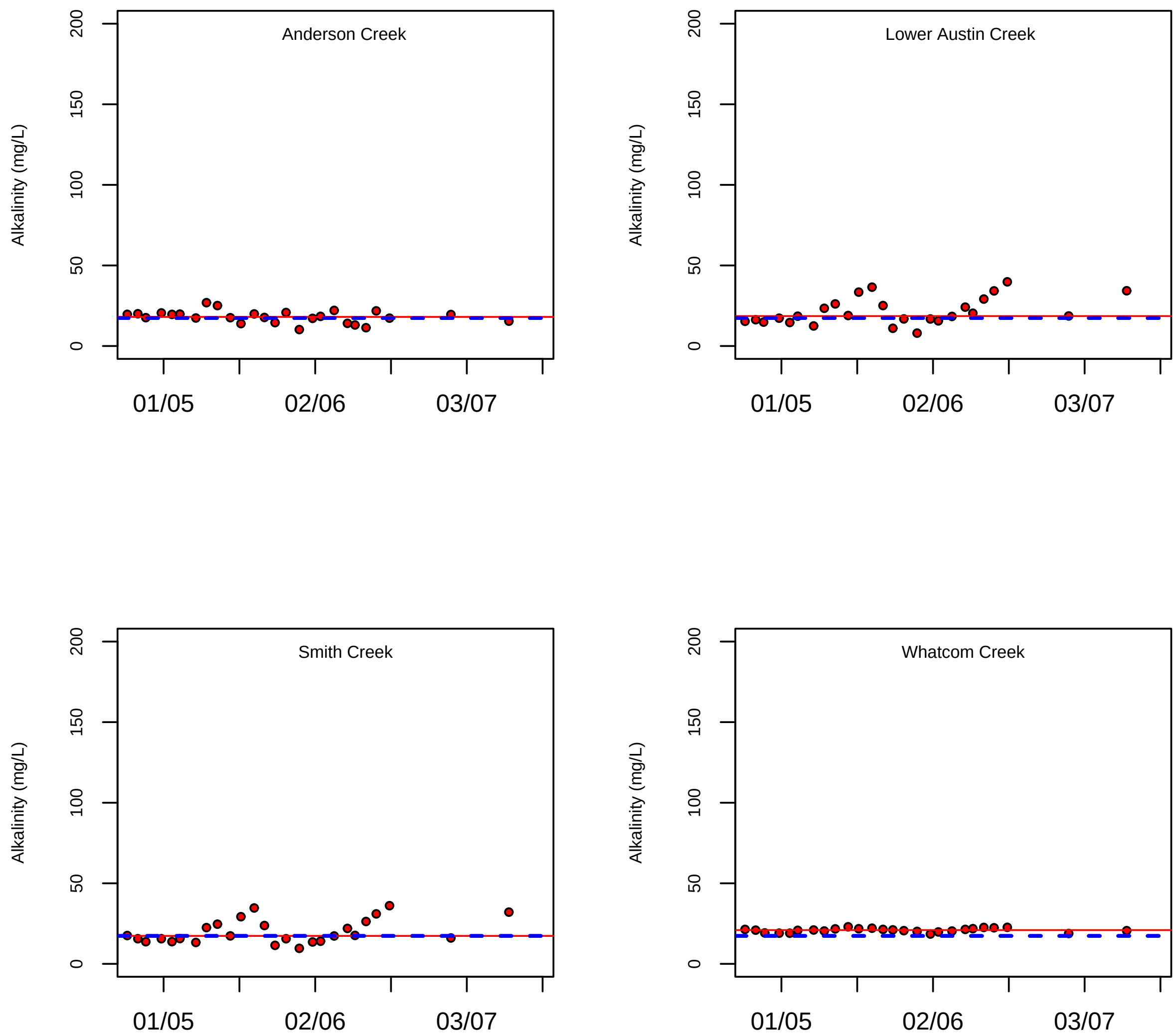


Figure B183: Alkalinity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

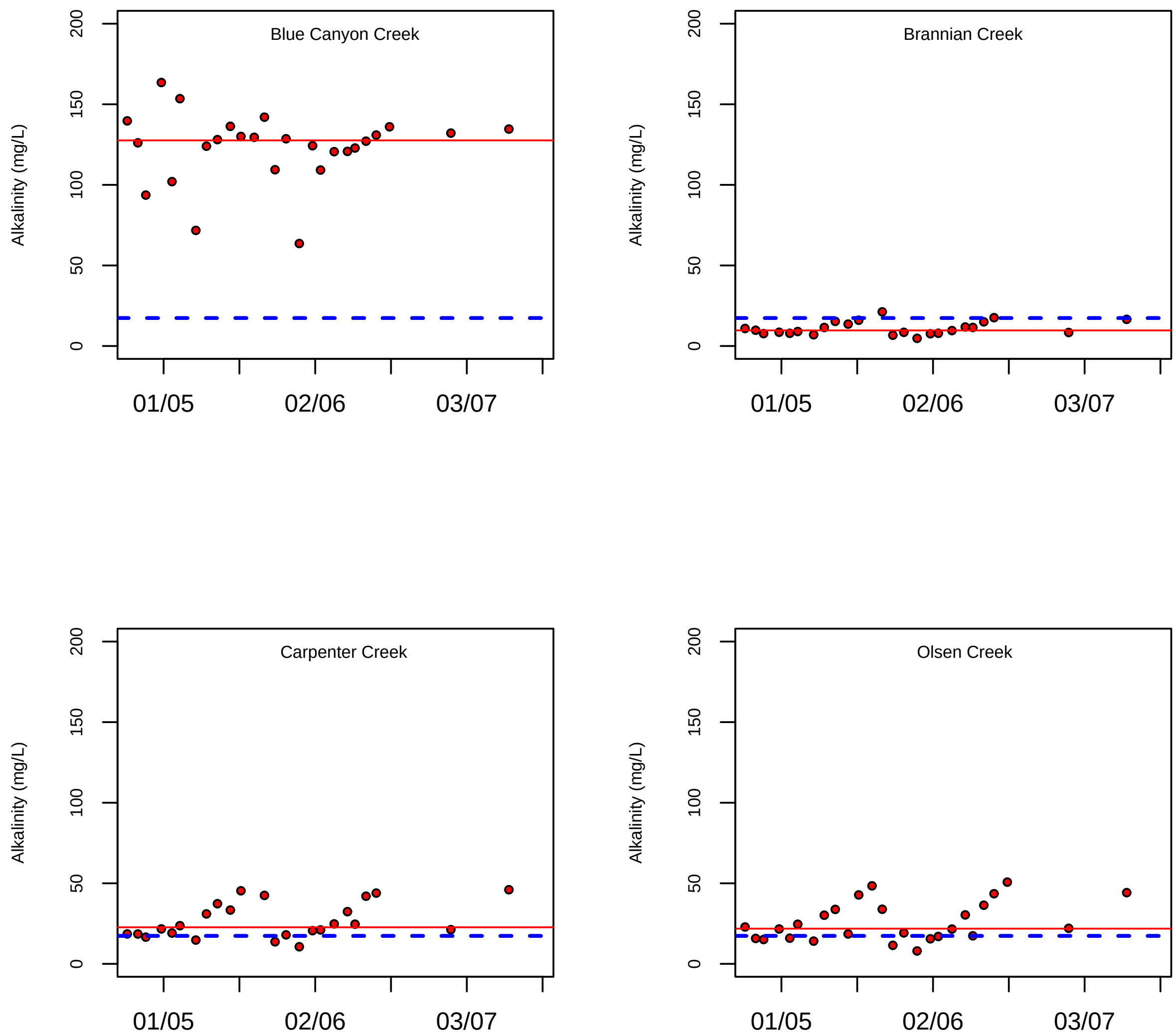


Figure B184: Alkalinity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

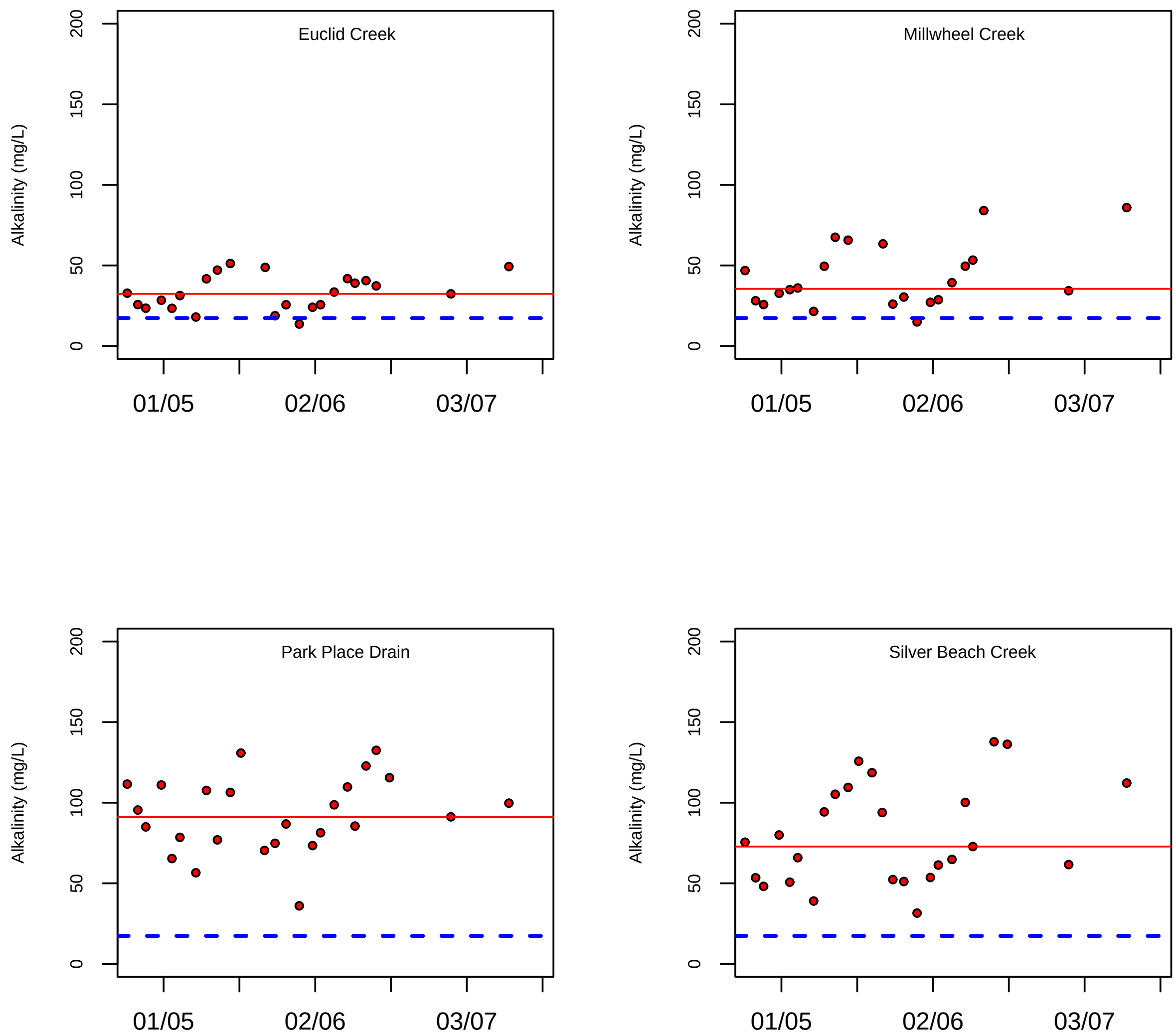


Figure B185: Alkalinity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

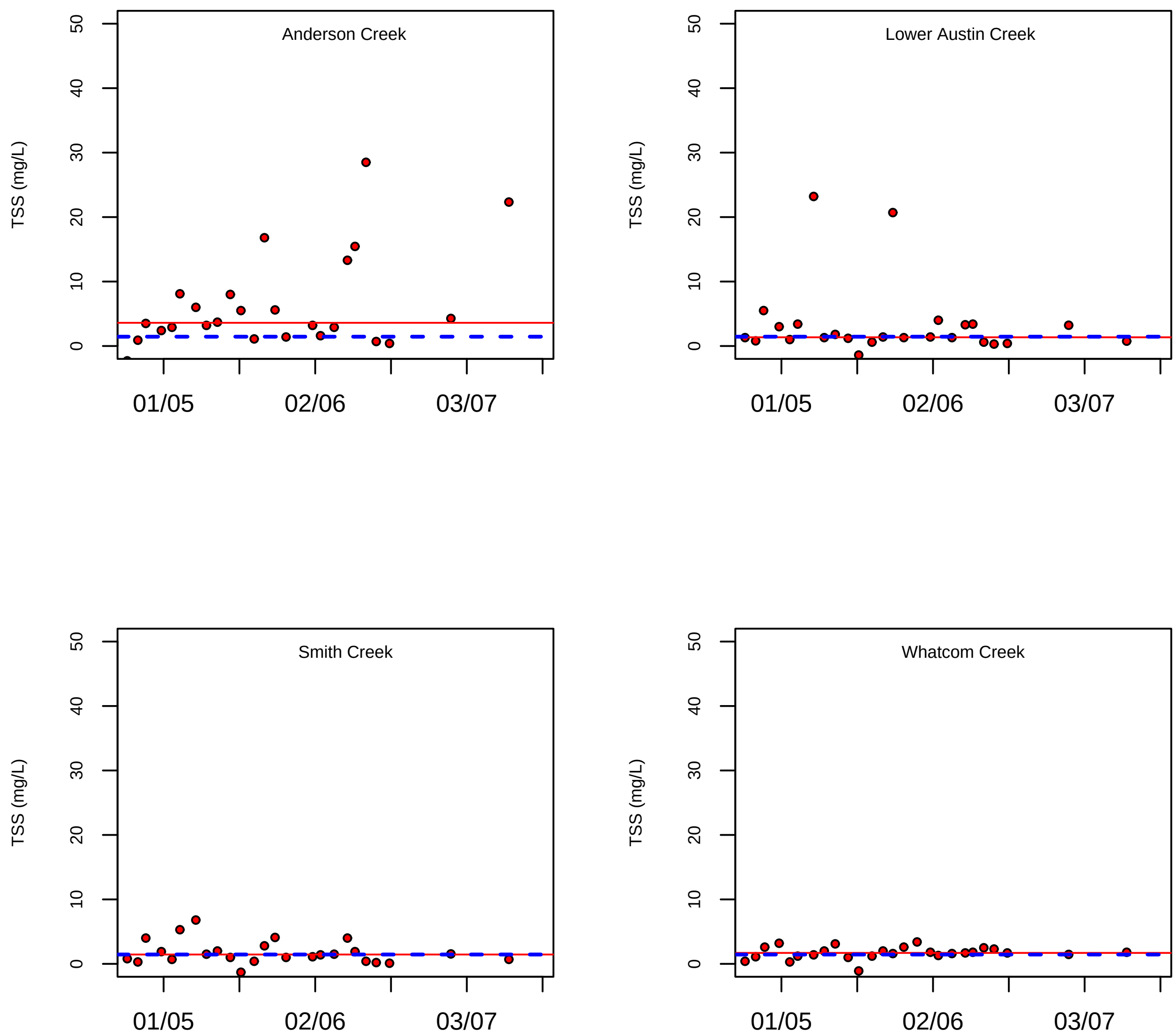


Figure B186: Total suspended solids data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

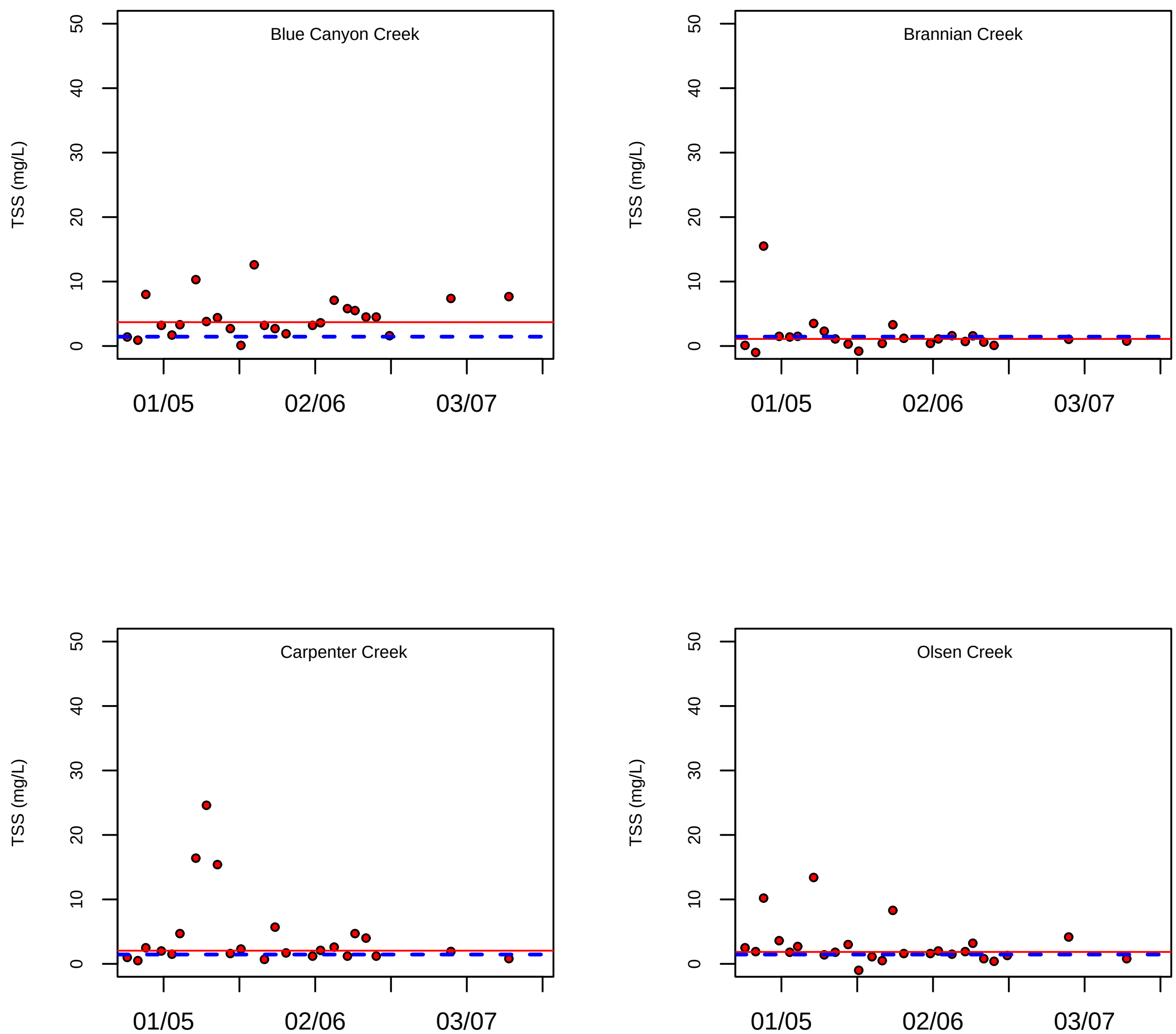


Figure B187: Total suspended solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

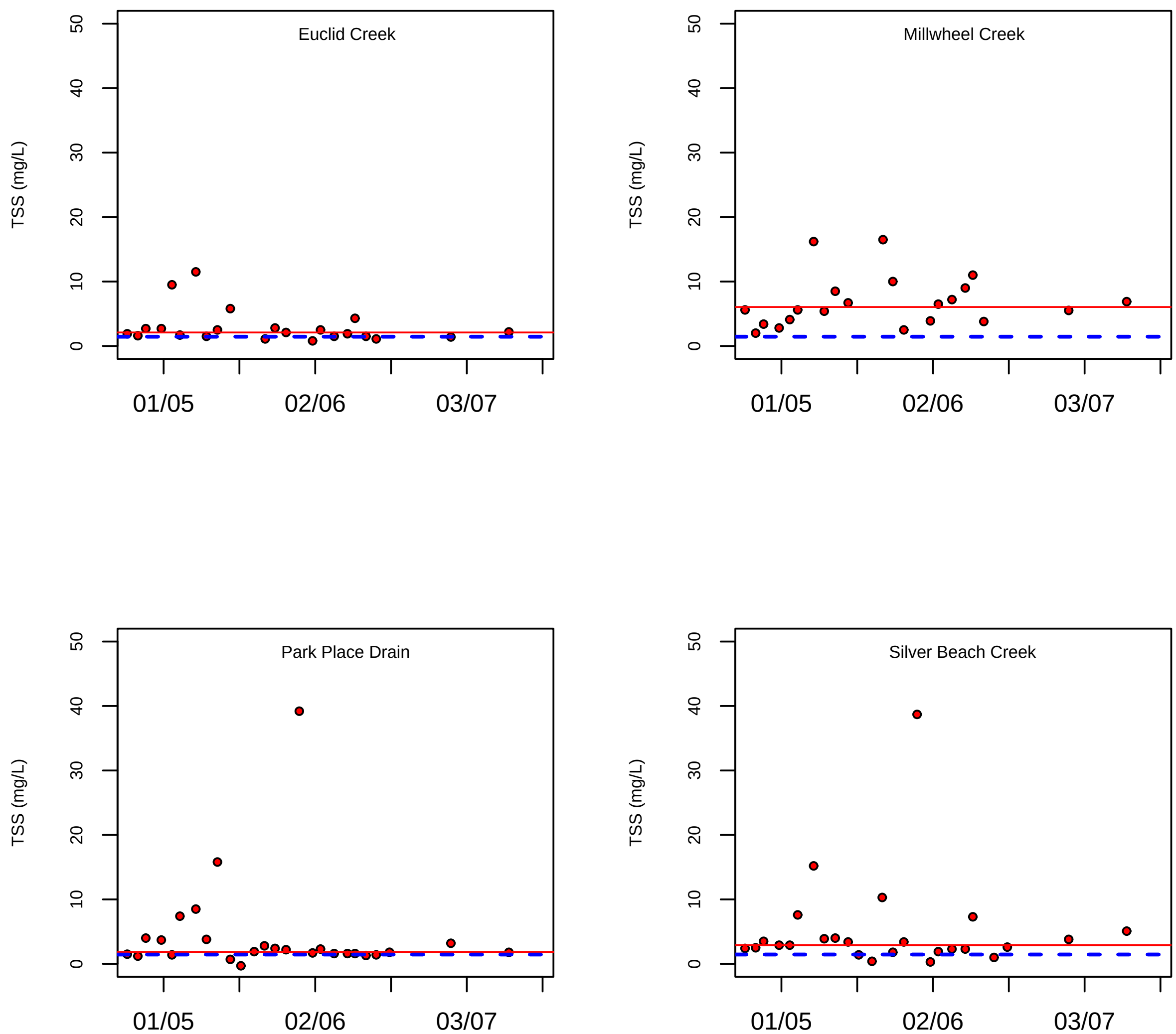


Figure B188: Total suspended solids data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

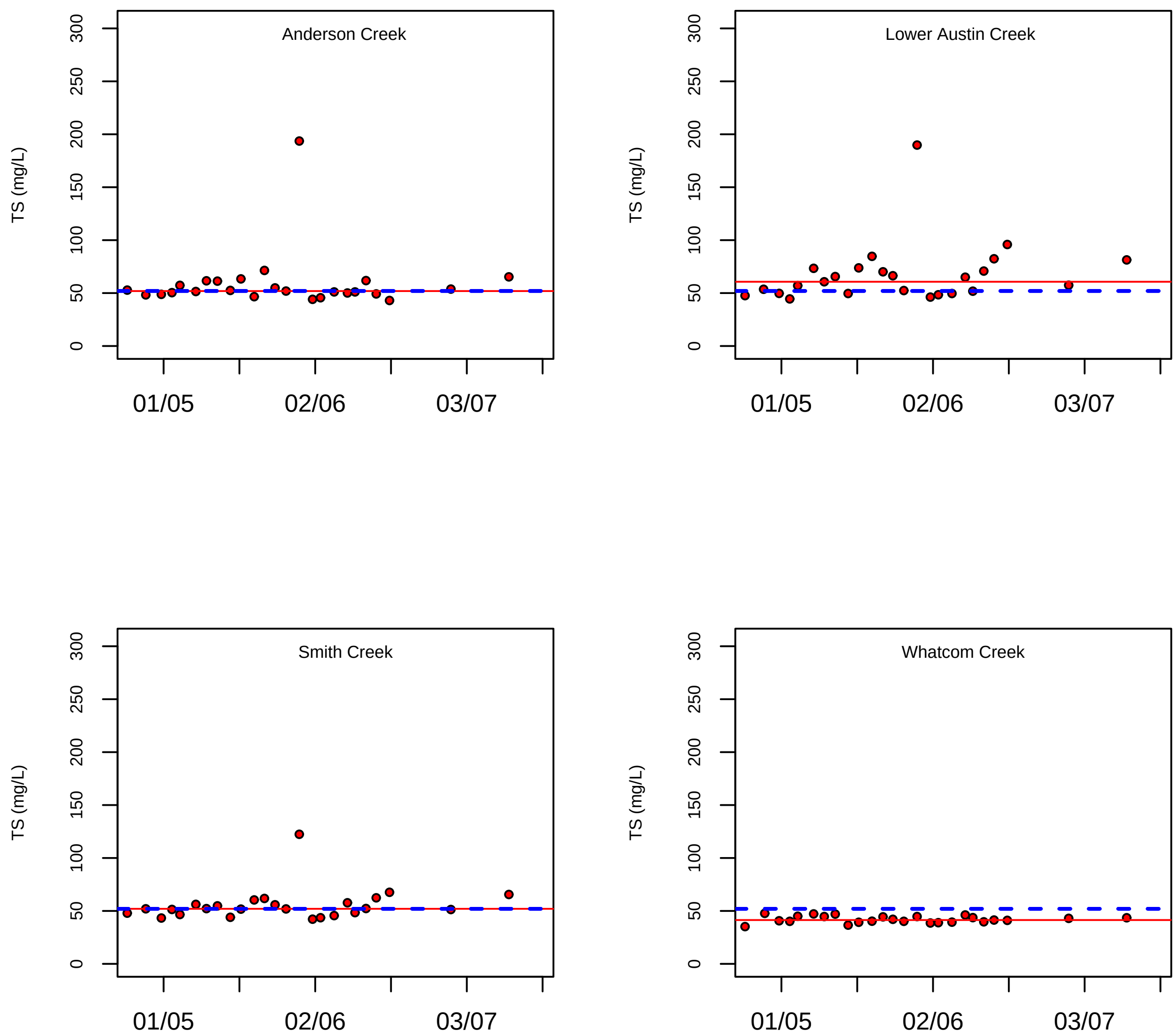


Figure B189: Total solids data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

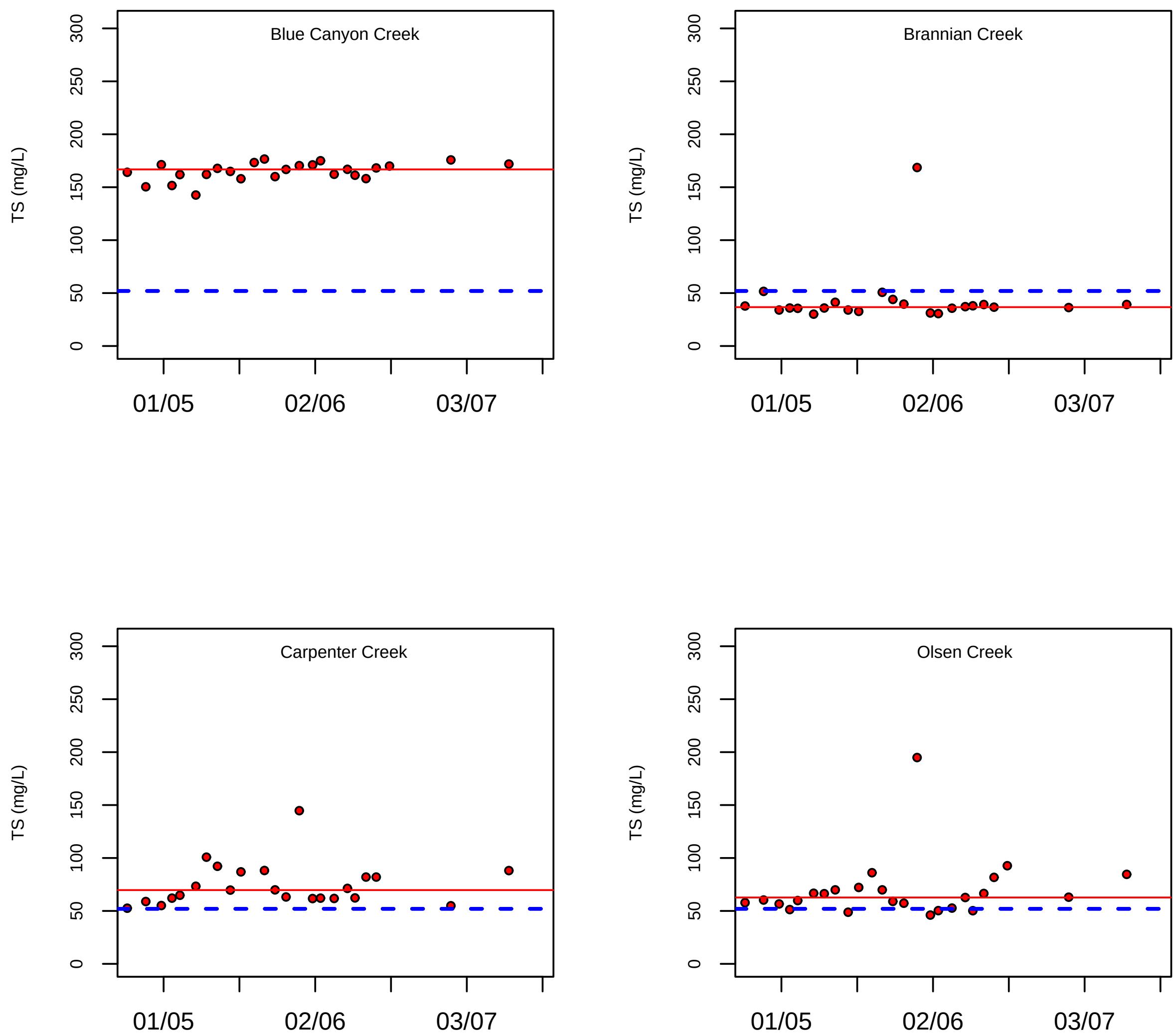


Figure B190: Total solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

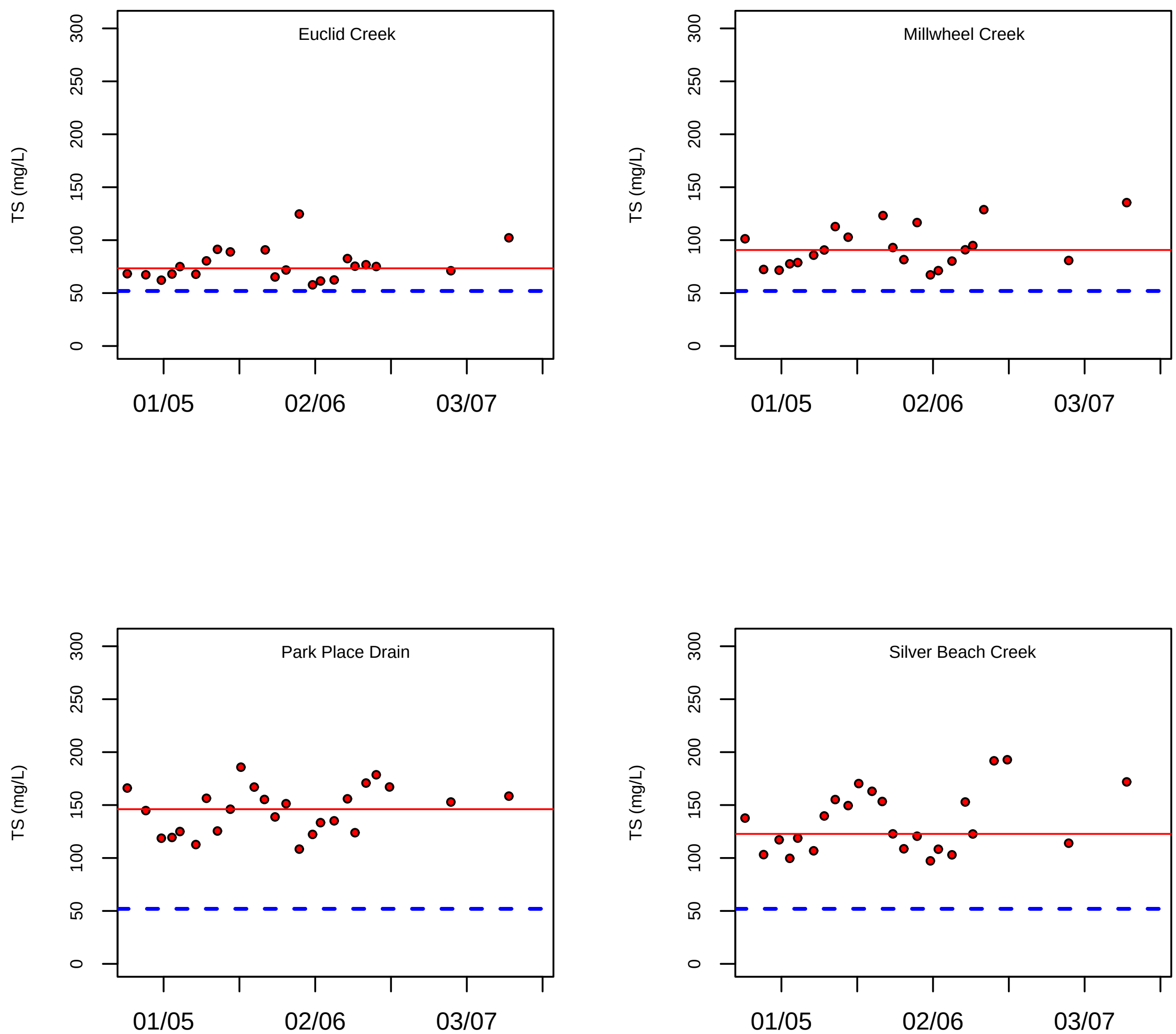


Figure B191: Total solids data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

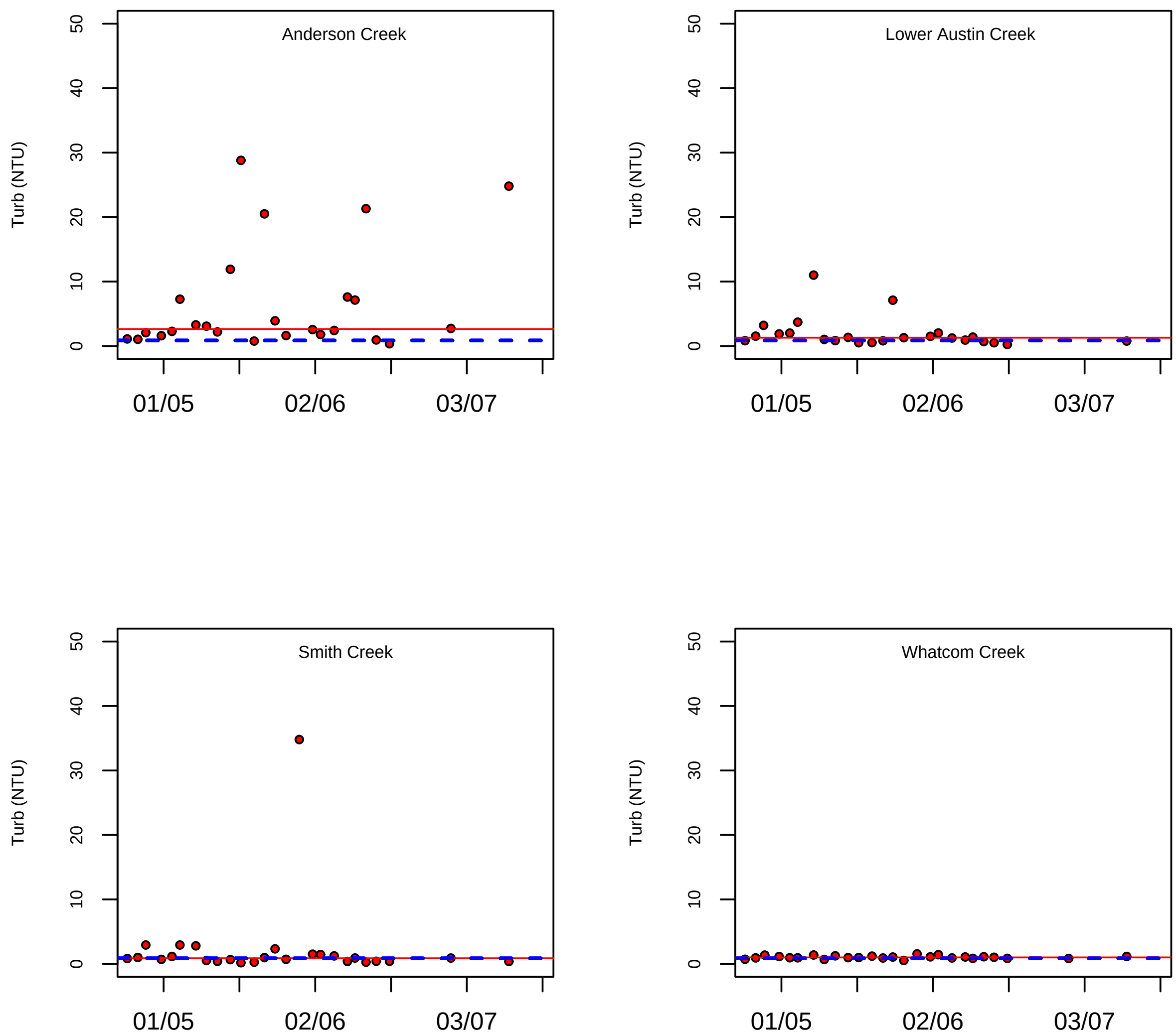


Figure B192: Turbidity data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

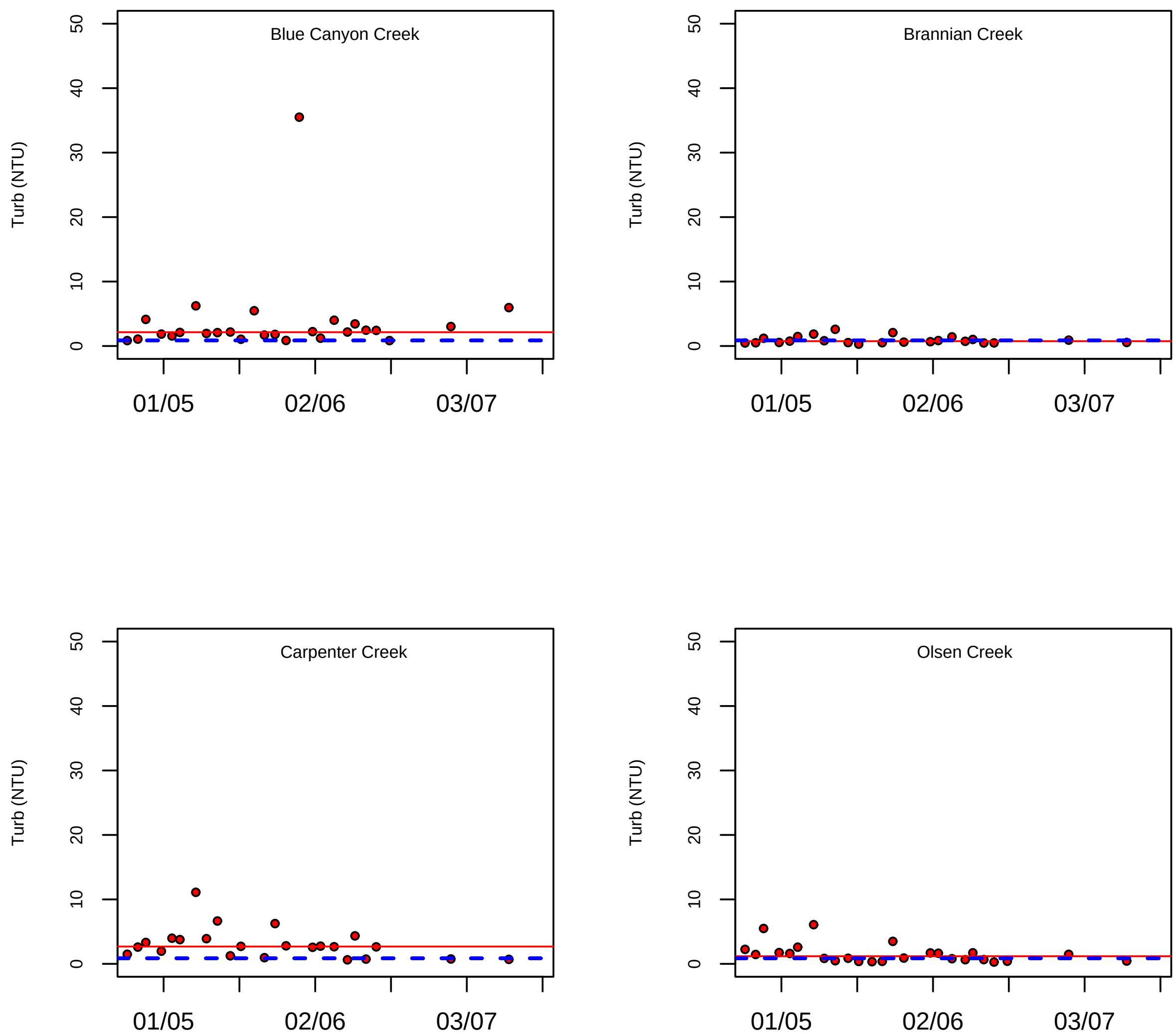


Figure B193: Turbidity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

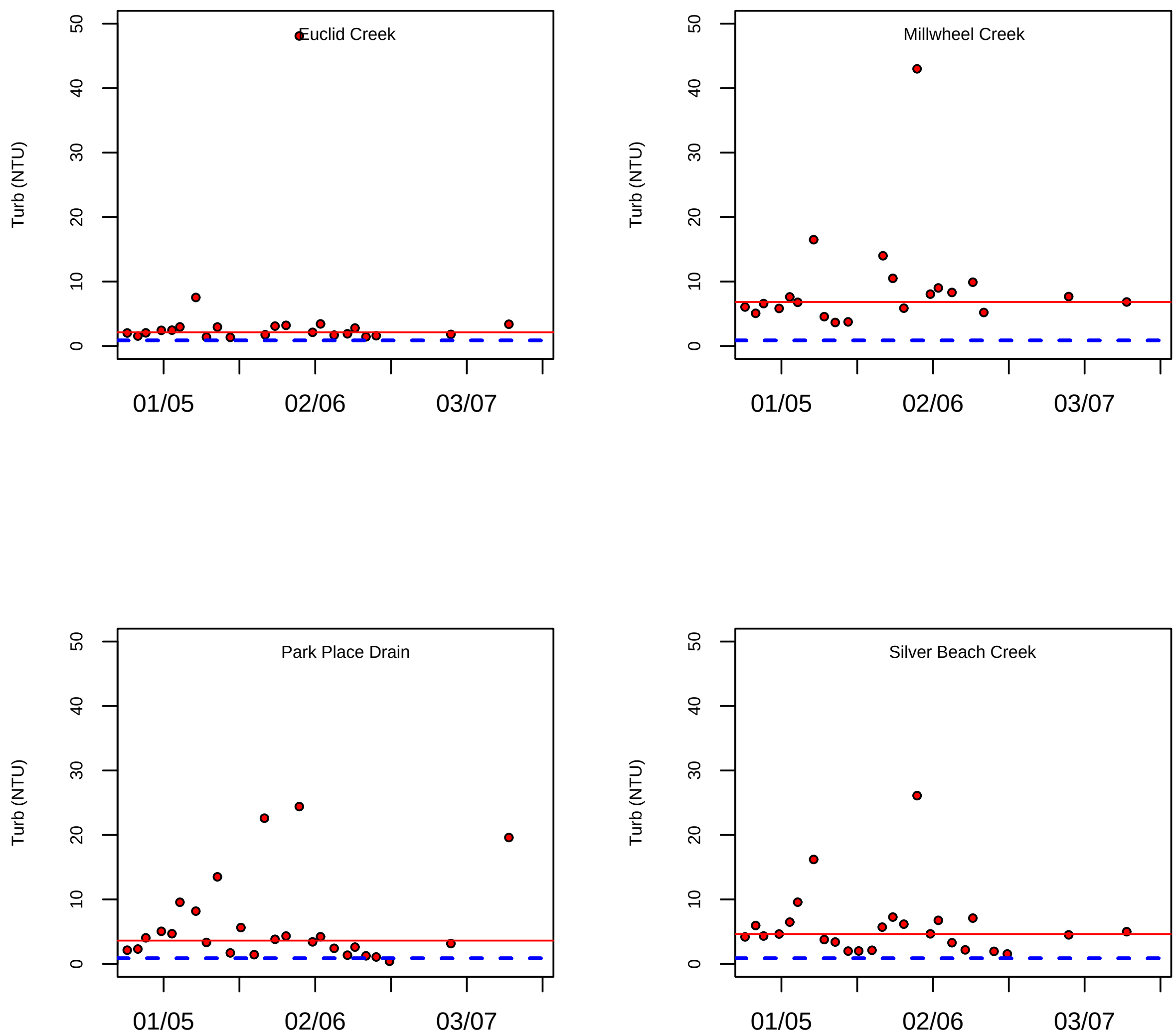


Figure B194: Turbidity data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

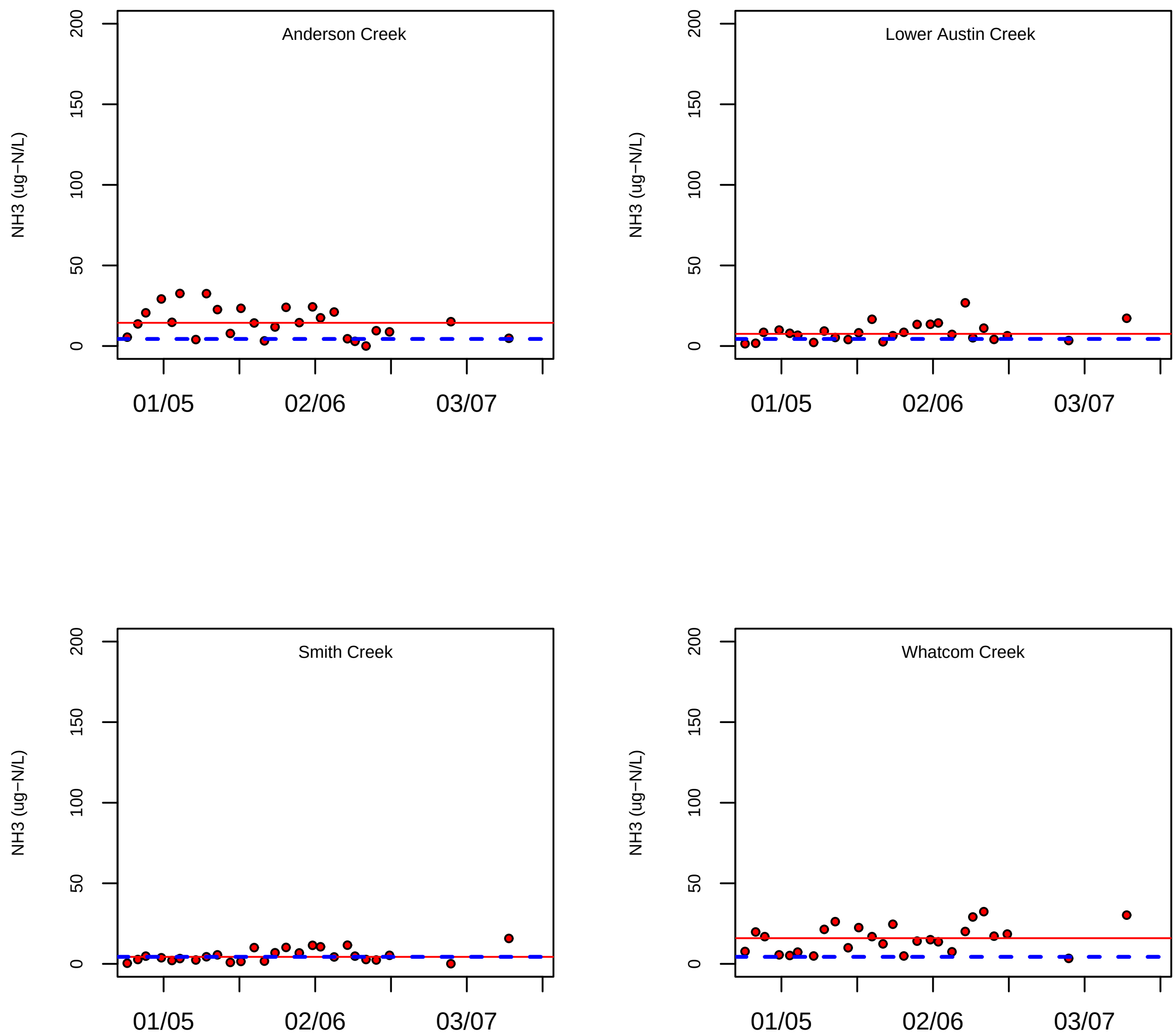


Figure B195: Ammonia data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

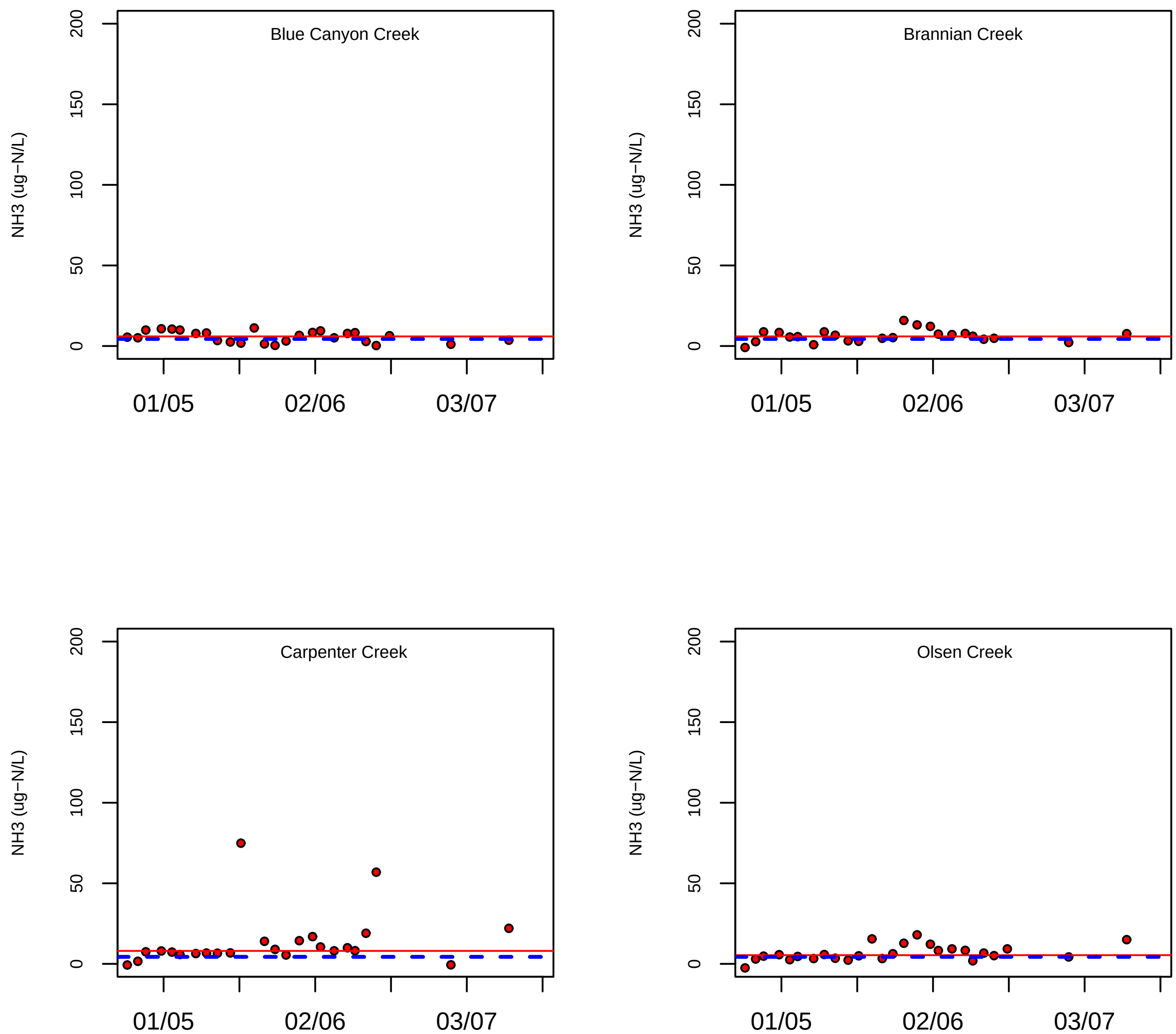


Figure B196: Ammonia data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

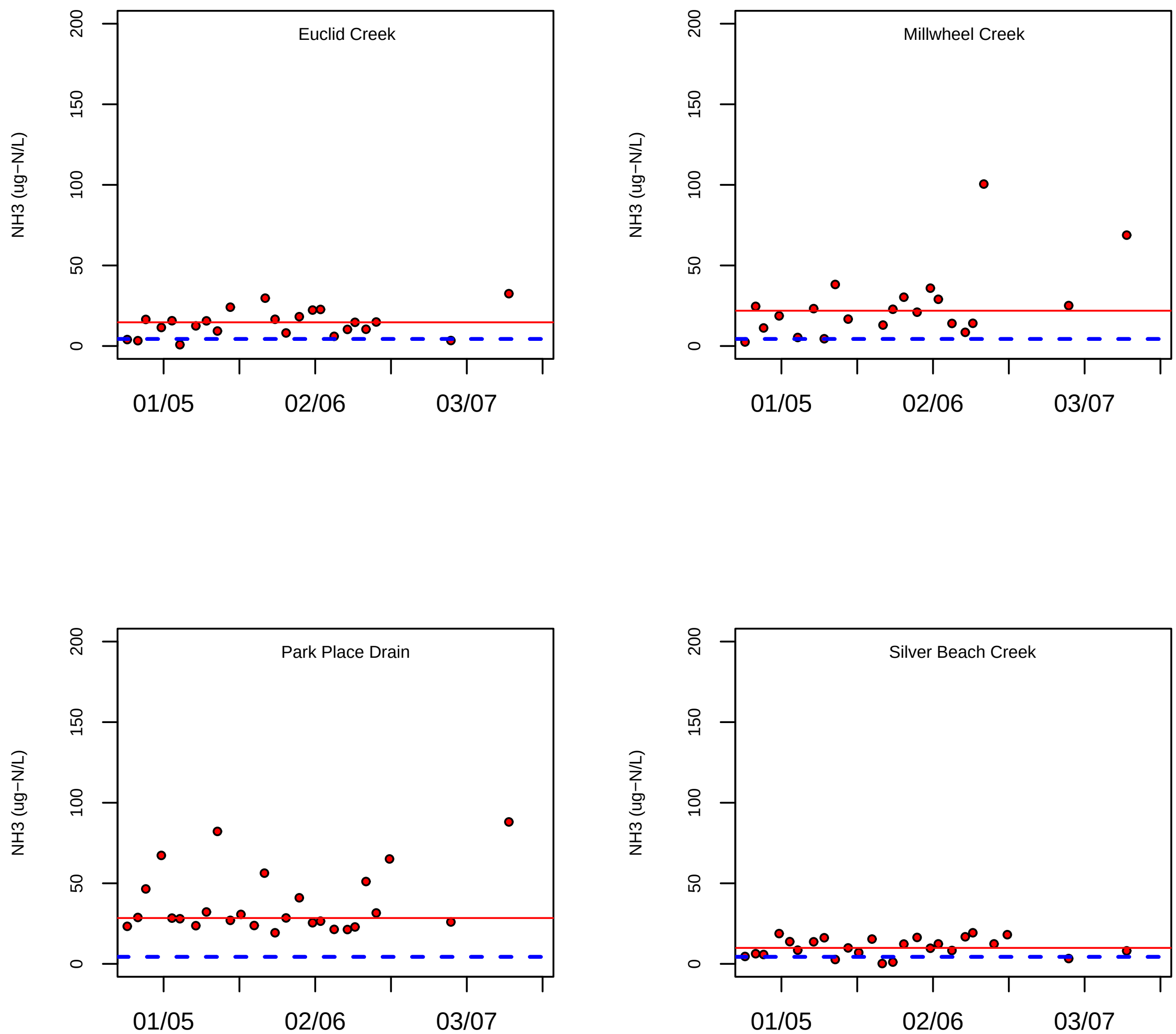


Figure B197: Ammonia data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

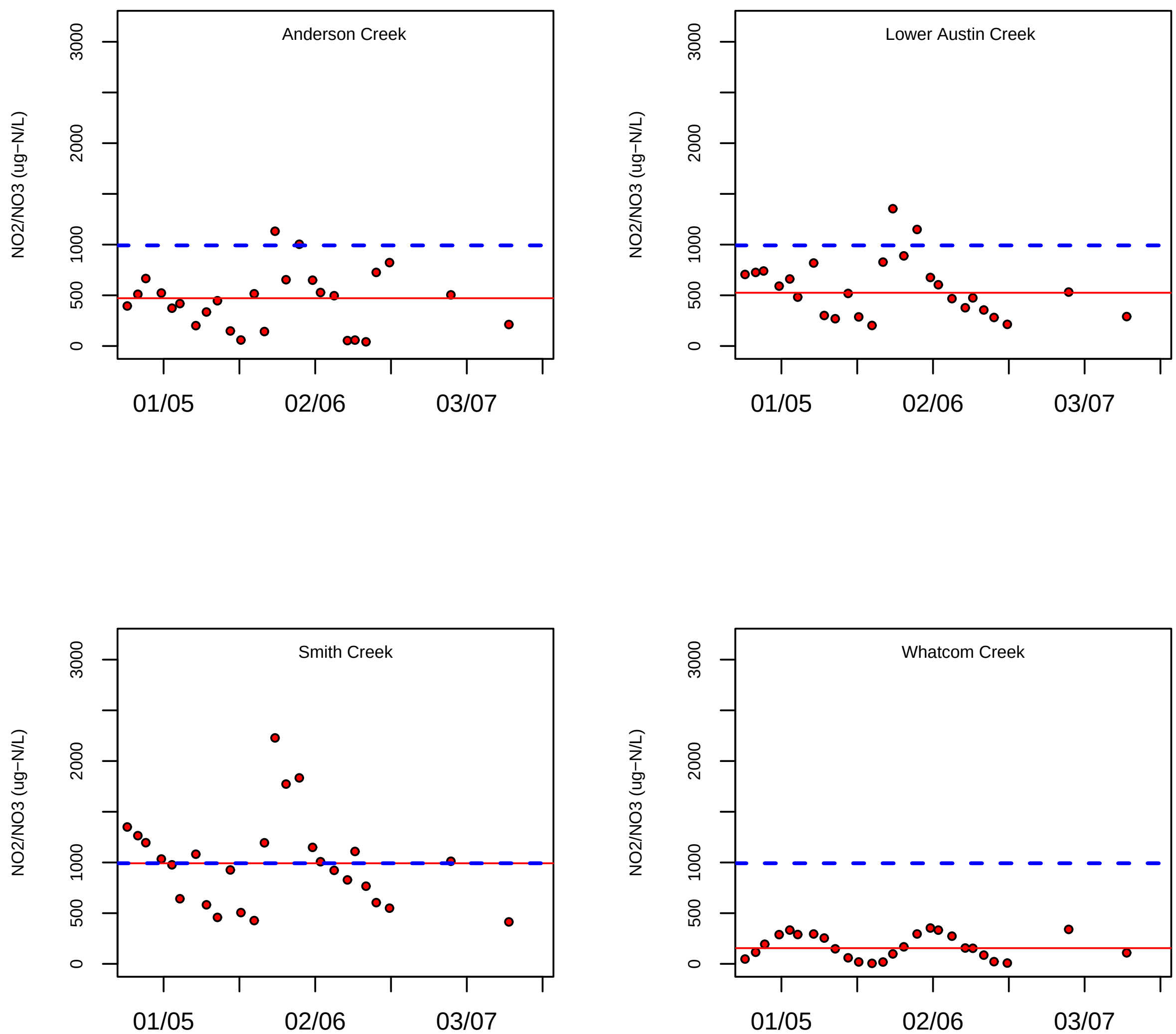


Figure B198: Nitrate/nitrite data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

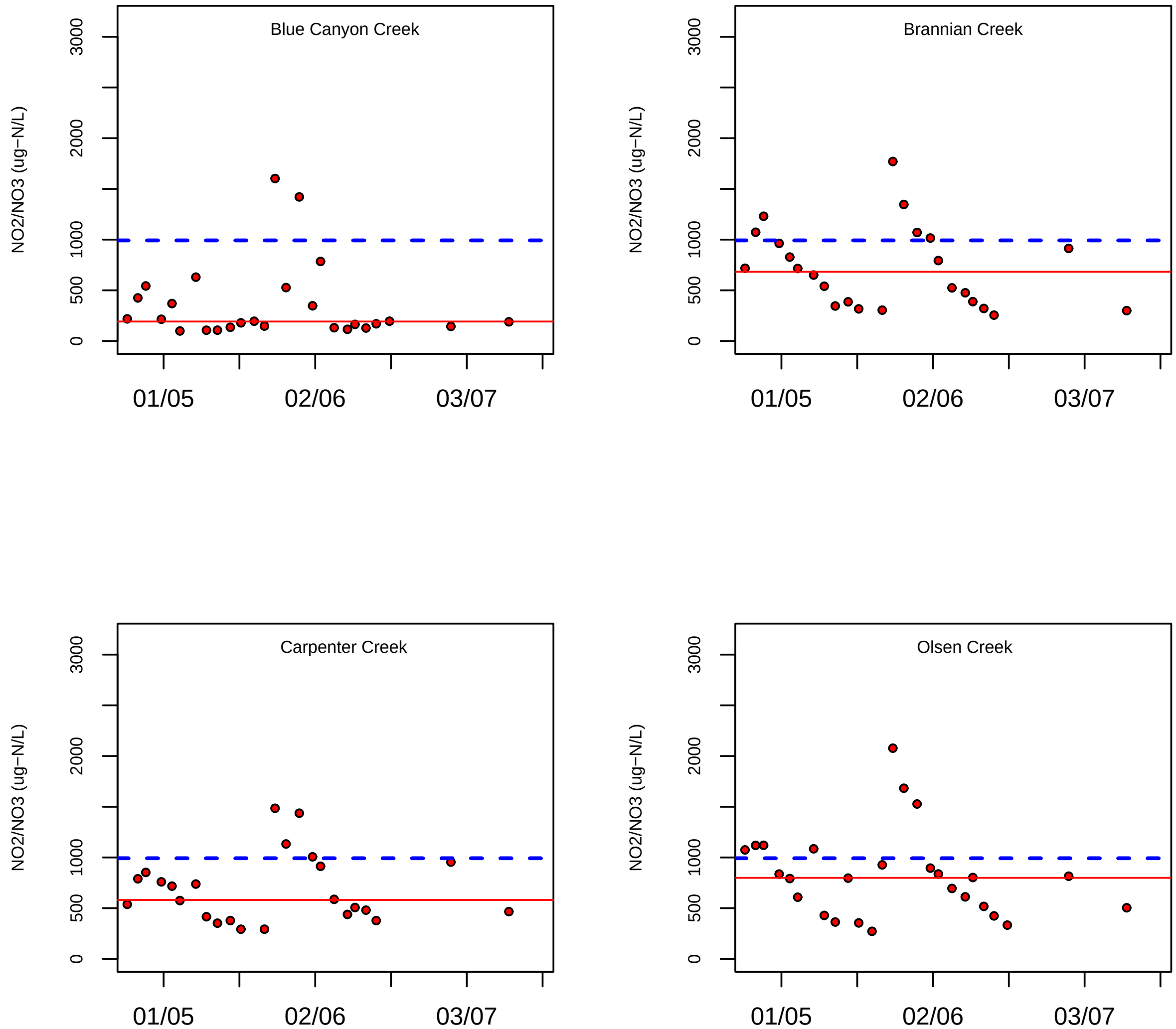


Figure B199: Nitrate/nitrite data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

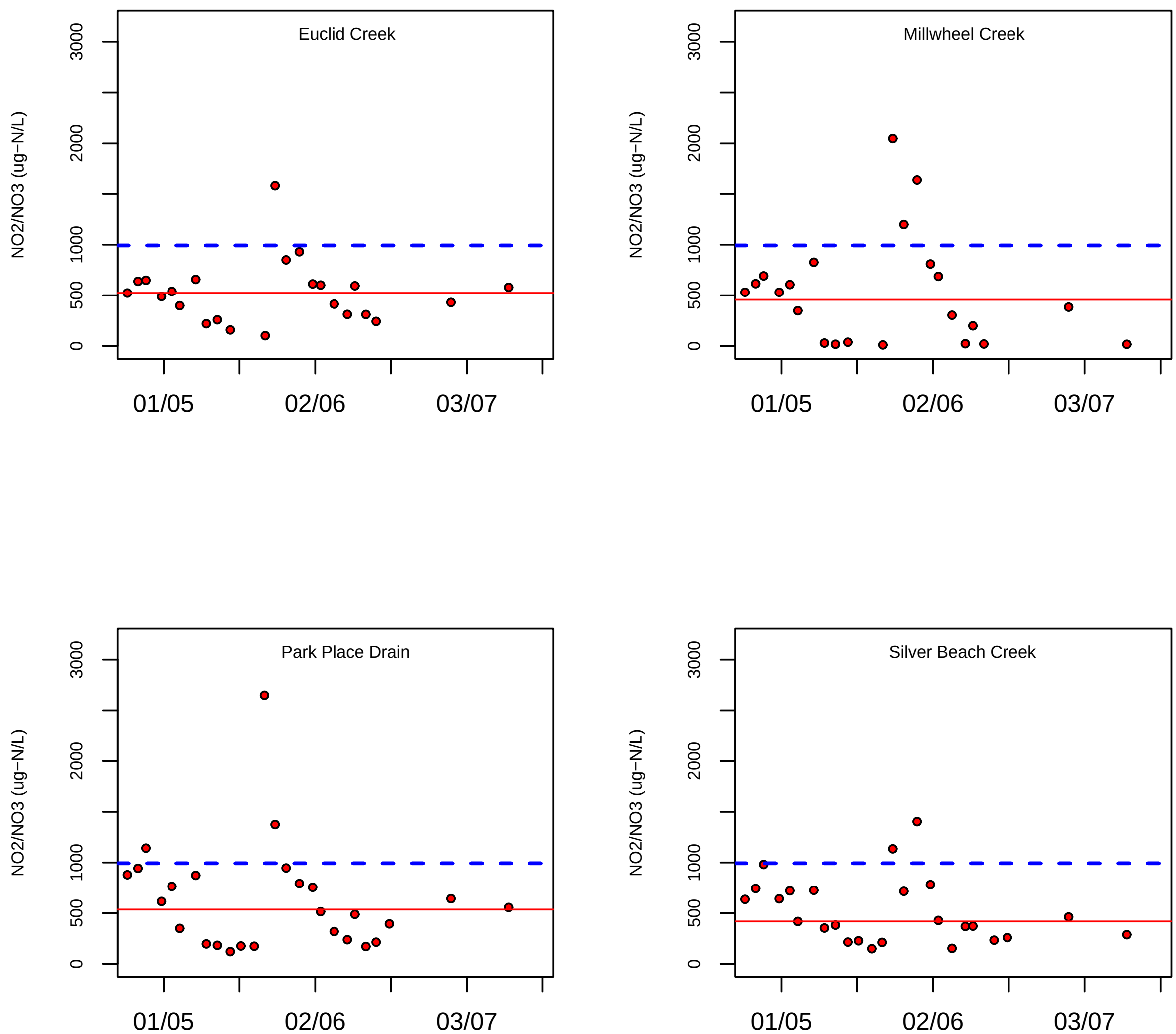


Figure B200: Nitrate/nitrite data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

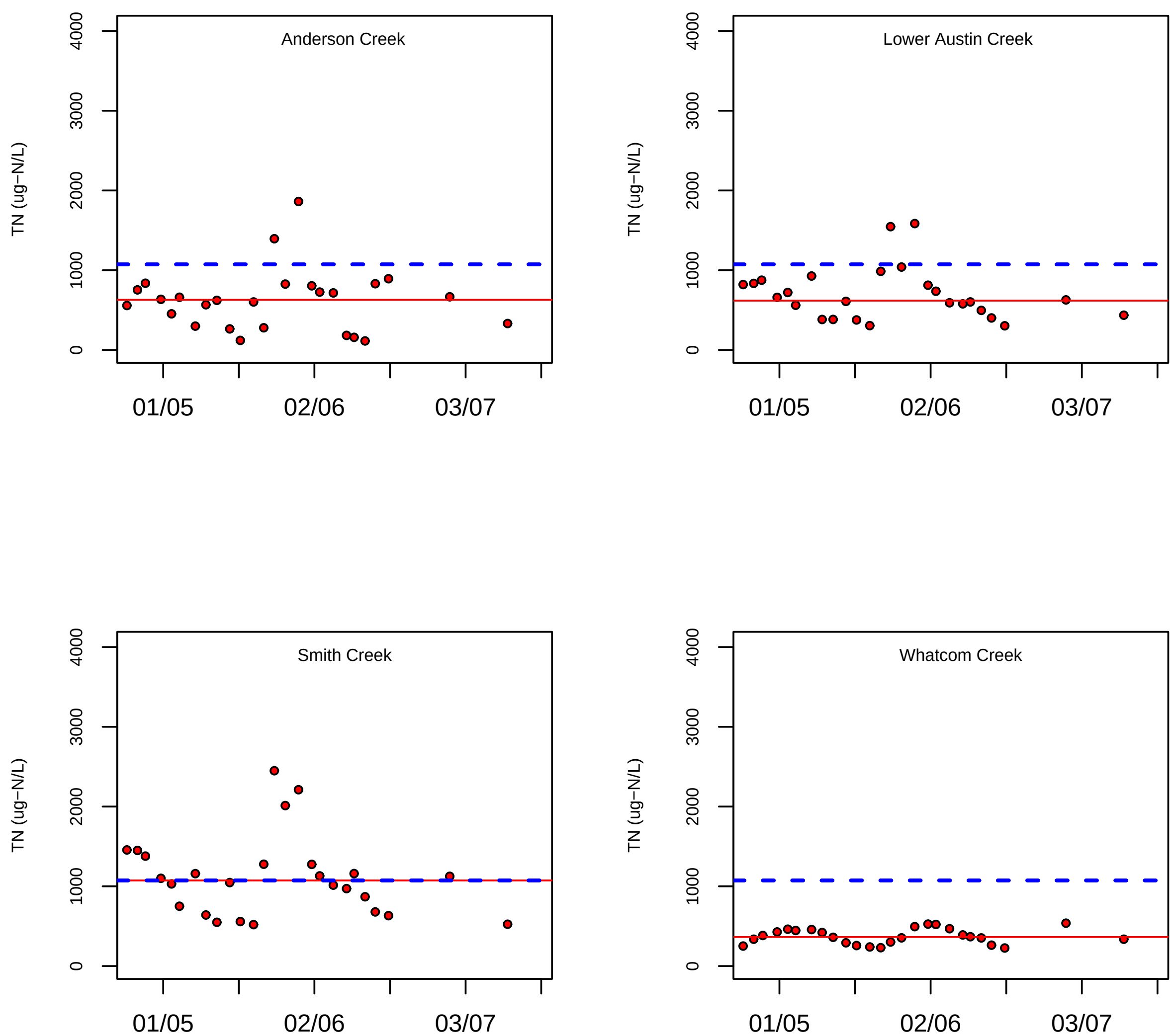


Figure B201: Total nitrogen data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

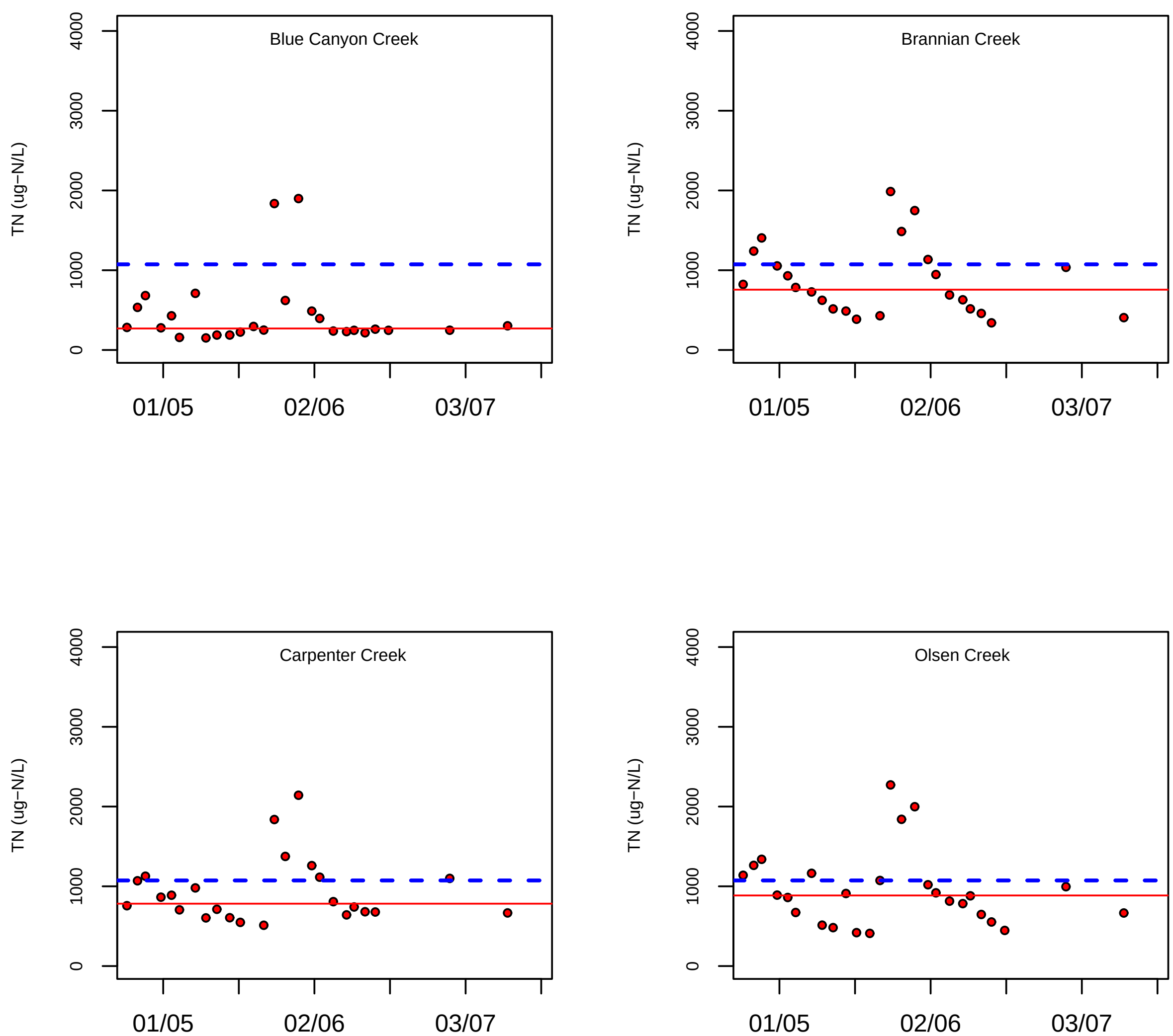


Figure B202: Total nitrogen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

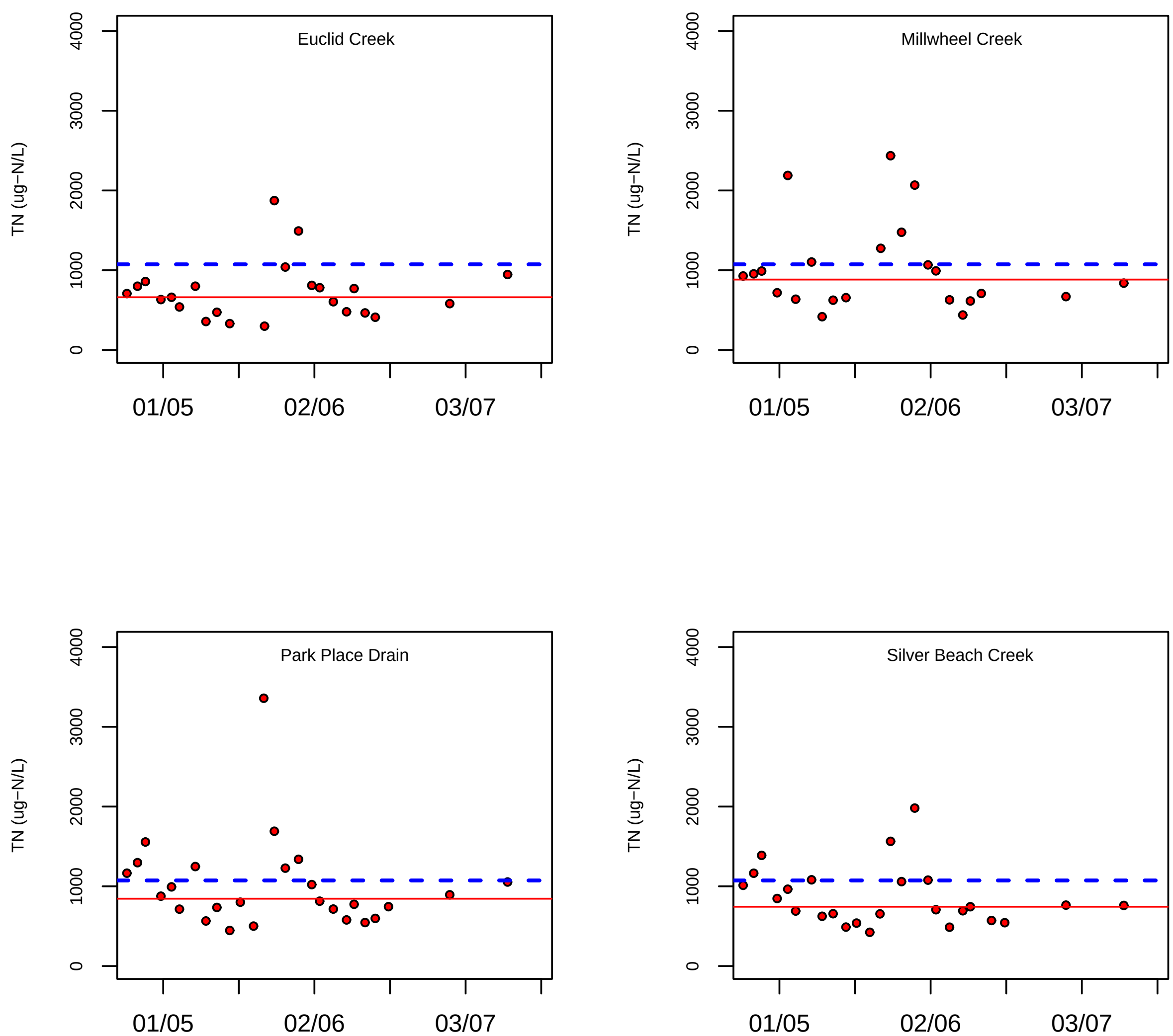


Figure B203: Total nitrogen data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

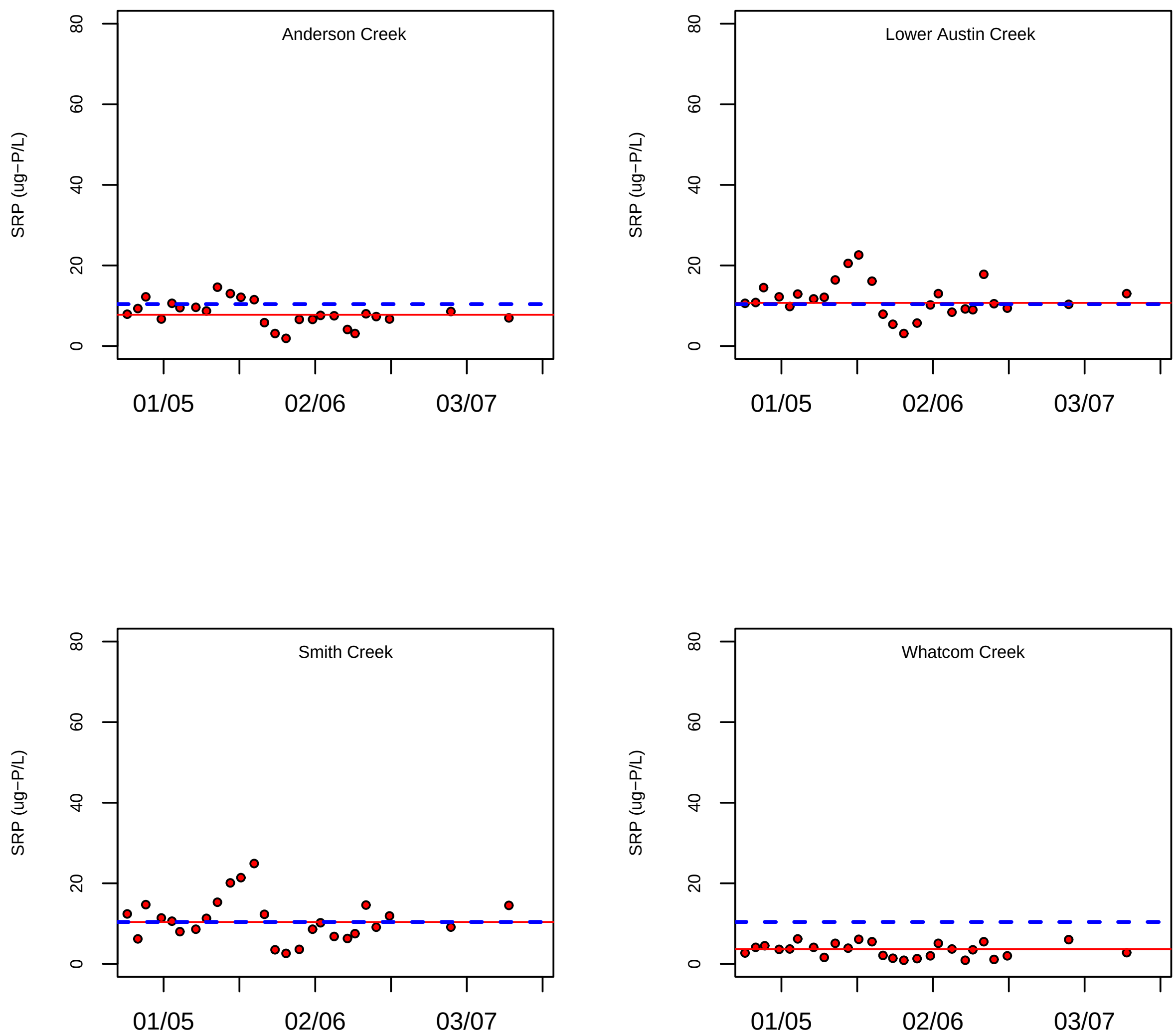


Figure B204: Soluble phosphate data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

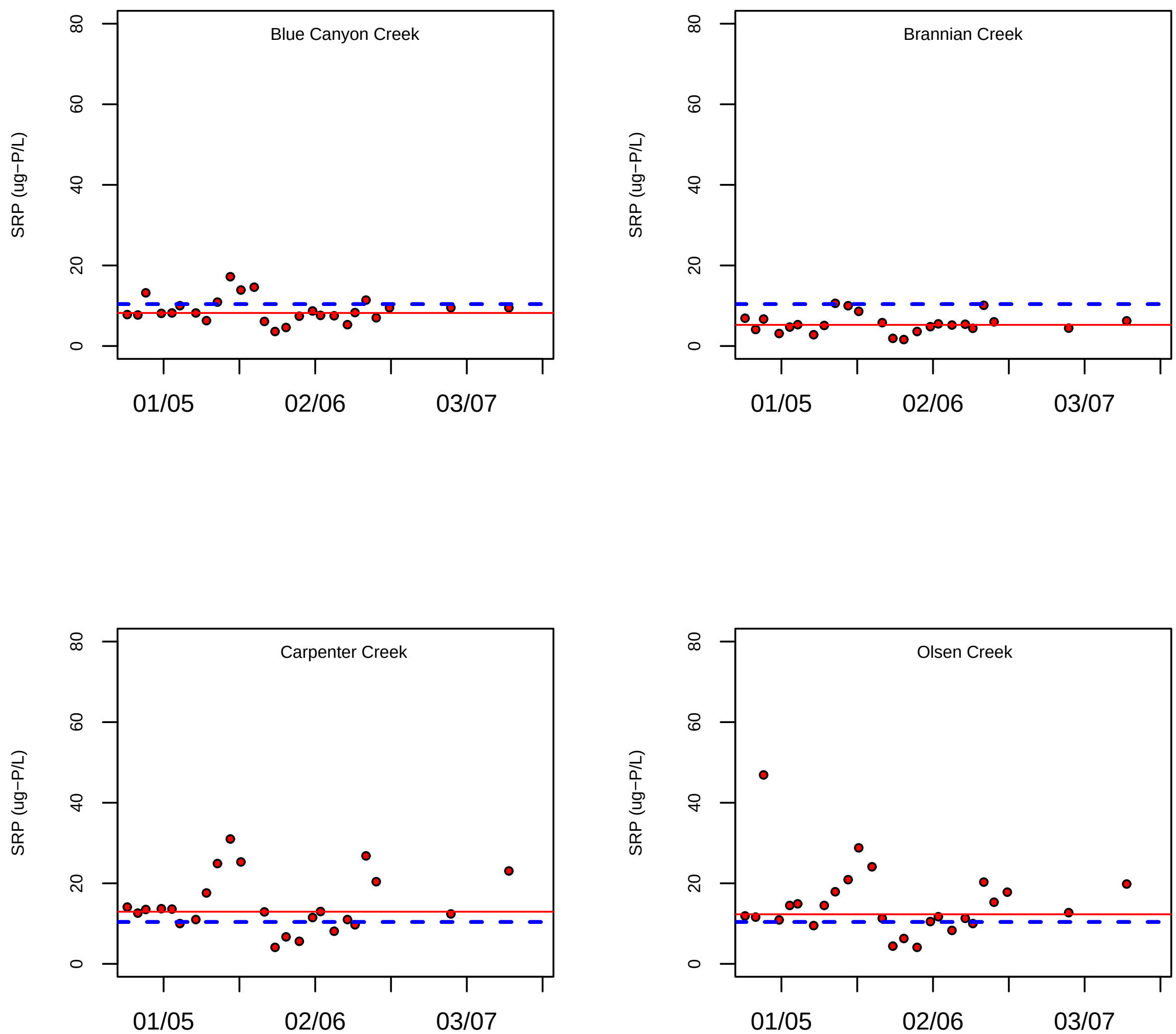


Figure B205: Soluble phosphate data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

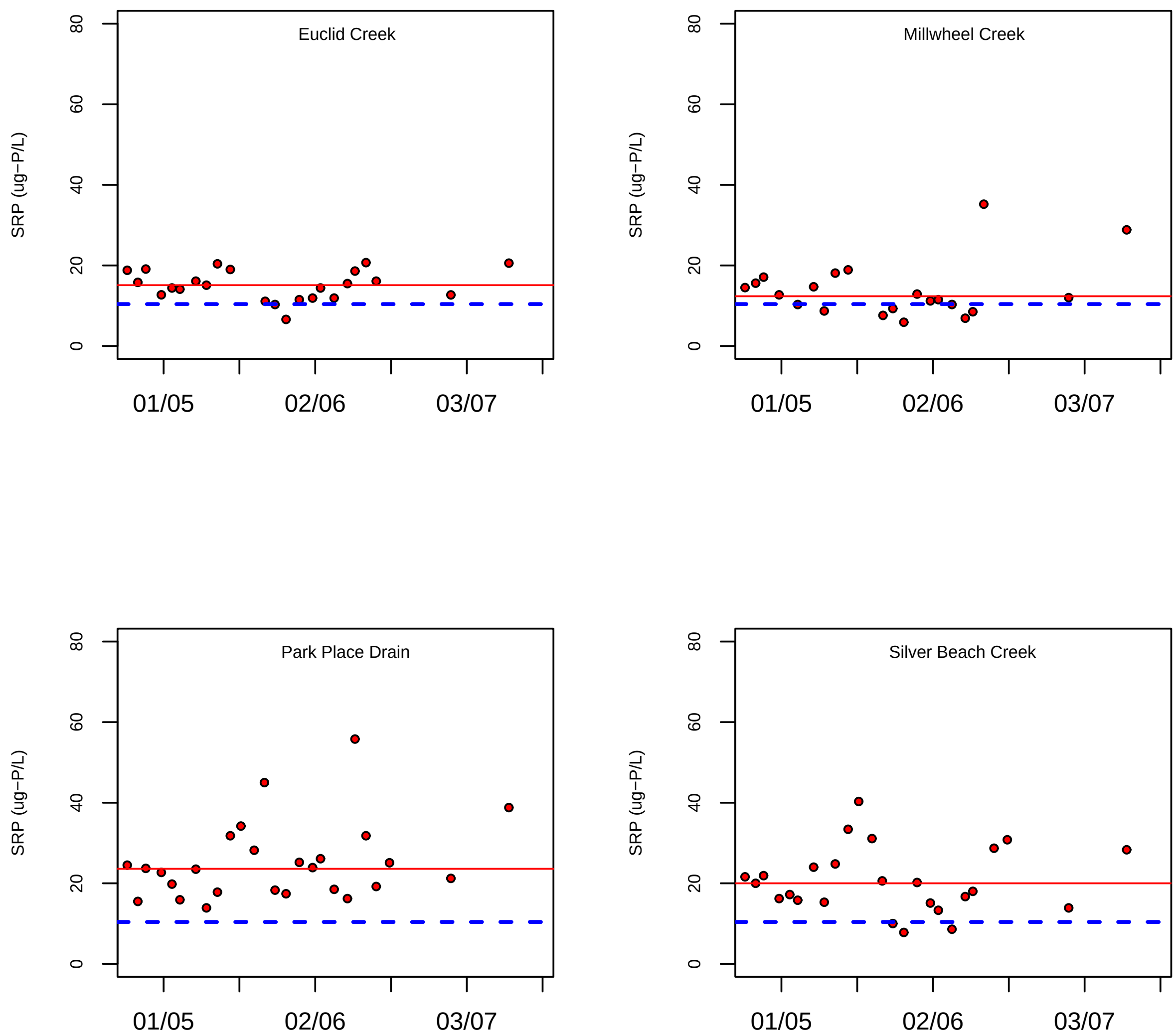


Figure B206: Soluble phosphate data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

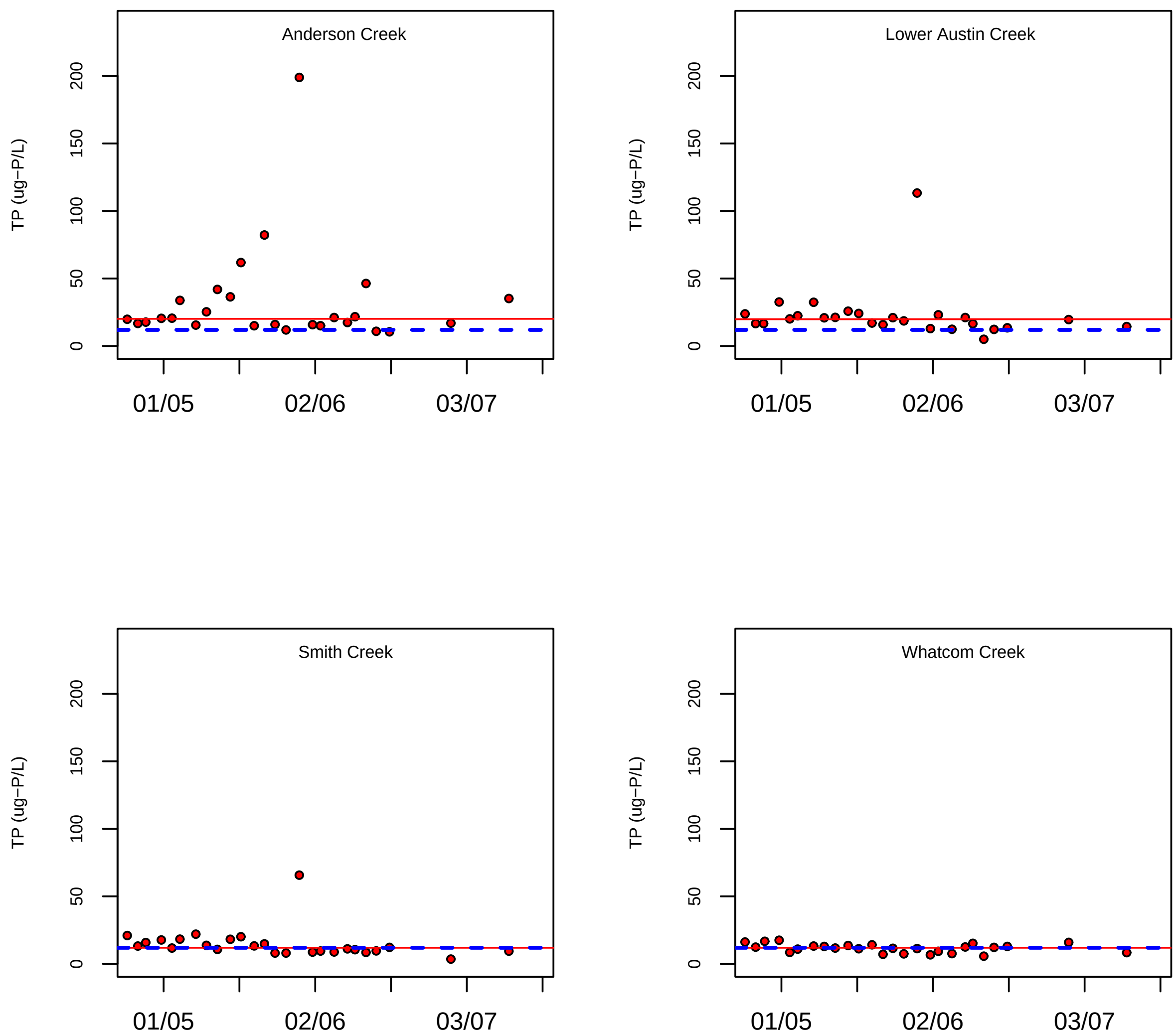


Figure B207: Total phosphorus data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

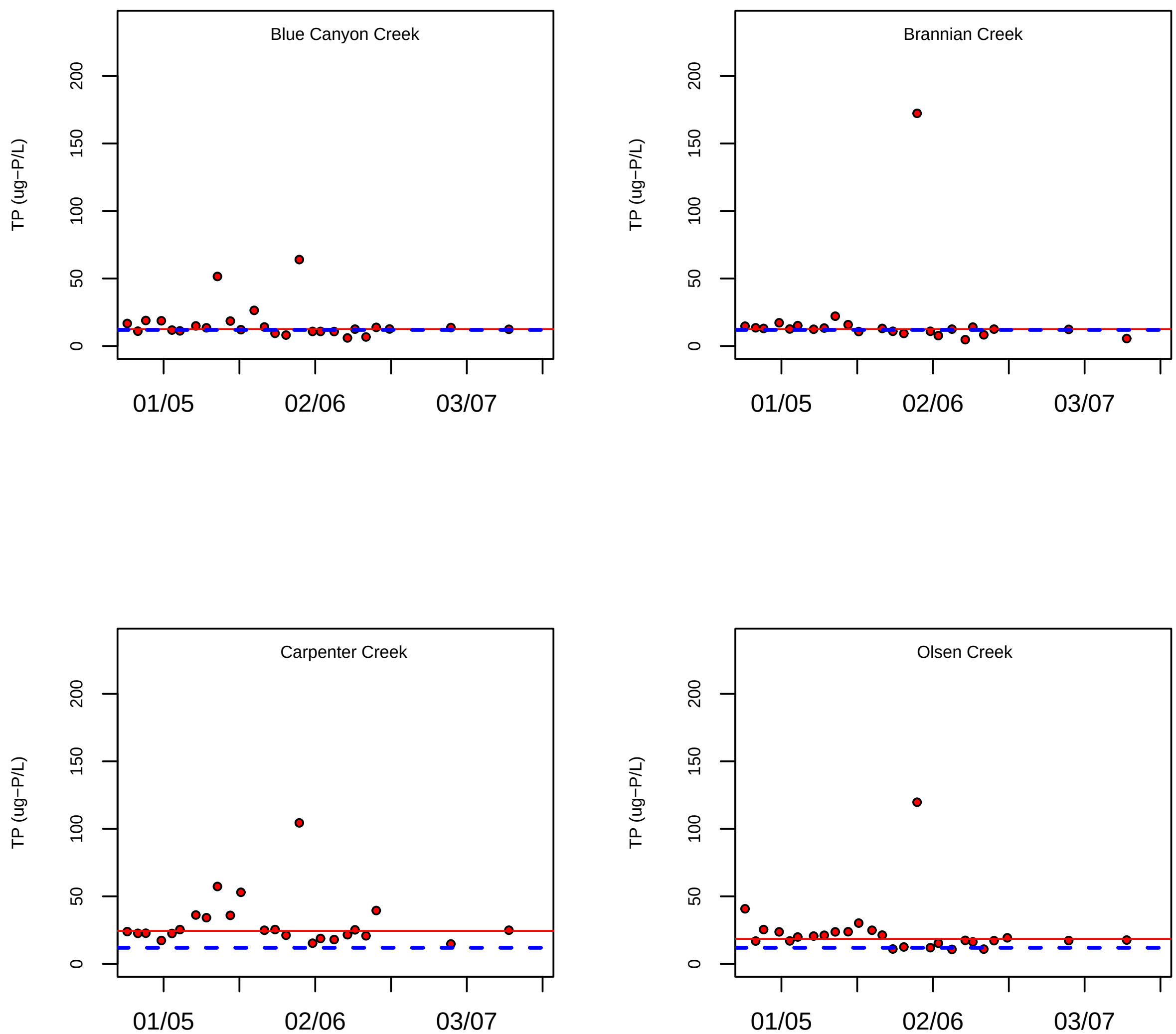


Figure B208: Total phosphorus data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

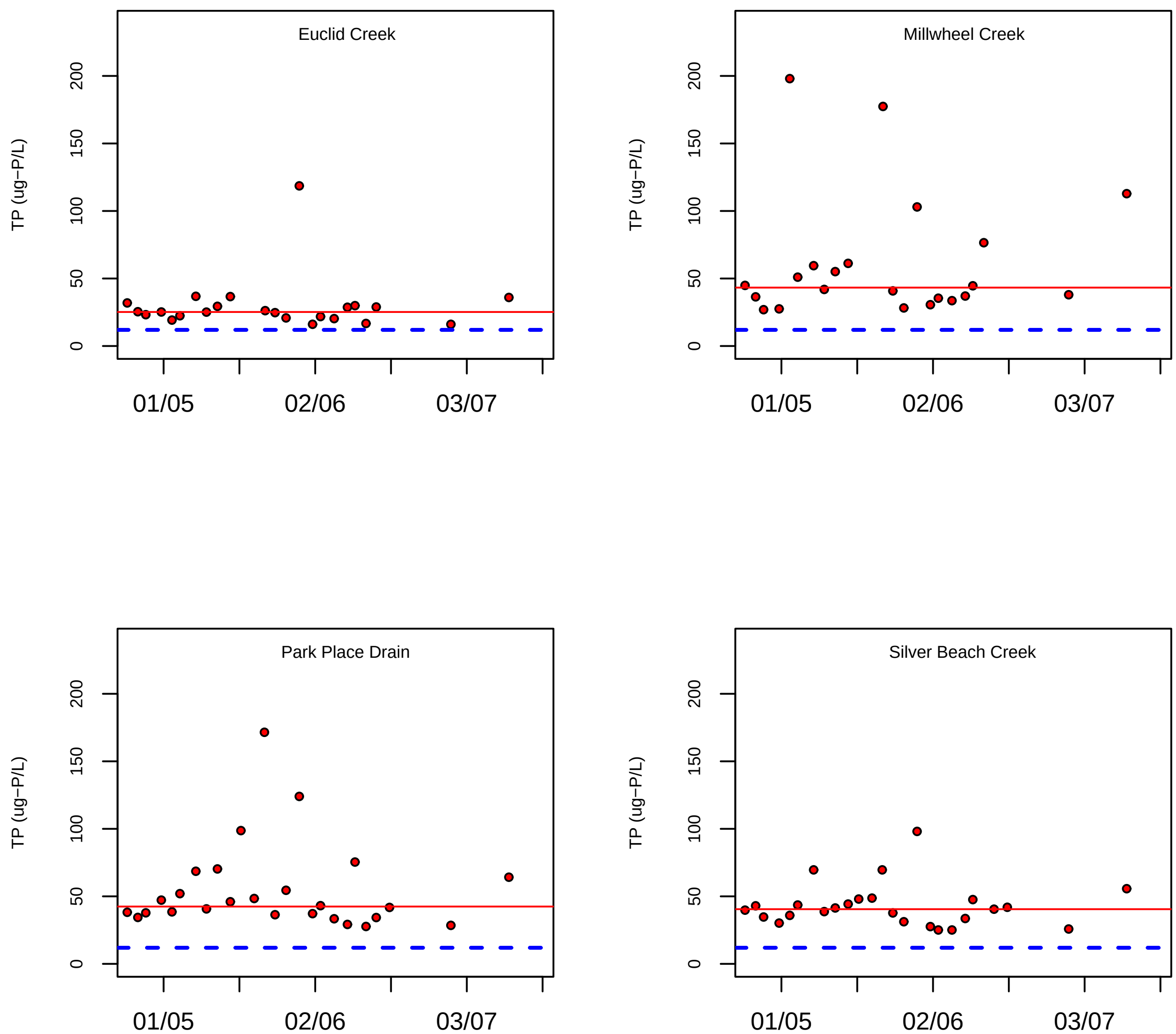


Figure B209: Total phosphorus data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

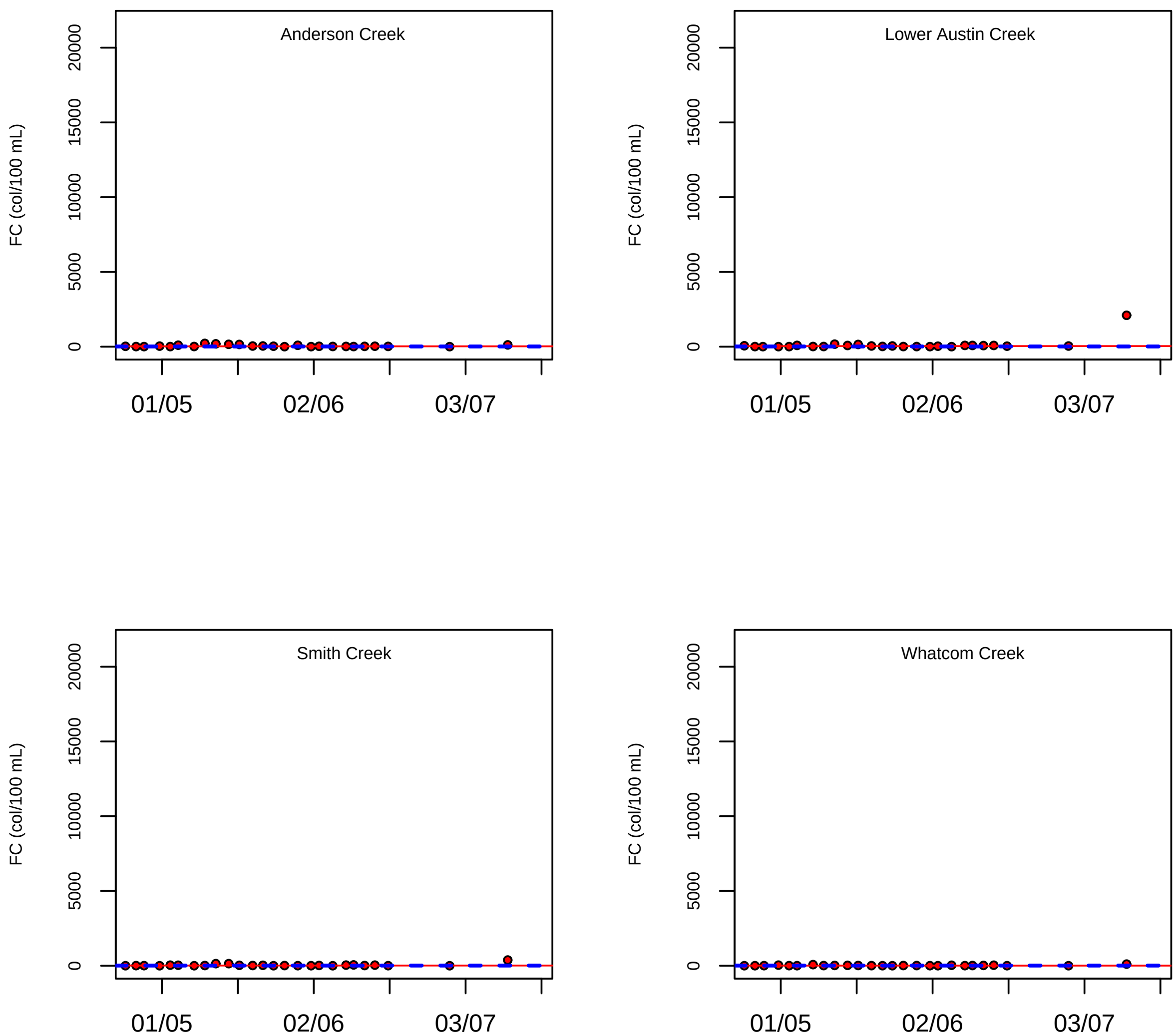


Figure B210: Fecal coliform data for Anderson, Austin, Smith, and Whatcom Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

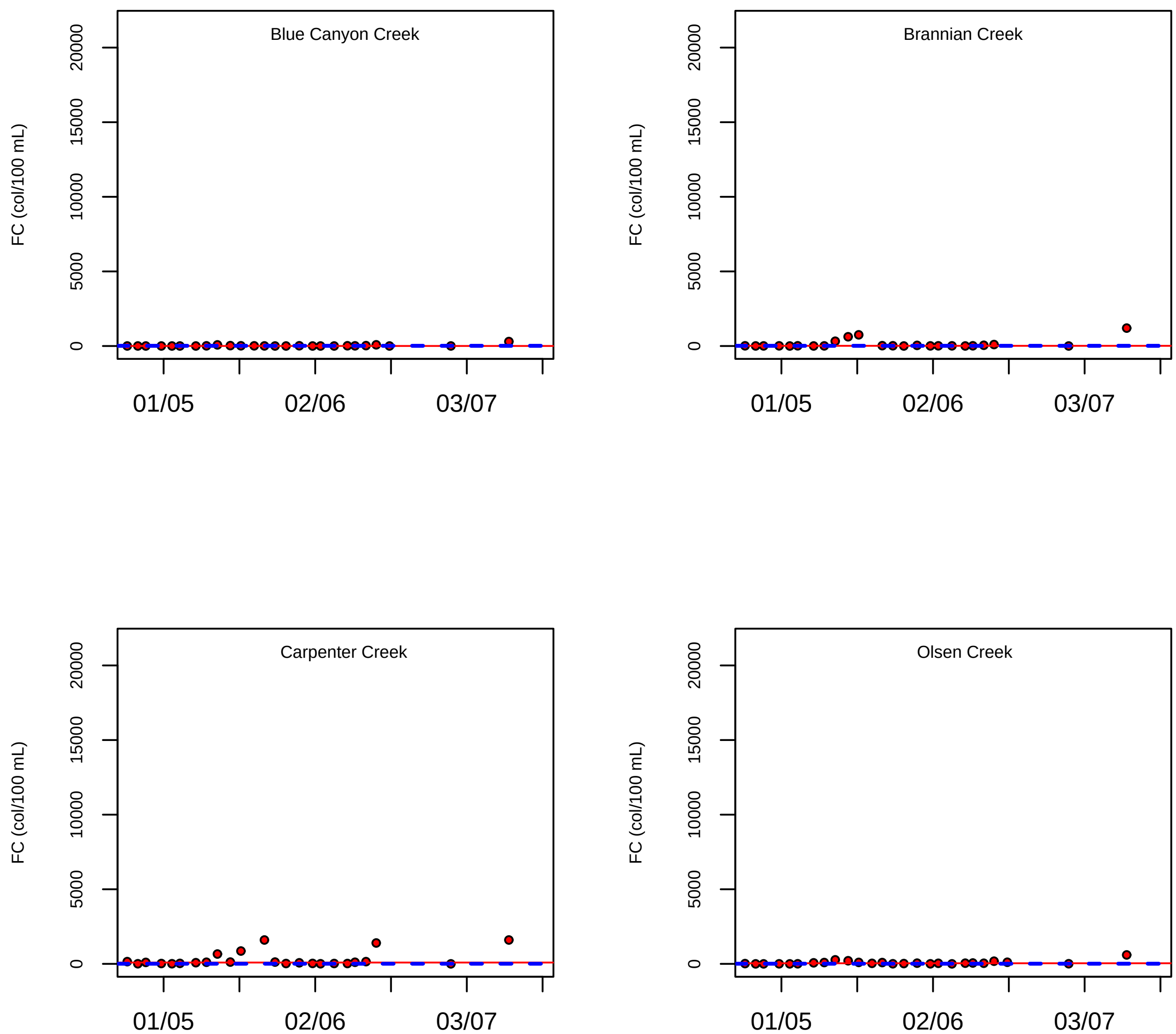


Figure B211: Fecal coliform data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

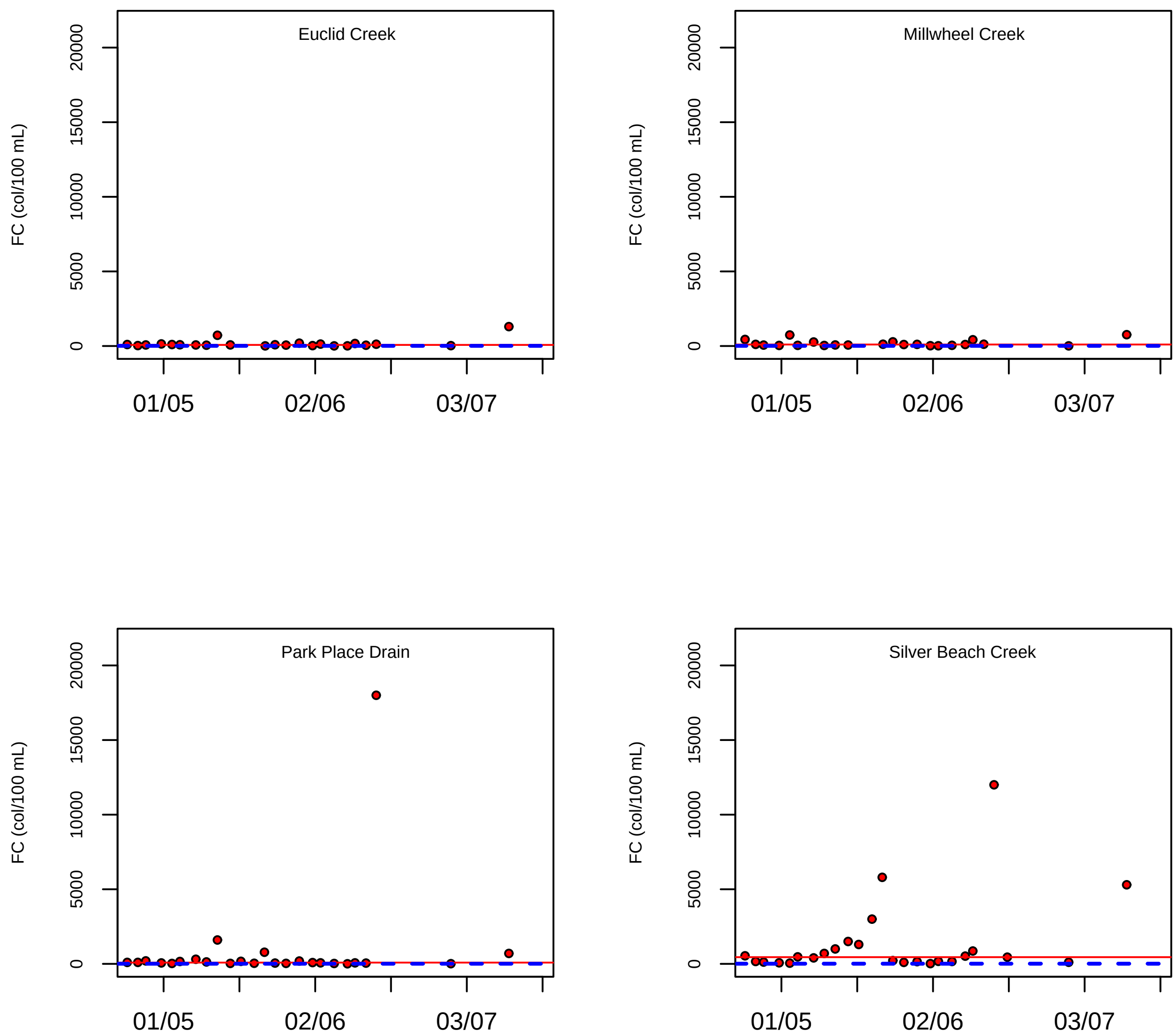


Figure B212: Fecal coliform data for Euclid, Millwheel, Park Place, and Silver Beach Creeks. Current bi-annual data (February and September 2007) are plotted with the monthly 2004–2006 results. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

C Quality Control

C.1 Performance Evaluation Reports

In order to maintain a high degree of accuracy and confidence in the water quality data all personnel associated with this project were trained according to standard operating procedures for the methods listed in Table 1 (page 16). Single-blind quality control tests were conducted as part of the IWS laboratory certification process (Tables C1–C2). All results from the single-blind tests were within acceptance limits.

	Reported Value[†]	True Value[†]	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	597.0	598	538–658	pass
Total alkalinity (mg/L as $CaCO_3$)	11.7	11.8	8.44–17.2	pass
Ammonia nitrogen, manual (mg-N/L)	14.7	14.8	11.0–18.3	pass
Ammonia nitrogen, autoanalysis (mg-N/L)	16.7	14.8	11.0–18.3	pass
Nitrate nitrogen, autoanalysis (mg-N/L)	9.45	9.40	7.32–11.3	pass
Orthophosphate, manual (mg-P/L)	4.31	4.30	3.54–5.09	pass
Orthophosphate, autoanalysis (mg-P/L)	4.07	4.30	3.54–5.09	pass
Total phosphorus, manual (mg-P/L)	4.86	4.78	3.92–5.70	pass
Total phosphorus, autoanalysis (mg-P/L)	4.77	4.78	3.92–5.70	pass
pH	9.21	9.20	9.00–9.40	pass
Solids, non-filterable (mg/L)	85.0	95.5	78.9–106	pass
Turbidity (NTU)	1.6	1.68	1.22–2.19	pass

Table C1: Single-blind quality control results, WP–117 (10/19/2007).

	Reported Value†	True Value†	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	476	485	436–534	pass
Total alkalinity (mg/L as $CaCO_3$)	44.5	43.3	37.1–50.1	pass
Ammonia nitrogen, manual (mg-N/L)	9.13	8.94	6.60–11.2	pass
Ammonia nitrogen, autoanalysis (mg-N/L)	9.34	8.94	6.60–11.2	pass
Nitrate nitrogen, autoanalysis (mg-N/L)	31.6	30.9	25.2–35.9	pass
Orthophosphate, manual (mg-P/L)	3.44	3.56	2.92–4.23	pass
Orthophosphate, autoanalysis (mg-P/L)	3.35	3.56	2.92–4.23	pass
Total phosphorus, manual (mg-P/L)	2.91	2.88	2.33–3.48	pass
Total phosphorus, autoanalysis (mg-P/L)	2.98	2.88	2.33–3.48	pass
pH	5.49	5.50	5.30–5.70	pass
Solids, non-filterable (mg/L)	65.8	67.4	54.1–75.7	pass
Solids, total (mg/L)	200	195	159–229	pass
Turbidity (NTU)	4.59	4.55	3.72–5.33	pass

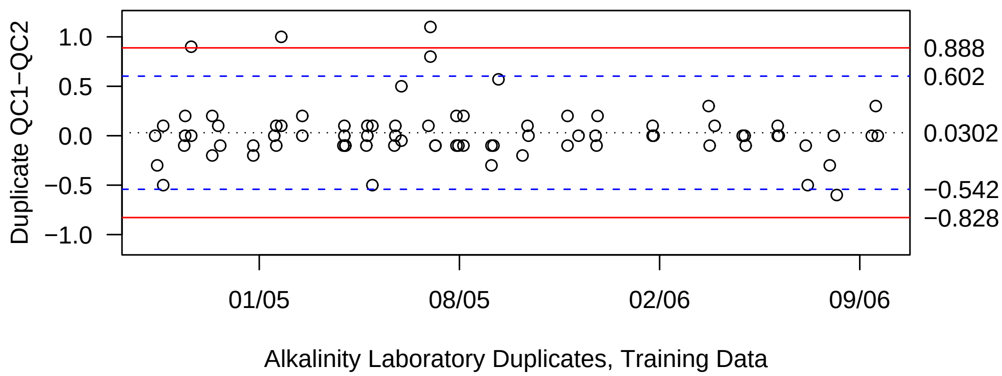
Table C2: Single-blind quality control results, WP–124 (04/02/2007).

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.[28]

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 2004 through September 2006 (upper examples in Figures C1–C21, pages 338–358), and used to evaluate data from October 2006 through September 2007 (lower examples in Figures C1–C21).

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



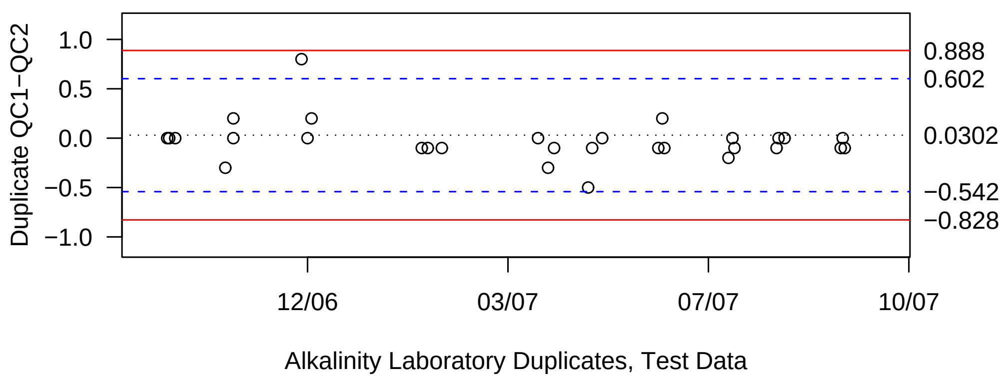
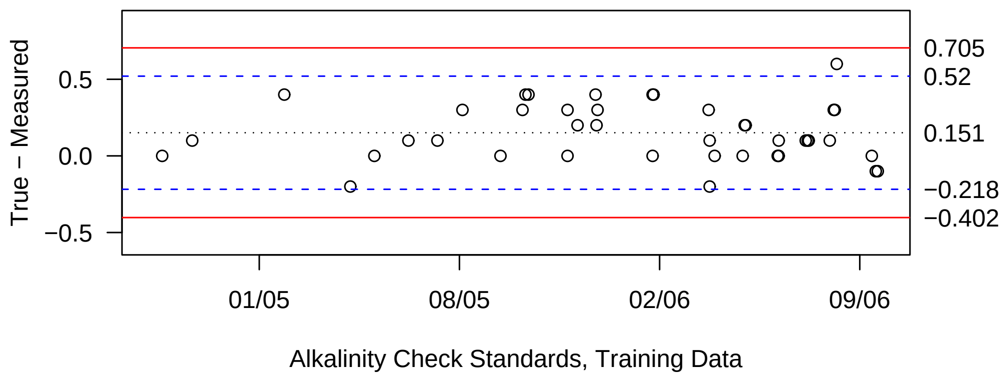


Figure C1: Alkalinity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



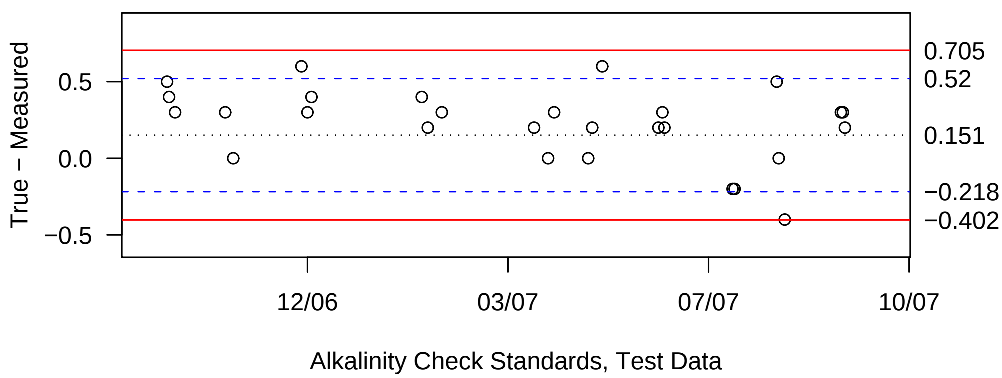
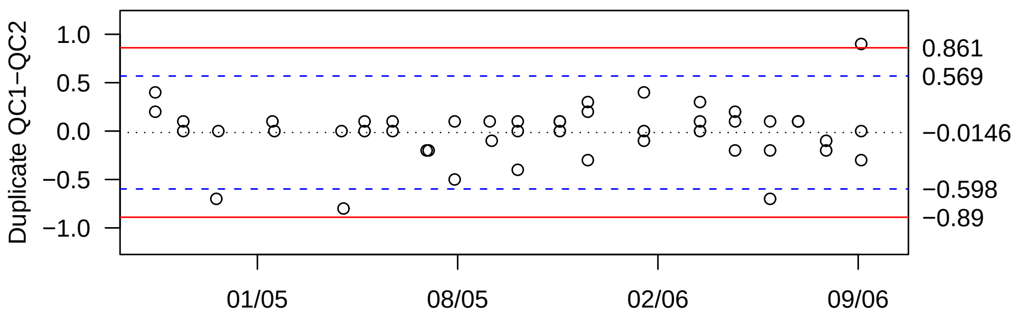
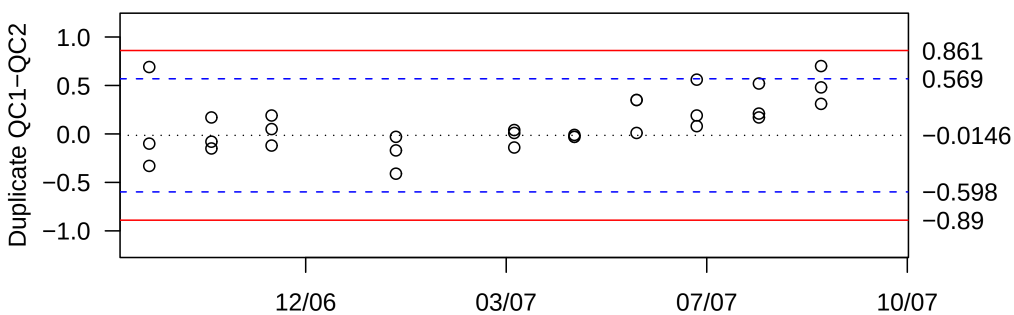


Figure C2: Alkalinity check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

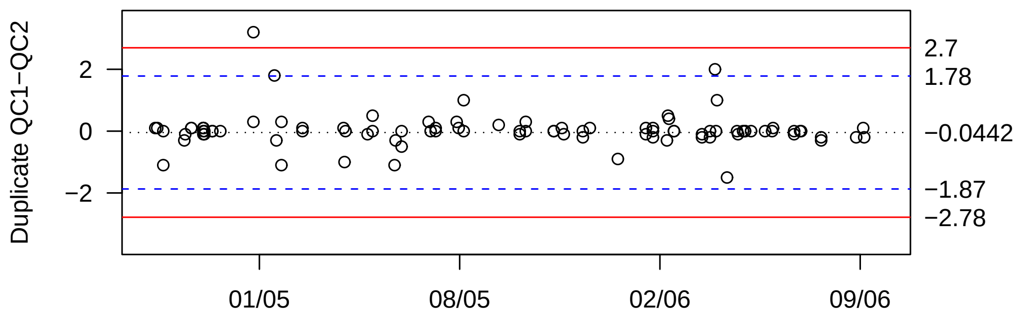


Chlorophyll Laboratory Duplicates, Training Data

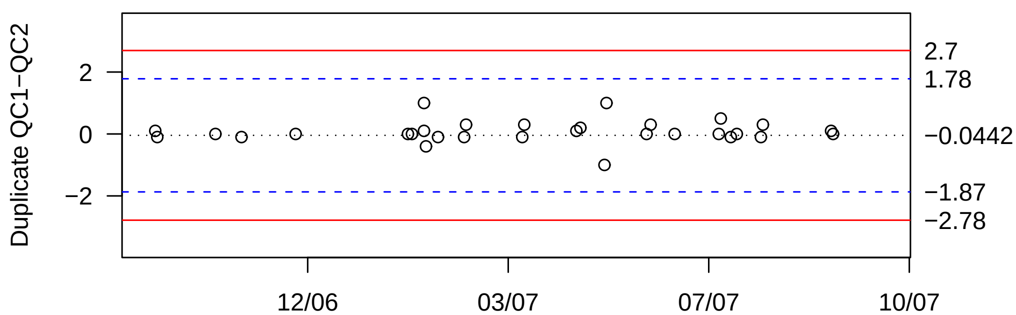


Chlorophyll Laboratory Duplicates, Test Data

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.

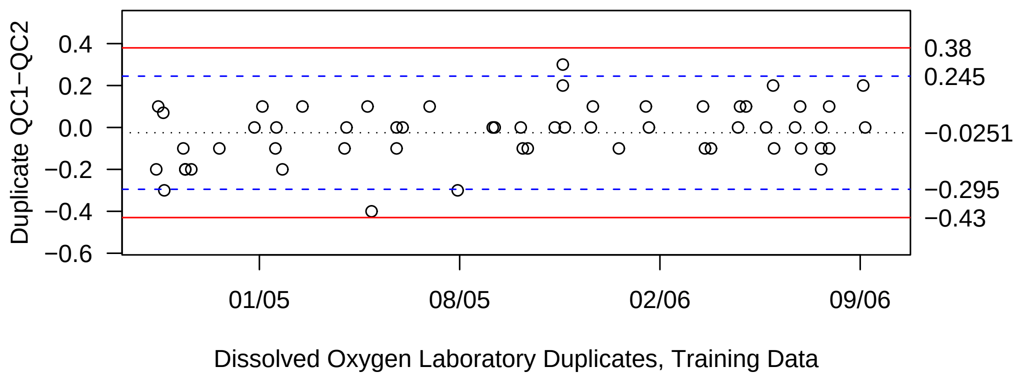


Conductivity Laboratory Duplicates, Training Data



Conductivity Laboratory Duplicates, Test Data

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



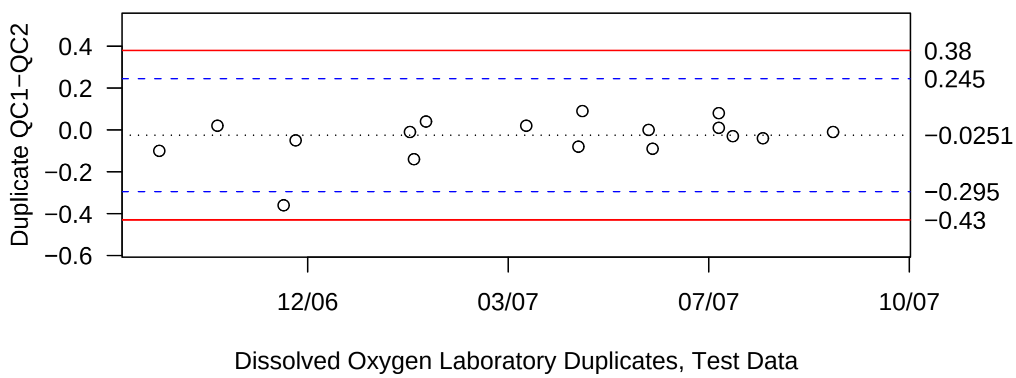
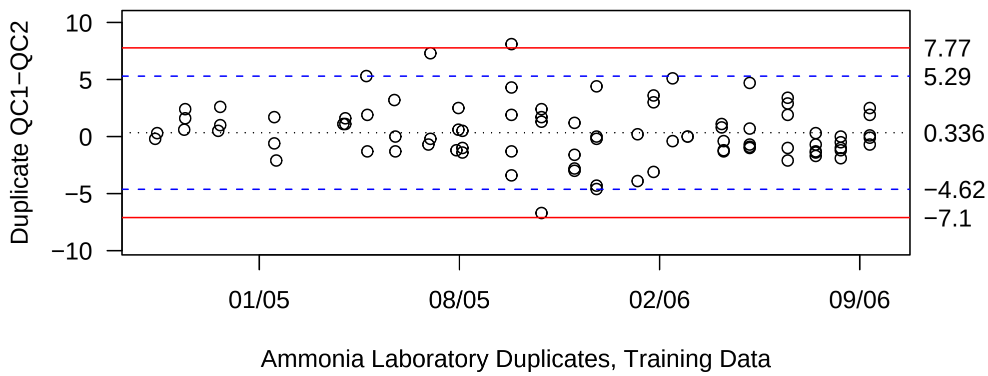


Figure C5: Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



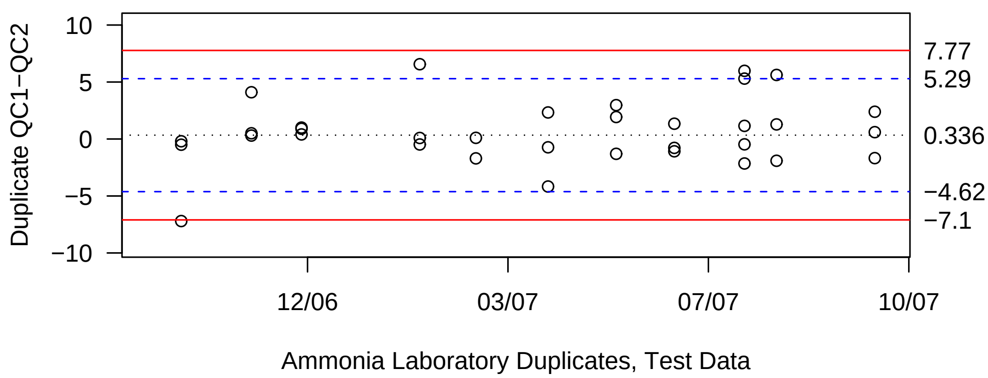


Figure C6: Ammonia laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

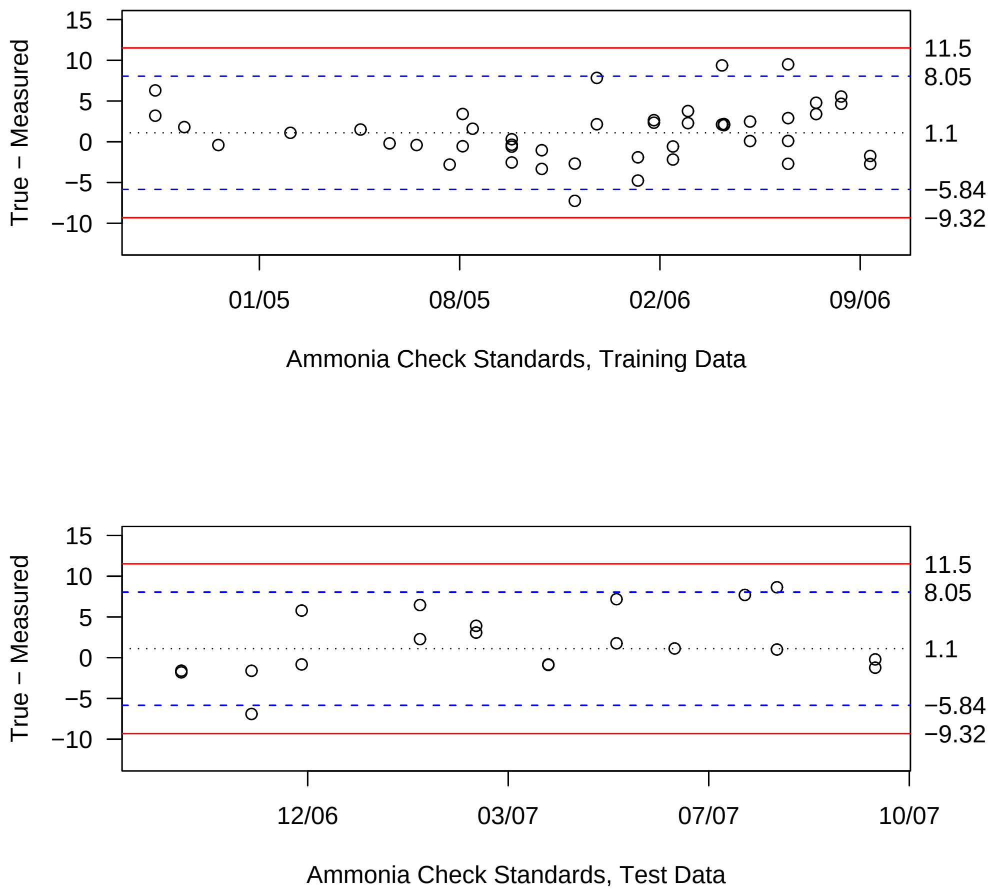
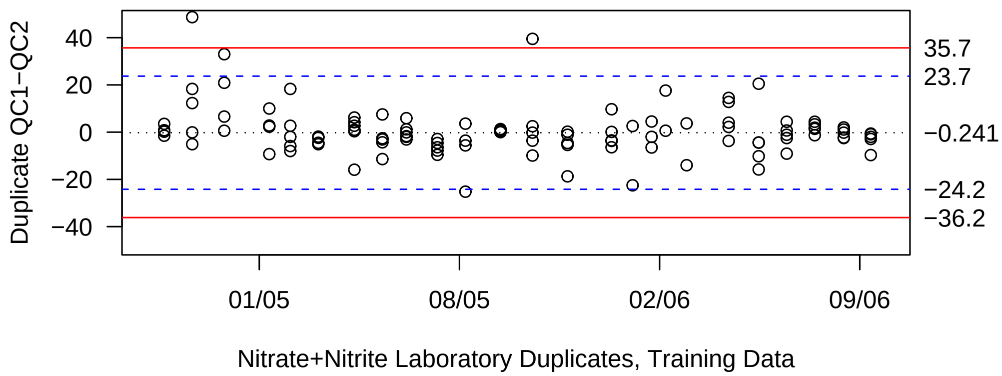


Figure C7: Ammonia check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



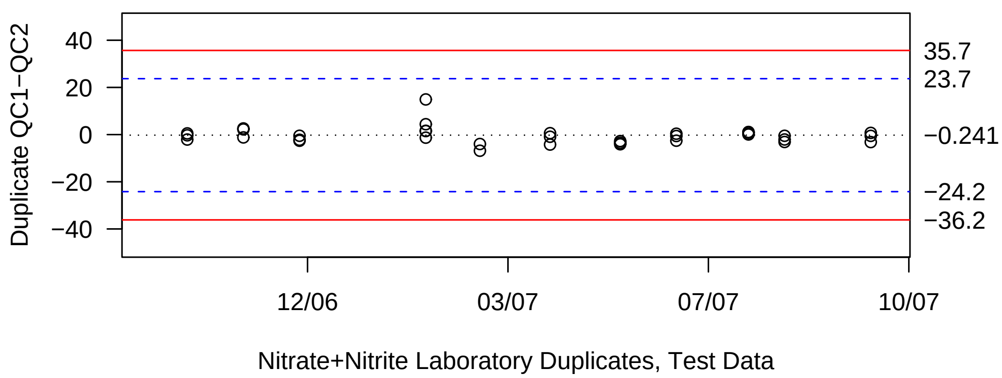
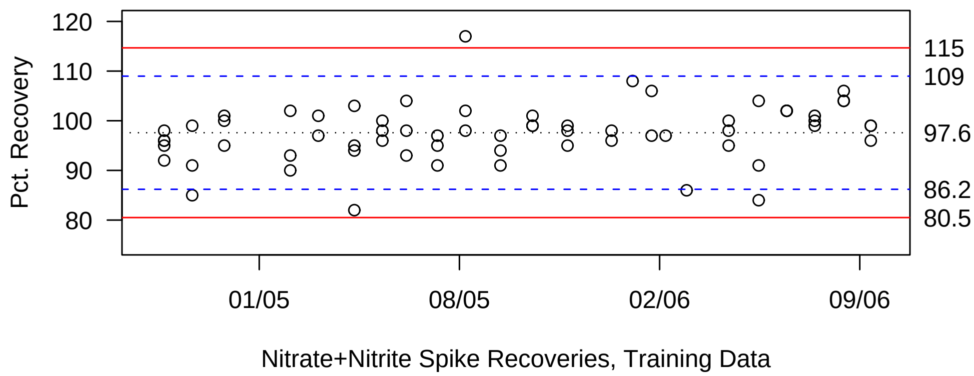


Figure C8: Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



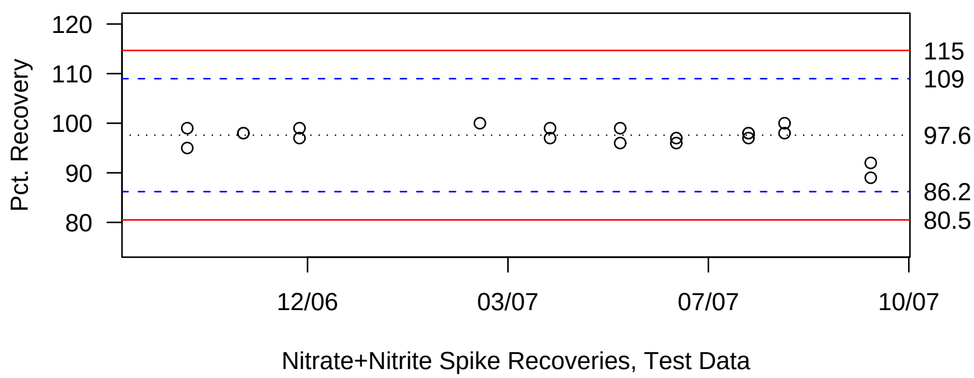
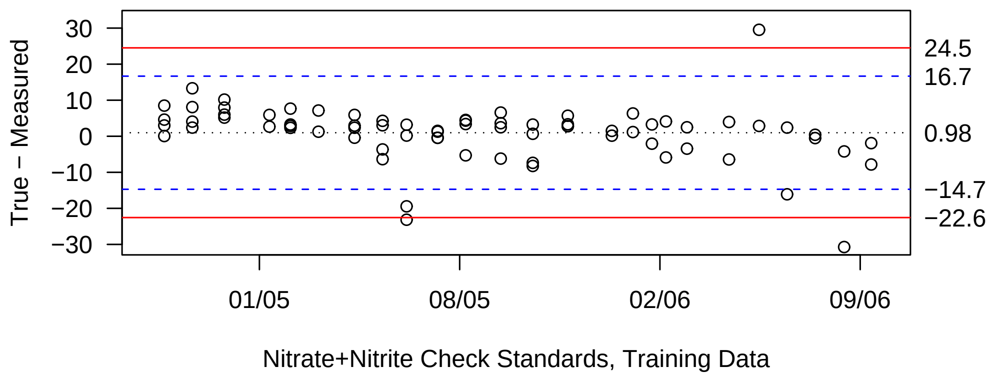


Figure C9: Nitrate/nitrite matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



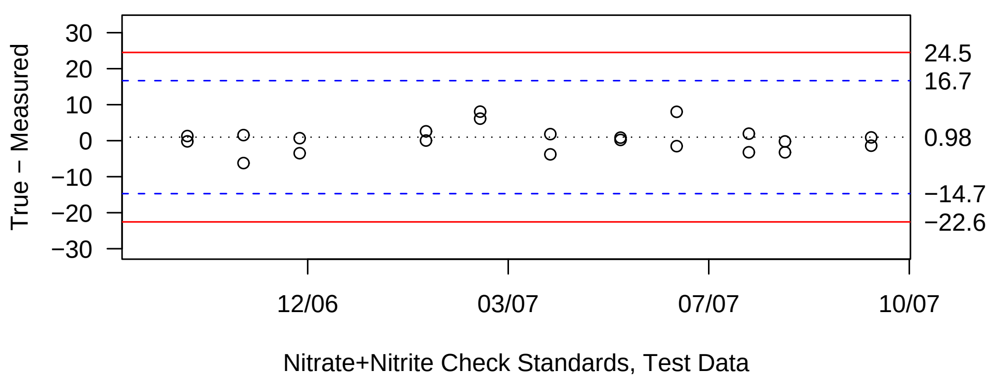
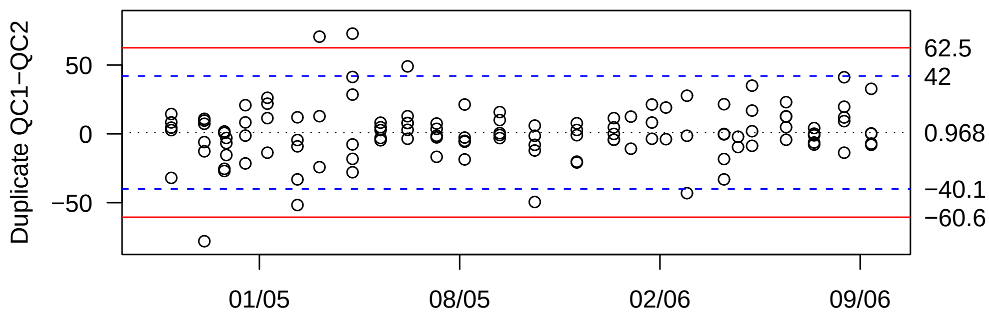
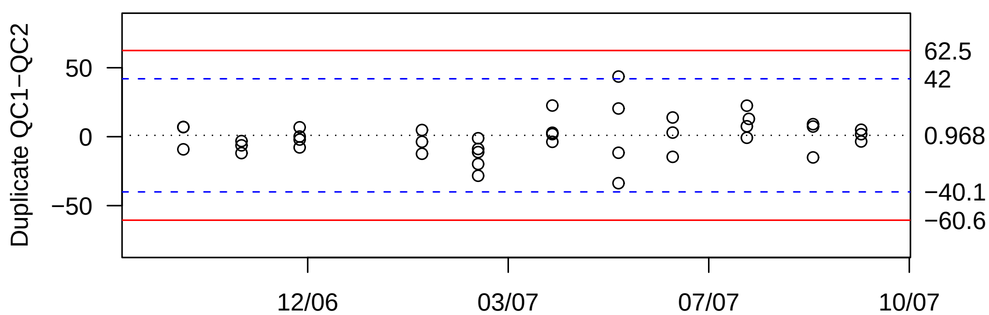


Figure C10: Nitrate/nitrite check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

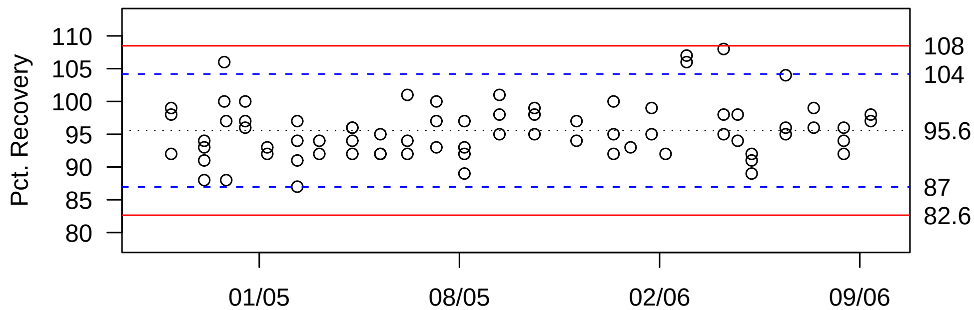


Total Persulfate Nitrogen Laboratory Duplicates, Training Data

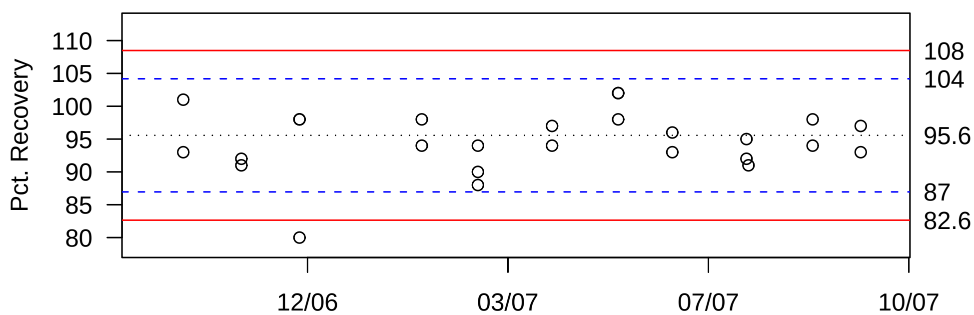


Total Persulfate Nitrogen Laboratory Duplicates, Test Data

Figure C11: 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.

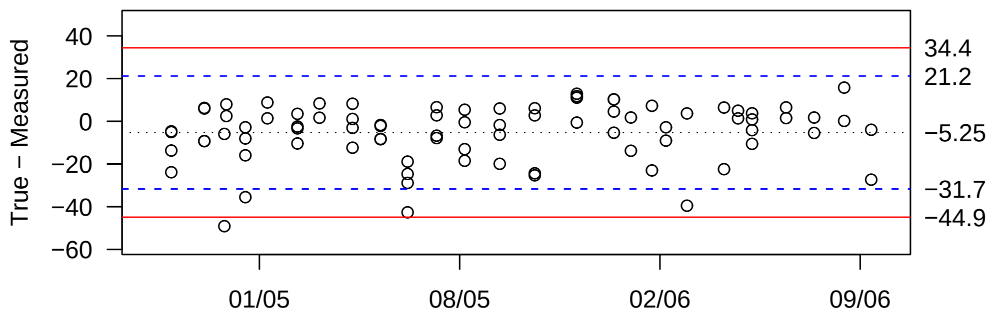


Total Persulfate Nitrogen Spike Recoveries, Training Data

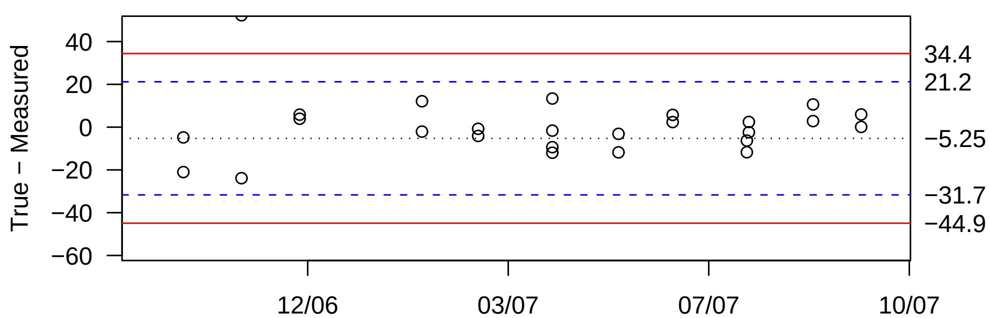


Total Persulfate Nitrogen Spike Recoveries, Test Data

Figure C12: 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 C13: 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.

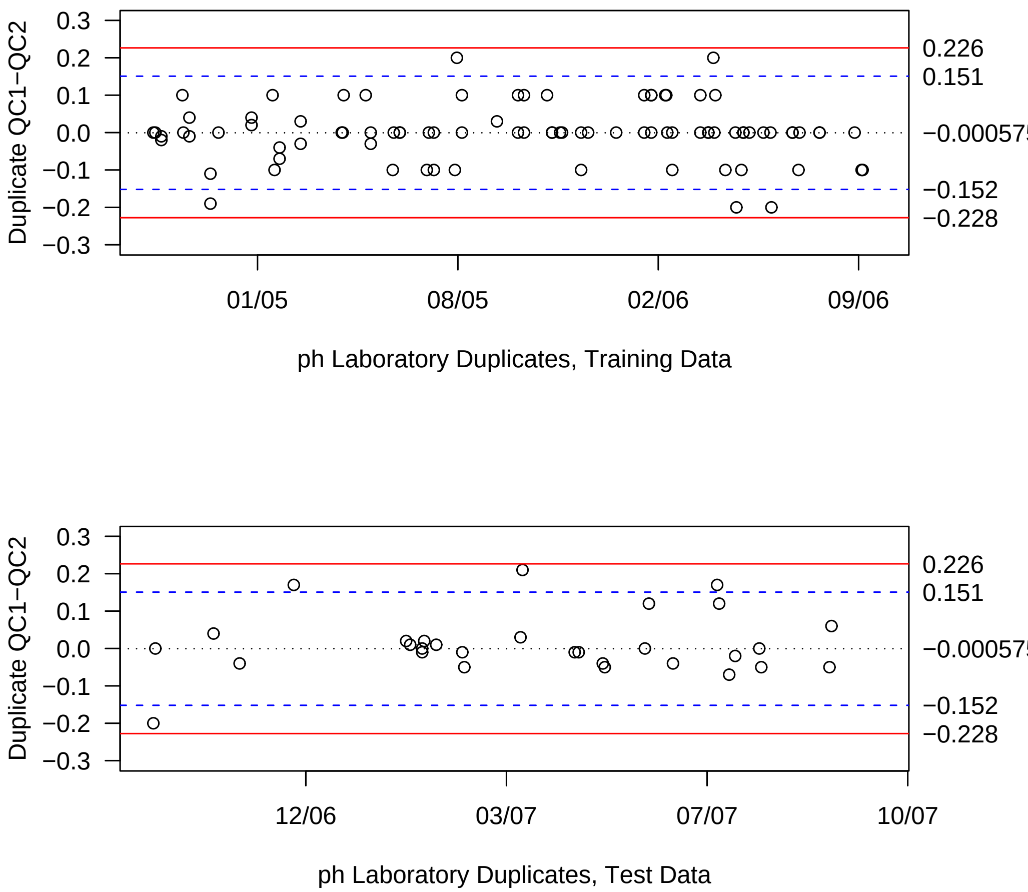
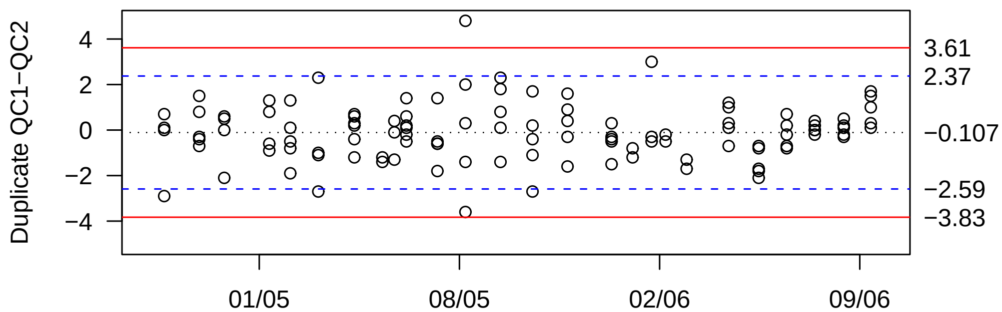
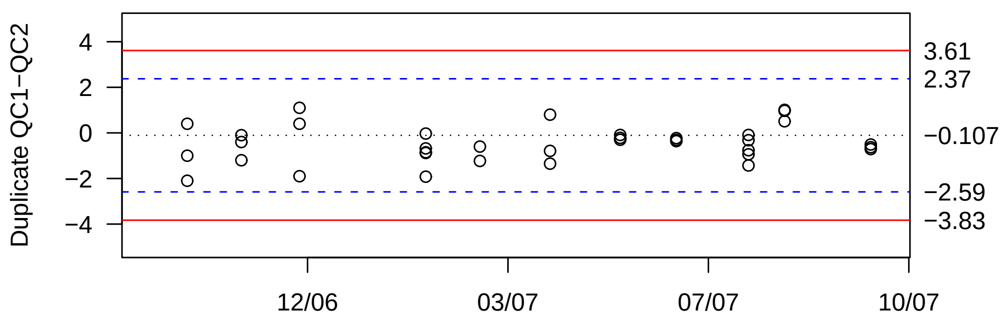


Figure C14: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



Soluble Phosphate Laboratory Duplicates, Training Data



Soluble Phosphate Laboratory Duplicates, Test Data

Figure C15: 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.

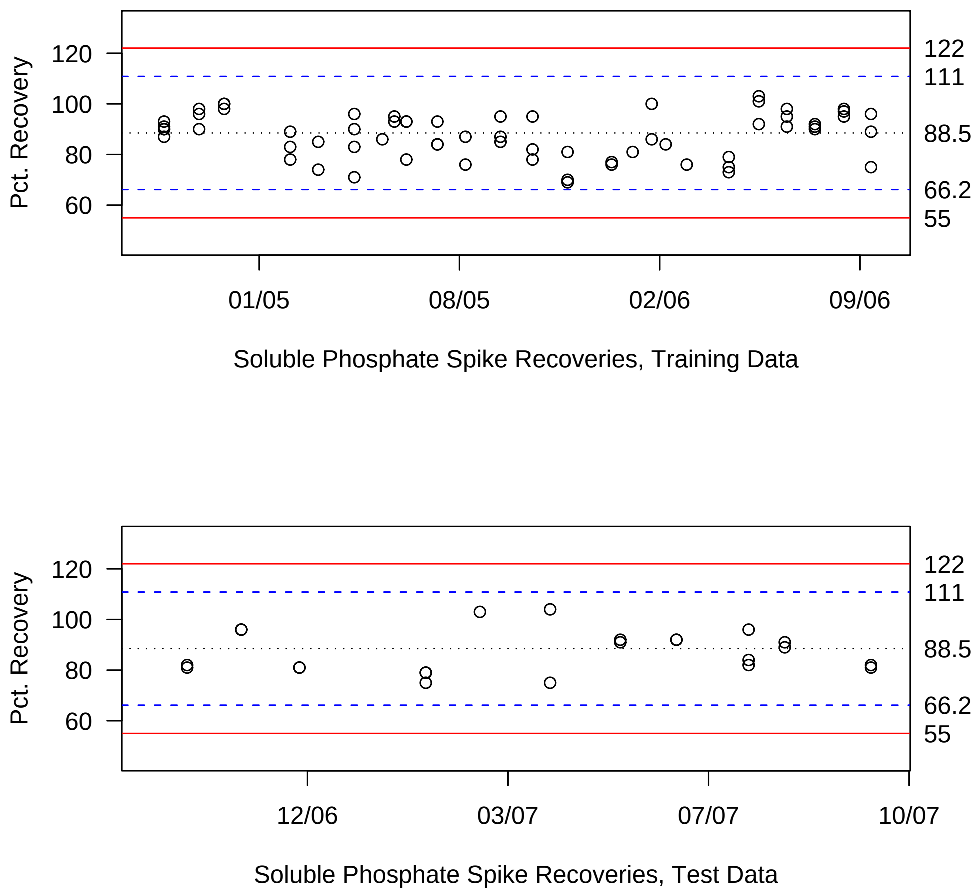
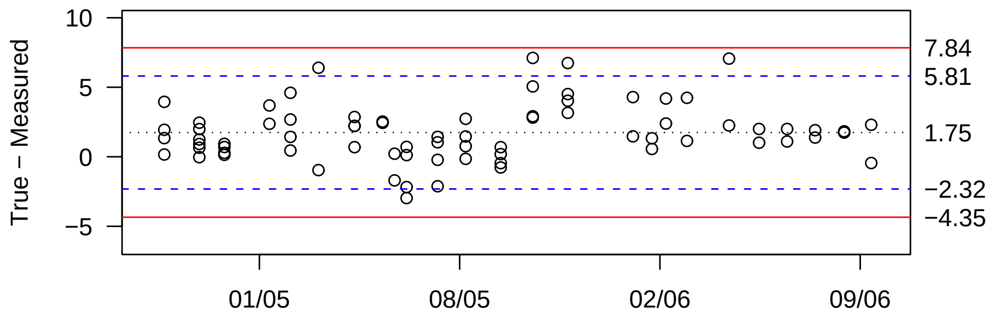
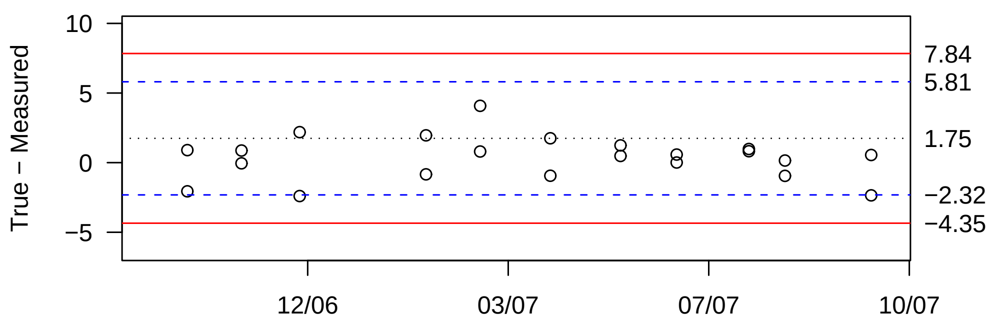


Figure C16: Soluble reactive phosphate matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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

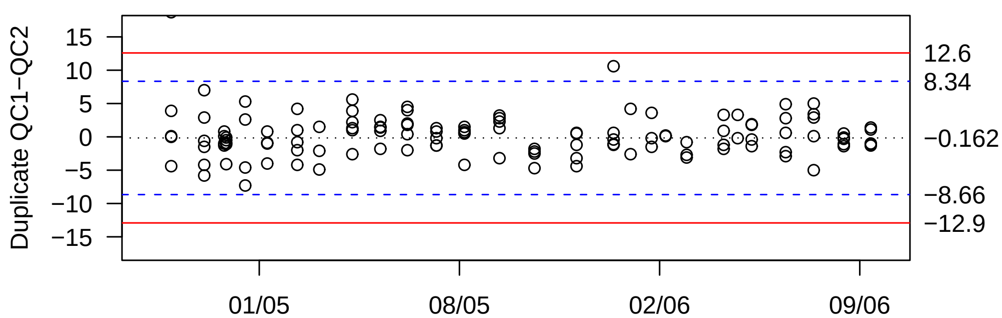


Soluble Phosphate Check Standards, Training Data

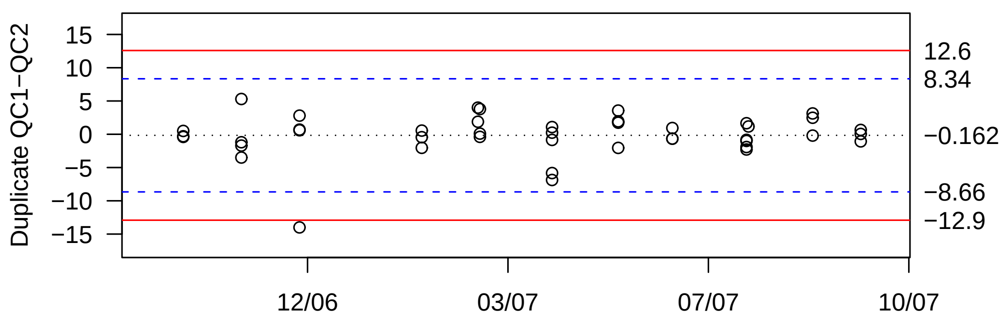


Soluble Phosphate Check Standards, Test Data

Figure C17: 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.

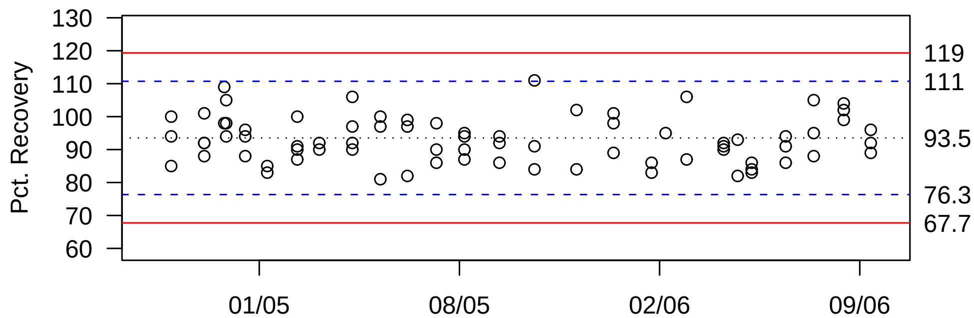


Total Phosphorus Laboratory Duplicates, Training Data

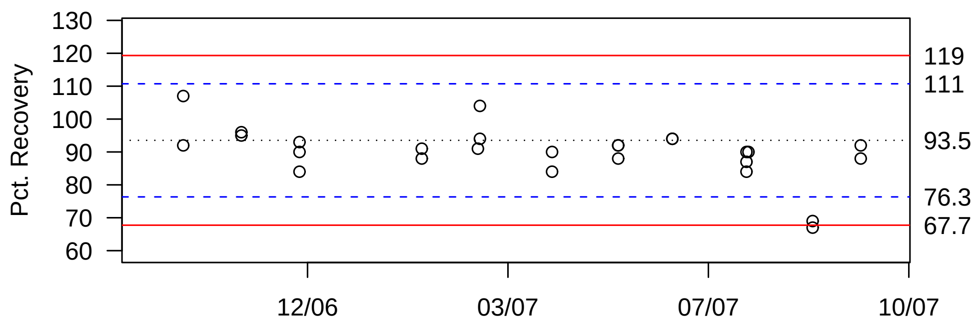


Total Phosphorus Laboratory Duplicates, Test Data

Figure C18: 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.

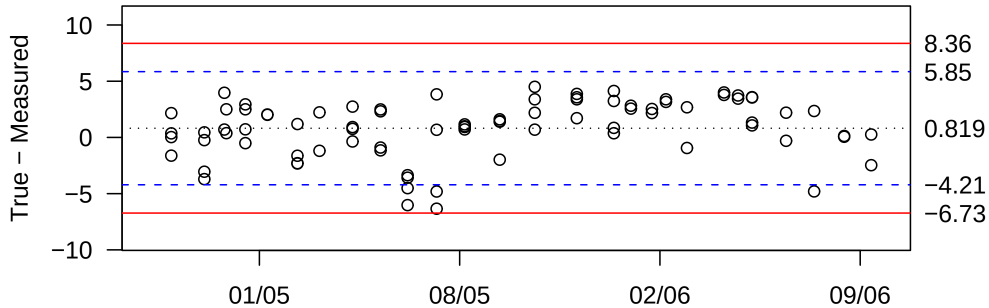


Total Phosphorus Spike Recoveries, Training Data

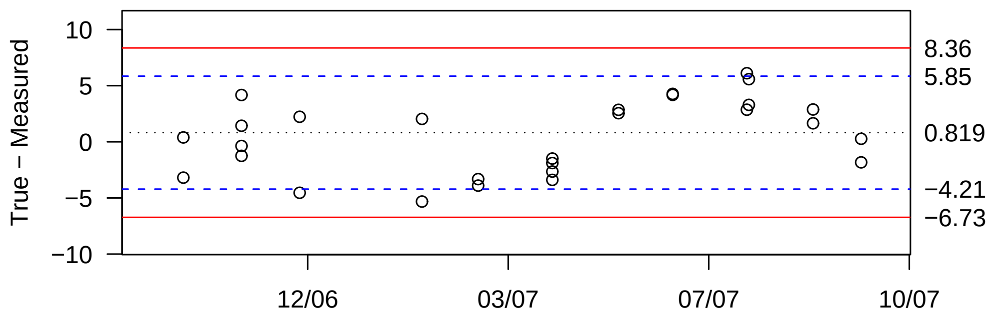


Total Phosphorus Spike Recoveries, Test Data

Figure C19: 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.

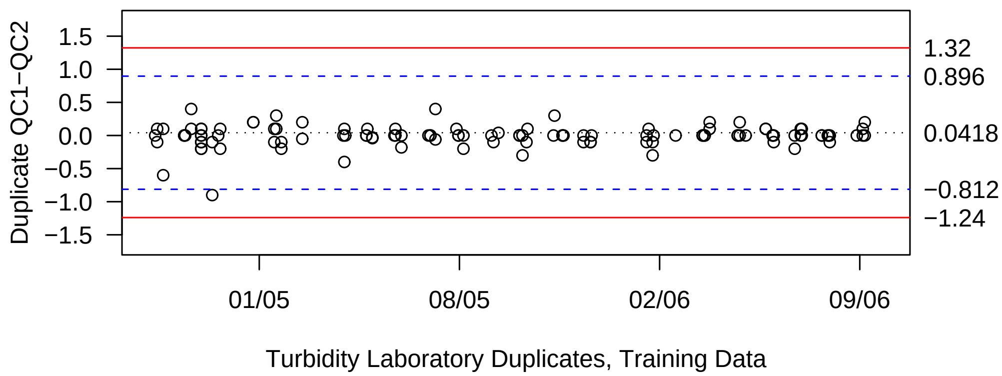


Total Phosphorus Check Standards, Training Data



Total Phosphorus Check Standards, Test Data

Figure C20: 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.



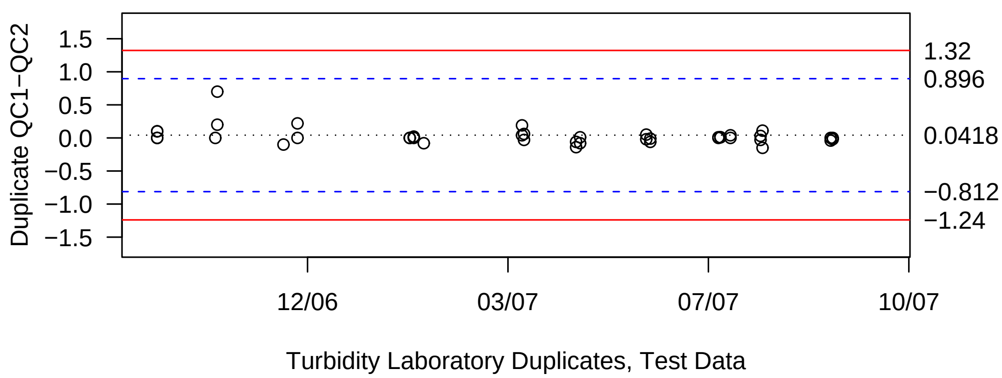


Figure C21: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

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 C22–C31, pages 360–369). 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 for the 2006/2007 lake data using the following equation:

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

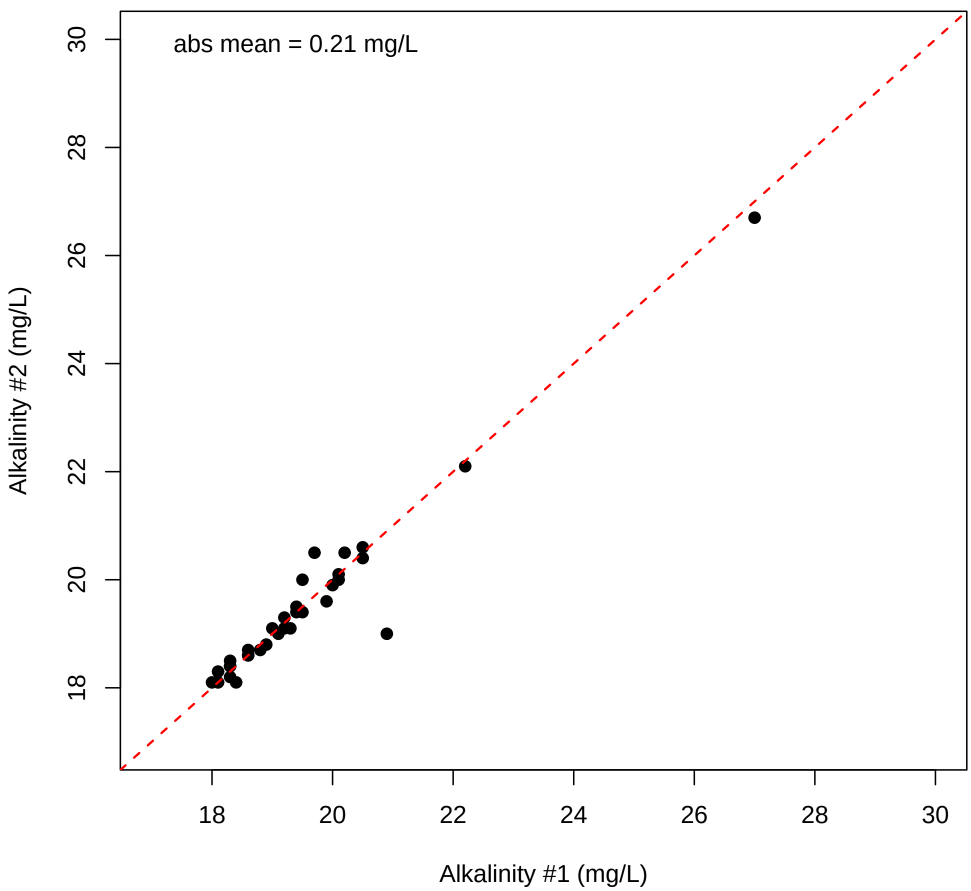


Figure C22: Alkalinity field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

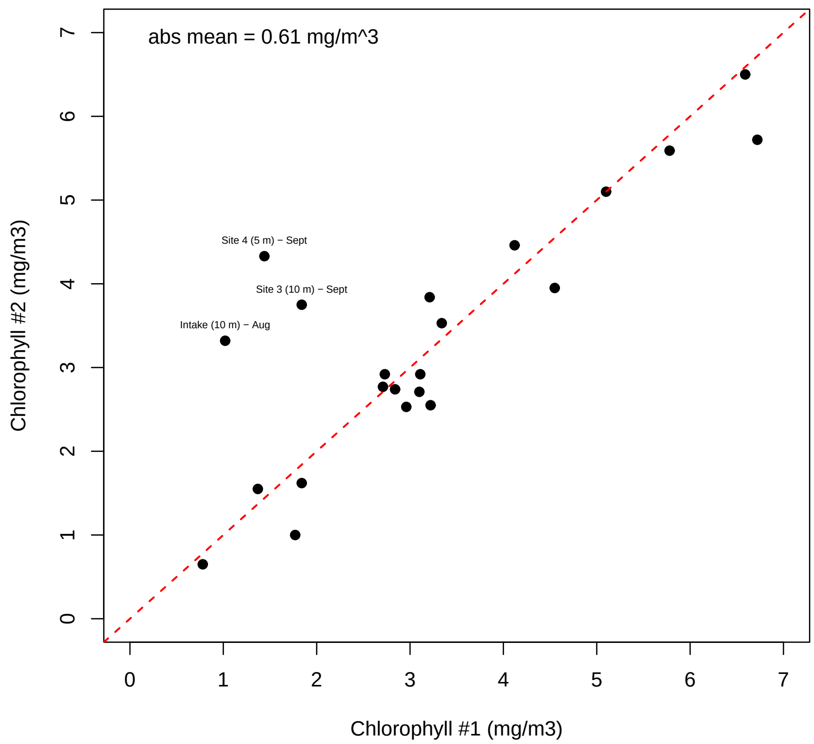


Figure C23: Chlorophyll field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The outliers were all epilimnetic samples collected during late summer when algal communities were highly stratified by depth.

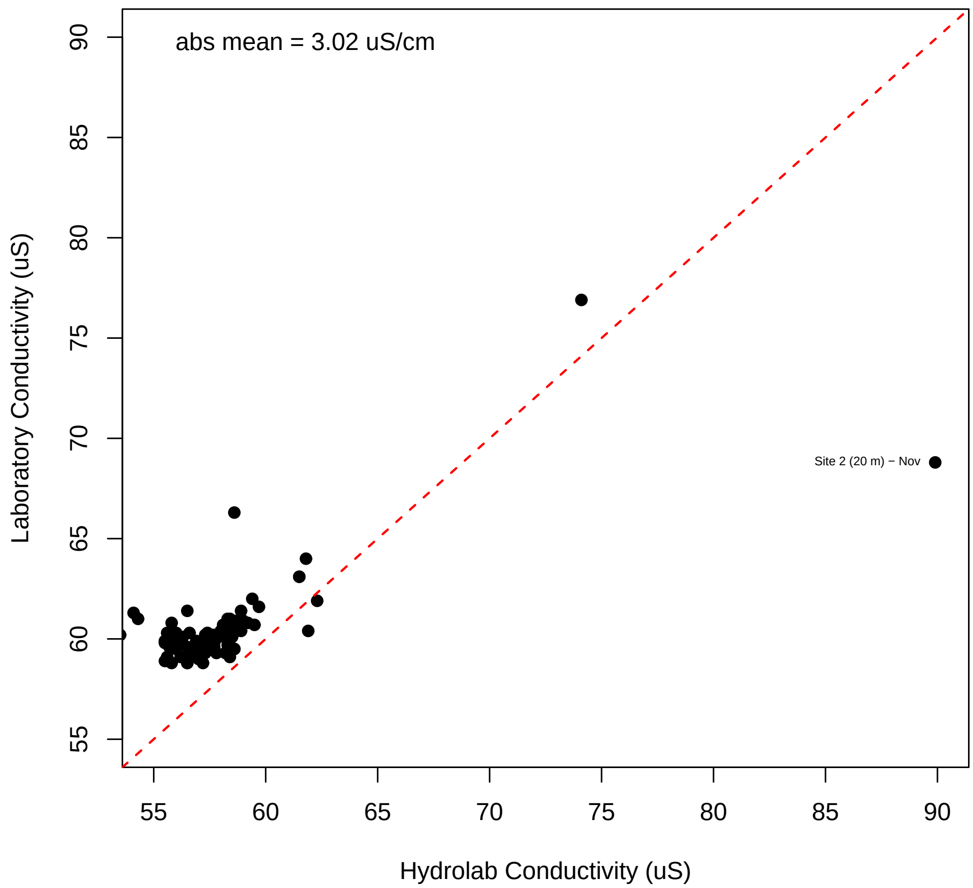


Figure C24: Conductivity field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The outlier was collected when there was a sharp conductivity gradient at the bottom of the lake.

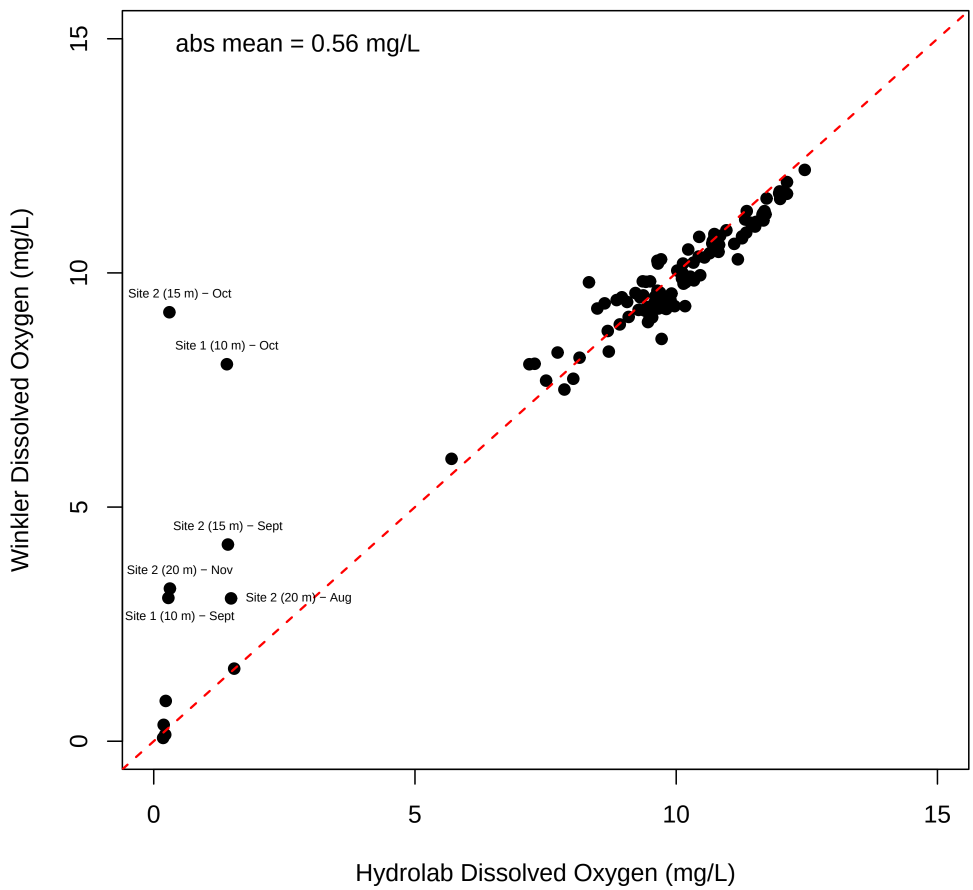


Figure C25: Dissolved oxygen field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The outliers were collected at Sites 1 and 2 during late summer when extreme oxygen gradients were present. The differences illustrate the variation between samples collected at true depth (Hydrolab) and depth measured using a marked line (Winkler), which is slightly shallower than true depth.

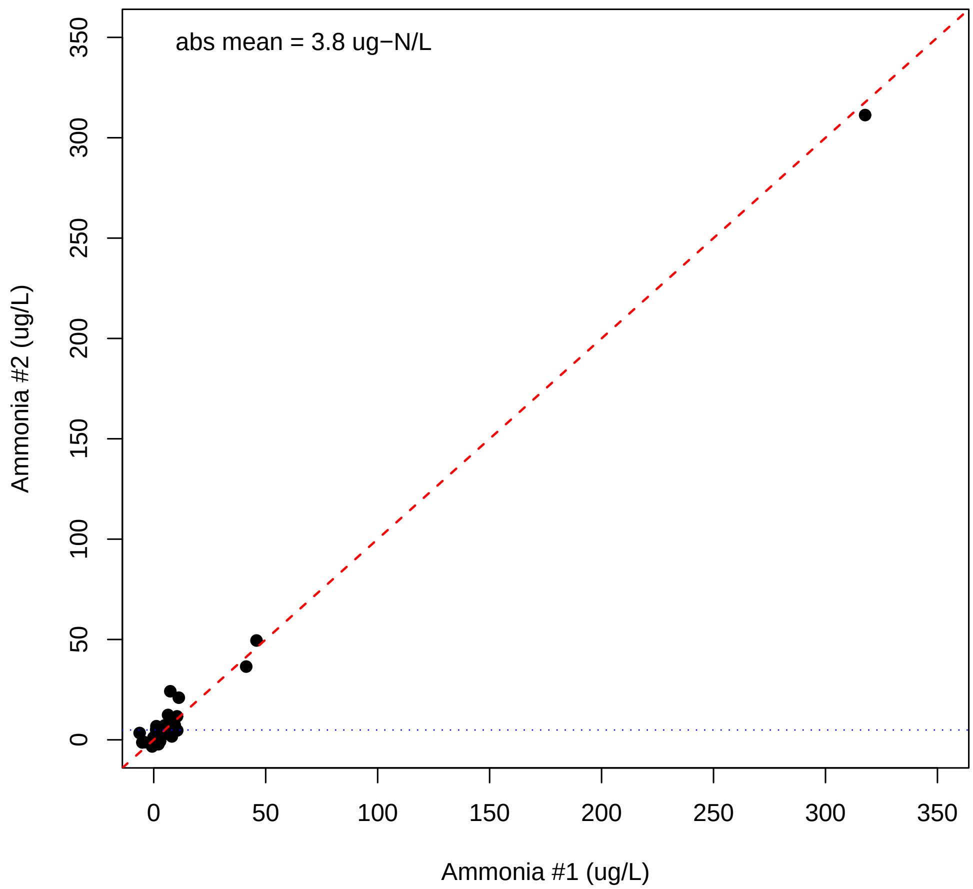


Figure C26: Ammonia field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

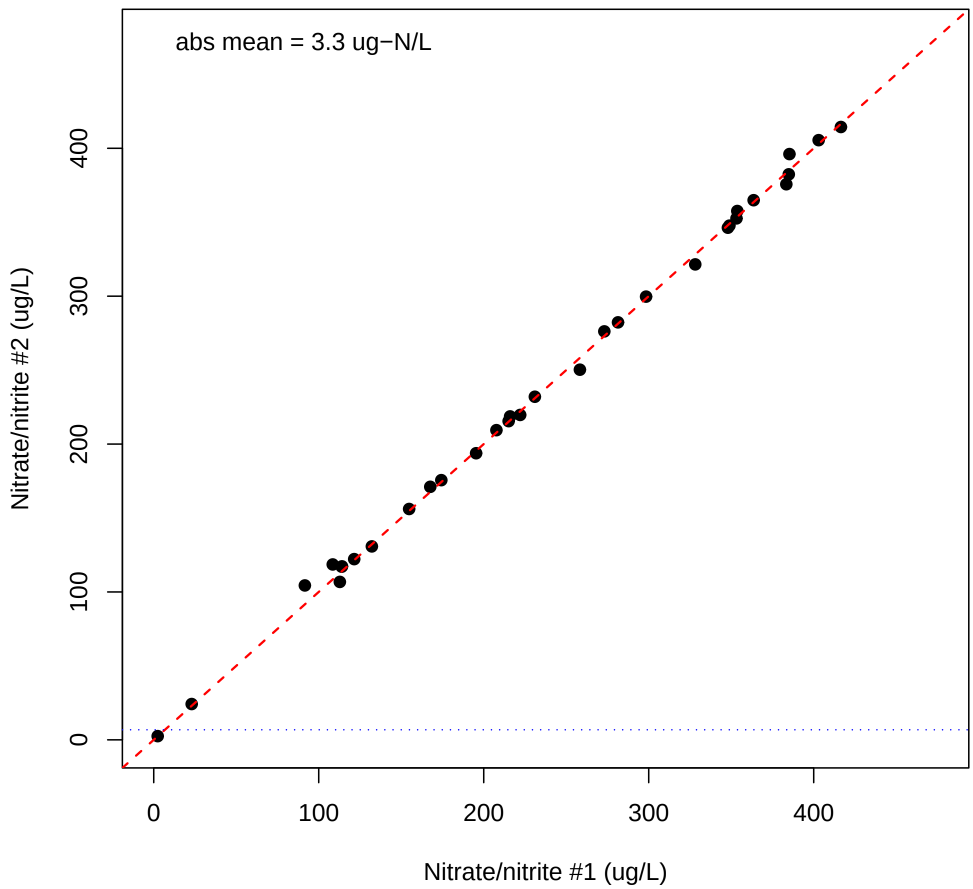


Figure C27: Nitrate/nitrite field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

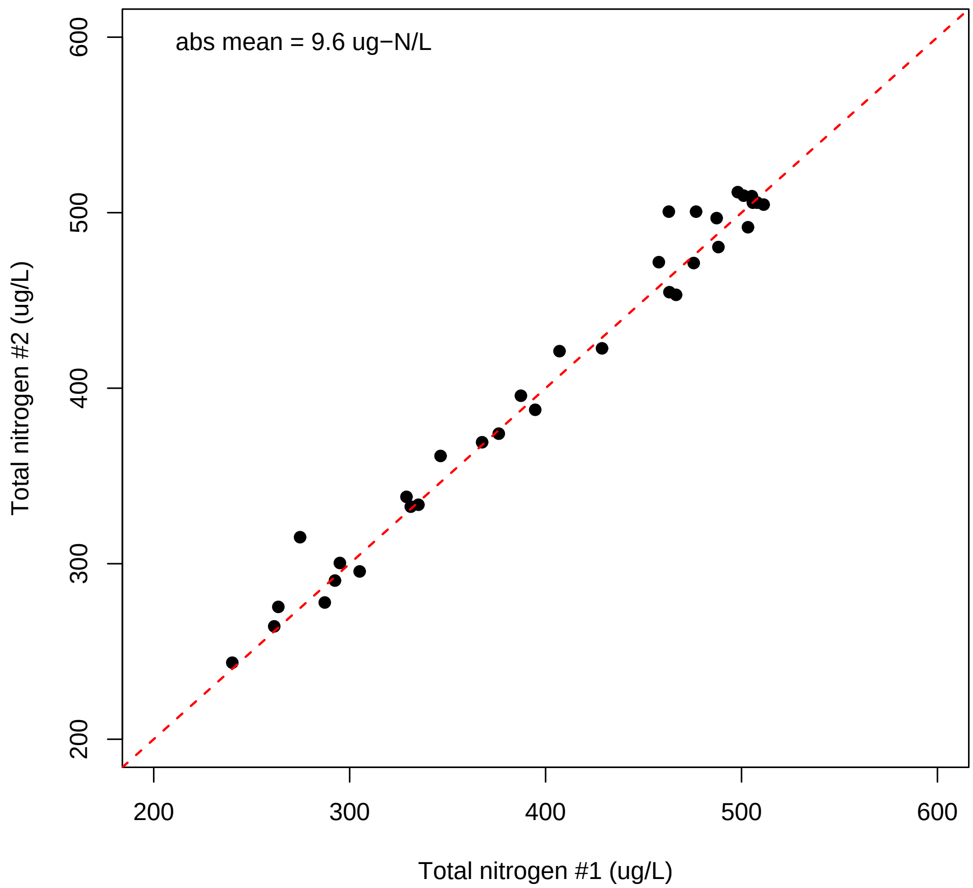


Figure C28: Total nitrogen field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

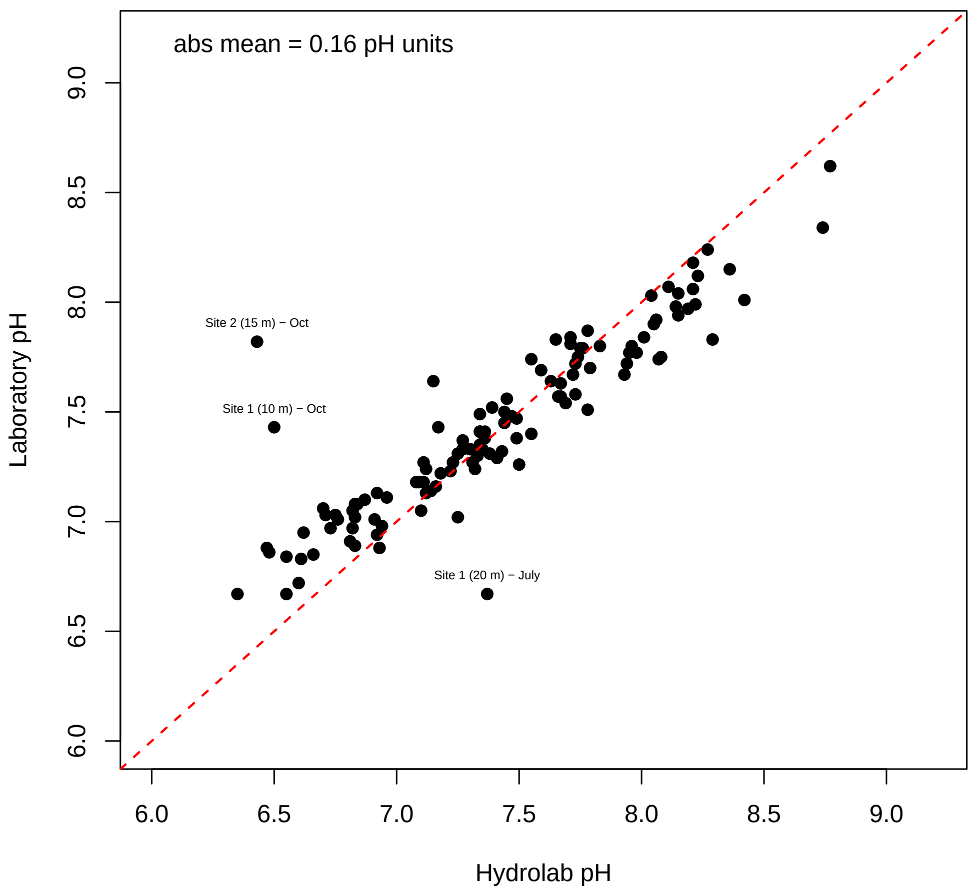


Figure C29: Field duplicates for pH from the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The results show a slight systematic bias due to changes in dissolved CO_2 and associated inorganic carbon ions between field and laboratory samples. The outliers were collected during late summer when extreme pH gradients were present.

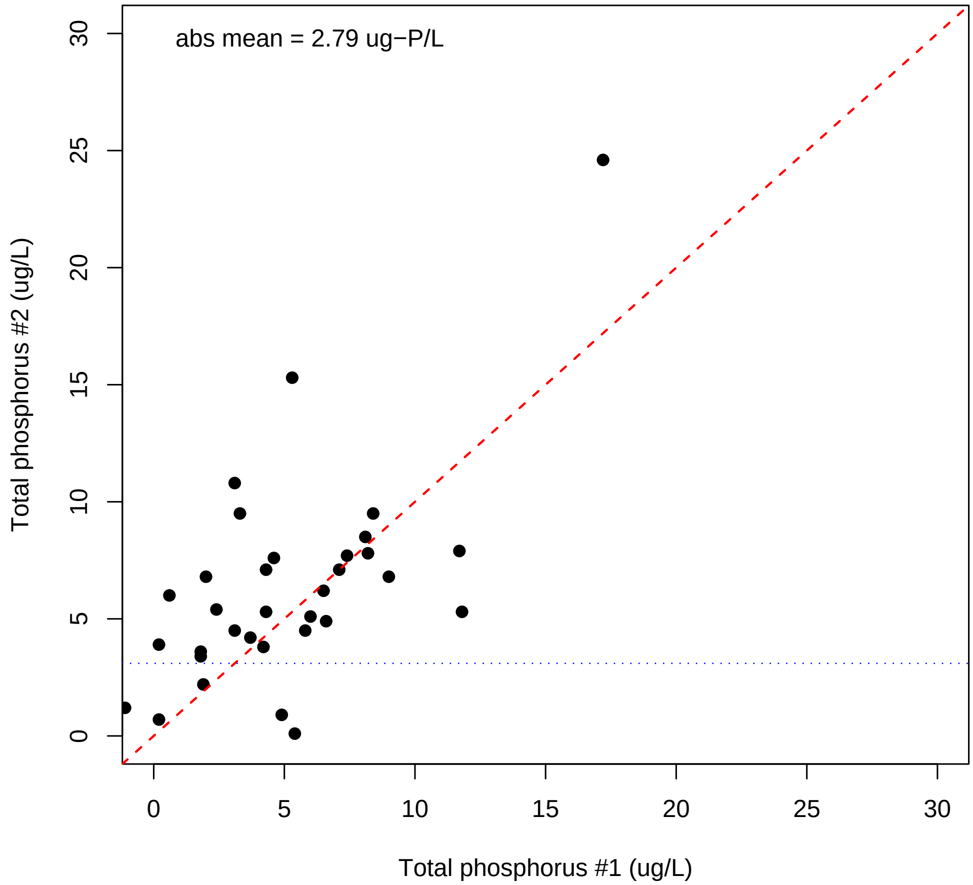


Figure C30: Total phosphorus field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

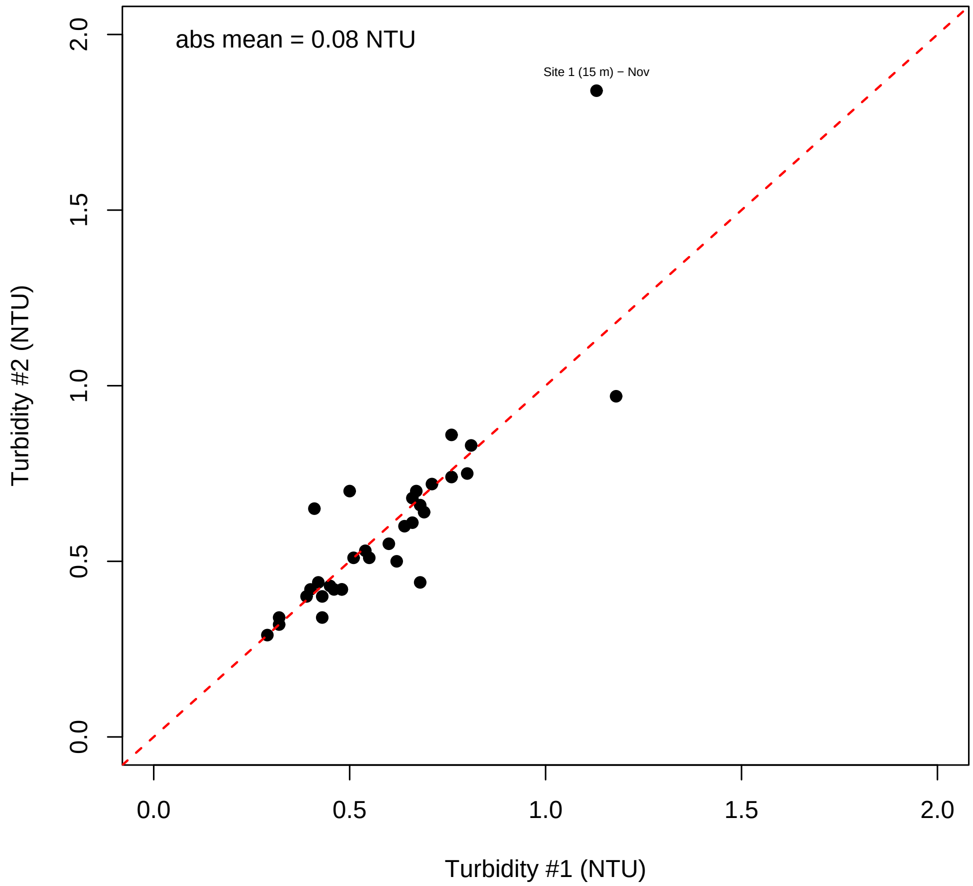


Figure C31: Turbidity field duplicates for the 2006/2007 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The outlier was collected close to lake destratification, which causes variation in water column turbidity levels.

D Lake Whatcom Data

The Lake Whatcom raw data are available in hardcopy format in printed versions of the annual reports, with the exception of the coliform data, which are available from the City of Bellingham Public Works Department. Online reports do not include printed copies of the raw data, but electronic copies of most current and historic data are posted on the Institute's website (http://www/ac/wwu/edu/∼iws).

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 in order to allow comparisons between all years.

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 specific 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.

Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity (±)	Abbrev.	Analysis	AmTest 2006/2007 Det. Limits (dl)
alk	Alkalinity	± 0.5 mg/L	As	arsenic, total	dl = 0.01
ecoli†	Bacteria, *E. coli*	dl = 2 cfu/100 mL	Cd	cadmium, total	dl = 0.0005
ent†	Bacteria, *Enterococcus*	dl = 2 cfu/100 mL	Cr	chromium, total	dl = 0.001
fc†	Bacteria, fecal coliforms	dl = 2 cfu/100 mL	Cu	copper, total	dl = 0.001
tc†	Bacteria, total coliforms	dl = 2 cfu/100 mL	Fe	iron, total	dl = 0.005
toc	Carbon, total organic	dl = 1.0 mg/L	Pb	lead, total	dl = 0.001
chl	Chlorophyll *a*	± 0.1 mg/m^3	Hg	mercury, total	dl = 0.0001
cond	Conductivity, Hydrolab	± 2 μS/cm	Ni	nickel, total	dl = 0.005
cond	Conductivity, lab	± 2 μS/cm	Zn	zinc, total	dl = 0.001
disch	Discharge	na			
nh3	Nitrogen, ammonia	dl = 10 μg-N/L			
no3	Nitrogen, nitrate/nitrite	dl = 20 μg-N/L			
tn	Nitrogen, total nitrogen	dl = 100 μg-N/L			
do	Oxygen, Hydrolab	± 0.1 mg/L			
do	Oxygen, Winkler	± 0.1 mg/L			
pH	pH, Hydrolab	± 0.1 pH unit			
pH	pH, lab	± 0.1 pH unit			
srp	Phosphate, soluble reactive	dl = 5 μg-P/L			
tp	Phosphorus, total	dl = 5 μg-P/L			
secchi	Secchi depth	± 0.1 m			
temp	Temperature	± 0.1° C			
tss	Total suspended solids	dl = 2 mg/L			
ts	Total solids	dl = 2 mg/L			
turb	Turbidity	± 0.2 NTU			

†Coliform data are available from the City of Bellingham Public Works Dept.
‡AmTest detection limits decreased in 1999 and 2002.

Table D1: Summary of analyses in the Lake Whatcom monitoring project. The historic detection limits listed in this table are conservative estimates designed to permit comparisons with historic data. Table 1 on page 16 lists the current IWS detection limits for selected analyses and Appendix D.5 lists the current AmTest detection limits.

D.1 Lake Whatcom Hydrolab Data

Hydrolab data from the current sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the historic Lake Whatcom Hydrolab data are available online at http://www.ac.wwu.edu/∼iws or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

D.2 Lake Whatcom Water Quality Data

Water quality data from the current sampling period are included in hardcopy format in the printed version of this report. Bacteria data have not been included in this appendix, but are available from the City of Bellingham Public Works Department. Electronic copies of the historic Lake Whatcom water quality data are available online at http://www.ac.wwu.edu/∼iws or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

D.3 Lake Whatcom Plankton Data

Lake Whatcom plankton data from the current sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the historic Lake Whatcom plankton data are available online at http://www.ac.wwu.edu/∼iws or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

D.4 Storm Water Treatment Monitoring Data

The storm water treatment data from the current sampling period are included in hardcopy format in the printed version of this report. Bacteria data have not been included in this appendix, but are available from the City of Bellingham Public Works Department. Electronic copies of the historic storm water treatment data are available online at http://www.ac.wwu.edu/∼iws or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

D.5 AmTest Metals and TOC

Copies of the AmTest analytical reports for metals and total organic carbon analyses are printed in the hardcopy version of this report (filed by collection date). Electronic copies of these data are not available.

Sample location	Date	Analyses
Lake Whatcom, surface and bottom	February 14, 2007	metals, total organic carbon
	September 14, 2007	metals, total organic carbon
Lake Whatcom tributaries	February 15, 2007	metals, total organic carbon
	July 19, 2007	metals, total organic carbon
Brentwood wet ponds	March 13, 2007	metals,total organic carbon
	June 21, 2007	metals,total organic carbon
Park Place sand filter	November 21, 2006	metals, total organic carbon
	March 13, 2007	metals, total organic carbon
	June 18, 2007	metals, total organic carbon
South Campus storm drain	April 19, 2007	metals, total organic carbon
	May 17, 2007	metals, total organic carbon

Sites codes for the AmTest reports are as follows:

Lake Sites		Storm Water Sites		Tributaries	
11 O	Site 1, surface (0.3 m)	BW IN	Brentwood inlet	AND	Anderson
11 B	Site 1, bottom (20 m)	BW OUT	Brentwood outlet	AUS	L. Austin
21 O	Intake, surface (0.3 m)	PP IN	Park Place inlet	BLU	Blue Canyon
21 B	Intake, bottom (10 m)	PP OUT	Park Place outlet	BRA	Brannian
22 O	Site 2, surface (0.3 m)	SC IN	S. Campus inlet	CAR	Carpenter
22 B	Site 2, bottom (20 m)	SC OUTE	S. Campus east outlet	EUC	Euclid
31 O	Site 3, surface (0.3 m)	SC OUTW	S. Campus west outlet	MIL	Millwheel
31 B	Site 3, bottom (80 m)			OLS	Olsen
32 O	Site 4, surface (0.3 m)			PAR	Park Place
32 B	Site 4, bottom (90 m)			SIL	Silver Beach
				SMI	Smith
				WHA	Whatcom