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Lake Whatcom Monitoring Project 2003/2004 Report

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2003/2004 Final Report

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Executive Summary

- This report describes the results from the 2003/2004 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.

- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The spring and summer surface water temperatures were warmer than usual and the lake stratified about 1 month earlier than in 2003.

- 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.

- During the period of stratification, the near-surface alkalinity and pH levels have increased since 1988 due to increasing photosynthetic activity. Hypolimnetic pH has decreased due to the effects of organic matter decomposition.

- Nitrate depletion was evident at all sites in the photosynthetic zone during the summer. At Site 1 the epilimnetic nitrate concentrations fell below 50 μg-N/L, creating an environment favorable for cyanobacteria. Stratified, near-surface levels of inorganic nitrogen have decreased significantly at all sites since 1988.

- Phosphorus concentrations were fairly low at most sites ($\leq$15 μg-P/L) except in the hypolimnion at Sites 1 and 2 during late summer and fall. Stratified, near-surface levels of phosphorus have increased significantly at Sites 3–4 since 1988.

- Site 1 continued to have the highest chlorophyll concentrations of all the sites, but chlorophyll concentrations have increased significantly at Sites 2–4 since 1994. Substantial blooms of cyanobacteria (Cyanophyta) and green algae (Chlorophyta) were present at all sites during summer and fall in 2004, and the algal counts for all taxa have increased significantly since 1991.

- The 2003/2004 total organic carbon concentrations were relatively high (1.8–5.2 mg/L) compared to previous years. Total organic carbon concentrations, along with plankton and chlorophyll data, are used to help assess the likelihood of developing potentially harmful disinfection by-products (e.g., trihalomethanes or THMs) through the reaction of chlorine with organic compounds during the drinking water treatment process

- Concurrent with the increasing algal densities in Lake Whatcom, there has been a significant increase in the amount of alum used to treat Bellingham's drinking water, particularly during months associated with diatom or cyanobacteria bloom. There has also been a significant increase in the concentrations of trihalomethanes in Bellingham's treated water, The concentrations of THMs are still below the recommended maximum of 0.08 mg/L.

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

- Most of the metals concentrations in the lake were at, or below, detection limits, and those that were detected were within normal concentration ranges for Lake Whatcom.

- Although most of the creek data fell within historic ranges, low flow during the summer of 2004 caused many measurements to be near the extreme high or low ends of the expected ranges. Compared to the streams in forested areas, the residential streams typically had poorer water quality, with higher conductivities; higher alkalinity and phosphorus; and much higher coliform counts.

- 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 included surface and subsurface runoff (69.0%), direct precipitation (18.6%), and water diverted from the Middle Fork of the Nooksack River (12.4%). Outputs included Whatcom Creek (71.2%), the City of Bellingham (11.8%), Georgia Pacific (5.4%), evaporation (7.7%), the Whatcom Falls Hatchery (3.4%), and Water District #10 (0.5%).

- Five storm water treatment systems were monitored in 2003/2004: the Park Place and Brentwood wet ponds; the Parkstone grass swale/wet pond; the Silvern underground storm water treatment vault; and the South Campus storm water treatment facility, which is outside the Lake Whatcom watershed, but is used as a reference site because it often provides better pollutant removal than systems inside the watershed.

- Among the three large storm water treatment facilities, the South Campus system provided the best phosphorus and sediment removal, with an annual average reduction of 76.6% for total suspended solids and 54.2% for total phosphorus. The Park Place wet pond provided virtually no sediment or phosphorus removal, and often had higher concentrations of sediments and phosphorus at the outlet than the inlet. The Brentwood wet pond produced a modest reduction of 14.7% for suspended solids and 27.2% for phosphorus.

- The Silvern vault provided a small sediment reduction (24.1%), a smaller phosphorus reduction (8.1%), and exported organic carbon (225% *increase* at the outlet). The Parkstone system had better water quality at the swale outlet than the pond outlet. There was a substantial reduction in suspended solids between the swale inlets and the swale outlet (74.5%), but little additional reduction between the pond inlet and outlet (6.4%). Similarly, there was some phosphorus removal in the swale system (32.7%), but an export of phosphorus from the pond system (40.0% *increase* at the pond outlet).

1 Introduction

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom also provides high quality water for the Georgia-Pacific Corporation mill[1], 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. In addition, since the City and WWU review the scope of work for the monitoring program each year, short-term water quality questions can be addressed as needed.

The major objectives of the 2003/2004 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.

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 2003/2004 monitoring data are printed in hardcopy version of this report in Appendix D and included in electronic format in the online version of this report. Table D1 on page 264 (at the beginning of Appendix D) lists all abbreviations and units used to describe water quality analyses in this document.

[1]The Georgia-Pacific Corporation closed its pulp mill operations in 2001, reducing its water requirements from 30–35 MGD to 7–12 MGD. The water requirements were further reduced to 5–9 MGD in 2003 when Georgia-Pacific closed all but its tissue production facility (City of Bellingham Public Works Dept.).

2 Lake Whatcom Monitoring

2.1 Site Descriptions

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (Figures A1–A3, pages 96–98, 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 ten times during the 2003/2004 monitoring program to measure the parameters listed in Table 1. Each sampling event is a multi-day task because of the distance between sites and the number of samples collected. The sampling dates were: October 7 & 9, November 4 & 6 and December 4 & 9, 2003; and February 3 & 5, April 6 & 8, May 5 & 6, June 9 & 14, July 7 & 8, August 3 & 4, and September 1 & 2, 2004.

A Surveyor IV 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 2 on page 18 (APHA, 1998; Hydrolab, 1997; Lind, 1985). Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.[2] 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. Unless otherwise noted, all other analyses were done by WWU personnel.

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

2.3 Results and Discussion

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

Tables 3–7 (pages 19–23) summarize the 2003/2004 field measurements, ambient water quality, and coliform data. The raw data are included in Appendix D, beginning on page 263, and in electronic format on the CD that accompanies this report. The monthly 2003/2004 Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 107–156).

The historic lake data are also plotted in Figures B51–B70 (pages 158–177) and Figures B71–B135 (pages 179–246). These figures are scaled to plot the full range of Lake Whatcom water quality data including minimum, maximum, and outlier values. As a result, they usually do not provide the best illustration of trends that occur at specific locations in the lake. Separate tables and figures are provided in this report for trend discussions.

2.3.1 Hydrolab field measurements

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

The summer Hydrolab profiles (e.g., Figures B46–B50) illustrate how the lake stratifies into a warm surface layer (the *epilimnion*) and a cool bottom layer (the *hypolimnion*). When stratified, the Hydrolab profiles show distinct differences between surface and bottom temperatures. 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.

Stratification develops gradually, and once stable, persists until fall or winter, depending on location in the lake. 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 early June (Figure 1, page 27). The actual stability of stratification is determined in part by the temperature differences in the water column, but also by water circulation and local weather patterns. However, once the water column temperature differs by at least 5° C, it is unlikely that the lake will destratify. Typically, all three basins reach a 5° C difference by early June (see summary of monthly water column temperature differences in Figure 1, page 27).

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) cool quickly because of their smaller volumes and destratify by the end of October (Figure 1). Basin 3 (Sites 3–4) cools slowly because of its large volume, and may still be stratified in November or early December. Complete destratification probably occurs in late December or early January, so that by February, the temperatures are relatively uniform throughout the water column.

The historic water temperature data show that although the annual median temperatures in basin 3 is cooler than basins 1 and 2, the two shallow basins experience more extreme temperature variations. The lowest and highest temperatures measured in the lake since 1988 were at Site 1 (4.2 °C on February 1, 1988; 23.2 °C on August 5, 1998). The large water volume in basin 3 moderates temperature fluctuations, so it will be less susceptible than the shallow basins to temperature changes in response to weather conditions.

The 2004 spring and summer surface water temperatures were warmer than usual, compared to 1988–2003 data (Figure 2, page 28). The lake was stratified by the first week in May (Figures B26–B30, pages 132–136), which was about 1 month earlier than in 2003.

As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures B41–B42 and B56–B57, pages 147–148 and 163–164). 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 very low concentrations of essential nutrients such as phosphorus, biological respiration has little influence on hypolimnetic oxygen concentrations (e.g., Figures B50 and B60, pages 156 and 167). In contrast, Site 1, which is located in nutrient-enriched waters, shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures B46 and B56, pages 152 and 163).

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 overturn; fish kills, particularly during lake overturn; 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.

During October and November, both Sites 3 and 4 developed a small oxygen sag at the thermocline (Figures B4–B5 and B9–B10, pages 110–111 and 115–116). This was probably caused by respiration by heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (DeLuna, 2004). The oxygen sag was also present in December at Sites 3 and 4, but was more uniformly distributed throughout the hypolimnion (Figures B14–B15, pages 120–121). By February 2004, basin 3 had turned over and oxygen concentrations were relatively uniform throughout the water column at all sites.

A positive orthograde oxygen curve was evident at Site 1 in May, July, and August (Figures B26, B36, and B41, pages 132, 142, and 147). DeLuna (2004) described this phenomenon, which is 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. The positive orthograde oxygen curve represents temporary oxygen supersaturation caused by rapid photosynthesis. It is common to see an increase in pH at the same depths, as the photosynthesizing organisms remove dissolved CO_2 from the water. Positive orthograde oxygen curves are usually measured during the day; at night, respiration from the same organisms can cause a temporary oxygen sag along the thermocline. Orthograde oxygen curves were also present at Site 2, but were not as sharply delineated as at Site 1 (e.g., Figure B42, page 148).

The Hydrolab pH and conductivity data followed trends that were typical for Lake Whatcom, with only small differences between sites and depths except during the summer. During the summer the surface pH increased due to photosynthetic activity. Hypolimnetic pH values decreased and conductivity values increased due to decomposition and the release of dissolved compounds from the sediments. A significant long-term trend was apparent in the conductivity data (Matthews, et al., 2004). 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 change in the actual conductivity in the lake. Due to Hydrolab equipment malfunctions, conductivity and pH data could not be collected on all sampling dates. The Hydrolab has been repaired, and has functioned normally since October 2004.

2.3.2 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 179–183). 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 and 2 (Figures B76–B80, pages 184–188). The high turbidity levels near the bottom are an indication of increasing turbulence in the lower hypolimnion as the lake nears turnover. 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 epilimnetic samples.

2.3.3 Nitrogen and phosphorus

The historic nitrogen and phosphorus data are plotted in Figures B81–B95 (pages 190–204). High ammonia concentrations were measured just prior to overturn in the hypolimnion at Sites 1 and 2 (Figures B81 & B82, pages 190 & 191). Elevated hypolimnetic ammonia concentrations have been common at both sites through out the monitoring period (1988–2004); however, we have measured atypically high ammonia concentrations at Site 2 for the last six summers. 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, such as the hypolimnion at Sites 1 and 2, ammonia accumulates until the lake destratifies.

Sites 3 and 4 had slightly elevated ammonia concentrations at 20 m. This was due to bacterial activity at the thermocline rather than low oxygen conditions (DeLuna, 2004). A similar pattern was observed by McNair (1995) in Lake Samish. Sites 3 and 4 occasionally have slightly elevated ammonia concentrations at 80–90 m during late summer, which is probably caused by decomposition of organic matter.

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 195–199), particularly at Site 1, where the epilimnetic nitrate concentrations fell below 50 μg-N/L. Nitrogen is an essential nutrient for plankton, and this depletion of nitrate during the summer is an indirect measure of phytoplankton productivity. The availability of nutrients is a major factor in determining the amount of algal growth in a lake. Phosphorus is assumed to be the most common limiting nutrient in unproductive lakes; however, recent studies show that nitrogen limitation and phosphorus/nitrogen co-limitation are common in freshwater lakes (see Elser, et al., 1990). Phosphorus/nitrogen co-limitation seems to occur at Site 1 in Lake Whatcom just prior to overturn (Matthews, et al., 2002a). Coincident with low nitrate concentrations, late summer is when we usually find the highest densities of nitrogen-fixing Cyanophyta (bluegreen bacteria or cyanobacteria) in the plankton samples. Epilimnetic nitrate concentrations decrease at Sites 2–4, but rarely fall below 150 μg-N/L, making it unlikely that nitrogen is limiting at these sites.

The hypolimnetic nitrate concentrations dropped below 10 μg-N/L at both 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 this reduction has been common at Site 1, but was not common at Site 2 until the summer of 1999.

Soluble phosphate concentrations were usually low ($\leq$10 μg-P/L) at all sites and depths except in the hypolimnion at Sites 1 and 2 just prior to overturn (Figures B96–B100, pages 205–209). Algal and bacterial growth in Lake Whatcom is limited by the amount of available phosphorus (Bittner, 1993; Liang, 1994; McDonald, 1994). As a result, soluble phosphate, which is easily taken up by microbiota, will not persist long in the water column, and instead will be bound inside living organisms or organic matter.

The highest total phosphorus (soluble phosphate + organic phosphorus) concentrations were measured in the hypolimnion at Sites 1 and 2 during late summer or early fall (Figures B101–B105, pages 210–214). Elevated soluble phosphate and total phosphorus levels are common in the hypolimnion at Sites 1 and 2 during stratification. As the summer progresses, sediment-bound phosphorus becomes soluble and leaches into the overlying water. If dissolved oxygen concentrations are low, the phosphorus remains soluble and diffuses throughout the hypolimnion. When the lake mixes in the fall, oxygen concentrations increase throughout the water column, and any soluble phosphorus that has not been taken up by biota will convert into insoluble forms. The insoluble phosphorus is much less available to biota, and usually sinks back to the sediments. This process can be seen in Figure 3 (page 29), which shows the gradient of total phosphorus at Site 1 from February through December, 2003 (DeLuna, 2004). (The isopleth map in Figure 3 is similar to a topographic map, but shows lines of similar concentration rather than similar elevation.) During most of the year, total phosphorus concentrations were $\leq$20 μg-P/L throughout the water column. In late summer and early fall, phosphorus concentrations began rising in the hypolimnion, reaching concentrations $>$60 μg-P/L) in October.

2.3.4 Chlorophyll, plankton, and Secchi depth

Site 1 continued to have the highest chlorophyll concentrations of all the sites (Figures B106–B110, pages 216–220). Samples from 20 m at Sites 1 and 2 usually had lower chlorophyll concentrations than samples nearer the surface. Twenty meters is near the lower limit of the photic zone, so the low light intensity is not optimal for algal growth. Also, algae are, for the most part, aerobic organisms, so the low oxygen conditions in the late summer hypolimnion will not be favorable for growth.[3] Peak chlorophyll concentrations were usually at 0–15 m.

The Lake Whatcom plankton counts were usually dominated by Chrysophyta[4] (Figures B111–B120, pages 221–230), consisting primarily of diatoms, *Dinobryon*, and *Mallomonas*. Substantial blooms of cyanobacteria (Cyanophyta) and

[3] Many cyanobacteria can photosynthesize under aerobic or anaerobic conditions (Lee, 1989).
[4] The Chrysophyta phylum name has been changed to Heterokontophyta in many taxonomies.

green algae (Chlorophyta) were also measured at all sites during summer and late fall. Previous analyses of algal biovolume in Lake Whatcom indicated that although Chrysophyta dominate the numerical plankton counts, Cyanophyta and Chlorophyta often dominate the plankton biovolume, particularly in late summer and early fall (Ashurst, 2003; Matthews, et al., 2002b).

Secchi depths showed no clear seasonal pattern because transparency in Lake Whatcom is a function of both summer algal blooms and winter storm events (Figures B121–B125, pages 231–235).

2.3.5 Coliform bacteria

Beginning in October 2002, the coliform monitoring was changed to include *Escherichia coli* (*E. coli*), along with fecal coliform counts. This change was made to reflect potential revisions in the Washington State Department of Ecology's approach to defining bacterial pollution in surface water. Total coliforms and *Enterococcus* counts were discontinued. For information about historic total coliform and *Enterococcus* levels in Lake Whatcom, refer to previous annual reports (e.g., Matthews, et al., 2003).

The suggested revisions to the surface water standards are based on "designated use" categories, which for Lake Whatcom is likely to be "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.*

The proposed standard is based on fecal coliform counts, but allows the use of alternate methods (e.g., *E. coli* counts) when there is evidence that most of the coliform contamination is not from warm-blooded animals. In surface water samples from the Lake Whatcom watershed, there is a very close correlation between fecal coliform counts and *E. coli* counts (Figure 4, page 30), so fecal coliform counts appear to be a reliable tool for determining compliance.[5]

All of the mid-basin (Sites 1–4) and Intake values for fecal coliforms and *E. coli* counts were less than 10 cfu[6]/100 mL (Figures B126–B135, pages 237–246) and passed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard. The Bloedel-Donovan counts, which are collected near the center of the log boom in the swimming area, were higher than Site 1 (mid-basin) counts, with geometric means of 11 and 6 cfu/100 mL for fecal coliforms and *E. coli*, respectively. The Bloedel-Donovan site passed both parts of the freshwater *Extraordinary Primary Contact Recreation* bacteria standard, but one sample exceeded 100 cfu/100 mL (the October 7, 2003 fecal coliform count was 390 cfu/100 mL and the *E. coli* count was 360 cfu/100 mL).

2.3.6 Metals and TOC

The metals data for Lake Whatcom are included in Table 8 (page 24). This table includes only the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); Appendix D.7 (beginning on page 308) lists concentrations for an additional 24 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 do not represent increases in the metals concentrations in the lake.

Most of the metals concentrations were near or below detection limits, and those that were detected were within normal concentration ranges for the lake. Zinc was detected at nearly all sites during February, but was below detection during September. Iron was detectable at most sites and depths in February and September. The highest iron concentrations, 1.2 mg/L and 1.1 mg/L, were measured in September at the bottom of Sites 1 and 2, respectively. The elevated iron con-

[5] Correlation analyses were used to examine the strength of relationships between two variables (e.g., fecal coliforms and *E. coli*). 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.

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

centrations 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, and mercury were detected in a few samples, but because the concentrations were at or near detection levels, it is unlikely that these detections represent an increase in metals concentrations in the lake.

Elevated concentrations of iron have been detected in raw water at the Lake Whatcom gatehouse[7] during late summer and fall (Figure 5, page 31), particularly during the first few weeks after the lake destratifies (see Figure 5, October–November peaks). The March 3, 2001 sample may have been contaminated with iron from renovations occurring inside the gatehouse during that time (Figure 5). Following lake turnover, most soluble iron is converted to insoluble iron, which slowly settles to the bottom. As a result, gatehouse iron concentrations were usually $\leq$0.05 mg/L during the rest of the year.

The 2003/2004 total organic carbon concentrations were relatively high, ranging from 1.8 mg/L to 5.2 mg/L (Table 9, page 25), and Lake Whatcom total organic carbon concentrations appear to be increasing over time (Figure 6, page 32). Total organic carbon concentrations, along with plankton and chlorophyll data, are used to help assess the likelihood of developing potentially harmful disinfection by-products (e.g., trihalomethanes or THMs) through the reaction of chlorine with organic compounds during the drinking water treatment process (see discussion in Section 2.4).

2.4 Long-Term Lake Trends

Pelletier (1998) and Matthews, et al. (2000) describe declining hypolimnetic oxygen conditions at Site 1, and Matthews, et al. (2004) describe additional water quality trends that suggest that the entire lake is moving toward a higher trophic state. Further analysis from this year's data supports the conclusion that Lake Whatcom is rapidly becoming more eutrophic. Evidence for the increasing trophic state can be found in the data from Lake Whatcom, and also in the City of Bellingham's water treatment data.

[7] The gatehouse is the structure that connects the intake in Lake Whatcom with an underground pipe that transports the water to the City's water treatment plant.

2.4.1 Hypolimnetic dissolved oxygen

The levels of hypolimnetic oxygen have declined over time at Site 1 (Matthews, et al., 2004; Pelletier, 1998), causing the lake to be listed by the Department of Ecology on the 1998 303D list of impaired waterbodies in the State of Washington.[8] 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 7–10 (pages 33–36), there were significant negative correlations between dissolved oxygen and time for nearly all samples collected from the hypolimnion during July and August (see footnote on page 10 for description of correlation analysis). All but one depth was significant at $p < 0.05$; the correlation for August at 14 m was significant at $p = 0.064$.

2.4.2 Indications of eutrophication

The biological productivity of Lake Whatcom appears to be increasing throughout the lake. There are both *direct* and *indirect* indicators of eutrophication[9] apparent in the historic water quality data from Lake Whatcom. *Direct* indicators of eutrophication in Lake Whatcom include significantly increasing algal densities (Figure 11, page 37) and increasing chlorophyll concentrations (Figure 12, page 38). Figure 11 shows a marked increase in algal cell counts for all of the common taxa over time. In order to show typical counts, Figure 11 does not include extreme outliers, but if they were included, the increase would be even more dramatic. Figure 12 shows that chlorophyll concentrations have increased in the lake since 1994. Prior to 1994, chlorophyll was sampled using a slightly less accurate method, resulting in more within-sample variation. If these earlier data are included, the correlations are not significant because the pattern is masked by sample variance.

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[8] Information about the 303(d) list is available at http://www.ecy.wa.gov/programs/wq/303d.

[9] *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. Most of Lake Whatcom is relatively unproductive, which makes it particularly vulnerable to eutrophication from phosphorus loading. See Wetzel (1983) for a discussion of the effects of eutrophication on lakes.

As lakes become more eutrophic, we also expect to see a number of *indirect* indicators of eutrophication. Alkalinity may increase throughout the lake as algae add organic carbon from biomass and inorganic carbon precipitated during photosynthesis. The near-surface, daytime pH should increase during the summer as algae remove CO_2 for photosynthesis. Conversely, hypolimnetic pH should decrease as bacteria decompose greater amounts of organic matter that "rains" down from the surface waters. There is often a decrease in near-surface, dissolved inorganic nitrogen due to incorporation of this important nutrient into algal biomass. Phosphorus concentrations in the water column may increase, but since phosphorus is limiting to algal growth, this may be more difficult to measure because the phosphorus will be rapidly removed from the water column and sequestered inside living organisms.

All of the above indirect indicators of eutrophication are present in Lake Whatcom. Alkalinity concentrations have increased significantly at all sites in near-surface ($\leq$5 m) samples collected during periods of lake stratification (Figure 13, page 39).[10] Near-surface pH has increased and deep water pH has decreased at all sites (Figures 14–15, pages 40–41). Total phosphorus has increased significantly at Sites 3–4 (Figure 16, page 42). This represents a serious concern for Lake Whatcom because phosphorus availability is the main factor limiting algal growth in the lake. Increasing phosphorus concentrations are the most likely cause of the increased algal growth in Lake Whatcom. While no significant trends were found at Sites 1–2, this was partly due to higher variability in the 1988–1993 data, which masks trends in 1994–2004. As with chlorophyll, our analytical methods were modified in 1994, which reduced within-sample variability and resulted in a lower detection limit (from $\sim$5 μg-P/L to 1–2 μg-P/L). When the 1994–2004 data were analyzed, total phosphorus was significantly correlated with year at all sites. Coupled with increasing algal growth in the lake, we can see decreasing concentrations of near-surface dissolved inorganic nitrogen (Figure 17, page 43). This is a common pattern in biologically productive lakes (Wetzel, 1983), and is caused by uptake of dissolved inorganic nitrogen by photosynthetic organisms (most heterotrophic organisms get their nitrogen by consuming other organisms). As dissolved inorganic nitrogen levels fall, conditions become increasingly favorable for blooms of N_2-fixing cyanobacteria. In Lake Whatcom, cyanobacteria are

[10] Near-surface and deep water samples collected during lake stratification were used for most trend analyses in order to analyze comparable data sets, as discussed by Matthews, et al., 2004. Annual chlorophyll and plankton data were used because algal blooms may occur when the lake is unstratified.

most common during late summer and early fall, just prior to overturn, at the time when near-surface dissolved inorganic nitrogen levels are lowest.

Site 2: Although Site 2 normally exhibits hypolimnetic oxygen depletion by October, anoxic conditions are usually confined to the deepest samples (>15 m). This portion of the lake is relatively small, and is represented by very few samples in any given year. Because of this, there have not been any significant trends in hypolimnetic oxygen depletion at Site 2. However, many of the indicators of hypolimnetic anoxia are as high or higher at Site 2 compared to Site 1 (Table 10, page 26; Figure B82, page 191). Late summer alkalinity peaks have begun appearing regularly in the bottom samples from Site 2 (Figure B72, page 180). Hypolimnetic nitrate concentrations regularly drop below detection (Figure B87, page 196) and hypolimnetic phosphorus concentrations regularly spike in October (Figure B102, page 211).

2.4.3 Drinking water trends

Alum dose: Water from Lake Whatcom undergoes a series of treatments before it is distributed as drinking water. Part of the treatment process involves adding aluminum sulfate (alum) to help remove small particles, including algae and other microorganisms. Alum reacts with natural alkalinity (calcium and magnesium bicarbonates) in the raw water to form a floc that traps small particles, making the particles easier to remove during the filtration process (Viessman and Hammer, 1985). One of the expected implications of increasing algal growth in Lake Whatcom is that the alum dose will need to be increased to handle the additional algae (particles) in the raw water.

Concurrent with the increasing trophic level in Lake Whatcom, the City of Bellingham has observed an increase in the amount of chemicals required to treat Bellingham's drinking water. Alum dose had the best linear relationship with time (Figure 18, page 44), especially during the months of May, August, October, and November (Figure 19, page 45). These months are often associated with diatom or cyanobacteria blooms in the lake.

As described in Section 2.4.2, Lake Whatcom phytoplankton counts have increased over time, particularly Cyanophyta (bluegreen "algae" or or cyanobacteria) and Chrysophyta (yellow-green algae, primarily diatoms, *Dinobryon*, and *Mallomonas*). These two groups of phytoplankton are often associated with water treatment problems. The best predictor of alum dose was Cyanophyta (Figure 20, page 46). Cyanophyta are increasingly abundant in Lake Whatcom, with peak densities in late summer and early fall. Comparisons between annual and summer/fall alum trends and Cyanophyta densities shows the close relationship between these variables (Figure 21, page 47).

Changes in the City's operational goals for treated drinking water may also have influenced alum dose over time. During the period of record in this report (1992-2004), the City has had three different operational goals for particle levels in treated water.[11] From 1992–1998, the City used a turbidity goal of 0.1 NTU. In 1999, the City began using particle counts rather than turbidity, with the goal of maintaining fewer than 10 particles/mL for particles larger than 2 μm (*Giardia*, *Cryptosporidium*, and most algae are larger than 2 μm). In 2002, the computer system that controls the water treatment plant was linked directly to the particle counter, making it easier to coordinate water treatment with the particle count goals. In November 2003, the particle goals were *increased* to 20 particles/mL in the >2 μm range. This was done to match EPA's Partnership for Safe Water goals (http://www.eap.gov/safewater/psw/psw.html), to increase water production, and to decrease drinking water treatment costs. This should have resulted in lower alum doses, beginning in November 2003, but as illustrated in Figure 18, no such reduction has occurred.

Disinfection by-products: As algal densities increase, we expect to see an increase in trihalomethanes (THMs), which are disinfection by-products created during the chlorination step in drinking water treatment. Algae excrete dissolved organic carbon into water, which, along with other decaying organic material, can react with chlorine to form chloroform and other 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 best approach is to prevent excessive algal growth in the source water.

During the 2003/2004 sampling period, the quarterly averages for THMs in the Bellingham water distribution system ranged from 0.025–0.041 mg/L, well below the recommended maximum THMs concentration for treated drinking water (0.080 mg/L). As illustrated in Figure 22 (page 48), THMs are increasing in Bellingham's treated drinking water, particularly during the fall (third quarter). Fall quarter total organic carbon concentrations at the Intake also shows a signif-

[11] Personal communications, City of Bellingham Public Works Department

icant regression with time (Figure 23, page 49). Haloacetic acids (another important disinfection by-product) do not appear to be increasing with time (Figure 22) and do not have a statistically significant regression with time. Unlike THMs, which are predictable based on algal concentration and chlorine dose, the formation of HAAs is not well correlated with algal concentration or chlorine dose (Sung, et al., 2000).

	2003			2004									
Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Location
DO - Hydrolab	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, Intake - every 1 m;
pH - Hydrolab	•	•	•		•		•	•	•	•	•	•	Sites 3, 4 - every 1 m to 10 m
Temp - Hydrolab	•	•	•		•		•	•	•	•	•	•	then every 5 m;
Cond - Hydrolab	•	•	•		•		•	•	•	•	•	•	Gatehouse
Secchi depth	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake
Ammonia	•	•	•		•		•	•	•	•	•	•	Sites 1, 2 - 0.3, 5, 10, 15, 20 m;
Nitrite/Nitrate	•	•	•		•		•	•	•	•	•	•	Intake - 0.3, 5, 10 m;
Total Nitrogen	•	•	•		•		•	•	•	•	•	•	Site 3 - 0.3, 5, 10, 20, 40, 60,
Soluble Phosphate	•	•	•		•		•	•	•	•	•	•	80 m;
Total Phosphorus	•	•	•		•		•	•	•	•	•	•	Site 4 - 0.3, 5, 10, 20, 40, 60,
Alkalinity	•	•	•		•		•	•	•	•	•	•	80, 90 m;
Turbidity	•	•	•		•		•	•	•	•	•	•	Gatehouse
Total Arsenic†					•						•		Sites 1, 2, 3, 4, Intake -
Total Cadmium					•						•		0.3 m and bottom only
Total Chromium					•						•		
Total Copper					•						•		
Total Iron					•						•		
Total Lead					•						•		
Total Mercury					•						•		
Total Nickel					•						•		
Total Zinc					•						•		
Total O. Carbon					•						•		Sites 1, 2, 3, 4, Intake - 0.3 m and bottom only
Chlorophyll	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4 - 0.3, 5, 10, 15, 20 m; Intake - 0.3, 5, 10 m
Plankton	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake; 5 m
Bacteria	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake, Bloedel-Donovan; 0.3 m
H_2S - opt										•	•	•	Sites 1, 2 - 10, 15, 20 m

†Twenty-four additional metals are included as part of the standard AmTest analytical procedure.

Table 1: Lake Whatcom 2003/2004 lake monitoring schedule.

Parameter	Method	Historic DL†	2003/2004 MDL†	Sensitivity or Confidence limit
Conductivity-field	Hydrolab (1997), field meter	–	–	$\pm$ 2 μS/cm
Conductivity-lab	APHA (1998) #2510, low-level, SOP-LW-9	–	–	$\pm$ 2.2 μS/cm
Dissolved oxygen-field	Hydrolab (1997), field meter	–	–	$\pm$ 0.1 mg/L
Dissolved oxygen-lab	APHA (1998) #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 (1998) #4500-H^+, low-ionic, SOP-LW-8	–	–	$\pm$ 0.1 pH unit
Temperature	Hydrolab (1997), field meter	–	–	$\pm$ 0.1° C
Alkalinity	APHA (1998) #2320, low level, SOP-IWS-15	–	–	$\pm$ 0.5 mg/L
Discharge	Lind (1985), rating curve, SOP-IWS-6	–	–	–
Secchi disk	Lind (1985)	–	–	$\pm$ 0.1 m
T. suspended solids	APHA (1998) #2540 D, gravimetric, SOP-LW-22	2 mg/L	2.9 mg/L	$\pm$ 2.3 mg/L
Turbidity	APHA (1998) #2130, nephelometric, SOP-LW-11	–	–	$\pm$ 0.2 NTUs
Ammonia	APHA (1998) #4500-NH_3 F., phenate, SOP-LW-21	10 μg-N/L	2.3 μg-N/L	$\pm$ 3.4 μg-N/L
Nitrite/nitrate	APHA (1998) #4500-NO_3 I., Cd reduction, SOP-IWS-19	20 μg-N/L	7.5 μg-N/L	$\pm$ 9.2 μg-N/L
T. nitrogen	APHA (1998) #4500-N C., persulfate digestion, SOP-IWS-19	100 μg-N/L	9.8 μg-N/L	$\pm$ 12.3 μg-N/L
Sol. phosphate	APHA (1998) #4500-P G., ascorbic acid, SOP-IWS-19	5 μg-P/L	2.8 μg-P/L	$\pm$ 2.2 μg-P/L
T. phosphorus	APHA (1998) #4500-P H., persulfate digestion, SOP-IWS-19	5 μg-P/L	2.5 μg-P/L	$\pm$ 2.5 μg-P/L
Chlorophyll	APHA (1998) #10200 H, acetone, SOP-IWS-16	–	–	$\pm$ 0.1 mg/m^3
Plankton	Lind (1985), Schindler trap	–	–	–
E. coli (City)	APHA (1998) #9213 D, membrane filter	2 cfu/100 mL	–	–
Fecal coliform (City)	APHA (1998) #9222 D, membrane filter	2 cfu/100 mL	–	–

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

Table 2: Summary of IWS and City of Bellingham analytical methods.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	18.0	19.5	20.2	27.1	2.2	50
Conductivity (μS/cm)	52.4	57.0	57.0	71.6	3.7	168
Dissolved oxygen (mg/L)	0.3	9.5	8.1	11.7	3.6	210
pH	6.3	7.3	7.3	8.9	0.6	178
Temperature (°C)	5.8	10.4	11.9	22.7	4.5	210
Turbidity (NTU)	0.3	0.9	1.1	9.0	1.3	50
Nitrogen - ammonia (μg-N/L)	<10	13.0	43.3	333.8	73.8	50
Nitrogen - nitrate/nitrite (μg-N/L)	<10	211.0	204.5	379.5	120.2	50
Nitrogen - total (μg-N/L)	243.5	423.1	397.9	512.7	79.8	50
Phosphorus - soluble (μg-P/L)	<5	<5	<5	11.2	1.7	45
Phosphorus - total (μg-P/L)	<5	9.5	12.2	65.7	11.0	50
Chlorophyll (mg/m^3)	0.3	2.5	2.9	8.8	1.9	50
Secchi depth (m)	2.5	4.7	4.9	6.9	1.3	8
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	2	na	10
Coliforms - E. coli (cfu/100 mL)‡	<1	1	1	5	na	10

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

Table 3: Summary of Site 1 ambient water quality data, Oct. 2003 – Sept. 2004.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.4	18.5	18.7	20.3	0.7	29
Conductivity (μS/cm)	51.3	54.6	54.2	57.0	1.8	88
Dissolved oxygen (mg/L)	8.2	9.9	9.9	11.9	1.1	110
pH	7.2	7.7	7.8	8.5	0.4	93
Temperature (°C)	6.5	15.2	14.5	22.3	5.2	110
Turbidity (NTU)	0.4	0.6	0.6	1.1	0.2	30
Nitrogen - ammonia (μg-N/L)	$<$10	$<$10	$<$10	19.1	4.6	30
Nitrogen - nitrate/nitrite (μg-N/L)	91.3	246.1	252.4	399.7	99.0	30
Nitrogen - total (μg-N/L)	289.7	407.5	396.9	503.1	74.6	30
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	7.4	1.3	27
Phosphorus - total (μg-P/L)	$<$5	6.7	6.8	11.5	2.4	30
Chlorophyll (mg/m^3)	0.9	2.1	2.5	7.3	1.6	30
Secchi depth (m)	3.8	4.8	4.9	6.6	0.8	10
Coliforms - fecal (cfu/100 mL)‡	$<$1	1	2	6	na	10
Coliforms - E. coli (cfu/100 mL)‡	$<$1	1	1	3	na	10

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

Table 4: Summary of Intake ambient water quality data, Oct. 2003 – Sept. 2004.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.3	18.6	18.8	26.0	1.5	50
Conductivity (μS/cm)	51.1	54.3	54.5	72.5	2.9	168
Dissolved oxygen (mg/L)	0.4	9.8	9.0	11.7	2.7	210
pH	6.3	7.4	7.4	8.2	0.5	178
Temperature (°C)	6.6	11.4	12.8	22.5	4.7	210
Turbidity (NTU)	0.3	0.6	0.7	2.0	0.3	50
Nitrogen - ammonia (μg-N/L)	$<$10	$<$10	28.9	340.0	64.6	50
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	259.8	270.0	404.5	102.3	50
Nitrogen - total (μg-N/L)	298.6	442.8	427.7	556.0	74.6	50
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	10.0	1.5	45
Phosphorus - total (μg-P/L)	$<$5	9.4	10.2	40.9	8.5	50
Chlorophyll (mg/m^3)	0.3	1.8	2.1	6.0	1.2	50
Secchi depth (m)	3.7	5.1	5.0	6.3	0.7	10
Coliforms - fecal (cfu/100 mL)‡	$<$1	1	1	3	na	10
Coliforms - E. coli (cfu/100 mL)‡	$<$1	1	1	4	na	10

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

Table 5: Summary of Site 2 ambient water quality data, Oct. 2003 – Sept. 2004.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.2	17.9	18.1	19.6	0.6	69
Conductivity (μS/cm)	52.4	54.3	54.4	57.2	1.3	148
Dissolved oxygen (mg/L)	6.5	9.6	9.6	11.5	0.9	248
pH	6.6	7.4	7.5	9.1	0.6	211
Temperature (°C)	6.8	8.0	10.7	22.1	4.9	248
Turbidity (NTU)	0.2	0.4	0.5	1.6	0.3	69
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	35.0	6.6	68
Nitrogen - nitrate/nitrite (μg-N/L)	150.1	389.1	342.1	426.8	91.4	69
Nitrogen - total (μg-N/L)	281.6	482.8	453.5	520.7	69.1	69
Phosphorus - soluble (μg-P/L)	<5	5.3	5.1	8.6	1.5	62
Phosphorus - total (μg-P/L)	<5	6.2	6.8	22.6	4.2	69
Chlorophyll (mg/m^3)	0.3	1.9	2.1	6.8	1.4	50
Secchi depth (m)	4.7	6.1	6.1	9.0	1.2	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	4	na	10
Coliforms - E. coli (cfu/100 mL)‡	<1	1	1	3	na	10

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

Table 6: Summary of Site 3 ambient water quality data, Oct. 2003 – Sept. 2004.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.2	17.8	18.0	19.6	0.5	80
Conductivity (μS/cm)	51.4	54.2	54.2	56.6	1.5	162
Dissolved oxygen (mg/L)	8.4	9.7	9.9	11.9	0.8	270
pH	6.7	7.3	7.4	8.4	0.5	232
Temperature (°C)	6.8	7.8	10.4	21.8	4.7	270
Turbidity (NTU)	0.2	0.4	0.4	1.4	0.2	80
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	31.4	5.6	79
Nitrogen - nitrate/nitrite (μg-N/L)	157.4	402.6	356.5	432.2	87.3	80
Nitrogen - total (μg-N/L)	287.2	483.8	461.6	532.8	62.6	80
Phosphorus - soluble (μg-P/L)	<5	5.2	5.0	8.8	1.5	72
Phosphorus - total (μg-P/L)	<5	5.8	6.5	25.6	4.0	80
Chlorophyll (mg/m^3)	0.3	1.7	1.9	5.8	1.1	50
Secchi depth (m)	4.6	5.8	5.8	6.7	0.7	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	2	na	10
Coliforms - E. coli (cfu/100 mL)‡	<1	1	1	2	na	10

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

Table 7: Summary of Site 4 ambient water quality data, Oct. 2003 – Sept. 2004.

Site	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 5, 2004	<0.01	<0.0005	<0.001	0.002	0.032	<0.0002	<0.005	<0.001	0.004
Site 1	20	Feb 5, 2004	<0.01	<0.0005	<0.001	0.004	0.036	<0.0002	<0.005	<0.001	0.006
Intake	0	Feb 5, 2004	<0.01	<0.0005	<0.001	<0.001	0.009	<0.0002	<0.005	<0.001	0.004
Intake	10	Feb 5, 2004	<0.01	<0.0005	0.001	0.002	0.020	<0.0002	<0.005	<0.001	0.006
Site 2	0	Feb 5, 2004	<0.01	<0.0005	<0.001	<0.001	0.028	<0.0002	<0.005	<0.001	0.006
Site 2	20	Feb 5, 2004	<0.01	<0.0005	<0.001	0.004	0.025	0.0002	<0.005	<0.001	0.014
Site 3	0	Feb 8, 2004	<0.01	<0.0005	<0.001	0.003	0.079	<0.0002	<0.005	<0.001	<0.001
Site 3	80	Feb 8, 2004	<0.01	<0.0005	<0.001	0.002	0.017	<0.0002	<0.005	<0.001	0.007
Site 4	0	Feb 8, 2004	<0.01	<0.0005	<0.001	0.004	0.036	<0.0002	<0.005	<0.001	0.004
Site 4	90	Feb 8, 2004	<0.01	<0.0005	<0.001	0.002	0.021	<0.0002	<0.005	<0.001	0.014
Site 1	0	Sept 2, 2004	<0.01	<0.0005	<0.001	<0.001	0.022	<0.0002	<0.005	<0.001	<0.001
Site 1	20	Sept 2, 2004	<0.01	<0.0005	<0.001	<0.001	1.300	<0.0002	<0.005	<0.001	<0.001
Intake	0	Sept 2, 2004	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	<0.005	<0.001	<0.001
Intake	10	Sept 2, 2004	<0.01	<0.0005	<0.001	<0.001	0.021	<0.0002	<0.005	<0.001	<0.001
Site 2	0	Sept 2, 2004	<0.01	<0.0005	<0.001	<0.001	0.013	<0.0002	<0.005	<0.001	<0.001
Site 2	20	Sept 2, 2004	<0.01	<0.0005	<0.001	<0.001	1.100	0.0002	<0.005	<0.001	<0.001
Site 3	0	Sept 1, 2004	<0.01	<0.0005	<0.001	<0.001	0.019	<0.0002	<0.005	<0.001	<0.001
Site 3	80	Sept 1, 2004	<0.01	<0.0005	<0.001	<0.001	0.099	<0.0002	<0.005	<0.001	<0.001
Site 4	0	Sept 1, 2004	<0.01	<0.0005	<0.001	<0.001	0.018	<0.0002	<0.005	<0.001	<0.001
Site 4	90	Sept 1, 2004	<0.01	<0.0005	<0.001	<0.001	0.110	<0.0002	<0.005	<0.001	<0.001

Table 8: Lake Whatcom 2003/2004 total metals data. Only the metals specified in the 2003/2004 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix D.7.

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 5, 2004	0	2.1	Sept 2, 2004	0	5.0
	Feb 5, 2004	20	2.2	Sept 2, 2004	20	2.5
Intake	Feb 5, 2004	0	2.5	Sept 2, 2004	0	3.0
	Feb 5, 2004	10	3.1	Sept 2, 2004	10	3.0
Site 2	Feb 5, 2004	0	4.0	Sept 2, 2004	0	2.5
	Feb 5, 2004	20	2.4	Sept 2, 2004	15	2.1
Site 3	Feb 8, 2004	0	1.8	Sept 1, 2004	0	3.1
	Feb 8, 2004	80	5.2	Sept 1, 2004	80	2.3
Site 4	Feb 8, 2004	0	2.3	Sept 1, 2004	0	2.3
	Feb 8, 2004	90	2.7	Sept 1, 2004	90	2.3

Table 9: Lake Whatcom 2003/2004 total organic carbon data.

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

Table 10: Site 1 and Site 2 hypolimnetic ammonia and hydrogen sulfide concentrations, October 1999–2004.

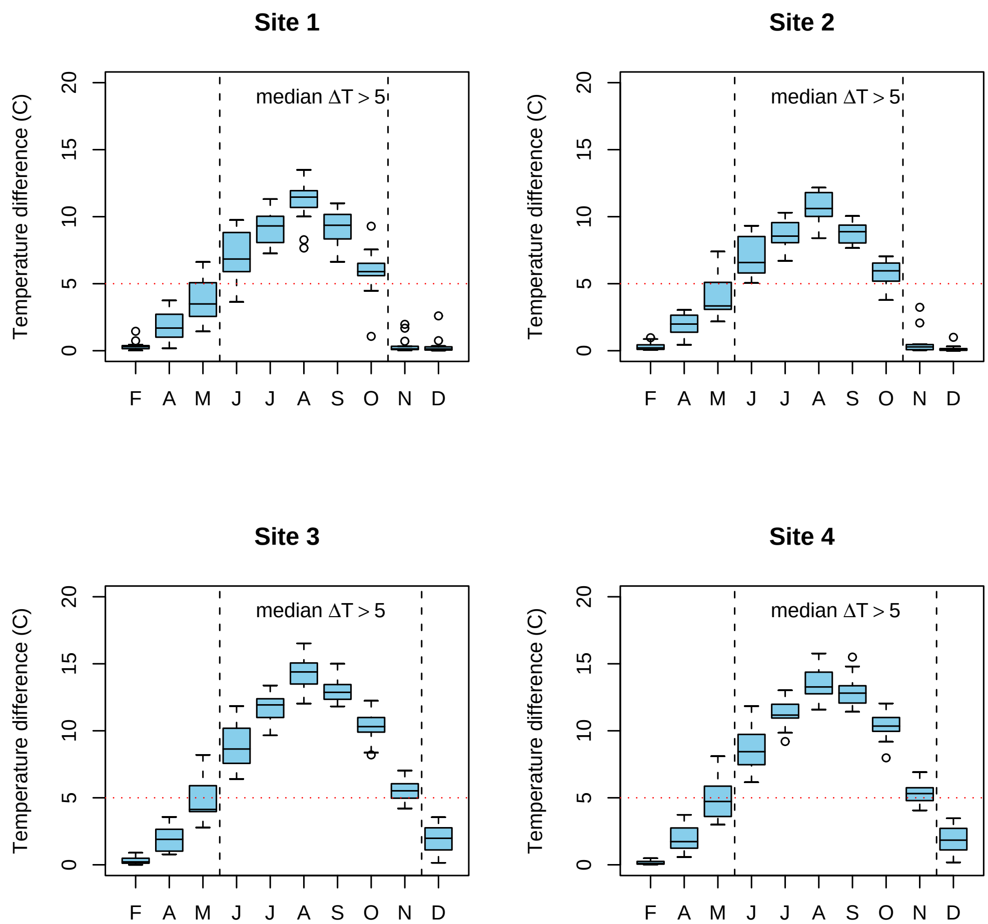

Figure 1: Summary of historic water column temperature differences in Lake Whatcom, 1988–2004. Temperature differences were calculated separately by site for each sampling period ($\Delta T = T_{max} - T_{min}$). Boxes show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value; outliers lie outside 1.5 $\times$ IQR. Horizontal line represents $\Delta T = 5°C$. Vertical lines show approximate stratification period where median $\Delta T > 5°C$.

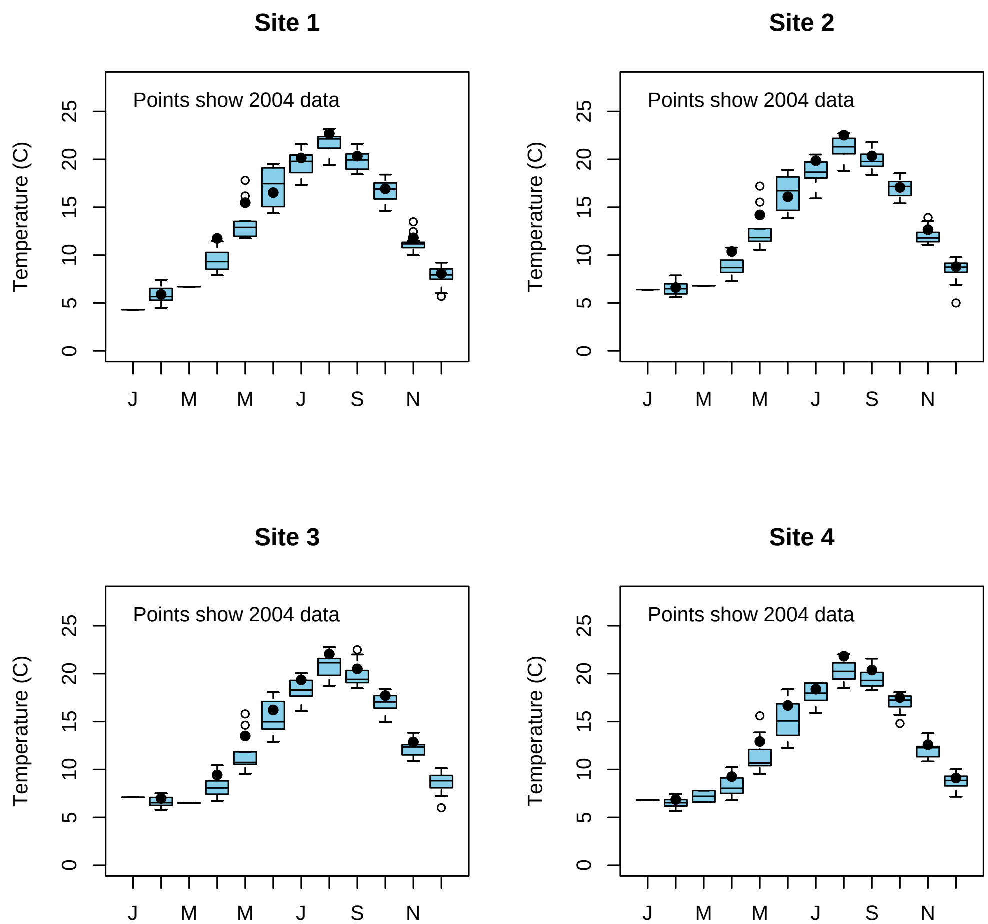

Figure 2: Comparison of 2004 surface water temperatures to boxplots showing 1988–2003 surface temperature medians and ranges (depth <1 m for all sites and years). Boxplots show median and upper/lower quartiles; whiskers extend 1.5 × interquartile range or to minimum value; outliers lie outside 1.5 × IQR. Site 3 was not sampled in December 2004 due to adverse weather conditions.

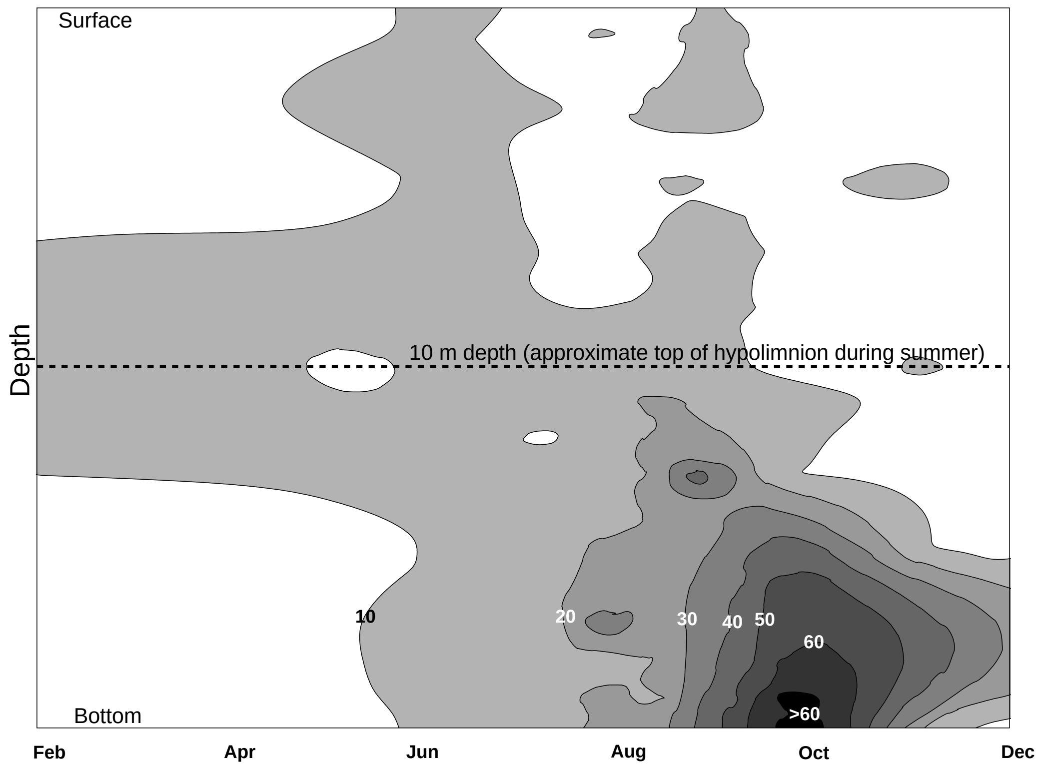

Figure 3: Lake Whatcom total phosphorus concentrations (μg-P/L) at Site 1, February – December, 2003. Isopleth interval = 10 μg-P/L. Redrawn (with permission) from DeLuna, 2004.

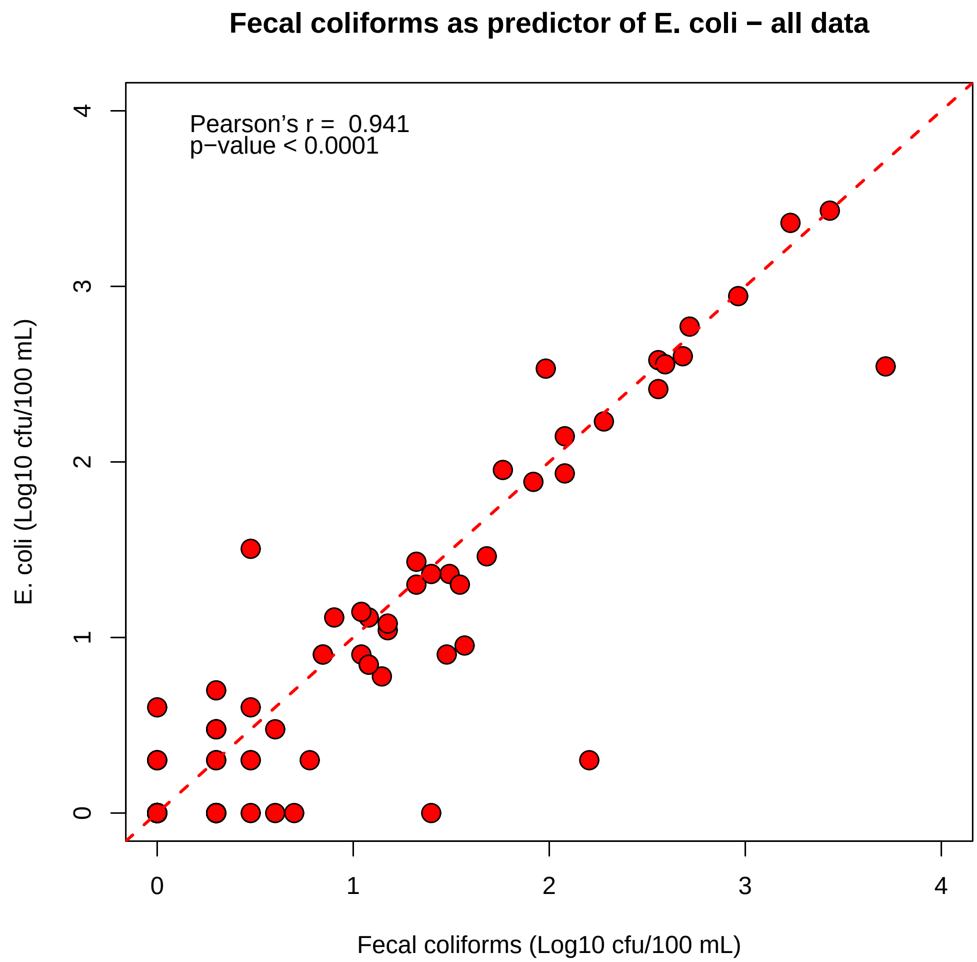

Figure 4: Correlation between fecal coliforms and *E. coli* counts in surface water samples (lake and stream) in the Lake Whatcom watershed, October 2002 – September 2004. Pearson's r correlation was used because the log-transformed data were monotonic-linear and the residuals were homogeneous. The diagonal line was added for reference to show a 1:1 relationship.

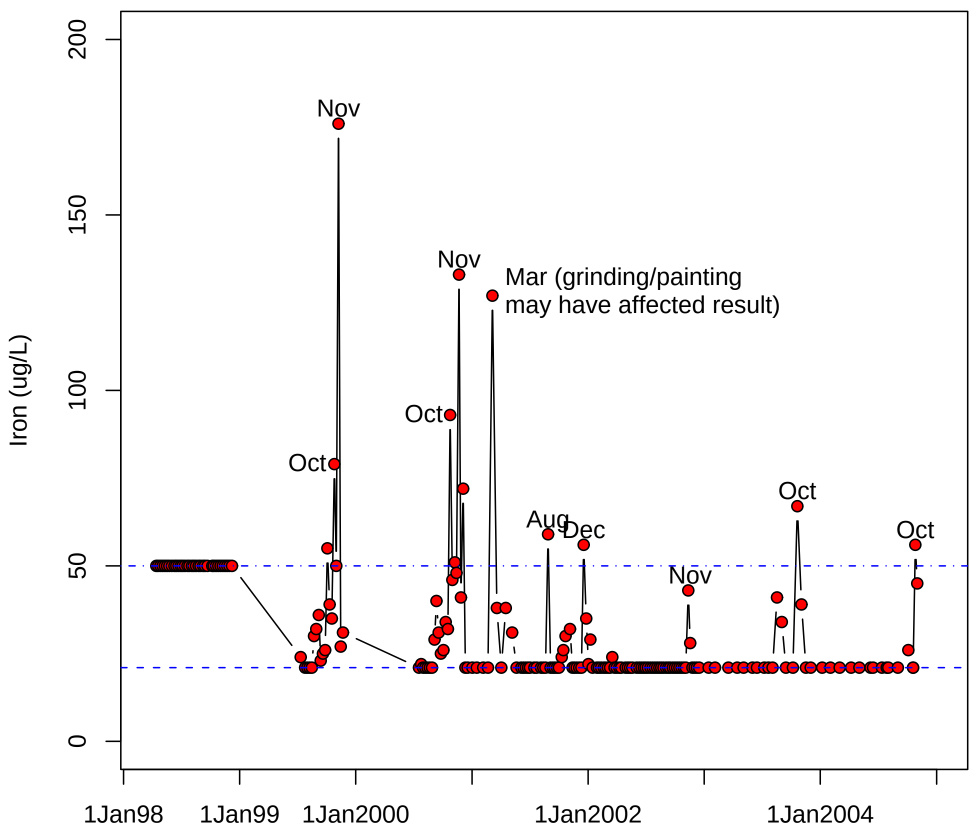

Figure 5: Iron concentration in untreated drinking water measured at the Lake Whatcom gatehouse, 1998–2004. Data were provided by the City of Bellingham Public Works Department.

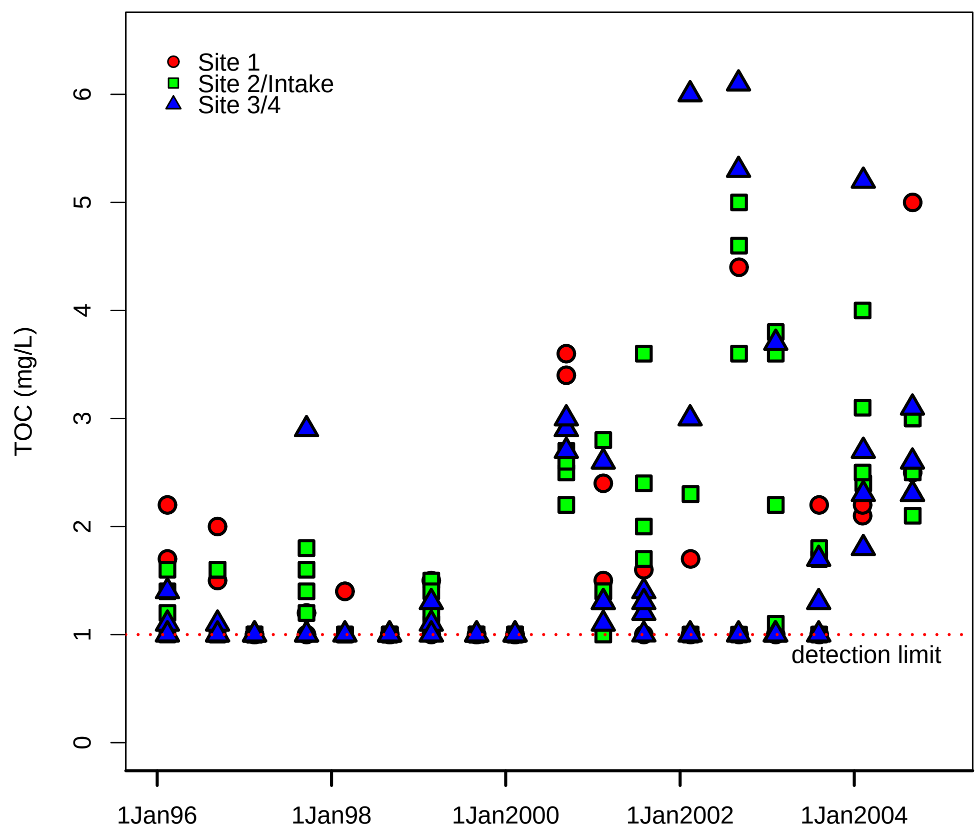

Figure 6: Lake Whatcom total organic carbon concentrations (1996–2004, surface and bottom).

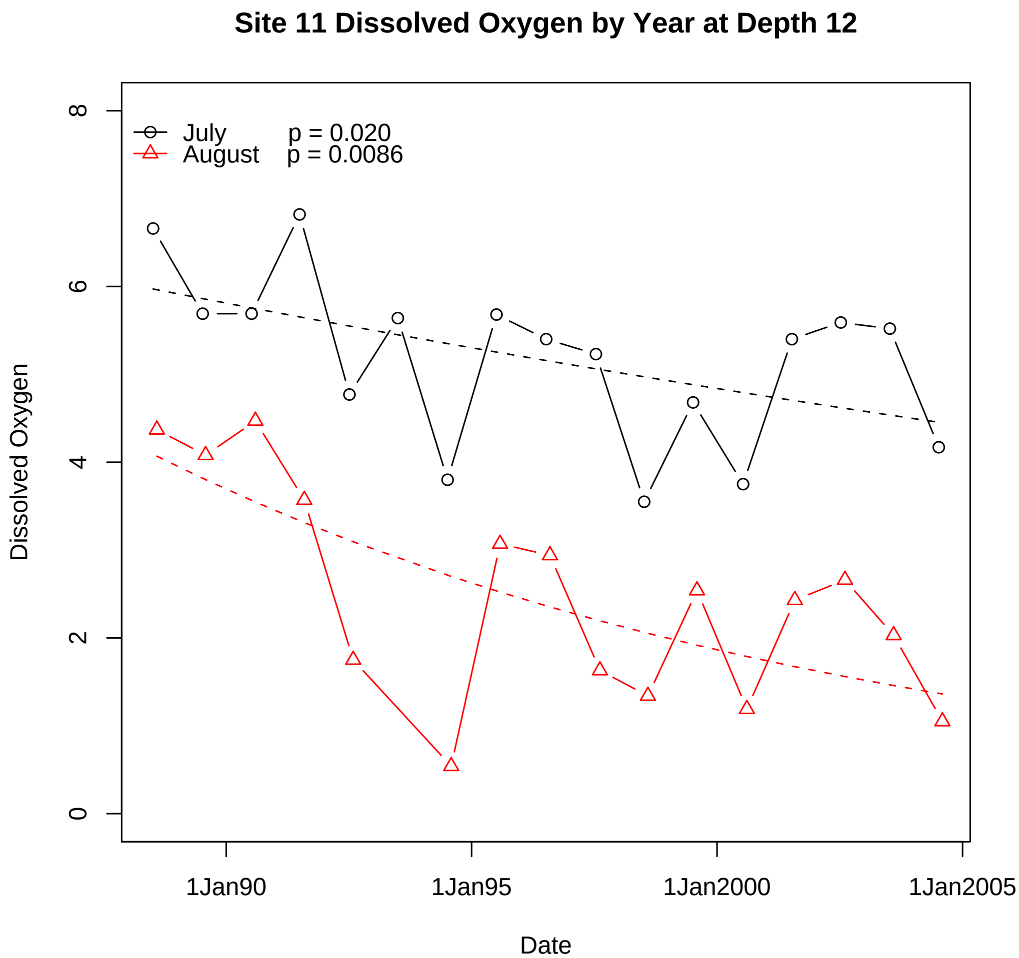

Figure 7: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

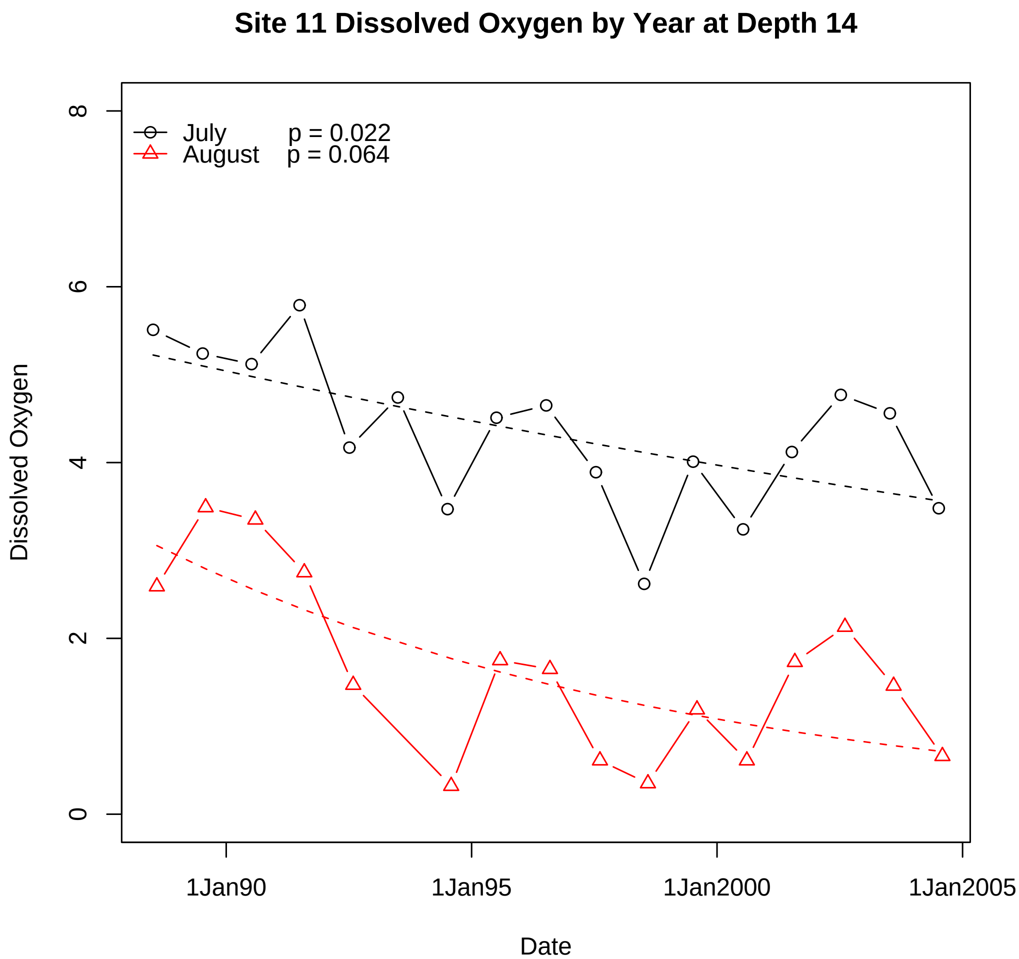

Figure 8: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; the correlation for July was significant at $p < 0.05$.

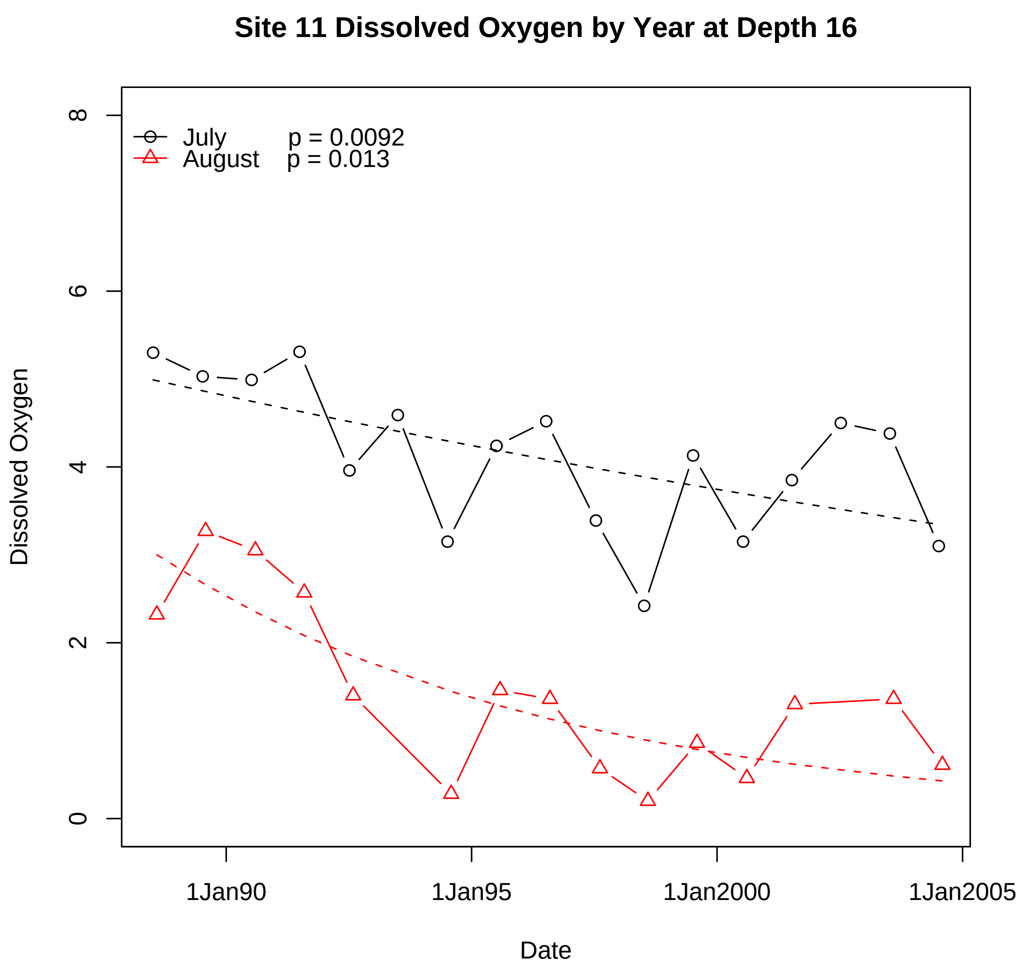

Figure 9: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

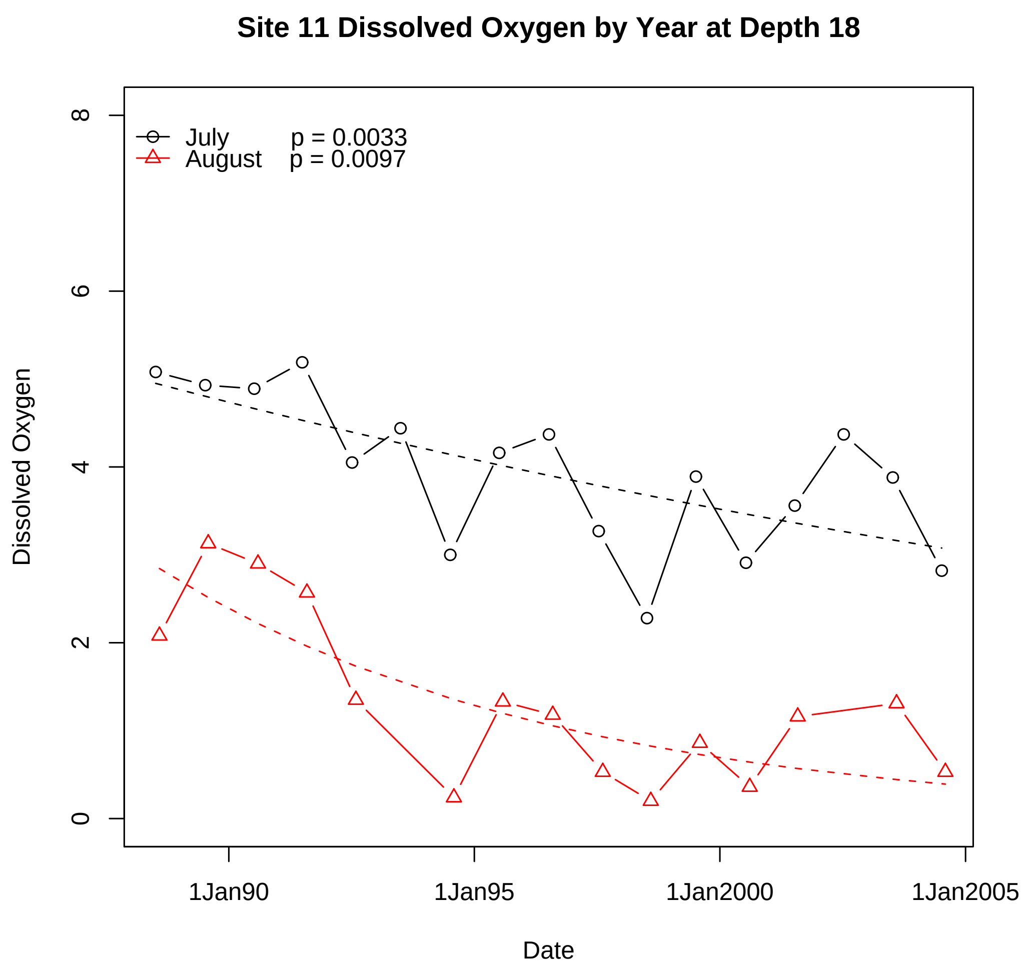

Figure 10: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

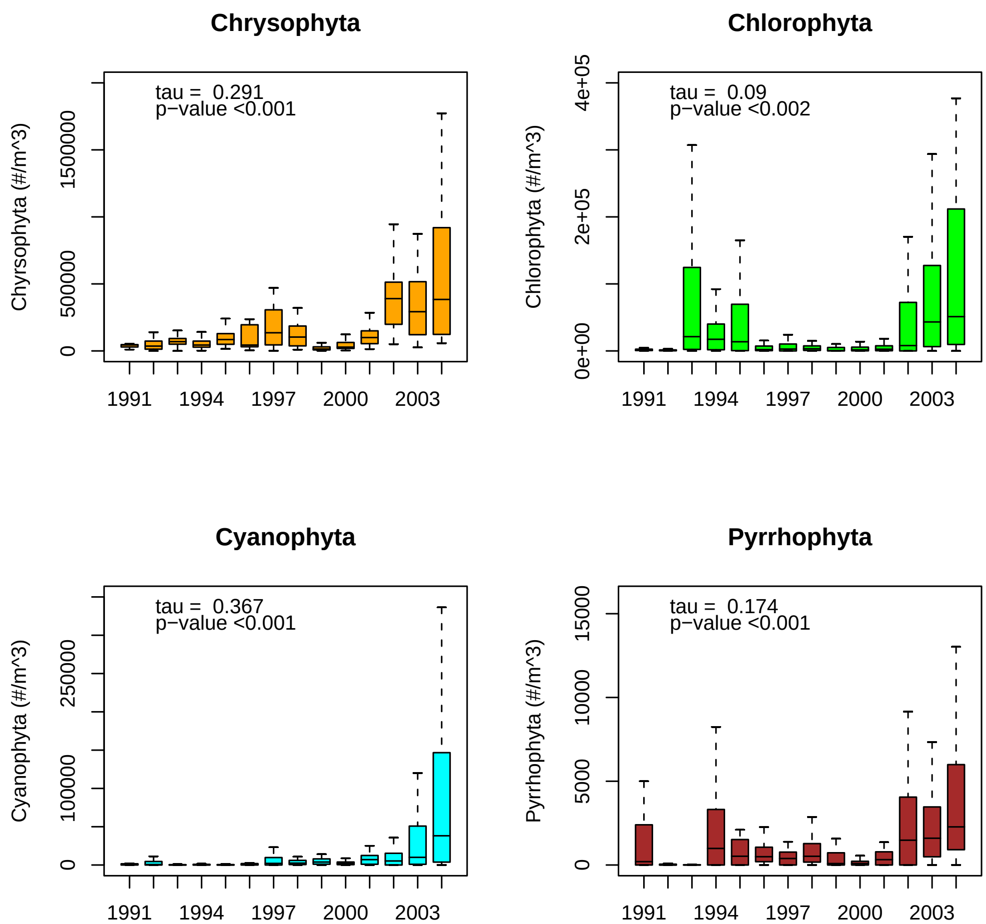

Figure 11: Lake Whatcom annual algal counts vs. year. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value; outliers were not plotted, but were included in the correlation analysis (see text for discussion). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

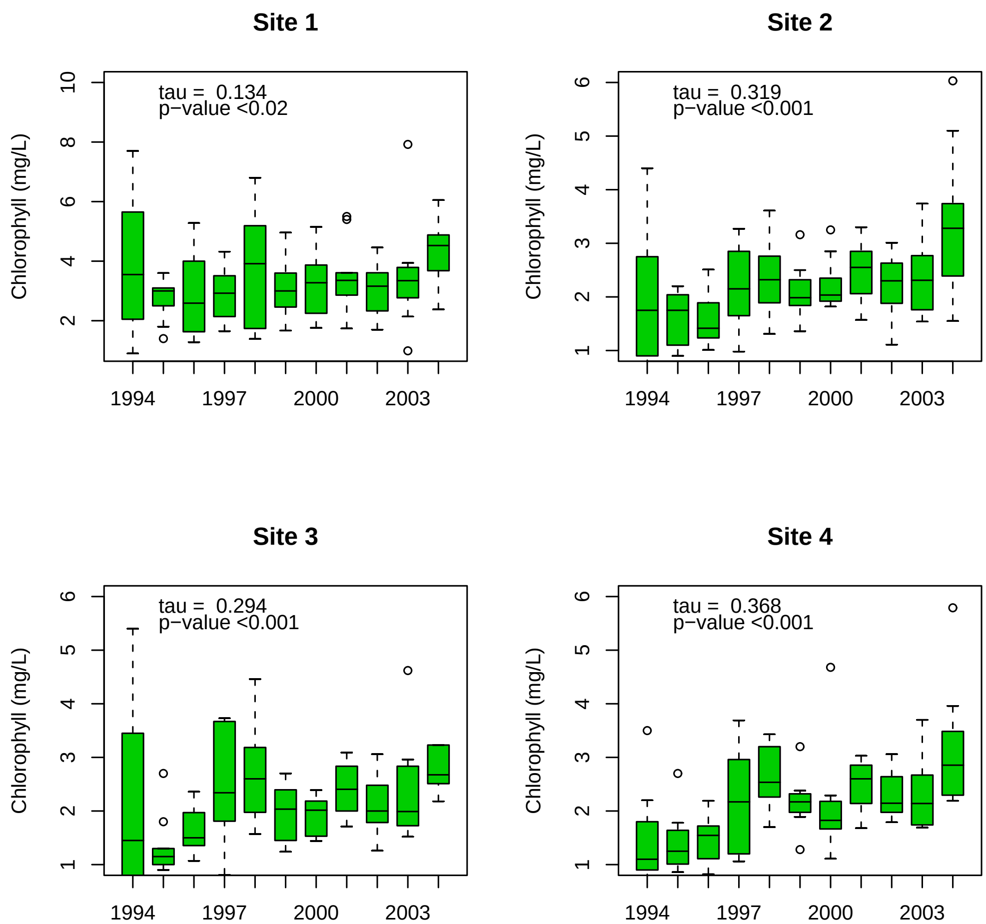

Figure 12: Lake Whatcom annual chlorophyll densities, 1994–2004. A different plotting scale is used for Site 1 because of the higher chlorophyll concentration at this site. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value; extreme outliers were not plotted, but were included in the correlation analysis (see text for discussion). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

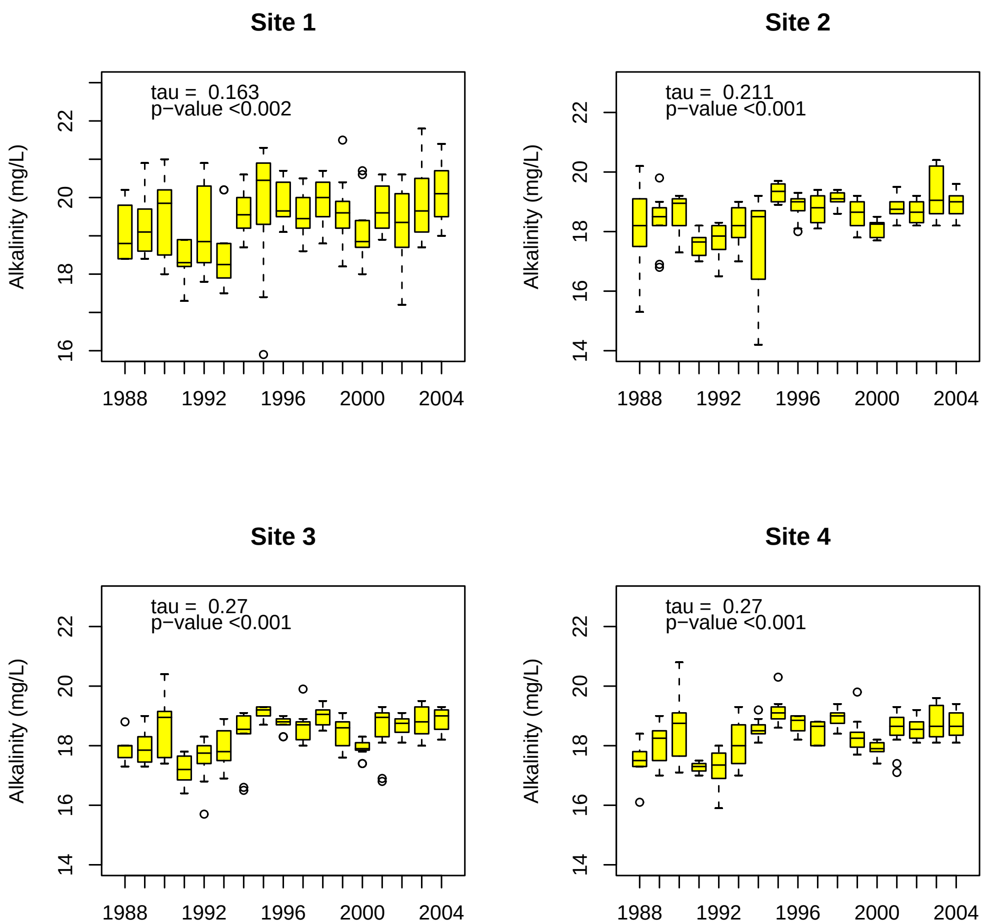

Figure 13: Lake Whatcom near-surface ($\leq$5 m depth) alkalinity concentrations during the period of basin stratification (May-October at Sites 1–2; May-November at Sites 3–4). Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at at $p < 0.05$.

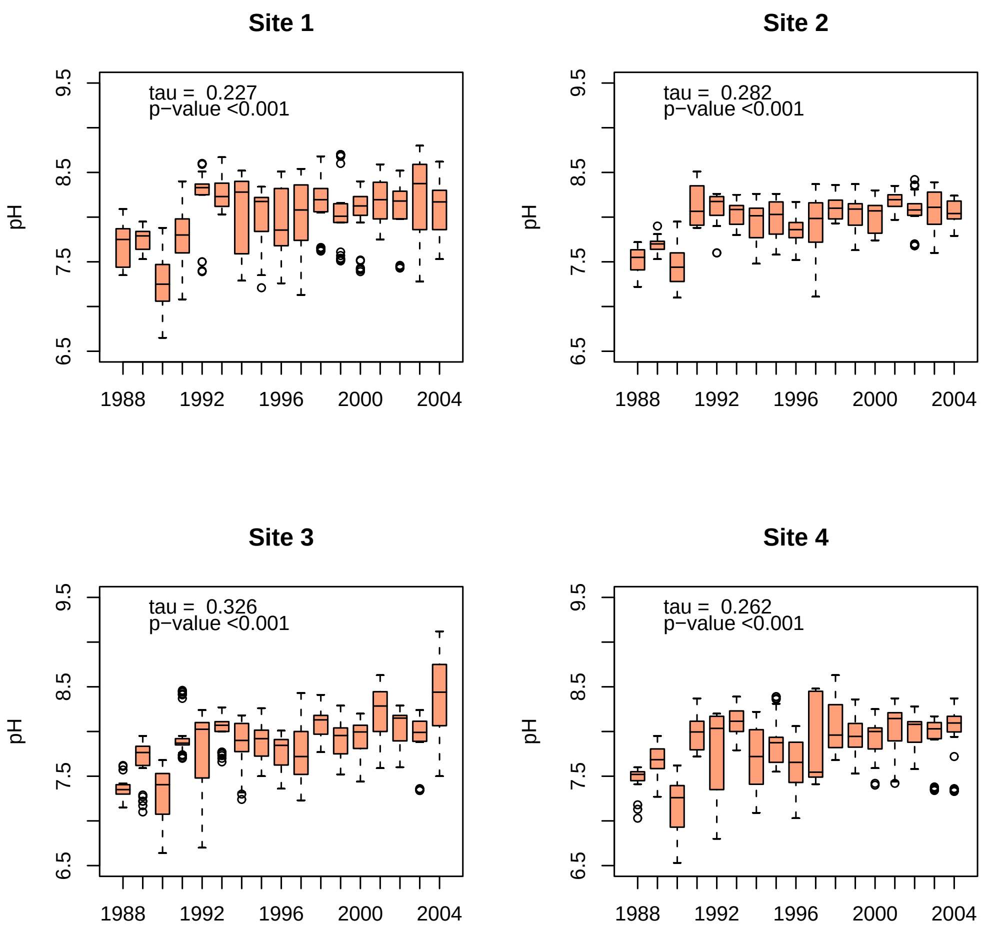

Figure 14: Lake Whatcom near-surface (≤5 m depth) pH values during the period of basin stratification (May-October at Sites 1–2; May-November at Sites 3–4). Boxplots show median and upper/lower quartiles; whiskers extend 1.5 × interquartile range or to minimum value. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations in basin 3 were significant at $p < 0.05$.

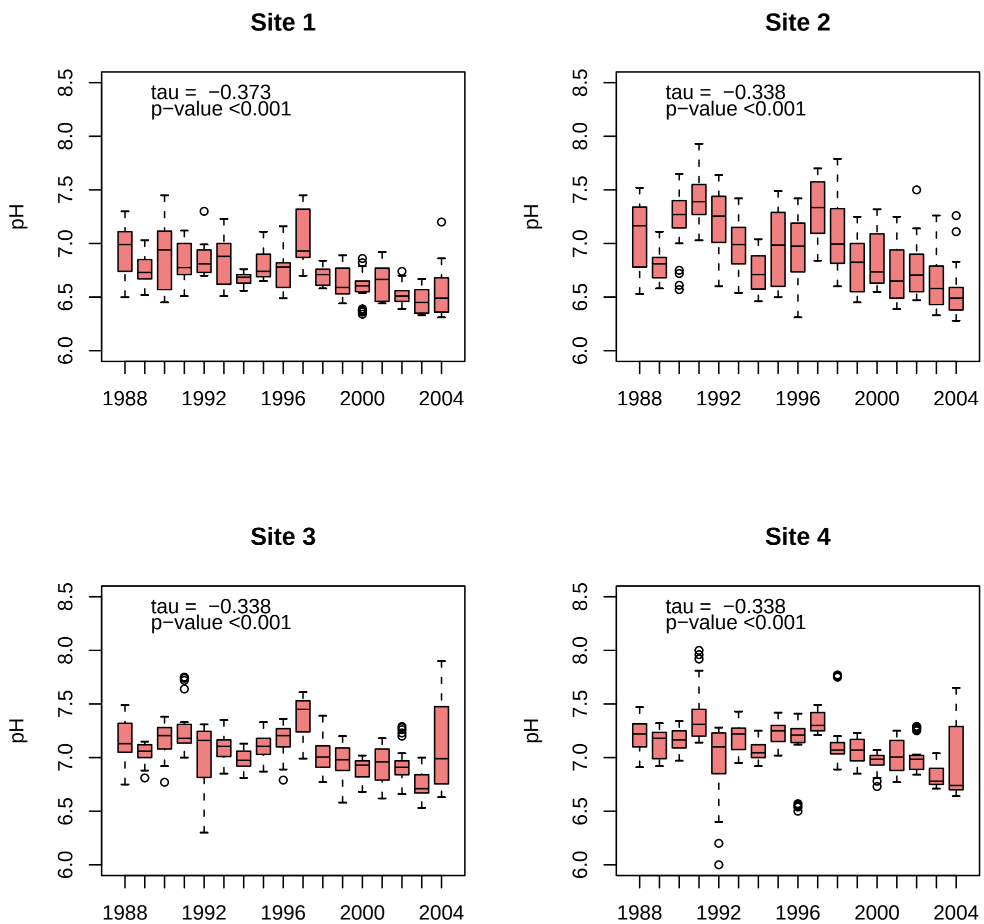

Figure 15: Lake Whatcom deep water ($\geq$ 15 m at Sites 1–2; $\geq$60 m at Sites 3–4) pH values during the period of basin stratification (May-October at Sites 1–2; May-November at Sites 3–4). Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

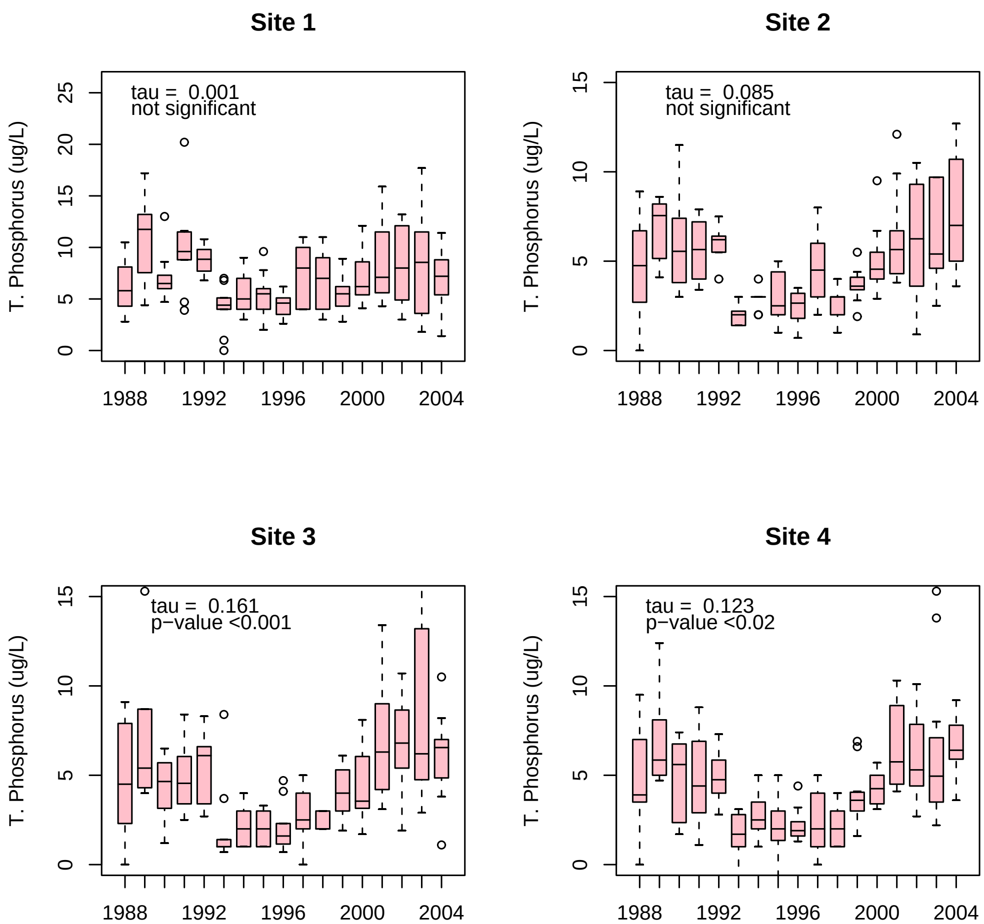

Figure 16: Lake Whatcom near-surface ($\leq$5 m depth) total phosphorus concentrations during the period of basin stratification (May-October at Sites 1–2; May-November at Sites 3–4). A different plotting scale is used for Site 1 because of the higher phosphorus levels at this site. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

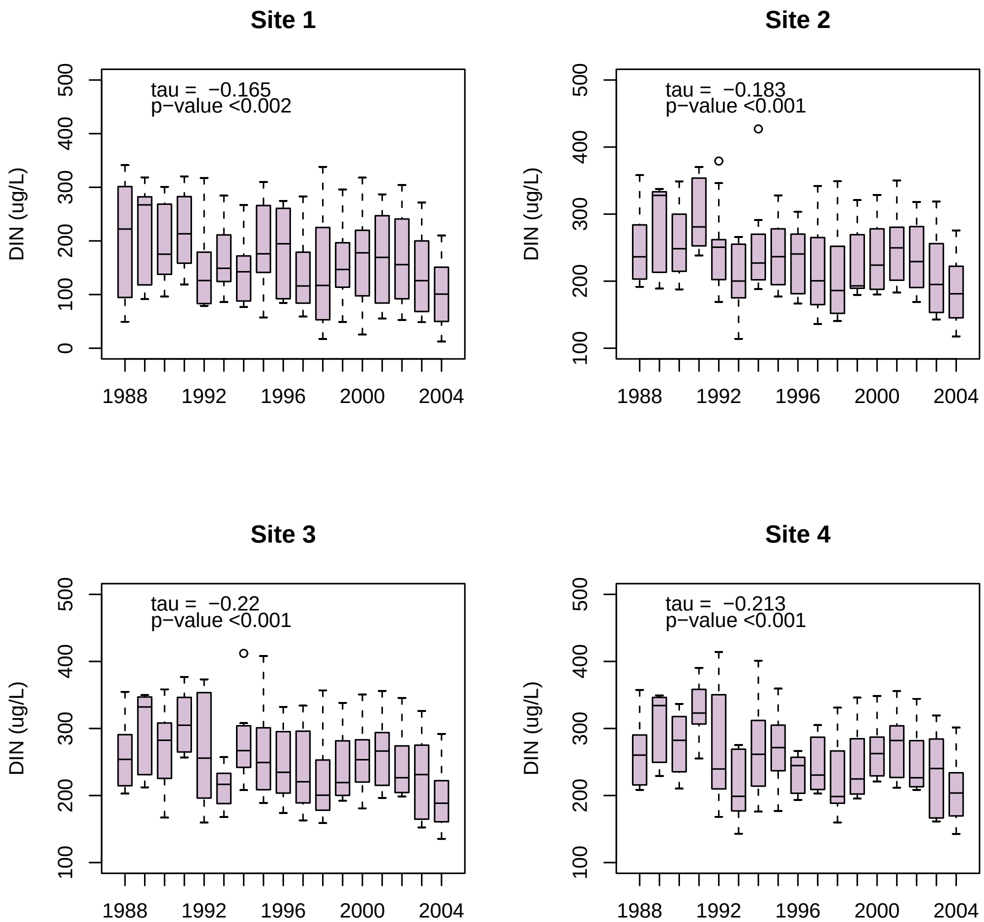

Figure 17: Lake Whatcom near-surface ($\leq$5 m depth) dissolved inorganic nitrogen concentrations (DIN = ammonia, nitrite, and nitrate) during the period of basin stratification (May-October at Sites 1–2; May-November at Sites 3–4). A different plotting scale is used for Site 1 because DIN drops lower at this site. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

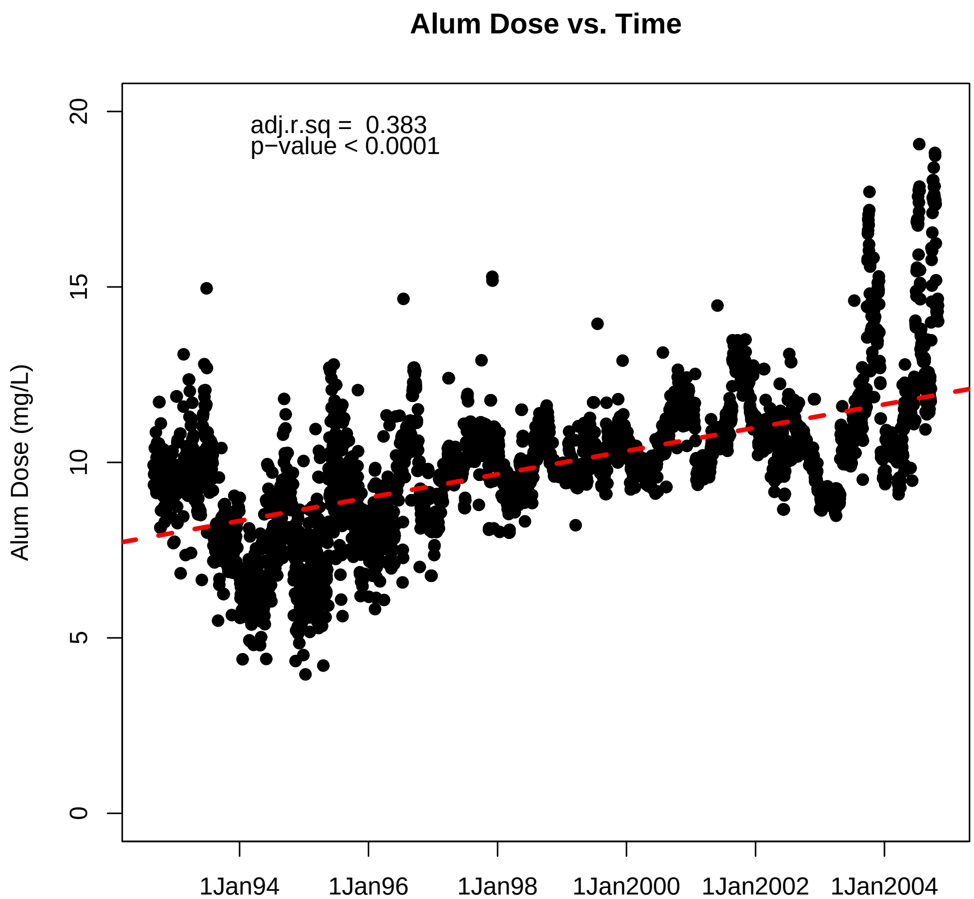

Figure 18: Increase in alum dose in Bellingham's drinking water treatment process over time. Regression is significant with time, despite seasonal, within-year variation. Data provided by City of Bellingham Public Works Department.

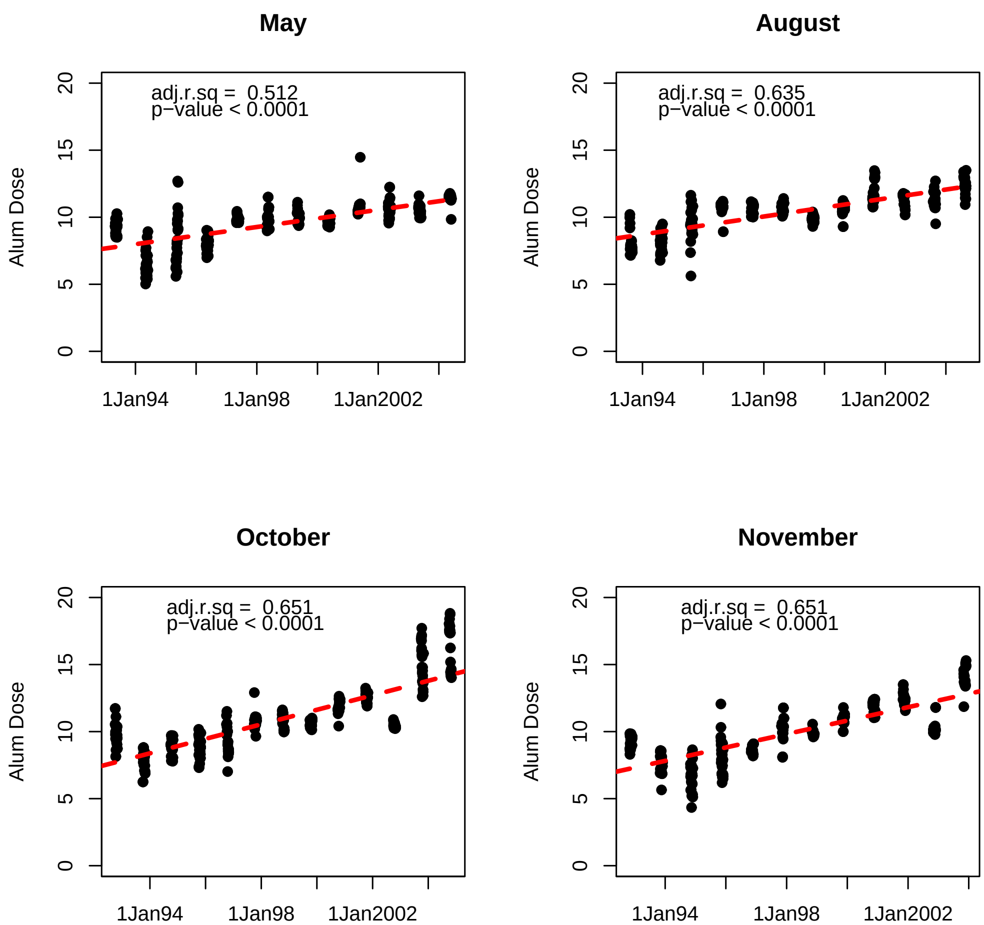

Figure 19: Monthly alum dose vs. time for the months showing the greatest change. All regressions are significant. Data provided by City of Bellingham Public Works Department.

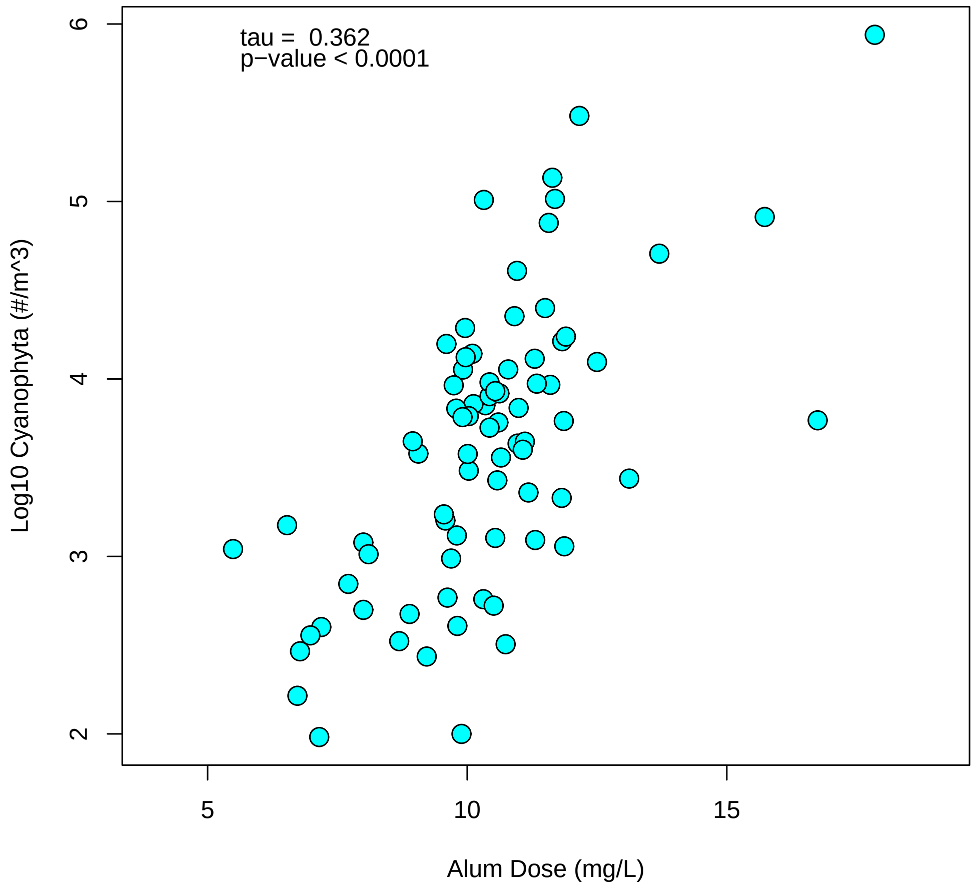

Figure 20: Correlation between Lake Whatcom Cyanophyta (bluegreen "algae") counts and alum dose used to treat Bellingham's drinking water. Cyanophyta counts are plotted on a log10 scale. Alum data were provided by City of Bellingham Public Works Department.

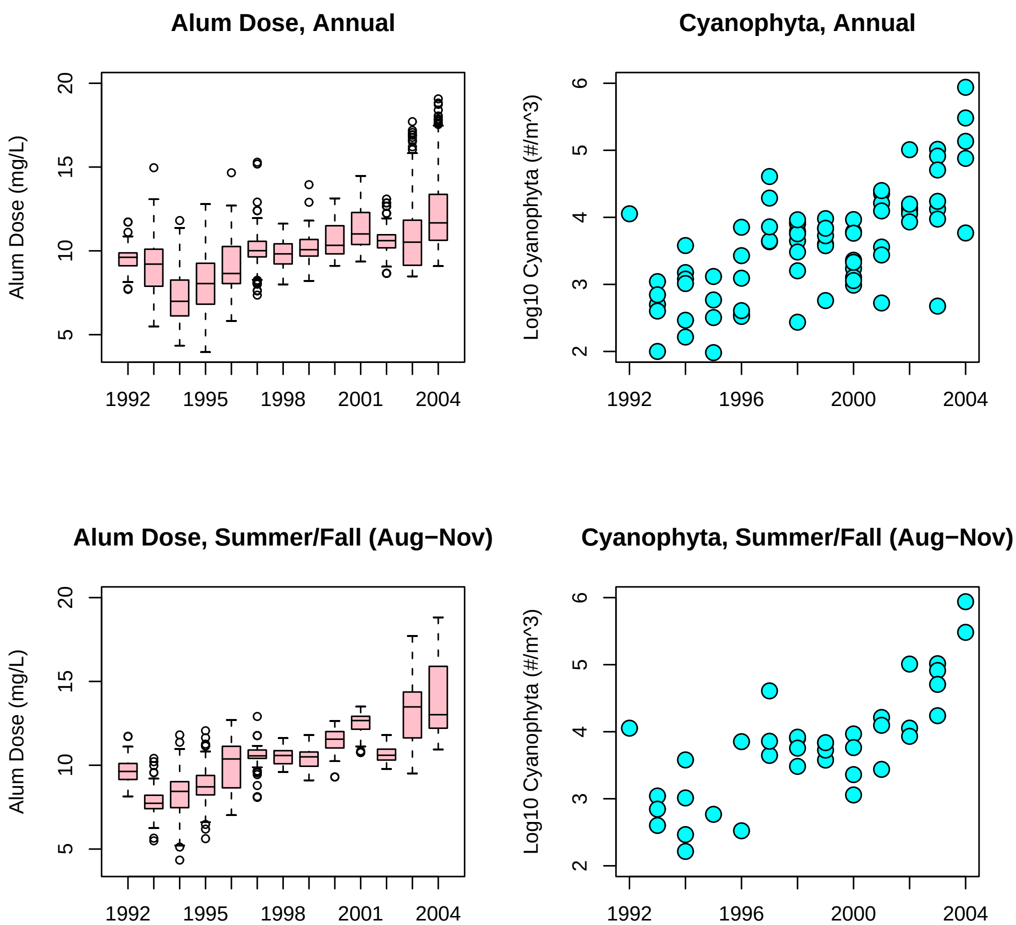

Figure 21: Annual and summer/fall alum dose and Cyanophyta (bluegreen "algae") counts. Cyanophyta counts are plotted on a log10 scale. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value; outliers lie outside 1.5 $\times$ IQR.

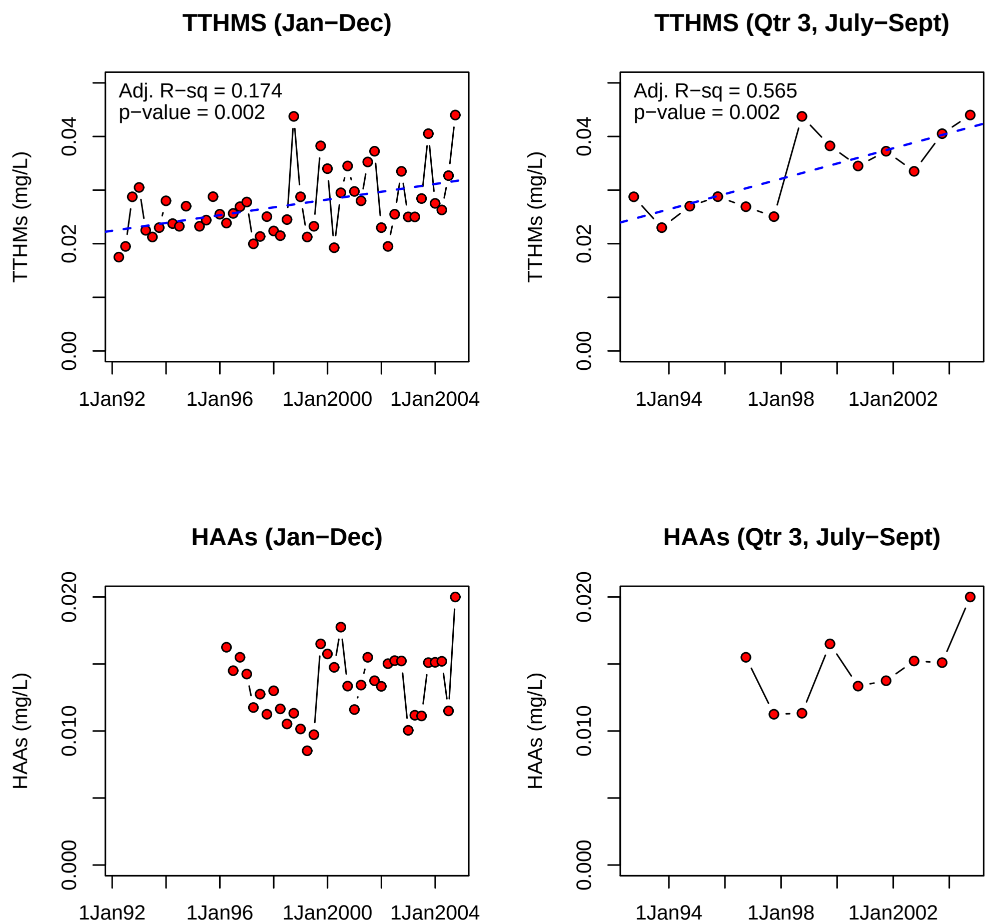

Figure 22: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2004. Regressions for Jan-Dec and Qtr 3 THMs vs. time were significant. Data were provided by the City of Bellingham Public Works Department.

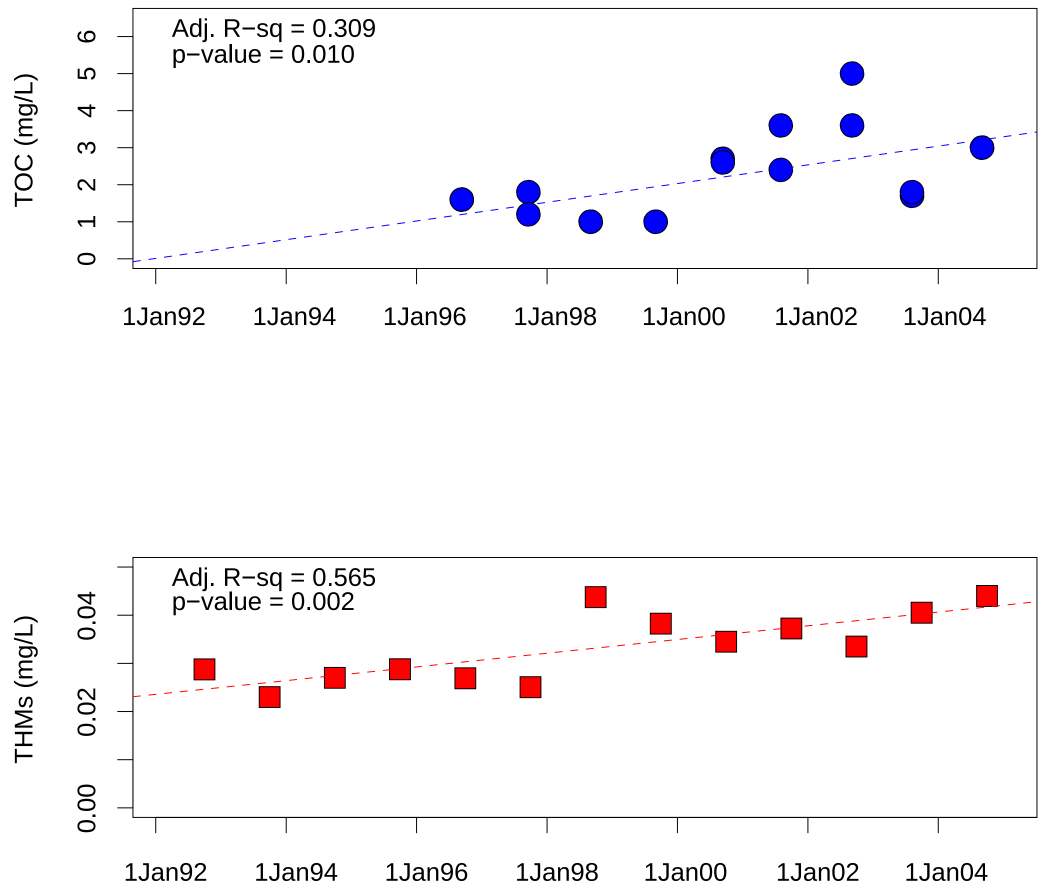

Figure 23: Relationship between fall total organic carbon at the Intake (August/September, 1996–2004) and Qtr 3 TTHMs in Bellingham's treated drinking water (1992–2004). Data were provided by the City of Bellingham Public Works Department.

3 Creek Monitoring

3.1 Site Descriptions

Seven creeks were sampled twice during the 2003/2004 monitoring program, including Austin Creek, Anderson Creek[12], the Park Place outfall, Silver Beach Creek, Smith Creek, the unnamed creek that flows through the Wildwood campground, and the northern unnamed creek on Blue Canyon Rd. (Blue Canyon #1). The exact sampling locations for these sites are described by Walker, et al. (1992), and are summarized in Appendix A.2 (beginning on page 99).

These creeks included two small, mostly forested creeks located in the southern portion of the watershed (Wildwood Creek and Blue Canyon Creek); a small residential creek located in the northeastern portion of the watershed (Silver Beach Creek); an outlet from a residential storm water system (Park Place outfall); two large, perennial creeks (Austin Creek and Smith Creek); and Anderson Creek, which can be a major water source for Lake Whatcom when it receives the diversion flow from the Middle Fork of the Nooksack River. These seven creeks represent water quality conditions ranging from heavily impacted by residential runoff (Silver Beach Creek and Park Place outfall) to relatively unaffected by residential development (Blue Canyon Creek and Smith Creek). Of the three large creeks, Austin Creek receives residential runoff from Sudden Valley in the lower portion of its watershed and Anderson Creek receives agricultural runoff in the lower portion of its watershed. Smith Creek has a few houses located near its mouth, but otherwise has a steep, forested, undeveloped watershed.

3.2 Field Sampling and Analytical Methods

The creeks were sampled on February 18 and July 13, 2004. The water quality measurements are summarized in Table 11 (page 53). The analytical procedures are summarized in Table 2 (page 18). All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory. Once in the laboratory the handling procedures that were relevant for each analysis were followed (see Table 2). The total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc)

[12] Anderson Creek was added to our routine sampling effort beginning in February 1995.

and total organic carbon analyses were done by AmTest. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. All other analyses were done by WWU personnel.

3.3 Results and Discussion

The primary purpose for the biannual creek monitoring was to provide data that can be compared to the more complete data set generated in 1990 during the storm water runoff project (Walker, et al., 1992). Tables 12–13 (pages 54–55) show the recent creek water quality data compared to the 1990 average water quality values for each creeks. Tables 14–16 show coliforms, metals, and total organic carbon data from the 2003/2004 sampling period. A new measurement, total solids (TS), was added to Table 12. In addition, metals were sampled twice in 2004 (February and July). This was done to complement a new creek monitoring effort initiated in October 2004 that will include monthly creek monitoring from October 2004 through September 2006.

Although most of the creek data fell within historic ranges, low flow during the summer caused many measurements to be near the extreme high or low ends of the expected ranges. Compared to the streams in forested areas, the residential streams typically had poorer water quality, with higher conductivities; higher alkalinity and phosphorus; and much higher coliform counts. These differences are typical for streams receiving urban runoff. Conductivities and alkalinities were also high in Blue Canyon Creek, but this is normal for this stream because it flows through mineral-rich soils.

The summer dissolved oxygen concentration was low and temperature was high in the Park Place outfall. This was probably due to the influence of the Park Place wet pond, located immediately upstream from our sampling site.

Most of the metals concentrations were near analytical detection limits (Table 14, page 56). Most iron and zinc concentrations were above detection limits, but all creek results were within expected ranges for surface water in the Lake Whatcom watershed. Park Place and Silver Beach Creeks often had higher concentrations of iron and zinc, which is normal for streams receiving residential runoff. One sample from Park Place contained detectable levels of chromium (0.003 mg/L), but the concentration was close to the detection limit (0.001 mg/L) and could represent analytical variability. Copper was detectable in most of the creek samples, particularly during July. Most of the copper concentrations were low ($\leq$0.006 mg/L), except for one sample from Smith Creek during July (0.022 mg/L). Nickel was detected in one sample from Blue Canyon (0.016 mg/L) and one sample from Smith Creek (0.067 mg/L). Lead was detected at low concentrations ($\leq$0.003 mg/L) in nearly all samples.

The total organic carbon concentrations (Table 15, page 57) were quite high in February, particularly at Smith Creek (9.8 mg/L). This was consistent with last year's results, where the highest TOC concentration was from Smith Creek in February (Matthews, et al., 2004). With the exception of the unusual Smith Creek value, the highest TOC concentrations were measured in the residential creeks (Silver Beach Creek and the Park Place outfall).

Coliform counts were high in the Park Place Silver Beach samples, particularly during July (Table 13, page 55). It is common to measure higher coliform counts in residential streams and lower counts in forested streams. Because of unusually high counts last year (Matthews, et al., 2004), all of the streams except Wildwood (which was dry in July) would fail the freshwater *Extraordinary Primary Contact Recreation* bacteria standard[13] because too many samples exceeded 100 cfu/100 mL (Table 16, page 58). The only sites that failed due to a high geometric mean were Silver Beach Creek and the Park Place outfall. Although Austin Creek had a geometric mean value below 50 cfu/100 mL, it has had high summer coliform counts for 4 out of the last 5 years (Table 17, page 59).

[13]This determination is based on a 5-year data set, and it should be noted that a more representative approach would be to collect a minimum of 10 samples within a season, or at most, within one year. The 2004–2006 monitoring program will collect monthly coliform data from creeks in the Lake Whatcom watershed, which should provide a better indication of which streams are in compliance with the freshwater bacteria standard.

	2003			2004								
Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Temperature					●					●		
Discharge					●					●		
Alkalinity					●					●		
Conductivity					●					●		
DO - Winkler					●					●		
pH					●					●		
T. Suspended Solids					●					●		
Total Solids					●					●		
Turbidity					●					●		
Ammonia					●					●		
Nitrite/Nitrate					●					●		
Total Nitrogen					●					●		
Soluble Phosphate					●					●		
Total Phosphorus					●					●		
Total Organic Carbon					●					●		
										●		
Total Arsenic†					●					●		
Total Cadmium					●					●		
Total Chromium					●					●		
Total Copper					●					●		
Total Iron					●					●		
Total Lead					●					●		
Total Mercury					●					●		
Total Nickel					●					●		
Total Zinc					●					●		
Bacteria					●					●		

†Twenty-four additional metals are included as part of the standard AmTest analytical procedure.

Table 11: Lake Whatcom 2003/2004 creek monitoring schedule.

Site	Date	pH	Cond. (μS/cm)	DO (mg/L)	TSS (mg/L)	TS (mg/L)	Alk. (mg/L)	Disch. (cfs)	Temp. (°C)	Turb. (ntu)
Blue	1990 min†	8.1	250	9.0	<2	na	na	0.02	4.0	na
Canyon	1990 avg†	8.4	344	10.5	5	na	na	0.05	10.9	na
	1990 max†	8.6	409	12.3	29	na	na	0.11	17.0	na
	Feb 18, 2004	8.3	284	11.5	<2	31.8	127.2	0.24	7.6	2.2
	July 13, 2004	8.4	282	10.3	3.4	163.8	136.0	0.08	14.0	2.0
Park	1990 min†	7.1	118	6.4	3	na	na	0.00	4.5	na
Place	1990 avg†	7.7	245	9.1	13	na	na	0.26	13.7	na
	1990 max†	8.1	410	11.8	57	na	na	0.91	23.0	na
	Feb 18, 2004	7.5	193	11.1	6.7	123.6	75.9	na	7.5	9.6
	July 13, 2004	7.5	243	6.1	5.5	153.4	109.8	na	19.8	2.3
Silver	1990 min†	7.4	103	6.9	<2	na	na	0.00	4.2	na
Beach	1990 avg†	7.9	187	9.8	6	na	na	0.86	11.1	na
	1990 max†	8.1	290	12.1	12	na	na	2.66	17.0	na
	Feb 18, 2004	7.7	125	11.4	5.1	87.0	44.6	na	7.7	8.0
	July 13, 2004	8.0	282	9.0	2.0	171.2	125.8	na	16.2	1.5
Wildwd	1990 min†	6.7	34	6.9	<2	na	na	0.01	4.0	na
	1990 avg†	7.2	54	10.0	2	na	na	0.76	10.0	na
	1990 max†	7.6	126	12.3	11	na	na	2.52	16.5	na
	Feb 18, 2004	7.1	44	11.7	2.7	42.7	6.8	1.81	7.0	0.2
	July 13, 2004	7.0	56	9.2	<2	41.9	14.0	0.01	15.0	0.1
Anderson	1990 min†	7.2	37	10.0	4	na	na	41.2	3.5	na
	1990 avg†	7.4	57	11.3	17	na	na	74.85	8.3	na
	1990 max†	8.4	71	13.0	48	na	na	92.00	12.5	na
	Feb 18, 2004	6.9	56	11.2	4.4	163.0	16.0	12.27	7.3	2.0
	July 13, 2004	7.0	69	9.4	2.2	49.5	22.3	na	14.5	1.6
Austin	1990 min†	7.1	50	8.3	<2	na	na	1.40	4.5	na
	1990 avg†	7.4	81	10.5	3	na	na	14.49	10.6	na
	1990 max†	7.6	121	12.1	13	na	na	29.60	19.5	na
	Feb 18, 2004	7.4	57	11.7	5.1	46.9	14.3	25.90	7.0	4.1
	July 13, 2004	7.7	117	9.7	<2	75.4	32.3	na	16.1	0.5
Smith	1990 min†	6.6	44	8.7	<2	na	na	0.80	3.4	na
	1990 avg†	7.5	64	10.5	3	na	na	7.63	10.0	na
	1990 max†	7.8	90	12.6	10	na	na	23.80	17.0	na
	Feb 18, 2004	7.4	50	12.1	<2	39.1	13.4	na	6.6	0.8
	July 13, 2004	7.7	80	10.1	<2	54.1	27.3	2.04	15.0	0.3

†The 1990 creek data do not include the November 1990 storm event.

Table 12: Physical water quality data for creeks in the Lake Whatcom watershed. Due to drought conditions and construction activities, discharge could not always be measured.

Site	Date	NH_3 (μg-N/L)	NO_{2+3} (μg-N/L)	TN (μg-N/L)	SRP (μg-P/L)	TP (μg-P/L)	FC (cfu/ 100 mL)	E. coli (cfu/ 100 mL)
Blue	1990 min	10	167	167	<5	<5	<2	na
Canyon	1990 avg	20	336	336	<5	13	7	na
	1990 max	34	545	545	12	25	27	na
	Feb 18, 2004	12	332	427	8	<5	1	1
	July 13, 2004	13	114	185	16	21	31	23
Park	1990 min	22	145	na	6	41	8	na
Place	1990 avg	51	357	na	22	66	1353	na
	1990 max	111	549	na	86	168	16000	na
	Feb 18, 2004	24	658	1191	17	62	96	340
	July 13, 2004	53	298	939	37	123	5200	350
Silver	1990 min	<10	173	na	<5	27	8	na
Beach	1990 avg	19	583	na	16	41	3307	na
	1990 max	43	1118	na	42	61	16000	na
	Feb 18, 2004	<10	612	915	14	32	58	90
	July 13, 2004	18	204	486	39	46	480	400
Wildwd	1990 min	<10	755	na	<5	<5	<2	na
	1990 avg	189	1790	na	<5	9	74	na
	1990 max	32	4857	na	9	33	1300	na
	Feb 18, 2004	<10	1565	1676	7	6	<1	<1
	July 13, 2004	<10	1245	1068	11	16	15	11
Anderson	1990 min	10	50	na	<5	6	<2	na
	1990 avg	19	121	na	<5	24	13	na
	1990 max	32	221	na	8	55	130	na
	Feb 18, 2004	16	538	741	10	15	3	32
	July 13, 2004	<10	621	744	15	21	83	77
Austin	1990 min	<10	259	na	<5	<5	7	na
	1990 avg	20	441	na	<5	13	950	na
	1990 max	40	658	na	9	23	5000	na
	Feb 18, 2004	<10	659	831	12	18	8	13
	July 13, 2004	10	194	313	16	26	130	92
Smith	1990 min	12	396	na	<5	<5	<2	na
	1990 avg	17	687	na	<5	6	14	na
	1990 max	37	1025	na	8	12	170	na
	Feb 18, 2004	<10	851	971	10	9	<1	1
	July 13, 2004	<10	430	525	14	12	21	20

The 1990 creek data do not include the November 1990 storm event.

Table 13: Chemical and biological water quality data for creeks in the Lake Whatcom watershed.

Site	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)
Blue Canyon	Feb 18, 2004	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	0.016	0.003	0.004
Park Place	Feb 18, 2004	<0.01	<0.0005	0.003	0.004	0.63	<0.0002	<0.005	0.003	0.014
Silver Beach	Feb 18, 2004	<0.01	<0.0005	<0.001	0.003	0.55	<0.0002	<0.005	0.002	0.007
Wildwood	Feb 18, 2004	<0.01	<0.0005	<0.001	0.002	0.20	<0.0002	<0.005	0.002	0.003
Anderson	Feb 18, 2004	<0.01	<0.0005	<0.001	0.002	0.088	<0.0002	<0.005	0.001	0.001
Austin	Feb 18, 2004	<0.01	<0.0005	<0.001	<0.001	0.18	<0.0002	<0.005	0.001	0.004
Smith	Feb 18, 2004	<0.01	<0.0005	<0.001	<0.001	0.18	<0.0002	<0.005	0.001	0.006
Blue Canyon	July 13, 2004	<0.01	<0.0005	<0.001	0.006	0.078	<0.0002	<0.005	<0.001	0.008
Park Place	July 13, 2004	<0.01	<0.0005	<0.001	0.005	0.88	<0.0002	<0.005	0.001	0.002
Silver Beach	July 13, 2004	<0.01	<0.0005	<0.001	0.004	0.13	<0.0002	<0.005	<0.001	0.008
Wildwood	July 13, 2004	<0.01	<0.0005	<0.001	0.006	<0.005	<0.0002	<0.005	0.002	0.003
Anderson	July 13, 2004	<0.01	<0.0005	<0.001	0.003	0.23	<0.0002	<0.005	0.001	0.003
Austin	July 13, 2004	<0.01	<0.0005	<0.001	0.006	0.14	<0.0002	<0.005	0.001	0.006
Smith	July 13, 2004	<0.01	<0.0005	<0.001	0.022	<0.005	<0.0002	0.067	<0.001	0.002

Table 14: Metals data for creeks in the Lake Whatcom watershed. Only the metals specified in the 2003/2004 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix D.7.

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Blue Canyon	Feb 18, 2004	4.9	July 13, 2004	<1
Park Place	Feb 18, 2004	6.7	July 13, 2004	6.1
Silver Beach	Feb 18, 2004	5.9	July 13, 2004	3.0
Wildwood	Feb 18, 2004	6.5	July 13, 2004	2.6
Anderson	Feb 18, 2004	1.6	July 13, 2004	<1
Austin	Feb 18, 2004	4.7	July 13, 2004	1.7
Smith	Feb 18, 2004	9.8	July 13, 2004	1.1

Table 15: Total organic carbon data for creeks in the Lake Whatcom watershed.

Site	Min.	Med.	Geom. Mean	Max.	N
Blue Canyon	<1	7	9	520	10
Park Place	33	1010	489	5,200	10
Silver Beach	12	480	234	1,900	10
Wildwood	<1	11	5	42	9
Anderson	1	9	17	360	10
Austin	3	81	46	560	10
Smith	<1	21	13	190	10

Table 16: Five-year summary of fecal coliform counts for creeks in the Lake Whatcom watershed (February 2000 to July 2004).

Winter counts		Summer counts	
Feb 9, 2000	32 cfu/100 mL	July 18, 2000	141 cfu/100 mL
Feb 22, 2001	5 cfu/100 mL	July 18, 2001	270 cfu/100 mL
Feb 20, 2002	3 cfu/100 mL	July 17, 2002	660 cfu/100 mL
Feb 11, 2003	12 cfu/100 mL	July 14, 2003	360 cfu/100 mL
Feb 18, 2004	8 cfu/100 mL	July 13, 2004	92 cfu/100 mL

Table 17: Five-year summary of Austin Creek fecal coliform counts.

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 24–26 (pages 65–67). The location of each hydrograph is described in Appendix A.2, beginning on page 99. All hydrograph data, including data from previous years, are included on the CD that accompanies this report. The CD also includes a `readme.txt` file that describes causes for missing 2003/2004 data that could not be collected due to technical problems or construction activities in the creeks.

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 27 (page 68) shows the rating curves for each hydrograph. Beginning in May 2004, a new rating curve was developed for Anderson Creek. Emergency bridge repair in May 2004 resulted in changes in the creek channel morphology, which required creating a new rating curve.

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 (i.e., inputs - outputs = change in storage) was employed. 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 Water District #10. 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.

Daily direct-precipitation magnitudes were estimated using the precipitation data recorded at the Geneva Gate house, Smith Creek, and Brannian Creek gauges. The Thiessen polygon method (Dingman, 1994) was used to estimate the 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 a Thiessen Polygon extension in ArcGIS (Figure 28, page 69). The average direct-precipitation depth (inches) for a given day was converted to a volume in millions of gallons (MG) via a rating curve generated from the lake level-area data developed by 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 2003/2004 was 56.2 inches.

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 2003/2004 was 21.4 inches, most of which occurs in the dry season (June to 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 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 average total lake volume in 2003/2004 was 252,692 MG.

Surface runoff and groundwater were combined into a single runoff component that is backed out from the water balance values by adding the outputs to the change in storage and subtracting the precipitation and diversion magnitudes. The runoff values are rough estimates and their error is magnified in the summer and early autumn because the water balance does not consider soil storage in the watershed. Evapotranspiration is considerable during these months and withdraws a significant amount of water out of the soils. Therefore, summer and autumn rains contribute more to soil storage than to surface runoff and groundwater.

Yearly water balance totals are listed in Table 18 (page 63) along with the yearly total values for the four previous water years. As indicated in Table 18, 2003/2004 was a wet year. The total inputs and outputs to the lake were estimated to be 40,995 MG and 37,855 MG, respectively. The diversion input volume from the Middle Fork of the Nooksack River was larger this year, primarily because it operated during a wetter than normal August and September. The total volume of outputs correspond to about 15% of the average total volume of the lake. Under the assumption that the lake is completely mixed and flow is steady state (inputs = outputs)[14], this would correspond to a 6.7 year residence time. Using these assumptions, the residence times for the past 5 years ranged from 5.1–10.7 years.

The daily water balance quantities were summed into 7-day totals, which were used to generate plots of the input, output, change in storage, and estimated runoff volumes (Figures 29–32, pages 70–72). All the inputs, except for runoff, are shown in Figure 29 and all the outputs, except for Whatcom Creek, are shown in Figure 30. The input from runoff and output to Whatcom Creek are shown along with the change in lake storage on Figure 31 because they have similar magnitudes. Figure 32 shows 7-day summed totals for inputs, outputs, and change in storage.

Table 19 (page 64) shows the 2003/2004 total input and output volumes along with the corresponding monthly percentage of each total. Table 19 also shows the June-September input and output volumes and their corresponding percentages. June through September is a critical water quality interval because the lake is stratified during this time.

Figure 33 (page 74) shows daily lake-volume values for the past five years. The curves were generated using the daily lake levels reported by the City and a rating curve generated from the lake level-capacity data developed by Ferrari and Nuanes (2001). The dramatic changes throughout the course of a year are due primarily to rainfall-runoff events and Whatcom Creek discharges. For example, the peaks in 2003/2004 correlate to unusually high rainfall in October and November 2003. The lower than normal lake volume in the spring of 2003/2004 was due to the extremely dry April in 2004. The high late-summer storage in 2004 was in part due to high August and September rainfall and a reduction in discharge into Whatcom Creek.

[14] 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.

	2003–2004	2002–2003	2002–2002	2000–2001	1999-2000
Inputs (MG)					
Direct Precipitation	7,612 (18.6%)	4,859 (19.5%)	7,078 (14.5%)	4,811 (19.3%)	7,077 (14.7%)
Diversion	5,095 (12.4%)	4,442 (17.8%)	4,693 (9.6%)	1,783 (7.1%)	4,607 (9.5%)
Runoff	28,288 (69.0%)	15,589 (62.6%)	36,920(75.8%)	18,345 (73.6%)	36,563 (75.8%)
Total	40,955 (100%)	24,890 (100%)	48,691(100%)	24,938 (100%)	48,247 (100%)
Outputs (MG)					
Whatcom Creek	26,948 (71.2%)	13,361 (53.5%)	38,223 (77.5%)	10,508 (44.5%)	27,280 (55.6%)
Hatchery	1,278 (3.4%)	1,124 (4.5%)	901 (1.8%)	1,074 (4.5%)	2,388 (4.9%)
Georgia Pacific	2,053 (5.4%)	2,988 (12.0%)	3,046 (6.2%)	4,851 (20.5%)	12,334 (25.1%)
City of Bellingham	4,449 (11.8%)	4,342 (17.4%)	4,234 (8.6%)	4,076 (17.3%)	4,112 (8.4%)
Water District 10	204 (0.5%)	136 (0.6%)	126 (0.3%)	140 (0.6%)	154 (0.3%)
Evaporation	2,924 (7.7%)	3,016 (12.1%)	2,812 (5.7%)	2,971 (12.6%)	2,777 (5.7%)
Total	37,855 (100%)	24,971 (100%)	49,341 (100%)	23,621 (100%)	49,045 (100%)
Net change in storage	3,139	-81	-651	1,318	-797
Median lake volume (MG)	252,970	252,075	252,368	251,978	251,766
Outflow percent of volume	15.0%	9.9%	19.6%	9.4%	9.4%
Residence time (years)*	6.7	10.1	5.1	10.7	5.1

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

Table 18: Annual water balance quantities for the Lake Whatcom watershed.

	Output Percents						Input Percents		
Month	WC	Hatch	GP	COB	WD10	Evap	Diver	Precip	Runoff
Oct	13.78	7.37	10.46	7.44	7.29	3.74	0.24	21.06	12.53
Nov	22.71	6.14	7.46	6.90	6.00	0.82	0.95	19.88	23.26
Dec	20.60	8.23	6.45	6.58	6.19	0.28	3.39	7.65	9.87
Jan	15.05	6.96	5.35	7.59	7.58	-0.02	13.15	12.15	17.15
Feb	18.60	7.83	5.10	6.67	6.51	1.21	0.00	4.23	11.45
Mar	2.65	10.31	6.64	6.76	7.56	4.71	15.26	8.98	10.89
Apr	2.29	10.59	6.87	7.64	7.77	11.31	11.94	1.20	5.06
May	1.04	8.22	7.80	8.93	8.48	12.33	12.90	5.87	2.61
Jun	0.96	9.18	9.57	9.66	9.17	17.01	20.01	3.43	2.62
Jul	0.86	9.57	11.44	13.50	12.66	21.77	2.52	0.54	0.77
Aug	0.73	7.72	12.35	11.22	11.40	17.07	10.17	9.37	1.25
Sep	0.74	7.89	10.51	7.11	9.39	9.77	9.47	5.62	2.53
Jun-Sep	3.29	34.36	43.87	41.49	42.62	65.61	42.17	18.97	7.17
	Output Volume (MG)						Input Volume (MG)		
Total	26,948	1278	2053	4449	204	2924	5095	7612	28,288
Jun-Sep	886	439	901	1846	87	1919	2148	1444	2029

Table 19: Monthly water balance quantities for the Lake Whatcom watershed, October 2003–September 2004.

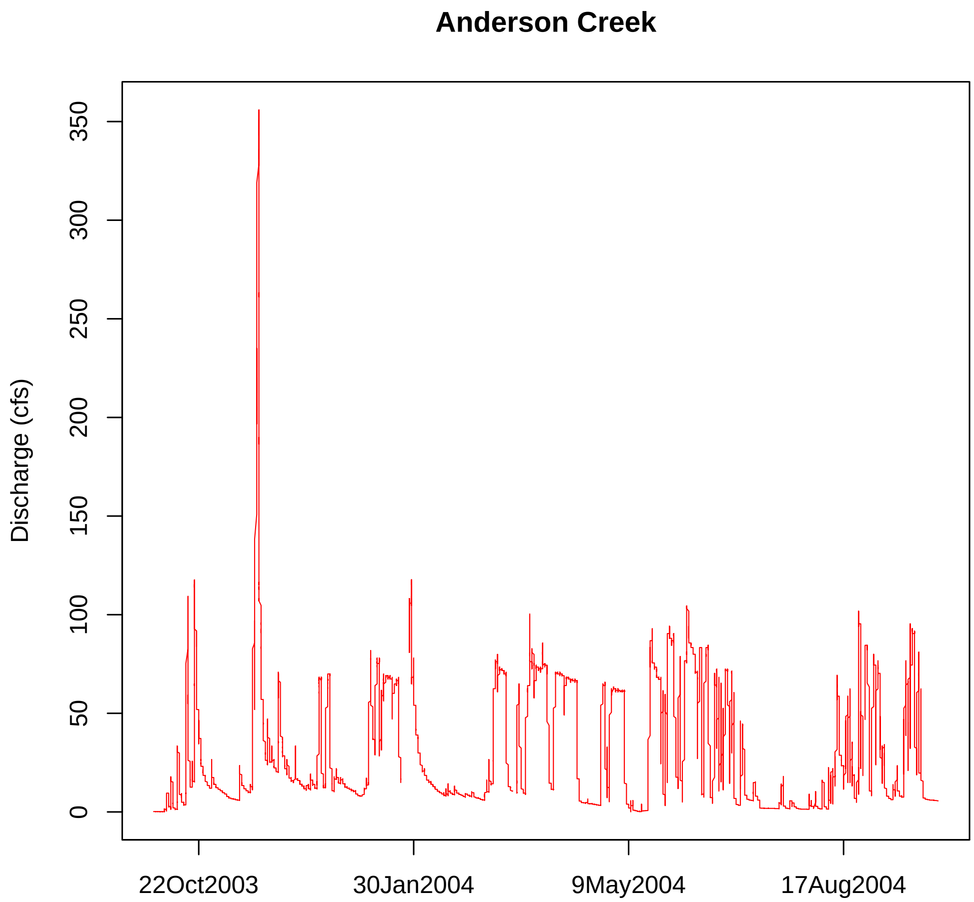

Figure 24: Anderson Creek hydrograph, October 1, 2003–September 30, 2004. Data were recorded at 15 minute intervals.

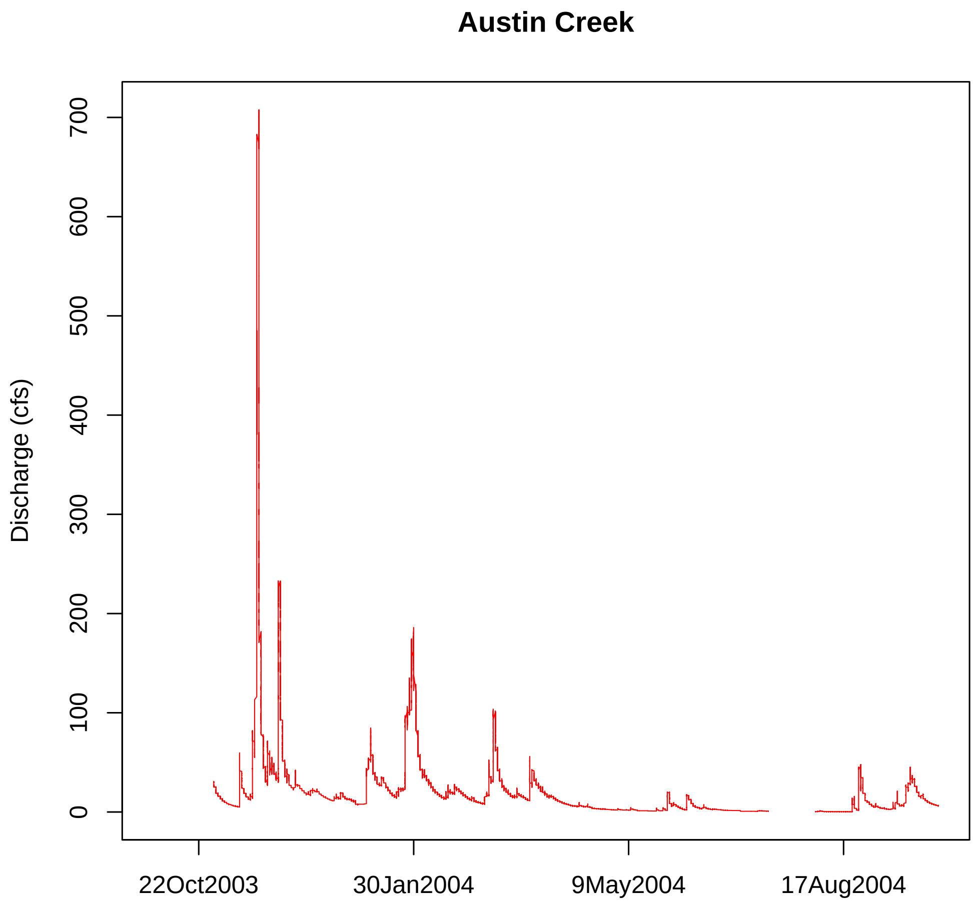

Figure 25: Austin Creek hydrograph, October 1, 2003–September 30, 2004. Data were recorded at 15 minute intervals.

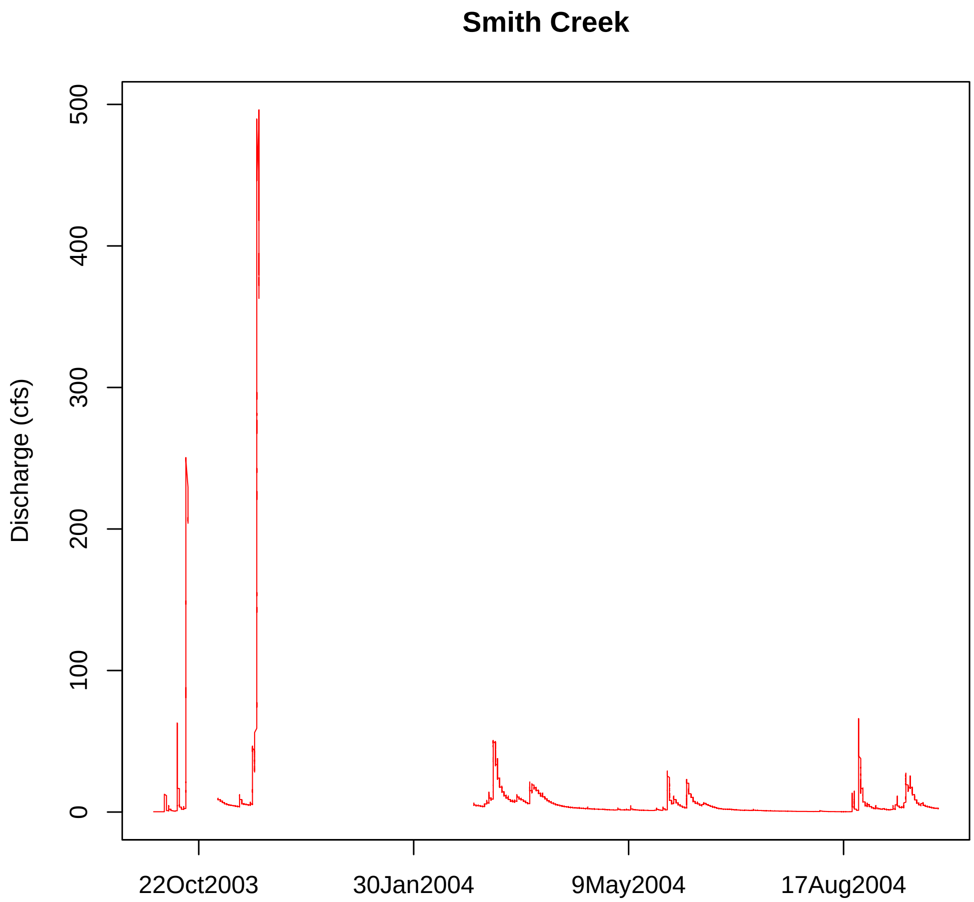

Figure 26: Smith Creek hydrograph, October 1, 2003–September 30, 2004. Data were recorded at 15 minute intervals.

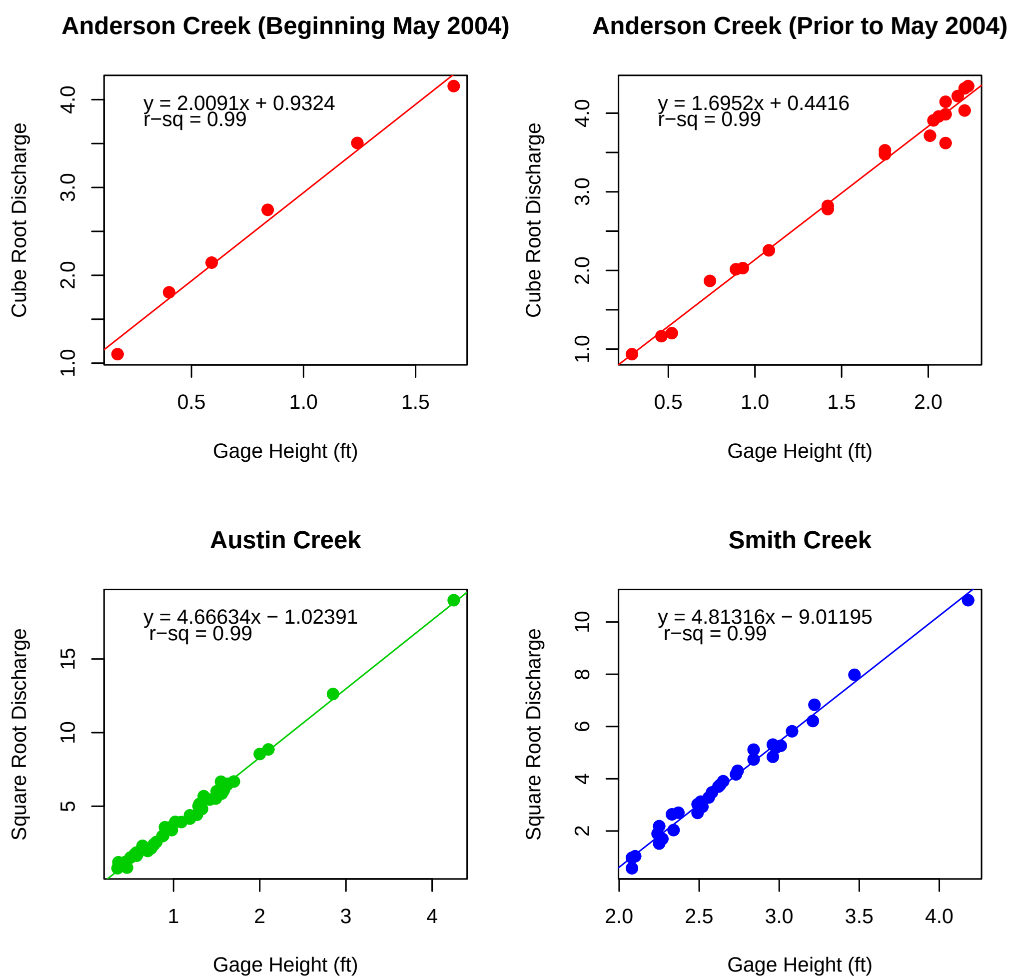

Figure 27: Anderson Creek, Austin Creek, and Smith Creek rating curves. Regressions show the relationship between gauge height (x) and transformed discharge (y). Best fit linear models were based on square root transforms for Austin and Smith Creeks and cube root transforms for Anderson Creek.

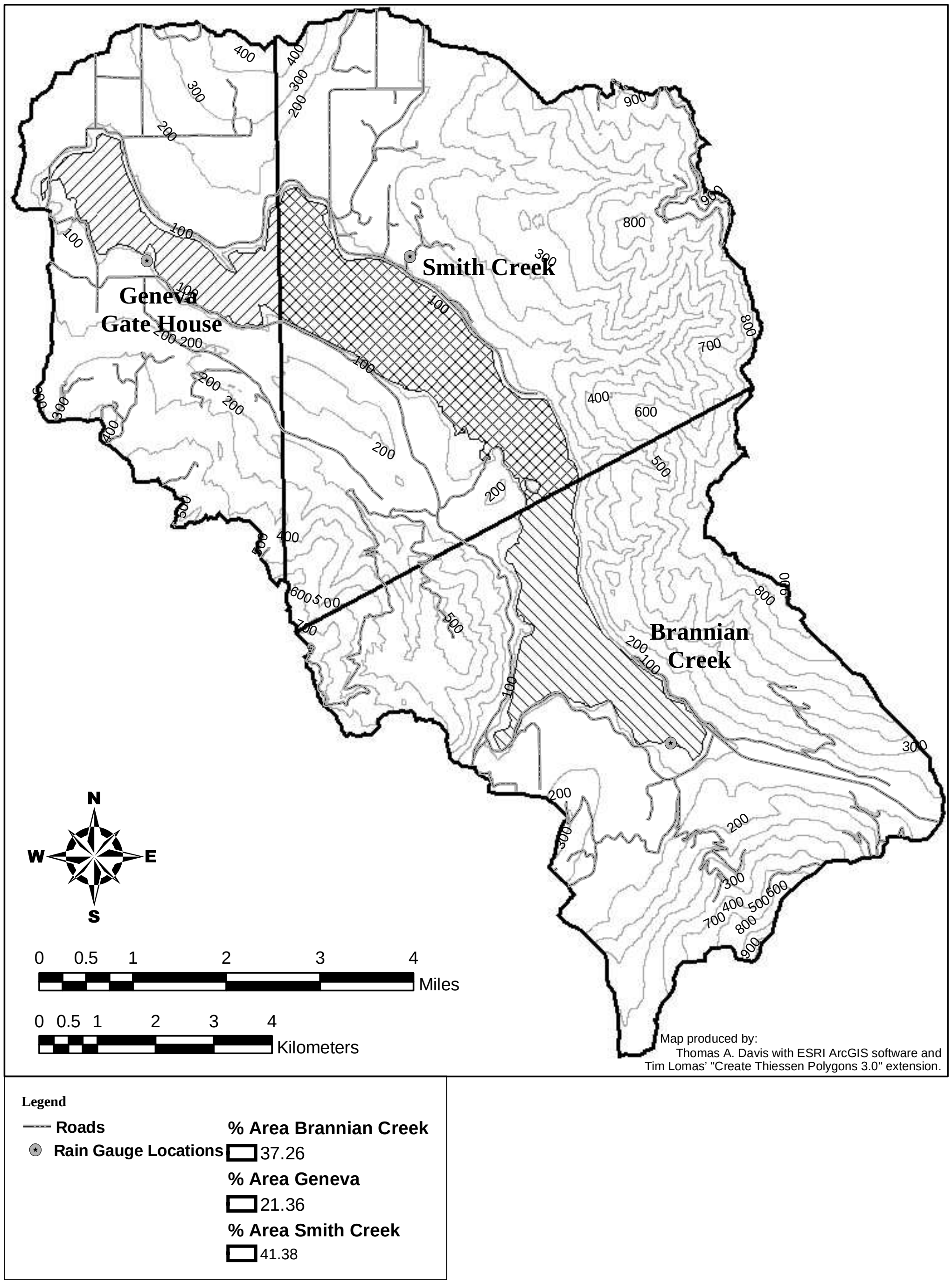

Figure 28: Lake Whatcom watershed precipitation groups and weighted areas, October 1, 2003–September 30, 2004.

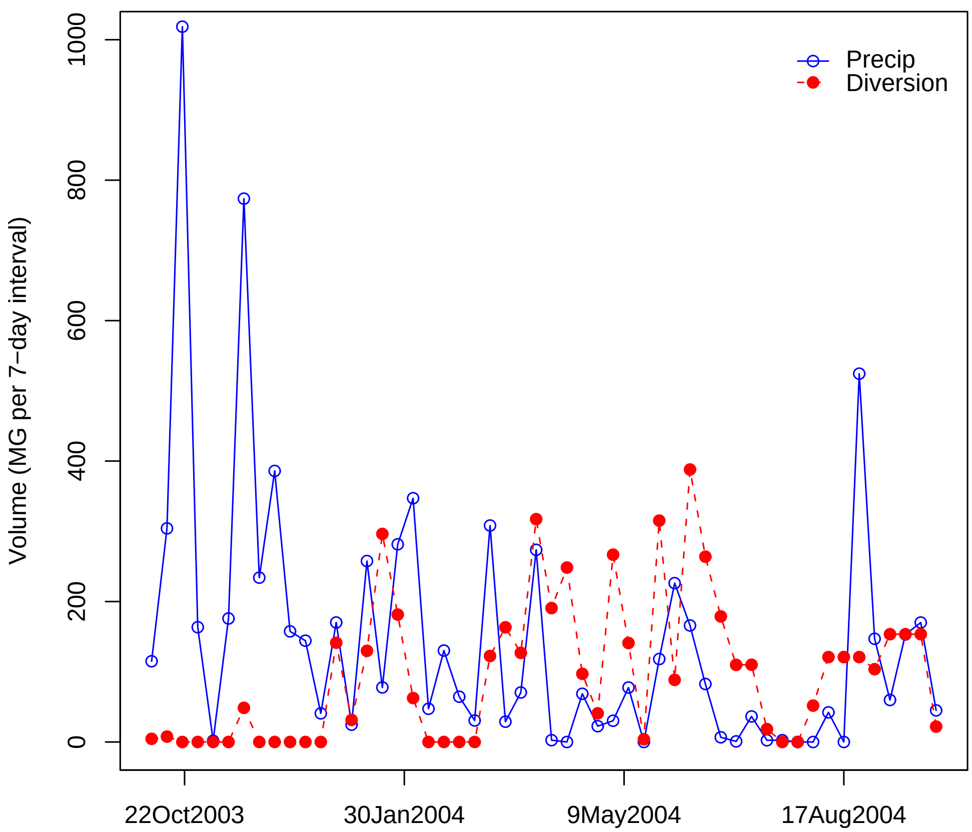

Figure 29: Lake Whatcom watershed direct hydrologic inputs, October 1, 2003–September 30, 2004.

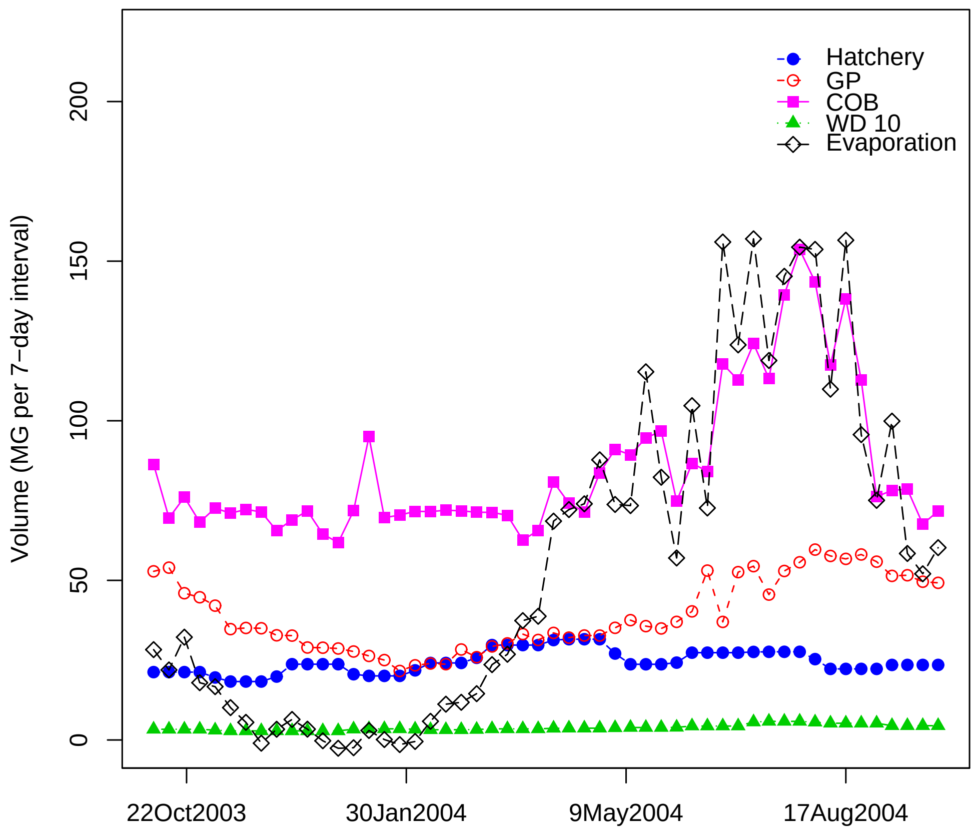

Figure 30: Lake Whatcom watershed hydrologic withdrawals, October 1, 2003–September 30, 2004.

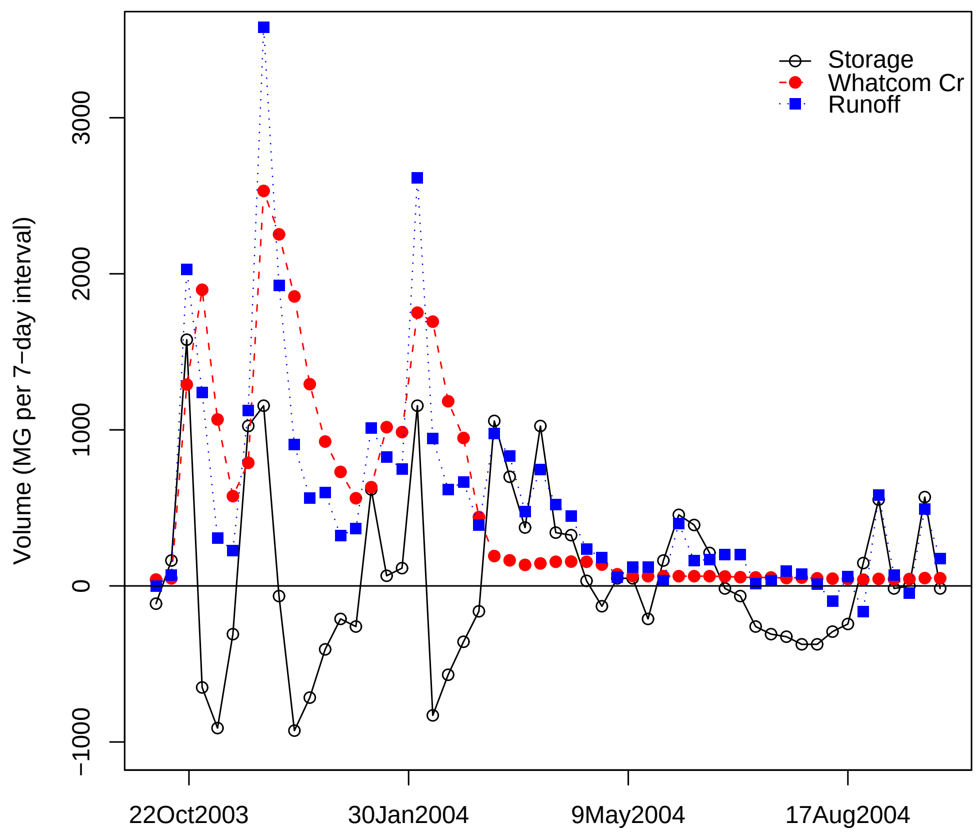

Figure 31: Summary of 7-day changes in Lake Whatcom storage, watershed runoff, and Whatcom Creek flows, October 1, 2003–September 30, 2004.

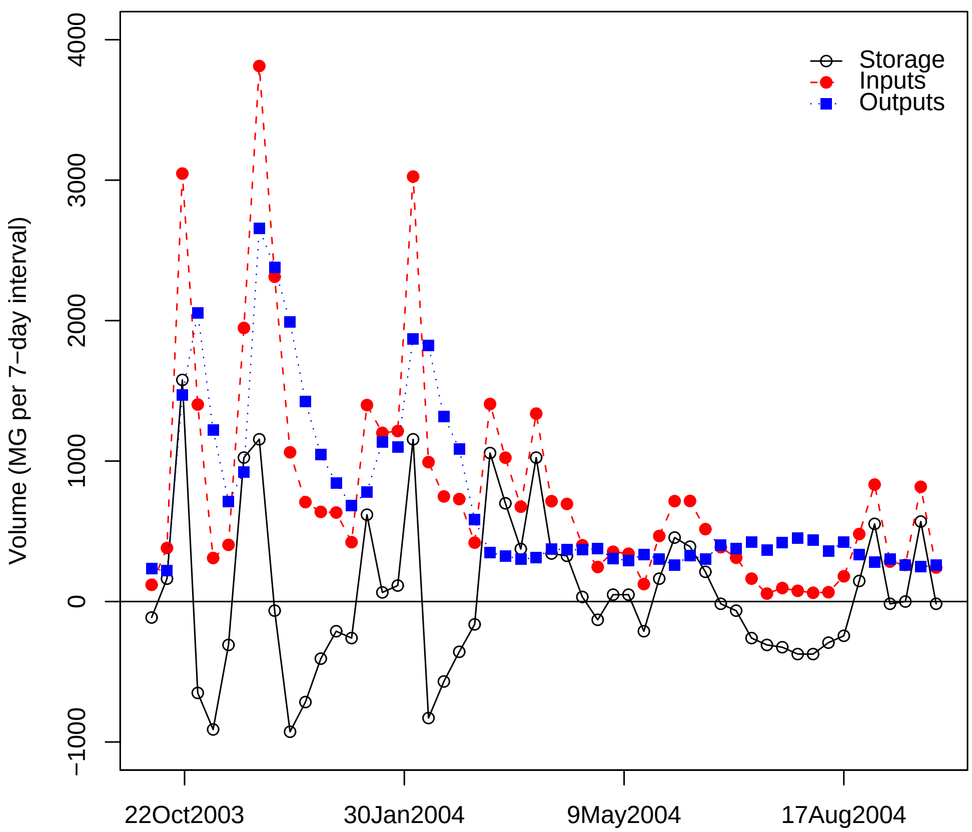

Figure 32: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2003–September 30, 2004.

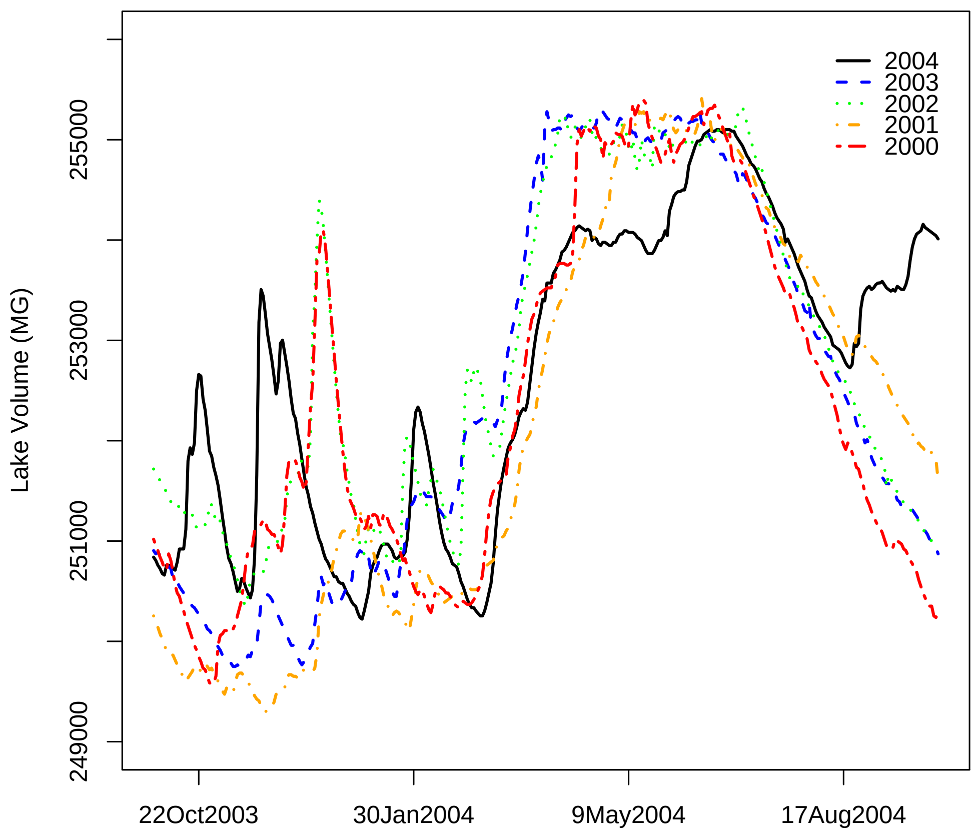

Figure 33: Comparison of Lake Whatcom daily lake volumes for 2000–2004.

5 Storm Water Treatment Monitoring

The objective of this portion of the lake monitoring project was to evaluate the water treatment efficiencies of representative storm water treatment facilities in the vicinity of the Lake Whatcom watershed. During the 2003/2004 monitoring period, samples were collected from the Park Place and Brentwood wet ponds, one underground storm water vault (Silvern), a grass swale/wet pond (Parkstone), and the South Campus storm water treatment facility.[15] The locations of the monitoring sites are shown on Figures A4–A5 (pages 103–104).

5.1 Sampling procedures

Park Place and Brentwood wet ponds were sampled on February 17–19, 2004 (wet season - storm flow) and July 20–22, 2004 (dry season - nominal flow). Due to drought conditions and construction activities at the Park Place storm water treatment system, we were not able to collect wet season - nominal flow samples.

Two small storm water treatment systems, the Parkstone swale/wet pond and the Silvern vault, were sampled once each during the 2003/2004 monitoring period. These systems have small drainages and can only be sampled during or immediately after a storm event. The Silvern vault, which consists of 6 underground canisters containing perlite, was sampled on May 10, 2004 (wet season - storm flow). It proved to be unsuitable as a sampling site, and will be replaced with another vault system in the 2004/2006 monitoring program. The Parkstone swale/wet pond was sampled on November 18–19, 2003 (wet season - storm flow).

The South Campus storm water treatment facility was sampled on November 11-13, 2003 (wet season - nominal flow), January 26–28, 2004 (wet season - storm flow), and August 24–25, 2004 (dry season - storm flow). Heavy precipitation 72 hours preceeding sampling in August resulted in unusually high flows for August.

Where possible, composite and grab samples were collected at inflow and outflow points for each site (Table 20, page 79).[16] Automatic composite samplers (ISCO type, supplied by the City of Bellingham) were placed at the inlet and outlet and

[15]The South Campus storm water treatment facility is a state-of-the-art combination of grass swales and rock/plant fi lters. Although outside the Lake Whatcom watershed, it is included in the monitoring effort as an indicator of potential treatment effectiveness.

[16]Some sites have multiple infbw or outfbw locations.

composite water samples were collected at 90 minute intervals over a 48 hour period. The composite samples were analyzed for total suspended solids, heavy metals (arsenic, cadmium, chromium, copper, iron, nickel, lead, and zinc), total organic carbon, total nitrogen, and total phosphorus. Grab samples were collected four times during the 48 hour period at the inflow(s) and outflow(s) at each site. The Hydrolab Surveyor IV was used to measure pH, temperature, dissolved oxygen, and conductivity in the field. Bacteria samples (fecal coliforms and *E. coli*) were analyzed by the City of Bellingham. Grab samples were used to measure total suspended solids, total nitrogen, and total phosphorus in the Parkstone and Silvern facilities because composite sampling was not feasible.

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 in the Brentwood pond began in 1998 and monitoring at the South Campus facility began in 2001. Monitoring at the Parkstone swale/wet pond and Silvern vault began in 2004.

Both the Brentwood and Park Place storm water treatment facilities consist of a series of wet ponds that develop extensive macrophyte growth during the summer (Figures 34 & 35, pages 86 & 87). The South Campus storm water treatment facility was constructed during the fall and winter of 2000. The rock/plant filters were planted with cattails (*Typha latifolia*), but only minimal growth had occurred by the end of summer, 2001. Due to excessive sediment loading from campus construction activities during 2001–2002, the gravel was replaced and the vegetation was replanted in the fall of 2002. The facility now supports a dense growth of emergent macrophytes (Figure 36, page 88).

The Parkstone treatment system is a complex sequence of grass swales and small wet ponds (Figure 37, page 89) with multiple inlets and outlets. The upper portion of the Parkstone system is a grass swale that receives water from a small wetland (Parkstone swale inlet #1) and paved roadway (Parkstone swale inlet #2). Partially treated water from the swale outlet mixes with untreated street runoff to form the Parkstone pond inlet. The water is discharged from the Parkstone pond outlet into Mill Wheel Creek, which flows into Lake Whatcom. Since the Parkstone pond outlet is what actually flows into Lake Whatcom, it is the best location for measuring contaminant levels exiting the Parkstone system. The Silvern vault is a simple, underground 6-canister system (Figure 38, page 90) containing perlite to help remove sediment and oil/grease/hydrocarbons from road runoff.

Tables 21–26 (pages 80–85) show the raw data from the storm water treatment systems. The tables also show the annual and seasonal percent reduction in concentration of contaminants between the inflow and outflow at the storm water treatment systems, calculated as follows:

$$\text{Average seasonal reduction} = \frac{\overline{x}_{\text{inlet}} - \overline{x}_{\text{outlet}}}{\overline{x}_{\text{inlet}}} \times 100$$

Some of the changes between inlet and outlet water quality were the result of water entering a pond environment. For example, summer water temperatures were generally warmer at the Park Place and Brentwood outlets compared to their inlets. These two ponds have extensive macrophyte growth, which caused supersaturation of dissolved oxygen in the summer for daytime samples, and oxygen depletion in evening or early morning samples. The Park Place and Brentwood ponds provided excellent coliform reduction, particularly during the summer. None of treatment facilities were consistent in reducing coliforms to levels that would meet surface water standards.

Among the three large storm water treatment facilities, the South Campus system provided the best phosphorus and sediment removal, with an annual average reduction of 76.6% for total suspended solids and 54.2% for total phosphorus. The Park Place wet pond provided virtually no sediment or phosphorus removal, and often had higher concentrations of sediments and phosphorus at the outlet than the inlet. This can be caused by a number of factors, including resuspension of pond sediments and phosphorus during storm events, sediment resuspension by wildlife entering the area, and release or solubilization of nutrients from low oxygen environments in the ponds. The Brentwood wet pond performed slightly better, with a modest reduction of 14.7% for suspended solids and 27.2% for phosphorus.

The Parkstone swale/wet pond and Silvern vault were each sampled once during the 2003/2004 monitoring period, so only seasonal percent reduction data are available. The Silvern vault provided a small sediment reduction (24.1%), a smaller phosphorus reduction (8.1%), and exported organic carbon (225% *increase* at the outlet). The Parkstone system had better water quality at the swale outlet than the pond outlet. There was a substantial reduction in suspended solids between the swale inlets and the swale outlet (74.5%), but little additional reduction between the pond inlet and outlet (6.4%). Similarly, there was fairly good phosphorus removal in the swale system (32.7%), but an export of phosphorus from the pond system (-40.0%).

As discussed by Matthews, et al. (2004), the best sediment and phosphorus removal in the storm water treatment systems usually occurred when concentrations were high at the inlet(s). Even when phosphorus reduction was achieved, the effluents from the storm water treatment facilities were usually higher than 40–50 μg-P/L, and the Parkstone and Silvern outlets were often higher than 100 μg-P/L. These levels are approximately 2–5 times higher than the background concentrations of 10–20 μg-P/L measured in forested streams flowing into Lake Whatcom (Blue Canyon, Wildwood, Anderson, and Smith Creeks).

Parameter	2003 Oct-Dec wet, low fbw	2004 Jan-Apr wet, high fbw	2004 Jul-Sept dry, low fbw	Location
Temperature	•	•	•	infbw, outfbw;
pH	•	•	•	4 grab samples in 48 hrs
Dissolved Oxygen	•	•	•	
Conductivity	•	•	•	
Bacteria	•	•	•	
T. Suspended Solids	•	•	•	48-hr composite sample
Total Nitrogen	•	•	•	
Total Phosphorus	•	•	•	
Total Organic Carbon	•	•	•	
Total Arsenic†	•	•	•	
Total Cadmium	•	•	•	
Total Chromium	•	•	•	
Total Copper	•	•	•	
Total Iron	•	•	•	
Total Lead	•	•	•	
Total Mercury	•	•	•	
Total Nickel	•	•	•	
Total Zinc	•	•	•	
Photos			•	all sites
Nuisance Checklist	•	•	•	all sites

†Twenty-four additional metals are included as part of the standard AmTest analytical procedure.

Table 20: Storm water treatment systems monitoring schedule (2003/2004).

Site	Date	TSS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
Brentwood inlet	Feb 17–19, 2004	2.88	5.0	1.385	0.030
Brentwood outlet	Feb 17–19, 2004	2.35	<1.0*	1.214	0.029
Brentwood inlet	Jul 20–22, 2004	4.30	5.1	1.909	0.086
Brentwood outlet	Jul 20–22, 2004	3.83	6.4	0.504	0.042
Annual % reduction		14.7	27.3	43.0	27.2
Park Place inlet	Feb 17–19, 2004	7.38	<1.0*	0.851	0.050
Park Place outlet	Feb 17–19, 2004	6.22	6.0	0.841	0.058
Park Place inlet	Jul 20–22, 2004	2.82	4.8	0.794	0.085
Park Place outlet	Jul 20–22,2004	9.57	8.2	0.750	0.083
Annual % reduction		-111.8	-285.4	3.4	-6.8
S. Campus inlet	Nov 11–13, 2003	22.48	<1.0*	1.139	0.056
S. Campus outletE	Nov 11–13, 2003	<2**	<1.0*	0.697	0.020
S. Campus outletW	Nov 11–13, 2003	0.80	<1.0*	0.660	0.028
S. Campus inlet	Jan 26–28, 2004	83.8	4.5	1.232	0.131
S. Campus outletE	Jan 26–28, 2004	14.5	1.0	1.091	0.064
S. Campus outletW	Jan 26–28, 2004	25.2	3.6	1.036	0.048
S. Campus inlet	Aug 24–26, 2004	14.7	7.3	1.232	0.100
S. Campus outletE	Aug 24–26, 2004	7.79	6.1	1.035	0.053
S. Campus outletW	Aug 24–26, 2004	6.81	6.0	1.065	0.057
Annual % reduction		76.6	31.4	22.1	54.2

*Value replaced with detection limit to calculate percent reduction.
**Original (uncensored) value used to calculate percent reduction.

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	Feb 17–19, 2004	<0.01	<0.0005	<0.001	0.005	0.69	<0.0002	0.032	0.002	0.008
Brentwood outlet	Feb 17–19, 2004	<0.01	<0.0005	<0.001	0.004	0.48	<0.0002	<0.005	0.002	0.005
Brentwood inlet	Jul 20–22, 2004	<0.01	<0.0005	<0.001	0.009	0.83	<0.0002	<0.005	0.002	0.012
Brentwood outlet	Jul 20–22, 2004	<0.01	<0.0005	0.003	0.005	0.54	<0.0002	<0.005	0.004	0.016
Annual % reduction		NA	NA	NA	32.2	32.7	NA	NA	-50.0	2.1
Park Place inlet	Feb 17–19, 2004	<0.01	<0.0005	0.001	0.005	0.66	<0.0002	0.030	0.003	0.160
Park Place outlet	Feb 17–19, 2004	<0.01	<0.0005	0.001	0.008	0.62	<0.0002	<0.005	0.003	0.013
Park Place inlet	Jul 20–22, 2004	<0.01	<0.0005	<0.001	0.007	1.30	<0.0002	<0.005	0.004	0.016
Park Place outlet	Jul 20–22, 2004	<0.01	<0.0005	<0.001	0.007	0.65	<0.0002	<0.005	0.002	<0.001*
Annual % reduction		NA	NA	NA	-30.0	28.0	NA	NA	25.0	92.8
S. Campus inlet	Nov 11–13, 2003	<0.01	<0.0005	<0.001	0.006	2.00	<0.0002	<0.005	<0.001	0.013
S. Campus outletE	Nov 11–13, 2003	<0.01	<0.0005	<0.001	0.006	0.06	<0.0002	<0.005	<0.001	<0.001*
S. Campus outletW	Nov 11–13, 2003	<0.01	<0.0005	<0.001	0.010	0.12	<0.0002	<0.005	<0.001	0.004
S. Campus inlet	Jan 26–28, 2004	<0.01	<0.0005	<0.001	0.016	4.20	0.0002	<0.005	0.001	0.043
S. Campus outletE	Jan 26–28, 2004	<0.01	<0.0005	0.003	0.011	1.10	<0.0002	0.006	<0.001	0.012
S. Campus outletW	Jan 26–28, 2004	<0.01	<0.0005	0.004	0.012	1.80	<0.0002	<0.005	<0.001	0.015
S. Campus inlet	Aug 24–26, 2004	<0.01	<0.0005	<0.001	0.008	1.20	<0.0002	<0.005	0.001	0.028
S. Campus outletE	Aug 24–26, 2004	<0.01	<0.0005	<0.001	0.007	0.47	<0.0002	<0.005	<0.001	0.017
S. Campus outletW	Aug 24–26, 2004	<0.01	<0.0005	<0.001	0.006	0.50	<0.0002	<0.005	<0.001	0.015
Annual % reduction		NA	NA	NA	14.6	77.2	NA	NA	NA	67.9

*Value replaced with detection limit to calculate percent reduction.

Table 21: Park Place/Brentwood wet ponds and South Campus rock/plant filter composite samples and average percent reductions between inlet and outlet samples. Data below detection were replaced with detection limit to estimate percent reduction. Negative values represent an increase in concentration at the outlet.

Site	Source	Time	Date	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
Brentwood	inlet	A	Feb 17, 2004	8.7	6.95	10.11	253.0	$<$1*	1
Brentwood	inlet	B	Feb 18, 2004	7.7	6.75	10.85	98.7	240	160
Brentwood	inlet	C	Feb 18, 2004	8.7	6.70	10.31	139.0	76	68
Brentwood	inlet	D	Feb 19, 2004	NA	6.90	10.08	240.0	1	$<$1*
Brentwood	outlet	A	Feb 17, 2004	6.5	7.30	10.44	219.0	$<$1*	4
Brentwood	outlet	B	Feb 18, 2004	6.4	7.37	10.17	215.0	13	16
Brentwood	outlet	C	Feb 18, 2004	7.3	7.29	10.65	212.0	1	$<$1*
Brentwood	outlet	D	Feb 19, 2004	NA	7.25	10.28	206.0	14	9
Seasonal % reduction				19.5	-7.0	-0.5	-16.6	90.9	87.0
Brentwood	inlet	A	Jul 20, 2004	20.2	6.90	7.23	281.0	2500	600
Brentwood	inlet	B	Jul 21, 2004	20.0	6.94	7.50	288.0	26,000	1000
Brentwood	inlet	C	Jul 21, 2004	20.0	7.01	7.41	281.0	6600	170
Brentwood	inlet	D	Jul 22, 2004	20.0	6.99	6.73	293.0	68,000	330
Brentwood	outlet	A	Jul 20, 2004	28.0	7.32	14.20	199.0	150	140
Brentwood	outlet	B	Jul 21, 2004	22.2	7.06	7.58	199.0	49	35
Brentwood	outlet	C	Jul 21, 2004	26.2	7.51	13.80	198.0	60	10
Brentwood	outlet	D	Jul 22, 2004	22.5	7.20	6.44	199.0	58	56
Seasonal % reduction				-23.3	-4.5	-45.6	30.5	99.7	88.5
Annual % reduction				-1.9	-5.8	-23.0	6.9	95.3	87.7

*Value replaced with detection limit to calculate percent reduction.

Table 22: Brentwood wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D. Negative values indicate an increase in concentration at the outlet.

Site	Source	Time	Date	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
Park Place	inlet	A	Feb 17, 2004	7.3	7.46	11.47	283.0	31,000	36,000
Park Place	inlet	B	Feb 18, 2004	7.5	7.47	11.39	154.0	5200	6400
Park Place	inlet	C	Feb 18, 2004	7.7	7.41	11.12	148.0	600	400
Park Place	inlet	D	Feb 19, 2004	NA	7.38	11.33	174.0	1000	730
Park Place	outlet	A	Feb 17, 2004	NA	NA	NA	NA	NA	NA
Park Place	outlet	B	Feb 18, 2004	6.7	7.48	10.39	187.0	750	890
Park Place	outlet	C	Feb 18, 2004	7.7	7.55	11.22	166.0	500	130
Park Place	outlet	D	Feb 19, 2004	NA	7.27	10.36	168.0	230	29
Seasonal % reduction				4.0	-0.0	5.9	8.5	94.8	96.8
Park Place	inlet	A	Jul 20, 2004	19.5	7.84	8.31	238.0	53	26
Park Place	inlet	B	Jul 21, 2004	19.2	7.70	8.54	226.0	800	400
Park Place	inlet	C	Jul 21, 2004	21.0	7.64	8.34	168.0	6700	94
Park Place	inlet	D	Jul 22, 2004	19.2	7.44	7.94	225.0	37	28
Park Place	outlet	A	Jul 20, 2004	21.0	7.01	16.70	242.0	1	1
Park Place	outlet	B	Jul 21, 2004	20.8	7.02	8.75	238.0	10	7
Park Place	outlet	C	Jul 21, 2004	20.0	7.07	17.20	236.0	7	3
Park Place	outlet	D	Jul 22, 2004	21.0	7.07	8.28	241.0	5	1
Seasonal % reduction				-4.9	8.0	-53.7	-11.7	99.7	97.8
Annual % reduction				-0.5	4.0	-23.9	-1.6	97.2	97.3

Table 23: Park Place wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D. Negative values indicate an increase in concentration at the outlet.

Site	Source	Time	Date	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
SC	inlet	A	Nov 11, 2003	9.5	7.48	10.02	238	790	760
SC	inlet	B	Nov 12, 2003	10.5	7.43	9.60	285	240	150
SC	inlet	C	Nov 12, 2003	10.5	7.39	9.42	298	510	360
SC	inlet	D	Nov 13, 2003	10.5	7.43	9.38	325	300	270
SC	outletE	A	Nov 11, 2003	9.0	7.60	7.72	256	64	54
SC	outletE	B	Nov 12, 2003	9.0	7.55	7.51	292	30	26
SC	outletE	C	Nov 12, 2003	9.0	7.53	7.43	302	11	9
SC	outletE	D	Nov 13, 2003	8.0	7.48	7.22	324	5	7
SC	outletW	A	Nov 11, 2003	8.5	7.64	7.88	261	64	50
SC	outletW	B	Nov 12, 2003	9.0	7.52	7.10	288	16	12
SC	outletW	C	Nov 12, 2003	9.0	7.54	7.36	297	11	12
SC	outletW	D	Nov 13, 2003	8.0	7.53	7.11	319	7	3
Seasonal % reduction				15.2	-1.6	22.8	-2.0	94.4	94.4
SC	inlet	A	Jan 26, 2004	8.5	7.60	9.48	287.0	63	27
SC	inlet	B	Jan 27, 2004	8.1	7.62	9.80	261.0	67	36
SC	inlet	C	Jan 27, 2004	8.5	7.66	9.81	255.0	380	260
SC	inlet	D	Jan 28, 2004	8.3	7.56	9.69	240.0	260	68
SC	outletE	A	Jan 26, 2004	8.7	7.53	10.73	280.0	6	3
SC	outletE	B	Jan 27, 2004	8.3	7.59	10.92	247.0	7	4
SC	outletE	C	Jan 27, 2004	8.5	7.61	10.92	253.0	100	43
SC	outletE	D	Jan 28, 2004	8.4	7.61	11.05	225.0	50	34
SC	outletW	A	Jan 26, 2004	8.5	7.47	9.57	288.0	4	3
SC	outletW	B	Jan 27, 2004	8.1	7.49	9.08	266.0	11	6
SC	outletW	C	Jan 27, 2004	8.4	7.53	10.46	256.0	140	44
SC	outletW	D	Jan 28, 2004	8.3	7.68	10.01	236.0	130	40
Seasonal % reduction				-0.6	0.6	-6.7	1.7	70.9	77.4
SC	inlet	A	Aug 24, 2004	18.0	7.41	8.21	306.0	360	310
SC	inlet	B	Aug 24, 2004	18.0	7.45	8.74	245.0	1300	540
SC	inlet	C	Aug 25, 2004	17.8	7.33	8.55	171.0	1300	1100
SC	inlet	D	Aug 25, 2004	17.8	7.38	8.74	211.0	1600	1200
SC	outletE	A	Aug 24, 2004	17.6	7.24	13.70	304.0	170	180
SC	outletE	B	Aug 24, 2004	17.9	7.28	6.38	273.0	550	620
SC	outletE	C	Aug 25, 2004	17.7	7.27	6.77	177.0	790	800
SC	outletE	D	Aug 25, 2004	17.8	7.27	6.92	203.0	950	660
SC	outletW	A	Aug 24, 2004	NA	NA	NA	NA	NA	NA
SC	outletW	B	Aug 24, 2004	17.9	7.41	6.70	263.0	1500	1500
SC	outletW	C	Aug 25, 2004	17.8	7.33	7.25	176.0	740	540
SC	outletW	D	Aug 25, 2004	17.9	7.34	7.54	205.0	710	530
Seasonal % reduction				0.6	1.2	7.8	1.9	32.2	12.4
Annual % reduction				5.1	0.1	8.0	0.5	65.8	61.4

Table 24: South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D. Negative values indicate an increase in concentration at the outlet.

Site	Source	Sample	Date	Temp (°C)	pH	DO (mg/L	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
Parkstone swale	inlet1	A	Nov 18, 2003	NA	6.81	10.76	40.9	270	160
Parkstone swale	inlet1	B	Nov 18, 2003	6.6	6.77	11.05	37.4	48	100
Parkstone swale	inlet1	C	Nov 19, 2003	8.3	6.29	6.72	114.5	36	22
Parkstone swale	inlet1	D	Nov 19, 2003	8.5	6.32	9.01	112.6	3	8
Parkstone swale	inlet2	A	Nov 18, 2003	NA	7.10	NA	61.9	1200	840
Parkstone swale	inlet2	B	Nov 18, 2003	7.0	7.05	NA	67.0	250	240
Parkstone swale	inlet2	C	Nov 19, 2003	7.5	6.76	NA	86.7	120	120
Parkstone swale	inlet2	D	Nov 19, 2003	7.3	6.80	NA	91.8	74	54
Parkstone swale	outlet	A	Nov 18, 2003	NA	6.96	10.00	62.4	470	420
Parkstone swale	outlet	B	Nov 18, 2003	6.8	6.96	10.36	59.6	400	390
Parkstone swale	outlet	C	Nov 19, 2003	6.7	6.79	9.99	80.5	150	120
Parkstone swale	outlet	D	Nov 19, 2003	6.9	6.80	6.81	87.1	58	33
Seasonal % reduction				9.7	-2.1	1.0	5.5	-7.8	-24.7
Parkstone pond	inlet	A	Nov 18, 2003	NA	6.76	NA	79.2	640	620
Parkstone pond	inlet	B	Nov 18, 2003	7.3	6.74	NA	80.4	320	390
Parkstone pond	inlet	C	Nov 19, 2003	8.0	6.47	NA	125.5	240	170
Parkstone pond	inlet	D	Nov 19, 2003	7.7	6.46	NA	134.0	230	140
Parkstone pond	outlet	A	Nov 18, 2003	NA	6.92	10.07	90.8	300	480
Parkstone pond	outlet	B	Nov 18, 2003	7.5	6.95	9.96	96.9	250	320
Parkstone pond	outlet	C	Nov 19, 2003	7.0	6.70	8.77	109.8	280	240
Parkstone pond	outlet	D	Nov 19, 2003	6.8	6.70	9.47	115.8	380	300
Seasonal % reduction				7.4	-3.2	NA	1.4	15.4	-1.5
Silvern	inlet	A	May 10, 2004	9.3	7.13	9.45	41.1	1500	240
Silvern	outlet	A	May 10, 2004	14.3	6.78	7.13	51.1	810	290
Seasonal % reduction				-53.8	4.9	24.6	-23.4	46.0	87.9

Table 25: Parkstone and Silvern grab samples and average percent reductions between inlet and outlet samples, temperature, oxygen, conductivity, and coliform data. Sample collection times were sequential from A–D. Negative values represent an increase in concentration at the outlet.

Site	Source	Sample	Date	TSS (mg/L)	TOC (mg/L)	TN (mg/L)	TP (mg/L)	Gasoline (mg/L)	Diesel (mg/L)	Oil (mg/L)
Parkstone swale	inlet1	A	Nov 18, 2003	30.47	NA	0.646	0.104	NA	NA	NA
Parkstone swale	inlet1	B	Nov 18, 2003	25.23	NA	0.554	0.081	NA	NA	NA
Parkstone swale	inlet1	C	Nov 19, 2003	7.47	NA	1.651	0.038	NA	NA	NA
Parkstone swale	inlet1	D	Nov 19, 2003	1.28	NA	1.622	0.028	NA	NA	NA
Parkstone swale	inlet2	A	Nov 18, 2003	199.73	NA	0.829	0.292	NA	NA	NA
Parkstone swale	inlet2	B	Nov 18, 2003	293.90	7.1	0.962	0.352	NA	NA	NA
Parkstone swale	inlet2	C	Nov 19, 2003	11.22	NA	1.593	0.075	NA	NA	NA
Parkstone swale	inlet2	D	Nov 19, 2003	11.28	NA	1.746	0.070	NA	NA	NA
Parkstone swale	outlet	A	Nov 18, 2003	23.87	NA	0.606	0.100	NA	NA	NA
Parkstone swale	outlet	B	Nov 18, 2003	38.13	7.1	0.642	0.114	NA	NA	NA
Parkstone swale	outlet	C	Nov 19, 2003	6.83	NA	1.203	0.075	NA	NA	NA
Parkstone swale	outlet	D	Nov 19, 2003	5.12	NA	1.436	0.061	NA	NA	NA
Seasonal % reduction				74.5	NA	19.0	32.7	NA	NA	NA
Parkstone pond	inlet	A	Nov 18, 2003	20.98	NA	1.070	0.096	NA	NA	NA
Parkstone pond	inlet	B	Nov 18, 2003	34.62	NA	1.179	0.122	NA	NA	NA
Parkstone pond	inlet	C	Nov 19, 2003	5.12	NA	2.062	0.076	NA	NA	NA
Parkstone pond	inlet	D	Nov 19, 2003	3.57	NA	2.063	0.066	NA	NA	NA
Parkstone pond	outlet	A	Nov 18, 2003	14.55	NA	1.537	0.177	NA	NA	NA
Parkstone pond	outlet	B	Nov 18, 2003	14.68	1.6	1.875	0.096	NA	NA	NA
Parkstone pond	outlet	C	Nov 19, 2003	14.45	NA	2.232	0.113	NA	NA	NA
Parkstone pond	outlet	D	Nov 19, 2003	16.50	NA	2.666	0.118	NA	NA	NA
Seasonal % reduction				6.4	NA	-30.4	-40.0	NA	NA	NA
Silvern	inlet	A	May 10, 2004	4.68	2.8	1.047	0.074	0.11	0.17	0.38
Silvern	outlet	A	May 10, 2004	3.55	9.1	1.066	0.068	0.12	0.16	0.51
Seasonal % reduction				24.1	-225.0	-1.8	8.1	-9.1	5.9	-34.2

Table 26: Parkstone and Silvern grab samples and average percent reductions between inlet and outlet samples, suspended solids, organic carbon, nitrogen, phosphorus, and hydrocarbon data coliform data. Sample collection times were sequential from A–D. Negative values indicate an increase in concentration at the outlet.

Figure 34: Brentwood wet pond, July 20, 2004.

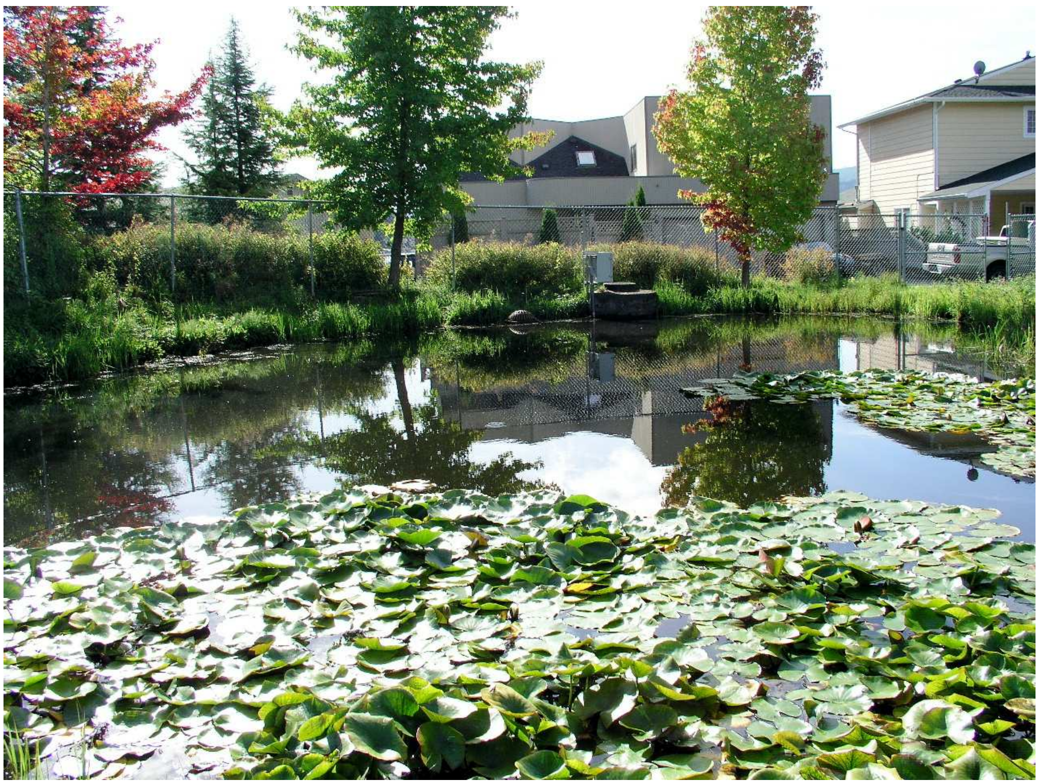

Figure 35: Park Place wet pond, July 20, 2004.

Figure 36: South Campus storm water treatment facility, August 26, 2004.

Figure 37: Parkstone water treatment facility, November 20, 2003.

Figure 38: Silvern storm water treatment vault, May 10, 2004.

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A Site Descriptions

Figures A1–A3 show the locations of the lake and creek monitoring sites. The four major lake sampling sites have been used since the early 1960's. Table A1 shows a summary of the identification codes that have been used for these five sites over time.

During the August 5, 1993 lake sampling, geographical locations for each site were determined using a GPS locater. These coordinates are listed below, but should be used with the caution because site locations in Lake Whatcom have always been approximate.

A.1 Lake Whatcom Monitoring Sites

Site 1 is located in basin 1 along a straight line from the Bloedel Donovan boat launch to a square, white house with a dark grey roof that is located about half way up the hillside (171 E. North Shore Rd.) The sampling site is at a point perpendicular to the second group of condominiums in a cluster of four. The depth at Site 1 should be at least 20 m. The GPS coordinates for Site 1 are 48° 45.36 N, 122° 24.38 W.

Site 2 is located in basin 2 just west of the intersection of a line between a boat house with a rust-colored roof (73 Strawberry Point) and the point of Geneva sill, and a line between three aspen trees on Lake Whatcom Blvd. and a red house on the west side of Strawberry sill (2170 Delestra Rd.). The depth at Site 2 should be at least 20 m. The GPS coordinates for Site 2 are 48° 44.36 N, 122° 22.54 W.

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

Site 3 is located 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. The GPS coordinates for Site 3 are 48° 44.16 N, 122° 20.09 W.

Site 4 is located at the intersection of a line between two points of land and a line parallel to the north edge of an inlet (see Figure A2). The depth at Site 4 should be at least 90 m. The GPS coordinates for Site 4 are 48° 41.41 N, 122° 18.15 W.

Site Code	Years Used	Site Description
1	1985–present	Located at approximately the deepest
11	1987–present	point in basin 1
A	1982–1984	
14	1982	(14 is near Site 1)
7	1960's–1981	
2	1985–present	Located at approximately the deepest
22	1987–present	point in basin 2
B	1982–1984	
13	1982	
6	1960's–1981	
Intake	1980–present	Located at the intake in basin 2
21	1987–present	
3	1985–present	Located at approximately the deepest
31	1987–present	point in N. sub-basin of basin 3
C	1982–1984	
5	1960's–1981	
4	1985–present	Located at approximately the deepest
32	1987–present	point in S. sub-basin of basin 3
E	1982–1984	
10	1960's–1981	

Table A1: Summary of site codes for Lake Whatcom water quality sampling.

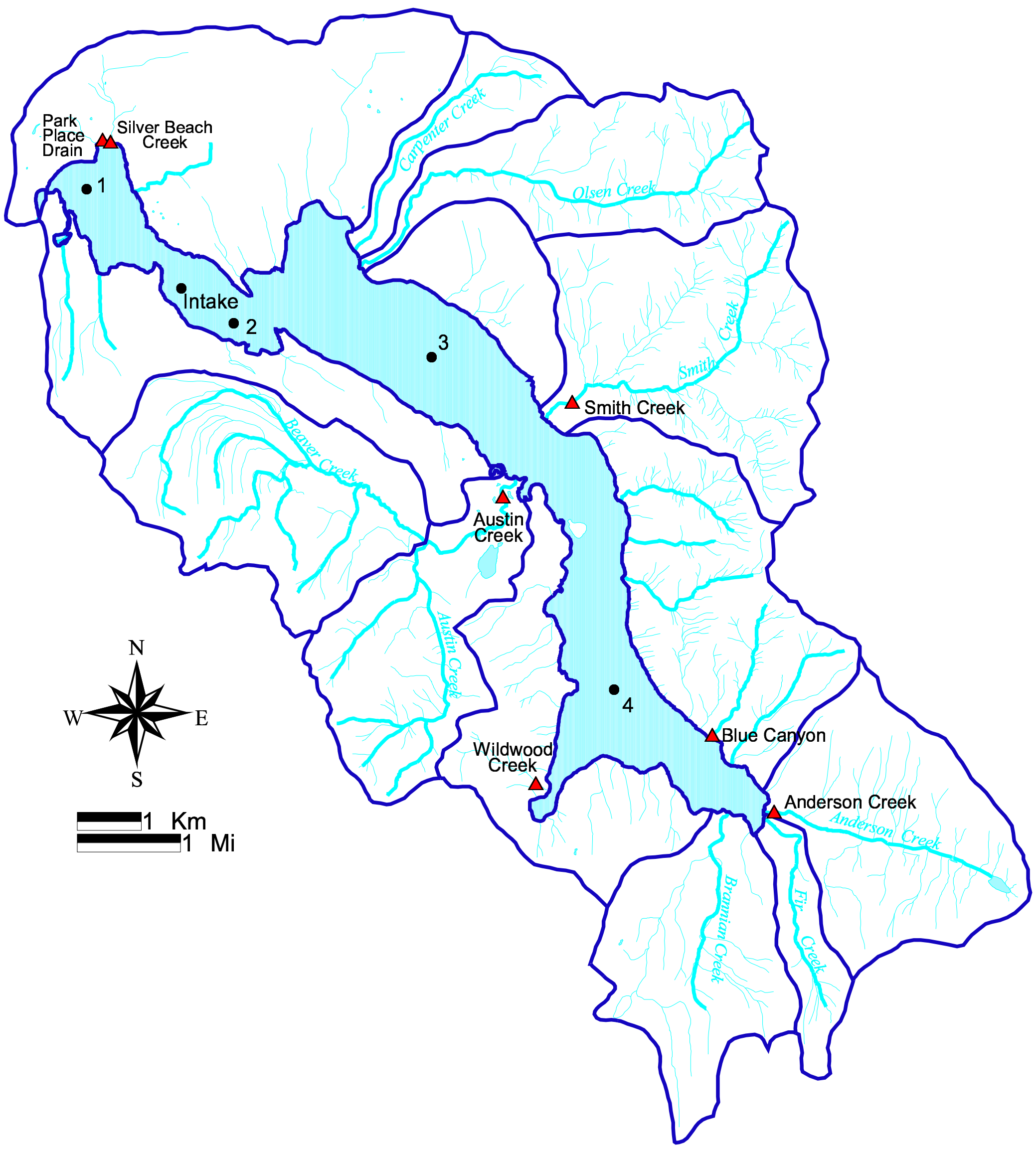


Figure A1: Lake Whatcom 2003/2004 lake and creek sampling sites.

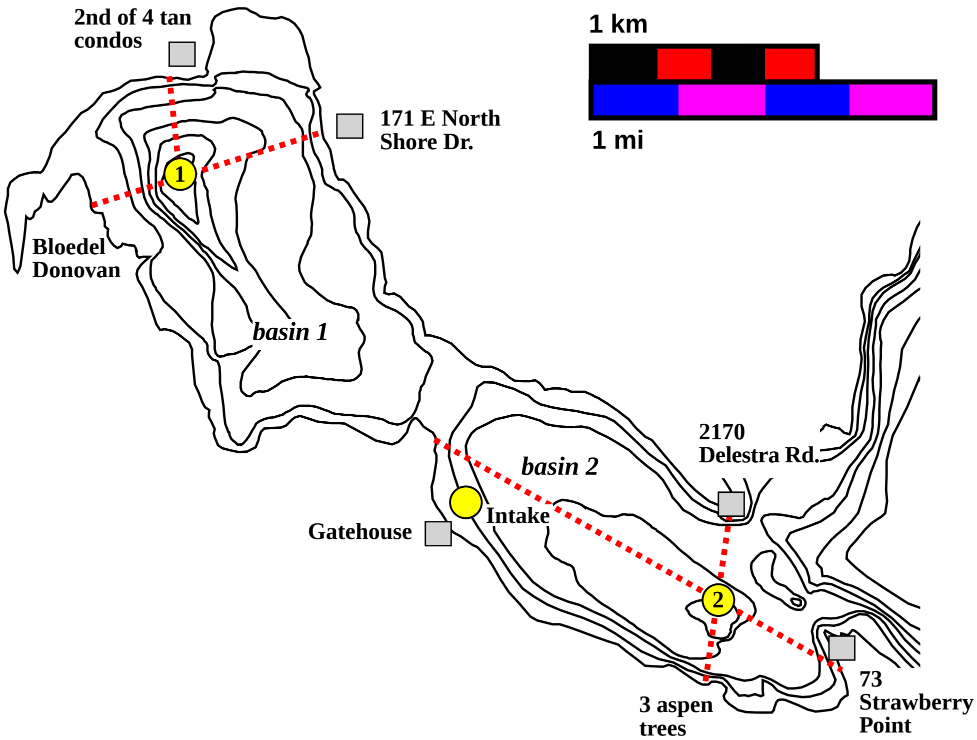


Figure A2: Lake Whatcom sampling sites, basins 1–2.

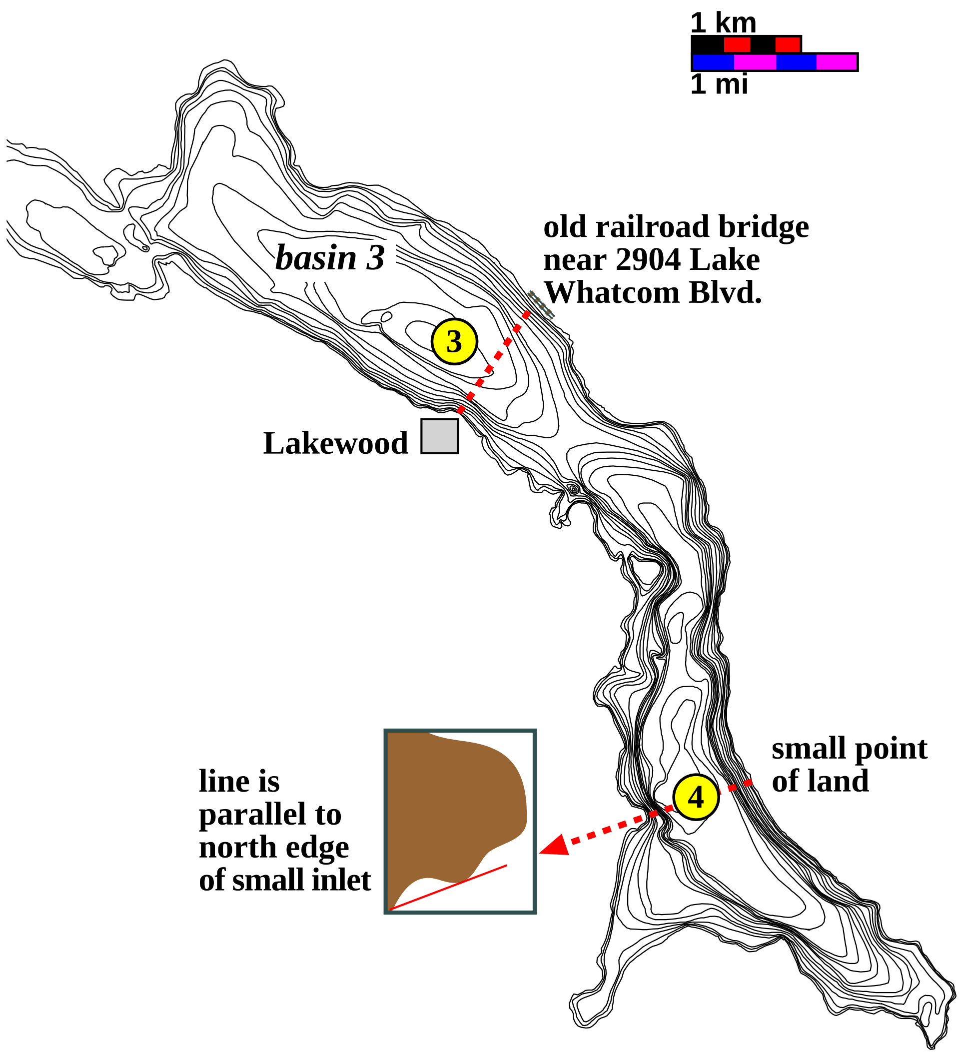


Figure A3: Lake Whatcom sampling sites, basin 3.

A.2 Creek Monitoring Sites

The creek water quality monitoring sites are described in detail by Walker, et al. (1992), and summarized below. Sites that have hydrograph data include a description of the location of the hydrograph gauge.

Smith Creek:
The Smith Creek hydrograph is mounted on the south wall of a sandstone bluff directly underneath the bridge over Smith Creek (North Shore Road) approximately 1 km upstream from the mouth the the creek. Water samples are collected at the gaging station. The GPS coordinates for Smith Creek at the bridge are 48° 43′ 55" N; 122° 18′ 31" W.

Silver Beach Creek:
All routine monitoring samples are collected immediately upstream from the culvert under North Shore Road. The GPS coordinates for Silver Beach Creek are 48° 46′ 07" N; 122° 24′ 25" W.

Park Place storm drain:
Samples are collected at the outlet from the storm water treatment system by accessing the storm drain manhole at Park Place (road off of North Shore Drive.) The GPS coordinates for the Park Place storm drain are 48° 46′ 08" N; 122° 24′ 33" W.

Austin Creek:
The Austin Creek gauge house is mounted on the east side of Lake Whatcom Blvd. (approximately 1 km upstream from the confluence with Lake Whatcom), with a bubbler system extending into the creek. Water samples are collected at the gaging station. The GPS coordinates for Austin Creek at the bridge are 48° 42′ 46" N; 122° 19′ 51" W.

Wildwood Creek:
The site is located approximately 30 feet south of the entrance to the Wildwood Resort at the culvert where South Lake Whatcom Boulevard crosses the creek. The GPS coordinates for Wildwood Creek at the culvert are 48° 40′ 40" N; 122° 19′ 07" W.

Anderson Creek:
The site is located at the bridge where South Bay Drive crosses the creek. Water samples and discharge measurements are collected upstream from the bridge.

The Anderson Creek hydrograph is mounted in the existing stilling well on the east side of Anderson Creek, directly adjacent to the bridge over Anderson Creek (South Bay Drive), approximately 0.5 km from the mouth of the creek. The GPS coordinates for Anderson Creek at the bridge are 48° 40′ 24” N; 122° 16′ 02” W.

Blue Canyon Creek:
This small creek is not shown on the USGS topographic map for the area. However, it is located just north of the two major Blue Canyon streams pictured on the USGS Lake Whatcom 7.5 min. quadrangle (Sect. 22, T 37N, R 4E). Samples are collected upstream from the culvert crossing the Blue Canyon road. The GPS coordinates for Blue Canyon Creek on Blue Canyon Road are 48° 41′ 08” N; 122° 16′ 58” W.

A.3 Storm Water Monitoring Sites

The storm water treatment monitoring sites are described below and the locations are illustrated in Figures A4–A5 (pages 103–104).

Brentwood wet pond:
The Brentwood storm water treatment facility is 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. No GPS coordinates are available for the Brentwood wet pond.

Park Place wet pond:
The Park Place storm water treatment facility 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 into an underground drain that flows directly into Lake Whatcom. The GPS coordinates for the Park Place wet pond are 48° 46′ 08” N; 122° 24′ 33” W.

South Campus storm water treatment facility:
The South Campus storm water treatment facility is located due south of the intersection between Bill McDonald Pky. and College Dr. The facility treats runoff from the southern portion of Western Washington University. The campus runoff flows into a large underground concrete settling vault (not sampled), located on the northwest corner of the intersection, then flows into a series of grass swales and gravel beds planted with aquatic vegetation. No GPS coordinates are available for the South Campus storm water treatment facility.

Parkstone storm water treatment facility: The Parkstone storm water treatment is located on the west side of Parkstone Ln. south of Lakeway Blvd. The facility is a complex system of grass swales, natural wetlands, and constructed ponds, with numerous inlets and outlets. We sample the two major inlets to the swale system, the swale outlet upstream from the pond, the major inlet into the pond (which includes flow from the swale and from new inlets) and the pond outlet. The pond outlet flows into Mill Wheel Creek, which is a tributary to Lake Whatcom. The GPS coordinates for the Parkstone storm water treatment facility are 48° 44′ 50” N; 122° 25′ 05” W.

Silvern storm water treatment vault:
The Silvern storm water treatment facility is located at the base of a cul de sac, north of North Shore Dr., and opposite the Park Place wet pond. The system consists of six underground canisters containing Perlite. The vault drains into the storm water connector that ties into the Park Place outlet. The GPS coordinates for the Silvern vault are 48° 46′ 09” N; 122° 24′ 34” W.

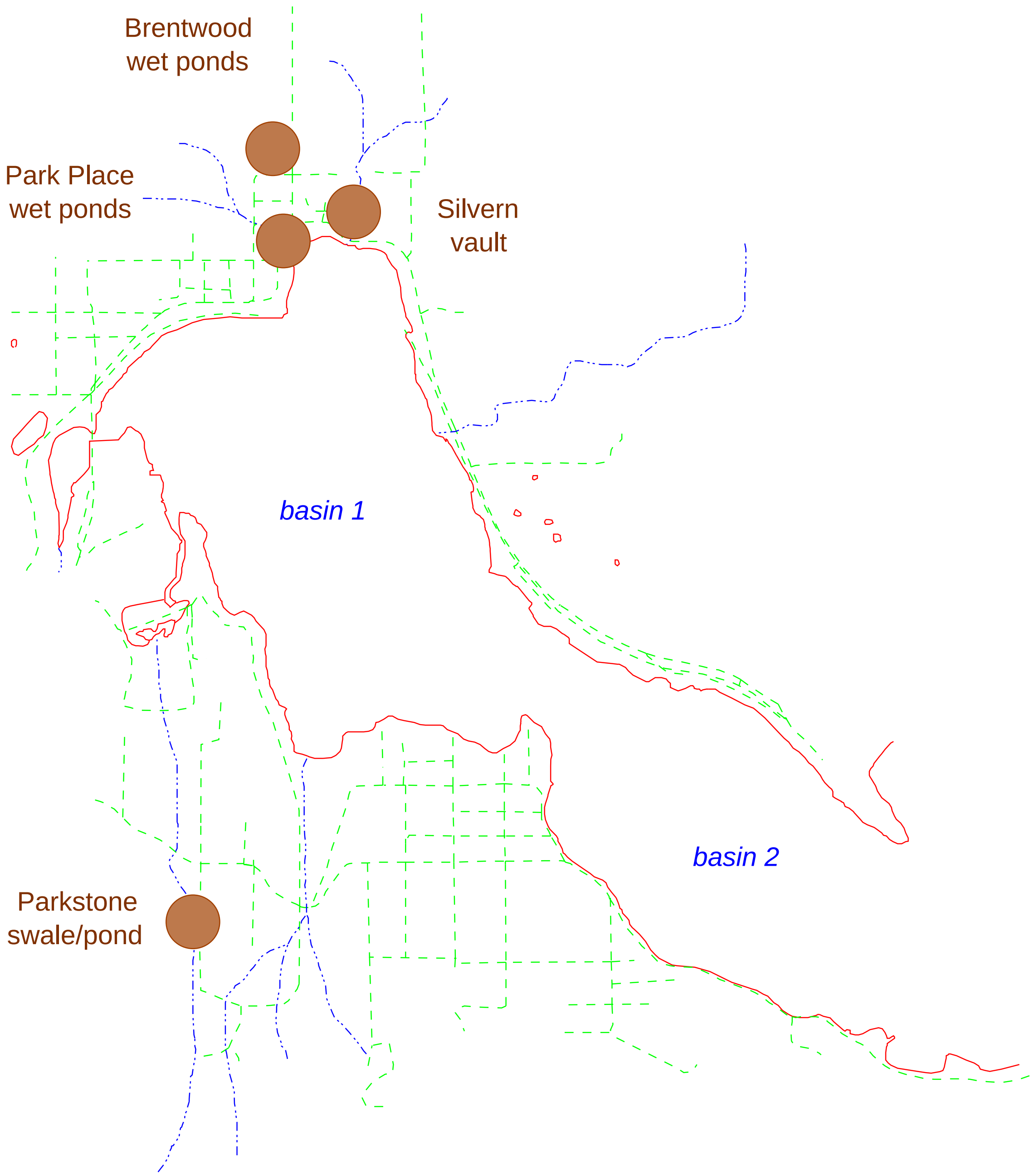


Figure A4: Locations of the Park Place and Brentwood wet ponds, the Parkstone swale/pond, and the Silvern vault.

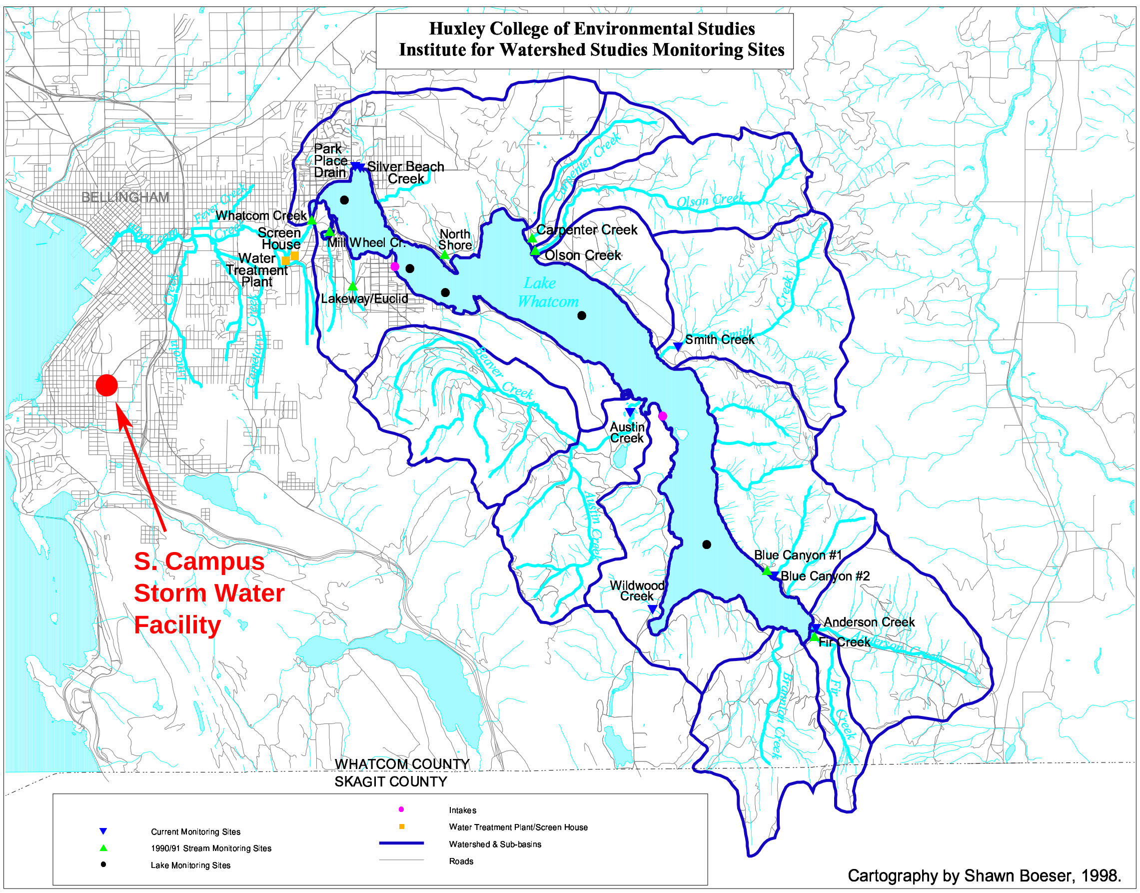


Figure A5: Locations of the South Campus storm water treatment facility.

B Lake Whatcom Historic 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 verified historic data set included on the CD with this report.

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, for example, current detection limits in Table 2, page 18). 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 173–177, 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. Trends that can not be explained by changes in analytical technique are discussed in Section 2.4 and in earlier reports.

Figure Category	**Pages**
Monthly Hydrolab Profiles	107 – 156
Temperature, Dissolved Oxygen, pH, and Conductivity	158 – 177
Alkalinity and Turbidity	179 – 188
Nitrogen and Phosphorus	190 – 214
Plankton, Chlorophyll, and Secchi Depth	216 – 235
Coliform Bacteria	237 – 246

B.1 Monthly Hydrolab Profiles

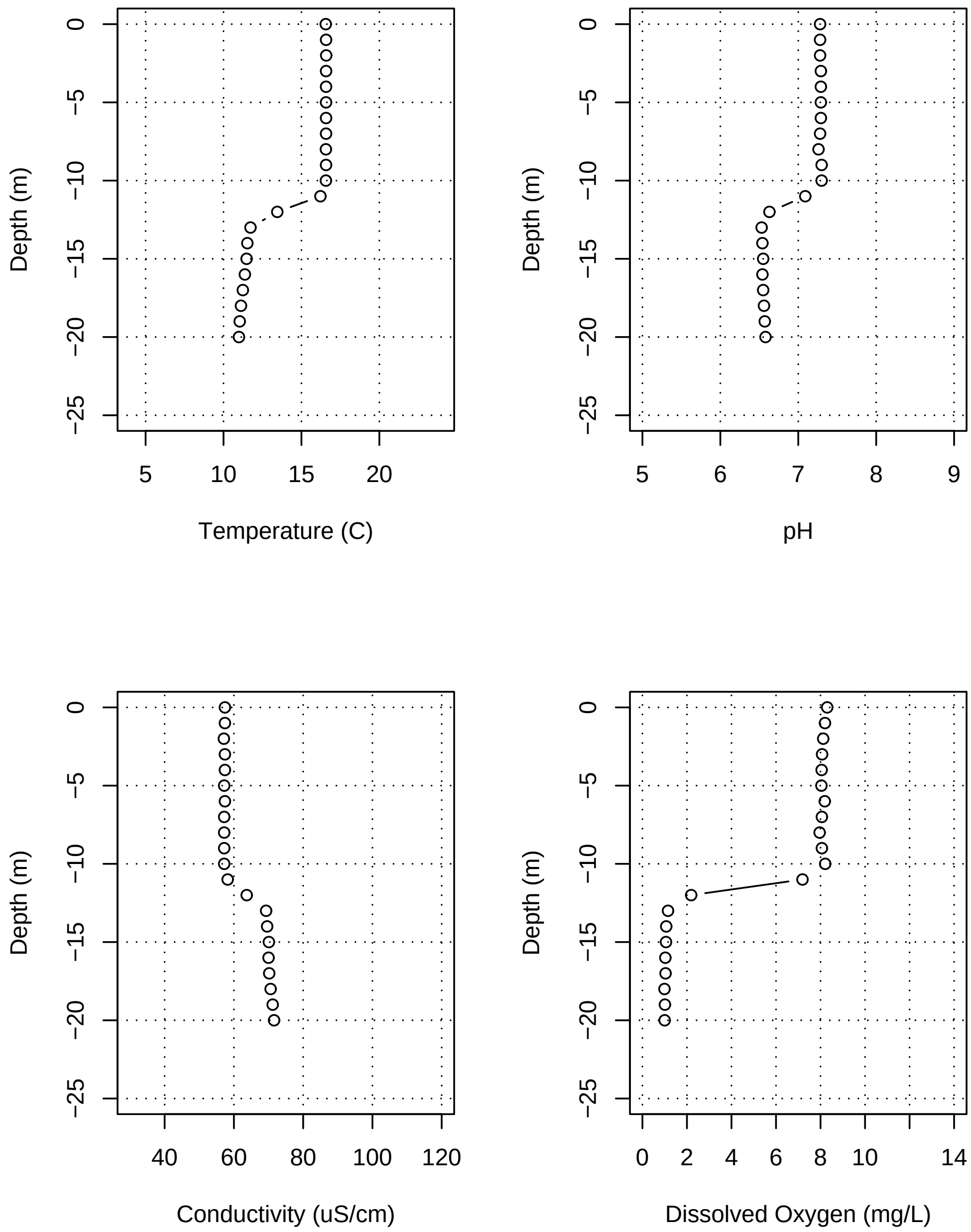


Figure B1: Lake Whatcom Hydrolab profile for Site 1, October 9, 2003.

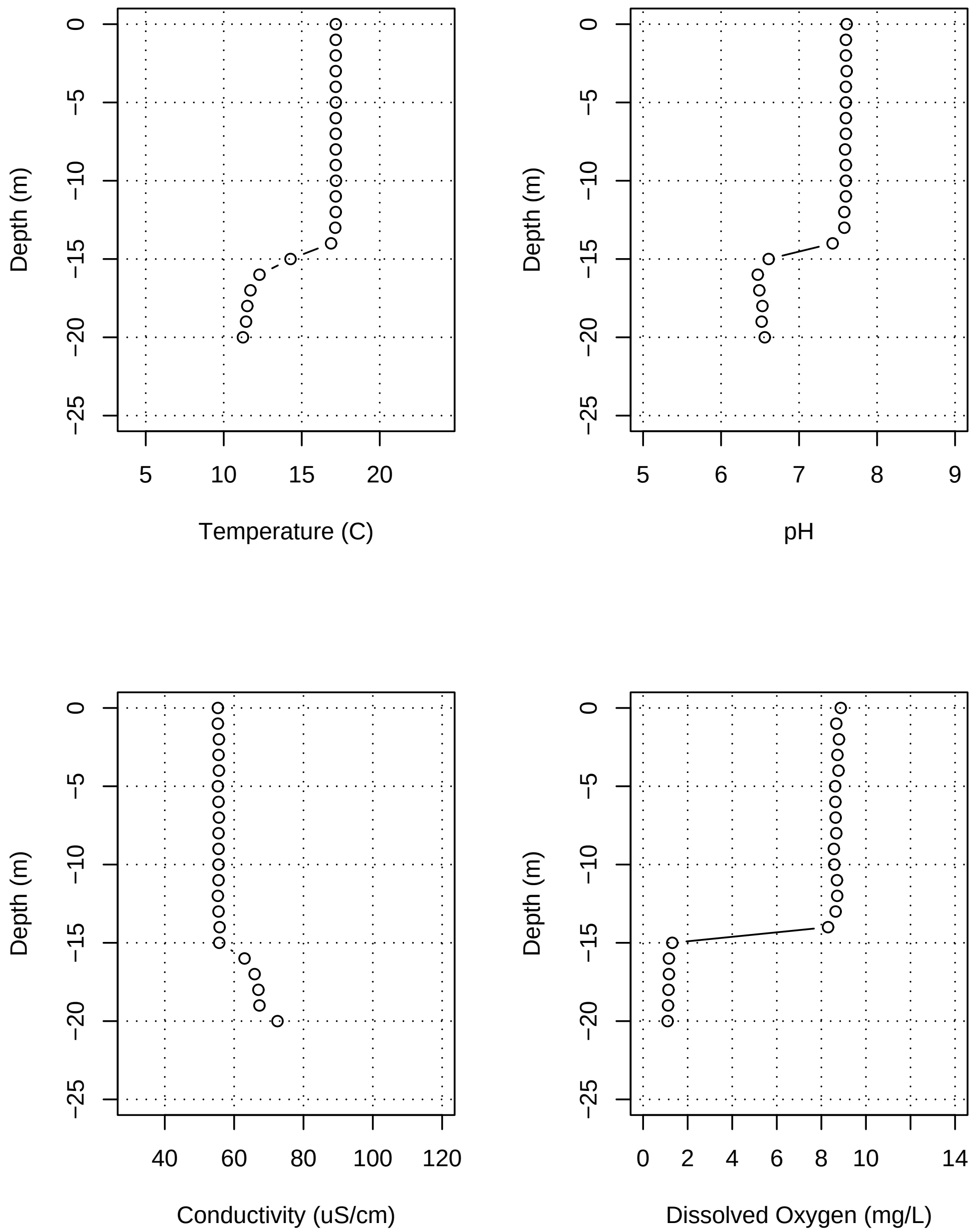


Figure B2: Lake Whatcom Hydrolab profile for Site 2, October 9, 2003.

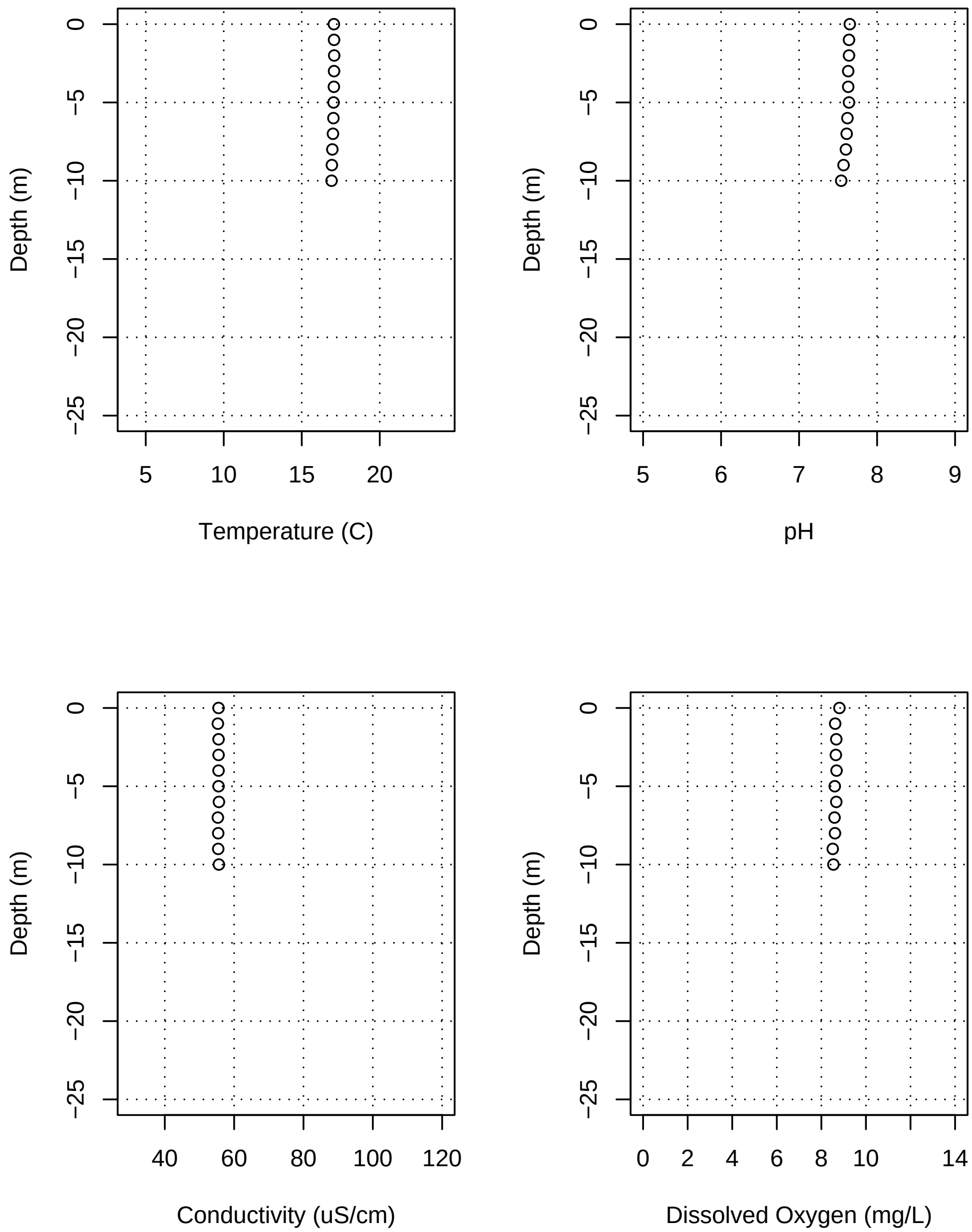


Figure B3: Lake Whatcom Hydrolab profile for the Intake, October 9, 2003.

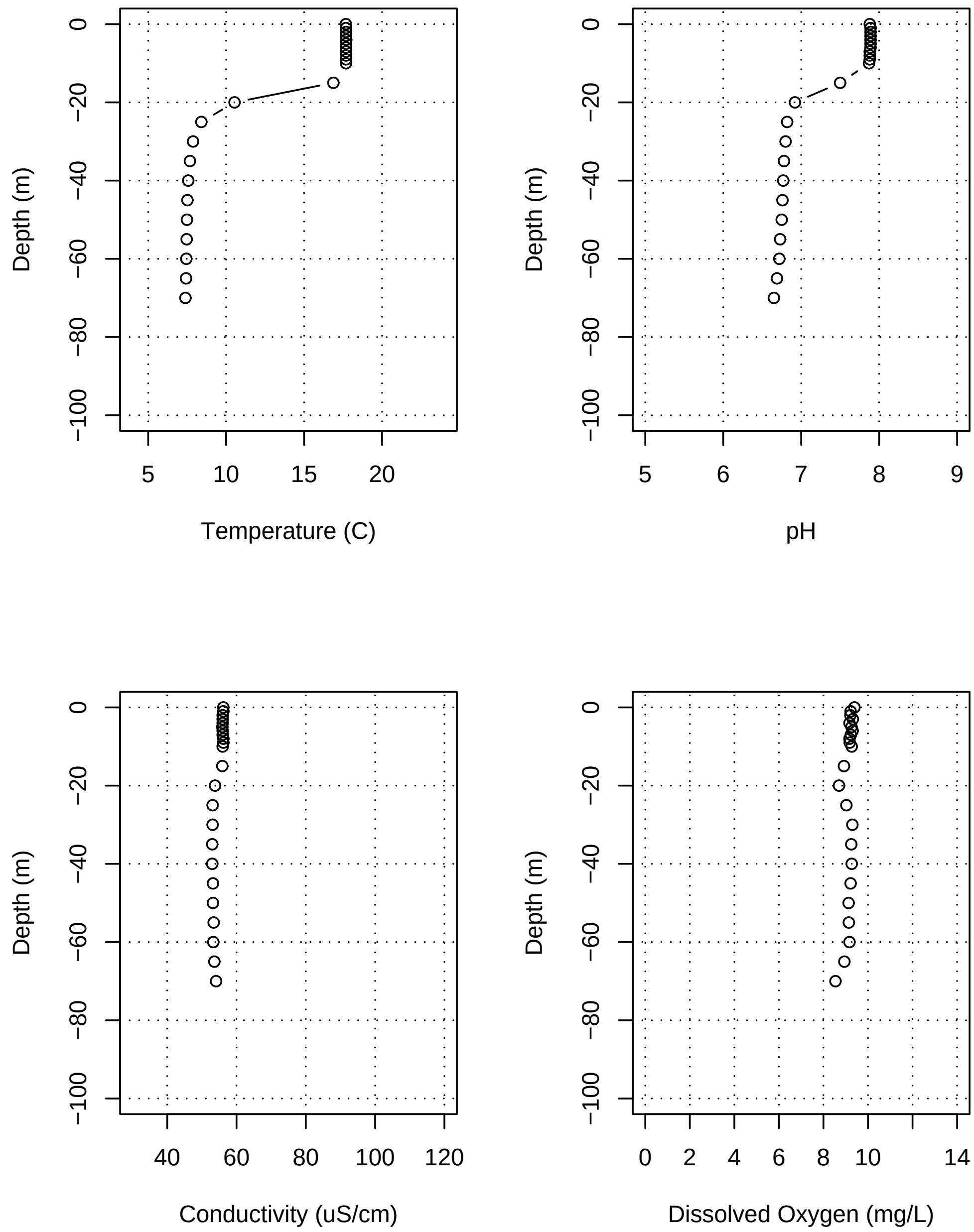


Figure B4: Lake Whatcom Hydrolab profile for Site 3, October 7, 2003.

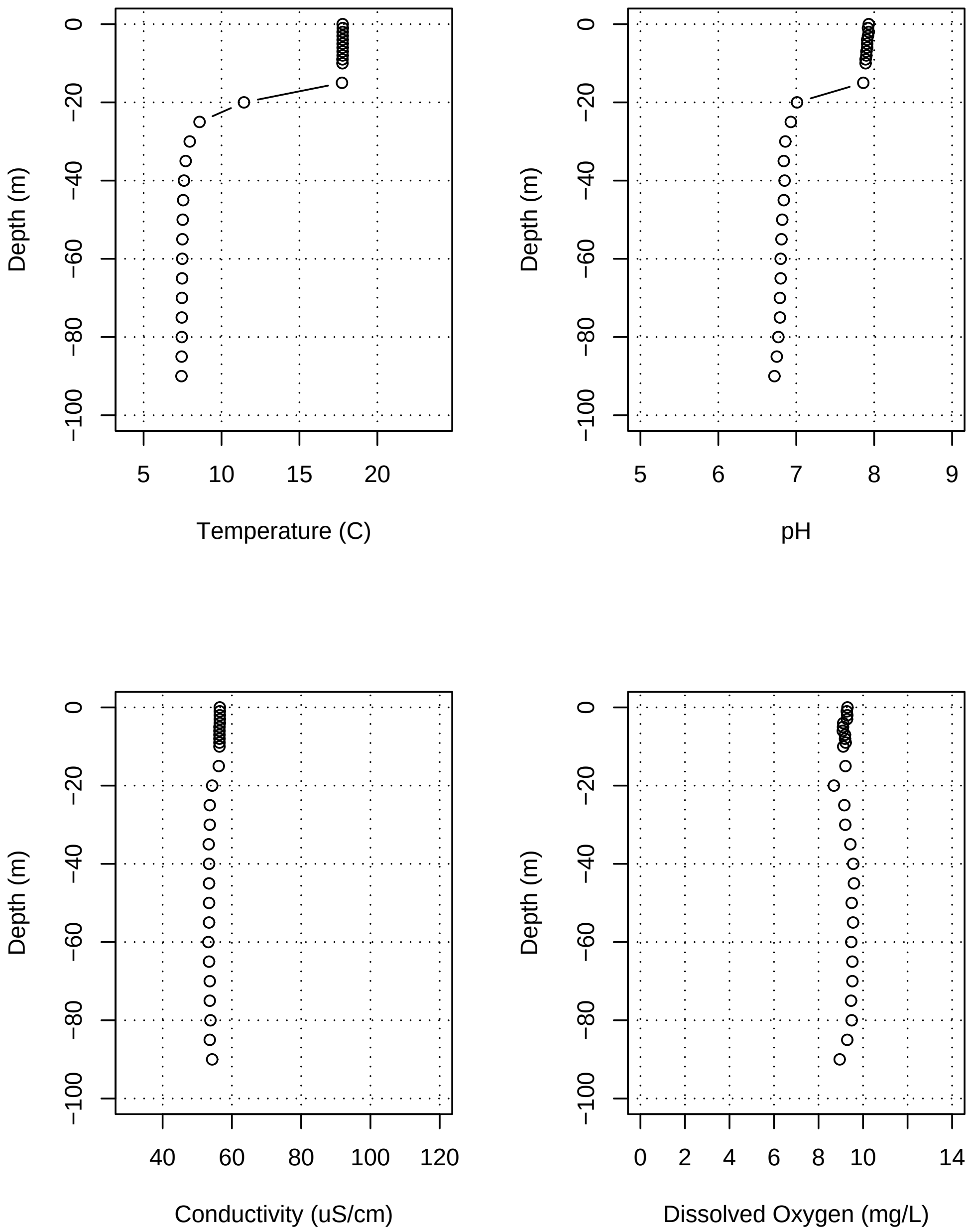


Figure B5: Lake Whatcom Hydrolab profile for Site 4, October 7, 2003.

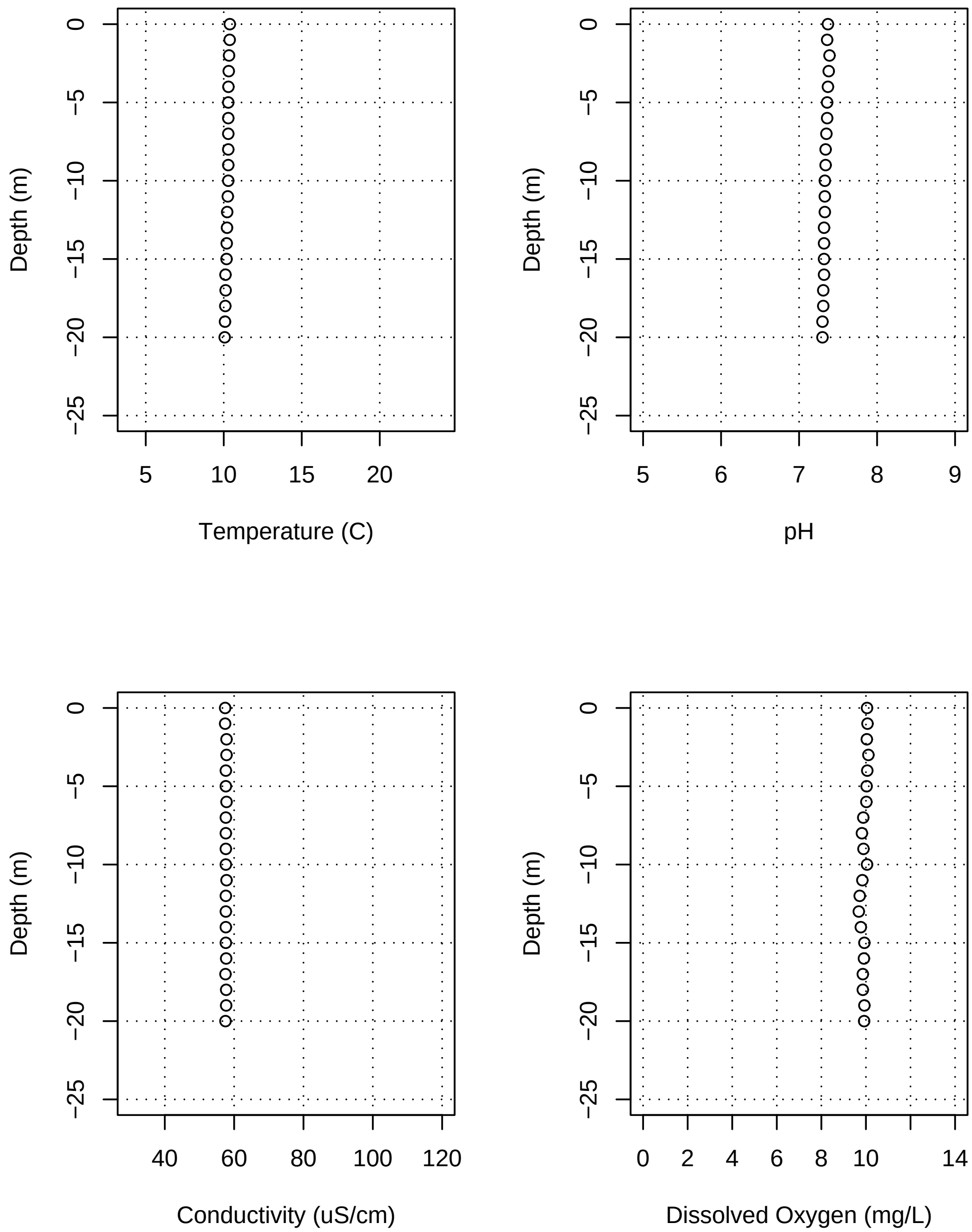


Figure B6: Lake Whatcom Hydrolab profile for Site 1, November 6, 2003.

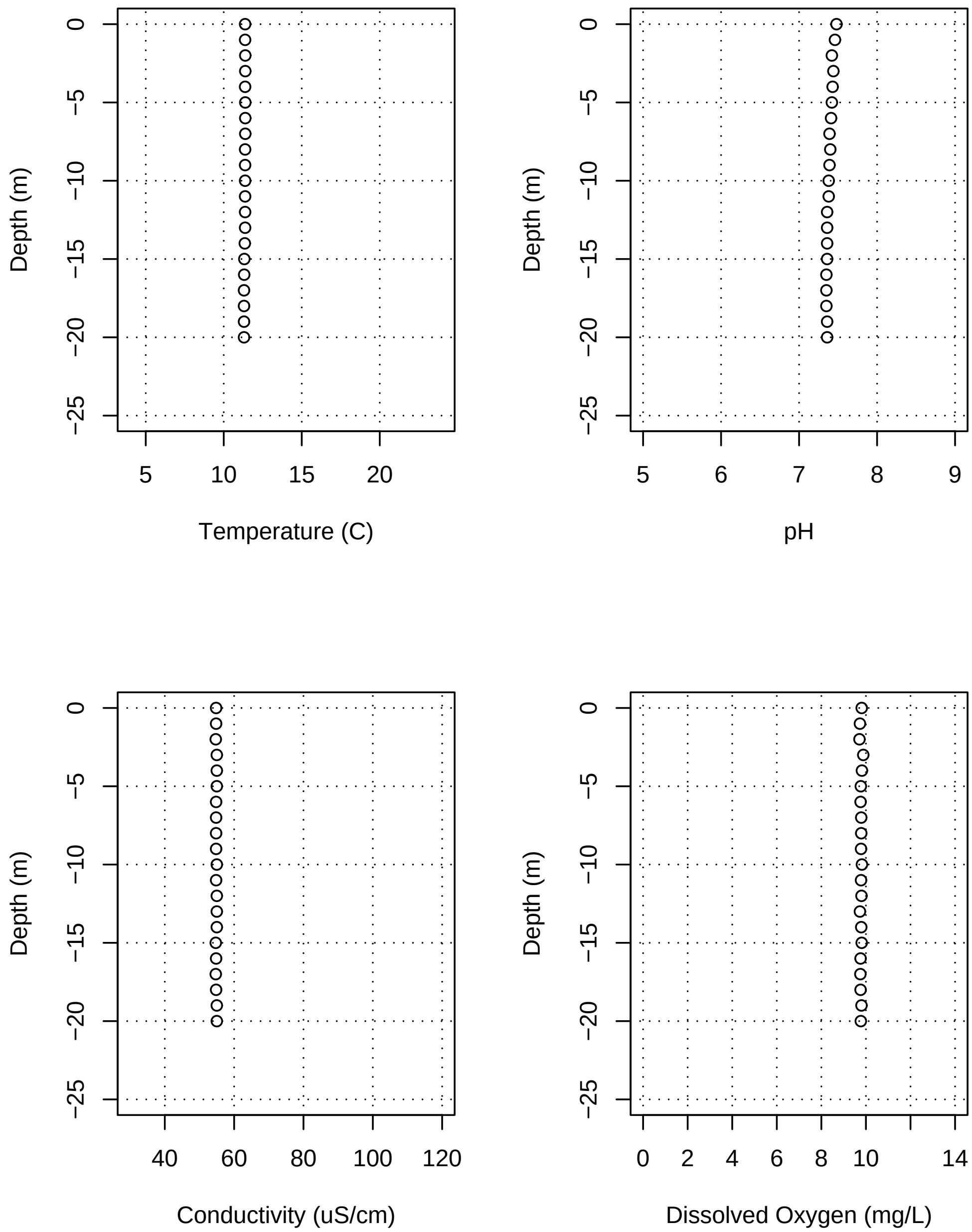


Figure B7: Lake Whatcom Hydrolab profile for Site 2, November 6, 2003.

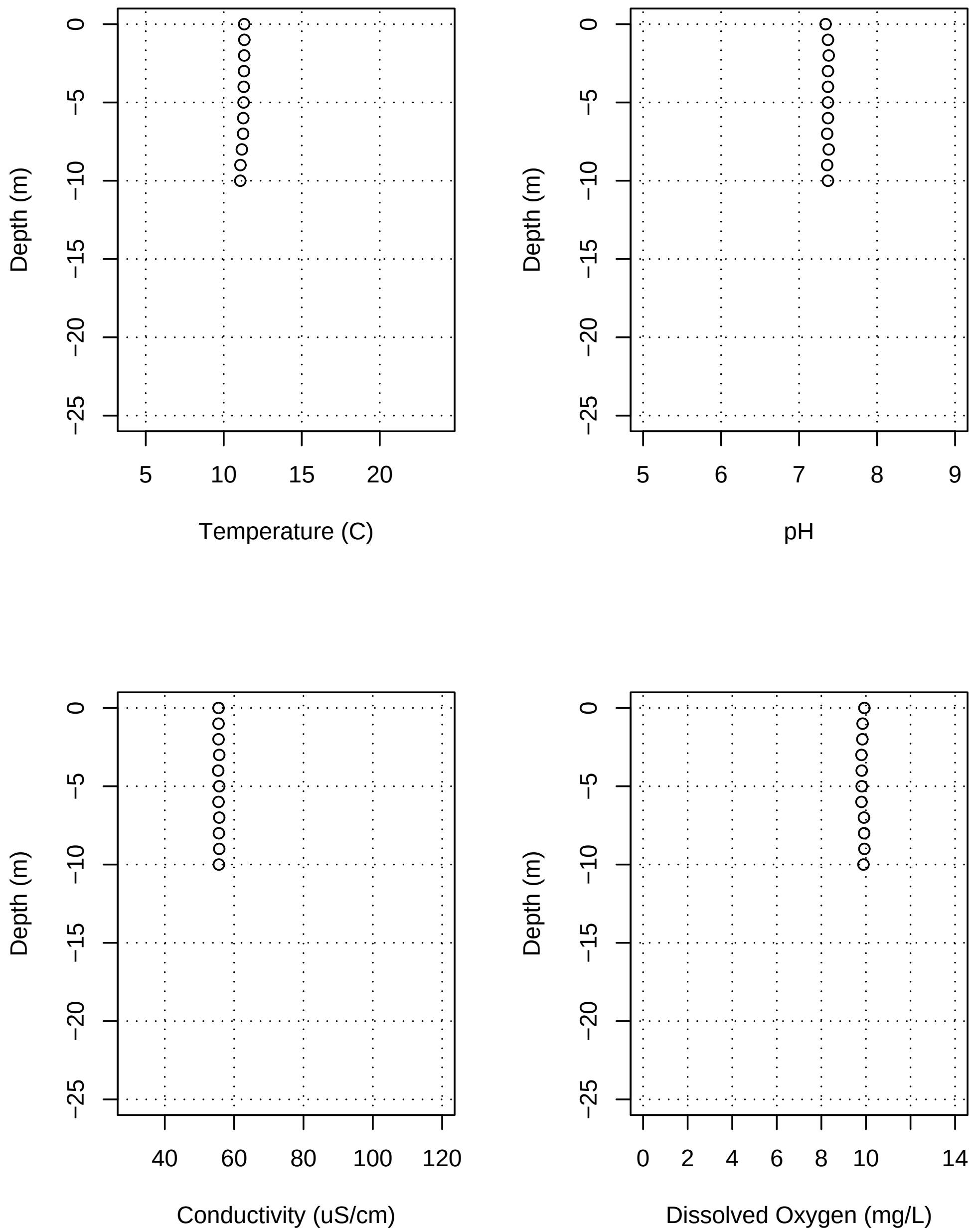


Figure B8: Lake Whatcom Hydrolab profile for the Intake, November 6, 2003.

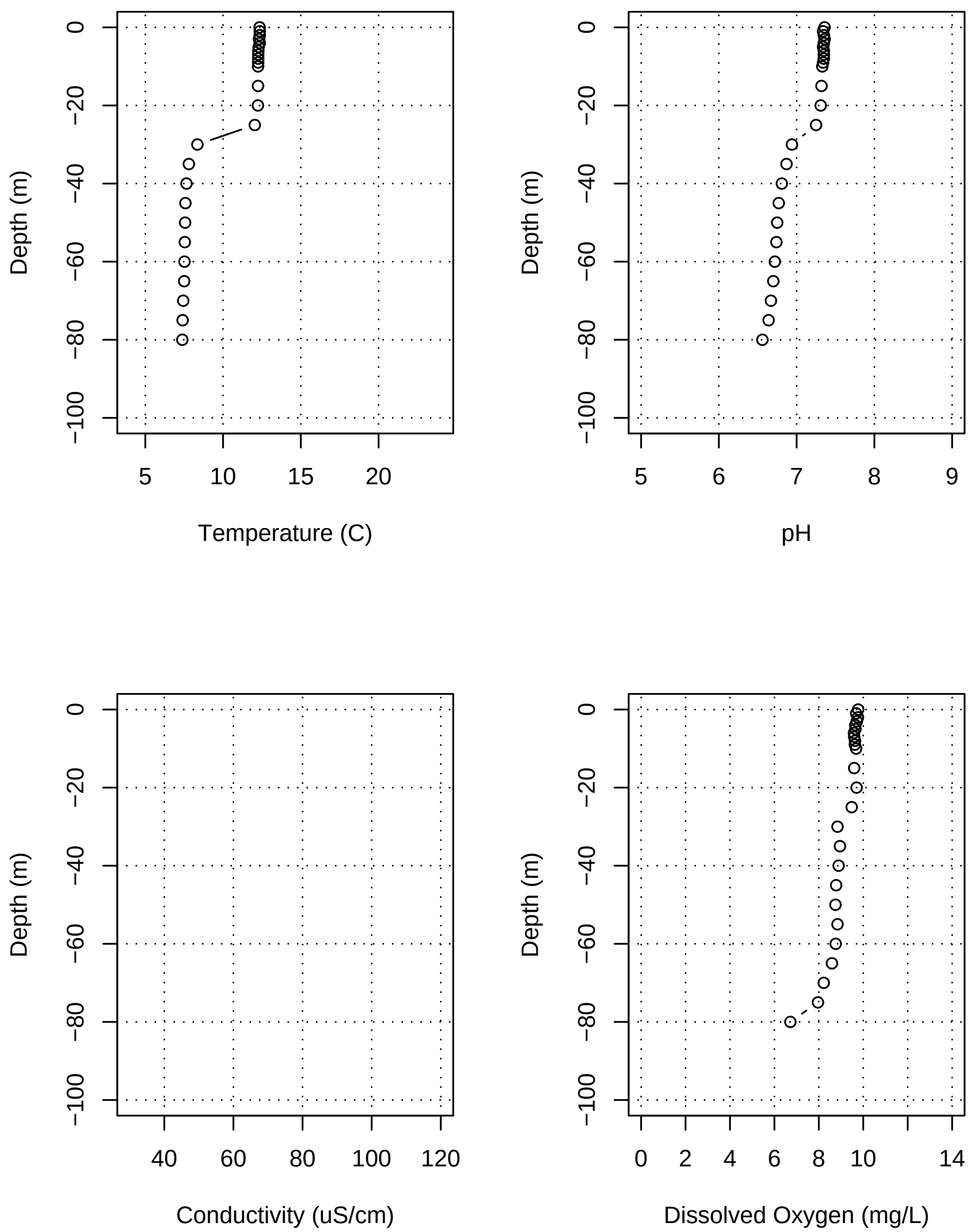


Figure B9: Lake Whatcom Hydrolab profile for Site 3, November 4, 2003. Conductivity data have been deleted due to Hydrolab malfunction.

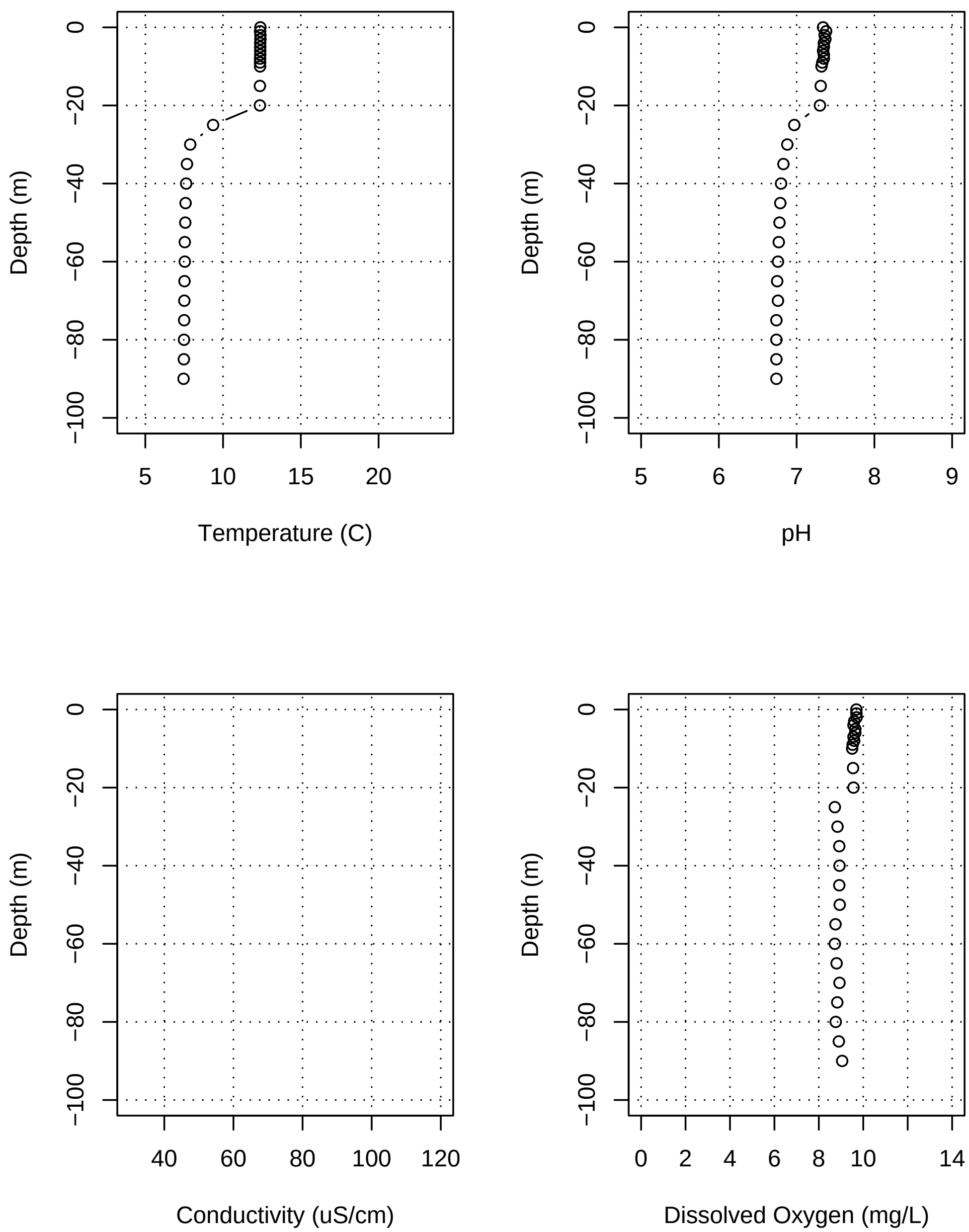


Figure B10: Lake Whatcom Hydrolab profile for Site 4, November 4, 2003. Conductivity data have been deleted due to Hydrolab malfunction.

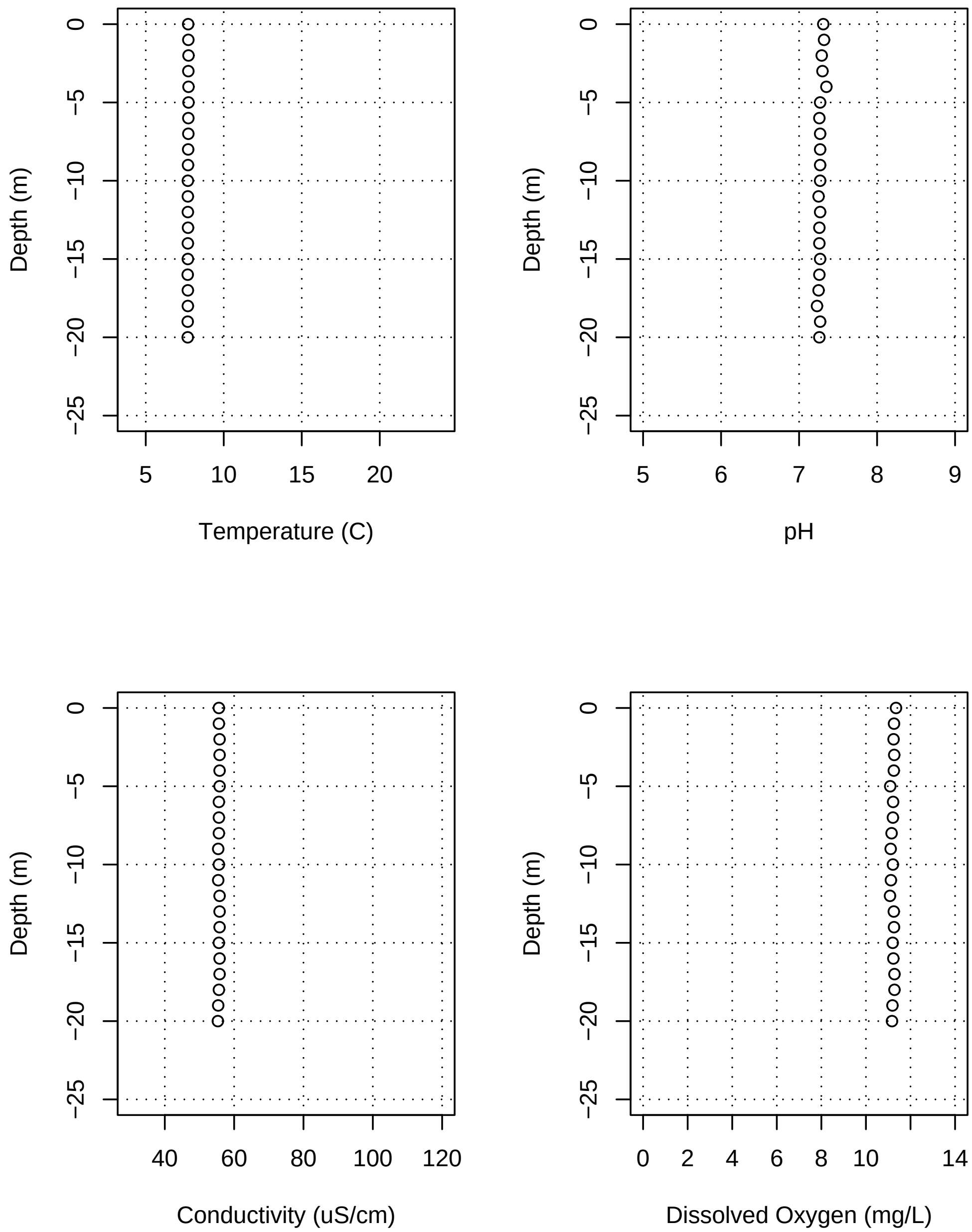


Figure B11: Lake Whatcom Hydrolab profile for Site 1, December 4, 2003.

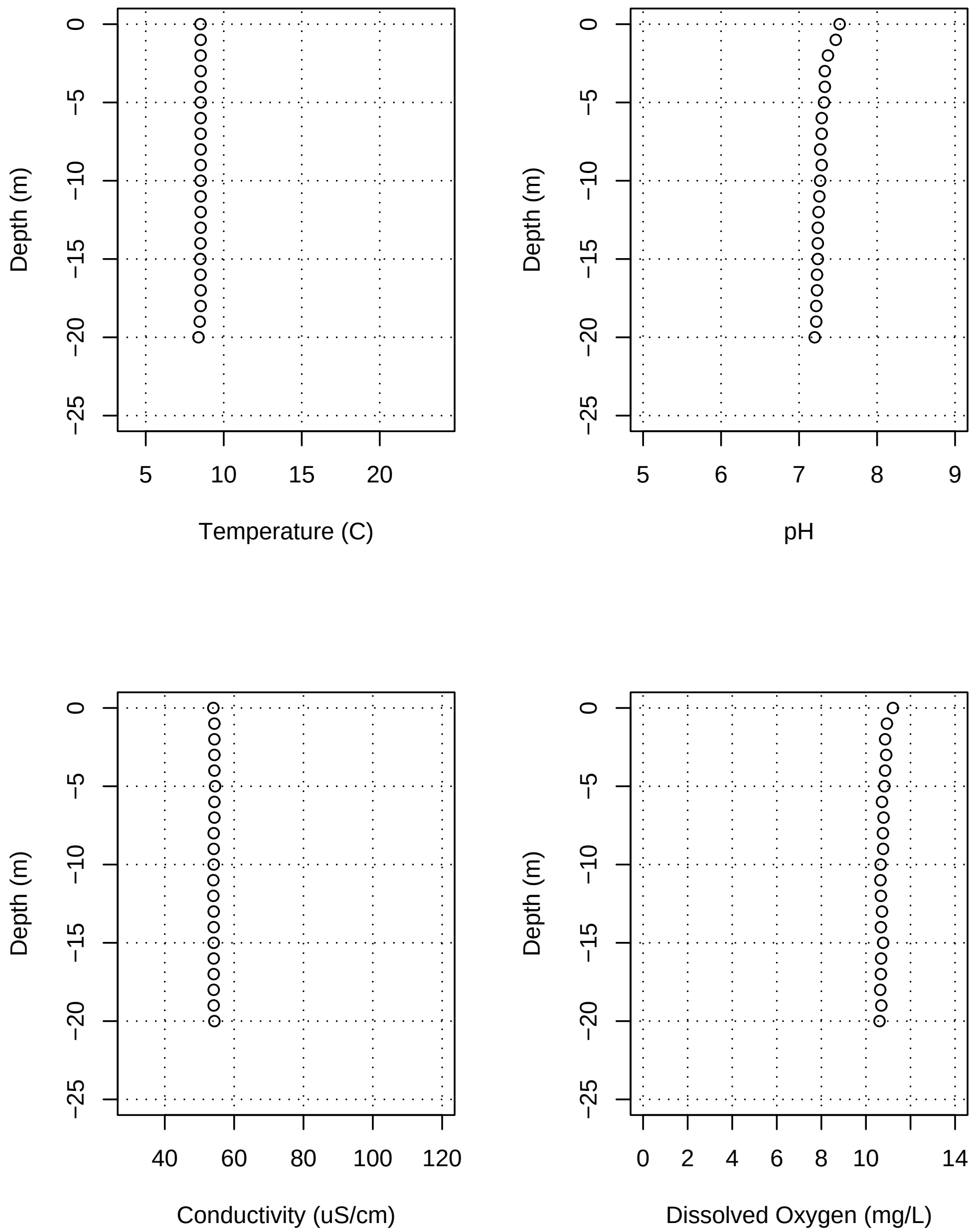


Figure B12: Lake Whatcom Hydrolab profile for Site 2, December 4, 2003.

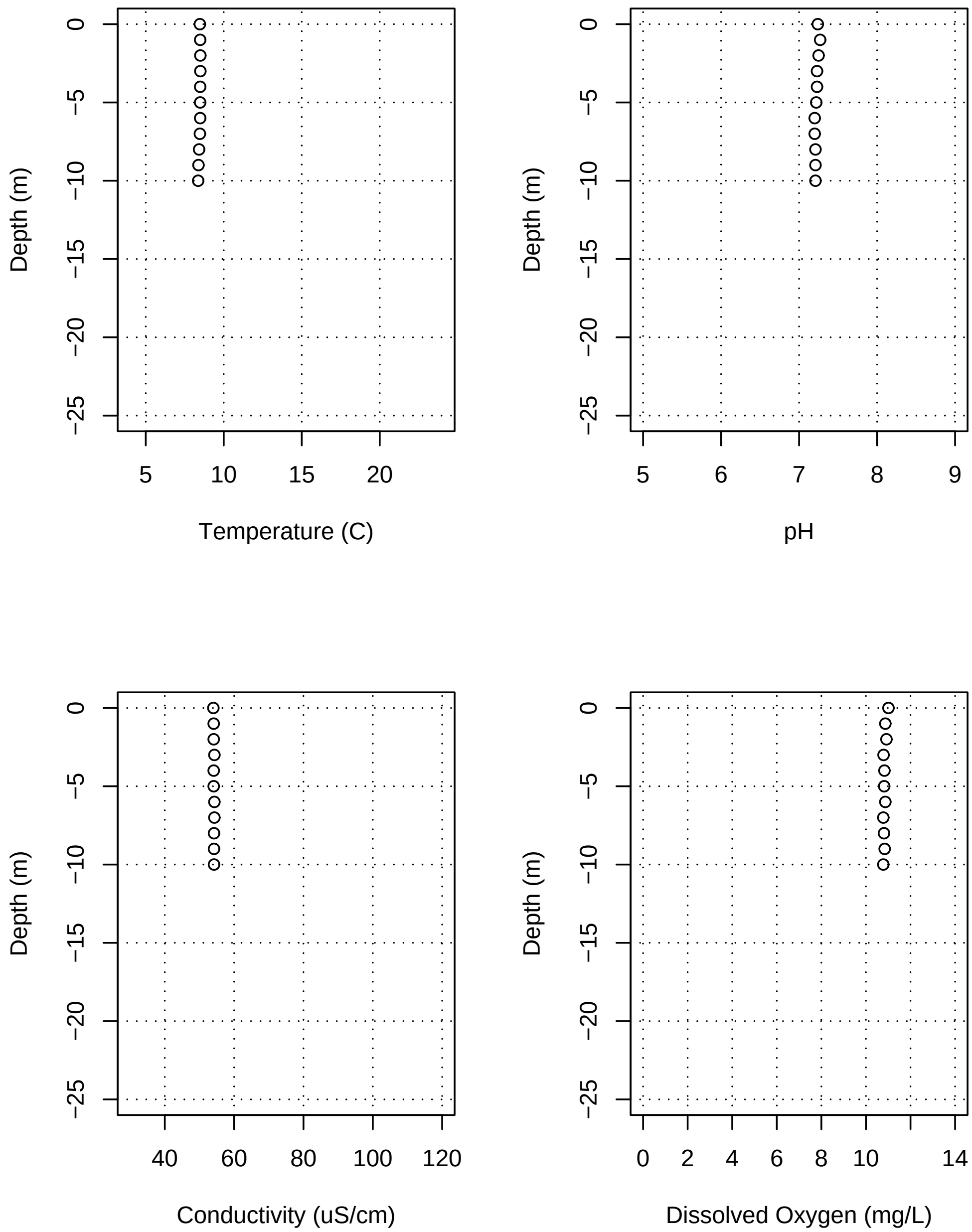


Figure B13: Lake Whatcom Hydrolab profile for the Intake, December 4, 2003.

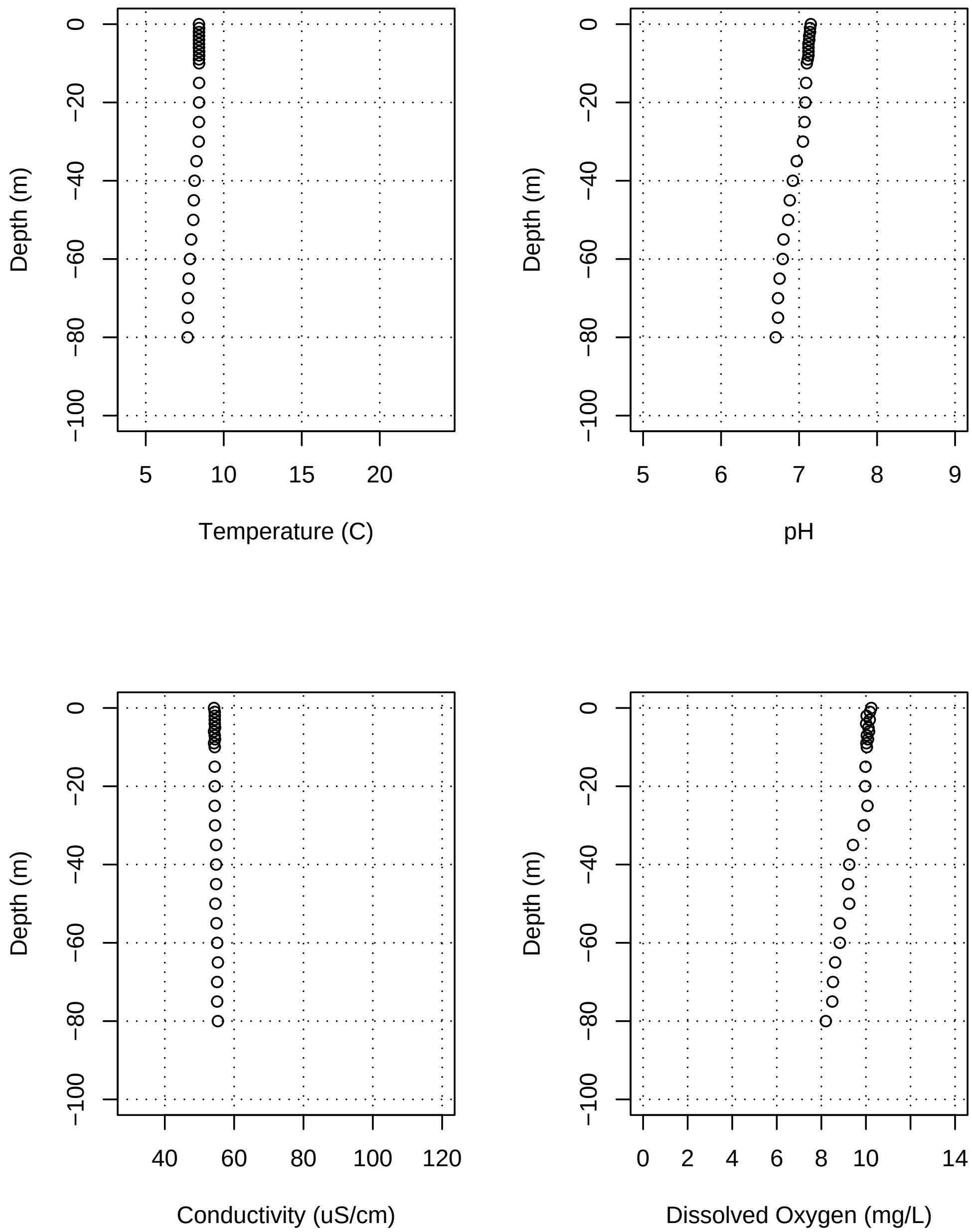


Figure B14: Lake Whatcom Hydrolab profile for Site 3, December 9, 2003.

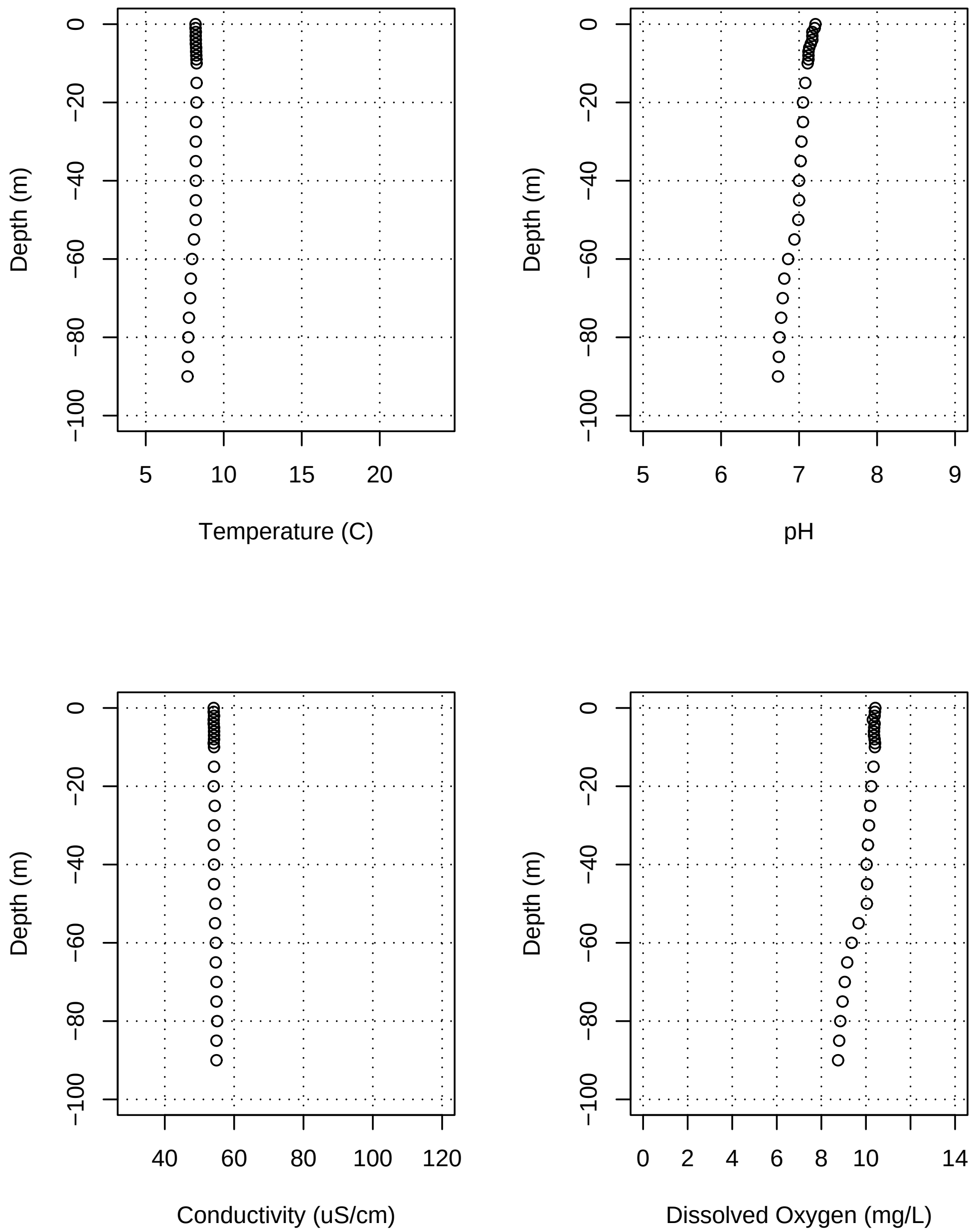


Figure B15: Lake Whatcom Hydrolab profile for Site 4, December 9, 2003.

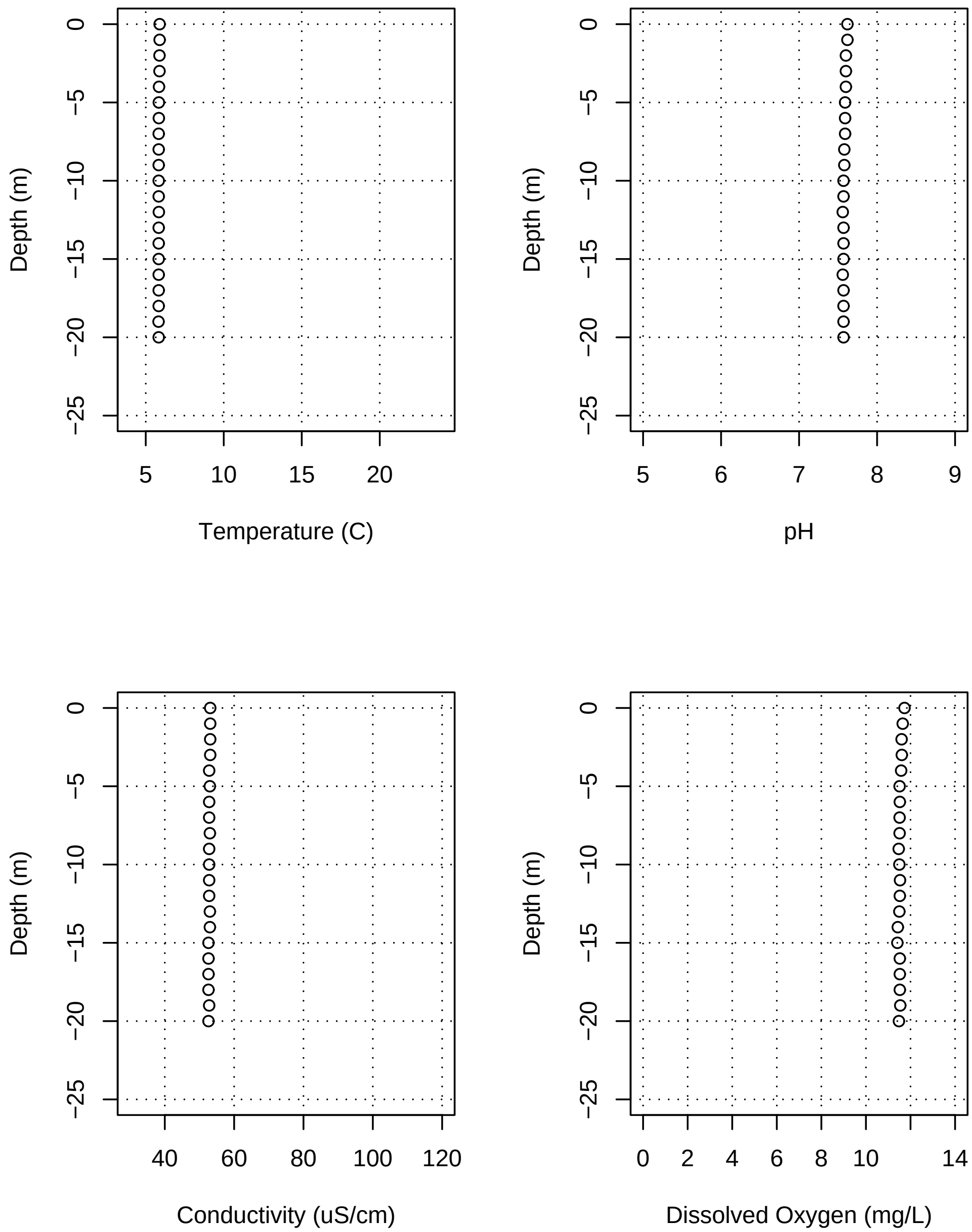


Figure B16: Lake Whatcom Hydrolab profile for Site 1, February 5, 2004.

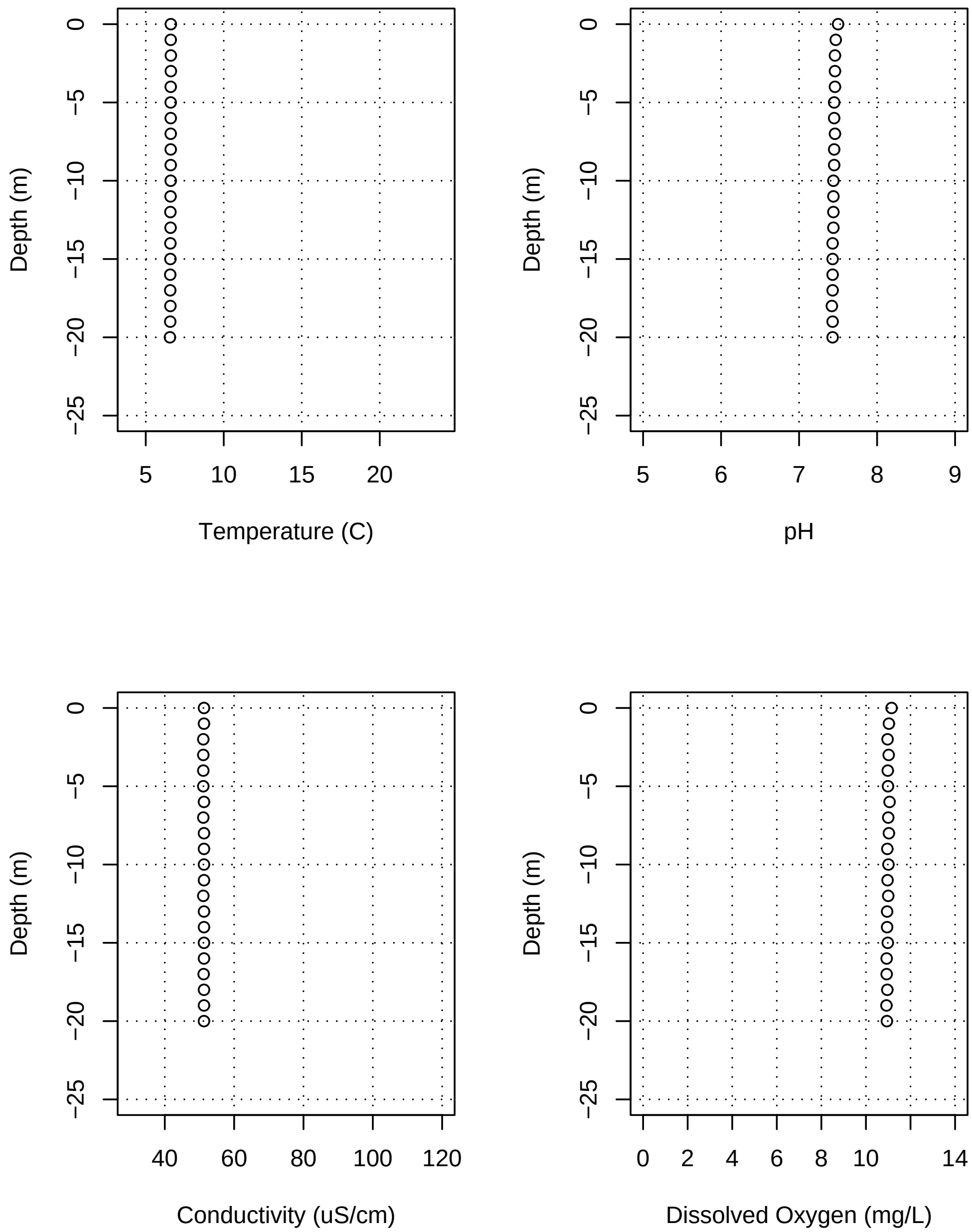


Figure B17: Lake Whatcom Hydrolab profile for Site 2, February 5, 2004.

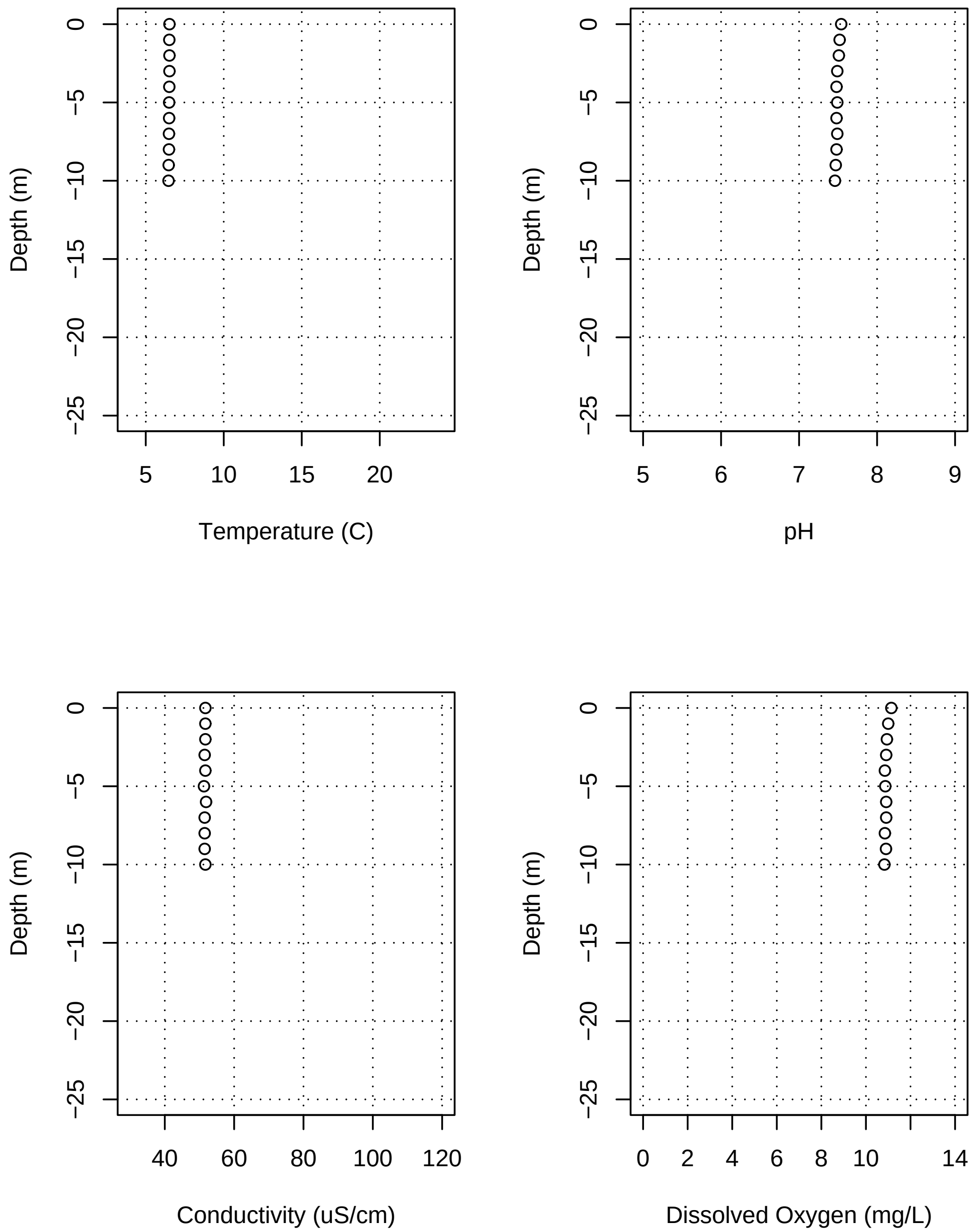


Figure B18: Lake Whatcom Hydrolab profile for the Intake, February 5, 2004.

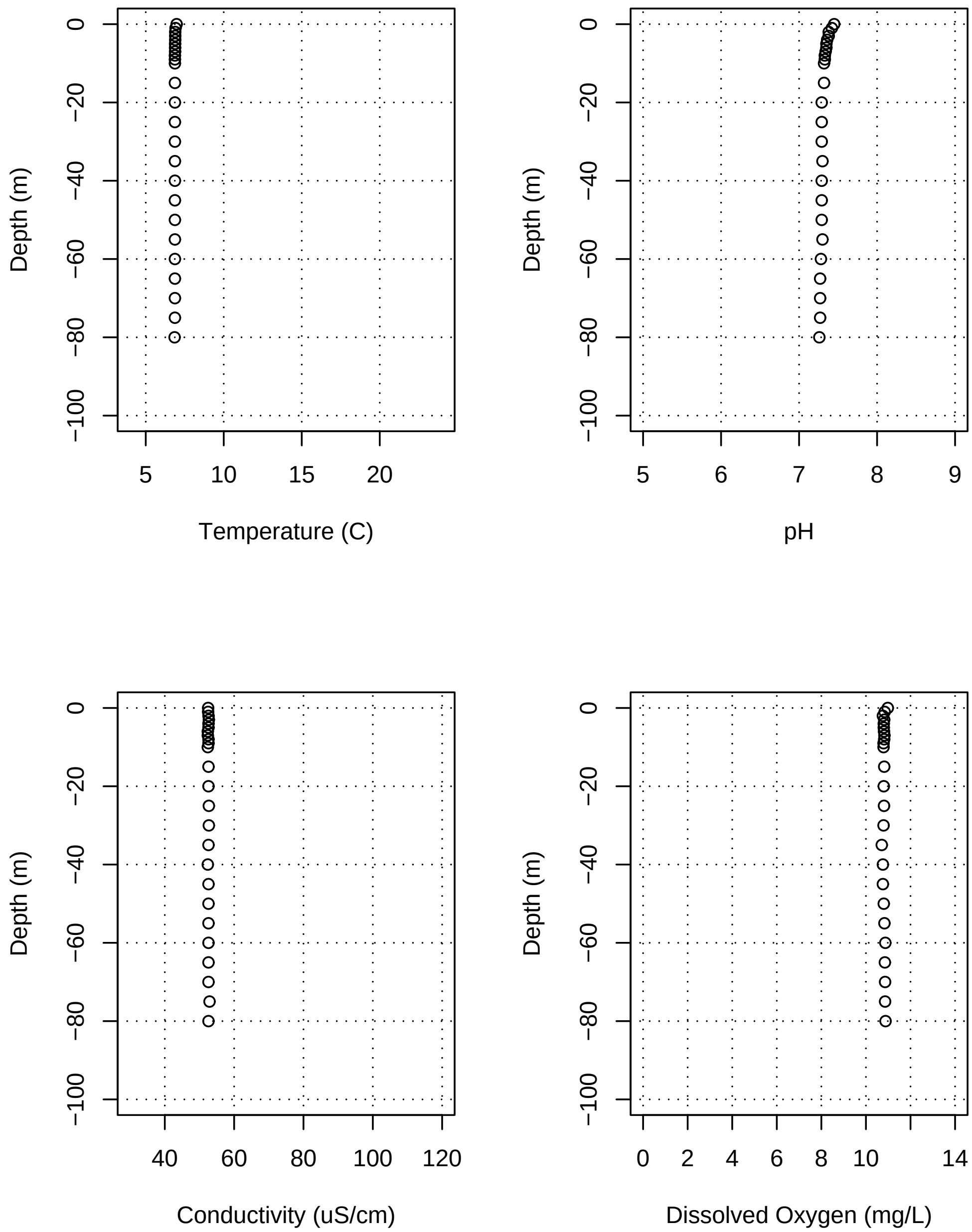


Figure B19: Lake Whatcom Hydrolab profile for Site 3, February 3, 2004.

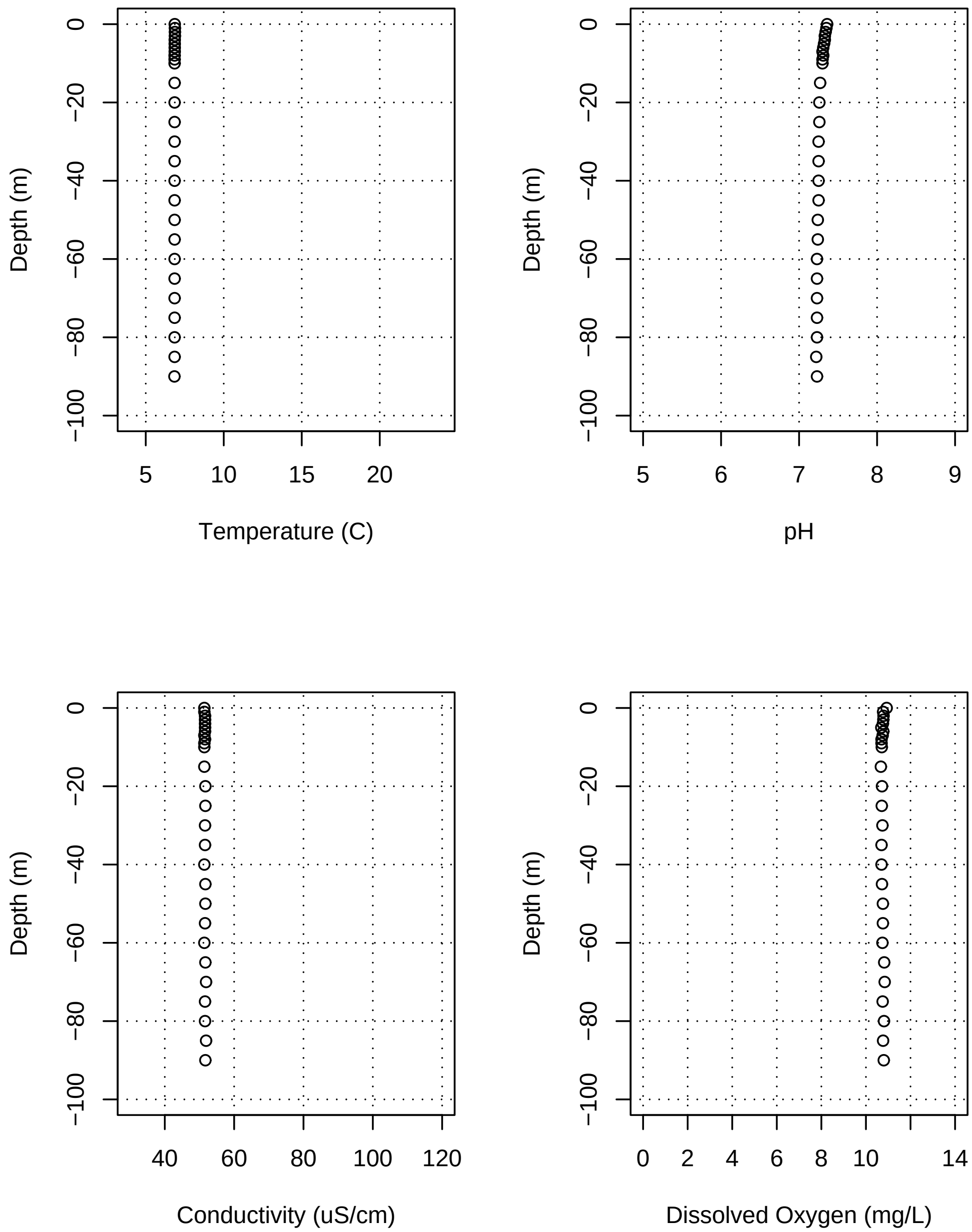


Figure B20: Lake Whatcom Hydrolab profile for Site 4, February 3, 2004.

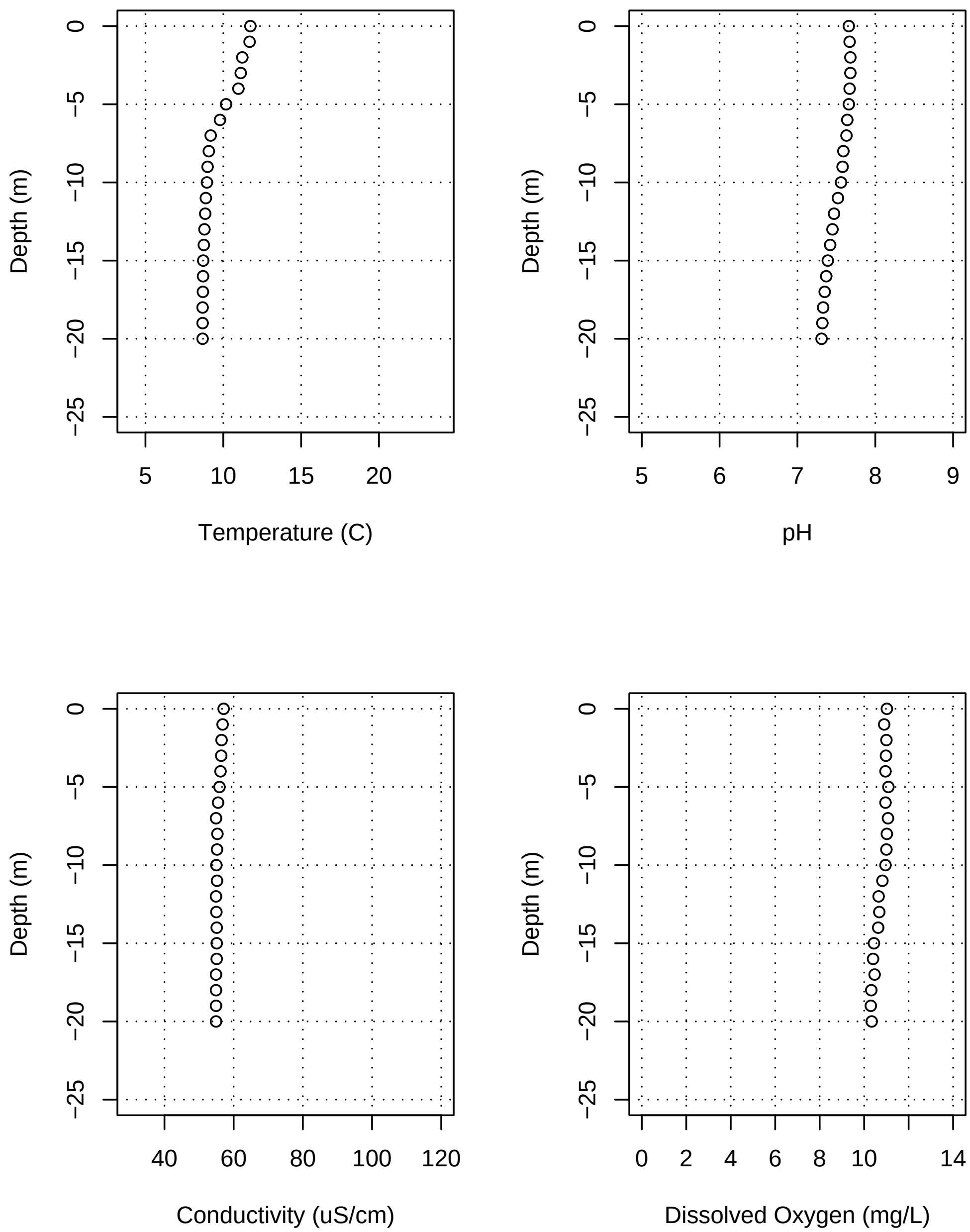


Figure B21: Lake Whatcom Hydrolab profile for Site 1, April 8, 2004.

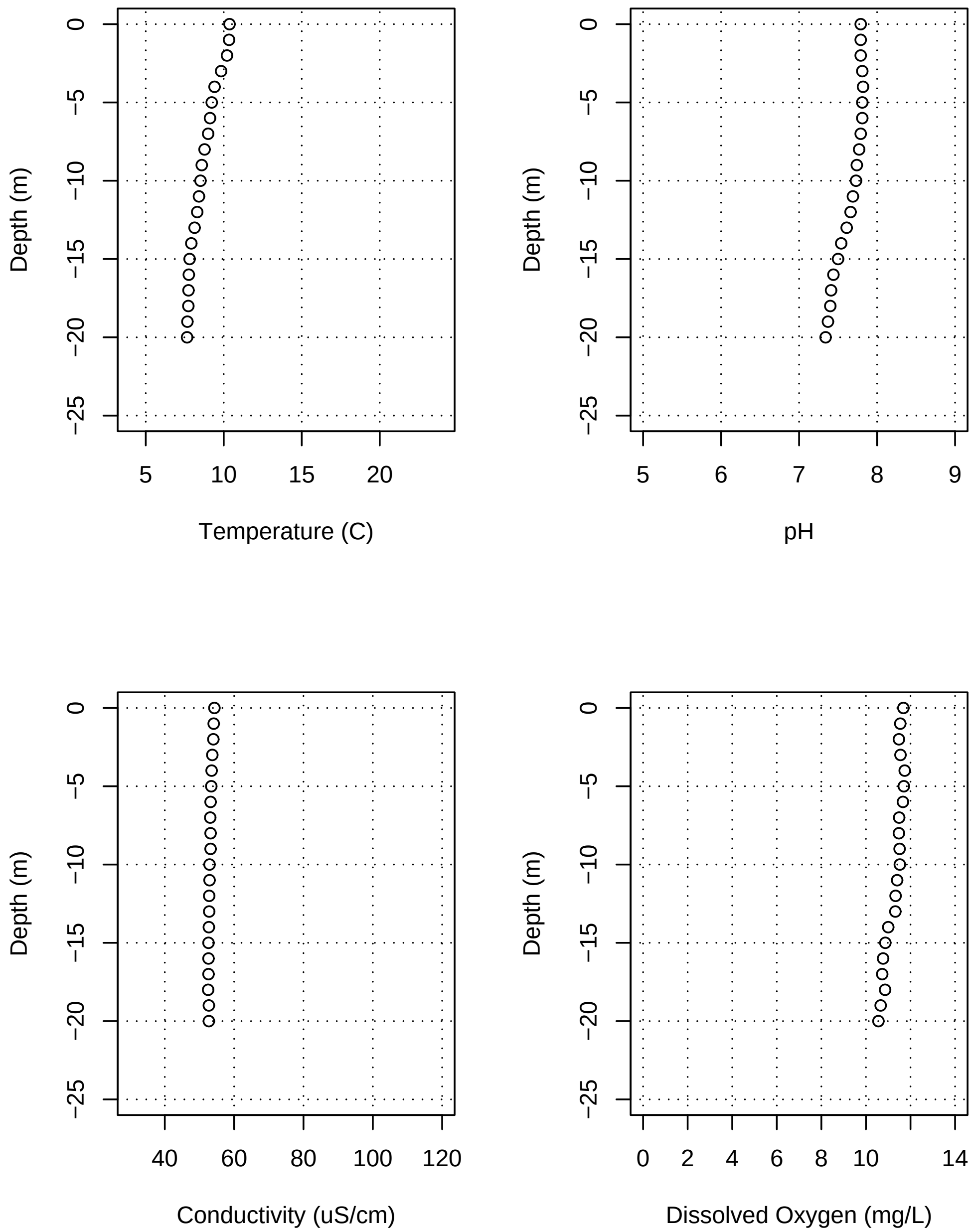


Figure B22: Lake Whatcom Hydrolab profile for Site 2, April 8, 2004.

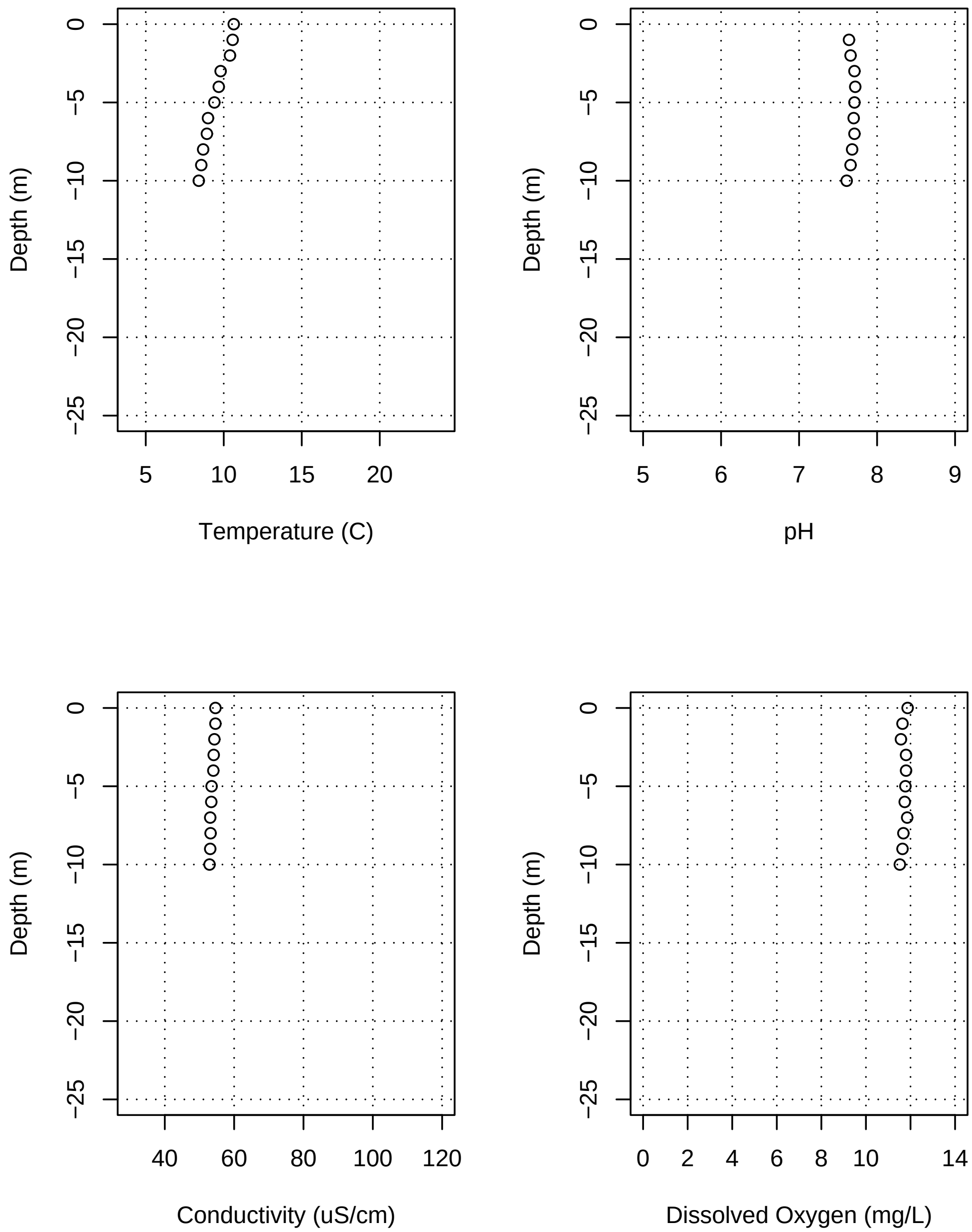


Figure B23: Lake Whatcom Hydrolab profile for the Intake, April 8, 2004.

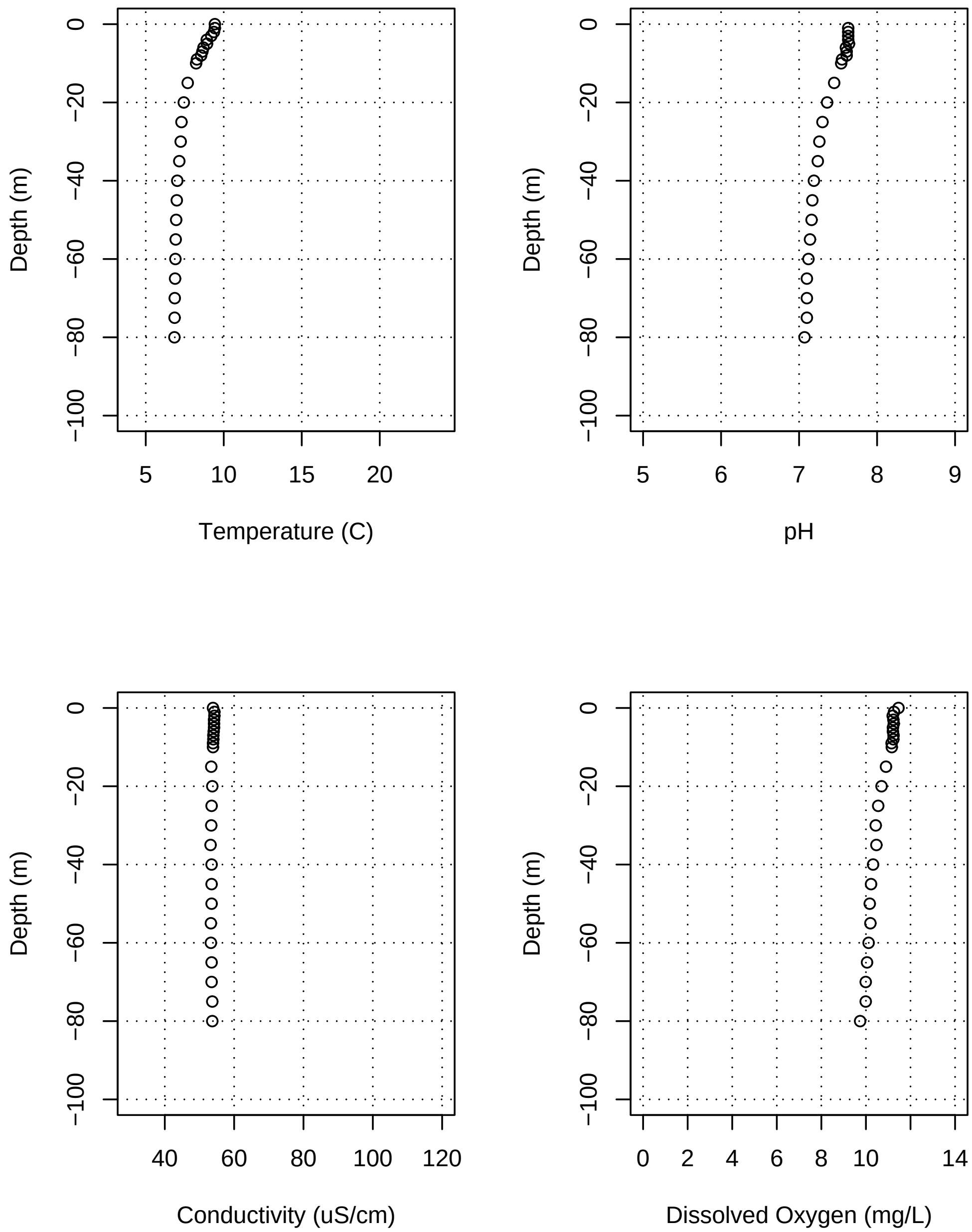


Figure B24: Lake Whatcom Hydrolab profile for Site 3, April 6, 2004.

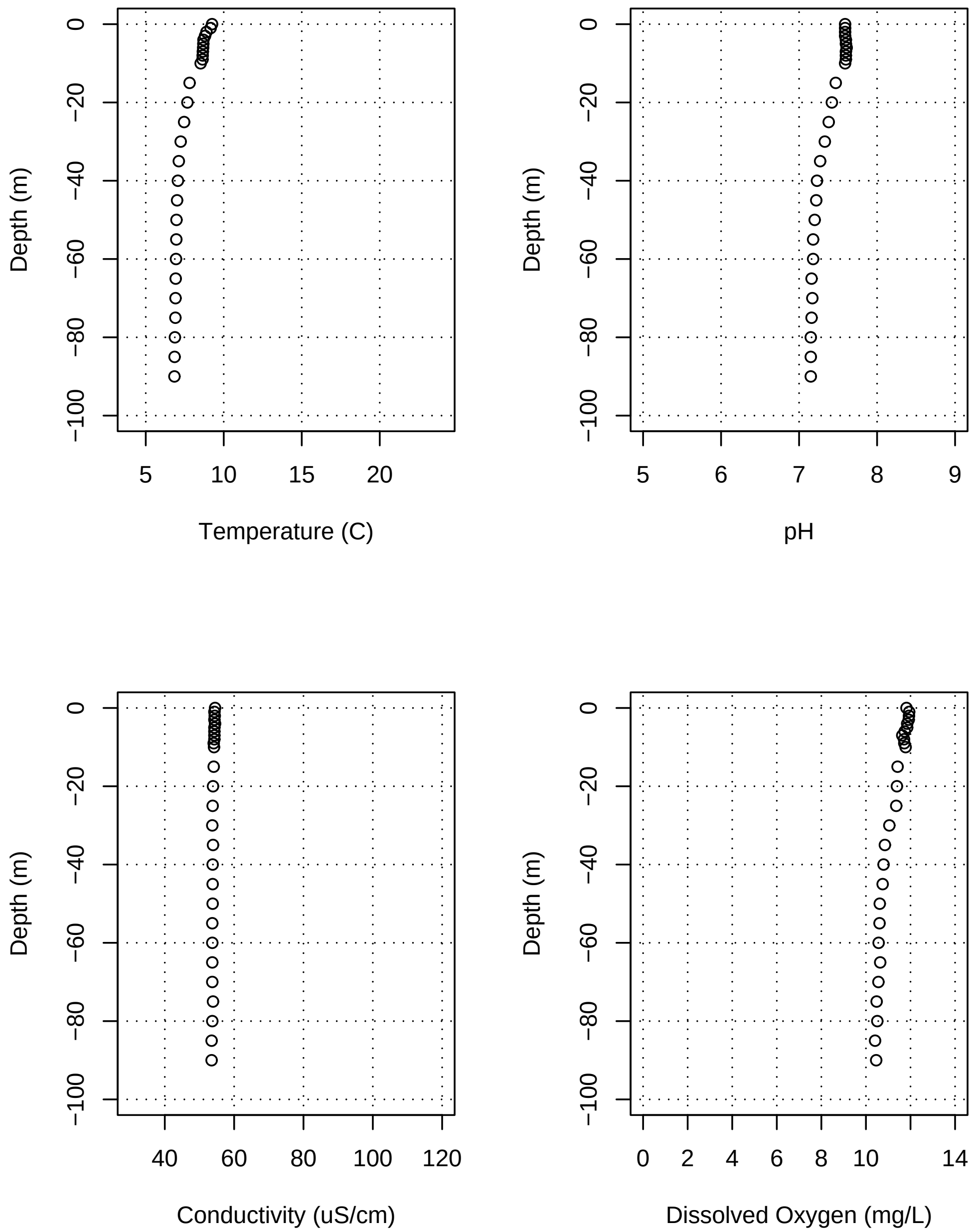


Figure B25: Lake Whatcom Hydrolab profile for Site 4, April 6, 2004.

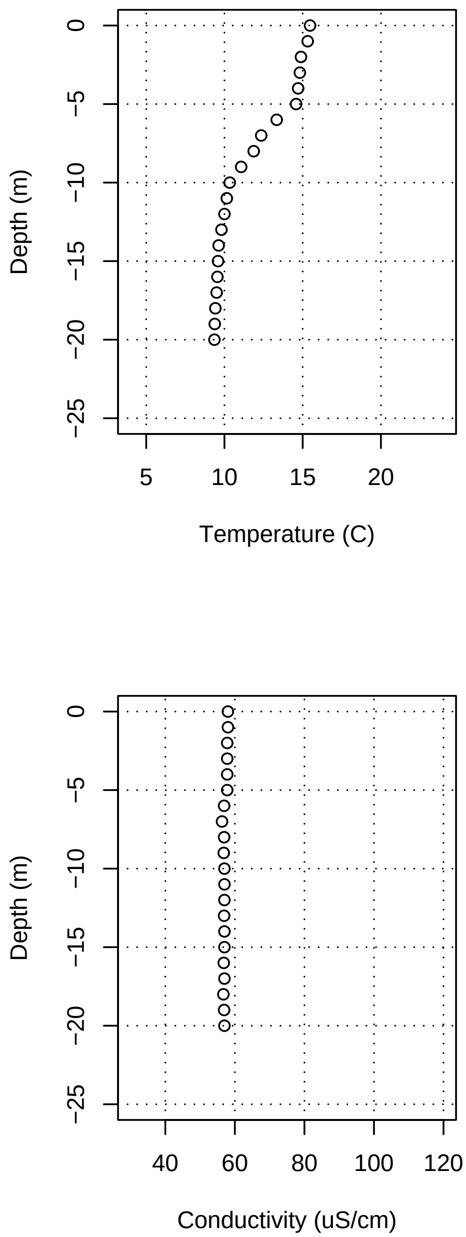


Figure B26: Lake Whatcom Hydrolab profile for Site 1, May 6, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals.

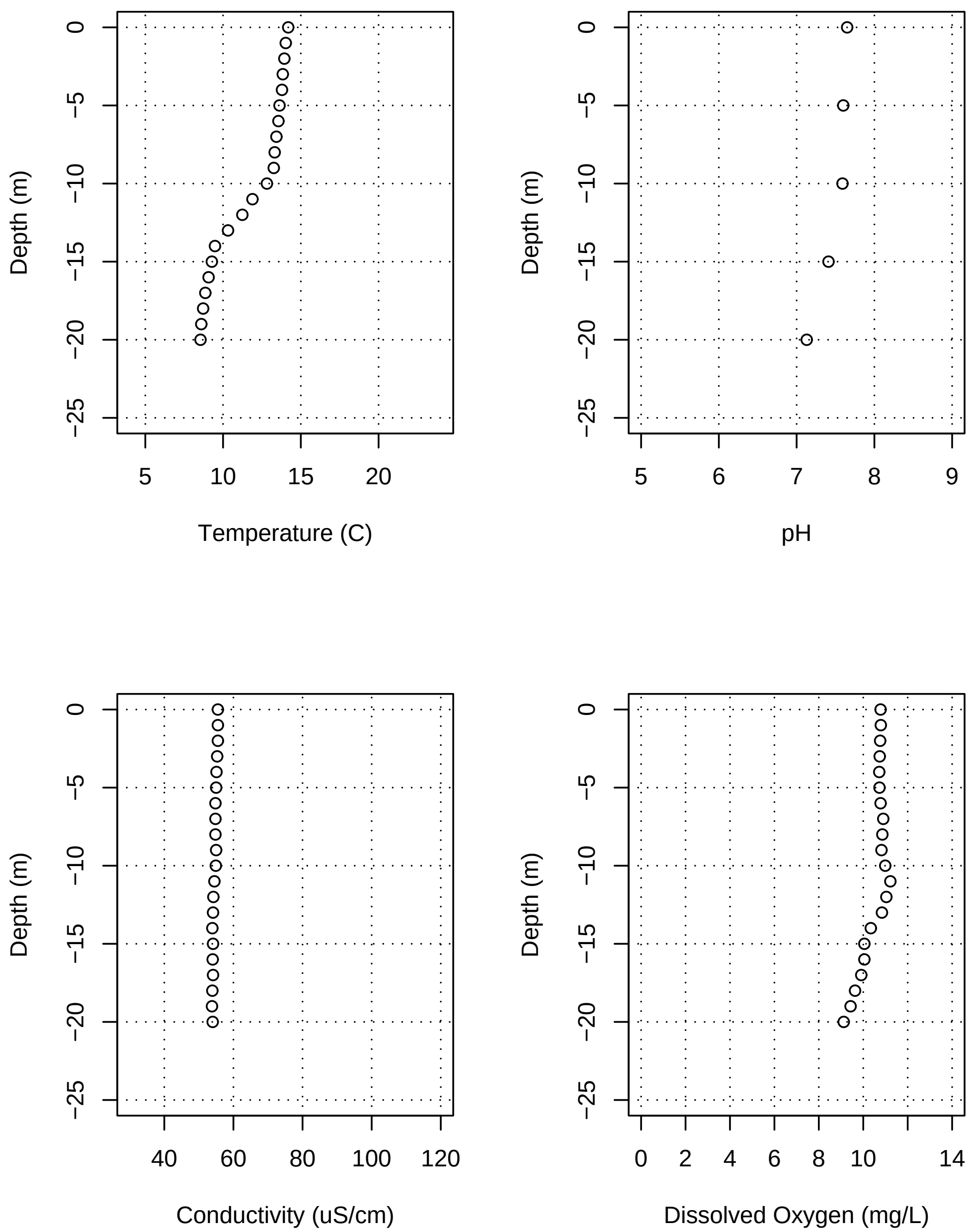


Figure B27: Lake Whatcom Hydrolab profile for Site 2, May 6, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals.

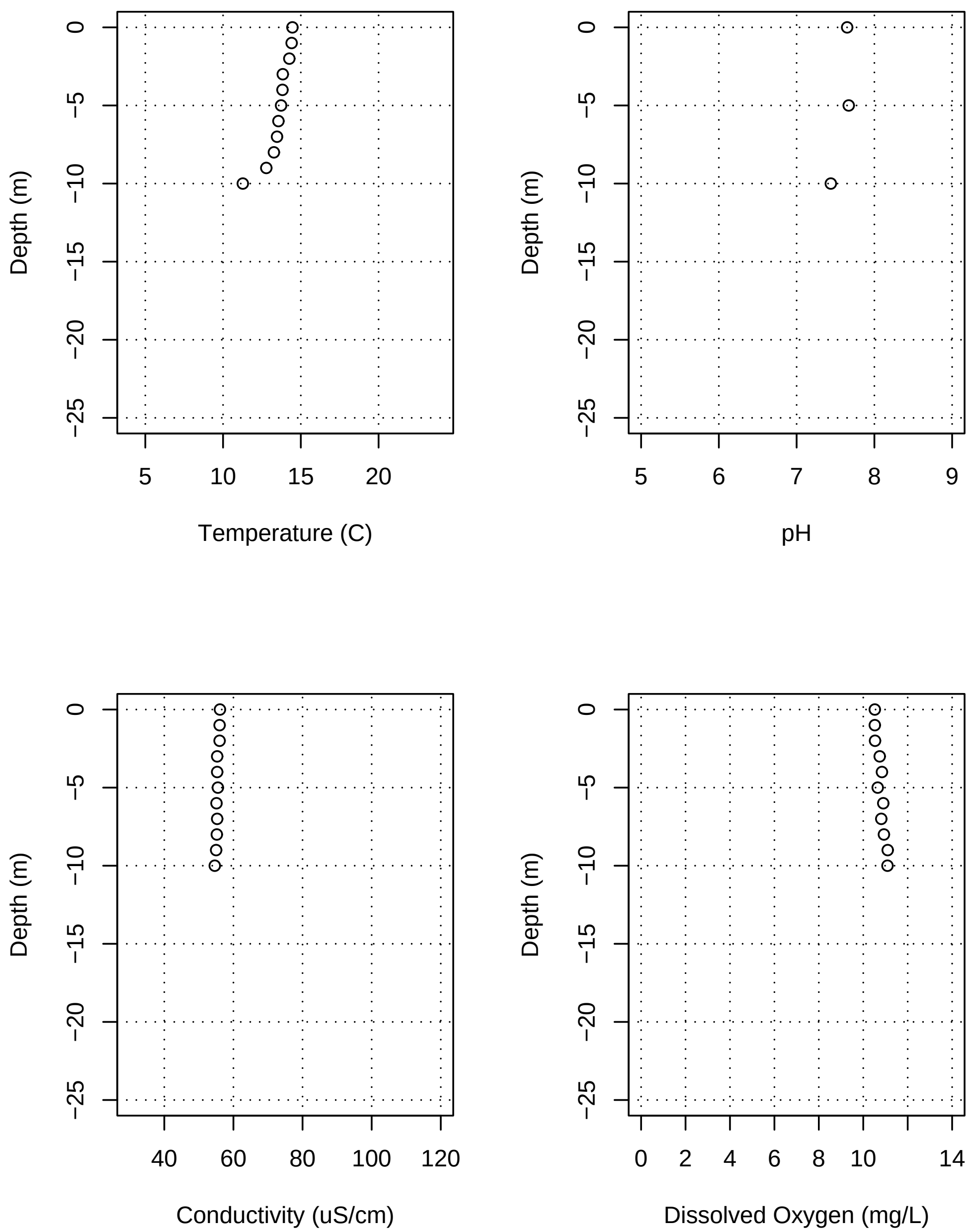


Figure B28: Lake Whatcom Hydrolab profile for the Intake, May 6, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals.

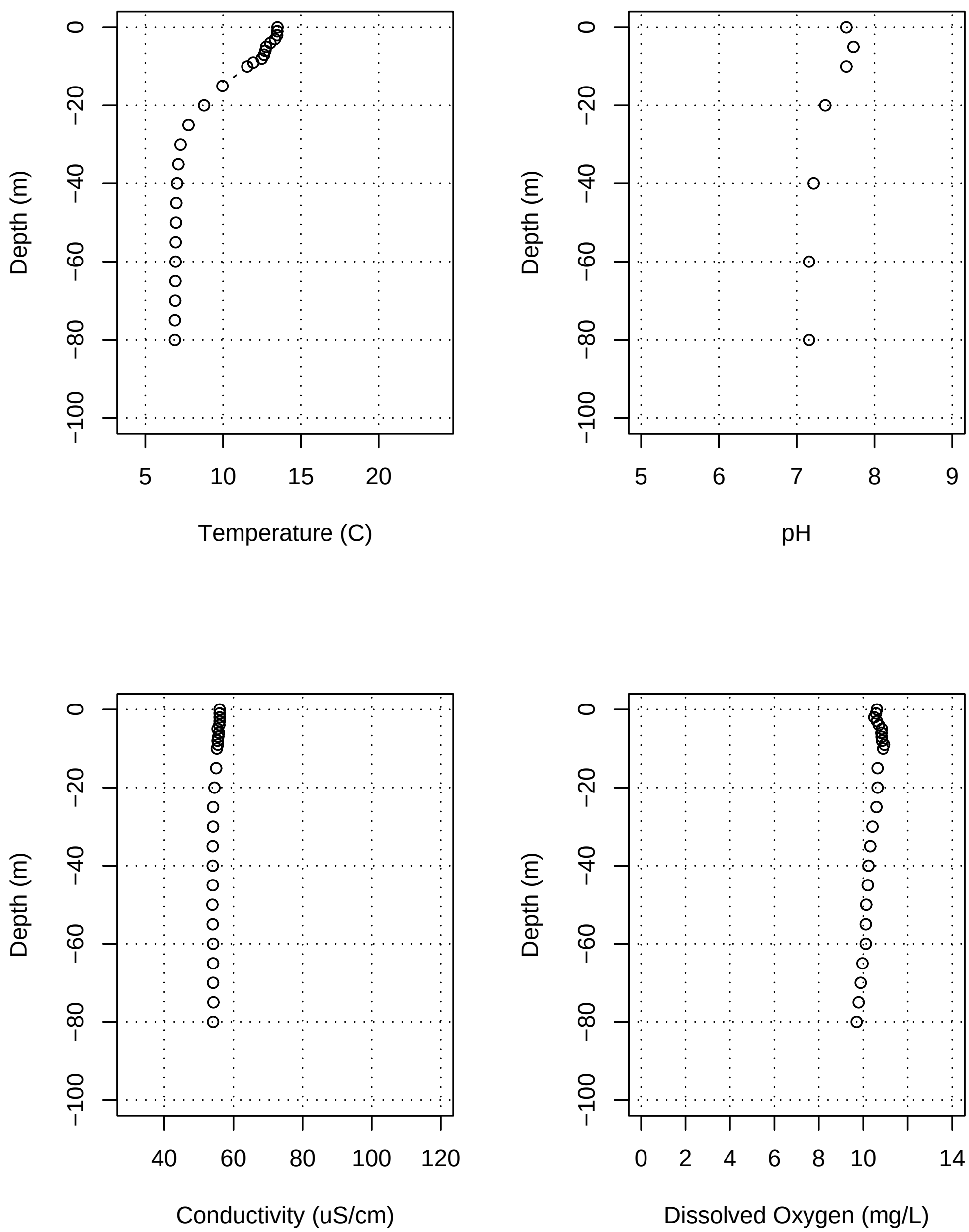


Figure B29: Lake Whatcom Hydrolab profile for Site 3, May 5, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals.

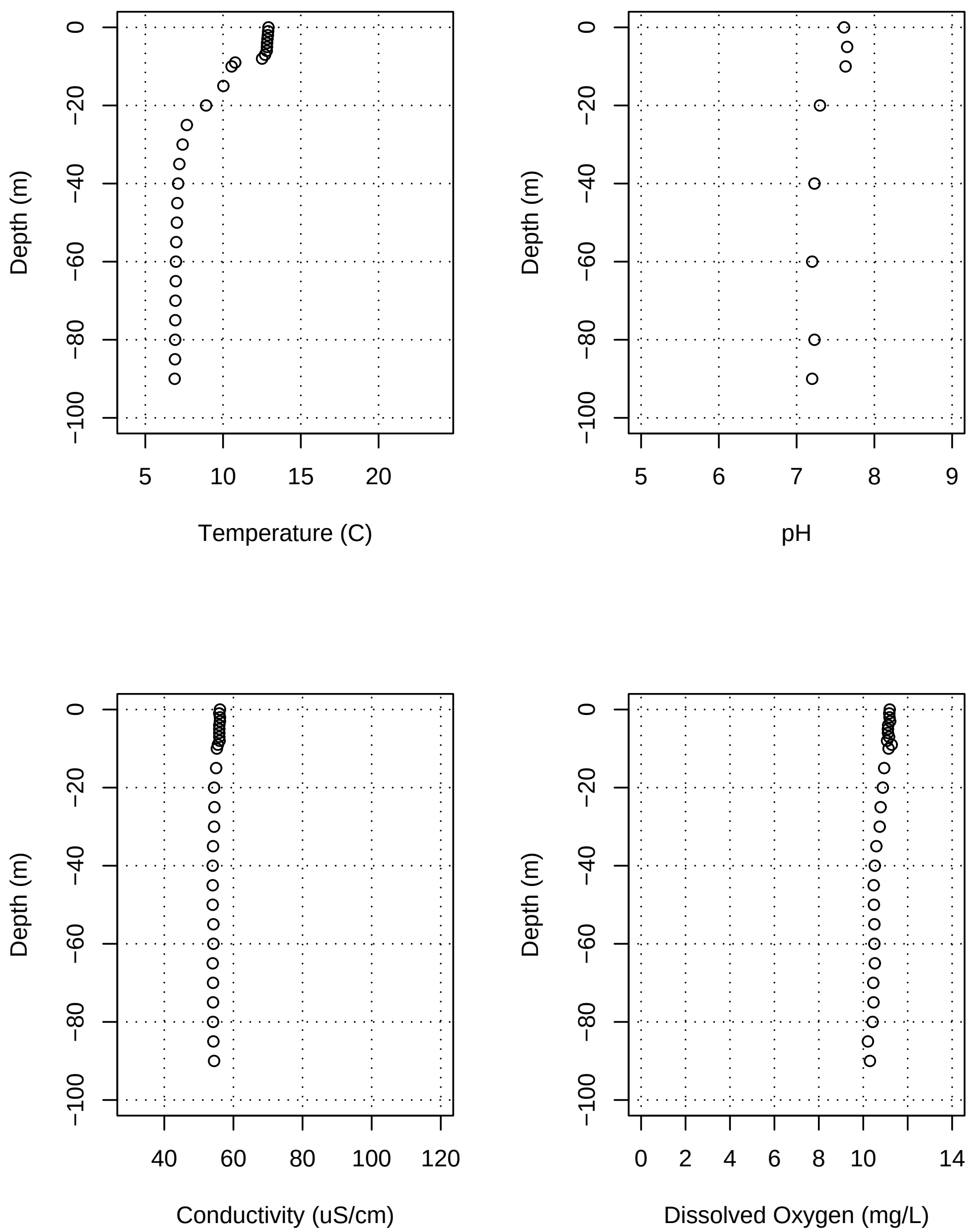


Figure B30: Lake Whatcom Hydrolab profile for Site 4, May 5, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals.

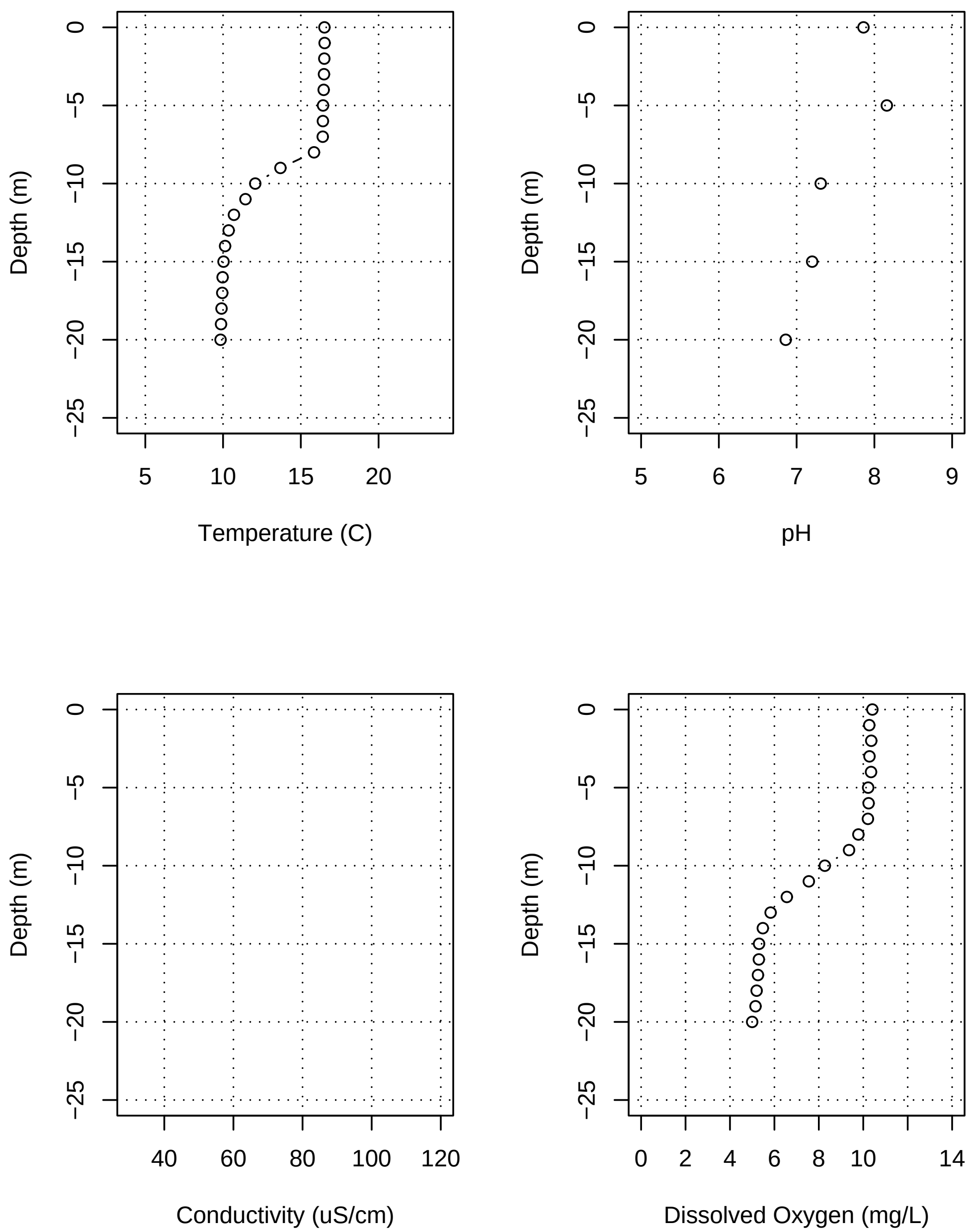


Figure B31: Lake Whatcom Hydrolab profile for Site 1, June 14, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals and conductivity data were deleted.

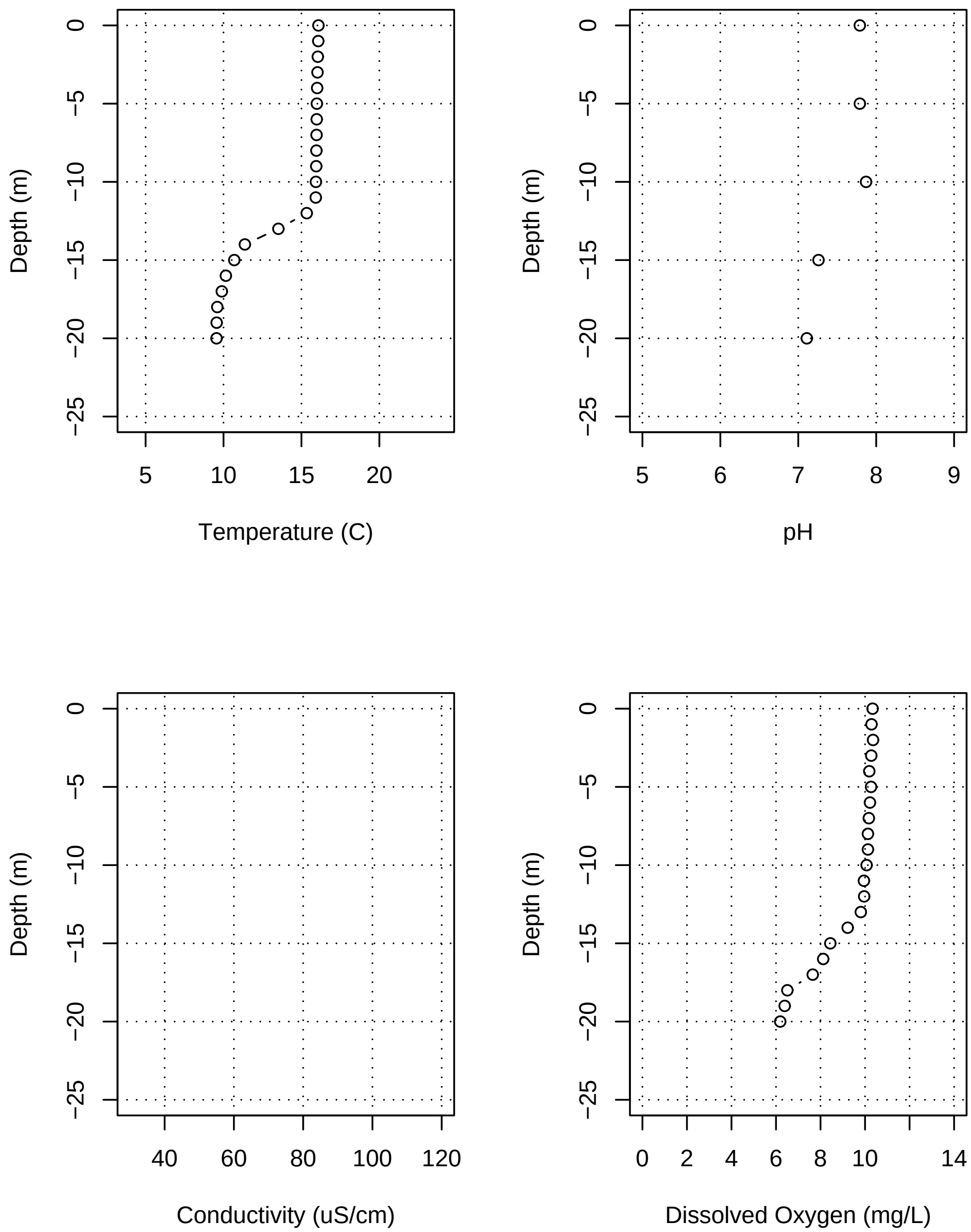


Figure B32: Lake Whatcom Hydrolab profile for Site 2, June 14, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals and conductivity data were deleted.

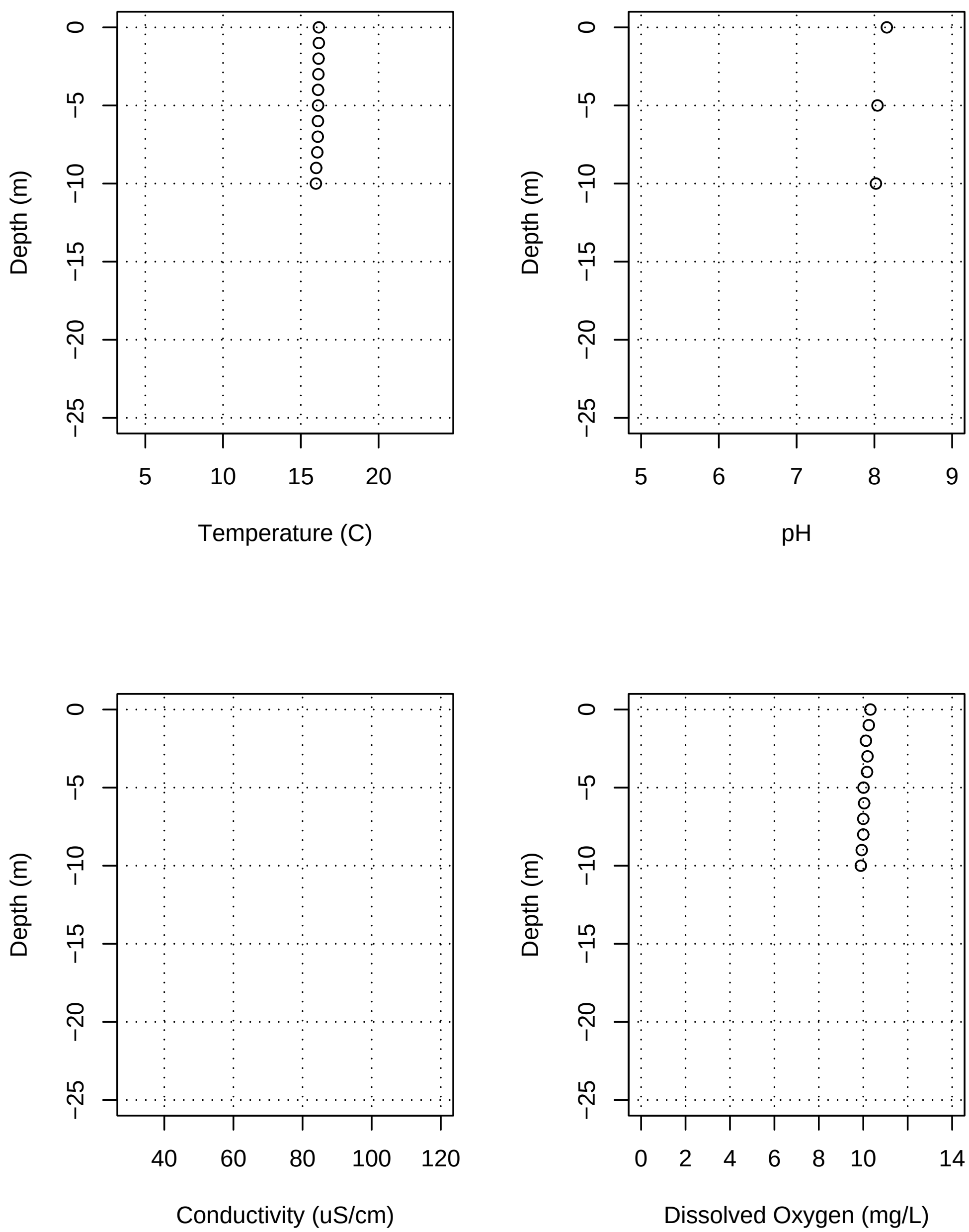


Figure B33: Lake Whatcom Hydrolab profile for the Intake, June 14, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals and conductivity data were deleted.

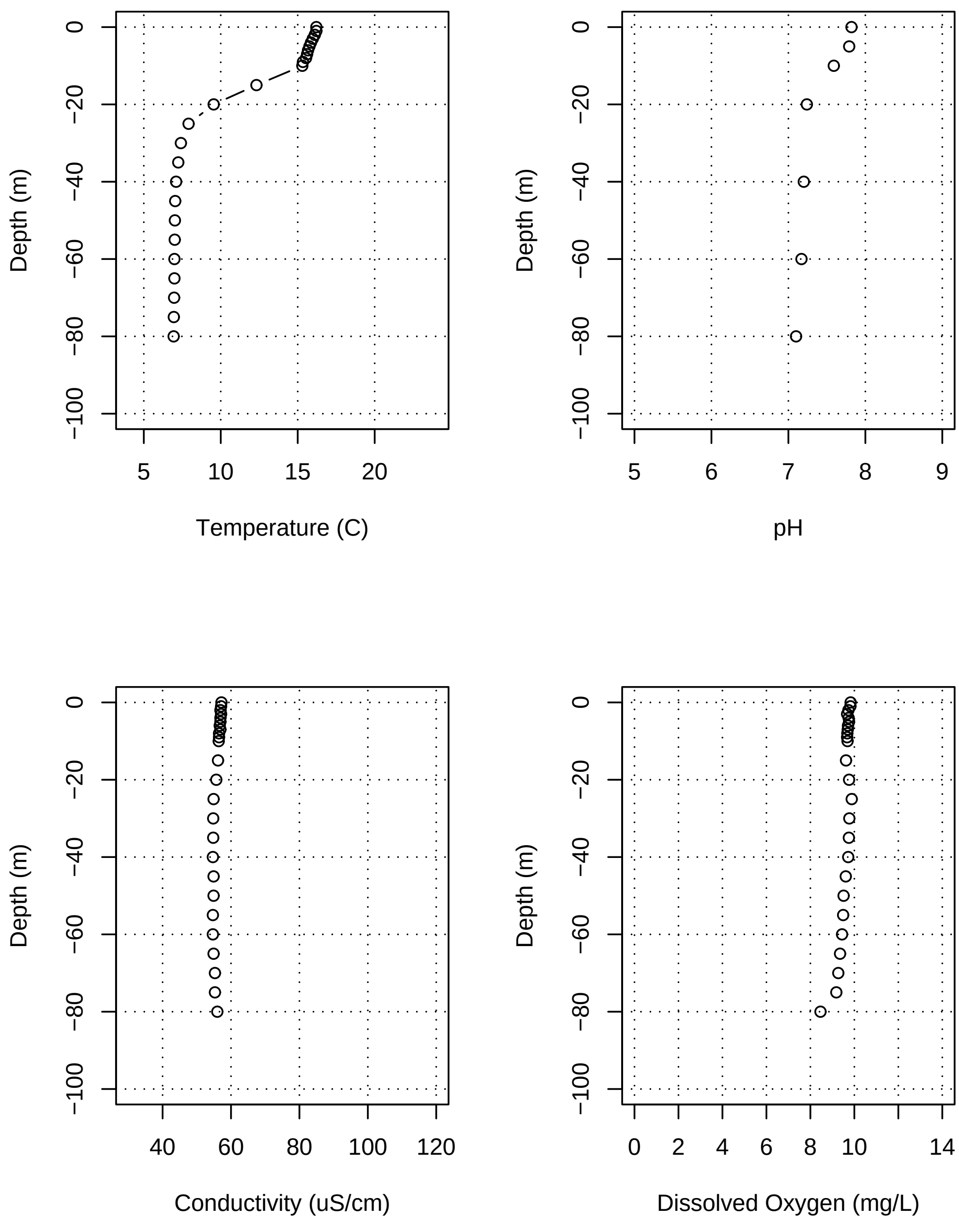


Figure B34: Lake Whatcom Hydrolab profile for Site 3, June 9, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals.

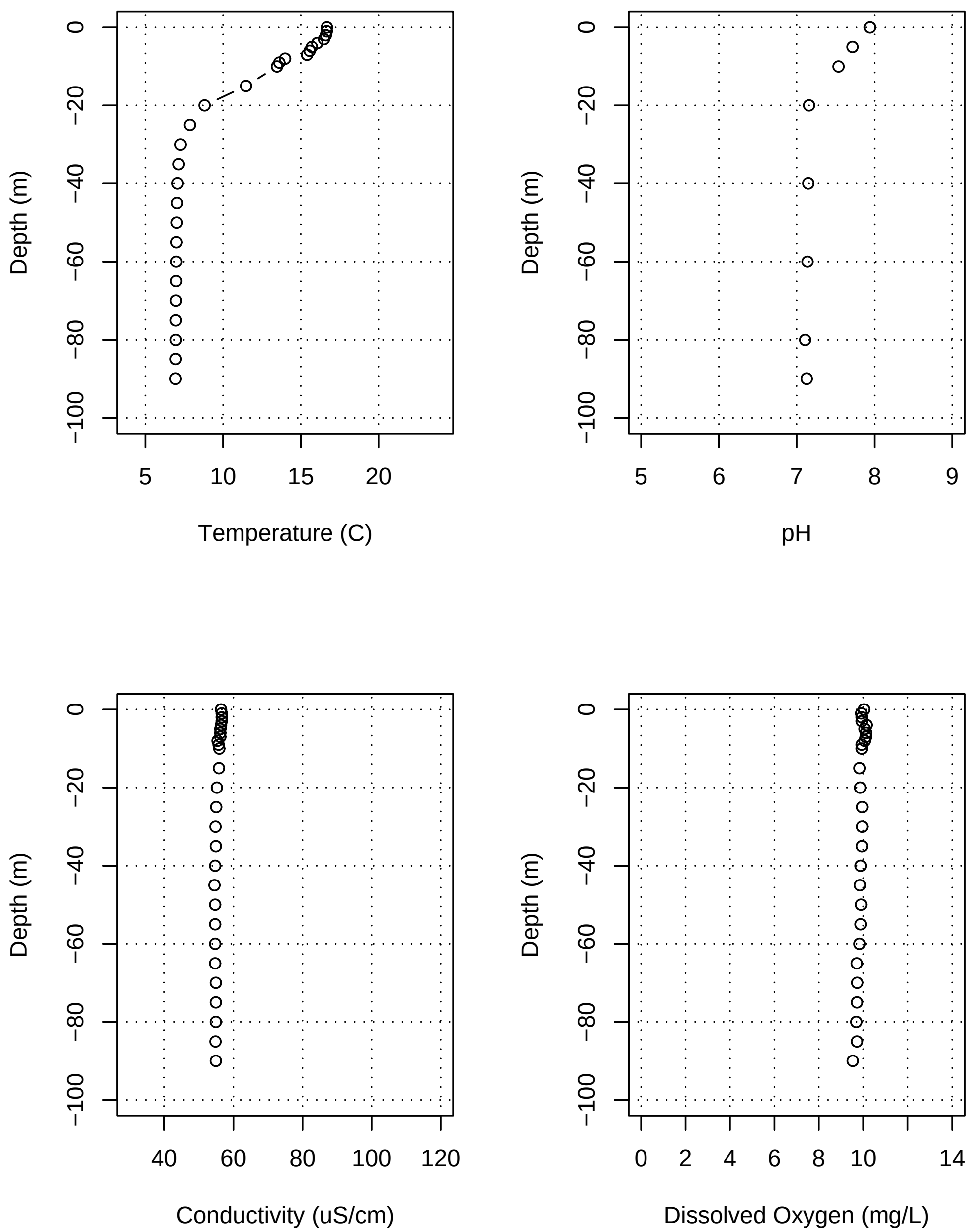


Figure B35: Lake Whatcom Hydrolab profile for Site 4, June 9, 2004. Due to Hydrolab malfunction, pH was measured from water samples collected at 5 m depth intervals.

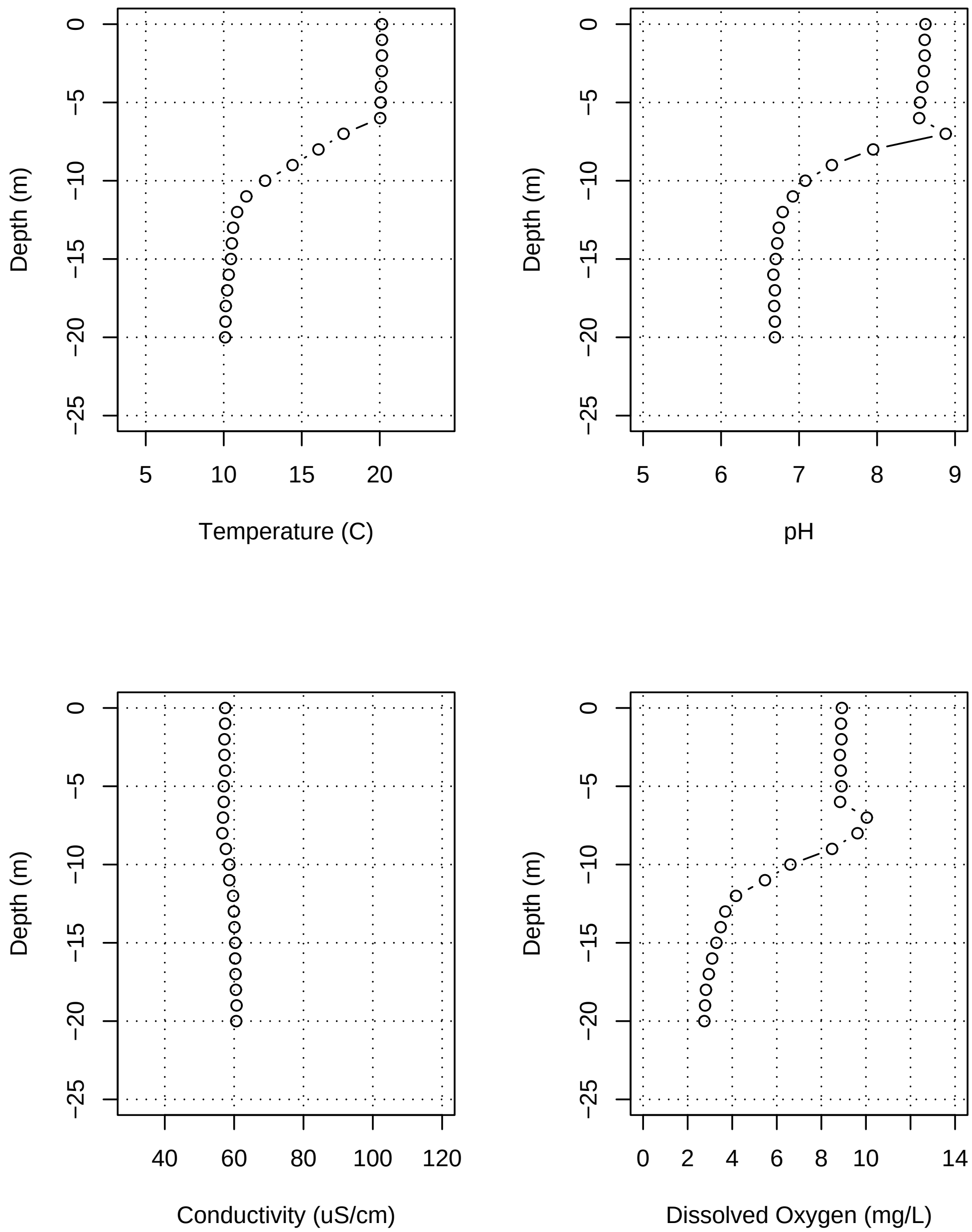


Figure B36: Lake Whatcom Hydrolab profile for Site 1, July 8, 2004.

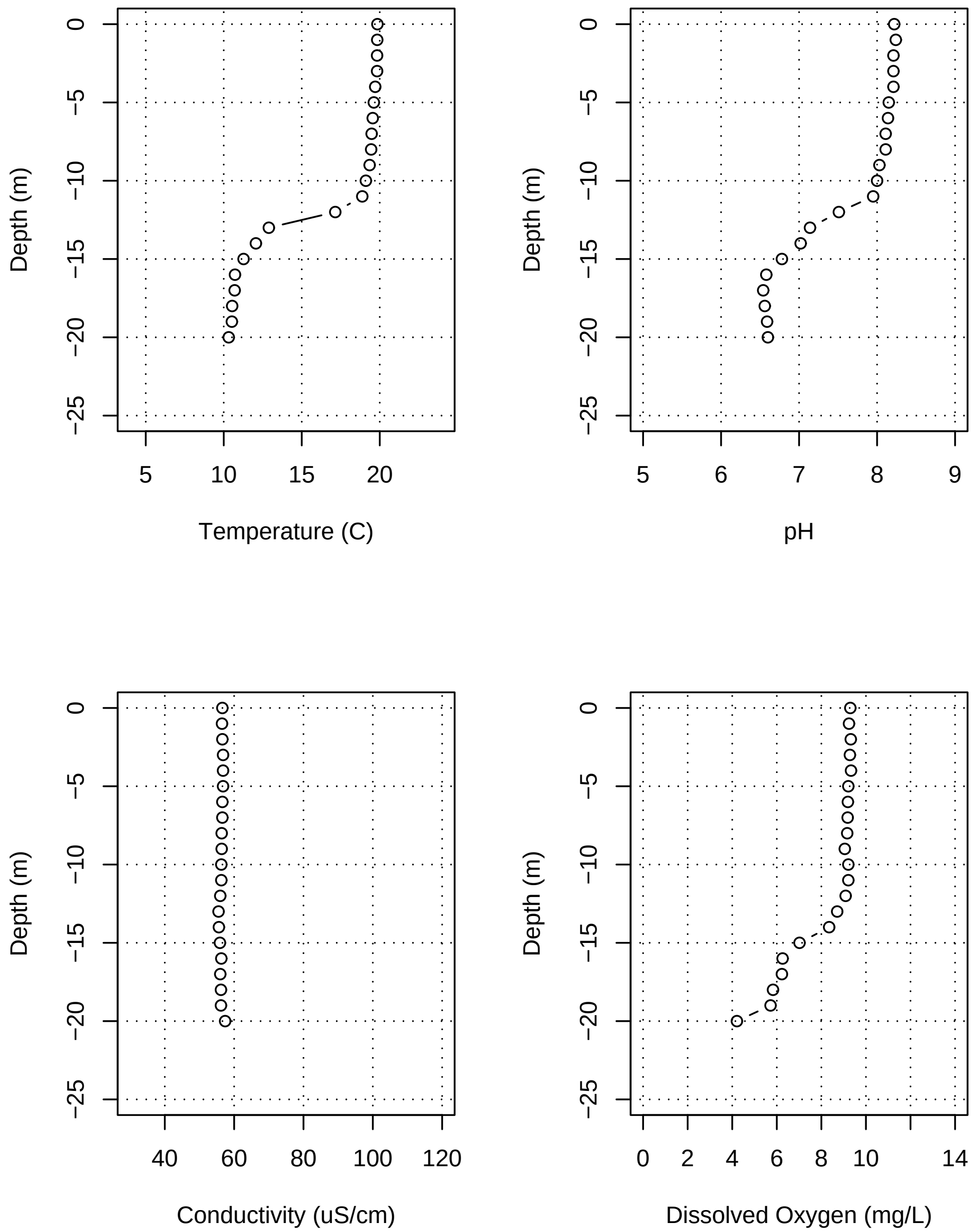


Figure B37: Lake Whatcom Hydrolab profile for Site 2, July 8, 2004.

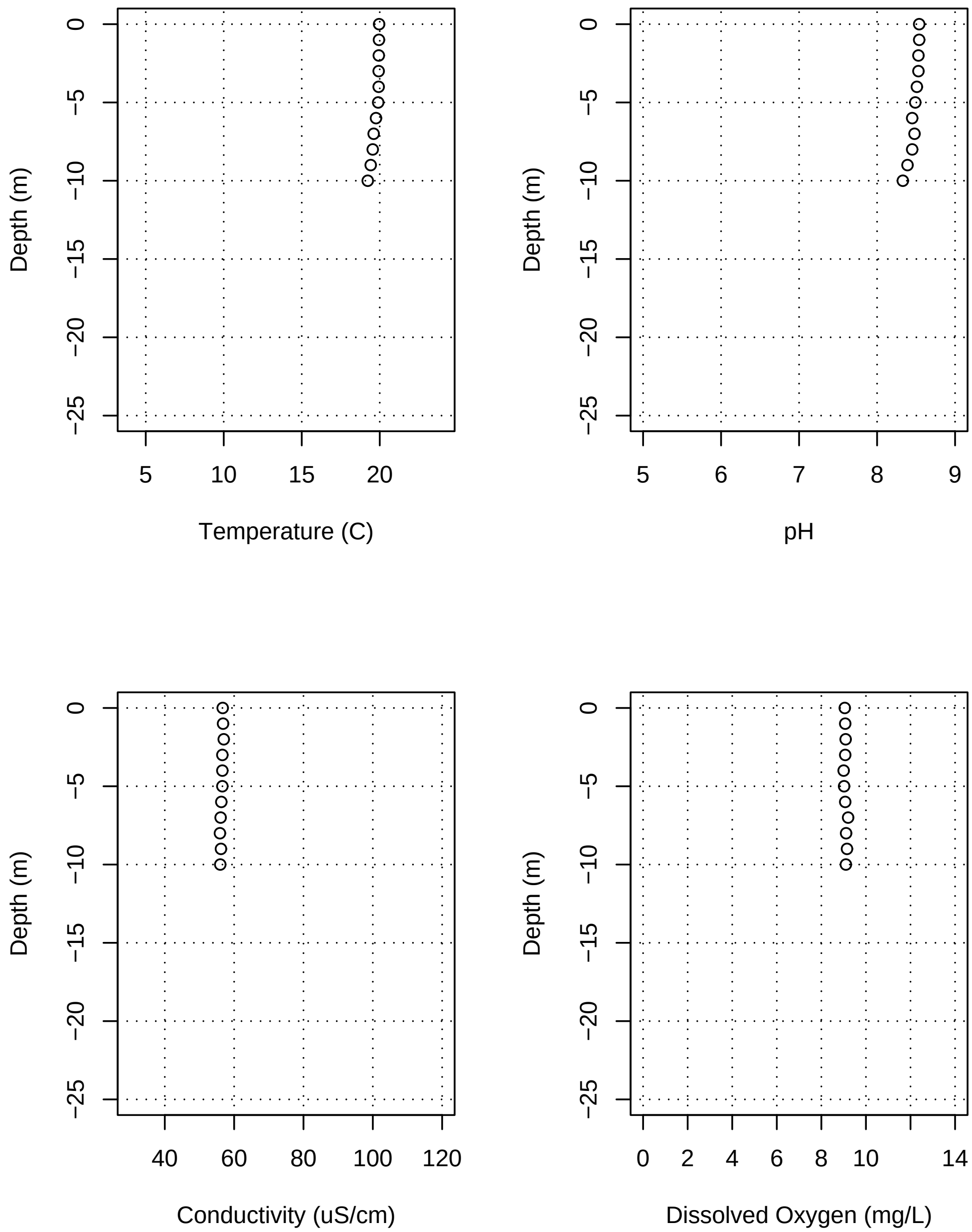


Figure B38: Lake Whatcom Hydrolab profile for the Intake, July 8, 2004.

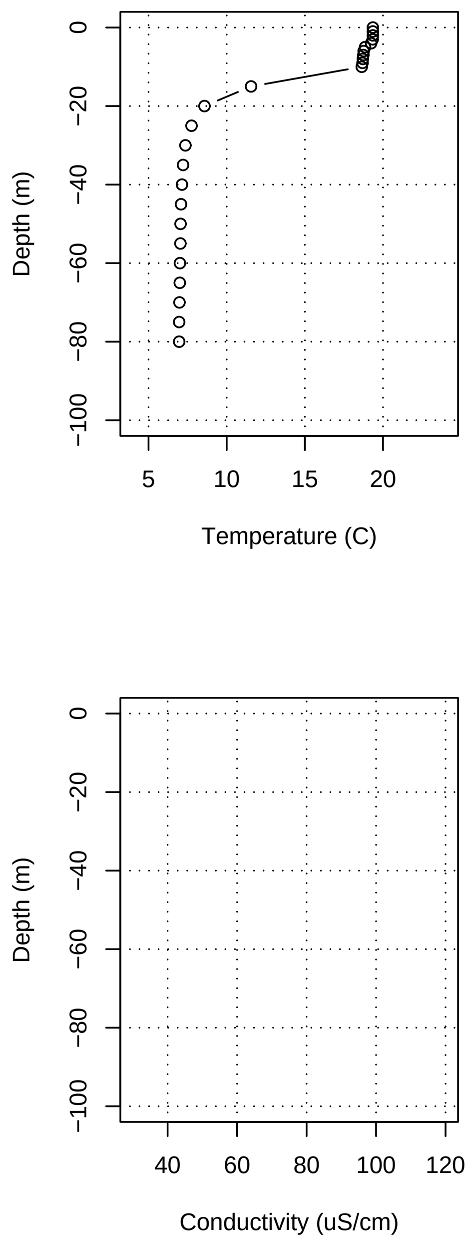


Figure B39: Lake Whatcom Hydrolab profile for Site 3, July 7, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

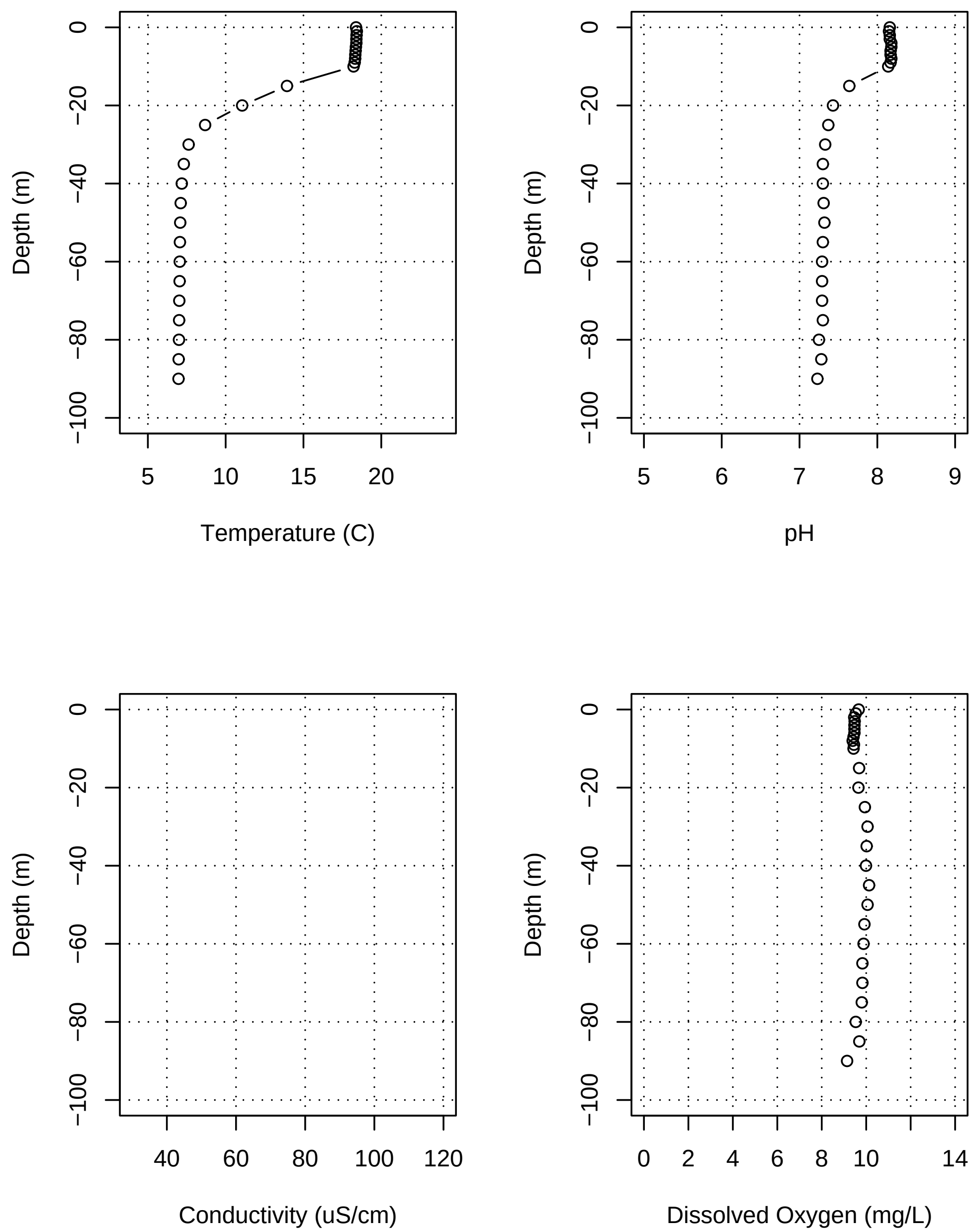


Figure B40: Lake Whatcom Hydrolab profile for Site 4, July 7, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

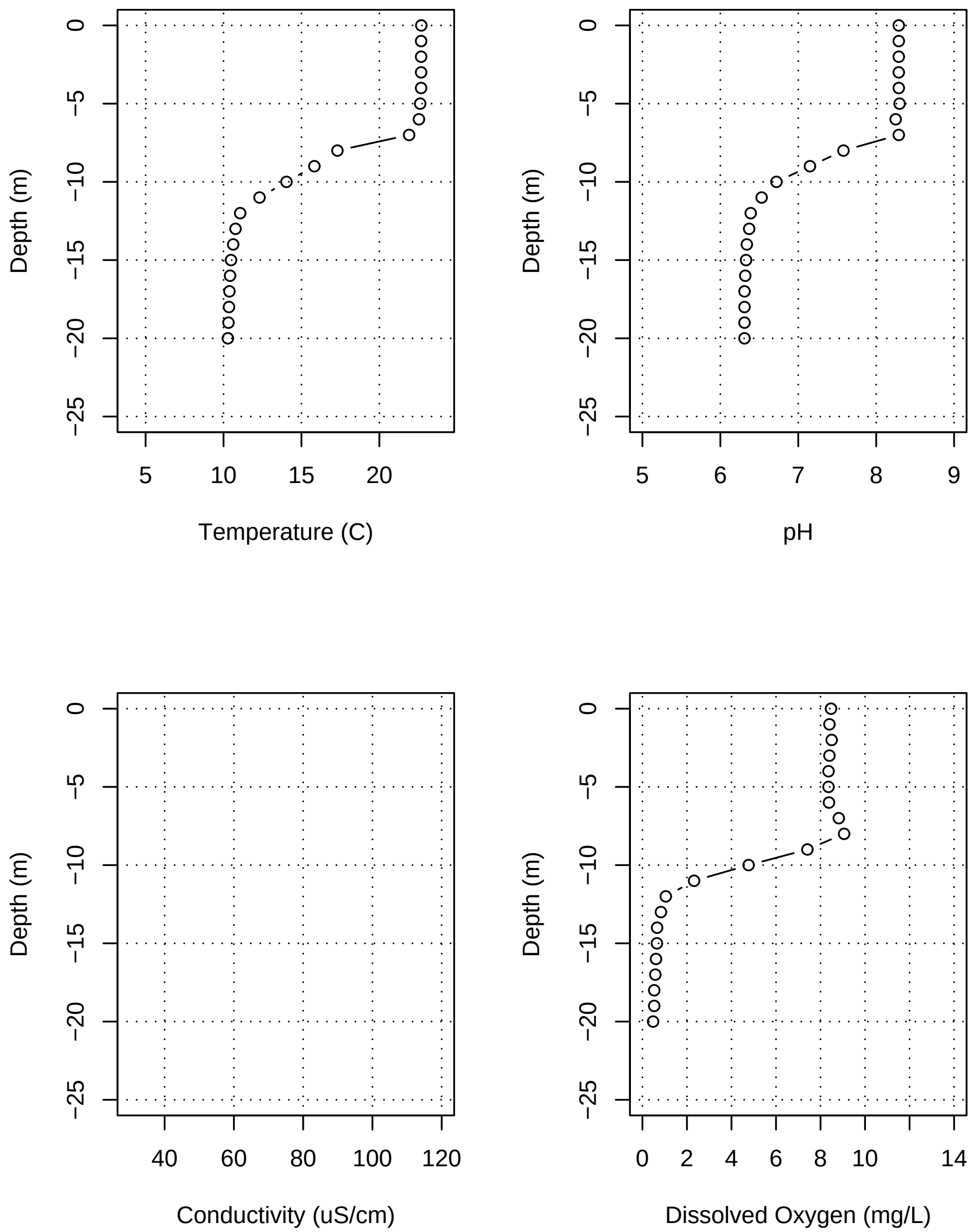


Figure B41: Lake Whatcom Hydrolab profile for Site 1, August 4, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

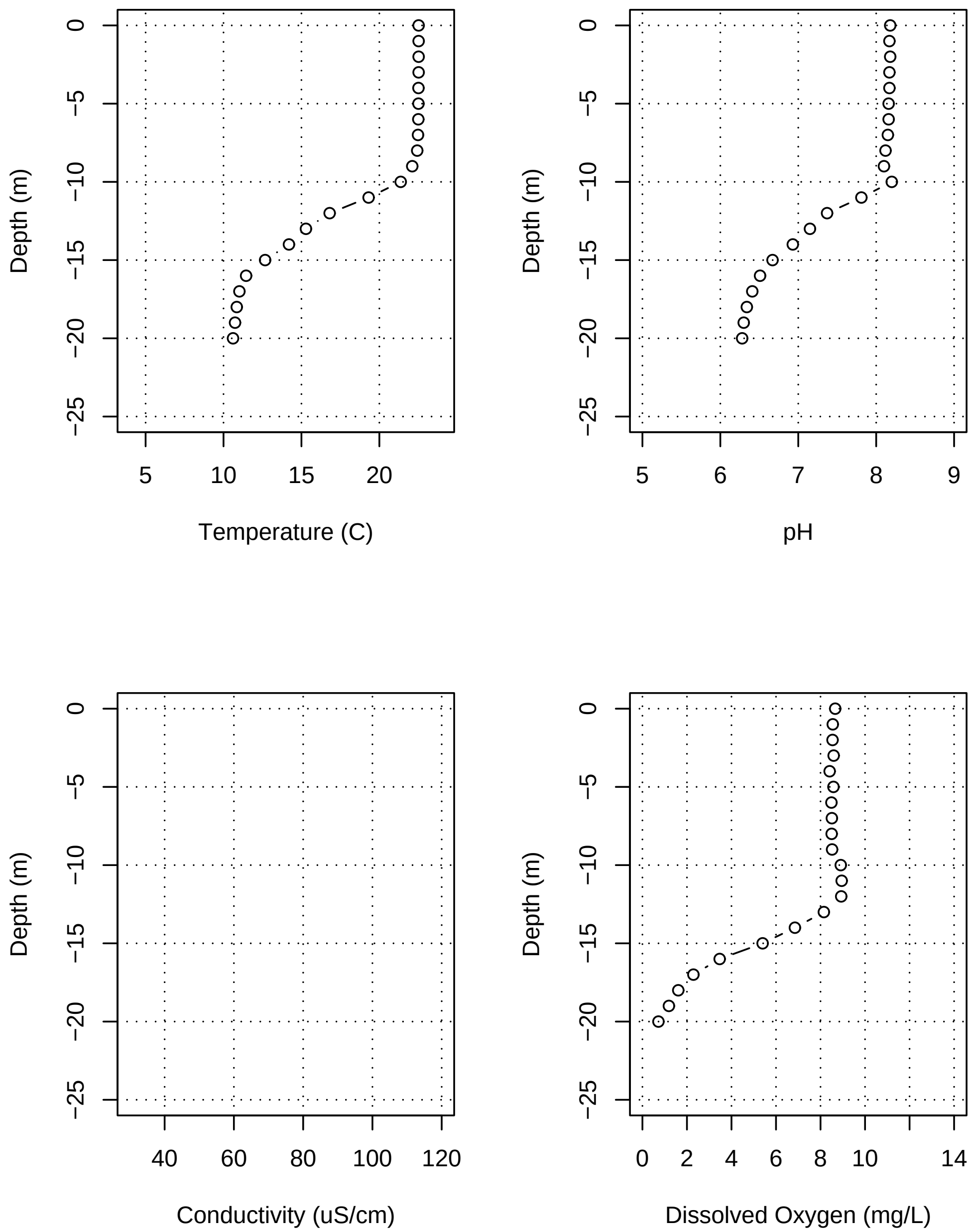


Figure B42: Lake Whatcom Hydrolab profile for Site 2, August 4, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

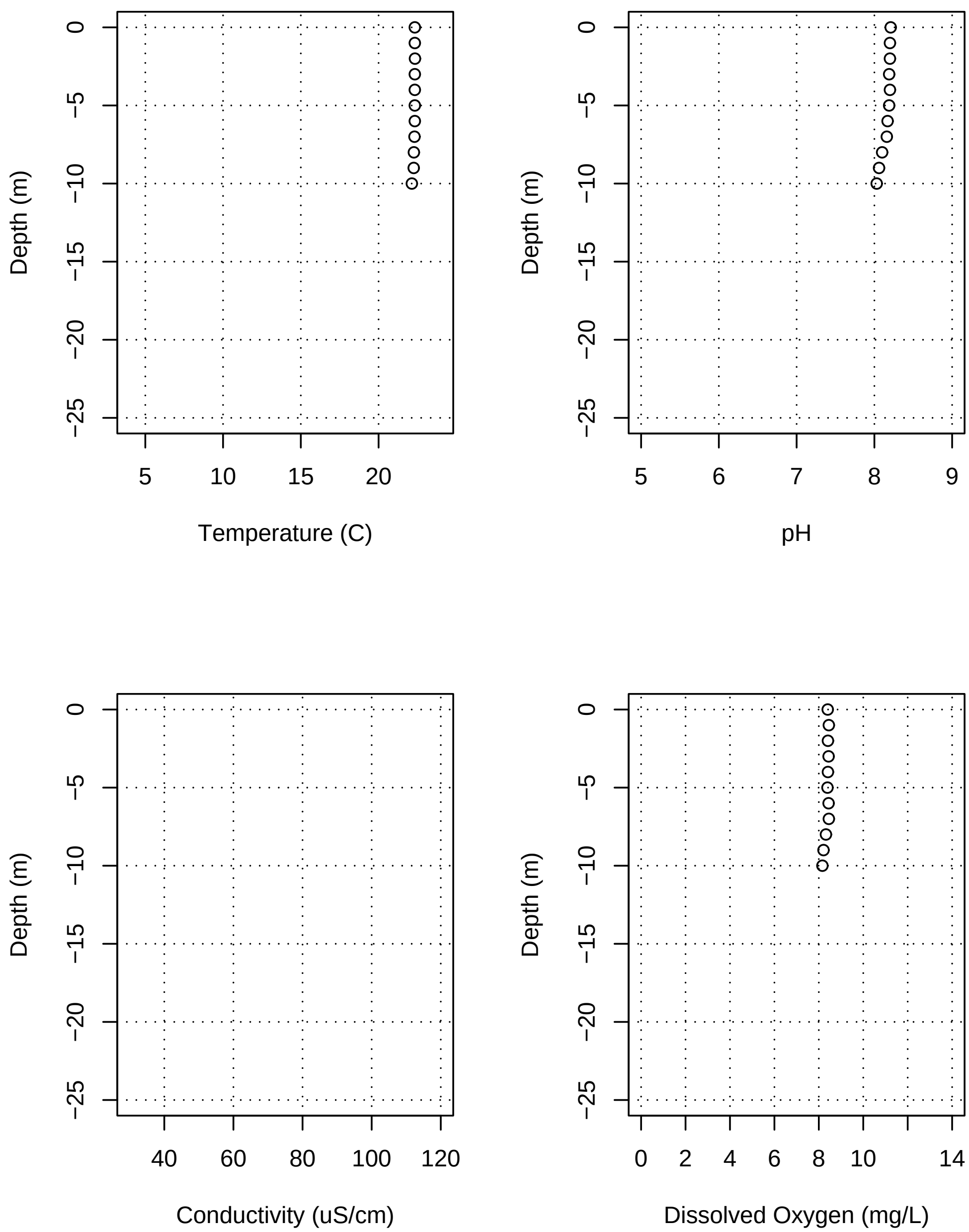


Figure B43: Lake Whatcom Hydrolab profile for the Intake, August 4, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

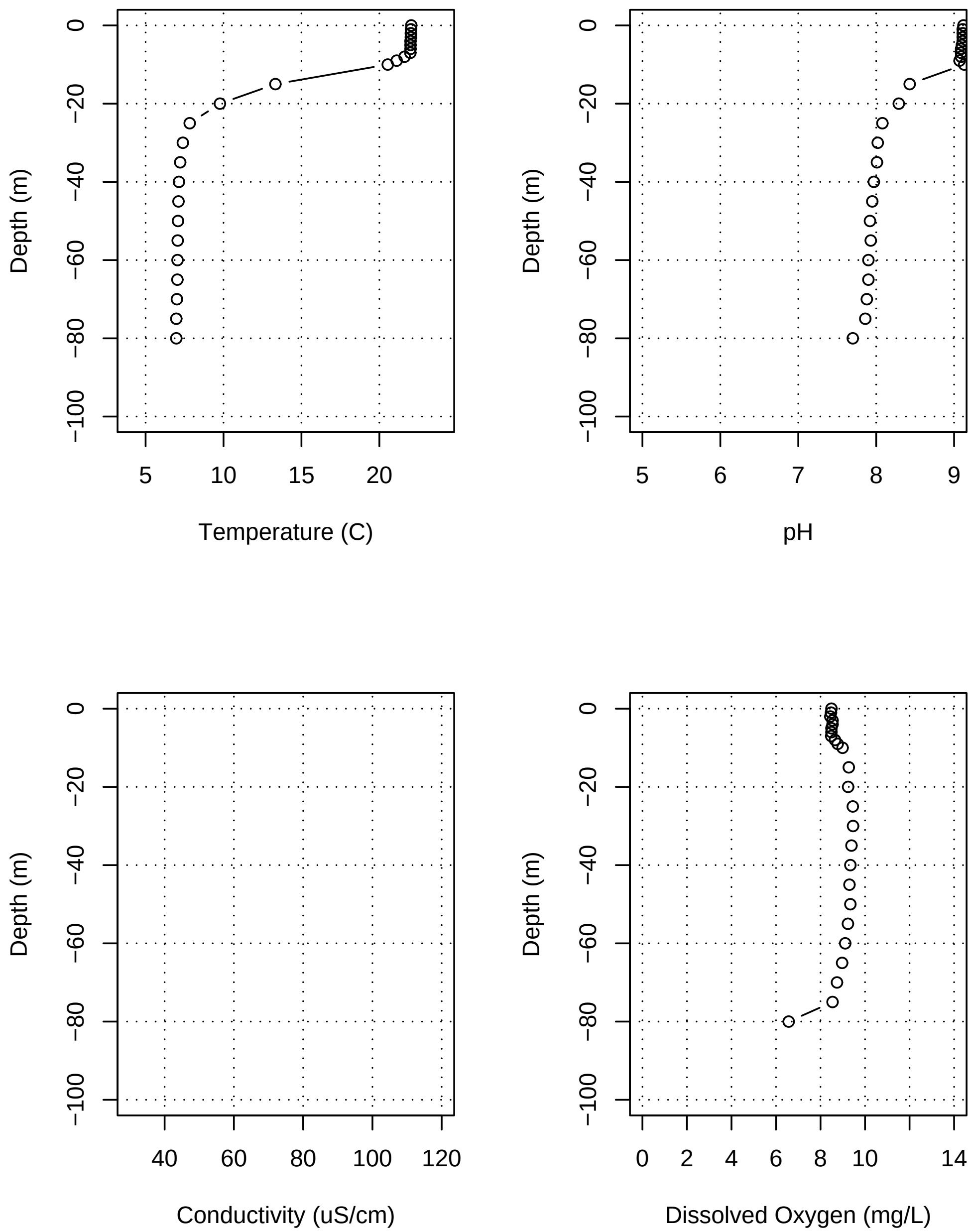


Figure B44: Lake Whatcom Hydrolab profile for Site 3, August 3, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

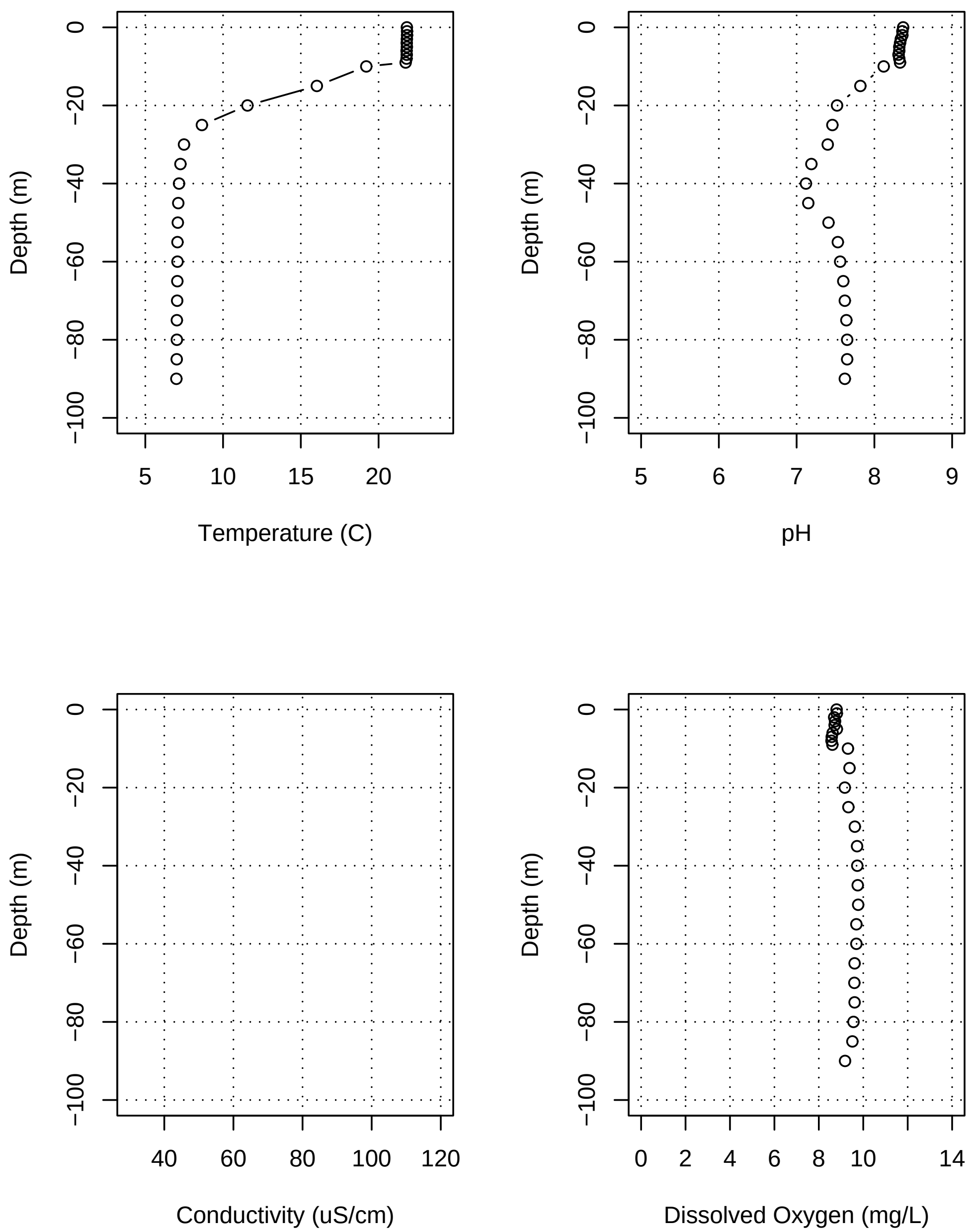


Figure B45: Lake Whatcom Hydrolab profile for Site 4, August 3, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

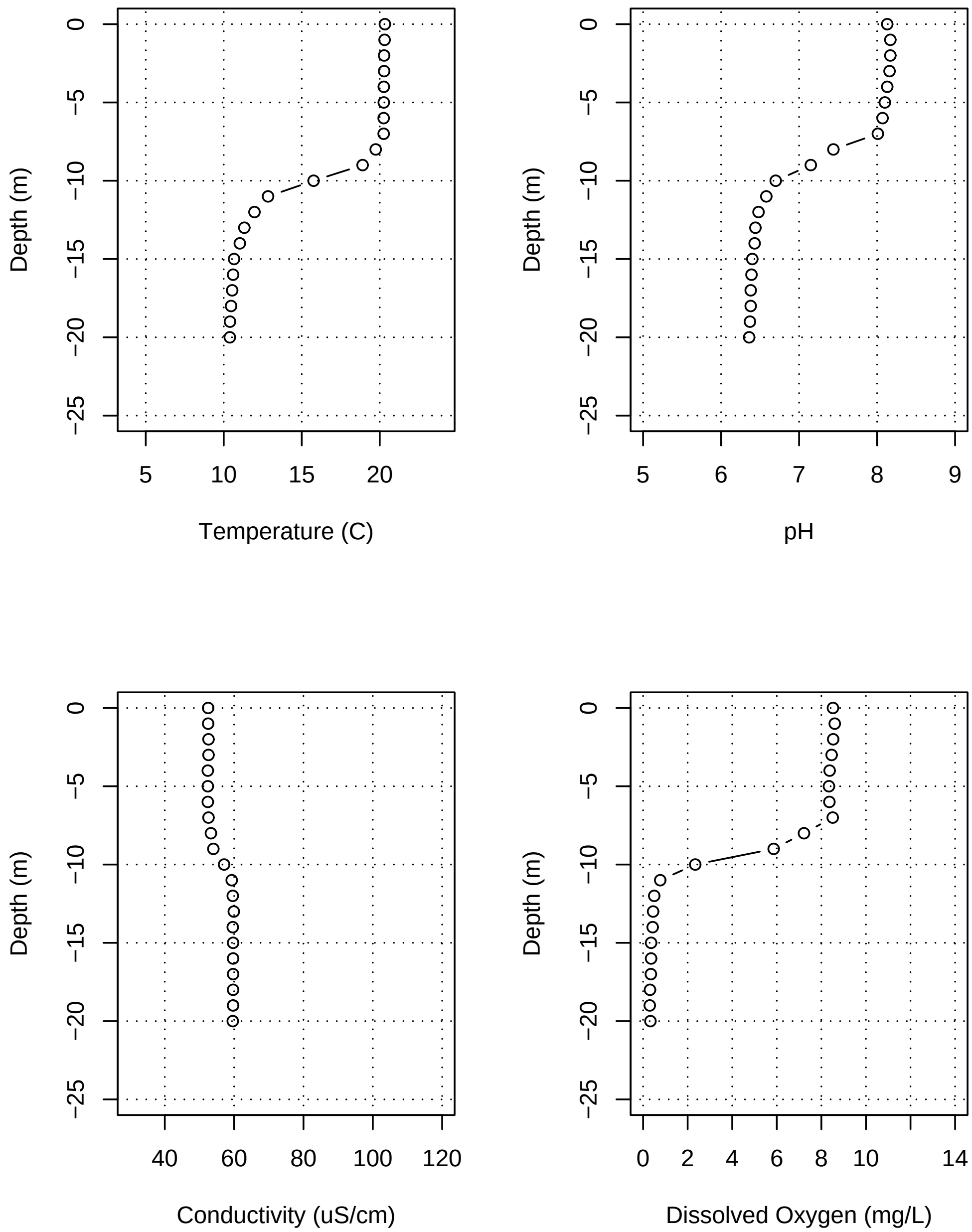


Figure B46: Lake Whatcom Hydrolab profile for Site 1, September 2, 2004.

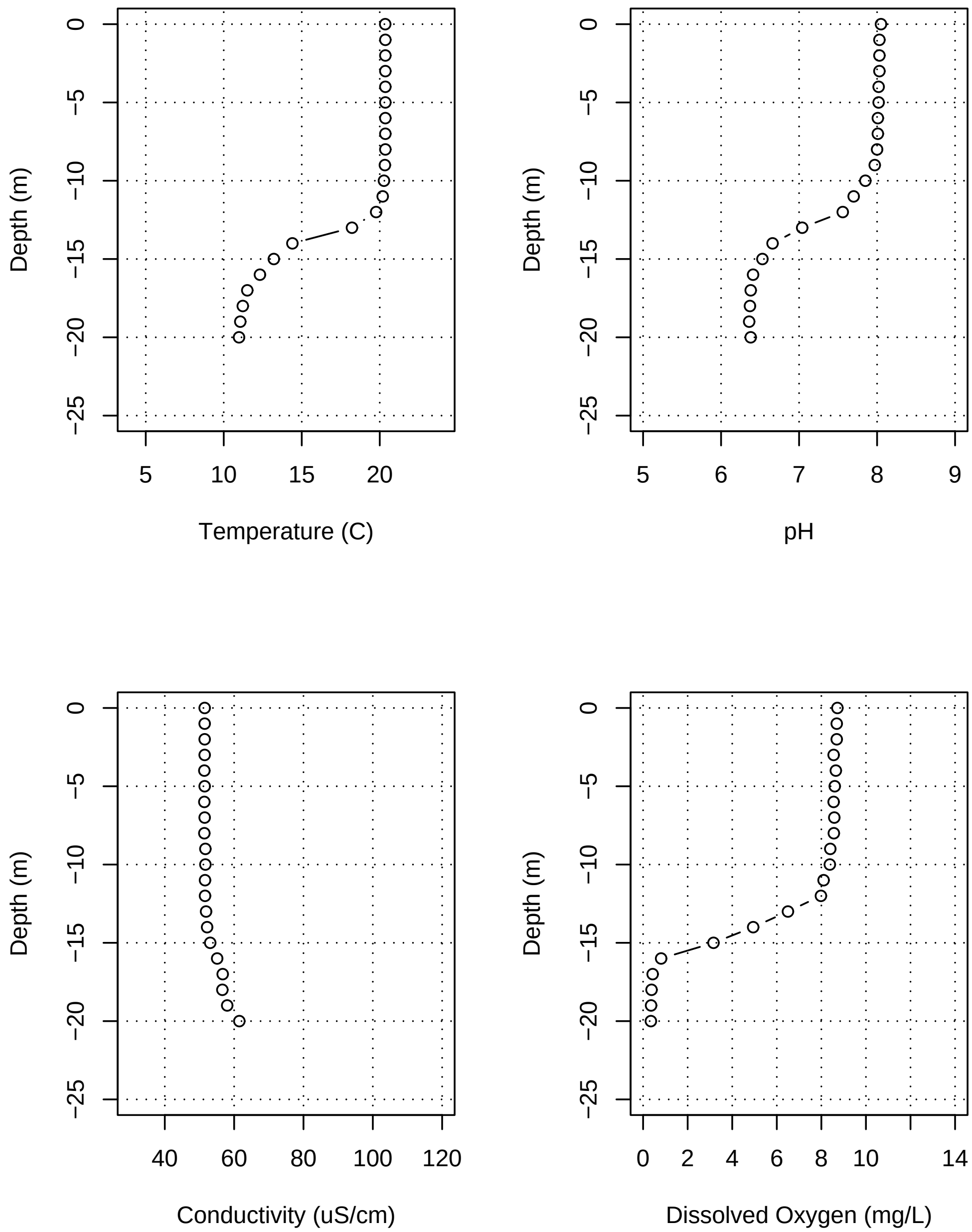


Figure B47: Lake Whatcom Hydrolab profile for Site 2, September 2, 2004.

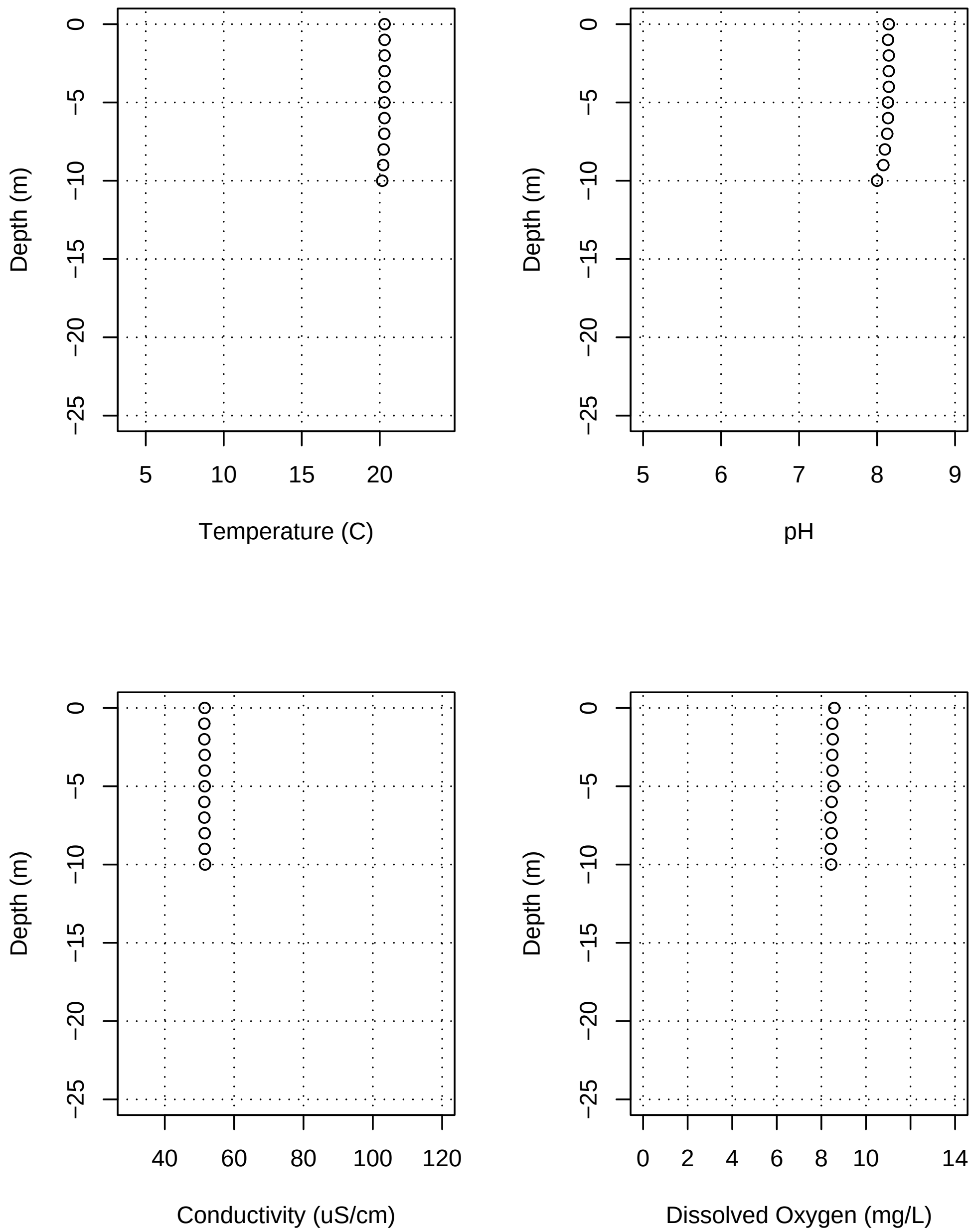


Figure B48: Lake Whatcom Hydrolab profile for the Intake, September 2, 2004.

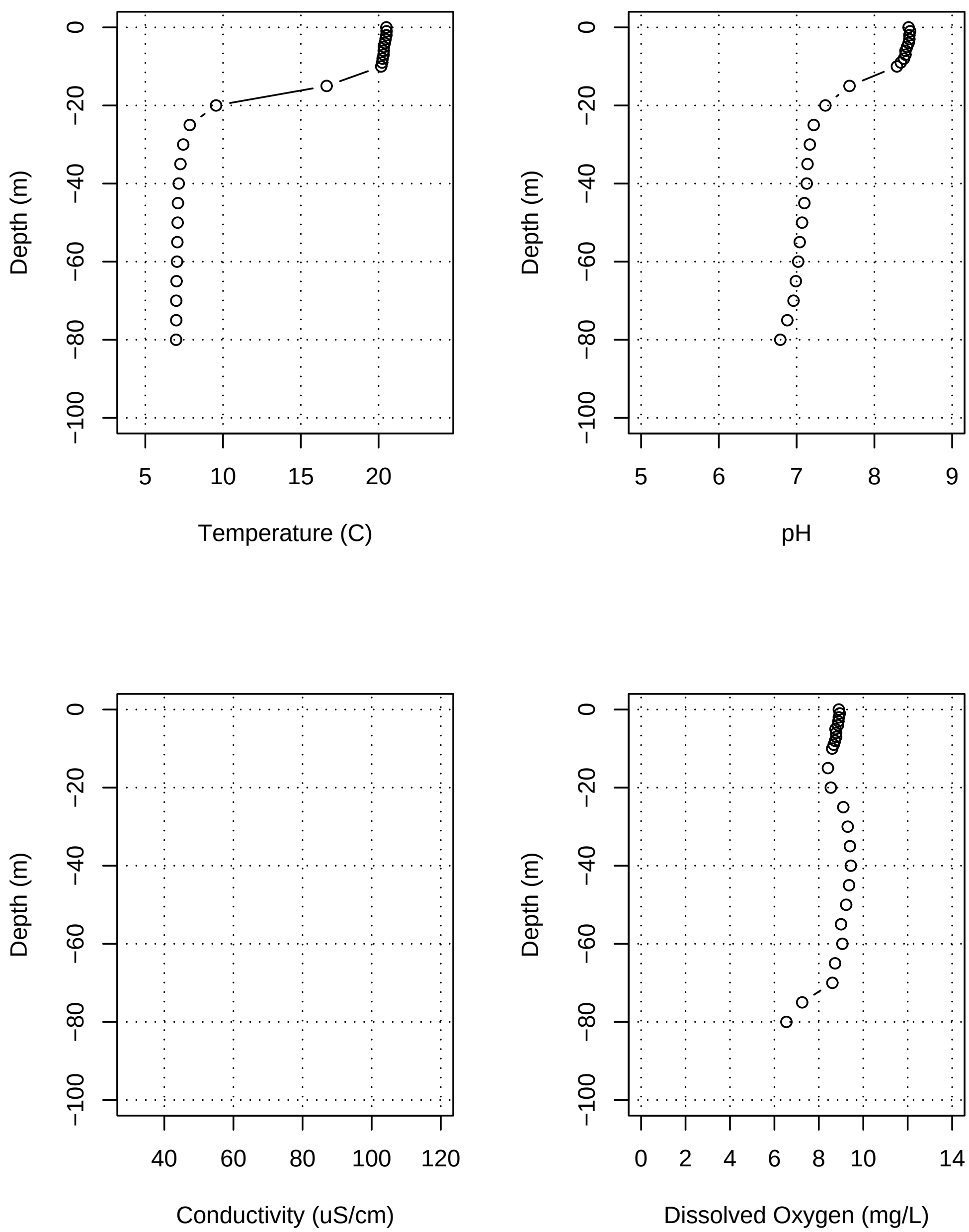


Figure B49: Lake Whatcom Hydrolab profile for Site 3, September 1, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

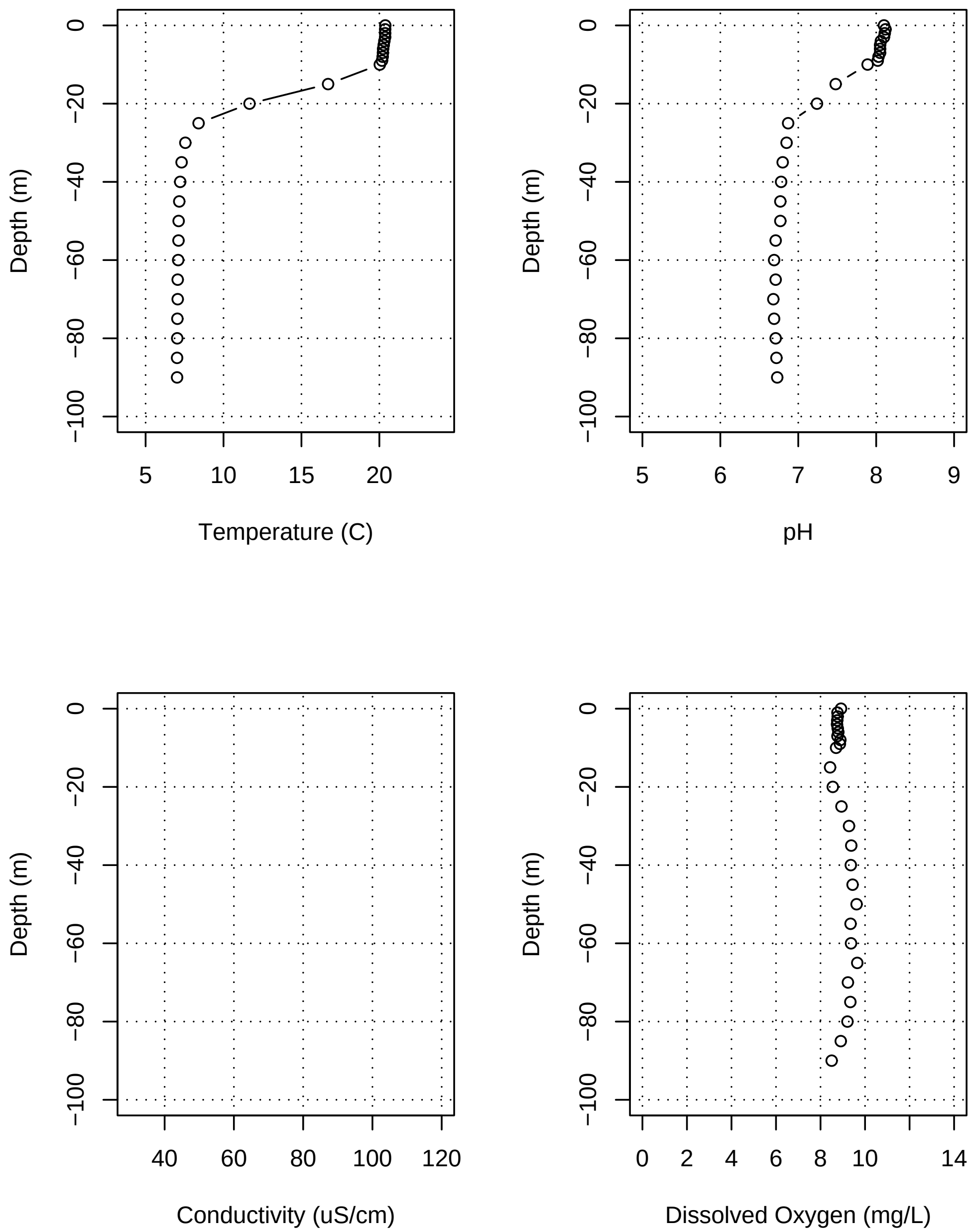


Figure B50: Lake Whatcom Hydrolab profile for Site 4, September 1, 2004. Conductivity data have been deleted due to Hydrolab malfunction.

B.2 Temperature, Dissolved Oxygen, pH, Conductivity

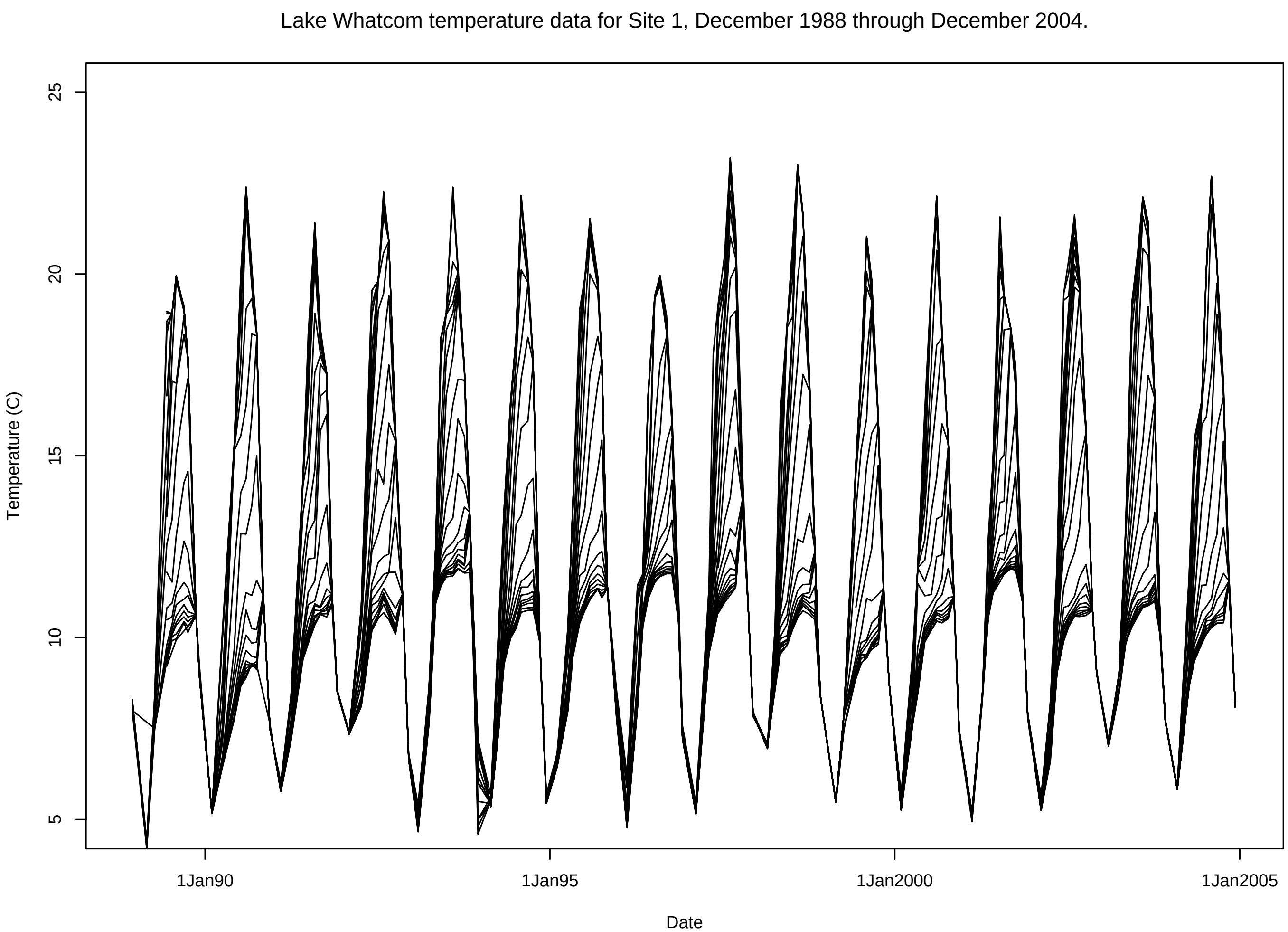


Figure B51: Lake Whatcom temperature data for Site 1 (1988–2004).

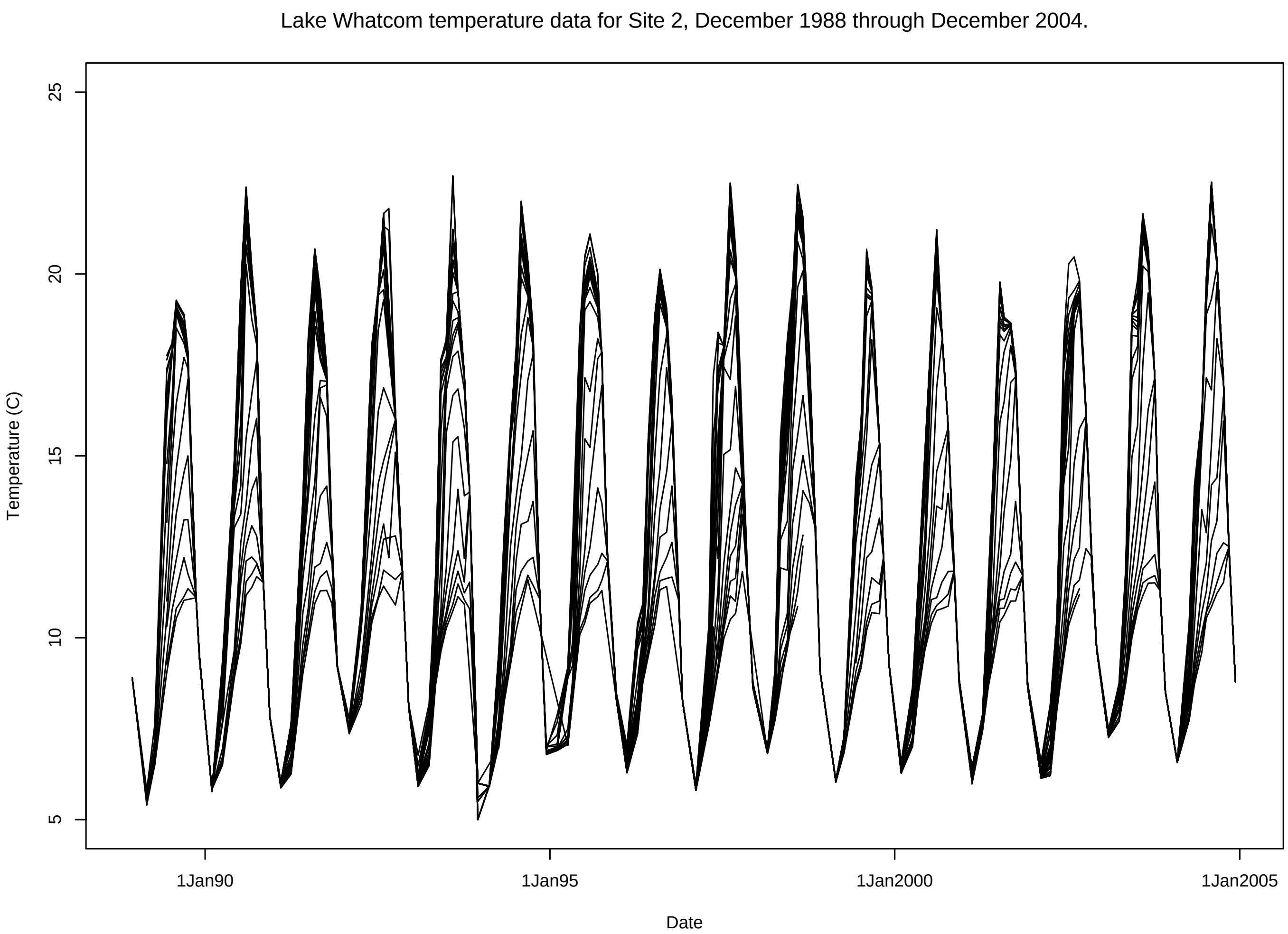


Figure B52: Lake Whatcom temperature data for Site 2 (1988–2004).

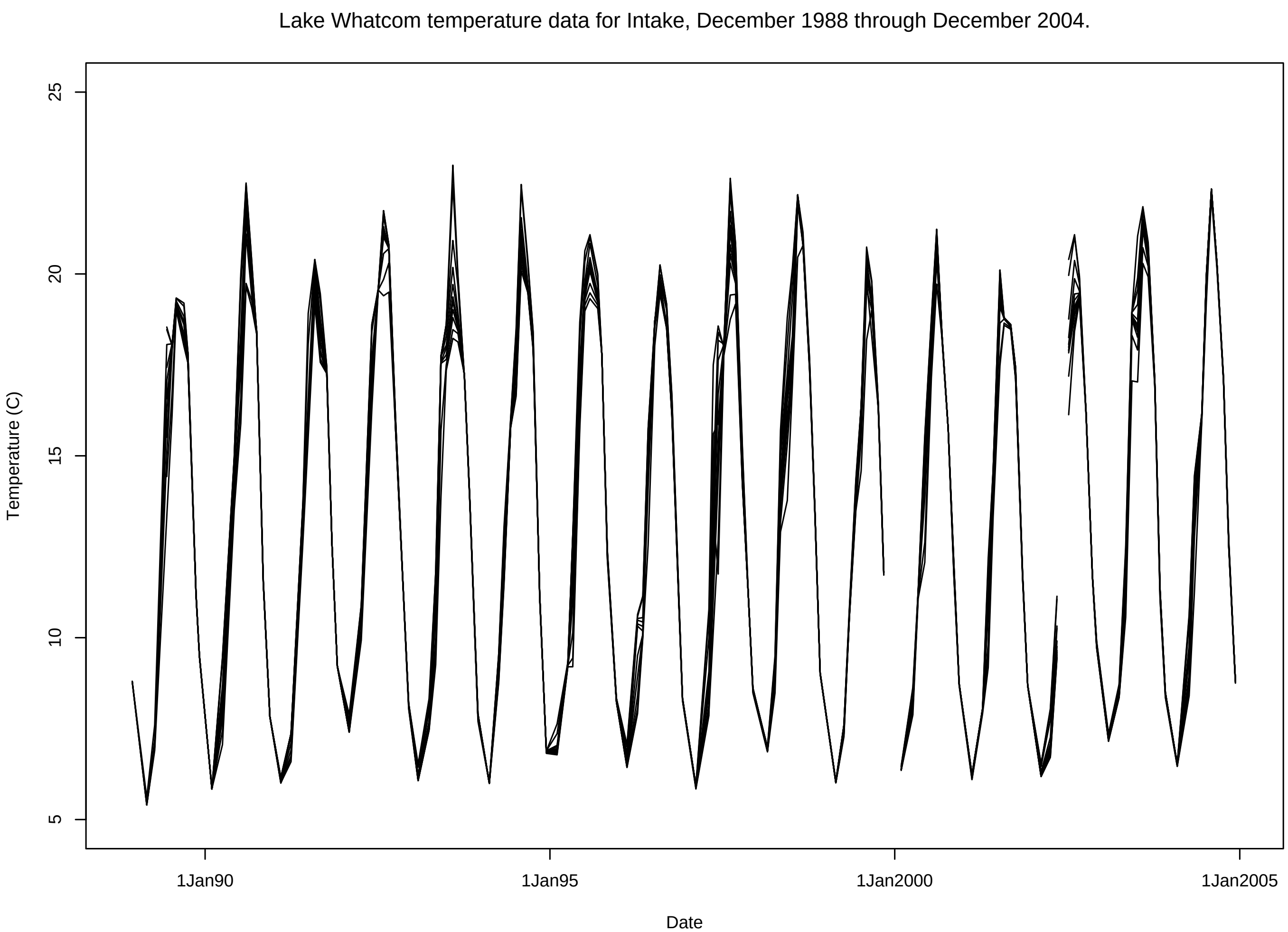


Figure B53: Lake Whatcom temperature data for the Intake (1988–2004).

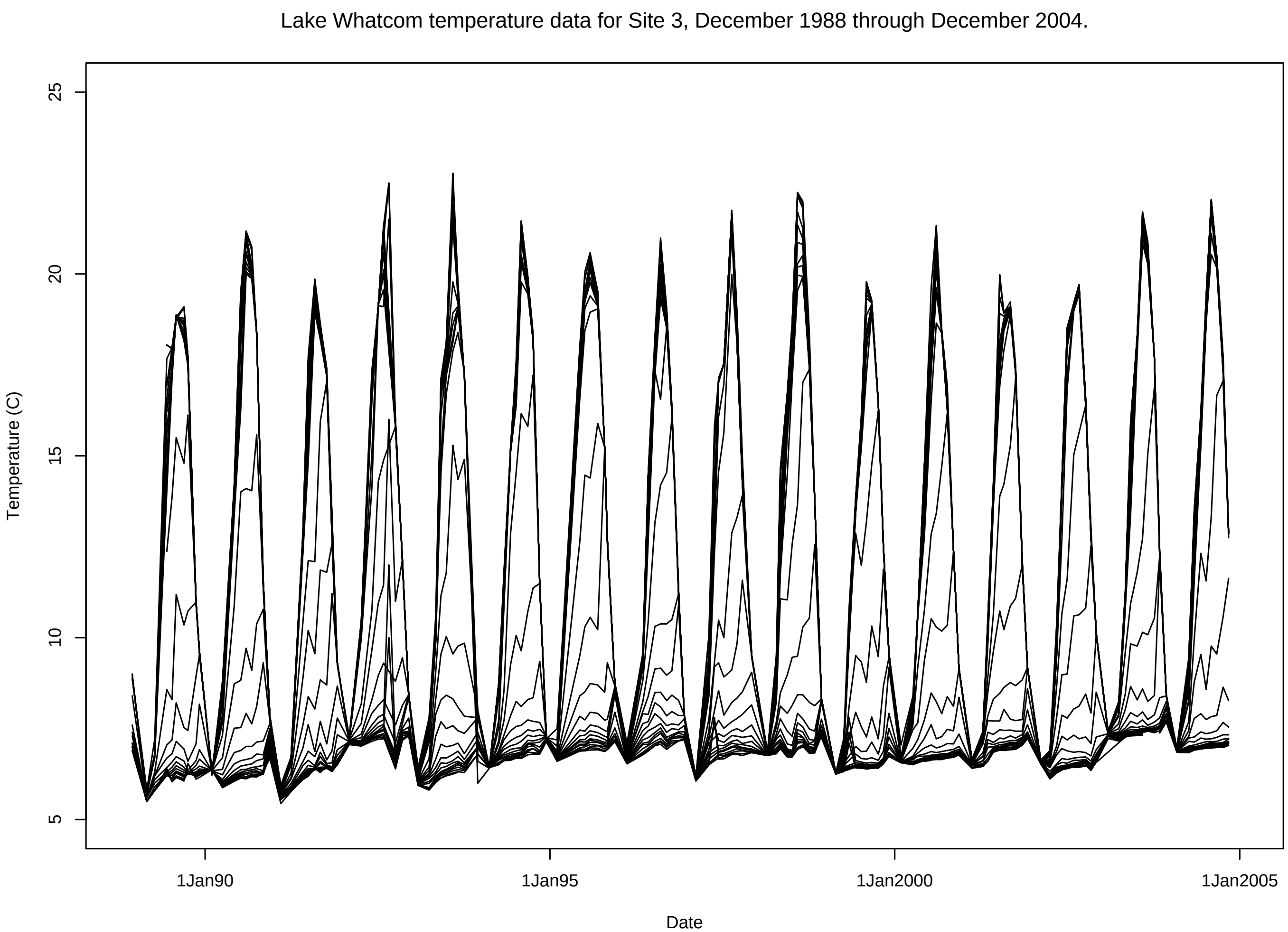


Figure B54: Lake Whatcom temperature data for Site 3 (1988–2004).

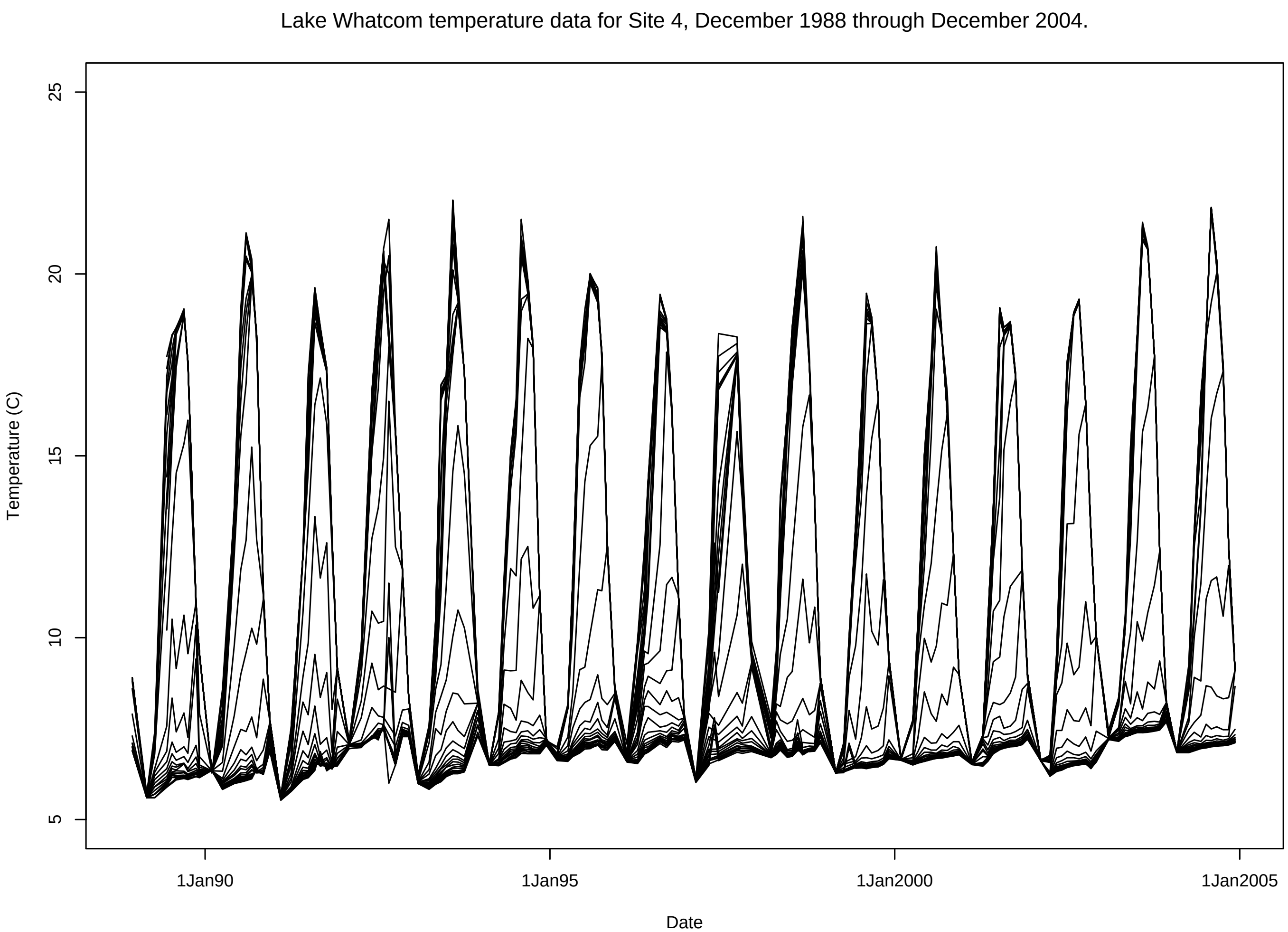


Figure B55: Lake Whatcom temperature data for Site 4 (1988–2004).

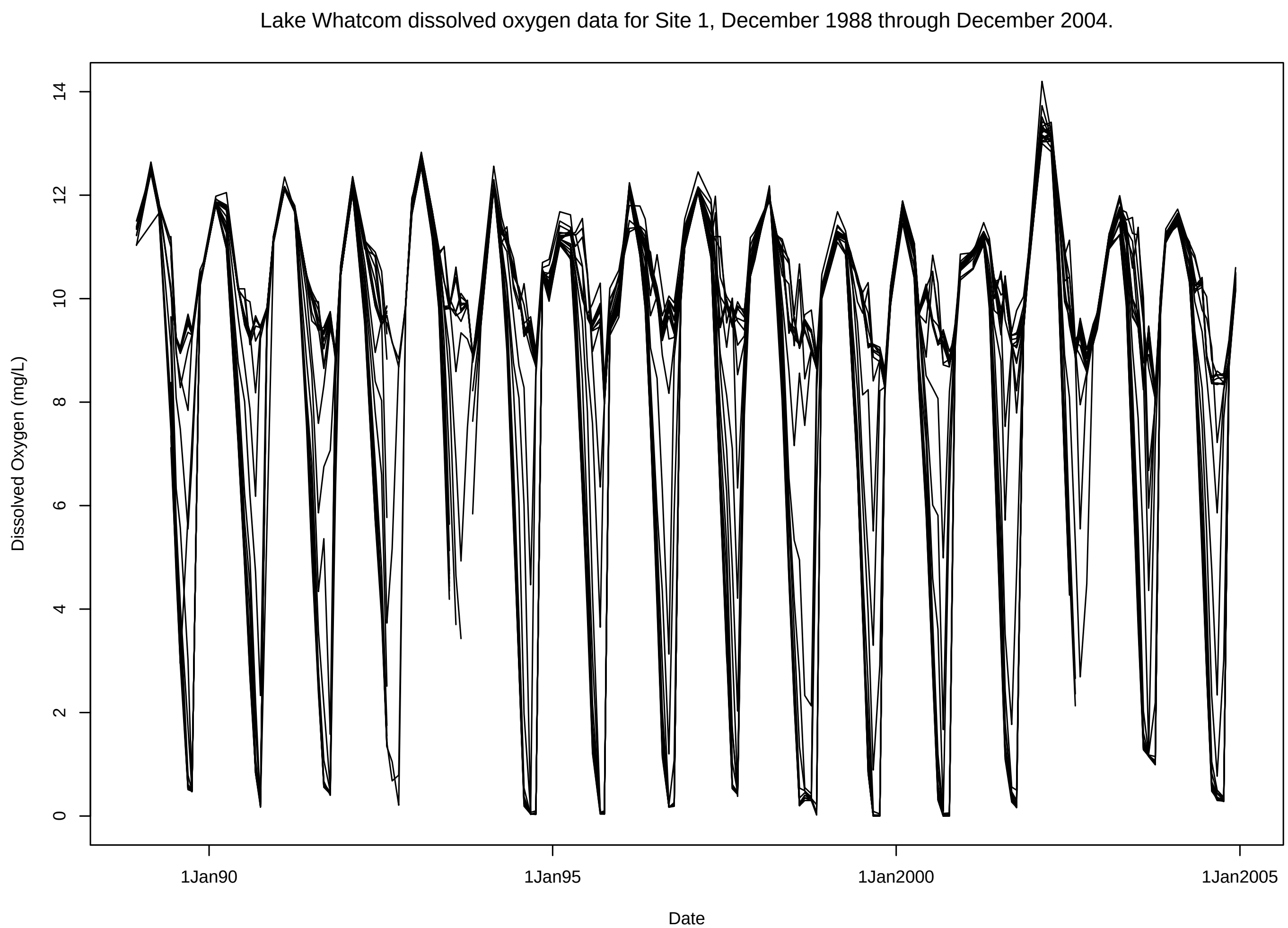


Figure B56: Lake Whatcom dissolved oxygen data for Site 1 (1988–2004).

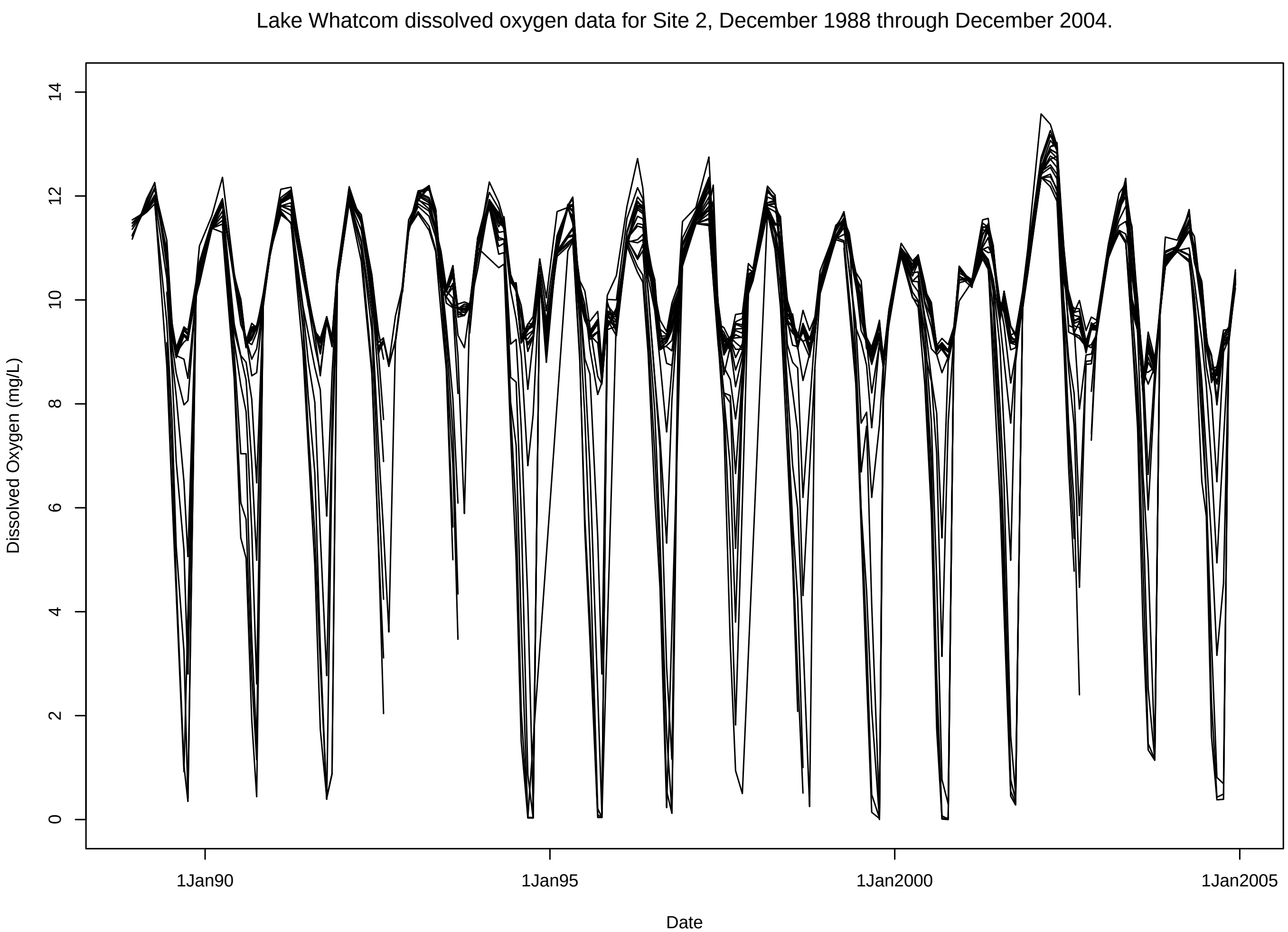


Figure B57: Lake Whatcom dissolved oxygen data for Site 2 (1988–2004).

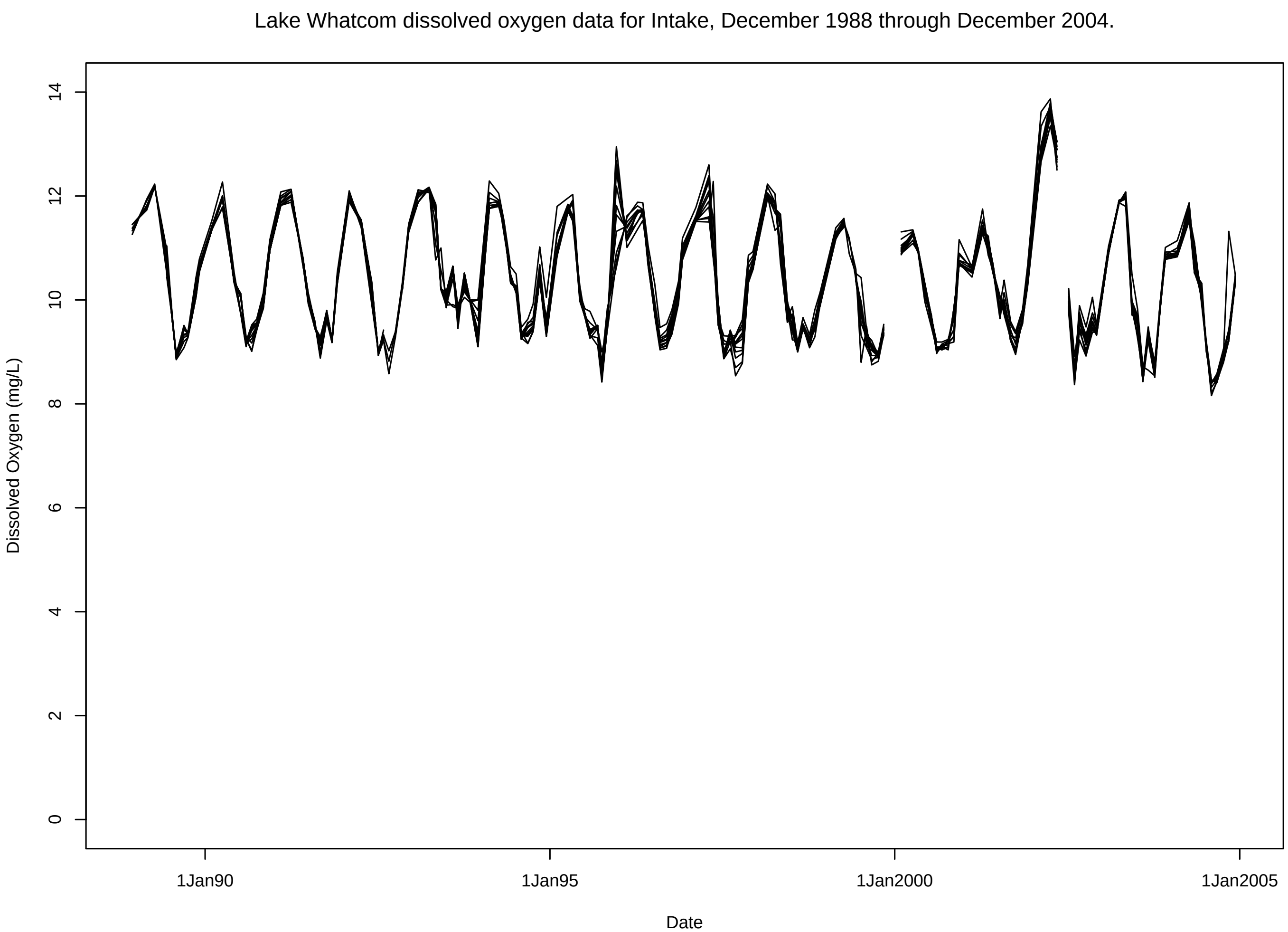


Figure B58: Lake Whatcom dissolved oxygen data for the Intake (1988–2004).

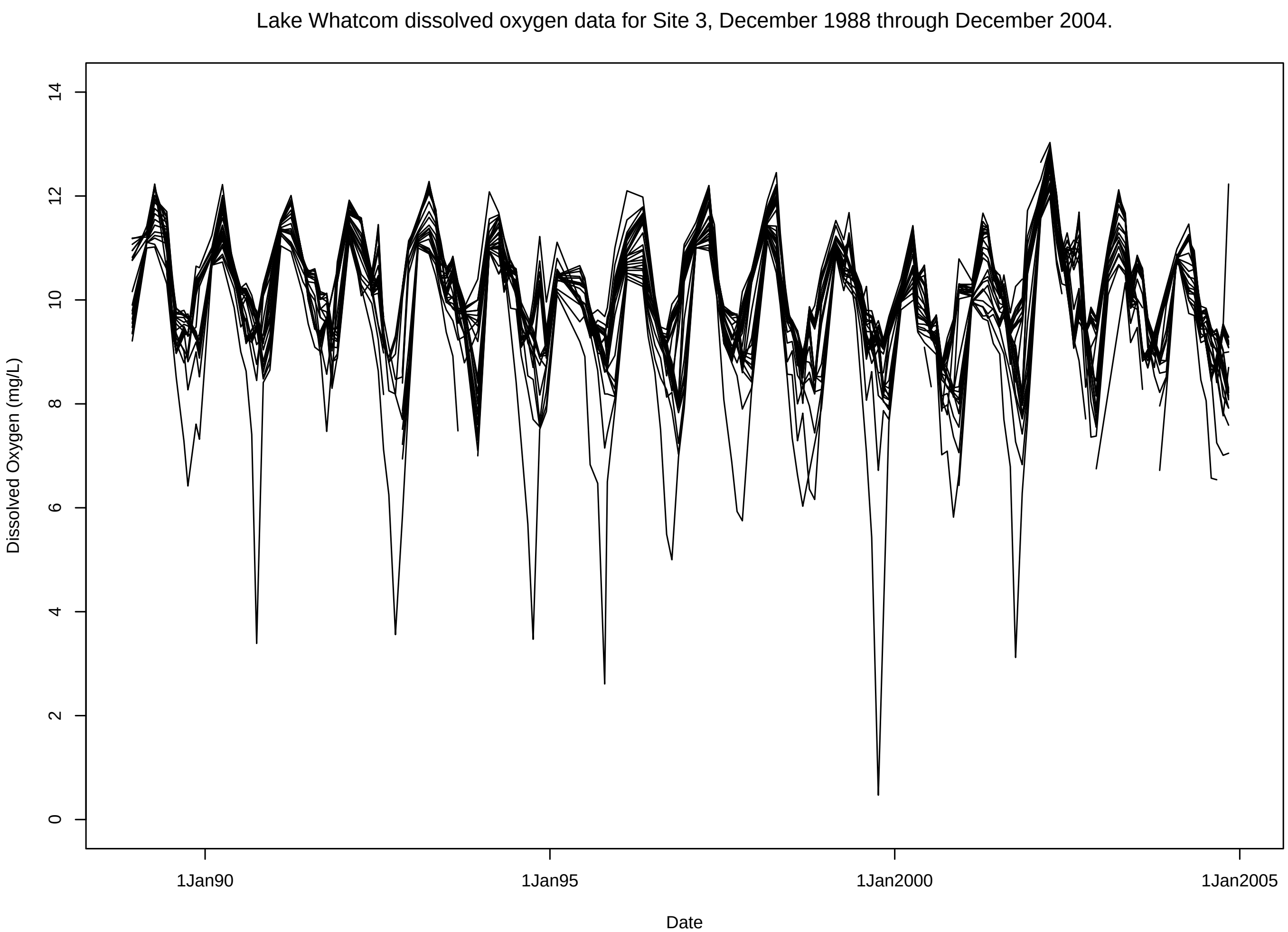


Figure B59: Lake Whatcom dissolved oxygen data for Site 3 (1988–2004).

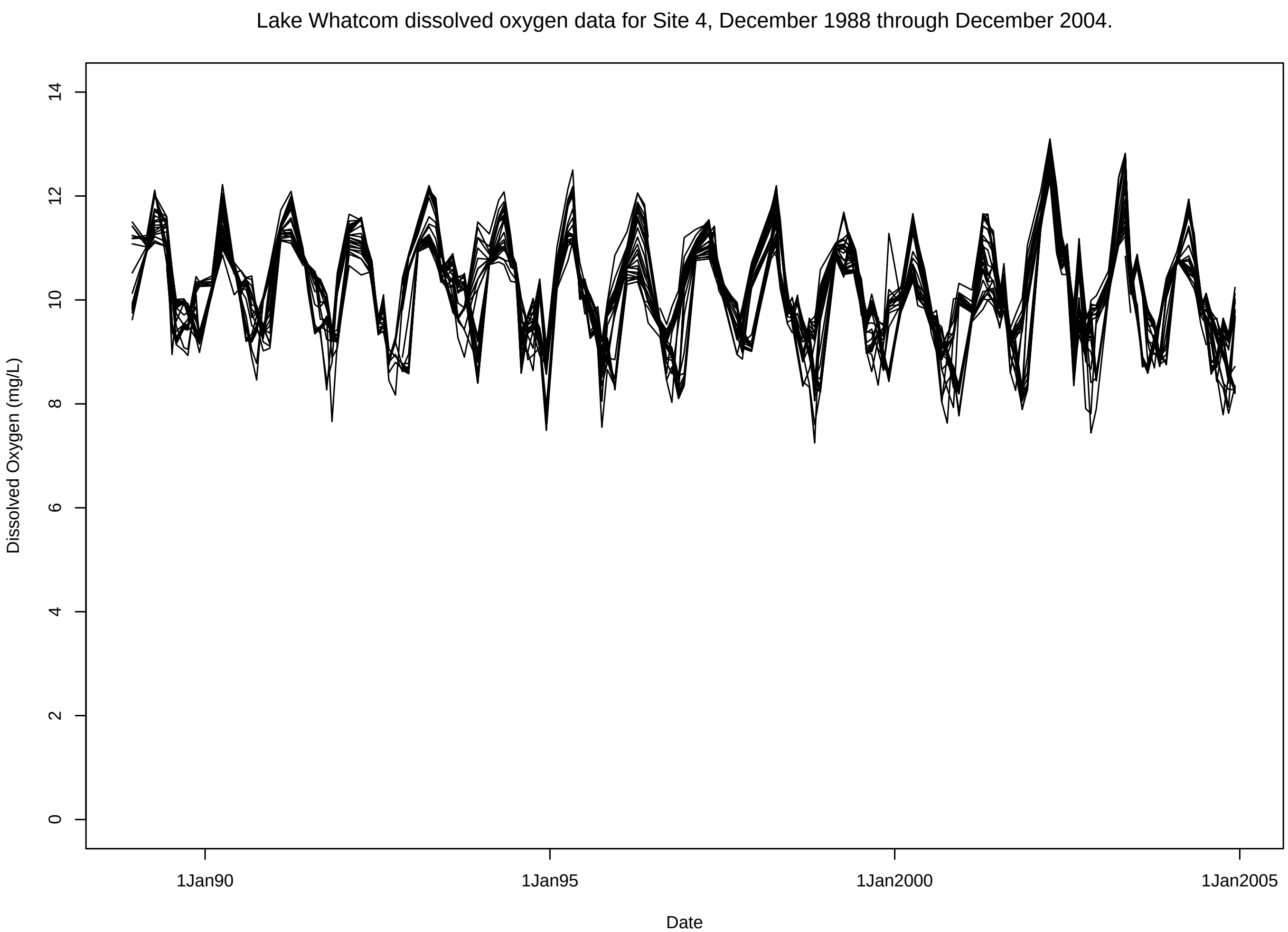


Figure B60: Lake Whatcom dissolved oxygen data for Site 4 (1988–2004).

Lake Whatcom pH data for Site 1, December 1988 through December 2004.

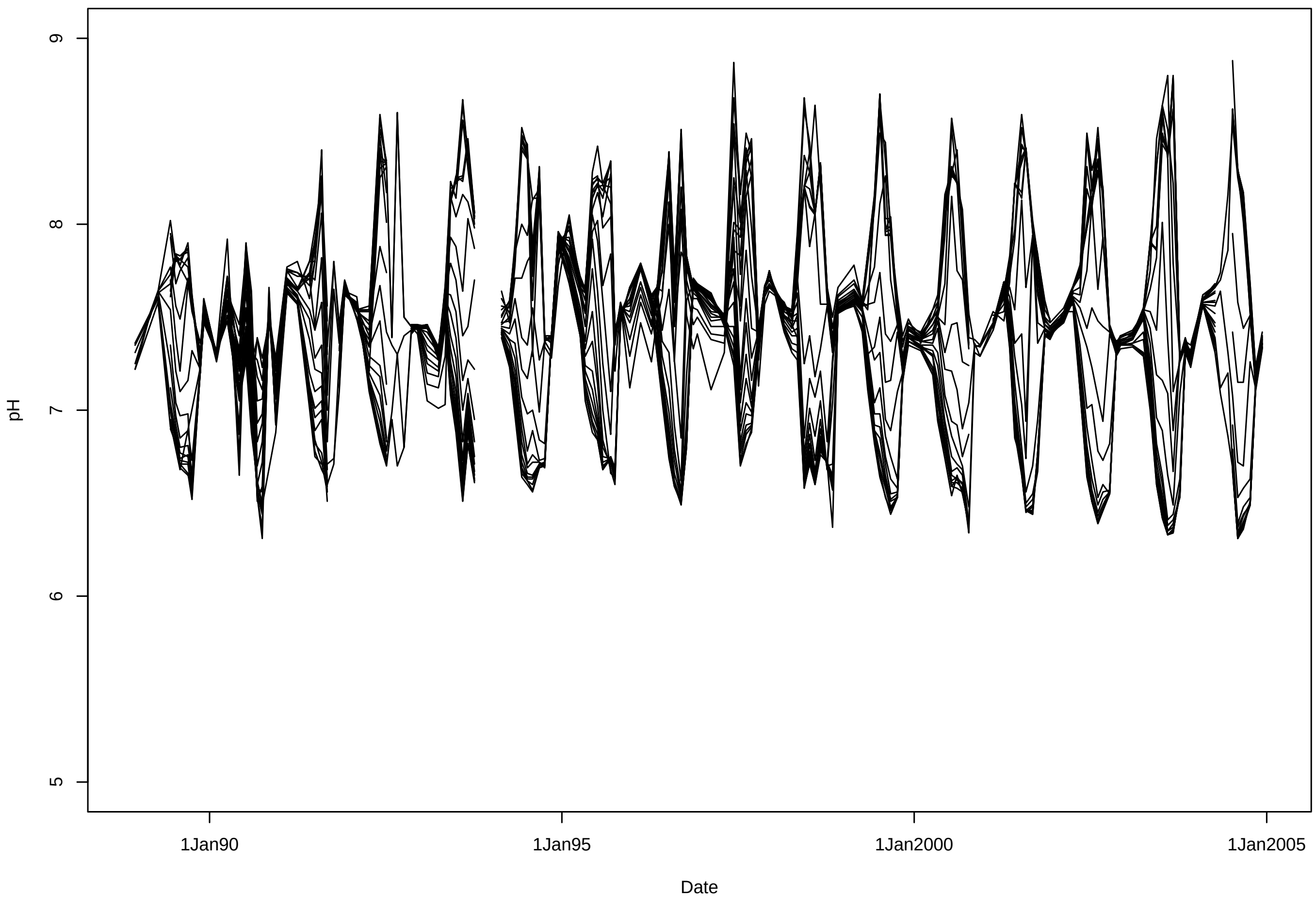


Figure B61: Lake Whatcom pH data for Site 1 (1988–2004).

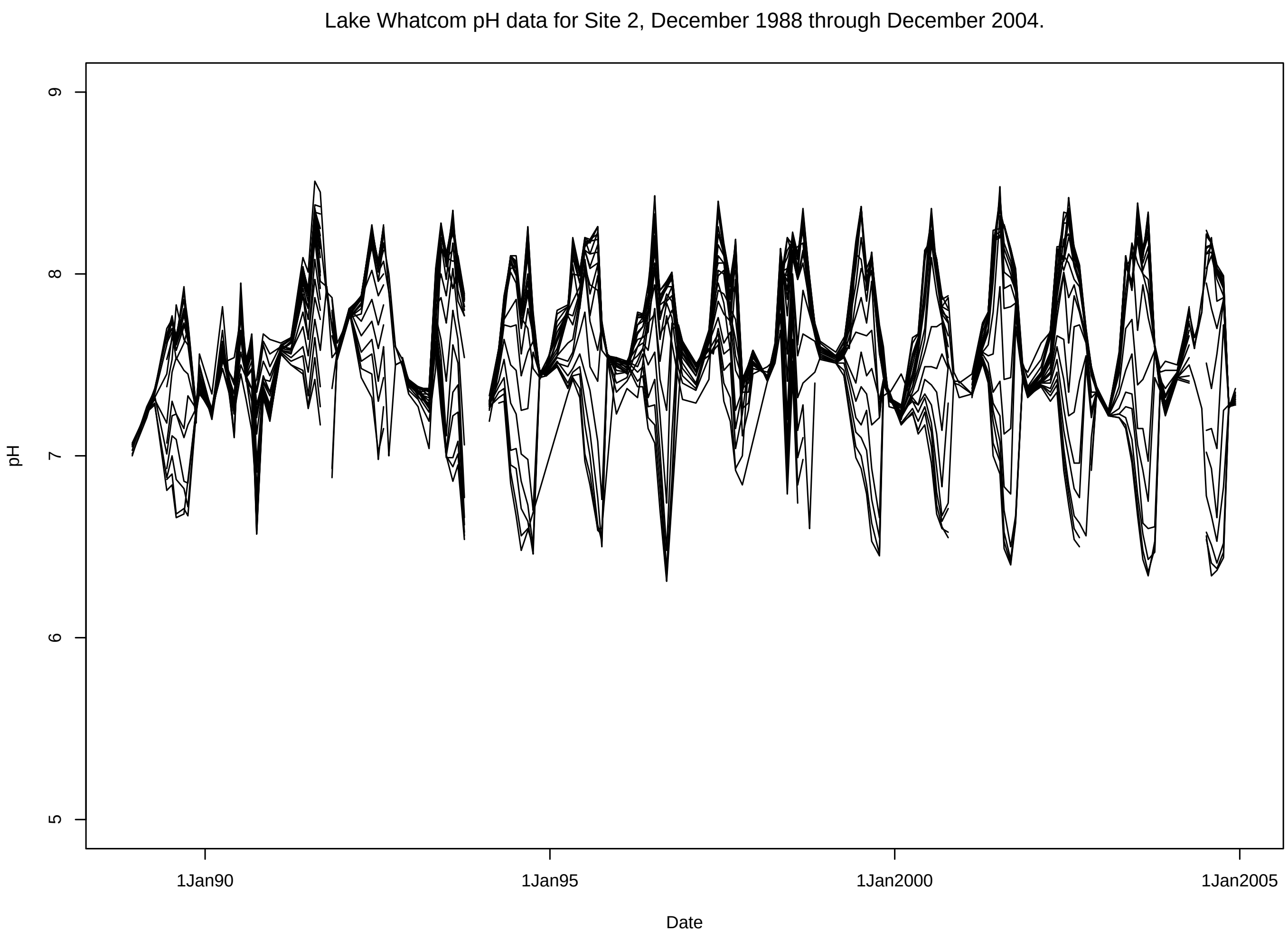


Figure B62: Lake Whatcom pH data for Site 2 (1988–2004).

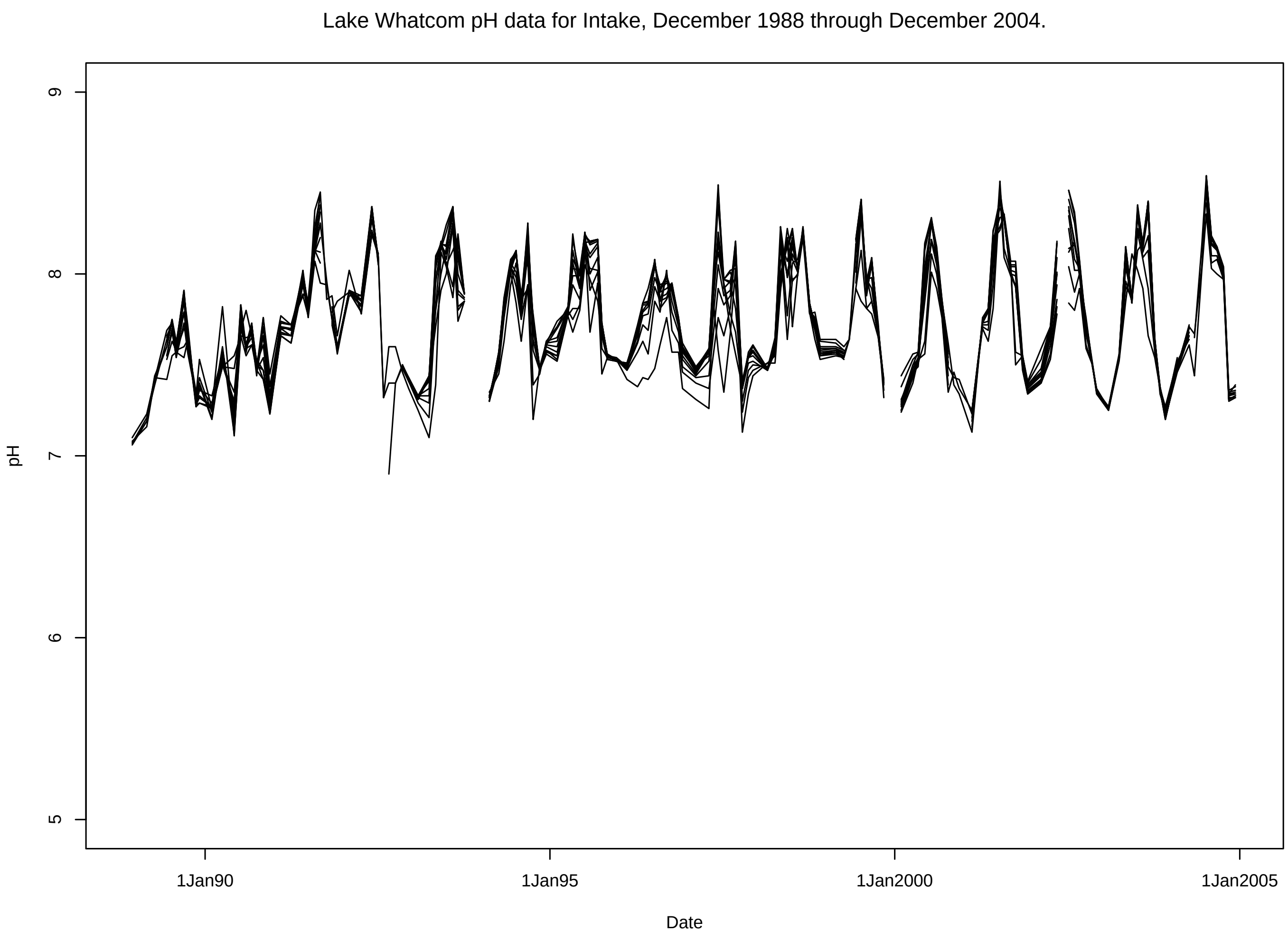


Figure B63: Lake Whatcom pH data for the Intake (1988–2004).

Lake Whatcom pH data for Site 3, December 1988 through December 2004.

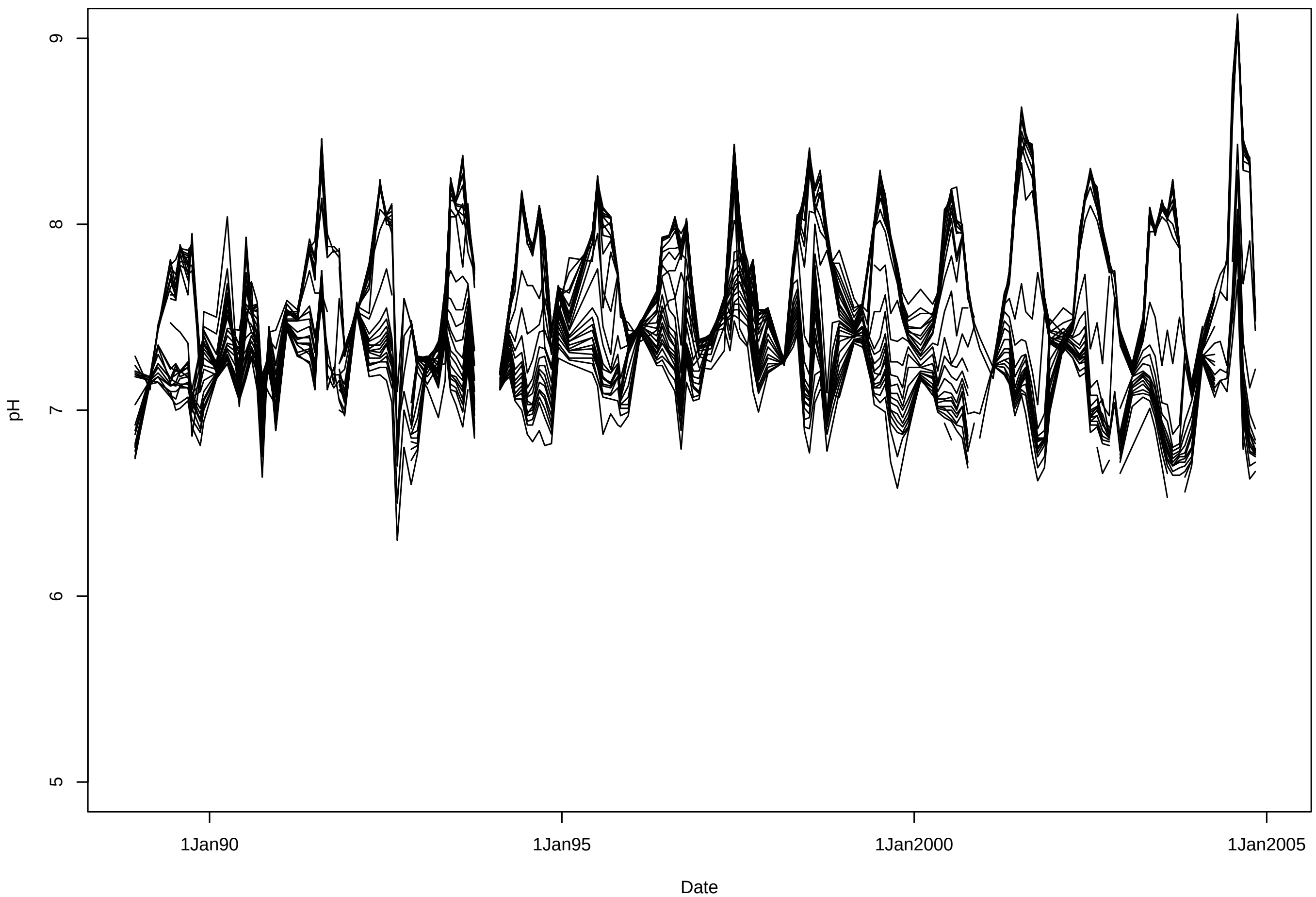


Figure B64: Lake Whatcom pH data for Site 3 (1988–2004).

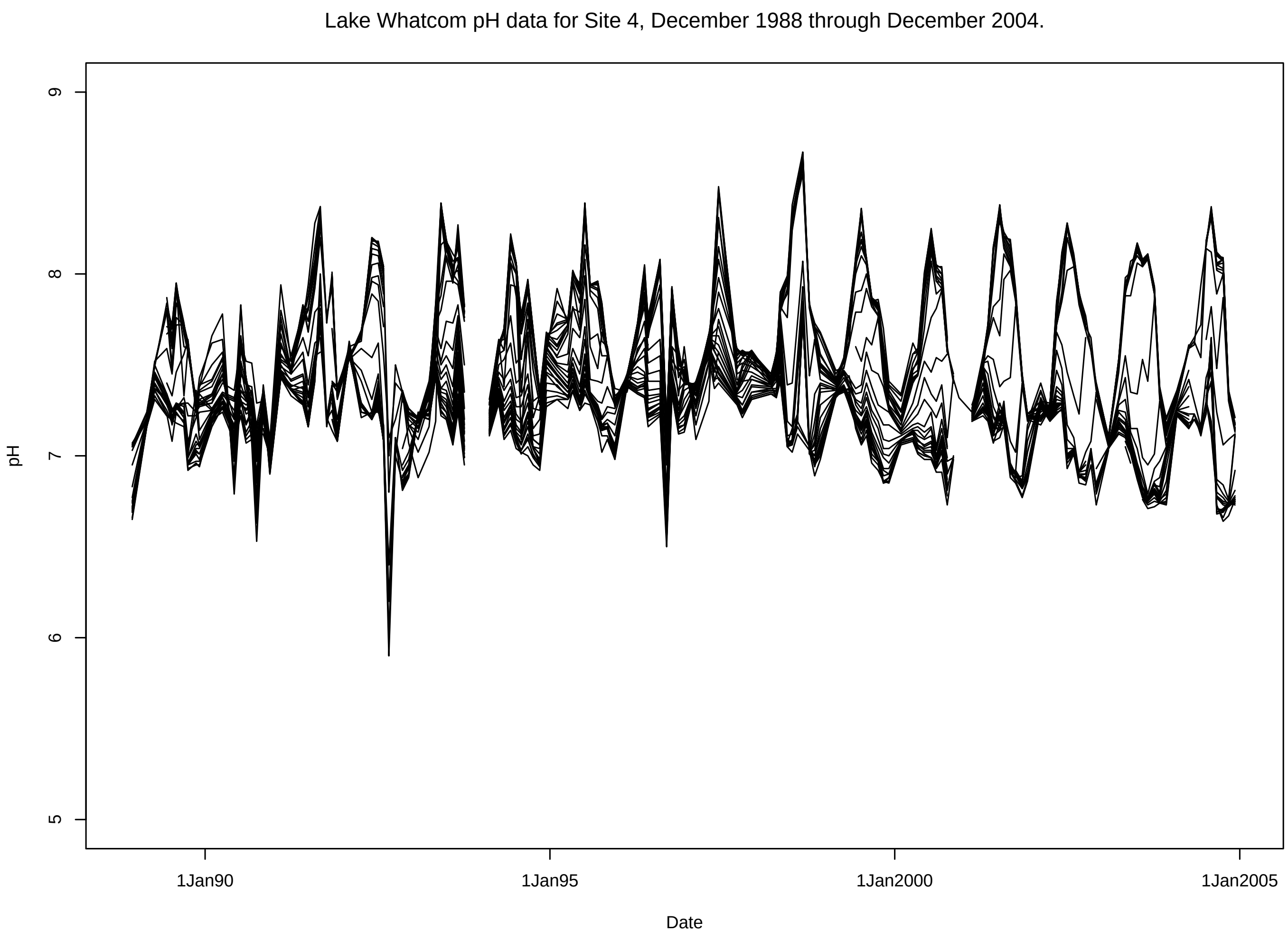


Figure B65: Lake Whatcom pH data for Site 4 (1988–2004).

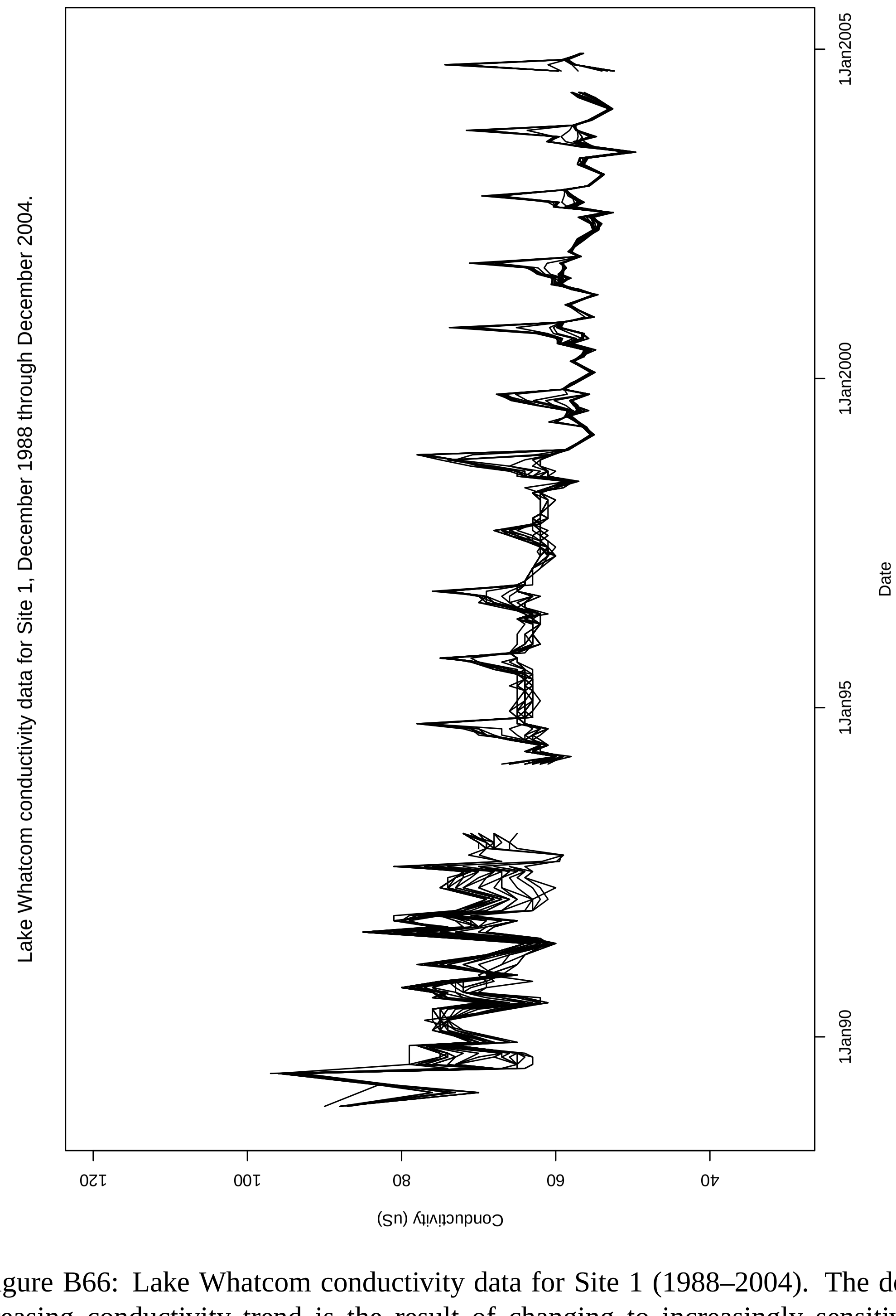


Figure B66: Lake Whatcom conductivity data for Site 1 (1988–2004). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

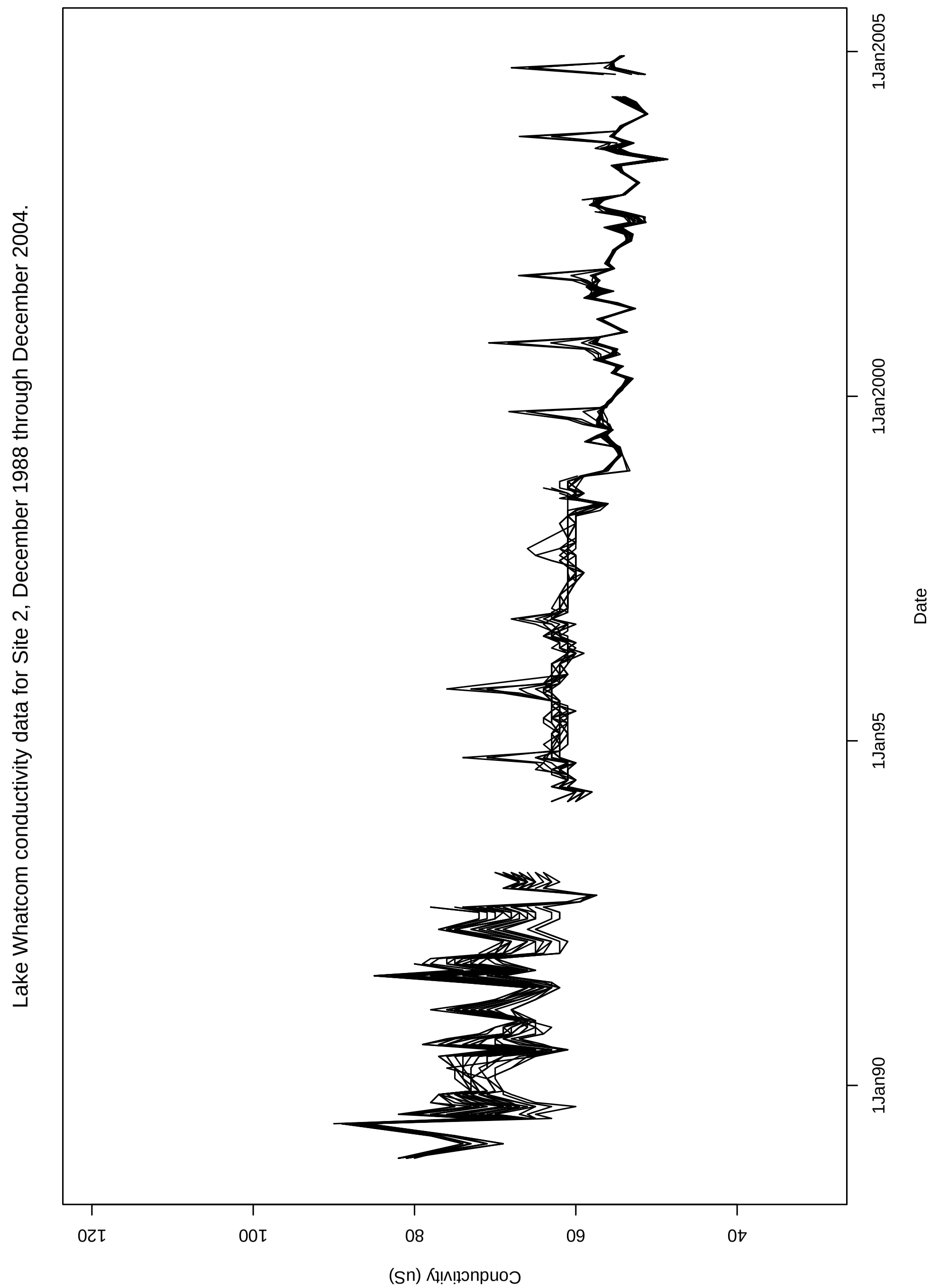


Figure B67: Lake Whatcom conductivity data for Site 2 (1988–2004). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

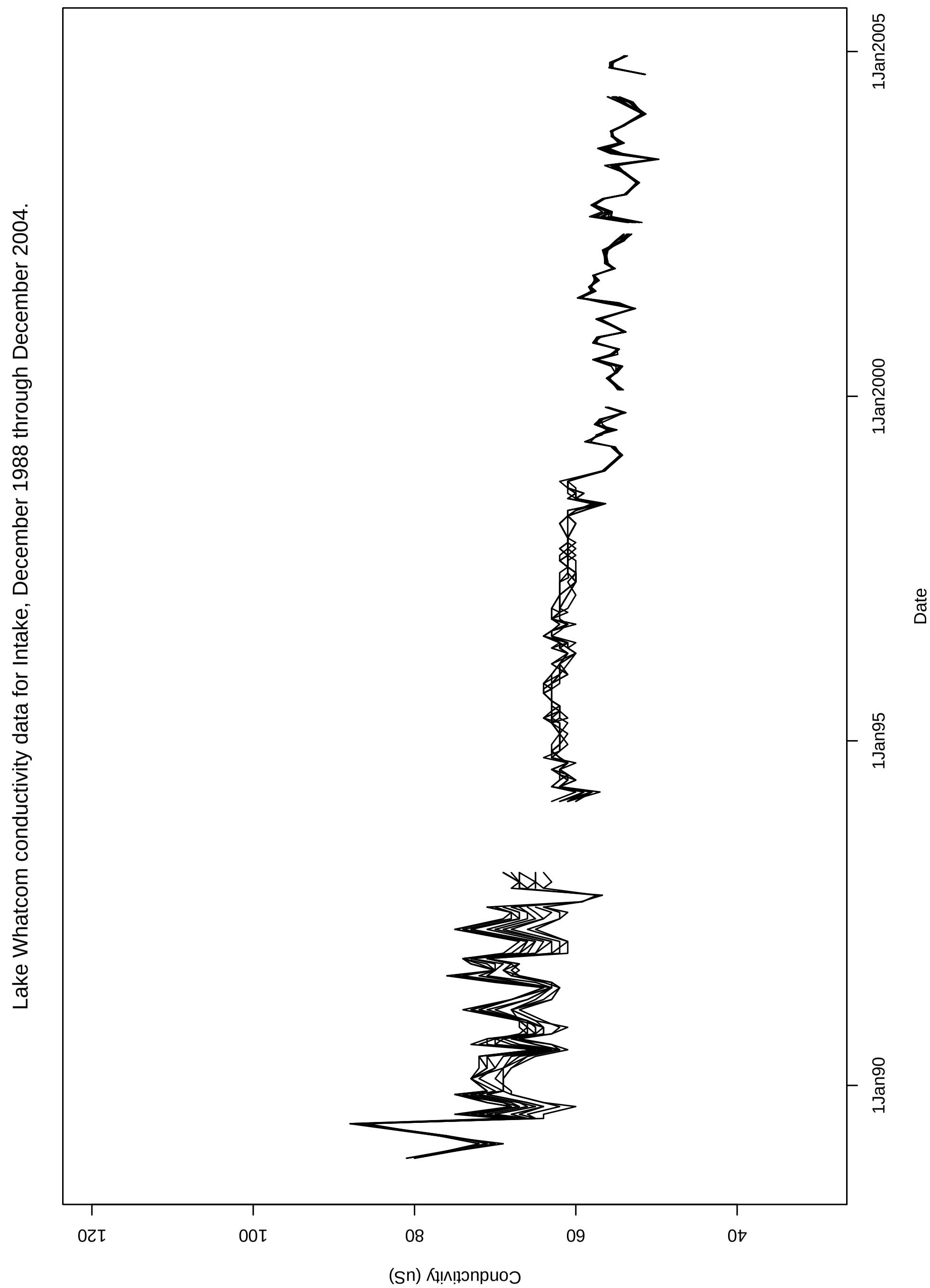


Figure B68: Lake Whatcom conductivity data for the Intake (1988–2004). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

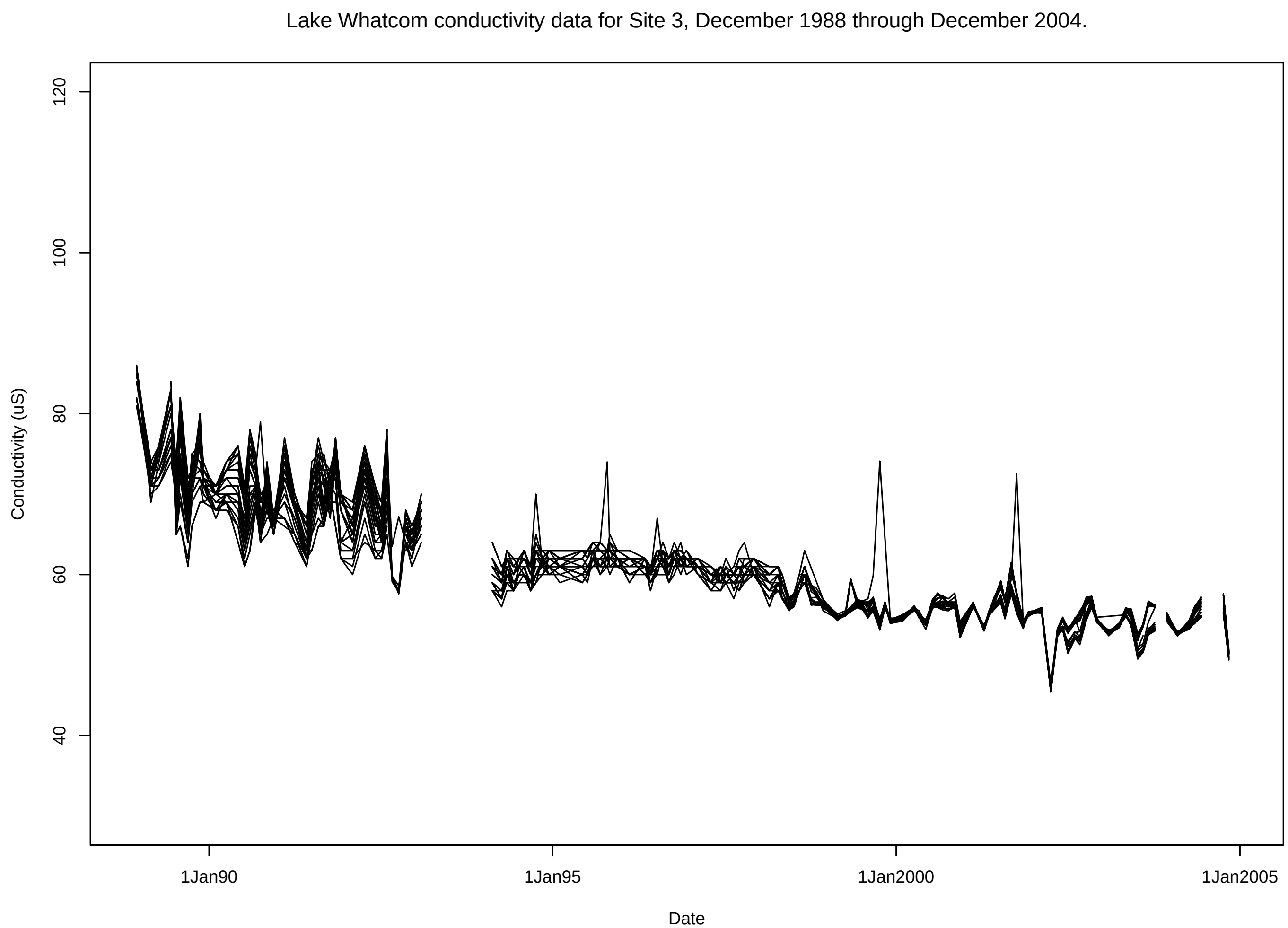


Figure B69: Lake Whatcom conductivity data for Site 3 (1988–2004). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

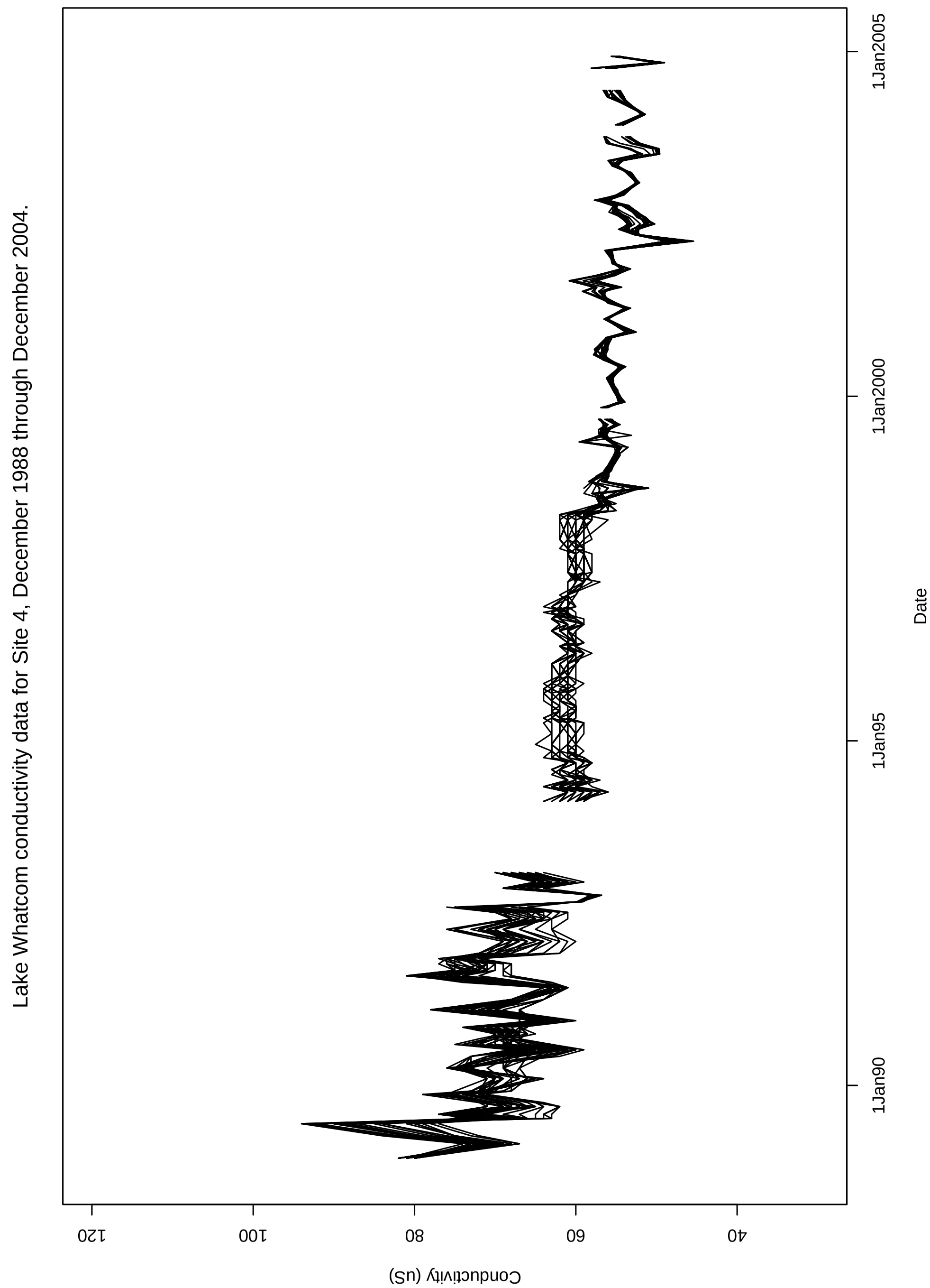


Figure B70: Lake Whatcom conductivity data for Site 4 (1988–2004). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

B.3 Alkalinity and Turbidity

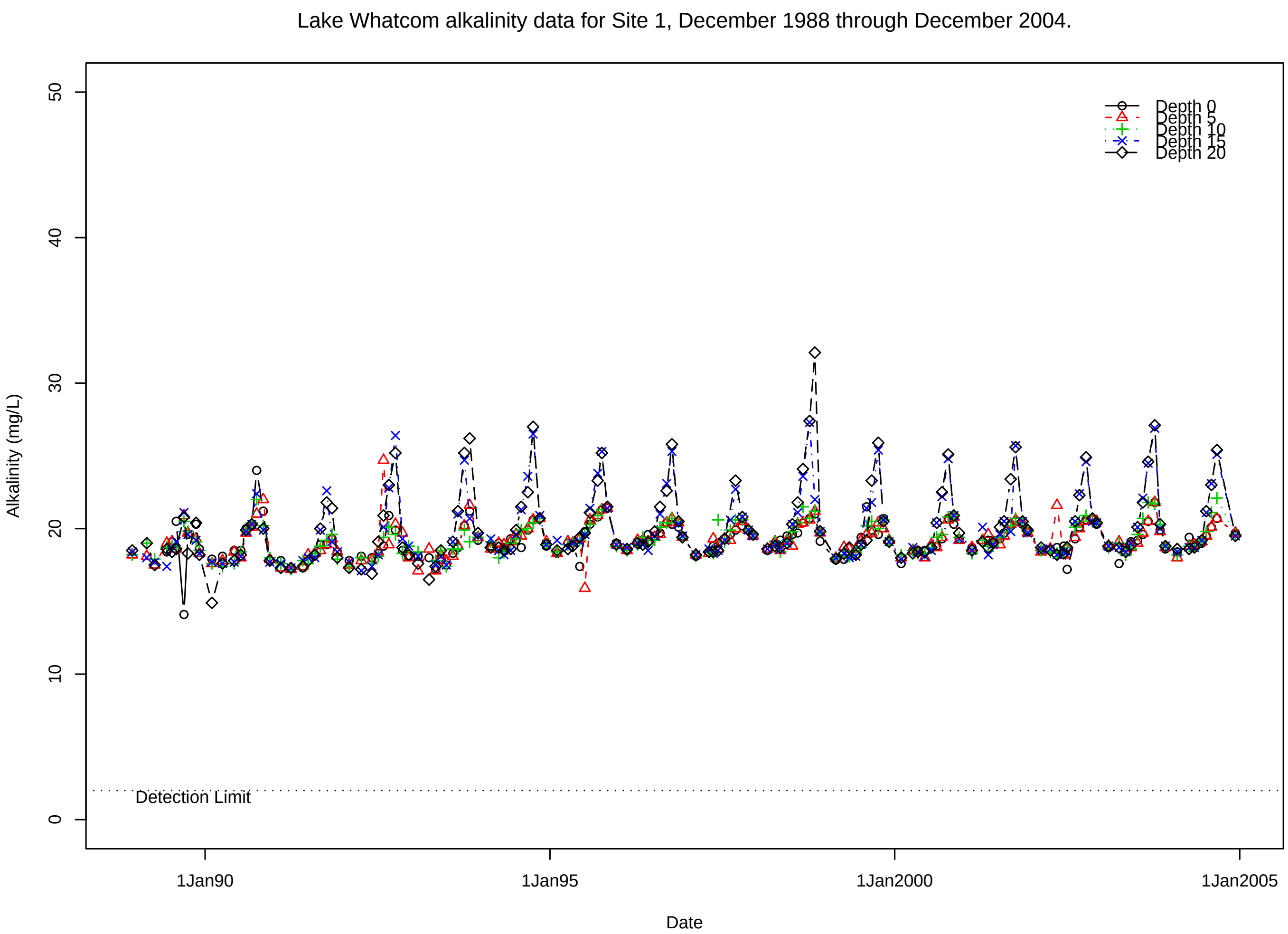


Figure B71: Lake Whatcom alkalinity data for Site 1 (1988–2004).

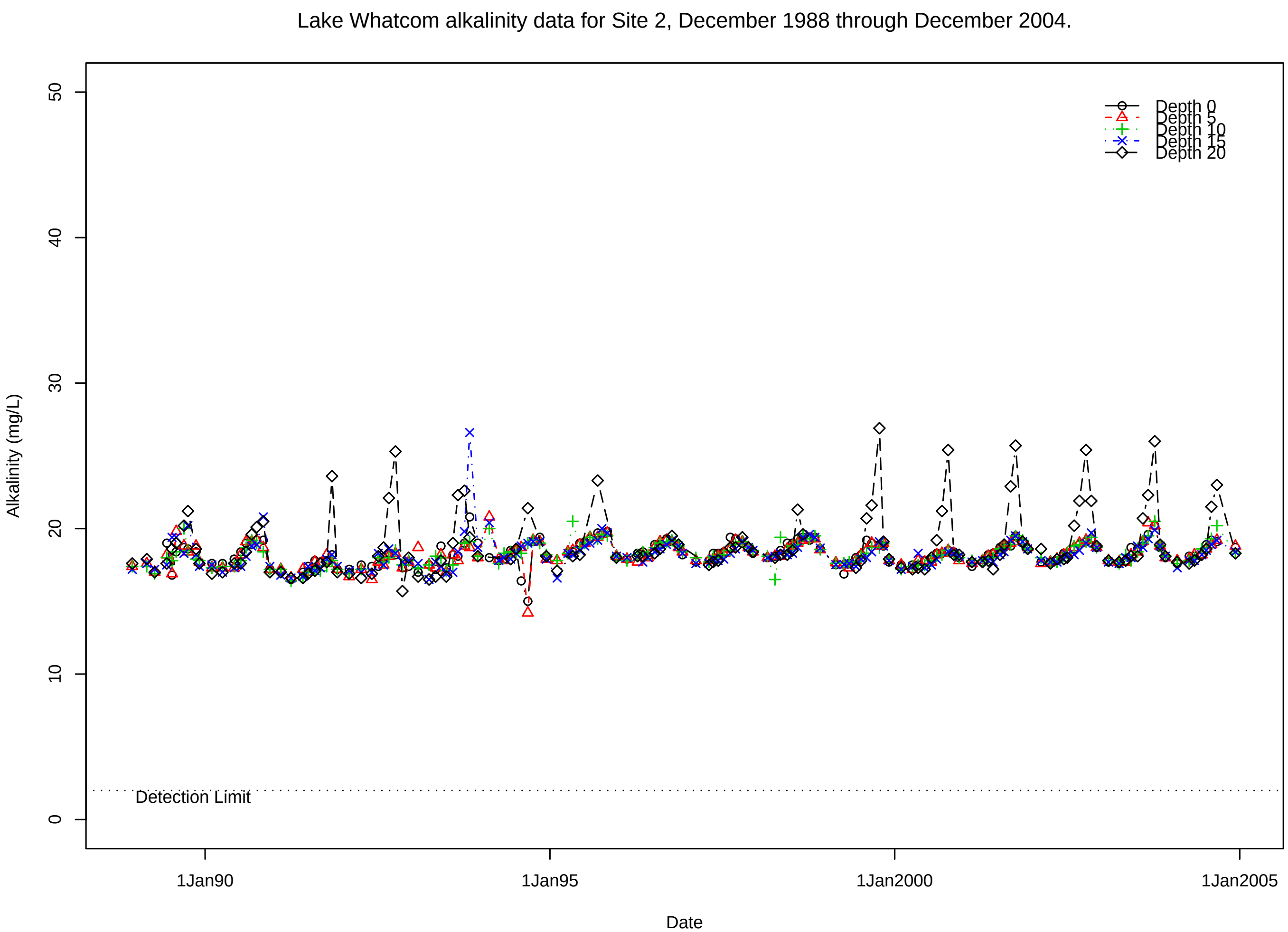


Figure B72: Lake Whatcom alkalinity data for Site 2 (1988–2004).

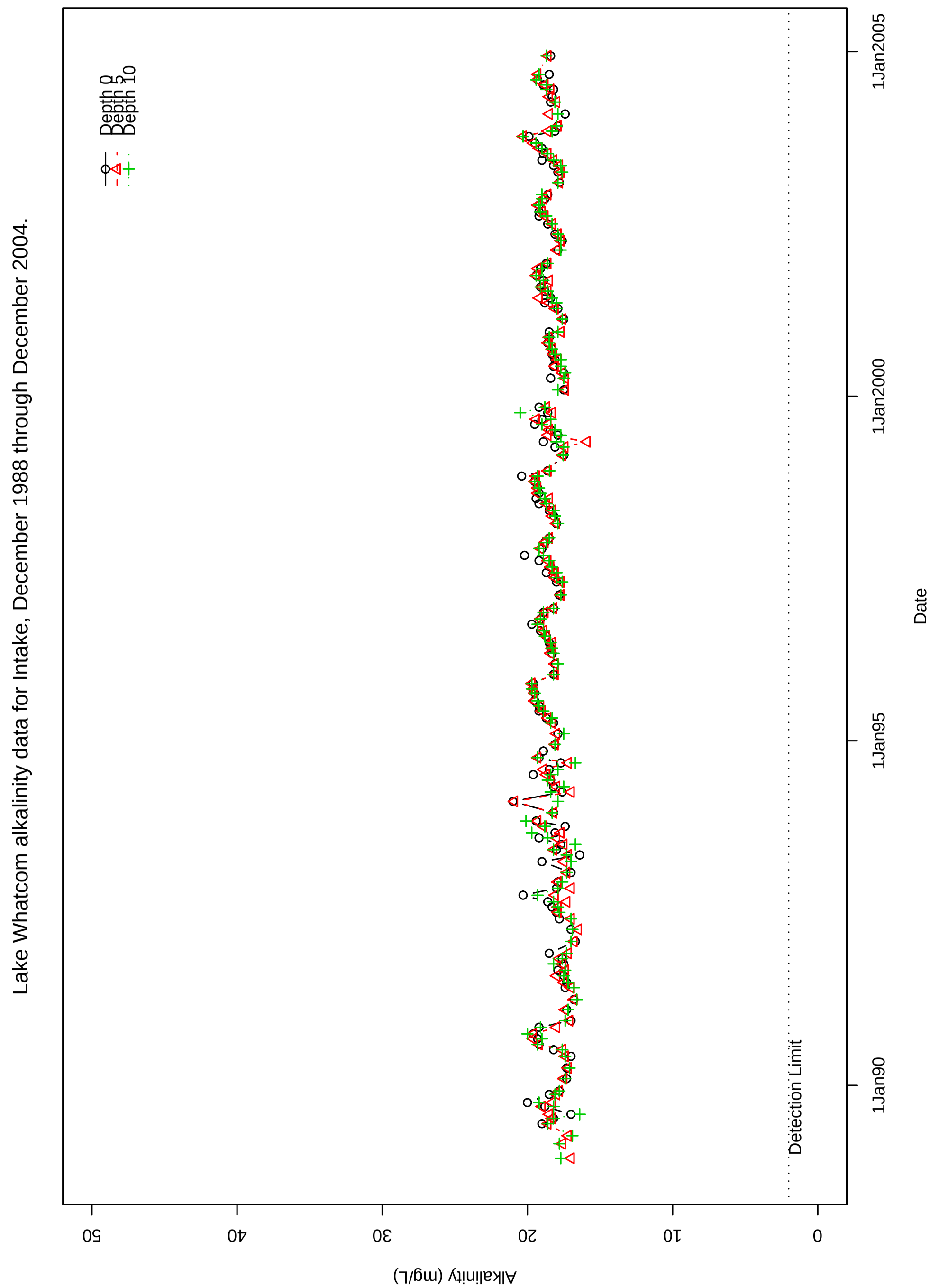


Figure B73: Lake Whatcom alkalinity data for the Intake (1988–2004).

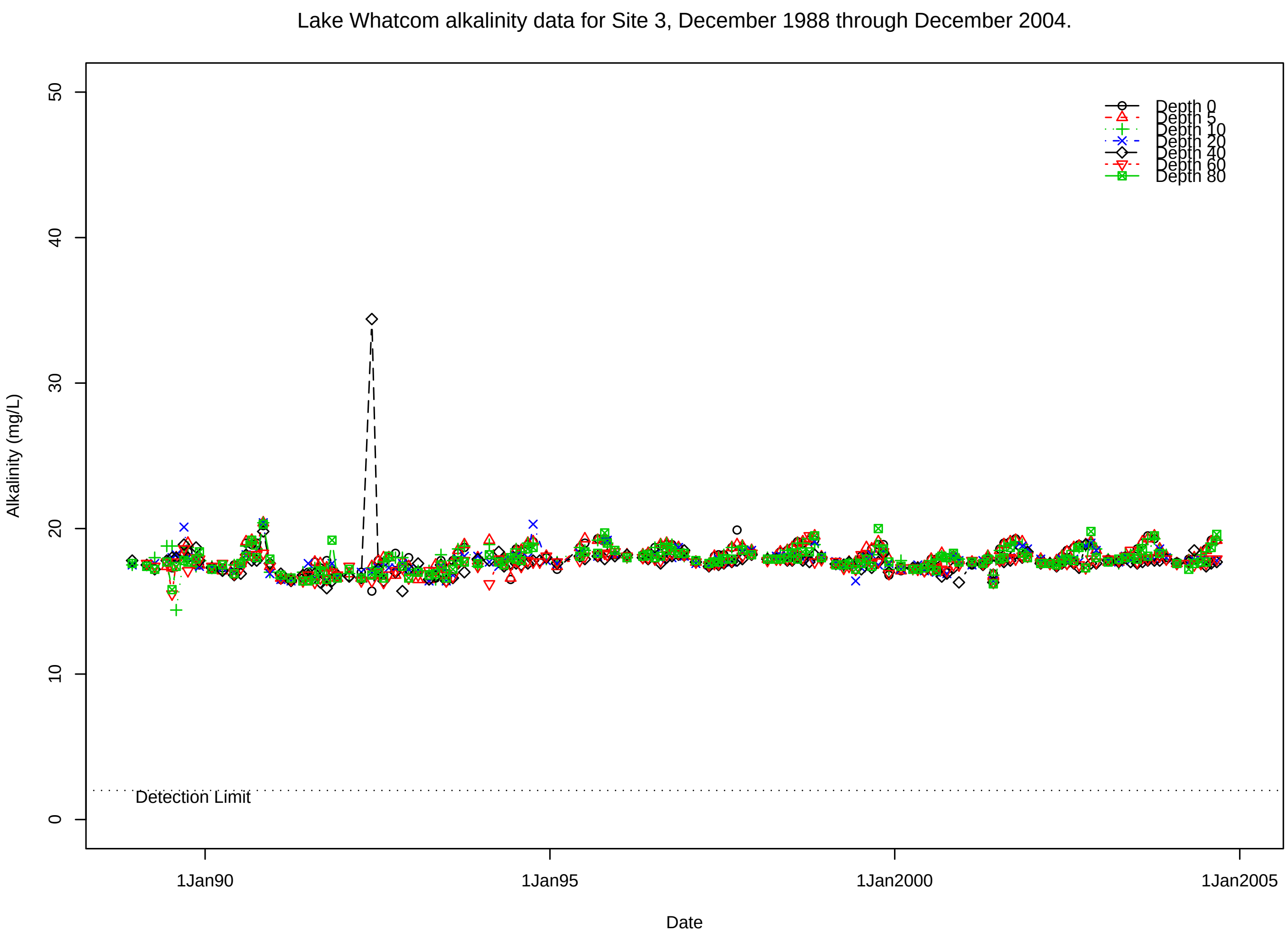


Figure B74: Lake Whatcom alkalinity data for Site 3 (1988–2004).

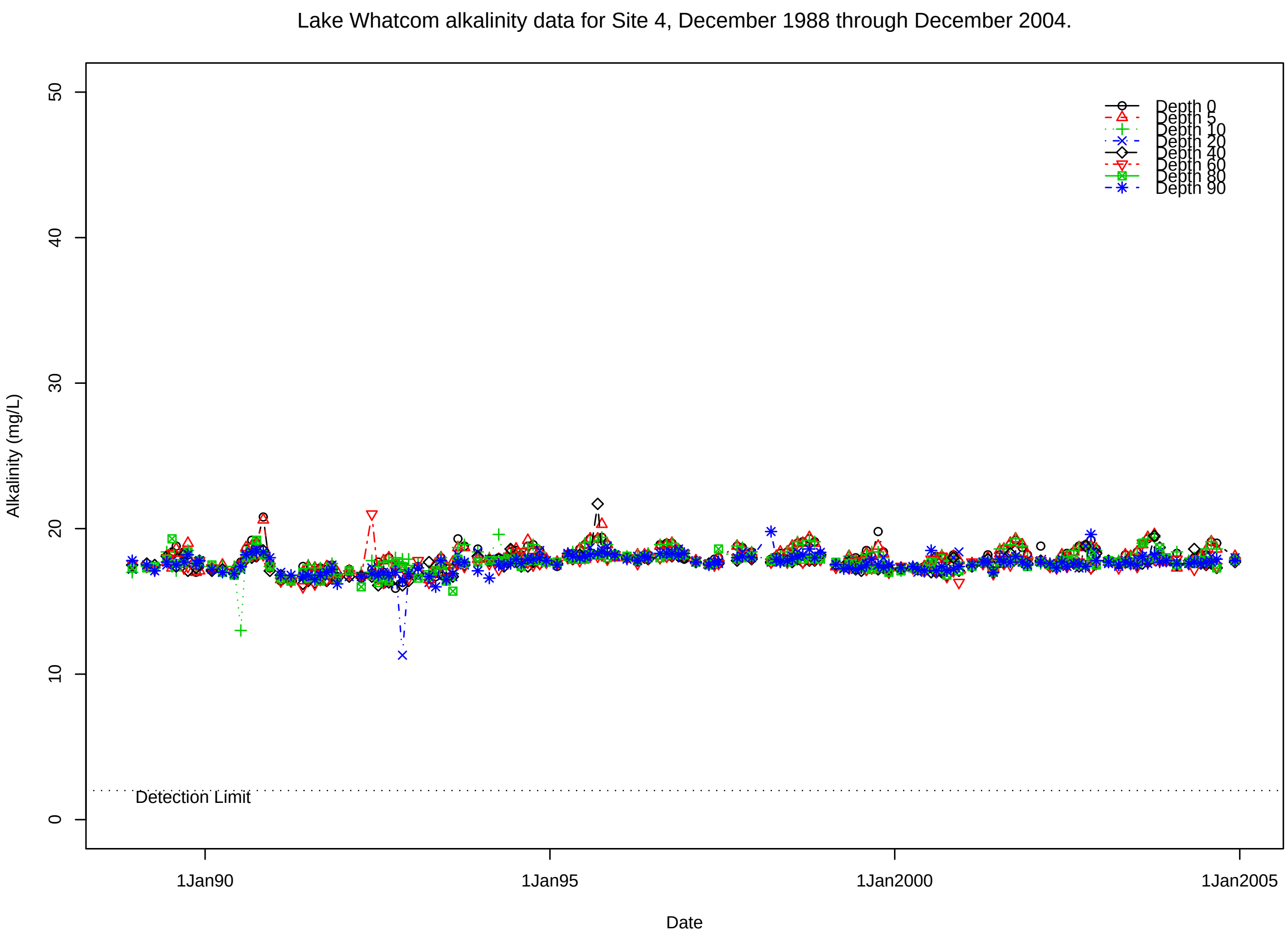


Figure B75: Lake Whatcom alkalinity data for Site 4 (1988–2004).

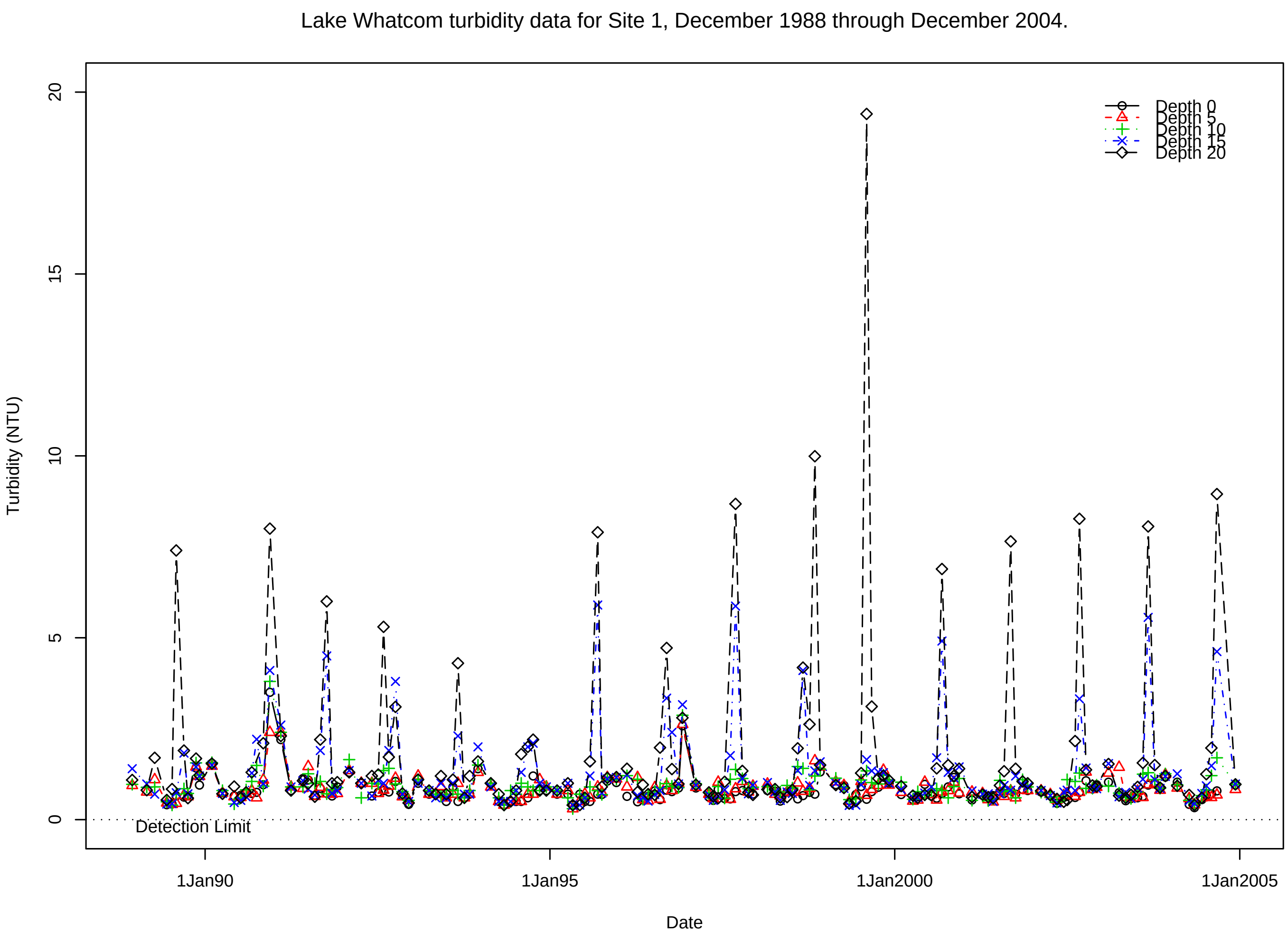


Figure B76: Lake Whatcom turbidity data for Site 1 (1988–2004).

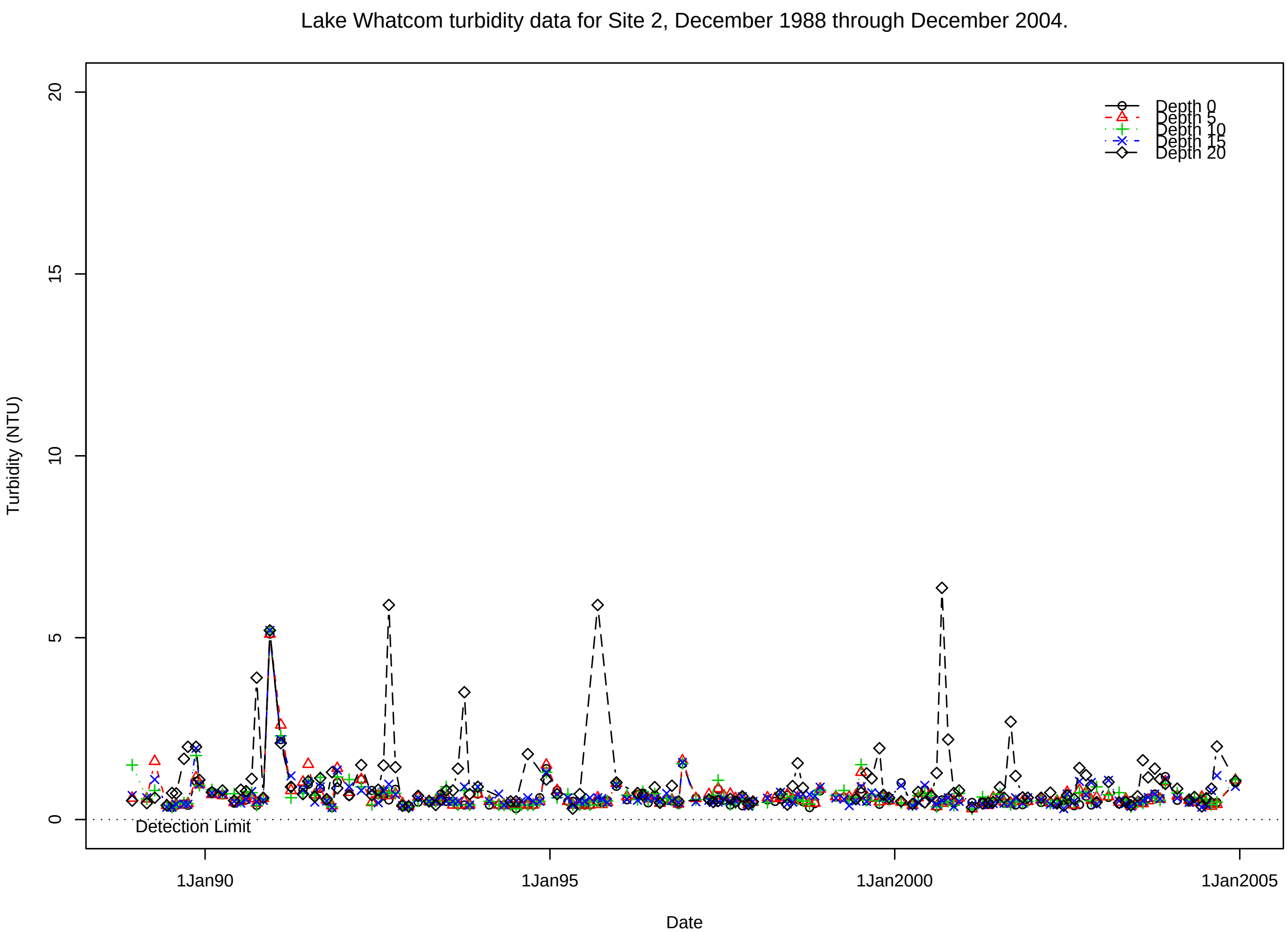


Figure B77: Lake Whatcom turbidity data for Site 2 (1988–2004).

Lake Whatcom turbidity data for Intake, December 1988 through December 2004.

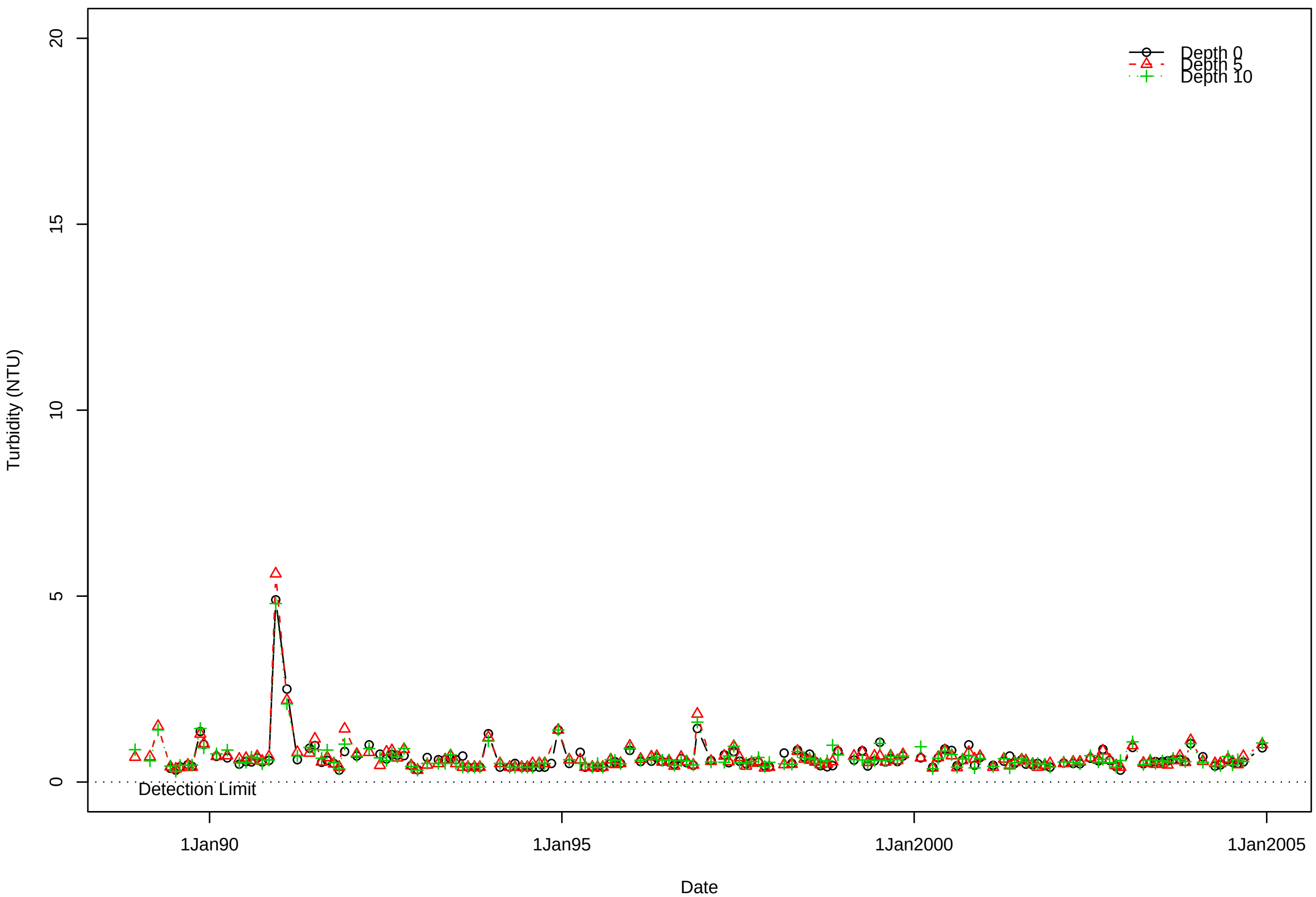


Figure B78: Lake Whatcom turbidity data for the Intake (1988–2004).

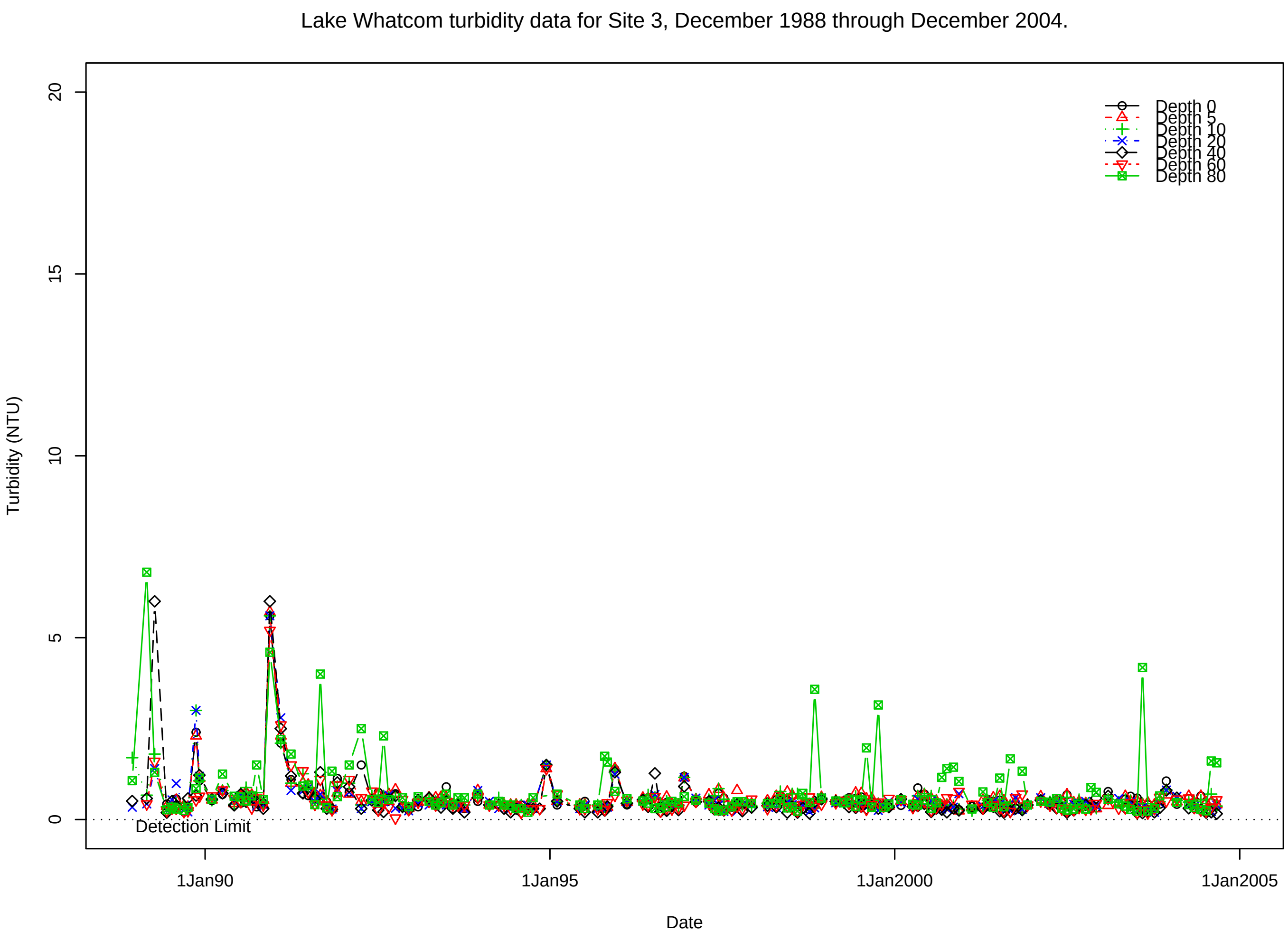


Figure B79: Lake Whatcom turbidity data for Site 3 (1988–2004).

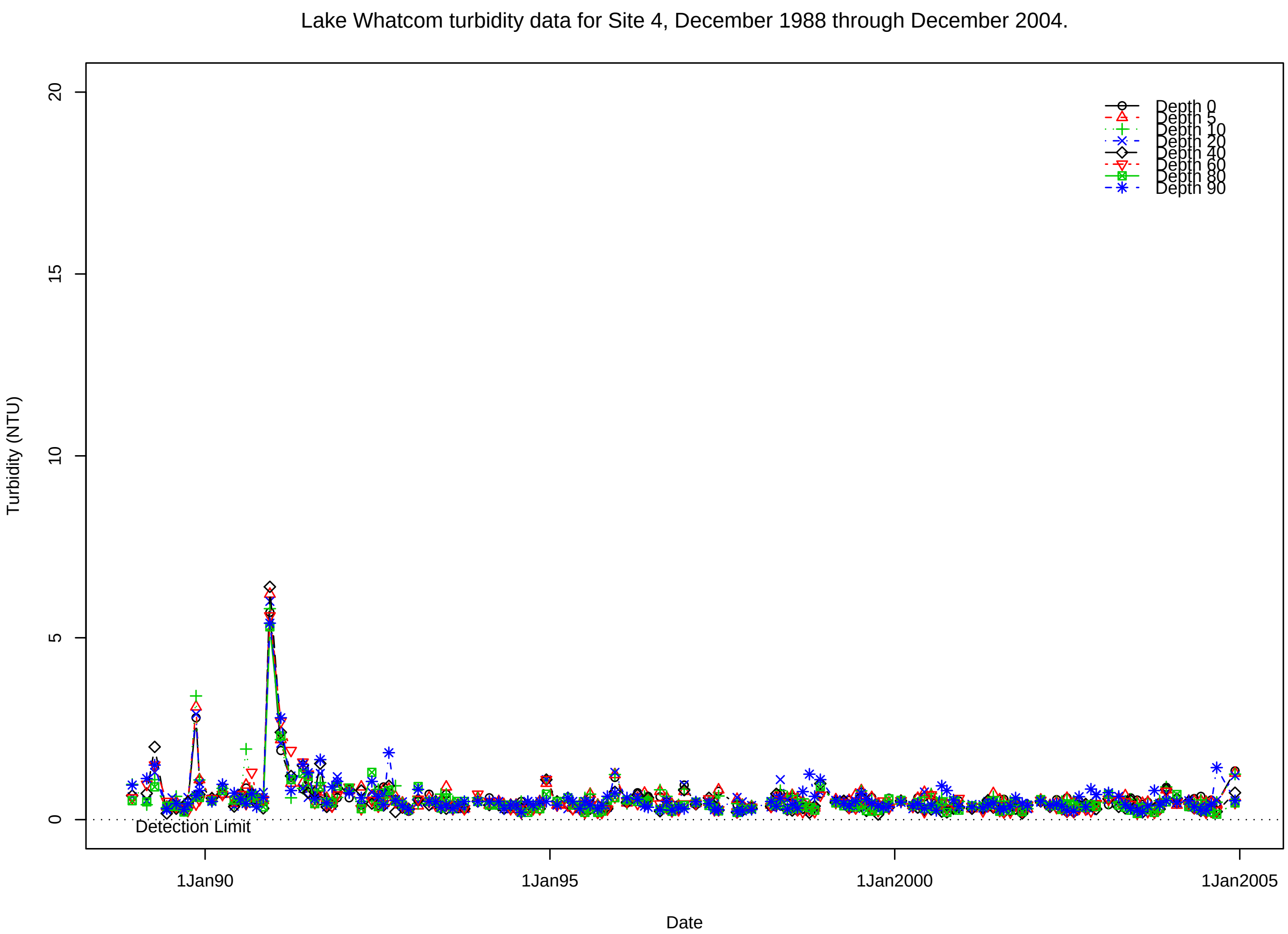


Figure B80: Lake Whatcom turbidity data for Site 4 (1988–2004).

B.4 Nitrogen and Phosphorus

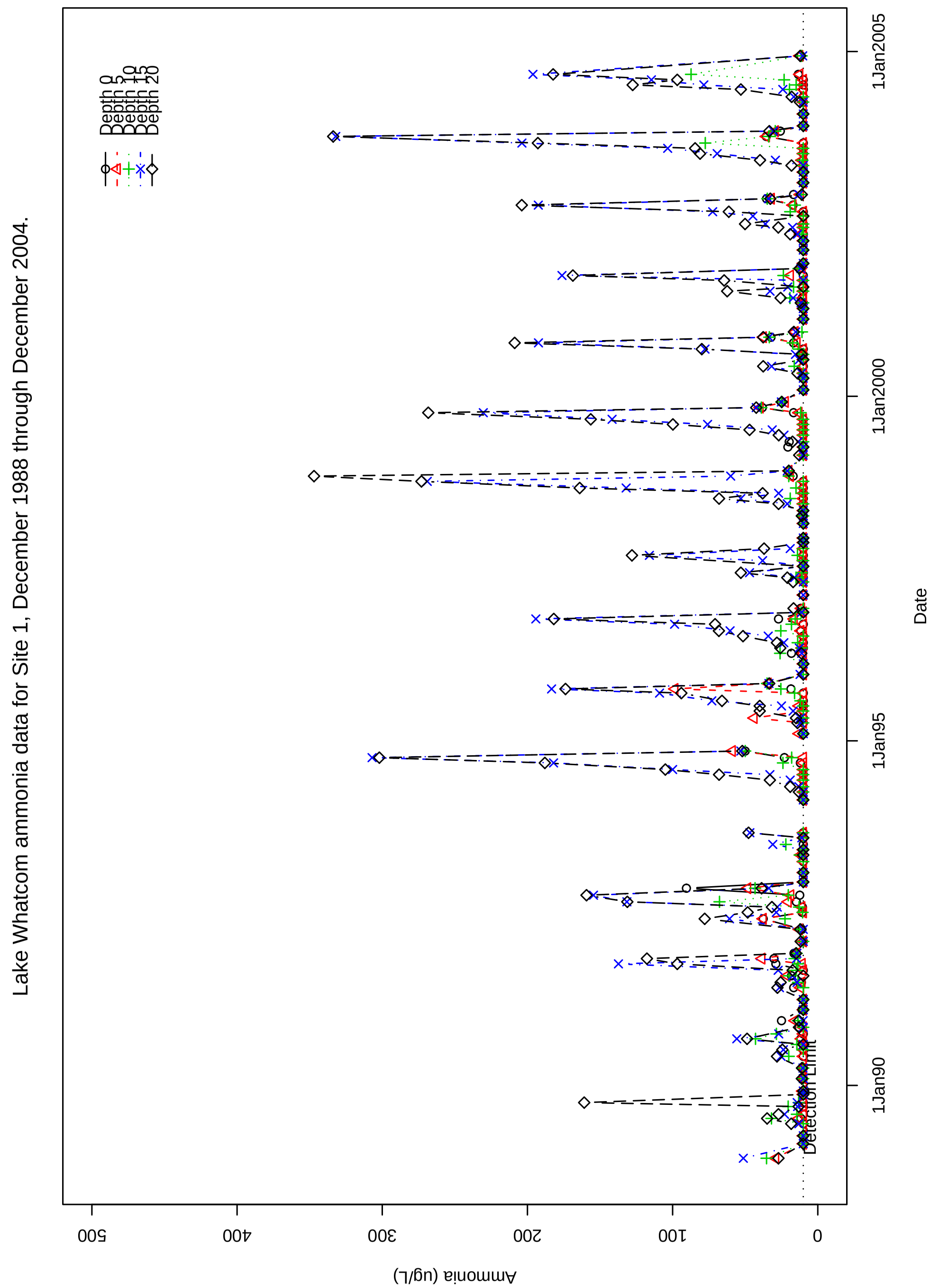


Figure B81: Lake Whatcom ammonia data for Site 1 (1988–2004).

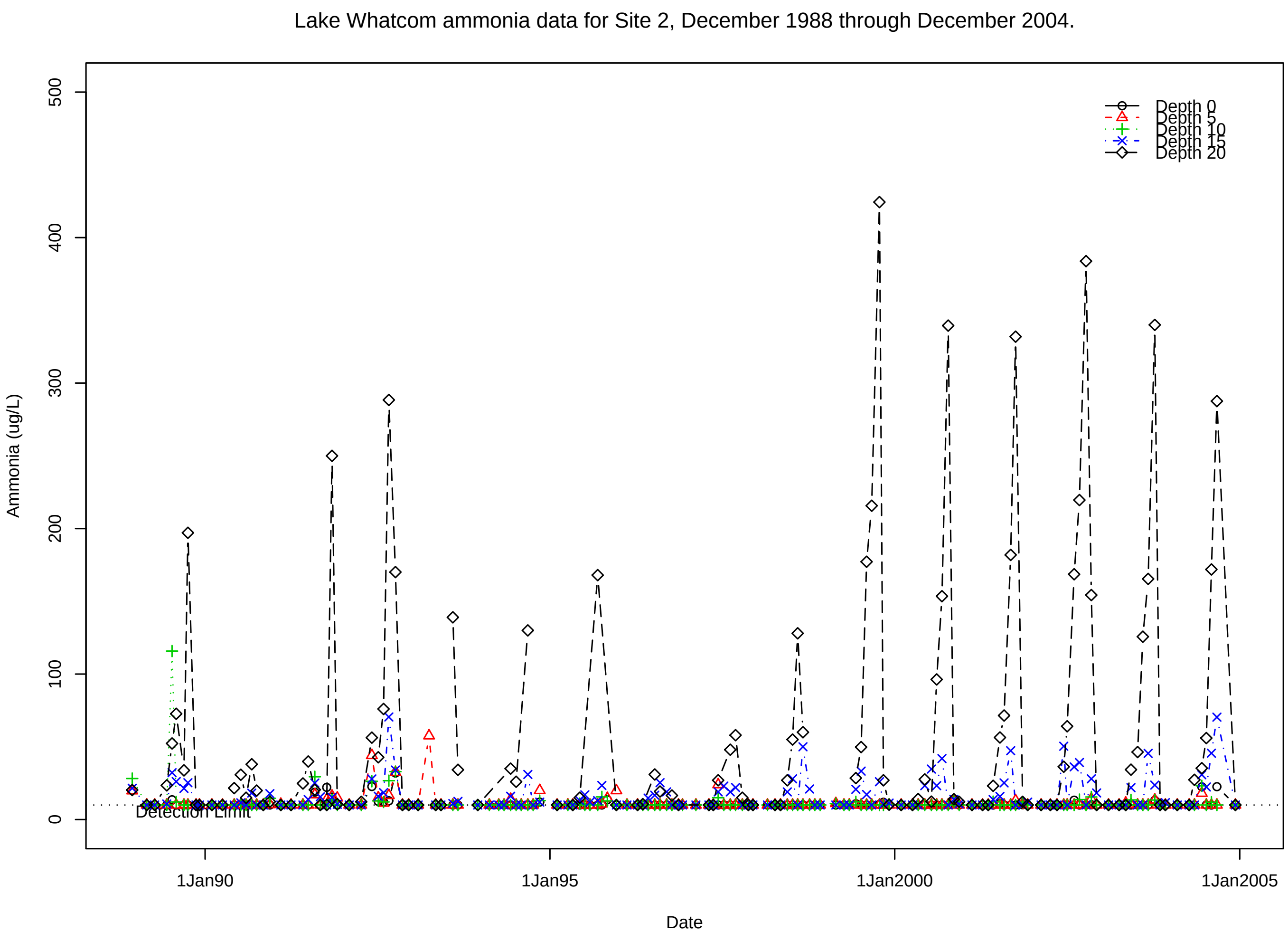


Figure B82: Lake Whatcom ammonia data for Site 2 (1988–2004).

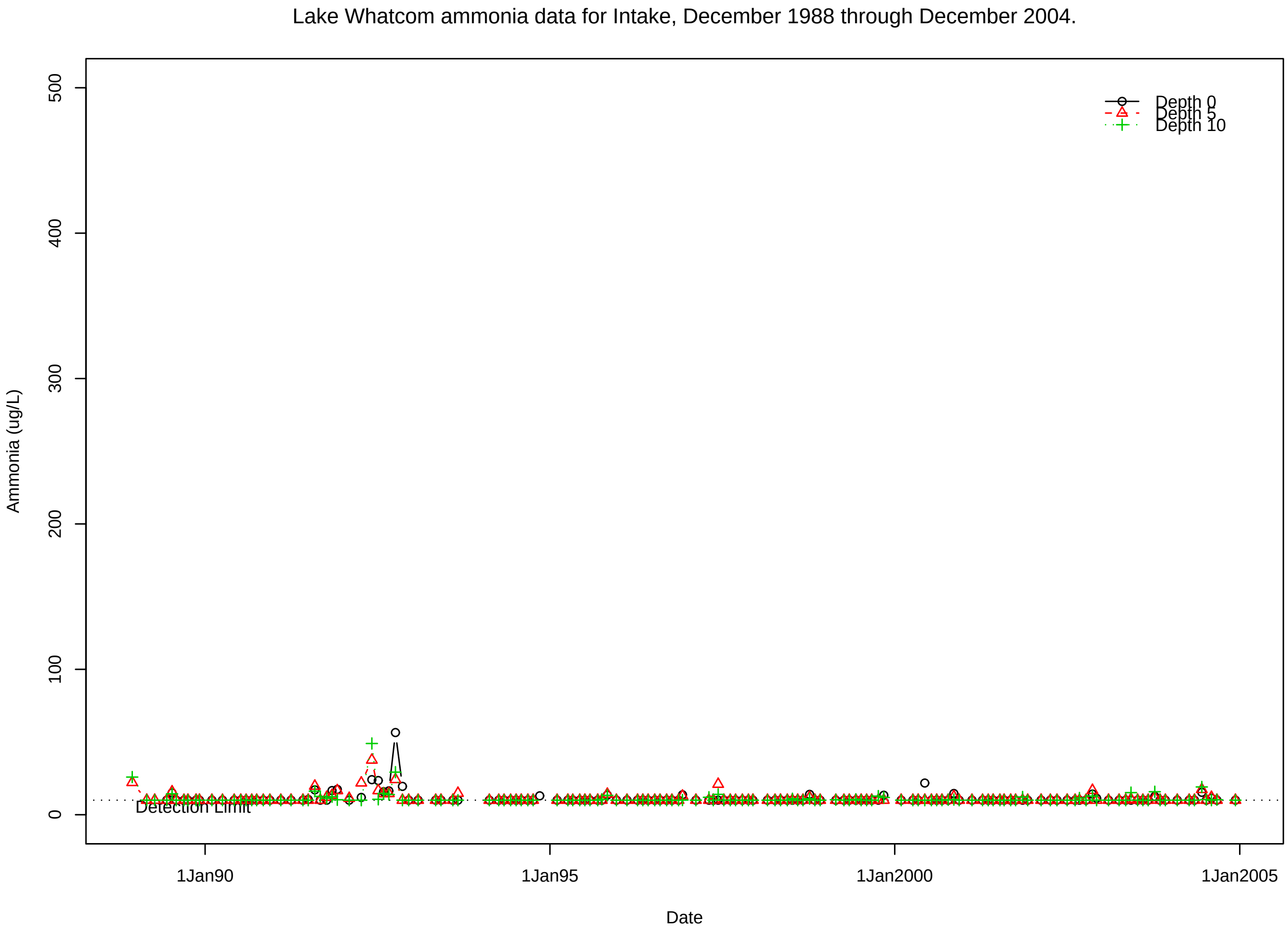


Figure B83: Lake Whatcom ammonia data for the Intake (1988–2004).

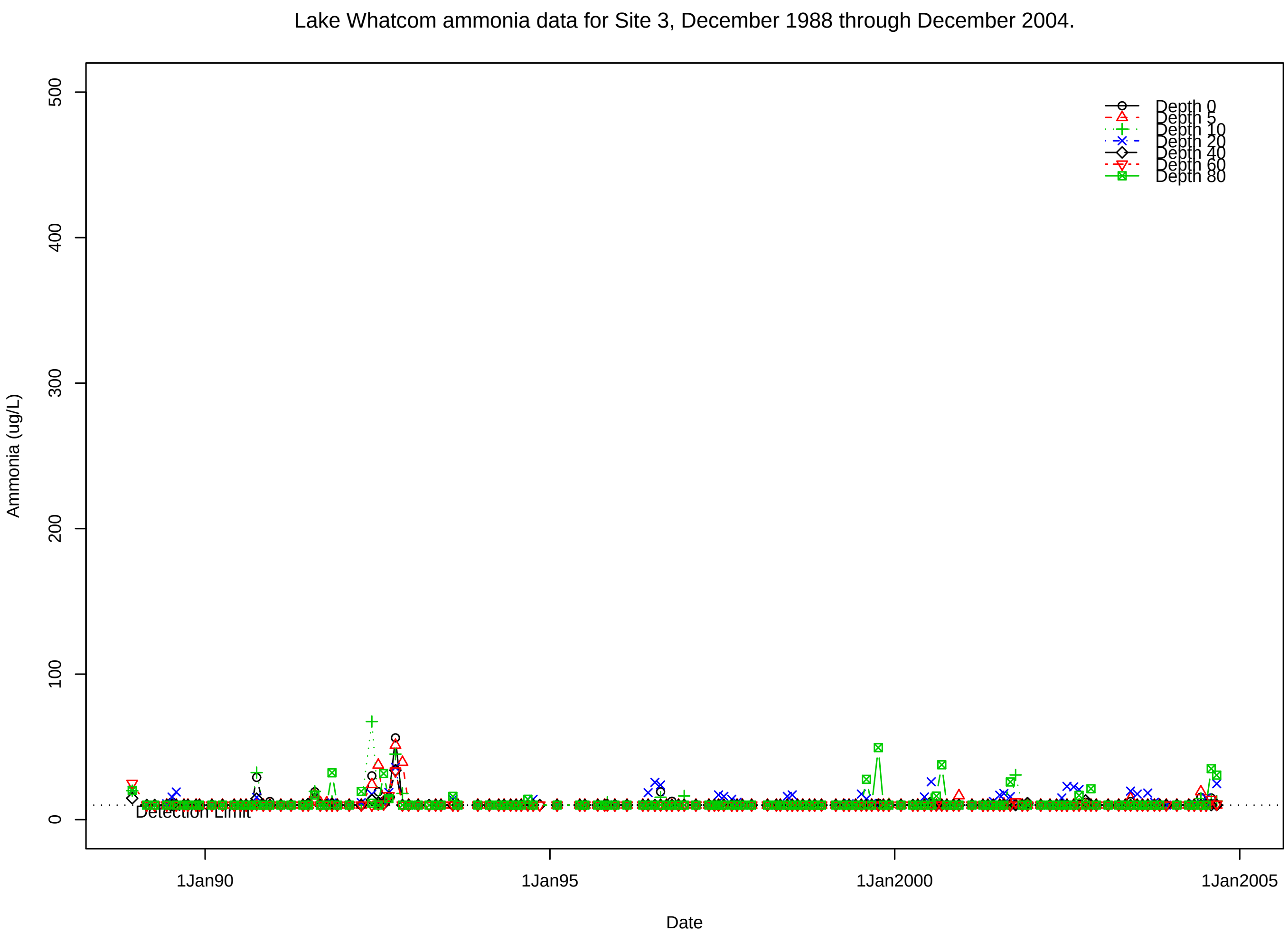


Figure B84: Lake Whatcom ammonia data for Site 3 (1988–2004).

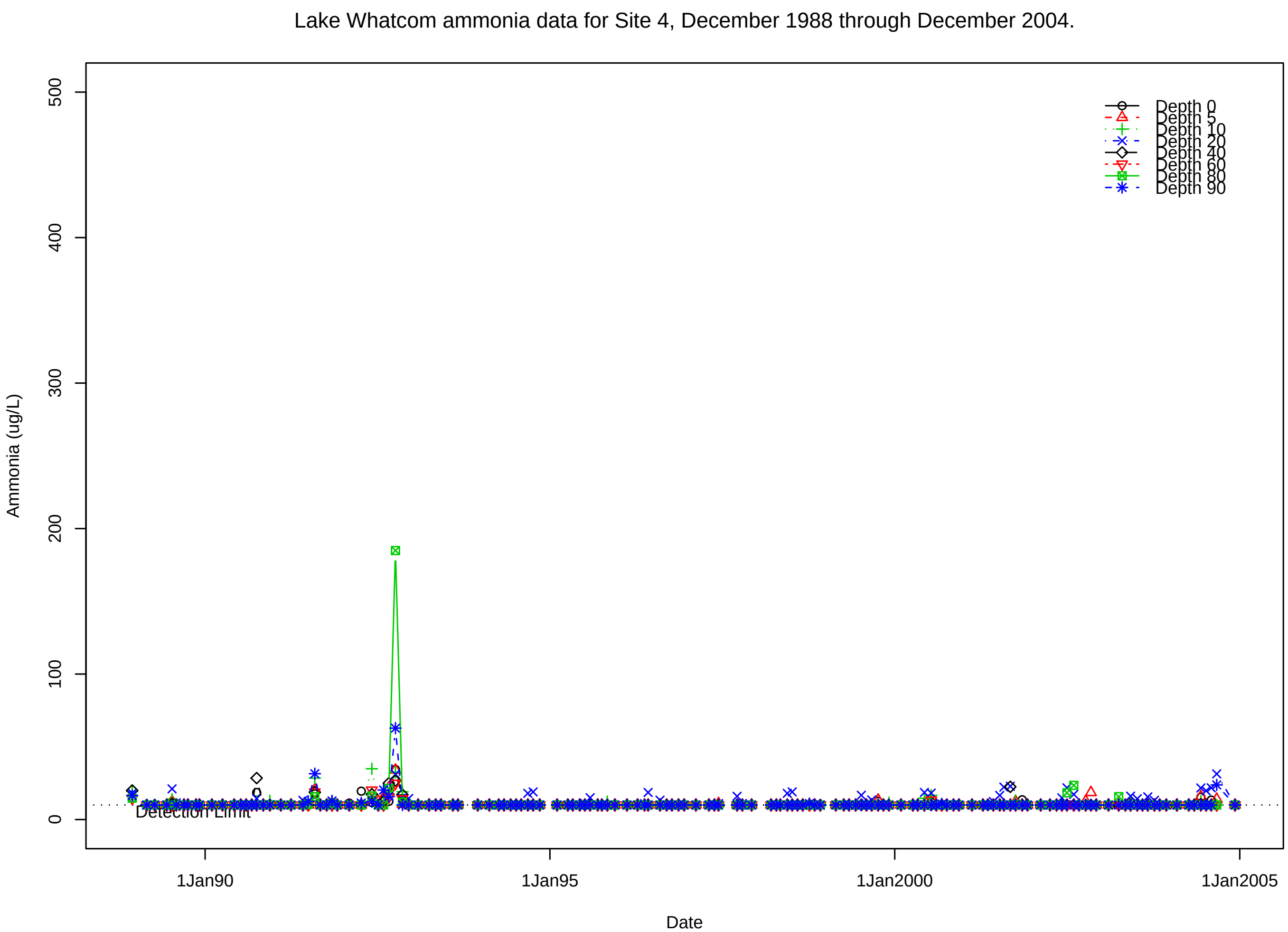


Figure B85: Lake Whatcom ammonia data for Site 4 (1988–2004).

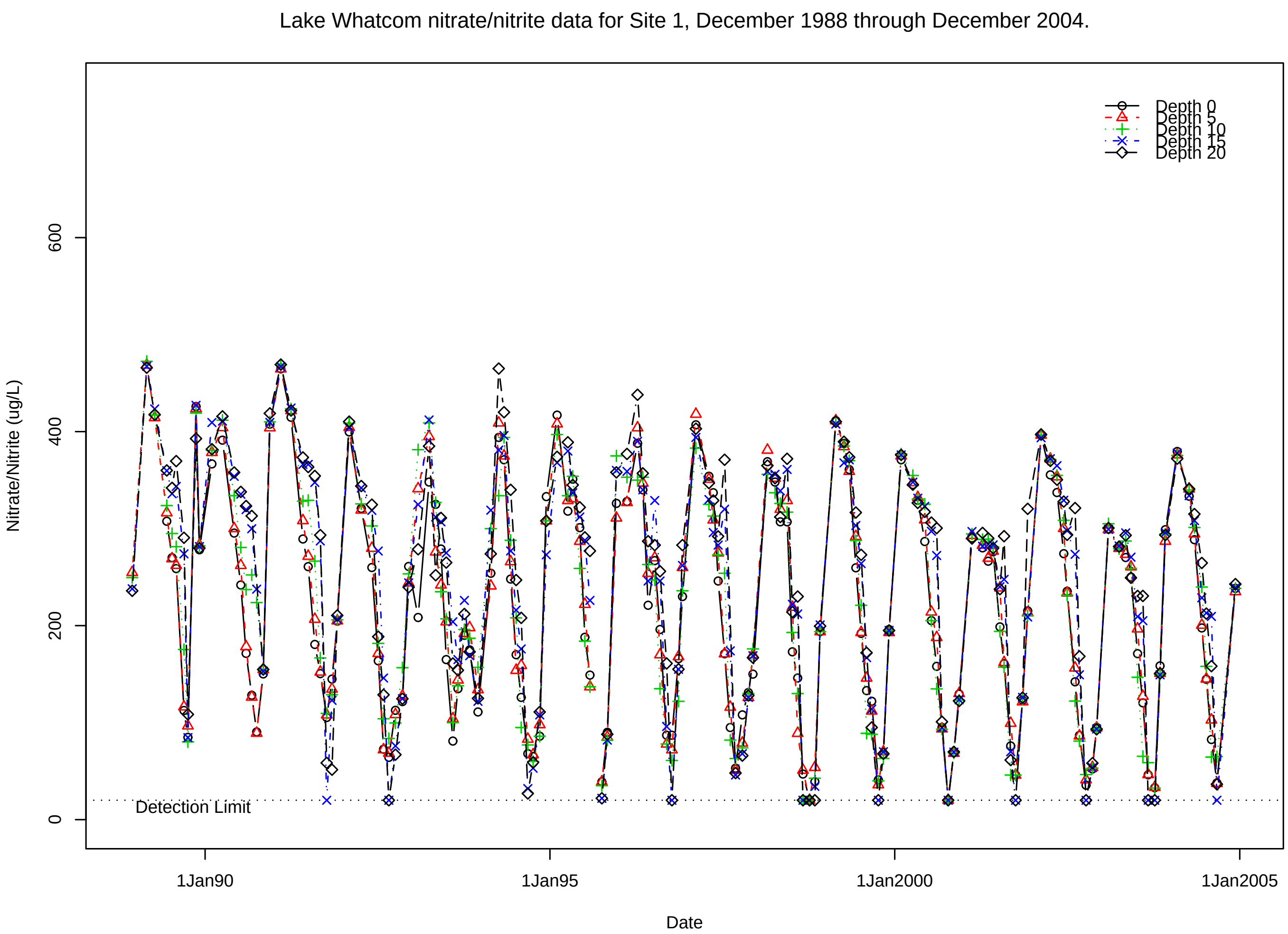


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1 (1988–2004).

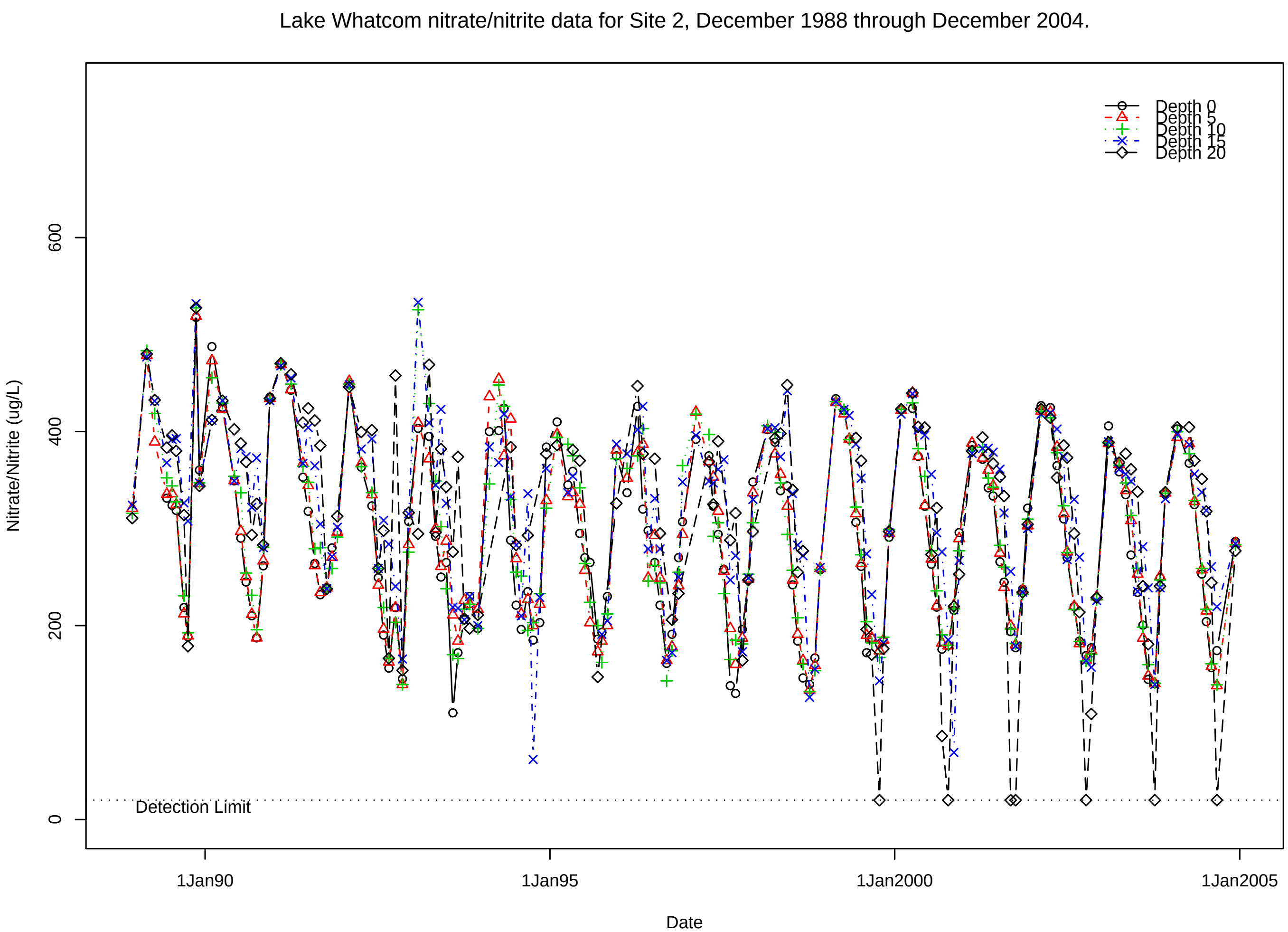


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2 (1988–2004).

Lake Whatcom nitrate/nitrite data for Intake, December 1988 through December 2004.

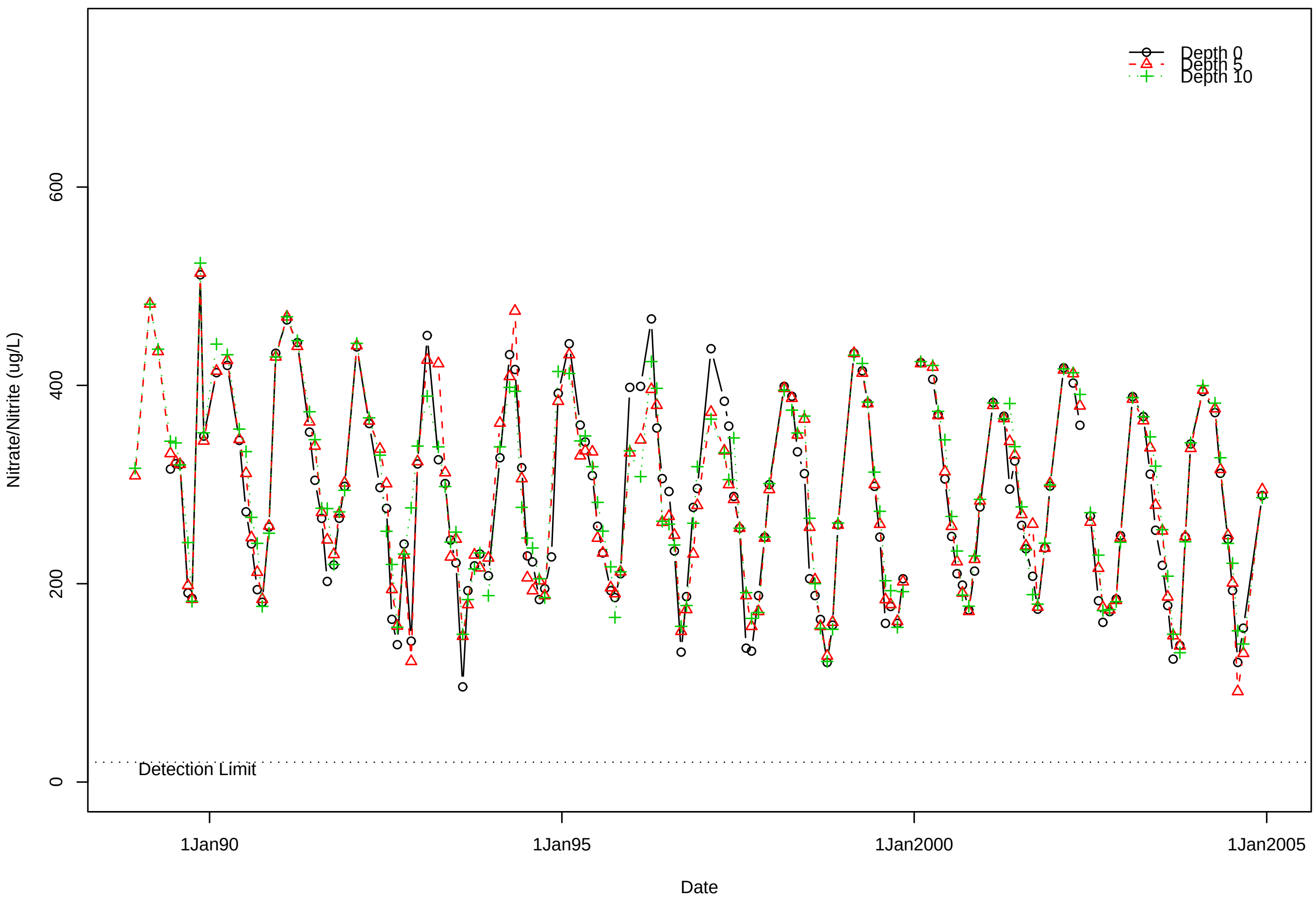


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake (1988–2004).

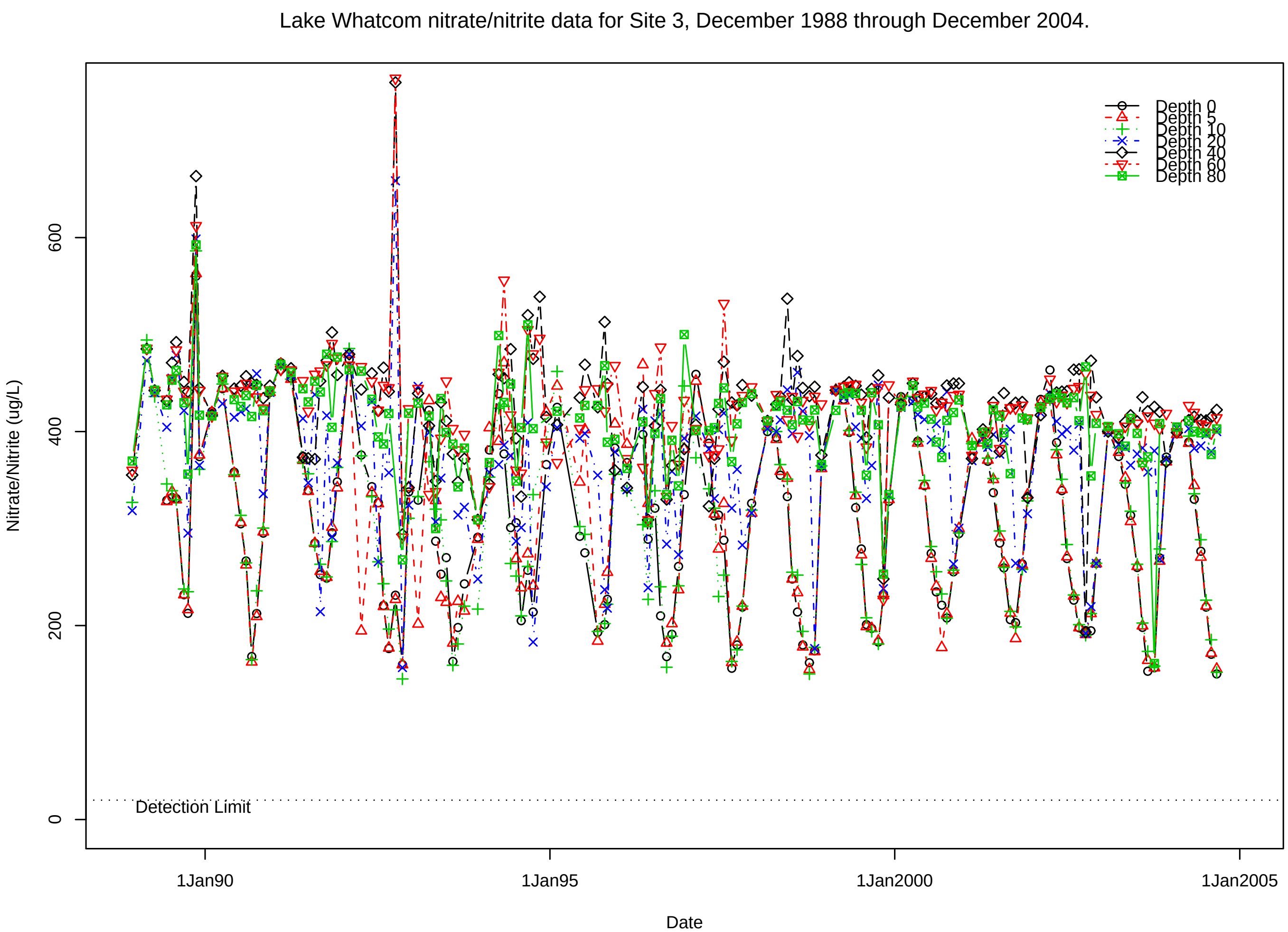


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3 (1988–2004).

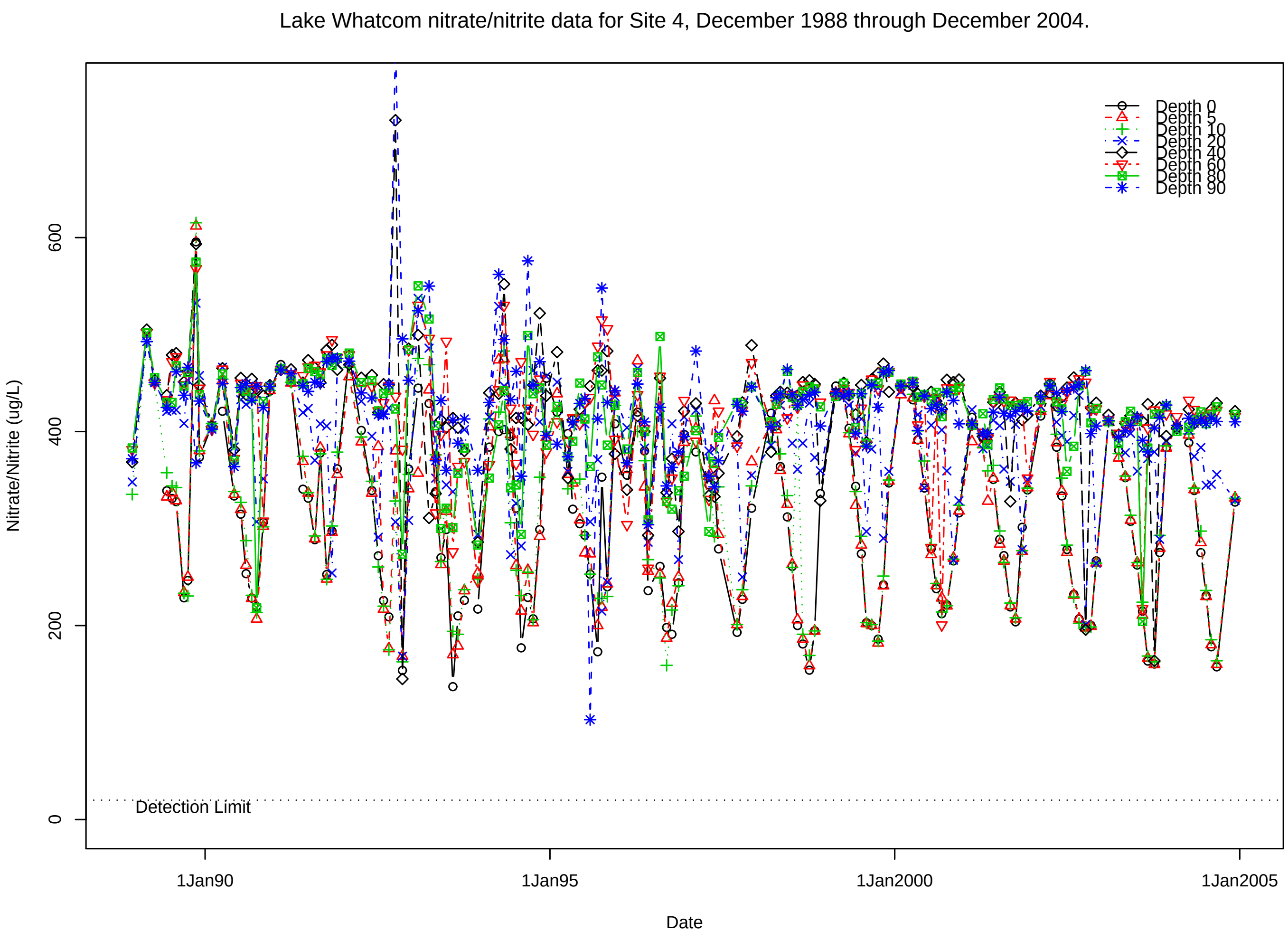


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4 (1988–2004).

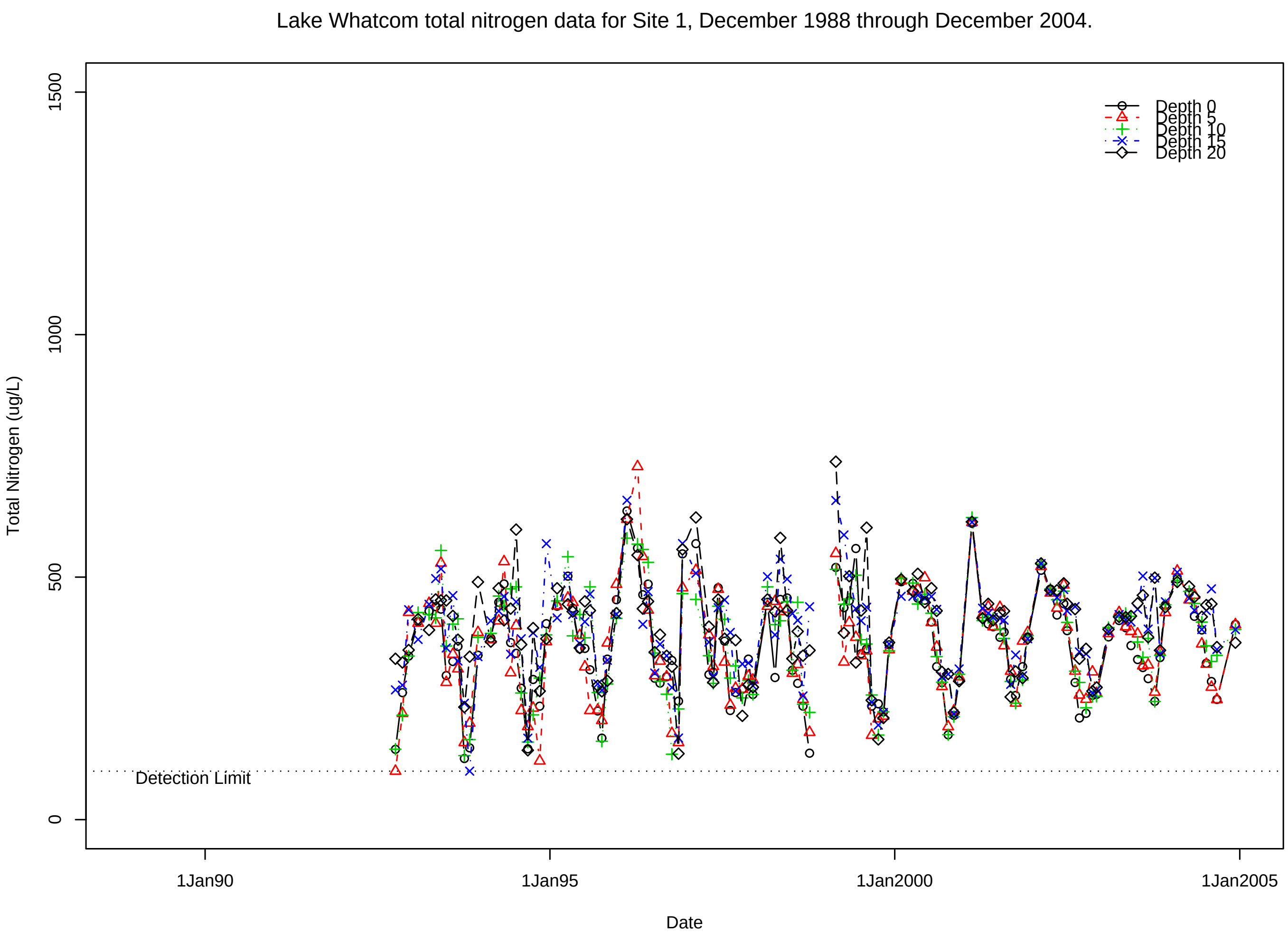


Figure B91: Lake Whatcom total nitrogen data for Site 1 (1988–2004).

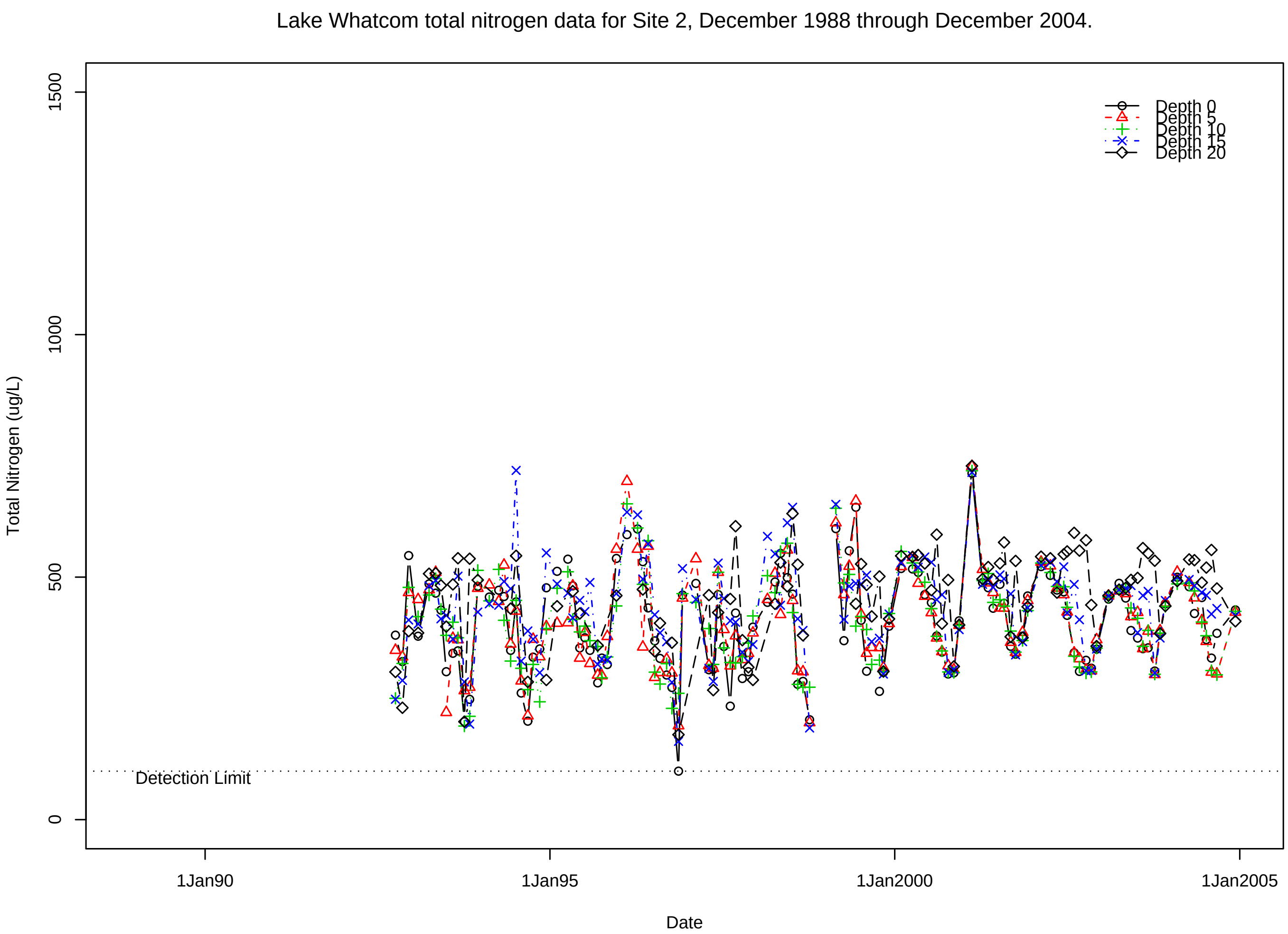


Figure B92: Lake Whatcom total nitrogen data for Site 2 (1988–2004).

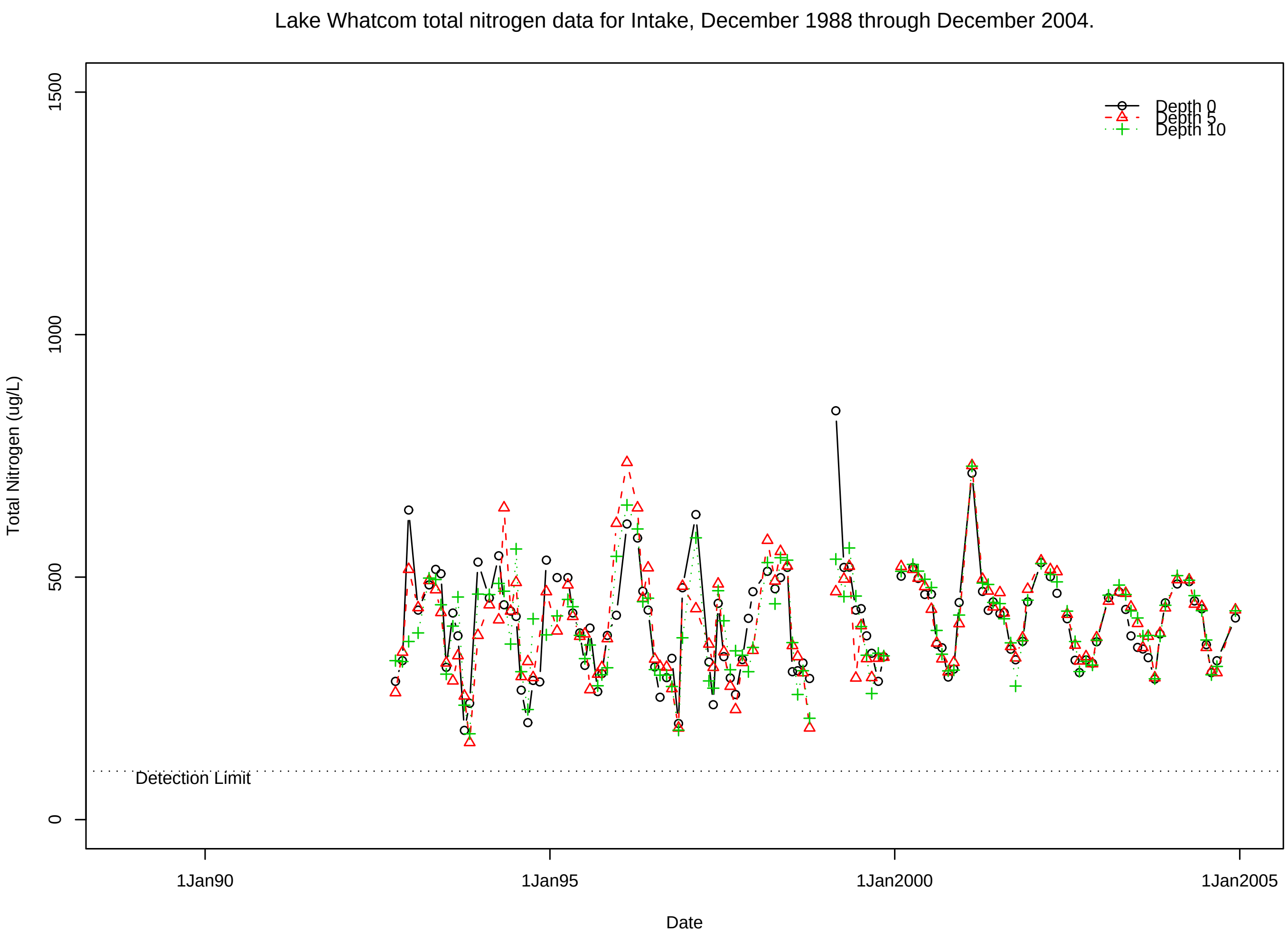


Figure B93: Lake Whatcom total nitrogen data for the Intake (1988–2004).

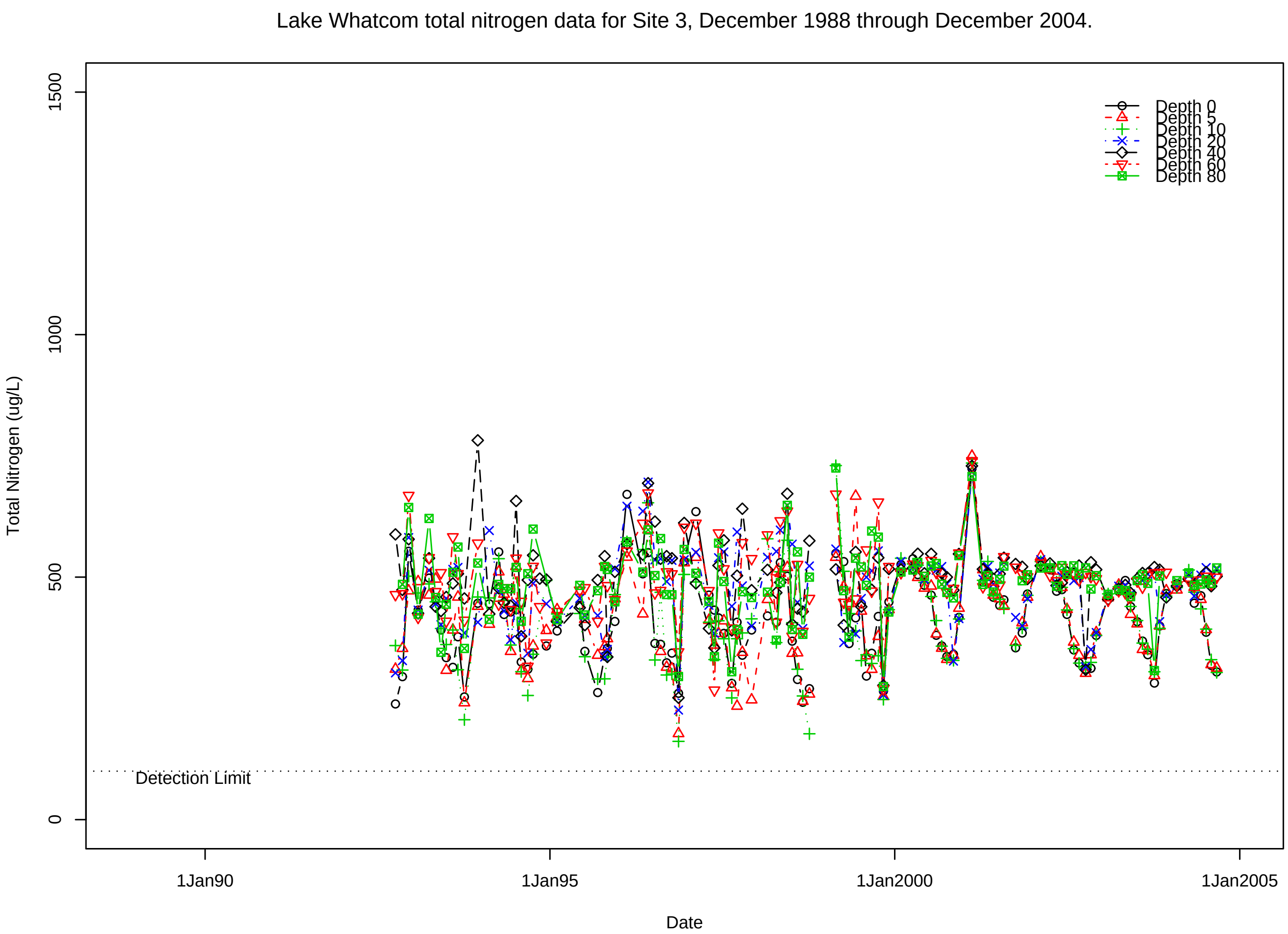


Figure B94: Lake Whatcom total nitrogen data for Site 3 (1988–2004).

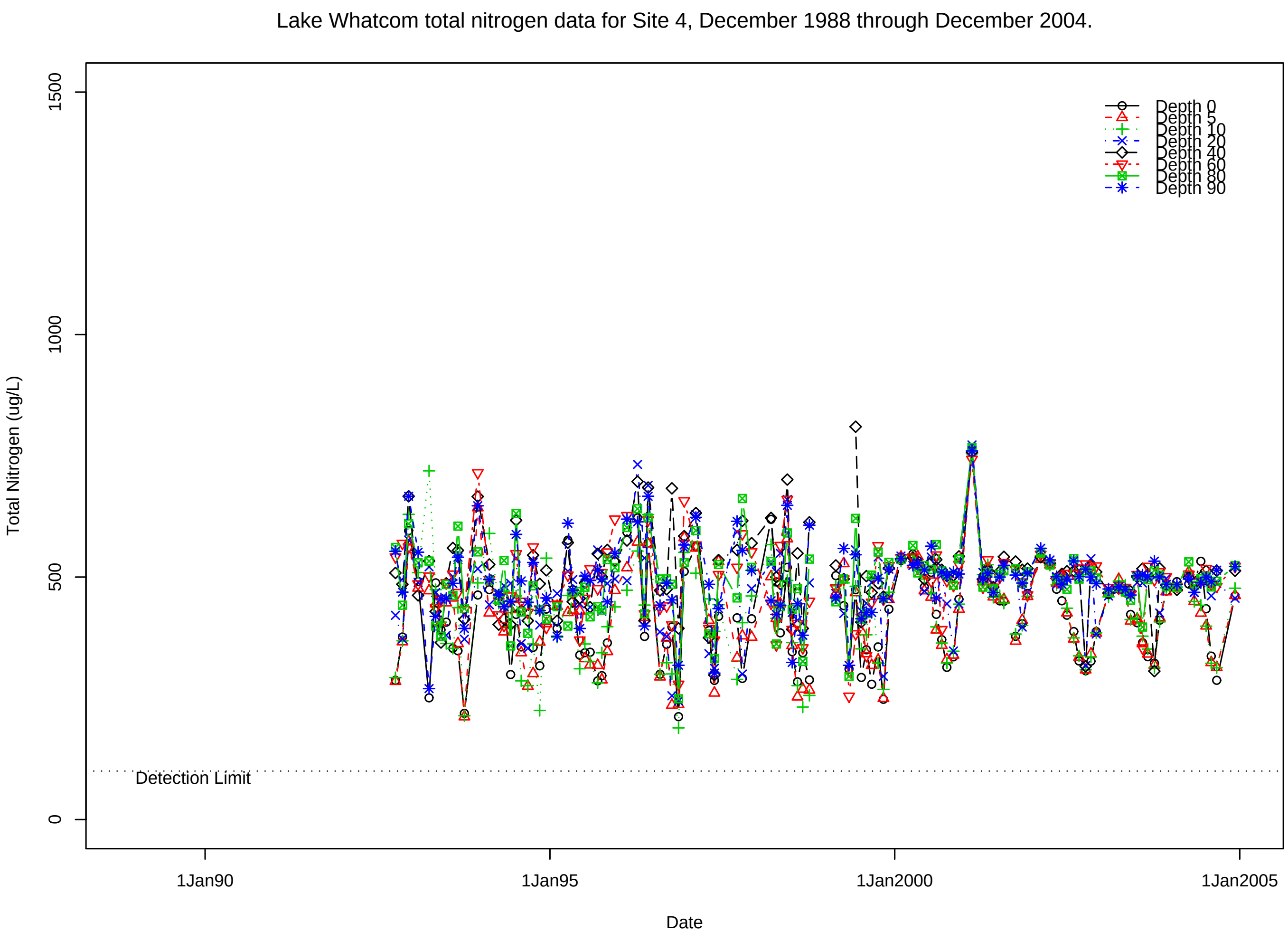


Figure B95: Lake Whatcom total nitrogen data for Site 4 (1988–2004).

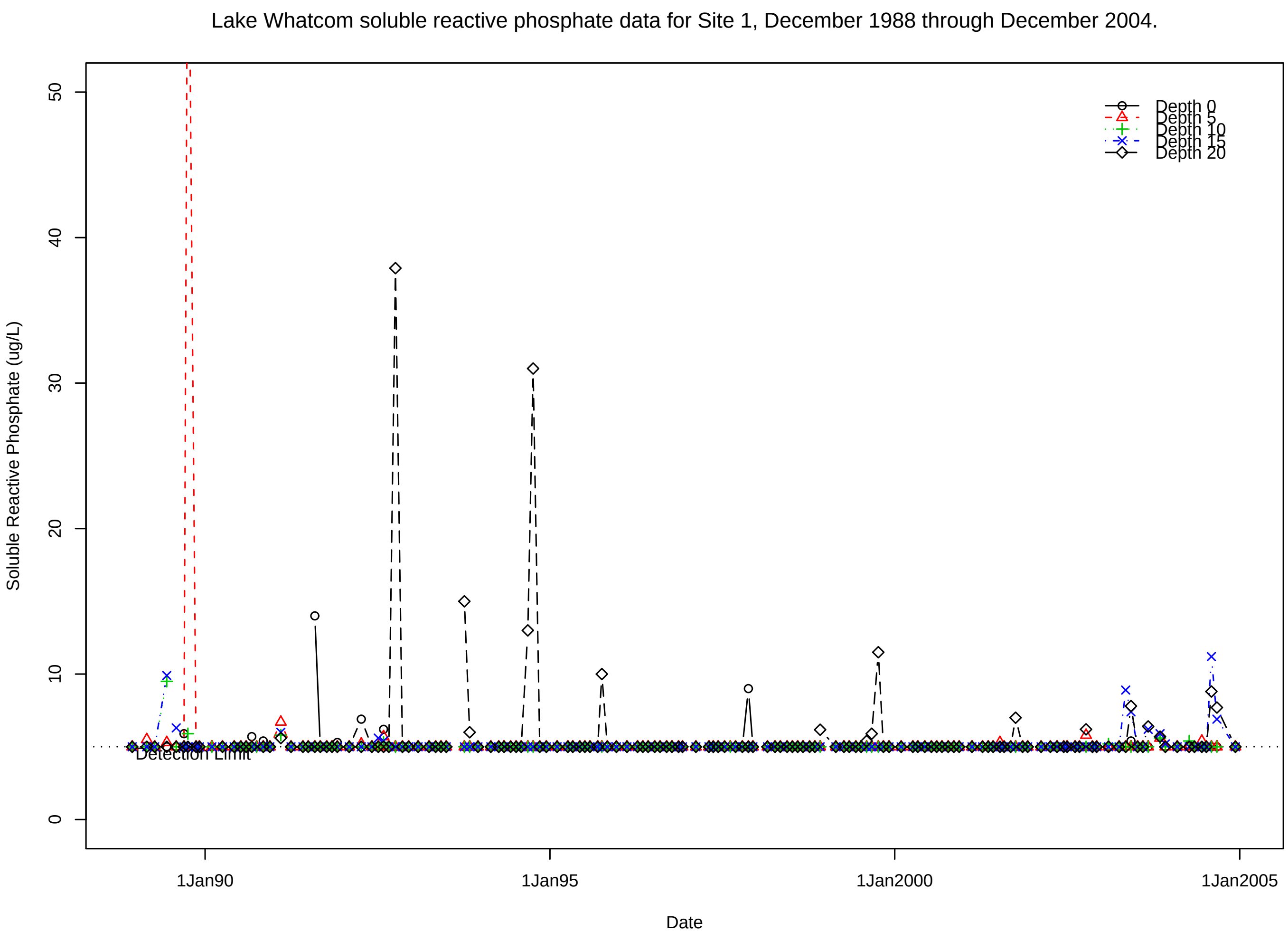


Figure B96: Lake Whatcom soluble phosphate data for Site 1 (1988–2004).

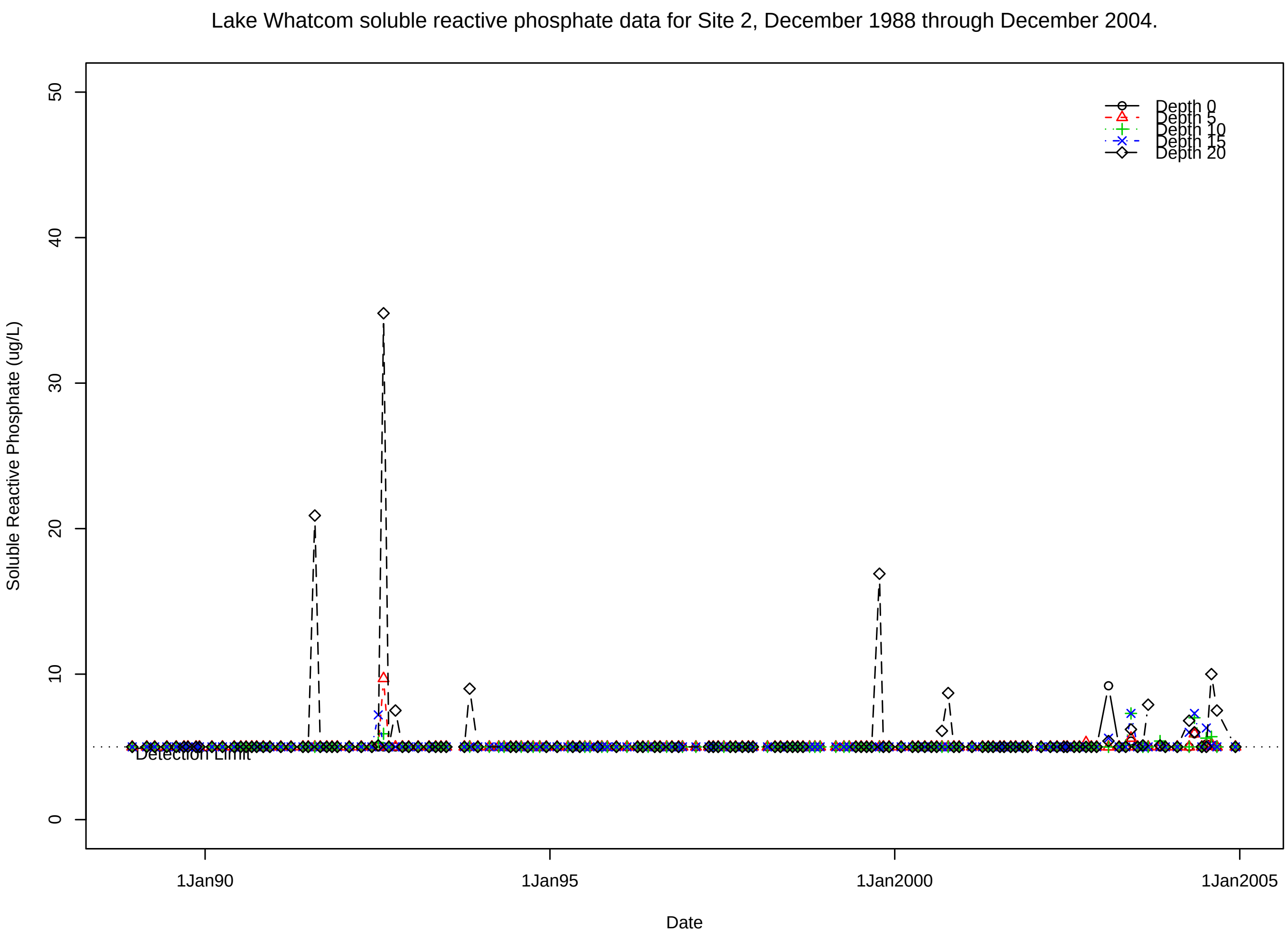


Figure B97: Lake Whatcom soluble phosphate data for Site 2 (1988–2004).

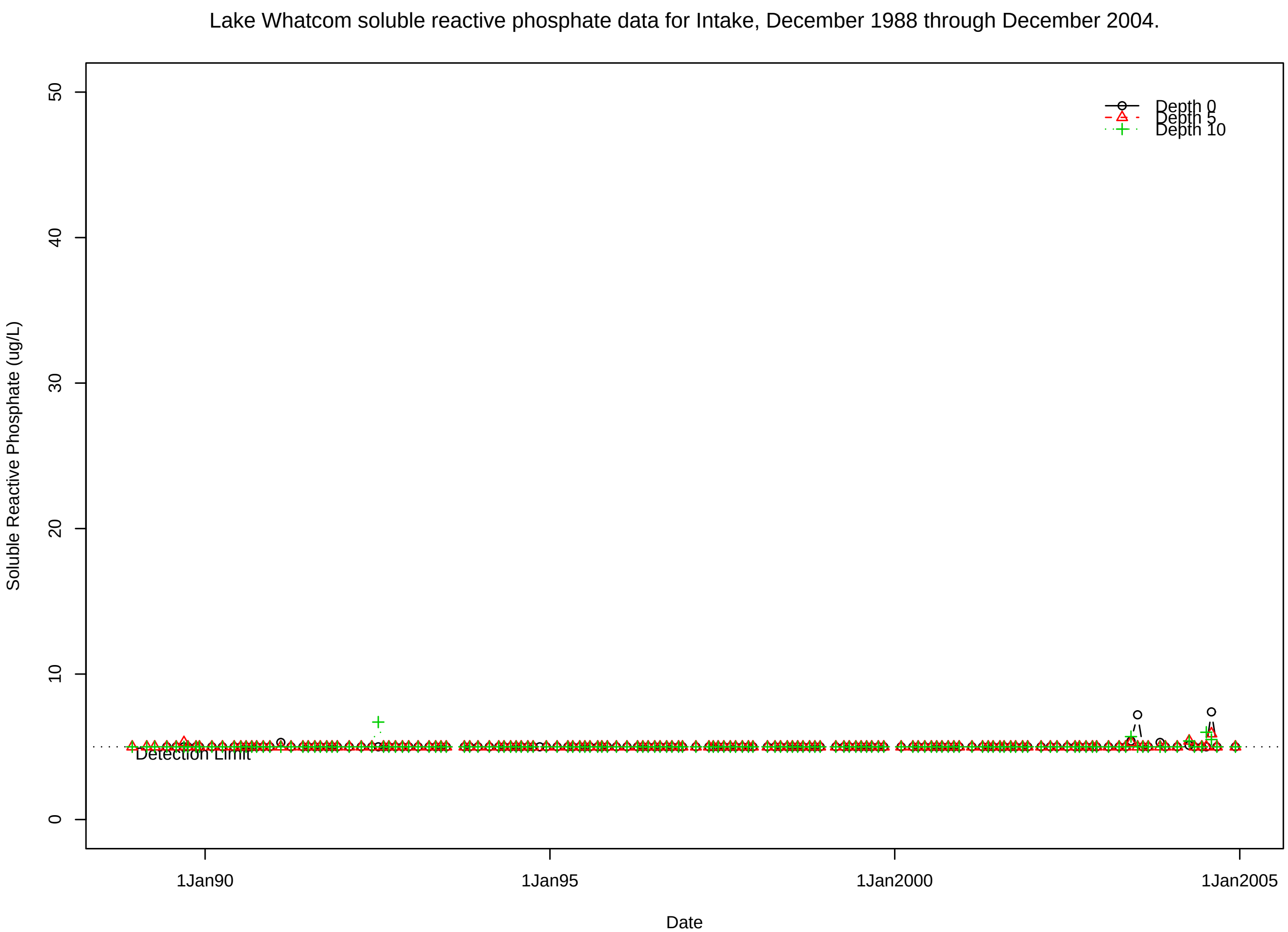


Figure B98: Lake Whatcom soluble phosphate data for the Intake (1988–2004).

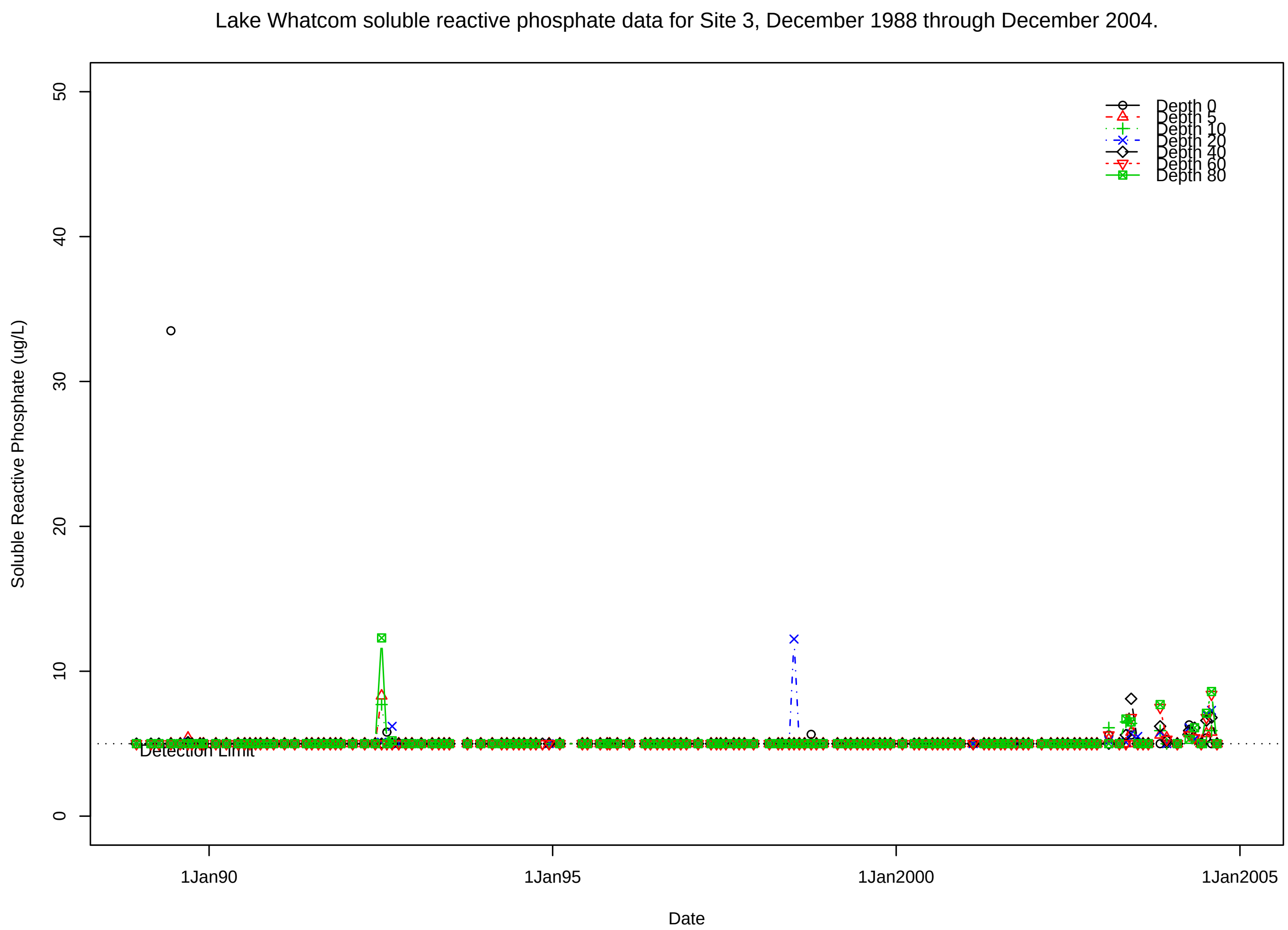


Figure B99: Lake Whatcom soluble phosphate data for Site 3 (1988–2004).

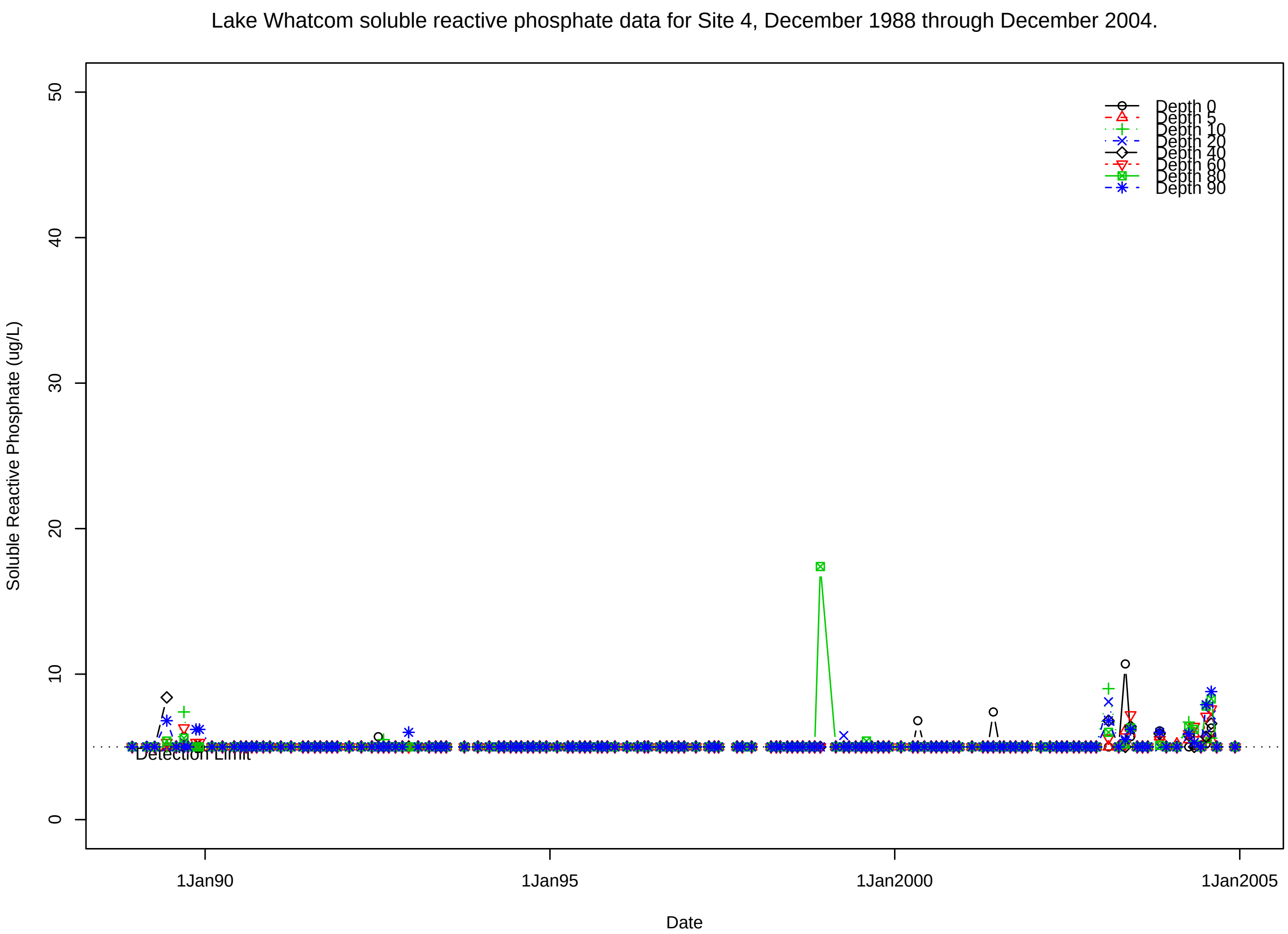


Figure B100: Lake Whatcom soluble reactive phosphate data for Site 4 (1988–2004).

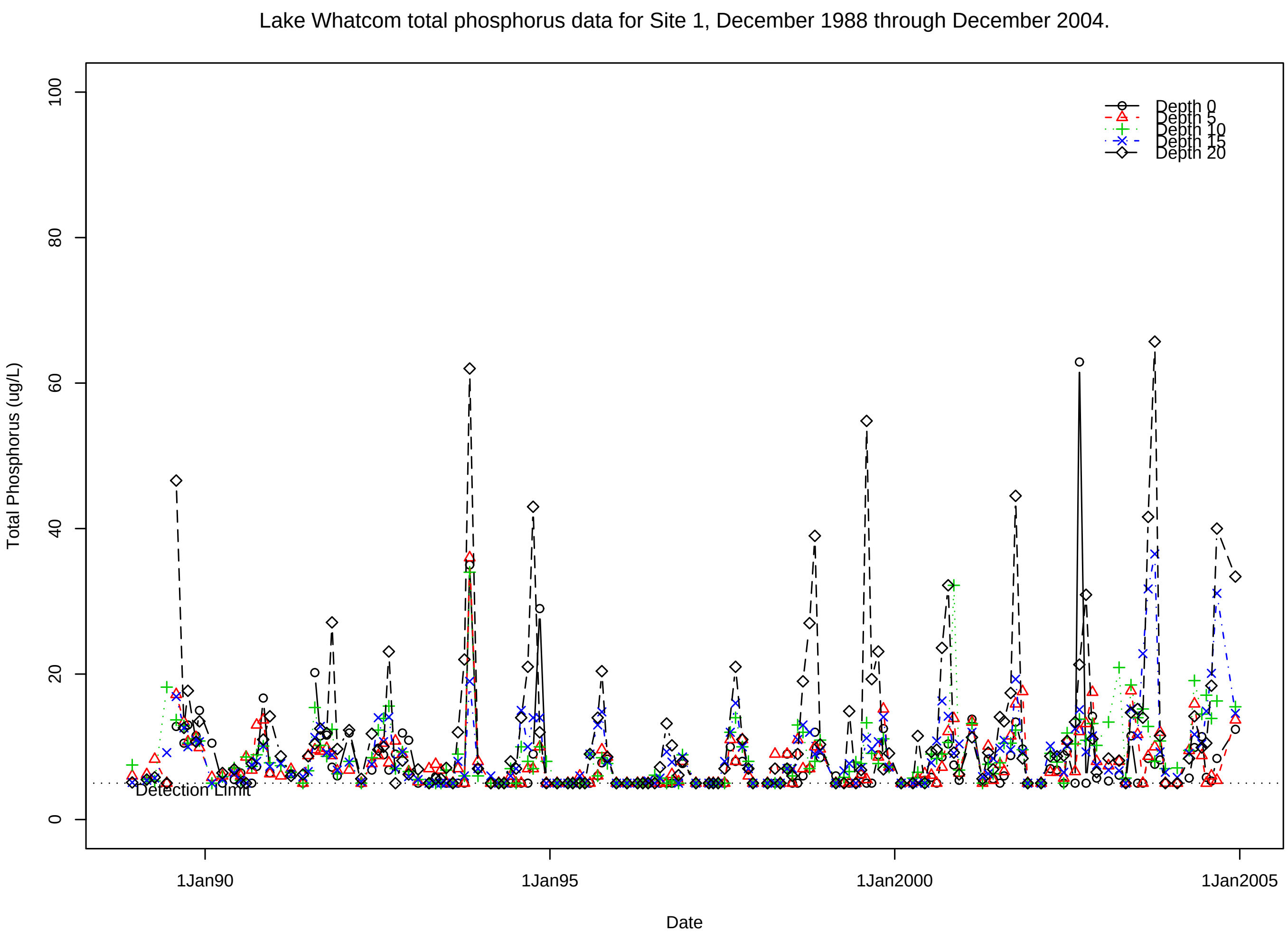


Figure B101: Lake Whatcom total phosphorus data for Site 1 (1988–2004).

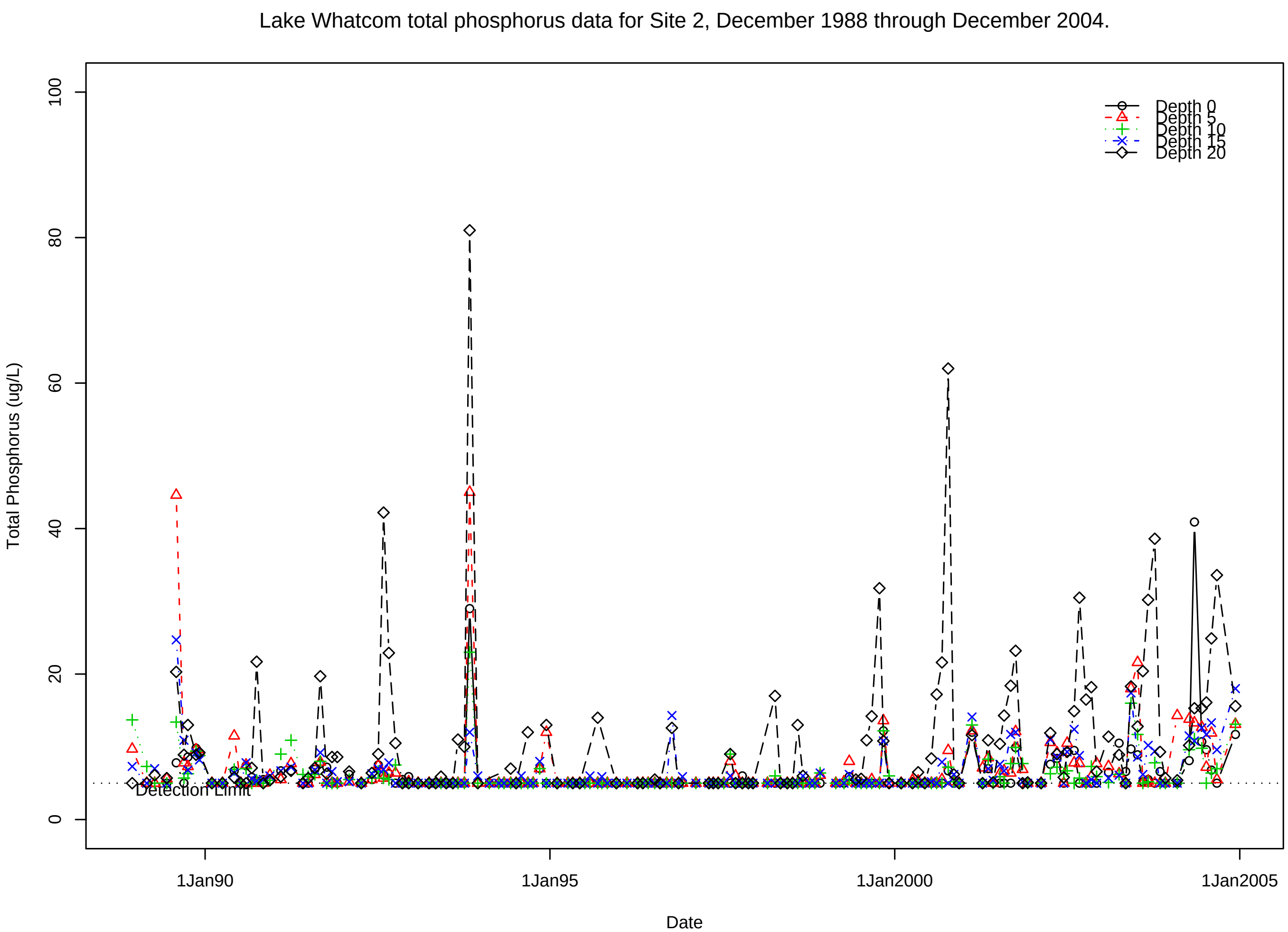


Figure B102: Lake Whatcom total phosphorus data for Site 2 (1988–2004).

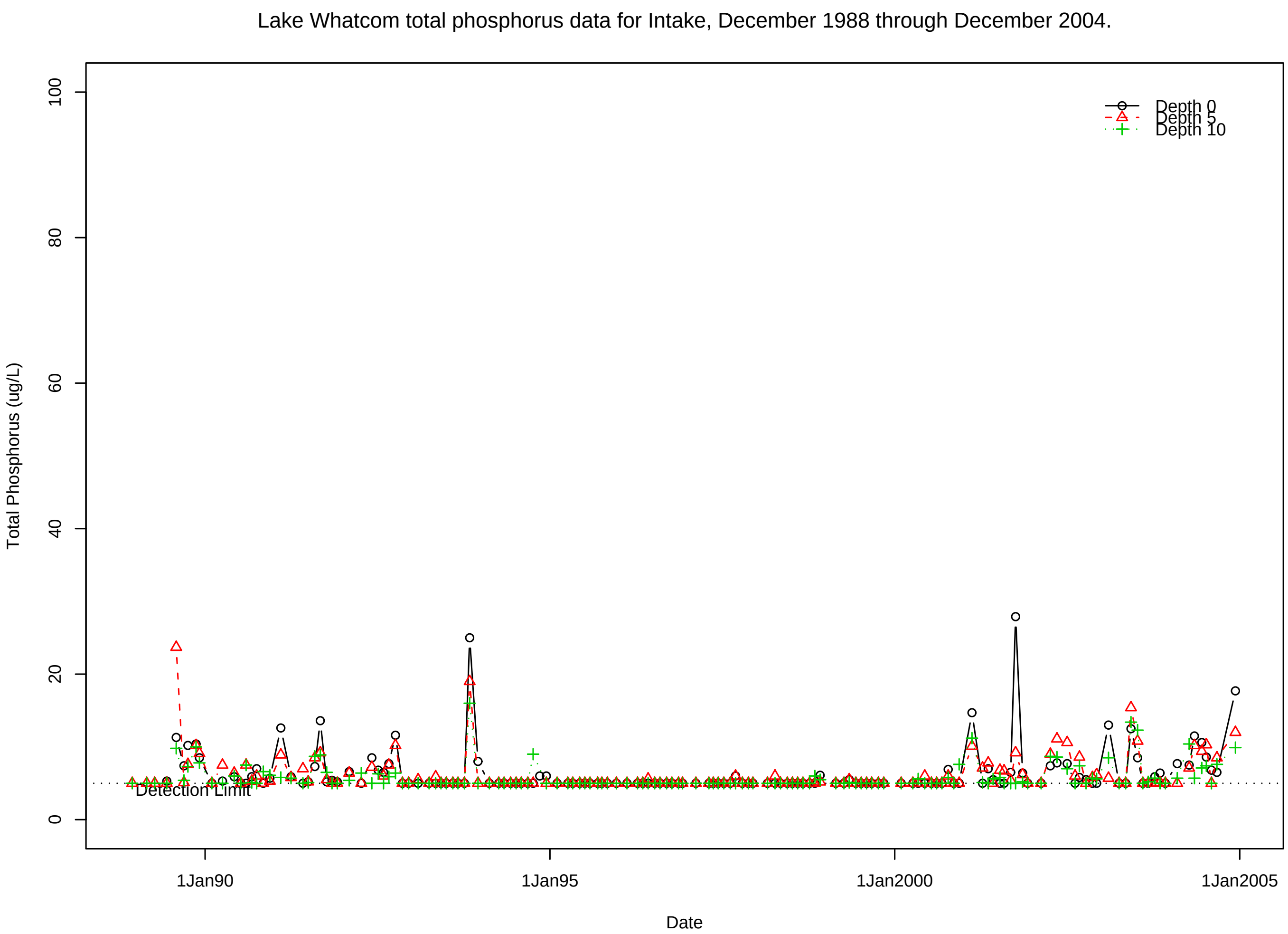


Figure B103: Lake Whatcom total phosphorus data for the Intake (1988–2004).

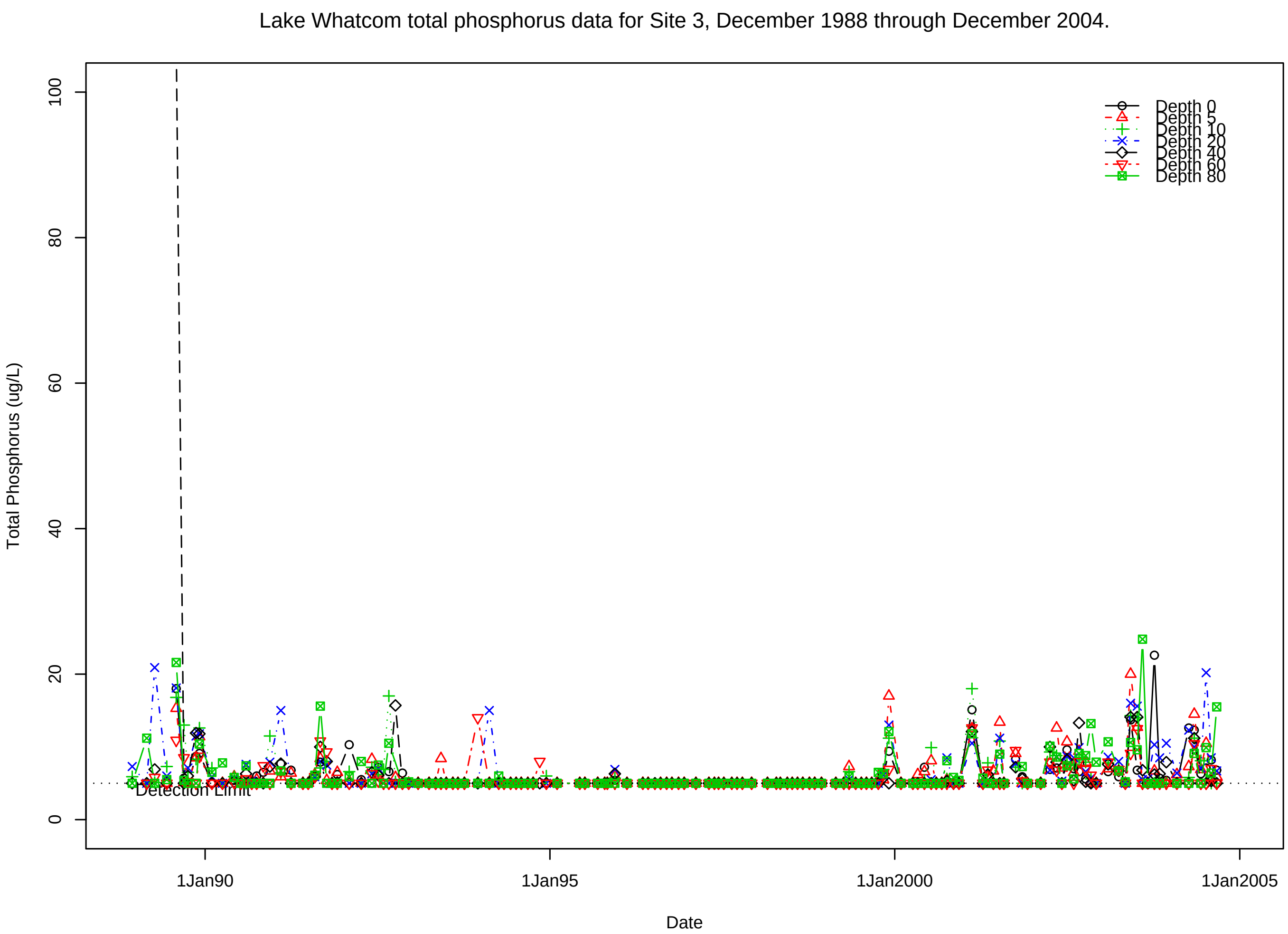


Figure B104: Lake Whatcom total phosphorus data for Site 3 (1988–2004).

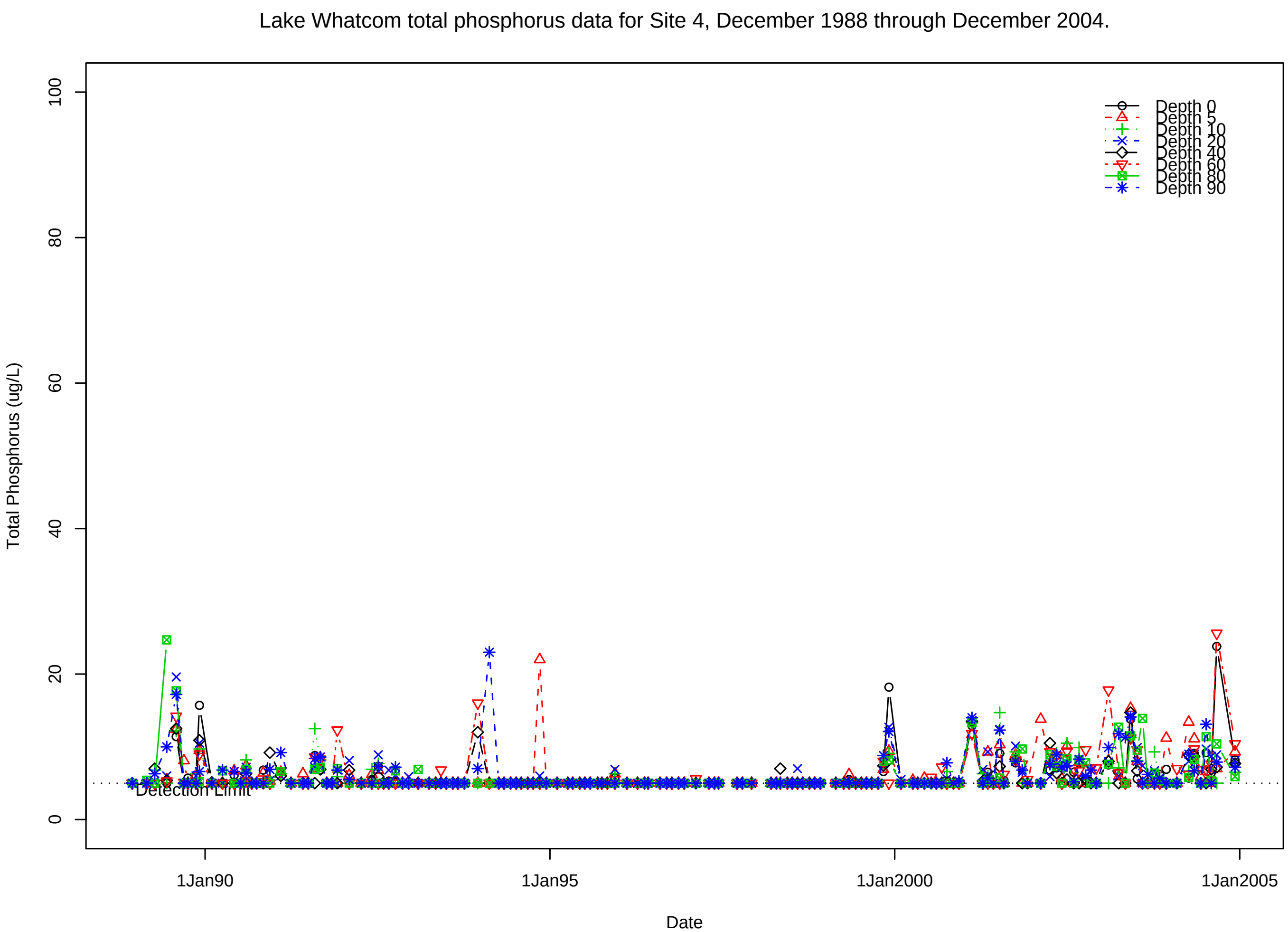


Figure B105: Lake Whatcom total phosphorus data for Site 4 (1988–2004).

B.5 Plankton, Chlorophyll, Secchi Depth

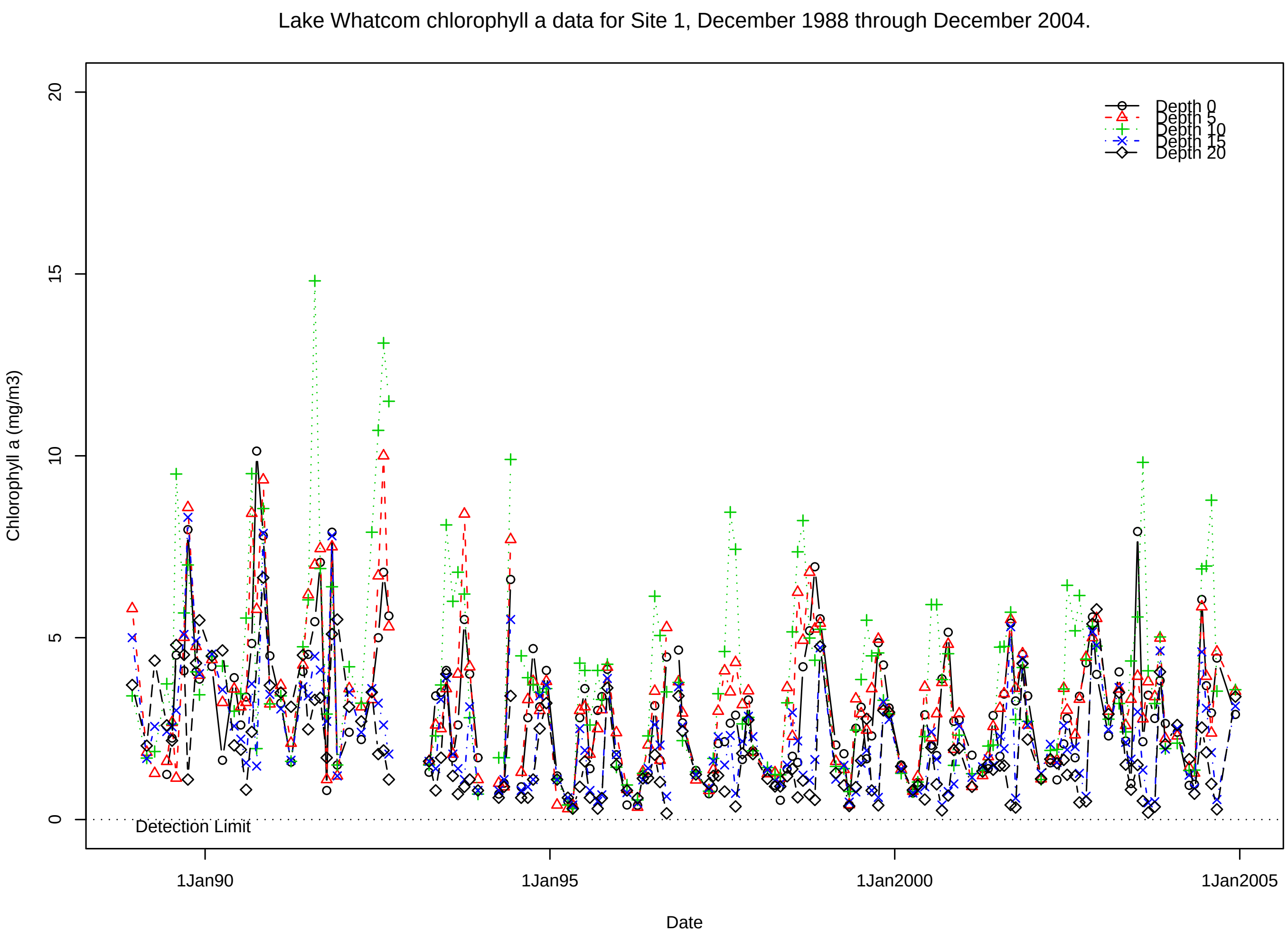


Figure B106: Lake Whatcom chlorophyll data for Site 1 (1988–2004).

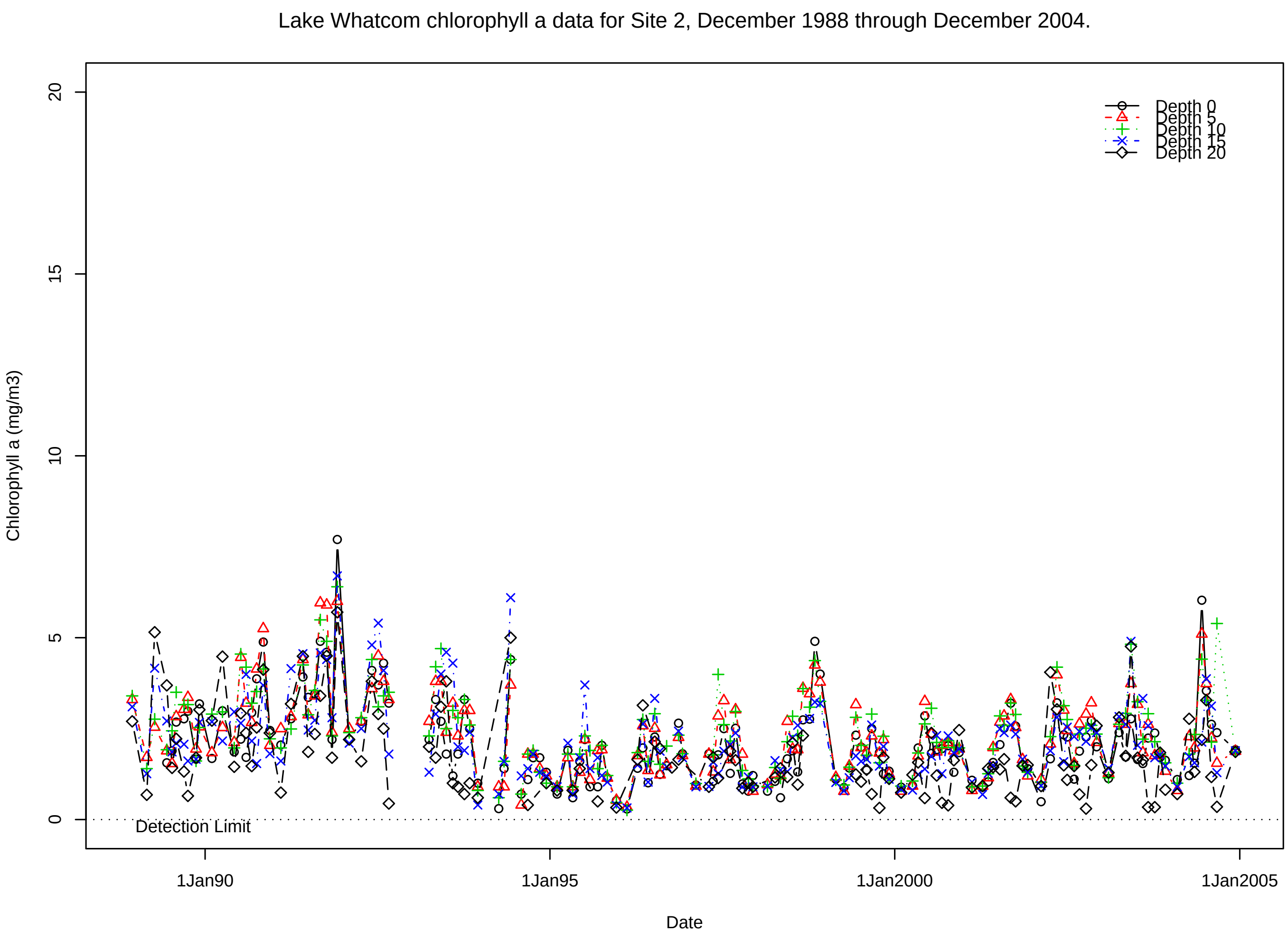


Figure B107: Lake Whatcom chlorophyll data for Site 2 (1988–2004).

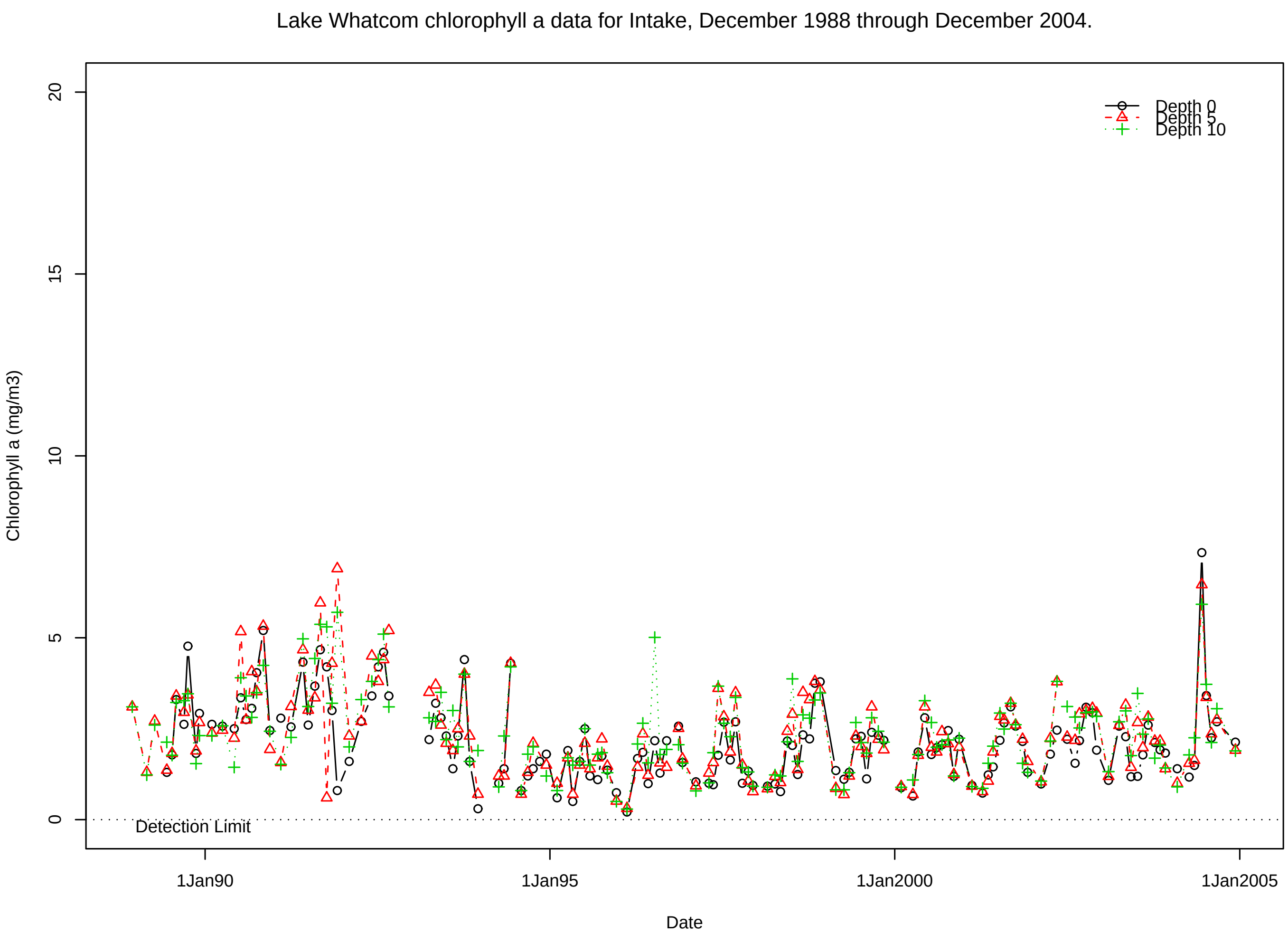


Figure B108: Lake Whatcom chlorophyll data for the Intake (1988–2004).

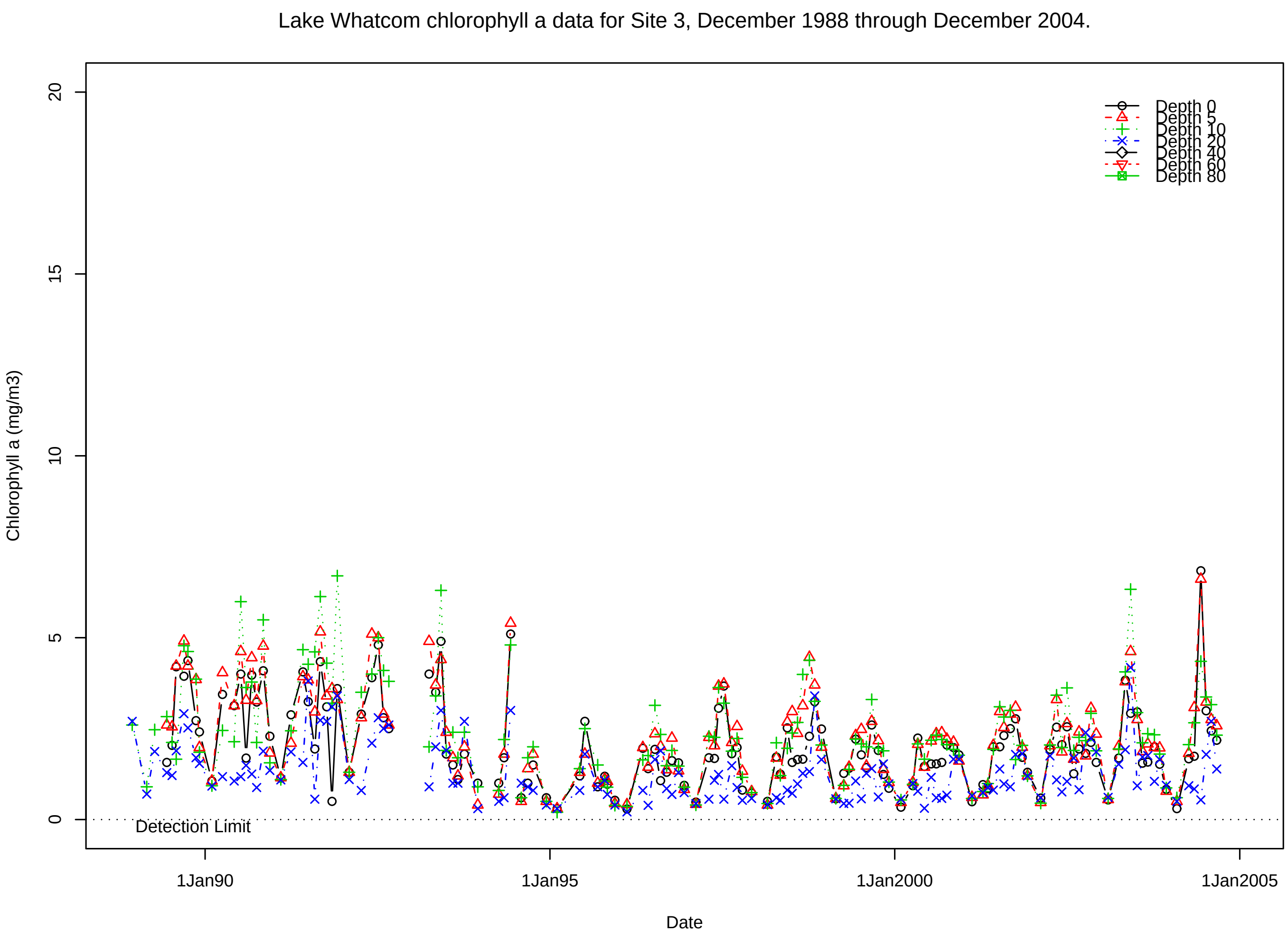


Figure B109: Lake Whatcom chlorophyll data for Site 3 (1988–2004).

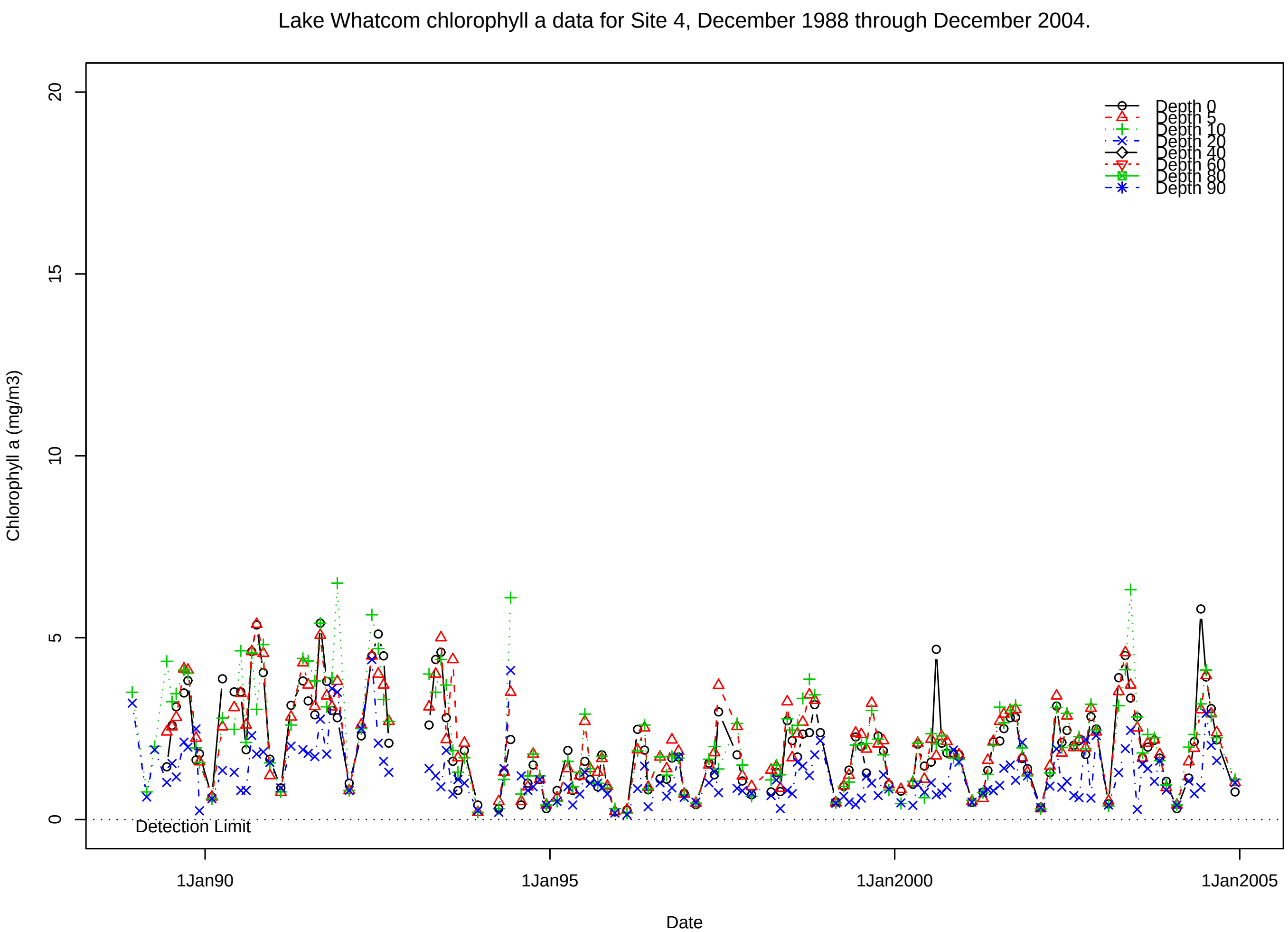


Figure B110: Lake Whatcom chlorophyll data for Site 4 (1988–2004).

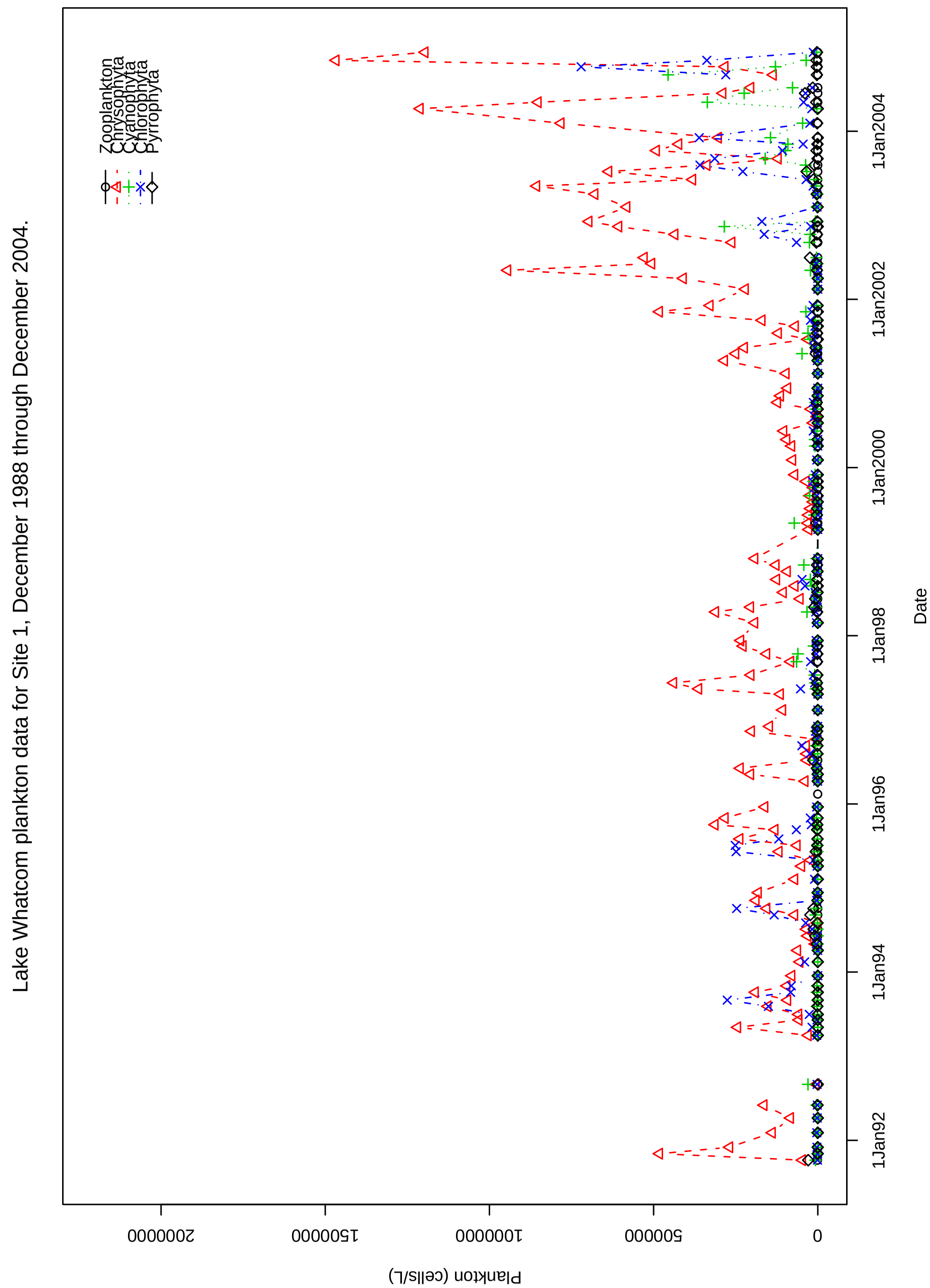


Figure B111: Lake Whatcom plankton data for Site 1 (1992–2004).

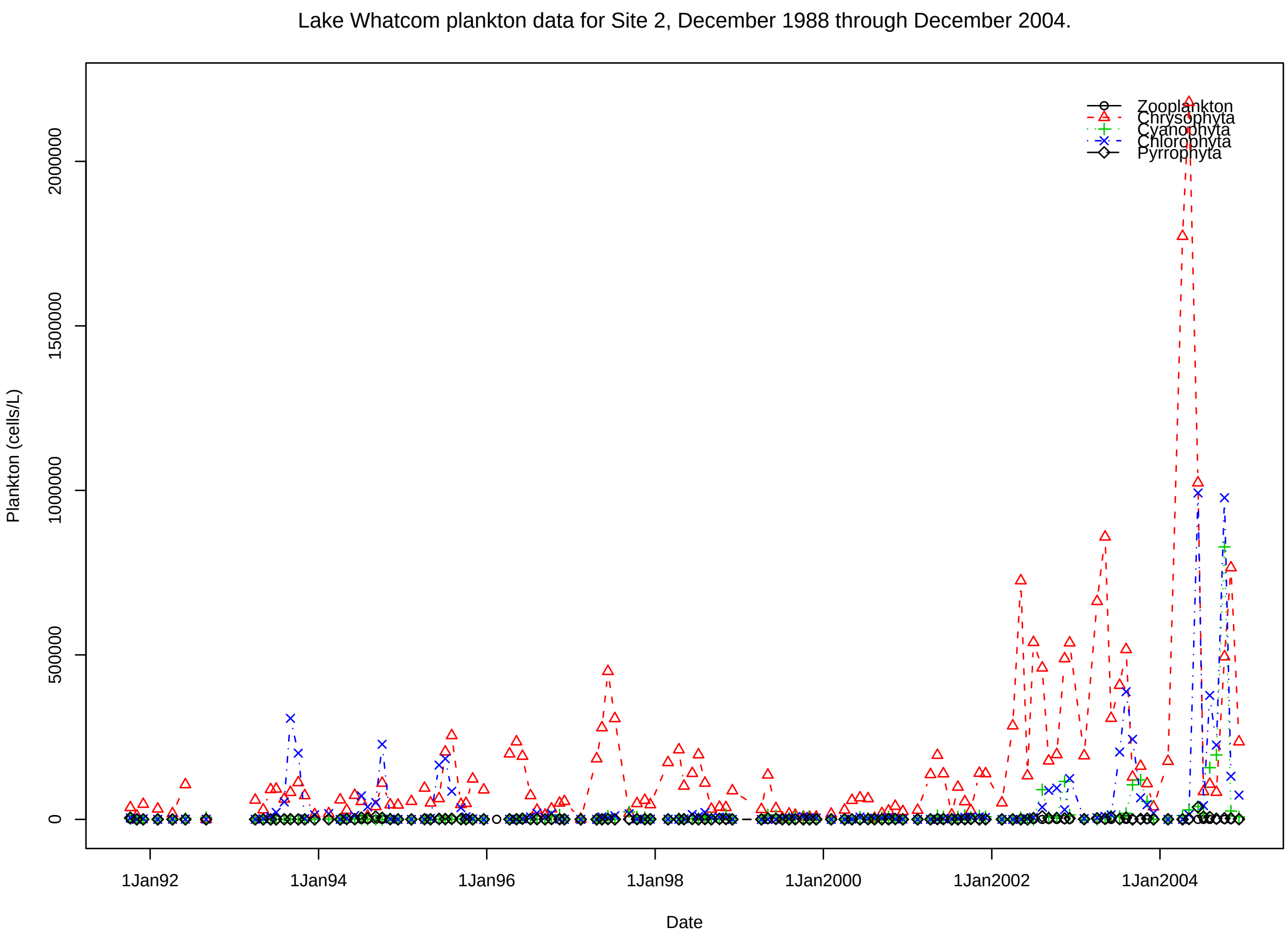


Figure B112: Lake Whatcom plankton data for Site 2 (1992–2004).

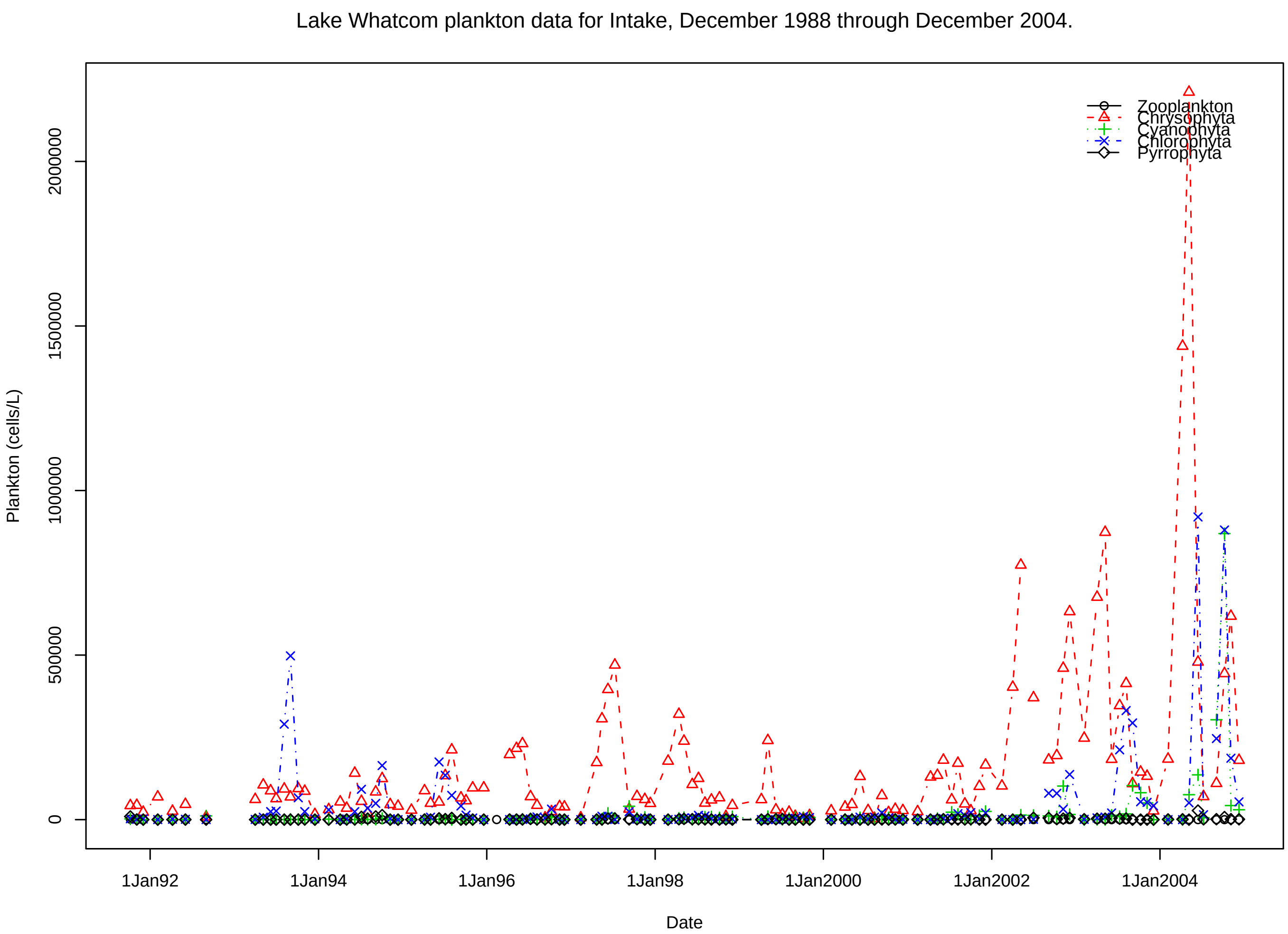


Figure B113: Lake Whatcom plankton data for the Intake (1992–2004).

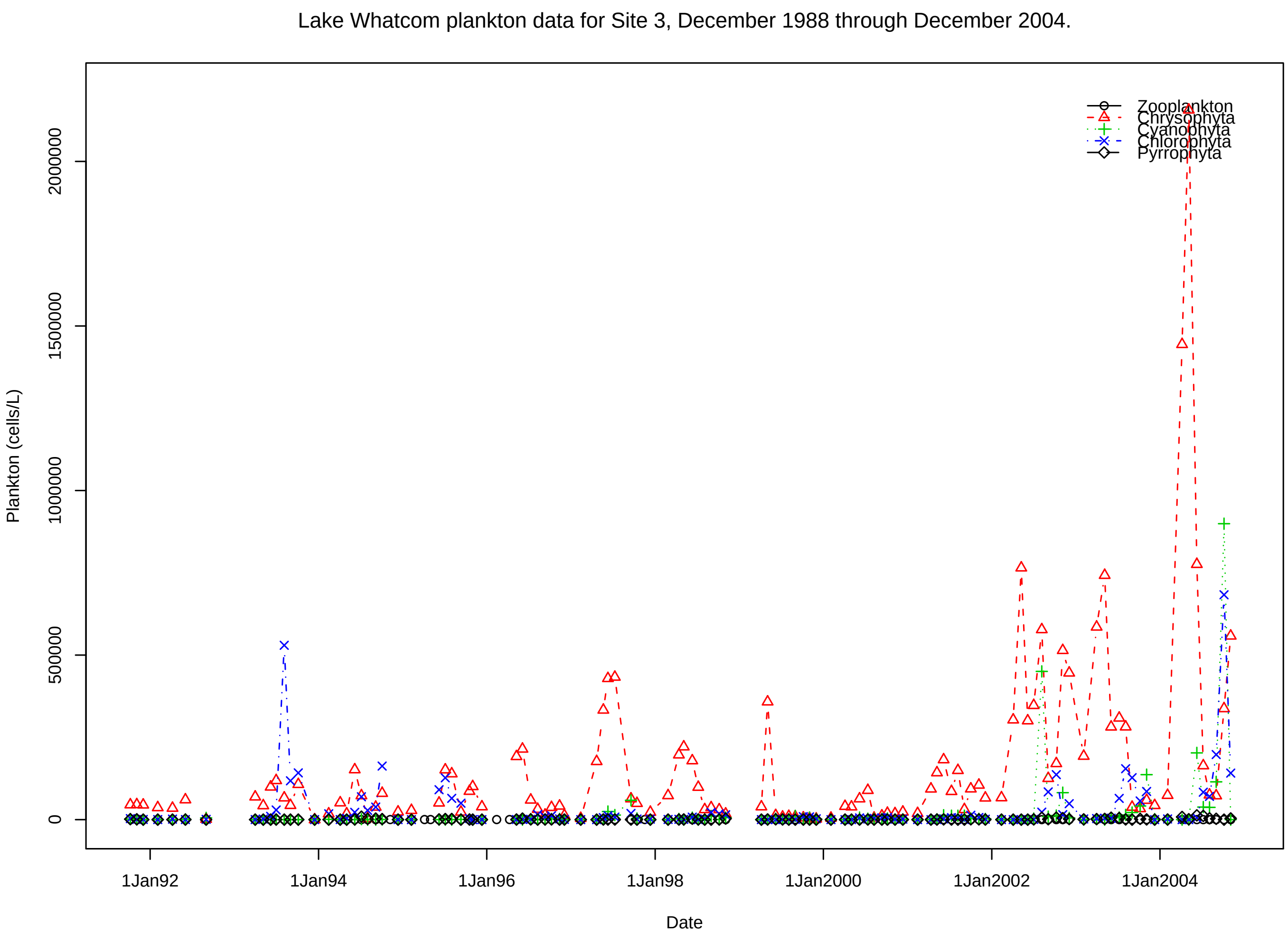


Figure B114: Lake Whatcom plankton data for Site 3 (1992–2004).

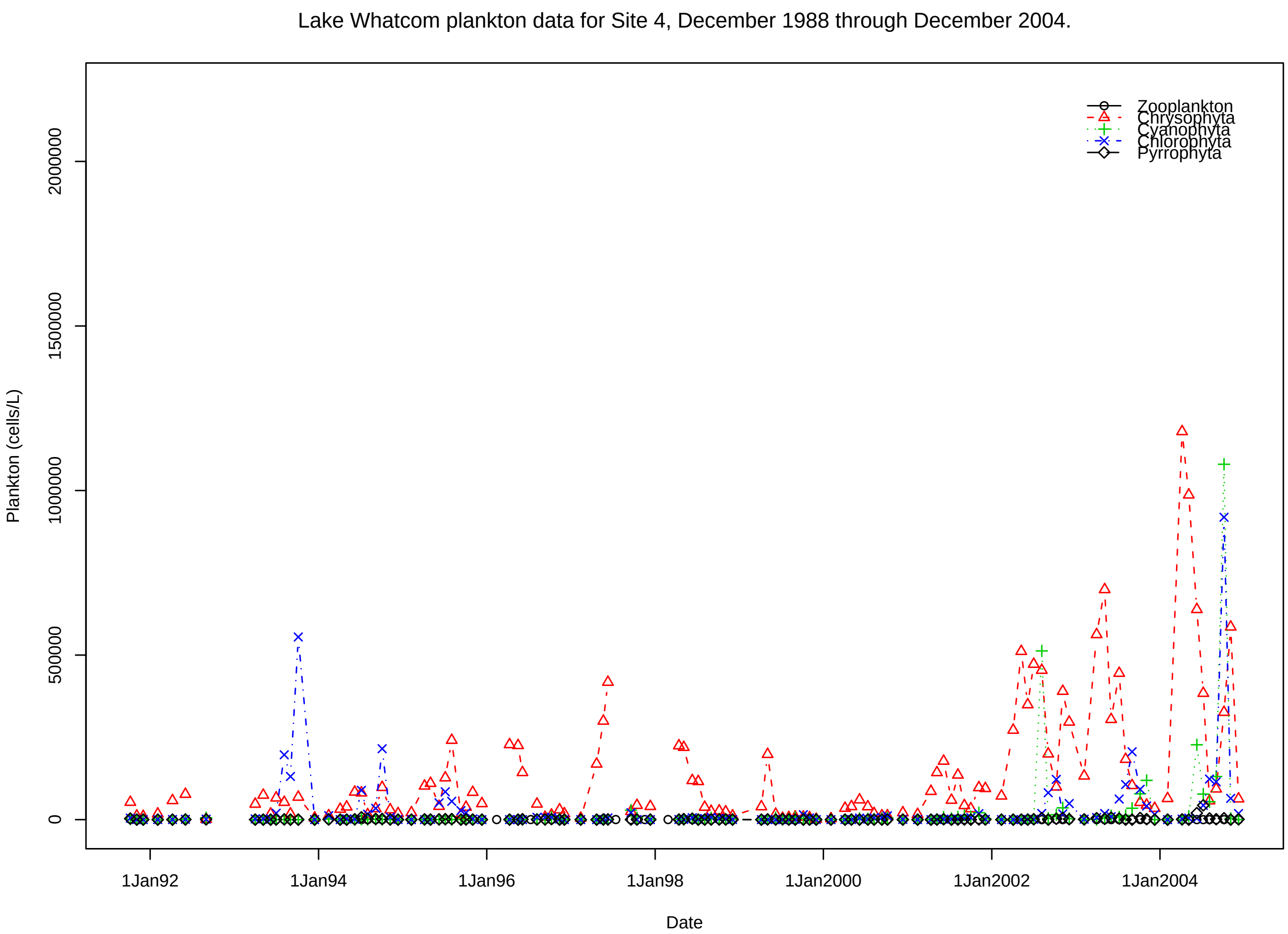


Figure B115: Lake Whatcom plankton data for Site 4 (1992–2004).

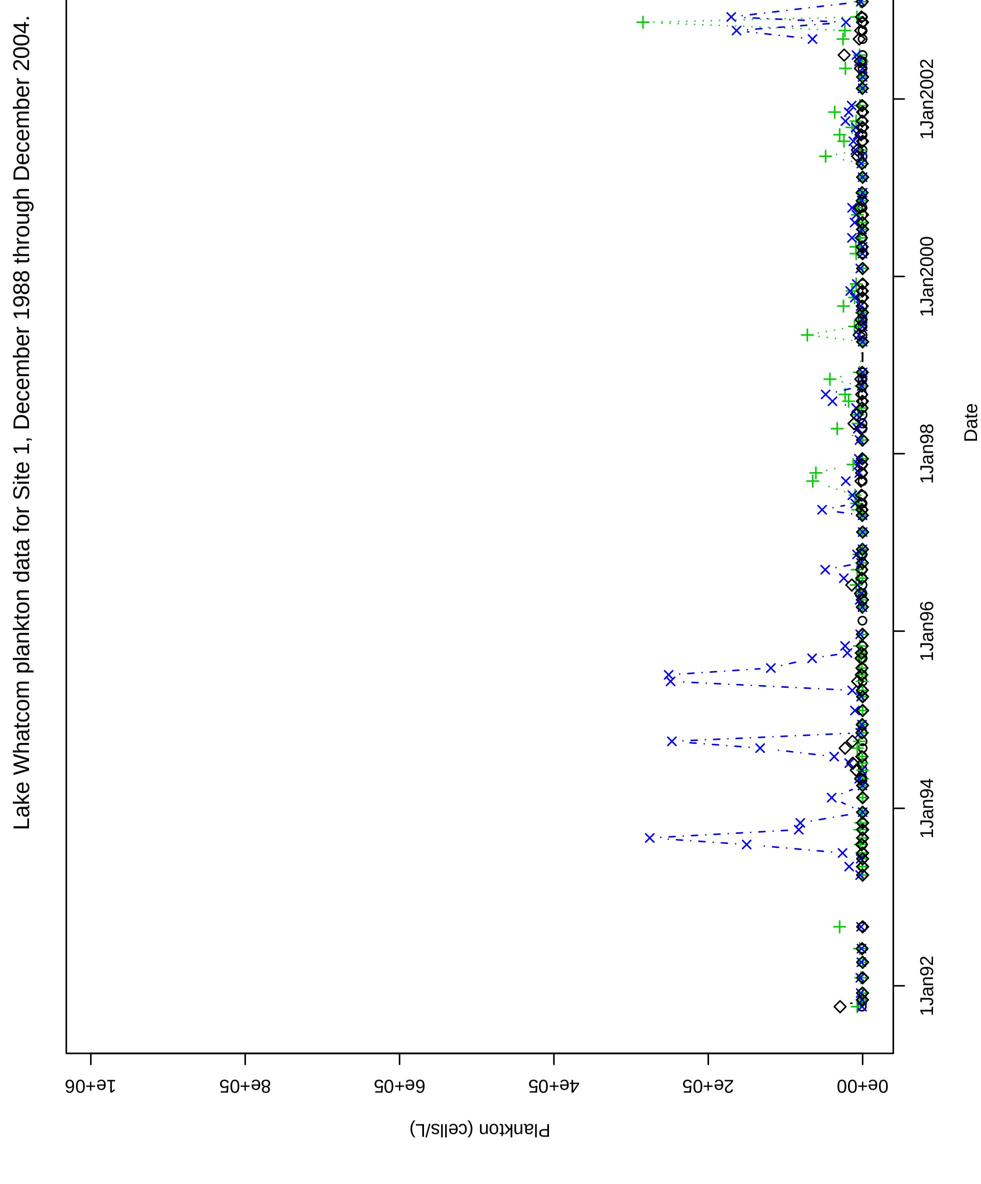


Figure B116: Lake Whatcom plankton data for Site 1, plot scaled to show zooplankton, Cyanophyta, Chlorophyta, and Pyrrhophyta (1992–2004).

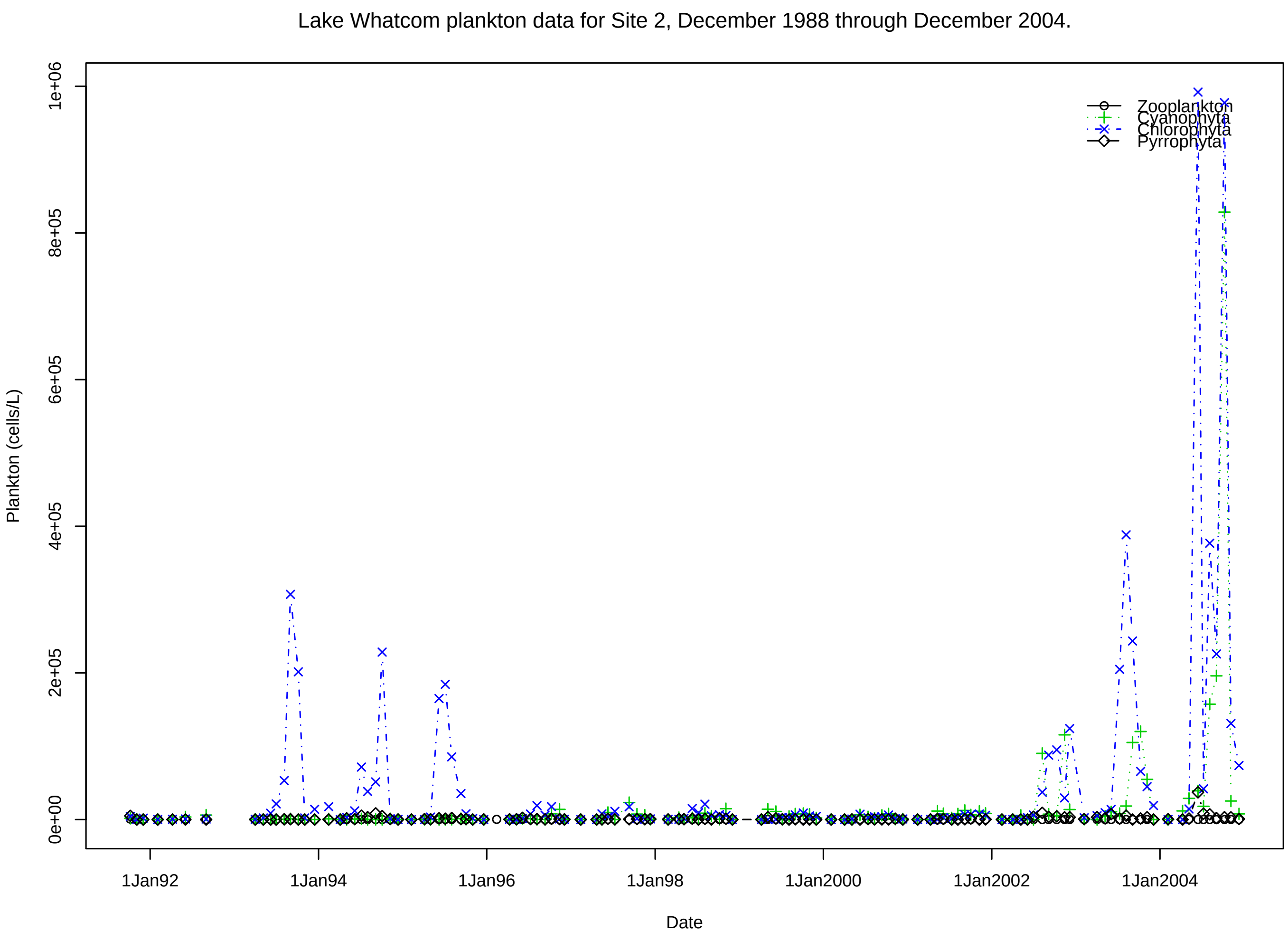


Figure B117: Lake Whatcom plankton data for Site 2, plot scaled to show zooplankton, Cyanophyta, Chlorophyta, and Pyrrhophyta (1992–2004).

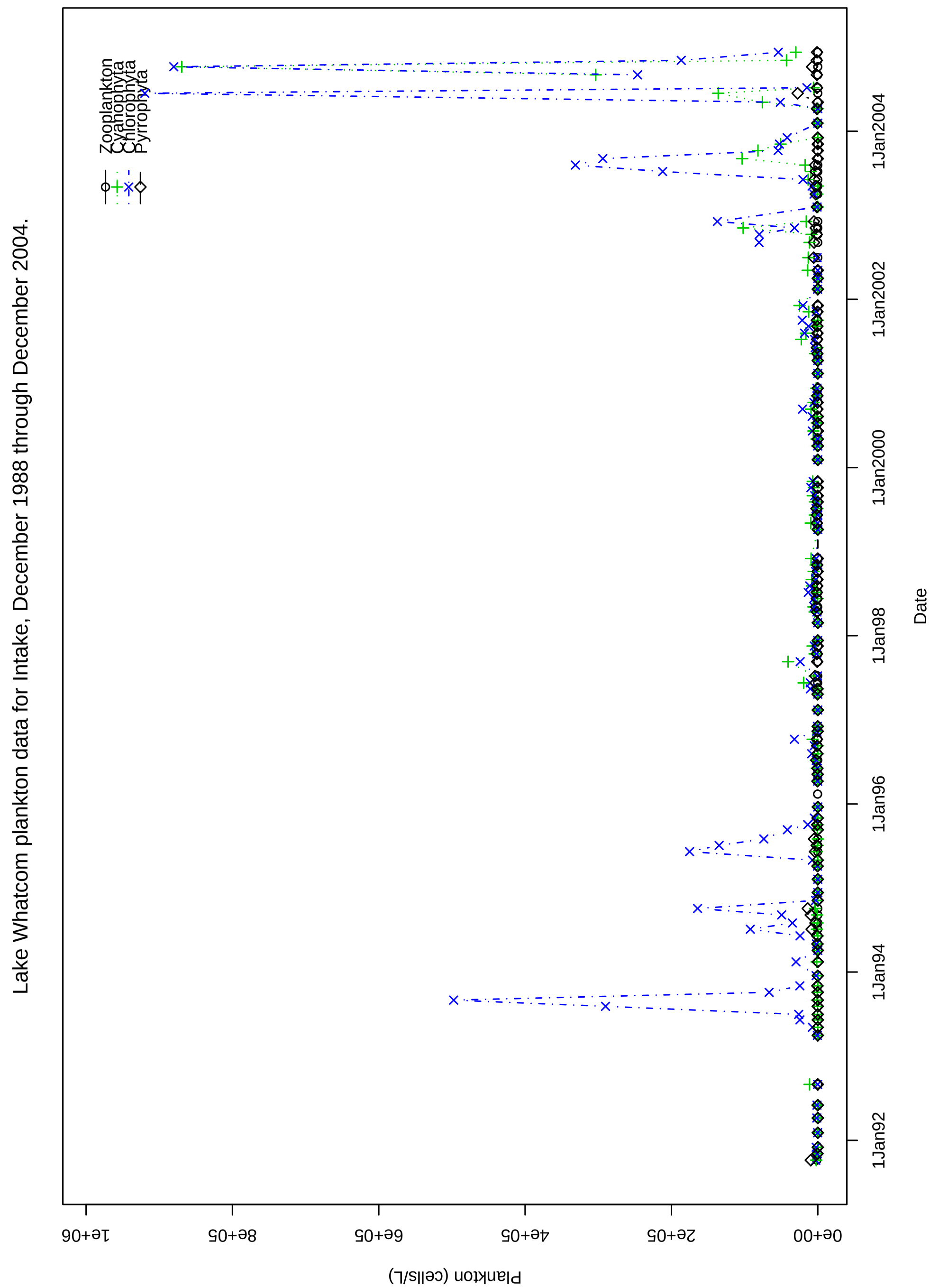


Figure B118: Lake Whatcom plankton data for the Intake, plot scaled to show zooplankton, Cyanophyta, Chlorophyta, and Pyrrhophyta (1992–2004).

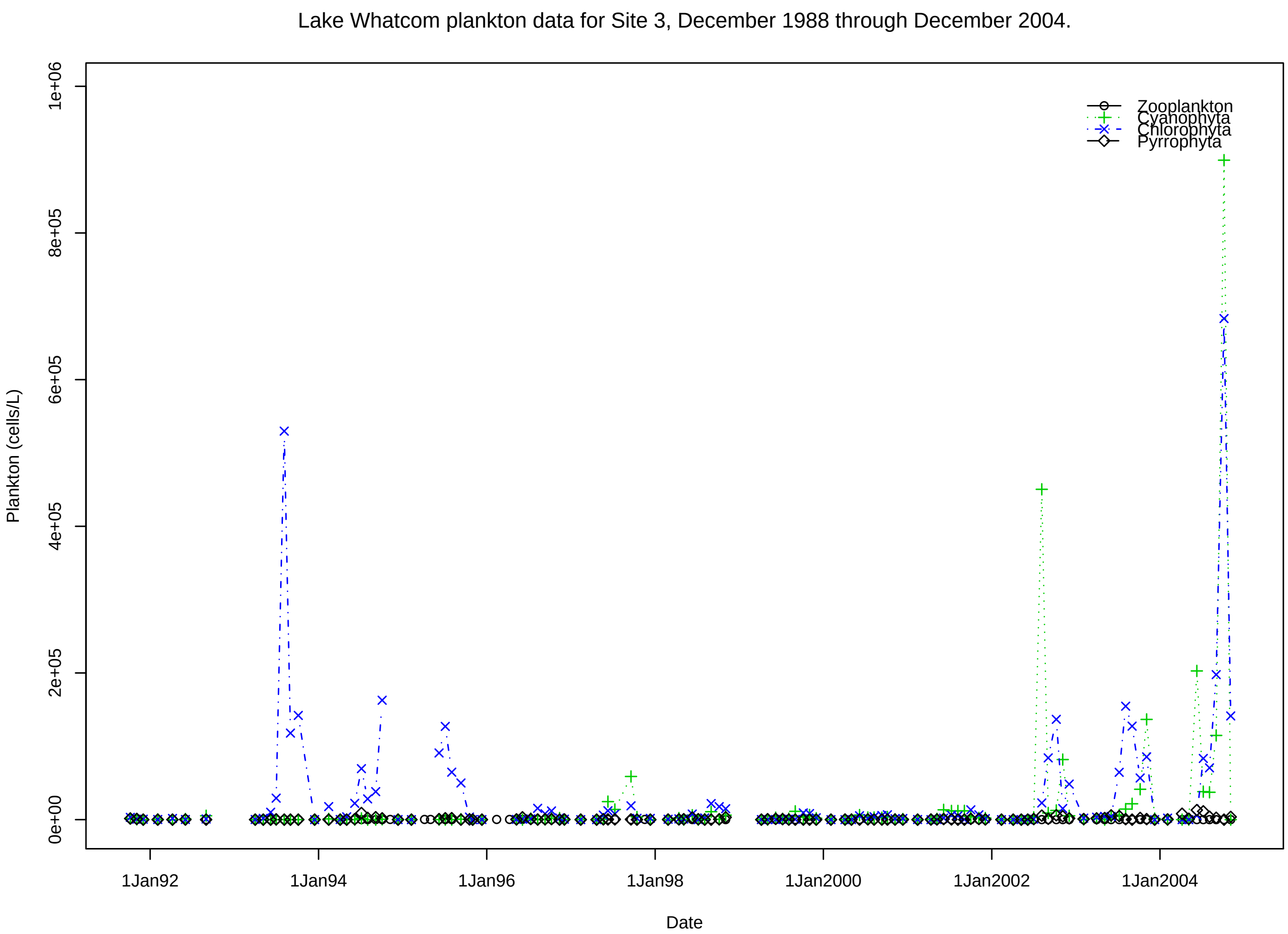


Figure B119: Lake Whatcom plankton data for Site 3, plot scaled to show zooplankton, Cyanophyta, Chlorophyta, and Pyrrophyta (1992–2004).

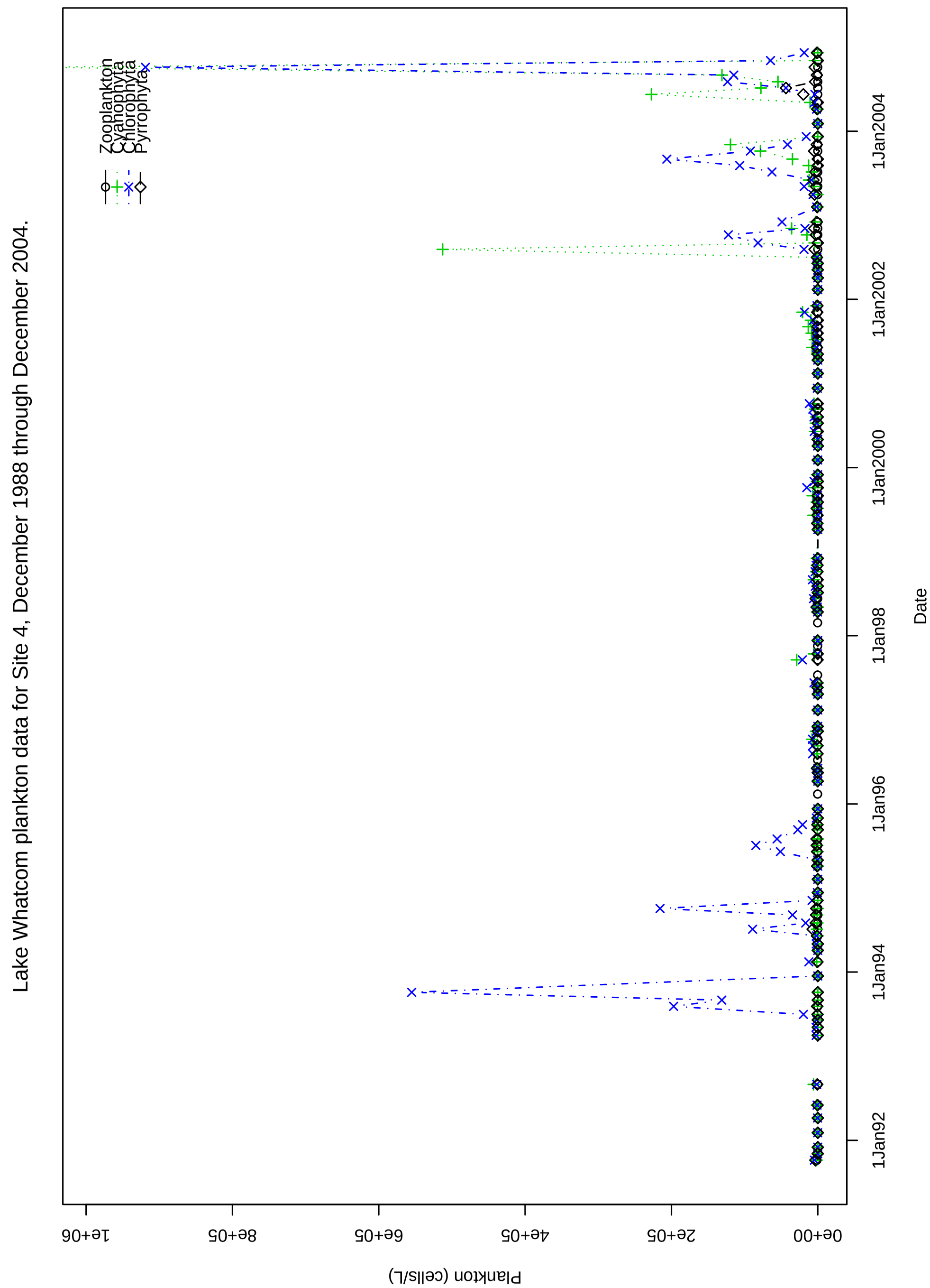


Figure B120: Lake Whatcom plankton data for Site 4, plot scaled to show zooplankton, Cyanophyta, Chlorophyta, and Pyrrhophyta (1992–2004).

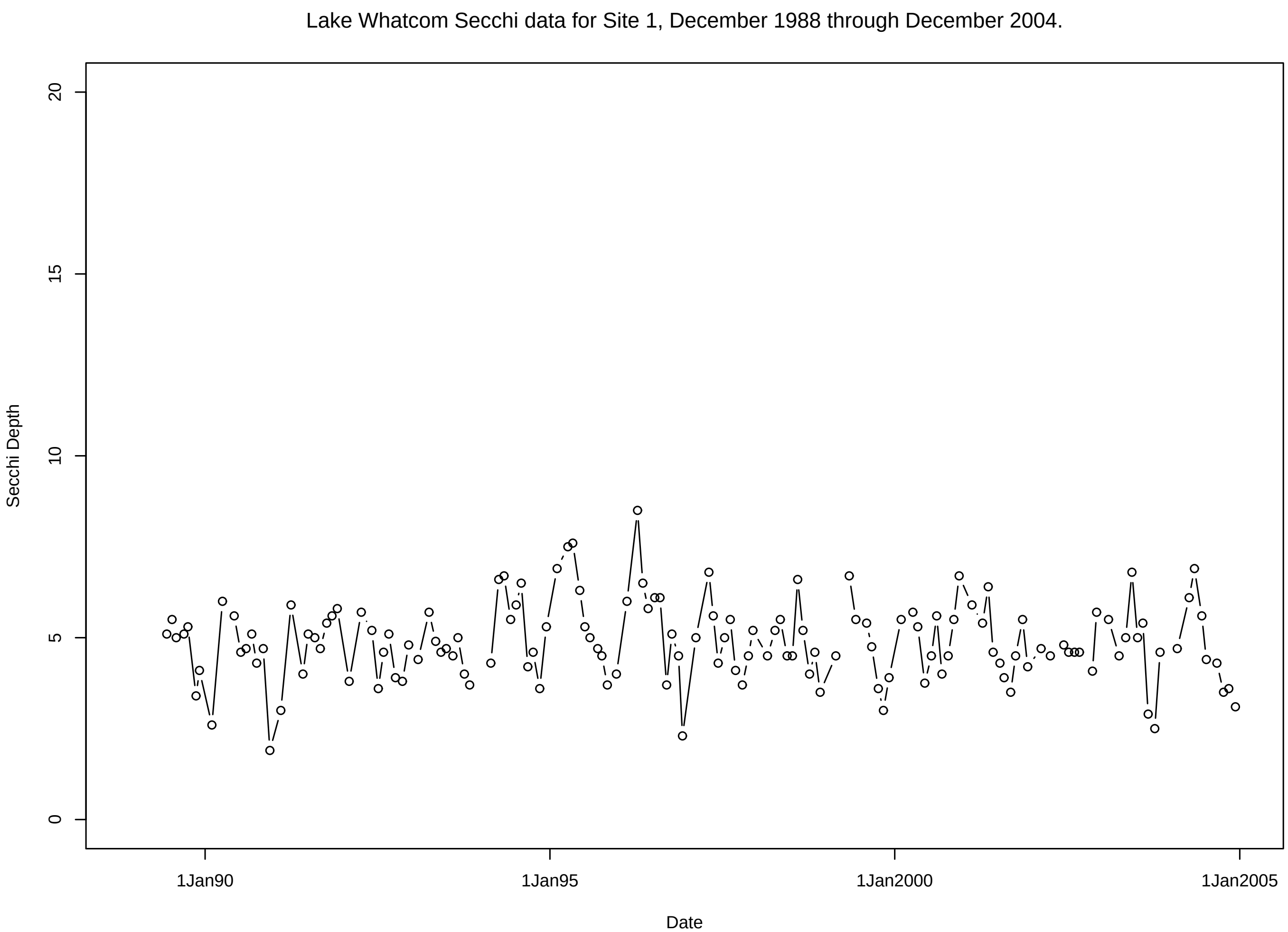


Figure B121: Lake Whatcom Secchi depths for Site 1.

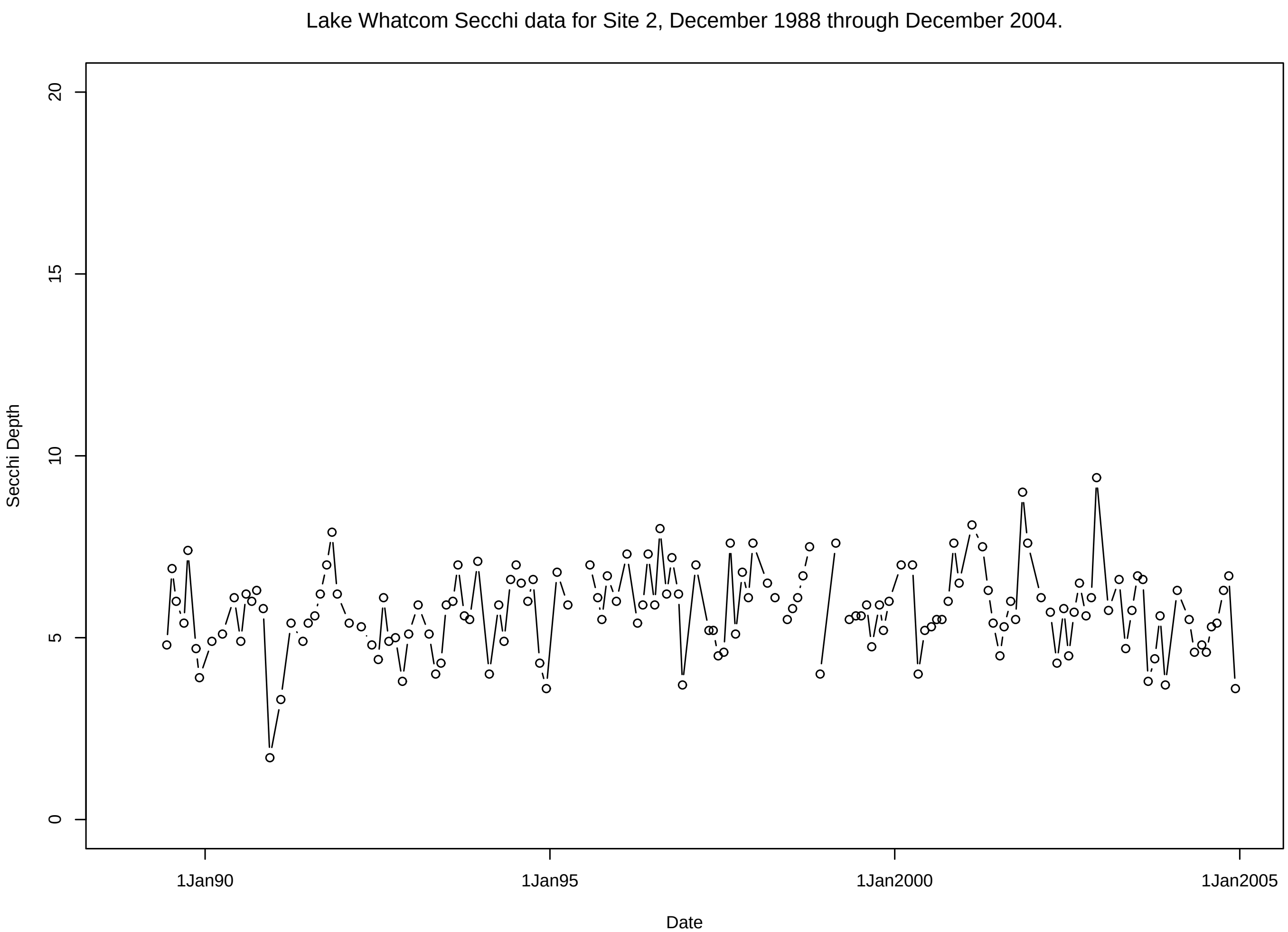


Figure B122: Lake Whatcom Secchi depths for Site 2.

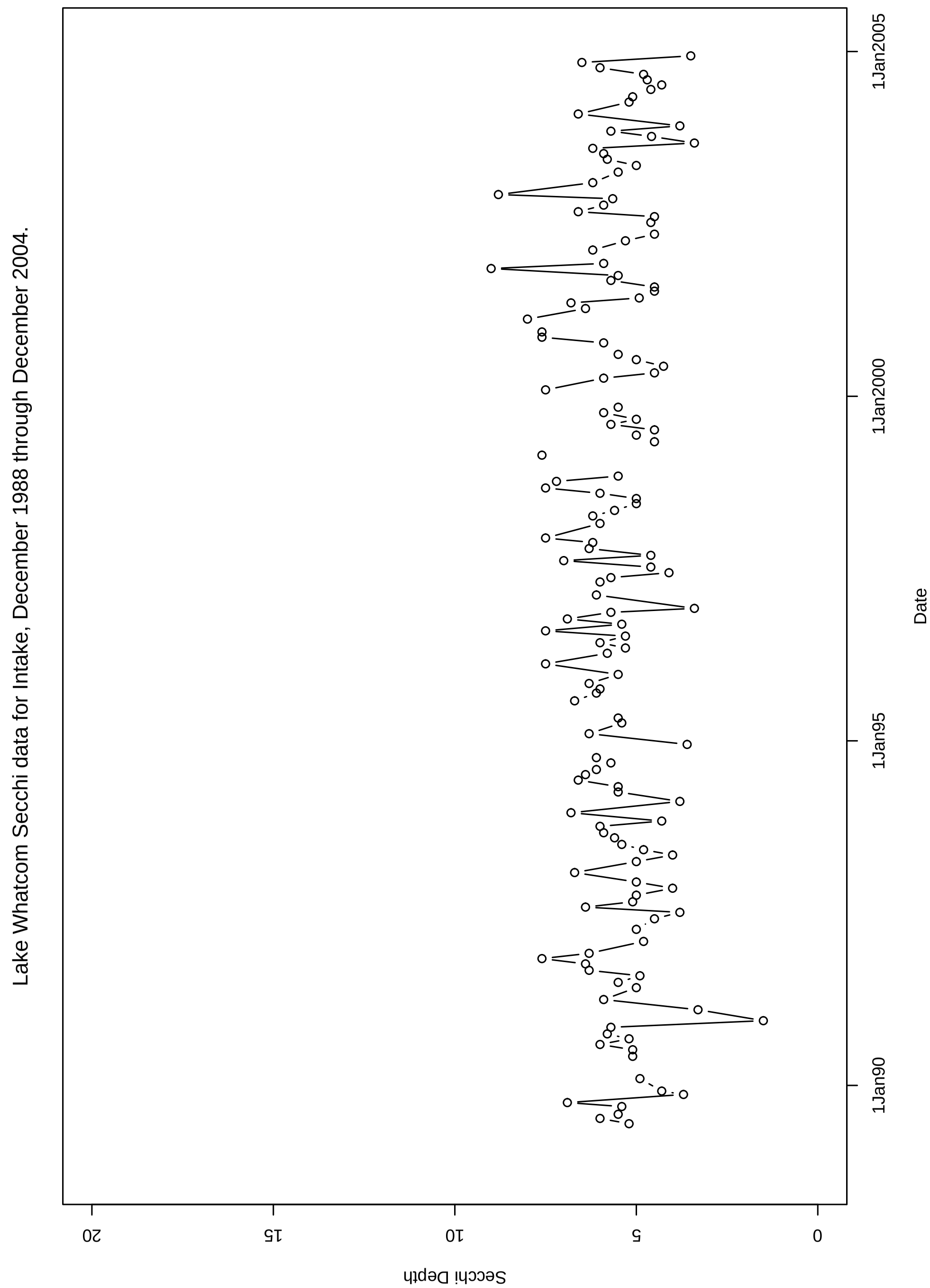


Figure B123: Lake Whatcom Secchi depths for the Intake.

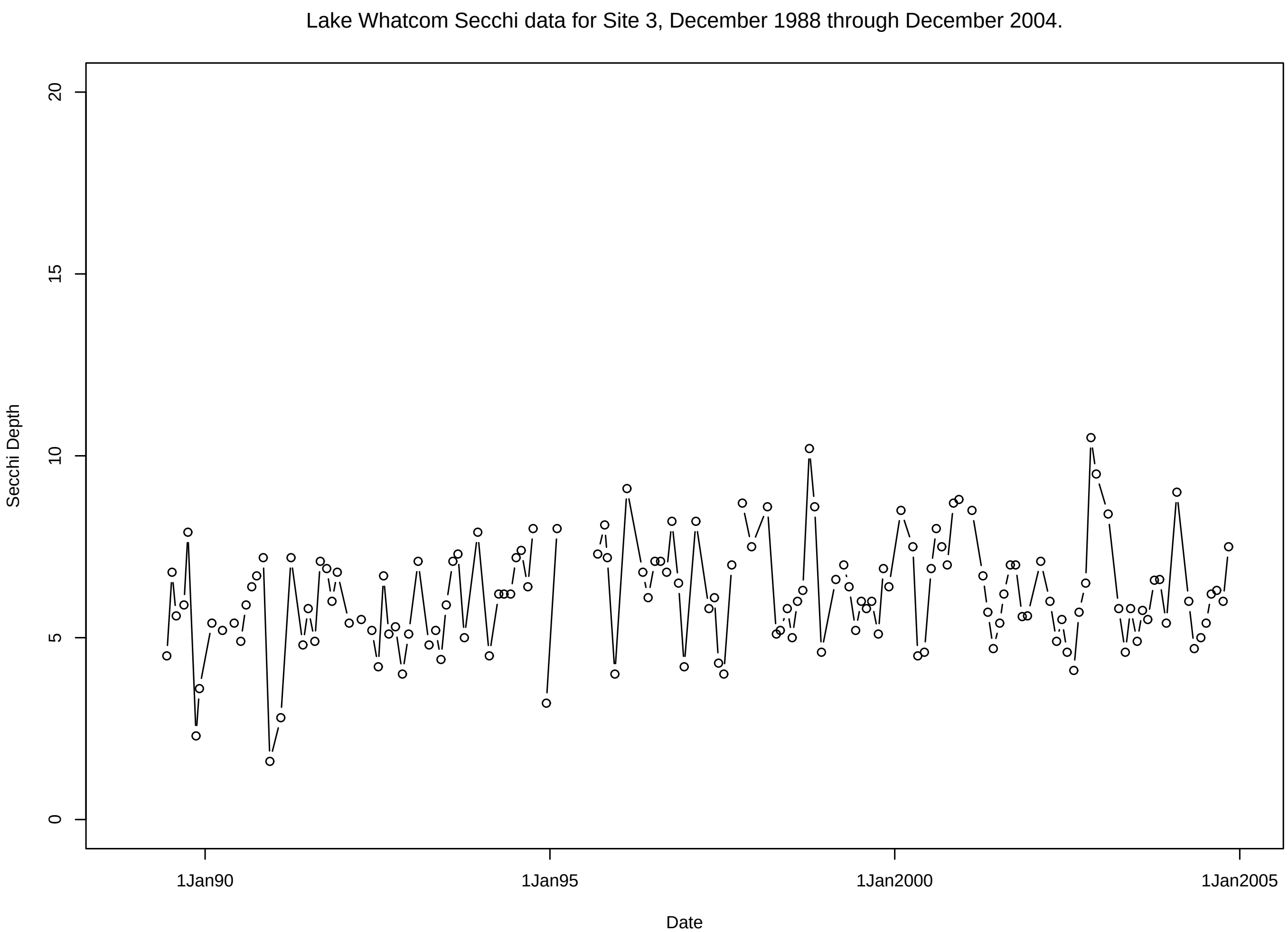


Figure B124: Lake Whatcom Secchi depths for Site 3.

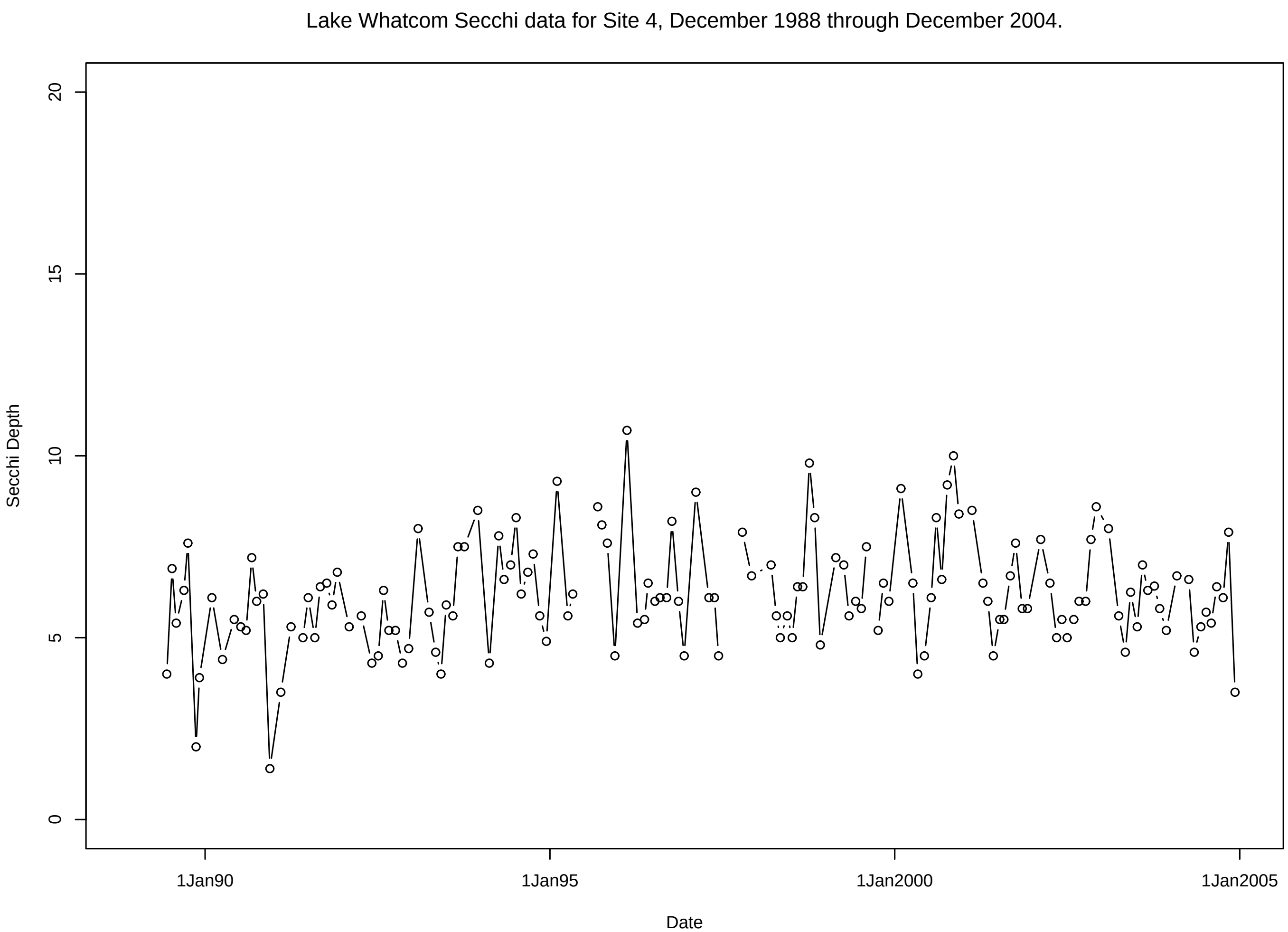


Figure B125: Lake Whatcom Secchi depths for Site 4.

B.6 Coliform Bacteria

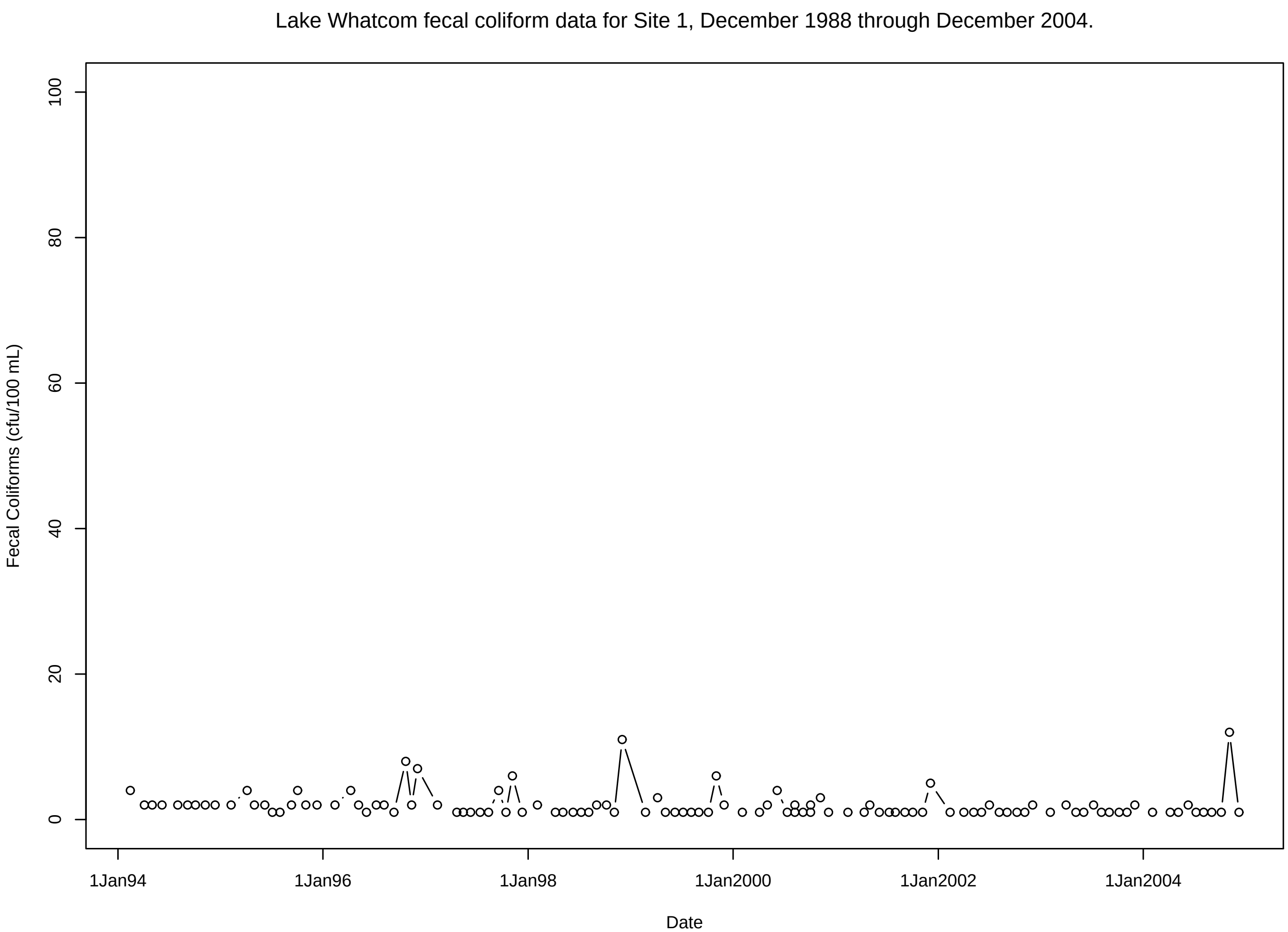


Figure B126: Lake Whatcom fecal coliform data for Site 1 (1994–2004).

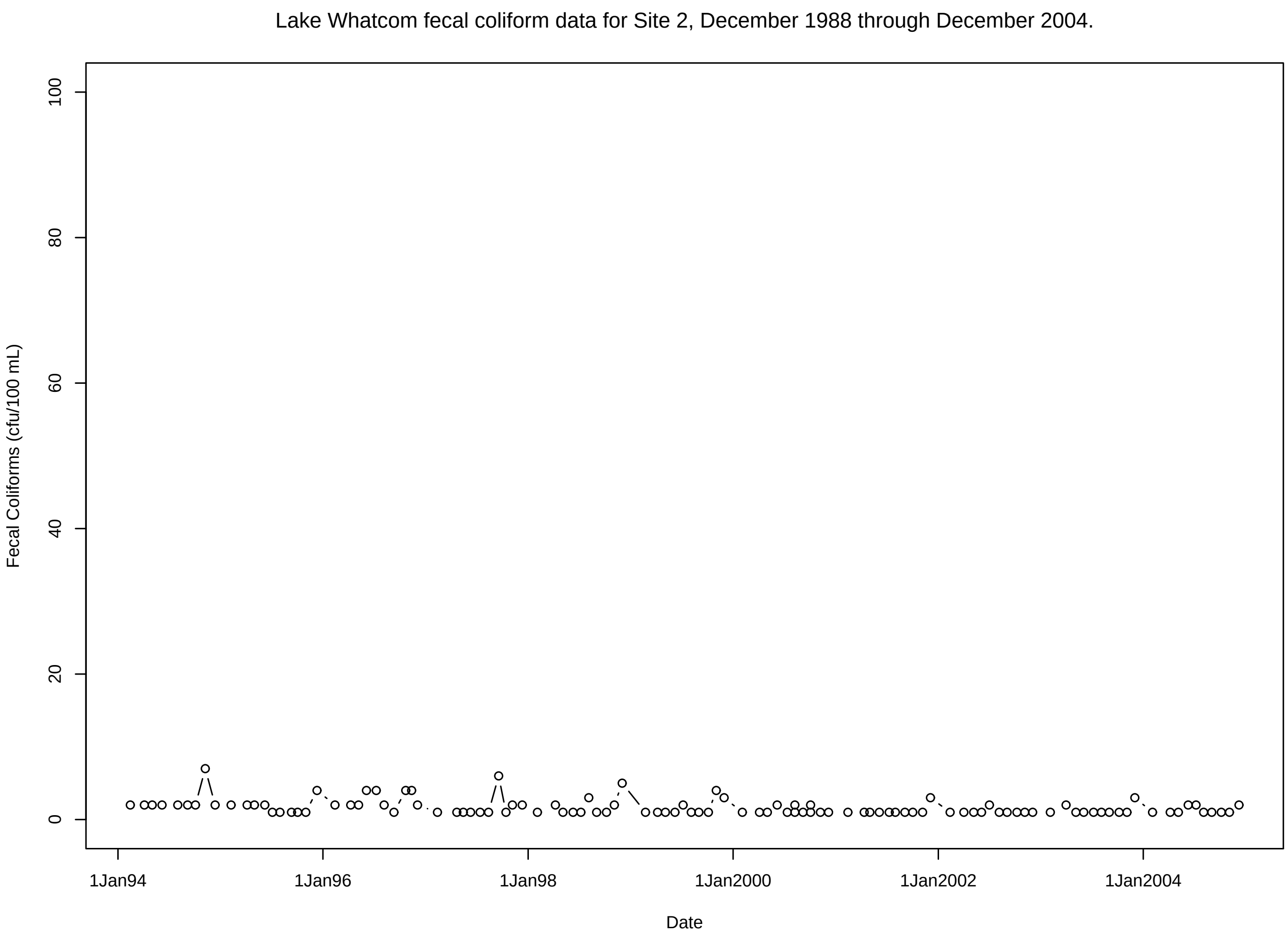


Figure B127: Lake Whatcom fecal coliform data for Site 2 (1994–2004).

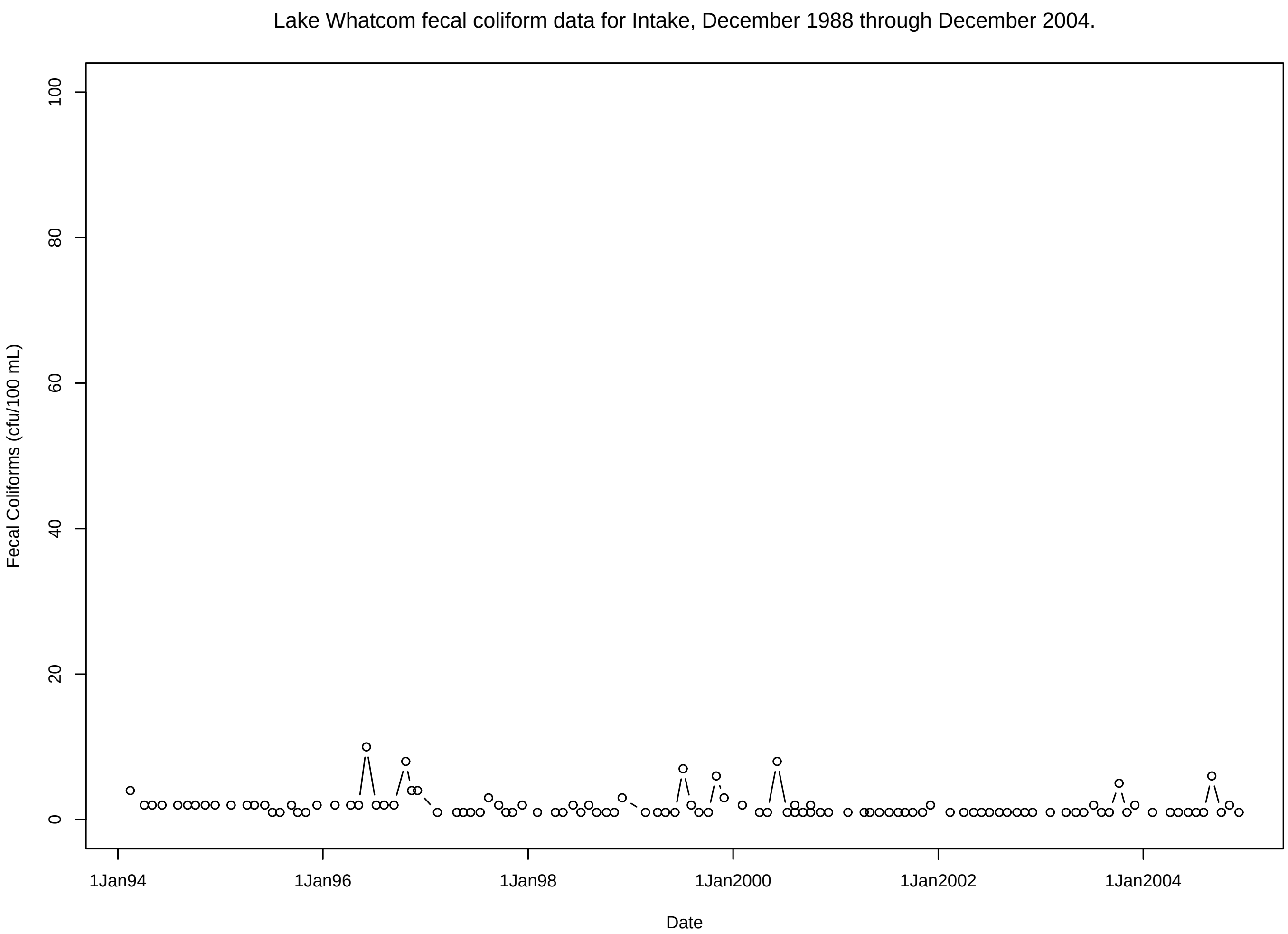


Figure B128: Lake Whatcom fecal coliform data for the Intake (1994–2004).

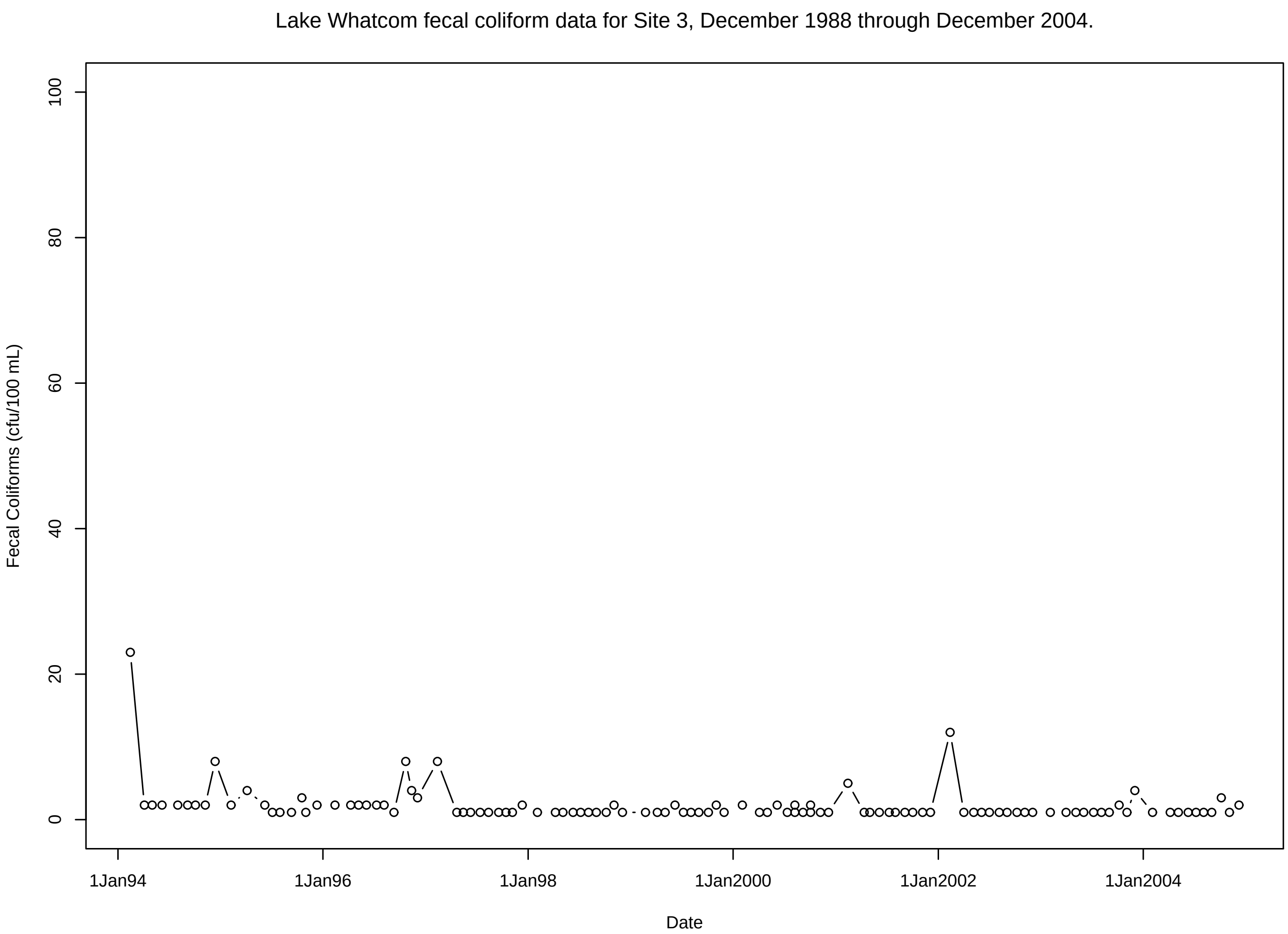


Figure B129: Lake Whatcom fecal coliform data for Site 3 (1994–2004).

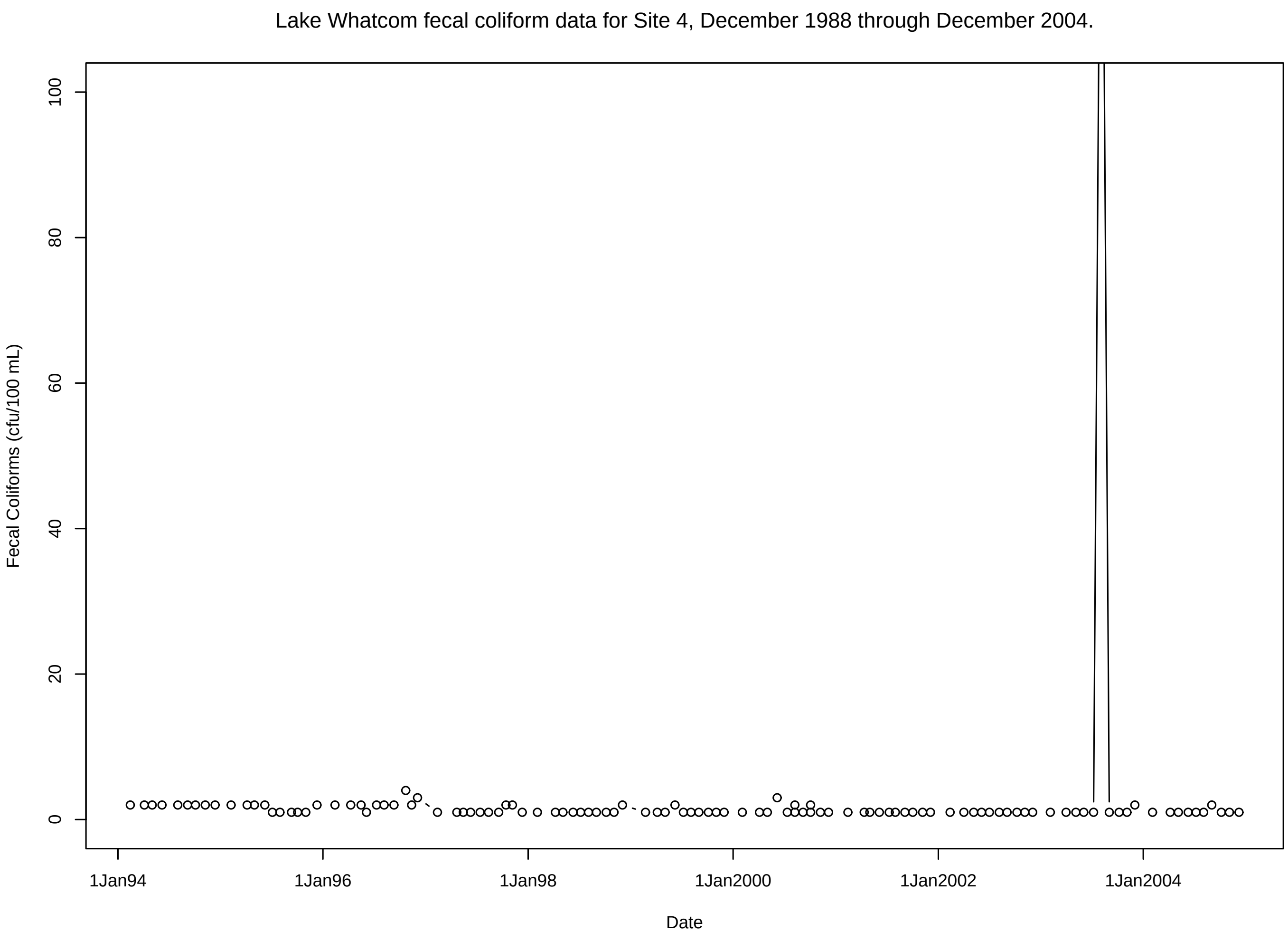


Figure B130: Lake Whatcom fecal coliform data for Site 4 (1994–2004).

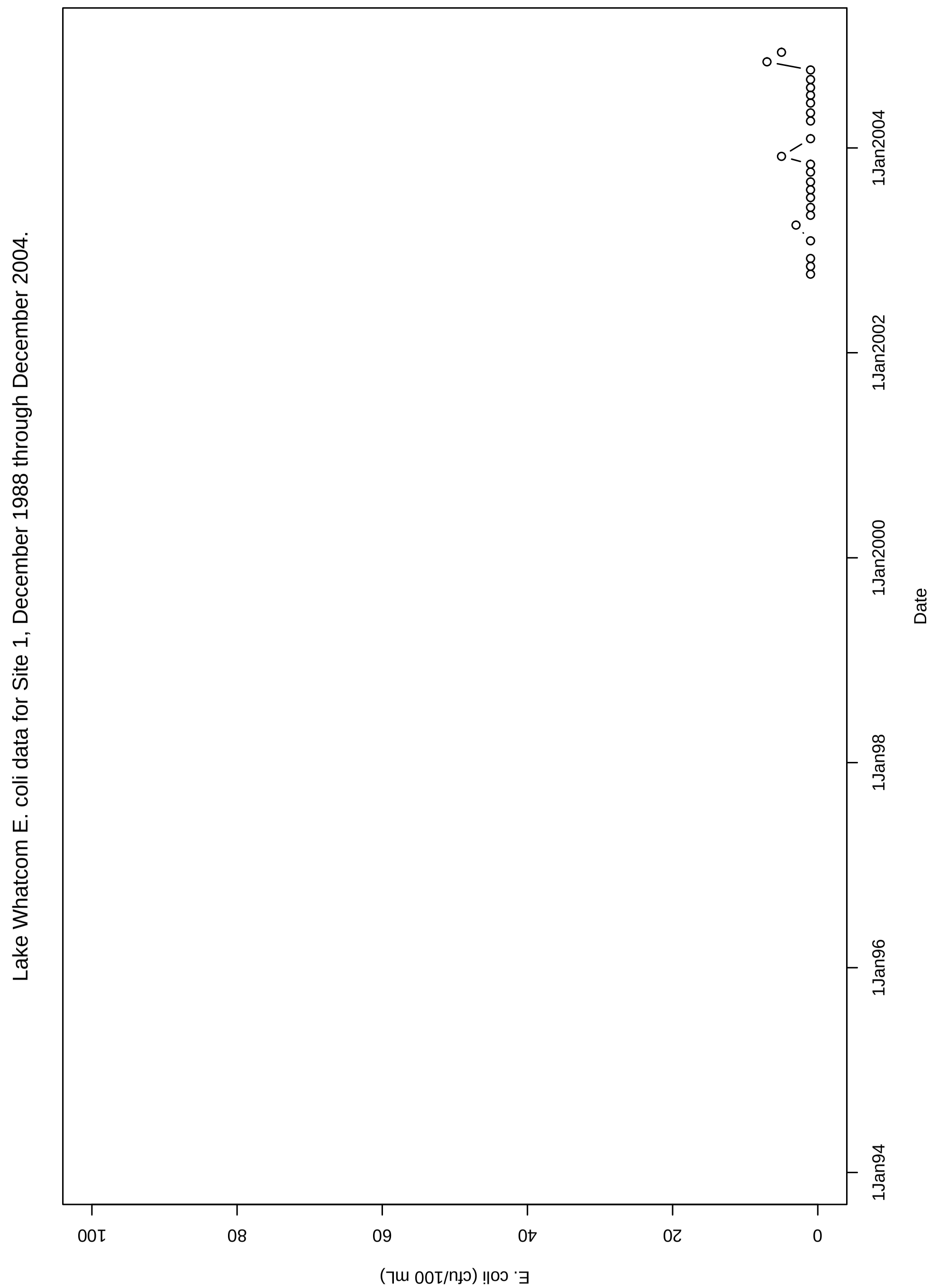


Figure B131: Lake Whatcom *E. coli* data for Site 1. Data collection started in October 2002.

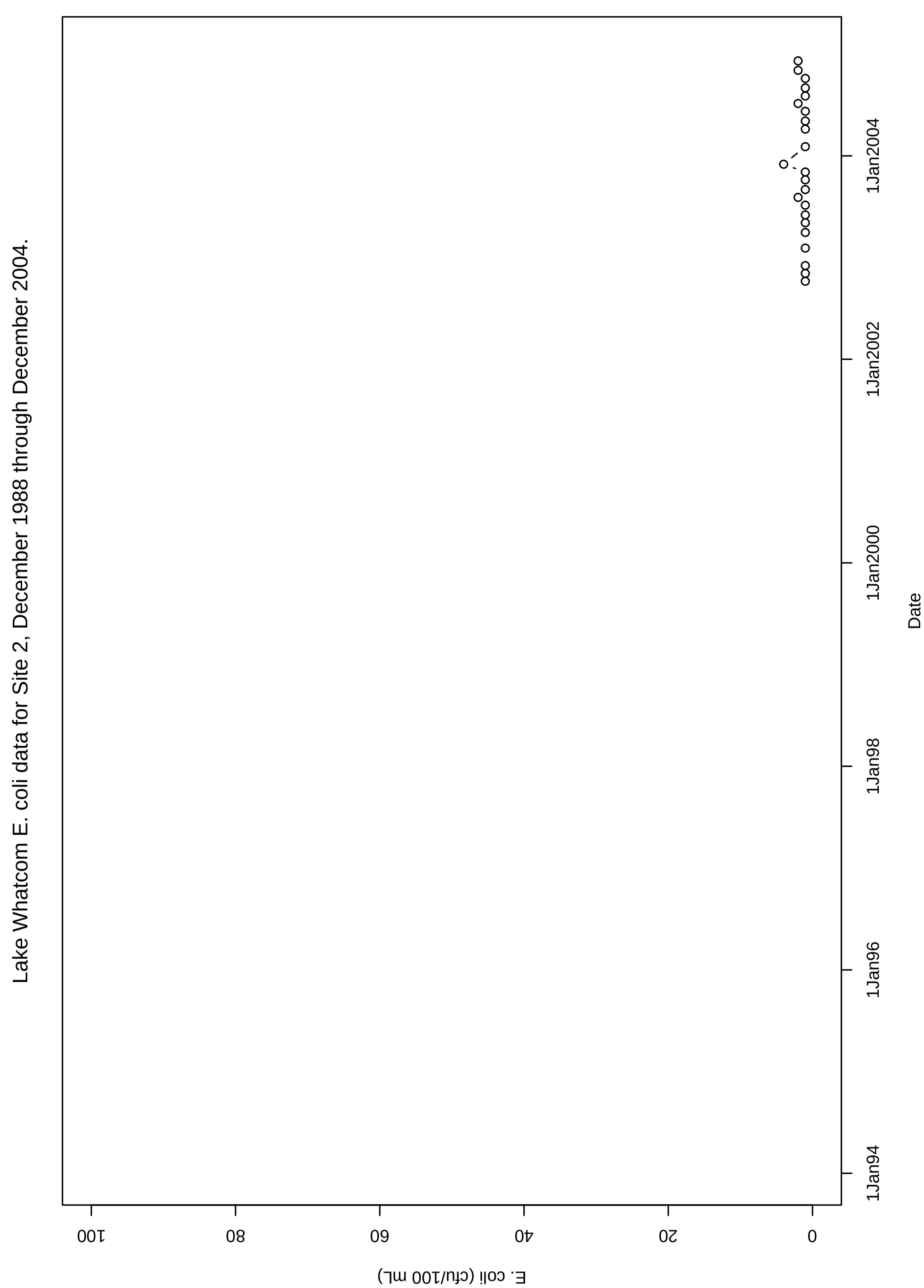


Figure B132: Lake Whatcom *E. coli* data for Site 2. Data collection started in October 2002.

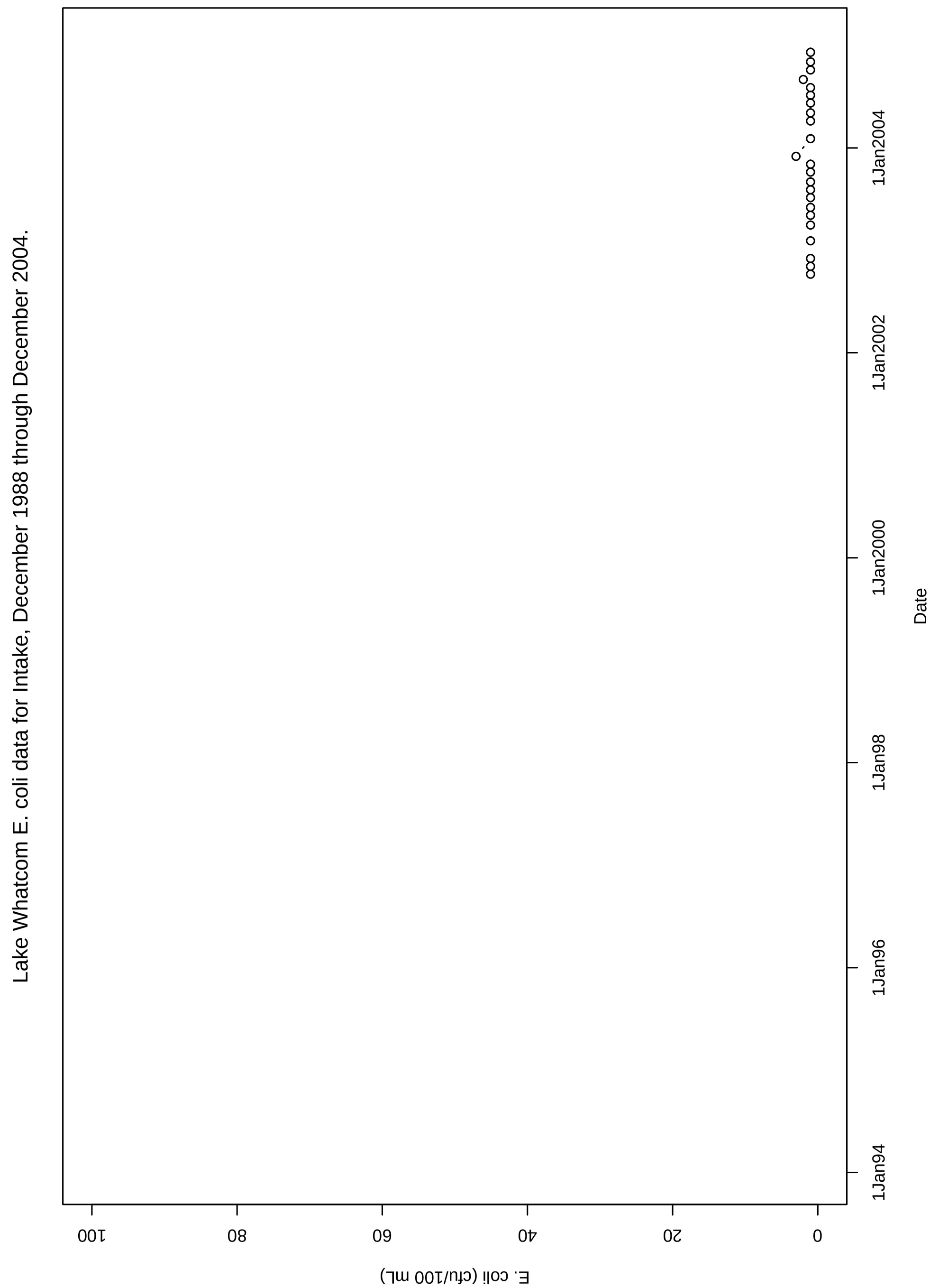


Figure B133: Lake Whatcom *E. coli* data for the Intake. Data collection started in October 2002.

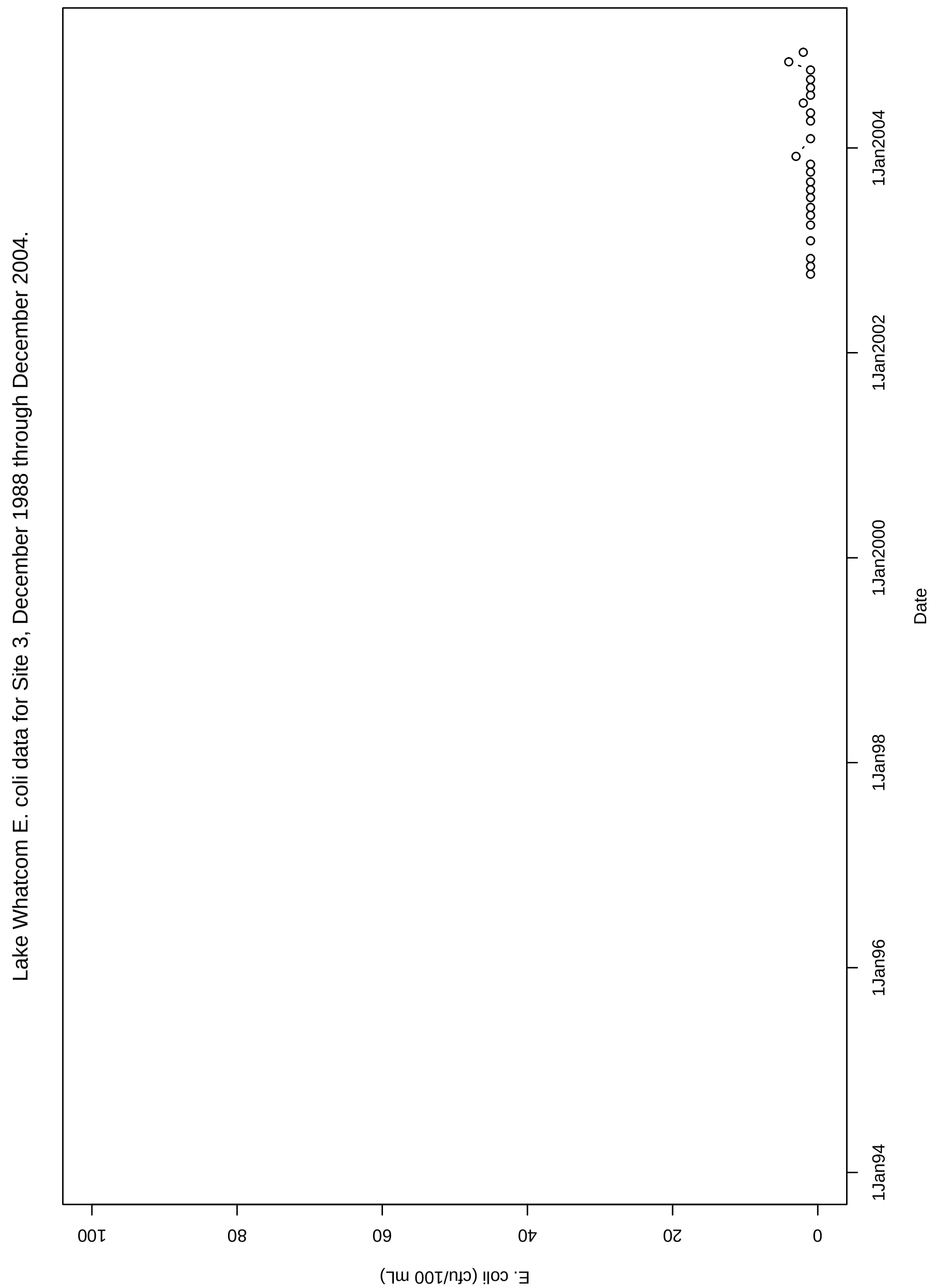


Figure B134: Lake Whatcom *E. coli* data for Site 3. Data collection started in October 2002.

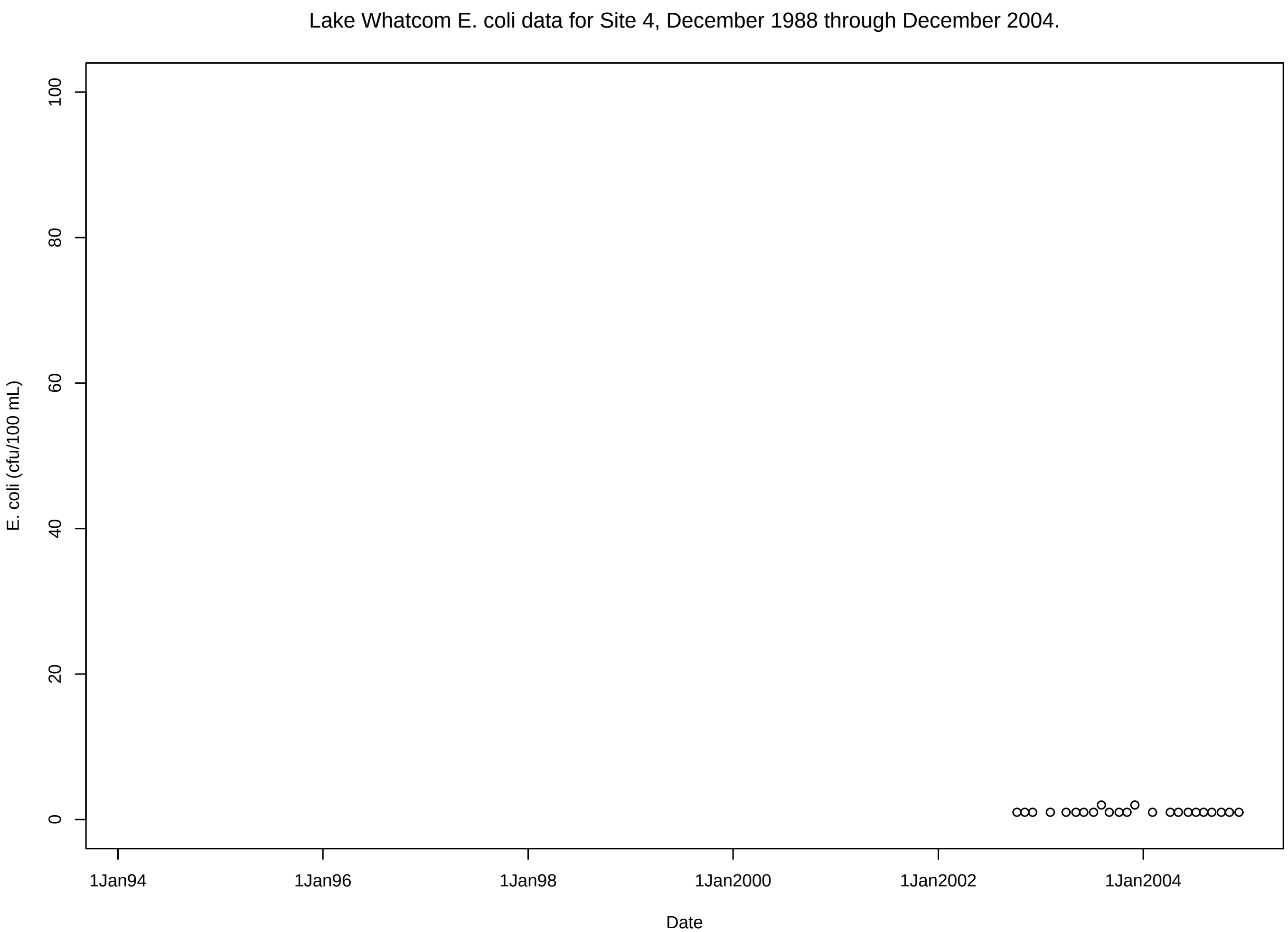


Figure B135: Lake Whatcom *E. coli* for Site 4. Data collection started in October 2002.

C Quality Control

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 2 (page 18). Single-blind quality control tests were conducted as part of the IWS laboratory certification process. The 2003/2004 results are presented in Table C1. All results from the single-blind tests were within acceptance limits.

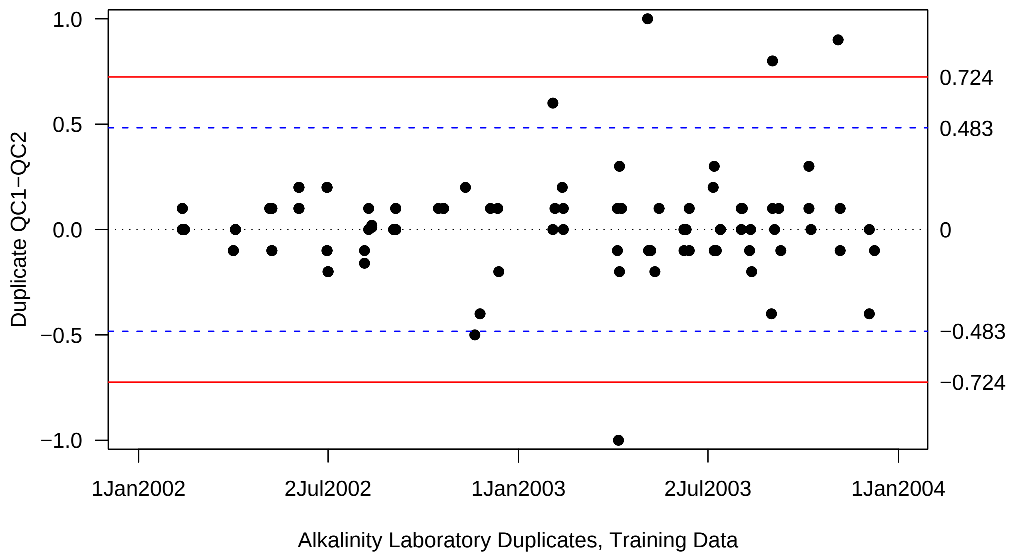
	Reported Value†	True Value†	Acceptance Limits
Specific conductivity (μS/cm at 25°C)	1140	1100	1008–1192
	465	462	426–499
Total alkalinity (mg/L as $CaCO_3$)	32.3	30.8	26.3–36.1
	70.1	66.5	59.6–73.4
Ammonia nitrogen, autoanalysis (mg-N/L)	5.39	5.36	4.11–6.57
	1.35	1.30	0.926–1.69
Ammonia nitrogen, manual (mg-N/L)	5.43	5.36	4.11–6.57
	1.31	1.30	0.926–1.69
Nitrate nitrogen, autoanalysis (mg-N/L)	9.46	9.39	7.42–11.2
	36.8	36.6	29.0–43.4
Orthophosphate, autoanalysis (mg-P/L)	2.41	2.47	2.10–2.86
	0.359	0.340	0.273–0.408
Orthophosphate, manual (mg-P/L)	2.52	2.47	2.10–2.86
	0.337	0.340	0.273–0.408
Total phosphorus, autoanalysis (mg-P/L)	4.87	5.28	4.01–6.19
	4.47	4.30	3.27–5.05
Total phosphorus, manual (mg-P/L)	5.08	5.28	4.01–6.19
	4.42	4.30	3.27–5.05
pH	5.68	5.70	5.58–5.86
	9.38	9.20	8.92–9.48
Non-filterable residue (mg/L)	43.4	52.7	39.9–56.6
	52.9	55.3	42.0–59.4
Turbidity (NTU)	3.33	3.00	2.34–3.92
	2.09	2.00	1.51–2.71

†Performance Evaluation Reports WP-077 (11/15/2002) and WP-073 (05/30/2003)

Table C1: Summary of 2003/2004 single-blind quality control results.

C.1 Laboratory Duplicates

Laboratory duplicates were analyzed for at least 10% of all water quality parameters except the Hydrolab data. Laboratory duplicates were used to create control charts that track analytical performance over time. Upper and lower acceptance limits ($\pm$ 2 std. dev. from mean pair difference) and upper and lower warning limits ($\pm$ 3 std. dev. from mean pair difference) were developed using 2002–2003 data (upper examples in Figures C1–C8, pages 249–256), and used to evaluate laboratory duplicates from 2004 (lower examples in Figures C1–C8). The control charts indicate that the laboratory duplicates have been consistent over time.



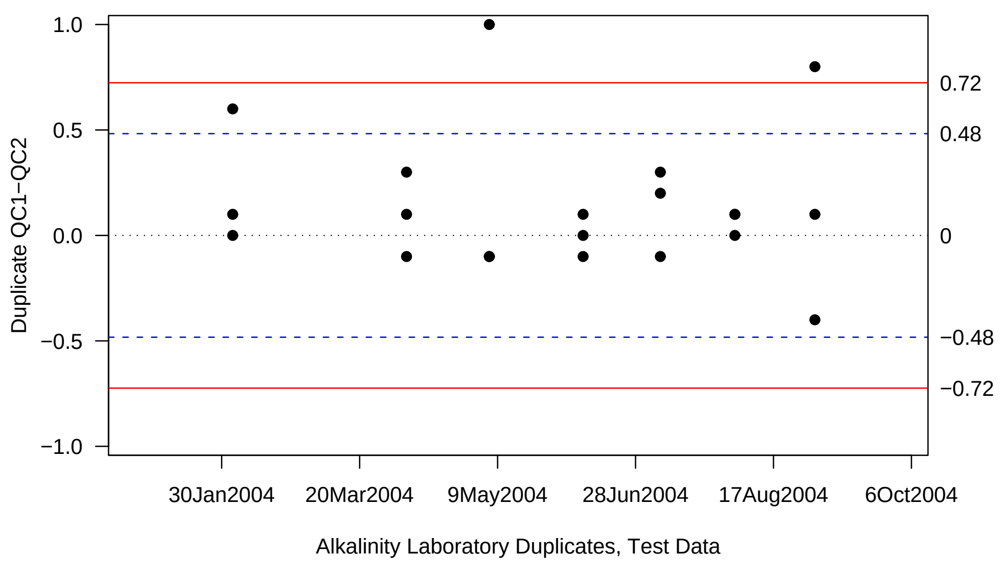
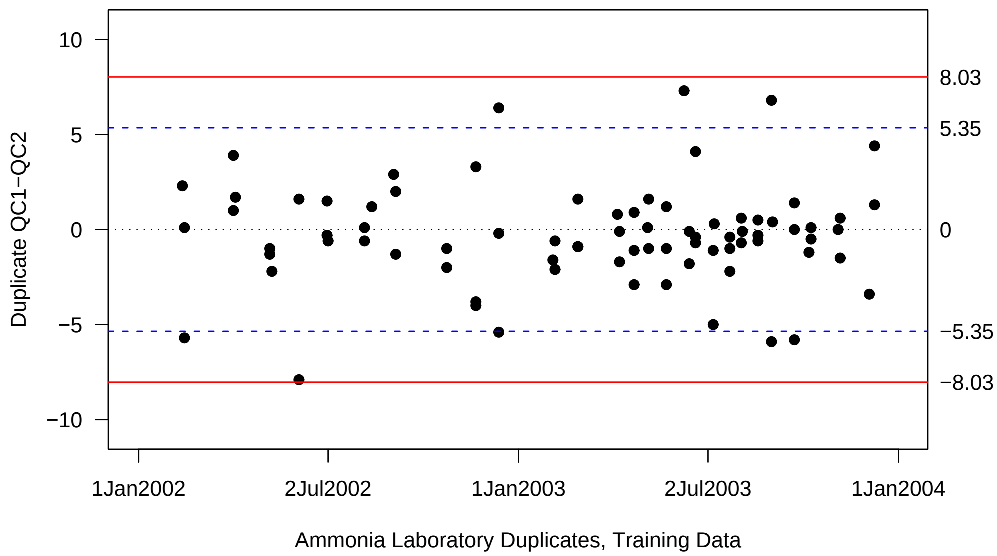


Figure C1: Alkalinity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



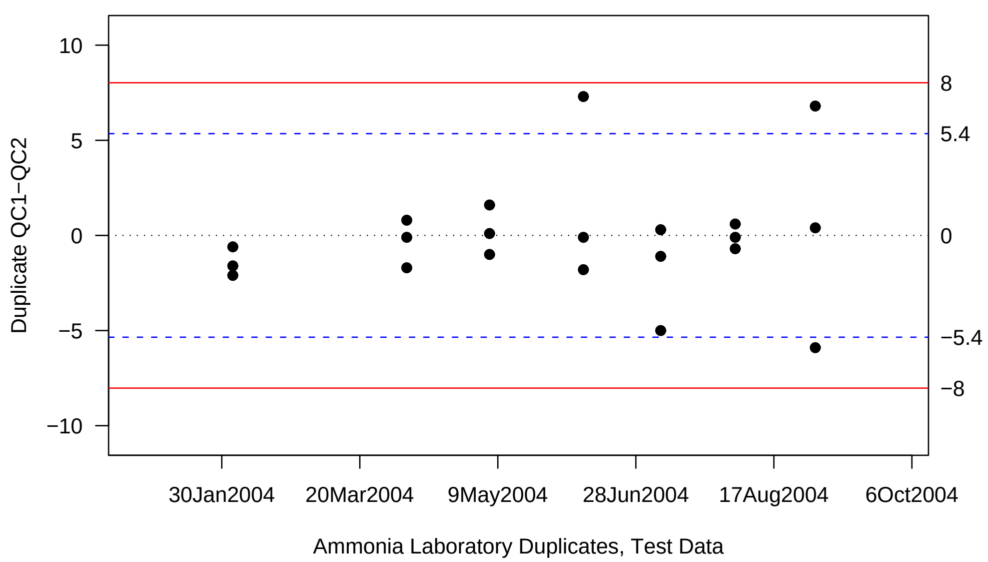
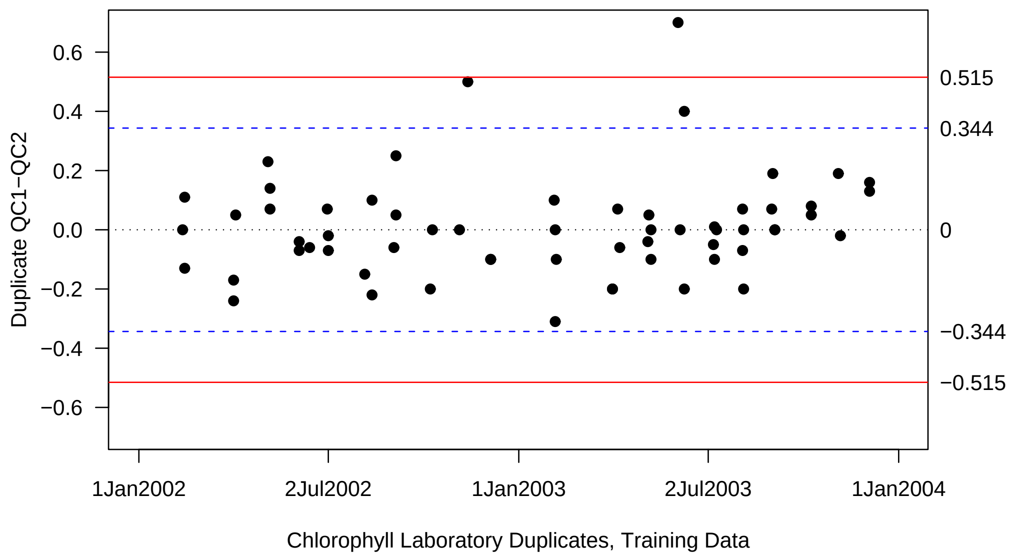


Figure C2: Ammonia laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



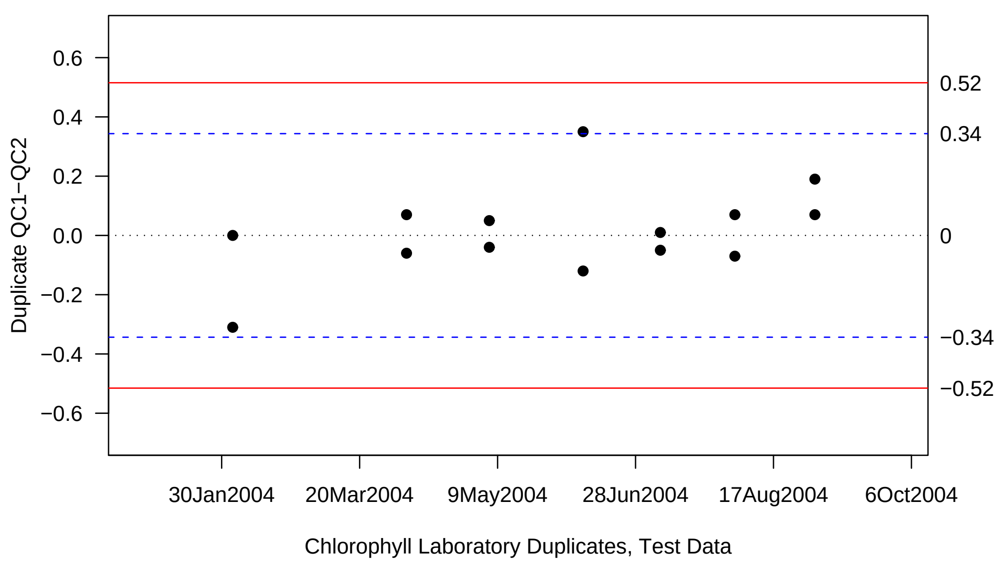
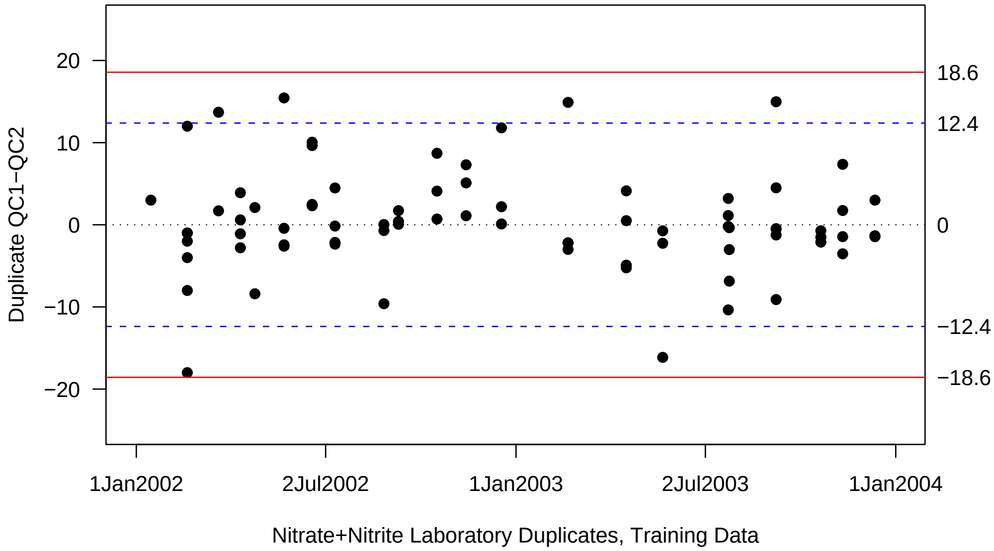


Figure C3: Chlorophyll laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab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



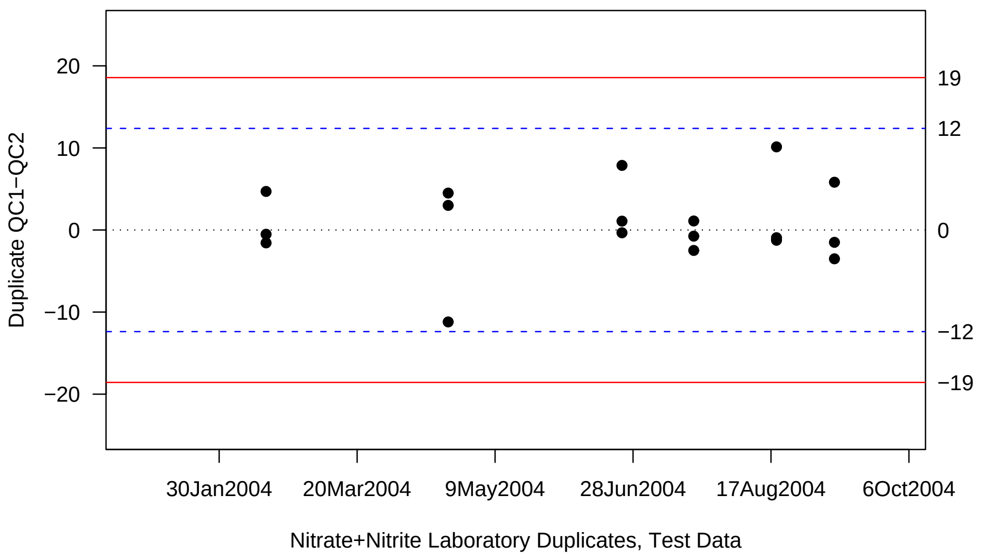
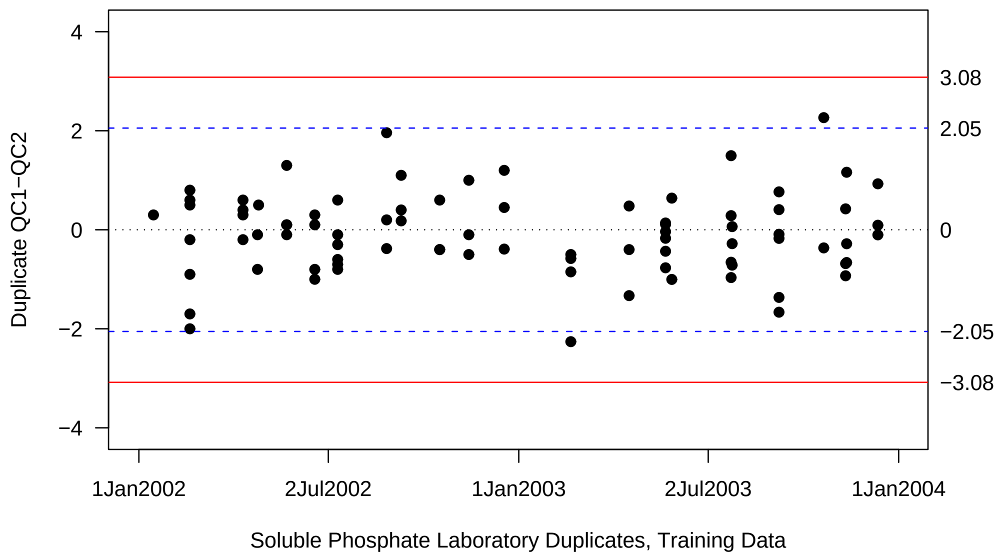


Figure C4: Nitrate/nitrite laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of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



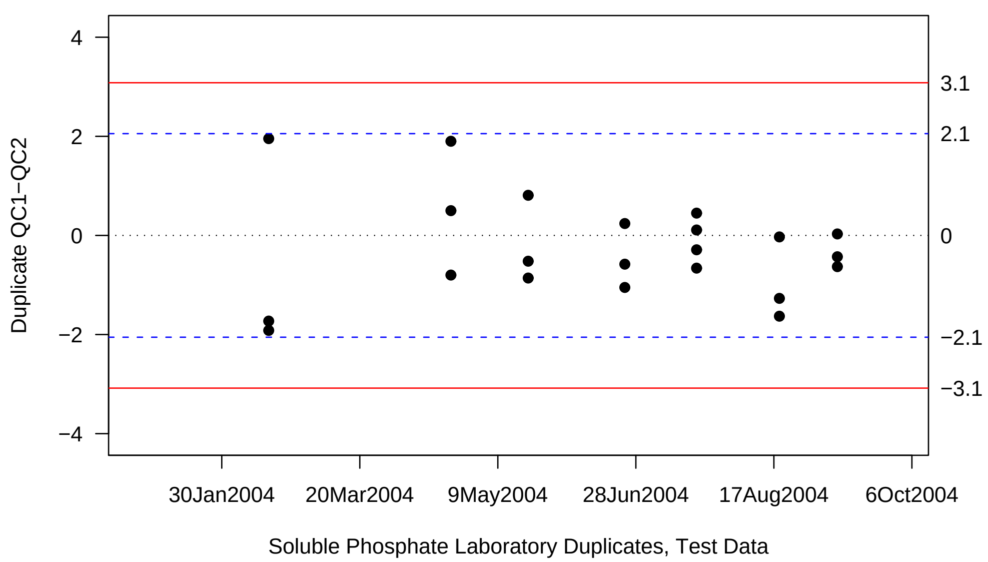
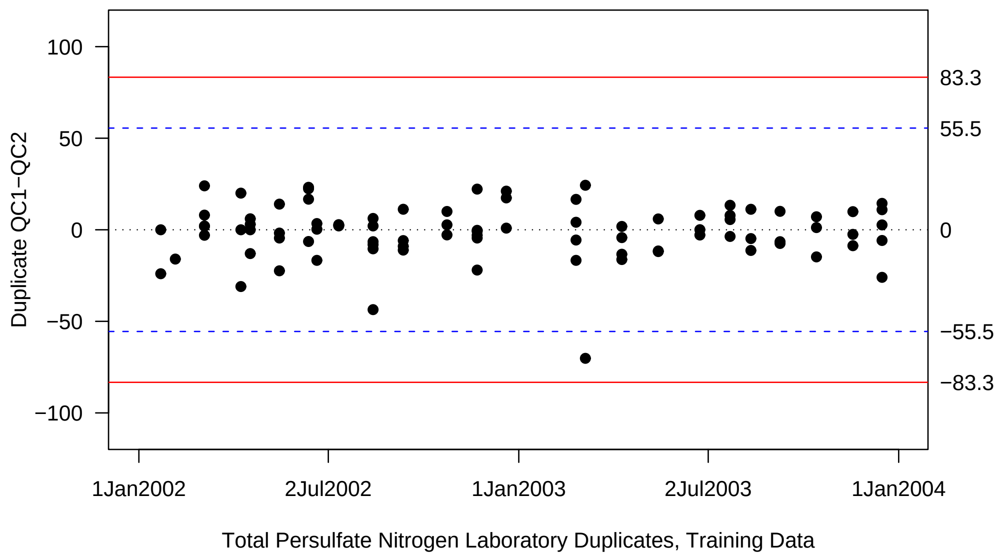


Figure C5: Soluble reactive phosphate laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two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



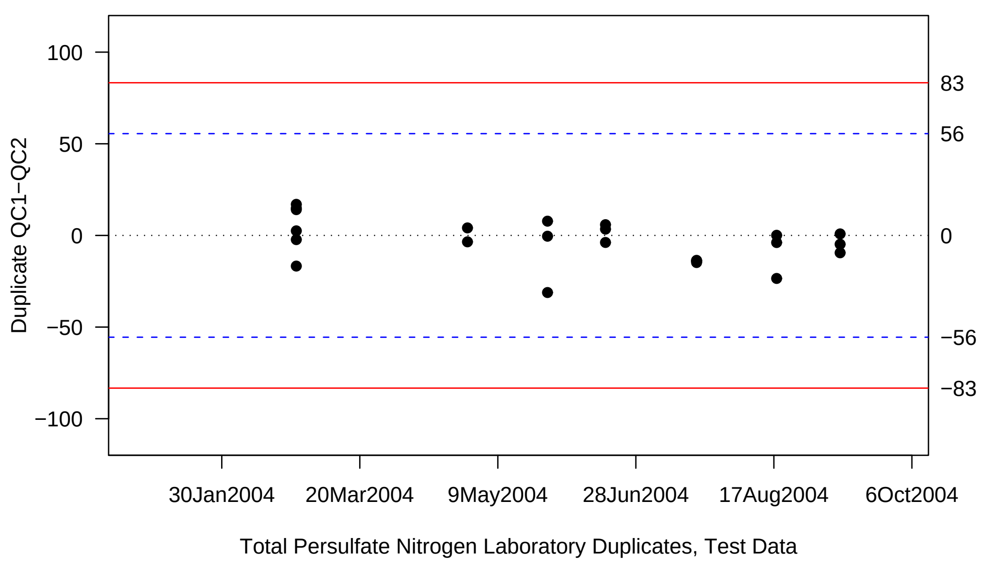
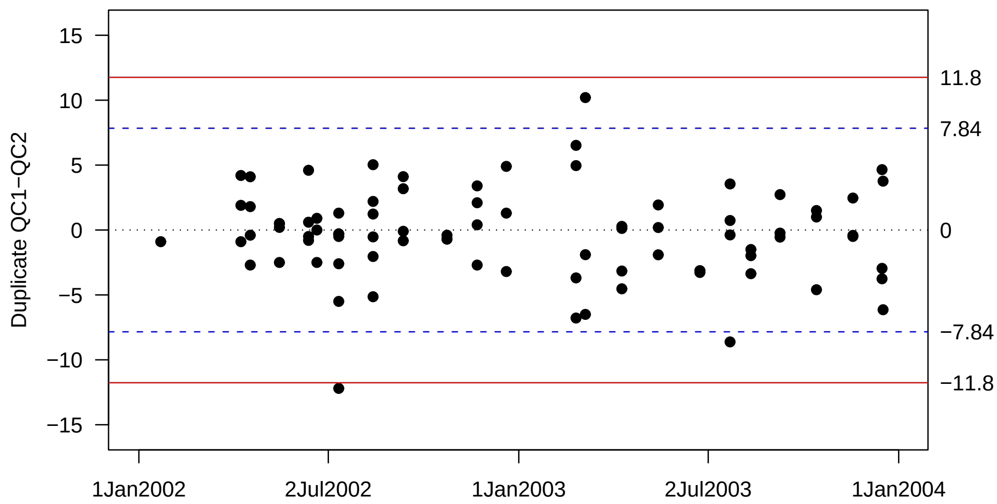
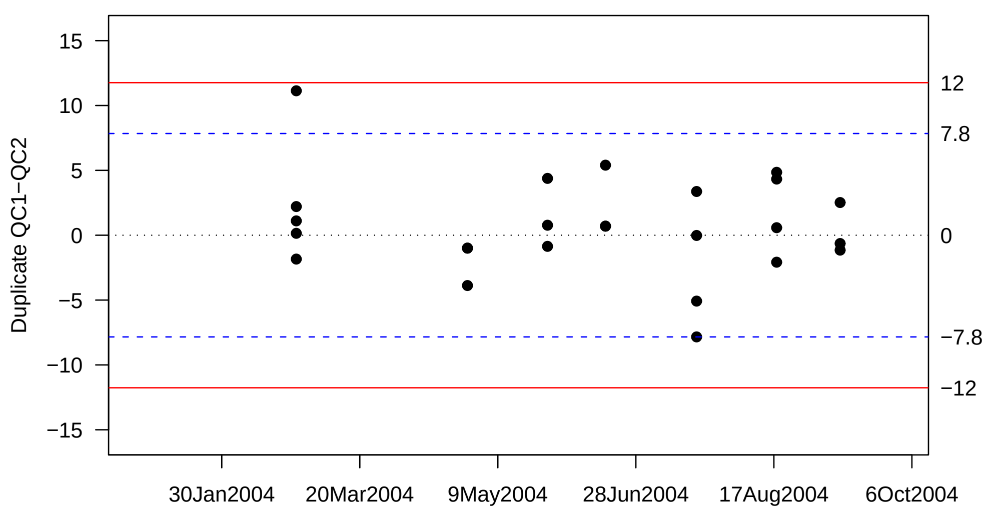


Figure C6: Total nitrogen laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab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

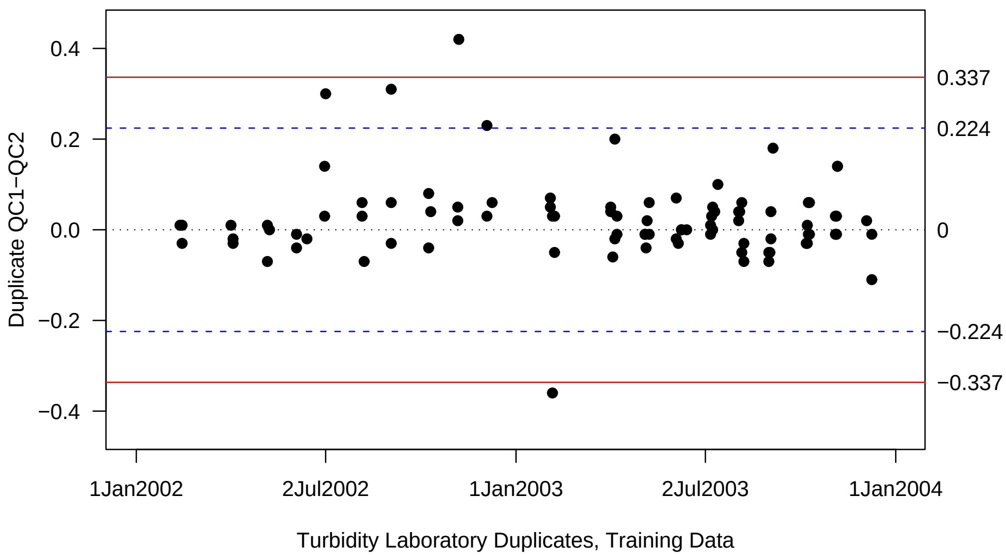


Total Phosphorus Laboratory Duplicates, Training Data



Total Phosphorus Laboratory Duplicates, Test Data

Figure C7: Total phosphorus laboratory duplicate control chart 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.



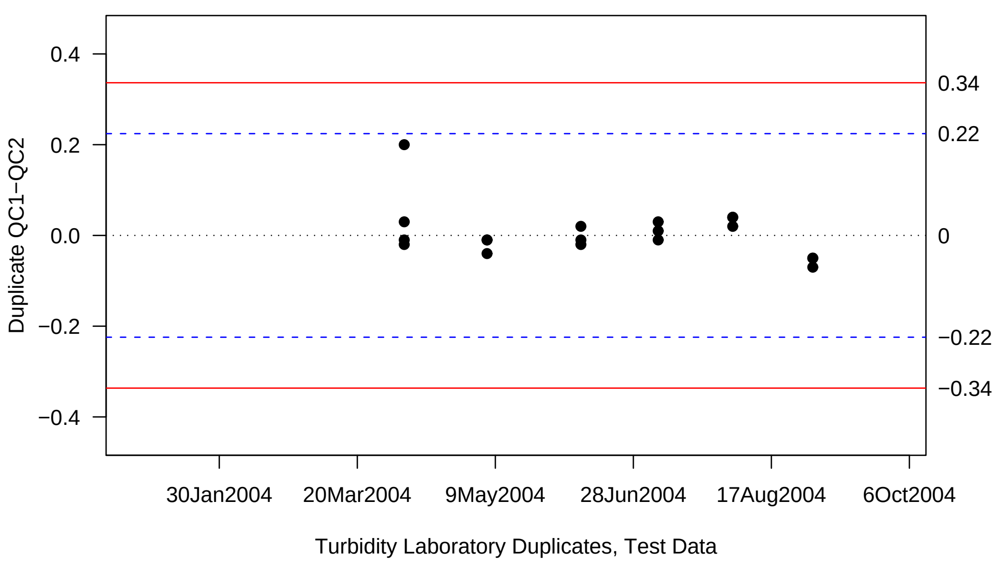


Figure C8: Turbidity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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

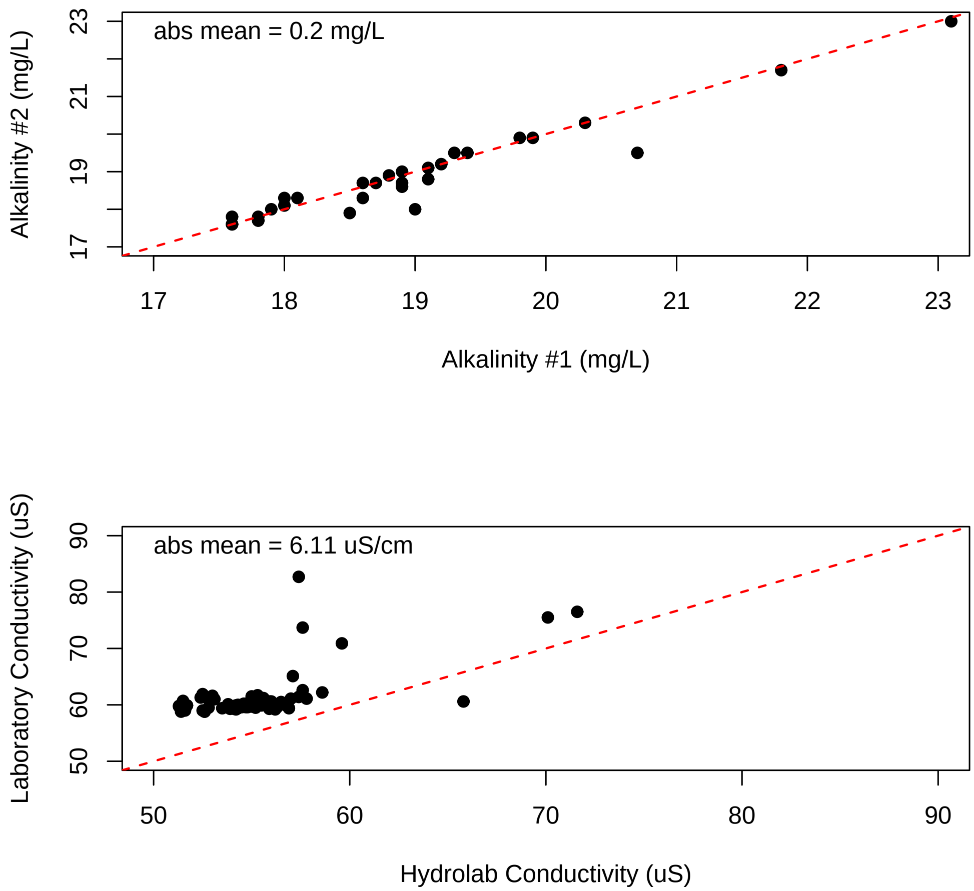
C.2 Field Duplicate Results

Separate field duplicates were collected and analyzed for a minimum of 10% of all of the water quality parameters except the Hydrolab data. 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* between field duplicates results indicated close agreement between duplicates, given that they came from different water samples (Figures C9–C13, pages 258–262).

$$^{*}\text{Absolute mean difference} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

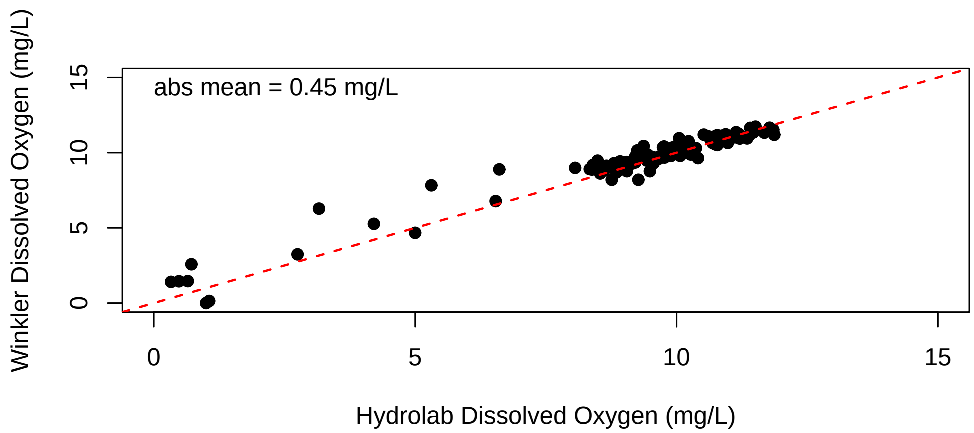
Field duplicates are rarely as close as laboratory duplicates. As in previous years, systematic bias was observed in the conductivity results because the Hydrolab field meter is much more sensitive than our laboratory meter. This appears as a flattening of the laboratory conductivity response at $\sim$60 μS (Figure C9) and a systematic bias that results in slightly higher laboratory conductivities across all samples. In addition, the conductivity probe in the current Hydrolab unit is more sensitive than the Surveyor II Hydrolab used in the early 1990s, which creates the appearance of a decrease in the lake's conductivity over time (Figures B66–B70, pages 173–177). These conductivity differences were generally $\leq$5 μS. There was a small systematic bias in the pH data, with the Hydrolab results showing a more extreme range than the laboratory pH results. This is most likely due to slight changes in the amount of dissolved CO_2 and associated inorganic carbon ions (bicarbonate and carbonate) that occurred after the samples were collected. This type of pH shift is common in low alkalinity water samples.

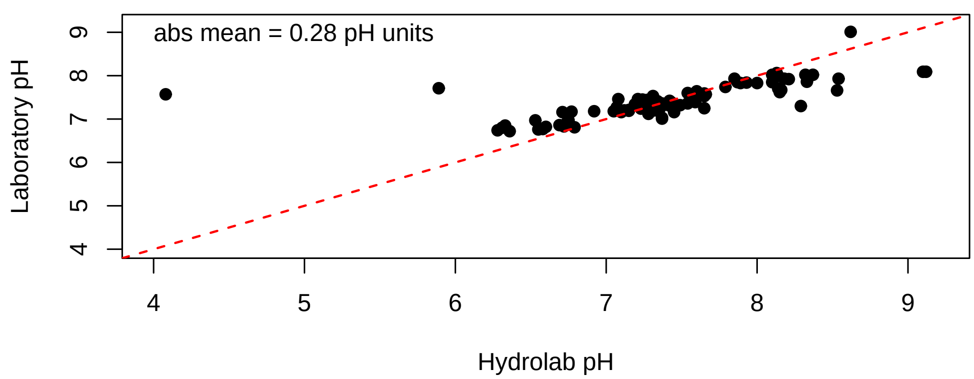
The absolute mean difference between Hydrolab and Winkler dissolved oxygen values was 0.45 mg/L. As in previous years, the only extreme differences occurred in samples collected in late summer from near the thermocline in basins 1 or 2, where oxygen concentrations drop rapidly with increasing depth. The field duplicate samples are collected using a marked line, which underestimates true depth (as measured by the Hydrolab) because of drift in the line. As a result, the field duplicate will contain slightly more oxygen when sampled near the thermocline.



$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

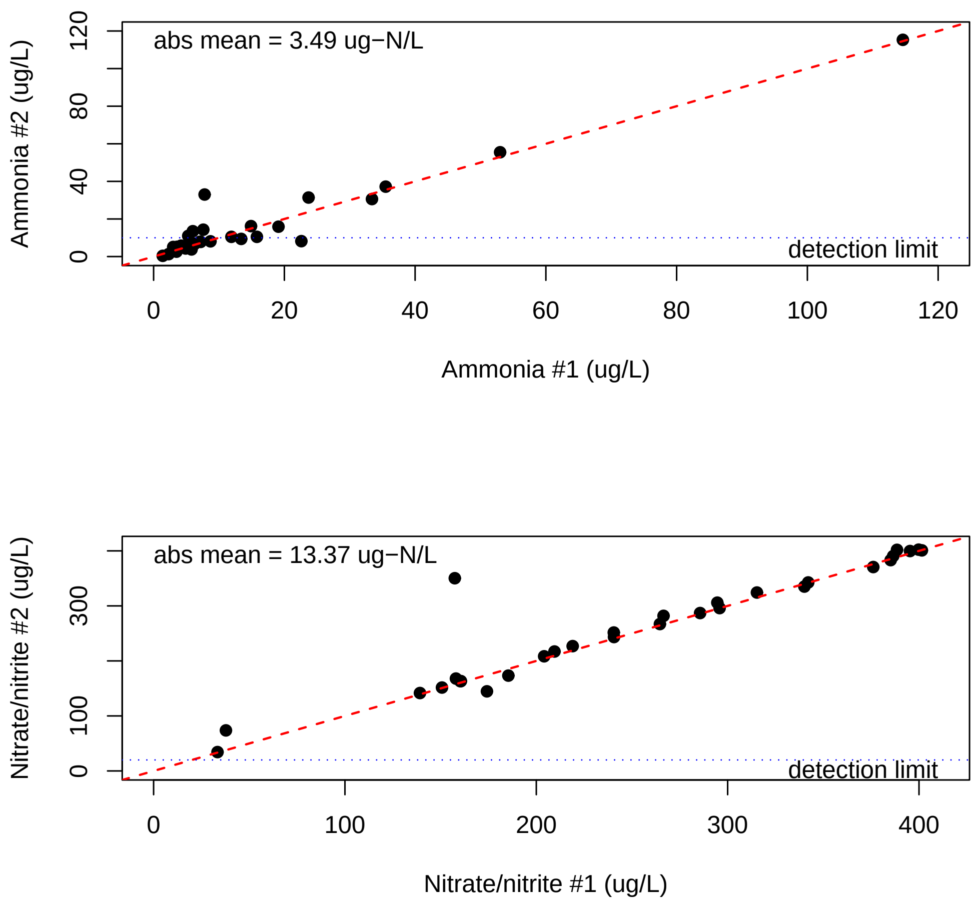
Figure C9: Alkalinity and conductivity field duplicates for the 2003/2004 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. Conductivity results show a systematic bias due to greater sensitivity of the Hydrolab field meter.





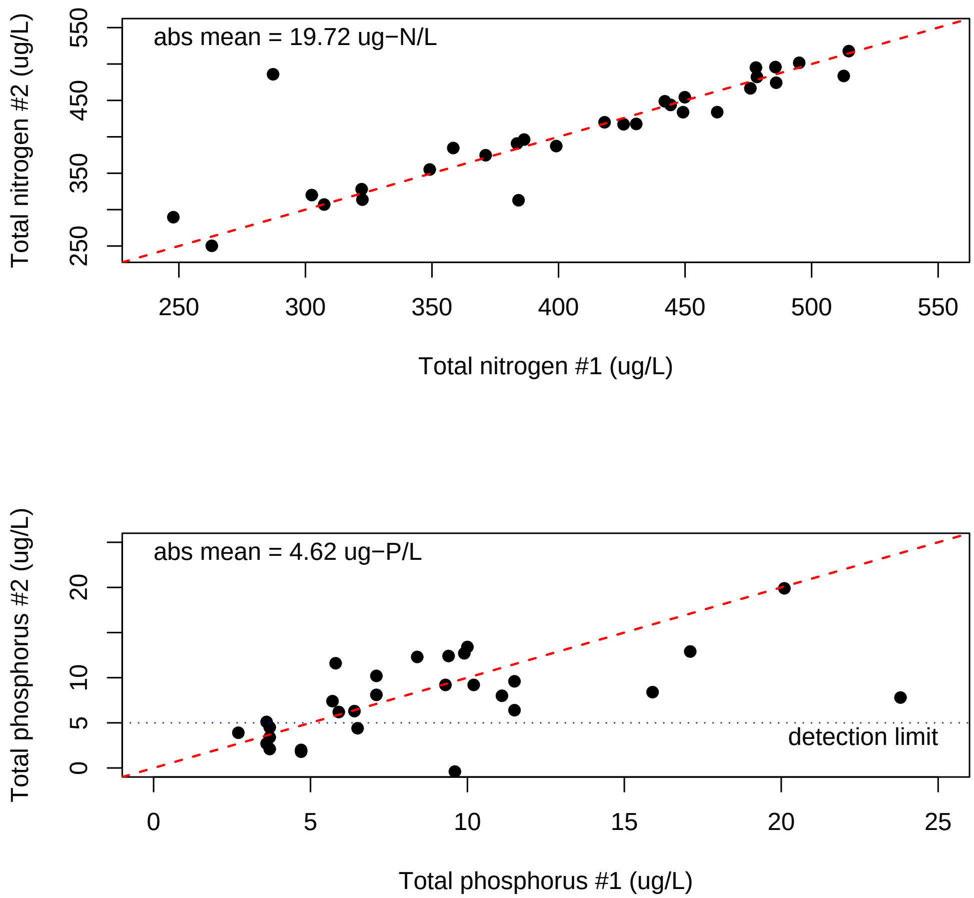
$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C10: Dissolved oxygen and pH field duplicates for the 2003/2004 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The pH results show a slight systematic bias due to changes in dissolved CO_2 and associated inorganic carbon ions between field and laboratory samples. Outlier Hydrolab pH value of 4.08 pH units was caused by equipment malfunction in April 2004; unit was repaired in May 2004.



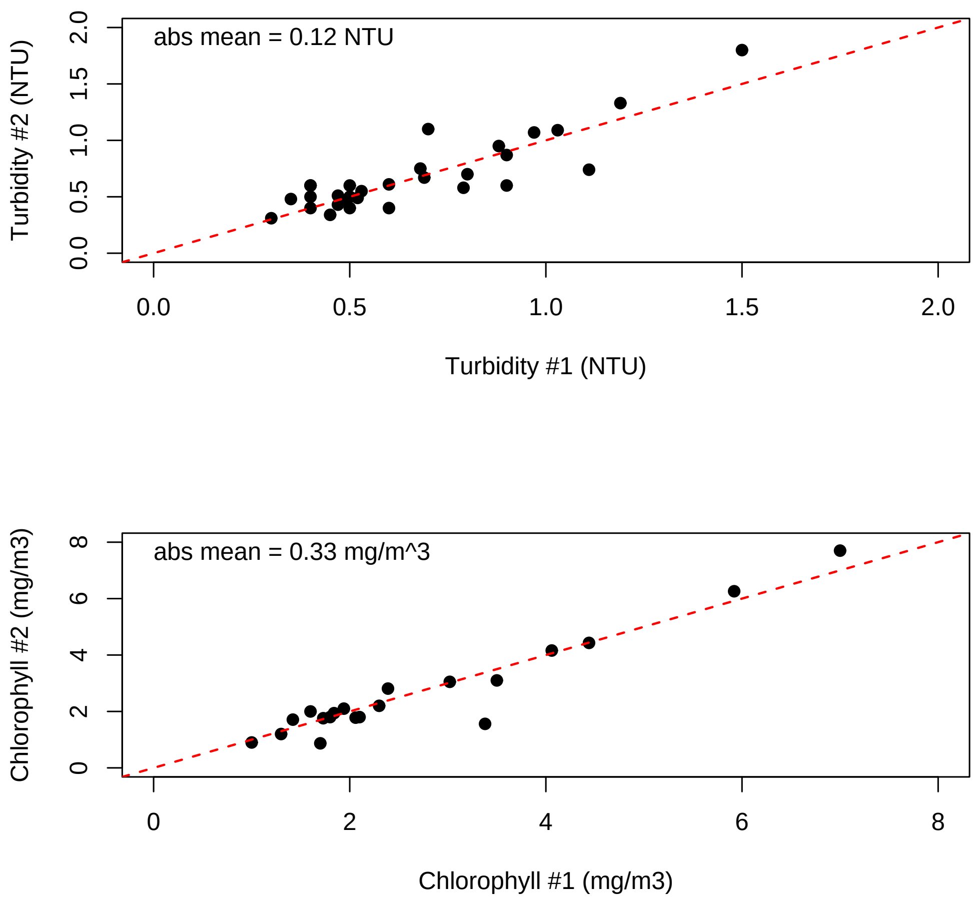
$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C11: Ammonia and nitrate/nitrite field duplicates for the 2003/2004 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the historic detection limits.



$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C12: Total nitrogen and total phosphorus field duplicates for the 2003/2004 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the historic detection limits. All total nitrogen samples were above the detection limit (100 μg-N/L).



$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C13: Turbidity and chlorophyll field duplicates for the 2003/2004 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

D Lake Whatcom Data

The 2003/2004 Lake Whatcom water quality data are included on the following pages in the hardcopy version of this report. The historic 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 verified historic data set included on the CD with this report.

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, for example, current detection limits in Table 2, page 18). 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.

Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity (±)	Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity (±)
alk	Alkalinity	± 0.5 mg/L	As	arsenic, total	dl = 0.03/0.01/0.001 mg/L
ecoli	Bacteria, *E. coli*	dl = 2 cfu/100 mL	Cd	cadmium, total	dl = 0.002/0.0005 mg/L
ent	Bacteria, *Enterococcus*	dl = 2 cfu/100 mL	Cr	chromium, total	dl = 0.006/0.001 mg/L
fc	Bacteria, fecal coliforms	dl = 2 cfu/100 mL	Cu	copper, total	dl = 0.002/0.001 mg/L
tc	Bacteria, total coliforms	dl = 2 cfu/100 mL	Fe	iron, total	dl = 0.01/0.005 mg/L
toc	Carbon, total organic	dl = 1.0 mg/L	Pb	lead, total	dl = 0.001 mg/L
chl	Chlorophyll *a*	± 0.1 mg/m^3	Hg	mercury, total	dl = 0.01 mg/L
cond	Conductivity, Hydrolab	± 2 μS/cm	Ni	nickel, total	dl = 0.01/0.005 mg/L
cond	Conductivity, lab	± 2 μS/cm	Zn	zinc, total	dl = 0.002/0.001 mg/L
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			
turb	Turbidity	± 0.2 NTU			

Historic detection limits listed in this table are conservative estimates designed to permit comparisons with historic data.
The AmTest detection limits for metals decreased in 1999 and 2002 (arsenic only); the older detection limits are listed first in this table.
Table 2 lists the current IWS detection limits for selected analyses; Appendix D.7 includes the the current AmTest reports and detection limits.

Table D1: Summary of analyses in the Lake Whatcom monitoring project.

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 on the CD that accompanies the printed report 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. Electronic copies of the historic Lake Whatcom water quality data are available on the CD that accompanies the printed report 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 on the CD that accompanies the printed report or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

D.4 Storm Water Treatment Monitoring Data

Brentwood, Park Place, and South Campus storm water treatment data from the current sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the historic storm water treatment data are available on the CD that accompanies the printed report or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

D.5 City of Bellingham Coliform Data

Historic Lake Whatcom and tributary streams coliform data are included in hard-copy format in this report. Other coliform data from the current monitoring program (e.g., storm water treatment samples) were included in tables cited earlier in this report. Electronic copies of all coliform data may be obtained by contacting the City of Bellingham Public Works Department, Bellingham, WA, 98229.

D.6 Lake Whatcom Electronic Data

The annual Lake Whatcom reports include a CD containing historic Hydrolab and water quality data; Austin Creek, Anderson Creek, and Smith Creek hydrograph data; plankton data; and storm water treatment monitoring data. The files included on the CD are described in **readme.txt**, which is printed below and included on the CD.

The electronic data files have **NOT** been censored to flag or otherwise identify below detection and above detection values. Refer to Tables 2 and D1 (pages 18 and 264) for applicable detection limits and abbreviations. 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.

Readme.txt:

```
*********************************
README FILE - LAKE WHATCOM DATA
*********************************
The CD included with this report included the following data files:

Hydrolab data       Water quality data         Hydrograph data
1988_hl.dat         1988_wq.dat                WY1998.dat
1989_hl.dat         1989_wq.dat                WY1999.dat
1990_hl.dat         1990_wq.dat                WY2000.dat
1991_hl.dat         1991_wq.dat                WY2001.dat
1992_hl.dat         1992_wq.dat                WY2002.dat
1993_hl.dat         1993_wq.dat                WY2003.dat
1994_hl.dat         1994_wq.dat                WY2004.dat
1995_hl.dat         1995_wq.dat
1996_hl.dat         1996_wq.dat                Plankton data
1997_hl.dat         1997_wq.dat                plankton.dat
1998_hl.dat         1998_wq.dat
1999_hl.dat         1999_wq.dat                Storm water data
2000_hl.dat         2000_wq.dat                comps.dat
2001_hl.dat         2001_wq.dat                grab.dat
2002_hl.dat         2002_wq.dat
2003_hl.dat         2003_wq.dat
2004_hl.dat         2004_wq.dat

The hydrolab data files contain the following variables: site, depth
(m), month, day, year, temperature (C), pH, conductivity (uS/cm),
dissolved oxygen (mg/L), lab conductivity quality control data
(uS/cm), and secchi depth (m).

The water quality data files contain the following variables: site,
depth (m), month, day, year, alkalinity (mg/L), turbidity (NTU),
ammonia (ug-N/L), total persulfate nitrogen (ug-N/L), nitrate/nitrite
```

```
(ug-N/L), soluble reactive phosphate (ug-P/L), total phosphorus
(ug-P/L), chlorophyll (mg/m3).

The hydrograph data file contains the following variables: month, day,
year, hour, min, sec, ander.g (ft), ander.cfs, austin.g (ft),
austin.cfs, smith.g (ft), and smith.cfs

The plankton data file contains the following variables: site depth
month day year zooplankton (#/L), chrysophyta (#/L), cyanophyta (#/L),
chlorophyta (#/L), phyrrophyta (#/L).

The storm water treatment composite data file (comps.dat) contains the
following variables: site, startmonth, endmonth, startday, endday,
year, total suspended solids (mg/L), total organic carbon (mg/L),
total nitrogen (mg/L), total phosphorus (mg/L), and AmTest data for 33
total metals analyses (mg/L for aluminum, antimony, arsenic, boron,
barium, beryllium, calcium, cadmium, cobalt, chromium, copper, iron,
mercury, potassium, lithium, magnesium, manganese, molybdenum, sodium,
nickel, phosphorus, lead, sulfur, selenium, silicon, silver, tin,
strontium, titanium. thallium, vanadium, yttrium, zinc).

The storm water treatment grab data file (grab.dat) contains the following
variables: site, sample (A-D, in order of collection), month, day, year, time
(am/pm), temperature (C), pH, dissolved oxygen (mg/L), conductivity (uS/cm),
total coliforms (cuf/100 mL), fecal coliforms (cfu/100 mL), and enterococcus
(cuf/100 mL).  Beginning in 2002, total coliforms and enterococcus analyses
were discontinued and E.˜coli was added.

The site codes in the data are as follows:
    11  = Lake Whatcom Site 1
    21  = Lake Whatcom Intake site
    22  = Lake Whatcom Site 2
    31  = Lake Whatcom Site 3
    32  = Lake Whatcom Site 4
    33  = Strawberry Sill site S1 (discontinued)
    34  = Strawberry Sill site S2 (discontinued)
    35  = Strawberry Sill site S3 (discontinued)

    BW1 (BW_in)    = Brentwood wet pond inlet
    BW2 (BW_out)   = Brentwood wet pond outlet
    PP1 (PP_cell1) =  Park Place wet pond cell 1 (discontinued)
    PP2 (PP_cell2) = Park Place wet pond cell 2 (discontinued)
    PP3 (PP_cell3) = Park Place wet pond cell 3 (discontinued)
    PP4 (PP_in)    = Park Place wet pond inlet
    PP5 (PP_out)   = Park Place wet pond outlet
    SC1 (SC_in)    = South Campus storm water facility inlet
    SC2 (SC_outE)  = South Campus storm water facility east outlet
    SC3 (SC_outW)  = South Campus storm water facility west outlet
    WL             = Grace Lane wetland (discontinued)

    CW1 = Smith Creek
    CW2 = Silver Beach Creek
    CW3 = Park Place drain
    CW4 = Blue Canyon Creek
    CW5 = Anderson Creek
    CW6 = Wildwood Creek
    CW7 = Austin Creek
```

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

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

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

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

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

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

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

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

1987-1993: The lake data were reviewed as above except that the IWS Director’s responsibilities were delegated to the Principle Investigator in charge of the lake monitoring contract (Dr. Robin Matthews). Prior to 1991, interim reports were prepared quarterly rather than monthly and annual reports were descriptive rather than interpretive.

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

D.7 AmTest Metals and TOC (Lake, Creeks, Storm Water)

The following AmTest data reports 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 3 & 5, 2004	metals, total organic carbon
	September 2, 2004	metals, total organic carbon
Park Place/Brentwood wet ponds	July 20, 2004	metals, total organic carbon
Parkstone storm water treatment system	November 18, 2003	metals, total organic carbon
Sylvan vault storm water treatment system	May 10, 2004	metals, total organic carbon, HCID hydrocarbons
South Campus storm drain	November 13, 2003	metals, total organic carbon
	February 2, 2004	metals, total organic carbon
	August 26, 2004	metals, total organic carbon
Watershed creeks	February, 19, 2004	metals, total organic carbon
	July 13, 2004	metals, total organic carbon

Sites Codes for the AmTest reports are as follows:

Lake Sites		Creek Sites		Storm Water Treatment Sites	
11-O	Site 1, surface (0.3 m)	CW1	Smith Creek	BW1	Brentwood inlet
11-B	Site 1, bottom (20 m)	CW2	Silver Beach Creek	BW2	Brentwood outlet
21-O	Intake, surface (0.3 m)	CW3	Park Place Drain	PP4	Park Place inlet
21-B	Intake, bottom (10 m)	CW4	Blue Canyon Creek	PP5	Park Place outlet
22-O	Site 2, surface (0.3 m)	CW5	Anderson Creek	PS2	Parkstone wetland inlet
22-B	Site 2, bottom (20 m)	CW6	Wildwood Creek	PS3	Parkstone swale outlet
31-O	Site 3, surface (0.3 m)	CW7	Austin Creek	PS5	Parkstone pond outlet
31-B	Site 3, bottom (80 m)			SCSD IN	South Campus inlet
32-O	Site 4, surface (0.3 m)			SCSD E	South Campus east outlet
32-B	Site 4, bottom (90 m)			SCSD W	South Campus west outlet
				SV1	Sylvan vault inlet
				SV2	Sylvan vault outlet