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Lake Whatcom Monitoring Project 2002/2003 Report

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Lake Whatcom Monitoring Project
2002/2003 Final Report

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Executive Summary

This report describes the results from the 2002/2003 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 the Park Place and Brentwood wet ponds and the South Campus storm water treatment system; continue collection of hydrologic data from Anderson, Austin, and Smith Creeks; and update the hydrologic model for Lake Whatcom. An additional objective for this year's report was to include an analysis of the 1988–2003 water quality data to help identify long-term trends in the lake.

The lake was sampled on October 8 & 10, November 5, 7, & 13 and December 3 & 5, 2002; and February 4 & 6, April 1 & 3, May 6 & 8, June 3 & 5, July 8 & 10, August 5 & 7, and September 2 & 4, 2003. During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The average water temperatures in 2003 were slightly warmer than usual, particularly in February, and from June through September. As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer.

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths. 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. The nutrient data from Site 1 continue to show that basin 1 is more productive than basin 3; however, Site 2 (basin 2) has been increasingly similar to Site 1. Site 1 continued to have the highest chlorophyll concentrations of all the sites. The plankton counts were dominated by Chrysophyta[1] consisting primarily of diatoms, *Dinobryon*, and *Mallomonas*. Substantial blooms of cyanobacteria (Cyanophyta) and green algae (Chlorophyta) were present at all sites during summer and late fall.

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. Most of the mid-basin

[1]The Chrysophyta phylum name has been changed to Heterokontophyta in many taxonomies.

fecal coliforms and *E. coli* counts were less than 50 cfu[2]/100 mL. Coliform counts from the Bloedel-Donovan recreational area were higher than mid-basin counts, particularly in the nearshore beach area.

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. Zinc was detected at nearly all sites and iron concentrations were elevated in most of the bottom samples. Chromium, copper, and nickel were detected in a few samples, but because the concentrations were near the analytical detection limits, it is unlikely that these detections represent an increase in metals concentrations in the lake.

Lake Whatcom had relatively low concentrations of total organic carbon in raw lake water ($<$1–3.81 mg/L), as well as relatively low concentrations of trihalomethanes (THMs) in treated water (0.025–0.041 mg/L; the maximum recommended concentration is 80 μg/L or 0.08 mg/L). The THMs appear to be increasing, however, particularly during the fall (3rd quarter).

The creeks were sampled on February 11 and July 14, 2003. Due to unusual drought conditions during the summer of 2003, many of the creeks had very low flows during the July sampling period. Although the summer drought caused some unusual water quality results, the residential streams continued to have poorer water quality than the forested streams, with higher conductivities; higher alkalinity and phosphorus; and much higher coliform counts. These differences are typical for streams receiving urban runoff. The metals concentrations were near detection limits at all sites except for copper, iron and zinc. Iron and zinc were within normal ranges for surface water in the Lake Whatcom watershed. Copper was detected in the samples from Blue Canyon (0.091 mg/L) and Silver Beach Creek (0.005 mg/L). It is not unusual to find slightly elevated concentrations of copper in residential streams like Silver Beach Creek. The copper concentration from Blue Canyon was unusual, but Blue Canyon flows through a mineral rich region of the watershed. Coliform counts were unusually high at all sites during July 2003, which caused all of the streams except Wildwood (which was dry in July) to fail the freshwater *Extraordinary Primary Contact Recreation* bacteria standard because too many samples exceeded 100 cfu/100 mL. The only sites that failed due to a high geometric mean were Silver Beach Creek and the Park Place outfall.

[2]colony forming unit/100 mL, cfu/100 mL is sometimes labeled “colonies/100 mL.”

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks, and the data are included in electronic format with this report.

A water balance model 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 (62.5%), direct precipitation (19.5%), and water diverted from the Middle Fork of the Nooksack River (17.8%). Outputs included Whatcom Creek (53.5%), the City of Bellingham (17.4%), Georgia Pacific (12.0%), evaporation (12.1%), the Whatcom Falls Hatchery (4.5%), and Water District #10 (0.6%). The summer of 2003 was unusually dry. The total input and output to the lake were estimated to be 24,890 MG and 24,971 MG, respectively, which was about 50% lower than last year.

Park Place and Brentwood wet ponds were sampled on November 12–14, 2002 (wet season - nominal flow), January 27–29, 2003 (wet season - storm flow), and July 21–23, 2003 (dry season - nominal flow). The South Campus storm water treatment facility was sampled on January 6–8, 2003 (wet season - nominal flow), February 18–20, 2003 (wet-season - storm flow), and August 12–14, 2003 (dry season - nominal flow). The best pollutant removal was achieved by the South Campus storm drain, with average annual reductions of 90.8% for total suspended solids, 45.2% for total phosphorus, 50.0% for total organic carbon, 90.1% for iron, and 57.8% for zinc. As in previous years, the two wet ponds (Park Place and Brentwood) were only marginally effective at removing phosphorus and suspended solids from storm water. All three facilities achieved reductions in coliforms.

1988–2003 Trends in Lake Whatcom Water Quality

There continued to be a long-term trend of decreasing hypolimnetic oxygen concentrations at Site 1. This trend is now modeled using a nonlinear regression, which provides a better fit as the oxygen levels approach zero. Although there are many factors that can increase the rate of hypolimnetic oxygen loss, the most likely in Lake Whatcom is increasing biological productivity. To evaluate whether there are any new temporal trends in the 1988–2003 lake data, we looked for changes in alkalinity, pH, nutrients, chlorophyll, plankton counts, and Secchi depths, all of which are potential indicators of increasing lake productivity. The trend analyses were conducted using near-surface ($\leq$5 m) and deep-water samples ($\geq$15 m at Sites 1–2; $\geq$60 m at Sites 3–4) collected during stratification (June-October for Sites 1–2; June-November for Sites 3-4). Plankton trends were also evaluated using the 12-month data set because diatoms, the dominant algal taxa in Lake Whatcom, normally bloom during the winter and early spring. The trend analysis revealed that soluble phosphate and total phosphorus concentrations increased over time at nearly all sites, particularly in the deep water samples. Near-surface nitrate/nitrite concentrations decreased at all sites, and epilimnetic alkalinity and pH increased at all sites. Cyanobacteria counts increased at all sites, particularly during summer stratification. These trends are consistent with increasing levels of lake productivity (see discussion in Section 2.3.4, beginning on page 13). Chlorophyll and Secchi depth results did not provide supporting evidence of increasing lake productivity. However, Secchi depths have never shown a consistent relationship with chlorophyll in Lake Whatcom because they are influenced by inorganic silt as well as algal blooms. The chlorophyll trend analysis was influenced by changes in analytical methods, which greatly reduced sampling variance after 1994. Post-1994 chlorophyll concentrations have significantly increased over time at all sites except Site 1.

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[3], 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 Lake Whatcom 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 2002/2003 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; monitor the effectiveness of the Park Place and Brentwood wet ponds and the South Campus storm water treatment system; continue collection of hydrologic data from Anderson, Austin, and Smith Creeks; and update the hydrologic model for Lake Whatcom. An additional objective for this year's report was to include an analysis of the 1988–2003 water quality data to help identify long-term trends in the lake.

[3]The Georgia-Pacifi c Corporation closed its pulp mill operations in March 2001, reducing its water requirements from 30–35 MGD to 7–12 MGD (Bill Evans, City of Bellingham Public Works Dept.).

This report is subdivided into the following sections:

Note that all of the tables and figures are located at the end of the report in Sections 8–9. Detailed site descriptions and raw data are included in the Appendices and on the CD at the end of this document. Table 31 on page 263 (at the beginning of Appendix B) lists all abbreviations and units used to describe water quality analyses in this document.

2 Lake Whatcom Monitoring

2.1 Site Descriptions

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (see Figure 1, page 66, and Figures 190–191 in Appendix A.1, pages 258–259). 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 2002/2003 monitoring program. 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 8 & 10, November 5, 7, & 13 and December 3 & 5, 2002; and February 4 & 6, April 1 & 3, May 6 & 8, June 3 & 5, July 8 & 10, August 5 & 7, and September 2 & 4, 2003. The water quality parameters measured for the 2002/2003 lake monitoring program are listed in Table 1 on page 36 (see Section 8, beginning on page 35, for all Tables).

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 37 (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.[4] 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.

2.3 Results and Discussion

2.3.1 Hydrolab data

Figures 2–51 (pages 67–116) show the 2002/2003 Hydrolab data for temperature, dissolved oxygen, conductivity, and pH. Figures 52–71 show historic Hydrolab data for Lake Whatcom, beginning in 1988.[5] The raw data are included in Appendix B.1, beginning on page 264, and in electronic format on the CD that accompanies this report.

The mid-winter Hydrolab profiles (e.g., Figures 17–21) and the multi-year temperature profiles (Figures 52–56) show that the water column mixes during the fall, winter, and early spring. As a result, temperatures, dissolved oxygen concen-

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

[5]This year's report includes a longer period of record, dating from 1988 for most figures.

trations, 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 47–51) 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 72, page 137). 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 72, page 137).

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 72). Basin 3 (Sites 3–4) cools slowly because of its large volume, and may still be stratified in November or early December. True 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 (Table 3, page 38). 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 most significant temperature difference between basins is found in the lower portion of the water column. The 1988–2003 median water temperature near the bottom at Sites 1 and 2 was ∼10 °C, compared to a very cool 6.7 °C at Sites 3–4.

The average water temperature values were slightly warmer in 2002/2003 than in 2001/2002 (see Tables 4–8, pages 39–43, and Matthews, et al., 2003). Compared to historic data, the 2002/2003 difference was small, but this was largely due to the influence of measurements collected from the deeper waters in basin 3, which rarely vary by more than 1–2° C, even in years when surface temperatures are relatively warm. By comparison, the 2003 surface water temperatures were unusually warm in February, and from June through September, compared to 1988–2002 surface water data (Figure 73, page 138).

As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures 42–43 and 57–58, pages 107–108 and 122–123). 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 51 and 61, pages 116 and 126). In contrast, Site 1, which is located in nutrient-enriched waters, shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures 47 and 57, pages 112 and 122).

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 2002, both Sites 3 and 4 developed a small oxygen sag at the thermocline (Figures 5–6 and 10–11, pages 70–71 and 75–76). This was probably caused by respiration by heterotrophic bacteria that accumulated along the density gradient between the epilimnion and hypolimnion. The oxygen sag was also present in December at Sites 3 and 4, but was more uniformly distributed throughout the hypolimnion (Figures 15–16, pages 80–81). By February 2003, 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 June, July, and August, 2003 (Figures 32, 37, and 42, pages 97, 102, and 107). As with the heterotrophic bacteria in basin 3, algae and cyanobacteria probably accumulated along the density gradient between the epilimnion and hypolimnion, where light and nutrients were 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 33, page 98).

The remaining 2002/2003 Hydrolab data, pH and conductivity, 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 (see Matthews, et al., 2000). This trend is the result of changing to increasingly sensitive equipment during the past two decades, resulting in lower values over time. This trend probably does not indicate any change in the actual conductivity in the lake, just our ability to measure the low conductivities with increasing sensitivity.

2.3.2 Other ambient water quality data

The remaining water quality data that were collected monthly or bimonthly (nutrients, alkalinity, turbidity, Secchi depth, chlorophyll, bacteria, and plankton) are shown on Figures 74–148 (pages 139–213) and summarized in Tables 4–8 (pages 39–43). In order to provide a better analysis of the water quality patterns in the lake, the graphs include data from 1988–2003. The raw water quality data are listed in Appendix B, beginning on page 262. Long term lake and hydrograph data are included in electronic format on the CD that accompanies this report. The metals data are listed in Table 9 (page 44); the original AmTest data reports for metals and total organic carbon are included in Appendix B.6 (beginning on page 318).

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures 74–78, pages 139–143). 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 79–83, pages 144–148). 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.

The nutrient data from Site 1 continue to show that basin 1 is more productive than basin 3 (Figures 84–103, pages 149–168). High ammonia concentrations were measured just prior to overturn in the hypolimnion at Sites 1 and 2 (Figure 89, page 154). Elevated hypolimnetic ammonia concentrations have been common at both sites through out the monitoring period (1988–2003); however, we have measured atypically high ammonia concentrations at Site 2 for the last five summers (see Section 2.3.4, beginning on page 13). 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. 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 may have been due to organic decomposition near the bottom.

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures 94–98, pages 159–163), 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. Summer, epilimnetic nitrate concentrations decreased at Sites 2–4, but didn't fall below 150 μg-N/L, making it unlikely that nitrogen was limiting at these sites.

The hypolimnetic nitrate concentrations dropped lower than the epilimnetic concentrations at Sites 1 and 2 ($<$10 μg-N/L). In anaerobic environments, bacteria reduce nitrate (NO_3^-) to nitrite (NO_2^-) and nitrogen gas (N_2). The historic data (1988 to present) indicate that this reduction has been common at Site 1, but was not detected at Site 2 until the summer of 1999.

Soluble phosphate concentrations were usually quite low ($<$10 μg-P/L) at all sites and depths (Figures 109–113, pages 174–178). 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. Occasionally, elevated concentrations of soluble phosphate can be found in the hypolimnion at Sites 1 and 2. This is most likely to occur during late summer, when soluble forms of phosphorus leach out of the anaerobic sediments into anaerobic overlying water.

Total phosphorus concentrations were high at Sites 1 and 2 during late summer, but relatively low at other sites (Figures 114–118, pages 179–183). Sediment-bound phosphorus becomes soluble in low oxygen environments. As with soluble phosphate, the highest total phosphorus concentrations were usually measured in hypolimnion at Sites 1 and 2 just prior to overturn (Figures 114 and 115). Another major source of phosphorus for Lake Whatcom is from storm runoff. Small peaks in total phosphorus measured throughout the water column during spring or winter (e.g., December 1999 at Sites 3–4) were most caused by storm runoff (Figures 117 and 118).

Site 1 continued to have the highest chlorophyll concentrations of all the sites (Figures 119–123, pages 184–188). Samples from 20 m at both 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. In addition, algae are, for the most part, aerobic, so the low oxygen conditions in the late summer hypolimnion will not be favorable for growth.[6] Peak chlorophyll concentrations were usually at 0–15 m.

The plankton counts at all sites were dominated by Chrysophyta[7] (Figures 124–133, pages 189–198), consisting primarily of diatoms, *Dinobryon*, and *Mallomonas*. Substantial blooms of cyanobacteria (Cyanophyta) and 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 134–138, pages 199–203).

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.*

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

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 relationship between fecal coliform counts and *E. coli* counts (Figure 149, page 214), so fecal coliform counts appear to be a reliable tool for determining compliance.

Most of the fecal coliforms and *E. coli* counts were less than 50 cfu[8]/100 mL (Figures 139–148, pages 204–213). There was an unusually high fecal coliform count on August 5, 2003 at Site 4. The corresponding *E. coli* count was very low ($<$2 cfu/100 mL), so the high fecal coliform count was probably sample contamination or analytical error. Assuming this to be the case, all lake sites passed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

In November 1994, we began collecting monthly bacteria samples from the Bloedel-Donovan swimming area near the center of the log boom (see Appendix B.5, beginning on page 302, for raw data). In addition, the City of Bellingham has collected samples from the nearshore (beach) area at Bloedel-Donovan. The Bloedel-Donovan bacteria counts were higher than Site 1 (mid-basin) counts (Table 10, page 45). The 2002/2003 Bloedel-Donovan nearshore and offshore geometric means were $\leq$20 cfu/100 mL. Both locations passed part of the freshwater *Extraordinary Primary Contact Recreation* bacteria standard, but had too many samples exceeding 100 cfu/100 mL to pass the second part of the standard. The swimming area at Bloedel-Donovan was closed periodically during the summer of 2003 due to high coliform counts. By comparison, the coliform counts at Lakewood passed both parts of the freshwater coliform standard (Table 10).

The metals data for Lake Whatcom are included in Table 9 (page 44). This table includes only the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); Appendix B.6 (beginning on page 318) 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 detected metals probably do not represent increases in the metals concentrations in the lake.

[8] colony forming unit/100 mL, cfu/100 mL is sometimes labeled "colonies/100 mL."

Most of the August metals concentrations were at, or below, detection limits, and those that were detected were within normal concentration ranges for the lake. Zinc was detected at nearly all sites. Iron concentrations were elevated in most of the bottom samples. The highest iron concentrations, 0.58 mg/L and 0.38 mg/L, were measured at Sites 1 and 2, respectively. The elevated iron concentrations at Sites 1 and 2 were the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water. Chromium, copper, and nickel 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[9] during late summer and fall (Figure 150, page 215), particularly during the first few weeks after the lake destratifies (see Figure 150, October–November peaks). Iron may have been introduced into the water supply during renovations in the vicinity of the gatehouse in 2001 (see March 3, 2001, Figure 150). 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 Lake Whatcom total organic carbon (TOC) concentrations ranged from $<$1 mg/L to 3.81 mg/L (Table 11, page 46), which are typical values for Lake Whatcom. 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.

During the 2002/2003 sampling period, the quarterly averages for THMs in the Bellingham water distribution system ranged from 0.025–0.041 mg/L, which was below the recommended maximum THMs concentration for treated drinking water (0.080 mg/L). Beginning in the fall of 1998, however, THMs concentrations started increasing in the treated water, particularly in the third (fall) quarter (Figure 151, page 216). This pattern has been consistent for the past five years, and is now showing a significant regression against time for the annual and third quarter data. Although Bellingham's treated water meets the current standards for THMs, EPA's Stage II Disinfection By-Product Rule (http://www.epa.gov/safewater/stage2/index.html) proposes a more stringent stan-

[9]The gatehouse is located along the shoreline of basin 2 adjacent to the Intake.

dard that will be difficult to meet if the THMs continue to increase. Haloacetic acids (another important disinfection by-product) do not appear to be increasing with time (Figure 151) 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).

2.3.3 Site 1 hypolimnetic oxygen trends

The levels of hypolimnetic oxygen appear to have declined over time at Site 1. This pattern was most apparent during July and August, after the lake developed a stable thermal stratification, but before oxygen levels dropped near zero. In earlier reports, this phenomenon has been illustrated using simple linear correlation (e.g., Matthews, et al., 2003) and hypolimnetic oxygen depletion rates (Pelletier, G., 1998). Ultimately, oxygen depletion can't continue to follow a linear model because it can't drop below zero; and, as the levels approach zero, the biota responsible for oxygen consumption (primarily aerobic bacteria) are replaced by anaerobic species. As a result, hypolimnetic oxygen depletion at Site 1 is better illustrated using a nonlinear model.

To model the long-term trends in hypolimnetic dissolved oxygen, we fitted the July–August data[10] with a generalized linear model with exponential mean and constant variance. Linear models fit the dependent variable (e.g., dissolved oxygen) with a linear function of the independent variable (e.g., time), plus residuals:

$$\begin{aligned} y &= \text{linear}(x) + \text{residuals} \\ &= \mu + \epsilon \end{aligned}$$

where it is assumed that the residuals have constant variance. Generalized linear models assume that both the mean of the prediction, μ, and the residuals, ϵ, can have nonlinear functions applied to them to get a better fit. In our case, our model assumes only that there is some exponential function applied to the mean:

$$y = \text{exponential}(\mu) + \epsilon$$

[10] June and September oxygen data were not modeled. June is too early in the stratification period to measure differences in hypolimnetic oxygen. In September the hypolimnetic oxygen concentrations are often <2 mg/L, which is close to the lower detection limit for the Hydrolab.

and that the variance in the residuals remains constant. The modeling software will find the best linear approximation to the mean (μ), as well as the best exponential function, to fit the data.

We used the **R** `glm` function, with a `gaussian` family and `log` link function, as described by Venables and Ripley (1997). As a simple demonstration, Figure 152 (page 217) illustrates synthetic data with exponential functions and constant variance fitted with this kind of model. This nonlinear model provides a good approximation for the hypolimnetic dissolved oxygen data from Site 1. First, the variance should be constant. Assuming that the precision of the Hydrolab probe is not severely changed within its range, this will correspond to a constant variance in the measured values. Second, since there is a natural zero to oxygen (unlike, say, temperature), the oxygen cannot continue to decline forever, and so its decline is more likely to fit an exponential decay function. This approach can be used for extrapolation, as well, to estimate the future behavior of dissolved oxygen in the lake.

As indicated in Figures 153–156 (pages 218–221), there were significant negative correlations between hypolimnetic dissolved oxygen and time during July and August.[11] All but one depth was significant at $p \leq 0.050$; the correlation for August at 14 m was significant at $p \leq 0.100$.

2.3.4 Indicators of changing lake productivity

The 1998/1999 Lake Whatcom Monitoring Report (Matthews, et al., 2000) included a review of the historic 1988–1999 lake water quality data. The most important trend revealed during that examination of the data was the deterioration of hypolimnetic oxygen conditions at Site 1. A second trend involving depletion of epilimnetic dissolved inorganic nitrogen (DIN = ammonia + nitrite + nitrate) at Site 1 was reported by Matthews, et al. (2002a).

Although there are many factors that can increase the rate of hypolimnetic oxygen loss, the most likely in Lake Whatcom is increasing biological productivity

[11] Kendall's τ correlation is a nonparametric test used to measure the amount of change in oxygen data that is correlated with "date." Strong positive or negative correlations will be close to ± 1.0. Weak correlations will be close to zero. Correlations that are significant at the 95% level have p-values ≤ 0.050; correlations that are significant at the 90% level have p-values ≤ 0.100. Because Kendall's τ is based on ranks, it is appropriate to use for nonlinear monotonic correlation analysis.

due to increased internal and external phosphorus loading. Because lakes take many years, even decades, to respond to changes in phosphorus loading, it does not necessarily follow that there must be a concurrent (i.e., 1988–2003) increase in phosphorus levels in the lake. It is more likely that phosphorus levels started increasing *prior to* the changes in oxygen patterns. There is some evidence, however, that phosphorus levels in the lake are increasing, along with several other water quality indicators. To evaluate whether there are temporal trends in the lake data, we looked for changes in nutrients, chlorophyll, plankton counts, and Secchi depths, all of which are potential indicators of increasing lake productivity. We also evaluated alkalinity and pH, which are indirect indicators of algal metabolism.

One statistical issue that affects trend analysis of the Lake Whatcom data is that a different number of water samples were collected at each site. For example, at Sites 1 and 2, pH was measured at 1 m intervals from the surface to the bottom ($\sim$19–21 measurements on each sampling date), while at Sites 3 and 4 pH was measured at 1 m intervals to 10 meters, then at 5 m intervals to the bottom ($\sim$25–27 measurements on each sampling date). Averaging, or using volume-weighted multipliers, will obscure hypolimnetic trends, while also presenting an incorrect estimate for the near-surface water, which comprises the largest volumetric fraction of the lake. Because of these concerns, we conducted separate trend analyses on near-surface and deep-water samples. Near-surface samples were defined as those collected from depths $\leq$5 m; deep water samples were defined as collections from $\geq$15 m at Sites 1–2, and $\geq$60 m at Sites 3–4.

A further complication is that when the lake is unstratified, the entire water column mixes, so near-surface and deep-water samples are similar. During stratification, however, the surface and bottom water quality diverges. The hypolimnion, in particular, takes on many distinctive water quality characteristics. To address this, we restricted our water quality trend analysis to samples collected during stratification (June-October for Sites 1–2; June-November for Sites 3-4). Plankton counts were analyzed during stratification and year-round because diatoms, the dominant algal taxa in Lake Whatcom, normally bloom during the winter and early spring.

To understand what might be occurring in Lake Whatcom, it is important to review the changes that occur in water quality as lakes becomes more productive. Algal growth in most temperate lakes, including Lake Whatcom, is limited primarily by phosphorus availability. As a result, one of the most important indicators of increasing lake productivity will be increasing phosphorus concentrations.

In Lake Whatcom, soluble phosphate and total phosphorus concentrations increased over time at nearly all sites, particularly in the deep water samples (Kendall's τ correlation analysis; Table 12, page 47). The 1988–2003 phosphorus concentrations were all relatively low, however, and many were below analytical detection limits. Because Kendall's τ correlation analyses are based on ranks, uncensored data can be used for the statistical analyses. This preserves the variability associated with the lower end of the data distribution (i.e. bdl values) and avoids some of the statistical problems associated with censored data. Nevertheless, it is important, to qualify correlations that include bdl values because they are more likely to be influenced by variations in analytical sensitivity. (For Lake Whatcom, this includes correlations involving soluble phosphate, and to a lesser degree, total phosphorus and ammonia.)

There were a number of other significant water quality trends that may indicate increasing algal productivity. Near-surface nitrate/nitrite concentrations decreased at all sites, which was most likely due to higher levels of uptake by algae (Table 12). Lake Whatcom has relatively low concentrations of epilimnetic DIN (Matthews, et al., 2002a). If the lake is becoming more productive, we would expect to see more depletion of epilimnetic DIN, unless the algal uptake was offset by higher nitrogen loading into the lake.

Epilimnetic alkalinity and pH increased at all sites, providing additional evidence that algal productivity may be increasing. Photosynthesis usually produces a temporary (i.e., daytime) increase in alkalinity and pH (Stumm and Morgan, 1996). Paired with the near-surface increase in pH, there should be (and was) a significant decrease in hypolimnetic pH due to higher respiration rates by bacteria (Table 12).

Although the phosphorus, nitrate, alkalinity, and pH data suggest a trend toward increasing lake productivity, two of the most obvious indicators, chlorophyll and Secchi depths, did not support this hypothesis. There were no significant correlations between time and Secchi depth. This was not surprising because the transparency of Lake Whatcom (Secchi depth is a measure of water transparency) is influenced by both inorganic sediments and algal booms, and Secchi depth readings in the lake have never shown a consistent relationship with chlorophyll concentrations. The 1988–2003 correlations for chlorophyll were even more enigmatic: the results were either nonsignificant (Sites 1–2) or showed chlorophyll *decreasing* with time (Sites 3–4). Reviewing Figures 119–123 (pages 184–188), it was apparent that the sampling variability has decreased over time, particularly after 1994. This type of pattern is probably due to improved analytical and sampling methods. (A similar pattern was evident in the Lake Whatcom conductivity data, illustrated on Figures 67–71, pages 132–136, which show step-wise reductions in conductivity due to the use of increasingly sensitive field equipment.) When the chlorophyll correlation analysis was repeated using only 1994–2003 data, all sites except Site 1 showed significantly increasing chlorophyll concentrations (Kendall's τ, $p \leq 0.050$).

Trends in the plankton counts supported the hypothesis that lake productivity has increased (Table 13, page 48). Cyanobacteria counts increased at all sites, particularly during summer stratification (see Figures 129–133, pages 194–198). Cyanobacteria are able to use dissolved N_2 gas as a nitrogen source, and can therefore outgrow other types of algae when epilimnetic DIN concentrations are low. Although the cyanobacteria densities increased significantly between 1988 and 2003, the higher cell densities were apparently not sufficient to cause a measurable increase in chlorophyll. Chrysophyta, the most common type of algae in the lake, increased at all sites in the year-round correlations. Chrysophyta usually grow best during winter and early spring, and are replaced by cyanobacteria during summer and early fall (see Figures 124–128, pages 189–193). As with cyanobacteria, the higher Chrysophyta counts were not sufficient to cause a measurable increase in chlorophyll. Chrysophyta are relatively small algae that do not contribute as much to the total algal biovolume in Lake Whatcom as their numbers might suggest (Ashurst, 2003). The Lake Whatcom zooplankton counts, when different, decreased over time. This was consistent with increasing densities of the largely inedible cyanobacteria.

Several of the significant trends in Table 12 appeared to be related to the low oxygen conditions at Sites 1 and 2. Ammonia concentrations increased significantly, and nitrate concentrations decreased significantly, in the deep-water samples at Sites 1 and 2. Ammonia is produced during the decomposition of organic compounds, and in low oxygen environments, it will accumulate until the lake turns over. Conversely, nitrate is depleted in low oxygen environments as denitrifying microbiota convert it into nitrite and dissolved N_2 gas. Because the hypolimnion in basin 3 remains aerobic throughout stratification, there were no significant changes in ammonia or nitrate in the deep-water samples from these sites.

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. During the past five summers, however, many of the indicators of hypolimnetic anoxia have been higher at Site 2 than Site 1. Ammonia concentrations have been higher at Site 2 for the past four years (Table 14, page 49; Figure 90, page 155), and hydrogen sulfide concentrations have been higher for three of the past four years.[12] Late summer alkalinity peaks have begun appearing regularly in the bottom samples from Site 2 (Figure 75, page 140). Although this has been a common pattern at Site 1, it was uncommon at Site 2 prior to 1999. Hypolimnetic nitrate concentrations dropped to below detection, and hypolimnetic phosphorus concentrations have been unusually high for the past four summers (Figure 95 and 115, pages 160 and 180).

Many of the near-surface and deep-water trends in the 1988–2003 data from Site 2 have already been discussed, and are summarized in Tables 12 and 13 (pages 47 and 48). Site 2 had the largest number of significant water quality trends of all the sites (Table 12). All of the trends at Site 2 were consistent with increasing lake productivity.

Most of the water quality changes at Site 2 coincide with drastic reductions in the amount of water diverted from the Middle Fork of the Nooksack River (Figure 157, page 222) and reductions in the water withdrawal from basin 2 to supply Georgia Pacific (see Section 4). The changes also coincide with a period of active residential construction around basin 2, as well as extreme and variable weather patterns (unusually late stratification; prolonged summer droughts; exceptionally warm winters, etc.). Because there are so many confounding factors, it is not possible to attribute the changing water quality at Site 2 to any specific action or activity. However, because of the importance of basin 2 as the drinking water intake location, the City should continue monitoring the water quality conditions at Site 2. In addition, because the hypolimnetic water quality appears to be changing rapidly at Site 2, we need to exercise caution when using pre-1999 data to describe hypolimnetic water quality at Site 2.

[12]Hydrogen sulfide levels were unusually low in 2003. Because H_2S develops very late in the stratification period, the low concentrations in 2003 were probably caused by sampling too early rather than any change in water quality.

3 Creek Monitoring

3.1 Site Descriptions

Seven creeks were sampled twice during the 2002/2003 monitoring program, including Austin Creek, Anderson Creek[13], 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 260).

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 11 and July 14, 2003. The water quality parameters measured for the 2002/2003 creek monitoring program are shown in Table 15 (page 50). The analytical procedures are summarized in Table 2 (page 37). 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, cop-

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

per, iron, mercury, nickel, lead, and zinc) 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 16–17 (pages 51–52) show the recent creek water quality data compared to the 1990 average water quality values for each creeks. Tables 18–20 show coliforms, metals, and total organic carbon data from the 2002/2003 sampling period.

Due to unusual drought conditions during the summer of 2003, many of the creeks had very low flows during the July sampling period. As a result, discharge measurements could not be collected at the Park Place outfall, Silver Beach Creek, or Wildwood Creek. The Park Place outfall and Silver Beach Creek had enough flow in July to collect water samples, but Wildwood Creek was dry. High flows prevented collection of discharge measurements at Wildwood and Anderson Creeks during February. Construction activities near the Park Place outfall prevented collection of discharge measurements in February.

Although most of the 2002/2003 creek data fell within expected ranges, the summer drought caused a number of measurements to be unusually high or low. 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 concentrations were slightly lower in the Park Place outfall and Silver Beach Creek compared to the forested streams. Summer temperatures were quite high at the Park Place outfall due to the warming influence of the Park Place wet pond.

Anderson Creek had unusually low total suspended solids and turbidity values. This may have been due to a reduction in the Nooksack River diversion (see Section 4), which contributes glacial silt to Anderson Creek, as well as drought conditions, which reduced the amount of surface runoff flowing into all creeks during the summer. The turbidity level in Blue Canyon Creek was unusually high during February, probably due to storm runoff.

Many sites had unusually high nutrient concentrations (soluble phosphate, total phosphorus, nitrate/nitrite, and total nitrogen) during both February and July (Table 17, page 52). In particular, most of the February nitrate/nitrite and July total phosphorus concentrations in Anderson, Austin, and Smith Creeks exceeded the upper range established in 1990. Since these three creeks make up a significant portion of the surface water input into the lake, they represent a major source of nutrients for the lake. There is no obvious reason for the higher nutrient concentrations during 2003. The summer drought would have made ground water a more significant source of water for the creeks (rather than surface runoff). Since ground water often contains higher concentrations of soluble nitrogen, this might account for the high nitrate levels in July. The sampling in February was conducted during a period of fairly heavy precipitation. Total phosphorous tends to be transported with surface runoff. Although the February discharge rates for Austin and Smith Creeks were below average (see Table 16), and the turbidity and total suspended solids concentrations were low, the creek water would have contained a relatively large fraction of surface runoff, which could account for the higher phosphorus concentrations.

The metals concentrations were near, or below, detection limits at all sites except for copper, iron and zinc (Table 18, page 53). Iron and zinc were within normal ranges for surface water in the Lake Whatcom watershed. Copper was detected in the samples from Blue Canyon (0.091 mg/L) and Silver Beach Creek (0.005 mg/L). It is not unusual to find slightly elevated concentrations of metals such as copper in residential streams like Silver Beach Creek. The relatively high copper concentration from Blue Canyon was unusual, but Blue Canyon flows through a mineral rich region of the watershed and there have often been detectable amounts of metals in samples from this site.

The total organic carbon results (Table 19, page 54) were somewhat unusual. Typically, the highest TOC concentrations are measured in the residential creeks (Silver Beach Creek and the Park Place outfall; see Matthews, et al., 2003). In February 2003, the highest concentration was in Smith Creek, followed by Anderson, Wildwood, and Austin Creeks. There was no obvious reason for this reversal.

Coliform counts[14] (Table 17, page 52) were unusually high at all sites in the watershed during July 2003. The February 2003 coliform results were more typical, with higher counts in the residential streams, and low counts in the forested streams. Because of the unusually high counts at all sites during July, all of the streams except Wildwood (which was dry in July) failed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard[15] because too many samples exceeded 100 cfu/100 mL (Table 20, page 55). 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 the past 4 years (Table 21, page 56).

4 Lake Whatcom Hydrology

4.1 Hydrograph Data

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks. The location of each hydrograph is described in Appendix A.2 (beginning on page 260). Copies of the hydrograph data are included on the CD that accompanies this report, and the data are summarized in Figures 158–160 (pages 223–225).

The 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, Millwheel, Olsen, and Silver Beach Creeks). Figure 161 (page 226) shows the rating curves for each hydrograph.

[14] Beginning in October 2002, we discontinued total coliforms and *Enterococcus* analyses, as discussed in Section 2.3.2.

[15] 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.

Anderson Creek The rating curve for Anderson Creek was based on 20 flow measurements collected at staff gage heights ranging from 0.29 ft to 2.23 ft from April 2000 through October 2003. The curve represented the range of staff gage heights fairly well, with the greatest logged staff gage height being 2.57 ft. About 10% of the logged staff gage data were between 2.23 ft and 2.57 ft. These gage heights accounted for about 35% of the total flow volume during the year. About 22% of the logged staff gage data were less than the smallest point on the rating curve. These occurrences only accounted for about 0.36% of the total flow volume. The smallest logged staff gage reading was 0.06 ft, while the smallest point used for the rating curve was 0.29 ft.

There are several periods during which we could not collect discharge data in Anderson Creek due to technical problems, including: October 22, 2002 (10:45) to October 23, 2002 (12:15); December 14, 2002 (13:30) to December 14, 2002 (23:45); and February 4, 2003 (10:15) to February 14, 2003 (10:30).

Austin Creek The discharge rating curve for Austin Creek was based on 44 flow measurements collected at staff gage heights ranging from 0.35 ft to 2.85 ft from October 1997 to October 2003. About 30% of the logged staff gage data were below 0.35 ft; however, this only makes up about 0.7% of the discharge by volume. A staff gage reading of less than 0.35 ft calculates into a discharge of less than 0.41 cfs. There were no staff gage data that were greater than the highest point on the rating curve, 2.85 ft.

Data from December 11, 2002 to February 4, 2003 were not collected due to technical problems. During this period we collected several manual staff gage readings, which were entered into the WY2003 data set.

Smith Creek The discharge rating curve for Smith Creek was based on 35 flow measurements collected at staff gage heights rating from 2.08 ft to 4.18 ft from November 1998 to October 2003. About 30% of the logged staff gage data were slightly below 2.08 ft, but these measurements only accounted for about 1.5% of the total discharge during the year. The smallest staff gage height was 1.94 ft.

Data from October 1, 2002 to December 15, 2002 were not collected due to technical problems.

4.2 Water Budget

A water balance model 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), surface runoff and 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, surface runoff and groundwater.

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 area percentage. The weighted areas were determined by a Thiessen Polygon extension in ArcGIS (Figure 162, page 227). 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 2002/2003 was 35.9 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 2002/2003 was 22.2 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.

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.

The yearly water balance totals are listed in Table 22 (page 57) along with the yearly total values for the three previous water years. As indicated from the values in the table, 2002/2003 was an exceptionally dry year. The total input and output to the lake were estimated to be 24,890 MG and 24,971 MG, respectively. These values are about 50% less than last year and were comparable to 2000/2001, an equally dry year.

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 163–166, pages 228–230). All the inputs, except for runoff, are shown in Figure 163 and all the outputs, except for Whatcom Creek, are shown in Figure 164. The input from runoff and output to Whatcom Creek are shown along with the change in lake storage on Figure 165 because they have similar magnitudes. Figure 166 shows 7-day summed totals for inputs, outputs, and change in storage.

Table 23 (page 58) shows the 2002/2003 total input and output volumes along with the corresponding monthly percentage of each total. Table 23 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 167 (page 232) shows daily lake-level values from June-September for the past four water years. Each time series starts at approximately the same lake level on June 1, but decreases to a different low value in September. The low lake level between June-September in 2000 was primarily due to a higher withdrawal by Georgia Pacific, approximately 4 times that withdrawn in 2003. The low lake levels for 2002 and 2003 were due to low summer precipitation . . . about twice the amount of precipitation fell on the lake during the summer of 2001. The change in lake storage during this time period illustrates the importance of the diverted water and summer precipitation on lake levels and residence times in Lake Whatcom.

4.3 Watershed Modeling

Western Washington University graduate student Katie Callahan[16] is calibrating the Distributed Hydrology-Soils-Vegetation Model (DHSVM) to the Lake Whatcom watershed to predict surface-water runoff into the lake. The DHSVM is a physically based, research-level, numerical model developed at the University of Washington and Pacific Northwest National Laboratory (Wigmosta et al., 1994). The model simulates a water and energy balance at the pixel scale (grid cell) of a digital elevation model (DEM). Its primary application has been in mountainous watersheds in the Pacific Northwest, simulating hydrologic responses to weather and land use conditions (e.g,, Storck et al., 1998; Bowling et al., 2000; VanSharr et al., 2002).

Watershed attributes in the DHSVM are defined by six geographic information system (GIS) grids: topography (DEM), watershed boundary, soil type, soil thickness, vegetation, and a flow network. The basin attributes vary from grid cell to grid cell. The input grids for the Lake Whatcom watershed were developed in ArcInfo using a 30 meter grid spacing. Land cover was provided by the USGS 1992 National Land Cover Data Set (Vogelmann et al., 2001). The soil grid was modified from the CONUS soil grid data set designed for hydrologic modeling (Miller and White, 1998).

The input meteorological requirements for the model include time series data for air temperature, humidity, wind speed, incoming short wave radiation, incoming long wave radiation and precipitation. These data were collected from the Northshore climate station in the watershed or were estimated using predictive models. The data were formatted as input for the DHSVM using one-hour time steps.

[16]This section describes the work in progress by Katie Callahan, WWU geology graduate student, as part of the requirements for her M. S. thesis.

The DHSVM simulates unsaturated and saturated subsurface water flow and evaluates a water balance on grid cells in the watershed at each time step (Wigmosta et al., 1994). Depending upon hydraulic head differences in grid cells, water is routed into or out of adjacent grid cells. Surface runoff is generated in a grid cell when ponding occurs or when the water table rises above the ground surface.

Calibration of the DHSVM to the Lake Whatcom watershed requires modification of the basin attributes and meteorological data until the simulated stream discharges provide an acceptable match to the actual recorded discharges. The model is being calibrated to a time series of discharge data collected from Smith Creek and Austin Creek. The climate data cover a period from January 1, 2001 to September 30, 2003. Due to equipment malfunctions, however, there are some data gaps. Initial hydrologic conditions for the watershed (e.g., depth to water table, soil moisture conditions, etc.) were established by starting a simulation with a dry watershed and allowing the soil saturation to evolve with the meteorological conditions for 6 months to a year. The soil-water conditions after this time frame were used as the initial conditions for the calibration simulations. Ms. Callahan used a climate input-time series from October 1, 2001 to September 30, 2002 to establish initial conditions for the watershed. Model calibration is on-going, but the preliminary results are encouraging. Examples of simulation results for Smith and Austin Creeks for October 2001 to December 2001 are shown in Figure 168 (page 233). The model is capturing the timing of peaks reasonably well, but varies in its capacity to estimate the volumes. Errors are attributed to one or more of the following:

- Inadequate soil data. The soil thickness and the horizontal and vertical permeability will influence the magnitudes and timings of peaks. We have not yet quantified these parameters sufficiently, especially for the bedrock in the watershed (fractured sandstone).

- Unsatisfactory precipitation lapse rate predictions. Point precipitation is distributed through the watershed via algorithms in the DHSVM. We have not explored all lapse rate variability options.

- Inaccurate solar radiation inputs. Errors in these inputs may be influencing transpiration and soil storage. We have not performed simulations using the aspect grid that models short wave radiation based on topographic aspect and slope variability.

- Inaccurate stream measurements. The rating curves used for estimating stream discharges are not accurate at high stages because of the lack of measurements at high stages.

We are confident that the DHSVM will be sufficiently calibrated after refining the basin characteristics and meteorological inputs. Once calibrated, the model will be used to refine the surface water and ground water inputs quantities to the lake and explore surface runoff scenarios in the watershed such as the influence of logging and increased urban development.

5 Storm Water Treatment Monitoring

The objective of this portion of the lake monitoring project was to evaluate the water treatment efficiencies in the Brentwood and Park Place wet ponds that were constructed to treat storm water runoff prior to release into Lake Whatcom. In March 2001, a new sampling site was added at the South Campus storm water treatment facility near Western Washington University. Although this site is located outside the Lake Whatcom watershed, the site incorporates a “state-of-the-art” rock/plant filter to treat storm water runoff, which should provide an indication of the levels of treatment that might be attainable within the watershed for systems incorporating similar designs. The locations of the Lake Whatcom watershed monitoring sites (Brentwood and Park Place) are shown on Figure 169 (page 234). The South Campus monitoring site is located south of Bill McDonald Pkwy, west of 25th Street, and north of Taylor Avenue (Figure 170, page 235).

5.1 Sampling procedures

Park Place and Brentwood wet ponds were sampled on November 12–14, 2002 (wet season - nominal flow), January 27–29, 2003 (wet season - storm flow), and July 21–23, 2003 (dry season - nominal flow). The South Campus storm water treatment facility was sampled on January 6–8, 2003 (wet season - nominal flow), February 18–20, 2003 (wet-season - storm flow), and August 12–14, 2003 (dry season - nominal flow).

Composite and grab samples were collected at the inflow and outflow(s) at each site (Table 24, page 59).[17] Automatic composite samplers (ISCO type, supplied by the City of Bellingham) were placed at the inlet and outlet and 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 and outflow 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.

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. Both ponds have extensive macrophyte growth, as shown on Figures 171–172 (pages 236–237). The South Campus storm water treatment facility was constructed during the fall and winter of 2000; monitoring began in March 2001. 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. Figure 173 (page 238), taken on February 20, 2003, shows that the South Campus facility is still receiving a heavy sediment load during storm events.

Tables 25–28 (pages 60–63) show the raw data from the Park Place, Brentwood, and South Campus treatment systems. The tables also show the annual and seasonal percent reduction in concentration of contaminants between the inflow and outflow at the Park Place and Brentwood ponds and South Campus storm water treatment facility. Average percent reductions were computed as follows:

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

[17] Brentwood and Park Place have a single outfbw; the South Campus site has two outfbws.

The best pollutant removal was achieved by the South Campus storm drain, with average annual reductions of 90.8% for total suspended solids, 45.2% for total phosphorus, 50.0% for total organic carbon, 90.1% for iron, and 57.8% for zinc. As in previous years, the two wet ponds (Park Place and Brentwood) were only marginally effective at removing phosphorus and suspended solids from storm water (see Matthews, et al., 2003, for a review of long-term performance for these storm water treatment systems). Park Place achieved an average total phosphorus reduction of 22.0%, but this was entirely due to phosphorus reduction in July (from 0.129 mg/L at the inlet to 0.059 mg/L at the outlet), during which time there was very little water movement through the pond. During November and January the phosphorus concentrations were essentially the same at the Park Place inlet and outlet. The Brentwood facility often had higher suspended solids concentrations in its effluent than in water entering the pond (an average increase of 65.2%), and neither facility achieved any reduction in total organic carbon concentrations. The wet ponds were also inconsistent in removing metals from storm water. All three facilities achieved reductions in coliforms.

Historically, only the South Campus treatment system has provided consistent sediment and phosphorus removal. Brentwood and Park Place often have similar (or higher) concentrations of total suspended solids and total phosphorus at the outlet as at the inlet (Figures 174 and 175, pages 239 and 240). This may be due to the relatively low concentrations of sediments and phosphorus entering the Brentwood and Park Place treatment systems (Figure 176, page 241). Schueler (1996) described this phenomenon as the "irreducible" lower concentration limits, below which the treatment systems do not provide much contaminant removal. Unfortunately, although the pollutant loads entering the Brentwood and Park Place treatment systems may be too low to be removed by the wet ponds, the phosphorus concentrations, in particular, are high enough to contribute to lake pollution.

6 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 37). Single-blind quality control tests were conducted as part of the IWS laboratory certification process. The 2002/2003 results are presented in Table 29 (page 64). All results from the single-blind tests were within acceptance limits.

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[18] 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 2001–2002 data (upper examples in Figures 177–184, pages 242–249), and used to evaluate laboratory duplicates from 2003 (lower examples in Figures 177–184). The control charts indicate that the laboratory duplicates have been consistent over time.

Separate field duplicates were collected and analyzed for at least 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 field duplicates results were in close agreement, given that they came from different water samples (Figures 185–189, pages 250–254). 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 185) 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 67–71, pages 132–136). 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 median difference between Hydrolab and Winkler dissolved oxygen values was 0.16 mg/L, and all but 2 of the samples ($\sim$1%) differed by less than 1.0 mg/L. During the summer of 2002, we experienced a significant drop in Hydrolab sensitivity when measuring extremely low oxygen concentrations. Despite

[18]The Institute for Watershed Studies maintains control charts for laboratory duplicates, check standards, and spikes for all of our routine water quality analyses. Addition quality control information may be obtained by contacting the Institute director.

frequent repairs and equipment replacement by Hydrolab, we were not able to measure oxygen concentrations less that 2.0 mg/L with any accuracy. Because of this, we censured all oxygen values less than 2.0 mg/L from July–October 2002 data set. Currently, the Hydrolab can measure oxygen concentrations as low as 1.0 mg/L, but the loss of sensitivity still seems to be a problem with the Hydrolab instrumentation.

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8 Tables

	2002			2003									
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 2002–2003 lake monitoring schedule

Parameter	Method	Historic DL†	2002/2003 MDL†	Sensitivity or Confidence limit
Conductivity-field	Hydrolab (1997), field meter	–	–	± 2 μS/cm
Conductivity-lab	APHA (1998) #2510, low-level, SOP-LW-9	–	–	± 2.2 μS/cm
Dissolved oxygen-field	Hydrolab (1997), field meter	–	–	± 0.1 mg/L
Dissolved oxygen-lab	APHA (1998) #4500-O.C., Winkler, SOP-LW-12	–	–	± 0.1 mg/L
pH-field	Hydrolab (1997), field meter	–	–	± 0.1 pH unit
pH-lab	APHA (1998) #4500-H^+, low-ionic, SOP-LW-8	–	–	± 0.1 pH unit
Temperature	Hydrolab (1997), field meter	–	–	± 0.1° C
Alkalinity	APHA (1998) #2320, low level, SOP-IWS-15	–	–	± 0.5 mg/L
Discharge	Lind (1985), rating curve, SOP-IWS-6	–	–	–
Secchi disk	Lind (1985)	–	–	± 0.1 m
T. suspended solids	APHA (1998) #2540 D, gravimetric, SOP-LW-22	2 mg/L	2 mg/L	± 2.3 mg/L
Turbidity	APHA (1998) #2130, nephelometric, SOP-LW-11	–	–	± 0.2 NTUs
Ammonia	APHA (1998) #4500-NH_3 F., phenate, SOP-LW-21	10 μg-N/L	2.5 μg-N/L	± 2.9 μg-N/L
Nitrite/nitrate	APHA (1998) #4500-NO_3 I., Cd reduction, SOP-IWS-19	20 μg-N/L	5.2 μg-N/L	± 9.2 μg-N/L
T. nitrogen	APHA (1998) #4500-N C., persulfate digestion, SOP-IWS-19	100 μg-N/L	5.3 μg-N/L	± 18.1 μg-N/L
Sol. phosphate	APHA (1998) #4500-P G., ascorbic acid, SOP-IWS-19	5 μg-P/L	1.4 μg-P/L	± 1.3 μg-P/L
T. phosphorus	APHA (1998) #4500-P H., persulfate digestion, SOP-IWS-19	5 μg-P/L	3.4 μg-P/L	± 3.3 μg-P/L
Chlorophyll	APHA (1998) #10200 H, acetone, SOP-IWS-16	–	–	± 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 B for additional information.

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

All depths and years						
	Min.	Med.	Mean	Max.	SD	N
Site 1	4.2	11.0	11.8	23.2	4.4	3,039
Site 2	5.0	11.5	12.5	22.7	4.6	2,881
Intake	5.3	14.3	13.9	23.0	4.9	1,681
Site 3	5.4	7.8	10.3	22.8	4.6	3,853
Site 4	5.5	7.4	9.9	22.0	4.4	4,108

Surface samples (depth $<$ 1 m)						
	Min.	Med.	Mean	Max.	SD	N
Site 1	4.5	15.4	14.4	23.2	5.5	151
Site 2	5.0	15.4	14.3	22.7	5.2	151
Intake	5.6	15.4	14.4	23.0	5.2	150
Site 3	5.8	14.8	14.1	22.8	5.1	147
Site 4	5.7	13.9	13.7	22.0	4.9	145

Deep samples ($>$15 m at Sites 1–2; $>$60 m at Sites 3–4)						
	Min.	Med.	Mean	Max.	SD	N
Site 1	4.2	10.2	9.5	13.7	2.0	719
Site 2	5.4	10.1	9.6	13.8	1.9	579
Intake†	na	na	na	na	na	na
Site 3	5.4	6.7	6.7	10.0	0.4	569
Site 4	5.5	6.7	6.7	10.0	0.4	857

†Intake does not stratify

Table 3: Summary of 1988–2003 water temperatures in Lake Whatcom. January and March data have been omitted due to small sample size.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.6	19.9	20.1	24.9	1.7	50
Conductivity - Hydrolab (μS/cm)	49.6	56.4	56.6	69.6	3.6	210
Conductivity - lab (μS/cm)	60.9	62.0	63.1	72.0	3.0	20
Dissolved oxygen (mg/L)	1.2	9.5	8.8	12.0	3.0	201
pH	6.3	7.4	7.4	8.8	0.6	210
Temperature (°C)	7.0	10.8	12.1	22.1	4.1	210
Turbidity (NTU)	0.5	0.9	1.1	8.1	1.2	50
Nitrogen - ammonia (μg-N/L)	<10	11.0	34.0	203.9	54.5	50
Nitrogen - nitrate/nitrite (μg-N/L)	<20	183.9	167.3	305.1	108.1	50
Nitrogen - total (μg-N/L)	219.2	376.5	355.3	502.3	70.4	50
Phosphorus - soluble (μg-P/L)	<5	<5	<5	8.9	1.9	50
Phosphorus - total (μg-P/L)	<5	10.6	11.5	41.6	7.9	50
Chlorophyll (mg/m^3)	0.2	3.4	3.4	9.8	1.9	50
Secchi depth (m)	2.9	5.0	5.0	6.8	1.1	9
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	2	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 Site 1 ambient water quality data, Oct. 2002 – Sept. 2003.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.6	18.7	18.6	19.6	0.6	30
Conductivity - Hydrolab (μS/cm)	49.7	54.6	54.6	58.1	2.1	110
Conductivity - lab (μS/cm)	59.4	60.0	60.0	61.0	0.4	20
Dissolved oxygen (mg/L)	8.4	9.6	10.0	12.1	1.1	110
pH	7.3	7.8	7.8	8.4	0.4	110
Temperature (°C)	7.2	14.3	14.4	21.9	5.0	110
Turbidity (NTU)	0.3	0.5	0.6	1.1	0.2	30
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	16.8	4.7	30
Nitrogen - nitrate/nitrite (μg-N/L)	124.0	247.4	254.5	388.6	83.8	30
Nitrogen - total (μg-N/L)	318.7	378.7	394.1	483.6	54.5	30
Phosphorus - soluble (μg-P/L)	<5	<5	<5	7.2	1.6	30
Phosphorus - total (μg-P/L)	<5	<5	6.3	15.4	3.7	30
Chlorophyll (mg/m^3)	1.1	2.6	2.4	3.5	0.7	30
Secchi depth (m)	3.4	5.9	5.8	8.8	1.3	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	2	na	10
Coliforms - E. coli (cfu/100 mL)‡	<1	1	1	1	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 Intake ambient water quality data, Oct. 2002 – Sept. 2003.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.6	18.7	18.8	25.4	1.4	50
Conductivity - Hydrolab (μS/cm)	48.6	54.3	54.3	59.2	2.3	203
Conductivity - lab (μS/cm)	59.3	59.8	60.2	63.8	1.2	20
Dissolved oxygen (mg/L)	1.2	9.5	9.5	12.3	2.0	202
pH	6.3	7.5	7.5	8.4	0.5	202
Temperature (°C)	7.3	11.7	12.9	21.7	4.5	203
Turbidity (NTU)	0.4	0.5	0.6	1.6	0.3	49
Nitrogen - ammonia (μg-N/L)	$<$10	6.7	24.9	383.8	62.6	50
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	239.8	260.6	405.8	94.1	50
Nitrogen - total (μg-N/L)	302.1	431.9	417.5	576.1	72.8	50
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	9.2	2.0	50
Phosphorus - total (μg-P/L)	$<$5	6.3	8.6	30.2	6.0	50
Chlorophyll (mg/m^3)	0.3	2.5	2.4	4.9	1.0	50
Secchi depth (m)	3.8	5.9	6.1	9.4	1.5	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 6: Summary of Site 2 ambient water quality data, Oct. 2002 – Sept. 2003.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.3	18.0	18.2	19.8	0.6	70
Conductivity - Hydrolab (μS/cm)	49.5	54.0	54.0	57.3	1.9	247
Conductivity - lab (μS/cm)	59.0	59.7	61.0	72.6	3.5	26
Dissolved oxygen (mg/L)	6.8	9.9	10.0	12.1	1.0	247
pH	6.5	7.2	7.4	8.2	0.5	229
Temperature (°C)	6.4	7.9	10.6	21.7	4.6	247
Turbidity (NTU)	0.2	0.4	0.5	4.2	0.5	69
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	21.2	5.3	70
Nitrogen - nitrate/nitrite (μg-N/L)	152.9	375.6	337.2	473.1	90.5	70
Nitrogen - total (μg-N/L)	301.8	466.6	440.4	530.7	65.5	70
Phosphorus - soluble (μg-P/L)	<5	<5	<5	8.1	1.7	70
Phosphorus - total (μg-P/L)	<5	6.6	7.3	24.8	4.5	70
Chlorophyll (mg/m^3)	0.5	2.1	2.4	6.4	1.2	50
Secchi depth (m)	4.6	5.8	6.7	10.5	2.0	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	1	na	10
Coliforms - E. coli (cfu/100 mL)‡	<1	1	1	1	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 3 ambient water quality data, Oct. 2002 – Sept. 2003.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.3	17.8	18.1	19.6	0.6	80
Conductivity - Hydrolab (μS/cm)	49.6	54.1	53.8	57.7	2.0	267
Conductivity - lab (μS/cm)	58.9	59.6	59.6	60.5	0.4	24
Dissolved oxygen (mg/L)	7.4	10.1	10.1	12.8	1.1	267
pH	6.7	7.1	7.3	8.2	0.5	247
Temperature (°C)	6.4	7.5	10.3	21.4	4.5	267
Turbidity (NTU)	0.2	0.4	0.4	0.8	0.1	80
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	18.6	4.6	80
Nitrogen - nitrate/nitrite (μg-N/L)	163.4	389.5	346.8	462.8	88.4	80
Nitrogen - total (μg-N/L)	306.9	472.2	448.4	537.9	64.9	80
Phosphorus - soluble (μg-P/L)	<5	<5	<5	10.7	2.0	80
Phosphorus - total (μg-P/L)	<5	5.8	6.6	17.8	3.7	80
Chlorophyll (mg/m^3)	0.3	2.3	2.4	6.3	1.3	50
Secchi depth (m)	4.6	6.3	6.5	8.6	1.3	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	2	160	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 8: Summary of Site 4 ambient water quality data, Oct. 2002 – Sept. 2003.

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	Aug 7, 2003	<0.01	<0.0005	0.001	<0.001	0.026	<0.01	<0.005	<0.001	0.002
Site 1	20	Aug 7, 2003	<0.01	<0.0005	<0.001	<0.001	0.58	<0.01	<0.005	<0.001	0.002
Intake	0	Aug 7, 2003	<0.01	<0.0005	<0.001	0.002	0.015	<0.01	<0.005	<0.001	<0.001
Intake	10	Aug 7, 2003	<0.01	<0.0005	<0.001	<0.001	0.006	<0.01	<0.005	<0.001	0.001
Site 2	0	Aug 7, 2003	<0.01	<0.0005	0.001	<0.001	0.01	<0.01	<0.005	<0.001	0.002
Site 2	20	Aug 7, 2003	<0.01	<0.0005	<0.001	<0.001	0.38	<0.01	<0.005	<0.001	0.002
Site 3	0	Aug 5, 2003	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	<0.001
Site 3	80	Aug 5, 2003	<0.01	<0.0005	0.001	<0.001	0.068	<0.01	0.006	<0.001	<0.001
Site 4	0	Aug 5, 2003	<0.01	<0.0005	<0.001	<0.001	0.024	<0.01	<0.005	<0.001	<0.001
Site 4	90	Aug 5, 2003	<0.01	<0.0005	<0.001	<0.001	0.02	<0.01	<0.005	<0.001	0.002

Table 9: Lake Whatcom 2002/2003 total metals data. Only the metals specified in the 2002/2003 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix B.6.

Site	Variable	Min.	Mean†	Med	Max.	N
Bloedel-Donovan swimming area	Coliforms, fecal (cfu/100 mL)	1	20	21	2,700	9
(Oct. 2002–Sept. 2003)	Coliforms, E. coli (cfu/100 mL)	1	17	8	2,700	9
Bloedel-Donovan wading area (Mar. 2003–Aug. 2003)	Coliforms, E. coli (cfu/100 mL)	<1	21	28	440	21
Lakewood, north beach (May 2003–Oct. 2003)	Coliforms, E. coli (cfu/100 mL)	1	3	3	7	5
Lakewood, main dock (May 2003–Oct. 2003)	Coliforms, E. coli (cfu/100 mL)	<1	1	1	2	5
Lakewood, crew dock (May 2003–Oct. 2003)	Coliforms, E. coli (cfu/100 mL)	<1	1	1	1	5
Lakewood, south beach (May 2003–Oct. 2003)	Coliforms, E. coli (cfu/100 mL)	<1	7	11	61	5

†Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 10: Summary of summer coliform data from the Bloedel-Donovan and Lakewood swimming and wading areas. Bloedel-Donovan wading area samples were collected at $\sim$0.3 m depths by the City of Bellingham Public Works Department; Bloedel-Donovan swimming area samples were collected by WWU at $\sim$1 m depths. Lakewood samples were collected by WWU off the docks or in the wading area.

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 6, 2003	0	< 1	Aug. 7, 2003	0	2.2
	Feb 6, 2003	20	na	Aug. 7, 2003	20	<1
Intake	Feb 6, 2003	0	2.2	Aug. 7, 2003	0	1.7
	Feb 6, 2003	10	1.1	Aug. 7, 2003	10	1.8
Site 2	Feb 6, 2003	0	3.6	Aug. 7, 2003	0	<1
	Feb 6, 2003	20	3.8	Aug. 7, 2003	15	<1
Site 3	Feb 4, 2003	0	<1	Aug. 5, 2003	0	1.3
	Feb 4, 2003	80	<1	Aug. 5, 2003	80	<1
Site 4	Feb 6, 2003	0	<1	Aug. 5, 2003	0	1.7
	Feb 6, 2003	90	3.7	Aug. 5, 2003	90	<1

Table 11: Lake Whatcom 2002/2003 total organic carbon data.

	Stratified, near-surface ($\leq$5 m at all sites)			
	Site 1	Site 2	Site 3	Site 4
Alkalinity	$\nearrow$	$\nearrow$	$\nearrow$	$\nearrow$
Chlorophyll (1988–2003)	ns[†]	ns	$\searrow$	$\searrow$
Chlorophyll (1994–2003)	ns	$\nearrow$	$\nearrow$	$\nearrow$
Nitrogen - ammonia	$\searrow$	ns	ns	ns
Nitrogen - nitrate/nitrite	$\searrow$	$\searrow$	$\searrow$	$\searrow$
Nitrogen - total	ns	ns	ns	ns
pH	$\nearrow$	$\nearrow$	$\nearrow$	$\nearrow$
Phosphorus - soluble	ns	$\nearrow$	$\nearrow$	$\nearrow$
Phosphorus - total	ns	ns	$\nearrow$	ns
Secchi depth	ns	ns	ns	ns

Stratified, deep-water ($\geq$15 m at Sites 1–2; $\geq$60 m at Sites 3–4)				
	Site 1	Site 2	Site 3	Site 4
Alkalinity	$\nearrow$	$\nearrow$	$\nearrow$	ns
Chlorophyll - not applicable - surface samples only				
Nitrogen - ammonia	$\nearrow$	$\nearrow$	ns	ns
Nitrogen - nitrate/nitrite	$\searrow$	$\searrow$	ns	ns
Nitrogen - total	ns	$\nearrow$	ns	$\nearrow$
pH	$\searrow$	$\searrow$	$\searrow$	$\searrow$
Phosphorus - soluble	$\nearrow$	$\nearrow$	$\nearrow$	$\nearrow$
Phosphorus - total	$\nearrow$	$\nearrow$	ns	$\nearrow$
Secchi depth - not applicable - surface samples only				

[†]ns = nonsignificant

Table 12: Summary of significant near-surface and deep-water trends between water quality and time for samples collected during stratified lake conditions (June-October for Sites 1–2; June-November for Sites 3–4) from 1988–2003. All comparisons were made within sites; different groups are shown as significantly increasing ($\nearrow$) or decreasing ($\searrow$) with time based on Kendall's τ nonparametric correlation analysis ($p \leq 0.050$). See discussion in text for analysis of chlorophyll trends.

	Year-round, near-surface (≤5 m at all sites)			
	Site 1	Site 2	Site 3	Site 4
Chlorophyta (green algae)	ns[†]	ns	ns	ns
Chrysophyta (diatoms and others)	↗	↗	↗	↗
Cyanophyta (bluegreen bacteria)	↗	↗	↗	↗
Pyrrophyta (dinoflagellates)	↗	ns	↗	ns
Zooplankton (heterotrophs)	ns	ns	↘	ns

	Stratified, near-surface (≤5 m at all sites)			
	Site 1	Site 2	Site 3	Site 4
Chlorophyta (green algae)	ns	ns	ns	ns
Chrysophyta (diatoms and others)	↗	ns	ns	↗
Cyanophyta (bluegreen bacteria)	↗	↗	↗	↗
Pyrrophyta (dinoflagellates)	ns	ns	ns	ns
Zooplankton (heterotrophs)	ns	↘	↘	ns

[†]ns = nonsignificant

Table 13: Summary of significant trends between plankton and time for samples collected year-round and during stratified lake conditions (June-October for Sites 1–2; June-November for Sites 3–4) from 1988–2003. All comparisons were made within sites; different groups are shown as significantly increasing (↗) or decreasing (↘) with time based on Kendall's τ nonparametric correlation analysis ($p \leq 0.050$).

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

Table 14: Site 1 and Site 2 hypolimnetic ammonia and hydrogen sulfide concentrations, October 1999–2003.

Parameter	2002 Oct	Nov	Dec	2003 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					•					•		
Nooksack diversion (ammonia, nitrate/nitrite, t. nitrogen, sol. phosphate, t. phosphorus)	•	•	•	•	•	•	•	•	•	•	•	•

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

Table 15: Lake Whatcom 2002–2003 creek monitoring schedule

Site	Date	pH	Cond. (μS/cm)	DO (mg/L)	TSS (mg/L)	Alk. (mg/L)	Disch. (cfs)	Temp. (°C)	Turb. (ntu)
Blue	1990 min†	8.1	250	9.0	<2	na	0.02	4.0	na
Canyon	1990 avg†	8.4	344	10.5	5	na	0.05	10.9	na
	1990 max†	8.6	409	12.3	29	na	0.11	17.0	na
	Feb 11, 2003	8.4	276	12.3	7.4	123.9	0.26	6.2	4.7
	July 14, 2003	8.5	293	10.1	8.1	143.9	0.05	13.2	22.5
Park	1990 min†	7.1	118	6.4	3	na	0.00	4.5	na
Place	1990 avg†	7.7	245	9.1	13	na	0.26	13.7	na
	1990 max†	8.1	410	11.8	57	na	0.91	23.0	na
	Feb 11, 2003	7.9	236	11.9	3.4	94.3	na	6.0	5.0
	July 14, 2003	8.3	216	9.2	<2	93.3	na	20.0	2.3
Silver	1990 min†	7.4	103	6.9	<2	na	0.00	4.2	na
Beach	1990 avg†	7.9	187	9.8	6	na	0.86	11.1	na
	1990 max†	8.1	290	12.1	12	na	2.66	17.0	na
	Feb 11, 2003	7.9	158	12.7	2.3	56.3	0.41	3.5	6.5
	July 14, 2003	8.1	204	9.0	2.1	87.7	na	16.0	3.0
Wildwd	1990 min†	6.7	34	6.9	<2	na	0.01	4.0	na
	1990 avg†	7.2	54	10.0	2	na	0.76	10.0	na
	1990 max†	7.6	126	12.3	11	na	2.52	16.5	na
	Feb 11, 2003	7.1	55	12.7	<2	6.9	na	4.1	0.3
	July 14, 2003	na	na	na	na	na	na	na	na
Anderson	1990 min†	7.2	37	10.0	4	na	41.2	3.5	na
	1990 avg†	7.4	57	11.3	17	na	74.85	8.3	na
	1990 max†	8.4	71	13.0	48	na	92.00	12.5	na
	Feb 11, 2003	7.0	66	12.3	2.2	19.6	na	5.0	1.3
	July 14, 2003	7.1	71	9.4	<2	22.9	0.51	13.6	2.2
Austin	1990 min†	7.1	50	8.3	<2	na	1.40	4.5	na
	1990 avg†	7.4	81	10.5	3	na	14.49	10.6	na
	1990 max†	7.6	121	12.1	13	na	29.60	19.5	na
	Feb 11, 2003	7.4	70	12.9	<2	16.8	9.00	3.5	0.8
	July 14, 2003	7.8	119	9.7	<2	7.6	0.68	16.2	0.7
Smith	1990 min†	6.6	44	8.7	<2	na	0.80	3.4	na
	1990 avg†	7.5	64	10.5	3	na	7.63	10.0	na
	1990 max†	7.8	90	12.6	10	na	23.80	17.0	na
	Feb 11, 2003	7.4	91	13.4	<2	14.8	5.74	2.5	0.6
	July 14, 2003	7.8	84	9.9	2.1	29.0	1.00	14.2	0.5

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

Table 16: Physical water quality data for creeks in the Lake Whatcom watershed.

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 11, 2003	<10	303	381	7	19	<1	<1
	July 14, 2003	<10	132	598	9	63	520	590
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 11, 2003	27	933	1242	17	46	37	9
	July 14, 2003	48	499	888	31	58	920	880
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 11, 2003	<10	718	979	16	31	12	13
	July 14, 2003	<10	279	658	24	51	1700	2300
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 11, 2003	<10	2260	2247	8	9	<1	<1
	July 14, 2003	na	na	na	na	na	na	na
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 11, 2003	<10	815	957	12	12	1	1
	July 14, 2003	<10	693	881	15	30	360	380
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 11, 2003	<10	828	884	13	13	12	7
	July 14, 2003	<10	259	395	15	30	360	260
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 11, 2003	<10	1381	1770	12	9	2	1
	July 14, 2003	<10	569	708	13	18	190	170

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

Table 17: Chemical and biological water quality data for creeks in the Lake Whatcom watershed.

Site	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)
Blue Canyon	Feb 11, 2003	<0.01	<0.0005	<0.001	0.091	0.034
Park Place	Feb 11, 2003	<0.01	<0.0005	<0.001	<0.001	0.35
Silver Beach	Feb 11, 2003	<0.01	<0.0005	<0.001	0.005	0.53
Wildwood	Feb 11, 2003	<0.01	<0.0005	<0.001	<0.001	0.25
Anderson	Feb 11, 2003	<0.01	<0.0005	<0.001	<0.001	0.051
Austin	Feb 11, 2003	<0.01	<0.0005	<0.001	<0.001	<0.005
Smith	Feb 11, 2003	<0.01	<0.0005	<0.001	<0.001	0.054

Site	Date	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
Smith	Feb 11, 2003	<0.01	<0.005	0.002	<0.001
Silver Beach	Feb 11, 2003	<0.01	<0.005	<0.001	0.003
Park Place	Feb 11, 2003	<0.01	<0.005	<0.001	0.008
Blue Canyon	Feb 11, 2003	<0.01	<0.005	<0.001	<0.001
Anderson	Feb 11, 2003	<0.01	<0.005	<0.001	<0.001
Wildwood	Feb 11, 2003	<0.01	<0.005	<0.001	<0.001
Austin	Feb 11, 2003	<0.01	<0.005	<0.001	0.003

Table 18: Metals data for creeks in the Lake Whatcom watershed. Only the metals specified in the 2002/2003 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix B.6.

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Blue Canyon	Feb 11, 2003	<1	July 14, 2003	2.5
Park Place	Feb 11, 2003	<1	July 14, 2003	<1
Silver Beach	Feb 11, 2003	<1	July 14, 2003	<1
Wildwood	Feb 11, 2003	2.9	July 14, 2003	na
Anderson	Feb 11, 2003	3.9	July 14, 2003	<1
Austin	Feb 11, 2003	2.0	July 14, 2003	<1
Smith	Feb 11, 2003	6.6	July 14, 2003	<1

Table 19: Total organic carbon data for creeks in the Lake Whatcom watershed.

Site	Min.	Med.	Geom. Mean	Max.	N
Blue Canyon	$<$1	7	10	520	10
Park Place	20	580	305	3,400	10
Silver Beach	12	490	263	1,850	10
Wildwood	$<$1	11	5	42	9
Anderson	1	7	13	360	10
Austin	3	44	43	660	10
Smith	2	22	17	190	10

Table 20: Five-year summary of fecal coliform counts for creeks in the Lake Whatcom watershed (March 1999 to July 2003).

Winter counts		Summer counts	
Feb 10, 1999	8 cfu/100 mL	July 15, 1999	56 cfu/100 mL
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

Table 21: Five-year summary of Austin Creek fecal coliform counts (March 1999 to July 2003).

	2002–2003		2001–2002		2000–2001		1999–2000	
Inputs (MG)								
Direct Precipitation	4,859	(19.5%)	7,078	(14.5%)	4,811	(19.3%)	7,077	(14.7%)
Diversion	4,442	(17.8%)	4,693	(9.6%)	1,783	(7.1%)	4,607	(9.5%)
Runoff	15,589	(62.6%)	36,920	(75.8%)	18,345	(73.6%)	36,563	(75.8%)
Total	24,890	(100%)	48,691	(100%)	24,938	(100%)	48,247	(100%)
Outputs (MG)								
Whatcom Creek	13,361	(53.5%)	38,223	(77.5%)	10,508	(44.5%)	27,280	(55.6%)
Hatchery	1,124	(4.5%)	901	(1.8%)	1,074	(4.5%)	2,388	(4.9%)
Georgia Pacific	2,988	(12.0%)	3,046	(6.2%)	4,851	(20.5%)	12,334	(25.1%)
City of Bellingham	4,342	(17.4%)	4,234	(8.6%)	4,076	(17.3%)	4,112	(8.4%)
Water District 10	136	(0.6%)	126	(0.3%)	140	(0.6%)	154	(0.3%)
Evaporation	3,016	(12.1%)	2,812	(5.7%)	2,971	(12.6%)	2,777	(5.7%)
Total	24,971	(100%)	49,341	(100%)	23,621	(100%)	49,045	(100%)
Net change in storage	-81		-651		1,318		-797	

Table 22: Annual water balance quantities for the Lake Whatcom watershed.

	Output Percents						Input Percents		
Month	WC	Hatch	GP	COB	WD10	Evap	Diver	Precip	Runoff
Oct	1.41	5.86	10.67	7.23	7.40	3.55	0.11	2.74	-0.91
Nov	3.51	5.98	10.09	6.82	7.53	1.64	6.81	11.72	3.42
Dec	11.05	8.32	9.46	6.55	8.42	0.74	7.50	16.03	9.19
Jan	28.85	8.99	8.63	7.19	8.48	0.76	20.85	18.94	23.35
Feb	13.41	8.94	7.47	6.06	7.15	1.75	3.66	7.45	16.89
Mar	4.76	7.60	7.53	6.80	7.95	4.77	16.07	15.63	18.39
Apr	25.93	8.39	6.84	6.86	7.35	8.16	17.09	9.47	20.39
May	4.66	10.18	5.61	7.80	8.07	12.29	13.14	6.46	4.77
Jun	2.64	8.36	5.21	10.66	8.78	16.92	10.79	4.58	1.41
Jul	1.29	10.28	9.58	12.56	10.76	22.07	0.69	1.51	2.75
Aug	1.59	9.02	9.99	12.38	9.94	17.44	2.15	1.19	0.26
Sep	0.91	8.08	8.94	9.09	8.17	9.90	1.16	4.27	0.09
Jun-Sep	6.43	35.74	33.71	44.69	37.65	66.34	14.78	11.56	4.50
	Output Volume (MG)						Input Volume (MG)		
Total	13,361	1,124	2,988	4,342	136	3,019	4,442	4,859	15,589
Jun-Sep	860	402	1,007	1,940	51	2,003	657	562	702

Table 23: Monthly water balance quantities for the Lake Whatcom watershed, October 2002–September 2003.

Parameter	2002 Oct-Dec wet, low fbw	2003 Jan-Apr wet, high fbw	2003 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 24: 2002–2003 storm water treatment systems monitoring schedule.

Site	Date	TSS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
BW inlet	November 12–14, 2002	4.78	<1*	1.208	0.057
BW inlet	January 27–29, 2003	2.99	1.1	1.833	0.060
BW inlet	July 21–23, 2003	2.91	<1*	1.912	0.062
BW outlet	November 12–14, 2002	9.92	<1*	1.114	0.070
BW outlet	January 27–29, 2003	4.75	3.4	1.440	0.045
BW outlet	July 21–23, 2003	2.97	2.4	0.550	0.066
Annual % reduction		-65.2	-119.4	37.3	-0.7
PP inlet	November 12–14, 2002	7.61	<1*	1.277	0.093
PP inlet	January 27–29, 2003	6.85	1.0	1.325	0.072
PP inlet	July 21–23, 2003	2.77	<1*	2.904	0.129
PP outlet	November 12–14, 2002	8.20	1.1	0.927	0.097
PP outlet	January 27–29, 2003	5.65	2.2	1.344	0.073
PP outlet	July 21–23, 2003	2.40	3.1	0.498	0.059
Annual % reduction		5.7	-113.3	49.7	22.0
SC inlet	January 6–8, 2003	13.78	1.0	2.296	0.060
SC inlet	February 18–20, 2003	18.32	18	1.198	0.091
SC inlet	August 12–14, 2003	5.48	<1*	1.410	0.048
SC outlet E	January 6–8, 2003	0.17	<1*	2.253	0.030
SC outlet E	February 18–20, 2003	2.33	6.9	0.960	0.033
SC outlet E	August 12–14, 2003	0.00	1.0	0.296	0.046
SC outlet W	January 6–8, 2003	0.94	2.7	2.162	0.033
SC outlet W	February 18–20, 2003	3.50	7.4	1.007	0.043
SC outlet W	August 12–14, 2003	0.00	<1*	0.307	0.033
Annual % reduction		90.8	50.0	28.8	45.2

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)
BW inlet	November 12–14, 2002	<0.01	<0.0005	<0.001	0.009	0.770	<0.01	<0.005	<0.001	0.012
BW inlet	January 27–29, 2003	<0.01	<0.0005	<0.001	0.014	0.490	<0.01	<0.005	<0.001	0.003
BW inlet	July 21–23, 2003	<0.01	<0.0005	0.001	0.004	0.690	<0.01	<0.005	<0.001	0.009
BW outlet	November 12–14, 2002	<0.01	<0.0005	<0.001	0.006	0.780	<0.01	<0.005	<0.001	0.008
BW outlet	January 27–29, 2003	<0.01	<0.0005	<0.001	0.007	0.610	<0.01	<0.005	<0.001	0.008
BW outlet	July 21–23, 2003	<0.01	<0.0005	<0.001	0.003	1.100	<0.01	<0.005	<0.001	0.007
Annual % reduction		na	na	na	40.7	-27.7	na	na	na	4.2
PP inlet	November 12–14, 2002	<0.01	<0.0005	<0.001	0.009	0.820	<0.01	<0.005	0.001	0.024
PP inlet	January 27–29, 2003	<0.01	<0.0005	<0.001	0.007	0.560	<0.01	<0.005	<0.001	0.061
PP inlet	July 21–23, 2003	<0.01	<0.0005	<0.001	0.003	1.100	<0.01	<0.005	<0.001	0.014
PP outlet	November 12–14, 2002	<0.01	<0.0005	<0.001	0.009	0.580	<0.01	<0.005	0.001	0.012
PP outlet	January 27–29, 2003	<0.01	<0.0005	<0.001	0.006	0.530	<0.01	<0.005	<0.001	0.016
PP outlet	July 21–23, 2003	<0.01	<0.0005	<0.001	0.003	0.610	<0.01	<0.005	<0.001	0.018
Annual % reduction		na	na	na	5.3	30.6	na	na	na	53.5
SC inlet	January 6–8, 2003	<0.01	<0.0005	<0.001	0.010	1.400	<0.01	<0.005	0.001	0.010
SC inlet	February 18–20, 2003	<0.01	<0.0005	<0.001	0.014	2.900	<0.01	0.013	0.001	0.026
SC inlet	August 12–14, 2003	<0.01	0.0019	<0.001	<0.001*	1.700	<0.01	<0.005	<0.001	0.028
SC outlet E	January 6–8, 2003	<0.01	<0.0005	0.007	0.01	0.072	<0.01	<0.005	0.002	0.011
SC outlet E	February 18–20, 2003	<0.01	<0.0005	<0.001	0.019	0.200	<0.01	<0.005	<0.001	0.009
SC outlet E	August 12–14, 2003	<0.01	0.0007	0.001	0.002	0.063	<0.01	<0.005	<0.001	0.003
SC outlet W	January 6–8, 2003	<0.01	<0.0005	0.004	0.009	0.300	<0.01	<0.005	<0.001	0.016
SC outlet W	February 18–20, 2003	<0.01	<0.0005	<0.001	0.016	0.470	<0.01	0.009	<0.001	0.009
SC outlet W	August 12–14, 2003	<0.01	<0.0005	<0.001	<0.001*	0.083	<0.01	<0.005	<0.001	0.006
Annual % reduction		na	na	na	-14.0	90.1	na	na	na	57.8

*Value replaced with detection limit to calculate percent reduction.

Table 25: Park Place/Brentwood wet ponds and South Campus rock/plant filter composite samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

Site	Time	Month	Day	Year	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
BW inlet	A	11	12	2002	12.2	6.91	8.57	172	316	315
BW inlet	B	11	13	2002	12.7	6.97	8.52	260	2100	2200
BW inlet	C	11	13	2002	12.9	7.08	8.97	271	1300	1100
BW inlet	D	11	14	2002	12.8	7.05	9.01	256	2100	2400
BW outlet	A	11	12	2002	10.1	7.47	7.45	222	290	270
BW outlet	B	11	13	2002	9.4	7.33	6.67	186	360	370
BW outlet	C	11	13	2002	10.1	7.40	7.88	189	192	480
BW outlet	D	11	14	2002	9.3	7.28	6.63	188	880	640
Seasonal % reduction					23.1	-5.2	18.4	18.2	70.4	70.7
BW inlet	A	1	27	2003	9.3	6.85	10.00	207	260	310
BW inlet	B	1	28	2003	9.5	6.80	9.94	231	2100	3280
BW inlet	C	1	28	2003	9.4	6.86	10.00	231	1300	1400
BW inlet	D	1	29	2003	7.0	6.70	10.67	103	140	220
BW outlet	A	1	27	2003	9.5	6.98	8.43	181	270	132
BW outlet	B	1	28	2003	8.0	6.93	8.61	185	900	820
BW outlet	C	1	28	2003	9.4	6.93	8.24	186	580	1300
BW outlet	D	1	29	2003	7.4	6.90	8.16	191	720	420
Seasonal % reduction					2.6	-1.9	17.7	3.8	35.0	48.7
BW inlet	A	7	21	2003	20.4	6.97	7.23	294	3200	1800
BW inlet	B	7	22	2003	20.1	7.08	7.50	282	2600	3700
BW inlet	C	7	22	2003	20.2	7.03	7.41	293	860	760
BW inlet	D	7	23	2003	20.0	6.86	6.73	286	28000	36000
BW outlet	A	7	21	2003	31.0	9.53	14.17	188	1	2
BW outlet	B	7	22	2003	23.6	8.52	7.58	195	6	4
BW outlet	C	7	22	2003	31.0	9.53	13.82	188	<1*	<1*
BW outlet	D	7	23	2003	23.0	8.21	6.44	196	3	<1*
Seasonal % reduction					-34.6	-28.1	-45.5	33.6	100.0	100.0
Annual % reduction					-9.2	-11.8	0.4	20.5	90.5	91.7

*Value replaced with detection limit to calculate percent reduction.

Table 26: Brentwood wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were as follows: A = afternoon, day 1; B = morning, day 2; C = afternoon, day 2; D = morning, day 3. Negative values represent an increase in concentration at the outlet.

Site	Time	Month	Day	Year	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
PP inlet	A	11	12	2002	11.3	7.32	10.07	53	1050	950
PP inlet	B	11	13	2002	10.6	7.51	10.16	184	108	124
PP inlet	C	11	13	2002	10.7	7.53	10.30	180	83	160
PP inlet	D	11	14	2002	10.5	7.48	10.18	179	60	90
PP outlet	A	11	12	2002	10.1	7.30	7.31	152	170	150
PP outlet	B	11	13	2002	9.6	7.21	6.54	146	400	320
PP outlet	C	11	13	2002	10.2	7.30	7.70	148	154	3600
PP outlet	D	11	14	2002	9.5	7.14	5.90	151	260	880
Seasonal % reduction					8.6	3.0	32.6	-0.2	24.4	-273.9
PP inlet	A	1	27	2003	8.7	7.22	10.55	152	124	176
PP inlet	B	1	28	2003	8.5	7.32	11.16	171	100	204
PP inlet	C	1	28	2003	8.5	7.28	11.12	169	96	116
PP inlet	D	1	29	2003	7.0	7.08	11.17	77	250	360
PP outlet	A	1	27	2003	8.8	7.22	10.17	157	216	240
PP outlet	B	1	28	2003	7.8	7.19	9.90	161	280	260
PP outlet	C	1	28	2003	8.5	7.19	10.79	163	230	260
PP outlet	D	1	29	2003	7.0	7.26	10.12	169	180	250
Seasonal % reduction					1.8	0.1	6.9	-14.3	-58.9	-18.0
PP inlet	A	7	21	2003	18.8	7.49	8.31	332	21000	13000
PP inlet	B	7	22	2003	19.0	7.66	8.54	239	92	40
PP inlet	C	7	22	2003	19.2	7.58	8.34	250	160	120
PP inlet	D	7	23	2003	18.5	7.31	7.94	231	43	170
PP outlet	A	7	21	2003	30.0	10.43	16.70	180	6	9
PP outlet	B	7	22	2003	21.0	9.59	8.75	163	<1*	<1*
PP outlet	C	7	22	2003	29.0	10.48	17.16	183	1	<1*
PP outlet	D	7	23	2003	21.0	9.42	8.28	166	<1*	<1*
Seasonal % reduction					-33.8	-32.9	-53.6	34.2	100.0	99.9
Annual % reduction					-14.0	-10.1	-1.3	12.5	91.8	61.5

*Value replaced with detection limit to calculate percent reduction.

Table 27: Park Place wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were as follows: A = afternoon, day 1; B = morning, day 2; C = afternoon, day 2; D = morning, day 3. Negative values represent an increase in concentration at the outlet.

Site	Time	Month	Day	Year	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
SC inlet	A	1	6	2003	10.5	7.38	9.26	327	40	20
SC inlet	B	1	7	2003	9.5	7.45	10.73	356	11	14
SC inlet	C	1	7	2003	9.7	7.39	9.61	361	11	9
SC inlet	D	1	8	2003	9.7	7.41	9.52	380	9	5
SC outlet E	A	1	6	2003	7.4	7.59	8.58	324	1	<1*
SC outlet E	B	1	7	2003	7.2	7.59	8.21	350	<1*	<1*
SC outlet E	C	1	7	2003	7.0	7.55	8.47	355	<1*	<1*
SC outlet E	D	1	8	2003	6.5	7.53	8.08	373	<1*	<1*
SC outlet W	A	1	6	2003	7.5	7.55	9.96	314	<1*	<1*
SC outlet W	B	1	7	2003	7.5	7.53	8.73	340	<1*	<1*
SC outlet W	C	1	7	2003	7.5	7.53	8.60	344	<1*	1
SC outlet W	D	1	8	2003	6.0	7.51	8.24	364	<1*	<1*
Seasonal % reduction					28.1	-1.9	12.0	2.9	94.4	91.7
SC inlet	A	2	18	2003	8.4	7.44	10.74	262	40	46
SC inlet	B	2	19	2003	8.5	7.51	10.55	293	17	49
SC inlet	C	2	19	2003	8.5	7.50	10.35	300	23	17
SC inlet	D	2	20	2003	8.5	7.87	10.30	291	24	54
SC outlet E	A	2	18	2003	7.5	7.74	8.76	281	<1*	1
SC outlet E	B	2	19	2003	7.5	7.73	8.36	296	4	1
SC outlet E	C	2	19	2003	7.5	7.72	8.95	303	1	1
SC outlet E	D	2	20	2003	7.6	7.70	8.65	310	8	12
SC outlet W	A	2	18	2003	7.8	7.78	9.32	278	2	13
SC outlet W	B	2	19	2003	7.5	7.79	8.42	293	3	1
SC outlet W	C	2	19	2003	8.0	7.78	8.87	295	3	2
SC outlet W	D	2	20	2003	8.1	7.83	10.54	310	8	12
Seasonal % reduction					9.3	-2.4	14.3	-3.2	85.6	87.0
SC inlet	A	8	12	2003	16.0	7.37	7.26	459	110	81
SC inlet	B	8	13	2003	15.0	7.29	7.34	465	33	70
SC inlet	C	8	13	2003	16.2	7.37	7.30	464	33	27
SC inlet	D	8	14	2003	16.3	7.26	7.41	462	58	32
SC outlet E	A	8	12	2003	17.0	7.44	4.48	446	35	48
SC outlet E	B	8	13	2003	17.0	7.39	4.69	453	21	19
SC outlet E	C	8	13	2003	16.9	7.43	5.17	452	33	16
SC outlet E	D	8	14	2003	17.0	7.33	4.76	458	29	37
SC outlet W	A	8	12	2003	18.0	7.40	3.74	440	68	75
SC outlet W	B	8	13	2003	17.0	7.35	3.69	445	21	15
SC outlet W	C	8	13	2003	16.8	7.36	3.77	445	8	8
SC outlet W	D	8	14	2003	16.8	7.36	3.97	449	65	71
Seasonal % reduction					-7.5	-0.8	41.5	3.0	40.2	31.2
Annual % reduction					6.9	-1.7	20.7	1.4	61.1	59.9

*Value replaced with detection limit to calculate percent reduction.

Table 28: South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Sample collection times were as follows: A = afternoon, day 1; B = morning, day 2; C = afternoon, day 2; D = morning, day 3. Negative values represent an increase in concentration at the outlet.

	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 29: Summary of 2002/2003 single-blind quality control results.

9 Figures

- Figure 1 (page 66) provides a general map of Lake Whatcom and its tributaries, and shows the current lake sampling sites. Refer to Appendix A, Figures 190–191 (pages 258–259) for detailed maps showing lake sampling locations.
- Figures 2–51 (pages 67–116) show single-day Hydrolab profiles from Lake Whatcom for all 2002/2003 sampling dates.
- Figures 52–71 (pages 117–136) show multi-year plots of Hydrolab data for Lake Whatcom. Lines connect data from a single sampling depth through time to help identify seasonal patterns; the lines do not represent continuous sampling. The minimum and maximum values represent only dates actually samples, not the annual extremes. Missing values were not interpolated.
- Figures 72 and 73 (pages 137 and 138) summarize 1988–2003 temperature data for the lake.
- Figures 74–138 (pages 139–203) show multi-year plots of water quality, chlorophyll, plankton, and Secchi depth data for Lake Whatcom.
- Figures 139–149 (pages 204–214) show multi-year plots of fecal coliforms and *E. coli* counts for Lake Whatcom, and comparisons between fecal coliform counts and E. coli counts.
- Figures 150 and 151 (pages 215 and 216) show iron concentrations in untreated drinking water (gatehouse) and average trihalomethanes concentrations in the Bellingham water distribution system.
- Figures 152–156 (pages 217–221) show correlations between date and dissolved oxygen during the summer at Site 1, 12–18 m.
- Figures 157–168 (pages 222–233) show the hydrograph data and rating curves from Austin, Anderson, and Smith Creeks; the water balance figures; and a summary of the Middle Fork diversion.
- Figures 169–173 (pages 234–238) show sampling locations for the Park Place and Brentwood wet ponds and the South Campus storm water treatment facility and current photographs of each site. Figures 174–176 (pages 239–241) summarize the total suspended solids and total phosphorus removal provided by each storm water treatment facility.
- Figures 177–189 (pages 242–254) show the field and laboratory quality control results and Hydrolab quality control comparisons.

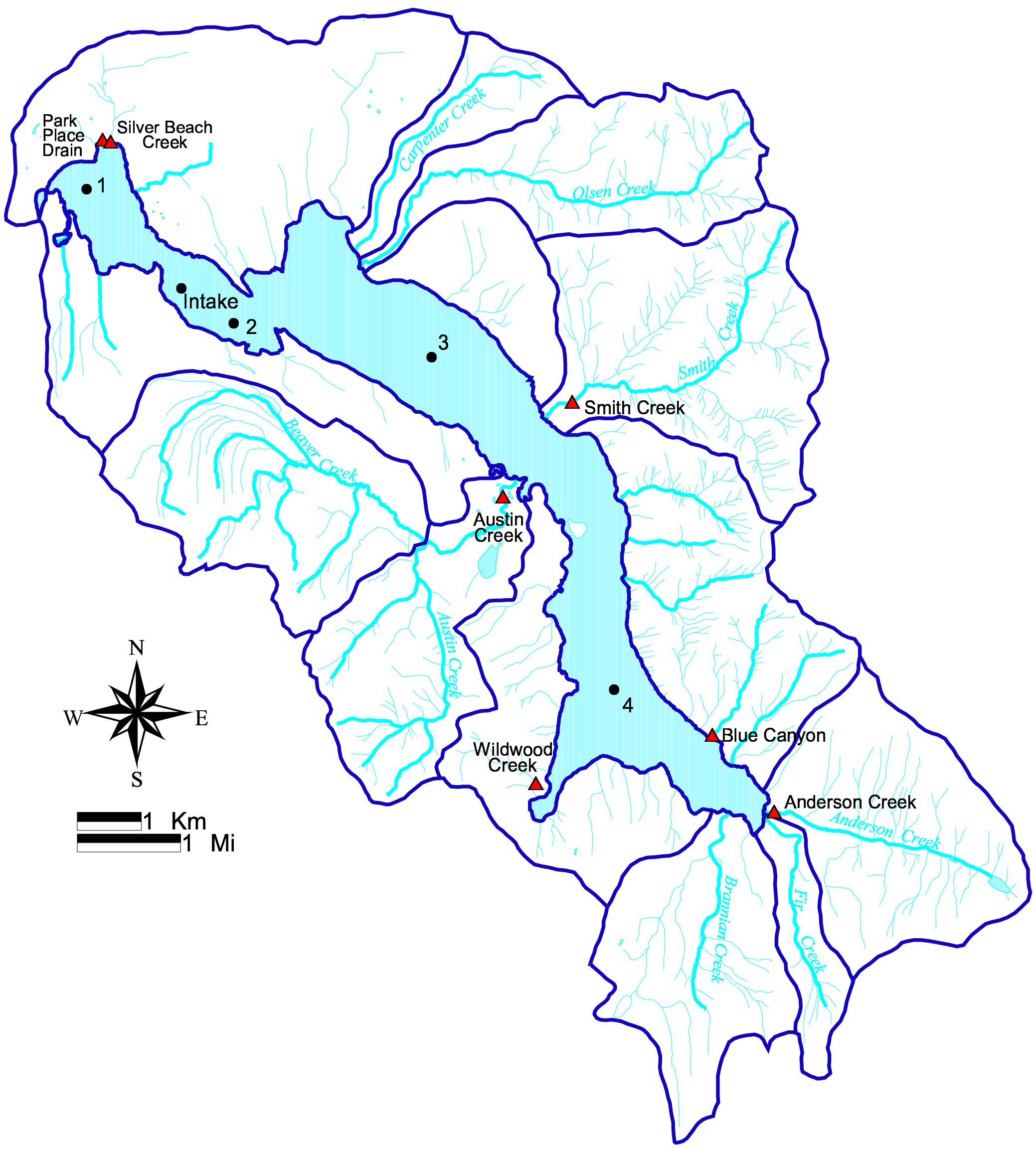


Figure 1: Lake Whatcom 2002/2003 sampling sites.

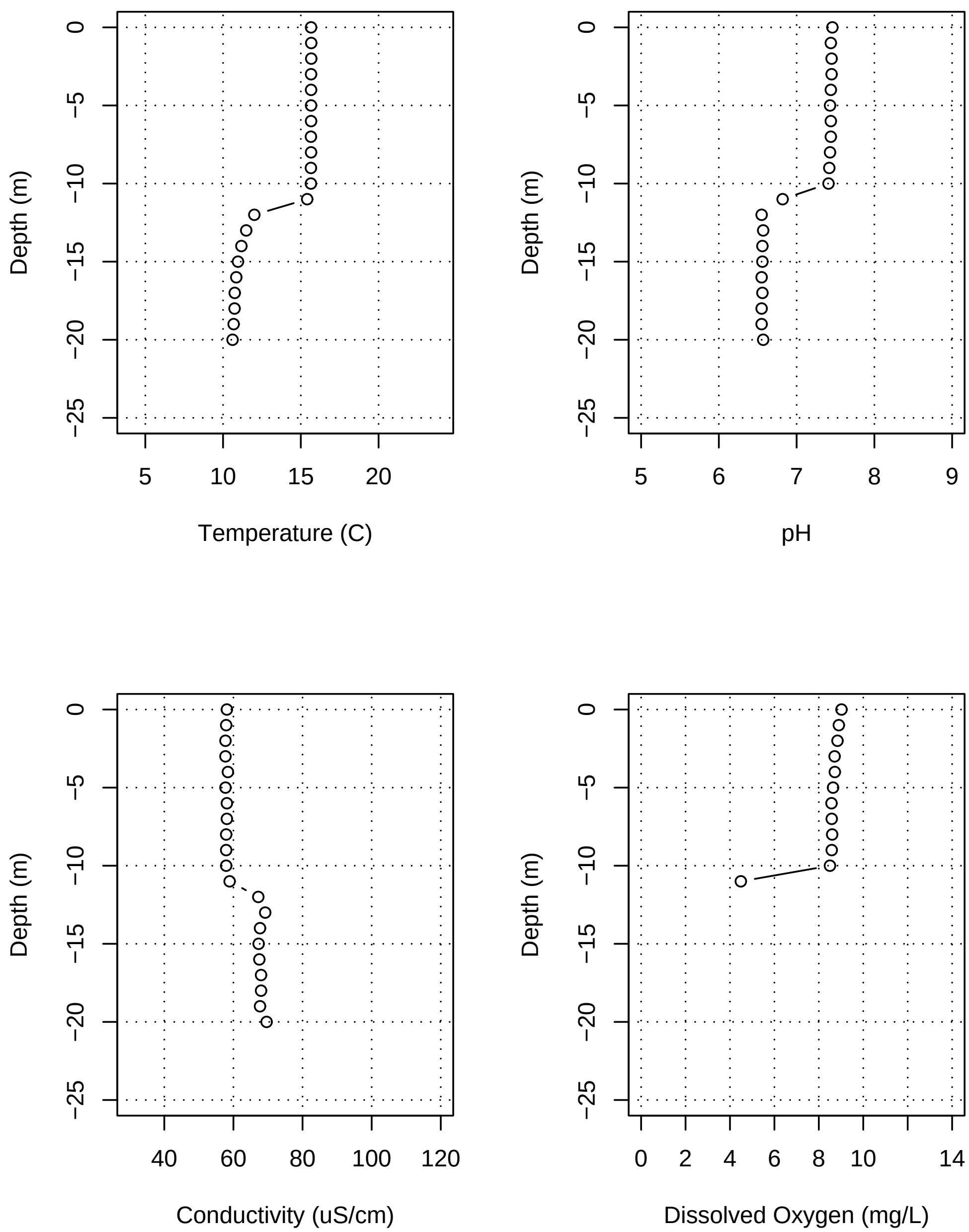


Figure 2: Lake Whatcom Hydrolab profile for Site 1, October 10, 2002. Values <2.0 mg/L have been deleted due to Hydrolab malfunction.

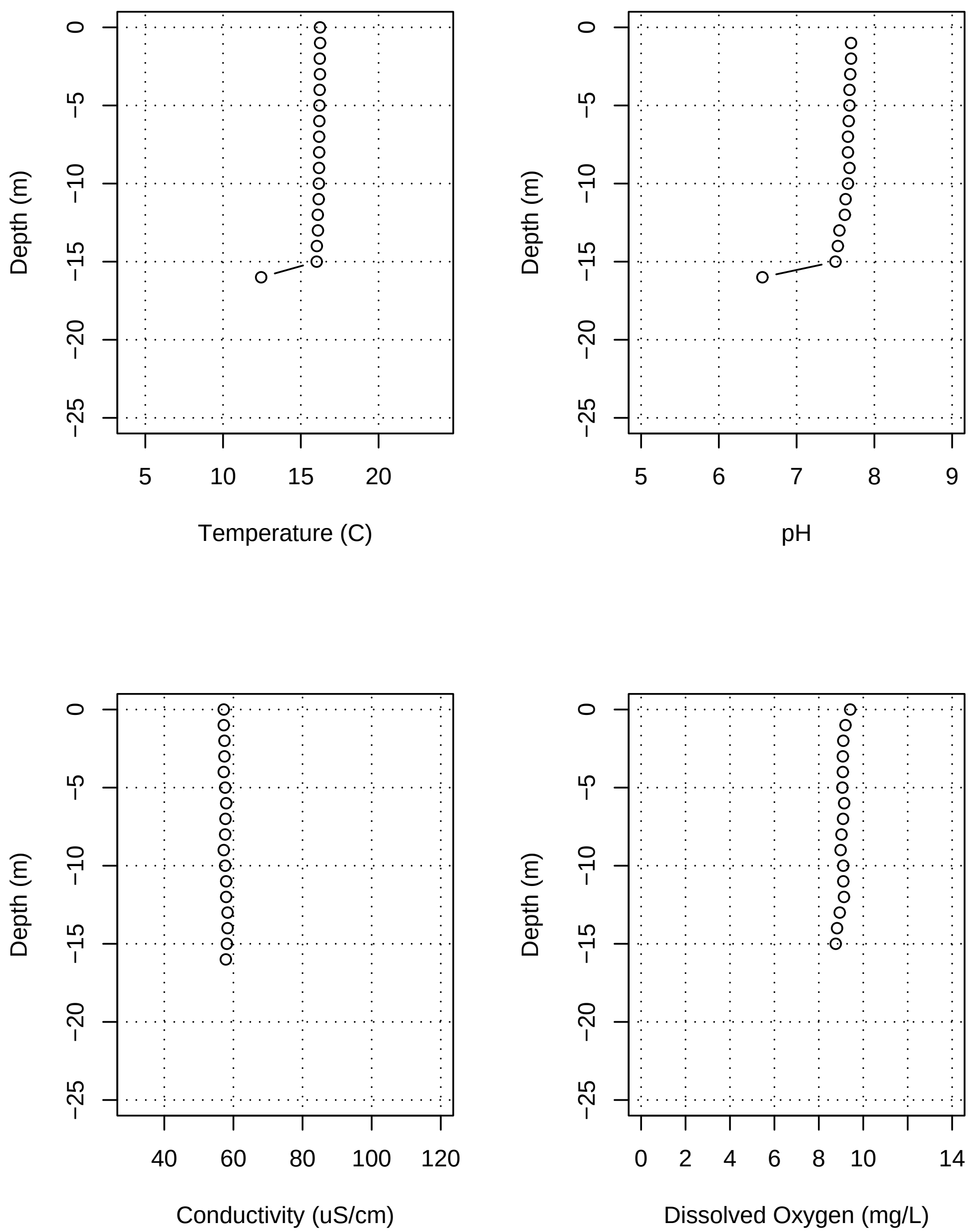


Figure 3: Lake Whatcom Hydrolab profile for Site 2, October 10, 2002. Values $<$2.0 mg/L have been deleted due to Hydrolab malfunction.

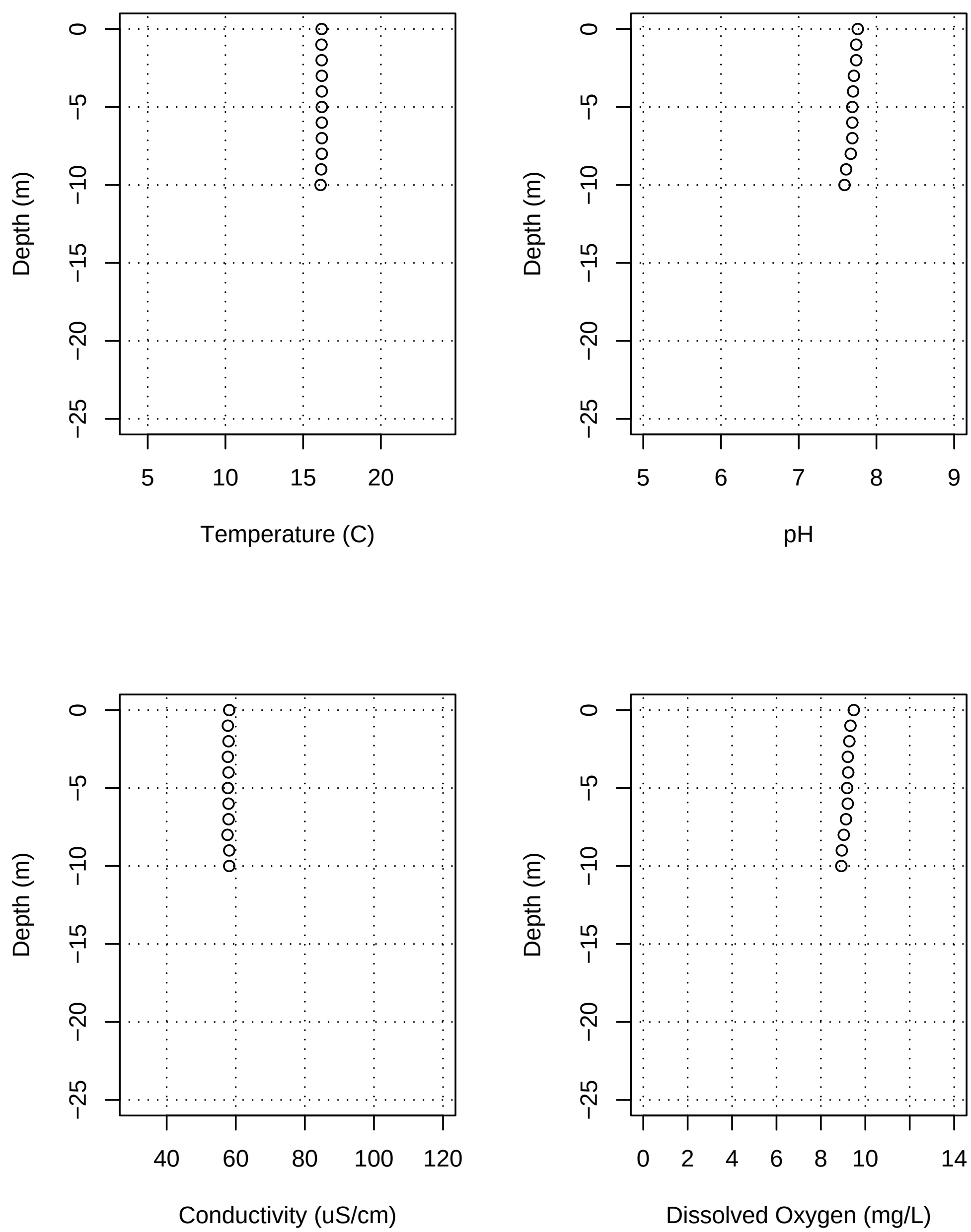


Figure 4: Lake Whatcom Hydrolab profile for the Intake, October 10, 2002.

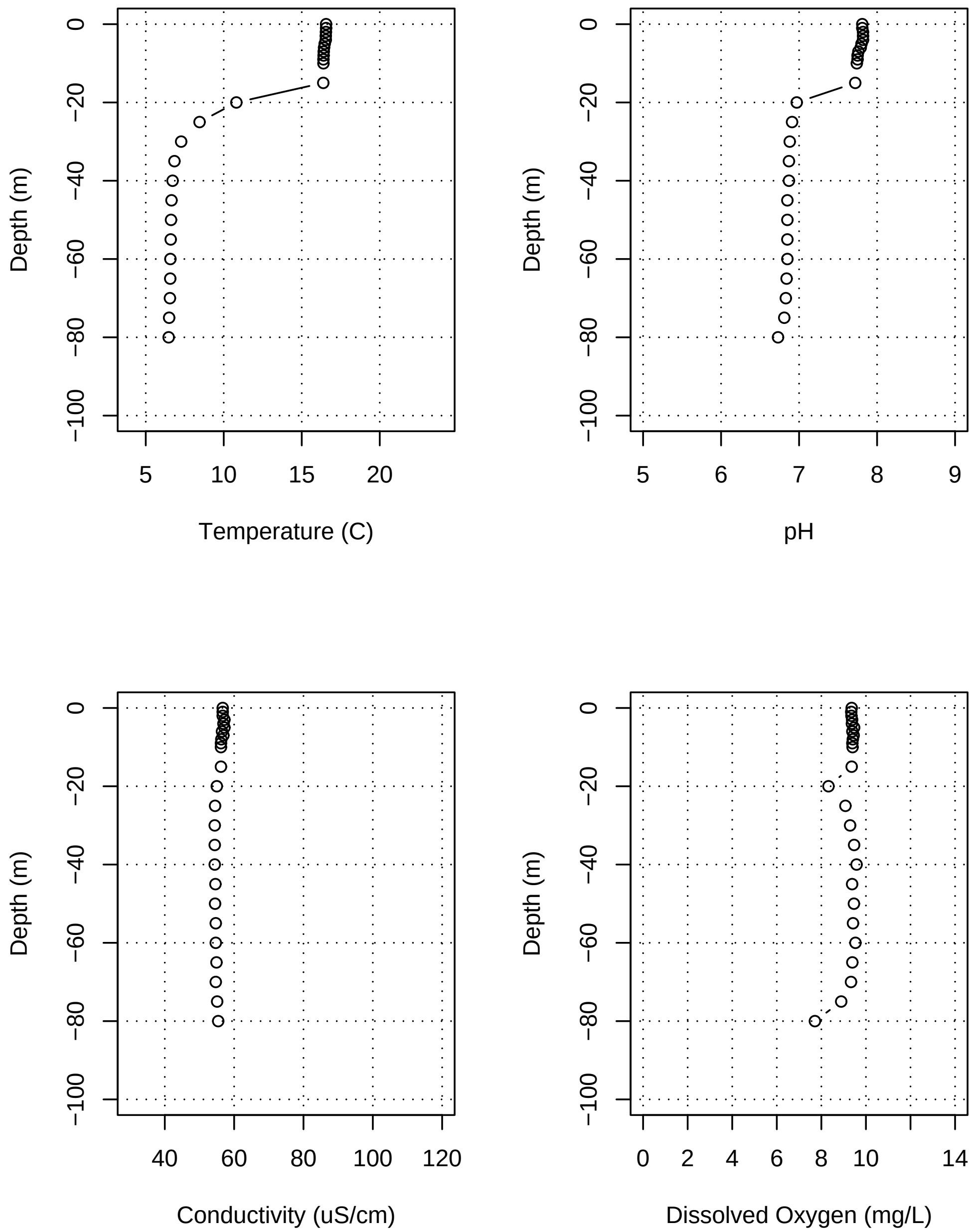


Figure 5: Lake Whatcom Hydrolab profile for Site 3, October 8, 2002.

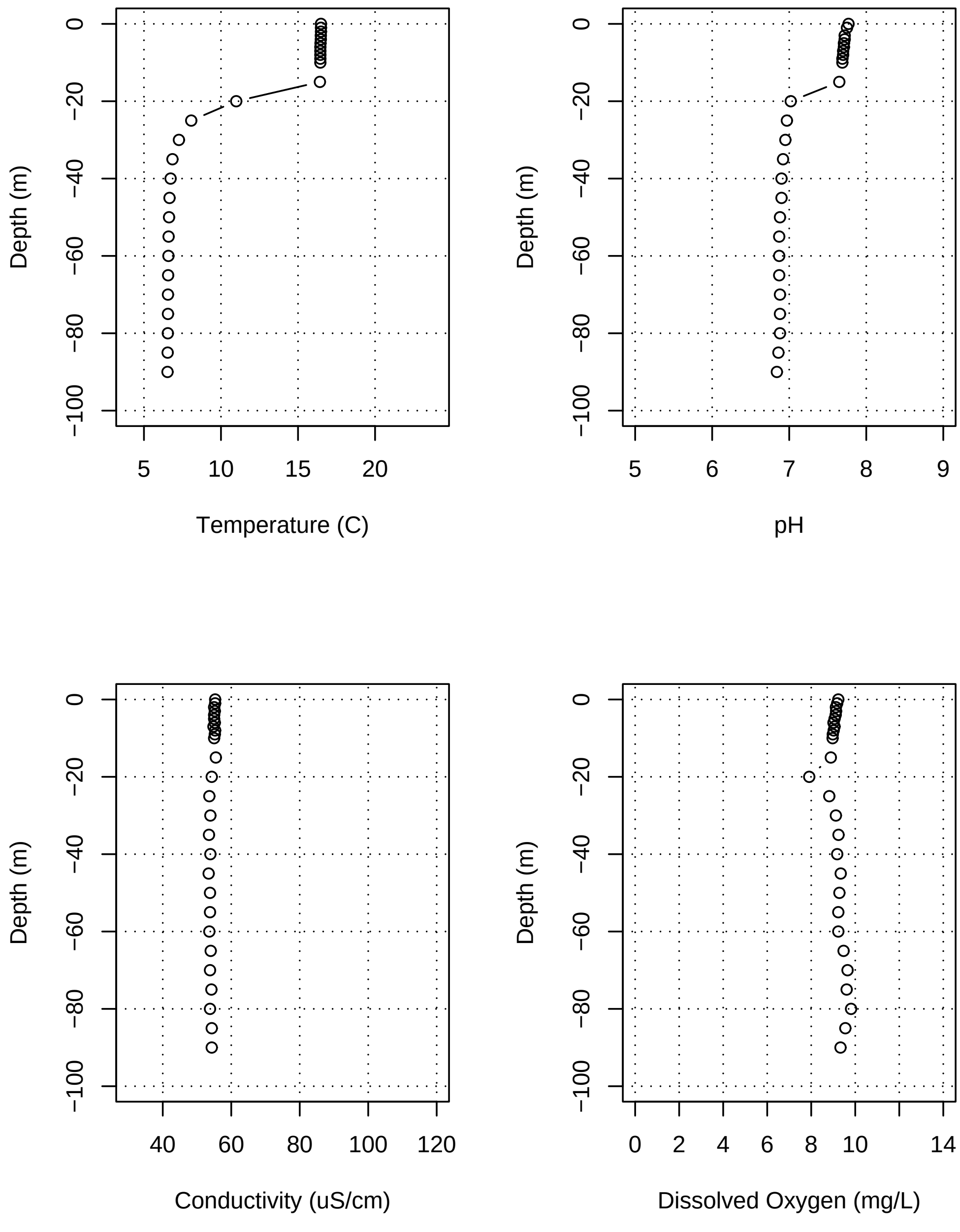


Figure 6: Lake Whatcom Hydrolab profile for Site 4, October 8, 2002.

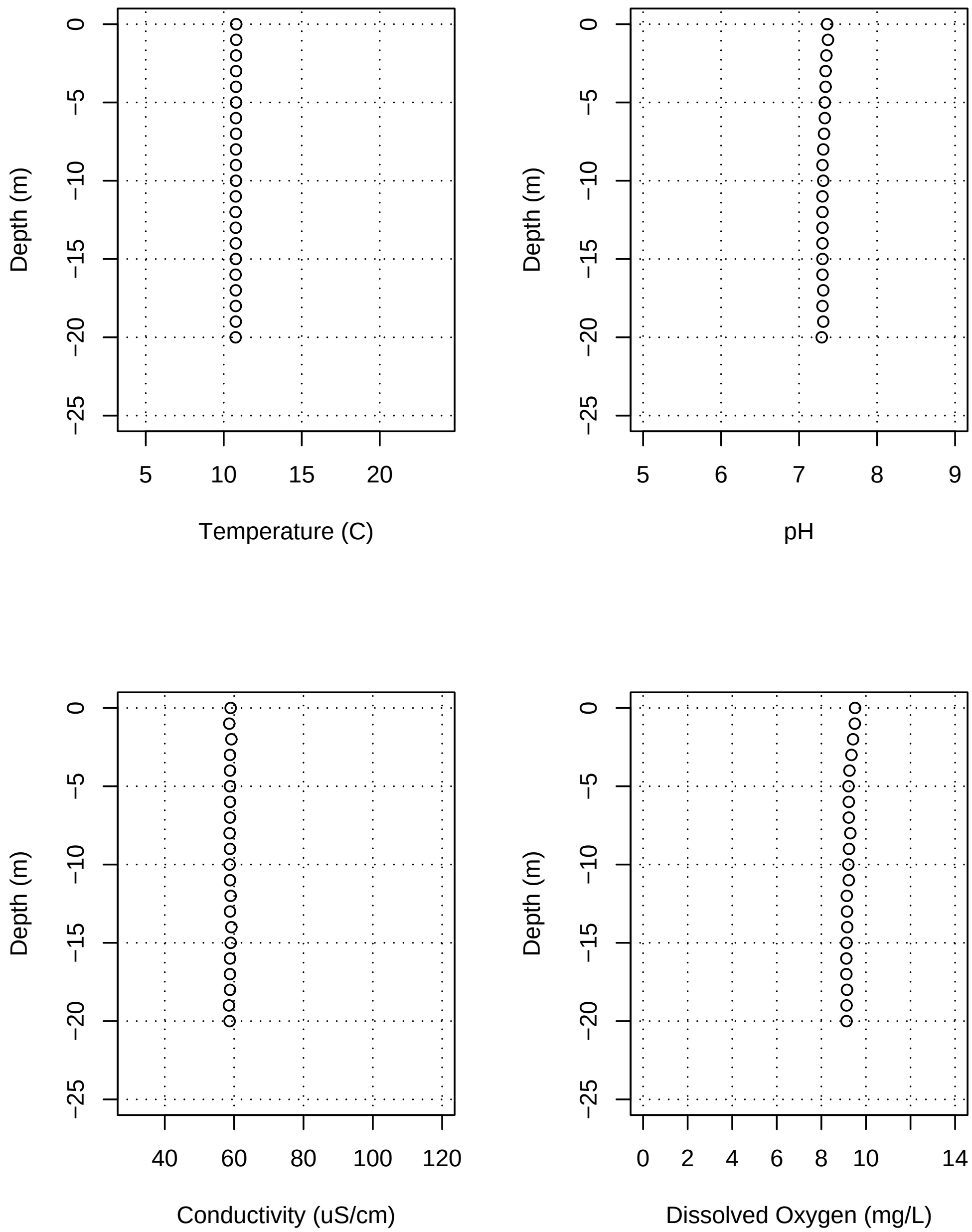


Figure 7: Lake Whatcom Hydrolab profile for Site 1, November 13, 2002.

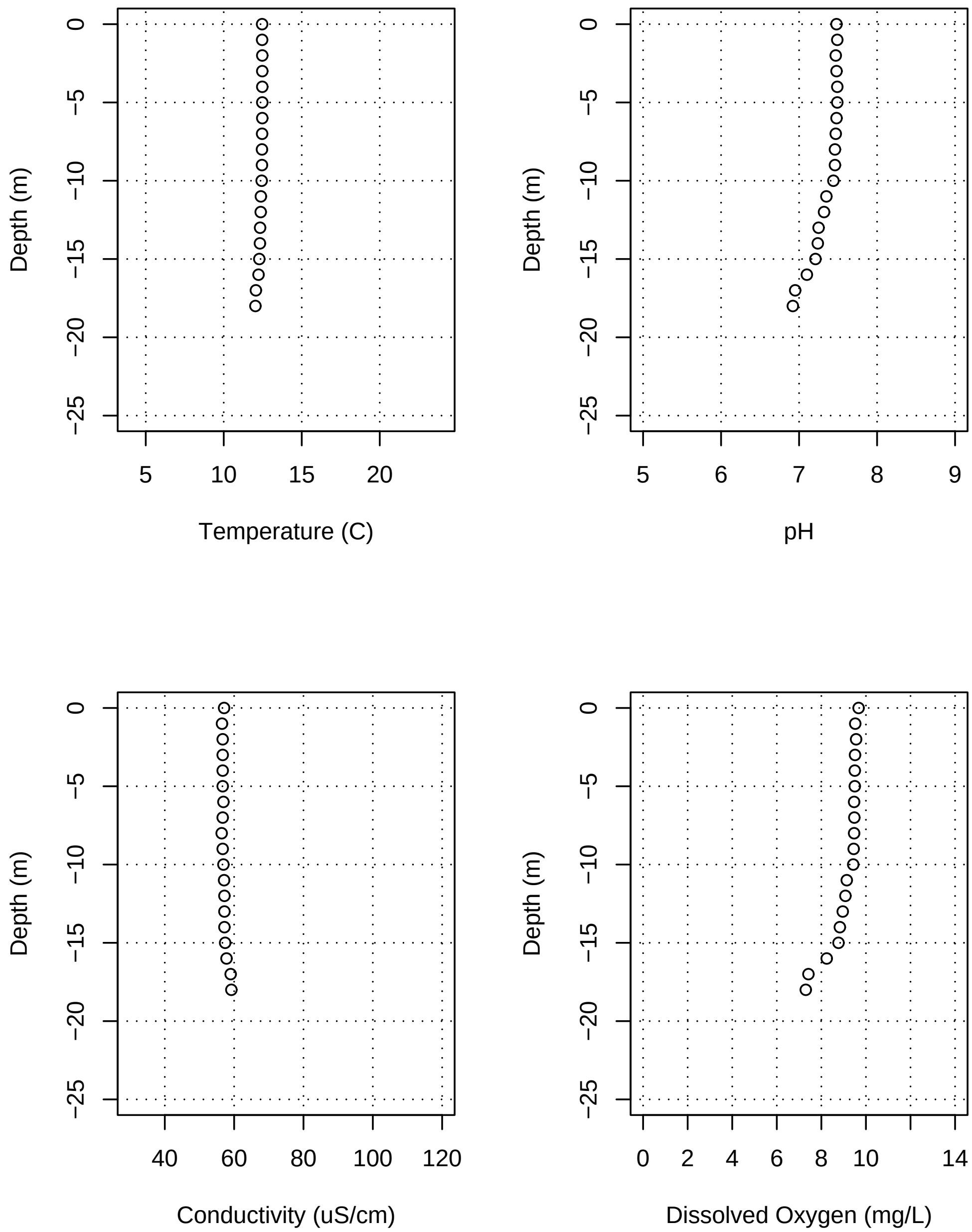


Figure 8: Lake Whatcom Hydrolab profile for Site 2, November 7, 2002.

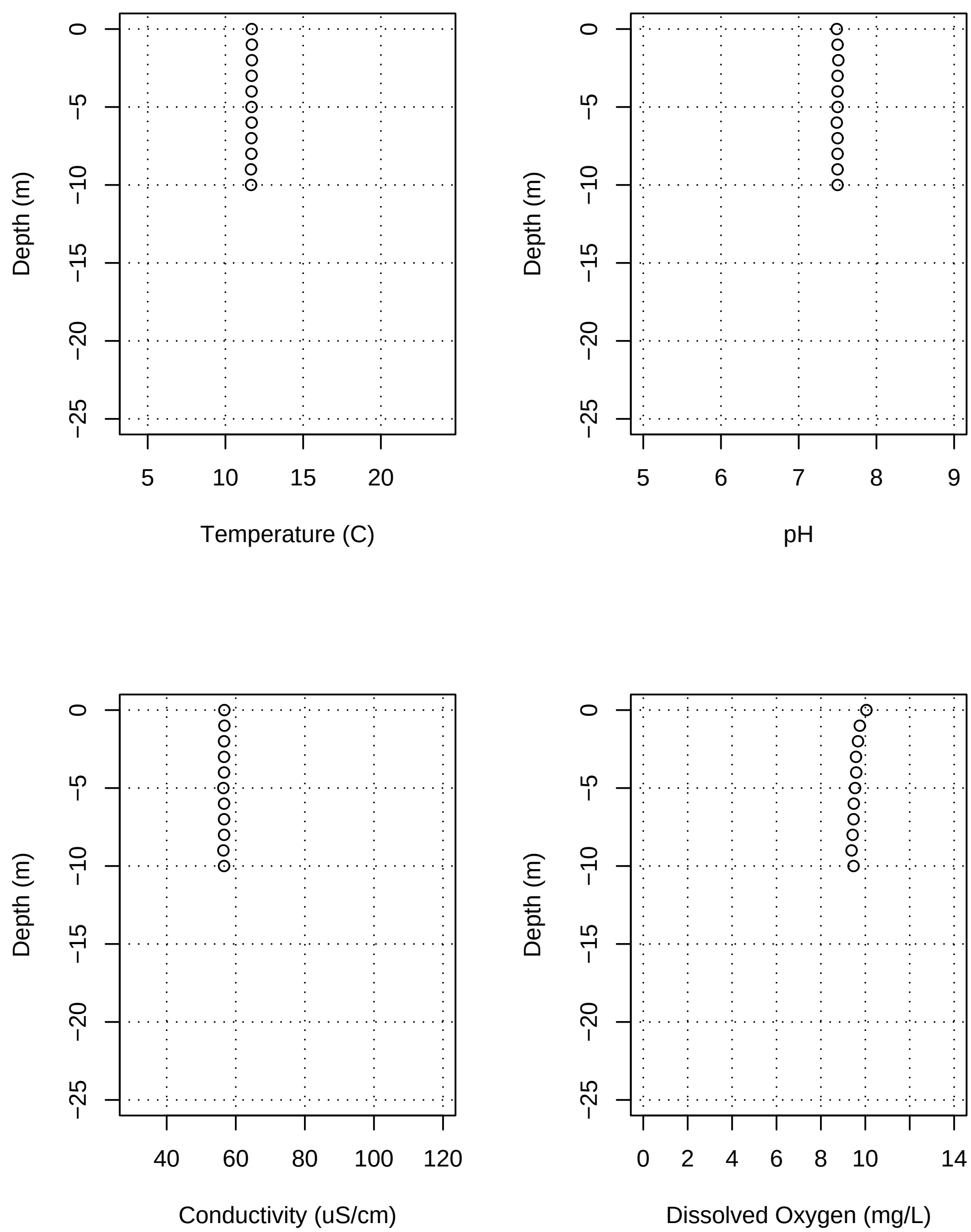


Figure 9: Lake Whatcom Hydrolab profile for the Intake, November 13, 2002.

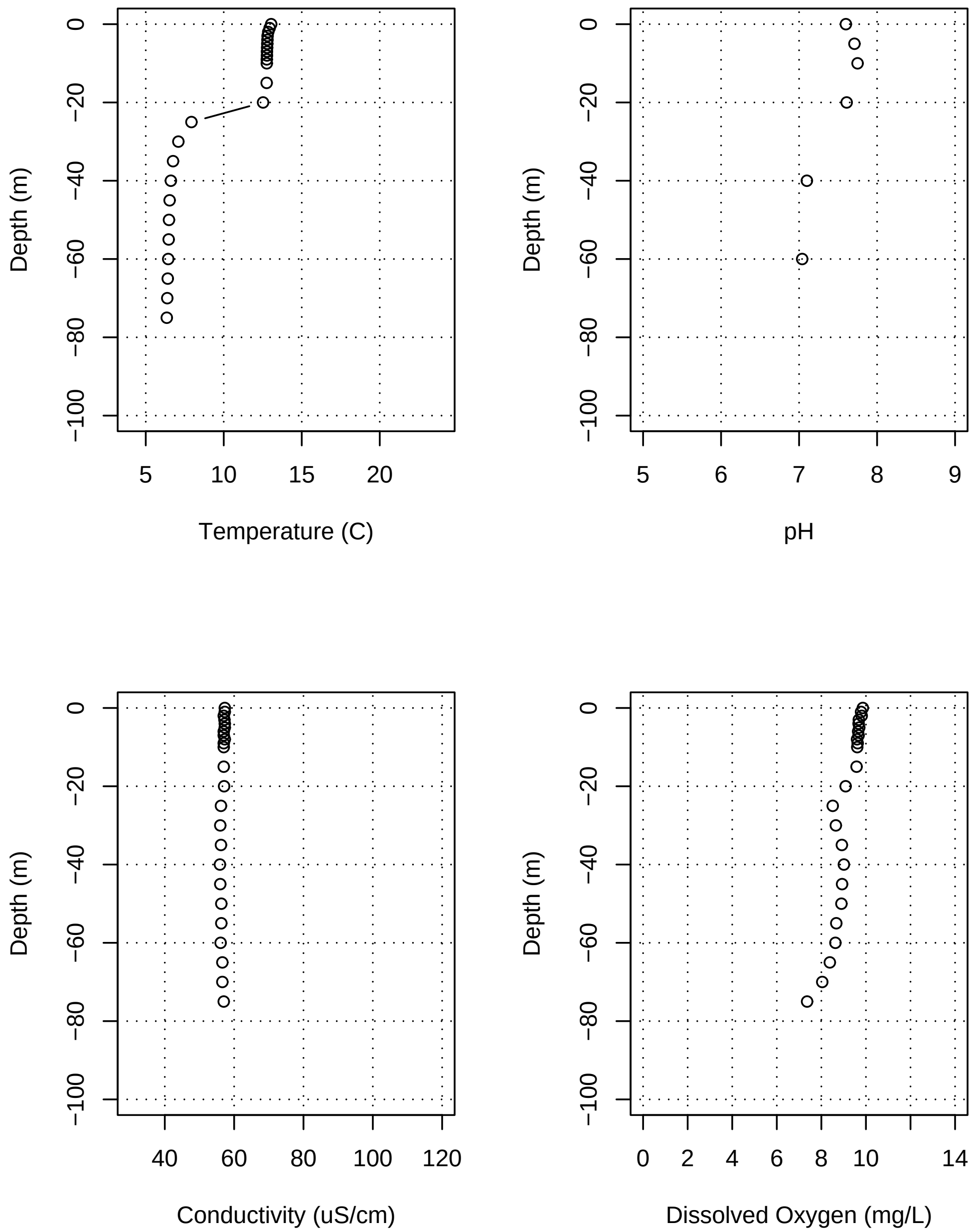


Figure 10: Lake Whatcom Hydrolab profile for Site 3, November 5, 2002.

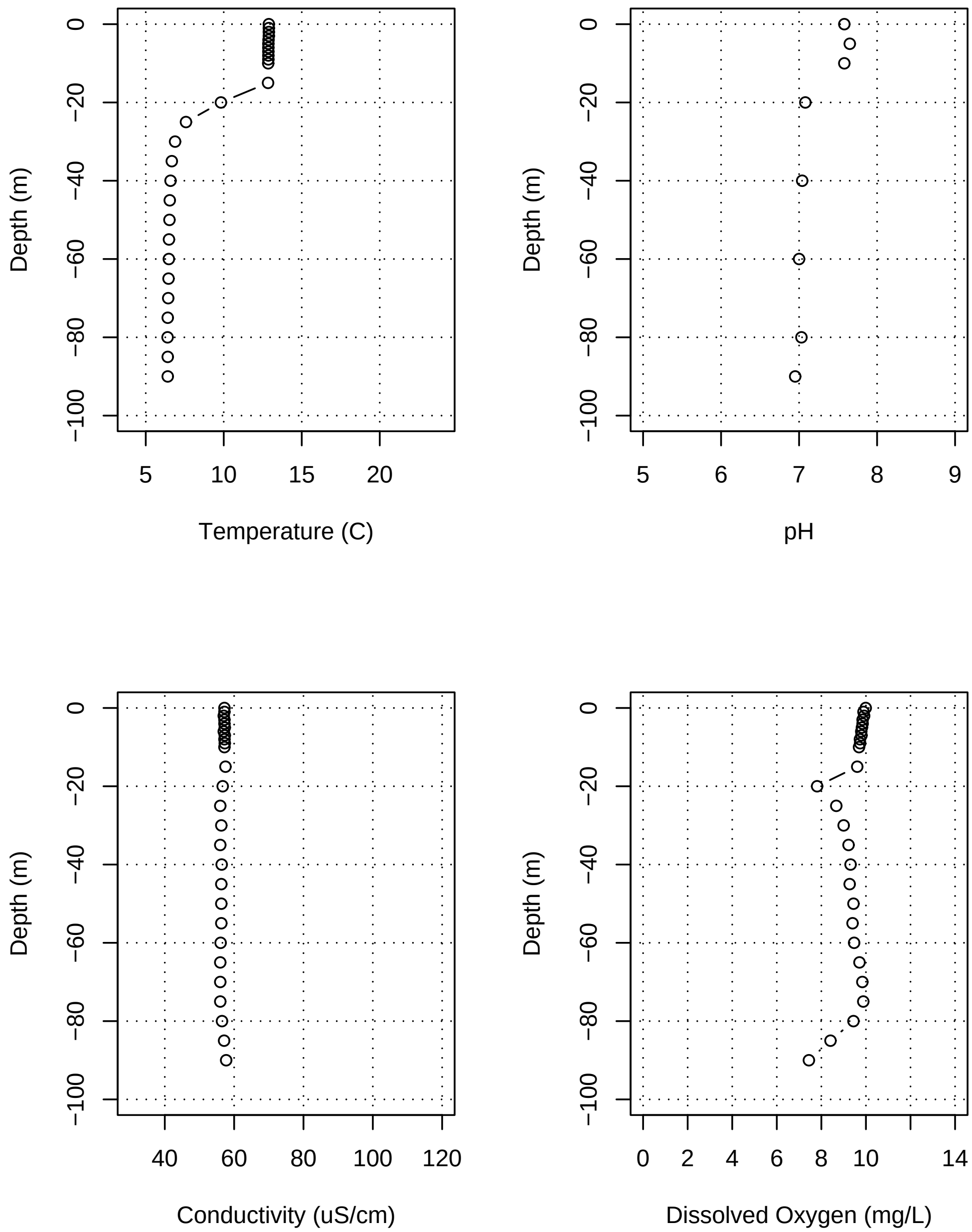


Figure 11: Lake Whatcom Hydrolab profile for Site 4, November 5, 2002.

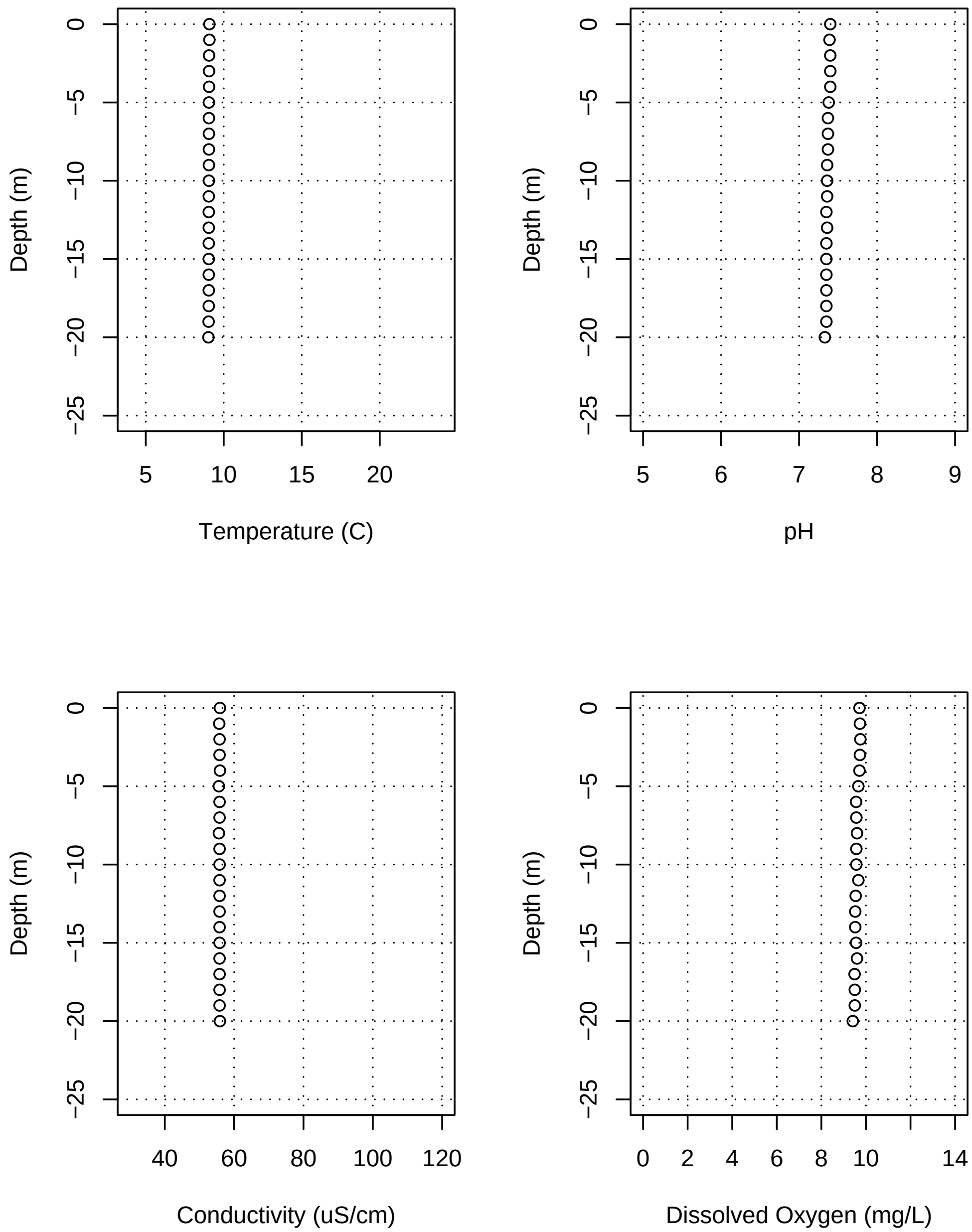


Figure 12: Lake Whatcom Hydrolab profile for Site 1, December 5, 2002.

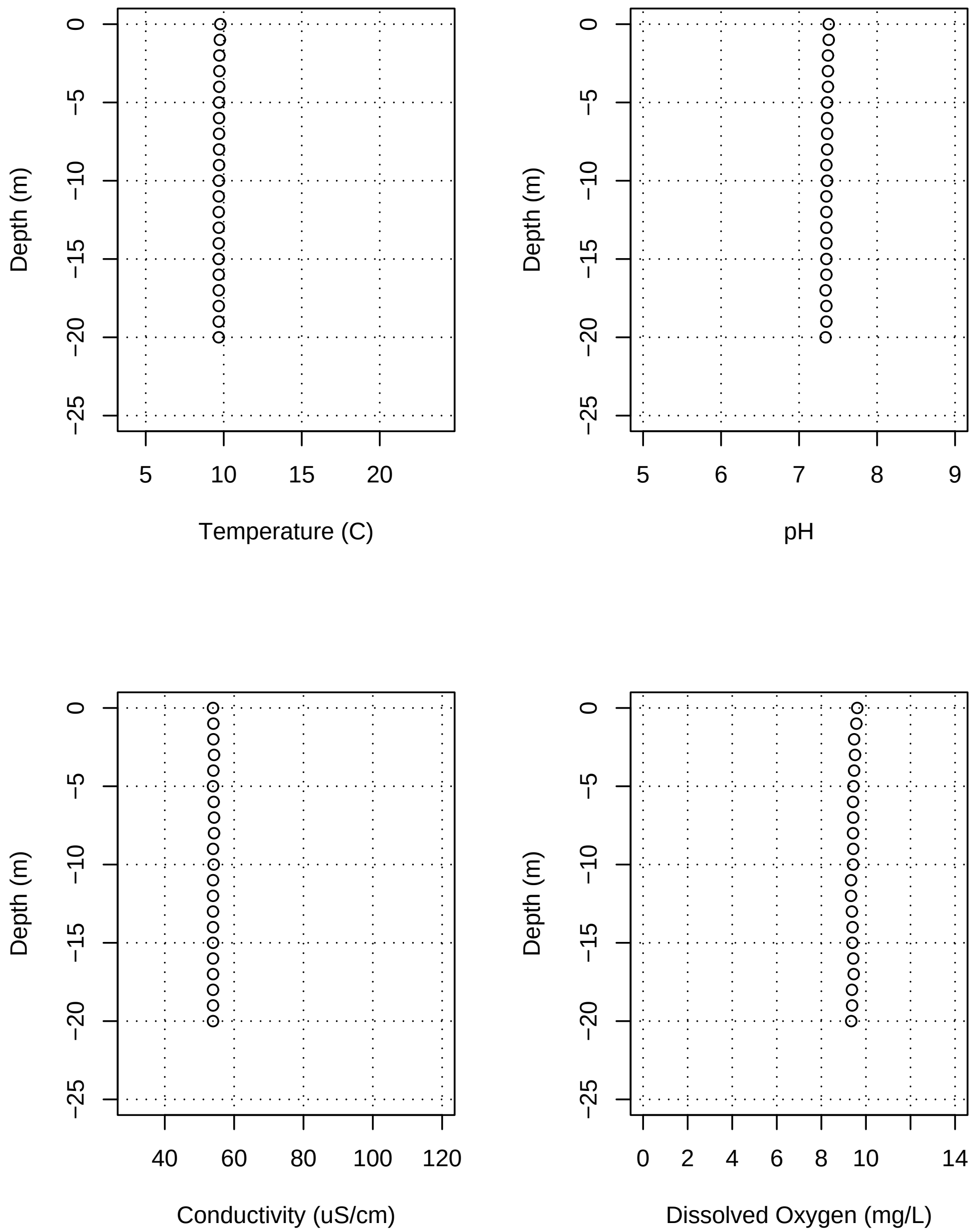


Figure 13: Lake Whatcom Hydrolab profile for Site 2, December 5, 2002.

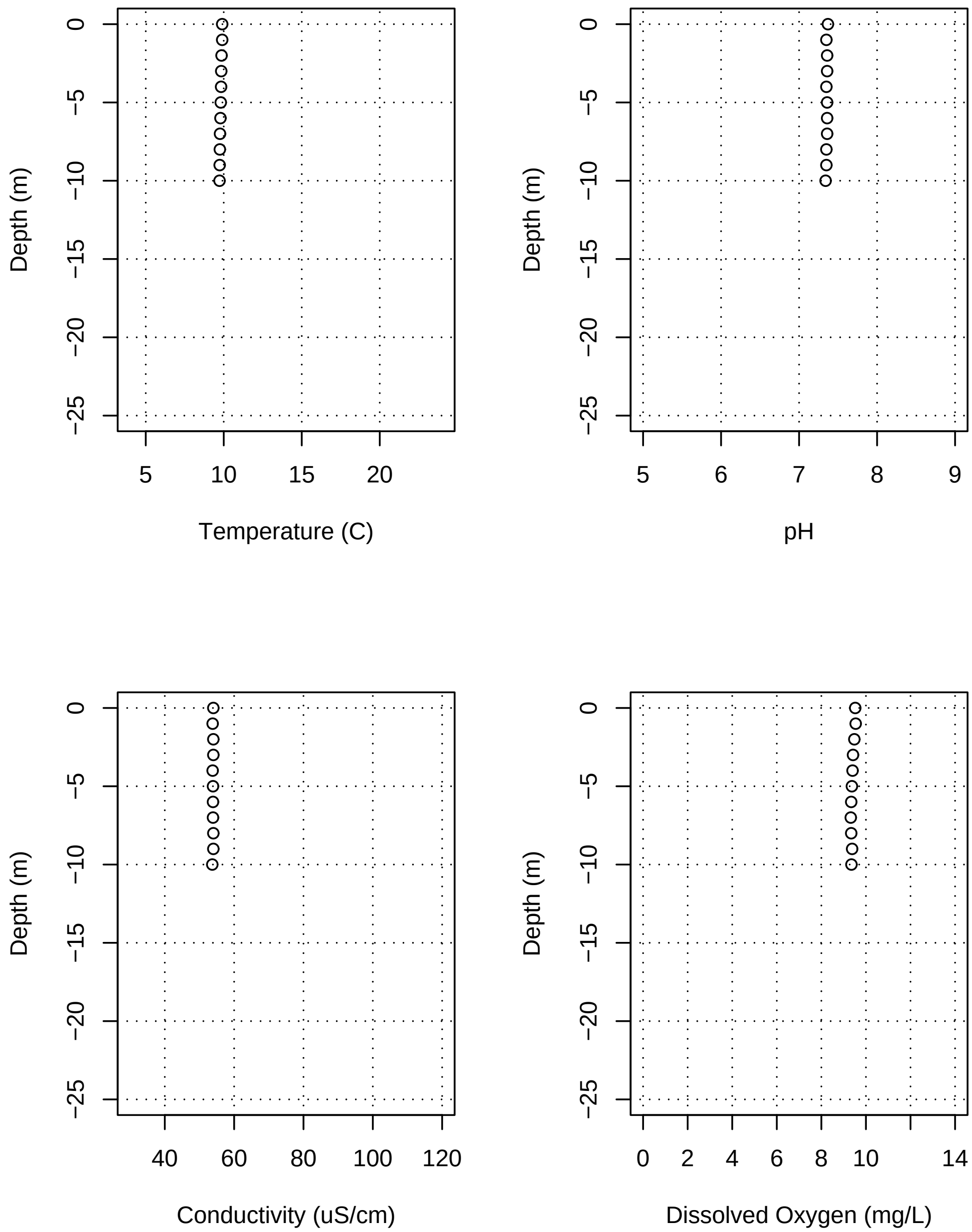


Figure 14: Lake Whatcom Hydrolab profile for the Intake, December 5, 2002.

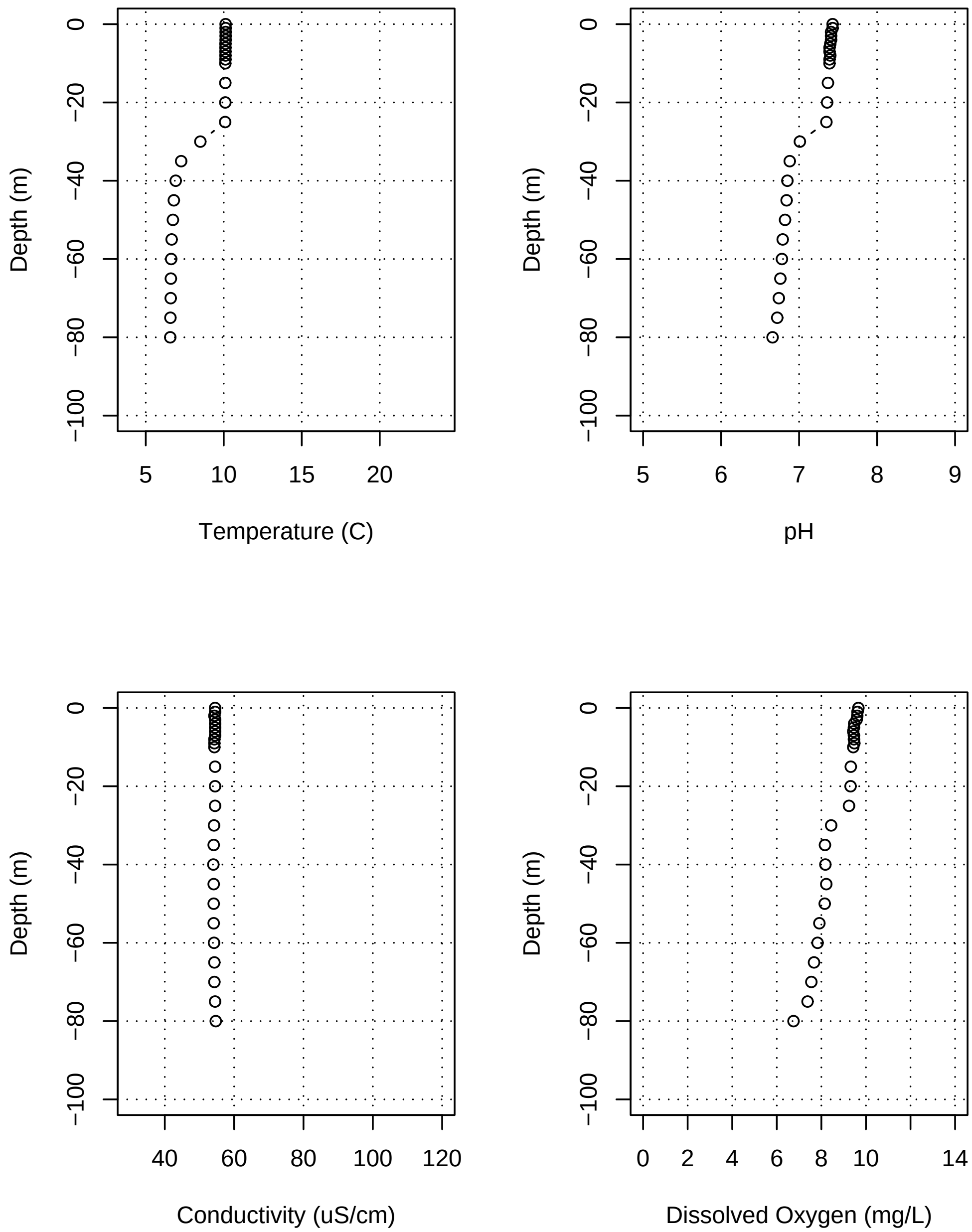


Figure 15: Lake Whatcom Hydrolab profile for Site 3, December 3, 2002.

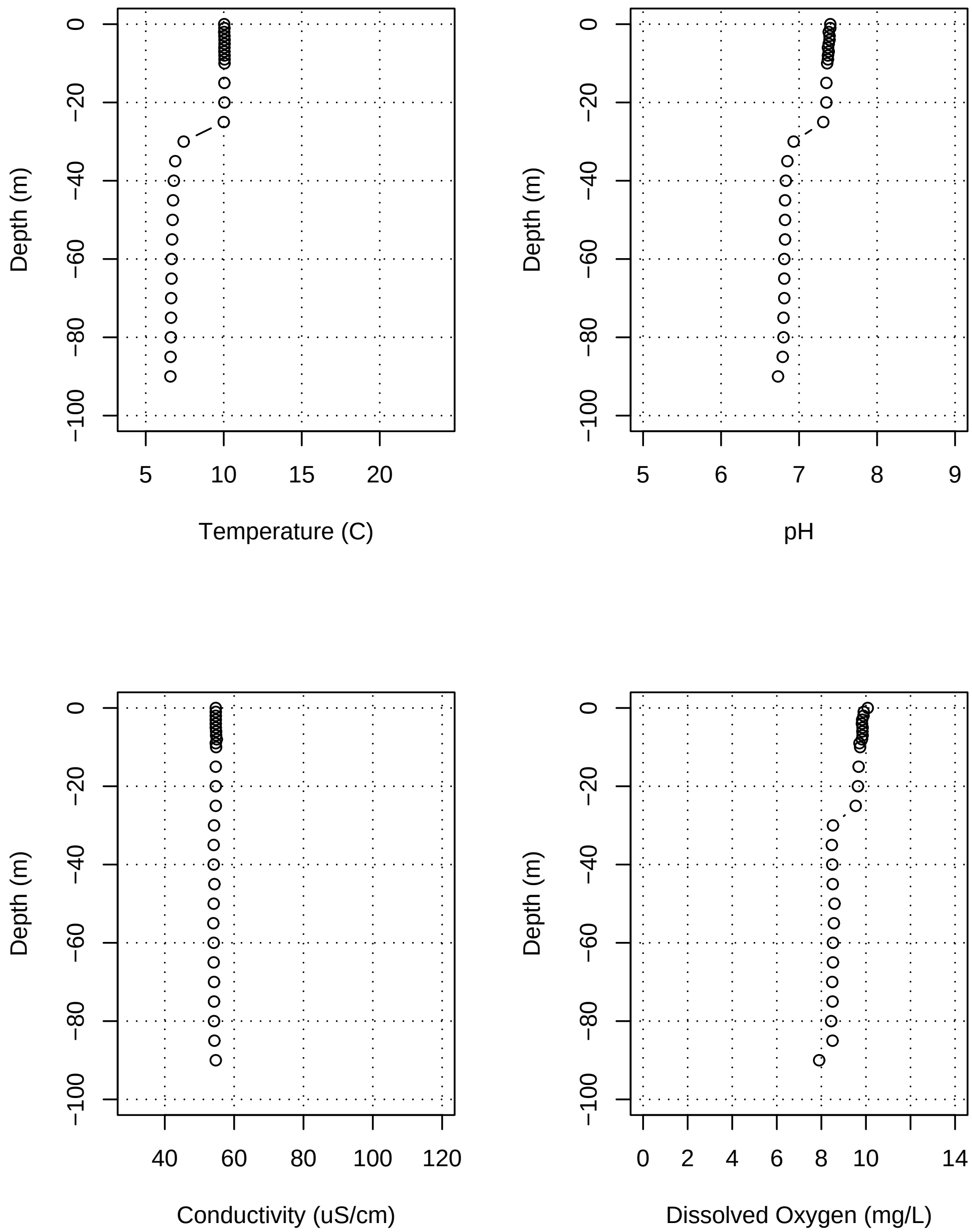


Figure 16: Lake Whatcom Hydrolab profile for Site 4, December 3, 2002.

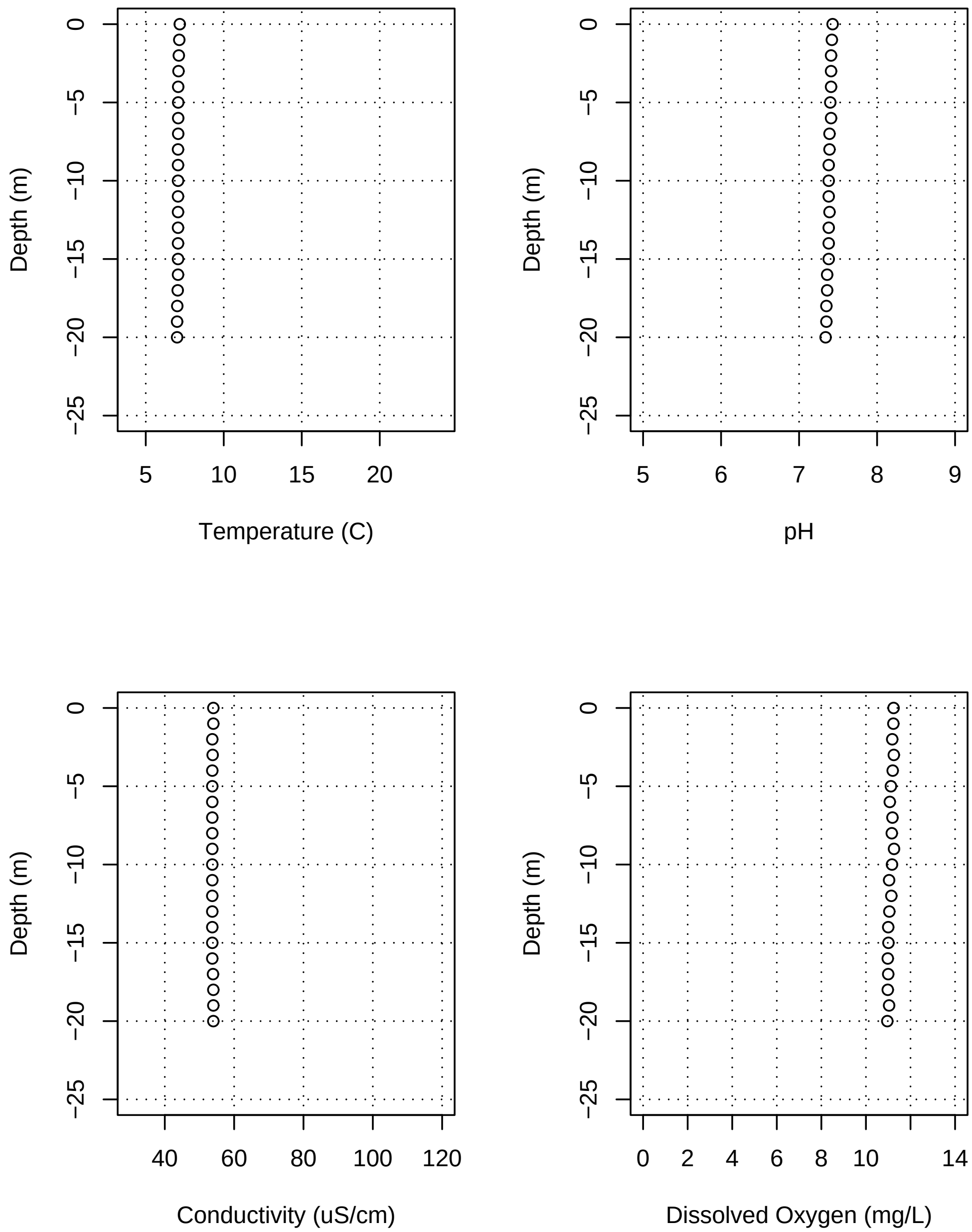


Figure 17: Lake Whatcom Hydrolab profile for Site 1, February 6, 2003.

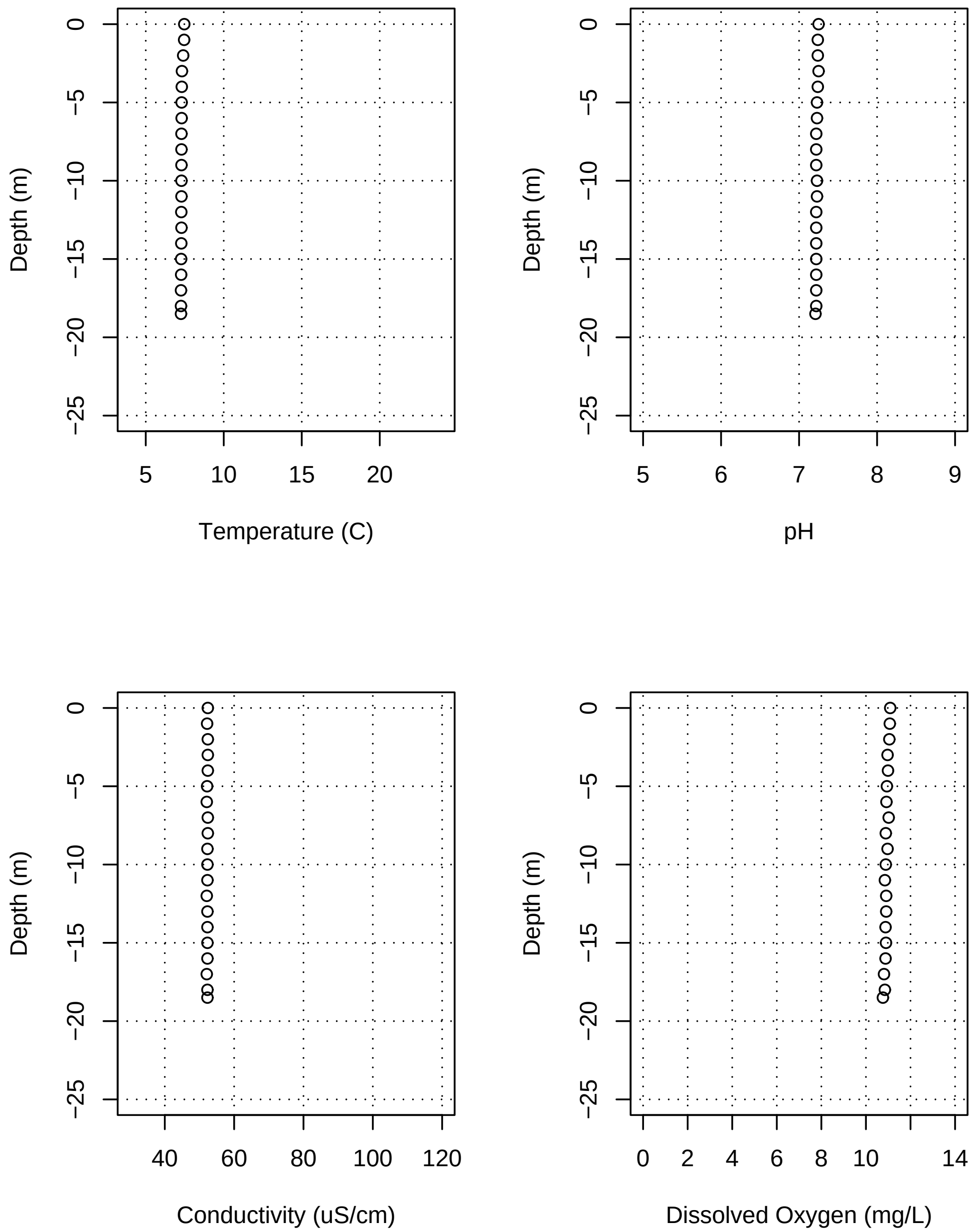


Figure 18: Lake Whatcom Hydrolab profile for Site 2, February 6, 2003.

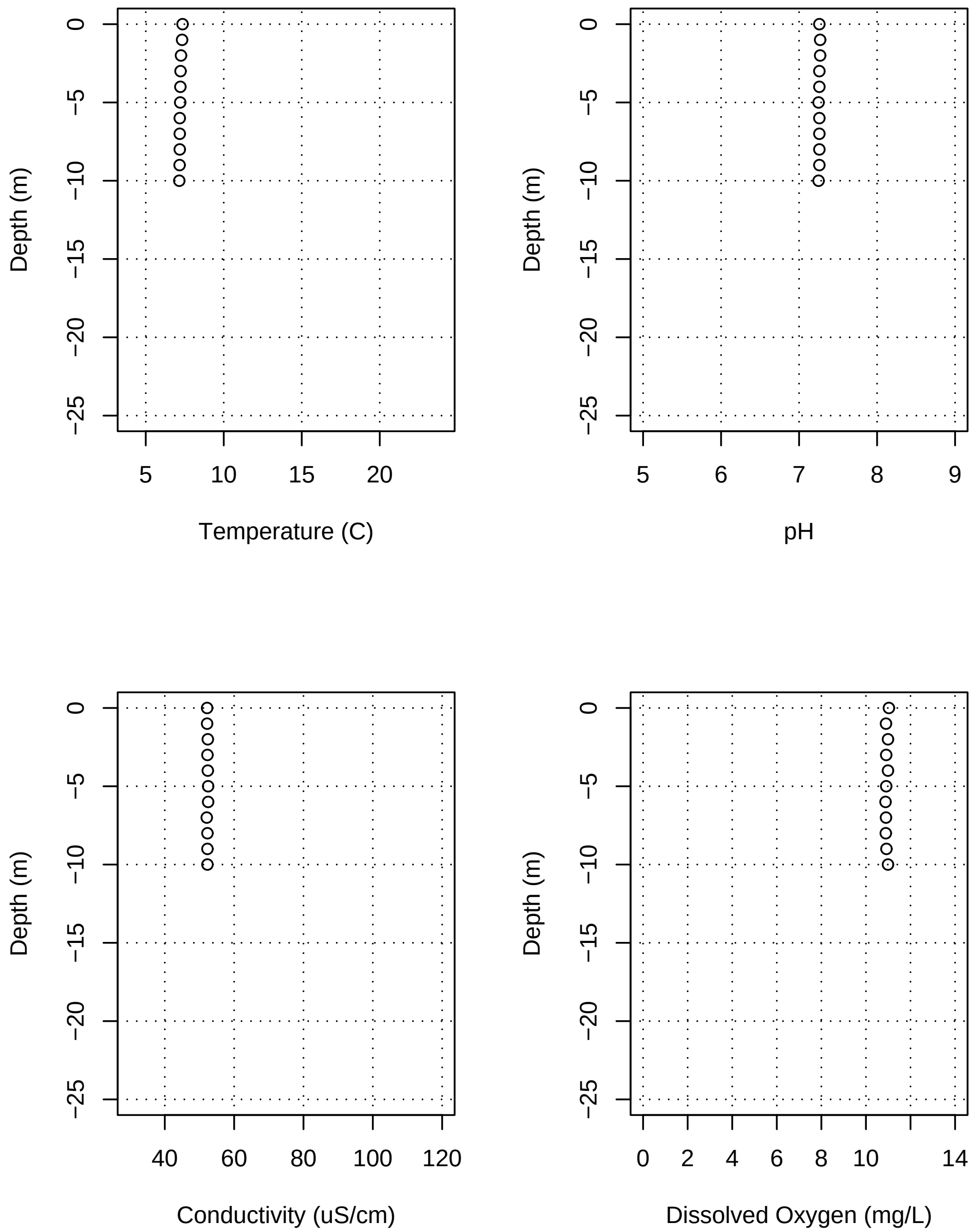


Figure 19: Lake Whatcom Hydrolab profile for the Intake, February 6, 2003.

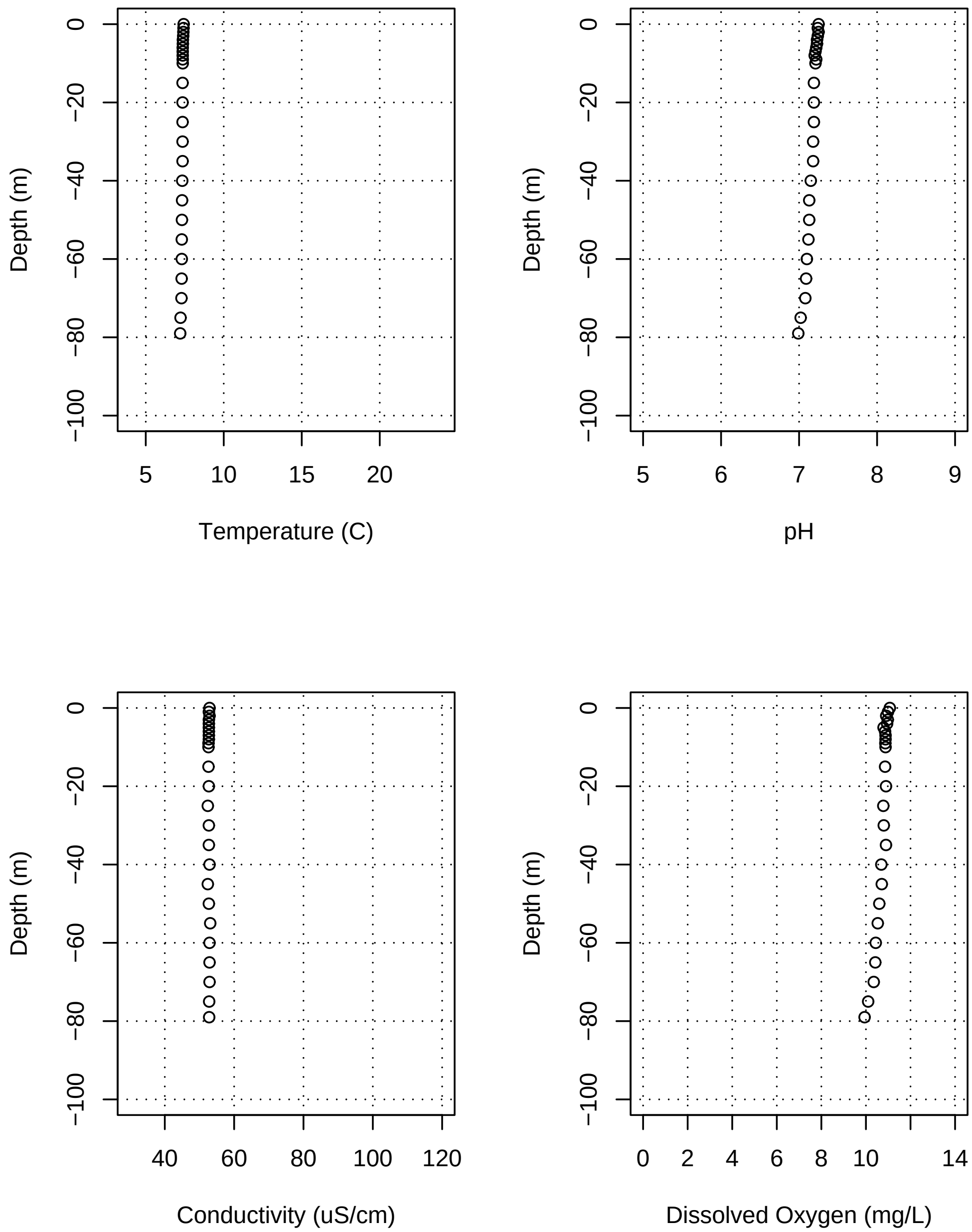


Figure 20: Lake Whatcom Hydrolab profile for Site 3, February 4, 2003.

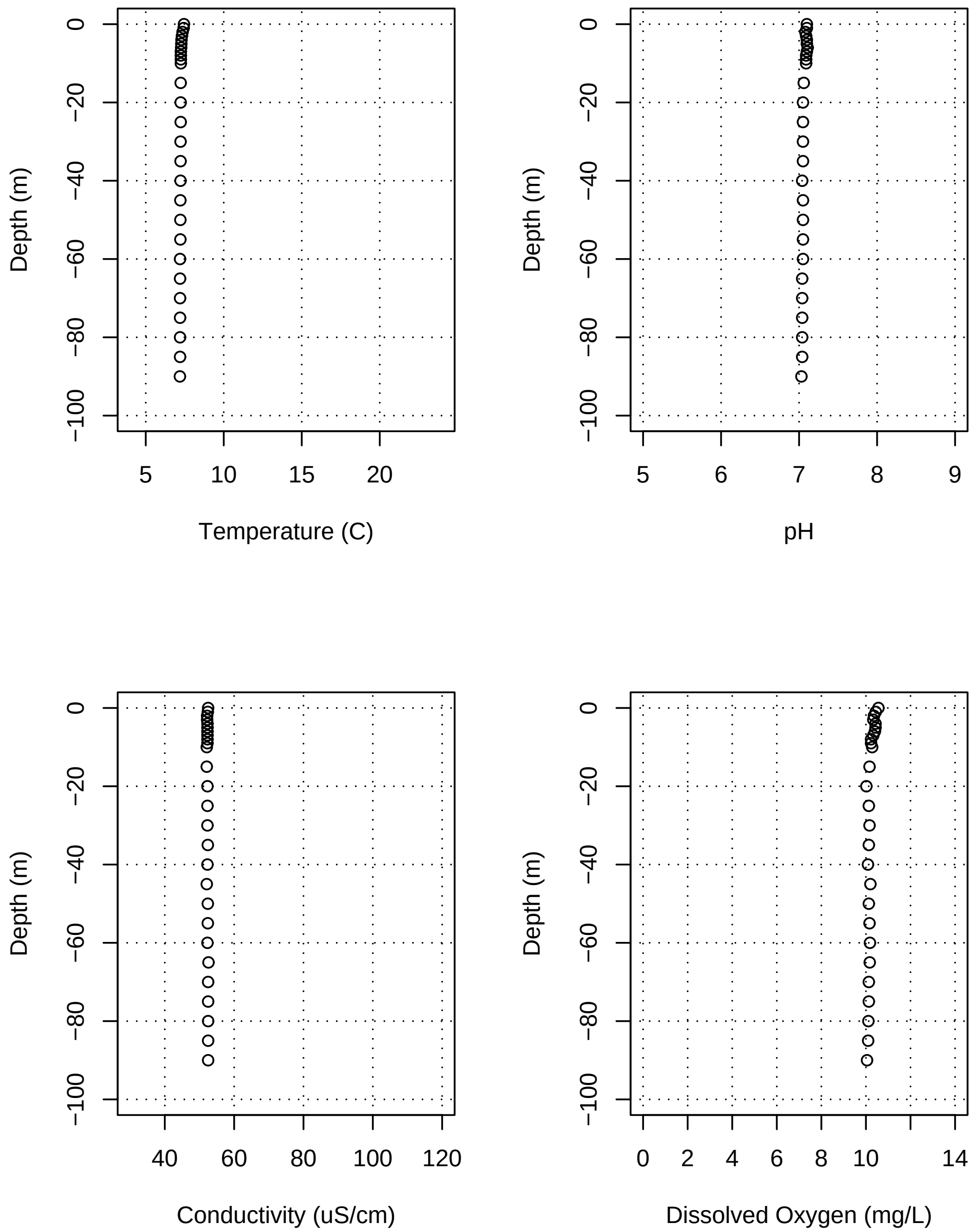


Figure 21: Lake Whatcom Hydrolab profile for Site 4, February 4, 2003.

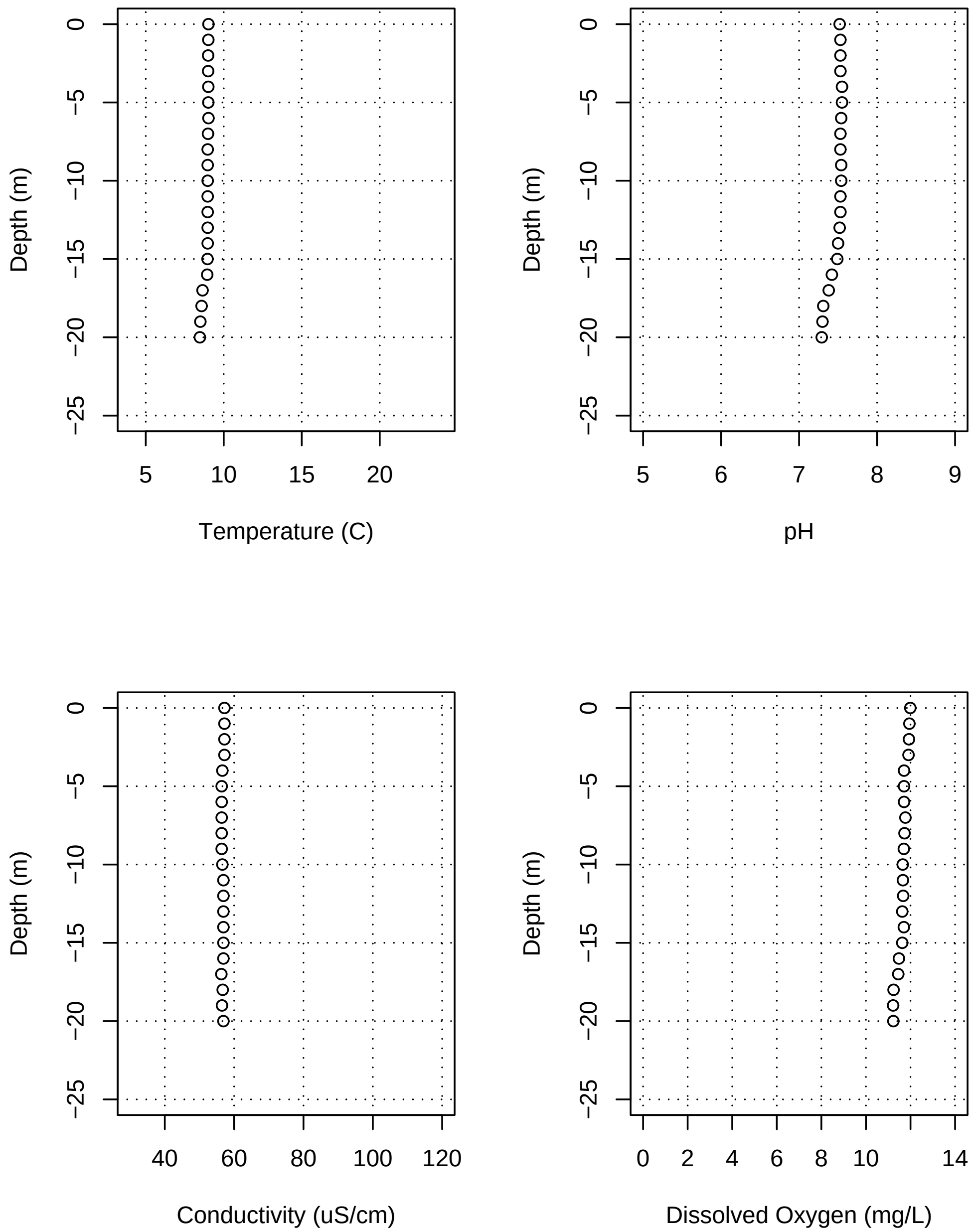


Figure 22: Lake Whatcom Hydrolab profile for Site 1, April 3, 2003.

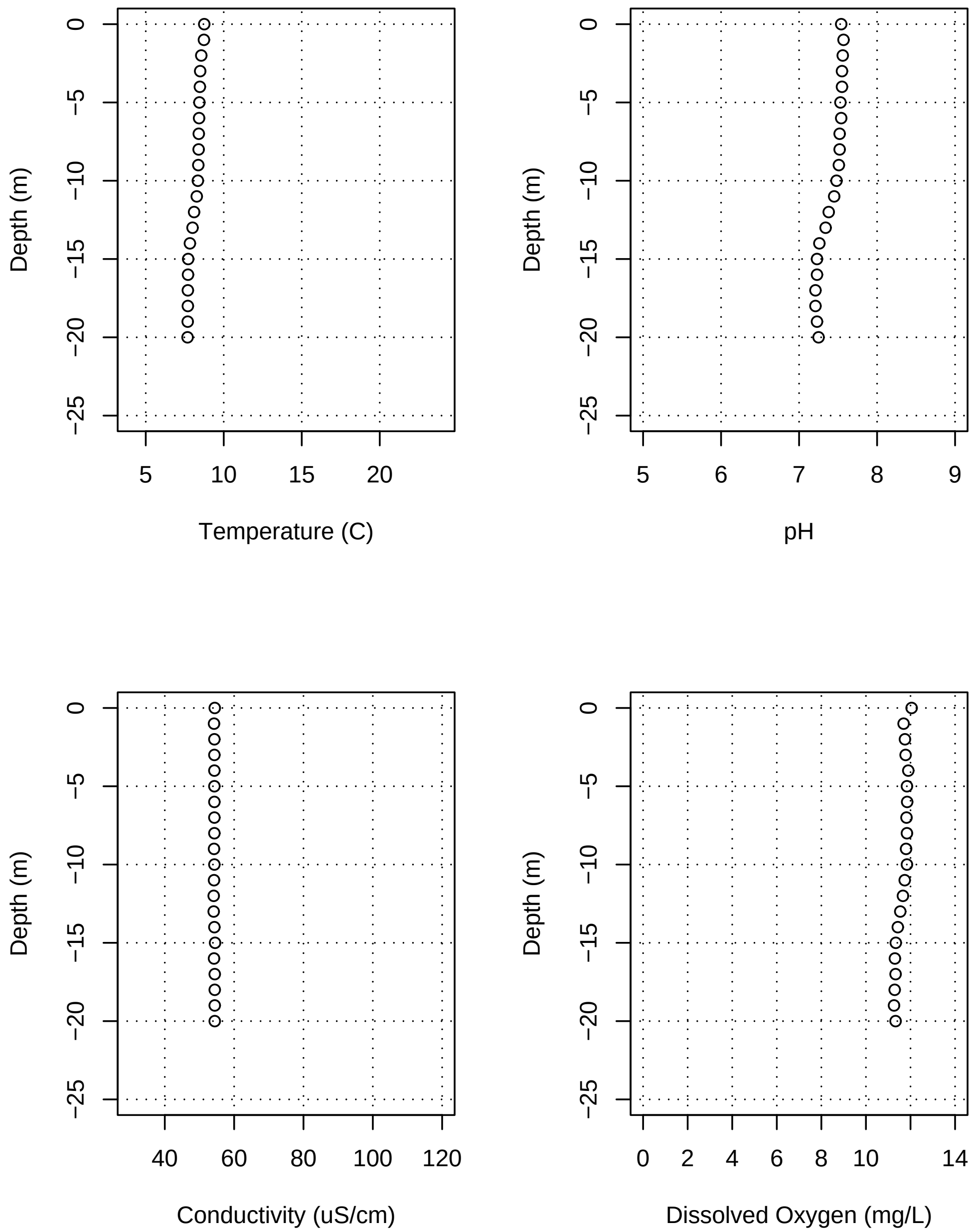


Figure 23: Lake Whatcom Hydrolab profile for Site 2, April 3, 2003.

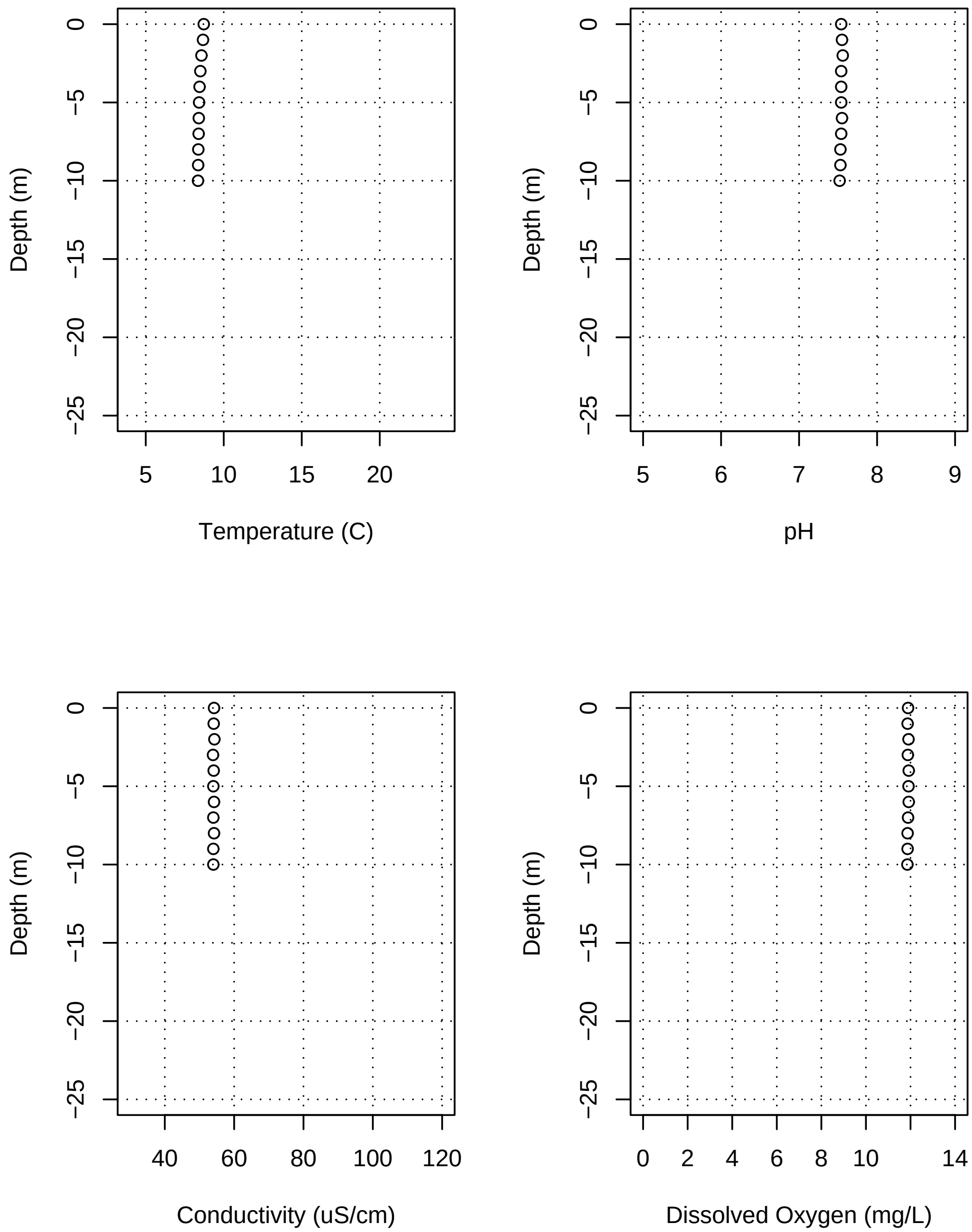


Figure 24: Lake Whatcom Hydrolab profile for the Intake, April 3, 2003.

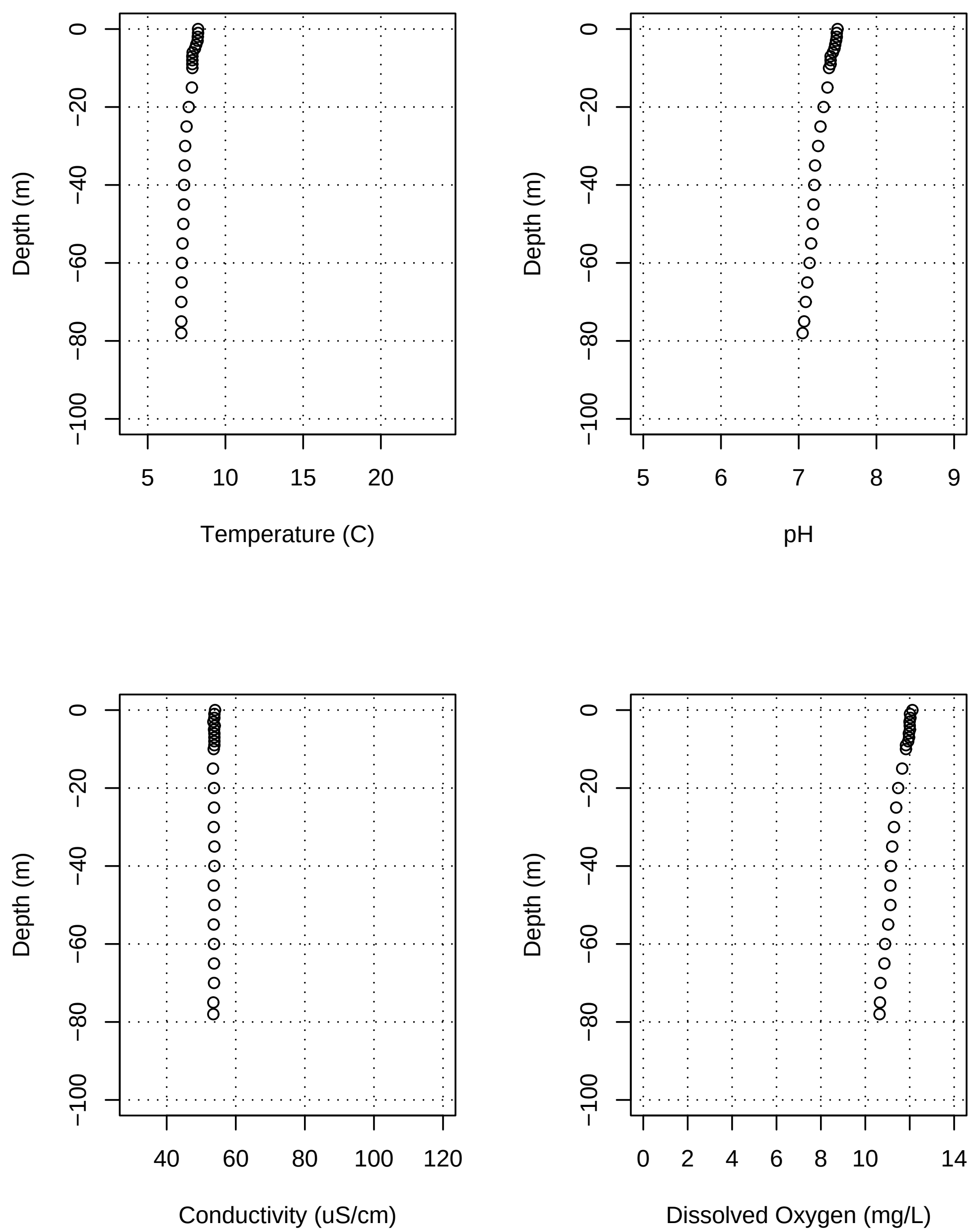


Figure 25: Lake Whatcom Hydrolab profile for Site 3, April 1, 2003.

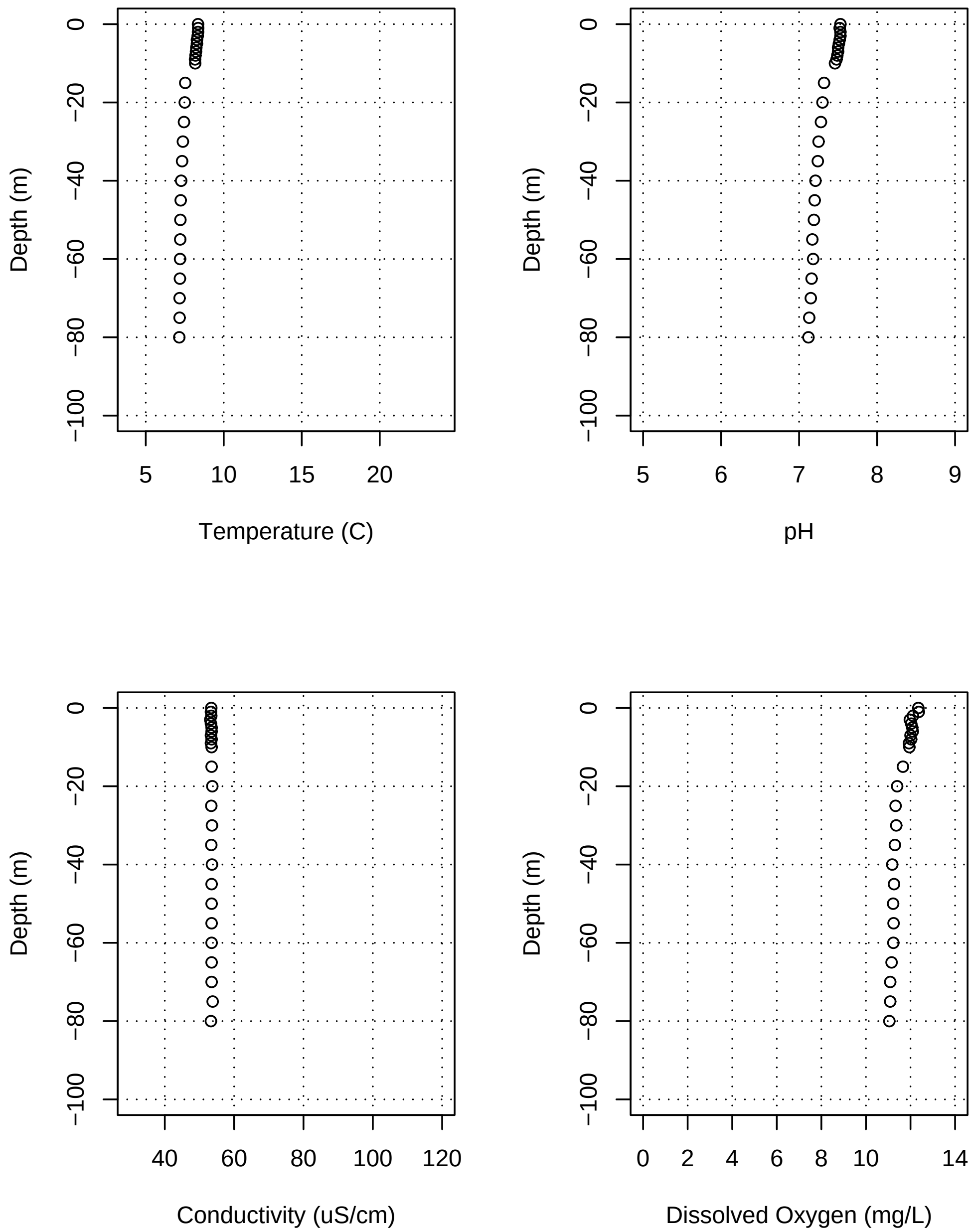


Figure 26: Lake Whatcom Hydrolab profile for Site 4, April 1, 2003.

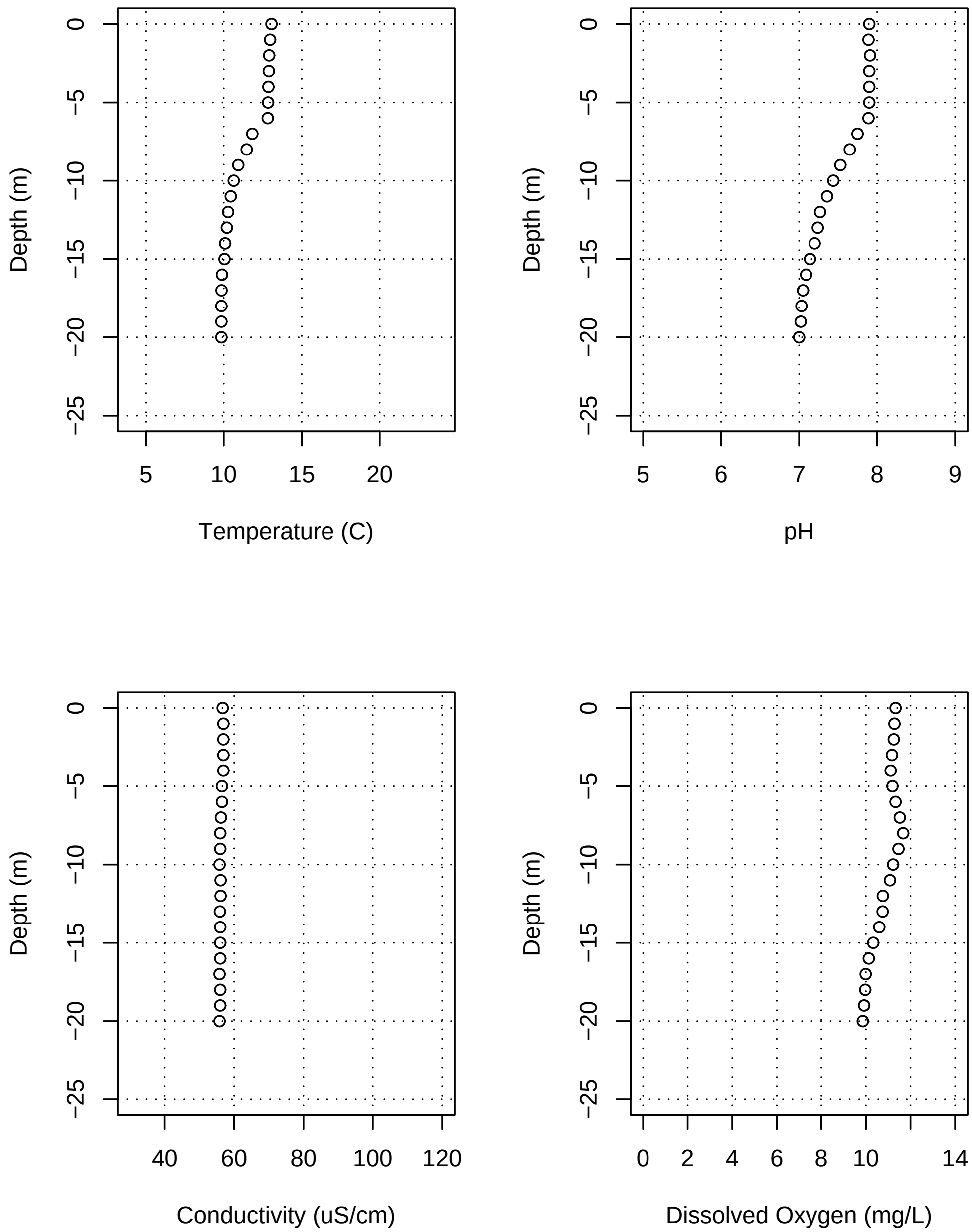


Figure 27: Lake Whatcom Hydrolab profile for Site 1, May 8, 2003.

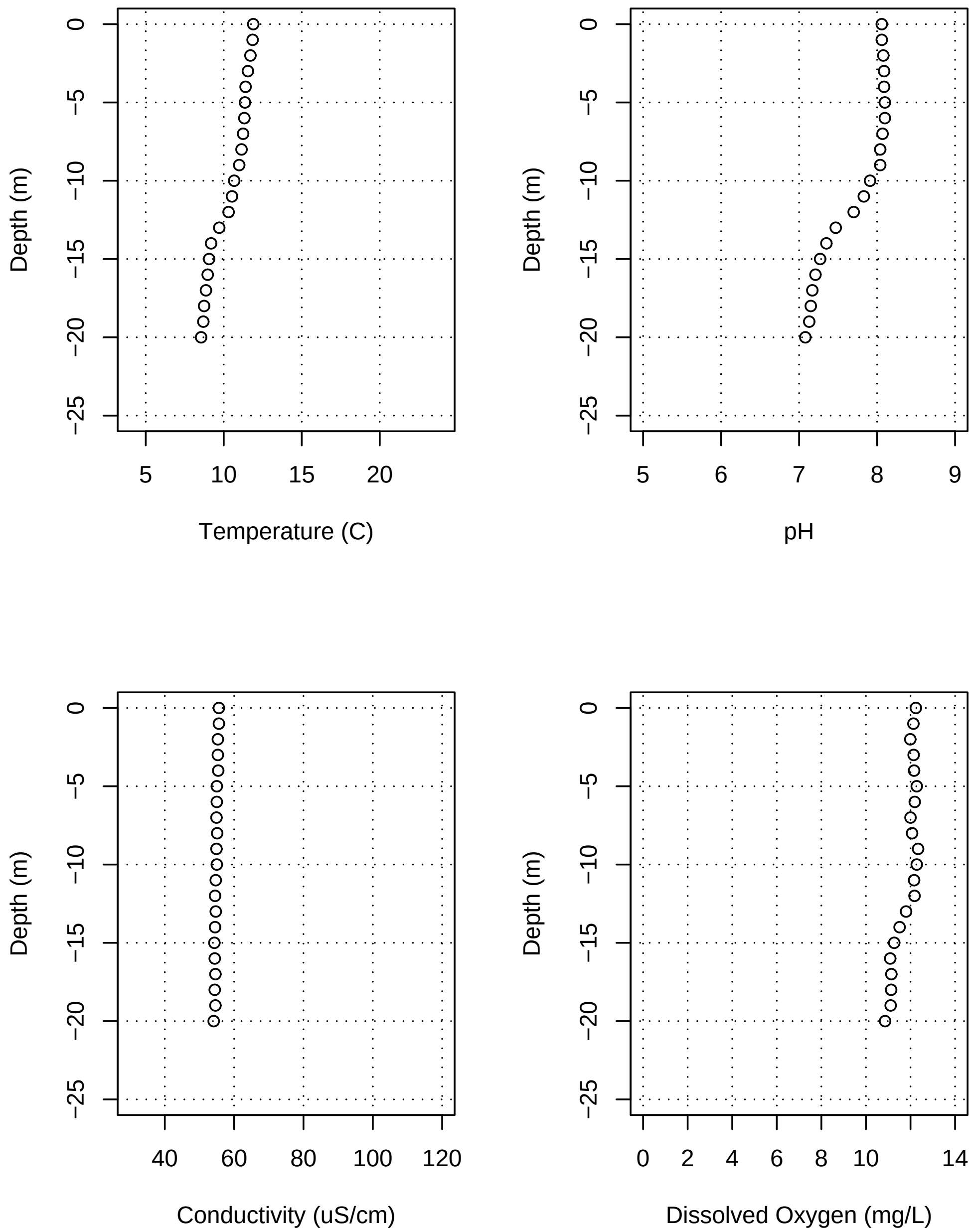


Figure 28: Lake Whatcom Hydrolab profile for Site 2, May 8, 2003.

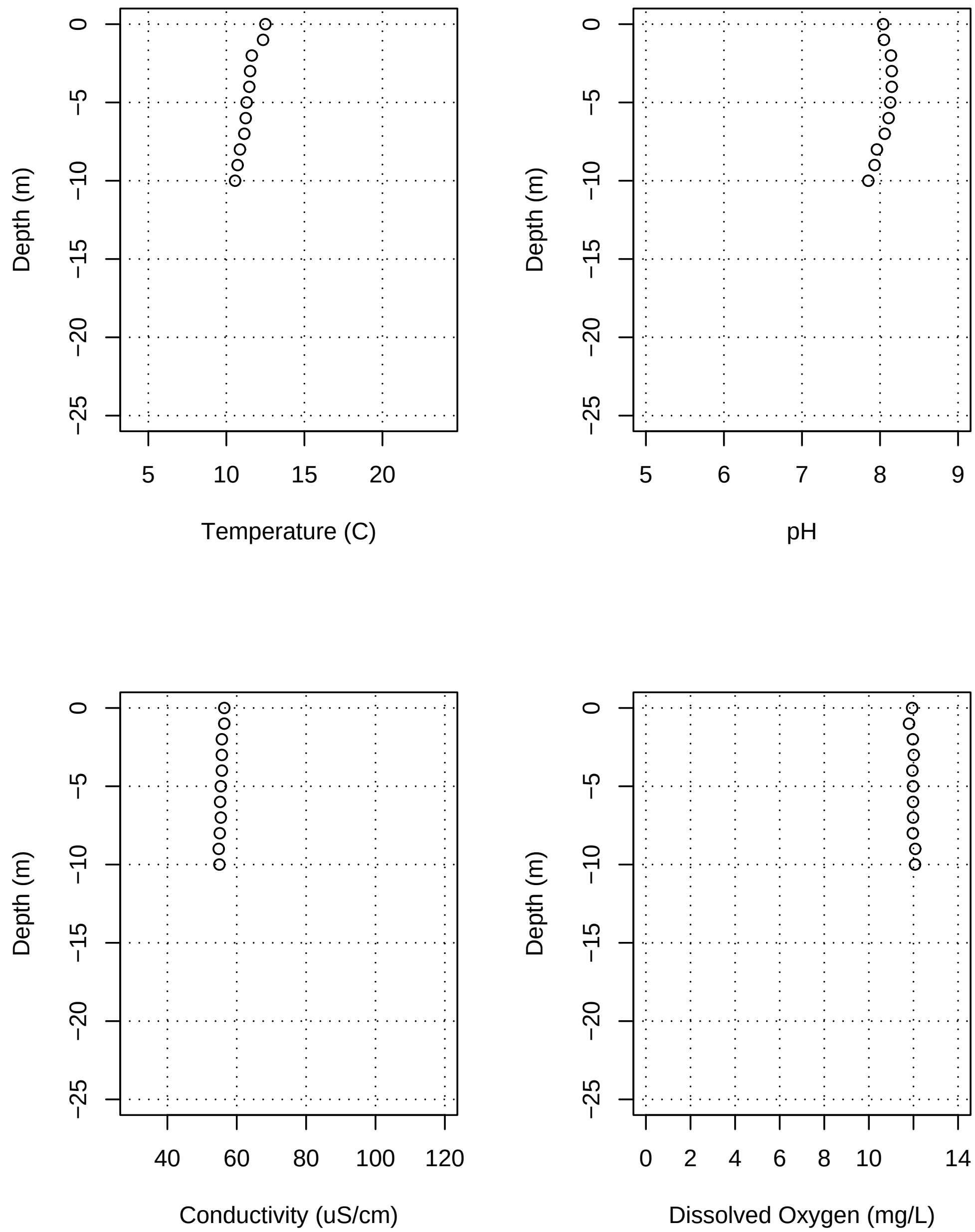


Figure 29: Lake Whatcom Hydrolab profile for the Intake, May 8, 2003.

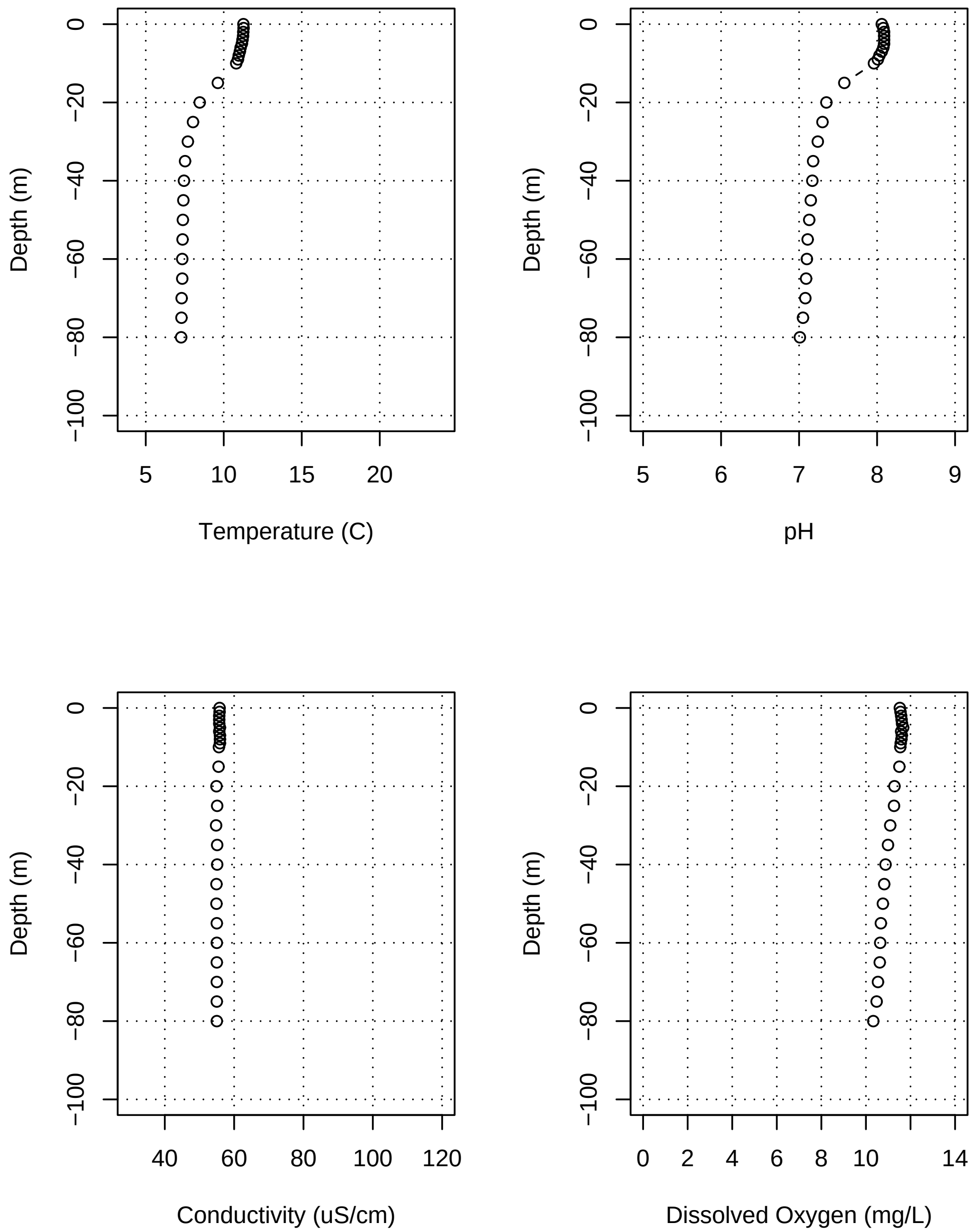


Figure 30: Lake Whatcom Hydrolab profile for Site 3, May 6, 2003.

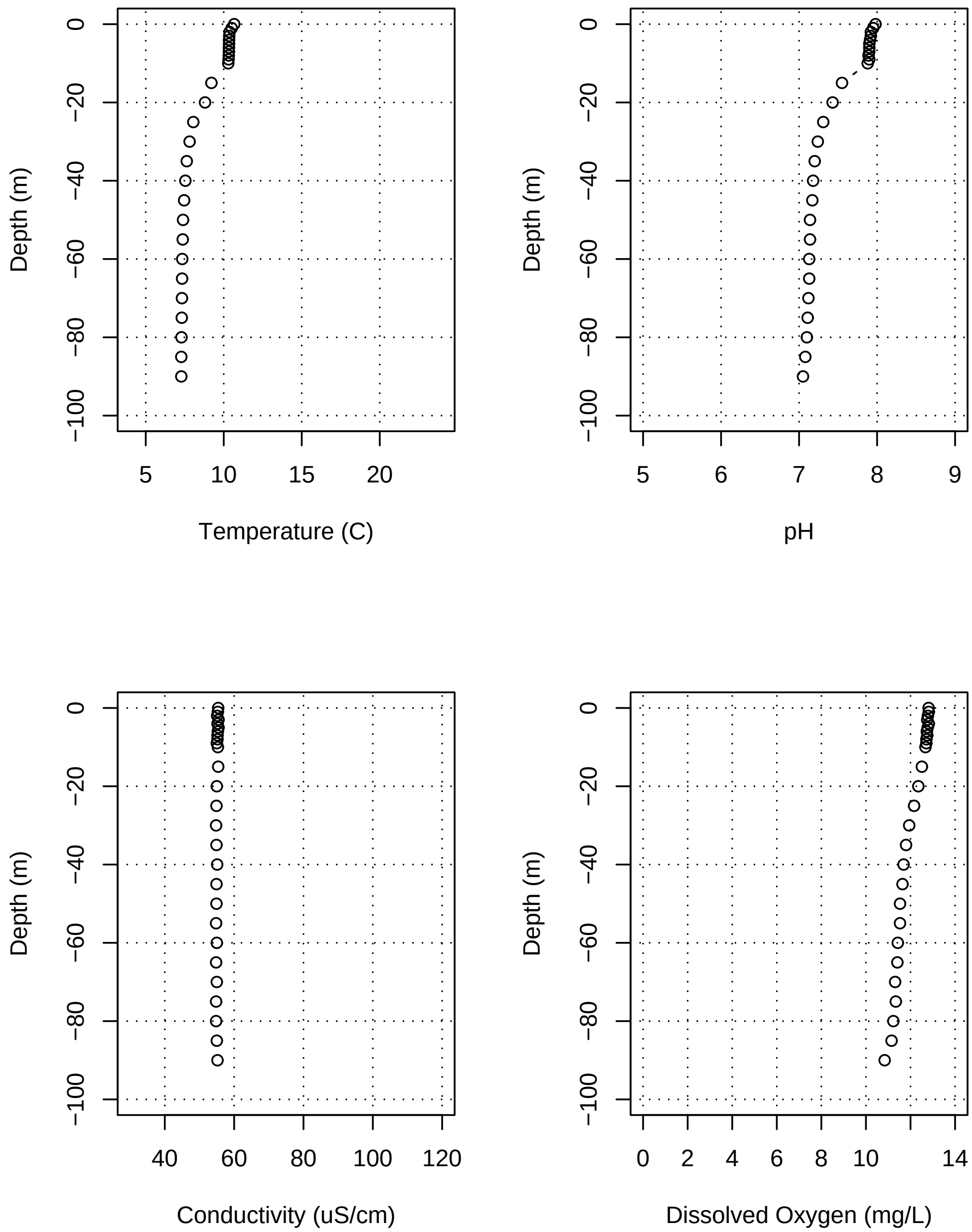


Figure 31: Lake Whatcom Hydrolab profile for Site 4, May 6, 2003.

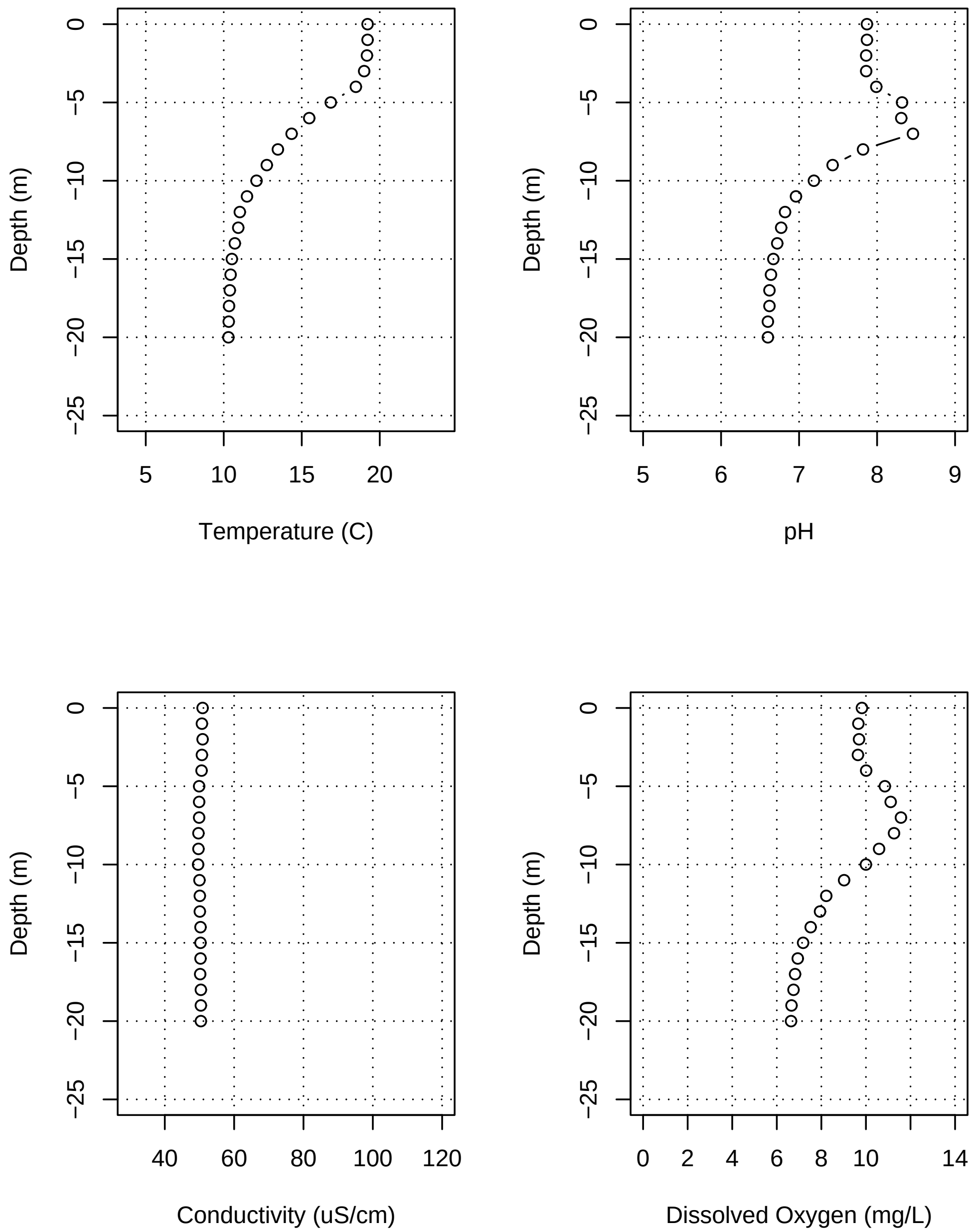


Figure 32: Lake Whatcom Hydrolab profile for Site 1, June 10, 2003.

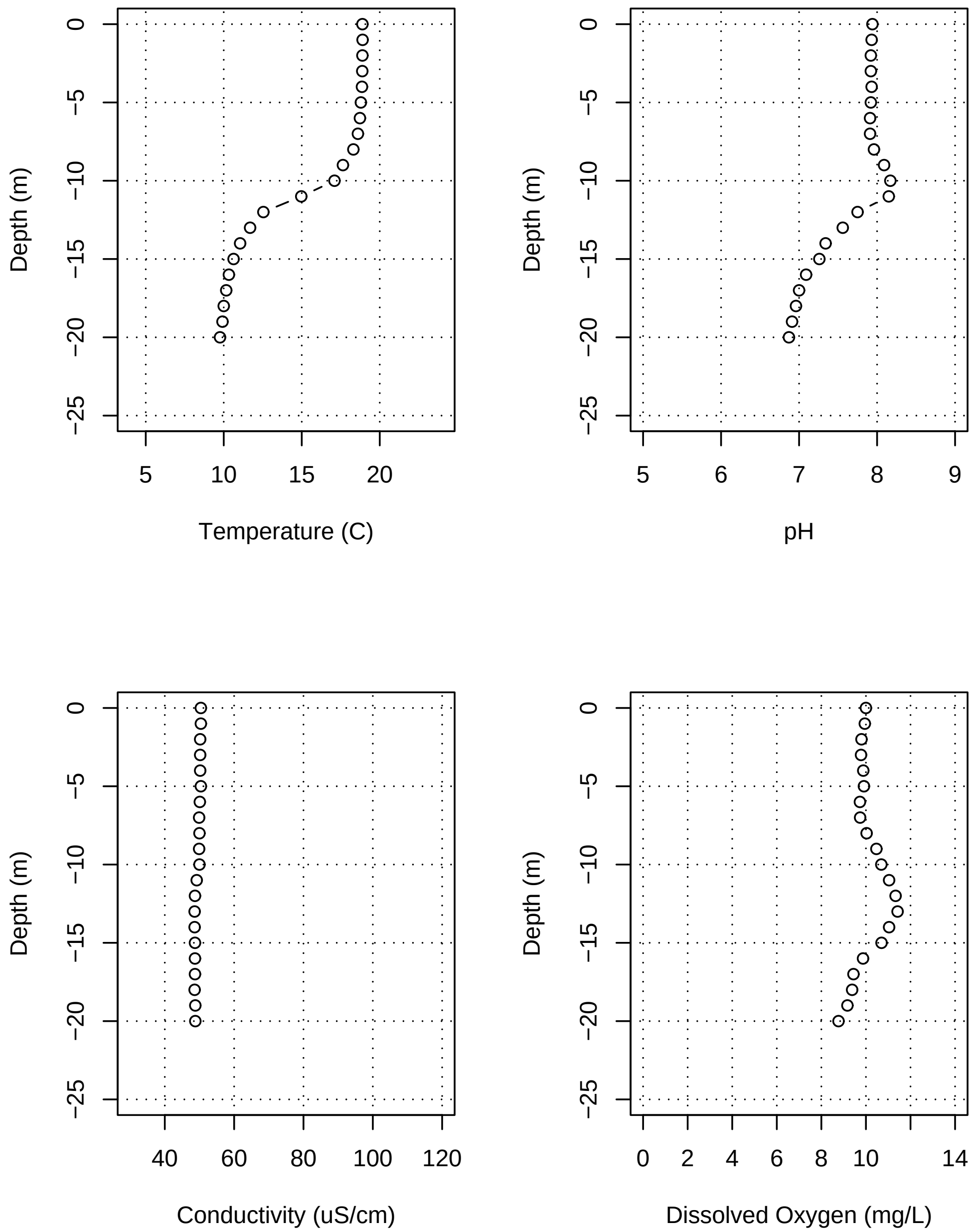


Figure 33: Lake Whatcom Hydrolab profile for Site 2, June 10, 2003.

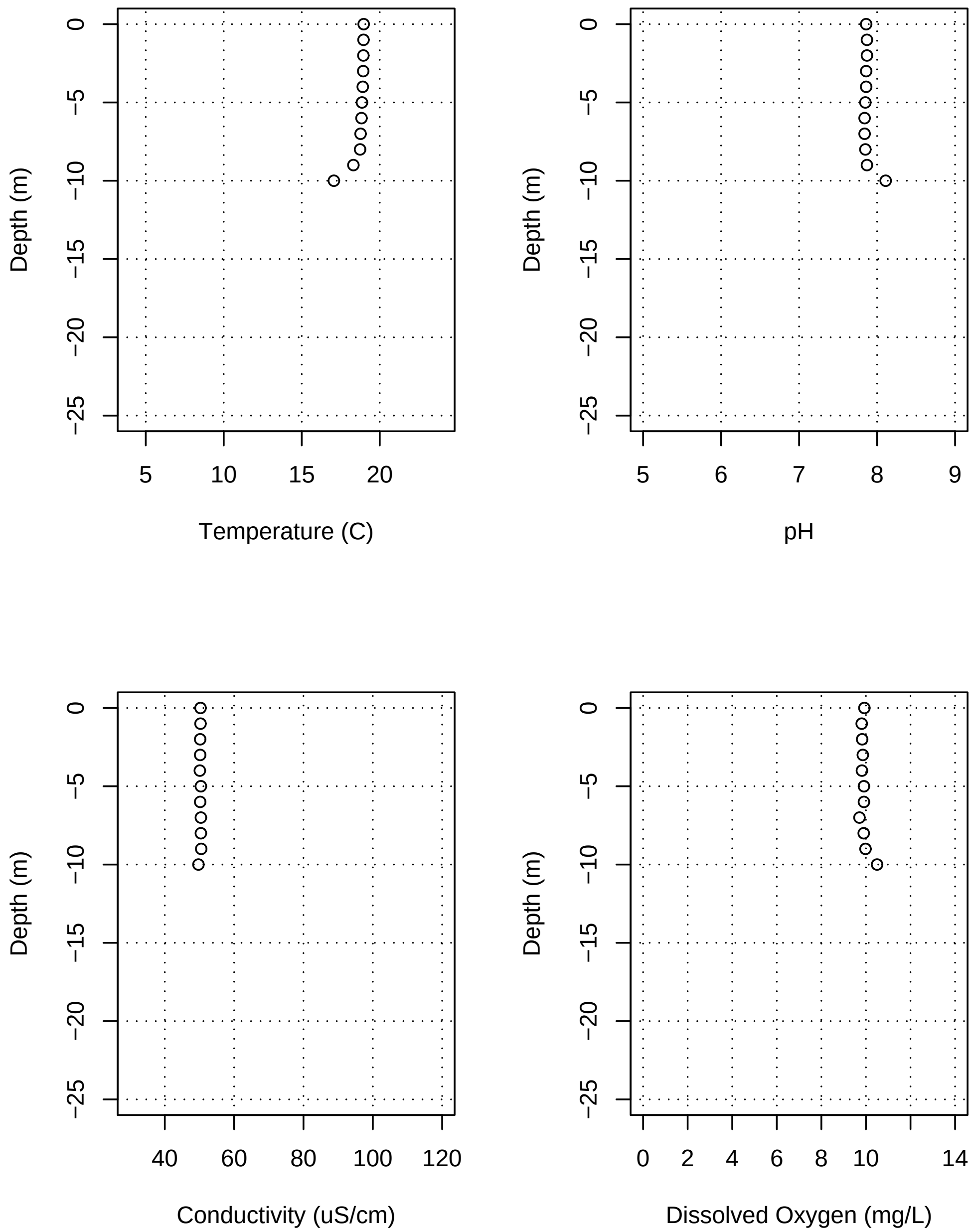


Figure 34: Lake Whatcom Hydrolab profile for the Intake, June 10, 2003.

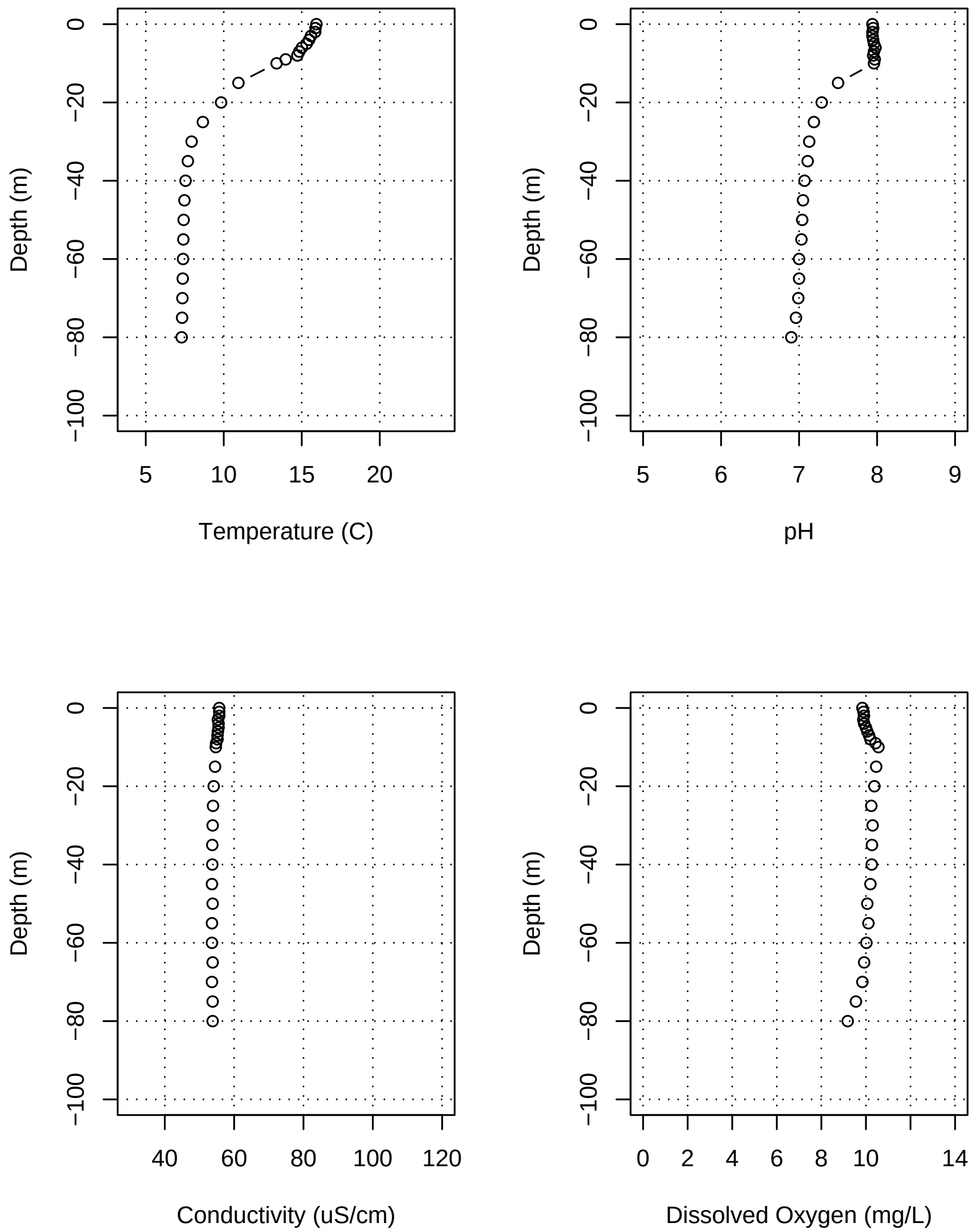


Figure 35: Lake Whatcom Hydrolab profile for Site 3, June 3, 2003.

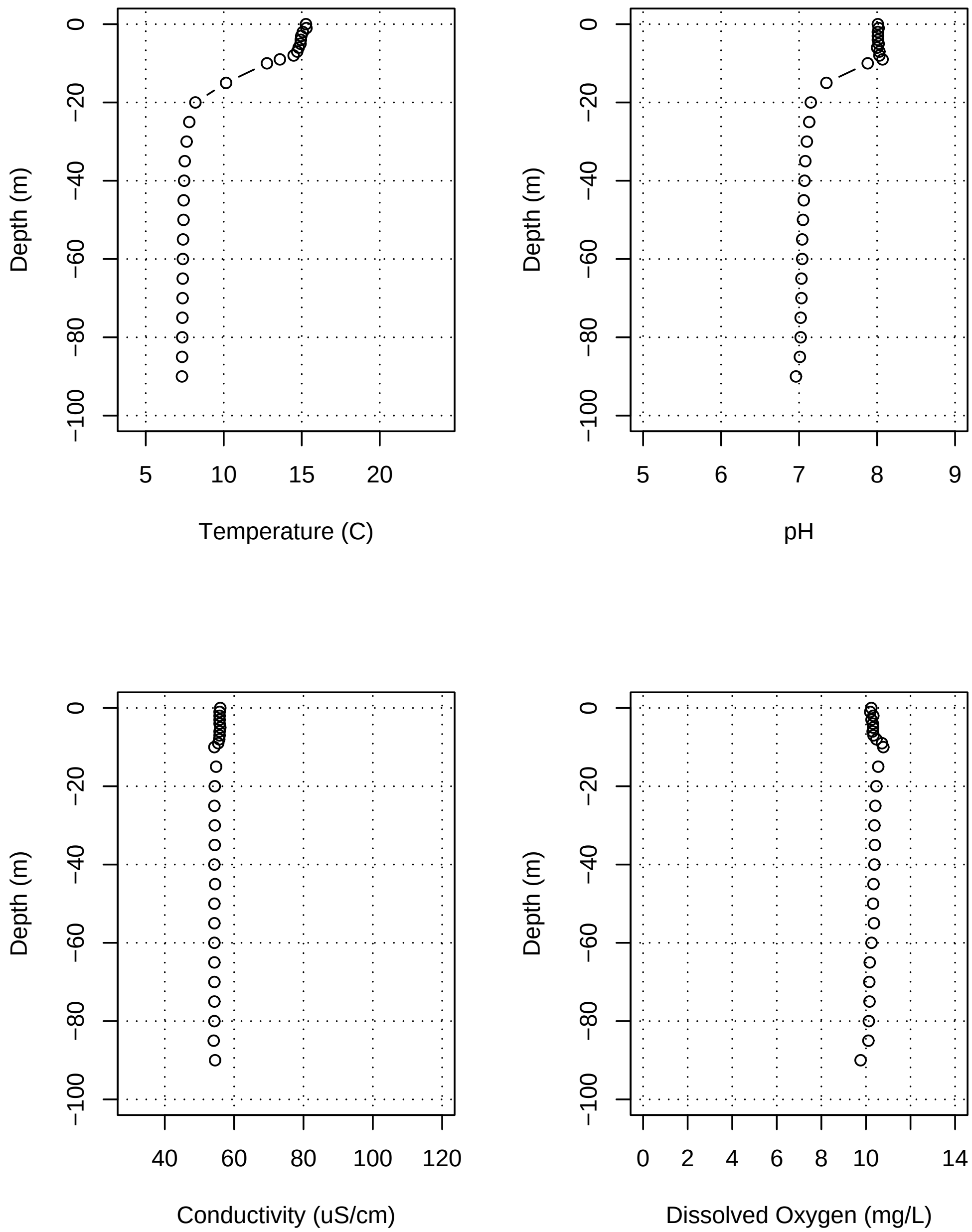


Figure 36: Lake Whatcom Hydrolab profile for Site 4, June 3, 2003.

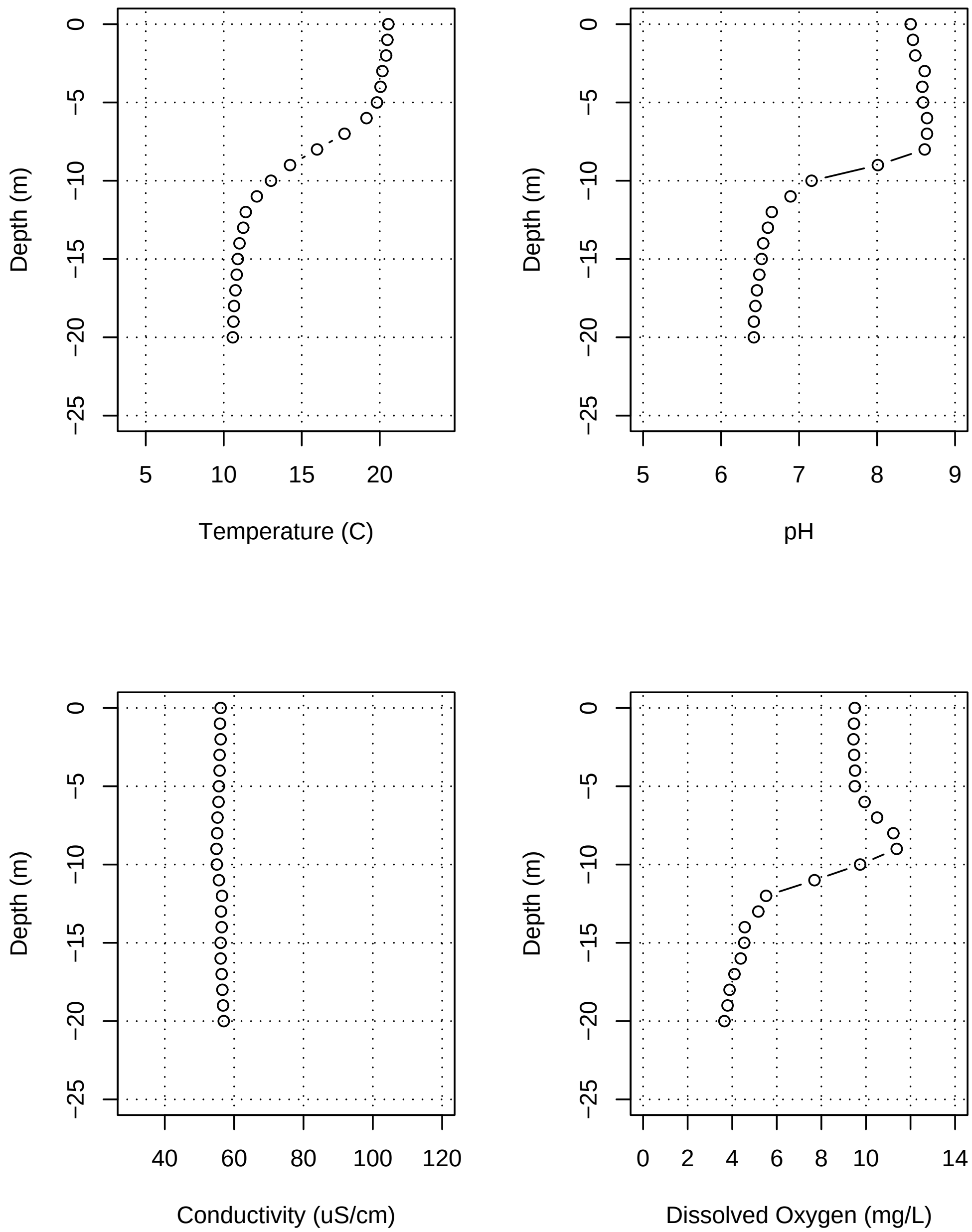


Figure 37: Lake Whatcom Hydrolab profile for Site 1, July 10, 2003.

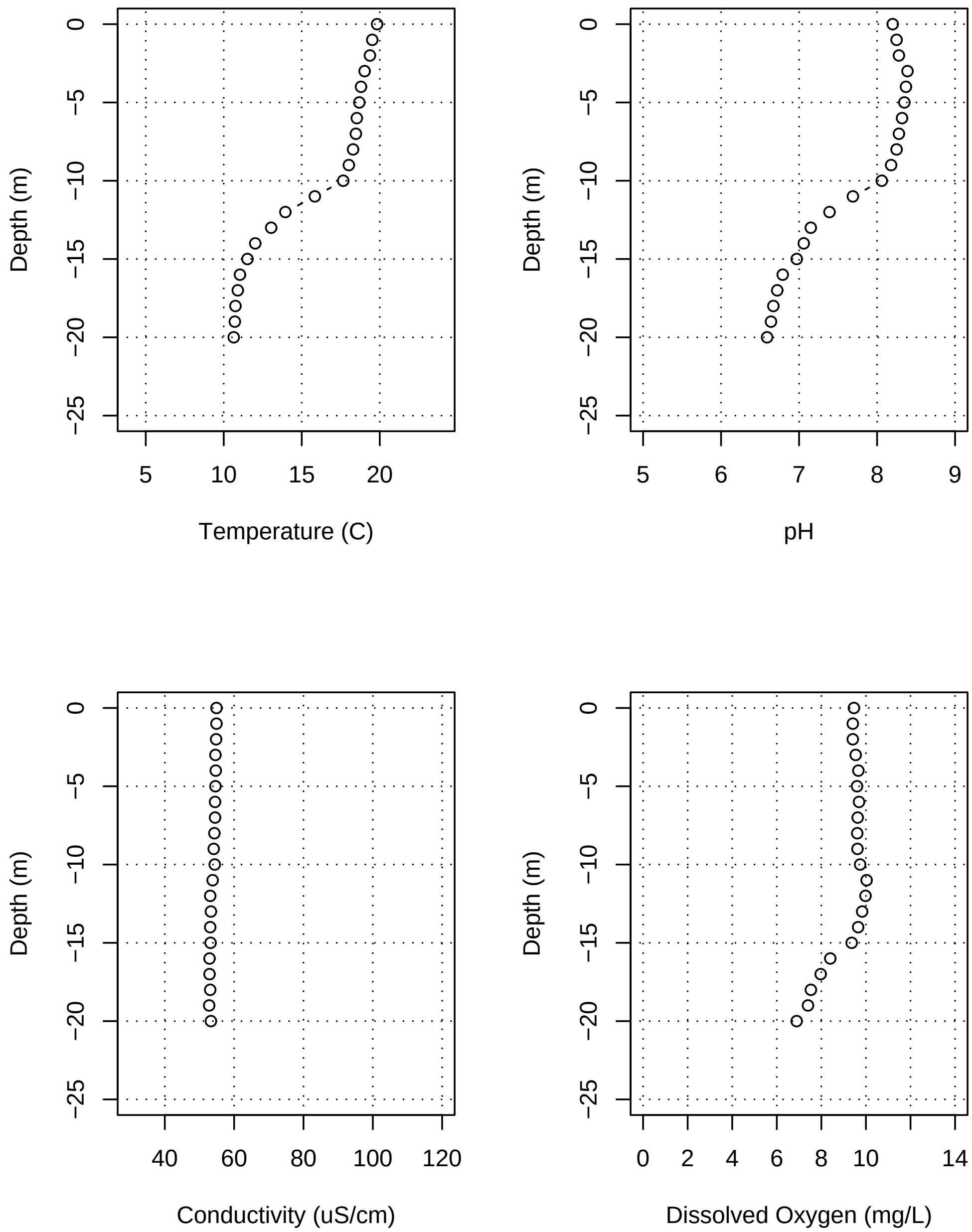


Figure 38: Lake Whatcom Hydrolab profile for Site 2, July 10, 2003.

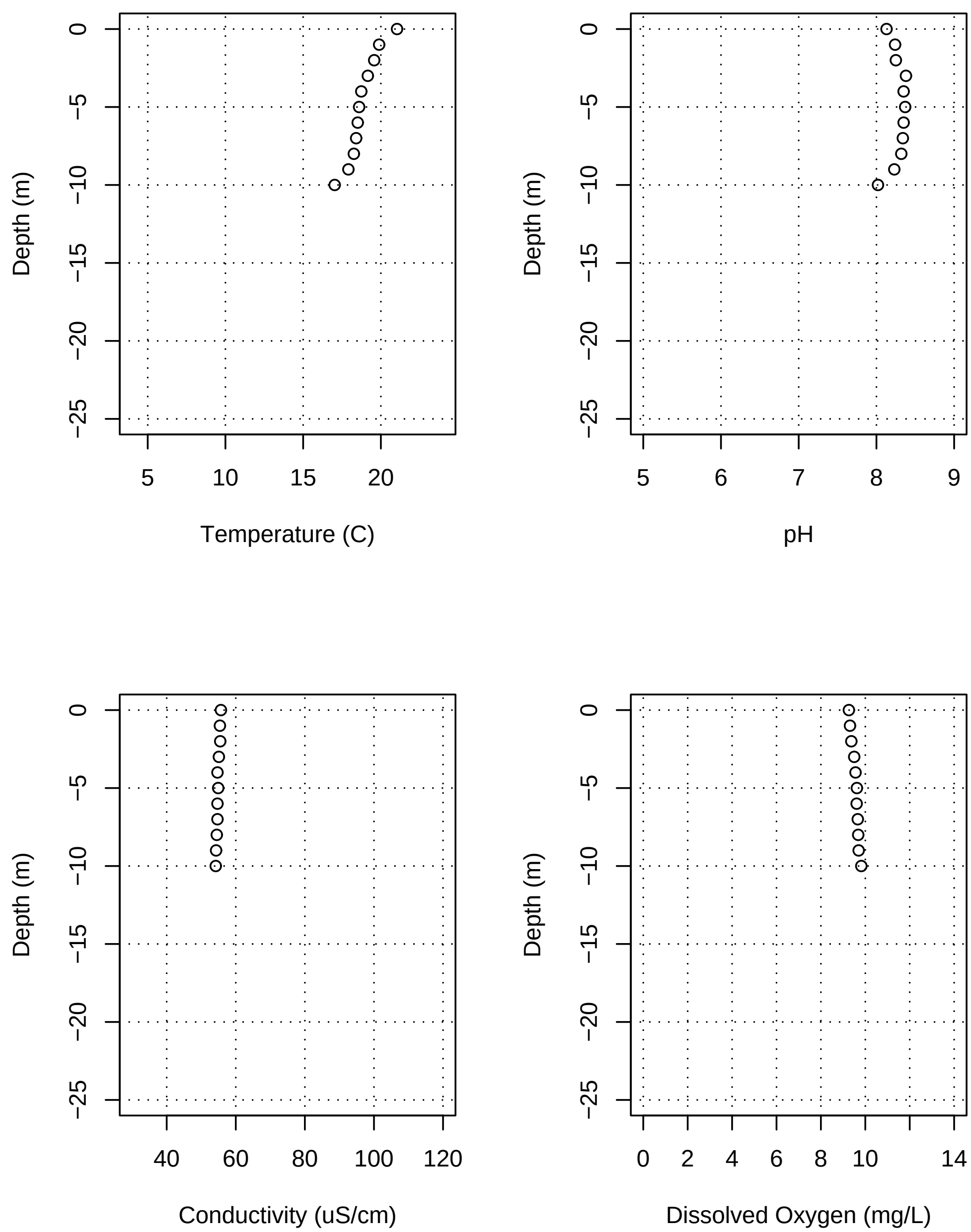


Figure 39: Lake Whatcom Hydrolab profile for the Intake, July 10, 2003.

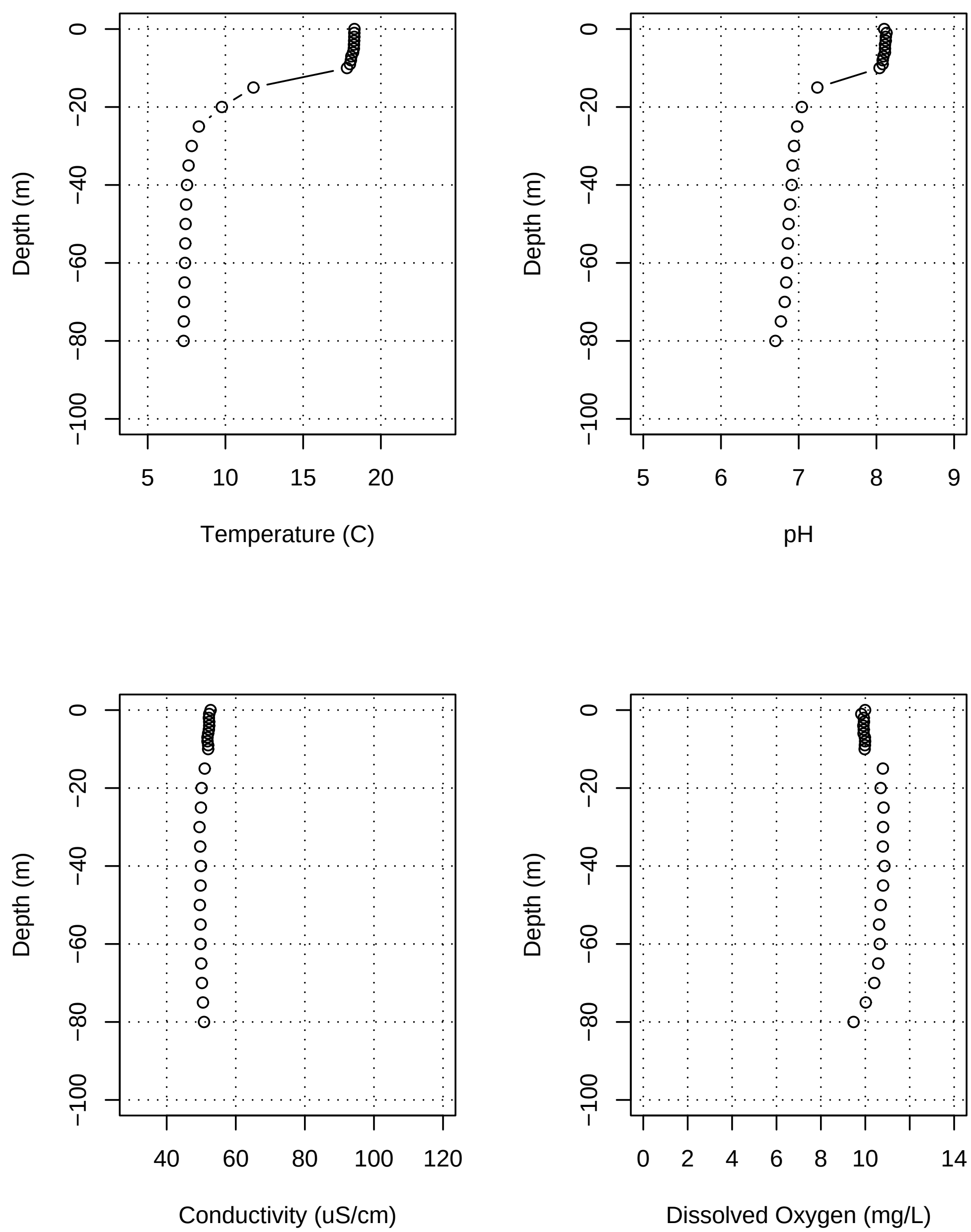


Figure 40: Lake Whatcom Hydrolab profile for Site 3, July 8, 2003.

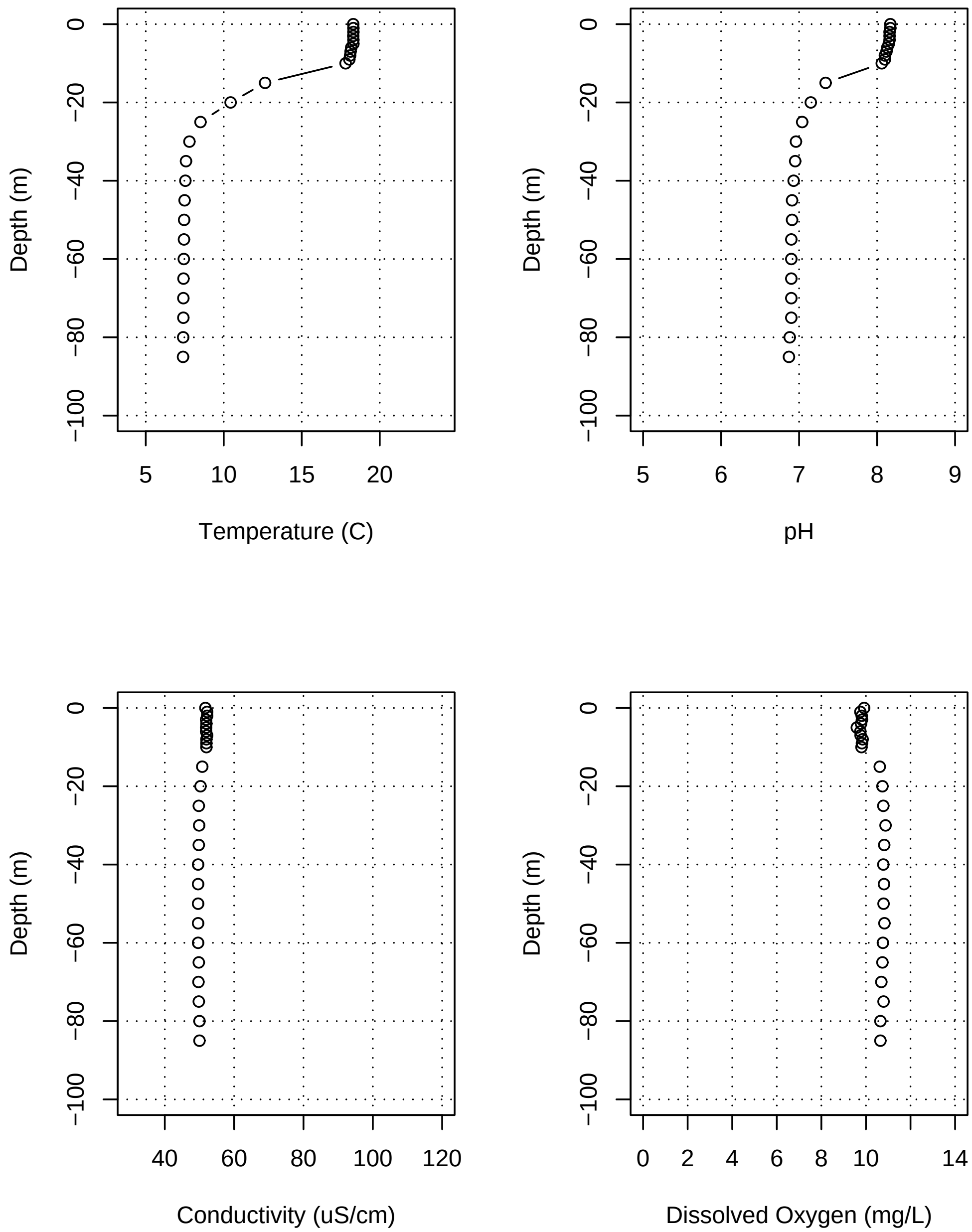


Figure 41: Lake Whatcom Hydrolab profile for Site 4, July 8, 2003.

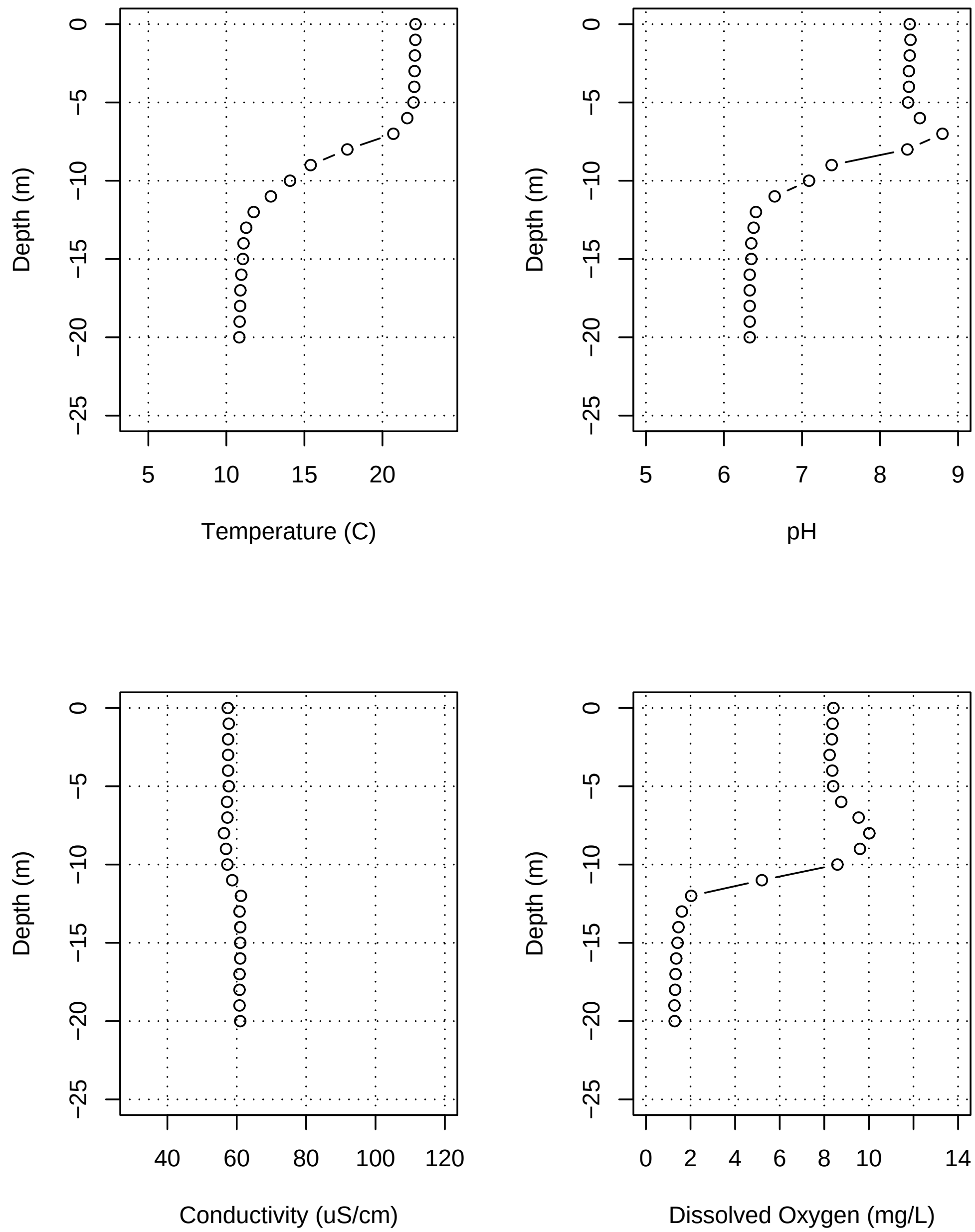


Figure 42: Lake Whatcom Hydrolab profile for Site 1, August 7, 2003.

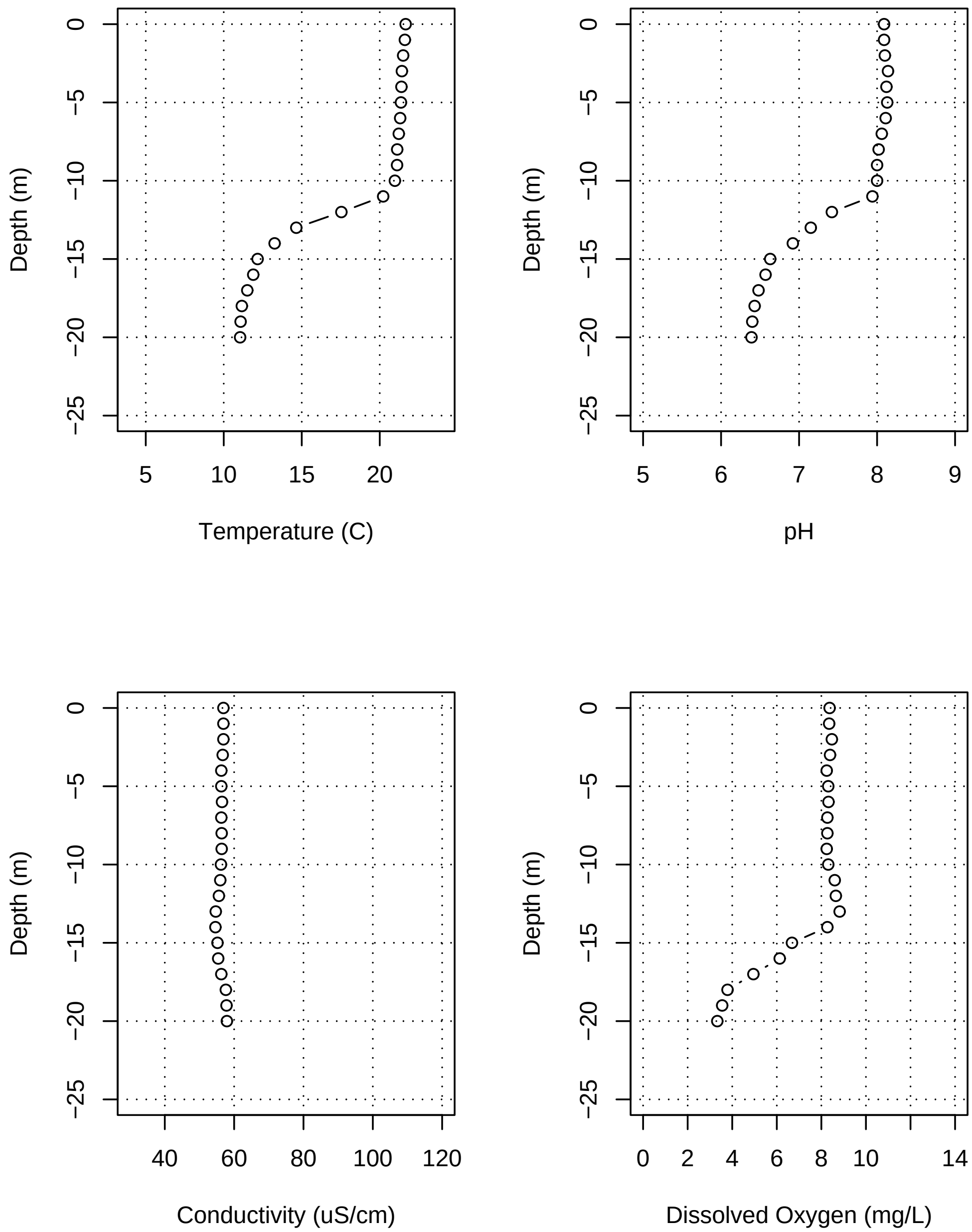


Figure 43: Lake Whatcom Hydrolab profile for Site 2, August 7, 2003.

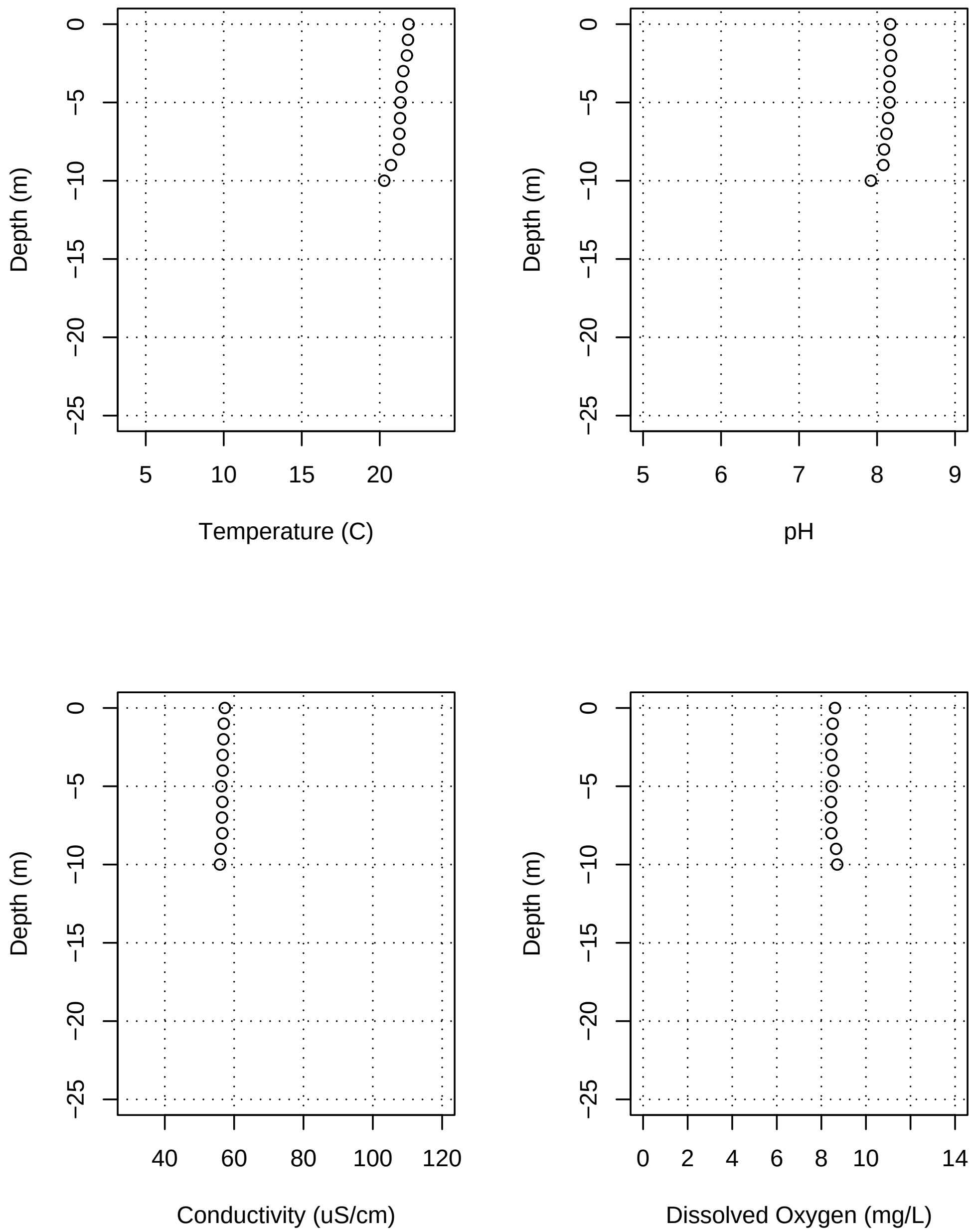


Figure 44: Lake Whatcom Hydrolab profile for the Intake, August 7, 2003.

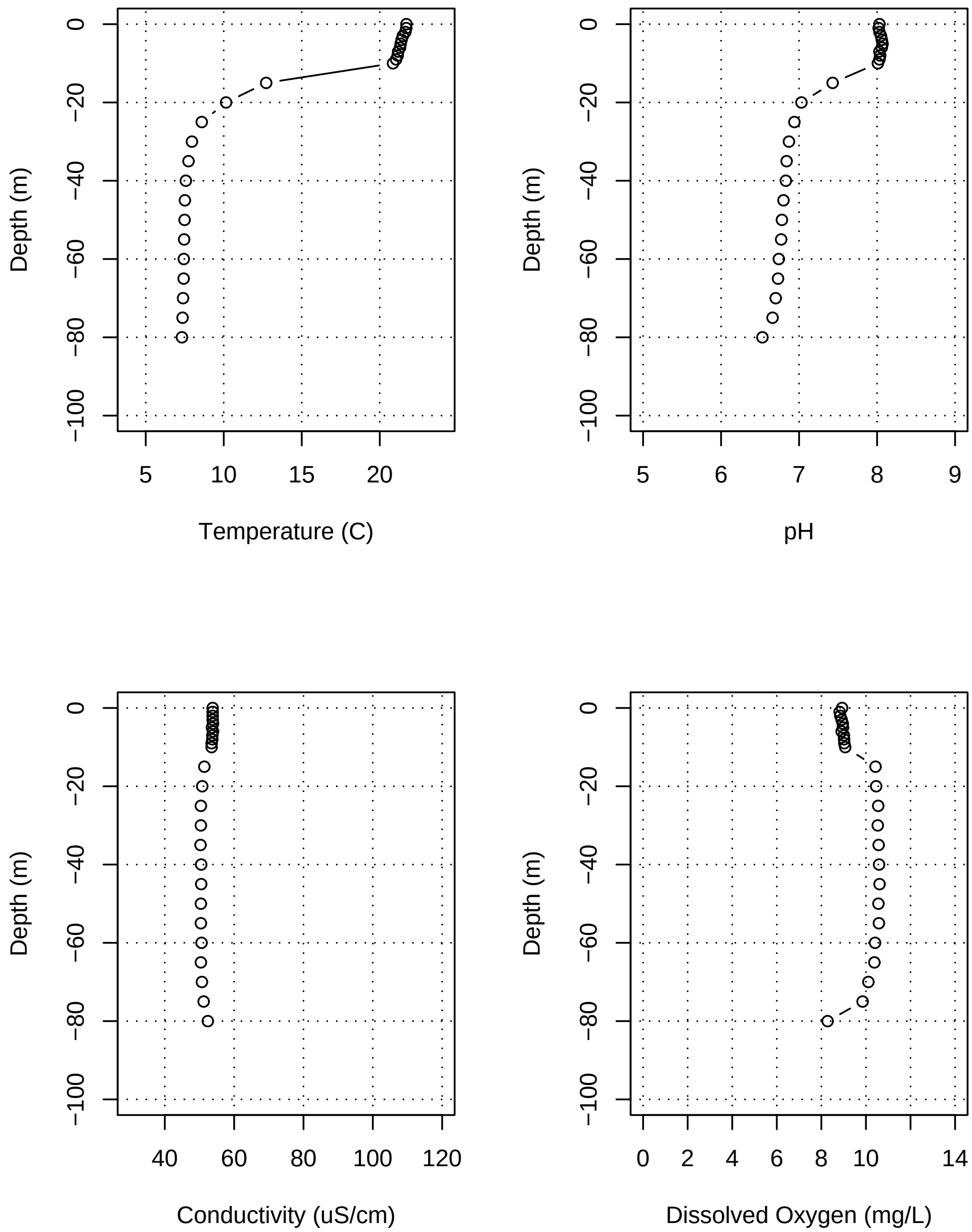


Figure 45: Lake Whatcom Hydrolab profile for Site 3, August 5, 2003.

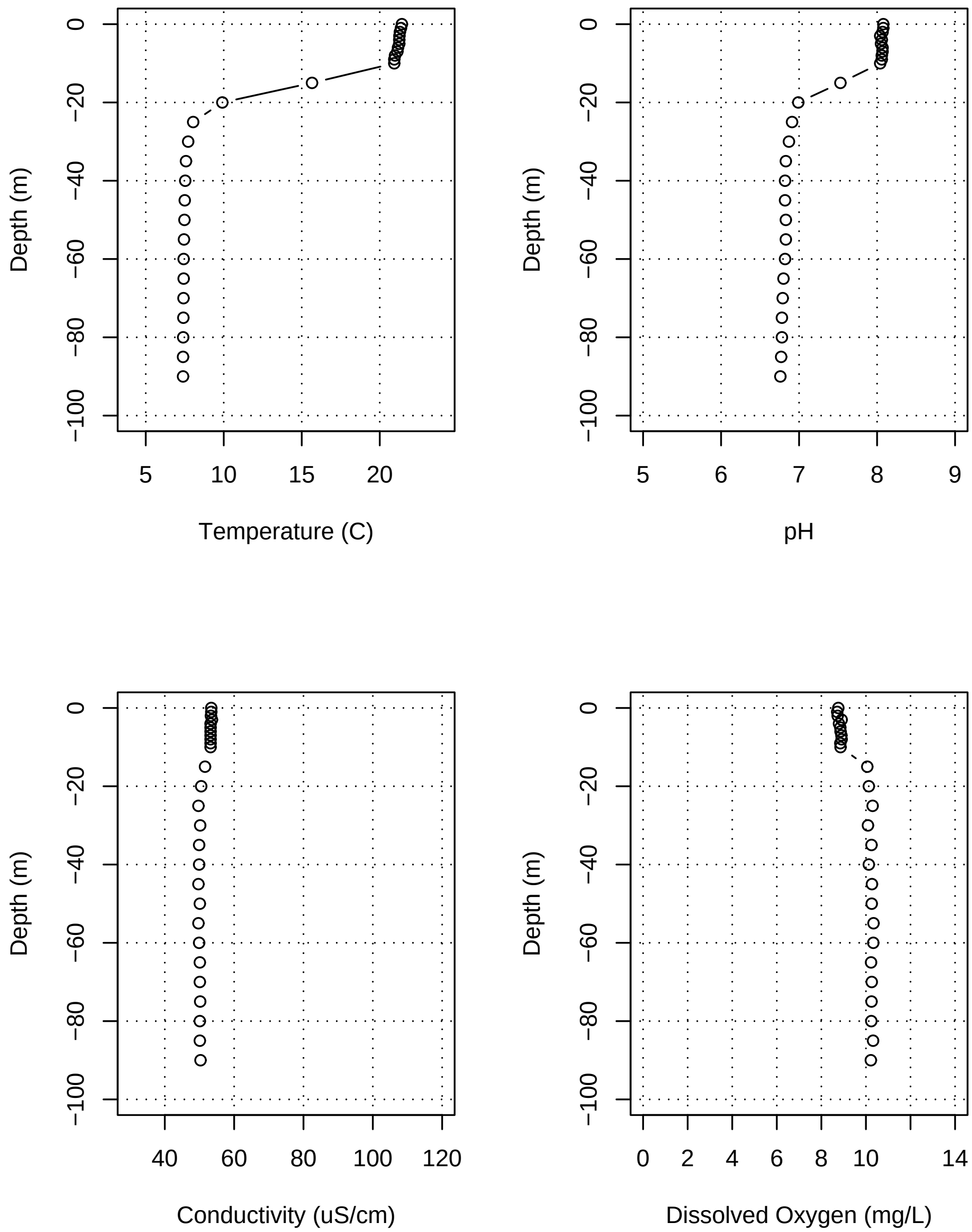


Figure 46: Lake Whatcom Hydrolab profile for Site 4, August 5, 2003.

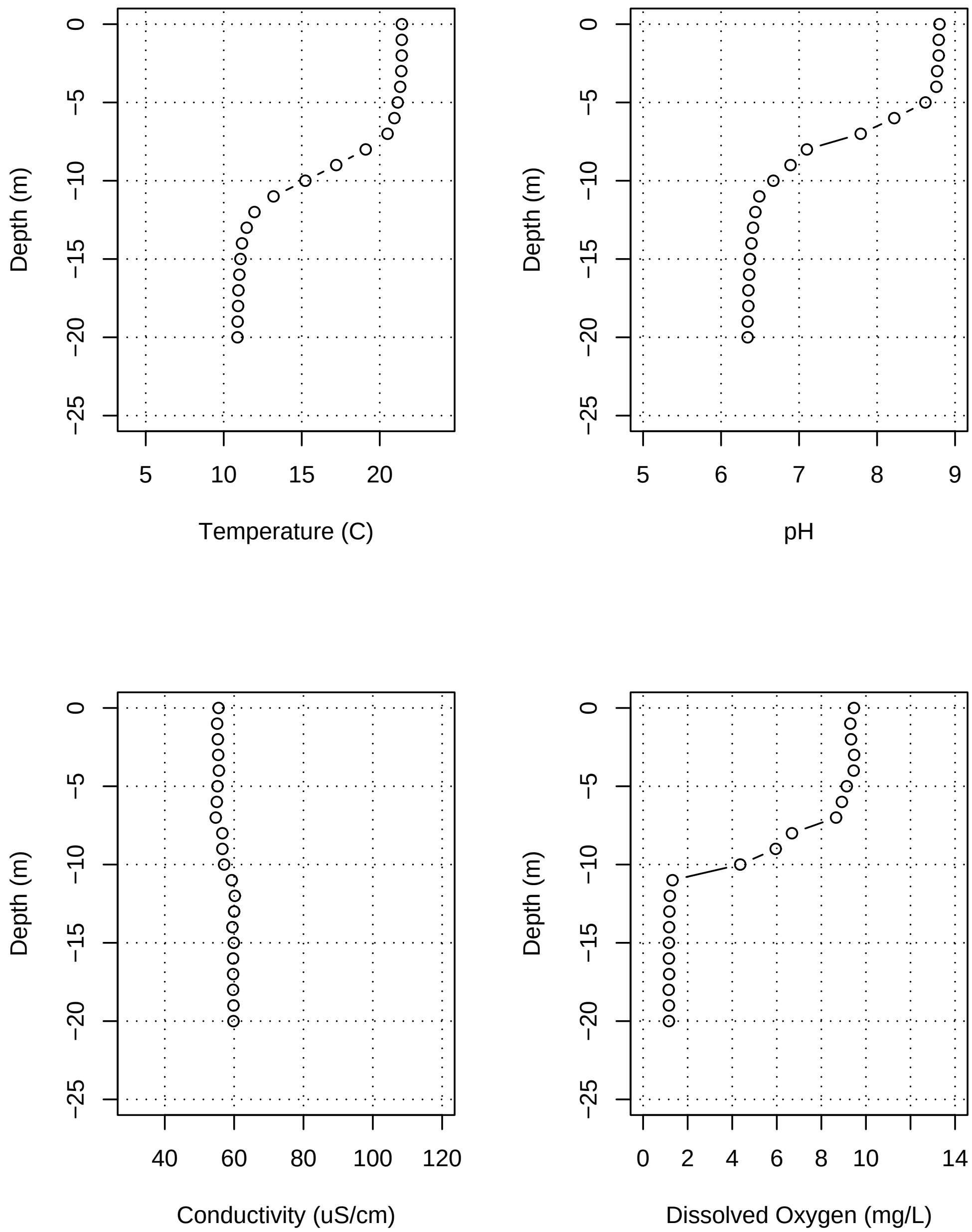


Figure 47: Lake Whatcom Hydrolab profile for Site 1, September 4, 2003.

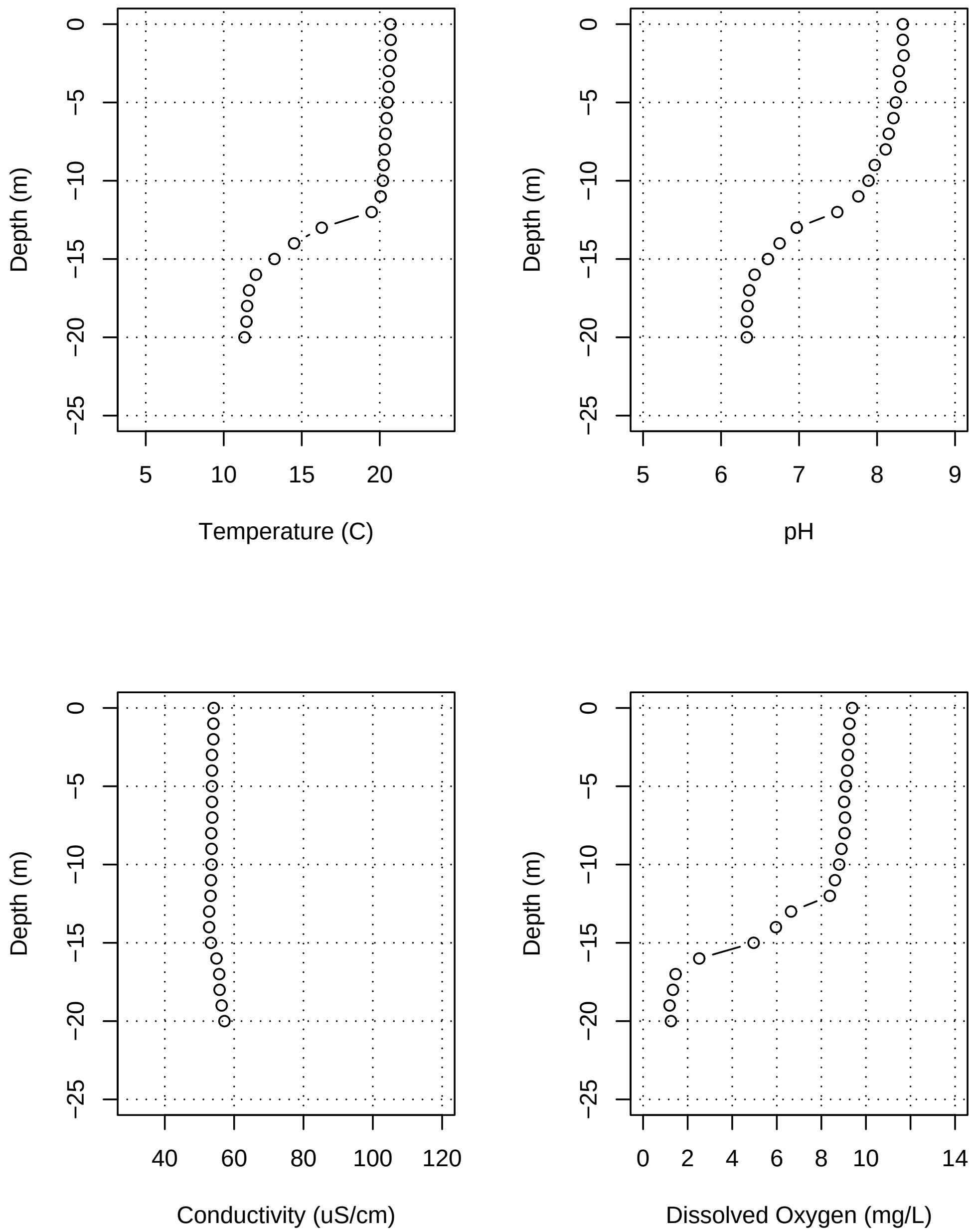


Figure 48: Lake Whatcom Hydrolab profile for Site 2, September 4, 2003.

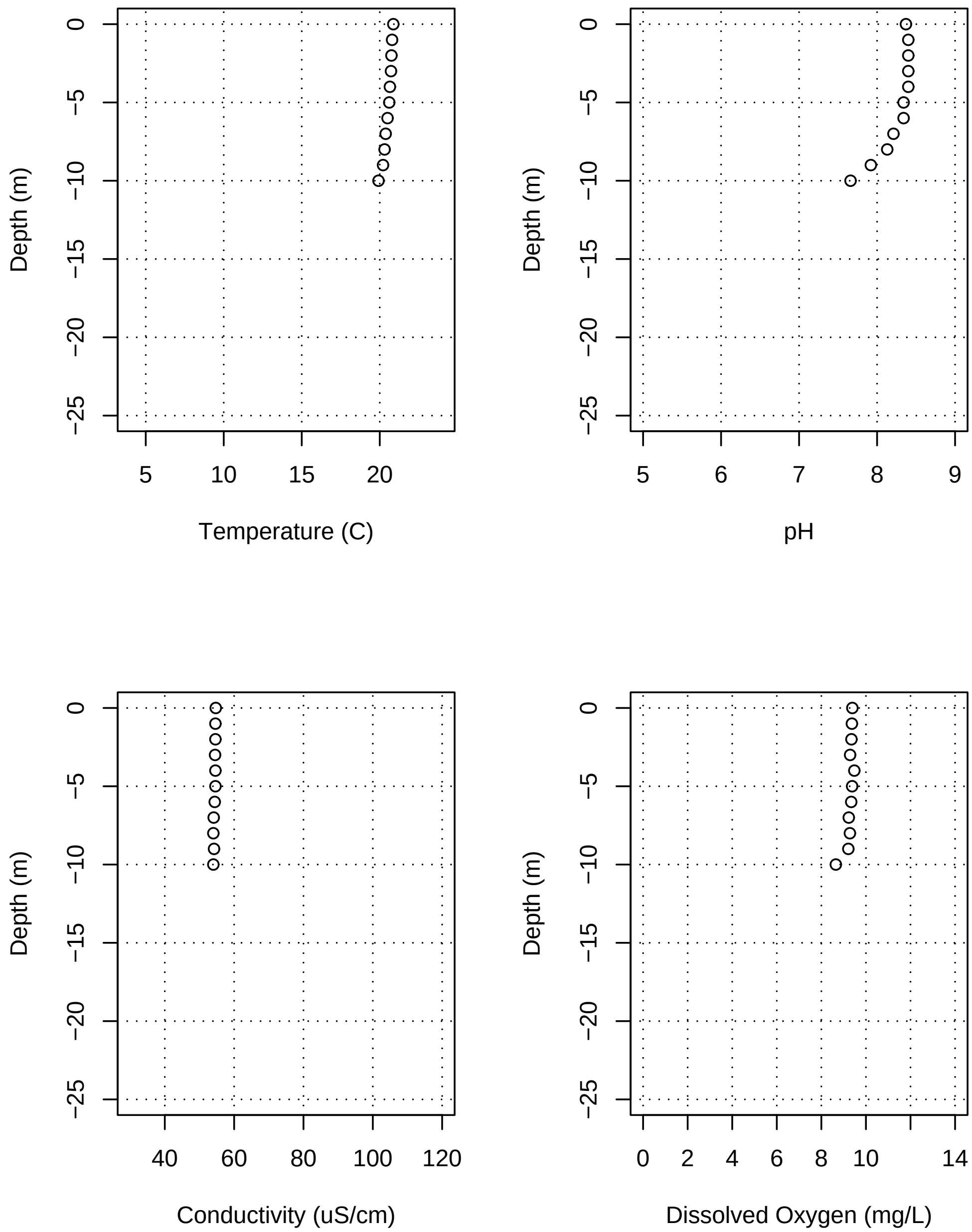


Figure 49: Lake Whatcom Hydrolab profile for the Intake, September 4, 2003.

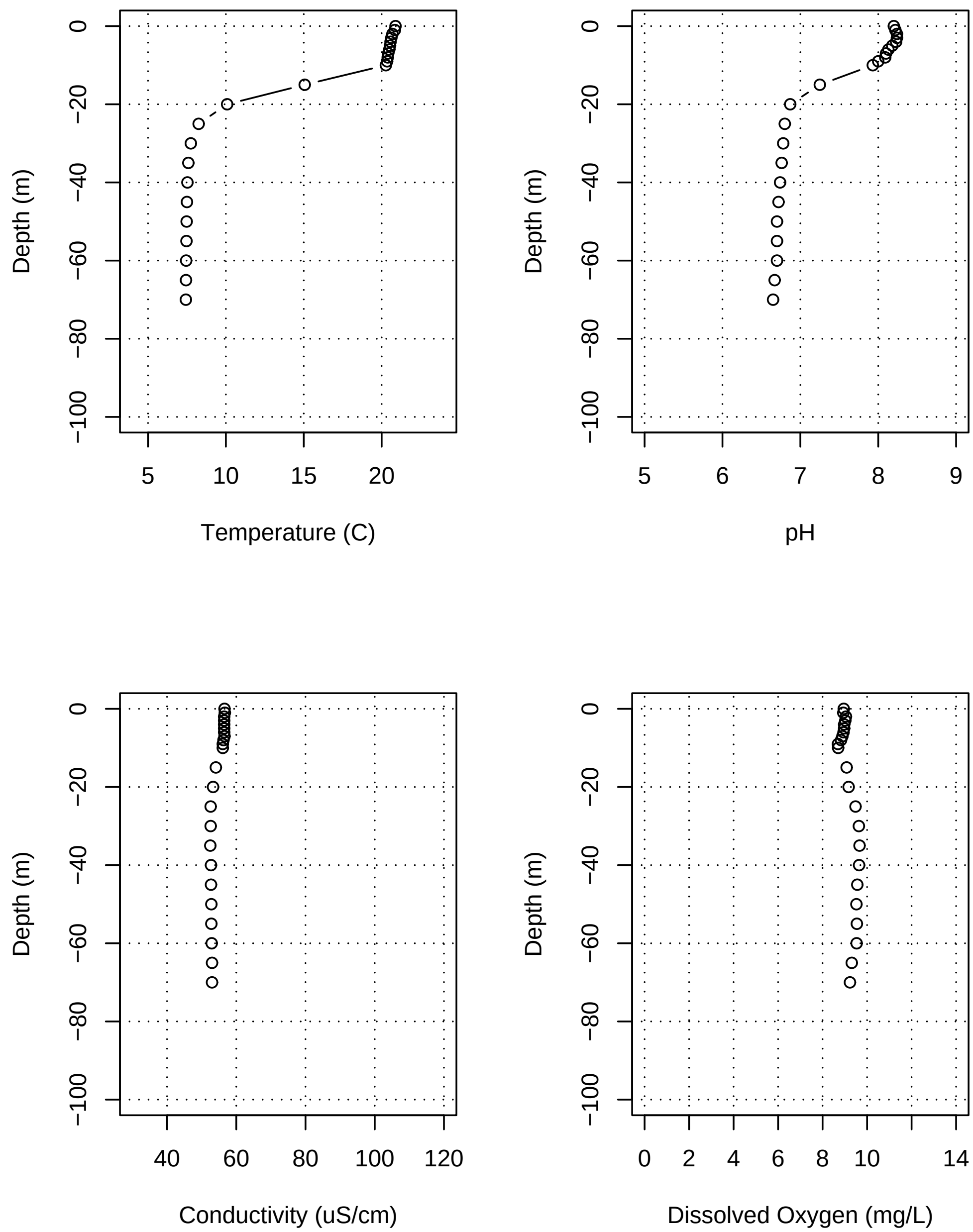


Figure 50: Lake Whatcom Hydrolab profile for Site 3, September 2, 2003.

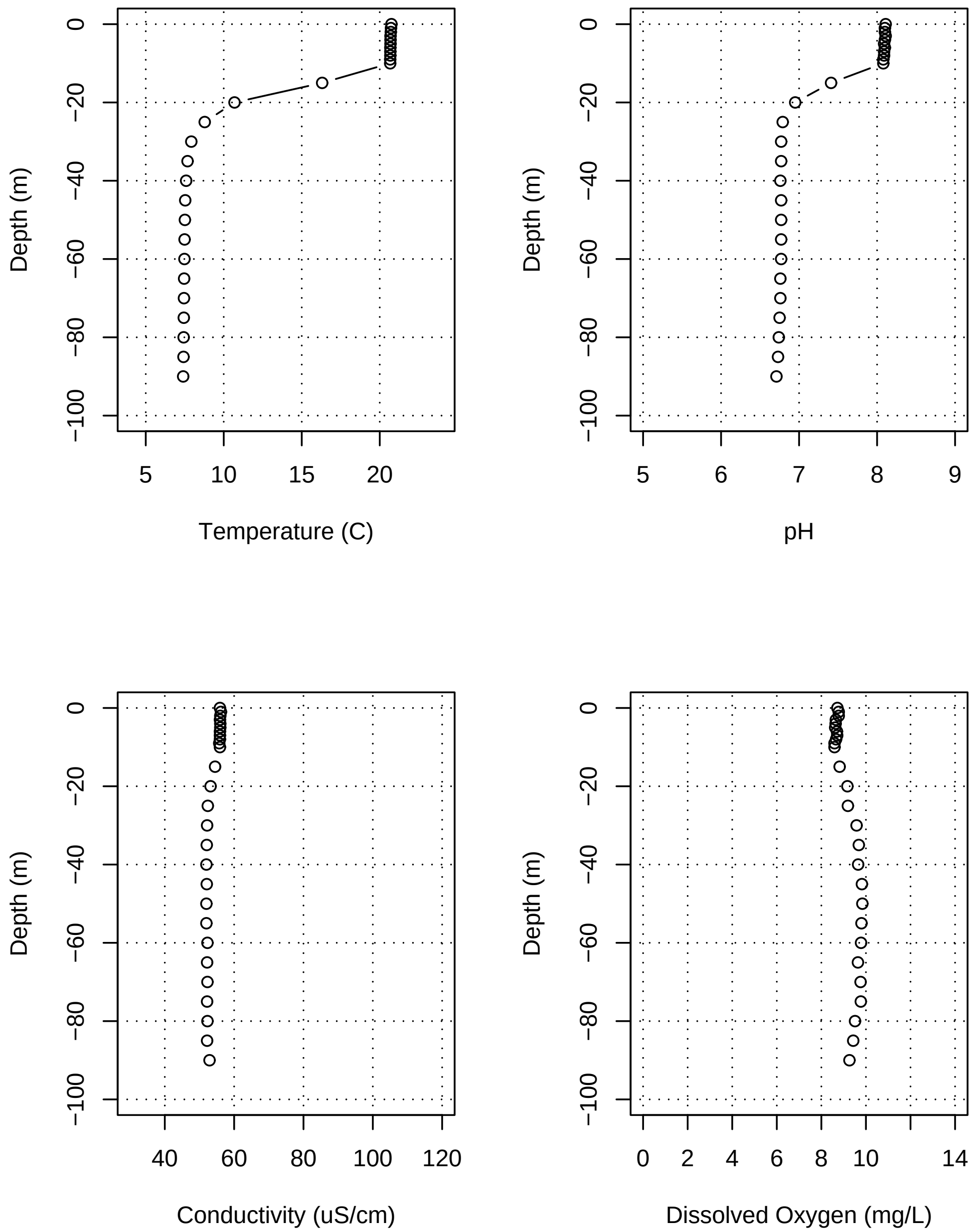


Figure 51: Lake Whatcom Hydrolab profile for Site 4, September 2, 2003.

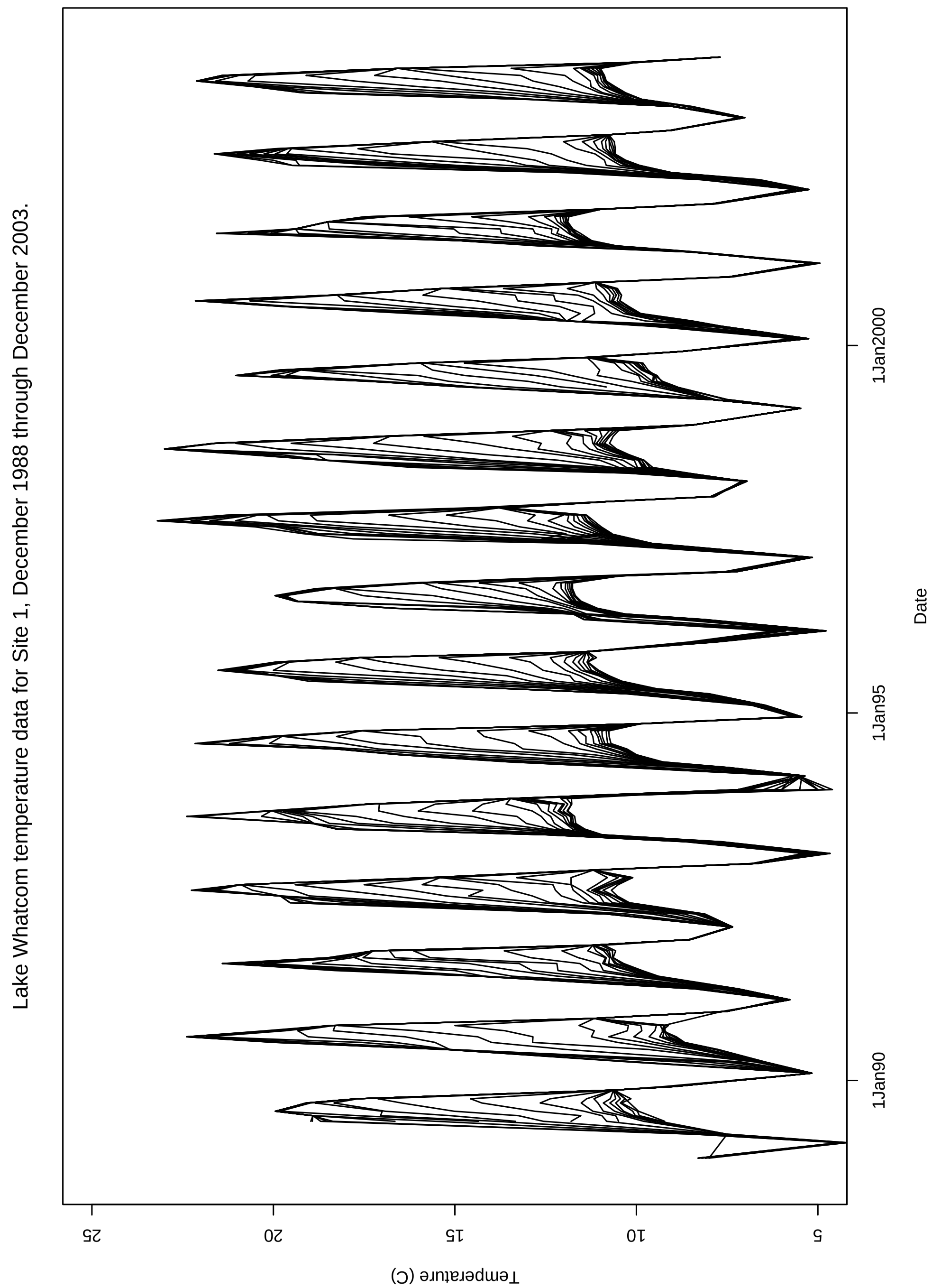


Figure 52: Lake Whatcom temperature data for Site 1 (1988–2003).

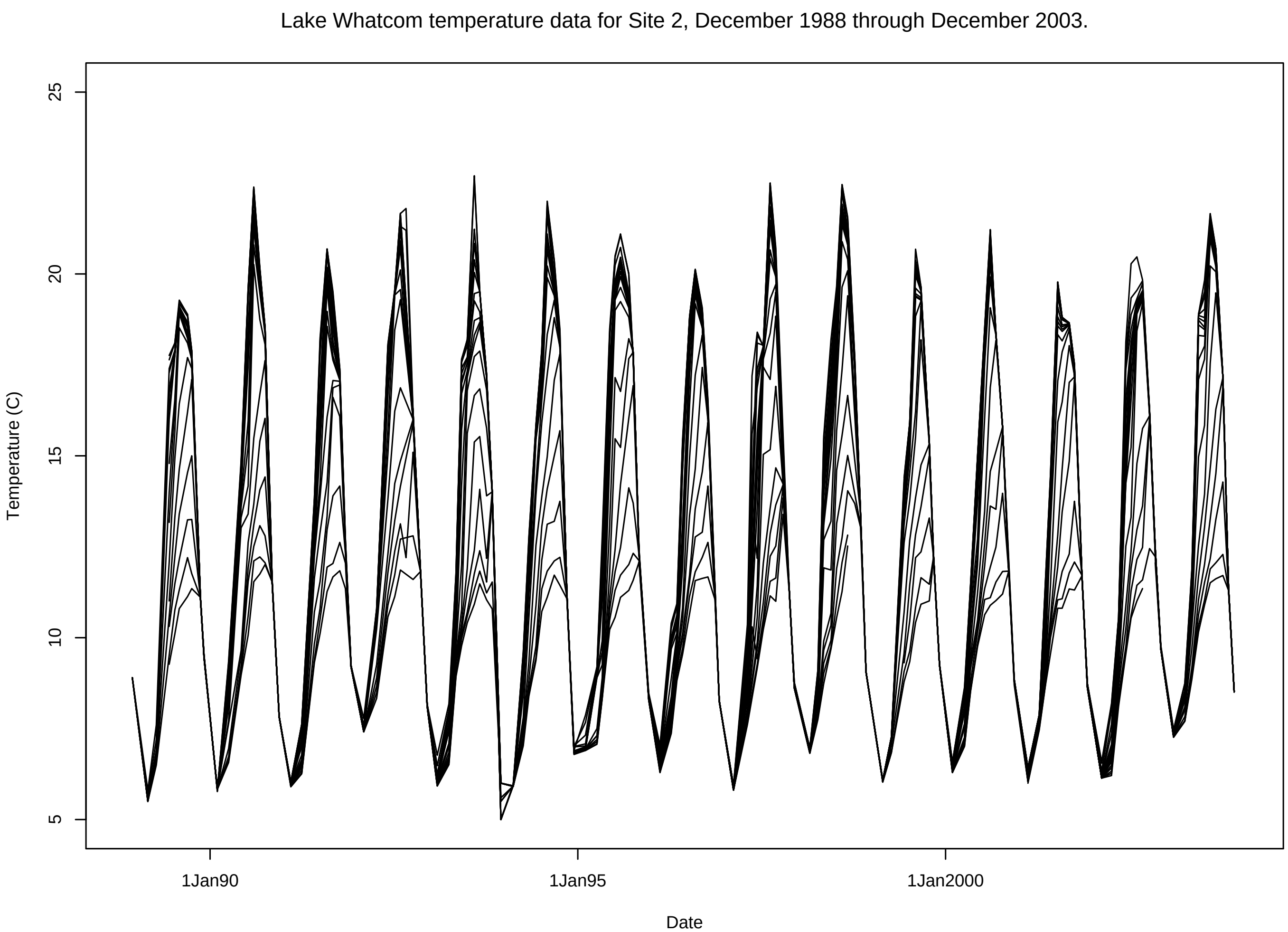


Figure 53: Lake Whatcom temperature data for Site 2 (1988–2003).

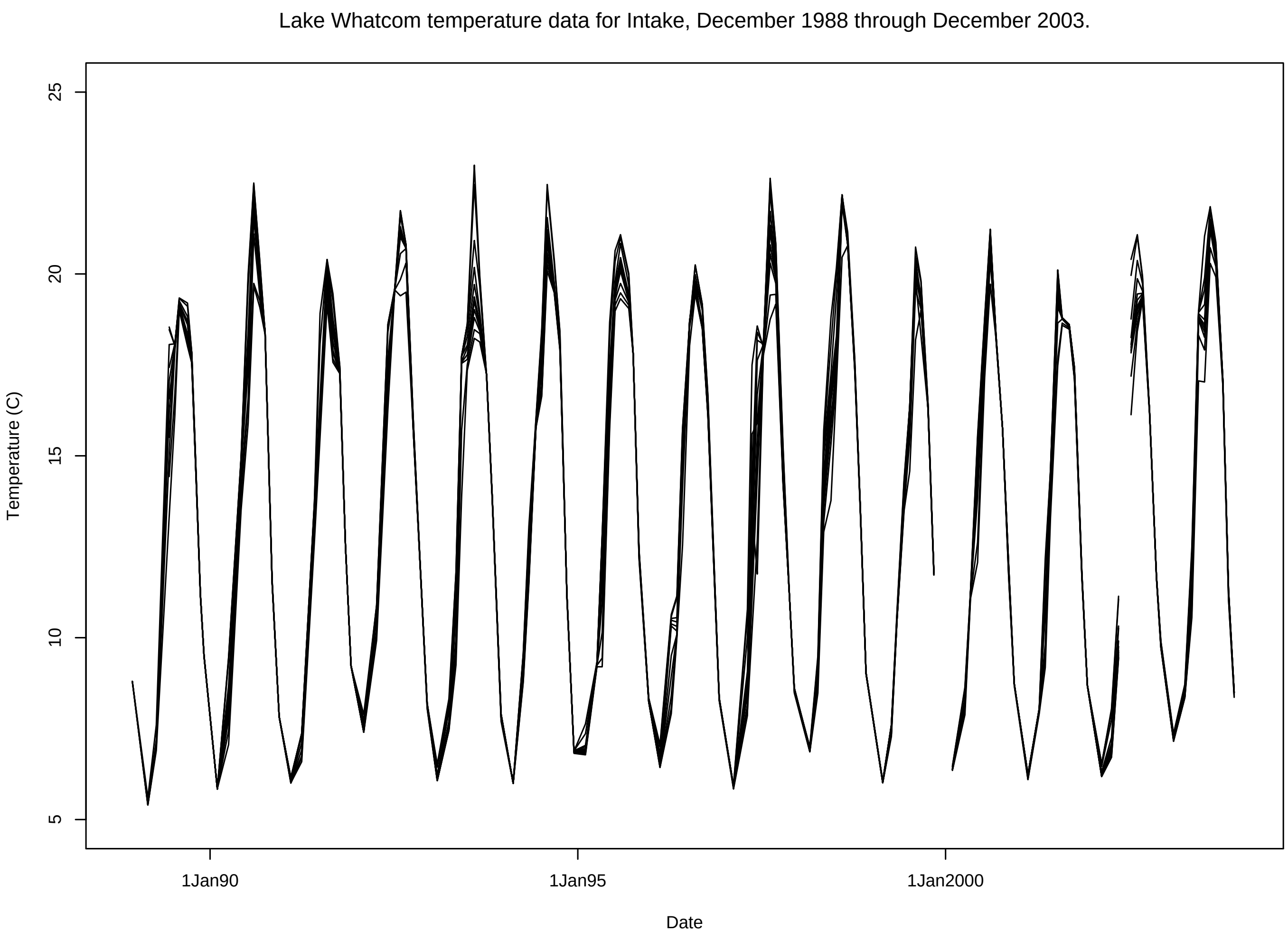


Figure 54: Lake Whatcom temperature data for the Intake (1988–2003).

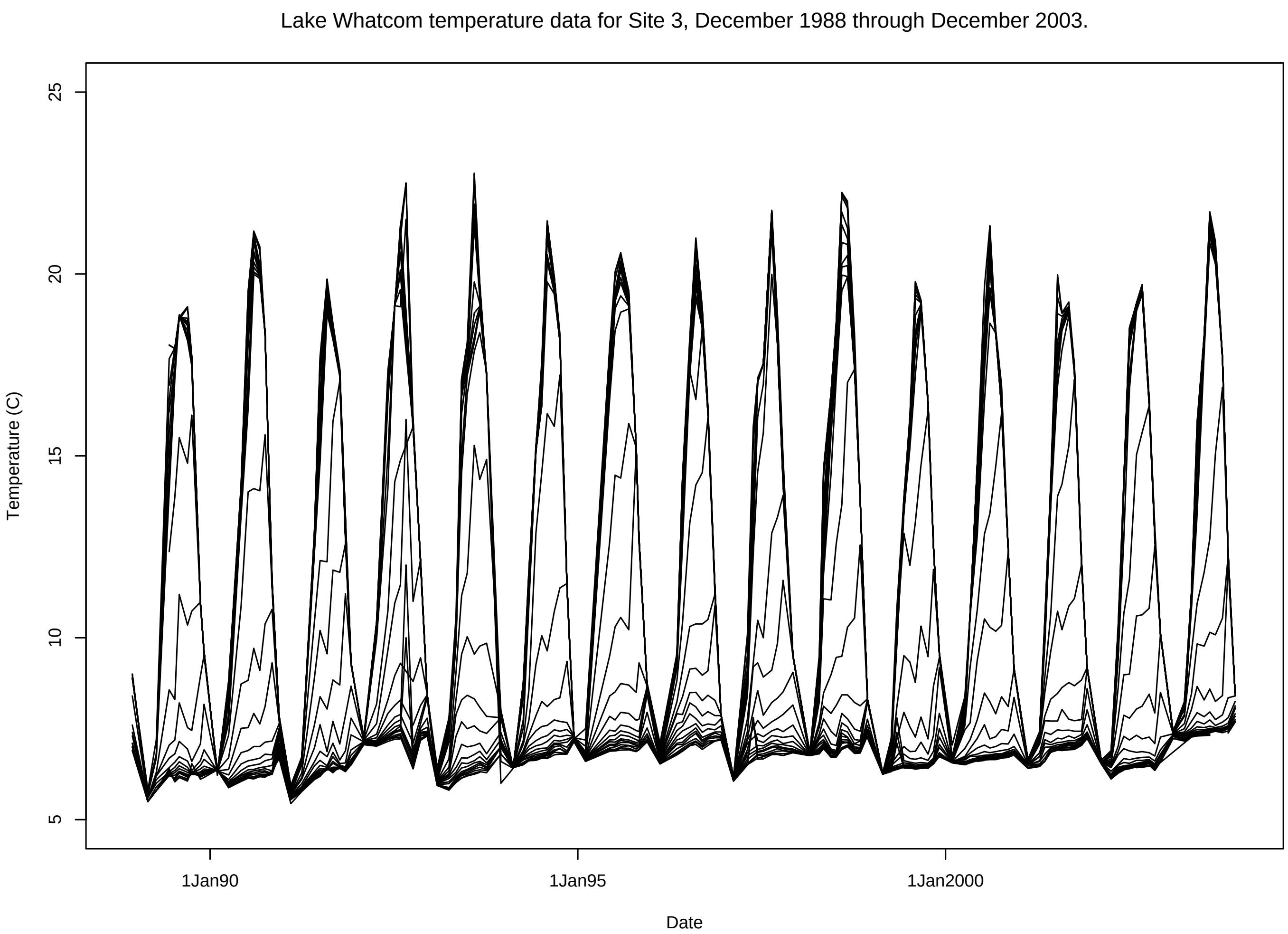


Figure 55: Lake Whatcom temperature data for Site 3 (1988–2003).

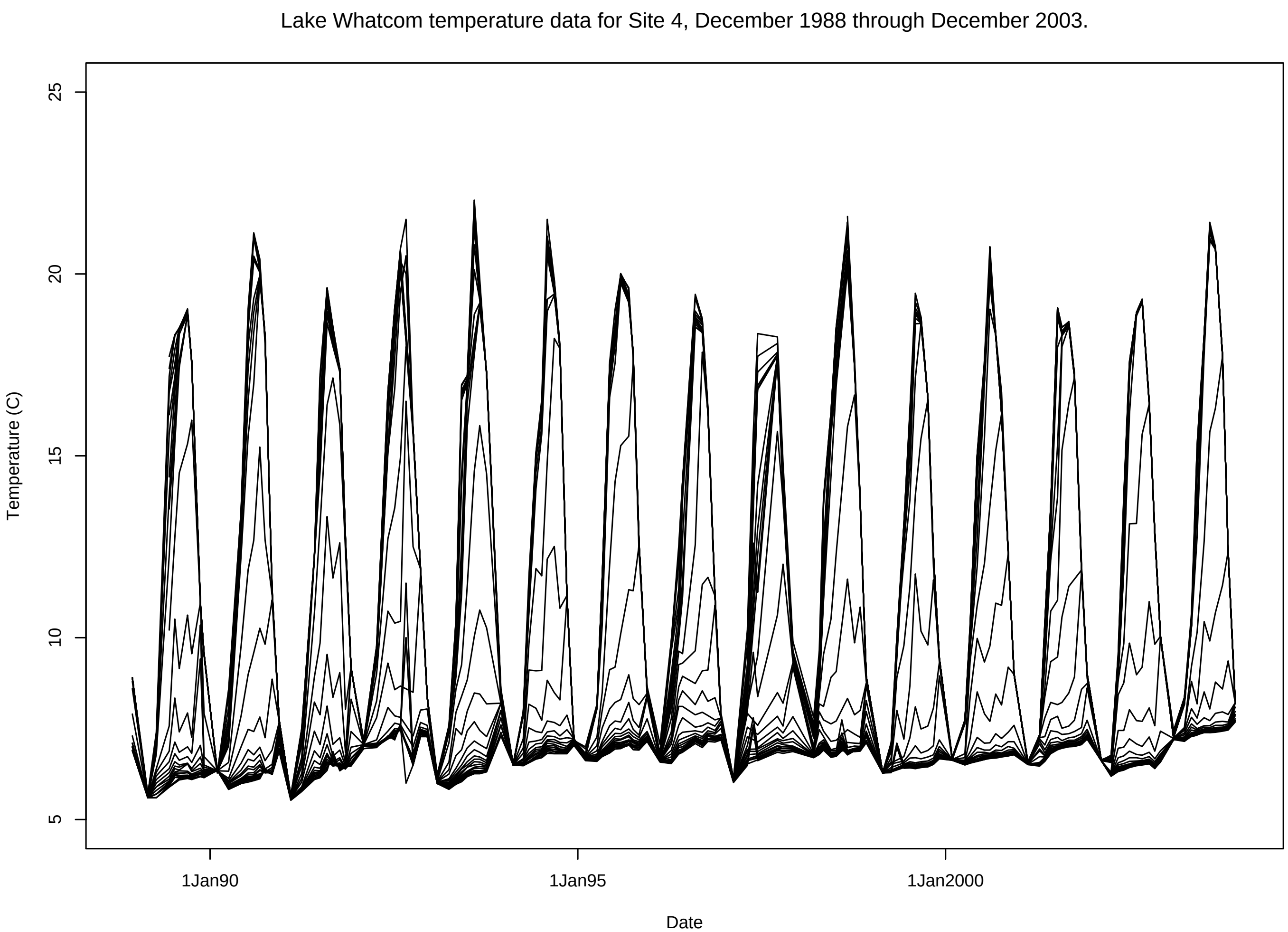


Figure 56: Lake Whatcom temperature data for Site 4 (1988–2003).

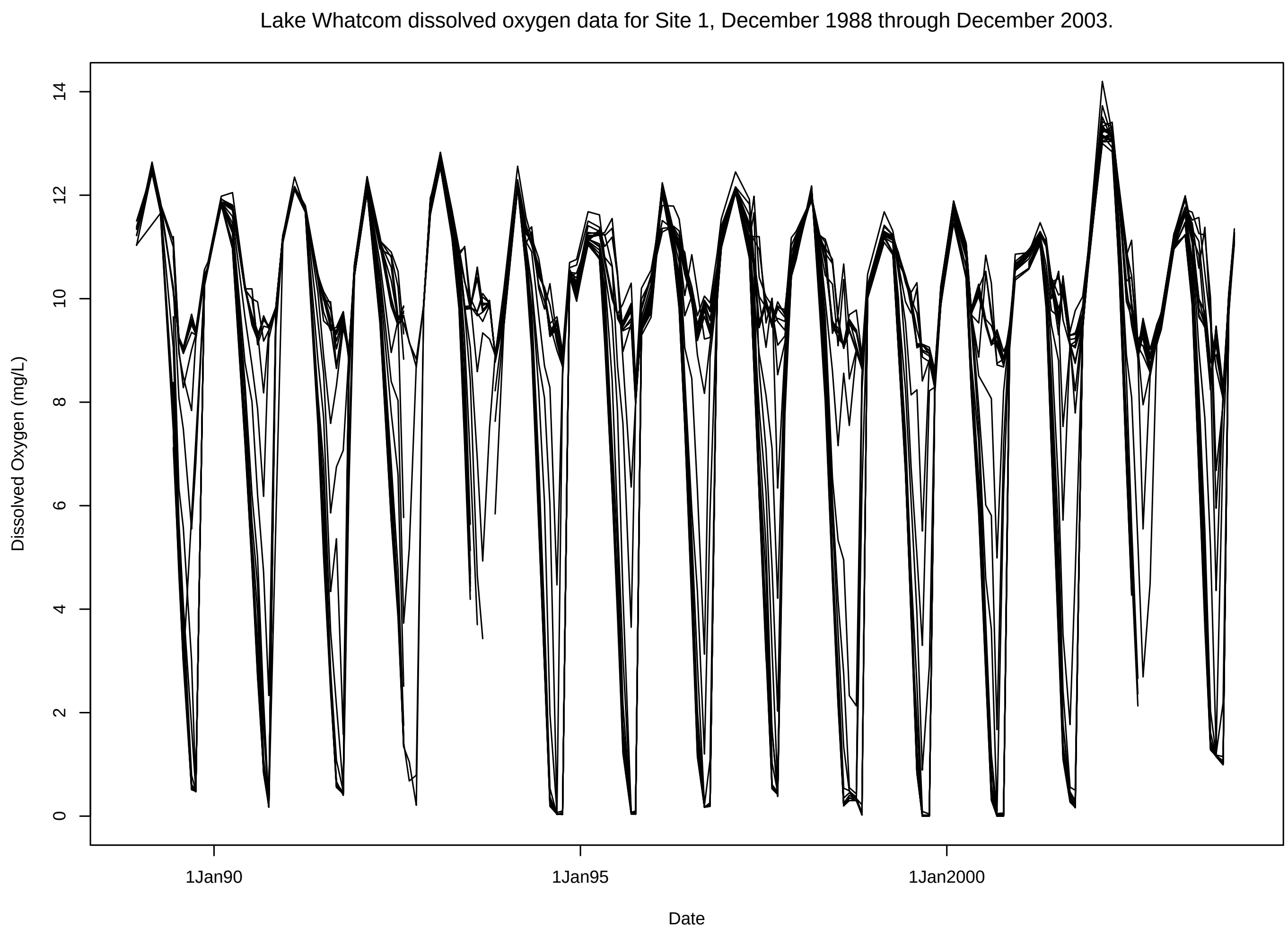


Figure 57: Lake Whatcom dissolved oxygen data for Site 1 (1988–2003).

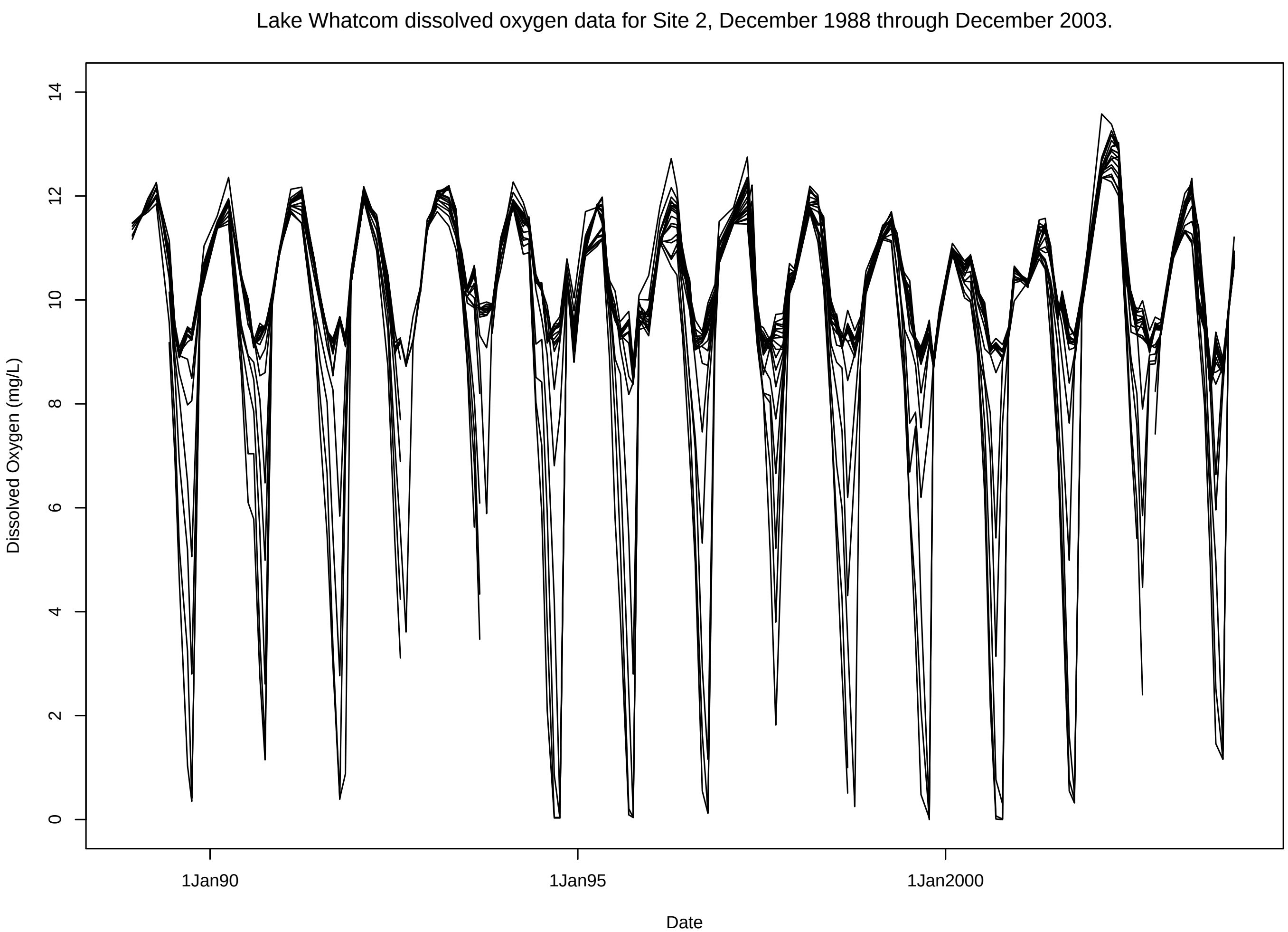


Figure 58: Lake Whatcom dissolved oxygen data for Site 2 (1988–2003).

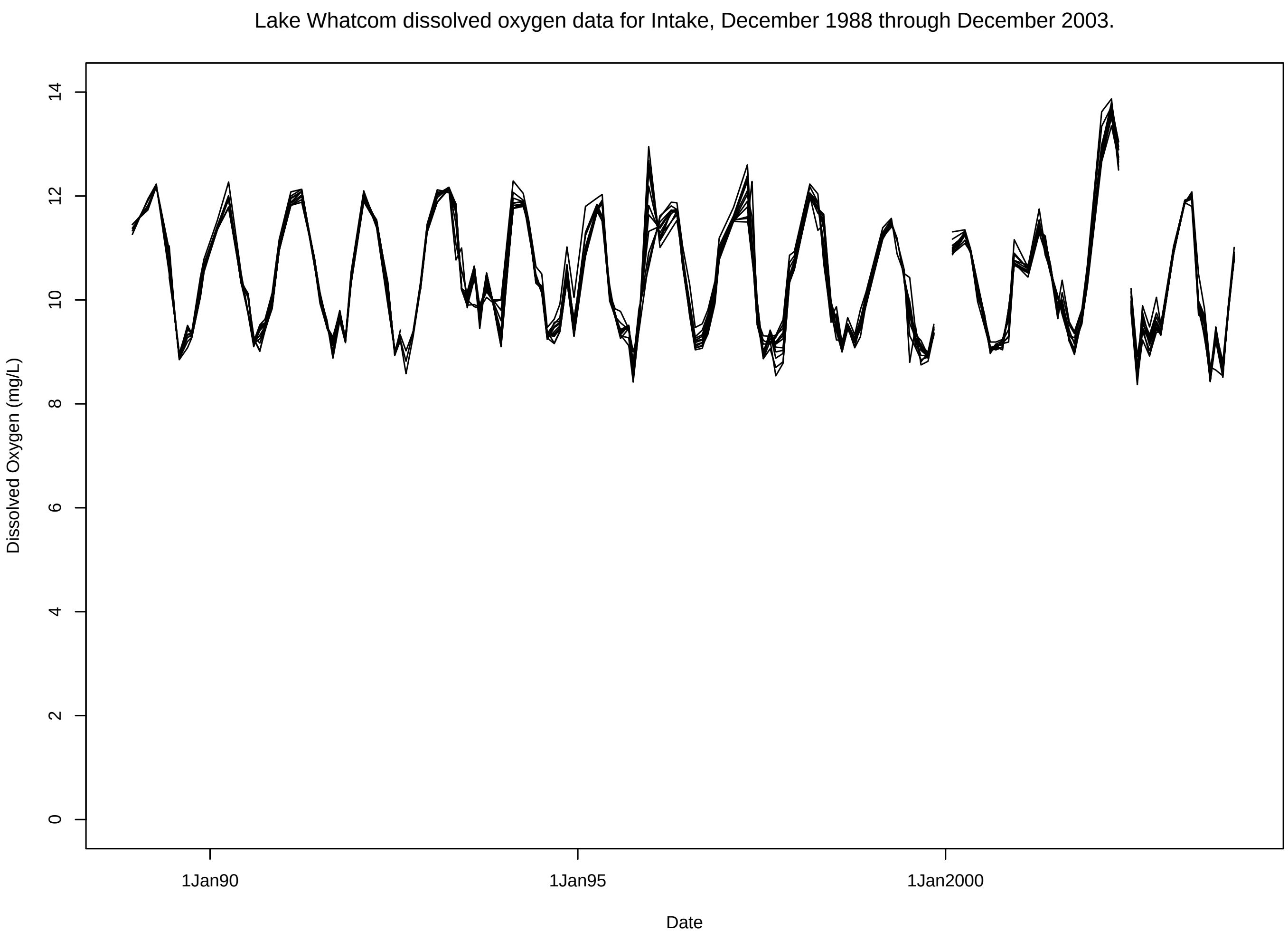


Figure 59: Lake Whatcom dissolved oxygen data for the Intake (1988–2003).

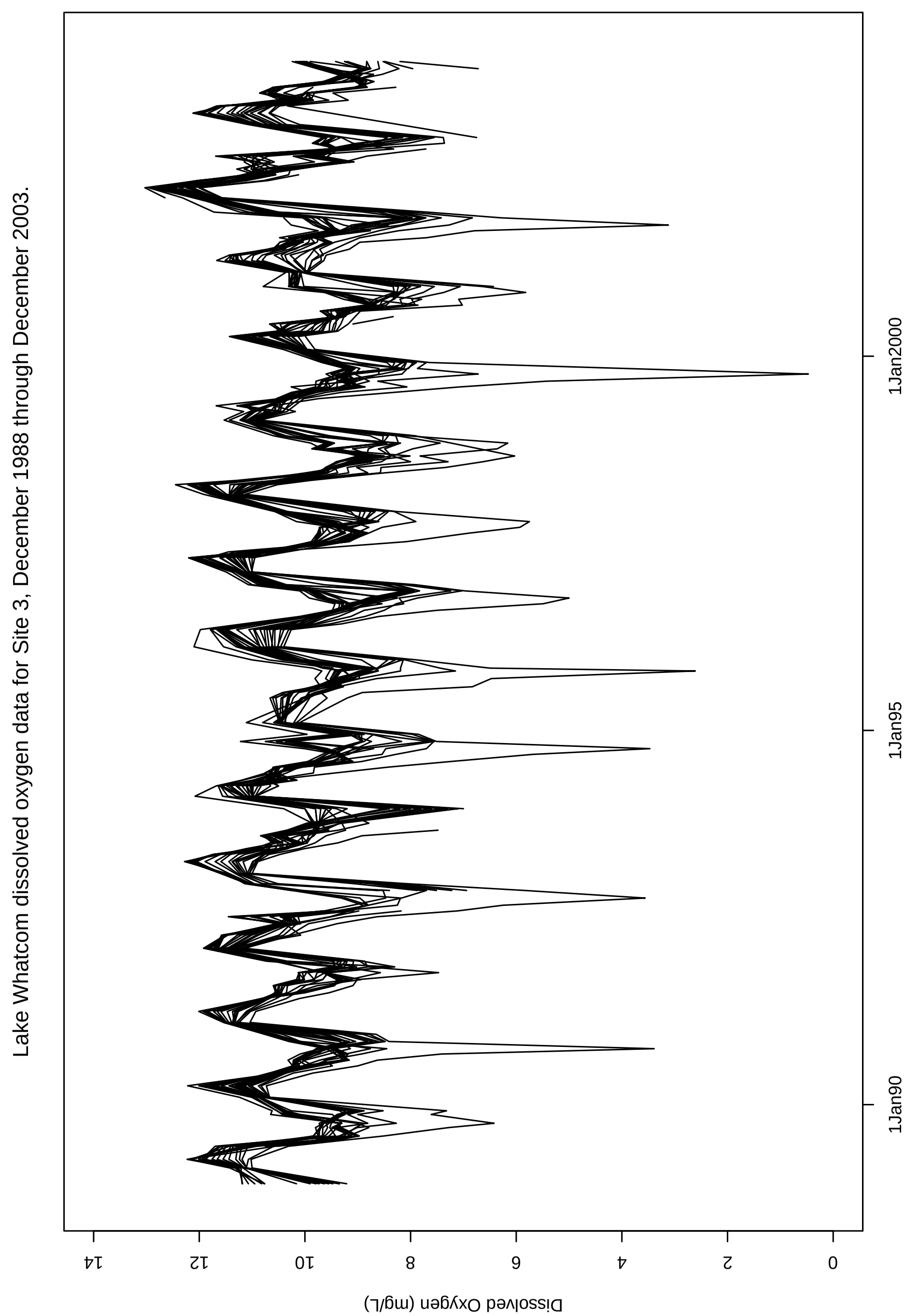


Figure 60: Lake Whatcom dissolved oxygen data for Site 3 (1988–2003).

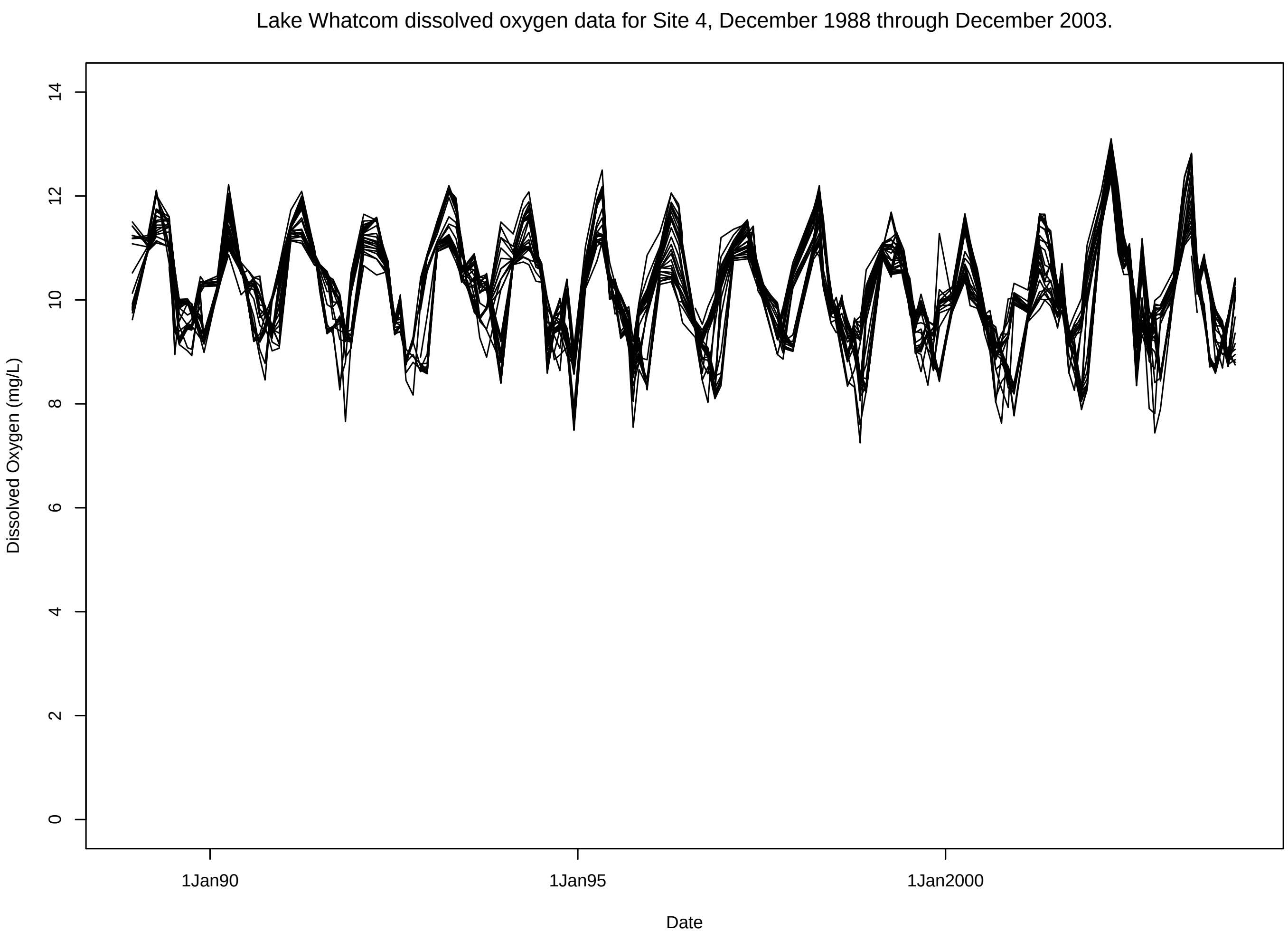


Figure 61: Lake Whatcom dissolved oxygen data for Site 4 (1988–2003).

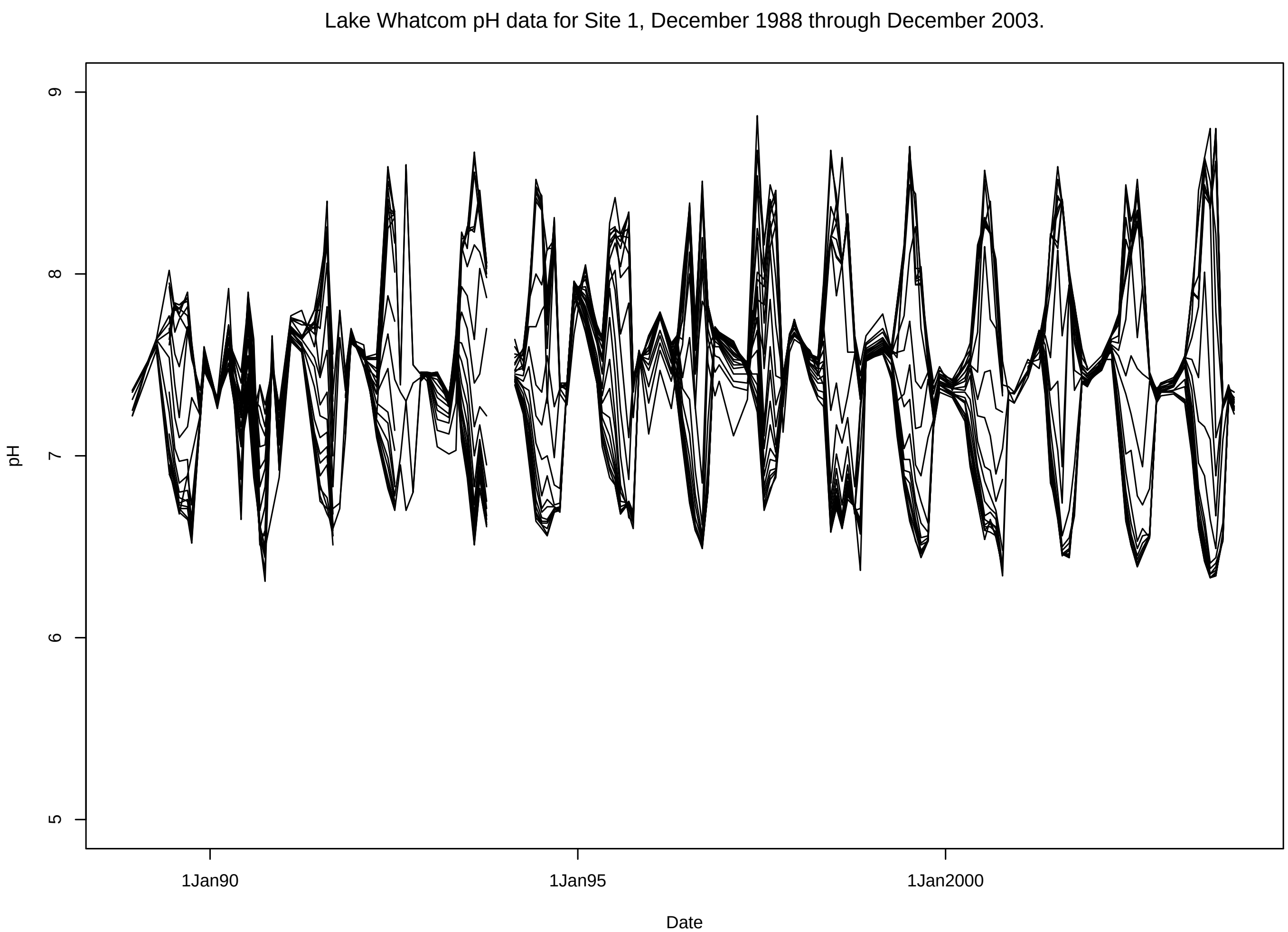


Figure 62: Lake Whatcom pH data for Site 1 (1988–2003).

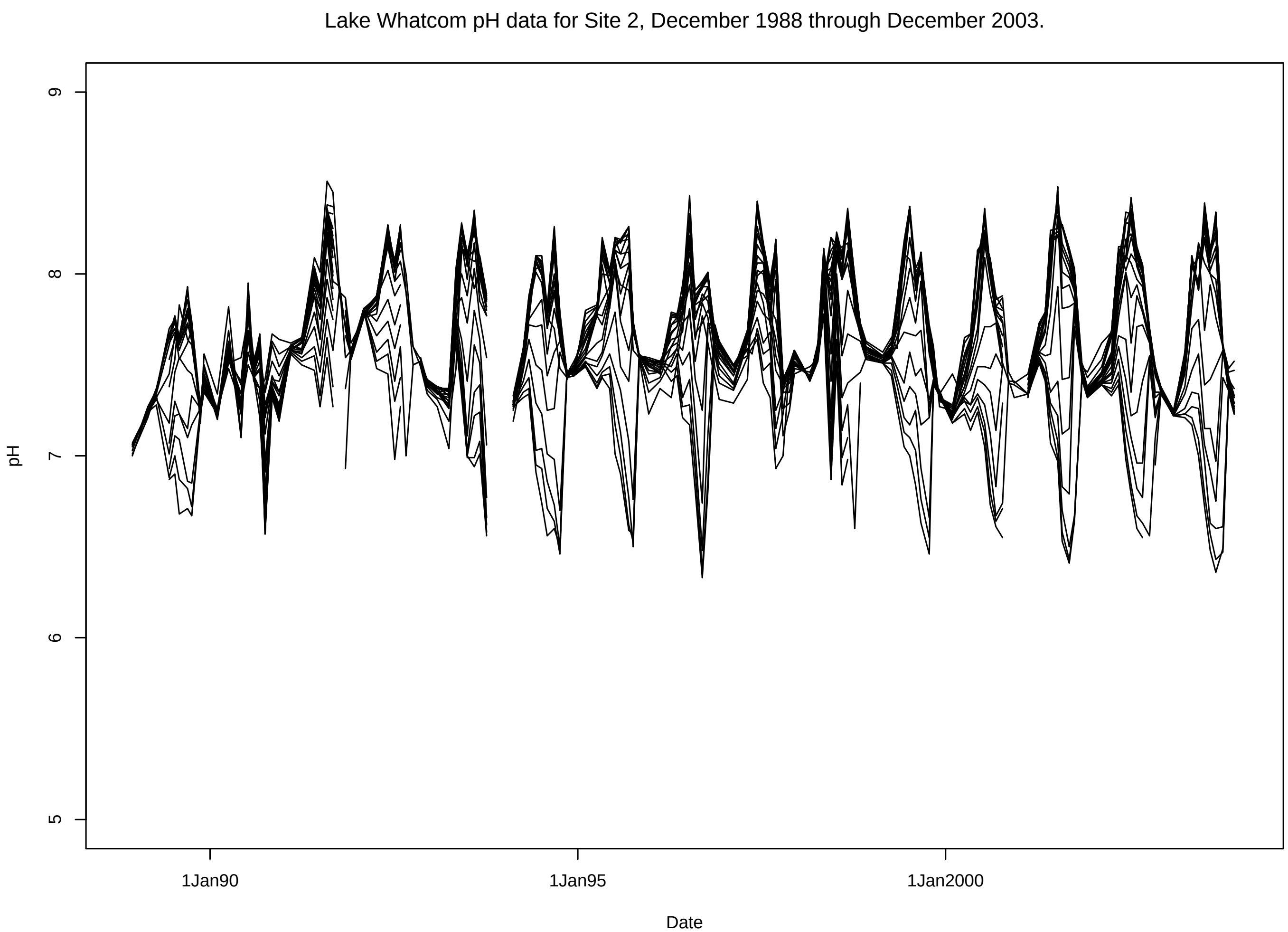


Figure 63: Lake Whatcom pH data for Site 2 (1988–2003).

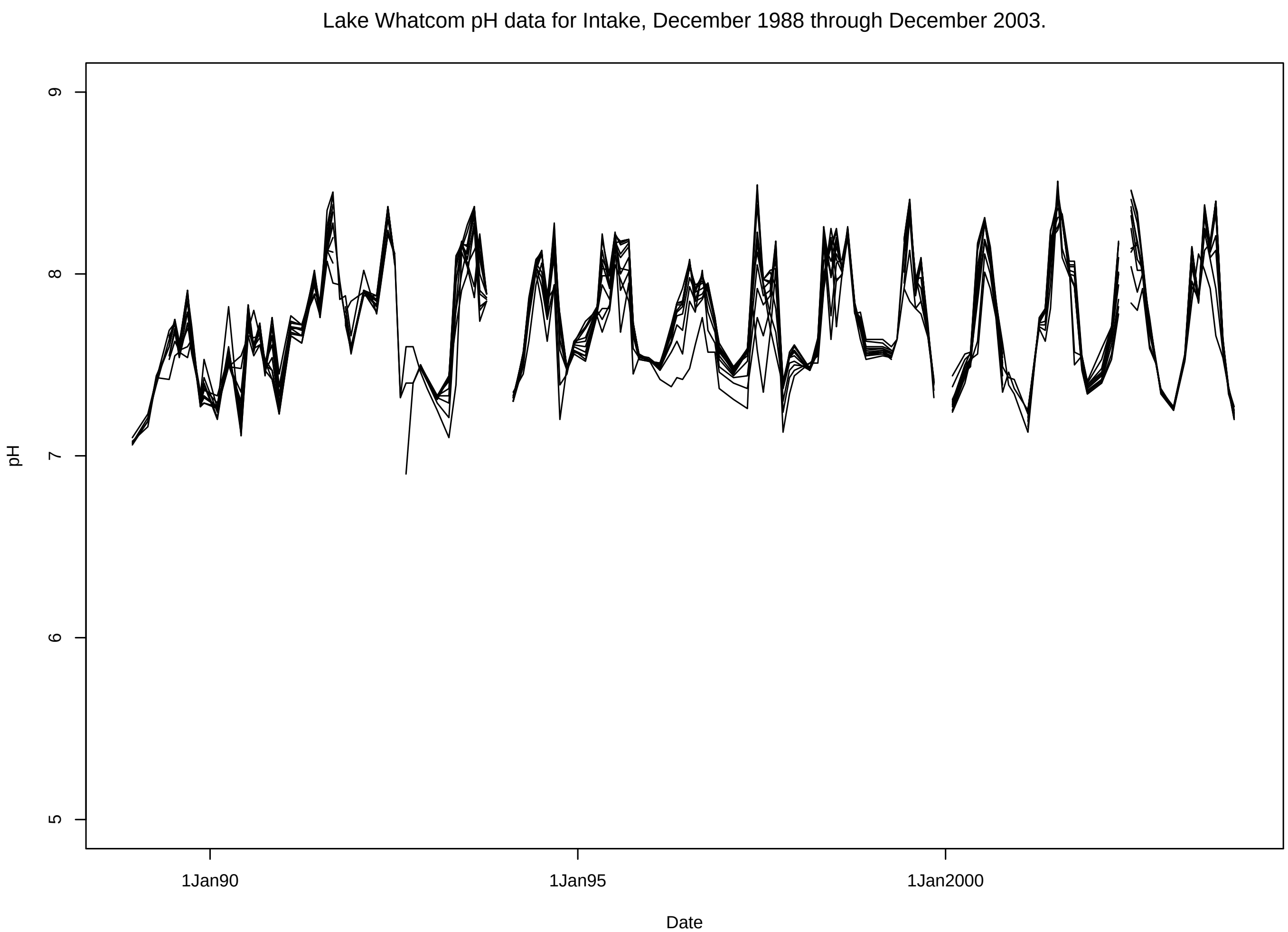


Figure 64: Lake Whatcom pH data for the Intake (1988–2003).

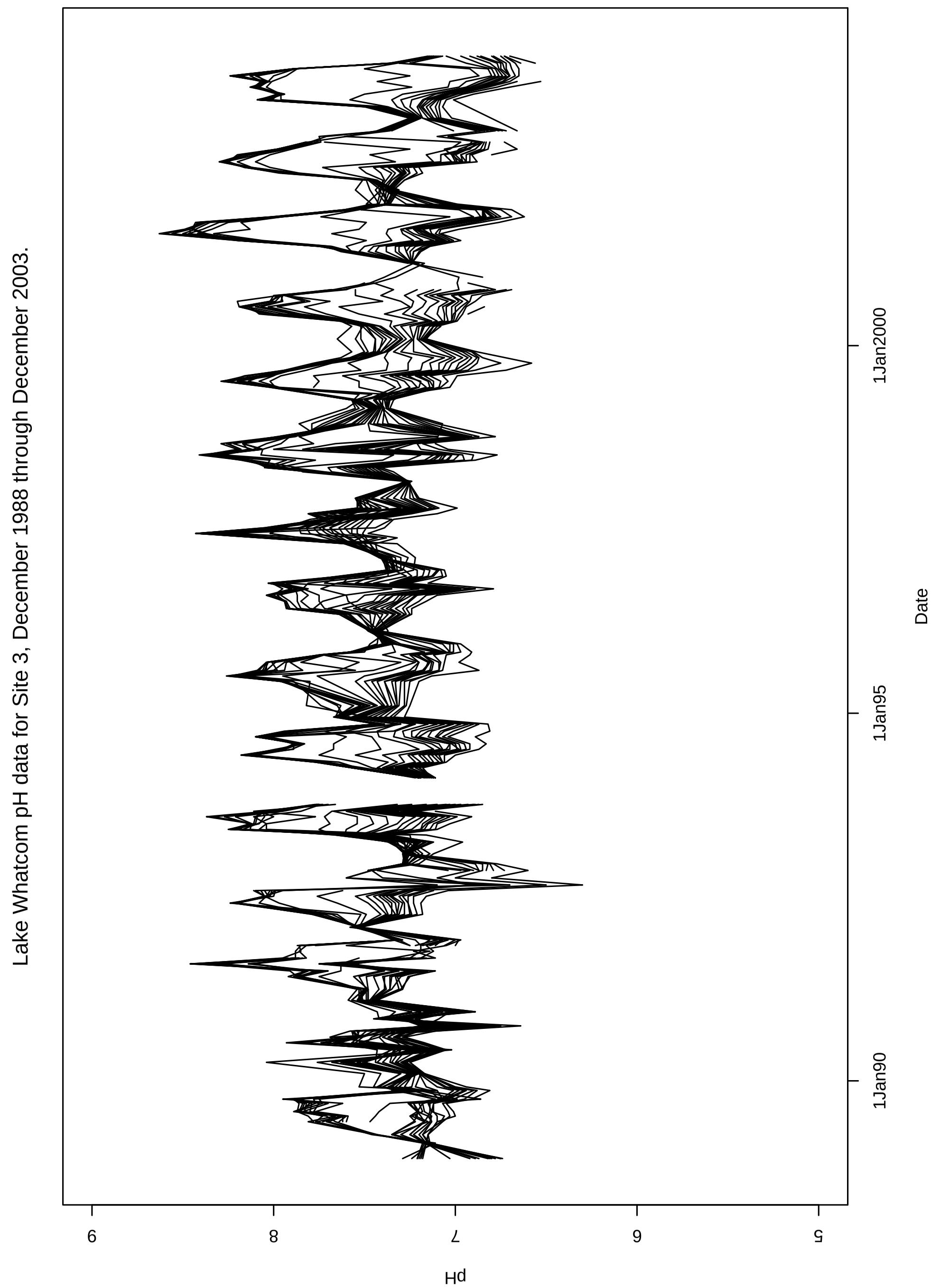


Figure 65: Lake Whatcom pH data for Site 3 (1988–2003).

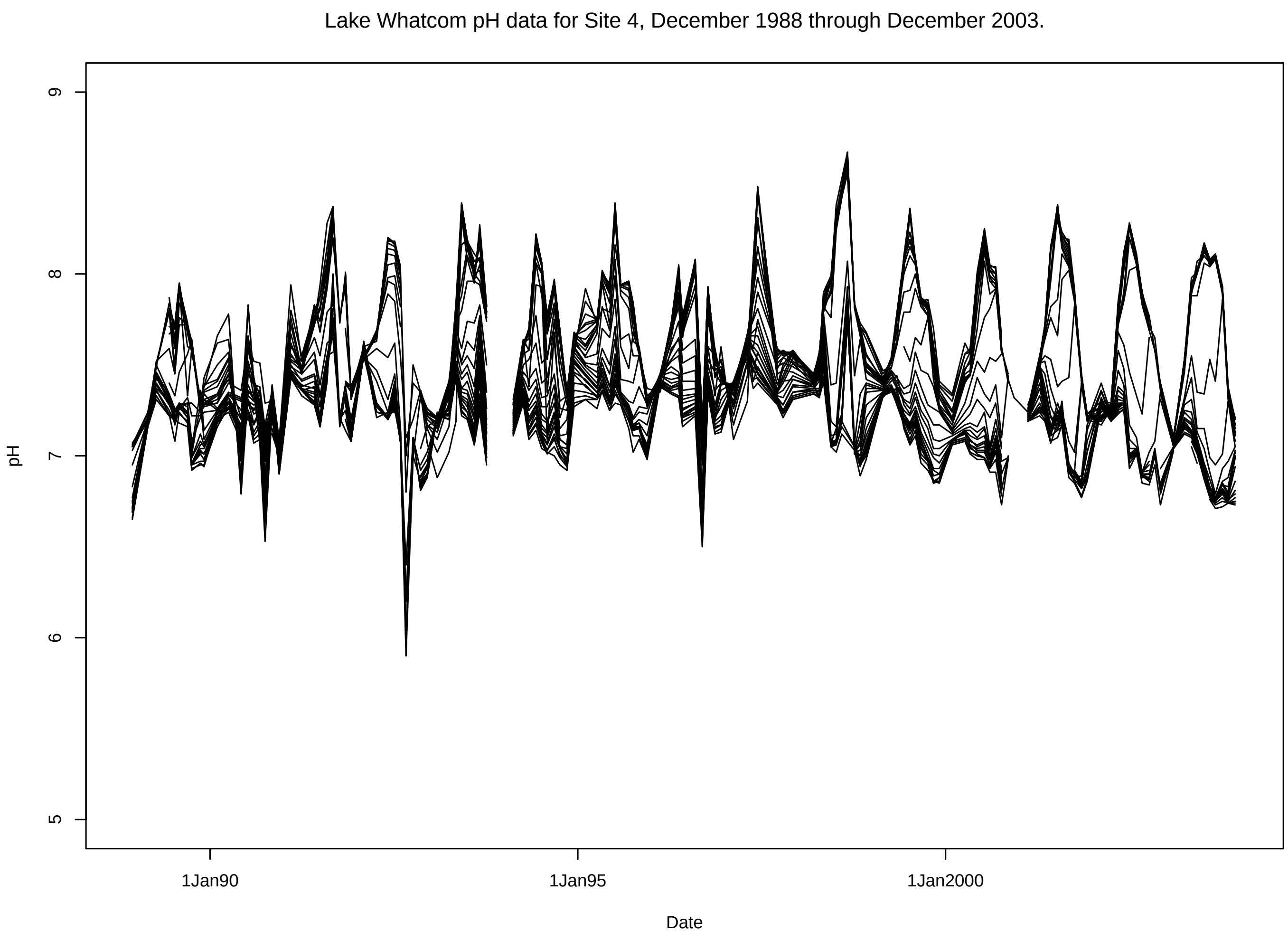


Figure 66: Lake Whatcom pH data for Site 4 (1988–2003).

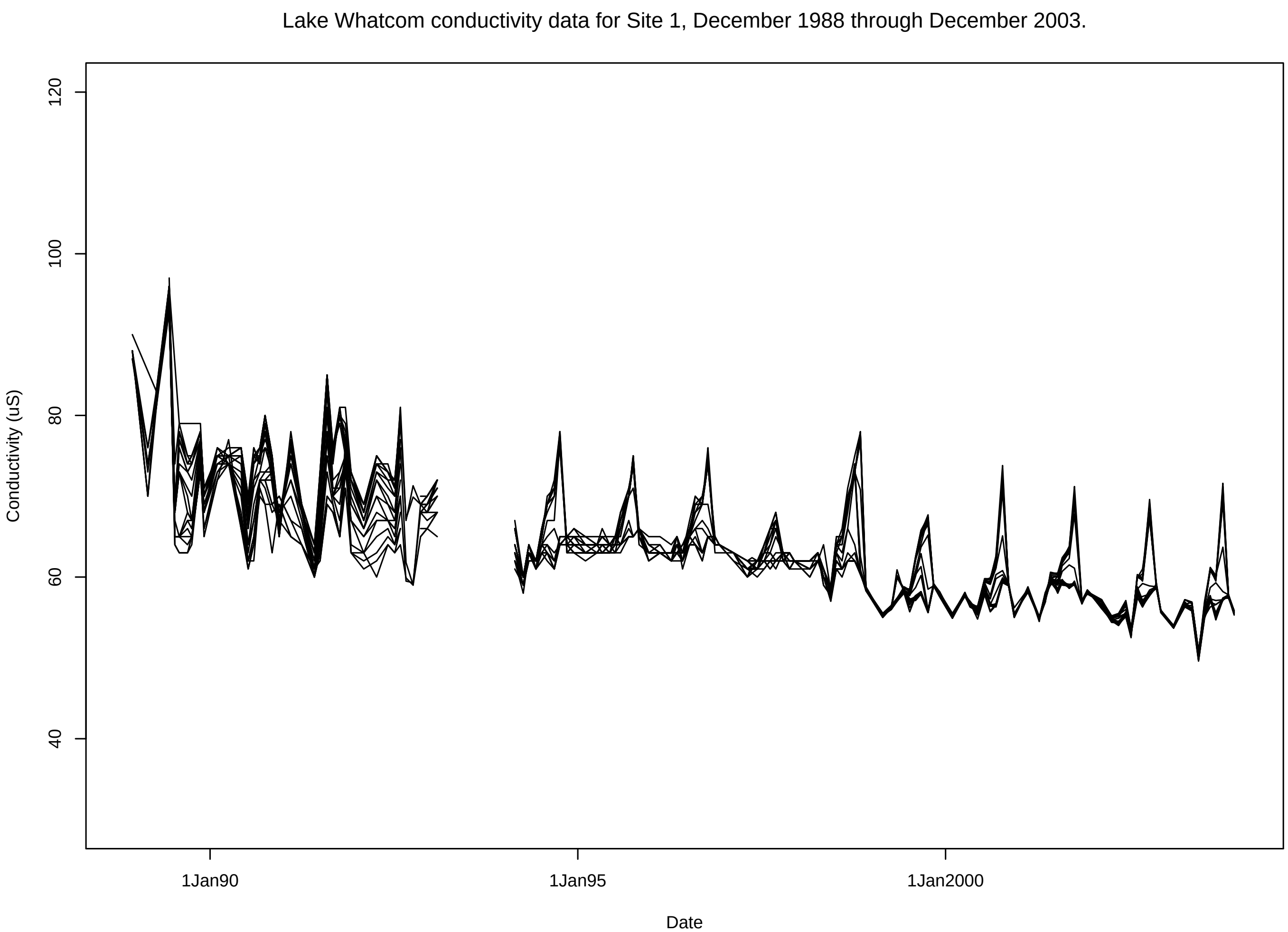


Figure 67: Lake Whatcom conductivity data for Site 1 (1988–2003).

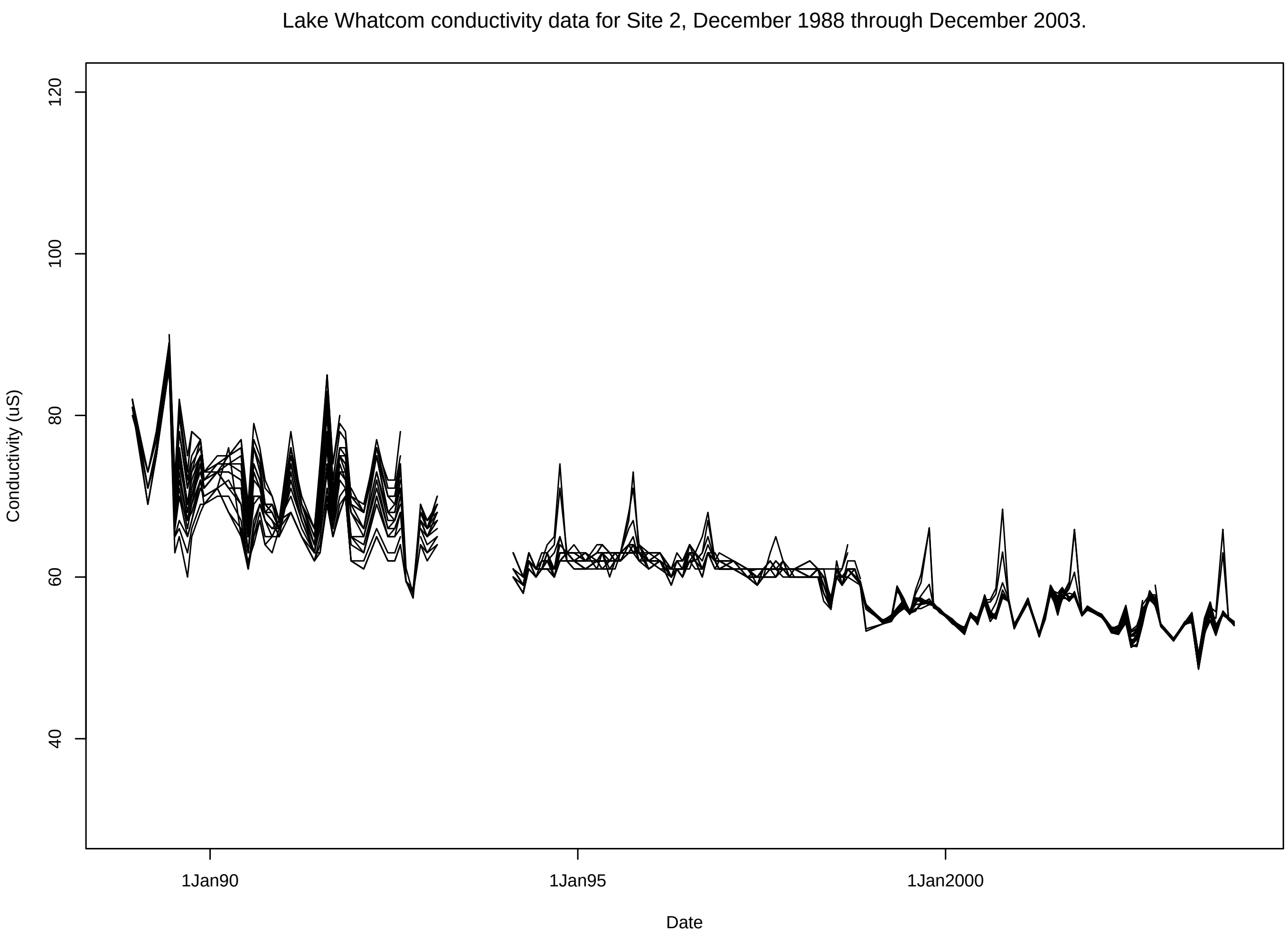


Figure 68: Lake Whatcom conductivity data for Site 2 (1988–2003).

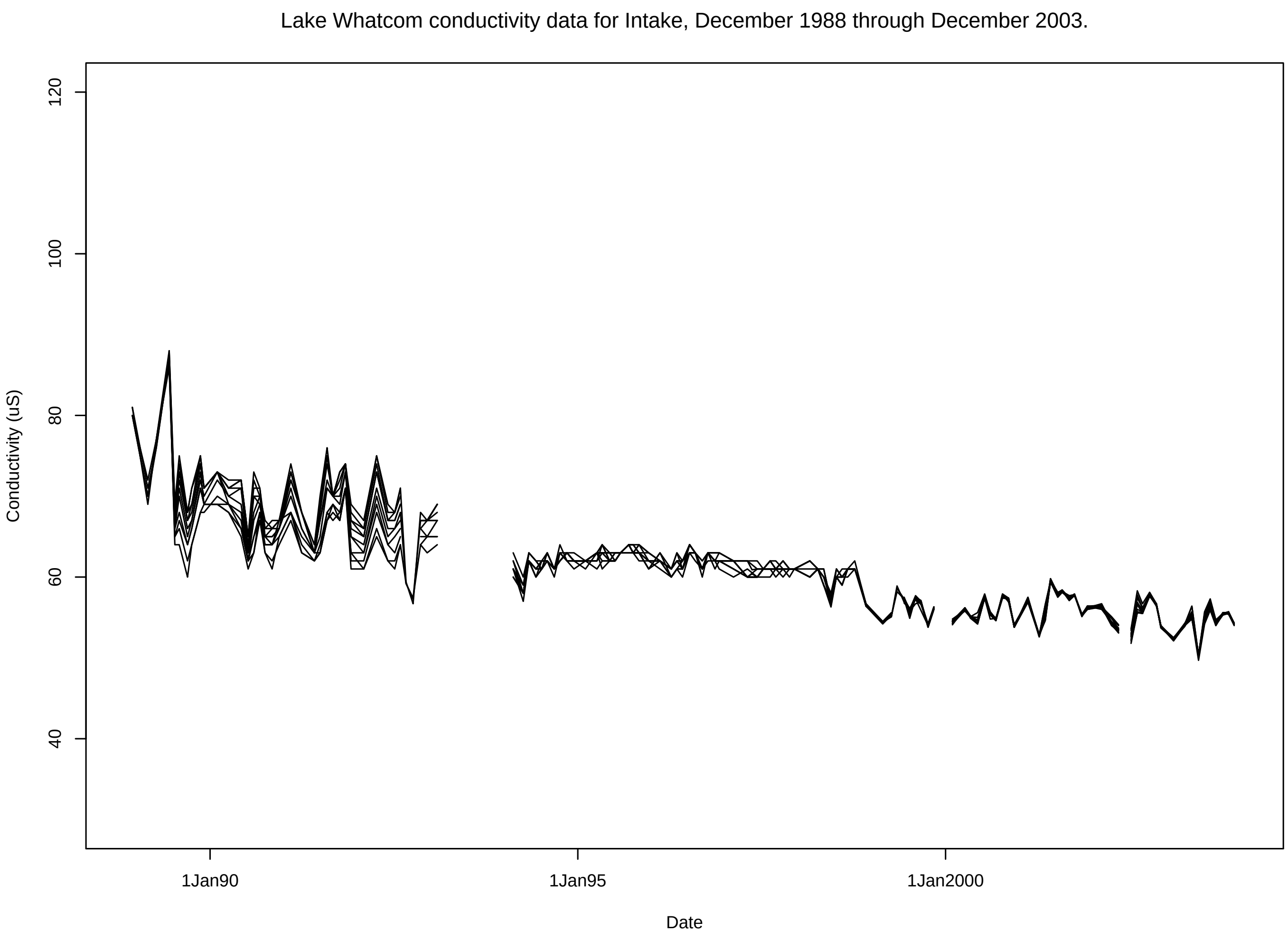


Figure 69: Lake Whatcom conductivity data for the Intake (1988–2003).

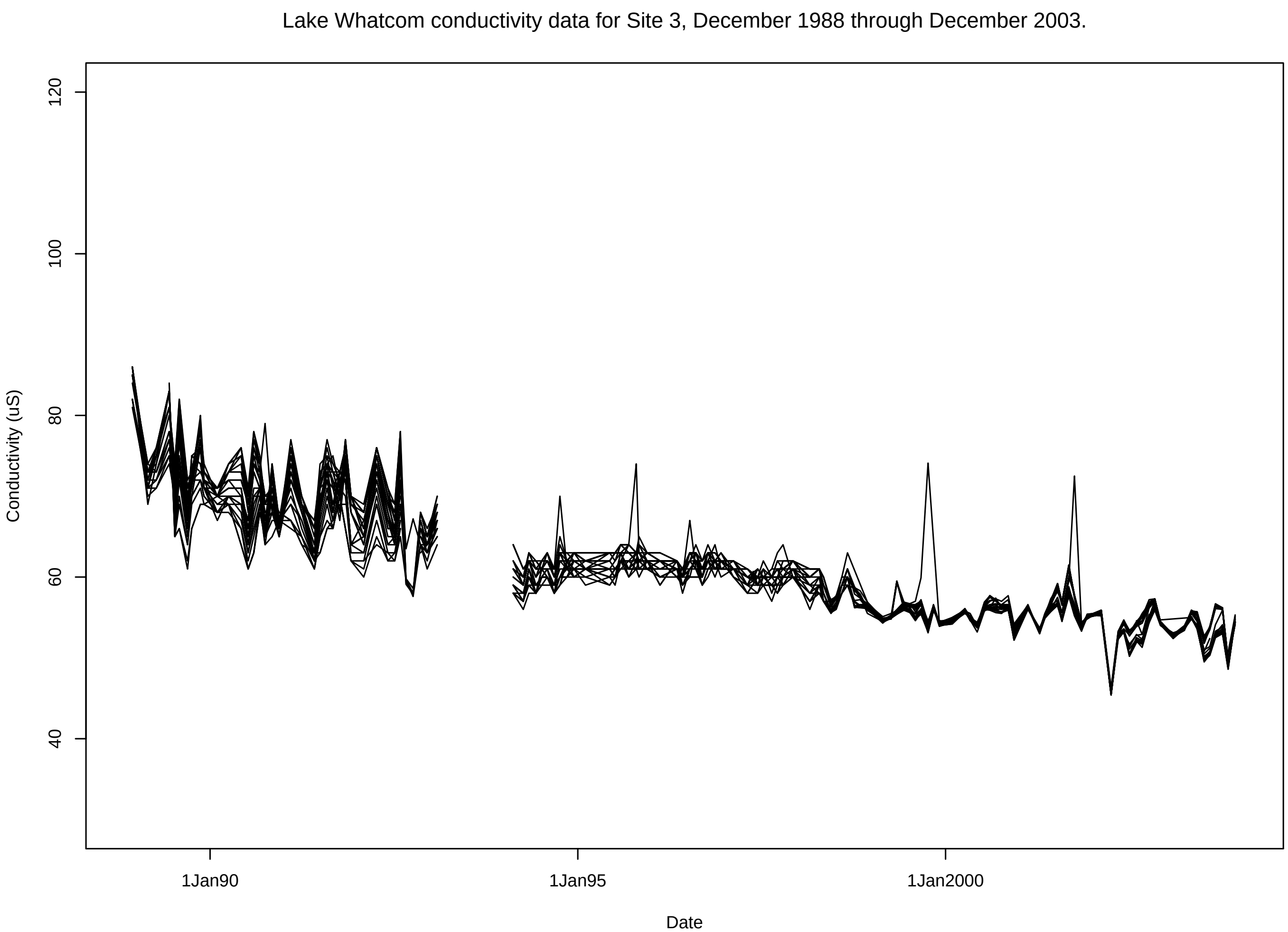


Figure 70: Lake Whatcom conductivity data for Site 3 (1988–2003).

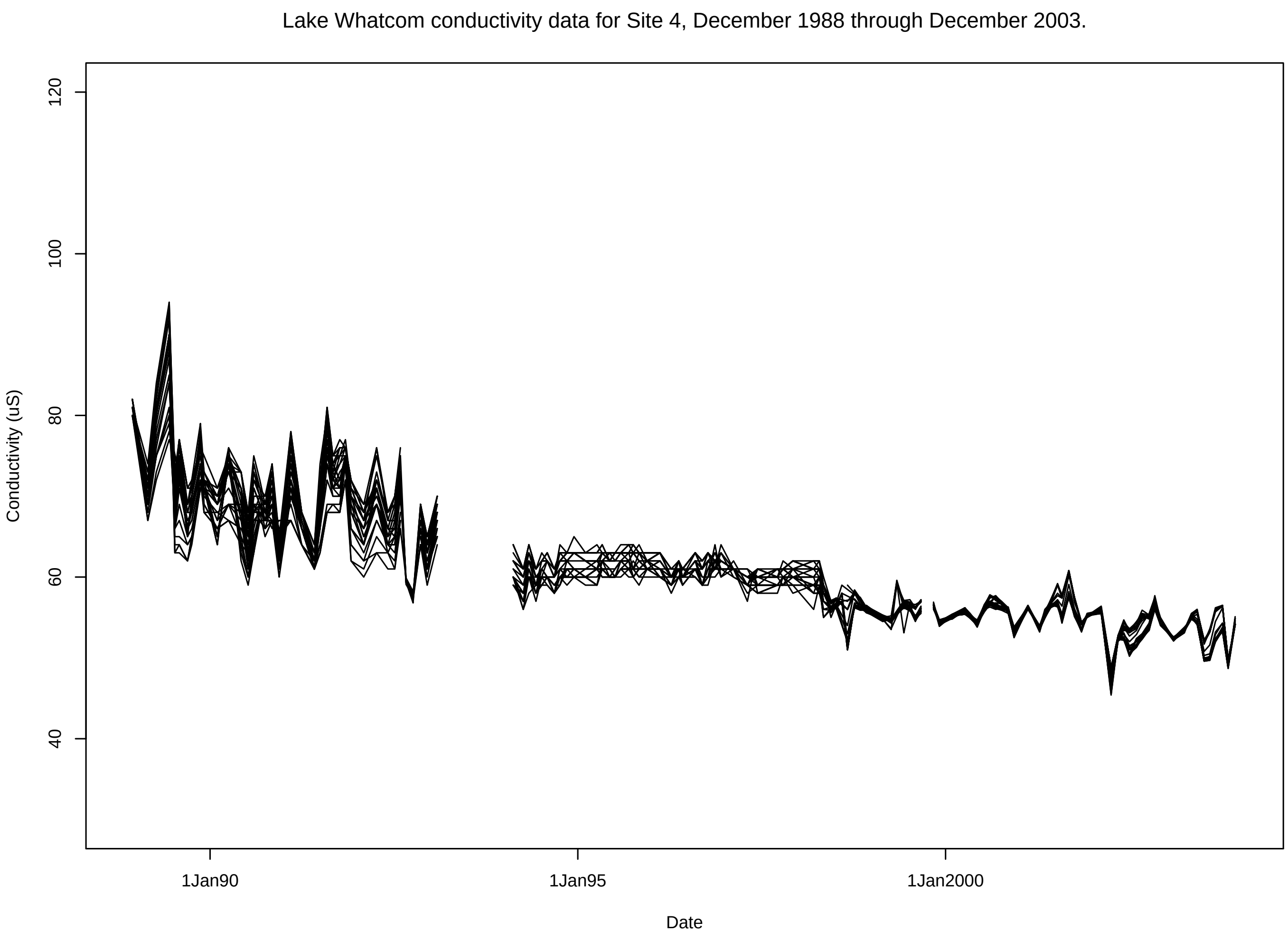


Figure 71: Lake Whatcom conductivity data for Site 4 (1988–2003).

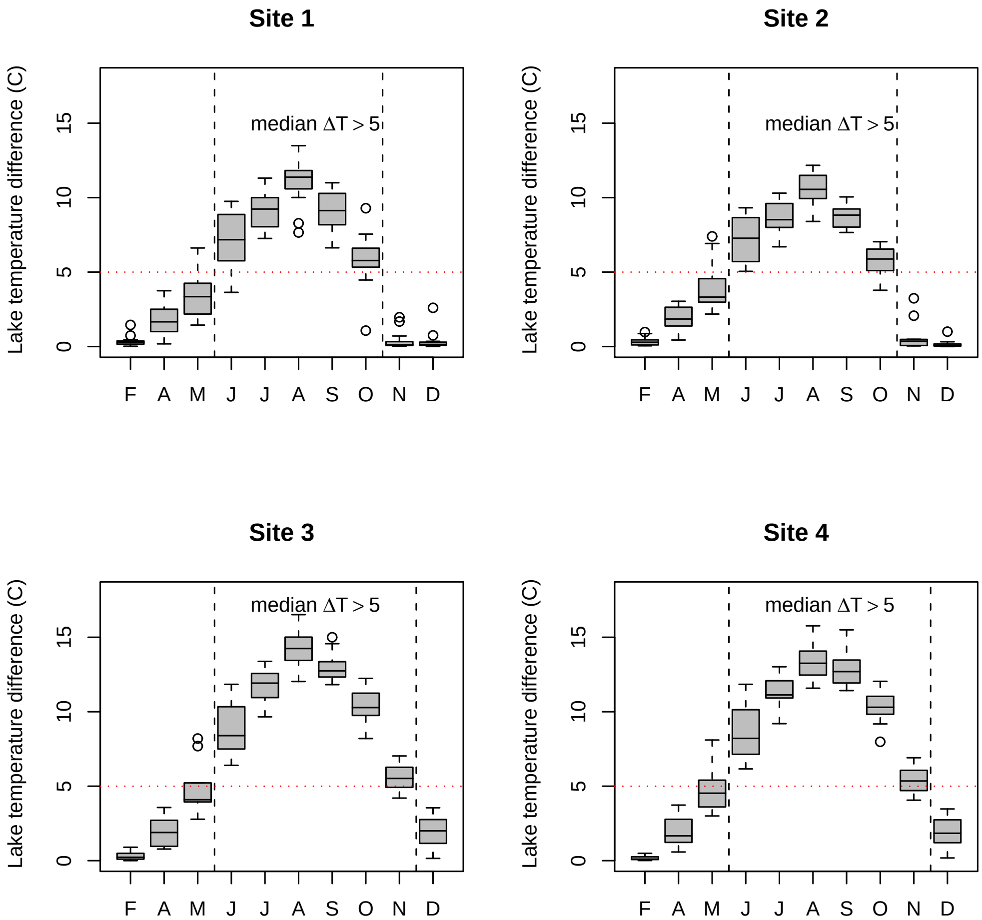


Figure 72: Summary of historic water column temperature differences in Lake Whatcom, 1988–2003. Temperature differences were calculated separately by site for each sampling period ($\Delta T = T_{max} - T_{min}$). Boxes show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to minimum value; outliers lie outside 1.5 $\times$ IQR.

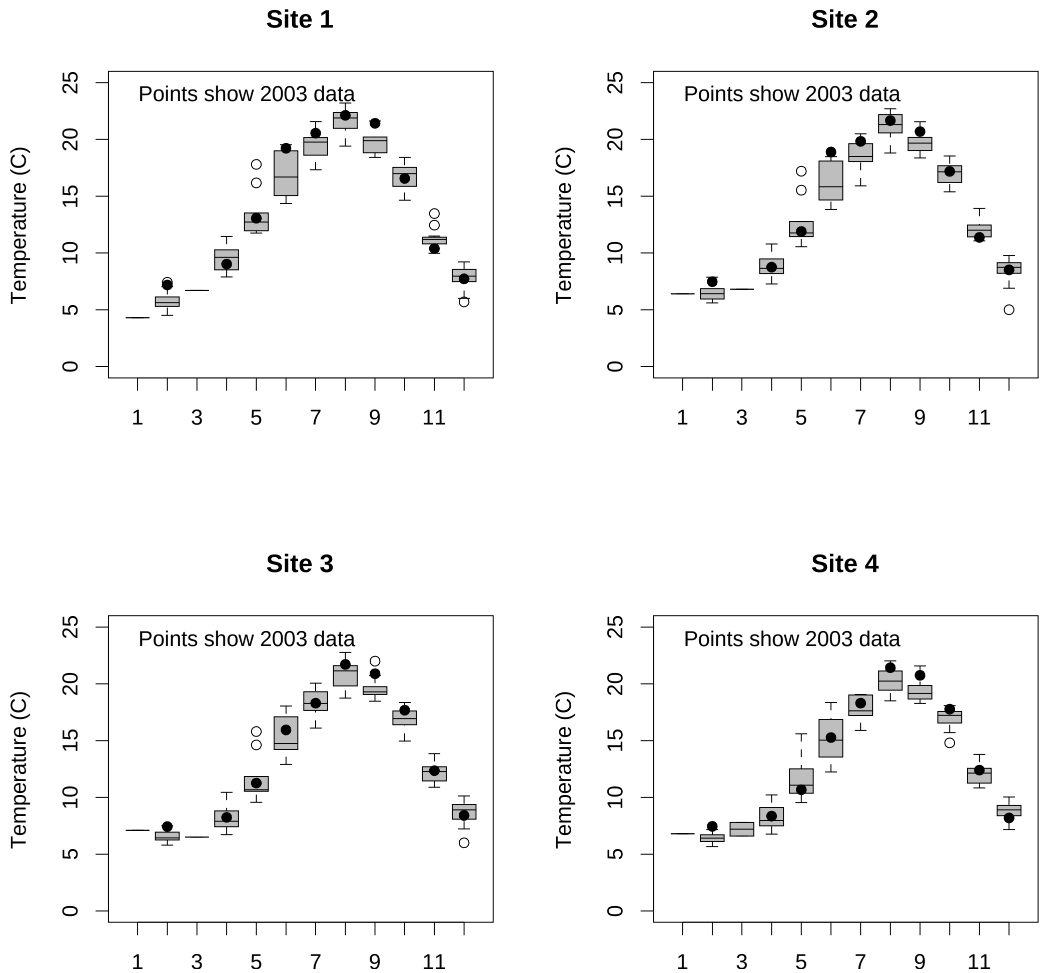


Figure 73: Comparison of 2003 surface water temperatures to boxplots showing 1988–2002 surface temperature medians and ranges (depth <1 m for all sites and years). Boxplots show median and upper/lower quartiles; whiskers extend 1.5 × interquartile range or to minimum value; outliers lie outside 1.5 × IQR.

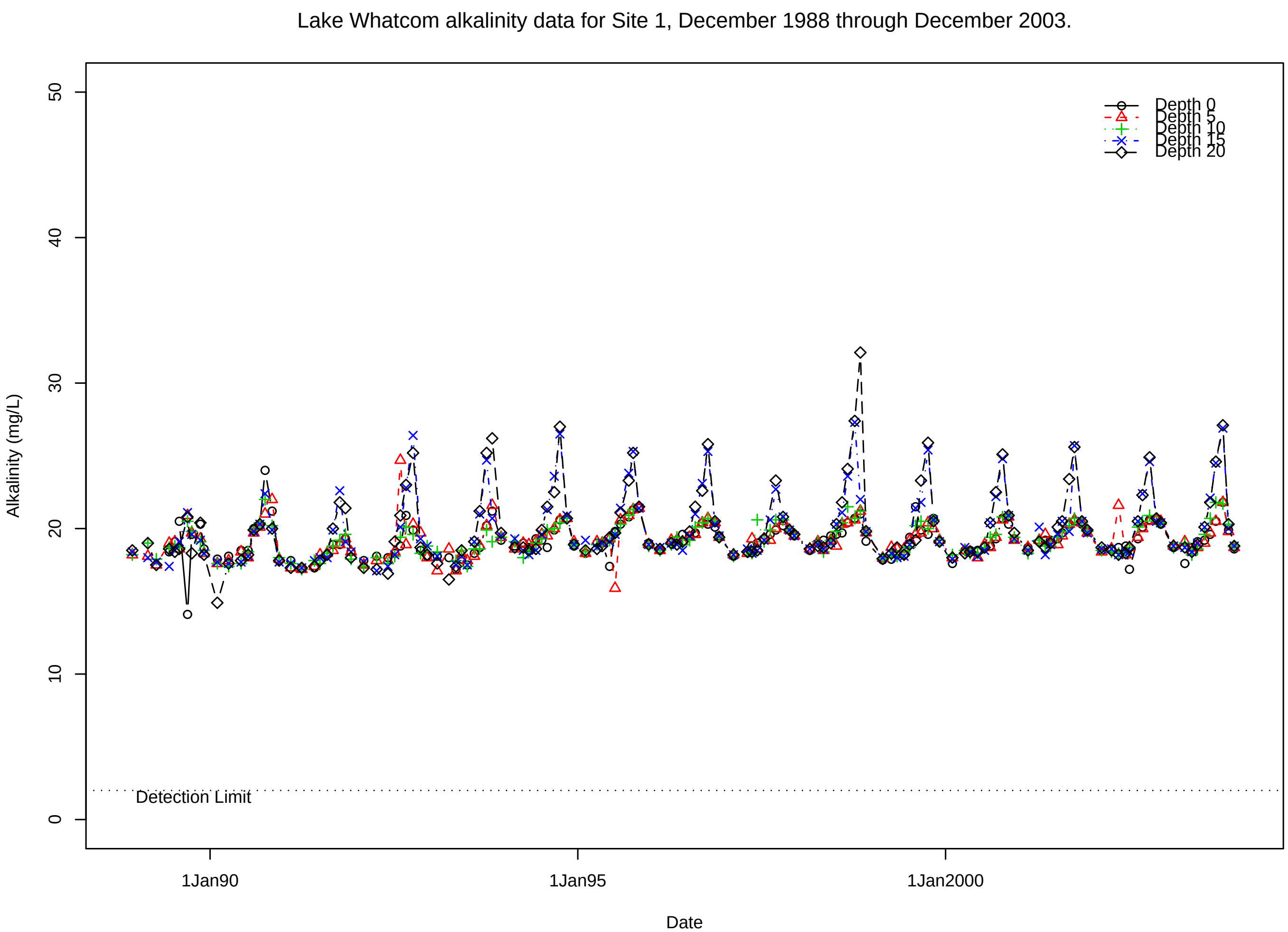


Figure 74: Lake Whatcom alkalinity data for Site 1 (1988–2003).

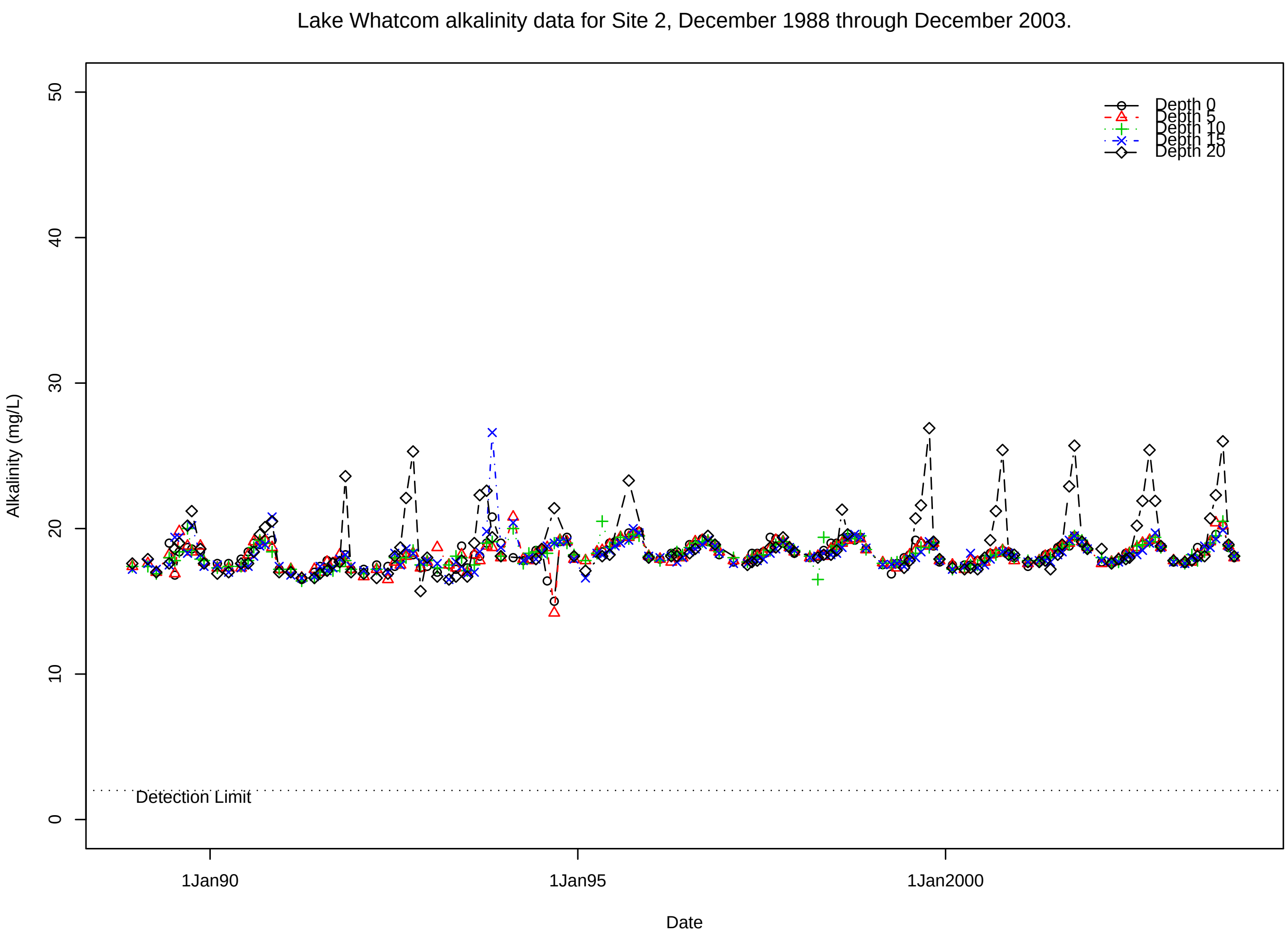


Figure 75: Lake Whatcom alkalinity data for Site 2 (1988–2003).

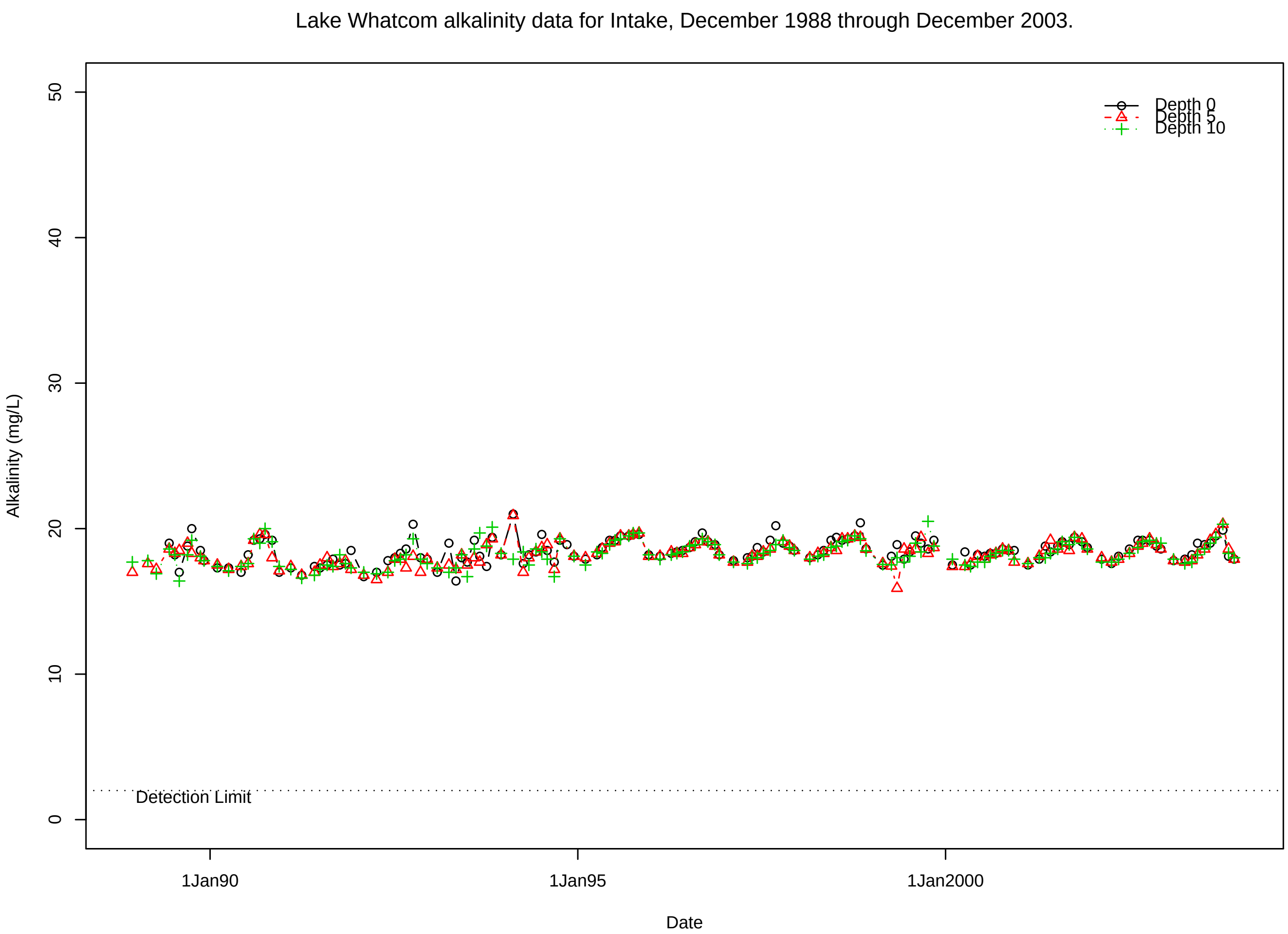


Figure 76: Lake Whatcom alkalinity data for the Intake (1988–2003).

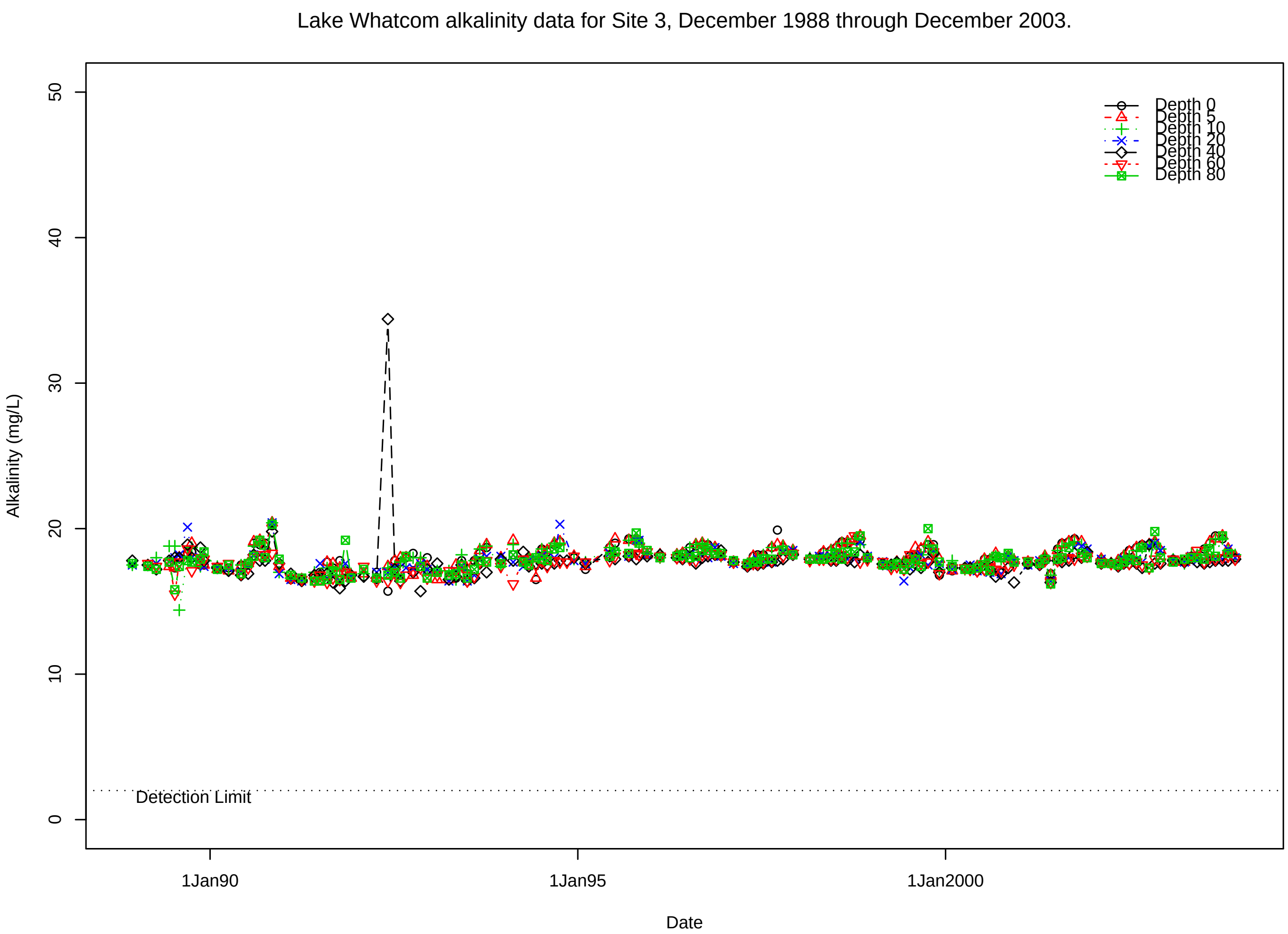


Figure 77: Lake Whatcom alkalinity data for Site 3 (1988–2003).

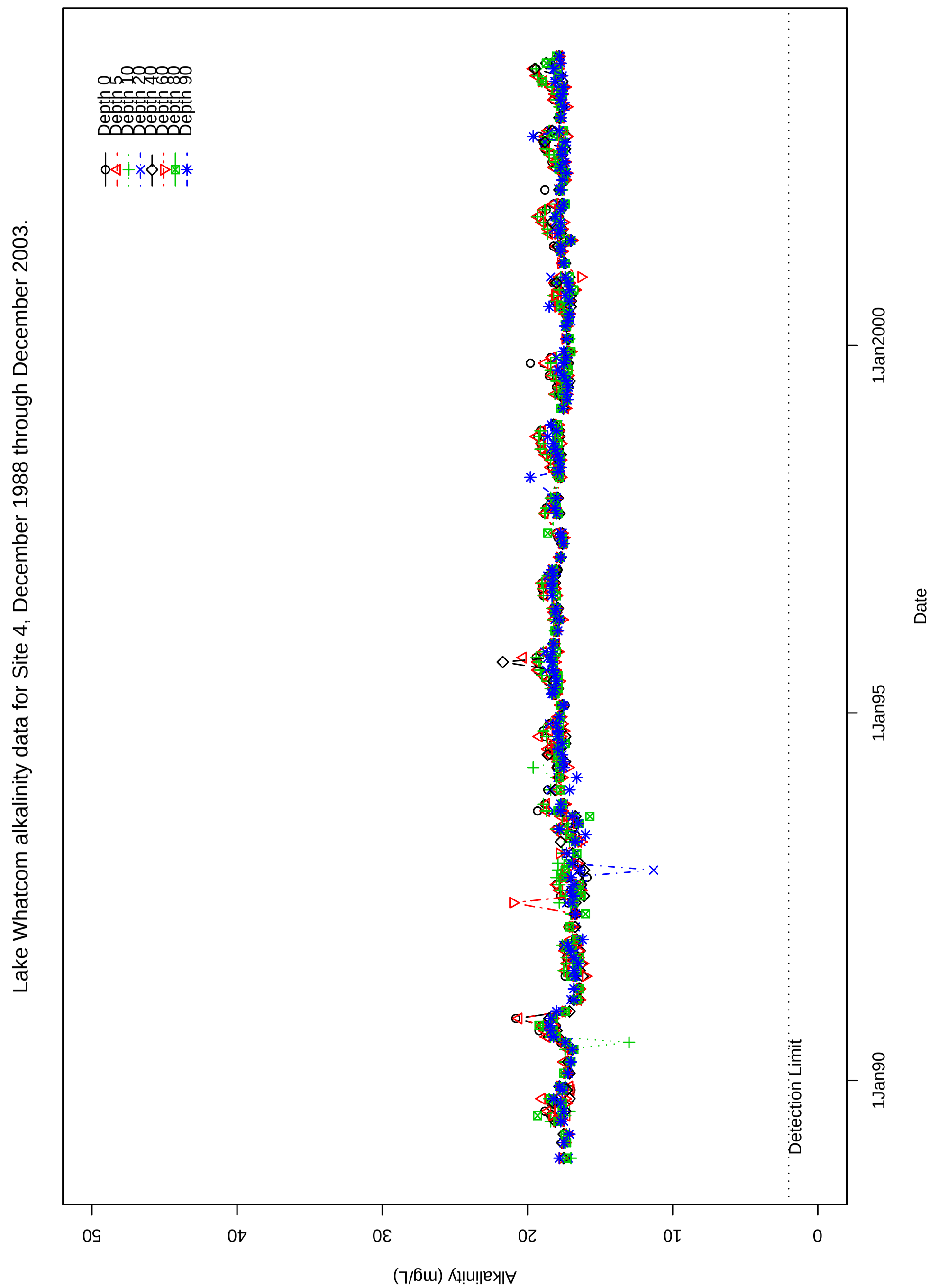


Figure 78: Lake Whatcom alkalinity data for Site 4 (1988–2003).

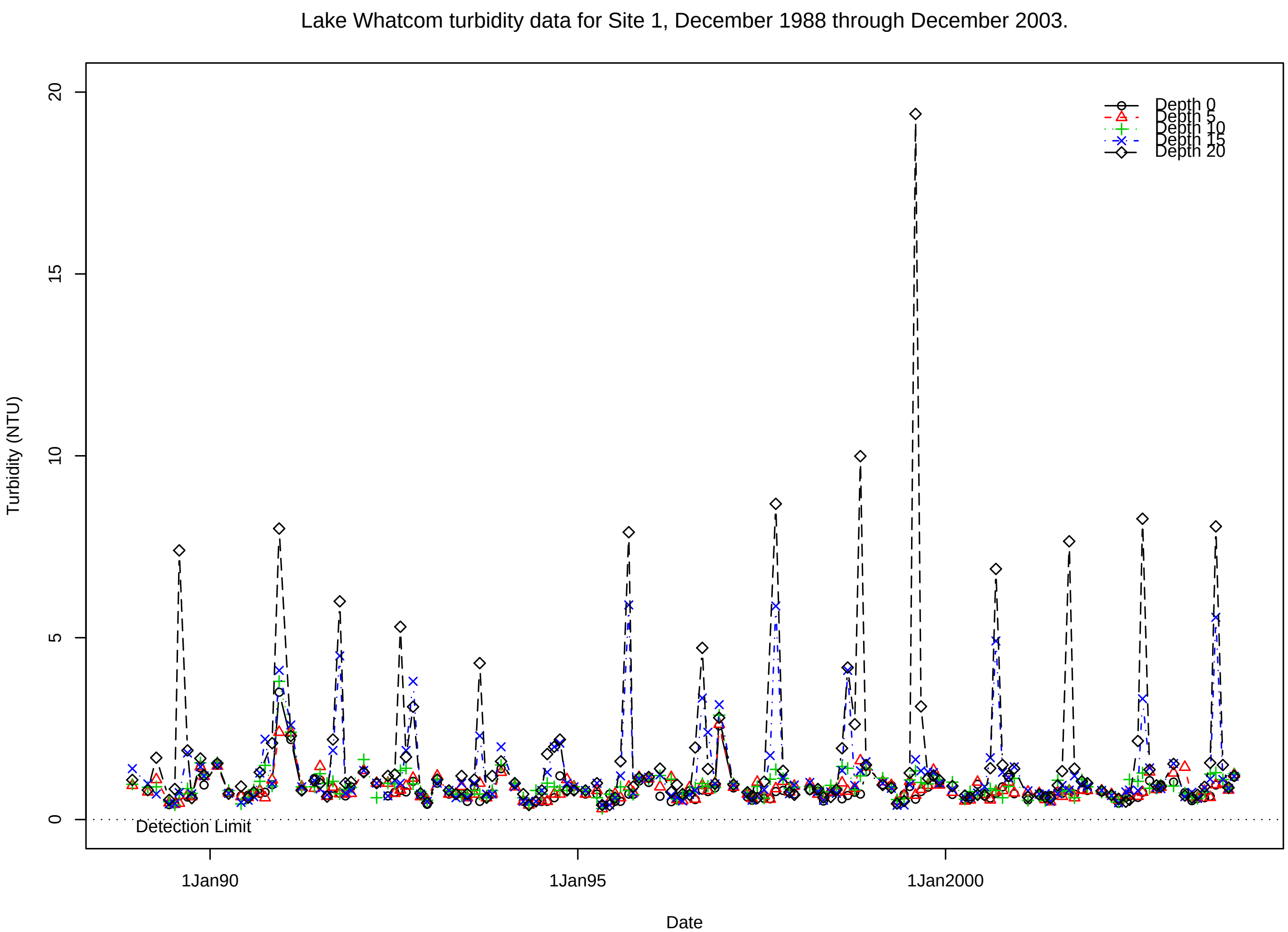


Figure 79: Lake Whatcom turbidity data for Site 1 (1988–2003).

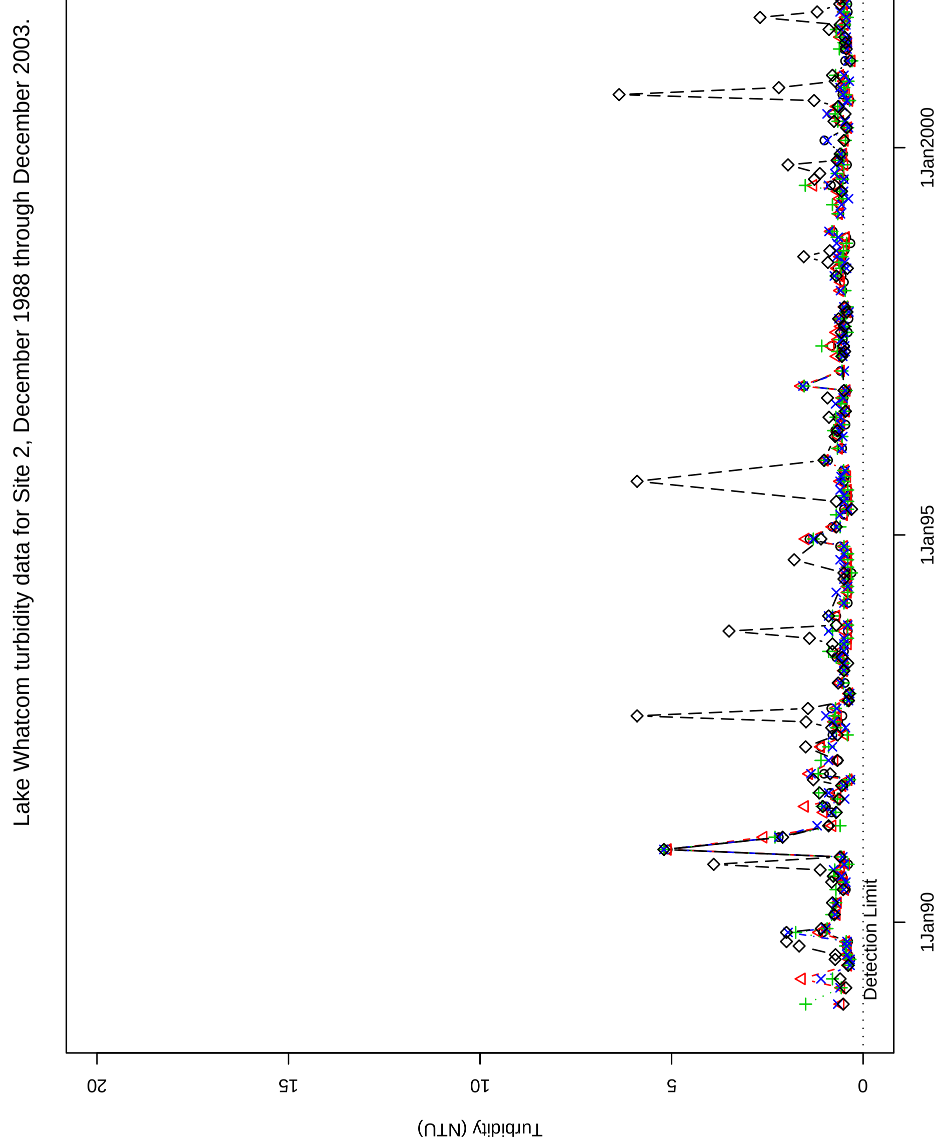


Figure 80: Lake Whatcom turbidity data for Site 2 (1988–2003).

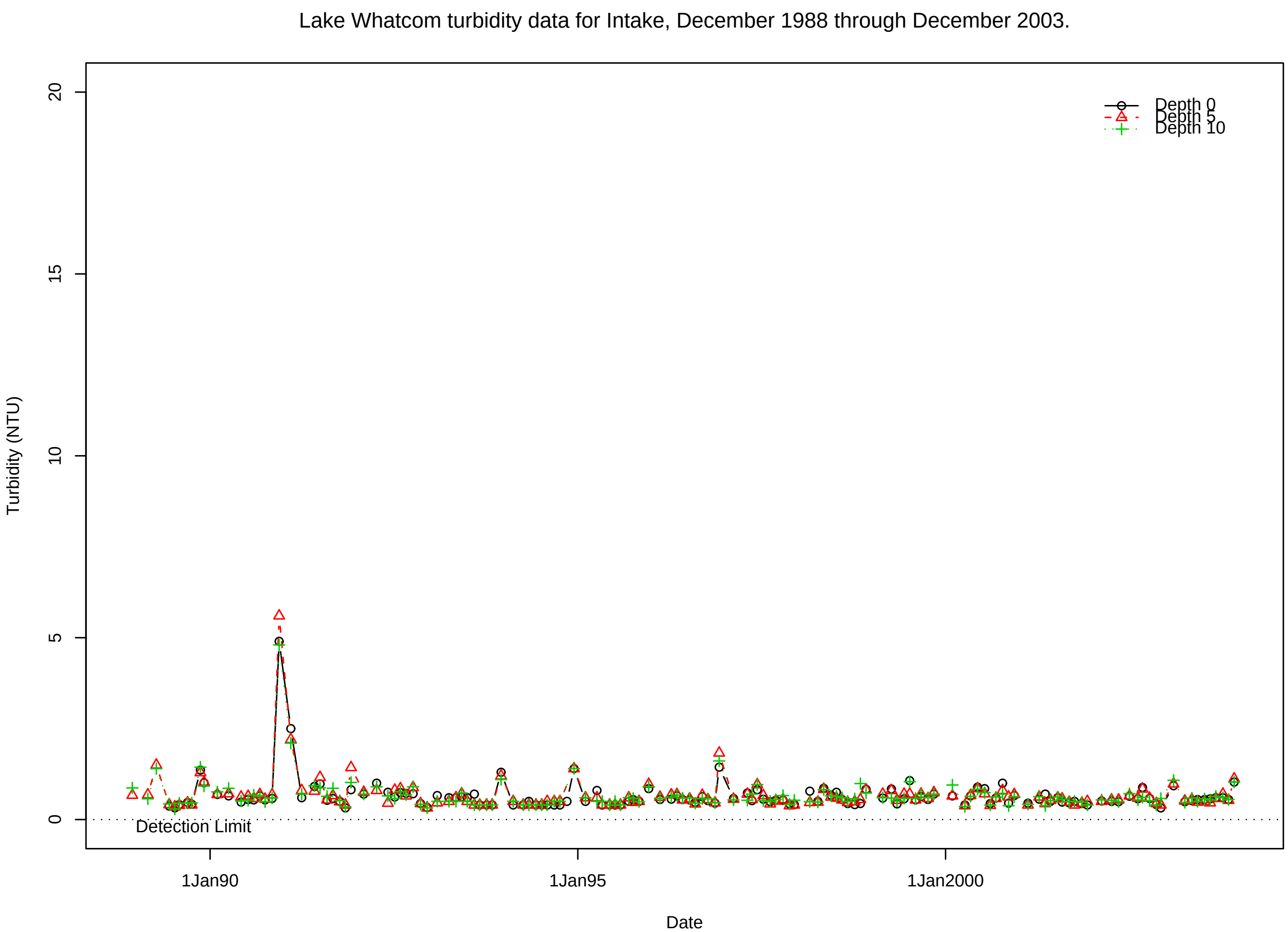


Figure 81: Lake Whatcom turbidity data for the Intake (1988–2003).

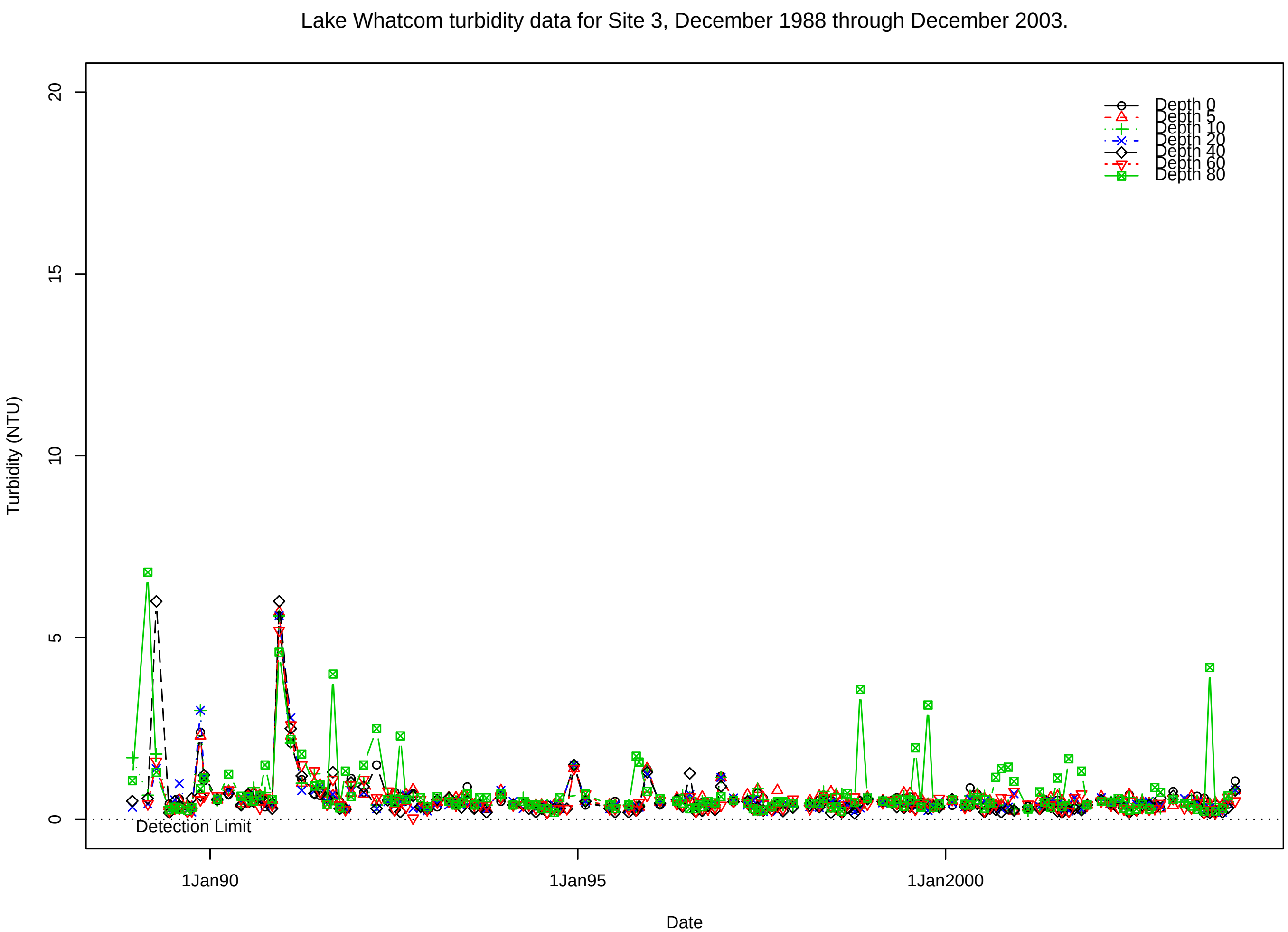


Figure 82: Lake Whatcom turbidity data for Site 3 (1988–2003).

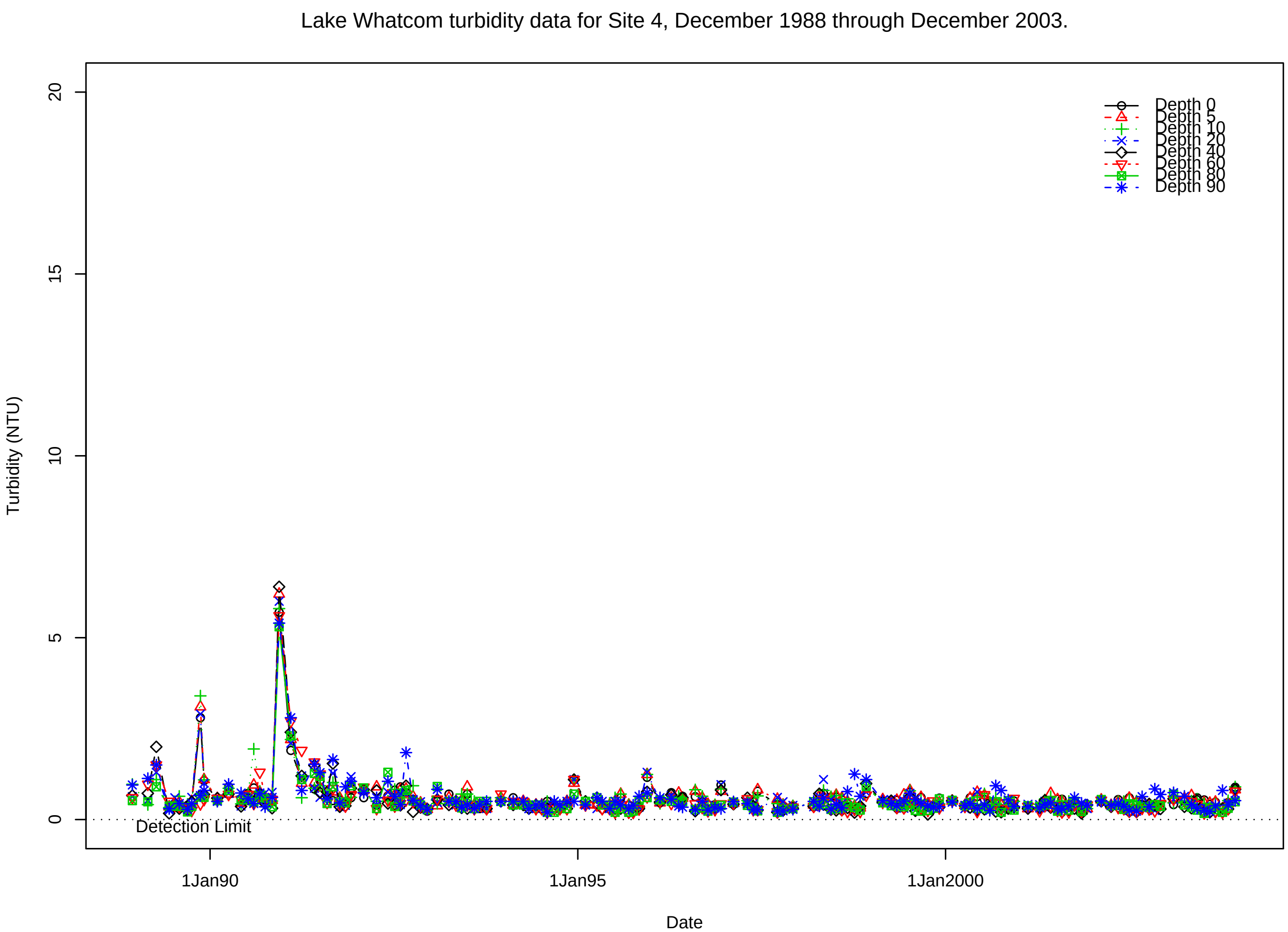


Figure 83: Lake Whatcom turbidity data for Site 4 (1988–2003).

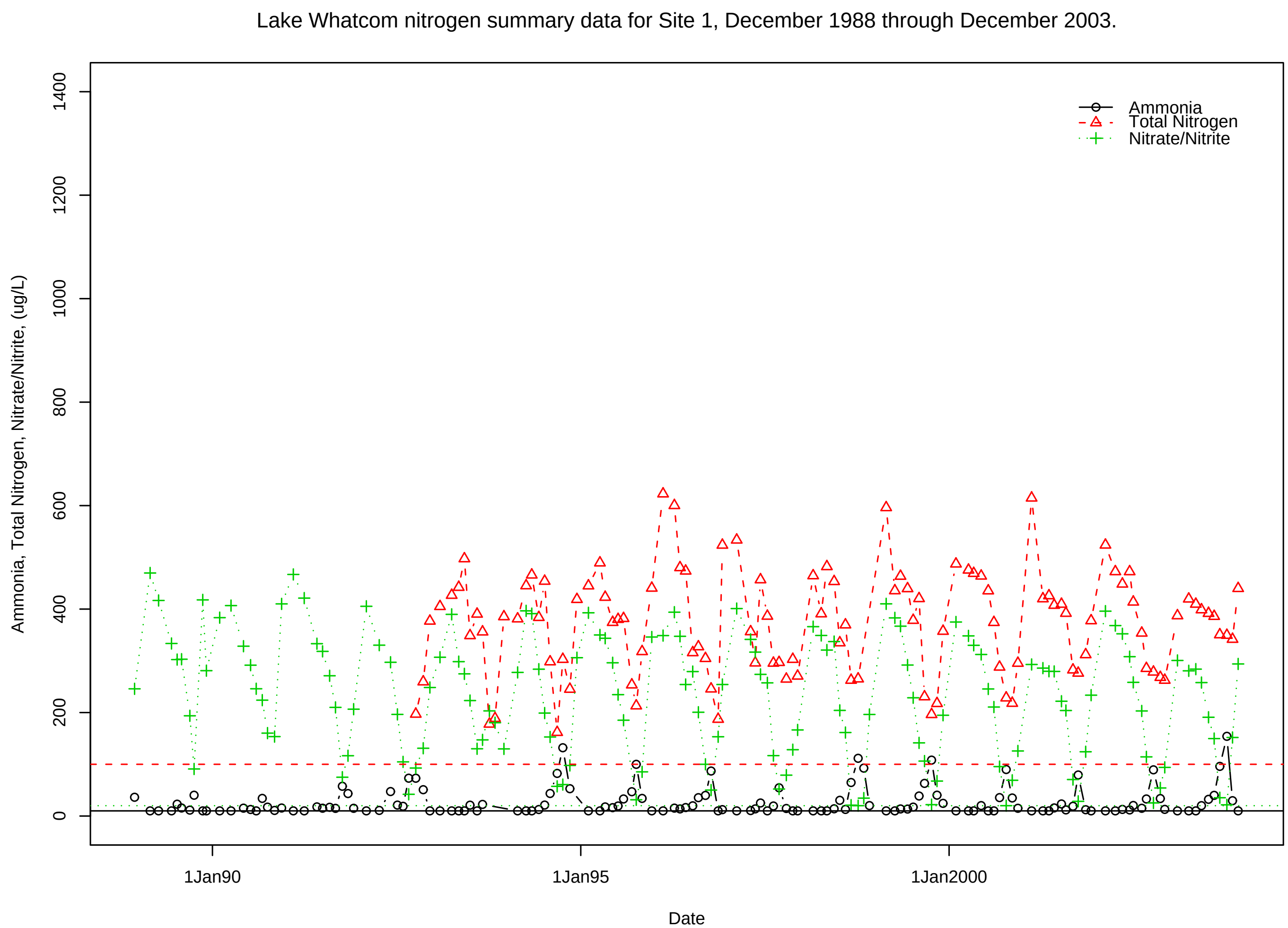


Figure 84: Lake Whatcom nitrogen summary data for Site 1 (1988–2003).

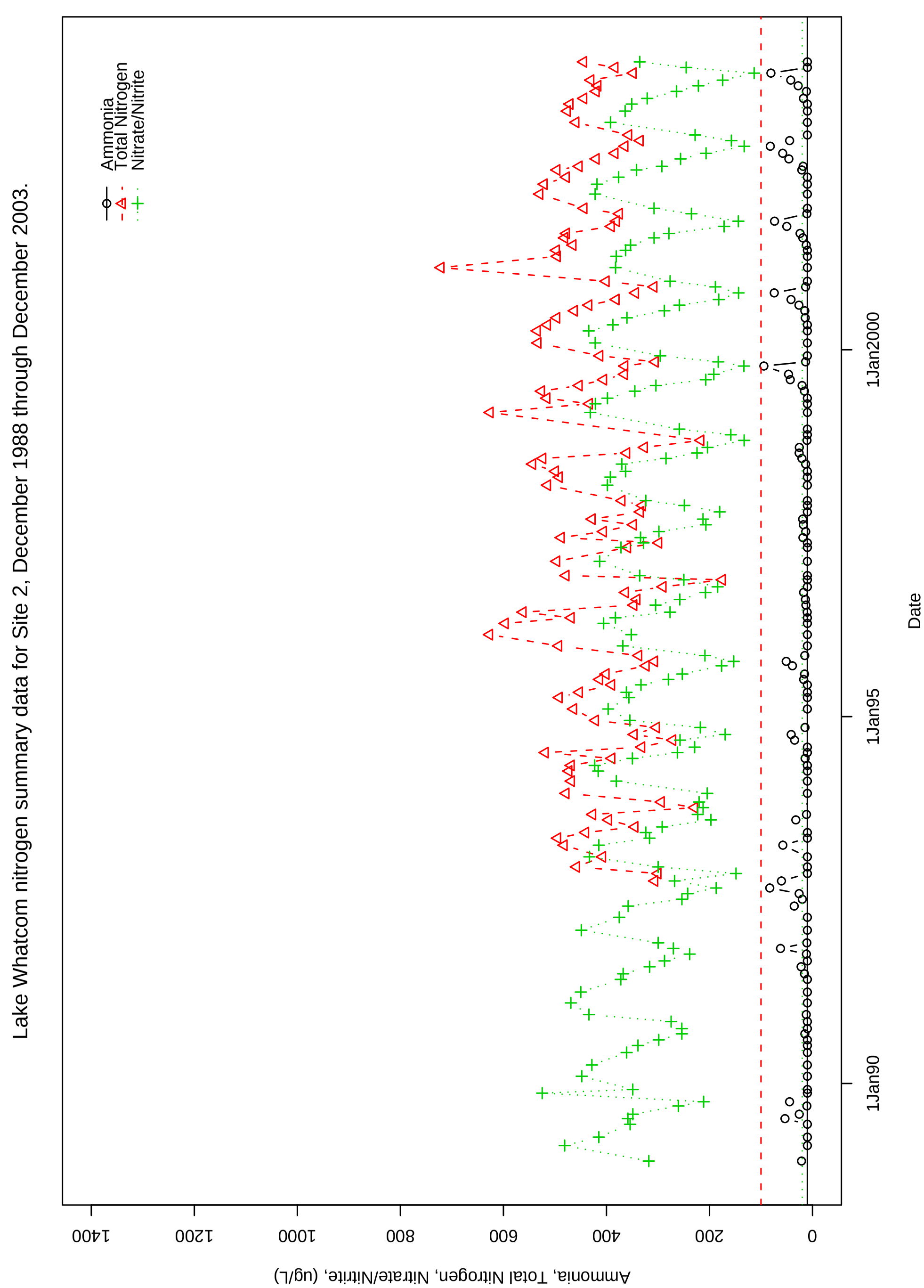


Figure 85: Lake Whatcom nitrogen summary data for Site 2 (1988–2003).

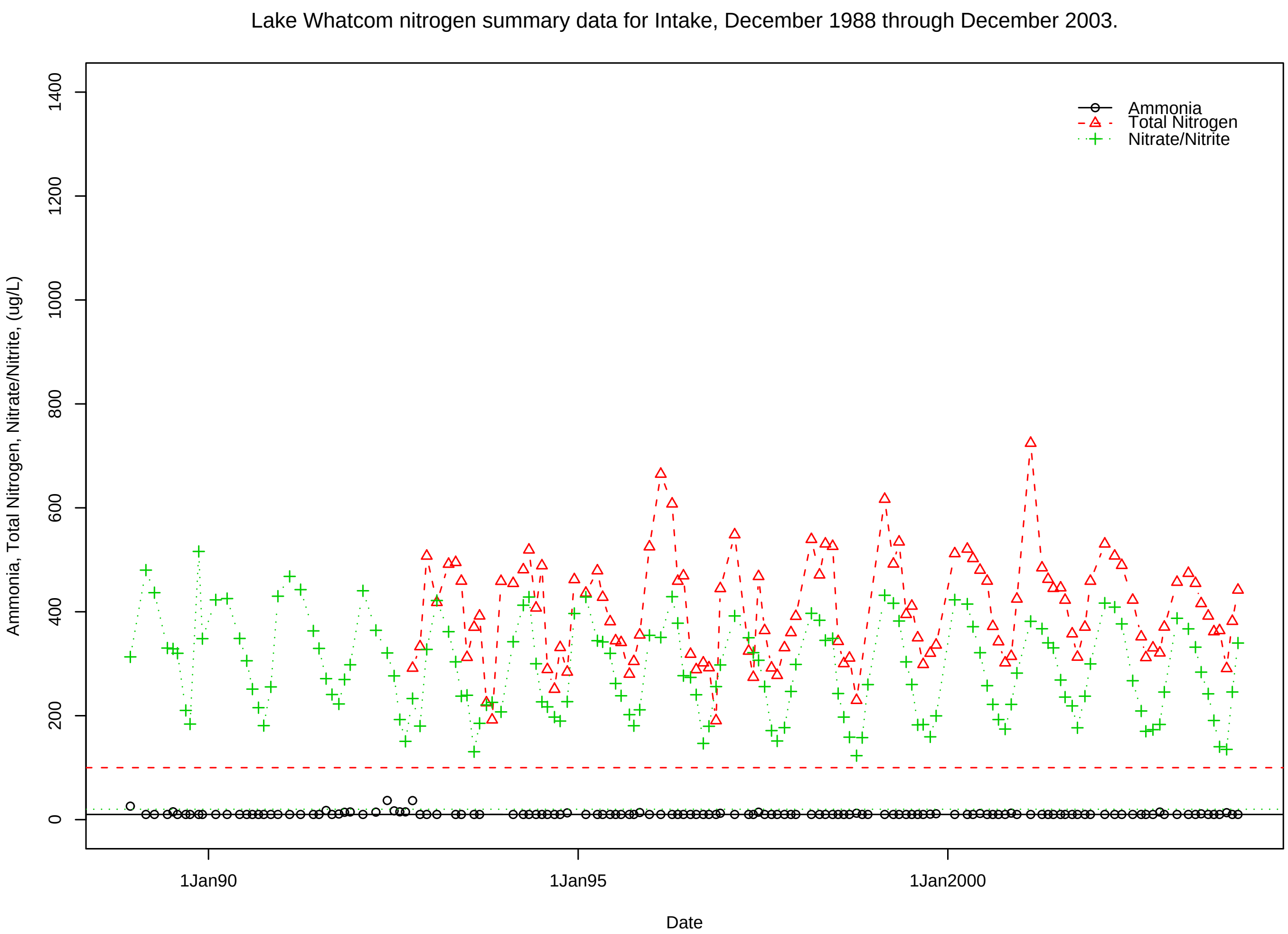


Figure 86: Lake Whatcom nitrogen summary data for the Intake (1988–2003).

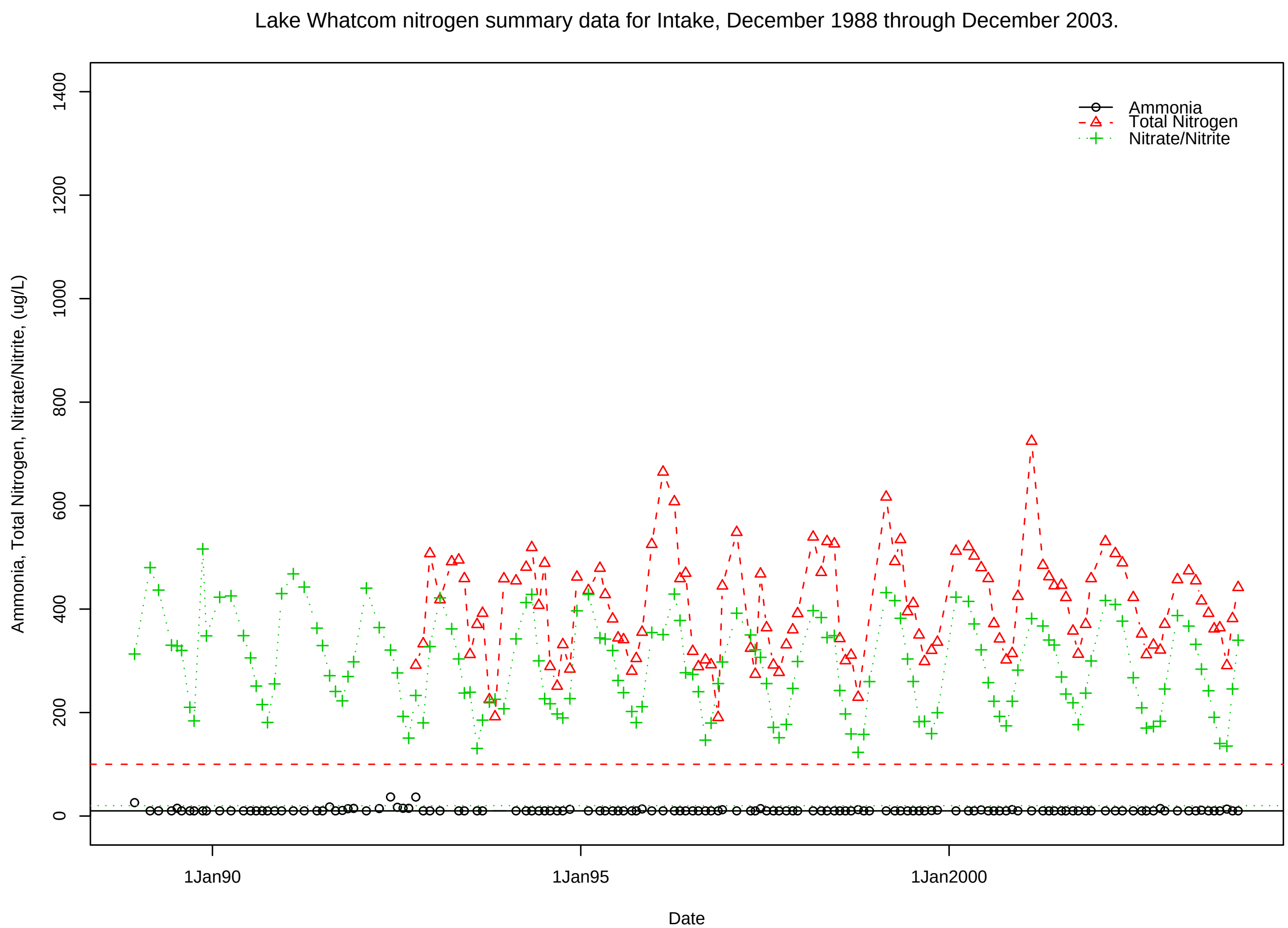


Figure 87: Lake Whatcom nitrogen summary data for Site 3 (1988–2003).

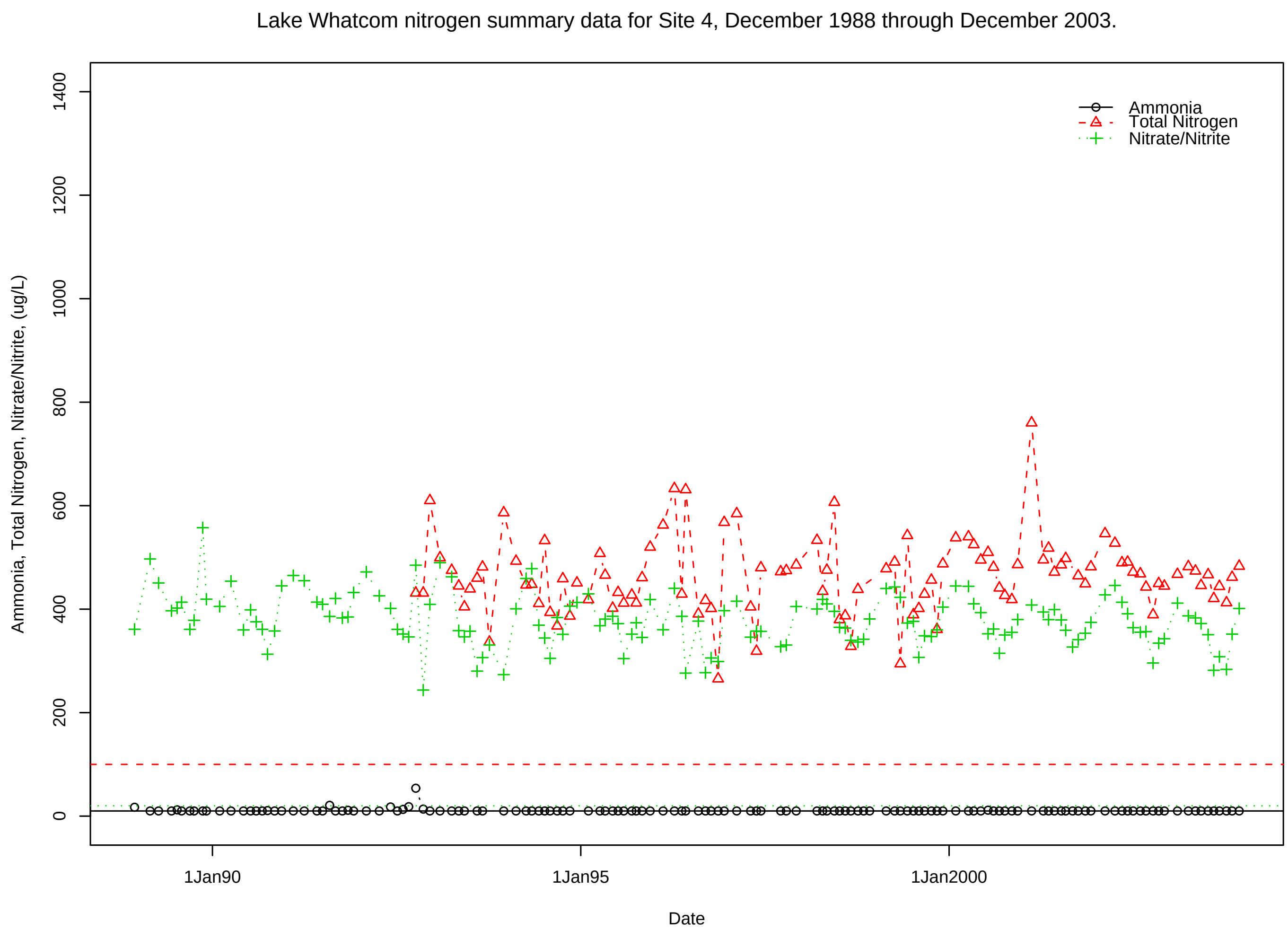


Figure 88: Lake Whatcom nitrogen summary data for Site 4 (1988–2003).

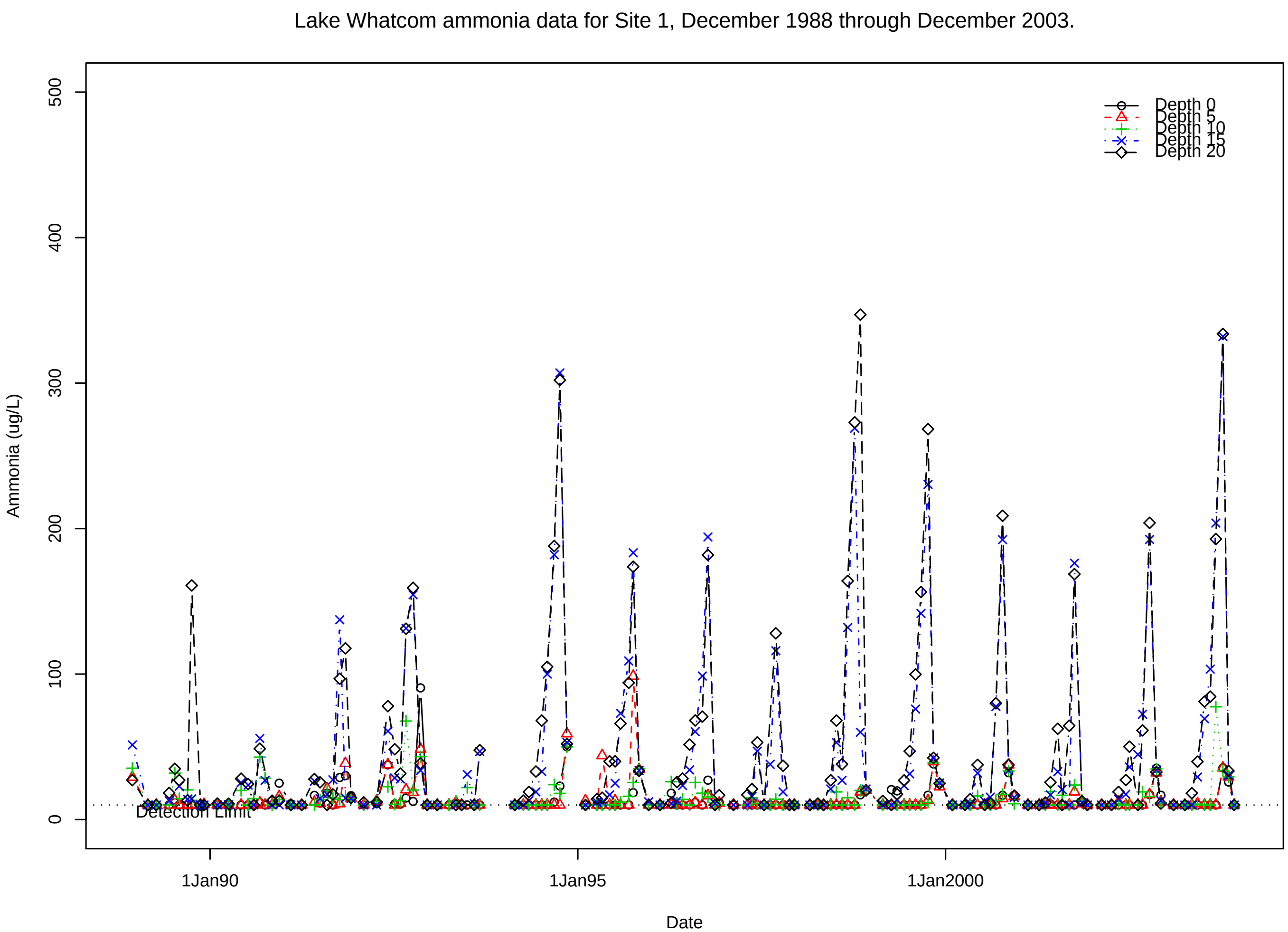


Figure 89: Lake Whatcom ammonia data for Site 1 (1988–2003).

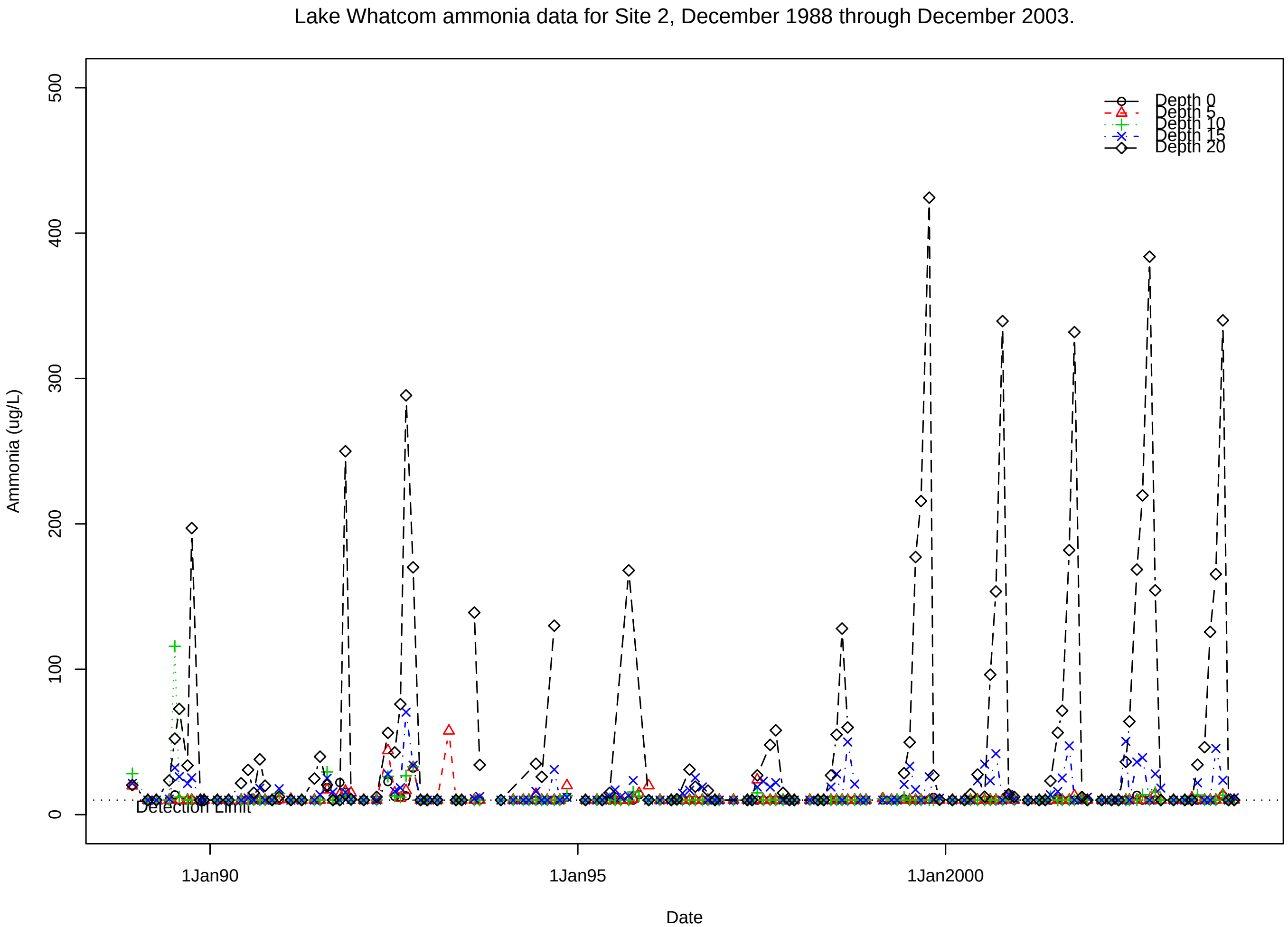


Figure 90: Lake Whatcom ammonia data for Site 2 (1988–2003).

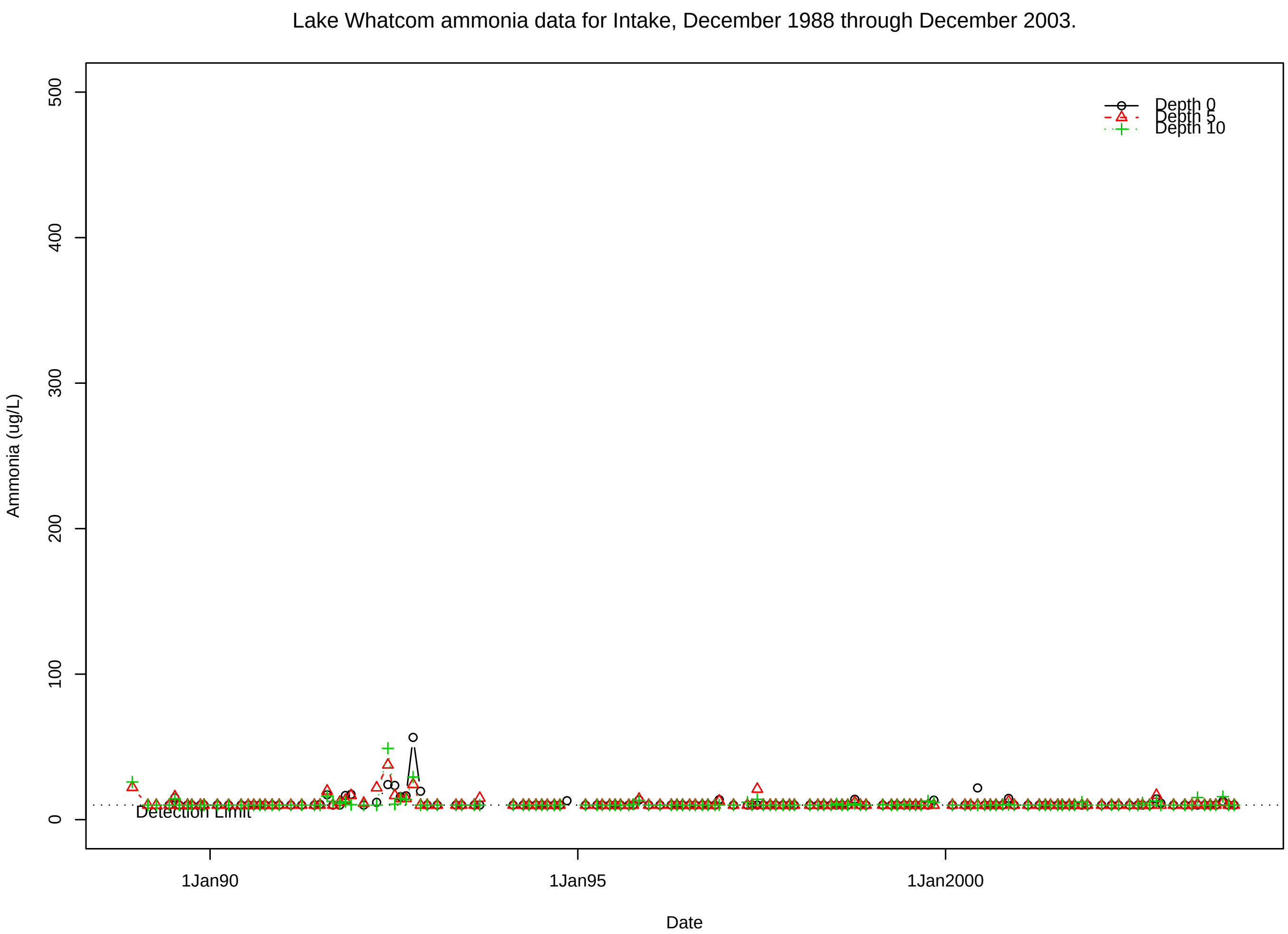


Figure 91: Lake Whatcom ammonia data for the Intake (1988–2003).

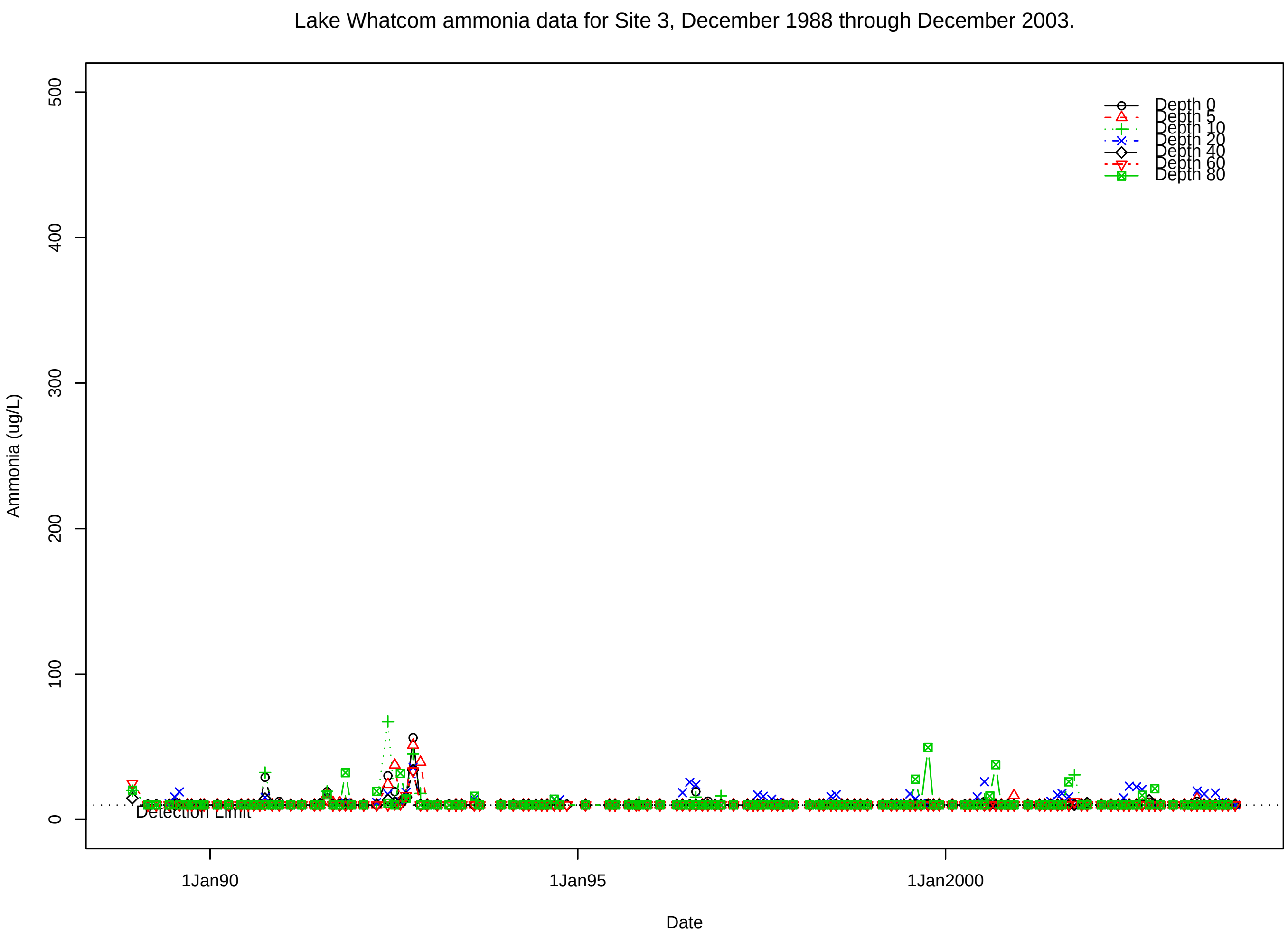


Figure 92: Lake Whatcom ammonia data for Site 3 (1988–2003).

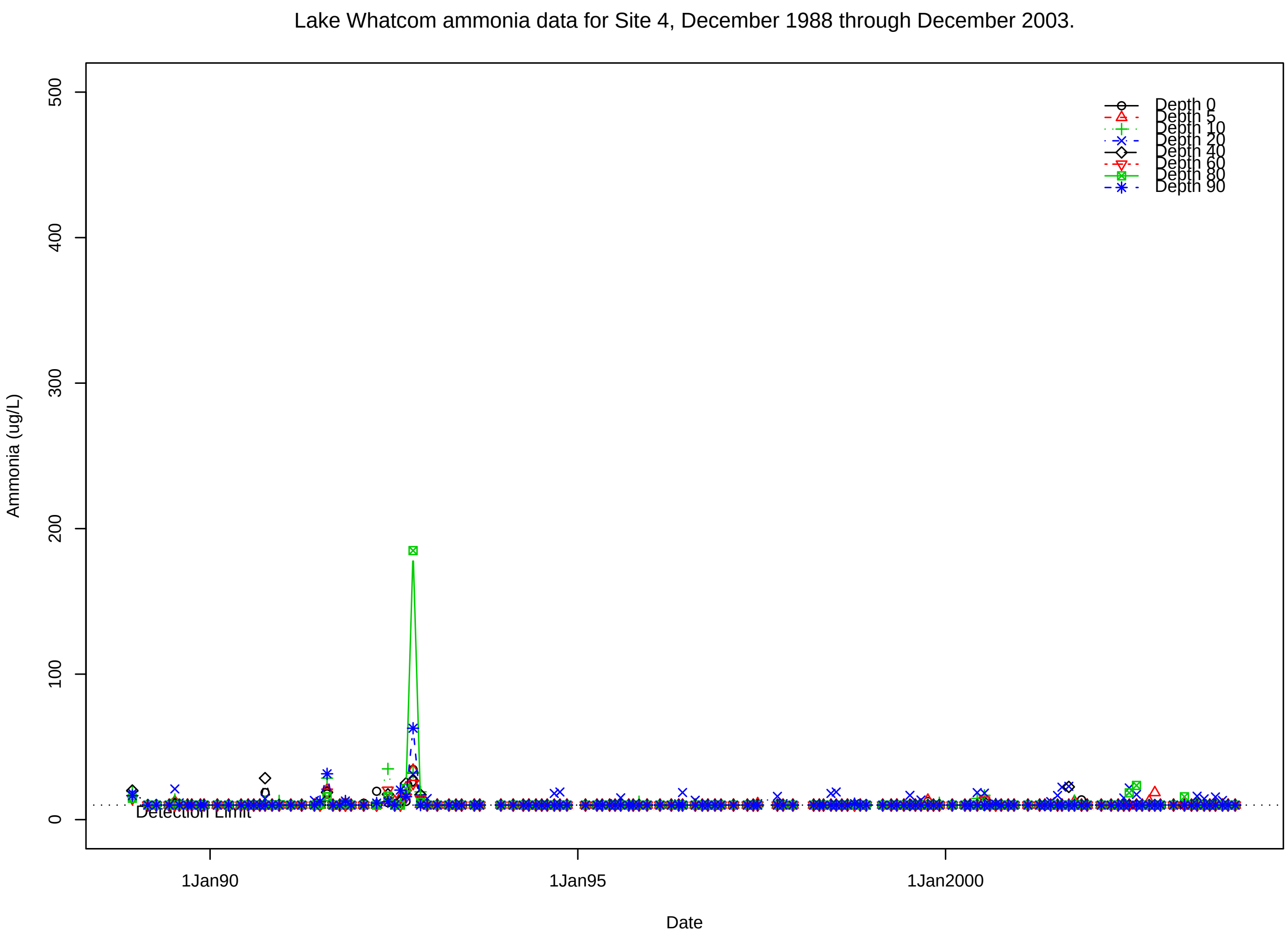


Figure 93: Lake Whatcom ammonia data for Site 4 (1988–2003).

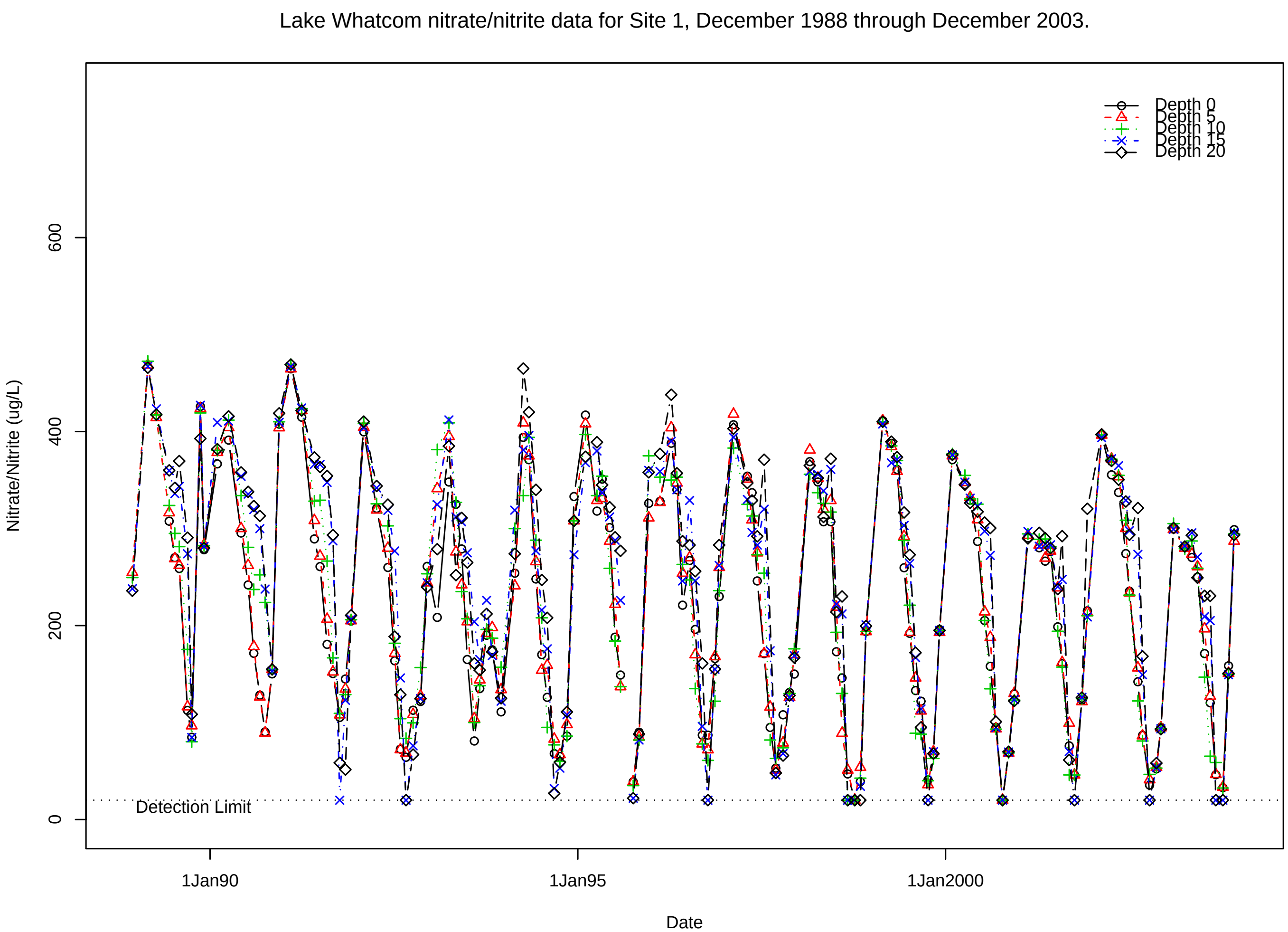


Figure 94: Lake Whatcom nitrate/nitrite data for Site 1 (1988–2003).

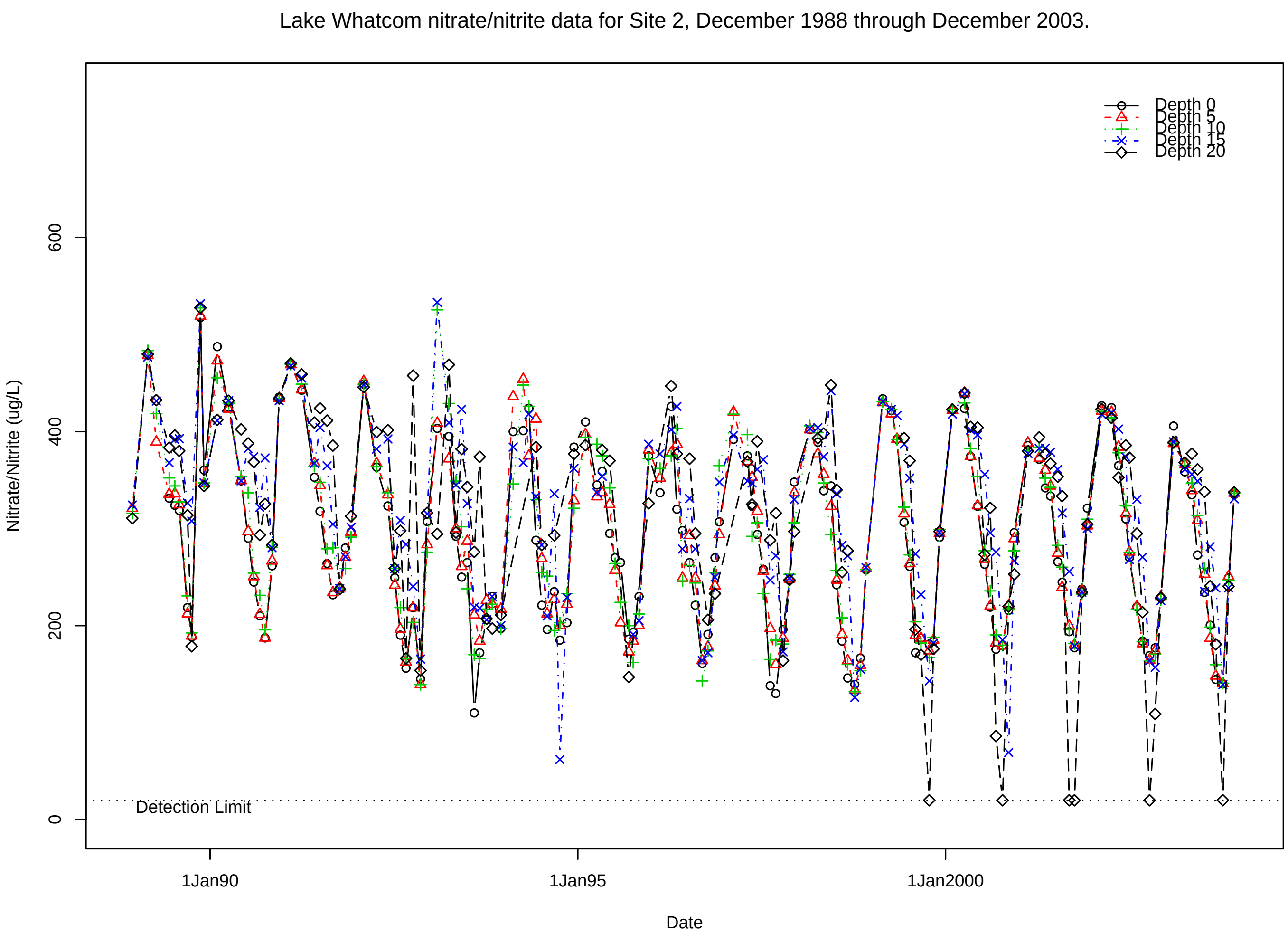


Figure 95: Lake Whatcom nitrate/nitrite data for Site 2 (1988–2003).

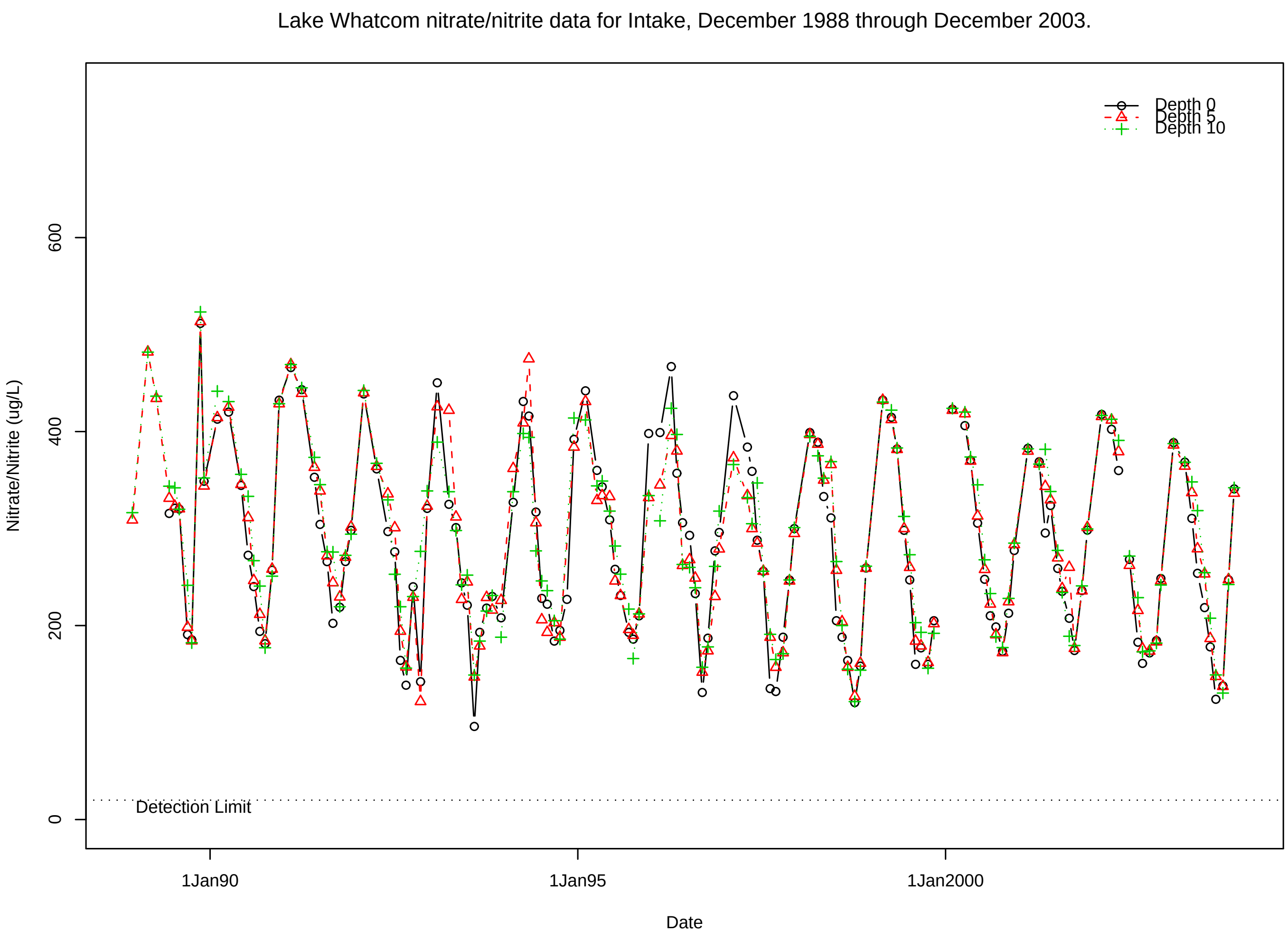


Figure 96: Lake Whatcom nitrate/nitrite data for the Intake (1988–2003).

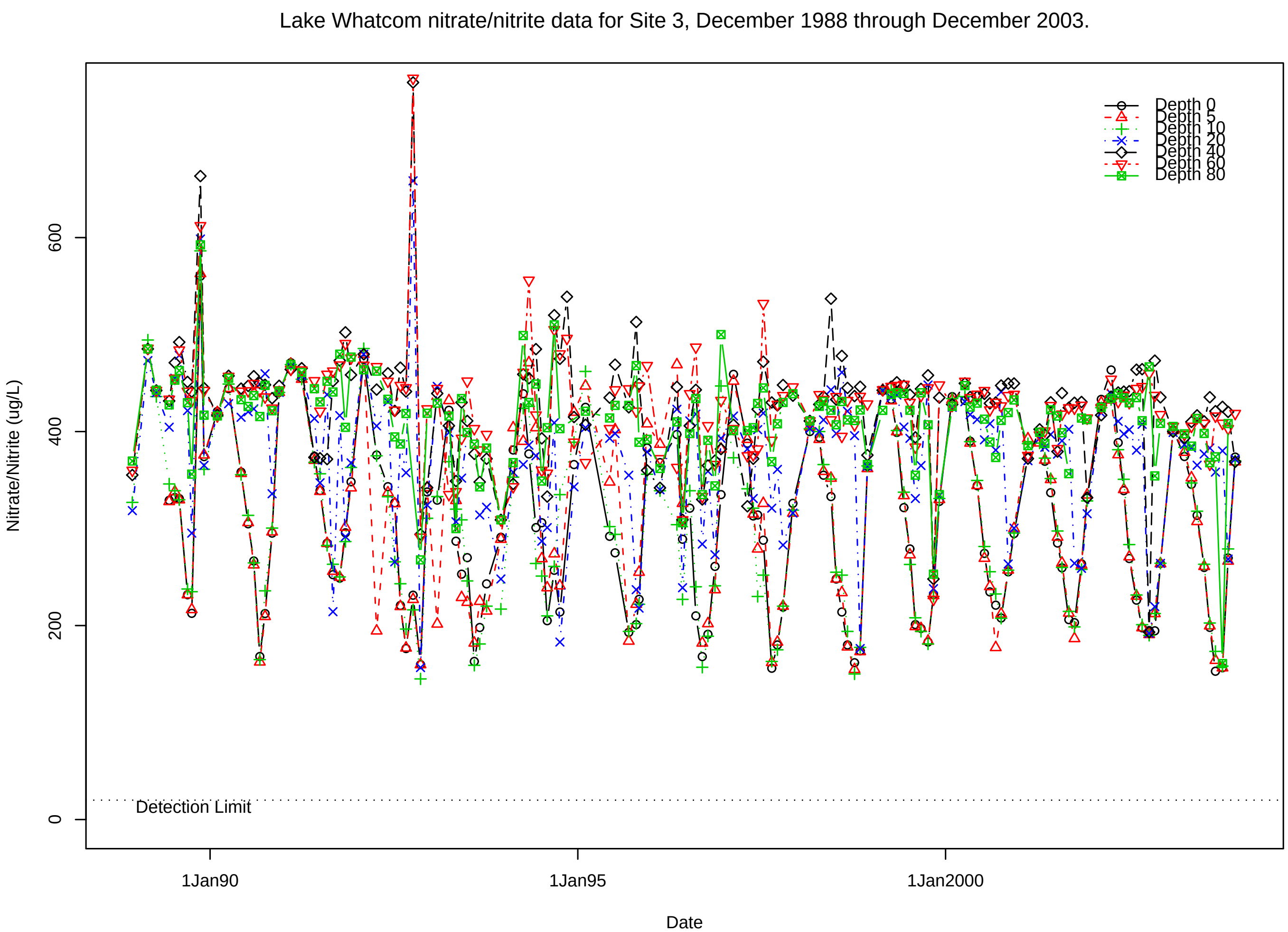


Figure 97: Lake Whatcom nitrate/nitrite data for Site 3 (1988–2003).

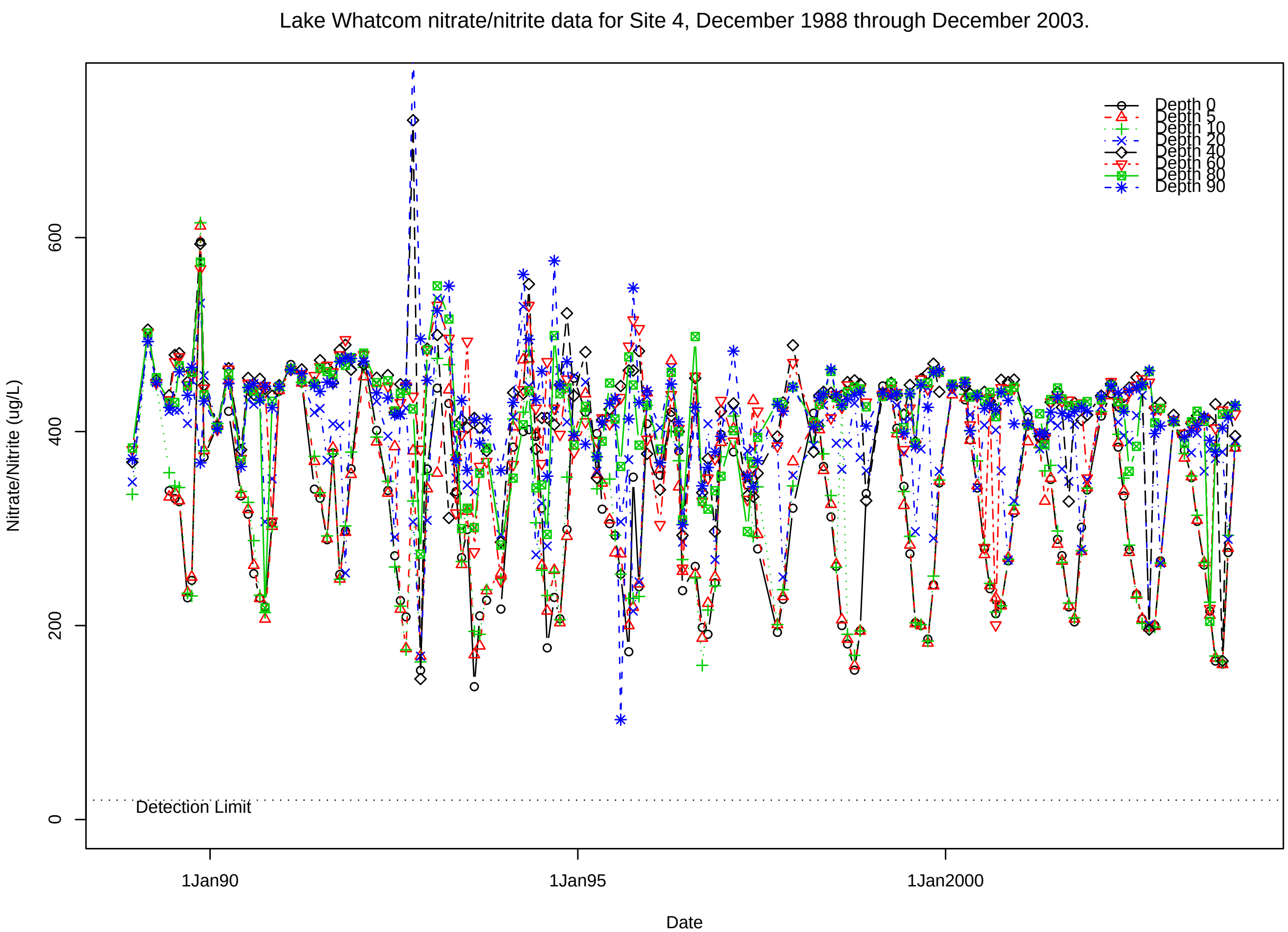


Figure 98: Lake Whatcom nitrate/nitrite data for Site 4 (1988–2003).

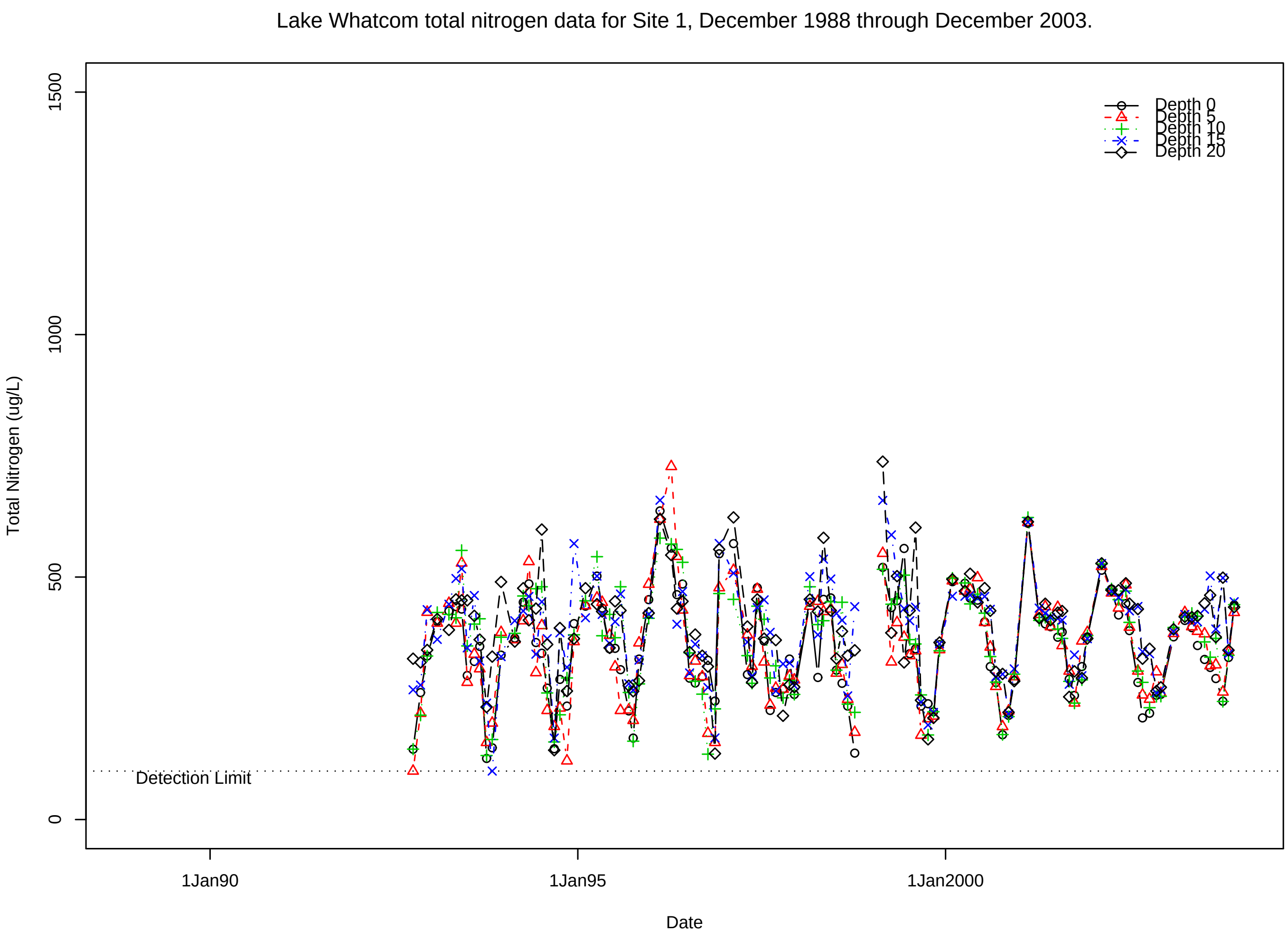


Figure 99: Lake Whatcom total nitrogen data for Site 1 (1988–2003).

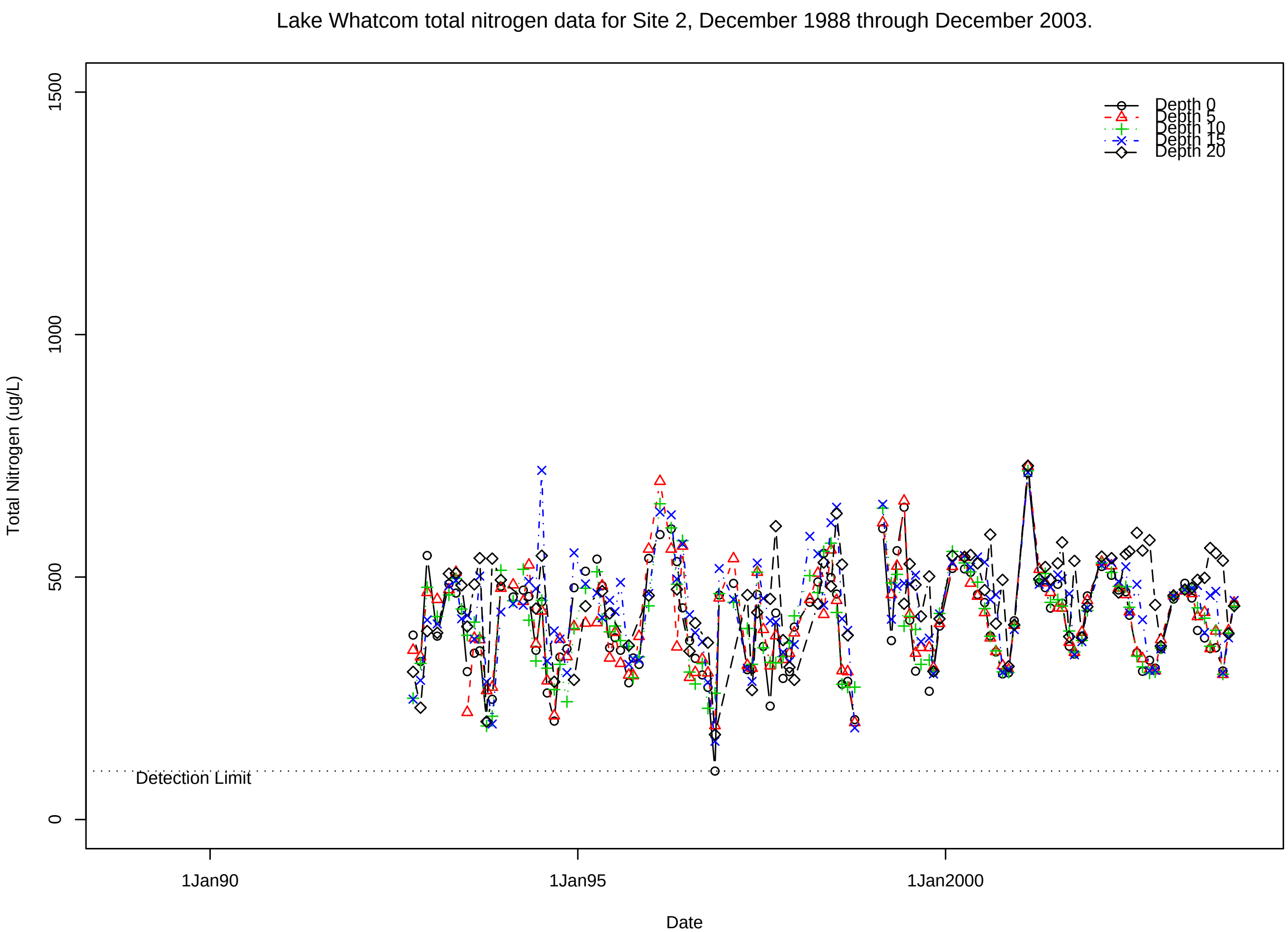


Figure 100: Lake Whatcom total nitrogen data for Site 2 (1988–2003).

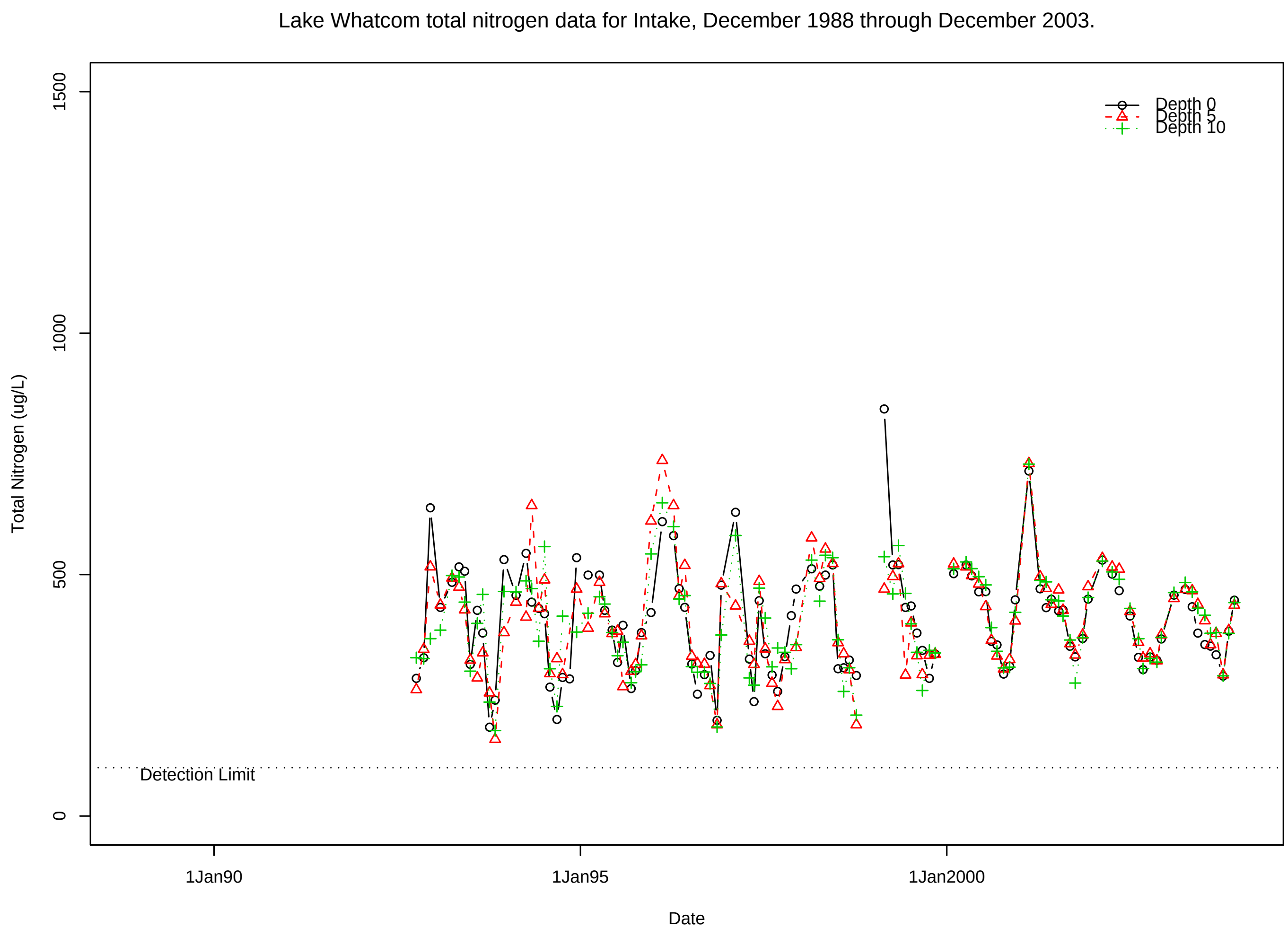


Figure 101: Lake Whatcom total nitrogen data for the Intake (1988–2003).

Lake Whatcom total nitrogen data for Site 3, December 1988 through December 2003.

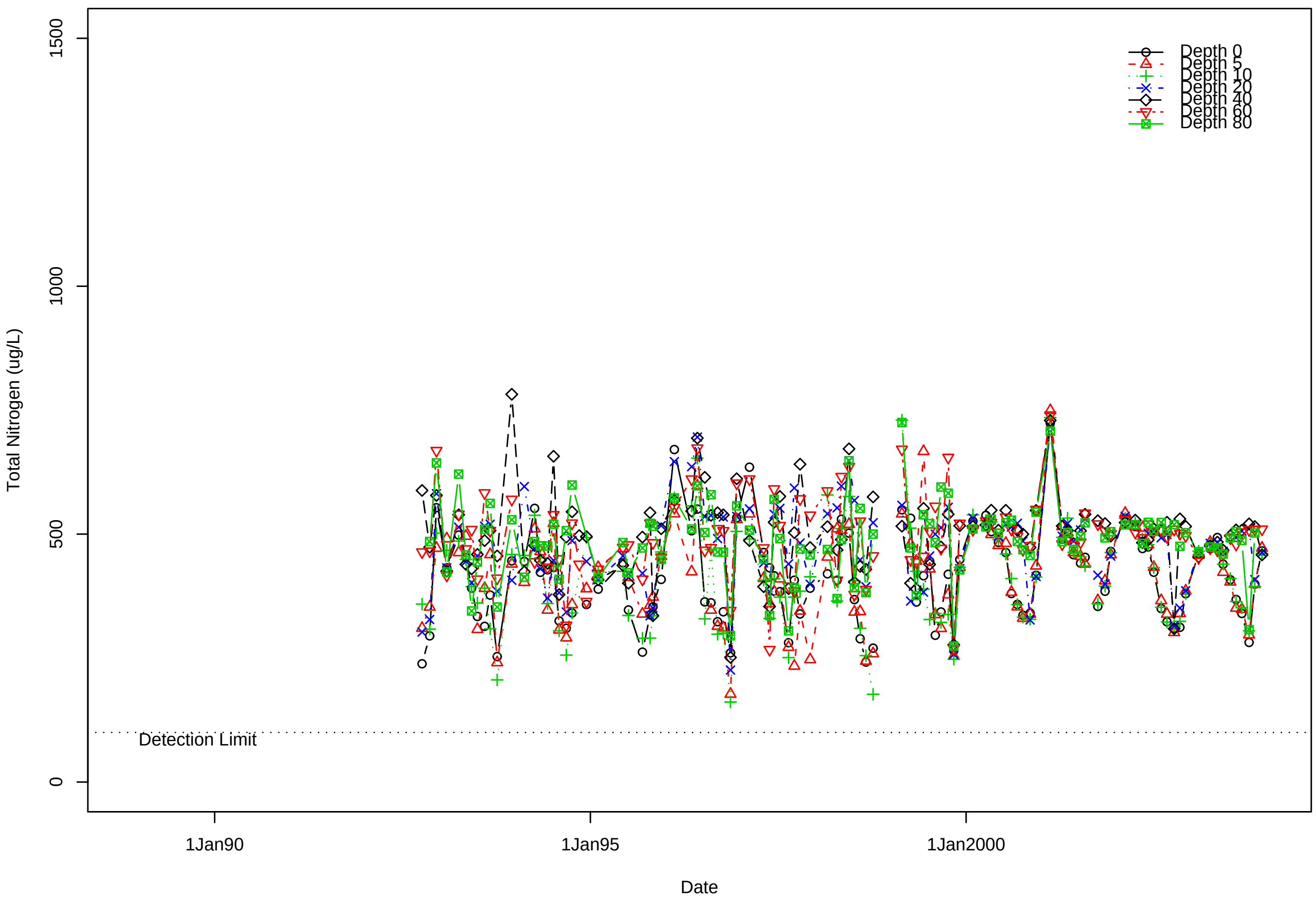


Figure 102: Lake Whatcom total nitrogen data for Site 3 (1988–2003).

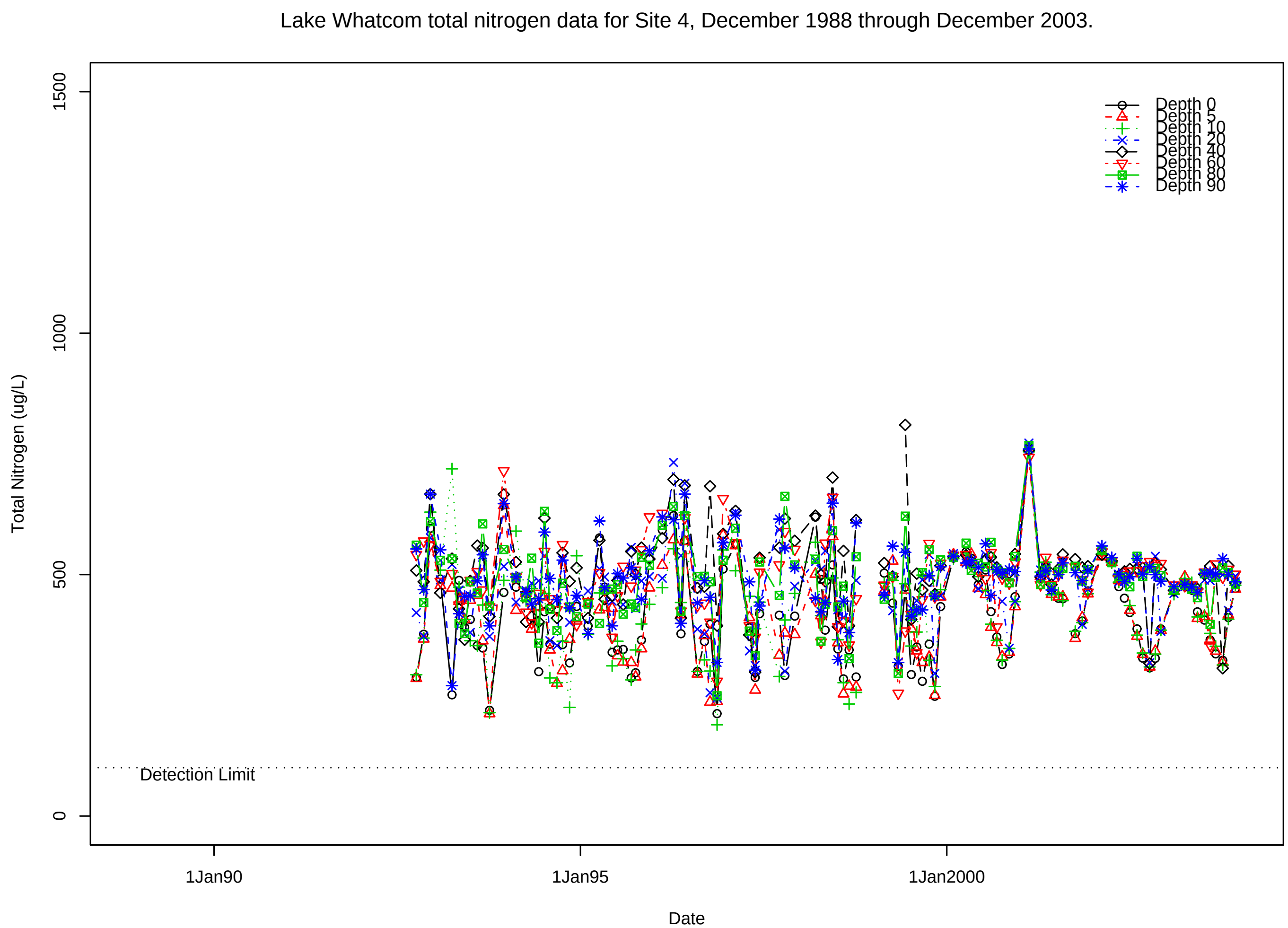


Figure 103: Lake Whatcom total nitrogen data for Site 4 (1988–2003).

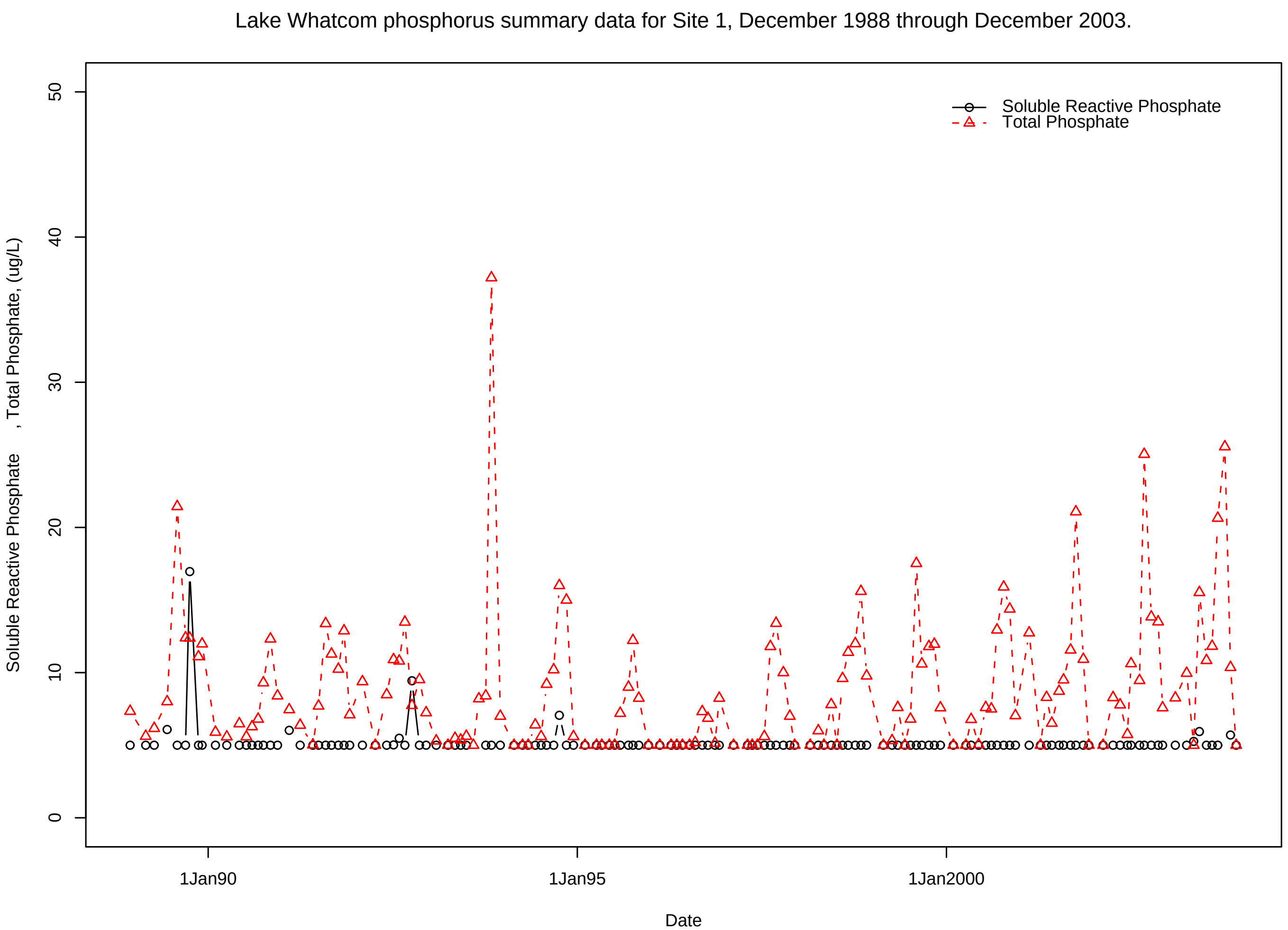


Figure 104: Lake Whatcom phosphorus summary data for Site 1 (1988–2003).

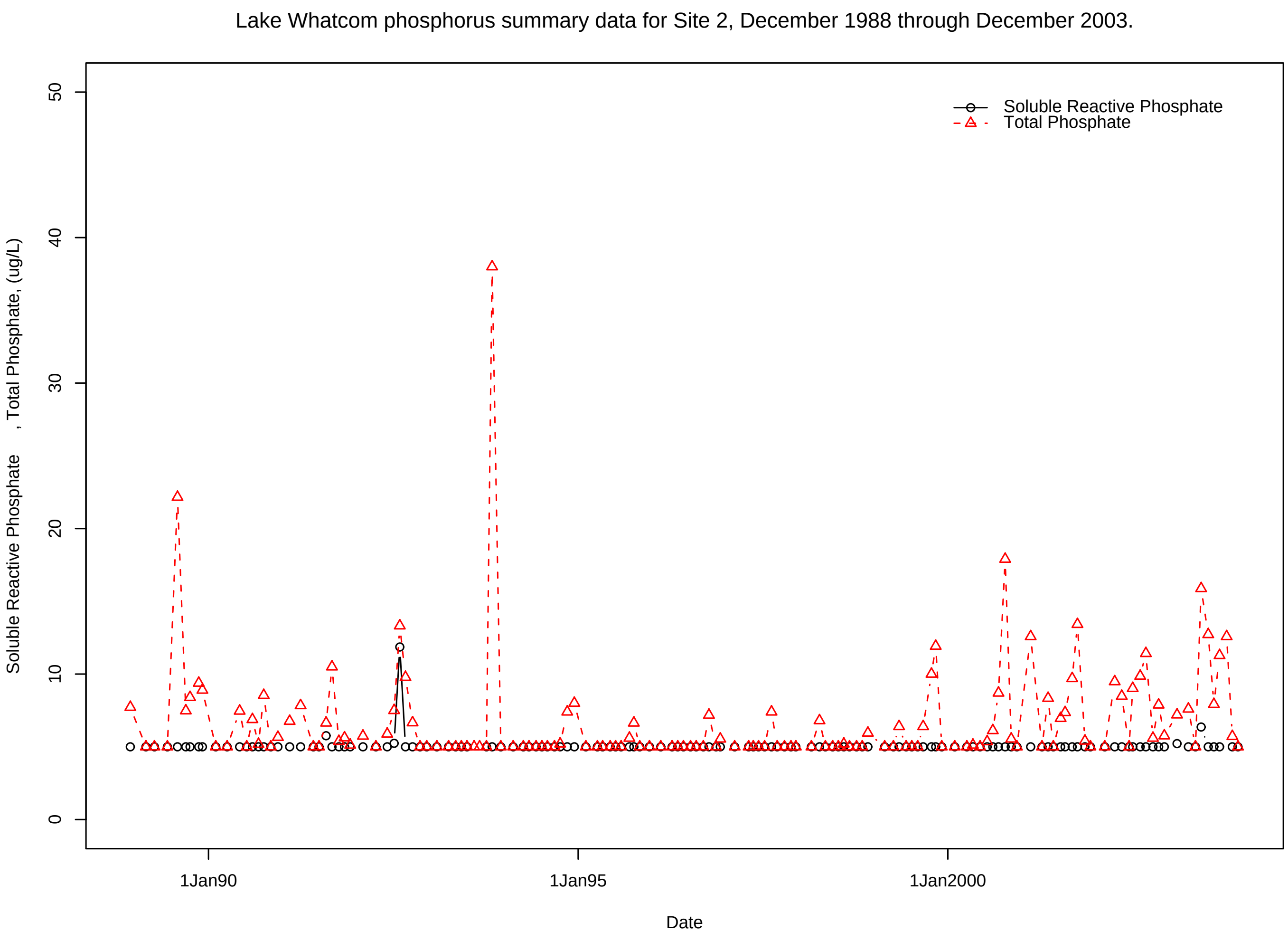


Figure 105: Lake Whatcom phosphorus summary data for Site 2 (1988–2003).

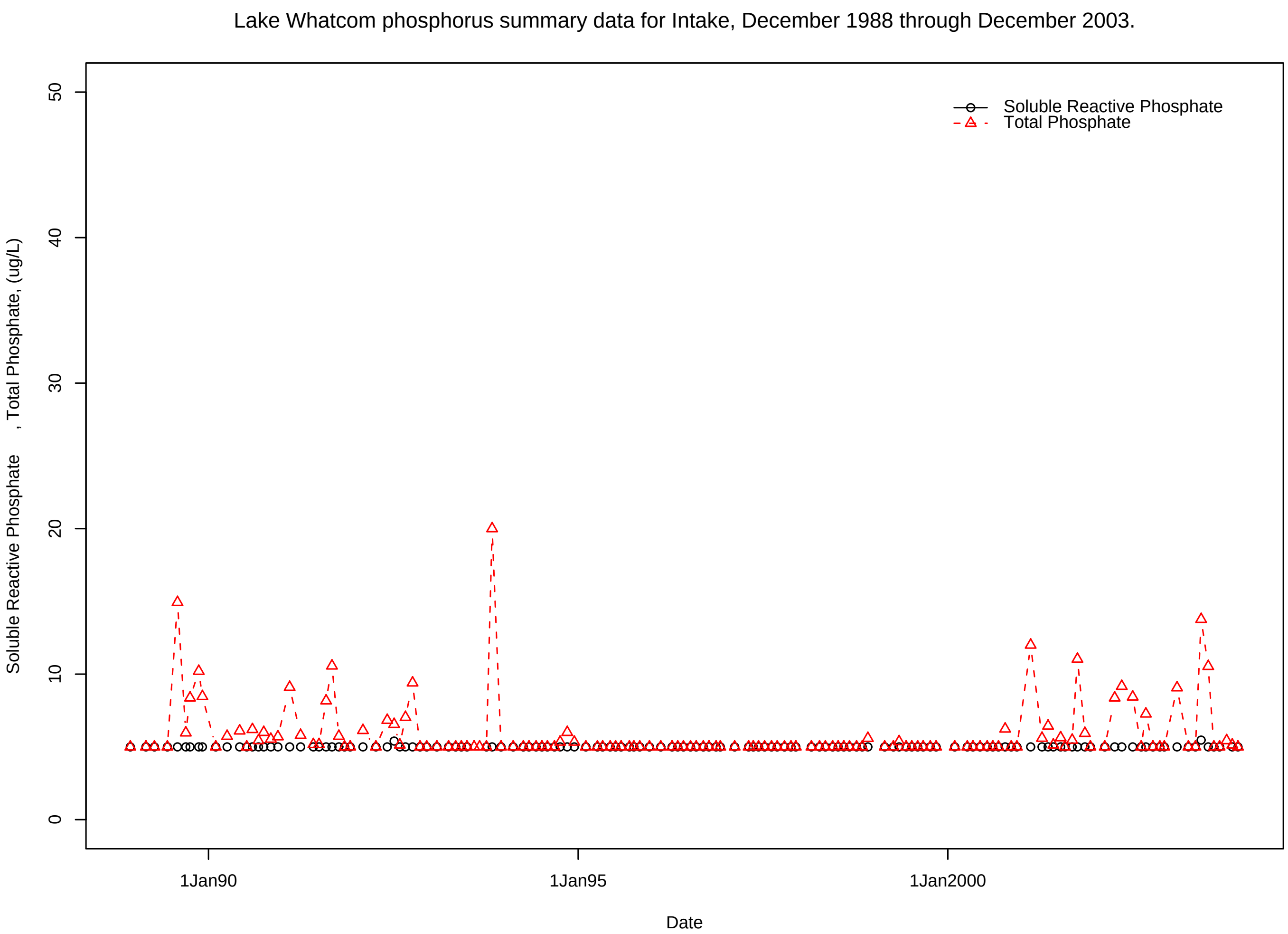


Figure 106: Lake Whatcom phosphorus summary data for the Intake (1988–2003).

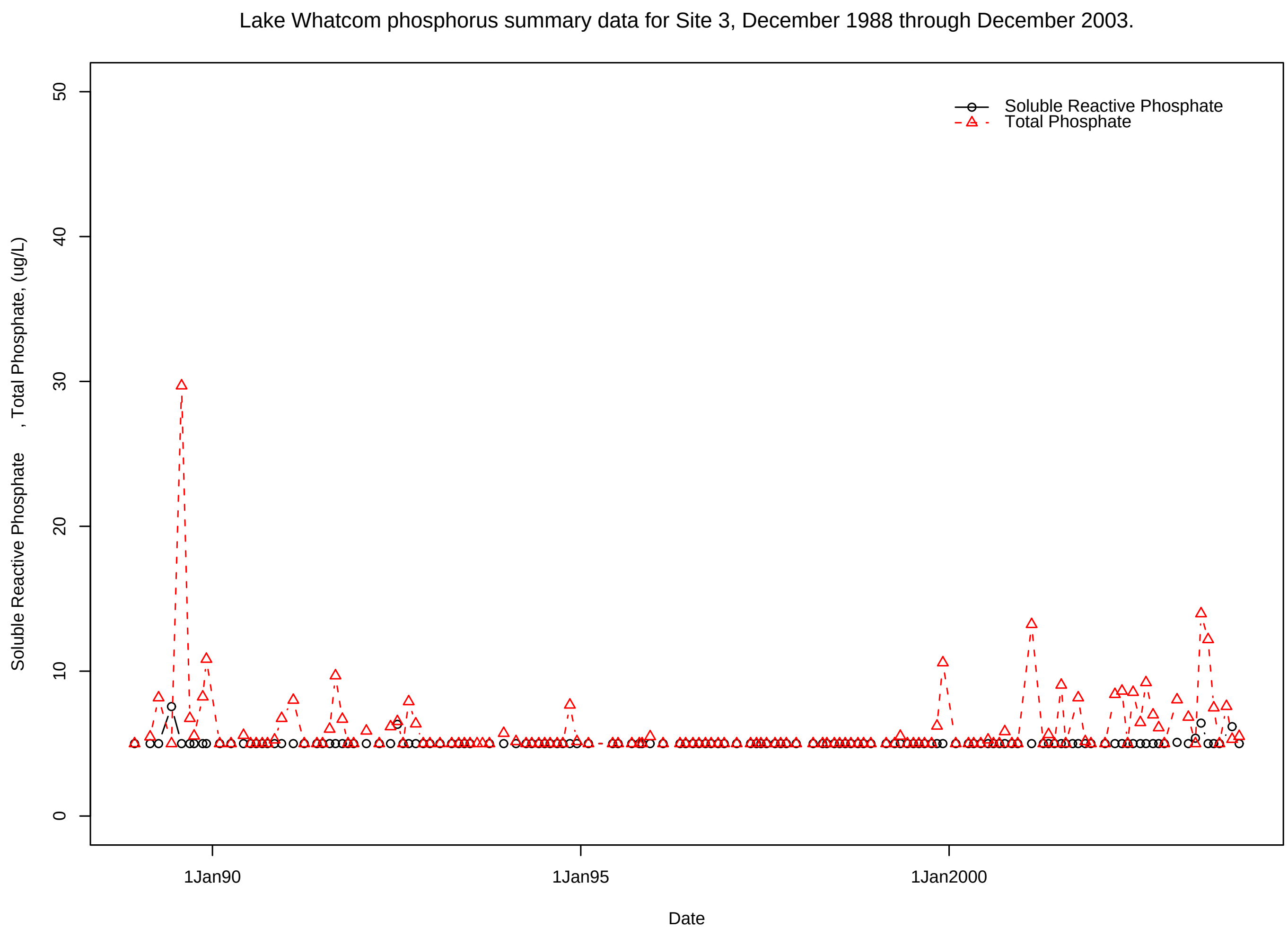


Figure 107: Lake Whatcom phosphorus summary data for Site 3 (1988–2003).

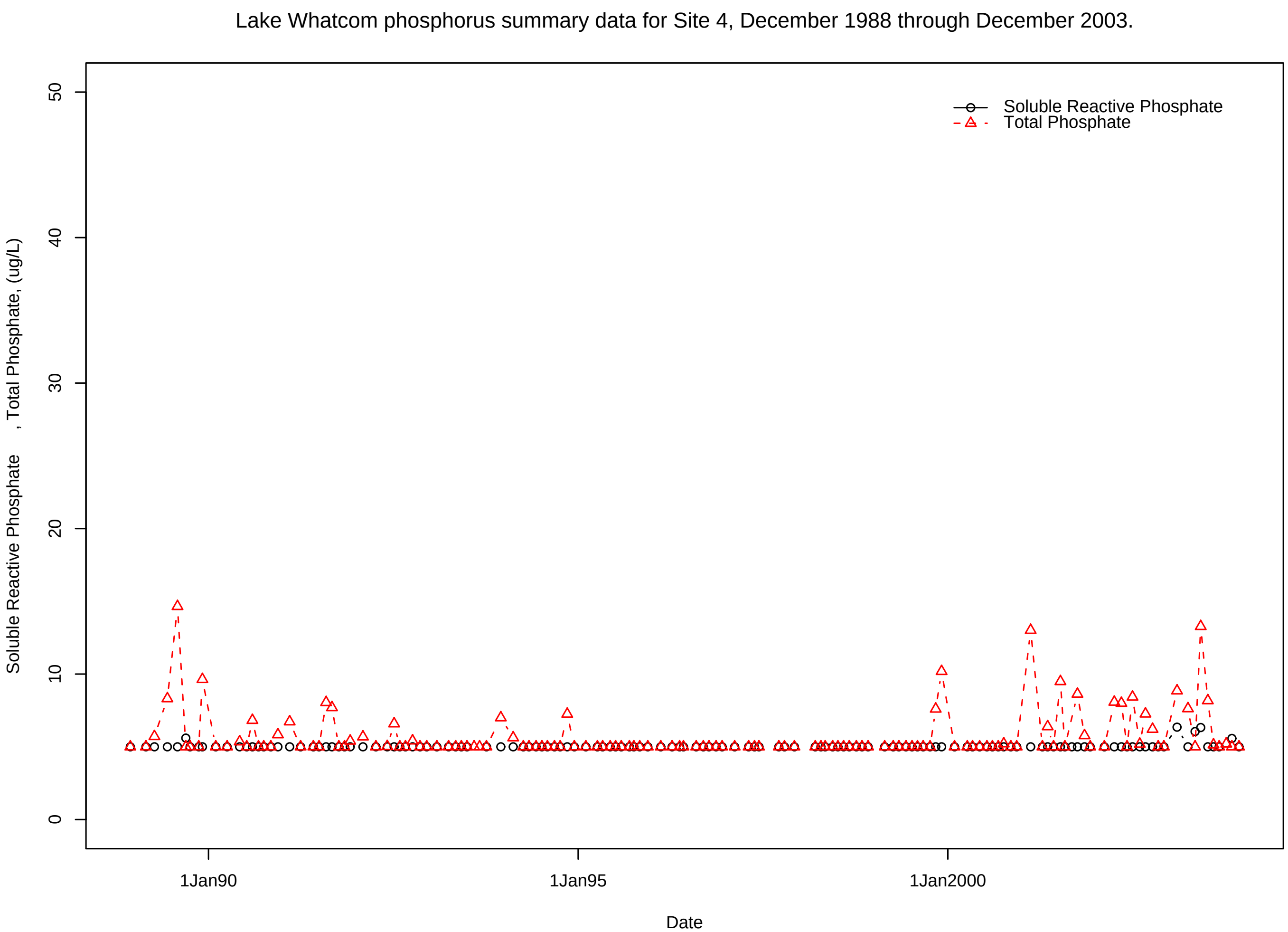


Figure 108: Lake Whatcom phosphorus summary data for Site 4 (1988–2003).

Lake Whatcom soluble reactive phosphate data for Site 1, December 1988 through December 2003.

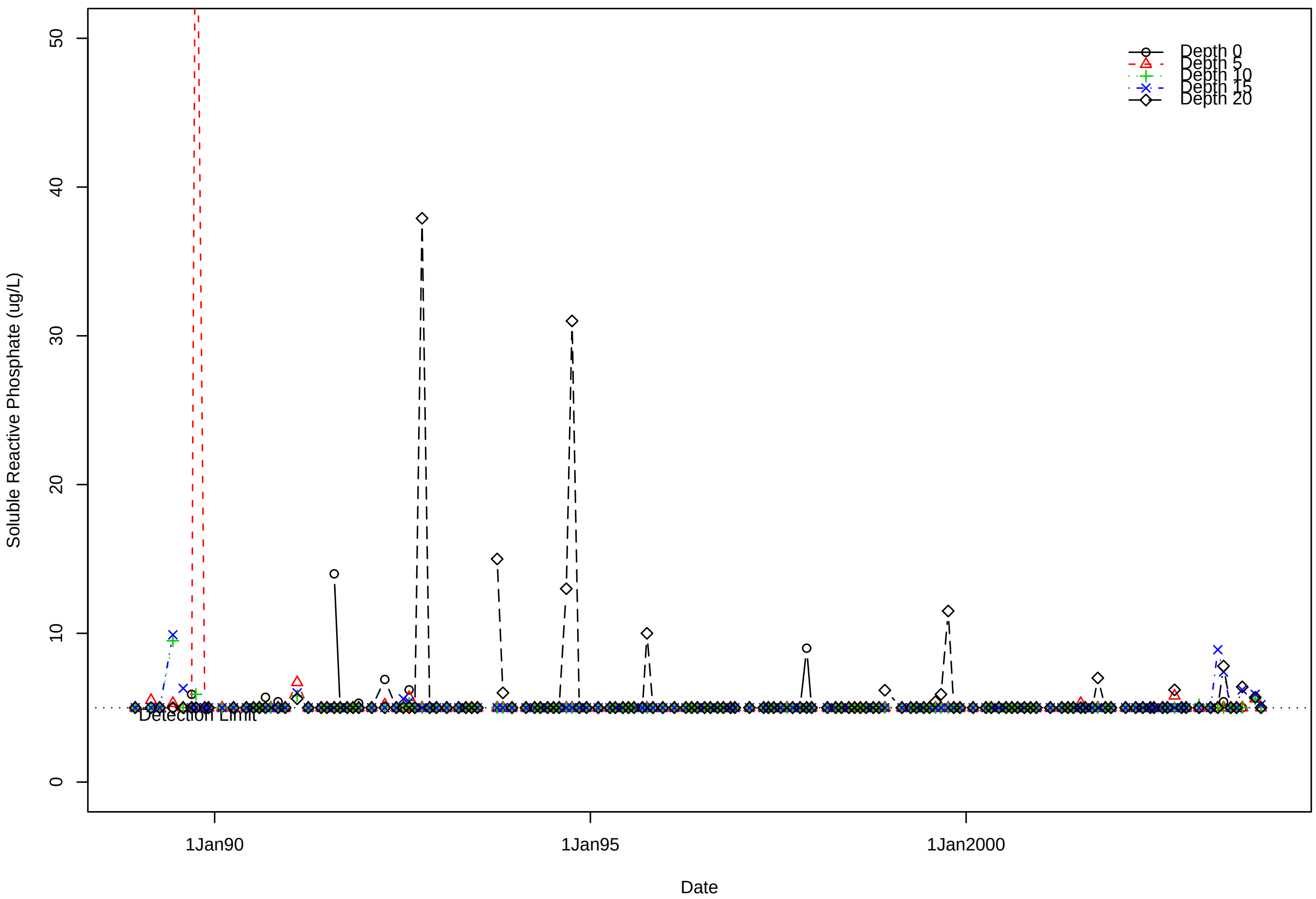


Figure 109: Lake Whatcom soluble phosphate data for Site 1 (1988–2003).

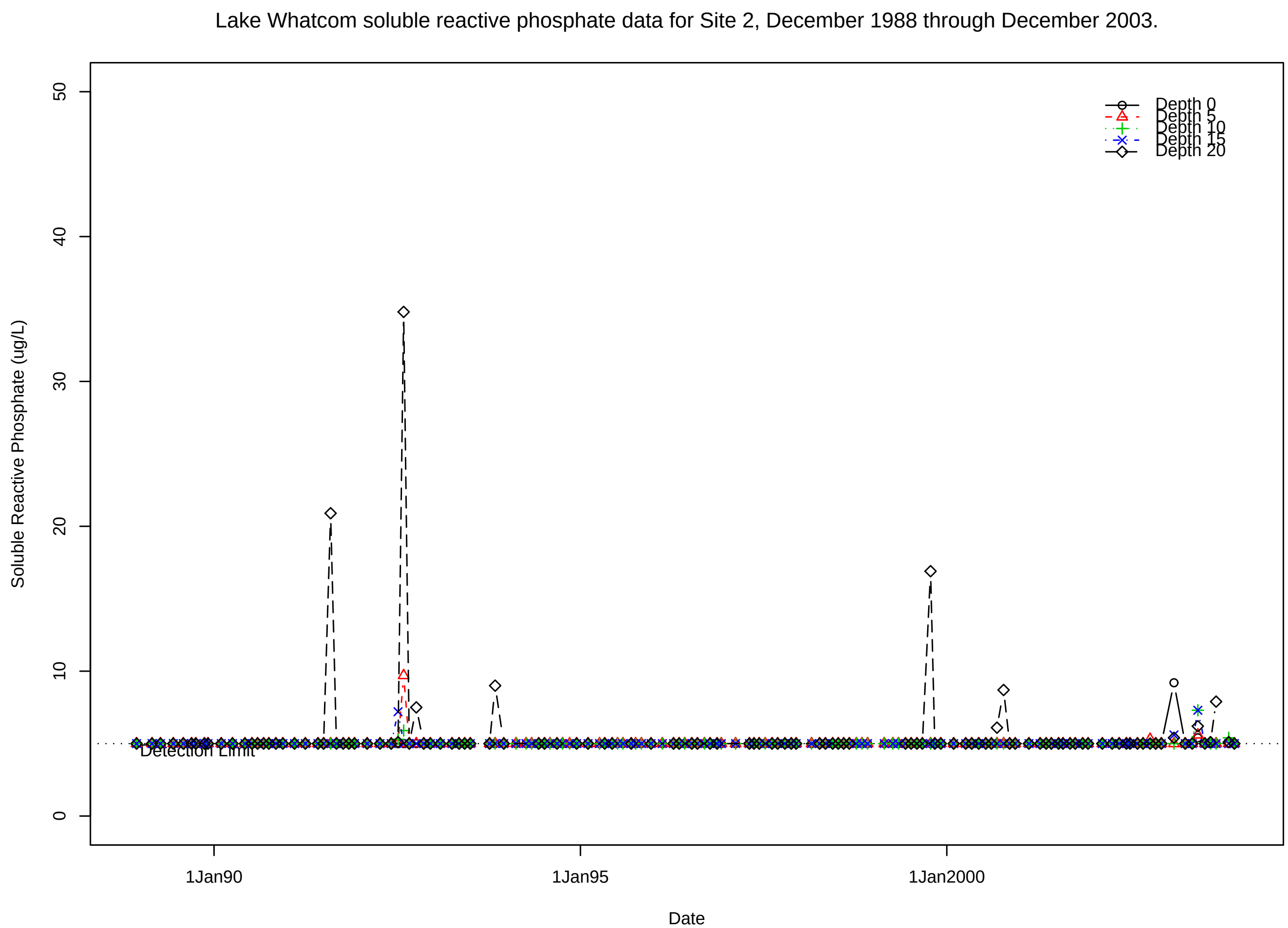


Figure 110: Lake Whatcom soluble phosphate data for Site 2 (1988–2003).

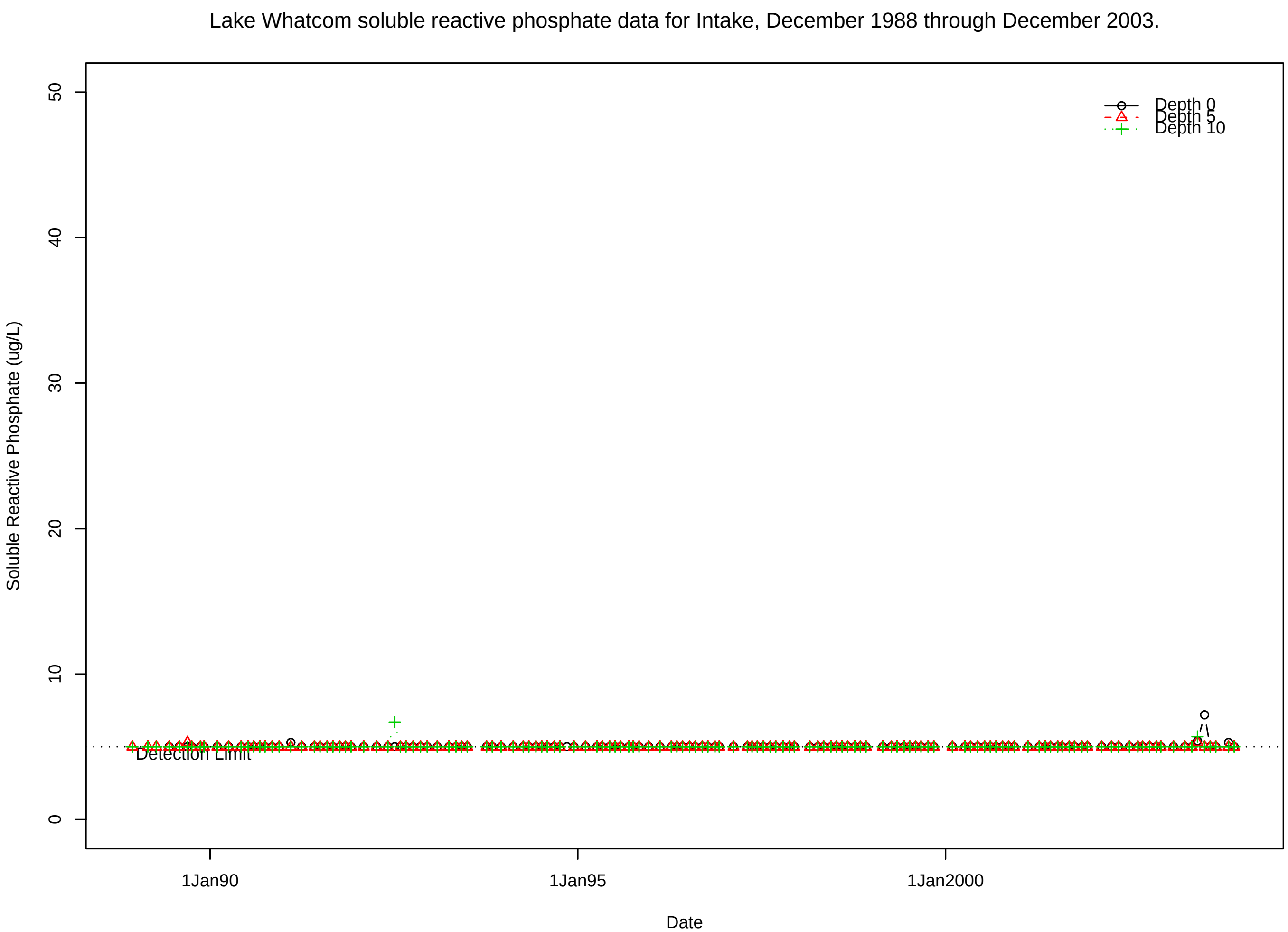


Figure 111: Lake Whatcom soluble phosphate data for the Intake (1988–2003).

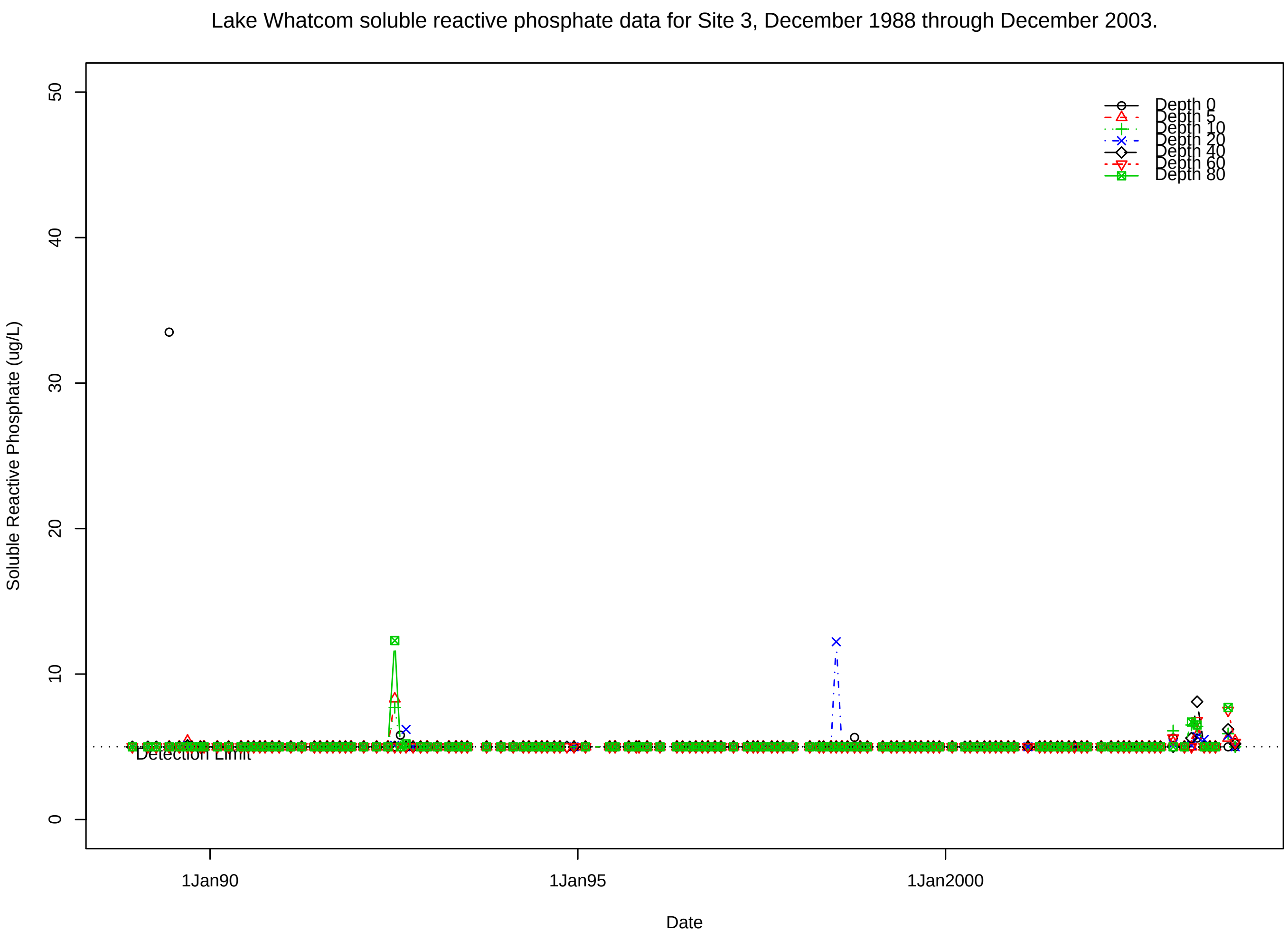


Figure 112: Lake Whatcom soluble phosphate data for Site 3 (1988–2003).

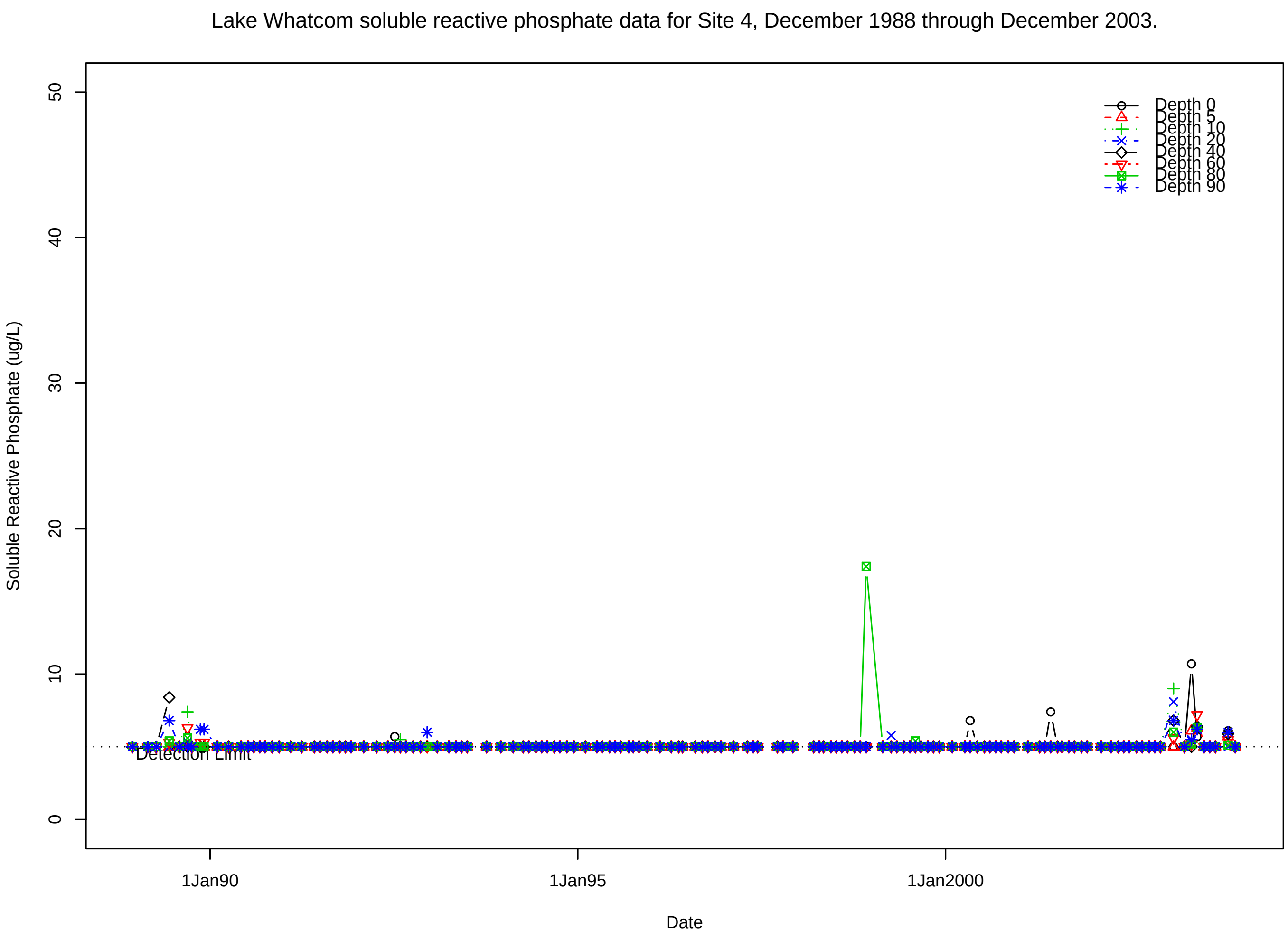


Figure 113: Lake Whatcom soluble phosphate data for Site 4 (1988–2003).

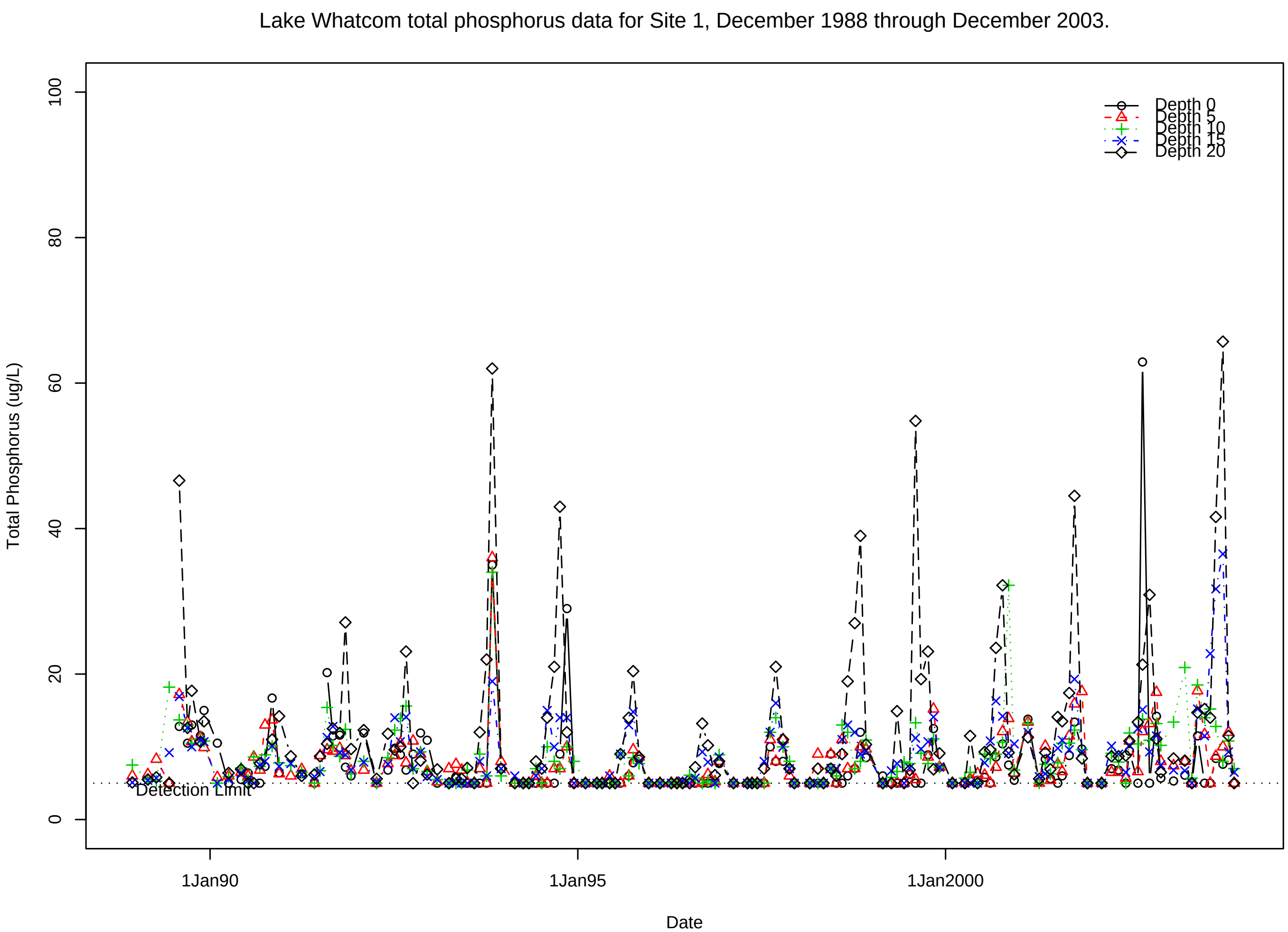


Figure 114: Lake Whatcom total phosphorus data for Site 1 (1988–2003).

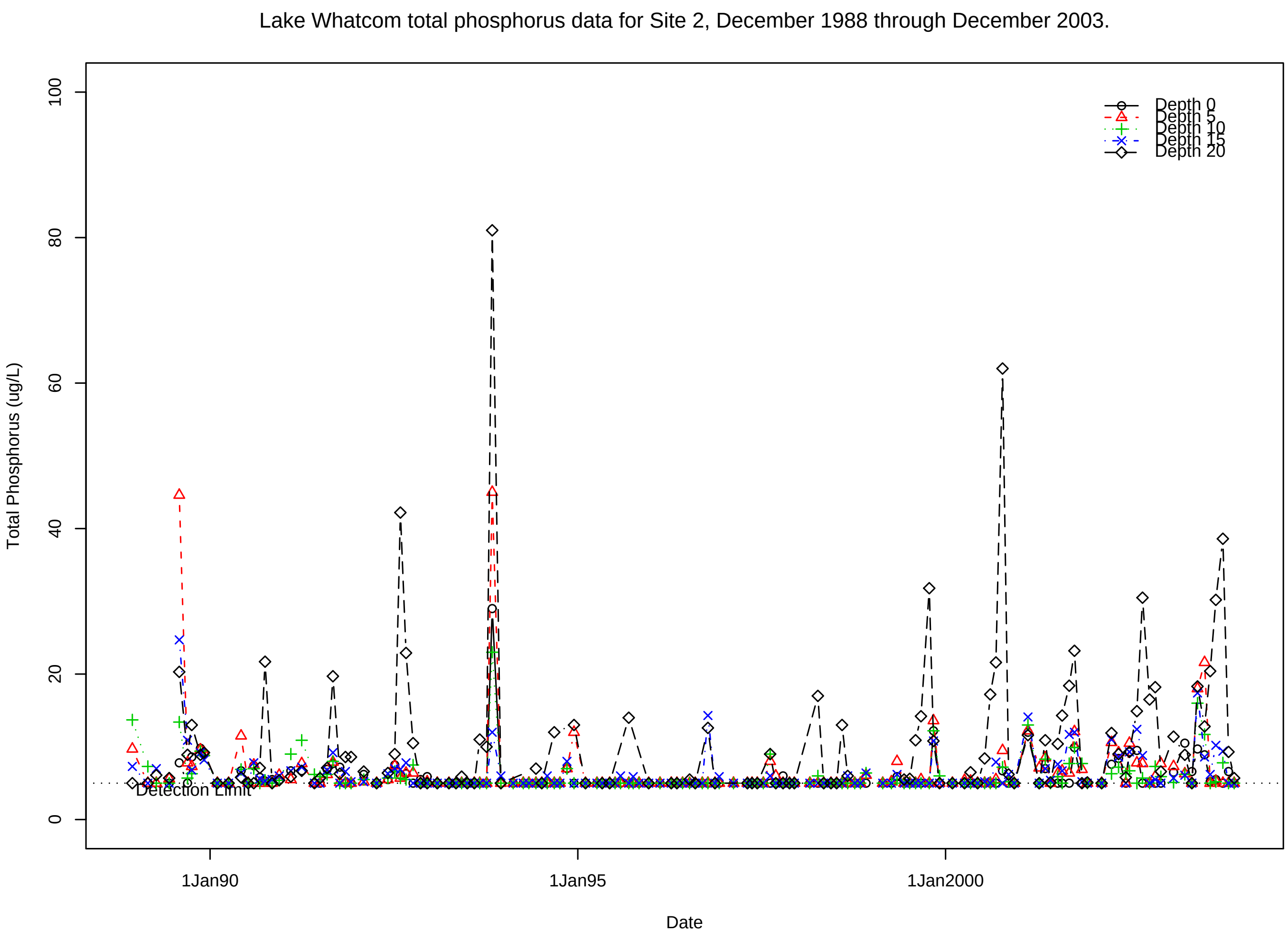


Figure 115: Lake Whatcom total phosphorus data for Site 2 (1988–2003).

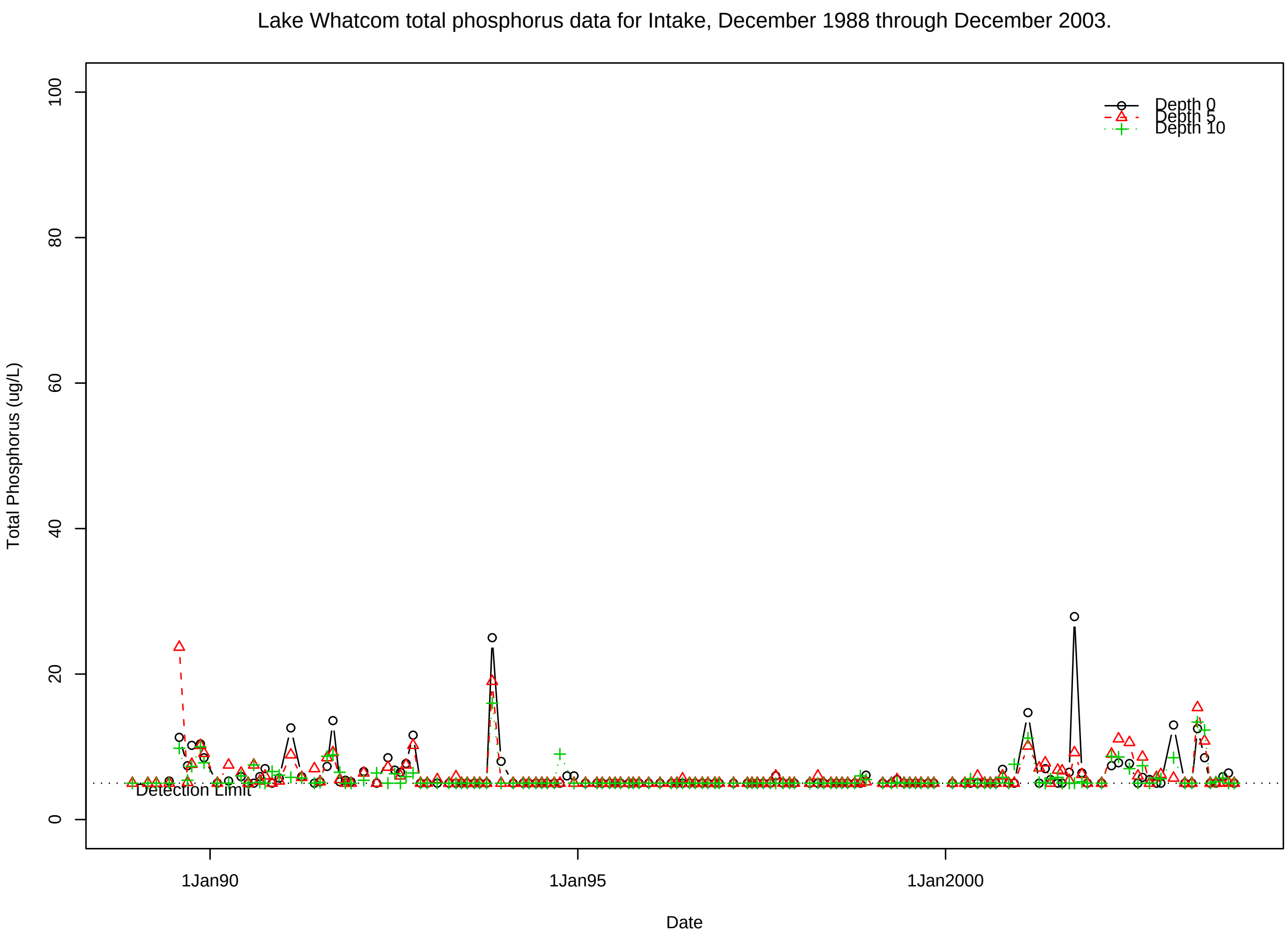


Figure 116: Lake Whatcom total phosphorus data for the Intake (1988–2003).

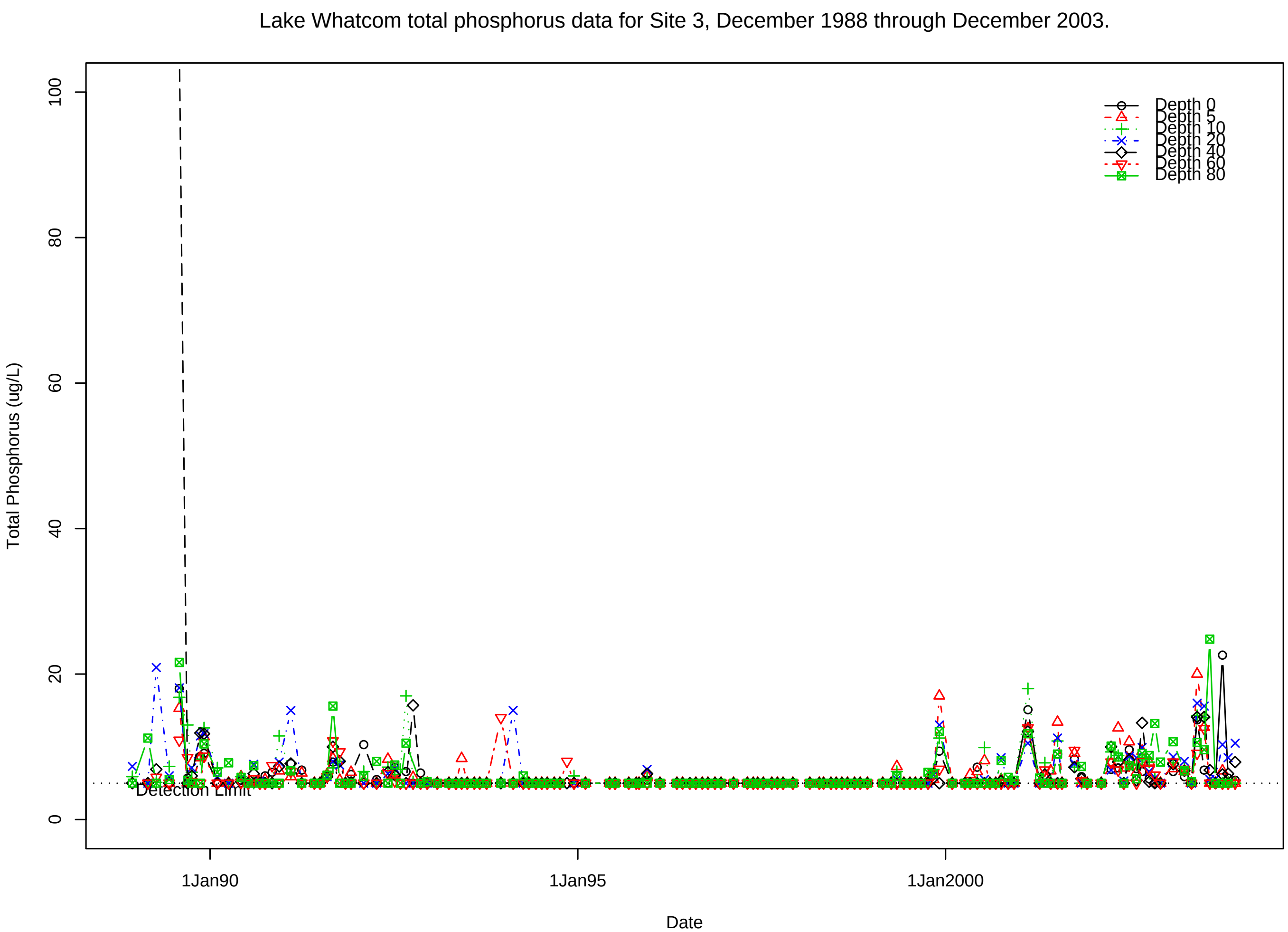


Figure 117: Lake Whatcom total phosphorus data for Site 3 (1988–2003).

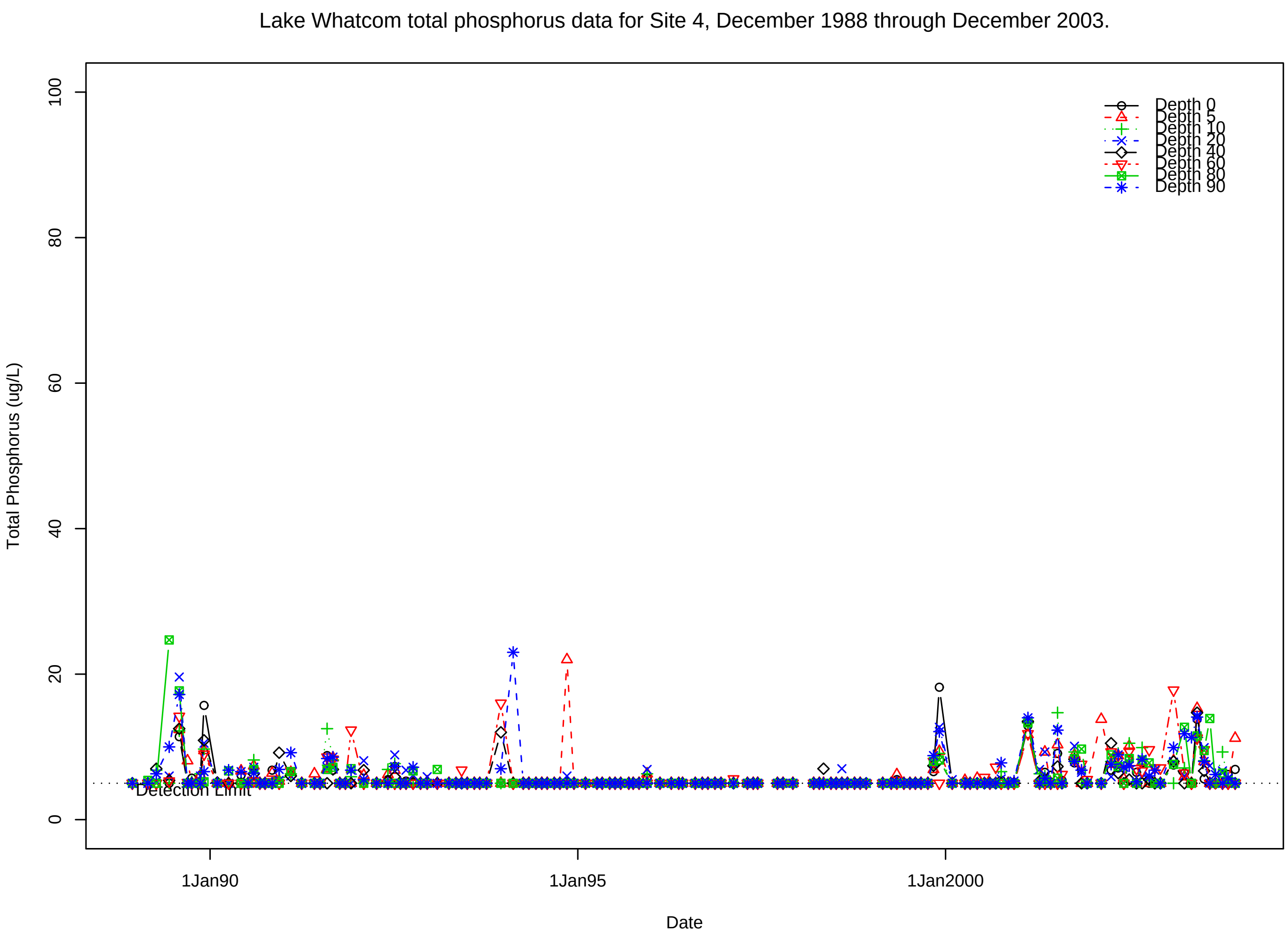


Figure 118: Lake Whatcom total phosphorus data for Site 4 (1988–2003).

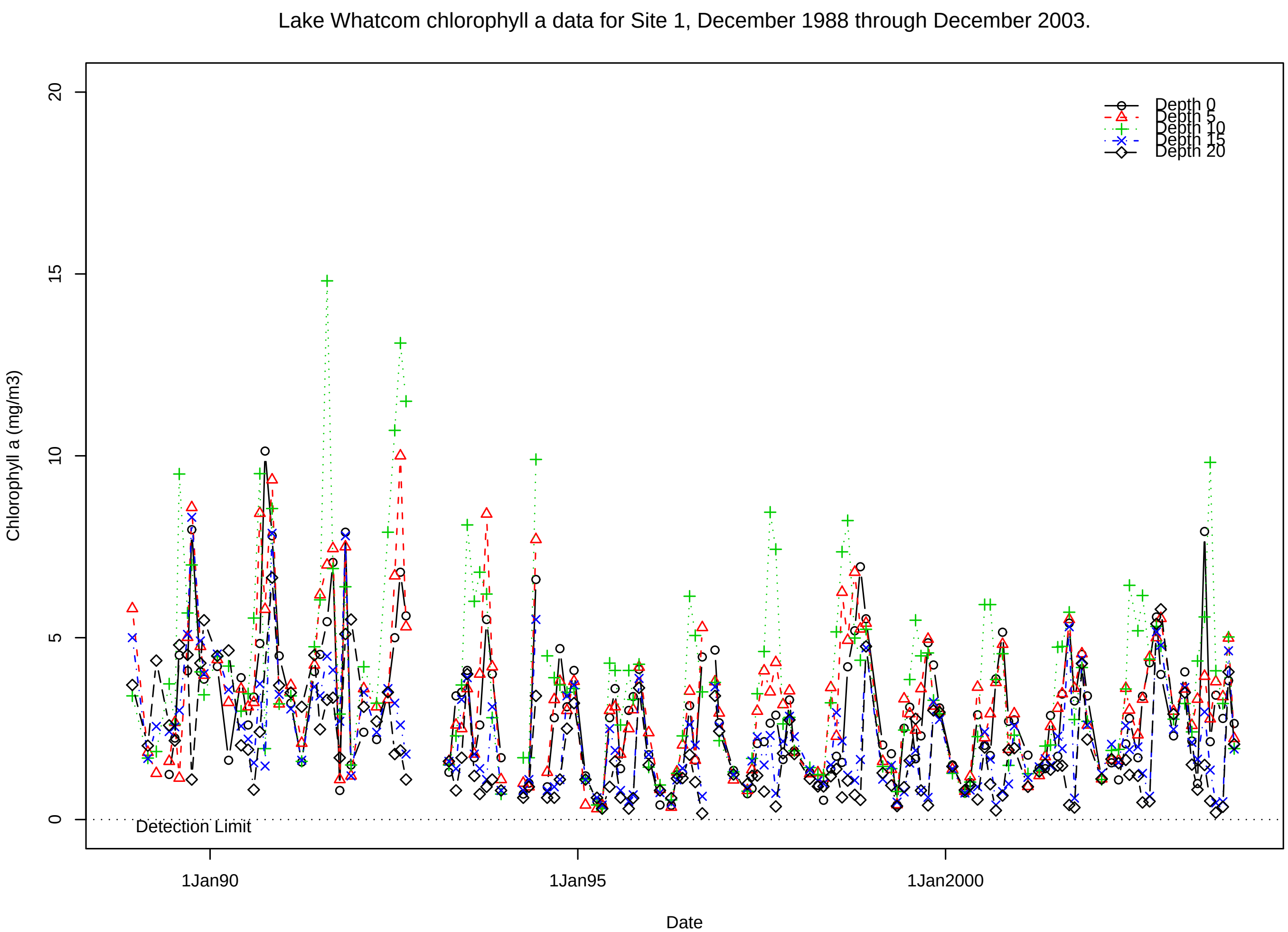


Figure 119: Lake Whatcom chlorophyll data for Site 1 (1988–2003).

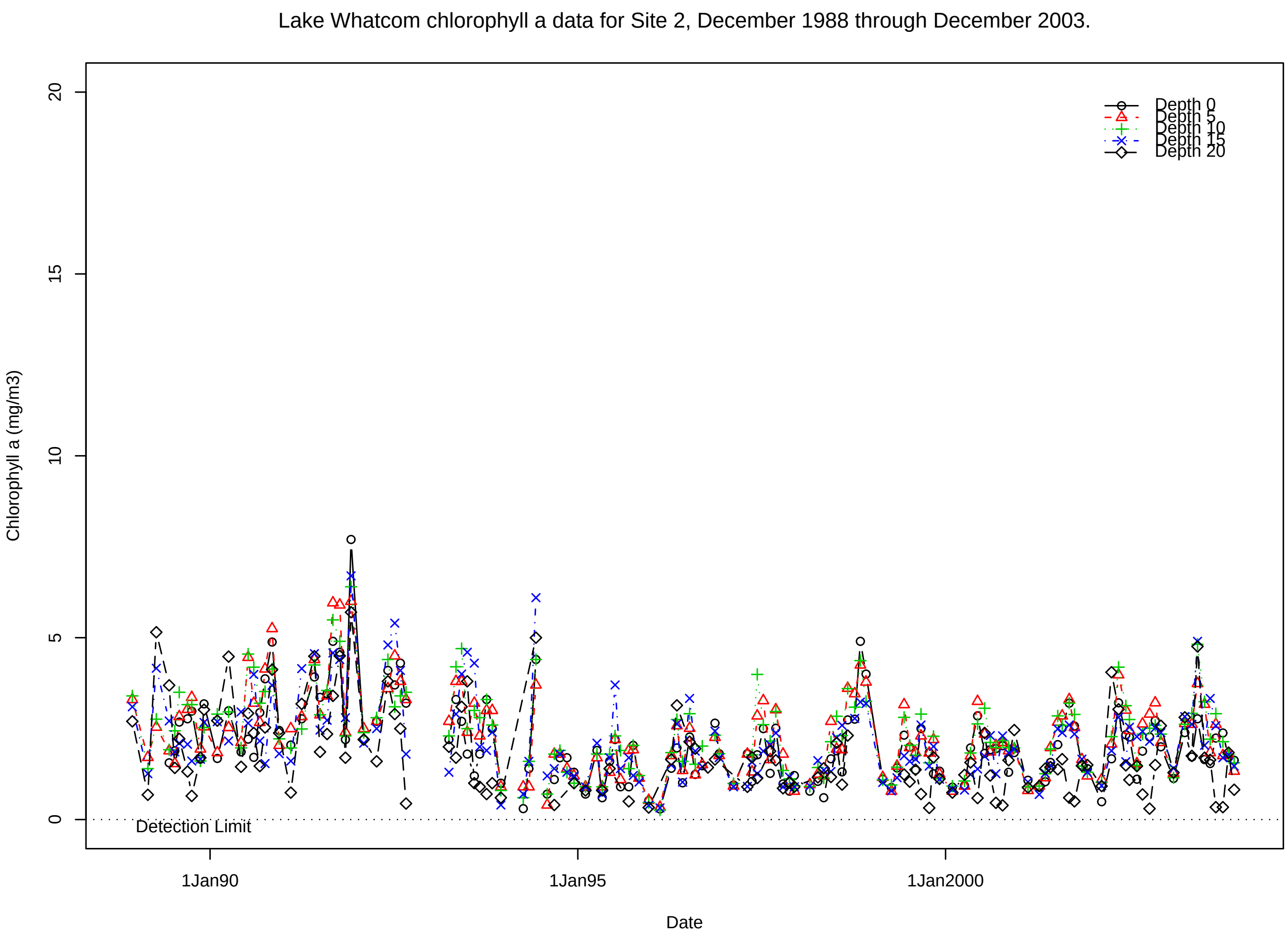


Figure 120: Lake Whatcom chlorophyll data for Site 2 (1988–2003).

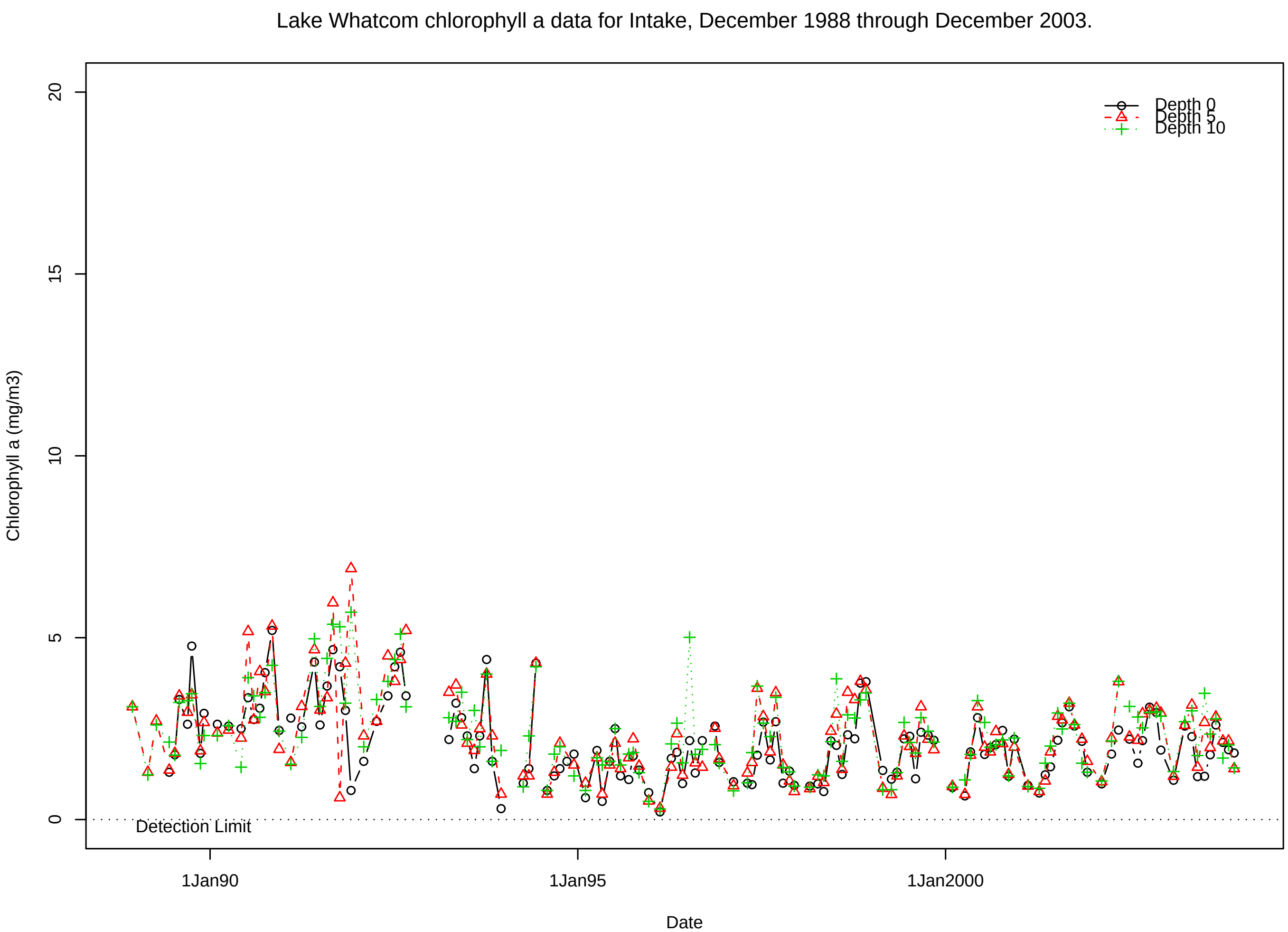


Figure 121: Lake Whatcom chlorophyll data for the Intake (1988–2003).

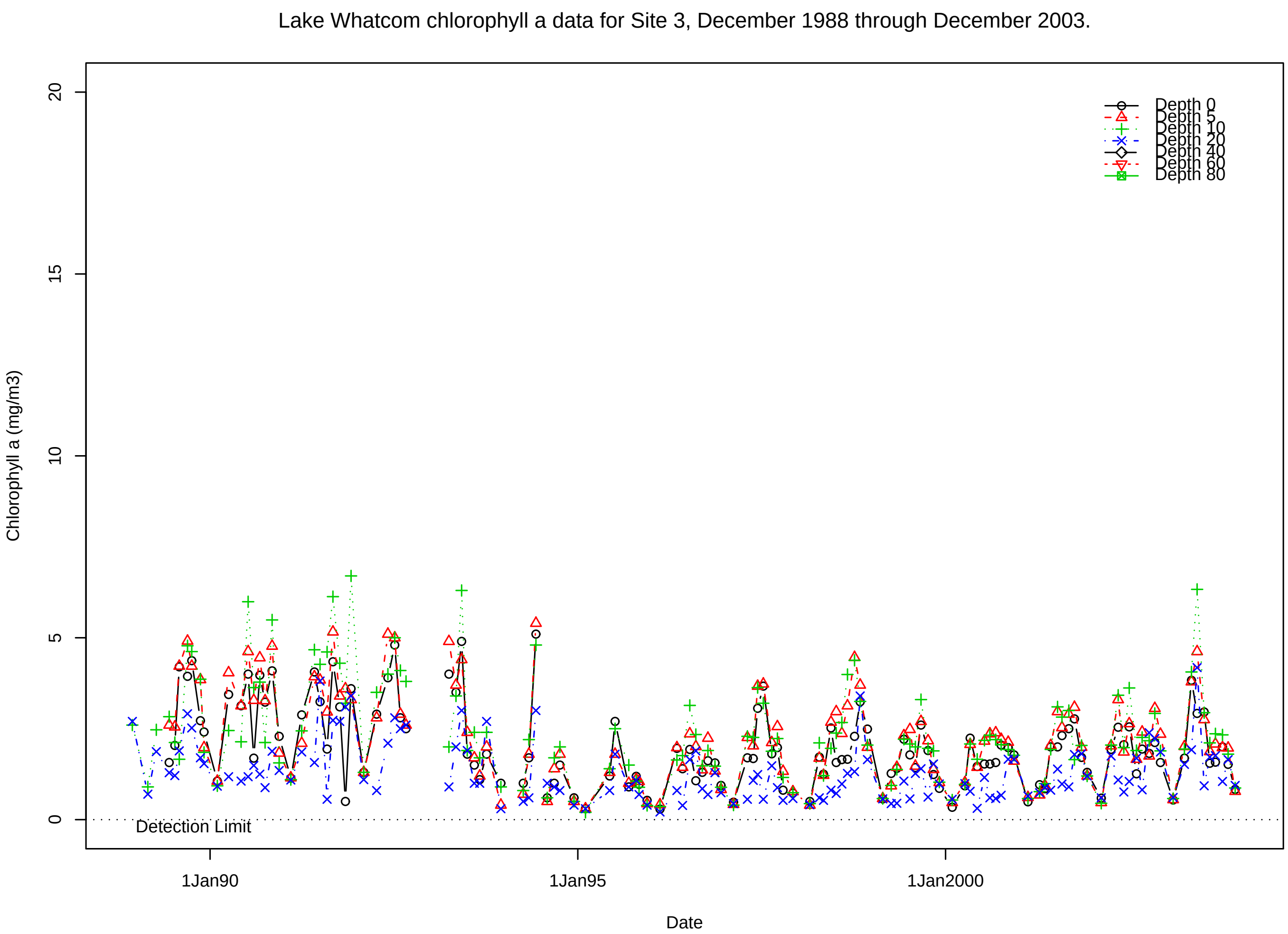


Figure 122: Lake Whatcom chlorophyll data for Site 3 (1988–2003).

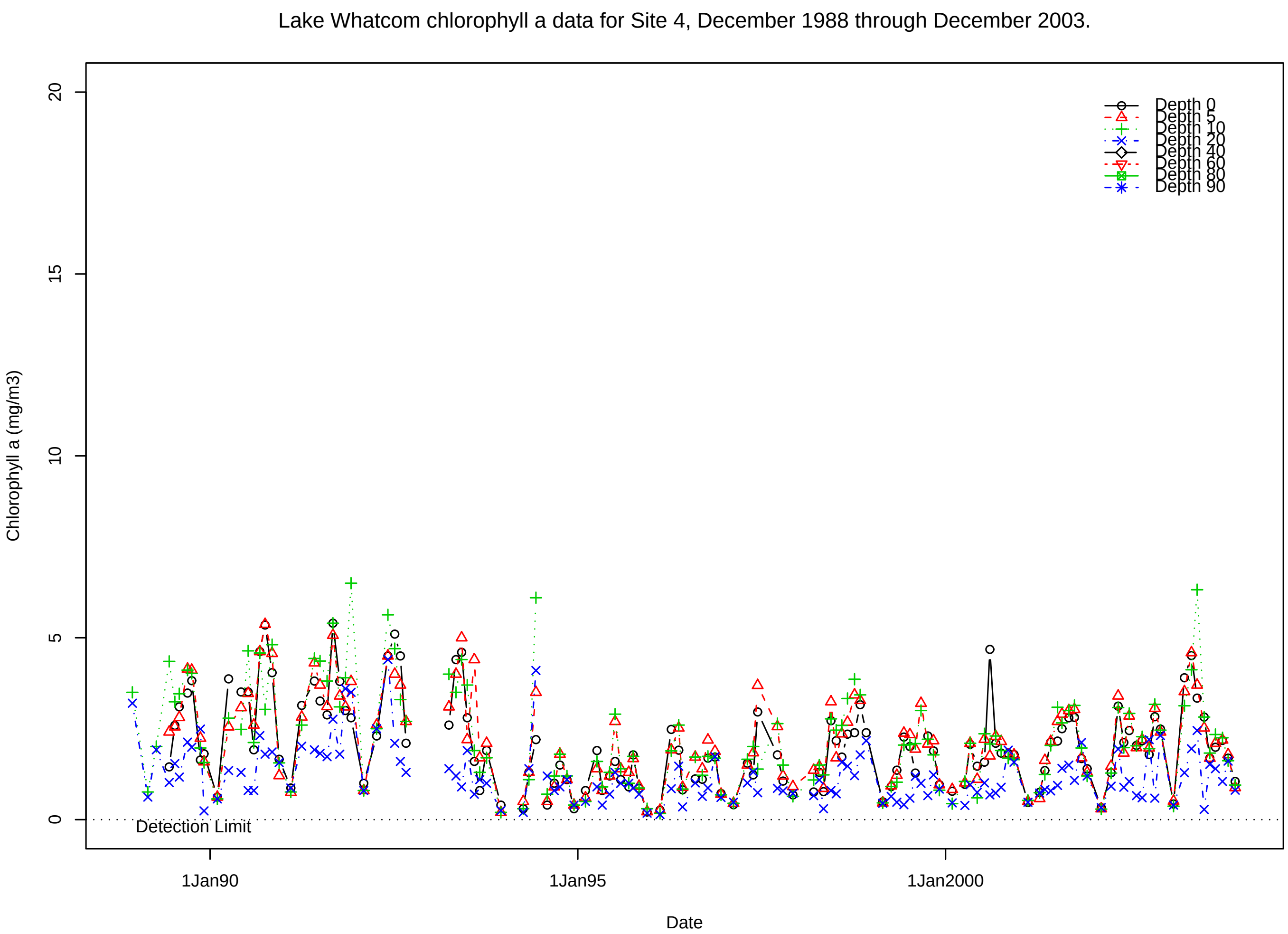


Figure 123: Lake Whatcom chlorophyll data for Site 4 (1988–2003).

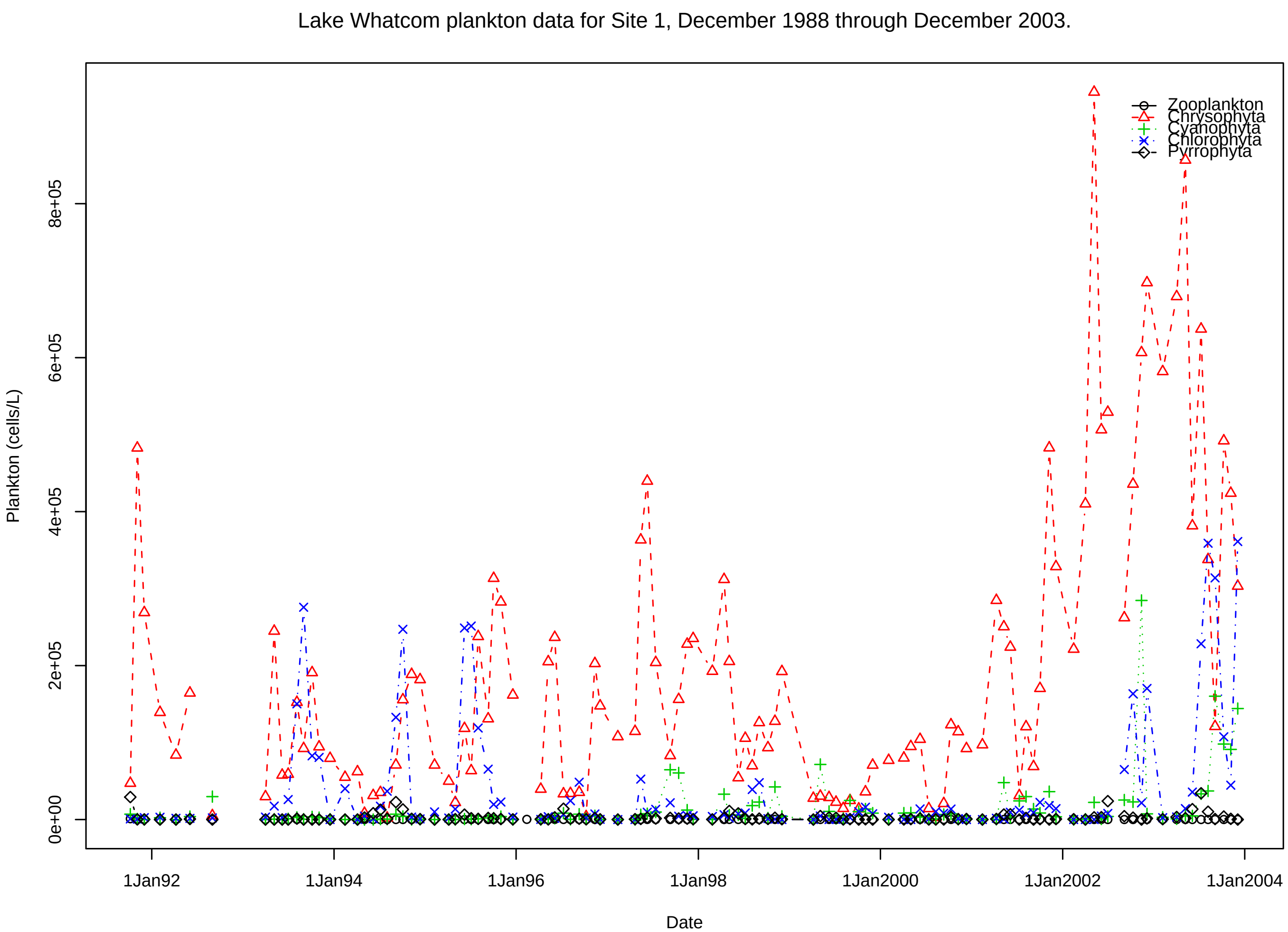


Figure 124: Lake Whatcom plankton data for Site 1 (1988–2003).

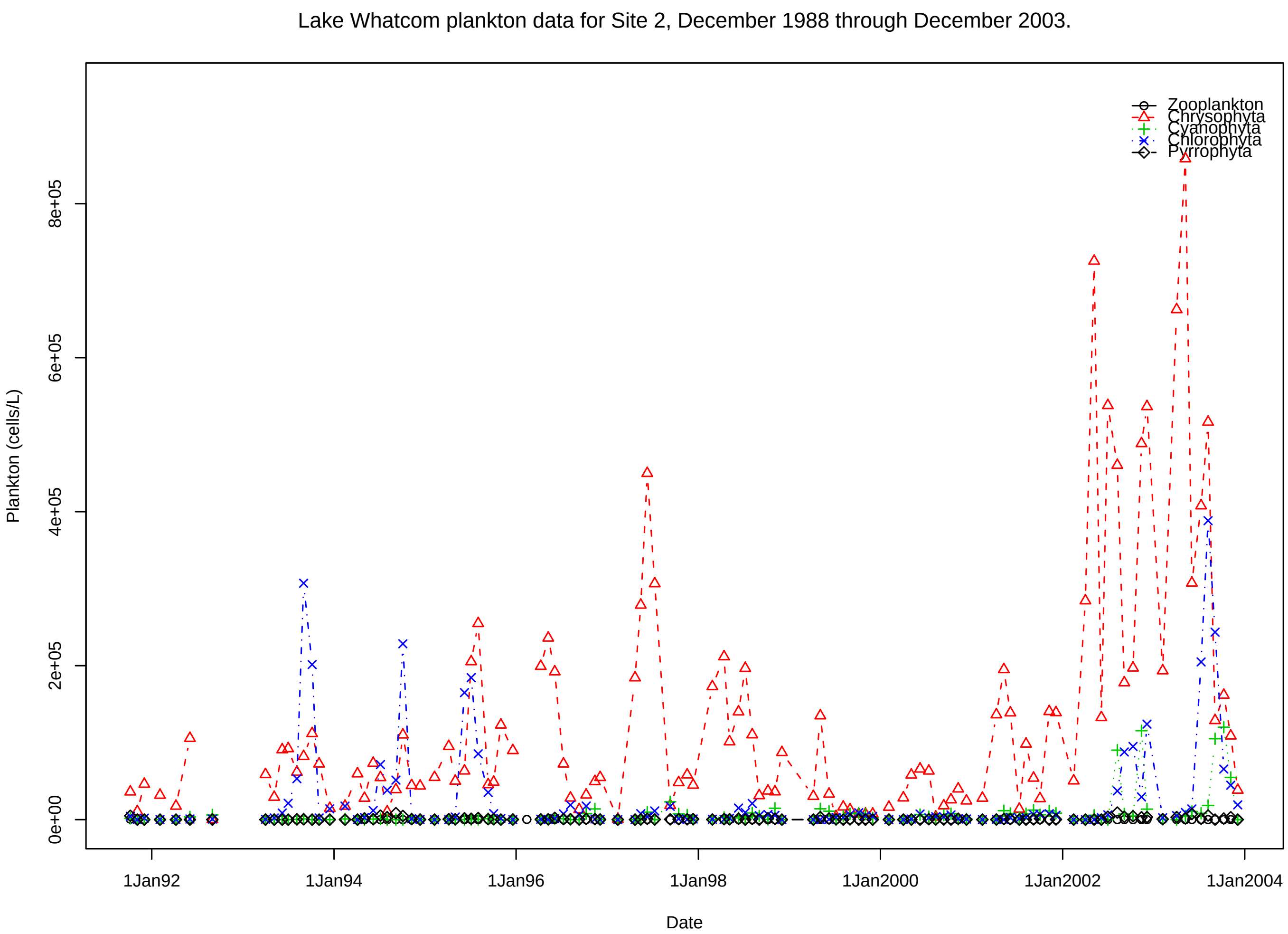


Figure 125: Lake Whatcom plankton data for Site 2 (1988–2003).

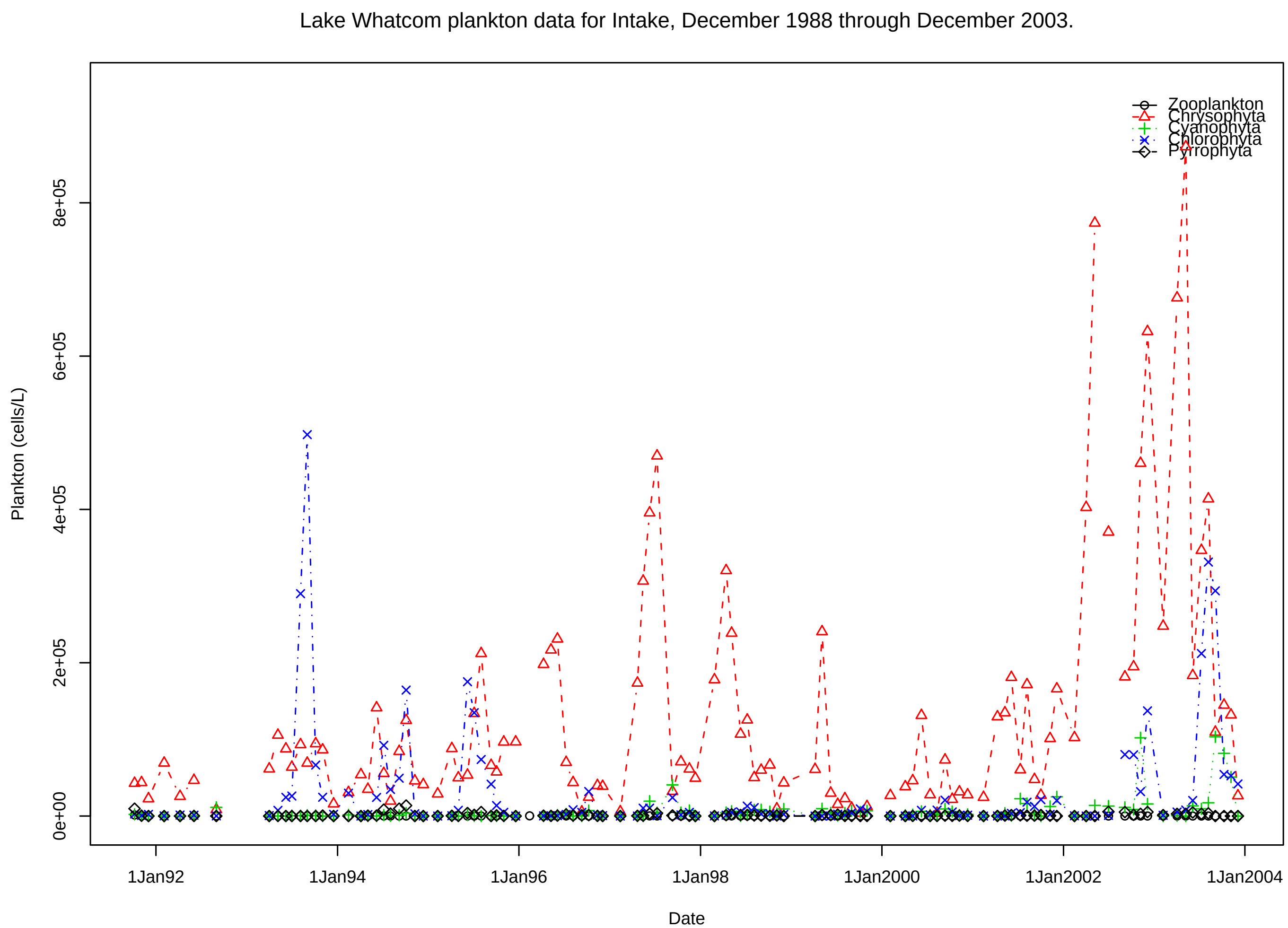


Figure 126: Lake Whatcom plankton data for the Intake (1988–2003).

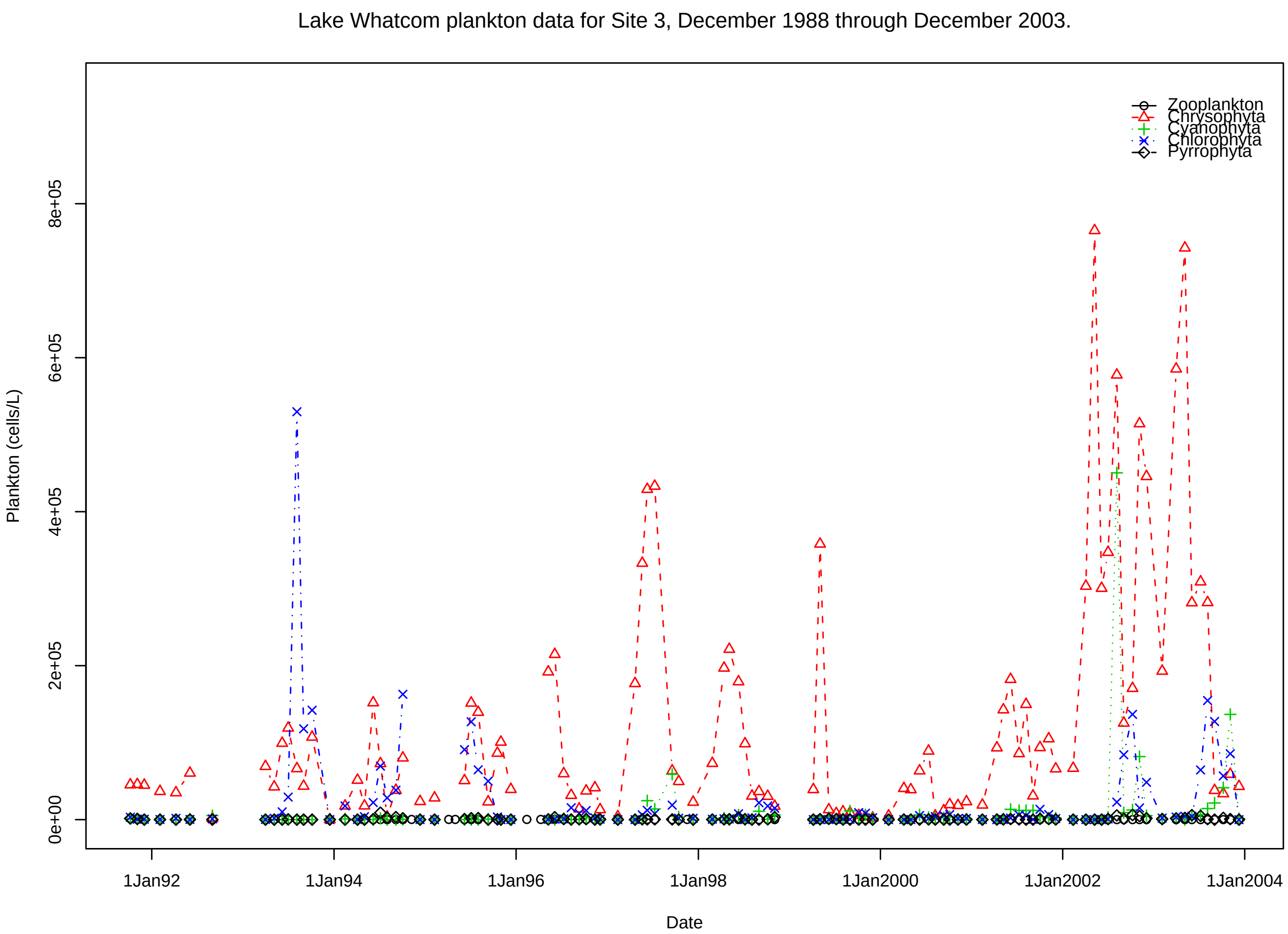


Figure 127: Lake Whatcom plankton data for Site 3 (1988–2003).

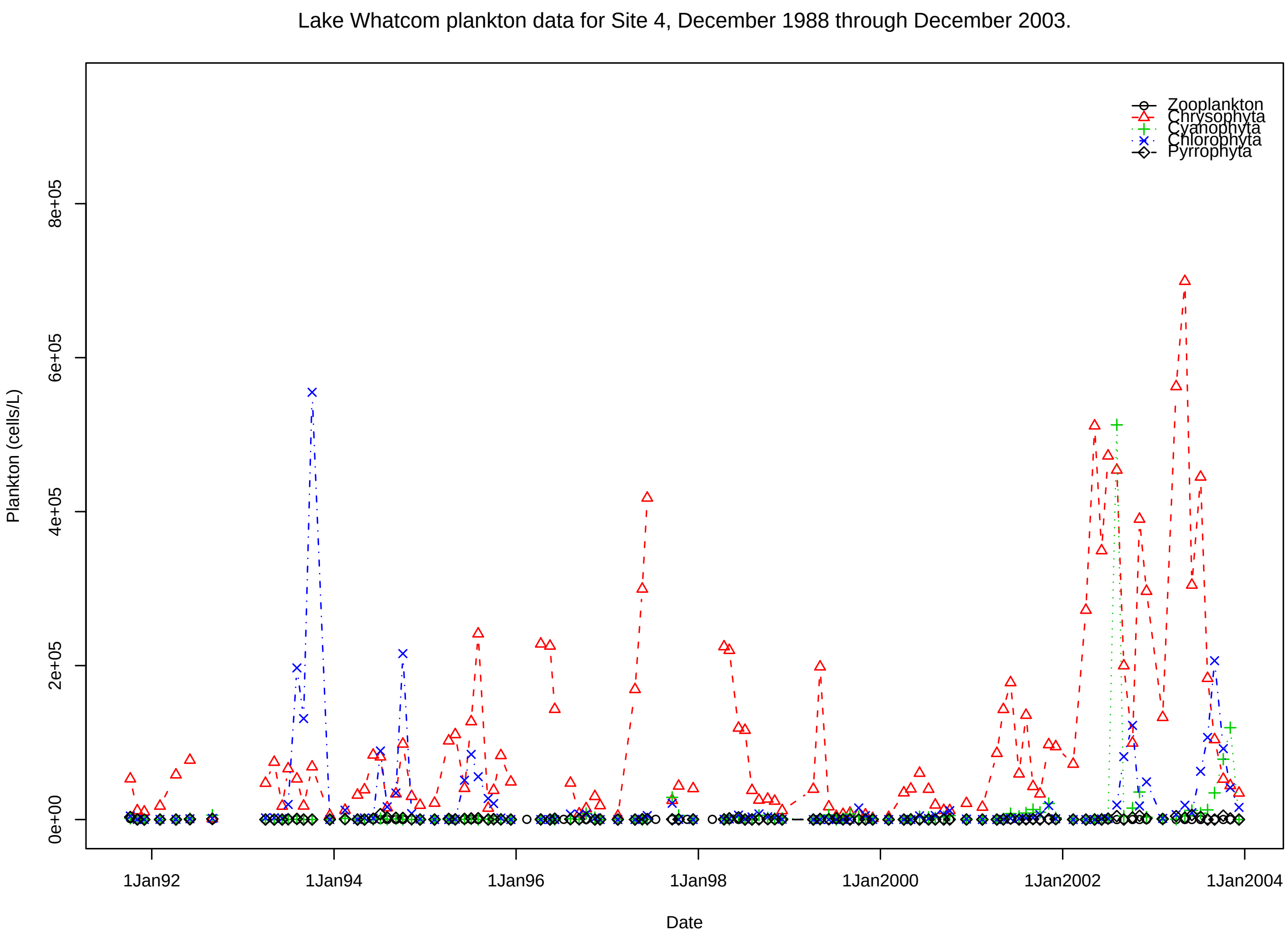


Figure 128: Lake Whatcom plankton data for Site 4 (1988–2003).

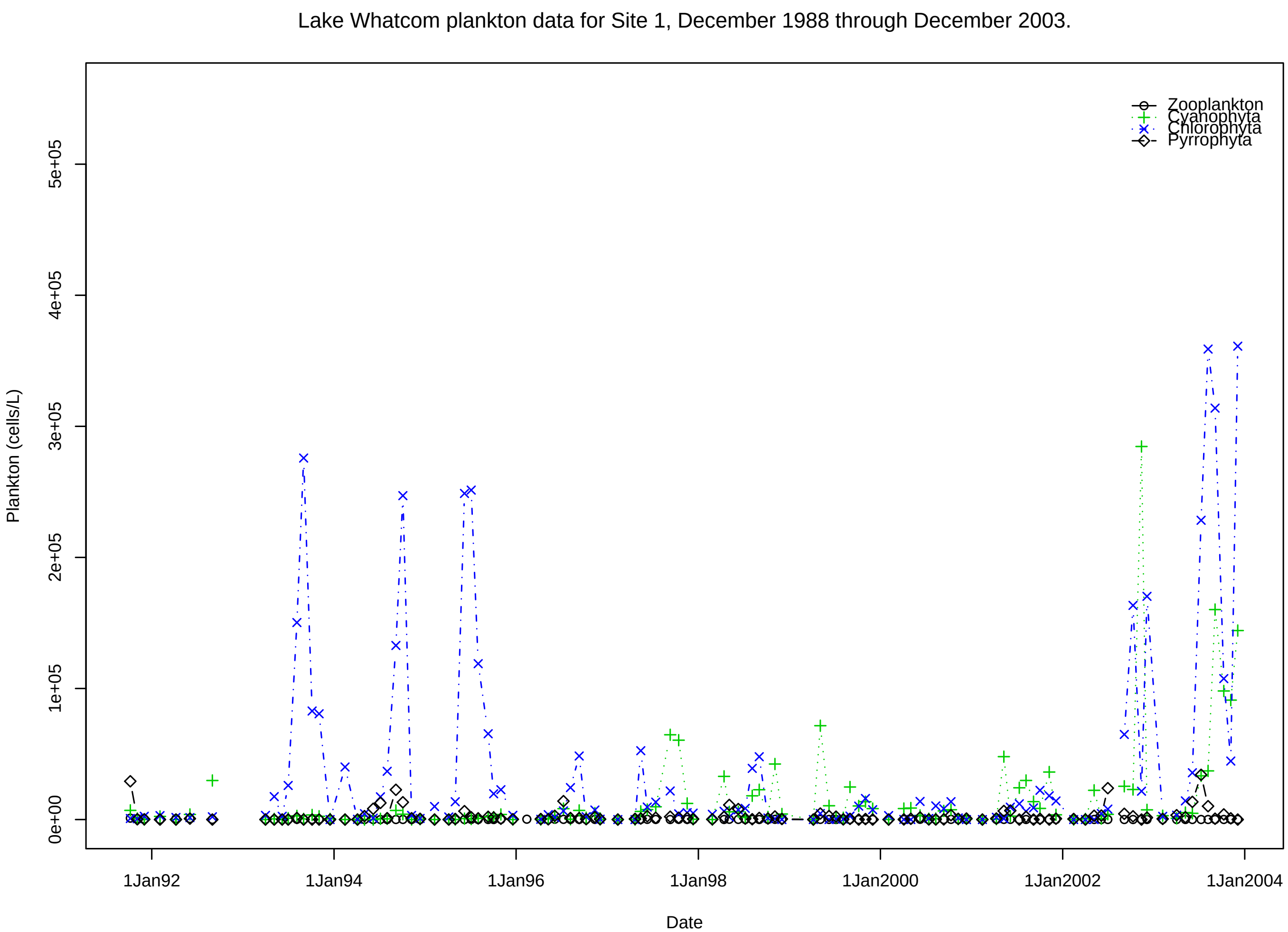


Figure 129: Lake Whatcom plankton data for Site 1, low range plot (1988–2003).

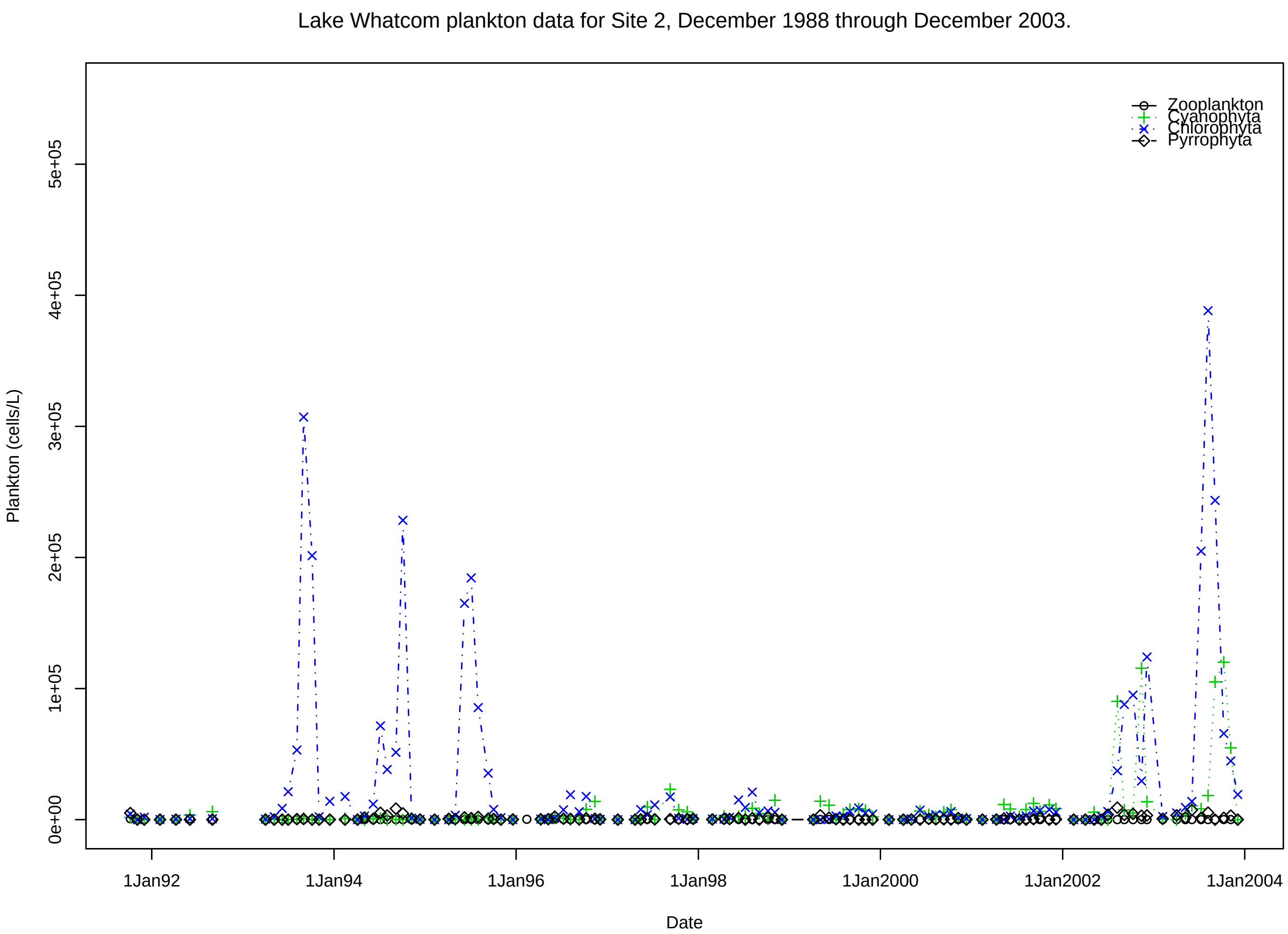


Figure 130: Lake Whatcom plankton data for Site 2, low range plot (1988–2003).

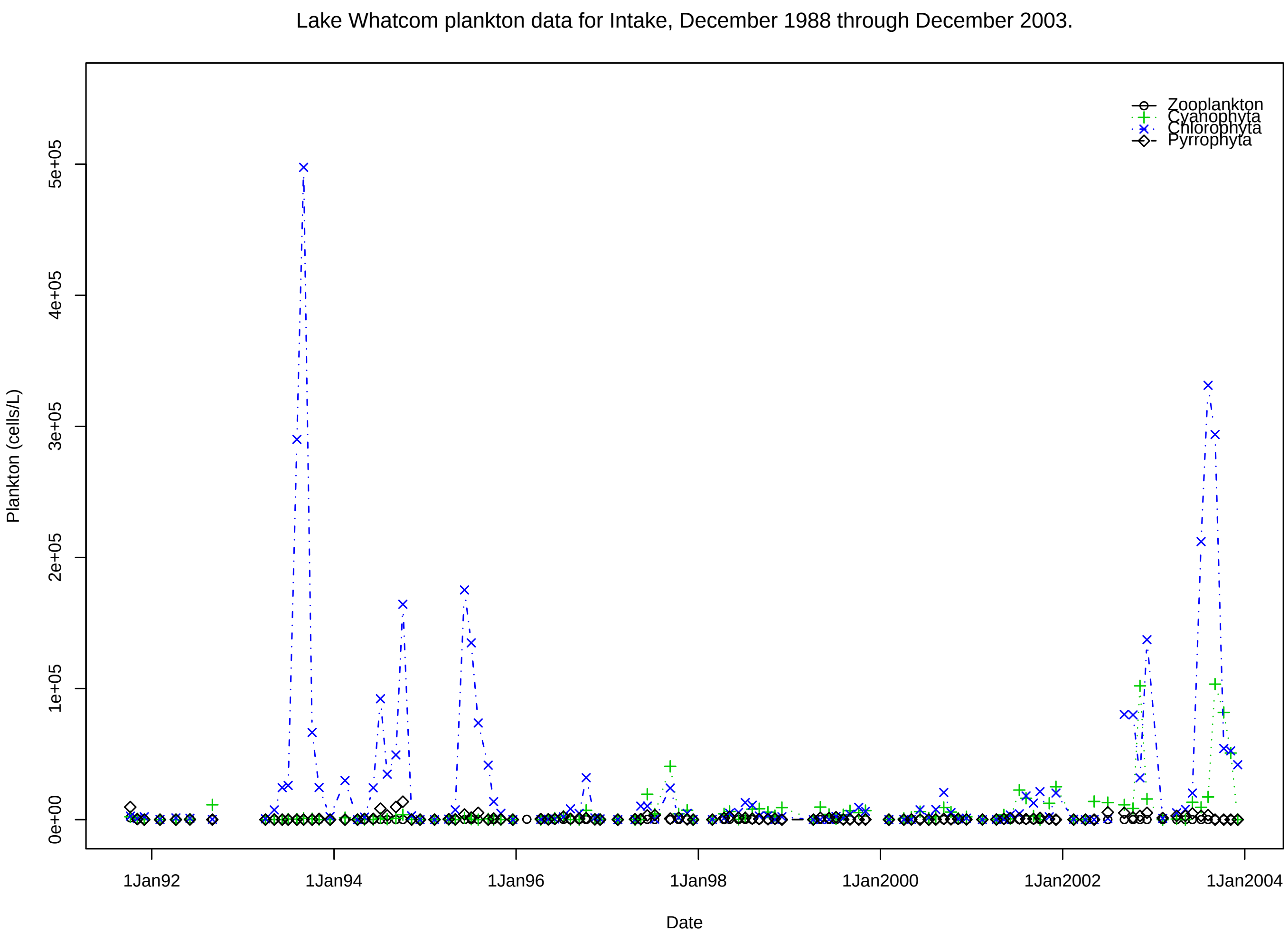


Figure 131: Lake Whatcom plankton data for the Intake, low range plot (1988–2003).

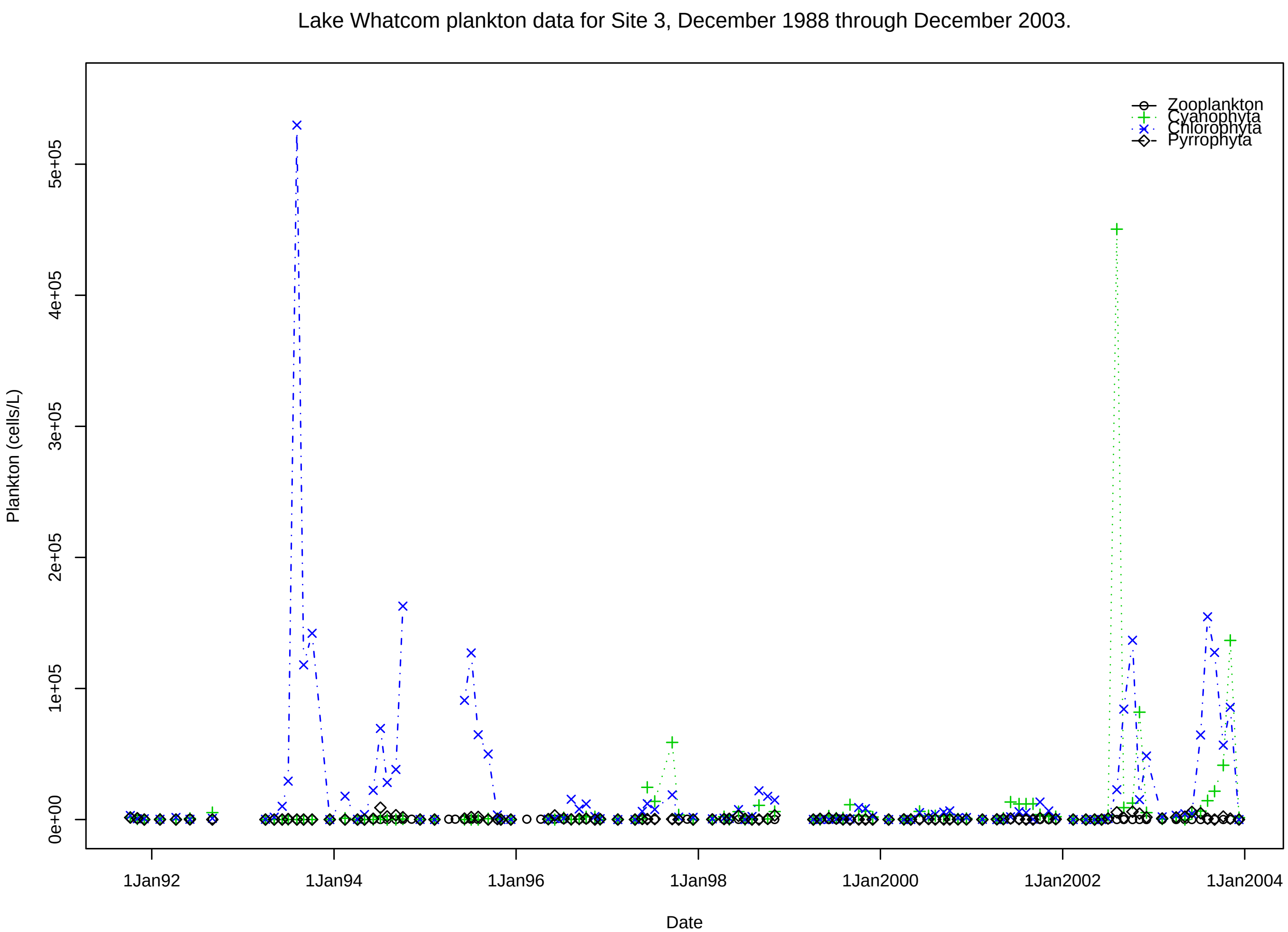


Figure 132: Lake Whatcom plankton data for Site 3, low range plot (1988–2003).

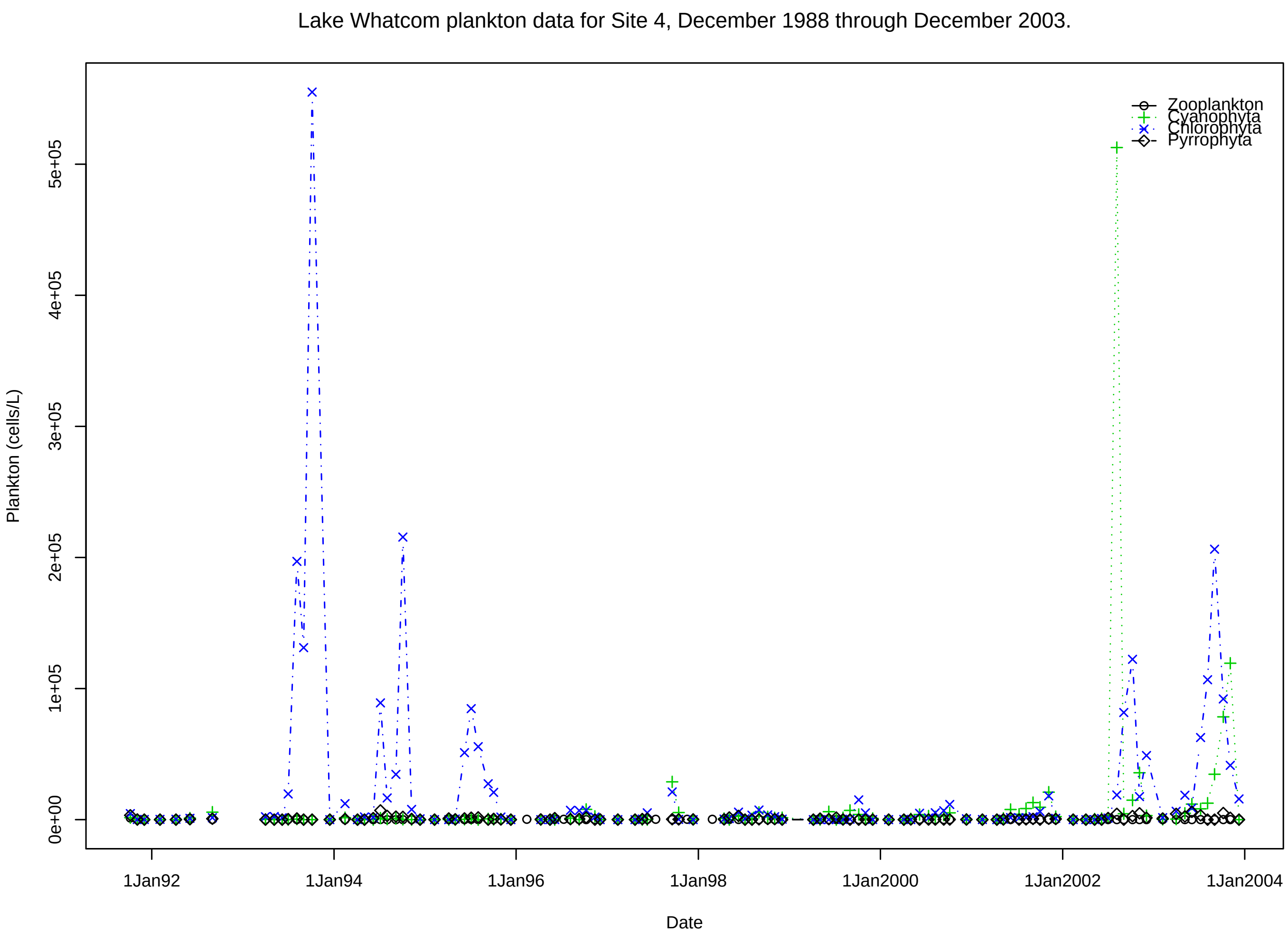


Figure 133: Lake Whatcom plankton data for Site 4, low range plot (1988–2003).

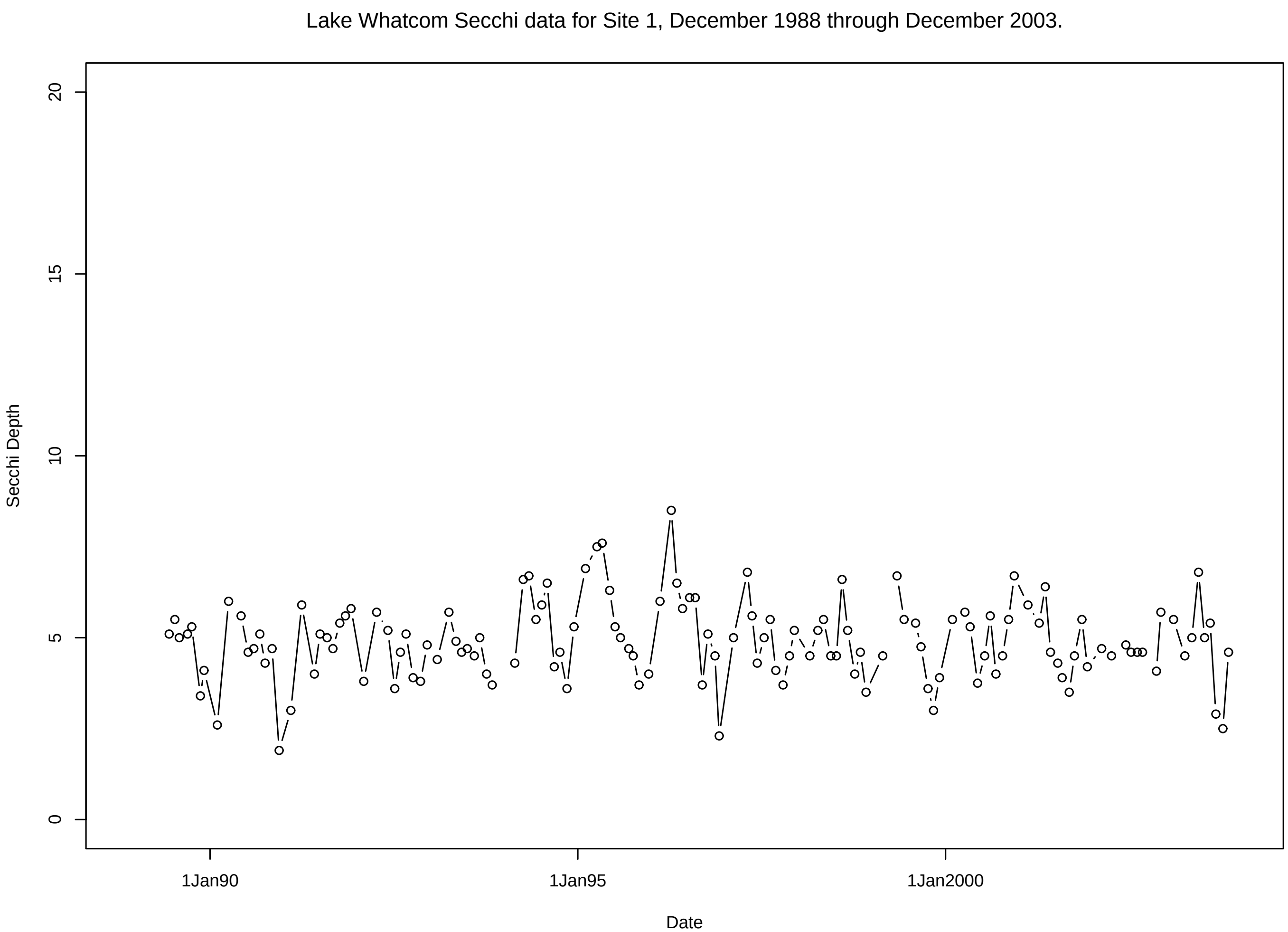


Figure 134: Lake Whatcom Secchi depths for Site 1.

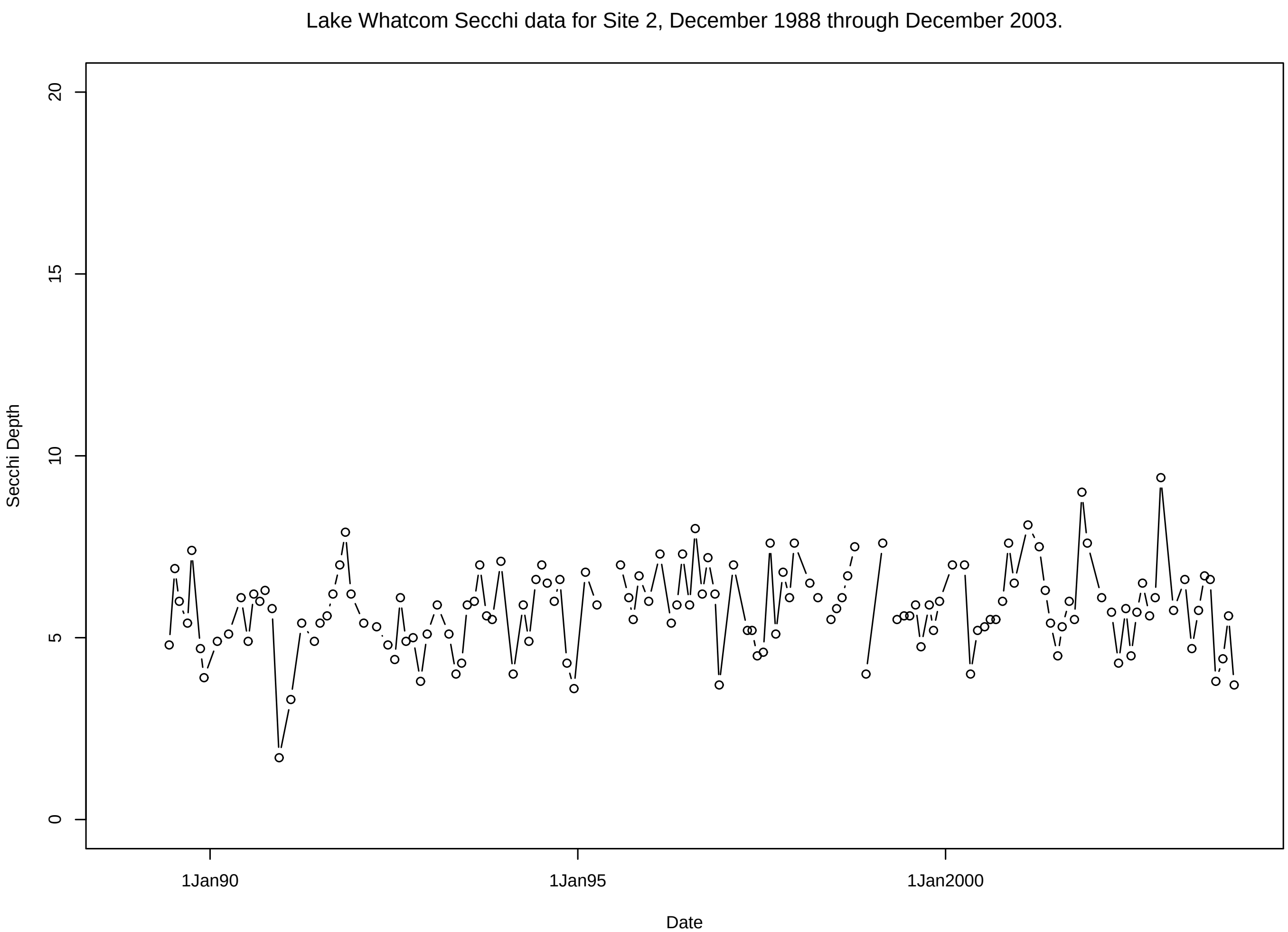


Figure 135: Lake Whatcom Secchi depths for Site 2.

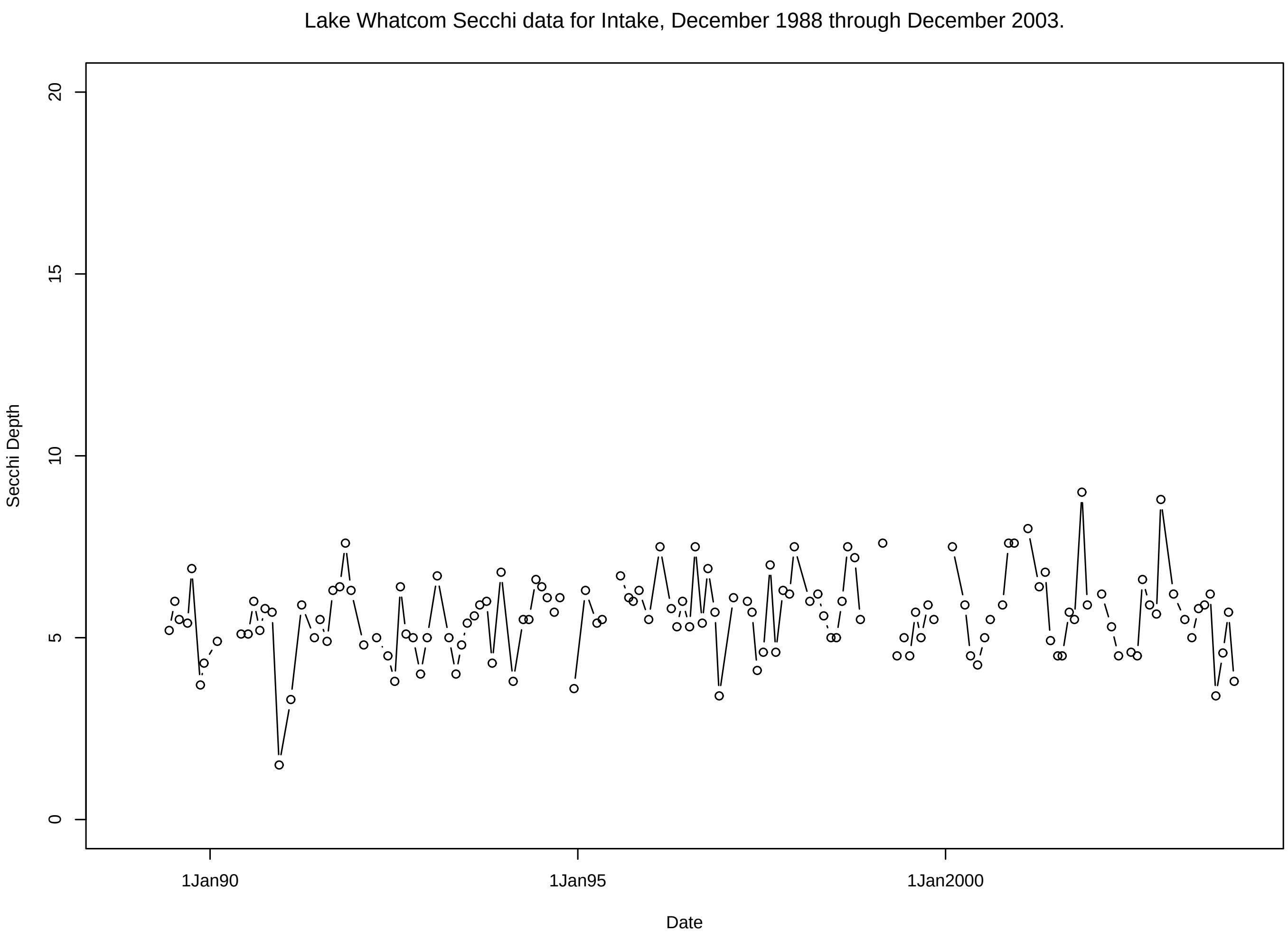


Figure 136: Lake Whatcom Secchi depths for the Intake.

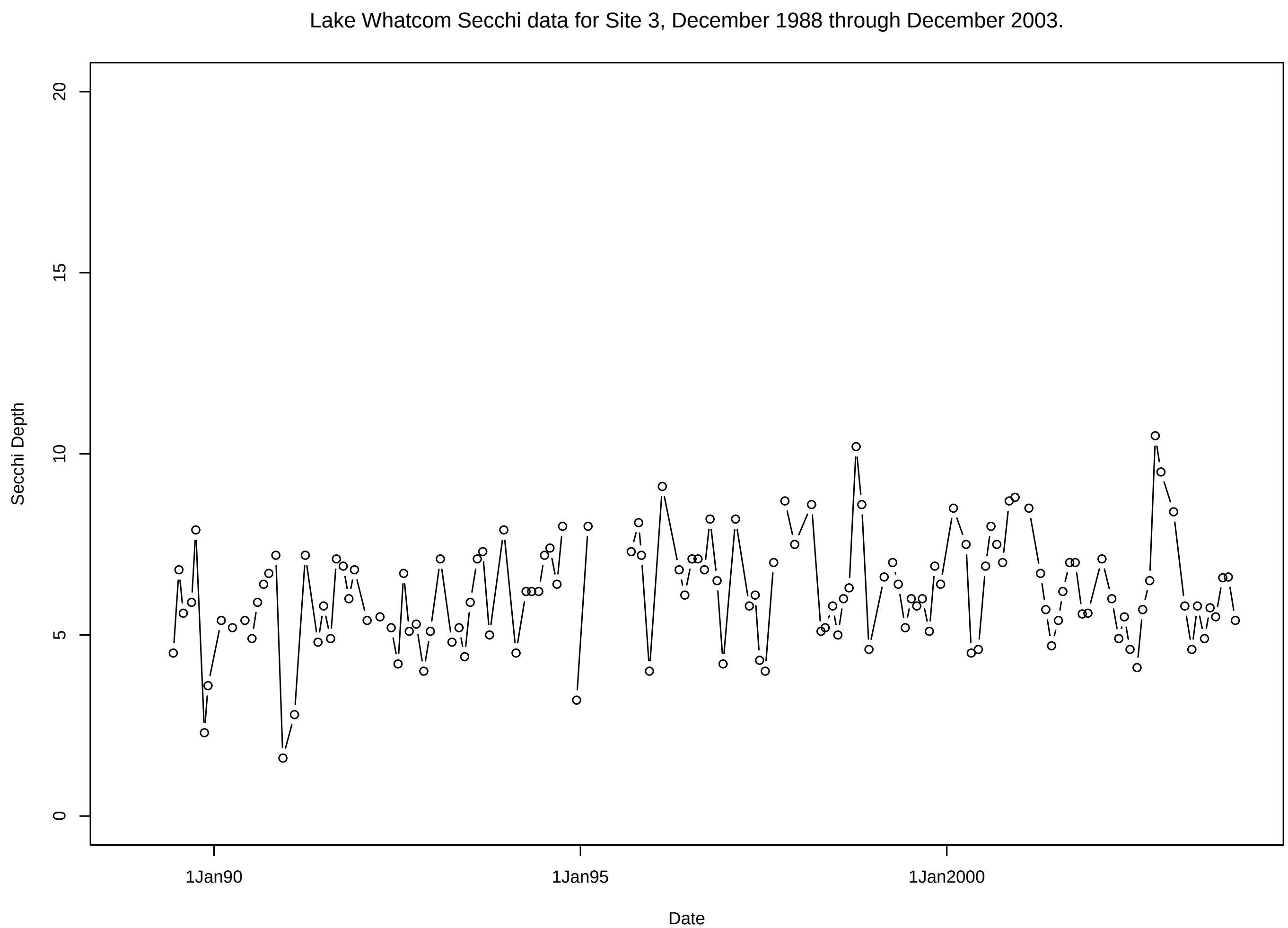


Figure 137: Lake Whatcom Secchi depths for Site 3.

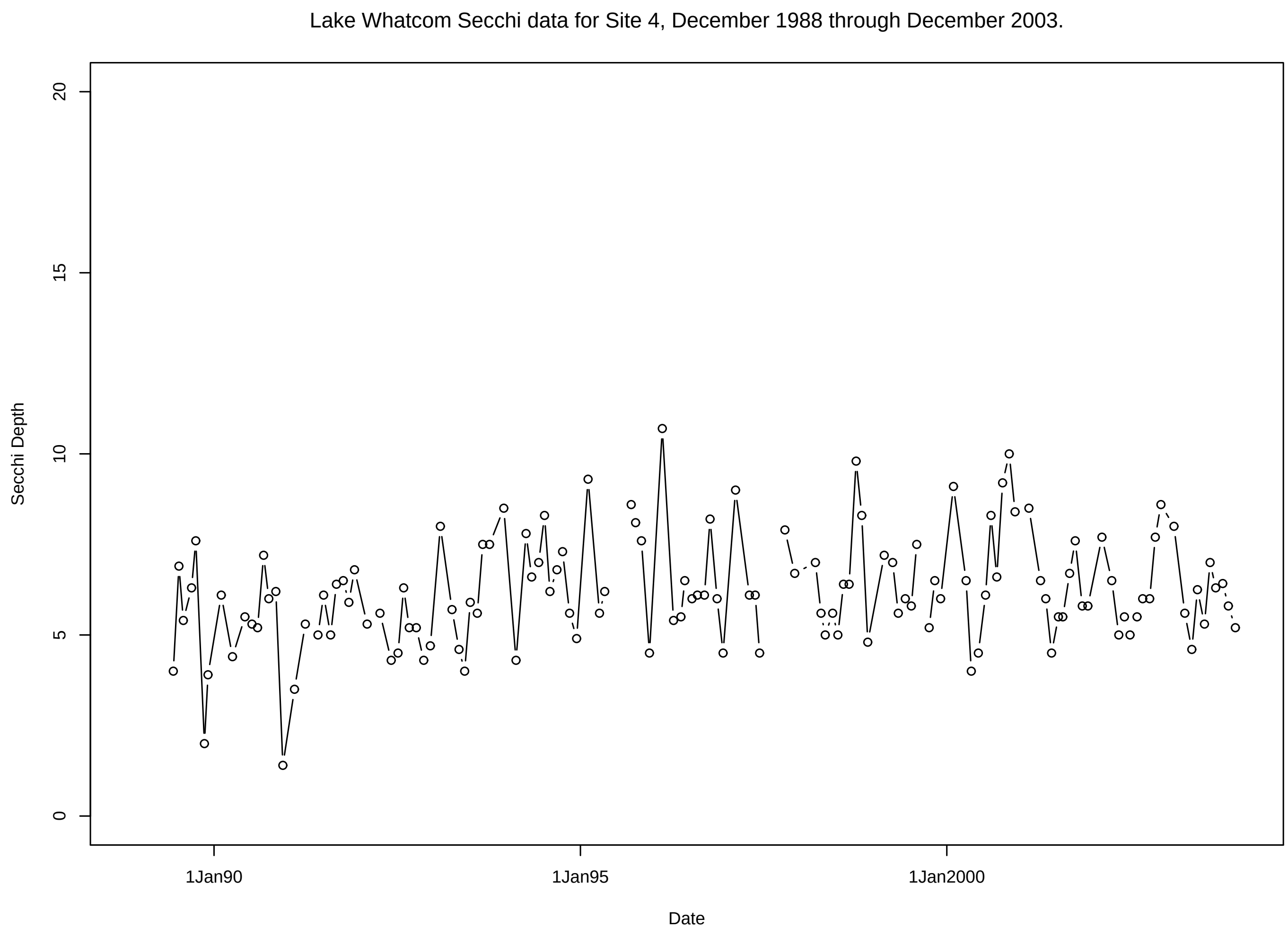


Figure 138: Lake Whatcom Secchi depths for Site 4.

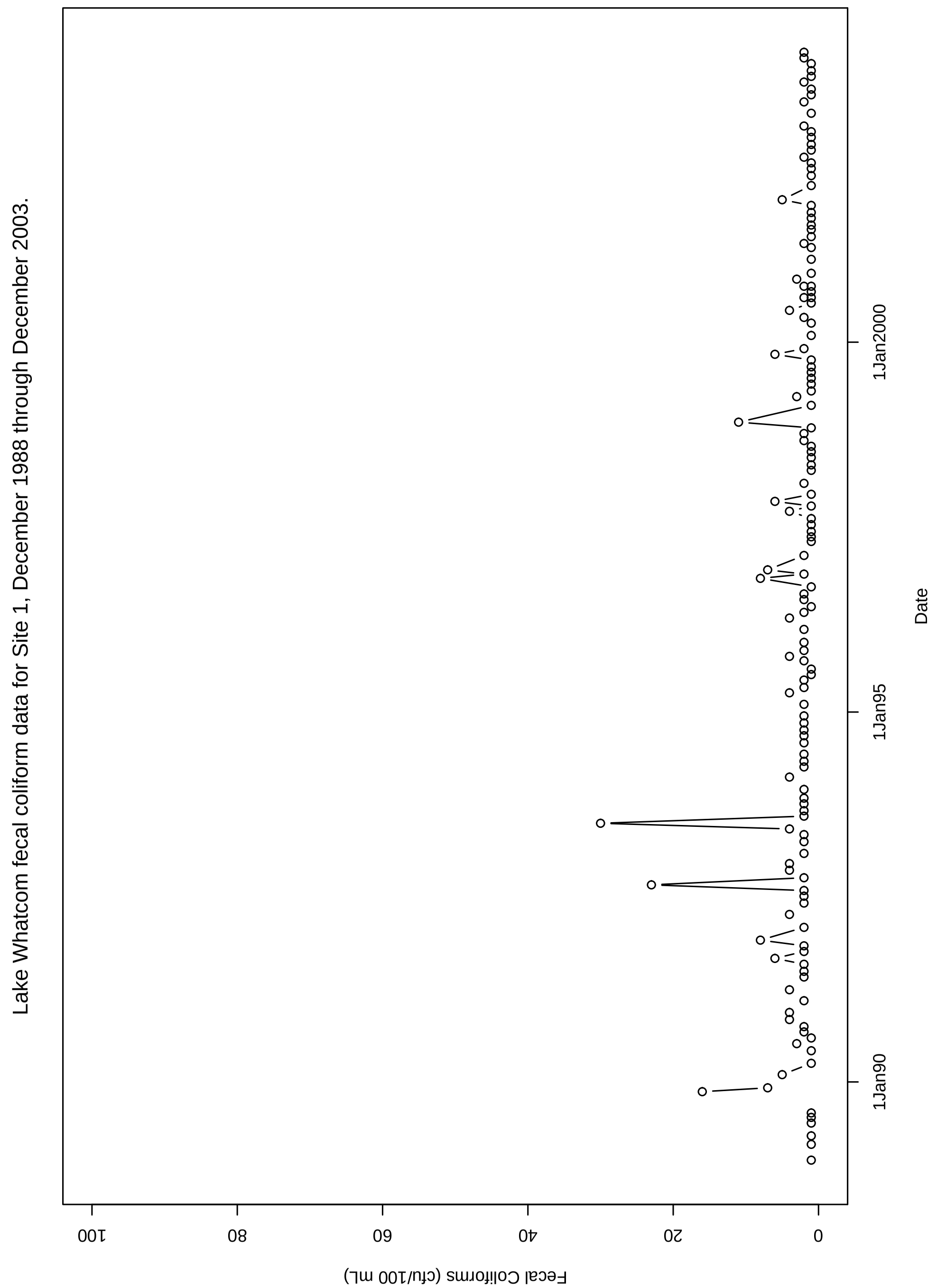


Figure 139: Lake Whatcom fecal coliform data for Site 1 (1988–2003).

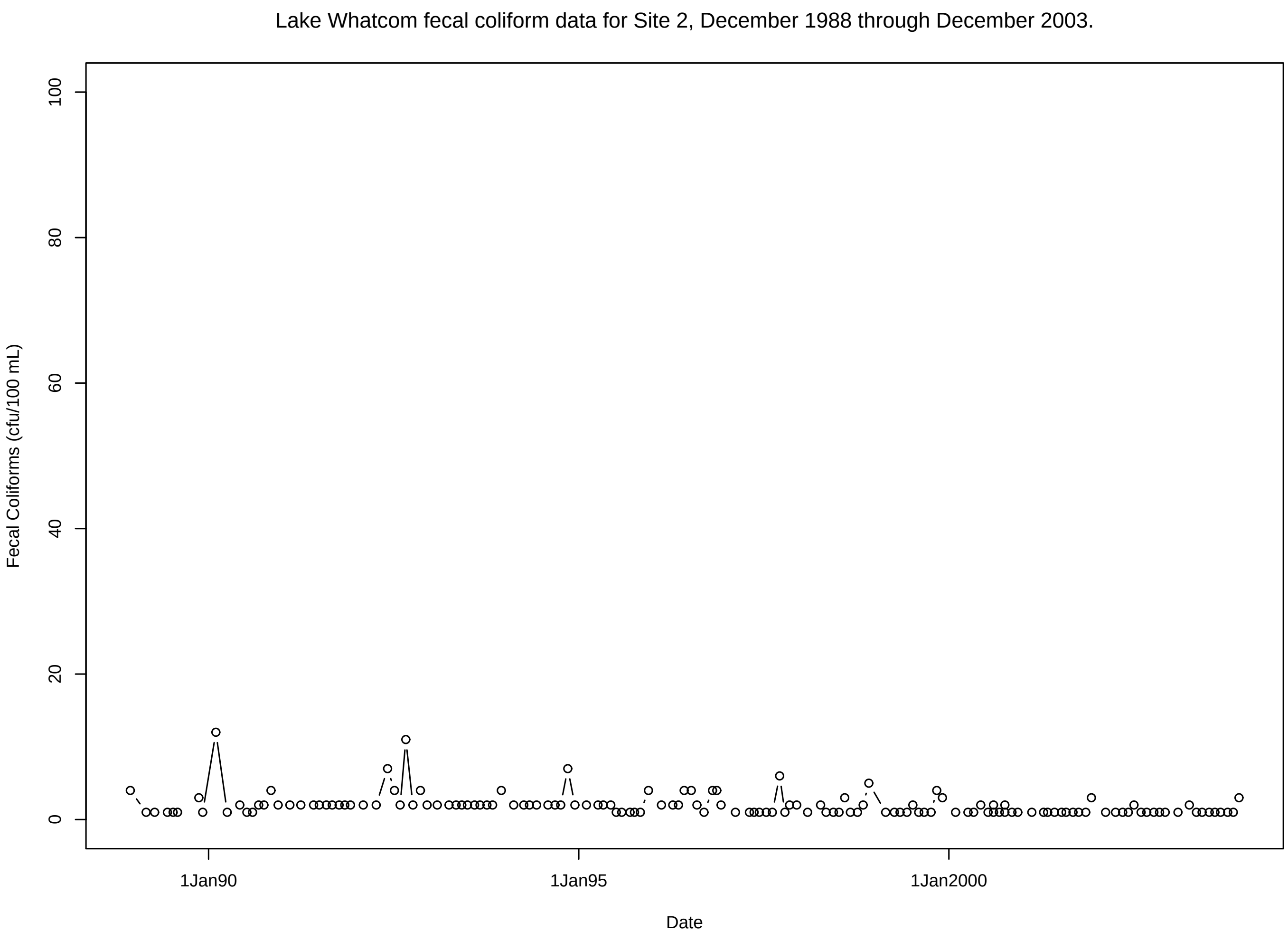


Figure 140: Lake Whatcom fecal coliform data for Site 2 (1988–2003).

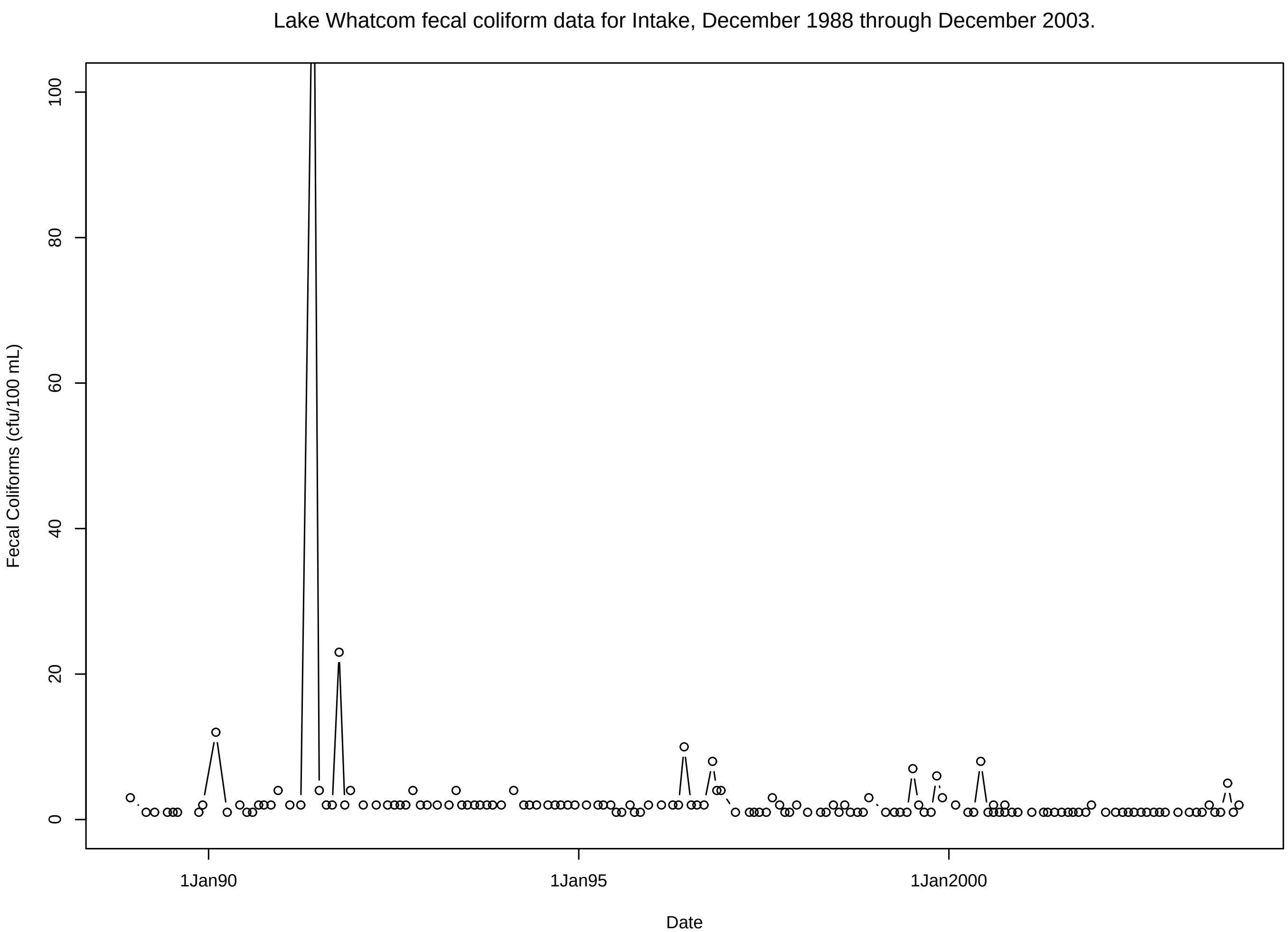


Figure 141: Lake Whatcom fecal coliform data for the Intake (1988–2003).

Lake Whatcom fecal coliform data for Site 3, December 1988 through December 2003.

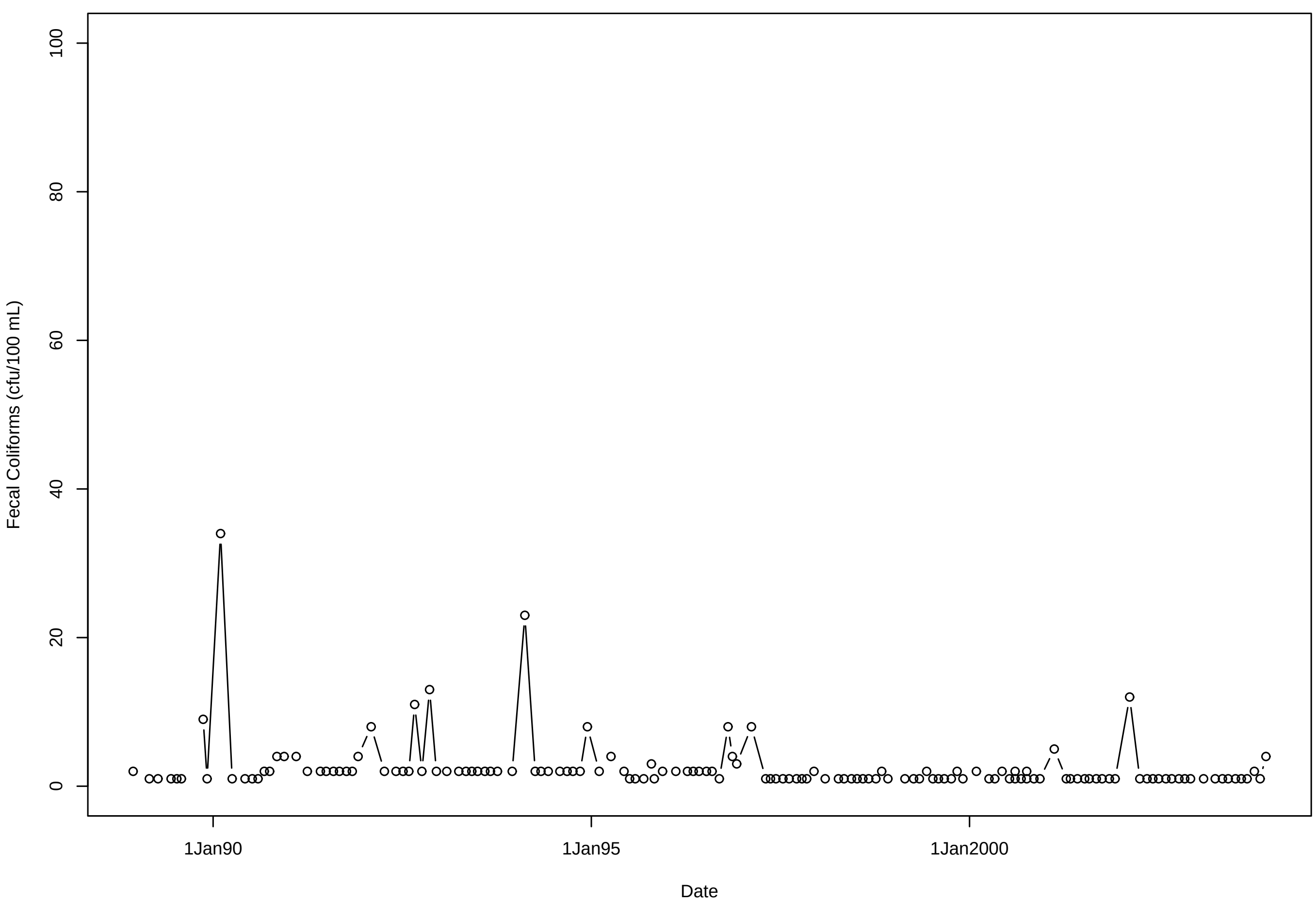


Figure 142: Lake Whatcom fecal coliform data for Site 3 (1988–2003).

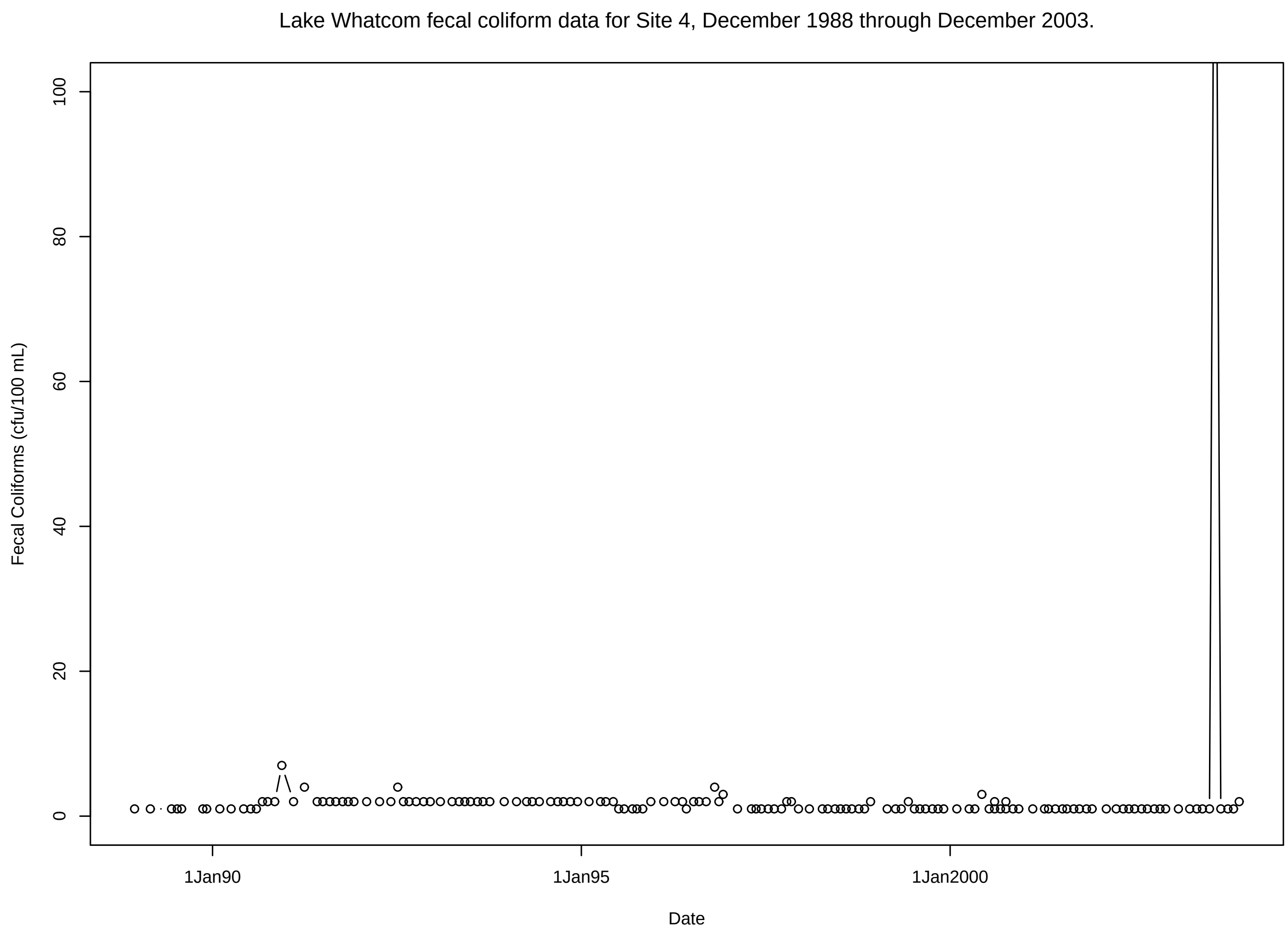


Figure 143: Lake Whatcom fecal coliform data for Site 4 (1988–2003).

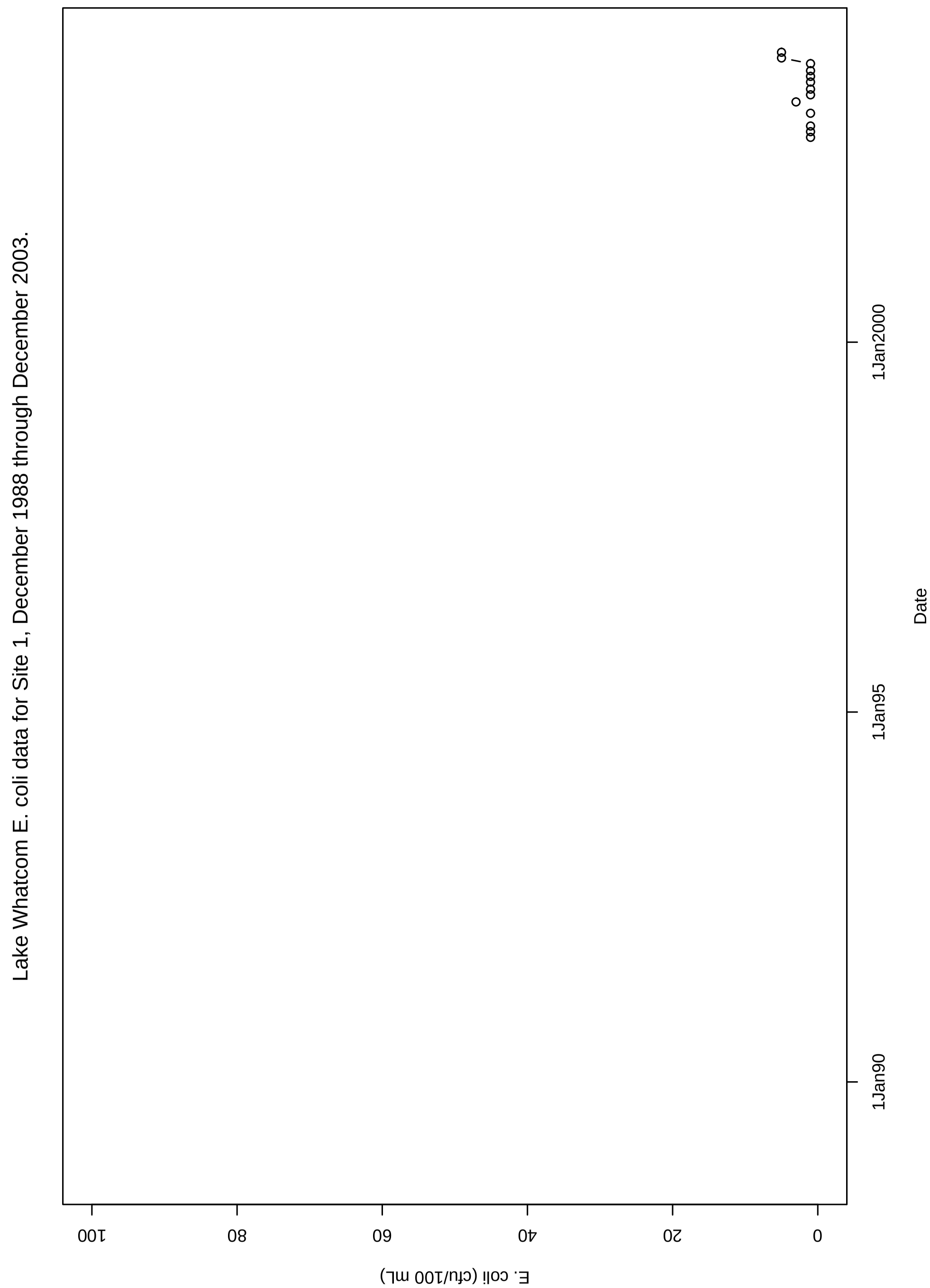


Figure 144: Lake Whatcom *E. coli* data for Site 1. Data collection started in October 2002.

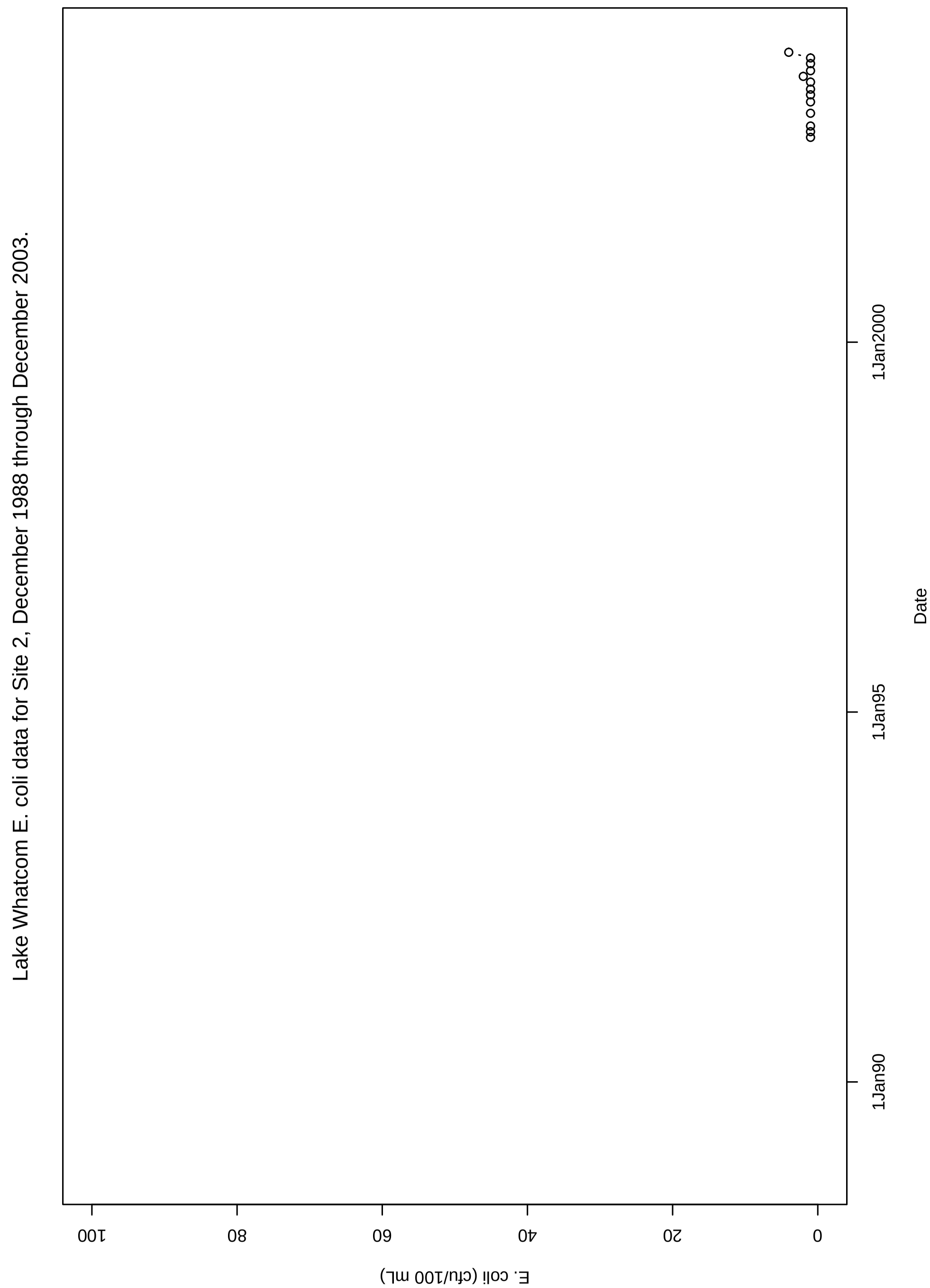


Figure 145: Lake Whatcom *E. coli* data for Site 2. Data collection started in October 2002.

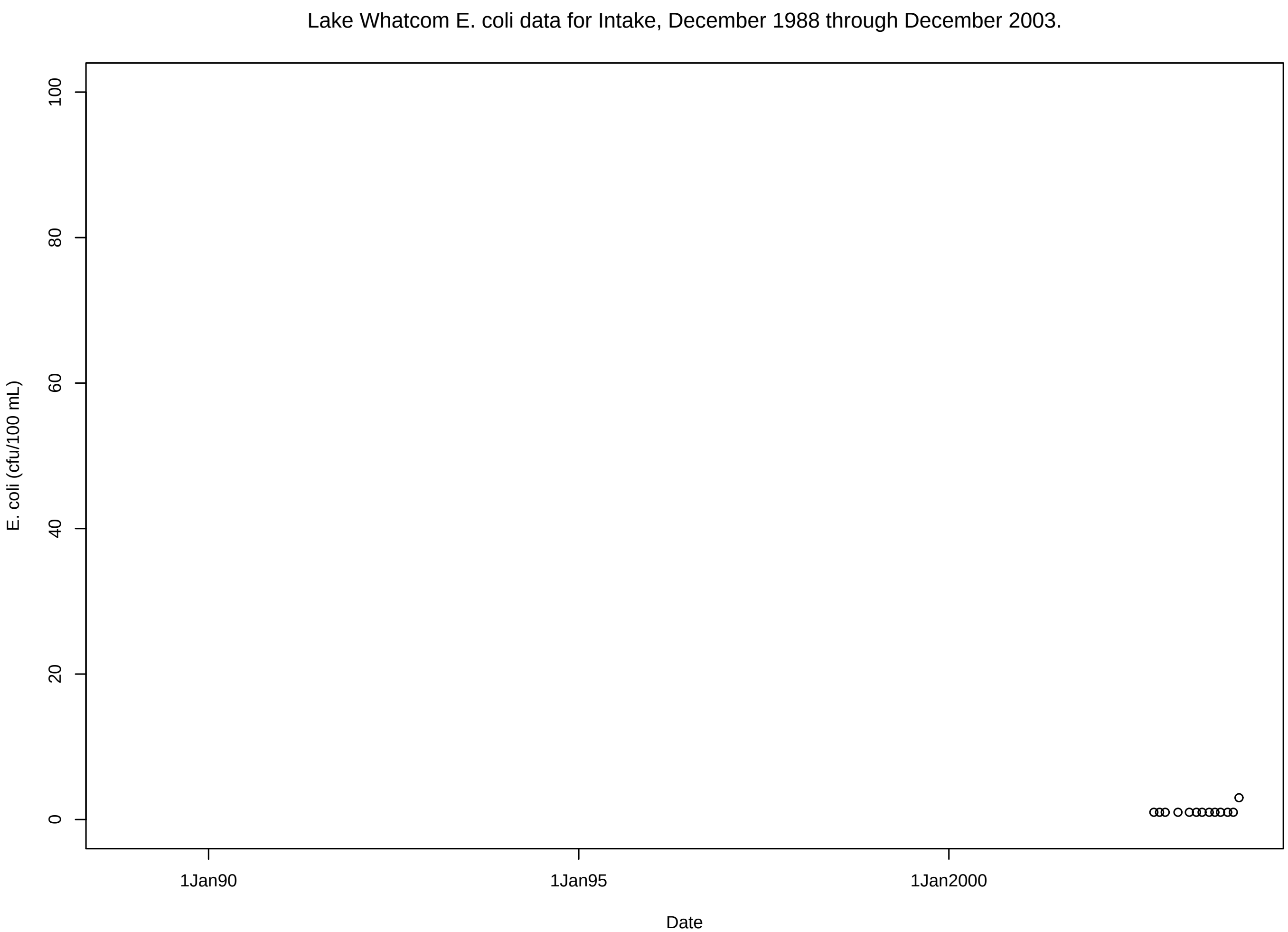


Figure 146: Lake Whatcom *E. coli* data for the Intake. Data collection started in October 2002.

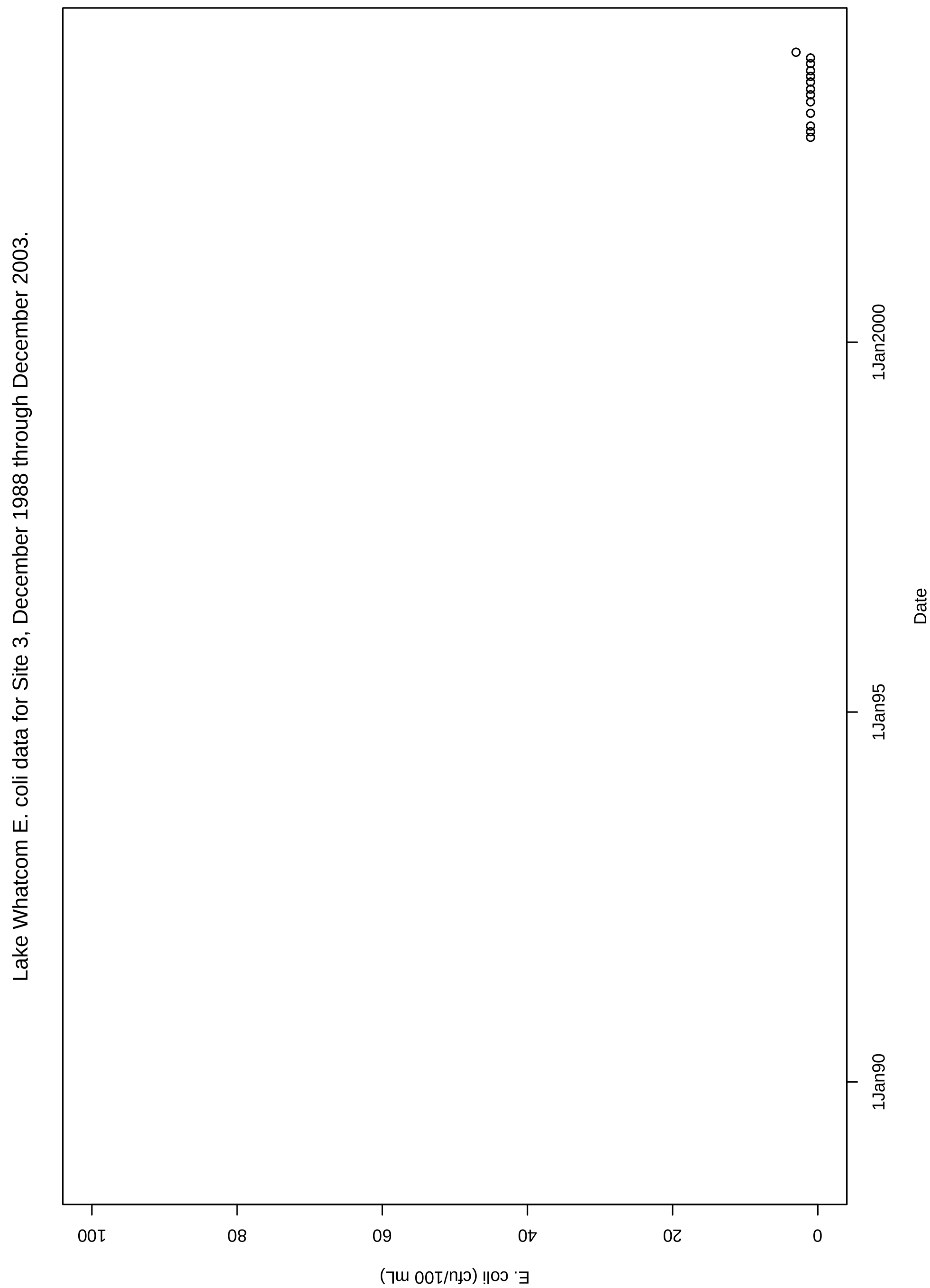


Figure 147: Lake Whatcom *E. coli* data for Site 3. Data collection started in October 2002.

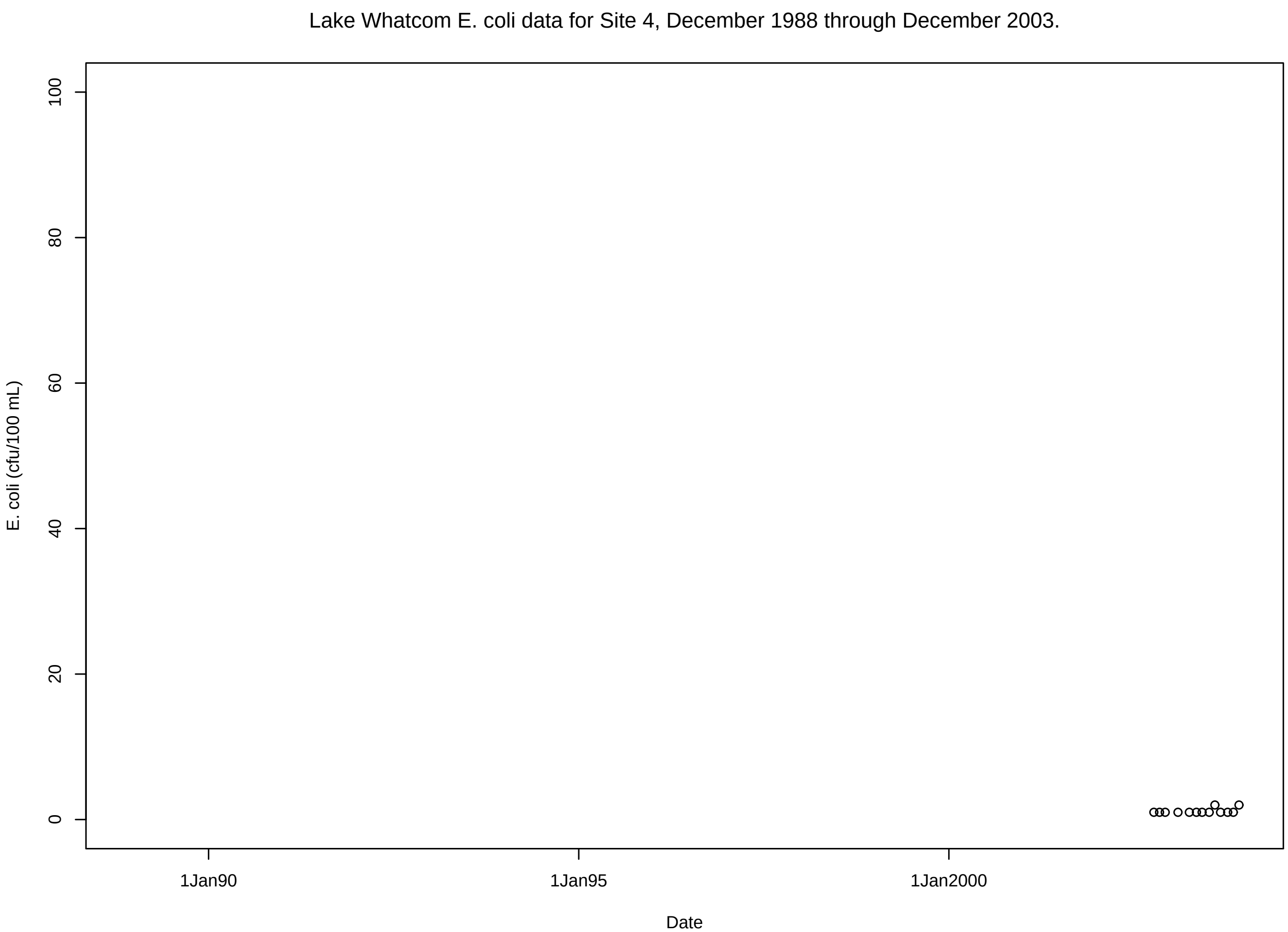


Figure 148: Lake Whatcom *E. coli* for Site 4. Data collection started in October 2002.

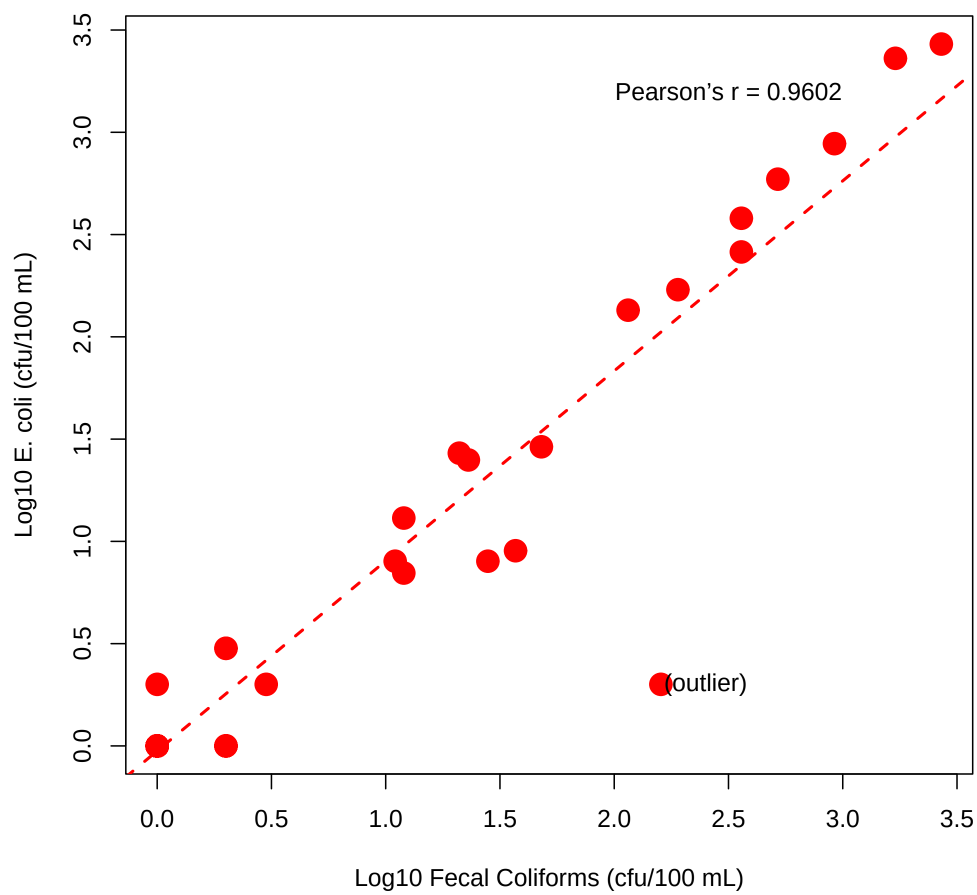


Figure 149: Correlation between fecal coliforms and *E. coli* counts in surface water samples (lake and streams) in the Lake Whatcom watershed, October 2002–September 2003. Pearson's r correlation analysis was used because the log-transformed data were monotonic-linear and the regression residuals were homogeneous. Diagonal line was added to show 1:1 correlation, and does not represent a linear regression model of the data.

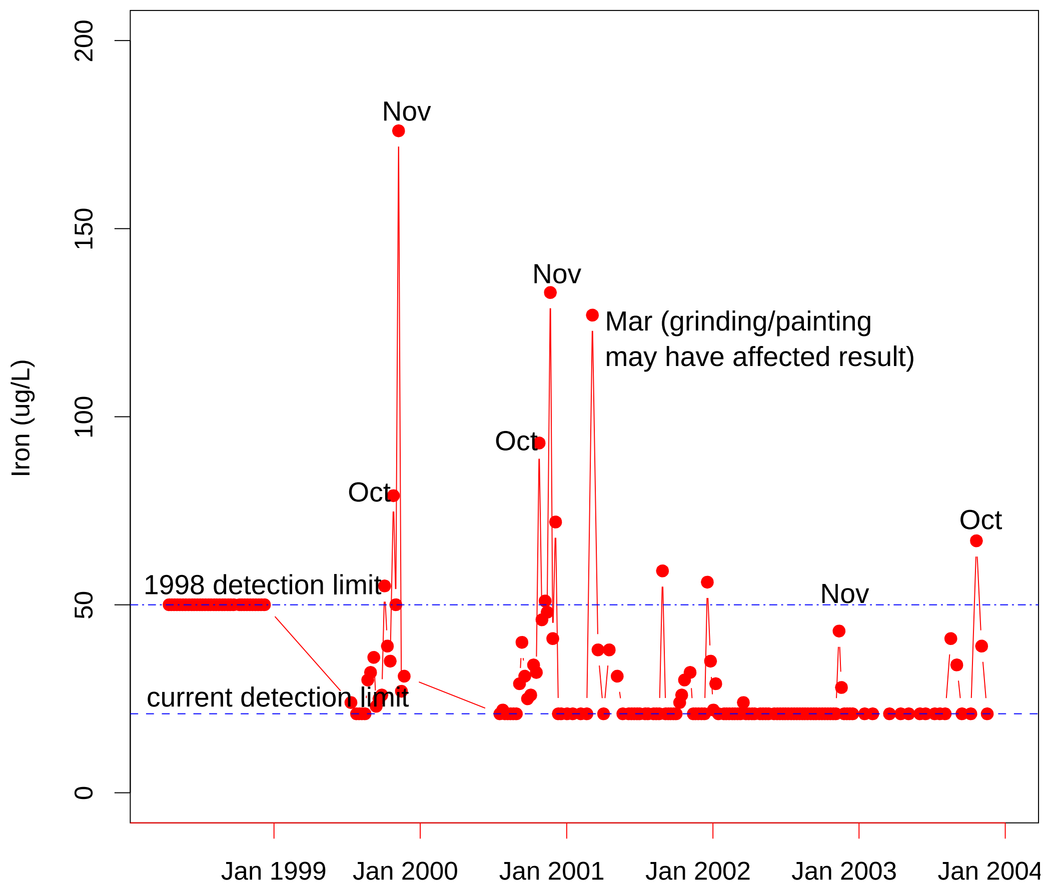


Figure 150: Iron concentration in untreated drinking water measured at the Lake Whatcom gatehouse, 1998–2003. Data were provided by the City of Bellingham Public Works Department.

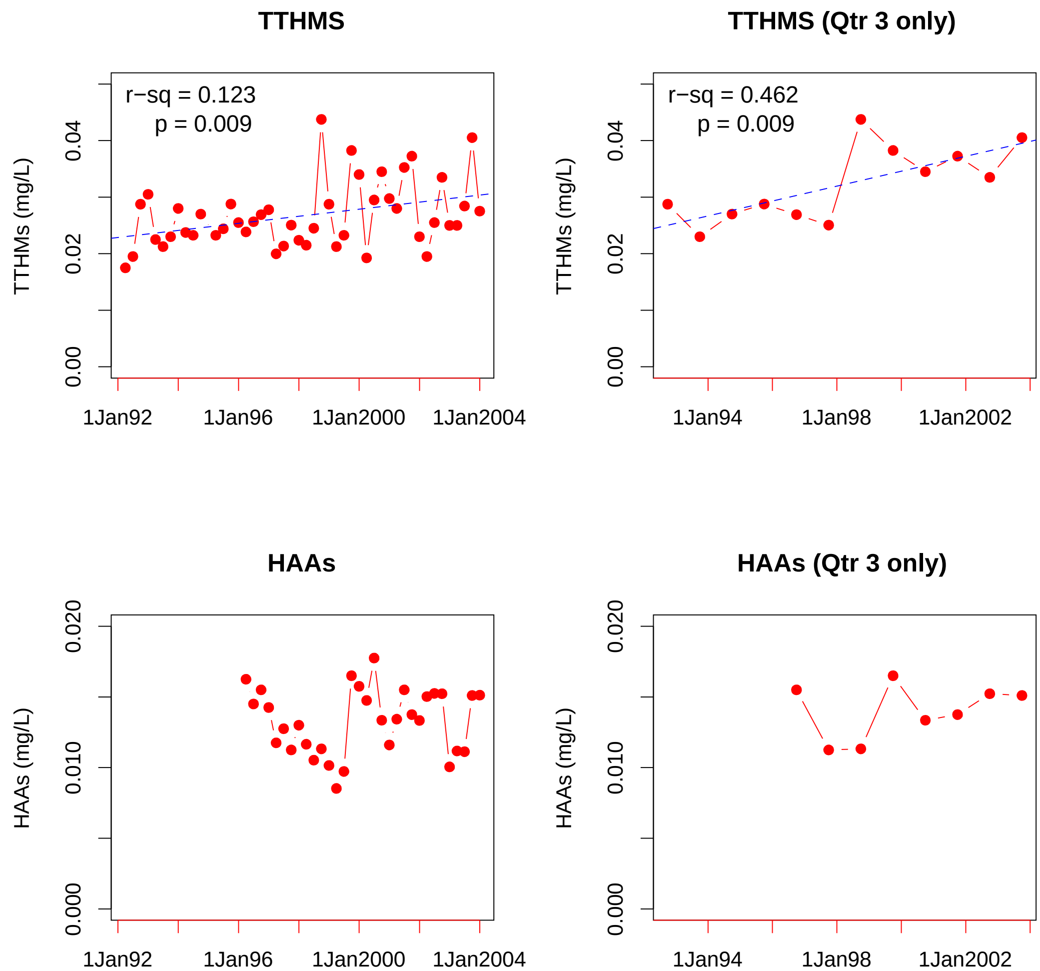
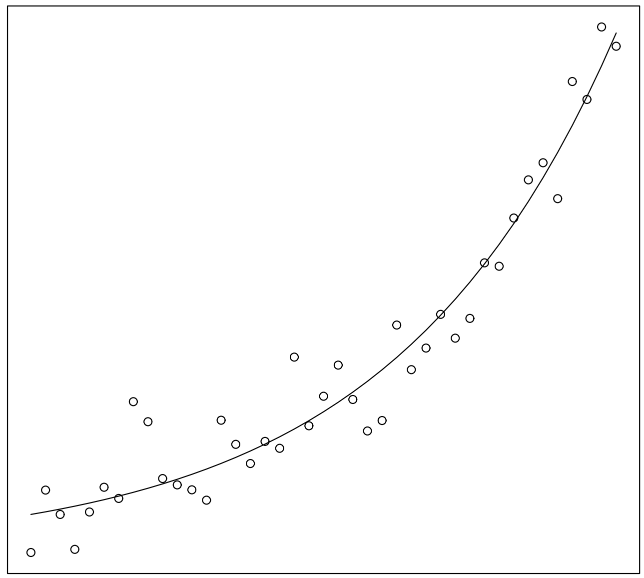
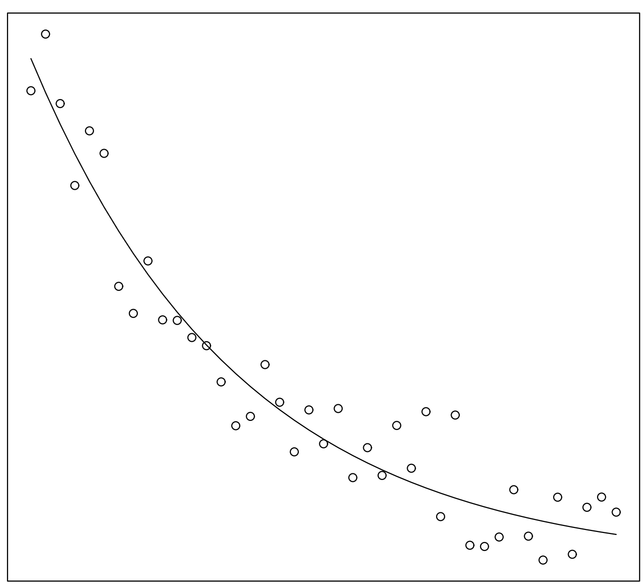


Figure 151: Total trihalomethanes (TTHMs) and haloacetic acids (HAA5) concentrations in the Bellingham water distribution system, 1992–2003 (fall). Linear regression for TTHMs (Qtr 3) vs. time was statistically significant. Data were provided by the City of Bellingham Public Works Department.



Exponential growth



Exponential decay

Figure 152: Two synthetic data sets with exponential means and constant variance fitted with a Gaussian generalized linear model with `log` link function. We used this model to fit curves to the 1988–2003 hypolimnetic dissolved oxygen data.

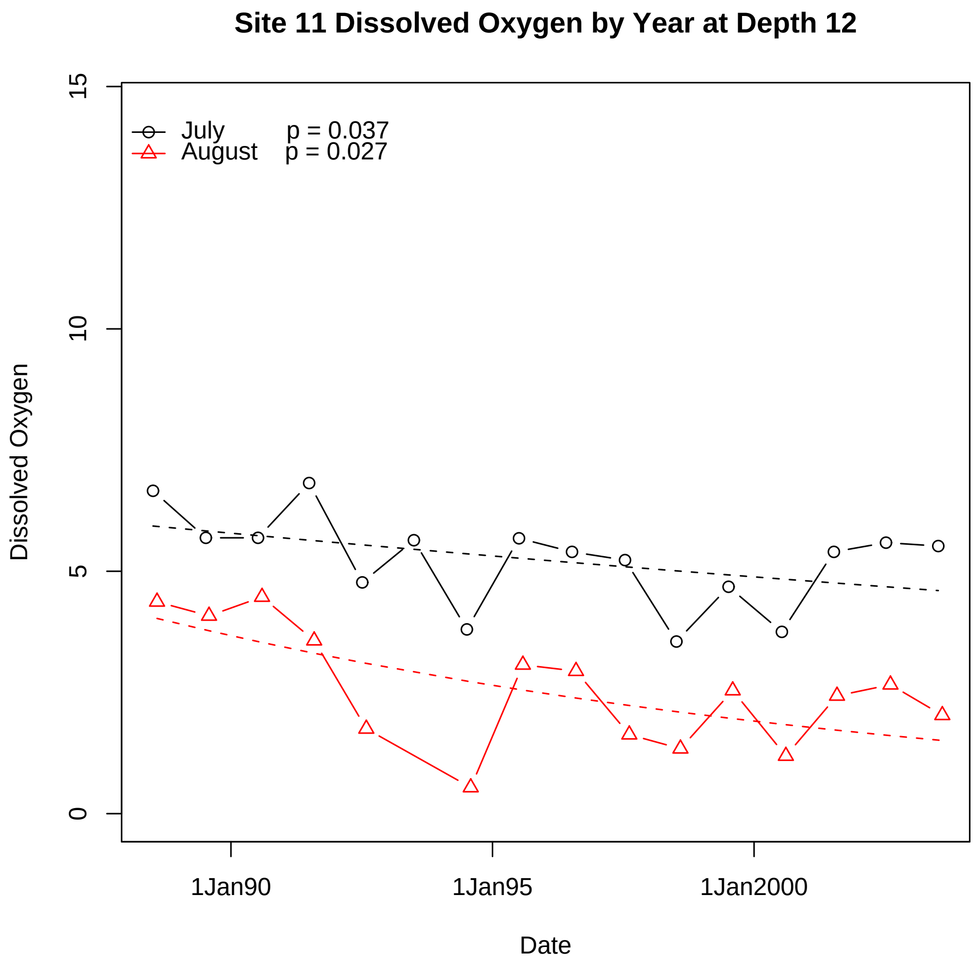


Figure 153: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 12 m. All Kendall's τ nonparametric correlations are significant ($p < 0.05$).

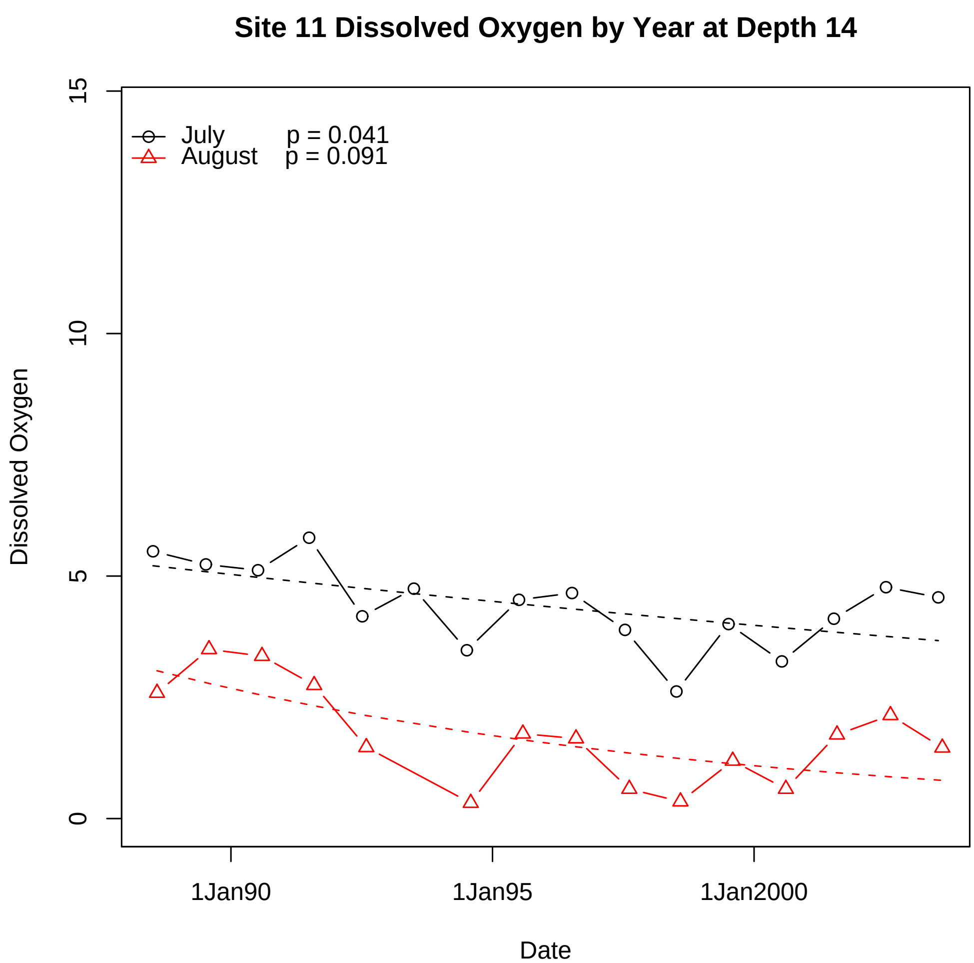


Figure 154: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ nonparametric correlation for July is significant at $p < 0.05$; August is significant at $p < 0.10$.

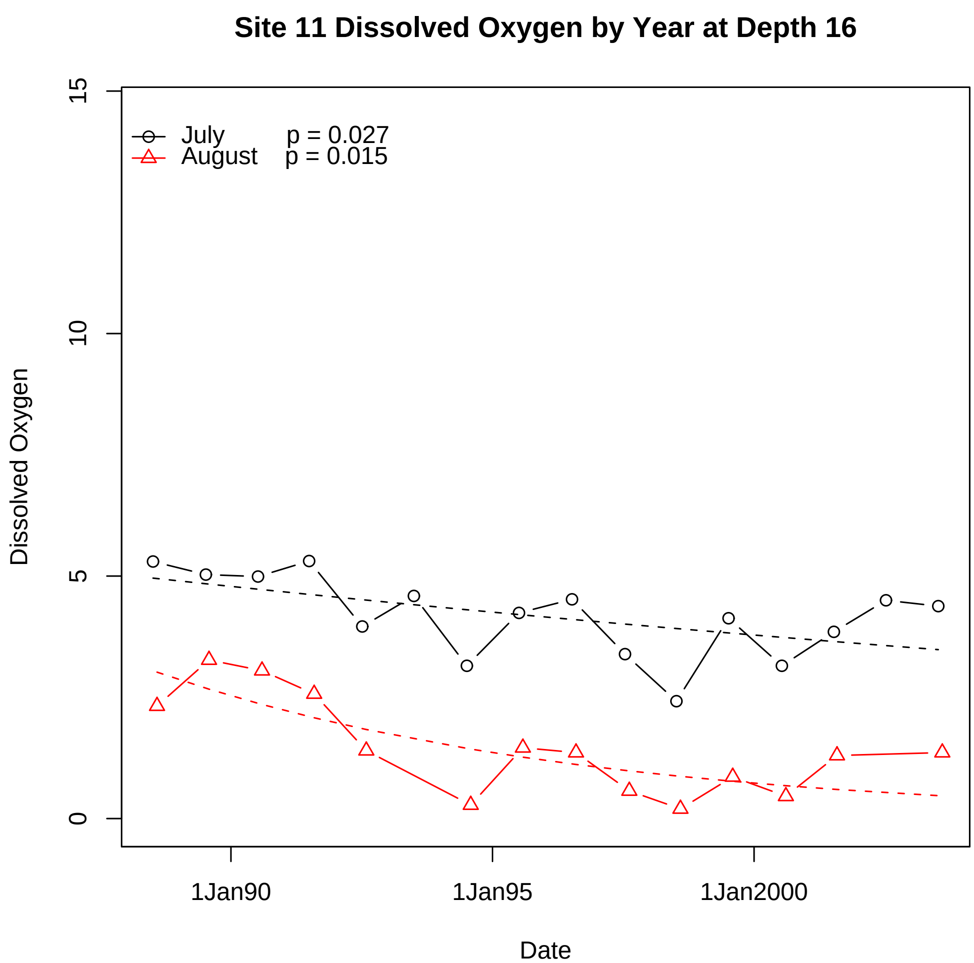


Figure 155: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 16 m. All Kendall's τ nonparametric correlations are significant ($p < 0.05$).

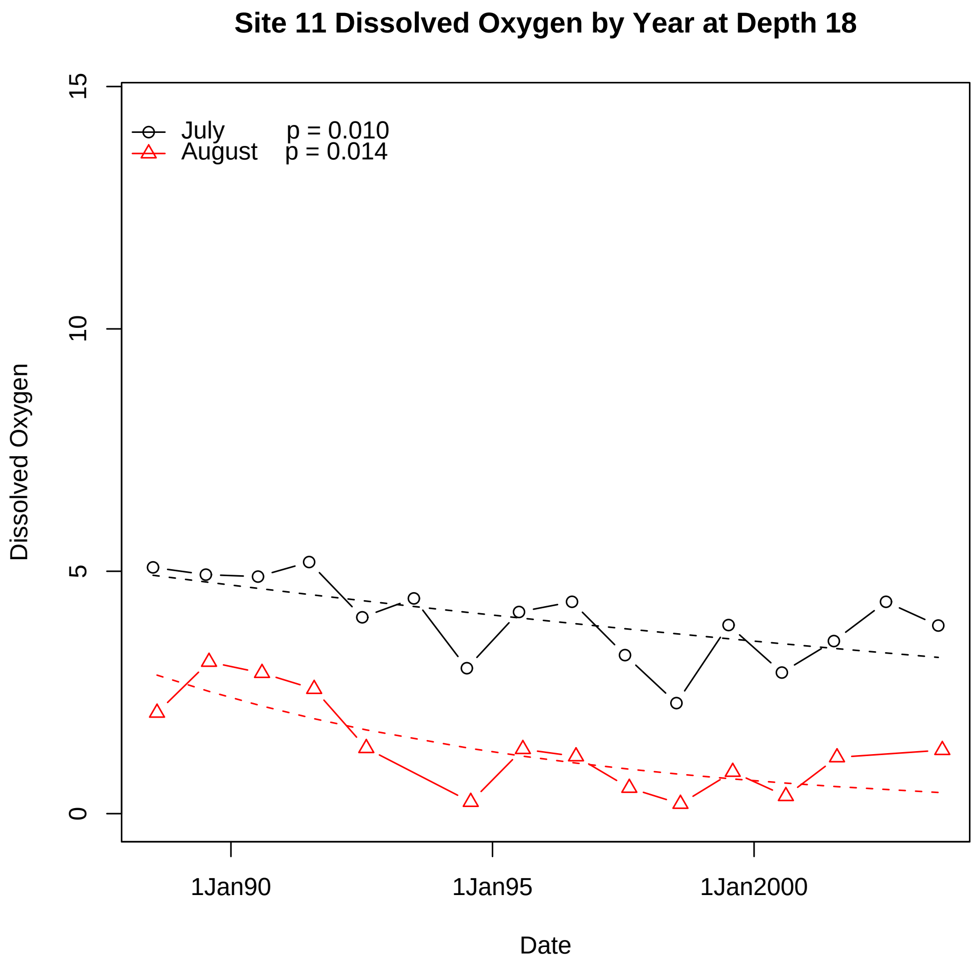


Figure 156: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 18 m. All Kendall's τ nonparametric correlations are significant ($p < 0.05$).

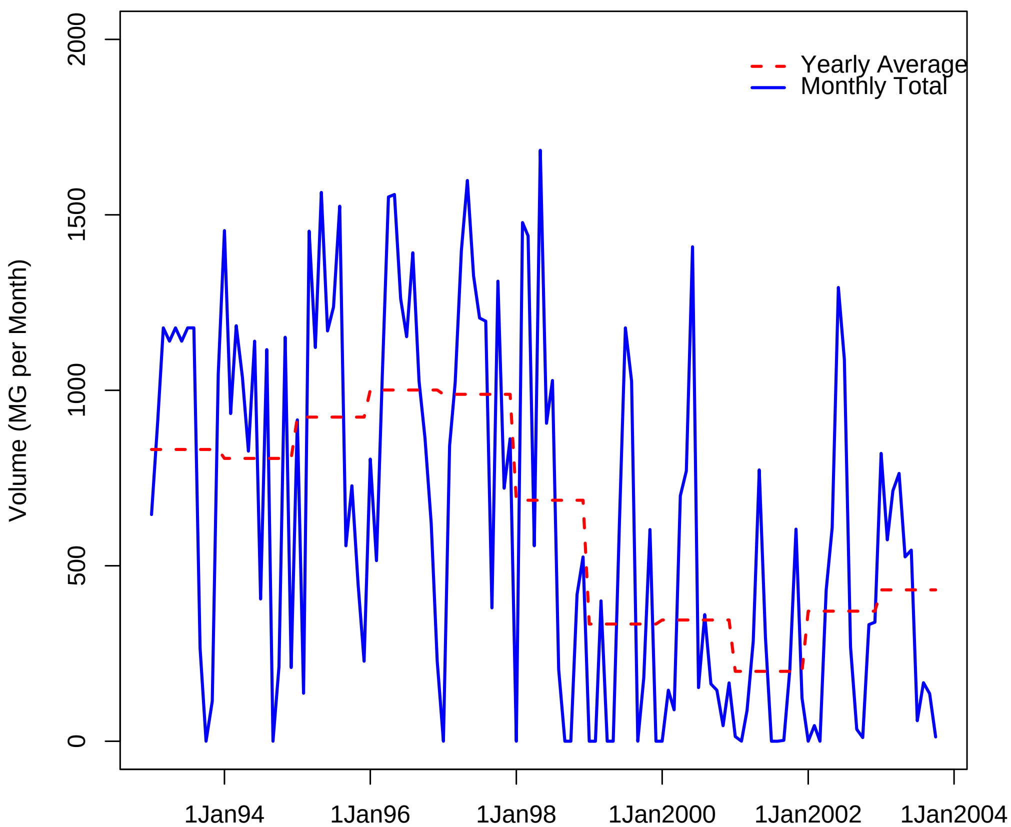


Figure 157: Middle Fork diversion flow into Lake Whatcom, 1993–2003.

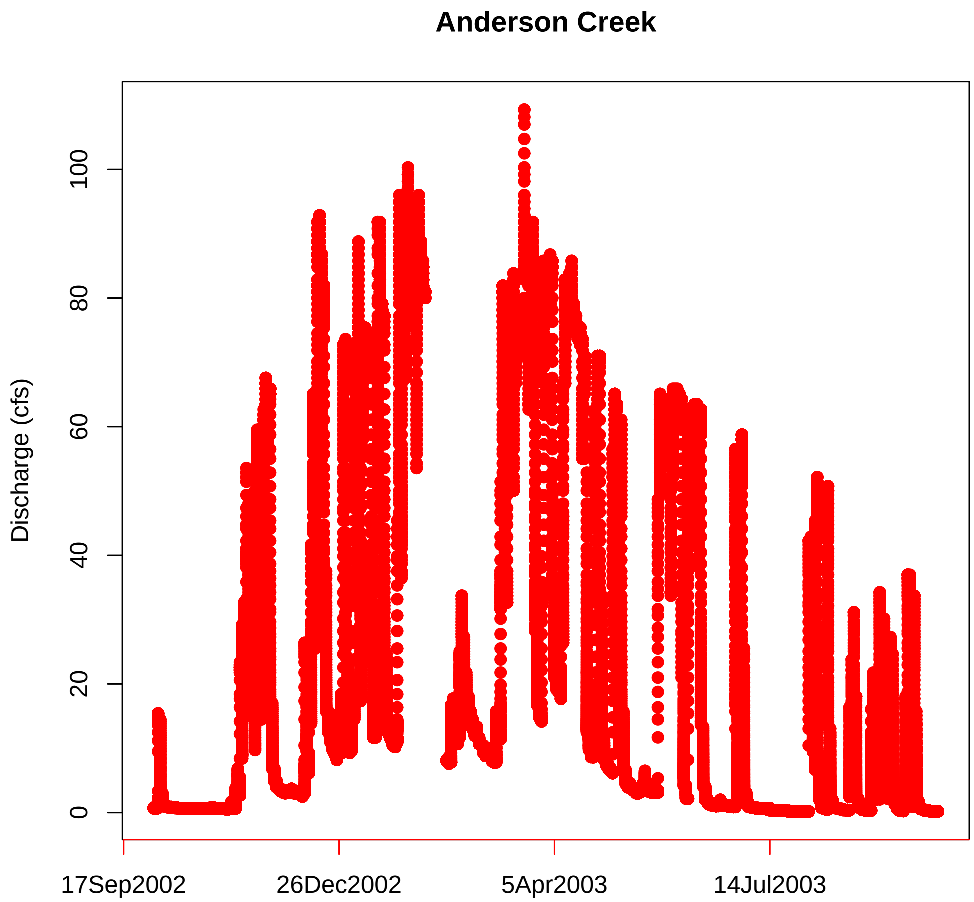


Figure 158: Anderson Creek hydrograph, October 1, 2002–September 30, 2003. Data were recorded at 15 minute intervals.

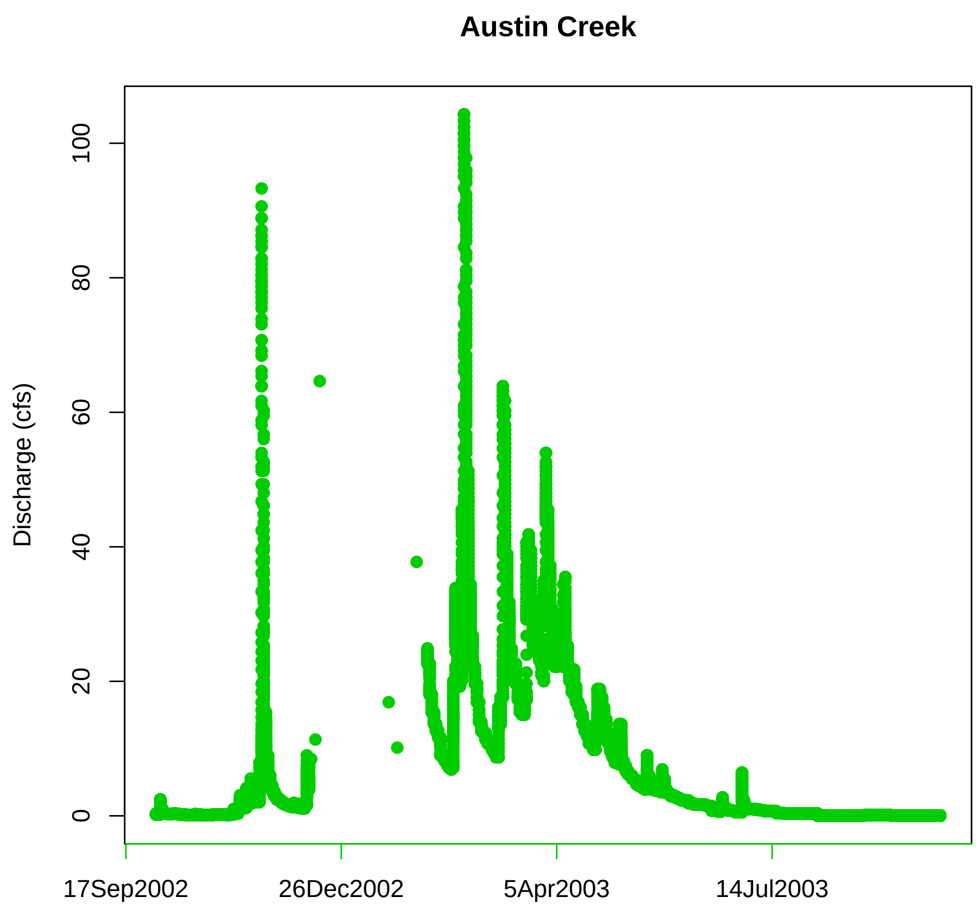


Figure 159: Austin Creek hydrograph, October 1, 2002–September 30, 2003. Data were recorded at 15 minute intervals.

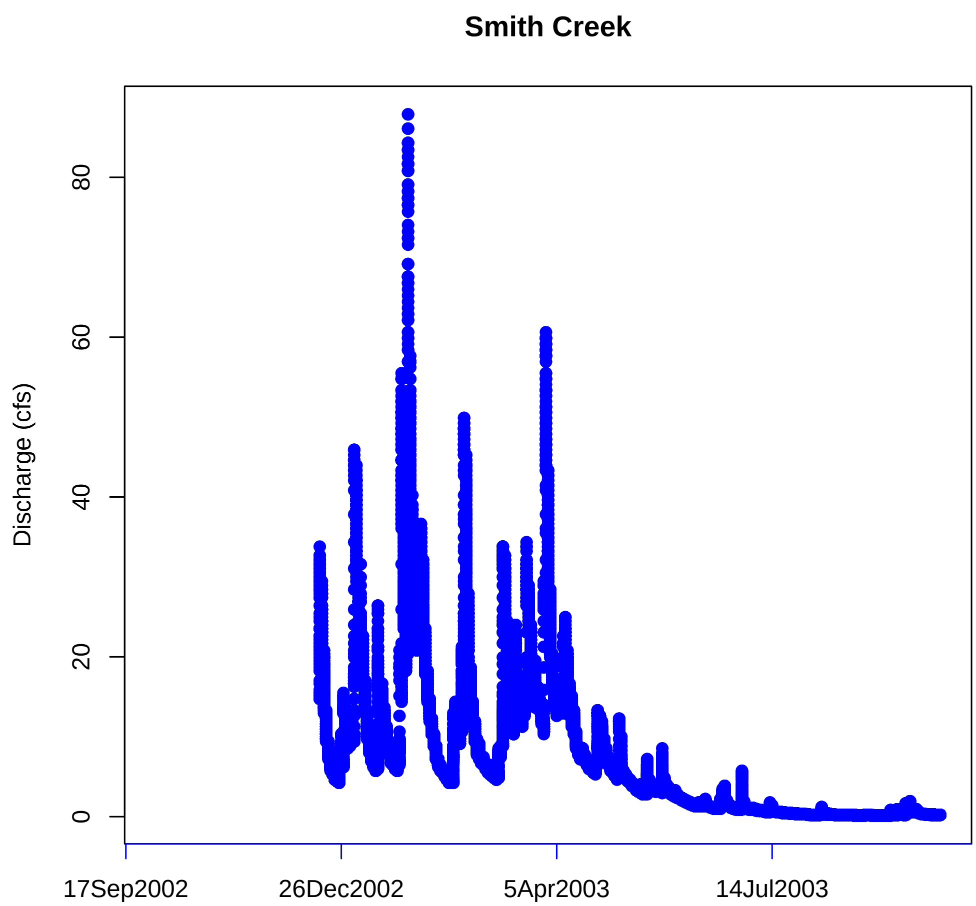


Figure 160: Smith Creek hydrograph, October 1, 2002–September 30, 2003. Data were recorded at 15 minute intervals.

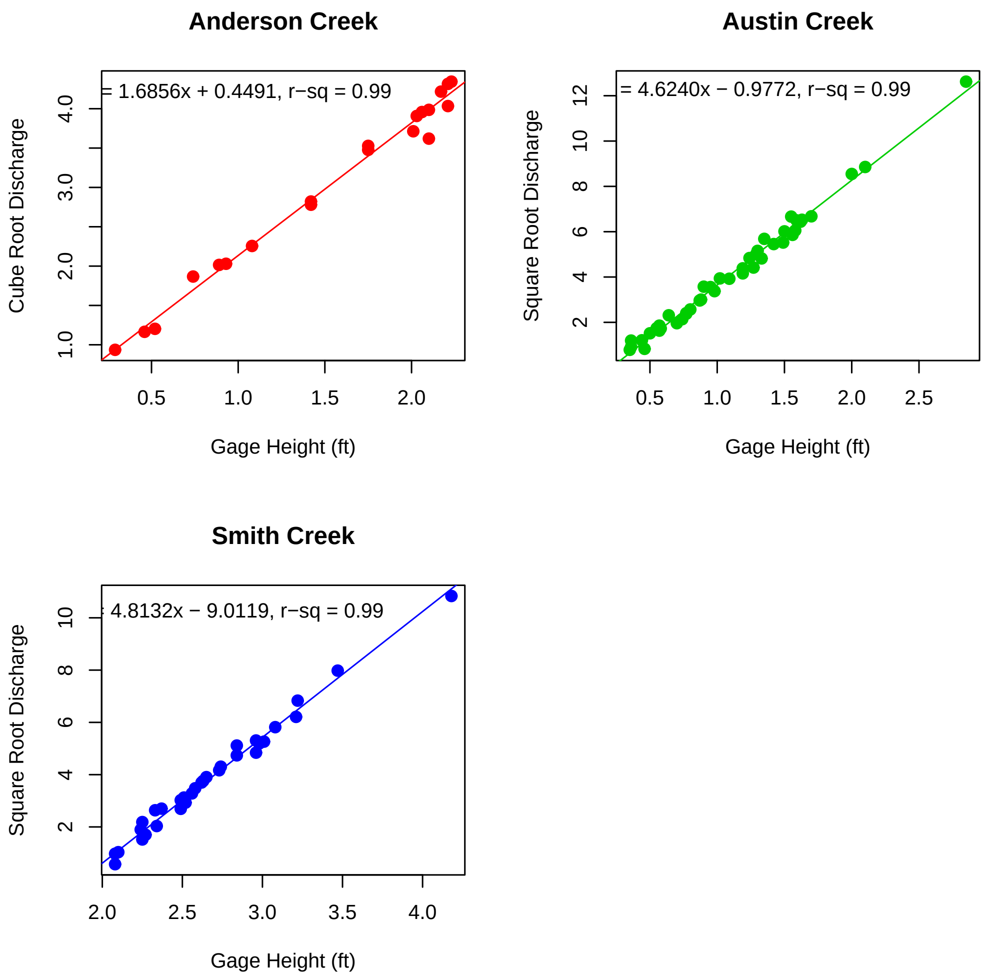


Figure 161: Anderson Creek, Austin Creek, and Smith Creek rating curves. Regressions show the relationship between gauge height (x) and transformed discharge (y). Best fit linear models were based on square root transforms for Austin and Smith Creeks and cube root transforms for Anderson Creek.

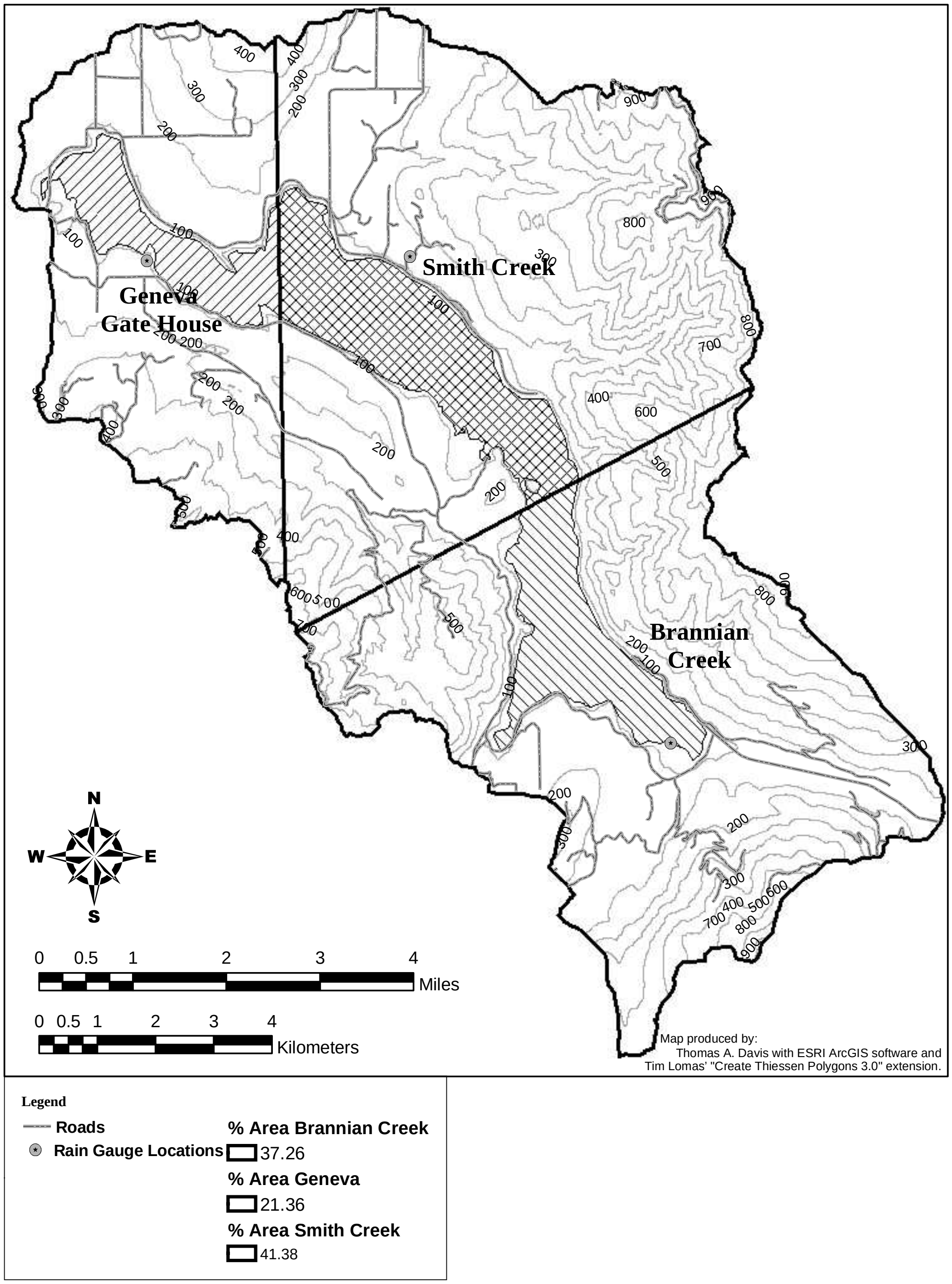


Figure 162: Lake Whatcom watershed precipitation groups and weighted areas, October 1, 2001–September 30, 2002.

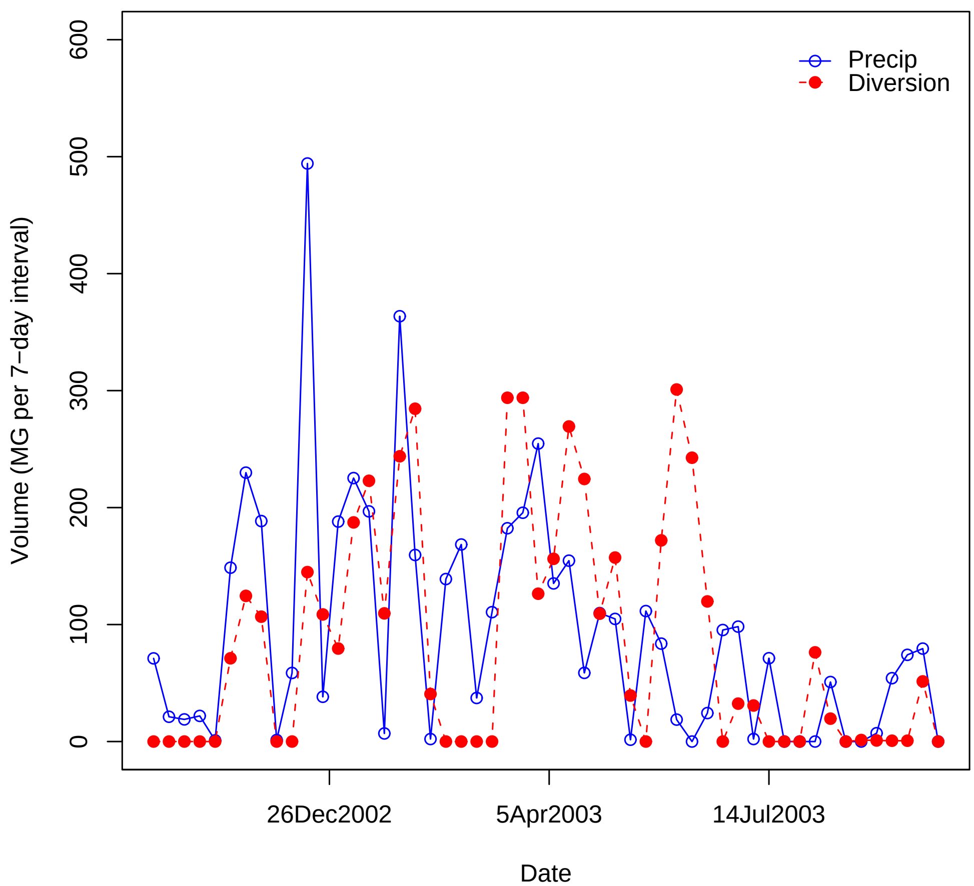


Figure 163: Lake Whatcom watershed direct hydrologic inputs, October 1, 2002–September 30, 2003.

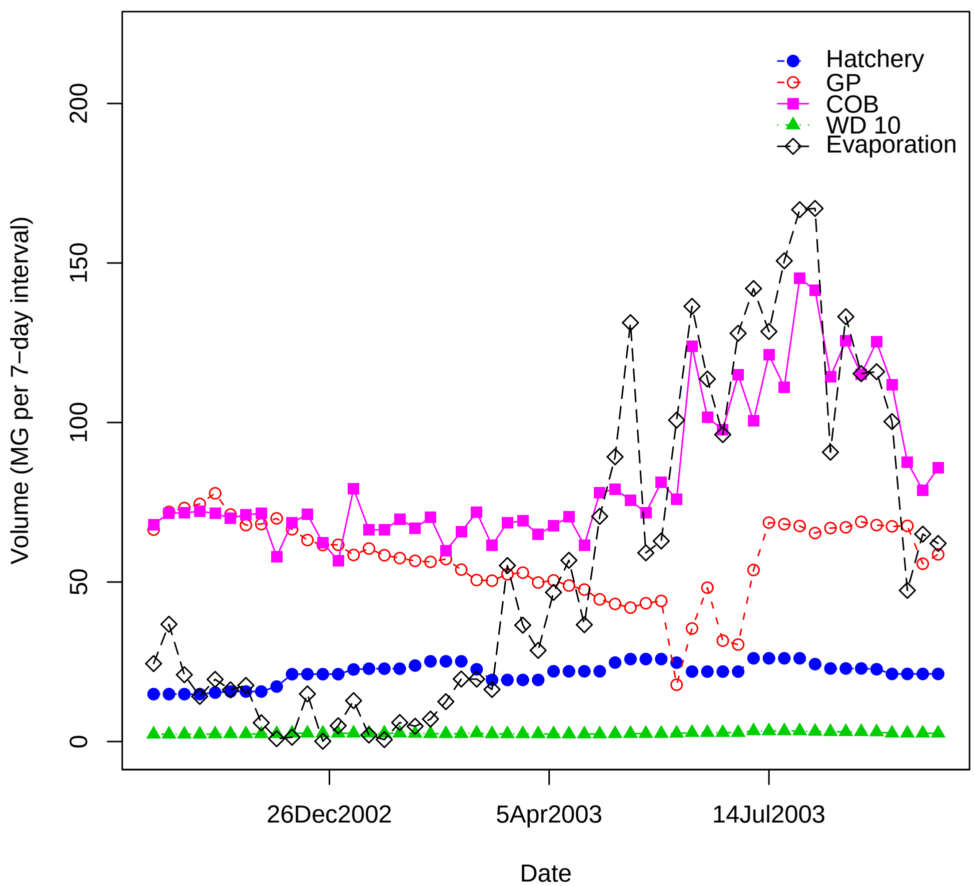


Figure 164: Lake Whatcom watershed hydrologic withdrawals, October 1, 2002–September 30, 2003.

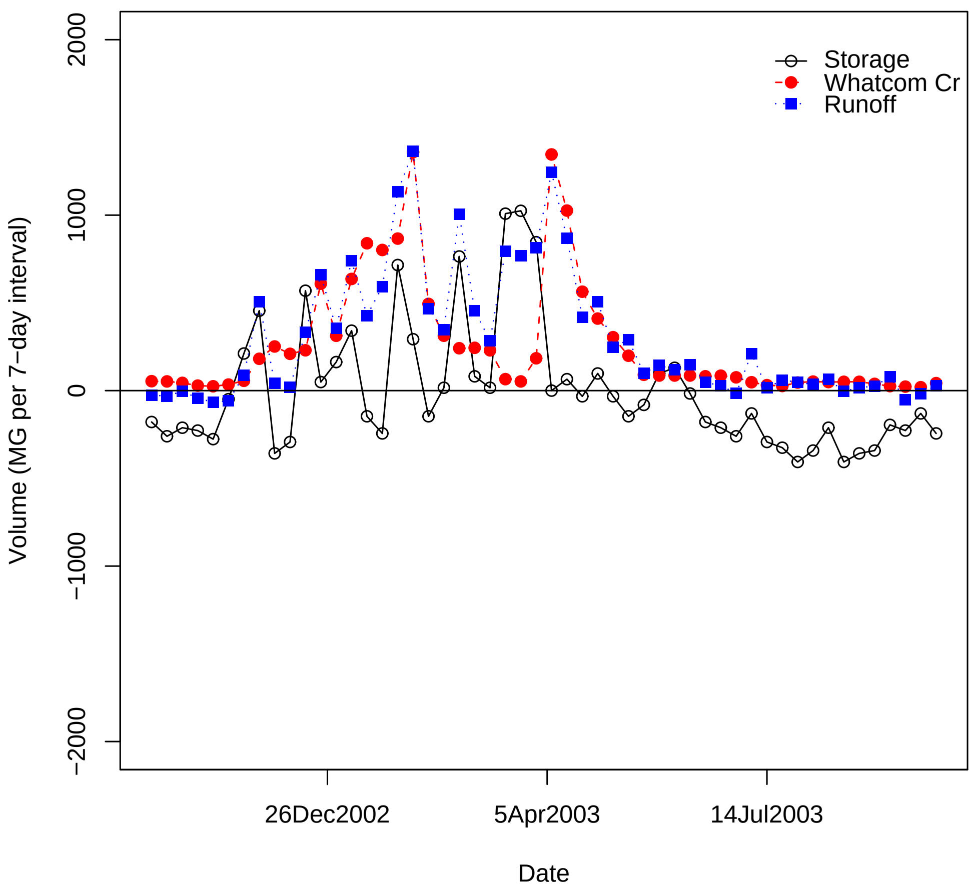


Figure 165: Summary of 7-day changes in Lake Whatcom storage, watershed runoff, and Whatcom Creek flows, October 1, 2002–September 30, 2003.

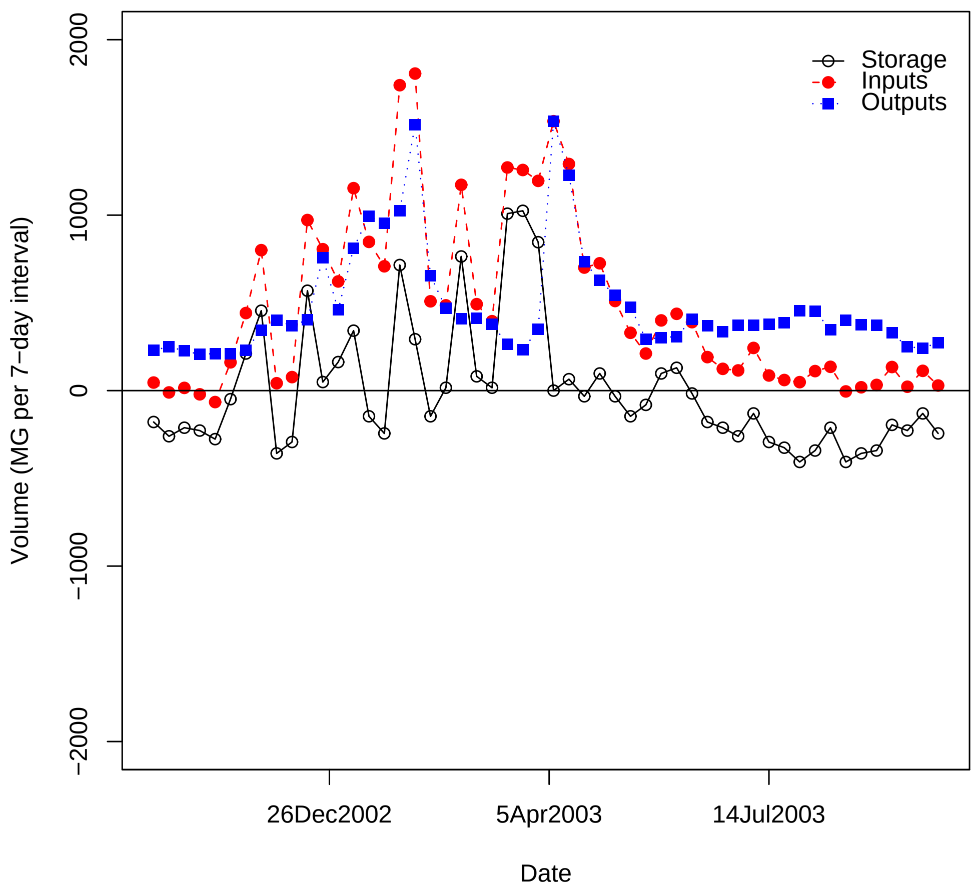


Figure 166: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2002–September 30, 2003.

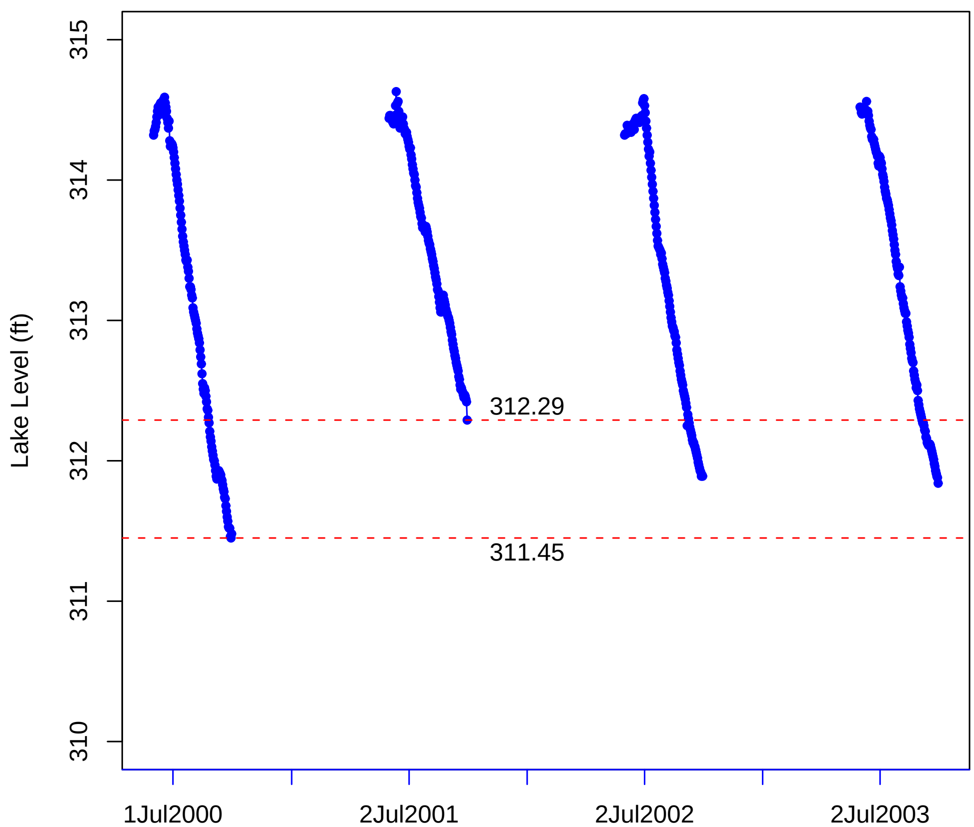


Figure 167: Summer lake levels (elevation in ft above MSL) for 2000–2003. Dashed lines show the range for September lake levels during this period.

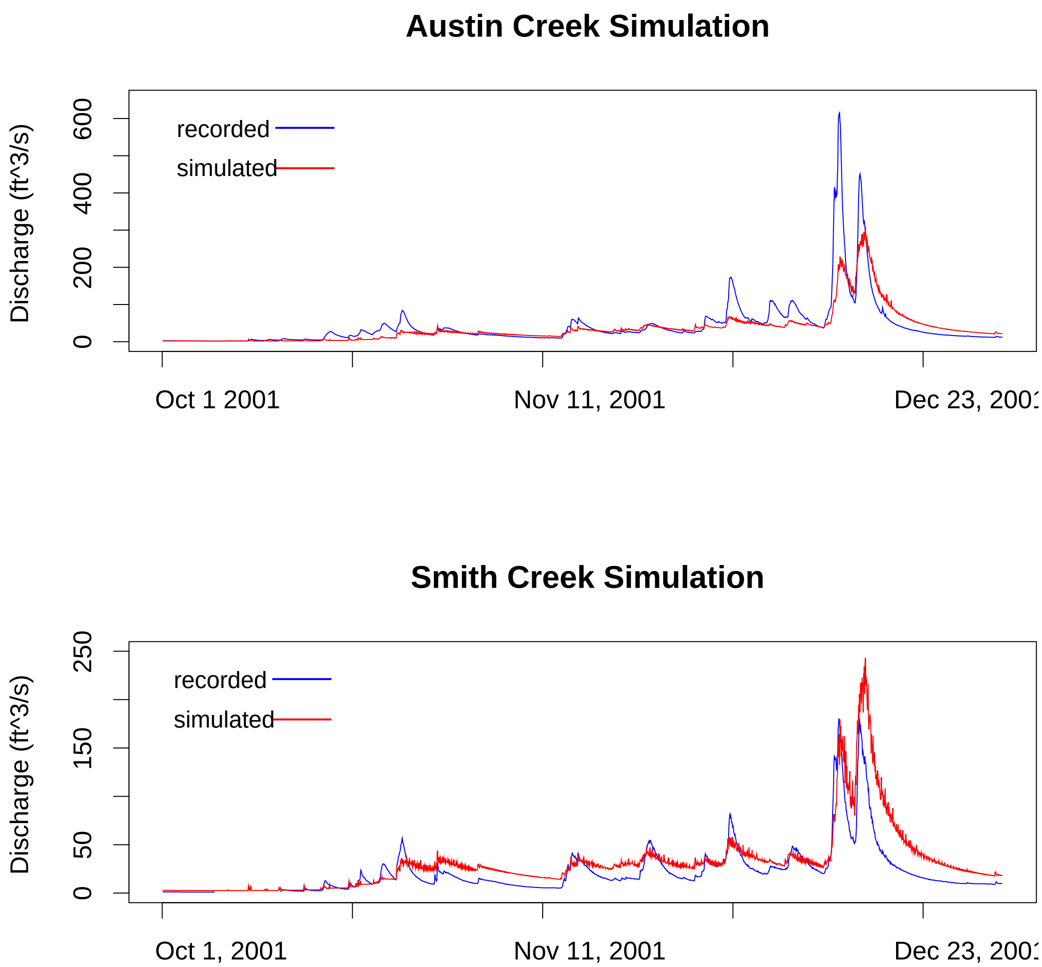


Figure 168: DHSVM simulations for Smith and Austin Creeks, October-December, 2001.

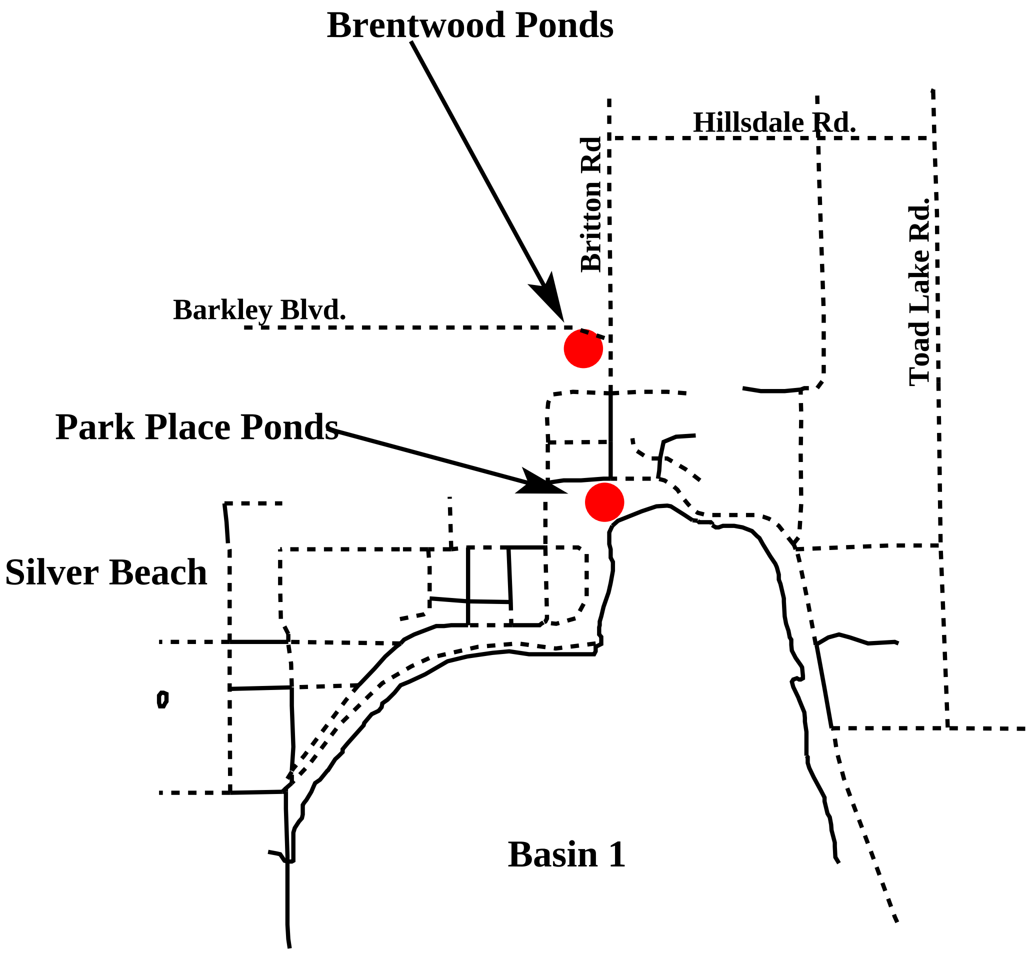


Figure 169: Locations of the sampling sites for the Park Place and Brentwood wet ponds.

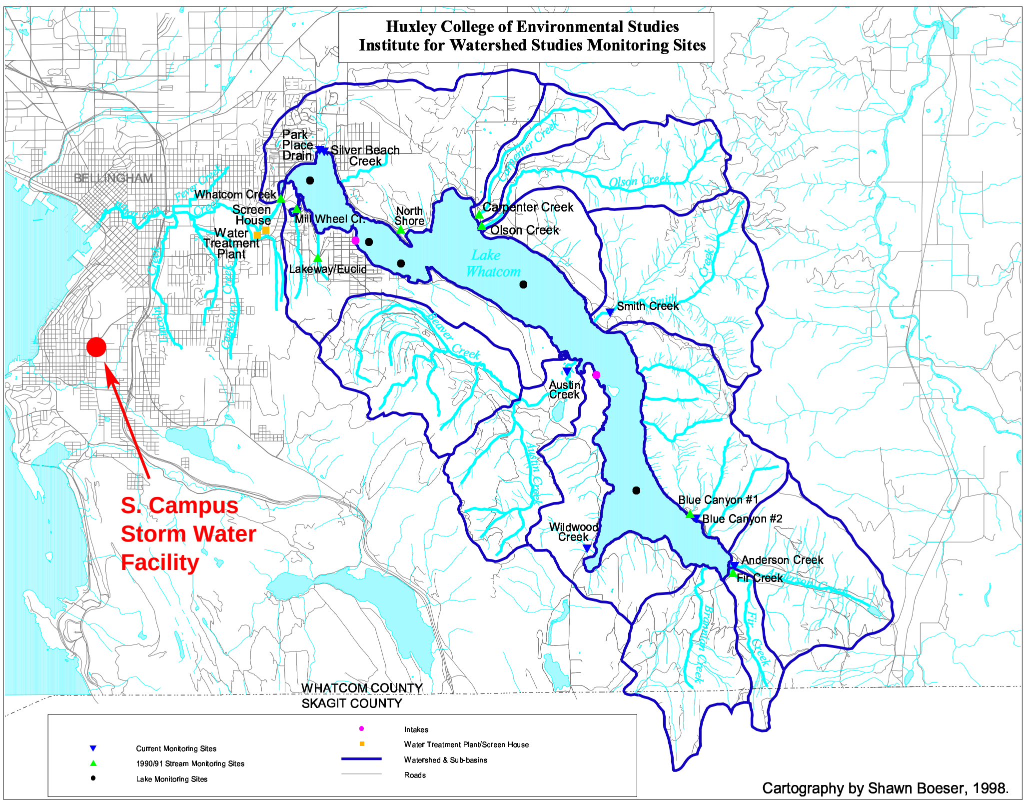


Figure 170: Locations of the South Campus storm water treatment facility.

Figure 171: Brentwood wet pond, July 23, 2003, cell 3.

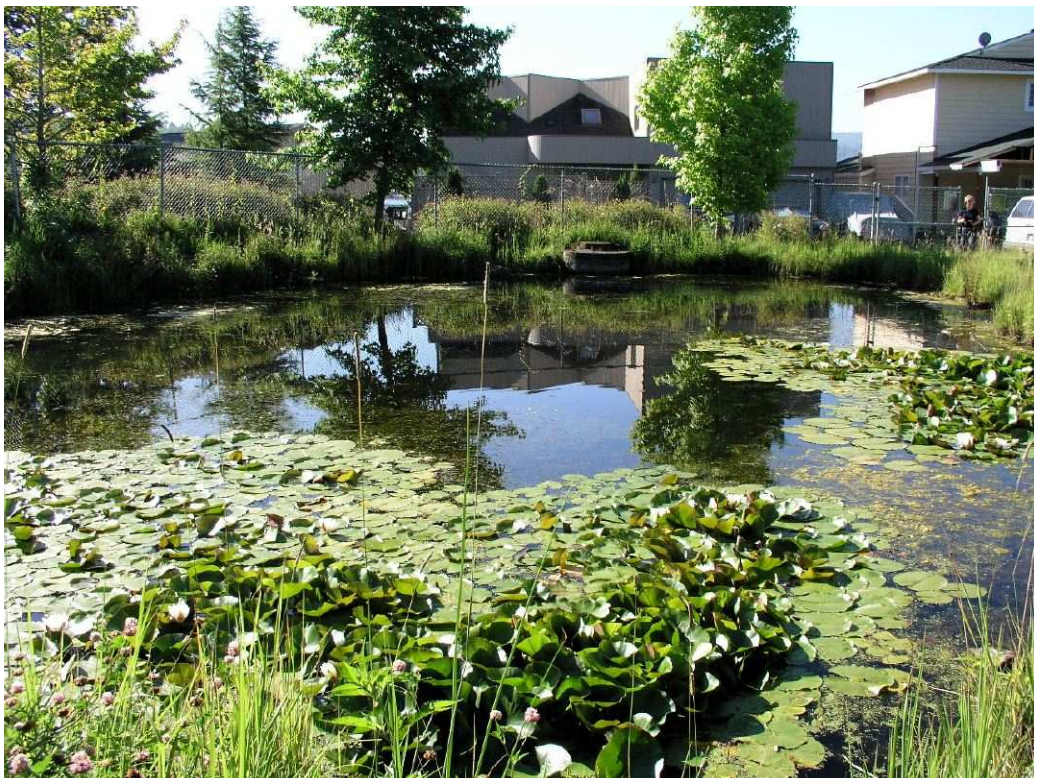


Figure 172: Park Place wet pond, July 21, 2003, cell 3.

Figure 173: South Campus storm water treatment facility, February 20, 2003.

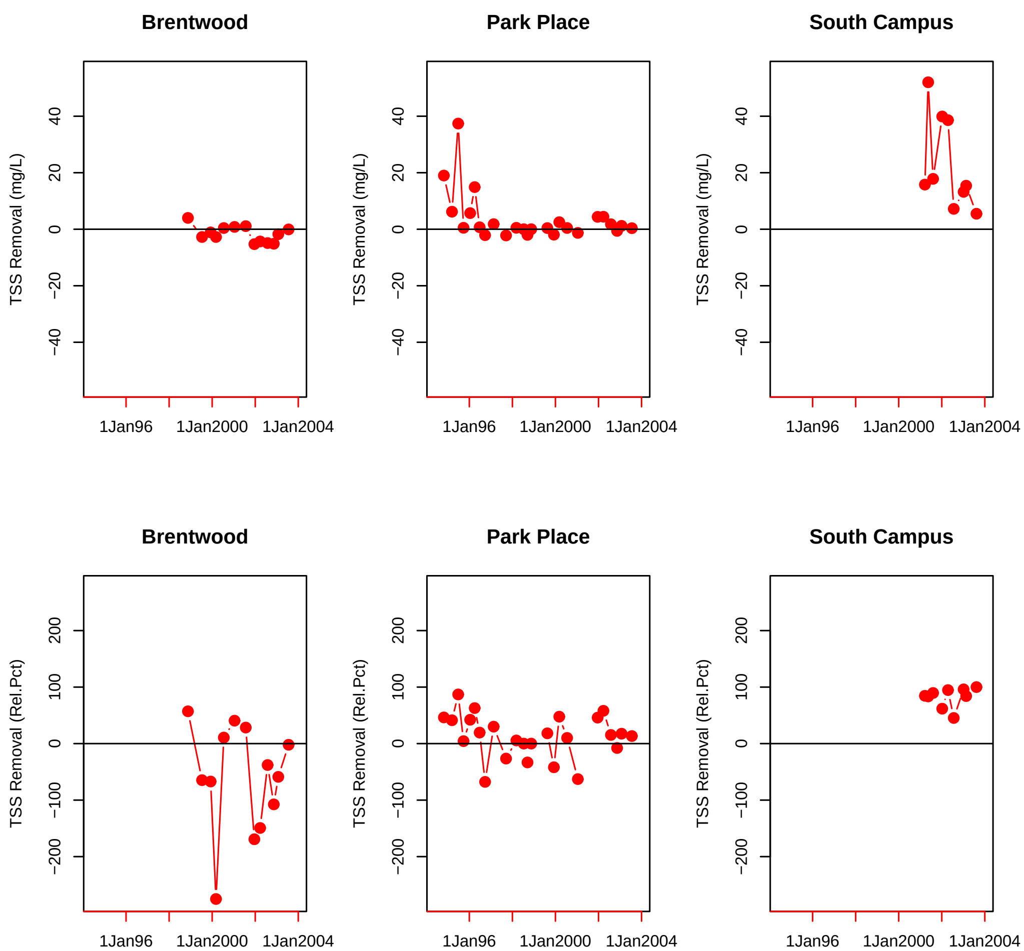


Figure 174: Total suspended solids removal at the Brentwood, Park Place, and south Campus storm water treatment systems. Values below the horizontal reference line indicate higher concentrations at the outlet than the inlet (no removal).

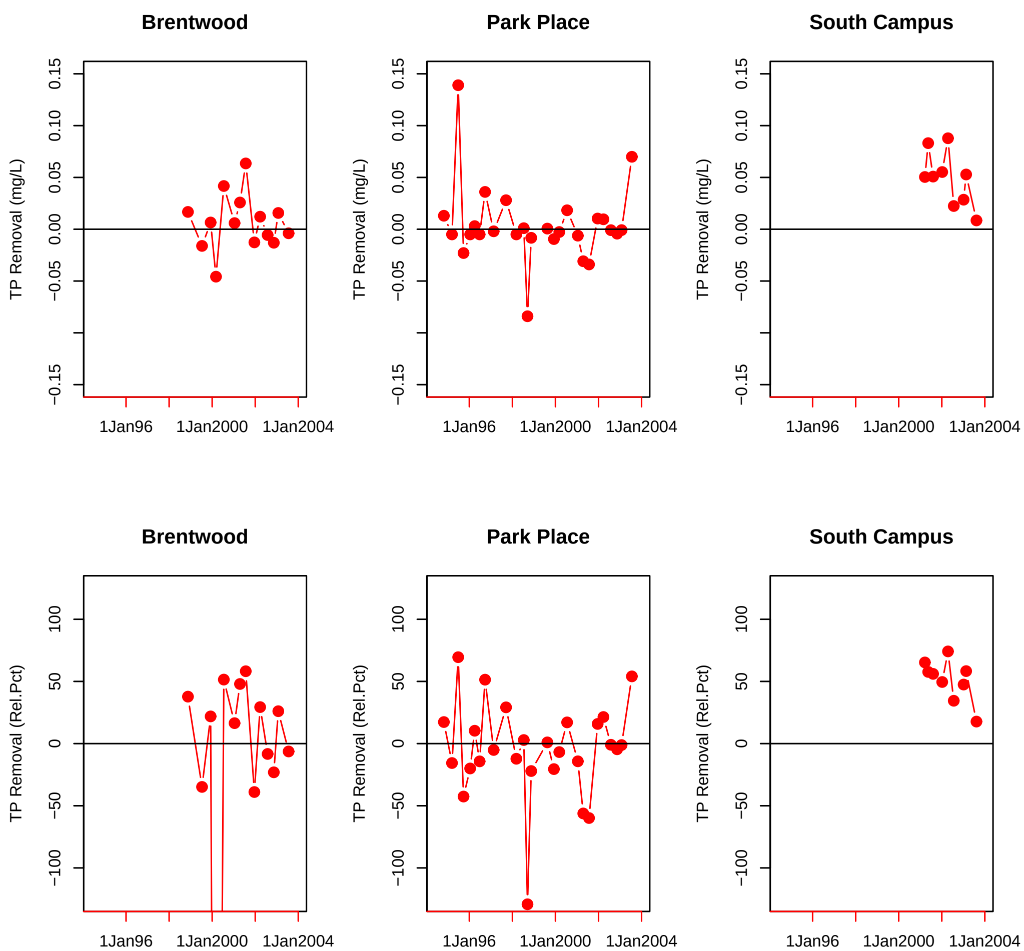


Figure 175: Total phosphorus removal at the Brentwood, Park Place, and South Campus storm water treatment systems. Values below the horizontal reference line indicate higher concentrations at the outlet than the inlet.

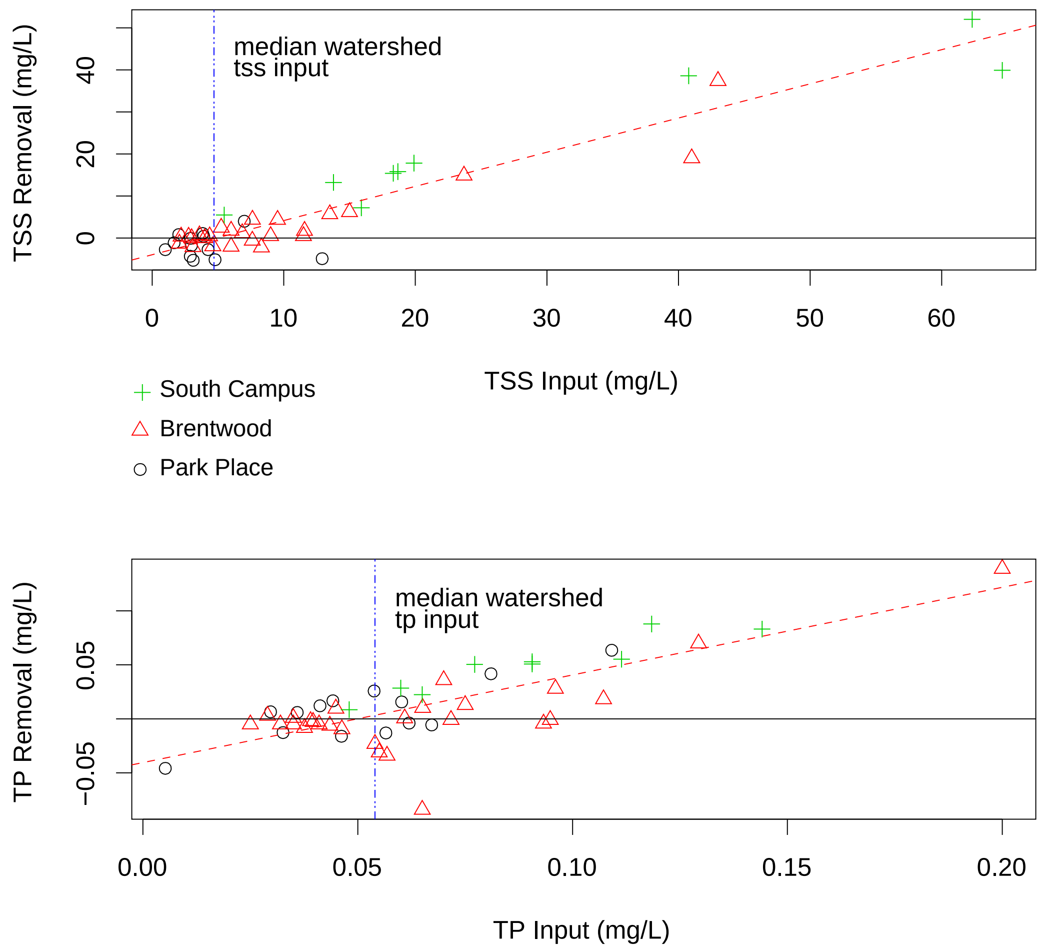


Figure 176: Comparison between pollutant loading concentration at the inlet and pollutant removal for the Brentwood, Park Place, and South Campus storm water treatment systems. Values below the horizontal reference line indicate higher concentrations at the outlet than the inlet. The vertical reference line shows the median loading concentration for the treatment systems inside the Lake Whatcom watershed (Brentwood and Park Place). Linear regression between TSS/TP input and TSS/TP removal was significant at $p \leq 0.05$.

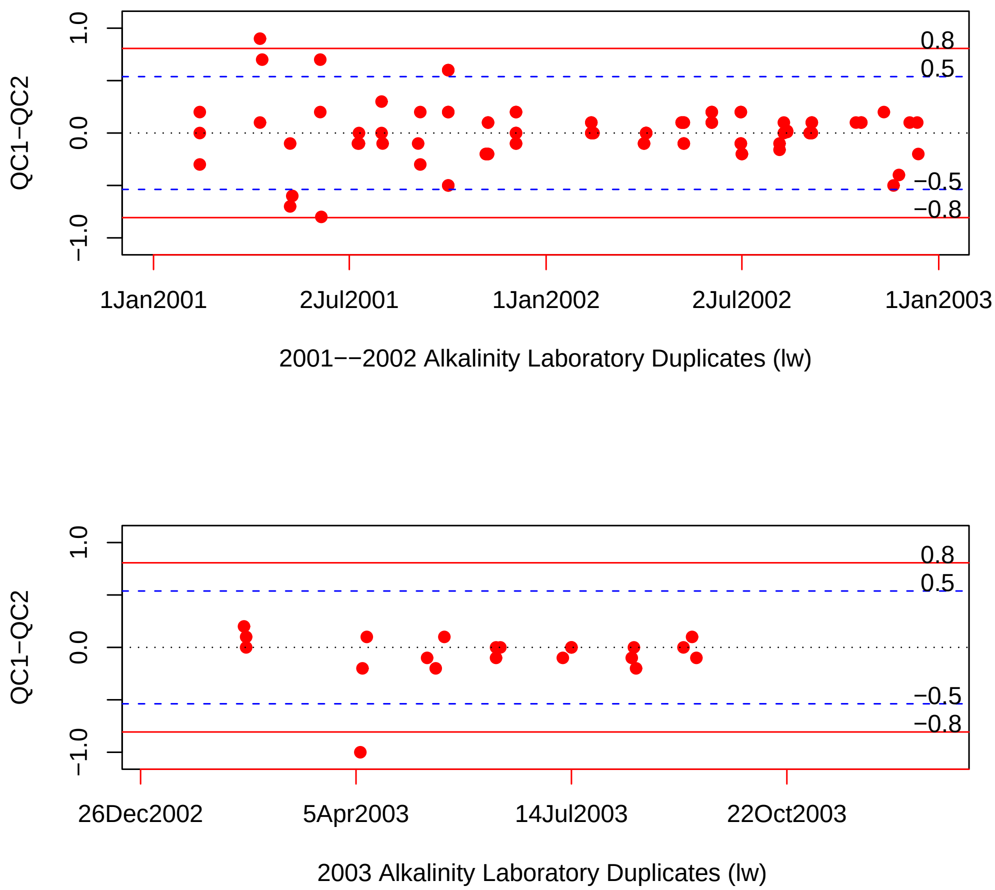
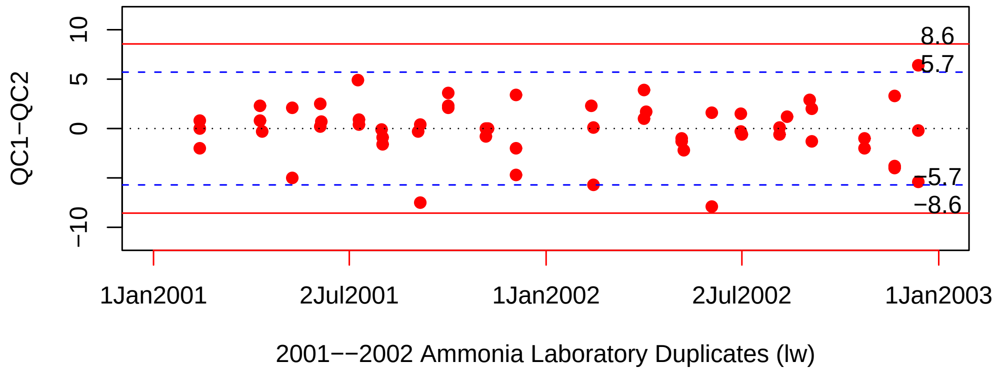


Figure 177: Alkalinity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



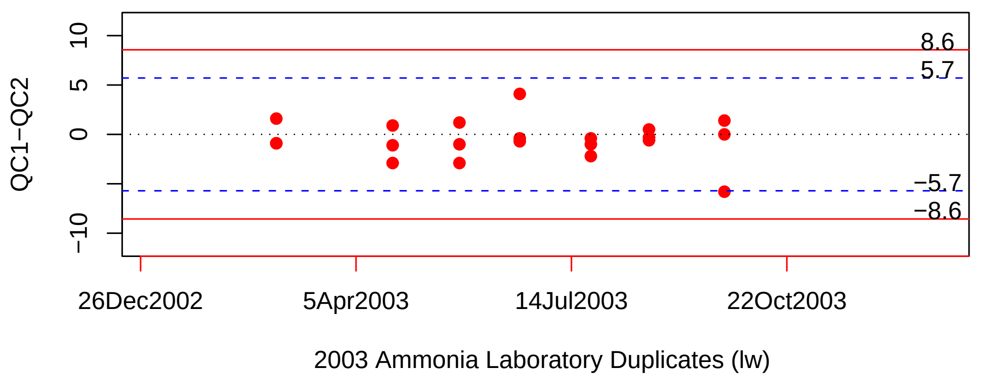
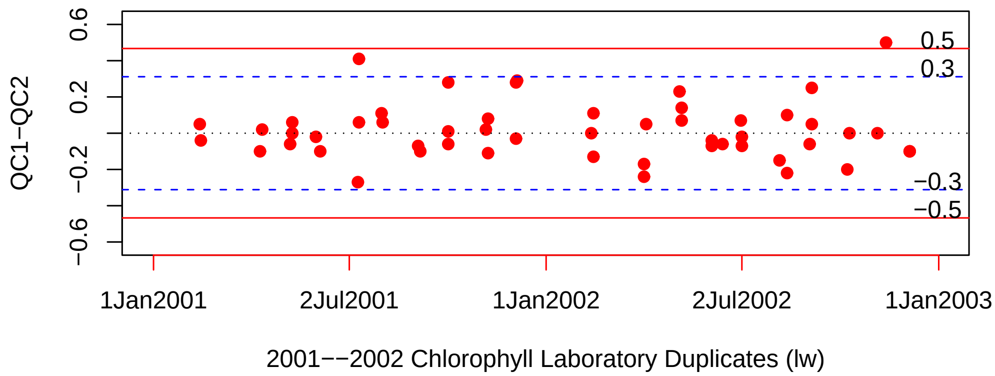


Figure 178: Ammonia laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



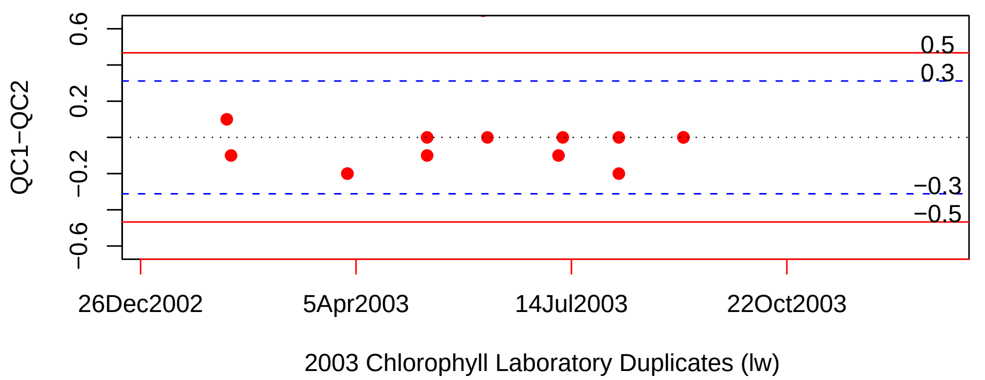


Figure 179: Chlorophyll laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

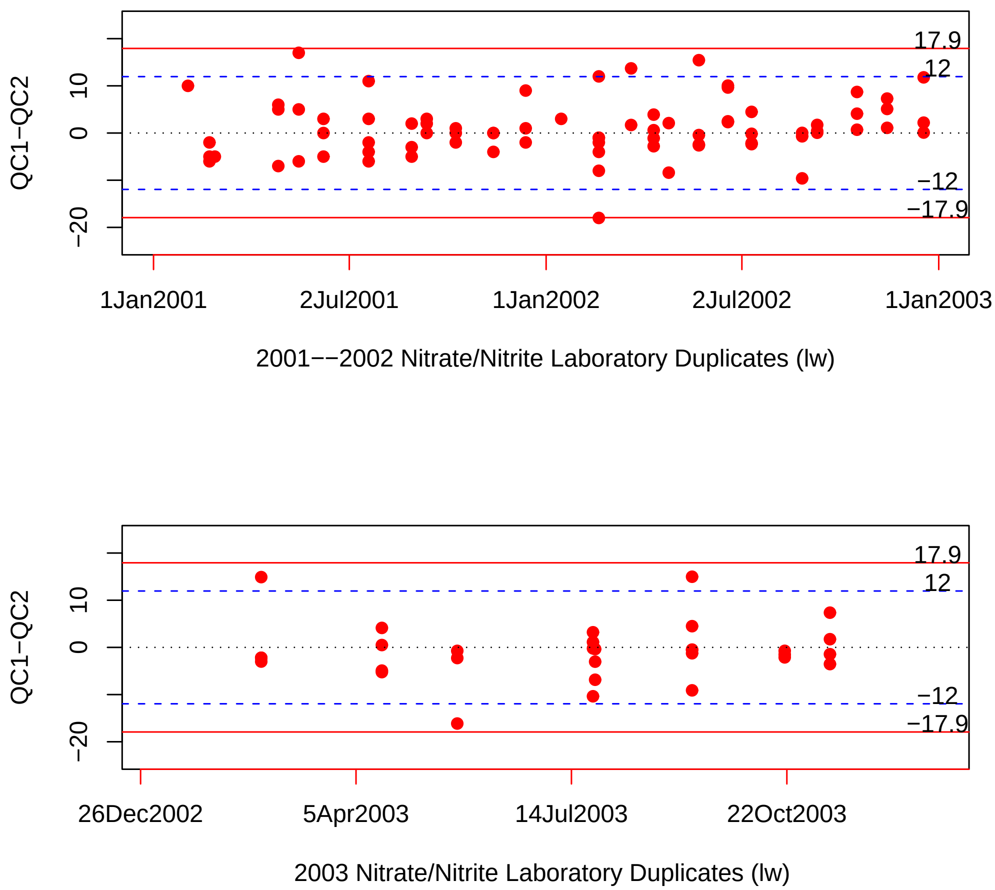


Figure 180: Nitrate/nitrite laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

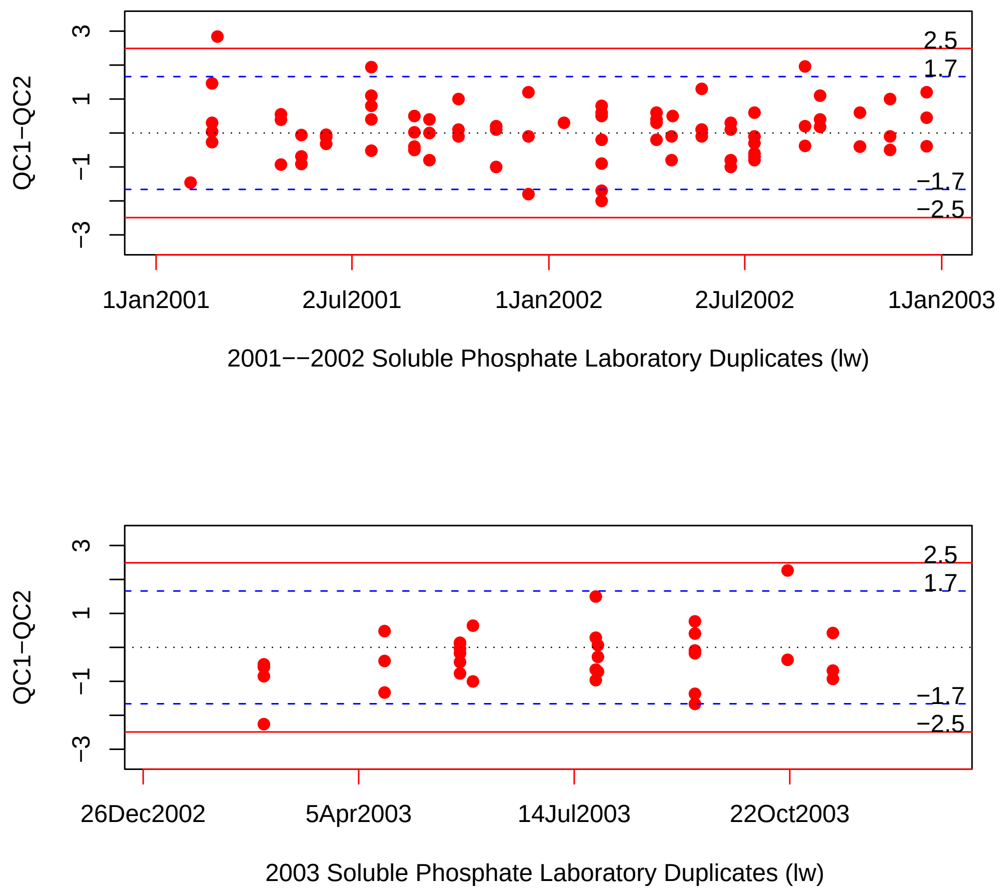
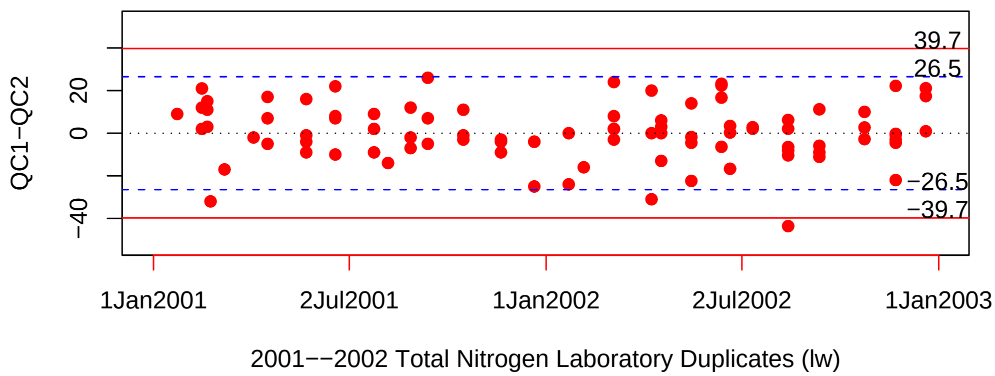


Figure 181: Soluble reactive phosphate laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



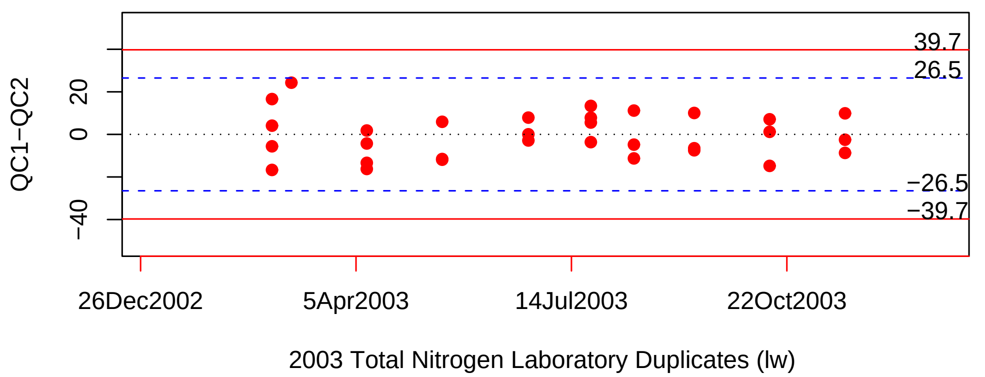
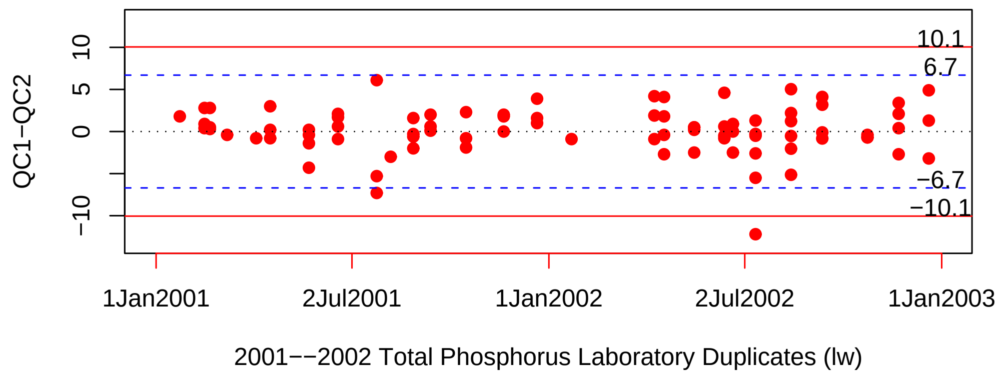


Figure 182: Total nitrogen laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



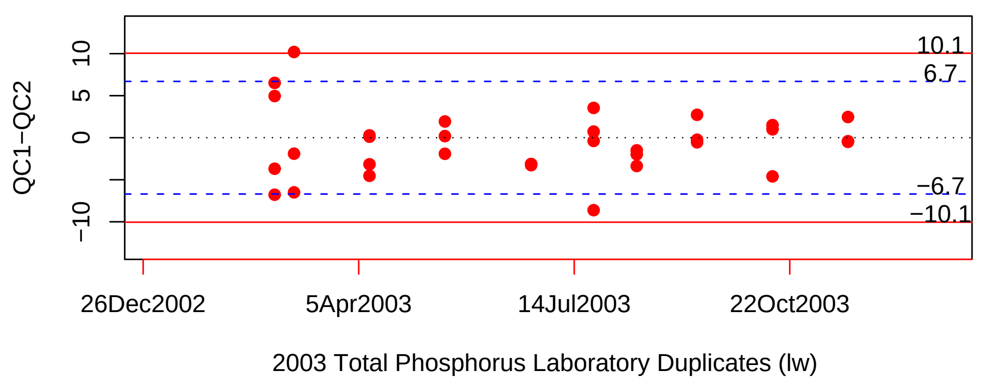


Figure 183: Total phosphorus laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

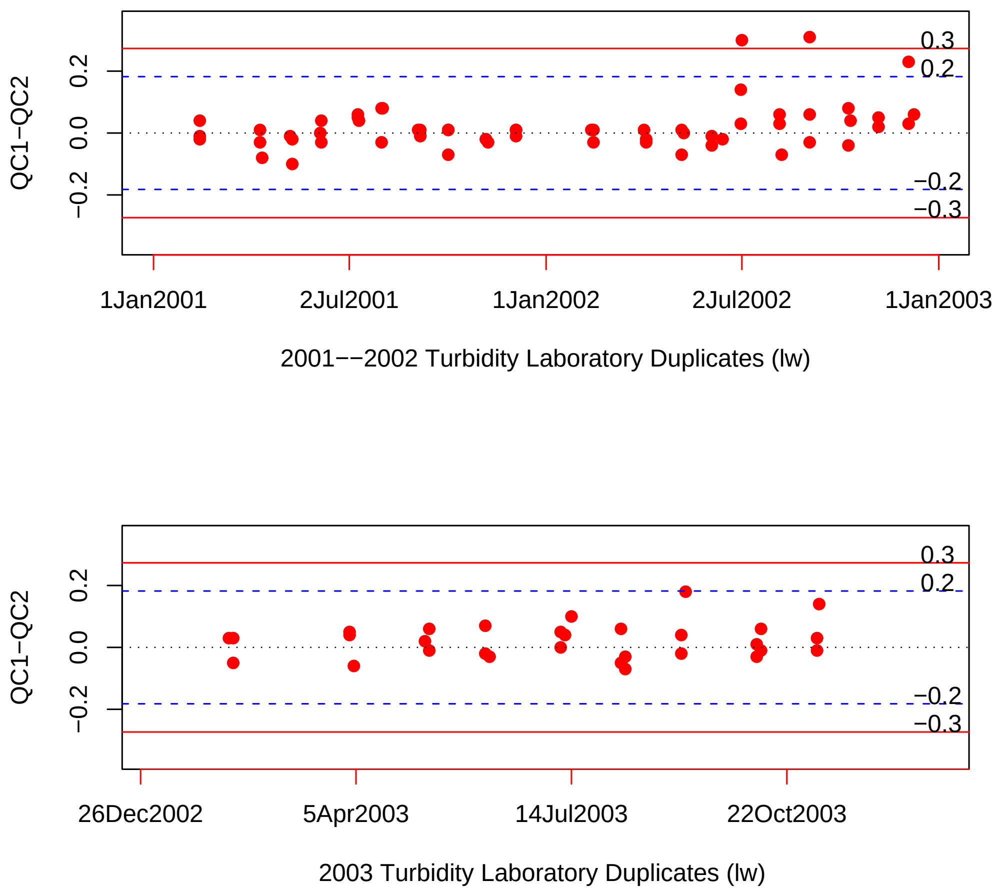


Figure 184: Turbidity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

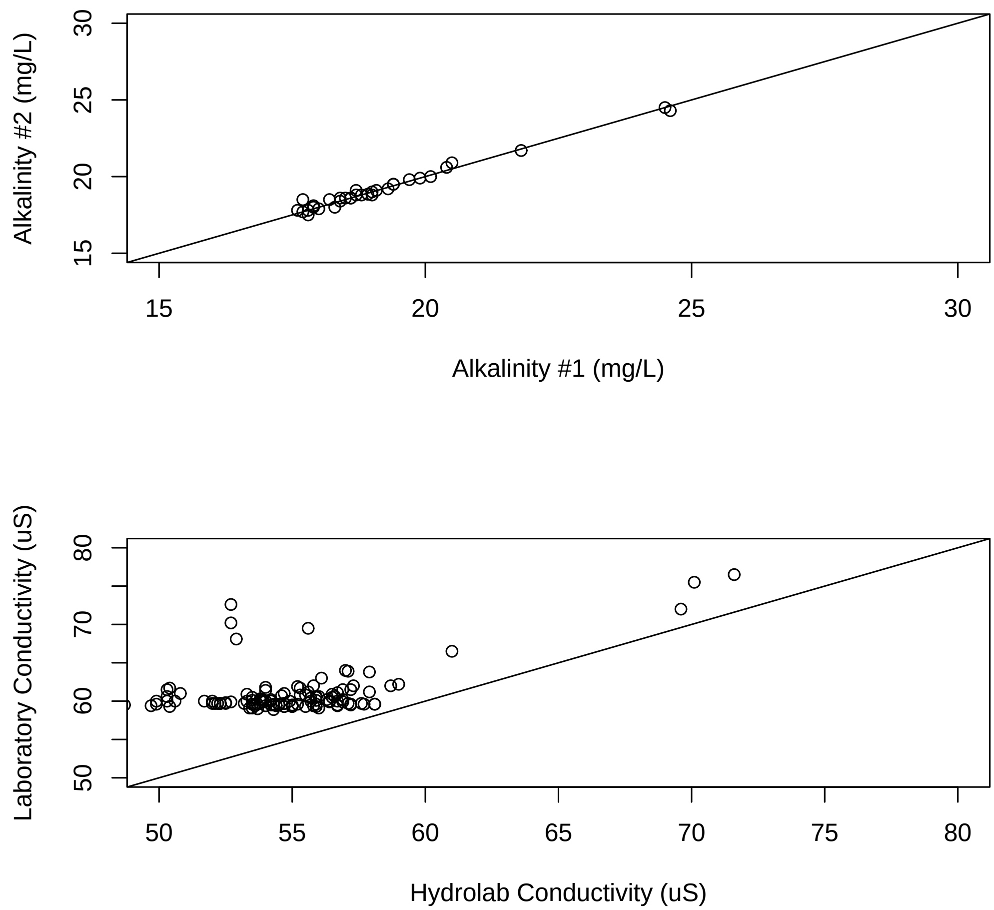


Figure 185: Alkalinity and conductivity field duplicates. Conductivity results show a systematic bias due to lower sensitivity of the laboratory meter (see Section 6).

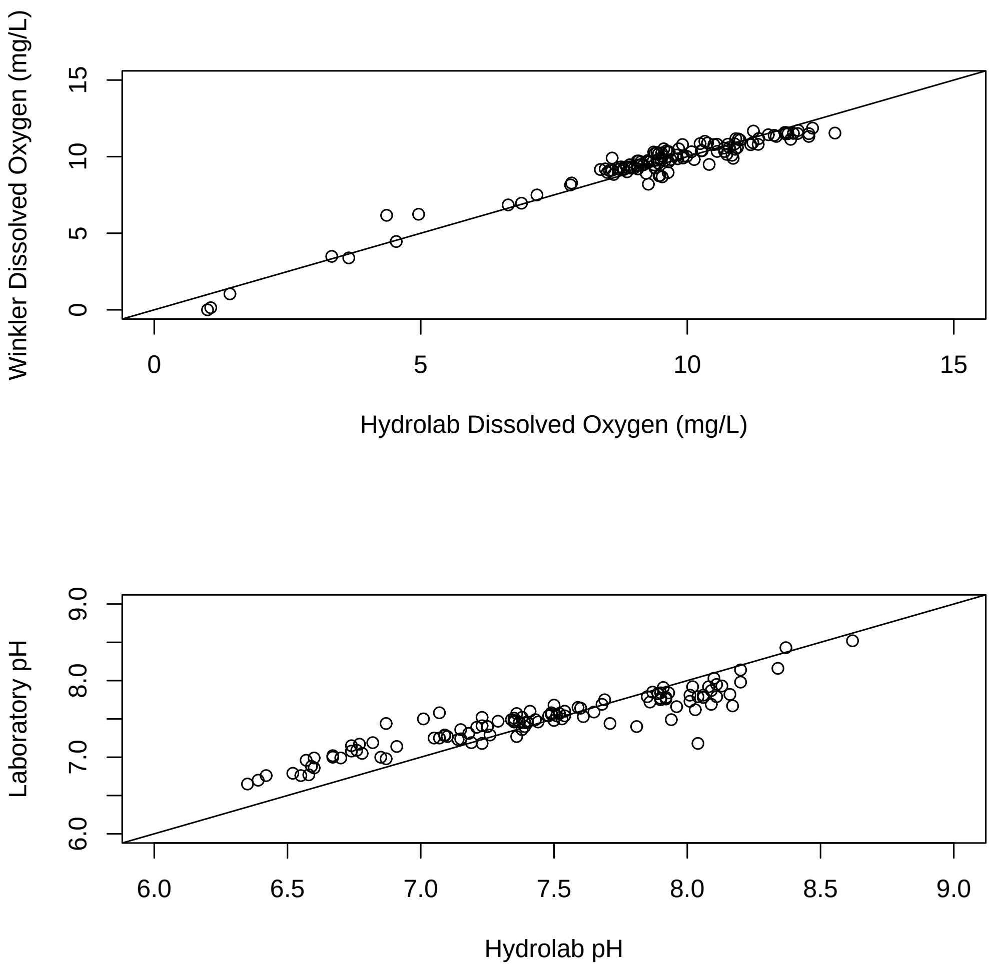


Figure 186: Dissolved oxygen and pH field duplicates. The pH results show a slight systematic bias due to changes in dissolved CO_2 and associated inorganic carbon ions between field and laboratory samples (see Section 6).

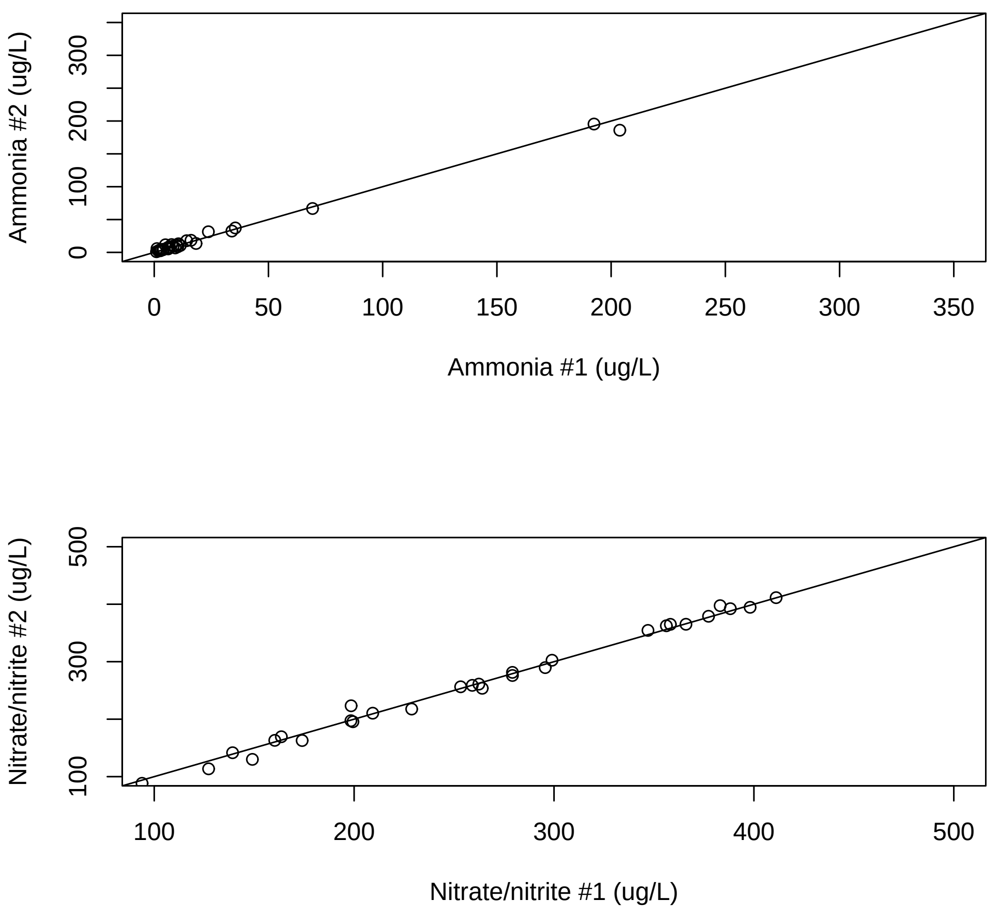


Figure 187: Ammonia and nitrate/nitrite field duplicates.

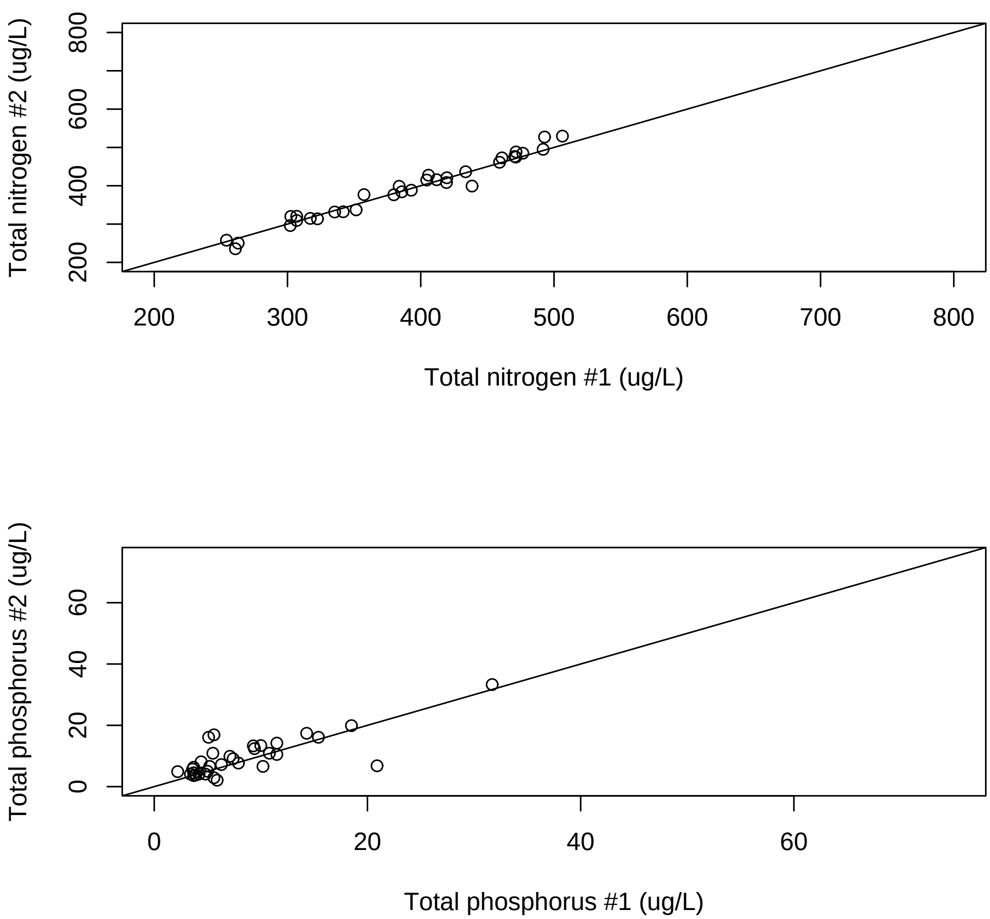


Figure 188: Total nitrogen and total phosphorus field duplicates.

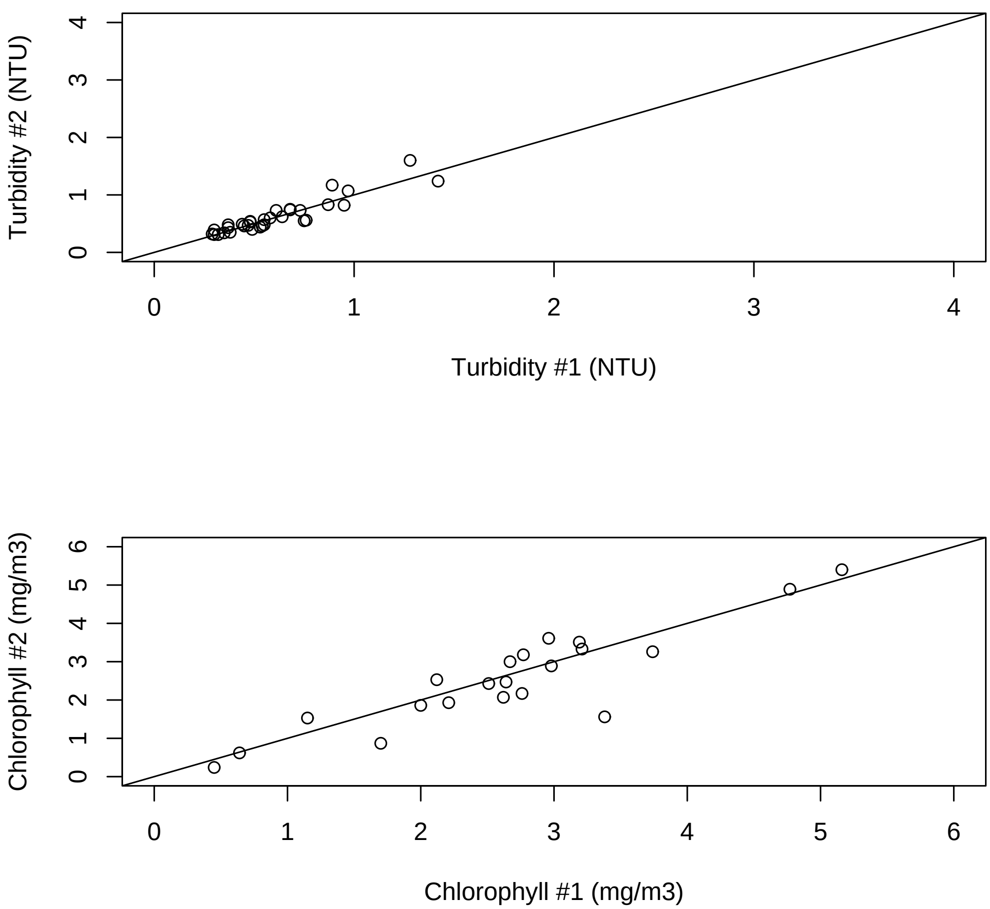


Figure 189: Turbidity and chlorophyll field duplicates.

A Site Descriptions

A.1 Lake Whatcom Monitoring Sites

Please refer to Figures 190–191 for assistance with locating each site. In the field, each site should be marked with an orange buoy; however, stormy weather or vandalism may have resulted in the movement or loss of a marker buoy. The four major lake sampling sites have been used since the early 1960's. Table 30 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.

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 on August 5, 1993 were: 48° 45.74 N, 122° 24.63 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 on August 5, 1993 were: 48° 44.55 N, 122° 22.81 W.

The **Intake Site** is located offshore from the City of Bellingham's raw water gatehouse. This site is one of the more difficult sites to locate because the marker buoy is frequently missing. The depth at the Intake site should be at least 13 m deep. The GPS coordinates for the Intake site on August 5, 1993 were: 48° 44.89 N, 122° 23.47 W.

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 deep. The GPS coordinates for Site 3 on August 5, 1993 were: 48° 44.27 N, 122° 20.25 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 deep. The GPS coordinates for Site 4 on August 5, 1993 were: 48° 41.53 N, 122° 18.01 W.

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

Table 30: Summary of site codes for Lake Whatcom water quality sampling.

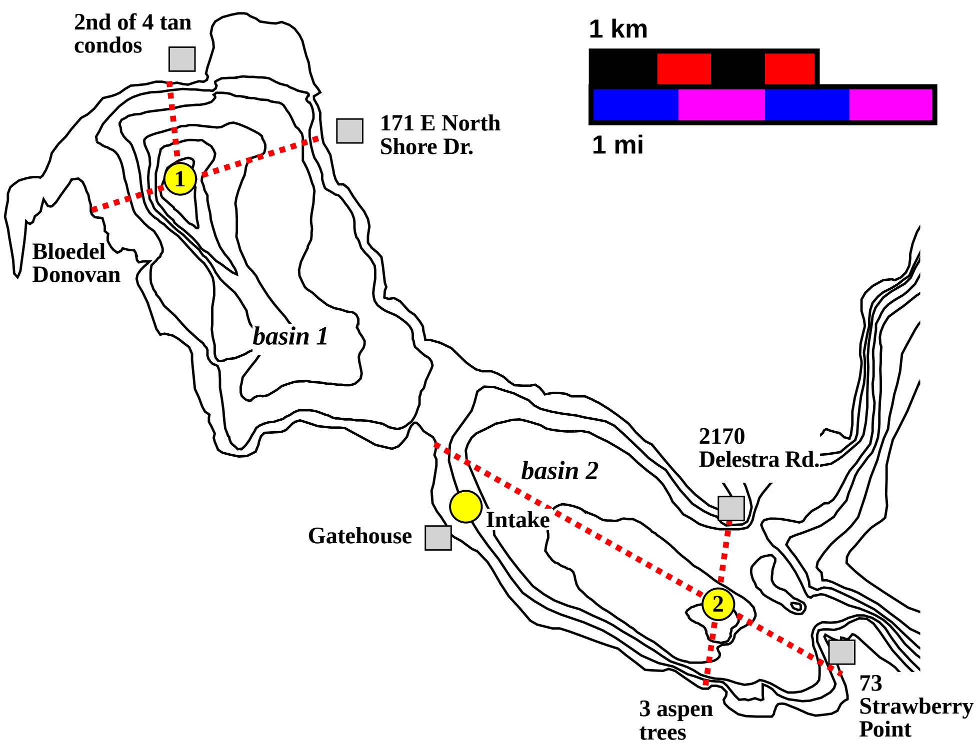


Figure 190: Lake Whatcom sampling sites, basins 1–2.

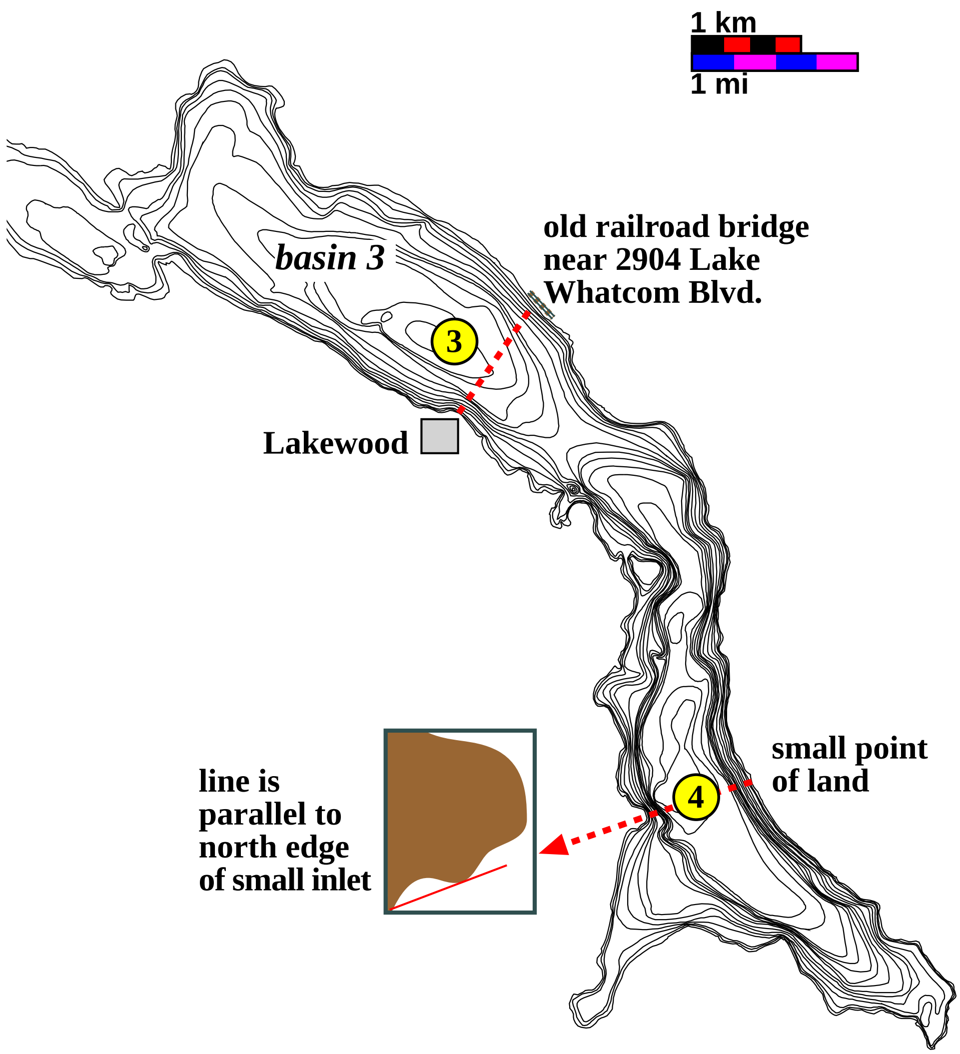


Figure 191: Lake Whatcom sampling sites, basin 3.

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 dead end of North Shore Road are 48° 43′ 46.3” N; 122° 18′ 51.1” W.

Silver Beach Creek:
All routine monitoring samples are collected immediately upstream from the culvert under North Shore Road. GPS coordinates are not available for Silver Beach Creek.

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.) GPS coordinates are not available for the Park Place storm drain.

Austin Creek:
The Austin Creek hydrograph is mounted on the north west support pillar directly underneath the bridge over Austin Creek (Lake Whatcom Blvd.), approximately 1 km from the mouth of the creek. Water samples are collected at the gaging station. The GPS coordinates for Austin Creek at the bridge are 48° 42′ 46.8” N; 122° 19′ 52.2” 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′ 41.1” N; 122° 19′ 04.9” 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′ 24.3” N; 122° 16′ 02.8” 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′ 06.3” N; 122° 17′ 00.7” W.

B Lake Whatcom Data

The 2002/2003 Lake Whatcom water quality data, including data from special sampling projects, are included on the following pages. The historic detection limits and abbreviations for each parameter are listed in Table 31. Table 31 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 37). 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 B.6 includes the the current AmTest reports and detection limits.

Table 31: Summary of analyses in the Lake Whatcom monitoring project.

B.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.

B.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.

B.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.

B.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.

B.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, 98225.

B.6 AmTest Metals and TOC (Lake, Creeks, Storm Water)

The following AmTest data reports are included in hardcopy format in the printed 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	August 5 & 7, 2003	metals; total organic carbon
	February 11, 2003	total organic carbon
Park Place/Brentwood wet ponds	November 15, 2002	metals; total organic carbon
	January 29, 2003	metals; total organic carbon
	July 24, 2003	metals; total organic carbon
South Campus storm drain	January 8, 2004	metals, total organic carbon
	February 20, 2003	metals, total organic carbon
	August 14, 2003	metals, total organic carbon
Watershed creeks	February, 11, 2003	metals; total organic carbon
	July 23, 2003	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	SCSD IN	South Campus inlet
22-B	Site 2, bottom (20 m)	CW6	Wildwood Creek	SCSD E	South Campus east outlet
31-O	Site 3, surface (0.3 m)	CW7	Austin Creek	SCSD W	South Campus west outlet
31-B	Site 3, bottom (80 m)				
32-O	Site 4, surface (0.3 m)				
32-B	Site 4, bottom (90 m)				

B.7 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 31 (pages 37 and 263) 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
1995_hl.dat          1995_wq.dat                Plankton data
1996_hl.dat          1996_wq.dat                plankton.dat
1997_hl.dat          1997_wq.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

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.