3-15-2002

Lake Whatcom Monitoring Project 2000/2001 Report

Robin A. Matthews
Western Washington University, robin.matthews@wwu.edu

Michael Hilles
Western Washington University, michael.hilles@wwu.edu

Joan Vandersypen
Western Washington University, joan.vandersypen@wwu.edu

Robert J. Mitchell
Western Washington University, robert.mitchell@wwu.edu

Geoffrey B. Matthews
Western Washington University, geoffrey.matthews@wwu.edu

Lake Whatcom Monitoring Project
2000/2001 Final Report

Dr. Robin A. Matthews,
Mr. Mike Hilles
Ms. Joan Vandersypen
Institute for Watershed Studies,
Huxley College of Environmental Studies
Western Washington University

Dr. Robert J. Mitchell
Geology Department
College of Arts & Sciences
Western Washington University

Dr. Geoffrey B. Matthews
Computer Science Department
College of Arts & Sciences
Western Washington University*

March 15, 2002

*Funding for this project was provided by the City of Bellingham, as part of their long-term commitment to environmental education and their concern for maintaining the water quality of Lake Whatcom. We thank Marilyn Desmul, Judy Kincaid-King, Jessica Anderson, Shannon Ashurst, Peter Best, Abram Brian, Annie Chapman, Matthew Chase, David Cox, Jeremy Gilman, Brent Olson, Dwight Osmon, Ann-Marie Osterback, Karel Tracy, Staryn Wagner, Jennifer Watkins, Kiyoshi Yamashita, and Ben Zimmerlund for their assistance with this project.

Contents

List of Figures

List of Tables

Executive Summary

This report describes the results from the 2000/2001 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, collect supplemental water quality data from basin 3 near Strawberry sill, update the hydrologic water balance model for Lake Whatcom, begin evaluating water movement patterns in basins 1, 2, and 3, and monitor the effectiveness of the Park Place and Brentwood wet ponds and the South Campus storm water treatment facility.

The lake was sampled on October 3, 5 & 10, November 7 & 9, December 6 & 7 2000, and February 13 & 14, April 10 & 12, May 8 & 10, June 5 & 6, July 10 & 11, Aug 1 & 2, and September 4 & 6, 2001. During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). As a result of a cool, windy spring, basin 1 was only weakly stratified by early June. Nevertheless, Sites 1 and 2 (basins 1 and 2) developed severe hypolimnetic oxygen deficits by mid-summer. As in previous years, there were statistically significant negative correlations between summer hypolimnetic dissolved oxygen levels and time. No significant correlations were found for hypolimnetic temperature vs. time or for lake level vs. hypolimnetic oxygen. Although Site 1 continued to develop severe, late summer, hypolimnetic anoxia, for the past three years, the concentrations of two water quality indicators of lake anoxia, ammonia and hydrogen sulfide, have been been higher at Site 2. The remaining Hydrolab data, pH and conductivity, followed trends that were typical for Lake Whatcom.

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 samples at 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 is beginning to look increasingly similar to Site 1. Site 1 continued to have the highest chlorophyll concentrations of all the sites. The plankton counts at all sites were dominated by Chrysophyta.[1] Plankton biovolume studies indicated that the numerical plankton counts underestimate the density of other taxa, particularly summer and fall blooms of Chlorophyta and Cyanophyta.

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

Most of the September metals concentrations were at, or below, detection limits, and those that were detected were within normal concentration ranges for surface water. Soluble iron was present in raw water at the Lake Whatcom gatehouse during late summer and fall. Low-level mercury analyses indicated that the water column concentrations of mercury were usually <0.0002 mg/L. Total organic carbon concentrations in the lake ranged from <1 mg/L to 2.7 mg/L, and were similar to the TOC concentrations measured by the City of Bellingham in raw water at the gatehouse.

Strawberry sill was sampled on October 10, November 7, and December 7, 2000, and January 18, April 12, May 8, June 6, July 10, August 1, and September 6, 2001. The water quality along the sill was very similar to Site 3.

The creeks were sampled on February 22 and July 18, 2001. Most of the 2000/2001 creek data fell within expected ranges. Compared to the streams in forested areas, the residential streams typically had poorer water quality, with higher conductivities; higher ammonia, phosphorus, and total suspended solids concentrations; and much higher total and fecal coliform counts. These differences are typical for streams receiving urban runoff. The Park Place drain and Silver Beach Creek exceeded Part A and B of the current Class AA fecal coliform standards.[2] Anderson, Austin, Blue Canyon, and Smith Creeks passed Part A but exceeded Part B of the current fecal coliform standard because more than 10% of the fecal coliform counts were greater than 100 cfu/100 mL. It is likely that all watershed creeks except the Park Place drain, Silver Beach Creek, and possibly Austin Creek, would pass the proposed *E. coli* standard for recreational waters.[3]

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 was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage in the watershed. The major inputs into the lake include surface and subsurface runoff (73.6%), direct precipitation (19.3%), and diversion from the Middle Fork of the Nooksack River (7.1%). The

[2] "Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; Part B: no more than 10 percent of all samples obtained for calculating the geometric mean value shall have values exceeding 100 colonies/100 mL" (WAC 173–201A–030).

[3] "In freshwaters, *E. coli* organisms levels must not exceed a geometric mean value of 100/100 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 200/100 mL" (See http://www.ecy.wa.gov/programs/wq/swqs/index.html).

largest output was Whatcom Creek (44.5%), followed by Georgia Pacific (20.5%), City of Bellingham (17.3%), evaporation (12.6%), the fish hatchery at Whatcom Falls Park (4.5%) and Water District #10 (0.6%). There was a 51.8% reduction in total outputs of the lake when compared to the 1999/2000 values. The most significant of these include a 61.5% reduction in Whatcom Creek outflow and a 60.7% reduction in Georgia Pacific outflow. Lake Whatcom water movement studies continued this year, and included studies of the dispersion of Anderson Creek into the lake and additional drifter studies. Temperature studies at the mouth of Anderson Creek indicated that the creek water enters the lake along a narrow thalweg (submerged channel in the delta) before dispersing in a fan shape. Drifter studies showed a clockwise rotation in basin 3 near the confluence of Anderson Creek. The movement of near-surface lake water probably affected the insertion dynamics of Anderson Creek water flowing into Lake Whatcom. Additional drifter experiments in basin 1 (just west of the Geneva Sill) showed clockwise water movement that followed the wind direction.

During the summer of 2000, Karel Tracy, a WWU geology graduate student, measured the bathymetry and sedimentation rate in Mirror Lake. Tracy estimated the volume of the lake to be 321,900 cubic meters, with a surface area of 57,510 square meters. The maximum depth of the lake was about 10.05 $\pm$0.15 meters. The post-diversion sediments were 2.5 meters thick near the delta, and 1.3 m thick in the middle of the lake. Tracy estimated that about 60,000 $\pm$6000 cubic meters, or about 1600 $\pm$160 cubic meters per year of sedimentation occurred between 1962 and 2000.

Park Place and Brentwood wet ponds were sampled on January 15–17 (wet season - nominal flow), April 17–19 (wet season - storm flow), and July 24–26, 2001 (dry season - nominal flow). A new site, the S. Campus storm water treatment facility, was sampled on March 20–22, May 15–17, and August 6–8, 2001. As in previous years, the Park Place wet pond continued to perform poorly for most types of contaminants, with no consistent reduction in total suspended solids, nutrients, total organic carbon, or metals concentrations between the inlet and outlet; however, both the Brentwood wet pond and the S. Campus storm water treatment facility provided reasonably consistent reductions in suspended solids, nutrients, and coliforms.

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[4], which, until this year, accounted for the largest withdrawal of water from the lake. 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 1960's. 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 2000/2001 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams, collect supplemental water quality data from basin 3 near Strawberry sill, update the hydrologic model for Lake Whatcom, and monitor the effectiveness of the Park Place and Brentwood wet ponds. In addition to monitoring the Park Place and Brentwood wet ponds, samples were collected from the inlet and outlet to a new, rock/plant storm water treatment system that was installed on the south side of Western Washington University. Although this system is located outside the Lake Whatcom watershed, it should serve as an indicator of the level of storm water treatment that might be accomplished within the watershed. This report also includes the preliminary results from seasonal plankton

[4] The Georgia-Pacific 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.).

biovolume studies and the results from a graduate student thesis project to update the bathymetry and sedimentation data for Mirror Lake.

This report is subdivided into the following sections:

Section 1: Introduction
Section 2: Lake Whatcom Monitoring
Section 3: Creek Monitoring
Section 4: Lake Whatcom Hydrology
Section 5: Storm Water Treatment Monitoring
Section 6: Quality Control
Section 7: References
Section 8: Tables
Section 9: Figures
Appendix A: Site Descriptions
Appendix B: Data
Appendix C: AmTest Reports

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 33 on page 218 (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 70 and Appendix A.1, page 209). 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 raw 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). Three additional sites were monitored on a transect across Strawberry sill (Figure 142, page 214 in Appendix A.1). These sites are located on the 40-m depth contour as described in Appendix A.1.

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 2000/2001 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 for 2000/2001 were: October 3, 5 & 10, November 7 & 9, December 6 & 7 2000, and February 13 & 14, April 10 & 12, May 8 & 10, June 5 & 6, July 10 & 11, Aug 1 & 2, and September 4 & 6, 2001. The water quality parameters measured for the 2000/2001 lake monitoring program are listed in Table 1 on page 38 (see Section 8, beginning on page 37, 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 39 (APHA, 1998; Ebina, et al., 1983; 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.[5] Plankton samples were placed in a cooler and returned to the laboratory unpreserved. In the laboratory the sample volumes were measured and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. All other analyses were done by the personnel hired by this grant.

2.3 Results and Discussion

2.3.1 Hydrolab data

Lake Whatcom Hydrolab data for temperature, dissolved oxygen, conductivity, and pH are illustrated on Figures 2–31 (pages 71–100). The raw data are included in Appendix B.1 (page 219) and in electronic format on the CD that accompanies this report. Figures 12–31 show a ten year history of results for Lake Whatcom. Matthews, et al. (2000) reviewed the long-term data and discussed apparent trends, so only new observations on long-term trends are discussed below.

Single-day Hydrolab profiles from February and September are illustrated on Figures 2–11 (pages 71–80). Single-day Hydrolab profiles are sent to the City of Bellingham Public Works Department approximately monthly as part of the reporting process for this project. These figures show typical winter and late summer vertical depth profiles for temperature, dissolved oxygen, pH, and conductivity.

The mid-winter Hydrolab profiles (Figures 2–6) and the multi-year temperature profiles (Figures 12–16) show that the water column mixes during the fall, winter, and early spring. As a result, temperatures, dissolved oxygen concentrations, pH, and conductivities are fairly uniform from the surface to the bottom of the lake, even at Site 4, which is over 300 ft. (100 m) deep.

During the summer 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. In Lake Whatcom, stratification usually begins in April or May at all sites except the Intake, which is too shallow to develop a stable stratification. Stratification develops

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

gradually, and may not be stable until June. Stratification persists until fall or winter, depending on location in the lake. Destratification often occurs abruptly. If the weather conditions are cold and windy, and the water temperatures at the surface and bottom are within a few degrees of each other, the lake will destratify within a few days. If, however, warm, calm weather returns, the destratification process will be prolonged for up to a week or more. The two shallow basins (Sites 1–2) cool quickly and destratify by late October or early November. Basin 3 (Sites 3–4) cools slowly because of its large volume and may not destratify until December or later.

The average water temperatures at each site (Tables 3–7, pages 40–44) were similar to last year's lake temperatures (see Matthews, et al., 2001). This year's average temperature for the entire lake was 11.03° C, which is close to the historic average of 11.22° C (October 1988–September 1999, all sites and depths). Despite this apparent similarity, there were striking differences in the 2000/2001 temperature data. As a result of a cool, windy spring, basin 1 was only weakly stratified by early June. On June 5, 2001, there was a 3.6° C temperature difference between surface and bottom samples at Site 1, which was about half the the average difference measured in previous years (see Table 8, page 45). The surface-to-bottom temperature difference at Site 2 was closer to the historic averages, but was still nearly 2° cooler than average.

Despite the late stratification in basins 1 and 2, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures 7–8 and 17–18, pages 76–77 and 86–87). 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 11 and 21, pages 80 and 90). In contrast, Site 1, which is located in nutrient-enriched waters, shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures 7 and 17, pages 76 and 86).

Historic data show that the bottom of basin 1 has experienced low oxygen conditions for at least 30 years. However, there is evidence that the oxygen conditions in the hypolimnion at Site 1 have deteriorated since 1988. Table 9 (page 46) shows the depths at Site 1 where oxygen first drops below 1 mg/L in early September, 1988–2000. Since 1994, this depth has moved several meters closer to the surface. There was no similar pattern in the early September temperature data (Table 10, page 47).

Pearson's r correlation analysis[6] of dissolved oxygen vs. date confirmed that there were statistically significant reductions in oxygen levels at all even depths ≥ 12 m from July through September (Figures 32–35, pages 101–104).[7] In previous years, the June correlations were also significant; however, in 2001, the unusual late stratification of the lake resulted in relatively high dissolved oxygen levels in the hypolimnion at Site 1 during June. As a result, the June correlations were no longer significant. The July–August oxygen correlations remained negatively correlated with time.

None of the hypolimnetic temperature data were significantly correlated with year at the 95% significance level. There were no significant correlations between lake level and hypolimnetic oxygen concentrations or between June–September lake levels and year.

A number of environmental factors can affect the rate of oxygen loss from the hypolimnion, either directly, by increasing biological respiration, or indirectly by increasing the residence time of water in the hypolimnion. Increased nutrient availability, higher water temperatures, and increased light intensity can stimulate biological productivity and respiration. Dry weather, early lake stratification, late turnover, reductions in the amount of water diverted from the Nooksack, and decreased discharges into Whatcom Creek could increase the residence time of water in the hypolimnion. In addition, if the lake level drops far enough, our sampling equipment (which measures depth from the surface) could be placed lower in the hypolimnion, thus creating the appearance of lower oxygen levels, when the only real change is lower lake levels. However, the absence of significant correlations between hypolimnetic temperature or lake level and dissolved oxygen indicate that the oxygen vs. year correlations were not an artifact of sampling lower in the lake, nor were they strictly the result of temperature effects. Also, the year-to-

[6]The Pearson's r correlation coefficient is a measure of the amount of change in the data that is predicted by "date." Strong positive or negative correlations will be close to ± 1.0. Weak correlations, or no correlation, will be close to zero. Statistically significant correlations have p values ≤ 0.05.

[7]Only even depths were plotted on Figures 32–35 because early Hydrolab data were collected at 2 meter intervals.

year variation in lake level during the summer was less than 1 meter, which is less than our minimum interval of measurement for dissolved oxygen concentrations. Although temperature and lake level undoubtedly modify hypolimnetic oxygen conditions (for example, the late stratification in 2001 resulted in unusually high June oxygen data at Site 1), the oxygen trends in Lake Whatcom are not simple correlates of water temperature or lake level.

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 drinking water treatment costs; increased taste and odor problems in drinking water; and increased risks associated with chlorination byproducts created during drinking water treatment process. Hydrogen sulfide was detected at Site 1 (0.42 mg/L) and Site 2 (0.76 mg/L) on October 9, 2001, and elevated concentrations of ammonia and phosphorus were detected on October 2. These compounds are all indicative of low oxygen conditions.

Although Site 1 continued to develop severe, late summer, hypolimnetic anoxia, for the past three years, the concentrations of two water quality indicators of lake anoxia, ammonia and hydrogen sulfide, have been been higher at Site 2 (Table 11, page 48). Correlation analyses of the hypolimnetic dissolved oxygen concentrations at Site 2 did not produce the same type of consistent downward trend in oxygen over time as is seen at Site 1. The hypolimnetic oxygen concentrations at Site 2 have varied widely since at least 1988, so trends are much more difficult to establish. At this time, it is not possible to tell whether Site 2 water quality is getting worse; however, the high ammonia and hydrogen sulfide levels are an indicator that water quality at this site should be watched carefully.

A second long-term oxygen trend is present in basin 3 (see Matthews, et al. 2000). Although not as dramatic as the hypolimnetic oxygen patterns at Site 1, the oxygen concentrations at Sites 3 and 4 have decreased significantly[8] during the past two decades (Figures 20–21, pages 89–90). Unlike the Site 1 hypolimnetic oxygen trend, the basin 3 oxygen trend does not appear to be restricted to the hypolimnion.

[8]Regressions of median dissolved oxygen concentrations vs. year were significant ($p \leq 0.05$) at Sites 3 and 4.

The remaining 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, especially at Site 1. 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 is apparent in the conductivity data (see Matthews, et al. 2000) at all sites. 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 36–115 (pages 105–184) and summarized in Tables 3–7 (pages 40–44). In order to provide a better analysis of the water quality patterns in the lake, the graphs include ten years of monitoring data. Matthews, et al. (2000) reviewed the long-term data and discussed apparent trends.

Because of the large amount of data collected for the Lake Whatcom monitoring program, only important or unusual patterns will be discussed in the text. The raw water quality data are listed in Appendix B and C, beginning on page 217, and portions of the data are included in electronic format on the CD that accompanies this report. The metals data are listed in Table 12 (page 49); the original AmTest data reports (metals and total organic carbon) are included in Appendix C (page 272) and on the CD that accompanies this report.

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures 36–40, pages 105–109). 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 samples at the lower depths at Sites 1 and 2 (Figures 41–45, pages 110–114). 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 46–65, pages 115–134). The nutrient data from Site 2 are beginning to look increasingly similar to Site 1, but it is too early to tell whether this represents normal variability or a water quality trend.

High ammonia concentrations were measured just prior to overturn in the hypolimnia at Sites 1 and 2 (Figure 51, page 120). High hypolimnetic ammonia concentrations have been common at both sites for more than ten years; however, the last three summers produced atypically high ammonia concentrations at Site 2. Ammonia is produced during decomposition of organic matter (Wetzel, 1983). 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 hypolimnia 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. Site 3 had elevated ammonia concentrations at 80 m during late summer, which was the result of low oxygen concentrations that were present in the hypolimnion during late summer.

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures 56–60, pages 125–129), particularly at Site 1, where the epilimnetic nitrate concentrations fell to <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 is common in freshwater lakes (see Elser, et al., 1990) and appears to occur at Site 1 in Lake Whatcom just prior to overturn (Matthews, et al., 2002). 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 seldom fell below 150 μg-N/L, making it unlikely that nitrogen was limiting at these sites.

In October 2000 and 2001 the hypolimnetic nitrate concentrations were lower than the epilimnetic concentrations at Sites 1 and 2 ($<$20 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 relatively low ($<$10 μg-P/L) at all sites and depths (Figures 71–75, pages 140–144). Total phosphorus concentrations were high at Sites 1 and 2 during late summer, but relatively low at other sites (Figures 76–80, pages 145–149). Sediment-bound phosphorus becomes soluble in low oxygen environments. As a result, in low oxygen environments, such as the hypolimnia at Sites 1 and 2, total phosphorus concentrations are often higher than 20 μg-P/L (Figures 76 and 77). Another major source of phosphorus for Lake Whatcom is from storm runoff. The small peaks in total phosphorus measured during December, 1999 at Sites 3–4 were probably from runoff because the concentrations were higher near the surface of the lake than at the bottom (Figures 79 and 80).

Site 1 continued to have the highest chlorophyll concentrations (Figures 81–85, pages 150–154) of all the sites. The chlorophyll concentrations during the summer of 2001 were about the same as in 2000. As in previous years, the 20 meter samples from Sites 1 and 2 had low chlorophyll concentrations. These depths are located in regions with low light intensities and low oxygen concentrations, which are not favorable for algal growth. Peak chlorophyll concentrations were usually at 0–15 m.

The plankton counts at all sites were dominated by Chrysophyta[9] (Figures 86–95, pages 155–164). Substantial blooms of Cyanophyta and Chlorophyta were also measured at all sites during summer and late fall. As part of the 2000/2001 lake monitoring project, we collected algal biovolume data to help characterize algal population dynamics in the lake. The results from this study will be discussed separately at the end of this section.

Secchi depths continue to show no clear seasonal pattern because transparency in Lake Whatcom is a function of both summer algal blooms and winter storm events

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

(Figures 96–100, pages 165–169).

Most of the coliform and *Enterococcus* counts were low ($\leq$ 50 cfu[10]/100 mL for total coliforms and $\leq$ 10 cfu/100 mL for fecal coliforms and *Enterococcus*, Figures 101–115, pages 170–184). The total coliform counts at Site 2 were unusually high in September and October 2001 (and again in December 2001), but the fecal coliform and *Enterococcus* counts were both low. Similarly, the total coliform count was high at the Intake in October 2001.

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.4 for raw data). The Bloedel-Donovan bacteria counts tend to be slightly higher than mid-basin counts, but the 5-year (1997–2001) geometric mean for fecal coliforms was 7.9 cfu/100 mL, which passed both Part A and B of the existing Class AA standards for fecal coliforms[11] and would most likely pass the proposed *E. coli* standard for recreational waters.[12]

The metals data for Lake Whatcom are included in Table 12 (page 49). This table includes only the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); an additional 24 metals, which are included "free" as part of the analytical procedure used by AmTest, are included in Appendix C and on the CD that accompanies this report. In 1999, AmTest upgraded their equipment used to analyzed all of the metals except lead. As a result, many of the analyses now have lower detection limits, resulting in fewer "below detection" data. These newly detected metals should not be misinterpreted as a trend toward higher metals concentrations in the lake.

Most of the September metals concentrations were at, or below, detection limits, and those that were detected were within normal concentration ranges for surface water. Zinc was detected at low concentrations at all sites. Iron concentrations were elevated in all of the bottom samples except at the Intake, which is typical for Lake Whatcom. The highest concentrations, 0.160 mg/L and 0.031 mg/L, were measured at Sites 1 and 2, respectively. The higher iron concentrations at

[10] cfu = colony forming unit

[11] "Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; Part B: no more than 10 percent of all samples obtained for calculating the geometric mean value shall have values exceeding 100 colonies/100 mL" (WAC 173–201A–030).

[12] "In freshwaters, *E. coli* organisms levels must not exceed a geometric mean value of 100/100 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 200/100 mL."

Sites 1 and 2 were the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water.

Soluble iron was also present in raw water at the Lake Whatcom gatehouse[13] during late summer and fall (Figure 116, page 185), particularly during the first few weeks after the lake destratified (November in Figure 116). Following lake turnover, most of the soluble iron is usually converted to insoluble iron, which slowly settles to the bottom. This year, however, there was a second spike in iron during March 2001. The cause of the March iron spike is not known.

Beginning in July, 2001, IWS started collecting additional water samples to check for mercury contamination in response to concern about mercury detected in fish and sediment samples from the lake (Serdar, et al., 1999; Mueller, et al., 2001). The samples were collected from the surface and bottom at Sites 1–4 and the Intake, and were sent to AmTest for low-level mercury analyses. On July 17, 2001, a field duplicate set of water samples were collected (two separate water samples were collected at each site and depth). The duplicate set was analyzed for low-level mercury by Environment Canada (Vancouver, BC). The water column concentrations of mercury were very low and most were below the detection levels for both laboratories (Table 13, page 50). AmTest detected mercury in samples from the Intake (0.0005 mg/L) and the bottom of Site 3 (0.0004 mg/L) on August 7, 2001. The City of Bellingham also detected mercury at the gatehouse on August 28, 2001 (∼0.0004 mg.L), as well as on June 5 & 12, 2001 (∼0.0002–0.0003 mg/L). The gatehouse results were below the laboratory detection limit, so the values should be considered estimates (Peg Wendling, City of Bellingham Public Works Department).

The Lake Whatcom total organic carbon concentrations ranged from <1 mg/L to 2.7 mg/L (Table 14, page 51). These concentrations were about the same as the October 2000–September 2001 TOC concentrations measured by the City of Bellingham in raw water at the gatehouse, which ranged from 1.5–3.9 mg/L, and averaged 2.2 mg/L.[14] 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) through the reaction of chlorine with organic compounds during the drinking water treatment process. Lake Whatcom had relatively low concentrations of TOC in raw water, as well as relatively low concentrations of trihalomethanes in treated water.

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

[14]Data from Public Works Department, Plants Division, City of Bellingham.

In 2001, the quarterly average THM concentrations in the Bellingham water distribution system ranged from 28.3–37.3 μg/L. These concentrations are below the recommended maximum THMs concentrations for treated drinking water (80 μg/L). Beginning in the fall of 1998, however, higher THM concentrations started showing up in the treated water, particularly in the fall (Figure 117, page 186). This pattern has been consistent for the past four years.

2.3.3 Plankton biovolume

Plankton biovolume is often used to estimate algal biomass, and is generally considered to be superior to simple taxonomic counts, which overestimate the importance of small, numerically dominant taxa such as single-cell diatoms and flagellates (Wetzel and Likens, 1991). Nearly all plankton biovolume studies begin by identifying plankton to the species level. Representatives from each species are matched to similarly shaped geometric solids, then appropriate length and width measurements are collected using a calibrated microscope. For example, the measured diameter from a round, single-celled organism, would be used to estimate the volume of a similarly shaped sphere. Wetzel and Likens (1991) illustrate appropriate measurements for a variety of geometric solids that approximate the biovolume of variously shaped algae.

In Lake Whatcom, plankton are counted using conventional procedures, but are only identified to phylum. Although we recognize that numerical counts are not a particularly accurate measurement of algal densities in the lake, the additional costs associated with conducting detailed plankton identifications are not justified in a long-term monitoring project. Accordingly, our objective in the 2001 biovolume study was to determine whether meaningful data could be obtained from generating plankton biovolume estimates for samples identified only to phylum.

The plankton biovolume data were collected by Shannon Ashurst, a graduate student in the Environmental Studies program at Huxley College, Western Washington University (Ashurst, 2001). Ashurst collected plankton samples from Lake Whatcom during the spring and summer of 2001. Using a Nikon Eclipse E400 microscope with a Cool Snap digital camera and specialized image analysis software (MetaMorph version 4.5r5), she compiled a digital library of plankton images and measured the biovolume for the following taxa:

Chlorophyta	Chrysophyta (Heterokontophyta)	Pyrrhophyta (Dinophyta)	Cyanophyta
Botryococcus	*Asterionella*-diatom	*Ceratium*	*Coelosphaerium*
Cosmarium	*Fragilaria*-diatom	*Peridinium*	*Gloeocapsa*
	Melosira-diatom		Nostocales
	Synedra-diatom		
	Dinobryon		
	Mallomonas		

The algal biovolume data are included in Appendix B.3 and summarized in Table 15 (page 52). Because of the very large variance in the data, medians and geometric means are more appropriate indicators of central tendency in the data than the arithmetic mean.

In the numerical counts, Chrysophyta usually dominate the algal samples (Figures 86–90, pages 155–159). However, the Chrysophyta have the lowest phylum-level algal biovolume, while the Pyrrhophyta (Dinophyta) and Chlorophyta have the largest. This is because diatoms and other members of Chrysophyta tend to be small, single-celled taxa or consist of filaments with small cells. The Pyrrhophyta are all very large single-cell organisms. Taxa in the phylum Chlorophyta have a considerable range of shapes and sizes, as indicated by the minimum and maximum biovolumes in Table 15.

One taxon in particular, *Botryococcus*, consists of hundreds to thousands of tiny cells joined into an irregularly shaped colony. In our numerical counts these colonies count as "one" counting unit because it is nearly impossible to enumerate individual cells. The biovolume of each colony is huge, and results in a large phylum-level biovolume average for Chlorophyta. For the past few years *Botryococcus* has been quite common in Lake Whatcom during late summer algal blooms, where it can be seen with the unaided eye, appearing as tiny, bright green flakes floating the the water. Lake Whatcom plankton studies from 1987–1988 (Ehinger, 1988) indicated that *Botryococcus* was present but not common. It is common for lakes to have periodic shifts in plankton dominance. In Lake Whatcom, the Chlorophyta may have episodic shifts between *Botryococcus* and smaller taxa such as green flagellates. This would explain the widely varying Chlorophyta counts seen in the 10-year plankton figures (Figures 91–95, pages 160–164).

During winter and spring, the large differences in phylum-level biovolumes are not relevant because the counts for all phyla except Chrysophyta are very low (often zero for Cyanophyta and Pyrrhophyta). During the summer and early fall, however, when Cyanophyta and Chlorophyta densities peak, biovolume conversions would accentuate the Cyanophyta and Chlorophyta blooms throughout the lake.

The results from our preliminary biovolume studies show that there is an unacceptably large amount of variance associated with calculating biovolume at the phylum level. There was up to five orders of magnitude difference between the minimum and maximum biovolume estimates for individual taxa within each phylum. Most of this variance comes from combining large and small sized taxa within a phylum. It seems unlikely that phylum-level biovolumes will prove to useful for estimating algal population densities.

2.3.4 Strawberry sill data

The Strawberry sill Hydrolab, water quality, and metals data are summarized in Tables 16–18 (pages 53–55) and the raw data are included in Appendix B.5 (page 263). The AmTest data reports for the metals and total organic carbon analyses are included in Appendix C (page 272) and are available in electronic format on the CD that accompanies this report.

Strawberry sill was sampled on October 10, November 7, and December 7, 2000, and January 18, April 12, May 8, June 6, July 10, August 1, and September 6, 2001. The water quality along the sill was very similar to Site 3. The water temperatures along the sill were generally within 1–2° C of temperatures at Site 3. The total nitrogen and total phosphorus concentrations were considerably higher at Site 3 in February compared to the January samples from the sill, but this could be the result of turnover replenishing epilimnetic nitrogen and phosphorus. Turnover often occurs in late December or early January in basin 3. Most of the metals concentrations were at or near the detection limits. Iron and zinc were detectable, but within ranges normal for the lake. Most of the sill total organic carbon concentrations were similar to Site 3. On January 17, an unusually high total organic carbon concentration was measured at the surface (6.3 mg/L); the reason for this high concentration is not known.

3 Creek Monitoring

3.1 Site Descriptions

Seven creeks were sampled twice during the 2000/2001 monitoring program, including Austin Creek, Anderson Creek[15], the Park Place storm drain, 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 (page 215).

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); one underground storm drain (Park Place drain); two large, perennial creeks (Austin Creek and Smith Creek); and Anderson Creek, which is a major water source for Lake Whatcom because 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 drain) 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 22 and July 18, 2001. The water quality parameters measured for the 2000/2001 creek monitoring program are shown in Table 19 (page 56). The analytical procedures are summarized in Table 2 (page 39). 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,

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

copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest, Inc. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. All other analyses were done by the field and laboratory personnel hired by this grant.

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 20–21 (pages 57–60) show the recent creek water quality data compared to the 1990 average water quality values for each creeks. Tables 22–24 show metals, total organic carbon, and coliform data from the 2000/2001 sampling period.

Most of the 2000/2001 creek data fell within expected ranges. Compared to the streams in forested areas, the residential streams typically had poorer water quality, with higher conductivities; higher ammonia, phosphorus, and total suspended solids concentrations; and much higher total and fecal coliform counts. These differences are typical for streams receiving urban runoff.

Conductivities were high in Blue Canyon Creek, which is normal for this stream because it flows through mineral-rich soils. The summer dissolved oxygen concentration was low and water temperature was high in the Park Place drain because the site drains the Park Place wet pond. The winter dissolved oxygen level was very low in the Silver Beach Creek sample, which is an unusual result for surface streams, even residential streams.

In previous years Anderson Creek has had high total suspended solids and turbidity values in the summer because of the glacial silt entering the creek from the Nooksack River diversion. However, the diversion was off during most of the 2000/2001 monitoring period, and the Anderson Creek solids and turbidity values were similar to Smith Creek. All of the streams had higher total suspended solids and turbidity values in the winter because of storm runoff.

The nitrite/nitrate and total nitrogen concentrations were higher in the winter samples at all sites due to leaching of soluble nitrogen compounds during the wet season. Ammonia concentrations were highest in the Park Place drain. Ammonia is converted fairly quickly to nitrate in turbulent water, so the ammonia in the

Lake Whatcom streams probably came from near-by watershed sources (animal wastes, swampy areas, etc.) or the Park Place storm water treatment pond. The phosphorus concentrations continued to be higher in the residential creeks (Park Place drain and Silver Beach Creek) than in the forested creeks (Smith Creek, Wildwood Creek, and Blue Canyon Creek). The Park Place drain has had a storm water treatment pond in place since 1994, but the treatment pond does not appear to be reducing the phosphate concentrations in the outflow. (Our sampling site is located downstream from the Park Place treatment pond.)

The metals concentrations were below detection limits at all sites except for chromium, copper, iron, and zinc. Iron and zinc were within normal ranges for surface water in the Lake Whatcom watershed. Chromium and copper were close to the limits of detection, and probably do not represent a change in the water quality of the creeks. Silver Beach Creek and the Park Place drain had the highest total organic carbon concentrations during February but Smith Creek had the highest concentration in July (Table 23, page 60). In previous years the total organic carbon concentrations from Smith Creek were usually less than 2.5 mg/L, so the July 2001 data are unusual. The higher concentration may be due to low flow conditions in 2001, but if so, the effect was not observed at the other creeks.

Coliform counts (Table 24, page 61) were higher in the Park Place drain and Silver Beach Creek than in the other streams, but all counts were within ranges normal for each stream. The Park Place drain and Silver Beach Creek[16] exceeded Part A and B of the Class AA fecal coliform standards.[17] Anderson, Austin, Blue Canyon, and Smith Creeks passed Part A but exceeded Part B of the fecal coliform standard because more than 10% of the fecal coliform counts were greater than 100 cfu/100 mL. Of the creeks that passed Part A but failed Part B, Austin Creek had the largest number of samples exceeding 100 cfu/100 mL (4 out of the last 10 samples). The historic data from Austin Creek (Table 25, page 62; Appendix B.4) show that the creek coliform counts are usually lower during the winter than the summer.

[16]Silver Beach Creek was placed on the 1998 303D List of Impaired and Threatened Waterbodies for high coliform counts.

[17]Current standard: "Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; Part B: no more than 10 percent of all samples obtained for calculating the geometric mean value shall have values exceeding 100 colonies/100 mL" (WAC 173–201A–030).

The Washington State Department of Ecology is considering revising the surface water bacteria standards to use *Escherichia coli* as the indicator organism rather that fecal coliforms.[18] *Escherichia coli* is usually the dominant species in fecal coliform counts, typically comprising 90–99% of the organisms. *Escherichia coli* counts correlate better with gastrointestinal illness in recreational waters than fecal coliform counts. Because *E. coli* is a subset of the fecal coliform count, the *E. coli* counts in the Lake Whatcom watershed creeks should be equal to or less than the historic fecal coliform counts. It is likely that all watershed creeks except the Park Place drain, Silver Beach Creek, and possibly Austin Creek, would pass the proposed *E. coli* standard.

[18]Proposed standard: "In freshwaters, *E. coli* organisms levels must not exceed a geometric mean value of 100/100 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 200/100 mL" (See http://www.ecy.wa.gov/programs/wq/swqs/index.html).

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 (page 215). Copies of the hydrograph data are included on the CD that accompanies this report, and the data are summarized on Figure 118 (page 187).

The hydrograph data were recorded at 30 minute intervals throughout the year, except during infrequent periods of recorder failure or extreme low flow. The stilling well at Anderson Creek was rebuilt during the fall of 2001 and was not operational for extended periods of time due to low flow and construction activities. The hydrograph for Austin Creek has no missing data and the Smith Creek hydrograph is complete except for 5 hours on March 18 2001 (battery failure).

Figure 119 (page 188) shows the rating curves for each hydrograph. Flow estimates for Anderson Creek were calculated using two rating curves. The first rating curve covered the period from October 1, 2000 through March 18, 2001. On March 18, a large debris jam, which had accumulated near the Anderson Creek flow recorder, was removed from the creek. All flow estimates after that date were calculated using a new rating curve.

4.2 Water Budget

A water balance was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage in the watershed. 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 fish hatchery at Whatcom Falls Park, City of Bellingham, Georgia Pacific, and Water District #10. 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 fish hatchery gauges. Precipitation data from the Water District #10, Division 30 gauge were substituted for the Brannian Creek location for the months of October and November 2000 and March and April 2001, because the Brannian Creek gauge was inoperable and the two gauges were found to be comparable during other months. Precipitation data from the Water District #10 District Office gauge were substituted for the Smith Creek location for the months of October and November 2000, because the Smith Creek gauge was inoperable. 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 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.

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 average local or regional energy and climate data. Actual lake evaporation was estimated from the free-water estimates by calibrating the values to pan evaporation data from the Post Point weather station. The estimated actual daily evaporation depth (inches) for a given day was converted to a volume (MG) via a rating curve generated from the lake level-area data developed by Ferrari and Nuanes (2001).

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 was backed out from the water balance values by adding the outputs to the change in storage and subtracting the precipitation and diversion magnitudes.

The yearly water balance totals are listed in Table 26 (page 63). The total input to the lake was 24,938 MG. Of the total, 73.6% was surface/subsurface runoff (including groundwater), 19.3% direct precipitation, and 7.1% was diversion water. Also listed in Table 26 are the yearly total values for the previous water year (1999/2000). There was a 48.3% reduction in total inputs into the lake when compared to the 1999–2000 values, which corresponds to a 32% reduction in total precipitation, a 61% reduction in diverted water, and a 49.8% reduction in runoff.

The total outputs summed to 23,621 MG. The largest output was Whatcom Creek (44.5%), followed by Georgia Pacific (20.5%), City of Bellingham (COB; 17.3%), evaporation (12.6%), the fish hatchery at Whatcom Falls Park (4.5%) and Water District #10 (0.6%). There was a 51.8% reduction in total outputs of the lake when compared to the 1999/2000 values. The most significant of these include a 61.5% reduction in Whatcom Creek outflow and a 60.7% reduction in Georgia Pacific outflow.

The daily water balance quantities were summed into weekly totals. The weekly totals were used to generate plots of the input, output, change in storage, and estimated runoff volumes (Figures 120–122, pages 189–191). All the inputs, except for runoff, are shown in Figure 120 and all the outputs, except for Whatcom Creek, are shown in Figure 121. The runoff and Whatcom Creek are shown with the change in storage values in Figure 122 because they have similar magnitudes. As indicated by the plots in Figure 122, large storage changes occur when the runoff is high and the Whatcom Creek discharge is low, and vice versa. Because of the decrease in inputs and outputs compared to the 1999/2001 water year, the residence time for water in the lake is longer, which may have impacts on water quality.

Changes in the Nooksack Diversion and Georgia Pacific Withdrawals

Two major hydrologic changes are occurring that are likely to influence water quantity and quality in Lake Whatcom. First is the reduction in withdrawals that occurred as a result of reduced operations at the Georgia Pacific pulp mill. Historically, Georgia Pacific was the largest withdrawal from Lake Whatcom; currently its withdrawal is about the same as the City of Bellingham (Figure 121). The second major change began several years ago when the City of Bellingham voluntarily started reducing the amount of water they diverted from the Middle Fork of the Nooksack River (Figure 123, page 192). These two changes will result in less water moving through the lake, particularly during the summer. At present, its not clear how much effect these changes will have on water quality in the lake. It is worth noting, however, that the reduction in diversion coincides with the worsening water quality in basin 2.

4.3 Influence of Anderson Creek on Lake Whatcom Hydrology

This section describes work in progress by Matt Chase, WWU geology graduate student, as part of the research requirements for his M.S. thesis.

When the diversion is operating, the temperature of Anderson Creek is discernibly colder than the epilimnion of Lake Whatcom when the lake is stratified. To examine the impact of the diverted water on the lake, the plunge and dispersion of Anderson Creek into Lake Whatcom was mapped by recording vertical and horizontal temperature values near the confluence in Lake Whatcom. The measurements were made on May 17, 2001 when the diversion was operating. The flow of the creek on that day was 0.99 m^3/sec. The lake was stratified and the thermocline was 12 m below the surface. A Montedoro Whitney Corp. Model TC-5C thermistor was placed in the lake and attached to a kayak. It continuously recorded temperature as the kayak was slowly paddled around the vicinity of the confluence. A Garmin ETrex GPS with an average accuracy of 6 meters was placed on the top of the kayak to map horizontal positions. This temperature mapping procedure was performed at the lake surface and at vertical depths of 1.0 meters and 2.54 meters.

The temperature contouring of the data set showed that the water from Anderson Creek would enter the lake along a narrow thalweg (submerged channel in the delta). The thalweg was physically visible when the lake was clear (no diverted water). The thalweg extended west into the lake from the northern side of the creek channel. Once the creek was no longer restricted laterally by the thalweg, it dispersed in a fan shape and plunged down the delta to an insertion depth of approximately 2.5 meters. Insertion means the creek became neutrally buoyant when its temperature was equal to the temperature of the lake. The shallow insertion depth was expected, given the small temperature contrast in between the creek and the lake in May ($\sim$2 °C). A second profiling was planned for the later part of the summer, but the diversion did not operate this year after June 15, 2001.

4.4 Drifter Studies

This section describes work in progress by Matt Chase, WWU geology graduate student, as part of the research requirements for his M.S. thesis.

Currents in some locations of the lake were measured by tracking the movement of drifters.[19] Drifters are drogue devices that are attached by a line to a surface float. The drifters move with the approximate speed and direction of the current at the depth at which the drifter is deployed. Drifters were placed at the surface and at 5-meter intervals below the surface, up to a 30-meter maximum. The drifters were tracked by monitoring the surface float positions using a Garmin ETrex GPS. The drifter experiments would typically last about 4 hours. Time was recorded using the GPS clock to the nearest minute.

The results of drifter experiments on April 10, 2001 showed a clockwise rotation in basin 3 near the confluence of Anderson Creek. The diversion was not operating at this time. The velocity of the currents decreased with depth from 73 meters per hour at the surface, to 10 meters per hour at a 20 meter depth. The currents wrapped around the basin in a clockwise direction following the bathymetry of the lake. The wind had an average speed of 54 meters per hour in the southeast direction. A second drifter experiment was performed on May 21, 2001 in the same vicinity of Anderson Creek in basin 3, when the diversion was operating. The drifters moved in the same direction as the wind, which had a southeast direction. Again, the current speed was greatest at the surface and decreased with depth. Near the surface, water moved in a southeast direction, up the mouth of Anderson Creek. The movement of near-surface lake water probably affected the insertion dynamics of Anderson Creek water flowing into Lake Whatcom.

Drifter experiments were performed in basin 1 just west of the Geneva Sill on April 15, 2001 and in basin 2 near the drinking water intake and over Geneva Sill on April 24, 2001. The wind was toward the northwest on both days. Both sets of drifters were deployed near the south shore of the lake and moved northwest (clockwise) in the direction of the wind. The speed of the currents decreased with depth. As expected, the maximum speed was at the surface and was controlled by the magnitude of the wind speed. The results also verified the strong communication between basins 1 and 2. The surface current velocity across Geneva Sill on April 24 was about 260 meters per hour in the northwest direction.

[19] See Matthews et al., 2000 and 2001 for more information about drifter studies in Lake Whatcom.

4.5 Internal Waves

This section describes work in progress by Matt Chase, WWU geology graduate student, as part of the research requirements for his M.S. thesis.

A common technique for examining internal wave dynamics is to deploy a chain of temperature sensors (thermistors) that record a times series of temperature values at the fixed locations spanning the stratification in the lake (Matthews et al., 2001). Stowaway Tidbit thermistors were tied in a vertical string between an anchor and a float, at 2 meter intervals starting at 5 meters below the surface to a depth of about 14 meters. Each thermistor recorded a temperature to a hundredth of a degree Celsius every 5 seconds. There were five thermistor strings deployed in the southernmost lobe of Lake Whatcom north of the mouth of Brannian Creek. The lake surface locations were marked with a Garmin ETrex GPS. The thermistor chains were underwater for approximately 2 months (March 22, 2001 to May 26, 2001). During the two-month recording duration, 15-minute wind speed values were collected at the North Shore weather station. This project is on-going and the data are not year available for inclusion in this report.

4.6 Mirror Lake Sedimentation

During the summer of 2000, Karel Tracy, a WWU geology graduate student, measured the bathymetry and sedimentation rate in Mirror Lake as part of his thesis research (Tracy, 2001). The purpose of his study was to characterize the changes in sedimentation rates that have occurred in Mirror Lake since the diversion from the Middle Fork of the Nooksack River began in 1962. A bathymetric map of the lake was produced and compared to the bathymetric map of Carpenter et al. (1992). The rate of sediment deposition was calculated from changes in bathymetry and using sediment cores extracted from three locations in the lake. The cores were also examined to characterize changes in the sizes of sediment deposited in the lake as a function of distance from the location where the diversion discharges into the lake.

Tracy characterized the bathymetry of Mirror Lake using 430 discrete depth measurements collected using an electronic total station and a 200 kHz single beam depth finder. The program Surfer 6.0 (Golden Software, 1997) was used to contour the data using a Kriging method (Figure 124, page 193). The measurement error was estimated to be 0.3 meters. Tracy estimated the volume of the lake to be 321,900 cubic meters, with a surface area of 57,510 square meters. The maximum depth of the lake was about 10.05 $\pm$0.15 meters. These values were calculated using Surfer 6.0 assuming the level of the lake when the diversion is operating is 111.59 $\pm$ 0.15 meters above Bellingham City datum. Bellingham City datum is 1.89 meters below the elevation of mean sea level that was established by the U.S. Coastal and Geodetic Survey (Joe Corbell, 2001, written communication).

Four sediment cores were extracted from the lake at three sites (Figure 124, page 193) using a Livingstone coring system. All the cores penetrated the post diversion sediments into the original organic lake bottom. The majority of the post-diversion sediment in each core was low-organic silt, mostly medium and coarse silt (diameter 0.031 to 0.063 mm). As might be expected, the thickness and grain size decreased away from the delta. The post-diversion sediments in core C3 contained about 45% medium and coarse silt, 25% very fine and fine sand, 20% very fine and fine silt, and 10% clay, in the Wentworth classification of grain sizes. In the Wentworth classification, the boundary between sand and silt is at 0.063 mm, the boundary between medium silt and fine silt is at 0.031 mm, and the boundary between silt and clay is at 0.004 mm. The composition of the sediments in cores C1 and C2 (middle of lake) was 50% medium and coarse silt, 25% very fine and fine silt, 15% very fine and fine sand, and 10% clay. Core C4, which was farthest from the delta, contained less sand (about 8% very fine sand) and more fine silt and clay (30% and 12% respectively) than cores from the center of the lake.

The post-diversion sediments were 2.5 meters thick in core C3, which was closest to the delta, and 1.3 m thick in cores C1 and C2 in the middle of the lake. Core C4, furthest from the delta, contained 1.0 m of post diversion sediment. Based on these depths, Tracy estimated that about 60,000 $\pm$6000 cubic meters, or about 1600 $\pm$160 cubic meters per year of sedimentation occurred between 1962 and 2000. This corresponds to about 3.4 cm per year in the middle of the lake. The infilling rate represents about 0.6% of the lake volume per year, assuming no settlement due to the consolidation of the original organic-lake bottom.

Tracy compared the bathymetric map of Carpenter et al. (1992) to the 2000 map using the Surfer 6.0 software. Except for a small region in the southeast portion of the lake near the delta, the apparent change in elevation of most of the lake bed was not significantly greater than the uncertainty in the depth measurements. Where possible, Tracy calculated differences between the maps and used information from the core depths to develop a map of apparent sedimentation between 1991 and 2000 (Figure 125. page 194). Based on this map, about 15,000 ±2000 cubic meters of sediment have been deposited between 1991 and 2000, or an average of 1700 ±220 cubic meters per year.

Reference Marker Location

A permanent reference marker was established in order to complete the bathymetry survey of Mirror Lake (Figure 124, page 193). The reference marker is a ∼0.3 m diameter concrete disk cemented into a bedrock outcropping along the southern part of the Mirror Lake shoreline. A detailed description of the reference marker site, along with a photograph showing its locations, is included in Mr. Tracey's thesis (Tracey, 2001).

5 Brentwood, Park Place, S. Campus Monitoring

The objective of this project was to continue monitoring 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 126 page 195). The new S. Campus monitoring site is located south of Bill McDonald Pkwy, west of 25th Street, and north of Taylor Avenue (Figure 127, page 196).

5.1 Sampling procedures

Park Place and Brentwood wet ponds were sampled on January 15–17 (wet season - nominal flow) April 17–19[20] (wet season - storm flow), and July 24–26, 2001 (dry season - nominal flow). The S. Campus storm water treatment facility was sampled on March 20–22, May 15–17, and August 6–8, 2001.

Composite and grab samples were collected at the inflow and outflow(s) at each site (Brentwood and Park Place have a single outflow; the S. Campus site has two outflows). 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. Total and fecal coliforms were analyzed by the City of Bellingham.

[20] During the first 24-hr of the April 17–19, 2001 sampling at the Park Place outlet and Brentwood inlet the ISCO samplers were not programmed correctly so the samples represent 24-hr composites rather than 48-hr composites.

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 (Matthews, et al., 2000). Both ponds have extensive macrophyte growth, as shown on Figures 128–129 (pages 197–198). The S. 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 the first summer (Figure 130, page 199).

January 15–17, 2001 and March 20–22 represented "wet season - nominal flow" sampling conditions. There was no precipitation for 48 hrs preceding sampling or during sampling. April 17–19 and May 15–17 represented "wet season - storm flow" conditions, having been preceded by wet weather for several weeks prior to sampling. Precipitation was below average during the winter and spring of 2001, however, so all of the 2001 wet season samples were collected under low to moderate flow conditions. All of the storm water runoff was flowing through the ponds during the January and April sampling periods. The July 24–26 and August 6–8 samples were collected during "dry season - nominal flow" conditions, during a unusually dry summer, with little to no precipitation for several weeks prior to sampling.

Tables 27–30 (pages 64–67) show the raw data from the Park Place, Brentwood, and S. 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 S. Campus storm water treatment facility. Average percent reductions were computed as follows:

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

The lower mercury detection limits for the S. Campus samples (Table 27) were the result of AmTest using low-level detection methodologies. Future samples will be analyzed using the same detection limits as are used for the Park Place and Brentwood samples.

As in previous years, the Park Place wet pond did not remove solids or phosphorus from the water flowing through the pond. On average, the concentrations of total suspended solids, total organic carbon, and total phosphorus were higher at the outlet than at the inlet (Table 27). In contrast, both the Brentwood and the S. Campus treatment facilities had lower total suspended solids, total nitrogen, and total phosphorus concentrations at the outlet. Park Place and Brentwood produced substantial reductions in coliforms and *Enterococcus* counts, but the S. Campus facility had higher *Enterococcus* counts at the outlet. The unusually high bacterial counts at the outlets from the S. Campus facility may reflect local use of the facility by people walking dogs along the gravel paths that surround the rock/plant filters (R. Matthews, personal observation, spring, 2001). The City has installed "Dog Mitt" stations at the entrances to the S. Campus facility, which may improve the situation

The S. Campus facility was particularly successful at removing total suspended solids (84.9% reduction) and total phosphorus (59.1% reduction). The facility is located downstream from an active construction site that has produced large amounts of sediment in the runoff entering the facility (19.9–62.3 mg/L). It is possible that the higher sediment loads allow the facility to work more efficiently. It was also encouraging to note that the Brentwood facility achieved an average of 32.6% reduction in total suspended solids and 47.9% reduction in total phosphorus. This is a substantial improvement compared to previous years, when both Park Place and Brentwood performed poorly for most contaminants. It is possible that the improved 2000/2001 performance is related to the unusually dry weather, which reduced flows through the ponds, increasing residence times. Increased residence times may also partially explain the high level of treatment afforded by the S. Campus facility, which was sized as large as could be accommodated at the site, with the intention of providing longer residence times.

In summary, the Park Place wet pond continued to perform poorly for most types of contaminants, with no consistent reduction in sediments, nutrients, total organic carbon, or metals concentrations between the inlet and outlet; however, both the Brentwood wet pond and the S. Campus storm water treatment facility provided reasonably consistent reductions in solids, nutrients, and coliforms.

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 39). Single-blind quality control tests were conducted as part of the IWS laboratory certification process. The 2000/2001 results are presented in Table 31 (page 68). 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. Control charts were developed that show the difference between each pair of duplicates (Figures 131–132, pages 200–201). Reference lines on each figure show $\pm$ 2 or $\pm 3 \times$ the standard deviation from the mean for the 2000/2001 quality control pairs for each analysis.

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 133–137, pages 202–206). Field duplicates are rarely as close as laboratory duplicates. A systematic bias was observed in the conductivity results because the Surveyor IV Hydrolab is more sensitive than the laboratory meter. This appears as a flattening of the laboratory conductivity response at $\sim$60 μS (Figure 133). In addition, the Surveyor IV Hydrolab is more sensitive than the old Surveyor II Hydrolab, which creates the appearance of a decrease in the lake's conductivity over time (Figures 27–31, pages 96–100). 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 0.2 mg/L, and 95% of the samples differed less than 1.0 mg/L. As in previous years, however, there were systematic differences between the Hydrolab dissolved oxygen concentrations and the laboratory results (Winkler test). These differences were not an analysis error or a problem with the Hydrolab, but rather the result of collecting water samples from slightly different depths at the thermocline. The Hydrolab has a depth meter, so the water samples are measured at true depth. Winkler samples are collected using a marked line, which can only measure approximate depth due to the effects of drift and lake currents. The difference between true and approximate depth is nearly impossible to measure accurately, but is likely to be less than 1–2 meters, even in extreme instances of drift. Normally, this difference is not critical. Most water quality parameters change gradually within the water column. The two major exceptions are temperature and dissolved oxygen. When the lake is stratified, dissolved oxygen concentrations in the thermocline may drop 5 mg/L in just 1–2 meters (see Table 9, page 46). Winkler samples are collected at slightly shallower depths than the marked line indicates, and in the thermocline, this will result in higher oxygen concentrations because the lake is sampled closer to the surface. In these instances, the Hydrolab is undoubtedly the more accurate measurement device because it is recording true depth along with the oxygen concentration.

Three total phosphorus duplicates, one chlorophyll duplicate, and two turbidity duplicates differed more than expected. All of these samples were collected in late summer from Sites 1 or 2 at depths where there are rapid changes in water quality over short distances, and therefore probably represent error associated with using a marked line to collect water samples (see discussion above). The practice of using a marked line to measure depth, although nearly universal in lake sampling, is an important source of sampling error whenever the sample is collected along a rapidly changing environmental gradient.

As part of our regular field quality control protocols, we measure initial and ending surface Hydrolab readings at each site. This is done to verify that we allowed a sufficient equilibration time during the first few samples for the Hydrolab to record accurate values. The results, shown in Figure 138 (page 207), indicate that there was no consistent bias between surface and bottom pH or temperature readings, but there was a small positive bias for conductivity and a small negative bias for dissolved oxygen. The median differences between conductivity readings was 0.3 units, and the median difference between oxygen readings was 0.3 mg/L. These differences are relatively small, but might be reduced by allowing more sensor equilibration time at each depth. The Hydrolab operating procedures will be revised to include additional instructions on equilibration times.

The Hydrolab pH probe failed in the field in October 2000, and had continuing calibration problems throughout the winter of 2000/2001. The unit was returned to the manufacturer for service in February, 2001. The Hydrolab continued to have mechanical problems during the spring of 2001, and was replaced with a new unit in May 2001. Comparisons were made between the old and new Hydrolab units, and the new unit was placed into service beginning June 2001. Whenever the Hydrolab failed to meet quality control performance standards, water samples were collected and analyses using benchtop methods as specified in the contract. Figure 139 (page 208) shows the results from the old and new Hydrolab comparison study.

7 References

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th Edition. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

Ashurst, S. 2001. Phytoplankton Microscopy. ENVR 500 Report submitted to Dr. R. Matthews, fall quarter 2001, Western Washington University, Bellingham, WA

Carpenter, M., C. Suczek, and R. Matthews. 1992. Mirror Lake sedimentation study, summary report: prepared for the City of Bellingham Public Works, Western Washington University, Bellingham WA.

Dingman, S. L. 1994. Physical Hydrology. Macmillan College Publishing Co., New York, NY.

Ebina, J., T. Tsutsui, and T. Shiai. 1983. Simultaneous determination of total nitrogen and total phosphorus in water using persulfate oxidation. Wat. Res. 17:1721–1726.

Ehinger, W. J. 1988. Phytoplankton Composition and Temporal Variation Among the Three Basins of Lake Whatcom, Washington. M. S. thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.

Elser, J. J., E. R. Marzolf, and C. R. Goldman. 1990. Phosphorus and nitrogen limitation of phytoplankton growth in the freshwaters of North America: a review and critique of experimental enrichments. Can. J. Fish Aquat. Sci. 47:1468–1477.

Ferrari, R. L. and S. Nuanes. 2001. Lake Whatcom 1999–2000 Area and Capacity Survey. U.S. Department of the Interior, Bureau of Reclamation. No. 0704–0188.

Golden Software, Inc. 1997. Surfer (Win 32) Version 6.04: Surface Mapping System, Copyright 1993 to 1997.

Hydrolab, 1997. Data Sonde 4 Water Quality Multiprobes User Manual, Revision D., August 1997. Hydrolab Corporation, Austin, TX.

Lind, O. T.. 1985. Handbook of Common Methods in Limnology, 2nd Edition. Kendall/Hunt Publishing Co., Dubuque, IA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. J. Mitchell, and G. B. Matthews. 2000. Lake Whatcom Monitoring Project 1998–1999 Final Report. Final Report prepared for the City of Bellingham Public Works Department, March, 2000, Bellingham, WA.

Matthews, R. A., M. Saunders, M. A. Hilles, and J. Vandersypen. 2001. Park Place Wet Pond Monitoring Project 1994–2000 Summary Report. Final Report prepared for the City of Bellingham Public Works Department, February, 2001, Bellingham, WA.

Matthews, R., M. Hilles, and G. Pelletier. 2002. Determining trophic state in Lake Whatom, Washington (USA), a soft water lake exhibiting seasonal nitrogen limitation. Hydrobiologia *in press*.

McNair, C. M. 1995. Dynamic chlorophyll maxima and their association with environmental gradients: a multivariate analysis. M. S. thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.

Mueller, K. W., D. M. Serdar, and D. E. McBride. 2001. Mercury in Sportfishes of Lake Whatcom, Washingotn, Including a Review of Potential Impacts to Aquatic Resources and People. Technical Report #FPT01–09, Washington State Department of Fish and Wildlife, P. O. Box 1100, La Conner, WA.

Serdar, D., D. Davis, and J. Hirsch. 1999. Lake Whatcom Watershed Cooperative Drinking Water Protection Project; Results of 1998 Water, Sediment, and Fish Tissue Sampling. Publication #99–337, Washington State Department of Ecology, P. O. Box 47600, Olympia, WA.

Tracy, K. 2001. Changes in Mirror Lake, Northwestern Washington, as a result of the diversion of water from the Nooksack River. M. S. thesis, Geology Department, Western Washington University, Bellingham, WA.

Walker, S., R. Matthews, and G. Matthews. 1992. Lake Whatcom Watershed Storm Water Runoff Monitoring Project. Final report prepared for the City of Bellingham, Public Works Department, January 1992, Bellingham, WA.

Wetzel, R. 1983. Limnology, Second Edition. Saunders College Publishing, Philadelphia, PA.

Wetzel, R. and G. Likens. 1991. Limnological Analyses, Second Edition. Springer-Verlag, New York, NY.

8 Tables

Parameter	2000 Oct	Nov	Dec	2001 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 metals												●	Sites 1, 2, 3, 4, Intake -
(arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, zinc†)												●	0.3 m and bottom only
T. organic 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 (City)	●	●	●		●		●	●	●	●	●	●	Sites 1, 2, 3, 4, Intake; 0.3 m

†Twenty-four additional metals are included without charge as part of the standard AmTest analytical procedure.

Table 1: Lake Whatcom 2000/2001 lake monitoring schedule.

Parameter	Method	Historic DL§	2000/2001 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	± 1.5 mg/L
Turbidity	APHA (1998) #2130, nephelometric, SOP-LW-11	–	–	± 0.2 NTUs
Ammonia	Wetzel & Likens (1991), phenate, SOP-LW-21	10 μg-N/L	4.7 μg-N/L	± 3.8 μg-N/L
Nitrite/nitrate	APHA (1998) #4500-NO_3 I., Cd reduction, SOP-IWS-19	20 μg-N/L	6.4 μg-N/L	± 4.6 μg-N/L
T. nitrogen	APHA (1998) #4500-N C., Ebinat al. (1983), SOP-IWS-19	100 μg-N/L	11.0 μg-N/L	± 26.3 μg-N/L
Sol. phosphate, man†	APHA (1998) #4500-P E., ascorbic acid, SOP-LW-20	5 μg-P/L	2.0 μg-P/L	± 1.4 μg-P/L
Sol. phosphate, auto‡	APHA (1998) #4500-P G., ascorbic acid, SOP-IWS-19	5 μg-P/L	1.5 μg-P/L	± 2.2 μg-P/L
T. phosphorus, man†	APHA (1998) #4500-P E., persulfate digestion, SOP-LW-18	5 μg-P/L	–	–
T. phosphorus, auto‡	APHA (1998) #4500-P H., persulfate digestion, SOP-IWS-19	5 μg-P/L	2.6 μg-P/L	± 3.4 μg-P/L
Chlorophyll	APHA (1998) #10200 H, acetone, SOP-IWS-16	–	–	± 0.1 mg/m^3
Plankton	Lind (1985), Schindler trap	–	–	–
		–	–	–
Total coliform (City)	APHA (1998) #9222 B, membrane filter	–	–	–
Fecal coliform (City)	APHA (1998) #9222 D, membrane filter	–	–	–
Enterococcus (City)	APHA (1998) #9223 A (mod.), MPN-methyl.	–	–	–

† Manual method; ‡ Autoanalysis method

§ Historic detection limits (DL) are set higher than the current method detection limits (MDL). See Appendix B for additional information.

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

Variable	Mean[†]	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	19.9	1.4	18.2	25.1
Conductivity - Hydrolab (μS/cm)	59.2	3.4	54.5	73.8
Conductivity - lab (μS/cm)	62.4	2.7	60.6	72.6
Dissolved oxygen (mg/L)	8.3	3.5	0.0	11.5
pH	7.4	0.6	6.3	8.6
Temperature (°C)	11.8	4.0	4.9	21.6
Turbidity (NTU)	1.0	1.0	0.5	7.7
Nitrogen, ammonia (μg-N/L)	22.6	39.3	$<$10	208.8
Nitrogen, nitrate/nitrite (μg-N/L)	183.3	105.3	$<$20	297.0
Nitrogen, total (μg-N/L)	369.4	115.5	174.9	622.9
Phosphorus, soluble (μg-P/L)	$<$5	1.0	$<$5	5.3
Phosphorus, total (μg-P/L)	10.0	5.6	$<$5	32.2
Chlorophyll a (mg/m^3)	2.4	1.5	0.4	5.7
Secchi depth (m)	5.1	1.1	3.5	6.7
Coliforms, total (cfu/100 mL)[‡]	2.7	na	$<$1	8
Coliforms, fecal (cfu/100 mL)[‡]	1.2	na	$<$1	3
Enterococcus (cfu/100 mL)[‡]	2.0	na	$<$2	2

[†]Arithmetic means except as noted.
[‡]Geometric means.

Table 3: Site 1 average ambient water quality data, Oct. 2000 – Sept. 2001.

Variable	Mean†	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	18.4	0.5	17.5	19.2
Conductivity - Hydrolab (μS/cm)	56.7	2.0	52.6	59.8
Conductivity - lab (μS/cm)	59.6	0.7	58.8	61.2
Dissolved oxygen (mg/L)	10.2	0.7	9.0	11.8
pH	7.8	0.4	7.1	8.5
Temperature (°C)	13.2	4.6	6.1	20.1
Turbidity (NTU)	0.6	0.1	0.4	1.0
Nitrogen, ammonia (μg-N/L)	<10	3.1	<10	14.6
Nitrogen, nitrate/nitrite (μg-N/L)	282.1	69.6	172.1	382.7
Nitrogen, total (μg-N/L)	438.4	114.7	294.0	730.1
Phosphorus, soluble (μg-P/L)	<5	1.0	<5	4.7
Phosphorus, total (μg-P/L)	5.9	2.6	<5	14.7
Chlorophyll a (mg/m^3)	1.9	0.8	0.7	3.2
Secchi depth (m)	6.2	1.3	4.5	8.0
Coliforms, total (cfu/100 mL)‡	2.2	na	<1	4
Coliforms, fecal (cfu/100 mL)‡	1.0	na	<1	1
Enterococcus (cfu/100 mL)‡	2.0	na	<2	2

†Arithmetic means except as noted.
‡Geometric means.

Table 4: Intake average ambient water quality data, Oct. 2000 – Sept. 2001.

Variable	Mean†	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	18.4	1.3	17.2	25.4
Conductivity - Hydrolab (μS/cm)	57.0	3.0	52.4	77.8
Conductivity - lab (μS/cm)	59.4	0.5	58.8	61.2
Dissolved oxygen (mg/L)	9.2	2.7	0.0	11.6
pH	7.5	0.5	6.4	8.5
Temperature (°C)	12.1	4.2	6.0	19.8
Turbidity (NTU)	0.6	0.4	0.3	2.7
Nitrogen, ammonia (μg-N/L)	21.6	53.4	<10	339.5
Nitrogen, nitrate/nitrite (μg-N/L)	284.6	97.0	<20	394.1
Nitrogen, total (μg-N/L)	458.3	114.5	300.2	729.3
Phosphorus, soluble (μg-P/L)	<5	1.3	<5	8.7
Phosphorus, total (μg-P/L)	8.0	8.6	<5	62.0
Chlorophyll a (mg/m^3)	1.8	0.7	0.4	3.3
Secchi depth (m)	6.3	1.1	4.5	8.1
Coliforms, total (cfu/100 mL)‡	3.7	na	<1	37
Coliforms, fecal (cfu/100 mL)‡	1.0	na	<1	1
Enterococcus (cfu/100 mL)‡	2.0	na	<2	2

†Arithmetic means except as noted.

‡Geometric means.

Table 5: Site 2 average ambient water quality data, Oct. 2000 – Sept. 2001.

Variable	Mean†	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	17.8	0.7	16.2	19.1
Conductivity - Hydrolab (μS/cm)	55.9	2.0	52.2	61.5
Conductivity - lab (μS/cm)	59.8	0.9	58.6	62.7
Dissolved oxygen (mg/L)	9.7	1.0	5.1	11.7
pH	7.5	0.5	6.7	8.6
Temperature (°C)	10.0	4.3	6.4	20.0
Turbidity (NTU)	0.5	0.3	0.2	1.7
Nitrogen, ammonia (μg-N/L)	<10	4.5	<10	25.9
Nitrogen, nitrate/nitrite (μg-N/L)	359.0	71.4	206.1	449.6
Nitrogen, total (μg-N/L)	495.8	100.9	326.9	749.5
Phosphorus, soluble (μg-P/L)	<5	1.2	<5	5.0
Phosphorus, total (μg-P/L)	5.8	3.5	<5	18.0
Chlorophyll a (mg/m^3)	1.6	0.8	0.5	3.1
Secchi depth (m)	6.9	1.4	4.7	8.8
Coliforms, total (cfu/100 mL)‡	1.6	na	<1	9
Coliforms, fecal (cfu/100 mL)‡	1.2	na	<1	5
Enterococcus (cfu/100 mL)‡	2.0	na	<2	2

†Arithmetic means except as noted.
‡Geometric means.

Table 6: Site 3 average ambient water quality data, Oct. 2000 – Sept. 2001.

Variable	Mean[†]	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	17.7	0.5	16.3	19.0
Conductivity - Hydrolab (μS/cm)	56.0	1.8	52.5	60.8
Conductivity - lab (μS/cm)	59.5	0.4	58.6	60.0
Dissolved oxygen (mg/L)	9.9	0.9	7.6	11.7
pH	7.4	0.4	6.7	8.4
Temperature (°C)	9.7	4.1	6.5	19.1
Turbidity (NTU)	0.4	0.1	0.2	0.8
Nitrogen, ammonia (μg-N/L)	<10	4.3	<10	22.9
Nitrogen, nitrate/nitrite (μg-N/L)	373.2	69.5	219.2	453.6
Nitrogen, total (μg-N/L)	506.7	105.0	313.8	772.3
Phosphorus, soluble (μg-P/L)	<5	1.2	<5	7.4
Phosphorus, total (μg-P/L)	6.1	3.4	<5	14.7
Chlorophyll a (mg/m^3)	1.6	0.8	0.5	3.1
Secchi depth (m)	7.1	1.8	4.5	10.0
Coliforms, total (cfu/100 mL)[‡]	1.5	na	<1	4
Coliforms, fecal (cfu/100 mL)[‡]	1.0	na	<1	1
Enterococcus (cfu/100 mL)[‡]	2.0	na	<2	2

[†]Arithmetic means except as noted.
[‡]Geometric means.

Table 7: Site 4 average ambient water quality data, Oct. 2000 – Sept. 2001.

	Sample Date	Surface Temp (°C)	Bottom Temp (°C)	Difference
Site 1	June, 6 1988	14.50	9.40	5.10
	June, 12 1989	18.97	9.22	9.75
	June, 4 1990	15.25	7.75	7.50
	June, 3 1991	14.36	9.39	4.67
	June, 2 1992	19.54	10.19	9.38
	June, 3 1993	18.23	11.42	6.81
	June, 7 1994	16.48	9.99	6.49
	June, 8 1995	19.03	10.40	8.63
	June, 4 1996	16.69	11.07	5.62
	June, 10 1997	19.18	10.67	8.51
	June, 10 1998	18.61	9.79	8.82
	June, 9 1999	14.77	8.87	5.90
	June, 8 2000	16.25	9.88	6.37
	June, 5 2001	14.87	11.23	3.64
Site 2	June 6, 1988	14.00	8.90	5.10
	June 12, 1989	17.76	8.93	8.83
	June 4, 1990	14.85	8.63	6.22
	June 3, 1991	13.83	8.78	5.05
	June 2, 1992	18.07	10.1	7.97
	June 3, 1993	17.61	9.63	7.98
	June 7, 1994	15.83	9.28	6.55
	June 8, 1995	18.48	9.99	8.49
	June 4, 1996	15.43	9.47	5.96
	June 10, 1997	18.4	9.08	9.32
	June 11, 1998	18.19	9.91	8.28
	June 9, 1999	14.39	8.59	5.80
	June 8, 2000	15.02	9.41	5.61
	June 5, 2001	14.49	9.16	5.33

Table 8: Site 1 surface and bottom temperatures, June 1988–2001. Average 1988–2000 surface-to-bottom temperature differences were 7.22° and 7.01° for Sites 1 and 2, respectively.

Depth	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
0	9.6	9.7	9.6	9.5	9.2	9.7	9.7	10.3	10.1	9.9	9.7	9.1	9.4	9.4
1		9.6	9.6	9.4		10.1	9.6	9.9	10.0	9.9	9.6	9.1	9.3	9.3
2	9.7	9.6	9.7	9.4		10.0	9.6	9.9	10.0	9.8	9.6	9.1	9.3	9.3
3		9.6	9.6	9.3		9.9	9.5	9.8	9.9	9.8	9.5	9.1	9.3	9.2
4	9.8	9.5	9.6	9.3		9.9	9.5	9.8	9.9	9.6	9.5	9.1	9.2	9.1
5		9.5	9.6	9.2	9.2	9.8	9.4	9.6	9.8	9.6	9.6	9.0	9.1	9.1
6	9.6	9.5	9.5	9.0		9.7	9.1	9.6	9.8	9.1	9.4	9.0	9.1	9.1
7		9.4	9.2	8.7		9.6	9.3	9.5	9.7	8.5	9.4	8.9	8.7	9.1
8	8.5	9.0	8.2	8.7		9.3	9.0	9.5	9.2	6.3	8.5	8.4	8.8	9.1
9		7.8	6.2	8.3		4.9	4.5	6.4	8.2	4.2	7.6	5.5	5.0	9.1
10	2.4	5.6	4.7	6.8	5.2	3.4	**0.1**	3.7	3.1	2.0	2.3	3.3	1.7	9.1
11		3.0	2.2	5.4			0.1	**0.1**	1.2	**0.6**	**0.6**	**0.9**	**0.1**	1.8
12	1.1	1.7	1.7	2.1			0.0	0.1	**0.2**	0.5	0.5	0.1	0.0	**0.6**
13		**0.8**	1.1	1.1			0.0	0.1	0.2	0.5	0.5	0.0	0.0	0.5
14	**0.7**	0.6	**0.8**	**0.6**			0.0	0.1	0.2	0.5	0.5	0.0	0.0	0.4
15		0.6	0.8	0.6	**0.7**		0.0	0.1	0.2	0.4	0.4	0.0	0.0	0.4
16	0.4	0.5	0.8	0.6			0.0	0.1	0.2	0.4	0.4	0.0	0.0	0.3
17		0.5	0.8	0.6			0.0	0.1	0.2	0.4	0.4	0.0	0.0	0.4
18	0.4	0.5	0.9	0.6			0.0	0.1	0.2	0.4	0.4	0.0	0.0	0.4
19		0.5	0.9	0.6			0.0	0.0	0.2	0.4	0.4	0.0	0.0	0.3
20			0.9	0.7	1.1		0.0	0.0	0.2	0.4	0.3	0.0	0.0	0.3

Boxed values mark depth where oxygen dropped below 1 mg/L.

Table 9: Dissolved oxygen concentrations (mg/L) at Site 1, Sept. 1988–2001.

Depth	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
0	19.7	19.1	20.2	18.5	20.9	20.2	20.2	19.9	18.8	21.3	21.6	19.8	18.4	18.5
1		19.1	20.1	18.5	20.9	20.1	20.1	19.9	18.6	21.2	21.6	19.8	18.4	18.5
2	19.5	19.1	20.1	18.4	20.9	20.1	20.0	19.9	18.6	21.1	21.6	19.8	18.4	18.5
3		19.1	20.0	18.4	20.9	20.1	20.0	19.9	18.5	21.0	21.6	19.5	18.4	18.5
4	19.3	19.1	20.0	18.3	20.9	20.0	20.0	19.9	18.5	20.8	21.6	19.4	18.4	18.5
5		19.1	19.8	18.2	20.9	19.9	19.9	19.8	18.4	20.6	21.6	19.3	18.4	18.5
6	19.1	19.1	19.7	18.0	20.9	19.7	19.8	19.8	18.4	20.4	21.6	19.2	18.3	18.5
7		19.0	19.3	17.8	20.9	19.6	19.8	19.7	18.4	20.2	21.0	19.2	18.2	18.5
8	18.3	18.9	18.4	17.8	19.4	19.4	19.7	19.6	18.3	19.0	19.5	19.0	18.1	18.5
9		18.3	16.1	17.5	17.5	17.1	18.3	18.3	18.2	16.8	17.2	15.6	15.9	18.5
10	15.0	16.5	13.6	16.7	15.9	16.0	16.0	17.0	15.4	15.2	14.4	14.1	13.3	18.4
11		14.3	11.2	15.7	13.8	14.5	14.2	14.6	14.1	12.8	12.6	12.4	12.3	14.8
12	12.2	12.7	10.3	12.9	12.3	12.9	12.4	12.9	13.1	12.0	11.9	11.0	11.6	13.5
13		11.5	9.9	11.6	11.8	12.6	11.7	12.3	12.7	11.9	11.5	10.4	11.2	12.7
14	11.4	11.1	9.5	10.9	11.8	12.4	11.4	12.0	12.3	11.7	11.2	10.1	10.9	12.3
15		10.9	9.3	10.8	11.1	12.3	11.2	11.8	12.1	11.6	11.2	10.0	10.7	12.2
16	11.1	10.7	9.2	10.7	10.9	12.2	11.1	11.6	12.0	11.5	11.1	9.9	10.6	12.1
17		10.6	9.2	10.7	10.8	12.1	11.0	11.5	11.9	11.5	11.0	9.8	10.6	12.0
18	10.8	10.4	9.2	10.7	10.7	12.0	10.9	11.4	11.8	11.4	11.0	9.8	10.5	12.0
19		10.4	9.3	10.7	10.6	11.9	10.8	11.3	11.8	11.4	10.9	9.8	10.4	11.9
20			9.3	10.6	10.5	11.9	10.8	11.3	11.8	11.4	10.7	9.7	10.4	11.9

Horizontal lines show 8, 10 and 12 meter reference depths.

Table 10: Water temperatures (°C) at Site 1, Sept. 1988–2001.

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

Table 11: Site 1 and Site 2 hypolimnetic ammonia and hydrogen sulfide concentrations, October 1999–2001.

Site	Depth	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)
Site 1	0	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.030	<0.01	0.015	<0.001	0.004
Site 1	20	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.160	<0.01	0.011	<0.001	0.006
Intake	0	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.016	<0.01	0.016	<0.001	0.004
Intake	10	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.016	<0.01	0.015	0.001	0.008
Site 2	0	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.011	<0.01	0.014	0.001	0.004
Site 2	20	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.031	<0.01	0.006	<0.001	0.007
Site 3	0	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.013	<0.01	0.016	<0.001	0.005
Site 3	80	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.015	<0.01	0.018	<0.001	0.011
Site 4	0	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.006	<0.01	0.016	<0.001	0.003
Site 4	90	Aug 6, 2001	<0.01	<0.0005	<0.001	<0.001	0.011	<0.01	0.016	0.001	0.015

Table 12: Lake Whatcom 2000/2001 total metals data. Only the metals specified in the 2000/2001 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix C and on the CD that accompanies this report.

Site	Depth	Date	AmTest mg-Hg/L	Date	Env. Canada mg-Hg/L
Site 1	0	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Site 1	20	July 17, 2001	<0.0002	July 17, 2001	0.00008
Intake	0	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Intake	10	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Site 2	0	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Site 2	20	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Site 3	0	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Site 3	80	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Site 4	0	July 17, 2001	<0.0002	July 17, 2001	<0.00005
Site 4	90	July 17, 2001	<0.0002	July 17, 2001	<0.00005

Site	Depth	Date	AmTest mg-Hg/L	Date	AmTest mg-Hg/L
Site 1	0	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002
Site 1	20	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002
Intake	0	Aug 7, 2001	0.0004	Sept 18, 2001	<0.0002
Intake	10	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002
Site 2	0	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002
Site 2	20	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002
Site 3	0	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002
Site 3	80	Aug 7, 2001	0.0005	Sept 18, 2001	<0.0002
Site 4	0	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002
Site 4	90	Aug 7, 2001	<0.0002	Sept 18, 2001	<0.0002

Table 13: Lake Whatcom 2000/2001 low level mercury results. Data were analyzed by AmTest (detection limit = 0.0002 mg/L = 0.2 μg/L) or Environment Canada (detection limit = 0.00005 mg/L = 0.05 μg/L).

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 13, 2000	0	2.4	Aug 6, 2001	0	1.6
	Feb 13, 2000	20	1.5	Aug 6, 2001	20	<1
Intake	Feb 13, 2000	0	<1	Aug 6, 2001	0	3.6
	Feb 13, 2000	10	1.4	Aug 6, 2001	10	2.4
Site 2	Feb 13, 2000	0	2.8	Aug 6, 2001	0	1.7
	Feb 13, 2000	20	1.4	Aug 6, 2001	15	2.0
Site 3	Feb 13, 2000	0	1.3	Aug 6, 2001	0	<1
	Feb 13, 2000	80	1.3	Aug 6, 2001	80	1.4
Site 4	Feb 13, 2000	0	1.1	Aug 6, 2001	0	1.2
	Feb 13, 2000	90	2.6	Aug 6, 2001	90	1.3

Table 14: Lake Whatcom 2000/2001 total organic carbon data.

Season	Phylum	Median (μm^3)	Geom. Mean (μm^3)	Mean (μm^3)	Minimum (μm^3)	Maximum (μm^3)	N
combined	Pyrrhophyta†	43,440	40,192	45,374	11,568	91,147	31
	Chlorophyta	24,101	146,801	1,449,647	10,322	14,118,412	37
	Cyanophyta	1,119	4,679	236,182	39	1,027,596	37
	Chrysophyta‡	597	762	1,174	202	8,244	95
spring	Pyrrhophyta†	42,961	37,066	42,237	11,568	73,099	21
	Chlorophyta	26,559	187,329	1,413,162	14,879	5,568,936	19
	Cyanophyta	1,074	3,686	231,913	40	1,027,596	24
	Chrysophyta‡	481	605	909	202	5,633	49
summer	Cyanophyta	168,654	7270	244,064	39	573,465	13
	Pyrrhophyta†	49,484	47,643	51,964	18,898	91,147	10
	Chlorophyta	18,824	113,494	1,488,160	10,322	14,118,412	18
	Chrysophyta‡	829	973	1,457	303	8,244	46

†Dinophyta in some taxonomies
‡Heterokontophyta in some taxonomies

Table 15: Lake Whatcom plankton biovolume summary. Spring samples were collected from April 25–June 3, 2001; summer samples were collected from June 27–August 3, 2001.

Site	Date	Depth (m)	Temp (C)	pH	Cond (μS/cm)	DO (mg/L)
Site 3	Oct 5, 2000	0–35	14.4	7.5	56.1	8.9
Site s2	Oct 10, 2000	0–35	14.3	7.4	56.3	8.7
Site 3	Nov 7, 2000	0–35	11.5	7.5	56.1	9.2
Site s2	Nov 7, 2000	0–35	11.5	NA	56.3	9.1
Site 3	Dec 6, 2000	0–35	9.0	7.4	52.5	10.1
Site s2	Dec 7, 2000	0–35	8.9	NA	54.0	10.3
Site 3	Feb 13, 2001	0–35	6.6	7.2	56.2	10.2
Site s2	Jan 18, 2001	0–35	6.9	7.5	54.8	9.8
Site 3	Apr 12, 2001	0–35	7.3	7.6	53.4	11.2
Site s2	Apr 12, 2001	0–35	7.4	7.5	53.5	11.1
Site 3	May 8, 2001	0–35	9.6	7.6	55.2	11.2
Site s2	May 8, 2001	0–35	9.7	7.7	54.8	11.2
Site 3	June 6, 2001	0–35	12.3	7.9	56.6	10.5
Site s2	June 6, 2001	0–35	12.5	7.9	57.5	10.5
Site 3	July 10, 2001	0–35	15.4	8.1	58.2	10.2
Site s2	July 10, 2001	0–35	16.0	8.2	58.2	9.8
Site 3	Aug 1, 2001	0–35	15.9	8.1	56.2	10.0
Site s2	Aug 2, 2001	0–35	15.8	8.1	56.2	10.0
Site 3	Sept 4, 2001	0–35	16.2	8.0	60.4	9.4
Site s2	Sept 6, 2001	0–35	16.1	7.7	56.5	9.3

Table 16: Strawberry sill 2001 hydrolab data compared to Site 3.

Site	Date	Depth (m)	Alk (mg/L)	Turb (NTU)	NH3 (μg-N/L)	TN (μg-N/L)	NO3 (μg-N/L)	SRP (μg-P/L)	TP (μg-P/L)
Site 3	Feb 13, 2001	0–40	17.6	0.3	<10	730.9	379.3	<5	13.6
Site s2	Jan 18, 2001	0–35	17.6	0.3	<10	447.1	381.3	<5	5.9
Site 3	Oct 3, 2001	0–40	17.4	0.3	<10	397.0	303.1	<5	5.6
Site s2	Oct 10, 2001	0–35	18.0	NA	<10	360.4	271.7	<5	5.3

Table 17: Strawberry sill 2000/2001 water quality data compared to Site 3.

Site	Depth	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)
s2	0	Oct 5, 2000	$<$0.01	$<$0.0005	0.003	$<$0.001	$<$0.005
s2	35	Oct 5, 2000	$<$0.01	$<$0.0005	0.003	$<$0.001	$<$0.005
s2	0	Jan 17, 2001	$<$0.01	$<$0.0005	$<$0.001	$<$0.001	0.024
s2	35	Jan 17, 2001	$<$0.01	$<$0.0005	$<$0.001	$<$0.001	0.020

Site	Depth	Date	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)	TOC (mg/L)
s2	0	Oct 5, 2000	$<$0.01	$<$0.005	$<$0.001	0.001	1.6
s2	35	Oct 5, 2000	$<$0.01	$<$0.005	$<$0.001	$<$0.001	$<$1
s2	0	Jan 17, 2001	$<$0.01	$<$0.005	$<$0.001	0.002	6.3
s2	35	Jan 17, 2001	$<$0.01	$<$0.005	$<$0.001	0.001	2.8

Table 18: Strawberry sill 2000/2001 metals and total organic carbon data. Only the metals specified in the 2000/2001 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix C and on the CD that accompanies this report.

Parameter	2000 Oct	Nov	Dec	2001 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Temperature					•					•		
Discharge					•					•		
Alkalinity					•					•		
Conductivity					•					•		
DO - Winkler					•					•		
pH					•					•		
T. suspended solids					•					•		
Turbidity					•					•		
Ammonia					•					•		
Nitrite/nitrate					•					•		
Total nitrogen					•					•		
Soluble phosphate					•					•		
Total phosphorus					•					•		
T. organic carbon					•					•		
Total metals					•							
(arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, zinc[†])												
Bacteria (City)					•					•		

[†]Twenty-four additional metals are included without charge.

Table 19: Lake Whatcom 2000/2001 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 Canyon	1990 min†	8.1	250	9.0	<2	na	0.02	4.0	na
	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 22, 2001	8.3	284	11.3	6.0	131.4	0.22	7.9	3.4
	July 18, 2001	8.4	293	10.1	5.6	140.6	0.10	10.8	2.4
Park Place	1990 min†	7.1	118	6.4	3	na	0.00	4.5	na
	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 22, 2001	7.5	222	11.1	6.0	79.5	NA	7.2	5.6
	July 18, 2001	8.0	263	7.3	4.2	119.9	NA	18.3	4.1
Silver Beach	1990 min†	7.4	103	6.9	<2	na	0.00	4.2	na
	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 22, 2001	7.8	151	3.2	5.6	56.8	0.76	6.6	9.6
	July 18, 2001	8.2	281	8.7	2.4	130.5	NA	14.0	2.4
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 22, 2001	7.3	57	12.1	<2	17.1	0.64	6.2	0.5
	July 18, 2001	7.1	61	9.2	<2	12.6	0.06	11.6	1.0
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 22, 2001	7.1	65	11.5	<2	19.6	18.4	7.0	0.9
	July 18, 2001	7.1	75	9.2	<2	26.4	NA	11.3	0.7
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 22, 2001	7.4	66	12.0	2.3	16.8	18.4	5.8	2.3
	July 18, 2001	7.8	103	9.7	<2	29.0	2.86	13.0	0.8
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 22, 2001	7.4	60	12.3	<2	15.2	6.8	5.2	0.9
	July 18, 2001	7.8	77	10.1	<2	26.0	2.01	14.0	0.2

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

Table 20: Physical water quality data for creeks in the Lake Whatcom watershed.

Site	Date	NH_3 (μg-N/L)	TN (μg-N/L)	NO_{2+3} (μg-N/L)	SRP (μg-P/L)	TP (μg-P/L)	TC (cfu/ 100 mL)	FC (cfu/ 100 mL)	EC (cfu/ 100 mL)
Blue	1990 min	10	na	167	<5	<5	90	<2	na
Canyon	1990 avg	20	na	336	<5	13	1163	7	na
	1990 max	34	na	545	12	25	9000	27	na
	Feb 22, 2001	<10	363	268	7.7	23.3	83	<1	<2
	July 18, 2001	16.6	223	124	9.0	13.9	100	8	7
Park	1990 min	22	na	145	6	41	230	8	na
Place	1990 avg	51	na	357	22	66	8254	1353	na
	1990 max	111	na	549	86	168	>16000	16000	na
	Feb 22, 2001	66.1	1016	683	11.9	51.2	3700	3400	3
	July 18, 2001	91.9	769	208	31.3	89.0	1400	33	2
Silver	1990 min	<10	na	173	<5	27	170	8	na
Beach	1990 avg	19	na	583	16	41	7110	3307	na
	1990 max	43	na	1118	42	61	>16000	16000	na
	Feb 22, 2001	<10	796	456	10.1	49.8	270	100	30
	July 18, 2001	17.3	510	214	32.7	59.7	3000	1850	900
Wildwd	1990 min	<10	na	755	<5	<5	23	<2	na
	1990 avg	189	na	1790	<5	9	1164	74	na
	1990 max	32	na	4857	9	33	>16000	1300	na
	Feb 22, 2001	<10	3092	3108	<5	17.7	210	<1	<2
	July 18, 2001	<10	1962	1915	12.0	18.0	60	11	4
Anderson	1990 min	10	na	50	<5	6	30	<2	na
	1990 avg	19	na	121	<5	24	344	13	na
	1990 max	32	na	221	8	55	2400	130	na
	Feb 22, 2001	17.2	915	772	5.5	24.5	56	5	2
	July 18, 2001	11.1	754	633	8.7	17.3	170	120	70
Austin	1990 min	<10	na	259	<5	<5	50	7	na
	1990 avg	20	na	441	<5	13	3366	950	na
	1990 max	40	na	658	9	23	16000	5000	na
	Feb 22, 2001	<10	960	858	6.2	25.5	48	5	<2
	July 18, 2001	10.4	422	315	14.6	17.8	520	270	30
Smith	1990 min	12	na	396	<5	<5	17	<2	na
	1990 avg	17	na	687	<5	6	1138	14	na
	1990 max	37	na	1025	8	12	9000	170	na
	Feb 22, 2001	<10	1708	1588	<5	21.8	48	2	<2
	July 18, 2001	11.7	833	705	11.2	11.0	120	91	8

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

Table 21: 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 22, 2001	<0.01	<0.0005	0.005	0.002	0.013
Park Place	Feb 22, 2001	<0.01	<0.0005	0.004	<0.001	0.40
Silver Beach	Feb 22, 2001	<0.01	<0.0005	0.005	<0.001	0.54
Wildwood	Feb 22, 2001	<0.01	<0.0005	<0.001	<0.001	0.006
Anderson	Feb 22, 2001	<0.01	<0.0005	0.004	<0.001	0.11
Austin	Feb 22, 2001	<0.01	<0.0005	0.002	<0.001	0.14
Smith Creek	Feb 22, 2001	<0.01	<0.0005	0.002	0.002	0.020

Site	Date	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
Blue Canyon	Feb 22, 2001	<0.01	<0.005	<0.001	0.003
Park Place	Feb 22, 2001	<0.01	<0.005	<0.001	0.008
Silver Beach	Feb 22, 2001	<0.01	<0.005	<0.001	0.005
Wildwood	Feb 22, 2001	<0.01	<0.005	<0.001	0.002
Anderson	Feb 22, 2001	<0.01	<0.005	<0.001	0.003
Austin	Feb 22, 2001	<0.01	<0.005	<0.001	0.004
Smith Creek	Feb 22, 2001	<0.01	<0.005	<0.001	0.004

Table 22: Metals data for creeks in the Lake Whatcom watershed. Only the metals specified in the 2000/2001 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix C and on the CD that accompanies this report.

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Blue Canyon	Feb 22, 2001	1.3	July 18, 2001	<1
Park Place	Feb 22, 2001	4.7	July 18, 2001	4.5
Silver Beach	Feb 22, 2001	4.7	July 18, 2001	2.2
Wildwood	Feb 22, 2001	<1	July 18, 2001	2.2
Anderson	Feb 22, 2001	2.4	July 18, 2001	2.7
Austin	Feb 22, 2001	1.2	July 18, 2001	2.1
Smith	Feb 22, 2001	2.2	July 18, 2001	5.1

Table 23: Total organic carbon data for creeks in the Lake Whatcom watershed.

Site		Min.	Max.	n	$\overline{x}^{\dagger}$
Blue Canyon	total coliforms	<4	300	10	103
	fecal coliforms	<1	120	10	8
	Enterococcus	<2	26	10	7
Park Place	total coliforms	163	10600	9	2218
	fecal coliforms	20	3400	10	293
	Enterococcus	2	1600	9	27
Silver Beach	total coliforms	270	3800	9	1490
	fecal coliforms	98	2500	10	534
	Enterococcus	7	900	9	106
Wildwood	total coliforms	13	230	9	73
	fecal coliforms	<1	48	9	5
	Enterococcus	<2	30	9	4
Anderson	total coliforms	16	2300	10	92
	fecal coliforms	2	154	10	16
	Enterococcus	<2	70	10	5
Austin	total coliforms	17	6400	9	231
	fecal coliforms	5	410	10	45
	Enterococcus	<2	240	9	11
Smith	total coliforms	<4	290	9	89
	fecal coliforms	<2	199	10	23
	Enterococcus	<2	30	9	4

†5-year geometric means from Feb 1997 to July 2001.

Table 24: Average coliform and *Enterococcus* counts for creeks in the Lake Whatcom watershed.

Date	Fecal coliforms	*Enterococcus*
	winter	
Feb 4, 1997	6 cfu/100 mL	<2 cfu/100 mL
March 10, 1998	42 cfu/100 mL	50 cfu/100 mL
Feb 10, 1999	8 cfu/100 mL	na
Feb 9, 2000	32 cfu/100 mL	2 cfu/100 mL
Feb 22, 2001	5 cfu/100 mL	<2 cfu/100 mL
	summer	
Aug 11, 1997	123 cfu/100 mL	17 cfu/100 mL
July 14, 1998	410 cfu/100 mL	240 cfu/100 mL
July 15, 1999	56 cfu/100 mL	8 cfu/100 mL
July 18, 2000	141 cfu/100 mL	8 cfu/100 mL
July 18, 2001	270 cfu/100 mL	30 cfu/100 mL

Table 25: Austin Creek fecal coliform and *Enterococcus* counts, 1997–2001.

Inputs	MG/Year 2000/2001	Percent total	MG/Year 1999/2000	Percent total	Percent change*
Direct precipitation	4,811	19.3	7,077	14.7	32.0 ↓
Diversion	1,783	7.1	4,607	9.5	61.3 ↓
Runoff	18,345	73.6	36,563	75.8	49.8 ↓
Total	24,938	100	48,247	100	48.3 ↓
Outputs					
Whatcom Creek	10,508	44.5	27,280	55.6	61.5 ↓
Hatchery	1,074	4.5	2,388	4.9	55 ↓
Georgia Pacific	4,851	20.5	12,334	25.1	60.7 ↓
City of Bellingham	4,076	17.3	4,112	8.4	0.9 ↓
Water District #10	140	0.6	154	0.3	8.9 ↓
Evaporation	2,971	12.6	2,777	5.7	-7.0 ↑
Total	23,621	100	49,045	100	51.8 ↓
Net change in storage	1318			-797	

Table 26: Lake Whatcom water balance comparison between 2000/2001 and 1999-2000.

Site	Date	TSS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
BW inlet	Jan 15–17, 2001	2.02	4.2	1.9650	0.0359
BW inlet	Apr 17–19, 2001	NA	5.2	1.9480	0.0538
BW inlet	Jul 24–26, 2001	3.84	5.8	2.5410	0.1091
BW outlet	Jan 15–17, 2001	1.20	5.9	1.4640	0.0300
BW outlet	Apr 17–19, 2001	NA	6.5	1.0570	0.0280
BW outlet	Jul 24–26, 2001	2.75	7.9	0.4976	0.0456
Annual % reduction		32.6	-33.6	53.2	47.9
PP inlet	Jan 15–17, 2001	2.07	1.9	0.7779	0.0435
PP inlet	Apr 17–19, 2001	NA	6.0	0.5460	0.0550
PP inlet	Jul 24–26, 2001	NA	4.9	1.0350	0.0568
PP outlet	Jan 15–17, 2001	3.37	6.3	0.8190	0.0497
PP outlet	Apr 17–19, 2001	NA	9.2	0.8337	0.0859
PP outlet	Jul 24–26, 2001	3.19	3.6	0.5240	0.0908
Annual % reduction		-58.5	-49.2	7.7	-45.8
SC inlet	Mar 20–22, 2001	18.67	3.3	1.0300	0.0772
SC inlet	May 15–17, 2001	62.31	8.2	1.0921	0.1441
SC inlet	Aug 6–8, 2001	19.90	3.0	1.1453	0.0906
SC outlet E	Mar 20–22, 2001	1.34	3.5	1.0340	0.0239
SC outlet E	May 15–17, 2001	10.92	5.9	0.7639	0.0668
SC outlet E	Aug 6–8, 2001	3.73	1.1	0.6152	0.0502
SC outlet W	Mar 20–22, 2001	4.41	3.9	1.1020	0.0297
SC outlet W	May 15–17, 2001	9.68	8.2	0.7229	0.0552
SC outlet W	Aug 6–8, 2001	0.42	<1	0.6231	0.0294
Annual % reduction		84.9	6.5	25.6	59.1

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	Jan 15–17, 2001	<0.01	<0.0005	<0.001	<0.001	0.73	<0.01	<0.005	<0.001	0.012
BW inlet	Apr 17–19, 2001	<0.01	<0.0005	<0.001	0.001	0.60	<0.01	<0.005	<0.001	0.009
BW inlet	Jul 24–26, 2001	<0.01	<0.0005	<0.001	<0.001	0.81	<0.01	0.006	0.001	0.002
BW outlet	Jan 15–17, 2001	<0.01	<0.0005	<0.001	<0.001	0.49	<0.01	<0.005	<0.001	0.011
BW outlet	Apr 17–19, 2001	<0.01	<0.0005	<0.001	<0.001	0.55	<0.01	<0.005	<0.001	0.012
BW outlet	Jul 24–26, 2001	<0.01	<0.0005	<0.001	<0.001	0.55	<0.01	<0.005	<0.001	0.007
Annual % reduction		NA	NA	NA	NA	25.7	NA	NA	NA	-30.4
PP inlet	Jan 15–17, 2001	<0.01	<0.0005	<0.001	<0.001	0.46	<0.01	<0.005	<0.001	0.009
PP inlet	Apr 17–19, 2001	<0.01	<0.0005	<0.001	0.007	0.87	<0.01	<0.005	0.002	0.340
PP inlet	Jul 24–26, 2001	<0.01	<0.0005	<0.001	0.001	0.68	<0.01	0.009	0.001	<0.001*
PP outlet	Jan 15–17, 2001	<0.01	<0.0005	<0.001	<0.001	0.58	<0.01	<0.005	<0.001	0.010
PP outlet	Apr 17–19, 2001	<0.01	<0.0005	<0.001	0.003	0.84	<0.01	<0.005	<0.001	0.017
PP outlet	Jul 24–26, 2001	<0.01	<0.0005	<0.001	<0.001	0.66	<0.01	<0.005	0.001	0.003
Annual % reduction		NA	NA	NA	NA	-3.5	NA	NA	NA	91.4
SC inlet	Mar 20–22, 2001	<0.01	<0.0005	0.002	0.002	3.40	<0.0002	<0.005	<0.001	0.012
SC inlet	May 15–17, 2001	<0.01	<0.0005	<0.001	0.036	5.50	<0.0002	<0.005	0.003	0.200
SC inlet	Aug 6–8, 2001	<0.01	<0.0005	<0.001	<0.001*	7.30	<0.0002	<0.005	<0.001	0.010
SC outlet E	Mar 20–22, 2001	<0.01	<0.0005	0.002	0.001	0.17	<0.0002	<0.005	<0.001	0.009
SC outlet E	May 15–17, 2001	<0.01	<0.0005	<0.001	0.023	0.72	<0.0002	<0.005	<0.001	0.067
SC outlet E	Aug 6–8, 2001	<0.01	<0.0005	<0.001	0.001	0.18	<0.0002	<0.005	<0.001	0.012
SC outlet W	Mar 20–22, 2001	<0.01	<0.0005	<0.001	0.002	0.31	<0.0002	0.006	<0.001	0.011
SC outlet W	May 15–17, 2001	<0.01	<0.0005	<0.001	0.025	0.81	<0.0002	<0.005	<0.001	0.089
SC outlet W	Aug 6–8, 2001	<0.01	<0.0005	<0.001	0.001	<0.01*	<0.0002	<0.005	<0.001	0.012
Annual % reduction		NA	NA	NA	32.1	93.2	NA	NA	NA	55.0

*Value replaced with detection limit to calculate percent reduction.

Table 27: 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	Month	Day	Year	Time	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
PP inlet	1	15	2001	pm	5.60	6.14	12.22	180.8	4300	200	13
PP inlet	1	16	2001	am	5.08	6.87	13.80	179.2	820000	12000	21
PP inlet	1	16	2001	pm	5.04	6.58	12.40	182.4	3400	200	13
PP inlet	1	17	2001	am	4.79	7.59	13.40	181.0	7700	390	2
PP outlet	1	15	2001	pm	5.28	6.25	10.23	151.1	10000	540	17
PP outlet	1	16	2001	am	4.46	6.89	10.37	163.8	9700	800	23
PP outlet	1	16	2001	pm	4.45	7.33	9.95	164.1	3200	73	2
PP outlet	1	17	2001	am	4.22	7.44	9.31	169.4	6500	270	7
Seasonal % reduction					10.2	-2.7	23.1	10.4	96.5	86.8	0.0
PP inlet	4	17	2001	pm	11.70	7.62	9.72	182.0	4800	2300	900
PP inlet	4	18	2001	am	9.70	7.47	10.23	151.0	1600	1500	300
PP inlet	4	18	2001	pm	10.50	7.41	10.39	150.0	1230	820	170
PP inlet	4	19	2001	am	9.10	7.43	10.07	149.0	730	700	240
PP outlet	4	17	2001	pm	15.30	9.10	15.38	145.0	330	31	17
PP outlet	4	18	2001	am	11.50	8.20	12.78	148.0	180	41	2
PP outlet	4	18	2001	pm	16.10	8.96	15.71	146.0	95	36	7
PP outlet	4	19	2001	am	11.00	8.44	13.19	149.0	1500	380	23
Seasonal % reduction					-31.5	-15.9	-41.2	7.0	74.8	90.8	97.0
PP inlet	7	24	2001	am	NA	7.73	8.48	248.0	51000	660	900
PP inlet	7	24	2001	pm	17.00	7.88	8.80	236.0	21000	580	170
PP inlet	7	25	2001	am	16.50	7.75	8.85	243.0	110000	1200	300
PP inlet	7	25	2001	pm	17.50	7.55	8.42	230.0	21000	440	500
PP outlet	7	24	2001	am	NA	9.31	11.43	211.0	400	<1*	<2*
PP outlet	7	24	2001	pm	26.70	9.91	14.70	203.0	39	<1*	<2*
PP outlet	7	25	2001	am	19.50	8.71	8.70	220.0	1000	1	<2*
PP outlet	7	25	2001	pm	26.70	9.66	14.56	206.0	75	32	<2*
Seasonal % reduction					-42.9	-21.6	-43.0	12.2	99.3	98.8	99.6
Annual % reduction					-29.1	-13.8	-15.4	10.2	96.8	89.5	97.0

*Value replaced with detection limit to calculate percent reduction.

Table 28: Park Place wet pond grab samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

Site	Month	Day	Year	Time	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
BW inlet	1	15	2001	pm	8.57	5.93	9.70	268.1	8000	6700	<2*
BW inlet	1	16	2001	am	8.38	6.89	10.73	274.5	9700	9200	<2*
BW inlet	1	16	2001	pm	8.46	6.82	9.63	275.9	4000	3200	<2*
BW inlet	1	17	2001	am	8.44	6.69	10.08	276.8	2040	170	4
BW outlet	1	15	2001	pm	3.60	5.92	8.50	200.7	1500	360	2
BW outlet	1	16	2001	am	4.53	6.99	6.96	230.0	560	280	<2*
BW outlet	1	16	2001	pm	3.94	6.78	6.93	226.9	180	100	<2*
BW outlet	1	17	2001	am	4.13	6.90	6.83	227.8	340	290	<2*
Seasonal % reduction					52.1	-1.0	27.2	19.2	89.1	94.7	20.0
BW inlet	4	17	2001	pm	11.00	6.74	8.69	286.0	660	100	4
BW inlet	4	18	2001	am	10.70	6.87	8.87	280.0	590	570	8
BW inlet	4	18	2001	pm	11.10	6.93	9.19	283.0	2800	140	2
BW inlet	4	19	2001	am	10.50	6.78	8.49	284.0	620	280	12
BW outlet	4	17	2001	pm	15.70	7.31	12.10	234.0	550	3	<2*
BW outlet	4	18	2001	am	12.30	7.24	11.99	234.0	1530	364	17
BW outlet	4	18	2001	pm	16.30	7.43	13.00	233.0	220	2	<2*
BW outlet	4	19	2001	am	11.80	7.23	11.57	233.0	100	17	<2*
Seasonal % reduction					-29.6	-6.9	-38.1	17.6	48.6	64.6	11.5
BW inlet	7	24	2001	am	NA	6.88	6.85	353.0	2	1	13
BW inlet	7	24	2001	pm	18.70	6.91	6.79	320.0	4400	760	50
BW inlet	7	25	2001	am	18.50	6.91	6.82	308.0	44000	1800	220
BW inlet	7	25	2001	pm	19.00	6.89	6.54	313.0	61000	4100	50
BW outlet	7	24	2001	am	NA	7.96	8.94	273.0	<20*	2	<2*
BW outlet	7	24	2001	pm	26.00	9.07	14.02	264.0	16	2	<2*
BW outlet	7	25	2001	am	19.70	7.63	5.73	274.0	2200	4	<2*
BW outlet	7	25	2001	pm	26.50	9.00	13.78	263.0	100	<1*	<2*
Seasonal % reduction					-28.5	-22.0	-57.3	17.0	97.9	99.9	97.6
Annual % reduction					-8.4	-10.1	-17.6	17.9	94.7	94.7	89.4

*Value replaced with detection limit to calculate percent reduction.

Table 29: Brentwood wet pond grab samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

Site	Month	Day	Year	Time	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
SC inlet	3	20	2001	pm	10.00	7.42	9.62	325.0	270	4	8
SC inlet	3	21	2001	am	9.50	7.39	9.76	329.0	210	3	<2*
SC inlet	3	21	2001	pm	10.00	7.41	9.47	331.0	180	<3*	2
SC inlet	3	22	2001	am	9.80	7.43	9.63	339.0	67	<4*	2
SC outlet E	3	20	2001	pm	9.00	7.66	9.04	332.0	54	4	<2*
SC outlet E	3	21	2001	am	9.50	7.65	8.23	339.0	23	2	2
SC outlet E	3	21	2001	pm	9.50	7.65	8.95	335.0	37	2	<2*
SC outlet E	3	22	2001	am	9.10	7.62	8.14	342.0	14	<1*	<2*
SC outlet W	3	20	2001	pm	9.20	7.63	9.15	331.0	15	1	<2*
SC outlet W	3	21	2001	am	10.00	7.60	8.48	334.0	4	<1*	<2*
SC outlet W	3	21	2001	pm	9.00	7.63	9.16	330.0	23	1	<2*
SC outlet W	3	22	2001	am	9.00	7.60	8.47	340.0	14	<1*	<2*
Seasonal % reduction					5.5	-2.9	9.5	-1.3	87.3	53.6	42.9
SC inlet	5	15	2001	pm	11.00	7.37	9.13	341.0	100	100	8
SC inlet	5	16	2001	am	11.00	7.53	9.61	261.0	1800	2300	30
SC inlet	5	16	2001	pm	11.50	7.52	9.62	307.0	2300	650	240
SC inlet	5	17	2001	am	10.80	7.41	9.60	344.0	1000	190	50
SC outlet E	5	15	2001	pm	11.50	7.83	7.92	231.0	2100	2000	>1600*
SC outlet E	5	16	2001	am	11.00	7.79	8.80	220.0	900	400	30
SC outlet E	5	16	2001	pm	11.20	7.74	8.64	257.0	500	68	17
SC outlet E	5	17	2001	am	12.50	7.64	6.91	322.0	30	52	2
SC outlet W	5	15	2001	pm	11.90	7.77	8.40	229.0	2400	1400	900
SC outlet W	5	16	2001	am	10.80	7.77	9.00	227.0	500	400	30
SC outlet W	5	16	2001	pm	11.90	7.77	8.46	260.0	200	96	30
SC outlet W	5	17	2001	am	12.50	7.61	7.39	321.0	33	17	2
Seasonal % reduction					-5.3	-3.8	13.7	17.5	35.9	31.6	-298.0
SC inlet	8	6	2001	pm	14.80	7.14	8.12	424.0	550	<5*	8
SC inlet	8	7	2001	am	14.50	7.09	8.11	425.0	1000	6	2
SC inlet	8	7	2001	pm	14.60	7.18	7.76	431.0	2000	8	8
SC inlet	8	8	2001	am	14.50	7.26	7.88	434.0	2000	8	4
SC outlet E	8	6	2001	pm	17.50	7.45	5.58	406.0	330	27	<2*
SC outlet E	8	7	2001	am	18.00	7.41	5.57	413.0	260	20	<2*
SC outlet E	8	7	2001	pm	17.60	7.59	5.83	422.0	310	11	4
SC outlet E	8	8	2001	am	18.00	7.58	5.47	423.0	300	14	2
SC outlet W	8	6	2001	pm	17.50	7.33	3.85	407.0	330	8	<2*
SC outlet W	8	7	2001	am	18.00	7.31	5.51	412.0	310	5	<2*
SC outlet W	8	7	2001	pm	17.60	7.45	5.29	421.0	260	11	4
SC outlet W	8	8	2001	am	18.00	7.47	5.39	421.0	200	7	<2*
Seasonal % reduction					-21.7	-3.9	33.3	3.0	79.3	-90.7	54.5
Annual % reduction					-9.1	-3.5	18.0	5.9	60.2	30.7	-263.6

*Value replaced with detection limit to calculate percent reduction.

Table 30: South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

	Reported Value†	True Value†	Acceptance Limits
Specific conductivity (μS/cm at 25°C)	823.0	814	738–890
	1090.0	1099	1033–1164
Total alkalinity (mg/L as $CaCO_3$)	50.4	49.8	44.1–56.0
	124.0	122	111–131
Ammonia nitrogen, autoanalysis (mg-N/L)	12.2	12.0	9.31–14.6
	14.5	15.0	11.7–18.2
Ammonia nitrogen, manual (mg-N/L)	10.7	12.0	9.31–14.6
	14.7	15.0	11.7–18.2
Nitrate nitrogen, autoanalysis (mg-N/L)	9.69	10.1	7.98–12.0
	5.91	5.87	4.62–7.00
Orthophosphate, autoanalysis (mg-P/L)	10.8	10.7	9.17–12.3
	0.133	0.104	0.0707–0.137
Orthophosphate, manual (mg-P/L)	10.7	10.7	9.17–12.3
	0.102	0.104	0.070–0.137
Total phosphorus, autoanalysis (mg-P/L)	5.02	5.23	3.98–6.13
	2.41	2.37	1.80–2.80
Total phosphorus, manual (mg-P/L)	4.93	5.23	3.98–6.13
	2.34	2.37	1.08–2.80
pH	9.23	9.30	3.01–9.58
	8.77	8.90	8.63–9.16
Non-filterable residue (mg/L)	63.8	73.5	56.6–79.3
	44.9	53.4	40.4–57.3

†Performance Evaluation Reports WP-063 and WP-066.

Table 31: Summary of 2000/2001 single-blind quality control results.

9 Figures

- Figure 1 (page 70) provides a general map of Lake Whatcom and its tributaries, and shows the current lake sampling sites. Refer to Appendix A, Figures 140–142 (pages 212–214) for detailed maps showing lake sampling locations.
- Figures 2–11 (pages 71–80) show single-day Hydrolab profiles from Lake Whatcom for the February and September sampling dates.
- Figures 12–31 (pages 81–100) show multi-year plots of Hydrolab data for Lake Whatcom. The lines connect data from a single sampling depth through time to help identify seasonal patterns of convergence and divergence; however, they 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 32–35 (pages 101–104) show correlations between year and dissolved oxygen during the summer at Site 1, 12–18 m, 1988–2000.
- Figures 36–100 (pages 105–169) show multi-year plots of water quality, chlorophyll, plankton, and Secchi depth data for Lake Whatcom.
- Figures 101–115 (pages 170–184) show multi-year plots of coliforms and *Enterococcus* data for Lake Whatcom.
- Figures 116 and 117 (pages 185 and 186) show iron concentrations in untreated drinking water (gatehouse) and average trihalomethanes concentrations in the Bellingham water distribution system.
- Figures 118–123 (pages 187–192) 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 from 1993–2001.
- Figures 124 and 125 (pages 193 and 194) illustrate the current bathymetry and sediment depths in Mirror Lake.
- Figures 126–130 (pages 195–199) show sampling locations and current photographs of the Park Place and Brentwood wet ponds.
- Figures 131–139 (pages 200–208) show the field and laboratory quality control results and Hydrolab quality control comparisons.

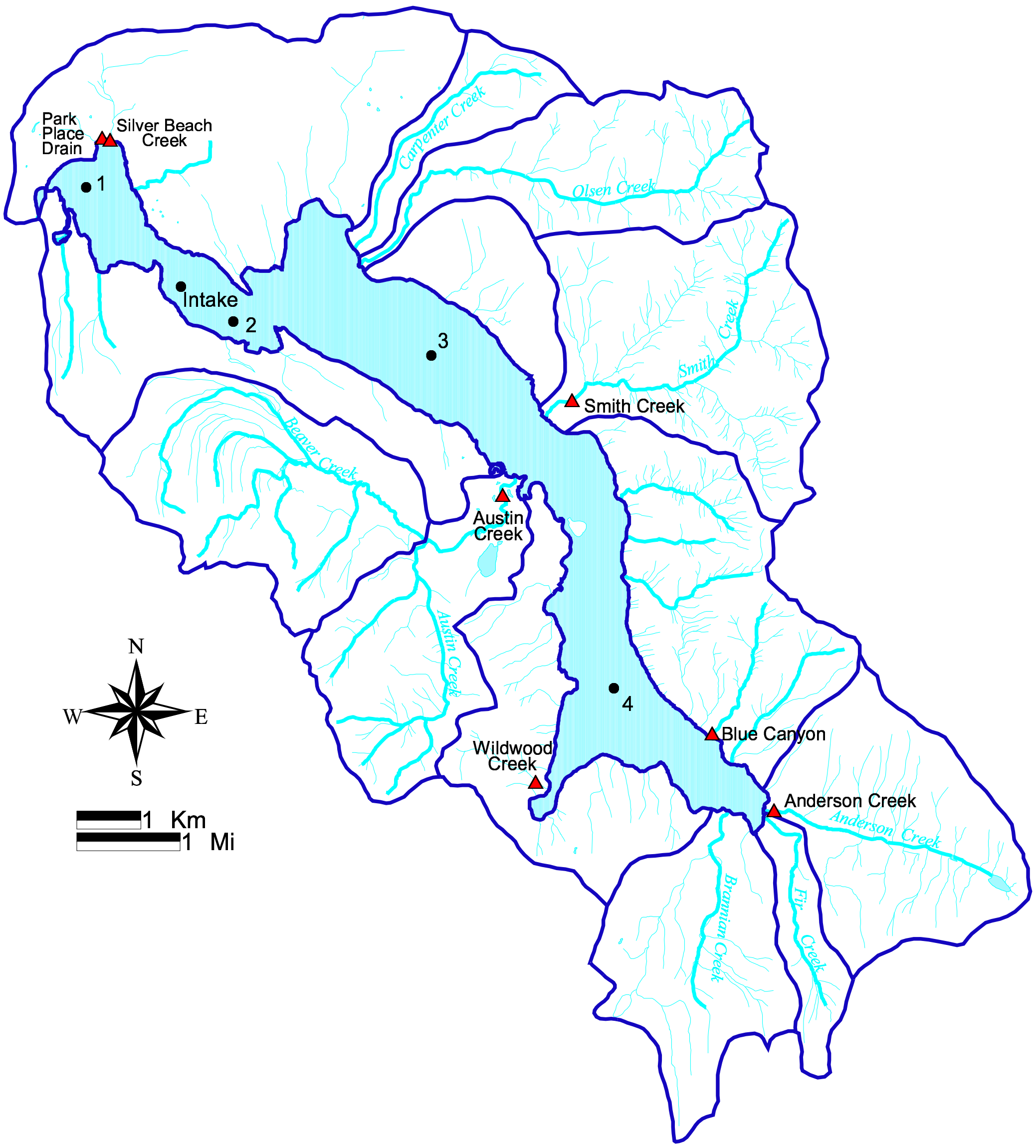

Figure 1: Lake Whatcom 2000/2001 sampling sites.

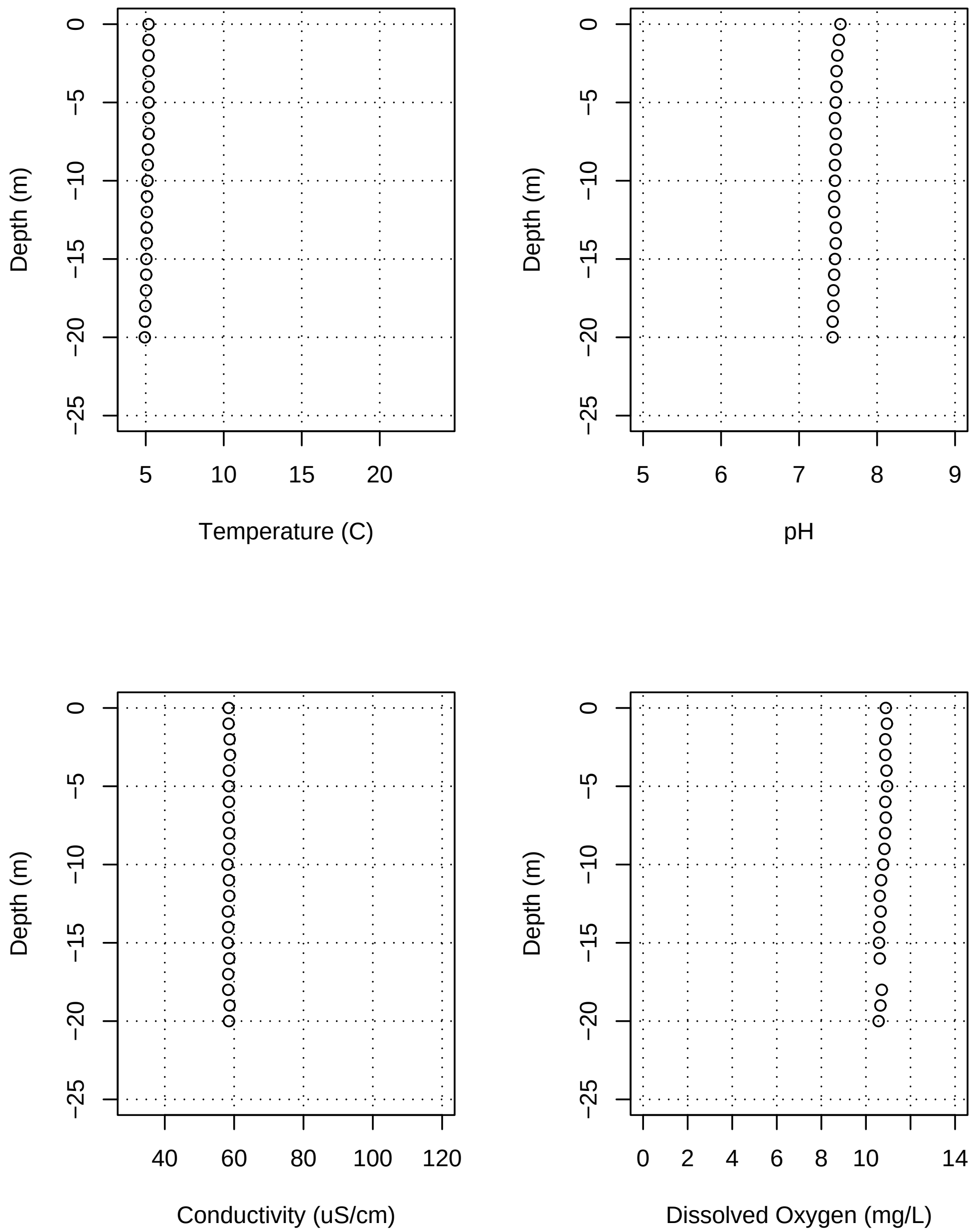

Figure 2: Lake Whatcom Hydrolab profile for Site 1, February 13, 2001.

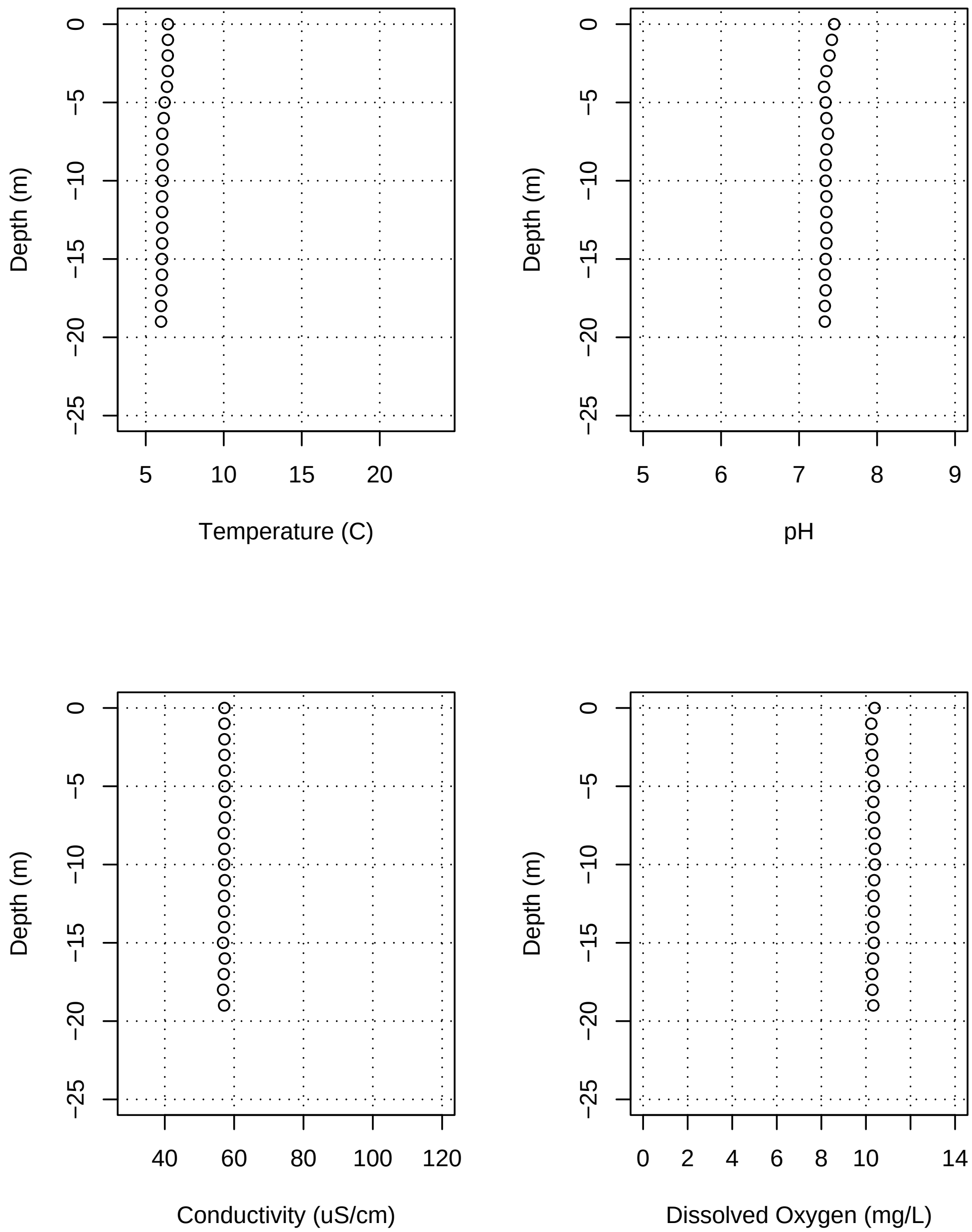

Figure 3: Lake Whatcom Hydrolab profile for Site 2, February 13, 2001.

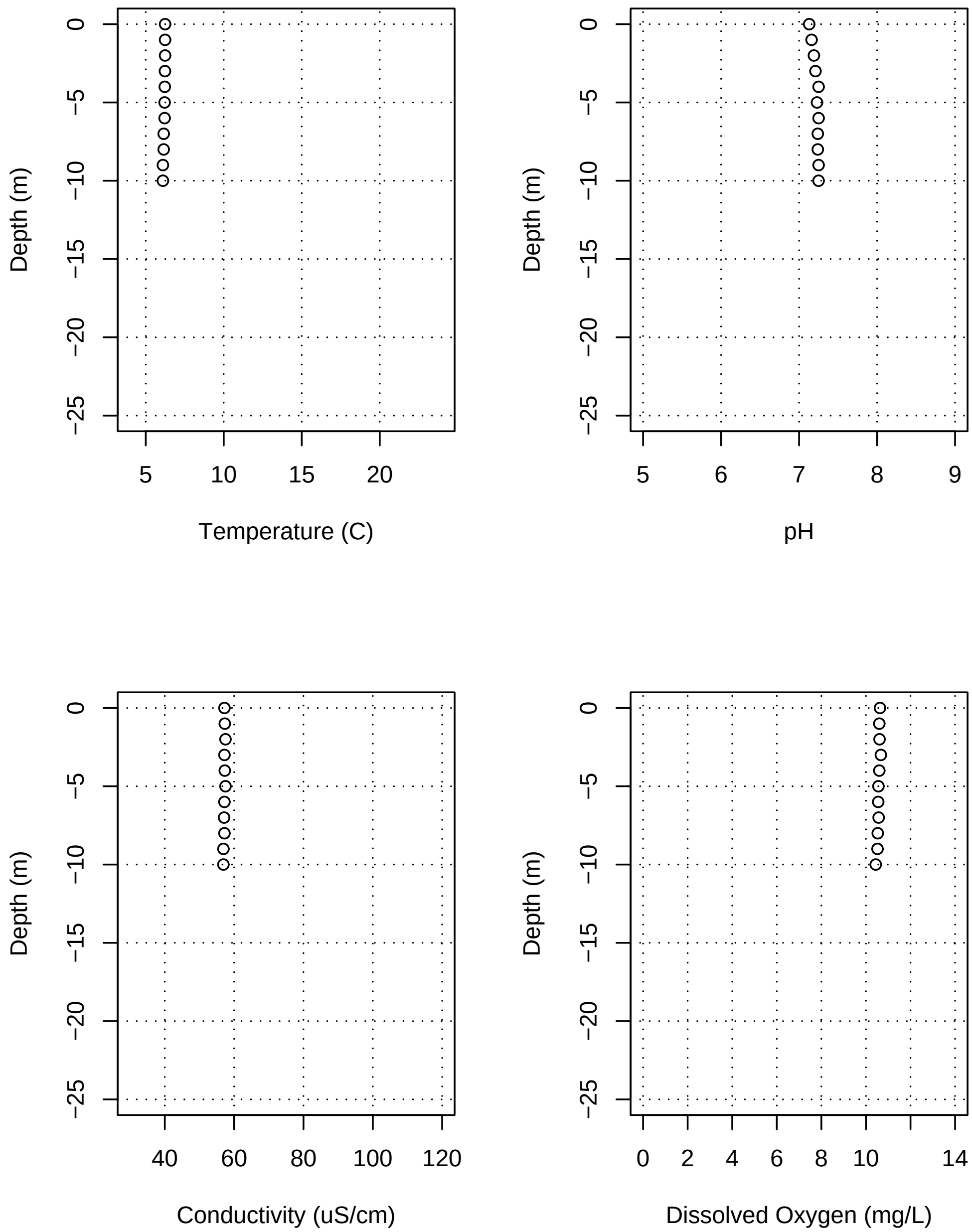

Figure 4: Lake Whatcom Hydrolab profile for the Intake, February 13, 2001.

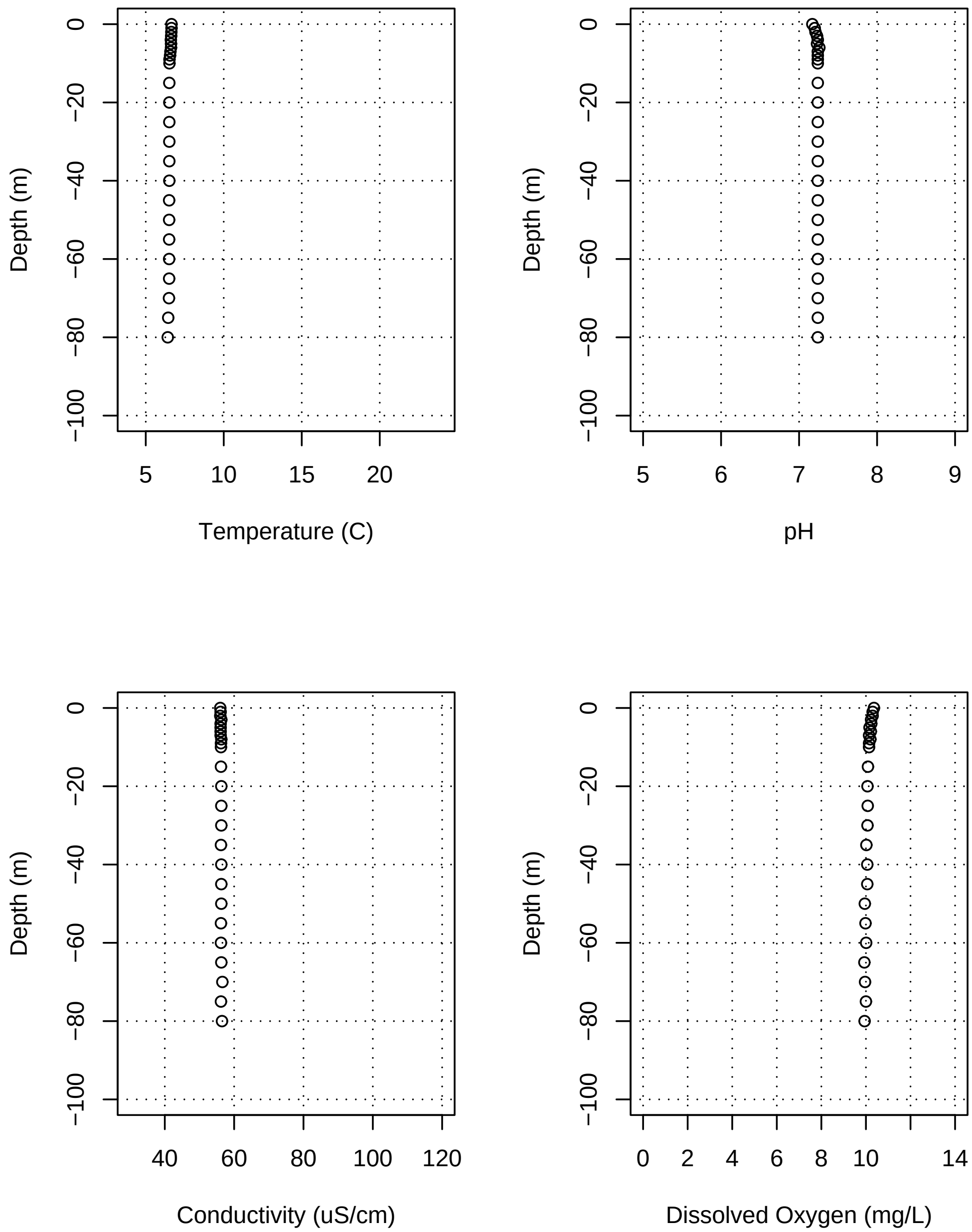

Figure 5: Lake Whatcom Hydrolab profile for Site 3, February 13, 2001.

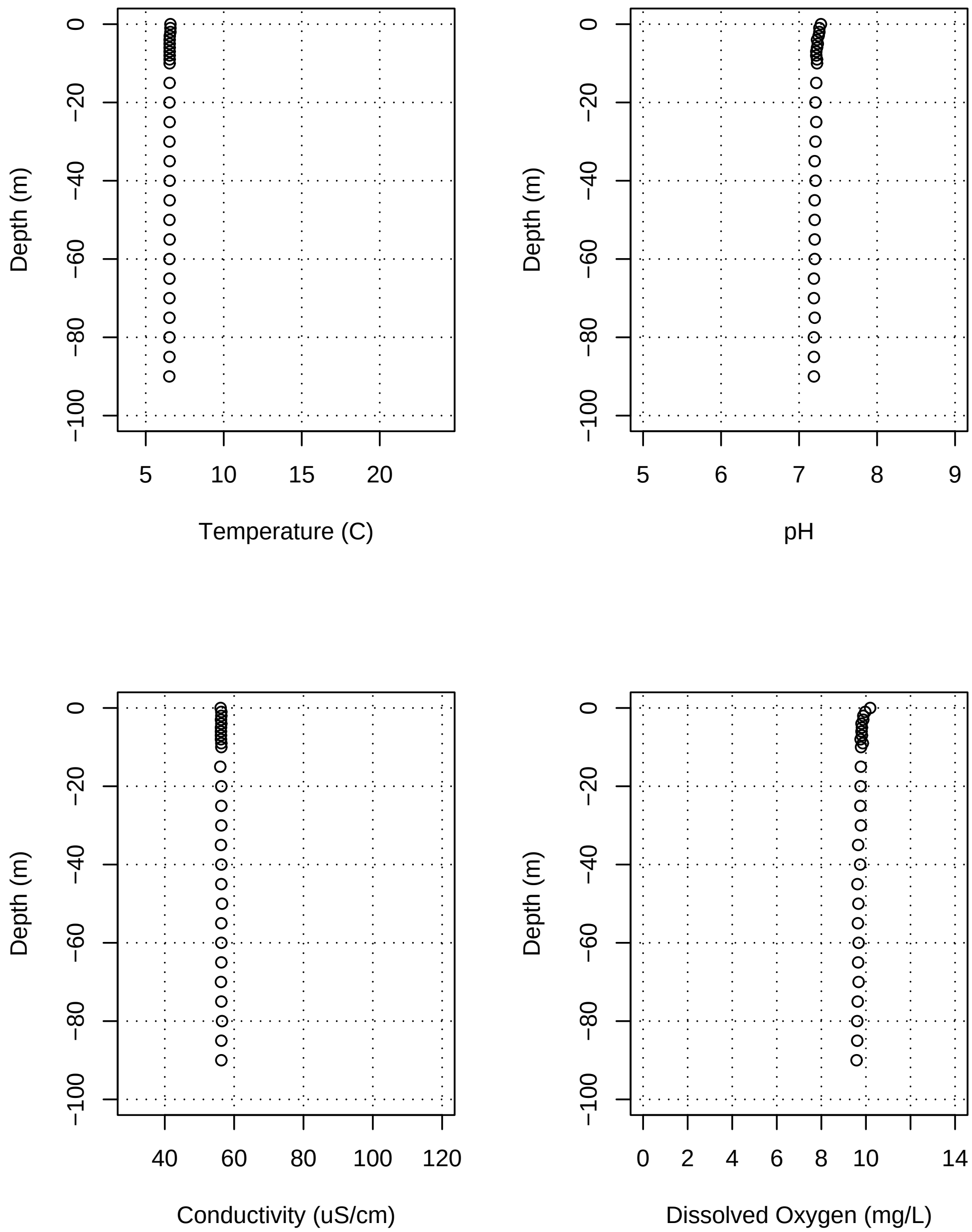

Figure 6: Lake Whatcom Hydrolab profile for Site 4, February 13, 2001.

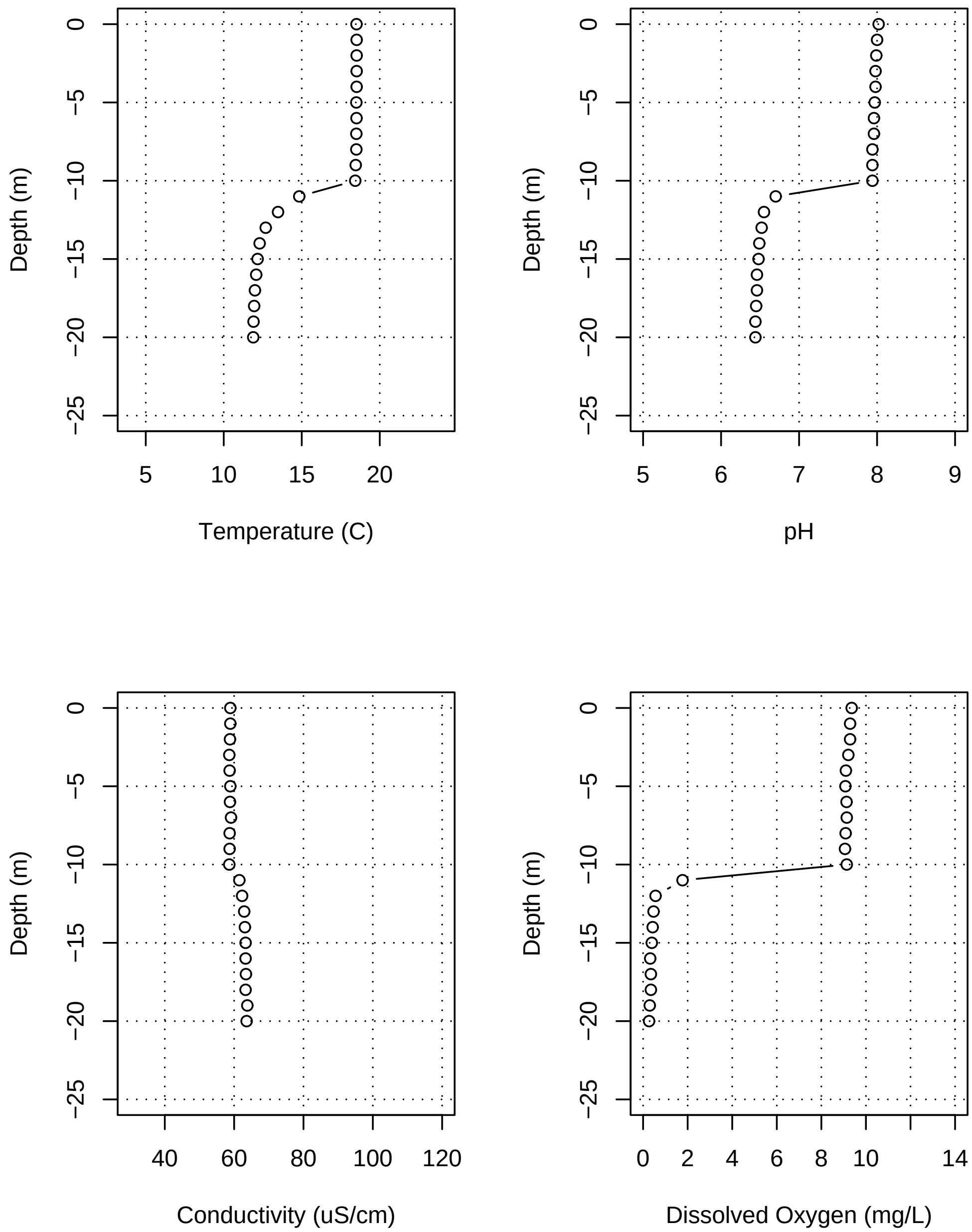

Figure 7: Lake Whatcom Hydrolab profile for Site 1, September 6, 2001.

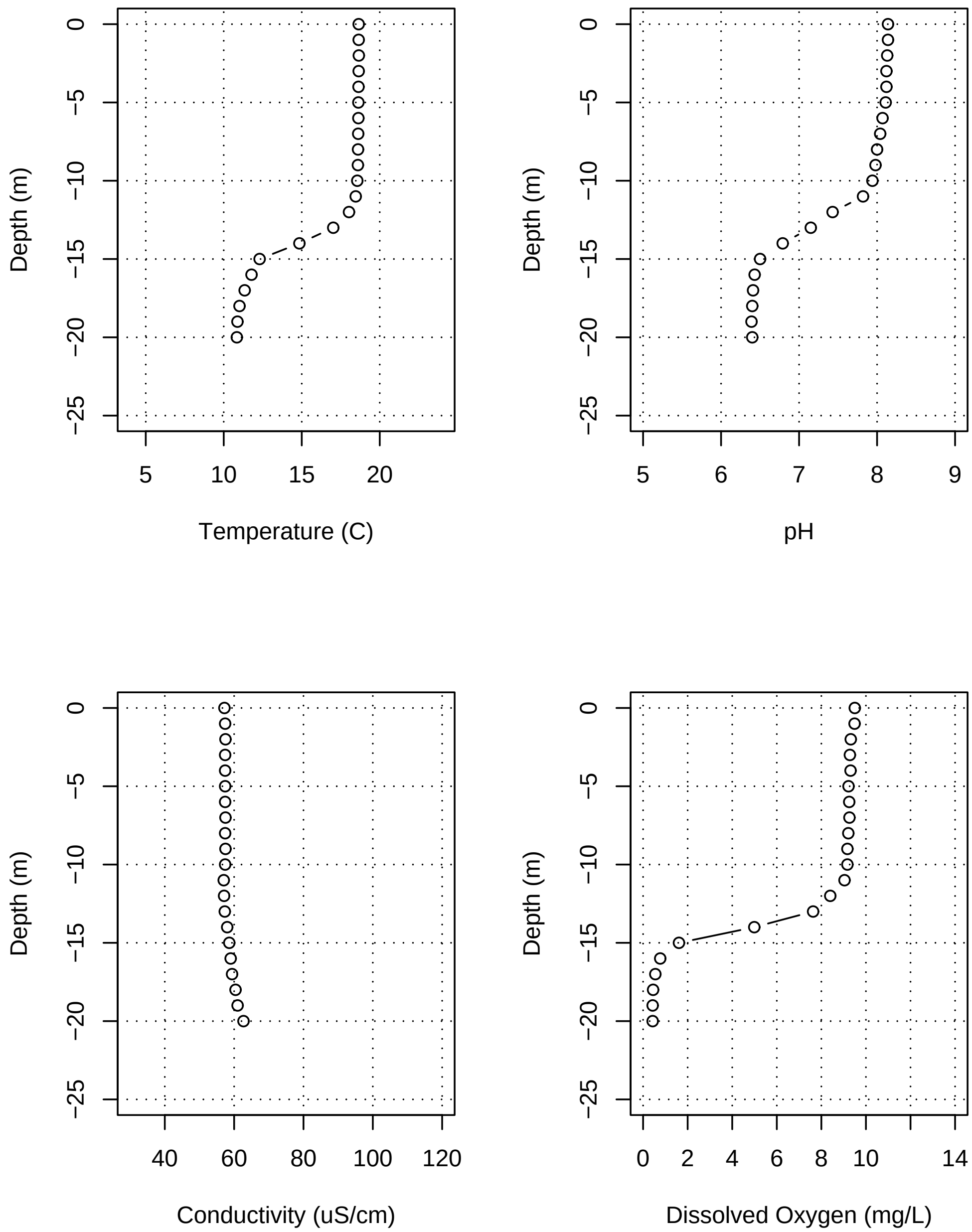

Figure 8: Lake Whatcom Hydrolab profile for Site 2, September 6, 2001.

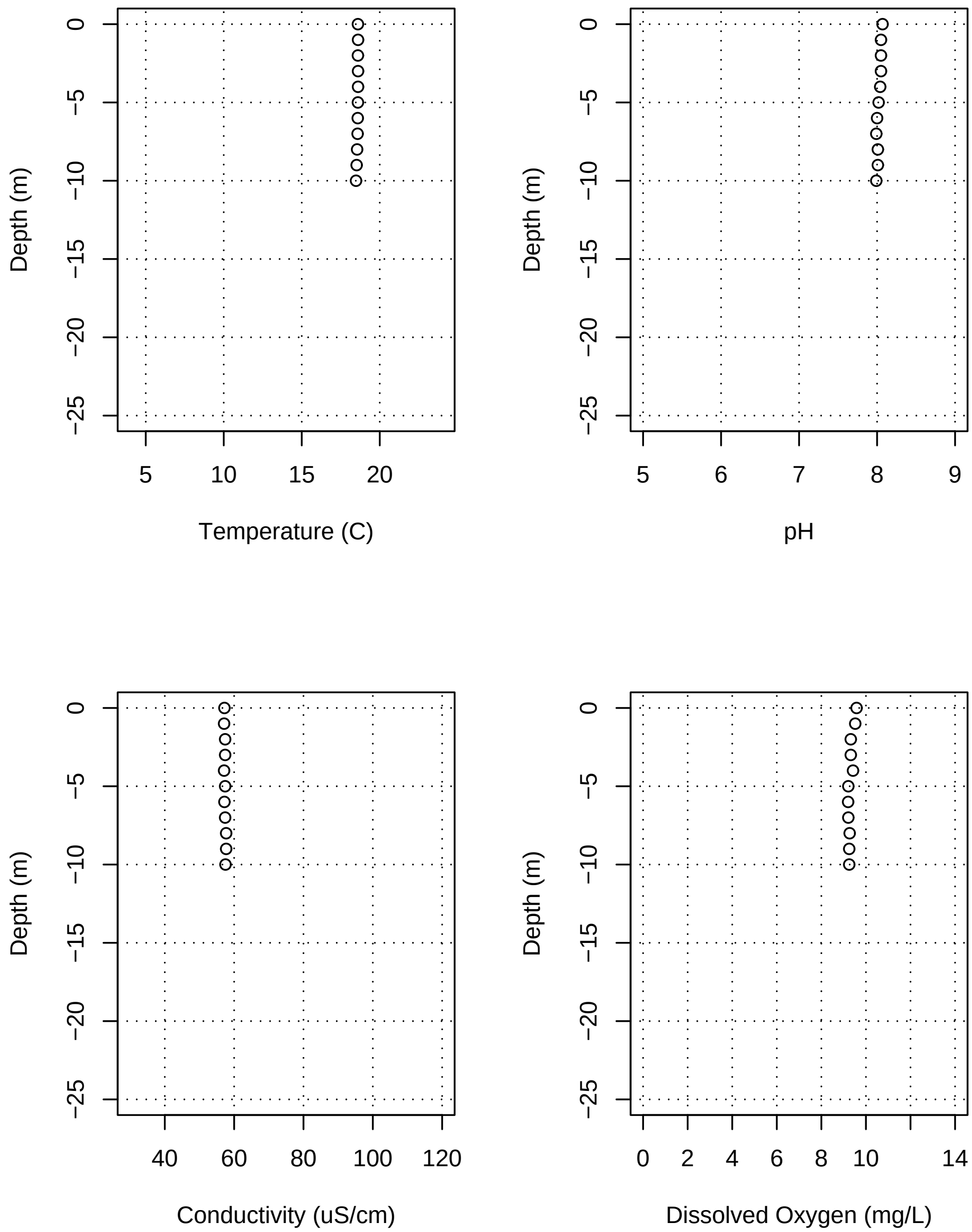

Figure 9: Lake Whatcom Hydrolab profile for the Intake, September 6, 2001.

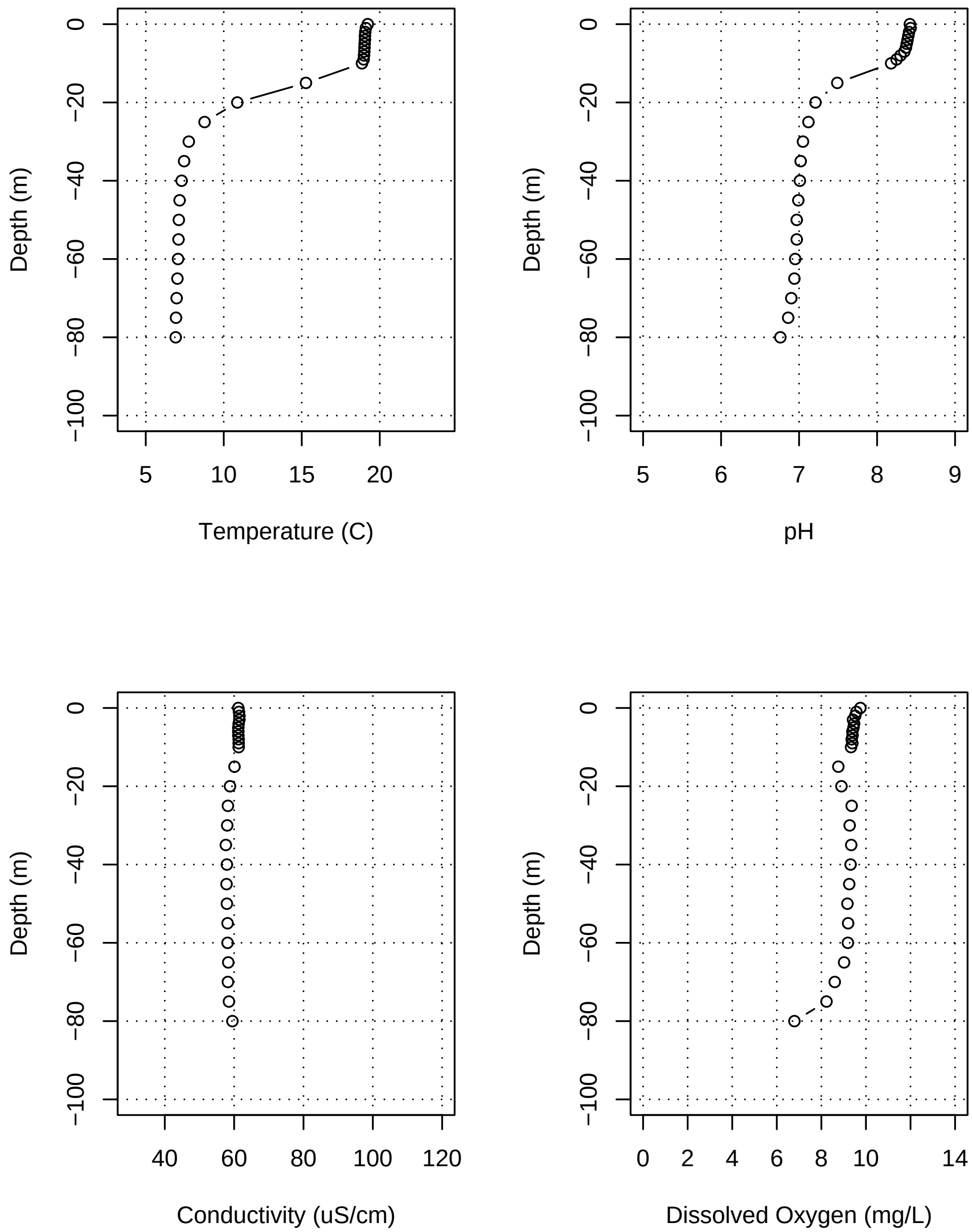

Figure 10: Lake Whatcom Hydrolab profile for Site 3, September 4, 2001.

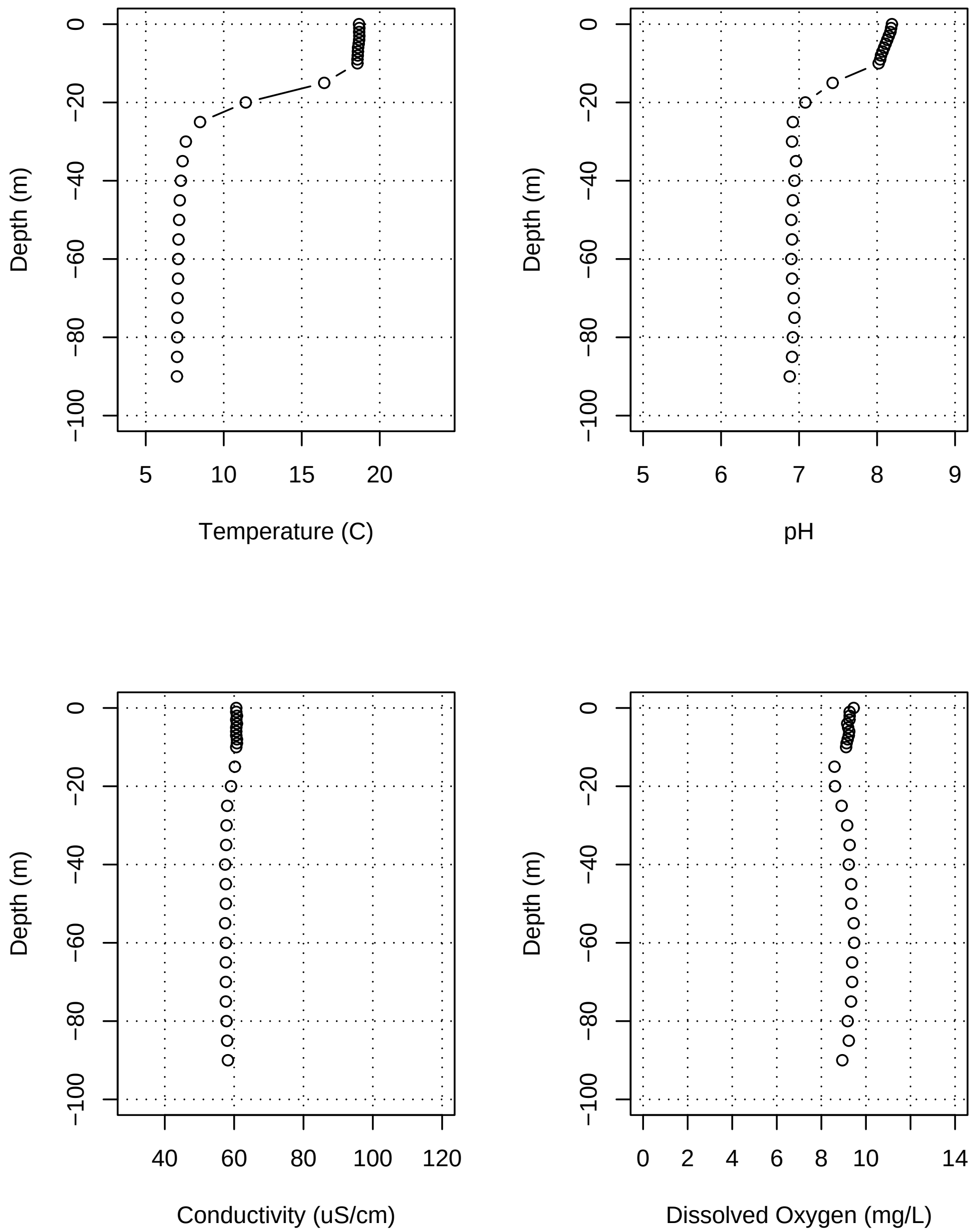

Figure 11: Lake Whatcom Hydrolab profile for Site 4, September 4, 2001.

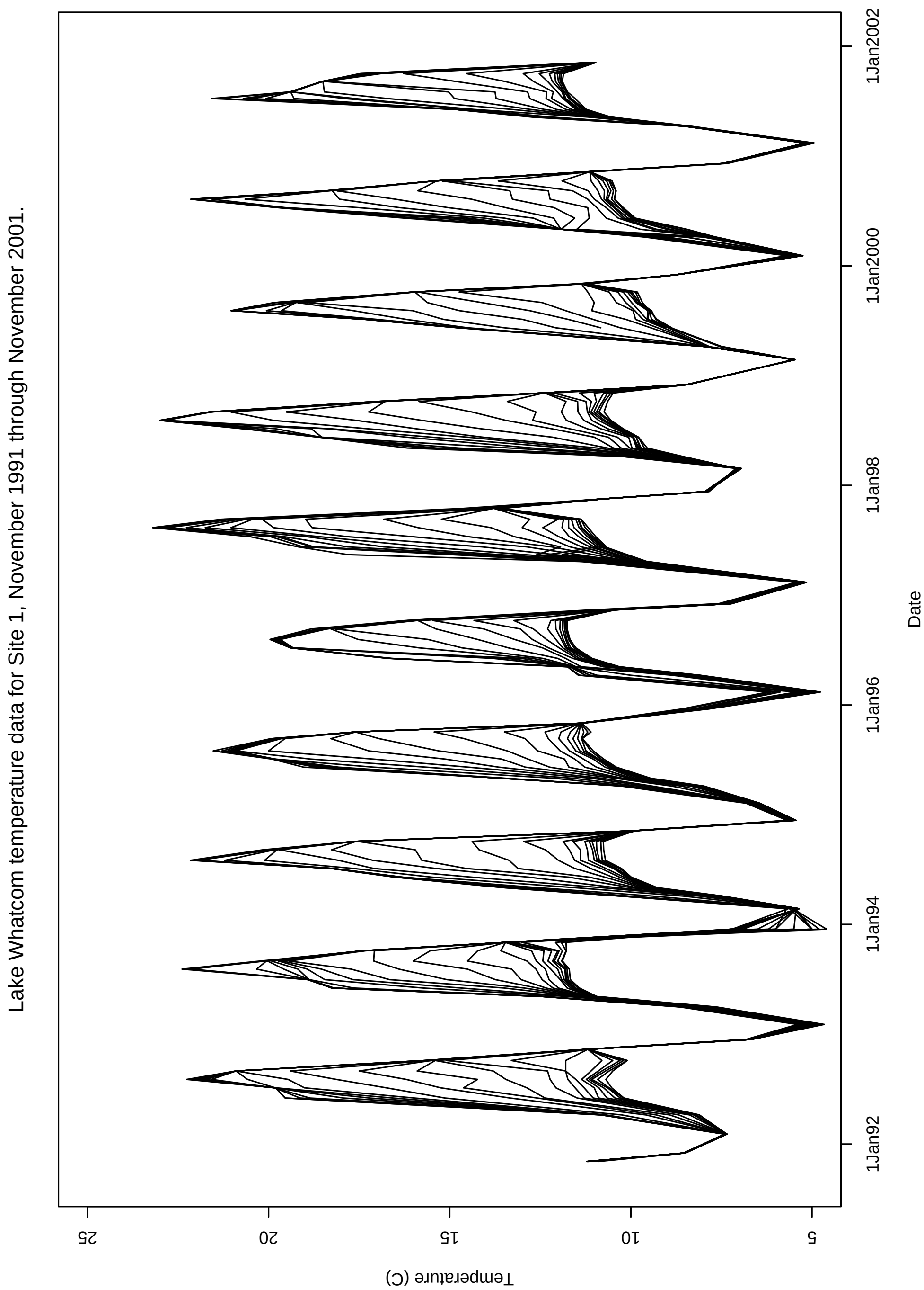

Figure 12: Lake Whatcom temperature data for Site 1.

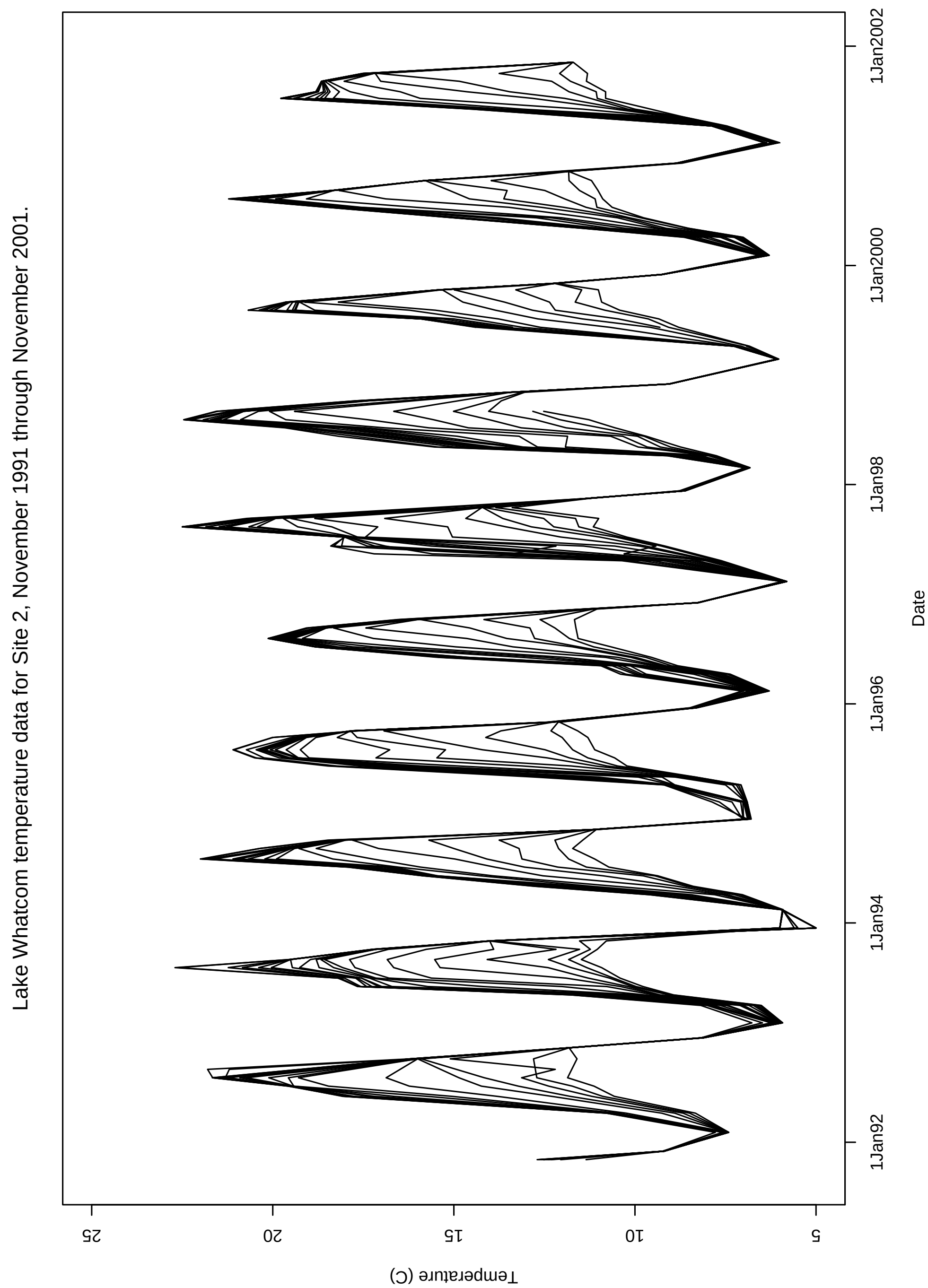

Figure 13: Lake Whatcom temperature data for Site 2.

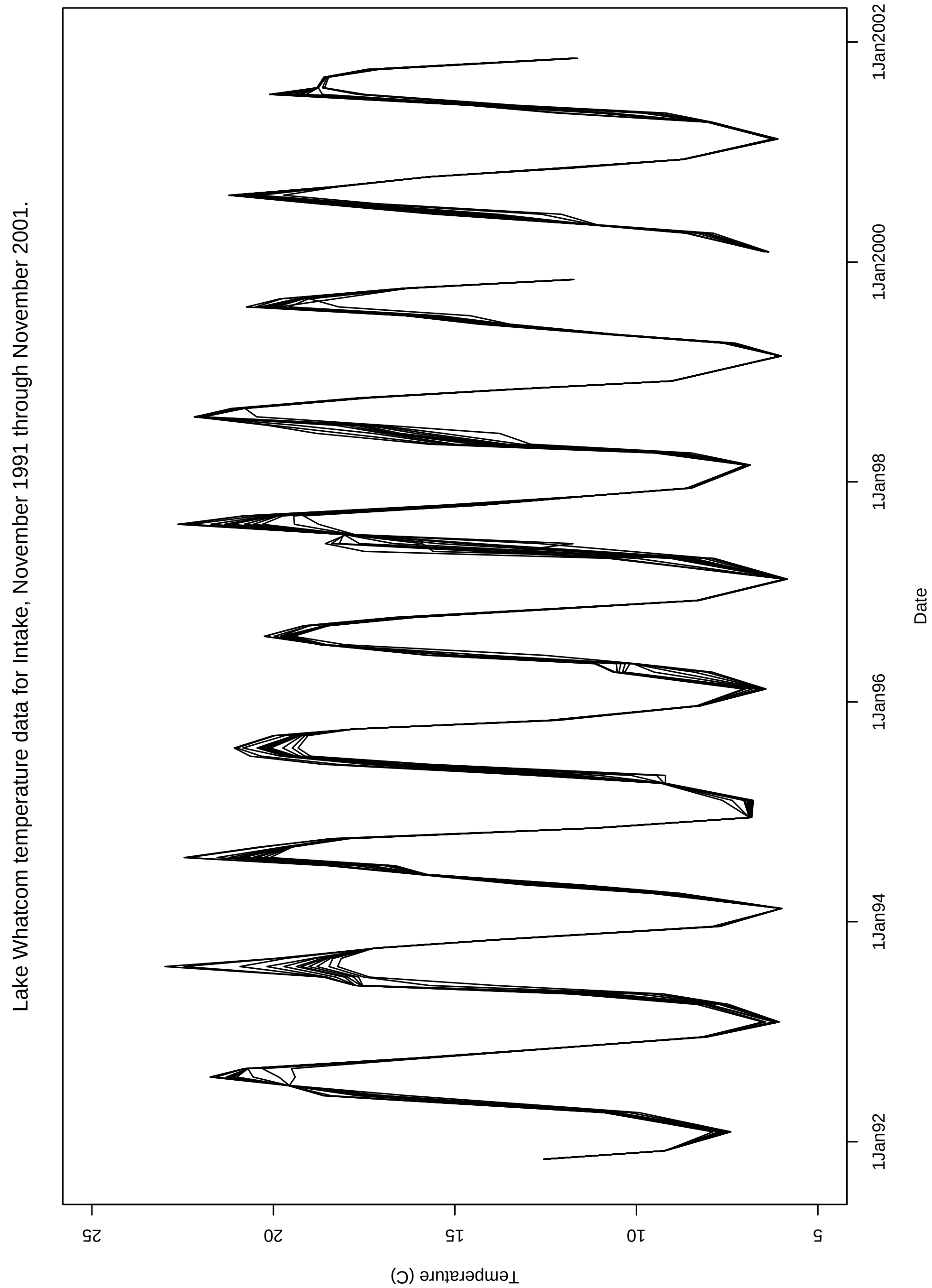

Figure 14: Lake Whatcom temperature data for the Intake.

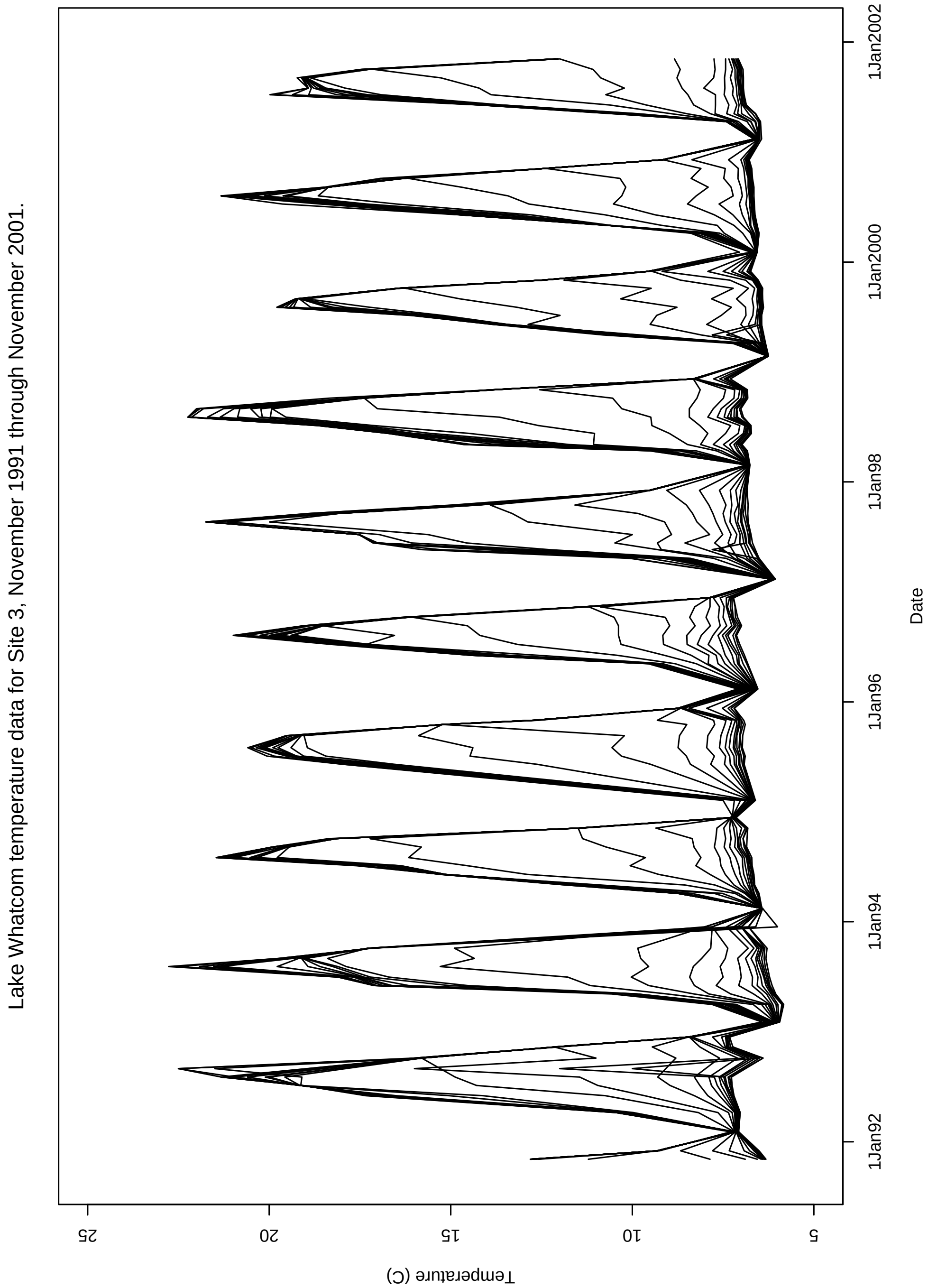

Figure 15: Lake Whatcom temperature data for Site 3.

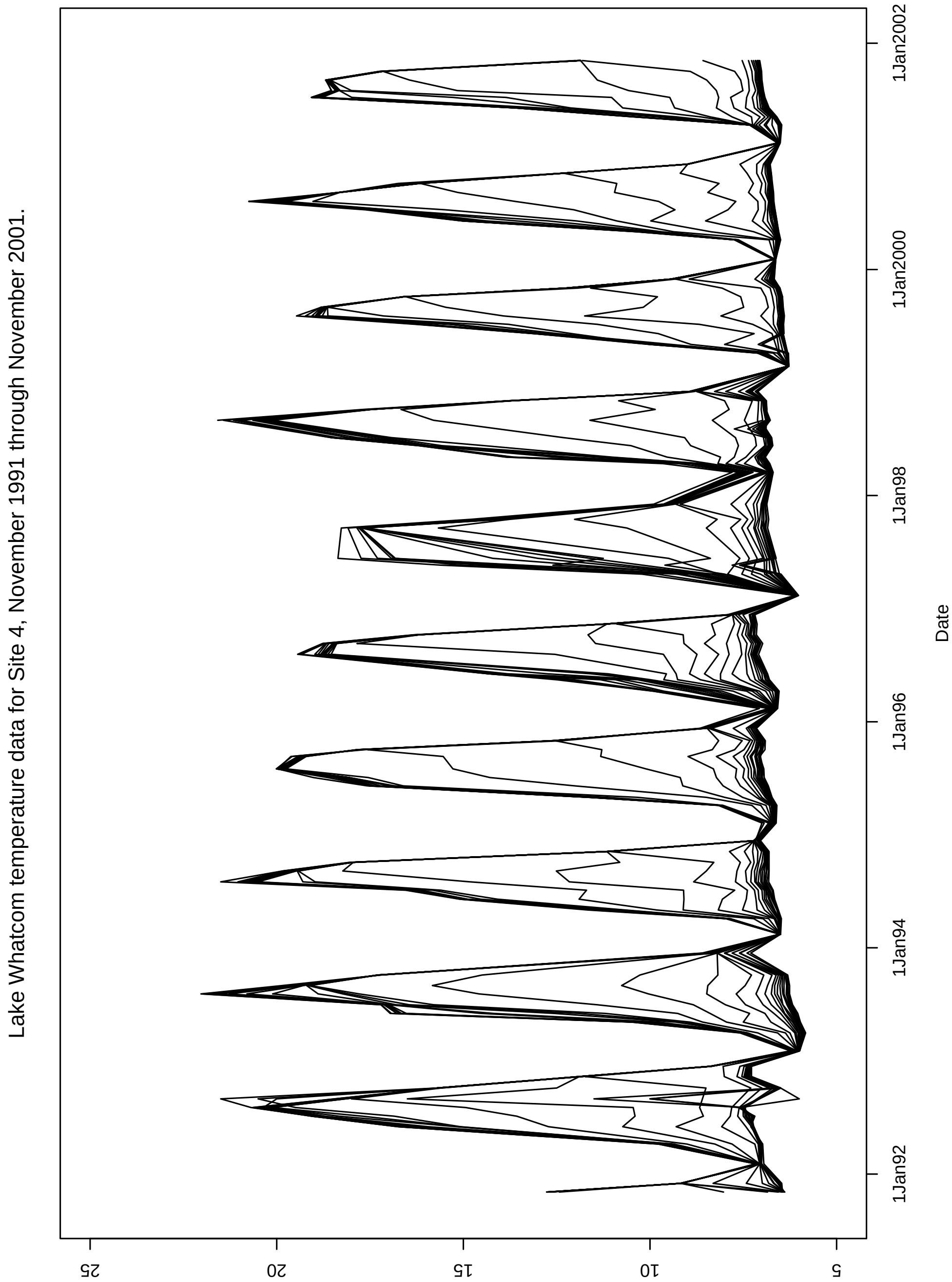

Figure 16: Lake Whatcom temperature data for Site 4.

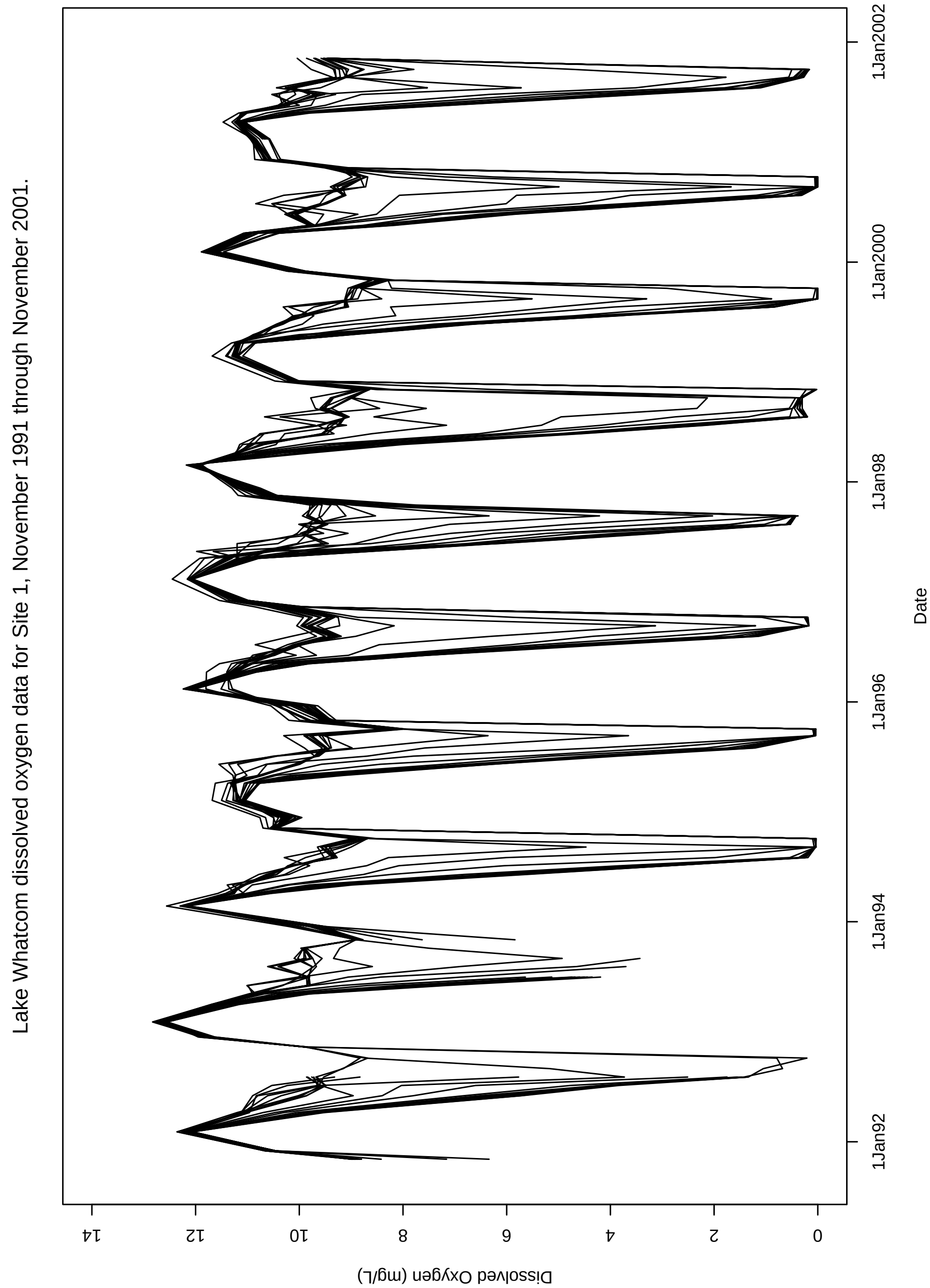

Figure 17: Lake Whatcom dissolved oxygen data for Site 1.

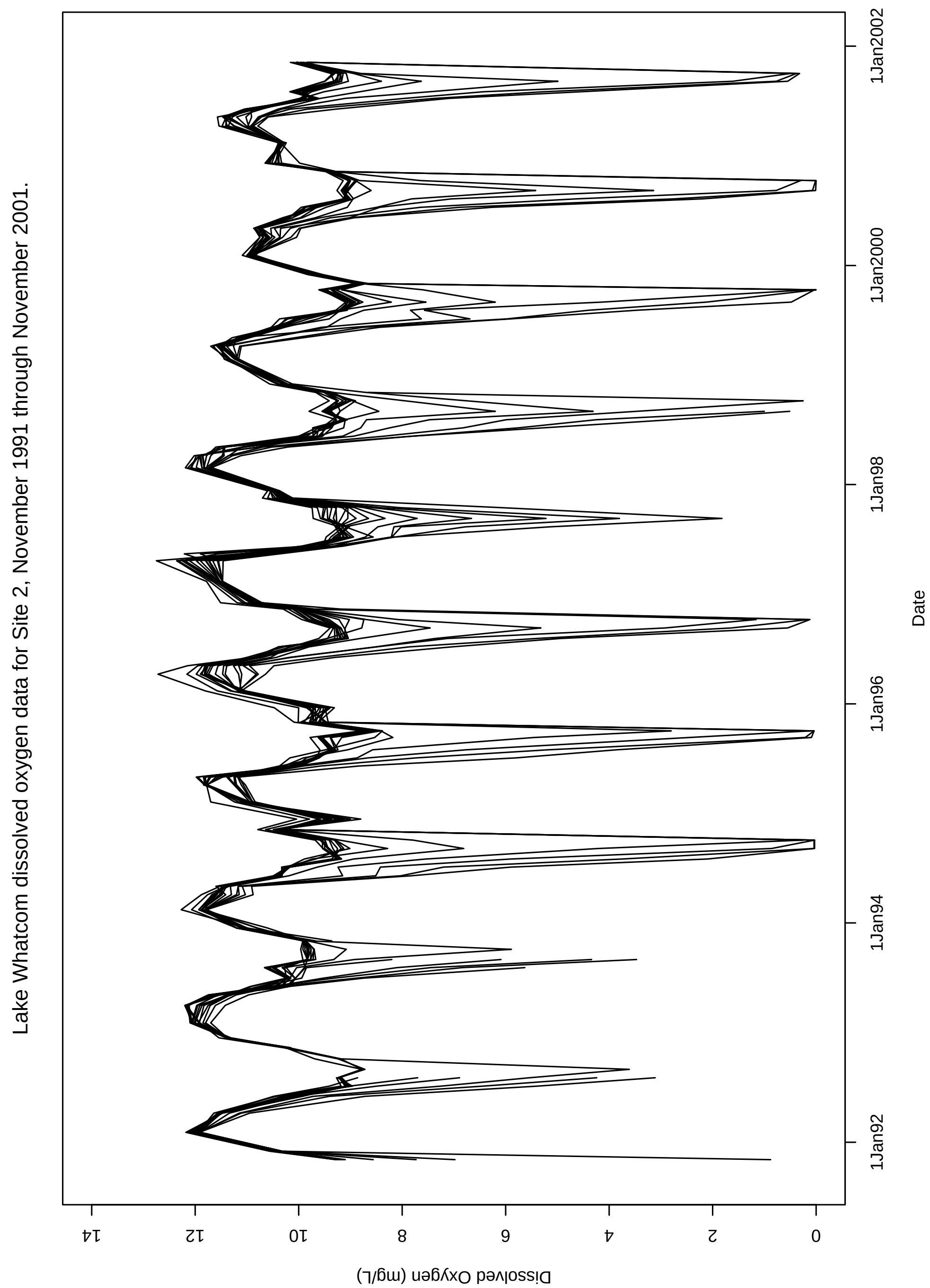

Figure 18: Lake Whatcom dissolved oxygen data for Site 2.

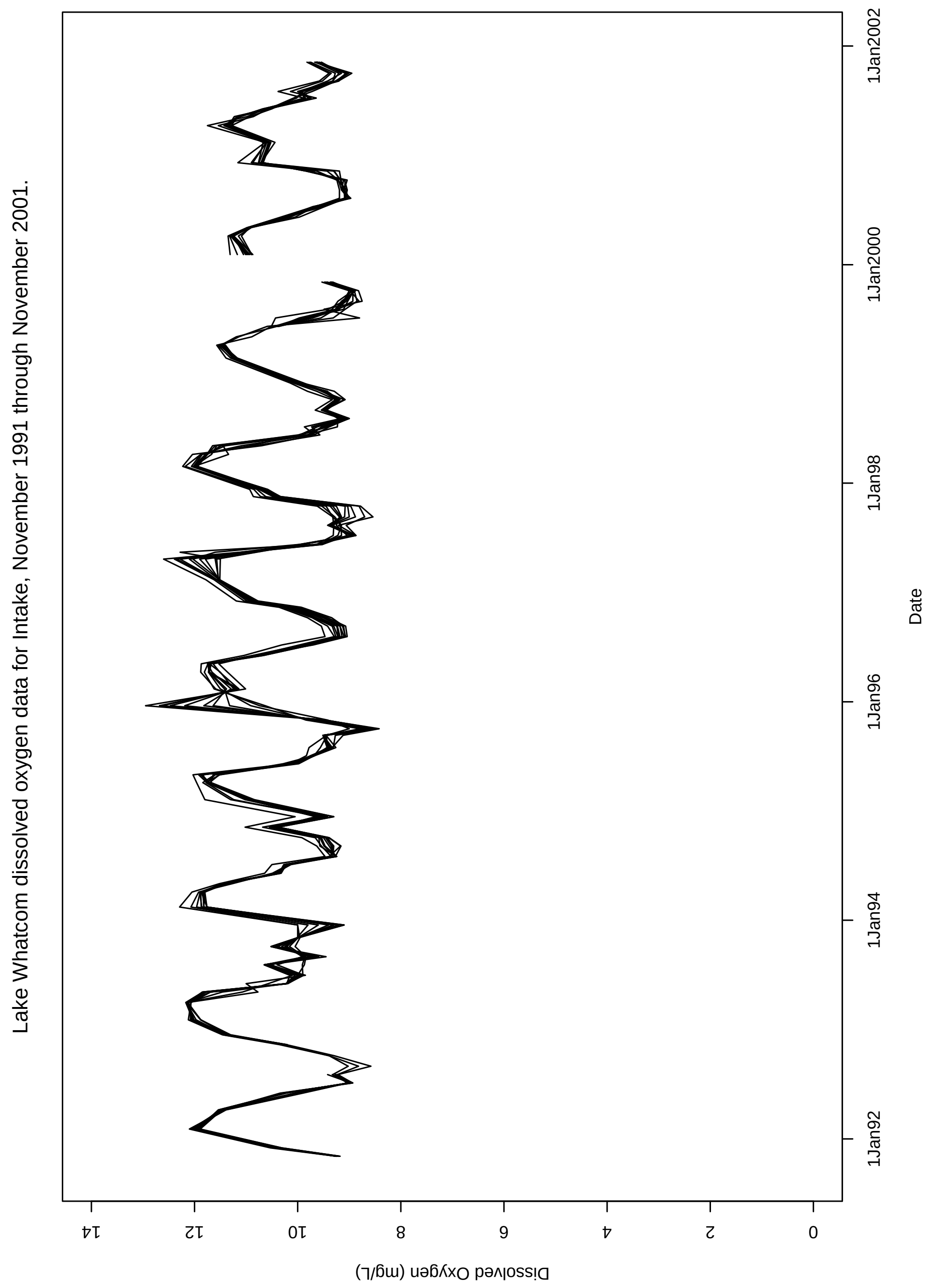

Figure 19: Lake Whatcom dissolved oxygen data for the Intake.

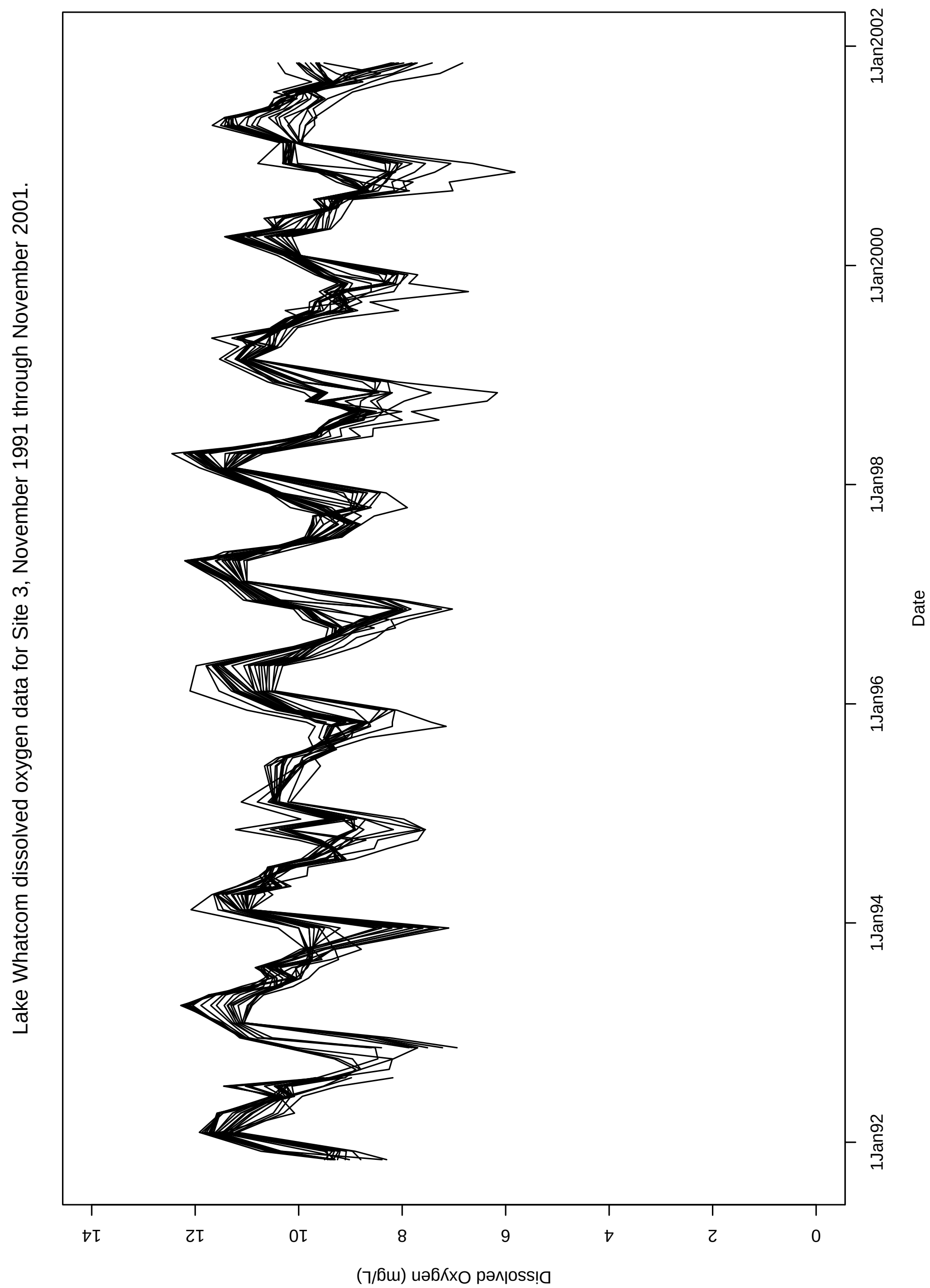

Figure 20: Lake Whatcom dissolved oxygen data for Site 3.

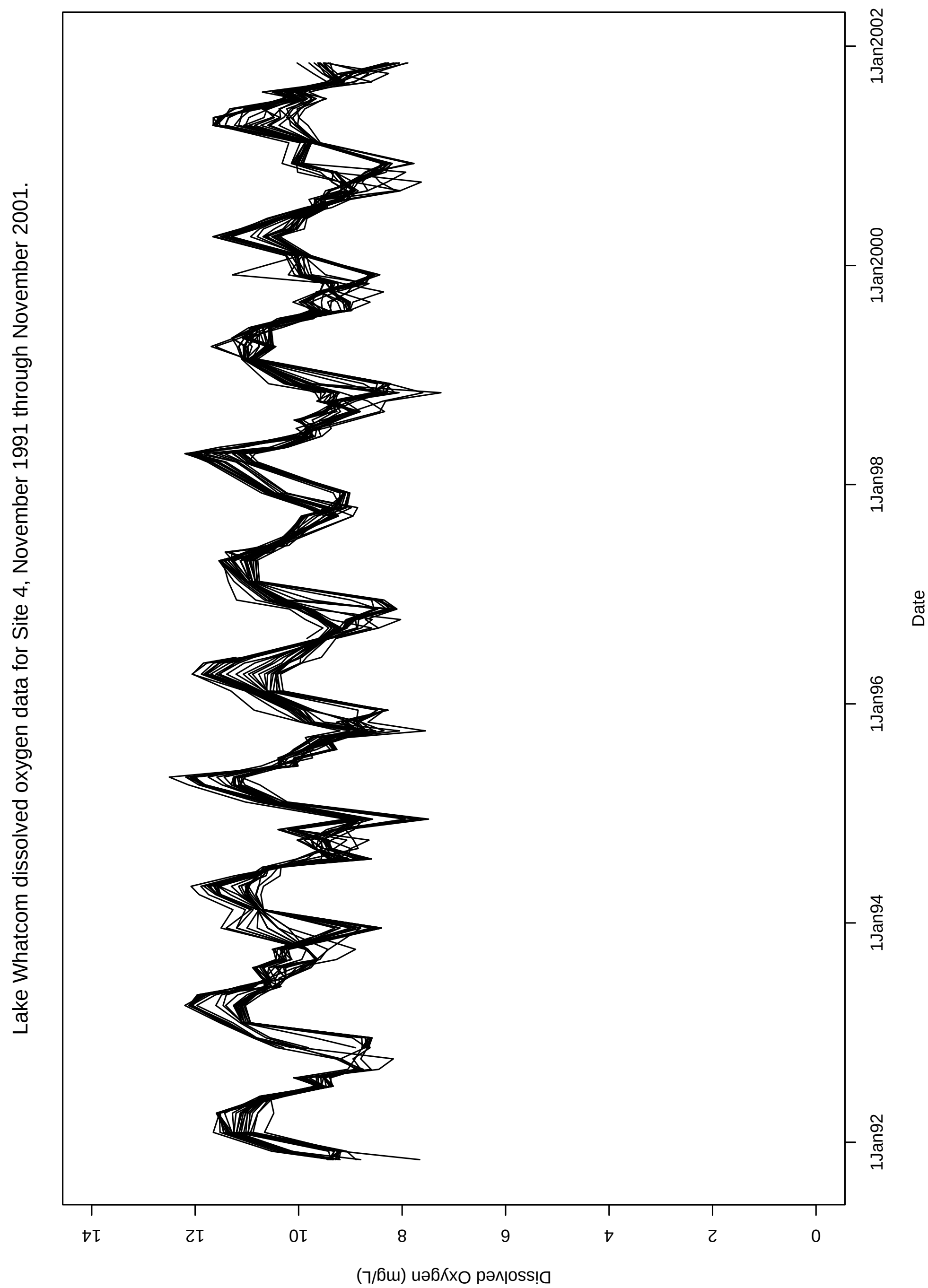

Figure 21: Lake Whatcom dissolved oxygen data for Site 4.

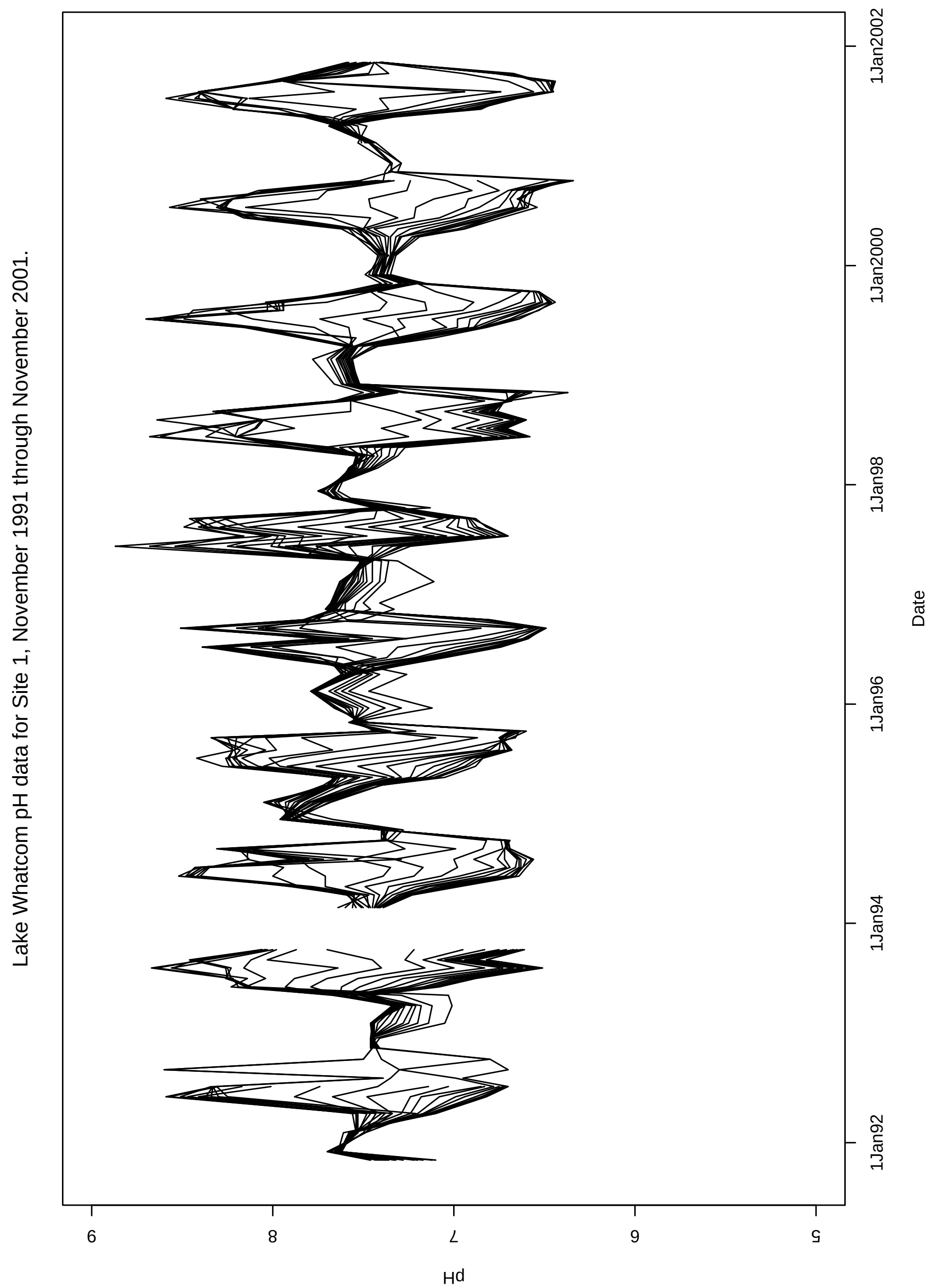

Figure 22: Lake Whatcom pH data for Site 1.

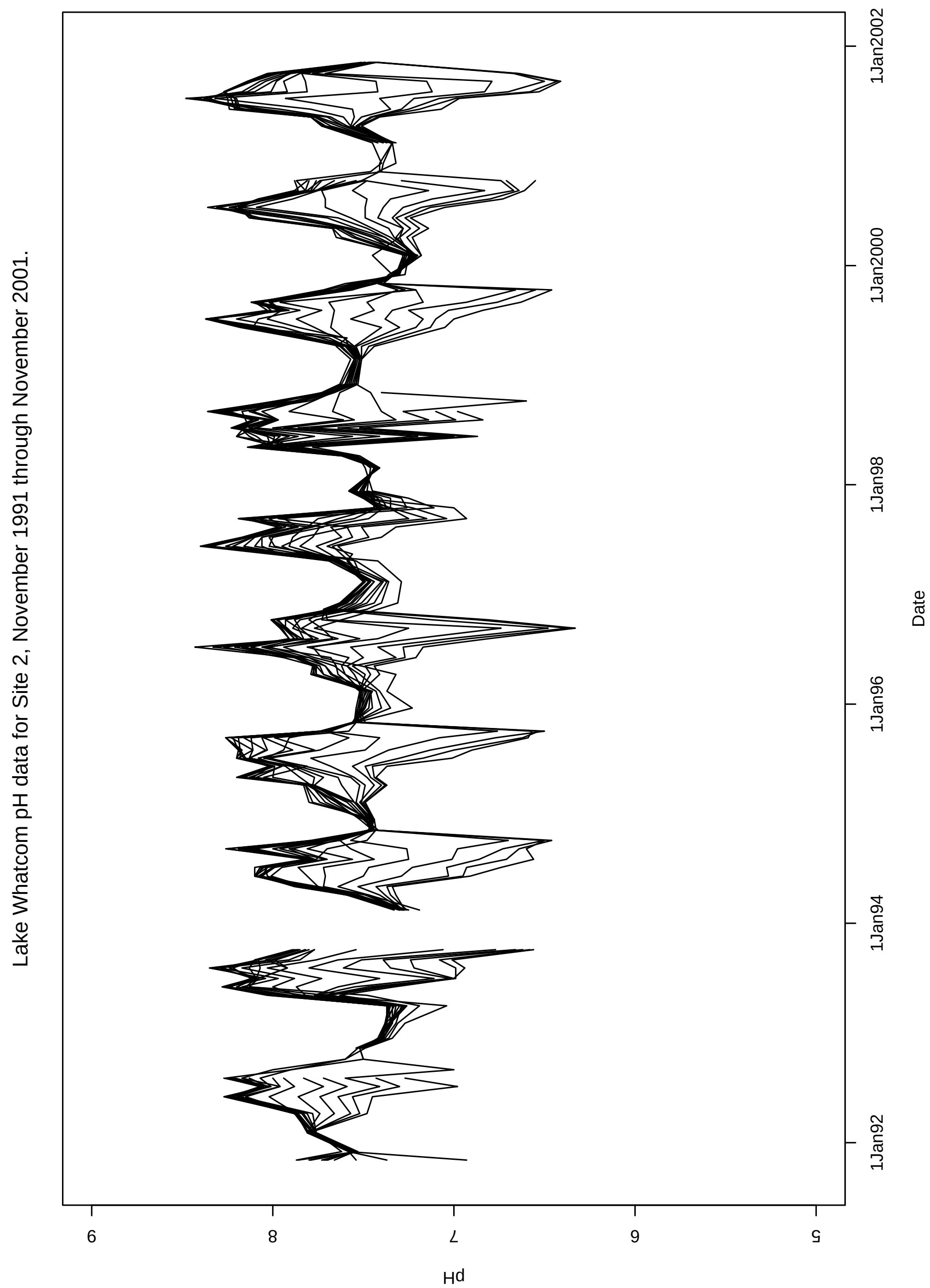

Figure 23: Lake Whatcom pH data for Site 2.

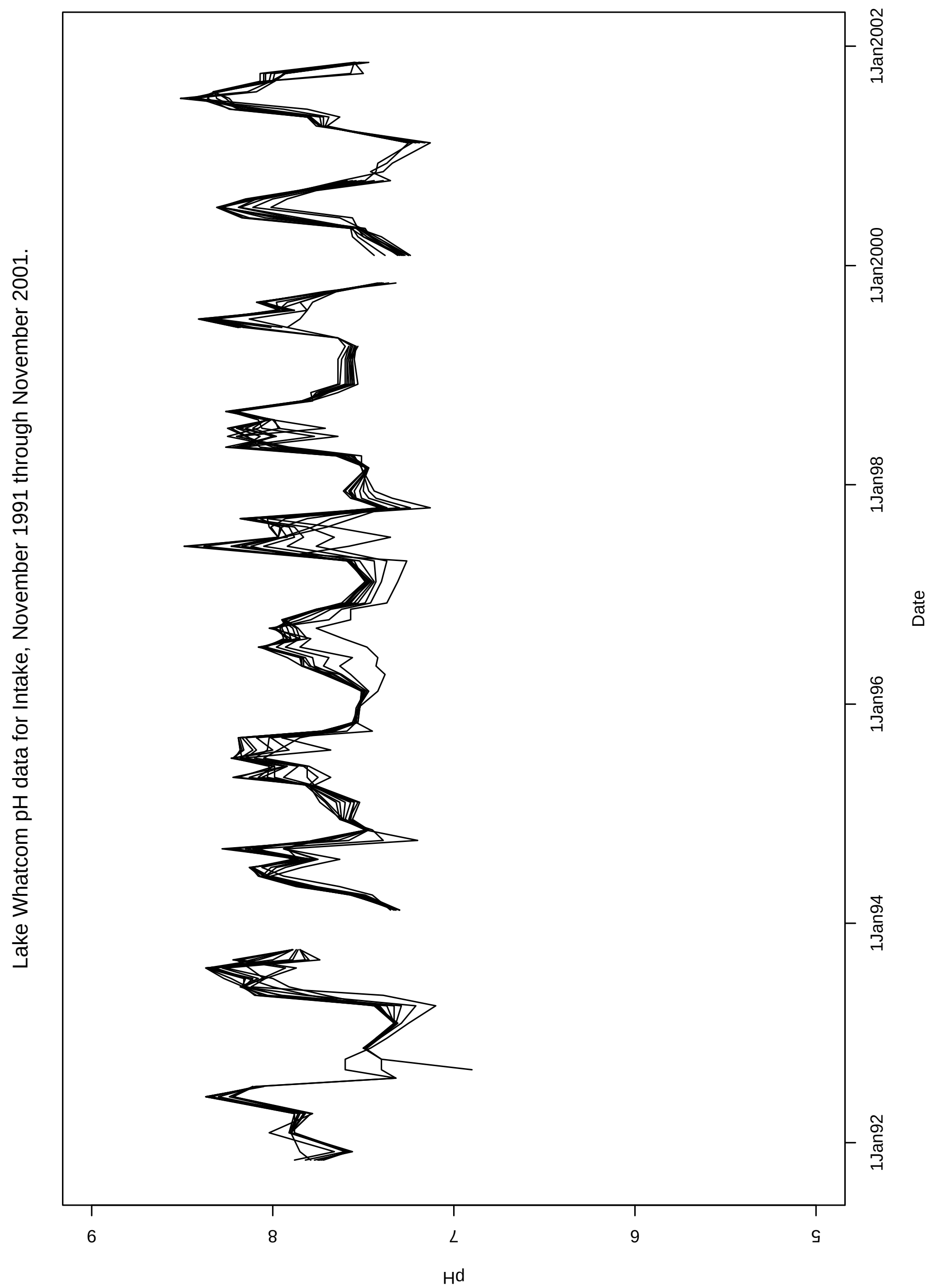

Figure 24: Lake Whatcom pH data for the Intake.

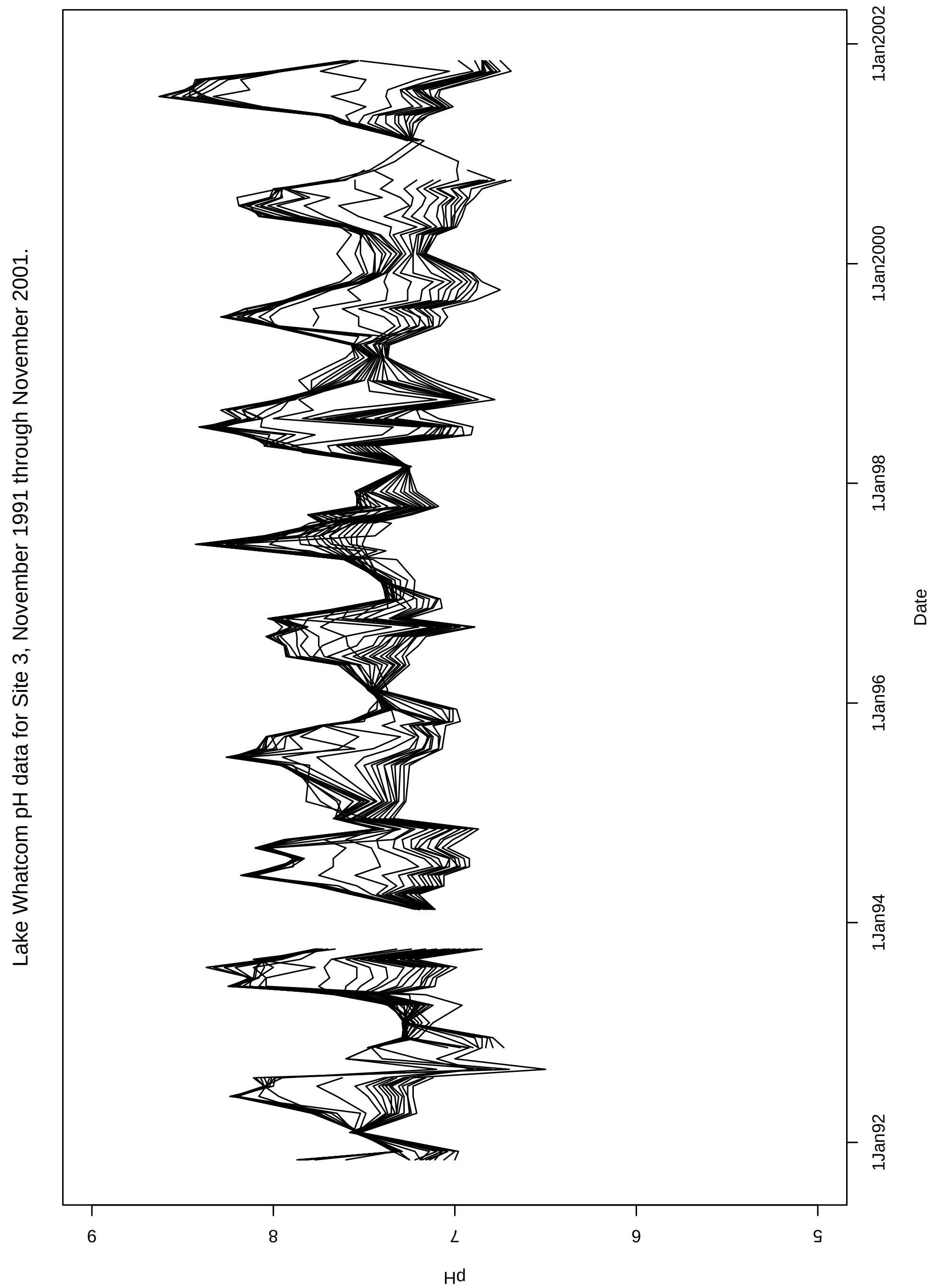

Figure 25: Lake Whatcom pH data for Site 3.

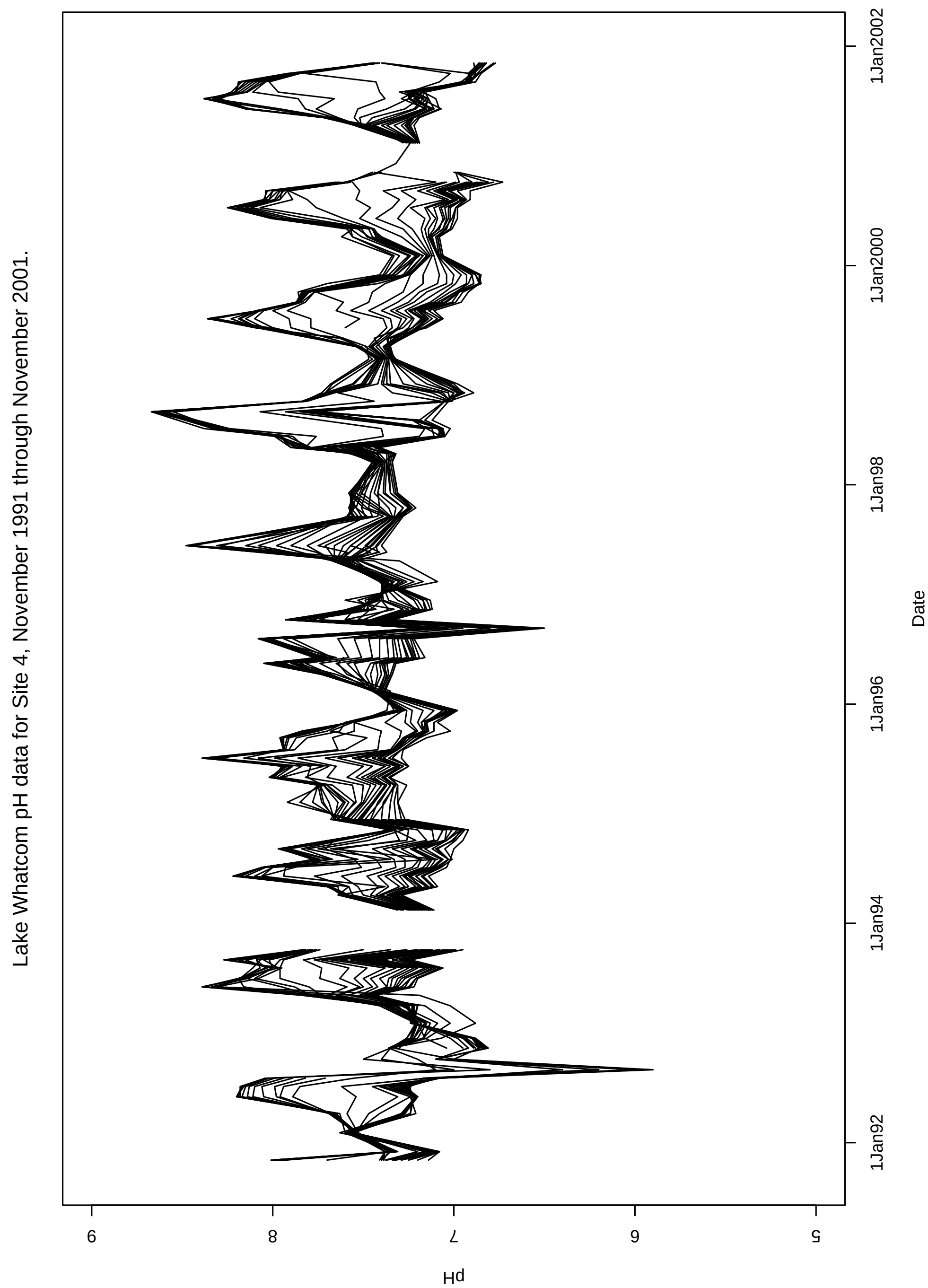

Figure 26: Lake Whatcom pH data for Site 4.

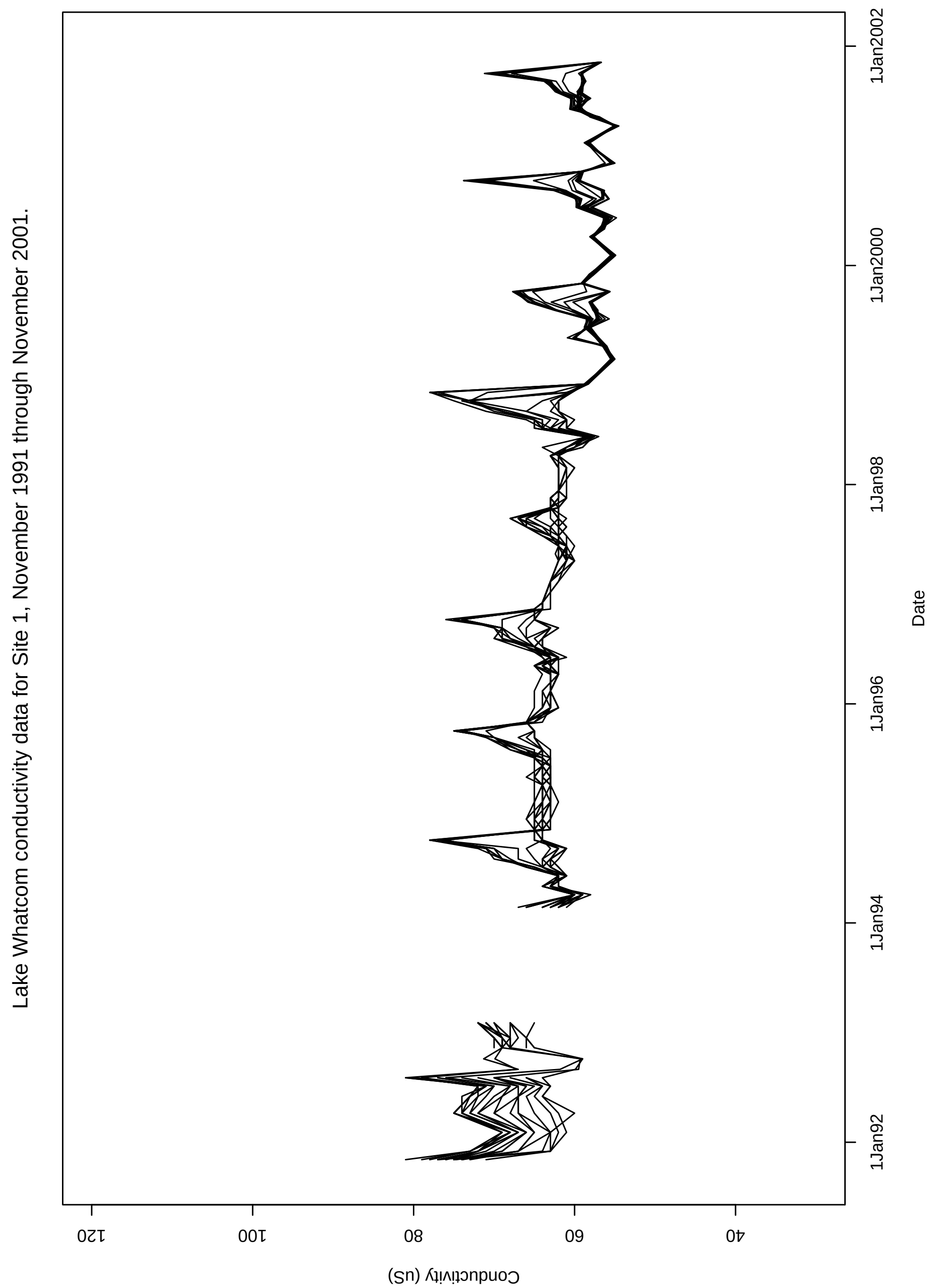

Figure 27: Lake Whatcom conductivity data for Site 1.

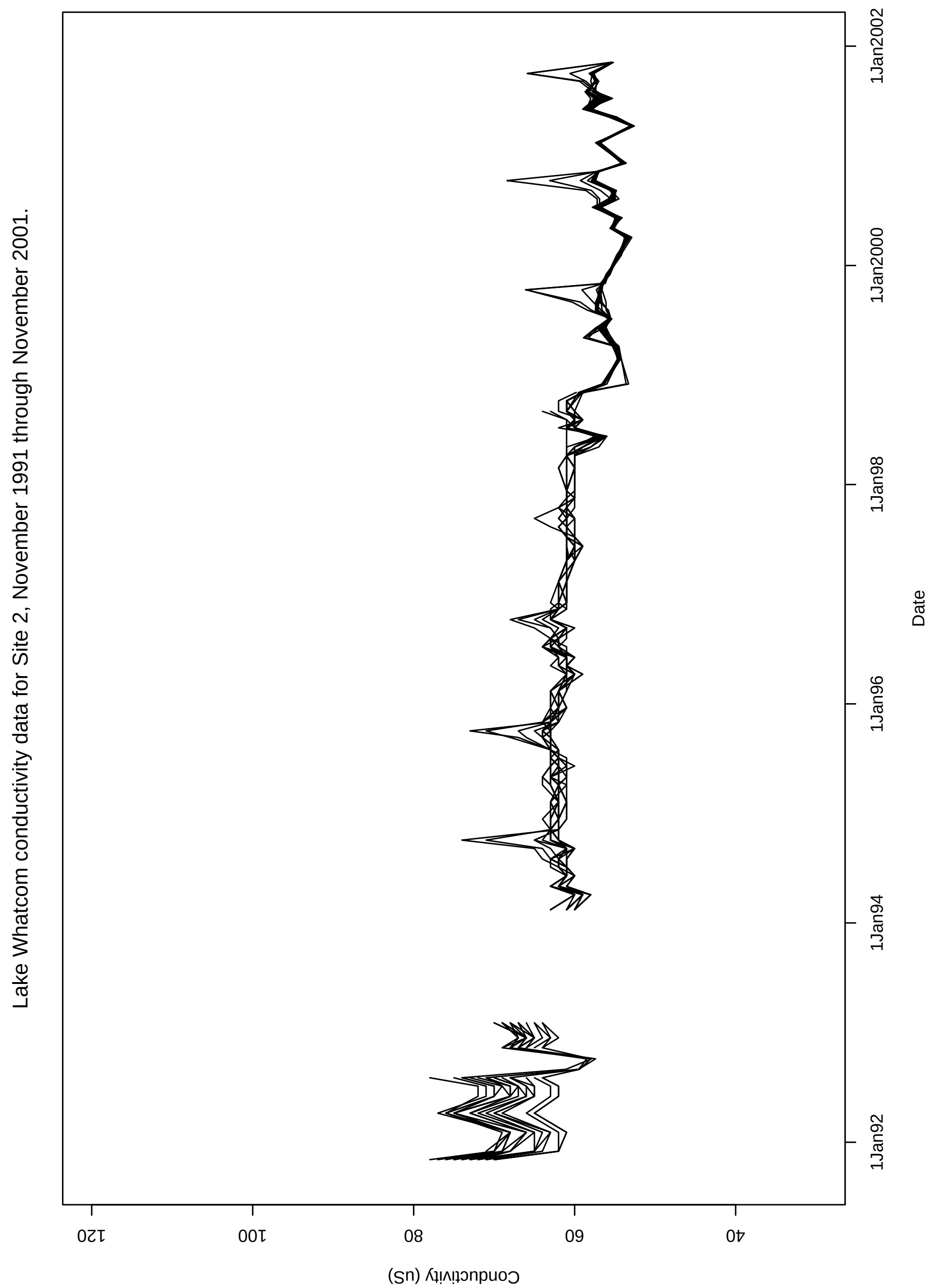

Figure 28: Lake Whatcom conductivity data for Site 2.

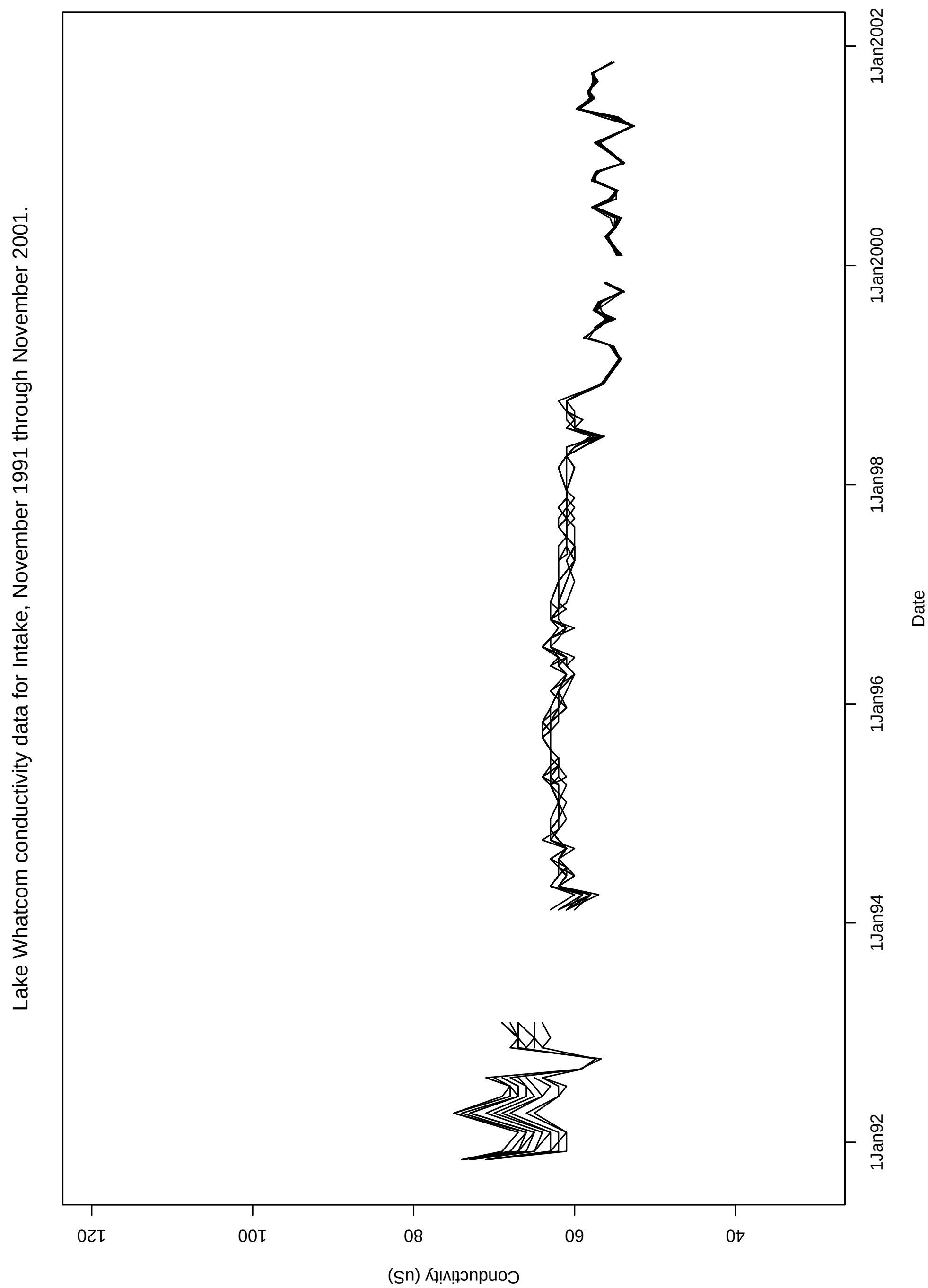

Figure 29: Lake Whatcom conductivity data for the Intake.

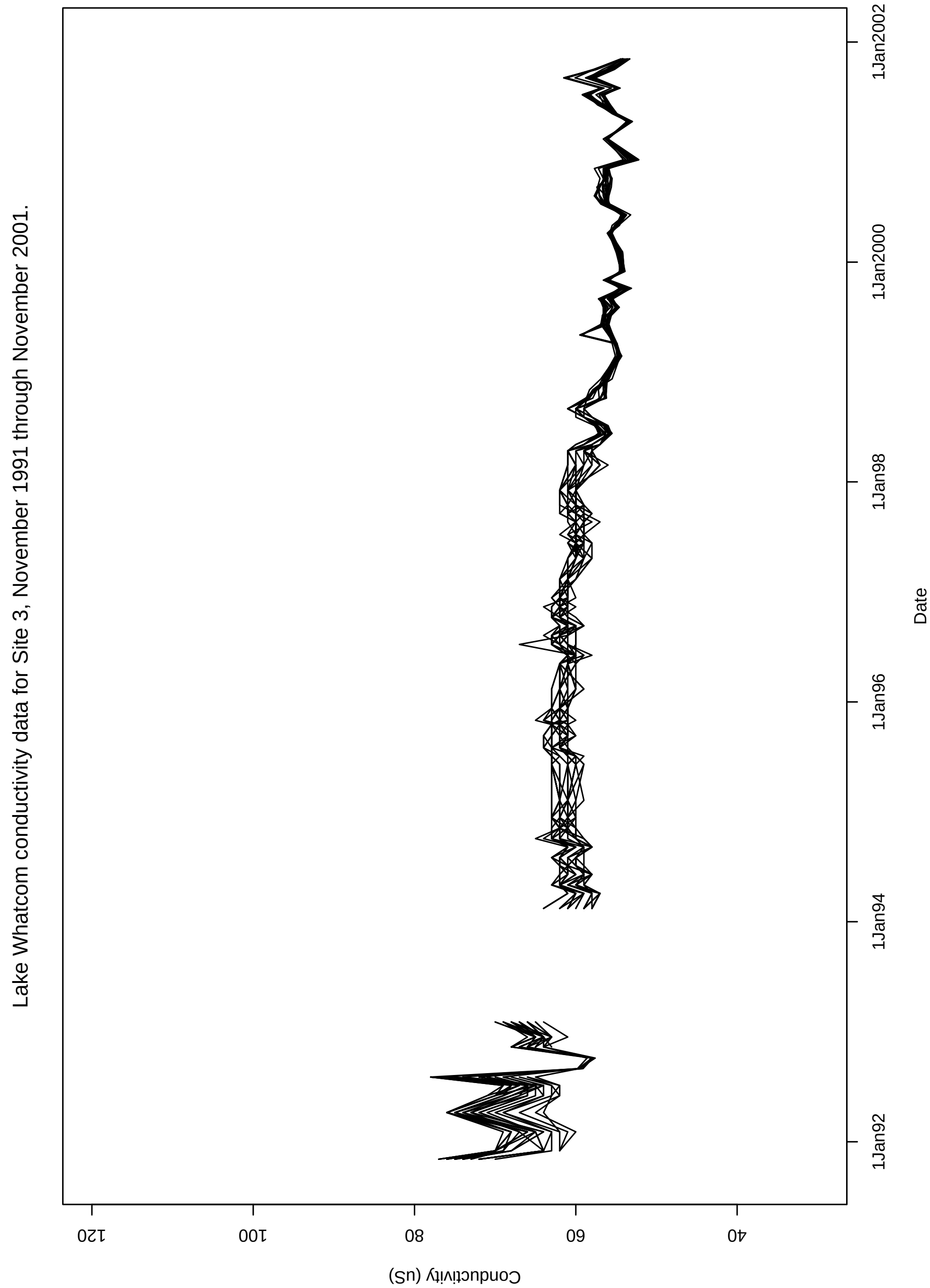

Figure 30: Lake Whatcom conductivity data for Site 3.

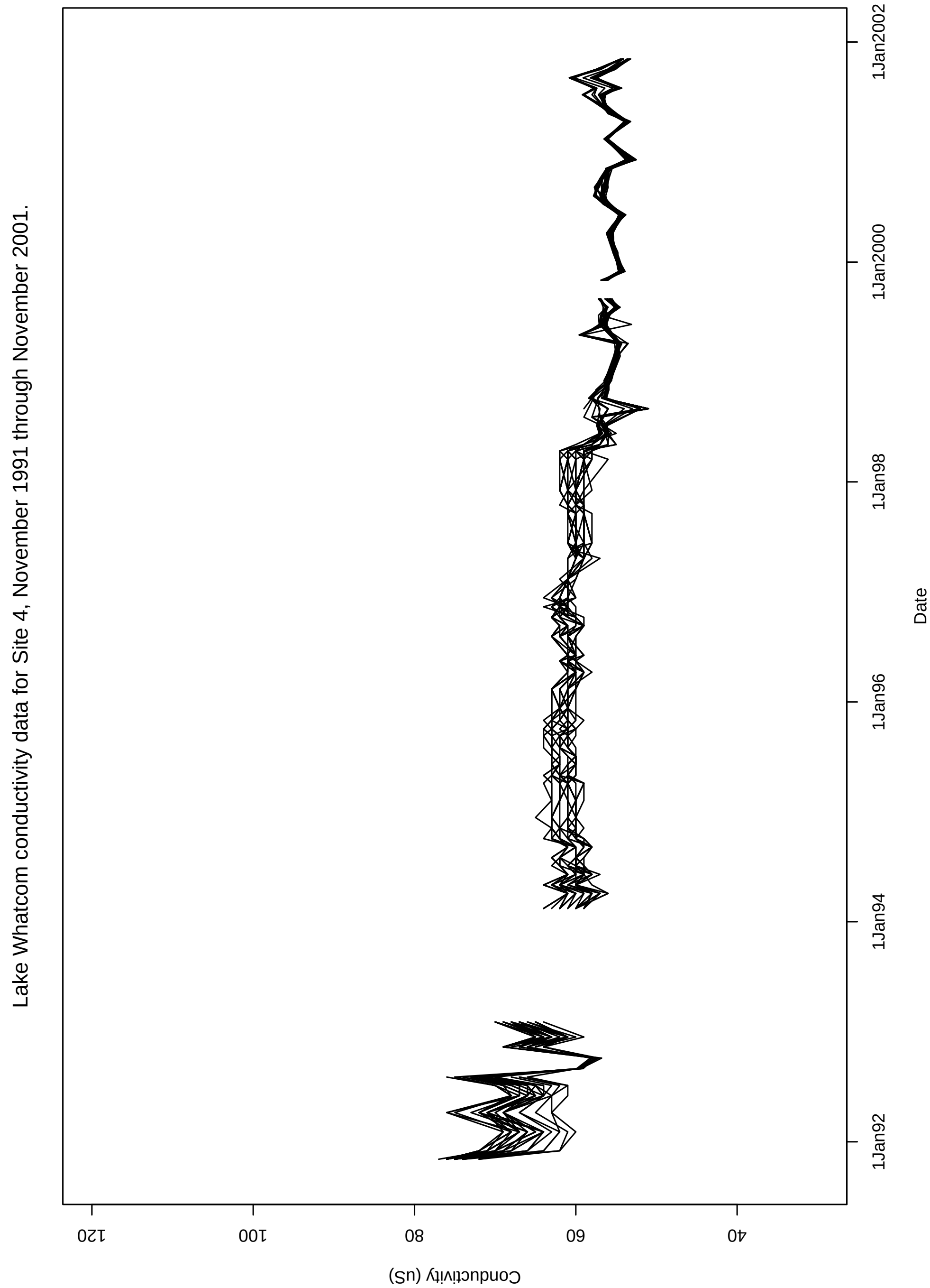

Figure 31: Lake Whatcom conductivity data for Site 4.

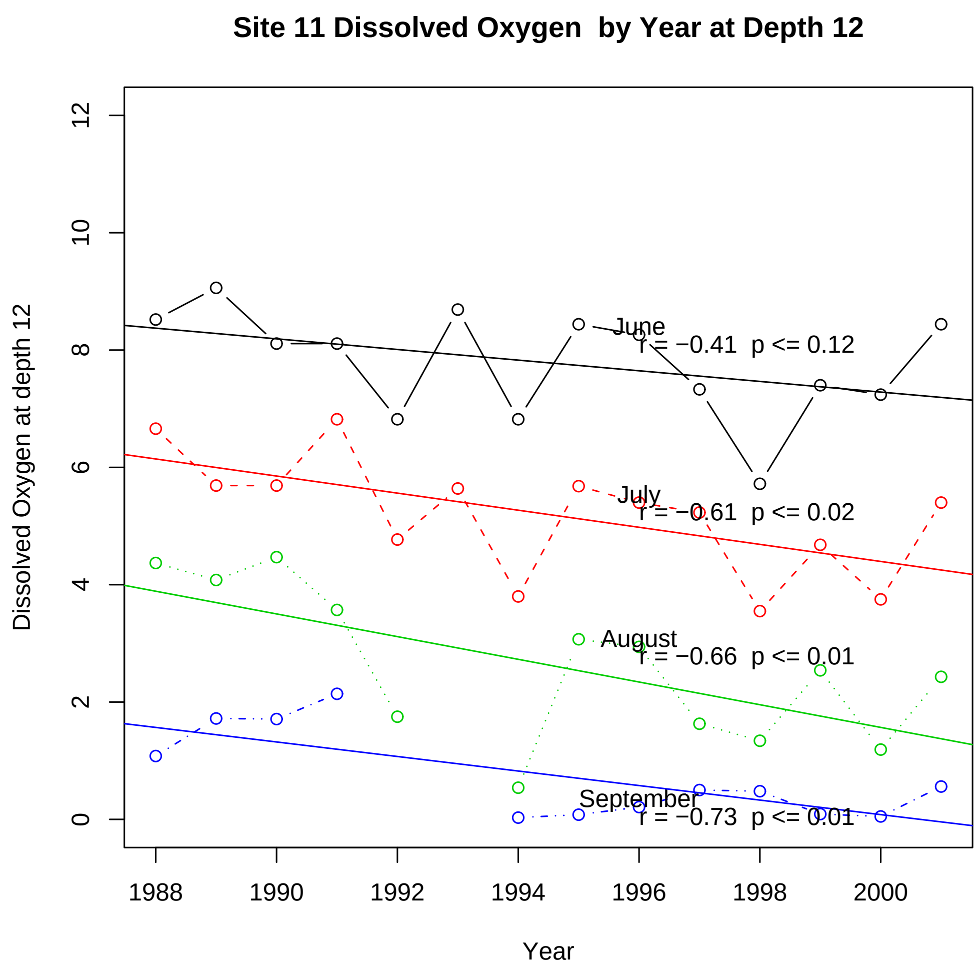

Figure 32: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (12 m). July-September results are statistically significant.

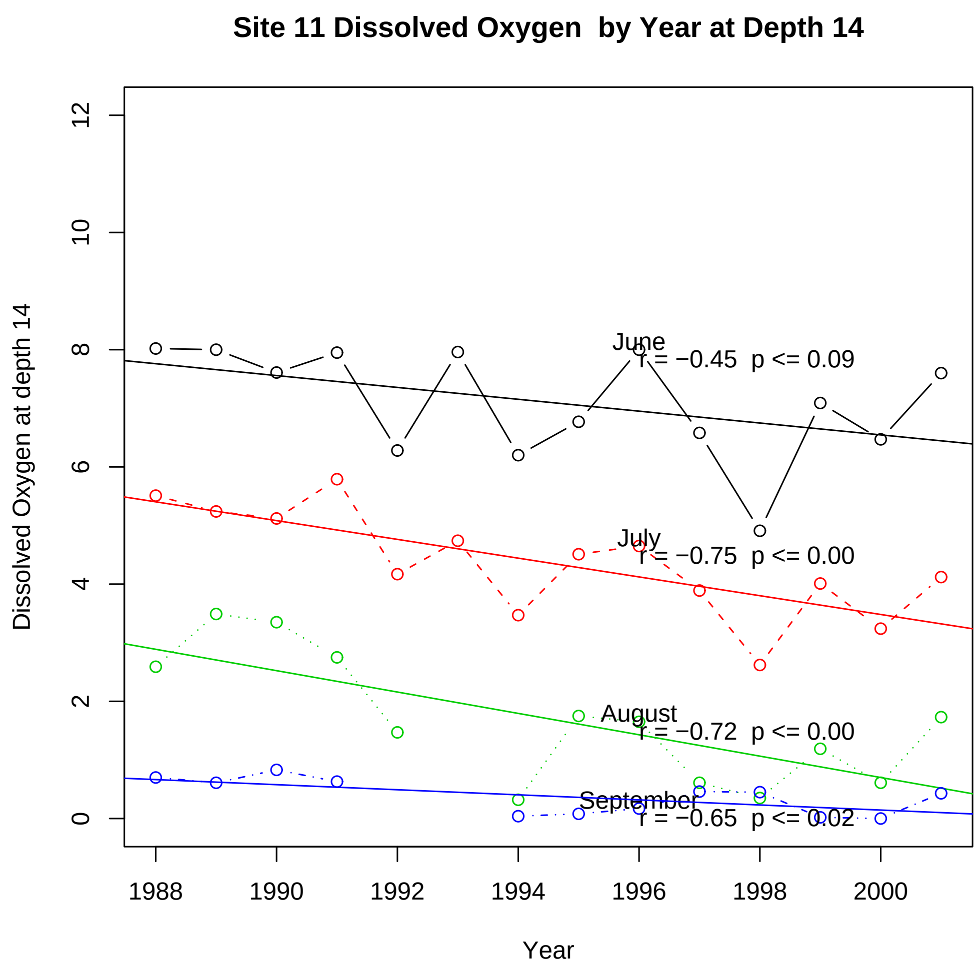

Figure 33: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (14 m). July-September results are statistically significant.

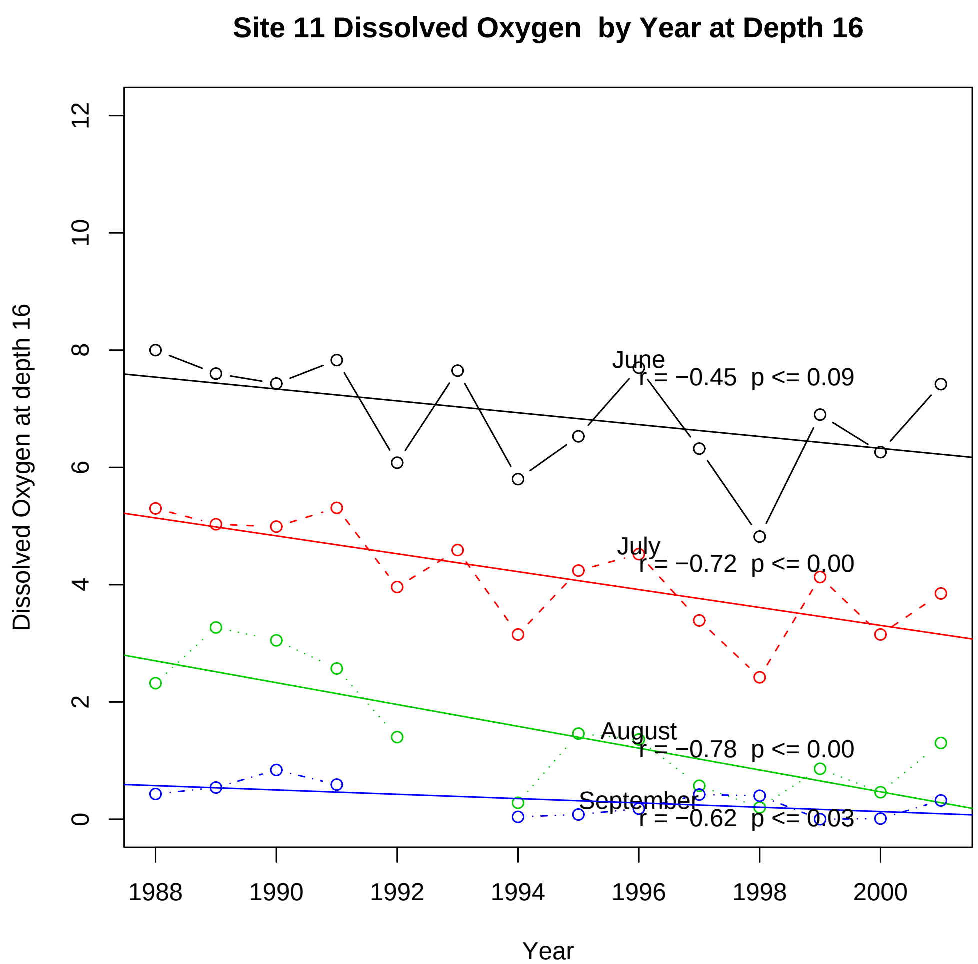

Figure 34: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (16 m). July-September results are statistically significant.

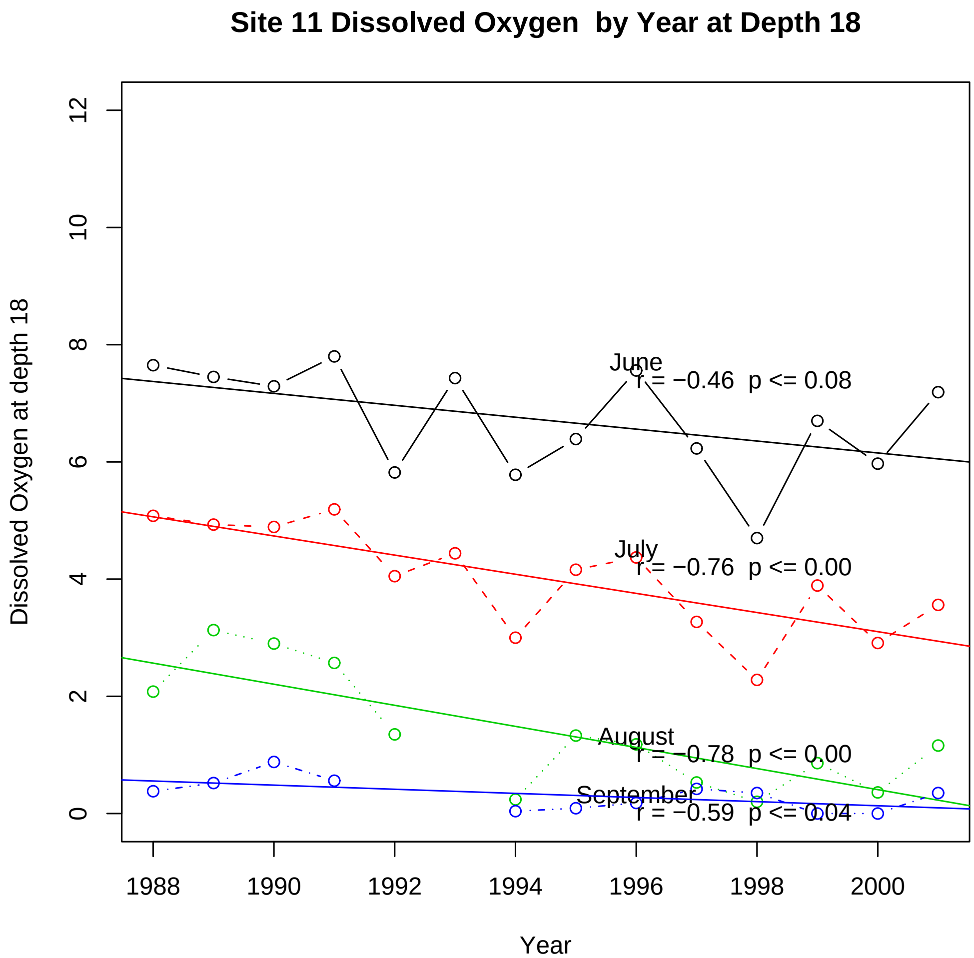

Figure 35: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (18 m). July-September results are statistically significant.

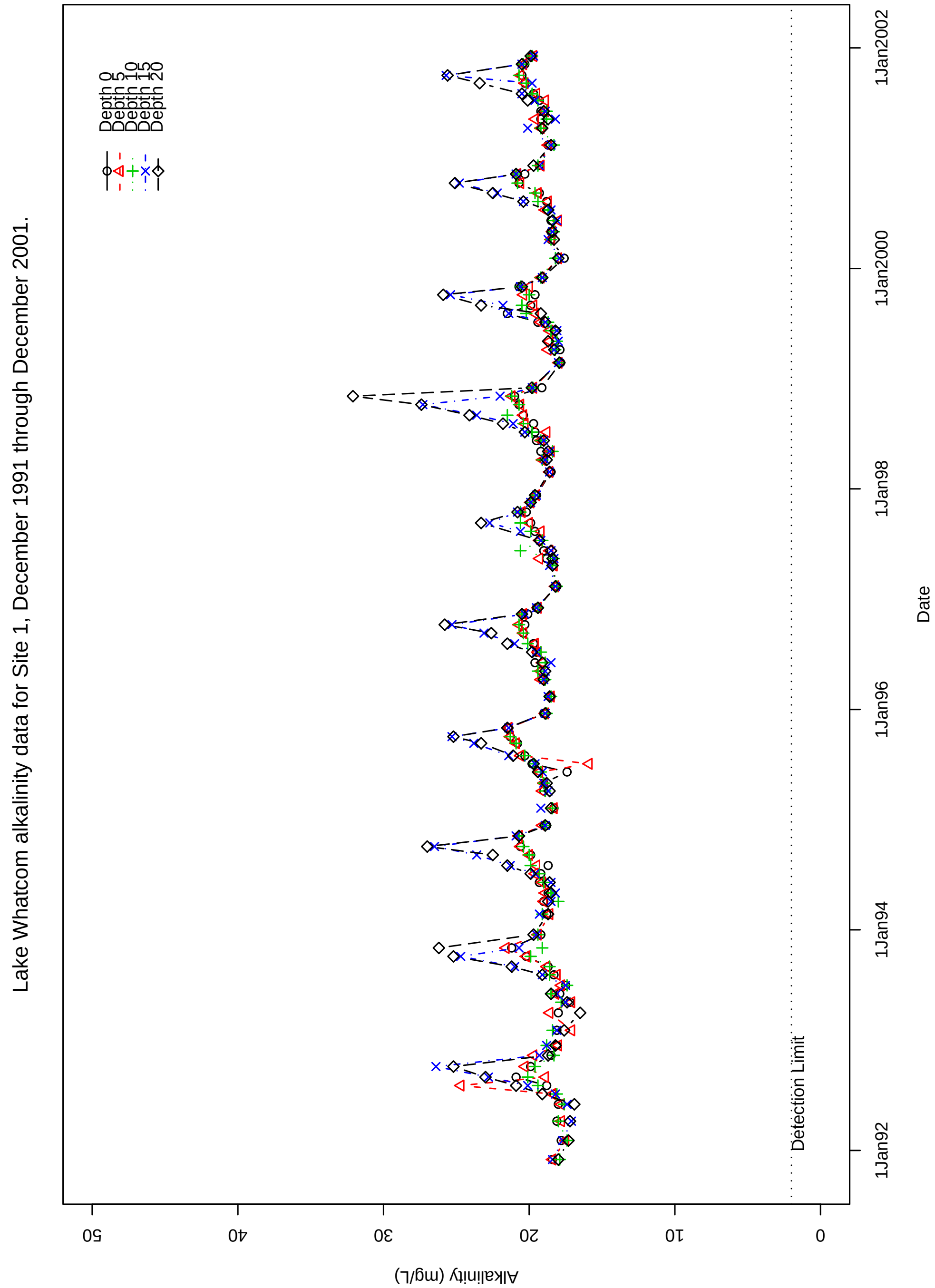

Figure 36: Lake Whatcom alkalinity data for Site 1.

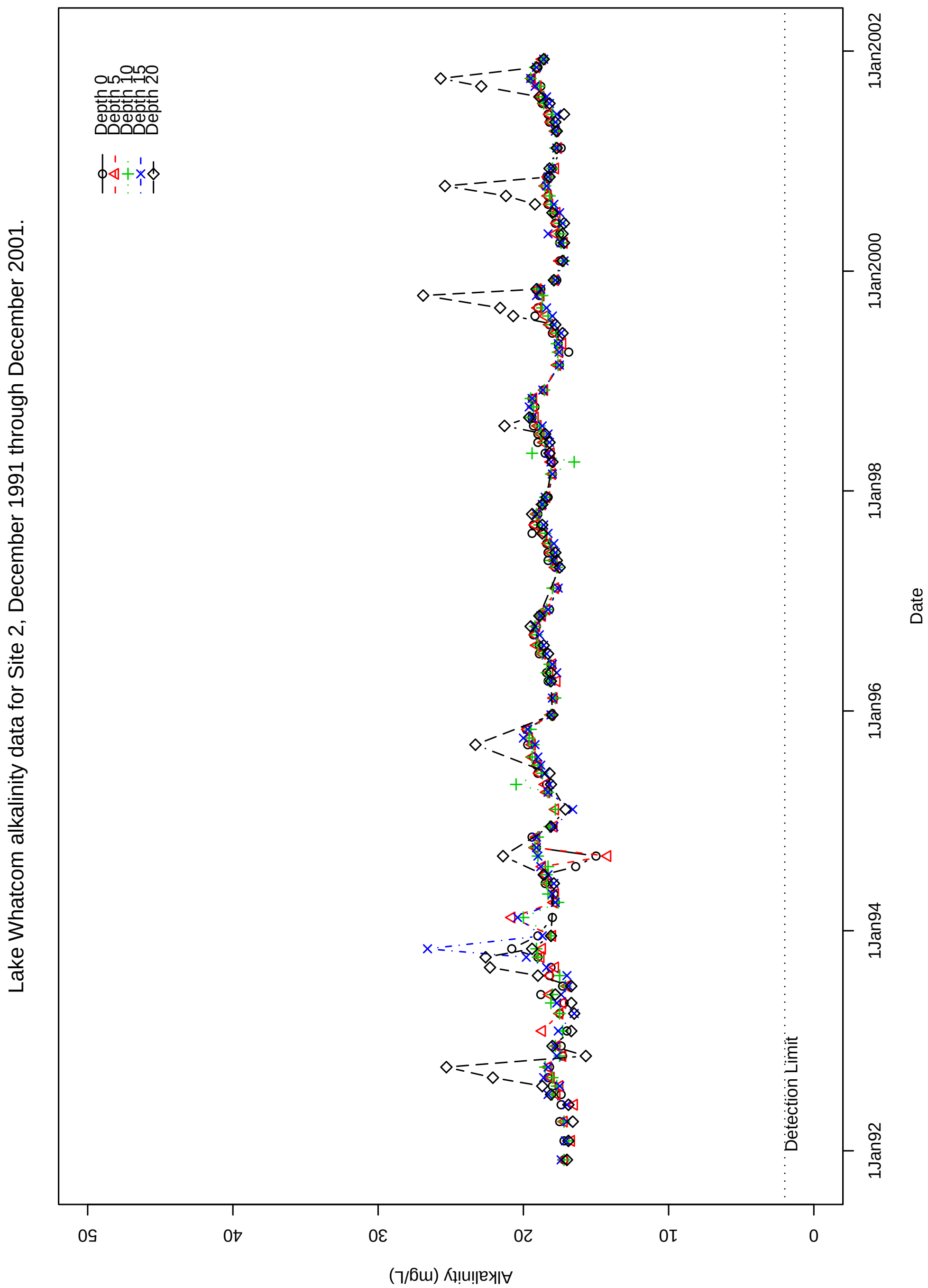

Figure 37: Lake Whatcom alkalinity data for Site 2.

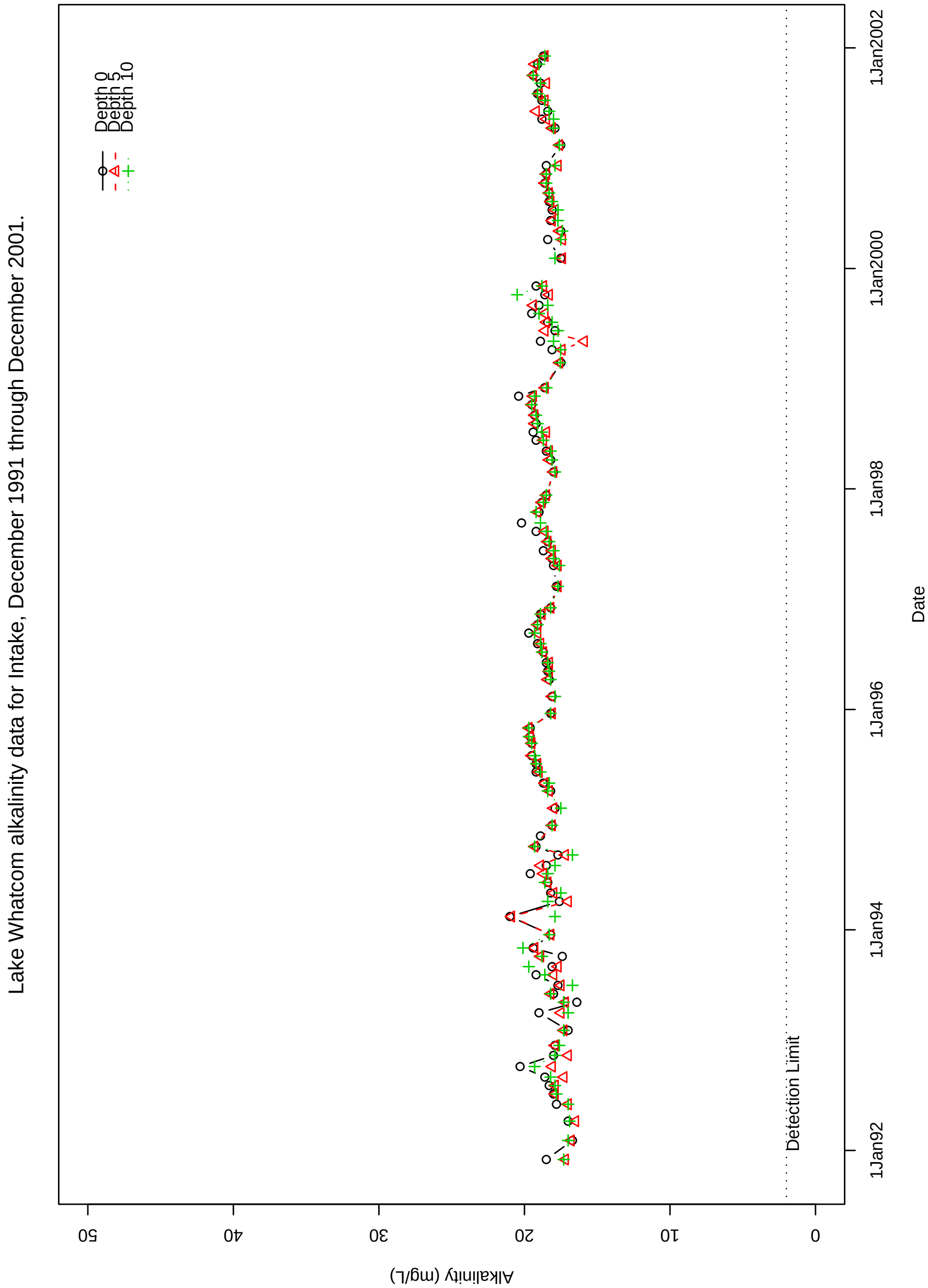

Figure 38: Lake Whatcom alkalinity data for the Intake.

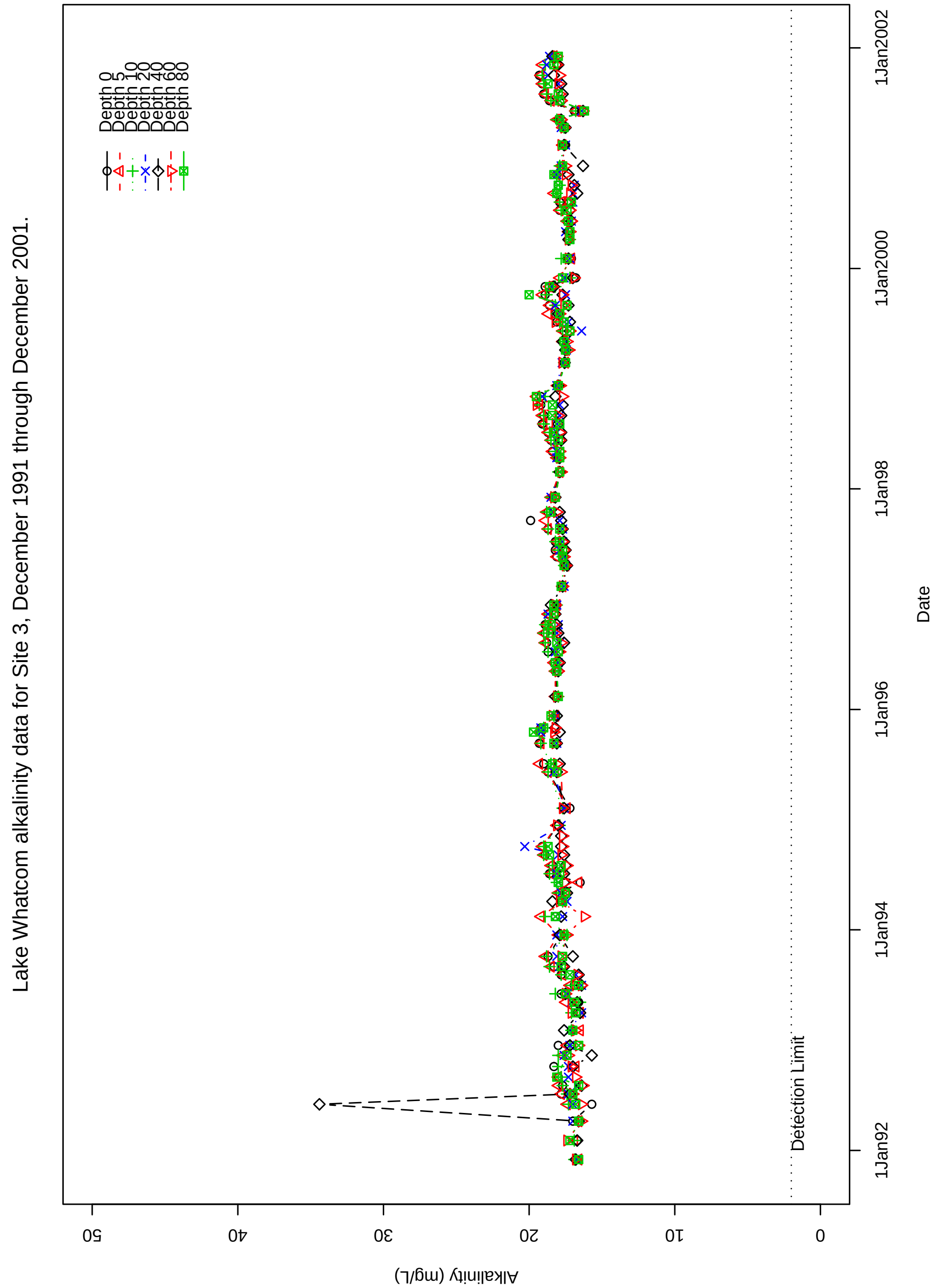

Figure 39: Lake Whatcom alkalinity data for Site 3.

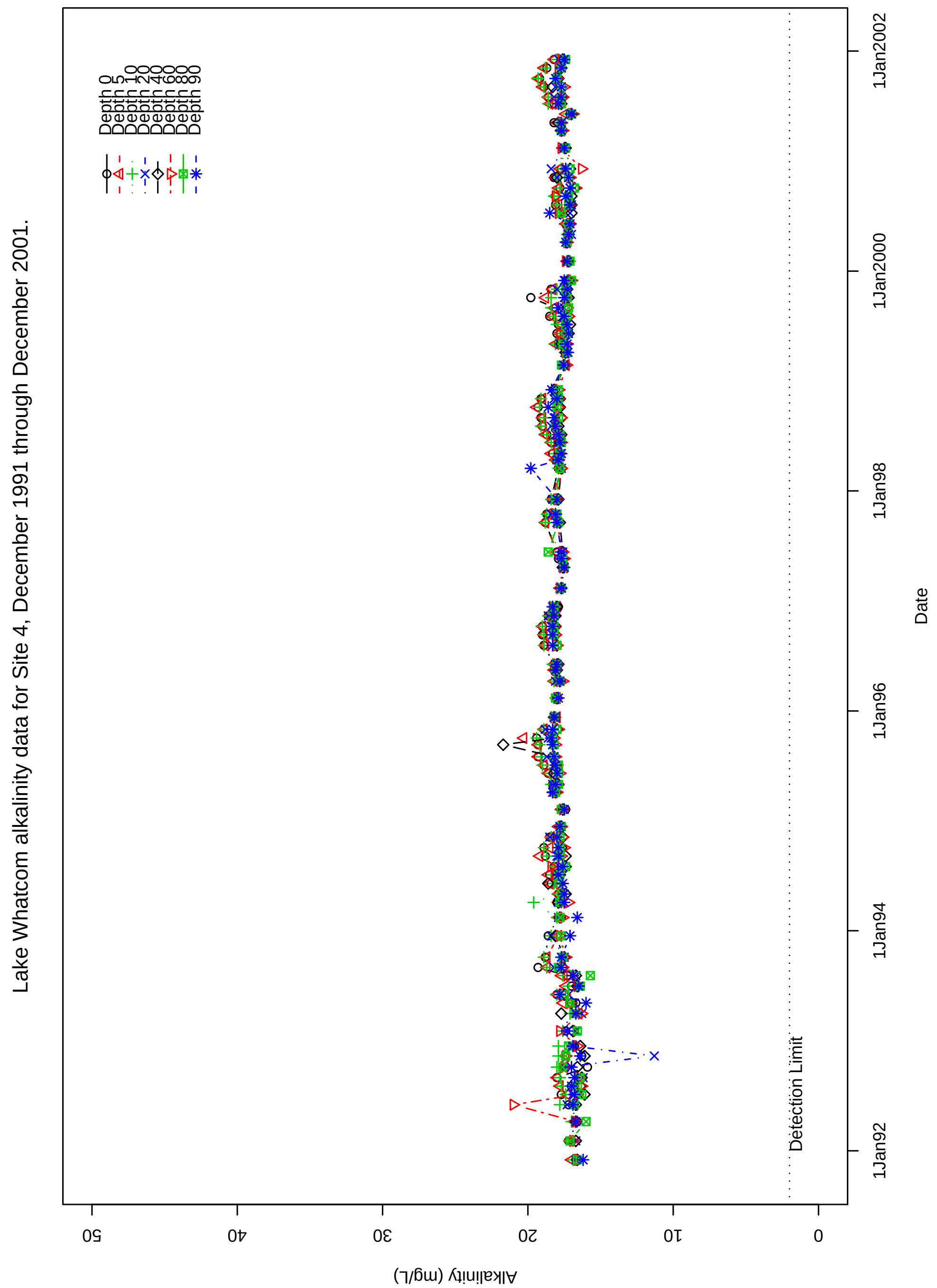

Figure 40: Lake Whatcom alkalinity data for Site 4.

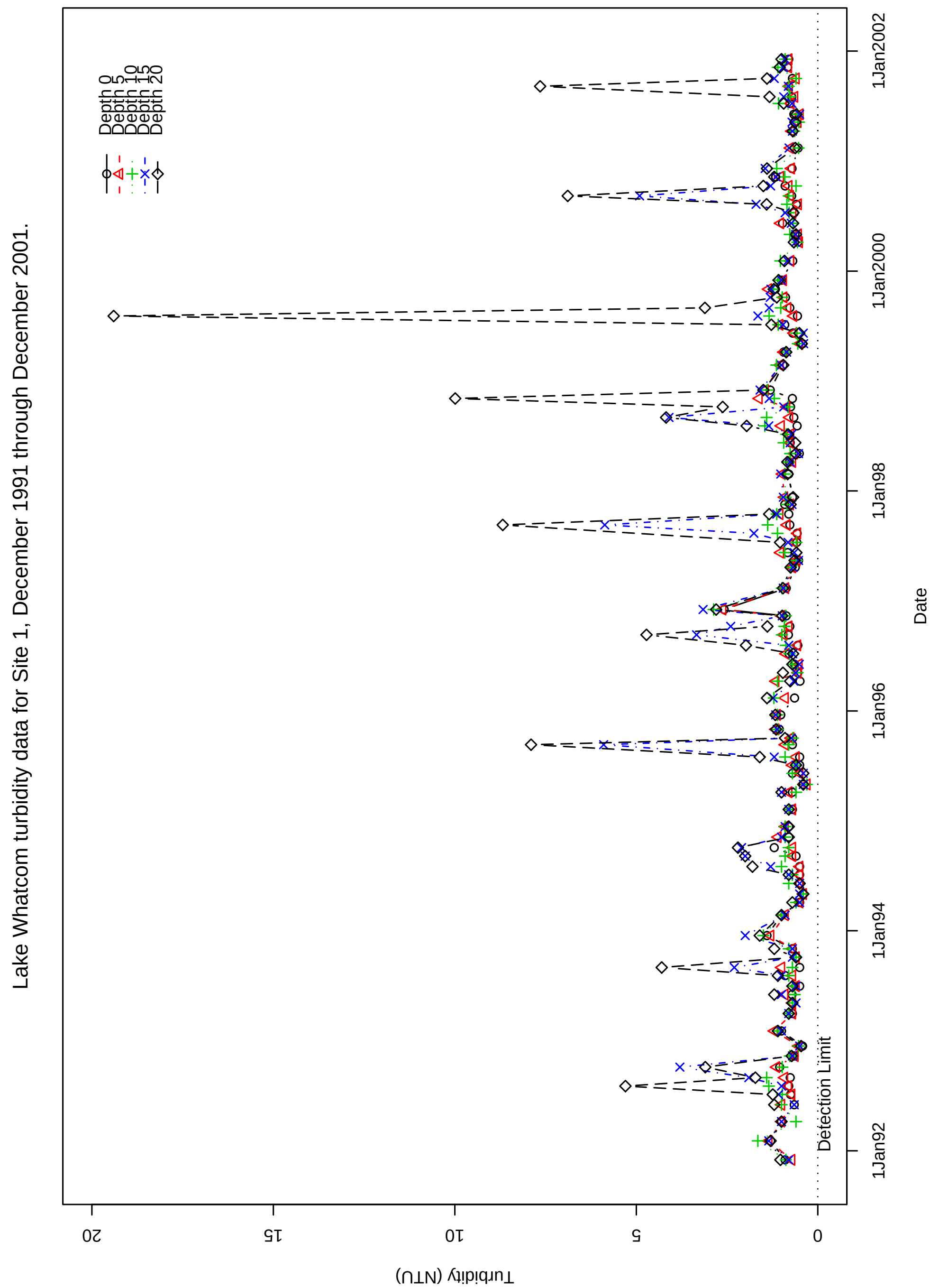

Figure 41: Lake Whatcom turbidity data for Site 1.

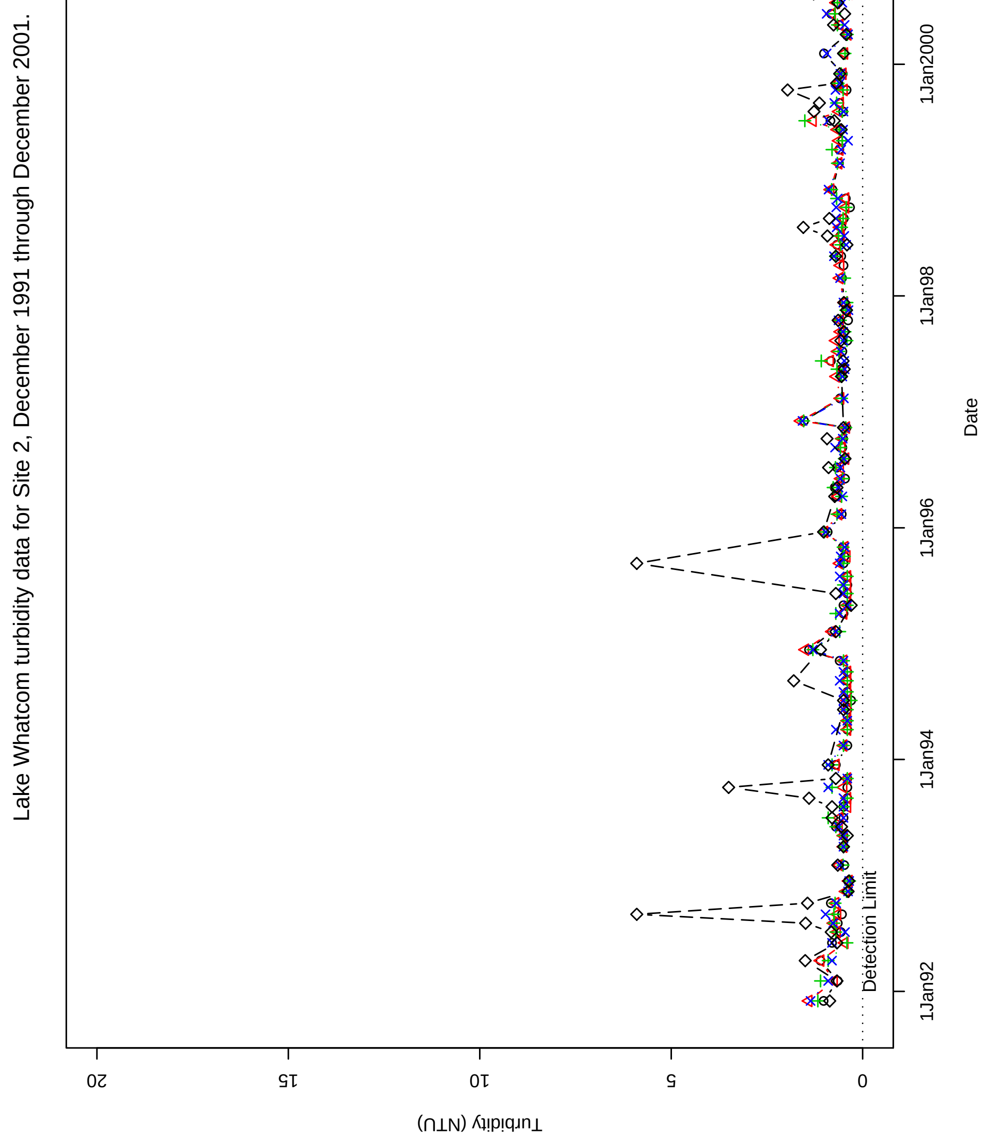

Figure 42: Lake Whatcom turbidity data for Site 2.

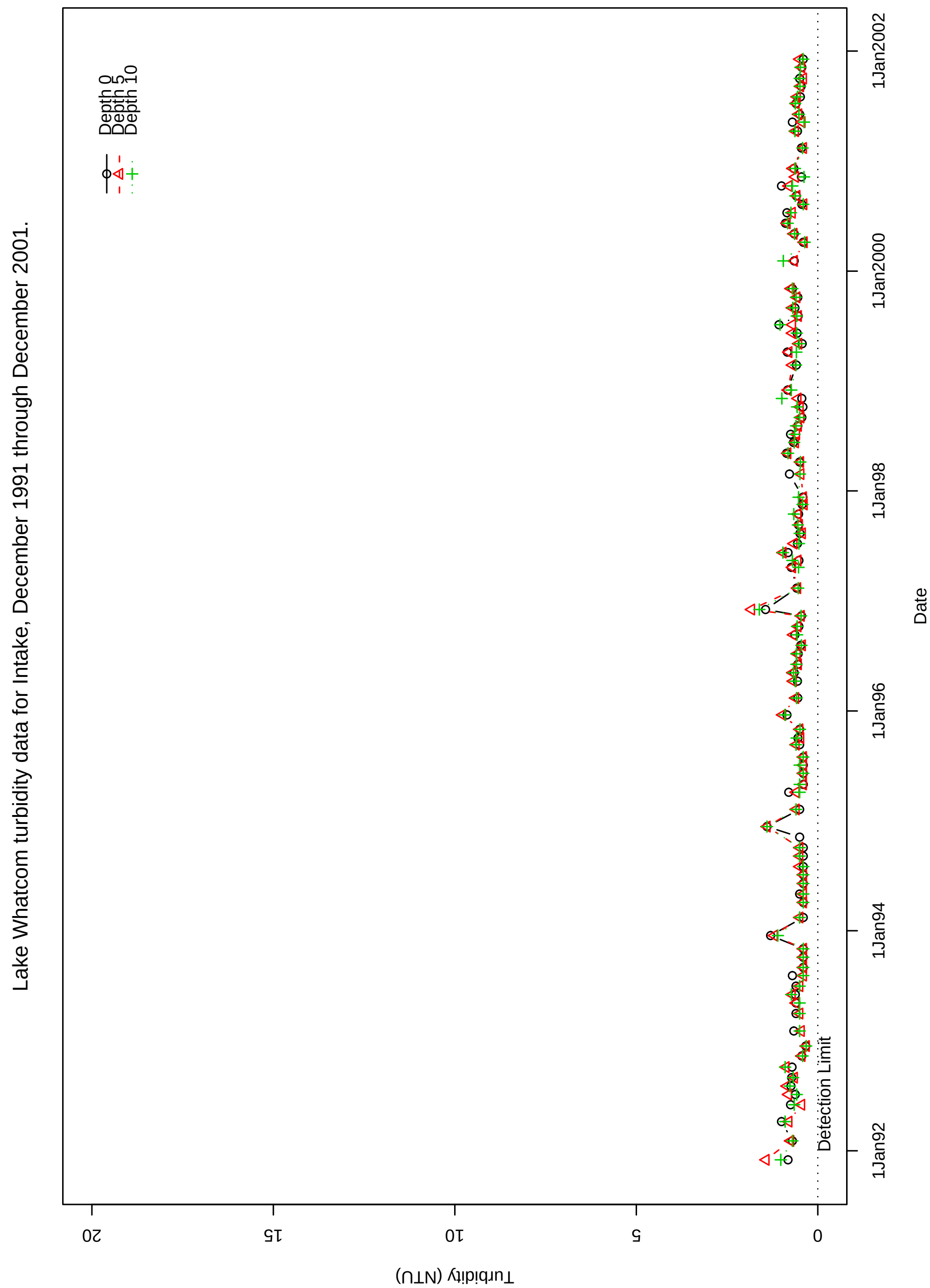

Figure 43: Lake Whatcom turbidity data for the Intake.

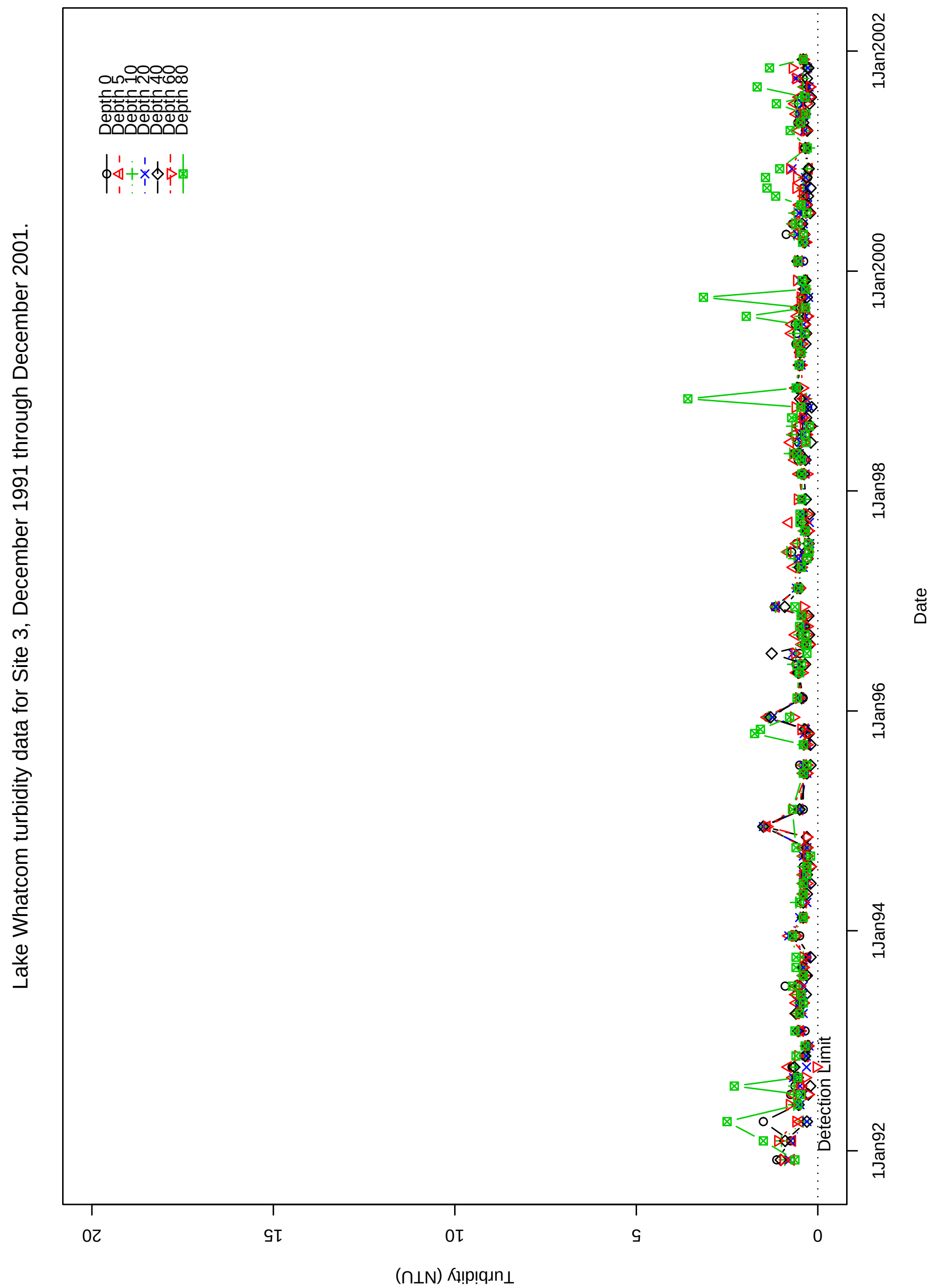

Figure 44: Lake Whatcom turbidity data for Site 3.

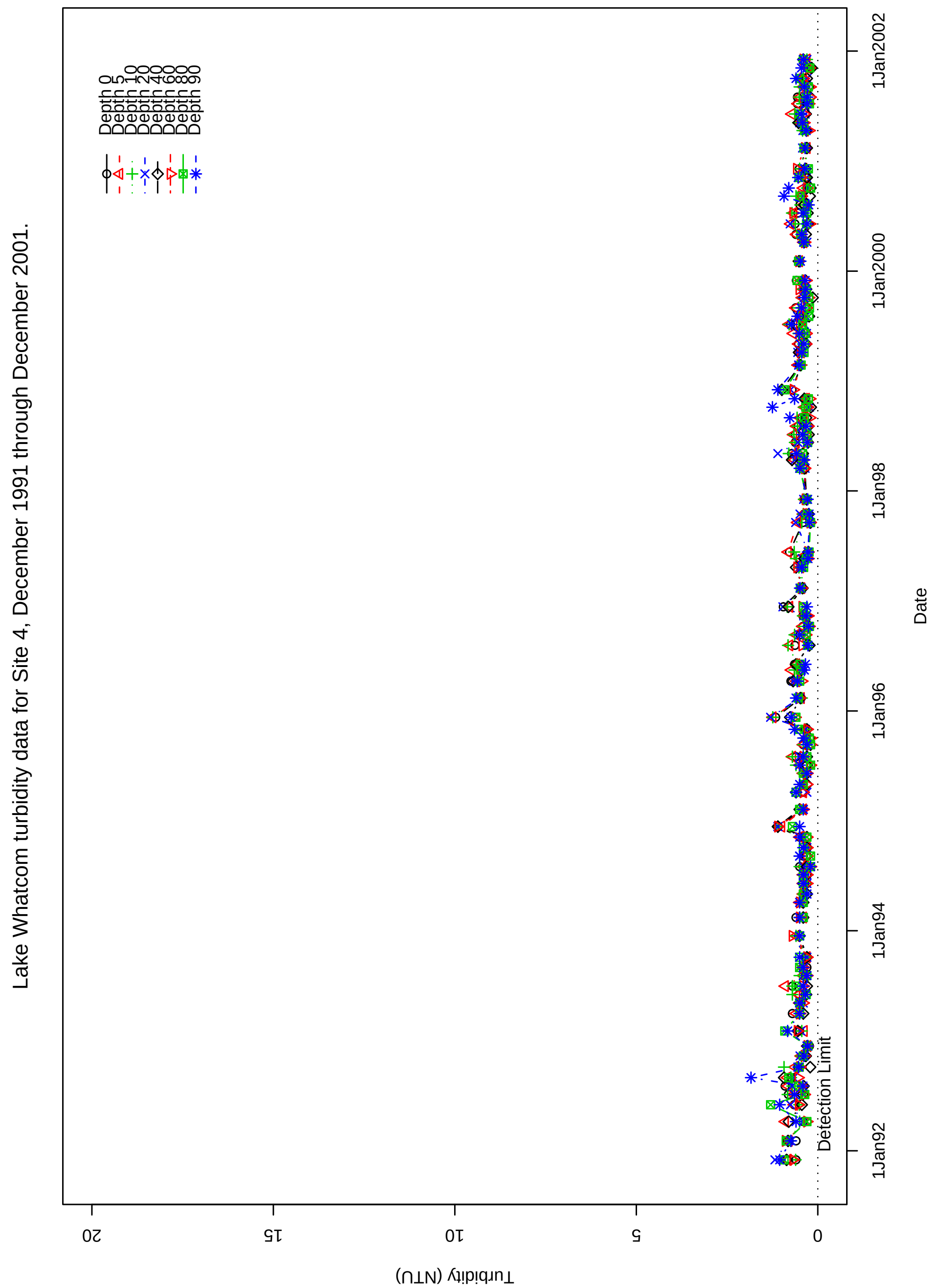

Figure 45: Lake Whatcom turbidity data for Site 4.

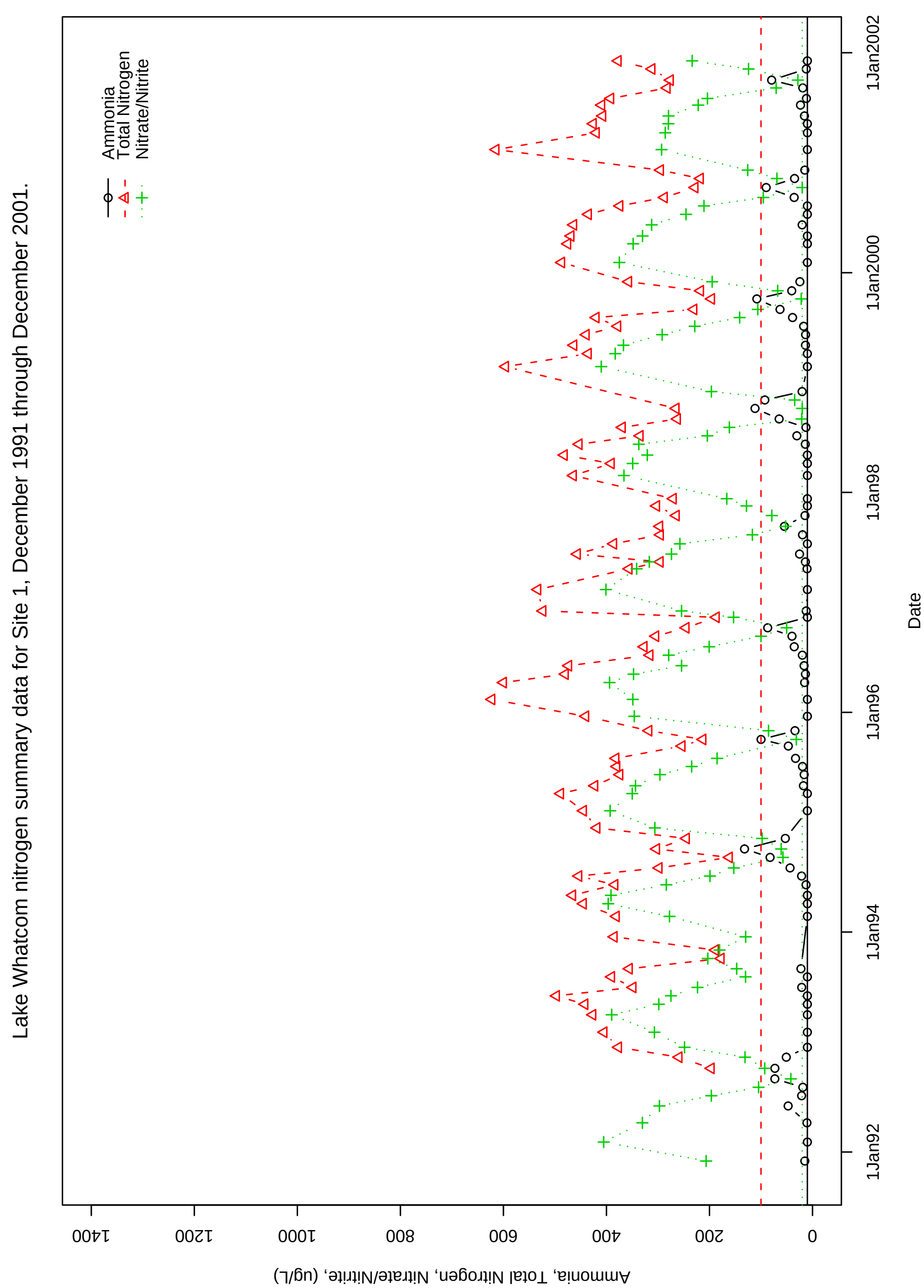

Figure 46: Lake Whatcom nitrogen summary data for Site 1.

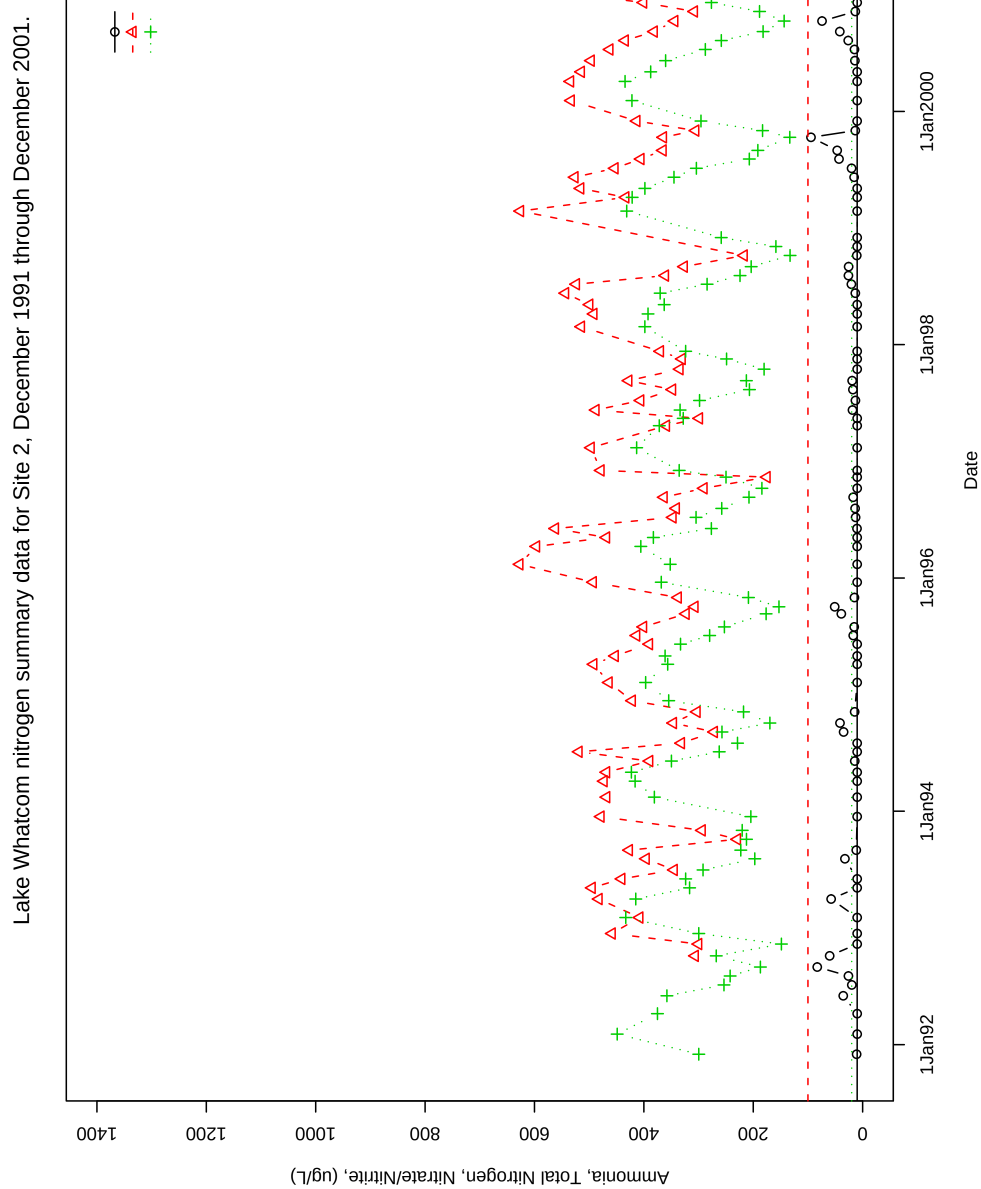

Figure 47: Lake Whatcom nitrogen summary data for Site 2.

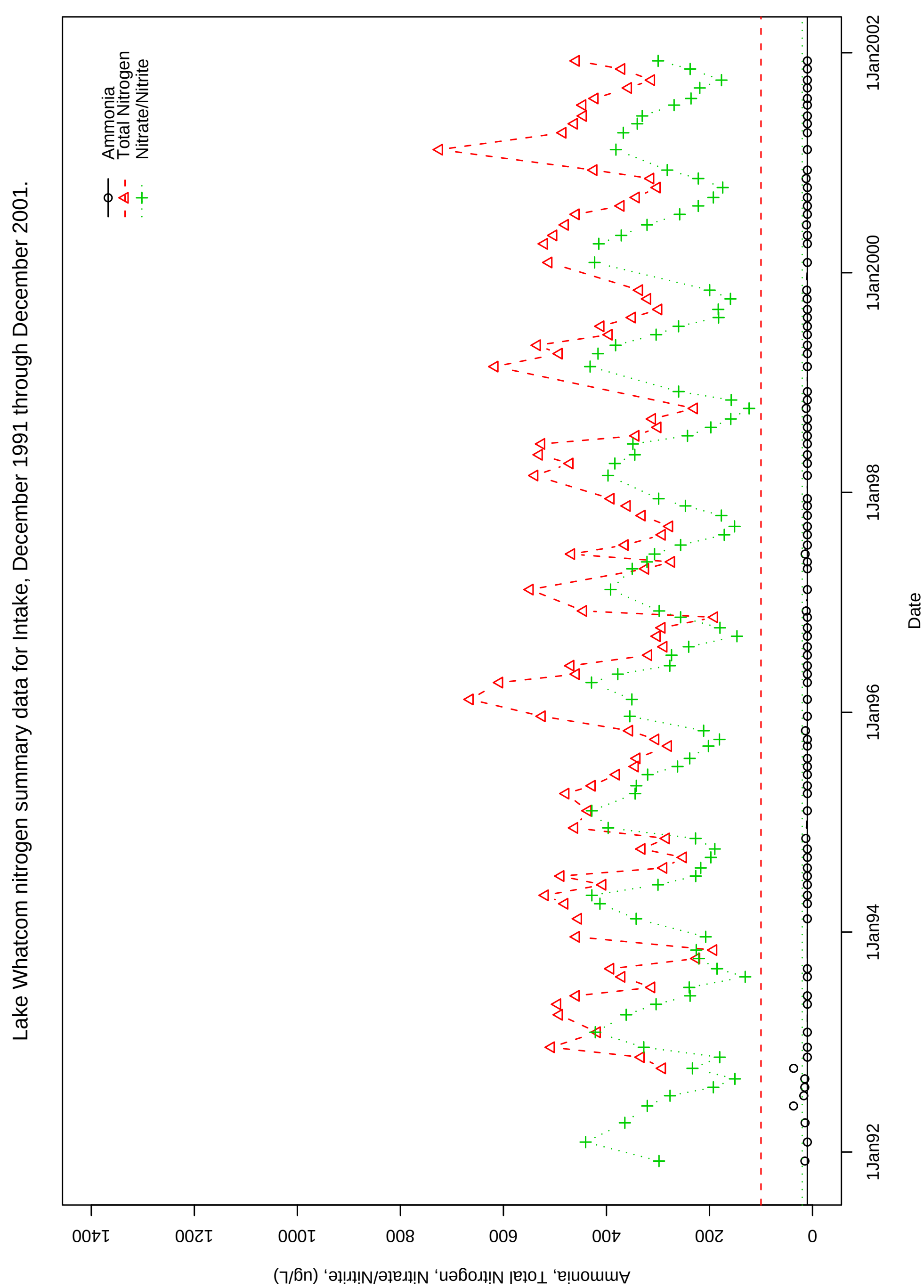

Figure 48: Lake Whatcom nitrogen summary data for the Intake.

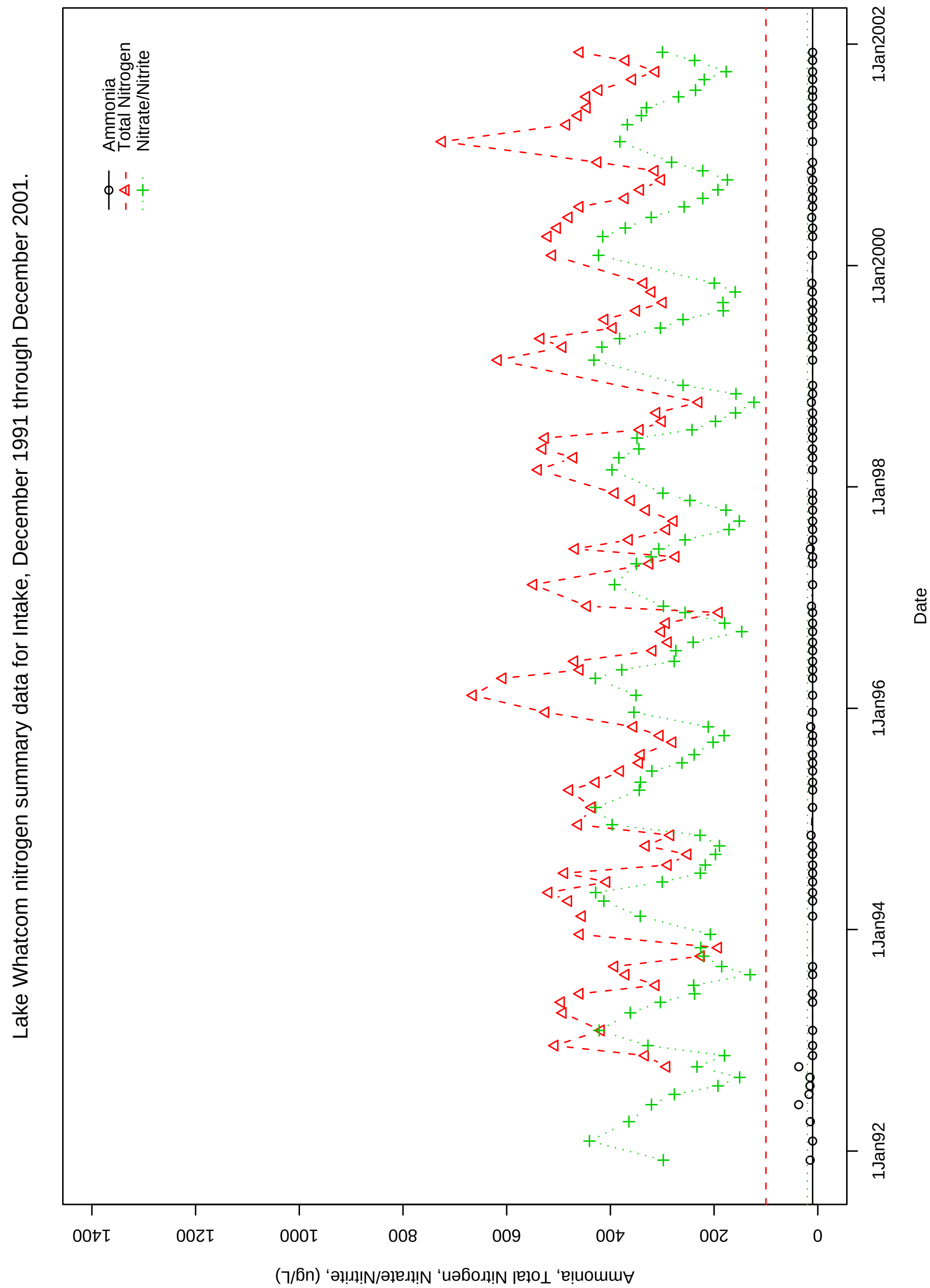

Figure 49: Lake Whatcom nitrogen summary data for Site 3.

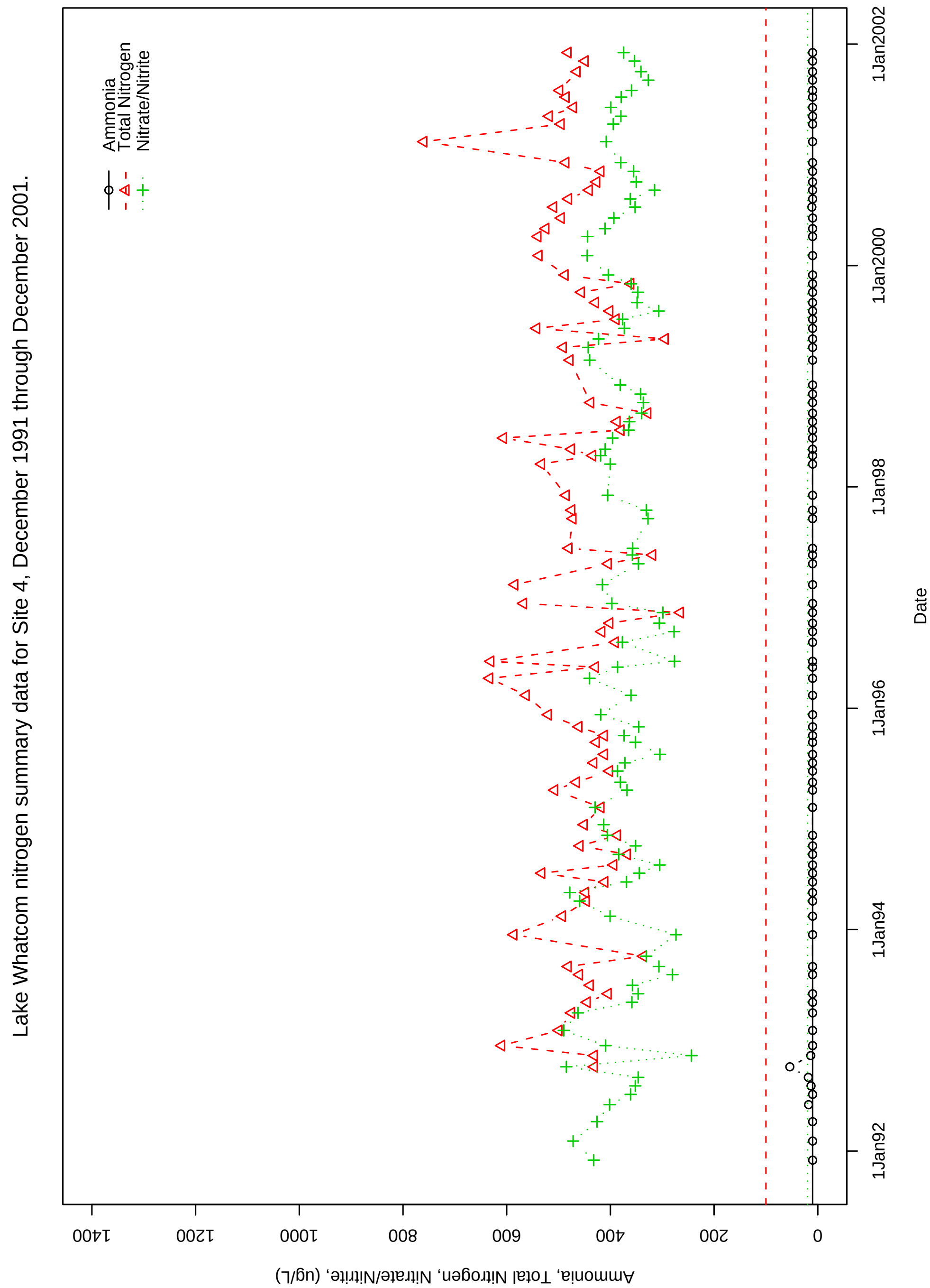

Figure 50: Lake Whatcom nitrogen summary data for Site 4.

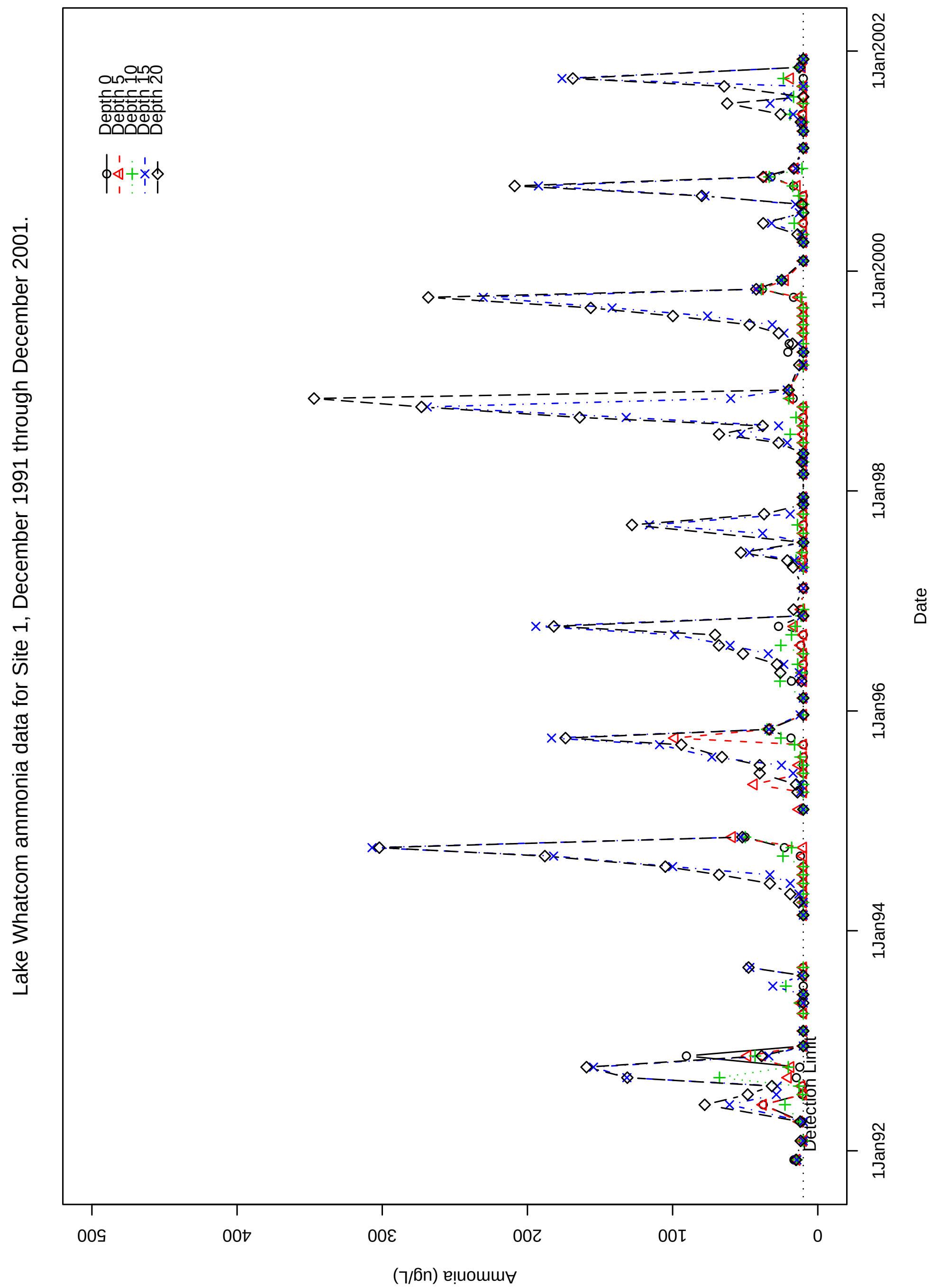

Figure 51: Lake Whatcom ammonia data for Site 1.

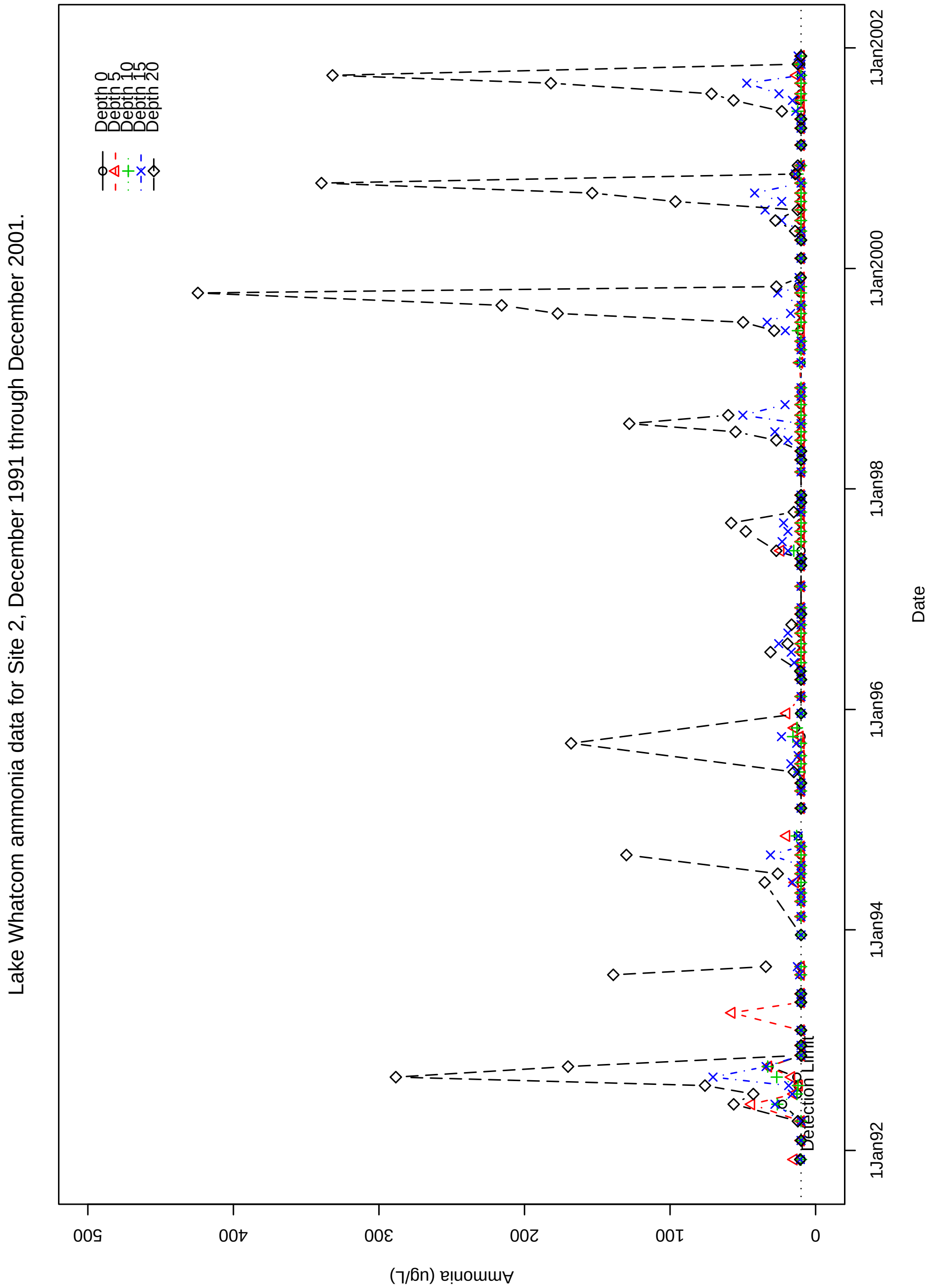

Figure 52: Lake Whatcom ammonia data for Site 2.

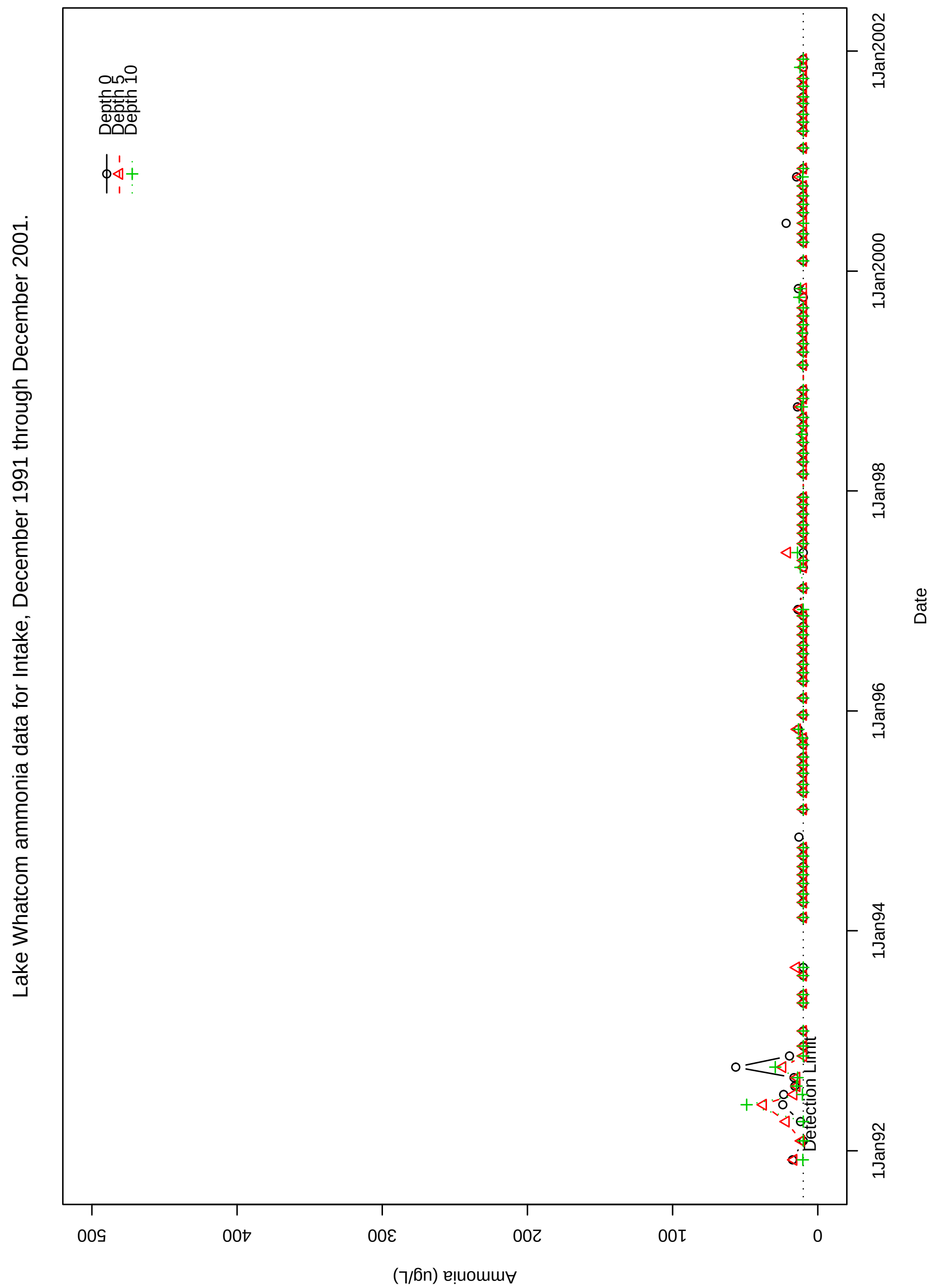

Figure 53: Lake Whatcom ammonia data for the Intake.

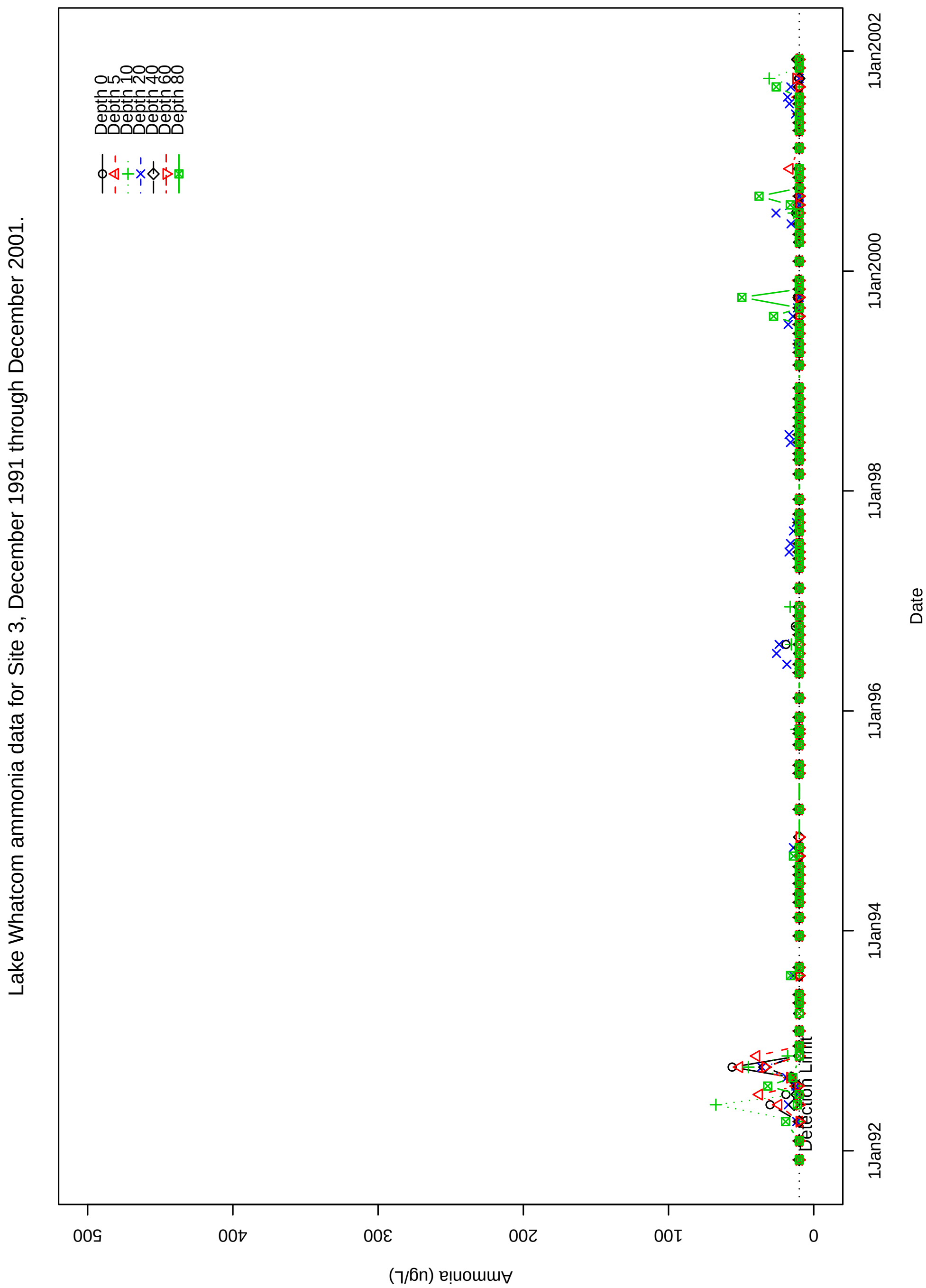

Figure 54: Lake Whatcom ammonia data for Site 3.

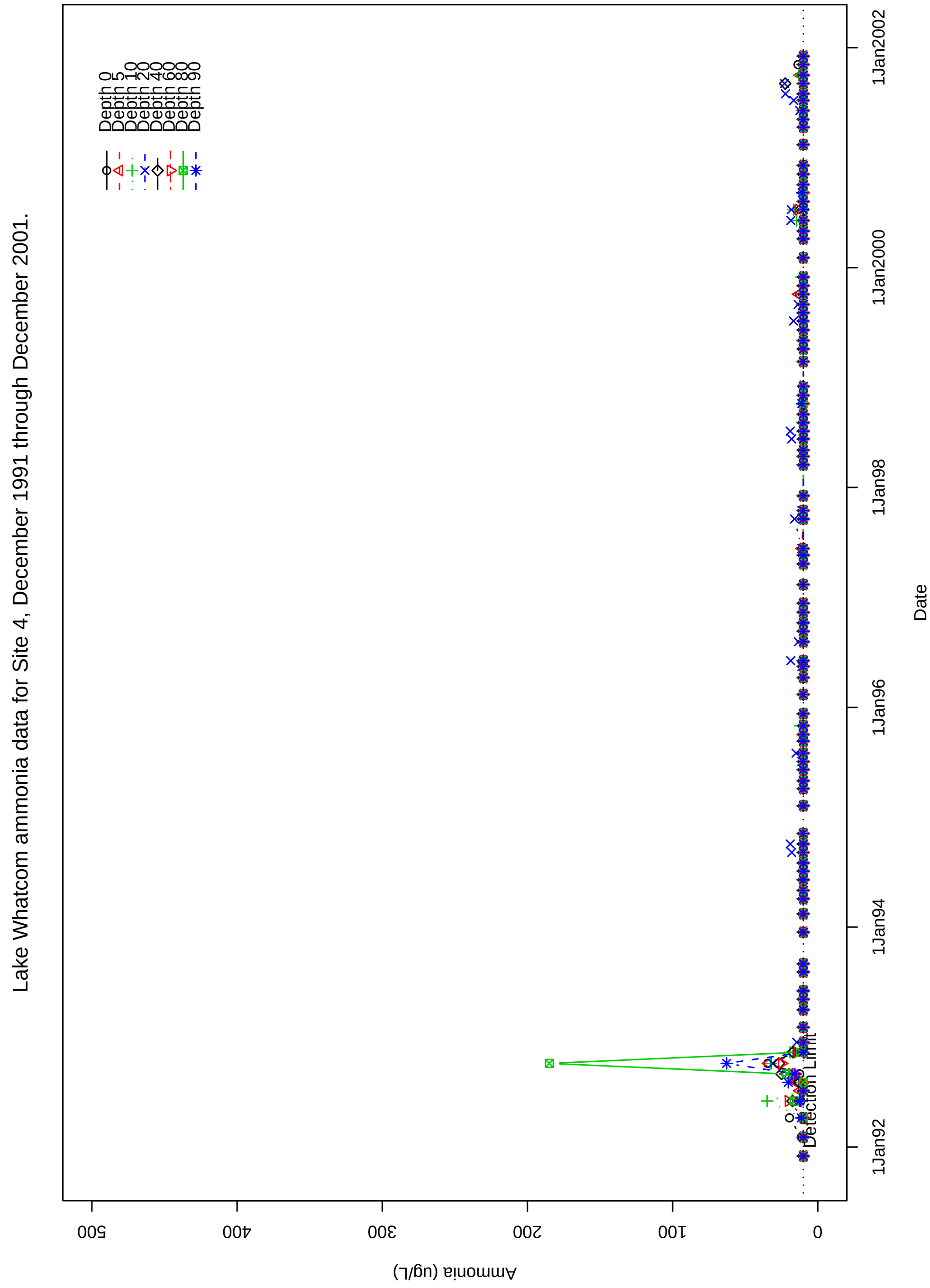

Figure 55: Lake Whatcom ammonia data for Site 4.

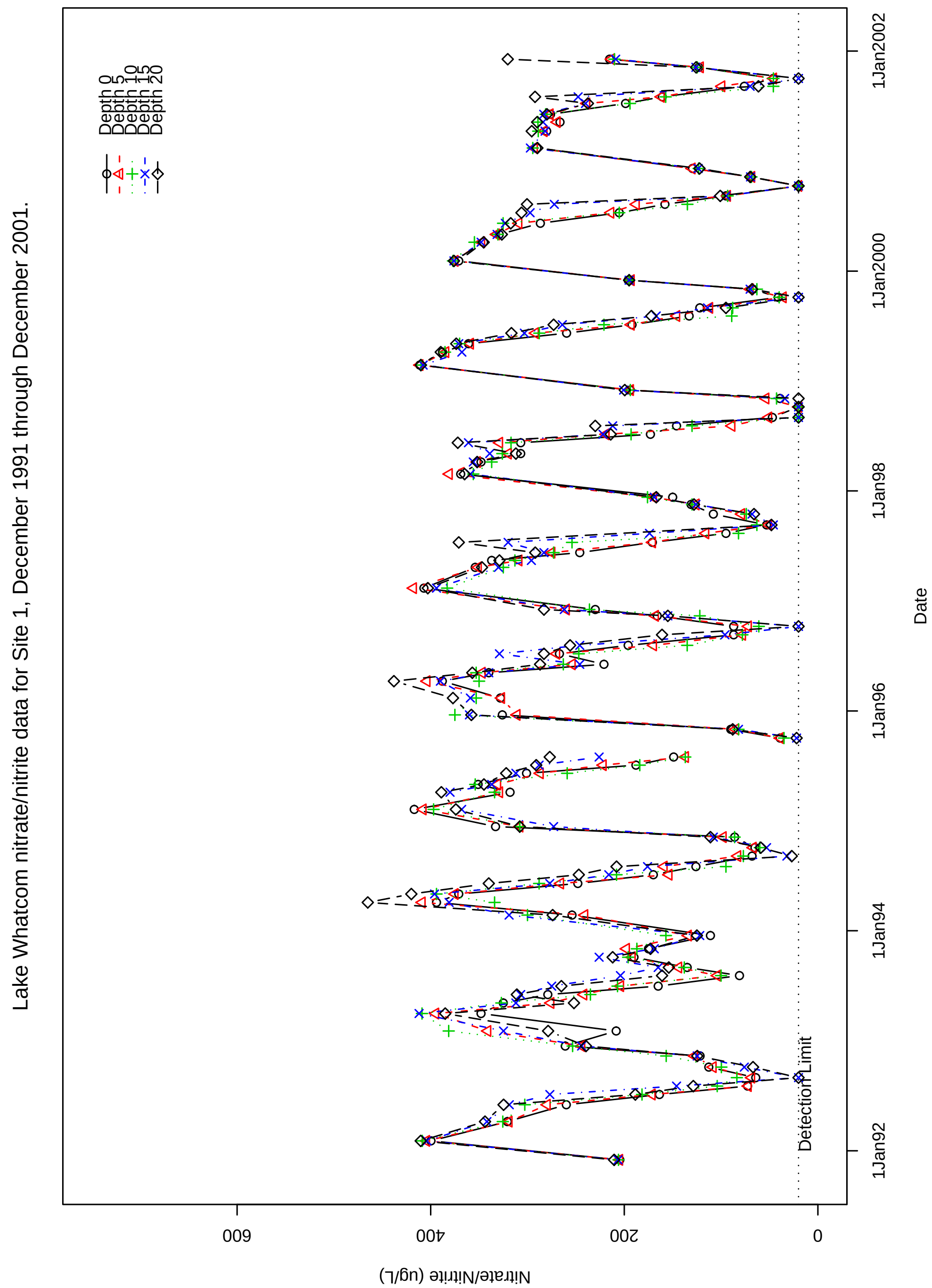

Figure 56: Lake Whatcom nitrate/nitrite data for Site 1.

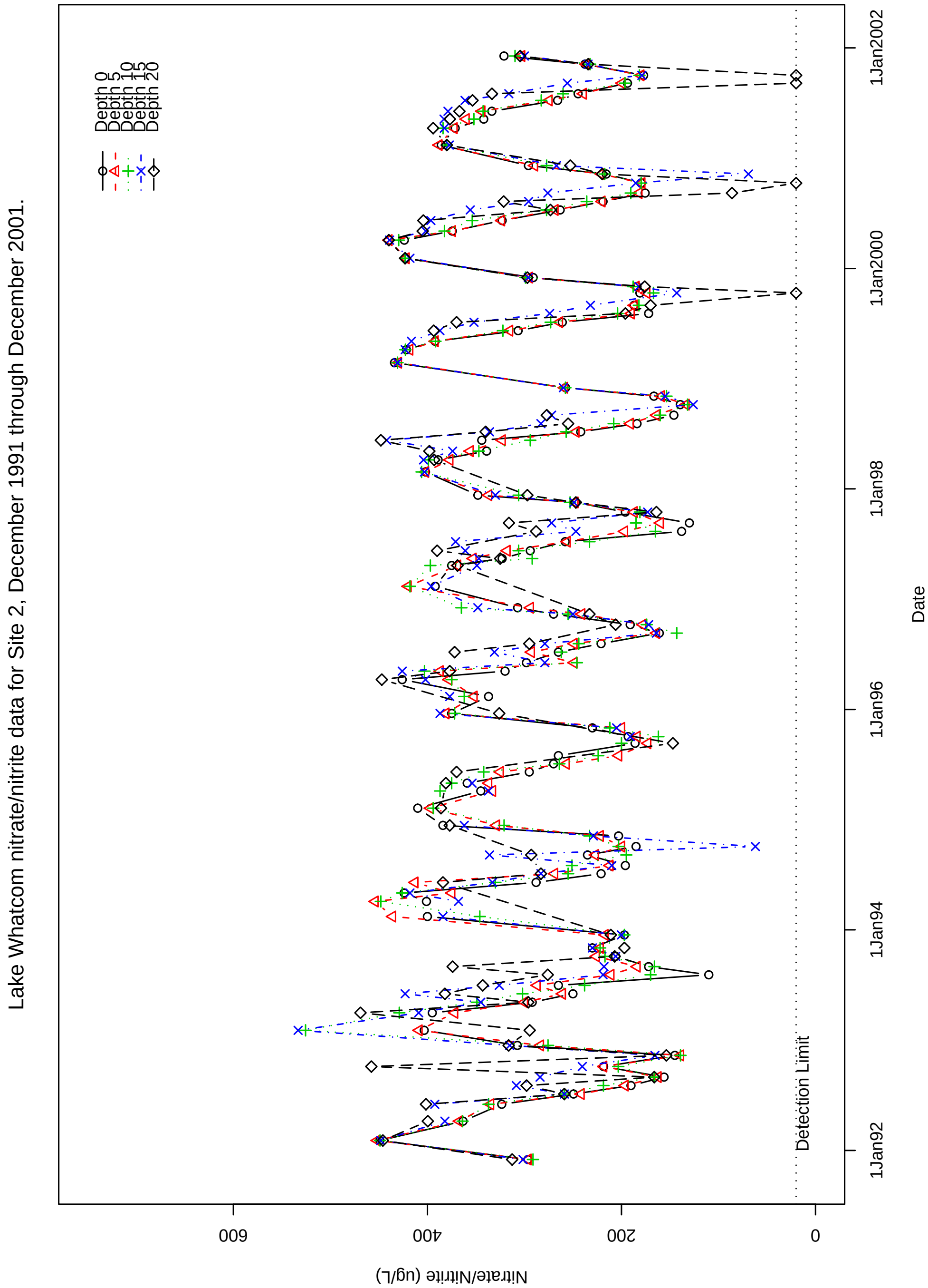

Figure 57: Lake Whatcom nitrate/nitrite data for Site 2.

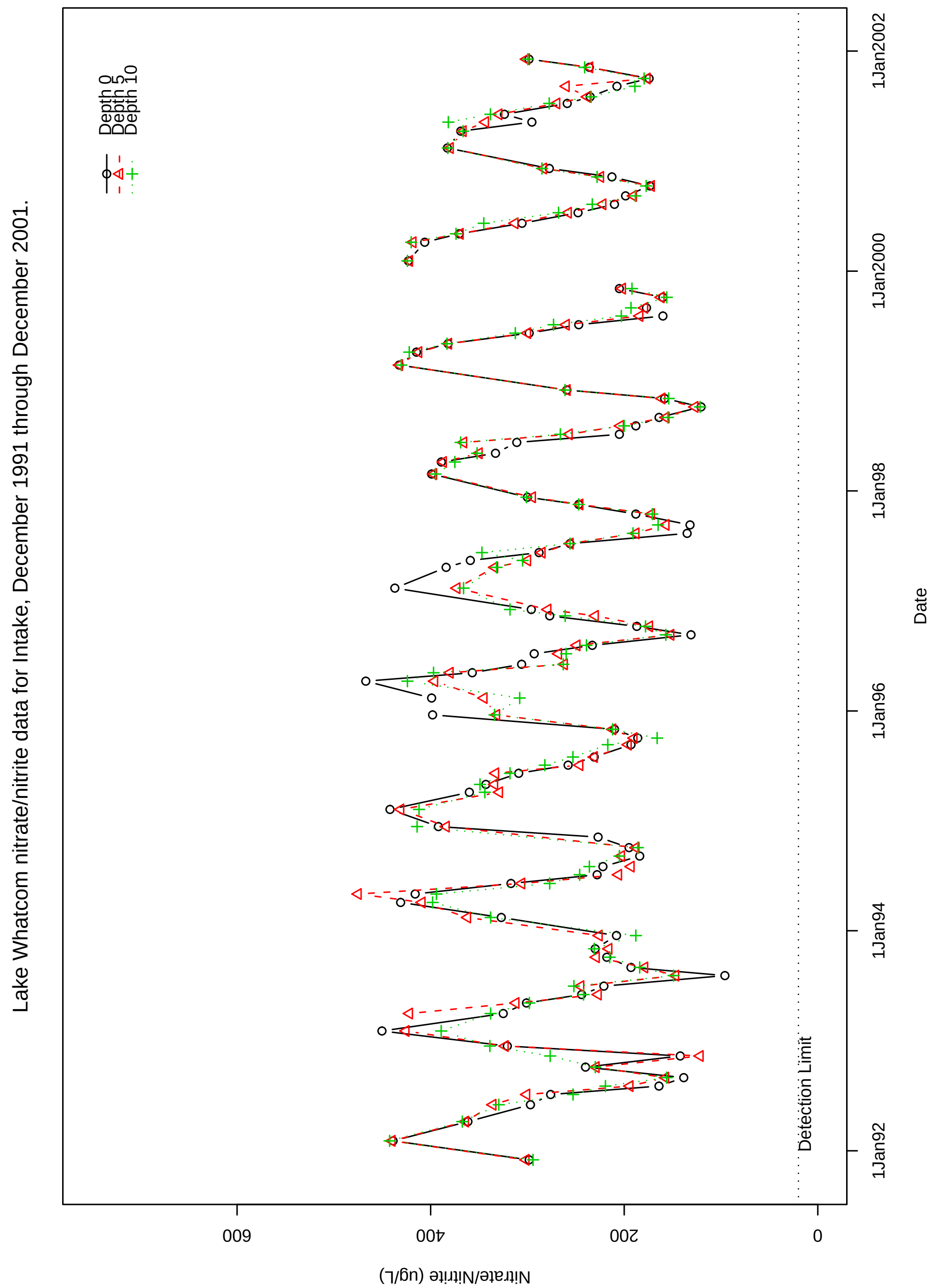

Figure 58: Lake Whatcom nitrate/nitrite data for the Intake.

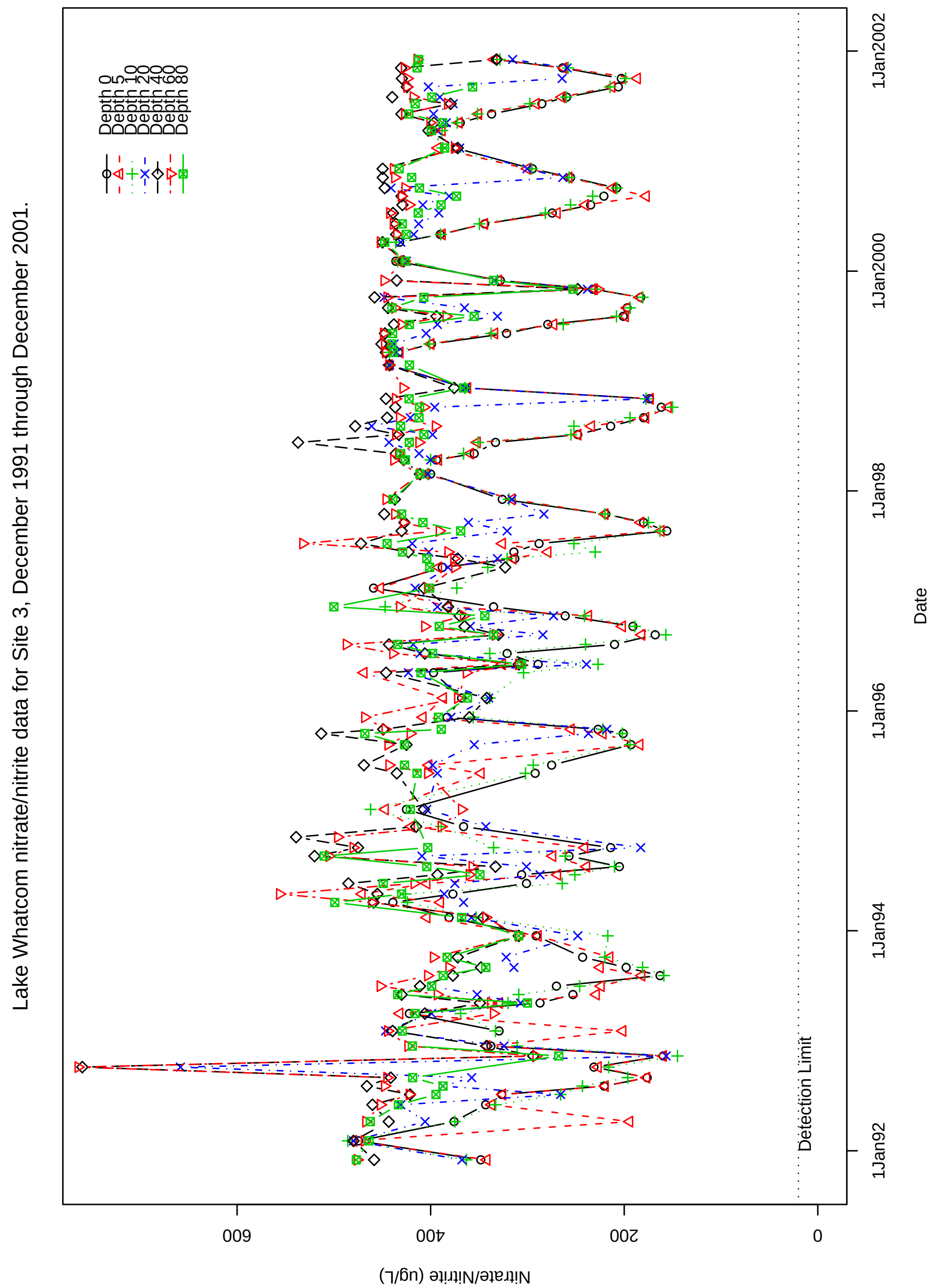

Figure 59: Lake Whatcom nitrate/nitrite data for Site 3.

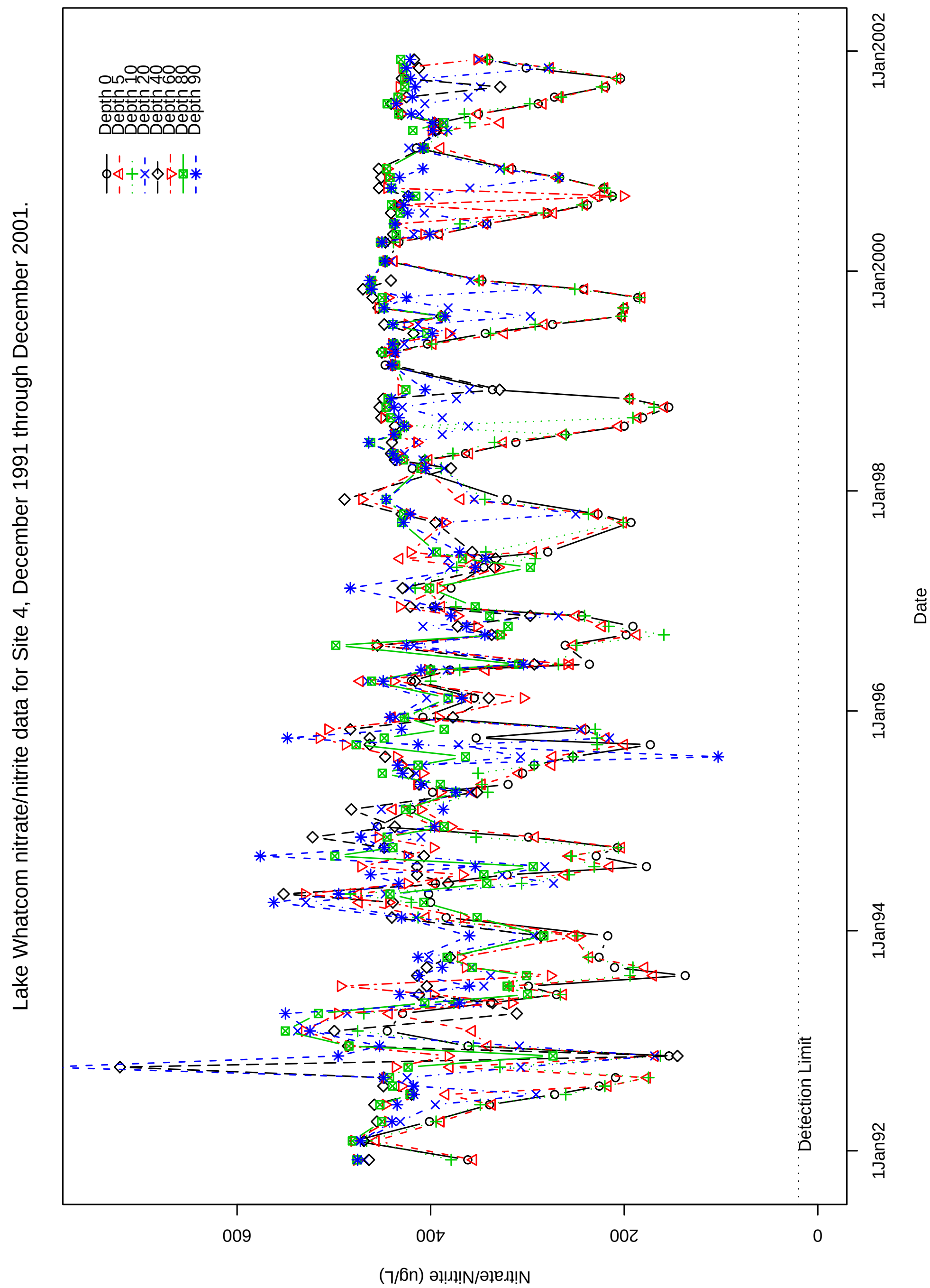

Figure 60: Lake Whatcom nitrate/nitrite data for Site 4.

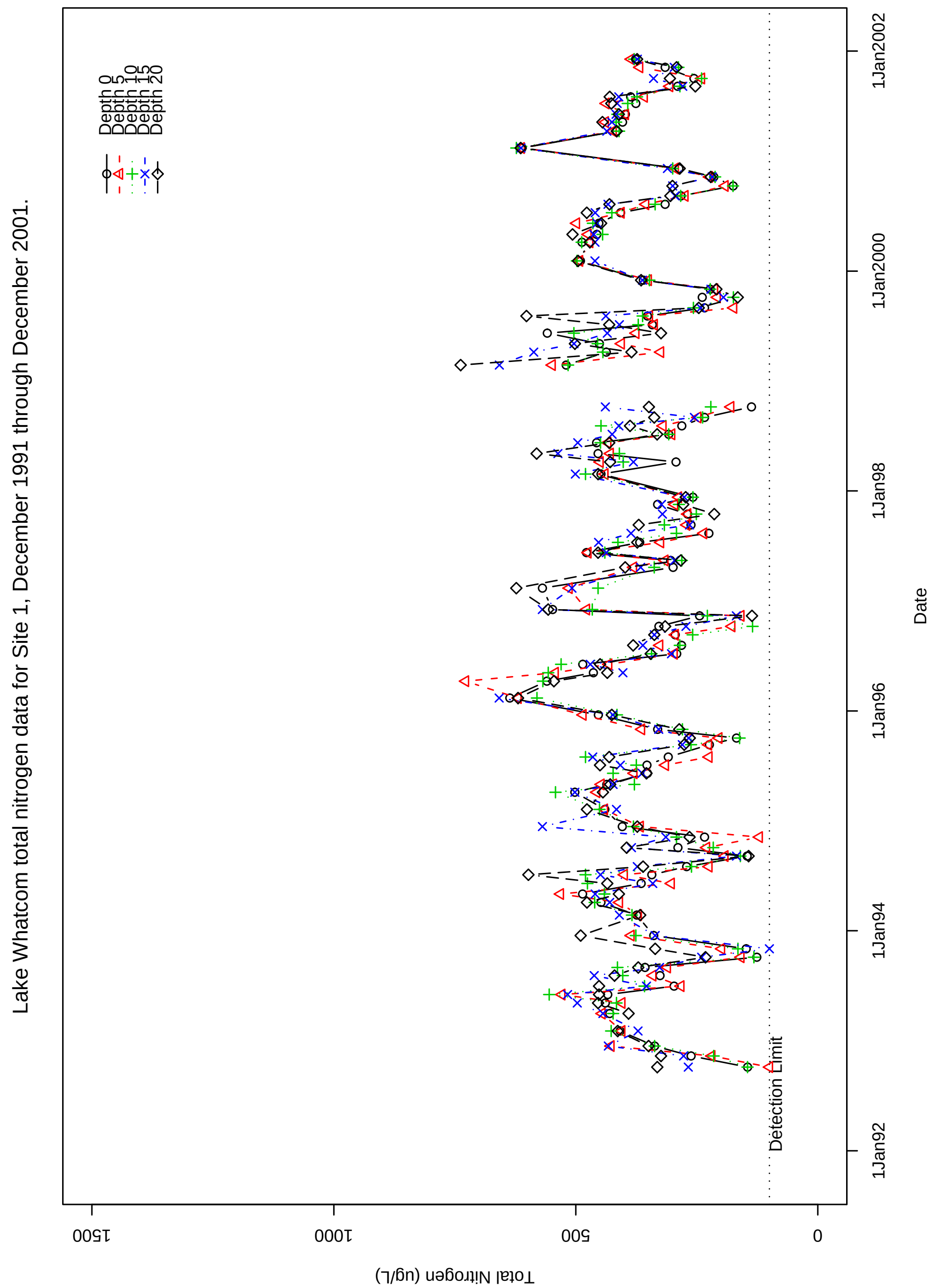

Figure 61: Lake Whatcom total nitrogen data for Site 1.

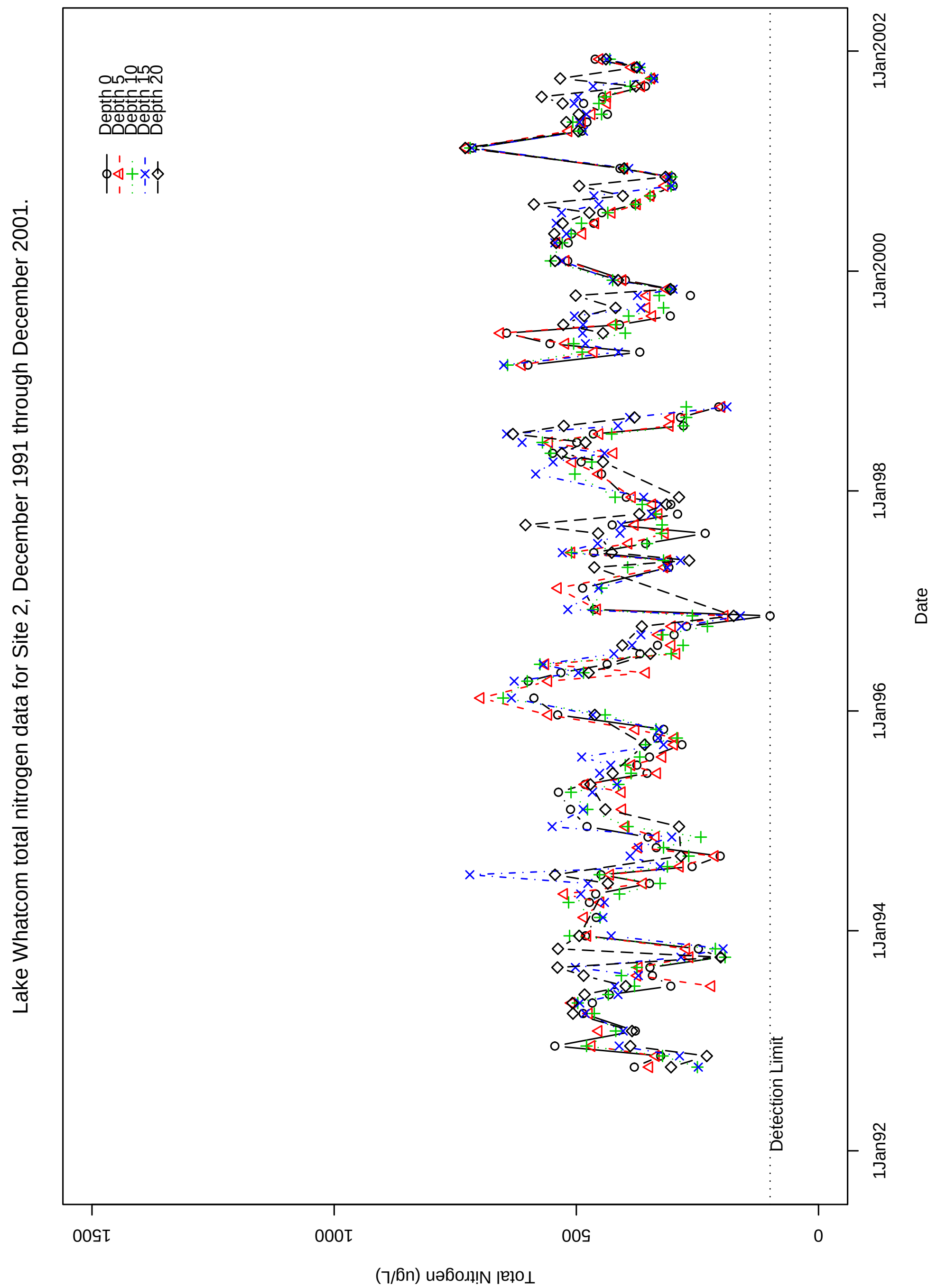

Figure 62: Lake Whatcom total nitrogen data for Site 2.

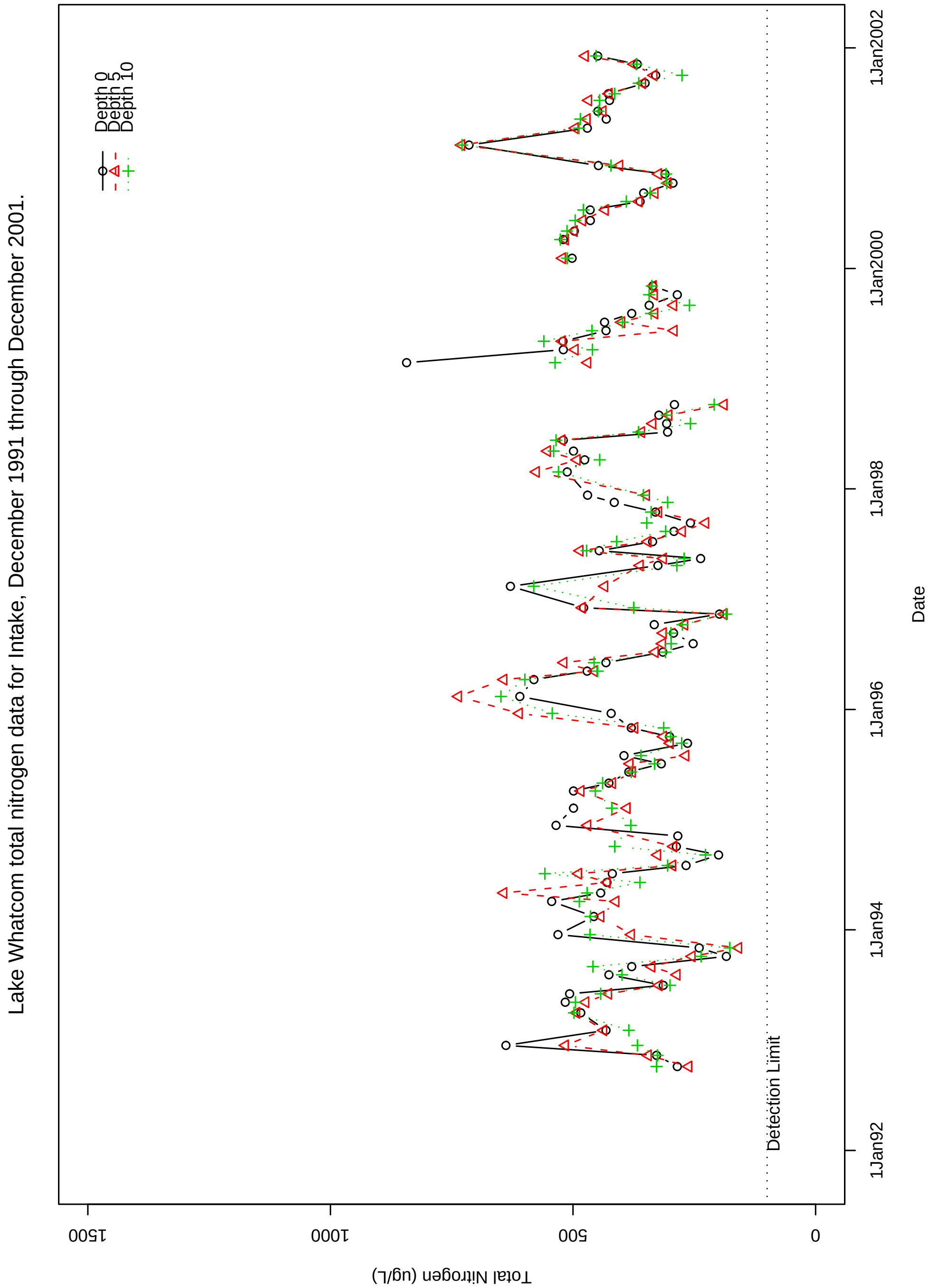

Figure 63: Lake Whatcom total nitrogen data for the Intake.

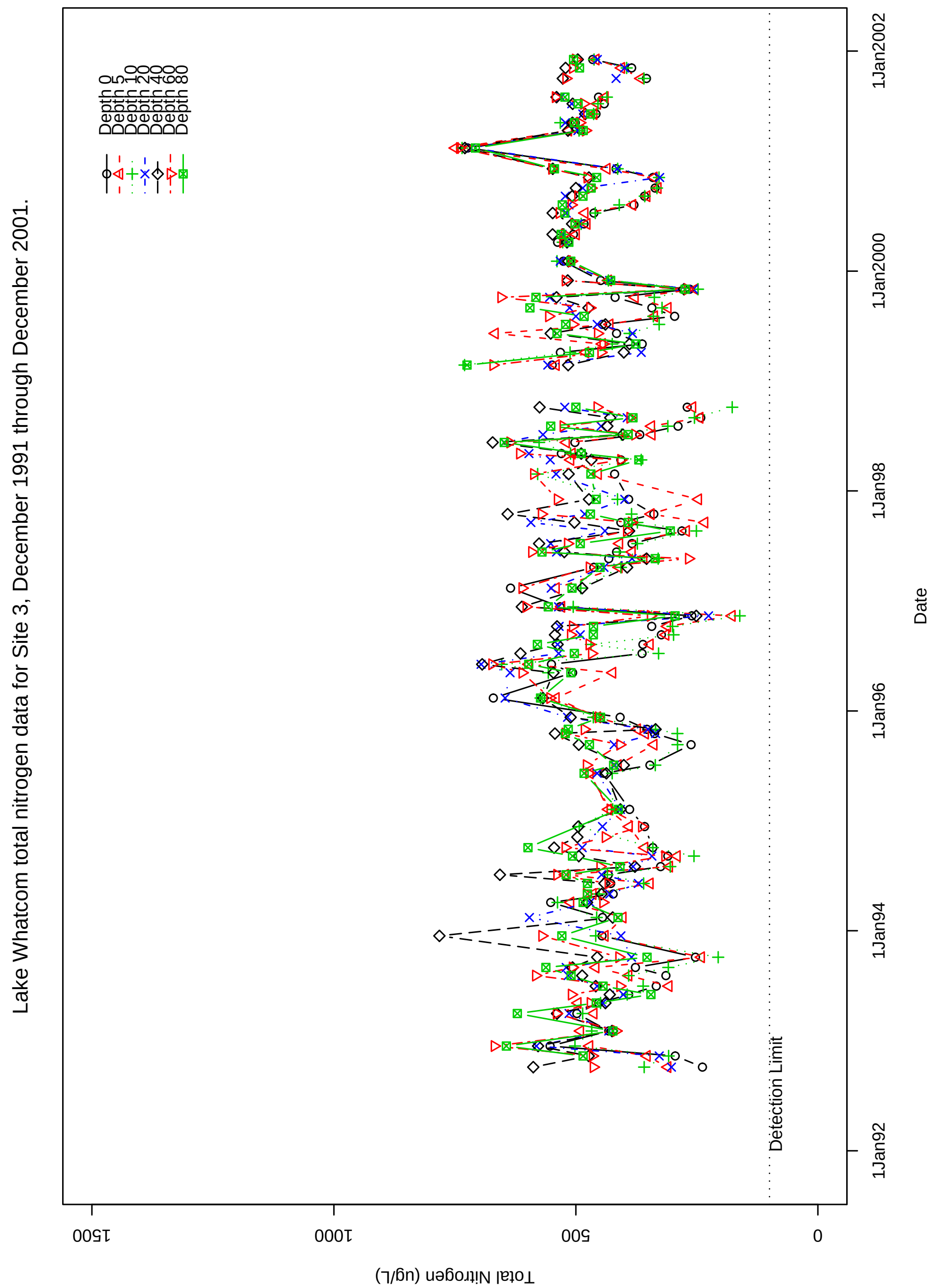

Figure 64: Lake Whatcom total nitrogen data for Site 3.

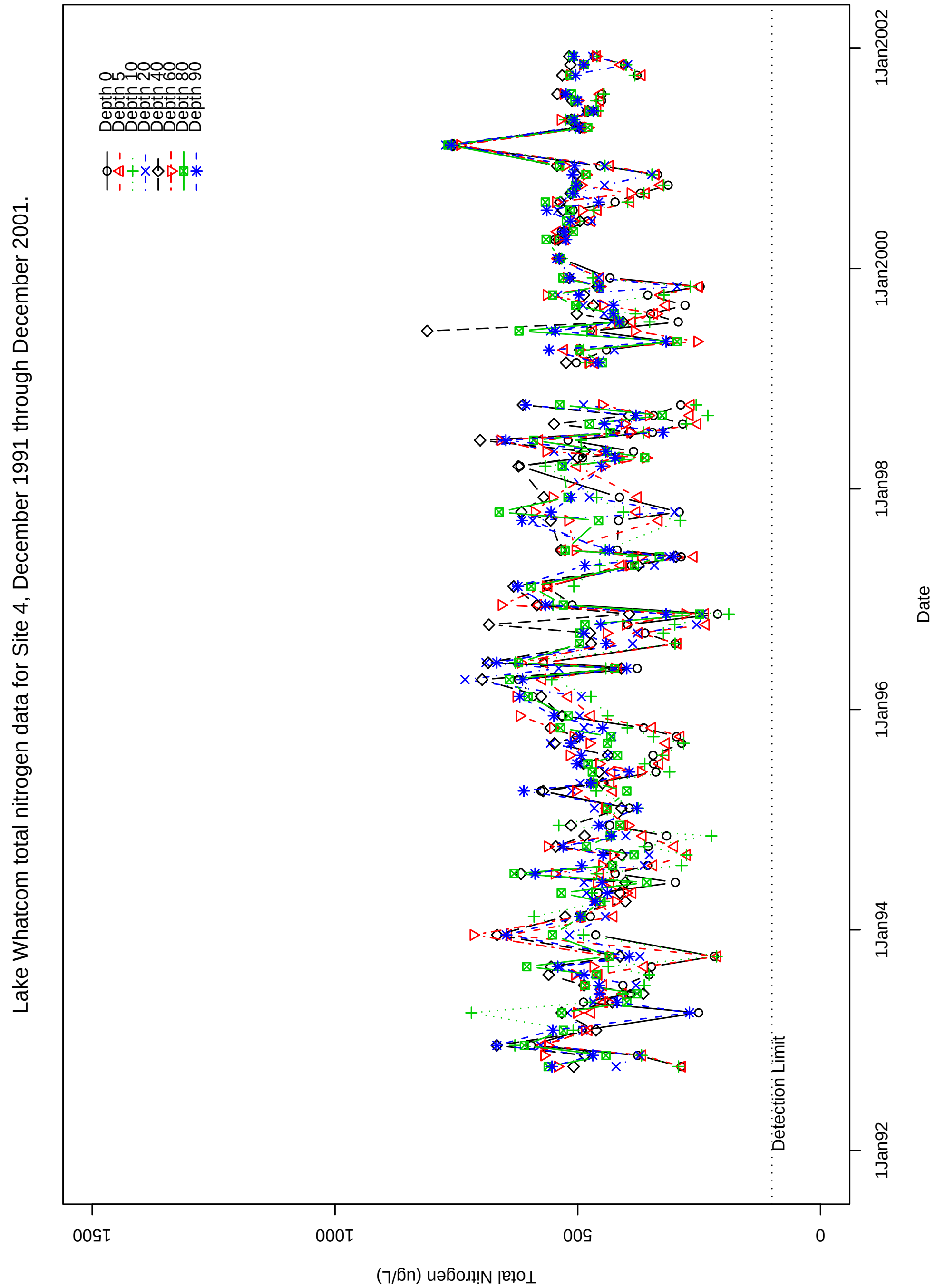

Figure 65: Lake Whatcom total nitrogen data for Site 4.

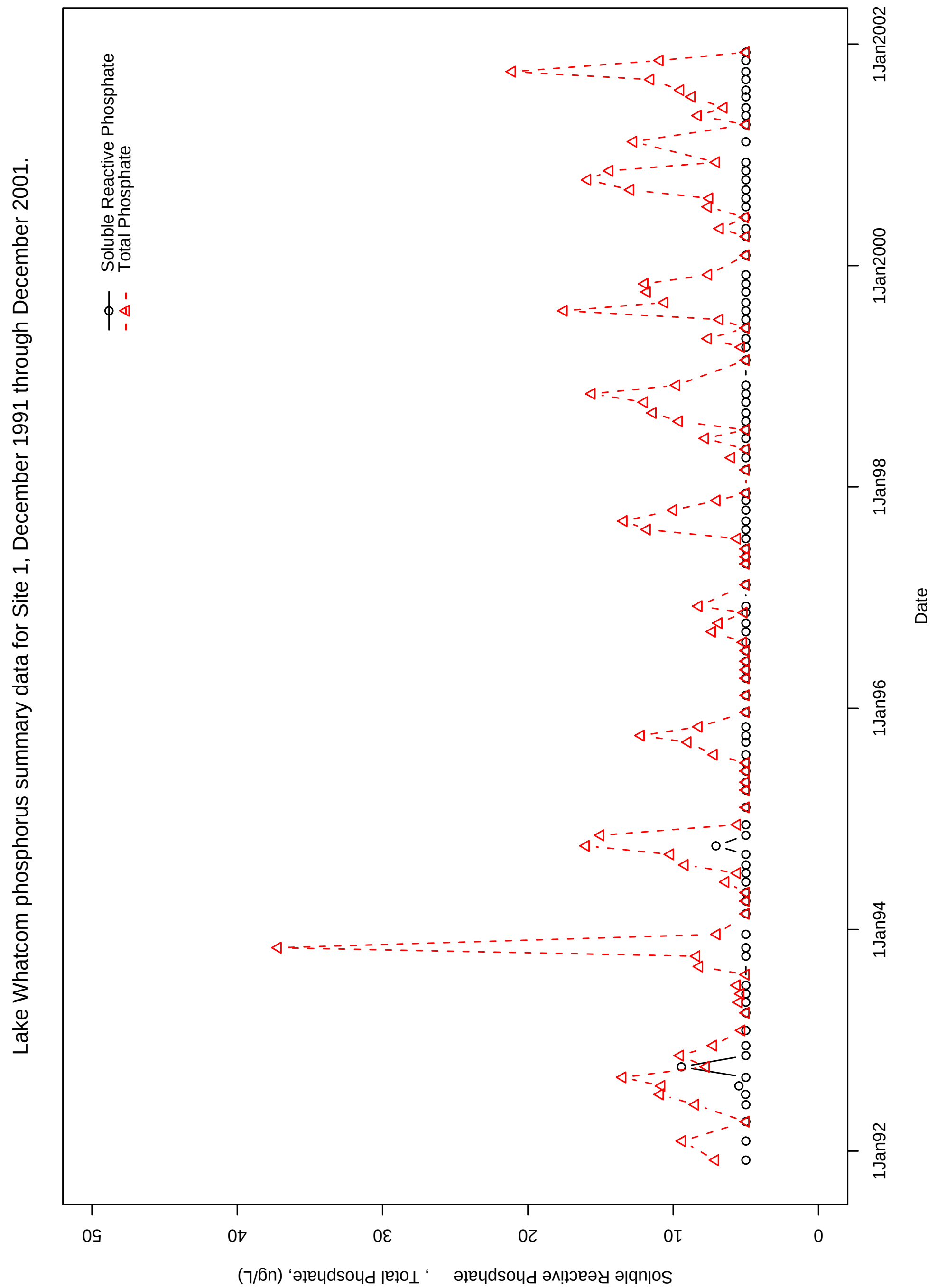

Figure 66: Lake Whatcom phosphorus summary data for Site 1.

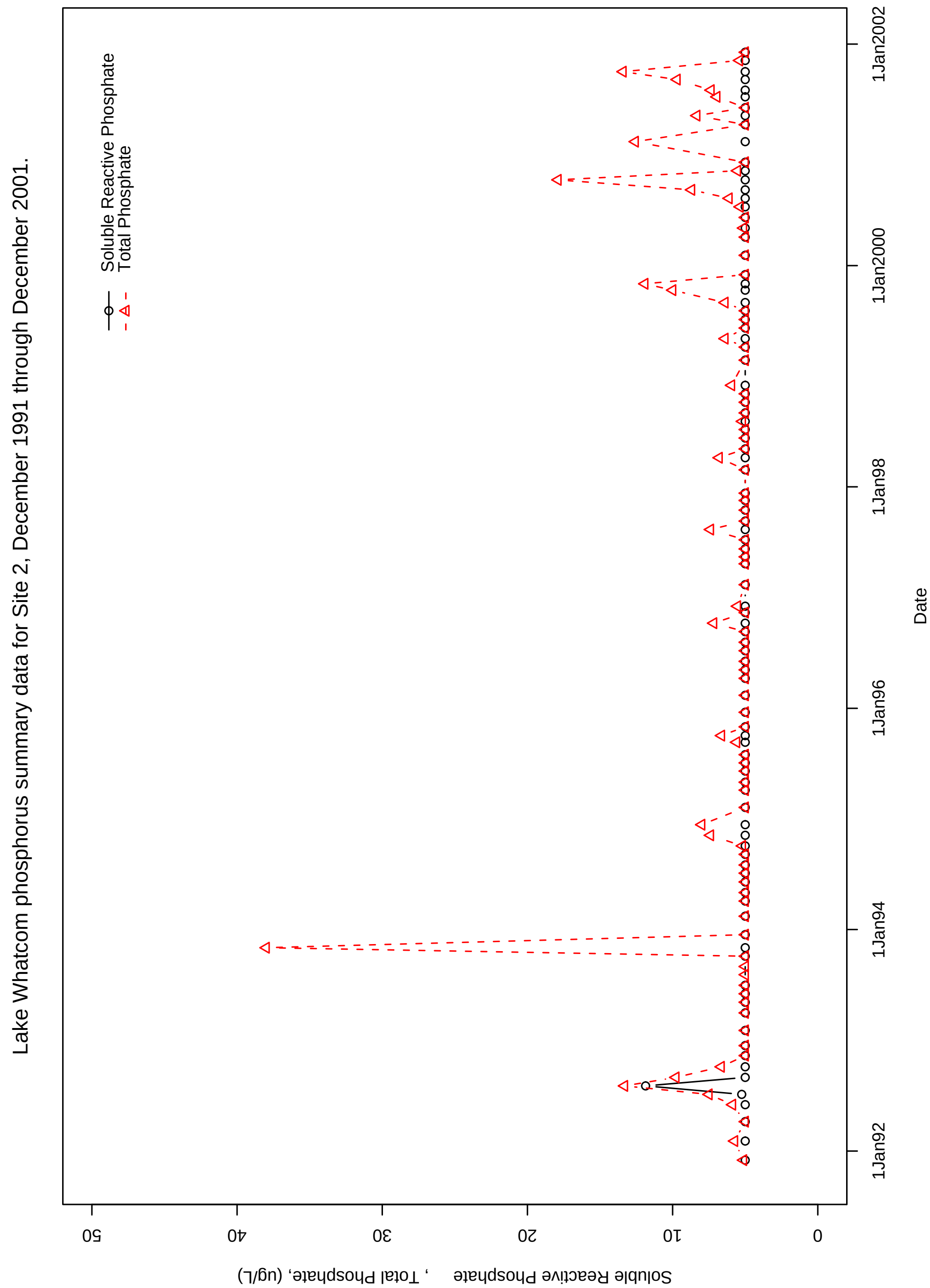

Figure 67: Lake Whatcom phosphorus summary data for Site 2.

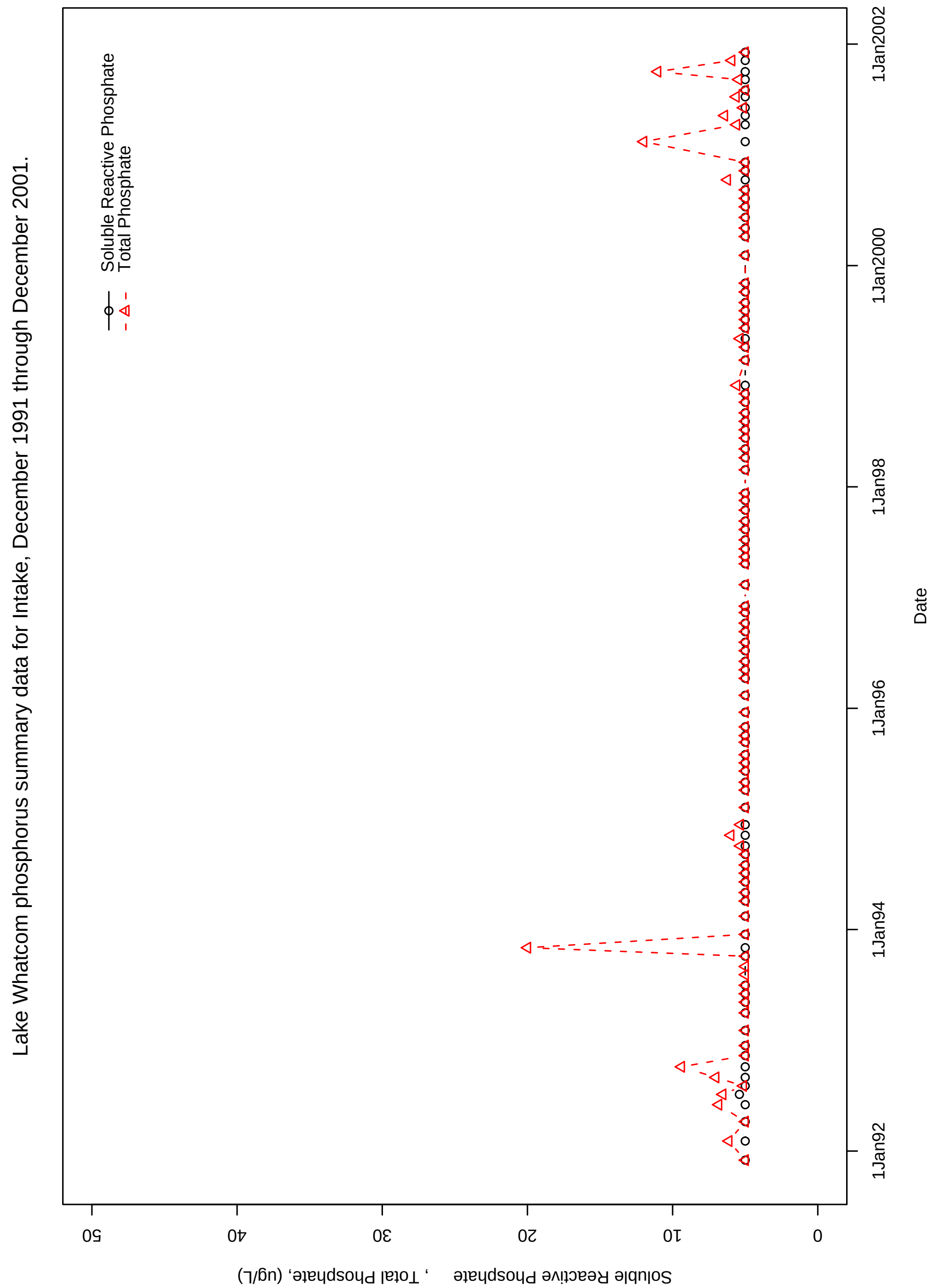

Figure 68: Lake Whatcom phosphorus summary data for the Intake.

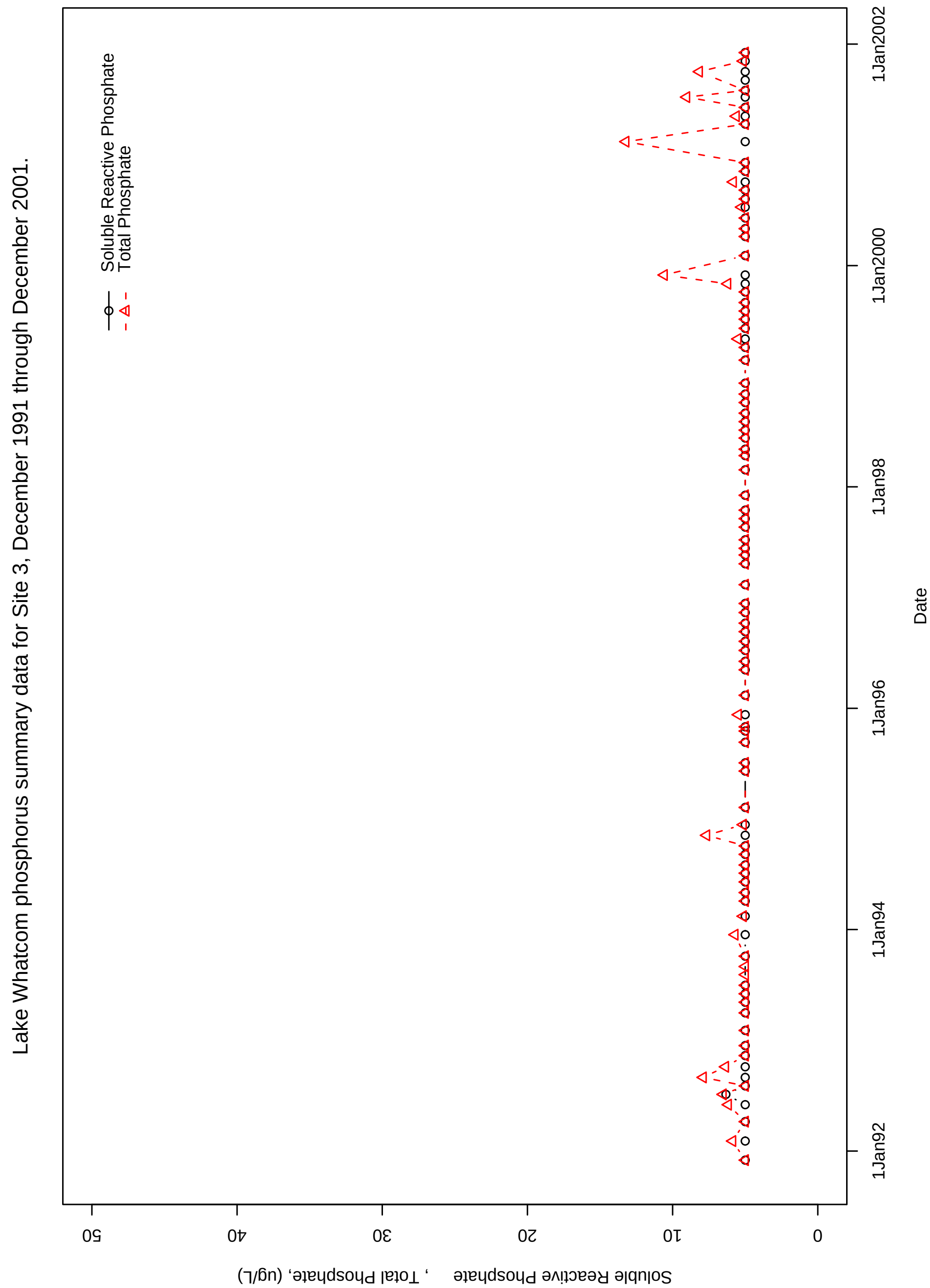

Figure 69: Lake Whatcom phosphorus summary data for Site 3.

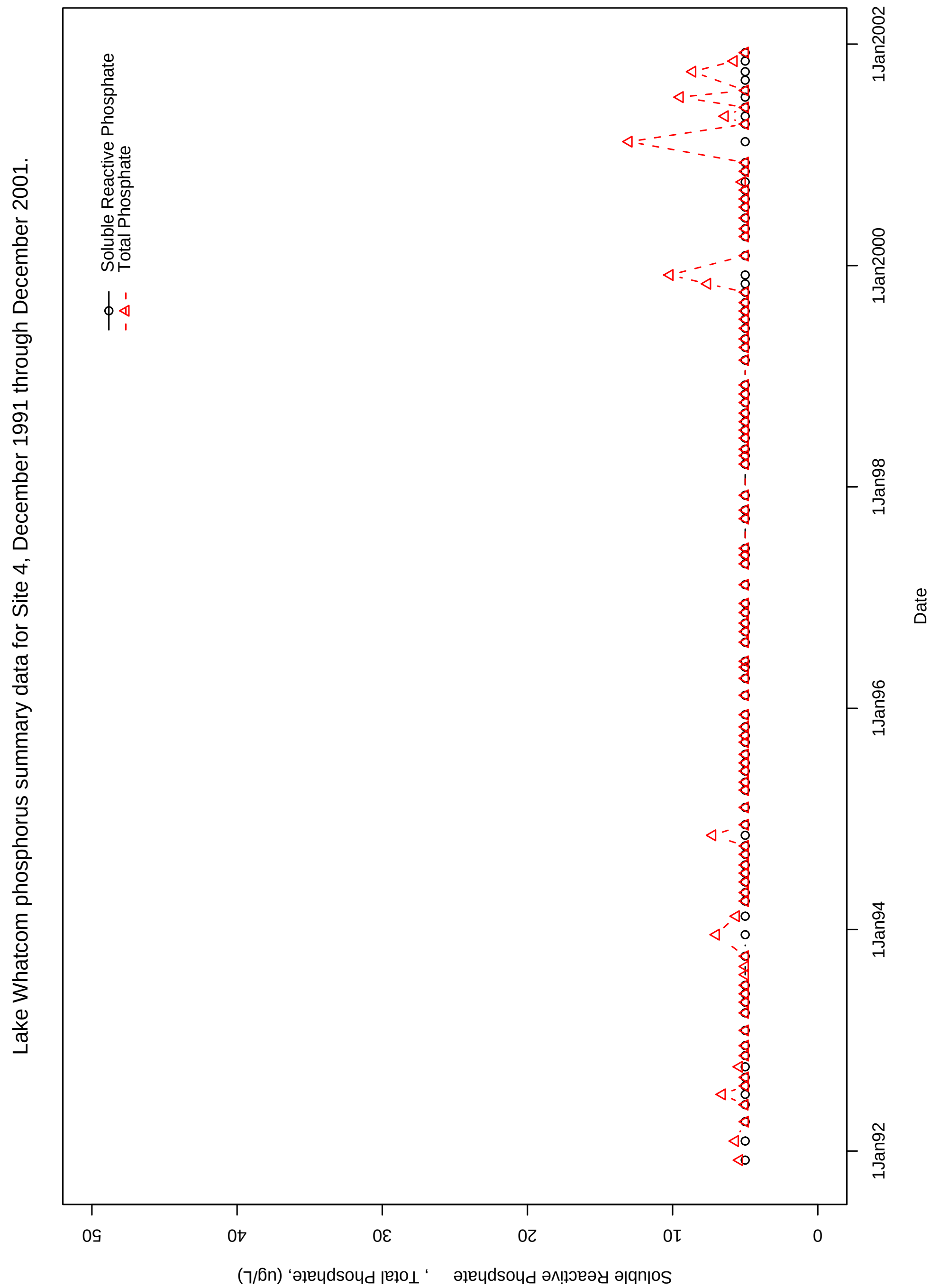

Figure 70: Lake Whatcom phosphorus summary data for Site 4.

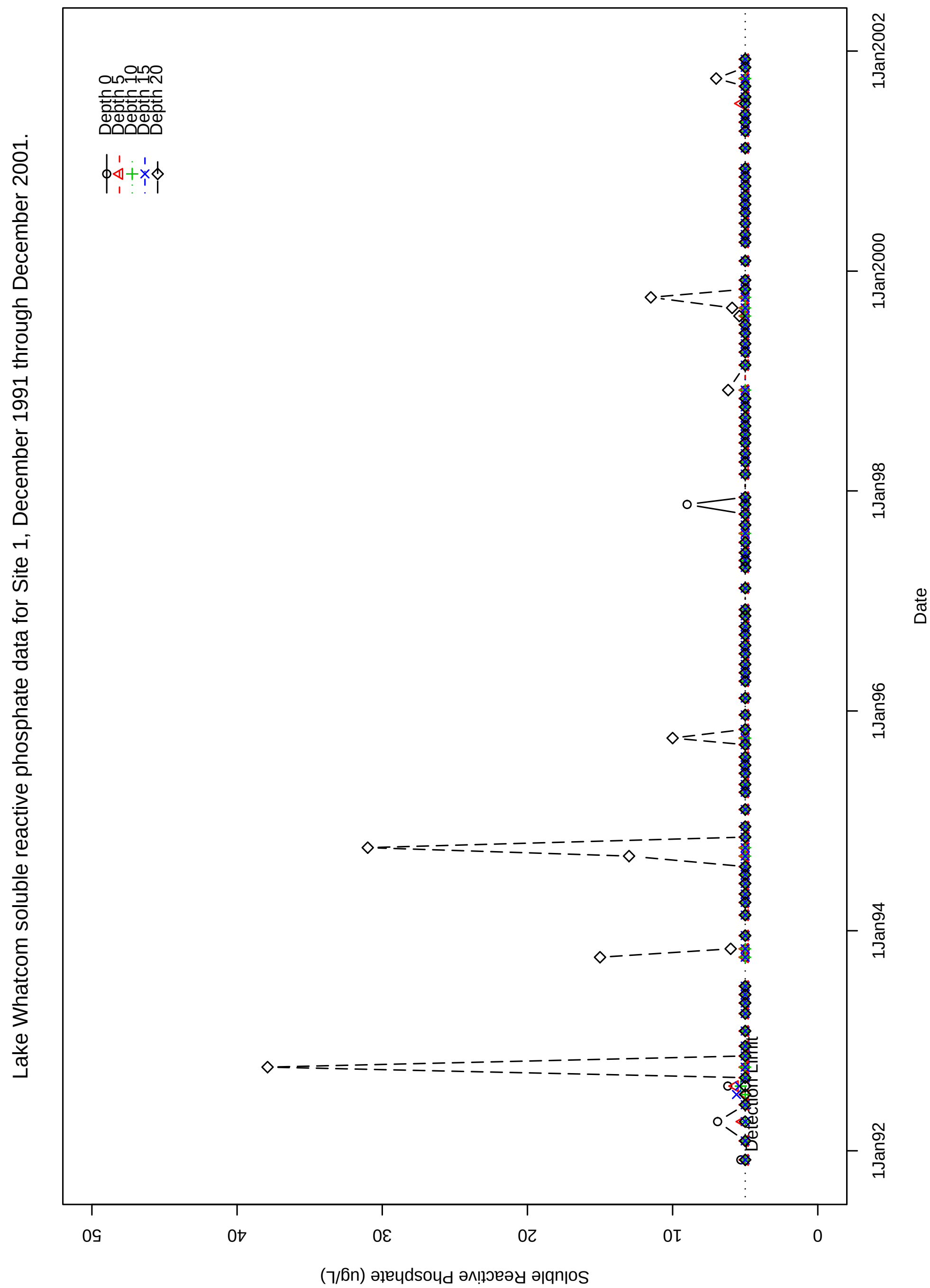

Figure 71: Lake Whatcom soluble phosphate data for Site 1.

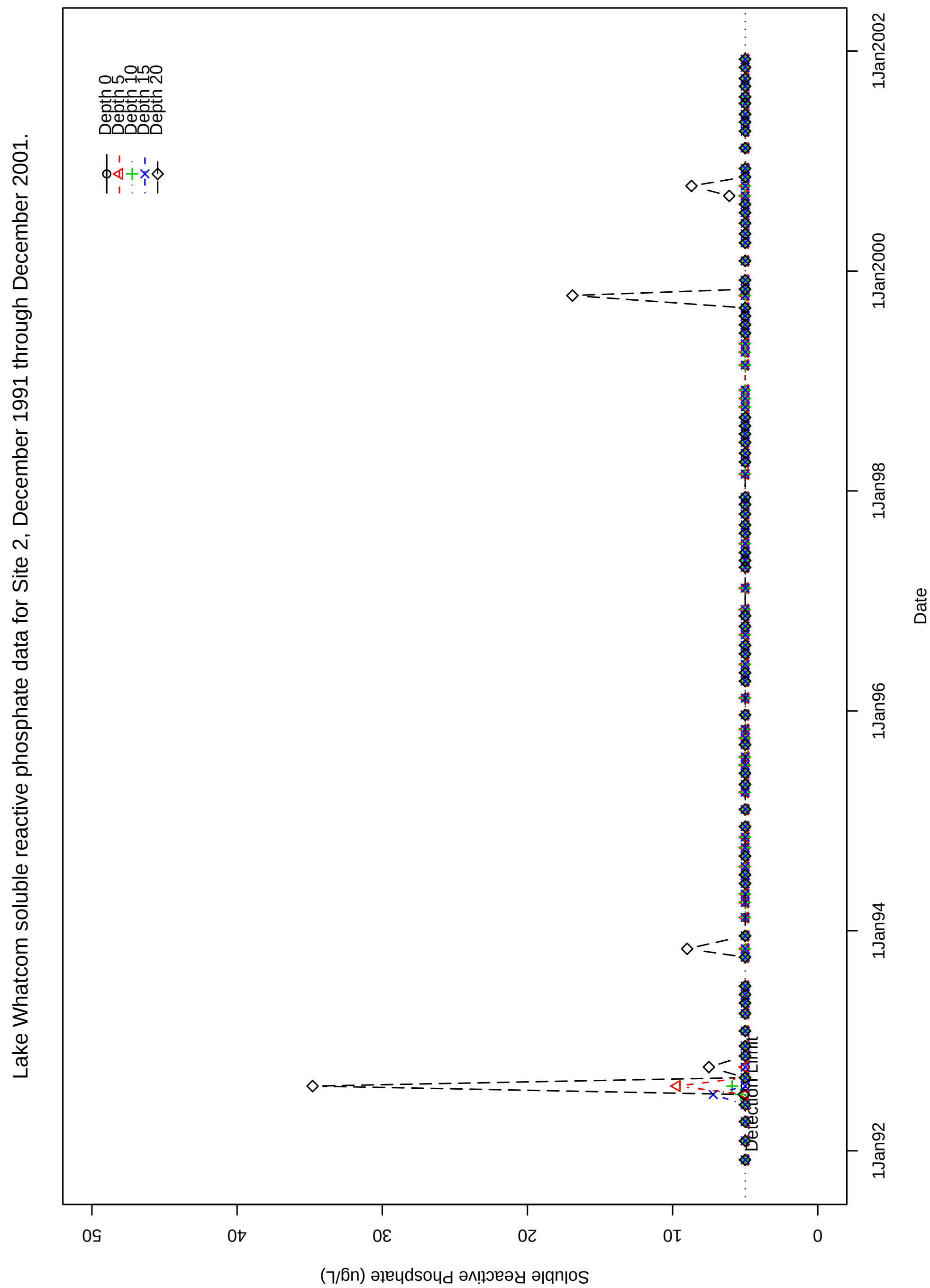

Figure 72: Lake Whatcom soluble phosphate data for Site 2.

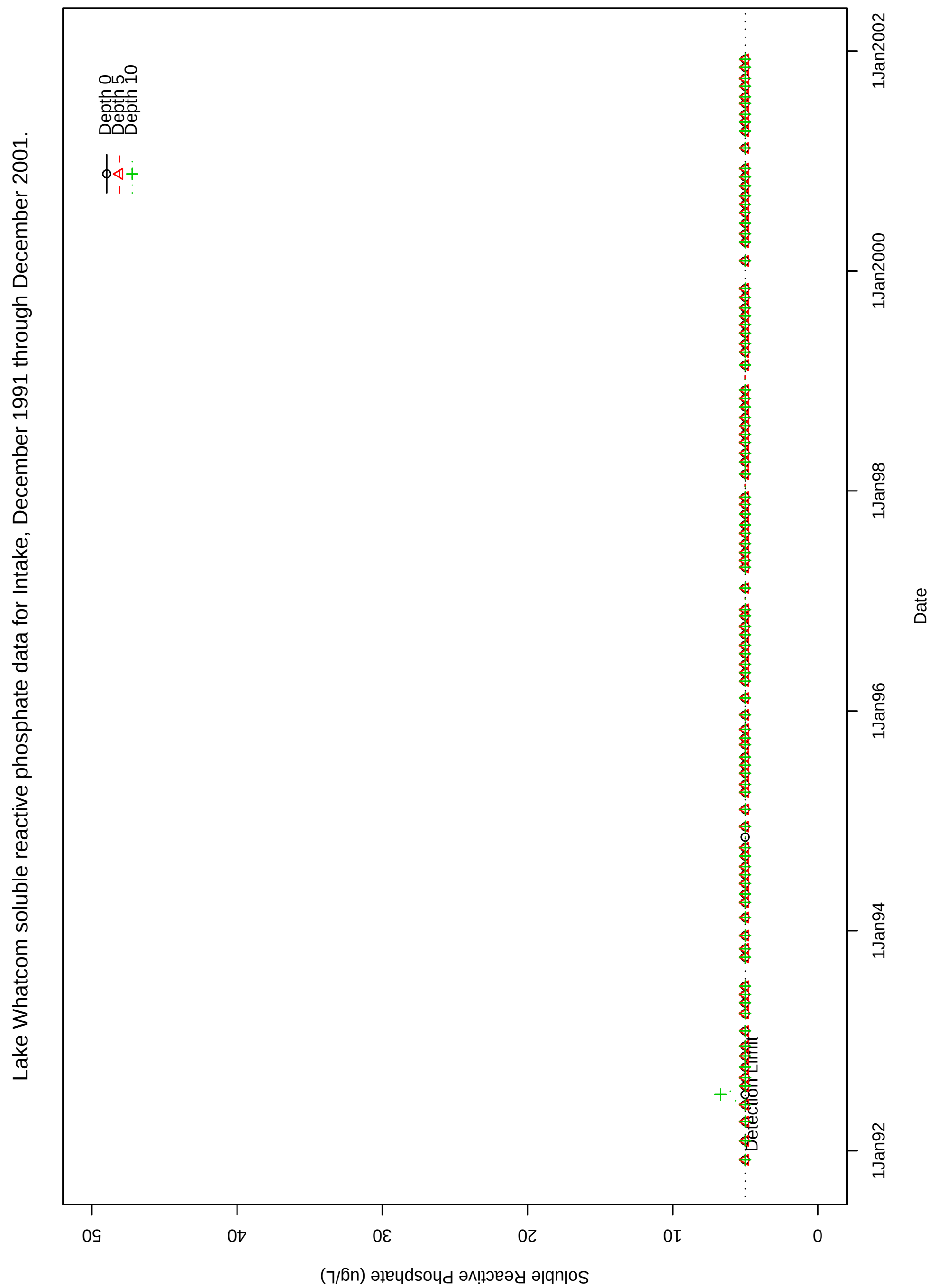

Figure 73: Lake Whatcom soluble phosphate data for the Intake.

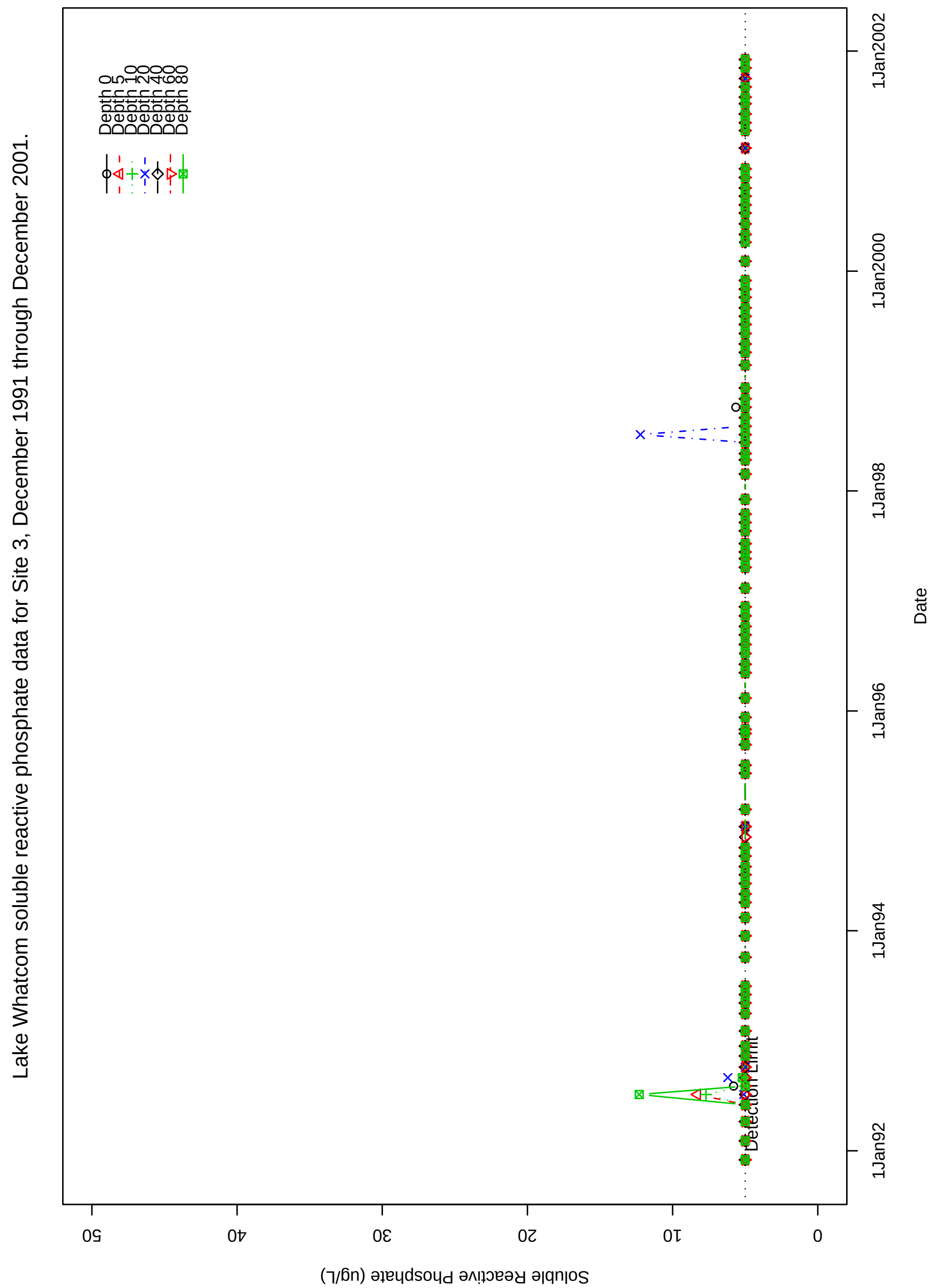

Figure 74: Lake Whatcom soluble phosphate data for Site 3.

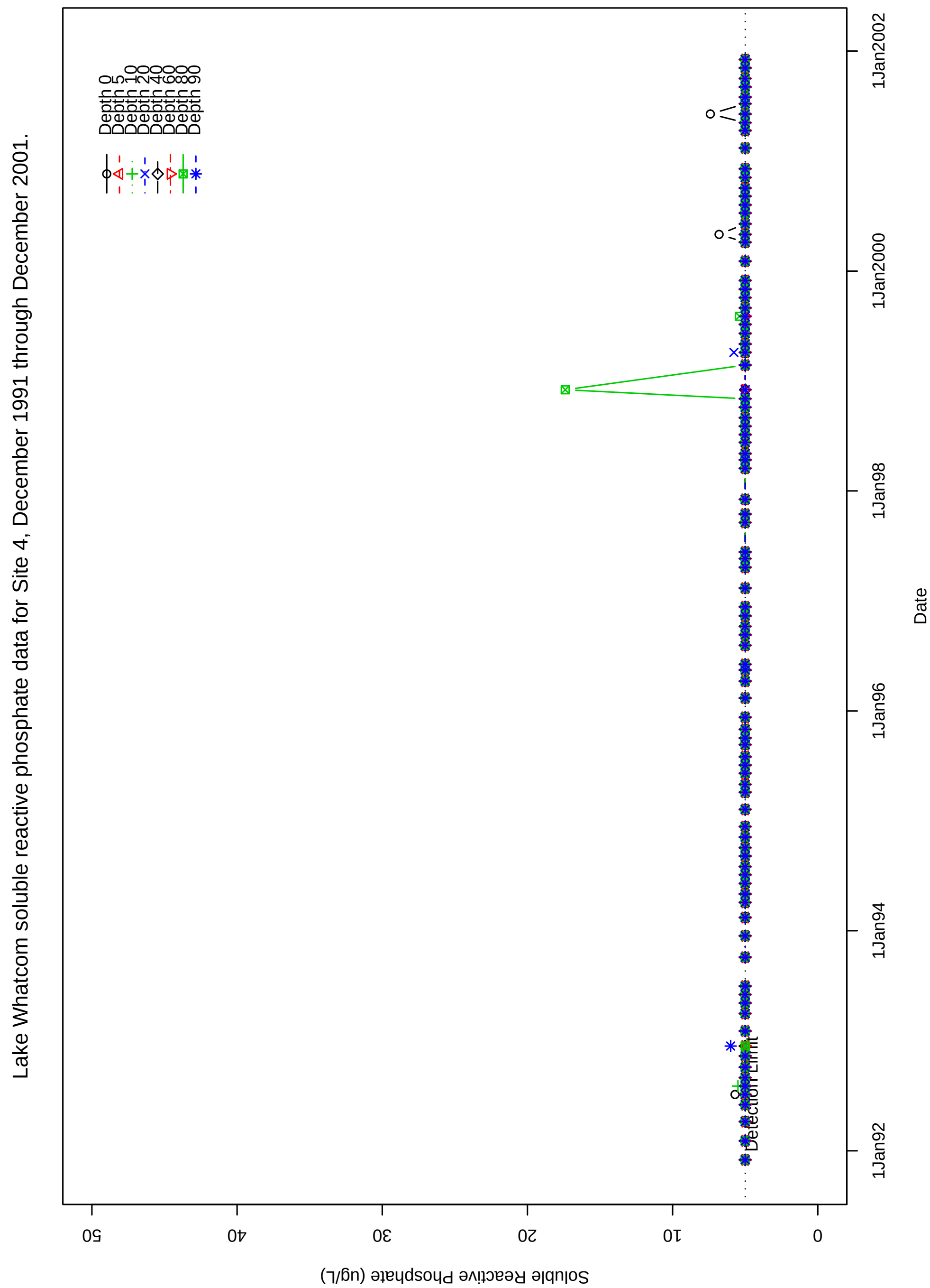

Figure 75: Lake Whatcom soluble phosphate data for Site 4.

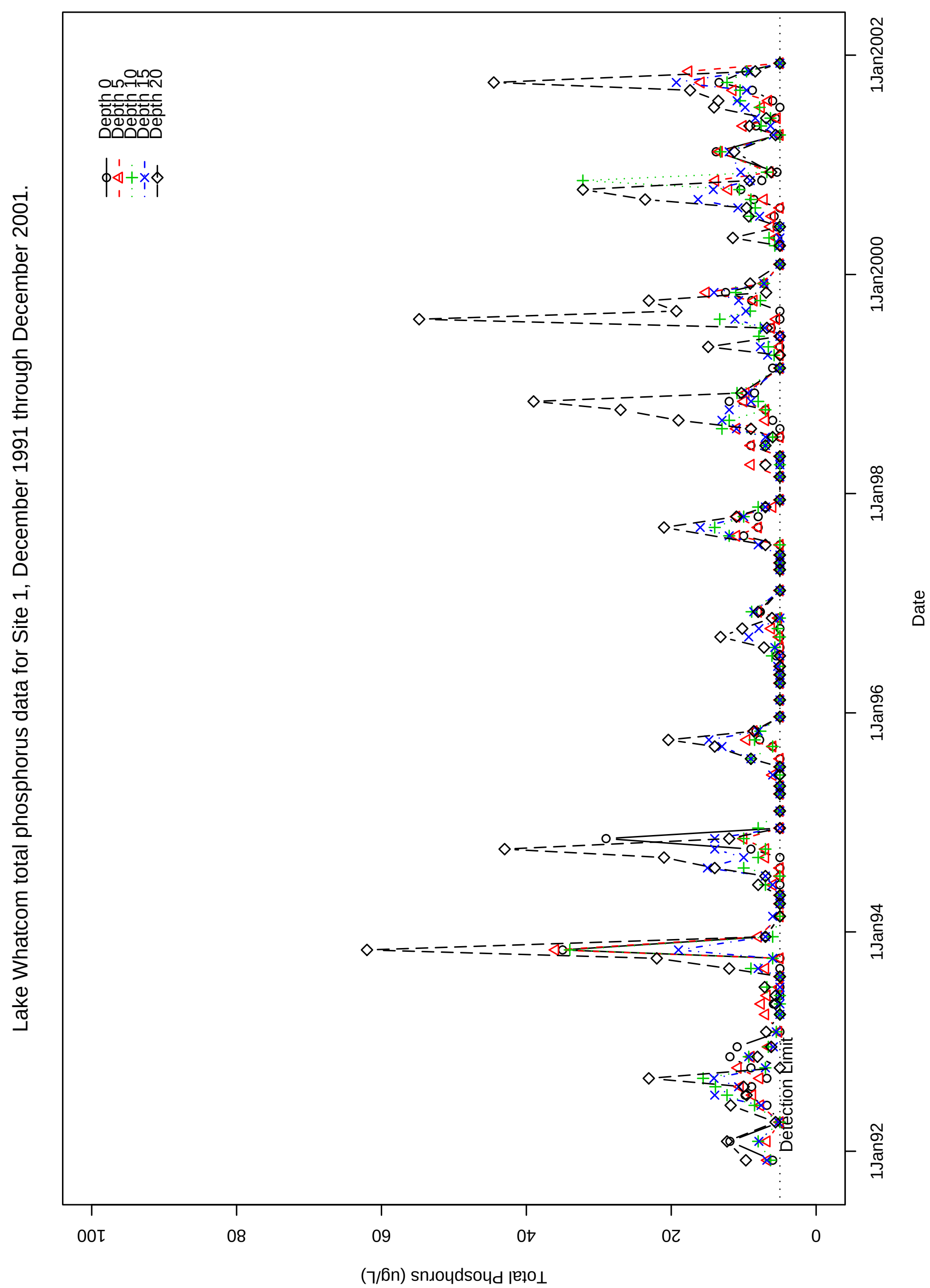

Figure 76: Lake Whatcom total phosphorus data for Site 1.

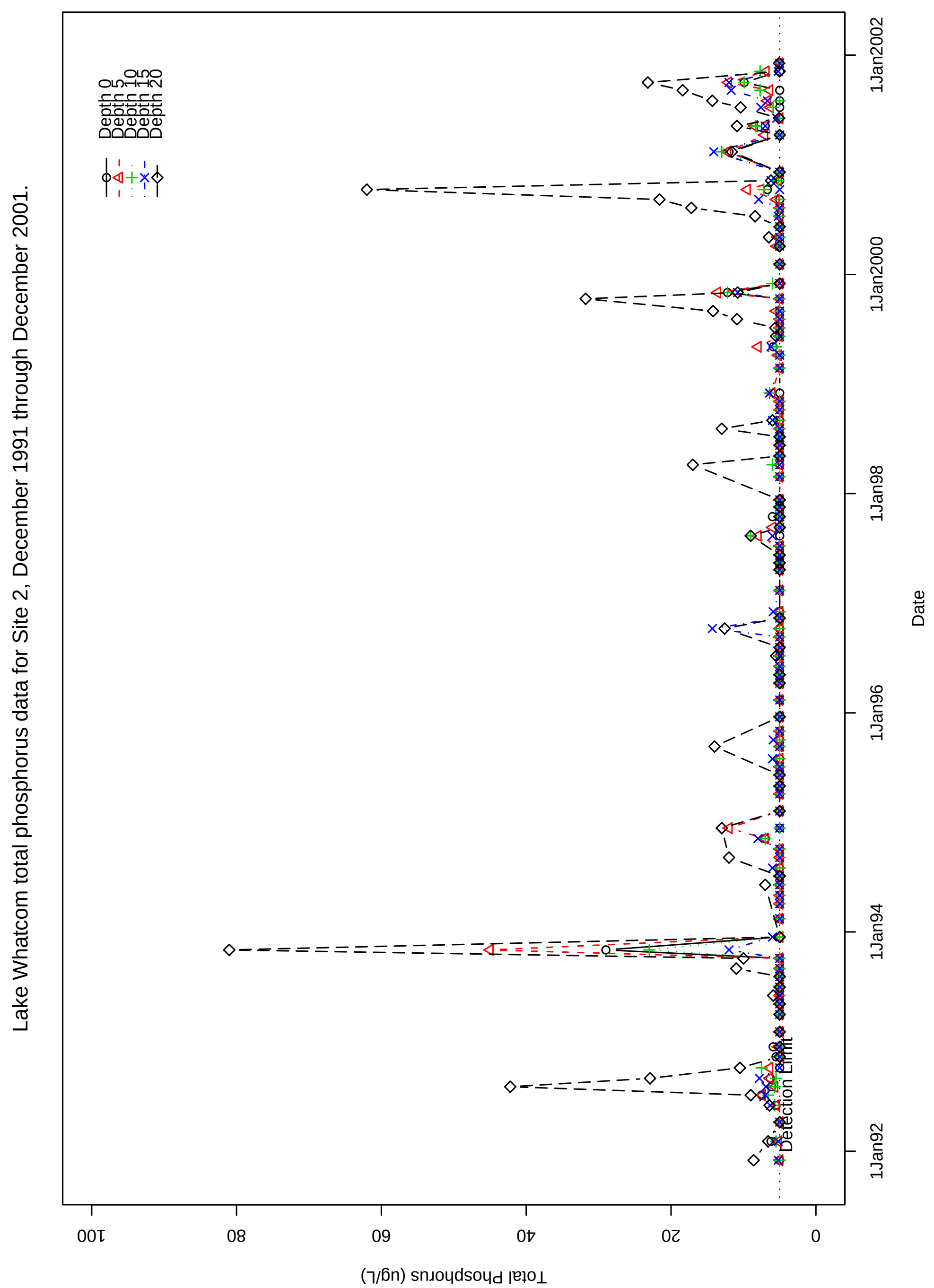

Figure 77: Lake Whatcom total phosphorus data for Site 2.

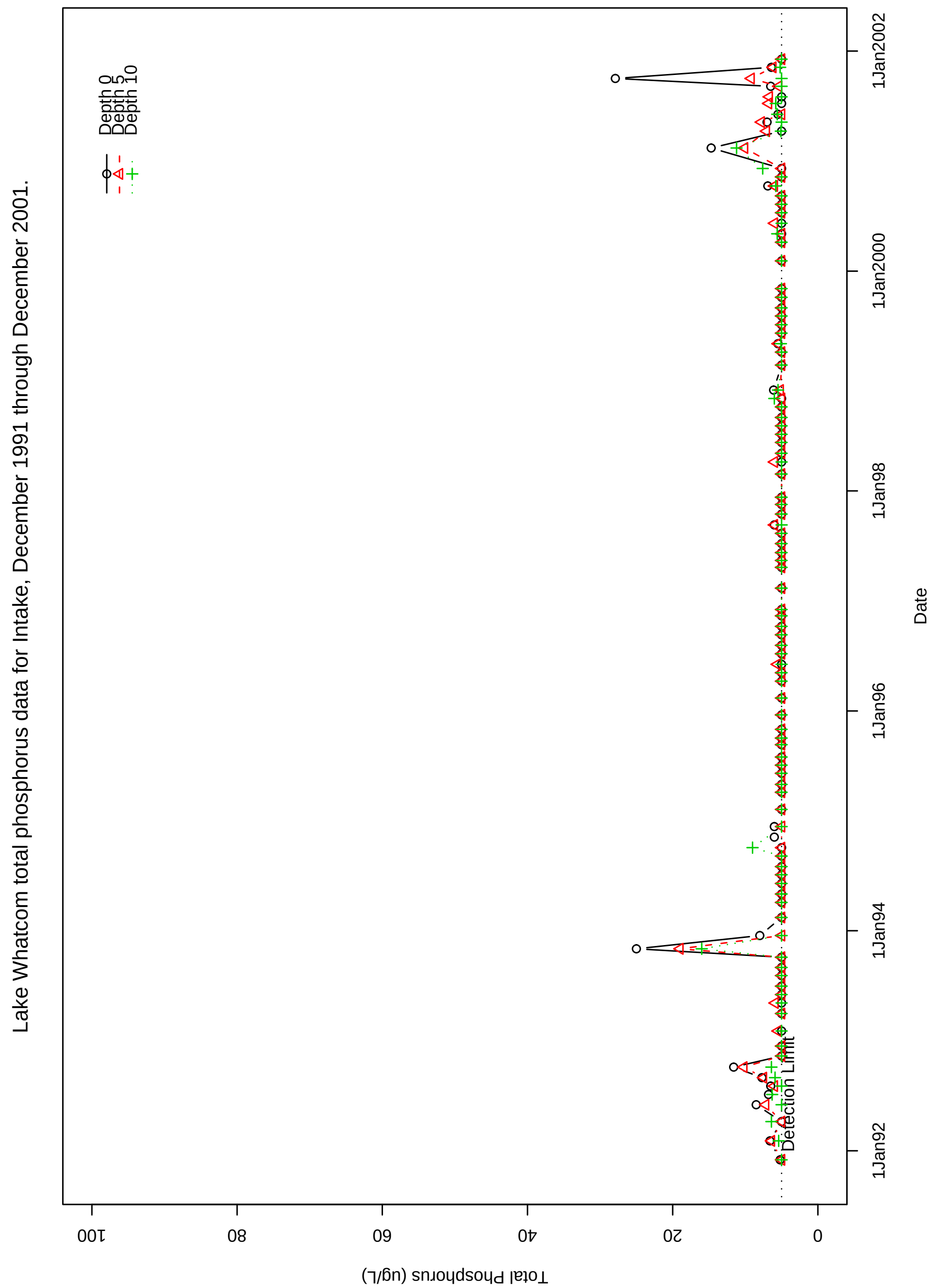

Figure 78: Lake Whatcom total phosphorus data for the Intake.

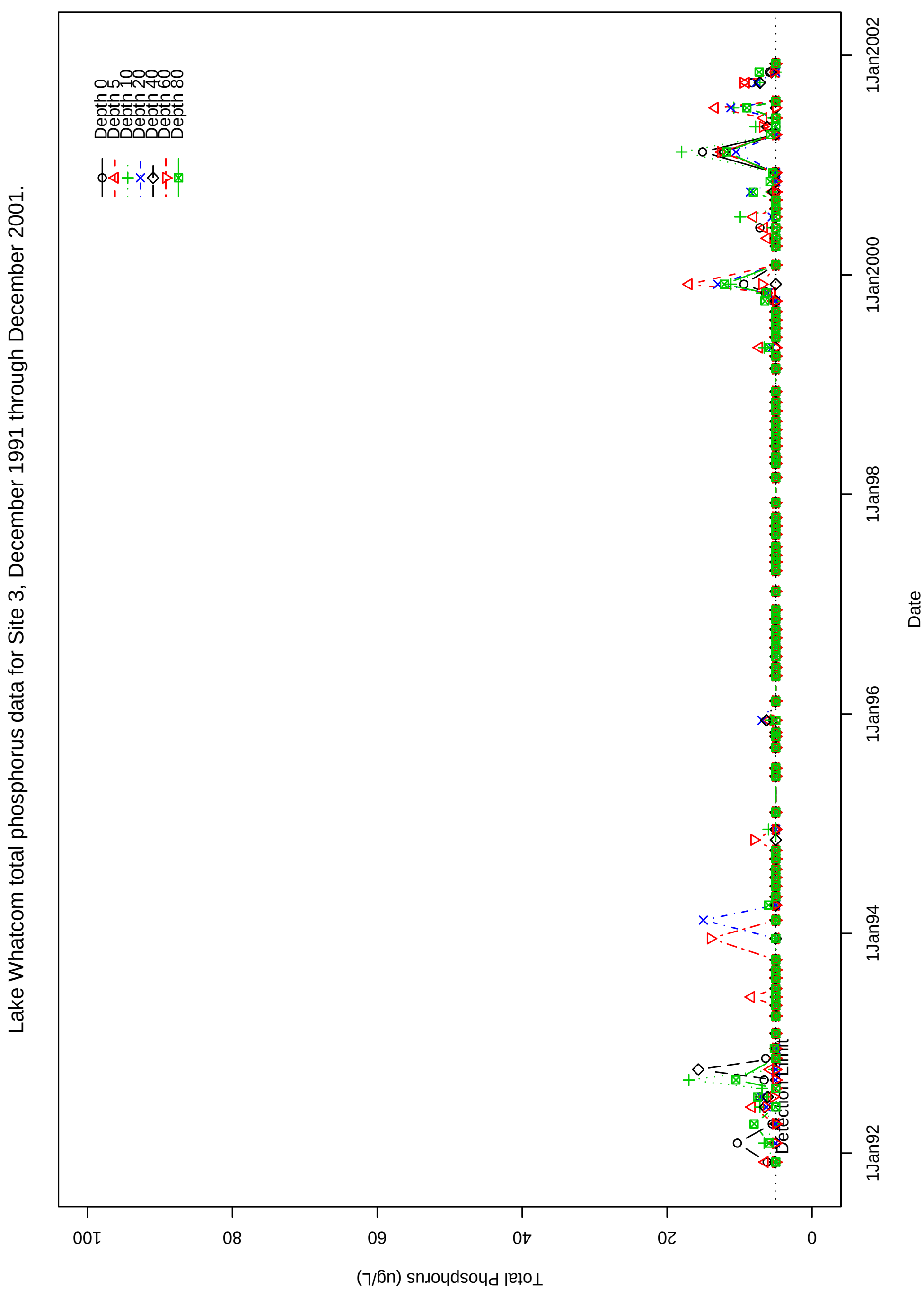

Figure 79: Lake Whatcom total phosphorus data for Site 3.

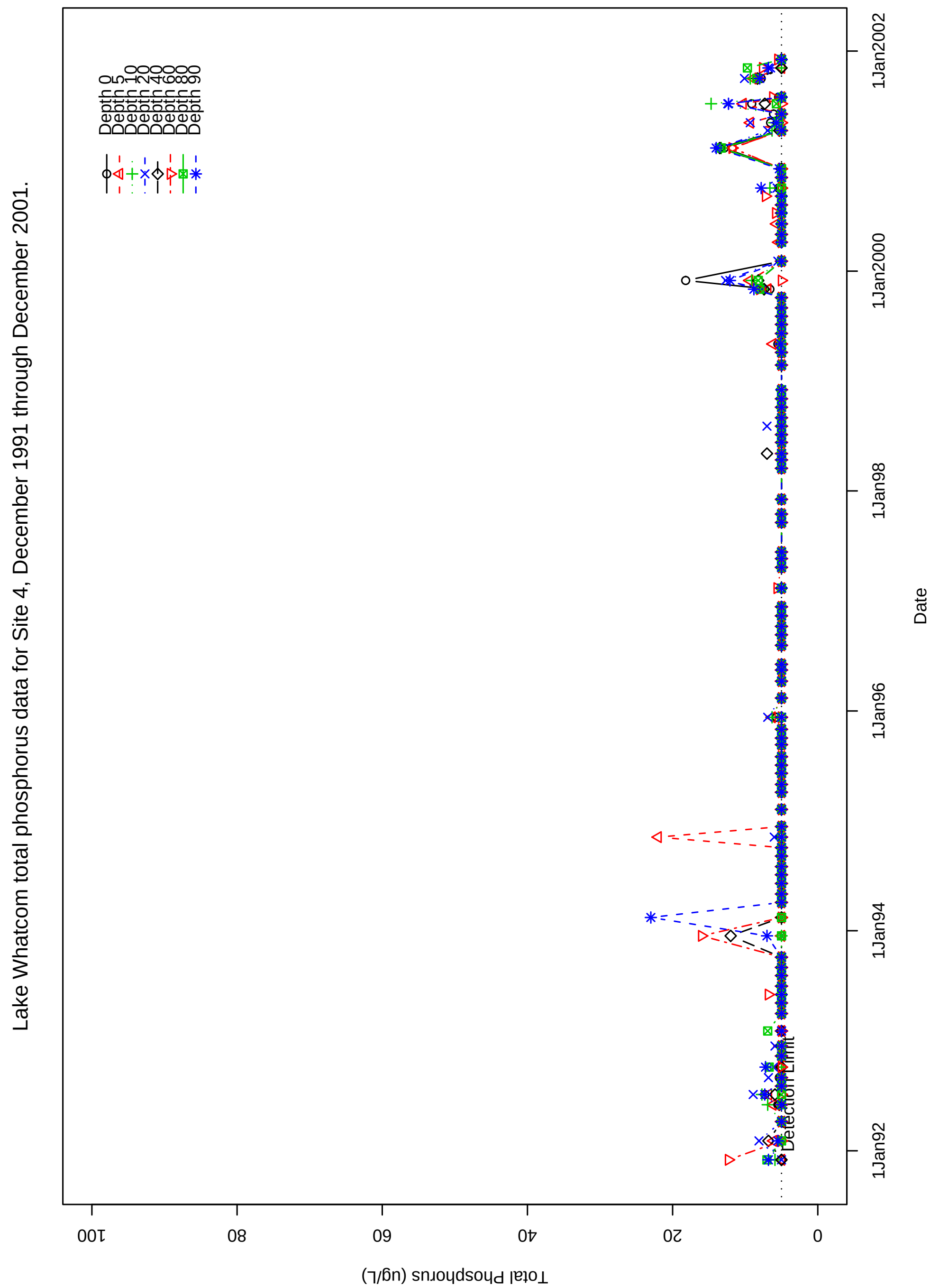

Figure 80: Lake Whatcom total phosphorus data for Site 4.

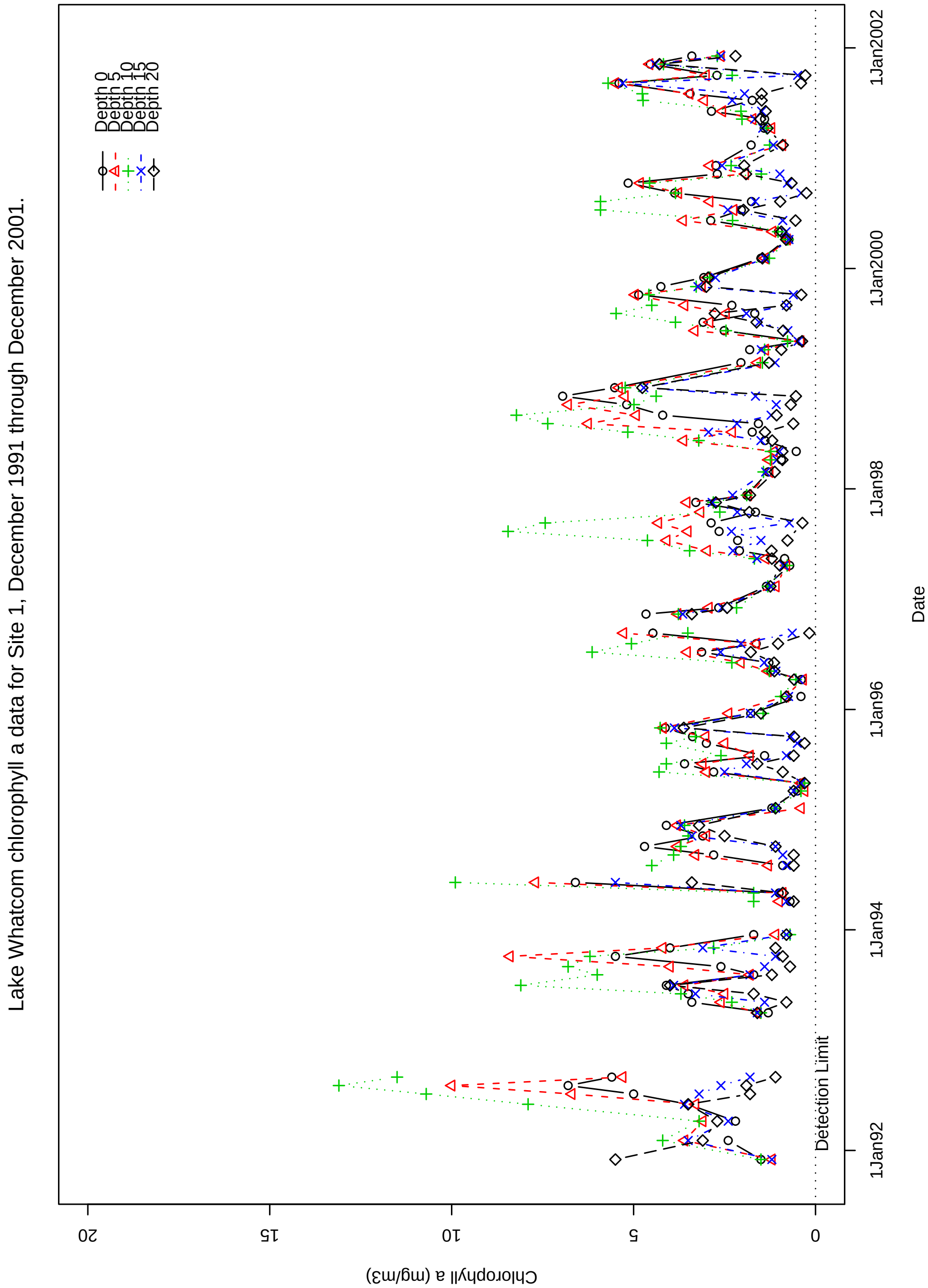

Figure 81: Lake Whatcom chlorophyll data for Site 1.

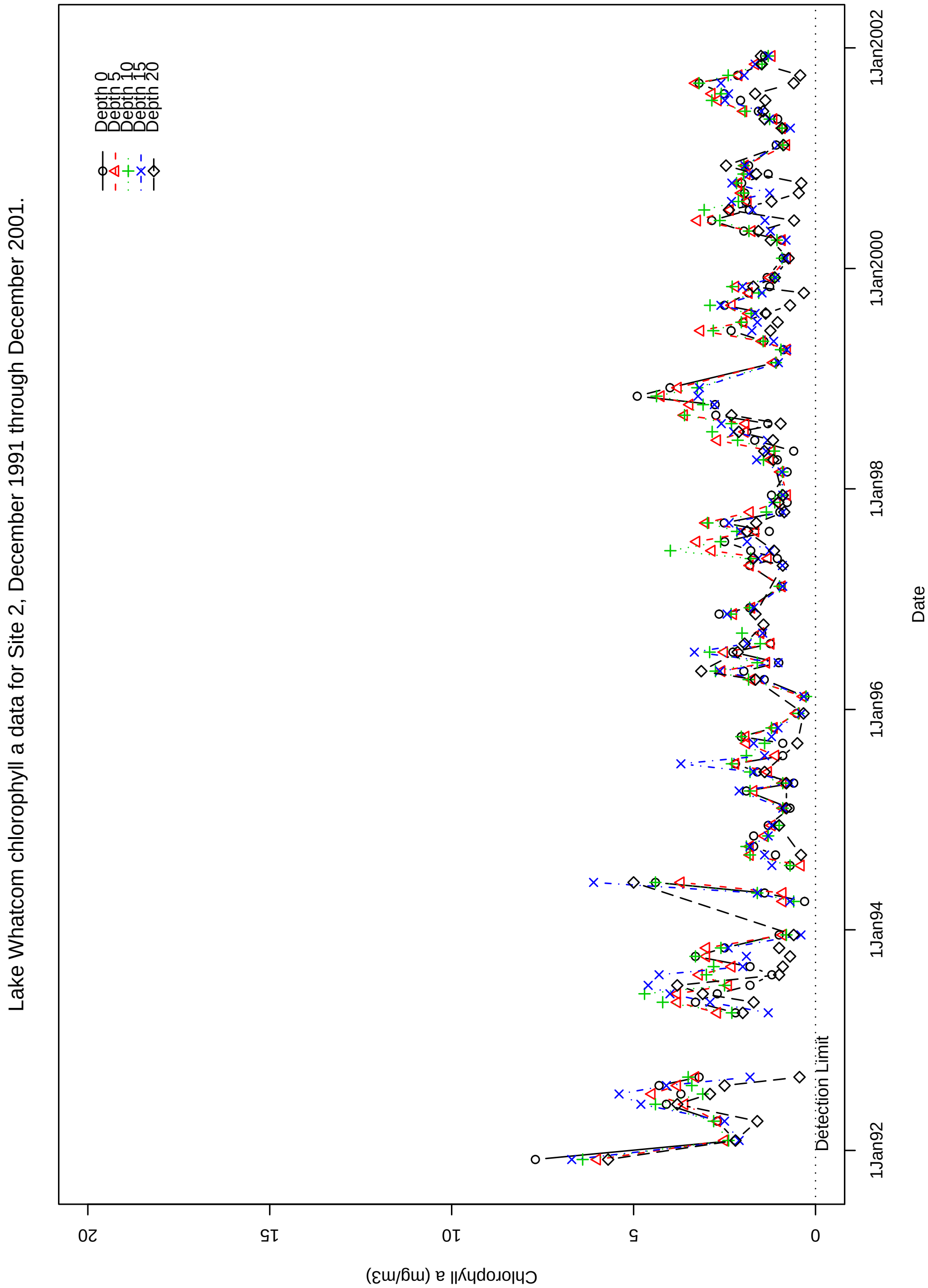

Figure 82: Lake Whatcom chlorophyll data for Site 2.

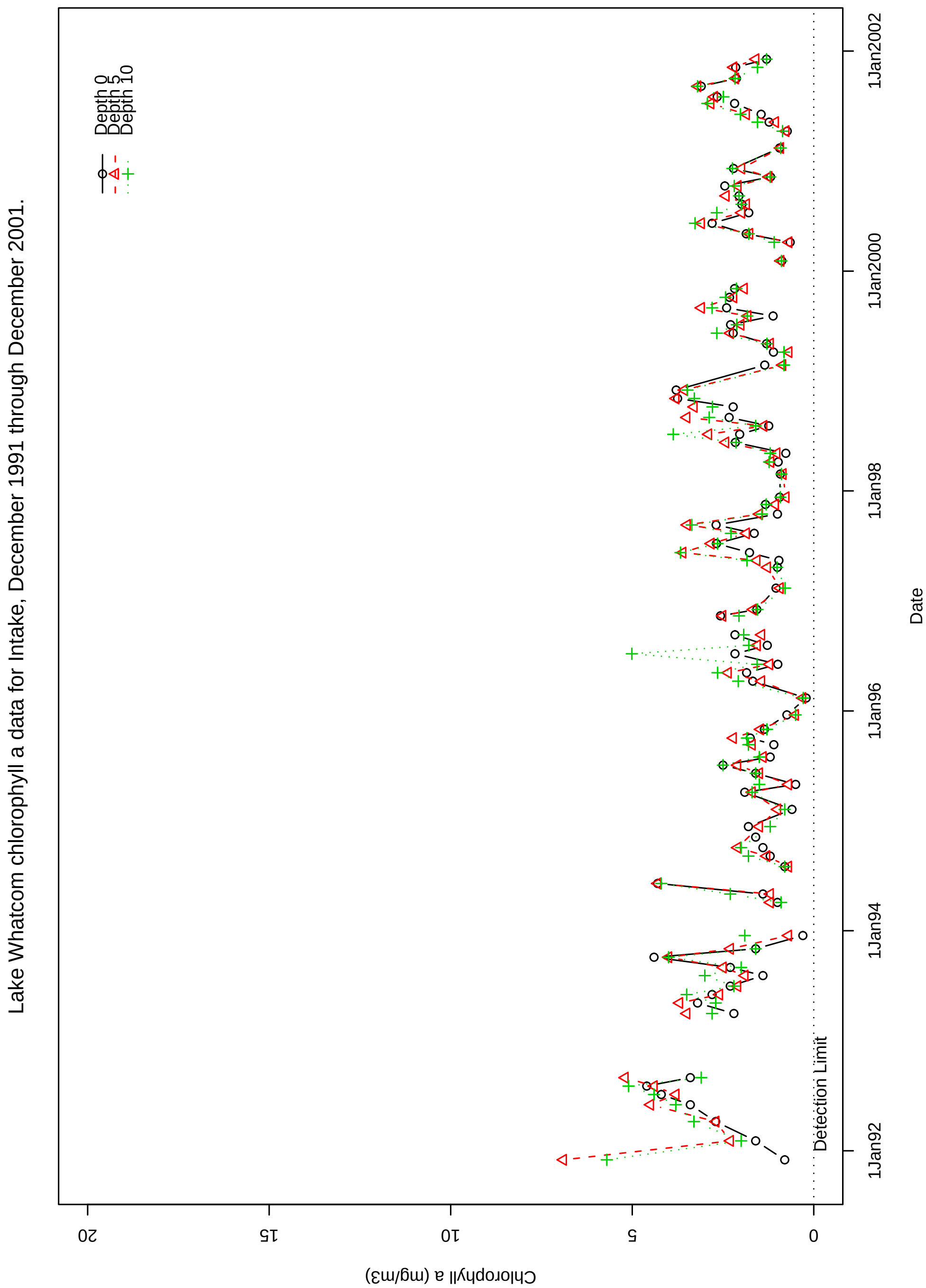

Figure 83: Lake Whatcom chlorophyll data for the Intake.

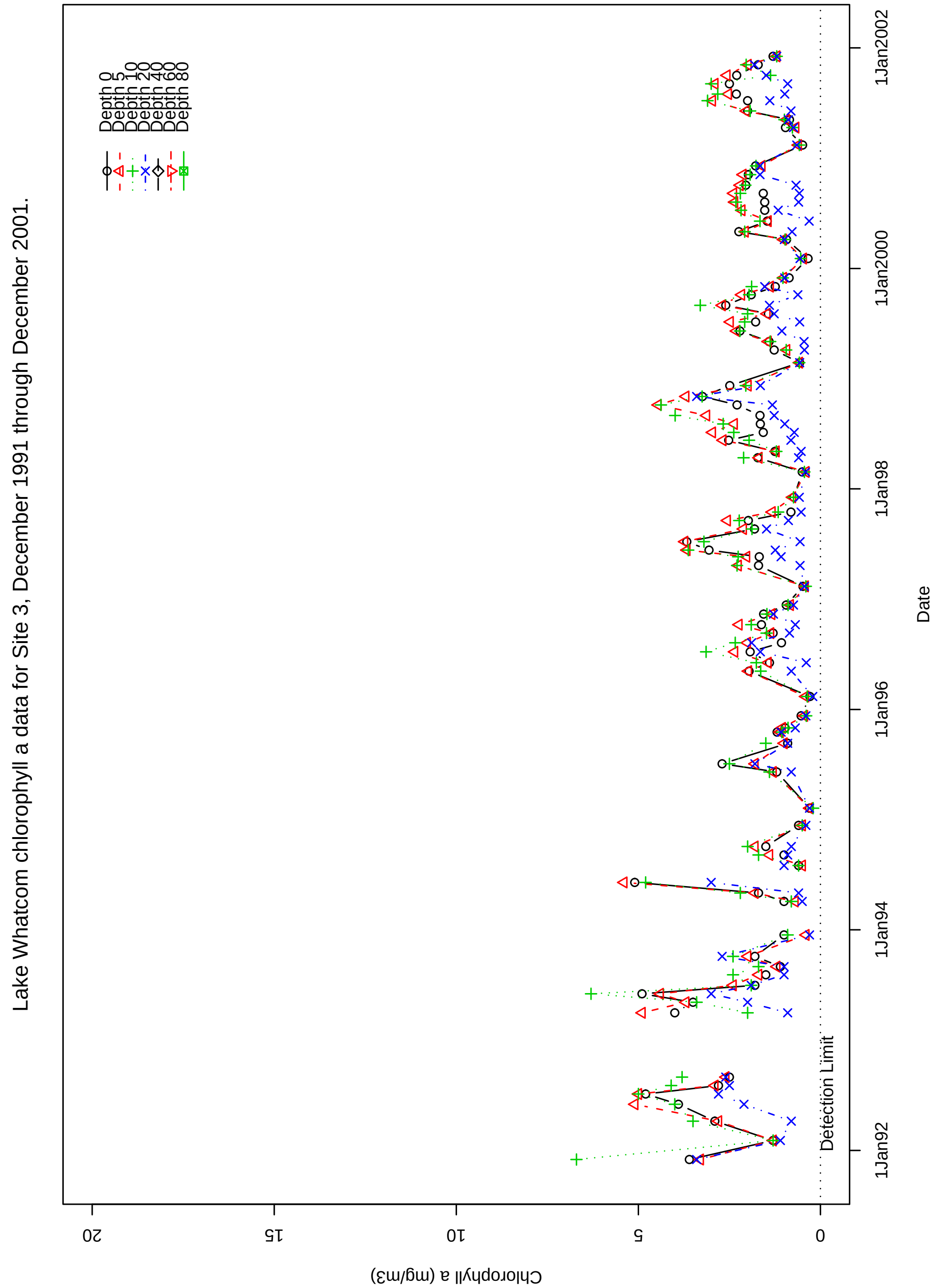

Figure 84: Lake Whatcom chlorophyll data for Site 3.

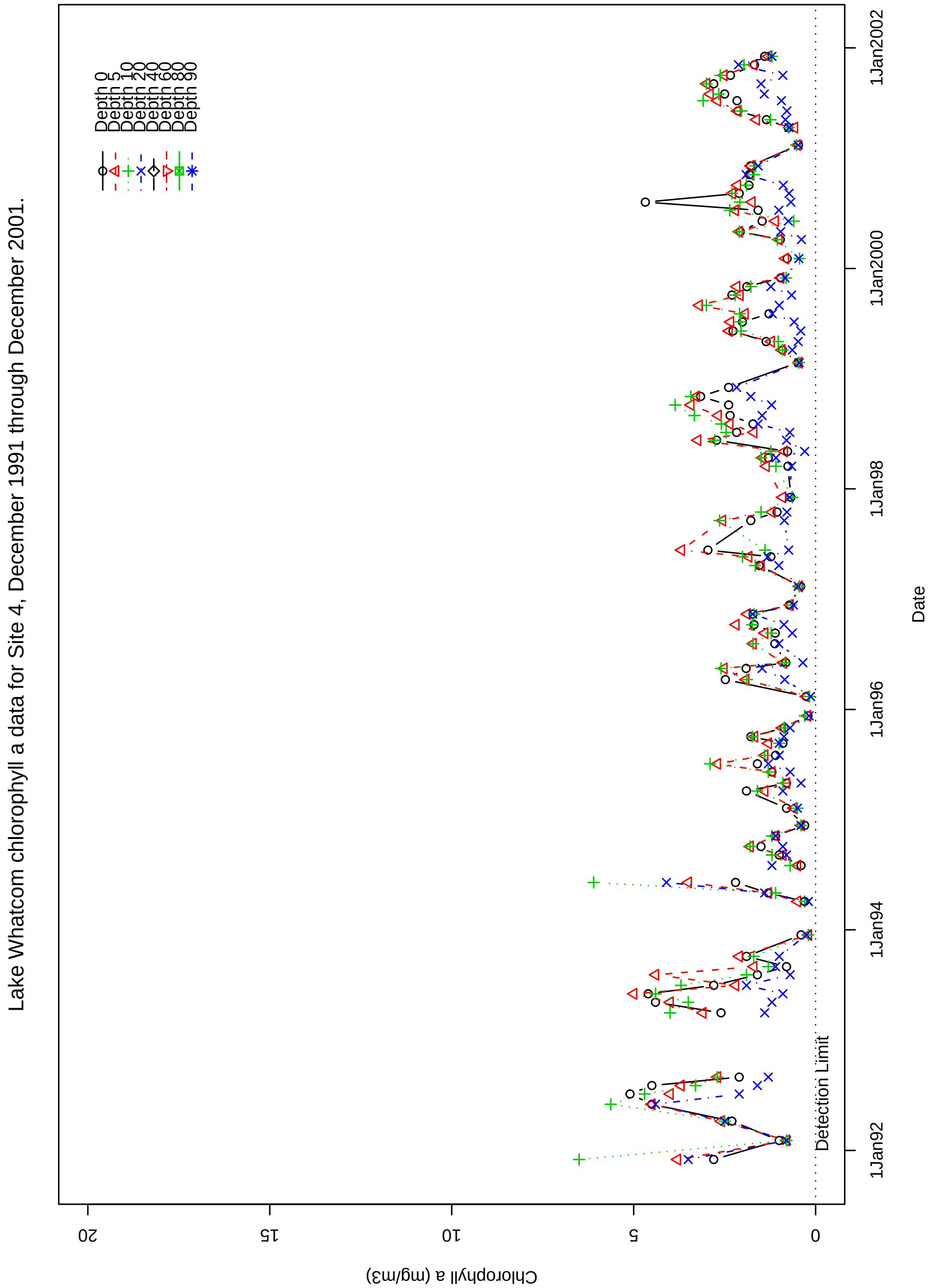

Figure 85: Lake Whatcom chlorophyll data for Site 4.

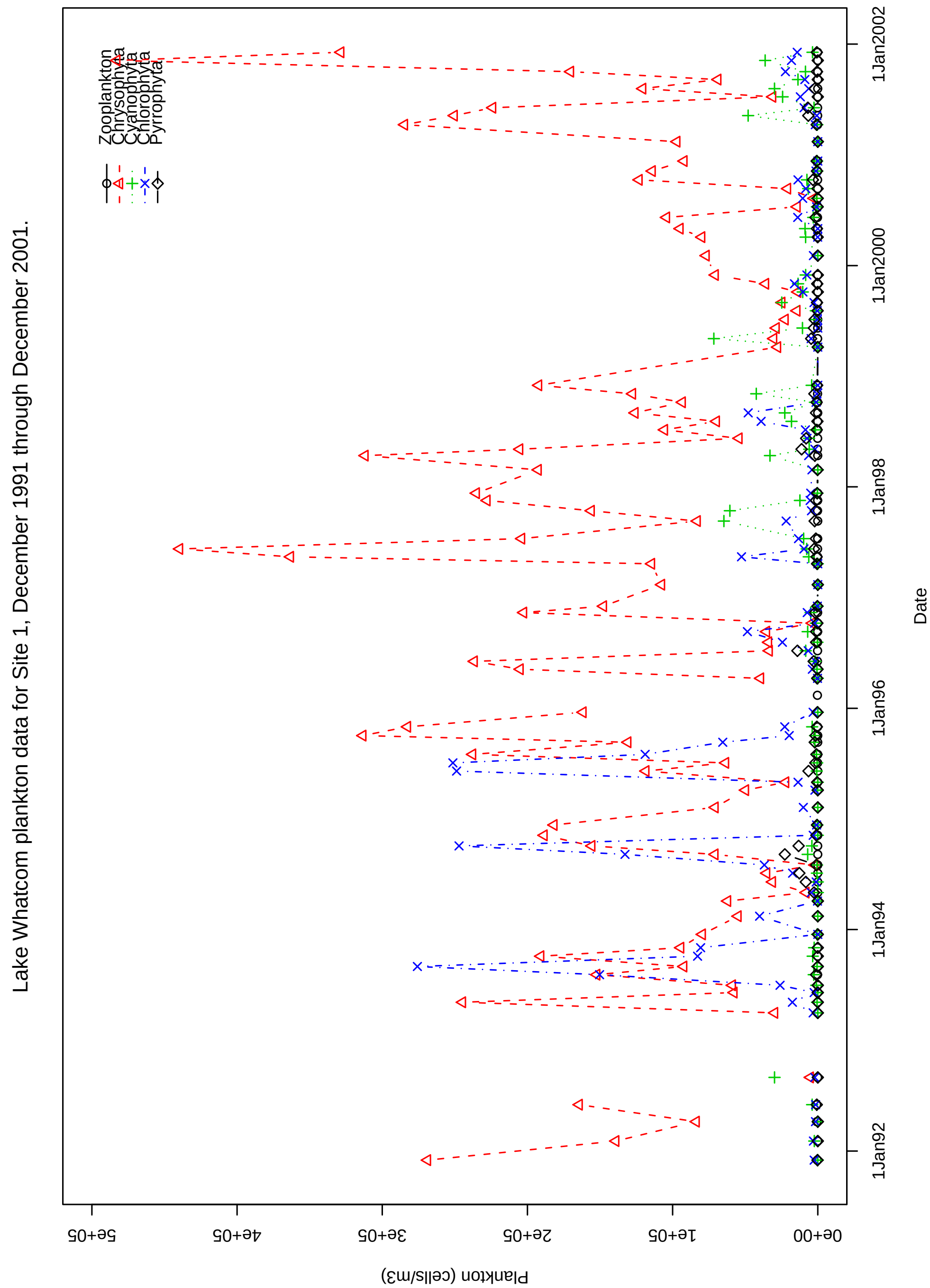

Figure 86: Lake Whatcom plankton data for Site 1.

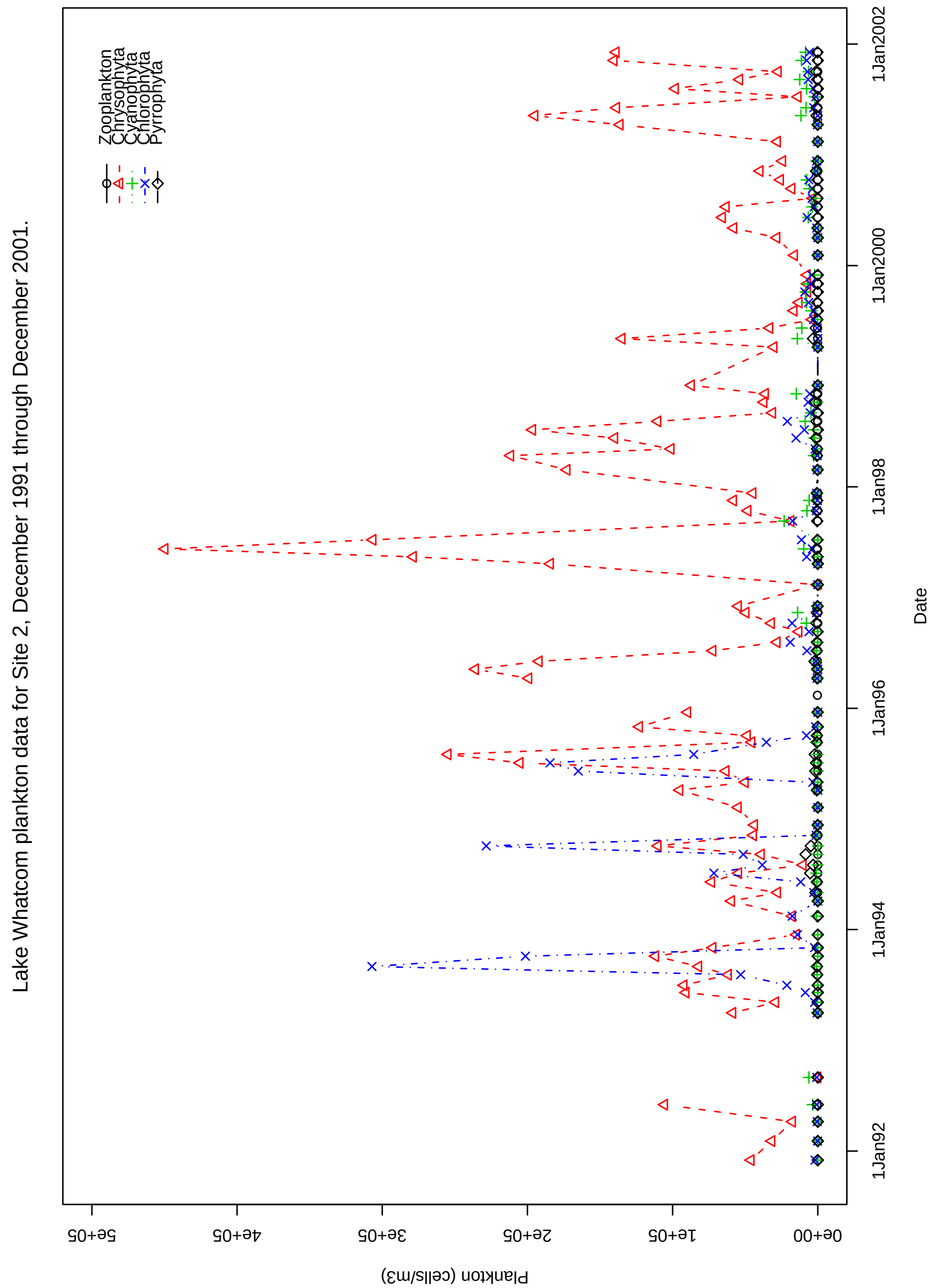

Figure 87: Lake Whatcom plankton data for Site 2.

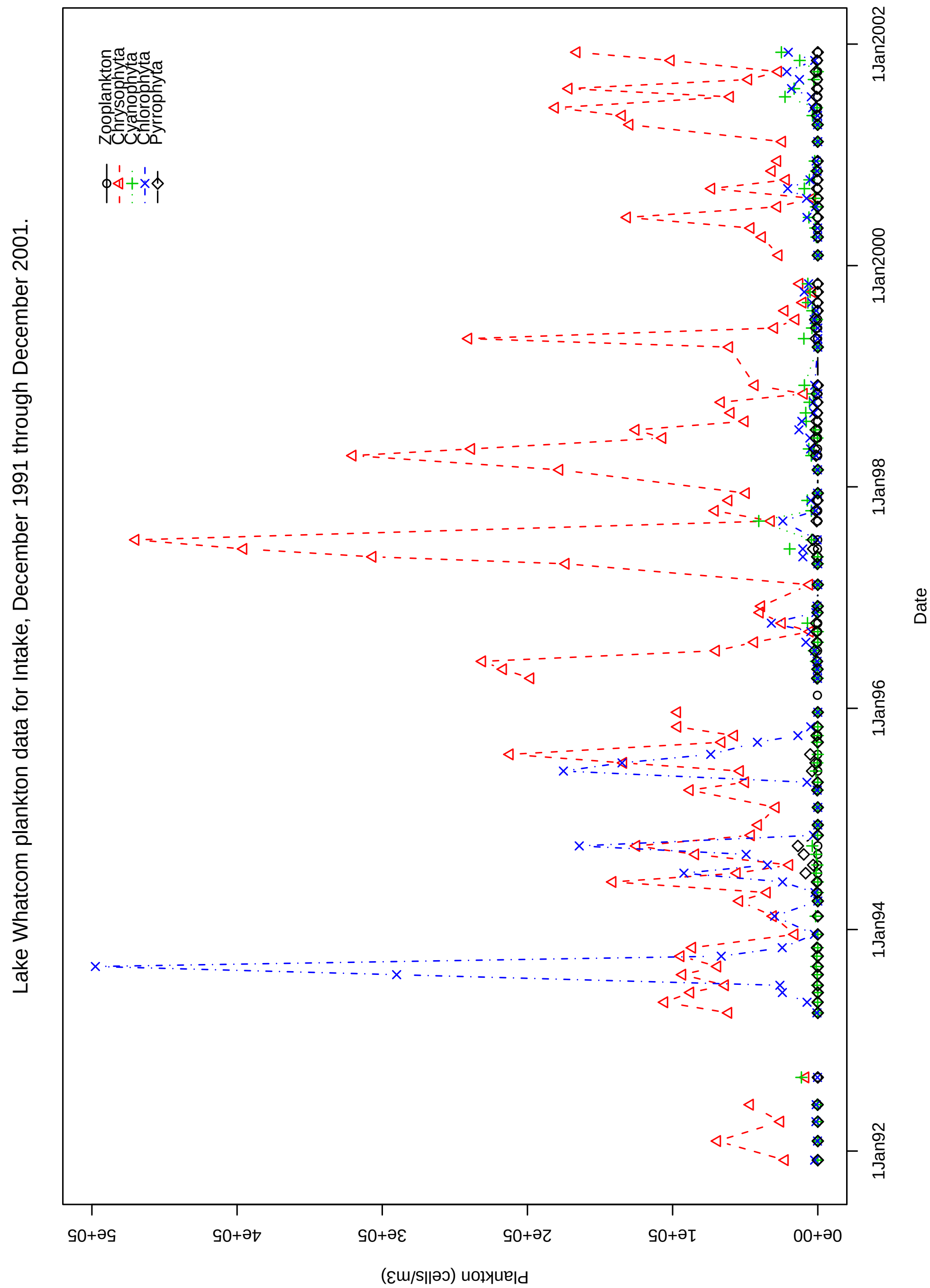

Figure 88: Lake Whatcom plankton data for the Intake.

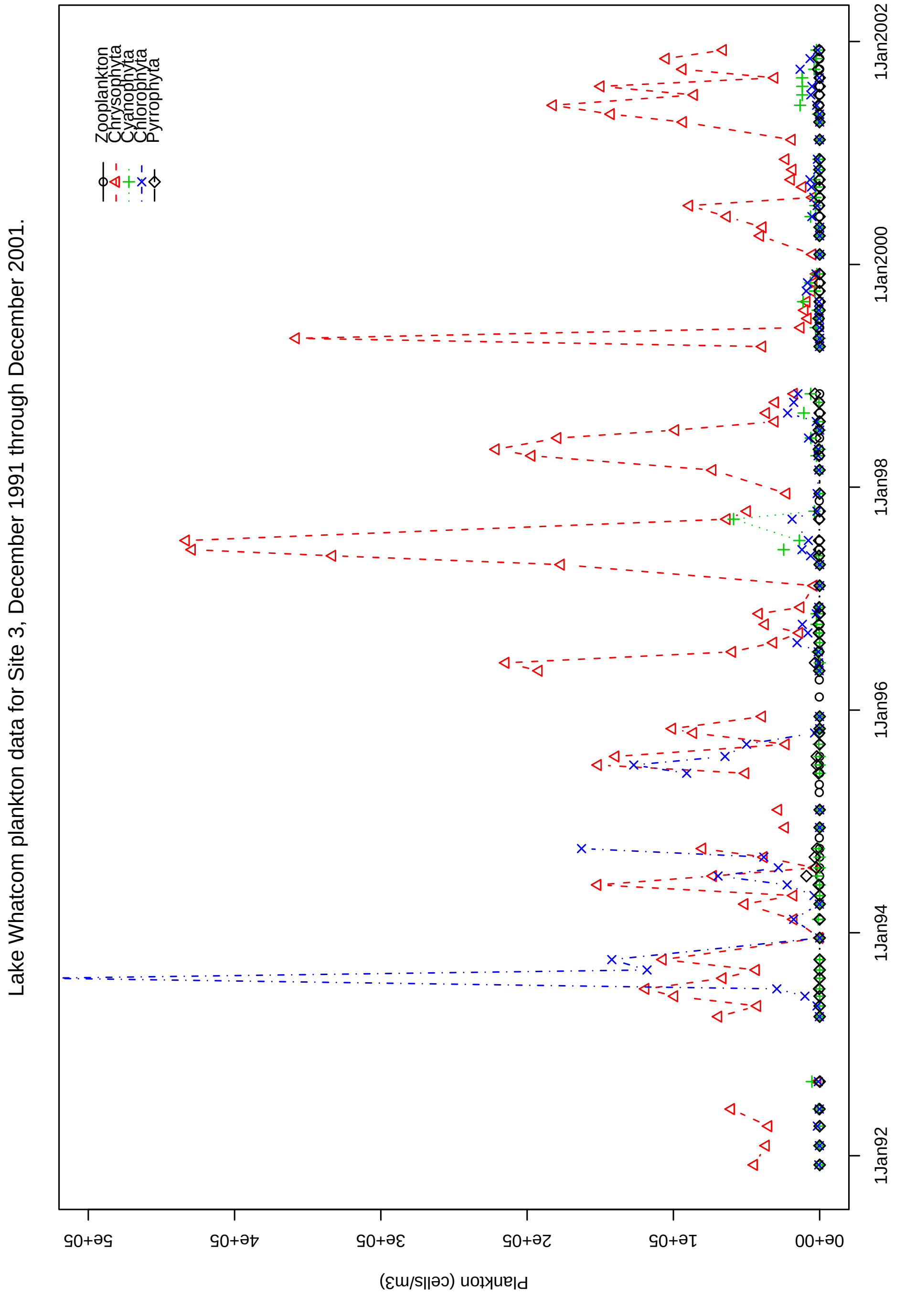

Figure 89: Lake Whatcom plankton data for Site 3.

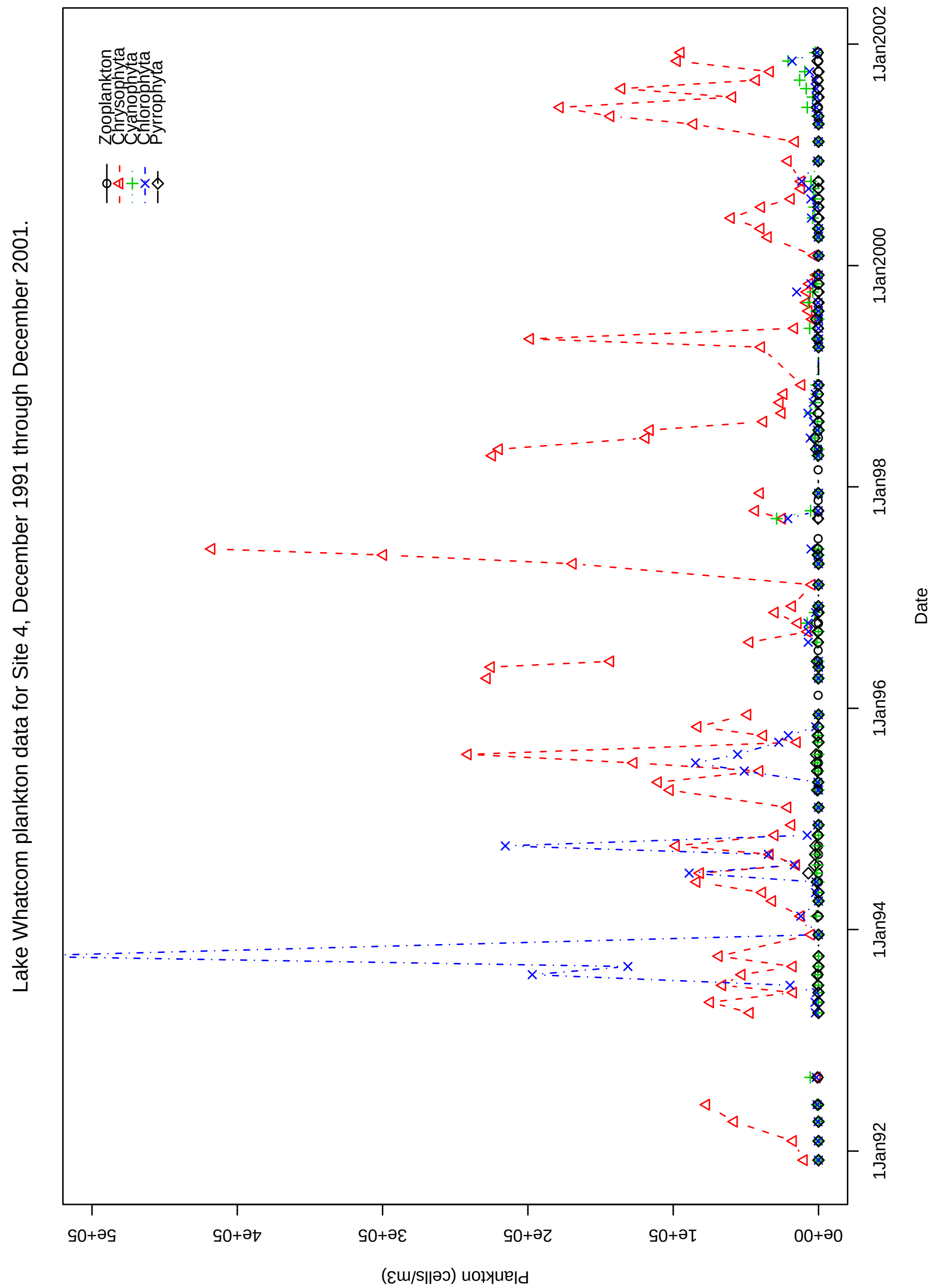

Figure 90: Lake Whatcom plankton data for Site 4.

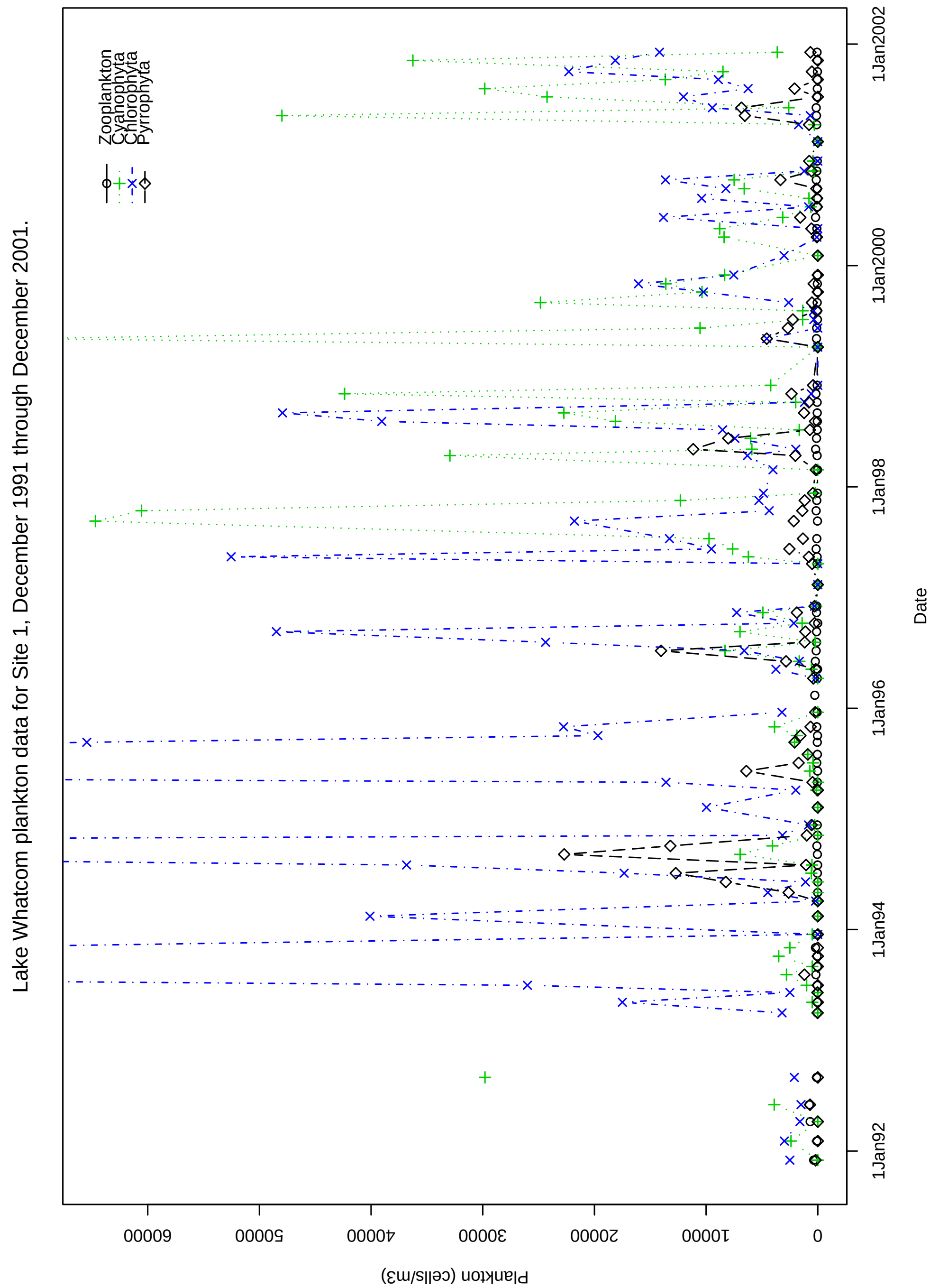

Figure 91: Lake Whatcom plankton data for Site 1, low range plot.

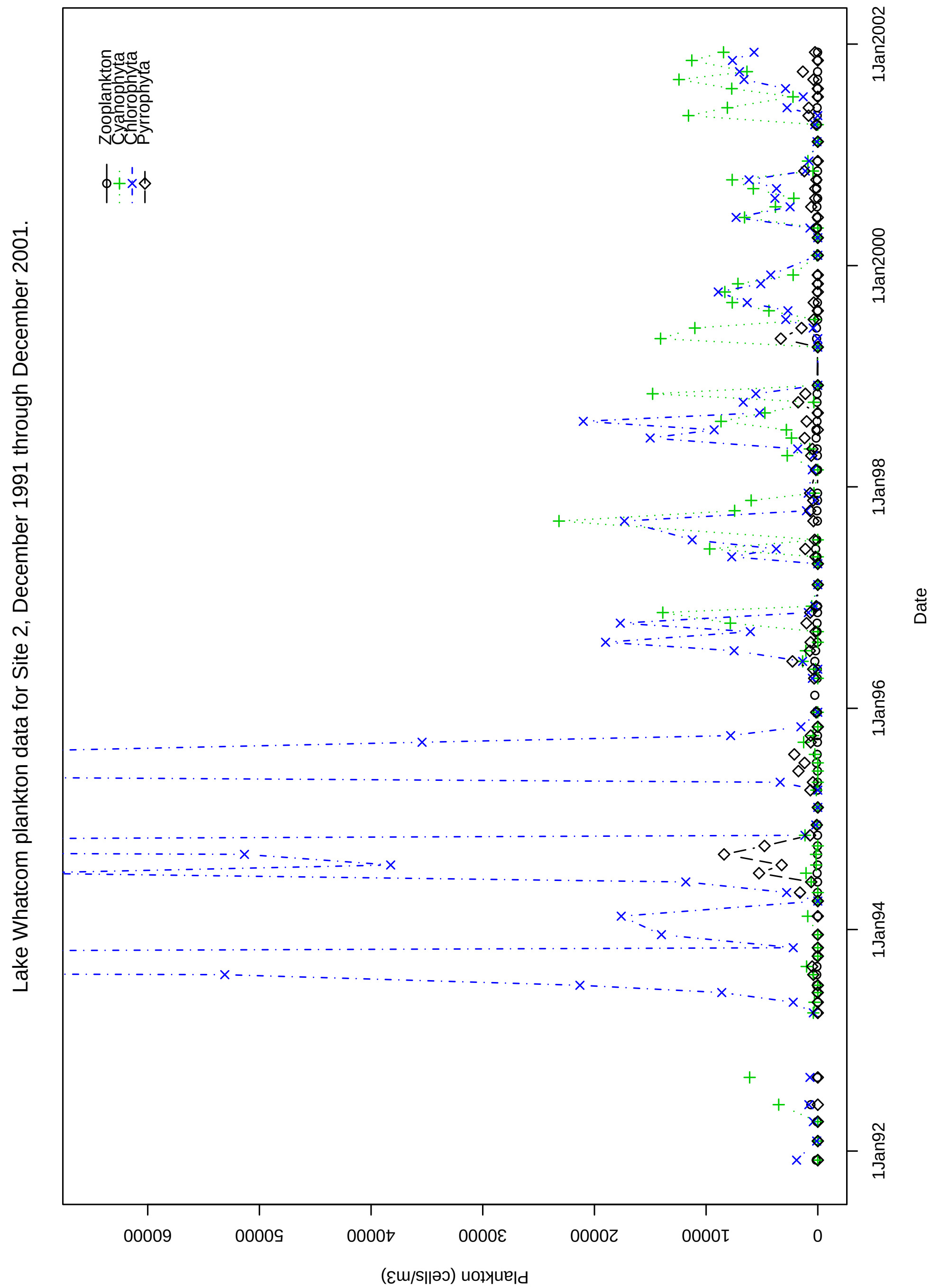

Figure 92: Lake Whatcom plankton data for Site 2, low range plot.

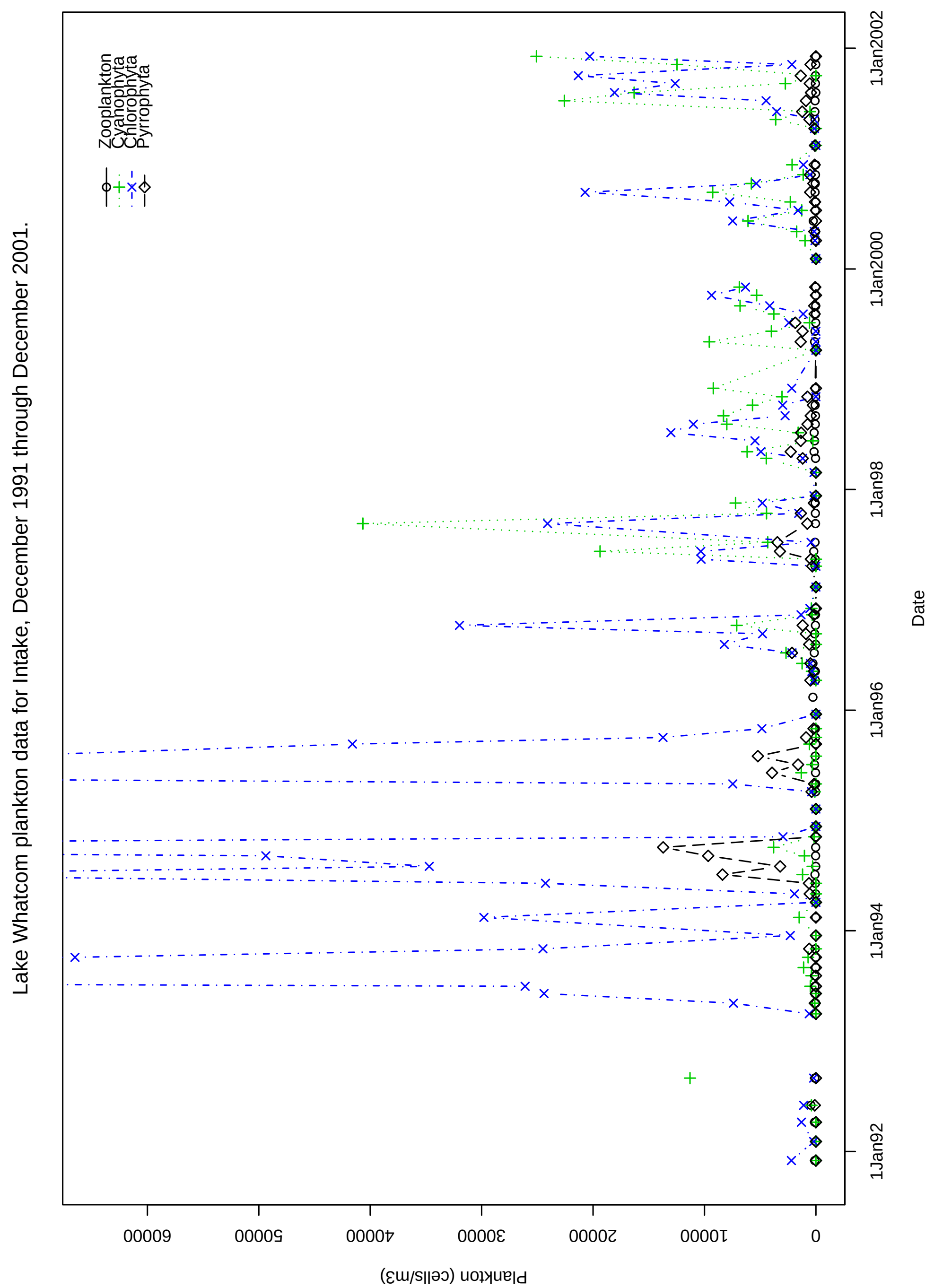

Figure 93: Lake Whatcom plankton data for the Intake, low range plot.

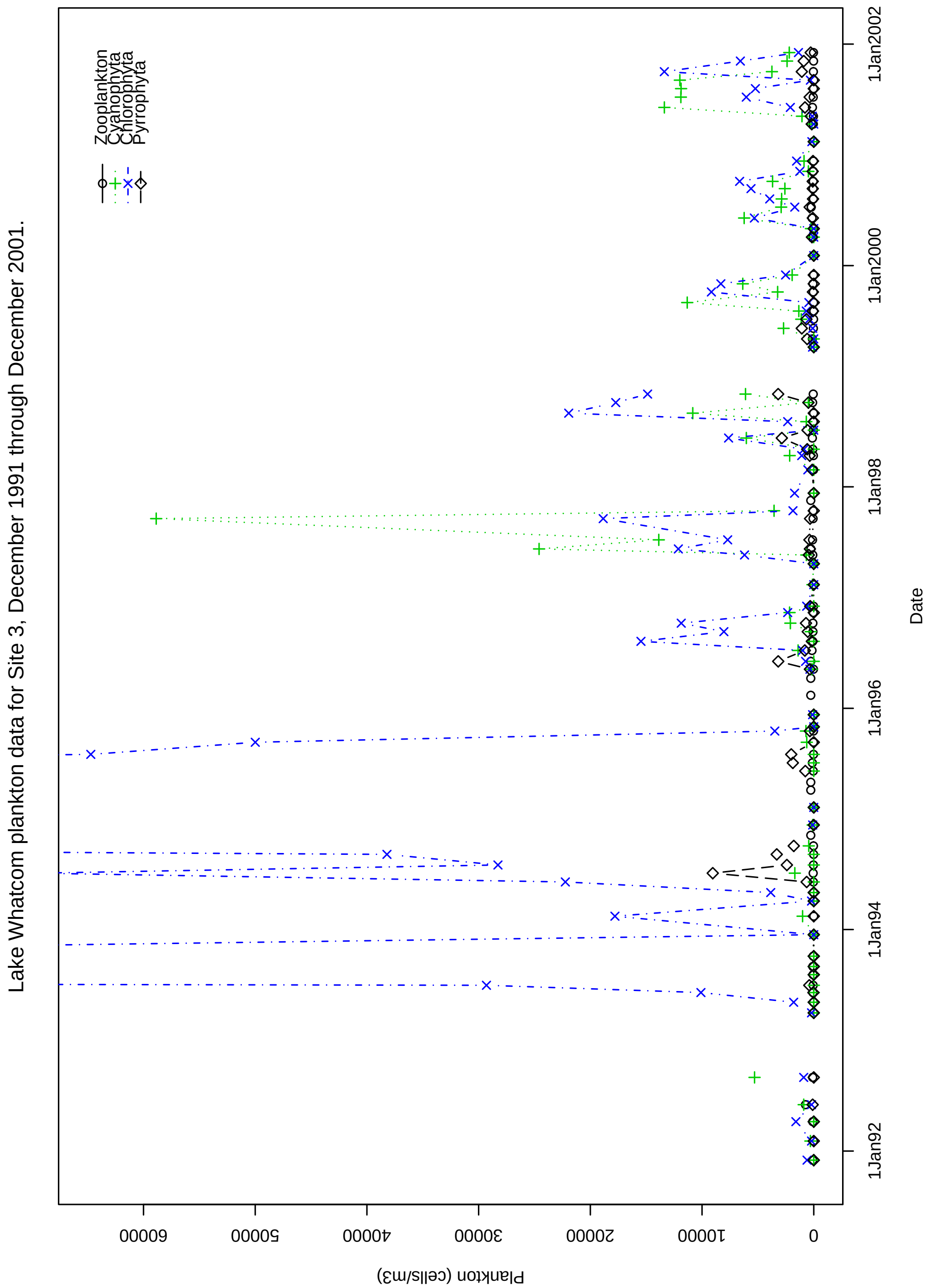

Figure 94: Lake Whatcom plankton data for Site 3, low range plot.

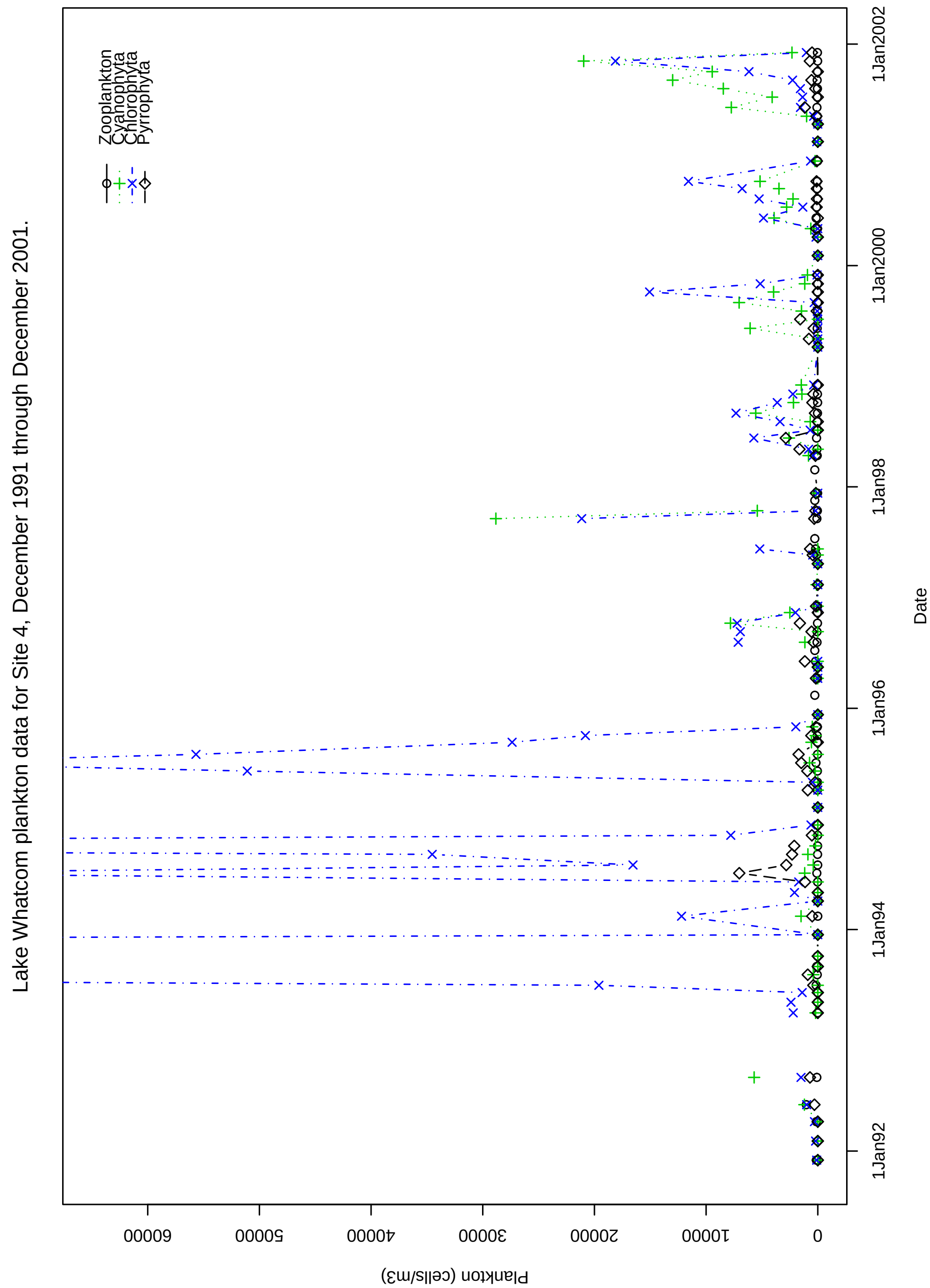

Figure 95: Lake Whatcom plankton data for Site 4, low range plot.

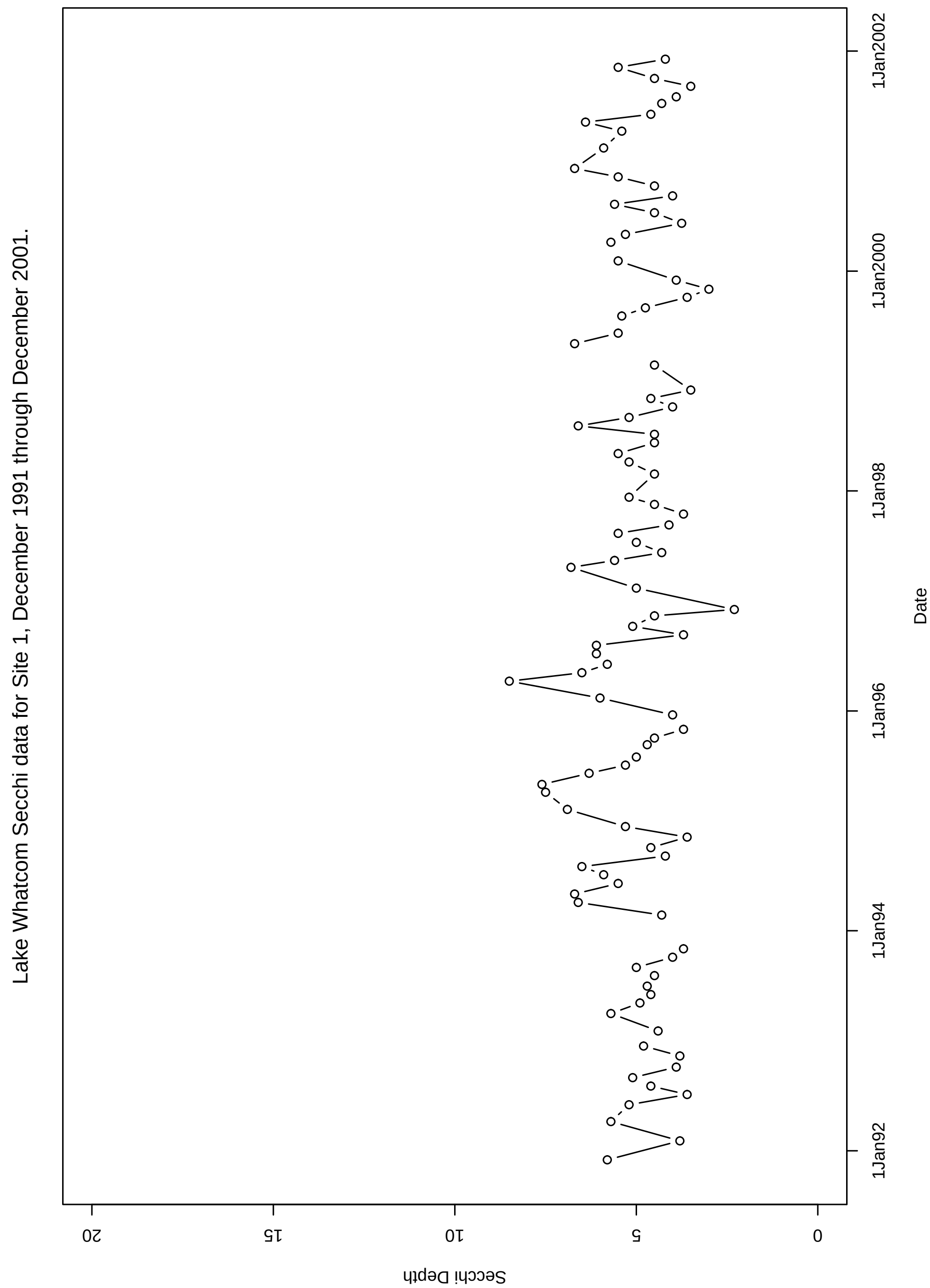

Figure 96: Lake Whatcom Secchi depths for Site 1.

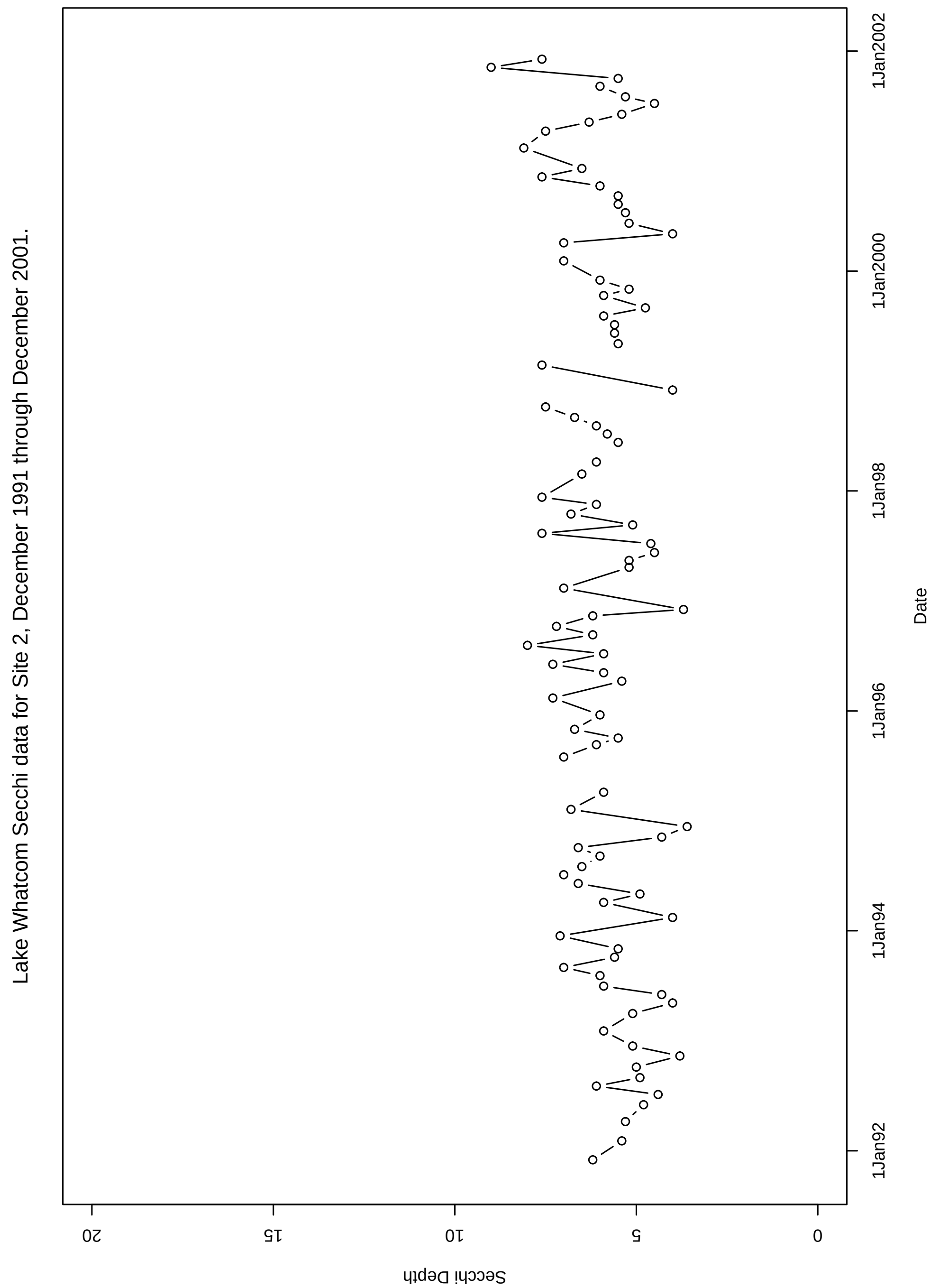

Figure 97: Lake Whatcom Secchi depths for Site 2.

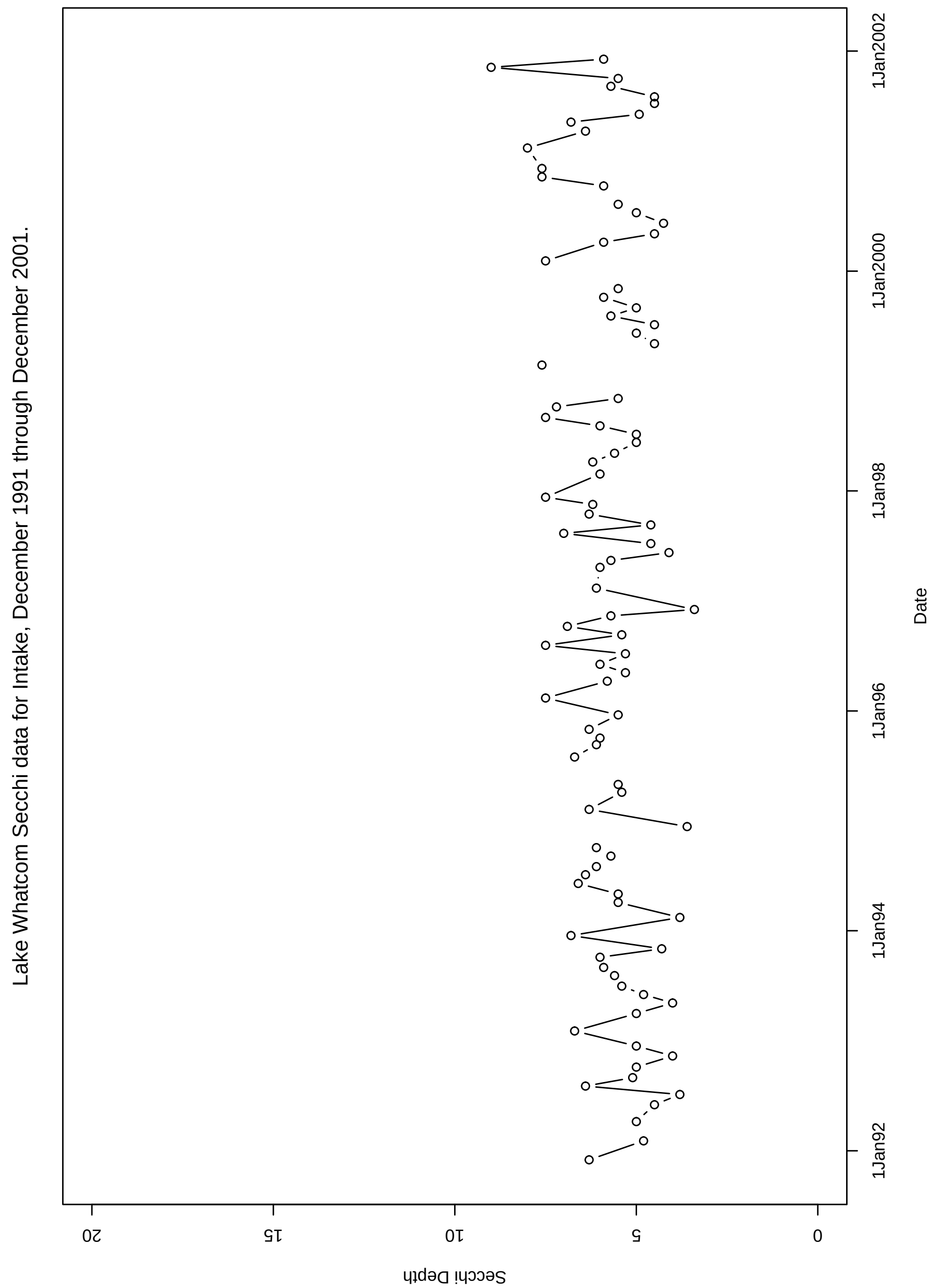

Figure 98: Lake Whatcom Secchi depths for the Intake.

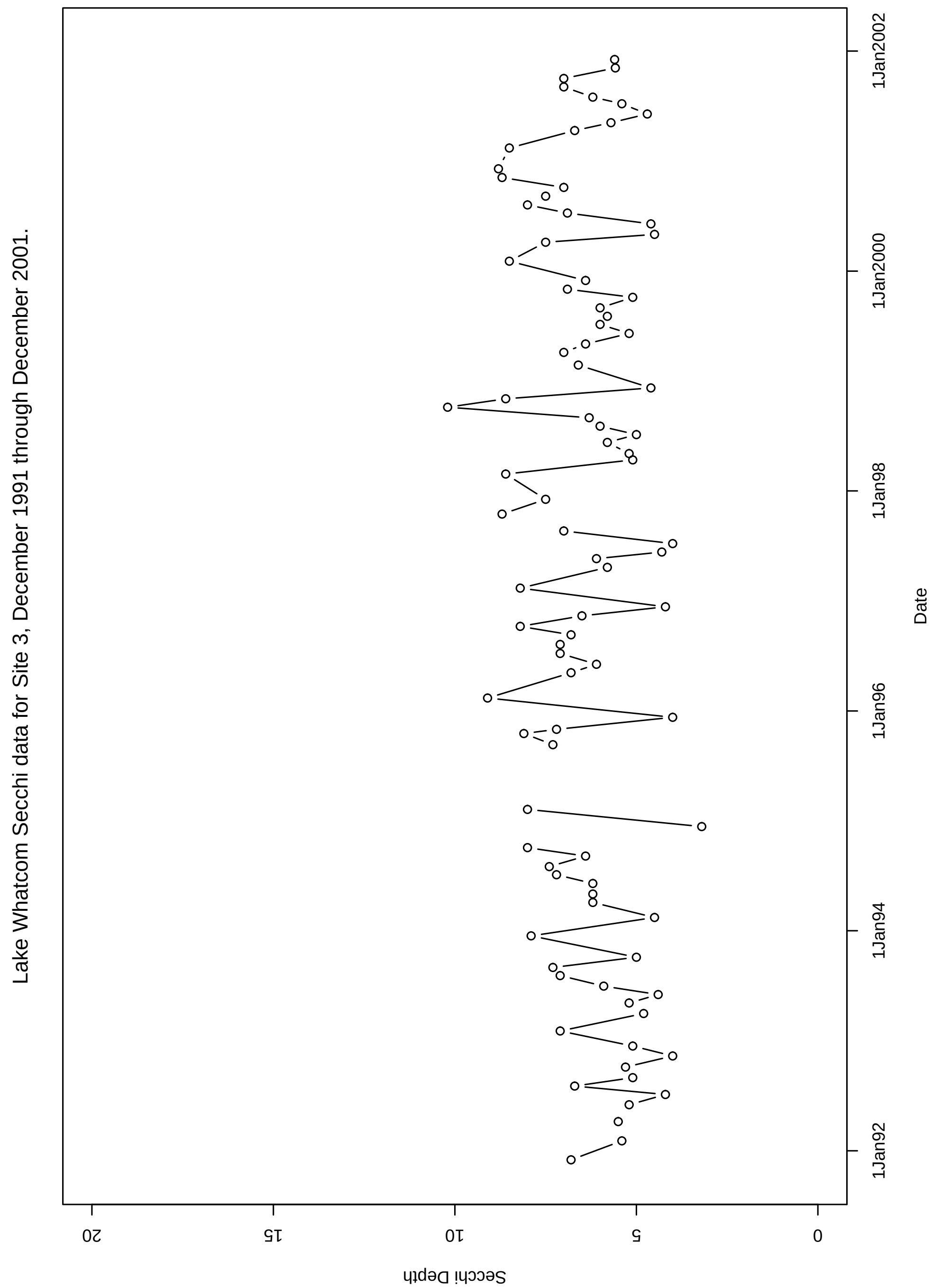

Figure 99: Lake Whatcom Secchi depths for Site 3.

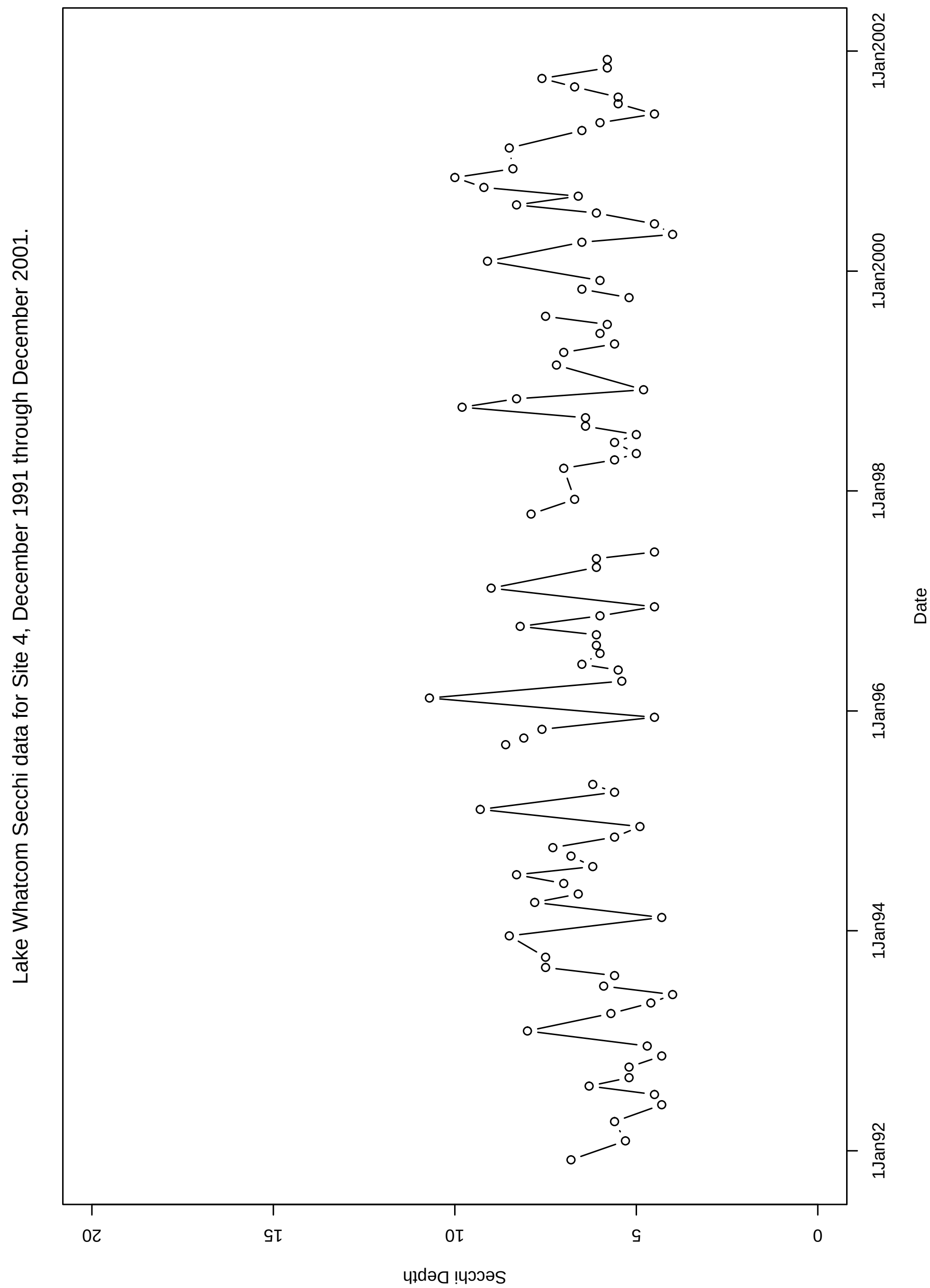

Figure 100: Lake Whatcom Secchi depths for Site 4.

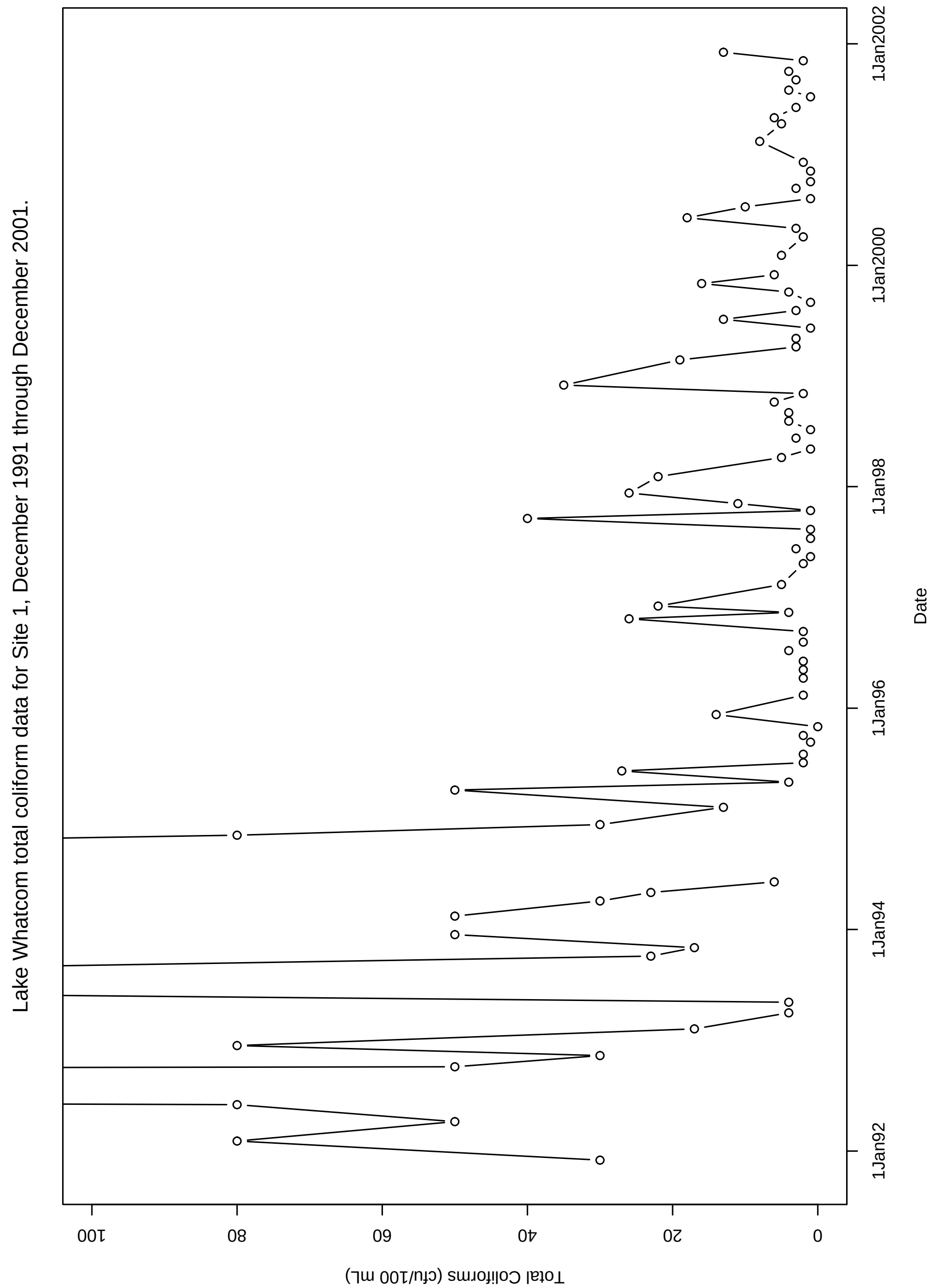

Figure 101: Lake Whatcom total coliform data for Site 1.

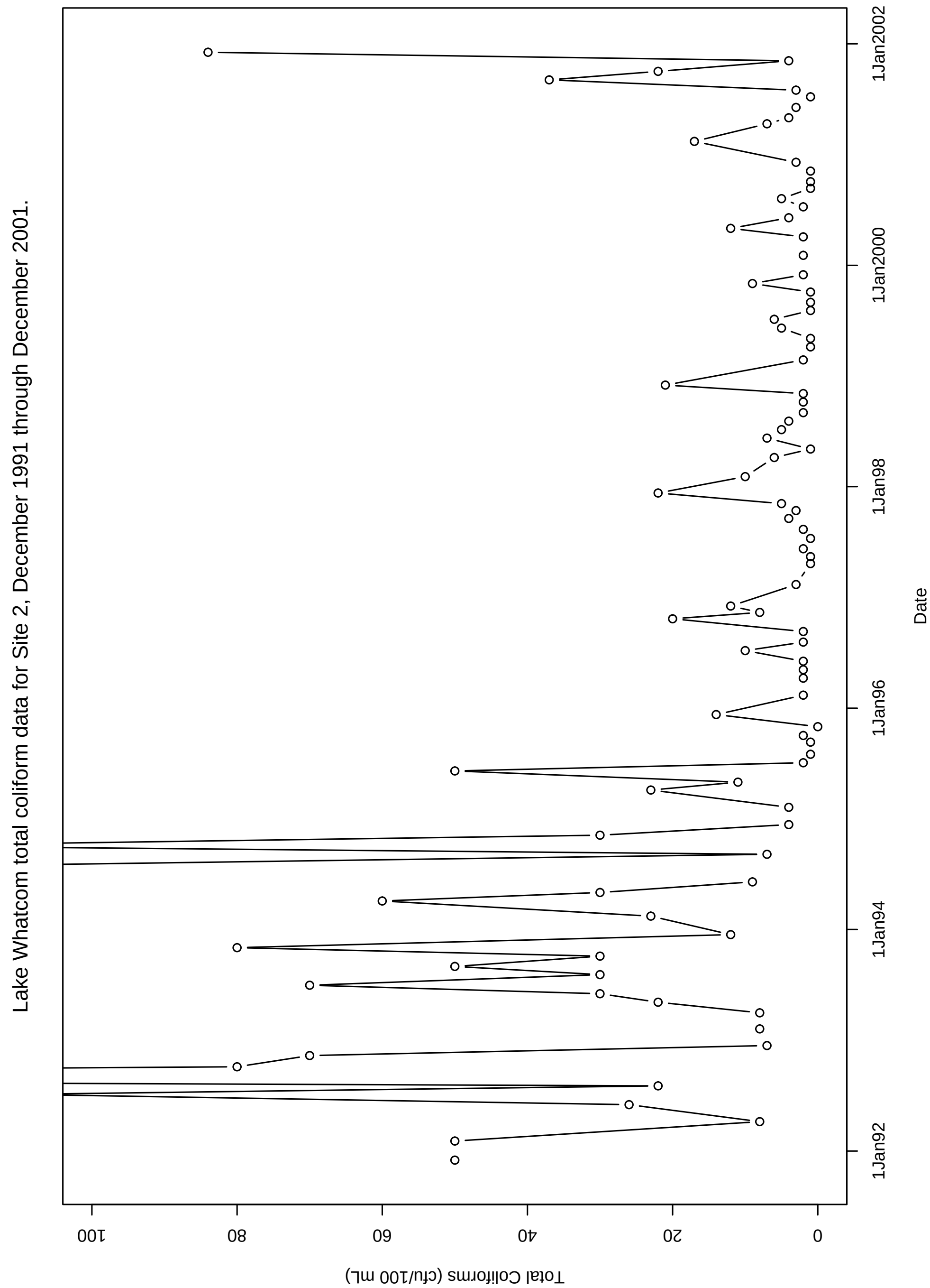

Figure 102: Lake Whatcom total coliform data for Site 2.

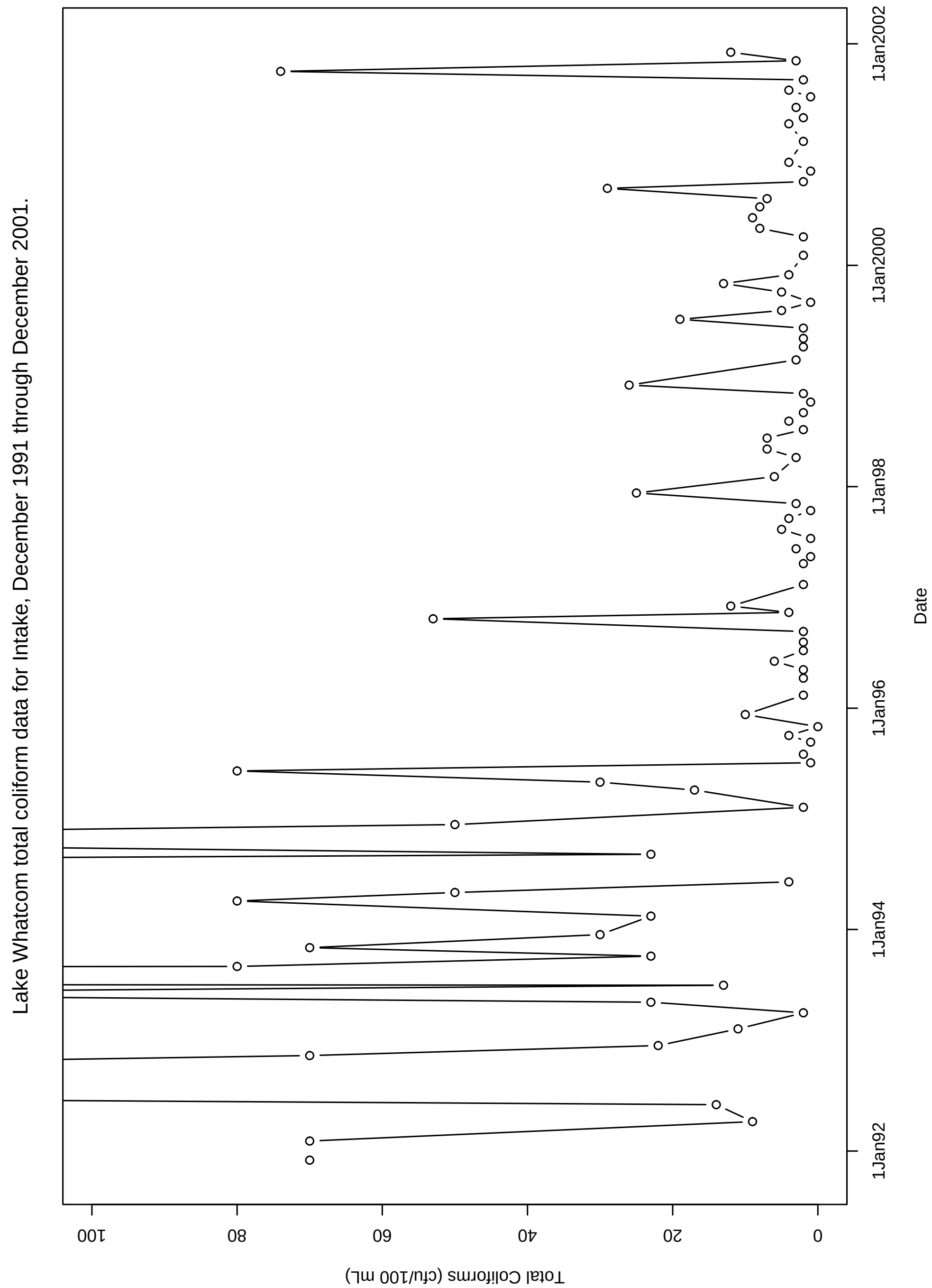

Figure 103: Lake Whatcom total coliform data for the Intake.

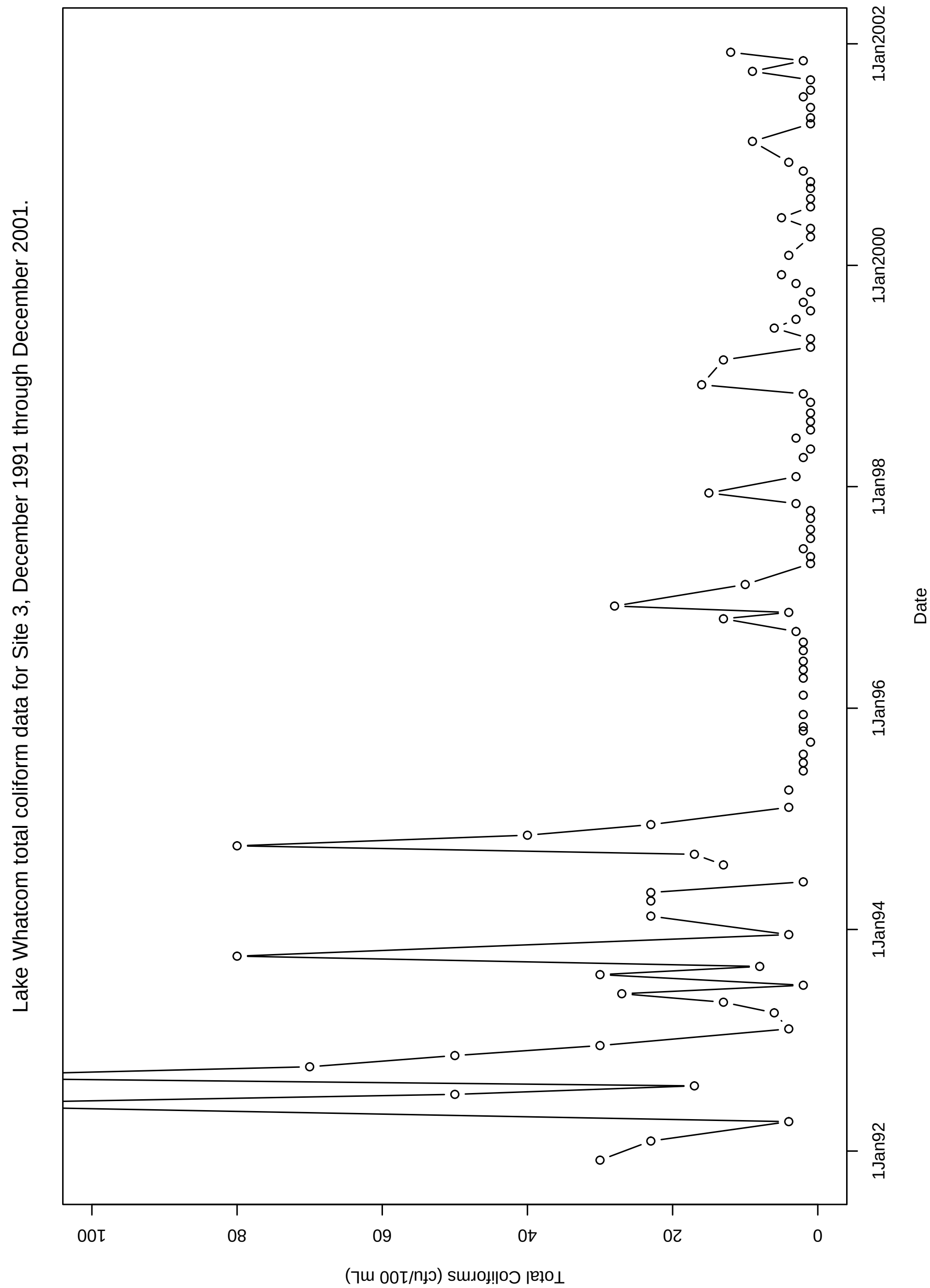

Figure 104: Lake Whatcom total coliform data for Site 3.

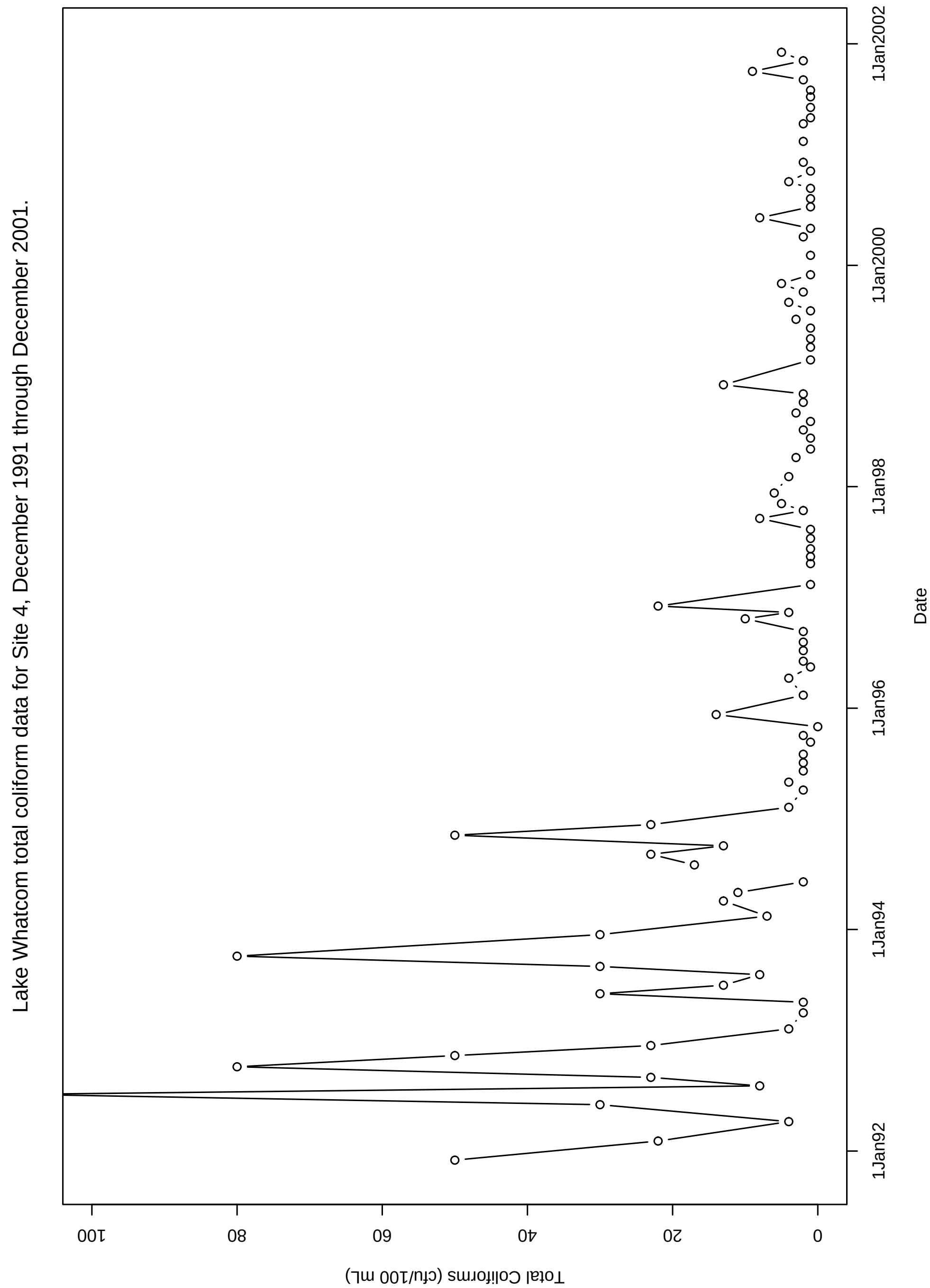

Figure 105: Lake Whatcom total coliform data for Site 4.

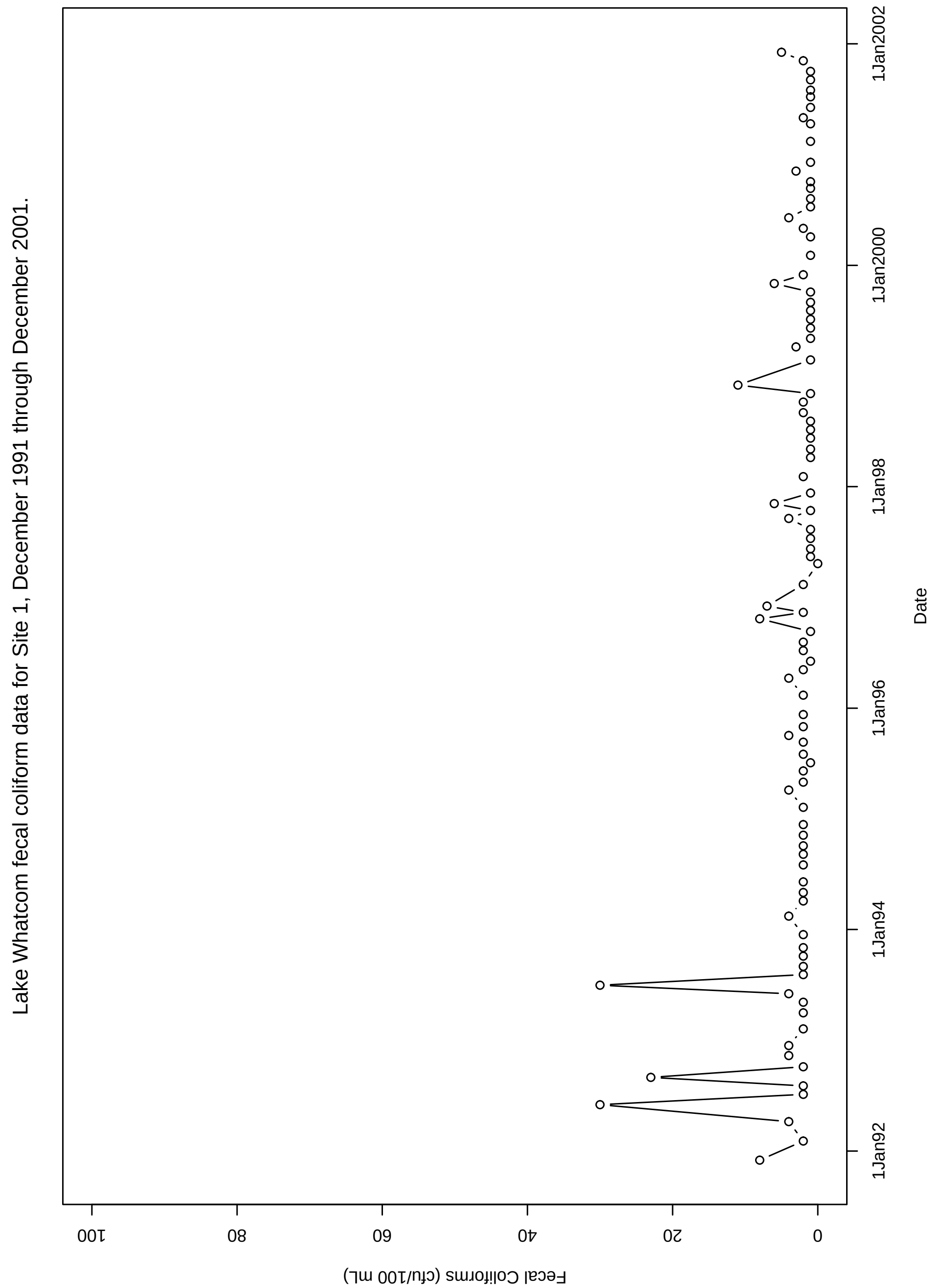

Figure 106: Lake Whatcom fecal coliform data for Site 1.

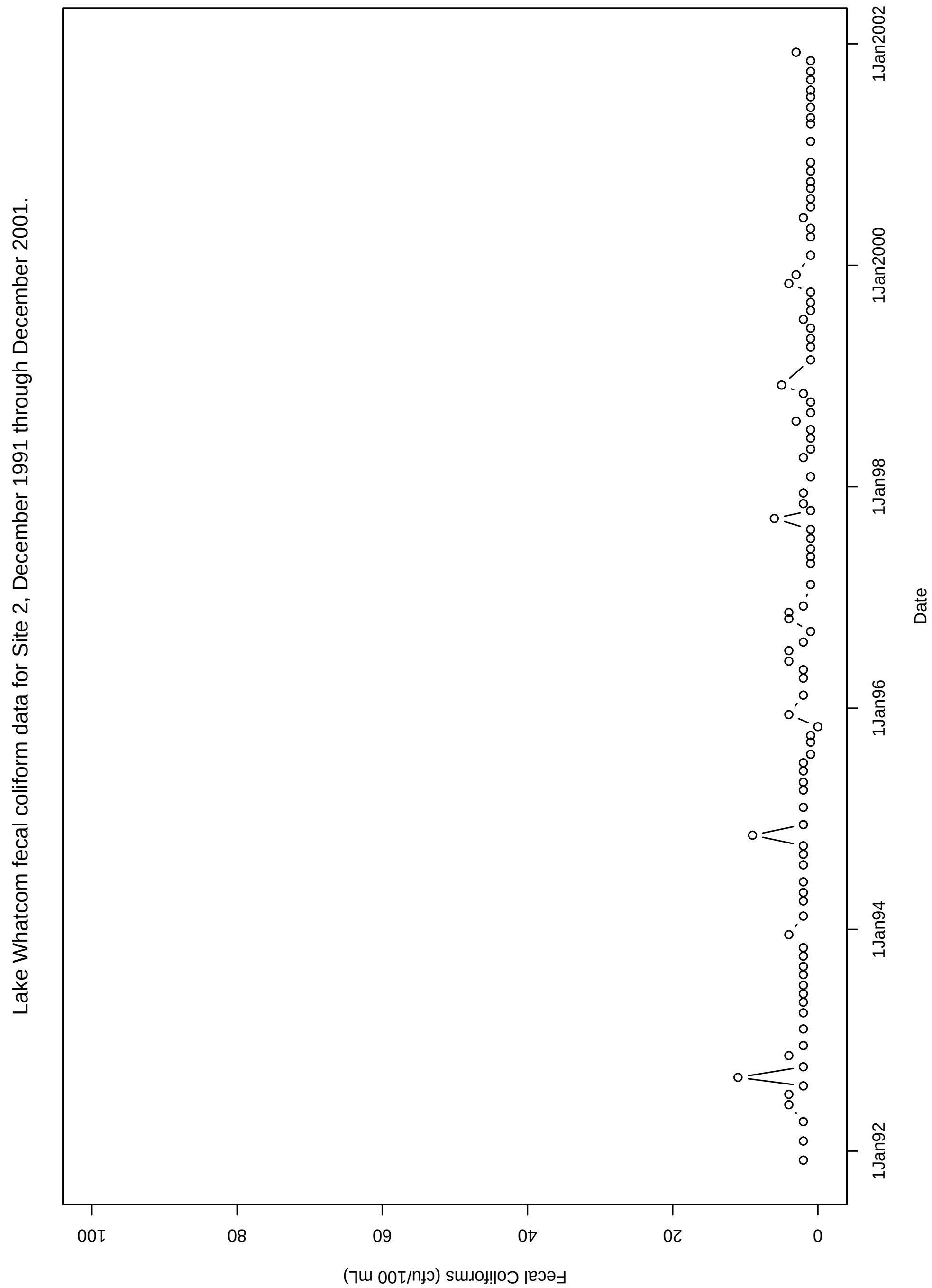

Figure 107: Lake Whatcom fecal coliform data for Site 2.

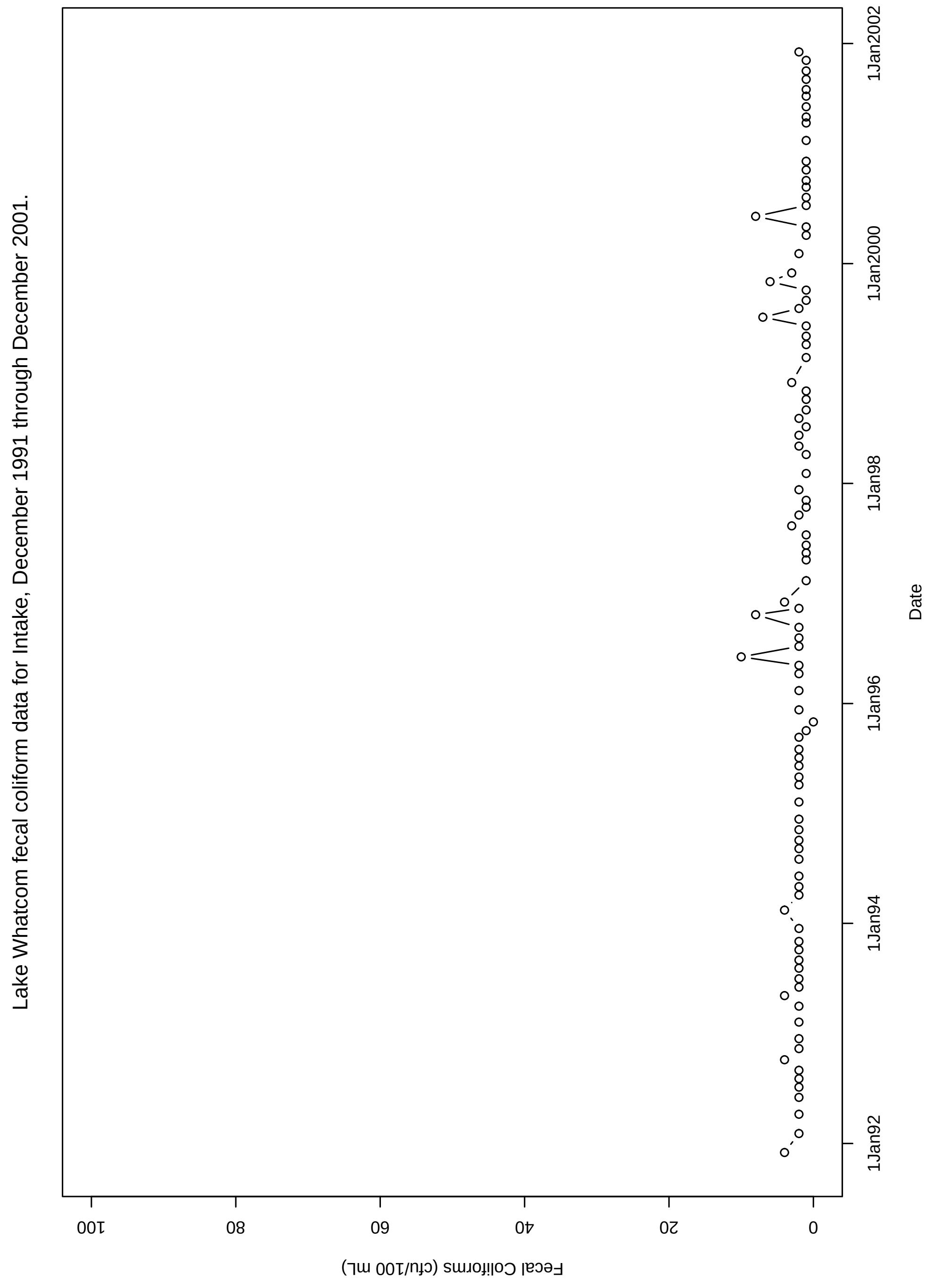

Figure 108: Lake Whatcom fecal coliform data for the Intake.

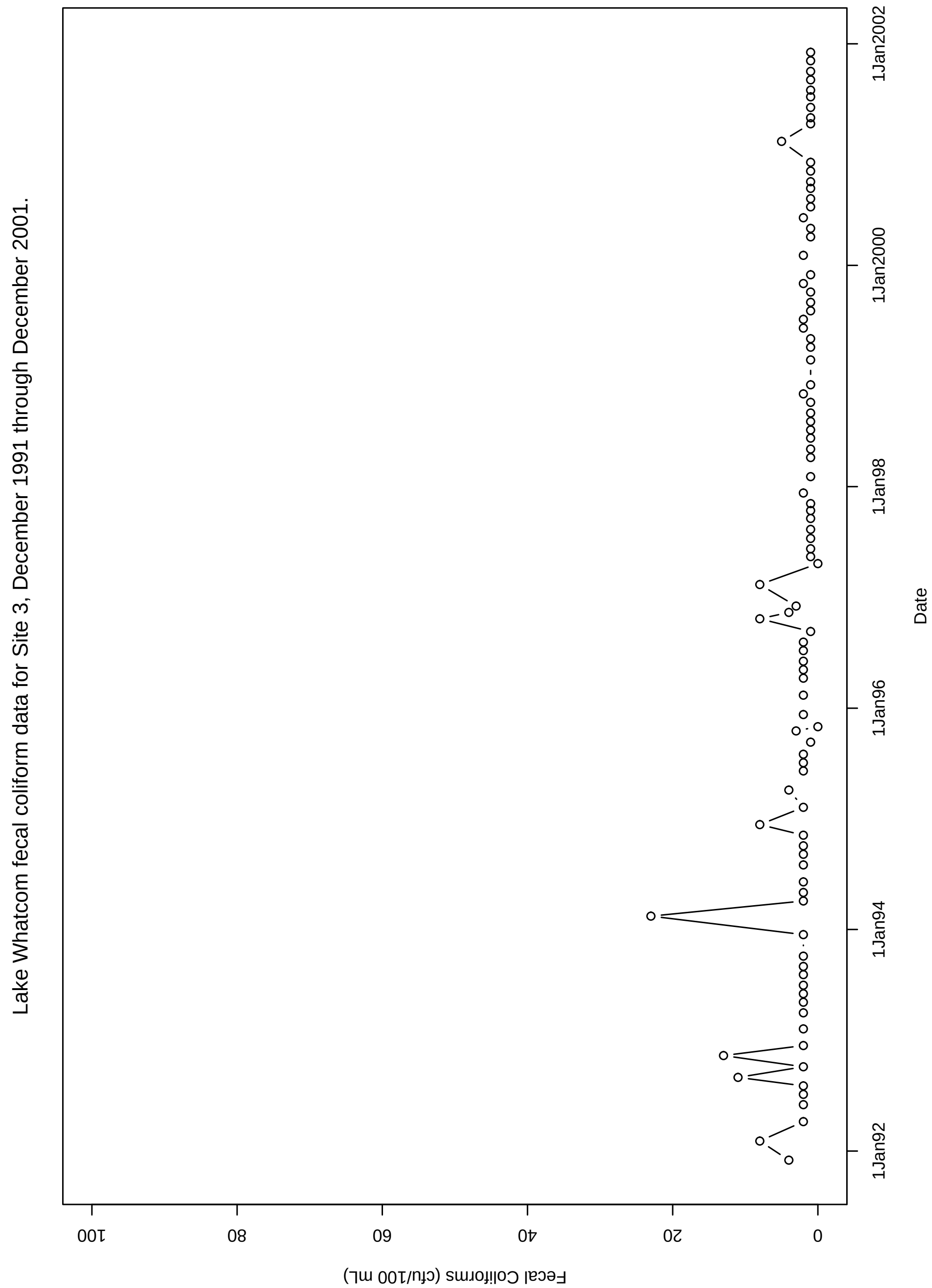

Figure 109: Lake Whatcom fecal coliform data for Site 3.

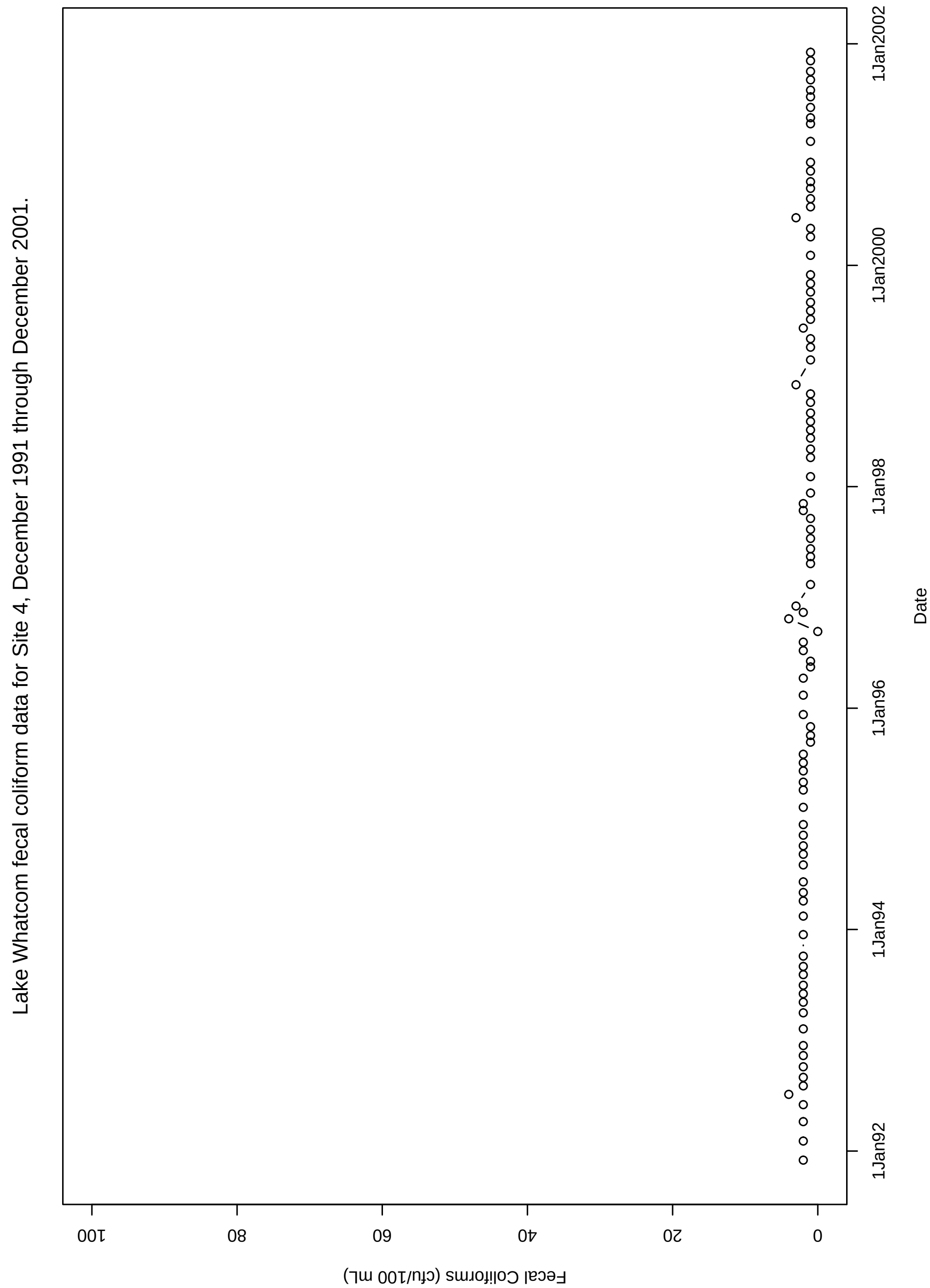

Figure 110: Lake Whatcom fecal coliform data for Site 4.

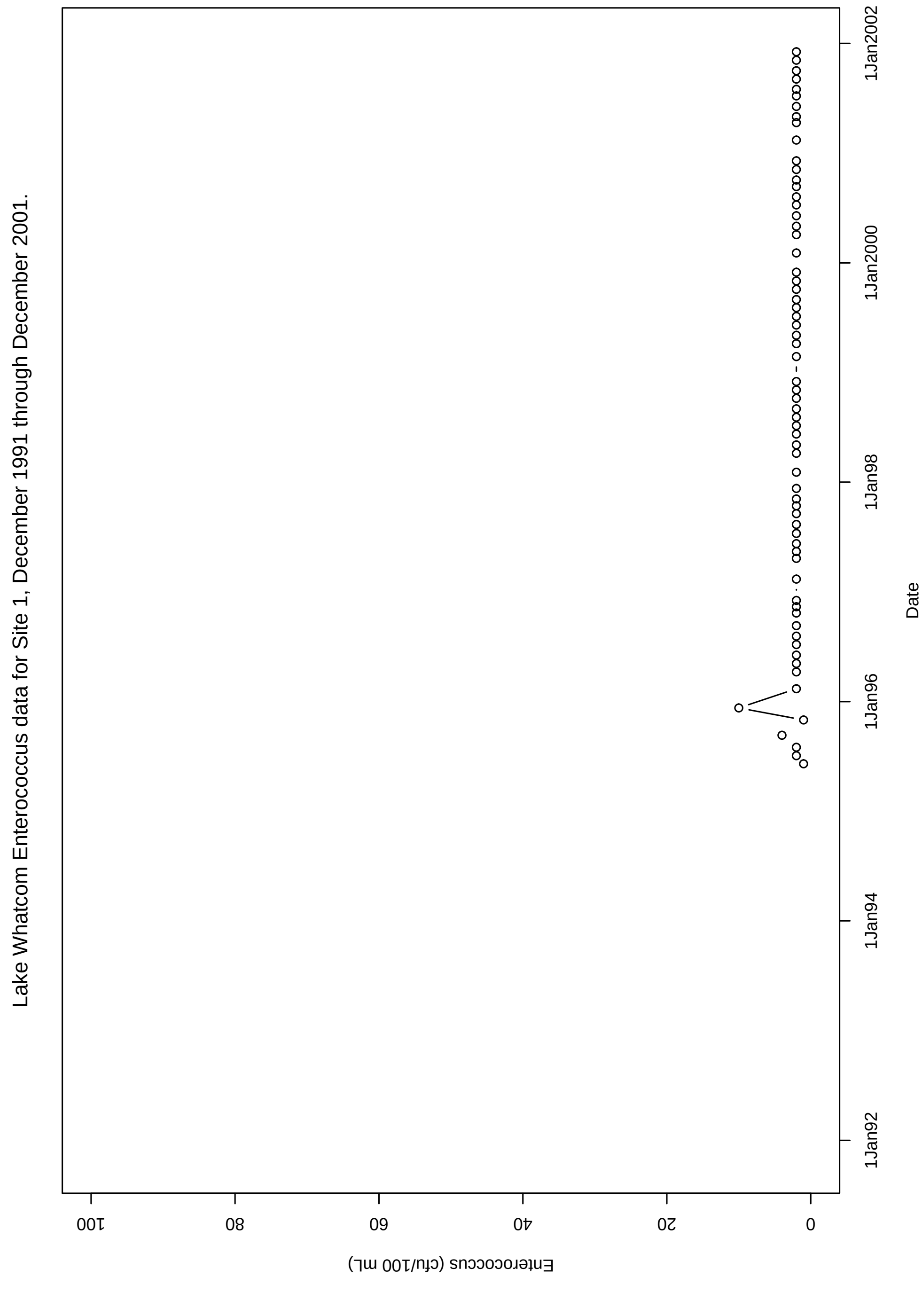

Figure 111: Lake Whatcom *Enterococcus* data for Site 1.

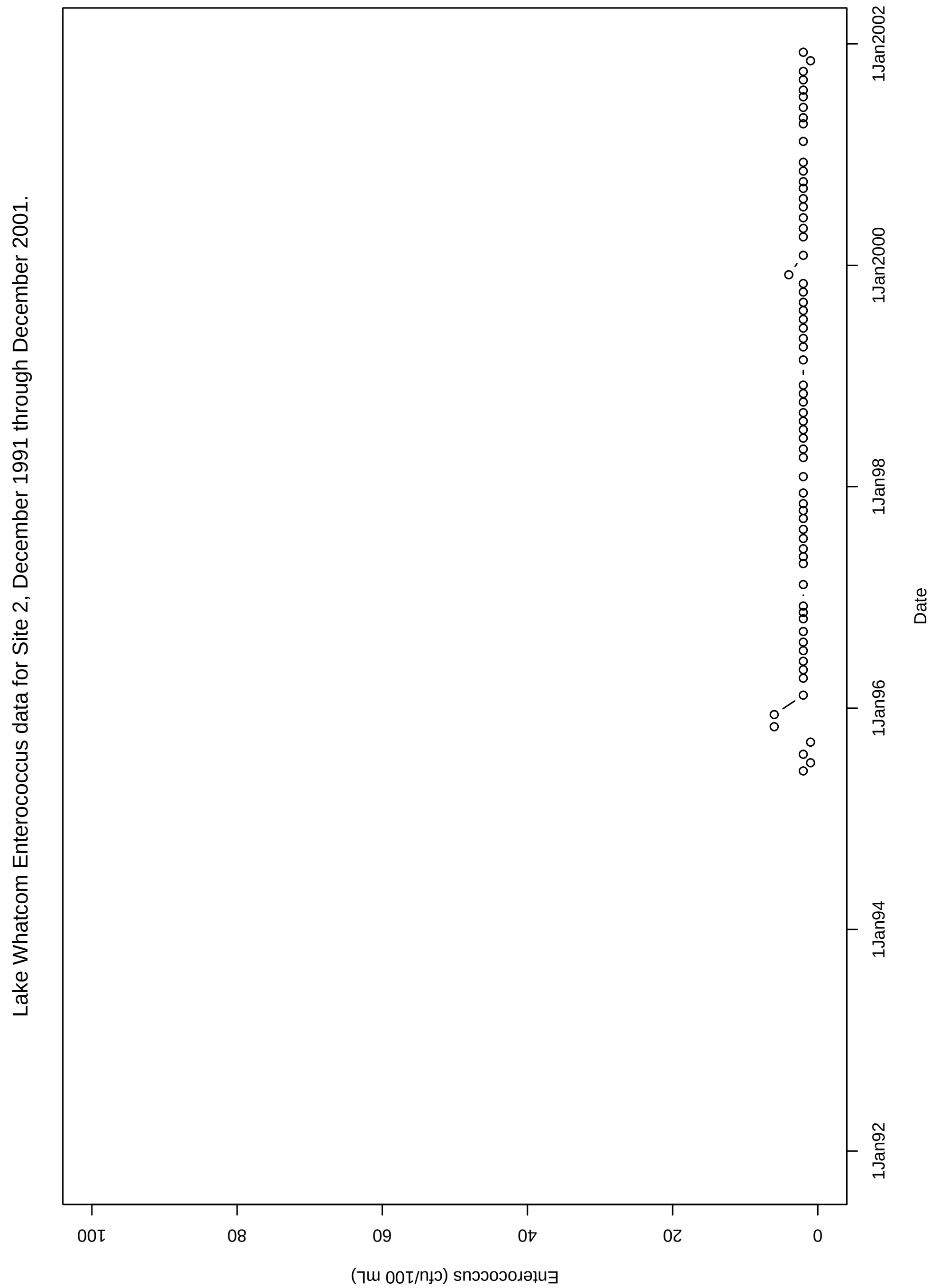

Figure 112: Lake Whatcom *Enterococcus* data for Site 2.

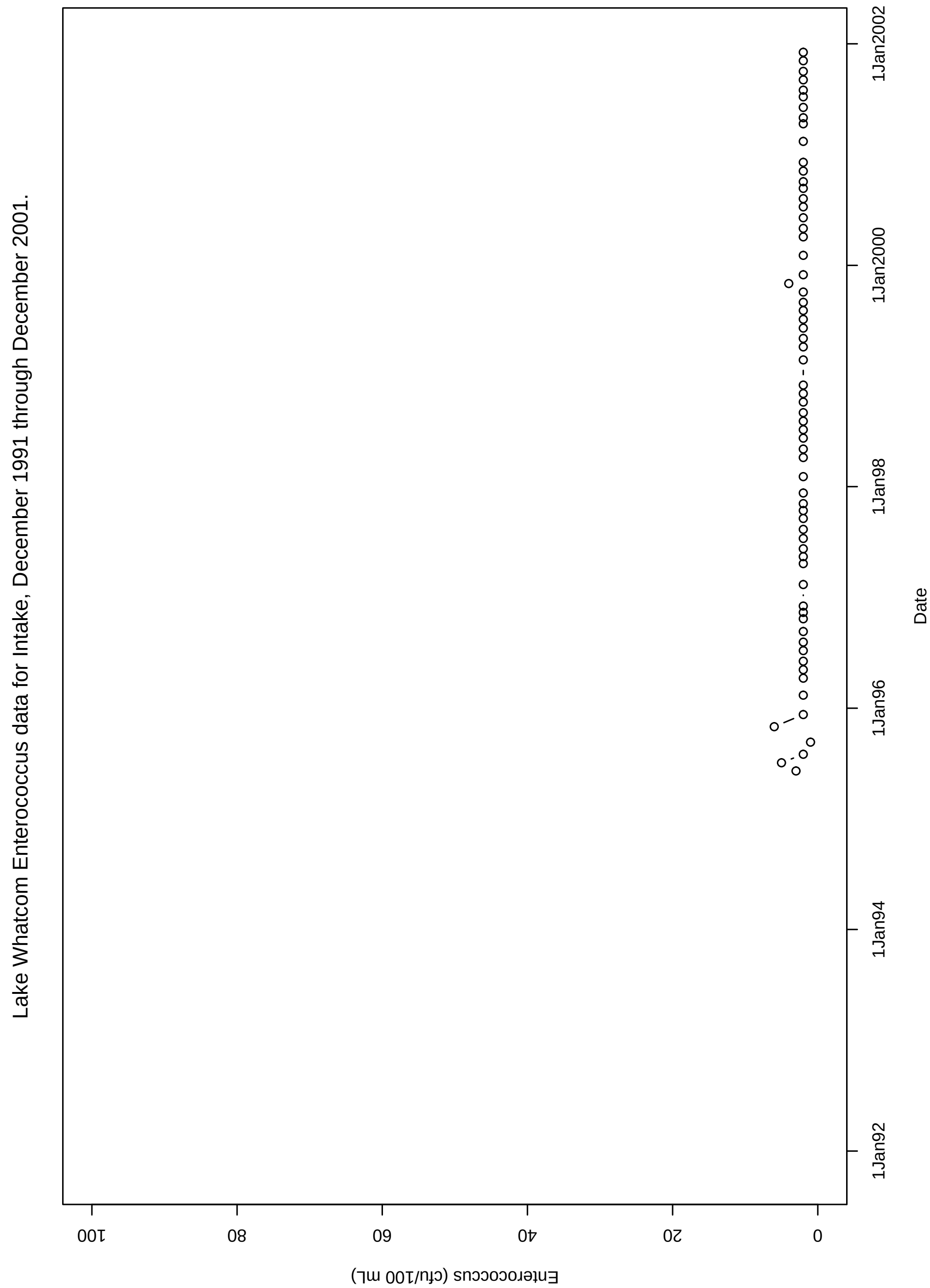

Figure 113: Lake Whatcom *Enterococcus* data for the Intake.

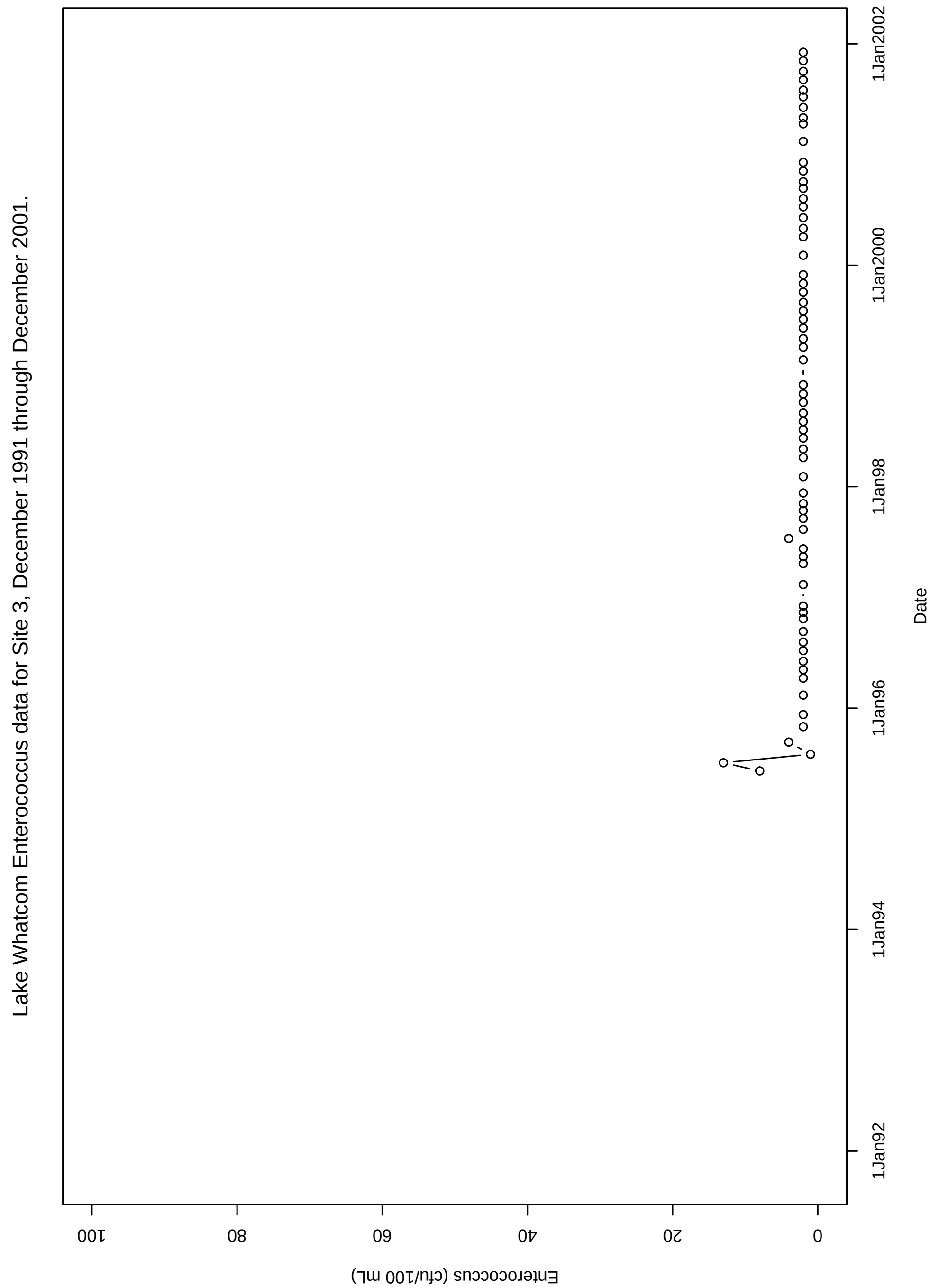

Figure 114: Lake Whatcom *Enterococcus* data for Site 3.

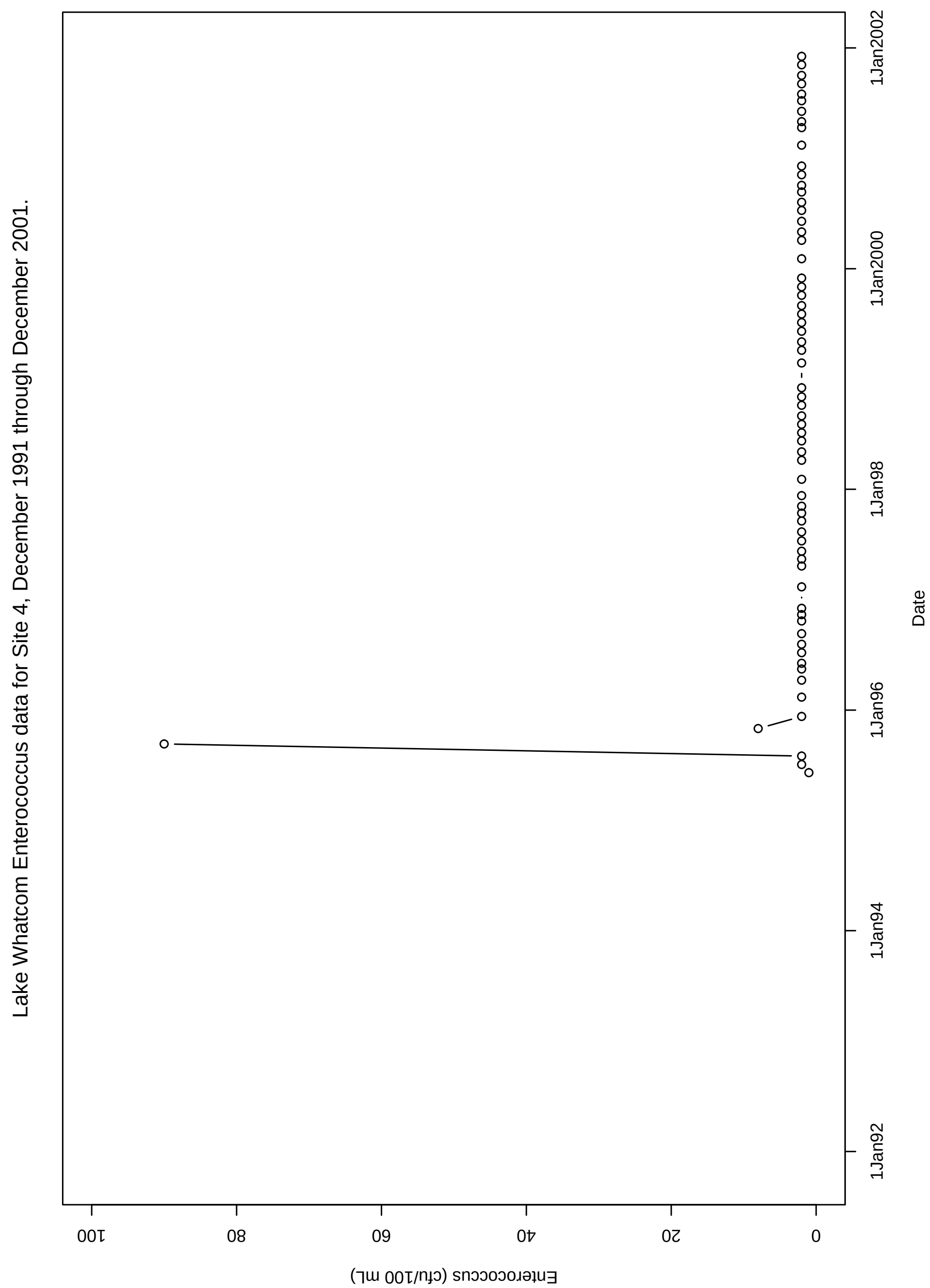

Figure 115: Lake Whatcom *Enterococcus* for Site 4.

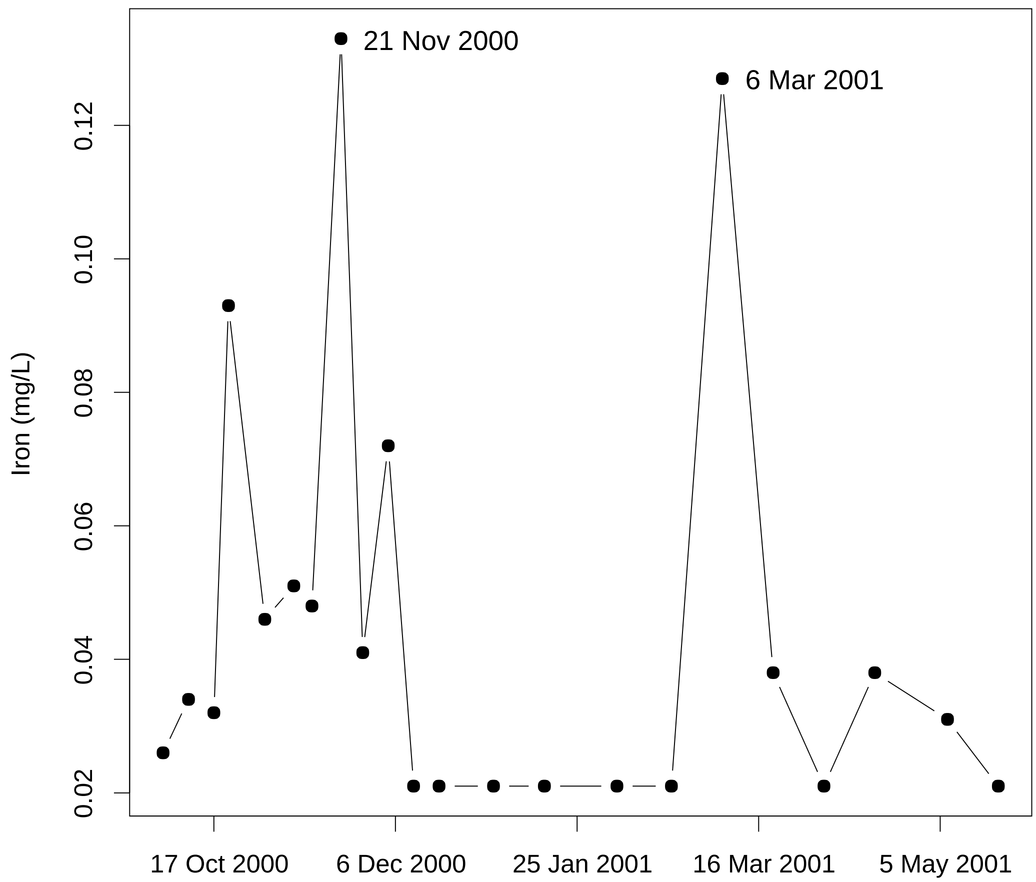

Figure 116: Iron concentration in untreated drinking water (measured at the Lake Whatcom gatehouse).

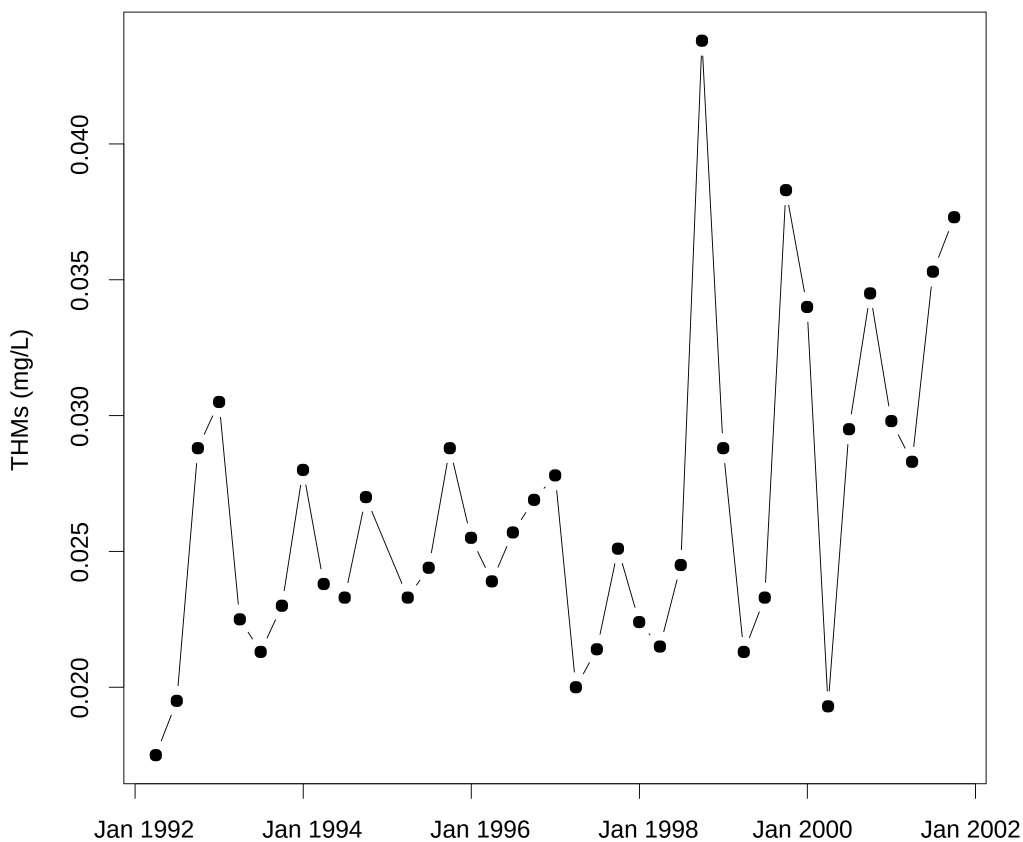

Figure 117: Total trihalomethanes concentrations in the Bellingham water distribution system, 1992–2001.

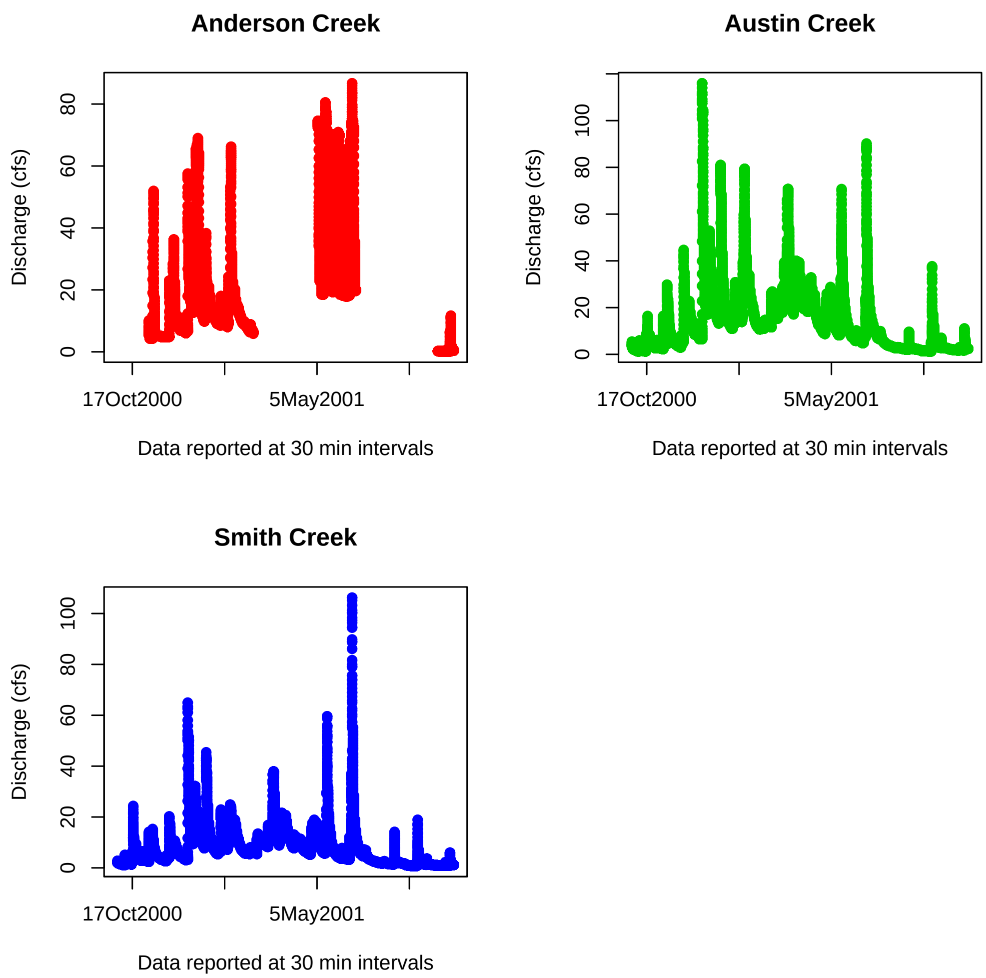

Figure 118: Anderson Creek, Austin Creek, and Smith Creek hydrographs, October 1, 2000–September 30, 2001.

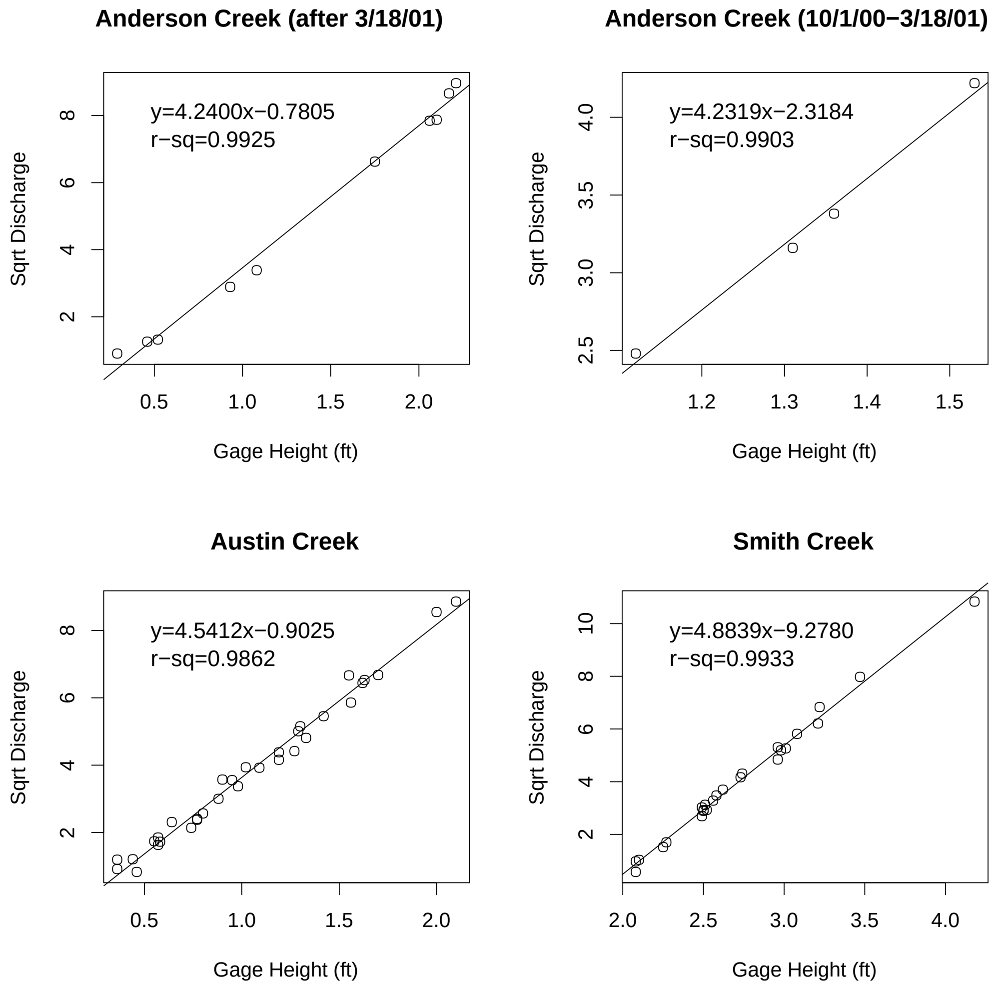

Figure 119: Anderson Creek, Austin Creek, and Smith Creek rating curves, October 1, 2000–September 30, 2001. Regressions show the relationship between gauge height (x) and square root of discharge (y). The Anderson Creek rating curve was recalculated following the removal of downstream debris that may have influenced flow patterns in the vicinity of the flow recorder.

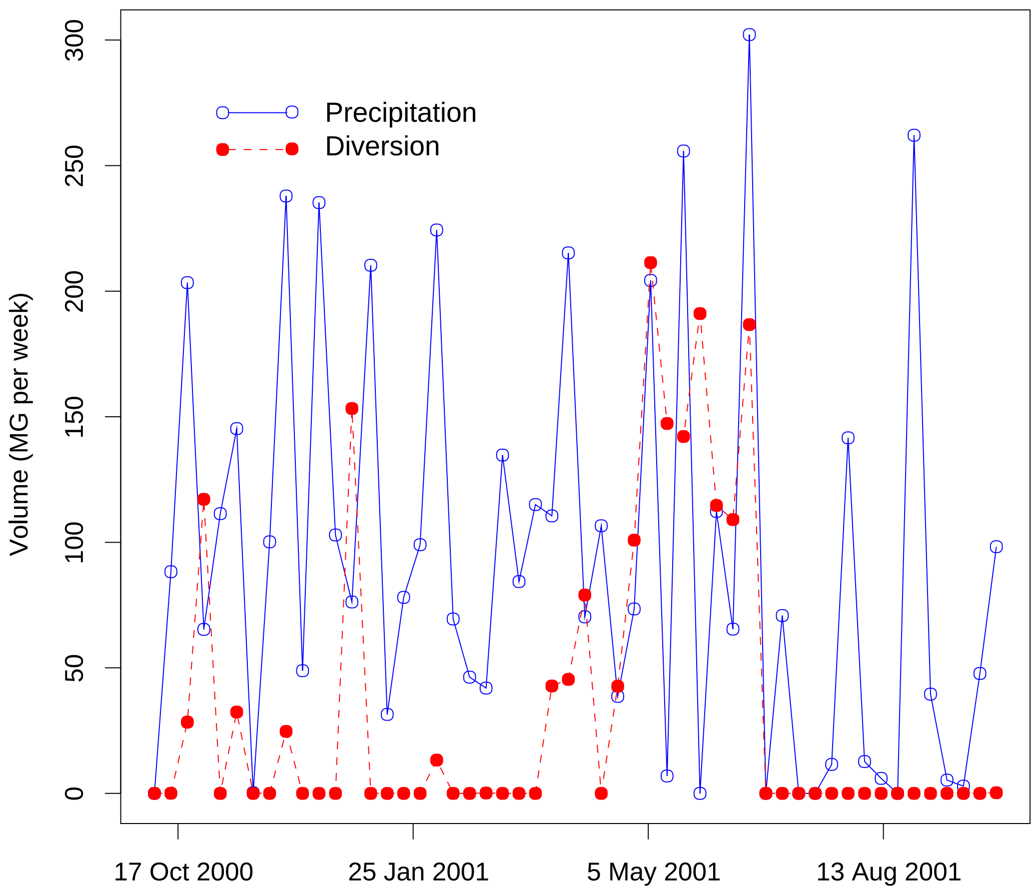

Figure 120: Lake Whatcom watershed direct hydrologic inputs, October 1, 2000–September 30, 2001.

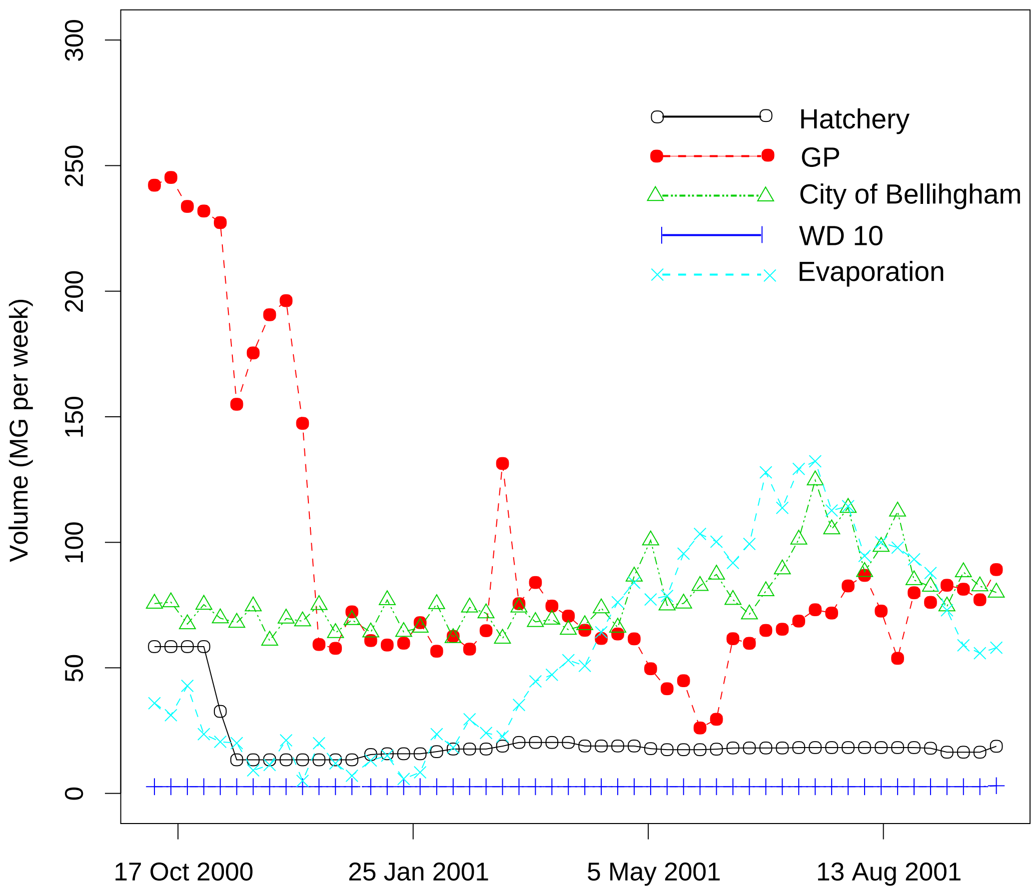

Figure 121: Lake Whatcom watershed hydrologic withdrawals, October 1, 2000–September 30, 2001.

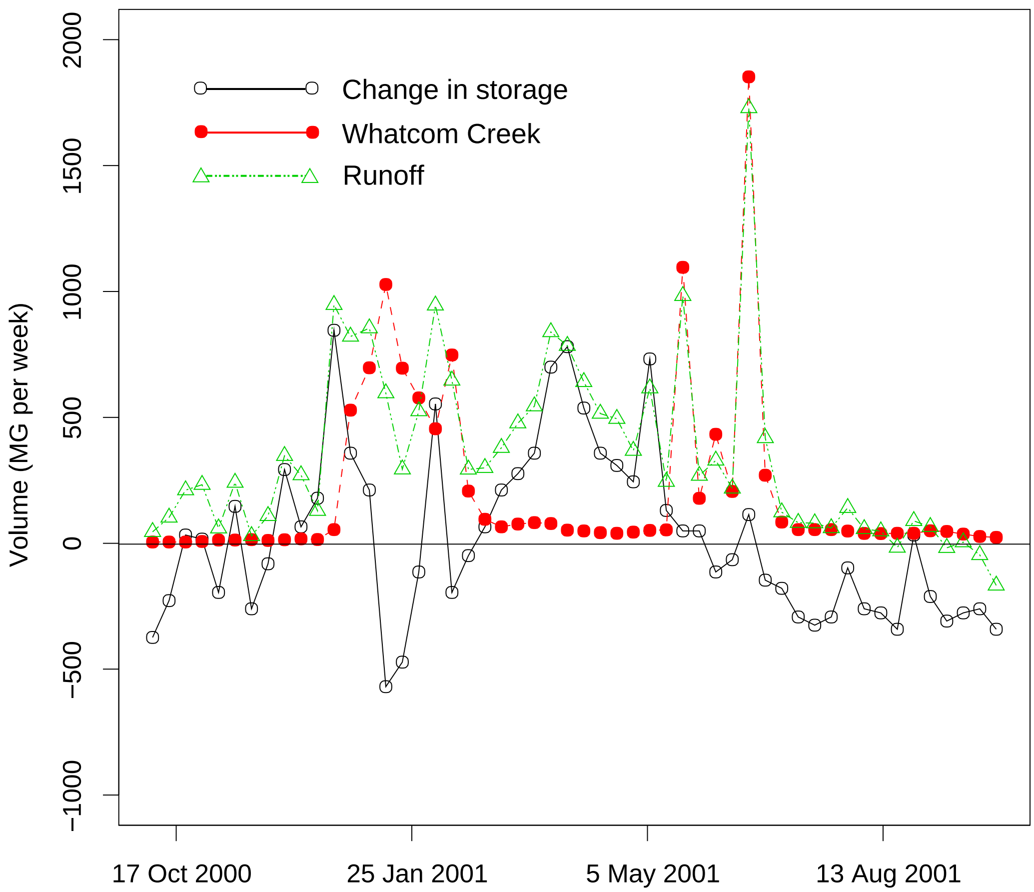

Figure 122: Change in Lake Whatcom storage, October 1, 2000–September 30, 2001.

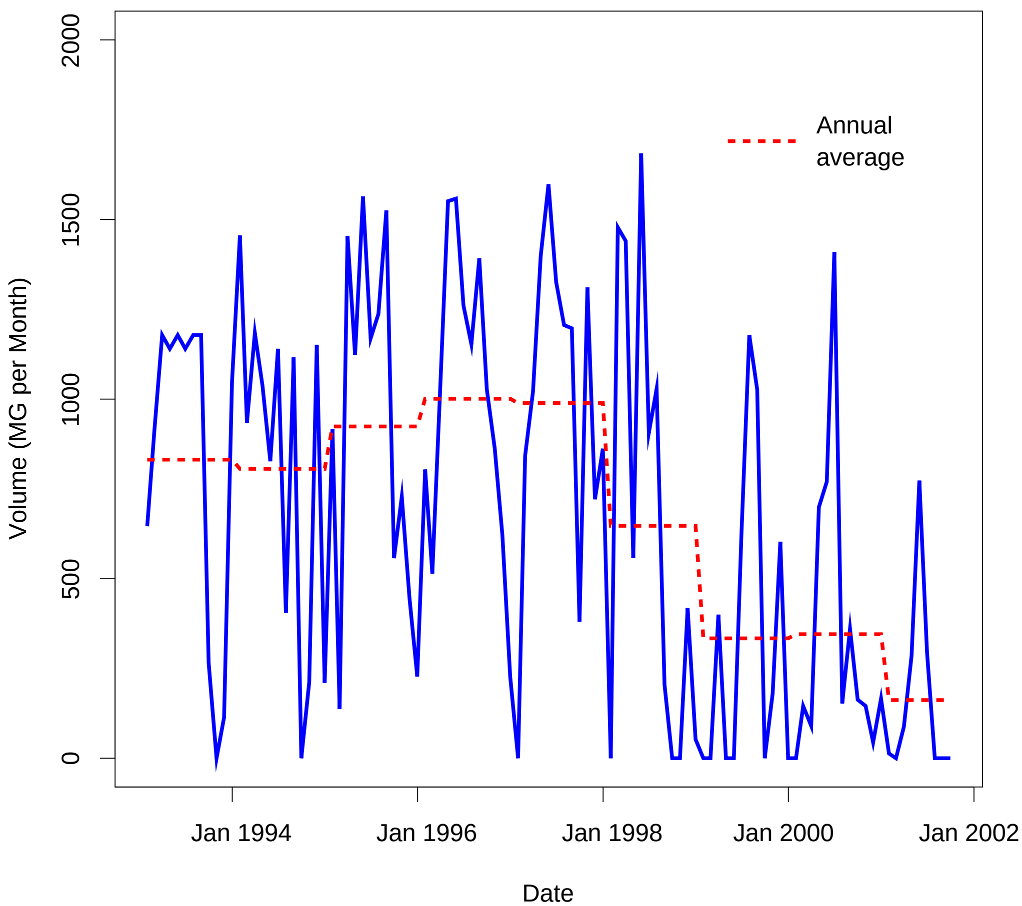

Figure 123: Middle Fork diversion flow into Lake Whatcom, 1993–2001.

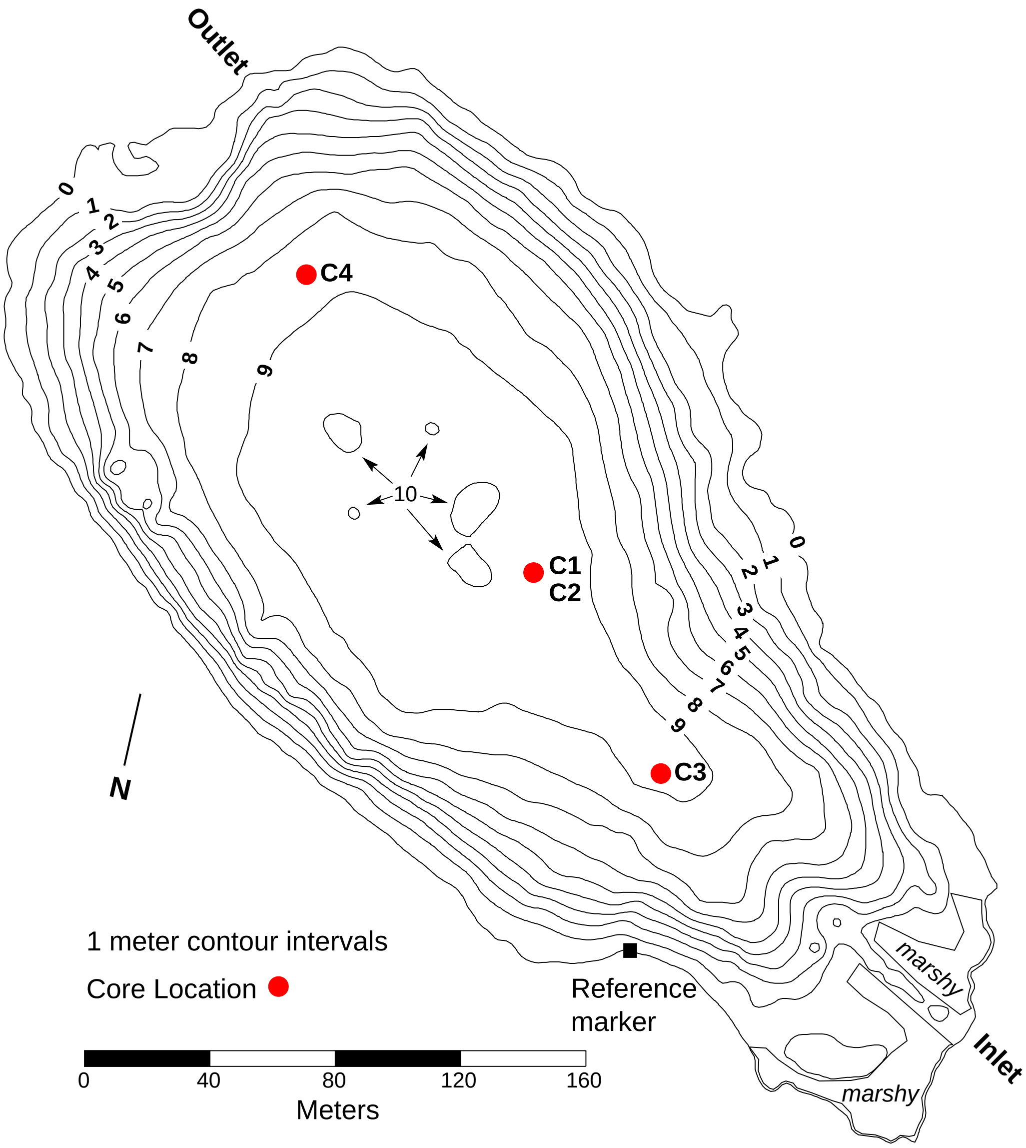

Figure 124: Mirror Lake bathymetry, summer 2000 (from Tracey, 2001).

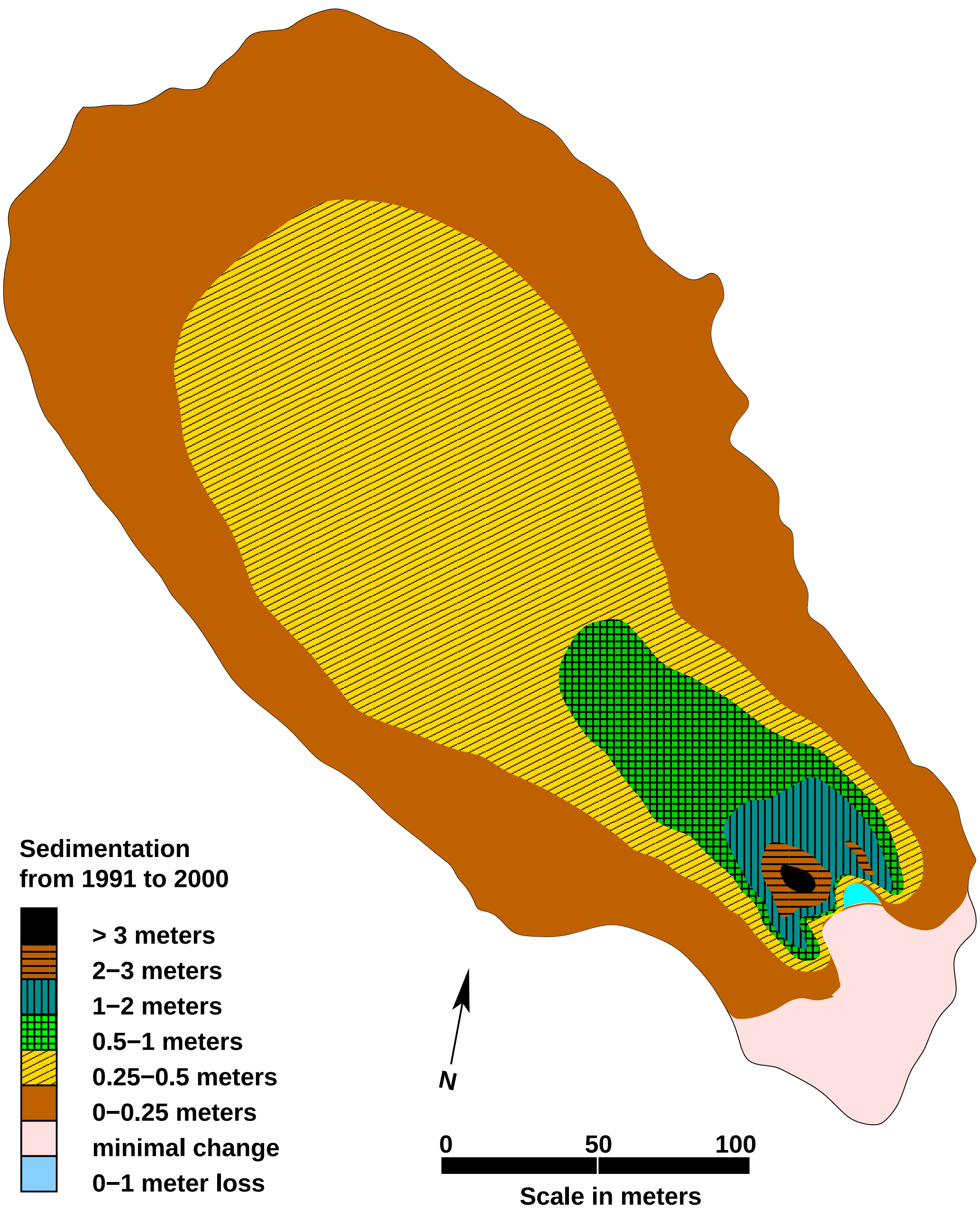

Figure 125: Mirror Lake sedimentation, 1991–2000 (redrawn from Tracey, 2001).

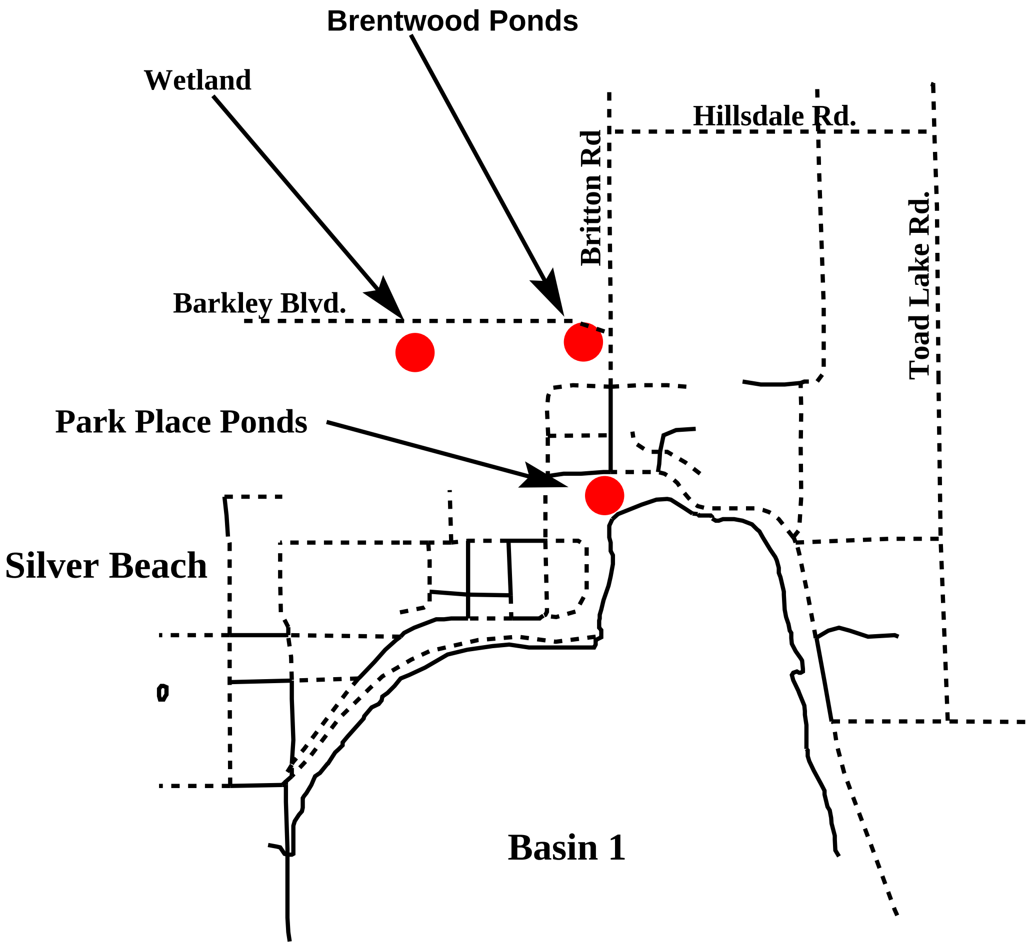

Figure 126: Locations of the sampling sites for the Park Place and Brentwood wet ponds.

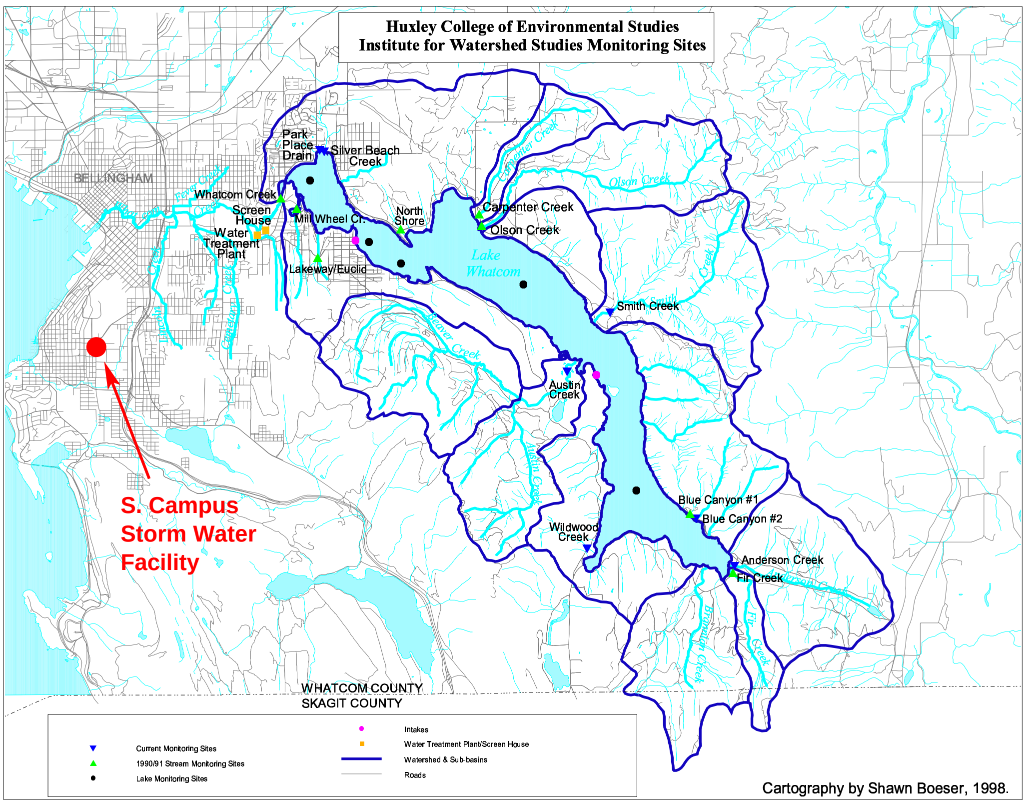

Figure 127: Locations of the South Campus storm water treatment facility.

This file is too large to include in the web version of this document. The image is included in the bound copy of the 2000/2001 Lake Whatcom Final Report, which is available from the City of Bellingham Public Works Department.

Figure 128: Park Place wet pond, September 10, 2001.

This file is too large to include in the web version of this document. The image is included in the bound copy of the 2000/2001 Lake Whatcom Final Report, which is available from the City of Bellingham Public Works Department.

Figure 129: Brentwood wet pond, July 25, 2001.

This file is too large to include in the web version of this document. The image is included in the bound copy of the 2000/2001 Lake Whatcom Final Report, which is available from the City of Bellingham Public Works Department.

Figure 130: South Campus storm water treatment facility, November 8, 2000 (construction phase).

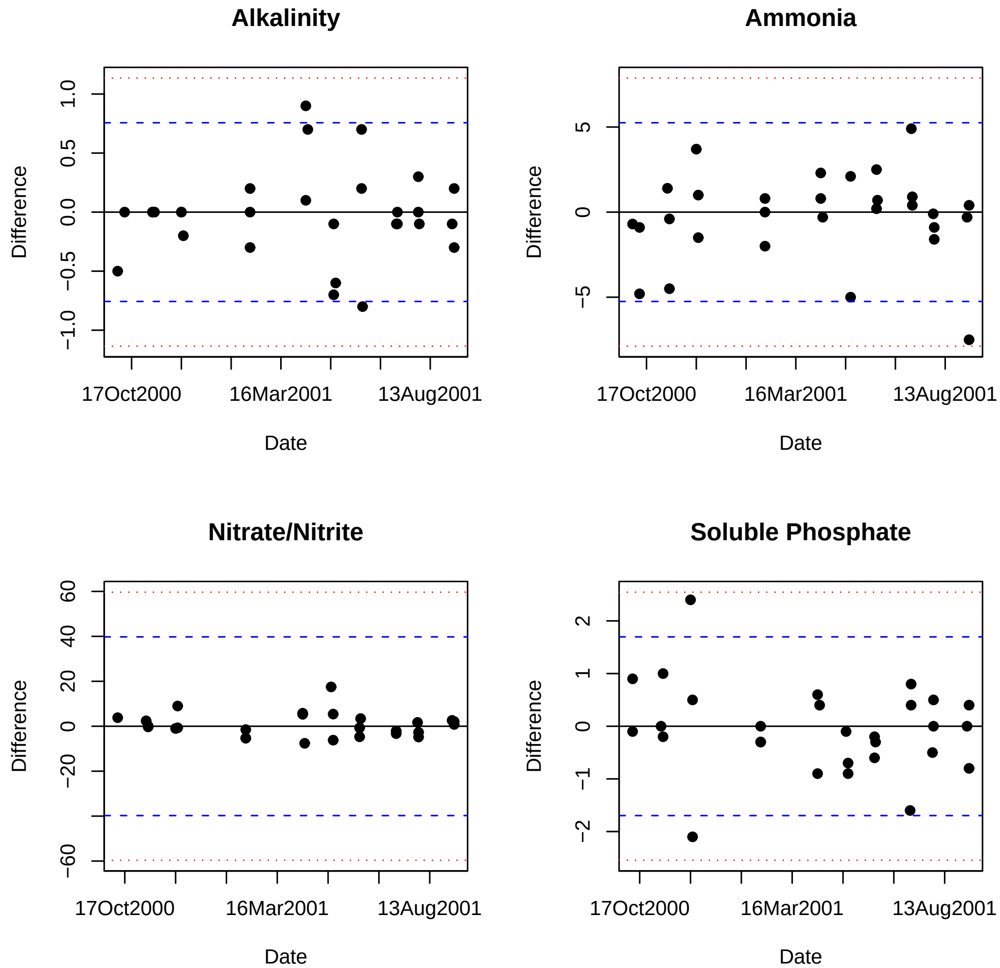

Figure 131: Control charts showing laboratory duplicates for alkalinity, ammonia, nitrate/nitrite, and soluble phosphate. Upper and lower lines indicate $\pm 2\times$ standard deviation and $\pm 3\times$ standard deviation of the paired samples.

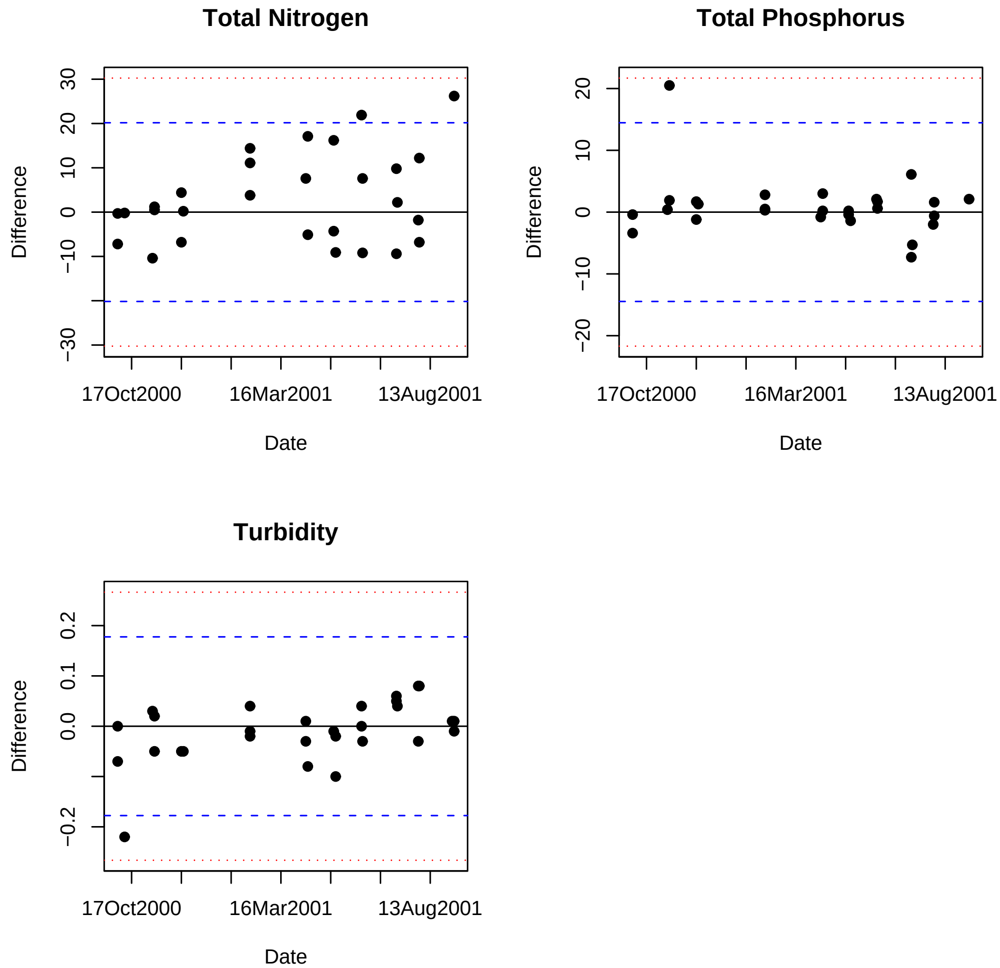

Figure 132: Control charts showing laboratory duplicates for total nitrogen, total phosphorus, and turbidity. Upper and lower lines indicate ±2× standard deviation and ±3× standard deviation of the paired samples.

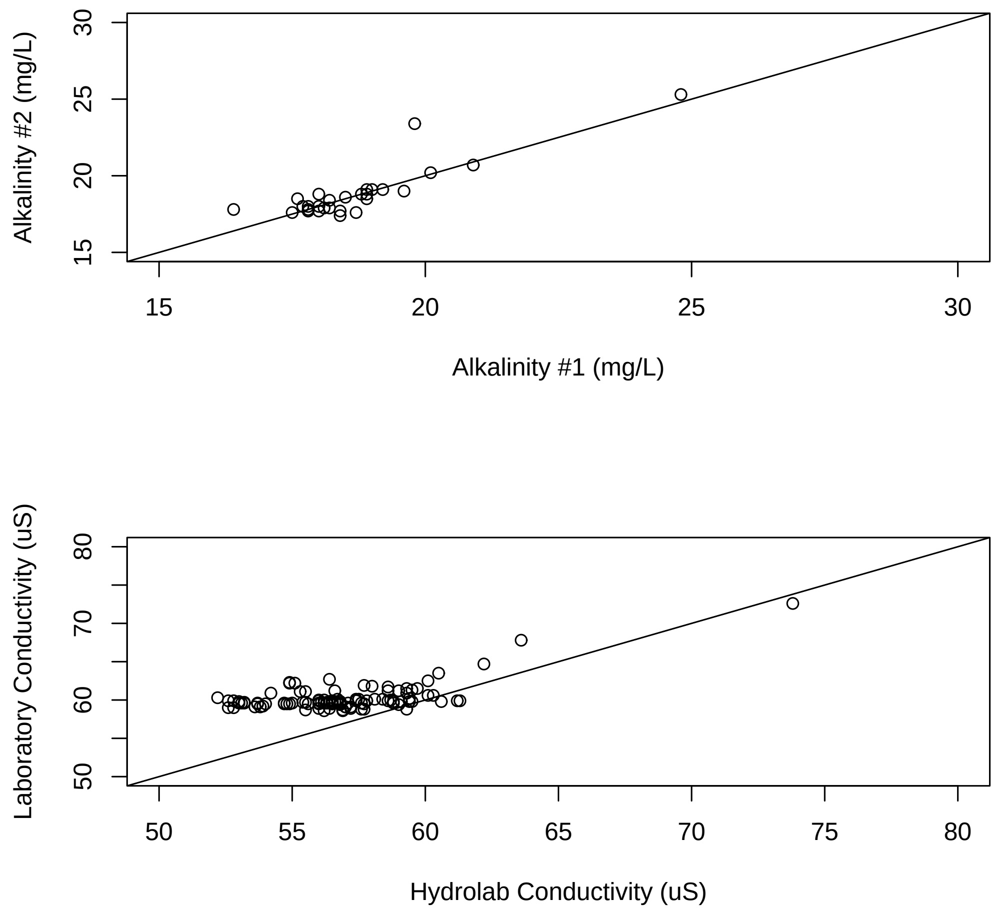

Figure 133: Alkalinity and conductivity field duplicates.

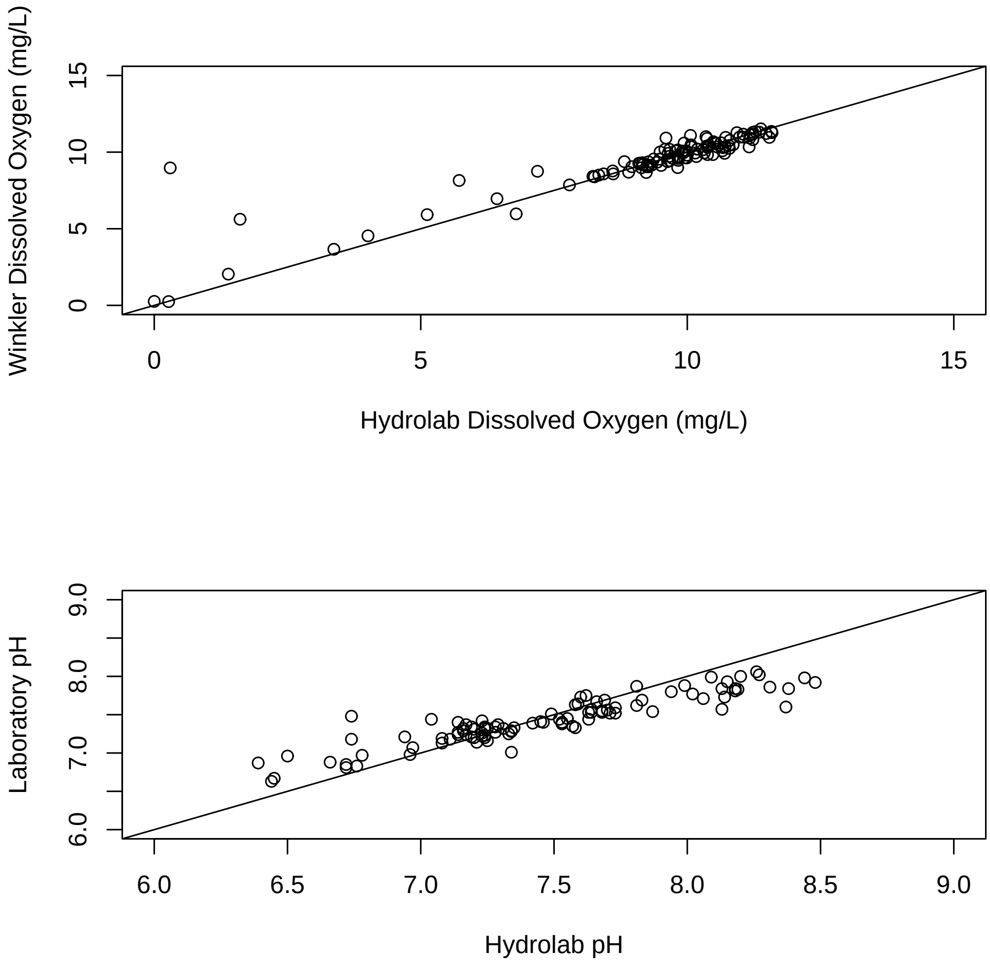

Figure 134: Dissolved oxygen and pH field duplicates.

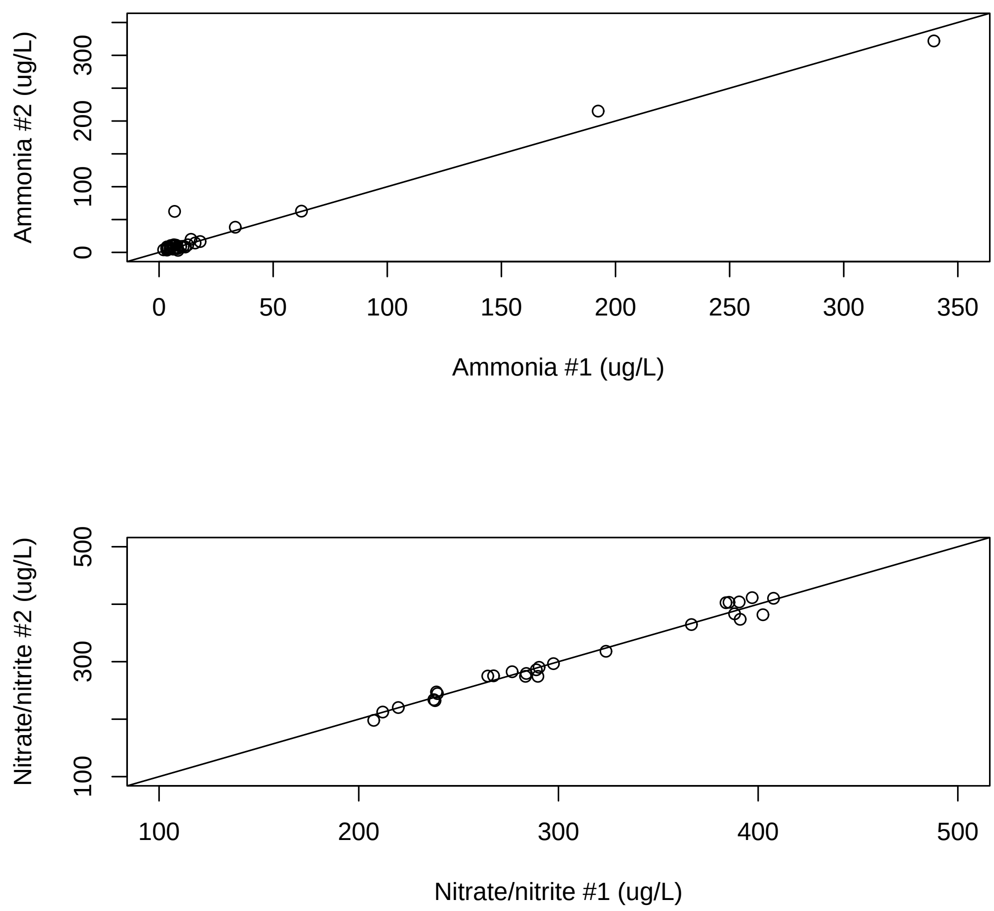

Figure 135: Ammonia and nitrate/nitrite field duplicates.

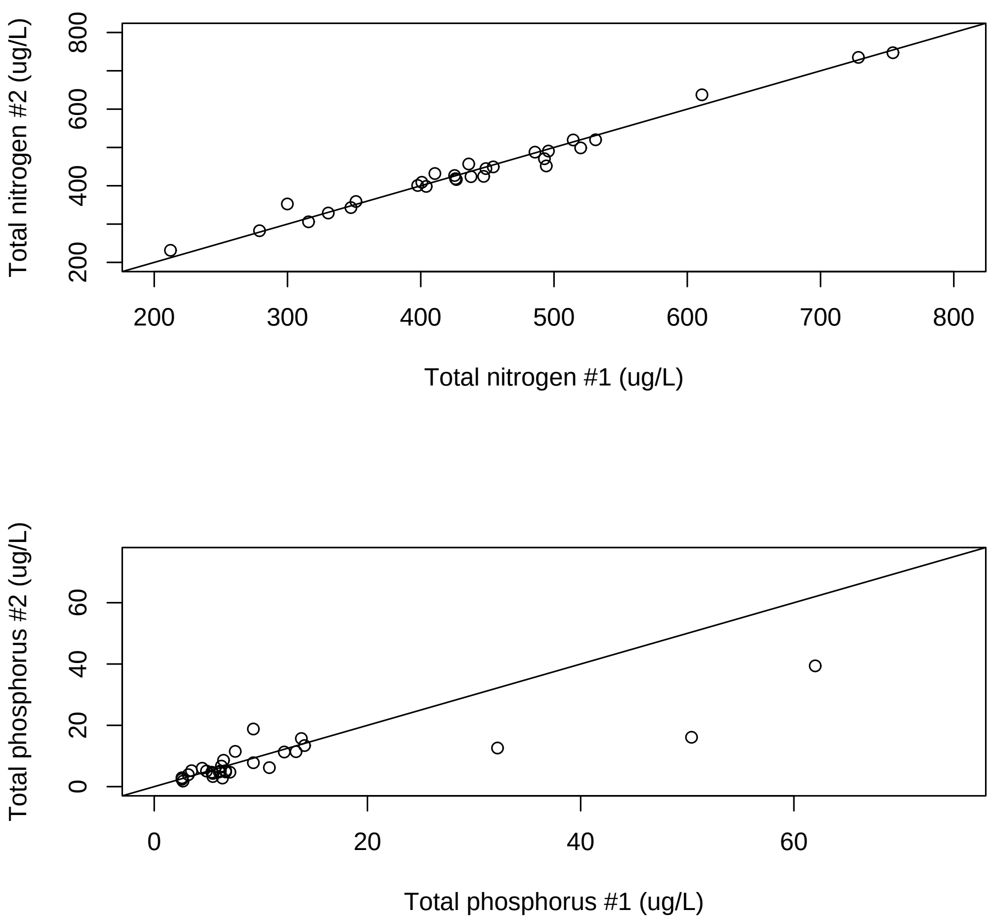

Figure 136: Total nitrogen and total phosphorus field duplicates.

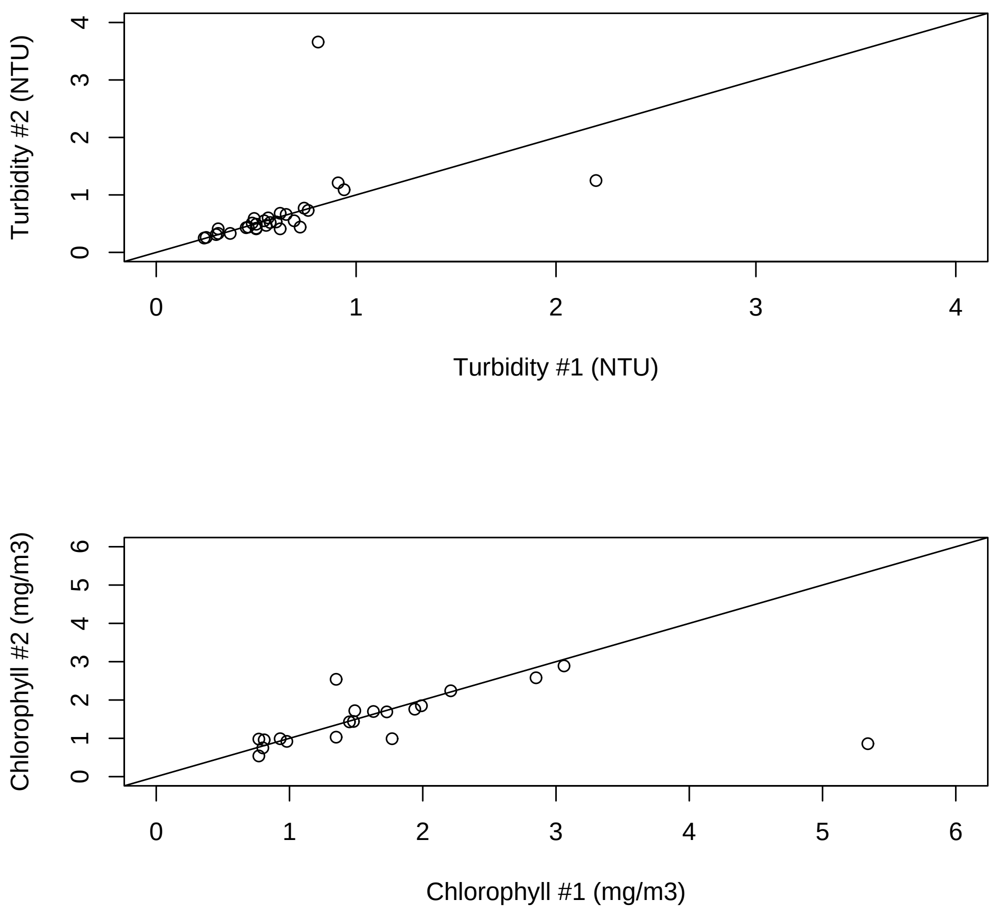

Figure 137: Turbidity and chlorophyll field duplicates.

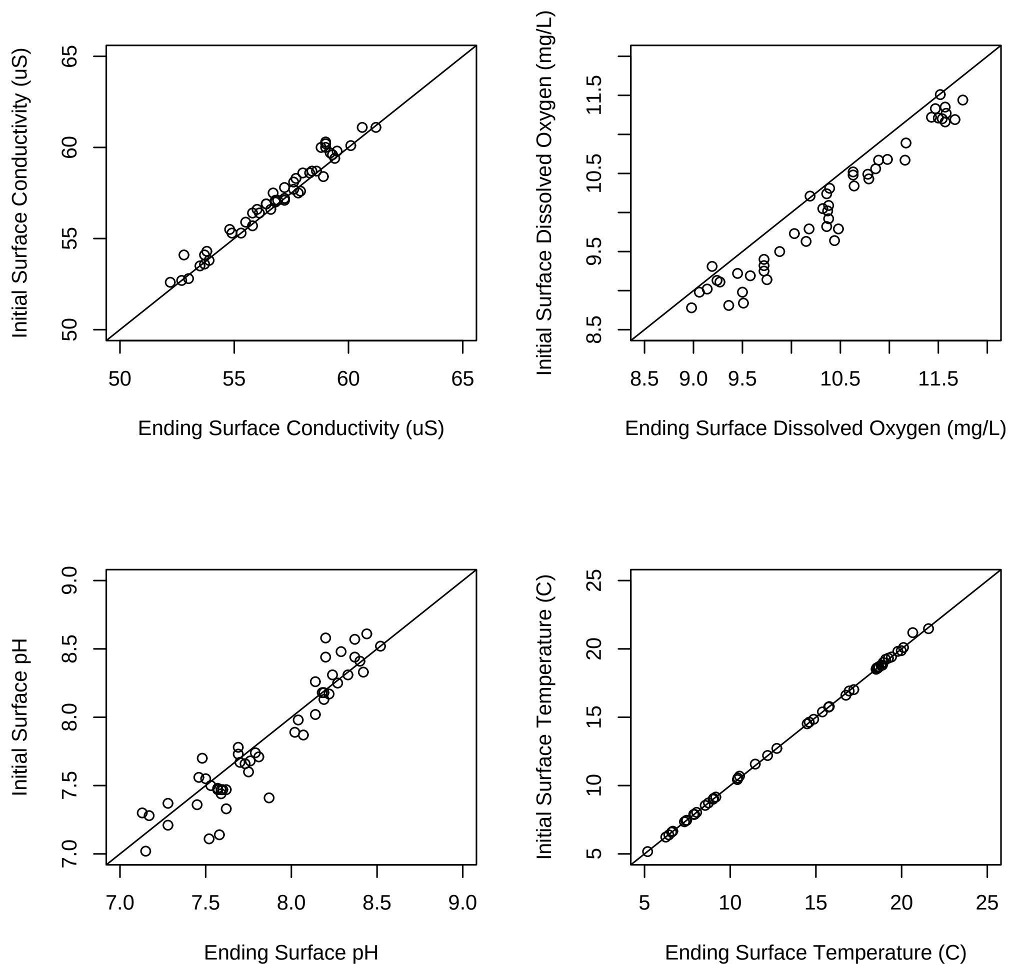

Figure 138: Comparison between initial and ending surface Hydrolab readings.

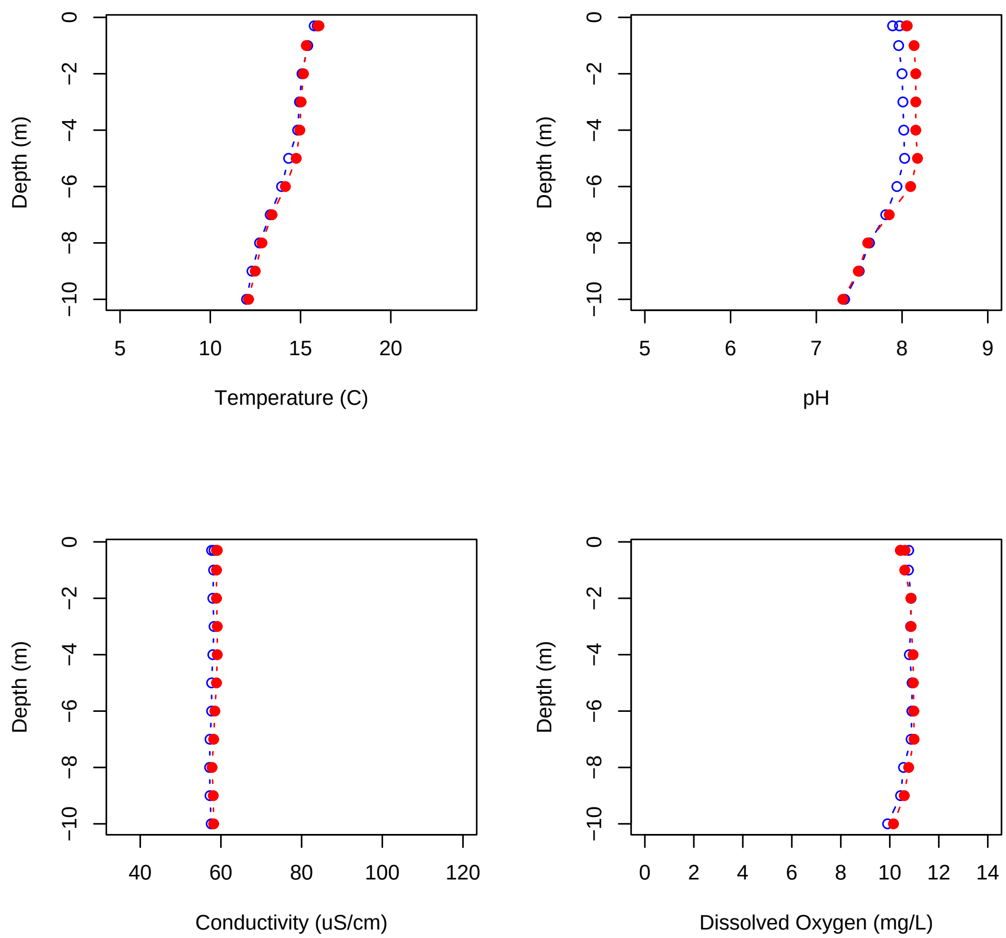

Figure 139: Comparison between old (○) and new (●) Hydrolab readings, May 31, 2001.

A Site Descriptions

A.1 Lake Whatcom Monitoring Sites

Please refer to Figures 140–142 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 32 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.

Three sites were added in the fall of 1996 along the 40 meter depth contour in basin 3 near Strawberry sill. These sites are identified as "s1–s3" in Figure 142. There are no permanent buoys at these sites; depth is determined at each site using an electronic depth finder.

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 s1 is located along the 40 m depth contour in the basin 3 side of Strawberry sill off the north-northwest shore of Lake Whatcom. The site is off a point with a house and dock as the lake shore curves into Agate Bay; the point of Delstra Park is on a bearing slightly south of west. The GPS coordinates are 48° 44.83 N, 122° 21.8 W, although the GPS response is erratic at this location due to topography.

Site s2 is located approximately mid-channel between Delestra Park and Strawberry sill. The site is midway between a flat-roofed, brown-grey boathouse with red trim on the northeast point of Delestra Park and a white boathouse with two square windows just back from the north side of Strawberry point. The GPS coordinated are 48° 44.65 N, 122° 22.42 W.

Site s3 is located off the southwest shore just before the road cut of Lake Whatcom Blvd., straight off and between two stair towers. The GPS coordinates are 48° 44.50 N, 122° 21.92 W.

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

Table 32: Summary of site codes for Lake Whatcom water quality sampling.

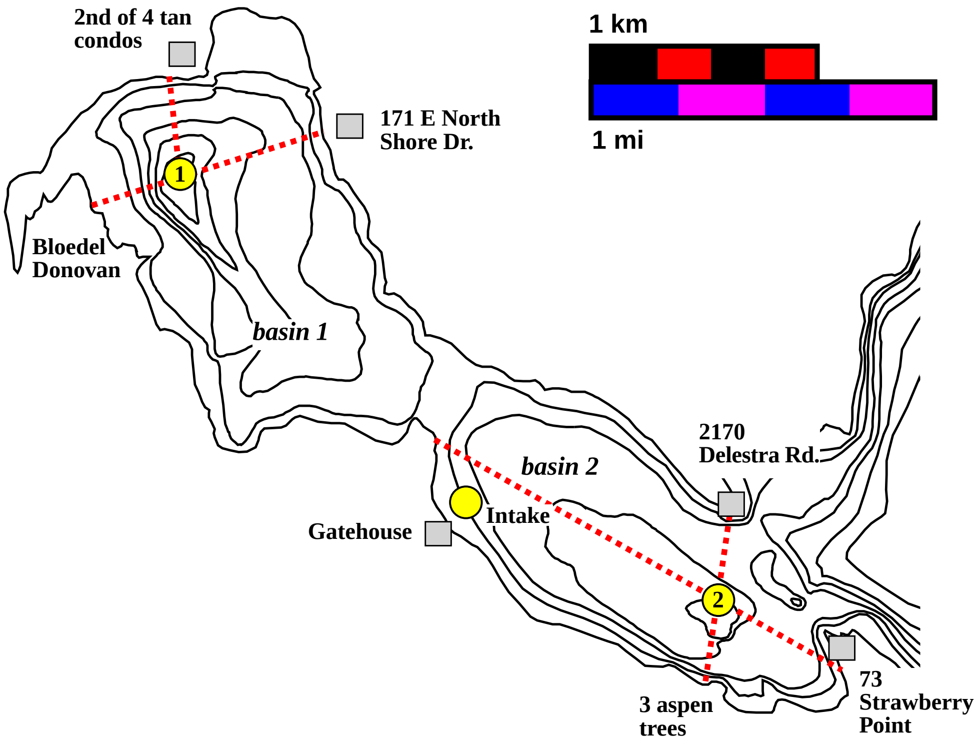

Figure 140: Lake Whatcom sampling sites, basins 1–2.

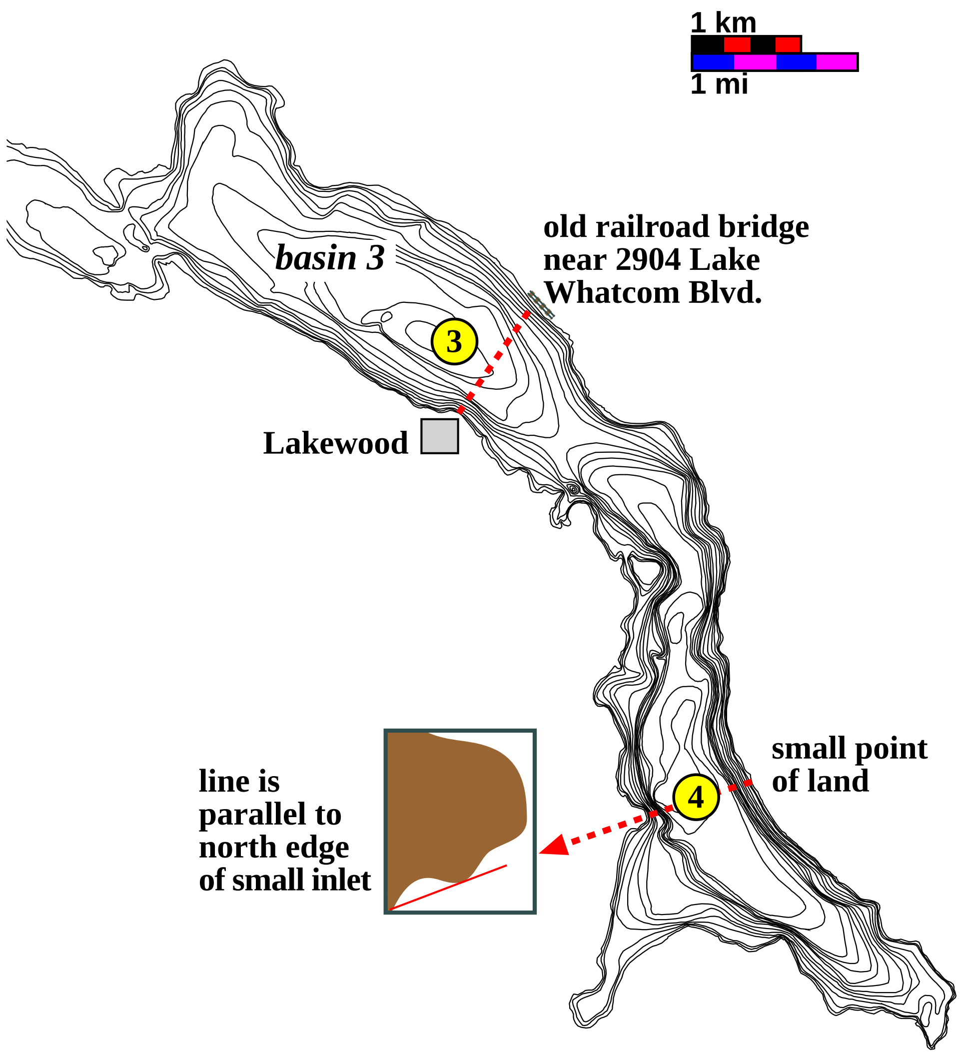

Figure 141: Lake Whatcom sampling sites, basin 3.

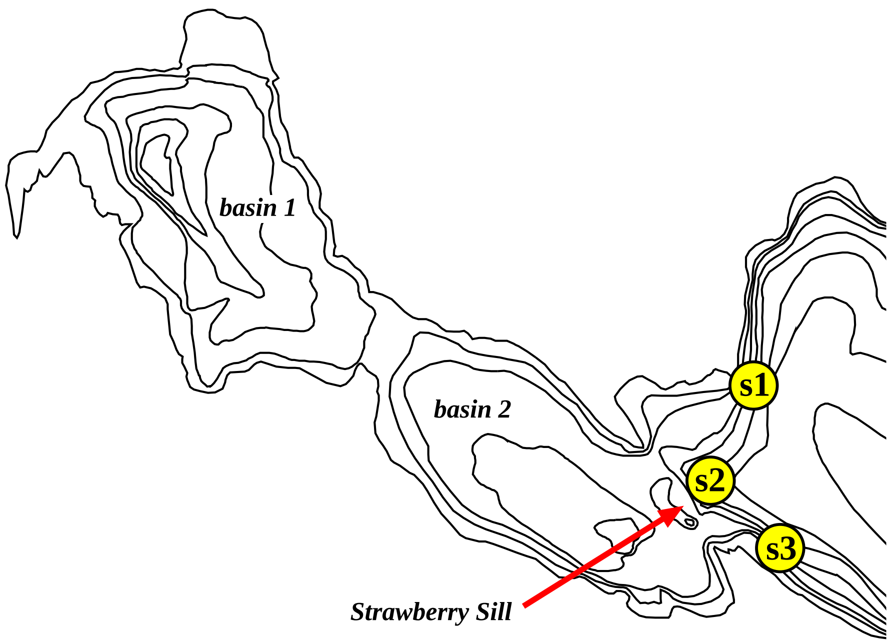

Figure 142: Strawberry sill sampling sites.

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:
Samples are collected approximately 100 yards upstream from Lake Whatcom. 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.

Silver Beach Creek:
All routine monitoring samples are collected immediately upstream from the culvert under North Shore Road.

Park Place storm drain:
Samples are collected inside the storm drain under Park Place (road off of North Shore Drive.) When the lake level is low enough, samples can be collected at the mouth of the outlet pipe flowing into the lake.

Austin Creek:
The site is located at the Sudden Valley golf course approximately 1800 ft upstream from where the creek flows into Lake Whatcom. 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.

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.

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.

Blue Canyon Creek:
This small creek is not shown on the USGS topographic map for the area. How-

ever, 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.

B Lake Whatcom Data

The 2000/2001 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 33. The historic detection limits for each parameter were estimated based on recommended lower detection ranges (APHA, 1998; Ebina, et al., 1983; Hydrolab, 1997; Lind, 1985) instrument limitations, and analyst judgement 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 39). Because the Lake Whatcom data set includes long-term monitoring data, which have been collected using a variety of analytical techniques, this report sets very conservative historic detection limits in order to allow comparisons between all years.

In the Lake Whatcom report, unless indicated, no data substitutions are used. Instead, we flag all data that fall below the historic detection limits listed in Table 33.

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 mg/L
toc	Carbon, total organic	dl = 1.0 mg/L	Cd	cadmium, total	dl = 0.002/0.0005 mg/L
chl	Chlorophyll *a*	± 0.1 mg/m^3	Cr	chromium, total	dl = 0.006/0.001 mg/L
fc	Coliforms, fecal	dl $\leq$ 2 col/100 mL	Cu	copper, total	dl = 0.002/0.001 mg/L
tc	Coliforms, total	dl $\leq$ 2 col/100 mL	Fe	iron, total	dl = 0.01/0.005 mg/L
cond	Conductivity, Hydrolab	± 2 μS/cm	Pb	lead, total	dl = 0.001 mg/L
cond	Conductivity, lab	± 2 μS/cm	Hg	mercury, total	dl = 0.01 mg/L
ec	*Enterococcus*	dl $\leq$ 2 col/100 mL	Hg	mercury, total	
nh3	Nitrogen, ammonia	dl = 10 μg-N/L		low-level: Env. Canada	dl = 0.00005 mg/L
no3	Nitrogen, nitrate/nitrite	dl = 20 μg-N/L		low-level: AmTest	dl = 0.0002 mg/L
tn	Nitrogen, total nitrogen	dl = 100 μg-N/L	Ni	nickel, total	dl = 0.01/0.005 mg/L
do	Oxygen, Hydrolab	± 0.1 mg/L	Zn	zinc, total	dl = 0.002/0.001 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; the first value shows in this table is the older, higher limit.
Table 2 lists the current IWS detection limits for selected analyses; Appendix C lists the current AmTest detection limits.

Table 33: Summary of analyses in the Lake Whatcom monitoring project.

B.1 Lake Whatcom Hydrolab Data

B.2 Lake Whatcom Water Quality Data

B.3 Lake Whatcom Plankton and Plankton Biovolume Data

B.4 Lake Whatcom Coliform Data (Lake and Creeks)

B.5 Strawberry Sill Hydrolab and Water Quality Data

B.6 Lake Whatcom Electronic Data

The annual Lake Whatcom reports include a CD containing long-term data files. The CD includes Hydrolab and water quality data from 1988 through 2001, the Austin Creek, Anderson Creek, and Smith Creek hydrograph data, and the AmTest metals data. The data files included on the CD are described in the readme.txt file on the CD.

⇒ The electronic data files have **NOT** been censored to identify below detection and above detection values. Refer to Tables 2 and 33 (pages 39 and 218) for applicable detection limits and abbreviations. It is essential that any statistical or analytical results that are generated using uncensored data be reviewed by a trained statistician or scientist familiar with statistical uncertainty associated with below detection data.

Readme.txt:

```
*********************************
README FILE - LAKE WHATCOM DATA
*********************************
The CD included with the 2000/2001 Lake Whatcom Monitoring 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 (current)
1992_hl.dat          1992_wq.dat
1993_hl.dat          1993_wq.dat
1994_hl.dat          1994_wq.dat
1995_hl.dat          1995_wq.dat
1996_hl.dat          1996_wq.dat
1997_hl.dat          1997_wq.dat
1998_hl.dat          1998_wq.dat
1999_hl.dat          1999_wq.dat
2000_hl.dat       2000_wq.dat
2001_hl.dat      2001_wq.dat

AmTest data
amtest_011701.txt amtest_071801.txt
amtest_011801.txt amtest_080101.txt
amtest_022001.txt amtest_080601.txt
amtest_022201.txt amtest_080701.txt
amtest_032201.txt amtest_080801.txt
amtest_041901.txt amtest_091801.txt
amtest_051701.txt amtest_100901.txt
amtest_071701.txt amtest_101501.txt
```

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 AmTest data contain sample results for up to 34 analytes, including total organic carbon, silver, aluminum, arsenic, boron, barium, beryllium, calcium, cadmium, cobalt, chromium, copper, iron, mercury, potassium, lithium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, lead, sulfur, antimony, selenium, silicon, tin, strontium, titanium, thallium, vanadium, yttrium, and zinc. The AmTest data are unformatted machine output, and should be compared to the hard copies in the report in order to interpret the results.

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
    35  = Strawberry Sill site S3 (discontinued)

    BW1 = Brentwood wet pond inlet
    BW2 = Brentwood wet pond outlet
    PP1 = Park Place wet pond inlet
    PP2 = Park Place wet pond outlet
    SC1 = South Campus storm water facility inlet
    SC2 = South Campus storm water facility east outlet
    SC3 = South Campus storm water facility west outlet

    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 1988-2001 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.

C AmTest Reports

The following AmTest data reports are included in this appendix (filed by date). Electronic copies of the data, in comma deliminated format, are included on the CD that accompanies this report.

Sample location	Date	Analyses
Lake Whatcom, surface and bottom	Feb 13, 2001	total organic carbon
	July 17, 2001	metals; low-level mercury only
	August 6, 2001	metals, total organic carbon
	August 7, 2001	metals; low-level mercury only
	September 18, 2001	metals; low-level mercury only
Strawberry sill, surface and 35 m	October 5, 2000	metals, total organic carbon
	January 17, 2001	metals, total organic carbon
Park Place/Brentwood wet ponds	January 17, 2001	metals, total organic carbon
	April 19, 2001	metals, total organic carbon
	August 2, 2001	metals, total organic carbon
South Campus storm drain	March 22, 2001	metals, total organic carbon
	May 17, 2001	metals, total organic carbon
	August 8, 2001	metals, total organic carbon
Watershed creeks	February 22, 200q	metals, total organic carbon
	July 18, 2001	total organic carbon