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Lake Whatcom Monitoring Project 1999/2000 Report

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Lake Whatcom Monitoring Project
1999/2000 Final Report

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Executive Summary

This report described the results from the 1999/2000 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.

The lake was sampled on October 5, 6, 7, & 12, November 2 & 4, December 1–2, 1999, and February 3–4, April 4 & 6, May 2 & 4, June 6 & 8, July 12–13, August 8 & 10, and September 6–7, 2000. During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). Despite relatively cool temperatures and late stratification, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer. As in previous years, Pearson's r correlation analyses of dissolved oxygen vs. year continued to show statistically significant reductions in hypolimnetic oxygen levels from June through September. No significant correlations were found for June through September hypolimnetic temperature data or for lake level vs. hypolimnetic oxygen. Although Site 1 continued to develop the earliest and most prolonged period of anoxia in the lake, Site 2 had higher hypolimnetic concentrations of hydrogen sulfide, ammonia, and iron, and greater denitrification (bacterial conversion of nitrate to N_2 in low oxygen environments), all of which suggest that the anoxic conditions at Site 2 were at least as severe as at Site 1. 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. 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 $<$ 1–2 NTU except in late summer samples from the lower depths at Sites 1 and 2. Site 1 usually had the highest chlorophyll concentrations in the lake, with peak concentrations occurring at depths $\leq$ 15 m. Low chlorophyll concentrations were measured during late summer at Site 1, 15–20 m, and Site 2, 20 m. These depths are located in regions with low light intensities and low oxygen concentrations, which are not favorable for algal growth. Total organic carbon (TOC) concentrations were low ($<$ 1 mg/L) in February 2000, but relatively high during September (2.2–3.6 mg/L) (Table 11, page 34). These concentrations were slightly higher than the TOC concentrations measured by the City of Bellingham in raw water at the gatehouse, where concentrations ranged from 1.5–2.4 mg/L. Most of the metals concentrations in Lake Whatcom were at, or below, detection limits, and those that were detected were within normal concentration ranges for surface water. Iron concentrations were elevated in

all of the bottom samples except at Site 4. The iron in basin 2 was evident at the gatehouse[1] during late summer and fall (Figure 118, page 171), particularly during the first few weeks after the lake destratifies (see November in Figure 118). Following lake turnover, most of the soluble iron is converted to insoluble iron, which slowly settles to the bottom.

Strawberry sill was sampled on October 12, November 4, and December 2, 1999, and January 4, February 3, April 4, May 4, June 6, July 12, August 8, and September 6, 2000. 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 those at Site 3, although the sill cooled slightly faster in the fall and warmed slightly faster in the spring. The sill samples were slightly more turbid than Site 3 during winter. Most of the metals concentrations were at or near the detection limits. Iron and zinc were detectable, but within ranges normal for the lake. Total organic carbon concentrations ranged from < 1 to 3.3 mg/L.

Seven creeks in the Lake Whatcom watershed were sampled on February 9 and July 18, 2000. Most of the 1999/2000 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. Austin Creek, Silver Beach Creek, and the Park Place drain exceeded the Class AA standards[2] for fecal coliforms, as well as the proposed standards for water contact recreation[3]. Silver Beach Creek and the Park Place drain exceeded both Part A and Part B of the coliform and *Enterococcus* standard. Austin Creek passed Part A of both standards because it had geometric means of 46 and 17 cfu/100 mL for fecal coliforms and *Enterococcus*, respectively. However, more than 10% of the bacteria counts exceeded Part B of the standards.

A water balance model was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage in the watershed. Whatcom Creek was the major hydrologic output from the lake during the winter months and in May and June of 2000. Georgia Pacific and the City of Bellingham were major withdrawals during periods of low flow in Whatcom Creek. Evaporation losses were on the same order of magnitude as the City withdrawals during the late spring and summer months. In past years, the diversion from the Middle Fork was often the major water source during the summer; however, beginning in 1998, the amount of water diverted from the Middle Fork was greatly reduced.

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

[2]"Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; and, 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 freshwater, enterococci organisms levels must not exceed a geometric mean value of 33/100 mL, with not more than 10 percent of all samples exceeding 61/100 mL (Draft Revised Language, WAC 173–201A, Washington State Dept. of Ecology, 2001).

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks. The hydrograph data were recorded at 30 minute intervals throughout the year, except during infrequent periods of recorder failure or extreme low flow.

Water movement studies in Lake Whatcom continued this year near the Geneva Sill, the confluence of Anderson Creek, and Strawberry sill in basin 3. The the primary objective was to examine internal wave dynamics. The results from data recorded by a thermistor located near the top of Geneva sill demonstrated that water from the hypolimnion of basin 1 can move as a wave into basin 2. Similarly, the temperature data from a string of thermistors suspended 10–40 m deep near the mouth of Anderson Creek recorded evidence suggesting internal waves moving in the vicinity of the thermocline.

Park Place and Brentwood wet ponds were sampled on December 6–8, 1999 (wet season - storm flow), March 6–8, 2000 (wet season - nominal flow), and July 17–19, 2000 (dry season - nominal flow). Composite and grab samples were collected at the inflow and outflow at each site. As in previous years, there were no consistent reductions for most contaminants. On July 18, 2000, the relatively clean water flowing from the Grace Lane wetland was diverted so that it no longer flows through the Park Place wet pond. This should improve the treatment capability of the Park Place pond by increasing residence time in the pond.

1 Introduction

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County (including Sudden Valley), and provides high quality water for the Georgia-Pacific Corporation mill. 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 1999/2000 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, begin evaluating water movement patterns in the lake, and monitor the effectiveness of the Park Place and Brentwood wet ponds.

This report is subdivided into the following sections covering the topics listed as major and secondary objectives:

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 30 at the beginning of Appendix B describes 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 54; Appendix A, page 208). 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 (Appendix A, Figure 162, page 212). These sites are located on the 40-m depth contour as described in Appendix A.

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 1999/2000 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 1999/2000 were: October 5, 6, 7, & 12[4], November 2 & 4, December 1–2, 1999, and February 3–4, April 4 & 6, May 2 & 4, June 6 & 8, July 12–13, August 8 & 10, and September 6–7, 2000. The water quality parameters measured for the 1999/2000 lake monitoring program are shown in Table 1 on page 24 (see Section 8, beginning on page 23, 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 25 (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.

[4]Repeated equipment failure in the field resulted in an unusually long sampling period for October, 1999.
[5]AmTest, 14603 N.E. 87th St., Redmond, WA, 98052.

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 55–84). Figures 12–31 show a ten year history of results for Lake Whatcom. Long-term patterns were discussed in the 1998/99 annual report (Matthews, et al., 2000); no new long-term trends were apparent in this year's plots of the data.

Single-day Hydrolab profiles from February and September are illustrated on Figures 2–11 (pages 55–64). 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 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 temperature at each site (Tables 3–7, pages 26–30) was similar to last year, and both years were slightly cooler ($\sim 0.4\ ^\circ$C) than historic averages[6]. The cooler temperatures were most apparent during the summer (Figures 12–16, pages 65–69).

[6]Historic Lake Whatcom data from 1988 through the present are included on a CD at the end of this report. The average lake temperature from October 1988–September 1998 was 11.4° C, compared to 11.0° C for October 1998–September 2000.

Despite the cool summer, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures 7–8 and 17–18, pages 60–61 and 70–71). 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 had very low concentrations of essential nutrients such as phosphorus, biological respiration had little influence on hypolimnetic oxygen concentrations (e.g., Figures 11 and 21, pages 64 and 74). In contrast, Site 1, which is located in nutrient-enriched waters, showed rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures 7 and 17, pages 60 and 70).

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 8 (page 31) 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 9, page 32).

Pearson's r correlation analysis[7] of dissolved oxygen vs. year confirmed that there were statistically significant reductions in oxygen levels at all even depths $\geq$ 12 m from June through September (Figures 32–35, pages 85–88)[8]. None of the June through September hypolimnetic temperature data were significantly correlated with year at the 95% significance level; however, there were slight negative correlations[9] at 10 meters in July and August that would be significant at the 90% level (Figure 36, page 89). 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

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

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

[9] Negative temperature correlations suggest that recent July and August water temperatures have been slightly cooler than the 13-year average.

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-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, 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 (0.27 mg/L) and Site 2 (0.53 mg/L) on October 10, 2000, as were high concentrations of ammonia, phosphorus, and iron. These compounds are all indicative of low oxygen conditions.

Although Site 1 continued to develop the earliest and most prolonged period of anoxia in the lake, Site 2 has had higher hydrogen sulfide concentrations for the past 2 years, and this year had higher hypolimnetic ammonia concentrations than Site 1 (see discussion below). 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. Site 3 developed low hypolimnetic oxygen conditions again this year (see Figure 10, page 63), but the levels did not fall as low as in 1999.

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.

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 37–117 (pages 90–170) and summarized in Tables 3–7 (pages 26–30). In order to provide a better analysis of the water quality patterns in the lake, the graphs include ten years of monitoring data. Long-term trends were discussed in the 1998/99 Final Report (Matthews, et al., 2000); no new long-term trends were apparent in this year's plots of the data.

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 data are listed in Appendix B, beginning on page 214, and included on a CD at the end of this report. The metals data are listed in Table 10 (page 33) and the original AmTest data reports (metals and total organic carbon) are included in Appendix C (page 287).

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures 37–41, pages 90–94). 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 < 1–2 NTU except during late summer samples at the lower depths at Sites 1 and 2 (Figures 42–46, pages 95–99). 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 47–66, pages 100–119). The late summer ammonia concentrations at Site 1 were very high at 15 and 20 m depths (Figure 52, page 105). High hypolimnetic ammonia concentrations have been common at Site 1 for at least ten years; however, the last three summers had atypically high concentrations, comparable only to the summer of 1994, which was an unusually warm summer. If the ammonia concentrations are increasing in the hypolimnion at Site 1, it would be consistent with the decreasing levels of hypolimnetic oxygen. Ammonia is produced primarily 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 hypolimnion at Site 1, ammonia accumulates until the lake destratifies.

Very high ammonia concentrations were again measured at the bottom of Site 2. In October 1999 and 2000, the maximum ammonia concentrations at Site 2 were 424 and 340 μg-N/L, respectively. These concentrations were higher than Site 1, and were among the highest ammonia concentrations measured at any location in Lake Whatcom since 1989.

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 57–61, pages 110–114), particularly at Site 1 where the epilimnetic nitrate concentrations fell to < 20 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). 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/L, making it unlikely that nitrogen was limiting at these sites.

Hypolimnetic nitrate concentrations were also < 20 μg-N/L at Site 1 and Site 2 in October. 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 remained low at all sites and depths except Sites 1 and 2, 20 m (Figures 72–76, pages 125–129). Total phosphorus concentrations were high at Sites 1 and 2 during late summer, but relatively low at other sites (Figures 77–81, pages 130–134). 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/L (Figures 77 and 78). 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 80 and 81).

Site 1 continued to have the highest chlorophyll concentrations (Figures 82–86, pages 135–139) of all the sites. The chlorophyll concentrations during the summer of 2000 were about the same as in 1999. As in 1999, low chlorophyll concentrations were measured during late summer at Site 1, 15–20 m, and Site 2, 20 m. 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.

As in 1999, the summer 2000 plankton counts at Site 1 were relatively low compared to previous years (Figure 87–96, pages 140–149). The winter, spring, and fall counts, however, were fairly typical. The Cyanophyta and Chlorophyta peaks were also relatively low; however, algal blooms tend to be highly variable from year to year. Also, we sample algae monthly, and blooms may come and go in between our sampling intervals. Increased sampling frequencies would help define the algal dynamics in the lake, but would require more time than is appropriate for the long-term monitoring program. Short term studies of the algal dynamics have been done in Lake Whatcom (e.g., Ehinger, 1988). During the 2000/2001 lake monitoring project, algal biovolume data will be collected as part of a on-going effort to improve the characterization of algal population dynamics in the lake.

Total organic carbon (TOC) concentrations were low ($<$ 1 mg/L) in February 2000, but relatively high during September (2.2–3.6 mg/L) (Table 11, page 34). These concentrations were slightly higher than the January–November 2000 TOC concentrations measured by the City of Bellingham in raw water at the gatehouse, where concentrations ranged from 1.5–2.4 mg/L.[10] 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. The 1999 average THM concentration in the Bellingham water distribution system was 29.2 μg/L, which is well below the recommended maximum drinking water concentration of 80 μg/L. Beginning in the fall of 1998, however, unusually high THM concentrations ($>$ 40 μg/L) were measured in treated water (Figure 97, page 150) during the 3rd quarter (fall). This pattern has been consistent for the past three years.

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 (Figures 98–102, pages 151–155).

Coliform and *Enterococcus* counts were low at all sites, $\leq$ 50 cfu[11]/100 mL for total coliforms, and $\leq$ 10 cfu/100 mL for fecal coliforms and *Enterococcus* (Figures 103–117, pages 156–170; raw data are listed in Appendix B). The total and fecal coliform counts were slightly higher during the winter, which was probably related to storm water runoff.

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 for raw data). The Bloedel-Donovan bacteria counts in 1999/2000 were slightly higher than mid-basin counts, but had a 5-year geometric mean of 7 cfu/100 mL and passed both Part A and B of the existing Class AA standards for fecal coliforms[12] as well as the proposed standards for water contact recreation[13].

[10]Peg Wendling, Bellingham Public Works Department, personal communications.

[11]cfu = colony forming unit

[12]"Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; and, 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).

[13]In freshwater, enterococci organisms levels must not exceed a geometric mean value of 33/100 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 61/100 mL (Draft Revised Language, WAC 173–201A, Washington State Dept. of Ecology, 2001).

The metals data for Lake Whatcom are included in Table 10 (page 33). This table includes the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) as well as 24 additional metals that are included "free" as part of the analytical procedure used by AmTest. 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. Only the regularly contracted metals will be discussed in this report.

Most of the September metals concentrations were at, or below, detection limits, and those that were detected were within normal concentration ranged for surface water. Copper and zinc were detected at low concentrations at most sites. Iron concentrations were elevated in all of the bottom samples except at Site 4. This is typical for the lake. The highest concentrations, 0.700 mg/L and 0.780 mg/L, were measured at Sites 1 and 2, respectively. The higher concentrations at Sites 1 and 2 were the result of iron converting to soluble forms under anaerobic conditions, and leaching into the overlying water. Once again, the highest concentration was measured at Site 2 rather than Site 1. The soluble iron in basin 2 was evident at the gatehouse[14] during late summer and fall (Figure 118, page 171), particularly during the first few weeks after the lake destratifies (see November in Figure 118). Following lake turnover, most of the soluble iron is converted to insoluble iron, which slowly settles to the bottom.

2.3.3 Strawberry sill data

The Strawberry sill Hydrolab, water quality, and metals data are summarized in Tables 12–14 (pages 35–37) and listed in Appendix B (page 214). The AmTest data reports for the metals and total organic carbon analyses are included in Appendix C (page 287).

Strawberry sill was sampled on October 12, November 4, and December 2, 1999, and January 4, February 3, April 4, May 4, June 6, July 12, August 8, and September 6, 2000. 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 those at Site 3, although the sill cooled slightly faster in the fall and warmed slightly faster in the spring. The sill samples were slightly more turbid than Site 3 during winter. Most of the metals concentrations were at or near the detection limits. Iron and zinc were detectable, but within ranges normal for the lake. Total organic carbon concentrations ranged from < 1 to 3.3 mg/L, which was similar to Site 3.

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

3 Creek Monitoring

3.1 Site Descriptions

Seven creeks were sampled twice during the 1999/2000 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 (page 208).

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 (Park Place drain) to relatively unaffected by residential development (e.g., Blue Canyon Creek). Of the three large creeks, Austin Creek, which is sampled near its mouth, receives residential runoff from Sudden Valley. Smith Creek and Anderson Creek, which are also sampled near their mouths, receive relatively little residential runoff.

3.2 Field Sampling and Analytical Methods

The creeks were sampled on February 9 and July 18, 2000. The water quality parameters measured for the 1999/2000 creek monitoring program are shown in Table 15 (page 38). The analytical procedures are summarized in Table 2 (page 25). All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory. Once in the laboratory the handling procedures that were relevant for each analysis were followed (see Table 2). The total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) 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.

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

3.3 Results and Discussion

The primary purpose for the biannual creek monitoring was to provide data that can be compared to the more complete data set generated in 1990 during the storm water runoff project (Walker, et al., 1992). Tables 16–17 (pages 39–42) show the recent creek water quality data compared to the 1990 average water quality values for each creeks. Tables 18–20 show metals, total organic carbon, and coliform data from the 1999/2000 sampling period.

Most of the 1999/2000 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. Anderson Creek had high total suspended solids and turbidity values in the summer because of the glacial silt entering the creek from the Nooksack River diversion. Most other 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 high in all residential creeks compared to 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 total phosphorus concentrations were also relatively high in Anderson Creek, although the concentrations were within the 1990 ranges. The Anderson Creek total phosphorus appears to be bound to sediment because the soluble phosphate concentrations were low ($< 5\ \mu$g/L).

The metals concentrations were below detection limits at all sites except for iron and zinc. Iron and zinc were within normal ranges for surface water in the Lake Whatcom watershed. Silver Beach Creek had the highest total organic carbon concentrations during both February and July (Table 19, page 42).

Coliform counts (Table 20, page 43) were higher in Park Place and Silver Beach Creek than in the other streams, but all counts were within ranges normal for each stream. Austin Creek, Silver Beach Creek, and the Park Place drain exceeded the Class AA standards[16] for fecal coliforms, as well as the proposed standards for water contact recreation[17].

Silver Beach Creek and the Park Place drain exceeded both Part A and Part B of the coliform and *Enterococcus* standard. Austin Creek passed Part A of both standards because it had geometric means of 46 and 17 cfu/100 mL for fecal coliforms and *Enterococcus*, respectively. However, more than 10% of the bacteria counts exceeded Part B of the standards. The historic data from Austin Creek (Table 21, page 44) show that the creek coliform counts are usually lower during the winter than the summer.

4 Lake Whatcom Hydrology

4.1 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 and water diverted from the Middle Fork of the Nooksack River. Outputs include evaporation, Whatcom Creek, the Whatcom Creek Hatchery, City of Bellingham, Georgia Pacific, and Water District #10. In recent years direct precipitation and evaporation were not considered in the water balance. By considering them this year, runoff (ground water and surface runoff) is left as the only unknown input into the lake. All quantities were provided by the City of Bellingham, except for the evaporation magnitudes, which were modeled using pan evaporation data from the Post Point weather station.

Daily precipitation magnitudes were estimated using the precipitation data recorded at the Geneva gatehouse, Smith Creek, and Brannian Creek hatchery gauges. Precipitation data from the Water District #10, Division 30 gauge was used for the month of September because the Brannian Creek gauge was inoperable. The Theissen polygon method (Dingman, 1994) was used to estimate the precipitation areal average over the lake by weighting the precipitation at each gauge by a respective area percentage. Daily lake evaporation was estimated using a model based on the Penman method (Dingman, 1994). The Penman method is a theoretically based model that estimates free-water evaporation using both

[16]"Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; and, 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).

[17]In freshwater, enterococci organisms levels must not exceed a geometric mean value of 33/100 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 61/100 mL (Draft Revised Language, WAC 173–201A, Washington State Dept. of Ecology, 2001).

energy-balance and mass transfer concepts. The method requires average local or regional energy and climate data. The model was calibrated to pan evaporation data from the Post Point weather station. Daily lake level change 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 level of the lake, precipitation depth, and evaporation depth were all estimated in inches. These values were multiplied by the surface area of the lake and converted to gallons. Changes in surface area of the lake due to lake level changes were ignored. Daily runoff was predicted from the lake water balance values by adding the outputs to the change in storage and subtracting the precipitation and diversion magnitudes.

The daily water balance quantities were summed to obtain monthly totals. The monthly totals were used to generate plots of the input, output, change in storage, and predicted runoff volumes (Figures 119–123, pages 172–176). Figure 119 shows that the direct lake surface precipitation volumes were larger than the Middle Fork diversion volumes for most of the year, except during the summer months. Both of these volumes were approximately an order of magnitude smaller than the predicted runoff volumes plotted in Figure 123 during the winter and spring. As illustrated in Figure 120, Whatcom Creek was the major hydrologic output from the lake during the winter months and in May and June of 2000. Georgia Pacific and the City of Bellingham were major withdrawals during periods of low flow in Whatcom Creek. Note also that evaporation losses were on the same order of magnitude as the City withdrawals during the late spring and summer months. The change in lake storage shown in Figure 121 reflects the pattern of high runoff and high Whatcom Creek discharge in the winter and lower runoff in the summer and fall.

In past years, the diversion from the Middle Fork was often the major water source during the summer. Beginning in 1998, the amount of water diverted from the Middle Fork was greatly reduced to help maintain in-stream flows in the Middle Fork (Figure 122, page 175). The effect of this reduction undoubtedly contributes to the negative lake storage during summer and fall (Figure 121).

Daily runoff magnitudes were examined by spreading the predicted runoff volumes over the land surface to attain a runoff depth and comparing this depth to the direct precipitation depth over the lake. The daily predicted runoff depths and direct lake precipitation depths were summed into weekly totals and plotted in Figure 124 (page 177). In theory, the land runoff depth should correlate (at least in shape, if not in magnitude) with the lake direct precipitation depth, assuming that when it rains on the lake it also rains on the land surface. Note, however, that the two curves did not always correlate. The predicted runoff depth curve followed a similar trend as the direct lake precipitation in the winter months, but not in the summer and fall. The shape of the direct runoff depth curve can, in part, be described by a change in storage in the watershed. The lake precipitation depth curve in Figure 124 indicates that most of the precipitation fell on the lake and watershed between October and April. Because of the higher rainfall amounts and minimal evapotranspiration during these months, the water content of the soil increases, which lowers the soils infiltration and storage capacity, causing a higher runoff when it rains. This produces a stronger correlation between the two curves in Figure 124 in the winter months. During the summer and early fall, less rainfall and higher evapotranspiration rates reduce the soil water content, which increases the infiltration and storage capacity of the soils. When rainfall events do occur in these months, a high percentage of the rain goes to replenishing soil storage rather than runoff. This explains the weak or inverse correlation between the two curves during the summer and early fall. As a result, during the summer months runoff may not be sufficient to maintain lake level.

4.2 Hydrograph Data

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks. The location of each hydrograph is described in Appendix A (page 208). The hydrograph data were recorded at 30 minute intervals throughout the year, except during infrequent periods of recorder failure or extreme low flow (Anderson Creek only). Figures 125–127 (pages 178–180) show that there is considerable variation between winter and summer discharge rates. Figures 128–130 (pages 181–183) show the current rating curves for each hydrograph. The hydrograph data are included on the CD that accompanies this report.

4.3 Water Movement

This section describes research conducted by graduate students Bert Rubash and Matt Chase from the Geology Department at Western Washington University.

Water movement studies in Lake Whatcom continued this year near the Geneva Sill, the confluence of Anderson Creek, and Strawberry sill in basin 3. Although some drifter experiments were performed to examine currents and circulation, the primary focus in these regions was to examine internal wave dynamics. Internal waves are an important phenomenon in stratified lakes because they have been documented to impact transport and mixing (Hodges et al., 1999). Internal waves propagate through the metalimnion and are driven by wind which generates a longitudinal pressure gradient in a lake (Stevens, 1999). 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 (Stevens, 1999). Single thermistors and chains of thermistors were used in Lake Whatcom for much of the water movement studies conducted this year (see Figure 131 for a diagram of a typical thermistor chain). The design of the thermistor configurations, data acquisition, and deployment and retrieval methods evolved throughout the summer with experimental attempts and preliminary analysis of the data. A conceptual synopsis of some of the results will discussed here. A thorough understanding of internal waves in the lake will require extensive spectral analyses of both the time series from the thermistors and wind data from the weather station, which is beyond the scope of this report.

The results from data recorded by a single thermistor located near the top of Geneva sill demonstrated that water from the hypolimnion of basin 1 can move as wave into basin 2. The thermistor was located 0.25 m from the bottom of the sill in water 4.5 m deep. We expected that the temperatures recorded by this thermistor would be almost constant, given that the sill is located in the unstratified, epilimnetic waters of basin 1. The data from a 6 day interval in late July revealed that the temperature remained relatively constant (19.5±0.5° C) throughout this period, except for anomalous cold water spikes that peaked at about 15.5° C on July 22, 2000 (Figure 132, page 185). The temperature profiles from July 13, 2000 at sites 1 and 2 in basins 1 and 2 indicate that we would expect to find 15.5° C water located at depths of 8 meters or deeper in basin 1 and 11.5 m or more in basin 2 (Figures 133 and 134, pages 186 and 187). The spike in temperature suggests that the cold water was an internal wave surge across the sill. The internal wave coincided with a thunderstorm that moved over the lake on July 22.

An expanded graph of the temperature plot (Figure 135, page 188), shows regular periodic features of the cold water pulses that supports the internal wave theory. There were three temperature oscillations illustrated in Figure 135, which appear to have periods of 39 minutes, 38.5 minutes, and 37 minutes. The shortening of the period from the front to the back of a wave train is characteristic of the dispersivity of water as a medium for gravity waves. A common example of dispersion of a surface wave is a boat wake, which begins as a single slosh of water away from the bow of a moving boat, but far away becomes a train of waves with longer waves leading the group and progressively smaller waves following behind. Each sinusoidal (Fourier) component of the original disturbance travels with a velocity that depends on its period, with long period waves traveling fastest.

Although the direction of travel of the wave train cannot be found in the temperature record, the direction of movement of the storm may provide a basis for determining the direction of wave train travel. If it is assumed that an internal wave train travels outward from the disturbance that generates it, then wave trains would be generated in two directions on a long, narrow lake such as Lake Whatcom, with a storm moving down its length; one wave train moving in the same direction as the storm, and the other in the opposite direction. A wave train moving opposite the storm would receive only an initial surge of energy and then begin to dissipate as the storm passed. In contrast, a wave train moving in the same direction as the storm would receive continuous energy input as long as it remained under the storm.

A comparison of wind records from a weather recording station in Squalicum Harbor in Bellingham and from the weather station located on the east shore of Lake Whatcom indicates that the storm moved from Bellingham southeastward onto the lake. These records show that it was a strong, but slow moving storm. Figure 136 (page 189) is a plot of these two wind speed records for July 22. This information implies that the probable direction of travel of the internal wave train was southeast, from basin 1 to basin 2.

We began examining the dynamics of water flow in the southeast bay of basin 3 in Lake Whatcom this summer by performing additional drifter studies and monitoring lake-water temperature near the confluence of Anderson Creek. Drifters (Figure 137, page 190) were placed in the southeast bay on three different days, but the results were too inconsistent to make general predictions about circulation patterns. In all cases, drifters at the surface to about 15 m below the surface, moved with the highest velocity and in the direction of the wind. Surface velocities ranged from 10 to 158 m per hour, depending on wind velocities. On two occasions the near surface water was moving in a southeast direction, up the mouth of Anderson Creek. This indicates that surface currents generated by wind shear may affect, to some degree, the impact of Anderson Creek discharge as it flows in Lake Whatcom. Deeper drifters (30 to 40 m) on the other hand moved slower, but in some cases in the opposite direction to the wind.

Because Anderson Creek discharge is colder than the epilimnion in the summer when the diversion from the Middle Fork is in operation, a temperature sensor was placed in the lake near the confluence of Anderson Creek to monitor the temperature change in the lake due to the diverted water. The temperature record of a thermistor anchored at a depth about 2.2 m clearly indicated drops in temperature that correlated with the times during the months when the diversion was in operation (Figure 138, page 191). We didn't measure how close the creek discharge was to the sensor during this experiment because the river channel in the delta (thalweg) is not yet known. The results from this experiment, however, have given us confidence that tracking water temperature to determine the discharge path of Anderson Creek into Lake Whatcom is feasible for future studies.

Another example of the dynamic internal structure of lake under stratified conditions can be observed in Figure 139 (page 192), which displays the temperature records from a thermistor array (Figure 131) that was placed southeast of Strawberry sill from early August to late September. As indicated on both Figures 139 and 131, the thermistor depths below the water surface ranged between 10 m and 40 m. The intent was to explore internal wave activity by monitoring the temperature variability in the epilimnion, thermocline and hypolimnion.

The temperature record of the thermistors at 10 m (epilimnion) and 40 m (hypolimnion) in Figure 139 remained relatively stable. Note that the temperature record of the 10 m thermistor decreases from about 20° C to close to 17° C, indicating the drop in temperature of the mixed region of the epilimnion in September. This was also documented by the pattern reflected by the temperature record from the 14 m thermistor. In August, the thermistor experienced larger temperature extremes. The thermistor may have been near the top of the thermocline and, therefore, experienced greater temperature fluctuations as if the thermocline was moving up and down. The 14 m temperature data became more constant in September and were equivalent to the temperature data from 10 m ($\sim$17° C). This could be explained by an epilimnion with a basal interface edging downward. As the base of the epilimnion migrates deeper, it would force the thermocline away from the 14 m sensor allowing it to record the mixed region of the epilimnion. A similar effect was apparent in the 18 m data. Although the 18 m temperature data were variable, they showed a general warming trend approaching the temperature of the epilimnion.

Our interpretation of the variability observed in the temperature records of the 18 m and 22 m thermistors in Figure 139 was based on the assumption that the sensors were in the thermocline. The 18 m thermistor was believed to be near the middle of the thermocline, which would explain the more radical fluctuations in the 18 m record. The 22 m thermistor was thought to be closer to the bottom of the thermocline where it would not experience large temperature swings. The fluctuations observed at these locations indicate the unstable and dynamic nature of the thermocline, and could be the result of internal waves propagating along the interface at the base of the epilimnion. As discussed above, wind energy is the most likely energy source responsible for the internal wave character. (Note, for example, the large spike around September 11.)

Another factor that could be contributing to some of the temperature variability observed on Figure 139 is the lateral movement of the float supporting the thermistors. The float that helps keep the sensors vertical probably moves laterally due to the currents that we know exist in the epilimnion. If the float does in fact move laterally, it would force the thermistors into deeper water (see Figure 140, page 193 for an illustration of this effect). If the currents waxed and waned and changed direction, the float would in affect move back and forth and force the thermistors up and down. The thermistors in or near the thermocline, would record fluctuating temperatures due to the temperature variability in this region. We will attempt to investigate this possibility in future experiments.

5 Brentwood and Park Place Monitoring

The objective of this project was to monitor 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 1999, a small, natural wetland located at the end of South Grace Lane was added to the sampling program. The outflow of this wetland was monitored to determine whether the wetland runoff could be diverted from the Park Place feeder system, which might improve storm water treatment in the Park Place wet pond by creating a longer residence time for the pond. The locations of the monitoring sites are shown on Figure 141 (page 194).

5.1 Sampling procedures

Park Place and Brentwood wet ponds were sampled on December 6–8, 1999, March 6–8, 2000, and July 17–19, 2000. Composite and grab samples were collected at the inflow and outflow at each site. 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.

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 142–143 (pages 195–196).

December 6–8 represented “wet season - storm flow” sampling conditions, having been preceded by several days of heavy precipitation. There was no precipitation during the sampling period. On December 6 the flow was very high at the inlet to Park Place and some of the storm water was bypassing the pond. On December 7 some of the flow still bypassed the pond, but by December 8 the flow rates had dropped so that most of the runoff flowed through the pond. March 6–8 represented “wet season - nominal” sampling conditions. There was no precipitation during the sampling period or for 24 hours prior to sampling. All of the water from the Park Place drainage was flowing through the pond. The July 17–19 samples constituted “dry season - nominal flow” conditions, with no precipitation during sampling or for 48 hours preceding sampling. All of the water from the Park Place drainage was flowing through the pond. On July 18 the flow from the Grace Land wetland was diverted so that it no longer flowed into the Park Place pond, but rather flowed directly into the lake. We were unable to ascertain the amount of flow through the Brentwood pond during these sampling periods.

Tables 22–25 (pages 45–48) show the raw data from the Park Place and Brentwood ponds, as well as the Grace Land wetland. 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. Average percent reductions were computed as follows:

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

As in previous years, there were no consistent reductions for most contaminants except coliforms, which were reduced in the Park Place samples and in most of the Brentwood samples. Total suspended solids were slightly reduced in the Park Place samples (5.3%), but increased 110% in the Brentwood samples. Total organic carbon and total phosphorus were consistently higher at the outlets for both ponds. Percent reductions were computed for detectable metals (most metals concentrations were below detection). Chromium, iron, and zinc were usually slightly reduced at the outlets for both ponds.

In summary, the Park Place and Brentwood wet ponds performed poorly for most types of contaminants, with no consistent reduction in sediments, nutrients, total organic carbon, or metals concentrations between the inlet and outlet.

On July 18, 2000, the flow from the Grace Lane wetland was diverted so that it no longer flows through the Park Place wet pond, but rather flows directly into Lake Whatcom. The water quality at the outlet from the wetland is generally cleaner than the Park Place inflow or outflow, so its diversion into the lake should not increase water quality problems in basin 1. Furthermore, by removing the wetland flow, the Park Place wet pond should be able to handle more storm flow without bypassing the pond, and should have a longer residence time in the pond. The bypass occurred during the July 17–19, 2000 sampling period, so we do not have results showing the effect of the diversion on Park Place. Next year's report will evaluate the difference between past Park Place performance and performance after the wetland diversion.

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 25). Single-blind quality control tests were conducted as part of the IWS laboratory certification process. The 1999/2000 results are presented in Table 26 (page 49). 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 Hydrolab data). Results from the laboratory duplicates are shown on Figures 144–154 (pages 197–202). The difference between laboratory duplicates is compared to the average difference expected for each analysis based on a larger sample of lab duplicates. Nearly all of the duplicates were in close agreement. Duplicates that differ by more than three standard deviations were investigated and the results are discussed in Table 27 (page 50).

Separate field duplicates were collected and analyzed for at least 10% of all of the water quality parameters (except Hydrolab). 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. Results from the field duplicates are shown on Figures 155–159 (pages 203–207).

The field duplicates were in close agreement, given that they came from different water samples. 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 155). 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 80–84). These conductivity differences were generally ≤ 5 μS.

The median difference between Hydrolab and Winkler dissolved oxygen values was 0.3 mg/L, and 86.9% of the samples differed by no more than 1.0 mg/L. As in previous years, 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 8, page 31). 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.

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. During August and September, we conducted a series to tests to measure the amount of variation between surface and bottom samples (Table 28, page 51). The results indicate that there was no consistent bias between surface and bottom temperature and conductivity samples, but there was a small positive bias for pH and dissolved oxygen. The average differences between measurements were very small ($\approx$ 0.1 unit), so no changes in Hydrolab operating procedures were instituted.

7 References

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8 Tables

	1999			2000									
Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Location
DO - hydrolab	●	●	●		●		●	●	●	●	●	●	Sites 1, 2, Intake - every 1 m;
pH - hydrolab	●	●	●		●		●	●	●	●	●	●	Sites 3, 4 - every 1 m to 10 m
Temp - hydrolab	●	●	●		●		●	●	●	●	●	●	then every 5 m;
Cond - hydrolab	●	●	●		●		●	●	●	●	●	●	Gatehouse
Secchi depth	●	●	●		●		●	●	●	●	●	●	Sites 1, 2, 3, 4, Intake
Ammonia	●	●	●		●		●	●	●	●	●	●	Sites 1, 2 - 0.3, 5, 10, 15, 20 m;
Nitrite/nitrate	●	●	●		●		●	●	●	●	●	●	Intake - 0.3, 5, 10 m;
Total nitrogen	●	●	●		●		●	●	●	●	●	●	Site 3 - 0.3, 5, 10, 20, 40, 60,
Soluble phosphate	●	●	●		●		●	●	●	●	●	●	80 m;
Total Phosphorus	●	●	●		●		●	●	●	●	●	●	Site 4 - 0.3, 5, 10, 20, 40, 60,
Alkalinity	●	●	●		●		●	●	●	●	●	●	80, 90 m;
Turbidity	●	●	●		●		●	●	●	●	●	●	Gatehouse
Total 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 1999/2000 lake monitoring schedule.

Parameter	Method	Historic DL§ or Sensitivity (±)	MDL 1999/2000
Conductivity-field	Hydrolab (1997), field meter	± 2 μS/cm	na
Conductivity-lab	APHA (1998) #2510, low-level, SOP-LW-9	± 2 μS/cm	na
Dissolved oxygen-field	Hydrolab (1997), field meter	± 0.1 mg/L	na
Dissolved oxygen-lab	APHA (1998) #4500-O.C., Winkler, SOP-LW-12	± 0.1 mg/L	na
pH-field	Hydrolab (1997), field meter	± 0.1 pH unit	na
pH-lab	APHA (1998) #4500-H^+, low-ionic, SOP-LW-8	± 0.1 pH unit	na
Temperature	Hydrolab (1997), field meter	± 0.1° C	na
Alkalinity	APHA (1998) #2320, low level, SOP-IWS-15	± 0.1 mg/L	na
Discharge	Lind (1985), rating curve, SOP-IWS-6	na	na
Secchi disk	Lind (1985)	± 0.1 m	na
Total suspended solids	APHA (1998) #2540 D, gravimetric, SOP-LW-22	DL = 2 mg/L	na
Turbidity	APHA (1998) #2130, nephelometric, SOP-LW-11	± 0.2 NTUs	na
Ammonia	Wetzel & Likens (1991), phenate, SOP-LW-21	DL = 10 μg/L	3.7
Nitrite/nitrate	APHA (1998) #4500-NO_3 I., Cd reduction, SOP-IWS-19	DL = 20 μg/L	16.3
Total nitrogen	APHA (1998) #4500-N C., Ebina et al. (1983), salicylate, SOP-IWS-19	DL = 100 μg/L	19.2
Soluble phosphate, man†	APHA (1998) #4500-P E., ascorbic acid, SOP-LW-20	DL = 5 μg/L	1.9
Soluble phosphate, auto‡	APHA (1998) #4500-P G., ascorbic acid, SOP-IWS-19	DL = 5 μg/L	1.9
Total phosphorus, man†	APHA (1998) #4500-P E., persulfate digestion, SOP-LW-18	DL = 5 μg/L	1.8
Total phosphorus, auto‡	APHA (1998) #4500-P H., persulfate digestion, SOP-IWS-19	DL = 5 μg/L	4.7
Chlorophyll	APHA (1998) #10200 H, acetone, SOP-IWS-16	± 0.1 mg/m^3	na
Plankton	Lind (1985), Schindler trap	na	na
			na
Total coliform (City)	APHA (1998) #9222 B, membrane filter	na	na
Fecal coliform (City)	APHA (1998) #9222 D, membrane filter	na	na
Enterococcus (City)	APHA (1998) #9223 A (mod.), MPN-methyl.	na	na

† 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 $CaCO_3$)	19.4	1.7	17.6	25.9
Conductivity - lab (μS)	61.9	2.7	59.9	73.2
Conductivity - Hydrolab (μS)	57.9	2.5	54.8	67.7
Dissolved Oxygen (mg/L)	7.9	3.6	0.0	11.9
pH	7.3	0.5	6.5	8.6
Temperature (°C)	11.4	4.0	5.3	22.2
Turbidity (NTU)	1.1	1.0	0.5	6.9
Nitrogen, ammonia (μg/L)	26.4	49.3	$<$10	268.3
Nitrogen, nitrate/nitrite (μg/L)	220.2	122.6	$<$20	377.0
Nitrogen, total (μg/L)	376.5	107.3	165.4	506.8
Phosphorus, soluble (μg/L)	$<$5	1.6	$<$5	11.5
Phosphorus, total (μg/L)	8.0	4.4	$<$5	23.6
Chlorophyll a (mg/m^3)	2.3	1.5	0.3	5.9
Secchi depth (m)	4.5	1.0	3.0	5.7
Coliforms, total (cfu/100 mL)‡	4.8	na	1	18
Coliforms, fecal (cfu/100 mL)‡	1.6	na	$<$1	6
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, 10/99–9/00.

Variable	Mean†	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	18.1	0.7	17.4	20.5
Conductivity - lab (μS)	59.0	0.4	58.4	59.9
Conductivity - Hydrolab (μS)	55.3	1.1	53.8	57.9
Dissolved Oxygen (mg/L)	9.9	0.9	8.8	11.4
pH	7.7	0.3	7.2	8.3
Temperature (°C)	14.0	4.7	6.4	21.2
Turbidity (NTU)	0.6	0.2	0.4	1.0
Nitrogen, ammonia (μg/L)	<10	4.5	<10	21.8
Nitrogen, nitrate/nitrite (μg/L)	284.6	97.0	156.0	424.0
Nitrogen, total (μg/L)	427.2	81.1	285.1	526.2
Phosphorus, soluble (μg/L)	<5	0.2	<5	<5
Phosphorus, total (μg/L)	<5	0.8	<5	6.0
Chlorophyll a (mg/m^3)	1.9	0.7	0.7	3.3
Secchi depth (m)	5.5	1.0	4.3	7.5
Coliforms, total (cfu/100 mL)‡	6.4	na	2	29
Coliforms, fecal (cfu/100 mL)‡	1.8	na	<1	8
Enterococcus (cfu/100 mL)‡	2.1	na	<2	4

†Arithmetic means except as noted.
‡Geometric means.

Table 4: Intake average ambient water quality data, 10/99–9/00.

Variable	Mean†	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	18.2	1.5	17.2	26.9
Conductivity - lab (μS)	60.1	3.1	58.3	73.3
Conductivity - Hydrolab (μS)	55.9	2.3	52.9	70.4
Dissolved Oxygen (mg/L)	8.8	2.7	0.0	11.1
pH	7.4	0.4	6.5	8.4
Temperature (°C)	12.0	4.1	6.2	21.2
Turbidity (NTU)	0.7	0.9	0.4	6.4
Nitrogen, ammonia (μg/L)	23.1	63.1	<10	424.4
Nitrogen, nitrate/nitrite (μg/L)	294.4	107.7	<20	439.8
Nitrogen, total (μg/L)	444.1	86.3	264.5	587.7
Phosphorus, soluble (μg/L)	<5	2.4	<5	16.9
Phosphorus, total (μg/L)	6.3	5.3	<5	31.8
Chlorophyll a (mg/m^3)	1.6	0.7	0.3	3.3
Secchi depth (m)	5.7	0.9	4.0	7.0
Coliforms, total (cfu/100 mL)‡	2.8	na	1	12
Coliforms, fecal (cfu/100 mL)‡	1.4	na	<1	4
Enterococcus (cfu/100 mL)‡	2.1	na	<2	4

†Arithmetic means except as noted.
‡Geometric means.

Table 5: Site 2 average ambient water quality data, 10/99–9/00.

Variable	Mean†	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	17.6	0.6	16.7	20.0
Conductivity - lab (μS)	59.3	0.6	58.4	61.3
Conductivity - Hydrolab (μS)	55.4	1.7	53.1	74.1
Dissolved Oxygen (mg/L)	9.4	1.1	0.5	11.4
pH	7.4	0.4	6.6	8.2
Temperature (°C)	10.0	4.4	6.4	21.3
Turbidity (NTU)	0.5	0.4	0.2	3.2
Nitrogen, ammonia (μg/L)	$<$10	8.0	$<$10	49.5
Nitrogen, nitrate/nitrite (μg/L)	361.4	88.4	177.4	458.0
Nitrogen, total (μg/L)	467.2	90.3	247.8	654.6
Phosphorus, soluble (μg/L)	$<$5	0.5	$<$5	$<$5
Phosphorus, total (μg/L)	$<$5	2.9	$<$5	17.0
Chlorophyll a (mg/m^3)	1.4	0.6	0.3	2.5
Secchi depth (m)	6.6	1.4	4.5	8.5
Coliforms, total (cfu/100 mL)‡	1.8	na	$<$1	5
Coliforms, fecal (cfu/100 mL)‡	1.2	na	$<$1	2
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, 10/99–9/00.

Variable	Mean†	SD	Min.	Max.
Alkalinity (mg/L $CaCO_3$)	17.5	0.5	17.0	19.8
Conductivity - lab (μS)	59.4	0.6	58.2	60.7
Conductivity - Hydrolab (μS)	55.7	1.0	53.8	57.8
Dissolved Oxygen (mg/L)	9.7	0.7	8.0	11.7
pH	7.3	0.4	6.9	8.3
Temperature (°C)	9.7	4.3	6.5	20.8
Turbidity (NTU)	0.4	0.1	0.1	0.9
Nitrogen, ammonia (μg/L)	<10	4.7	<10	18.6
Nitrogen, nitrate/nitrite (μg/L)	383.2	86.3	182.0	470.0
Nitrogen, total (μg/L)	483.4	76.3	248.0	566.8
Phosphorus, soluble (μg/L)	<5	0.8	<5	6.8
Phosphorus, total (μg/L)	<5	2.9	<5	18.2
Chlorophyll a (mg/m^3)	1.5	0.8	0.4	4.7
Secchi depth (m)	6.3	1.6	4.0	9.1
Coliforms, total (cfu/100 mL)‡	1.7	na	<1	8
Coliforms, fecal (cfu/100 mL)‡	1.1	na	<1	3
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, 10/99–9/00.

Depth	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
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
1		9.6	9.6	9.4		10.1	9.6	9.9	10.0	9.9	9.6	9.1	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
3		9.6	9.6	9.3		9.9	9.5	9.8	9.9	9.8	9.5	9.1	9.3
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
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
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
7		9.4	9.2	8.7		9.6	9.3	9.5	9.7	8.5	9.4	8.9	8.7
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		7.8	6.2	8.3		4.9	4.5	6.4	8.2	4.2	7.6	5.5	5.0
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
11		3.0	2.2	5.4			0.1	**0.1**	1.2	**0.6**	**0.6**	**0.9**	**0.1**
12	1.1	1.7	1.7	2.1			0.0	0.1	**0.2**	0.5	0.5	0.1	0.0
13		**0.8**	1.1	1.1			0.0	0.1	0.2	0.5	0.5	0.0	0.0
14	**0.7**	0.6	**0.8**	**0.6**			0.0	0.1	0.2	0.5	0.5	0.0	0.0
15		0.6	0.8	0.6	**0.7**		0.0	0.1	0.2	0.4	0.4	0.0	0.0
16	0.4	0.5	0.8	0.6			0.0	0.1	0.2	0.4	0.4	0.0	0.0
17		0.5	0.8	0.6			0.0	0.1	0.2	0.4	0.4	0.0	0.0
18	0.4	0.5	0.9	0.6			0.0	0.1	0.2	0.4	0.4	0.0	0.0
19		0.5	0.9	0.6			0.0	0.0	0.2	0.4	0.4	0.0	0.0
20			0.9	0.7	1.1		0.0	0.0	0.2	0.4	0.3	0.0	0.0

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

Table 8: Dissolved oxygen concentrations (mg/L) at Site 1, September 1988–2000.

Depth	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
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
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
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
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
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
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
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
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
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
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
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
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
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		11.5	9.9	11.6	11.8	12.6	11.7	12.3	12.7	11.9	11.5	10.4	11.2
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
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
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
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
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
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
20			9.3	10.6	10.5	11.9	10.8	11.3	11.8	11.4	10.7	9.7	10.4

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

Table 9: Water temperatures (°C) at Site 1, September 1988–2000.

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	Sept 11, 2000	<0.01	<0.0005	<0.001	0.003	0.033	<0.01	<0.005	<0.001	0.008
Site 1	20	Sept 11, 2000	<0.01	<0.0005	<0.001	0.002	0.700	<0.01	<0.005	0.005	0.005
Intake	0	Sept 11, 2000	<0.01	<0.0005	<0.001	0.002	0.026	<0.01	<0.005	0.003	0.003
Intake	10	Sept 11, 2000	<0.01	<0.0005	<0.001	0.001	0.031	<0.01	<0.005	0.001	0.004
Site 2	0	Sept 11, 2000	<0.01	<0.0005	<0.001	0.001	0.012	<0.01	<0.005	0.001	0.002
Site 2	20	Sept 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.780	<0.01	<0.005	0.002	0.002
Site 3	0	Sept 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.008	<0.01	<0.005	0.001	0.002
Site 3	80	Sept 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.009	<0.01	<0.005	0.001	0.004
Site 4	0	Sept 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.026	<0.01	<0.005	<0.001	0.004
Site 4	90	Sept 11, 2000	<0.01	<0.0005	<0.001	0.003	0.023	<0.01	<0.005	0.001	0.005

Site	Depth	Date	Al (mg/L)	Sb (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Ca (mg/L)	Co (mg/L)	K (mg/L)
Site 1	0	Sept 11, 2000	<0.01	<0.01	<0.05	0.0064	<0.0005	6.1	<0.001	0.52
Site 1	20	Sept 11, 2000	<0.01	<0.01	<0.05	0.0095	<0.0005	6.1	<0.001	0.56
Intake	0	Sept 11, 2000	<0.01	<0.01	<0.05	0.0064	<0.0005	5.0	<0.001	0.45
Intake	10	Sept 11, 2000	<0.01	<0.01	<0.05	0.0072	<0.0005	5.3	<0.001	0.46
Site 2	0	Sept 11, 2000	<0.01	<0.01	<0.05	0.0064	<0.0005	5.0	<0.001	0.44
Site 2	20	Sept 11, 2000	<0.01	<0.01	<0.05	0.0080	<0.0005	5.9	<0.001	0.54
Site 3	0	Sept 11, 2000	<0.01	<0.01	<0.05	0.0062	<0.0005	5.0	<0.001	0.45
Site 3	80	Sept 11, 2000	<0.01	<0.01	<0.05	0.0066	<0.0005	5.6	<0.001	0.54
Site 4	0	Sept 11, 2000	<0.01	<0.01	<0.05	0.0067	<0.0005	5.4	<0.001	0.49
Site 4	90	Sept 11, 2000	<0.01	<0.01	<0.05	0.0062	<0.0005	4.9	<0.001	0.46

Site	Depth	Date	Li (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	P (mg/L)	S (mg/L)	Se (mg/L)
Site 1	0	Sept 11, 2000	<0.005	1.8	0.0069	<0.005	2.6	<0.01	1.3	<0.01
Site 1	20	Sept 11, 2000	<0.005	1.9	0.2000	<0.005	2.1	0.04	1.3	<0.01
Intake	0	Sept 11, 2000	<0.005	1.7	0.0026	<0.005	2.3	0.03	1.5	<0.01
Intake	10	Sept 11, 2000	<0.005	1.8	0.0033	<0.005	2.3	0.02	1.5	<0.01
Site 2	0	Sept 11, 2000	<0.005	1.7	0.0015	<0.005	2.2	0.02	1.4	<0.01
Site 2	20	Sept 11, 2000	<0.005	1.9	0.1500	<0.005	2.0	0.02	1.2	<0.01
Site 3	0	Sept 11, 2000	<0.005	1.7	0.0007	<0.005	2.3	<0.01	1.4	<0.01
Site 3	80	Sept 11, 2000	<0.005	1.8	0.0079	<0.005	2.3	0.03	1.5	<0.01
Site 4	0	Sept 11, 2000	<0.005	1.8	0.0013	<0.005	2.4	0.02	1.5	<0.01
Site 4	90	Sept 11, 2000	<0.005	1.7	0.0150	<0.005	2.1	<0.01	1.5	<0.01

Site	Depth	Date	Si (mg/L)	Ag (mg/L)	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	Tl (mg/L)	V (mg/L)	Y (mg/L)
Site 1	0	Sept 11, 2000	1.6	<0.01	<0.005	0.046	<0.001	<0.01	<0.005	<0.0005
Site 1	20	Sept 11, 2000	3.3	<0.01	<0.005	0.051	<0.001	<0.01	<0.005	<0.0005
Intake	0	Sept 11, 2000	1.8	<0.01	<0.005	0.043	<0.001	<0.01	<0.005	<0.0005
Intake	10	Sept 11, 2000	1.8	<0.01	<0.005	0.044	<0.001	<0.01	<0.005	<0.0005
Site 2	0	Sept 11, 2000	1.7	<0.01	<0.005	0.042	<0.001	<0.01	<0.005	<0.0005
Site 2	20	Sept 11, 2000	3.3	<0.01	<0.005	0.048	<0.001	<0.01	<0.005	<0.0005
Site 3	0	Sept 11, 2000	1.8	<0.01	<0.005	0.042	<0.001	<0.01	<0.005	<0.0005
Site 3	80	Sept 11, 2000	2.7	<0.01	<0.005	0.045	<0.001	<0.01	<0.005	<0.0005
Site 4	0	Sept 11, 2000	1.9	<0.01	<0.005	0.044	<0.001	<0.01	<0.005	<0.0005
Site 4	90	Sept 11, 2000	2.5	<0.01	<0.005	0.043	<0.001	<0.01	<0.005	<0.0005

Table 10: Lake Whatcom 1999/2000 total metals data.

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 9, 2000	0	<1	Sept 11, 2000	0	3.6
	Feb 9, 2000	20	<1	Sept 11, 2000	20	3.4
Intake	Feb 9, 2000	0	<1	Sept 11, 2000	0	2.7
	Feb 9, 2000	10	<1	Sept 11, 2000	10	2.6
Site 2	Feb 9, 2000	0	<1	Sept 11, 2000	0	2.5
	Feb 9, 2000	20	<1	Sept 11, 2000	15	2.2
Site 3	Feb 9, 2000	0	<1	Sept 11, 2000	0	2.7
	Feb 9, 2000	80	<1	Sept 11, 2000	80	2.9
Site 4	Feb 9, 2000	0	<1	Sept 11, 2000	0	2.9
	Feb 9, 2000	90	<1	Sept 11, 2000	90	3.0

Table 11: Lake Whatcom 1999/2000 total organic carbon data.

Site	Date	Depth (m)	Temp (C)	pH	Cond (μS)	DO (mg/L)
Site 3	Oct 6, 1999	0–35	14.2	7.6	54.0	9.2
Site 3	Nov 2, 1999	0–35	11.5	7.4	56.3	8.9
Site 3	Dec 1, 1999	0–35	9.4	7.4	54.2	9.4
Site 3	Feb 3, 2000	0–35	6.6	7.4	54.5	10.1
Site 3	Apr 6, 2000	0–35	7.7	7.4	55.8	11.2
Site 3	May 2, 2000	0–35	9.7	7.5	54.8	10.3
Site 3	Jun 6, 2000	0–35	12.3	7.7	53.9	10.2
Site 3	July 12, 2000	0–35	15.2	7.8	56.5	9.4
Site 3	Aug 8, 2000	0–35	16.9	7.7	57.0	9.3
Site 3	Sept 6, 2000	0–35	15.6	7.8	56.8	8.6
Site s1	Oct 12, 1999	0–35	13.7	7.6	56.8	9.5
Site s1	Nov 4, 1999	0–35	10.8	7.3	55.5	9.1
Site s1	Dec 2, 1999	0–35	9.4	7.3	55.3	9.4
Site s1	Jan 4, 2000	0–35	7.4	7.2	54.7	9.9
Site s1	Feb 3, 2000	0–35	6.6	7.3	54.7	10.0
Site s1	Apr 4, 2000	0–35	8.2	7.5	53.8	11.4
Site s1	May 4, 2000	0–35	10.3	7.5	54.9	10.7
Site s1	Jun 6, 2000	0–35	12.7	7.8	53.7	9.8
Site s1	July 12, 2000	0–35	15.1	8.0	56.1	9.3
Site s1	Aug 8, 2000	0–35	16.8	7.7	57.3	9.3
Site s1	Sept 6, 2000	0–35	16.5	7.8	56.9	8.4
Site s2	Oct 12, 1999	0–35	13.7	7.5	56.5	9.3
Site s2	Nov 4, 1999	0–35	10.8	7.4	55.6	9.0
Site s2	Dec 2, 1999	0–35	9.4	7.4	55.2	9.4
Site s2	Jan 4, 2000	0–35	7.4	7.2	55.0	10.0
Site s2	Feb 3, 2000	0–35	6.6	7.2	54.8	10.1
Site s2	Apr 4, 2000	0–35	8.1	7.4	53.7	10.9
Site s2	May 4, 2000	0–35	10.4	7.5	54.9	10.5
Site s2	Jun 6, 2000	0–35	13.1	7.8	54.2	10.1
Site s2	July 12, 2000	0–35	15.4	7.9	56.7	9.3
Site s2	Aug 8, 2000	0–35	17.1	7.7	57.3	9.3
Site s2	Sept 6, 2000	0–35	15.8	7.7	56.7	8.4
Site s3	Oct 12, 1999	0–35	13.6	7.5	56.4	9.3
Site s3	Nov 4, 1999	0–35	10.8	7.4	55.4	8.9
Site s3	Dec 2, 1999	0–35	9.4	7.3	55.0	9.3
Site s3	Jan 4, 2000	0–35	7.4	7.2	55.1	10.1
Site s3	Feb 3, 2000	0–35	6.6	7.2	54.7	10.2
Site s3	Apr 4, 2000	0–35	8.1	7.4	53.5	10.8
Site s3	May 4, 2000	0–35	9.8	7.5	54.5	10.2
Site s3	Jun 6, 2000	0–35	12.8	7.8	54.0	9.9
Site s3	July 12, 2000	0–35	15.2	8.0	56.4	9.2
Site s3	Aug 8, 2000	0–35	17.0	7.8	57.3	9.2
Site s3	Sept 6, 2000	0–35	15.7	7.8	56.8	8.3

Table 12: Strawberry sill 1999/2000 hydrolab data compared to Site 3.

Site	Date	Depth (m)	Alk (mg/L)	Turb (NTU)	NH3 (μg/L)	TN (μg/L)	NO3 (μg/L)	SRP (μg/L)	TP (μg/L)
Site 3	Oct 6, 1999	0–35	18.6	0.4	<10	422.2	249.0	<5	<5
Site 3	Dec 1, 1999	0–35	17.4	0.4	<10	436.3	330.8	<5	12.7
Site 3	Feb 3, 2000	0–35	17.3	0.5	<10	528.9	432.0	<5	<5
Site s1	Oct 12, 1999	0–35	17.9	0.3	na	388.7	286.6	<5	<5
Site s1	Jan 4, 2000	0–35	17.5	1.1	<10	487.4	416.9	<5	5.0
Site s2	Oct 12, 1999	0–35	18.0	0.4	na	397.9	306.8	<5	<5
Site s2	Jan 4, 2000	0–35	17.3	1.1	<10	491.2	412.0	<5	<5
Site s3	Oct 12, 1999	0–35	18.2	0.4	na	386.1	290.5	<5	<5
Site s3	Jan 4, 2000	0–35	17.3	1.1	<10	497.7	416.1	<5	<5

Table 13: Strawberry sill 1999/2000 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)	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
s1	0	Oct 14, 1999	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	0.007
s1	35	Oct 14, 1999	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	0.002
s2	0	Oct 14, 1999	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	0.006
s2	35	Oct 14, 1999	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	0.004
s3	0	Oct 14, 1999	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	<0.001
s3	35	Oct 14, 1999	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	0.003
s1	0	Jan 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.021	<0.01	<0.005	<0.001	0.003
s1	35	Jan 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.024	<0.01	<0.005	<0.001	0.017
s2	0	Jan 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.016	<0.01	<0.005	<0.001	<0.001
s2	35	Jan 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.021	<0.01	<0.005	<0.001	<0.001
s3	0	Jan 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.031	<0.01	<0.005	<0.001	0.016
s3	35	Jan 11, 2000	<0.01	<0.0005	<0.001	<0.001	0.019	<0.01	<0.005	<0.001	0.001

Site	Depth	Date	Al (mg/L)	Sb (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Ca (mg/L)	Co (mg/L)	K (mg/L)	Li (mg/L)
s1	0	Oct 14, 1999	<0.01	<0.01	<0.05	0.0065	<0.0005	4.2	<0.001	0.72	<0.005
s1	35	Oct 14, 1999	<0.01	<0.01	<0.05	0.0066	<0.0005	4.1	<0.001	0.66	<0.005
s2	0	Oct 14, 1999	<0.01	<0.01	<0.05	0.0064	<0.0005	4.2	<0.001	0.64	<0.005
s2	35	Oct 14, 1999	<0.01	<0.01	<0.05	0.0066	<0.0005	4.1	<0.001	0.65	<0.005
s3	0	Oct 14, 1999	<0.01	<0.01	<0.05	0.0067	<0.0005	4.2	<0.001	0.71	<0.005
s3	35	Oct 14, 1999	<0.01	<0.01	<0.05	0.0067	<0.0005	4.2	<0.001	0.73	<0.005
s1	0	Jan 11, 2000	0.03	<0.01	<0.05	0.0061	<0.0005	4.6	0.001	0.28	<0.005
s1	35	Jan 11, 2000	0.03	<0.01	<0.05	0.0060	<0.0005	4.5	<0.001	0.29	<0.005
s2	0	Jan 11, 2000	0.02	<0.01	<0.05	0.0066	<0.0005	4.6	<0.001	0.30	<0.005
s2	35	Jan 11, 2000	0.02	<0.01	<0.05	0.0062	<0.0005	4.6	<0.001	0.29	<0.005
s3	0	Jan 11, 2000	0.03	<0.01	<0.05	0.0062	<0.0005	4.6	<0.001	0.28	<0.005
s3	35	Jan 11, 2000	0.02	<0.01	<0.05	0.0061	<0.0005	4.7	<0.001	0.27	<0.005

Site	Depth	Date	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	P (mg/L)	S (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)
s1	0	Oct 14, 1999	1.8	0.0013	<0.005	3.7	<0.01	1.6	0.01	2.0	<0.01
s1	35	Oct 14, 1999	1.8	0.0018	<0.005	3.6	<0.01	1.6	<0.01	2.7	<0.01
s2	0	Oct 14, 1999	1.8	0.0006	<0.005	3.7	<0.01	1.6	<0.01	1.9	<0.01
s2	35	Oct 14, 1999	1.8	0.0012	<0.005	3.6	<0.01	1.6	<0.01	2.7	<0.01
s3	0	Oct 14, 1999	1.8	0.0009	<0.005	3.6	<0.01	1.6	<0.01	2.1	<0.01
s3	35	Oct 14, 1999	1.8	0.0015	<0.005	3.7	<0.01	1.7	<0.01	2.8	<0.01
s1	0	Jan 11, 2000	1.6	0.0017	<0.005	2.8	0.01	1.4	<0.01	1.5	<0.01
s1	35	Jan 11, 2000	1.6	0.0019	<0.005	2.8	0.01	1.4	<0.01	1.5	<0.01
s2	0	Jan 11, 2000	1.6	0.0018	<0.005	2.9	0.01	1.4	<0.01	1.5	<0.01
s2	35	Jan 11, 2000	1.6	0.0018	<0.005	2.9	0.01	1.4	<0.01	1.5	<0.01
s3	0	Jan 11, 2000	1.6	0.0019	<0.005	2.8	<0.01	1.4	<0.01	1.5	<0.01
s3	35	Jan 11, 2000	1.6	0.0020	<0.005	2.8	<0.01	1.5	<0.01	1.5	<0.01

Site	Depth	Date	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	Tl (mg/L)	V (mg/L)	Y (mg/L)			TOC (mg/L)
s1	0	Oct 14, 1999	<0.005	0.052	<0.001	<0.01	<0.005	<0.0005			1.5
s1	35	Oct 14, 1999	<0.005	0.053	<0.001	<0.01	<0.005	<0.0005			<1
s2	0	Oct 14, 1999	0.007	0.052	<0.001	<0.01	<0.005	<0.0005			<1
s2	35	Oct 14, 1999	<0.005	0.053	<0.001	<0.01	<0.005	<0.0005			1.7
s3	0	Oct 14, 1999	<0.005	0.052	<0.001	<0.01	<0.005	<0.0005			2.0
s3	35	Oct 14, 1999	<0.005	0.053	<0.001	<0.01	<0.005	<0.0005			<1
s1	0	Jan 11, 2000	<0.005	0.051	<0.001	<0.01	0.006	<0.0005			<1
s1	35	Jan 11, 2000	<0.005	0.050	<0.001	<0.01	0.006	<0.0005			<1
s2	0	Jan 11, 2000	<0.005	0.051	<0.001	<0.01	0.008	<0.0005			<1
s2	35	Jan 11, 2000	<0.005	0.051	<0.001	<0.01	0.006	<0.0005			<1
s3	0	Jan 11, 2000	<0.005	0.051	<0.001	<0.01	0.008	<0.0005			1.1
s3	35	Jan 11, 2000	<0.005	0.051	<0.001	<0.01	0.006	<0.0005			3.3

Table 14: Strawberry sill 1999/2000 metals and total organic carbon data.

Parameter	1999 Oct	Nov	Dec	2000 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 15: Lake Whatcom 1999/2000 creek monitoring schedule.

Site	Date	pH	Cond. (µS)	DO (mg/L)	TSS (mg/L)	Alk. (cfs)	Disch. (m^3/sec)	Temp. (°C)	Turb. (ntu)
Blue	1990 min†	8.1	250	9.0	<2	na	0.02	4.0	na
Canyon	1990 avg†	8.4	344	10.5	5	na	0.05	10.9	na
	1990 max†	8.6	409	12.3	29	na	0.11	17.0	na
	Feb 9, 2000	8.4	261	na	3	114.7	2.13	6.5	3.98
	July 18, 2000	8.6	289	10.3	6	139.1	0.18	13.0	2.99
Park	1990 min†	7.1	118	6.4	3	na	0.00	4.5	na
Place	1990 avg†	7.7	245	9.1	13	na	0.26	13.7	na
	1990 max†	8.1	410	11.8	57	na	0.91	23.0	na
	Feb 9, 2000	7.7	182	11.1	7	72.1	0.35	6.0	12.50
	July 18, 2000	8.0	265	7.7	2	127.8	0.00	20.5	2.98
Silver	1990 min†	7.4	103	6.9	<2	na	0.00	4.2	na
Beach	1990 avg†	7.9	187	9.8	6	na	0.86	11.1	na
	1990 max†	8.1	290	12.1	12	na	2.66	17.0	na
	Feb 9, 2000	7.8	126	11.6	6	48.2	1.54	5.5	17.10
	July 18, 2000	8.2	279	9.0	<2	128.8	0.07	15.8	3.20
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 9, 2000	7.2	48	11.8	<2	6.5	0.65	5.2	0.40
	July 18, 2000	7.3	57	9.7	<2	12.2	0.04	14.2	0.42
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 9, 2000	7.2	49	11.9	6	15.4	29.29	4.1	6.92
	July 18, 2000	7.3	45	9.9	15	13.5	68.29	15.0	15.80
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 9, 2000	7.4	52	11.8	2	13.1	35.33	4.8	2.61
	July 18, 2000	7.8	99	10.2	<2	28.4	2.03	15.3	0.61
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 9, 2000	7.4	42	12.5	2	11.6	29.22	4.0	3.22
	July 18, 2000	7.8	76	10.2	<2	25.9	1.91	14.4	0.31

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

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

Site	Date	NH_3 (μg/L)	TN (μg/L)	NO_{2+3} (μg/L)	SRP (μg/L)	TP (μg/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 9, 2000	<10	620.9	508	<5	8.5	40	1	<2
	July 18, 2000	11.1	178.1	101	<5	10.5	300	71	13
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 9, 2000	33.8	1019.9	693	10	45.9	2500	1450	30
	July 18, 2000	55.8	731.7	187.1	33.9	60.8	4200	1300	280
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 9, 2000	<10	897.7	544	8.7	49.5	1860	1230	50
	July 18, 2000	22	617	285.6	22.9	35.1	3800	500	300
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 9, 2000	<10	2189.7	2206	<5	<5	42	2	<2
	July 18, 2000	<10	1308	1249	6.4	9.6	230	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 9, 2000	11.6	509.2	366	<5	22.8	22	8	<2
	July 18, 2000	<10	181.9	28.5	<5	43.7	370	154	50
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 9, 2000	<10	691.5	600	5.6	10.3	55	32	2
	July 18, 2000	14.2	321.7	228.5	5.2	10.8	650	141	8
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 9, 2000	<10	873.7	779	<5	7.0	44	20	<2
	July 18, 2000	11.9	569.9	488.4	<5	10.2	90	66	<2

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

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

Site	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
Blue Canyon	Feb 9, 2000	<0.01	<0.0005	<0.001	<0.001	0.18	<0.01	<0.005	<0.001	0.002
Park Place	Feb 9, 2000	<0.01	<0.0005	<0.001	<0.001	0.60	<0.01	<0.005	<0.001	0.005
Silver Beach	Feb 9, 2000	<0.01	<0.0005	<0.001	<0.001	0.77	<0.01	<0.005	<0.001	0.004
Wildwood	Feb 9, 2000	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.01	<0.005	<0.001	<0.001
Anderson	Feb 9, 2000	<0.01	<0.0005	<0.001	<0.001	0.35	<0.01	<0.005	<0.001	0.002
Austin	Feb 9, 2000	<0.01	<0.0005	<0.001	<0.001	0.18	<0.01	<0.005	<0.001	0.006
Smith Creek	Feb 9, 2000	<0.01	<0.0005	<0.001	<0.001	0.12	<0.01	<0.005	<0.001	0.009

Site	Date	Al (mg/L)	Sb (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Ca (mg/L)	Co (mg/L)	K (mg/L)	Li (mg/L)
Blue Canyon	Feb 9, 2000	0.14	<0.01	0.08	0.0640	<0.0005	27.0	<0.001	1.40	<0.005
Park Place	Feb 9, 2000	0.28	<0.01	<0.05	0.0240	<0.0005	17.0	<0.001	1.10	<0.005
Silver Beach	Feb 9, 2000	0.43	<0.01	<0.05	0.0230	<0.0005	11.0	<0.001	0.95	<0.005
Wildwood	Feb 9, 2000	0.02	<0.01	<0.05	0.0026	<0.0005	3.0	<0.001	0.16	<0.005
Anderson	Feb 9, 2000	0.22	<0.01	<0.05	0.0110	<0.0005	4.3	<0.001	0.25	<0.005
Austin	Feb 9, 2000	0.10	<0.01	<0.05	0.0066	<0.0005	3.2	<0.001	0.24	<0.005
Smith Creek	Feb 9, 2000	0.12	<0.01	<0.05	0.0034	<0.0005	3.1	<0.001	0.14	<0.005

Site	Date	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	P (mg/L)	S (mg/L)	Se (mg/L)	Si (mg/L)	Ag (mg/L)
Blue Canyon	Feb 9, 2000	6.7	0.01	<0.005	14	0.02	5.5	<0.01	3.4	<0.01
Park Place	Feb 9, 2000	6.6	0.11	<0.005	7.2	0.03	3.3	<0.01	6.3	<0.01
Silver Beach	Feb 9, 2000	4	0.074	<0.005	5.5	0.03	1.9	<0.01	5.3	<0.01
Wildwood	Feb 9, 2000	0.99	<0.0005	<0.005	2.3	<0.01	0.7	<0.01	3.8	<0.01
Anderson	Feb 9, 2000	1.5	0.024	<0.005	1.1	0.02	1.2	<0.01	3.5	<0.01
Austin	Feb 9, 2000	0.93	0.0093	<0.005	3.6	0.01	1.0	<0.01	4.2	<0.01
Smith Creek	Feb 9, 2000	0.96	0.0017	<0.005	2.1	<0.01	0.7	<0.01	4.3	<0.01

Site	Date	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	Tl (mg/L)	V (mg/L)	Y (mg/L)
Blue Canyon	Feb 9, 2000	0.008	0.780	<0.001	<0.01	<0.005	<0.0005
Park Place	Feb 9, 2000	<0.005	0.120	0.008	<0.01	<0.005	<0.0005
Silver Beach	Feb 9, 2000	<0.005	0.082	0.020	<0.01	0.008	<0.0005
Wildwood	Feb 9, 2000	<0.005	0.040	<0.001	<0.01	0.007	<0.0005
Anderson	Feb 9, 2000	<0.005	0.048	<0.001	<0.01	0.007	<0.0005
Austin	Feb 9, 2000	<0.005	<0.0005	0.038	<0.01	0.007	<0.0005
Smith Creek	Feb 9, 2000	<0.005	0.038	<0.001	<0.01	0.008	<0.0005

Table 18: Metals data for creeks in the Lake Whatcom watershed.

Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Blue Canyon	Feb 9, 2000	1.4	July 18, 2000	1.1
Park Place	Feb 9, 2000	3.5	July 18, 2000	5.9
Silver Beach	Feb 9, 2000	4.9	July 18, 2000	6.4
Wildwood	Feb 9, 2000	<1	July 18, 2000	1.8
Anderson	Feb 9, 2000	2.7	July 18, 2000	<1
Austin	Feb 9, 2000	1.5	July 18, 2000	1.7
Smith	Feb 9, 2000	2.4	July 18, 2000	2.3

Table 19: 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	83
	fecal coliforms	<1	120	10	9
	Enterococcus	<2	26	10	7
Park Place	total coliforms	163	10600	9	1669
	fecal coliforms	20	1450	10	262
	Enterococcus	8	1600	9	70
Silver Beach	total coliforms	200	3800	9	1216
	fecal coliforms	98	1600	10	522
	Enterococcus	7	290	9	163
Wildwood	total coliforms	7	230	9	44
	fecal coliforms	1	48	9	5
	Enterococcus	<2	30	9	4
Anderson	total coliforms	17	2300	10	60
	fecal coliforms	2	154	10	13
	Enterococcus	<2	50	10	4
Austin	total coliforms	17	6400	9	231
	fecal coliforms	6	410	10	46
	Enterococcus	<2	240	9	17
Smith	total coliforms	<4	290	9	66
	fecal coliforms	<2	199	10	19
	Enterococcus	<2	30	9	3

†5-year geometric means from Feb 1996 to July 2000.

Table 20: Average coliform and *Enterococcus* counts for creeks in the Lake Whatcom watershed.

Date	Fecal coliforms	*Enterococcus*
	winter	
Feb 2, 1996	12 cfu/100 mL	20 cfu/100 mL
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
	summer	
July 8, 1996	124 cfu/100 mL	110 cfu/100 mL
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

Table 21: Austin Creek fecal coliform and *Enterococcus* counts, 1996–2000.

Site	Date	TSS (mg/L)	TOC (mg/L)	TN (mg/L)	TP (mg/L)
PP inlet	Dec 6-8, 1999	4.61	3.8	0.9110	0.0463
PP outlet	Dec 6-8, 1999	6.54	5.5	0.9700	0.0558
PP inlet	Mar 6-8, 2000	5.25	2.6	1.1046	0.0396
PP outlet	Mar 6-8, 2000	2.75	2.1	0.7585	0.0423
PP inlet	Jul 17-19, 2000	4.37	5.2	1.1479	0.1072
PP outlet	Jul 17-19, 2000	3.93	9.4	0.5594	0.0889
Annual % reduction		5.3	-35.4	25.4	-3.4
BW inlet	Dec 6-8, 1999	1.67	4.7	1.8580	0.0297
BW outlet	Dec 6-8, 1999	2.79	5.5	1.2880	0.0232
BW inlet	Mar 6-8, 2000	1.00	<1*	0.5080	0.0052
BW outlet	Mar 6-8, 2000	3.75	1.7	1.9858	0.0510
BW inlet	Jul 17-19, 2000	3.92	7.0	2.1169	0.0810
BW outlet	Jul 17-19, 2000	3.50	8.4	0.4468	0.0393
Annual % reduction		-110.4	-35.7	-60.4	-269.1
Wetland	Dec 6-8, 1999	1.42	3.2	1.1430	0.0170
Wetland	Mar 6-8, 2000	1.00	2.0	0.7566	0.0369
Wetland	Jul 17-19, 2000	5.10	6.7	0.5682	0.0468

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)
PP inlet	Dec 6-8, 1999	<0.01	<0.0005	0.003	0.001	0.390	<0.01	<0.005	<0.001	0.008
PP outlet	Dec 6-8, 1999	<0.01	<0.0005	0.004	0.001	0.400	<0.01	<0.005	<0.001	0.008
PP inlet	Mar 6-8, 2000	<0.01	<0.0005	<0.001*	<0.001	0.690	<0.01	<0.005	0.0020	0.005
PP outlet	Mar 6-8, 2000	<0.01	<0.0005	0.001	<0.001	0.400	<0.01	<0.005	<0.001	0.003
PP inlet	Jul 17-19, 2000	<0.01	<0.0005	0.007	<0.001	1.100	<0.01	<0.005	<0.001	0.004
PP outlet	Jul 17-19, 2000	<0.01	<0.0005	0.004	0.009	0.097	<0.01	<0.005	<0.001	<0.001*
Annual % reduction		na	na	3.17	na	43.6	na	na	na	33.3
BW inlet	Dec 6-8, 1999	<0.01	<0.0005	0.004	0.002	0.34	<0.01	<0.005	<0.001	0.001
BW outlet	Dec 6-8, 1999	<0.01	<0.0005	0.003	0.002	0.22	<0.01	<0.005	<0.001	0.001
BW inlet	Mar 6-8, 2000	<0.01	<0.0005	<0.001*	<0.001	0.51	<0.01	<0.005	0.001	0.002
BW outlet	Mar 6-8, 2000	<0.01	<0.0005	<0.001*	<0.001	0.36	<0.01	<0.005	0.001	0.001
BW inlet	Jul 17-19, 2000	<0.01	<0.0005	0.006	<0.001	1.10	<0.01	<0.005	<0.001	0.006
BW outlet	Jul 17-19, 2000	<0.01	<0.0005	0.005	<0.001	0.66	<0.01	<0.005	<0.001	0.011
Annual % reduction		na	na	13.9	na	34.9	na	na	na	-11.1
Wetland	Dec 6-8, 1999	<0.01	<0.0005	0.004	<0.001	0.14	<0.01	<0.005	<0.001	<0.001
Wetland	Mar 6-8, 2000	<0.01	<0.0005	0.001	<0.001	0.22	<0.01	<0.005	<0.001	<0.001
Wetland	Jul 17-19, 2000	<0.01	<0.0005	0.007	<0.001	0.48	<0.01	<0.005	0.001	<0.001

*Value replace with detection limit to calculate percent reduction.

Table 22: Park Place/Brentwood wet ponds and Grace Lane wetland 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)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
PP inlet	12	6	1999	pm	8.25	6.70	10.61	136.7	3065	295	30
PP inlet	12	7	1999	am	7.03	7.11	11.54	152.6	10818	1140	80
PP inlet	12	7	1999	pm	7.66	7.14	11.33	154.4	20000	920	30
PP inlet	12	8	1999	am	6.99	7.13	11.71	147.7	3300	233	240
PP outlet	12	6	1999	pm	7.45	6.99	9.70	124.7	14000	260	50
PP outlet	12	7	1999	am	6.72	7.45	9.50	143.5	7400	200	30
PP outlet	12	7	1999	pm	7.04	7.40	10.62	147.0	7000	233	30
PP outlet	12	8	1999	am	6.45	7.61	10.03	154.4	9692	383	17
Seasonal % reduction					7.6	-4.9	11.8	3.7	-2.4	58.4	66.6
PP inlet	3	6	2000	pm	6.19	7.22	11.51	148.7	3000	1600	2
PP inlet	3	7	2000	am	4.86	7.25	12.14	147.6	2100	400	23
PP inlet	3	7	2000	pm	7.19	7.36	11.37	145.5	4100	2000	23
PP inlet	3	8	2000	am	na	na	na	na	1120	430	7
PP outlet	3	6	2000	pm	7.01	7.26	13.25	148.3	1800	68	8
PP outlet	3	7	2000	am	4.81	7.15	11.14	149.0	1260	282	13
PP outlet	3	7	2000	pm	6.89	7.56	14.97	144.9	920	180	4
PP outlet - omit	3	8	2000	am	5.70	7.49	11.79	145.5	3100	461	22
Seasonal % reduction					-2.6	-0.6	-12.4	-0.1	31.4	77.6	14.5
PP inlet	7	17	2000	pm	16.71	7.32	7.59	263.9	4400	460	80
PP inlet	7	18	2000	am	16.44	7.54	8.24	246.5	52000	830	300
PP inlet	7	18	2000	pm	16.90	7.61	8.22	215.5	3700	500	170
PP inlet	7	19	2000	am	16.74	7.31	7.47	188.0	10000	7100	1600
PP outlet	7	17	2000	pm	24.88	7.59	7.23	255.5	1600	<4*	<2*
PP outlet	7	18	2000	am	19.38	7.55	6.52	253.8	1000	2	23
PP outlet	7	18	2000	pm	22.23	7.59	8.11	258.3	2000	7	<2*
PP outlet	7	19	2000	am	19.06	7.45	5.70	252.4	59	5	2
Seasonal % reduction					-28.1	-1.3	12.6	-11.6	93.4	99.8	98.7
Annual avg. % reduction					-7.69	-2.29	4.00	-2.67	40.77	78.62	59.93

*Value replace with detection limit to calculate percent reduction.

Table 23: 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)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
BW inlet	12	6	1999	pm	10.29	6.41	9.29	192.0	429	18	8
BW inlet	12	7	1999	am	10.45	6.60	9.41	206.7	295	162	23
BW inlet	12	7	1999	pm	10.59	6.73	9.44	210.1	174	83	170
BW inlet	12	8	1999	am	10.19	6.75	9.27	201.8	480	233	110
BW outlet	12	6	1999	pm	7.14	6.60	8.63	166.9	2400	1300	30
BW outlet	12	7	1999	am	6.03	6.80	7.90	163.8	720	600	23
BW outlet	12	7	1999	pm	6.10	7.00	8.65	162.7	310	433	14
BW outlet	12	8	1999	am	5.45	6.95	7.75	162.3	330	233	8
Seasonal % reduction					40.5	-3.2	12.0	19.1	-172.9	-417.3	75.9
BW inlet	3	7	2000	pm	9.04	6.62	9.48	245.7	4200	3300	8
BW inlet	3	8	2000	am	8.43	6.78	9.78	232.4	17000	8567	4
BW inlet	3	8	2000	pm	8.62	6.89	9.67	228.4	3600	4800	4
BW inlet	3	9	2000	am	na	na	na	na	6667	3800	2
BW outlet	3	7	2000	pm	8.56	6.87	12.82	179.6	260	<5*	<2*
BW outlet	3	8	2000	am	5.71	6.99	9.63	189.0	560	<11*	<2*
BW outlet	3	8	2000	pm	8.23	7.11	12.71	190.5	148	<9*	<2*
BW outlet	3	9	2000	am	na	na	na	na	920	<9*	2
Seasonal % reduction					13.8	-3.4	-21.5	20.9	94.0	99.8	55.6
BW inlet	7	17	2000	pm	18.74	6.71	6.47	296.0	39000	4800	240
BW inlet	7	18	2000	am	18.30	6.89	7.09	300.6	36000	36000	30
BW inlet	7	18	2000	pm	18.47	6.85	7.05	290.0	64000	33000	300
BW inlet	7	19	2000	am	18.41	6.92	7.01	300.1	21000	9800	80
BW outlet	7	17	2000	pm	25.07	7.18	4.75	275.1	1000	52	23
BW outlet	7	18	2000	am	20.66	7.21	1.55	273.5	2000	86	4
BW outlet	7	18	2000	pm	23.98	7.36	5.72	274.1	200	38	2
BW outlet	7	19	2000	am	20.29	7.20	1.99	265.0	33	140	7
Seasonal % reduction					-21.8	-5.8	49.3	8.3	98.0	99.6	94.5
Annual avg. % reduction					10.8	-4.1	13.2	16.1	6.4	-72.6	75.3

*Value replace with detection limit to calculate percent reduction.

Table 24: 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)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
Wetland	12	6	1999	pm	7.74	7.04	9.51	143.9	153	71	30
Wetland	12	7	1999	am	5.34	7.23	10.21	188.7	2300	3940	50
Wetland	12	7	1999	pm	6.61	7.22	9.82	190.3	268	108	80
Wetland	12	8	1999	am	5.71	7.41	10.02	194.1	1500	43	50
Wetland	3	7	2000	pm	5.47	7.19	10.97	192.9	74	41	4
Wetland	3	8	2000	am	4.26	7.50	11.62	193.4	82	28	13
Wetland	3	8	2000	pm	7.07	7.52	10.45	192.8	86	51	8
Wetland	3	9	2000	am	na	na	na	na	72	49	2
Wetland	7	17	2000	pm	15.77	7.88	8.40	402.4	900	16	13
Wetland	7	18	2000	am	13.85	8.00	8.70	401.3	650	35	$<$2
Wetland	7	18	2000	pm	14.95	7.98	8.49	399.6	580	36	7
Wetland	7	19	2000	am	13.90	7.99	8.78	389.0	860	22	4

Table 25: Grace Lane wet pond grab samples.

	Reported Value†	True Value†	Acceptance Limits
Specific conductivity (μS/cm at 25°C)	899.0	876	803–949
	731.0	717	658–776
Total alkalinity (mg/l as $CaCO_3$)	46.5	47.5	41.9–53.6
	64.5	63.5	56.8–70.3
Ammonia nitrogen, autoanalysis (mg/L)	12.1	11.6	9.00–14.1
	7.83	8.00	7.77–8.23
Ammonia nitrogen, manual (mg/L)	12.0	11.6	9.00–14.1
	7.96	8.00	6.18–9.75
Nitrate nitrogen, autoanalysis (mg/L)	16.8	16.7	13.2–19.8
	14.0	12.7	10.1–15.1
Orthophosphate, autoanalysis (mg/L)	4.97	4.47	3.82–5.16
	4.6	4.56	3.90–5.27
Orthophosphate, manual (mg/L)	4.69	4.47	3.82–5.16
	4.55	4.56	3.90–5.27
Total phosphorus, autoanalysis (mg/L)	6.12	5.58	4.24–6.53
	0.902	1.01	0.764–1.22
Total phosphorus, manual (mg/L)	5.40	5.58	4.24–6.53
	1.02	1.01	0.764–1.22
pH	8.55	8.50	8.25–8.75
	8.04	8.00	7.77–8.23
Non-filterable residue (mg/L)	38.2	43.5	32.5–46.5

†Performance Evaluation Reports WP00–1 and WP00-7.

Table 26: Summary of 1999/2000 single-blind quality control results.

Analysis	**Date**	Sample	QC	Δ	**Discussion**
Nitrate/nitrite	9/6/00	228.5	205.8	22.7	Unknown; all other qc samples ok
Total nitrogen	2/3/00	537.3	507.0	30.3	Unknown; all other qc samples ok
Ammonia	6/6/00	18.6	5.7	12.9	All other qc samples ok Possible sample mislabel
Total phosphorus	11/2/99	15.2	5.2	10.0	Unknown; all other qc samples ok
Alkalinity	10/14/99	17.1	18.4	1.3	pH electrode failure; probe replaced
Chlorophyll a	6/6/00	1.36	0.86	0.50	New operator; training provided
	7/12/00	1.93	2.39	0.46	New operator; training provided
Conductivity	11/2/99	60.1	59.4	0.70	Unknown; all other qc samples ok

Table 27: Evaluation of laboratory duplicates exceeding 3 SD from mean.

Site	Date	Temp	Δ Temp	pH	Δ pH	Cond	Δ Cond	DO	Δ DO
1	Aug 10, 2000	21.47	-0.15	7.99	0.05	55.8	-0.2	9.02	-0.07
1	Aug 10, 2000	21.62		7.94		56.0		9.09	
Intake	Aug 10, 2000	21.23	-0.03	8.13	0.03	55.5	-0.2	9.19	0.14
Intake	Aug 10, 2000	21.26		8.10		55.7		9.05	
2	Aug 10, 2000	21.22	0.02	8.07	0.10	55.7	0.1	9.12	0.11
2	Aug 10, 2000	21.20		7.97		55.6		9.01	
3	Aug 8, 2000	21.33	-0.07	8.02	0.03	57.6	-0.1	9.36	0.3
3	Aug 8, 2000	21.40		7.99		57.7		9.06	
4	Aug 8, 2000	20.75	-0.59	8.05	0.13	57.6	0.0	9.28	0.26
4	Aug 8, 2000	21.34		7.92		57.6		9.02	
s1	Aug 8, 2000	21.37	-0.24	8.08	0.09	58.2	0.3	9.31	0.18
s1	Aug 8, 2000	21.61		7.99		57.9		9.13	
s2	Aug 8, 2000	21.74	-0.13	8.00	0.04	58.0	-0.1	9.33	0.04
s2	Aug 8, 2000	21.87		7.96		58.1		9.29	
s3	Aug 8, 2000	21.96	-0.06	8.12	0.16	58.1	0.1	9.12	0.11
s3	Aug 8, 2000	22.02		7.96		58.0		9.01	
1	Sept 7, 2000	18.42	0.02	8.08	0.20	56.3	-0.5	9.40	0.23
1	Sept 7, 2000	18.40		7.88		56.8		9.17	
Intake	Sept 7, 2000	18.36	-0.01	7.85	-0.01	54.8	-0.1	9.19	0.03
Intake	Sept 7, 2000	18.37		7.86		54.9		9.16	
2	Sept 7, 2000	18.37	-0.01	7.82	0.09	55.0	0.1	9.26	0.14
2	Sept 7, 2000	18.38		7.73		54.9		9.12	
3	Sept 6, 2000	18.47	-0.18	8.00	0.18	57.1	0.2	8.76	0.06
3	Sept 6, 2000	18.65		7.82		56.9		8.70	
4	Sept 6, 2000	18.33	0.00	8.03	0.15	57.2	-0.6	9.18	0.12
4	Sept 6, 2000	18.33		7.88		57.8		9.06	
s1	Sept 6, 2000	18.65	0.08	8.04	0.12	56.9	-0.7	8.68	0
s1	Sept 6, 2000	18.57		7.92		57.6		8.68	
s2	Sept 6, 2000	18.87	0.24	7.99	0.13	57.0	0.1	8.60	0.02
s2	Sept 6, 2000	18.63		7.86		56.9		8.58	
s3	Sept 6, 2000	18.62	0.02	8.02	0.12	57.3	0.2	8.66	0.24
s3	Sept 6, 2000	18.60		7.90		57.1		8.42	
	Median Δ	Temp: –0.02		pH: 0.11		Cond: –0.05		DO: 0.12	
	Average Δ	Temp: –0.07		pH: 0.10		Cond: –0.09		DO: 0.12	

Table 28: Hydrolab quality control comparisons of initial and ending surface samples.

9 Figures

- Figure 1 (page 54) provides a general map of Lake Whatcom and its tributaries, and shows the current lake sampling sites. Sampling locations for the Brentwood and Park Place wet ponds are shown in Figure 141 (page 194). Refer to Appendix A, Figures 160–162 (pages 210–212) for detailed maps showing lake sampling locations.

- Figures 2–11 (pages 55–64) show single-day Hydrolab profiles from Lake Whatcom for the February and September sampling dates. Additional profiles for July (Figures 133 and 134, pages 186 and 187) are included in the hydrology discussion of the report.

- Figures 12–31 (pages 65–84) 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 85–88) show correlations between year and dissolved oxygen during the summer at Site 1, 12–18 m, 1988–2000. Figure 36 (page 89) shows the nonsignificant correlation between year and temperature at Site 1, 10 m.

- Figures 37–102 (pages 90–155) show multi-year plots of water quality, chlorophyll, plankton, and Secchi depth data for Lake Whatcom.

- Figures 103–117 (pages 156–170) show multi-year plots of coliforms and *Enterococcus* data for Lake Whatcom.

- Figure 118 (page 171) illustrates iron concentrations at the Bellingham Water Treatment Pland Gatehouse.

- Figures 119–140 (pages 172–193) show the water balance, hydrograph, and water movement plots for 1999/2000.

- Figures 141–143 (pages 194–196) show sampling locations and current photographs of the Park Place and Brentwood wet ponds.

- Figures 144–154 (pages 197–202) and 155–159 (pages 203–207) show the quality control results from field and laboratory duplicate samples.

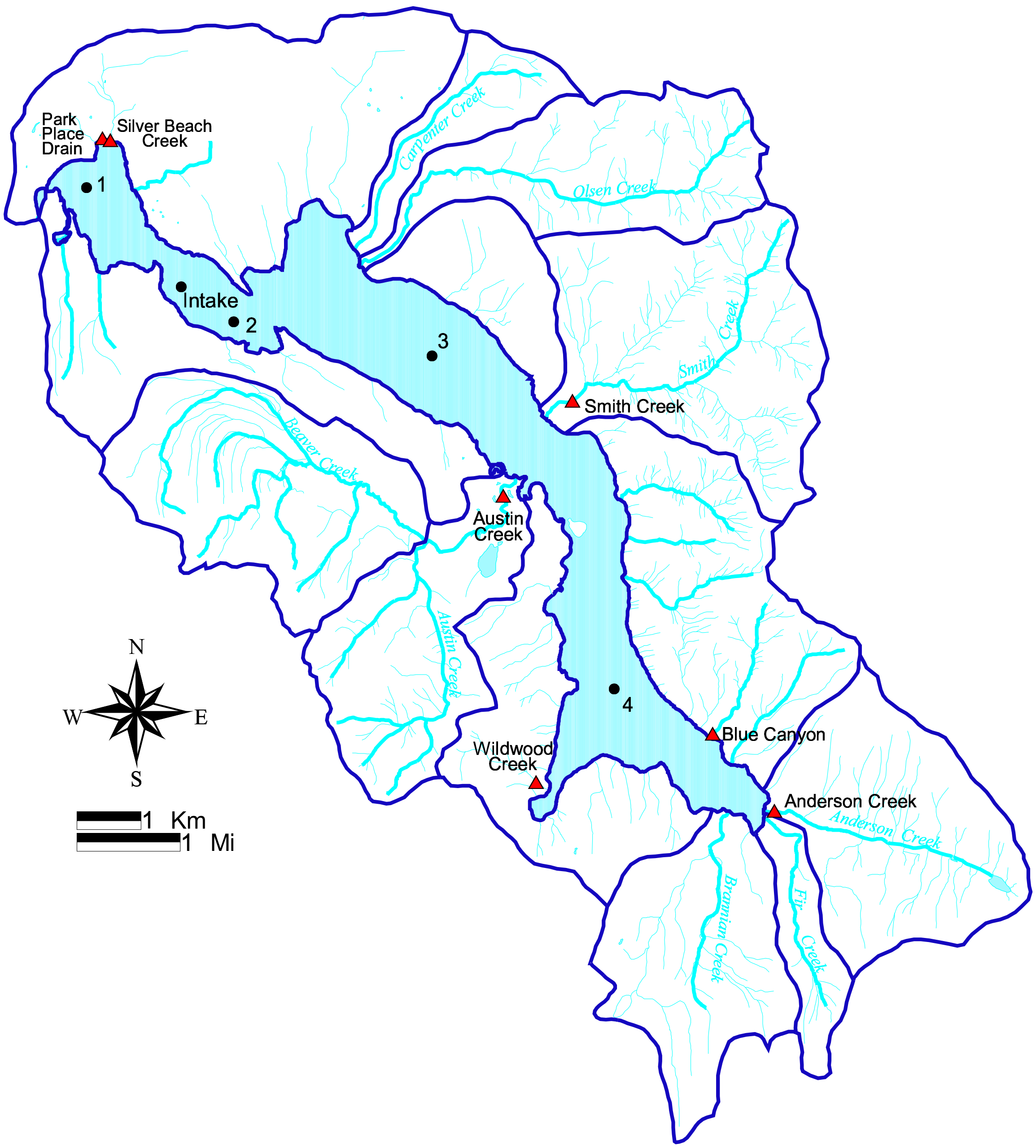


Figure 1: Lake Whatcom 1999/2000 sampling sites.

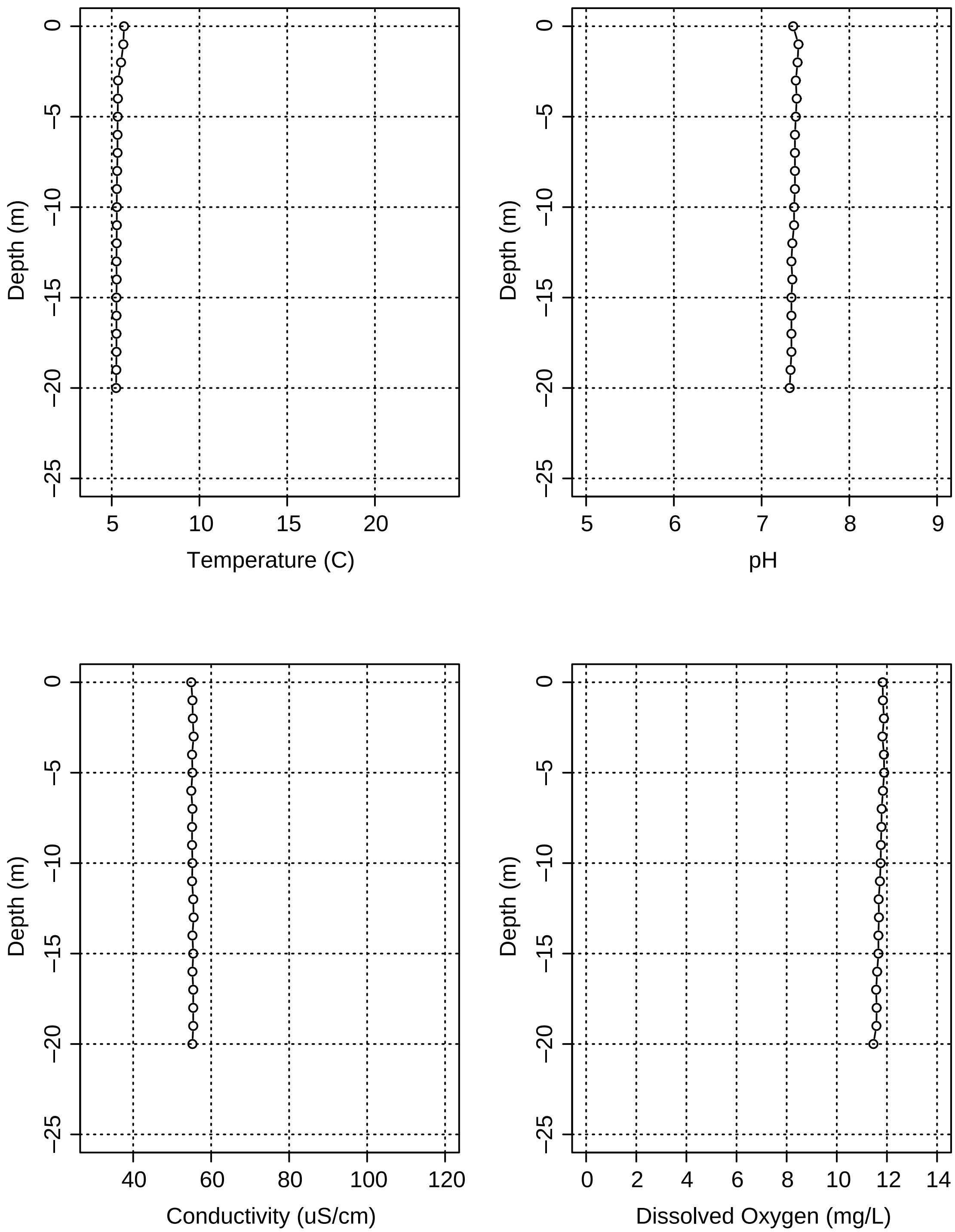


Figure 2: Lake Whatcom Hydrolab profile for Site 1, February 4, 2000.

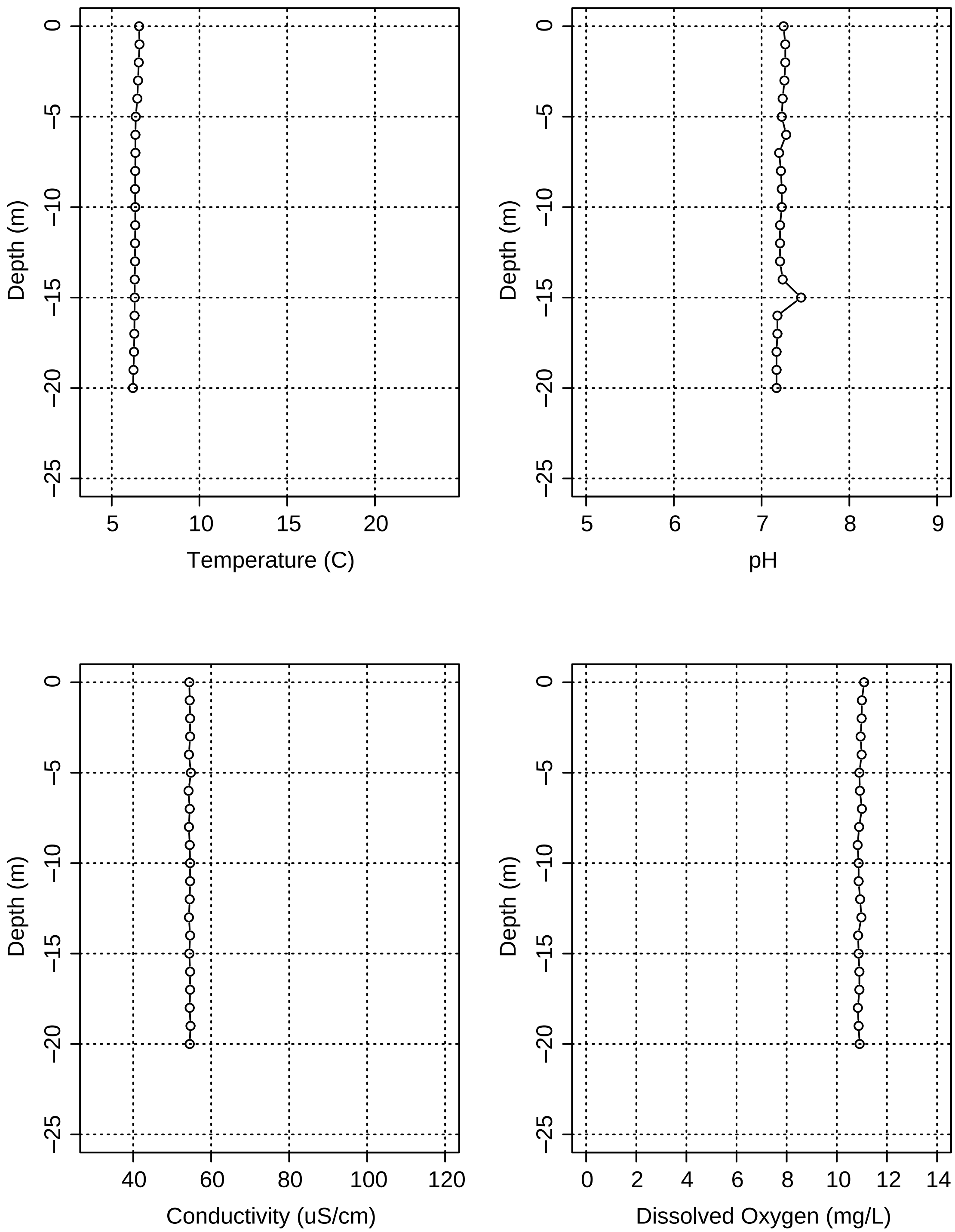


Figure 3: Lake Whatcom Hydrolab profile for Site 2, February 4, 2000.

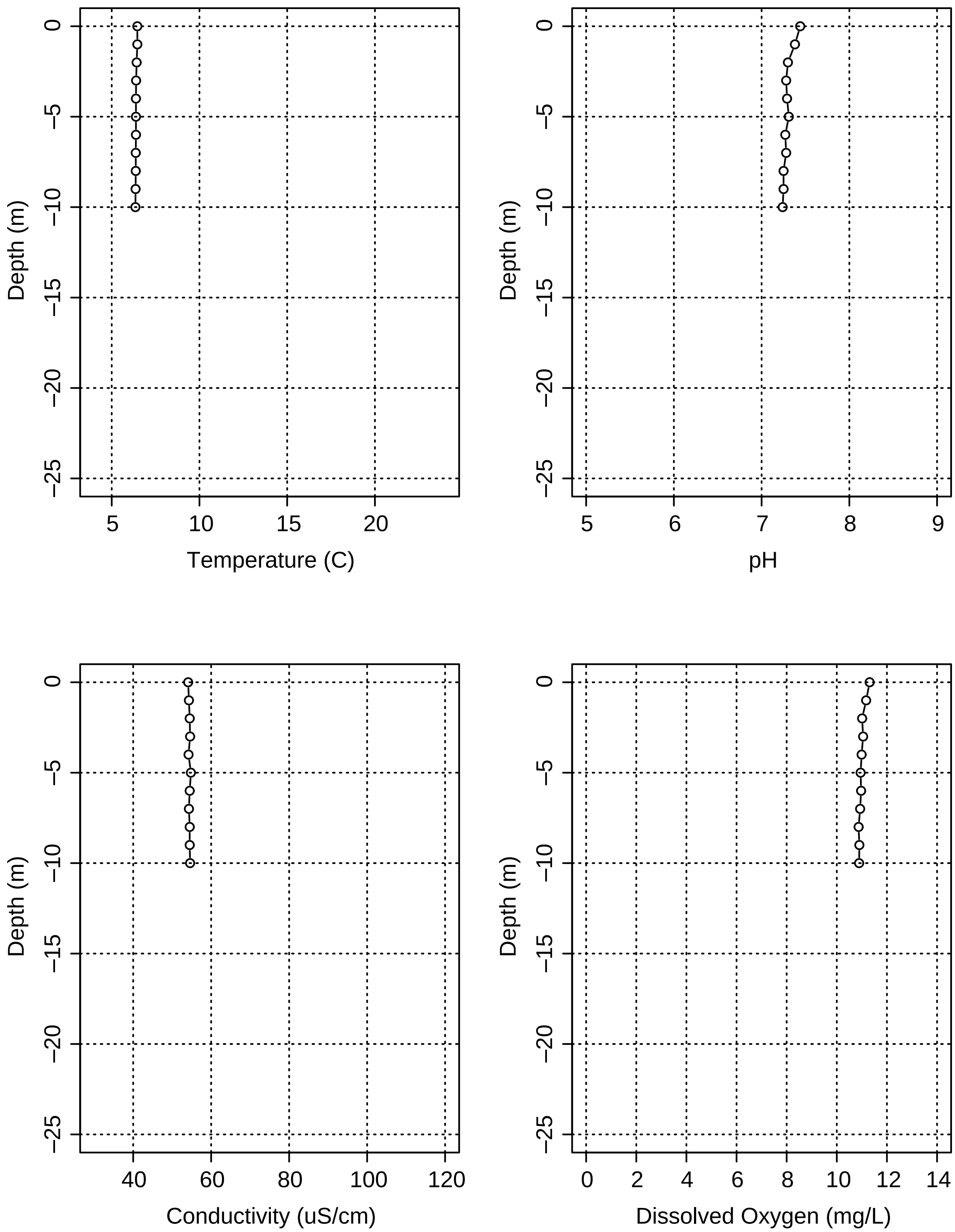


Figure 4: Lake Whatcom Hydrolab profile for the Intake, February 4, 2000.

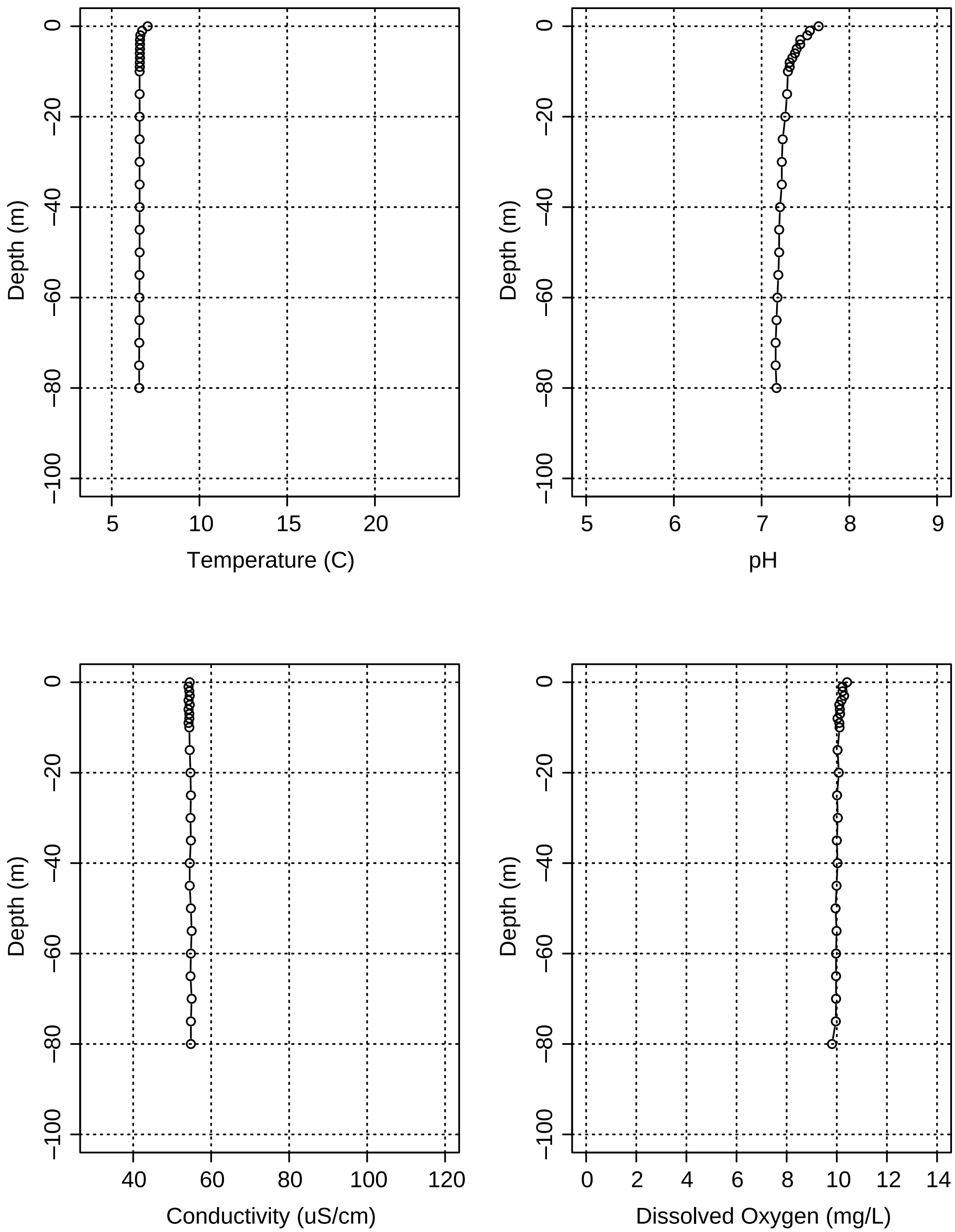


Figure 5: Lake Whatcom Hydrolab profile for Site 3, February 3, 2000.

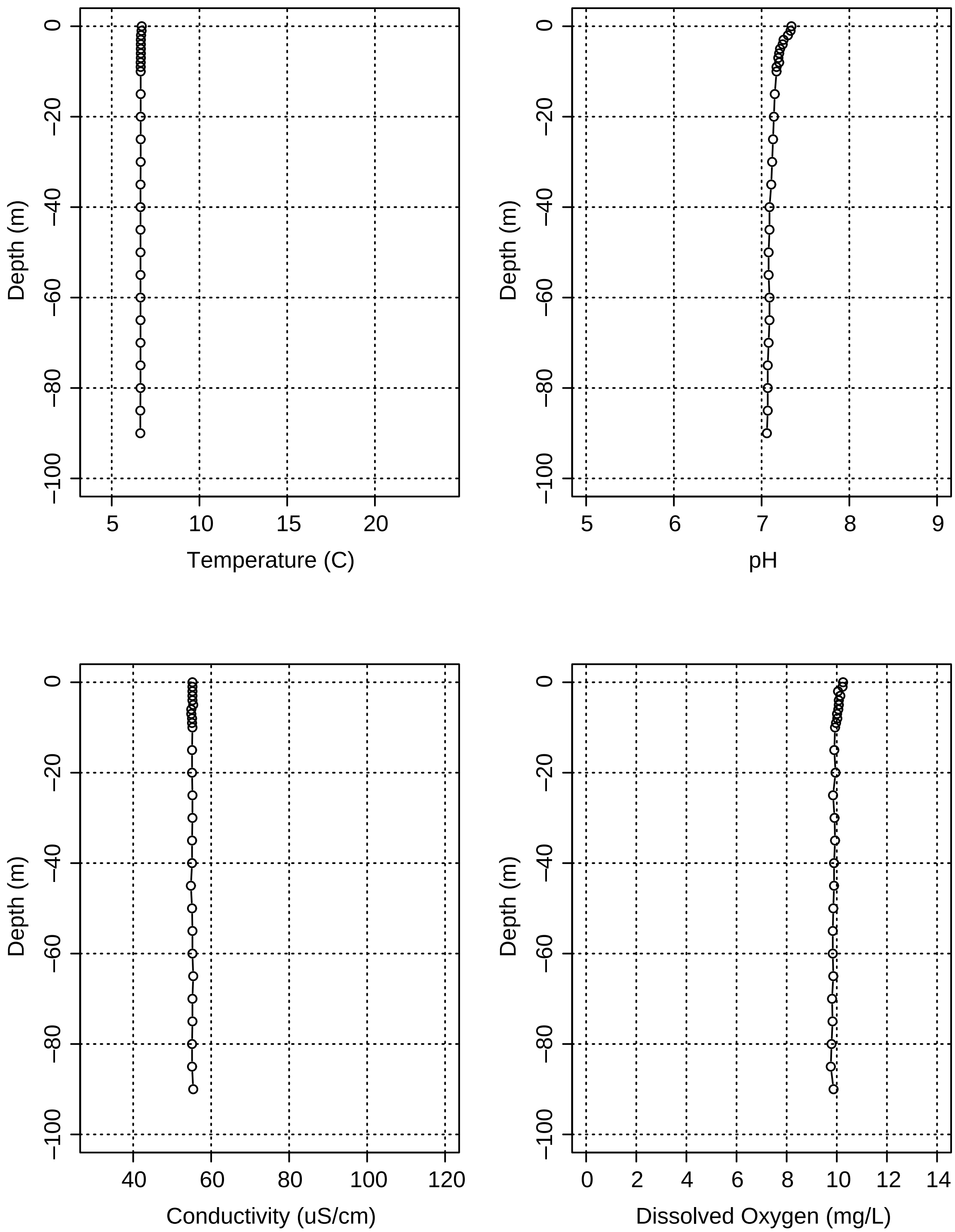


Figure 6: Lake Whatcom Hydrolab profile for Site 4, February 3, 2000.

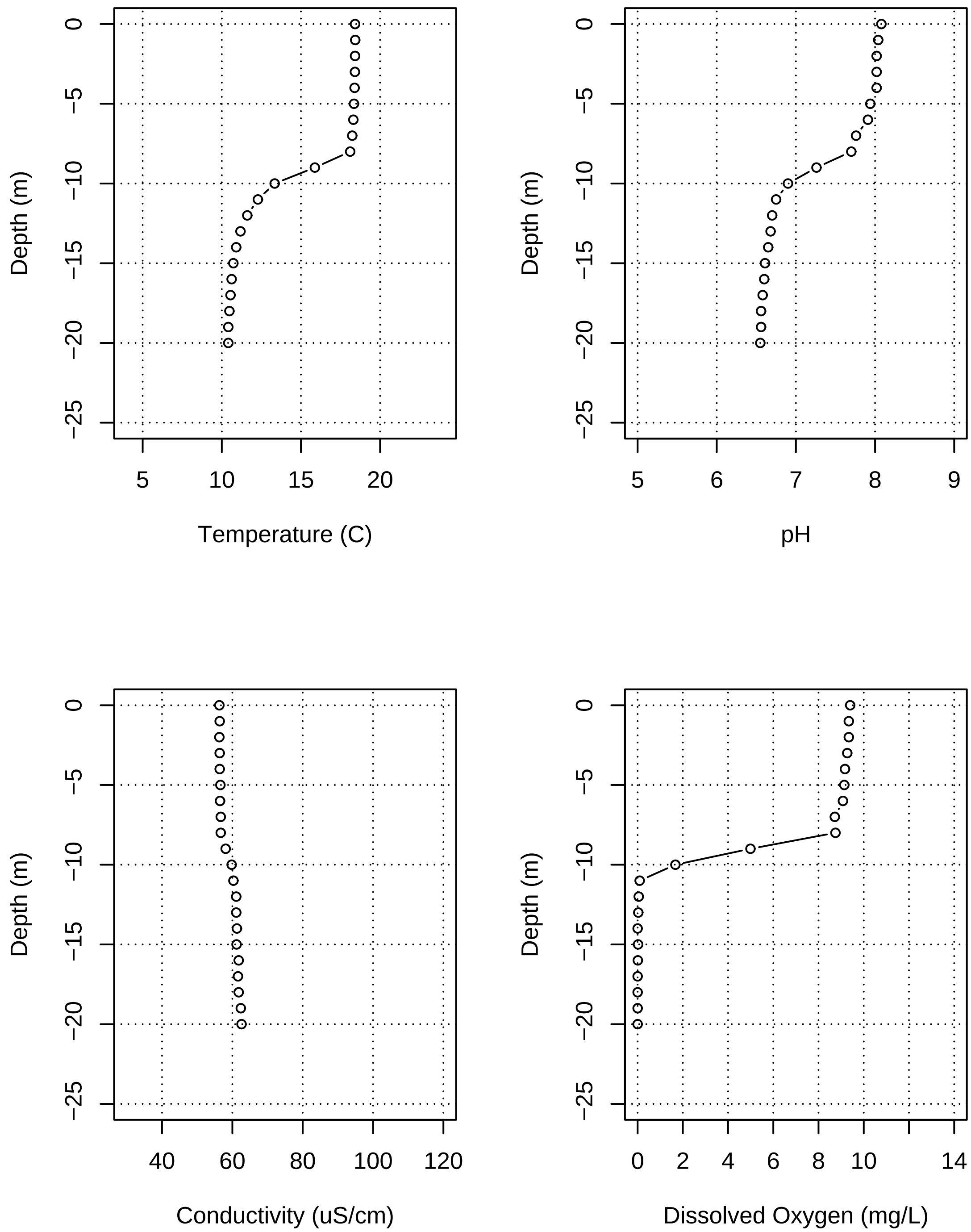


Figure 7: Lake Whatcom Hydrolab profile for Site 1, September 7, 2000.

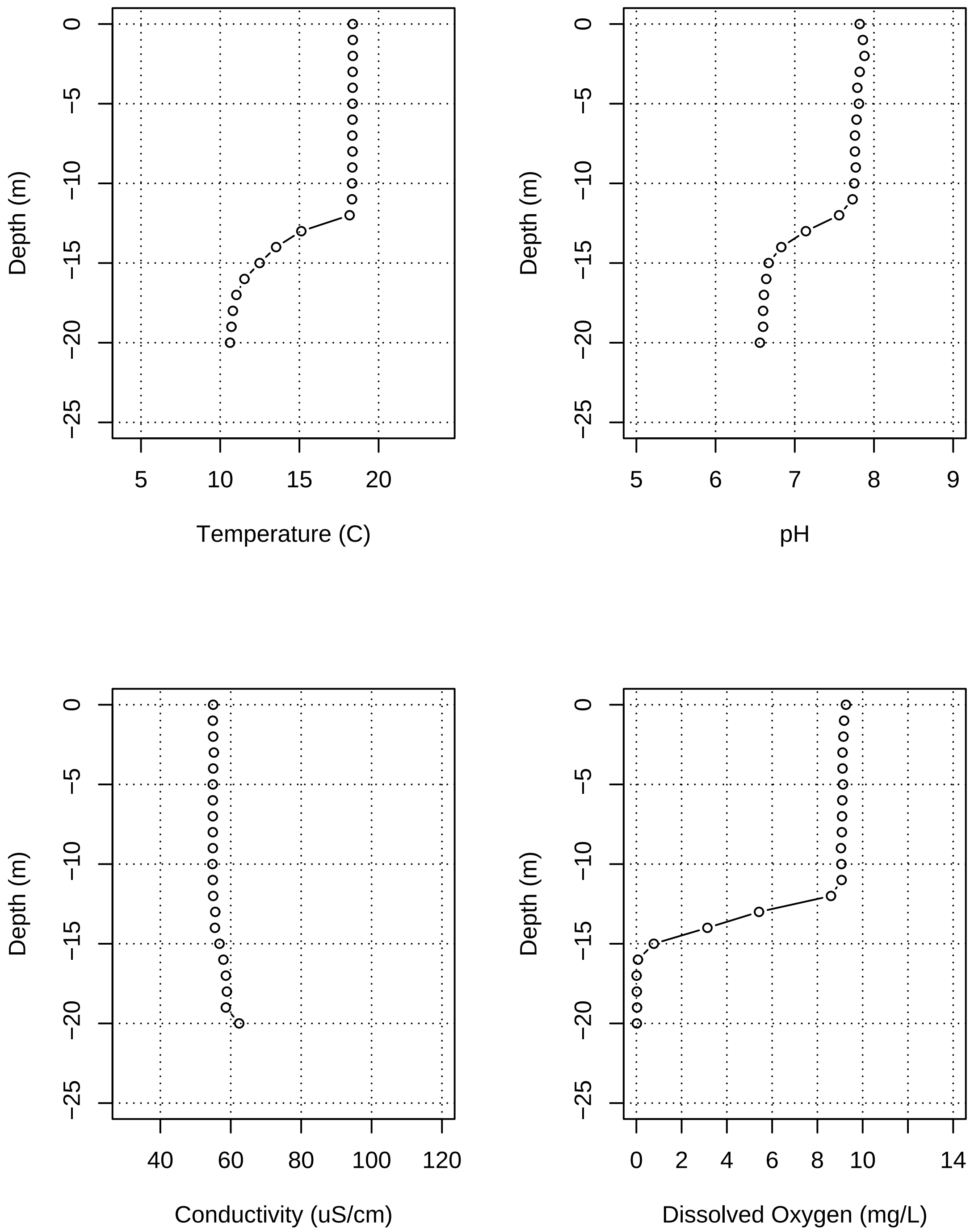


Figure 8: Lake Whatcom Hydrolab profile for Site 2, September 7, 2000.

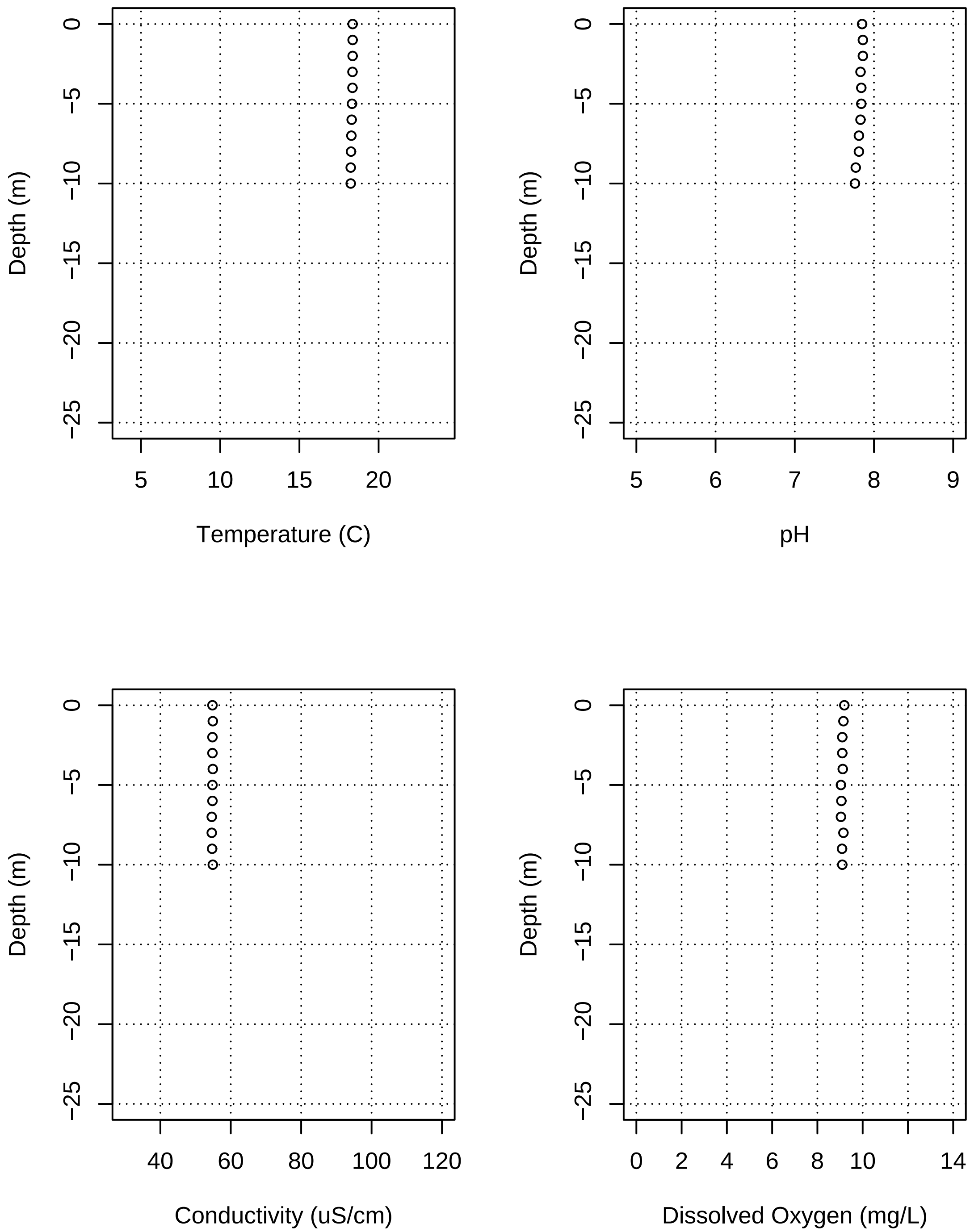


Figure 9: Lake Whatcom Hydrolab profile for the Intake, September 7, 2000.

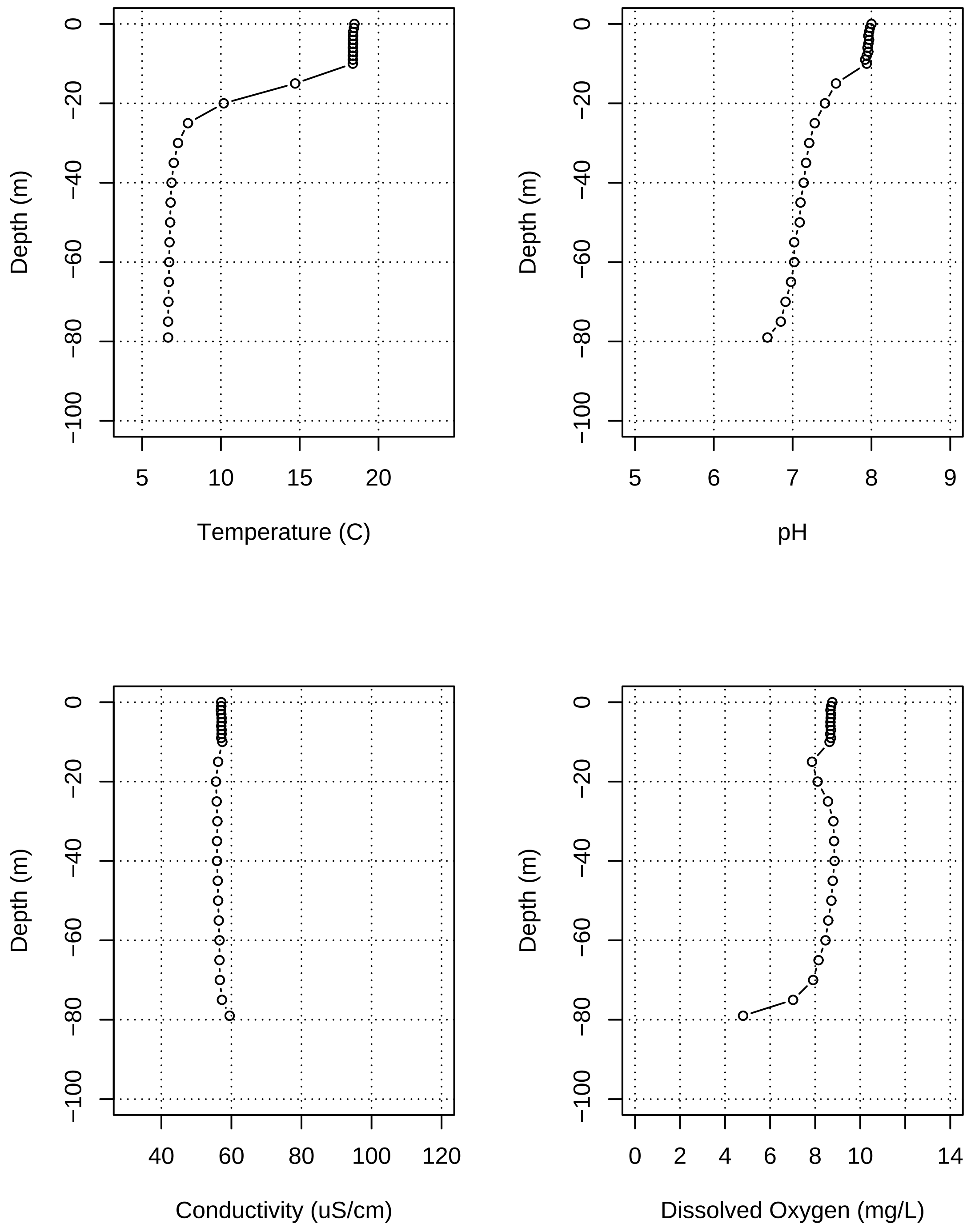


Figure 10: Lake Whatcom Hydrolab profile for Site 3, September 6, 2000.

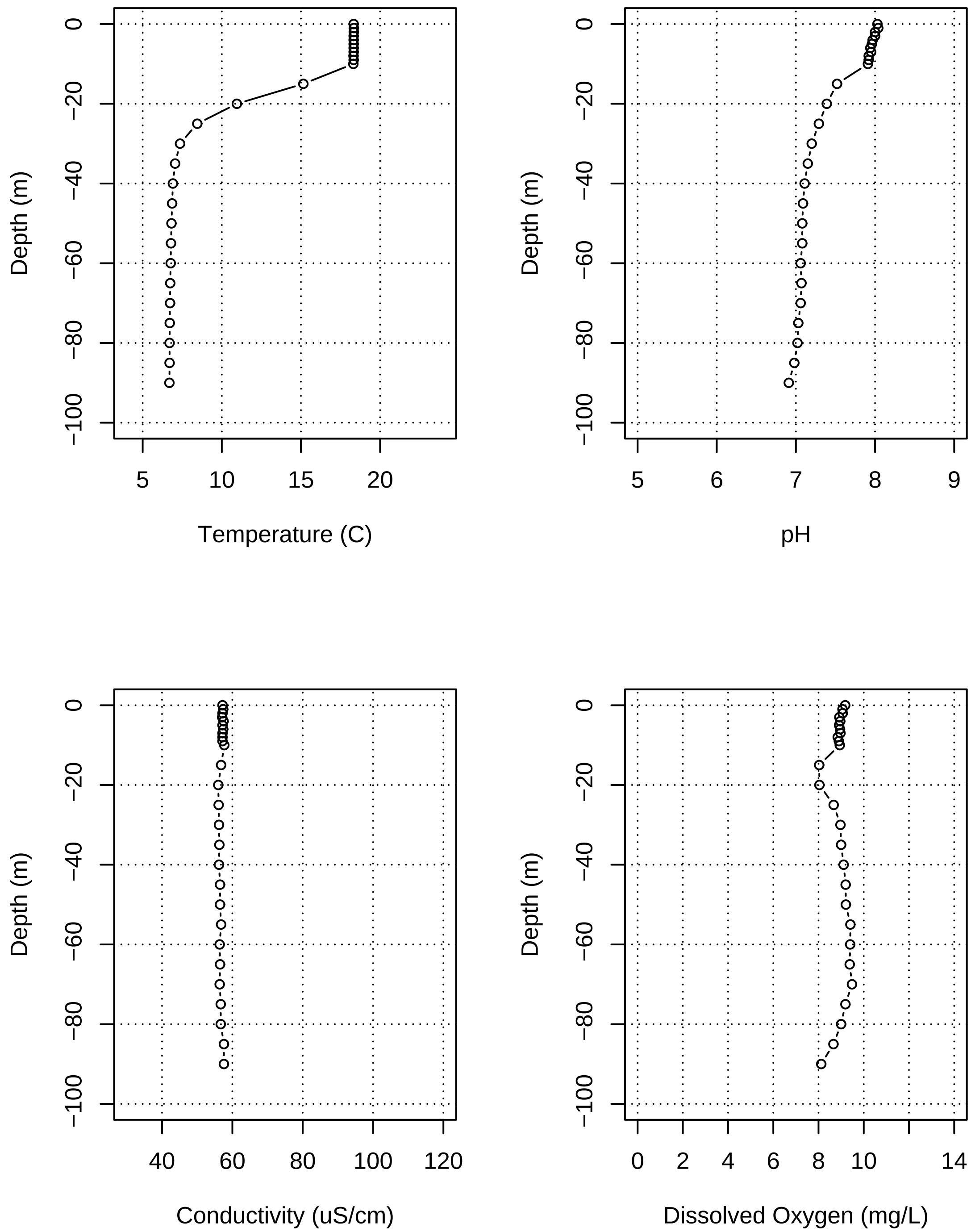


Figure 11: Lake Whatcom Hydrolab profile for Site 4, September 6, 2000.

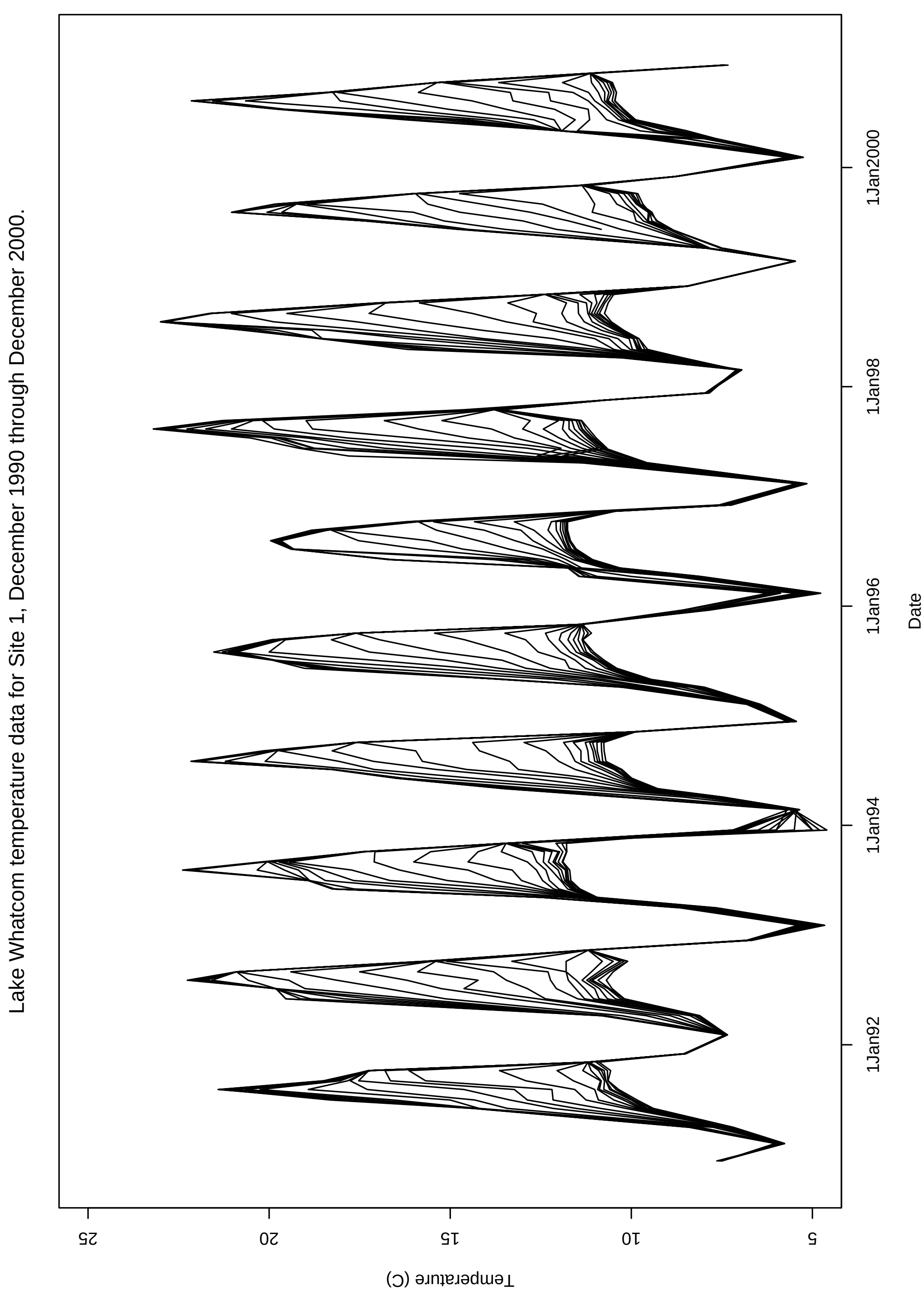


Figure 12: Lake Whatcom temperature data for Site 1.

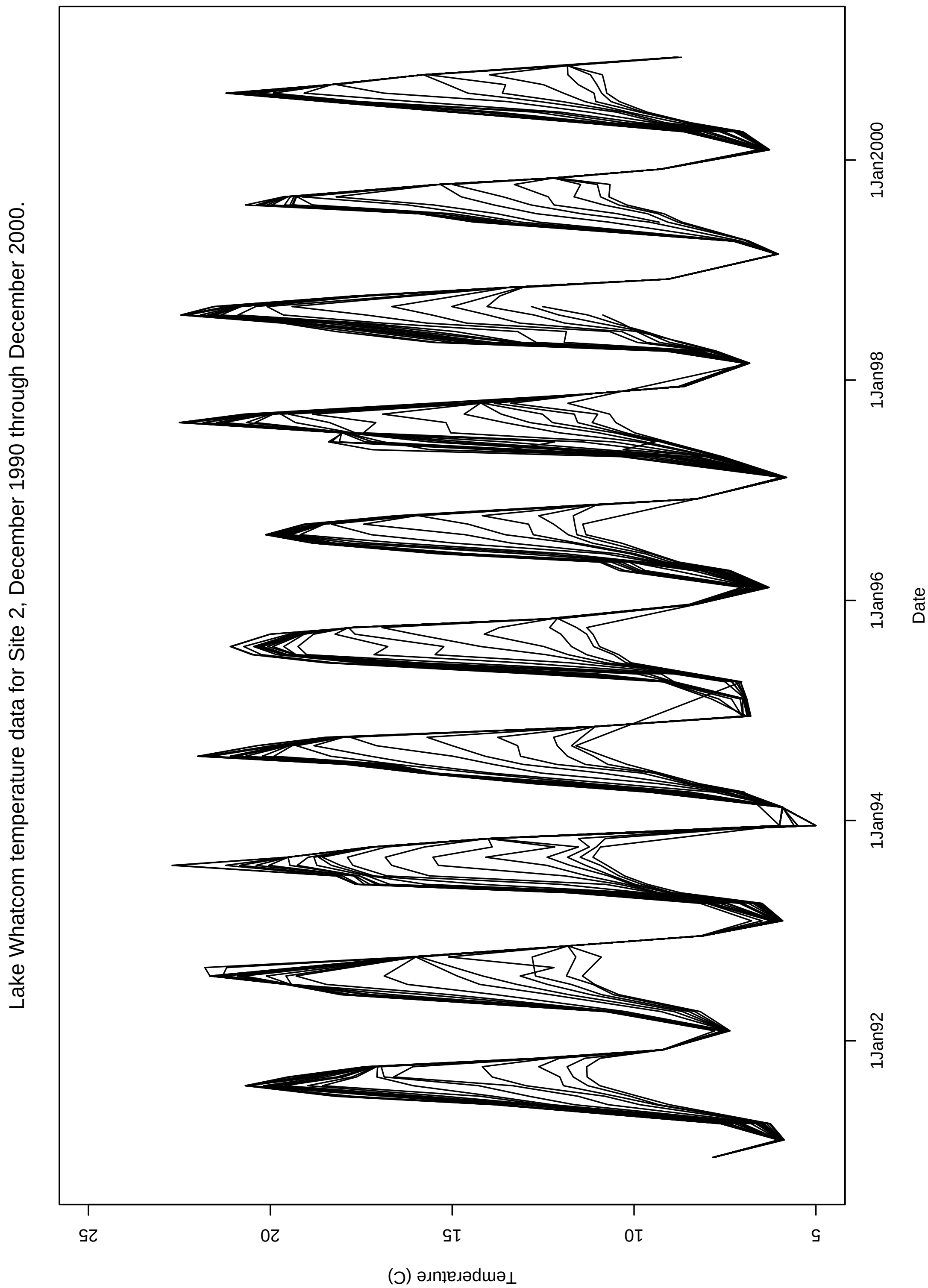


Figure 13: Lake Whatcom temperature data for Site 2.

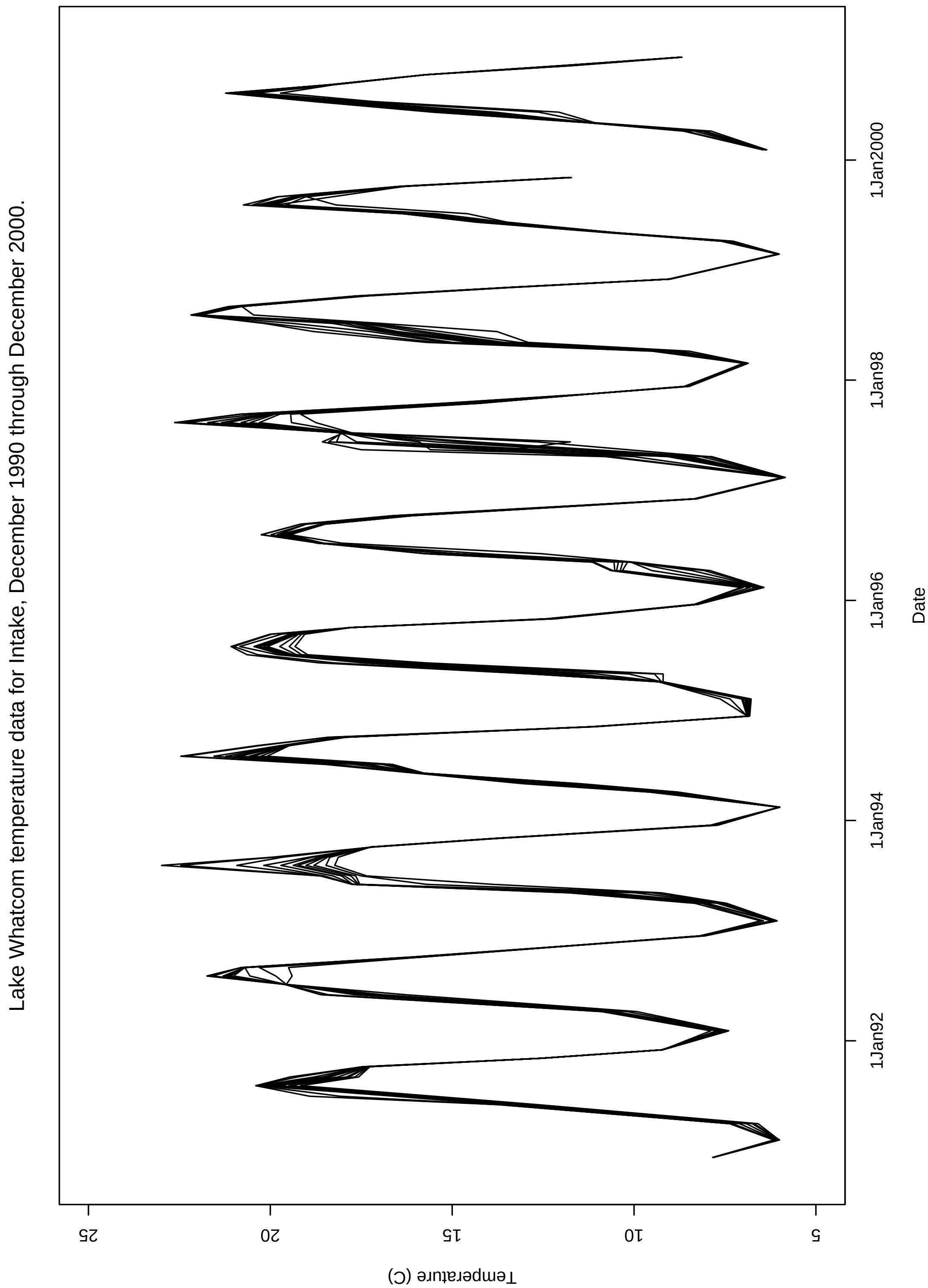


Figure 14: Lake Whatcom temperature data for the Intake.

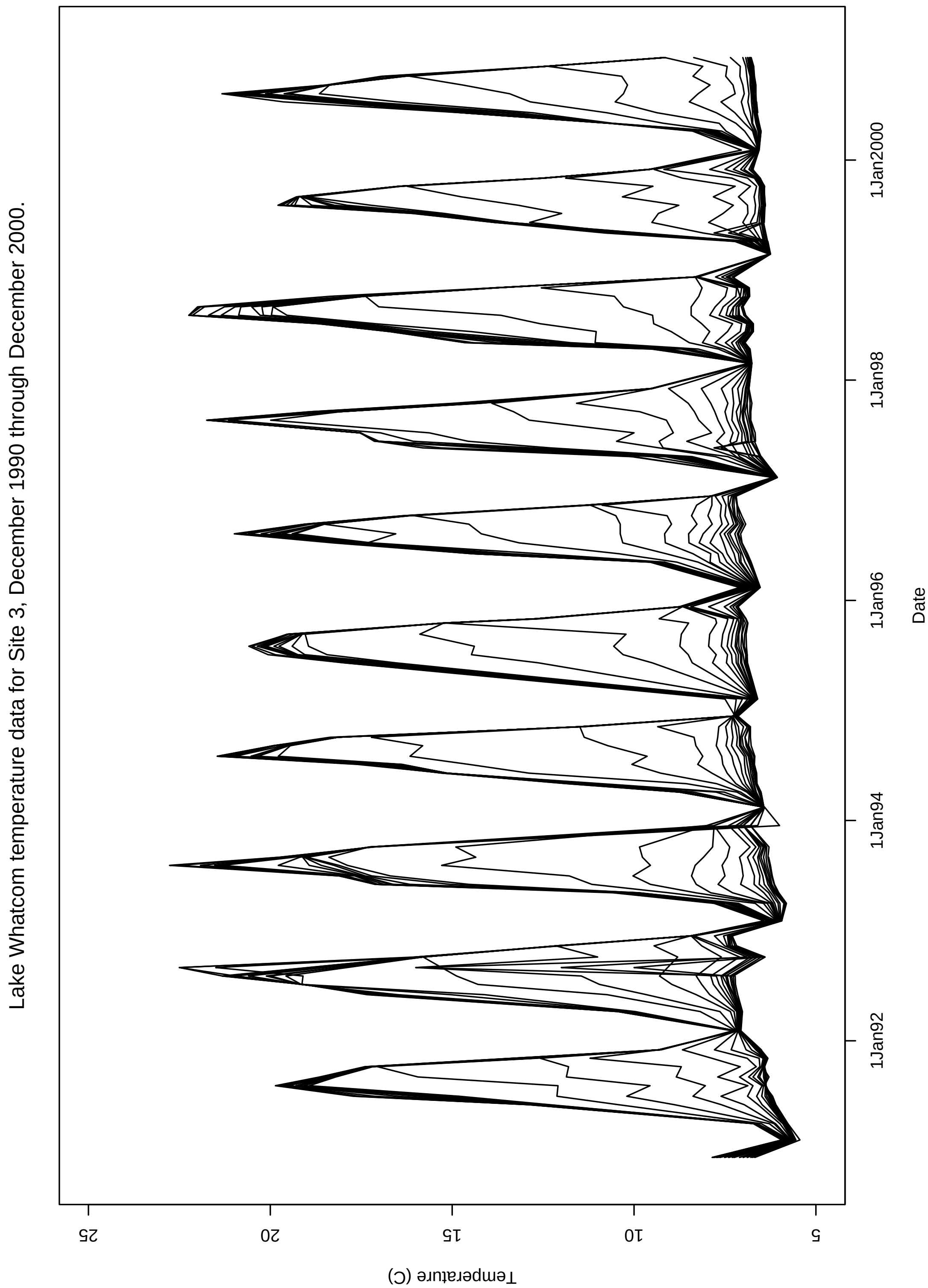


Figure 15: Lake Whatcom temperature data for Site 3.

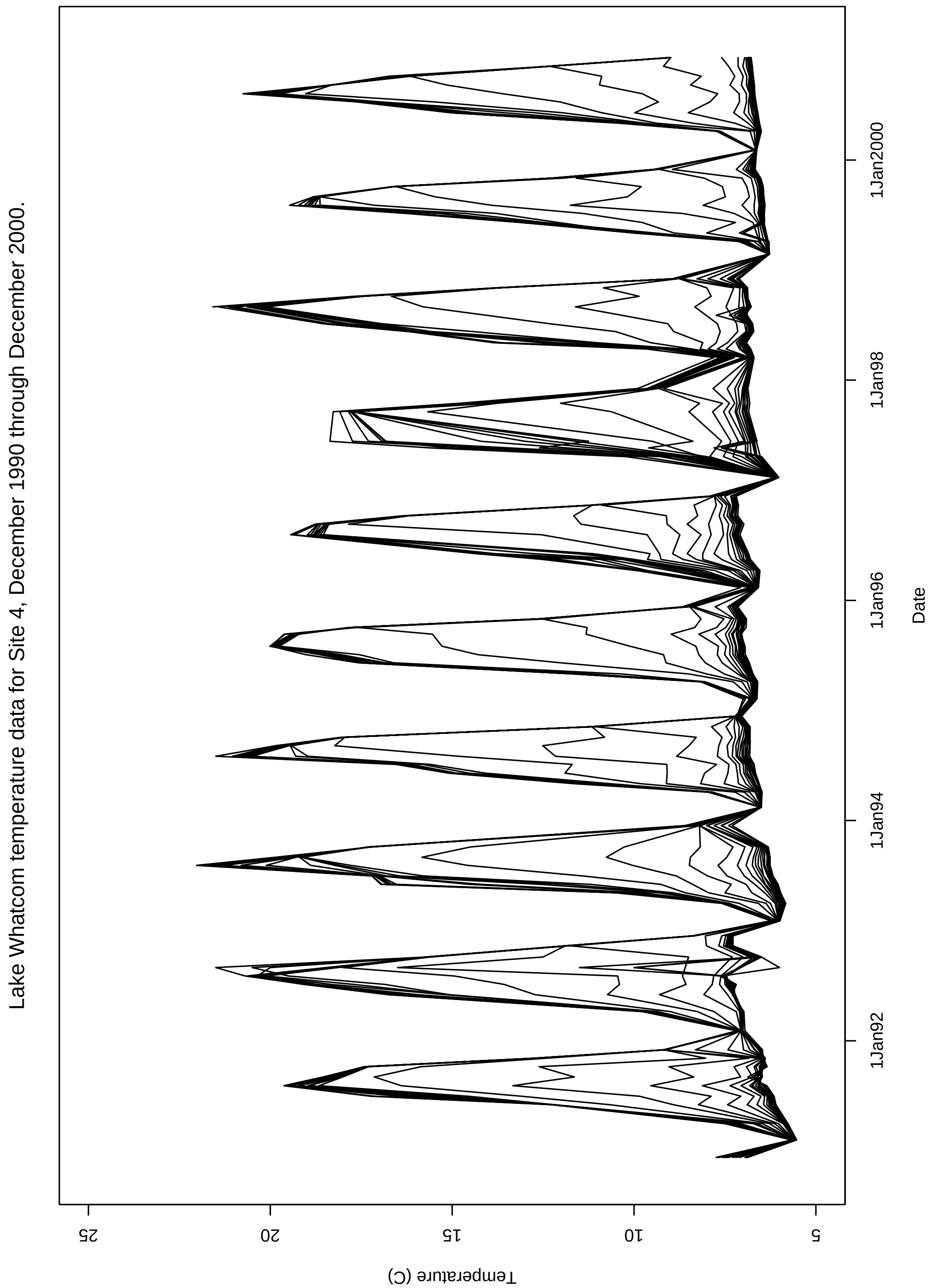


Figure 16: Lake Whatcom temperature data for Site 4.

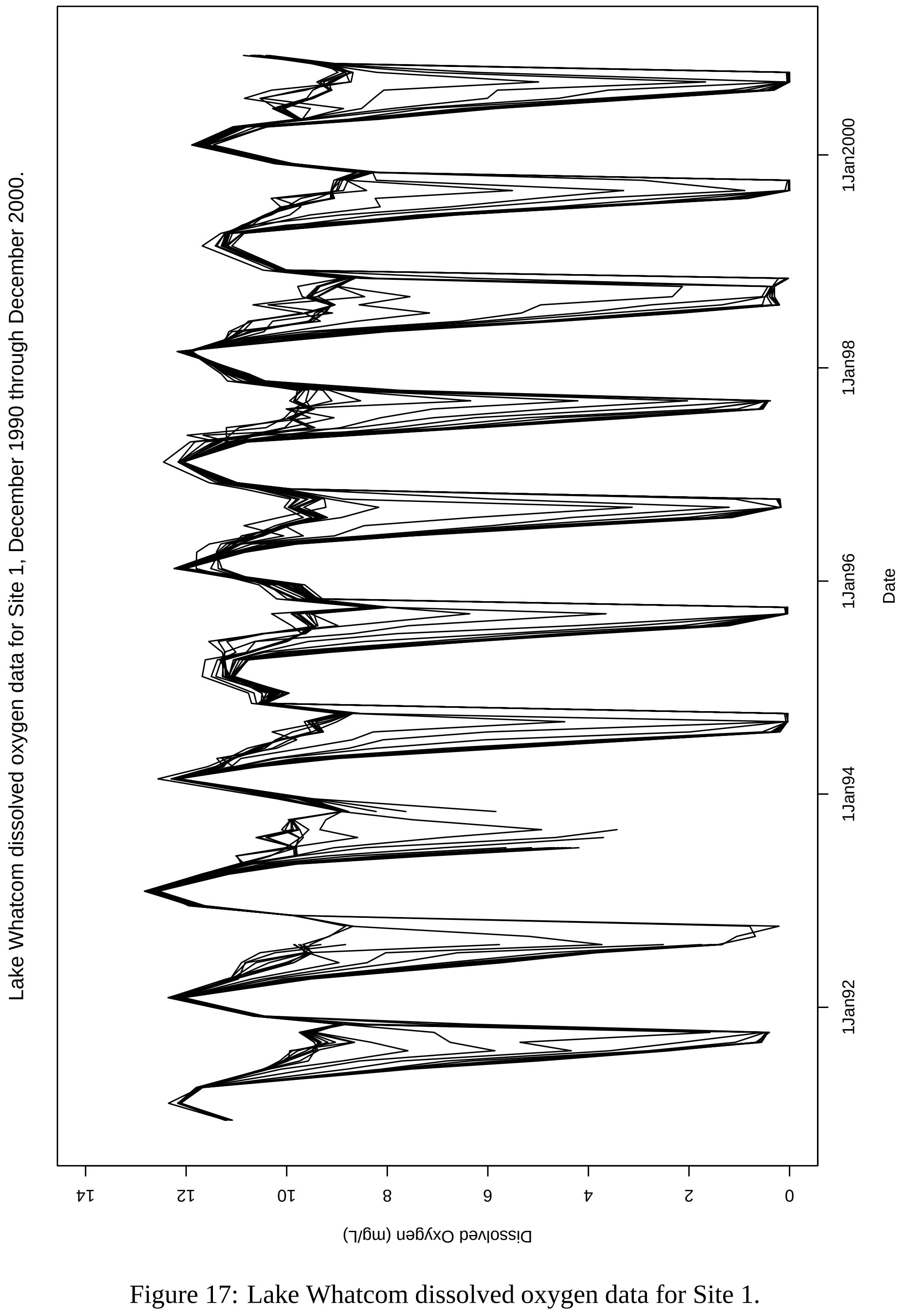


Figure 17: Lake Whatcom dissolved oxygen data for Site 1.

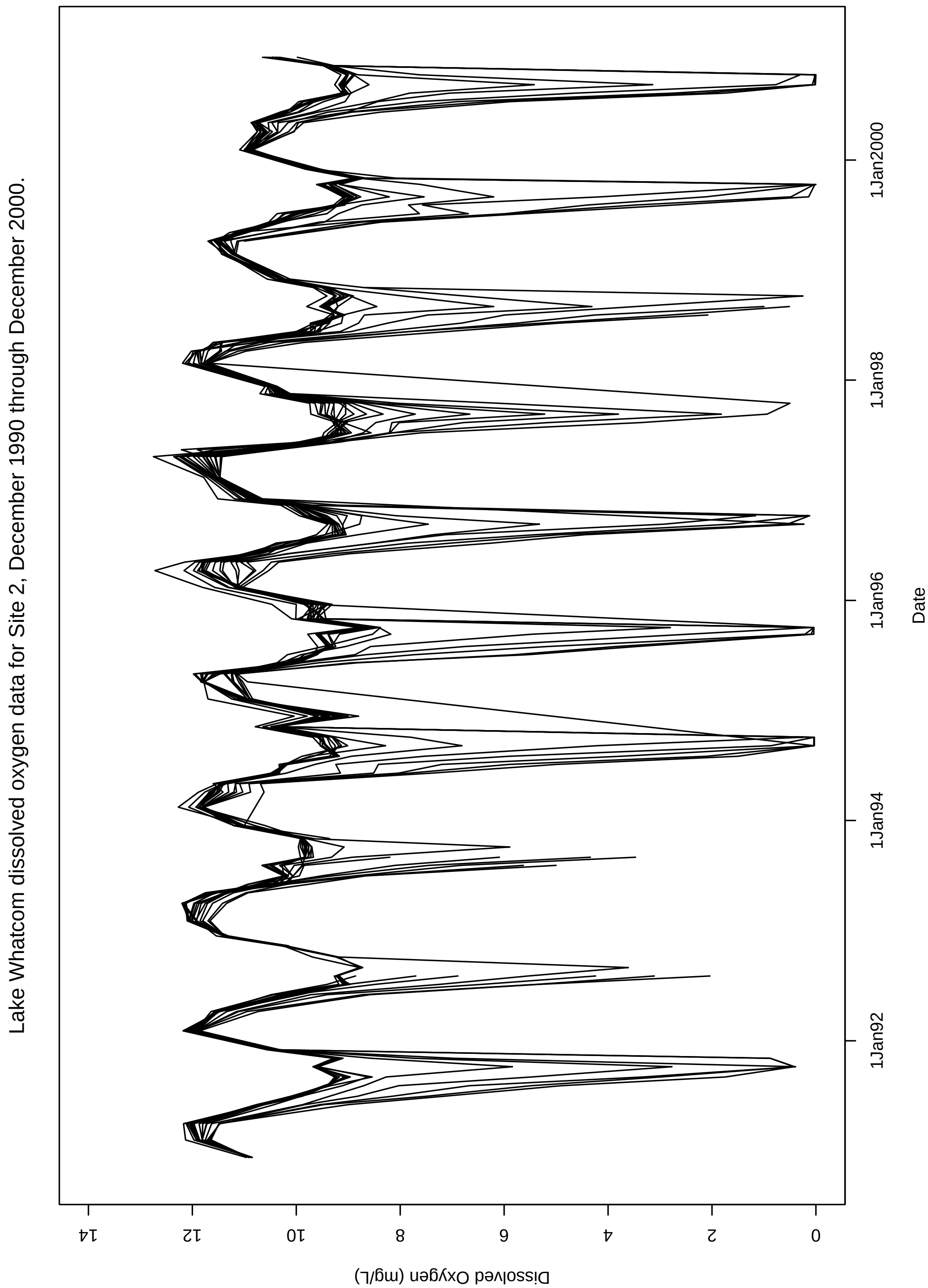


Figure 18: Lake Whatcom dissolved oxygen data for Site 2.

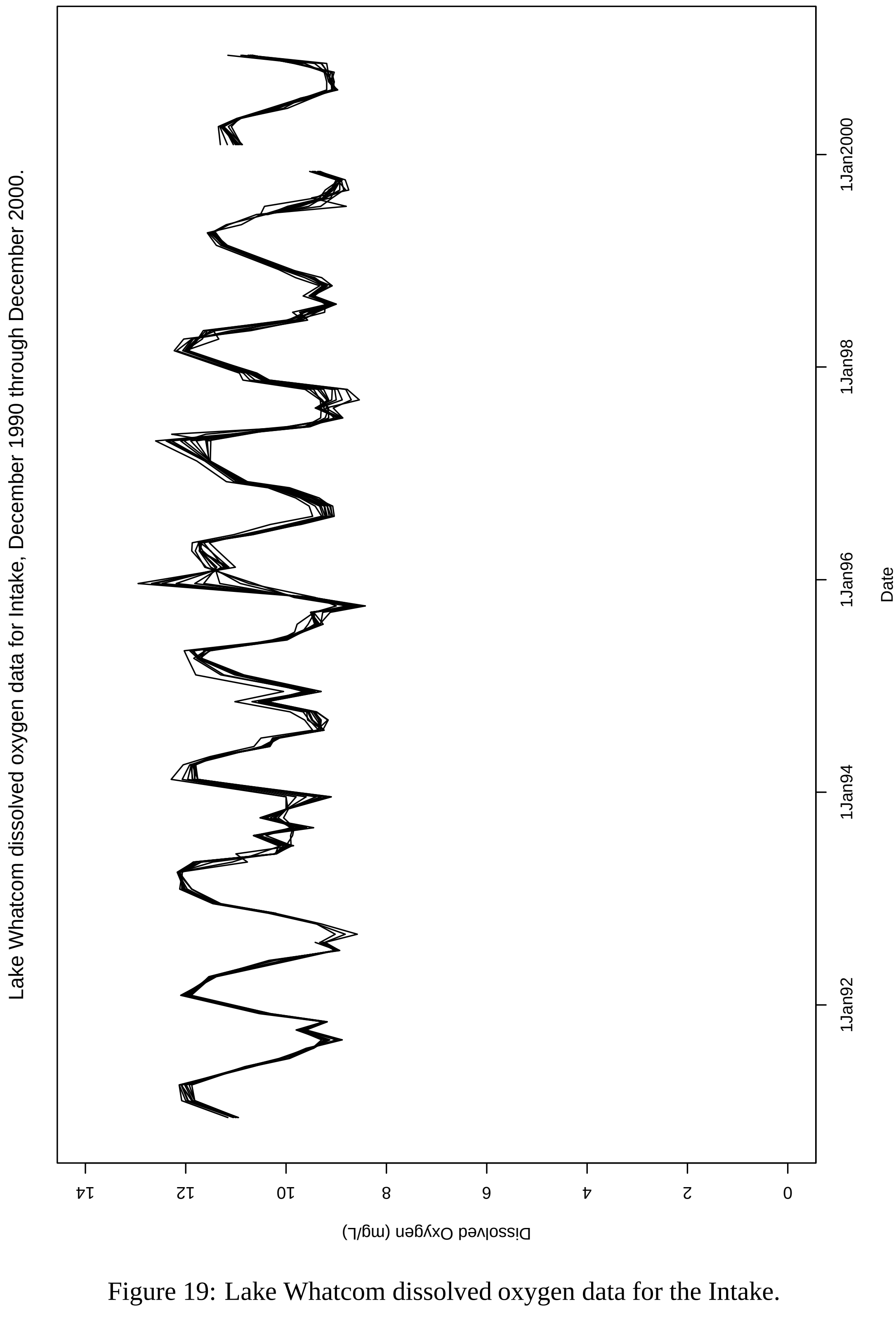


Figure 19: Lake Whatcom dissolved oxygen data for the Intake.

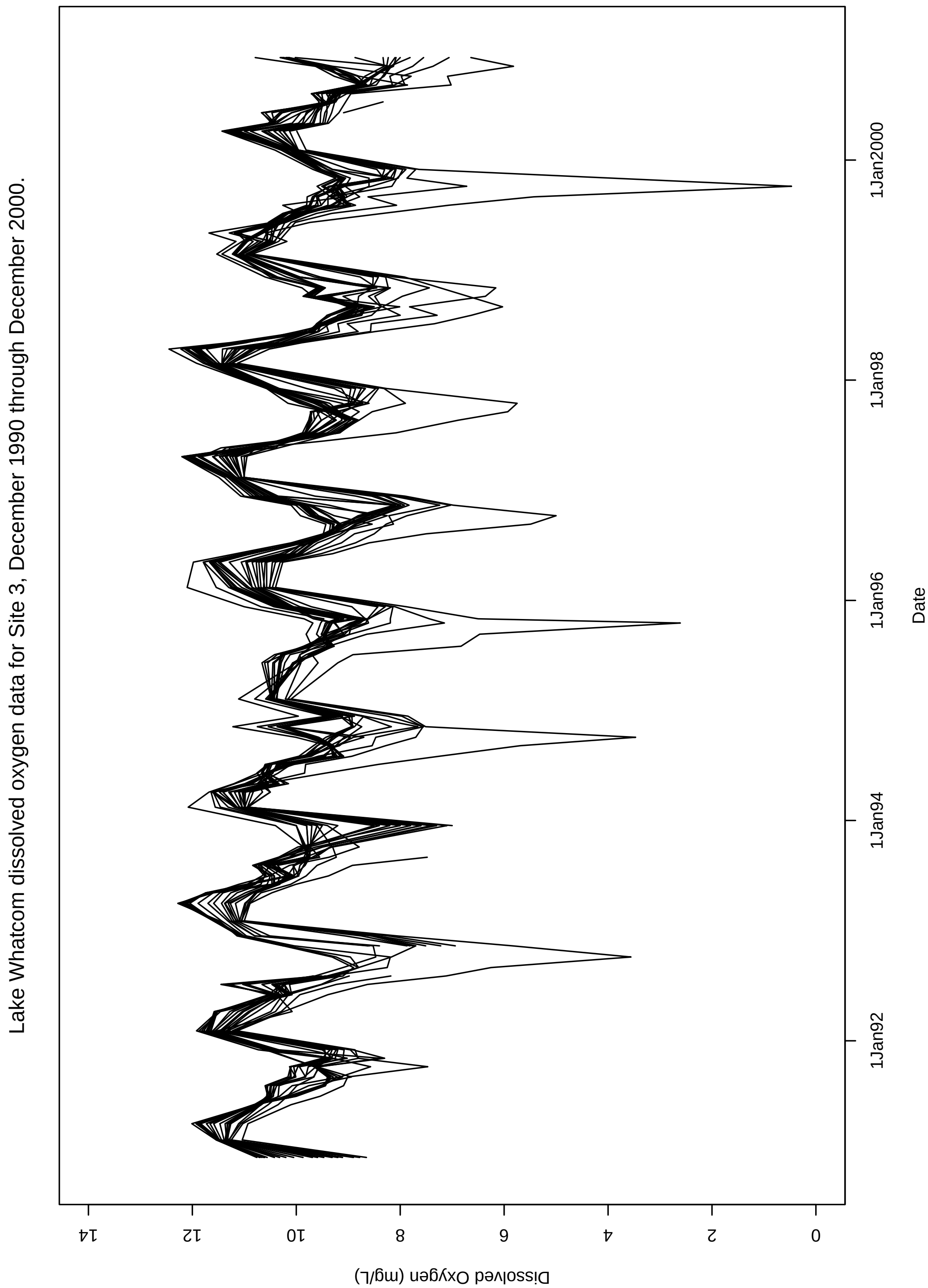


Figure 20: Lake Whatcom dissolved oxygen data for Site 3.

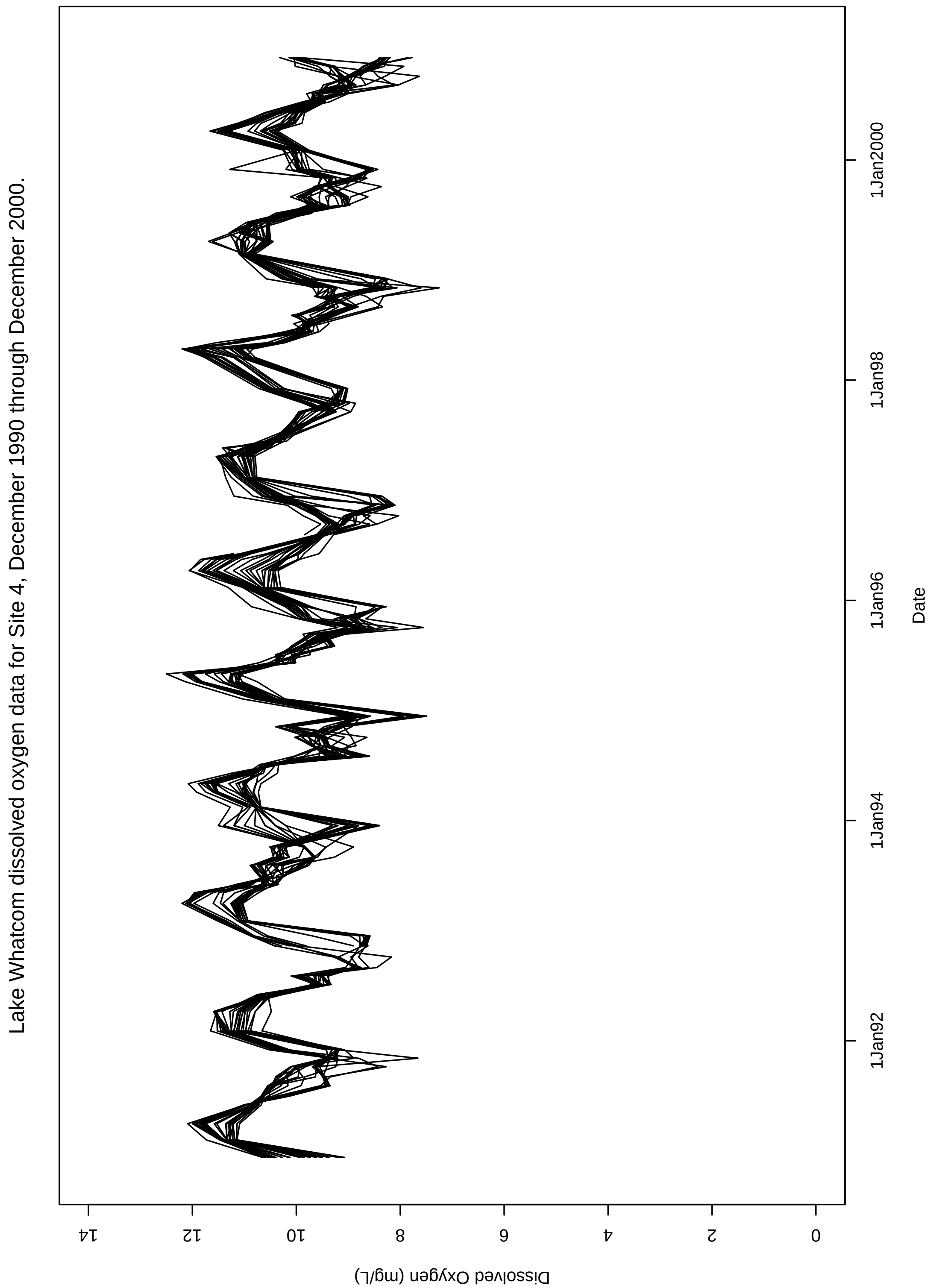


Figure 21: Lake Whatcom dissolved oxygen data for Site 4.

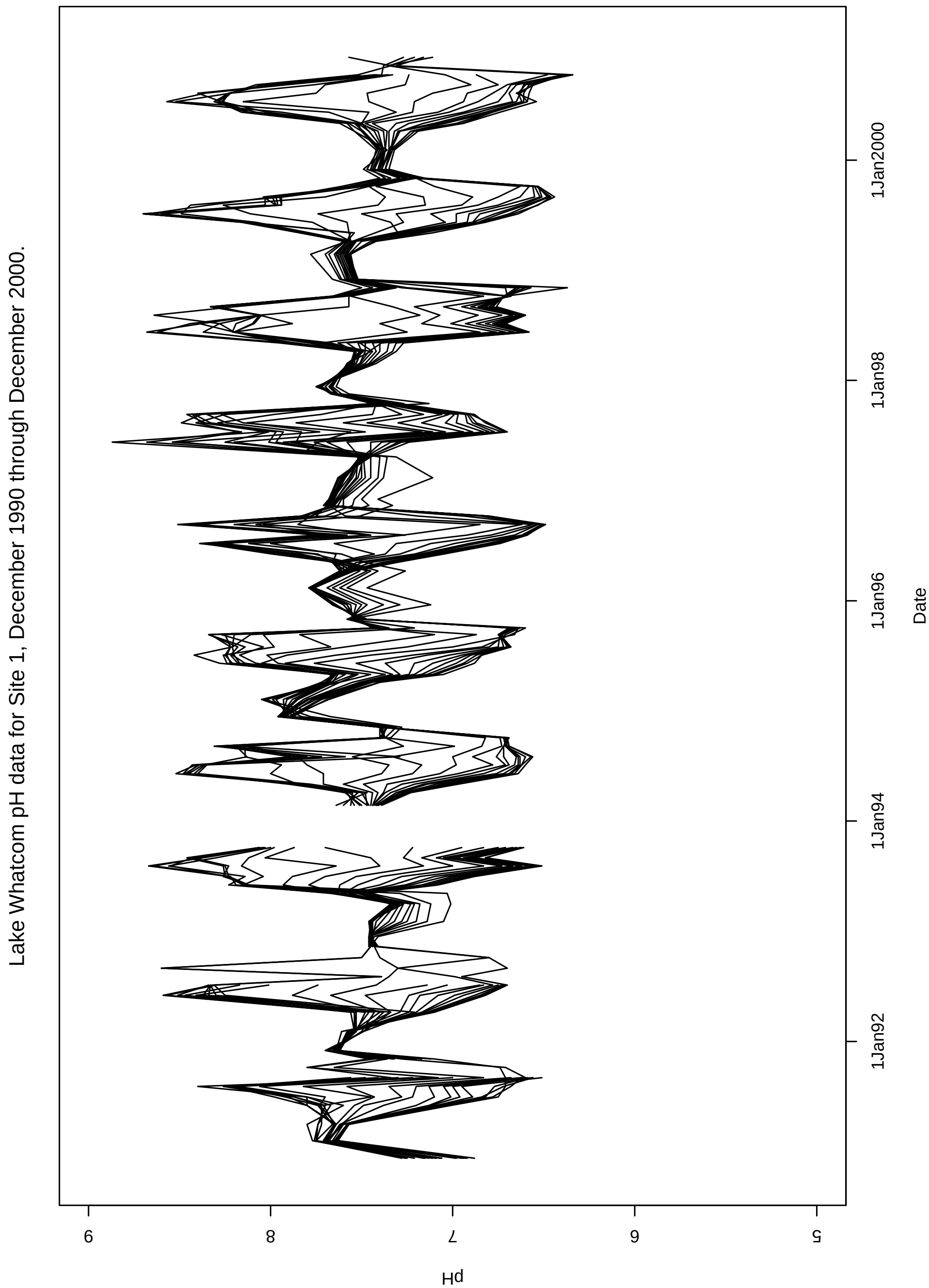


Figure 22: Lake Whatcom pH data for Site 1.

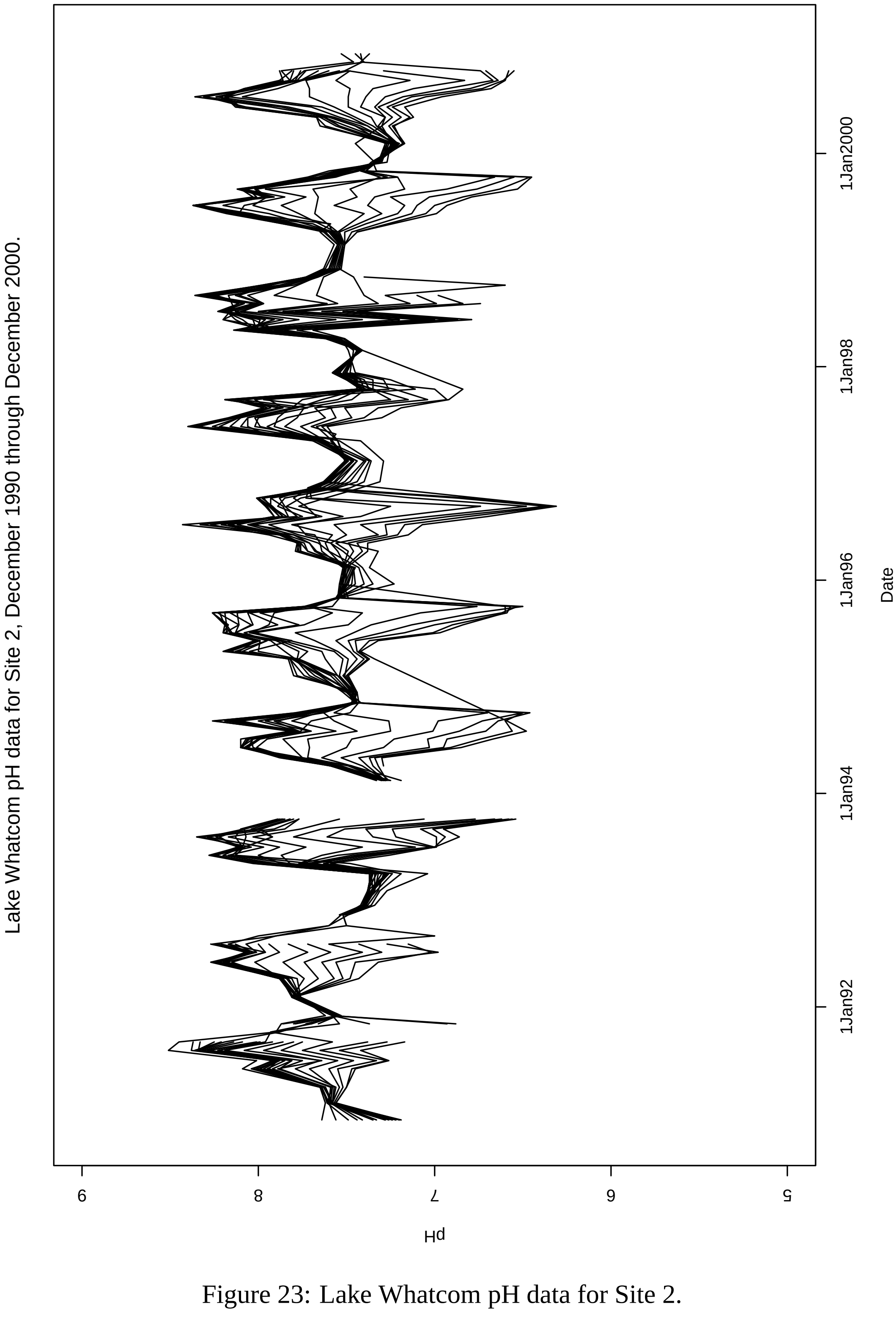


Figure 23: Lake Whatcom pH data for Site 2.

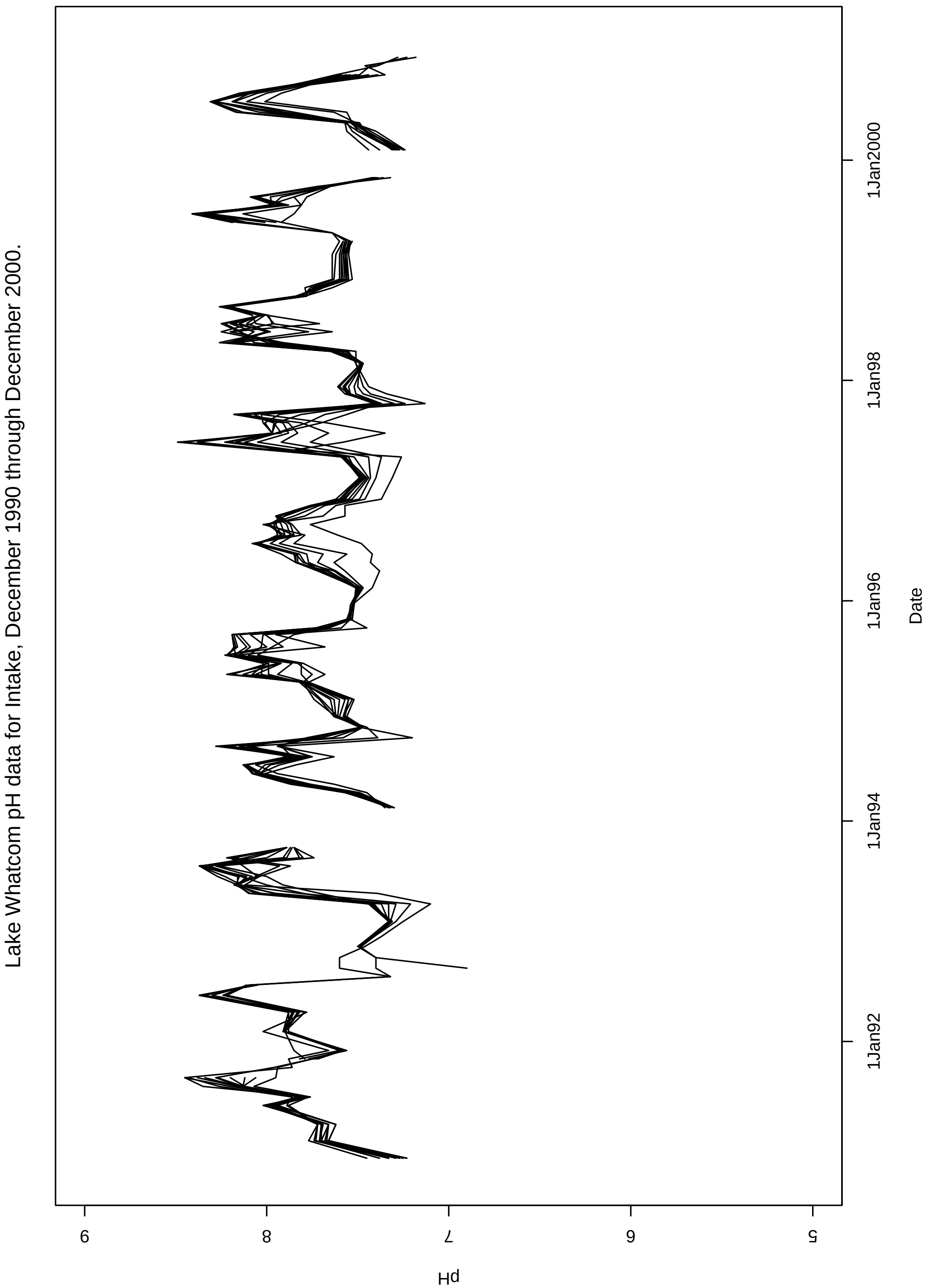


Figure 24: Lake Whatcom pH data for the Intake.

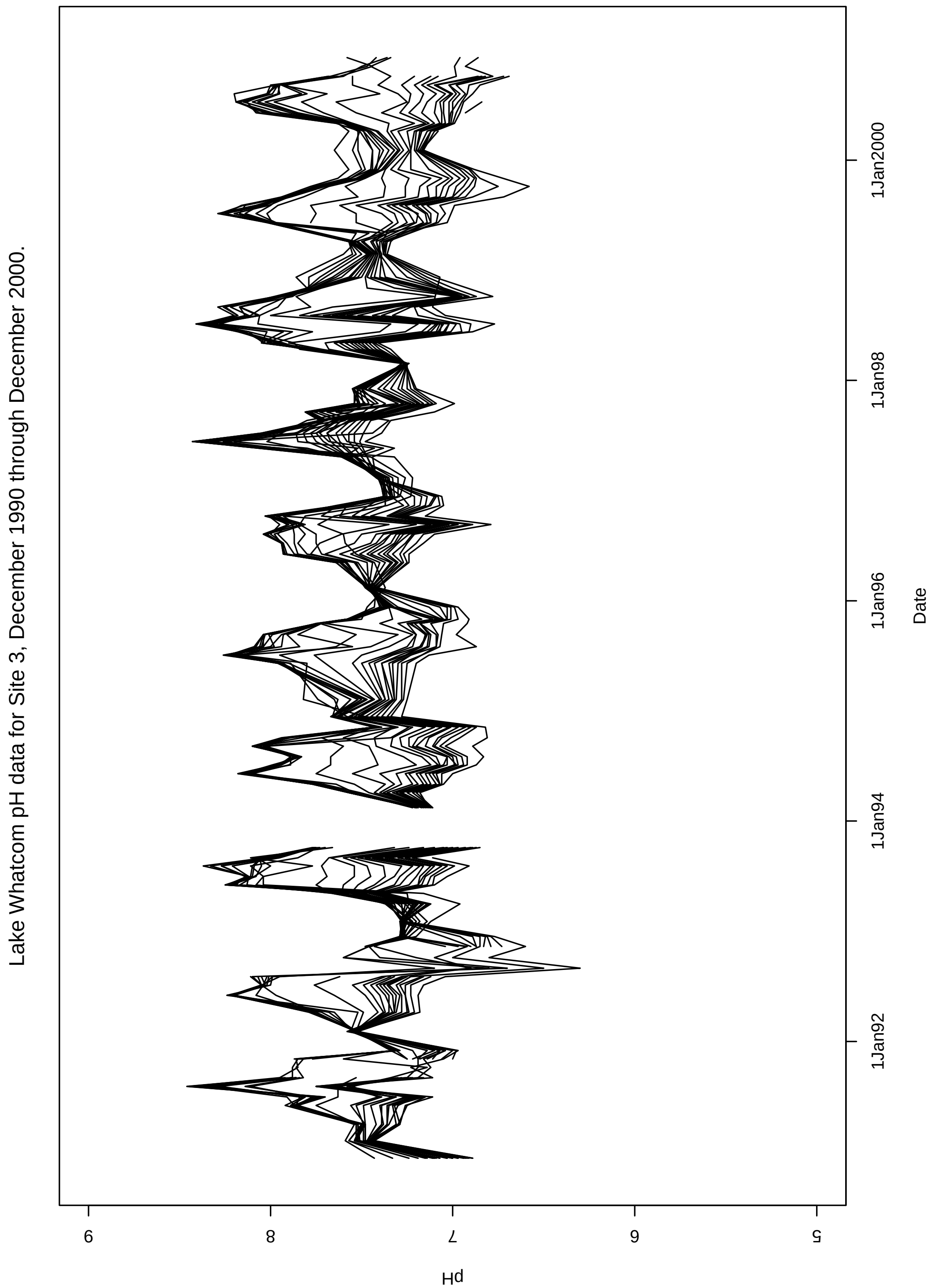


Figure 25: Lake Whatcom pH data for Site 3.

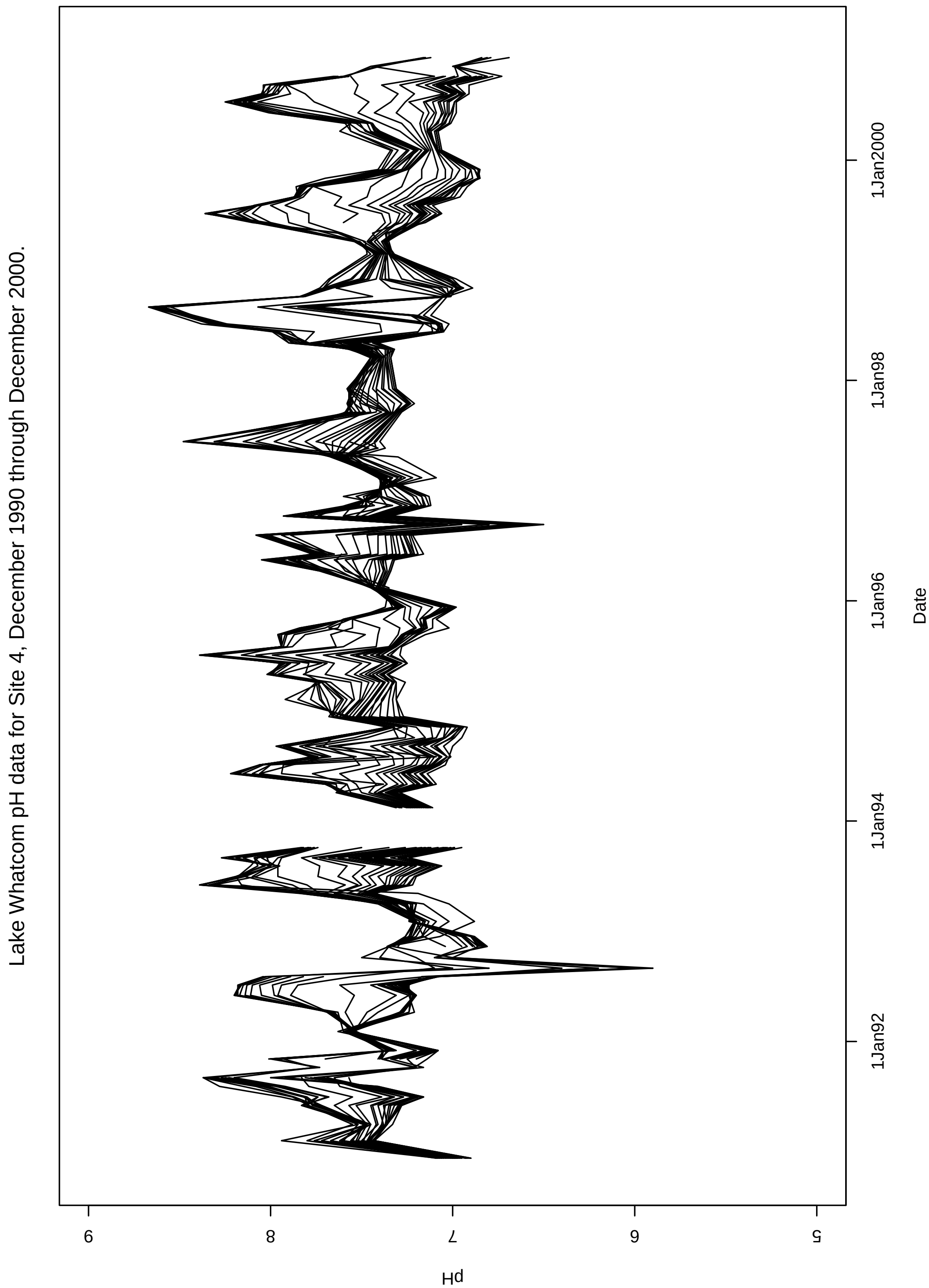


Figure 26: Lake Whatcom pH data for Site 4.

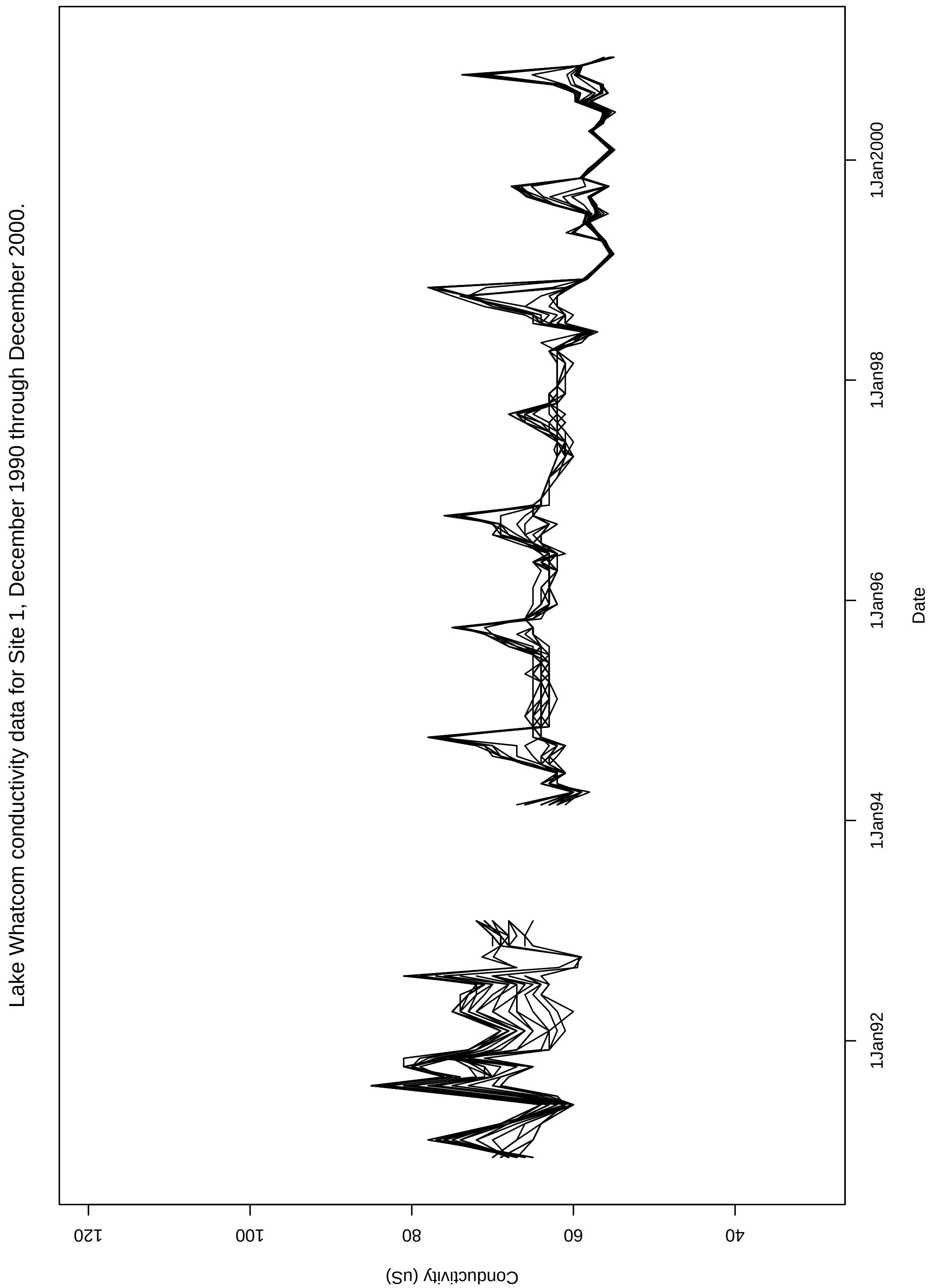


Figure 27: Lake Whatcom conductivity data for Site 1.

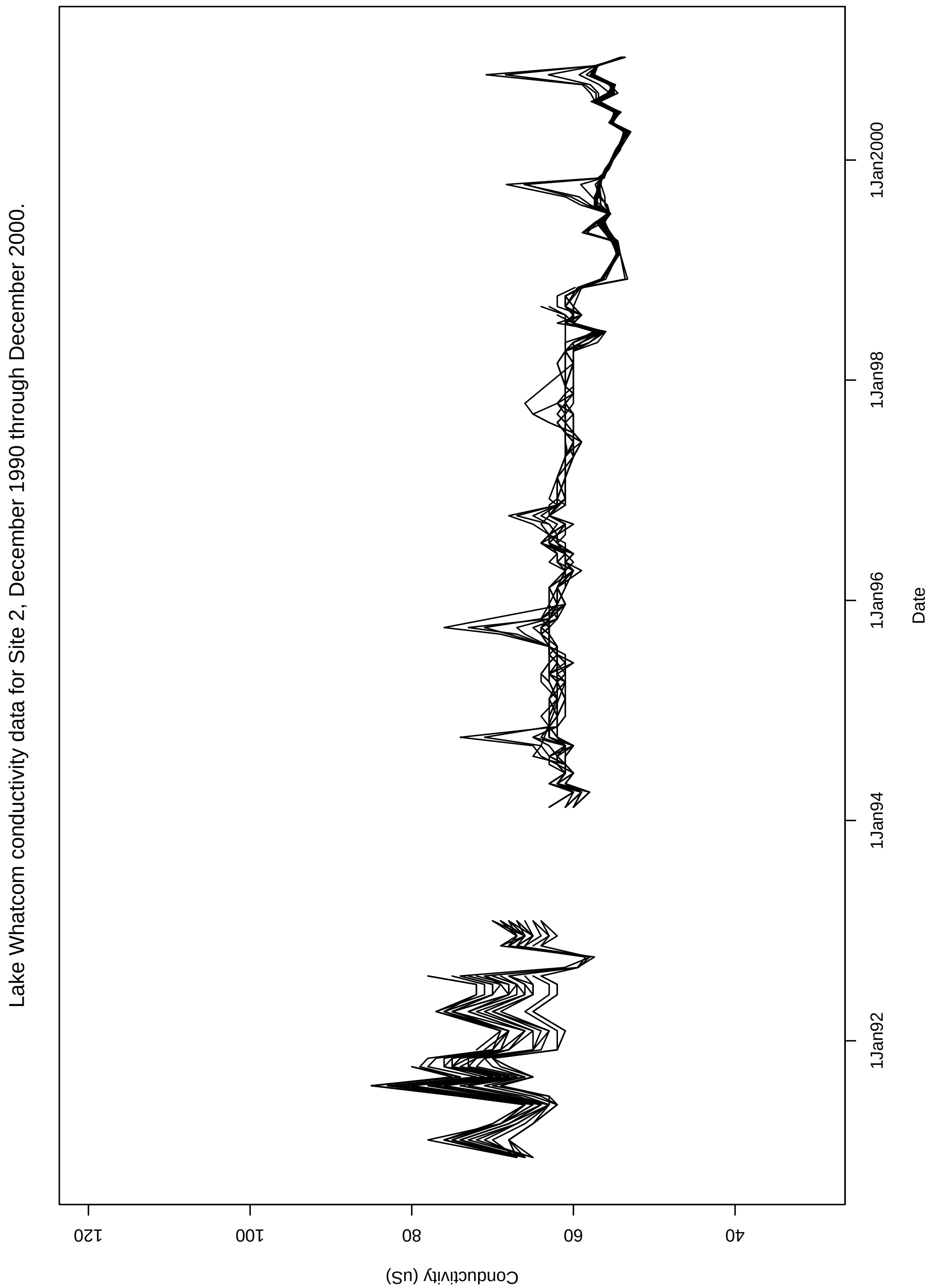


Figure 28: Lake Whatcom conductivity data for Site 2.

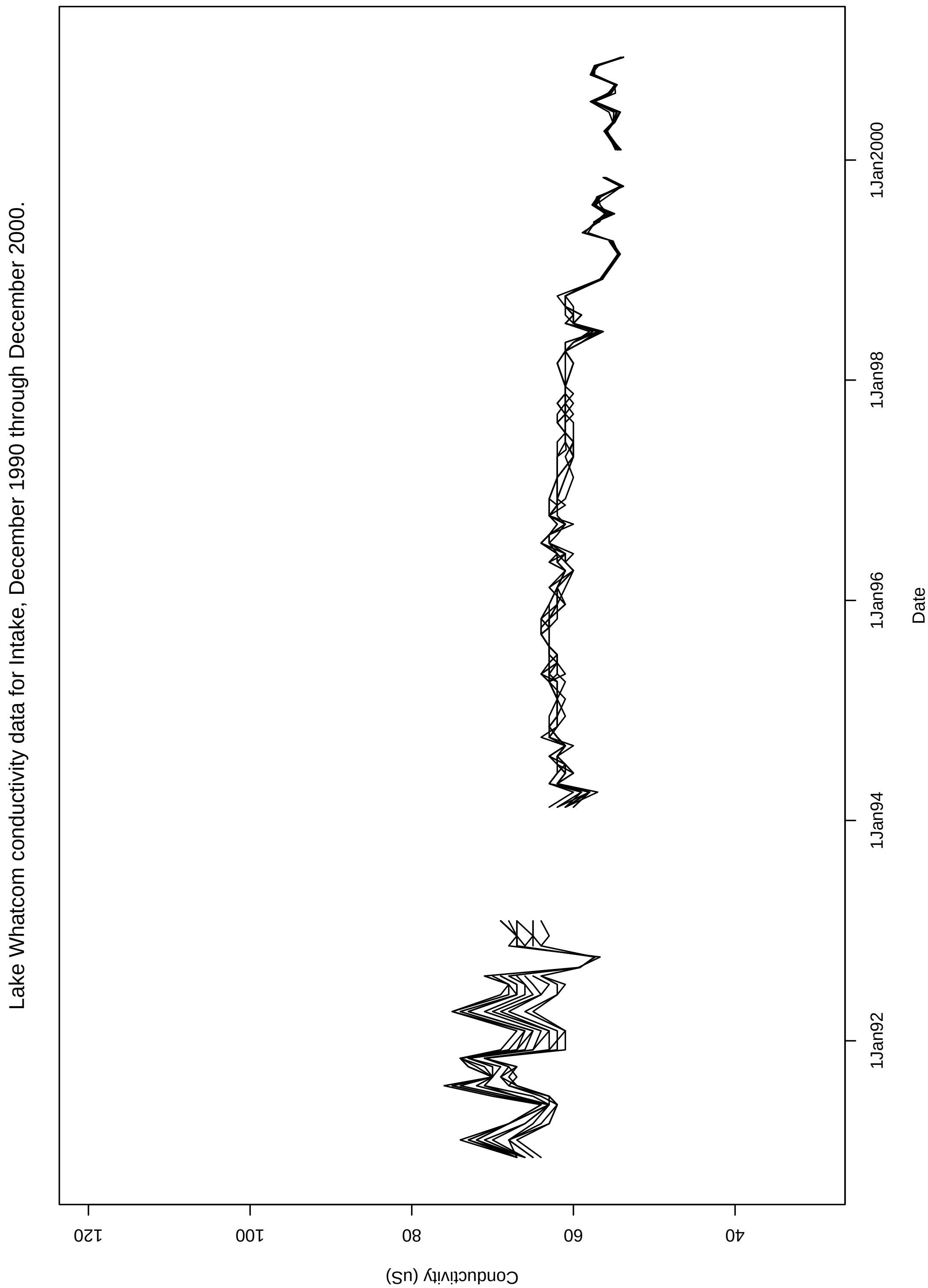


Figure 29: Lake Whatcom conductivity data for the Intake.

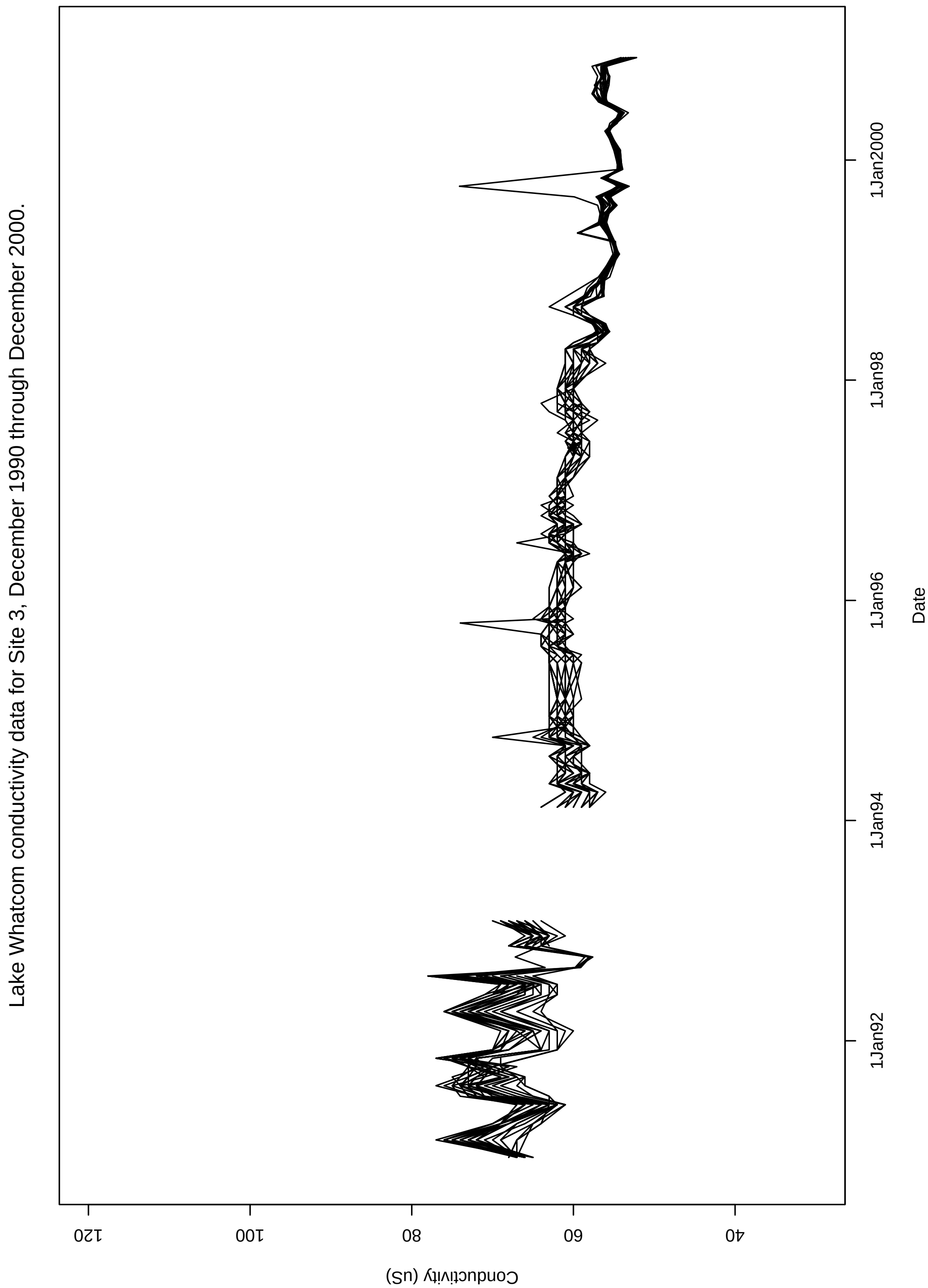


Figure 30: Lake Whatcom conductivity data for Site 3.

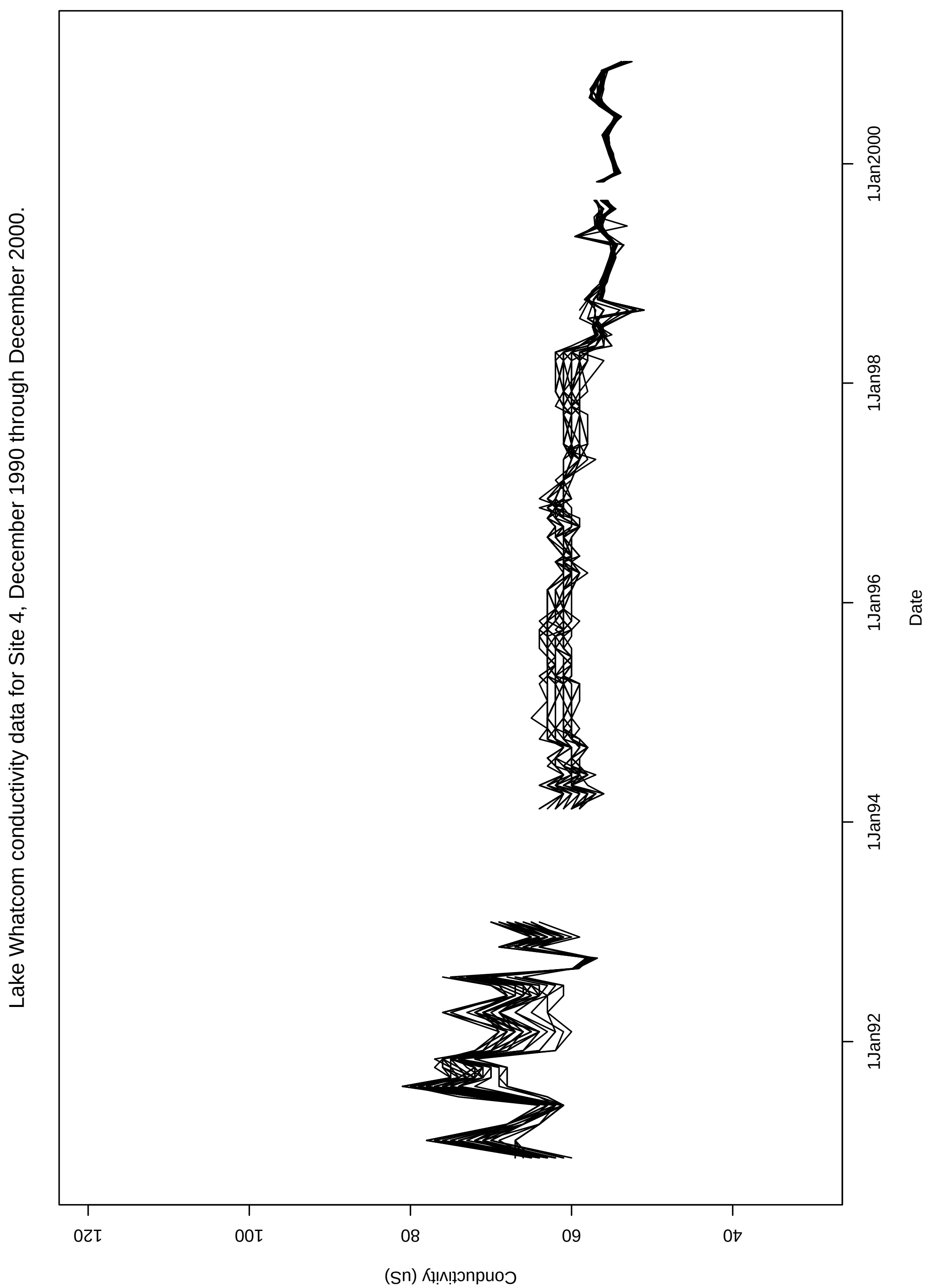


Figure 31: Lake Whatcom conductivity data for Site 4.

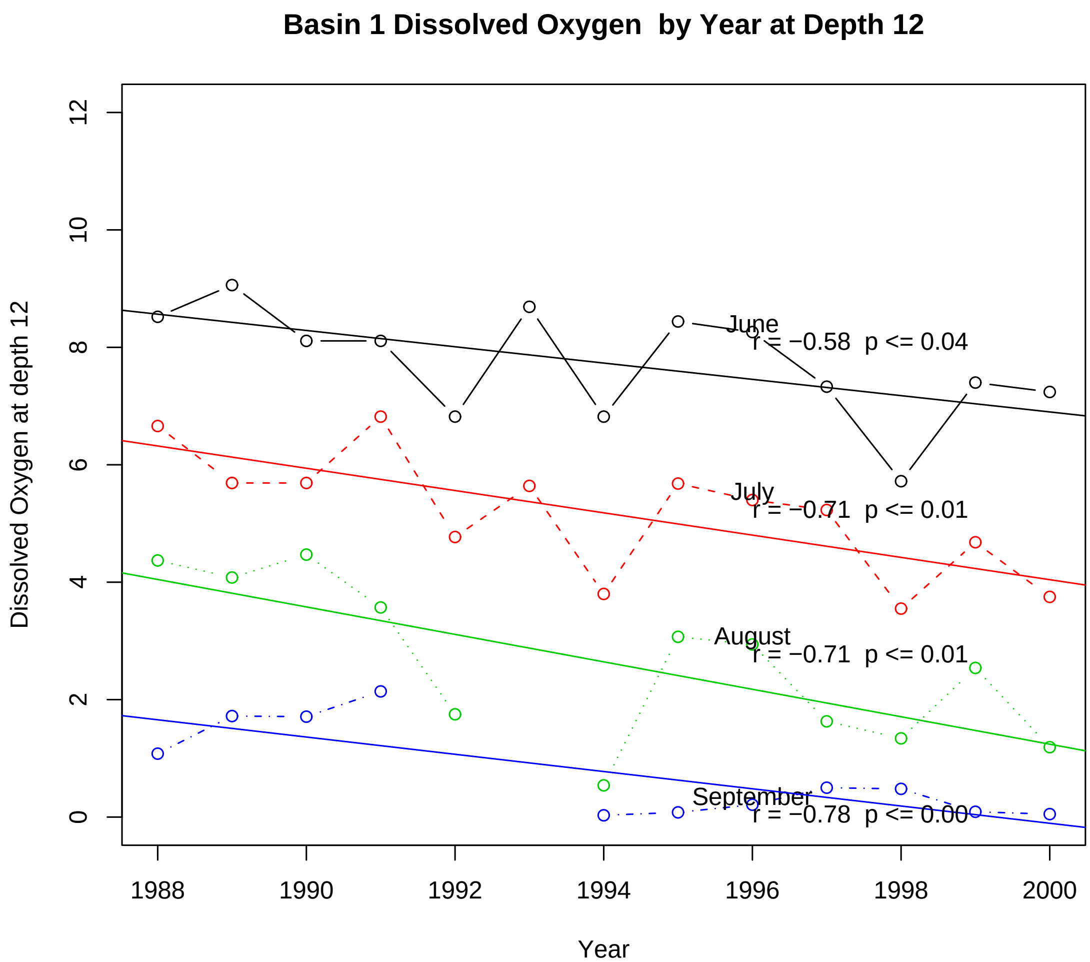


Figure 32: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (12 m). All results are statistically significant.

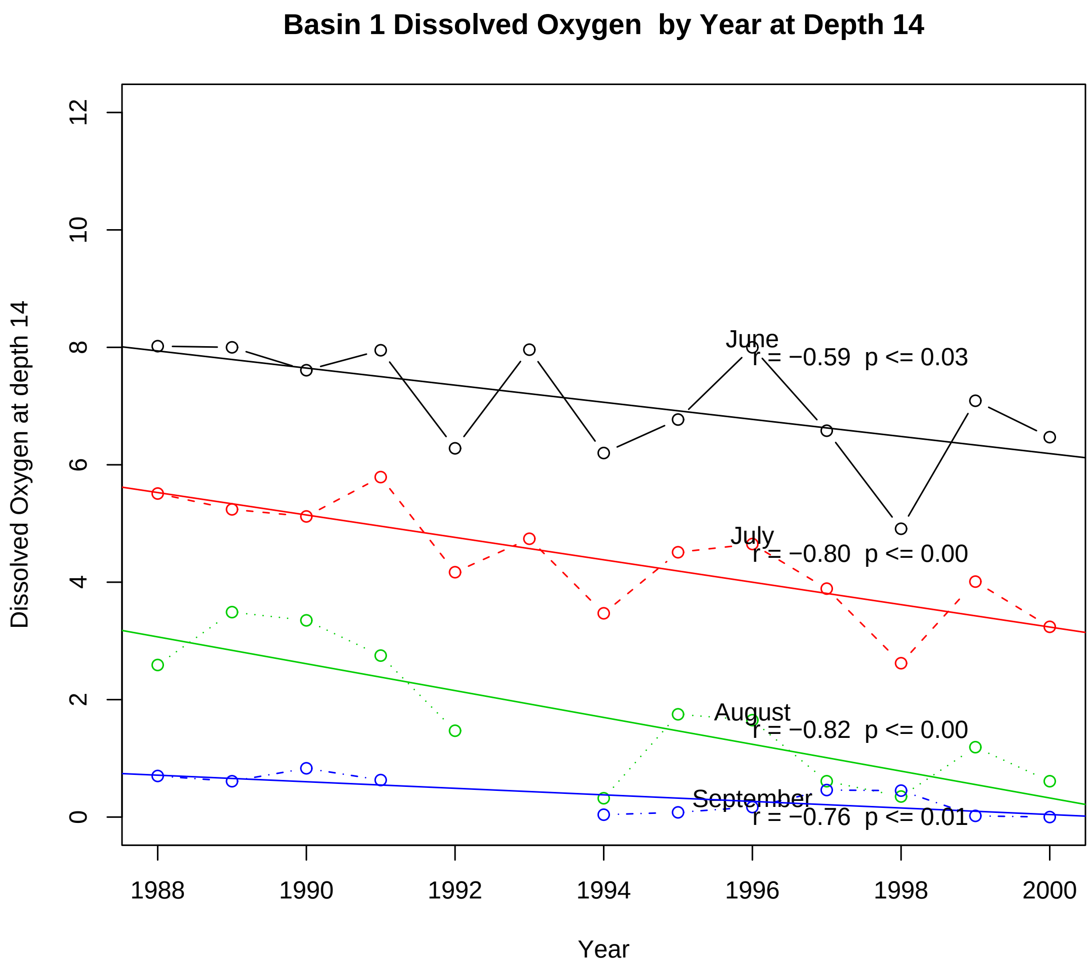


Figure 33: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (14 m). All results are statistically significant.

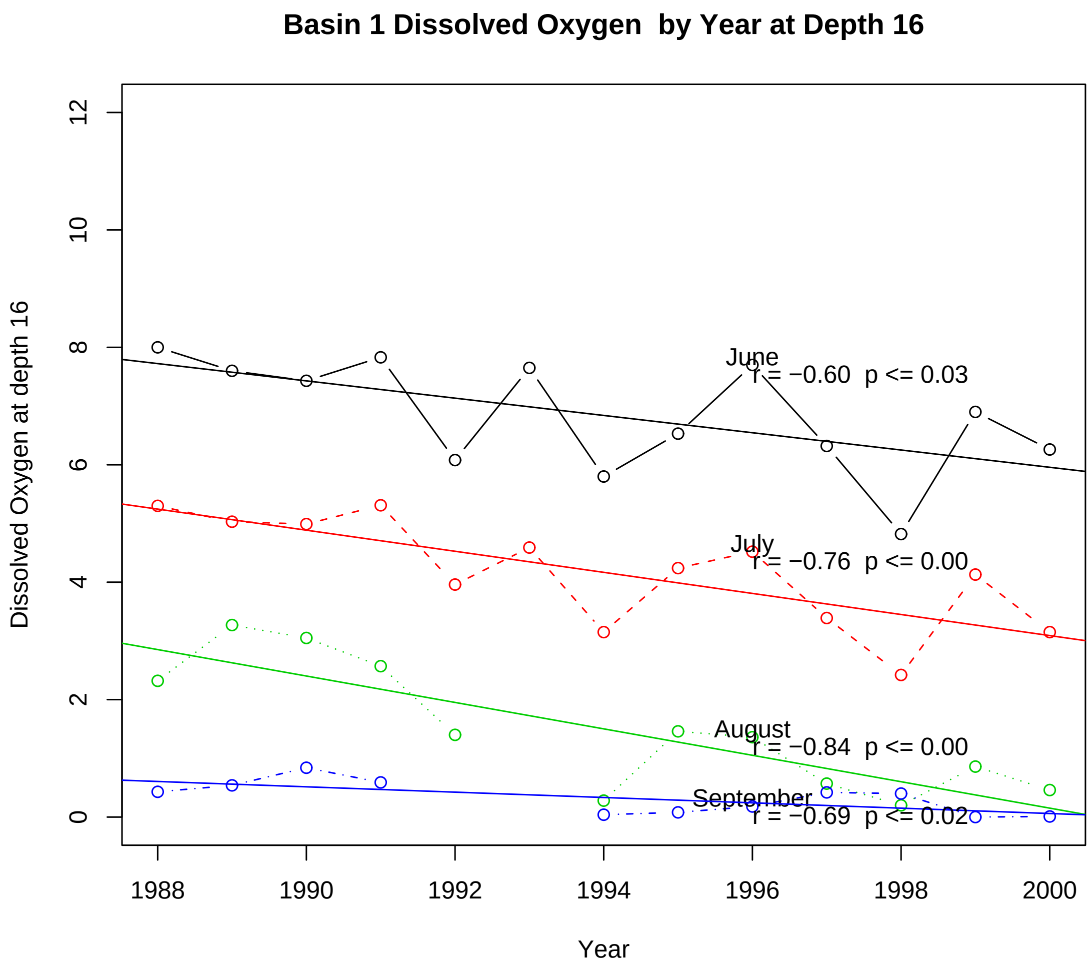


Figure 34: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (16 m). All results are statistically significant.

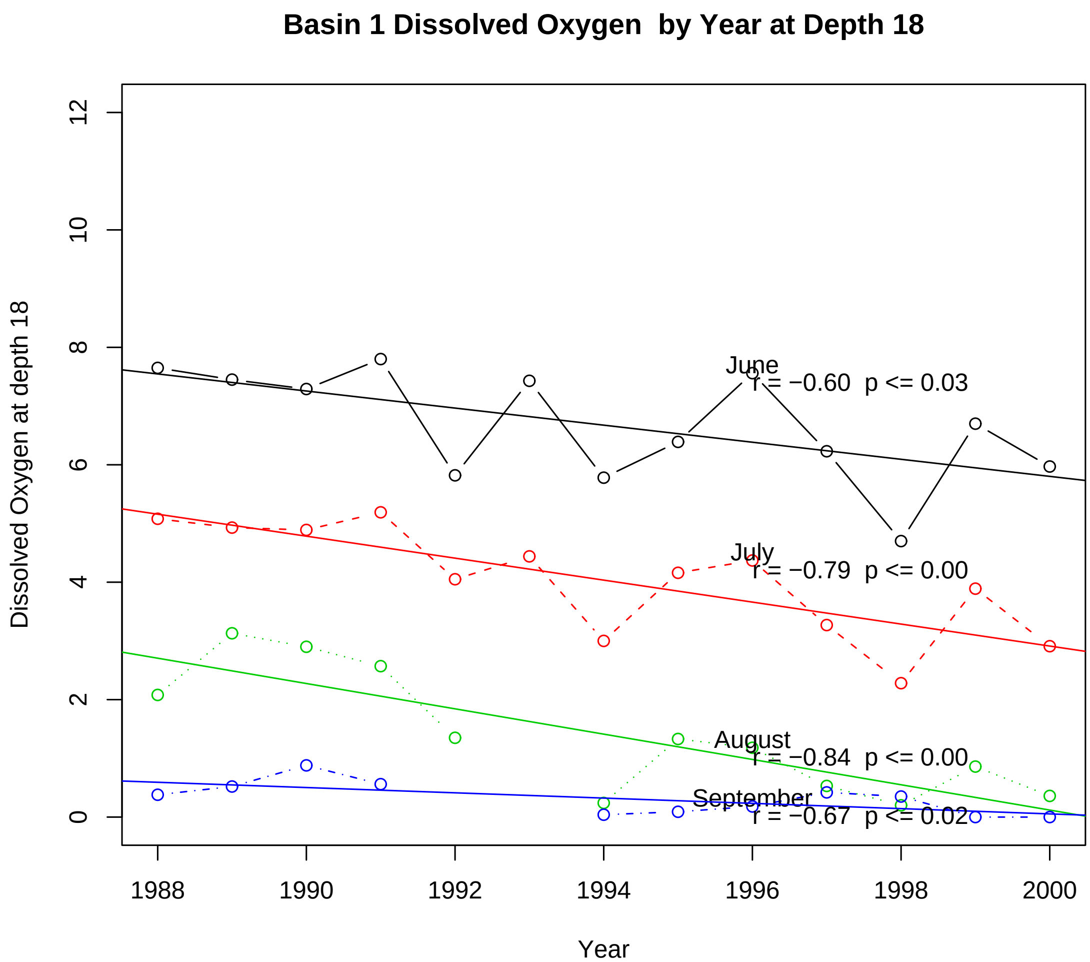


Figure 35: Pearson's r correlation of dissolved oxygen concentrations by year, Site 1 (18 m). All results are statistically significant.

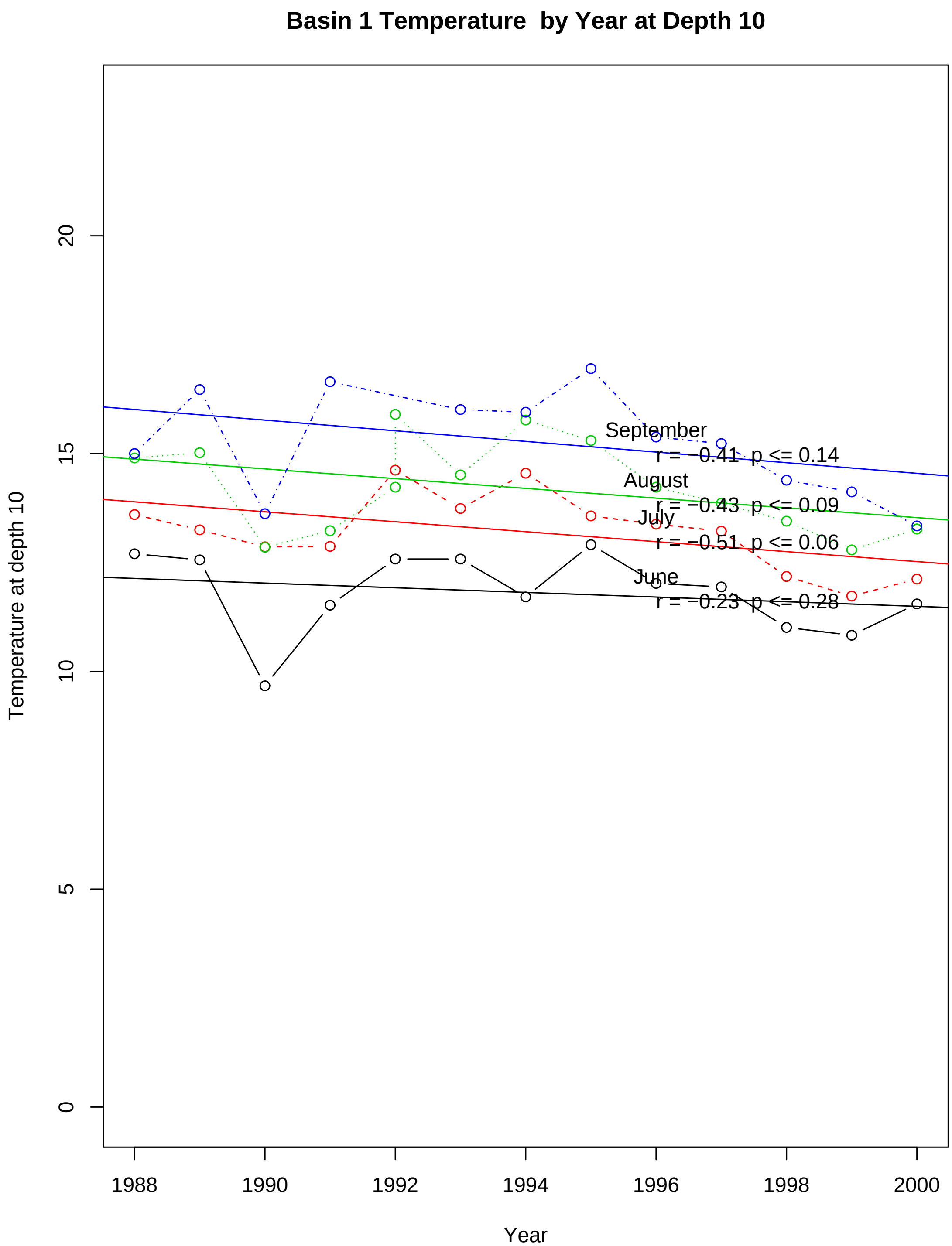


Figure 36: Correlation of water temperature by year, Site 1 (10 m). Results are not statistically significant at the 95% level.

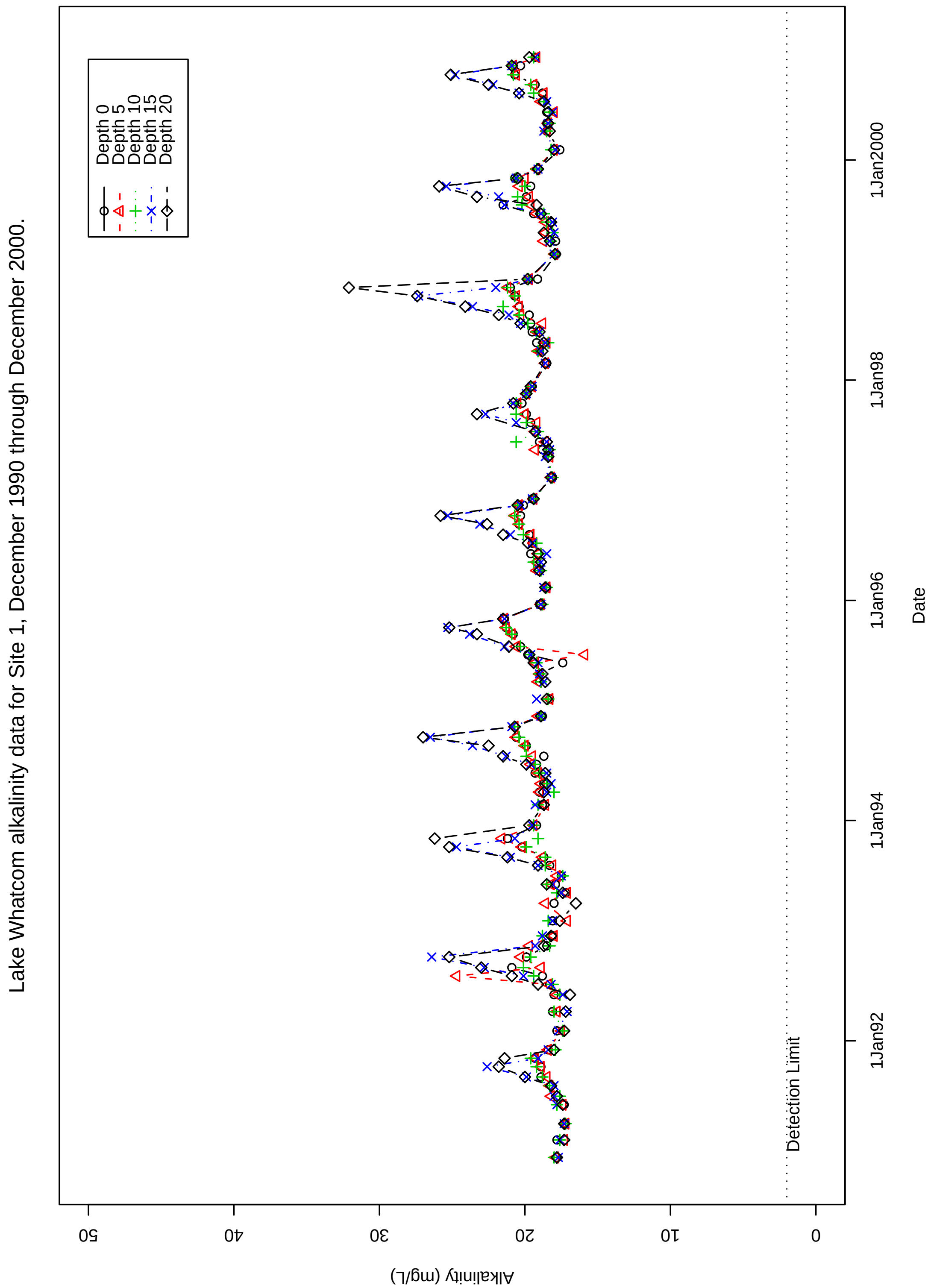


Figure 37: Lake Whatcom alkalinity data for Site 1.

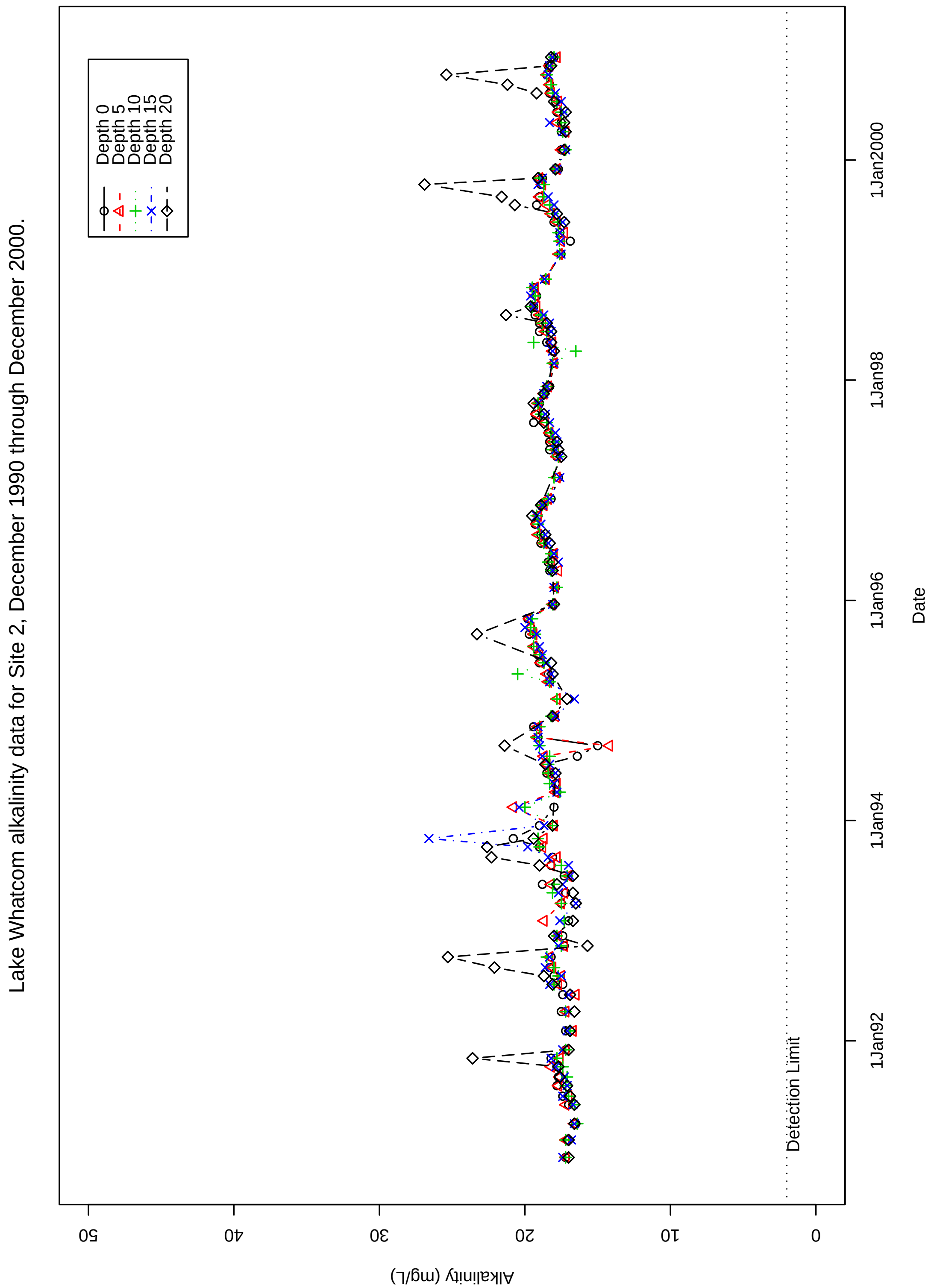


Figure 38: Lake Whatcom alkalinity data for Site 2.

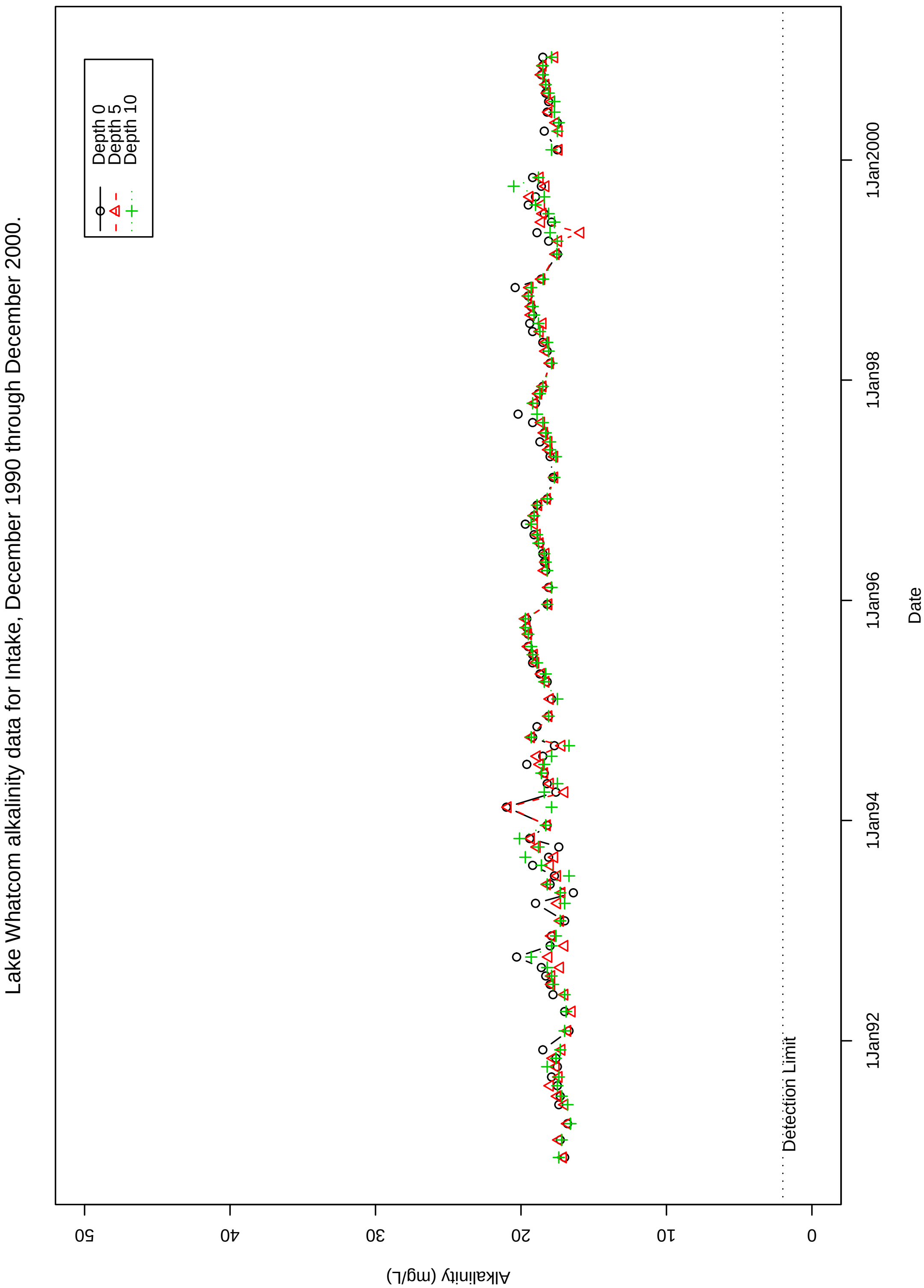


Figure 39: Lake Whatcom alkalinity data for the Intake.

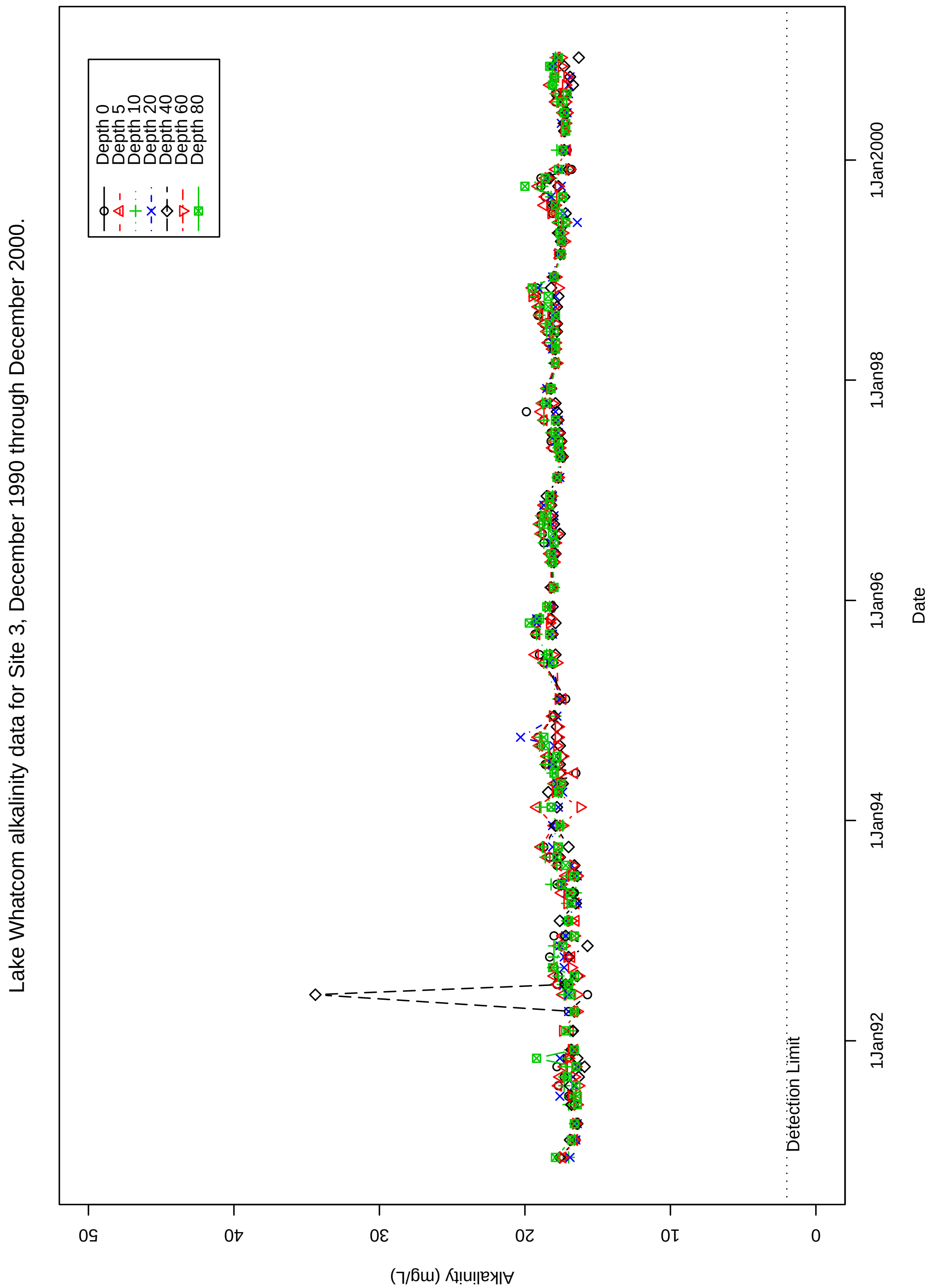


Figure 40: Lake Whatcom alkalinity data for Site 3.

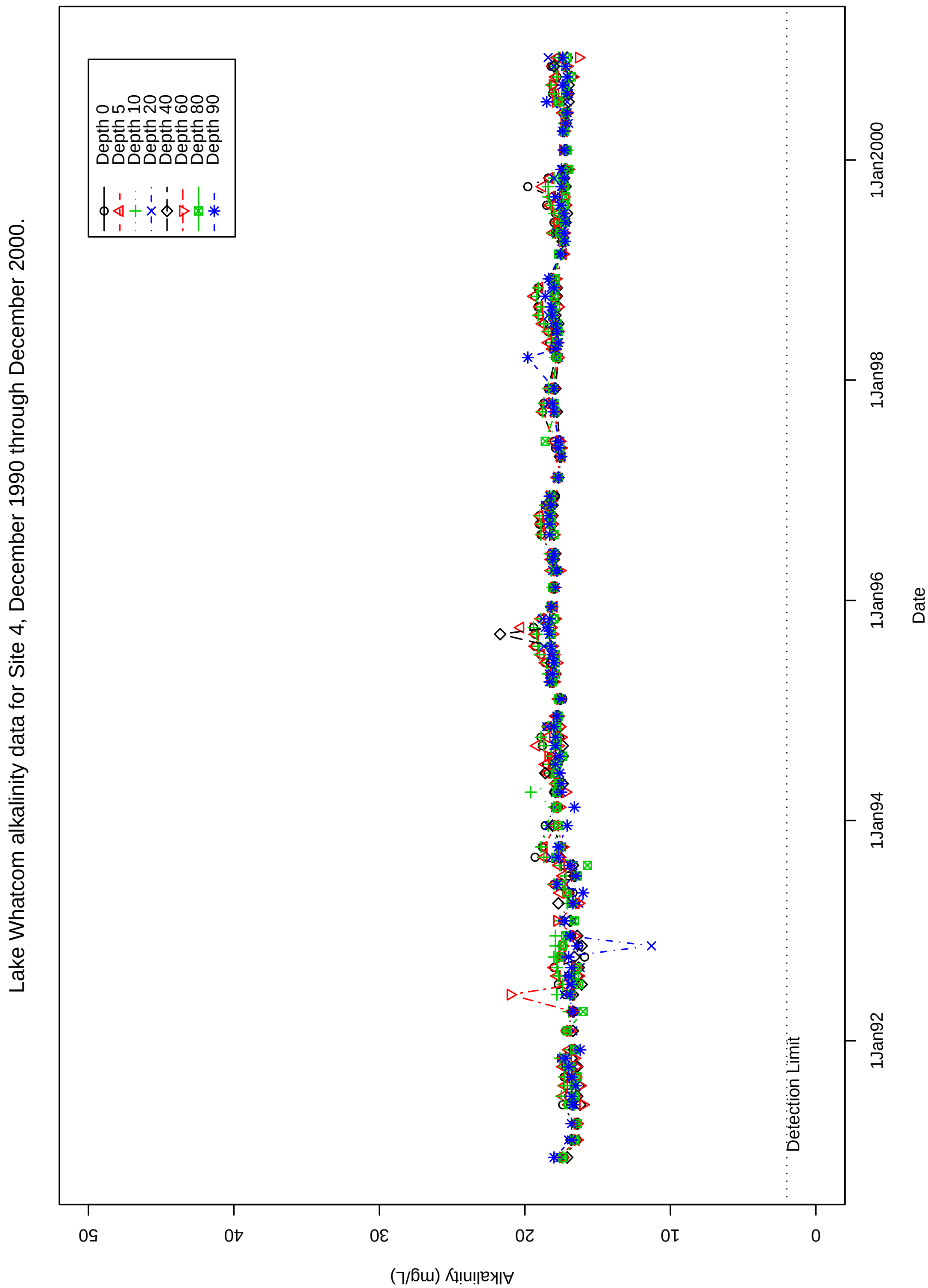


Figure 41: Lake Whatcom alkalinity data for Site 4.

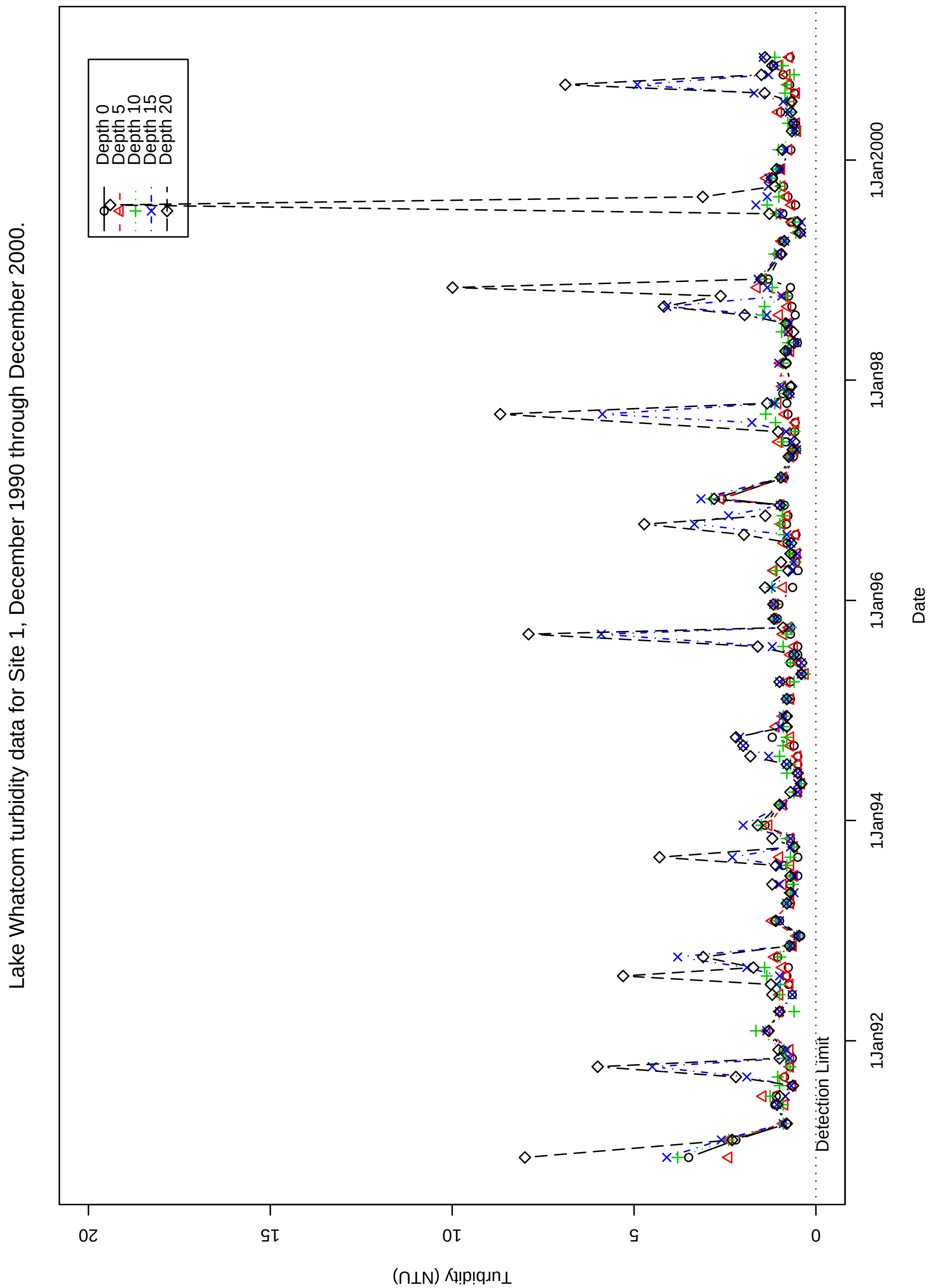


Figure 42: Lake Whatcom turbidity data for Site 1.

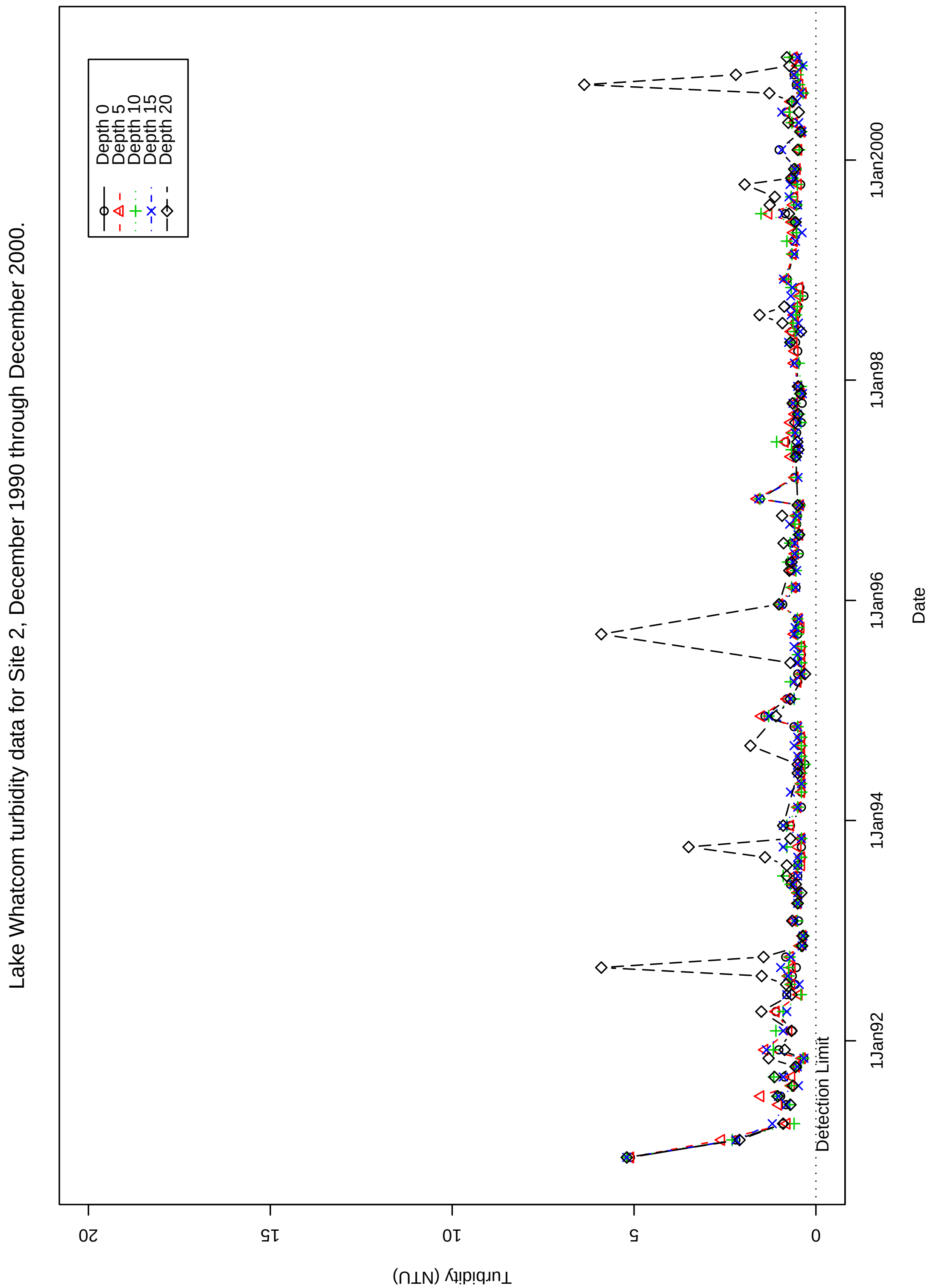


Figure 43: Lake Whatcom turbidity data for Site 2.

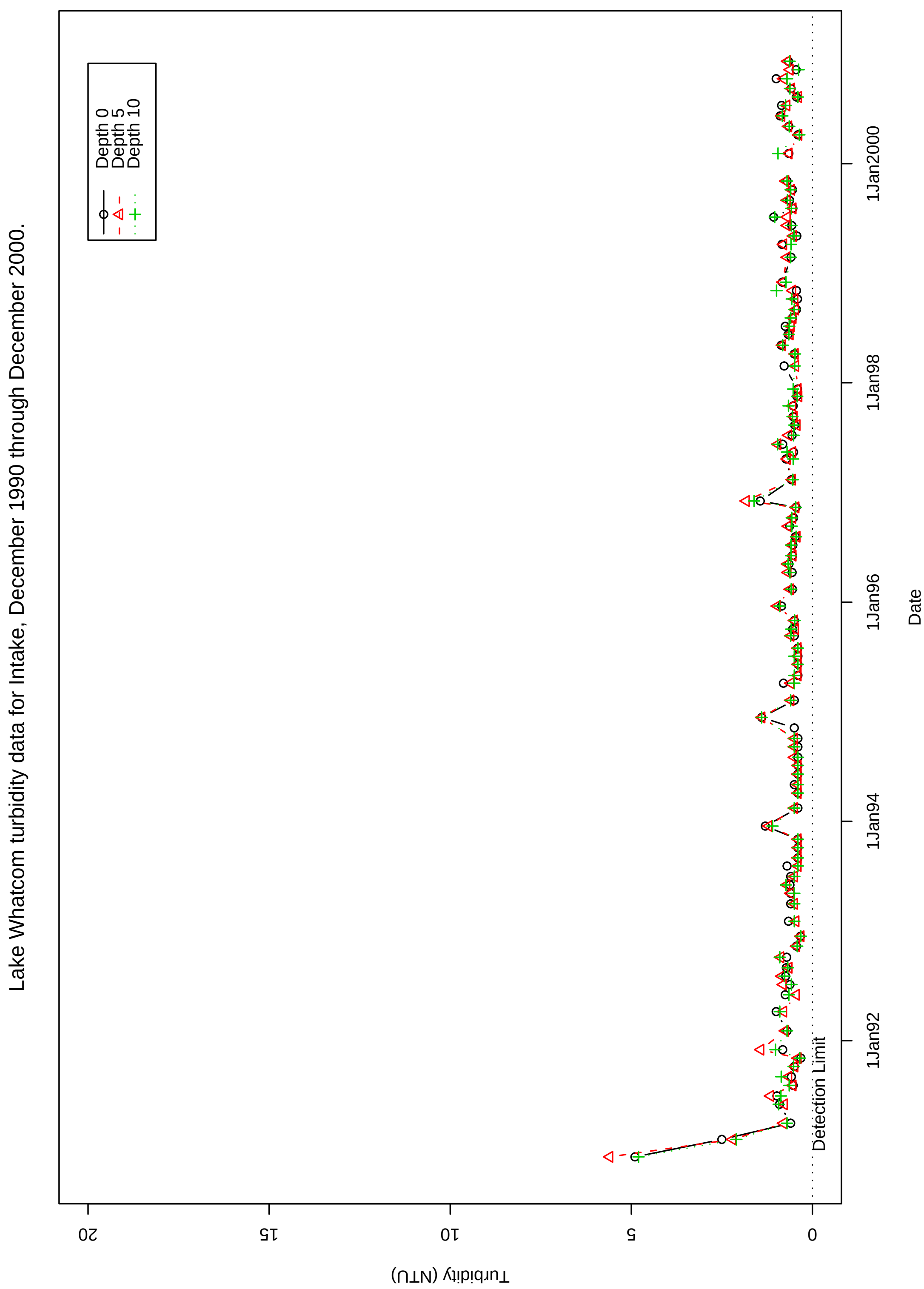


Figure 44: Lake Whatcom turbidity data for the Intake.

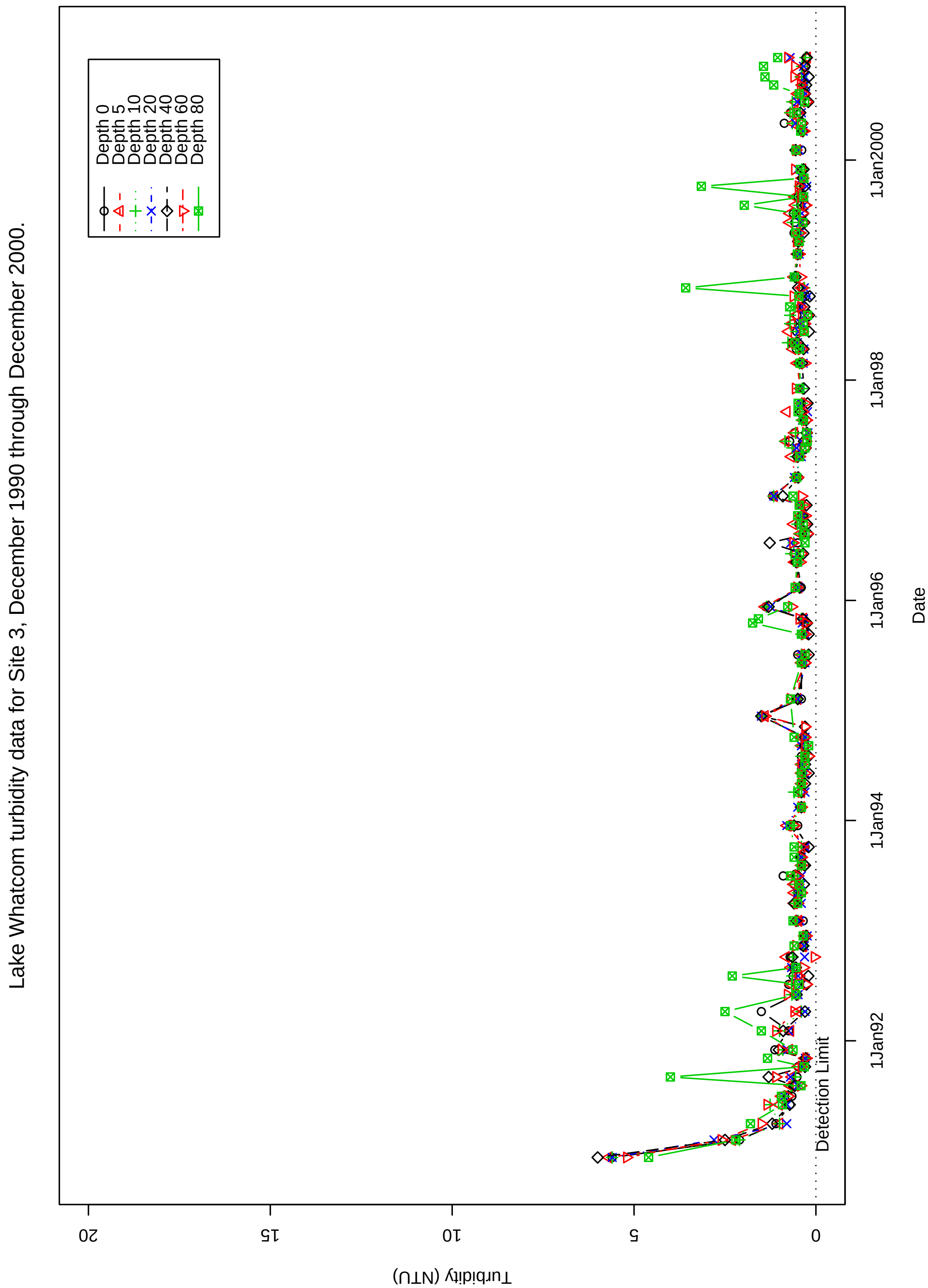


Figure 45: Lake Whatcom turbidity data for Site 3.

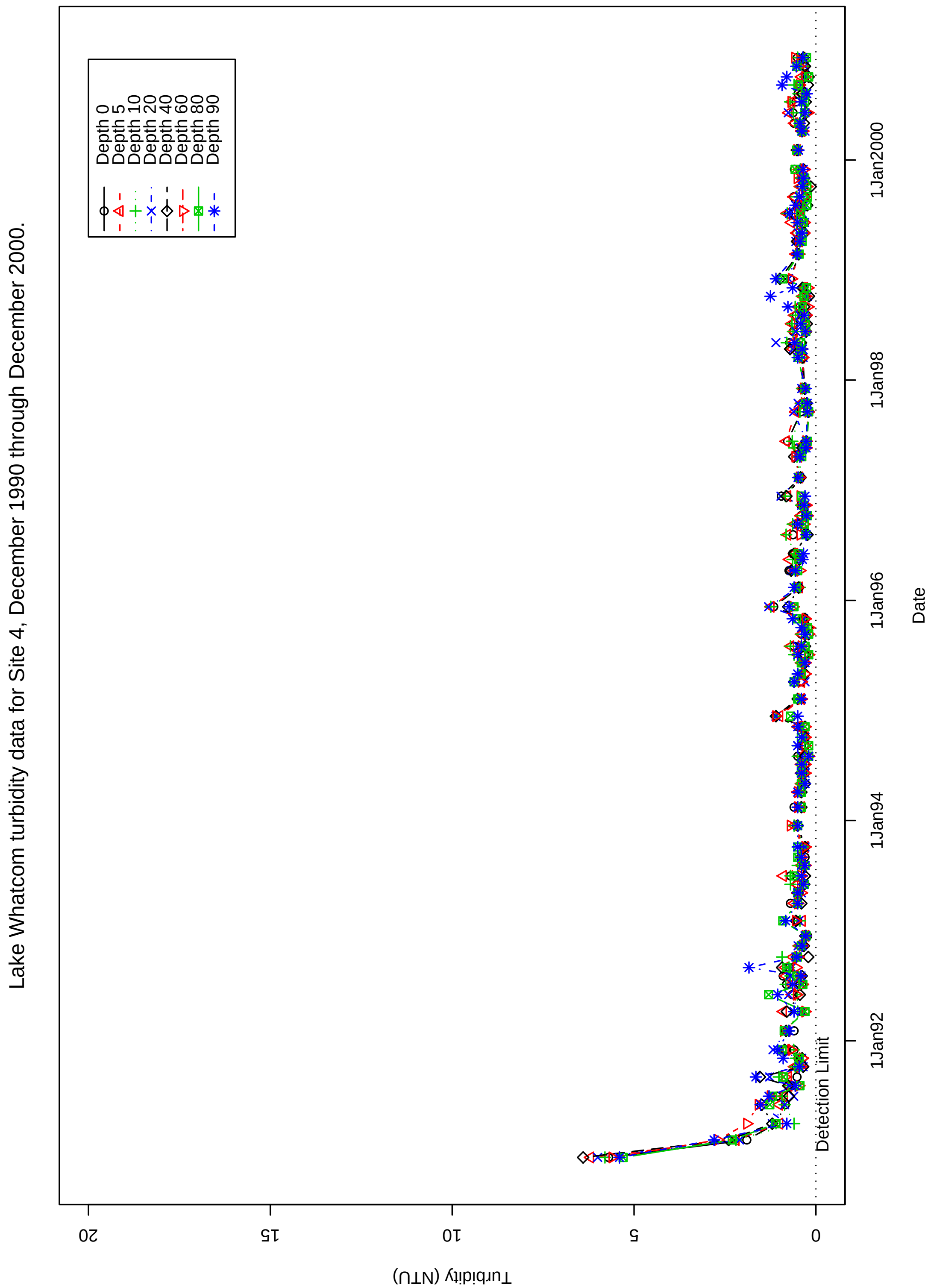


Figure 46: Lake Whatcom turbidity data for Site 4.

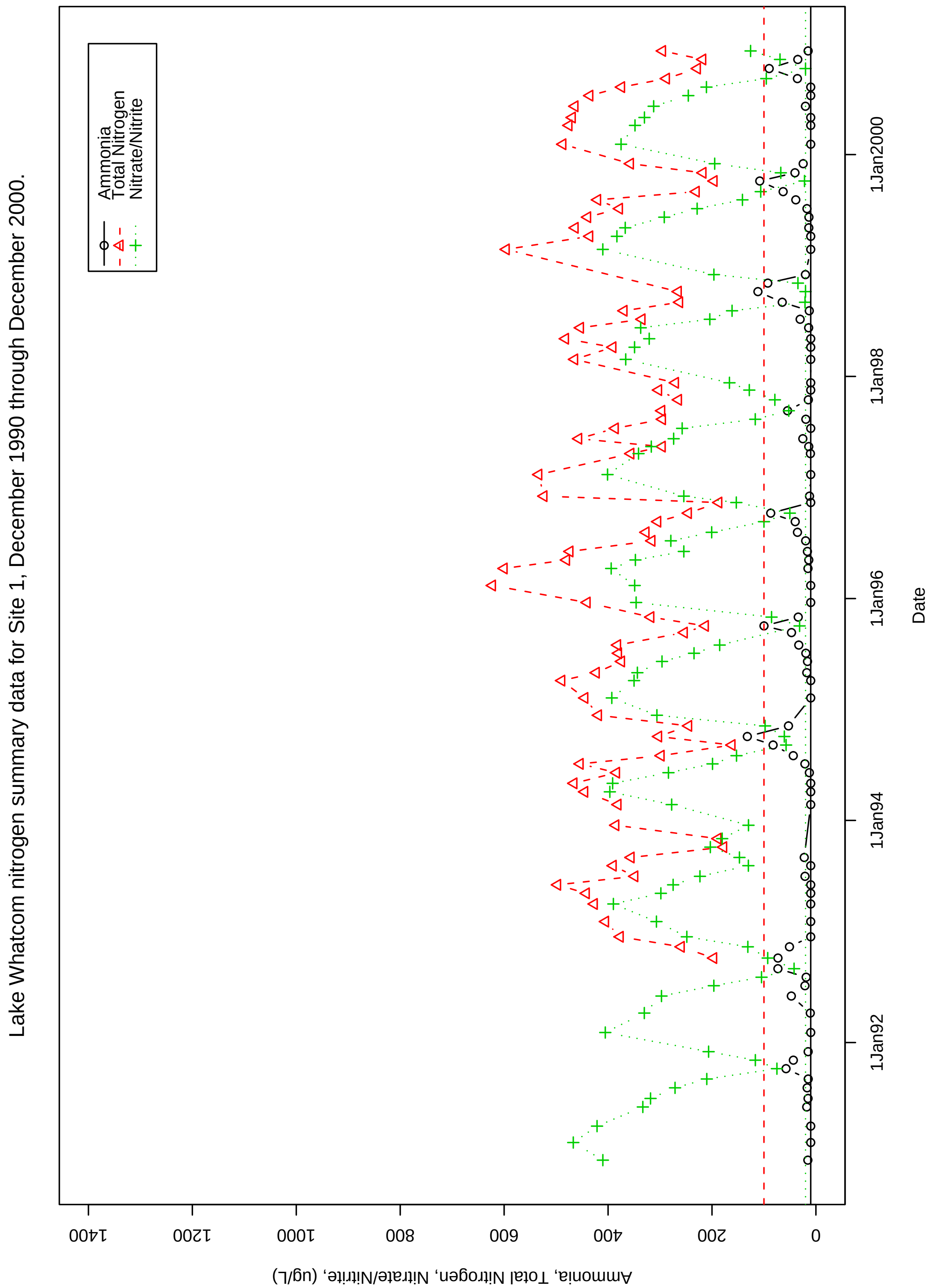


Figure 47: Lake Whatcom nitrogen summary data for Site 1.

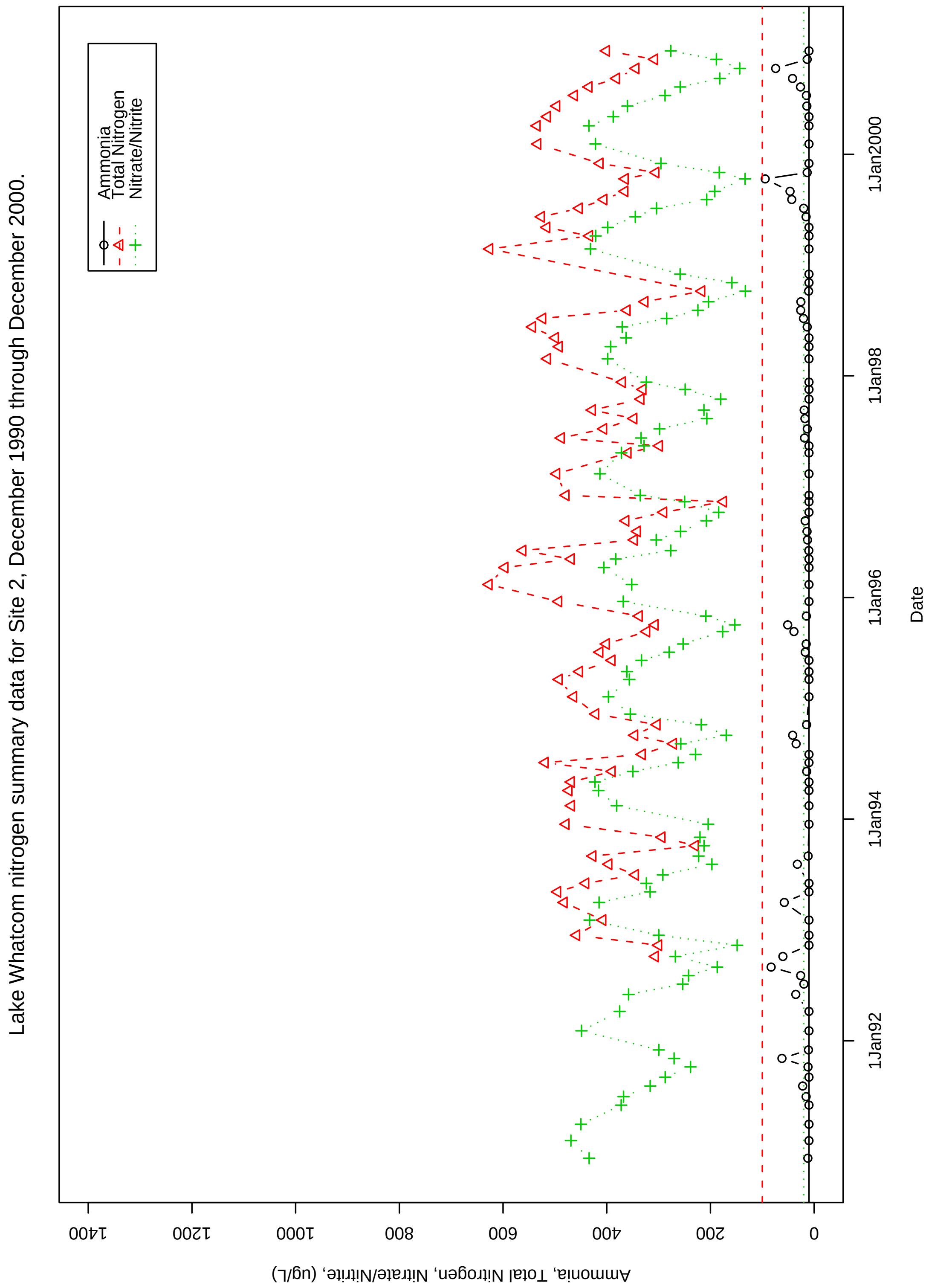


Figure 48: Lake Whatcom nitrogen summary data for Site 2.

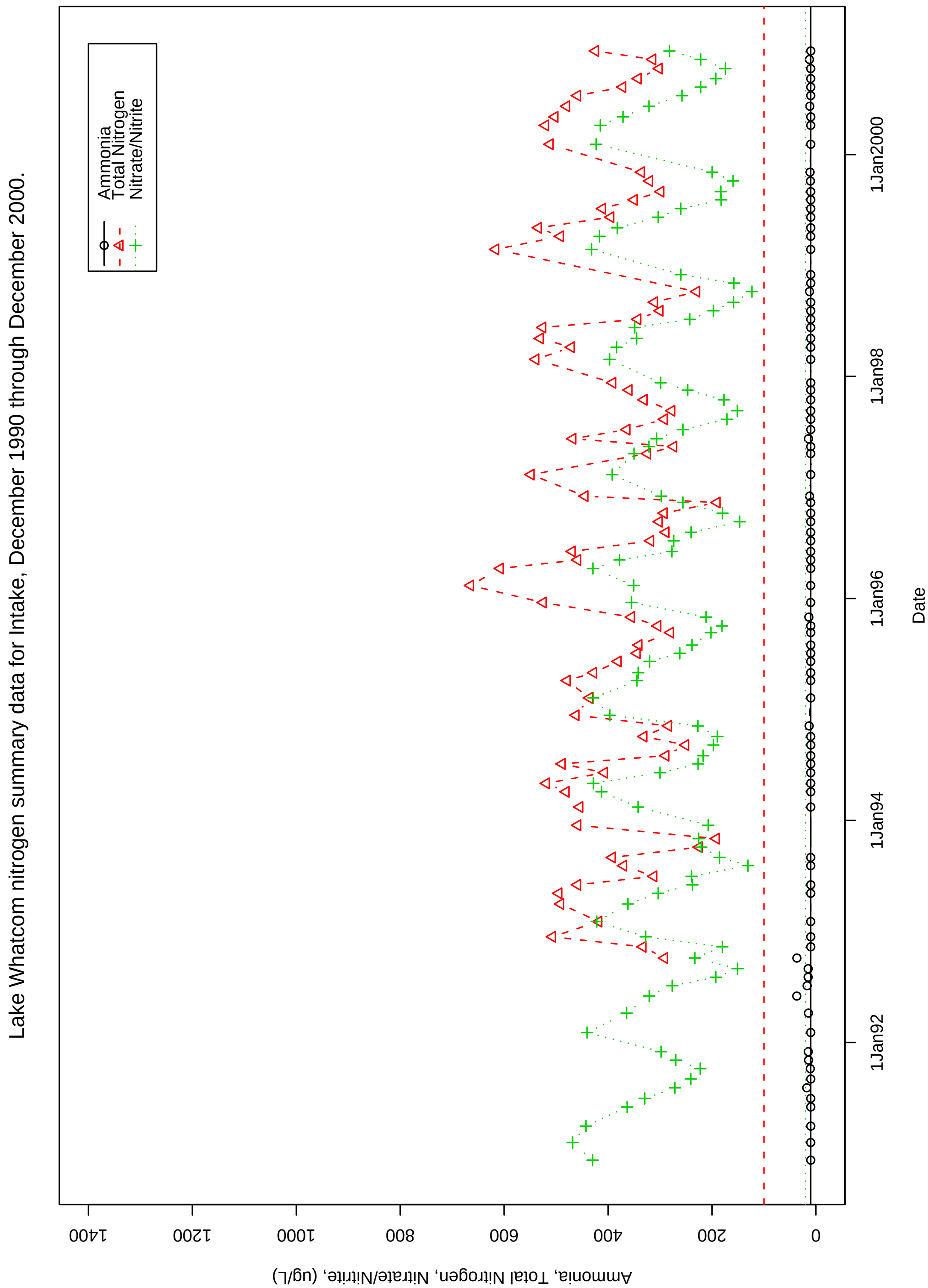


Figure 49: Lake Whatcom nitrogen summary data for the Intake.

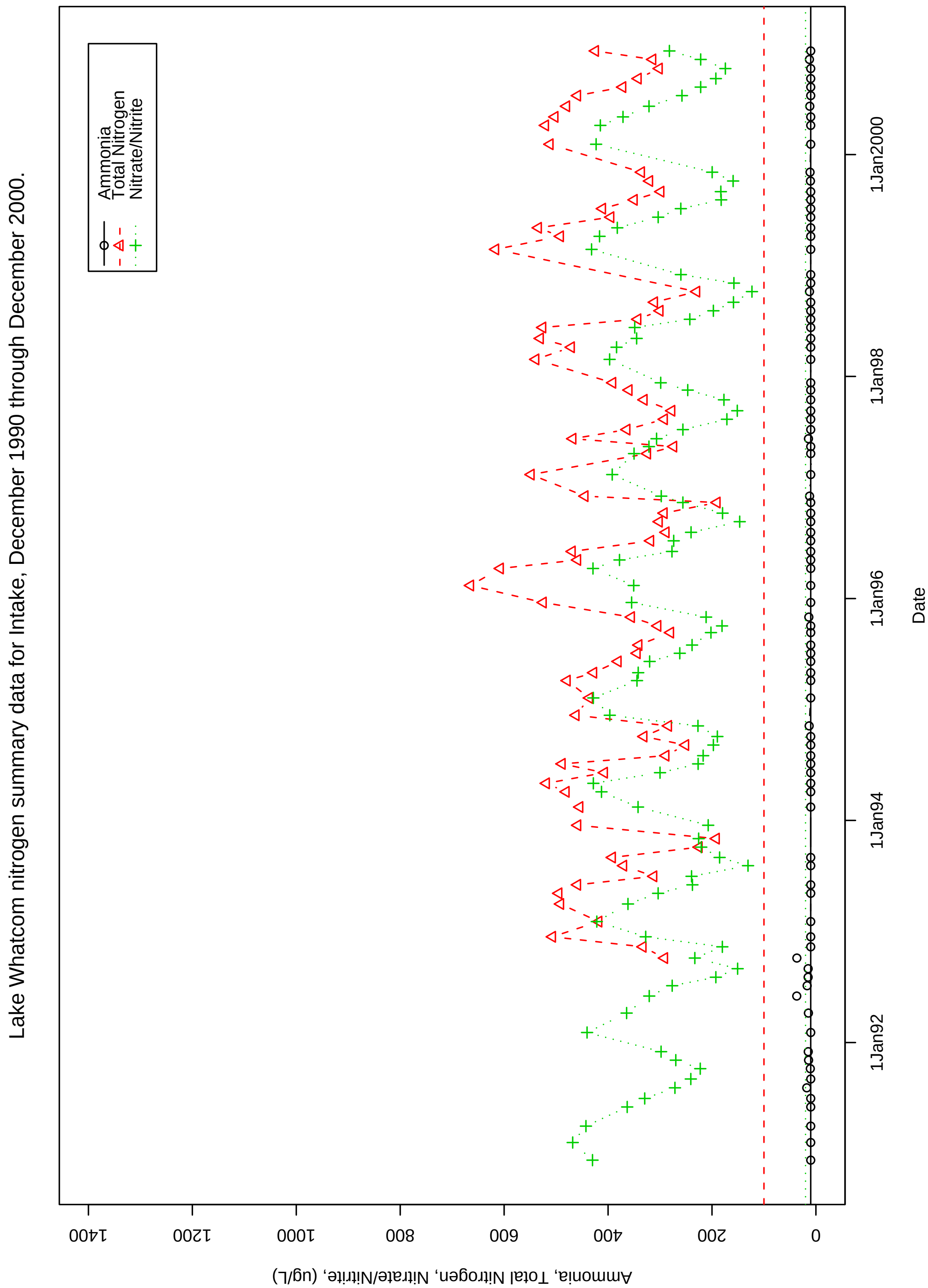


Figure 50: Lake Whatcom nitrogen summary data for Site 3.

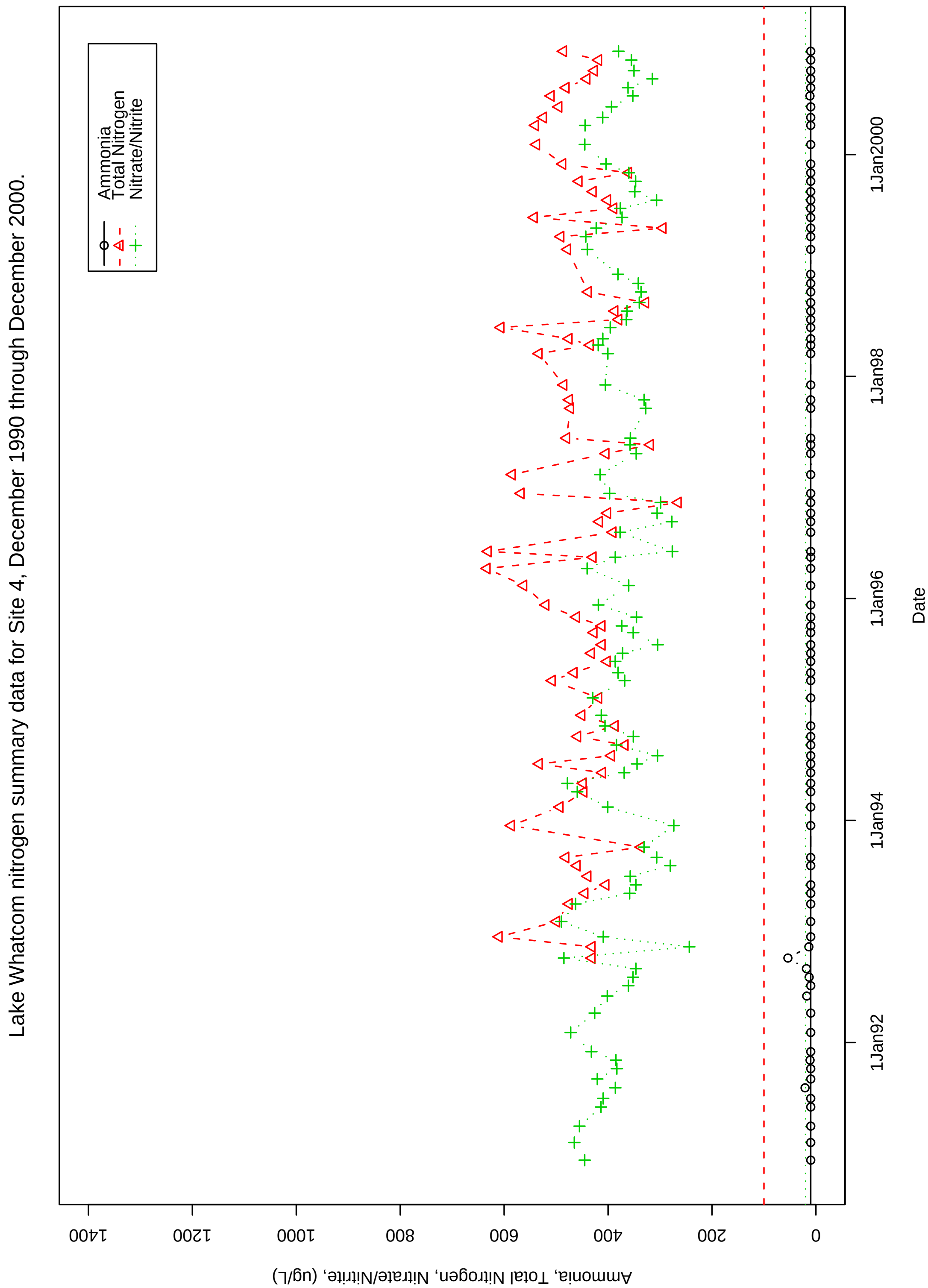


Figure 51: Lake Whatcom nitrogen summary data for Site 4.

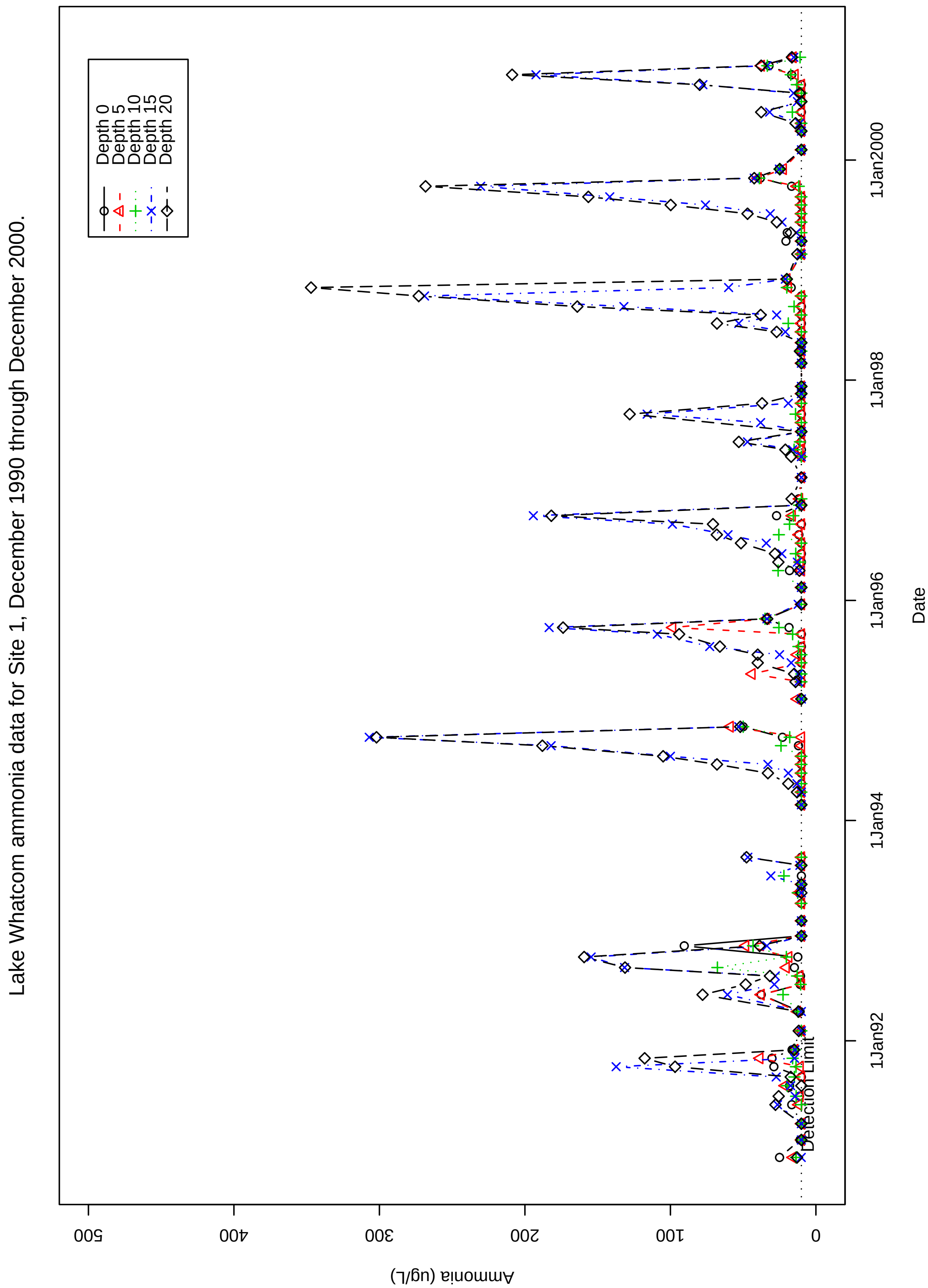


Figure 52: Lake Whatcom ammonia data for Site 1.

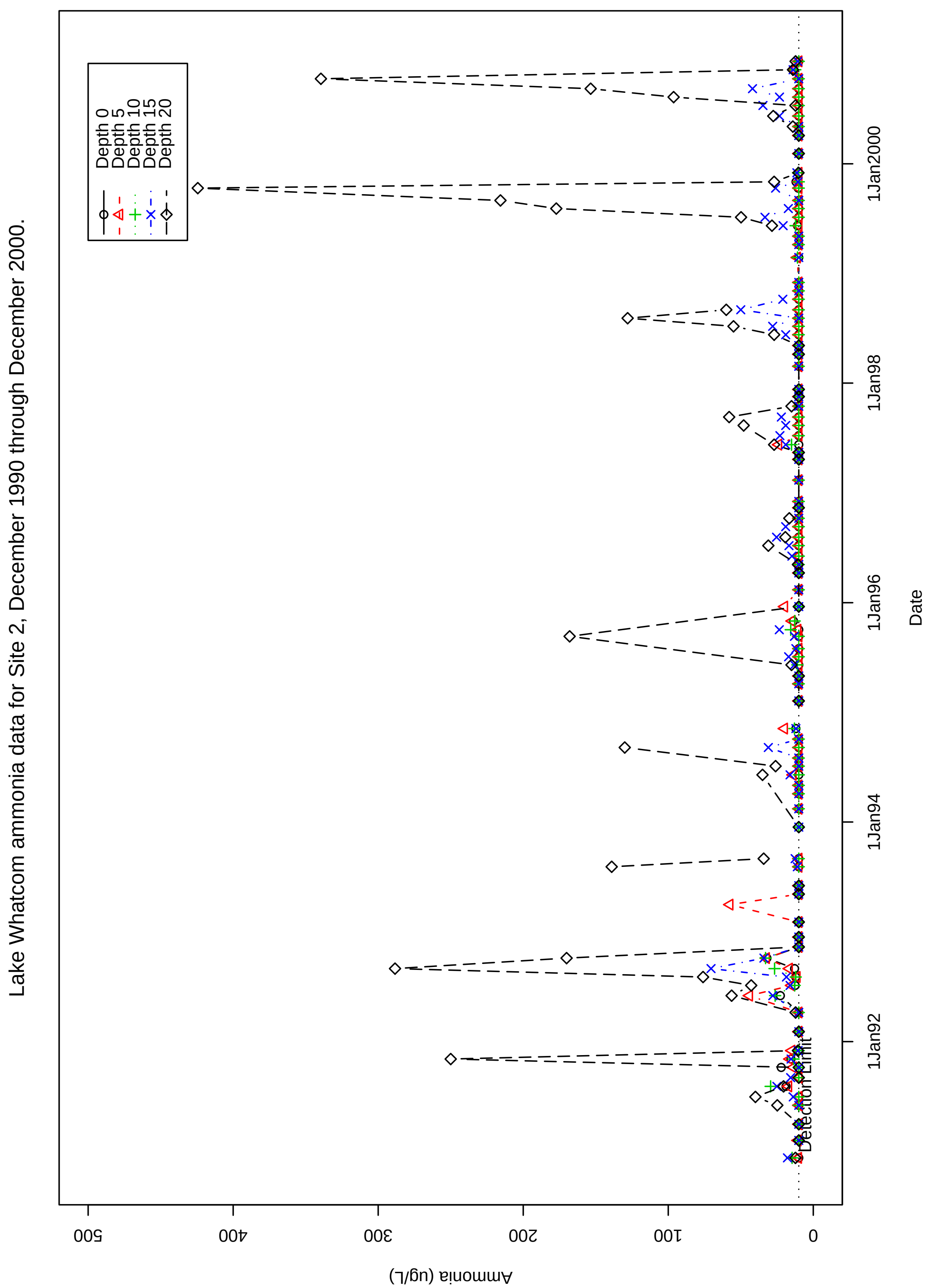


Figure 53: Lake Whatcom ammonia data for Site 2.

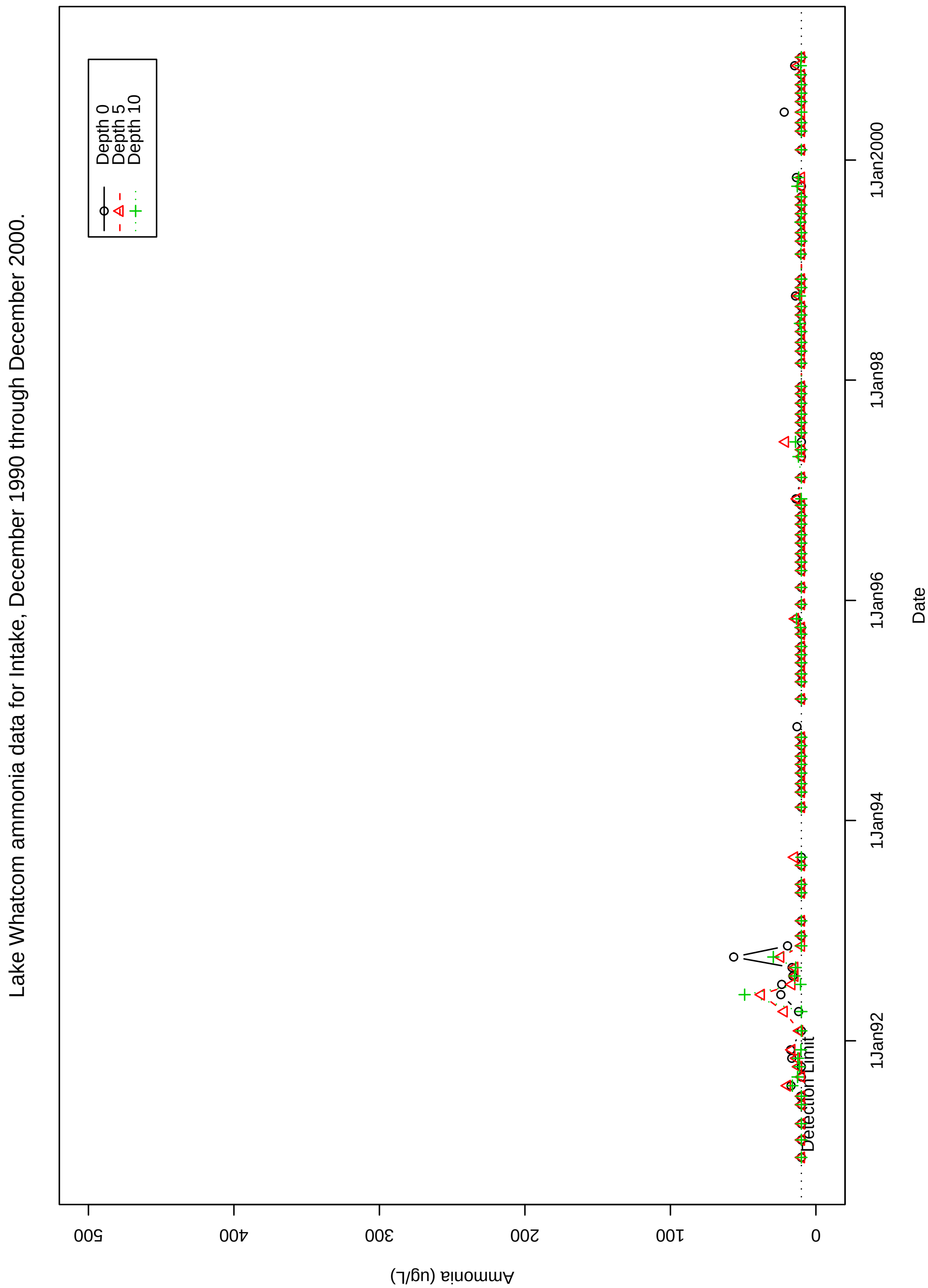


Figure 54: Lake Whatcom ammonia data for the Intake.

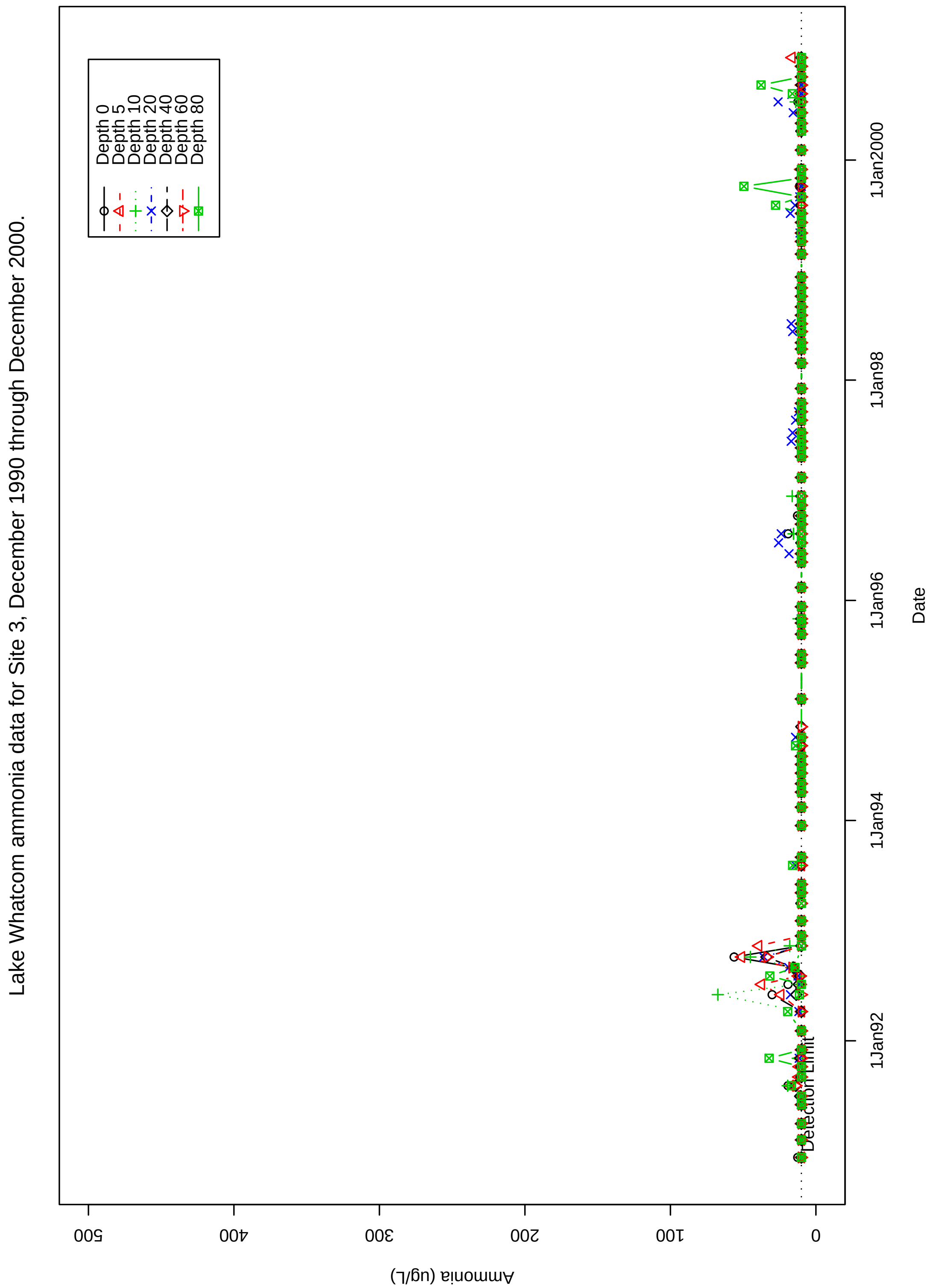


Figure 55: Lake Whatcom ammonia data for Site 3.

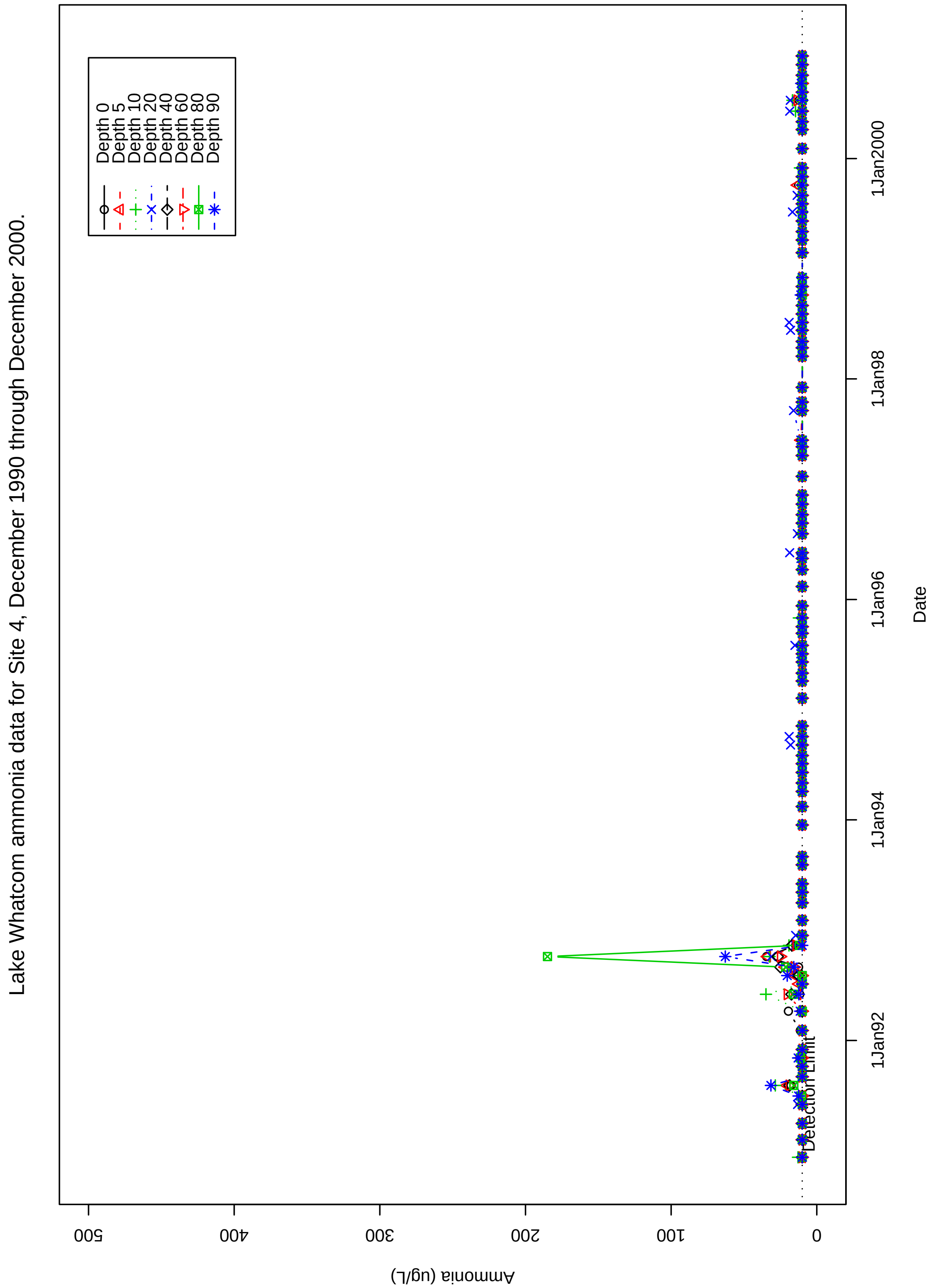


Figure 56: Lake Whatcom ammonia data for Site 4.

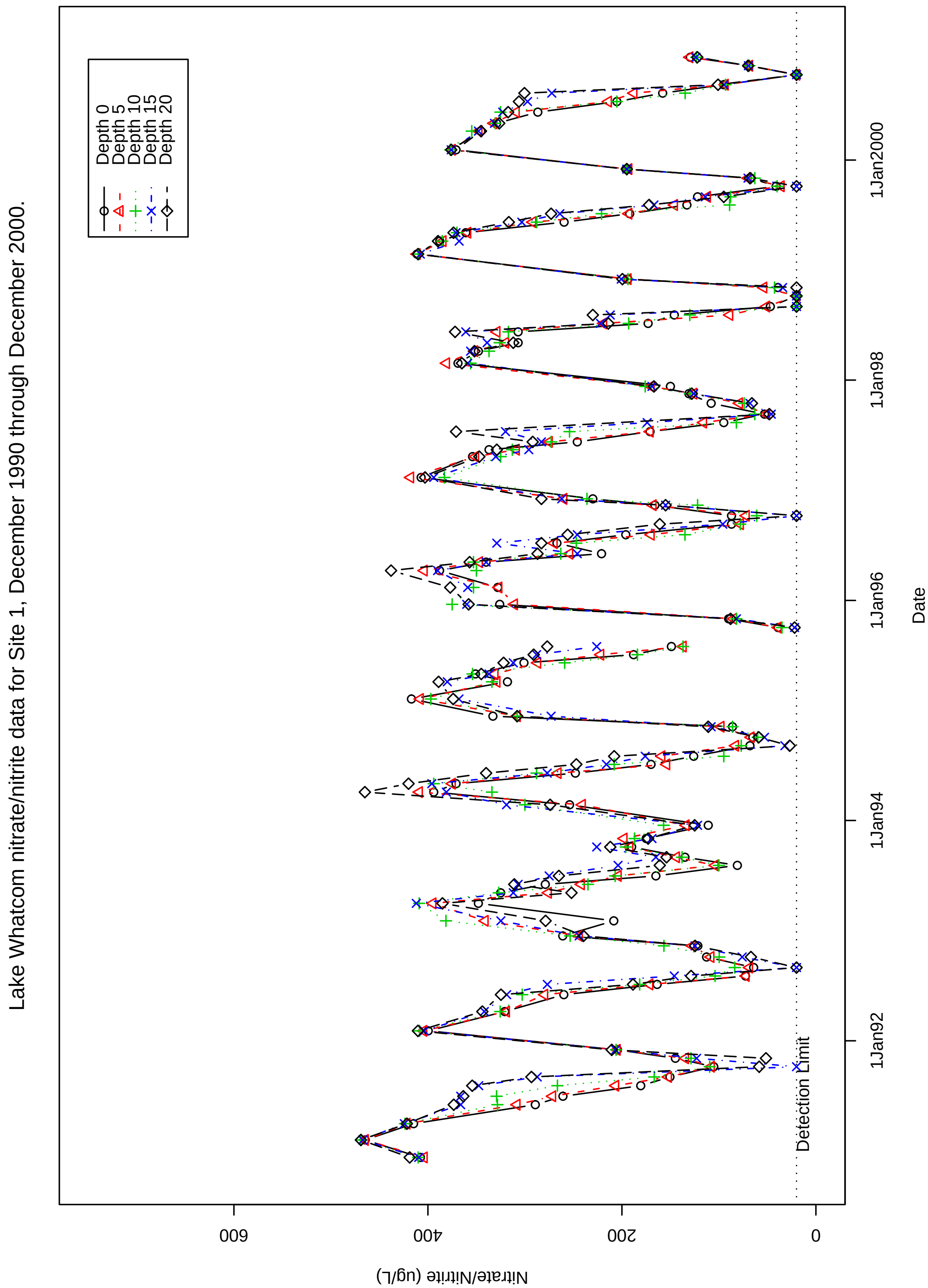


Figure 57: Lake Whatcom nitrate/nitrite data for Site 1.

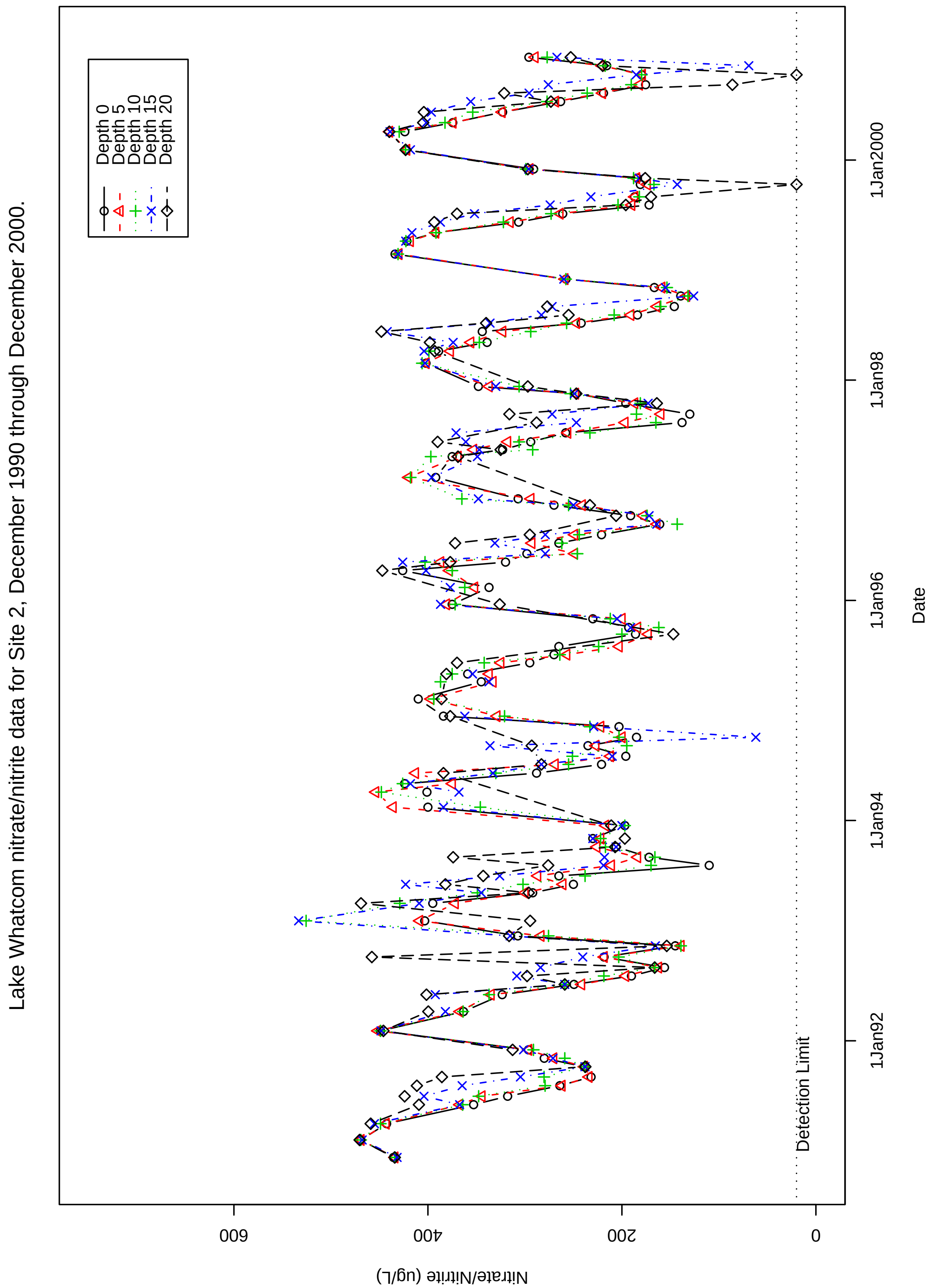


Figure 58: Lake Whatcom nitrate/nitrite data for Site 2.

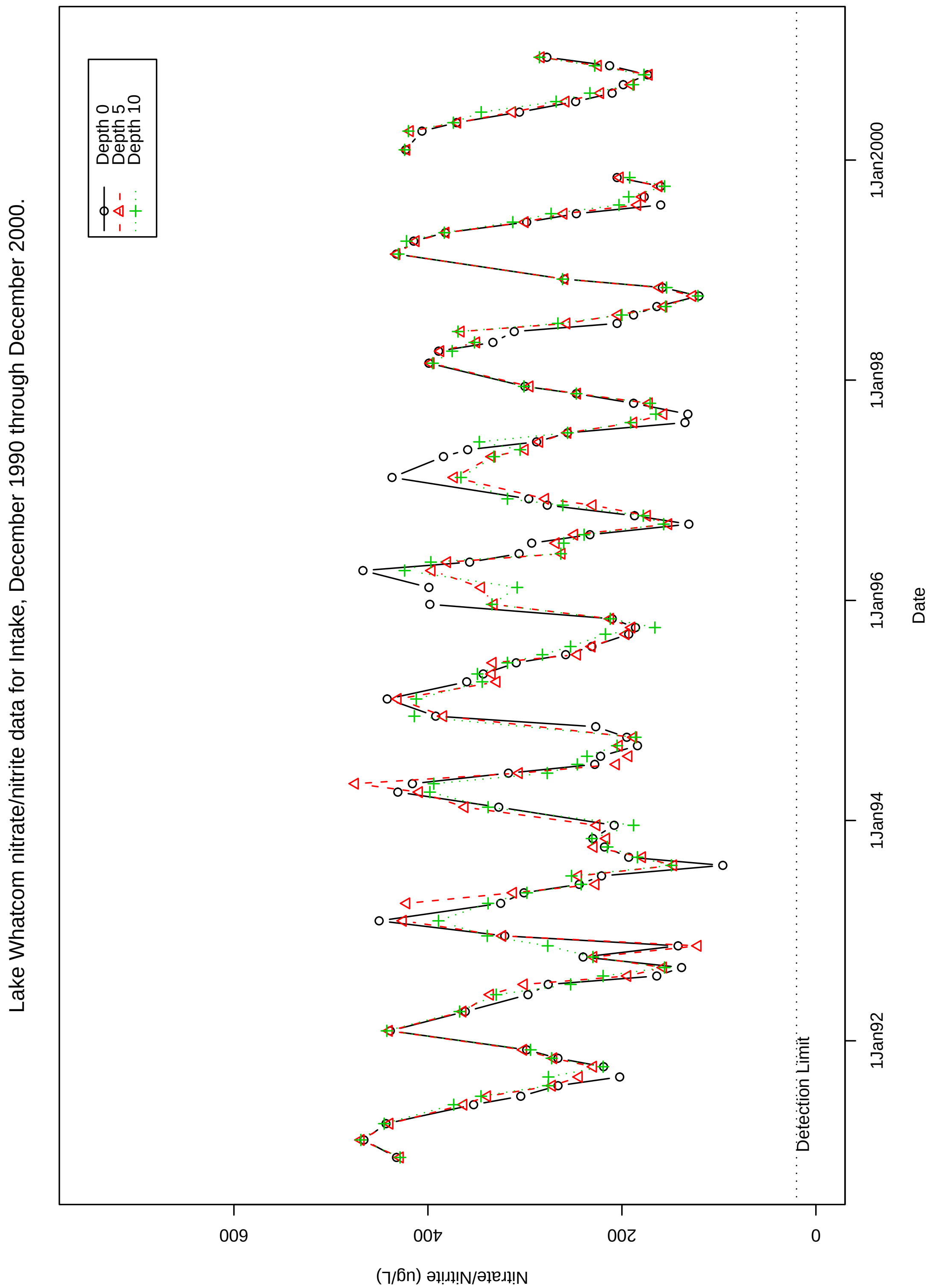


Figure 59: Lake Whatcom nitrate/nitrite data for the Intake.

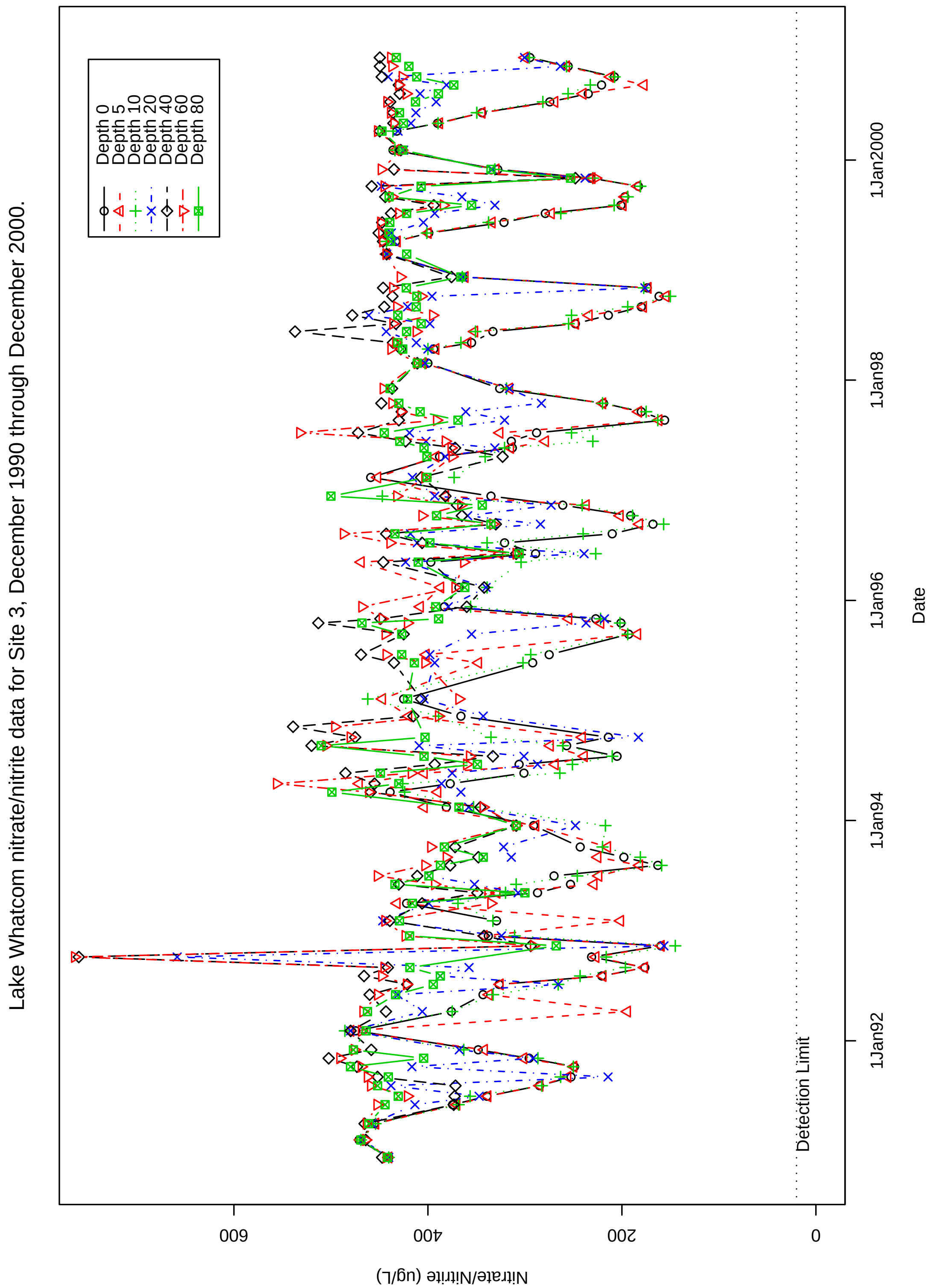


Figure 60: Lake Whatcom nitrate/nitrite data for Site 3.

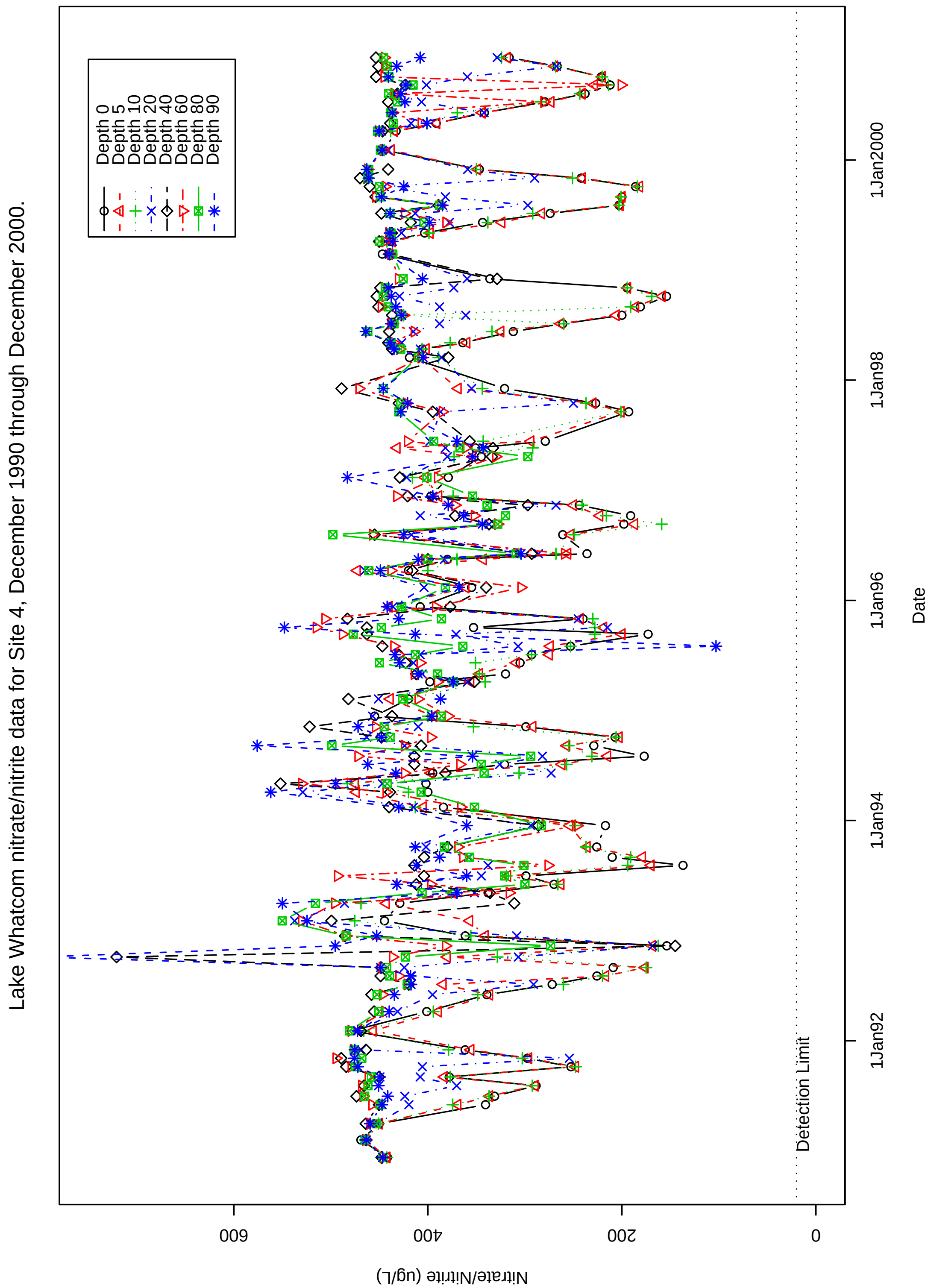


Figure 61: Lake Whatcom nitrate/nitrite data for Site 4.

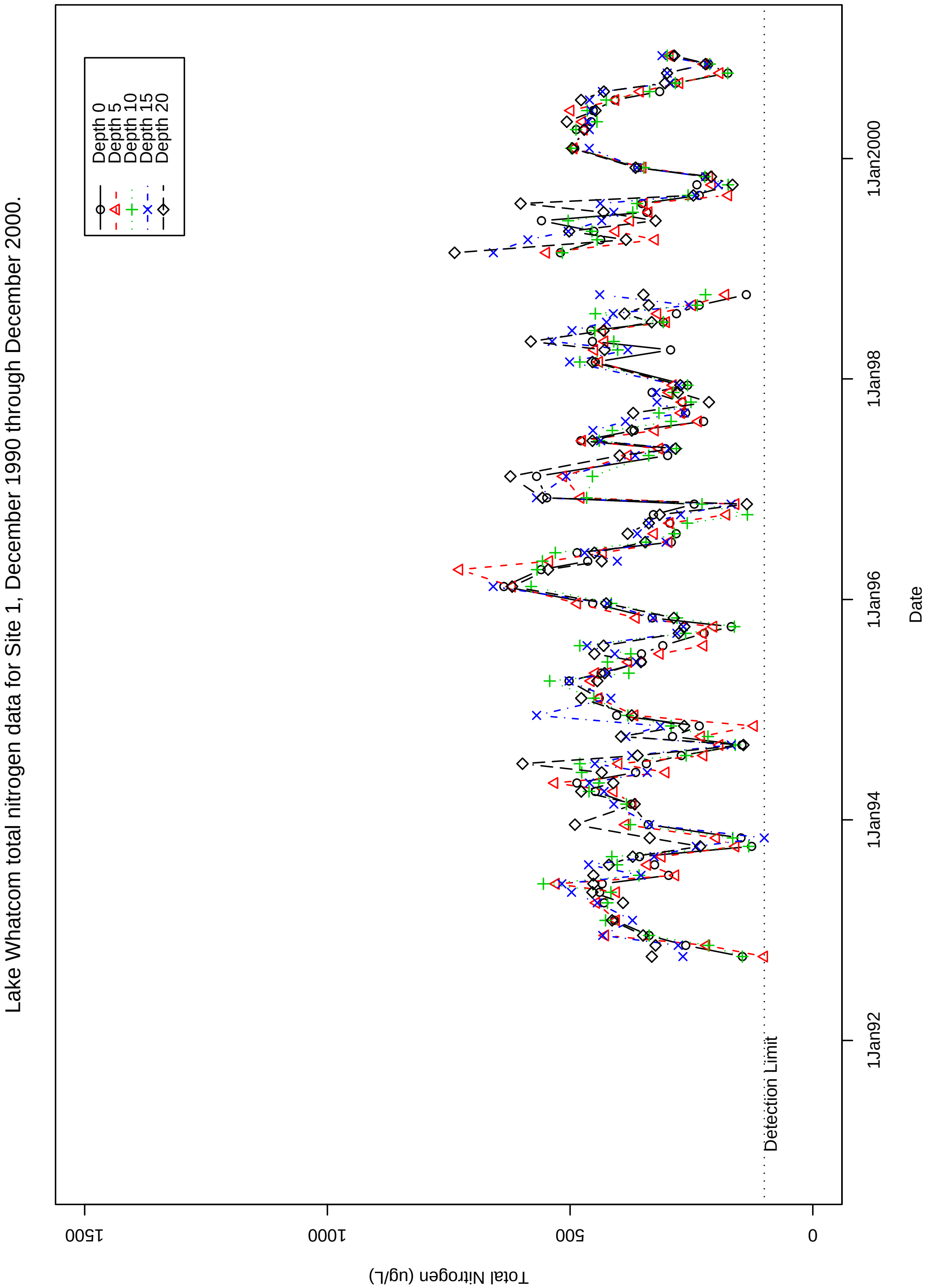


Figure 62: Lake Whatcom total nitrogen data for Site 1.

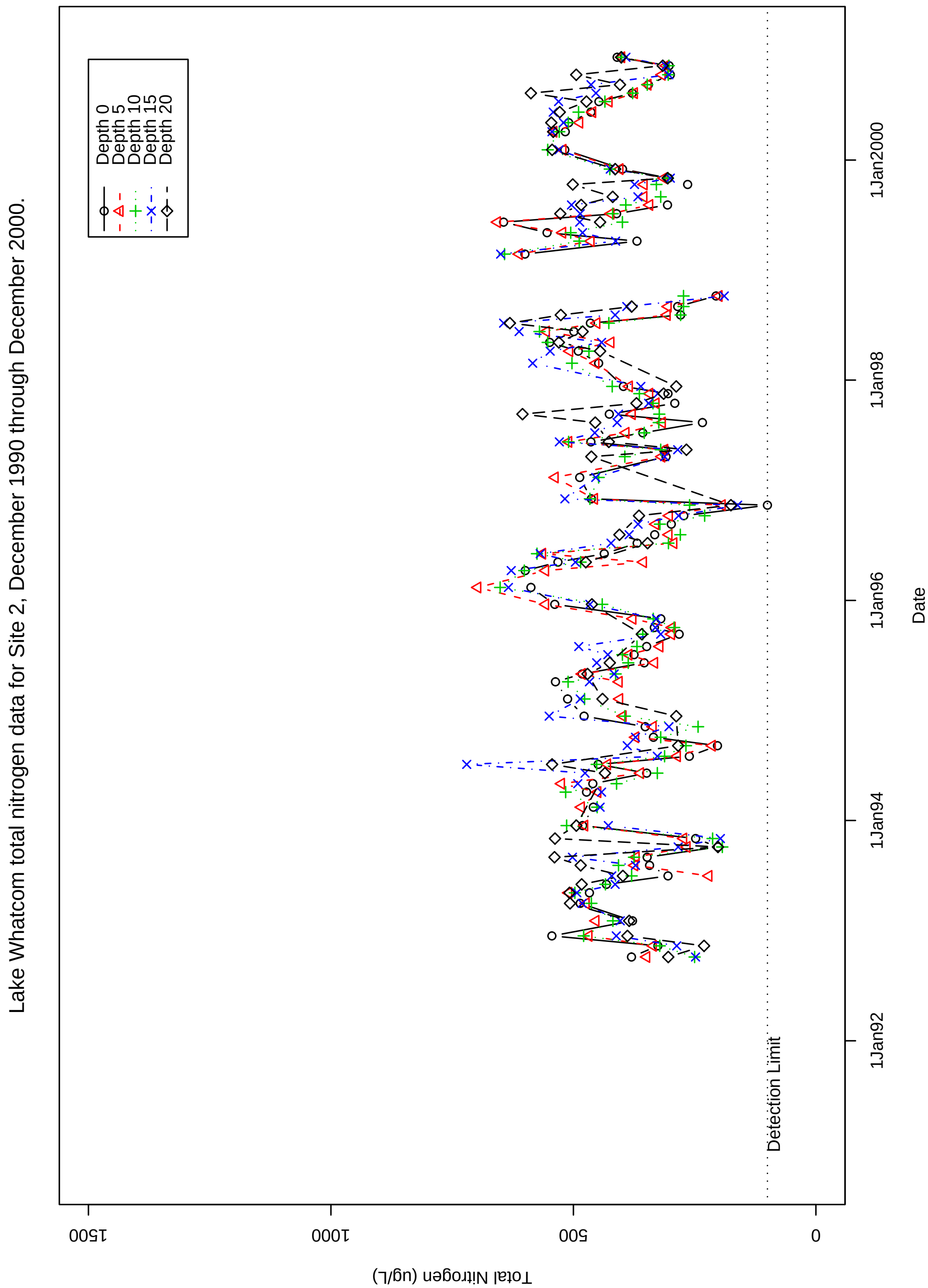


Figure 63: Lake Whatcom total nitrogen data for Site 2.

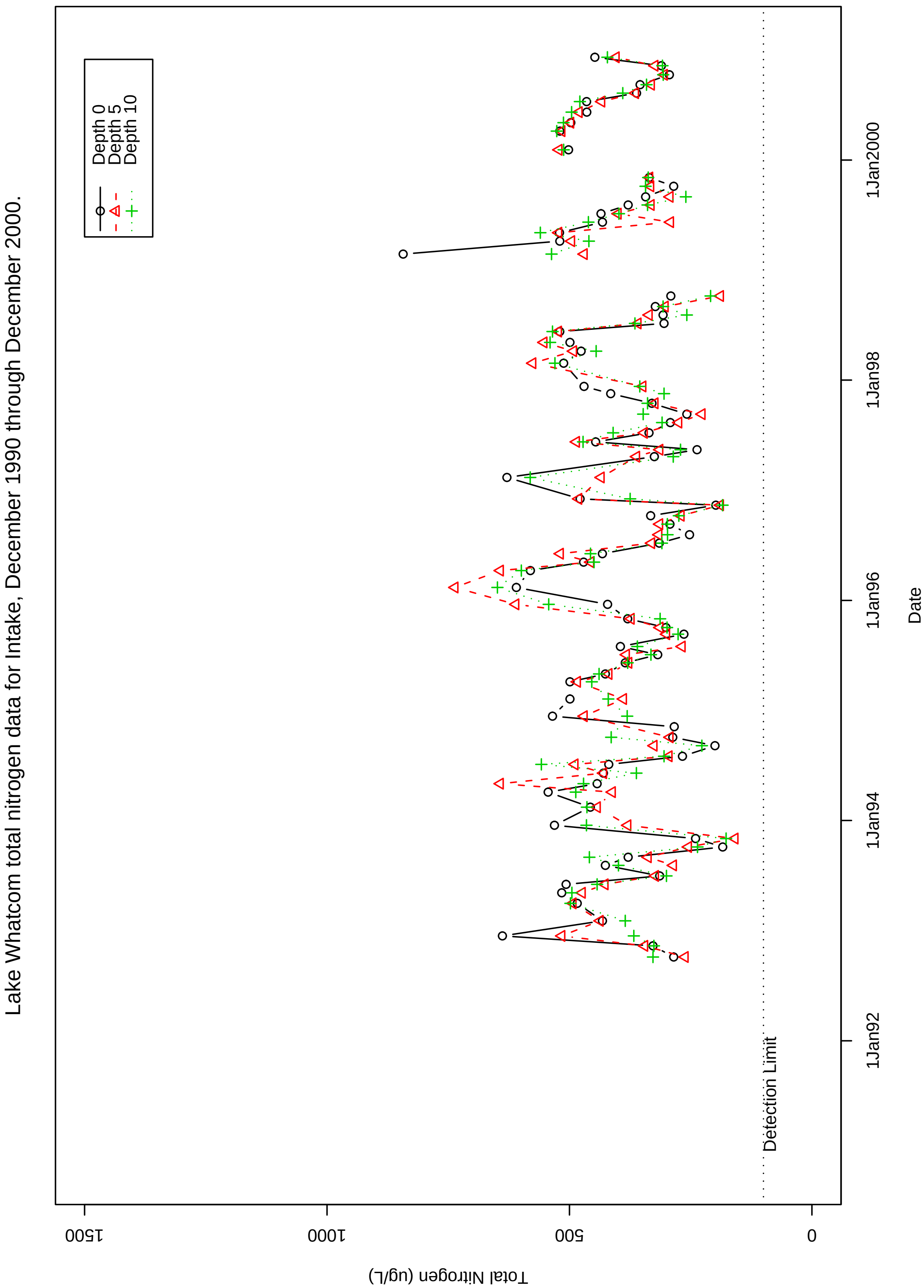


Figure 64: Lake Whatcom total nitrogen data for the Intake.

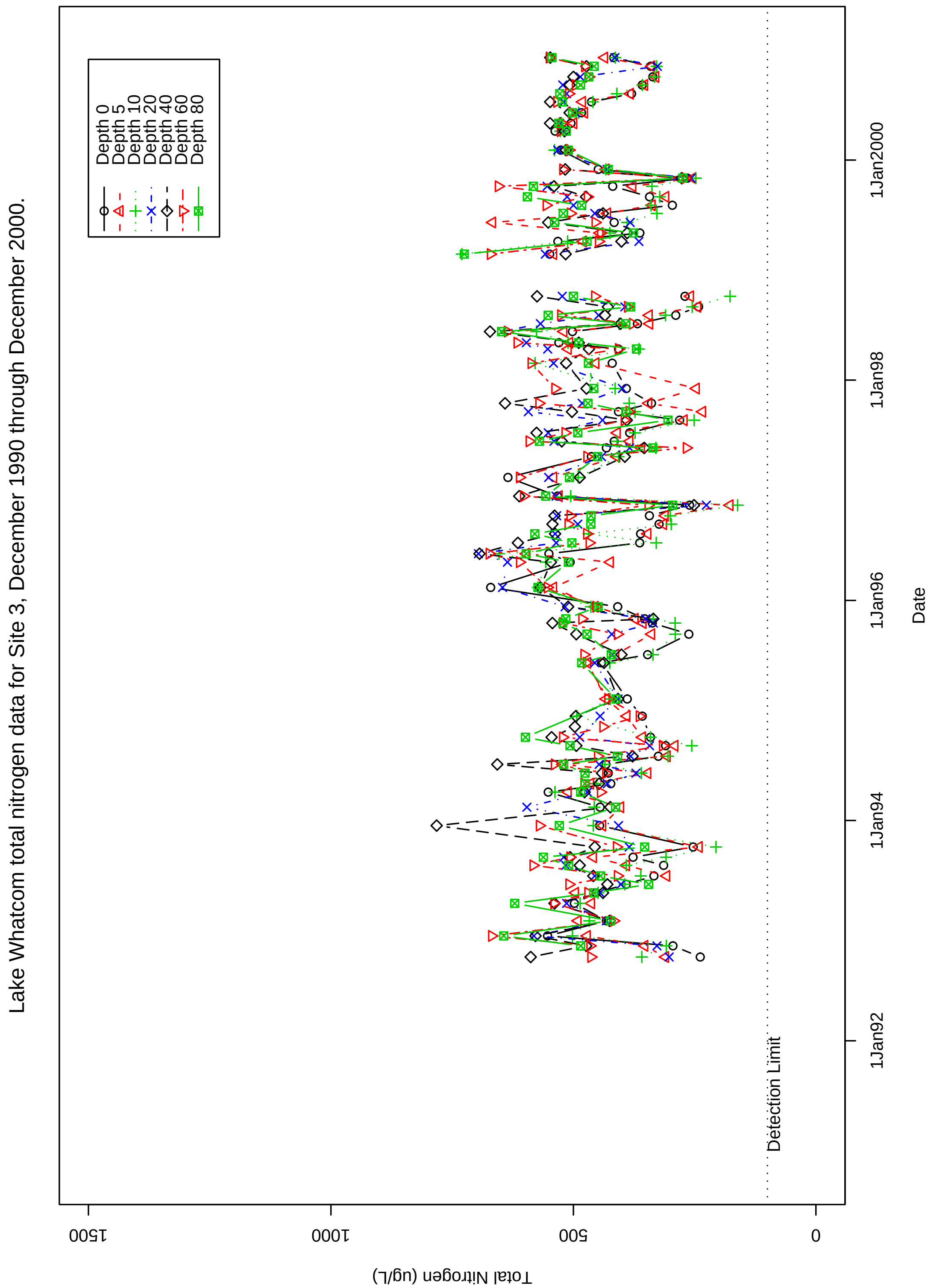


Figure 65: Lake Whatcom total nitrogen data for Site 3.

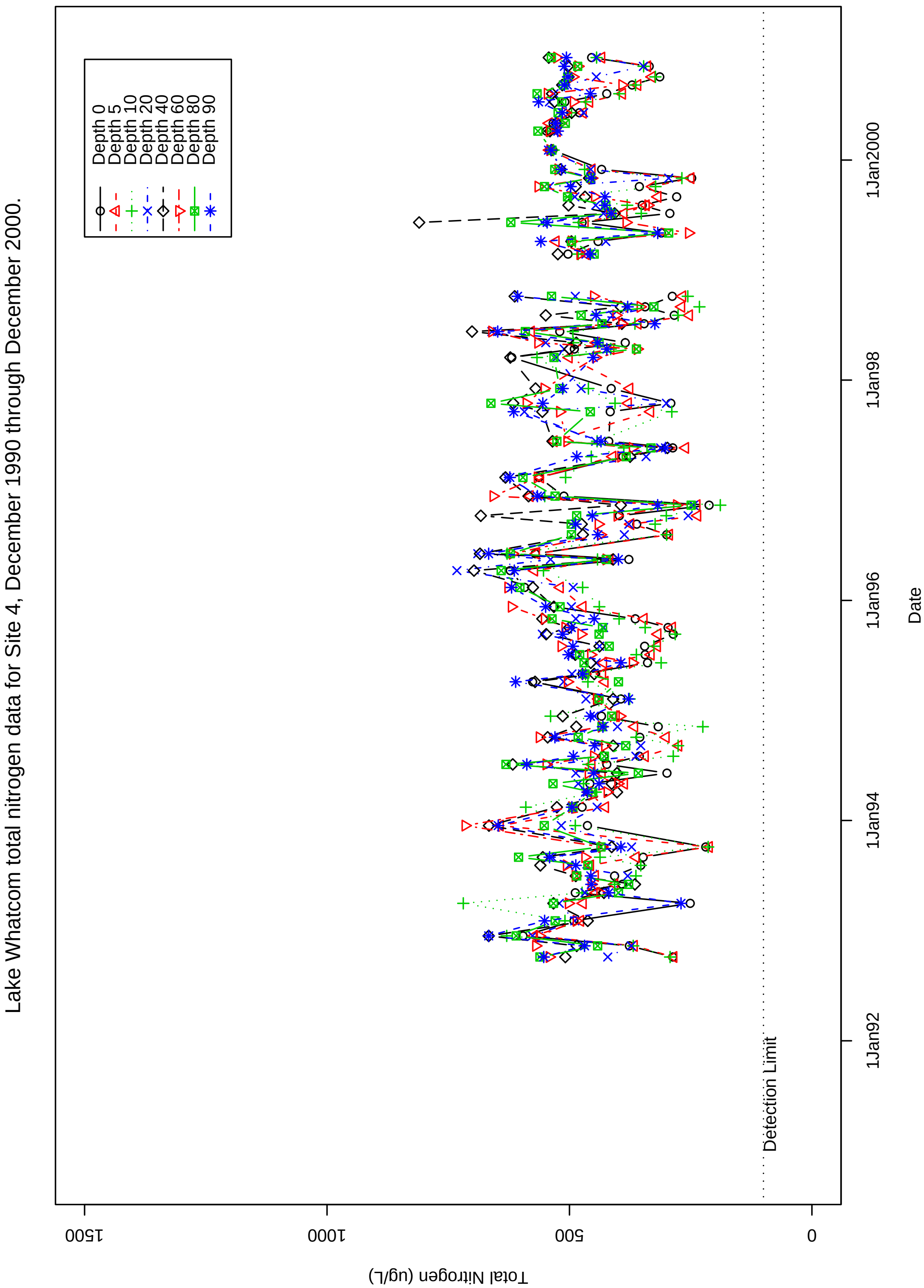


Figure 66: Lake Whatcom total nitrogen data for Site 4.

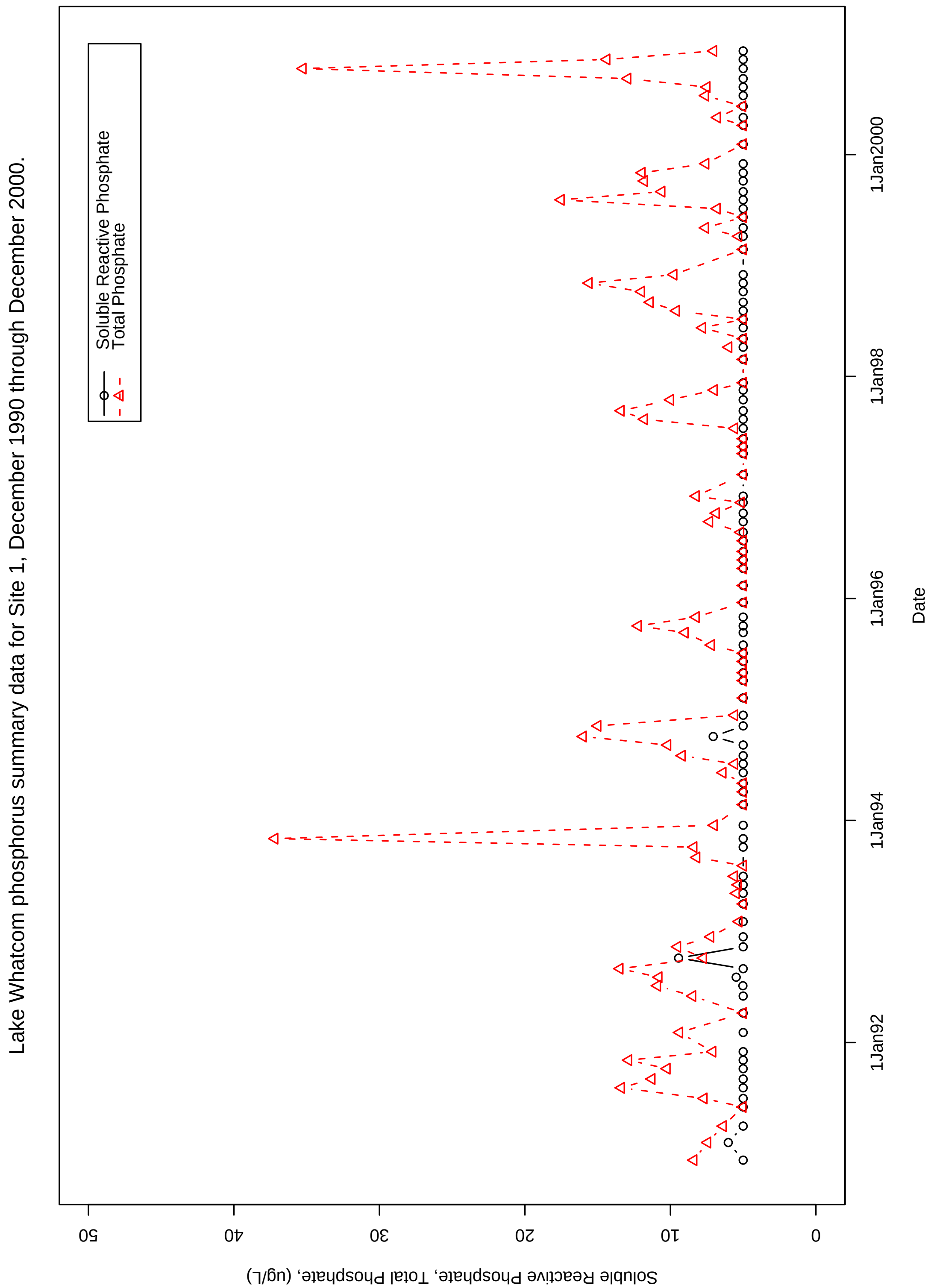


Figure 67: Lake Whatcom phosphorus summary data for Site 1.

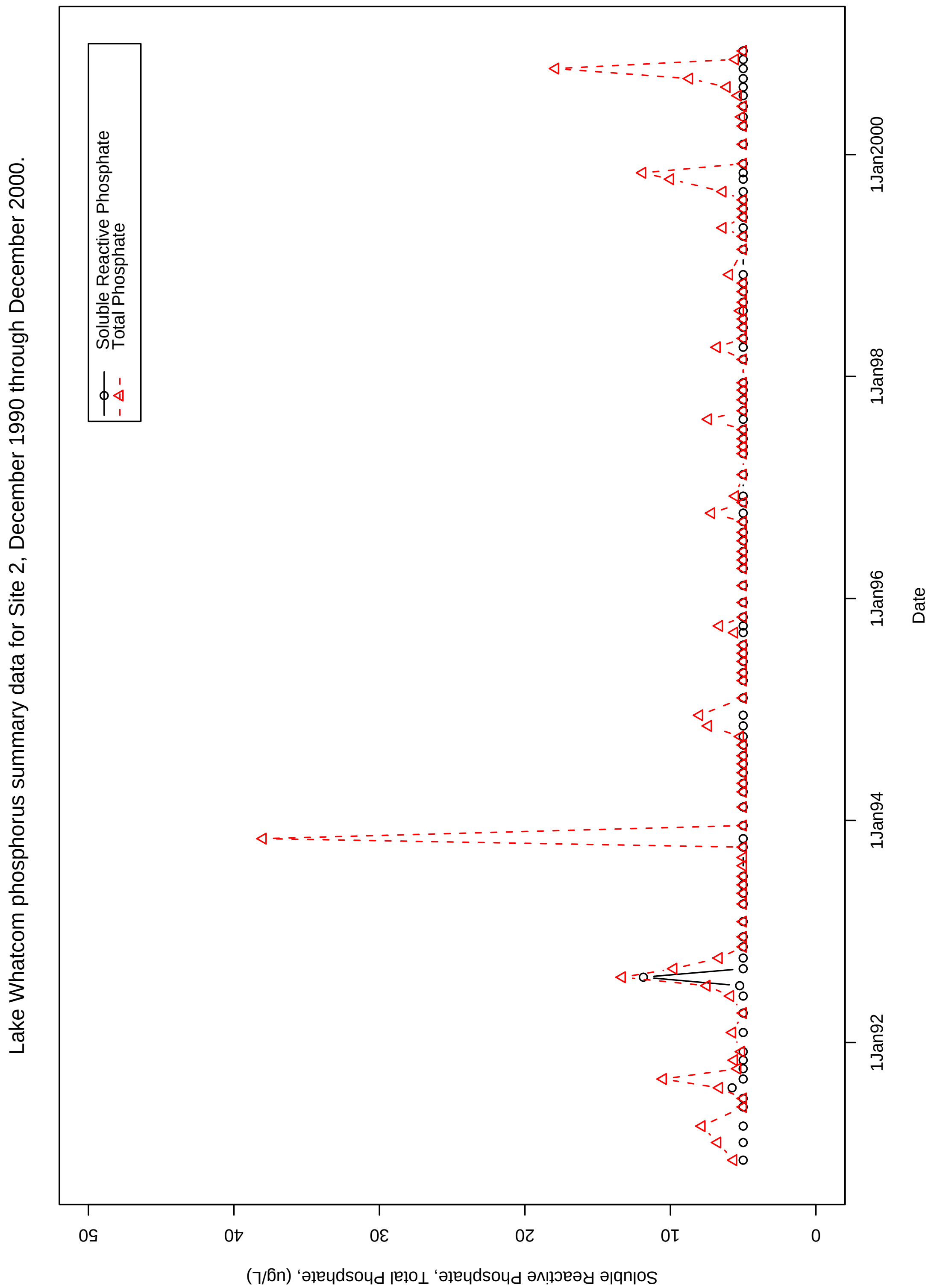


Figure 68: Lake Whatcom phosphorus summary data for Site 2.

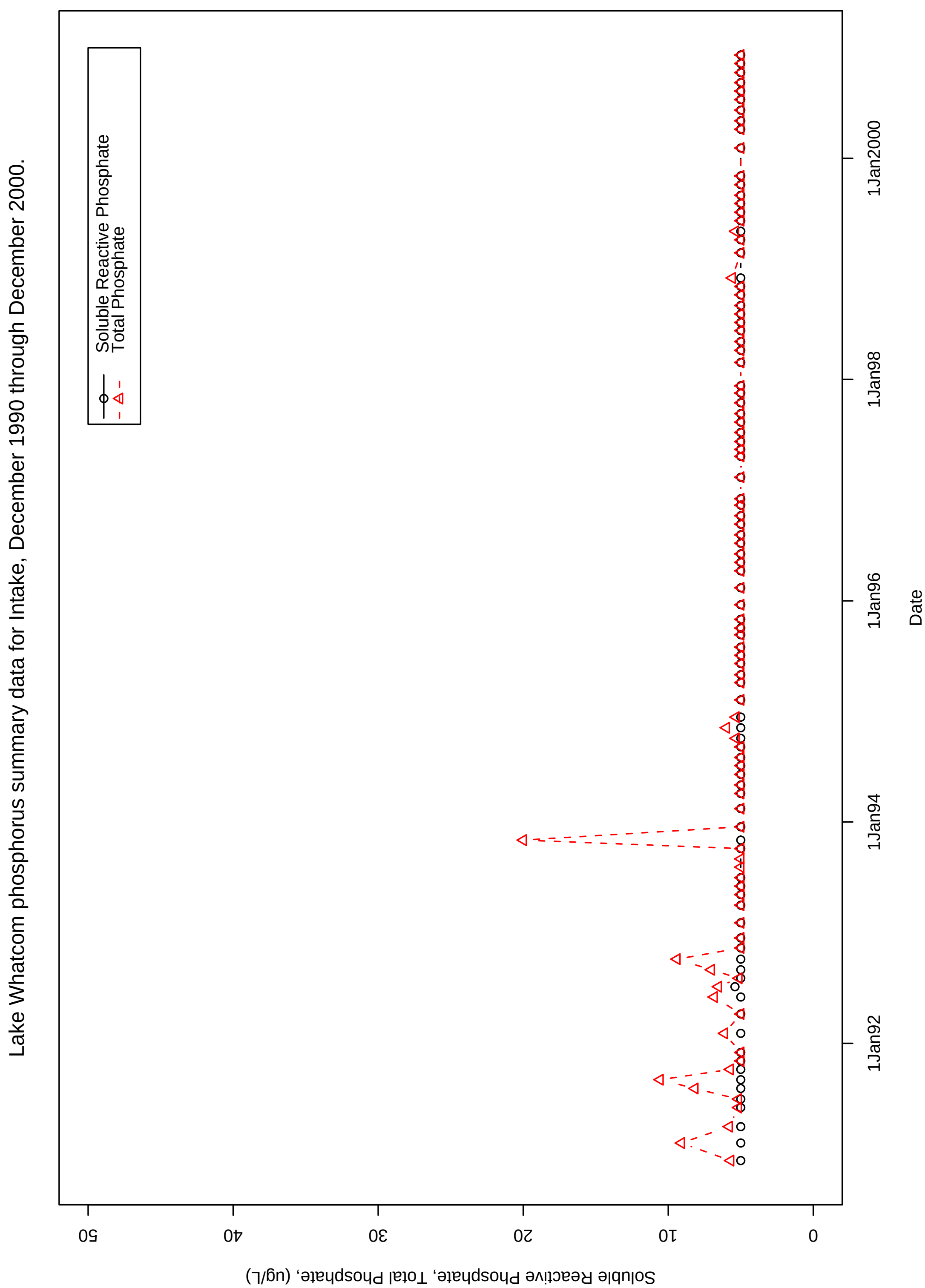


Figure 69: Lake Whatcom phosphorus summary data for the Intake.

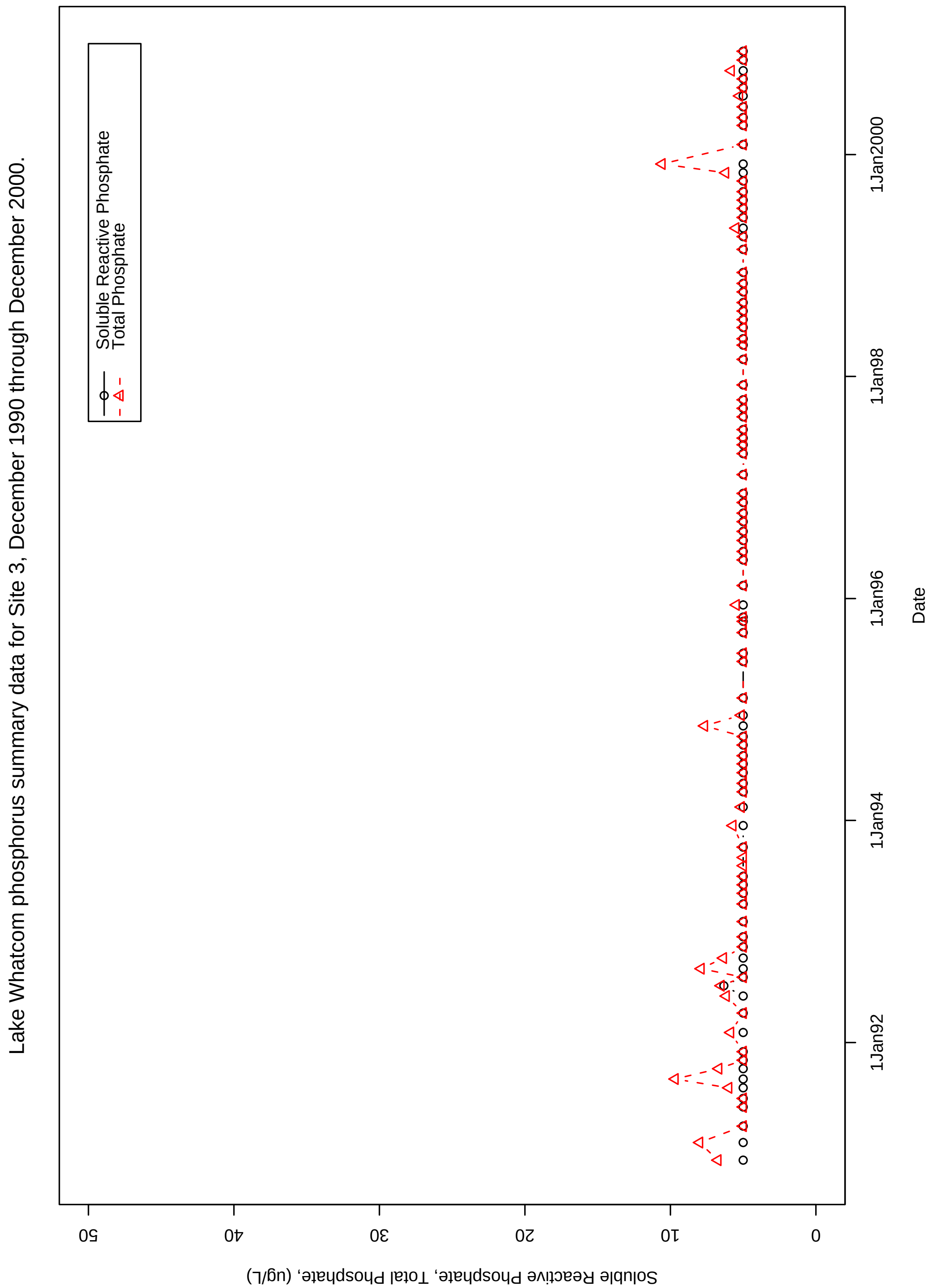


Figure 70: Lake Whatcom phosphorus summary data for Site 3.

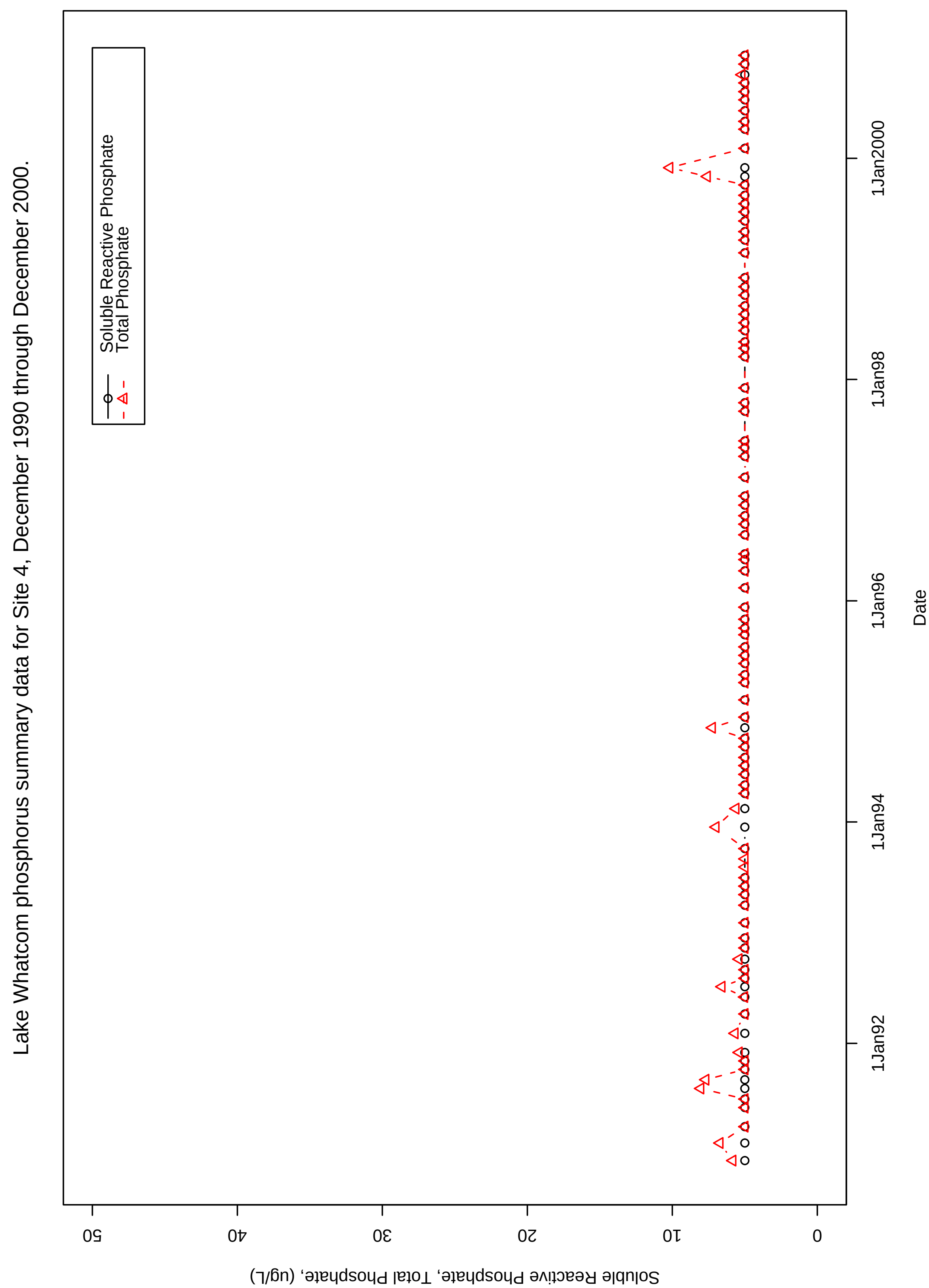


Figure 71: Lake Whatcom phosphorus summary data for Site 4.

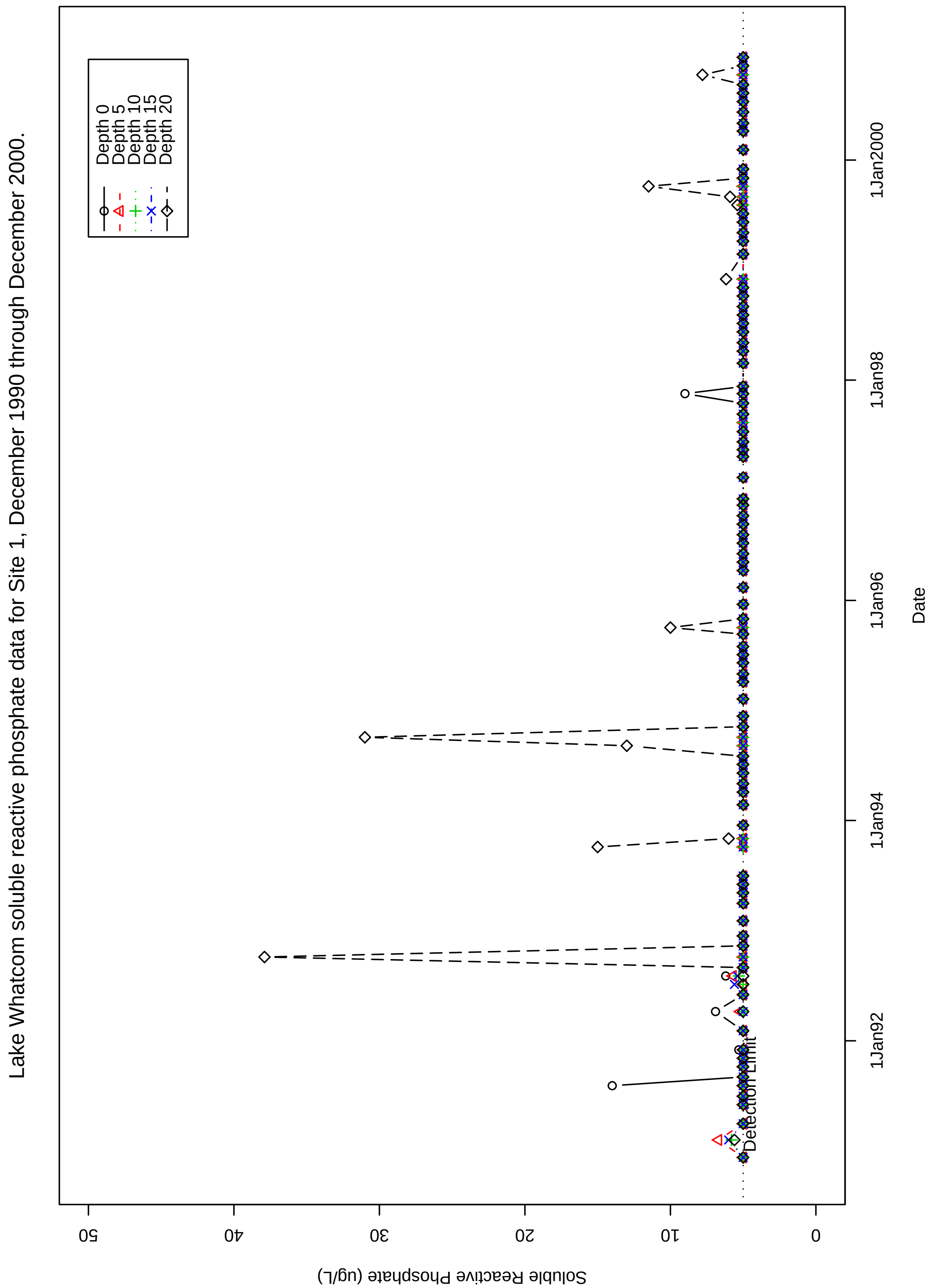


Figure 72: Lake Whatcom soluble phosphate data for Site 1.

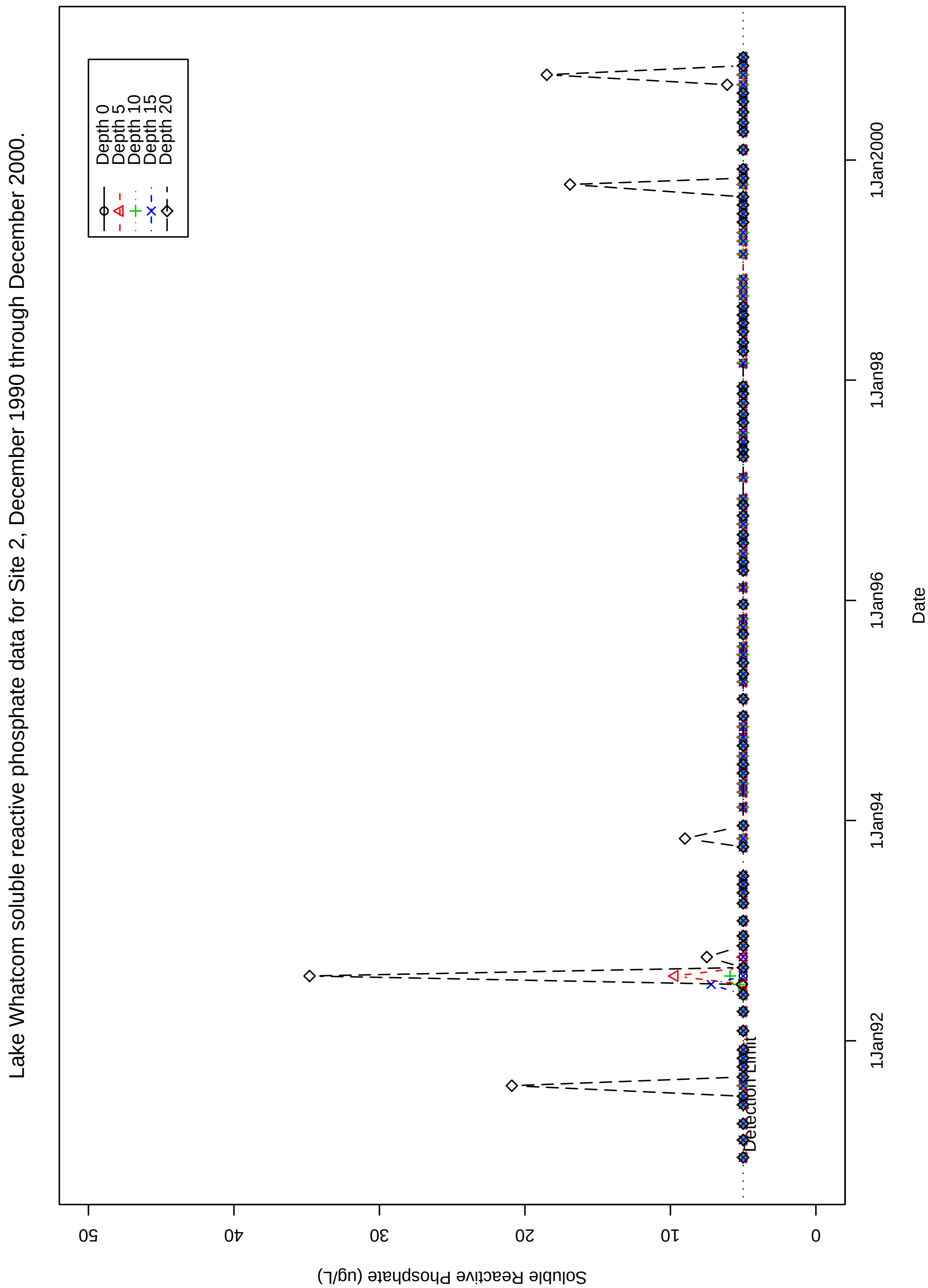


Figure 73: Lake Whatcom soluble phosphate data for Site 2.

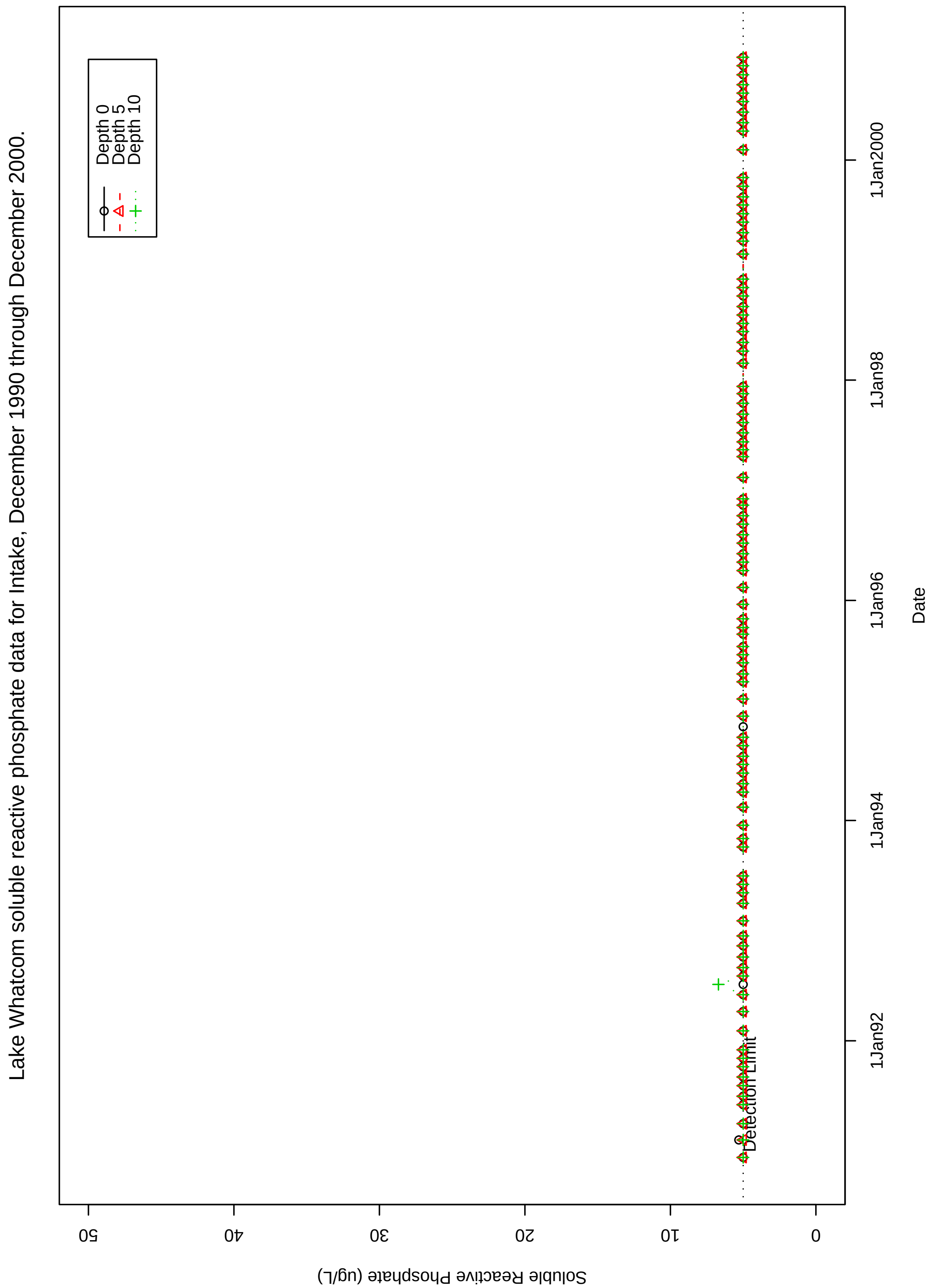


Figure 74: Lake Whatcom soluble phosphate data for the Intake.

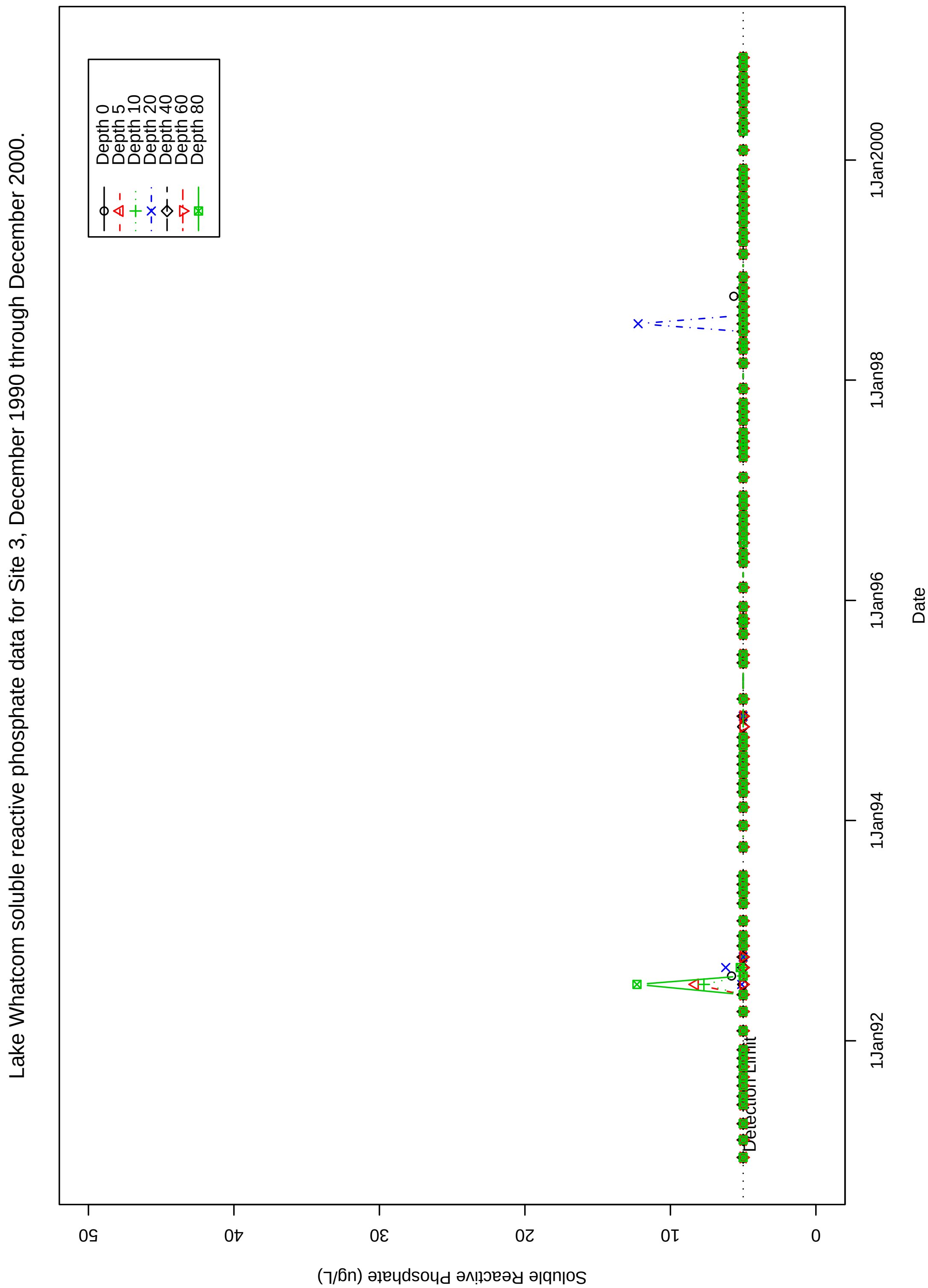


Figure 75: Lake Whatcom soluble phosphate data for Site 3.

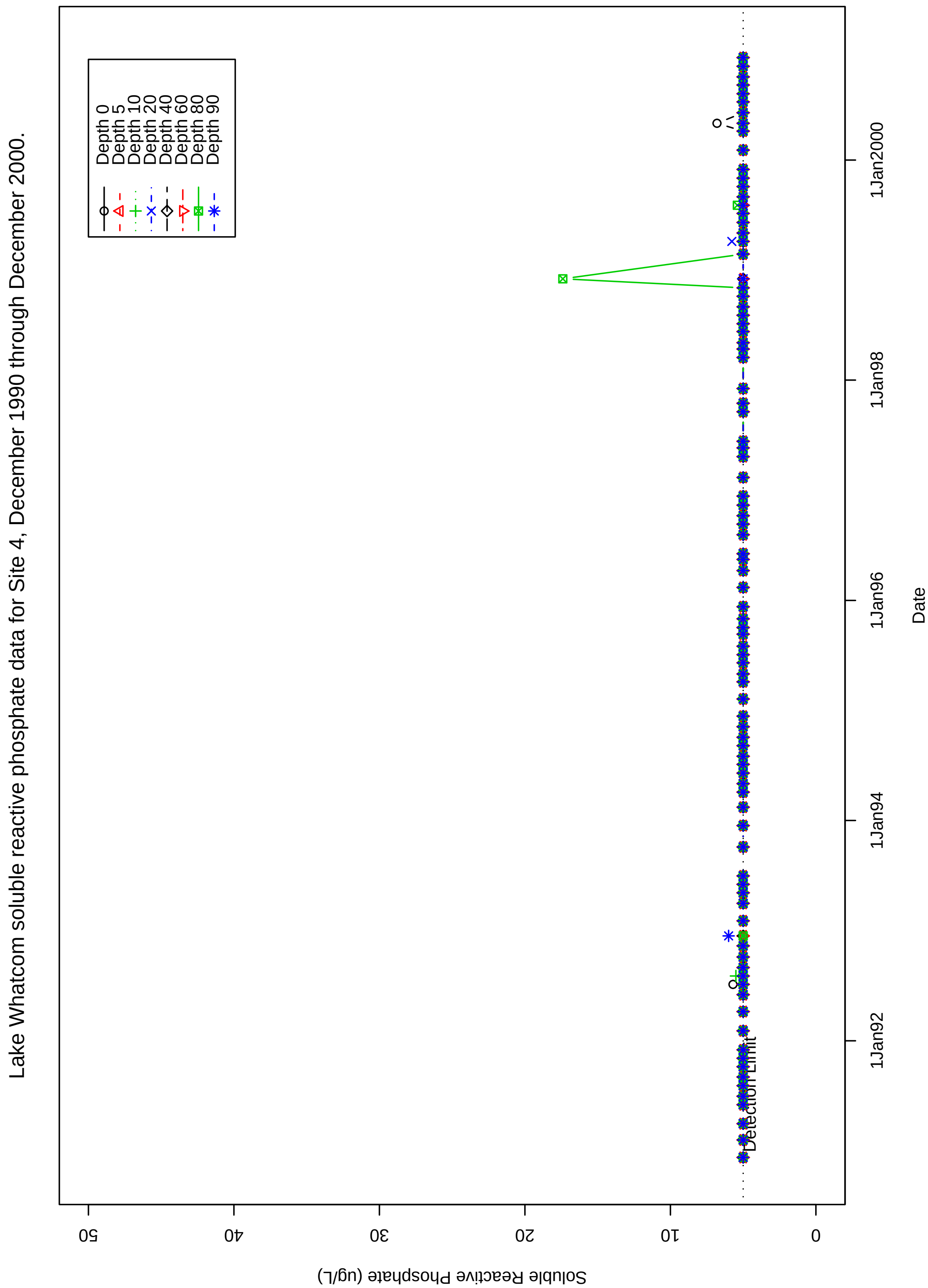


Figure 76: Lake Whatcom soluble phosphate data for Site 4.

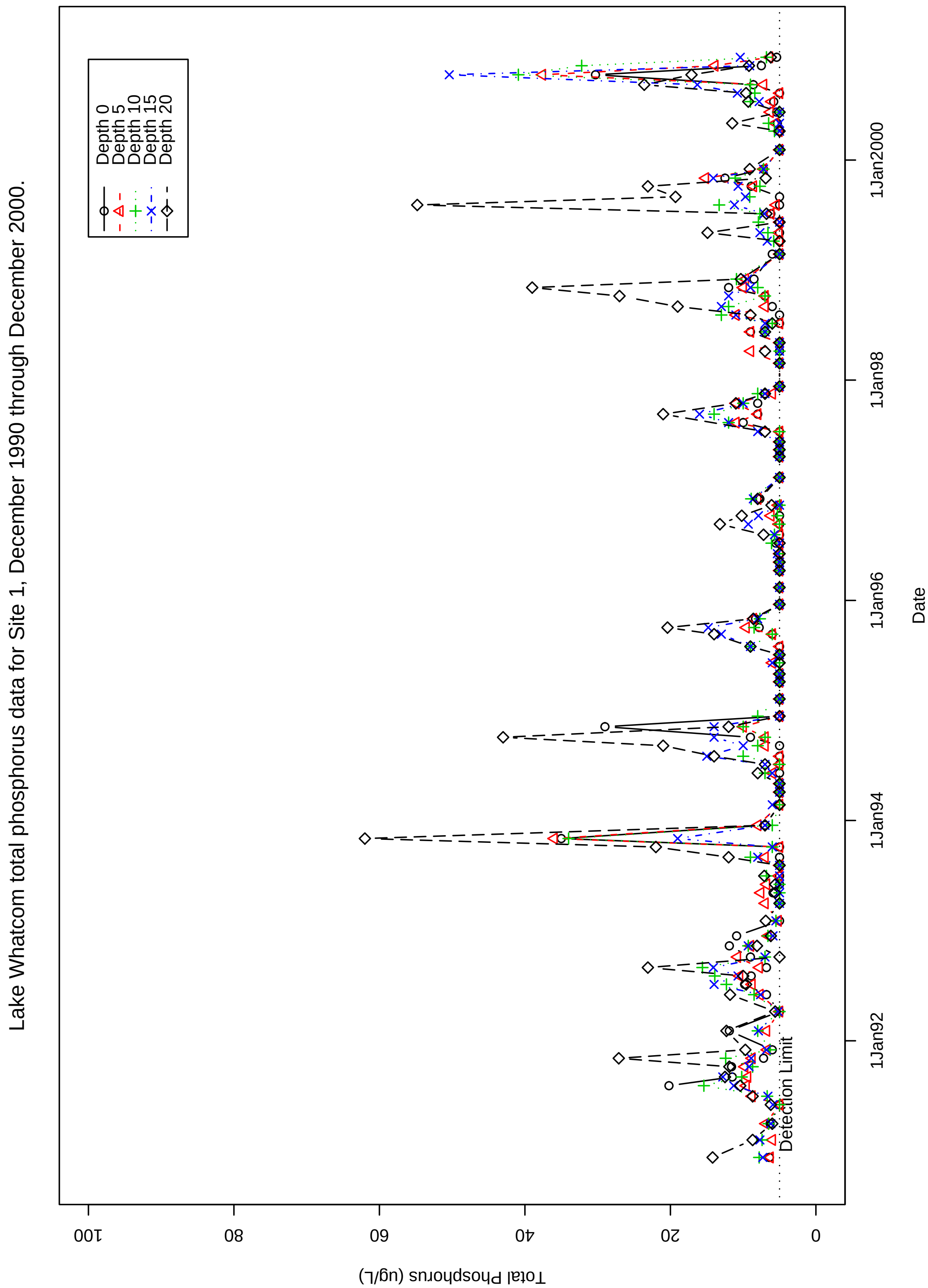


Figure 77: Lake Whatcom total phosphorus data for Site 1.

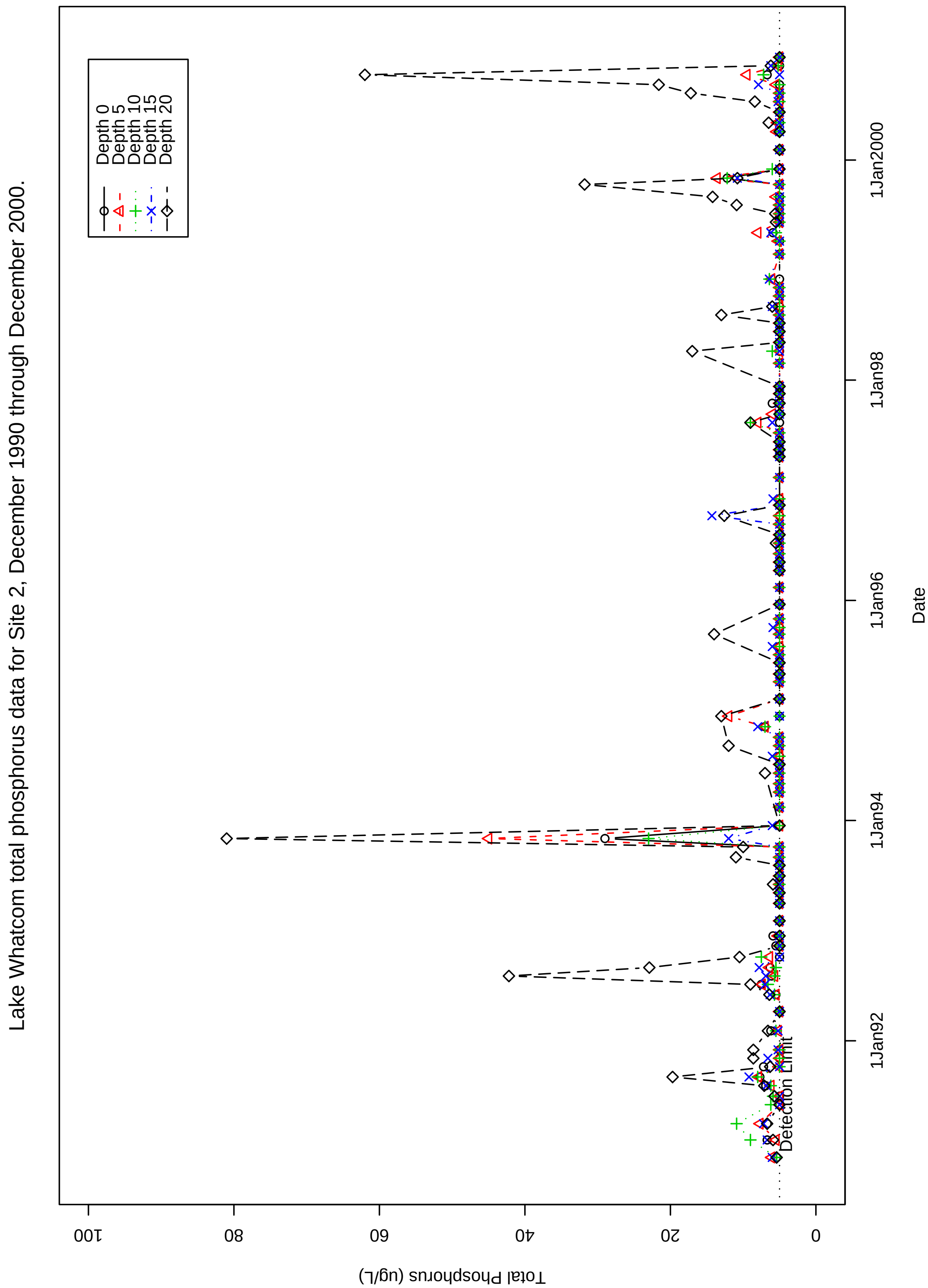


Figure 78: Lake Whatcom total phosphorus data for Site 2.

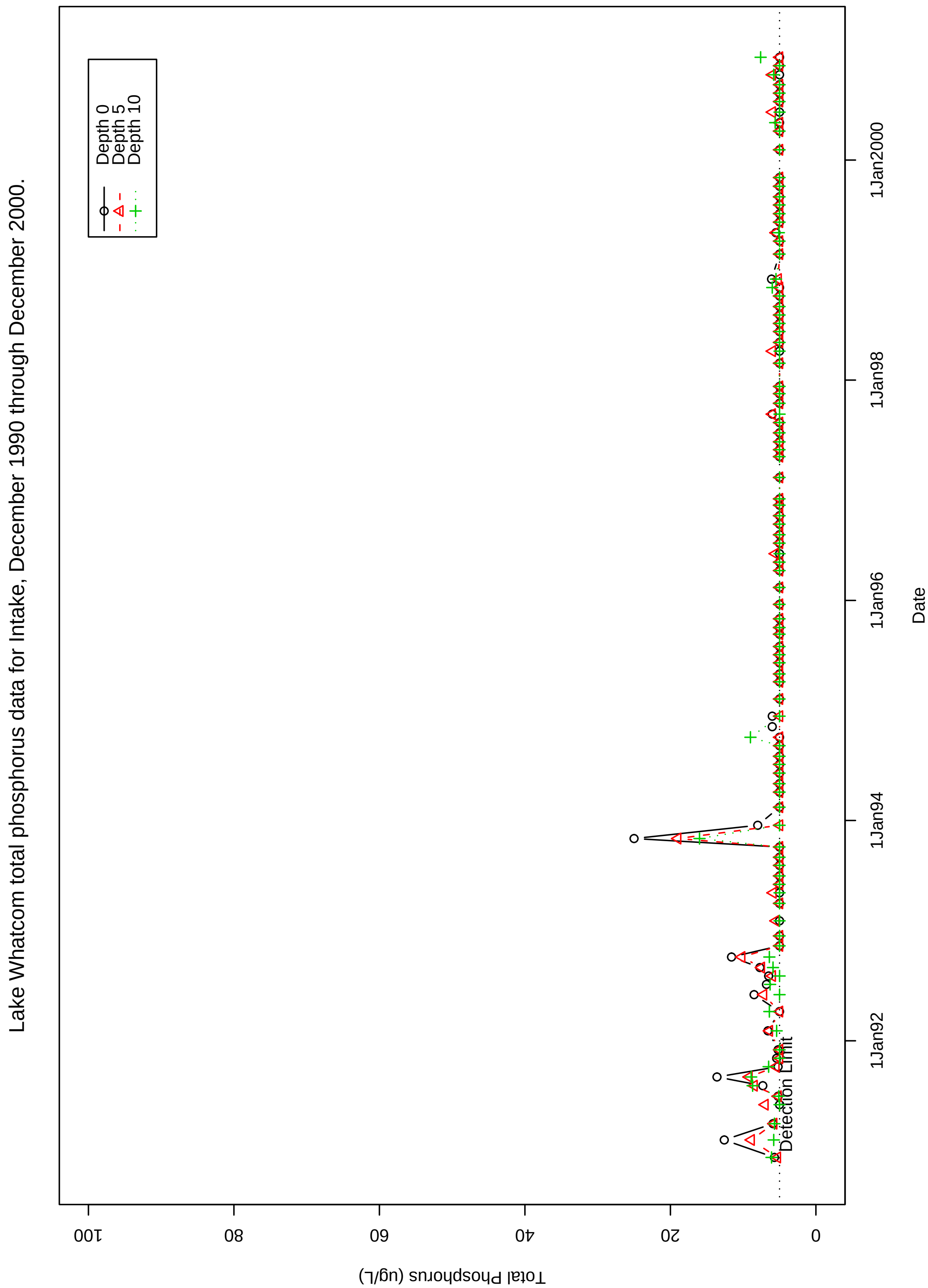


Figure 79: Lake Whatcom total phosphorus data for the Intake.

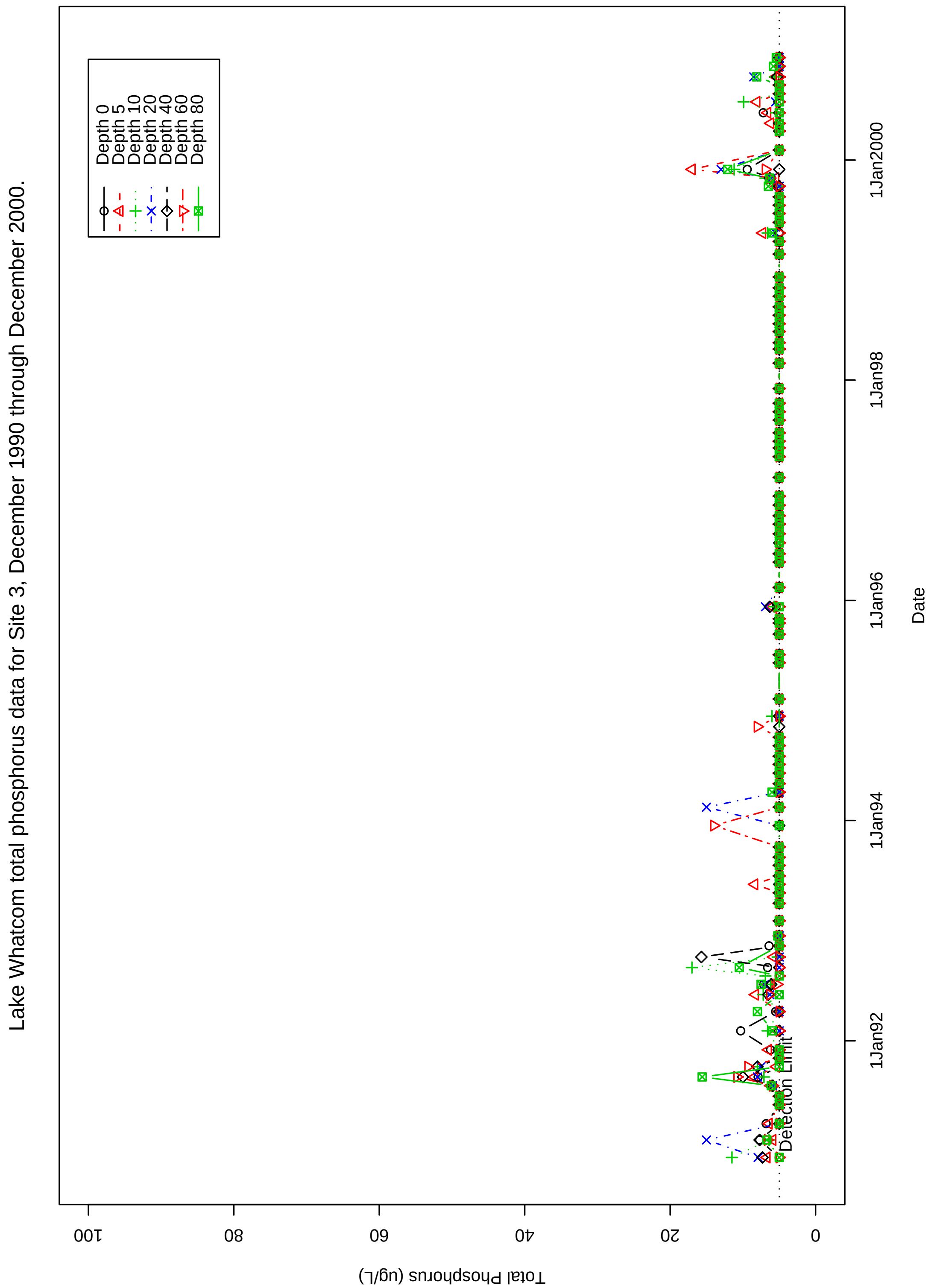


Figure 80: Lake Whatcom total phosphorus data for Site 3.

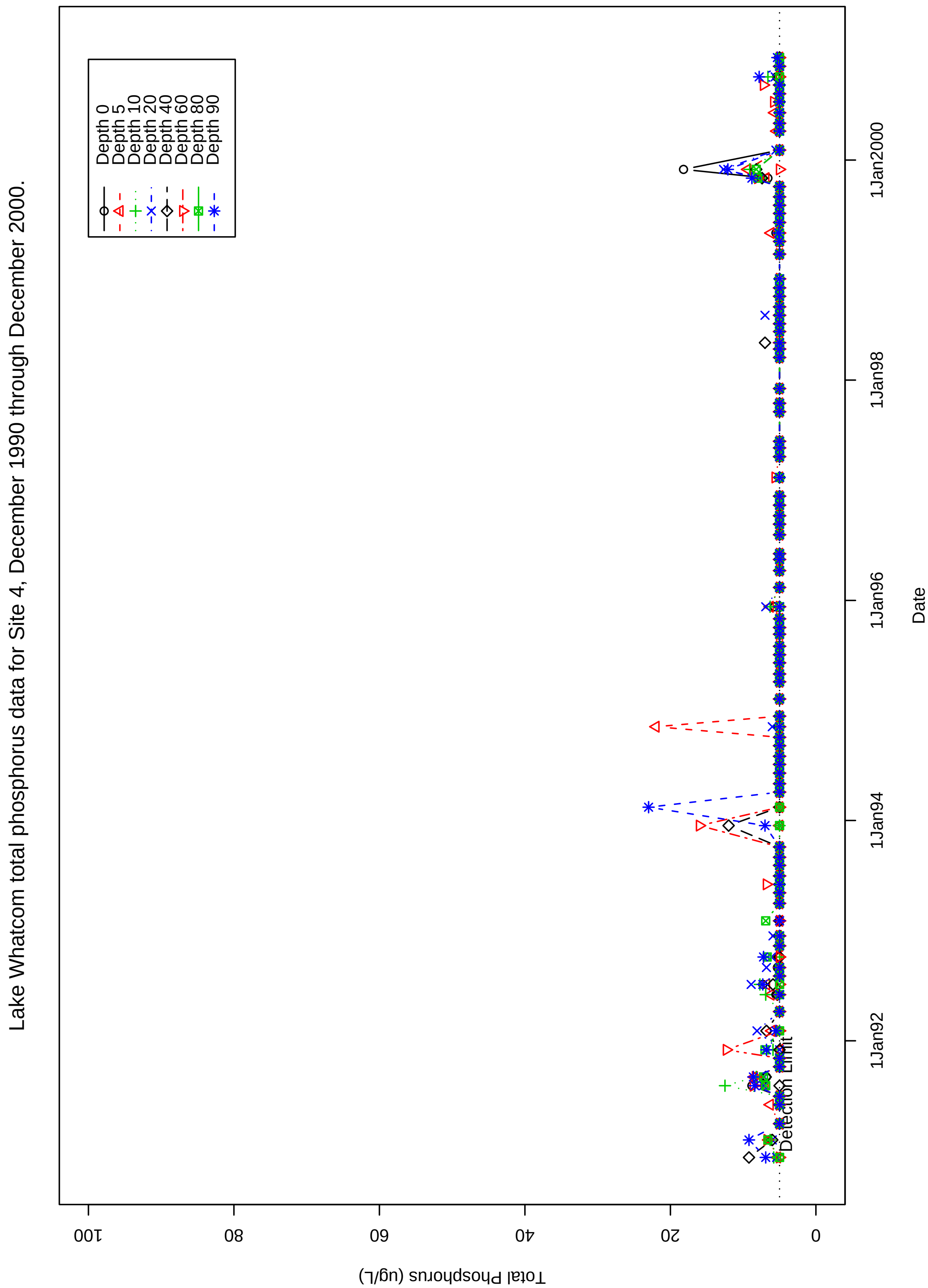


Figure 81: Lake Whatcom total phosphorus data for Site 4.

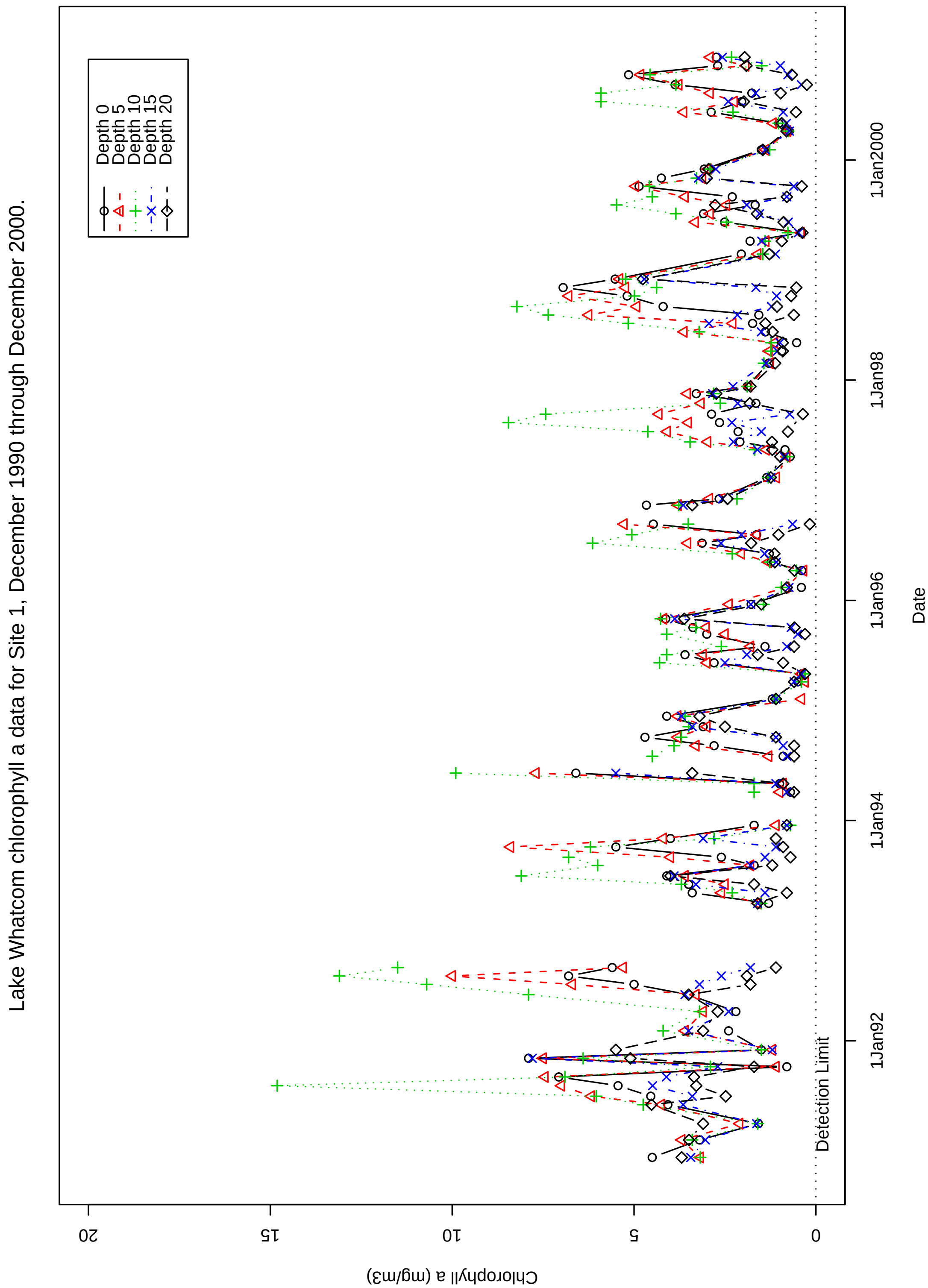


Figure 82: Lake Whatcom chlorophyll data for Site 1.

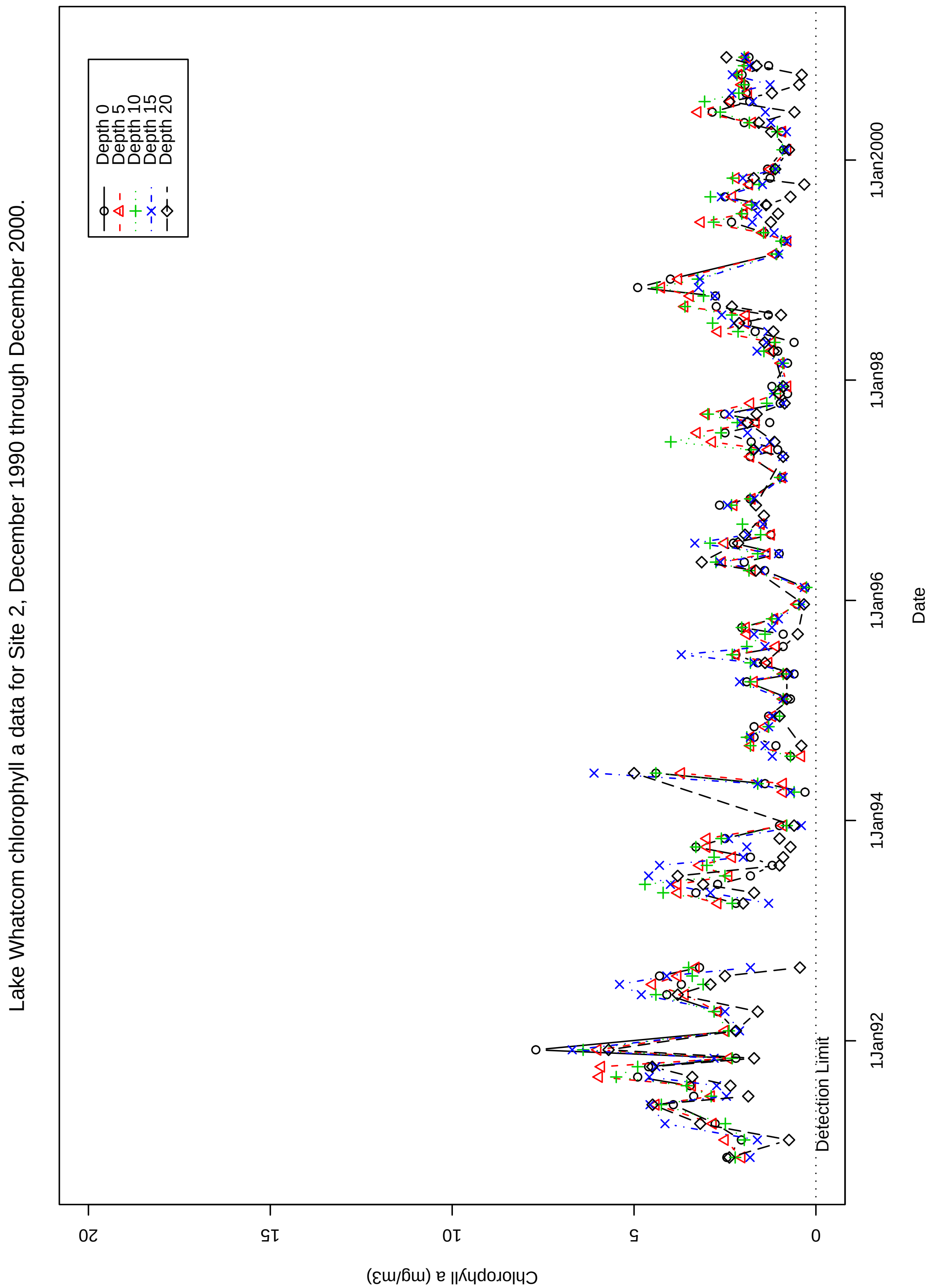


Figure 83: Lake Whatcom chlorophyll data for Site 2.

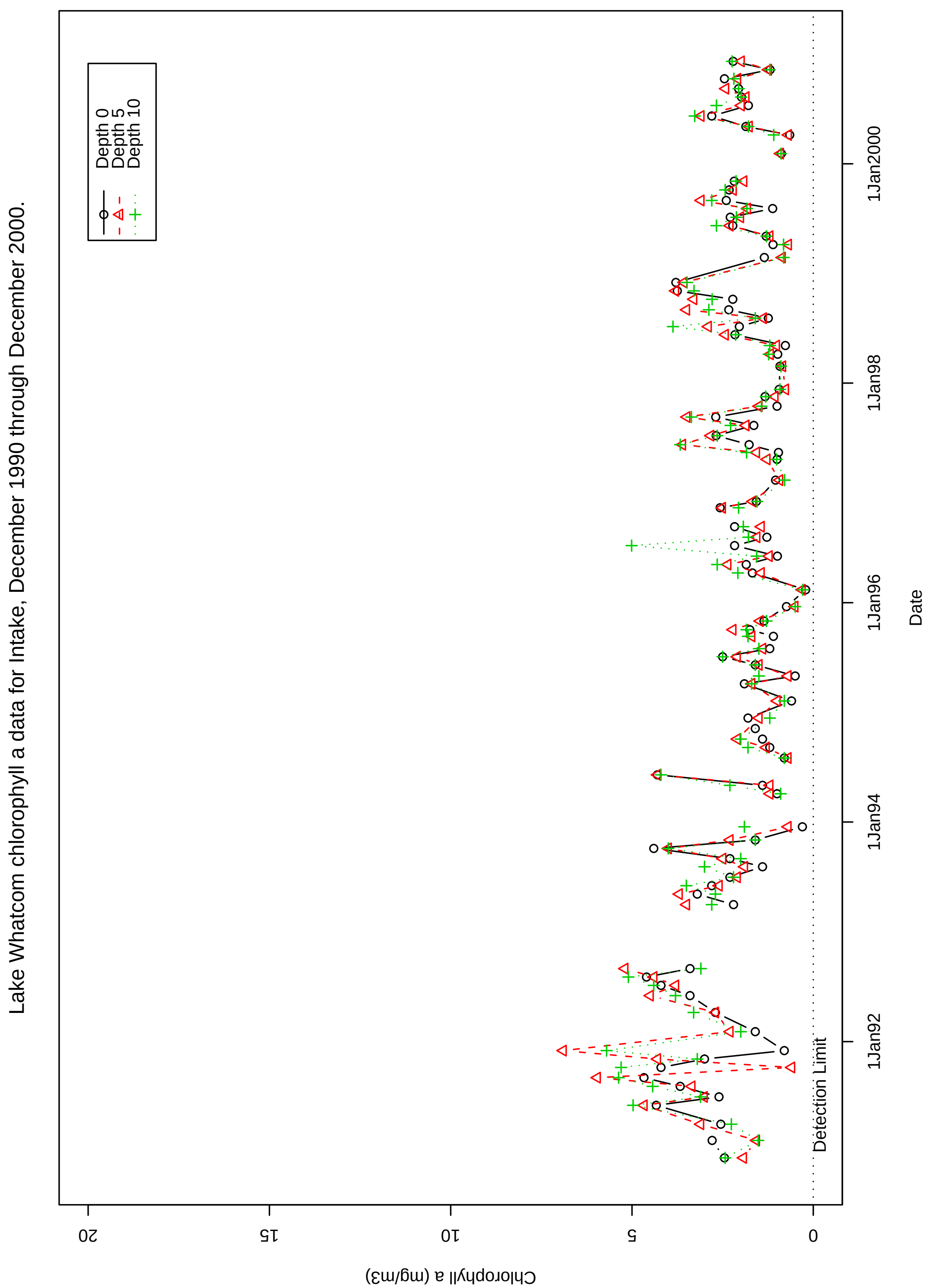


Figure 84: Lake Whatcom chlorophyll data for the Intake.

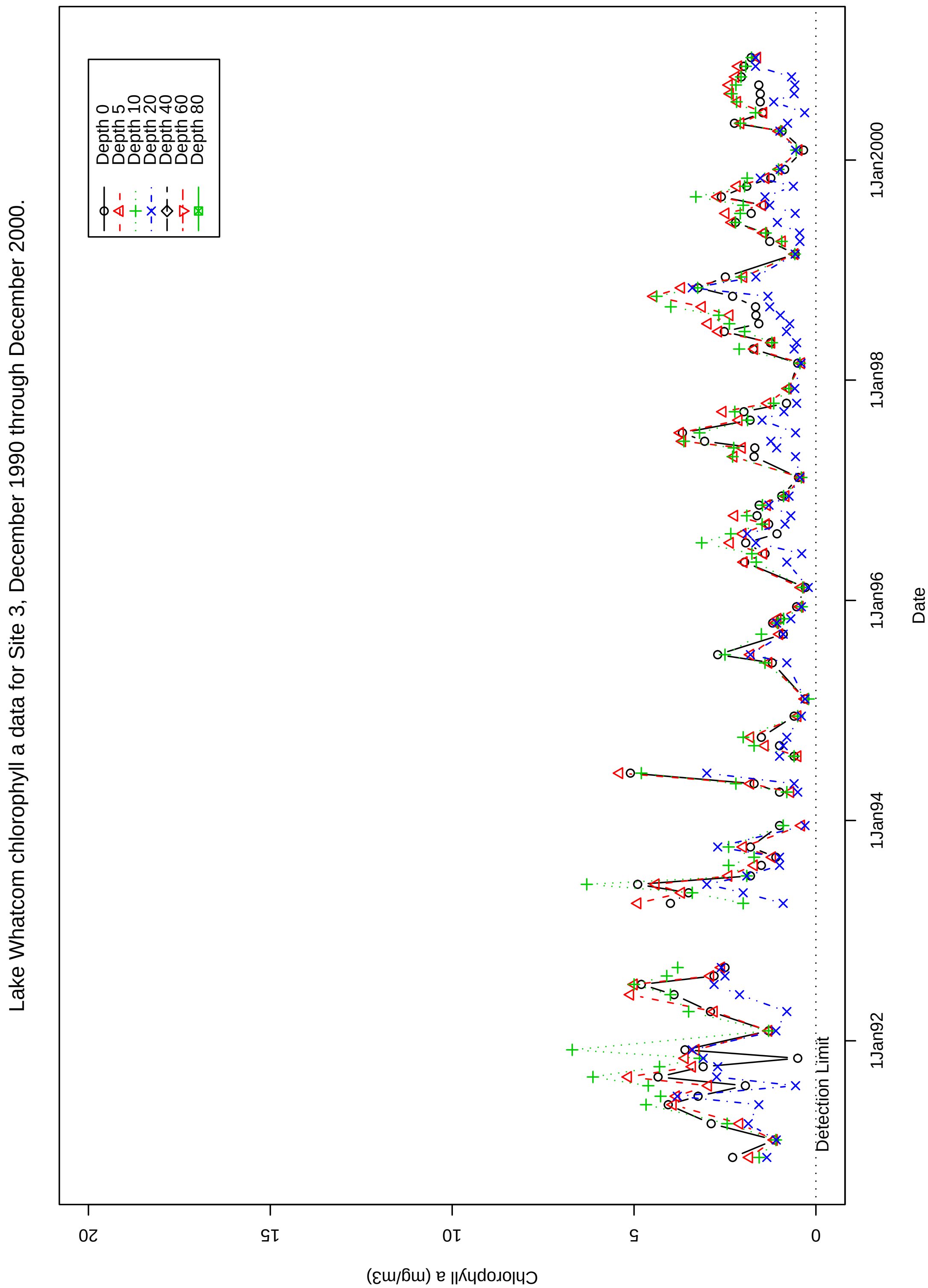


Figure 85: Lake Whatcom chlorophyll data for Site 3.

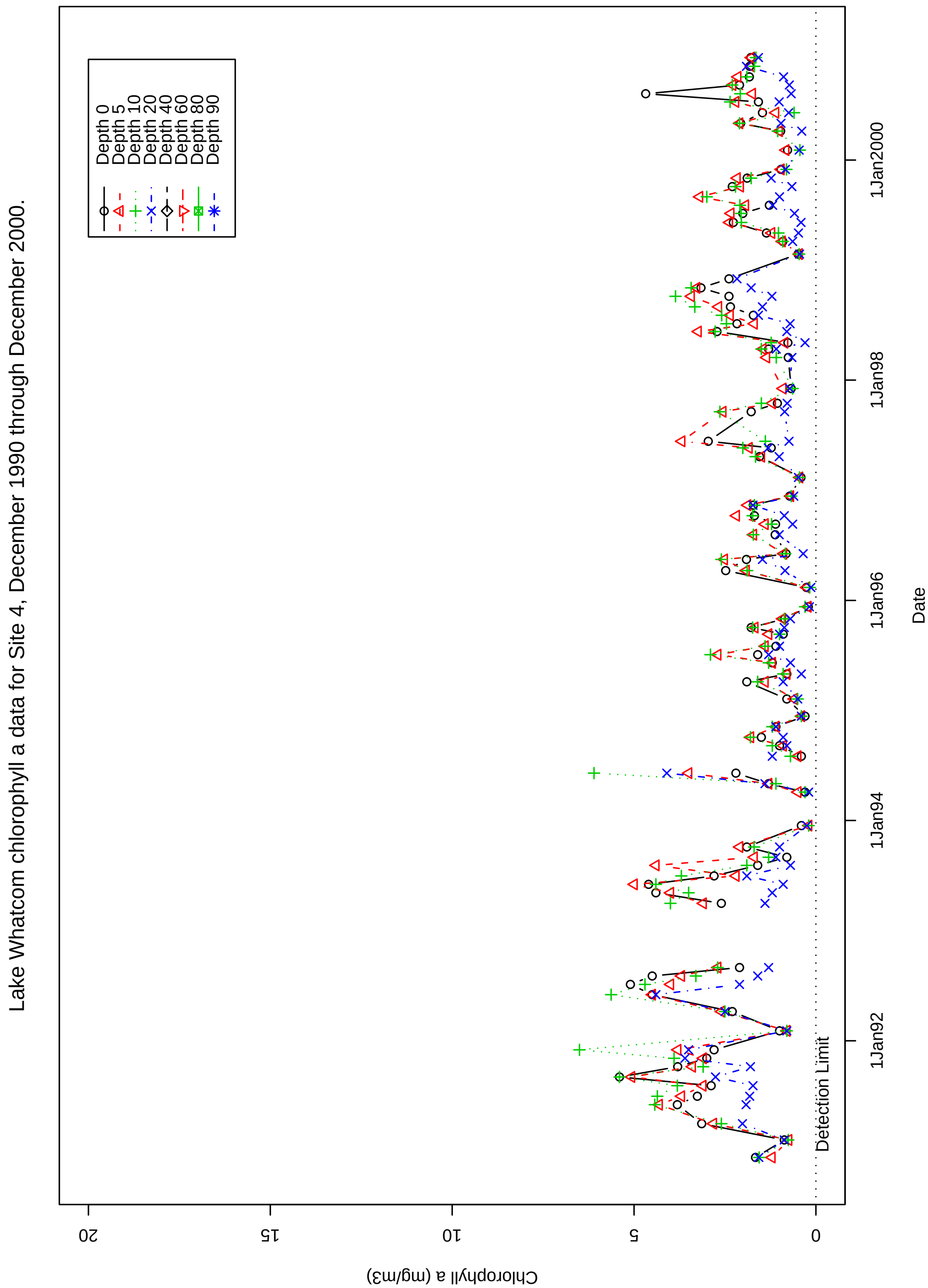


Figure 86: Lake Whatcom chlorophyll data for Site 4.

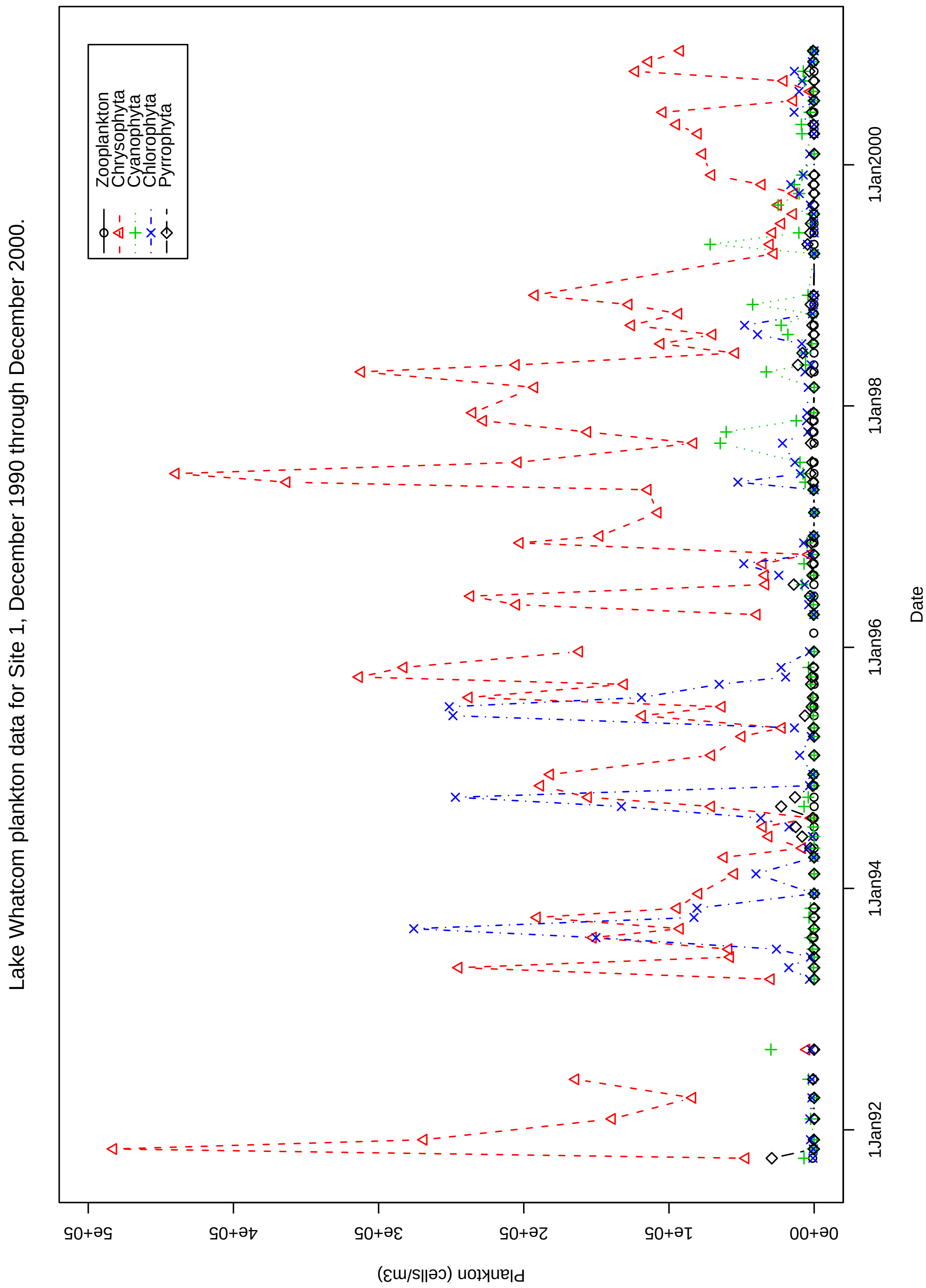


Figure 87: Lake Whatcom plankton data for Site 1.

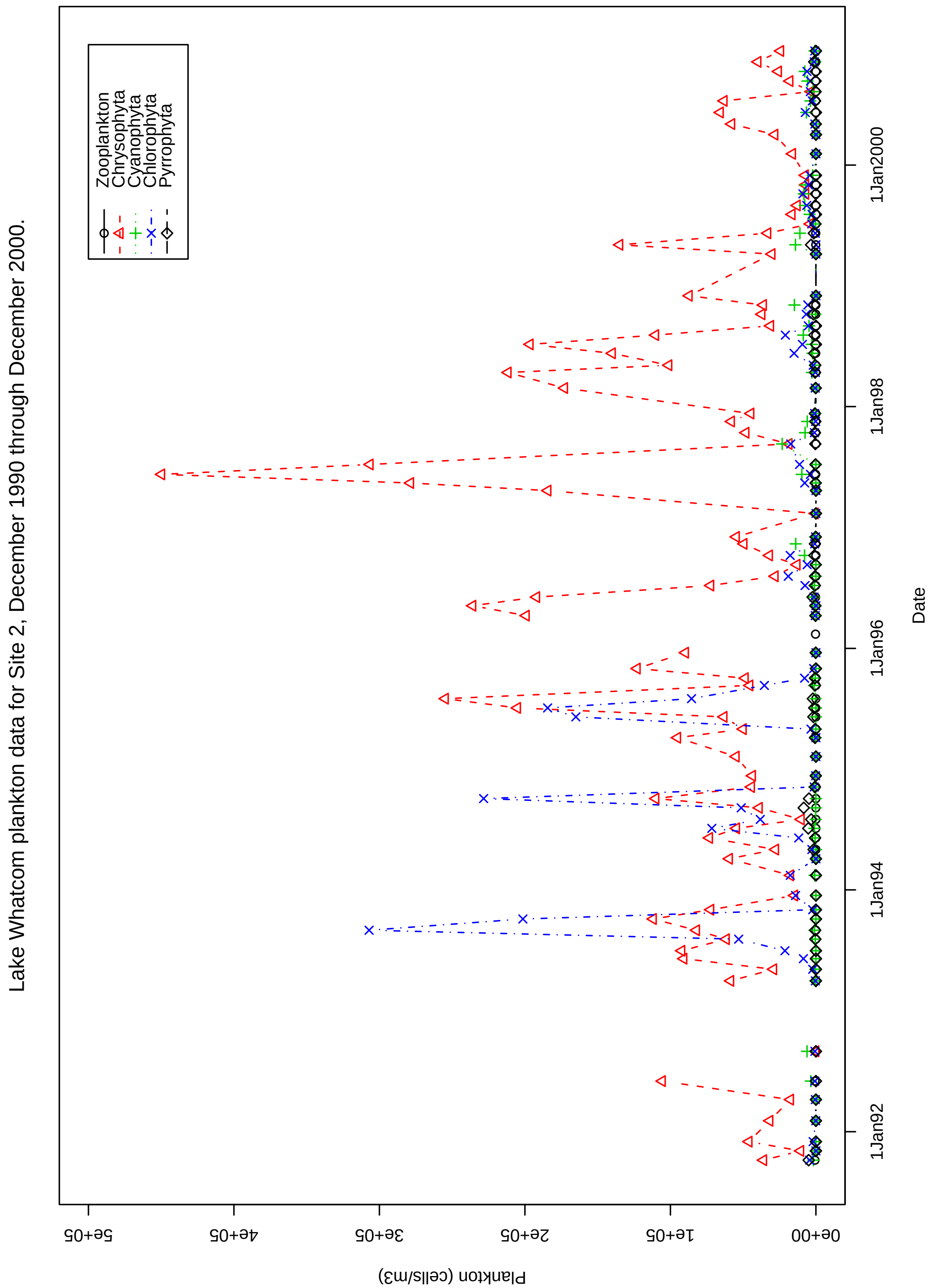


Figure 88: Lake Whatcom plankton data for Site 2.

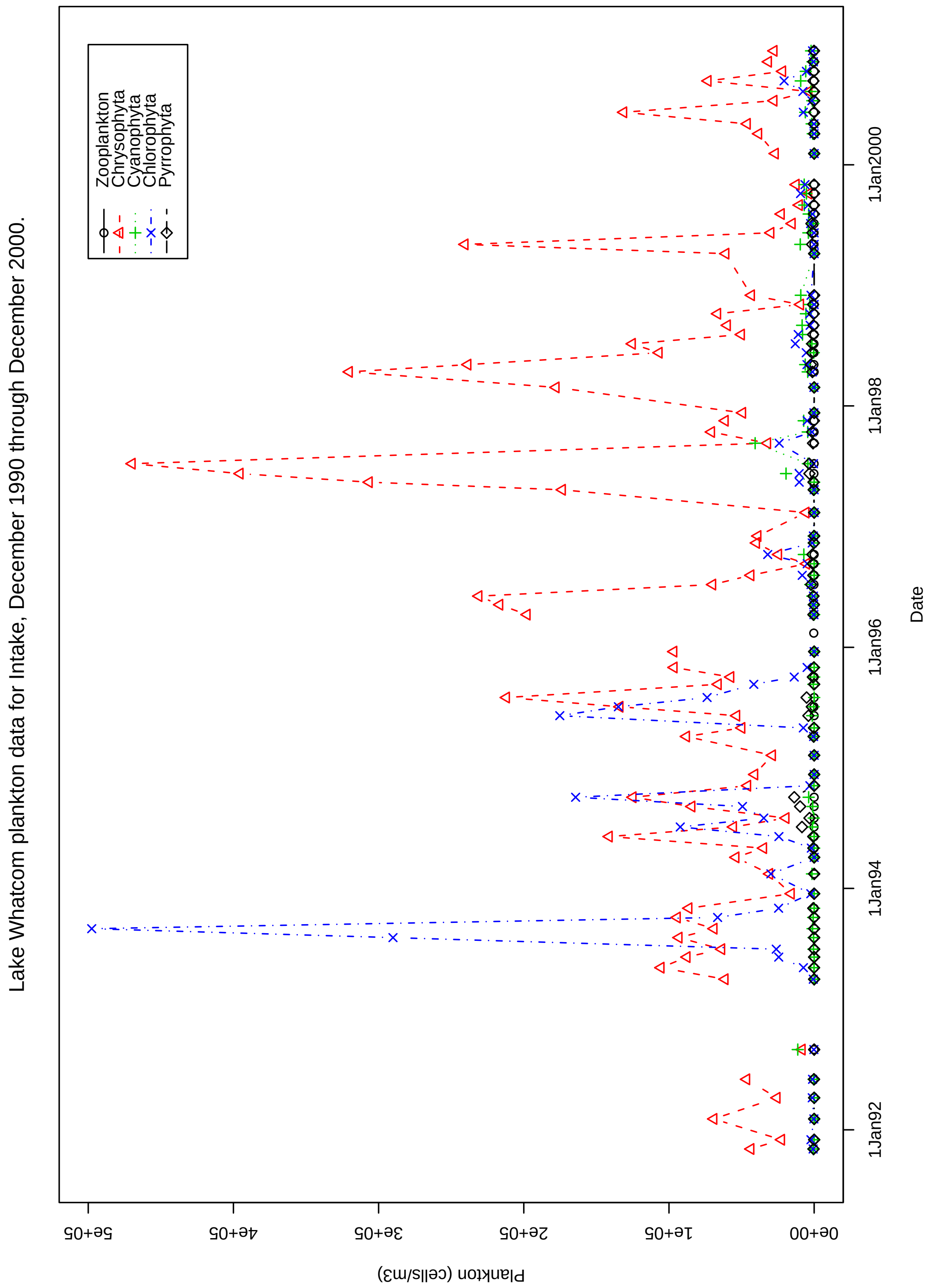


Figure 89: Lake Whatcom plankton data for the Intake.

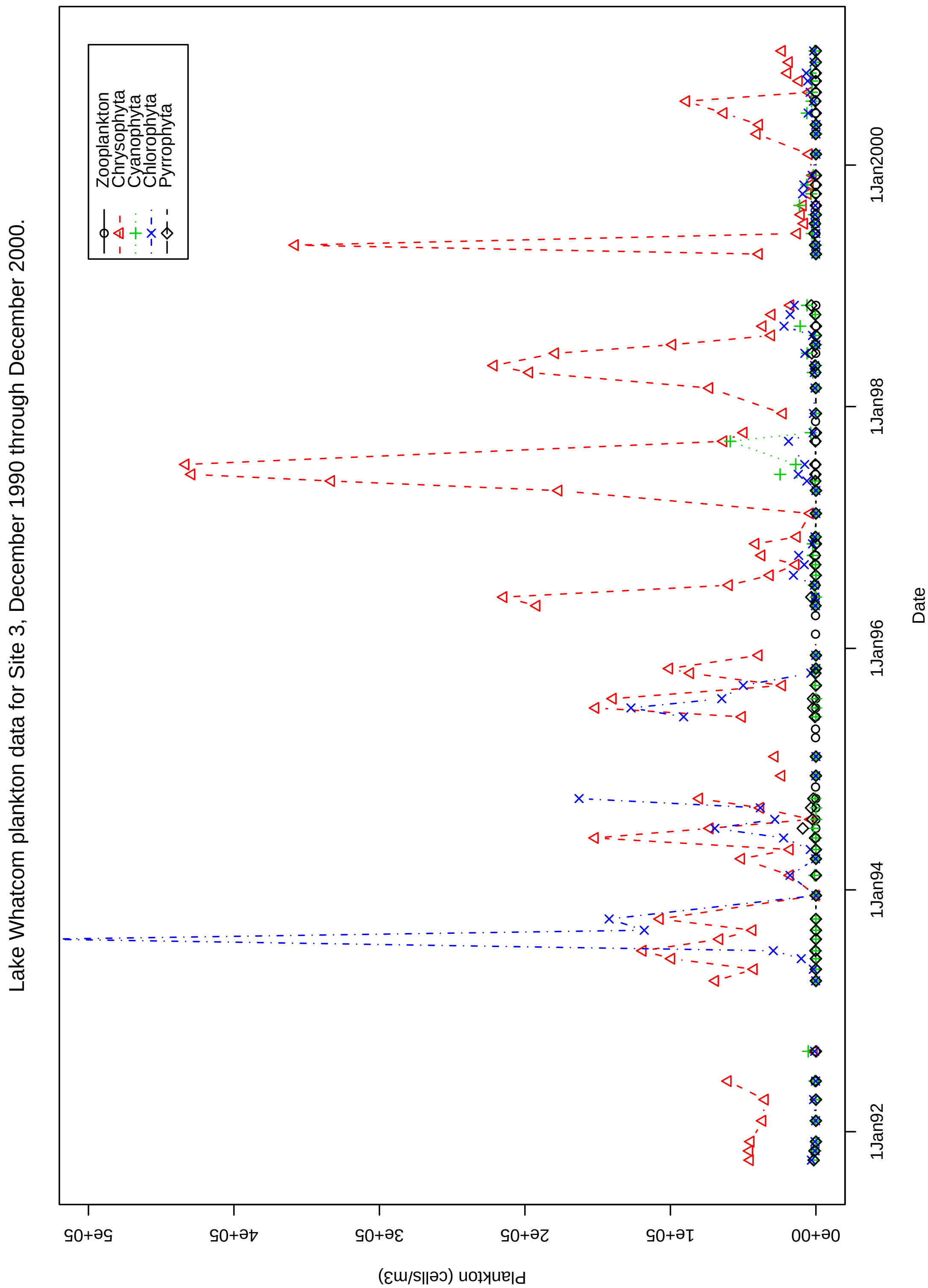


Figure 90: Lake Whatcom plankton data for Site 3.

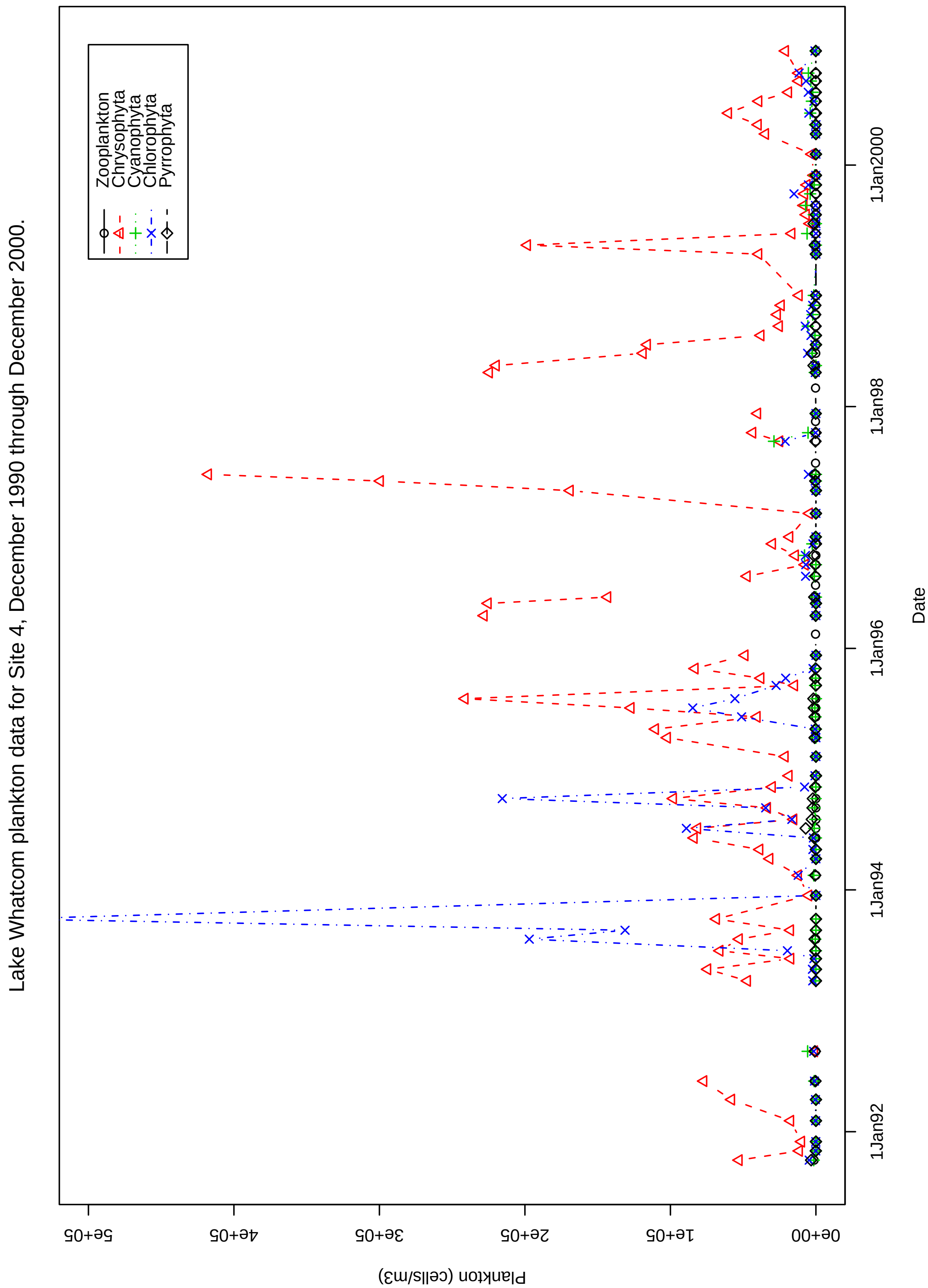


Figure 91: Lake Whatcom plankton data for Site 4.

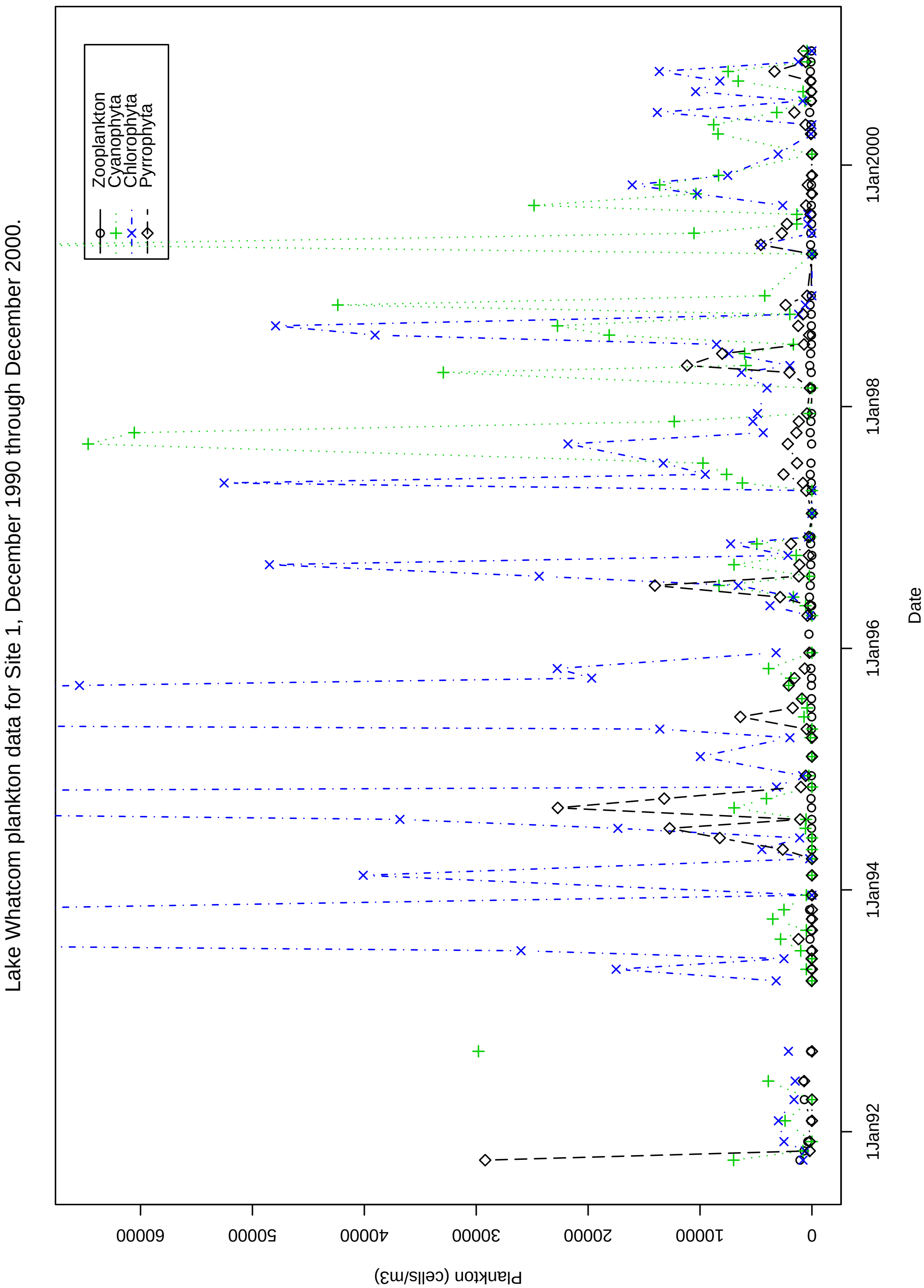


Figure 92: Lake Whatcom plankton data for Site 1, low range plot.

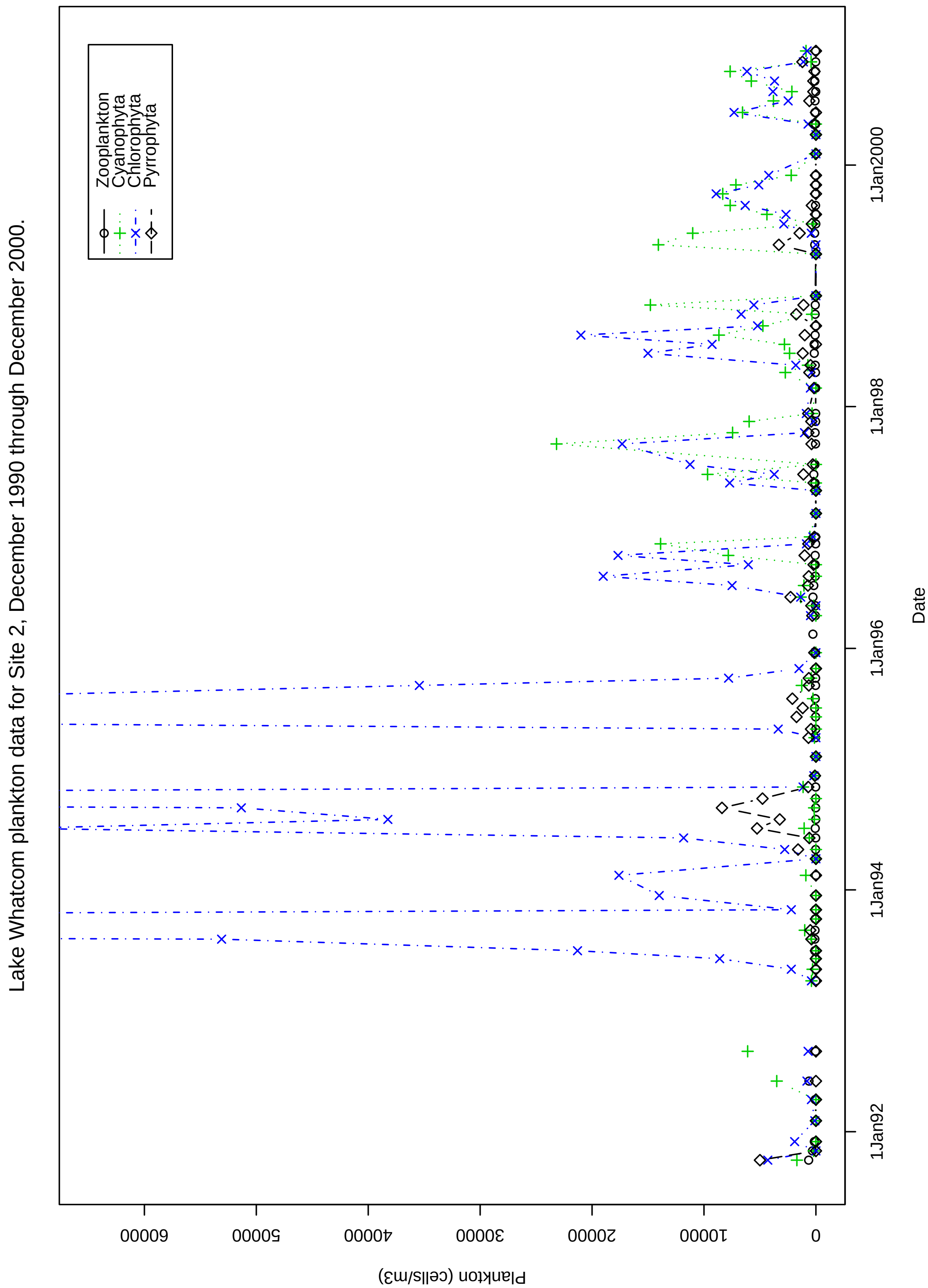


Figure 93: Lake Whatcom plankton data for Site 2, low range plot.

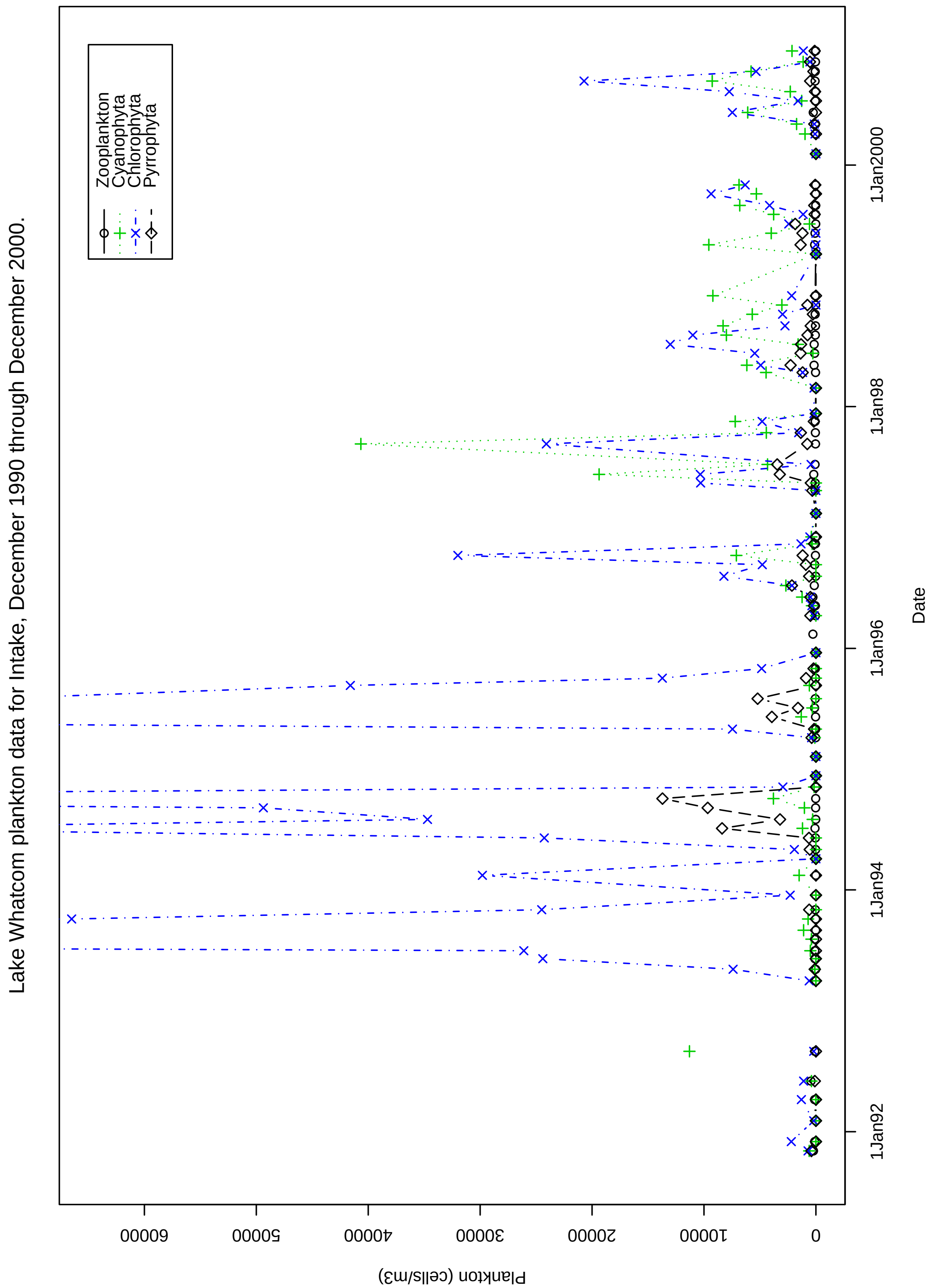


Figure 94: Lake Whatcom plankton data for the Intake, low range plot.

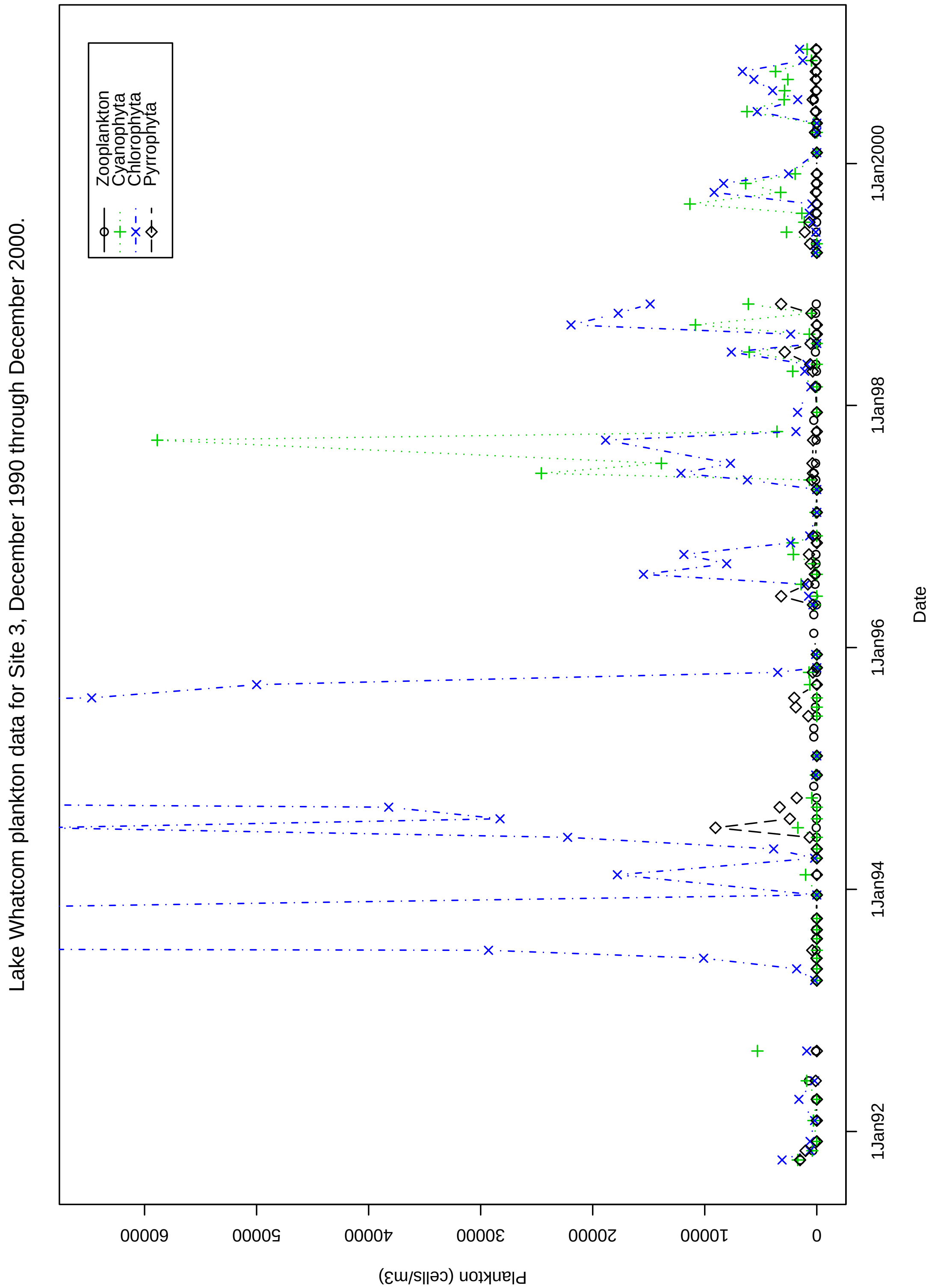


Figure 95: Lake Whatcom plankton data for Site 3, low range plot.

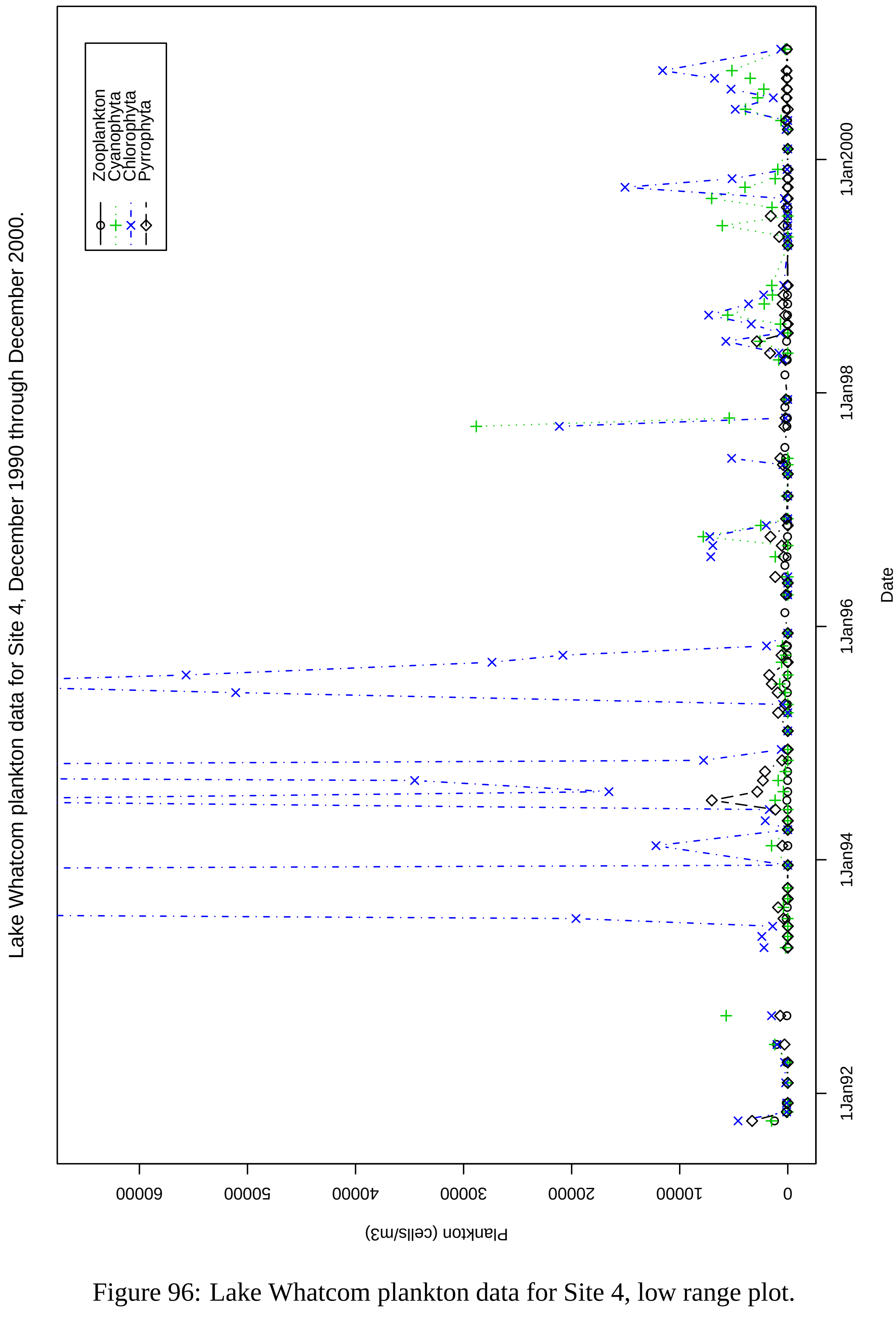


Figure 96: Lake Whatcom plankton data for Site 4, low range plot.

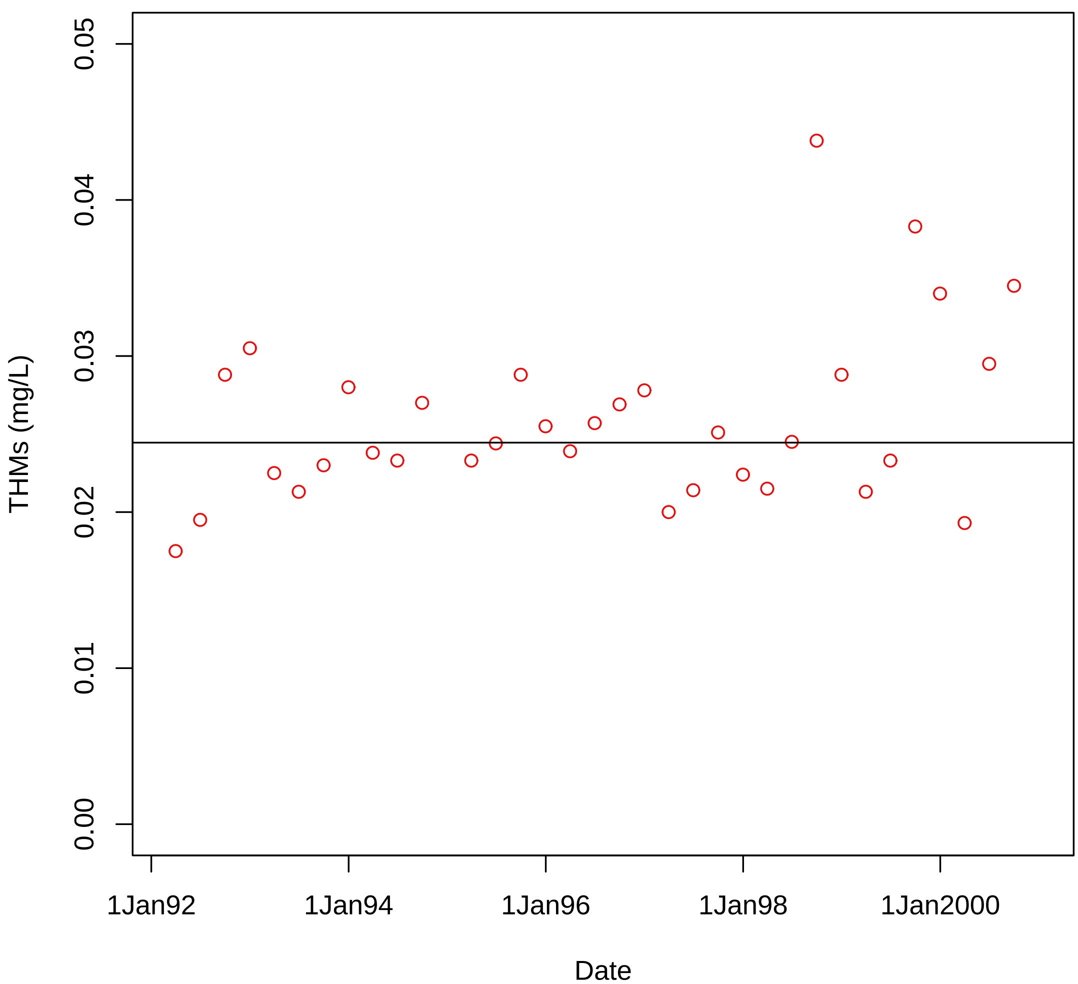


Figure 97: Total trihalomethanes concentrations in the Bellingham water distribution system, 1992–2000. Horizontal line represents the 1992–2000 median concentration. All points represent quarterly running averages.

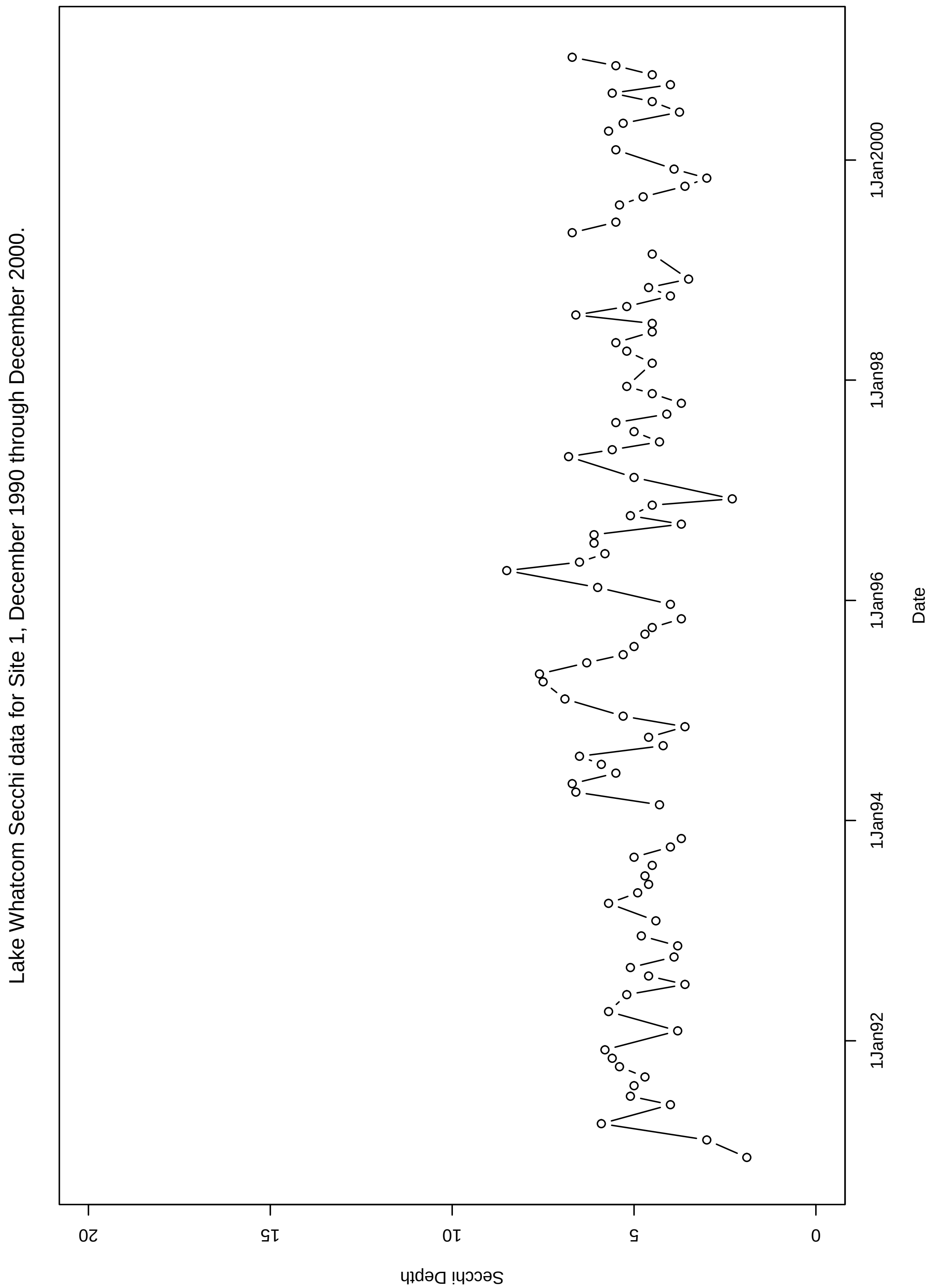


Figure 98: Lake Whatcom Secchi depths for Site 1.

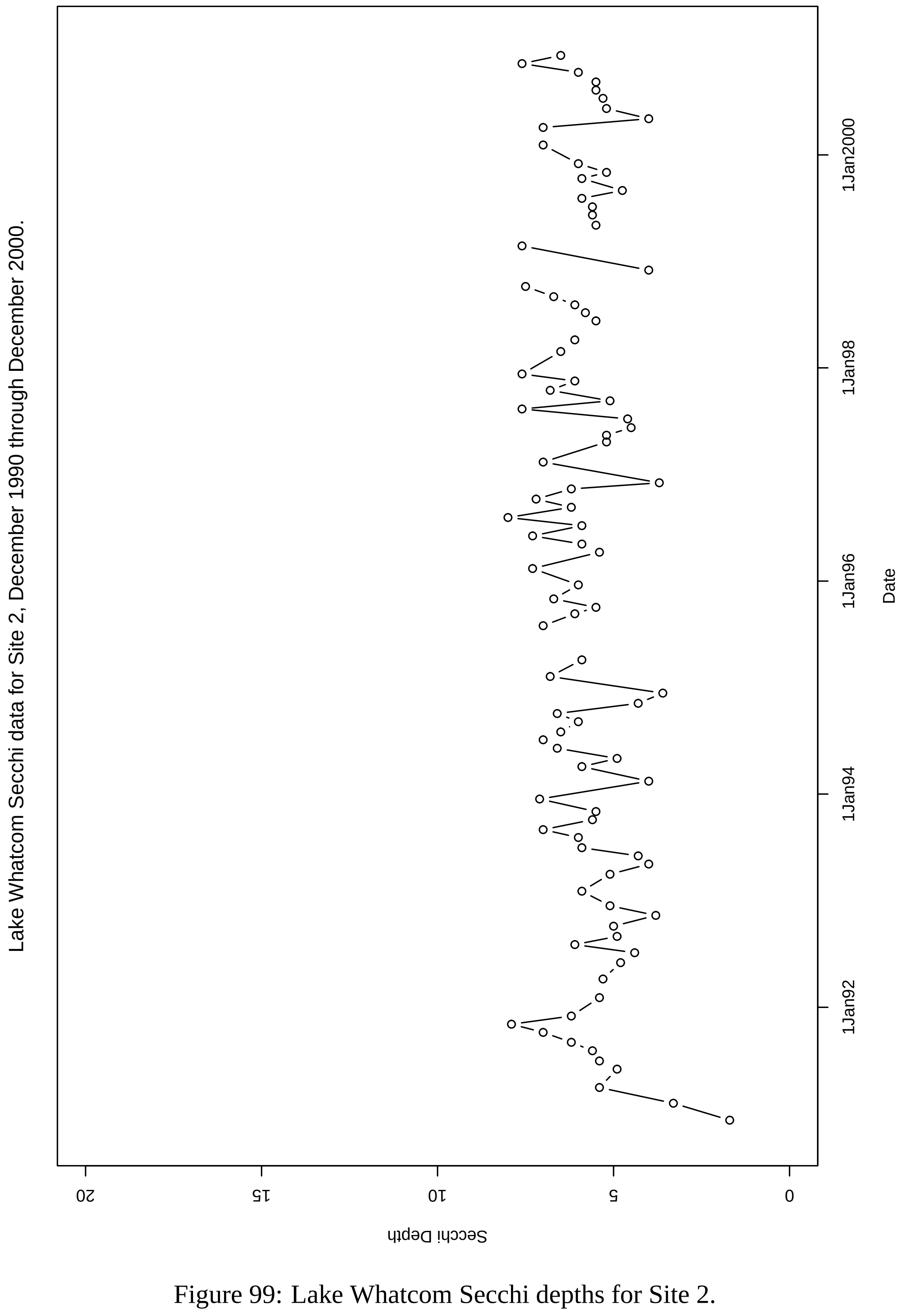


Figure 99: Lake Whatcom Secchi depths for Site 2.

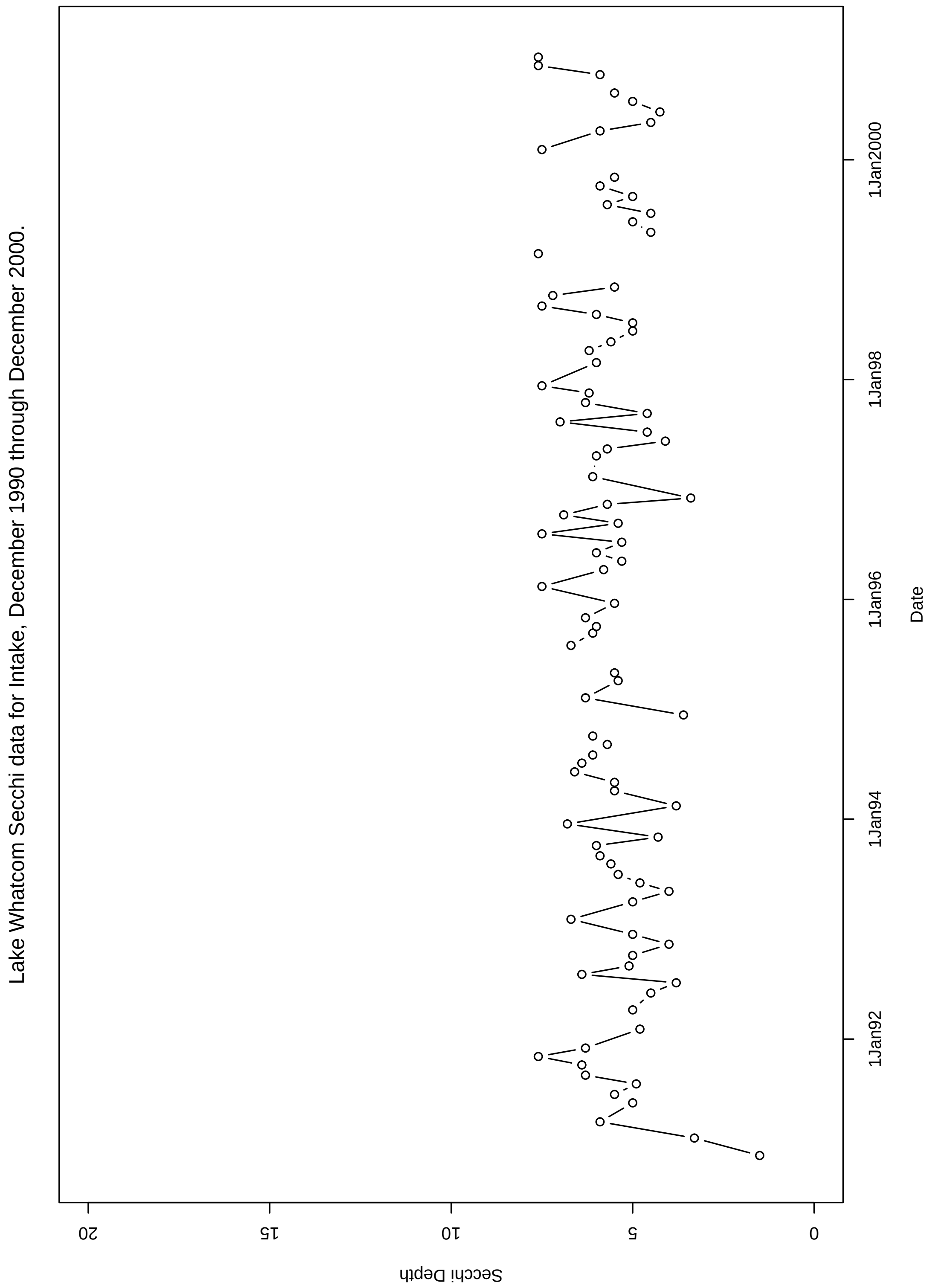


Figure 100: Lake Whatcom Secchi depths for the Intake.

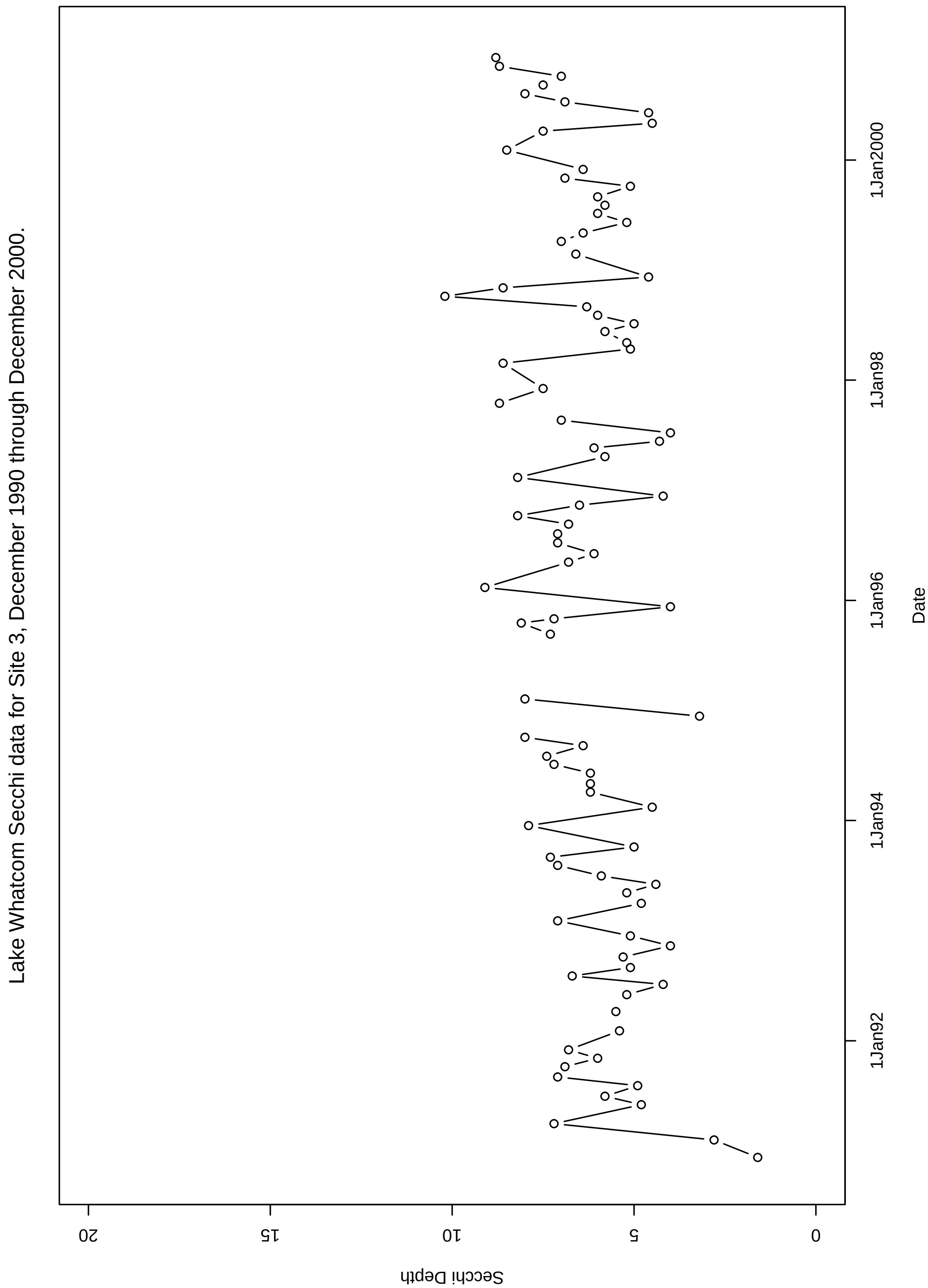


Figure 101: Lake Whatcom Secchi depths for Site 3.

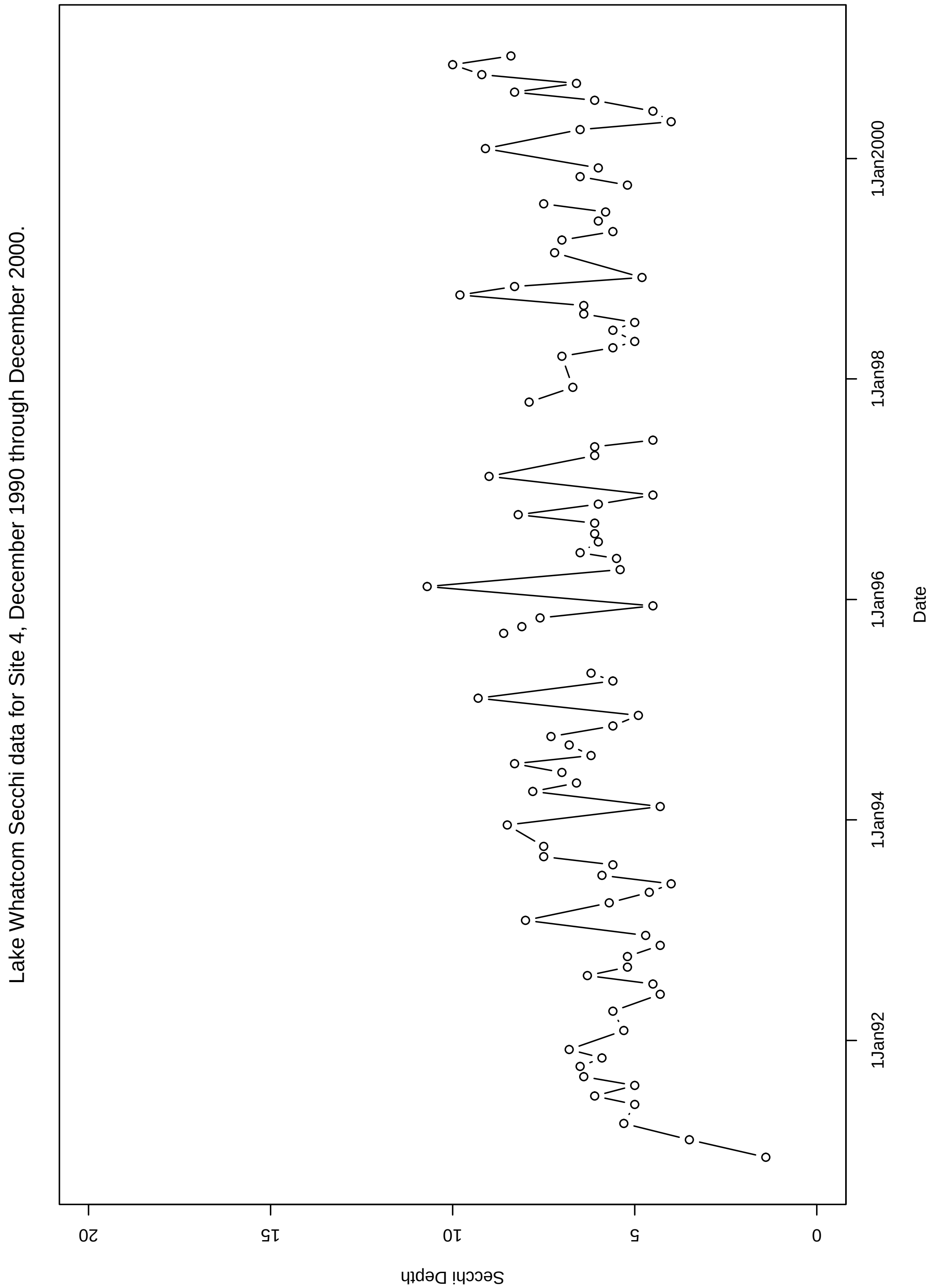


Figure 102: Lake Whatcom Secchi depths for Site 4.

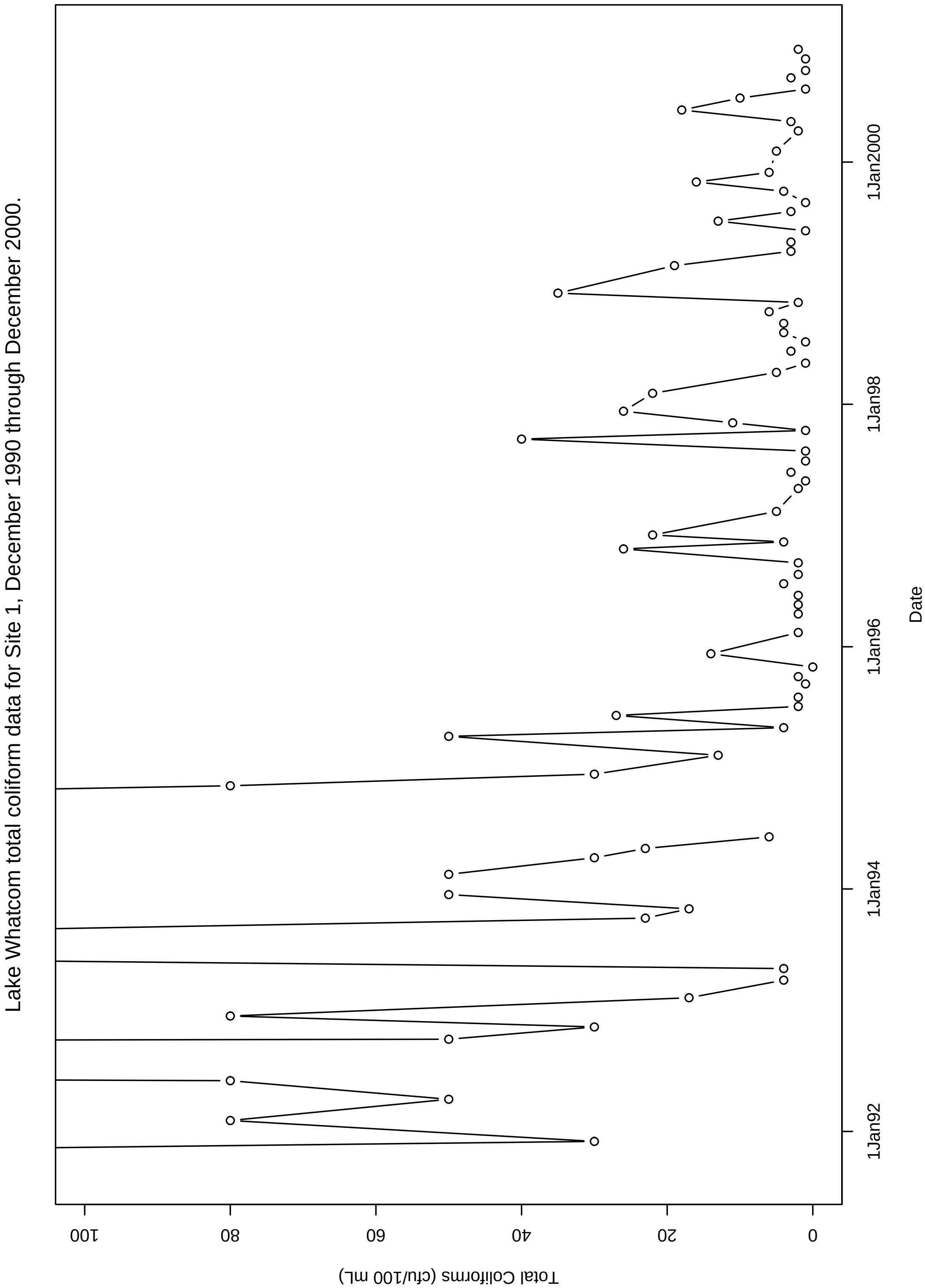


Figure 103: Lake Whatcom total coliform data for Site 1.

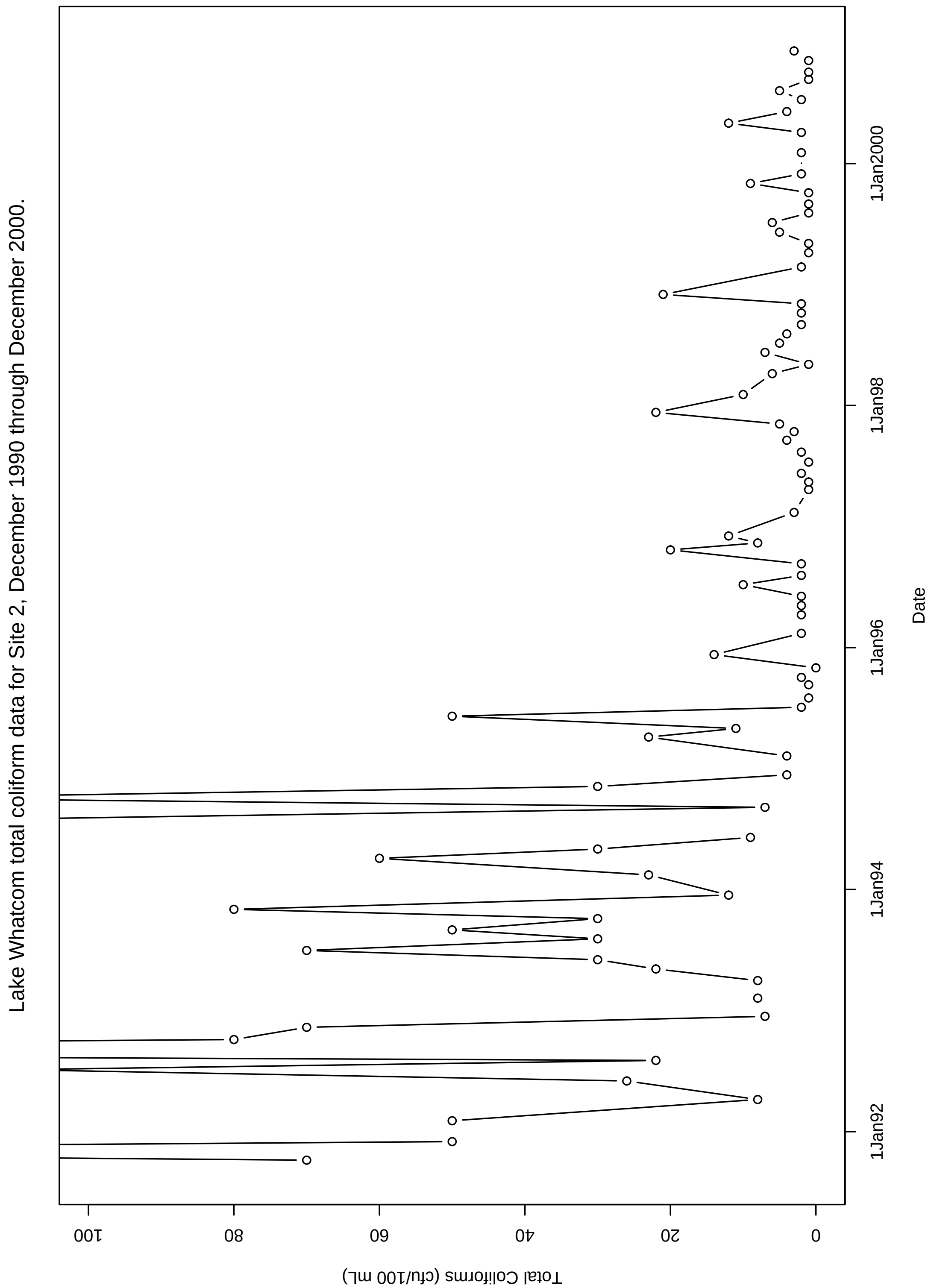


Figure 104: Lake Whatcom total coliform data for Site 2.

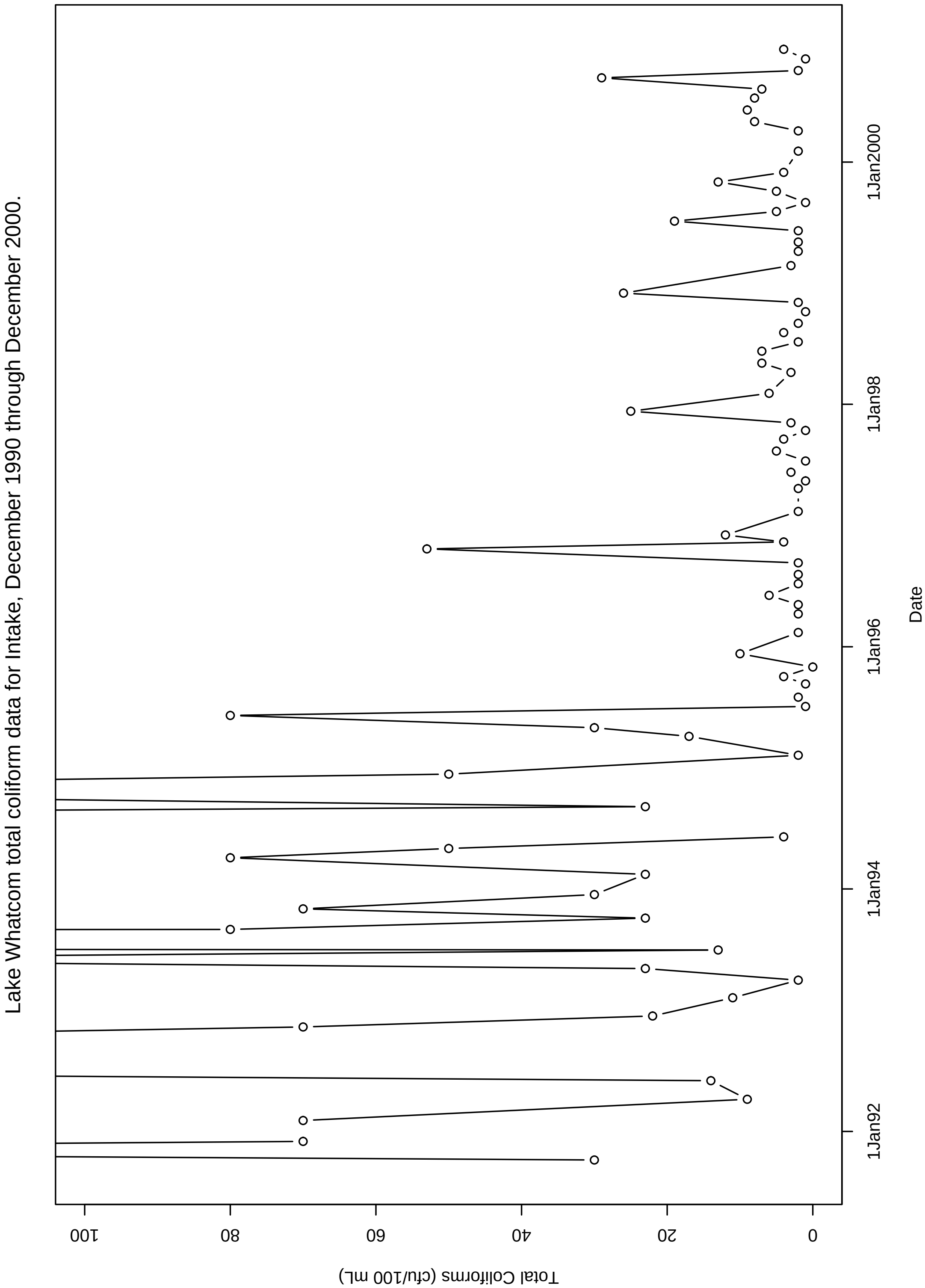


Figure 105: Lake Whatcom total coliform data for the Intake.

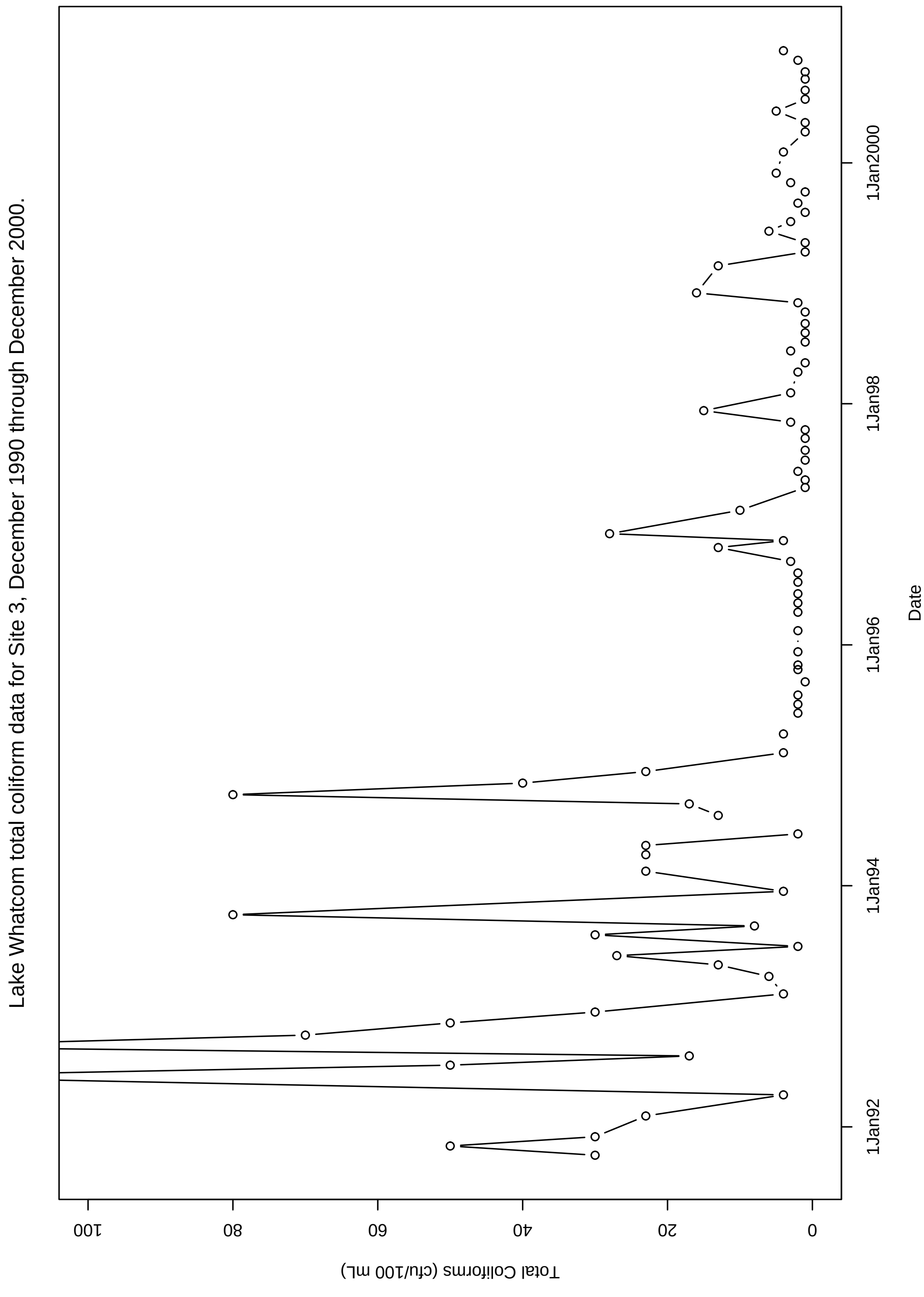


Figure 106: Lake Whatcom total coliform data for Site 3.

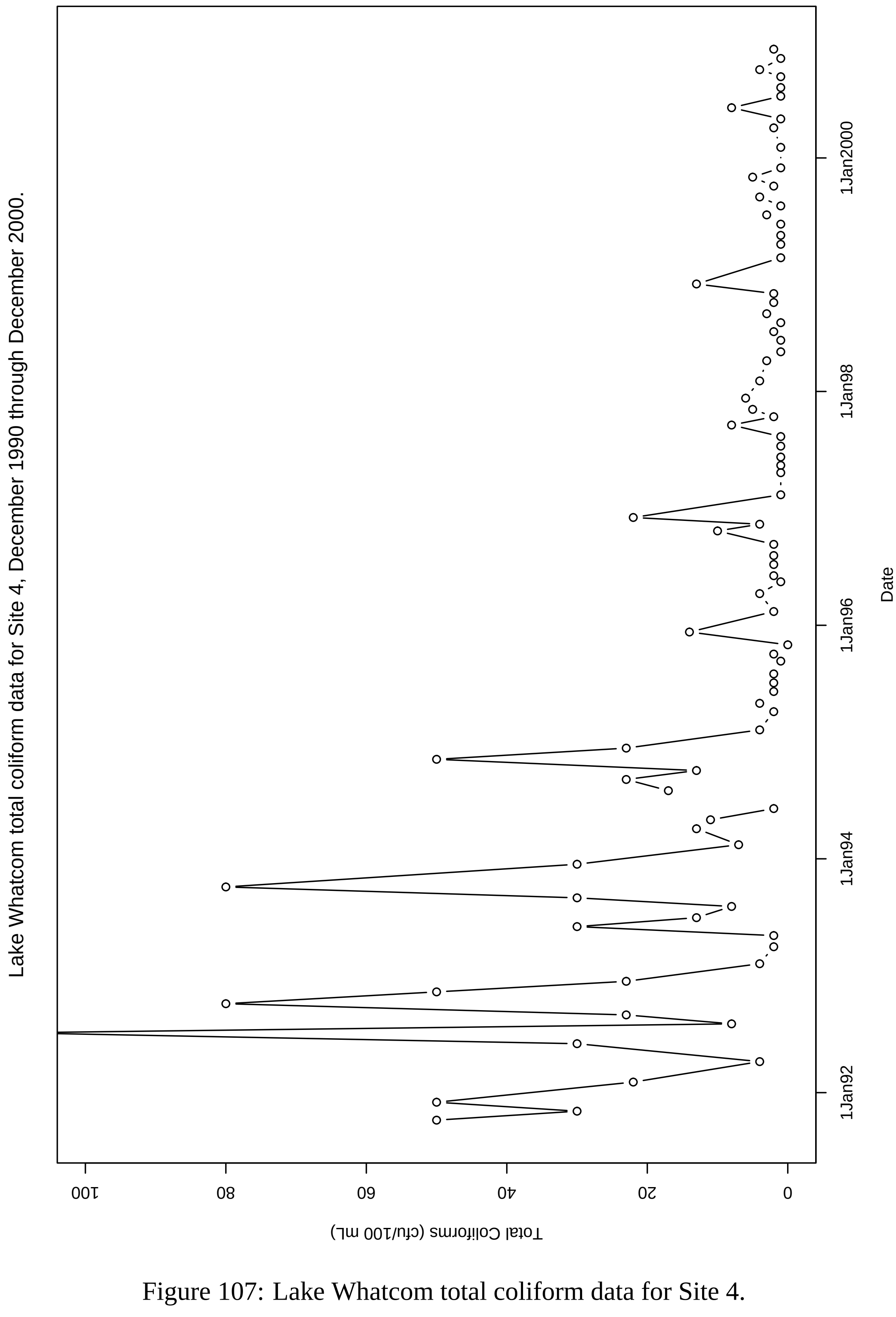


Figure 107: Lake Whatcom total coliform data for Site 4.

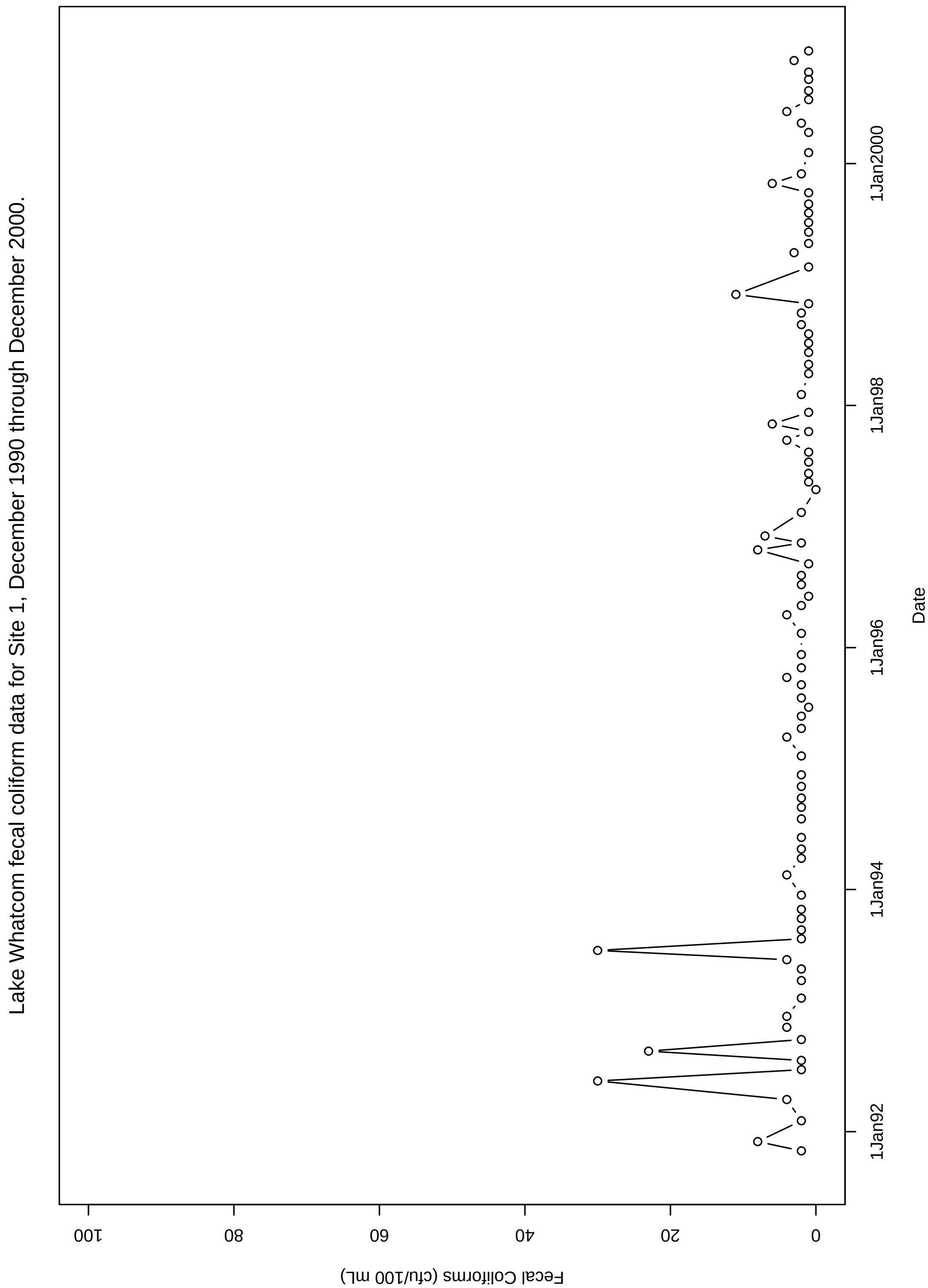


Figure 108: Lake Whatcom fecal coliform data for Site 1.

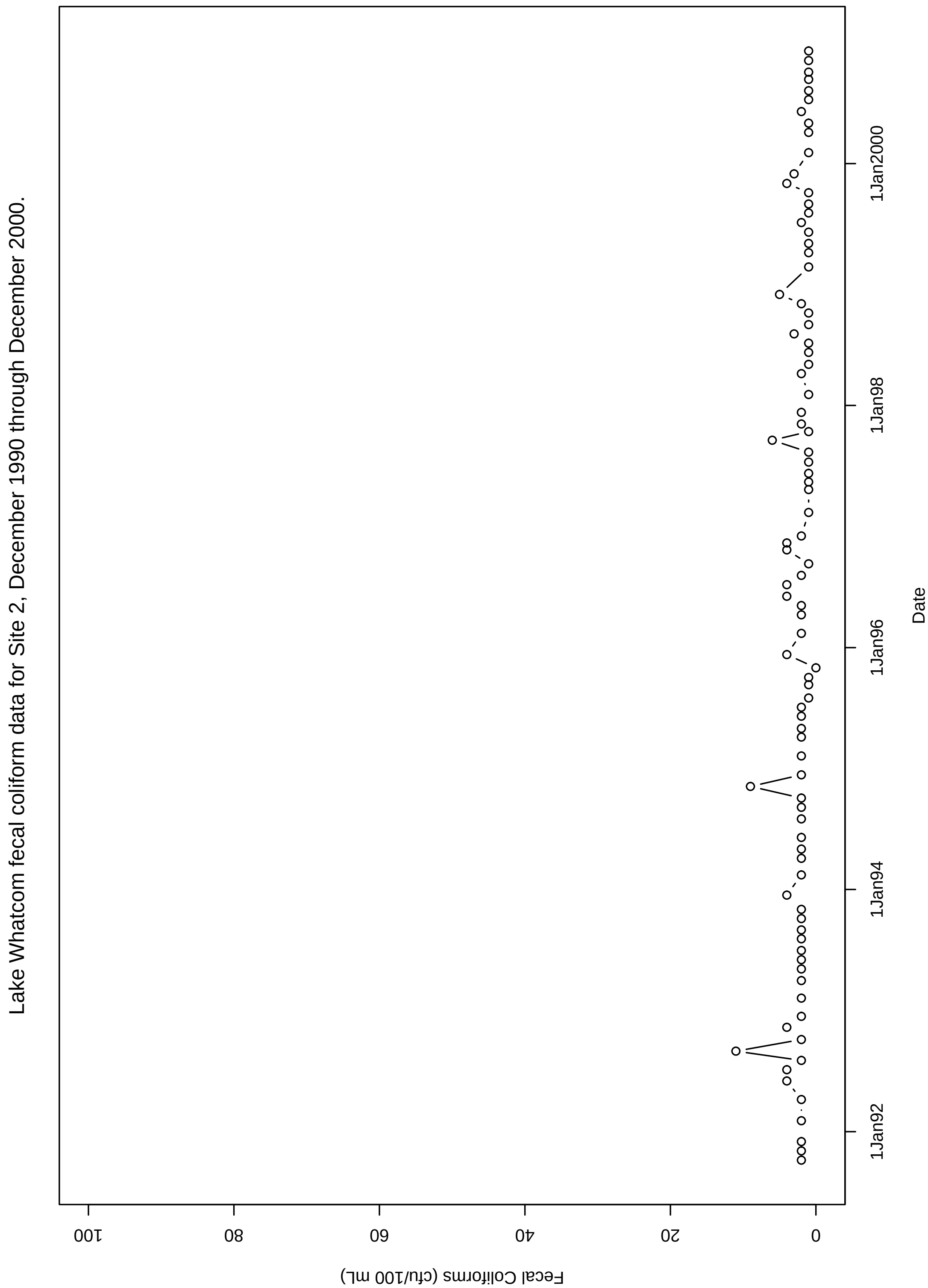


Figure 109: Lake Whatcom fecal coliform data for Site 2.

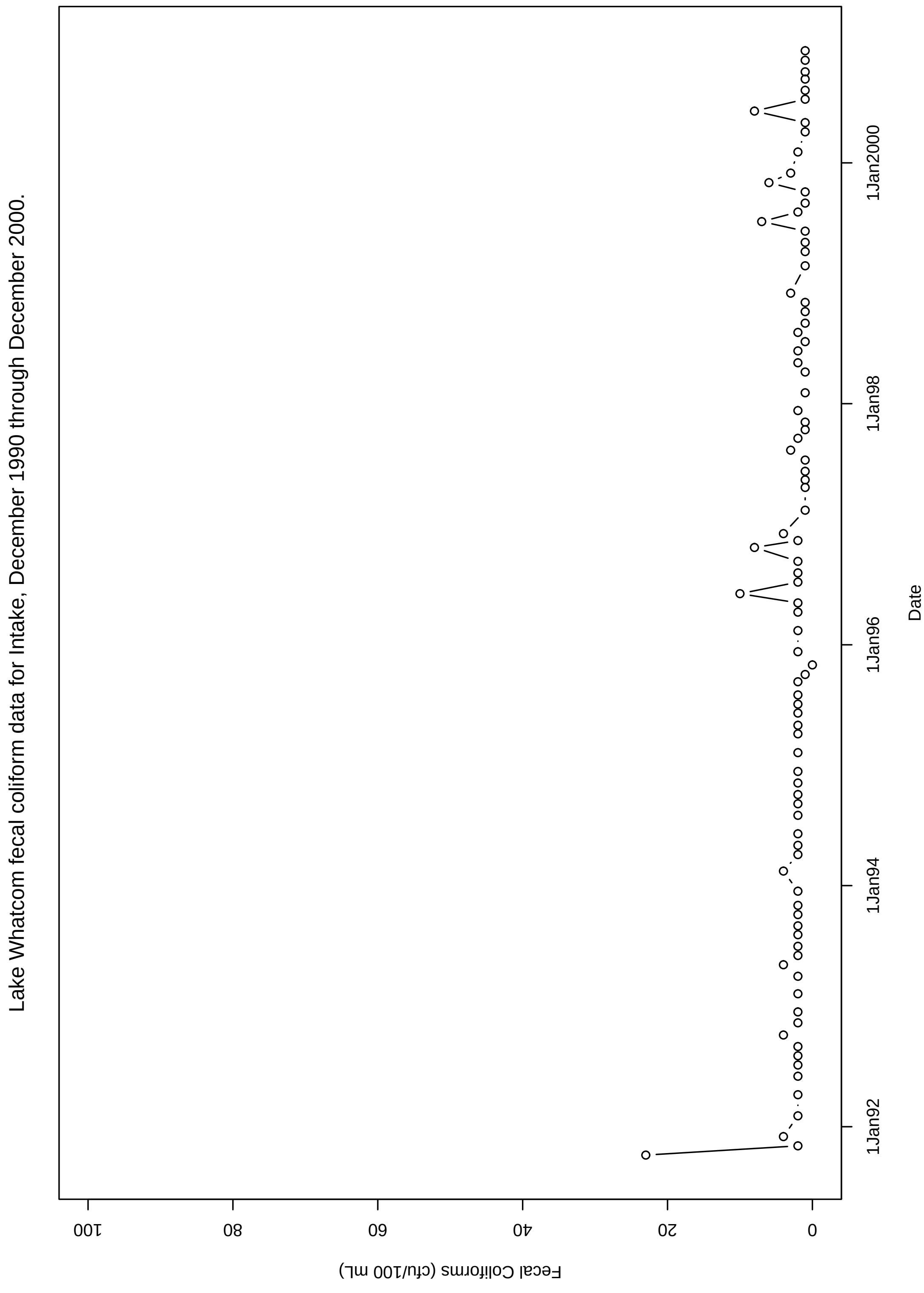


Figure 110: Lake Whatcom fecal coliform data for the Intake.

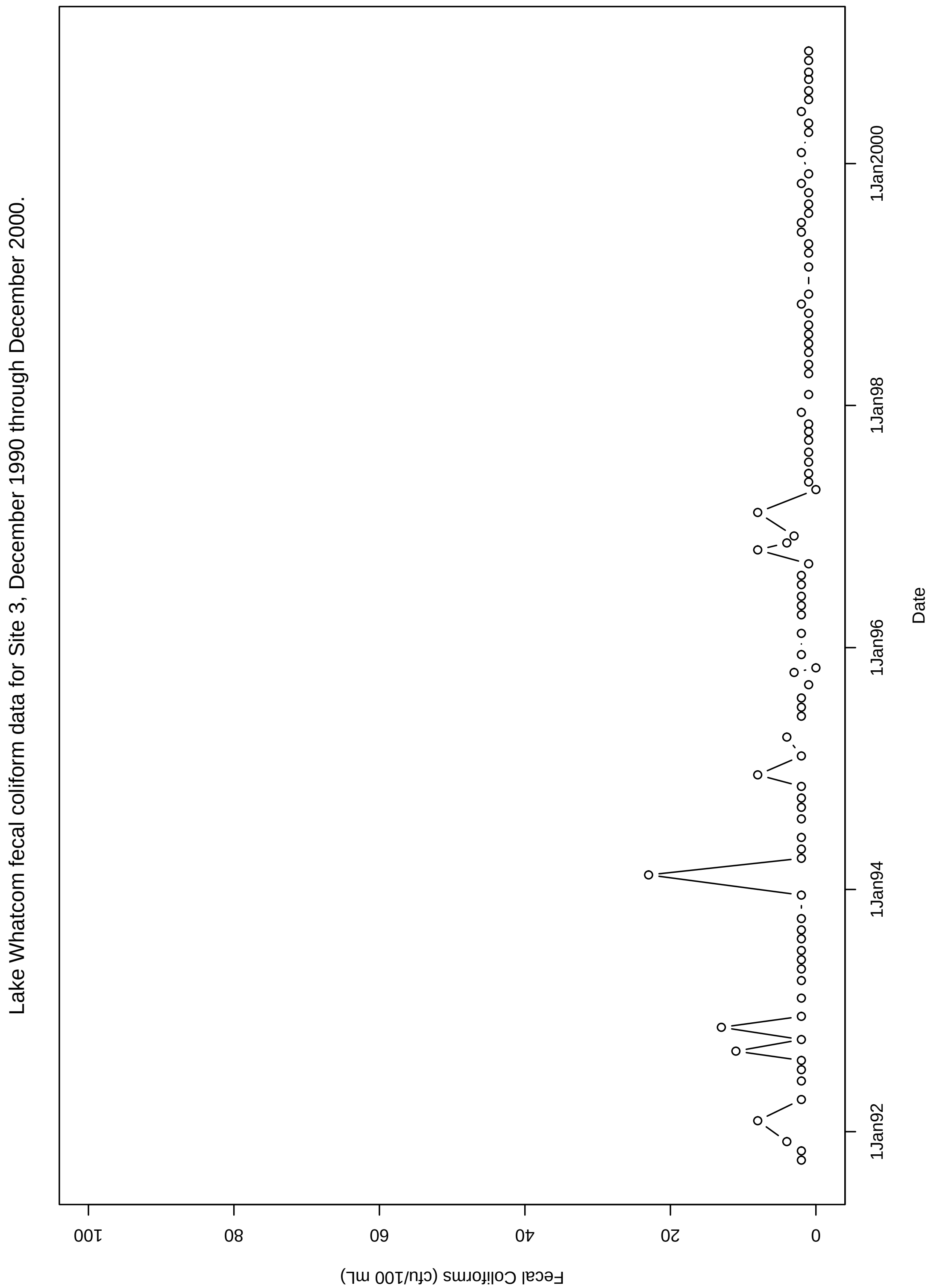


Figure 111: Lake Whatcom fecal coliform data for Site 3.

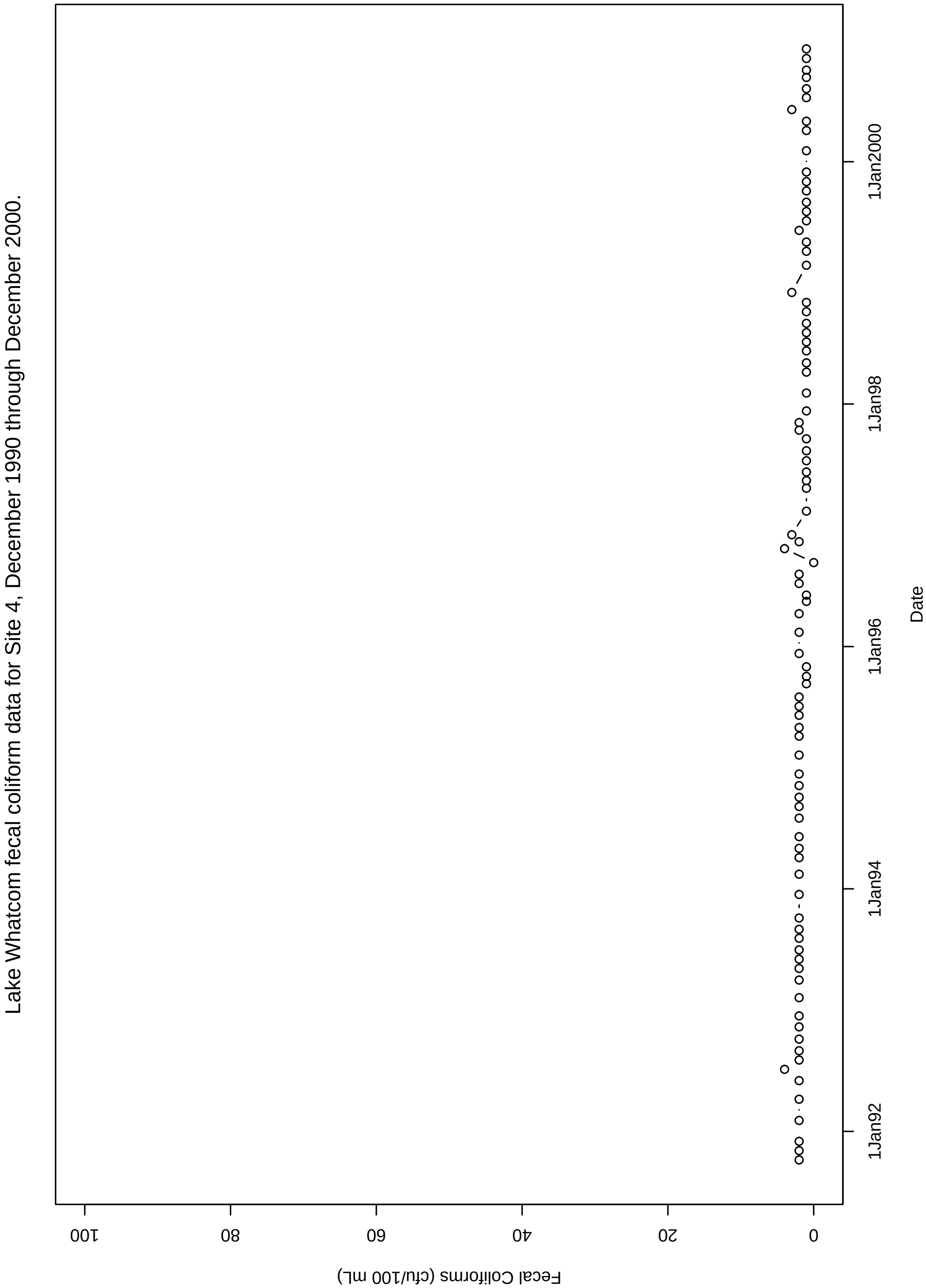


Figure 112: Lake Whatcom fecal coliform data for Site 4.

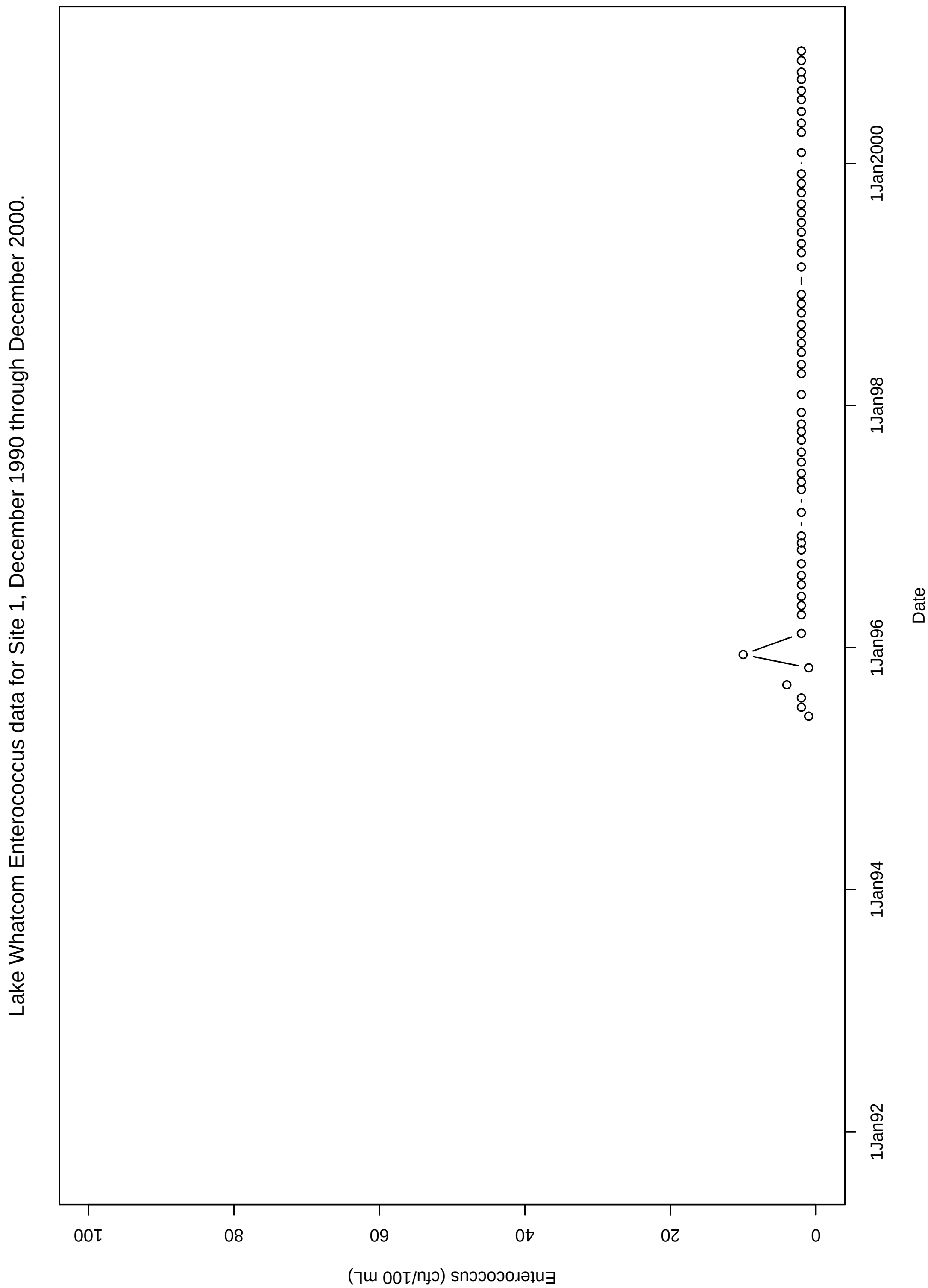


Figure 113: Lake Whatcom *Enterococcus* data for Site 1.

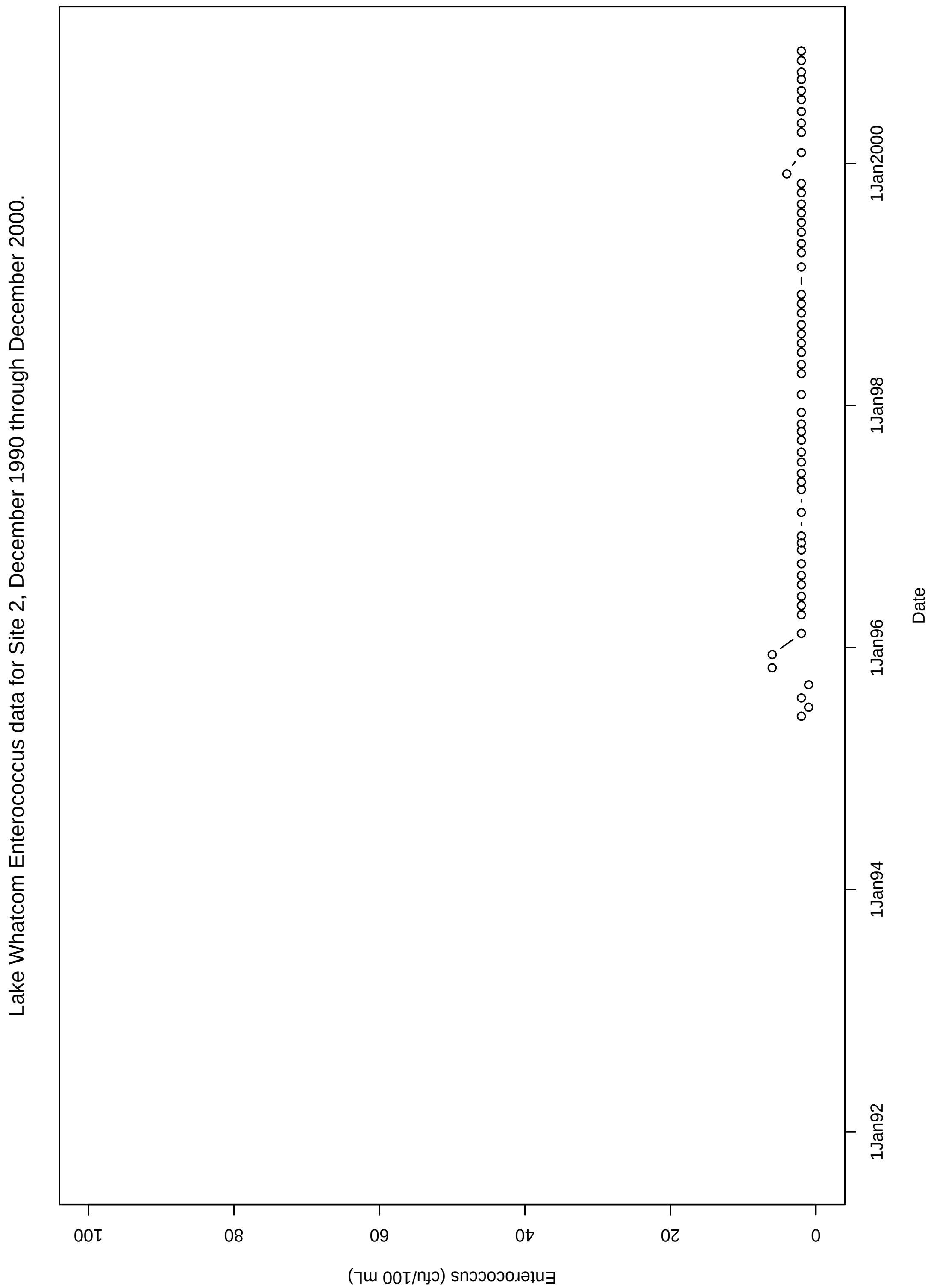


Figure 114: Lake Whatcom *Enterococcus* data for Site 2.

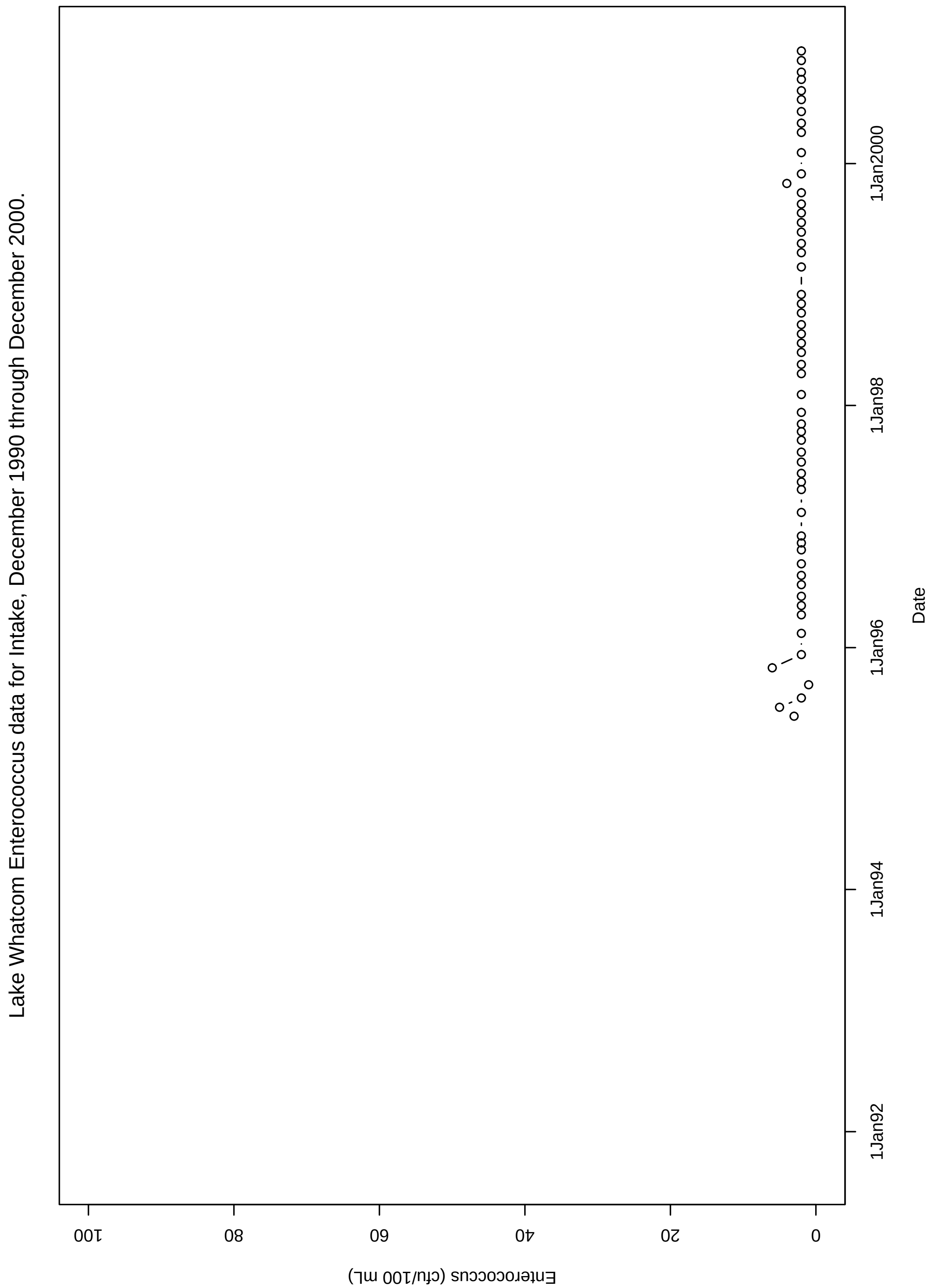


Figure 115: Lake Whatcom *Enterococcus* data for the Intake.

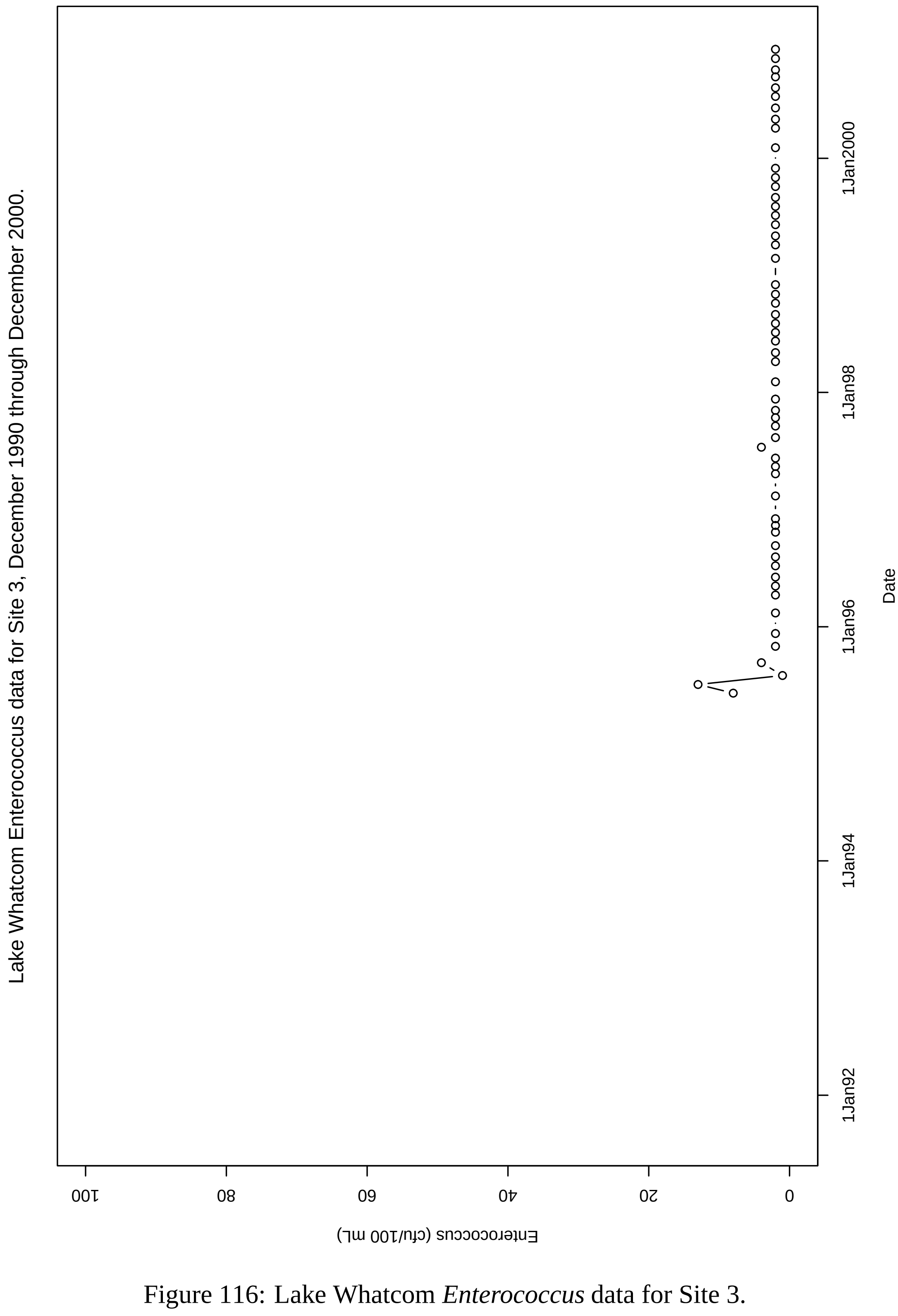


Figure 116: Lake Whatcom *Enterococcus* data for Site 3.

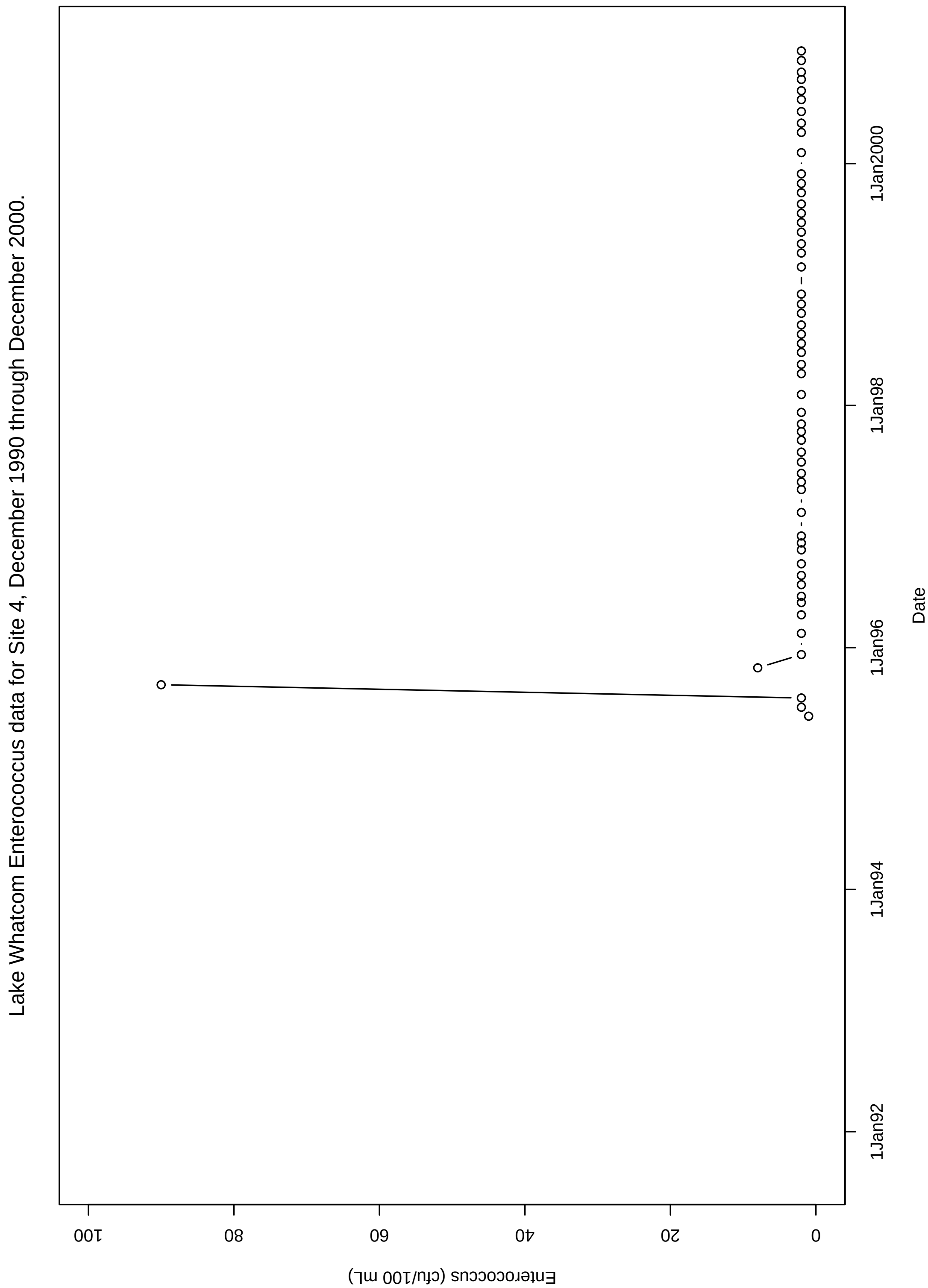


Figure 117: Lake Whatcom *Enterococcus* for Site 4.

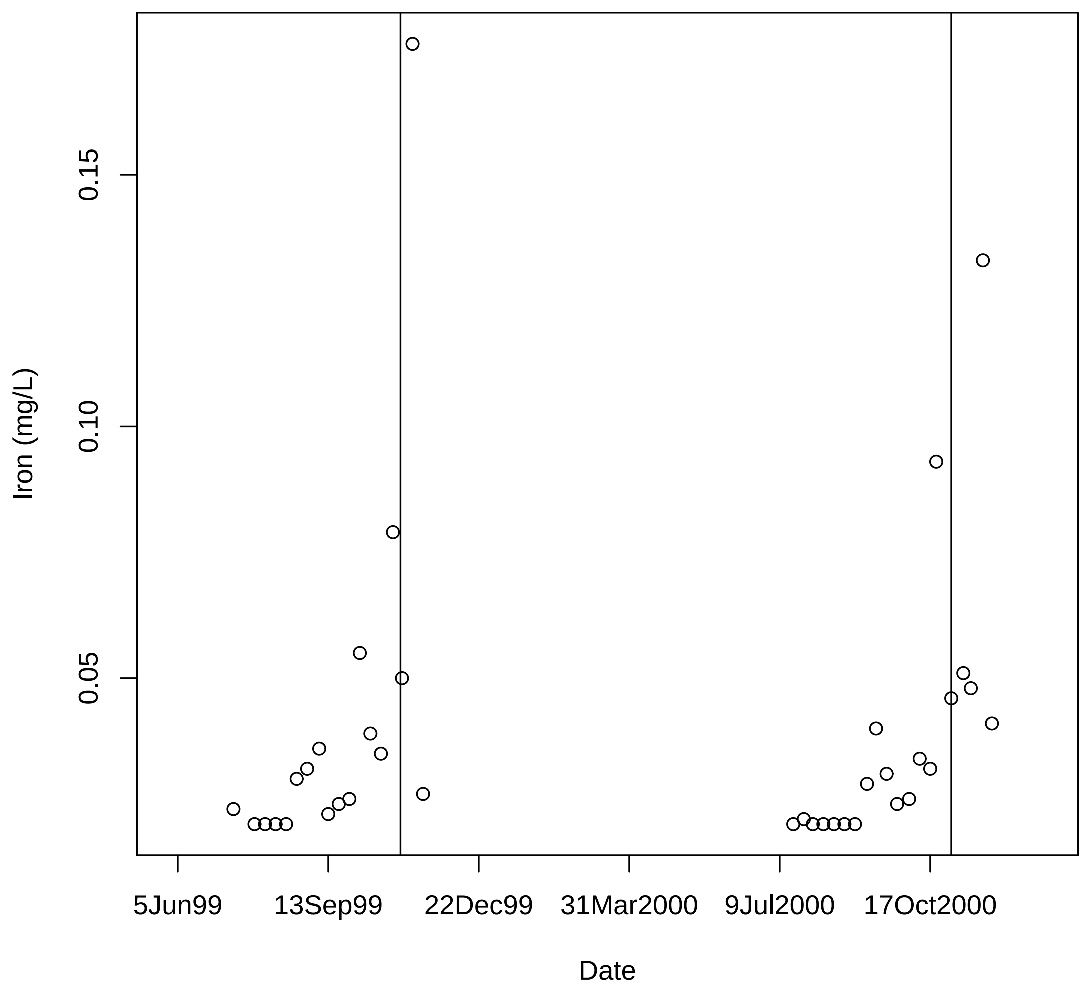


Figure 118: Iron concentrations at the Gatehouse, 1999–2000. Vertical lines mark October 31, 1999 and October 31, 2000, at which time basin 2 had recently destratified.

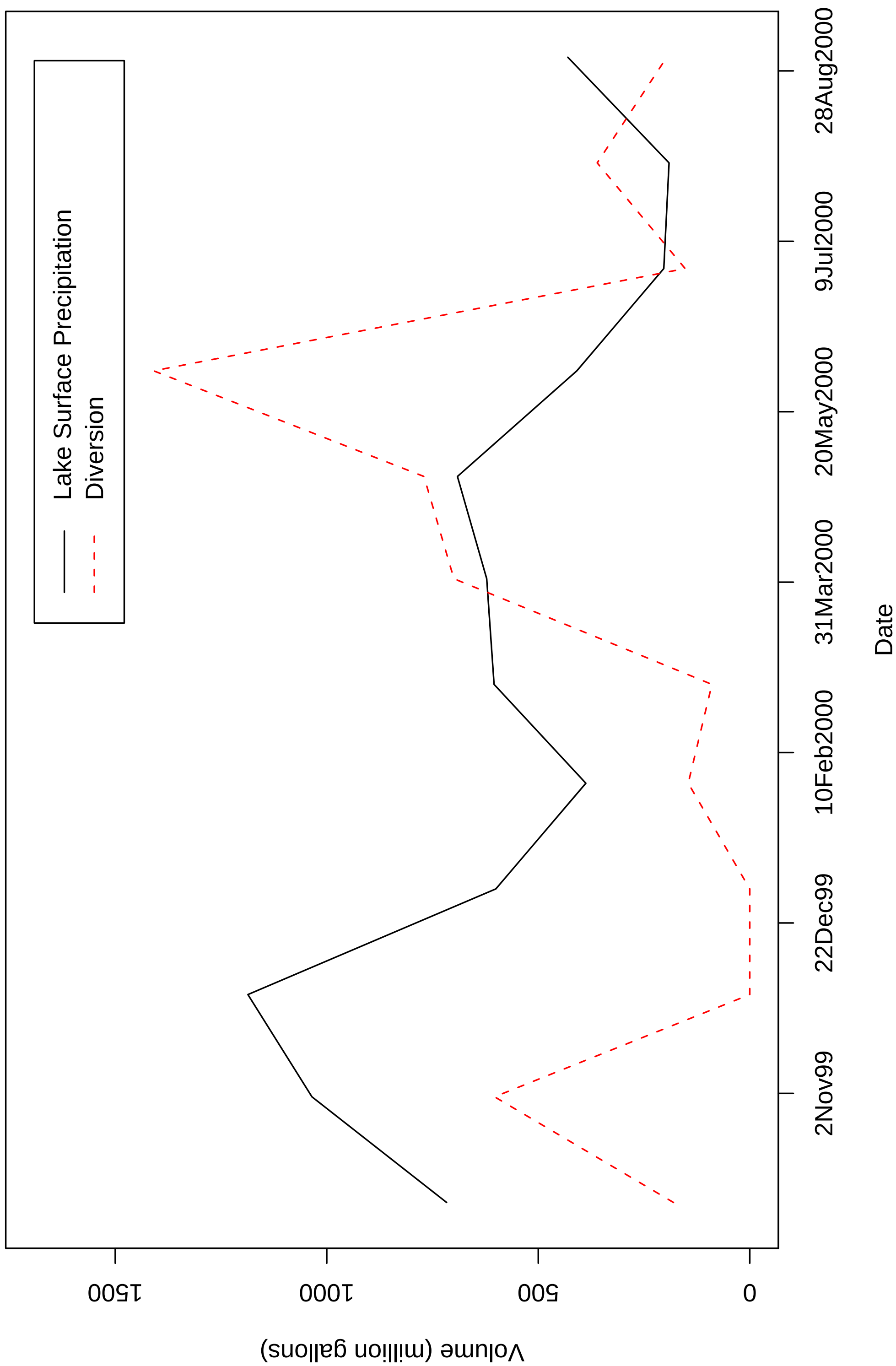


Figure 119: Lake Whatcom watershed direct hydrologic inputs, October 1, 1999–September 30, 2000.

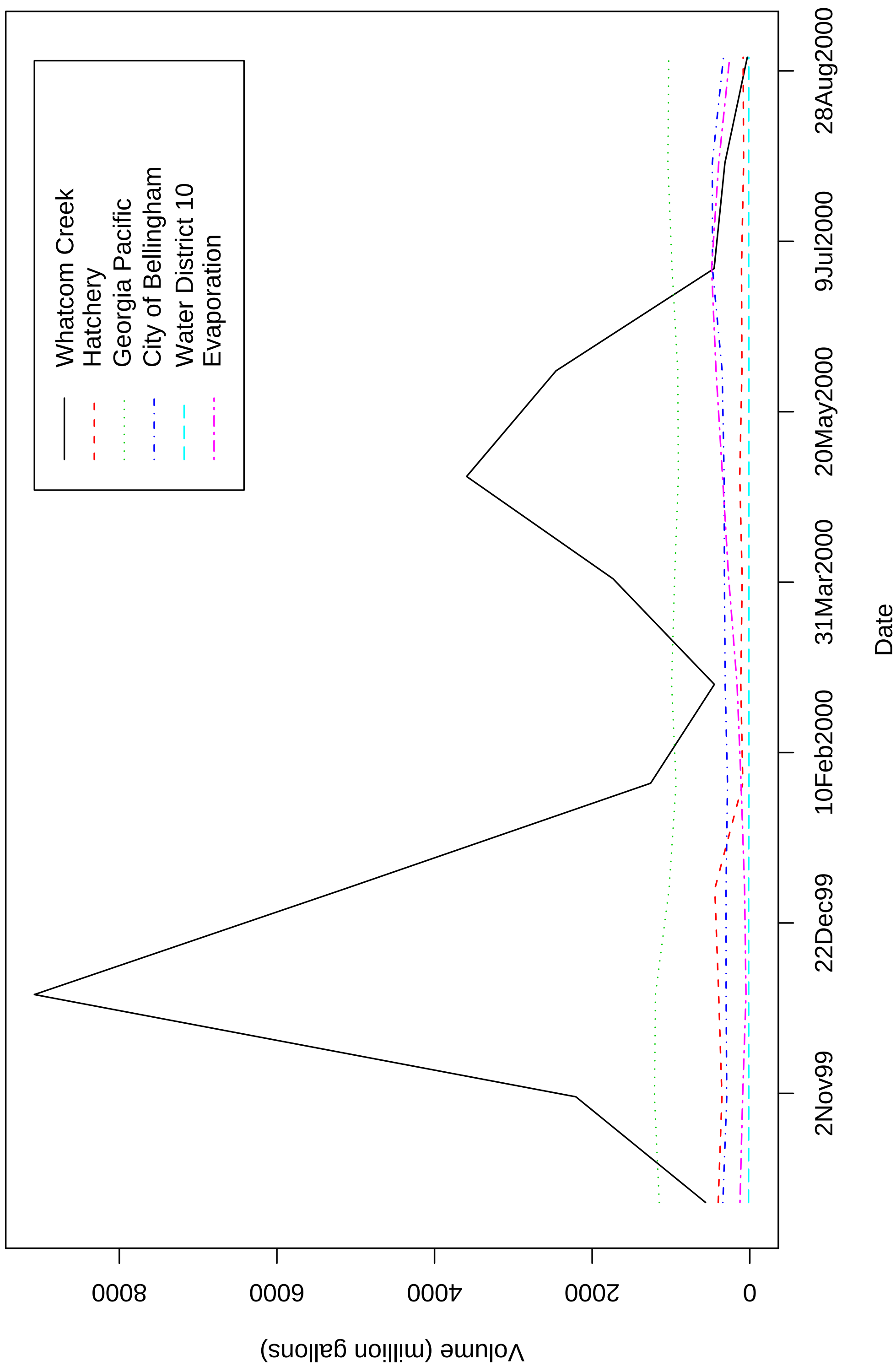


Figure 120: Lake Whatcom watershed hydrologic withdrawals, October 1, 1999–September 30, 2000.

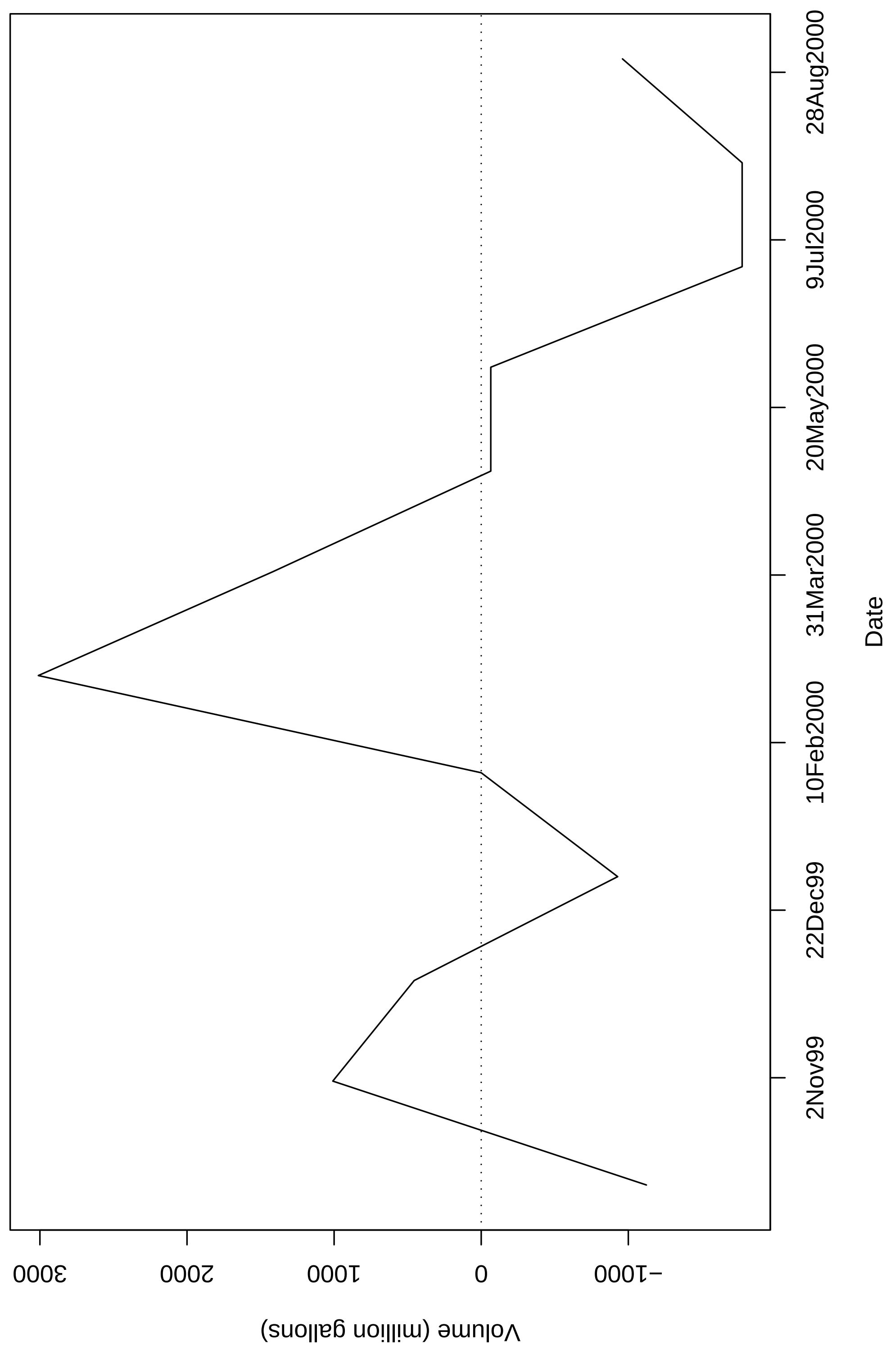


Figure 121: Change in Lake Whatcom storage, October 1, 1999–September 30, 2000.

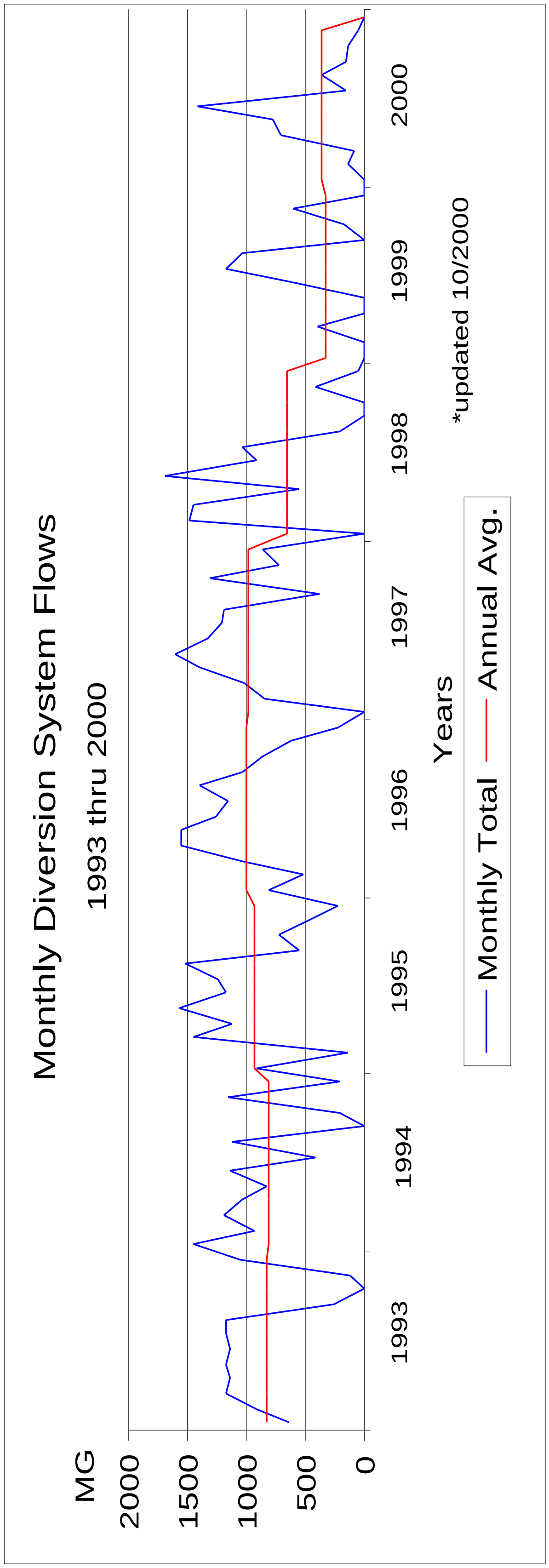


Figure 122: Middle Fork diversion flow into Lake Whatcom, 1993–2000.

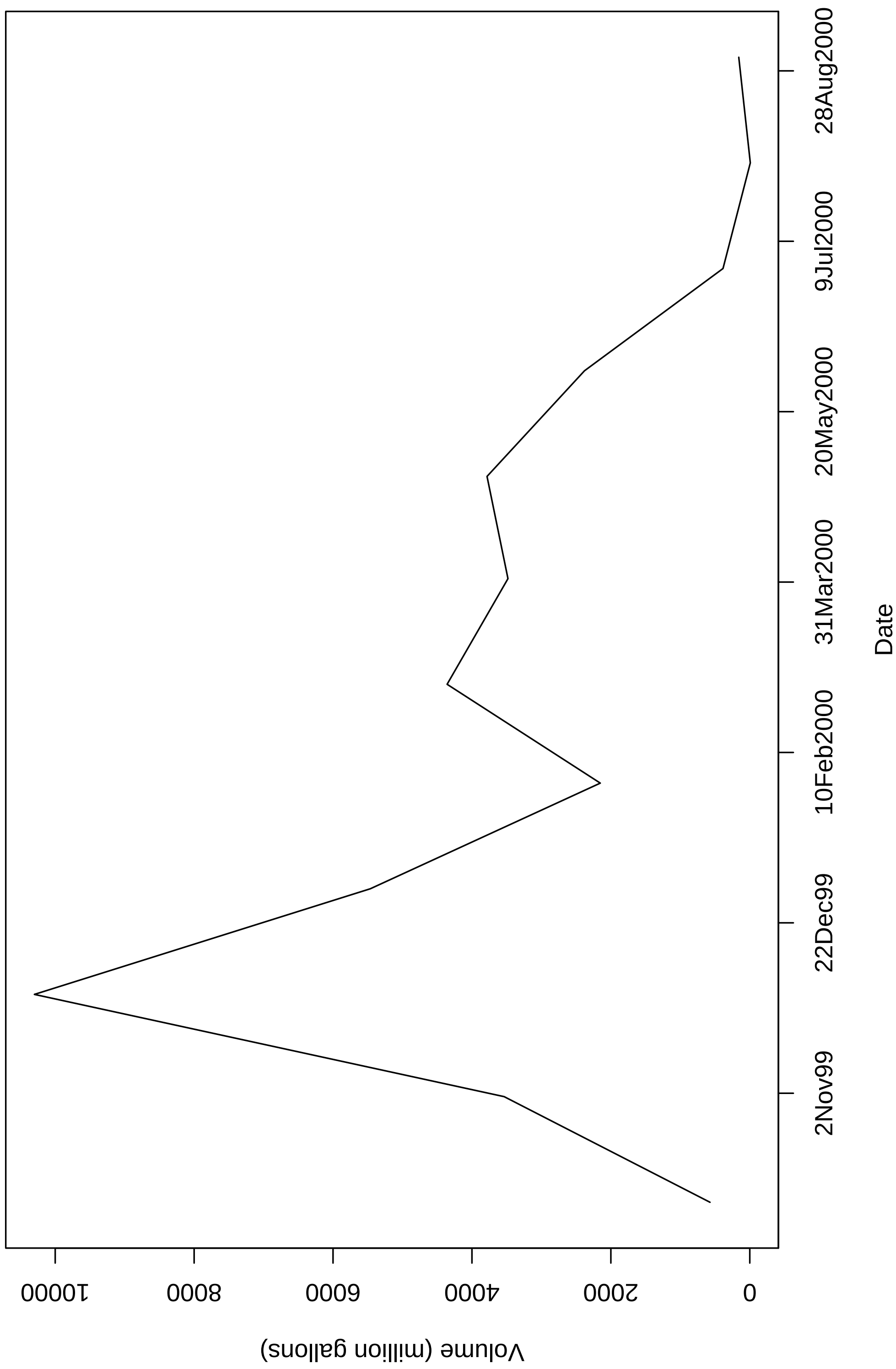


Figure 123: Predicted Lake Whatcom watershed runoff, October 1, 1999–September 30, 2000.

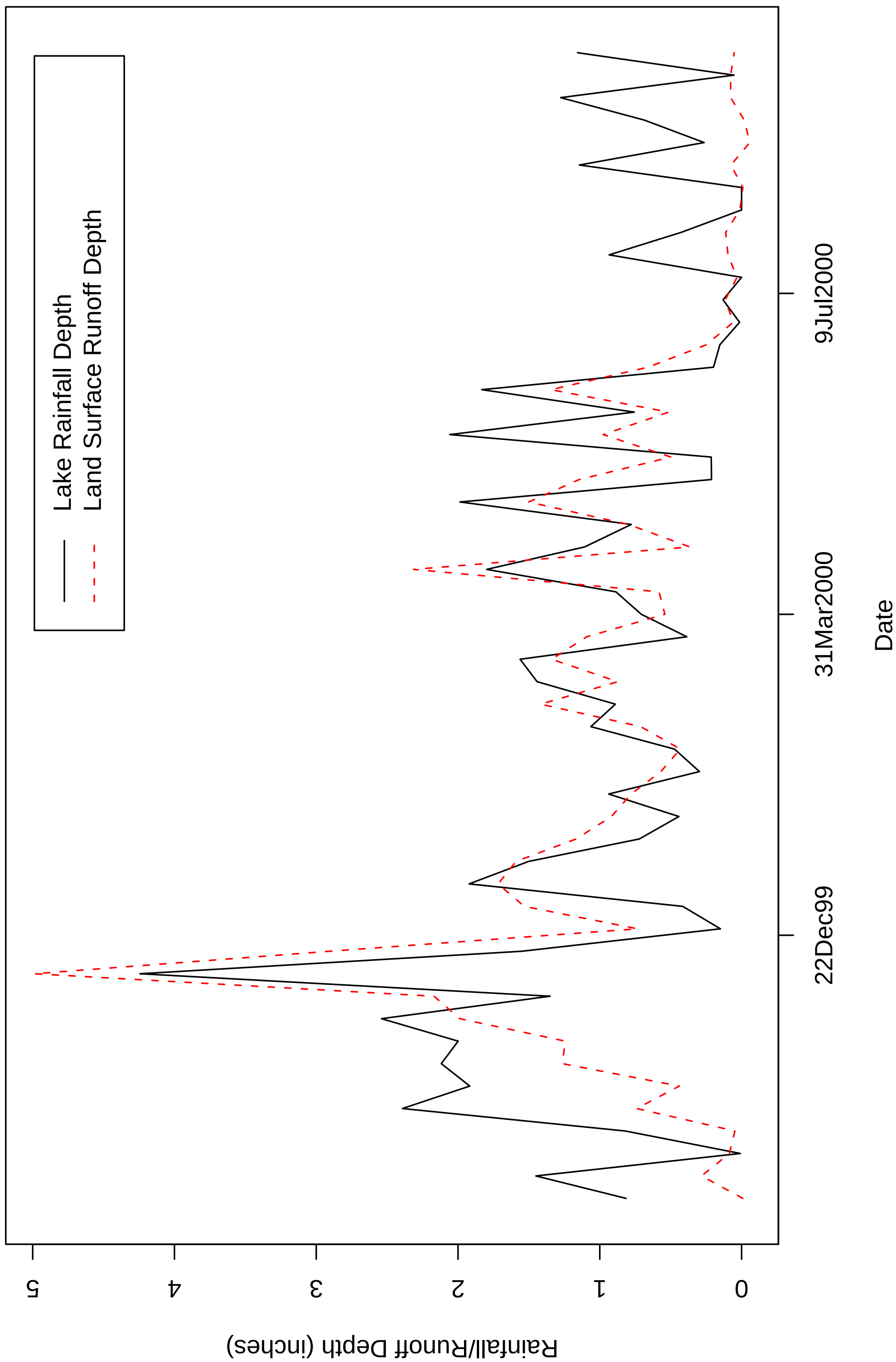


Figure 124: Predicted Lake Whatcom watershed runoff compared to measured rainfall depth, October 1, 1999–September 30, 2000.

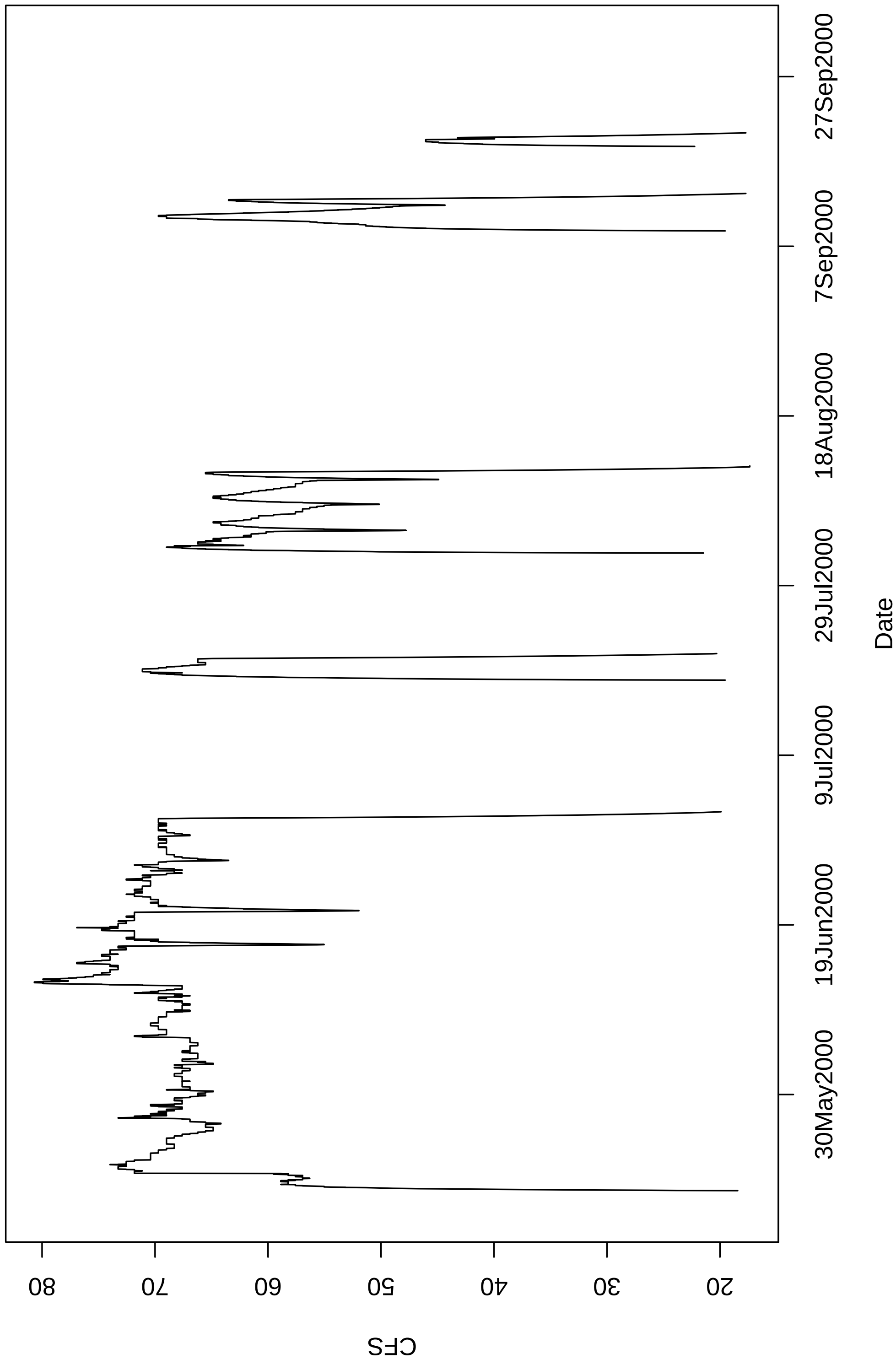


Figure 125: Anderson Creek hydrograph, October 1, 1999–September 30, 2000.

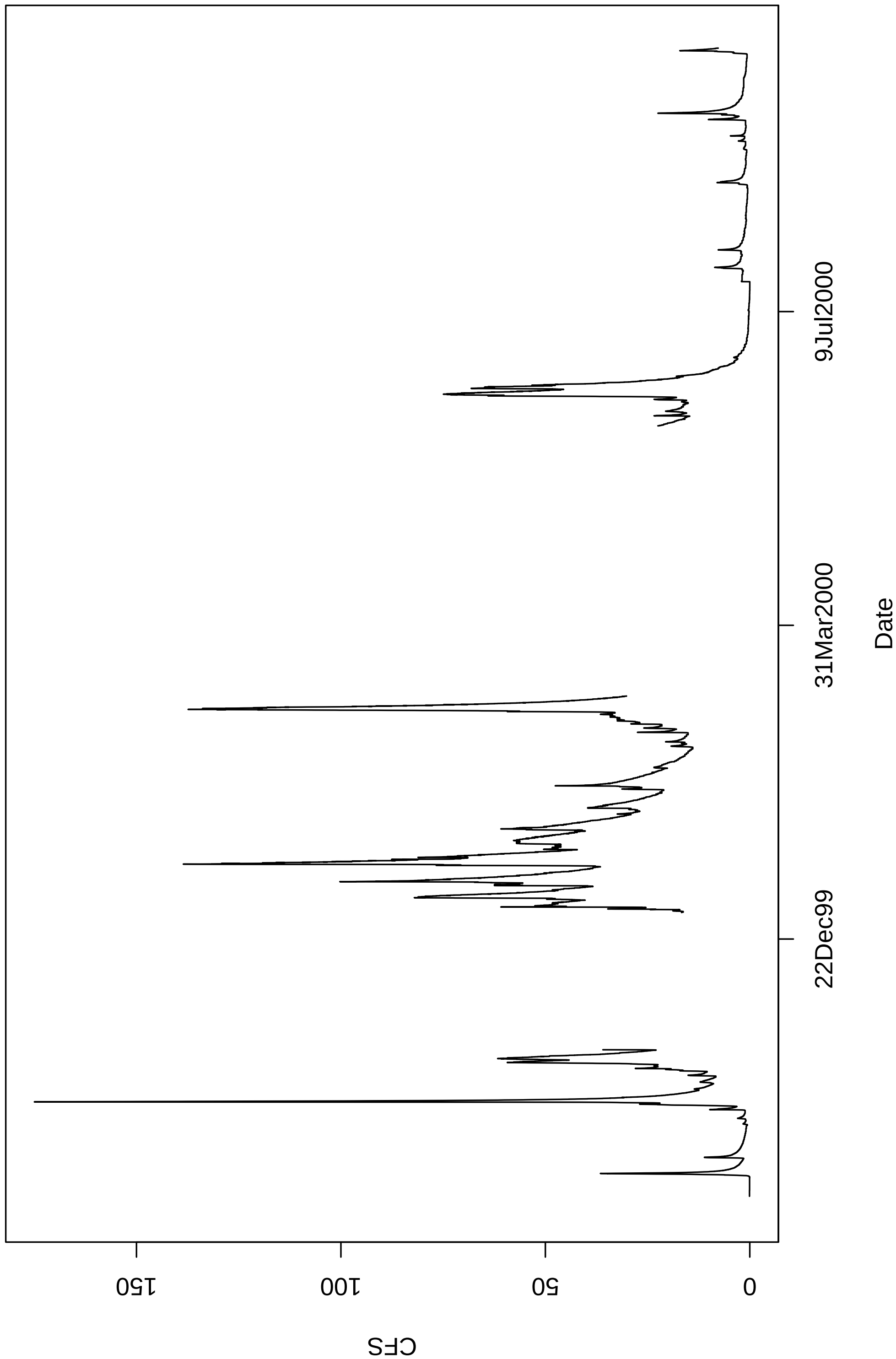


Figure 126: Austin Creek hydrograph, October 1, 1999–September 30, 2000.

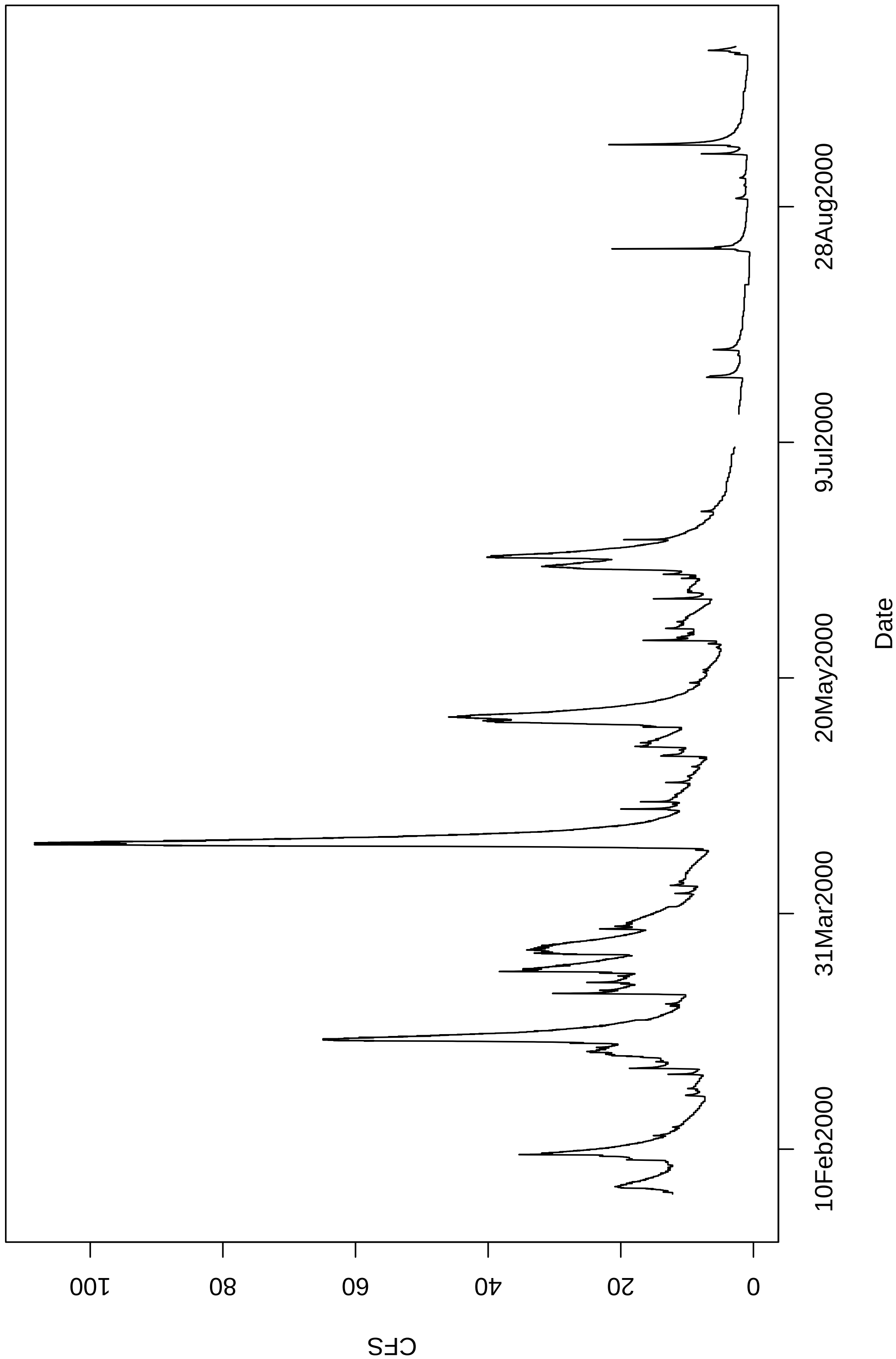


Figure 127: Smith Creek hydrograph, October 1, 1999–September 30, 2000.

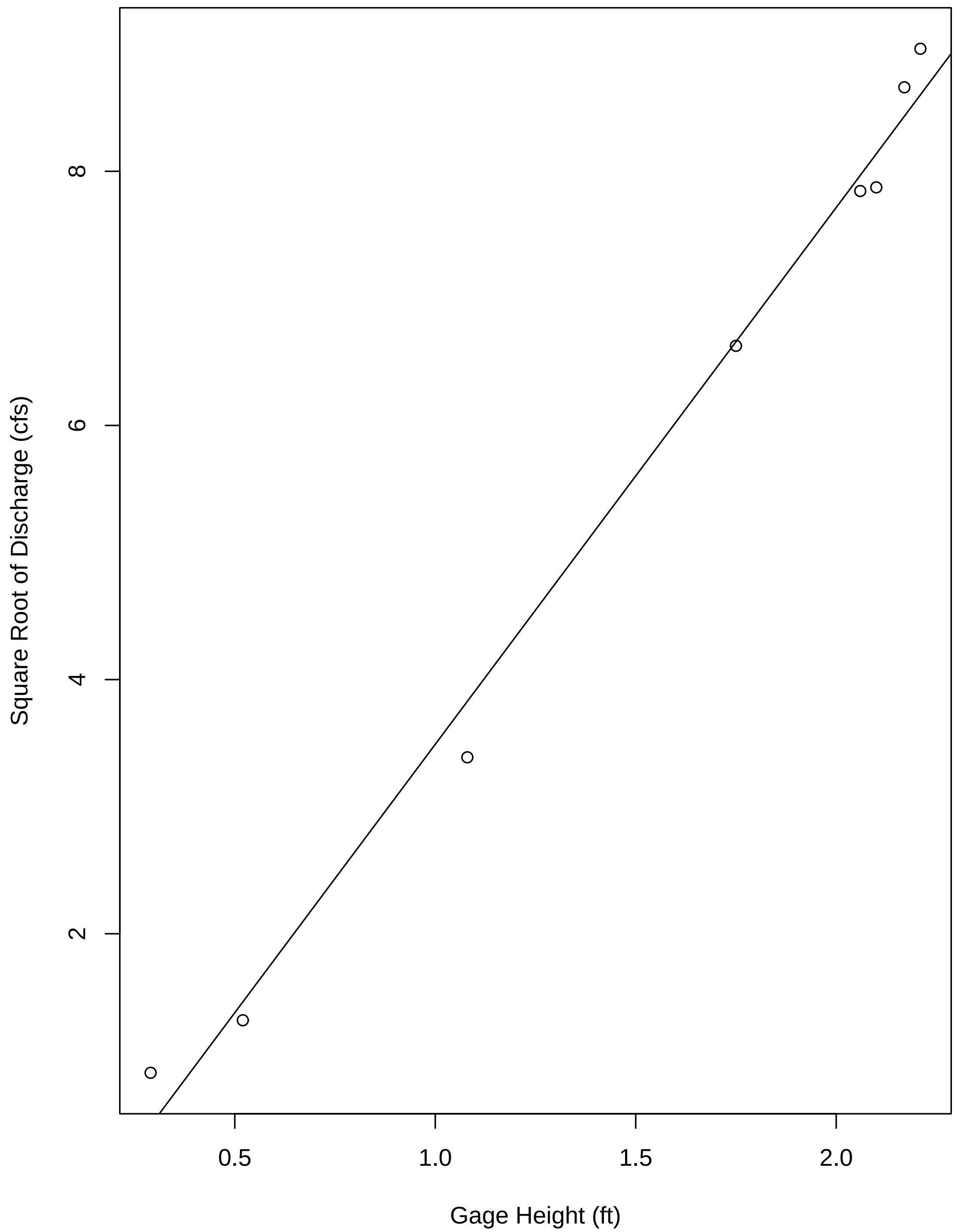


Figure 128: Anderson Creek rating curve, October 1, 1999–September 30, 2000.

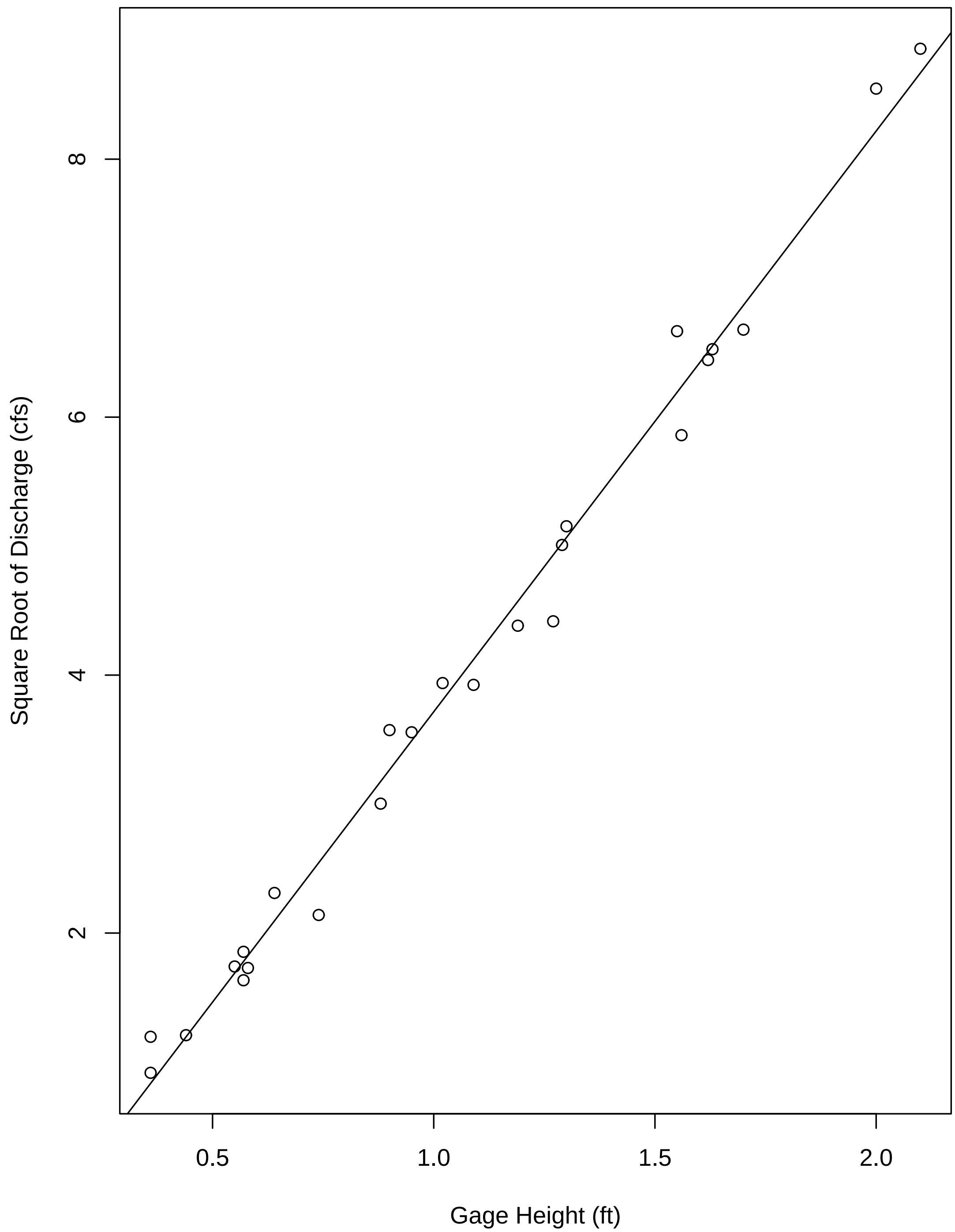


Figure 129: Austin Creek rating curve, October 1, 1999–September 30, 2000.

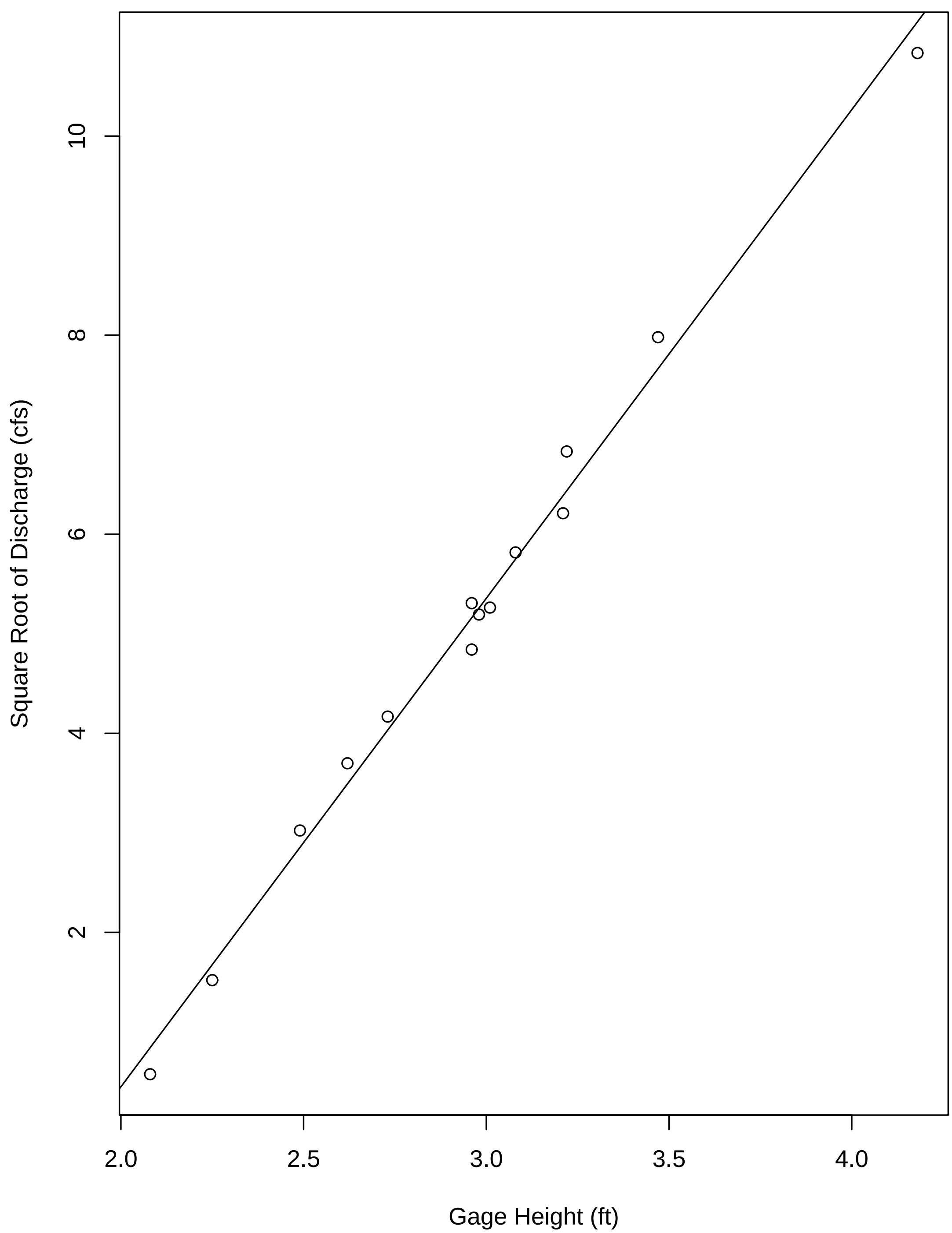


Figure 130: Smith Creek rating curve, October 1, 1999–September 30, 2000.

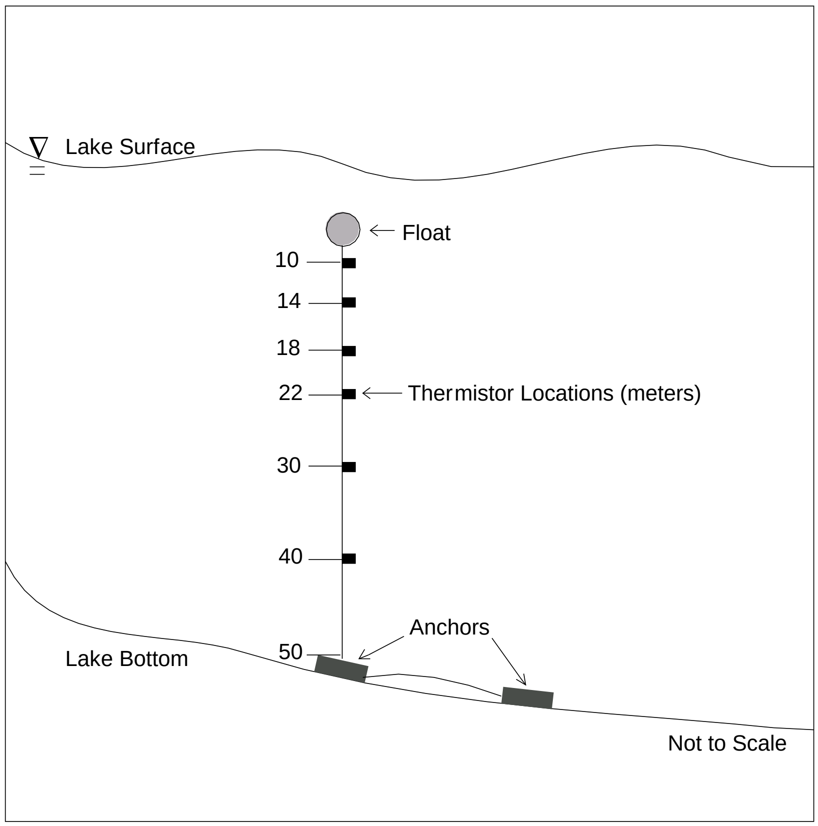


Figure 131: Diagram of the temperature sensor array.

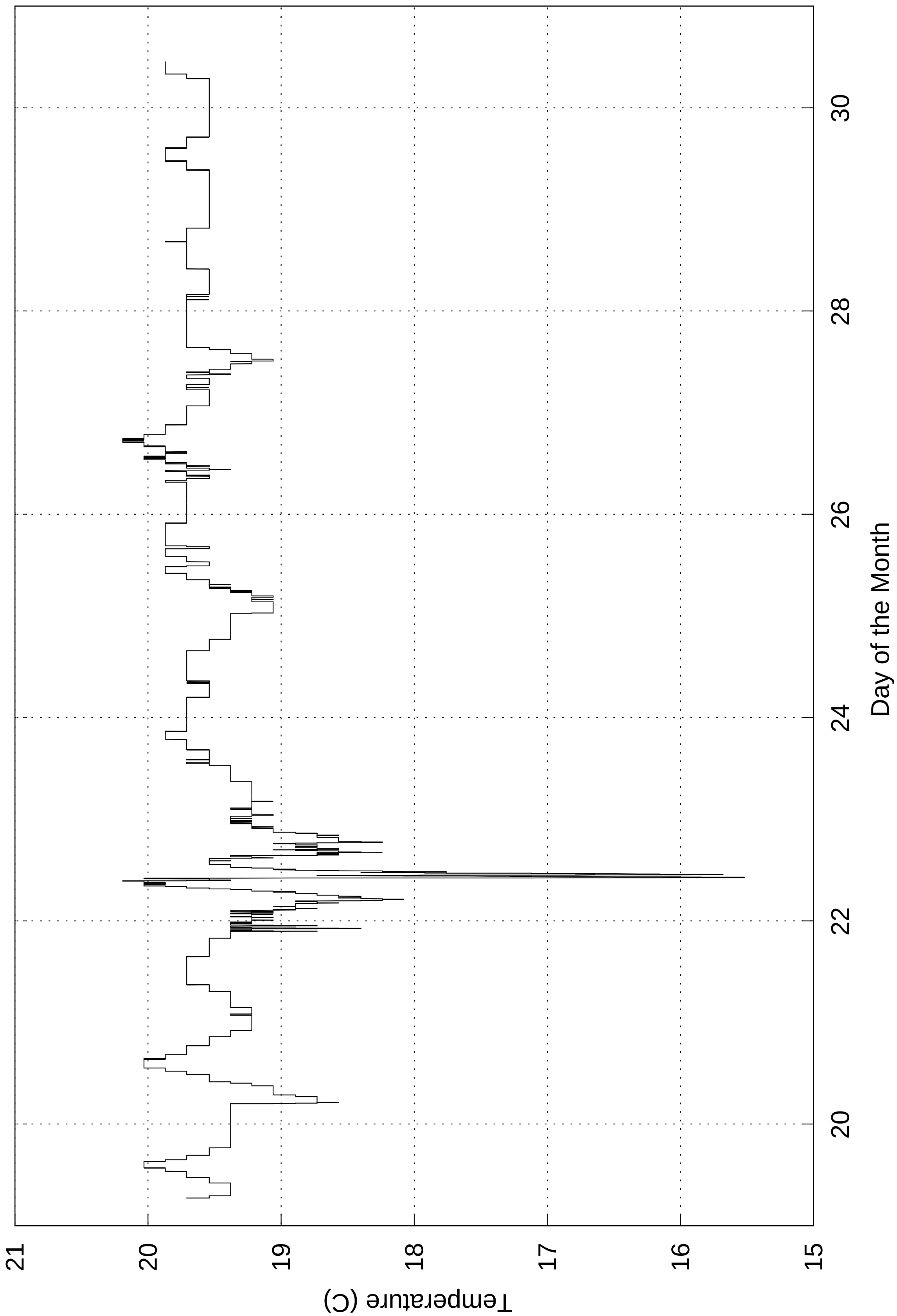


Figure 132: Geneva sill water temperature measurements at 4.5 m, July 19–30, 2000.

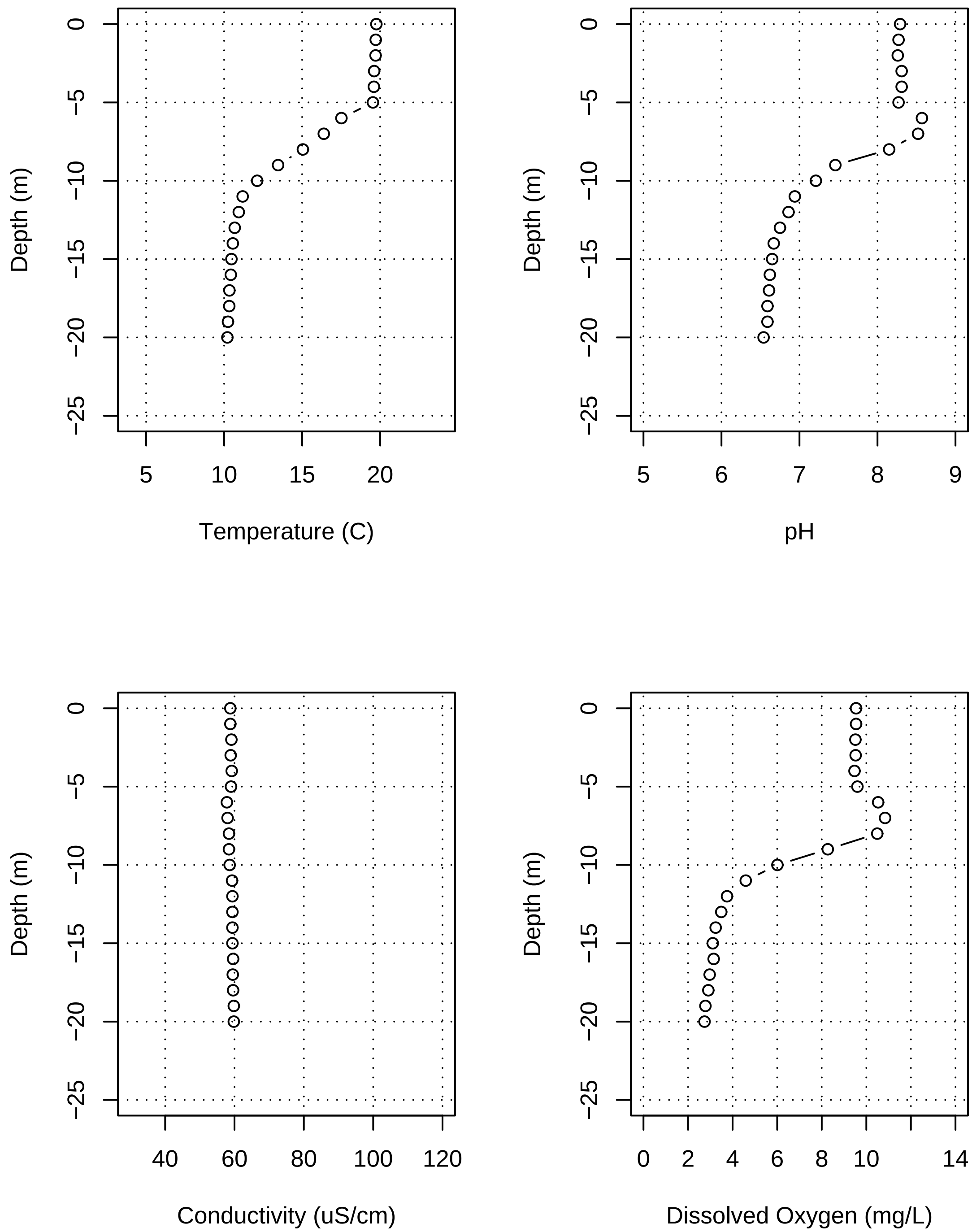


Figure 133: Lake Whatcom Hydrolab profile for Site 1, July 13, 2000.

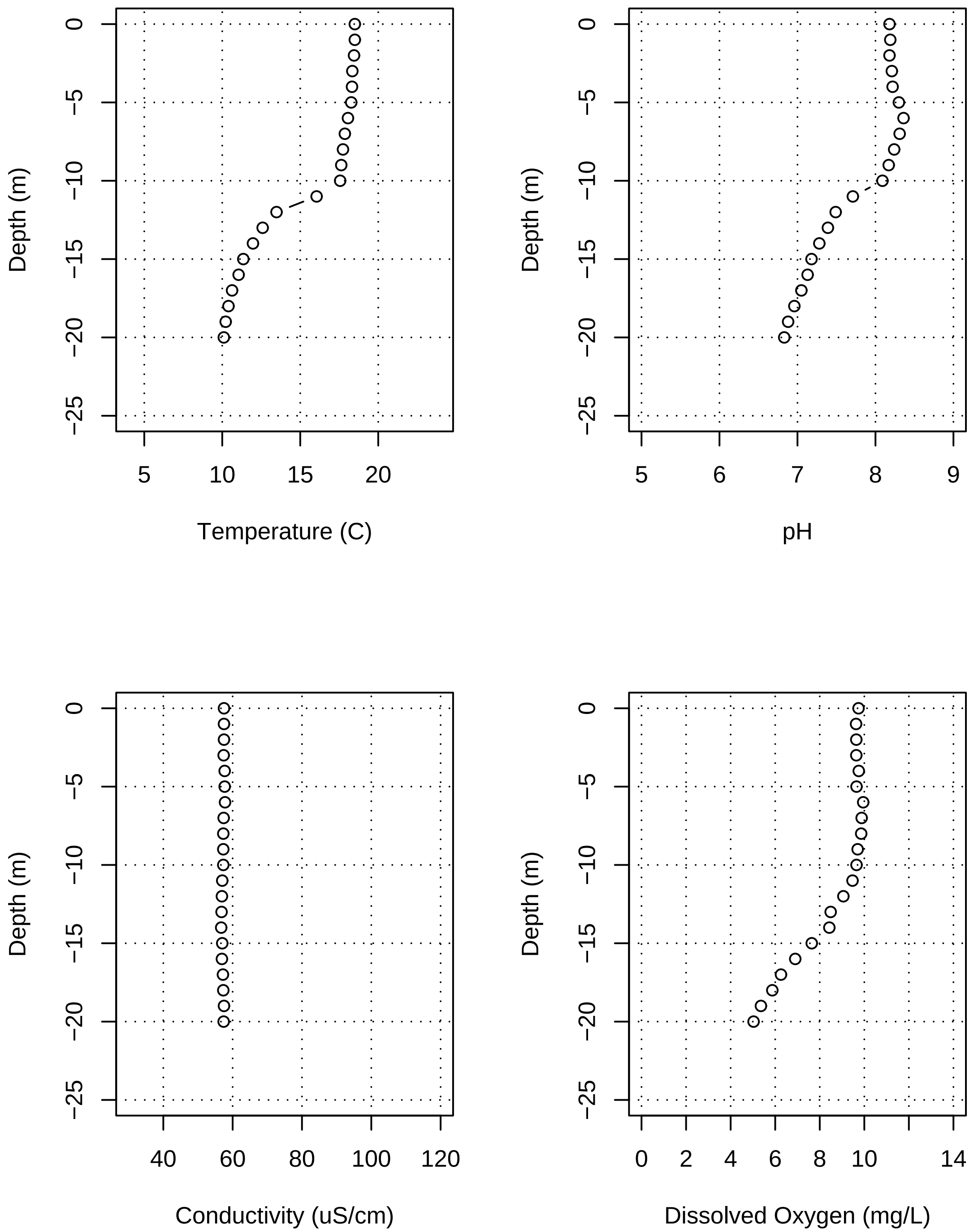


Figure 134: Lake Whatcom Hydrolab profile for Site 2, July 13, 2000.

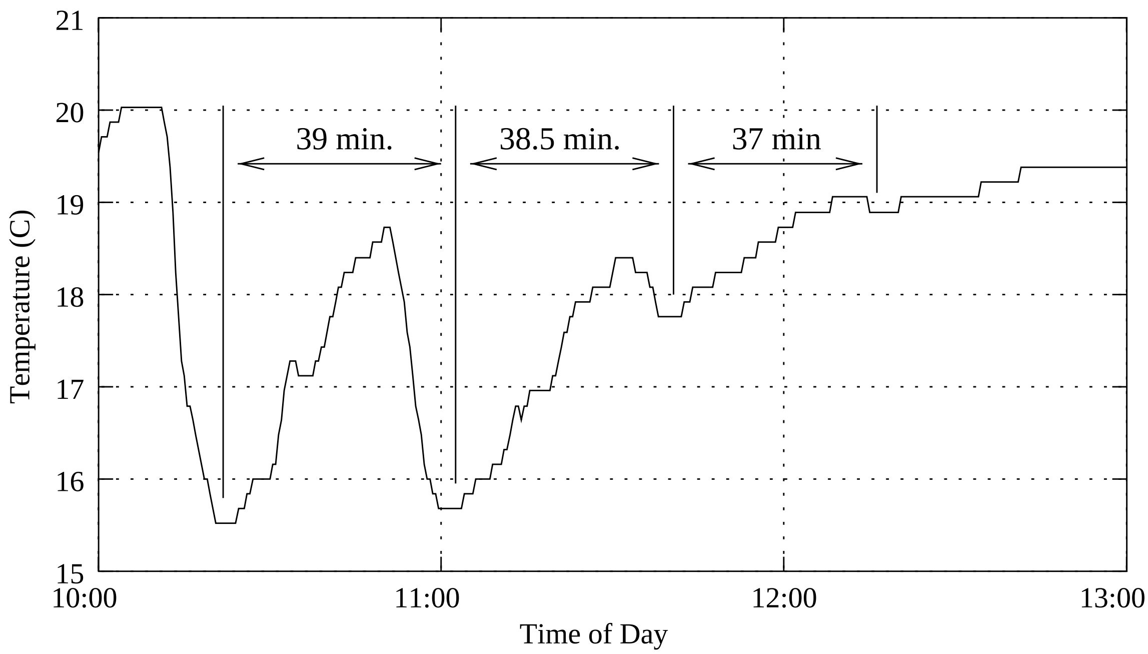


Figure 135: Geneva sill water temperature measurements at 4.5 m; expanded scale for July 22, 2000 showing periodicity of internal wave.

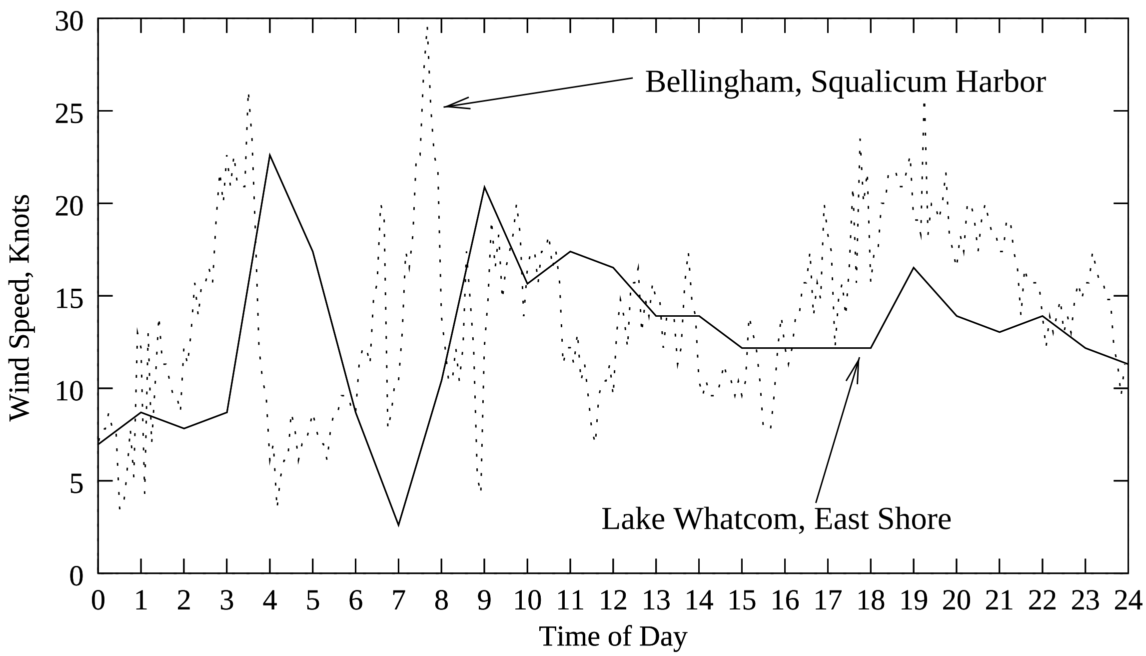


Figure 136: Wind speed records from Squalicum Harbor and the east shore of Lake Whatcom, July 22, 2000.

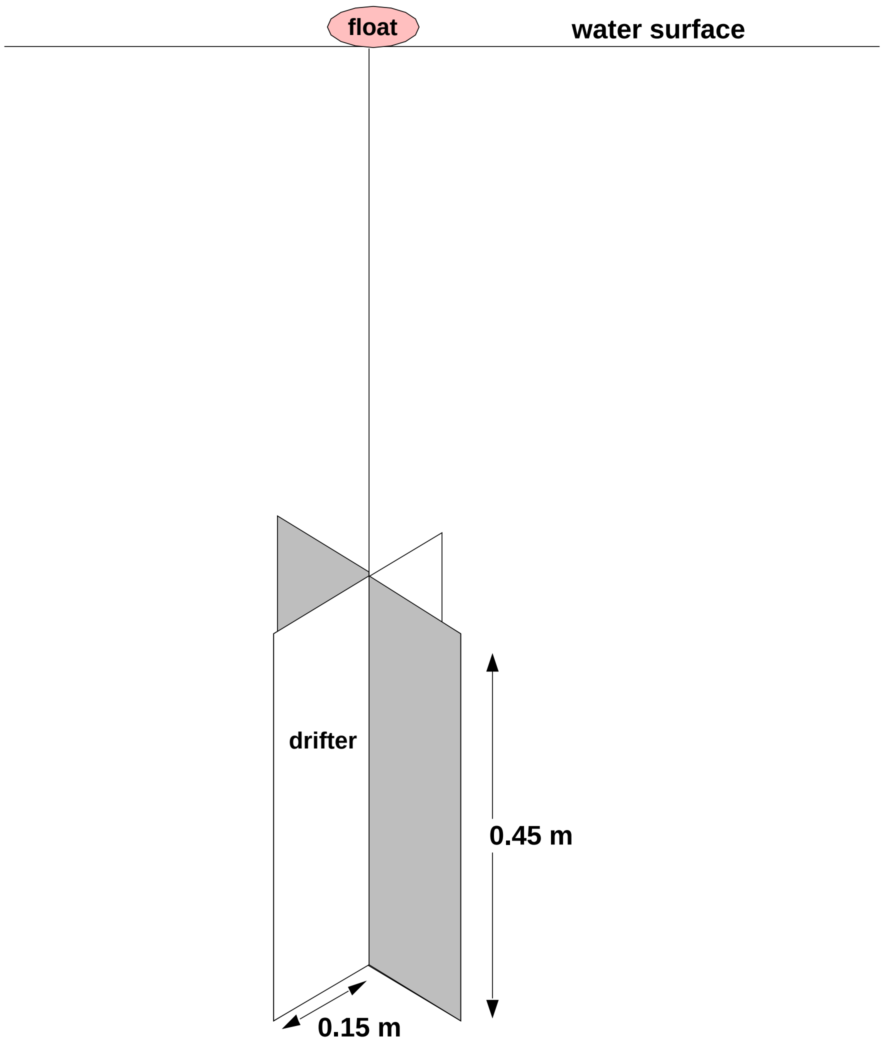


Figure 137: Diagram of a drifter used to evaluate water movement.

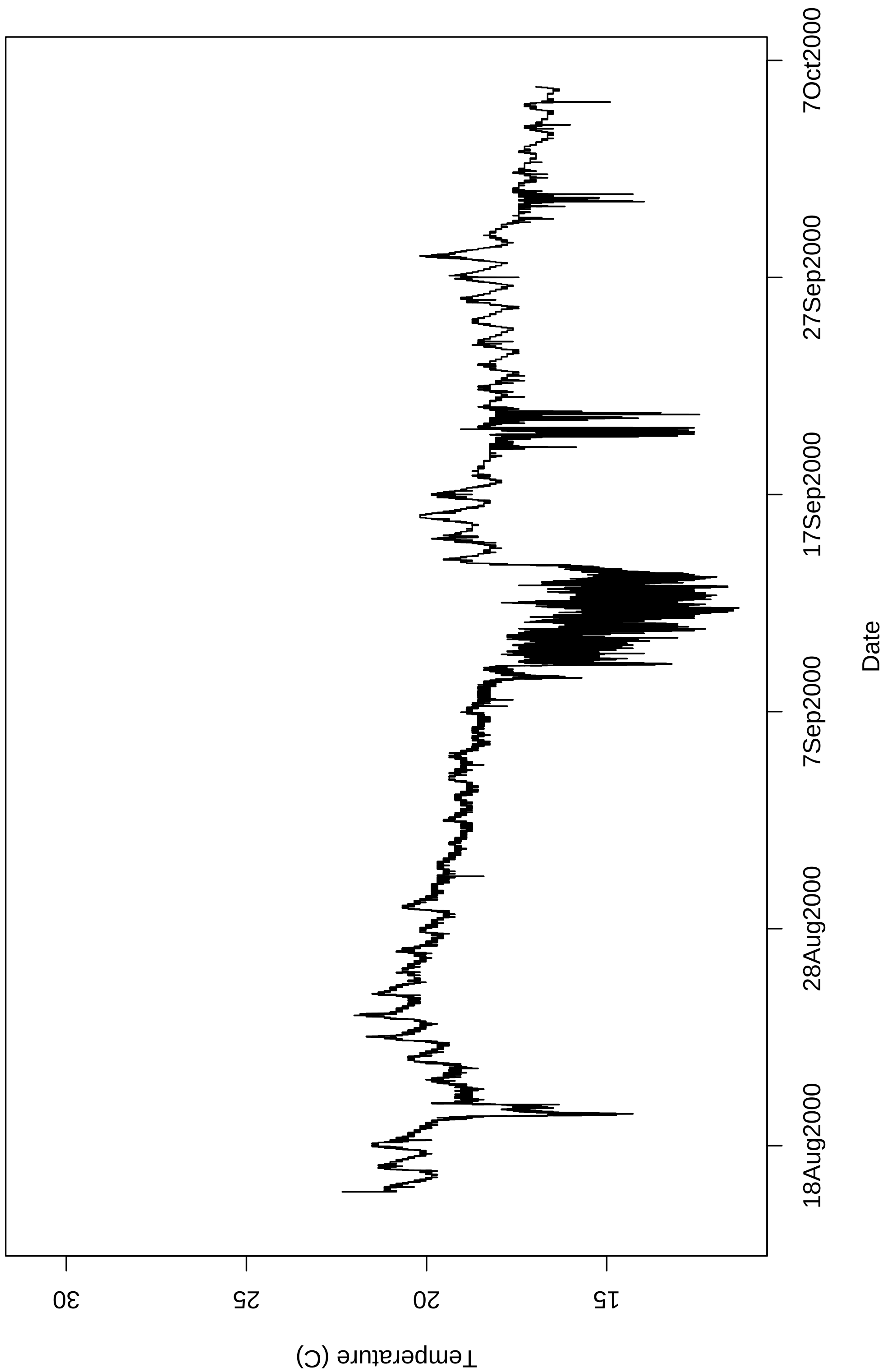


Figure 138: Anderson Creek delta temperature data, 2.2 m depth, August 16–October 5, 2000.

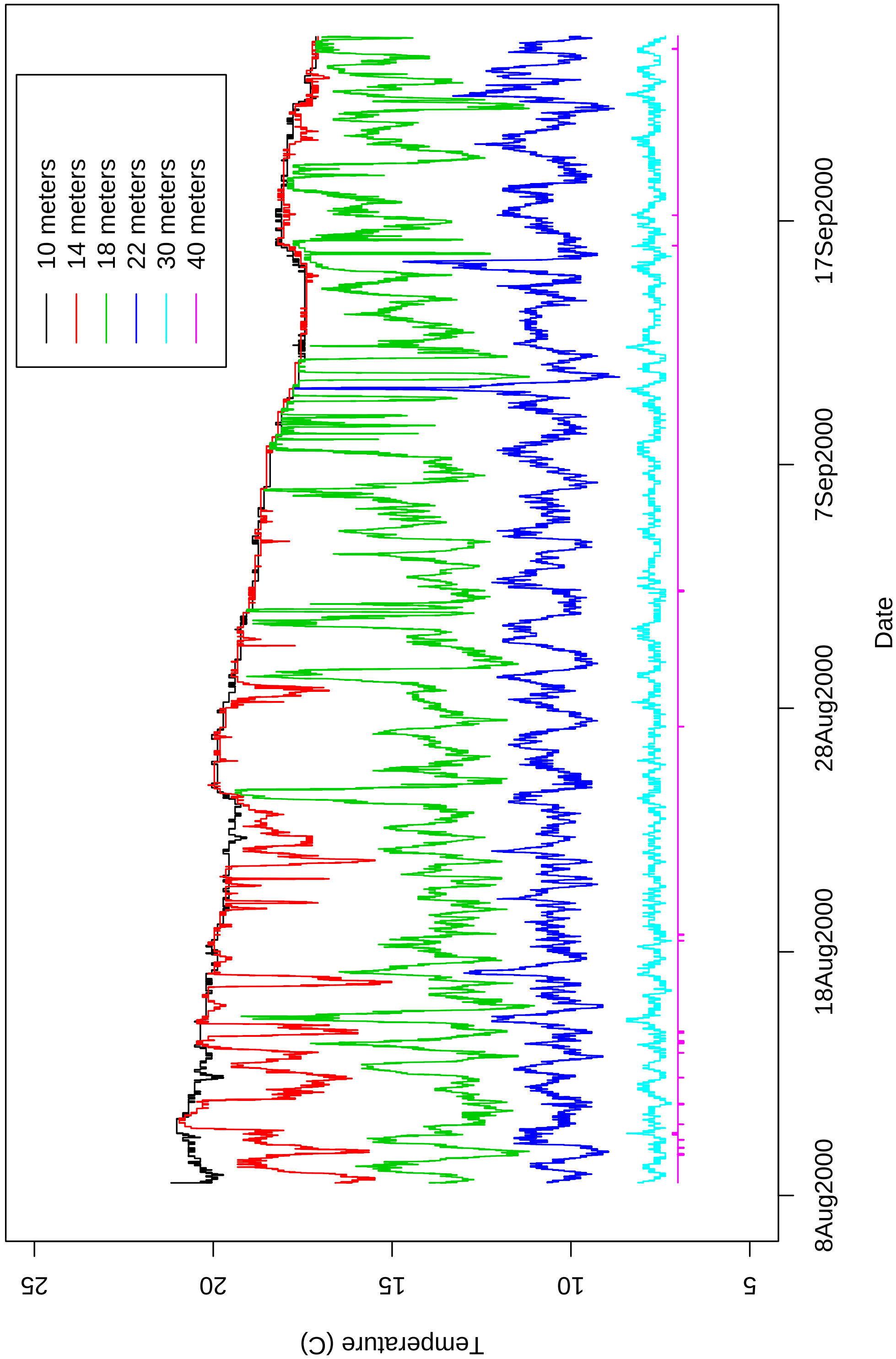


Figure 139: Temperature data from basin 3 southeast of Strawberry Sill, August 10–September 19, 2000.

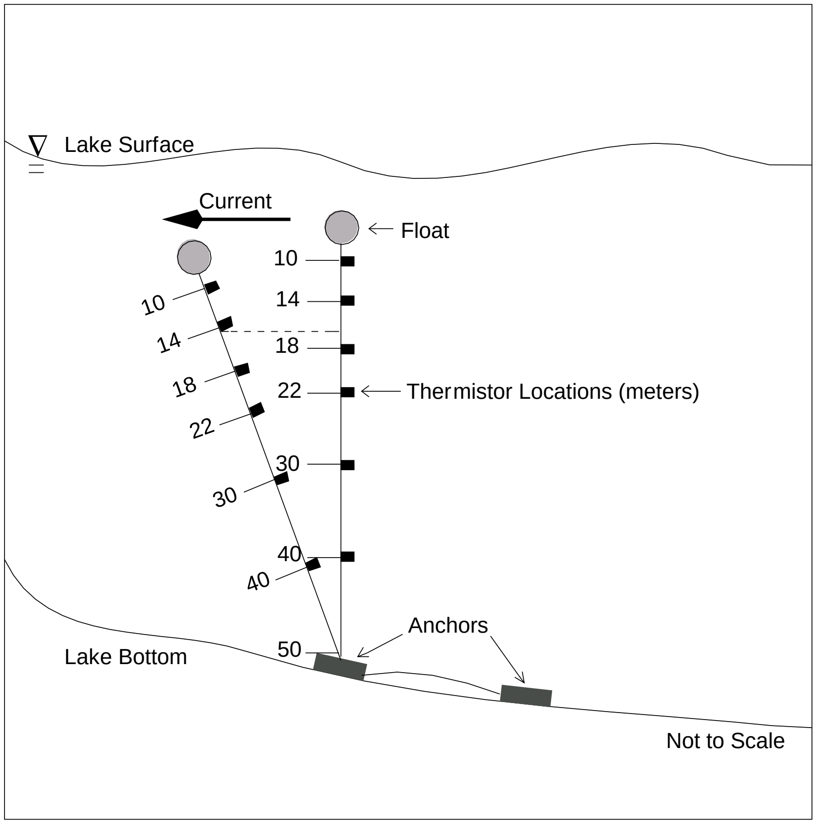


Figure 140: Diagram of temperature sensor array showing possible influence of subsurface currents.

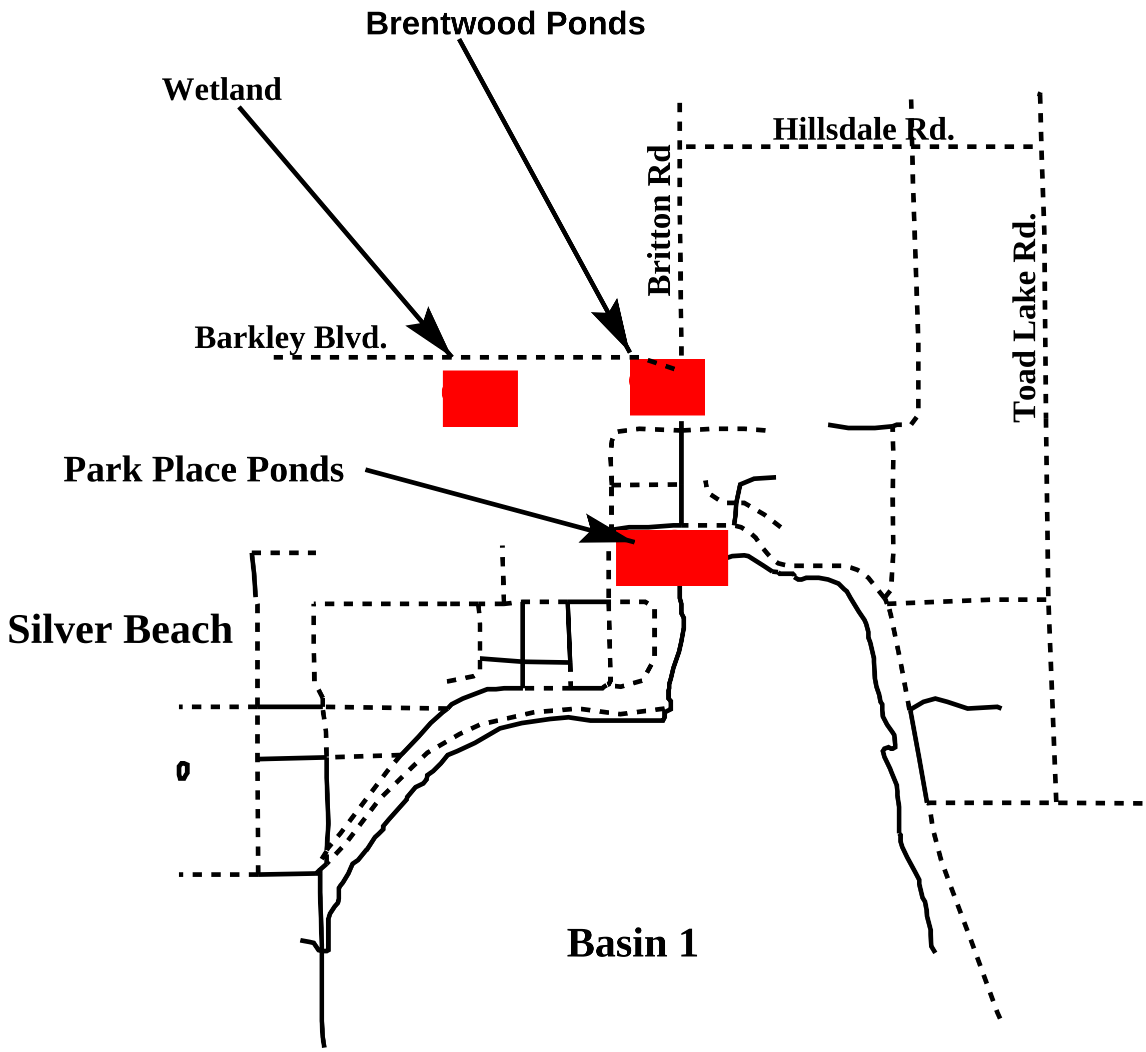


Figure 141: Locations of the sampling sites for the Park Place and Brentwood wet ponds and the South Grace Lane wetland.

This file is too large to include in the web version of this document. The image is included in the bound copy of the 1999/2000 Lake Whatcom Final Report, which is available from the City of Bellingham Public Works Department.

Figure 142: Park Place wet pond, July 19, 2000.

This file is too large to include in the web version of this document. The image is included in the bound copy of the 1999/2000 Lake Whatcom Final Report, which is available from the City of Bellingham Public Works Department.

Figure 143: Brentwood wet pond, July 19, 2000.

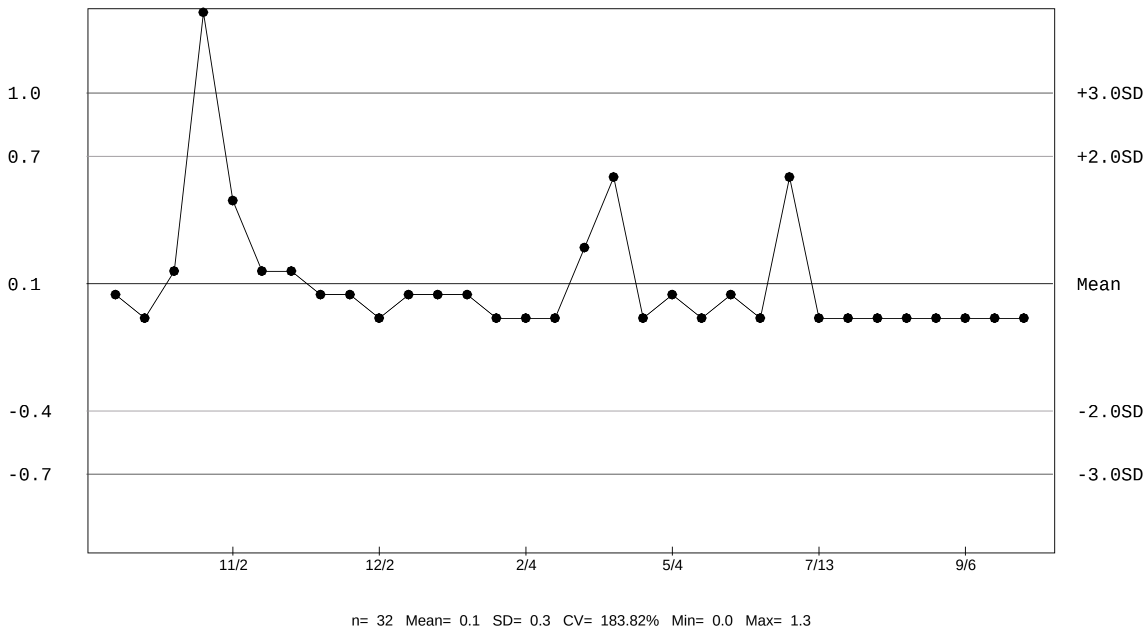


Figure 144: Alkalinity laboratory duplicates control chart.

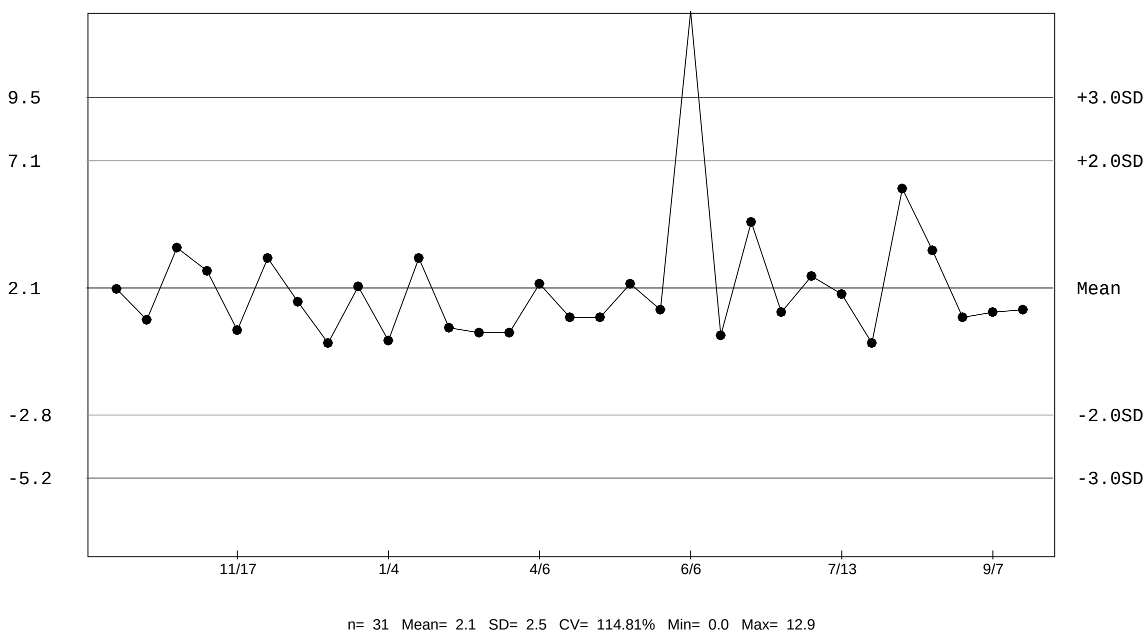


Figure 145: Ammonia laboratory duplicates control chart.

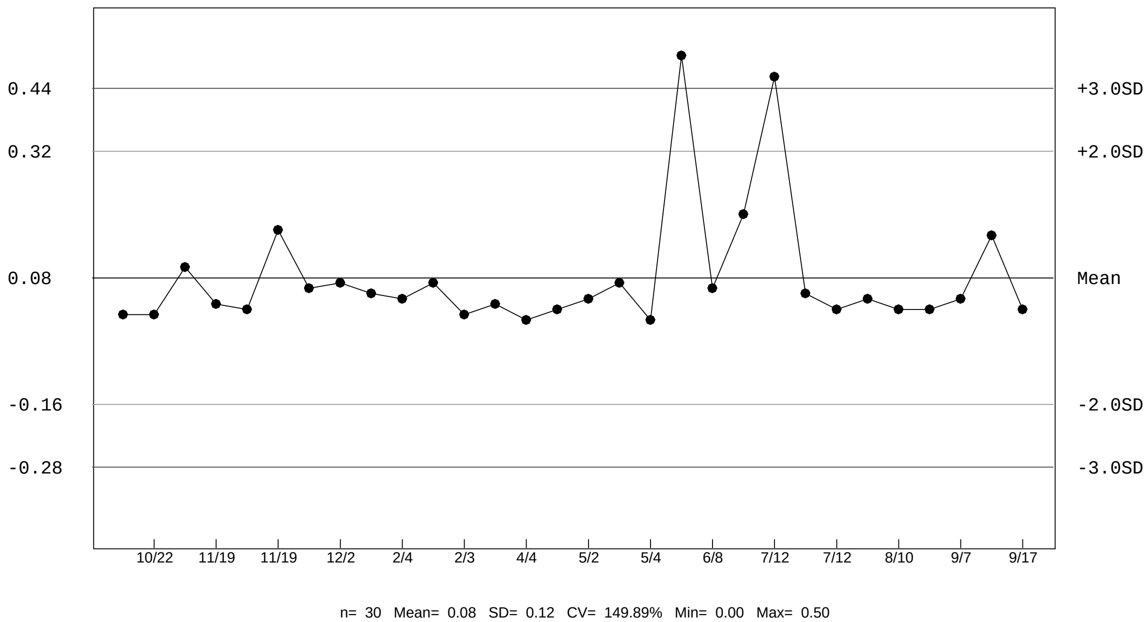


Figure 146: Chlorophyll laboratory duplicates control chart.

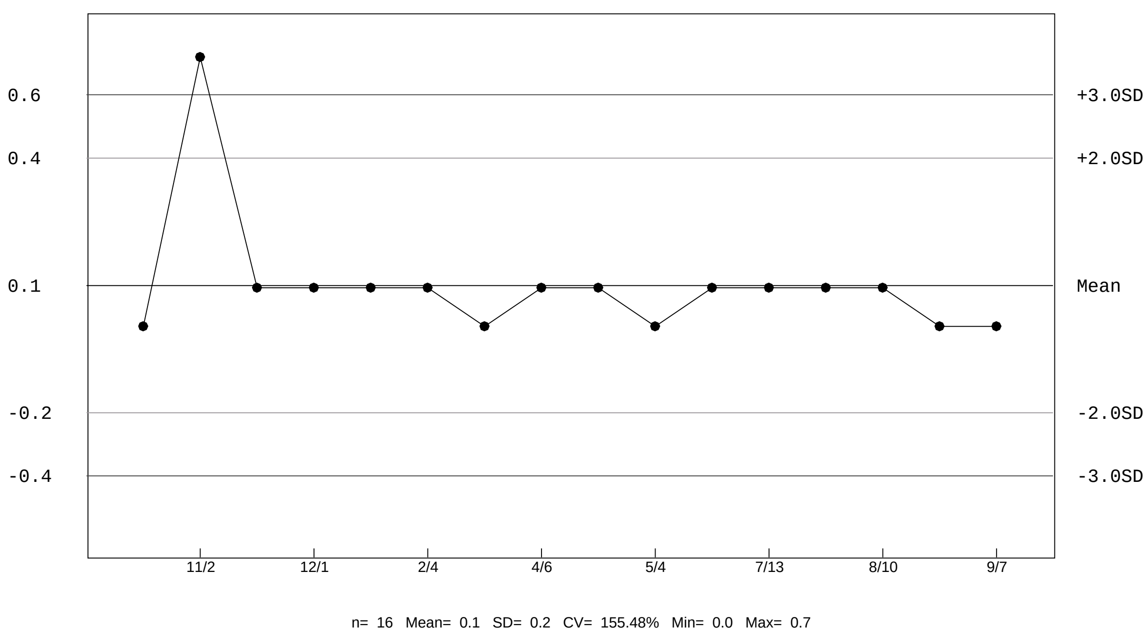


Figure 147: Conductivity laboratory duplicates control chart.

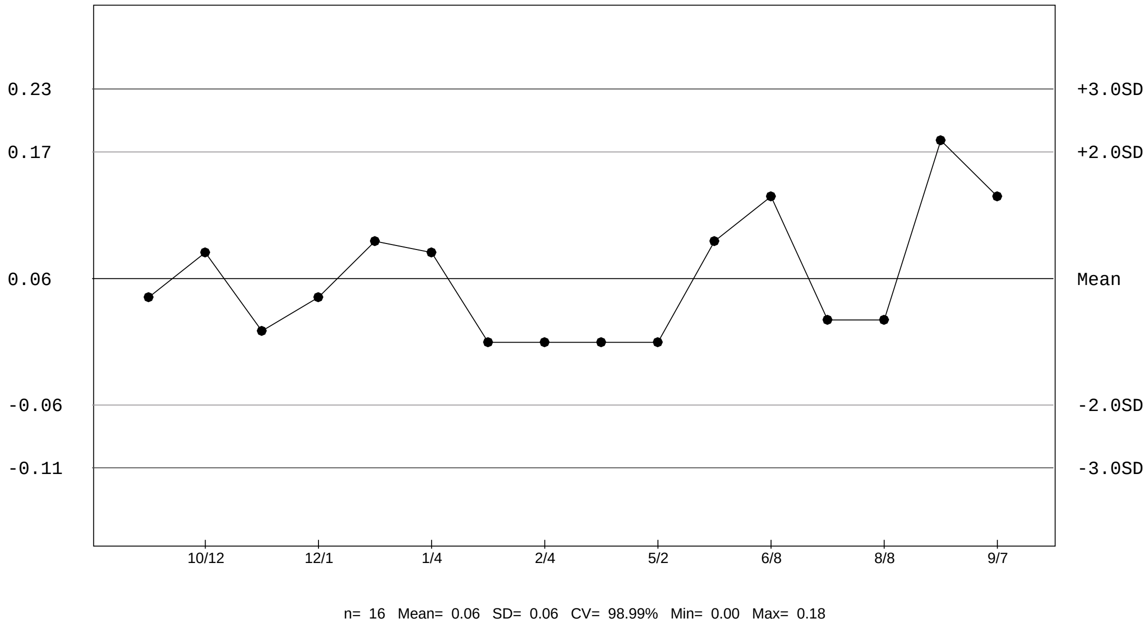


Figure 148: Dissolved oxygen laboratory duplicates control chart.

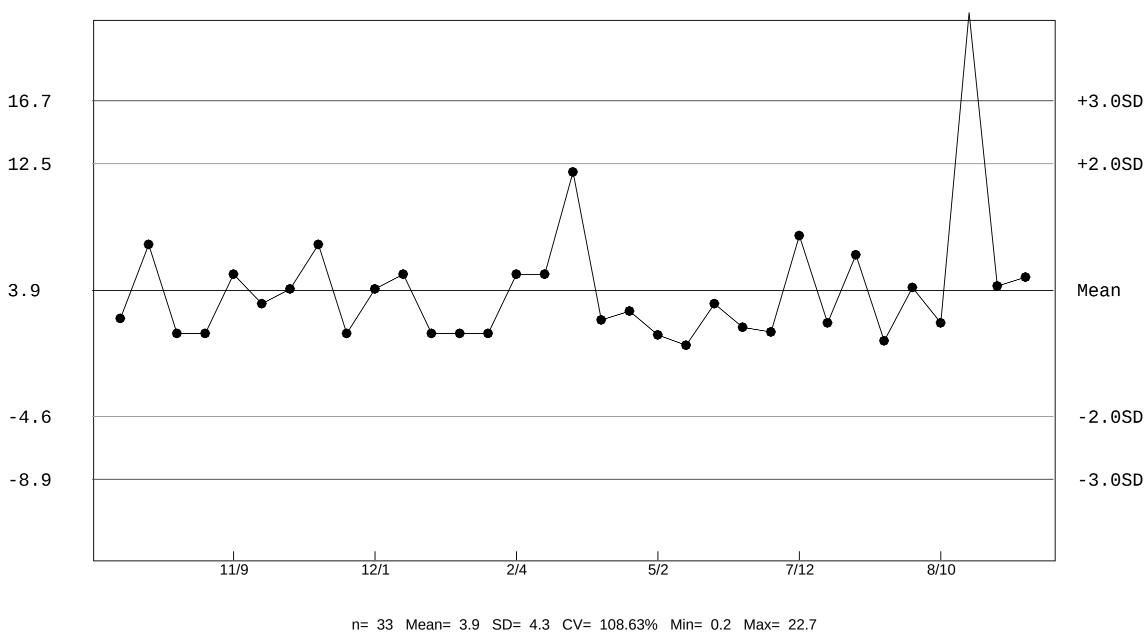


Figure 149: Nitrate/nitrite laboratory duplicates control chart.

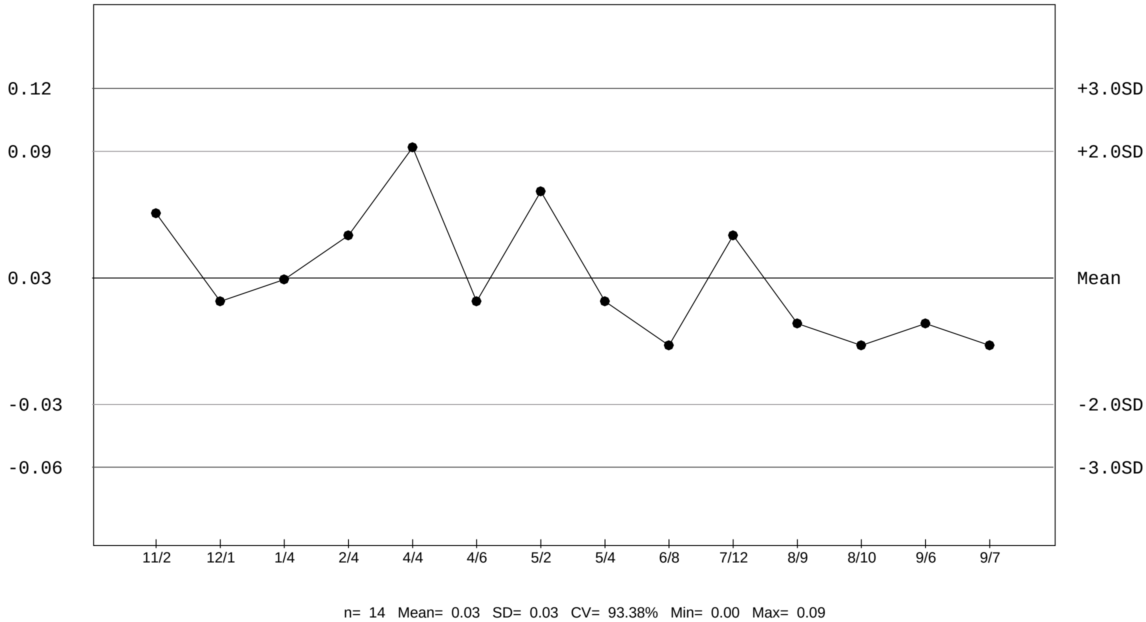


Figure 150: pH laboratory duplicates control chart.

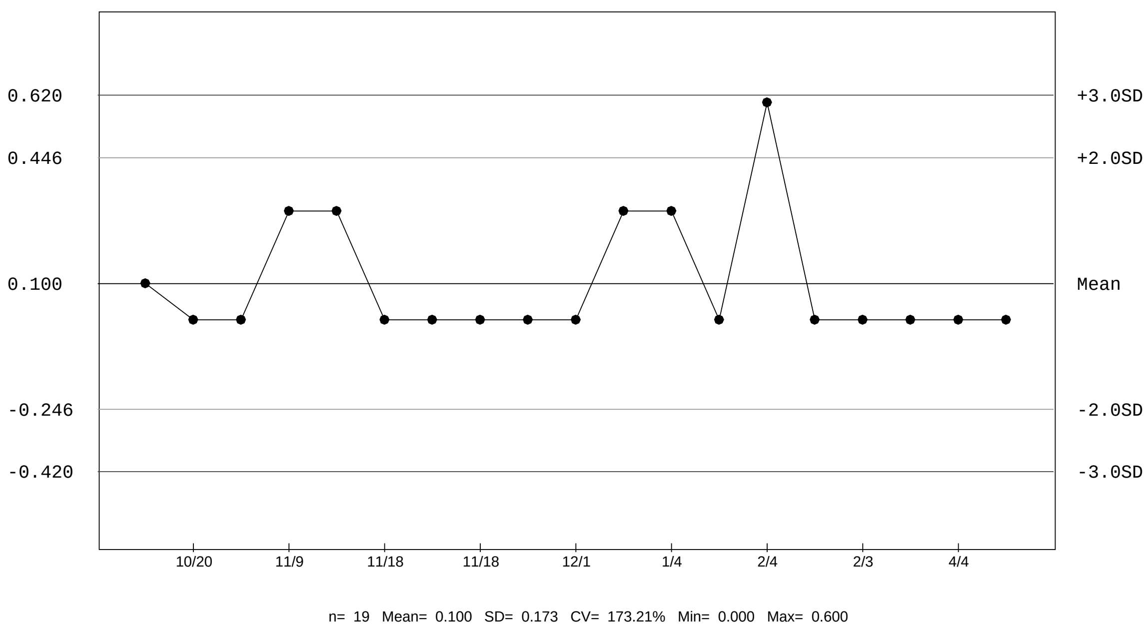


Figure 151: Soluble reactive phosphate laboratory duplicates control chart.

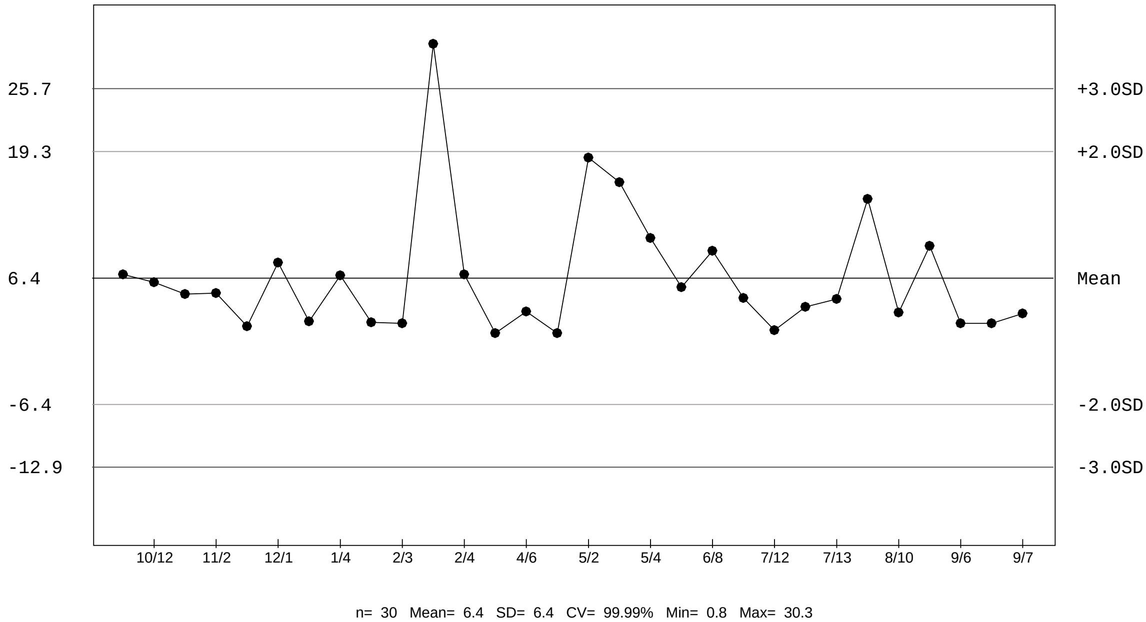


Figure 152: Total nitrogen laboratory duplicates control chart.

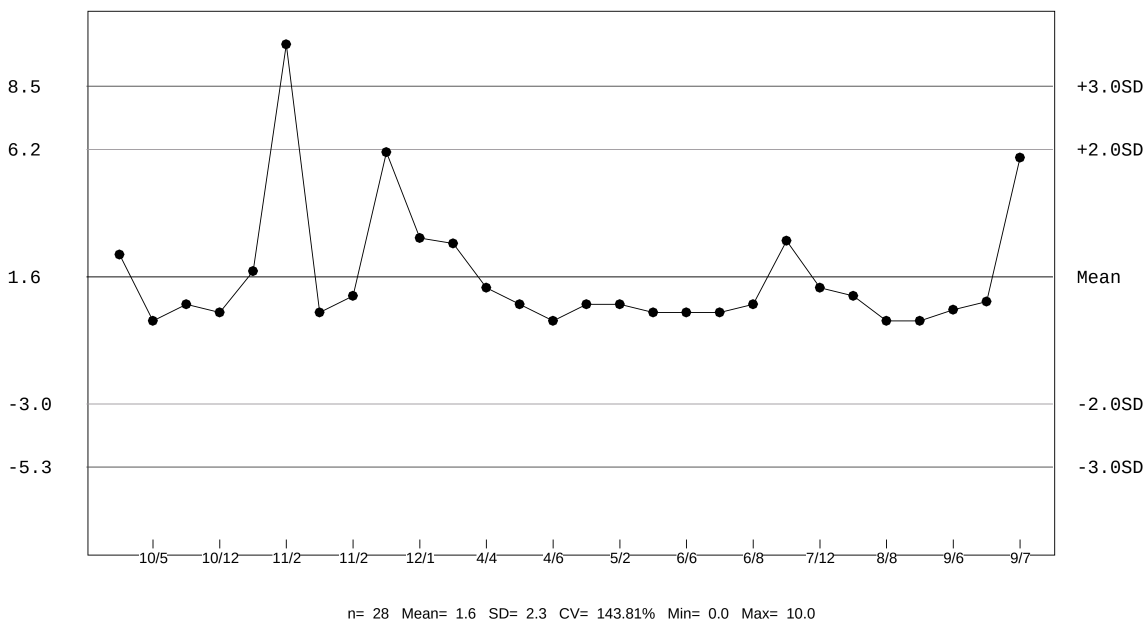


Figure 153: Total phosphorus laboratory duplicates control chart.

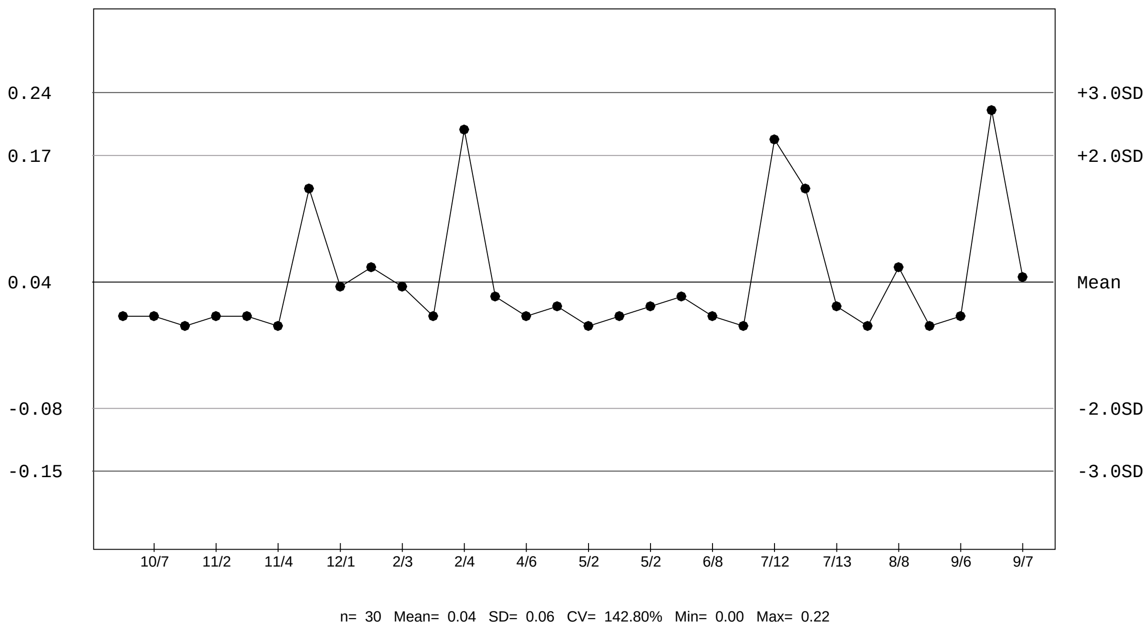
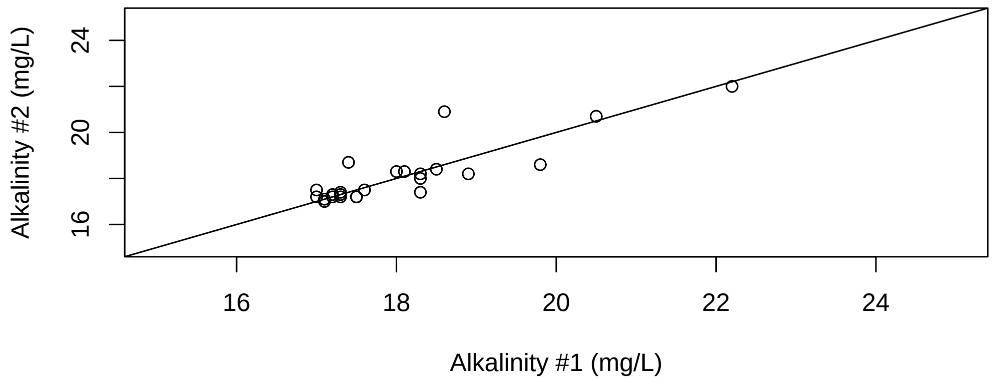


Figure 154: Turbidity laboratory duplicates control chart.



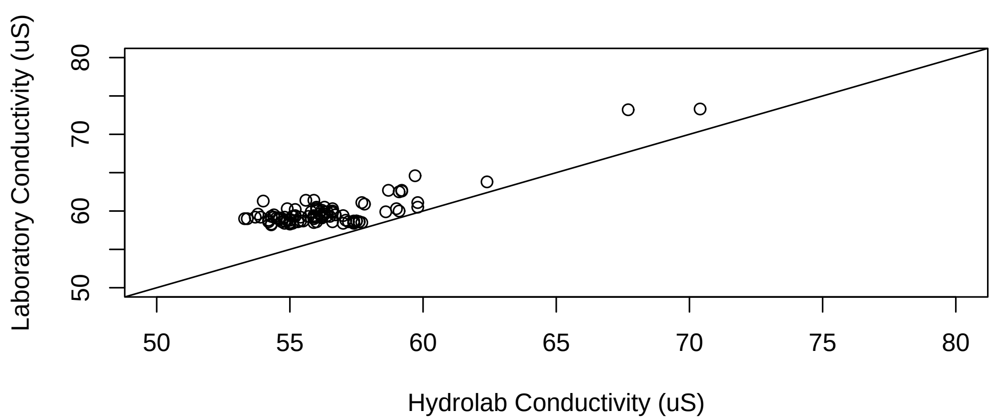


Figure 155: Alkalinity and conductivity field duplicates.

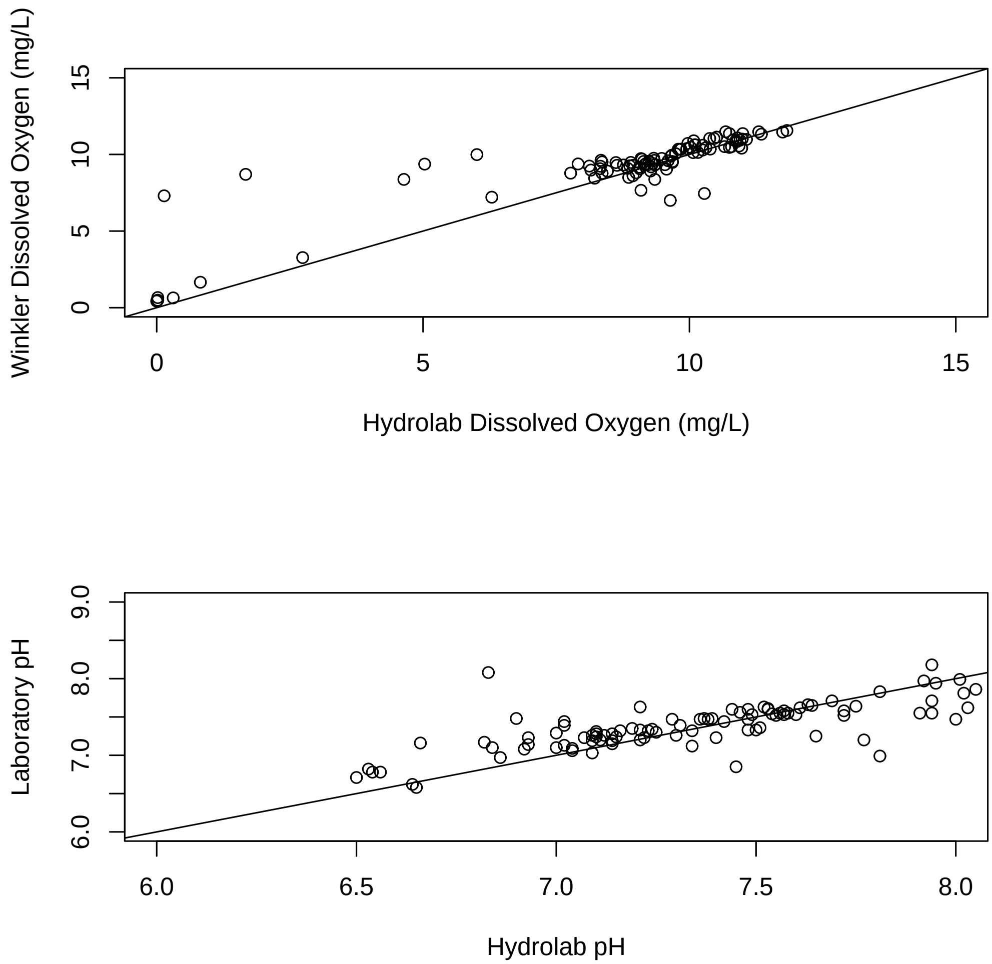


Figure 156: Dissolved oxygen and pH field duplicates.

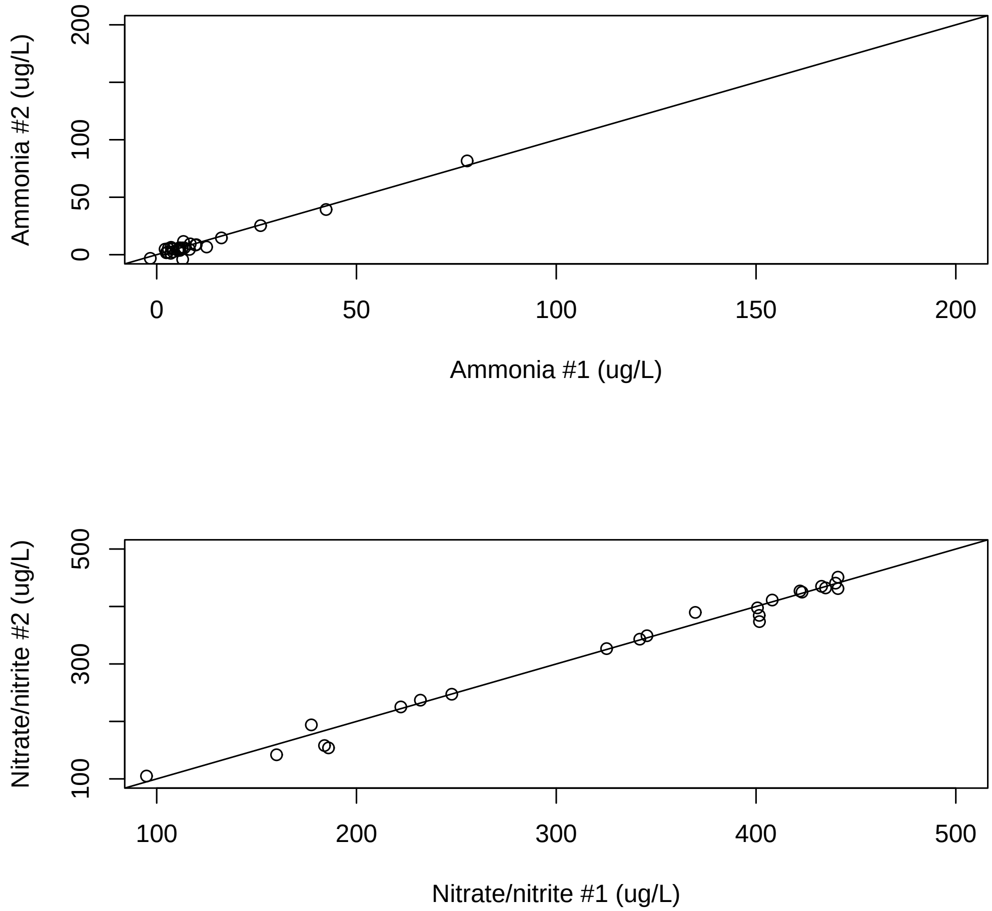
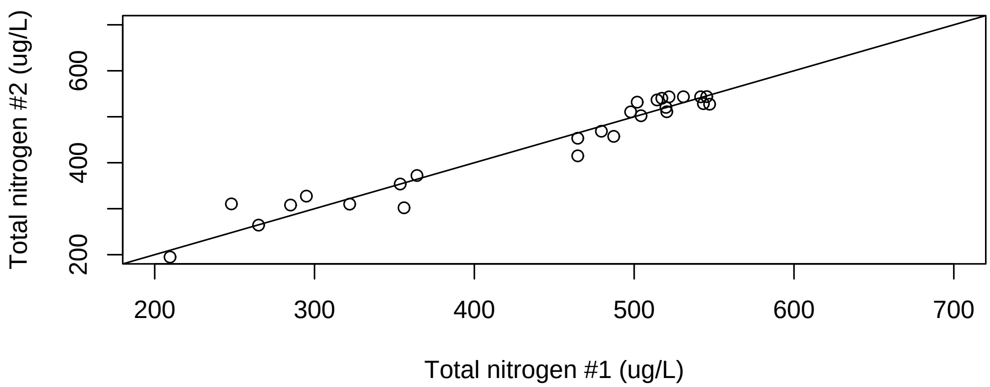


Figure 157: Ammonia and nitrate/nitrite field duplicates.



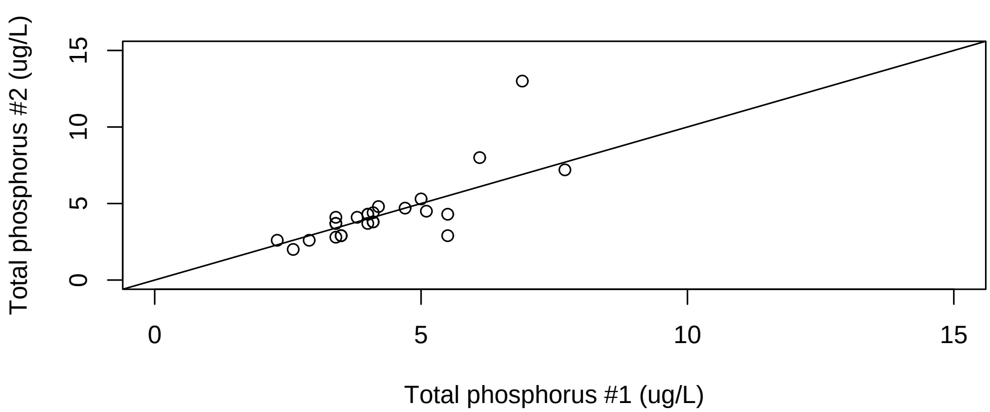
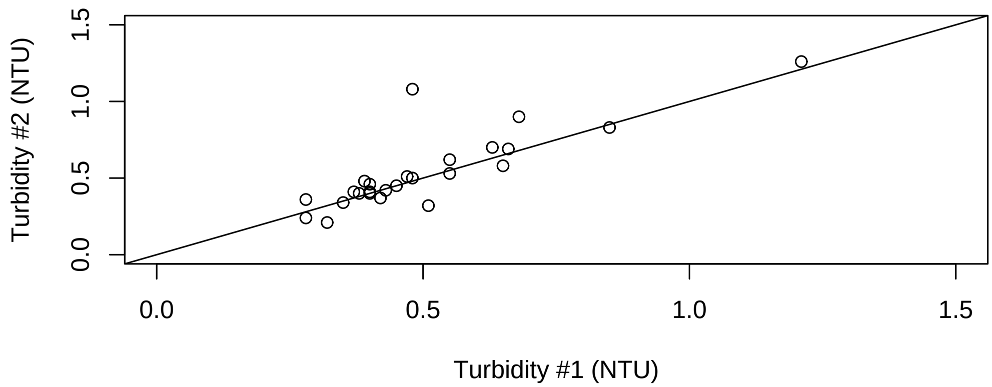


Figure 158: Total nitrogen and total phosphorus field duplicates.



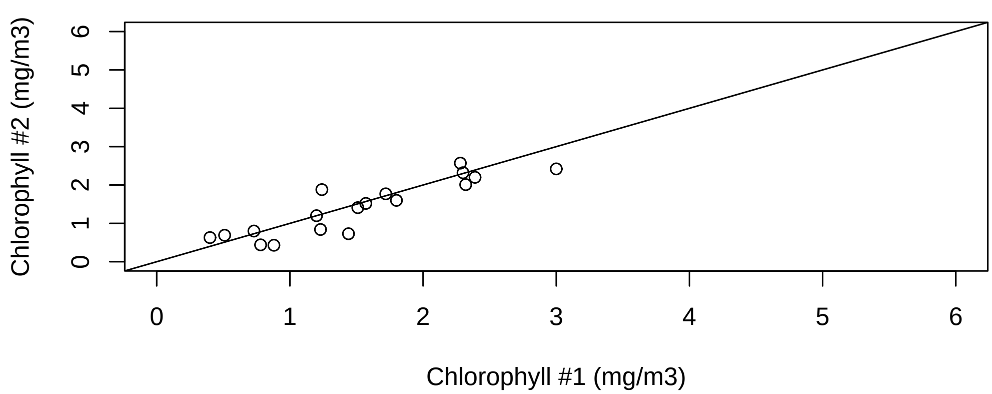


Figure 159: Turbidity and chlorophyll field duplicates.

A Site Descriptions

A.1 Lake Whatcom Monitoring Sites

Please refer to Figures 160–162 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 29 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 162. 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

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

Table 29: Summary of site codes for Lake Whatcom water quality sampling.

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 north-east 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.

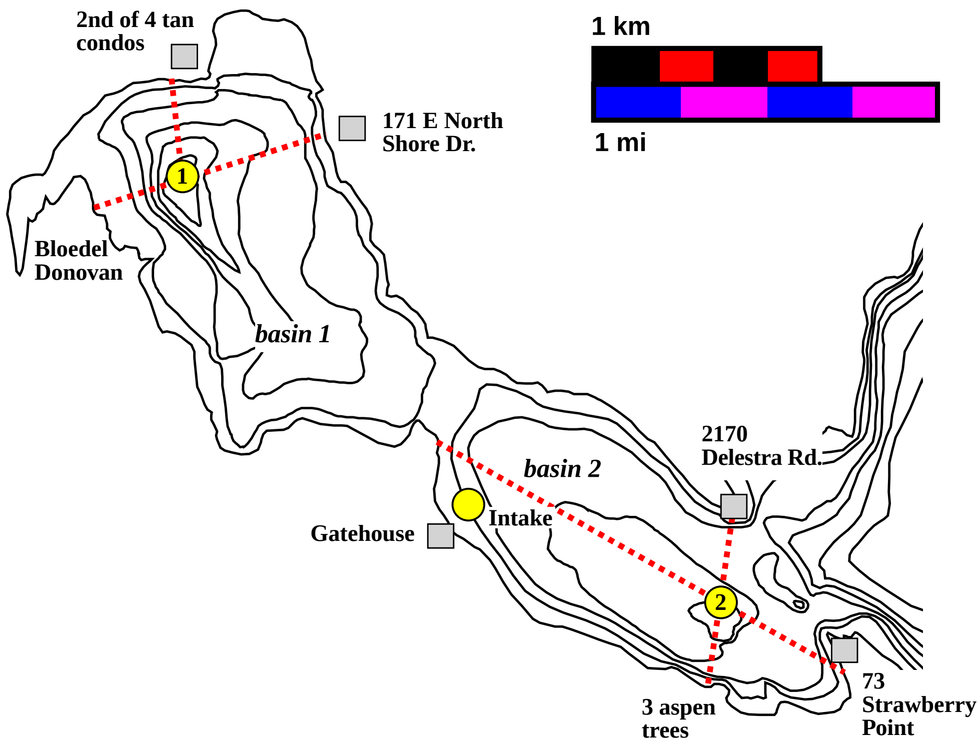


Figure 160: Lake Whatcom sampling sites, basins 1–2.

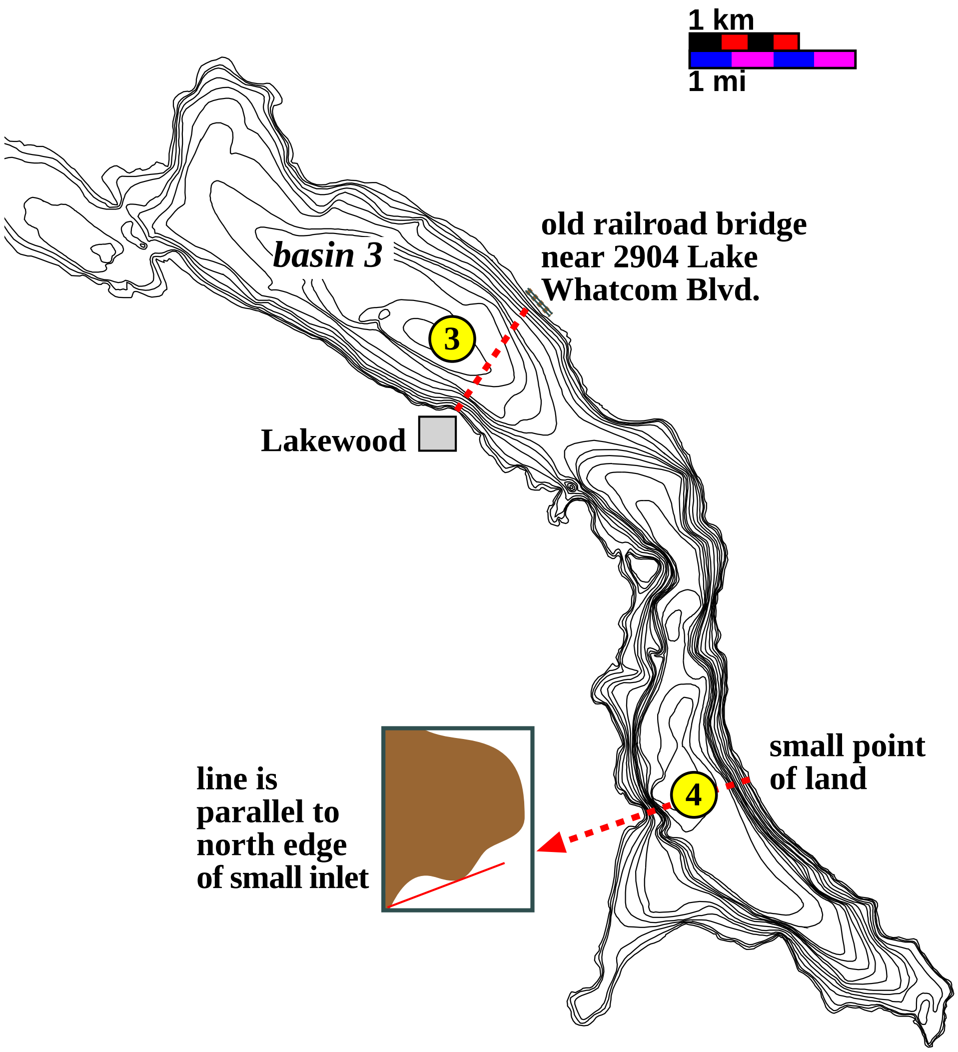


Figure 161: Lake Whatcom sampling sites, basin 3.

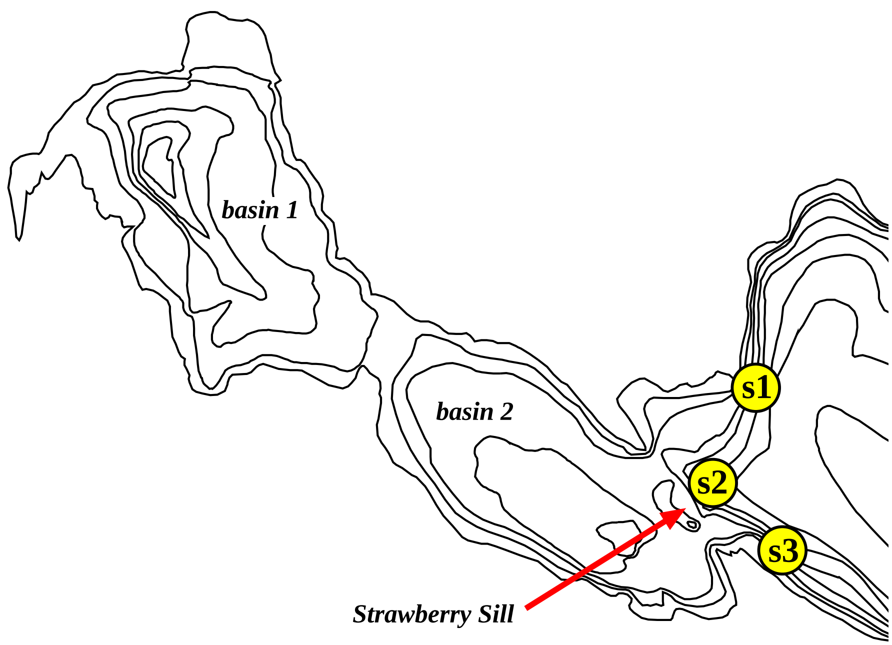


Figure 162: Strawberry sill sampling sites.

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. However, it is located just north of the two major Blue Canyon streams pictured on the USGS Lake Whatcom 7.5 min. quadrangle (Sect. 22, T 37N, R 4E). Samples are collected upstream from the culvert crossing the Blue Canyon road.

B Lake Whatcom Data

The 1999/2000 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 below. The historic detection limits for each parameter were estimated based on recommended lower detection ranges (APHA, 1992; 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 Table 31, page 216). 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 30.

In October 2000, Joan Vandersypen (IWS Laboratory Supervisor) revised the calculations of nutrient detection limits to follow APHA guidelines (1992). The current IWS nutrient detection limits are shown in Table 31. The only historic detection limit (Table 30) that changed was for nitrate/nitrite, which was raised from 10 μg/L to 20 μg/L.

Abbrev.	Analysis	Detection Limits (dl) or Sensitivity (±)	Abbrev.	Analysis	Detection Limits (dl) or Sensitivity (±)
alk	Alkalinity	± 0.1 mg/L	As	arsenic, total	dl = 0.03 mg/L
toc	Carbon, total organic	± 0.1 mg/L	Al	aluminum, total	dl = 0.01 mg/L
chl	Chlorophyll *a*	± 0.1 mg/m^3	Sb	antimony, total	dl = 0.02 mg/L
fc	Coliforms, fecal	dl ≤ 2 col/100 mL	Ba	barium, total	dl = 0.003 mg/L
tc	Coliforms, total	dl ≤ 2 col/100 mL	Be	beryllium, total	dl = 0.005 mg/L
cond	Conductivity, Hydrolab	± 2 μS/cm	Bo	boron, total	dl = 0.10 mg/L
cond	Conductivity, lab	± 2 μS/cm	Cd	cadmium, total	dl = 0.002 mg/L
ec	*Enterococcus*	dl ≤ 2 col/100 mL	Ca	calcium, total	dl = 0.10 mg/L
nh3	Nitrogen, ammonia	dl = 10 μg/L	Cr	chromium, total	dl = 0.006 mg/L
no3	Nitrogen, nitrate/nitrite	dl = 20 μg/L	Co	cobalt, total	dl = 0.003 mg/L
tn	Nitrogen, total nitrogen	dl = 100 μg/L	Cu	copper, total	dl = 0.002 mg/L
do	Oxygen, Hydrolab	± 0.1 mg/L	Fe	iron, total	dl = 0.01 mg/L
do	Oxygen, Winkler	± 0.1 μg/L	Pb	lead, total	dl = 0.001 mg/L
pH	pH, Hydrolab	± 0.1 pH unit	Li	lithium, total	dl = 0.02 mg/L
pH	pH, lab	± 0.1 pH unit	Mg	magnesium, total	dl = 0.10 mg/L
srp	Phosphate, soluble reactive	dl = 5 μg/L	Mn	manganese, total	dl = 0.002 mg/L
tp	Phosphorus, total	dl = 5 μg/L	Hg	mercury, total	dl = 0.01 mg/L
secchi	Secchi depth	± 0.1 m	Mo	molybdenum, total	dl = 0.01 mg/L
temp	Temperature	± 0.1° C	Ni	nickel, total	dl = 0.01 mg/L
tss	Total suspended solids	dl = 2 mg/L	P	phosphorus, total	dl = 0.05 mg/L
turb	Turbidity	± 0.2 NTU	K	potassium, total	dl = 1.0 mg/L
			Ag	silver, total	dl = 0.01 mg/L
			Na	sodium, total	dl = 0.5 mg/L
			S	sulfur, total	dl = 0.1 mg/L
			Se	selenium, total	dl = 0.03 mg/L
			Si	silicon, total	dl = 0.1 mg/L
			Sr	strontium, total	dl = 0.003 mg/L
			Sn	tin, total	dl = 0.02 mg/L
			Ti	titanium, total	dl = 0.01 mg/L
			Tl	thallium, total	dl = 0.03 mg/L
			V	vanadium, total	dl = 0.002 mg/L
			Y	yttrium, total	dl = 0.001 mg/L
			Zn	zinc, total	dl = 0.002 mg/L

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 values shows in this table are the older, higher limits.
Table 31 lists the current IWS detection limits for selected analyses; Appendix C lists the current AmTest detection limits.

Table 30: Summary of analyses in the Lake Whatcom monitoring project.

Abbrev.	Analysis	IDL	LLD	MDL[†]	MDL[‡]
nh3	Ammonia, autoanalysis	4.6	5.9	na	na
nh3	Ammonia, manual	1.1	2.2	3.7 (5 μg/L)	3.0 (20 μg/L)
tn	T. nitrogen, autoanalysis	0.8	1.6	19.2 (10 μg/L)	27.8 (100 μg/L)
tp	T. phosphorus, autoanalysis	2.0	3.9	4.7 (5 μg/L)	4.8 (20 μg/L)
tp	T. phosphorus, manual	1.0	1.9	3.3 (5 μg/L)	1.8 (20 μg/L)
srp	Sol. Phosphate, autoanalysis	1.2	2.4	1.9 (2.5 μg/L)	1.0 (20 μg/L)
srp	Sol. Phosphate, manual	0.5	1.1	1.9 (2.5 μg/L)	3.2 (20 μg/L)
no3	Nitrate/nitrite, autoanalysis	3.3	6.7	16.3 (10 μg/L)	14.2 (25 μg/L)

[†]Low-level detection limits; concentrations shown in parentheses.
[‡]High-level detection limits; concentrations shown in parentheses.

Table 31: Current IWS analytical detection limits.

Instrument Detection Limit (IDL) = Concentration needed to produce a signal = 1.645 $\times$ Std. Dev. of replicate blanks (n=60).

Lower Level of Detection (LLD) = Concentration that produces a signal sufficiently large that 99% of the trials with that amount will produce a detectable signal = 2 $\times$ 1.645 $\times$ Std. Dev. of replicate blanks (n=40).

Method Detection Limit (MDL) = 3.14 $\times$ Std. Dev. of seven replicate standards near the MDL and higher concentrations in the analytical range from at least 3 different analytical runs.

B.1 Lake Whatcom Hydrolab Data

B.2 Lake Whatcom Water Quality Data

B.3 Lake Whatcom Plankton Data

B.4 Lake Whatcom Coliform Data

B.5 Strawberry Sill Hydrolab Data

B.6 Strawberry Sill Water Quality Data

B.7 Brentwood and Park Place Grab Sample Data

B.8 Brentwood and Park Place Composite Data

B.9 Lake Whatcom Long Term 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 2000, along with the 1999/2000 Austin Creek, Anderson Creek, and Smith Creek hydrograph 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 30 and 31 (pages 215 and 216) 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 1999/2000 Lake Whatcom Monitoring Report
included the following data files:

Hydrolab data        Water quality data         Hydrograph data
1988_hl.dat          1988_wq.dat                1999_2000_austin.dat
1989_hl.dat          1989_wq.dat                1999_2000_anderson.dat
1990_hl.dat          1990_wq.dat 1999_2000_smith.dat
1991_hl.dat          1991_wq.dat
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

The hydrolab data files contain the following variables: site, depth
(m), month, day, year, temperature (C), pH, conductivity (uS),
dissolved oxygen (mg/L), lab conductivity quality control data (uS),
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 site codes in the hydrolab and water quality files are as follows:
site 11 = site 1; site 21 = intake; site 22 = site 2; site 31 = site
3; site 32 = site 4.

The Hydrograph data file contains the following variables: month, day,
year, hour, minute, second, head (ft), discharge (cfs).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VERIFICATION PROCESS FOR THE 1988-2000 LAKE WHATCOM DATA FILES
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During the summer of 1998 the Institute for Watershed Studies began creating an electronic data file that would contain long term data records for Lake Whatcom. These data were to be 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 benchsheets 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 benchsheets. 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.

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

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

B.10 Hydrograph Data from Anderson, Austin, and Smith Creeks

There are staff gages and a continuously recording Stevens data loggers on Anderson, Austin and Smith Creeks. The data loggers collect stream flow data at 30-minute intervals. The following sections provide details about the data collected during the 2000 water year (October 1, 1999 – September 30, 2000).

B.10.1 Anderson Creek WY 2000

The data logger was installed May 18, 2000 in the existing stilling well by Jim Mullen (City of Bellingham, Public Works Department).

Logger adjustments at Anderson Creek occurred on the following dates in WY 2000: (5/20/00) from 1.99 to 2.18, (8/2/00) from 2.13 to 2.04, (8/8/00) from 2.04 to 2.06, and on 8/17/00 the logger was reset when it was discovered that the intake was out of the water and the float was probably resting on the bottom of the stilling well. This was undone on the same day so that future values would remain accurate. No adjustments were made to the data.

It was observed in the field that the intake pipe was frequently <1 ft out of the water when stream water levels were low and the Nooksack diversion was off. From field observations and reviewing data, the estimated depth below which the float is resting on the base of the stilling well is about 1.09 to 1.15 ft. Any records at or below 1.15 ft should be considered "less than or equal to 1.15 ft." Similarly, discharge values from days containing logger readings below 1.15 ft should be considered maximum values. Actual values may be considerably lower. No data were adjusted to compensate for this source of error. Days affected include: (5/18/00), (8/12/00 – 9/8/00), (9/13/00 – 9/18/00), and (9/20/00 – 9/31/00)

On 08/08/00, the logger stopped recording measurements due to low power. This was discovered on the same day. Only the 14:30, 15:00, and 15:30 measurements were lost. Gauge heights were within 0.01 ft on either side of the data gap, so the missing data were estimated in order to have a complete daily discharge for that date.

Events at Anderson Creek			
04/26/00	In stream staff gauge installed		
05/18/00	Logger installed in existing stilling well by Jim Mullen		
05/20/00	Adjusted logger to staff	Logger 1.99	Staff 2.18
08/02/00	Adjusted logger to staff	Logger 2.13	Staff 2.04
08/08/00	Low power shutoff. Adjusted logger to staff	Logger 2.04	Staff 2.06
08/17/00	Stilling well intake 1 ft above water surface	Logger 1.09	Staff 0.29
09/01/00	Intake out of water	Logger 1.11	Staff –
09/22/00	Intake out of water	Logger 1.13	Staff 0.52
09/22/00	Intake out of water	Logger 1.11	Staff 0.52

B.10.2 Austin Creek WY 2000

Data from 11/16/99 to 12/30/99 were lost due to equipment failure. The data logger was replaced with loaned equipment from Stevens on 12/21/99, but problems continued. On 12/30/00 it was determined that the encoder was not functioning properly. It was also replaced with loaned equipment from Stevens. All appeared to be functioning after encoder replacement.

The logger was consistently drifting away from true value with time. The logger was usually lower than staff reading, although this was not always the case. The logger may have been off by as little as a few tenths of a foot or as much as greater than 0.5 feet. In an attempt to correct the problem, on 06/02/00 the weight 8 oz weight was replaced with a 177 g weight and a plastic sleeve was placed around the stilling well to decrease turbulence in the well. However, the logger continued to drift. On 09/14/00 a non-perforated plastic sleeve was put over a portion of the stilling well. The lowest portion of the well was also sleeved on 09/28/00. Approximately 6 days following the addition of the lower sleeve, the logger had drifted by -0.04 ft.

Data collected from 3/8/00 to 6/2/00 were discarded because logger readings were as great as 0.6 ft different than staff readings. After assessing the staff gage readings that correspond to logger readings at various times the year, we estimate that the calculated flows could be off by as much as 10% to 20% during the year.

The logger was discovered to be off by -0.27 feet on 7/18/00; no adjustment made. It was not checked again until 8/8/00, at which time it was off by -0.29 feet and adjusted. The data between 7/18/00 13:00 and 08/08/00 13:00 was adjusted by subtracting 0.28 feet from each logged depth. The data collected prior to 7/18/00 were probably similarly underestimated, but no adjustments were made.

On 8/11/00 the battery was replaced. At that time, it was discovered that the replacement battery was exhausted and could not be used. The original battery was reconnected. The following day, a new battery was brought out. When the logger was checked, it was found to be recording values near 500 feet deep. The field personnel concluded that, when replacing the original battery, they forgot to reset the logger and left it at 0.00. When the stream depth decreased, rather than logging negative values, the logger cycled back to its maximum of 500 ft and went down from there. The data between 08/11/00 11:30 and 08/12/00 11:30 were corrected accordingly.

B.10.3 Smith Creek WY 2000

Most differences between the logger and staff readings during the winter and spring were due to normal drift between the two readings. And adjustment made to the logger on 4/15/00 should not have been made, as it was most likely made due to error in reading the staff. On 4/19/00 the logger and staff disagreed by almost the exact amount the logger was adjusted to on 4/19/00. After the error was realized, the data between 4/15/00, 13:00 and 4/19/00, 11:30 were changed to compensate. No significant discrepancies occurred after 4/19/00.

On 8/2/00 data was downloaded onto a damaged disk. Most of the data was retrievable, but data were lost between 7/8, 00:00 and 7/14, 23:30.

In summary, the Smith Creek logger worked well during water year 2000 and the data are believed to be accurate.

C AmTest Reports

The following AmTest data reports are filed by sampling date:

Sample location	Date	Analyses
Strawberry sill, surface and 35 m	October 12, 1999	metals, total organic carbon
Park Place/Brentwood wet ponds	December 8, 1999	metals, total organic carbon
Strawberry sill, surface and 35 m	January 4, 2000	metals, total organic carbon
Watershed creeks/lake	February 9, 2000	metals, total organic carbon
Park Place/Brentwood wet ponds	March 8, 2000	metals, total organic carbon
Watershed creeks	July 18, 2000	total organic carbon only
Park Place/Brentwood wet ponds	July 19, 2000	metals, total organic carbon
Lake Whatcom, surface and bottom	September 11, 2000	metals, total organic carbon