

4-21-2003

# Lake Whatcom Monitoring Project 2001/2002 Report

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## Recommended Citation

Matthews, Robin A.; Hilles, Michael; Vandersypen, Joan; Mitchell, Robert J.; and Matthews, Geoffrey B., "Lake Whatcom Monitoring Project 2001/2002 Report" (2003). *Lake Whatcom Annual Reports*. 11.  
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# Lake Whatcom Monitoring Project 2001/2002 Final Report

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April 21, 2003

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\*Funding for this project was provided by the City of Bellingham, as part of their long-term commitment to environmental education and their concern for maintaining the water quality of Lake Whatcom. We thank Marilyn Desmul, Judy Kincaid-King, Jessica Anderson, Shannon Ashurst, Katherine Callahan, Joan Clark, Sawyer Cozart, Allison Daniels, Molly Glynn, Liliana Guifarro-Hanson, Wyatt Leighton, Kei Nishida, Dwight Osmon, Ann-Marie Osterback, Jennifer Watkins, and Benjamin Zimmerlund for their assistance with this project.

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## Executive Summary

This report describes the results from the 2001/2002 Lake Whatcom monitoring program. The objectives of this program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; monitor the effectiveness of the Park Place and Brentwood wet ponds and the South Campus storm water treatment system; collect supplemental water quality data from basin 3 near Strawberry sill; continue collection of hydrologic data from Anderson, Austin, and Smith Creeks; and update the hydrologic model for Lake Whatcom.

The lake was sampled on October 2, November 6 & 8, and December 4 & 5, 2001; and February 12 & 14, April 2 & 4, May 7 & 9, June 4 & 14, July 1 & 2, August 6, 8, & 13, and September 3 & 5, 2002. During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). Although the average lake water temperatures were similar in 2001/2002 compared to the previous sampling year, Sites 1 and 2 were only weakly stratified by June. The June Hydrolab profiles showed intense warming near the surface, which resulted in considerable variation in the epilimnetic temperature at these two sites. By July, all sites except the Intake had developed a stable stratification. Despite the late stratification in basins 1 and 2, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer. There continued to be a long-term trend of decreasing hypolimnetic oxygen concentrations at Site 1. The remaining Hydrolab data, temperature, pH, and conductivity, followed trends that were typical for Lake Whatcom.

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths. During the summer the alkalinity and conductivity values at the bottom of Sites 1–2 increased due to decomposition and the release of dissolved compounds in the lower waters. The turbidity values were mostly less than 1–2 NTU except during late summer samples from the lower depths at Sites 1 and 2. The nutrient data continue to show that Site 1 (basin 1) is more productive than Sites 3 and 4 (basin 3); however, for the past four years, Site 2 (basin 2) has been increasingly similar to Site 1. Site 1 continued to have the highest chlorophyll concentrations of all the sites. The plankton counts at all sites were dominated by Chrysophyta<sup>1</sup>, but substantial blooms of Cyanophyta and Chlorophyta were measured at all sites during summer and late fall.

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<sup>1</sup>The Chrysophyta phylum name has been changed to Heterokontophyta in many taxonomies.

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. Zinc was detected at low concentrations at all sites. Iron concentrations were elevated in most of the bottom samples, which is typical for Lake Whatcom. The highest concentrations, 0.72 mg/L and 0.62 mg/L, were measured at Sites 1 and 2, respectively. Lead was detected at Site 4 (surface and bottom samples), but because the concentration was at the level of detection, it is unlikely that this represents an increase in lead concentrations in the lake.

From July 2001 through September 2002, IWS collected water samples to measure trace concentrations of water column mercury in response to concerns about mercury detected in fish and sediment samples from the lake. Additional low-level mercury samples were collected at the gatehouse and from treated water by the City of Bellingham. In October 2001, water samples were collected from Lake Whatcom, the Middle Fork of the Nooksack River (upstream from the diversion channel), and several tributaries to the lake by Exponent.<sup>2</sup> The water column, gatehouse, and treated water mercury concentrations were very low, and most were below detection levels (0.0002–0.0005 mg/L). The samples collected by Exponent, and a subset of gatehouse and treated water samples collected by the City, were measured using ultra-low analytical techniques, so most of these samples had trace amounts of mercury. Whatcom County has contracted USGS to study mercury sources and movement in the Lake Whatcom watershed. This study is on-going, and results should be available by 2004.

Lake Whatcom had relatively low concentrations of total organic carbon in raw water (<1–6.1 mg/L), as well as relatively low concentrations of trihalomethanes (THMs) in treated water. The quarterly averages for THMs in the Bellingham water distribution system ranged from 0.0195–0.0335 mg/L (the maximum recommended concentration is 80 µg/L or 0.08 mg/L). The THMs concentrations appear to be increasing, particularly in the fall, and there are significant regressions against time for both the annual and third quarter THMs.

The water quality at Site 2 seems to have changed during the past four years. Many of the indicators of hypolimnetic anoxia (e.g., hydrogen sulfide and ammonia) have been higher at Site 2 than Site 1. Late summer alkalinity peaks are appearing regularly at 20 m, hypolimnetic nitrate concentrations have dropped below detection limit, and hypolimnetic phosphorus has been higher than expected,

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<sup>2</sup>Exponent, 15375 SE 30th Place, Suite 250, Bellevue, WA 98007

based on historic data. These changes coincide with drastic reductions in the amount of water diverted from the Middle Fork of the Nooksack River, reductions in the water withdrawal from basin 2, a period of active residential construction around basin 2, as well as extreme and variable weather patterns.

Strawberry sill was sampled on October 9 and November 8, 2001, and January 10, February 14, April 2, May 9, June 6, July 1, August 8, and September 12, 2002. The water quality along the sill was very similar to Site 3.

The creeks were sampled on February 20 and July 17, 2002. Compared to the streams in forested areas, the residential streams typically had poorer water quality, with higher conductivities; higher ammonia, phosphorus, and total suspended solids concentrations; and much higher total and fecal coliform counts. These differences are typical for streams receiving urban runoff. The metals concentrations were near or 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. Chromium and arsenic were detected at several sites, but the concentrations were close to the limits of detection and probably do not represent a change in the water quality of the creeks.

Coliform counts were much higher in the Park Place drain and Silver Beach Creek than in the other streams. The Park Place drain and Silver Beach Creek exceeded Part A and B of the current Class AA fecal coliform standards<sup>3</sup> and would most likely fail the proposed criteria<sup>4</sup> that are being considered by the Washington State Department of Ecology. Anderson, Austin, Blue Canyon, and Smith Creeks passed Part A but exceeded Part B of the current fecal coliform standard; only Austin Creek would be likely to fail Part B of the proposed standards.

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks, and the data are included in electronic format with this report. A water balance was applied to Lake Whatcom to identify its major water inputs and

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<sup>3</sup>Current standard: Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; Part B: no more than 10 percent of all samples obtained for calculating the geometric mean value shall have values exceeding 100 colonies/100 mL (WAC 173-201A-030).

<sup>4</sup>Proposed standard: *E. coli* organism levels must not exceed a geometric mean value of 100/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200/100 mL. See Proposed chapter 173-201A WAC, December 19, 2002, <http://www.ecy.wa.gov/laws-rules/activity/wac173201a.html>.

outputs and to examine runoff and storage. The major inputs into the lake include surface and subsurface runoff (75.8%), direct precipitation (14.5%), and water diverted from the Middle Fork of the Nooksack River (9.6%). Outputs include Whatcom Creek (77.5%), the City of Bellingham (8.6%), Georgia Pacific (6.2%), evaporation (5.7%), the Whatcom Falls Hatchery (1.83%) and Water District #10 (0.26%). The majority of the rainfall in the Lake Whatcom watershed falls between October and May (90% in 2001/2002). During this time, the diversion magnitudes are insignificant compared to runoff volumes. In the summer, however, the volume of water diverted from the Nooksack River may be larger than the inputs from direct precipitation and runoff. In 2001/2002, for example, 2,726 MG was diverted during June–September, compared to 1,520 MG that entered the lake from direct precipitation and runoff. As a result, diverted water plays an important role in sustaining summer lake levels and reducing lake residence times.

Park Place and Brentwood wet ponds were sampled on December 17–19, 2001 (wet season - storm flow), March 25–27, 2002 (wet season - nominal flow), and July 30–August 1, 2002 (dry season - nominal flow). The South Campus storm water treatment facility was sampled on January 8–10, 2002 (wet season - storm flow), April 16–18, 2002 (wet-season - nominal), and July 23–25, 2002 (dry season - nominal flow). During 2001/2002, the best nutrient removal was achieved by the South Campus storm drain, with an average total suspended solids reduction of 71% and an average total phosphorus reduction of 56%. The Park Place and Brentwood wet ponds were only marginally effective at removing phosphorus and suspended solids from storm water. All three facilities achieved substantial reductions in coliforms and *Enterococcus* counts. The long term performance of the two wet ponds has been erratic, but both ponds tended to remove a greater percentage of sediments when the influent sediment concentration was high. Phosphorus removal has been marginal for both wet ponds. The South Campus facility was the only treatment system that has demonstrated consistent phosphorus removal, and its record is limited to two years, under high pollutant loading conditions.

# **1 Introduction**

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom also provides high quality water for the Georgia-Pacific Corporation mill<sup>5</sup>, which, prior to 2001, was the largest user of Lake Whatcom water. The lake and parts of the watershed provide recreational opportunities, as well as providing important habitats for fish and wildlife. The lake is used as a storage reservoir to buffer peak storm water flows in Whatcom Creek. Much of the watershed is zoned for forestry and is managed by state or private timber companies. Because of its aesthetic appeal, much of the Lake Whatcom watershed is highly valued for residential development.

The City of Bellingham and Western Washington University have collaborated on investigations of the water quality in Lake Whatcom since the early 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 2001/2002 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; monitor the effectiveness of the Park Place and Brentwood wet ponds and the South Campus storm water treatment system; collect supplemental water quality data from basin 3 near Strawberry sill; continue collection of hydrologic data from Anderson, Austin, and Smith Creeks; and update the hydrologic model for Lake Whatcom.

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<sup>5</sup>The Georgia-Pacific Corporation closed its pulp mill operations in March 2001, reducing its water requirements from 30–35 MGD to 7–12 MGD (Bill Evans, City of Bellingham Public Works Dept.).

This report is subdivided into the following sections:

**Section 1:** Introduction

**Section 2:** Lake Whatcom Monitoring

**Section 3:** Creek Monitoring

**Section 4:** Lake Whatcom Hydrology

**Section 5:** Storm Water Treatment Monitoring

**Section 6:** Quality Control

**Section 7:** References

**Section 8:** Tables

**Section 9:** Figures

**Appendix A:** Site Descriptions

**Appendix B:** Lake Whatcom Data

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 38 on page 264 (at the beginning of Appendix B) lists all abbreviations and units used to describe water quality analyses in this document.

## **2 Lake Whatcom Monitoring**

### **2.1 Site Descriptions**

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (see Figure 1, page 66, and Figures 190–191 in Appendix A.1, pages 258–259). Sites 1–2 are located at the deepest points in their respective basins. The Intake site is located adjacent to the underwater intake point where the City of Bellingham withdraws 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). One additional lake site was monitored on the 40-m depth contour on Strawberry sill (Figure 192, page 260 in Appendix A.1). Water samples were also collected at the City of Bellingham Water Treatment Plant gatehouse, which is located onshore and west of the intake site.

### **2.2 Field Sampling and Analytical Methods**

The lake was sampled ten times during the 2001/2002 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 2001/2002 were: October 2, November 6 & 8, and December 4 & 5, 2001; and February 12 & 14, April 2 & 4, May 7 & 9, June 4 & 14, July 1 & 2, August 6, 8, & 13, and September 3 & 5, 2002. The water quality parameters measured for the 2001/2002 lake monitoring program are listed in Table 1 on page 29 (see Section 8, beginning on page 28, 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 30 (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.<sup>6</sup> Plankton samples were placed in a cooler and returned to the laboratory unpreserved. The plankton sample volumes were measured in the laboratory and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. Unless otherwise noted, all other analyses were done by the personnel hired by this grant.

## **2.3 Results and Discussion**

### **2.3.1 Hydrolab data**

Figures 2–51 (pages 67–116) show the 2001/2002 Hydrolab data for temperature, dissolved oxygen, conductivity, and pH. Figures 52–71 show a ten year history of Hydrolab data for Lake Whatcom. Matthews, et al. (2000) reviewed the long-term data and discussed apparent trends, so only new observations on long-term trends are discussed below. The raw data are included in Appendix B.1, beginning on page 265, and in electronic format on the CD that accompanies this report.

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

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<sup>6</sup>AmTest, 14603 N.E. 87th St., Redmond, WA, 98052.

The summer Hydrolab profiles (e.g., Figures 47–51) illustrate how the lake stratifies into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). When stratified, the Hydrolab profiles show distinct differences between surface and bottom temperatures. Climatic differences alter the timing of lake stratification: if the spring is cool, cloudy, and windy, the lake will stratify later than when it has been hot and sunny.

In Lake Whatcom, stratification may begin as early as March or April, or as late as May or early June. All sites except the Intake, which is too shallow to develop a stable stratification, are usually stratified by mid-June. Stratification develops gradually, and once stable, 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 lake water temperatures at each site were either similar, or slightly lower than 2000/2001 (see Tables 3–7, pages 31–35 and Matthews, et al., 2002b). The average 2001/2002 temperature for the entire lake ( $10.9^{\circ}\text{C}$ ) was slightly lower than the historic average ( $11.21^{\circ}\text{C}$ ; October 1988–September 2001, all sites and depths) and the 2000/2001 average ( $11.03^{\circ}$ , all sites and depths). Although Sites 1 and 2 were only weakly stratified by June, the Hydrolab profiles showed intense warming near the surface (Figures 32–33, pages 97–98), which resulted in considerable variation in the epilimnetic temperature at these two sites. By July, all sites except the Intake had developed a stable stratification.

Despite the late stratification in basins 1 and 2, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures 42–43 and 57–58, pages 107–108 and 122–123). At Site 1, the 20 m oxygen concentrations dropped from 6.8 mg/L on June 14 to  $<2$  mg/L by August 10 (8 weeks).<sup>7</sup>

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

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<sup>7</sup>We were not able to measure oxygen concentrations lower than 2 mg/L during the summer of 2002 due to loss of Hydrolab sensitivity. See discussion in Section 6.



biological respiration consumes the oxygen dissolved in the water. Biological productivity and respiration are increased when there is an abundant supply of nutrients, as well as by other environmental factors such as warm water temperatures. In basin 3, which has very low concentrations of essential nutrients such as phosphorus, biological respiration has little influence on hypolimnetic oxygen concentrations (e.g., Figures 51 and 61, pages 116 and 126). In contrast, Site 1, which is located in nutrient-enriched waters, shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures 47 and 57, pages 112 and 122).

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. Pearson's  $r$  correlation analysis<sup>8</sup> of dissolved oxygen vs. date confirmed that there were statistically significant reductions in oxygen levels at all even depths  $\geq 12$  m from July through September (Figures 72–75, pages 137–140).<sup>9</sup>

A number of environmental factors can affect the rate of oxygen loss from the hypolimnion, either directly, by increasing biological respiration, or indirectly by increasing the residence time of water in the hypolimnion. Increased nutrient availability, higher water temperatures, and increased light intensity can stimulate biological productivity and respiration. Dry weather, early lake stratification, late turnover, reductions in the amount of water diverted from the Nooksack, and decreased discharges into Whatcom Creek could increase the residence time of water in the hypolimnion. In addition, if the lake level drops far enough, our sampling equipment (which measures depth from the surface) could be placed lower in the hypolimnion, thus creating the appearance of lower oxygen levels, when the only real change is lower lake levels. However, there have not been any correlations between hypolimnetic temperature and dissolved oxygen or lake level and dissolved oxygen during the same time period in which we detect the negative correlations between oxygen and date.

Low oxygen conditions are associated with a number of unappealing water quality problems in lakes, including loss of aquatic habitat; release of nutrients (phospho-

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<sup>8</sup>The Pearson's  $r$  correlation coefficient is a measure of the amount of change in the data that is predicted by "date." Strong positive or negative correlations will be close to  $\pm 1.0$ . Weak correlations will be close to zero. Statistically significant correlations have  $p$  values  $\leq 0.05$ .

<sup>9</sup>Only even depths were plotted on Figures 72–75 because early Hydrolab data were collected at 2 meter intervals.

rus 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 the drinking water treatment process. Hydrogen sulfide was detected at Site 1 (0.088 mg/L) and Site 2 (0.32 mg/L) on October 10, 2002, along with elevated concentrations of ammonia and phosphorus (Figures 91–92 and 111–112, pages 156–157 and 176–177). These compounds are all indicative of low oxygen conditions.

For the past four years, the concentrations of two water quality indicators of lake anoxia, ammonia and hydrogen sulfide, have been higher at Site 2 than at Site 1 (Table 8, page 36). Although there are no significant correlations at Site 2 between hypolimnetic oxygen and time, 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 difficult 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. We discuss the water quality changes at Site 2 in more detail on page 13.

During February and April, 2002, we measured unusually high dissolved oxygen concentrations throughout the lake, particularly at Sites 1–2 and the Intake. The oxygen concentrations were supersaturated, meaning that the amount of oxygen was higher than expected, based on the water temperature.<sup>10</sup> Supersaturation usually indicates intense algal photosynthesis, and although it is routinely measured in Lake Whatcom during the summer, it is not common during the winter and early spring. We have had continuing problems with our Hydrolab field meter, and although the instrument met all quality control calibration requirements and appeared to be functioning correctly on those dates, it is possible that the unusual readings were the result of equipment malfunction.

The remaining Hydrolab data, pH and conductivity, followed trends that were typical for Lake Whatcom, with only small differences between sites and depths except during the summer. During the summer the surface pH increased due to photosynthetic activity, especially at Site 1. Hypolimnetic pH values decreased and conductivity values increased due to decomposition and the release of dissolved compounds from the sediments. A significant long-term trend was apparent in the

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<sup>10</sup>The amount of oxygen that can dissolve in water depends on water temperature; colder water can hold more oxygen than warm water.

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

### **2.3.2 Other ambient water quality data**

The remaining water quality data that were collected monthly or bimonthly (nutrients, alkalinity, turbidity, Secchi depth, chlorophyll, bacteria, and plankton) are shown on Figures 76–155 (pages 141–220) and summarized in Tables 3–7 (pages 31–35). In order to provide a better analysis of the water quality patterns in the lake, the graphs include ten years of monitoring data. Matthews, et al. (2000) reviewed the long-term data and discussed apparent trends.

Because of the large amount of data collected for the Lake Whatcom monitoring program, only important or unusual patterns will be discussed in the text. The raw water quality data are listed in Appendix B, beginning on page 263. Long term lake and hydrograph data are included in electronic format on the CD that accompanies this report. The metals data are listed in Table 10 (page 38); the original AmTest data reports for metals and total organic carbon are included in Appendix B.7 (beginning on page 366).

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures 76–80, pages 141–145). During the summer the alkalinity and conductivity values at the bottom of Sites 1–2 increased due to decomposition and the release of dissolved compounds in the lower waters. The turbidity values were mostly less than 1–2 NTU except during late summer in samples from the lower depths at Sites 1 and 2 (Figures 81–85, pages 146–150). 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 86–105, pages 151–170). High ammonia concentrations

were measured just prior to overturn in the hypolimnia at Sites 1 and 2 (Figure 91, page 156). High hypolimnetic ammonia concentrations have been common at both sites for more than ten years; however, we have measured atypically high ammonia concentrations at Site 2 for the last four summers (see Site 2 discussion, beginning on page 13). Ammonia is produced during decomposition of organic matter. Ammonia is readily taken up by plants as a growth nutrient. In oxygenated environments, ammonia is rarely present in high concentrations because it is rapidly converted to nitrite and nitrate through biological and chemical processes. In low oxygen environments, such as the hypolimnia at Sites 1 and 2, ammonia accumulates until the lake destratifies.

Sites 3 and 4 had slightly elevated ammonia concentrations at 20 m. This was due to bacterial activity at the thermocline rather than low oxygen conditions. A similar pattern was observed by McNair (1995) in Lake Samish. Sites 3 and 4 also had slightly elevated ammonia concentrations at 80 m during late summer, which may have been due to organic decomposition near the bottom.

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures 96–100, pages 161–165), particularly at Site 1, where the epilimnetic nitrate concentrations fell below  $50 \mu\text{g-N/L}$ . Nitrogen is an essential nutrient for plankton, and this depletion of nitrate during the summer is an indirect measure of phytoplankton productivity. The availability of nutrients is a major factor in determining the amount of algal growth in a lake. Phosphorus is assumed to be the most common limiting nutrient in unproductive lakes; however, recent studies show that nitrogen limitation and phosphorus/nitrogen co-limitation are common in freshwater lakes (see Elser, et al., 1990). Phosphorus/nitrogen co-limitation seems to occur at Site 1 in Lake Whatcom just prior to overturn (Matthews, et al., 2002a). Coincident with low nitrate concentrations, late summer is when we usually find the highest densities of nitrogen-fixing Cyanophyta (bluegreen bacteria or cyanobacteria) in the plankton samples. Summer, epilimnetic nitrate concentrations decreased at Sites 2–4, but didn't fall below  $150 \mu\text{g-N/L}$ , making it unlikely that nitrogen was limiting at these sites.

The hypolimnetic nitrate concentrations dropped lower than the epilimnetic concentrations at Sites 1 and 2 ( $<10 \mu\text{g-N/L}$ ). In anaerobic environments, bacteria reduce nitrate ( $\text{NO}_3^-$ ) to nitrite ( $\text{NO}_2^-$ ) and nitrogen gas ( $\text{N}_2$ ). The historic data (1988 to present) indicate that this reduction has been common at Site 1, but was not detected at Site 2 until the summer of 1999.

Soluble phosphate concentrations were relatively low ( $<10 \mu\text{g-P/L}$ ) at all sites and depths (Figures 111–115, pages 176–180). Total phosphorus concentrations were high at Sites 1 and 2 during late summer, but relatively low at other sites (Figures 116–120, pages 181–185). 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  $20 \mu\text{g-P/L}$  (Figures 116 and 117). 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 119 and 120). In September 2002 the concentration of total phosphorus in the surface sample at Site 1 was unusually high. This is an atypical result, and may have been due to sample contamination.

Site 1 continued to have the highest chlorophyll concentrations of all the sites (Figures 121–125, pages 186–190). The chlorophyll concentrations during the summer of 2002 were about the same as in previous years. Samples from 20 m usually had lower chlorophyll concentrations than samples nearer the surface. Twenty meters is near the lower limit of the photic zone, and the low light intensity is not optimal for algal growth. Peak chlorophyll concentrations were usually at 0–15 m.

The plankton counts at all sites were dominated by Chrysophyta<sup>11</sup> (Figures 126–135, pages 191–200). Substantial blooms of Cyanophyta and Chlorophyta were also measured at all sites during summer and late fall. Previous analyses of algal biovolume in Lake Whatcom indicated that although Chrysophyta dominate the numerical plankton counts, Cyanophyta and Chlorophyta often dominate the plankton biovolume, particularly in late summer and early fall (Matthews, et al., 2002b).

Secchi depths showed no clear seasonal pattern because transparency in Lake Whatcom is a function of both summer algal blooms and winter storm events (Figures 136–140, pages 201–205).

Most of the coliform and *Enterococcus* counts were low ( $\leq 50 \text{ cfu}^{12}/100 \text{ mL}$  for total coliforms and  $\leq 10 \text{ cfu}/100 \text{ mL}$  for fecal coliforms and *Enterococcus*; Figures 141–155, pages 206–220). The total coliform counts at Site 2 were unusually

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<sup>11</sup>The Chrysophyta phylum name has been changed to Heterokontophyta in many taxonomies.

<sup>12</sup>colony forming unit

high in September, October, and December 2001, but the fecal coliform and *Enterococcus* counts were low during these months. The fecal coliform and *Enterococcus* counts were slightly elevated at Site 3 in February 2002, which may have been due to storm 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.6, beginning on page 319, for raw data). The Bloedel-Donovan bacteria counts tend to be slightly higher than mid-basin counts, but the 5-year (1998–2002) geometric mean for fecal coliforms was 7.1 cfu/100 mL, which passed both Part A and B of the existing Class AA standards for fecal coliforms<sup>13</sup> and would most likely pass the proposed *E. coli* standard<sup>14</sup> for recreational waters. The swimming area at Bloedel-Donovan was closed periodically during the summer of 2002 due to high coliform counts in the nearshore beach area. The City of Bellingham is investigating the source(s) of coliforms in the beach area. Preliminary data suggest that the high coliform counts may be associated with fine sediments in the nearshore area at Bloedel-Donovan. High coliform counts were also measured in Silver Beach Creek, but not in the offshore beach at Bloedel-Donovan, and not in nearshore or offshore samples collected from Lake Padden and Lake Samish (Table 9, page 37; Appendix B.6, beginning on page 319).

The metals data for Lake Whatcom are included in Table 10 (page 38). This table includes only the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); Appendix B.7 (beginning on page 366) lists concentrations for an additional 24 metals that are included as part of the analytical procedure used by AmTest. In 1999, AmTest upgraded their equipment and analytical procedures for most metals. As a result, many of the analyses now have lower detection limits, resulting in fewer “below detection” data. These newly detected metals probably do not represent increases in the metals concentrations in the lake.

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

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<sup>13</sup>Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; Part B: no more than 10 percent of all samples obtained for calculating the geometric mean value shall have values exceeding 100 colonies/100 mL.

<sup>14</sup>Proposed standard: *E. coli* organism levels must not exceed a geometric mean value of 100/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200/100 mL.

Zinc was detected at all sites. Iron concentrations were elevated in most of the bottom samples (and one surface sample). The highest concentrations, 0.72 mg/L and 0.62 mg/L, were measured at Sites 1 and 2, respectively. The higher iron concentrations at Sites 1 and 2 were the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water. Lead (Pb) was detected at Site 4 (surface and bottom samples), but because the concentrations were at the level of detection, it is unlikely that this represents an increase in lead concentrations at this site.

Soluble iron has been present in raw water at the Lake Whatcom gatehouse<sup>15</sup> during late summer and fall (Figure 156, page 221), particularly during the first few weeks after the lake destratifies (see Figure 156, October–November peaks). Iron may also be introduced into the water supply during routine maintenance in the vicinity of the gatehouse (e.g., March 3, 2001). Following lake turnover, most soluble iron is converted to insoluble iron, which slowly settles to the bottom. As a result, iron concentrations are usually  $\leq 0.05$  mg/L.

From July 2001 through September 2002, IWS collected additional water samples to measure water column mercury concentrations in response to concerns about mercury detected in fish and sediment samples from the lake (Serdar, et al., 1999; Mueller, et al., 2001). The samples were collected from the surface and bottom at Sites 1–4 and the Intake, and were sent to AmTest for low-level mercury analyses (Table 11, page 39; Appendix B.7, beginning on page 366). On July 17, 2001, the water samples were split and sent to two testing laboratories (AmTest and Environment Canada<sup>16</sup>) to evaluate analytical variation between laboratories (Table 12, page 40; see Appendix B.8, beginning on page 536 for Environment Canada data).

The 2001–2002 water column concentrations of mercury were very low and most were below detection levels ( $<0.0002$  mg/L).<sup>17</sup> Mercury was detected in water samples from the Intake (0.0005 mg/L) and the bottom of Site 3 (0.0004 mg/L) on August 7, 2001, but because these concentrations are close to the analytical

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<sup>15</sup>The gatehouse is located along the shoreline of basin 2 adjacent to the Intake.

<sup>16</sup>Environment Canada, Pacific Environmental Science Centre, 2645 Dollarton Hwy, North Vancouver, BC, Canada, V7H–1B1.

<sup>17</sup>Because of the public concern over mercury in Lake Whatcom, many of the water samples collected since 2001 have been analyzed using lower detection limits. In order to help clarify which methods were used, detection limits will be listed for all mercury results discussed in this report.

detection limit, they should be considered estimates. The City of Bellingham also detected mercury at the gatehouse on August 28, 2001 ( $\sim 0.0004$  mg/L), as well as on June 5 & 12, 2001 ( $\sim 0.0002$ – $0.0003$  mg/L), but the concentrations were below the detection limit ( $0.0005$  mg/L), and should also be considered estimates (Peg Wendling, City of Bellingham Public Works Department). The City monitors mercury concentrations on a regular basis at the gatehouse and in treated drinking water. Most of the samples collected since August 2001 have had mercury concentrations lower than  $0.0005$  mg/L.

On October 15, 2001, water samples were collected from Lake Whatcom, the Middle Fork of the Nooksack River (upstream from the diversion channel), and several tributaries to the lake by Exponent.<sup>18</sup> The samples were analyzed by Frontier Geosciences,<sup>19</sup> a laboratory that specialized in measuring extremely low concentrations of total and methyl mercury (Table 13, page 41; Appendix B.8). On September 23, 2002, December 17, 2002, and January 1, 2003, the City collected additional water samples from the gatehouse and treated water, and sent these samples to Frontier Geosciences for analysis (Table 14, page 42).

Because Frontier Geosciences can measure trace amounts of mercury ( $0.00000015$ – $0.00000002$  mg/L), most samples analyzed by Frontier Geosciences had detectable quantities of mercury. The highest total and methyl mercury concentrations in the lake were from the bottom of Site 2. The highest stream concentrations were measured in the Middle Fork of the Nooksack River, Anderson Creek (which carries diversion water from the Middle Fork of the Nooksack), and the Park Place drain. The gatehouse mercury concentrations were slightly higher than treated water, but even the highest concentration ( $0.00000079$  mg/L at the gatehouse on January 14, 2003) was well below the EPA drinking water standard for mercury ( $0.002$  mg/L).

In response to community concern over mercury concentrations in Lake Whatcom, Whatcom County has contracted USGS to study mercury sources and movement in the Lake Whatcom watershed. This study is on-going, and results should be available by 2004.

The Lake Whatcom total organic carbon (TOC) concentrations ranged from  $<1$  mg/L to  $6.1$  mg/L (Table 15, page 43). These concentrations were slightly higher than those measured in the previous sampling year, but were within normal ranges

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<sup>18</sup>Exponent, 15375 SE 30th Place, Suite 250, Bellevue, WA 98007.

<sup>19</sup>Frontier Geosciences, Inc., 414 Pontius Ave N., Suite B, Seattle, WA 98109.



for Lake Whatcom. Total organic carbon concentrations, along with plankton and chlorophyll data, are used to help assess the likelihood of developing potentially harmful disinfection by-products (e.g., trihalomethanes or THMs) through the reaction of chlorine with organic compounds during the drinking water treatment process. Lake Whatcom had relatively low concentrations of TOC in raw water, as well as relatively low concentrations of THMs in treated water.

During the 2001/2002 sampling period, the quarterly averages for THMs in the Bellingham water distribution system ranged from 0.0195–0.0335 mg/L, which was well below the recommended maximum THMs concentration for treated drinking water (80  $\mu\text{g/L}$ ). Beginning in the fall of 1998, however, THMs concentrations started increasing in the treated water, particularly in the third (fall) quarter (Figure 157, page 222). This pattern has been consistent for the past five years, and is currently showing a significant regression against time for both the annual and third quarter THMs averages. Haloacetic acids (another important disinfection by-product) do not appear to be increasing with time (Figure 157).

### 2.3.3 Site 2 trends

Although Site 2 normally exhibits hypolimnetic oxygen depletion by October, anoxic conditions are usually confined to the deepest samples (>15 m). This portion of the lake is relatively small, and is represented by very few samples in any given year. Because of this, we have not seen any statistical trends in hypolimnetic oxygen depletion at Site 2. However, during the past four summers, many of the indicators of hypolimnetic anoxia have been higher at Site 2 than Site 1. Hydrogen sulfide and ammonia concentrations have been higher at Site 2 for the past four years (Table 8, page 36; Figure 92, page 157). Late summer alkalinity peaks have begun appearing regularly at Site 2, 20 m (Figure 77, page 142). Although this has been a common pattern at Site 1, it was uncommon at Site 2 prior to 1999. Hypolimnetic nitrate concentrations dropped to below detection, and hypolimnetic phosphorus concentrations have been unusually high for the past four summers (Figure 97 and 117, pages 162 and 182). Table 16 (page 44) shows that there are significant differences between the average alkalinity, ammonia, nitrate, and total phosphorus concentrations for samples collected during August–October, 1988–1998 vs. 1999–2003 in the deepest samples from Site 2.

These water quality changes coincide with drastic reductions in the amount of water diverted from the Middle Fork of the Nooksack River (Figure 166, page 231)

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

#### **2.3.4 Strawberry sill data**

Strawberry sill was sampled on October 9 and November 8, 2001, and January 10, February 14, April 2, May 9, June 6, July 1, August 8, and September 12, 2002 to measure the parameters specified in Table 17 (page 45).<sup>20</sup>

The sill data are summarized in Tables 18–20 (pages 46–48) and the raw data are included in Appendix B.4 (beginning on page 288). The AmTest data reports for the metals and total organic carbon analyses are included in Appendix B.7 (beginning on page 366).

The water quality along the sill was very similar to Site 3. The water temperatures along the sill were generally within 1–2° C of temperatures at Site 3. The total phosphorus concentrations were slightly higher in the sill samples compared to Site 3, but this is not a consistent pattern (see Matthews, et al., 2002b).

Most of the metals concentrations were at or near the detection limits. Iron and zinc were detectable, but within ranges normal for the lake. Most of the sill total organic carbon concentrations were similar to Site 3. On October 9, 2001, unusually high lead concentrations were measured in both of the sill samples (0.010–0.019 mg/L); the reason for these high concentrations is not known.

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<sup>20</sup>There are no Hydrolab data from July 1, 2002 due to equipment failure.

## **3 Creek Monitoring**

### **3.1 Site Descriptions**

Seven creeks were sampled twice during the 2001/2002 monitoring program, including Austin Creek, Anderson Creek<sup>21</sup>, the Park Place storm drain, Silver Beach Creek, Smith Creek, the unnamed creek that flows through the Wildwood campground, and the northern unnamed creek on Blue Canyon Rd. (Blue Canyon #1). The exact sampling locations for these sites are described by Walker, et al. (1992), and are summarized in Appendix A.2 (beginning on page 261).

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

### **3.2 Field Sampling and Analytical Methods**

The creeks were sampled on February 20 and July 17, 2002. The water quality parameters measured for the 2001/2002 creek monitoring program are shown in Table 21 (page 49). The analytical procedures are summarized in Table 2 (page 30). 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,

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<sup>21</sup> Anderson Creek was added to our routine sampling effort beginning in February 1995.

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

### **3.3 Results and Discussion**

The primary purpose for the biannual creek monitoring was to provide data that can be compared to the more complete data set generated in 1990 during the storm water runoff project (Walker, et al., 1992). Tables 22–23 (pages 50–51) show the recent creek water quality data compared to the 1990 average water quality values for each creeks. Tables 24–26 show metals, total organic carbon, and coliform data from the 2001/2002 sampling period.

Most of the 2001/2002 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 concentrations were slightly lower in the Park Place drain and Silver Beach Creek, compared to the forested streams. This is not unusual for storm drains and slow moving residential streams

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. Silver Beach Creek had unusually high total suspended solids and turbidity values in the summer, along with unusually high total phosphorus and total nitrogen concentrations. Although the exact cause for these elevated concentrations is not known, the data are consistent with sediment loading, possibly from localized construction or soil disruption.

Except for the unusually high July total nitrogen concentration in Silver Beach Creek, the nitrite/nitrate and total nitrogen concentrations were higher in winter samples due to leaching of soluble nitrogen compounds during the wet season. Ammonia concentrations were highest in the Park Place drain. In turbulent water,

ammonia is quickly volatilized or converted to nitrate, so the ammonia probably came from near-by watershed sources such as animal wastes, swampy areas, or the Park Place storm water treatment wet pond.

The phosphorus concentrations continued to be higher in the residential creeks (Park Place drain and Silver Beach Creek) than in the forested creeks (Smith Creek, Wildwood Creek, and Blue Canyon Creek). Although the Park Place drain has had a storm water treatment pond in place since 1994, the pond has not proven to be particularly effective for removing phosphorus (see Section 5).

Silver Beach Creek and the Park Place drain had the highest total organic carbon concentrations during February (Table 25, page 53). All creeks had very low concentrations of total organic carbon in July (<1 mg/L).

The metals concentrations were near, or 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. Chromium and arsenic were detected at several sites, but the concentrations were close to the limits of detection and probably do not represent a change in the water quality of the creeks.

Coliform counts (Table 23, page 51) were much higher in the Park Place drain and Silver Beach Creek<sup>22</sup> than in the other streams. The Park Place drain and Silver Beach Creek exceeded Part A and B of the current Class AA fecal coliform standards (Table 26, page 54).<sup>23</sup> Anderson, Austin, Blue Canyon, and Smith Creeks passed Part A but exceeded Part B of the fecal coliform standard because more than 10% of the fecal coliform counts were greater than 100 cfu/100 mL. Of the creeks that passed Part A but failed Part B, Austin Creek had the largest number of samples exceeding 100 cfu/100 mL (4 out of the last 10 samples). The historic data from Austin Creek (Table 27, page 55; Appendix B.6, beginning on page 319) show that the creek coliform counts are usually lower during the winter than the summer.

The Washington State Department of Ecology is considering revisions to Chapter 173–201A of the Washington Administrative Code, Water Quality Standards for

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<sup>22</sup>Silver Beach Creek was placed on the 1998 303D List of Impaired and Threatened Waterbodies for high coliform counts.

<sup>23</sup>Current standard: Freshwater - Part A: fecal coliform organism levels shall not exceed a geometric mean value of 50 colonies/100 mL; Part B: no more than 10 percent of all samples obtained for calculating the geometric mean value shall have values exceeding 100 colonies/100 mL.

Surface Waters of the State of Washington. These revisions include major changes in the bacteria standards in surface water. Silver Beach Creek and the Park Place drain would most likely fail to meet the new criteria<sup>24</sup>, and Austin Creek would likely fail the second part of the criteria because 30% of the 1998–2002 fecal counts (3 out of the last 10 samples) were greater than 200 col/100 mL. (We are assuming that most of the fecal coliforms are *E. coli*, which is usually true in surface water.) Anderson, Blue Canyon, and Smith Creeks would most likely pass both parts of the proposed criteria. Because the proposed criteria are based on *E. coli* rather than fecal coliforms, the City began measuring *E. coli* counts in the fall of 2002, and we will include these data in future reports.

## 4 Lake Whatcom Hydrology

### 4.1 Hydrograph Data

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks. The location of each hydrograph is described in Appendix A.2 (beginning on page 261). Copies of the hydrograph data are included on the CD that accompanies this report, and the data are summarized in Figures 158–160 (pages 223–225).

The hydrograph data were recorded at 30 minute intervals until mid-summer, when new recorders were installed at all sites. The new recorders log data at 15 minute intervals. The primary reason for changing the logging interval was to conform with USGS hydrograph data that are being collected at six additional sites in the Lake Whatcom watershed (Brannian, Carpenter, Euclid, Millwheel, Olsen, and Silver Beach Creeks).

Figure 161 (page 226) shows the rating curves for each hydrograph. The rating curve for Anderson Creek was revised after March 18, 2001, following the removal of a large debris jam. All other rating curves include data collected from the beginning of operation for each hydrograph.

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<sup>24</sup>Proposed standard: *E. coli* organism levels must not exceed a geometric mean value of 100/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200/100 mL.

## 4.2 Water Budget

A water balance was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage. The traditional method of estimating a water balance (i.e., inputs - outputs = change in storage) was employed. Inputs into the lake include direct precipitation, water diverted from the Middle Fork of the Nooksack River (diversion), surface runoff and groundwater. Outputs include evaporation, Whatcom Creek, the Hatchery, City of Bellingham, Georgia Pacific, and Water District #10. All of these are measured quantities provided by the City of Bellingham except for evaporation, surface runoff and groundwater.

Daily direct-precipitation magnitudes were estimated using the precipitation data recorded at the Geneva Gate house, Smith Creek, and Brannian Creek hatchery gauges. The Thiessen polygon method (Dingman, 1994) was used to estimate the direct-precipitation areal average over the lake by weighting the precipitation at each gauge by a respective area percentage. The weighted areas were determined by a Thiessen Polygon extension in ArcGIS (Figure 162, page 227). The average direct-precipitation depth (inches) for a given day was converted to a volume in millions of gallons (MG) via a rating curve generated from the lake level-area data developed by Ferrari and Nuanes (2001). The rating curve accounts for changes in surface area of the lake due to lake level changes. The average annual direct rainfall to the lake for the water year 2001/2002 was 52.2 inches.

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 energy-balance and mass transfer concepts. The method requires daily average incident solar radiation, air temperature, dew point temperature, and wind speed. Hourly data from two weather stations in the watershed (Smith Creek and Brannian Creek) were used to estimate daily averages. Pan evaporation data collected from the Post Point weather station were used to validate the estimates. The daily evaporation depths (inches) predicted by the model were converted to volumes (MG) via the Ferrari and Nuanes (2001) rating curve for lake level-area data.

Daily change in storage was determined by subtracting each day's lake level by the subsequent day's level. This resulted in negative values when the lake level was decreasing and positive values when the lake level was increasing. The daily net change in lake level (inches) was converted to volumes (MG) via the Ferrari and Nuanes (2001) rating curve for lake level-area data.

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

The yearly water balance totals for 1999/2000, 2000/2001, and 2001/2002 are listed in Table 28 (page 56). The total input to the lake in 2001/2002 was 48,691 MG. Of the total, 75.8% was surface/subsurface runoff (including groundwater), 14.5% direct precipitation, and 9.6% was diversion water. As indicated in Table 28, the previous year, 2000/2001, was exceptionally dry (total inputs = 24,938 MG), while the inputs in 1999/2000 were nearly identical to 2001/2002 (48,247 and 48,691, respectively). It should be noted, however, that the water balance estimates for the year 1999/2000 were calculated using a constant lake surface area of 4994 acres, not the rating curve of Ferrari and Nuanes (2001).

The total outputs in 2001/2002 summed to 49,341 MG. The largest output was Whatcom Creek (77.5%), followed by the City of Bellingham (8.6%), Georgia Pacific (6.2%), evaporation (5.7%), the Whatcom Falls Hatchery (1.8%) and Water District #10 (0.3%). As indicated from the values in Table 28, the 2001/2002 total output was similar in magnitude to the 1999/2000 total output. Note, however, the differences between the Whatcom Creek and Georgia Pacific magnitudes for the two years. It appears that the decrease in volume withdrawn by Georgia Pacific due to operation down sizing, was compensated by an increase in discharge in Whatcom Creek in 2001/2002.

The daily water balance quantities were summed into weekly totals. The weekly totals were used to generate plots of the input, output, change in storage, and estimated runoff volumes (Figures 163–165, pages 228–230). All the inputs except runoff are shown in Figure 163 and all the outputs except Whatcom Creek are shown in Figure 164. The runoff and Whatcom Creek are shown with the change in storage values in Figure 165 because they have similar magnitudes. As indicated by the plots in Figure 165, large storage changes occurred when the runoff was high and the Whatcom Creek discharge was low, and vice versa.



Table 29 (page 57) lists the 2001/2002 total input and output volumes along with the corresponding monthly percentage of each total. Table 29 also shows the 2001/2002 June–September input and output volumes and their corresponding percentages. June through September is a critical water quality interval because the lake is stratified during this time.

The majority of the rainfall in the Lake Whatcom watershed falls between October and May (90% in 2001/2002). During this time, the diversion magnitudes are insignificant compared to runoff volumes. In the summer, however, the volume of water diverted from the Nooksack River may be larger than the inputs from direct precipitation and runoff. In 2001/2002, for example, 2,726 MG was diverted during June–September, compared to 1,520 MG that entered the lake from direct precipitation and runoff. As a results, diverted water plays an important role in sustaining summer lake levels and reducing lake residence times.

## **5 Storm Water Treatment Monitoring**

The objective of this portion of the lake monitoring project was to evaluate the water treatment efficiencies in the Brentwood and Park Place wet ponds that were constructed to treat storm water runoff prior to release into Lake Whatcom. In March 2001, a new sampling site was added at the South Campus storm water treatment facility near Western Washington University. Although this site is located outside the Lake Whatcom watershed, the site incorporates a “state-of-the-art” rock/plant filter to treat storm water runoff, which should provide an indication of the levels of treatment that might be attainable within the watershed for systems incorporating similar designs. The locations of the Lake Whatcom watershed monitoring sites (Brentwood and Park Place) are shown on Figure 167 (page 232). The South Campus monitoring site is located south of Bill McDonald Pkwy, west of 25th Street, and north of Taylor Avenue (Figure 168, page 233).

### **5.1 Sampling procedures**

Park Place and Brentwood wet ponds were sampled on December 17–19, 2001 (wet season - storm flow), March 25–27, 2002 (wet season - nominal flow), and July 30–August 1, 2002 (dry season - nominal flow). The South Campus storm

water treatment facility was sampled on January 8–10, 2002 (wet season - storm flow), April 16–18, 2002 (wet-season - nominal flow), and July 23–25, 2002 (dry season - nominal flow).

Composite and grab samples were collected at the inflow and outflow(s) at each site (Table 30, page 58).<sup>25</sup> 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 and *Enterococcus* were analyzed by the City of Bellingham.

## 5.2 Results and Discussion

The Park Place wet pond has been monitored since 1994 and annual water quality data are summarized by Matthews, et al. (2001). Monitoring in the Brentwood pond began in 1998 and monitoring at the South Campus facility began in 2001. Both ponds have extensive macrophyte growth, as shown on Figures 169–170 (pages 234–235). The South Campus storm water treatment facility was constructed during the fall and winter of 2000; monitoring began in March 2001. The rock/plant filters were planted with cattails (*Typha latifolia*), but only minimal growth had occurred by the end of the first summer (Figure 171, page 236). Due to excessive sediment loading from campus construction activities during 2001–2002, the gravel was replaced and new vegetation was planted in the fall of 2002.

Tables 31–34 (pages 59–62) show the raw data from the Park Place, Brentwood, and South Campus treatment systems. The tables also show the annual and seasonal percent reduction in concentration of contaminants between the inflow and outflow at the Park Place and Brentwood ponds and South Campus storm water treatment facility. Average percent reductions were computed as follows:

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

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<sup>25</sup>Brentwood and Park Place have a single outflow; the South Campus site has two outflows.

The best nutrient removal was achieved by the South Campus storm drain, with an average total suspended solids reduction of 71% and an average total phosphorus reduction of 56%. As in previous years, the two wet ponds (Park Place and Brentwood) were only marginally effective at removing phosphorus and suspended solids from storm water. Park Place achieved an average total suspended solids reduction of 37%, which is its best performance in years. The Brentwood facility often had higher suspended solids concentrations in its effluent than in water entering the pond (an average increase of 77%), and neither facility achieved a significant reduction in phosphorus or total organic carbon. The wet ponds were also inconsistent in removing metals from storm water. All three facilities achieved substantial reductions in coliforms and *Enterococcus*.

The long term performance of the two wet ponds has been highly erratic (Figures 172–174, pages 237–239). At least part of the poor performance may be due to the effects of pollutant concentration on removal efficiency. In many storm water treatment systems, the highest removal efficiencies occur when contaminant loading is high (Schueler, 1996). The Park Place wet pond had much higher sediment removal efficiencies when the total suspended solids concentration at the inlet was higher than 10 mg/L (Table 35, page 63). At this level of sediment loading, Park Place performed nearly as well as the South Campus facility. Brentwood rarely had sediment loads higher than 10 mg/L, so its performance can only be compared at lower sediment loads, which averaged a dismal -65% (65% *increase*) at the outlet.<sup>26</sup>

Phosphorus removal has been marginal for both wet ponds (Figure 175 and Table 35). The South Campus facility was the only treatment system that has demonstrated consistent phosphorus removal, and its record is limited to two years, under high pollutant loading conditions. Its success may also be due to design features that help retain fine sediment and encourage biological uptake by rooted perennials. The Brentwood facility had much better phosphorus removal efficiencies under high loading conditions (Table 35); however, these conditions are not common in the Lake Whatcom watershed. It is important to note that the “low” pollutant loading concentrations for phosphorus and sediment in Table 35 represent concentrations that are elevated compared to nonresidential streams in the watershed, and may still contribute to lake eutrophication.

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<sup>26</sup>Algal growth may have contributed to the increase in suspended sediments in the effluent from the Brentwood wet pond.

## 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 30). Single-blind quality control tests were conducted as part of the IWS laboratory certification process. The 2001/2002 results are presented in Table 36 (page 64). All results from the single-blind tests were within acceptance limits.

Laboratory duplicates were analyzed for at least 10% of all water quality parameters except the Hydrolab data. Laboratory duplicates were used to create control charts<sup>27</sup> that track analytical performance over time. Upper and lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper and lower warning limits ( $\pm 3$  from mean pair difference) were developed using 2000–2001 data (upper examples in Figures 176–183, pages 241–248), and used to evaluate laboratory duplicates from 2002 (lower examples in Figures 176–183). The control charts indicate that the laboratory duplicates have been consistent over time.

Separate field duplicates were collected and analyzed for at least 10% of all of the water quality parameters except the Hydrolab data. To check the Hydrolab measurements, duplicate samples were analyzed for at least 10% of the Hydrolab measurements using water samples collected from the same depth as the Hydrolab measurement. The field duplicates results were in close agreement, given that they came from different water samples (Figures 184–188, pages 249–253). Field duplicates are rarely as close as laboratory duplicates. As in previous years, systematic bias was observed in the conductivity results because the Hydrolab field meter is more sensitive than our laboratory meter. This appears as a flattening of the laboratory conductivity response at  $\sim 60 \mu\text{S}$  (Figure 184). In addition, the conductivity probe in the current Hydrolab unit is more sensitive than the Surveyor II Hydrolab used in the early 1990s, which creates the appearance of a decrease in the lake's conductivity over time (Figures 67–71, pages 132–136). These conductivity differences were generally  $\leq 5 \mu\text{S}$ . There was a small systematic bias in the pH data, with the Hydrolab results showing a more extreme range than the laboratory pH results. This is most likely due to slight changes in the amount of dissolved  $\text{CO}_2$  and associated inorganic carbon ions (bicarbonate and carbonate)

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<sup>27</sup>The Institute for Watershed Studies maintains control charts for laboratory duplicates, check standards, and spikes for all of our routine water quality analyses. Additional quality control information may be obtained by contacting the Institute director.

that occurred after the samples were collected. This type of pH shift is common in low alkalinity water samples.

The median difference between Hydrolab and Winkler dissolved oxygen values was 0.47 mg/L, and most of the samples differed by less than 1.0 mg/L. As in previous years, the only extreme differences occurred in samples collected in late summer from near the thermocline in basins 1 or 2. These differences are to be expected, and are caused by collecting water samples from slightly different depths at the thermocline. During the summer of 2002, however, we experienced a significant drop in Hydrolab sensitivity when measuring extremely low oxygen concentrations. Despite frequent repairs and equipment replacement by Hydrolab, we were not able to measure oxygen concentrations less than 2.0 mg/L with any accuracy. Because of this, we censured all oxygen values less than 2.0 mg/L from the 2002 data records. In addition, the Hydrolab results were consistently higher than the Winkler results in the 12–15 mg/L range. Although the Hydrolab unit we used in 2001/2002 is relatively new, and has been sent to Hydrolab repeatedly for repair and service, it does not appear to be as accurate as previous units. We are working with the City to test alternate field meters.

As part of our regular field quality control protocols, we measure initial and ending surface Hydrolab readings at each site. This is done to verify that we allowed a sufficient equilibration time during the first few samples for the Hydrolab to record accurate values. The results, shown in Figure 189 (page 254), indicate that there was no consistent bias between surface and bottom conductivity, pH, or temperature readings. There was a slight tendency for the ending dissolved oxygen values to be higher than the initial values. This may be consistent with the loss of Hydrolab meter sensitivity that caused censoring of the low oxygen values.

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## **8 Tables**



Parameter	2001 Oct	Nov	Dec	2002 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 disk	•	•	•		•		•	•	•	•	•	•	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 <sup>†</sup> (arsenic, cadmium, chromium, copper, iron, lead, mercury <sup>‡</sup> , nickel, zinc)												•	Sites 1, 2, 3, 4, Intake - 0.3 m and bottom only
Low-level Mercury <sup>§</sup>	○		○		○		○	○				○	Sites 1, 2, 3, 4, Intake - 0.3 m and bottom only
Total O. Carbon					•							•	Sites 1, 2, 3, 4, Intake - 0.3 m and bottom only
Chlorophyll	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4 - 0.3, 5, 10, 15, 20 m; Intake - 0.3, 5, 10 m
Plankton	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake; 5 m
Bacteria	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake, Bloedel-Donovan; 0.3 m
H <sub>2</sub> S - opt										•	•	•	Sites 1, 2 - bottom only

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

<sup>‡</sup>Conventional mercury analysis detection limit = 0.01 mg/L.

<sup>§</sup>Low-level mercury analysis detection limit = 0.0002 mg/L.

Table 1: Lake Whatcom 2001–2002 lake monitoring schedule

Parameter	Method	Historic DL <sup>†</sup>	2001/2002 MDL <sup>†</sup>	Sensitivity or Confidence limit
Conductivity-fi eld	Hydrolab (1997), fi eld meter	—	—	± 2 µS/cm
Conductivity-lab	APHA (1998) #2510, low-level, SOP-LW-9	—	—	± 2.2 µS/cm
Dissolved oxygen-fi eld	Hydrolab (1997), fi eld meter	—	—	± 0.1 mg/L
Dissolved oxygen-lab	APHA (1998) #4500-O.C., Winkler, SOP-LW-12	—	—	± 0.1 mg/L
pH-fi eld	Hydrolab (1997), fi eld meter	—	—	± 0.1 pH unit
pH-lab	APHA (1998) #4500-H <sup>+</sup> , low-ionic, SOP-LW-8	—	—	± 0.1 pH unit
Temperature	Hydrolab (1997), fi eld meter	—	—	± 0.1 °C
Alkalinity	APHA (1998) #2320, low level, SOP-IWS-15	—	—	± 0.5 mg/L
Discharge	Lind (1985), rating curve, SOP-IWS-6	—	—	—
Secchi disk	Lind (1985)	—	—	± 0.1 m
T. suspended solids	APHA (1998) #2540 D, gravimetric, SOP-LW-22	2 mg/L	2 mg/L	± 1.5 mg/L
Turbidity	APHA (1998) #2130, nephelometric, SOP-LW-11	—	—	± 0.2 NTUs
Ammonia	APHA (1998) #4500-NH <sub>3</sub> , phenate, SOP-LW-21	10 µg-N/L	3.3 µg-N/L	± 2.4 µg-N/L
Nitrite/nitrate	APHA (1998) #4500-NO <sub>3</sub> I., Cd reduction, SOP-IWS-19	20 µg-N/L	4.9 µg-N/L	± 4.7 µg-N/L
T. nitrogen	APHA (1998) #4500-N C., Ebina et al. (1983), SOP-IWS-19	100 µg-N/L	10.5 µg-N/L	± 9.7 µg-N/L
Sol. phosphate	APHA (1998) #4500-P G., ascorbic acid, SOP-IWS-19	5 µg-P/L	0.8 µg-P/L	± 2.0 µg-P/L
T. phosphorus	APHA (1998) #4500-P H., persulfate digestion, SOP-IWS-19	5 µg-P/L	1.8 µg-P/L	± 3.6 µg-P/L
Chlorophyll	APHA (1998) #10200 H, acetone, SOP-IWS-16	—	—	± 0.1 mg/m <sup>3</sup>
Plankton	Lind (1985), Schindler trap	—	—	—
Total coliform (City)	APHA (1998) #9222 B, membrane fi lter	—	—	—
Fecal coliform (City)	APHA (1998) #9222 D, membrane fi lter	—	—	—
<i>Enterococcus</i> (City)	APHA (1998) #9223 A (mod.), MPN-methyl.	—	—	—

<sup>†</sup> 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 <sup>†</sup>	SD	Min.	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	19.7	1.7	17.2	25.7
Conductivity - Hydrolab (μS/cm)	57.1	3.3	52.5	71.2
Conductivity - lab (μS/cm)	62.0	2.9	59.7	72.4
Dissolved oxygen (mg/L)	9.7	3.2	0.2	14.2
pH	7.4	0.5	6.4	8.5
Temperature (°C)	11.5	4.5	5.3	21.6
Turbidity (NTU)	1.0	1.1	0.5	8.3
Nitrogen, ammonia (μg-N/L)	19.2	35.1	<10	176.2
Nitrogen, nitrate/nitrite (μg-N/L)	238.6	121.7	<20	397.1
Nitrogen, total (μg-N/L)	393.6	88.9	209.6	528.3
Phosphorus, soluble (μg-P/L)	<5	1.0	<5	7.0
Phosphorus, total (μg-P/L)	10.6	10.1	<5	62.9
Chlorophyll a (mg/m <sup>3</sup> )	2.5	1.4	0.3	6.4
Secchi depth (m)	4.7	0.4	4.2	5.5
Coliforms, total (cfu/100 mL) <sup>‡</sup>	2.8	na	<1	28
Coliforms, fecal (cfu/100 mL) <sup>‡</sup>	1.3	na	<1	5
<i>Enterococcus</i> (cfu/100 mL) <sup>‡</sup>	2.0	na	<2	2

<sup>†</sup>Arithmetic means except as noted.

<sup>‡</sup>Geometric means.

Table 3: Site 1 average ambient water quality data, Oct. 2001 – Sept. 2002.

Variable	Mean <sup>†</sup>	SD	Min.	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	18.6	0.6	17.6	19.4
Conductivity - Hydrolab (μS/cm)	55.4	1.6	51.8	58.3
Conductivity - lab (μS/cm)	59.5	0.4	58.8	60.3
Dissolved oxygen (mg/L)	10.7	1.8	8.4	13.9
pH	7.8	0.3	7.3	8.5
Temperature (°C)	13.2	5.2	6.2	21.1
Turbidity (NTU)	0.5	0.1	0.4	0.9
Nitrogen, ammonia (μg-N/L)	<10	3.1	<10	12.2
Nitrogen, nitrate/nitrite (μg-N/L)	284.7	93.2	161.0	417.7
Nitrogen, total (μg-N/L)	417.3	81.8	275.4	533.7
Phosphorus, soluble (μg-P/L)	<5	0.6	<5	<5
Phosphorus, total (μg-P/L)	6.5	5.5	<5	27.9
Chlorophyll a (mg/m <sup>3</sup> )	2.2	0.7	1.0	3.8
Secchi depth (m)	5.8	1.4	4.5	9.0
Coliforms, total (cfu/100 mL) <sup>‡</sup>	5.8	na	1	74
Coliforms, fecal (cfu/100 mL) <sup>‡</sup>	1.1	na	<1	2
<i>Enterococcus</i> (cfu/100 mL) <sup>‡</sup>	2.0	na	<2	2

<sup>†</sup>Arithmetic means except as noted.

<sup>‡</sup>Geometric means.

Table 4: Intake average ambient water quality data, Oct. 2001 – Sept. 2002.

Variable	Mean <sup>†</sup>	SD	Min.	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	18.7	1.3	17.6	25.7
Conductivity - Hydrolab (μS/cm)	55.0	2.6	51.3	70.9
Conductivity - lab (μS/cm)	60.3	2.5	58.8	71.1
Dissolved oxygen (mg/L)	10.0	2.6	0.2	13.6
pH	7.5	0.5	6.5	8.4
Temperature (°C)	12.0	4.5	6.1	20.5
Turbidity (NTU)	0.6	0.2	0.3	1.4
Nitrogen, ammonia (μg-N/L)	24.4	58.9	<10	331.9
Nitrogen, nitrate/nitrite (μg-N/L)	300.0	94.4	<20	426.7
Nitrogen, total (μg-N/L)	448.3	77.6	305.6	591.3
Phosphorus, soluble (μg-P/L)	<5	0.6	<5	<5
Phosphorus, total (μg-P/L)	7.7	5.2	<5	30.5
Chlorophyll a (mg/m <sup>3</sup> )	2.0	0.9	0.5	4.2
Secchi depth (m)	6.1	1.4	4.3	9.0
Coliforms, total (cfu/100 mL) <sup>‡</sup>	4.5	na	1	83
Coliforms, fecal (cfu/100 mL) <sup>‡</sup>	1.2	na	<1	3
<i>Enterococcus</i> (cfu/100 mL) <sup>‡</sup>	2.0	na	<1	2

<sup>†</sup>Arithmetic means except as noted.

<sup>‡</sup>Geometric means.

Table 5: Site 2 average ambient water quality data, Oct. 2001 – Sept. 2002.

Variable	Mean <sup>†</sup>	SD	Min.	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	18.1	0.5	17.3	19.3
Conductivity - Hydrolab (μS/cm)	53.3	3.2	45.4	72.5
Conductivity - lab (μS/cm)	59.1	1.6	52.2	60.3
Dissolved oxygen (mg/L)	10.5	1.4	3.1	13.0
pH	7.4	0.4	6.6	8.3
Temperature (°C)	10.0	4.5	6.1	19.7
Turbidity (NTU)	0.4	0.2	0.2	1.3
Nitrogen, ammonia (μg-N/L)	<10	6.0	<10	30.7
Nitrogen, nitrate/nitrite (μg-N/L)	368.5	85.1	186.6	464.3
Nitrogen, total (μg-N/L)	473.1	60.5	322.7	542.2
Phosphorus, soluble (μg-P/L)	<5	0.6	<5	<5
Phosphorus, total (μg-P/L)	6.3	2.9	<5	13.3
Chlorophyll a (mg/m <sup>3</sup> )	1.8	0.8	0.5	3.6
Secchi depth (m)	5.6	1.0	4.1	7.1
Coliforms, total (cfu/100 mL) <sup>‡</sup>	2.4	na	<1	15
Coliforms, fecal (cfu/100 mL) <sup>‡</sup>	1.3	na	<1	12
<i>Enterococcus</i> (cfu/100 mL) <sup>‡</sup>	2.1	na	<1	4

<sup>†</sup>Arithmetic means except as noted.

<sup>‡</sup>Geometric means.

Table 6: Site 3 average ambient water quality data, Oct. 2001 – Sept. 2002.

Variable	Mean <sup>†</sup>	SD	Min.	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	17.9	0.5	17.3	19.3
Conductivity - Hydrolab (μS/cm)	53.2	2.6	45.4	57.5
Conductivity - lab (μS/cm)	59.4	0.6	58.4	60.4
Dissolved oxygen (mg/L)	10.5	1.3	7.9	13.1
pH	7.4	0.4	6.8	8.3
Temperature (°C)	9.6	4.3	6.2	19.3
Turbidity (NTU)	0.4	0.1	0.2	0.6
Nitrogen, ammonia (μg-N/L)	<10	4.8	<10	23.5
Nitrogen, nitrate/nitrite (μg-N/L)	382.3	77.6	202.2	455.8
Nitrogen, total (μg-N/L)	483.3	56.0	327.0	559.3
Phosphorus, soluble (μg-P/L)	<5	0.7	<5	<5
Phosphorus, total (μg-P/L)	6.2	2.8	<5	13.8
Chlorophyll a (mg/m <sup>3</sup> )	1.8	0.9	0.3	3.9
Secchi depth (m)	6.0	1.0	5.0	7.7
Coliforms, total (cfu/100 mL) <sup>‡</sup>	2.2	na	<1	10
Coliforms, fecal (cfu/100 mL) <sup>‡</sup>	1.0	na	<1	1
<i>Enterococcus</i> (cfu/100 mL) <sup>‡</sup>	2.0	na	<2	2

<sup>†</sup>Arithmetic means except as noted.

<sup>‡</sup>Geometric means.

Table 7: Site 4 average ambient water quality data, Oct. 2001 – Sept. 2002.

Date		H <sub>2</sub> S (mg/L)	NH <sub>3</sub> (μg-N/L)
October 1999	Site 1 (bottom)	0.03–0.04	268.3
	Site 2 (bottom)	0.40	424.4
October 2000	Site 1 (bottom)	0.27	208.8
	Site 2 (bottom)	0.53	339.5
October 2001	Site 1 (bottom)	0.42	168.7
	Site 2 (bottom)	0.76	331.9
October 2002	Site 1 (bottom)	0.09	203.9
	Site 2 (bottom)	0.32	383.8

Table 8: Site 1 and Site 2 hypolimnetic ammonia and hydrogen sulfide concentrations, October 1999–2002.



Site	Location	<i>E. coli</i>				Fecal coliforms			
		Geom. Mean	Min	Max	N	Geom. Mean	Min	Max	N
Lake Whatcom - Bloedel-Donovan	Nearshore	71	1	780	57	135	36	572	12
Lake Whatcom - Bloedel-Donovan	Offshore	21	<1	556	57	76	8	660	12
Lake Whatcom - Lakewood	North beach	10*	na	na	1	na	na	na	na
Lake Whatcom - Lakewood	Main dock	<1*	na	na	1	na	na	na	na
Lake Whatcom - Lakewood	Crew dock	<1*	na	na	1	na	na	na	na
Lake Whatcom - Lakewood	South beach	1*	na	na	1	na	na	na	na
Lake Padden	Nearshore	3	<1	20	11	na	na	na	na
Lake Padden	Offshore	2	<1	6	11	na	na	na	na
Lake Samish	Nearshore	4	<1	73	11	na	na	na	na
Lake Samish	Offshore	4	<1	76	11	na	na	na	na
Silver Beach Creek	Confluence-west	22	2	352	10	28	<1	258	10
Silver Beach Creek	Confluence-east	7	<1	31	11	11	1	60	11
Silver Beach Creek	Confluence-mouth	448	118	7000	11	624	200	7800	11

\*Single samples collected on September 26, 2002.

Table 9: Summary of summer coliform data from Lake Whatcom at the Bloedel-Donovan and Lakewood swimming areas, Lake Padden swimming area, Lake Samish swimming area, and Silver Beach Creek. Nearshore samples were collected in wading areas (~0.3 m depth) and offshore samples were collected in swimming areas (~1 m depth). Lakewood samples were collected by WWU; all other samples were collected by the City of Bellingham Public Works Department.

Site	Depth (m)	Date	T. As (mg/L)	T. Cd (mg/L)	T. Cr (mg/L)	T. Cu (mg/L)	T. Fe (mg/L)	T. Hg (mg/L)	T. Ni (mg/L)	T. Pb (mg/L)	T. Zn (mg/L)
Site 1	0	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	0.012	<0.0002	0.008	<0.001	0.007
Site 1	20	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	0.72	<0.0002	0.038	<0.001	0.008
Intake	0	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	0.012	<0.001	0.003
Intake	10	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	0.012	<0.001	0.007
Site 2	0	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	0.033	<0.001	0.008
Site 2	20	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	0.62	<0.0002	0.012	<0.001	0.004
Site 3	0	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	0.011	<0.001	0.003
Site 3	80	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	0.011	<0.001	0.004
Site 4	0	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	<0.005	<0.0002	0.031	0.001	0.003
Site 4	90	Sept 5, 2002	<0.01	<0.0005	<0.001	<0.001	0.009	<0.0002	0.011	0.001	0.004

Table 10: Lake Whatcom 2001/2002 total metals data. Only the metals specified in the 2001/2002 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix B.7.

Site	Depth (m)	Date	Total Hg (mg/L)	Date	Total Hg (mg/L)	Date	Total Hg (mg/L)
Site 1	0	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 1	20	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Intake	0	Aug 7, 2001	0.0004	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Intake	10	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 2	0	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 2	20	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 3	0	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 3	80	Aug 7, 2001	0.0005	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 4	0	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 4	90	Aug 7, 2001	<0.0002	Sept 19, 2001	<0.0002	Oct 15, 2001	<0.0002
Site 1	0	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Site 1	20	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Intake	0	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Intake	10	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Site 2	0	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Site 2	20	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Site 3	0	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	0.0002
Site 3	80	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	0.0002
Site 4	0	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Site 4	90	Dec 5, 2001	<0.0002	Feb 14, 2002	<0.0002	Apr 4, 2002	<0.0002
Site 1	0	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Site 1	20	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Intake	0	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Intake	10	May 9, 2002	0.0002	Sept 5, 2002	<0.0002		
Site 2	0	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Site 2	20	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Site 3	0	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Site 3	80	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Site 4	0	May 9, 2002	<0.0002	Sept 5, 2002	<0.0002		
Site 4	90	May 9, 2002	0.0002	Sept 5, 2002	<0.0002		

Table 11: Low level mercury results for monthly samples collected in Lake Whatcom 2001–2002. Data were analyzed by AmTest (detection limit = 0.0002 mg/L).

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

Table 12: Low level mercury results for split samples collected in Lake Whatcom on July 17, 2001 and analyzed by AmTest (detection limit = 0.0002 mg/L) and Environment Canada (detection limit = 0.00005 mg/L). Note that Environment Canada's original results were reported as  $\mu\text{g/L}$  in Appendix B.8 ( $1 \mu\text{g/L} = 0.001 \text{ mg/L}$ ).

Site	Date	TSS mg/L	Methyl Hg, mg/L		Total Hg, mg/L	
			Total	Dissolved	Total	Dissolved
MF Nooksack	Oct 11, 2001	9.2	0.000000026	0.000000026	0.00000481	0.00000292
Anderson Cr	Oct 11, 2001	1.6	0.000000149	0.000000135	0.00000215	0.00000157
Silver Beach Cr	Oct 11, 2001	na	0.000000060	na	0.00000270	na
Austin Cr	Oct 11, 2001	na	0.000000130	na	0.00000251	na
Park Place	Oct 11, 2001	na	0.000000248	na	0.00000123	na
Smith Cr	Oct 11, 2001	na	0.000000045	na	0.00000289	na
LW Site 1 - 8 m	Oct 15, 2001	1.6	0.000000075	0.000000046	0.00000051	0.00000066
LW Site 1 - 24 m	Oct 15, 2001	6.4	0.000000527	0.000000347	0.00000106	0.00000054
LW Site 2 - 8 m	Oct 15, 2001	0.8	0.000000039	<0.00000002	0.00000037	0.00000029
LW Site 2 - 19 m	Oct 15, 2001	2.8	0.00000163	0.00000133	0.00000256	0.00000140
LW Site 3 - 8 m	Oct 15, 2001	<0.5	<0.00000002	<0.00000002	0.00000061	0.00000038
LW Site 3 - 23 m	Oct 15, 2001	0.8	<0.00000002	<0.00000002	0.00000073	0.00000054
LW Site 3 - 30m	Oct 15, 2001	0.8	<0.00000002	<0.00000002	0.00000077	0.00000035

Table 13: Low level mercury results for samples collected in Lake Whatcom, selected tributary creeks, and the Middle Fork of the Nooksack River on October 11 and 15, 2001 by Exponent. All samples were analyzed by Frontier Geosciences (detection limit = 0.00000002 mg/L for methyl hg; 0.0000002 mg/L for total hg). Note that Frontier Geosciences' original results were reported as ng/L in Appendix B.8 (1 ng/L = 0.000001 mg/L).

Date	Total Hg (mg/L)	
	Gatehouse	Treated
Sept 23, 2002	0.00000077	na
Dec 17, 2002	0.00000065	<0.00000015
Jan 14, 2003	0.00000079	0.00000065

Table 14: Low level mercury results for gatehouse and treated drinking water samples analyzed by Frontier Geosciences (detection limit = 0.00000015 mg/L). Samples were collected by the City of Bellingham Public Works Department.

Site	Date	Depth	TOC	Date	Depth	TOC
			(mg/L)			(mg/L)
Site 1	Feb 14, 2002	0	1.7	Sept 5, 2002	0	4.4
	Feb 14, 2002	20	< 1	Sept 5, 2002	20	<1
Intake	Feb 14, 2002	0	2.3	Sept 5, 2002	0	3.6
	Feb 14, 2002	10	<1	Sept 5, 2002	10	5.0
Site 2	Feb 14, 2002	0	2.3	Sept 5, 2002	0	4.6
	Feb 14, 2002	20	<1	Sept 5, 2002	15	<1
Site 3	Feb 12, 2002	0	1.0	Sept 5, 2002	0	6.1
	Feb 12, 2002	80	6.0	Sept 5, 2002	80	<1
Site 4	Feb 12, 2002	0	<1	Sept 5, 2002	0	5.3
	Feb 12, 2002	90	3.0	Sept 5, 2002	90	<1

Table 15: Lake Whatcom 2001/2002 total organic carbon data.

	1988–1998	1999–2002	Sig.
Alkalinity (mg/L as CaCO <sub>3</sub> )	20.3	22.5	0.0089
Ammonia (μg-N/L)	93.4	230.3	0.0002
Nitrate (μg-N/L)	94.4	135.6	0.0011
Total phosphorus (μg-P/L)	11.6	23.0	0.0018

Table 16: Mean alkalinity, ammonia, nitrate, and total phosphorus concentrations from bottom samples at Site 2 during August–October, grouped into year classes (1988–1998 vs. 1999–2002). The year classes had significantly different mean concentrations for all four water quality parameters (Analysis of Variance,  $p \leq 0.05$ ).



Parameter	2001			2002									Location
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul <sup>†</sup>	Aug	Sep	
DO - Hydrolab	•	•		•	•		•	•	•	•	•	•	One site along sill every 1 m to 10 m; then every 5 m
pH - Hydrolab	•	•		•	•		•	•	•	•	•	•	
Temp - Hydrolab	•	•		•	•		•	•	•	•	•	•	
Cond - Hydrolab	•	•		•	•		•	•	•	•	•	•	
Ammonia	•			•									One site along sill - every 5 m
Nitrite/Nitrate	•			•									
Total Nitrogen	•			•									
Soluble Phosphate	•			•									
Total Phosphorus	•			•									
Alkalinity	•			•									
Turbidity	•			•									
Total metals <sup>‡</sup> (arsenic, cadmium, chromium, copper, iron, lead, mercury <sup>§</sup> , nickel, zinc)	•			•									One site along sill - 0.3 m and bottom
Total O. Carbon	•			•									0.3 m and bottom

<sup>†</sup> July Hydrolab data were lost due to equipment failure.

<sup>‡</sup> Twenty-four additional metals are included as part of the standard AmTest analytical procedure.

<sup>§</sup> Conventional mercury analysis detection limit = 0.01 mg/L.

Table 17: 2001–2002 Strawberry Sill monitoring schedule

Site	Date	Depth (m)	Alk (mg/L)	Turb (NTU)	NH3 ( $\mu\text{g-N/L}$ )	TN ( $\mu\text{g-N/L}$ )	NO3 ( $\mu\text{g-N/L}$ )	SRP ( $\mu\text{g-P/L}$ )	TP ( $\mu\text{g-P/L}$ )
Site 3	Oct 2, 2001	0–40	18.9	0.4	12.9	404.7	256.4	<5	7.9
Site s2	Oct 9, 2001	0–35	18.6	0.4	<10	444.9	311.7	<5	10.6
Site 3	Dec 4, 2001	0–40	18.4	0.4	<10	467.6	328.4	<5	<5
Site s2	Jan 10, 2002	0–35	17.9	0.4	<10	480.5	419.9	<5	8.6
Site 3	Feb 12, 2002	0–40	17.8	0.6	<10	533.2	424.7	<5	<5

Table 18: Strawberry Sill 2001/2002 water quality data compared to Site 3.

Site	Date	Depth (m)	Temp (C)	pH	Cond ( $\mu$ S/cm)	DO (mg/L)
Site 3	Oct 2, 2001	0–35	15.2	7.7	57.1	9.4
Site s2	Oct 9, 2001	0–35	14.3	7.3	55.5	8.7
Site 3	Nov 6, 2001	0–35	11.3	7.4	54.1	9.5
Site s2	Nov 8, 2001	0–35	11.4	7.4	55.0	9.5
Site 3	Dec 4, 2001	0–35	9.1	7.4	55.1	10.7
Site s2	Jan 10, 2002	0–35	7.6	7.2	54.4	11.6
Site 3	Feb 12, 2002	0–35	6.6	7.4	55.7	12.0
Site s2	Feb 14, 2002	0–35	6.5	7.4	55.3	12.1
Site 3	Apr 2, 2002	0–35	6.7	7.4	45.8	12.8
Site s2	Apr 2, 2002	0–35	6.7	7.5	46.7	12.7
Site 3	May 7, 2002	0–35	9.0	7.8	52.9	11.8
Site s2	May 9, 2002	0–35	9.1	7.8	53.3	12.8
Site 3	Jun 4, 2002	0–35	12.3	7.9	54.0	11.0
Site s2	Jun 6, 2002	0–35	12.5	7.6	52.3	11.0
Site 3	Aug 6, 2002	0–35	16.1	7.8	53.6	9.5
Site s2	Aug 8, 2002	0–35	16.3	7.8	52.3	9.9
Site 3	Sept 3, 2002	0–35	16.5	7.7	54.0	10.1
Site s2	Sept 12, 2002	0–35	15.9	7.6	53.6	9.3

Table 19: Strawberry Sill 2001/2002 Hydrolab data compared to Site 3. July data are missing due to equipment failure.

Site	Depth	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)
s2	0	Oct 9, 2001	<0.01	<0.0005	<0.001	<0.001	0.006
s2	35	Oct 9, 2001	<0.01	<0.0005	<0.001	<0.001	0.12
s2	0	Jan 10, 2002	0.001*	<0.0005	<0.001	<0.001	0.012
s2	35	Jan 10, 2002	0.001*	<0.0005	<0.001	<0.001	0.010

Site	Depth	Date	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)	TOC (mg/L)
s2	0	Oct 9, 2001	<0.01	<0.005	0.019	0.002	3.7
s2	35	Oct 9, 2001	<0.01	<0.005	0.010	0.005	6.5
s2	0	Jan 10, 2002	<0.01	<0.005	<0.001	<0.001	1.5
s2	35	Jan 10, 2002	<0.01	<0.005	<0.001	<0.001	<1

\*Note lower detection limit for arsenic in 2002 samples.

Table 20: Strawberry Sill 2001/2002 metals and total organic carbon data. Only the metals specified in the 2001/2002 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix B.7.

Parameter	2001			2002								
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Temperature					•					•		
Discharge					•					•		
Alkalinity					•					•		
Conductivity					•					•		
DO - Winkler					•					•		
pH					•					•		
T. Suspended Solids					•					•		
Total Solids					•					•		
Turbidity					•					•		
Ammonia					•					•		
Nitrite/Nitrate					•					•		
Total Nitrogen					•					•		
Soluble Phosphate					•					•		
Total Phosphorus					•					•		
Total Organic Carbon					•					•		
Total metals <sup>†</sup> (arsenic, cadmium, chromium, copper, iron, lead, mercury <sup>‡</sup> , nickel, zinc)					•							
Bacteria					•					•		

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

<sup>‡</sup>Conventional mercury analysis detection limit = 0.01 mg/L.

Table 21: Lake Whatcom 2001–2002 creek monitoring schedule

Site	Date	pH	Cond. ( $\mu$ S/cm)	DO (mg/L)	TSS (mg/L)	Alk. (mg/L)	Disch. (cfs)	Temp. (°C)	Turb. (ntu)
Blue Canyon	1990 min <sup>†</sup>	8.1	250	9.0	<2	na	0.02	4.0	na
	1990 avg <sup>†</sup>	8.4	344	10.5	5	na	0.05	10.9	na
	1990 max <sup>†</sup>	8.6	409	12.3	29	na	0.11	17.0	na
	Feb 20, 2002	8.3	283	11.7	8.8	126.5	0.24	6.4	3.3
	July 17, 2002	8.5	275	10.6	4.9	132.0	0.17	11.5	2.54
Park Place	1990 min <sup>†</sup>	7.1	118	6.4	3	na	0.00	4.5	na
	1990 avg <sup>†</sup>	7.7	245	9.1	13	na	0.26	13.7	na
	1990 max <sup>†</sup>	8.1	410	11.8	57	na	0.91	23.0	na
	Feb 20, 2002	7.6	171	11.0	6.7	68.2	na	6.4	8.1
	July 17, 2002	8.6	218	8.2	4.7	95.8	na	20.5	2.95
Silver Beach	1990 min <sup>†</sup>	7.4	103	6.9	<2	na	0.00	4.2	na
	1990 avg <sup>†</sup>	7.9	187	9.8	6	na	0.86	11.1	na
	1990 max <sup>†</sup>	8.1	290	12.1	12	na	2.66	17.0	na
	Feb 20, 2002	7.8	133	12.1	3.3	52.0	na	5.2	7.3
	July 17, 2002	8.1	282	8.8	37.2	125.0	na	15.9	25.2
Wildwd	1990 min <sup>†</sup>	6.7	34	6.9	<2	na	0.01	4.0	na
	1990 avg <sup>†</sup>	7.2	54	10.0	2	na	0.76	10.0	na
	1990 max <sup>†</sup>	7.6	126	12.3	11	na	2.52	16.5	na
	Feb 20, 2002	7.2	44	11.9	0.7	6.3	1.06	5.1	0.6
	July 17, 2002	7.2	49	9.8	<2	11.2	0.12	13.5	0.28
Anderson	1990 min <sup>†</sup>	7.2	37	10.0	4	na	41.2	3.5	na
	1990 avg <sup>†</sup>	7.4	57	11.3	17	na	74.85	8.3	na
	1990 max <sup>†</sup>	8.4	71	13.0	48	na	92.00	12.5	na
	Feb 20, 2002	7.0	58	11.8	<2	16.8	18.11	5.9	1.1
	July 17, 2002	7.3	43	10.9	26.3	12.0	na	10.1	24.1
Austin	1990 min <sup>†</sup>	7.1	50	8.3	<2	na	1.40	4.5	na
	1990 avg <sup>†</sup>	7.4	81	10.5	3	na	14.49	10.6	na
	1990 max <sup>†</sup>	7.6	121	12.1	13	na	29.60	19.5	na
	Feb 20, 2002	7.3	49	11.8	2.2	12.1	20.69	5.1	1.7
	July 17, 2002	7.7	91	9.6	<2	25.3	1.14	15.0	0.7
Smith	1990 min <sup>†</sup>	6.6	44	8.7	<2	na	0.80	3.4	na
	1990 avg <sup>†</sup>	7.5	64	10.5	3	na	7.63	10.0	na
	1990 max <sup>†</sup>	7.8	90	12.6	10	na	23.80	17.0	na
	Feb 20, 2002	7.3	42	12.5	2.7	11.1	18.4	4.8	1.7
	July 17, 2002	7.8	68	9.9	<2	23.7	1.38	15.0	0.32

<sup>†</sup>The 1990 creek data do not include the November 1990 storm event.

Table 22: Physical water quality data for creeks in the Lake Whatcom watershed.

Site	Date	NH <sub>3</sub> (μg-N/L)	TN (μg-N/L)	NO <sub>2+3</sub> (μg-N/L)	SRP (μg-P/L)	TP (μg-P/L)	TC (cfu/ 100 mL)	FC (cfu/ 100 mL)	EC (cfu/ 100 mL)
Blue Canyon	1990 min	10	na	167	<5	<5	90	<2	na
	1990 avg	20	na	336	<5	13	1163	7	na
	1990 max	34	na	545	12	25	9000	27	na
	Feb 20, 2002	<10	439	357	<5	10	16	6	4
	July 17, 2002	11	145	107	6	13	180	51	11
Park Place	1990 min	22	na	145	6	41	230	8	na
	1990 avg	51	na	357	22	66	8254	1353	na
	1990 max	111	na	549	86	168	>16000	16000	na
	Feb 20, 2002	41	760	501	12	39	1800	192	4
	July 17, 2002	86	935	222	32	87	17000	1060	300
Silver Beach	1990 min	<10	na	173	<5	27	170	8	na
	1990 avg	19	na	583	16	41	7110	3307	na
	1990 max	43	na	1118	42	61	>16000	16000	na
	Feb 20, 2002	<10	813	567	7	38	100	16	13
	July 17, 2002	20	1056	292	25	182	2700	480	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 20, 2002	11	1919	1863	<5	<5	58	42	<2
	July 17, 2002	<10	1397	1319	9.6	17	100	13	<2
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 20, 2002	16	850	744	5.3	11	4	3	2
	July 17, 2002	<10	70	53	5.5	51	60	1	<2
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 20, 2002	<10	598	531	<5	10	4	3	2
	July 17, 2002	13	464	383	11.6	20	1200	660	13
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 20, 2002	15	835	760	<5	<5	4	3	<2
	July 17, 2002	11	608	537	10.3	16	160	23	<2

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

Table 23: Chemical and biological water quality data for creeks in the Lake Whatcom watershed.

Site	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)
Blue Canyon	Feb 20, 2002	<0.01	<0.0005	0.002	<0.001	0.18
Park Place	Feb 20, 2002	<0.01	<0.0005	<0.001	<0.001	0.59
Silver Beach	Feb 20, 2002	<0.01	<0.0005	<0.001	<0.001	0.58
Wildwood	Feb 20, 2002	0.01	<0.0005	<0.001	<0.001	0.014
Anderson	Feb 20, 2002	0.01	<0.0005	<0.001	<0.001	0.12
Austin	Feb 20, 2002	0.01	<0.0005	<0.001	<0.001	0.13
Smith	Feb 20, 2002	0.01	<0.0005	<0.001	<0.001	<0.005

Site	Date	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
Smith	Feb 20, 2002	<0.01	<0.005	<0.001	0.026
Silver Beach	Feb 20, 2002	<0.01	<0.005	<0.001	0.005
Park Place	Feb 20, 2002	<0.01	<0.005	<0.001	0.024
Blue Canyon	Feb 20, 2002	<0.01	<0.005	<0.001	0.002
Anderson	Feb 20, 2002	<0.01	<0.005	<0.001	0.002
Wildwood	Feb 20, 2002	<0.01	<0.005	<0.001	0.002
Austin	Feb 20, 2002	<0.01	<0.005	<0.001	0.003

Table 24: Metals data for creeks in the Lake Whatcom watershed. Only the metals specified in the 2001/2002 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix B.7.



Site	Date	TOC (mg/L)	Date	TOC (mg/L)
Blue Canyon	Feb 20, 2002	3.2	July 17, 2002	<1
Park Place	Feb 20, 2002	4.4	July 17, 2002	<1
Silver Beach	Feb 20, 2002	5.7	July 17, 2002	<1
Wildwood	Feb 20, 2002	1.5	July 17, 2002	<1
Anderson	Feb 20, 2002	2.0	July 17, 2002	<1
Austin	Feb 20, 2002	1.9	July 17, 2002	<1
Smith	Feb 20, 2002	2.5	July 17, 2002	<1

Table 25: Total organic carbon data for creeks in the Lake Whatcom watershed.

Site		Min.	Max.	n	$\bar{x}^\dagger$
Blue Canyon	total coliforms	16	300	10	113
	fecal coliforms	<1	120	10	10
	<i>Enterococcus</i>	<2	26	10	7
Park Place	total coliforms	163	17000	9	2945
	fecal coliforms	20	3400	10	323
	<i>Enterococcus</i>	2	1600	9	26
Silver Beach	total coliforms	100	3800	9	1204
	fecal coliforms	16	2500	10	433
	<i>Enterococcus</i>	13	900	9	118
Wildwood	total coliforms	13	230	10	82
	fecal coliforms	<1	48	10	7
	<i>Enterococcus</i>	<2	30	10	4
Anderson	total coliforms	4	2300	10	76
	fecal coliforms	1	154	10	12
	<i>Enterococcus</i>	<2	70	10	5
Austin	total coliforms	4	6400	9	229
	fecal coliforms	3	660	10	50
	<i>Enterococcus</i>	<2	240	9	11
Smith	total coliforms	4	290	9	87
	fecal coliforms	2	199	10	21
	<i>Enterococcus</i>	<2	30	9	4

<sup>†</sup>5-year geometric means from March 1998 to July 2002.

Table 26: Average coliform and *Enterococcus* counts for creeks in the Lake Whatcom watershed.

Date	Fecal coliforms	<i>Enterococcus</i>
<i>winter</i>		
March 10, 1998	42 cfu/100 mL	50 cfu/100 mL
Feb 10, 1999	8 cfu/100 mL	na
Feb 9, 2000	32 cfu/100 mL	2 cfu/100 mL
Feb 22, 2001	5 cfu/100 mL	<2 cfu/100 mL
Feb 20, 2002	3 cfu/100 mL	2 cfu/100 mL
<i>summer</i>		
July 14, 1998	410 cfu/100 mL	240 cfu/100 mL
July 15, 1999	56 cfu/100 mL	8 cfu/100 mL
July 18, 2000	141 cfu/100 mL	8 cfu/100 mL
July 18, 2001	270 cfu/100 mL	30 cfu/100 mL
July 17, 2002	660 cfu/100 mL	13 cfu/100 mL

Table 27: Austin Creek fecal coliform and *Enterococcus* counts, 1998–2002.

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

Table 28: Annual water balance quantities for the Lake Whatcom watershed.

Month	Output Percents						Input Percents		
	WC	Hatch	GP	COB	WD10	Evap	Diver	Precip	Runoff
Oct	4.40	6.54	10.71	7.49	7.57	5.70	4.34	11.27	3.20
Nov	10.55	7.66	8.84	6.69	7.64	3.92	12.82	11.51	8.83
Dec	27.21	9.29	8.09	6.82	8.31	2.11	2.63	19.54	27.14
Jan	17.44	9.30	7.39	7.12	7.63	2.44	0.00	15.23	17.31
Feb	13.92	8.63	7.09	6.52	7.42	5.93	0.00	10.71	17.24
Mar	3.73	8.74	8.02	6.36	7.96	5.78	0.00	8.70	9.46
Apr	9.75	8.46	6.63	6.46	7.76	10.27	9.46	7.79	10.23
May	4.32	6.02	6.75	7.87	8.32	11.11	12.65	4.82	4.47
Jun	1.50	6.43	6.89	10.74	8.80	14.59	28.17	4.95	1.31
Jul	5.93	8.57	8.28	12.02	10.10	14.58	23.48	1.64	1.01
Aug	0.90	9.23	11.12	13.19	10.30	14.12	5.72	0.64	-0.03
Sep	0.35	11.12	10.17	8.73	8.20	9.46	0.72	3.21	-0.18
Jun-Sept	8.7	35.3	36.5	44.7	37.4	52.7	58.1	10.4	2.1
Output Volume (MG)							Input Volume (MG)		
Total	38,223	901	3,046	4,234	126	2,812	4,693	7,078	36,920
Jun-Sept	3,316	318	1,111	1,891	47	1,483	2,726	738	782

Table 29: Monthly water balance quantities for the Lake Whatcom watershed.

Parameter	2001 Oct-Dec wet, low fbw	2002 Jan-Apr wet, high fbw	2002 Jul-Sept dry, low fbw	Location
Temperature	•	•	•	infbw, outfbw; 4 grab samples in 48 hrs
Conductivity	•	•	•	
Dissolved Oxygen	•	•	•	
pH	•	•	•	
Bacteria	•	•	•	
Total Nitrogen	•	•	•	infbw, outfbw; 48-hr composite sample
Total Phosphorus	•	•	•	
Total Organic Carbon	•	•	•	
T. Suspended Solids	•	•	•	
Total metals (arsenic, cadmium, chromium, copper, iron, lead, mercury <sup>†</sup> , nickel, zinc)	•	•	•	
Pond Photos			•	wet-pond cells
Nuisance Checklist	•	•	•	

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

<sup>‡</sup>Conventional mercury analysis detection limit = 0.01 mg/L.

Table 30: 2001–2002 wet ponds monitoring schedule

Site	Date	TSS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)					
BW inlet	Dec 17-19, 2001	3.12	<1.0*	2.123	0.033					
BW inlet	Mar 25-27, 2002	2.90	3.5	1.693	0.041					
BW inlet	Jul 30-Aug 1, 2002	12.92	<1.0*	1.858	0.067					
BW outlet	Dec 17-19, 2001	8.40	<1.0*	1.587	0.045					
BW outlet	Mar 25-27, 2002	7.23	5.5	0.909	0.029					
BW outlet	Jul 30-Aug 1, 2002	17.82	4.3	0.800	0.073					
Annual % reduction		-76.6	-96.4	41.9	-4.4					
PP inlet	Dec 17-19, 2001	9.53	<1.0*	1.383	0.065					
PP inlet	Mar 25-27, 2002	7.62	5.2	0.605	0.045					
PP inlet	Jul 30-Aug 1, 2002	11.58	<1.0*	0.976	0.095					
PP outlet	Dec 17-19, 2001	5.15	<1.0*	1.355	0.055					
PP outlet	Mar 25-27, 2002	3.20	4.7	0.531	0.035					
PP outlet	Jul 30-Aug 1, 2002	9.81	3.8	0.530	0.096					
Annual % reduction		36.8	-31.9	18.5	9.3					
SC inlet	Jan 8-10, 2002	64.60	1.6	1.059	0.111					
SC inlet	Apr 16-18, 2002	40.77	5.6	0.990	0.118					
SC inlet	Jul 23-25, 2002	15.90	1.1	1.174	0.065					
SC outlet E	Jan 8-10, 2002	21.40	1.2	0.937	0.050					
SC outlet E	Apr 16-18, 2002	1.74	5.5	0.510	0.029					
SC outlet E	Jul 23-25, 2002	8.34	<1.0*	0.368	0.048					
SC outlet W	Jan 8-10, 2002	28.00	3.2	0.969	0.062					
SC outlet W	Apr 16-18, 2002	2.60	4.6	0.660	0.032					
SC outlet W	Jul 23-25, 2002	9.04	<1.0*	0.344	0.037					
Annual % reduction		70.67	0.6	41.2	56.1					
Site	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
BW inlet	Dec 17-19, 2001	<0.01	<0.0005	<0.001	0.002	0.52	<0.01	<0.005	<0.001	0.004
BW inlet	Mar 25-27, 2002	<0.01	<0.0005	<0.001	0.008	0.79	<0.01	<0.005	0.002	0.008
BW inlet	Jul 30-Aug 1, 2002	<0.01	<0.0005	0.003	0.008	1.1	<0.01	0.008	<0.001	0.011
BW outlet	Dec 17-19, 2001	<0.01	<0.0005	<0.001	0.004	0.72	<0.01	<0.005	<0.001	0.005
BW outlet	Mar 25-27, 2002	<0.01	<0.0005	<0.001	0.009	0.44	<0.01	<0.005	0.002	<0.001*
BW outlet	Jul 30-Aug 1, 2002	<0.01	<0.0005	<0.001	0.004	1.3	<0.01	0.008	<0.001	0.008
Annual % reduction		NA	NA	NA	5.56	-2.07	NA	NA	NA	39.13
PP inlet	Dec 17-19, 2001	<0.01	<0.0005	<0.001*	0.002	0.65	<0.01	<0.005	0.001	0.013
PP inlet	Mar 25-27, 2002	<0.01	<0.0005	0.002	0.005	0.66	<0.01	<0.005	0.003	0.011
PP inlet	Jul 30-Aug 1, 2002	<0.01	<0.0005	<0.001*	0.005	1.00	<0.01	0.005	<0.001*	0.008
PP outlet	Dec 17-19, 2001	<0.01	<0.0005	<0.001*	<0.001*	0.46	<0.01	<0.005	0.321**	0.010
PP outlet	Mar 25-27, 2002	<0.01	<0.0005	0.003	0.005	0.56	<0.01	<0.005	0.003	0.008
PP outlet	Jul 30-Aug 1, 2002	<0.01	<0.0005	0.001	0.007	1.20	<0.01	0.007	<0.001*	0.020
Annual % reduction		NA	NA	-25.0	-8.3	3.9	NA	NA	-6400.0	-18.8
SC inlet	Jan 8-10, 2002	0.00	<0.0005	0.002	0.007	2.50	<0.01	<0.005	0.002	0.020
SC inlet	Apr 16-18, 2002	<0.01	<0.0005	0.002	0.009	2.40	<0.01	<0.005	0.004	0.026
SC inlet	Jul 23-25, 2002	<0.01	<0.0005	<0.001	0.012	1.70	<0.01	0.006	<0.001*	0.007
SC outlet E	Jan 8-10, 2002	<0.01	<0.0005	<0.001	0.003	1.30	<0.01	<0.005	0.002	0.010
SC outlet E	Apr 16-18, 2002	<0.01	<0.0005	<0.001	0.005	0.32	<0.01	<0.005	0.002	0.015
SC outlet E	Jul 23-25, 2002	<0.01	<0.0005	0.004	0.009	0.12	<0.01	0.006	<0.001*	0.035
SC outlet W	Jan 8-10, 2002	0.00	<0.0005	<0.001	0.011	1.40	<0.01	<0.005	0.005	0.009
SC outlet W	Apr 16-18, 2002	<0.01	<0.0005	<0.001	0.006	0.39	<0.01	<0.005	0.002	0.098
SC outlet W	Jul 23-25, 2002	<0.01	<0.0005	<0.001	0.008	0.13	<0.01	0.005	<0.001*	0.008
Annual % reduction		NA	NA	NA	25.0	72.3	NA	NA	7.1	-65.1

\*Value replaced with detection limit to calculate percent reduction.

\*\*Unusually high value, possible due to contamination of sample.

Table 31: Park Place/Brentwood wet ponds and South Campus rock/plant filter composite samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

Site	Time	Month	Day	Year	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
BW inlet	A	12	17	2001	8.1	6.88	9.27	213.0	450	156	13
BW inlet	B	12	18	2001	8.7	6.83	9.77	225.0	2100	1200	4
BW inlet	C	12	18	2001	8.8	6.84	9.54	228.0	960	1750	4
BW inlet	D	12	19	2001	8.9	6.77	9.80	220.0	3200	2100	2
BW outlet	A	12	17	2001	6.0	6.97	10.23	157.7	300	300	80
BW outlet	B	12	18	2001	5.0	6.94	7.64	164.0	640	310	23
BW outlet	C	12	18	2001	5.6	7.05	7.98	169.4	600	350	23
BW outlet	D	12	19	2001	5.0	6.96	8.14	175.8	680	380	30
Seasonal % reduction					37.4	-2.2	11.4	24.7	66.9	74.3	-578.3
BW inlet	A	3	25	2002	NA	6.89	9.75	248.0	8700	5400	<2*
BW inlet	B	3	26	2002	8.8	6.82	9.38	253.0	4400	1400	27
BW inlet	C	3	26	2002	8.6	6.66	9.49	188.0	99000	480	8
BW inlet	D	3	27	2002	8.8	6.90	9.79	255.0	1400	1100	2
BW outlet	A	3	25	2002	NA	7.37	15.84	231.0	45	<2*	<2*
BW outlet	B	3	26	2002	9.2	7.27	14.75	232.0	140	3	<2*
BW outlet	C	3	26	2002	10.0	7.44	16.80	229.0	67	8	4
BW outlet	D	3	27	2002	8.3	7.39	15.84	229.0	NA	NA	NA
Seasonal % reduction					-5.0	-8.1	-64.6	2.4	99.7	99.8	72.6
BW inlet	A	7	30	2002	18.8	6.95	6.86	303.0	800	2820	>1600*
BW inlet	B	7	31	2002	19.0	6.92	6.49	297.0	22000	9800	>1600*
BW inlet	C	7	31	2002	19.3	7.03	6.95	301.0	29	1930	240
BW outlet	A	7	30	2002	21.5	7.44	9.81	263.0	75	2	<2*
BW outlet	B	7	31	2002	19.2	7.36	6.26	260.0	100	12	23
BW outlet	C	7	31	2002	23.5	8.51	12.68	254.0	24000	2	23
BW inlet	D	8	1	2002	19.4	6.91	6.67	294.0	86000	28400	300
BW outlet	D	8	1	2002	19.7	7.93	10.98	257.0	33	32	30
Seasonal % reduction					-4.1	-8.4	-21.5	8.5	-380.8	-95.5	89.1
Annual % reduction					3.1	-7.6	-32.0	13.3	87.3	97.3	94.8

\*Value replaced with detection limit to calculate percent reduction.

Table 32: 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	Time	Month	Day	Year	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
PP inlet	A	12	17	2001	7.0	7.24	11.17	142.7	1600	88	30
PP inlet	B	12	18	2001	7.6	7.27	11.26	135.6	1700	81	30
PP inlet	C	12	18	2001	7.0	7.24	11.09	130.0	13000	63	70
PP inlet	D	12	19	2001	6.4	7.18	11.46	129.2	3500	64	50
PP outlet	A	12	17	2001	6.0	7.23	10.86	132.9	810	92	50
PP outlet	B	12	18	2001	5.5	7.26	NA	141.1	450	46	23
PP outlet	C	12	18	2001	6.1	7.32	11.31	140.5	580	36	50
PP outlet	D	12	19	2001	5.5	7.16	10.51	124.1	1800	100	50
Seasonal % reduction					17.5	-0.1	3.1	-0.2	81.6	7.4	3.9
PP inlet	A	3	25	2002	NA	7.33	10.65	140.0	1600	1100	17
PP inlet	B	3	26	2002	6.6	7.44	10.45	145.0	17000	178	30
PP inlet	C	3	26	2002	8.0	7.40	11.26	135.0	2600	500	110
PP inlet	D	3	27	2002	7.0	7.48	11.34	138.0	1750	33	17
PP outlet	A	3	25	2002	NA	9.16	12.08	145.0	360	1	2
PP outlet	B	3	26	2002	8.2	7.64	10.74	146.0	1030	116	8
PP outlet	C	3	26	2002	9.0	8.69	15.45	144.0	500	32	<2*
PP outlet	D	3	27	2002	7.4	7.66	12.78	143.0	1600	135	23
Seasonal % reduction					-13.9	-11.8	-16.8	-3.6	84.8	84.3	79.9
PP inlet	A	7	30	2002	17.8	7.56	8.50	250.0	180000	549	>1600*
PP inlet	B	7	31	2002	17.1	7.59	8.61	219.0	36000	930	>1600*
PP inlet	C	7	31	2002	17.5	7.62	8.78	205.0	3150	755	>1600*
PP outlet	A	7	30	2002	19.8	8.69	11.68	195.0	40	2	13
PP outlet	B	7	31	2002	17.8	7.55	6.15	204.0	450	3	23
PP outlet	C	7	31	2002	21.5	9.41	15.32	197.0	40	1	23
PP inlet	D	8	1	2002	17.4	7.68	8.56	219.0	8000	320	500
PP outlet	D	8	1	2002	17.9	8.64	12.10	204.0	50	1	23
Seasonal % reduction					-3.3	-5.8	-12.1	5.2	96.1	85.5	88.2
Annual % reduction					7.3	-7.5	-17.8	9.0	97.7	90.4	96.1

\*Value replaced with detection limit to calculate percent reduction.

Table 33: 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	Time	Month	Day	Year	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	TC (cfu/100 mL)	FC (cfu/100 mL)	EC (cfu/100 mL)
SC inlet	A	1	8	2002	10.0	7.66	10.85	161.9	1100	2530	110
SC inlet	B	1	9	2002	9.6	7.35	10.51	211.0	1200	380	500
SC inlet	C	1	9	2002	9.6	7.30	10.55	228.0	670	110	30
SC inlet	D	1	10	2002	9.6	7.36	10.33	257.0	440	110	30
SC outlet E	A	1	8	2002	10.0	7.65	10.08	167.1	500	230	240
SC outlet E	B	1	9	2002	9.0	7.48	9.26	219.0	80	40	23
SC outlet E	C	1	9	2002	9.8	7.54	9.07	234.0	130	65	8
SC outlet E	D	1	10	2002	8.6	7.50	8.98	261.0	24	35	4
SC outlet W	A	1	8	2002	10.0	7.67	10.32	162.8	440	460	240
SC outlet W	B	1	9	2002	9.0	7.52	9.69	215.0	250	80	50
SC outlet W	C	1	9	2002	10.0	7.49	9.54	228.0	36	55	13
SC outlet W	D	1	10	2002	8.5	7.59	9.24	256.0	36	55	13
Seasonal % reduction					3.5	-1.9	9.8	-1.6	78.1	54.9	55.9
SC inlet	A	4	16	2002	10.0	7.59	10.00	246.0	1550	88	<2
SC inlet	B	4	17	2002	9.7	7.51	10.20	265.0	370	50	70
SC inlet	C	4	17	2002	9.8	7.51	9.79	272.0	686	51	50
SC inlet	D	4	18	2002	11.0	7.46	10.28	292.0	800	20	11
SC outlet E	A	4	16	2002	9.3	7.55	8.58	255.0	6	1	<2
SC outlet E	B	4	17	2002	9.7	7.55	7.95	276.0	5	<1	2
SC outlet E	C	4	17	2002	10.1	7.54	8.34	273.0	4	2	<2
SC outlet E	D	4	18	2002	9.2	7.52	8.34	296.0	2	1	<2
SC outlet W	A	4	16	2002	9.8	7.61	9.32	252.0	26	5	<2
SC outlet W	B	4	17	2002	9.6	7.61	8.25	273.0	3	1	<2
SC outlet W	C	4	17	2002	9.7	7.58	8.43	265.0	20	6	4
SC outlet W	D	4	18	2002	9.4	7.56	8.43	293.0	8	5	<2
Seasonal % reduction					5.2	-0.6	16.0	-1.5	98.9	94.7	NA
SC inlet	A	7	23	2002	14.5	7.36	7.84	393.0	550	45	17
SC inlet	B	7	24	2002	14.5	7.26	7.75	390.0	1050	26	27
SC inlet	C	7	24	2002	15.0	7.24	8.22	388.0	50	28	23
SC inlet	D	7	25	2002	14.5	7.33	7.99	394.0	150	14	30
SC outlet E	A	7	23	2002	17.5	7.57	5.23	401.0	940	78	8
SC outlet E	B	7	24	2002	17.3	7.47	5.01	406.0	540	153	50
SC outlet E	C	7	24	2002	16.5	7.49	5.16	405.0	425	170	8
SC outlet E	D	7	25	2002	17.5	7.53	5.18	403.0	225	24	2
SC outlet W	A	7	23	2002	18.5	7.53	4.06	399.0	900	40	4
SC outlet W	B	7	24	2002	18.7	7.37	4.01	401.0	1030	28	4
SC outlet W	C	7	24	2002	18.0	7.40	4.28	399.0	1030	32	2
SC outlet W	D	7	25	2002	18.5	7.44	4.64	398.0	750	19	4
Seasonal % reduction					-21.8	-2.4	40.9	-2.6	-62.2	-140.7	57.7
Annual % reduction					-6.7	-1.6	20.7	-2.0	57.0	45.4	53.8

\*Value replaced with detection limit to calculate percent reduction.

Table 34: South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

Site	Years	Total suspended solids concentrations at inlet		
		All Data (n)	≤10 mg/L (n)	>10 mg/L (n)
Brentwood	1998–2002	-63% (10)	-65% (9)	na (1)*
Park Place	1994–2002	14% (22)	0% (15)	43% (7)
South Campus	2001–2002	53% (6)	na (0)	53% (6)
Site	Years	Total phosphorus concentration at inlet		
		All Data (n)	≤0.05 mg/L	>0.05 mg/L
Brentwood	1998–2002	-64% (11)	-121% (7)	37% (4)
Park Place	1994–2002	-8% (24)	-8% (12)	-7% (12)
South Campus	2001–2002	13% (6)	na (0)	13% (6)

\*Sample size = 1; average not calculated

Table 35: Influence of initial concentration on total suspended solids and total phosphorus reduction in the Brentwood, Park Place, and South Campus storm water treatment facilities. Negative values represent an increase in concentration at the outlet.

	Reported Value <sup>†</sup>	True Value <sup>†</sup>	Acceptance Limits
Specific conductivity ( $\mu\text{S}/\text{cm}$ at 25°C)	919.0 952.0 1140	913 934 1100	857–970 856–1012 1008–1192
Total alkalinity (mg/L as $\text{CaCO}_3$ )	29.9 33.8 32.3	28.8 32.5 30.8	24.5–34.0 27.9–37.9 26.3–36.1
Ammonia nitrogen, autoanalysis (mg-N/L)	17.6 14.1 5.39	17.1 14.5 5.36	13.3–20.7 11.3–17.6 4.11–6.57
Ammonia nitrogen, manual (mg-N/L)	17.4 13.6 5.43	17.1 14.5 5.36	13.3–20.7 11.3–17.6 4.11–6.57
Nitrate nitrogen, autoanalysis (mg-N/L)	15.9 23.2 9.46	15.6 22.5 9.39	12.4–18.5 17.8–26.7 7.42–11.2
Orthophosphate, autoanalysis (mg-P/L)	3.39 4.12 2.41	3.36 3.94 2.47	2.87–3.88 3.36–4.55 2.10–2.86
Orthophosphate, manual (mg-P/L)	3.26 3.91 2.52	3.36 3.94 2.47	2.87–3.88 3.36–4.55 2.10–2.86
Total phosphorus, autoanalysis (mg-P/L)	na 4.65 4.87	na 4.98 5.28	na 3.79–5.84 4.01–6.19
Total phosphorus, manual (mg-P/L)	9.70 4.69 5.08	9.91 4.98 5.28	7.54–11.6 3.79–5.84 4.01–6.19
pH	9.12 5.16 5.68	9.00 5.20 5.70	8.73–9.27 5.10–5.31 5.58–5.86
Non-filterable residue (mg/L)	77.5 71.6 43.4	80.5 80.0 52.7	62.2–86.9 61.8–86.3 39.9–56.6
Turbidity (NTU) - new PE test added 11/2002	3.33	3.00	2.34–3.92

<sup>†</sup>Performance Evaluation Reports WP-072 (03/11/2002), WP-073 (05/22/2002), and WP-077(11/15/2002).

Table 36: Summary of 2001/2002 single-blind quality control results.

## 9 Figures

- Figure 1 (page 66) provides a general map of Lake Whatcom and its tributaries, and shows the current lake sampling sites. Refer to Appendix A, Figures 190–192 (pages 258–260) for detailed maps showing lake sampling locations.
- Figures 2–51 (pages 67–116) show single-day Hydrolab profiles from Lake Whatcom for the February and September sampling dates.
- Figures 52–71 (pages 117–136) 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 sampled, not the annual extremes. Missing values were not interpolated.
- Figures 72–75 (pages 137–140) show correlations between date and dissolved oxygen during the summer at Site 1, 12–18 m.
- Figures 76–140 (pages 141–205) show multi-year plots of water quality, chlorophyll, plankton, and Secchi depth data for Lake Whatcom.
- Figures 141–155 (pages 206–220) show multi-year plots of coliforms and *Enterococcus* data for Lake Whatcom.
- Figures 156 and 157 (pages 221 and 222) show iron concentrations in untreated drinking water (gatehouse) and average trihalomethanes concentrations in the Bellingham water distribution system.
- Figures 158–166 (pages 223–231) show the hydrograph data and rating curves from Austin, Anderson, and Smith Creeks; the water balance figures; and a summary of the Middle Fork diversion.
- Figures 167–175 (pages 232–240) show sampling locations for the Park Place and Brentwood wet ponds and the South Campus storm water treatment facility, current photographs of each site, and multi-year inlet/outlet concentrations for selected contaminants.
- Figures 176–189 (pages 241–254) show the field and laboratory quality control results and Hydrolab quality control comparisons.

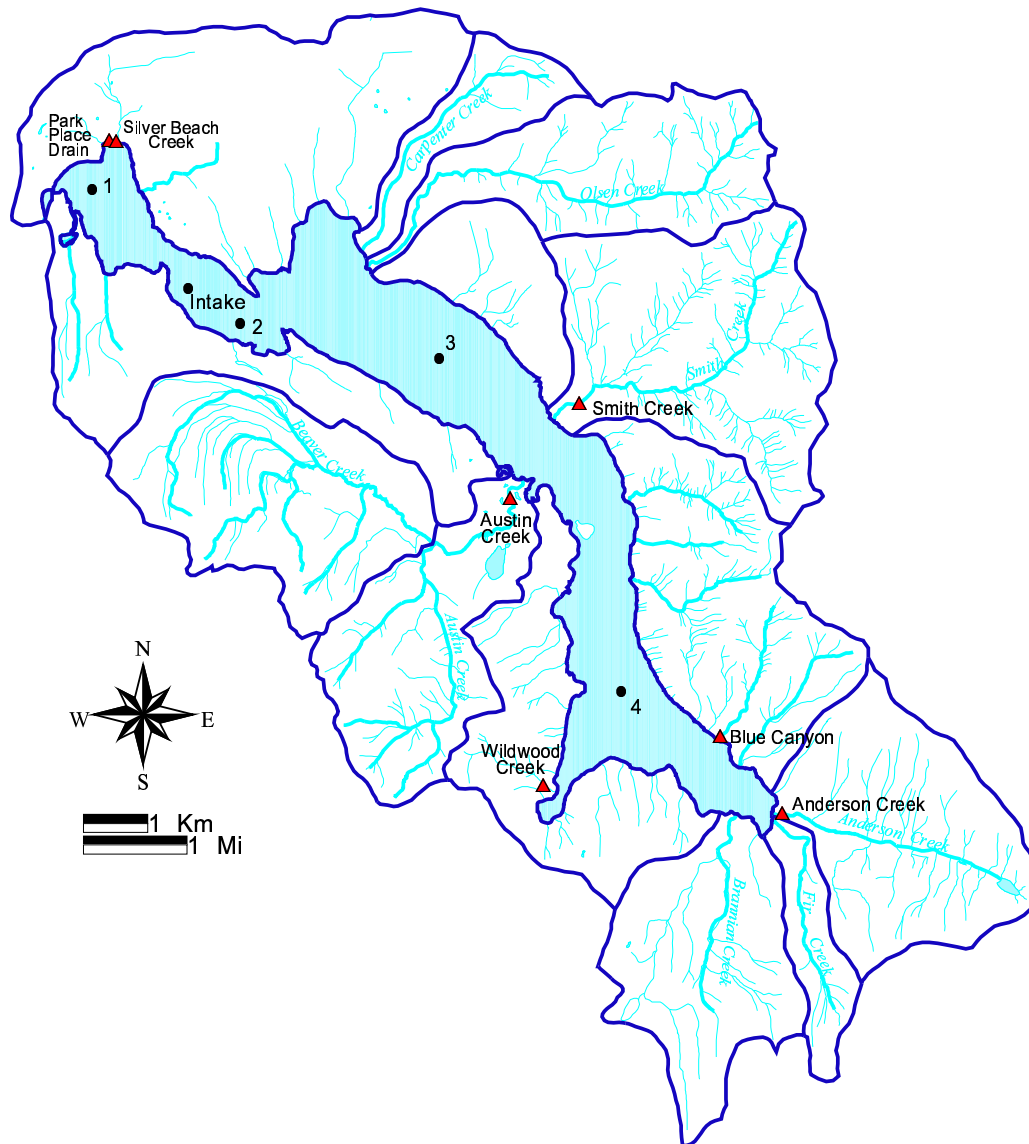


Figure 1: Lake Whatcom 2001/2002 sampling sites.

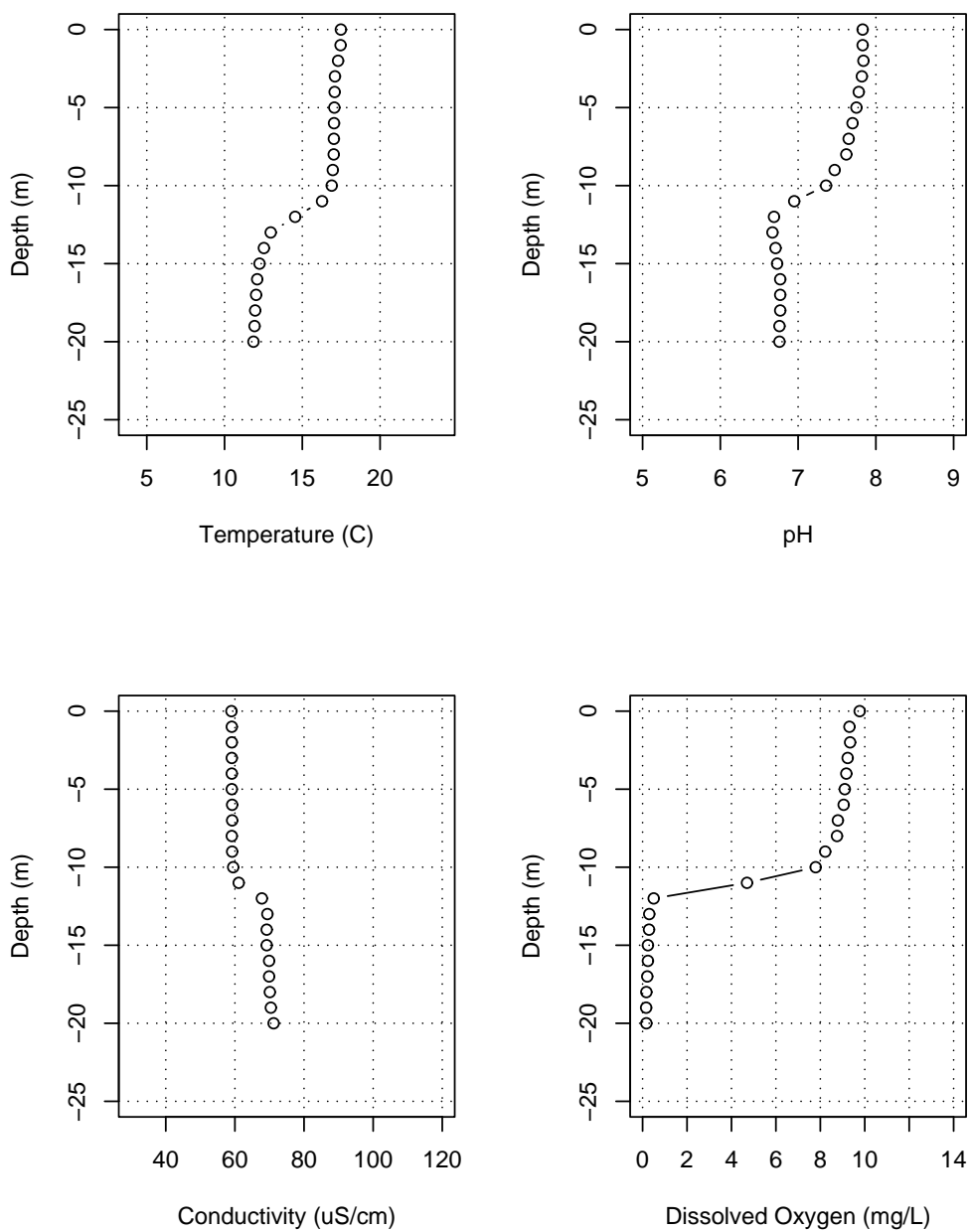


Figure 2: Lake Whatcom Hydrolab profile for Site 1, October 2, 2001.

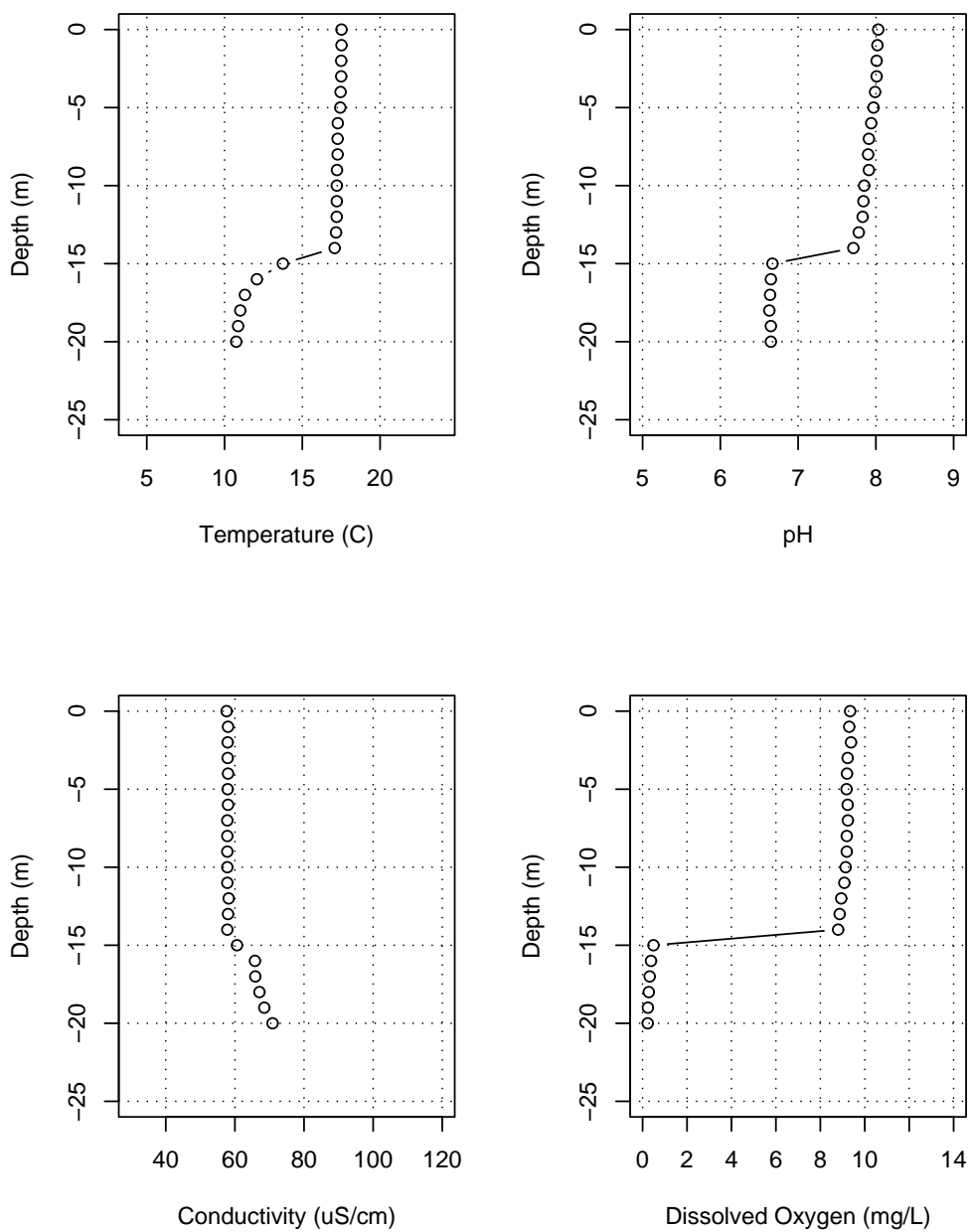


Figure 3: Lake Whatcom Hydrolab profile for Site 2, October 2, 2001.



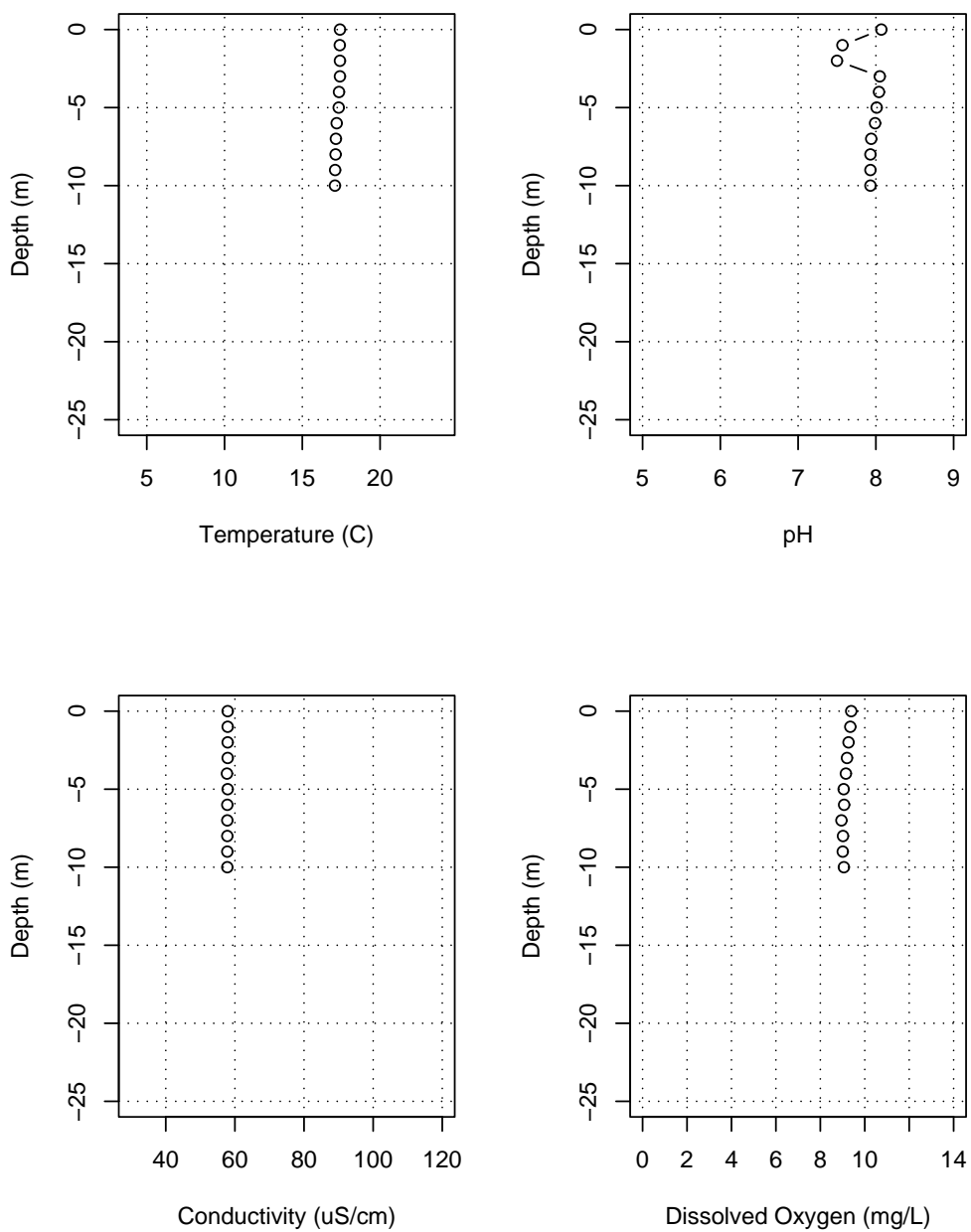


Figure 4: Lake Whatcom Hydrolab profile for the Intake, October 2, 2001.

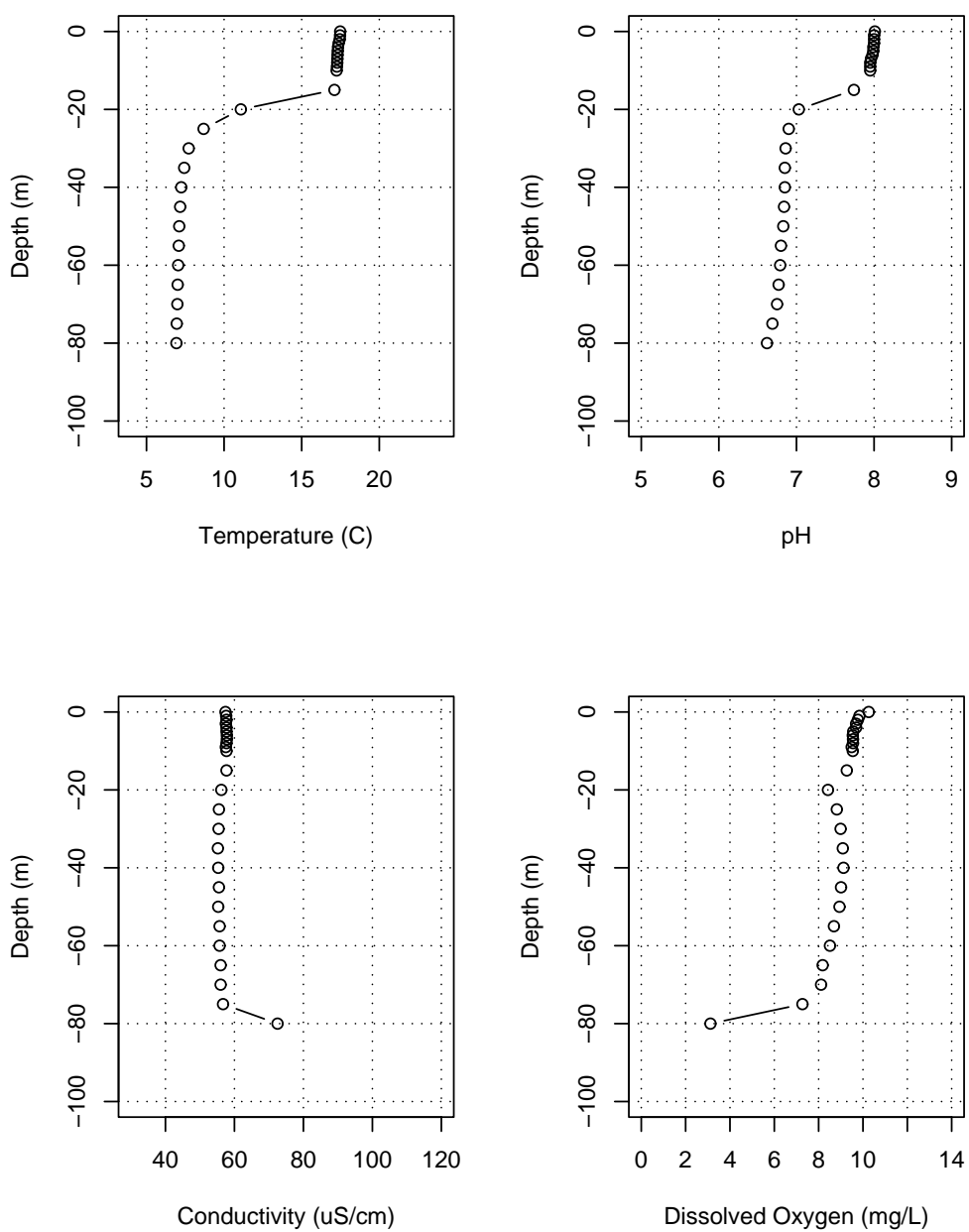


Figure 5: Lake Whatcom Hydrolab profile for Site 3, October 2, 2001.

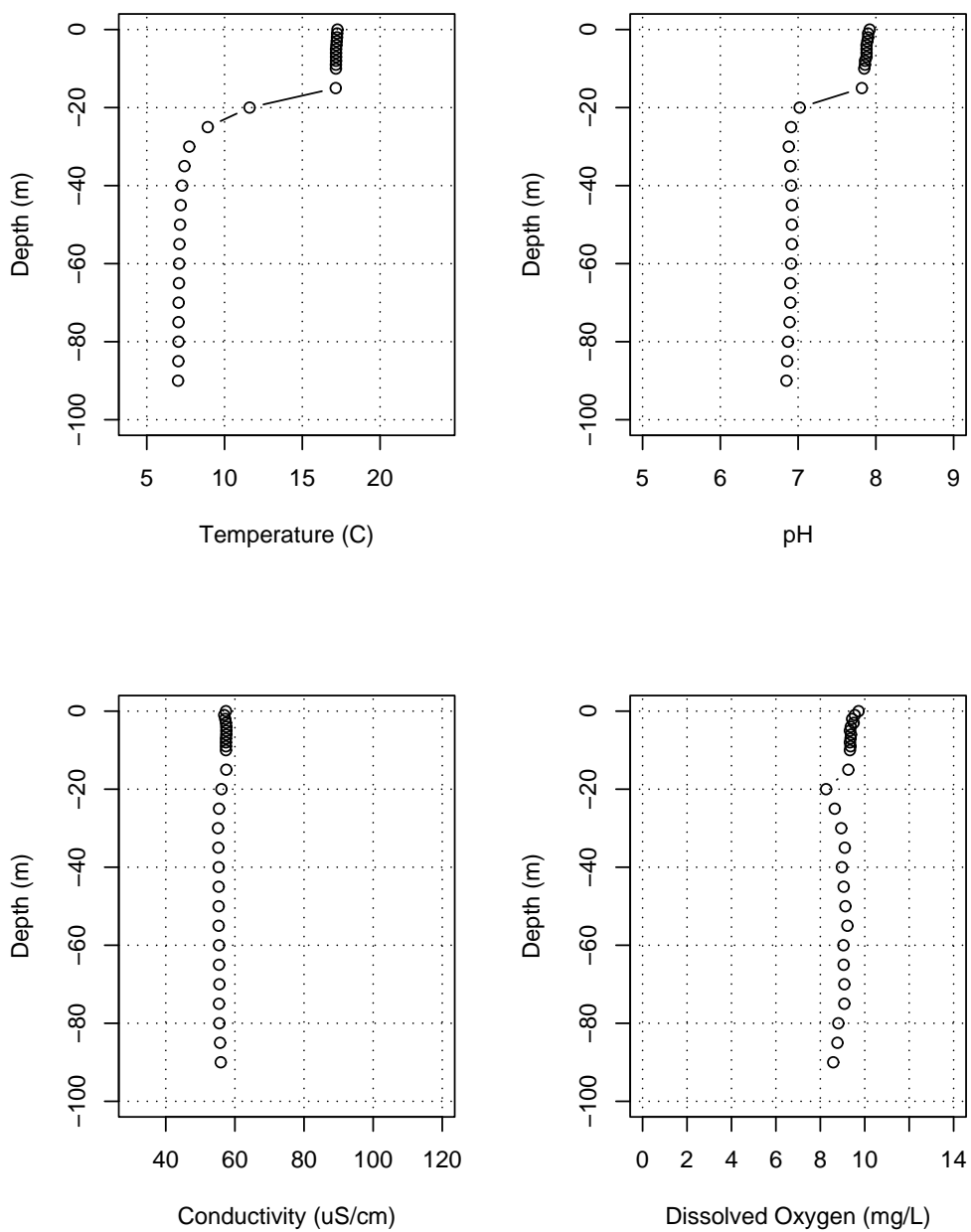


Figure 6: Lake Whatcom Hydrolab profile for Site 4, October 2, 2001.

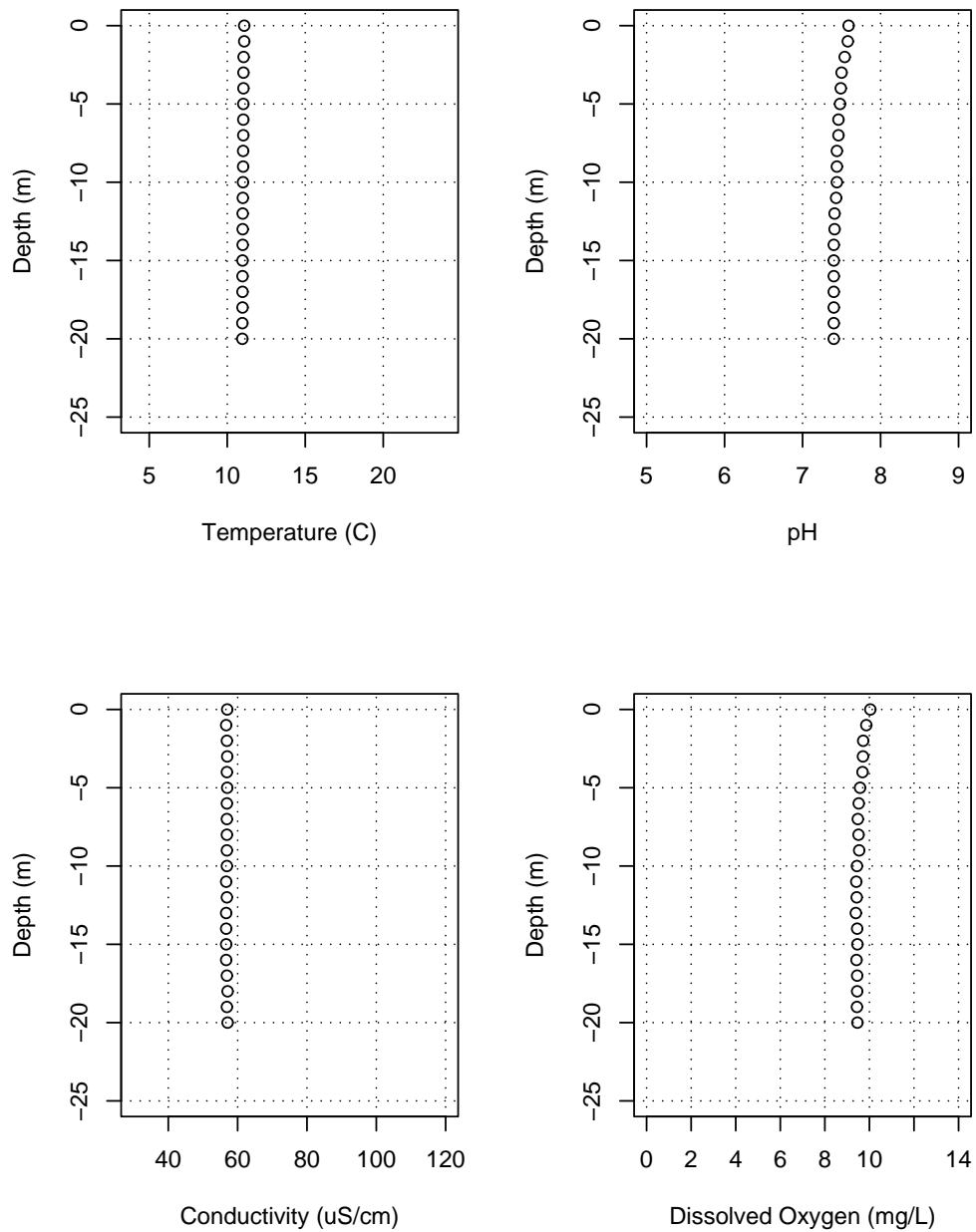


Figure 7: Lake Whatcom Hydrolab profile for Site 1, November 8, 2001.

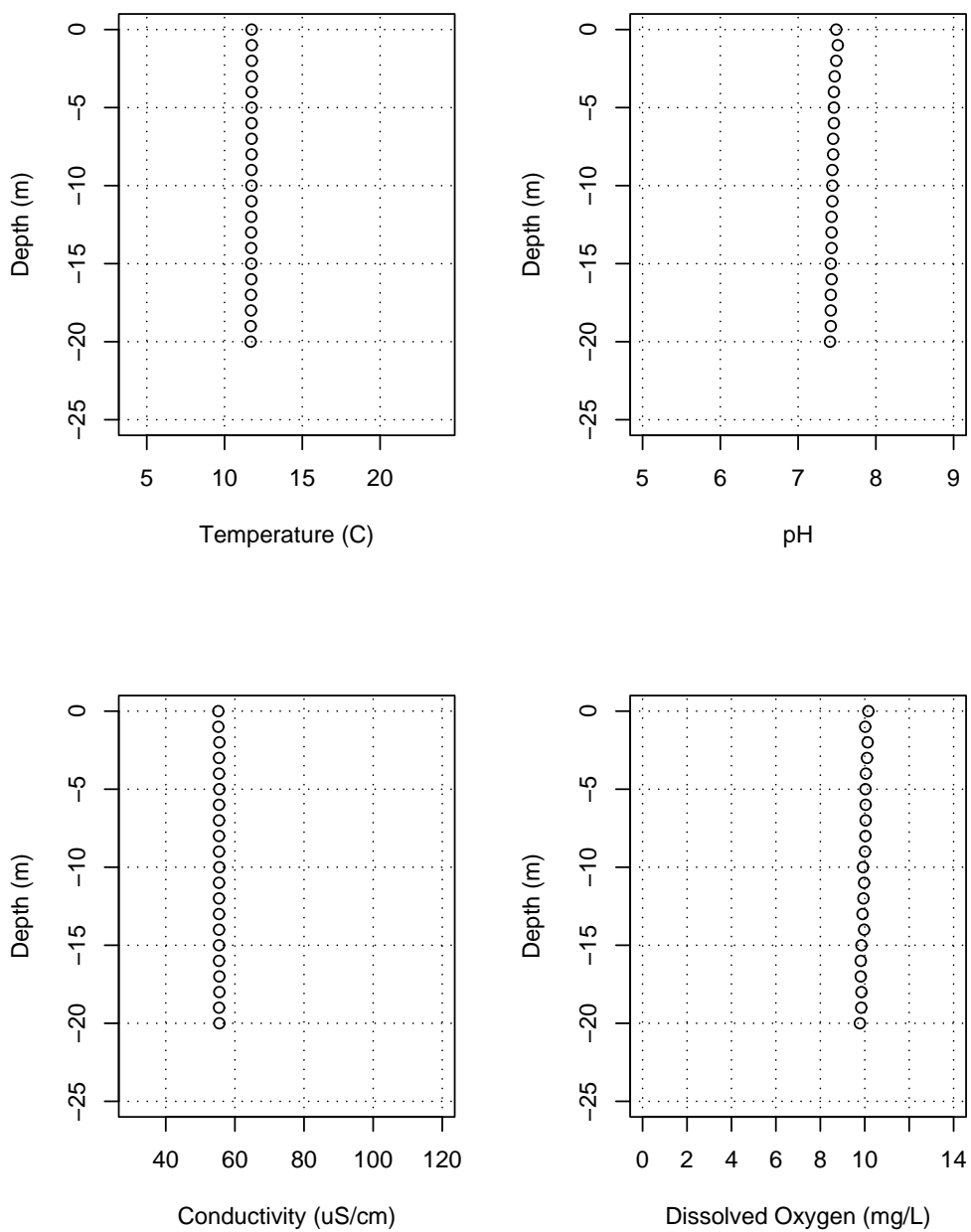


Figure 8: Lake Whatcom Hydrolab profile for Site 2, November 8, 2001.

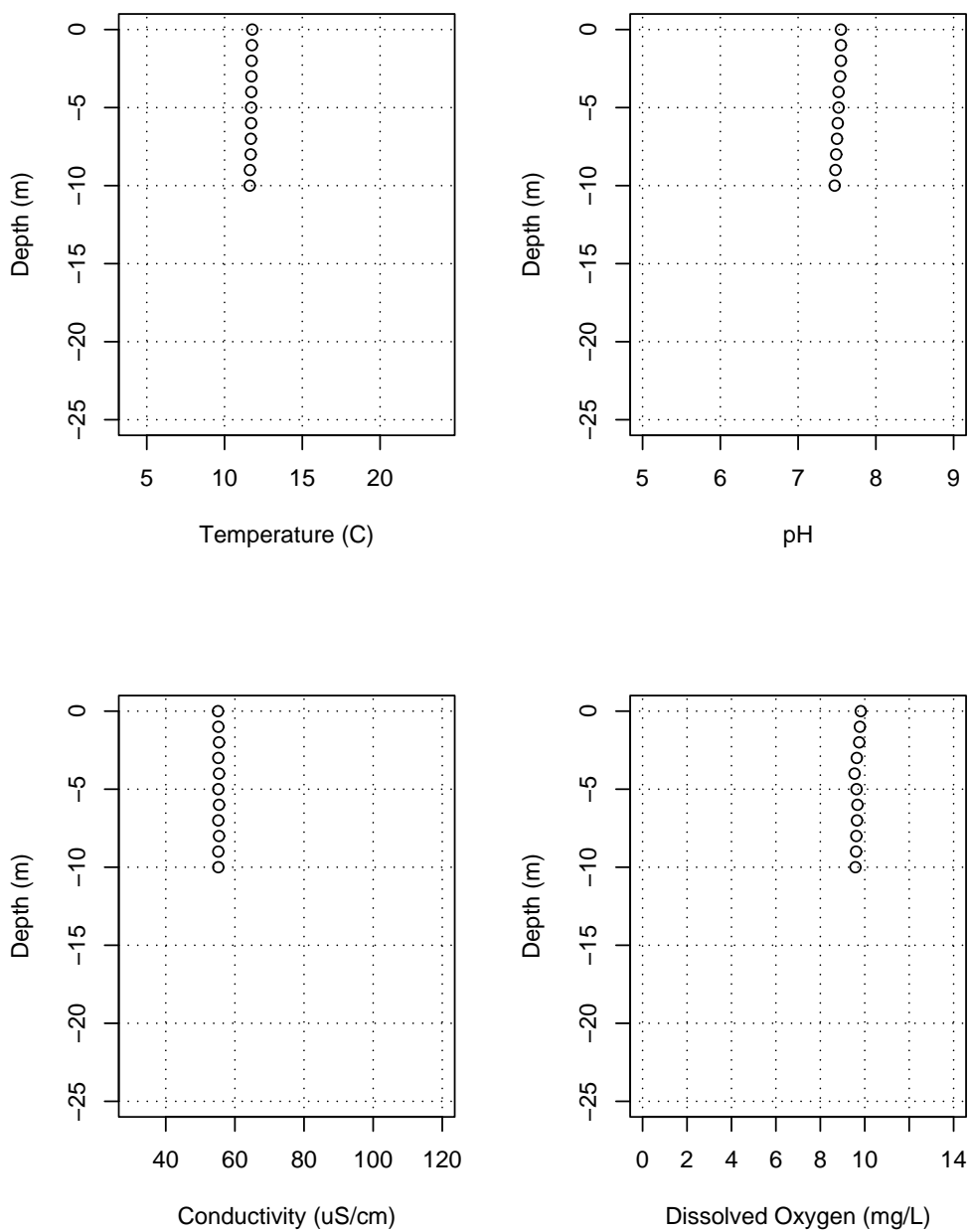


Figure 9: Lake Whatcom Hydrolab profile for the Intake, November 8, 2001.

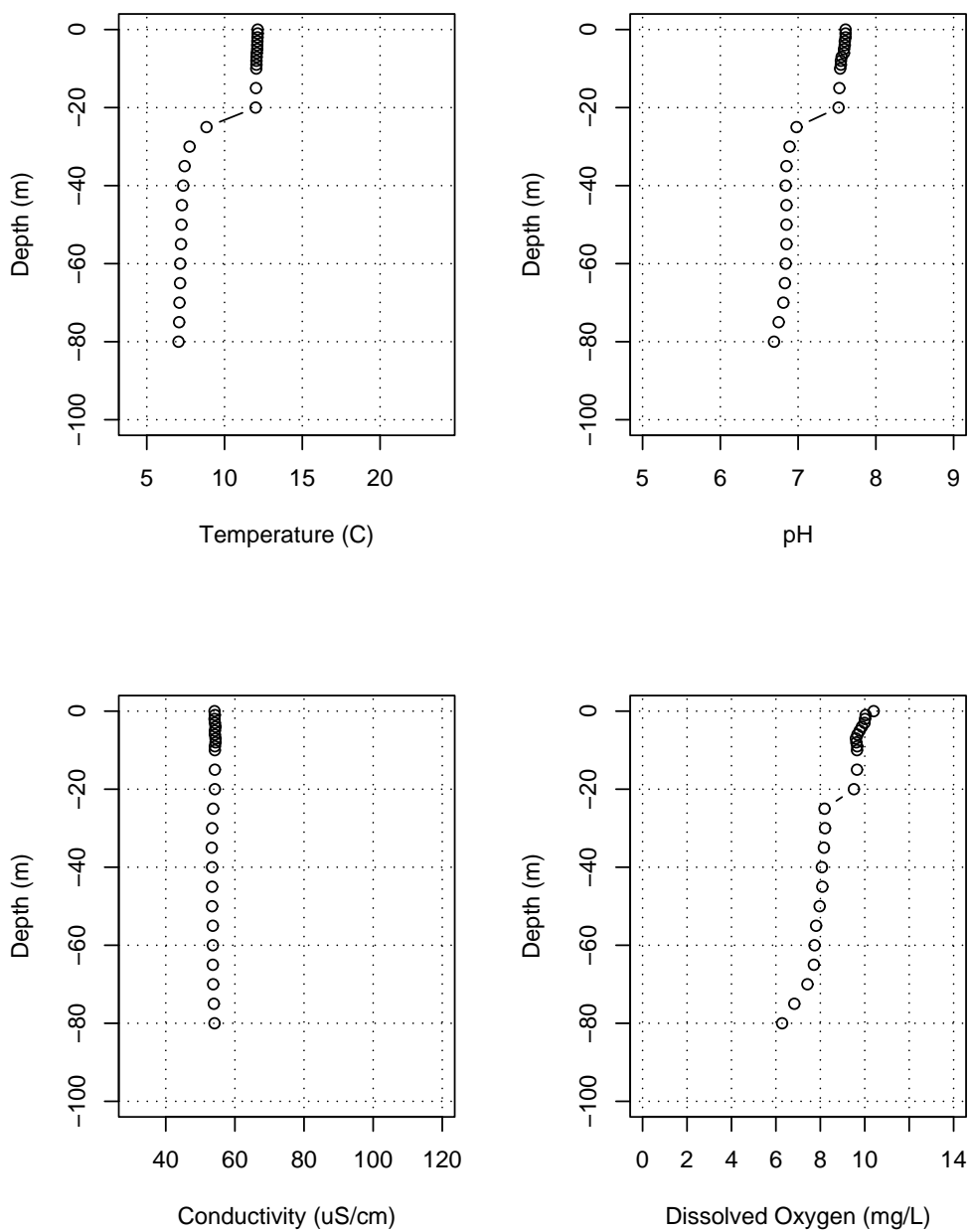


Figure 10: Lake Whatcom Hydrolab profile for Site 3, November 6, 2001.

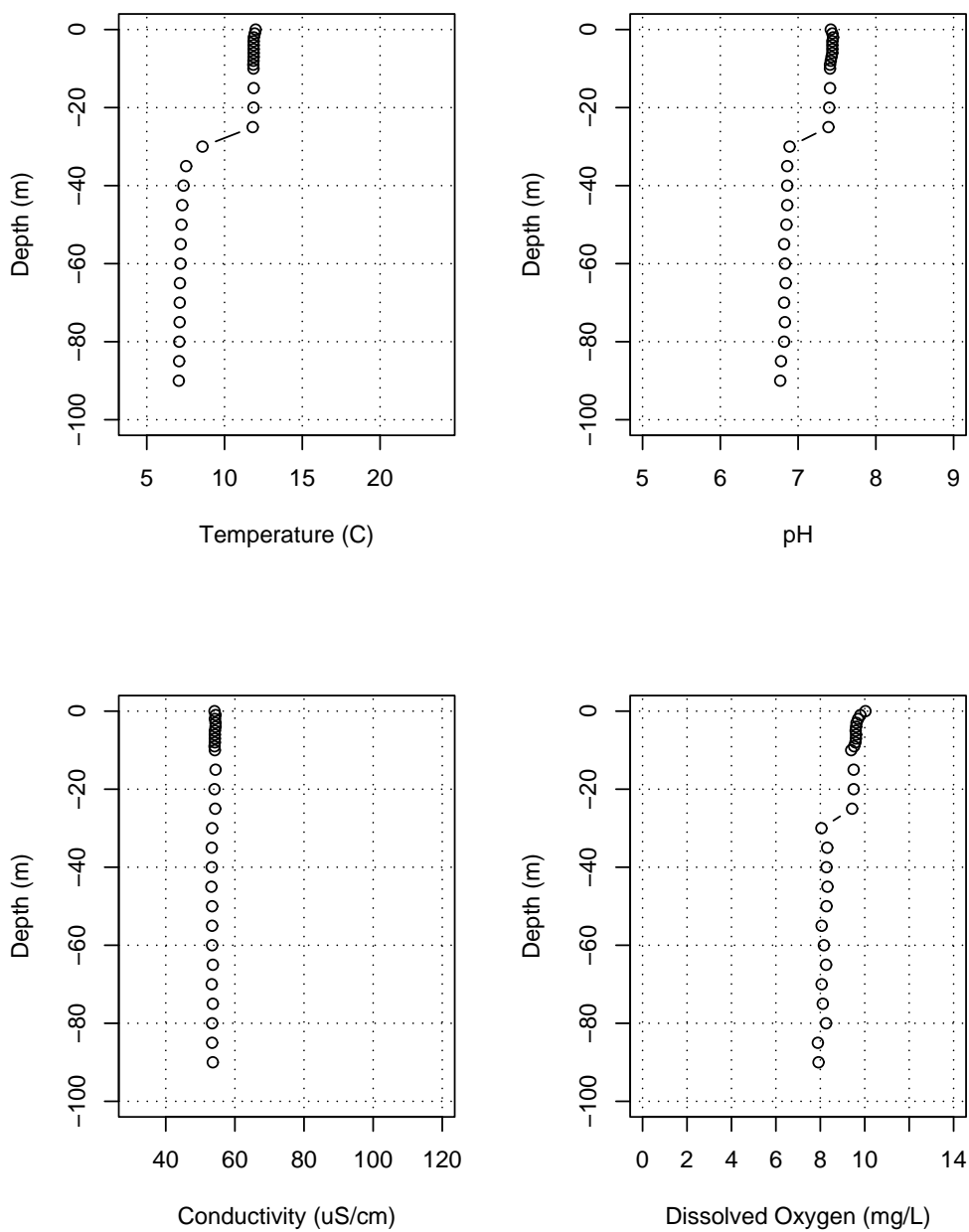


Figure 11: Lake Whatcom Hydrolab profile for Site 4, November 6, 2001.



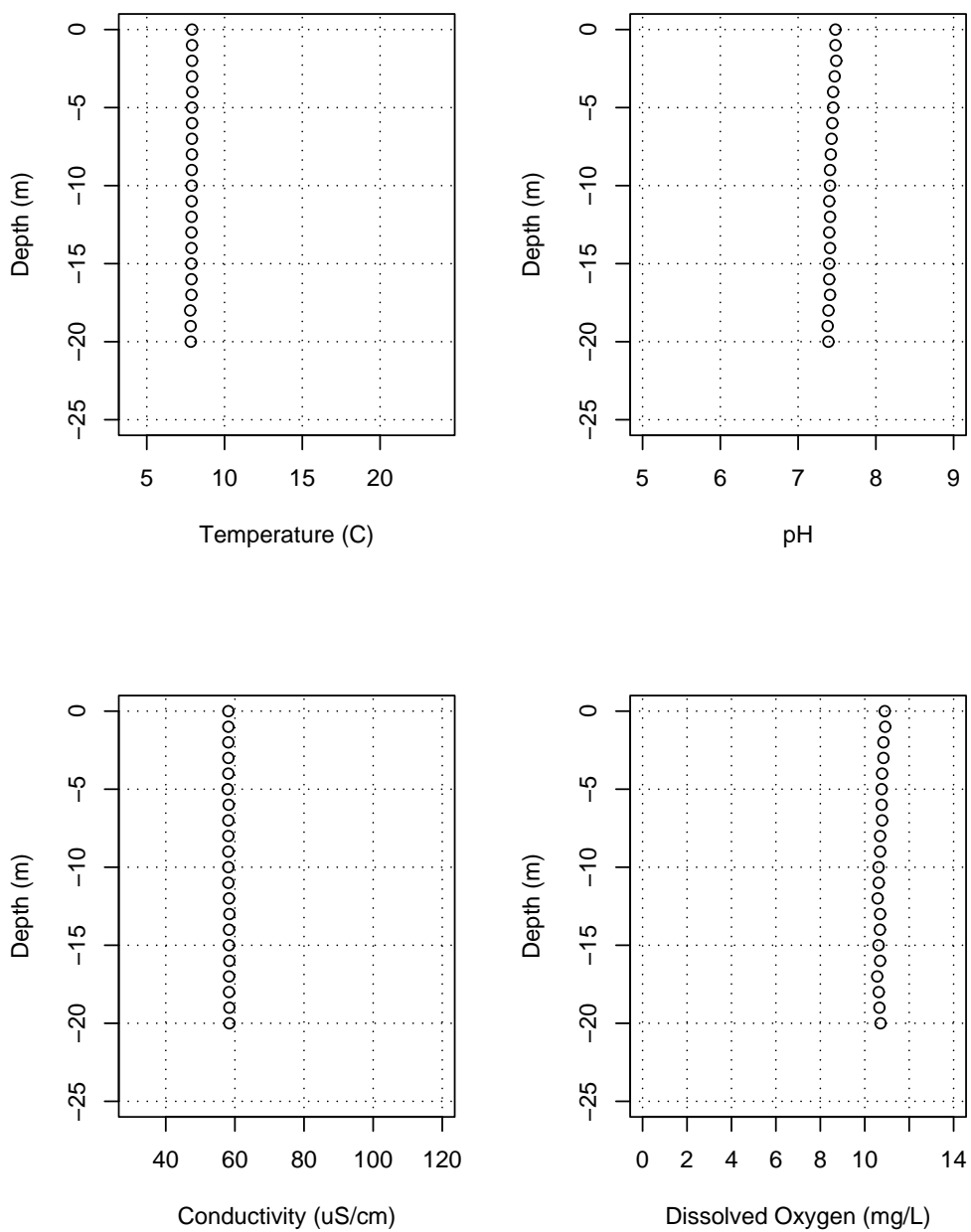


Figure 12: Lake Whatcom Hydrolab profile for Site 1, December 5, 2001.

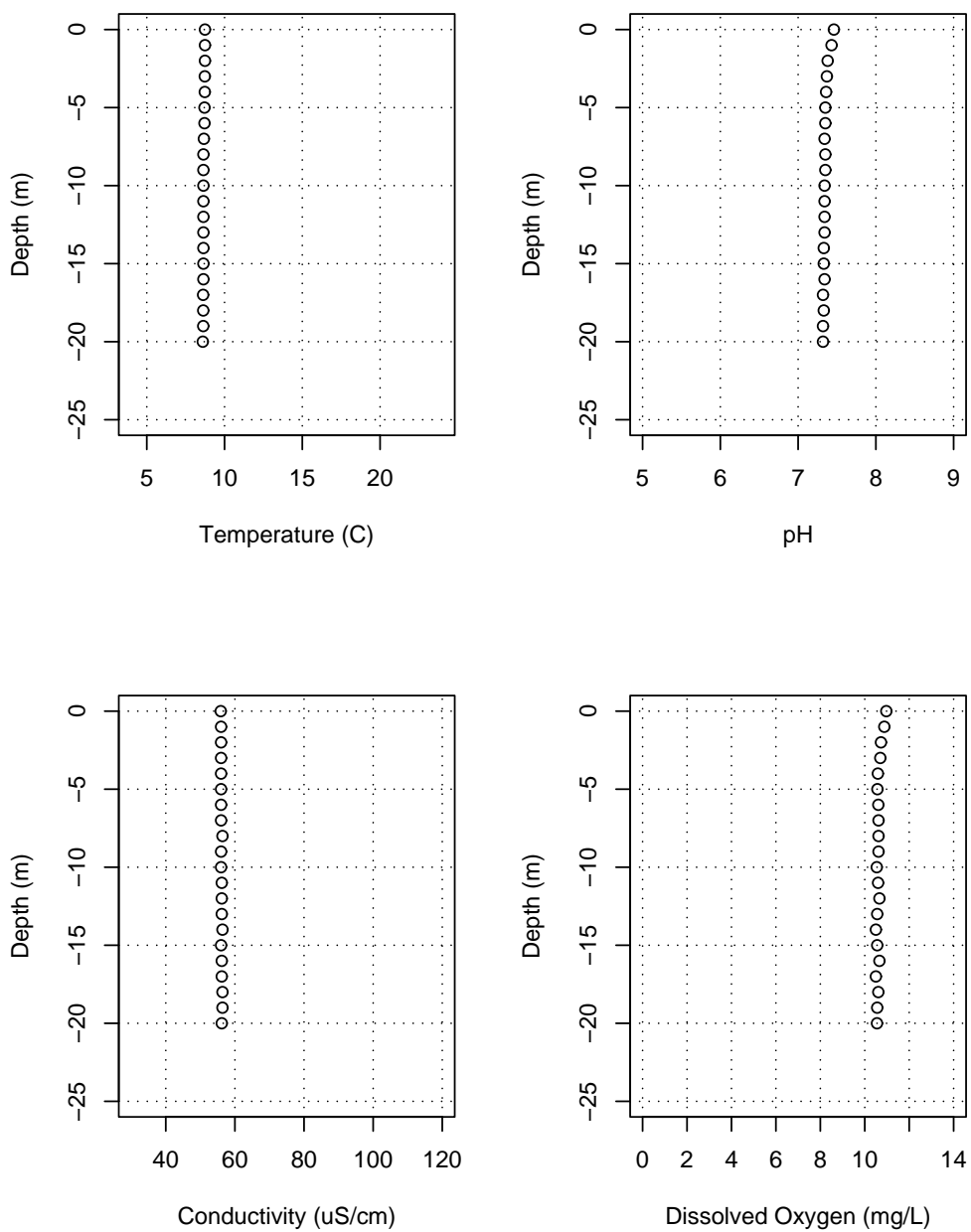


Figure 13: Lake Whatcom HydroLab profile for Site 2, December 5, 2001.

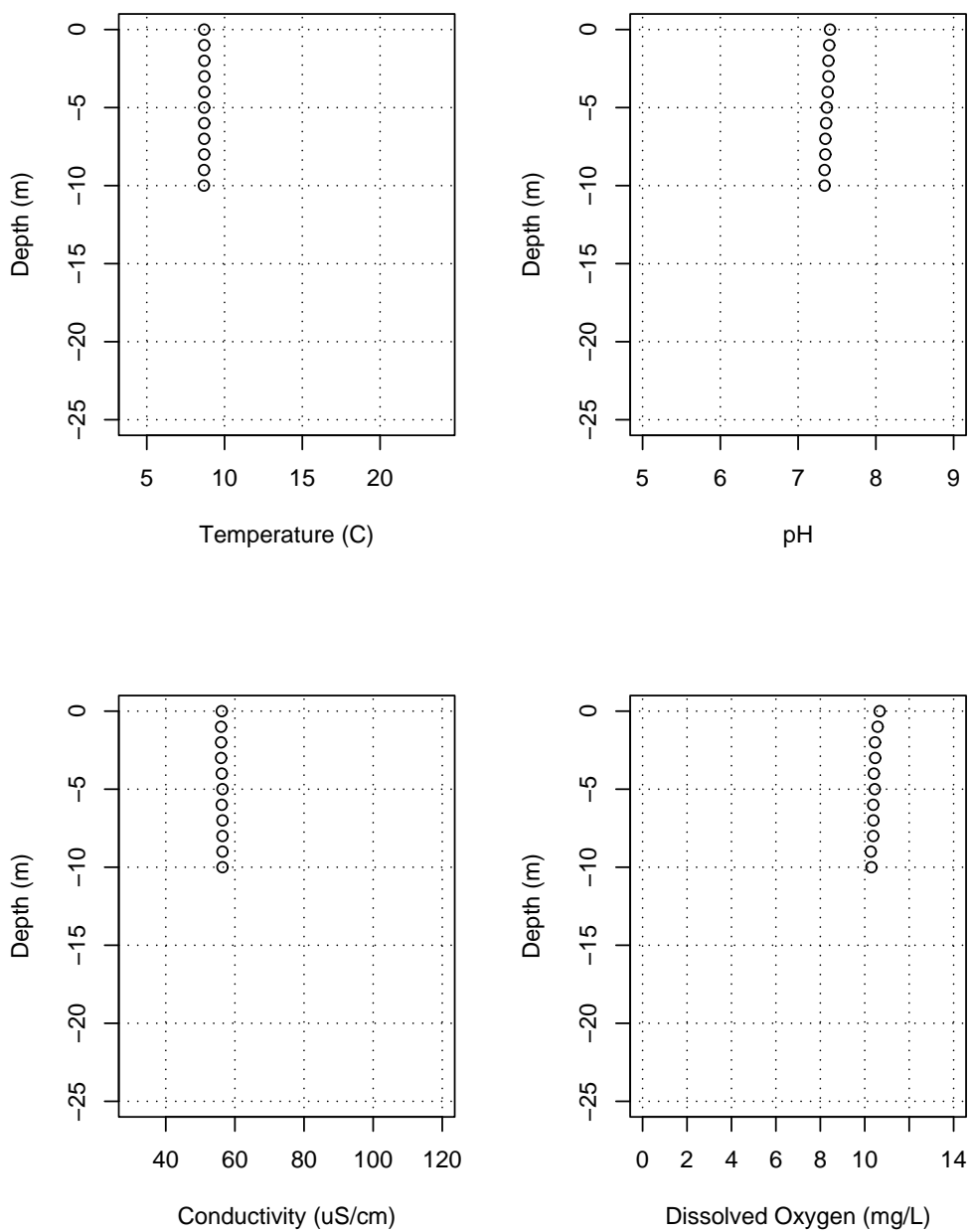


Figure 14: Lake Whatcom Hydrolab profile for the Intake, December 5, 2001.

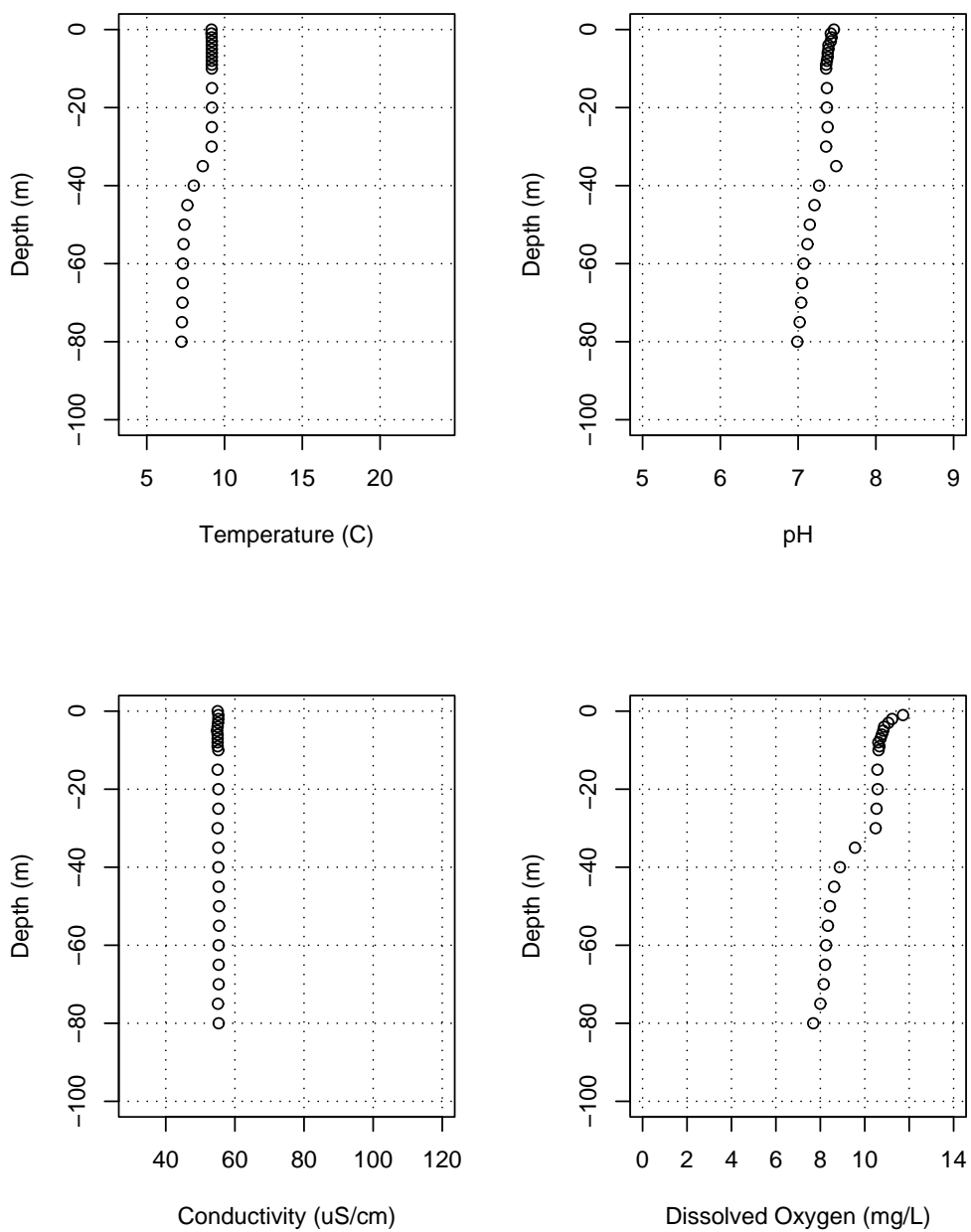


Figure 15: Lake Whatcom Hydrolab profile for Site 3, December 4, 2001.

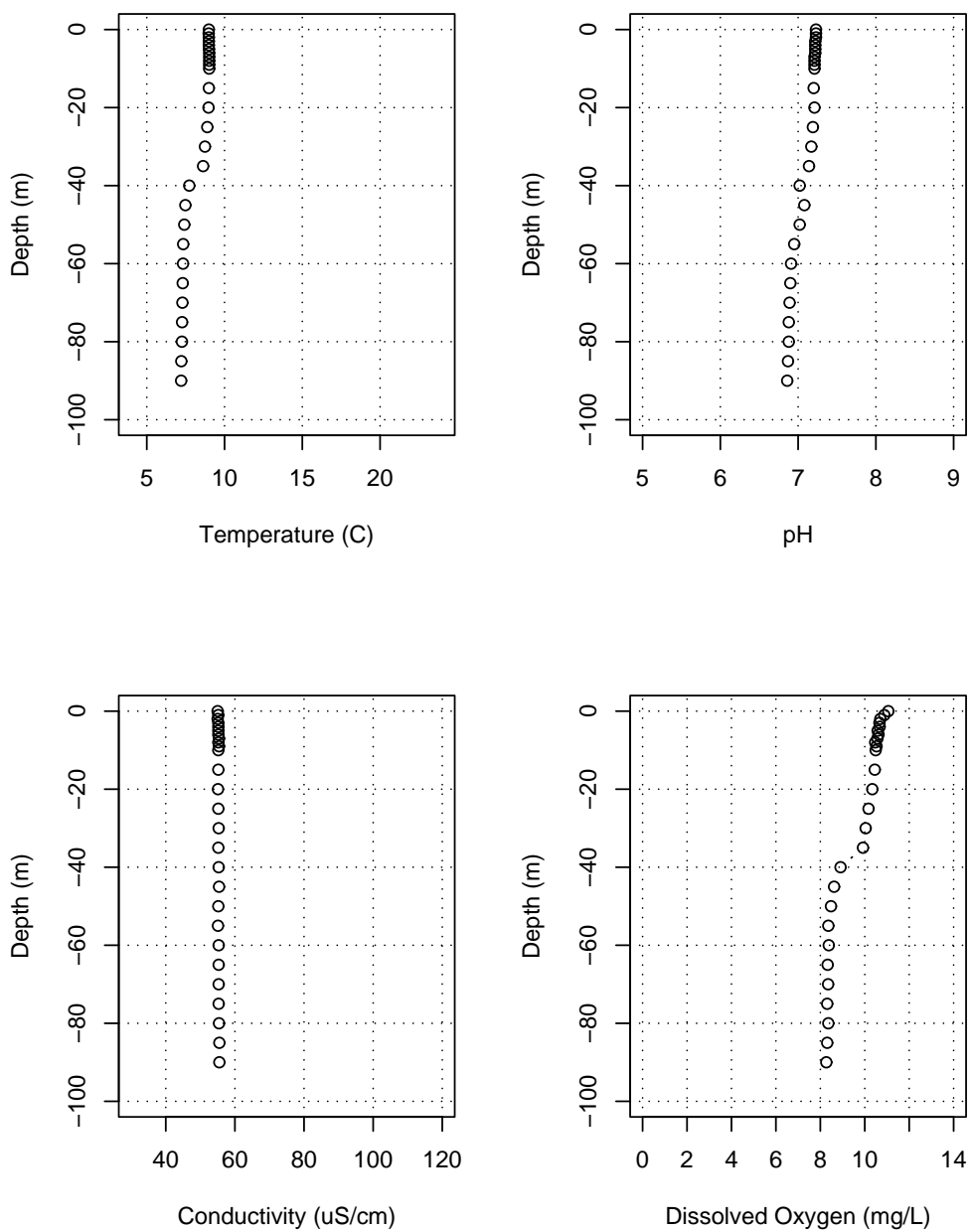


Figure 16: Lake Whatcom Hydrolab profile for Site 4, December 4, 2001.

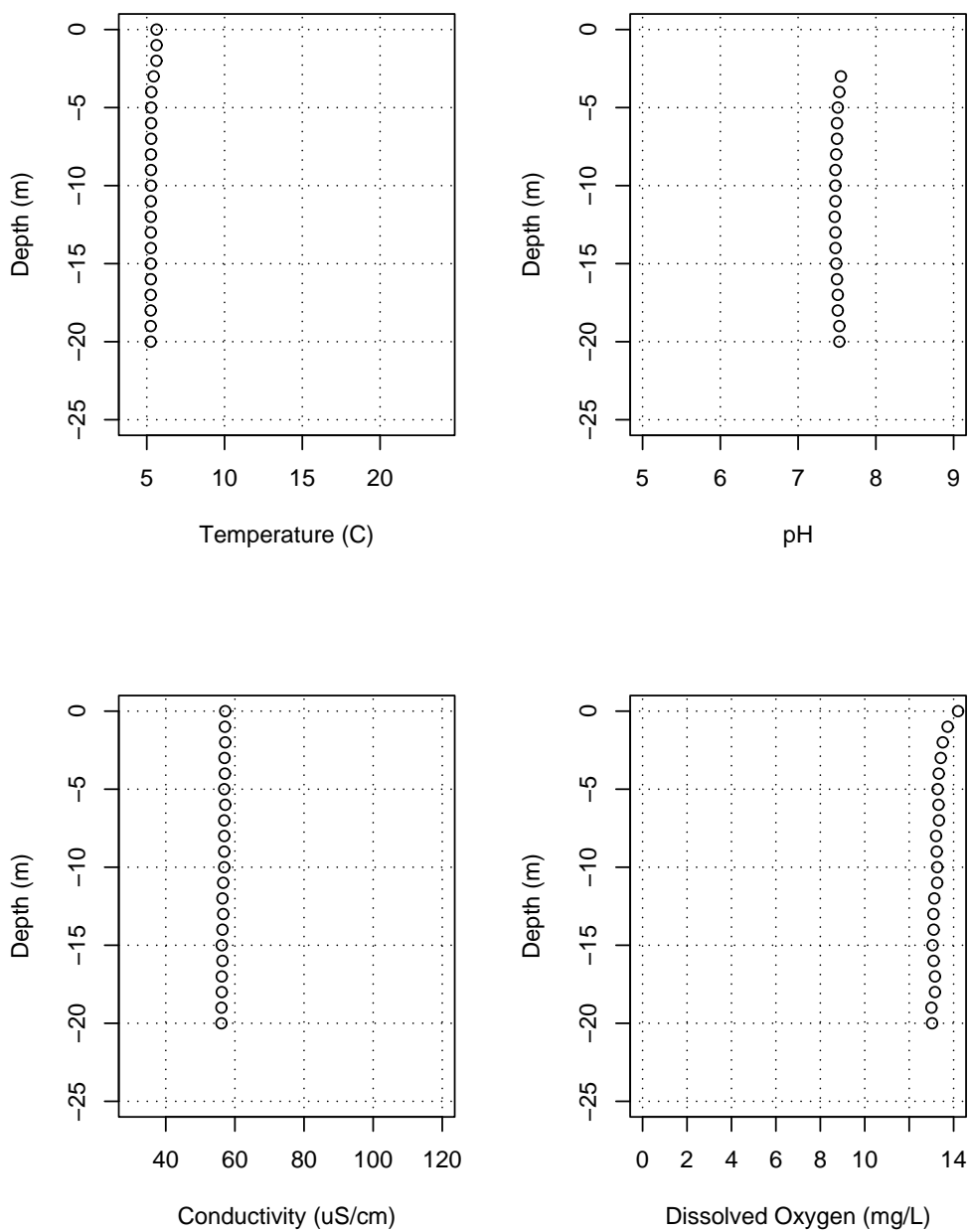


Figure 17: Lake Whatcom Hydrolab profile for Site 1, February 14, 2002.

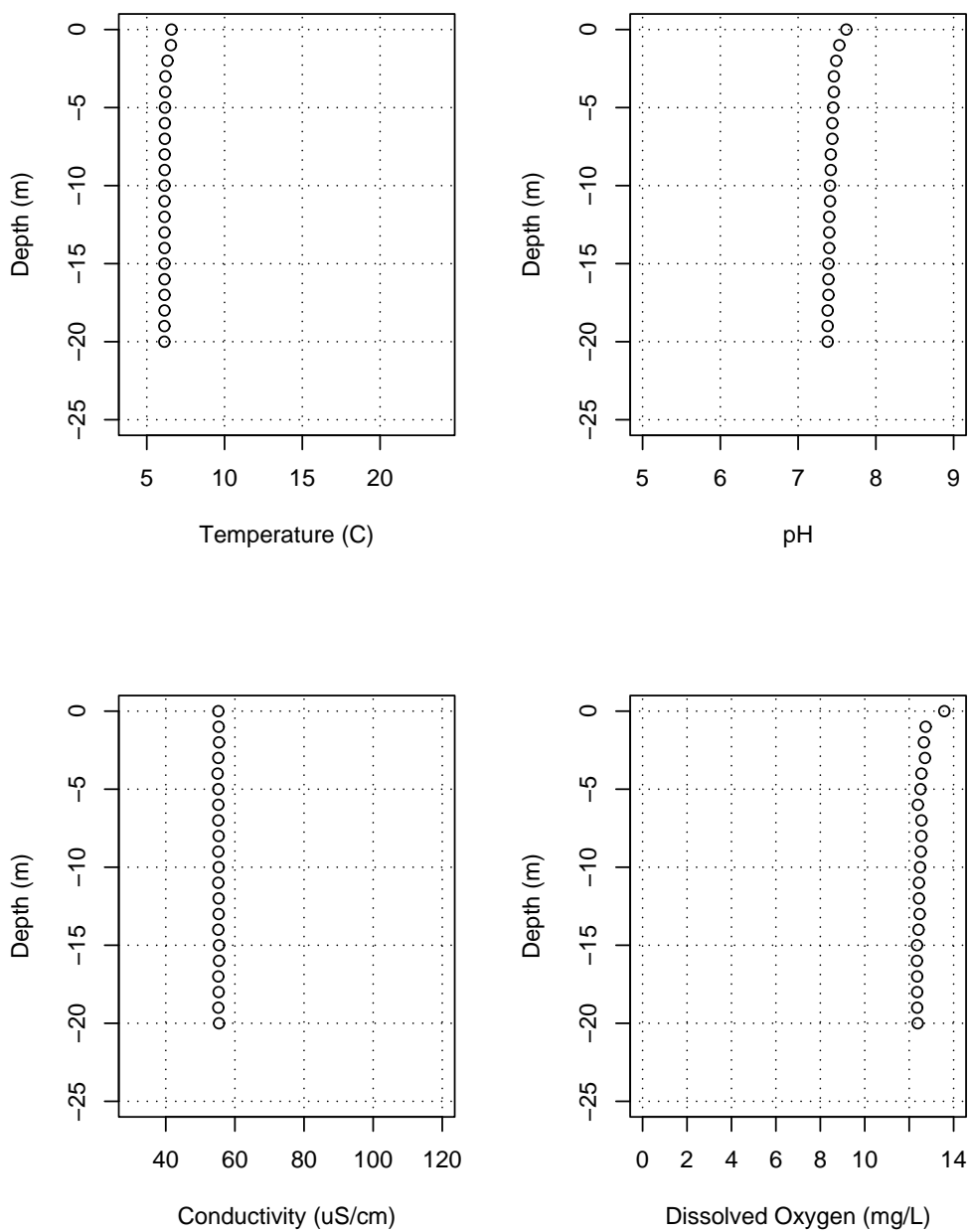


Figure 18: Lake Whatcom Hydrolab profile for Site 2, February 14, 2002.

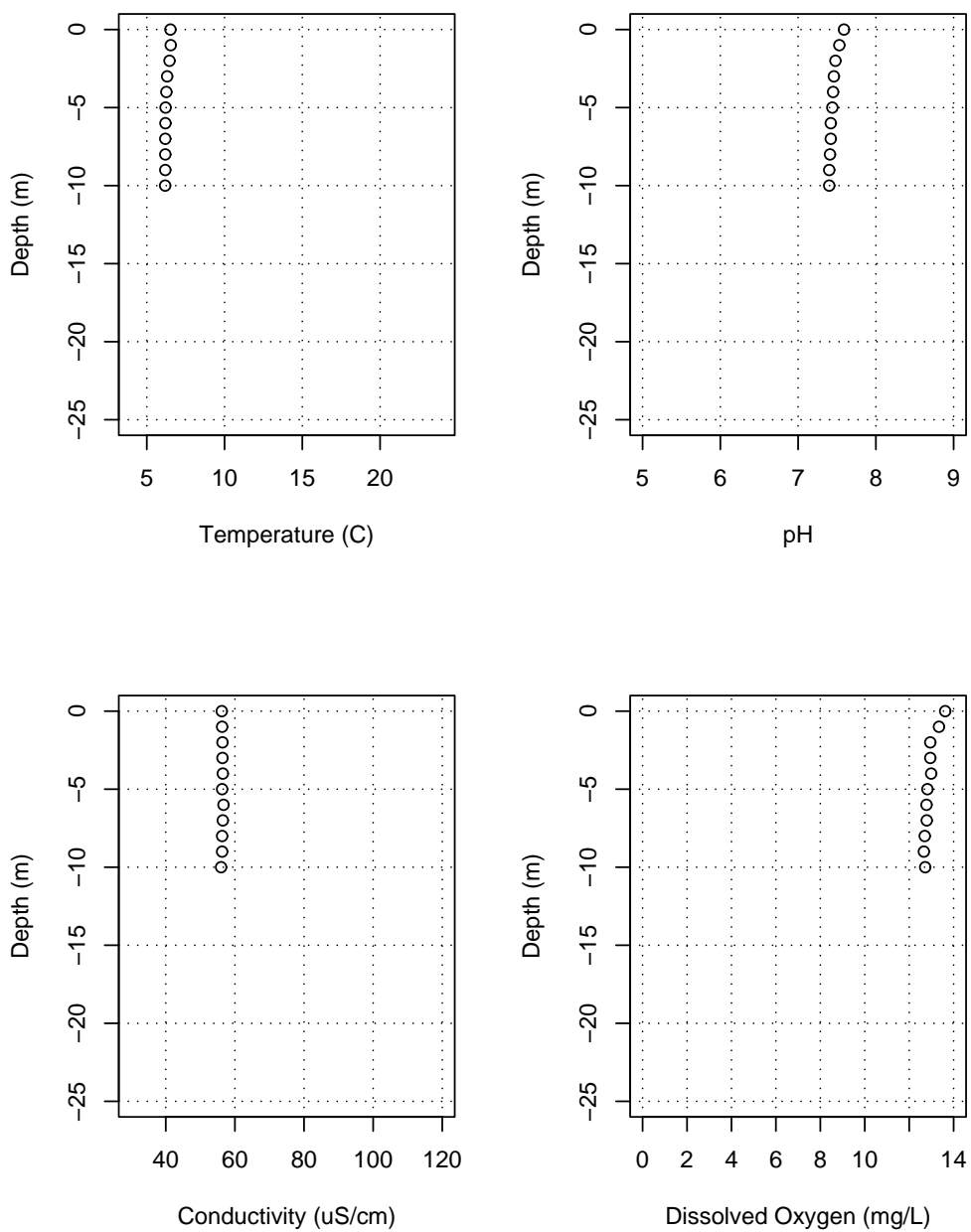


Figure 19: Lake Whatcom Hydrolab profile for the Intake, February 14, 2002.



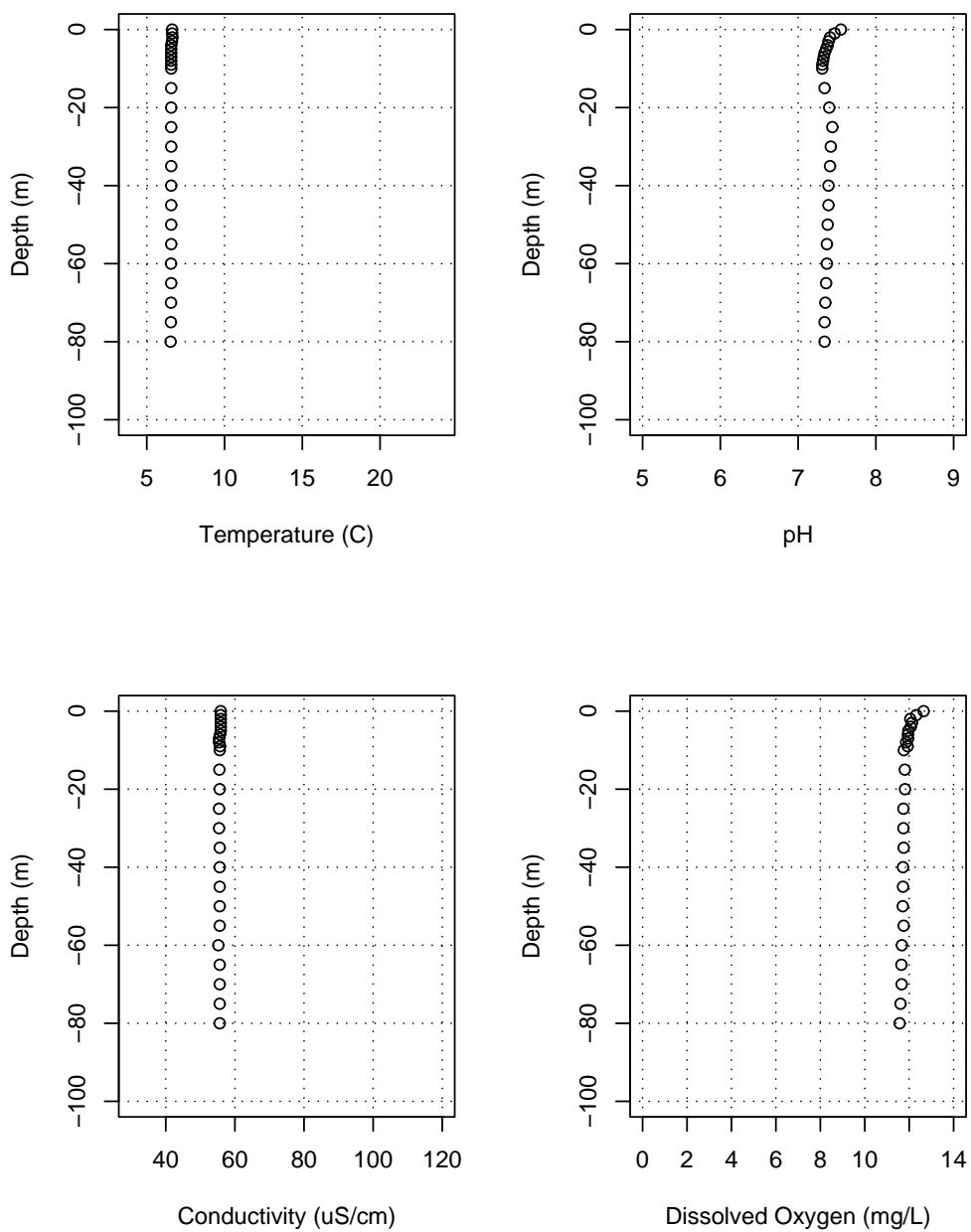


Figure 20: Lake Whatcom Hydrolab profile for Site 3, February 12, 2002.

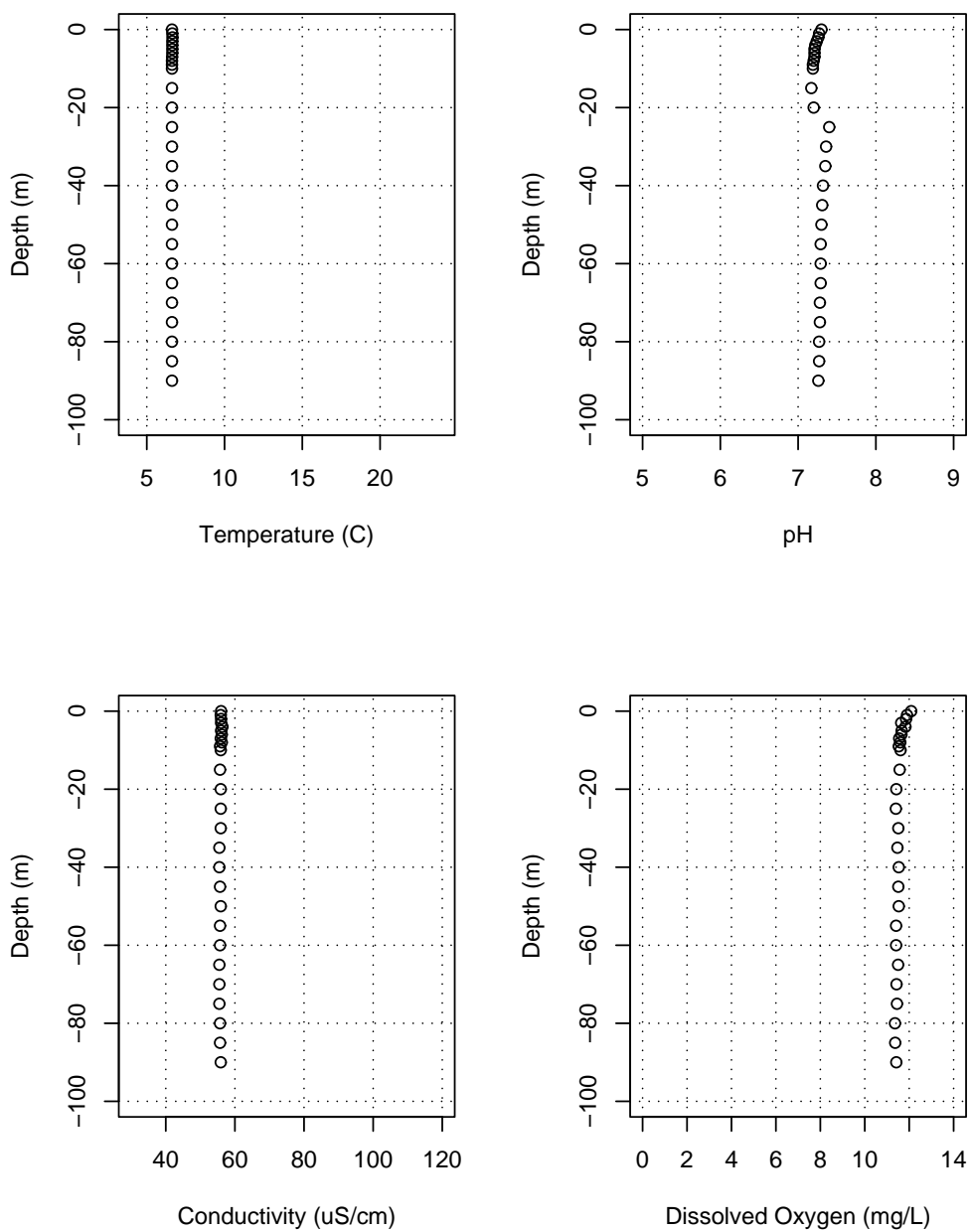


Figure 21: Lake Whatcom Hydrolab profile for Site 4, February 12, 2002.

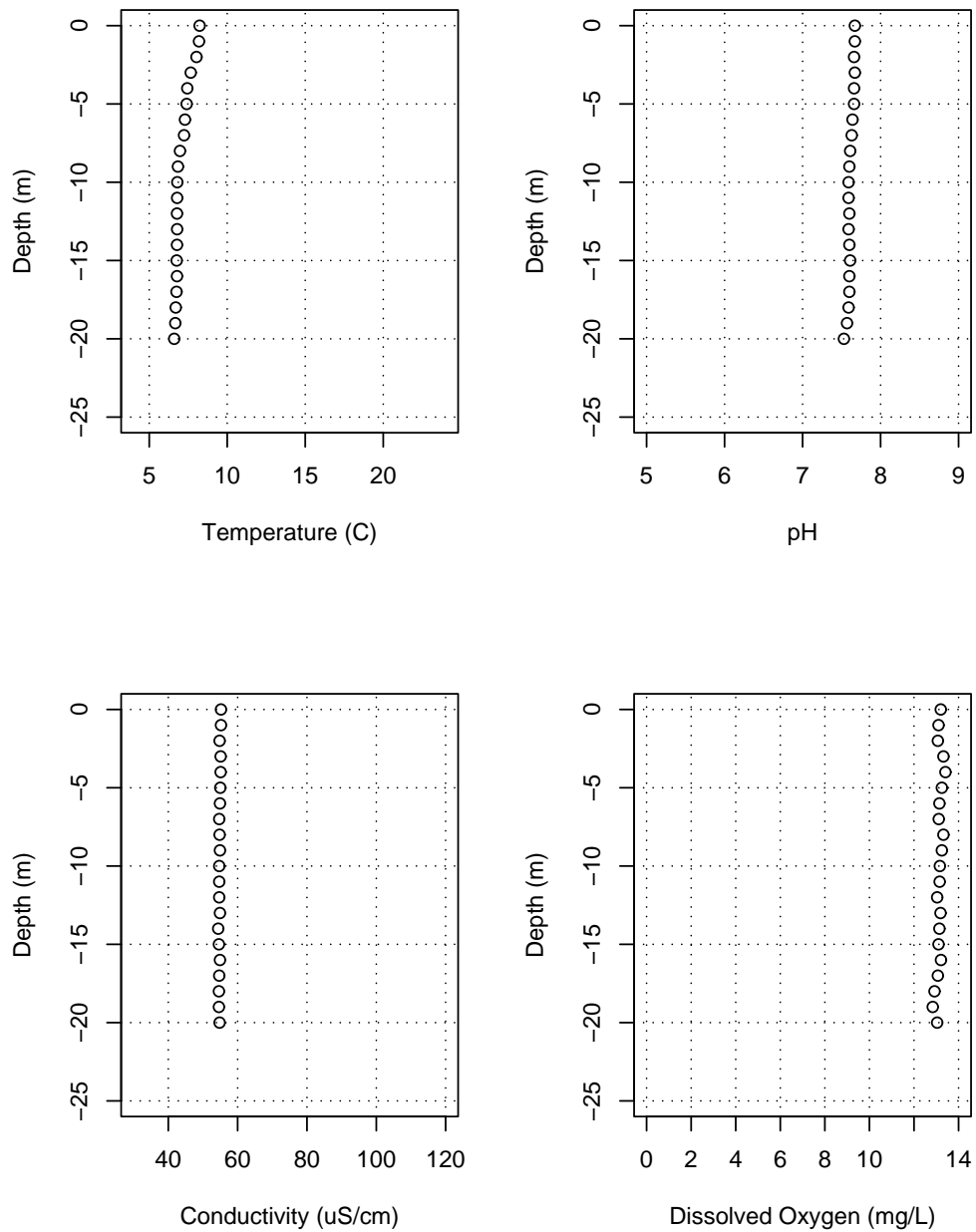


Figure 22: Lake Whatcom Hydrolab profile for Site 1, April 4, 2002.

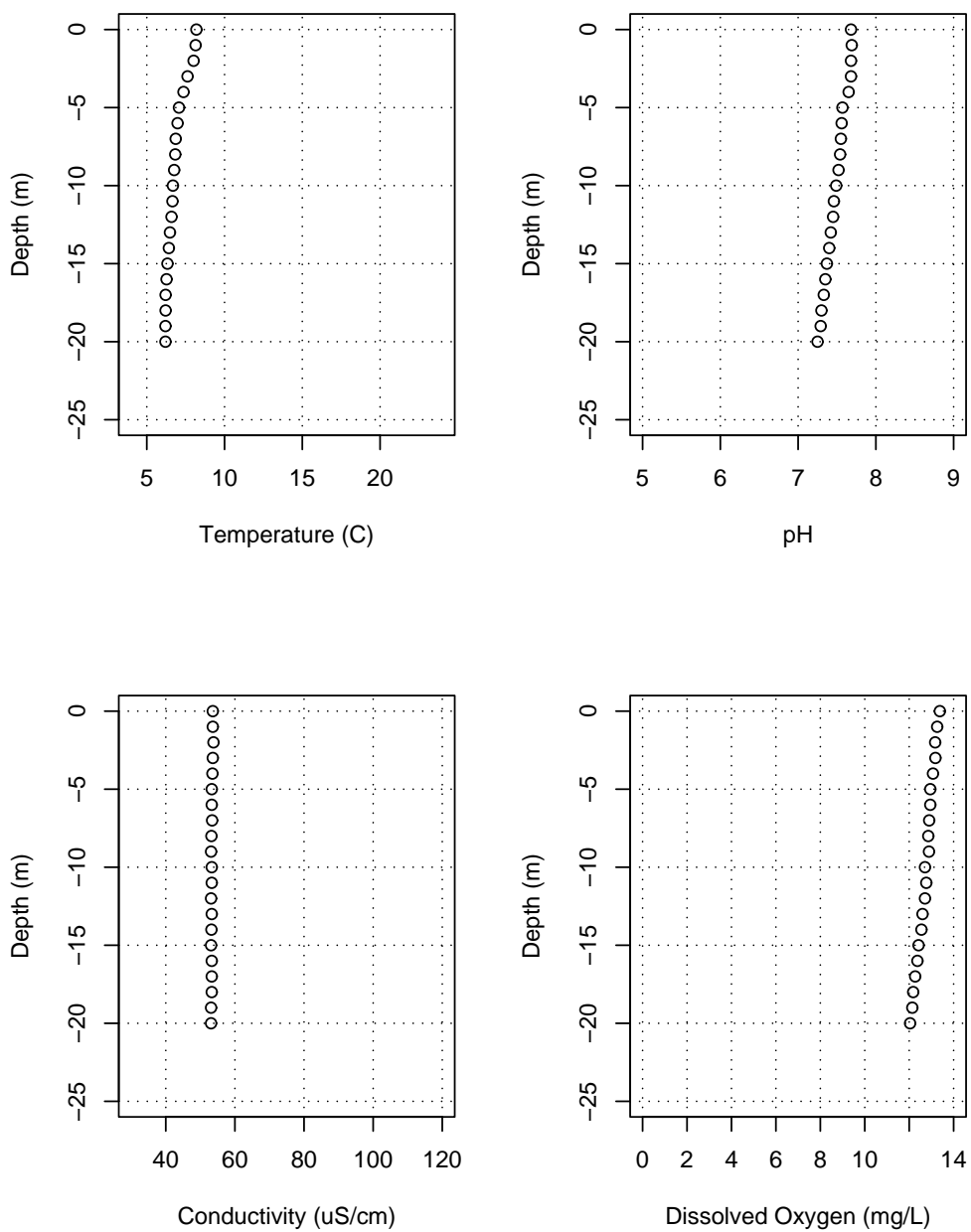


Figure 23: Lake Whatcom Hydrolab profile for Site 2, April 4, 2002.

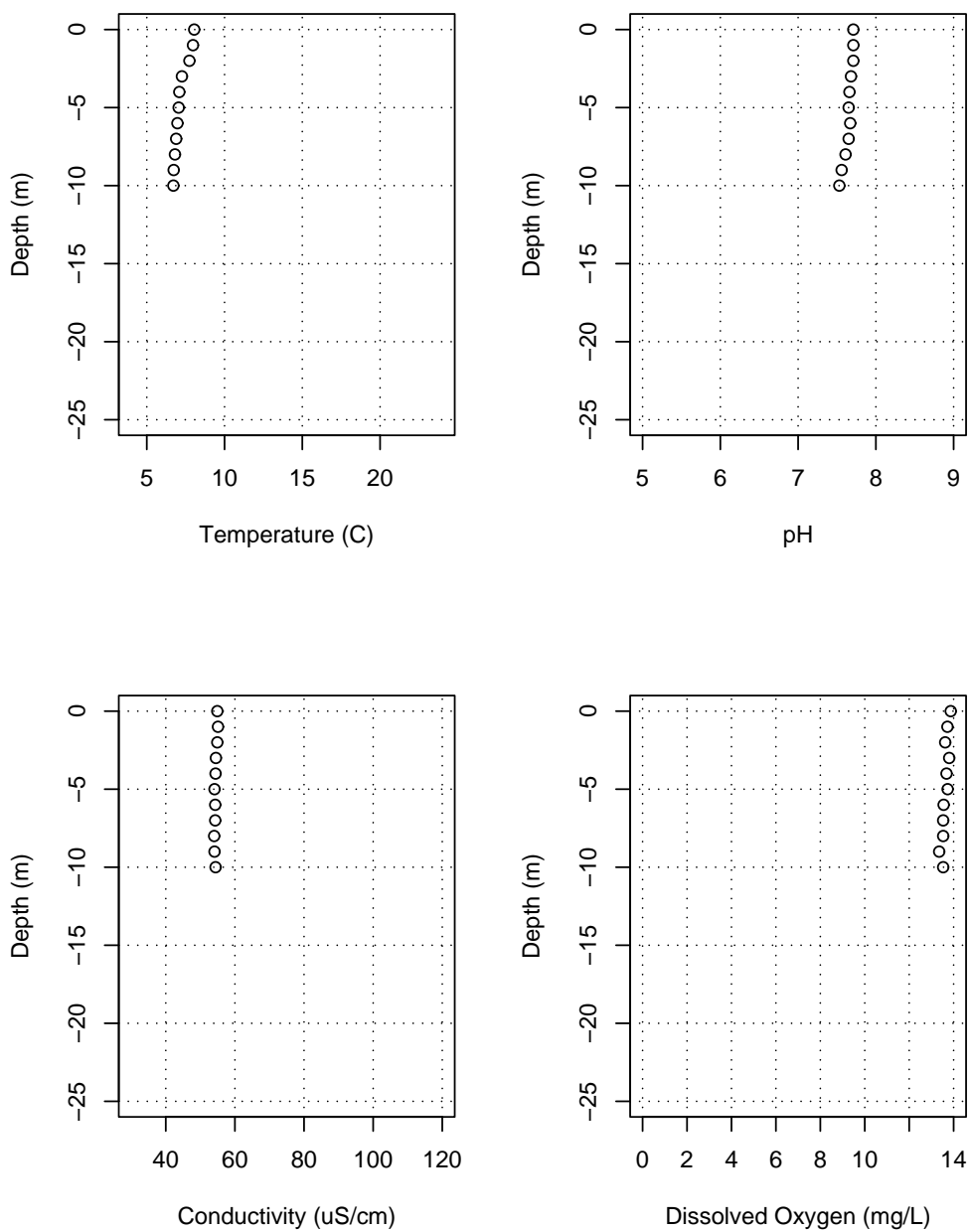


Figure 24: Lake Whatcom Hydrolab profile for the Intake, April 4, 2002.

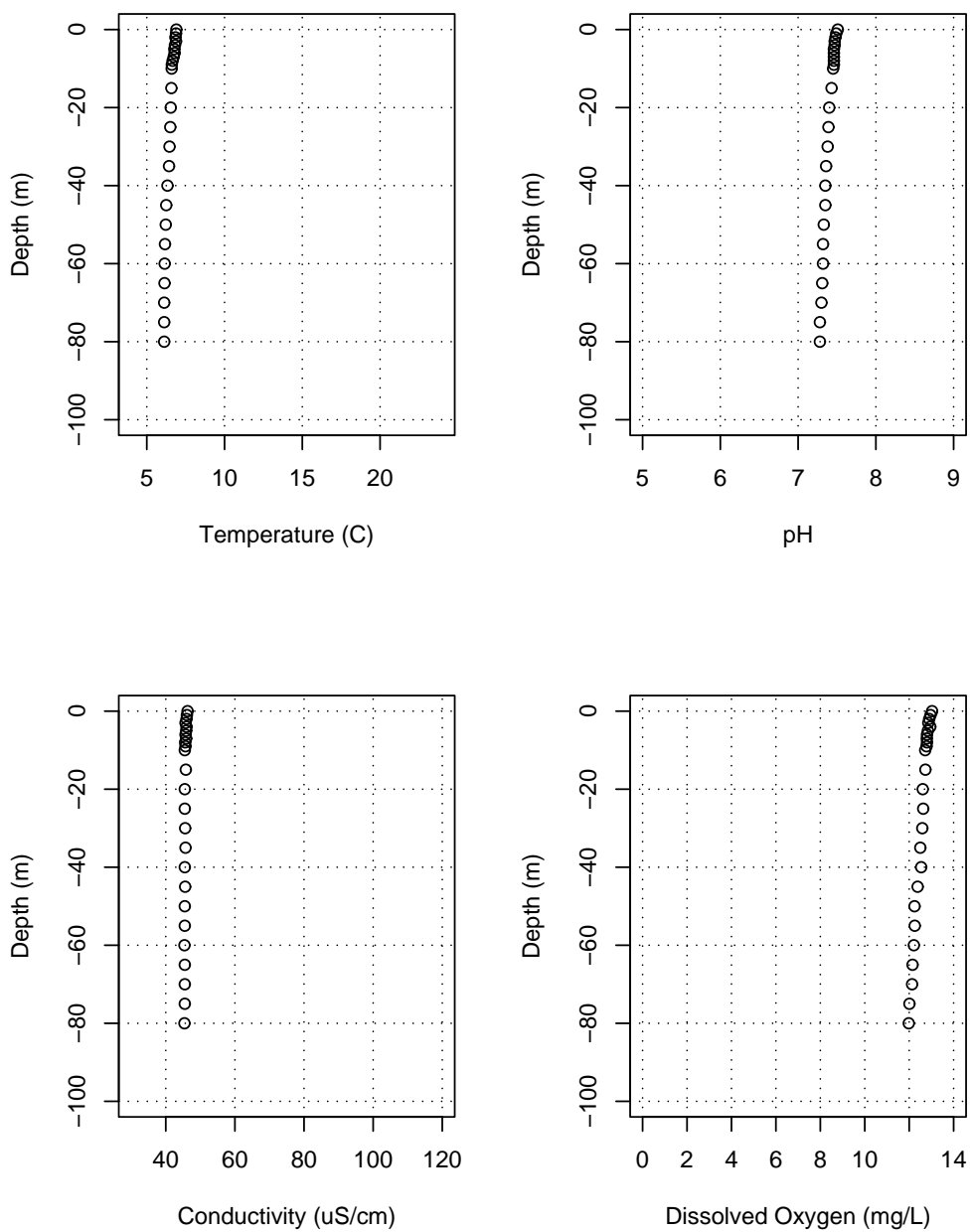


Figure 25: Lake Whatcom Hydrolab profile for Site 3, April 2, 2002.

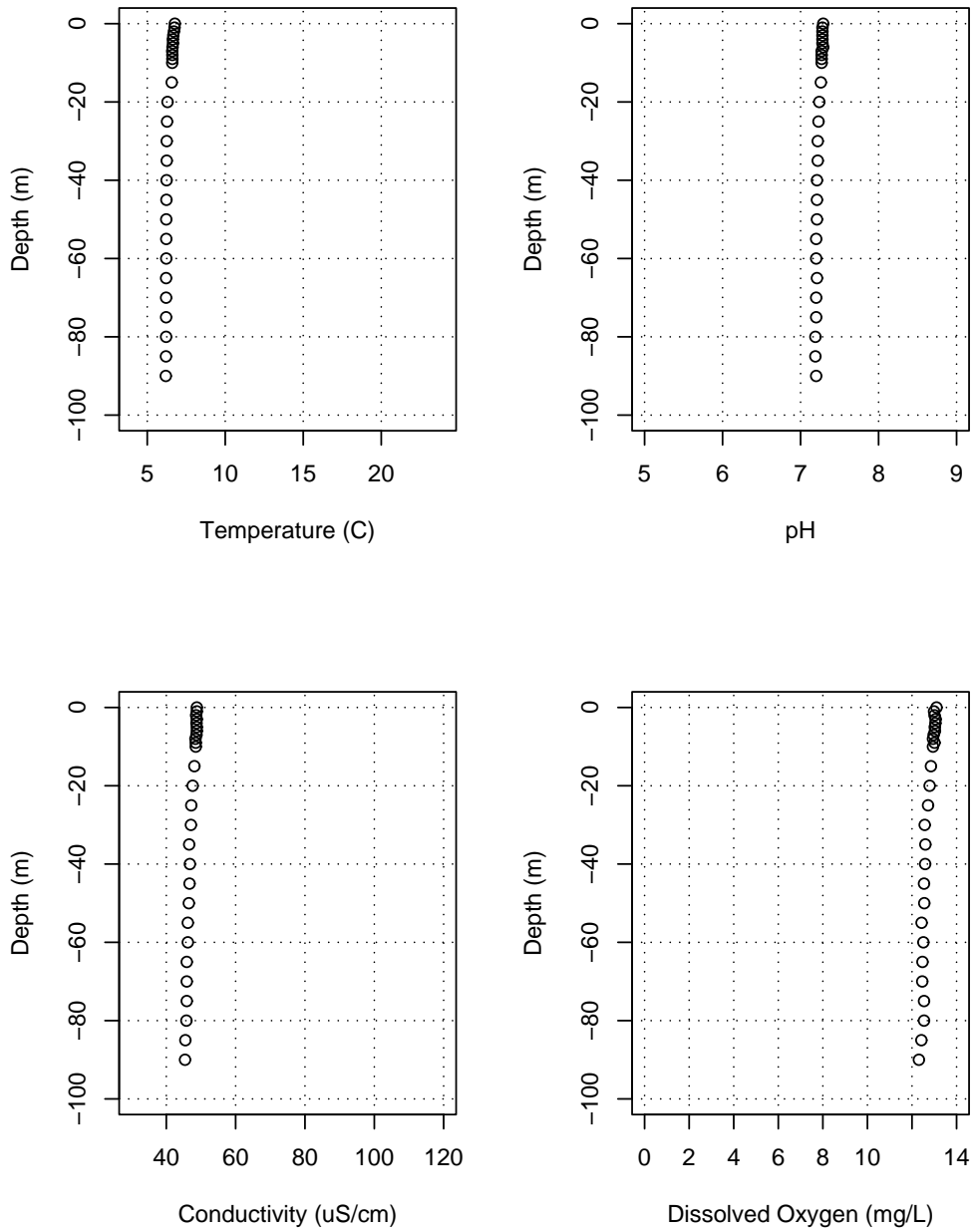


Figure 26: Lake Whatcom Hydrolab profile for Site 4, April 2, 2002.

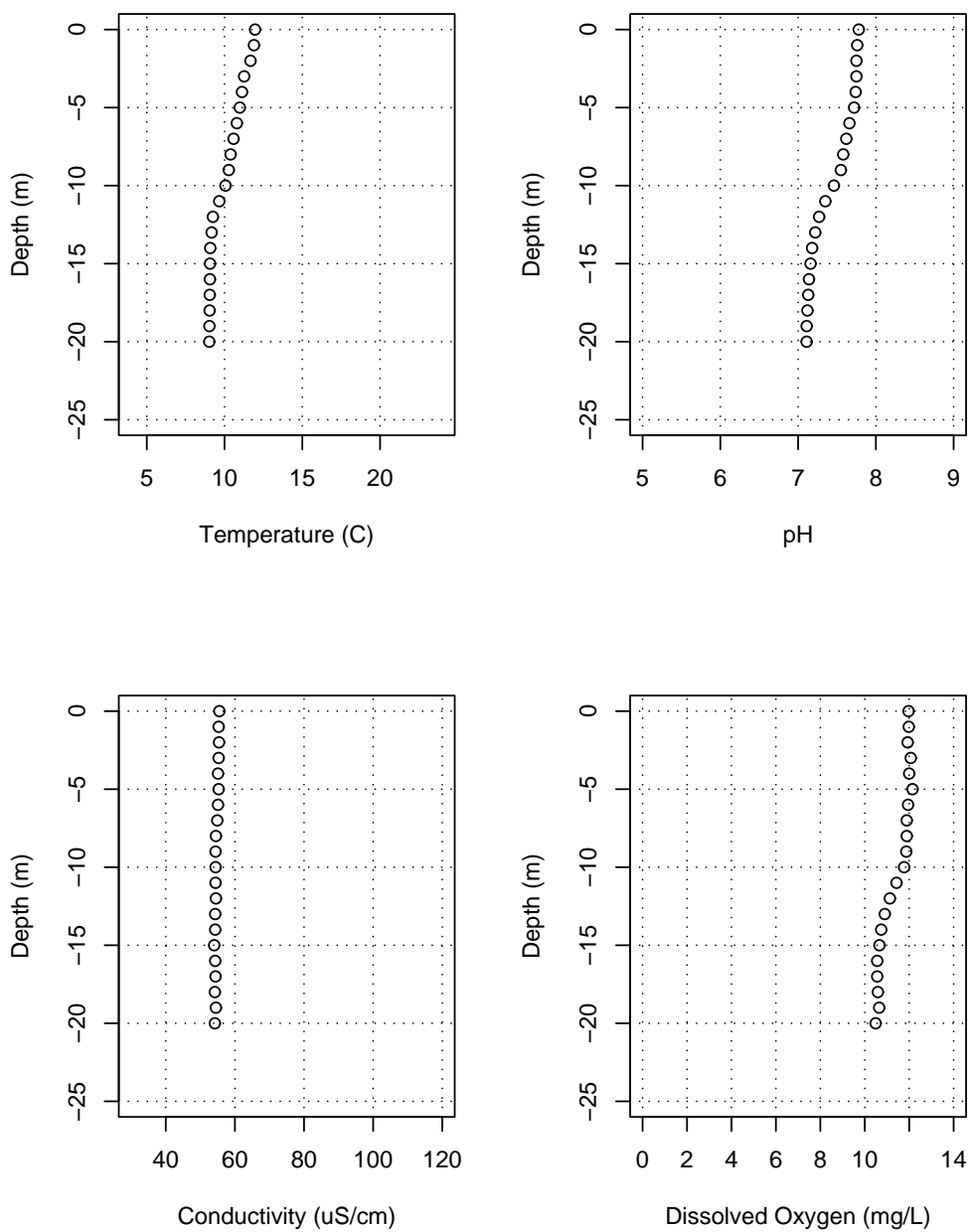


Figure 27: Lake Whatcom Hydrolab profile for Site 1, May 9, 2002.



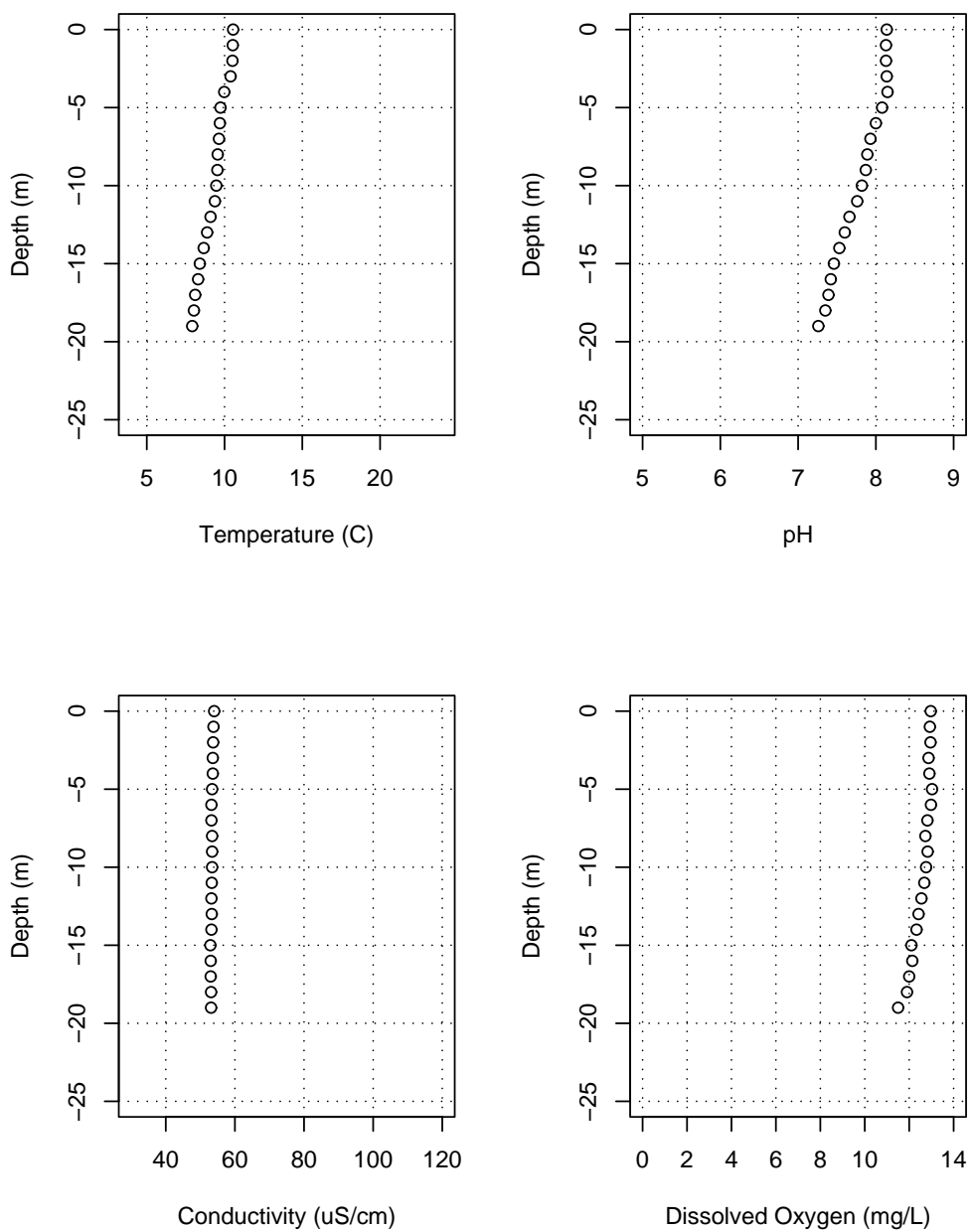


Figure 28: Lake Whatcom Hydrolab profile for Site 2, May 9, 2002.

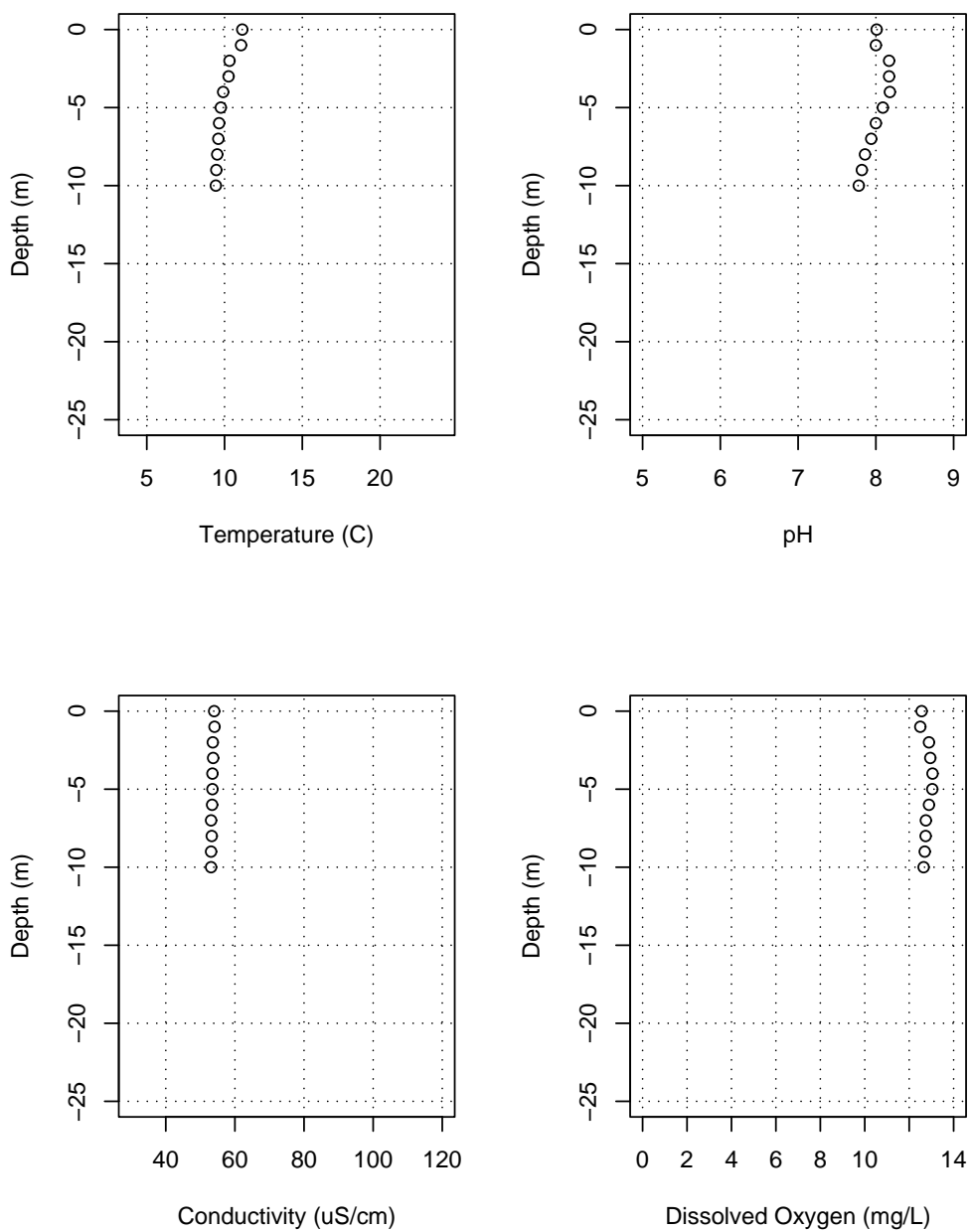


Figure 29: Lake Whatcom Hydrolab profile for the Intake, May 9, 2002.

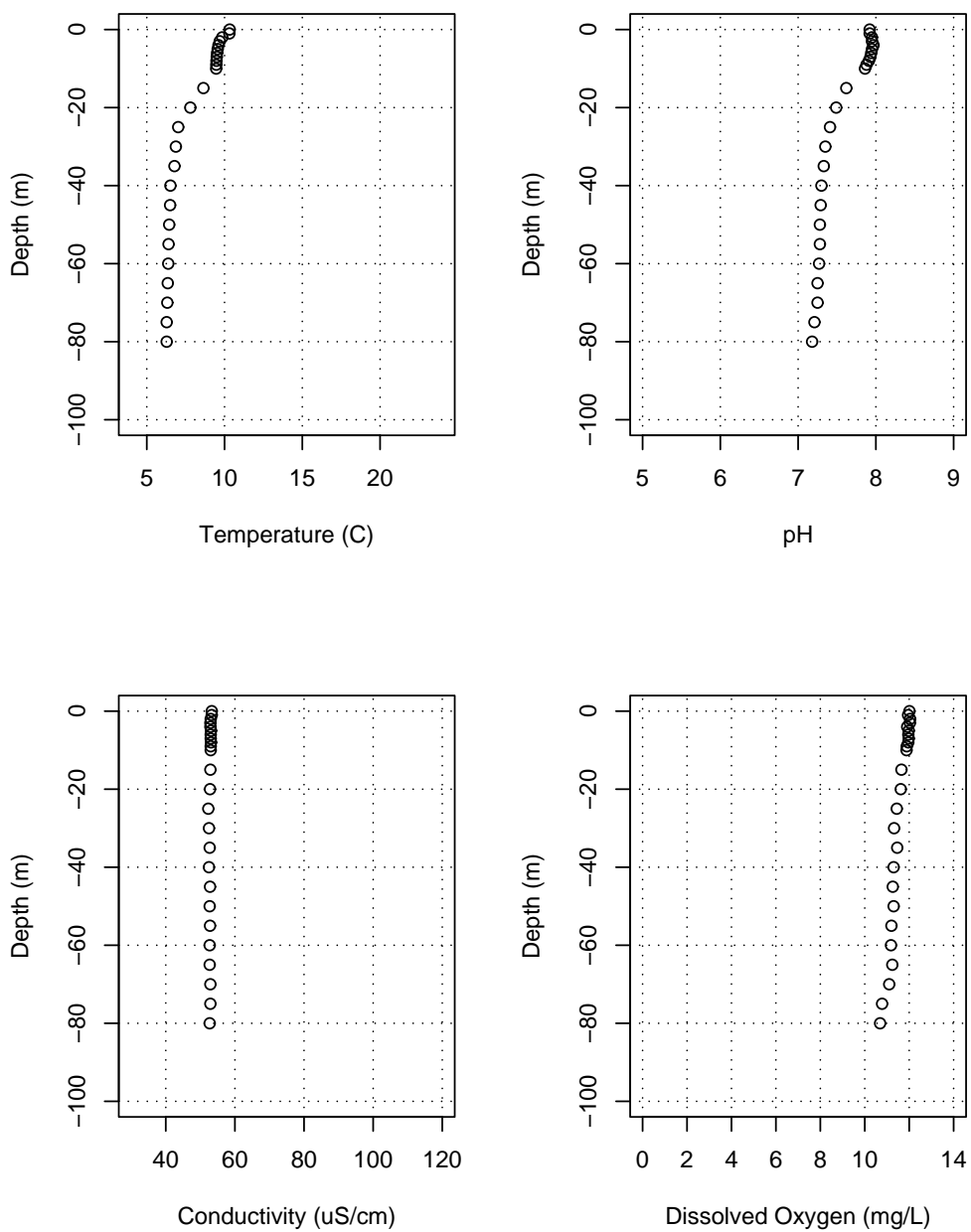


Figure 30: Lake Whatcom Hydrolab profile for Site 3, May 7, 2002.

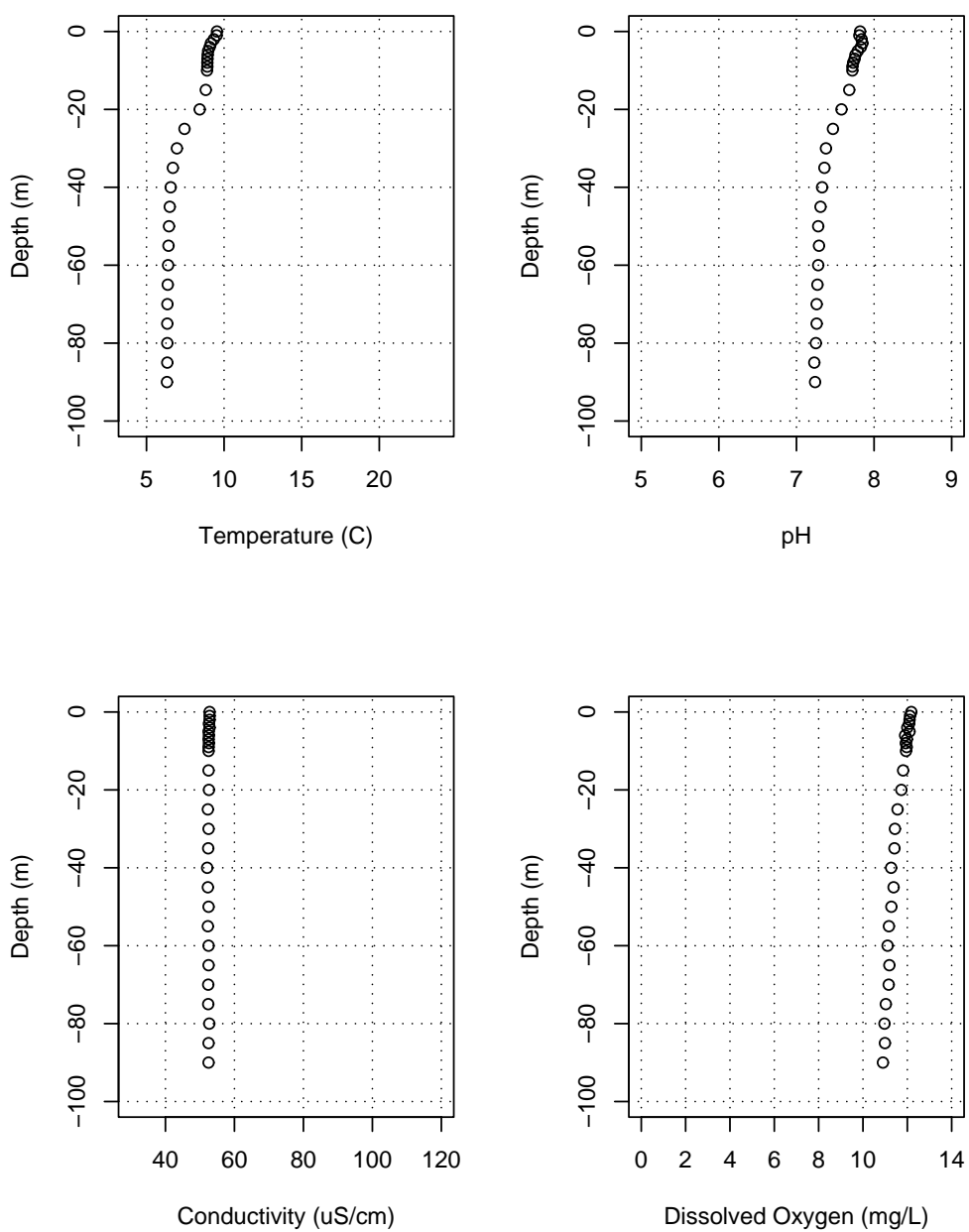


Figure 31: Lake Whatcom Hydrolab profile for Site 4, May 7, 2002.

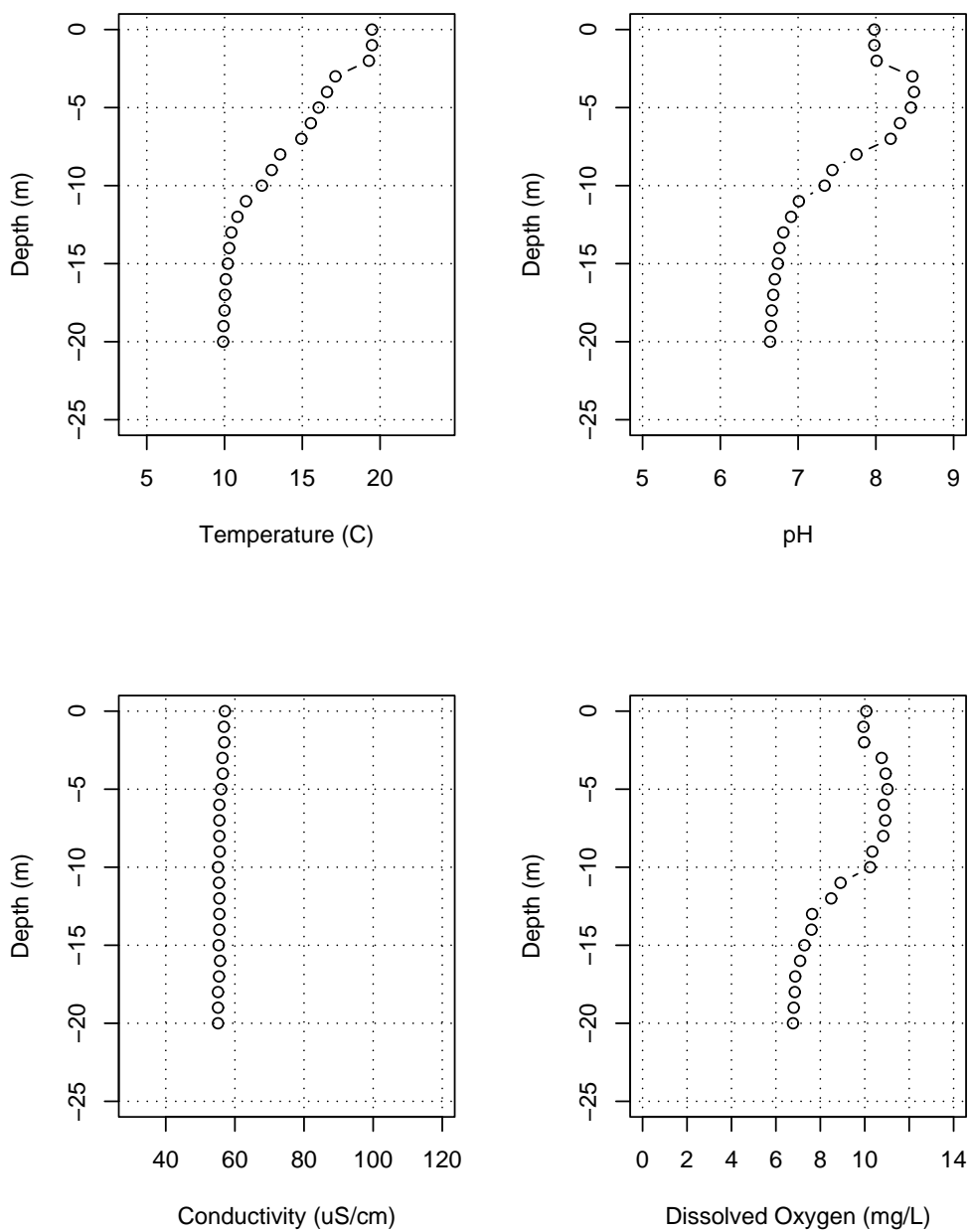


Figure 32: Lake Whatcom Hydrolab profile for Site 1, June 14, 2002.

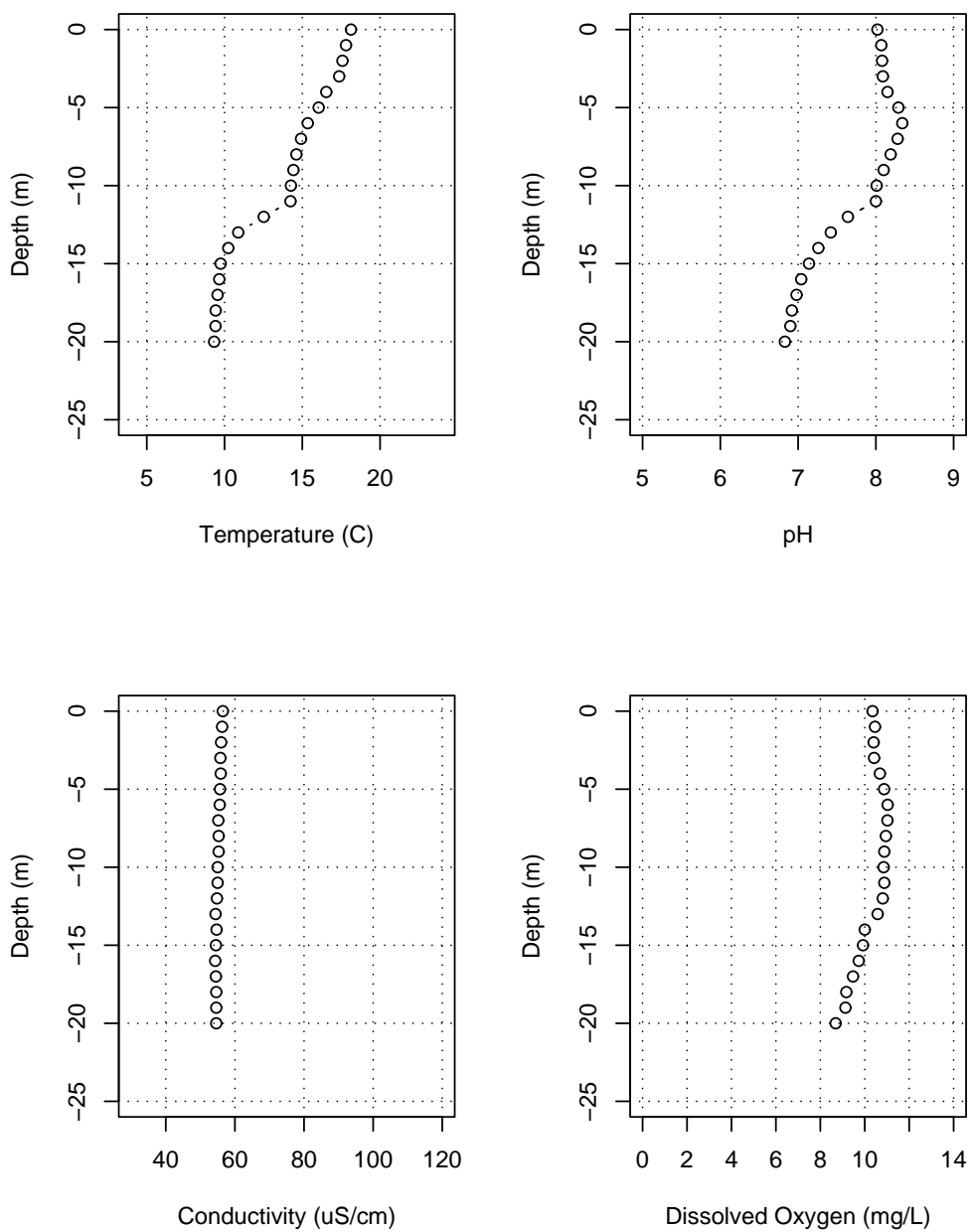


Figure 33: Lake Whatcom Hydrolab profile for Site 2, June 14, 2002.

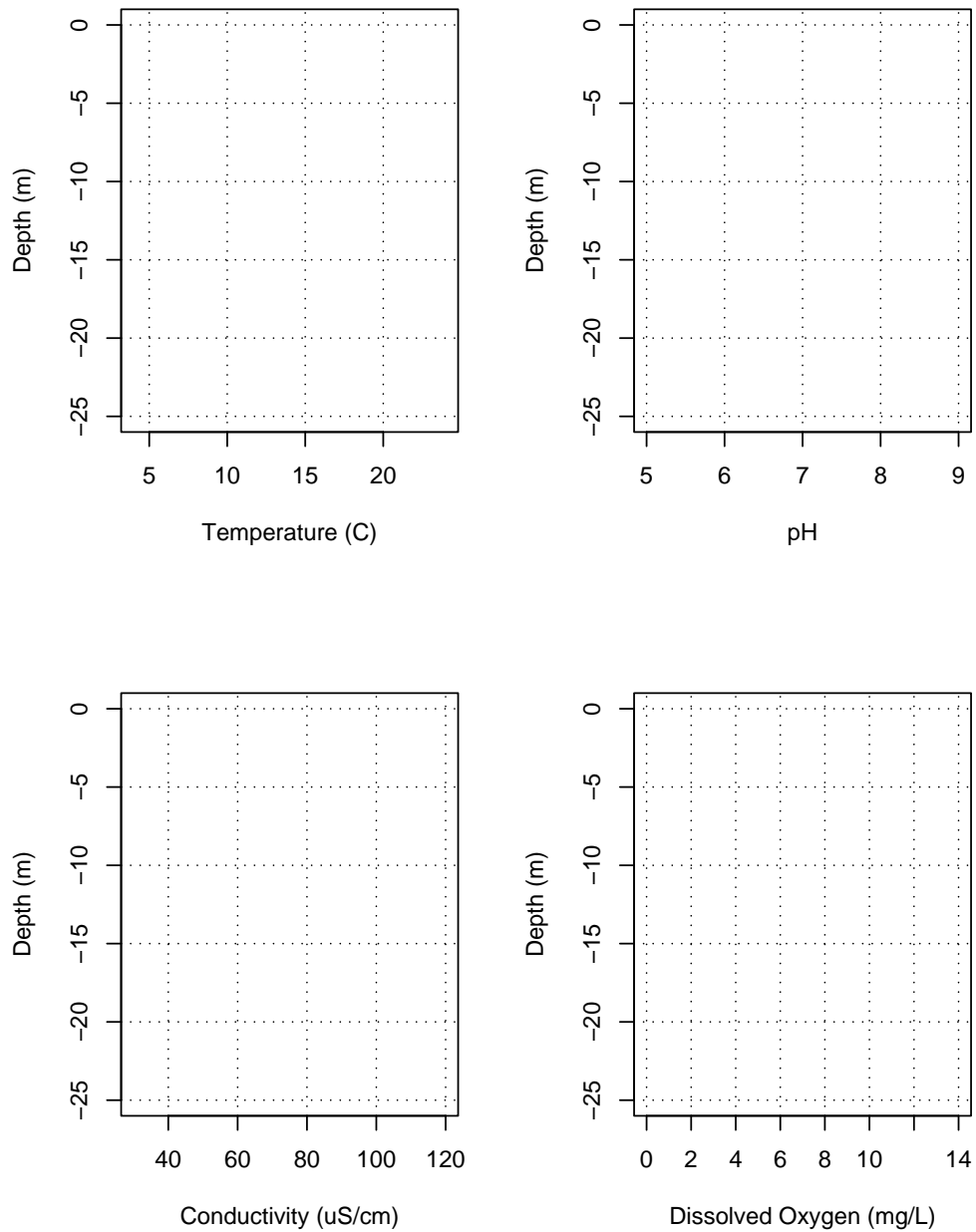


Figure 34: Lake Whatcom Hydrolab profile for the Intake, June 14, 2002. (No data collected – equipment failure.)

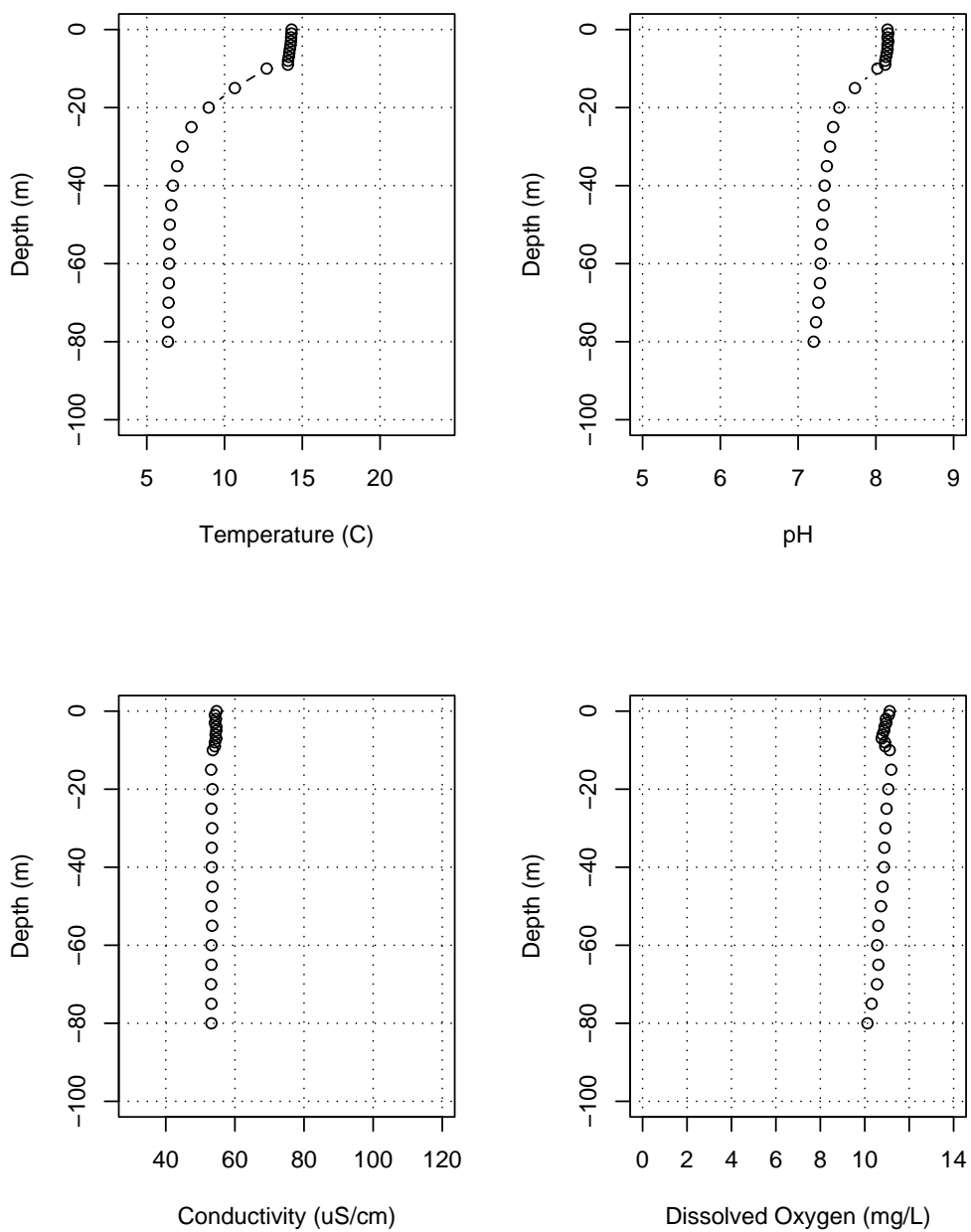


Figure 35: Lake Whatcom Hydrolab profile for Site 3, June 4, 2002.



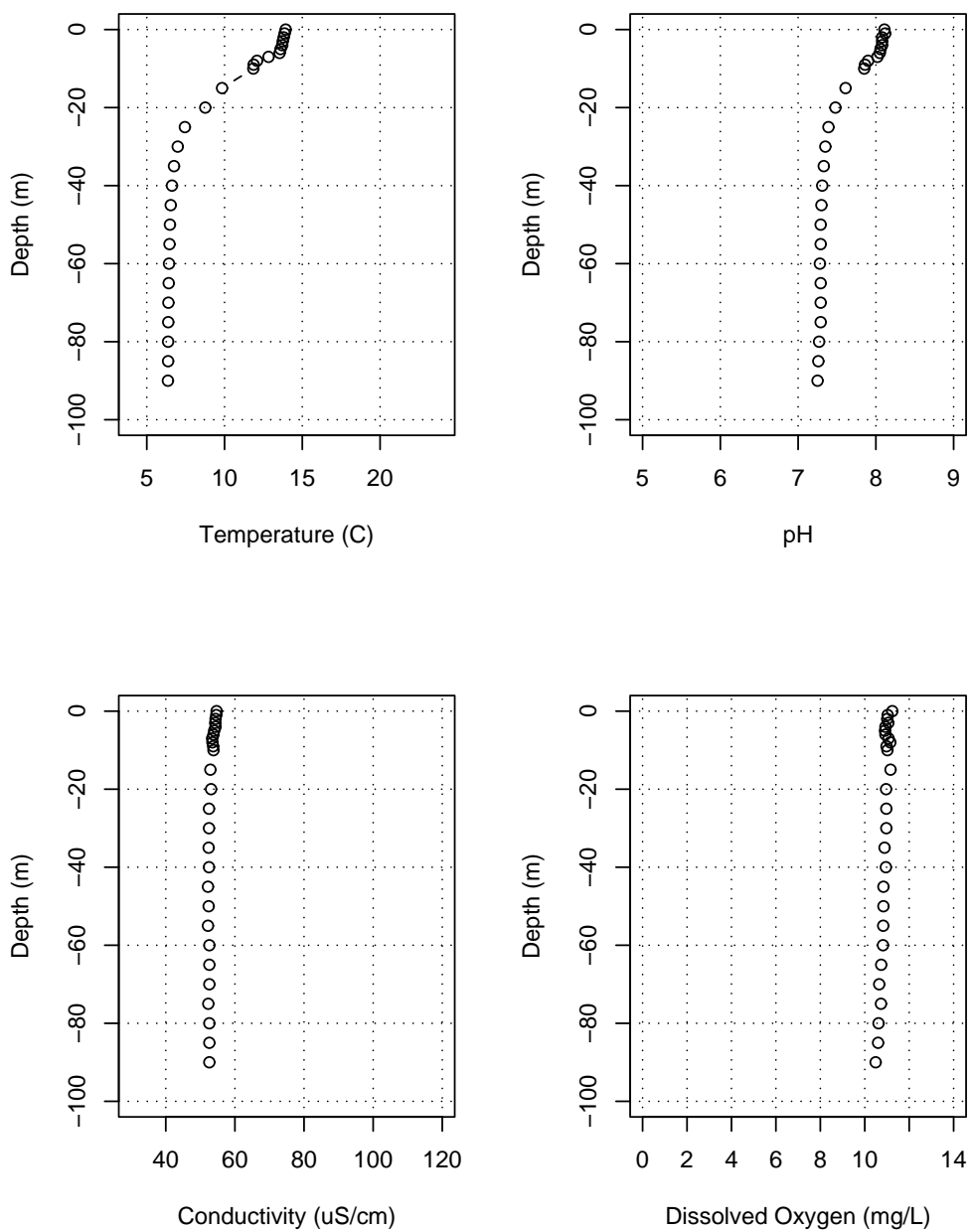


Figure 36: Lake Whatcom Hydrolab profile for Site 4, June 4, 2002.

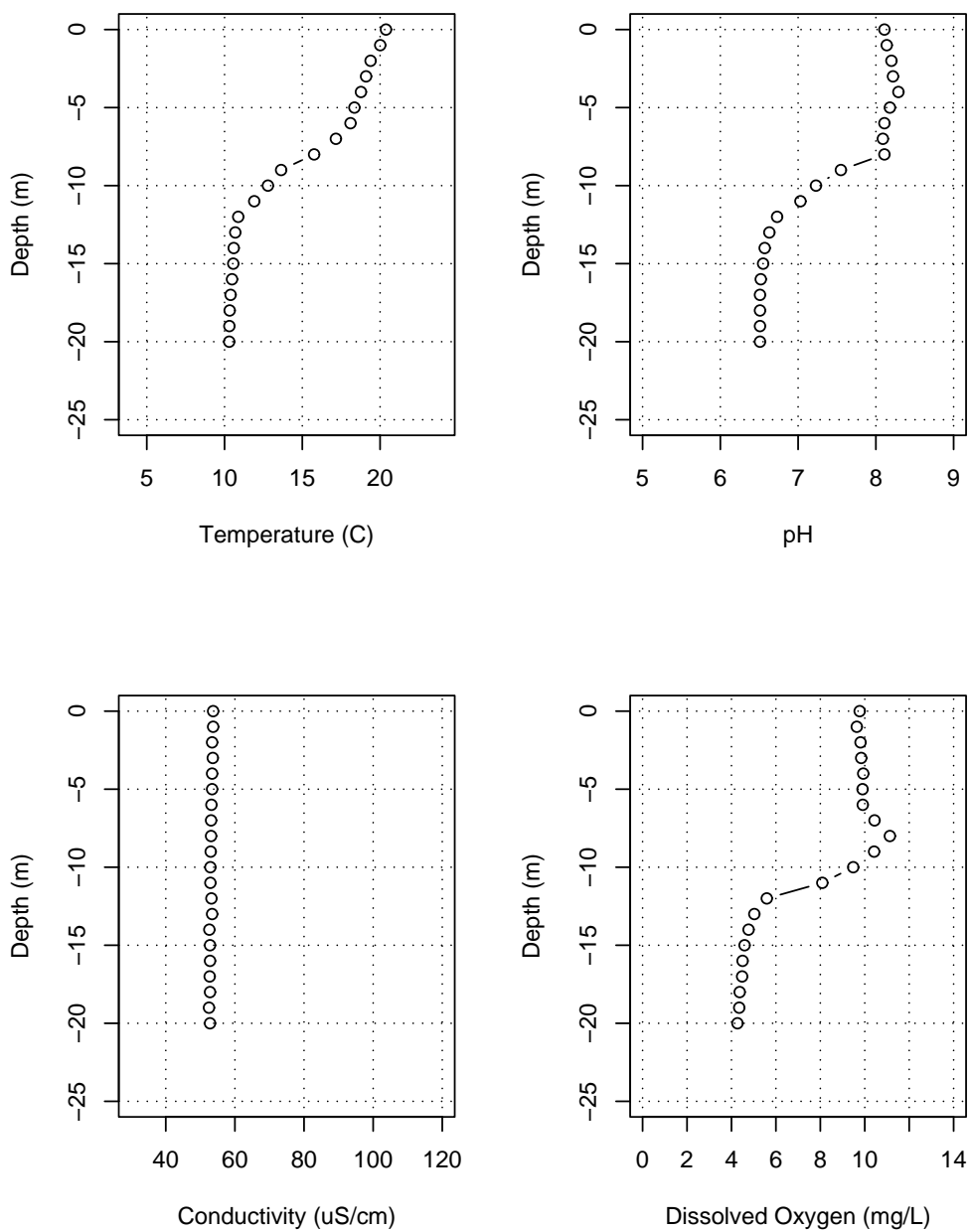


Figure 37: Lake Whatcom Hydrolab profile for Site 1, July 10, 2002.

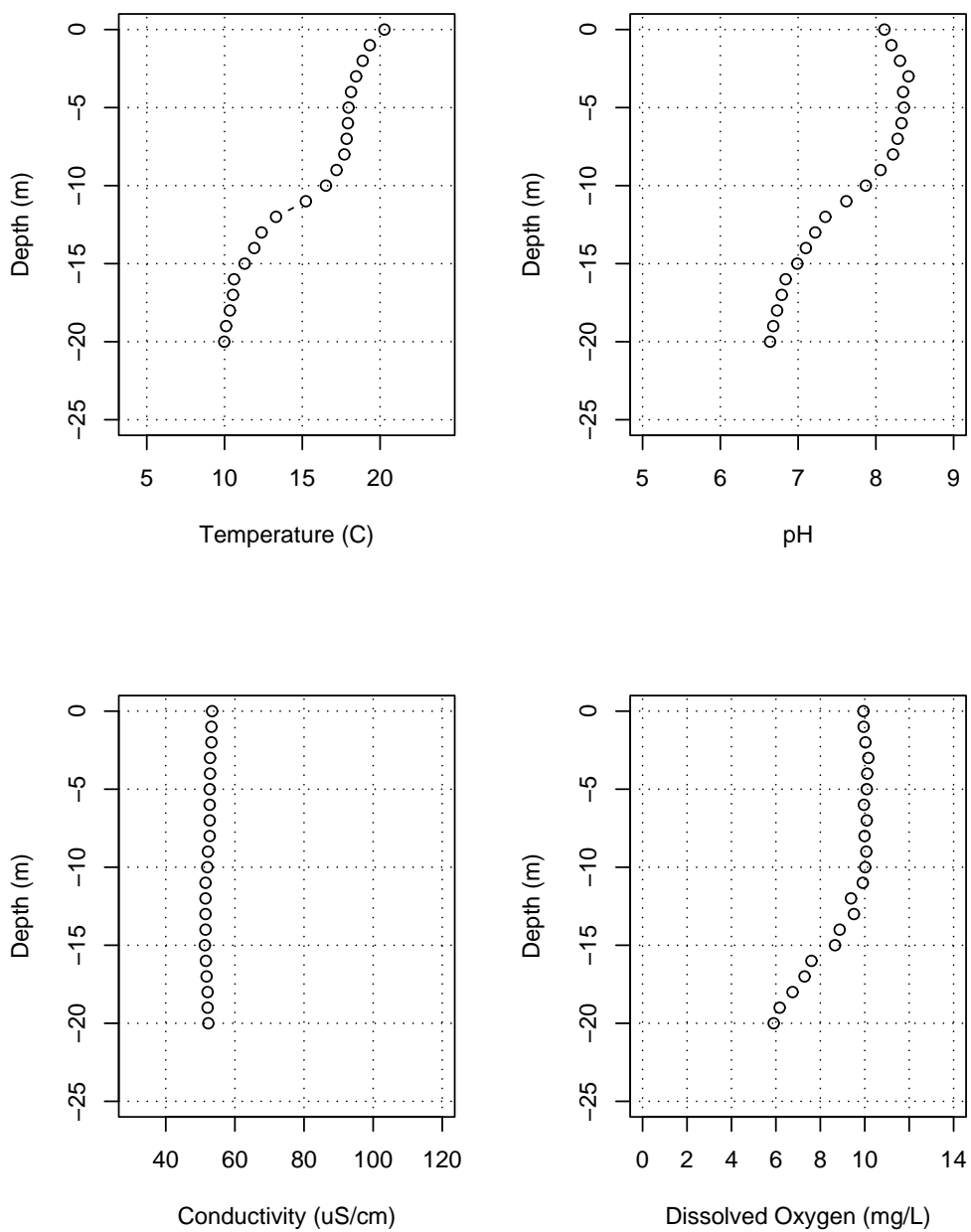


Figure 38: Lake Whatcom Hydrolab profile for Site 2, July 10, 2002.

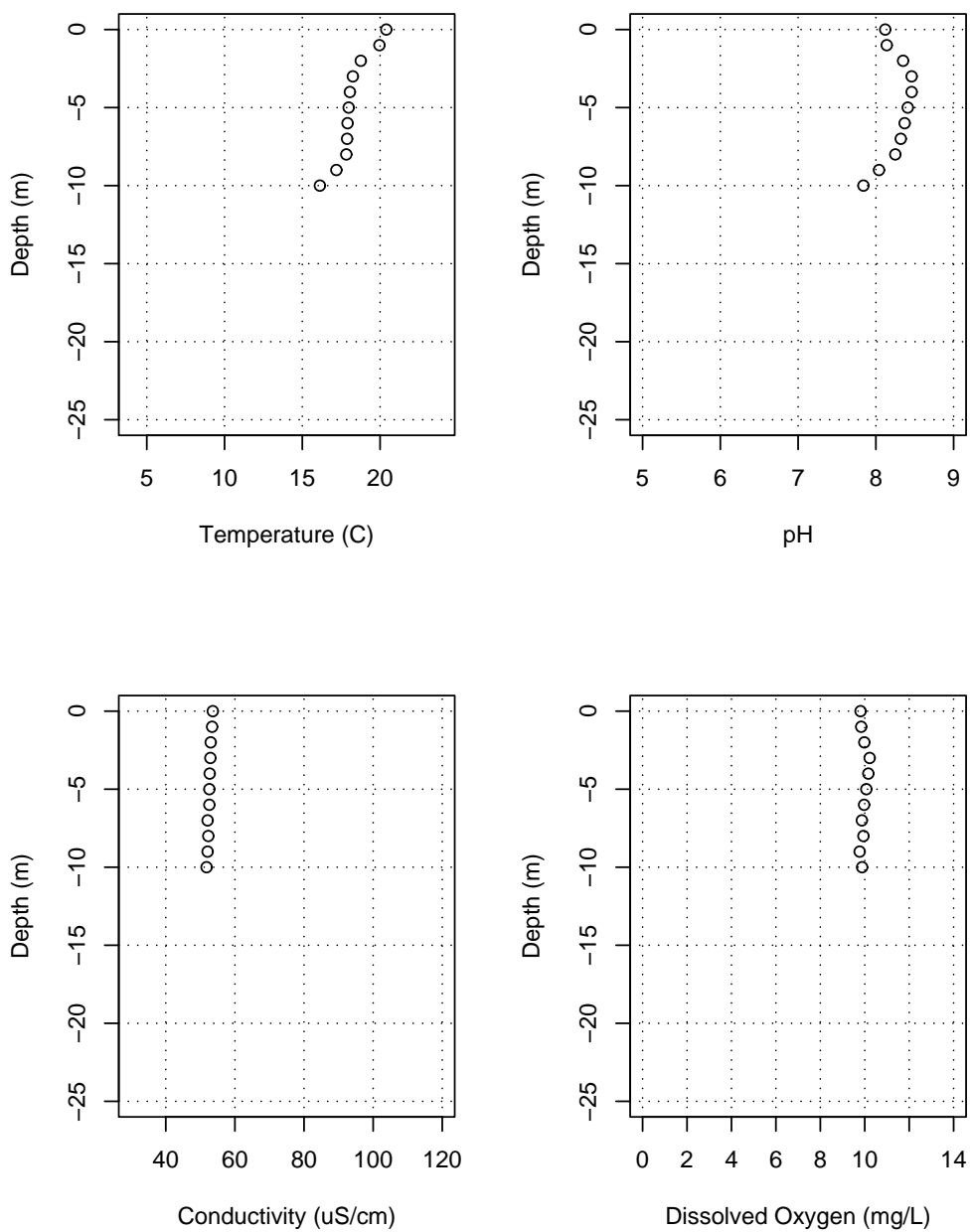


Figure 39: Lake Whatcom Hydrolab profile for the Intake, July 10, 2002.

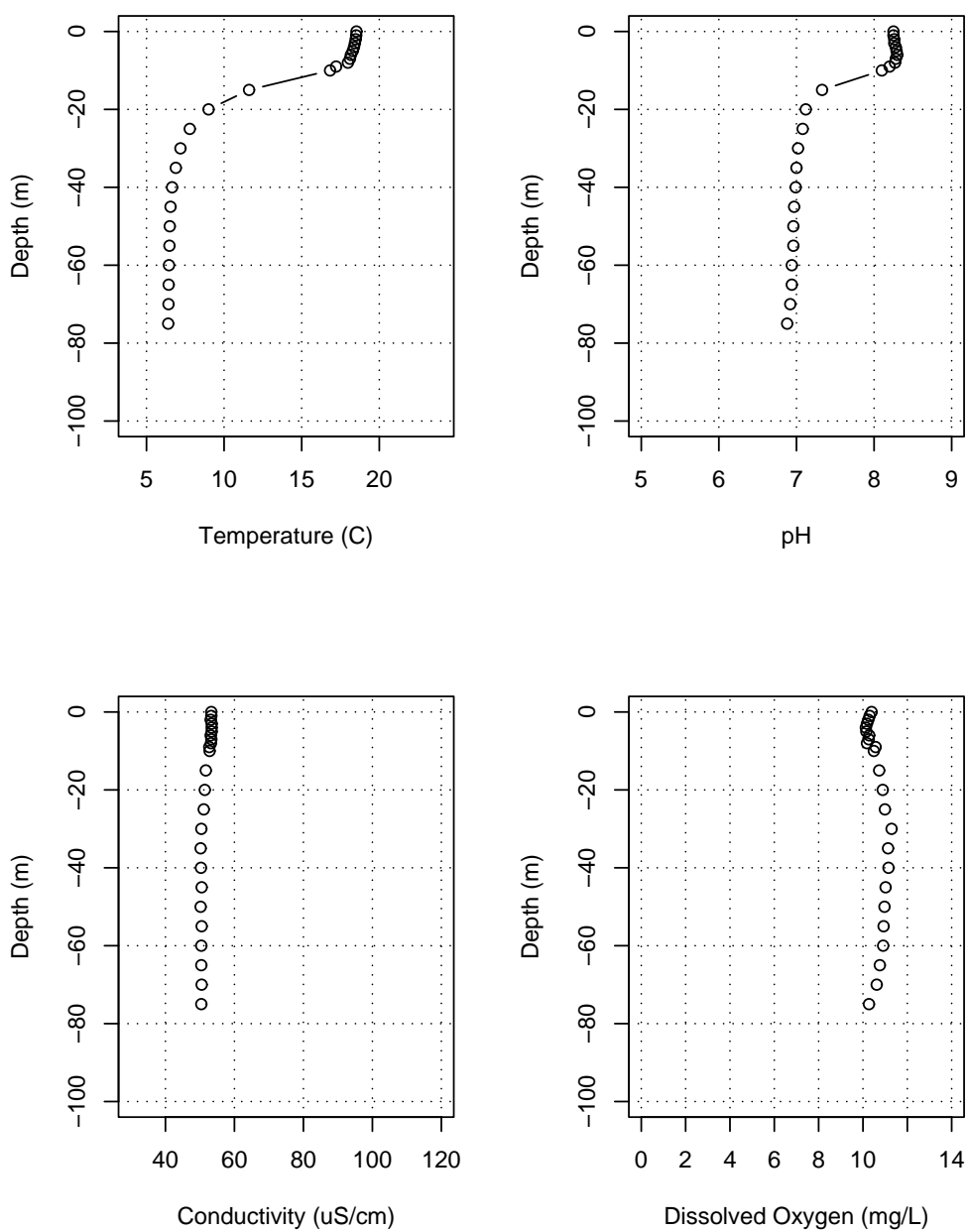


Figure 40: Lake Whatcom Hydrolab profile for Site 3, July 2, 2002.

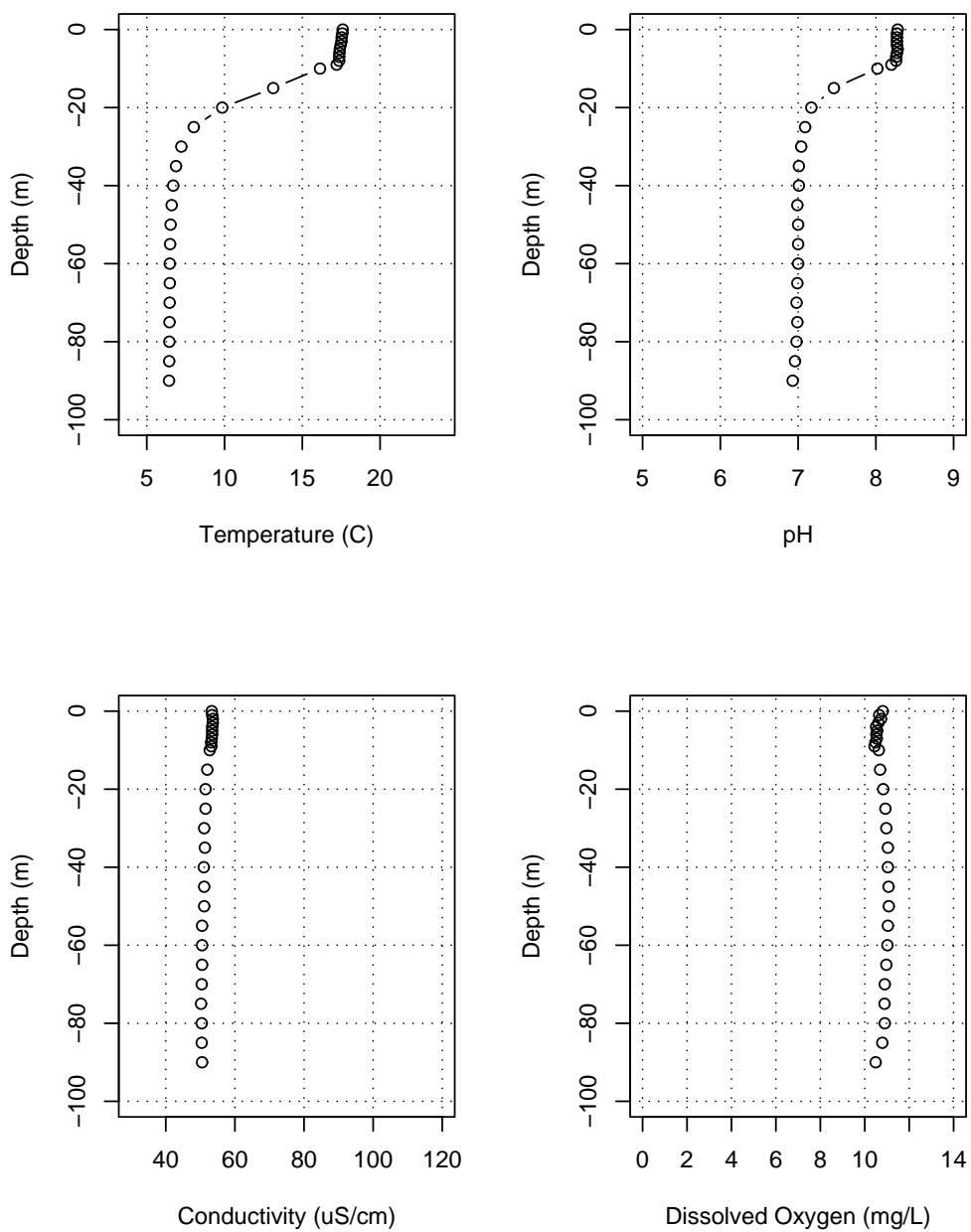


Figure 41: Lake Whatcom Hydrolab profile for Site 4, July 2, 2002.

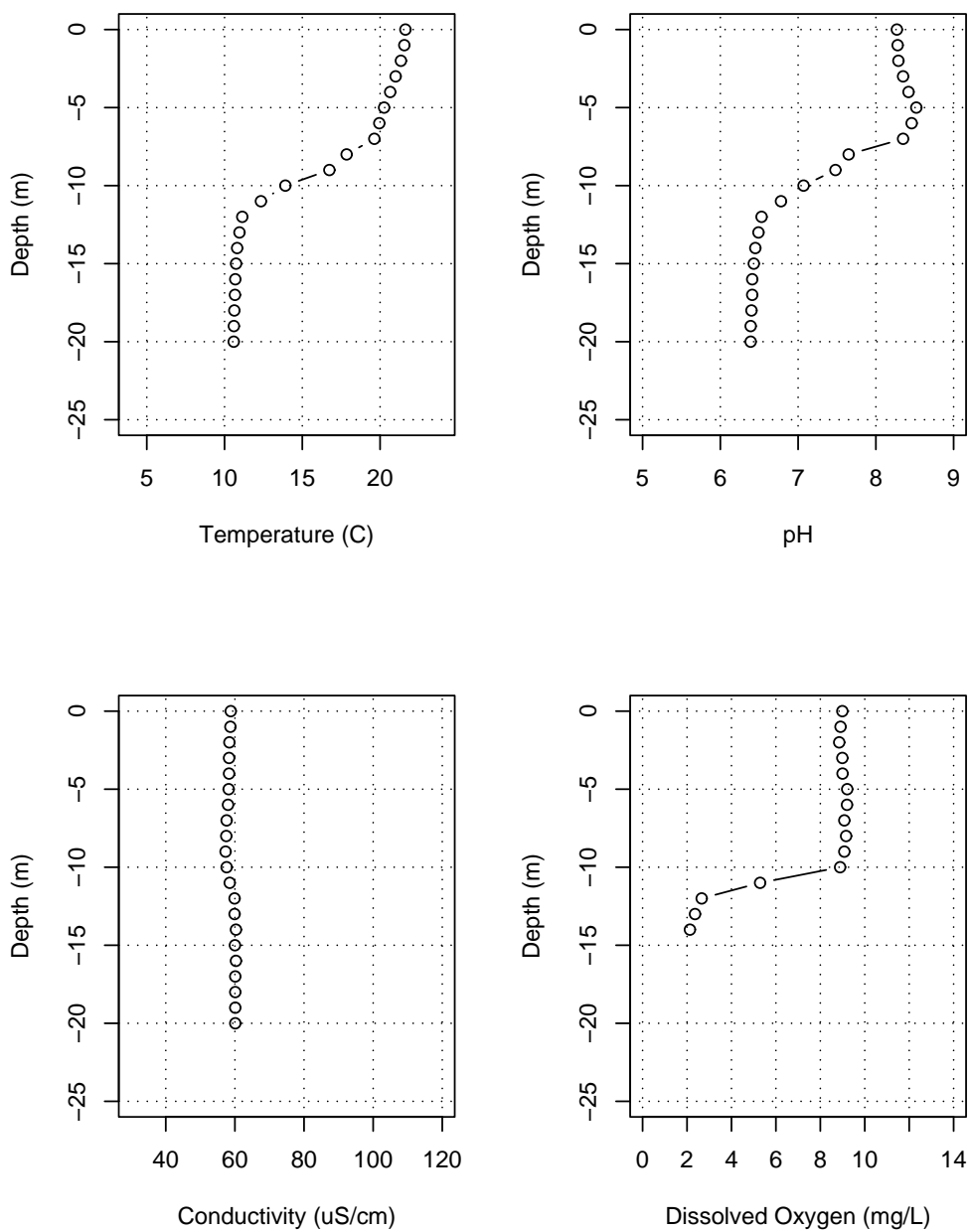


Figure 42: Lake Whatcom Hydrolab profile for Site 1, August 10, 2002.

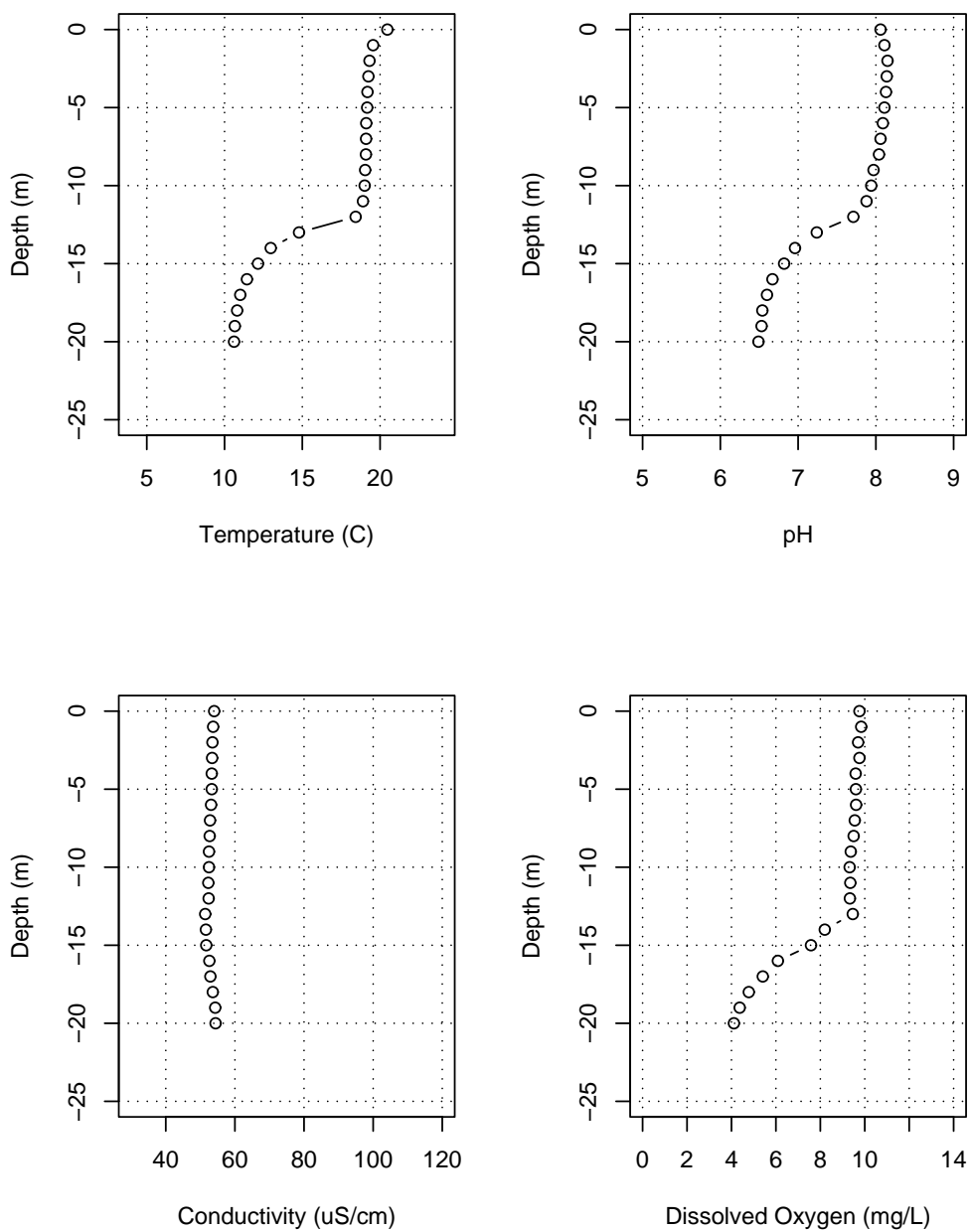


Figure 43: Lake Whatcom Hydrolab profile for Site 2, August 8, 2002.



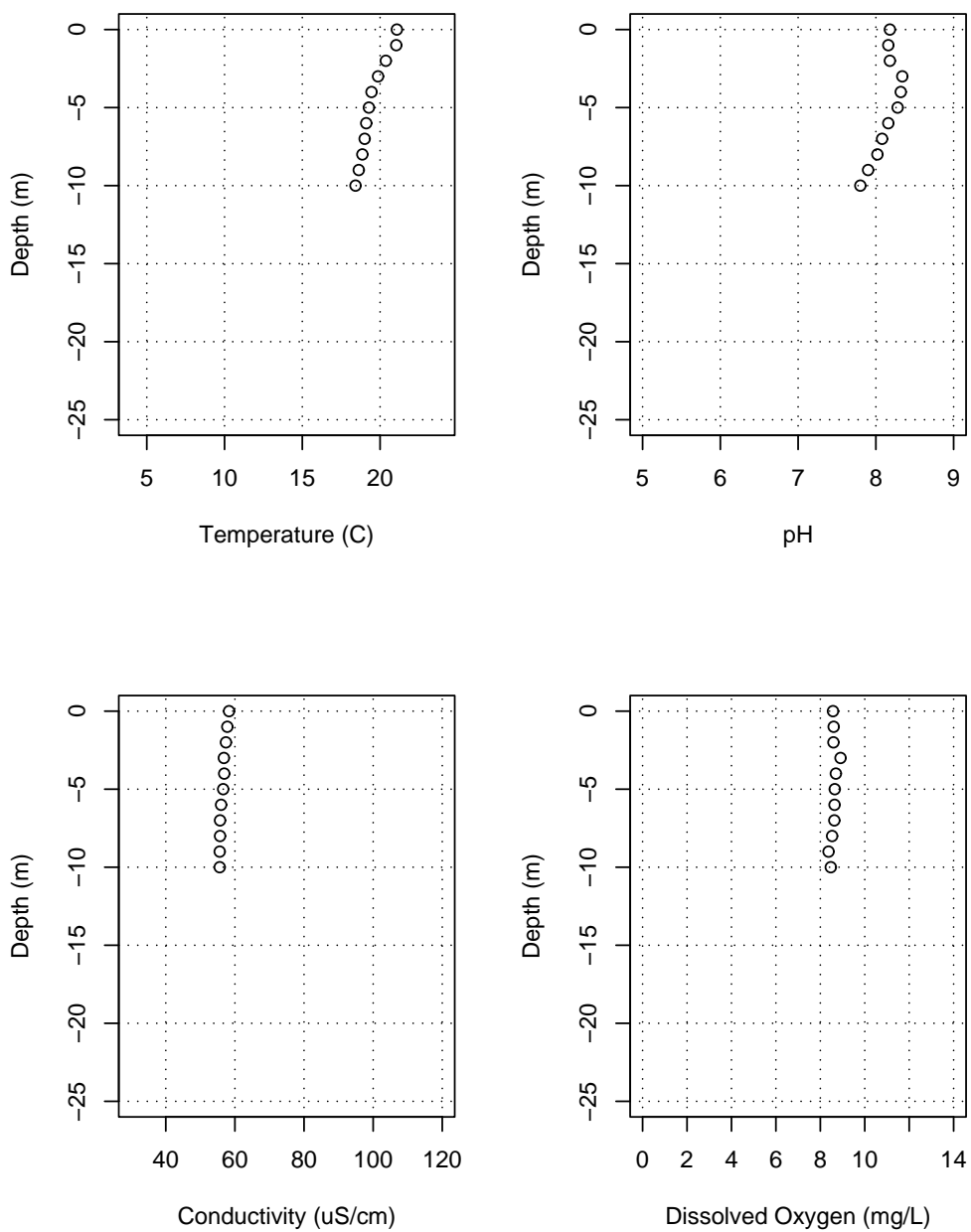


Figure 44: Lake Whatcom Hydrolab profile for the Intake, August 10, 2002.

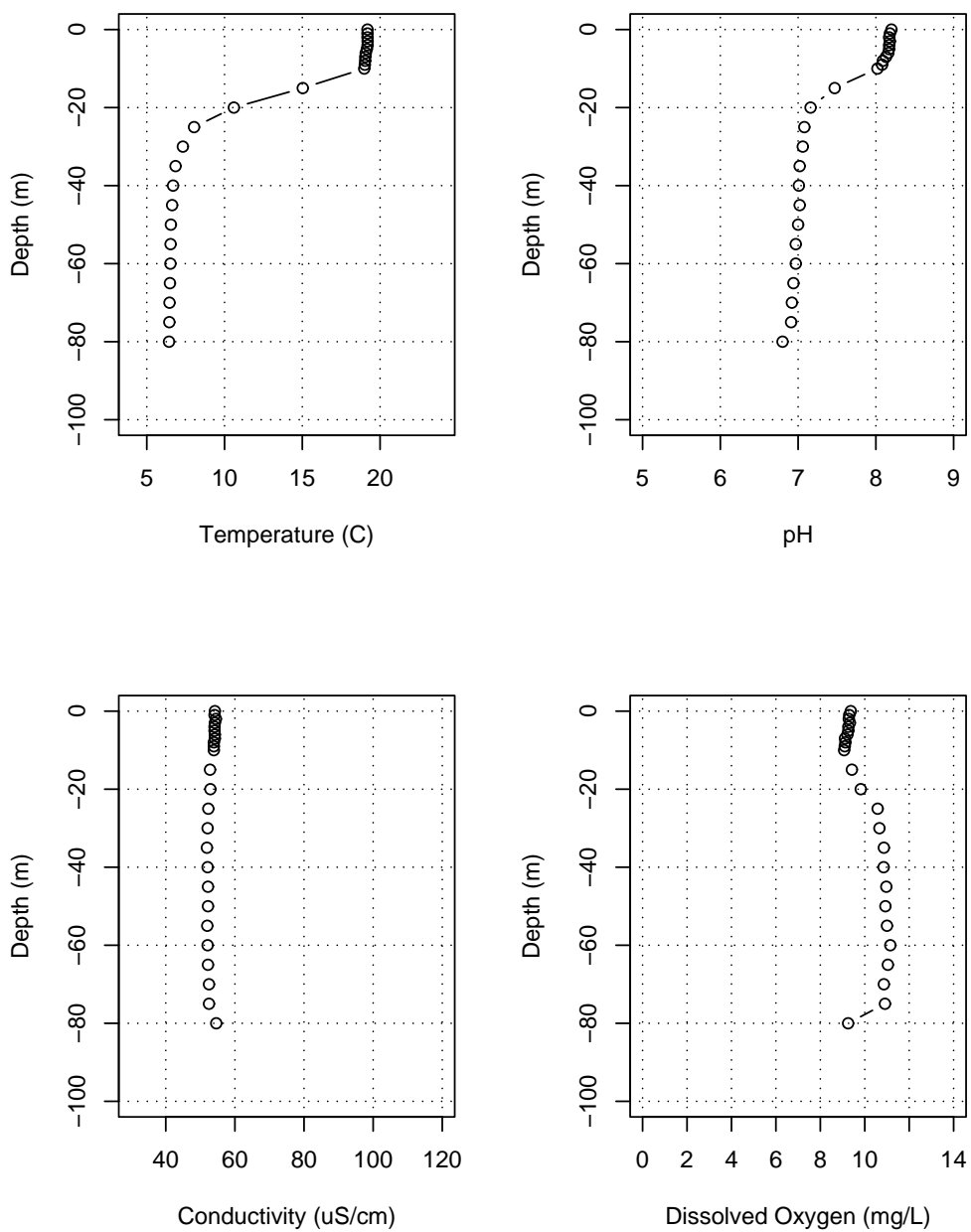


Figure 45: Lake Whatcom Hydrolab profile for Site 3, August 6, 2002.

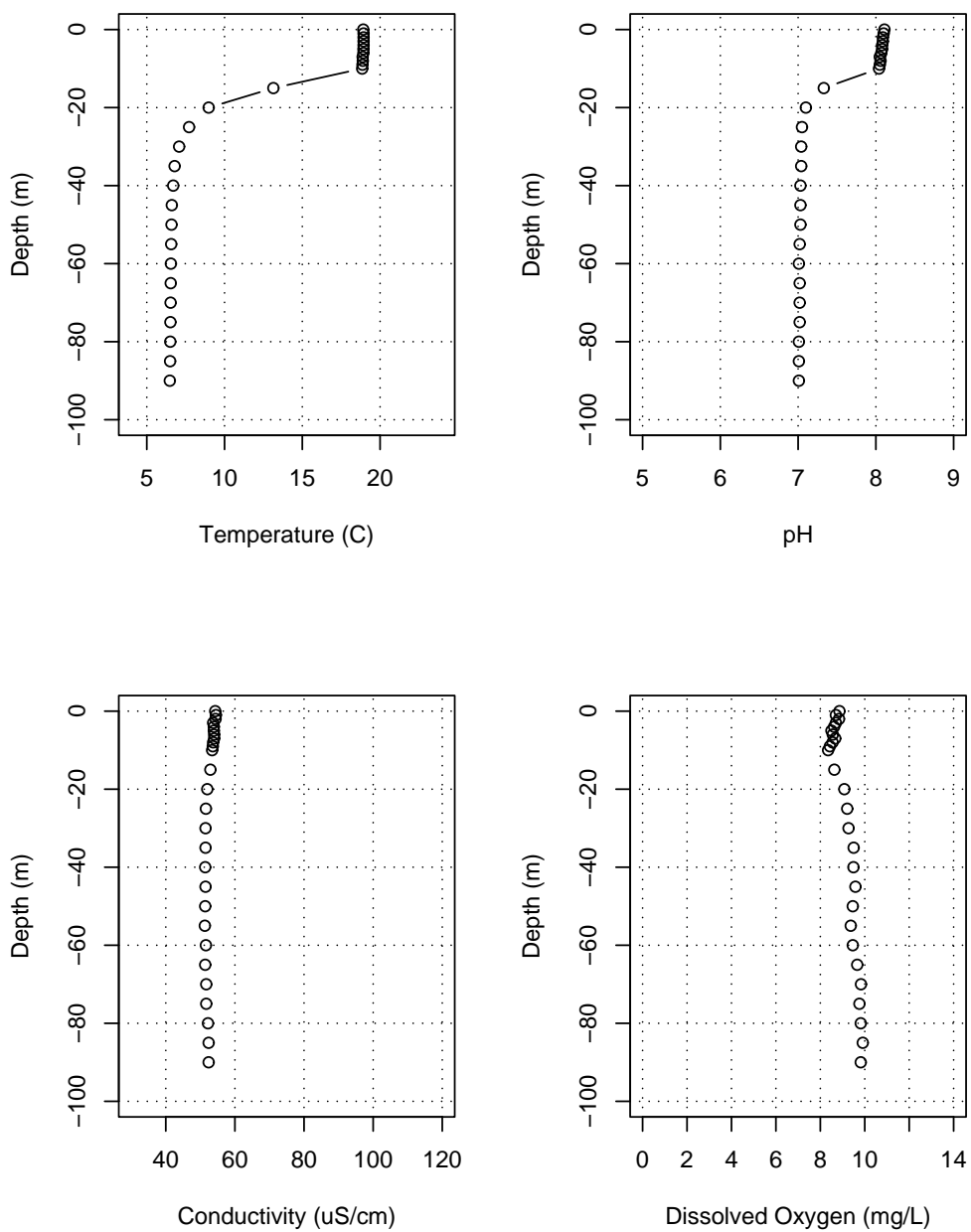


Figure 46: Lake Whatcom Hydrolab profile for Site 4, August 6, 2002.

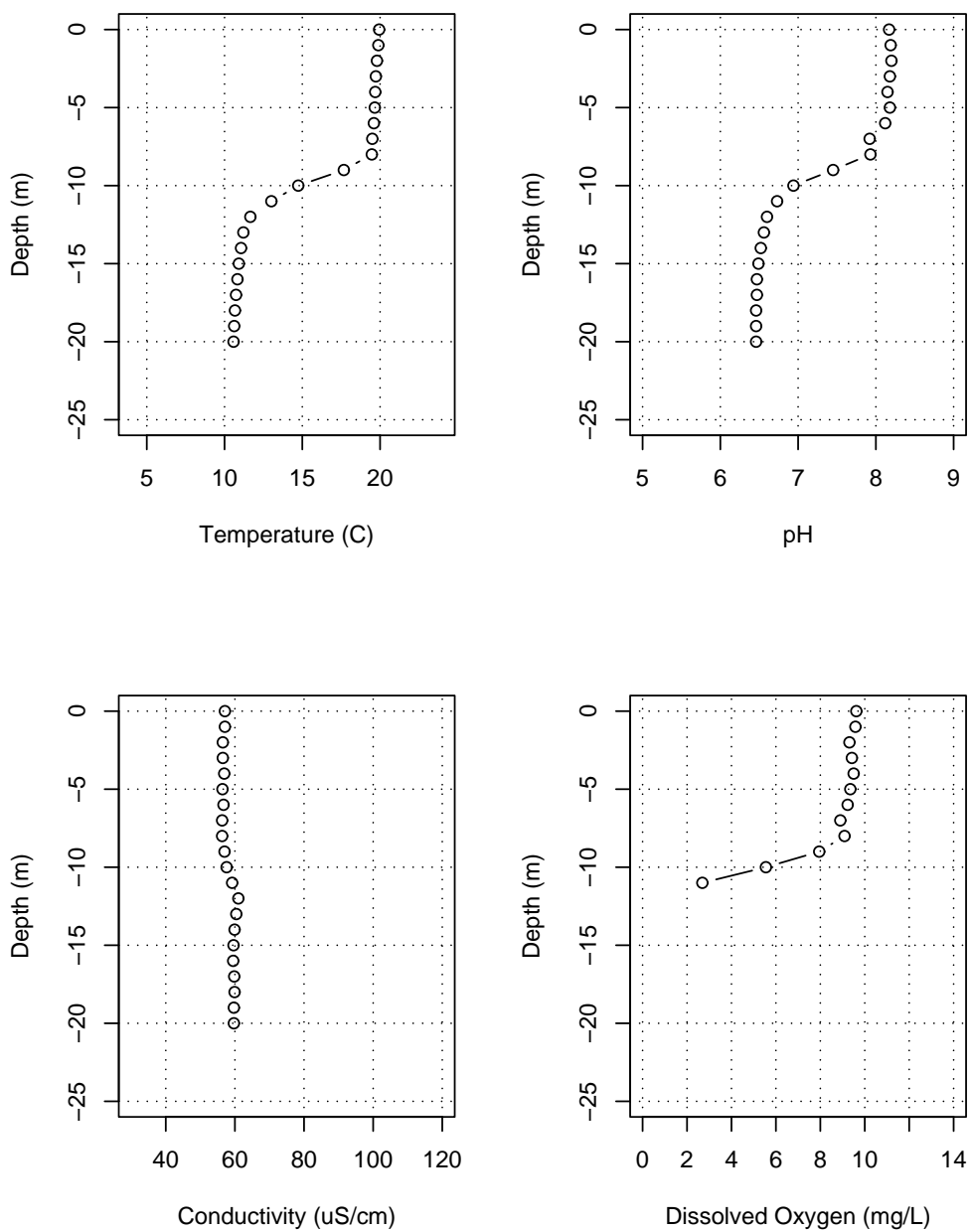


Figure 47: Lake Whatcom Hydrolab profile for Site 1, September 5, 2002.

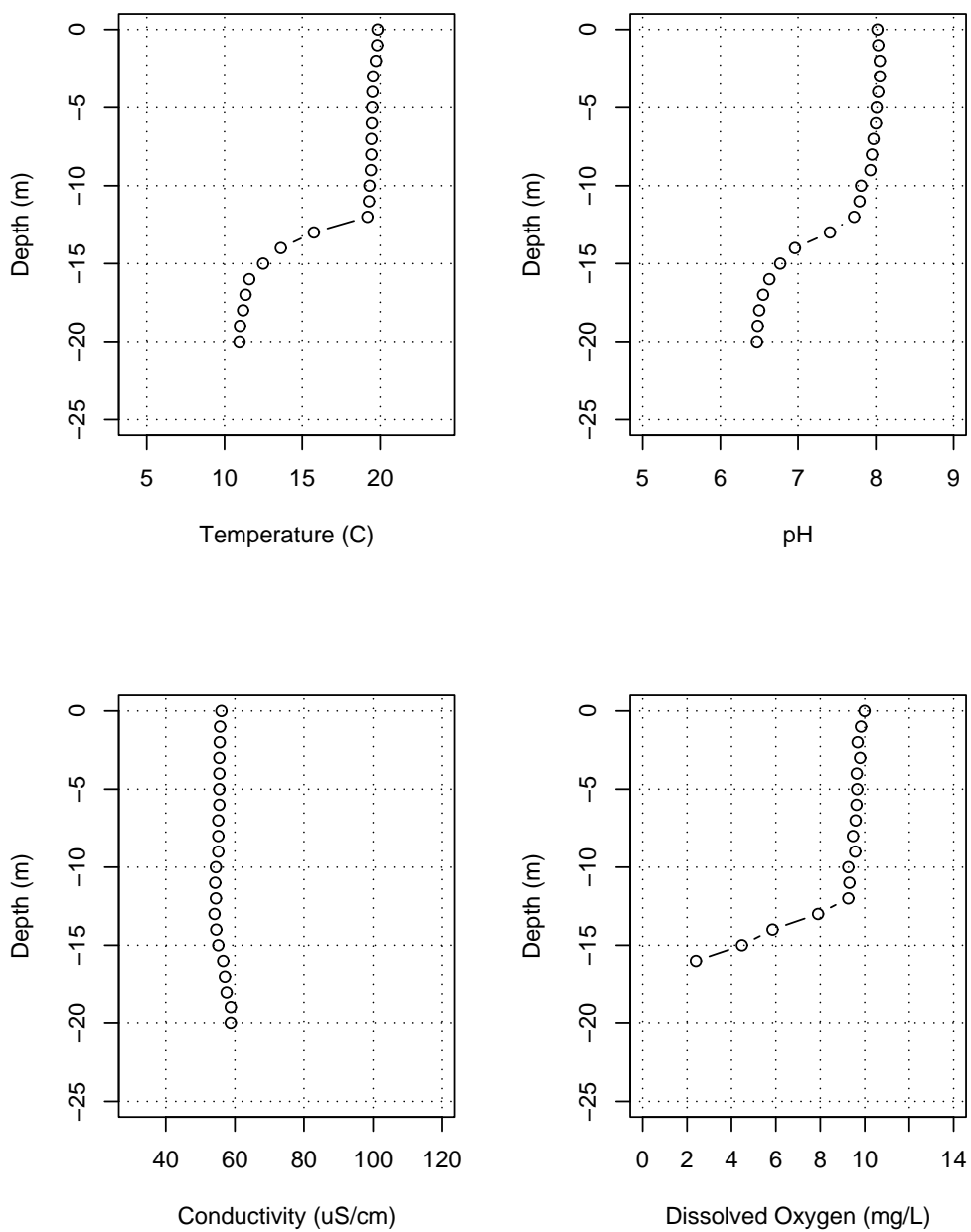


Figure 48: Lake Whatcom Hydrolab profile for Site 2, September 5, 2002.

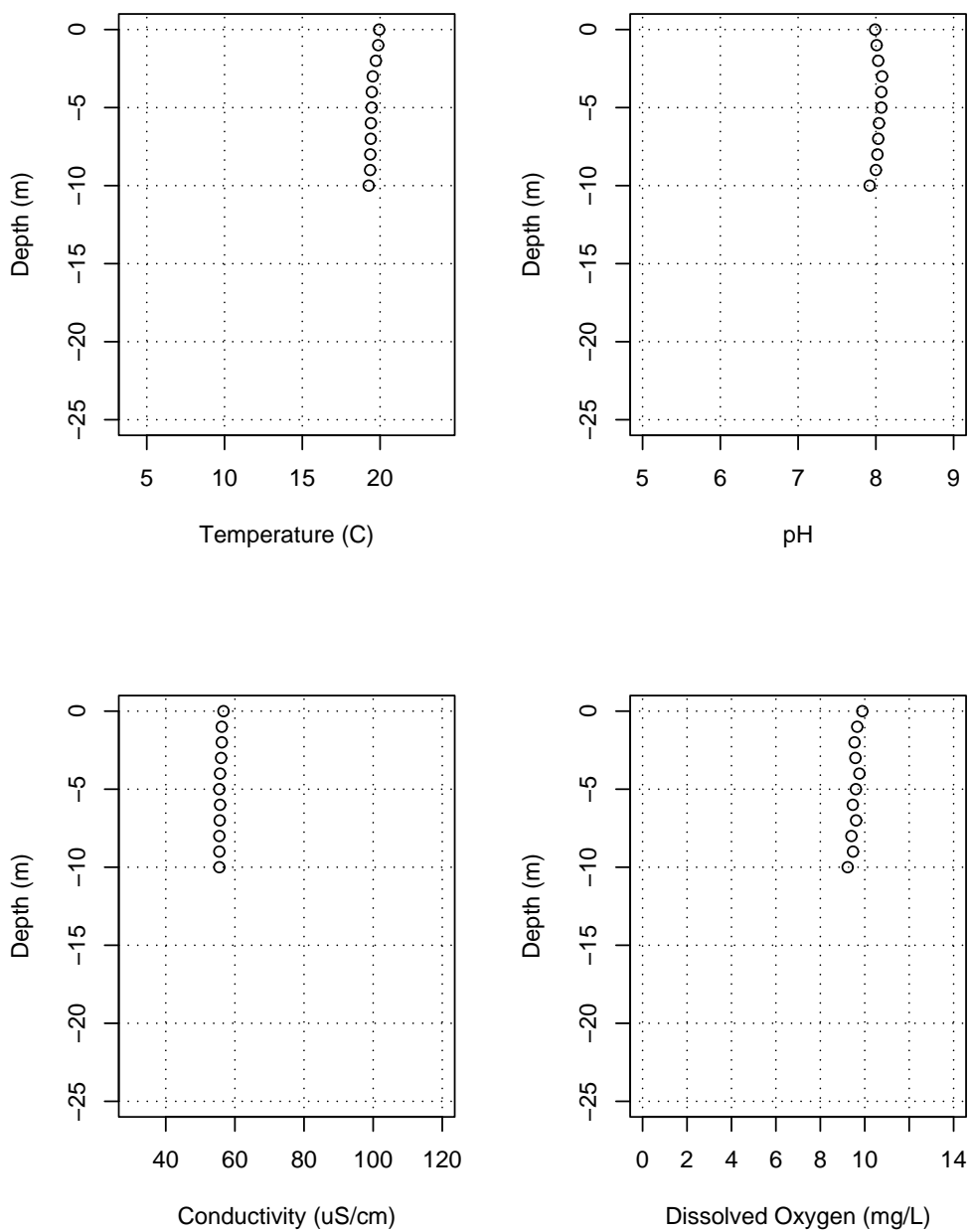


Figure 49: Lake Whatcom Hydrolab profile for the Intake, September 5, 2002.

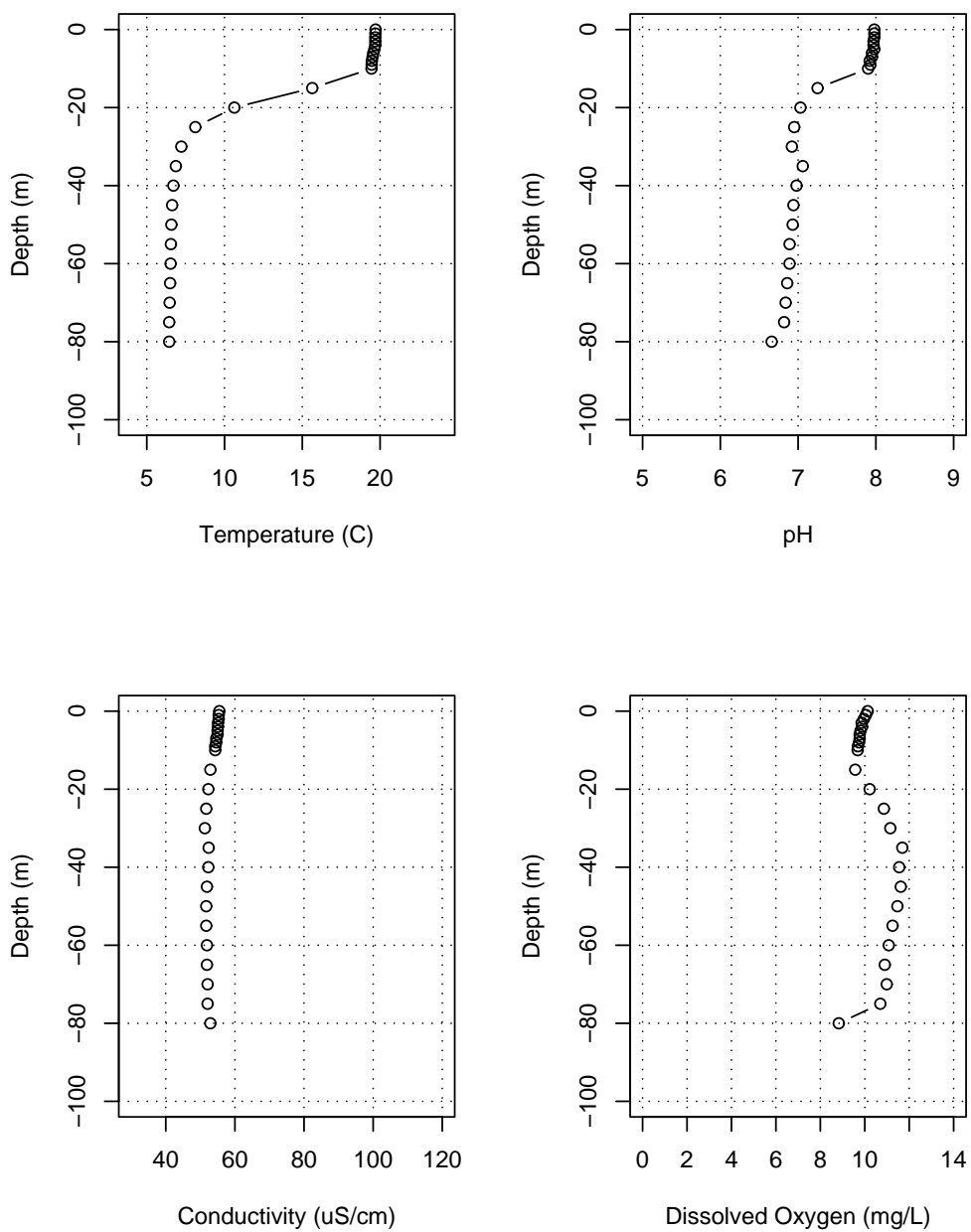


Figure 50: Lake Whatcom Hydrolab profile for Site 3, September 3, 2002.

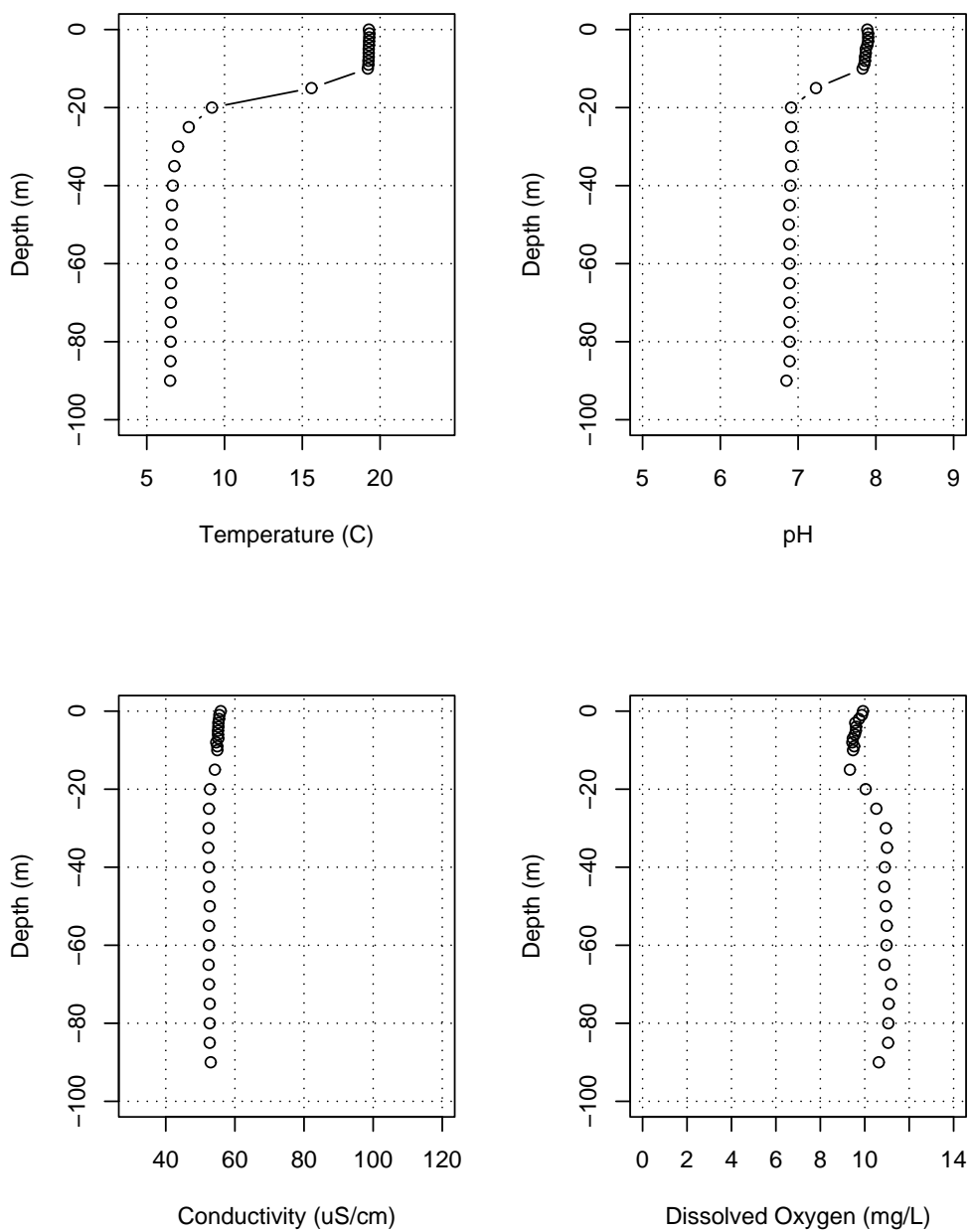


Figure 51: Lake Whatcom Hydrolab profile for Site 4, September 3, 2002.



Lake Whatcom temperature data for Site 1, December 1992 through December 2002.

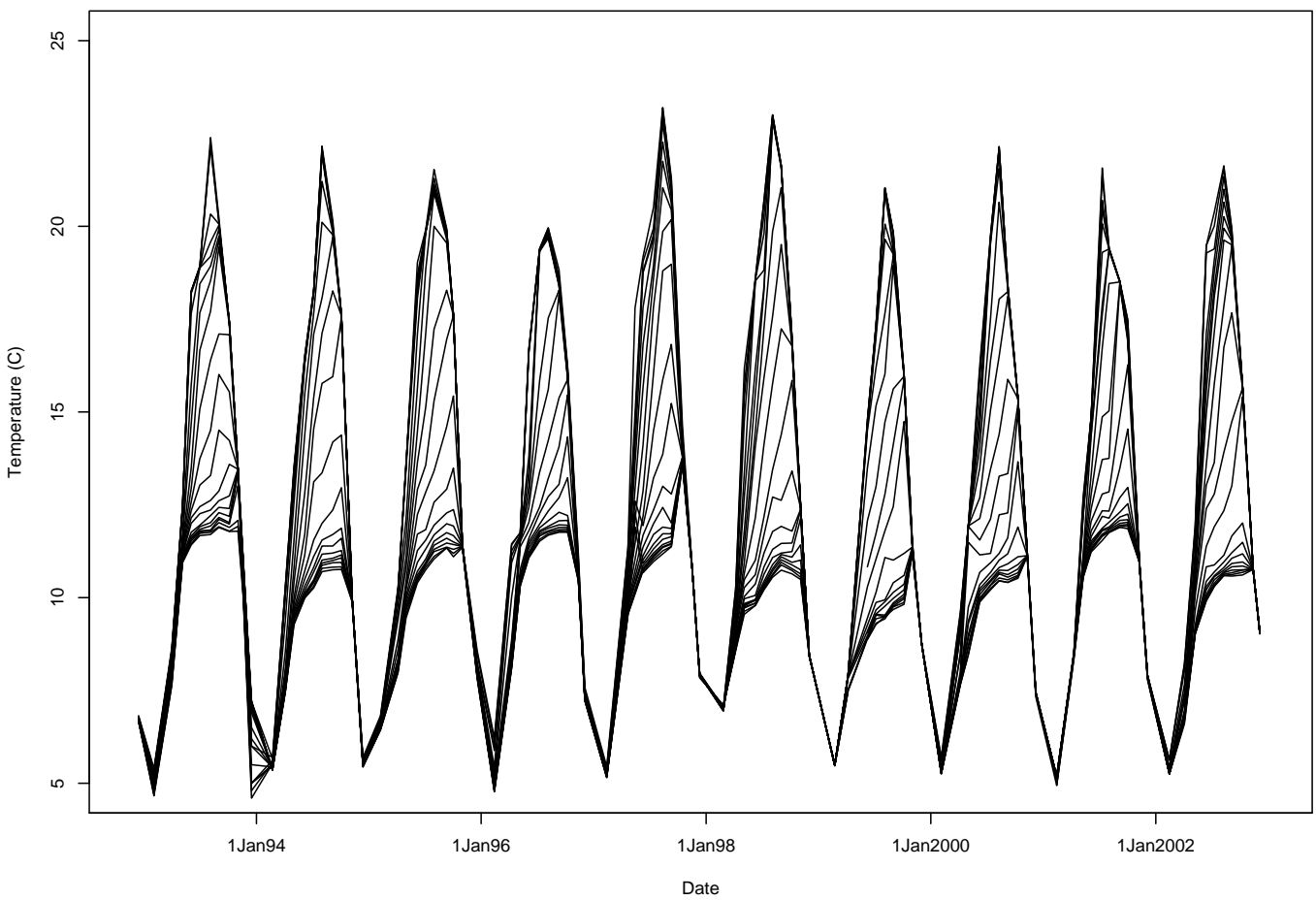


Figure 52: Lake Whatcom temperature data for Site 1.

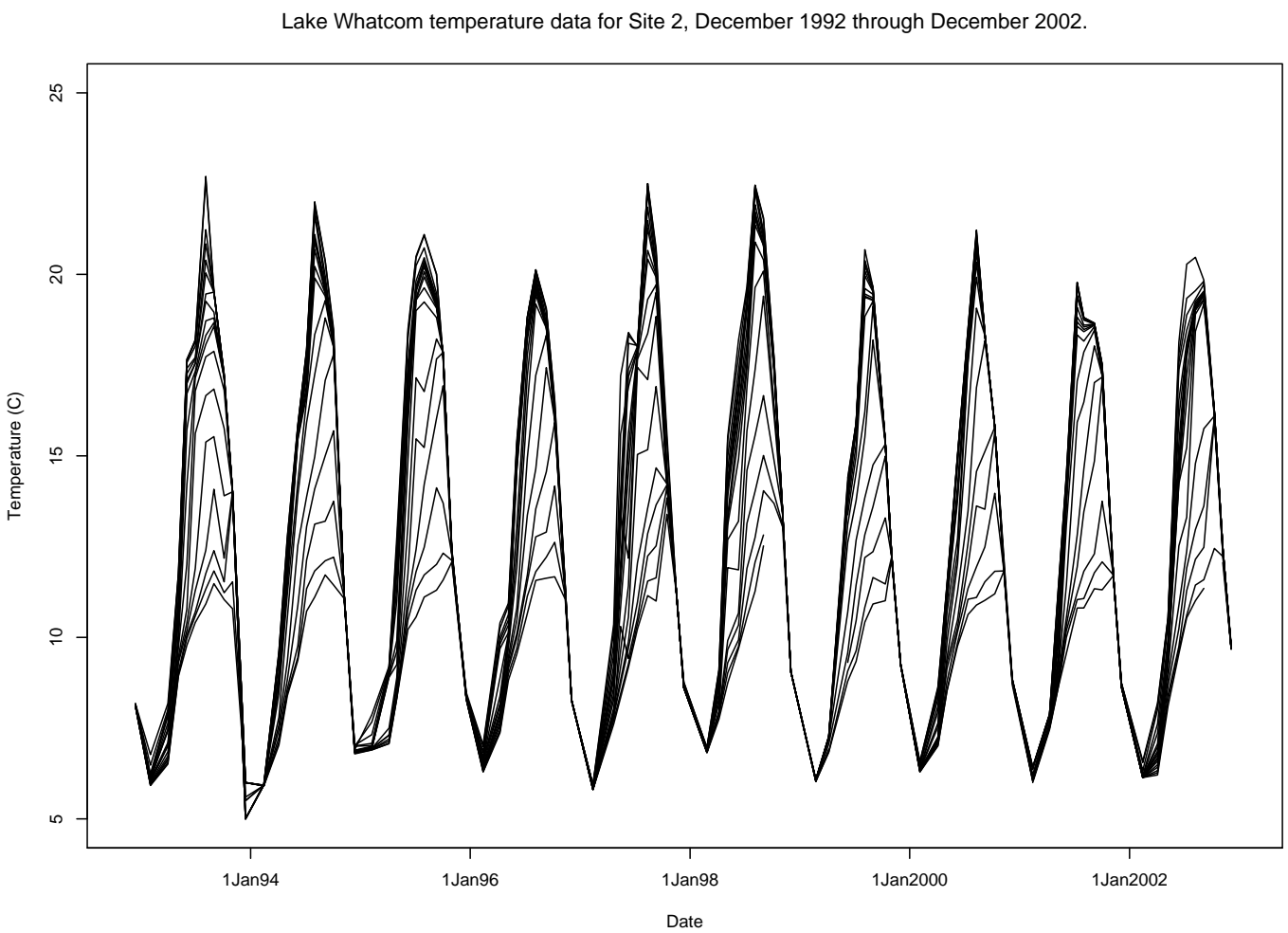


Figure 53: Lake Whatcom temperature data for Site 2.

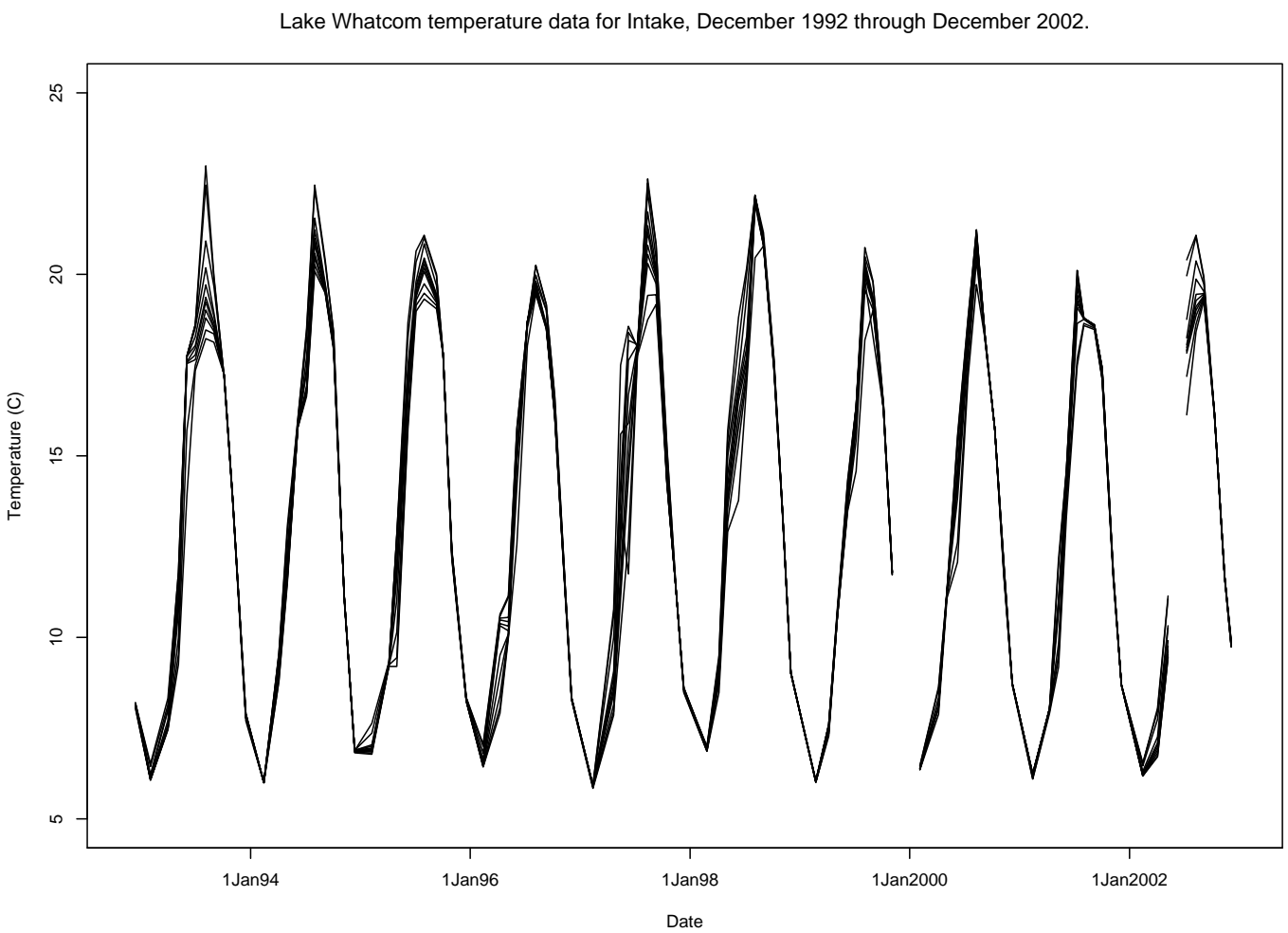


Figure 54: Lake Whatcom temperature data for the Intake.

Lake Whatcom temperature data for Site 3, December 1992 through December 2002.

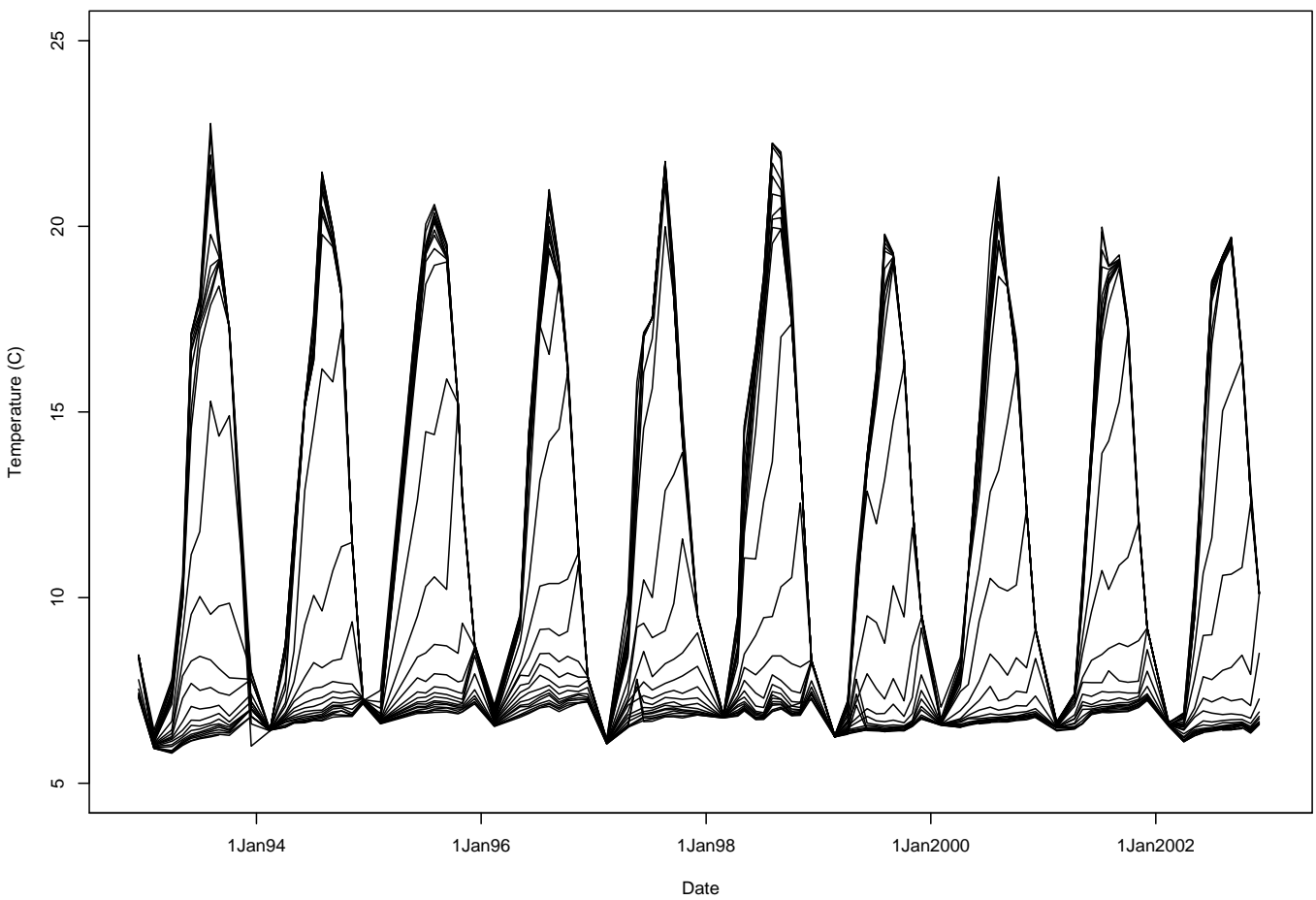


Figure 55: Lake Whatcom temperature data for Site 3.

Lake Whatcom temperature data for Site 4, December 1992 through December 2002.

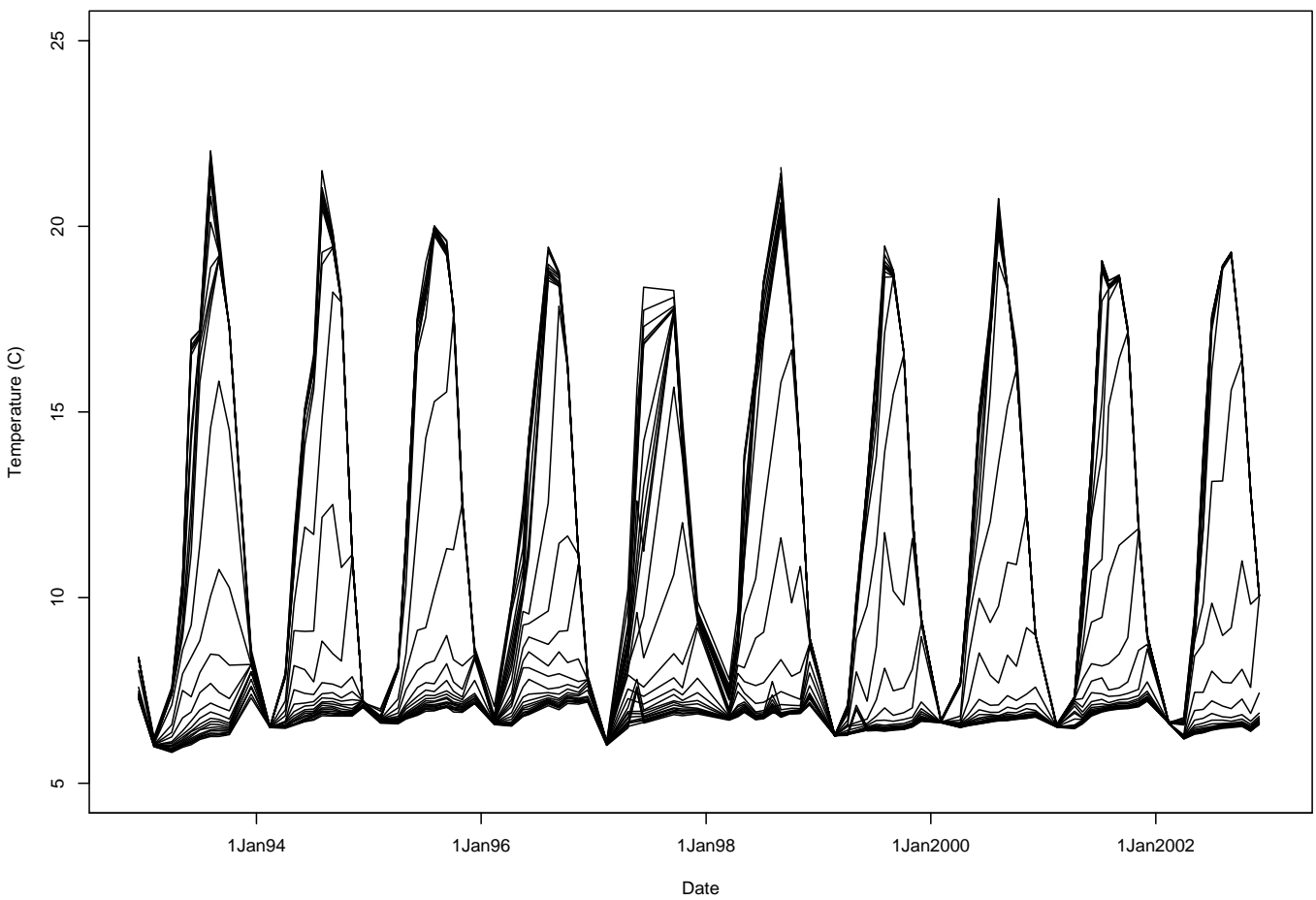


Figure 56: Lake Whatcom temperature data for Site 4.

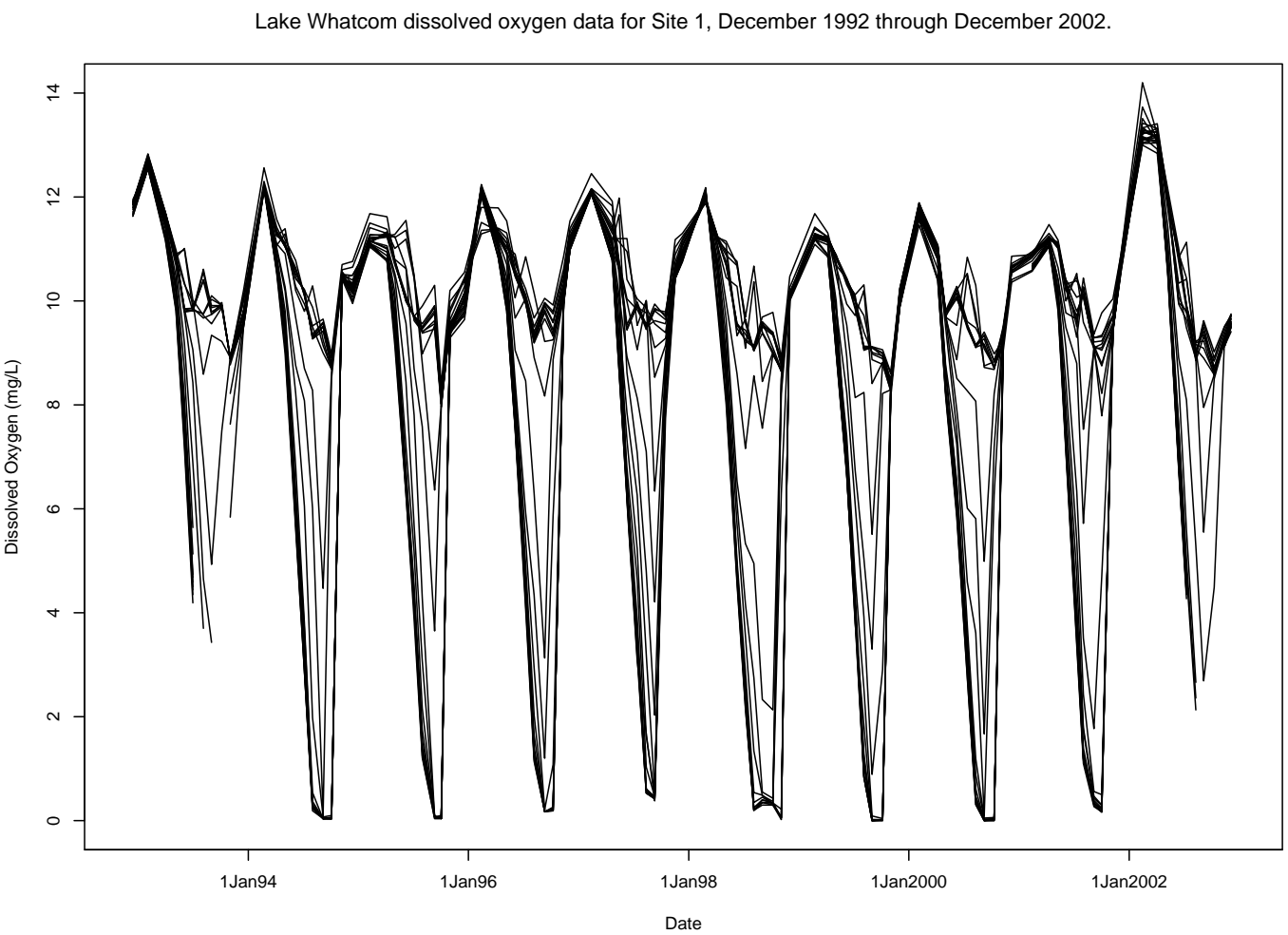


Figure 57: Lake Whatcom dissolved oxygen data for Site 1.

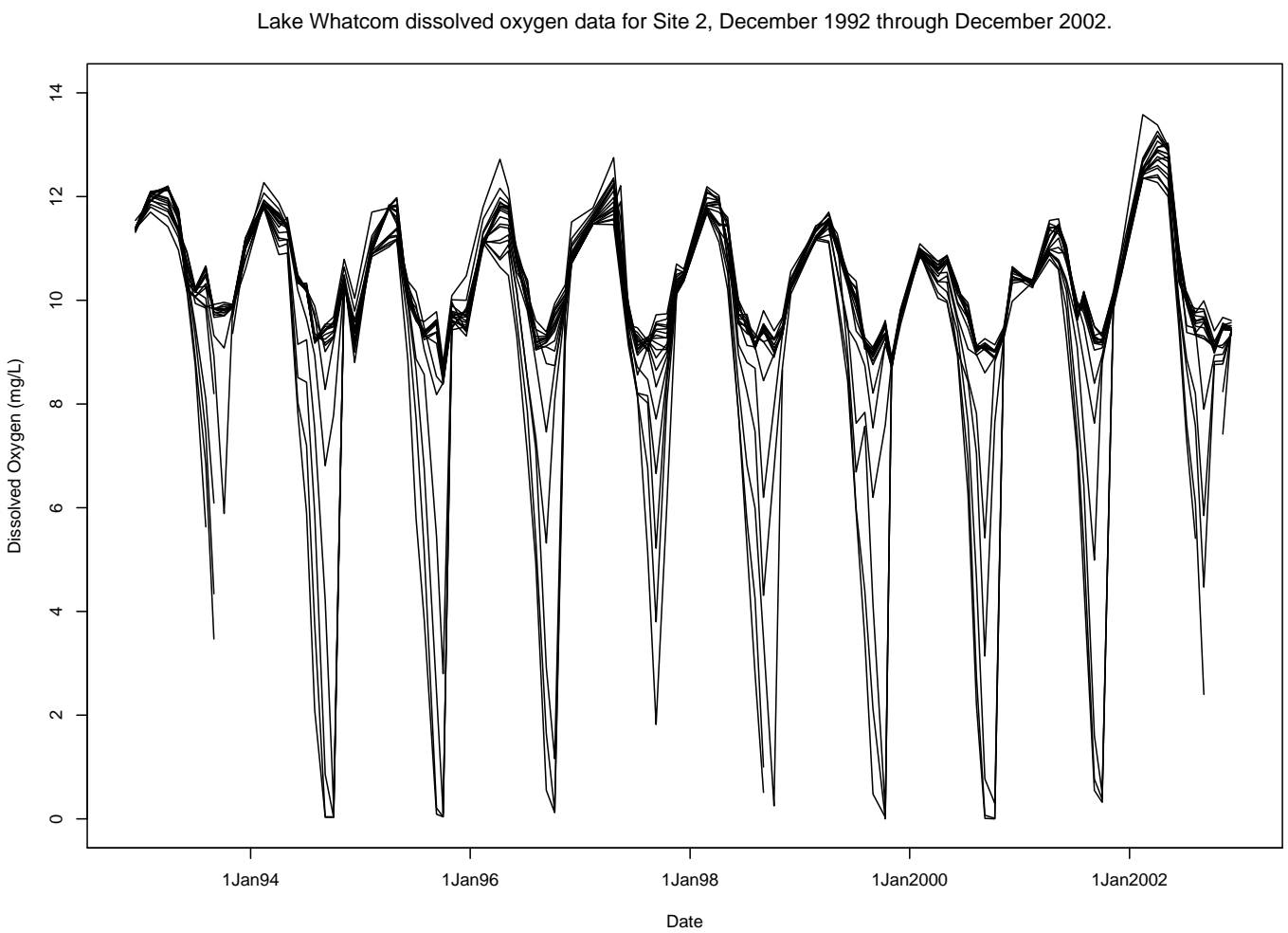


Figure 58: Lake Whatcom dissolved oxygen data for Site 2.

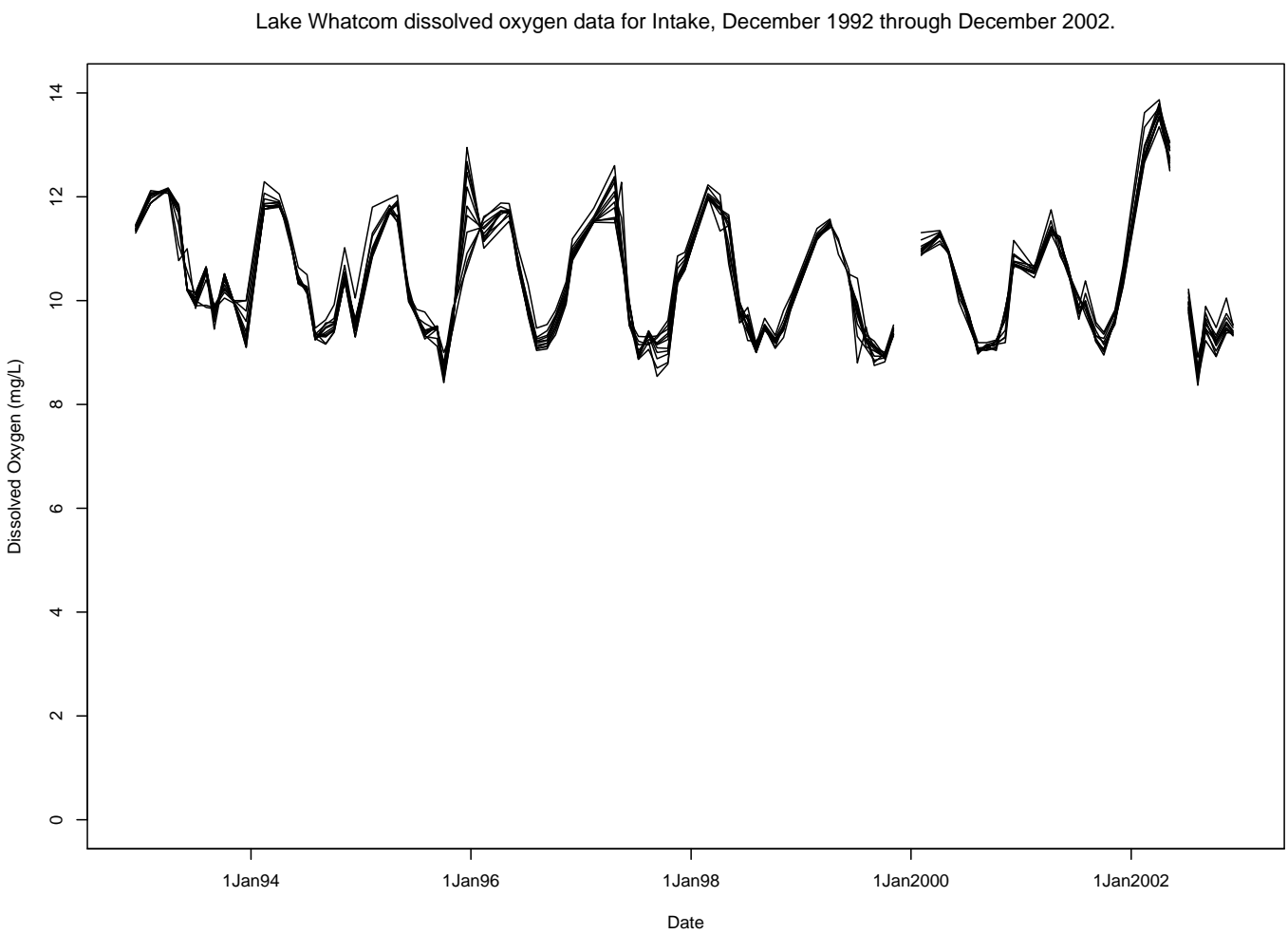


Figure 59: Lake Whatcom dissolved oxygen data for the Intake.



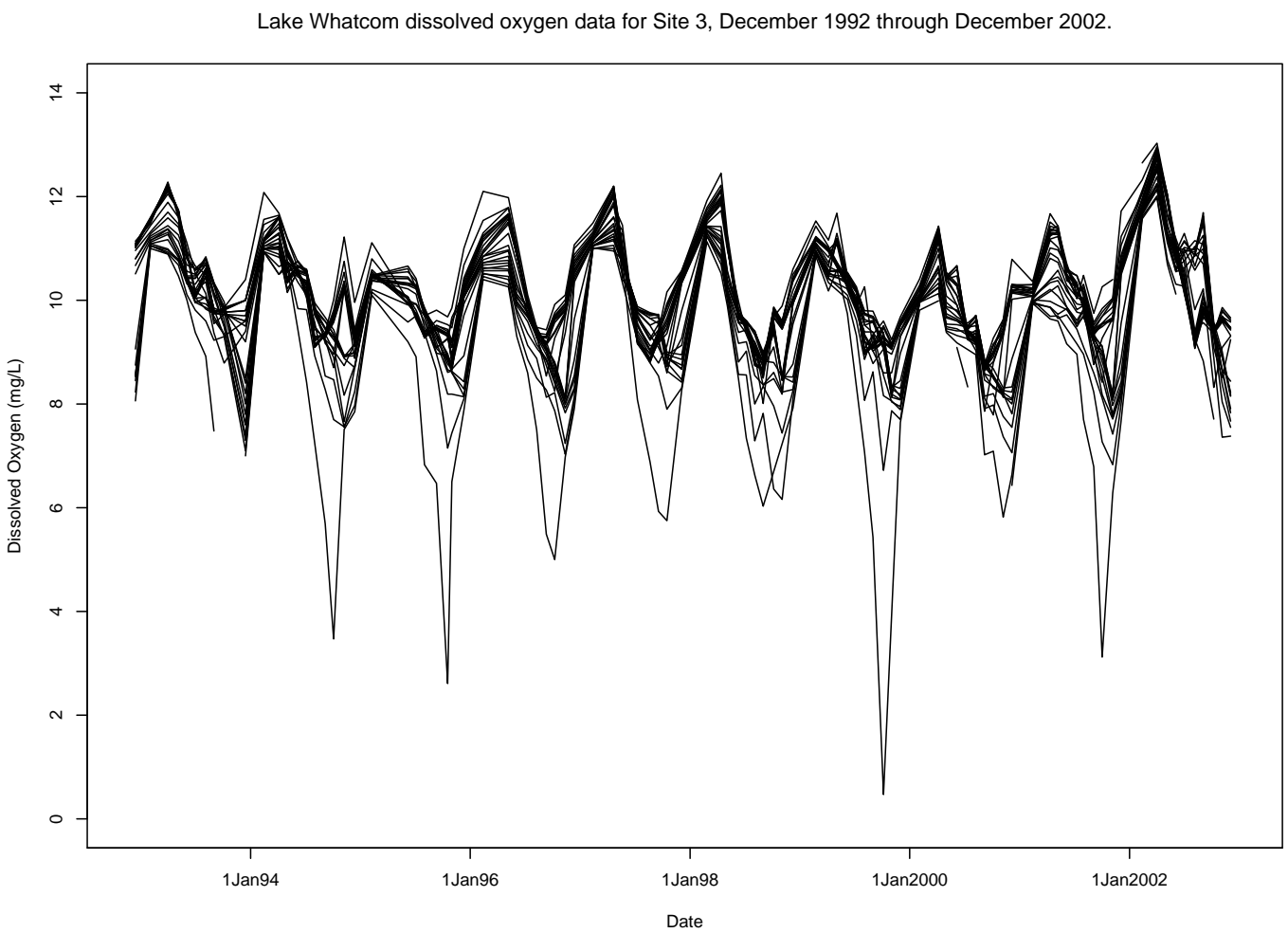


Figure 60: Lake Whatcom dissolved oxygen data for Site 3.

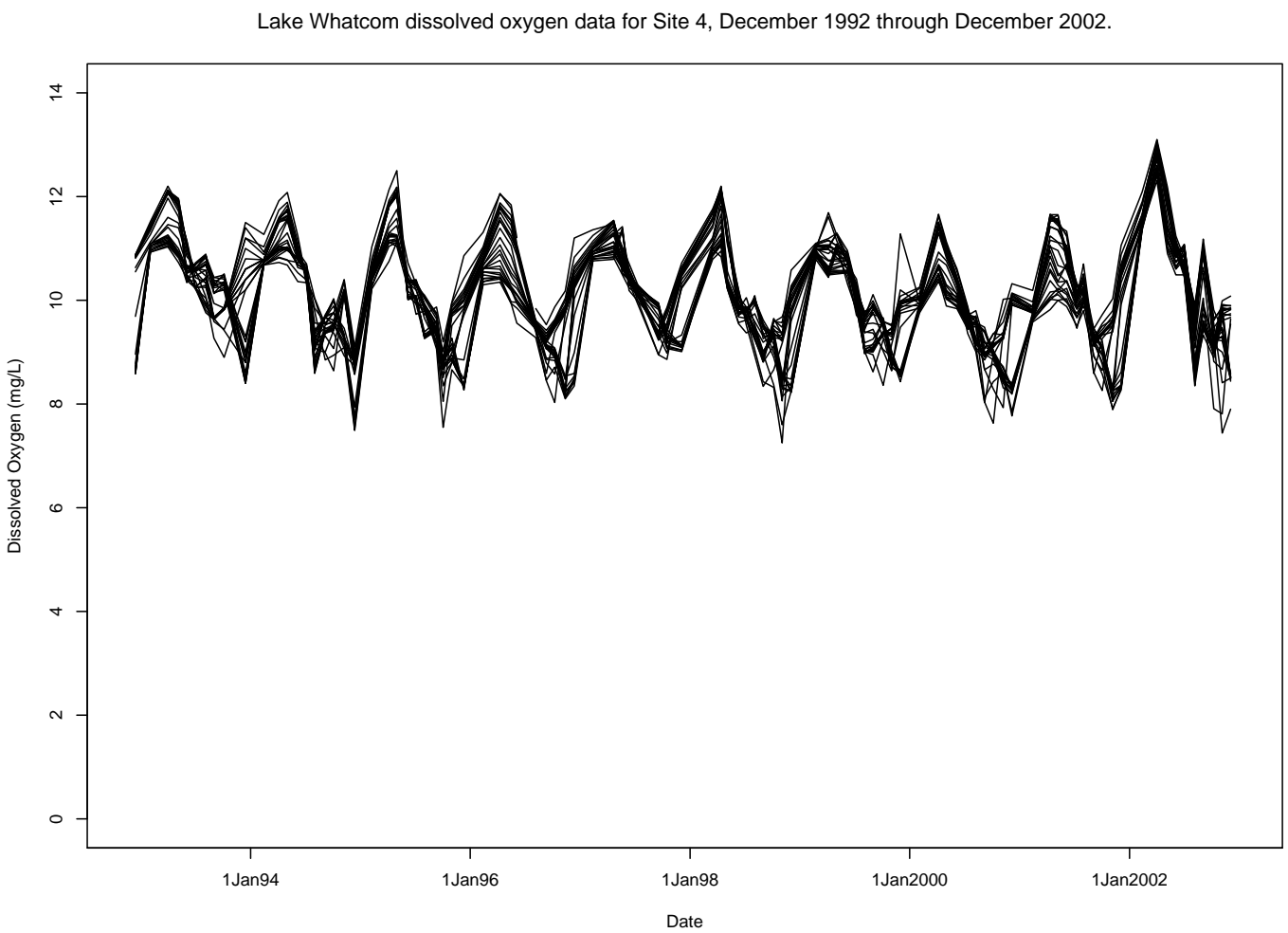


Figure 61: Lake Whatcom dissolved oxygen data for Site 4.

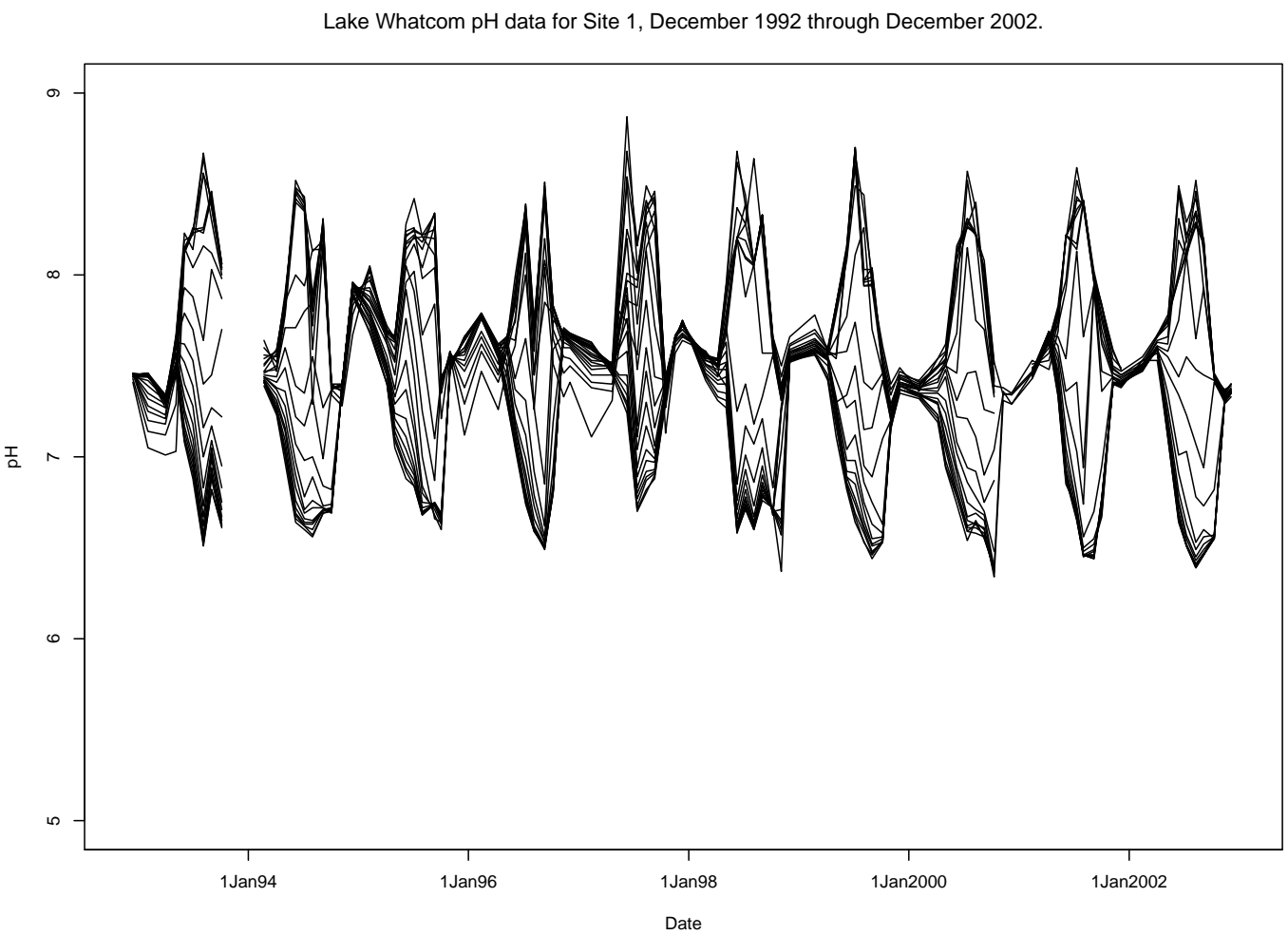


Figure 62: Lake Whatcom pH data for Site 1.

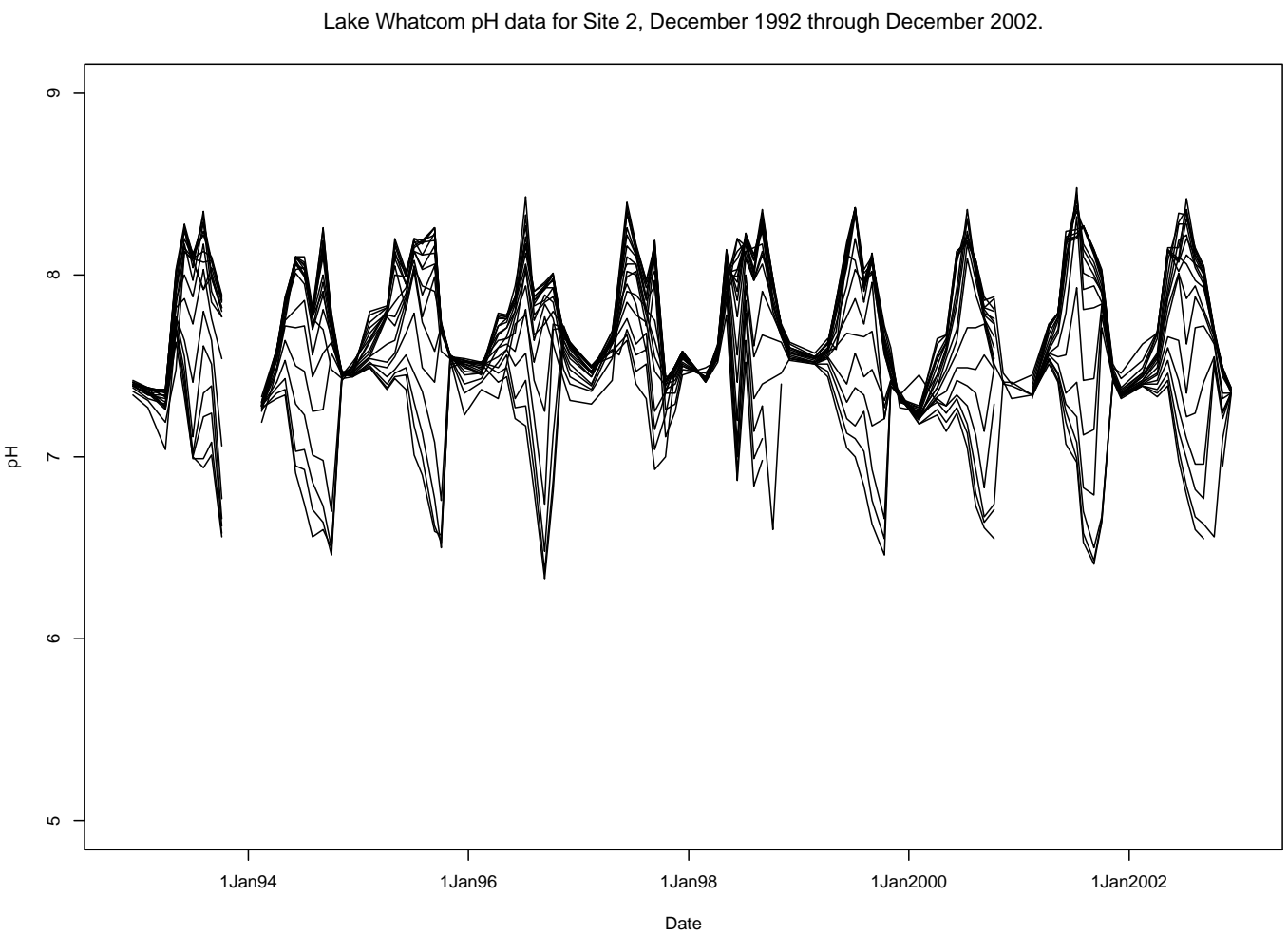


Figure 63: Lake Whatcom pH data for Site 2.

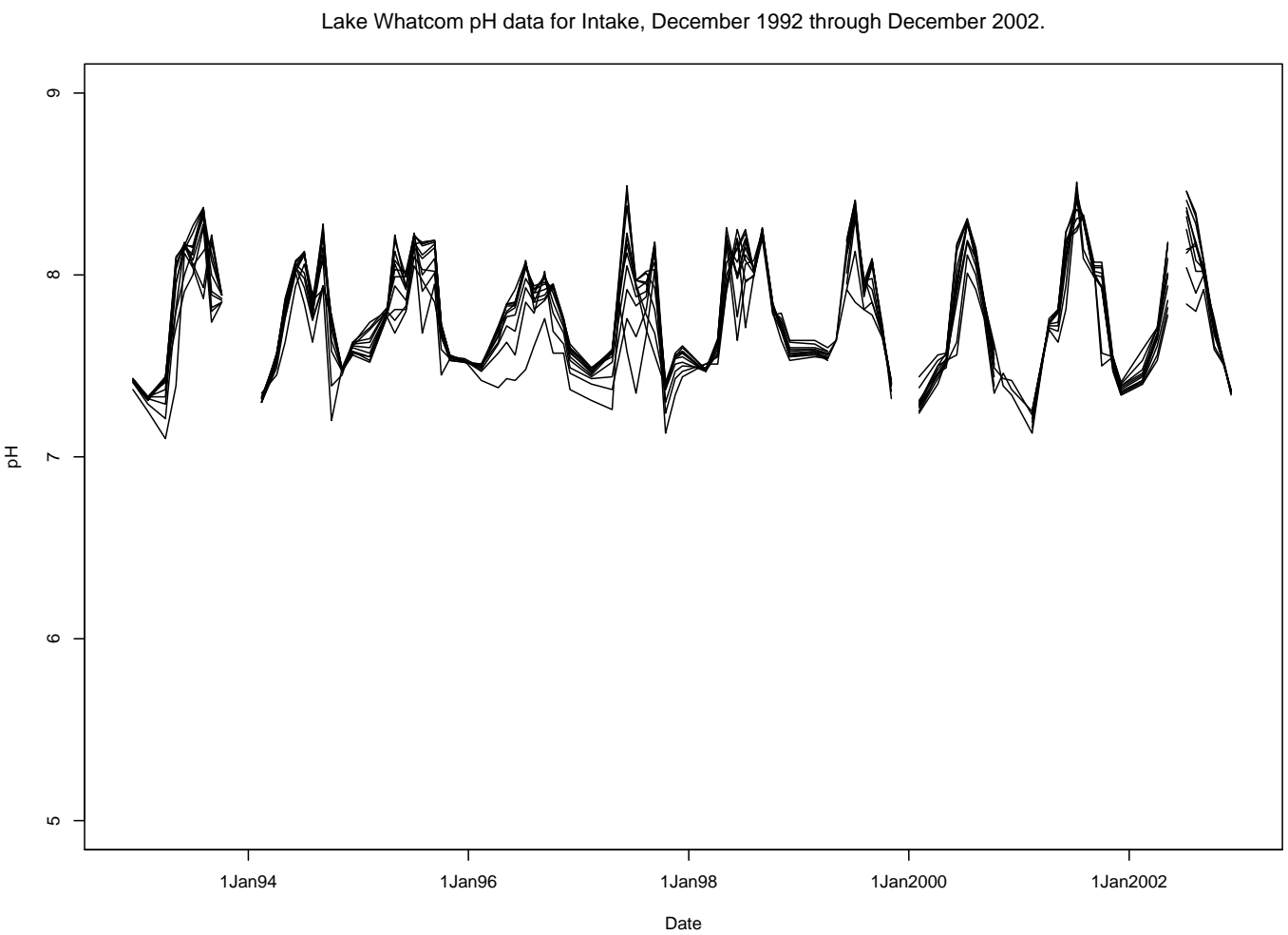


Figure 64: Lake Whatcom pH data for the Intake.

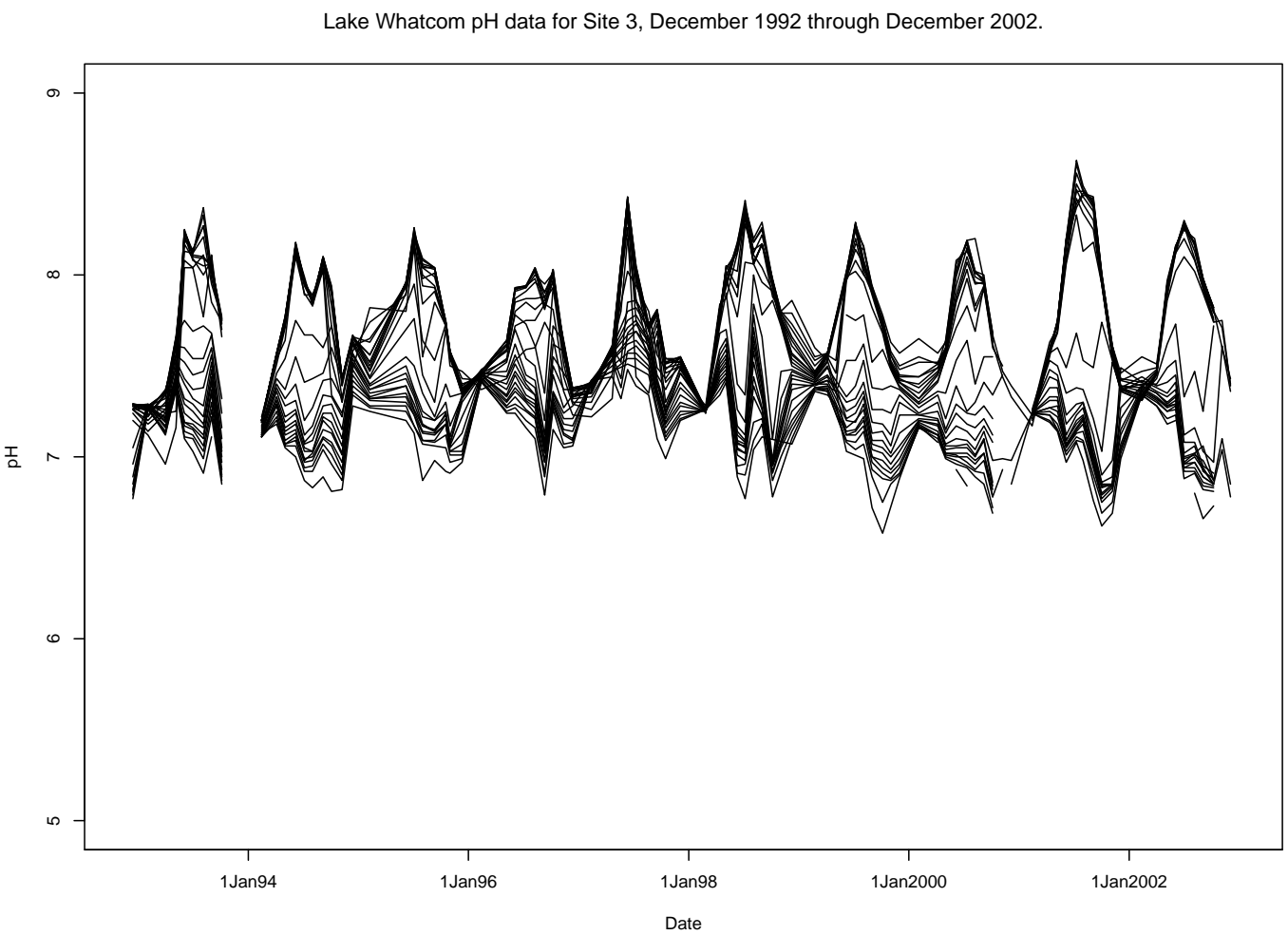


Figure 65: Lake Whatcom pH data for Site 3.

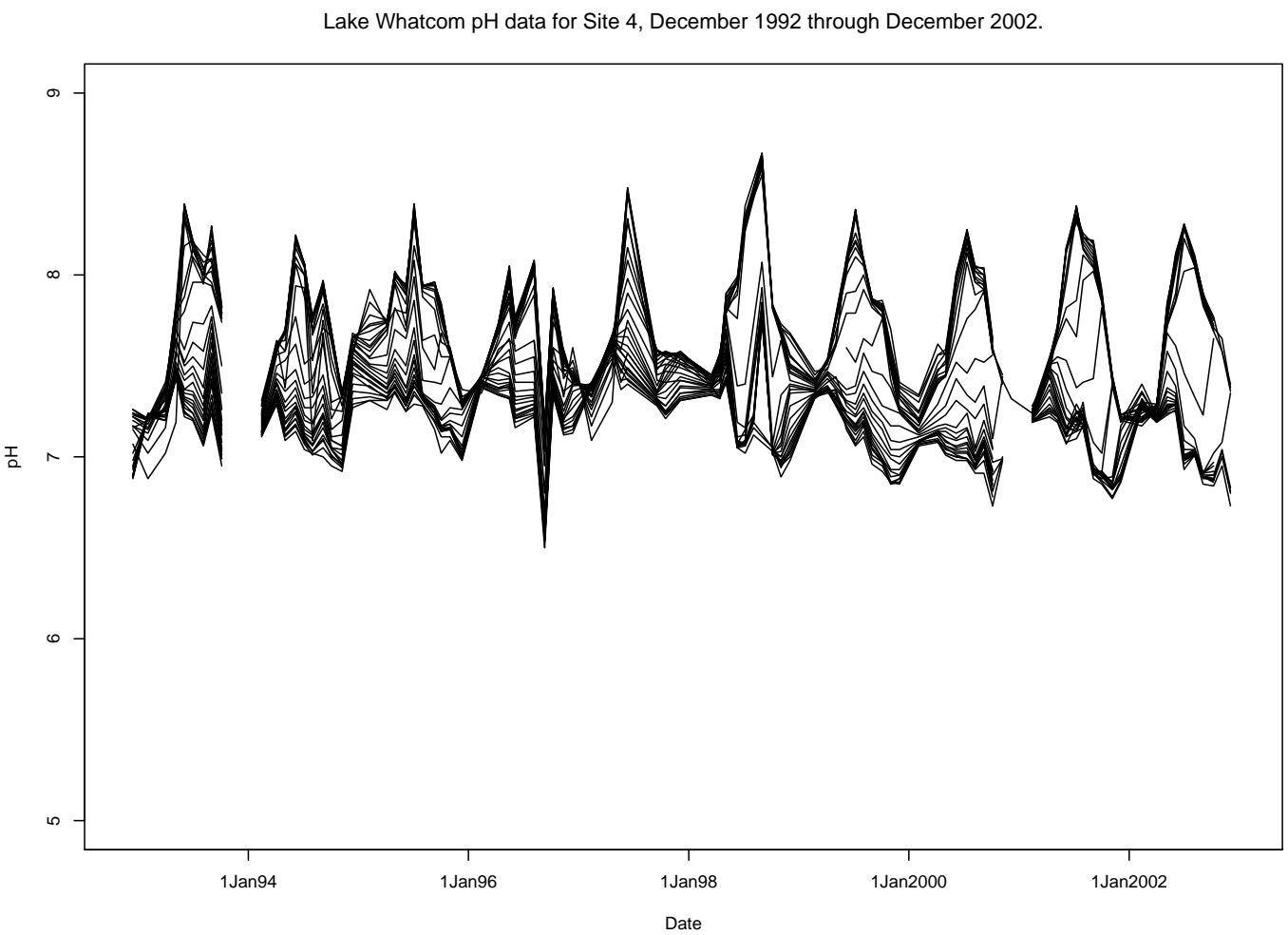


Figure 66: Lake Whatcom pH data for Site 4.

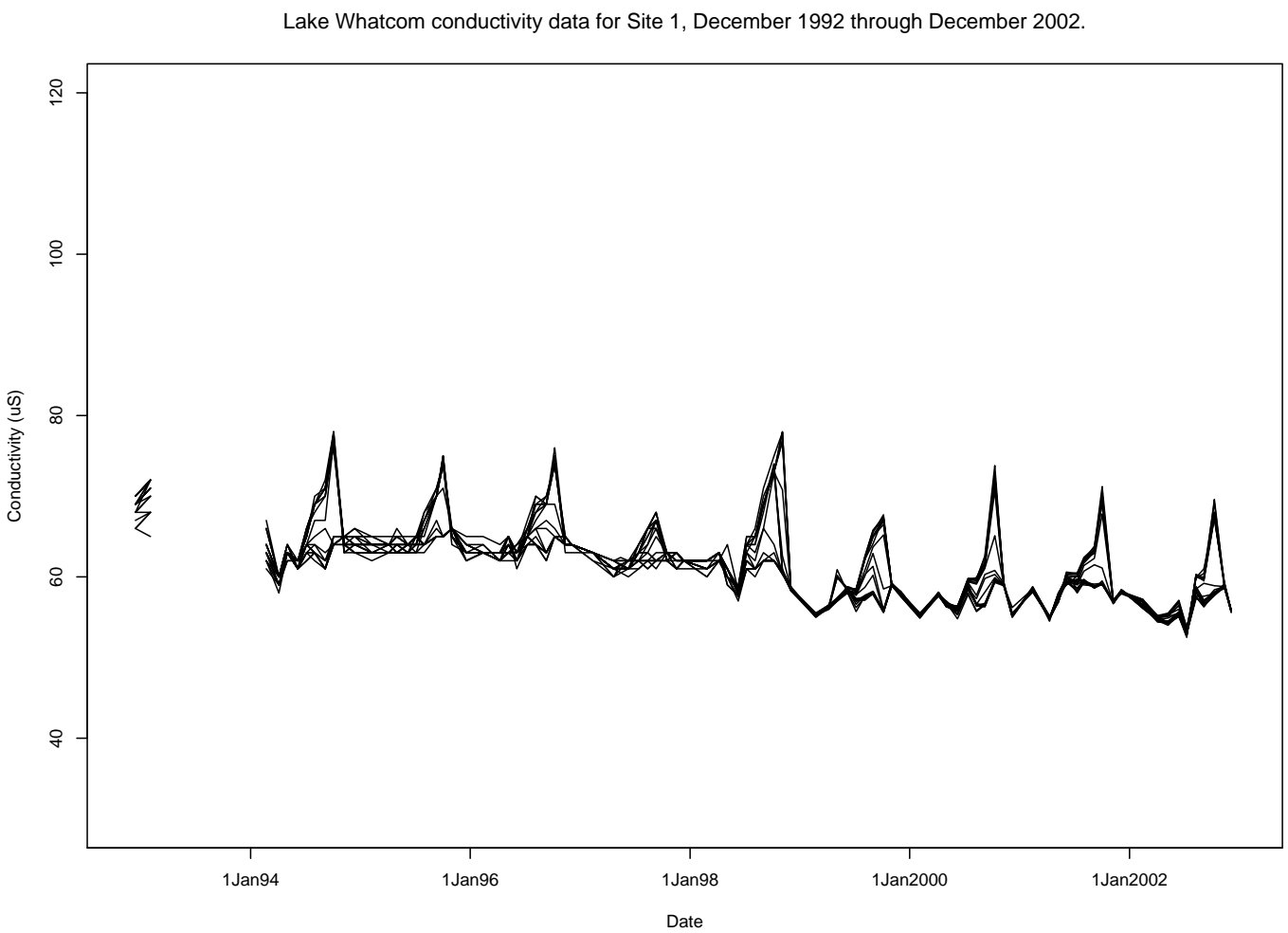


Figure 67: Lake Whatcom conductivity data for Site 1.



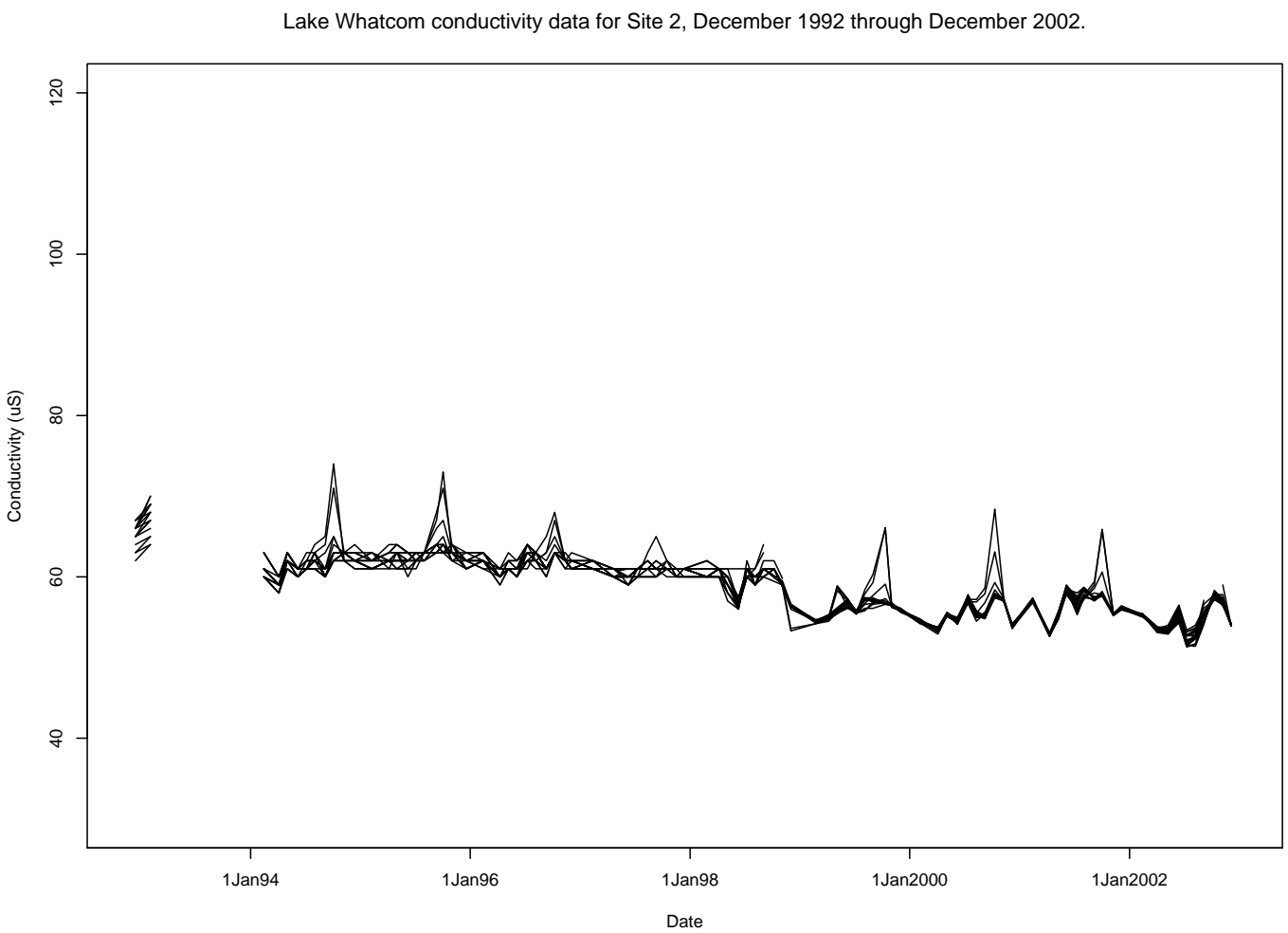


Figure 68: Lake Whatcom conductivity data for Site 2.

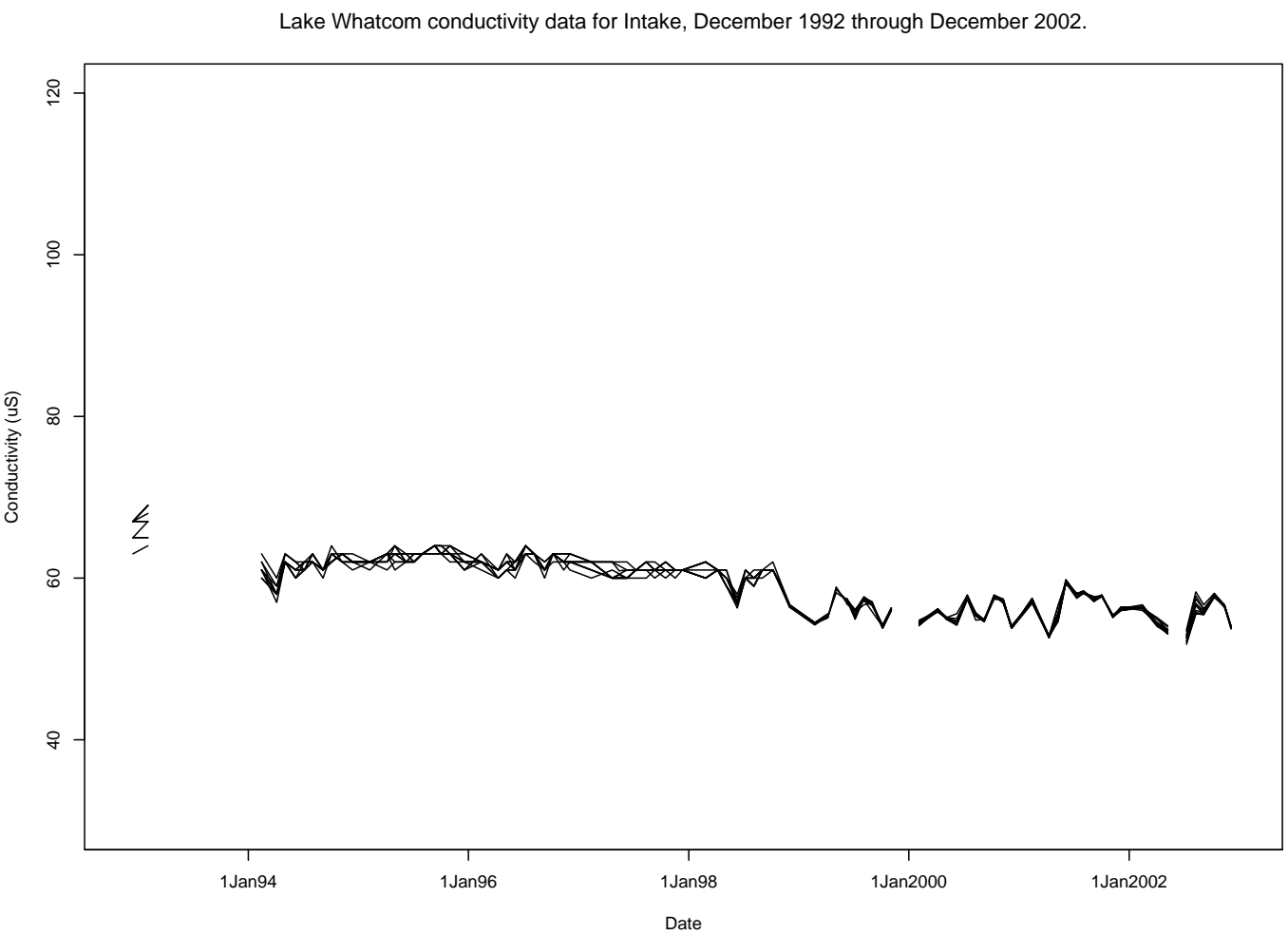


Figure 69: Lake Whatcom conductivity data for the Intake.

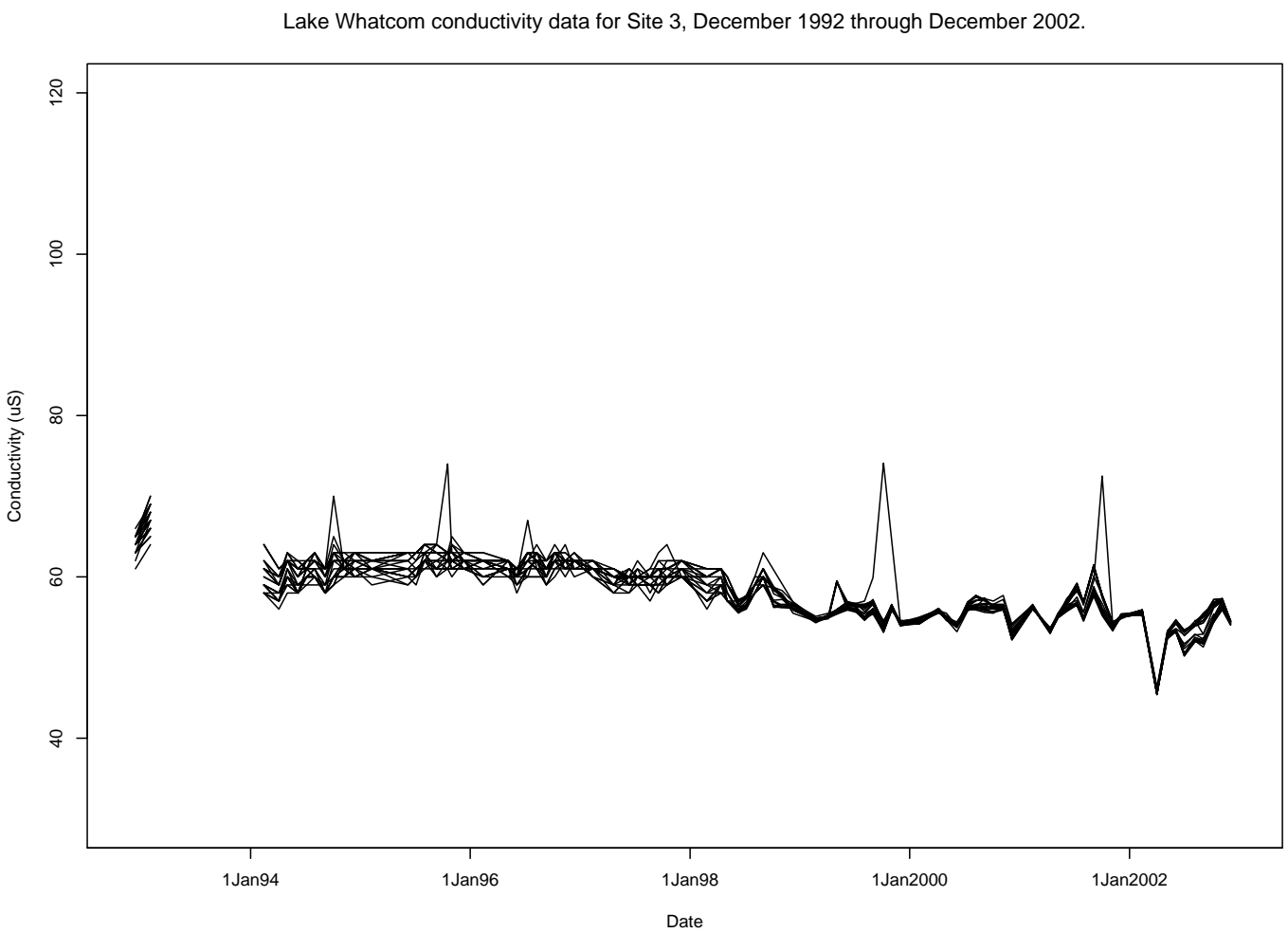


Figure 70: Lake Whatcom conductivity data for Site 3.

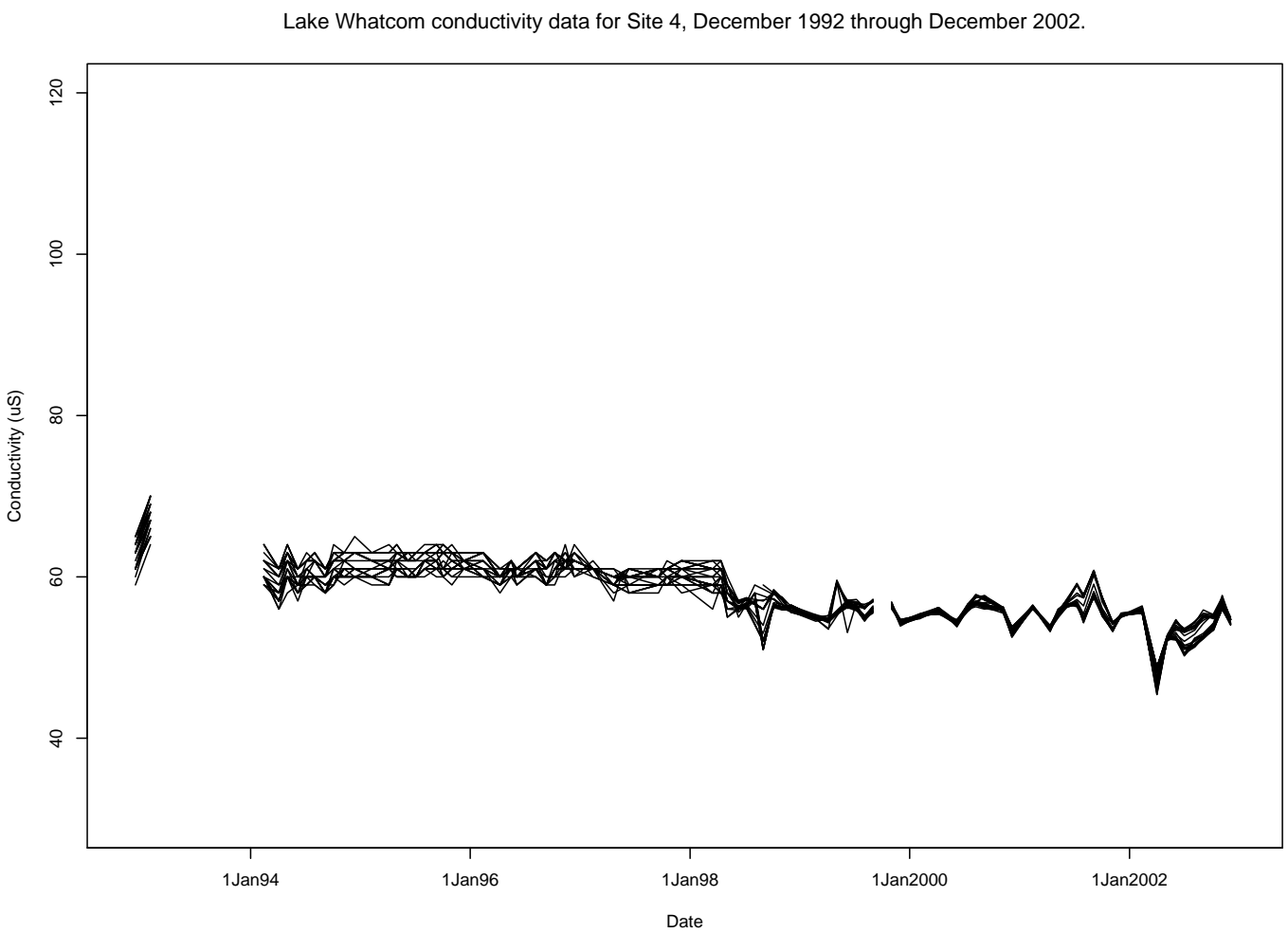


Figure 71: Lake Whatcom conductivity data for Site 4.

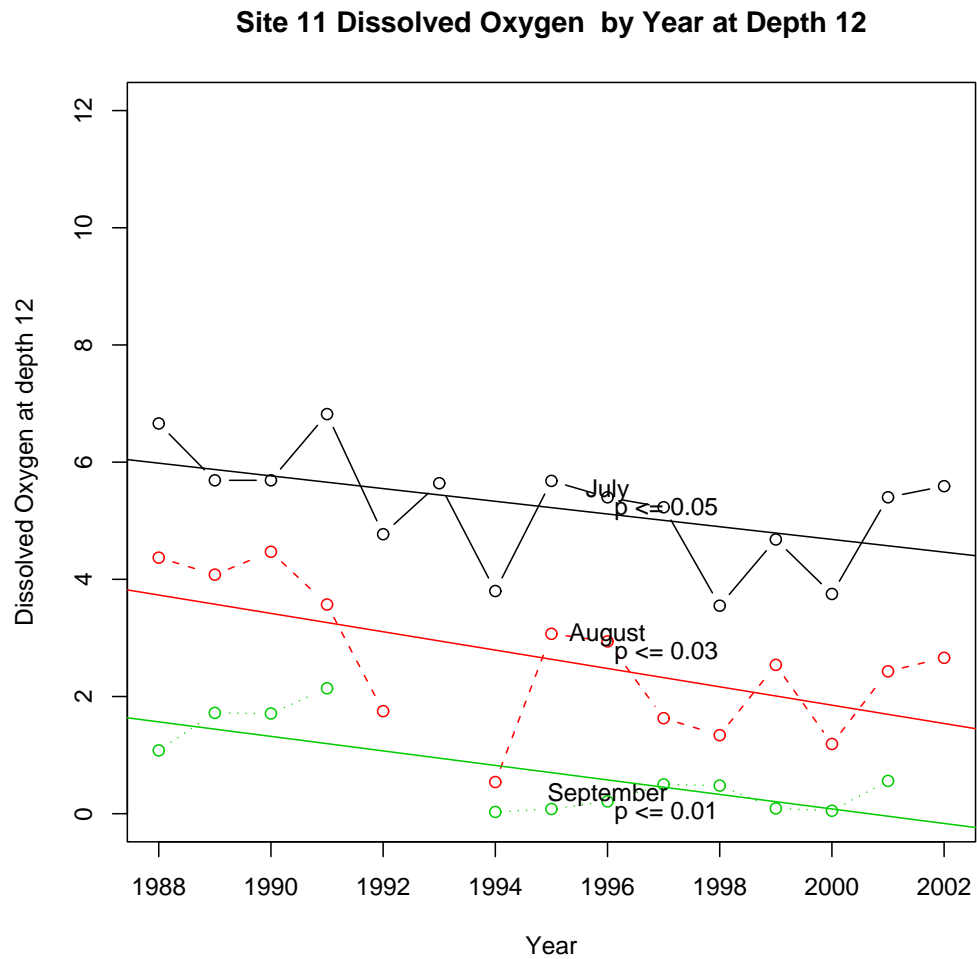


Figure 72: Pearson's  $r$  correlation of dissolved oxygen concentrations by year, Site 1 (12 m). July-September results are statistically significant.

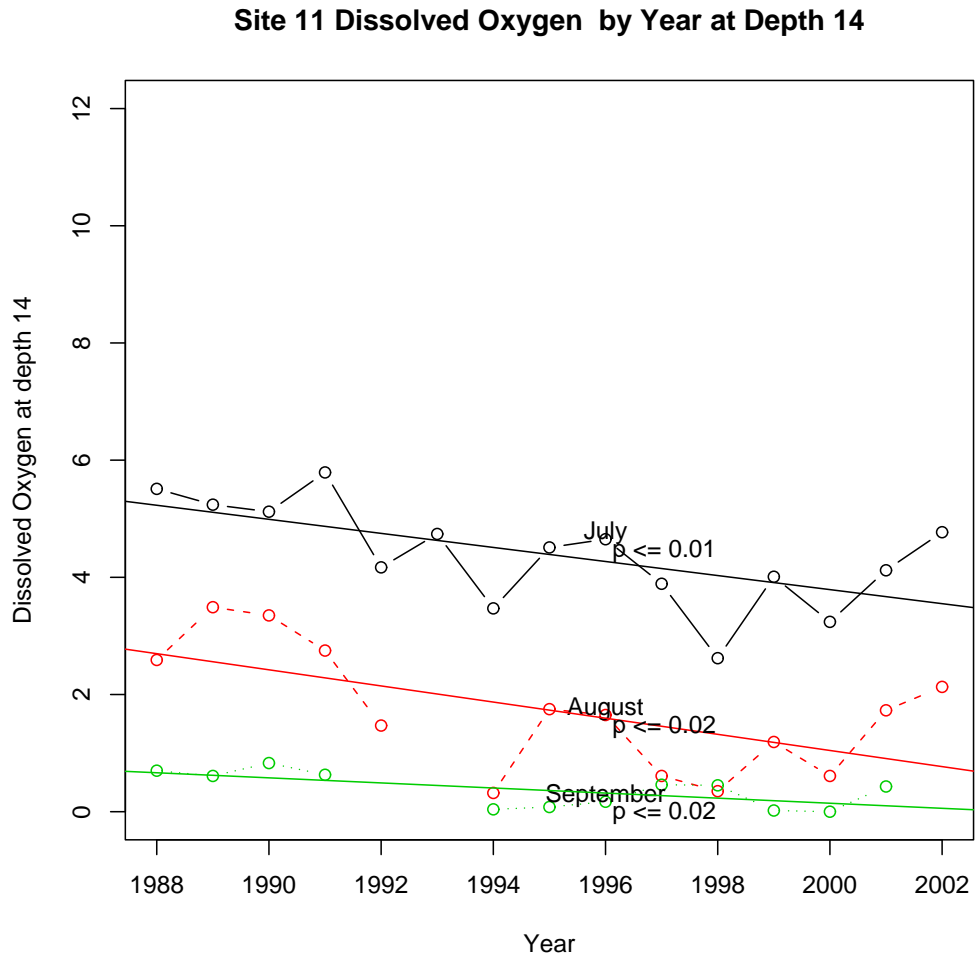


Figure 73: Pearson's  $r$  correlation of dissolved oxygen concentrations by year, Site 1 (14 m). July-September results are statistically significant.

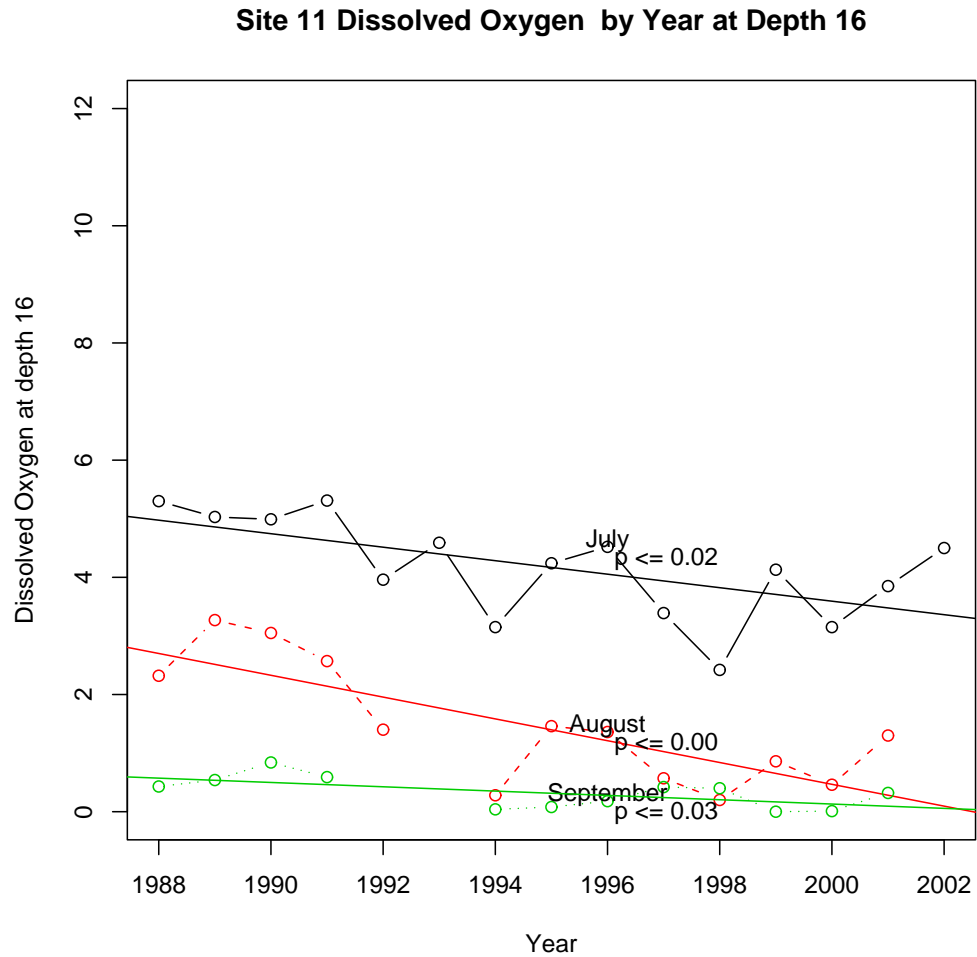


Figure 74: Pearson's  $r$  correlation of dissolved oxygen concentrations by year, Site 1 (16 m). July-September results are statistically significant.

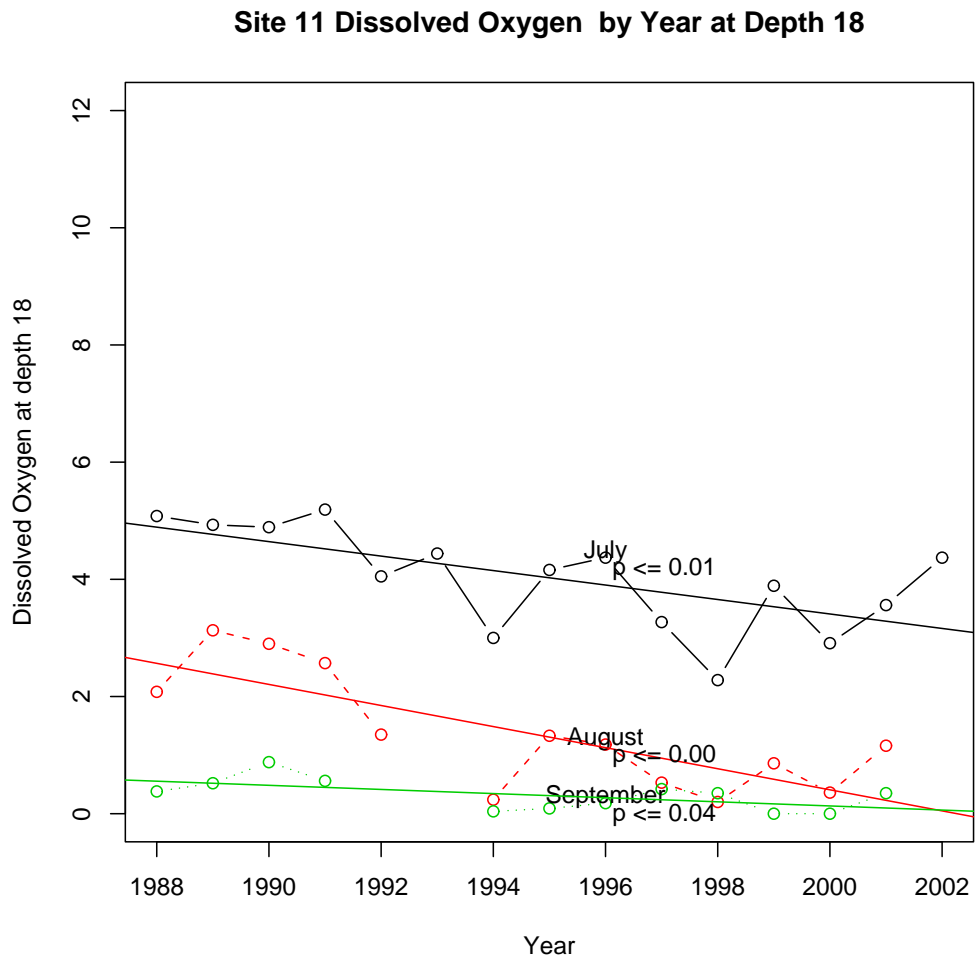


Figure 75: Pearson's  $r$  correlation of dissolved oxygen concentrations by year, Site 1 (18 m). July-September results are statistically significant.



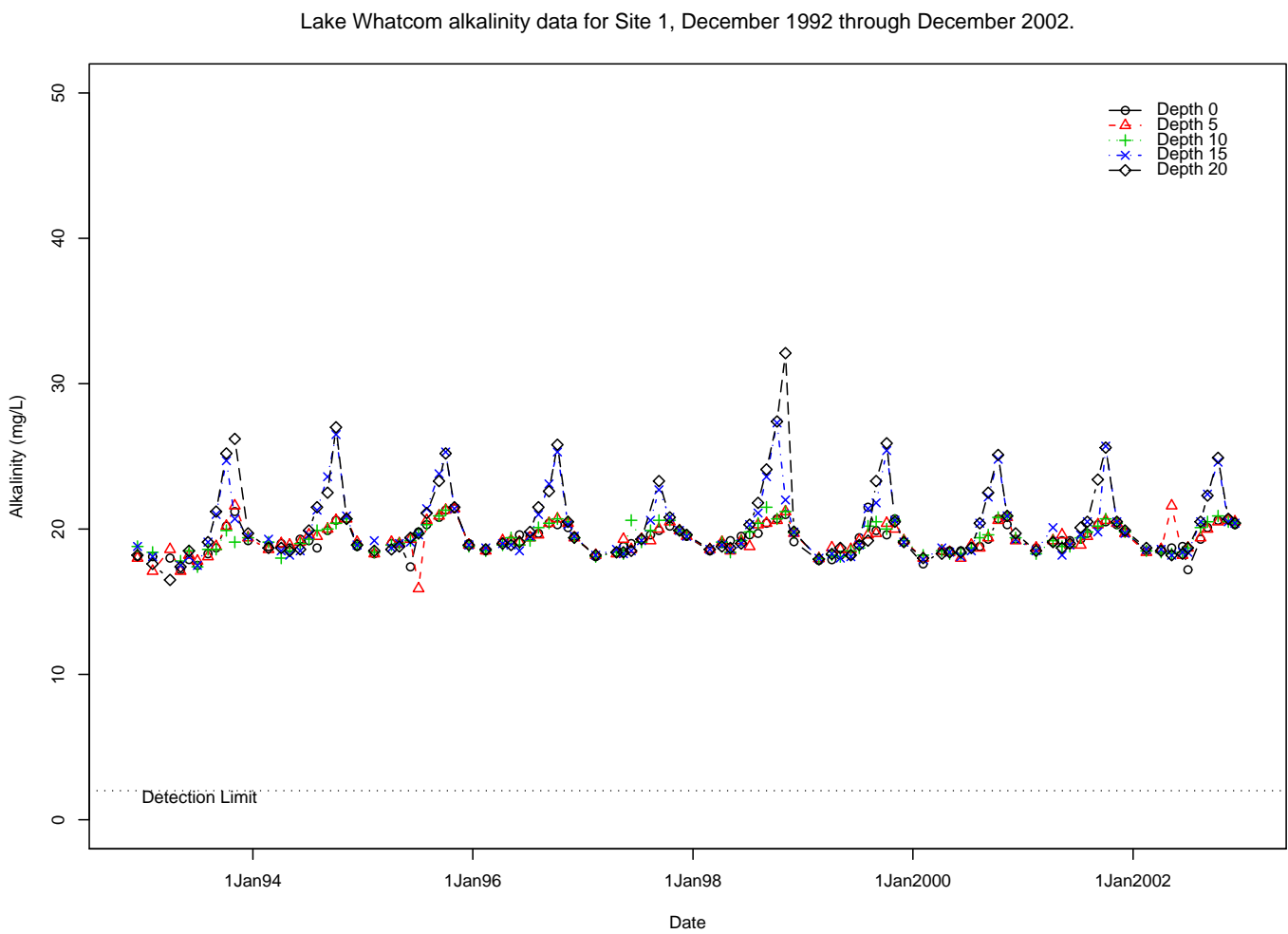


Figure 76: Lake Whatcom alkalinity data for Site 1.

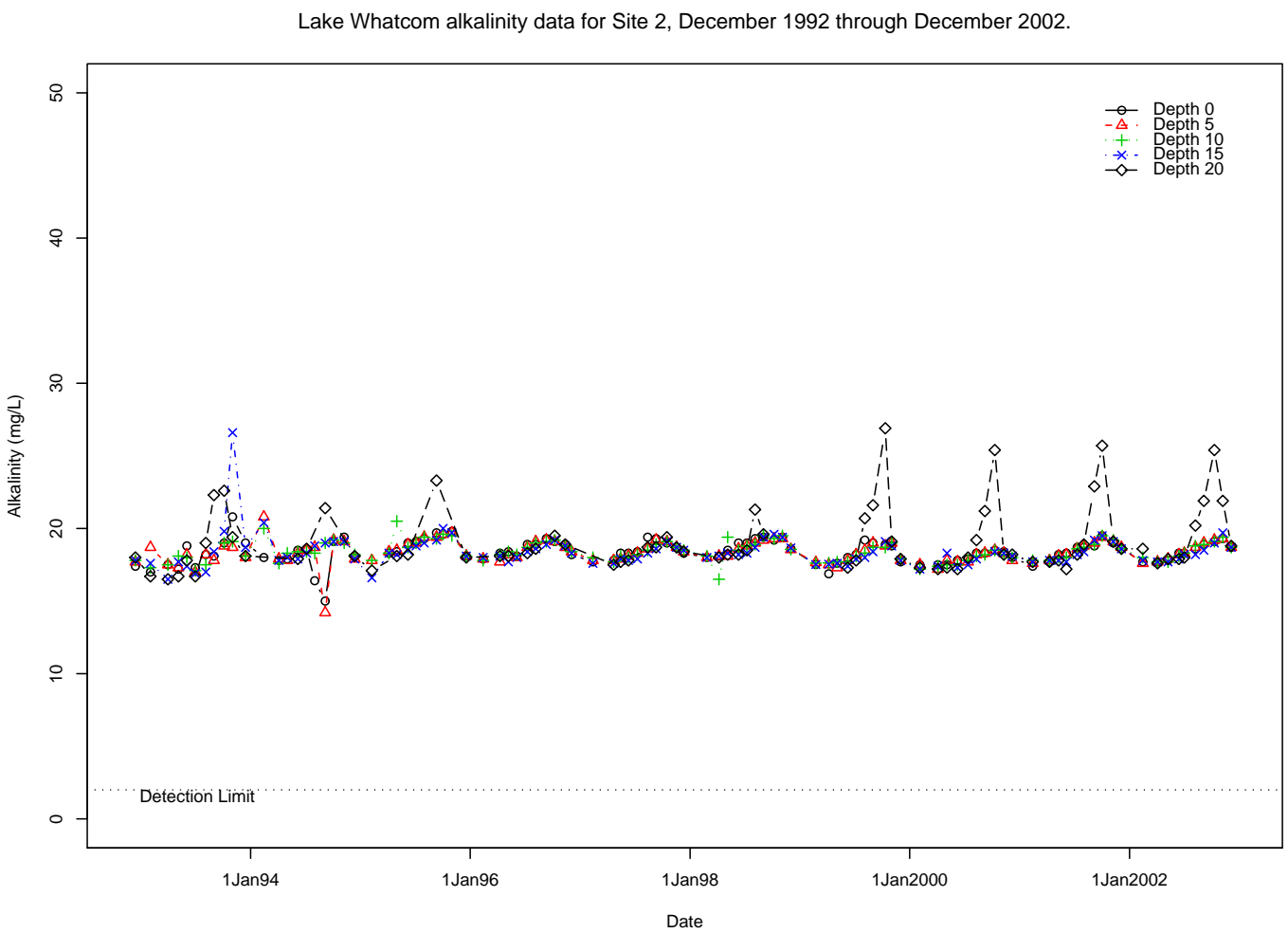


Figure 77: Lake Whatcom alkalinity data for Site 2.

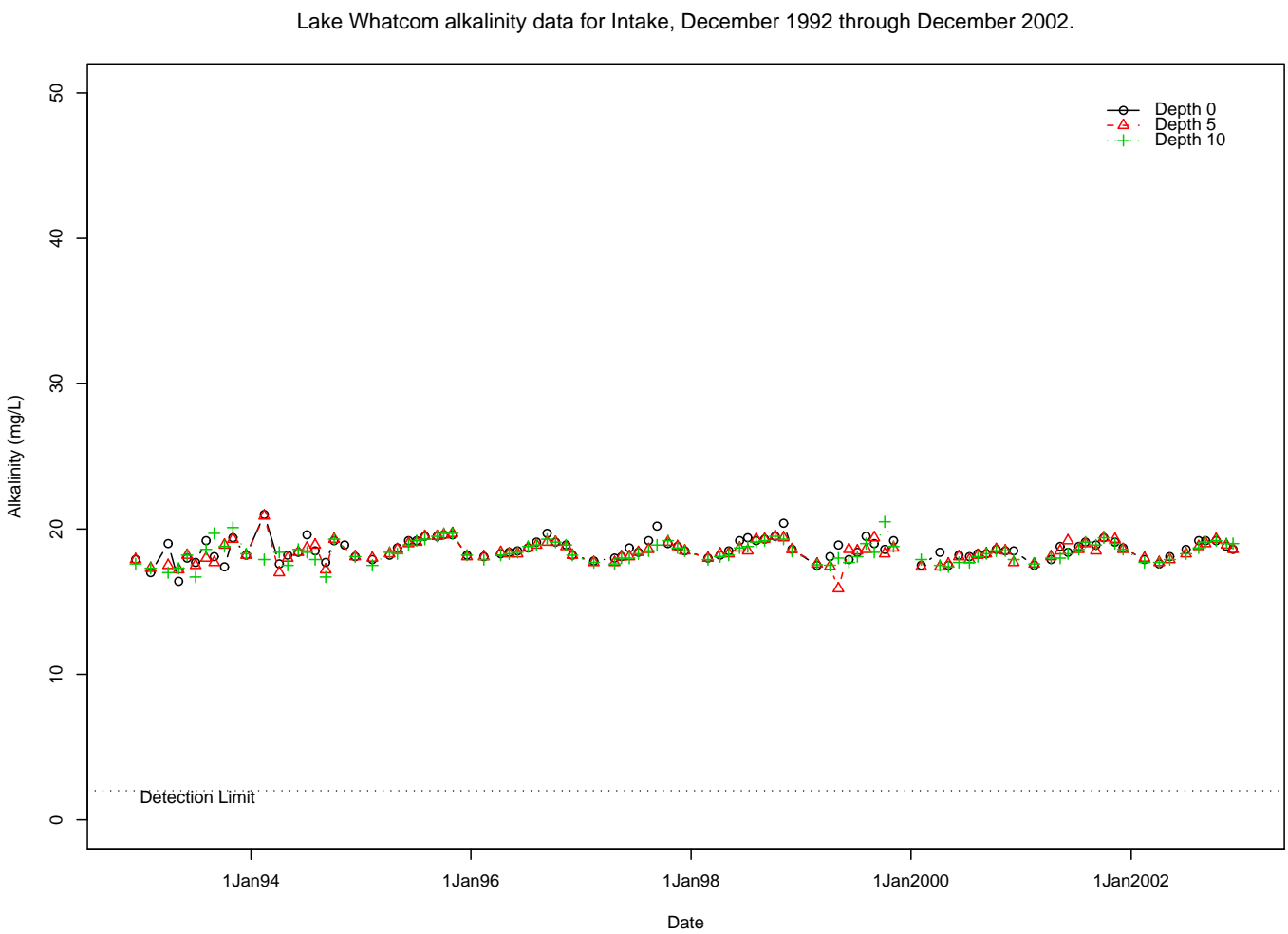


Figure 78: Lake Whatcom alkalinity data for the Intake.

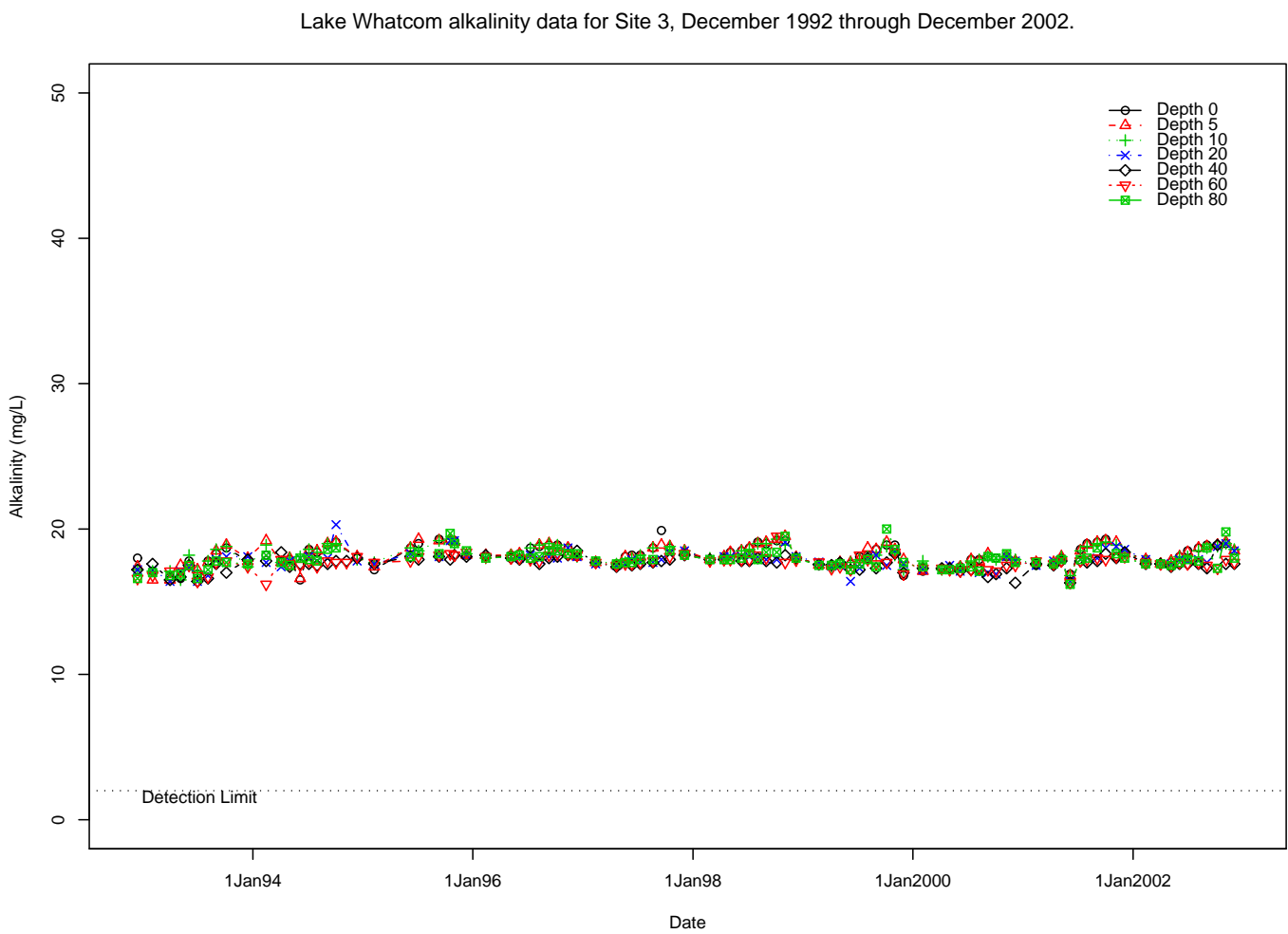


Figure 79: Lake Whatcom alkalinity data for Site 3.

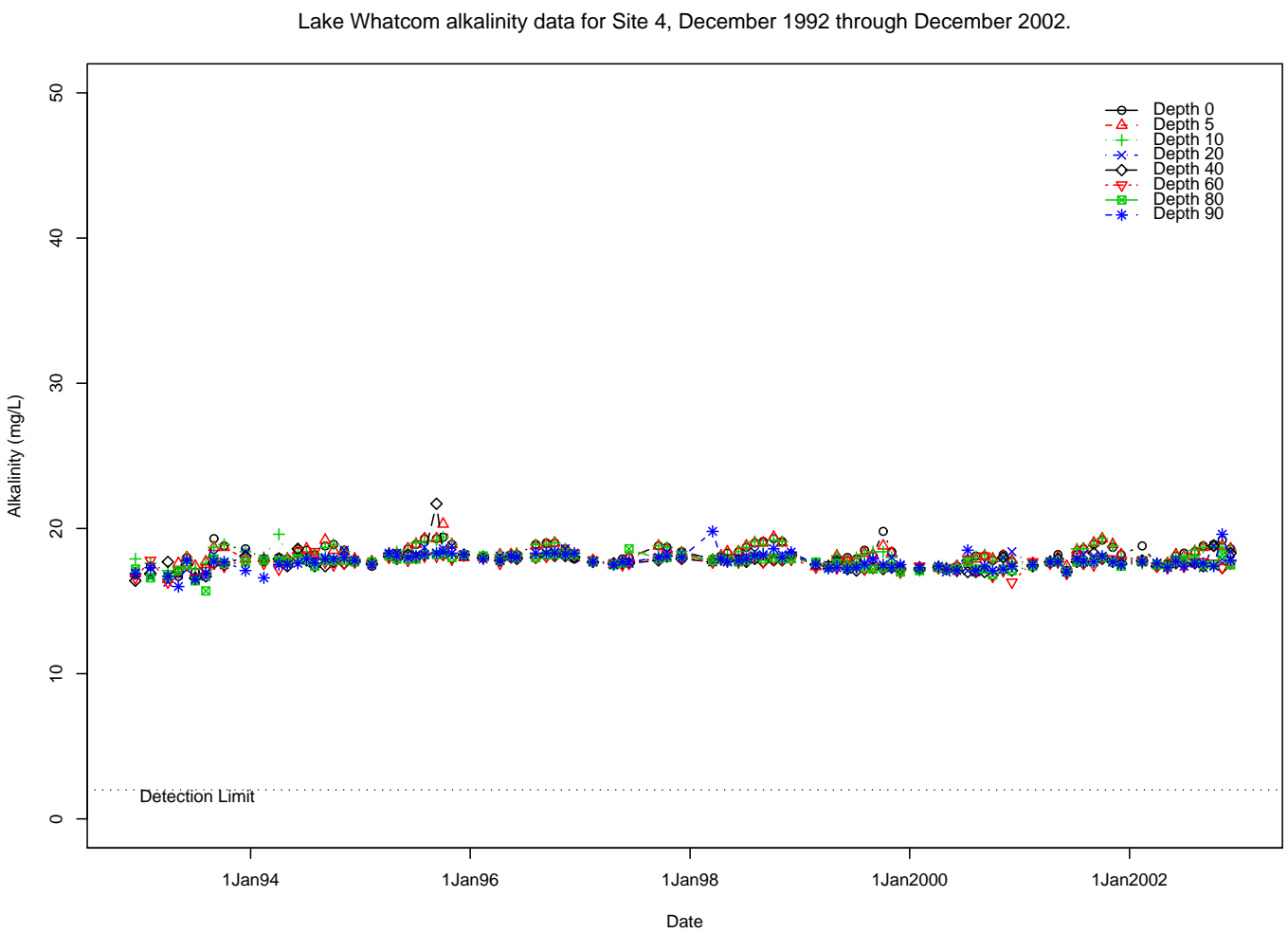


Figure 80: Lake Whatcom alkalinity data for Site 4.

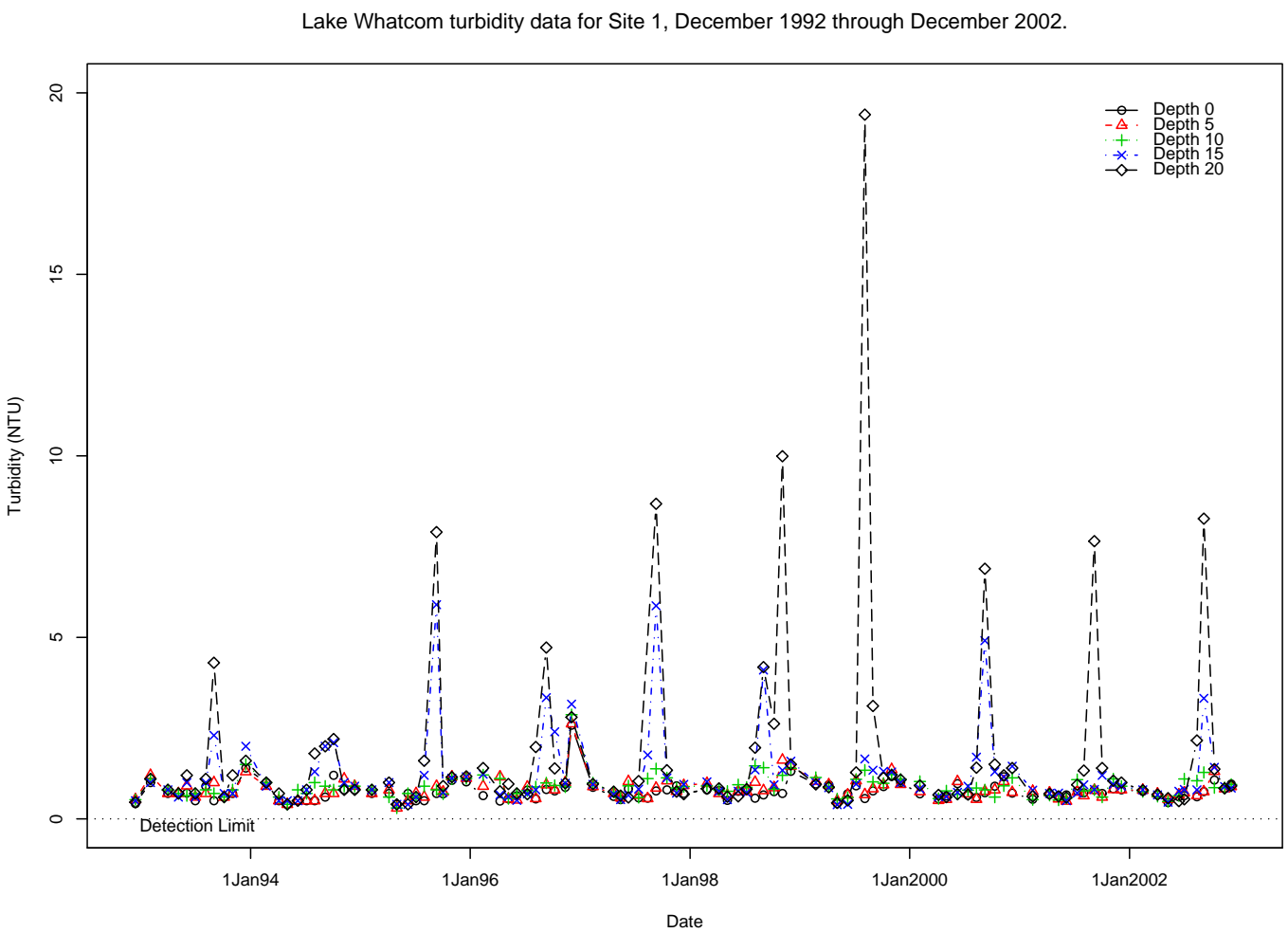


Figure 81: Lake Whatcom turbidity data for Site 1.

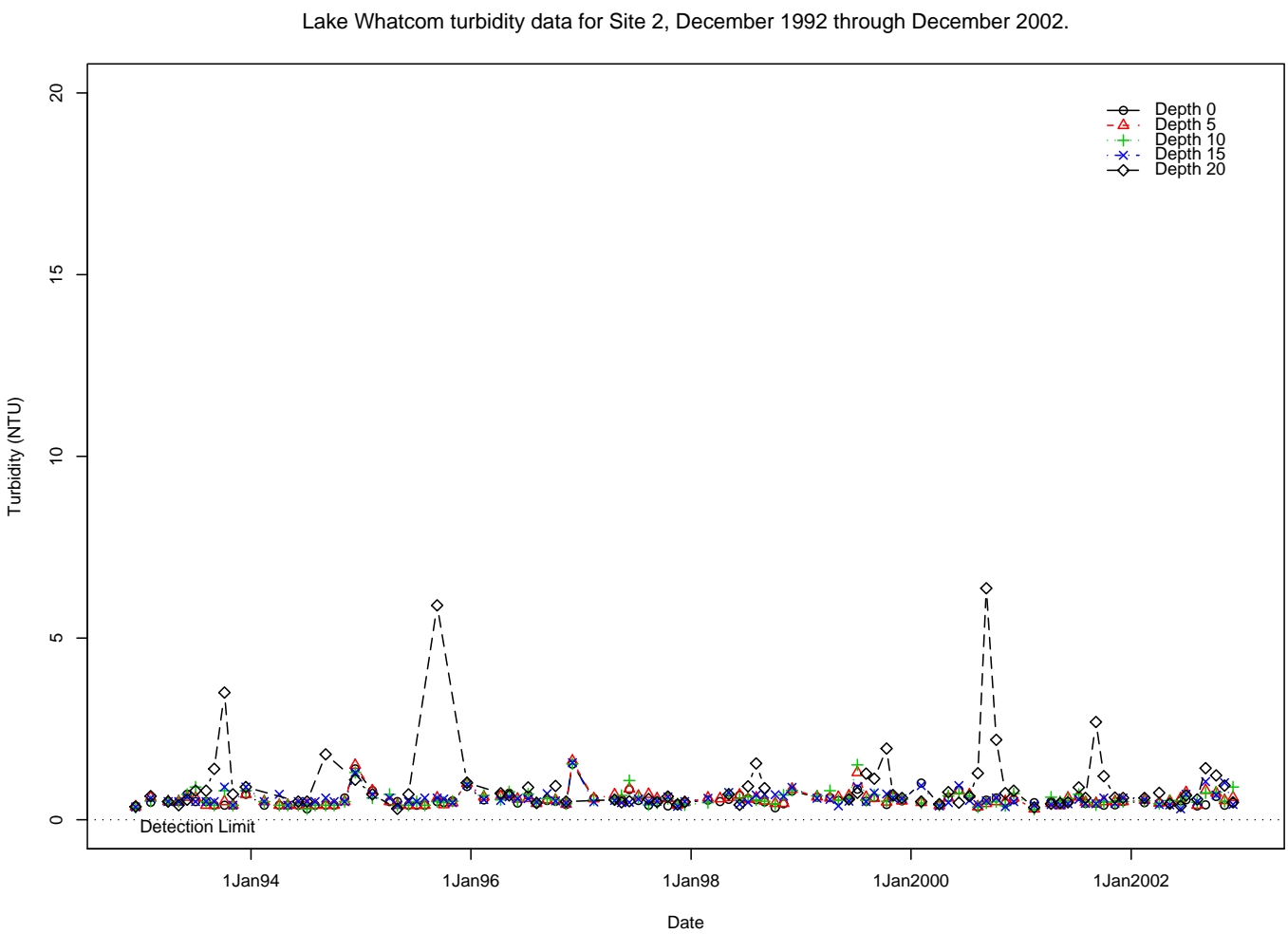


Figure 82: Lake Whatcom turbidity data for Site 2.

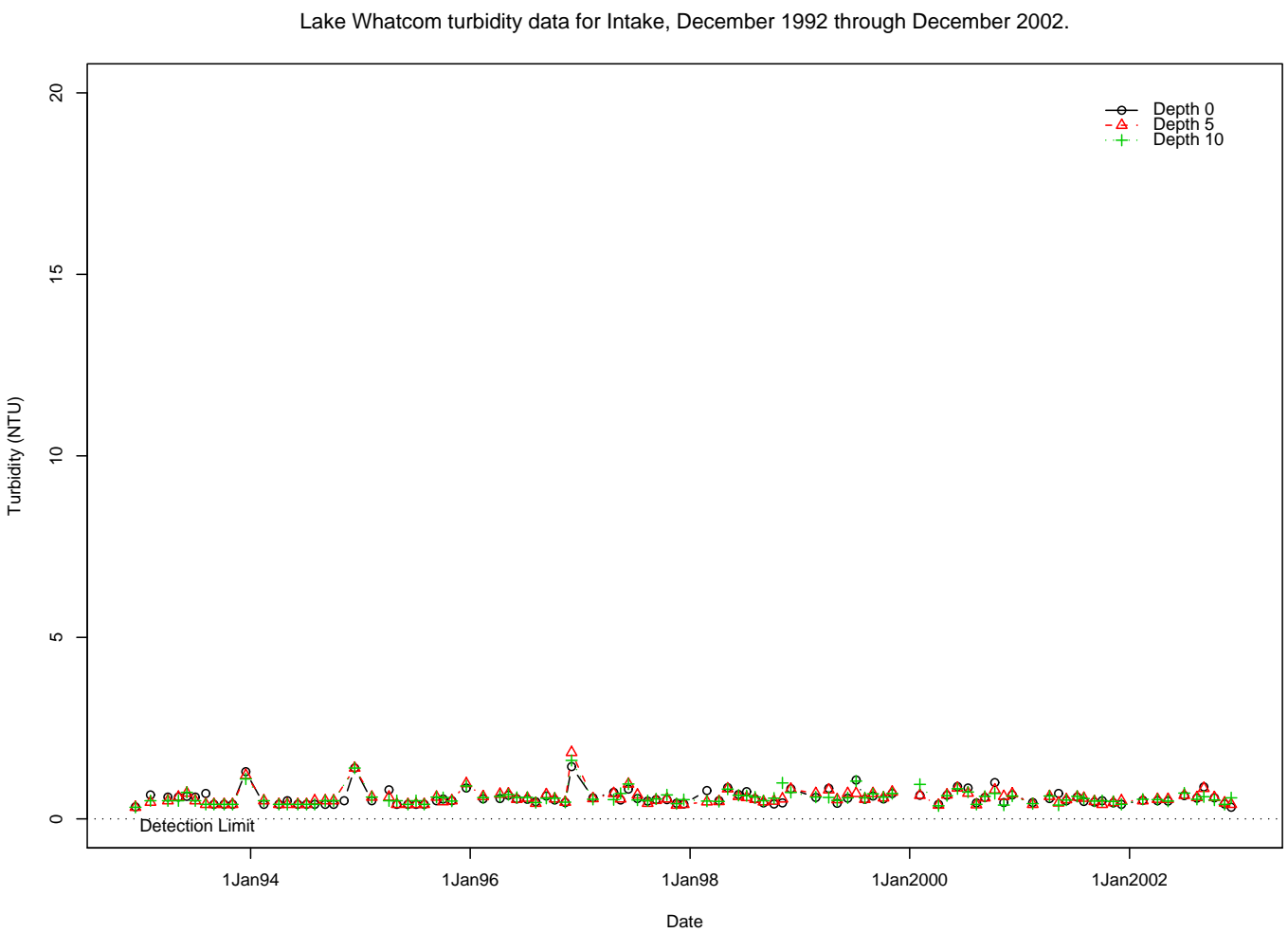


Figure 83: Lake Whatcom turbidity data for the Intake.



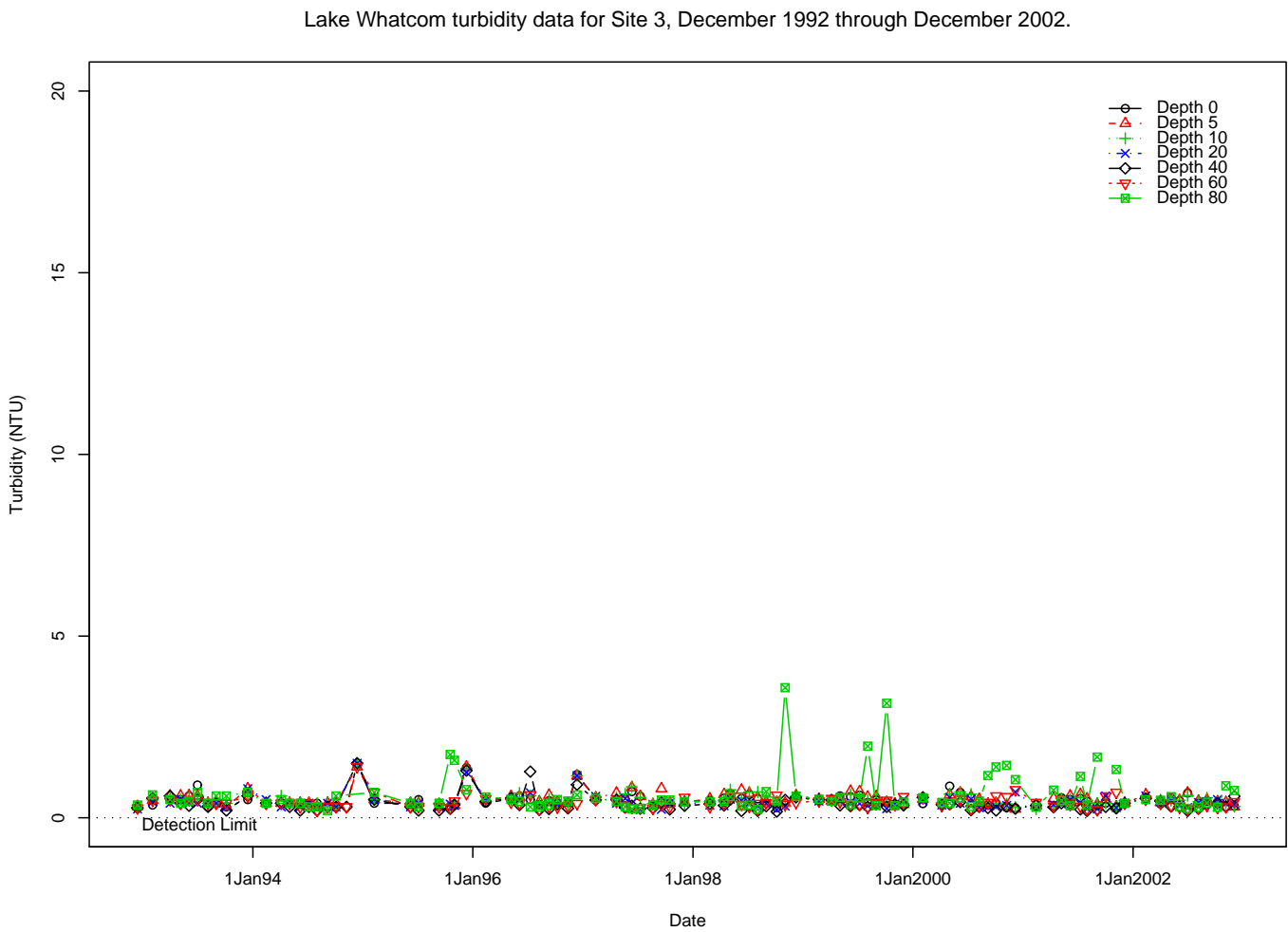


Figure 84: Lake Whatcom turbidity data for Site 3.

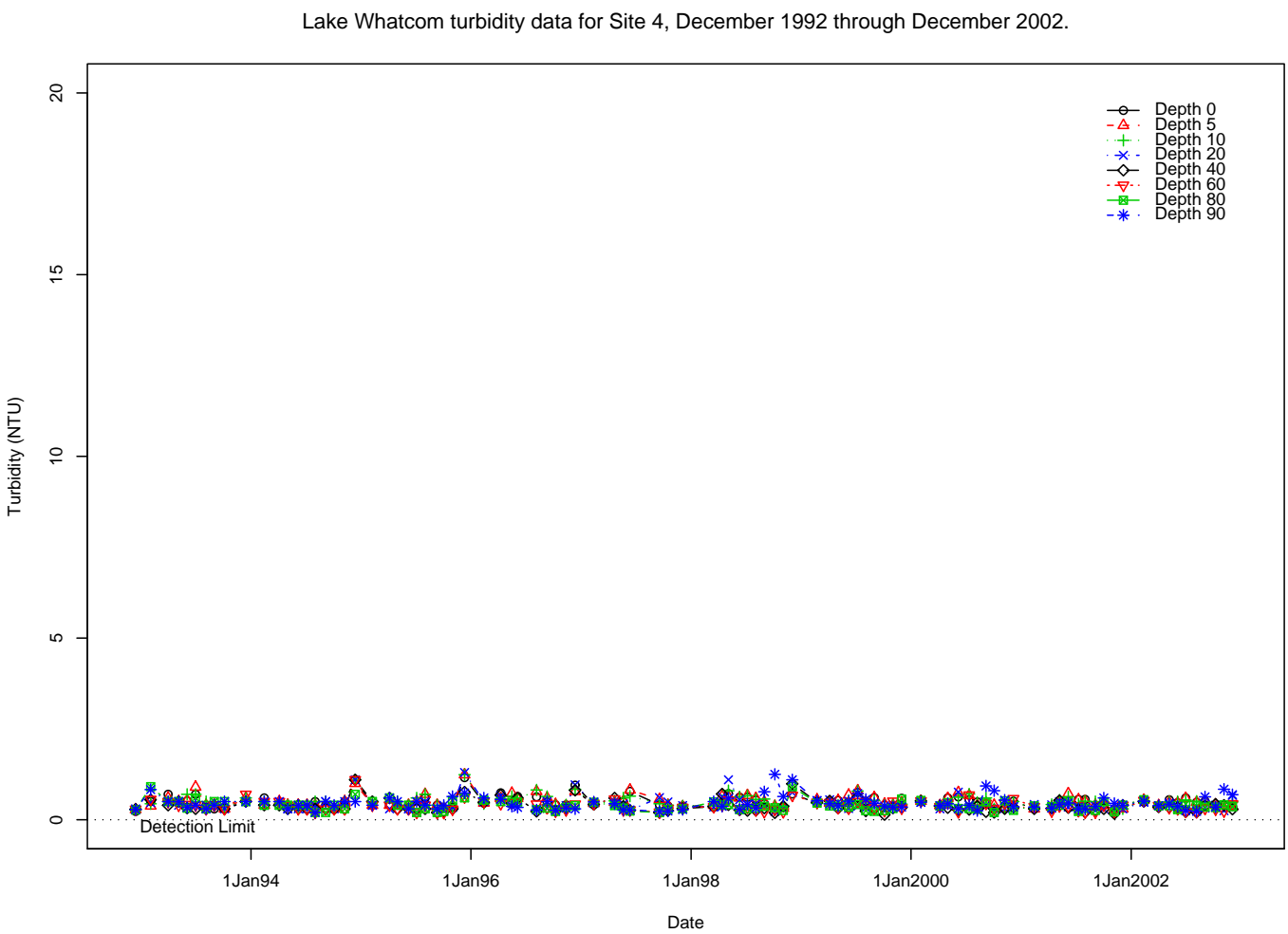


Figure 85: Lake Whatcom turbidity data for Site 4.

Lake Whatcom nitrogen summary data for Site 1, December 1992 through December 2002.

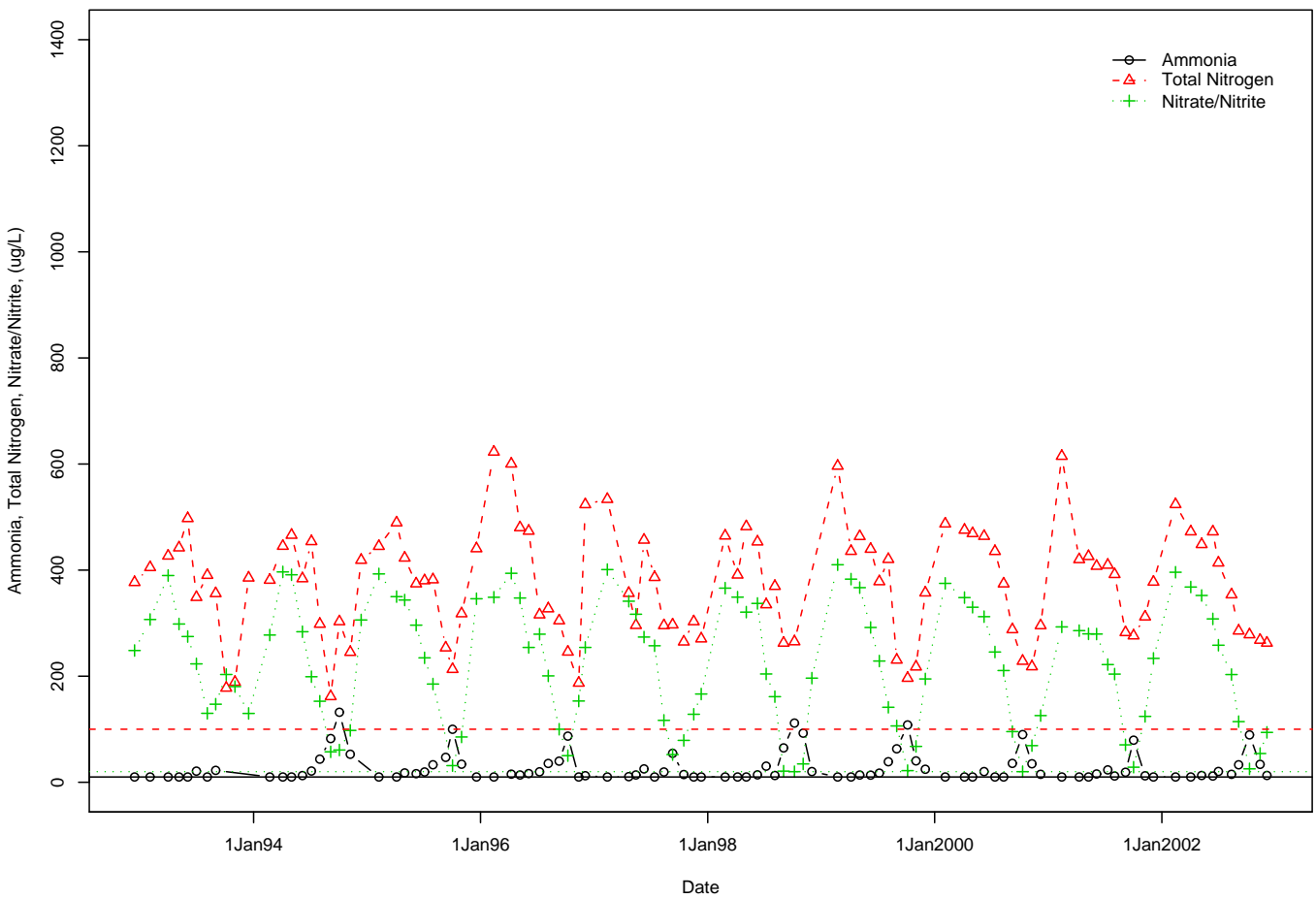


Figure 86: Lake Whatcom nitrogen summary data for Site 1.

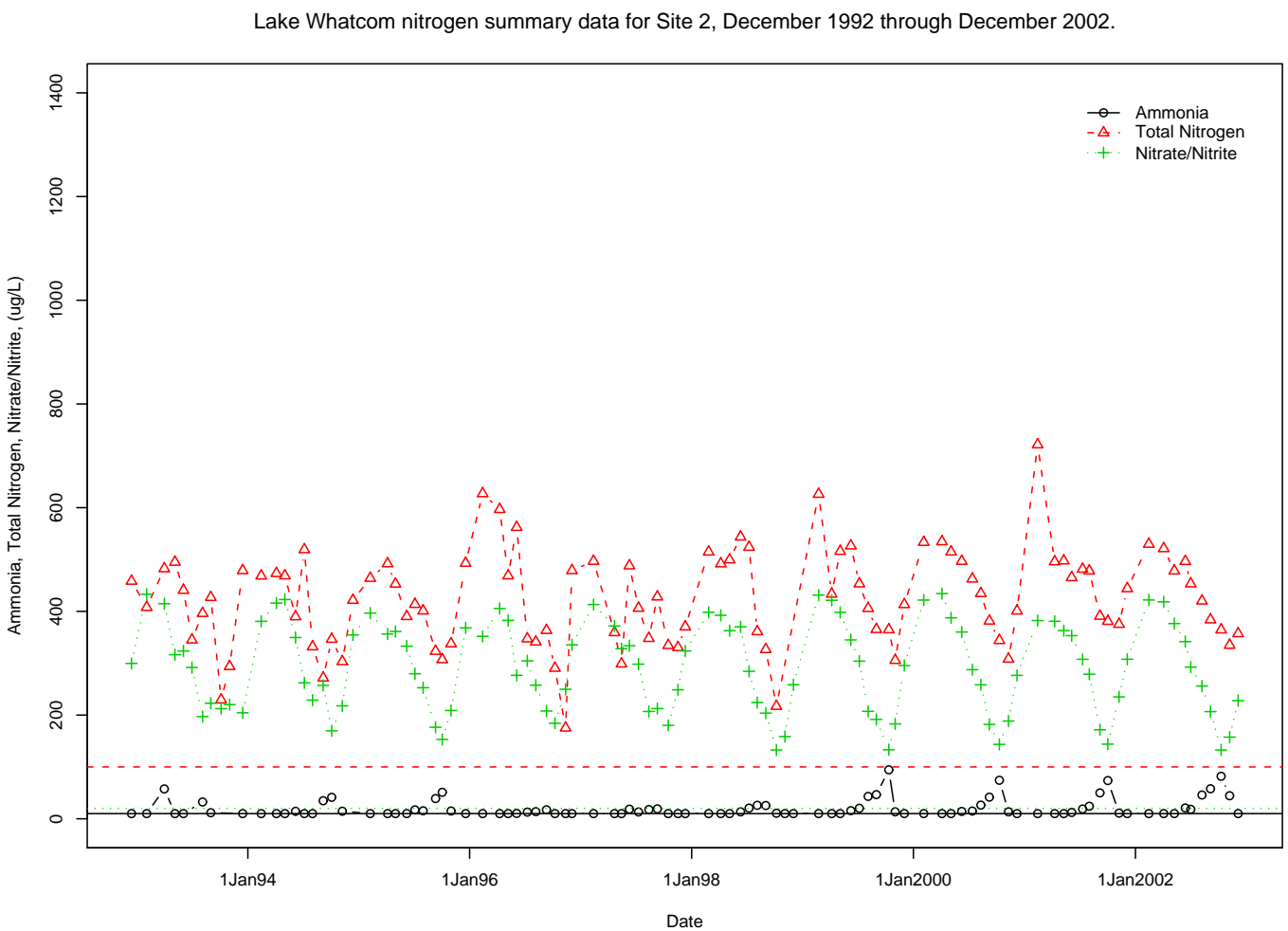


Figure 87: Lake Whatcom nitrogen summary data for Site 2.

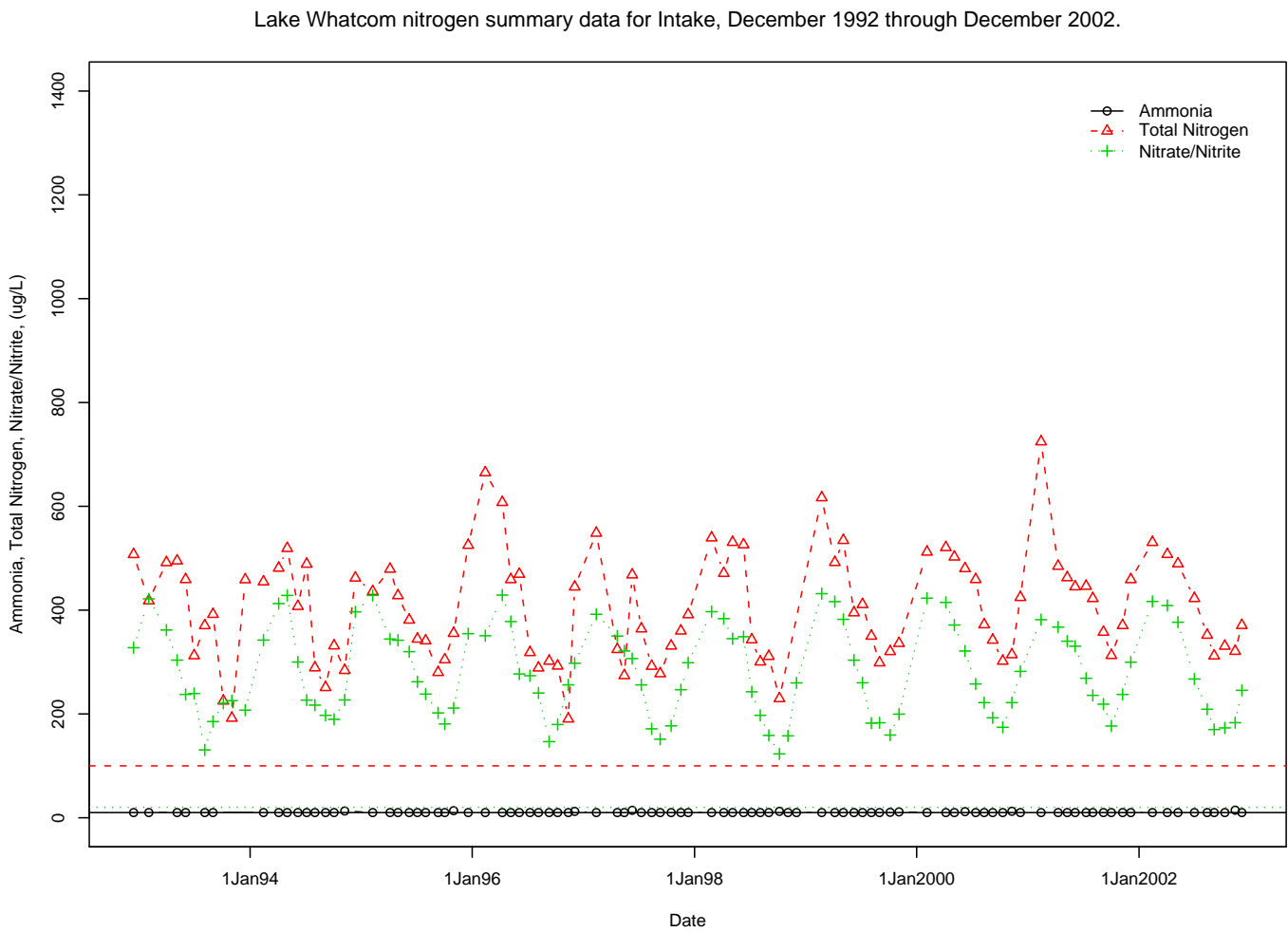


Figure 88: Lake Whatcom nitrogen summary data for the Intake.

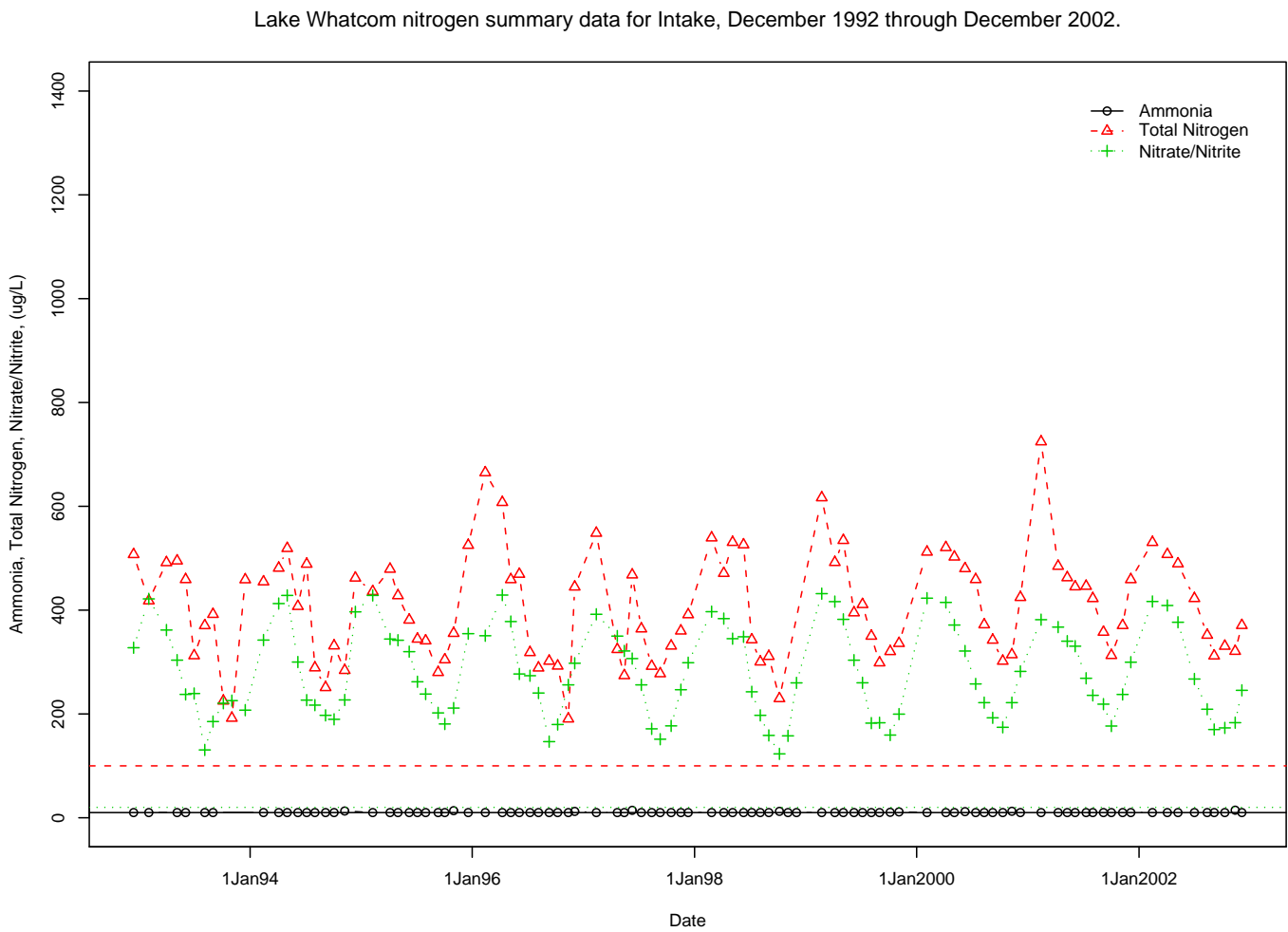


Figure 89: Lake Whatcom nitrogen summary data for Site 3.

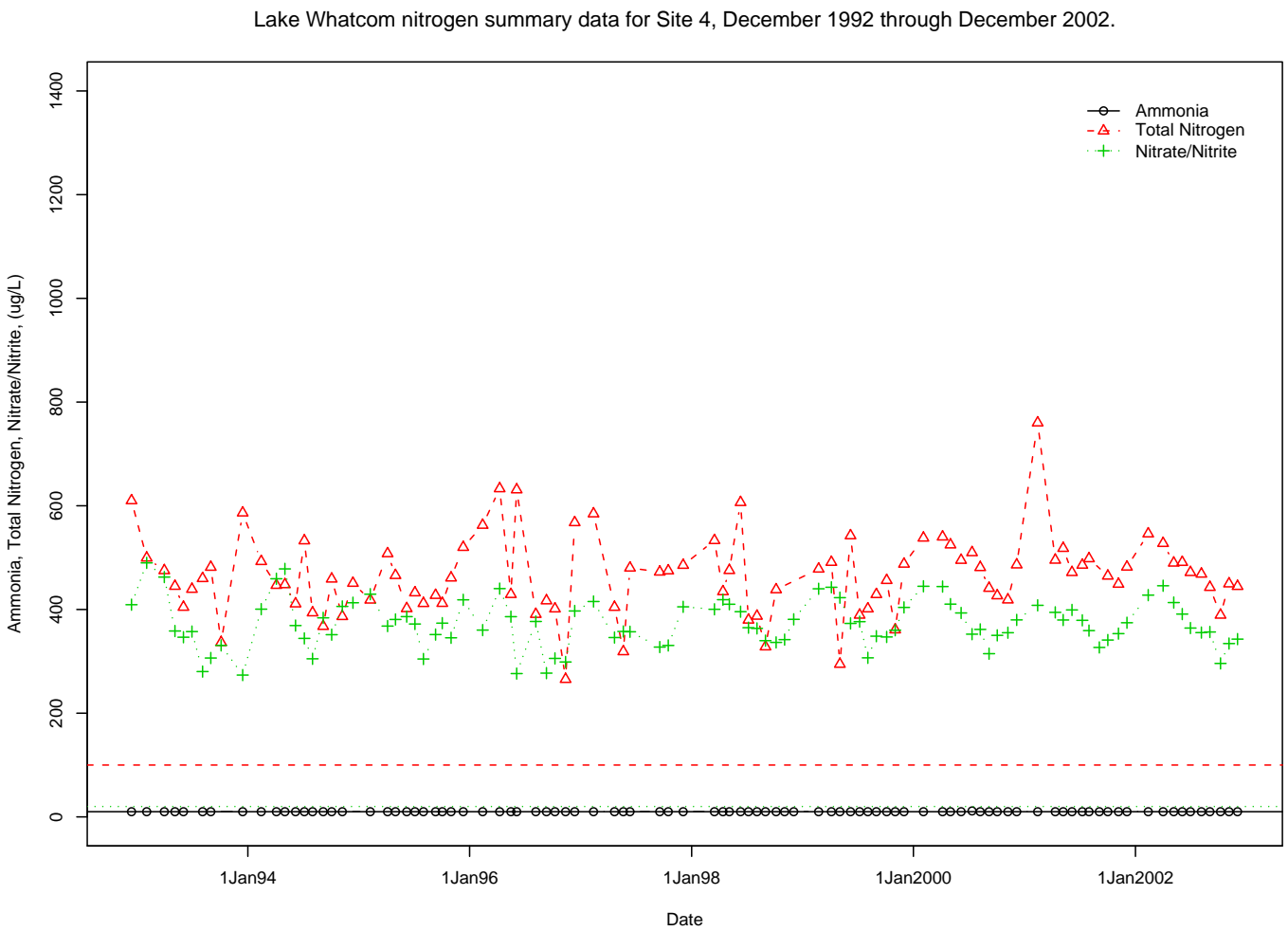


Figure 90: Lake Whatcom nitrogen summary data for Site 4.

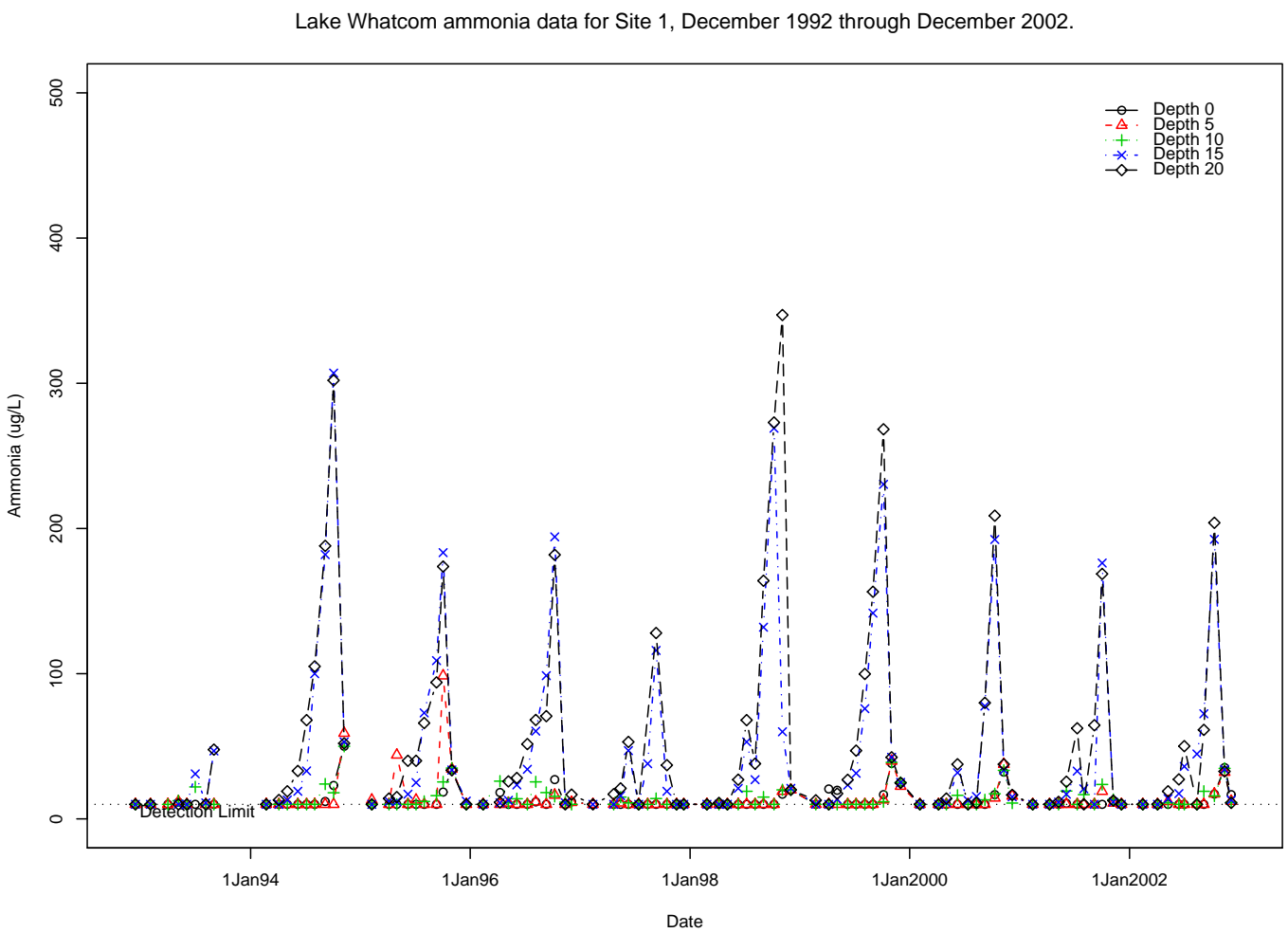


Figure 91: Lake Whatcom ammonia data for Site 1.



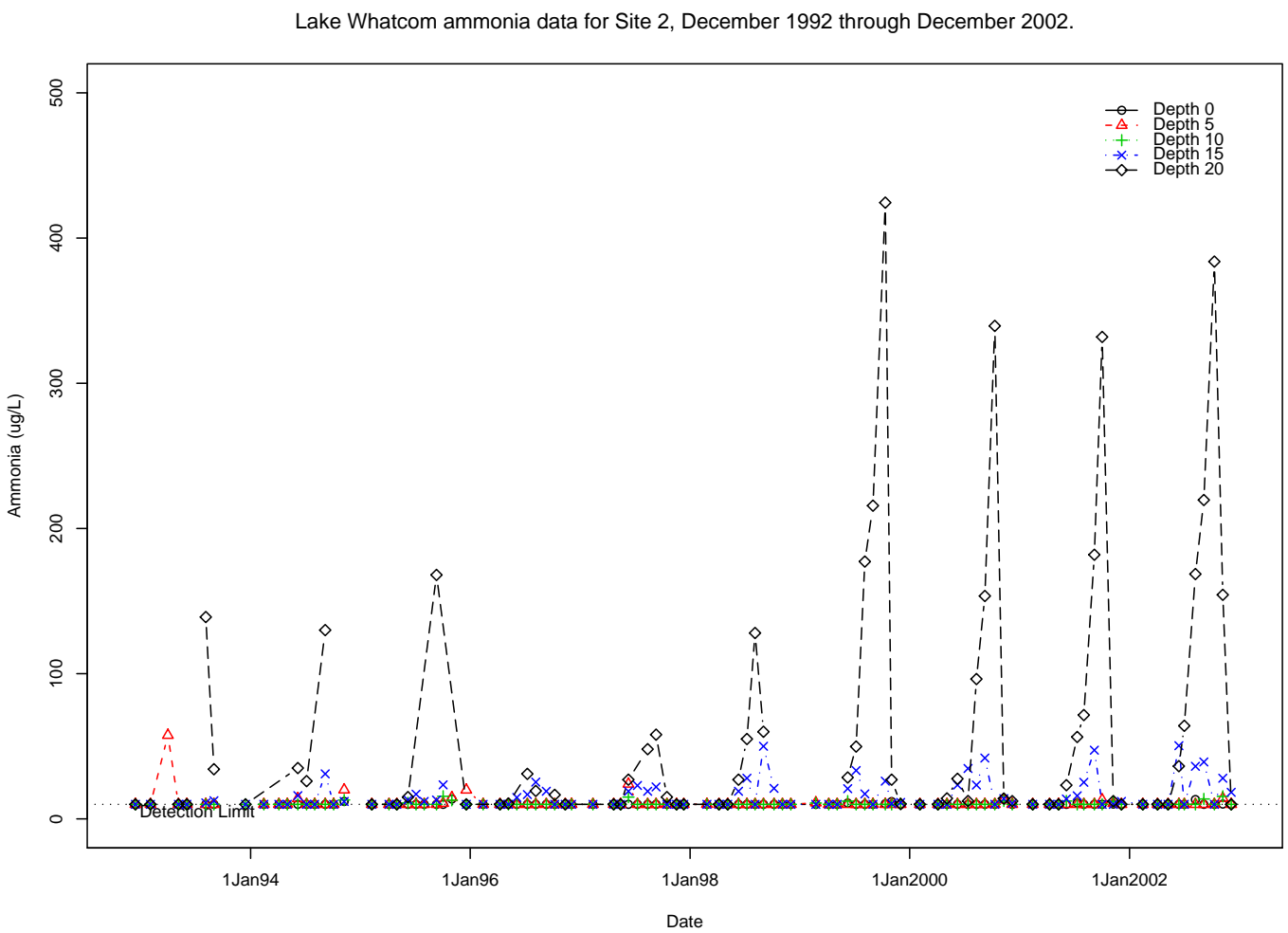


Figure 92: Lake Whatcom ammonia data for Site 2.

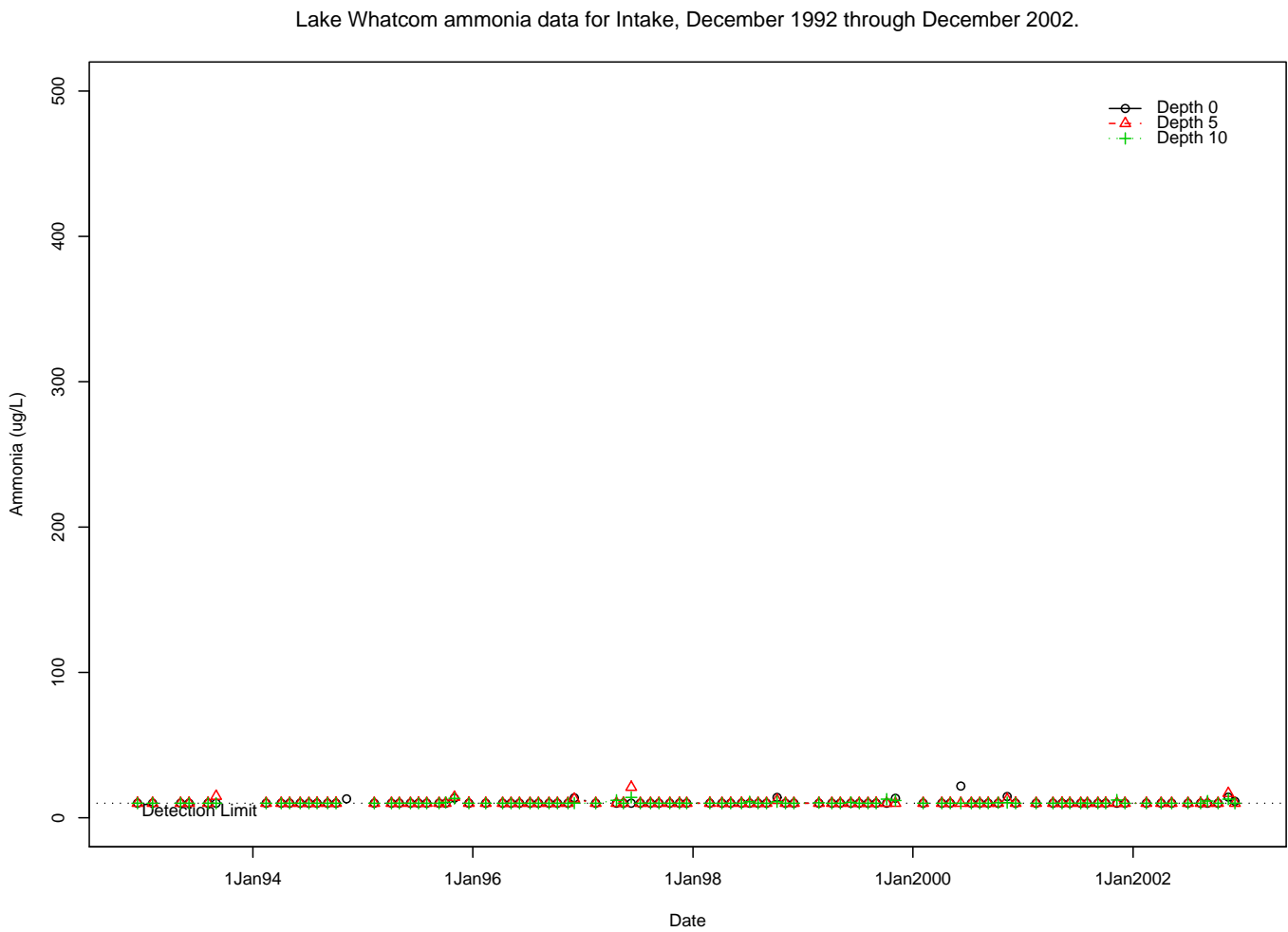


Figure 93: Lake Whatcom ammonia data for the Intake.

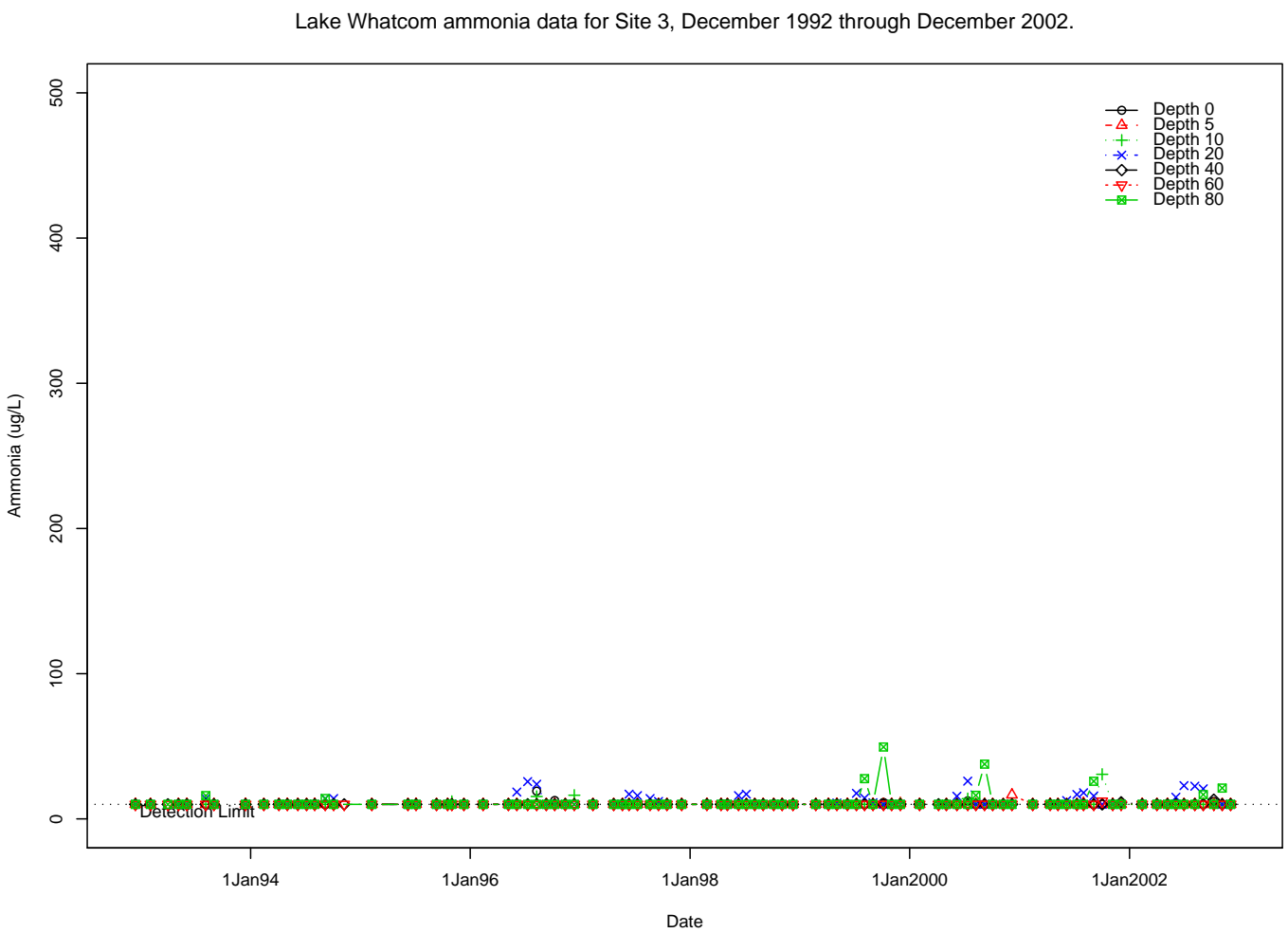


Figure 94: Lake Whatcom ammonia data for Site 3.

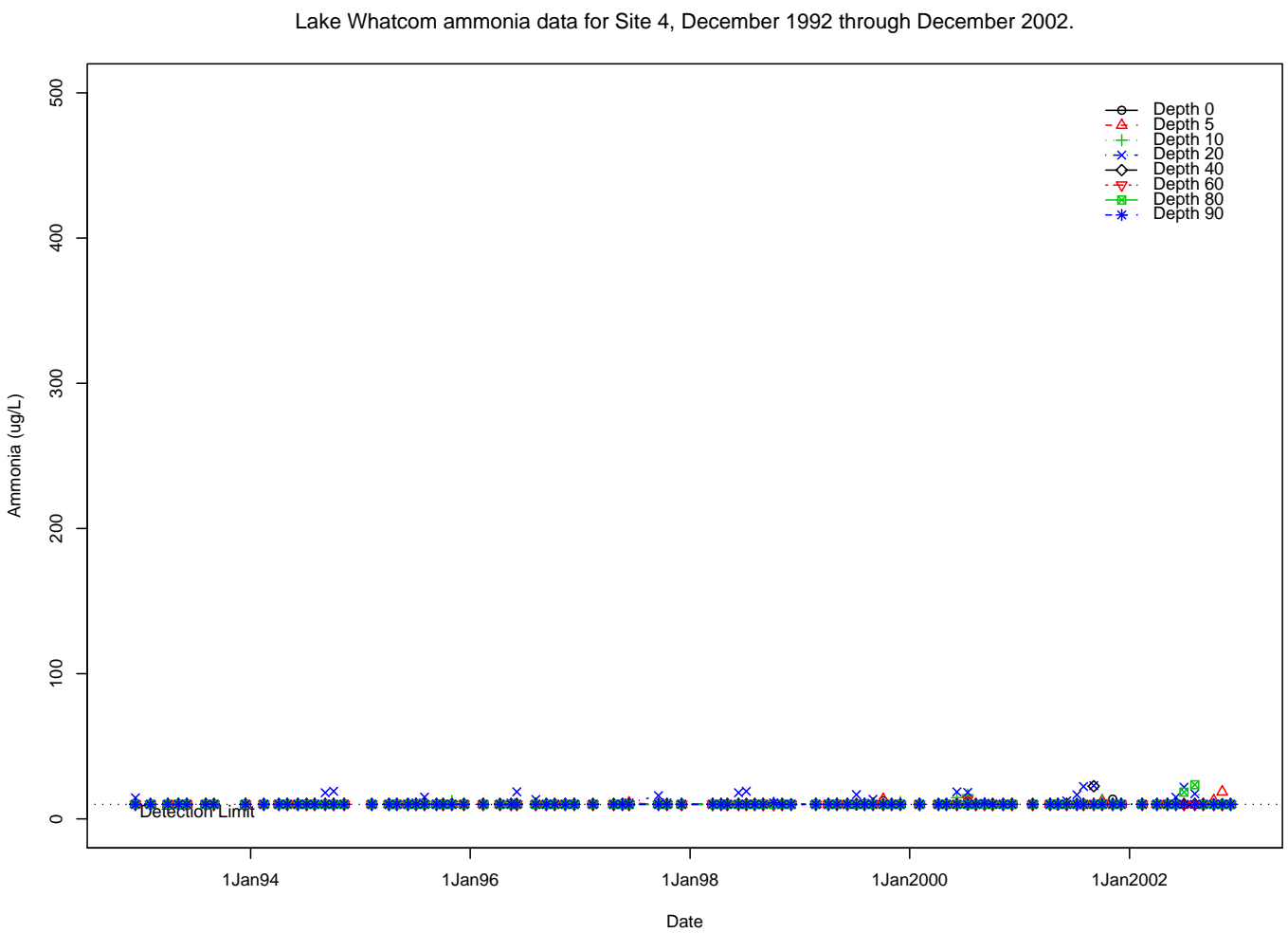


Figure 95: Lake Whatcom ammonia data for Site 4.

Lake Whatcom nitrate/nitrite data for Site 1, December 1992 through December 2002.

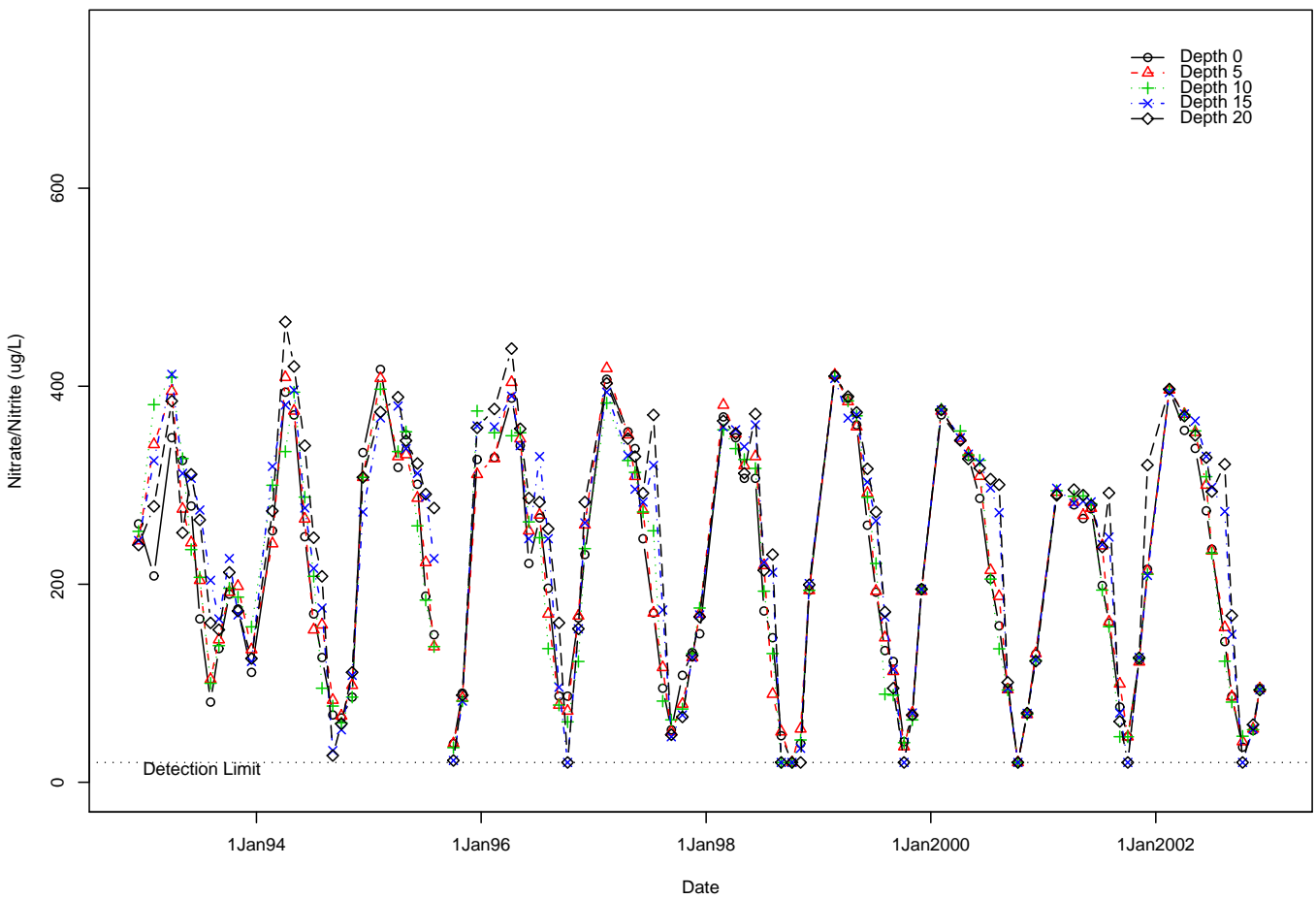


Figure 96: Lake Whatcom nitrate/nitrite data for Site 1.

Lake Whatcom nitrate/nitrite data for Site 2, December 1992 through December 2002.

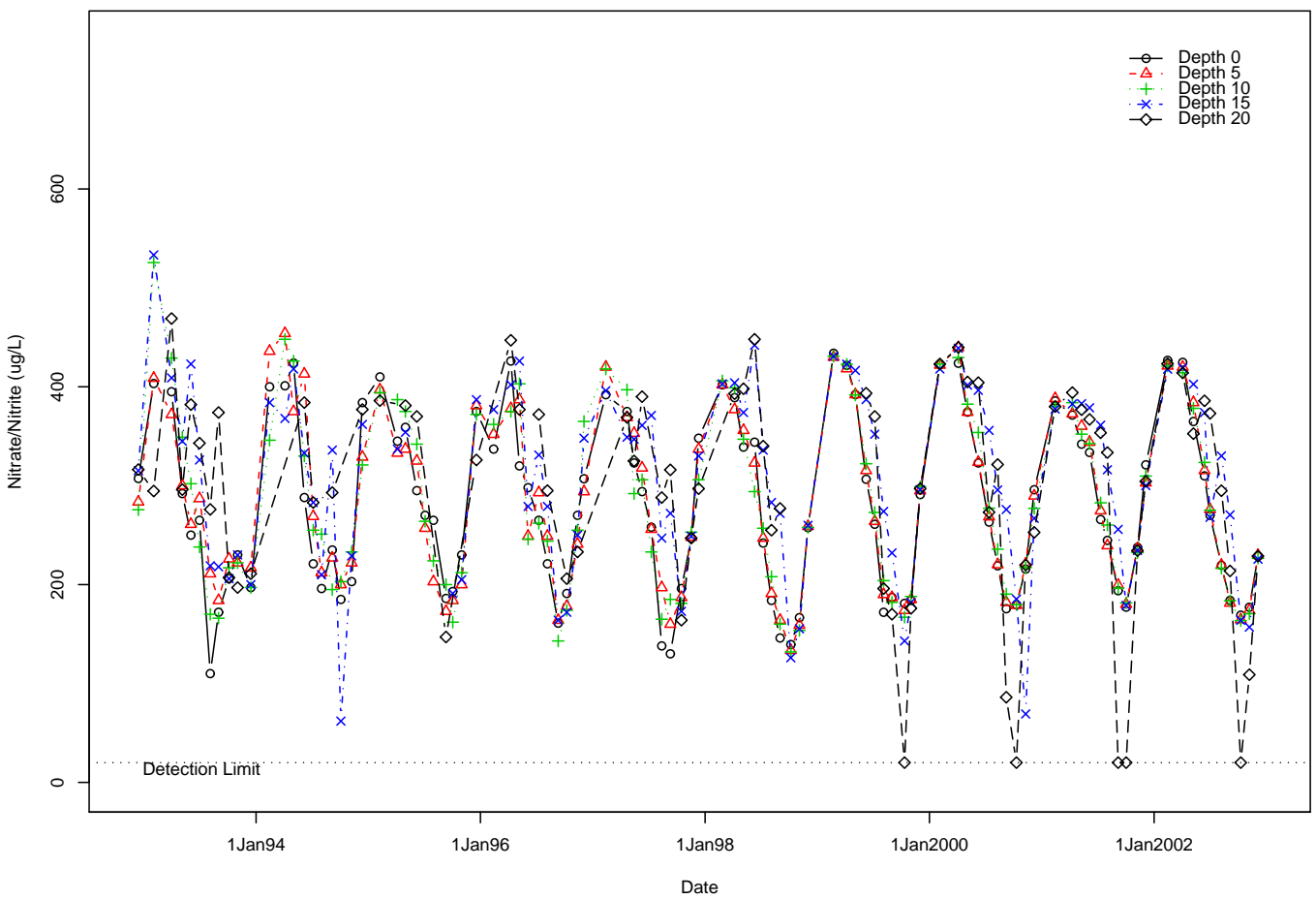


Figure 97: Lake Whatcom nitrate/nitrite data for Site 2.

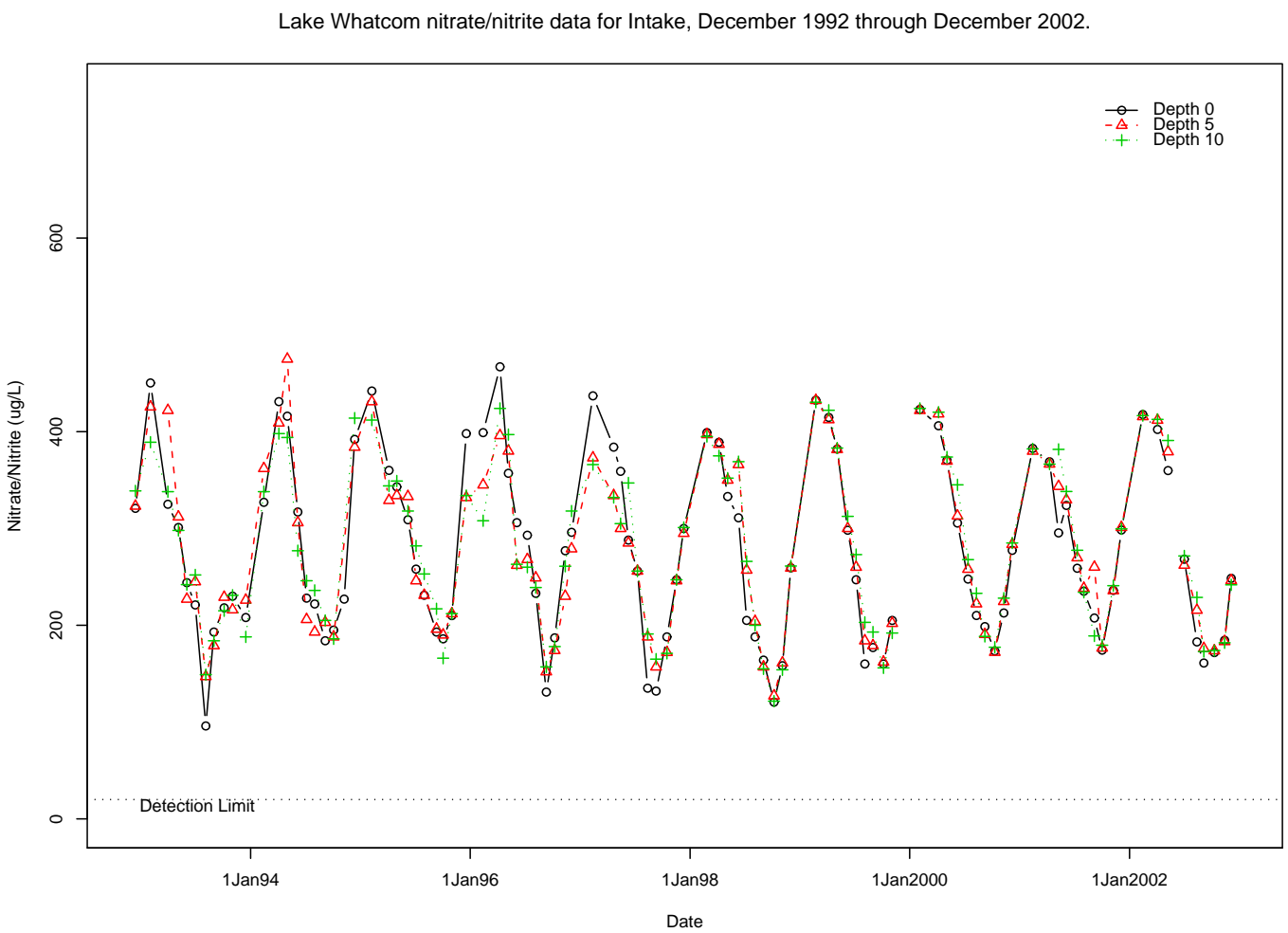


Figure 98: Lake Whatcom nitrate/nitrite data for the Intake.

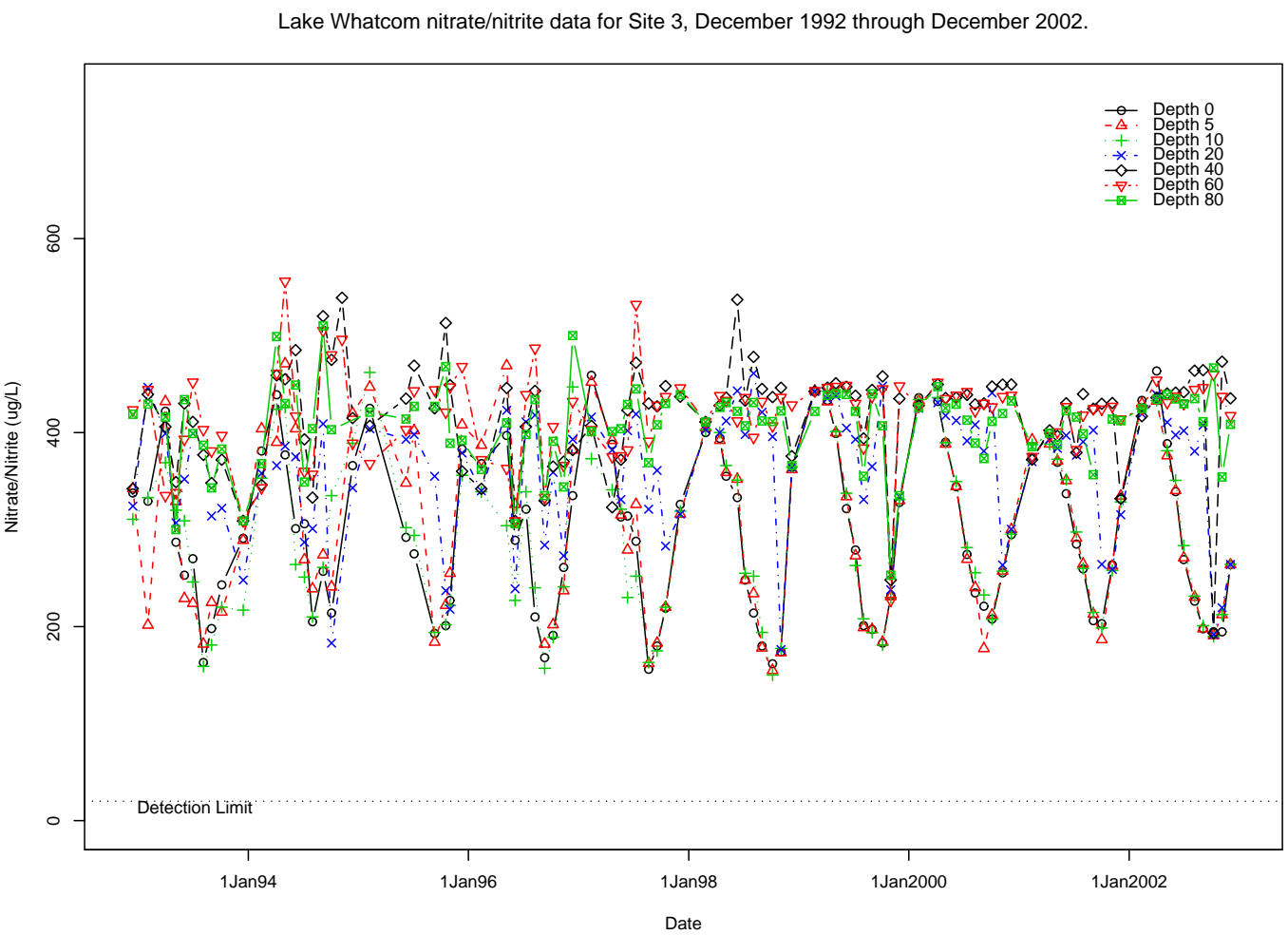


Figure 99: Lake Whatcom nitrate/nitrite data for Site 3.



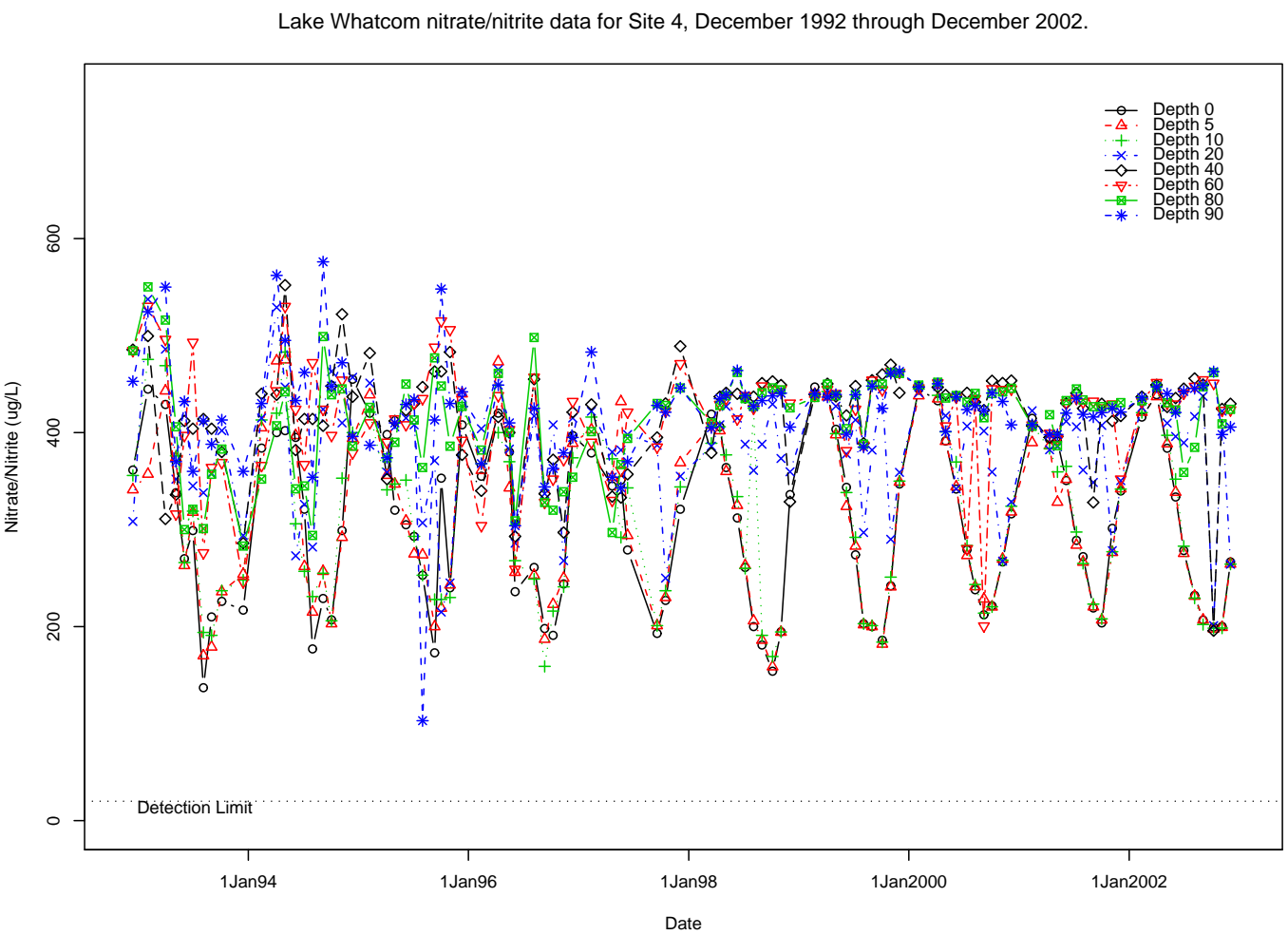


Figure 100: Lake Whatcom nitrate/nitrite data for Site 4.

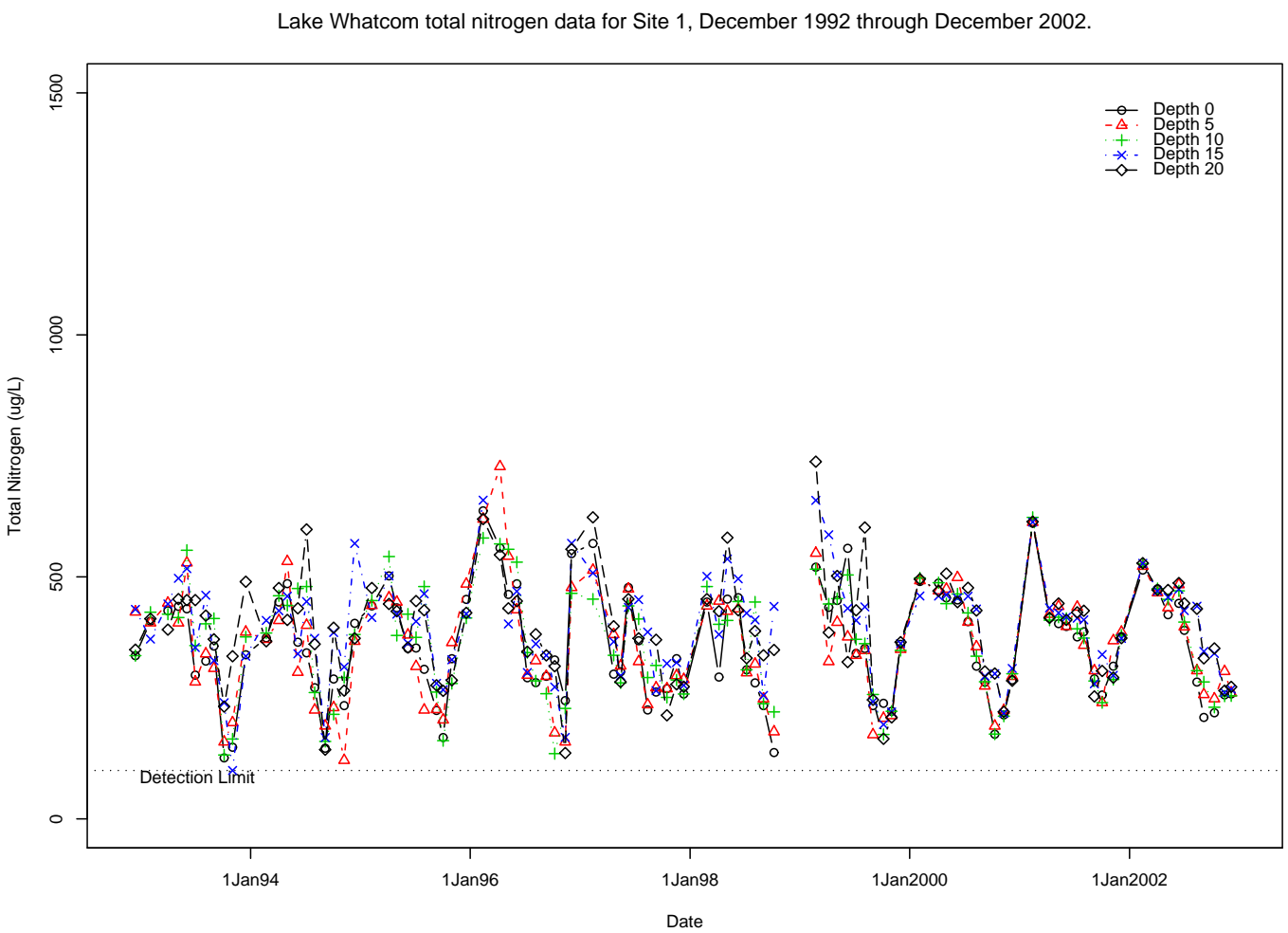


Figure 101: Lake Whatcom total nitrogen data for Site 1.

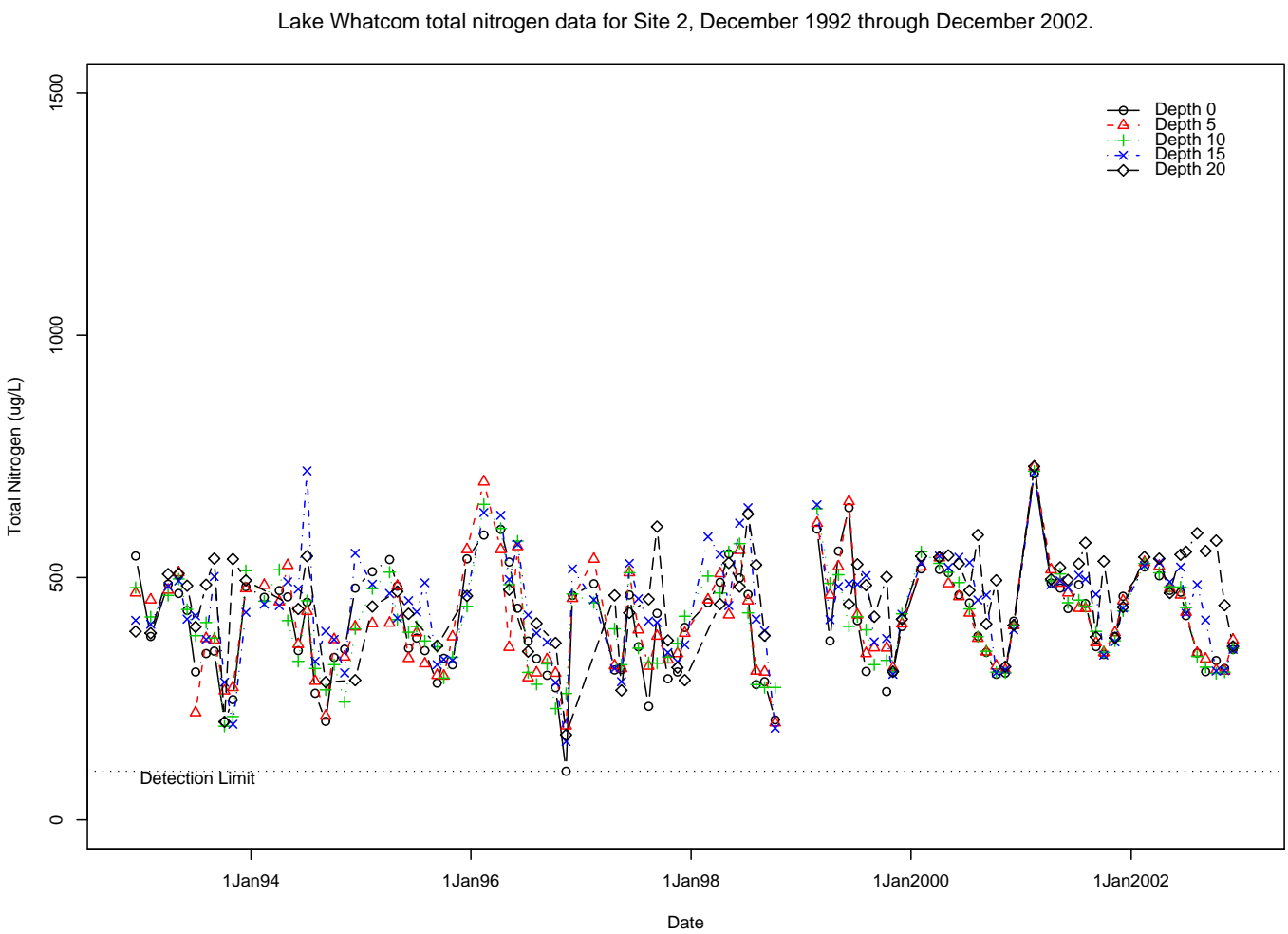


Figure 102: Lake Whatcom total nitrogen data for Site 2.

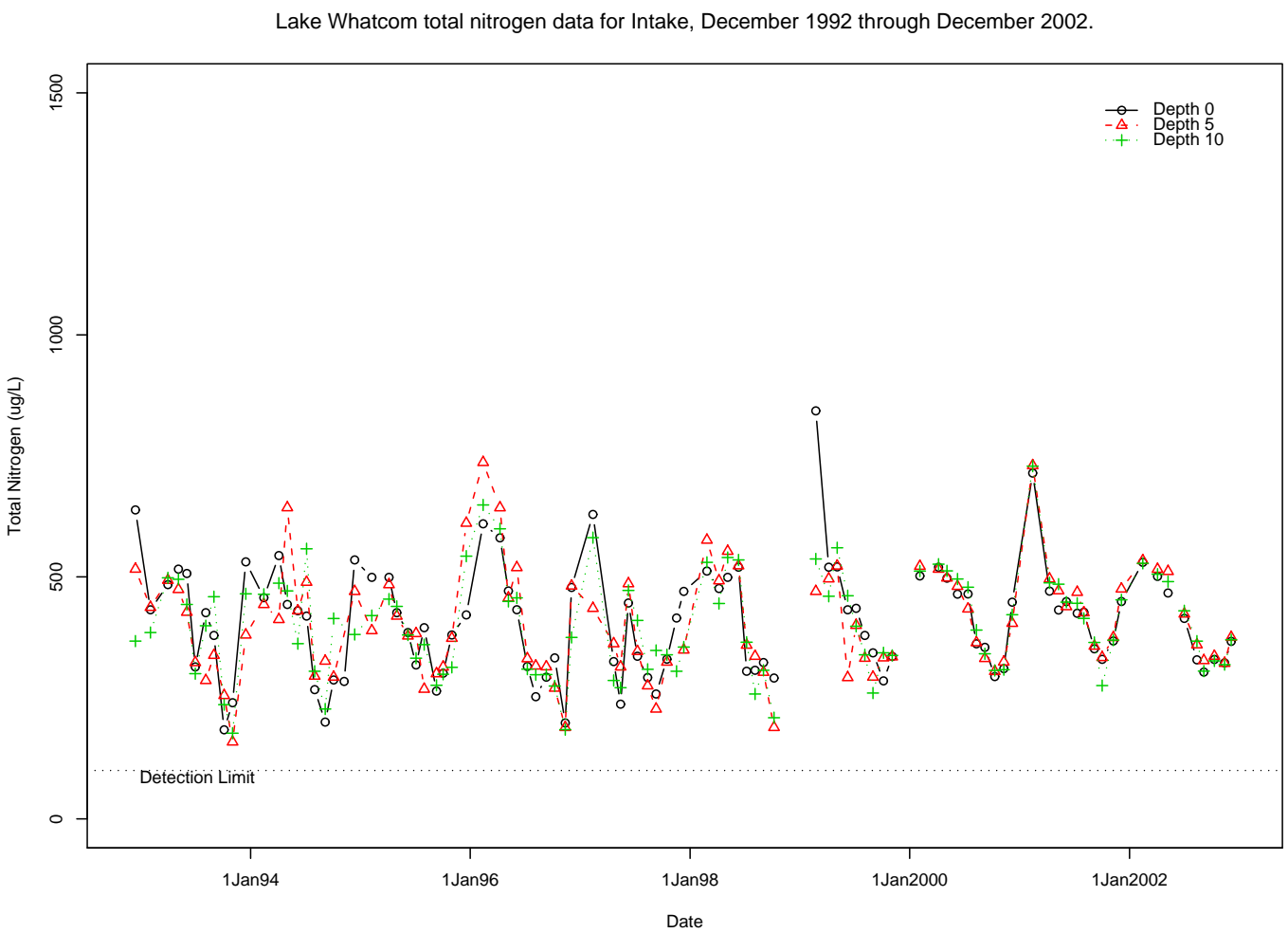


Figure 103: Lake Whatcom total nitrogen data for the Intake.

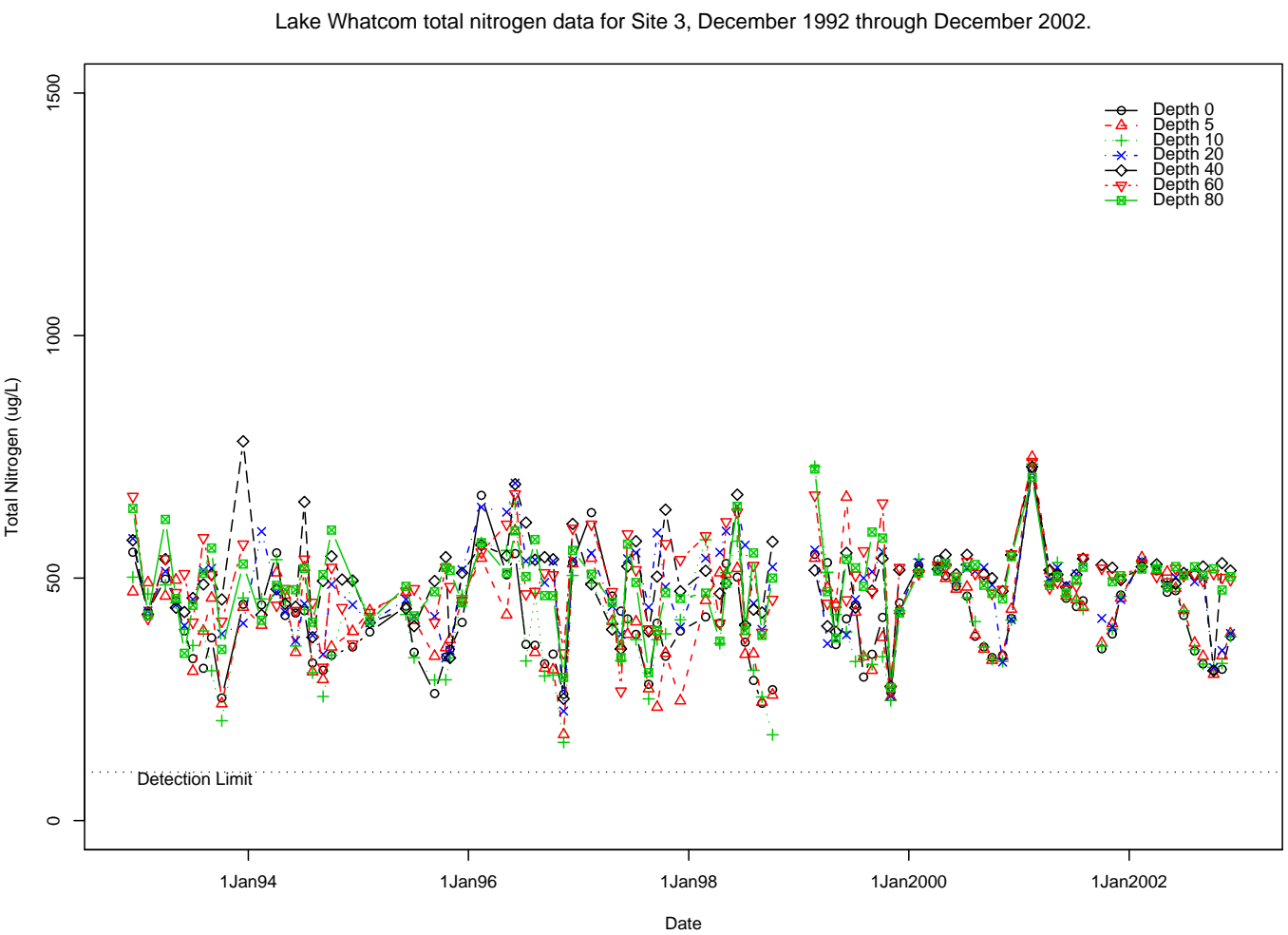


Figure 104: Lake Whatcom total nitrogen data for Site 3.

Lake Whatcom total nitrogen data for Site 4, December 1992 through December 2002.

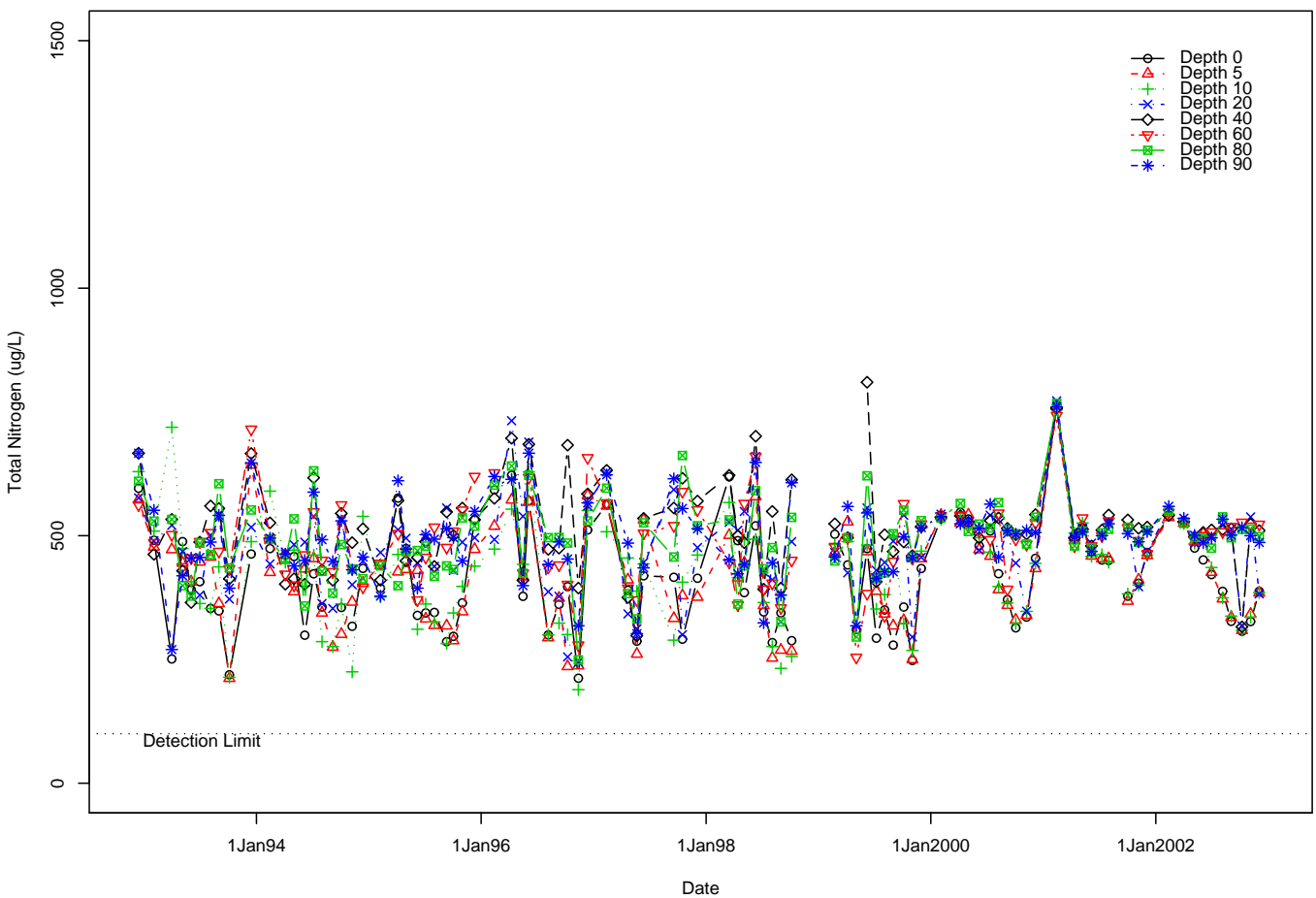


Figure 105: Lake Whatcom total nitrogen data for Site 4.

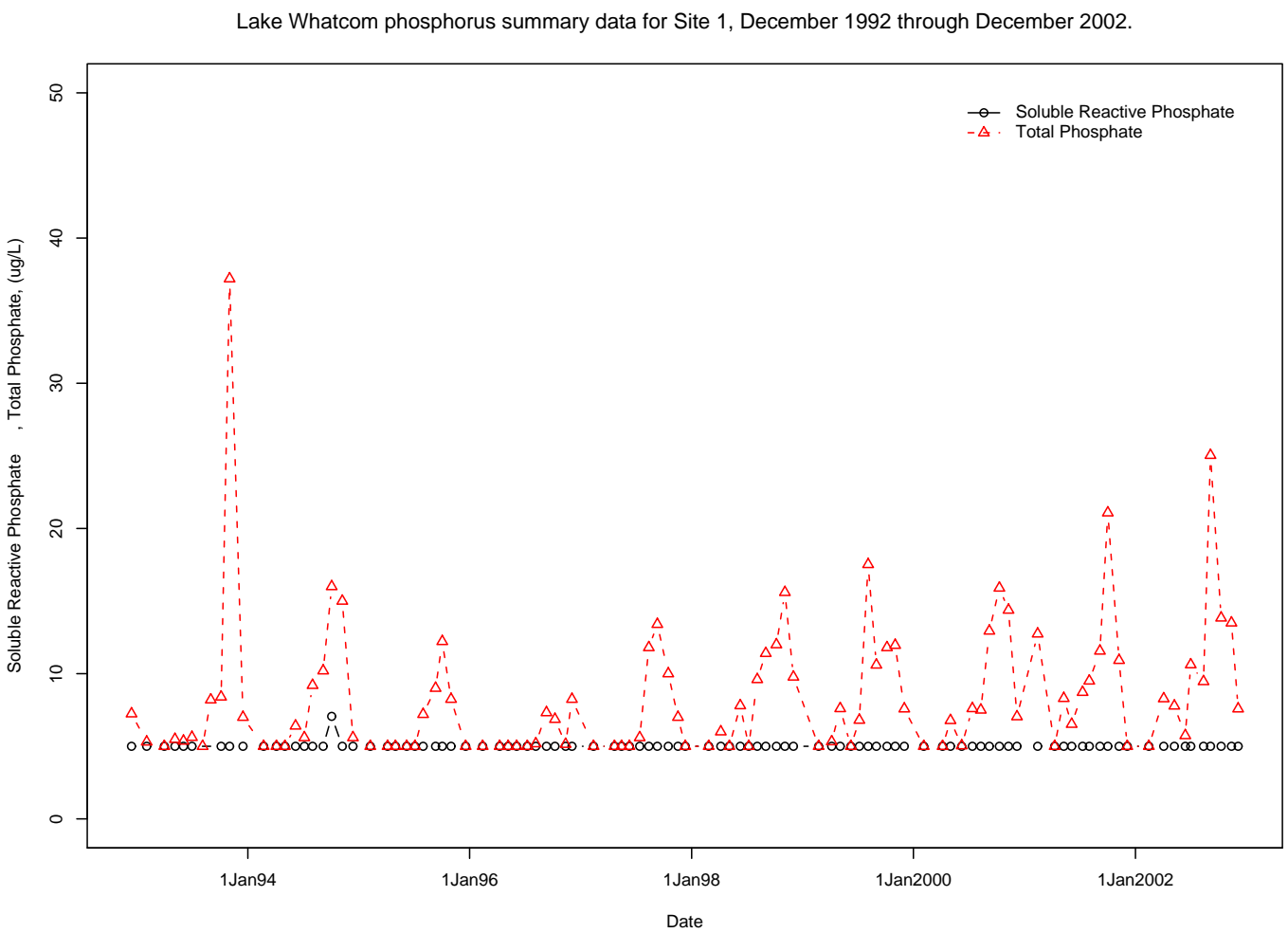


Figure 106: Lake Whatcom phosphorus summary data for Site 1.

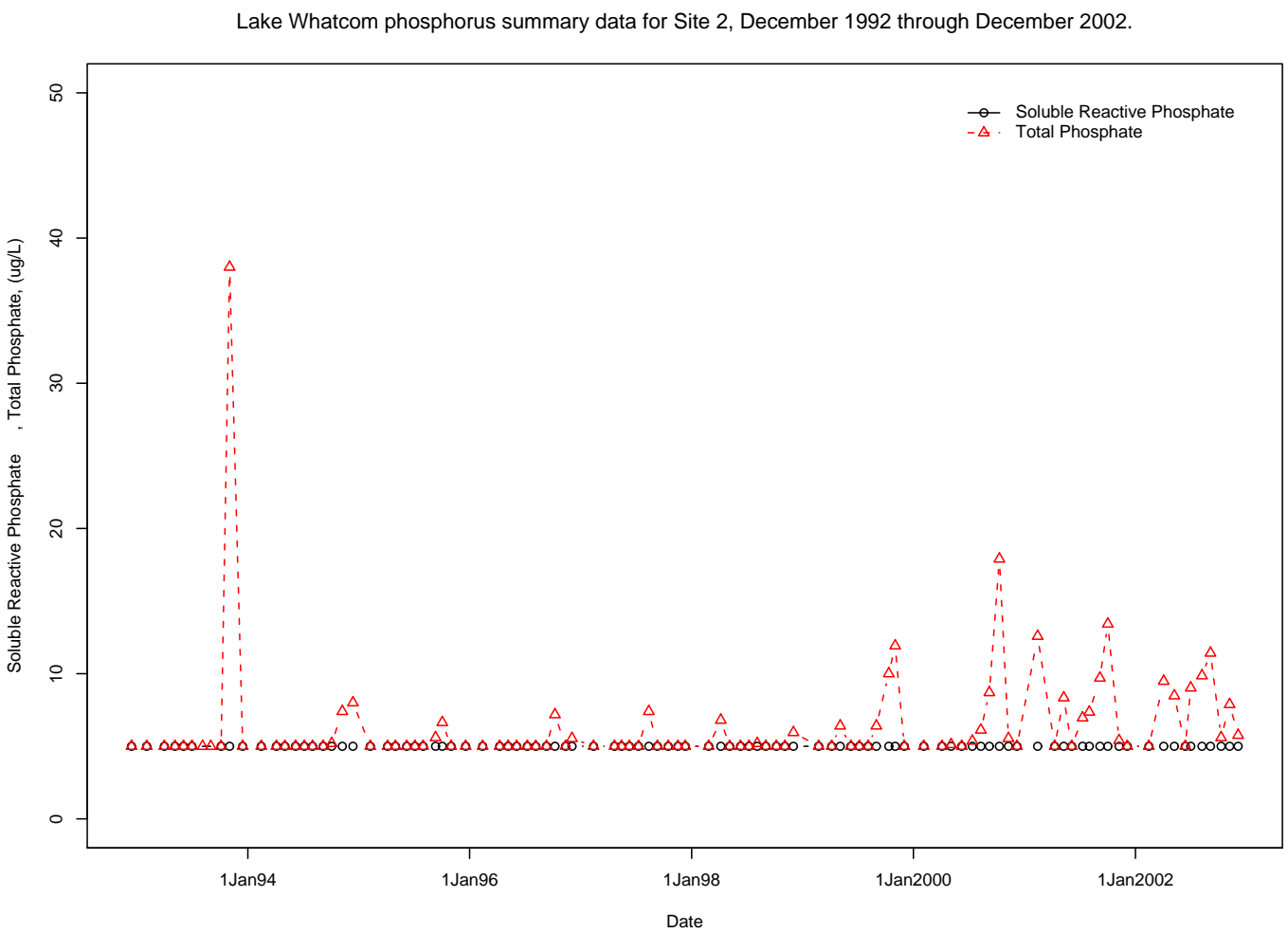


Figure 107: Lake Whatcom phosphorus summary data for Site 2.



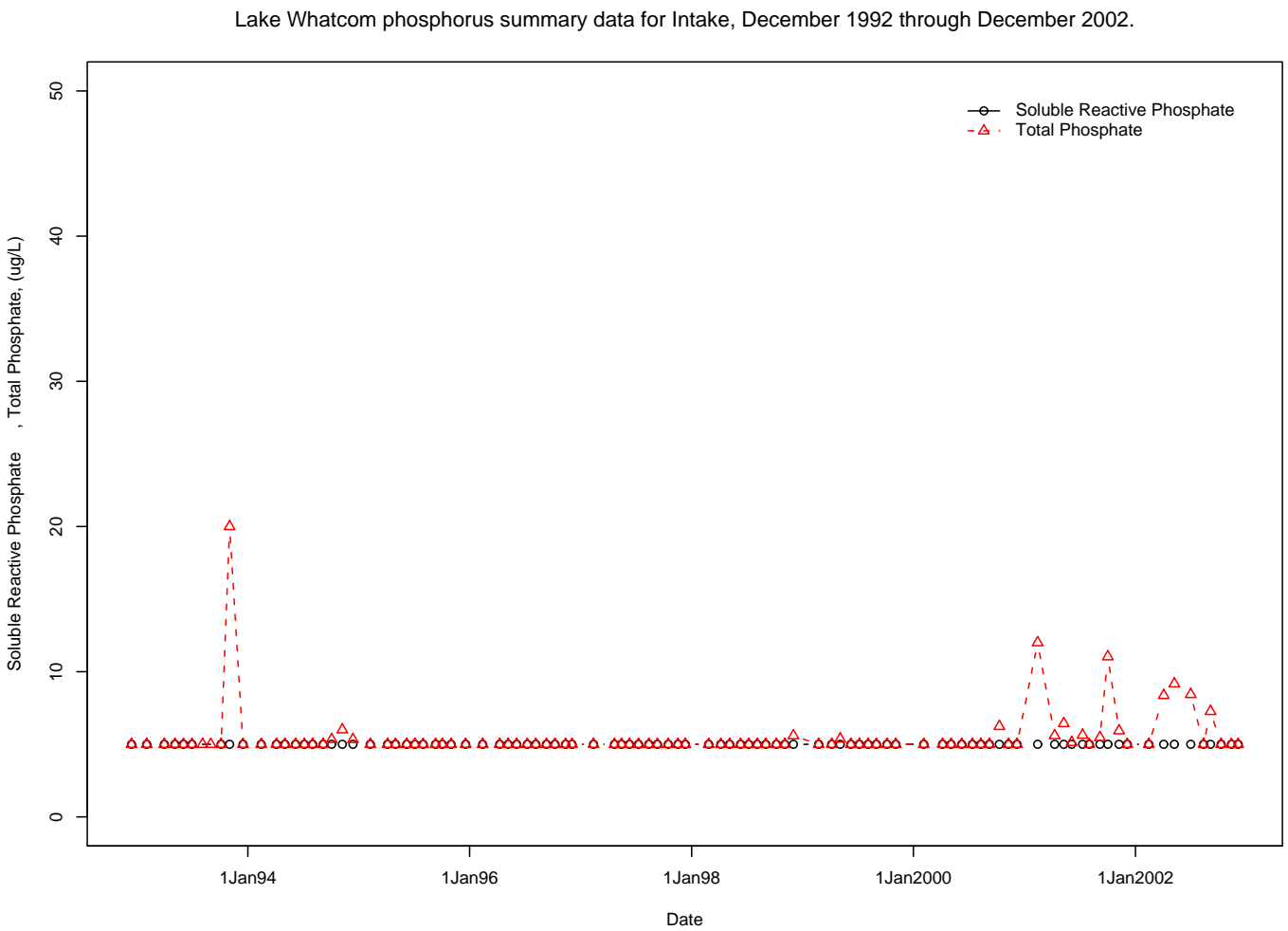


Figure 108: Lake Whatcom phosphorus summary data for the Intake.

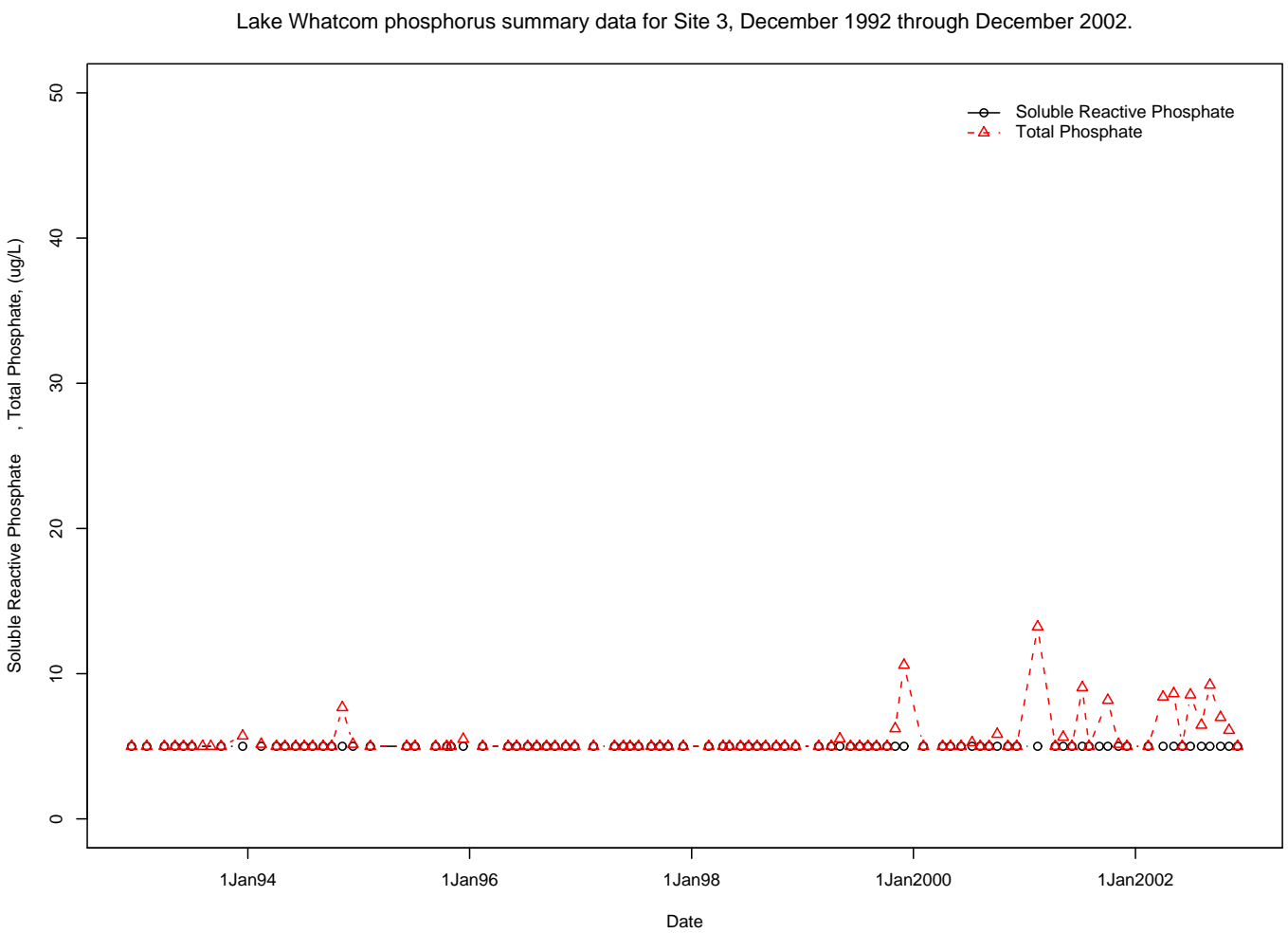


Figure 109: Lake Whatcom phosphorus summary data for Site 3.

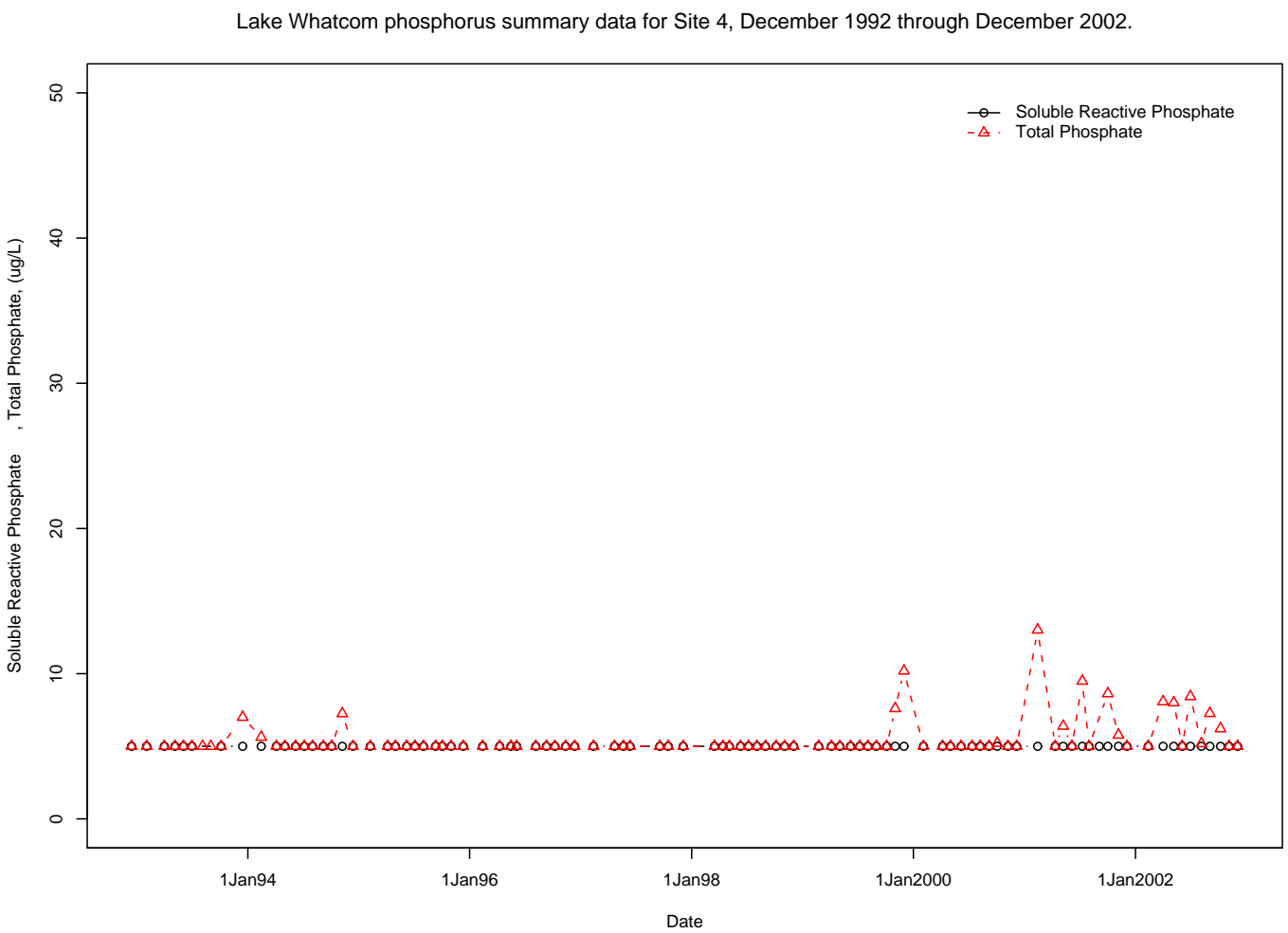


Figure 110: Lake Whatcom phosphorus summary data for Site 4.

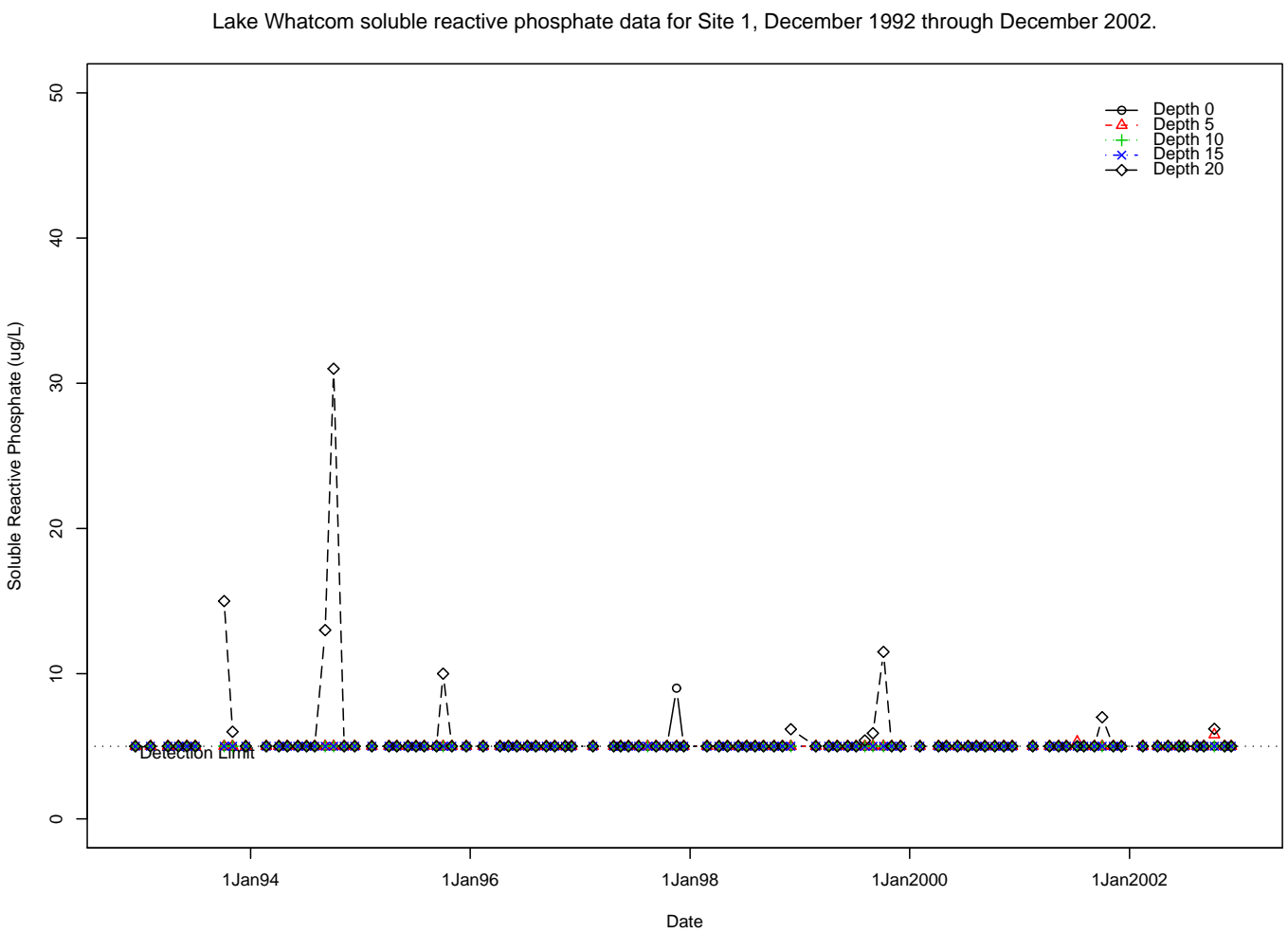


Figure 111: Lake Whatcom soluble phosphate data for Site 1.

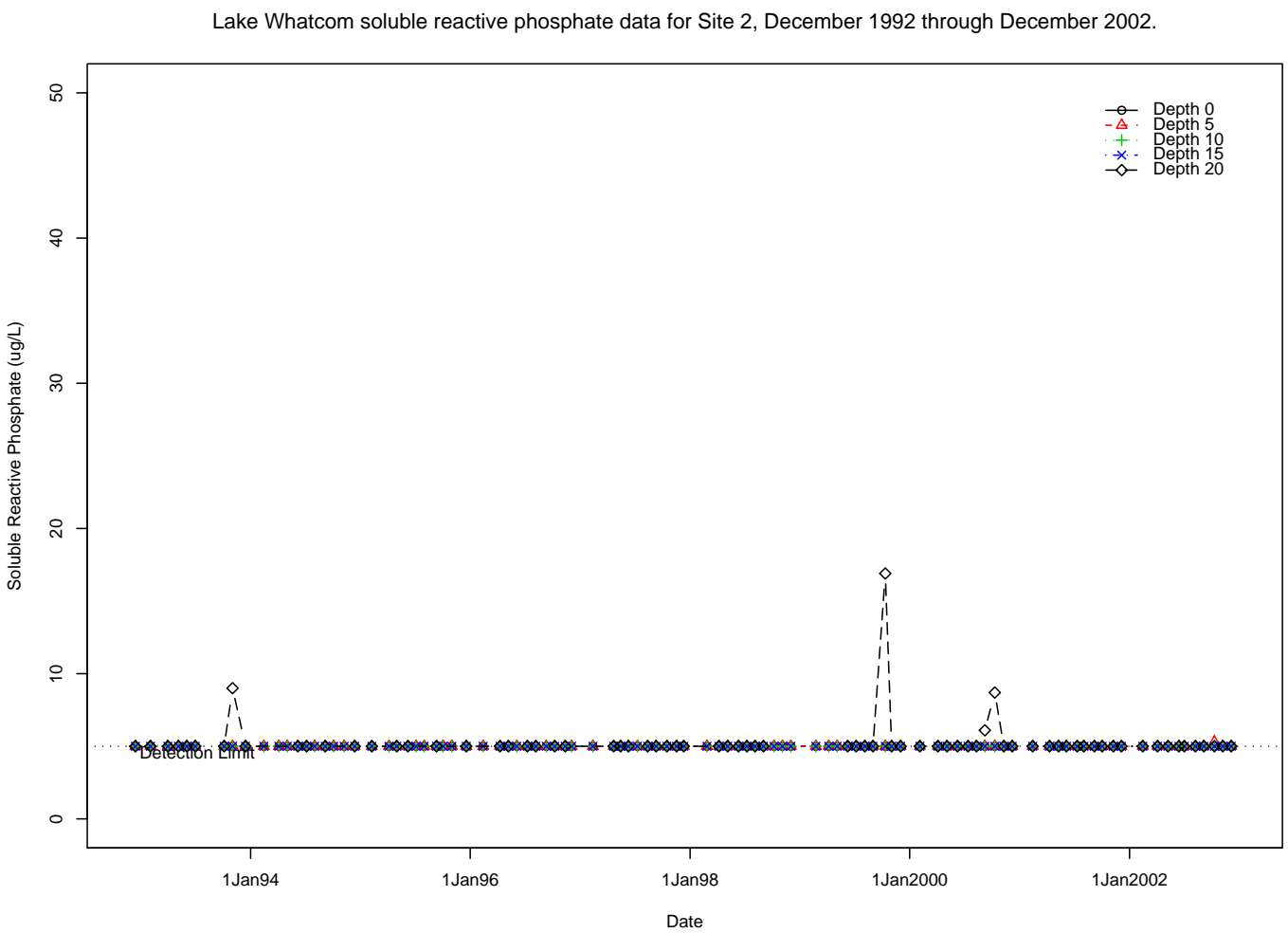


Figure 112: Lake Whatcom soluble phosphate data for Site 2.

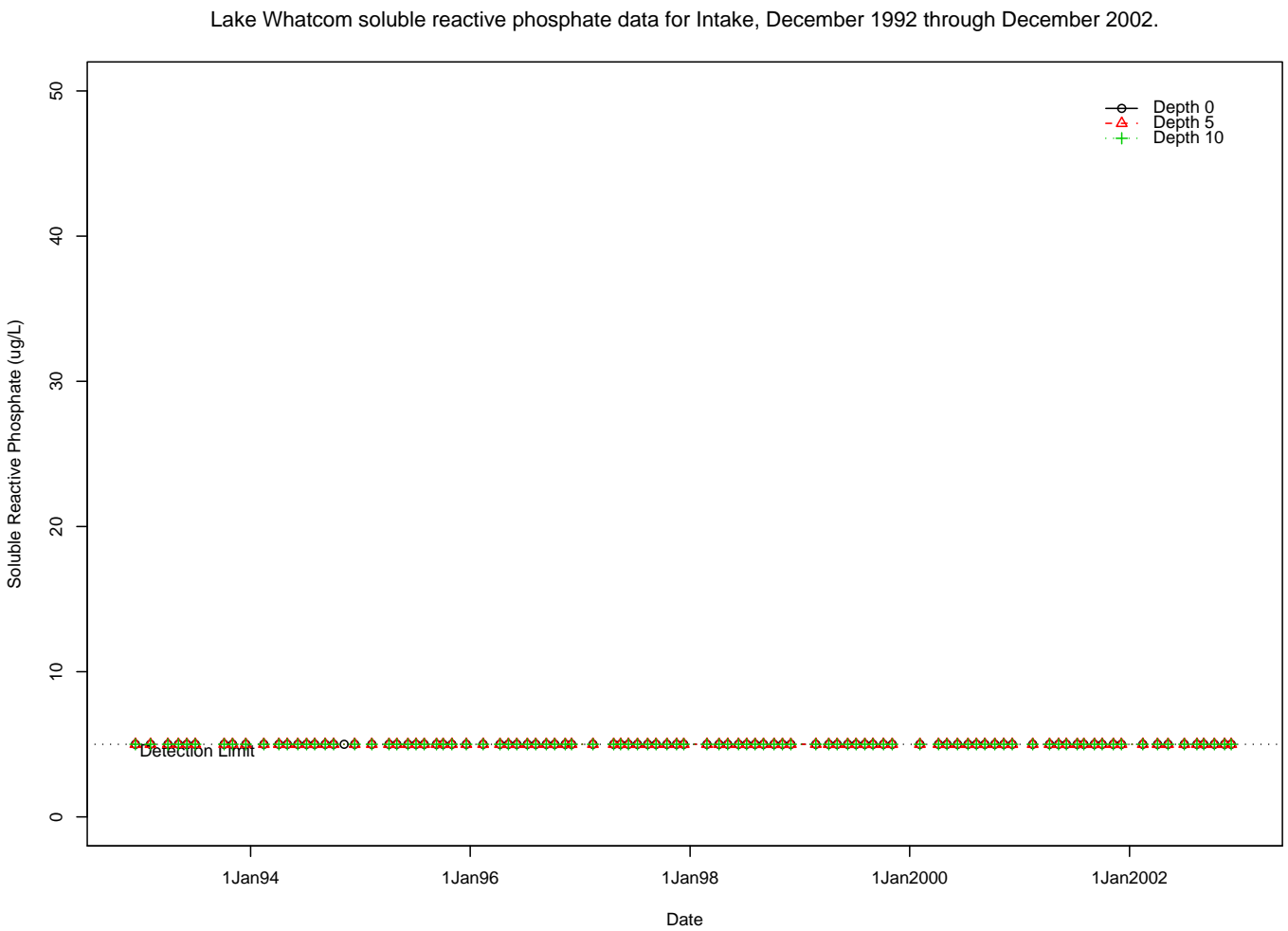


Figure 113: Lake Whatcom soluble phosphate data for the Intake.

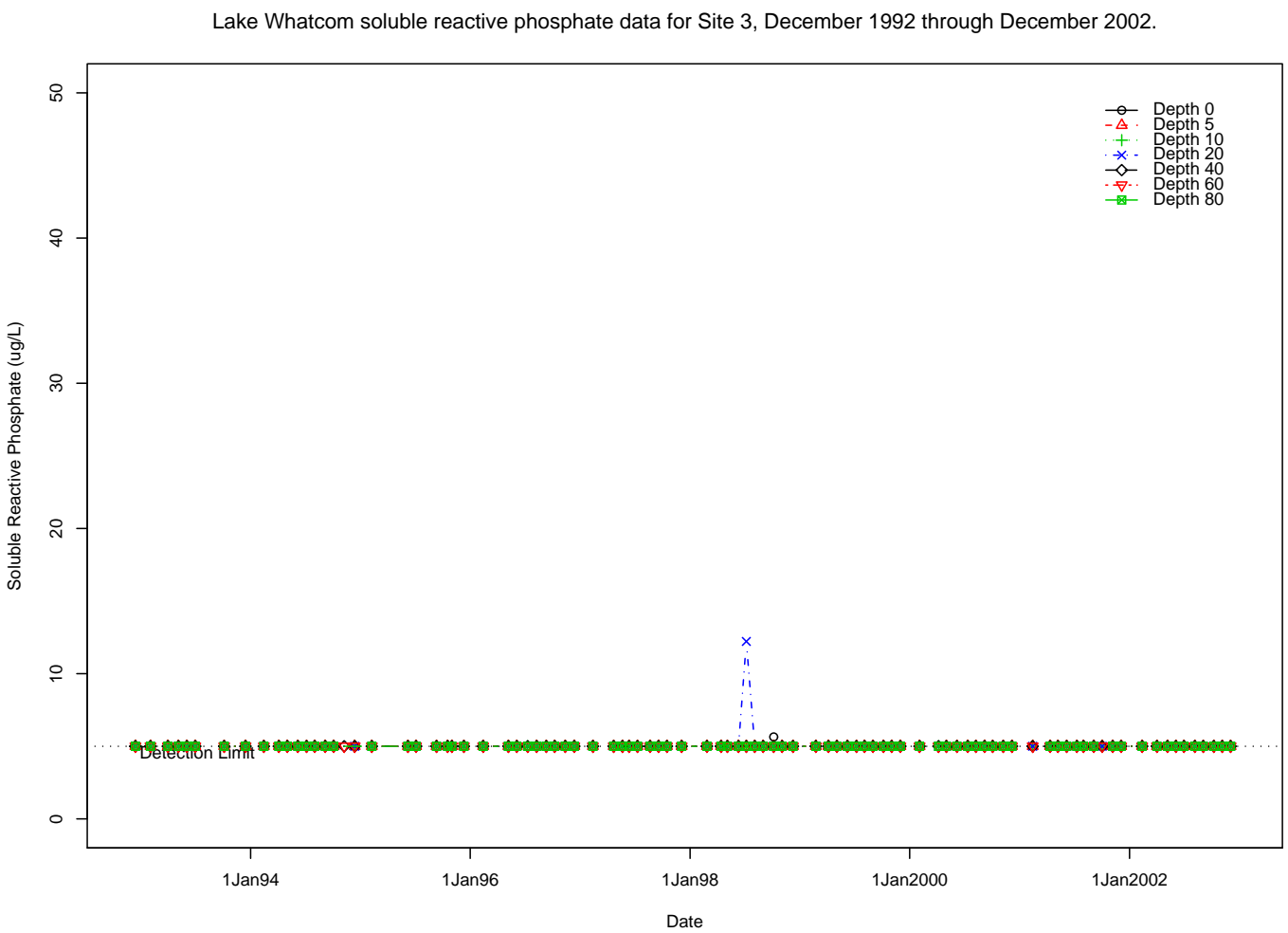


Figure 114: Lake Whatcom soluble phosphate data for Site 3.

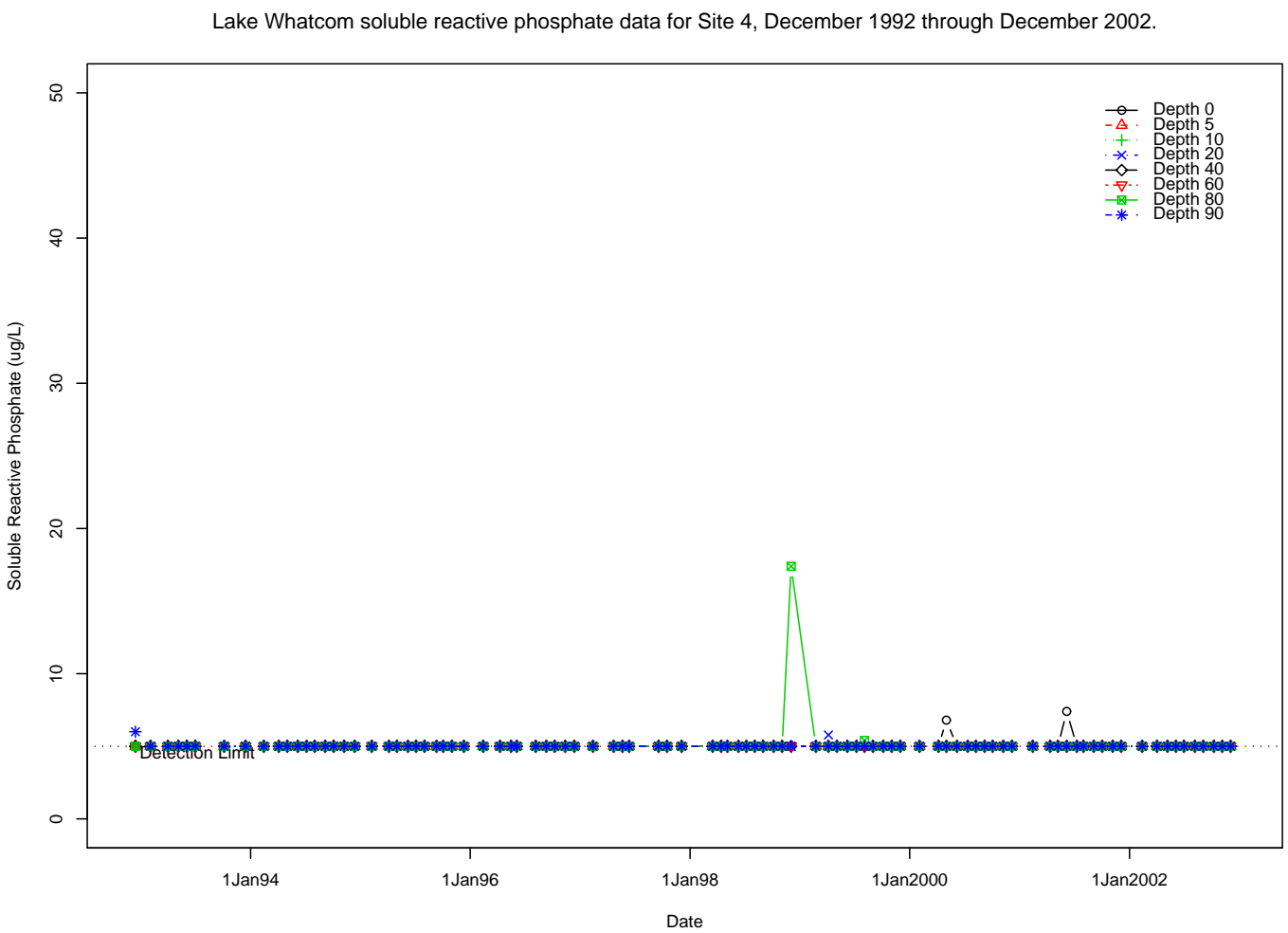


Figure 115: Lake Whatcom soluble phosphate data for Site 4.



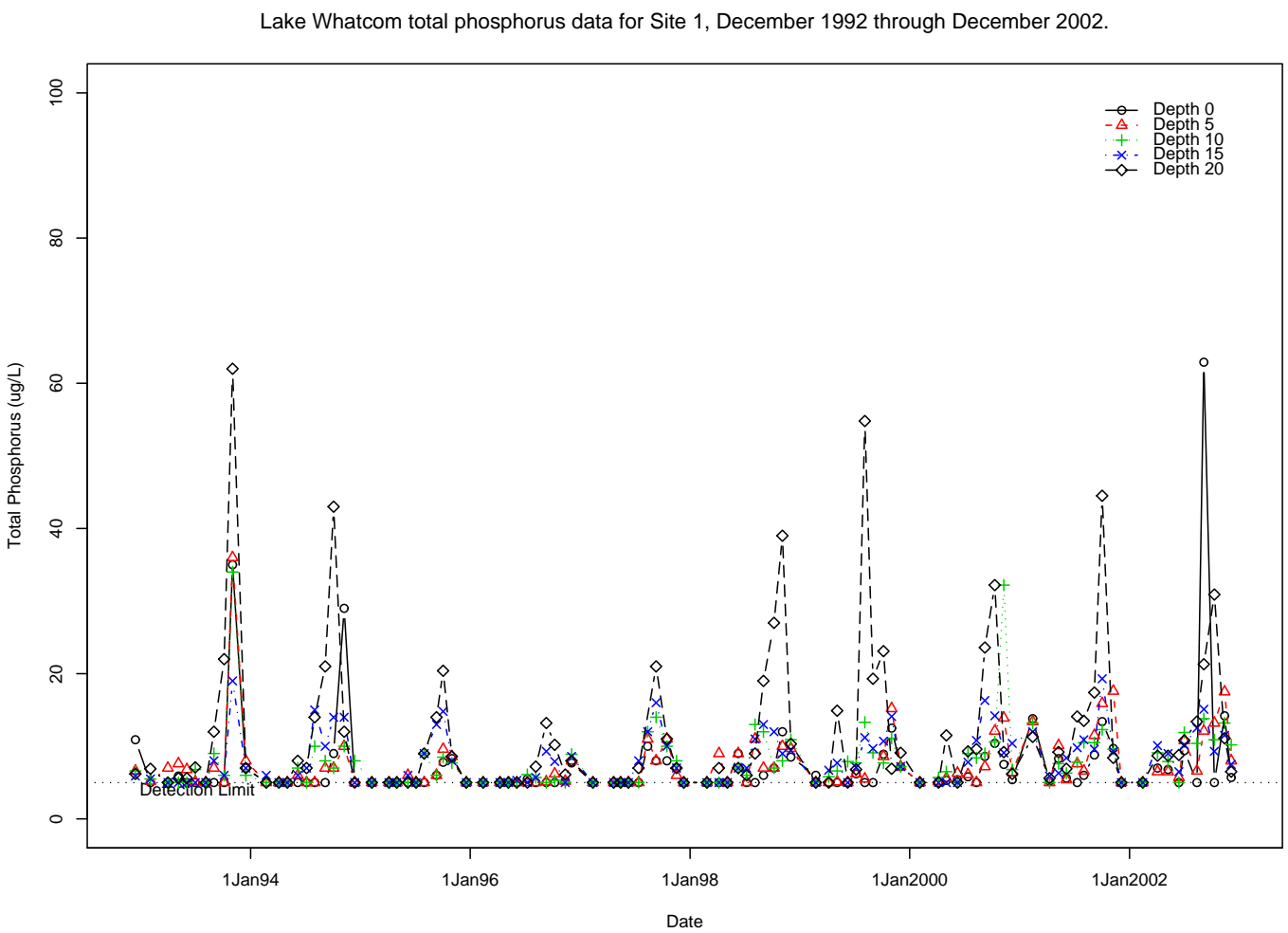


Figure 116: Lake Whatcom total phosphorus data for Site 1.

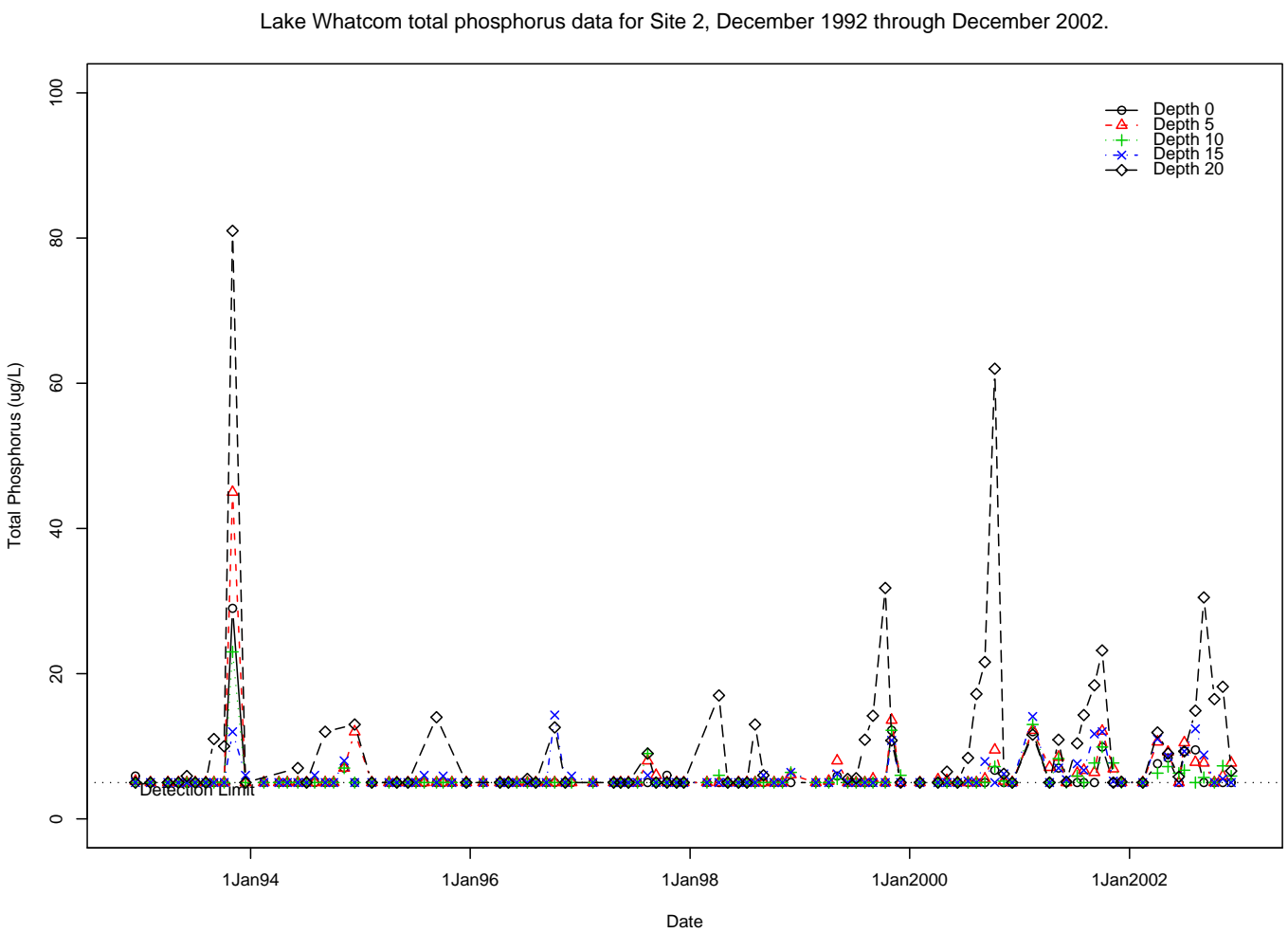


Figure 117: Lake Whatcom total phosphorus data for Site 2.

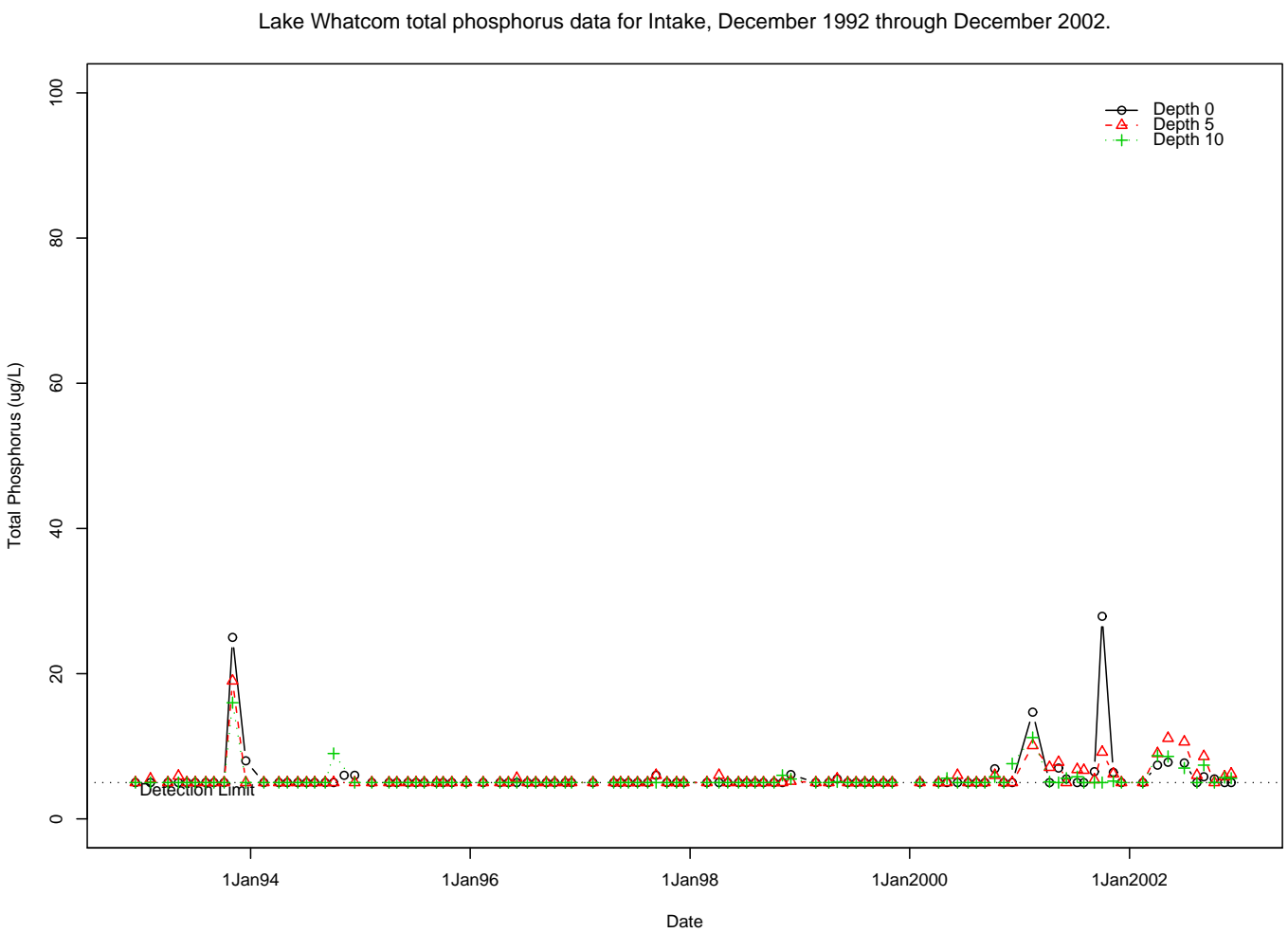


Figure 118: Lake Whatcom total phosphorus data for the Intake.

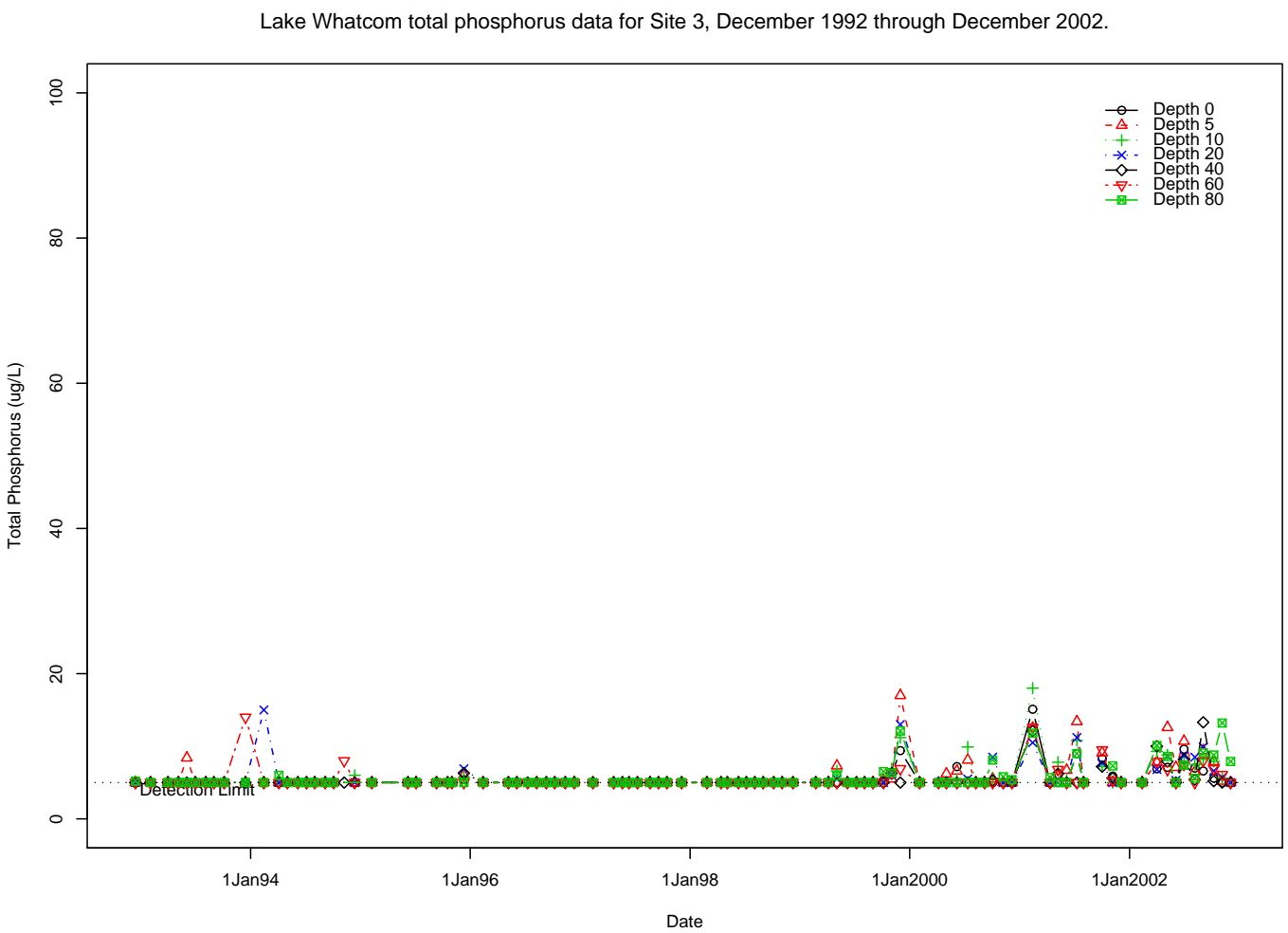


Figure 119: Lake Whatcom total phosphorus data for Site 3.

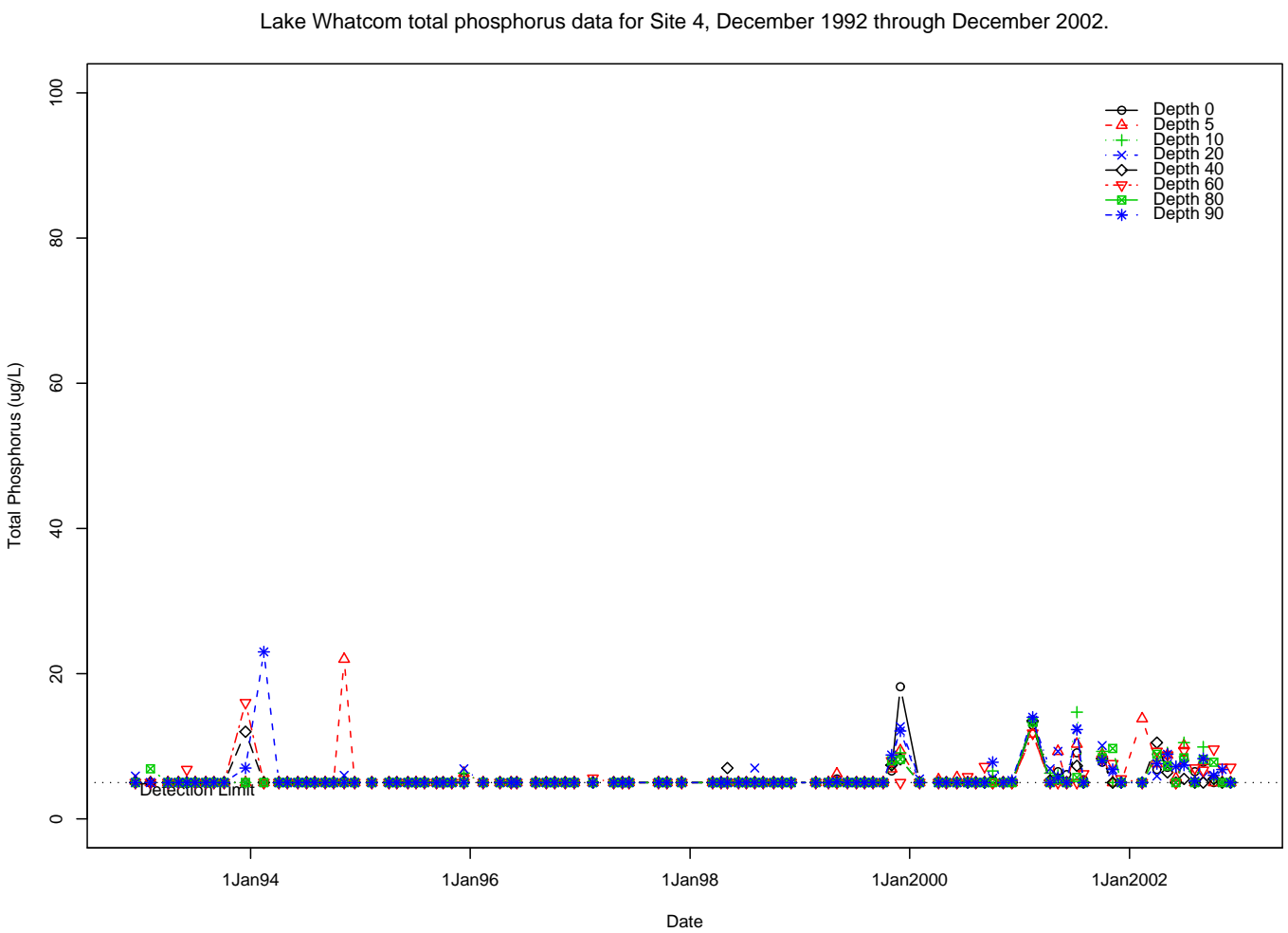


Figure 120: Lake Whatcom total phosphorus data for Site 4.

Lake Whatcom chlorophyll a data for Site 1, December 1992 through December 2002.

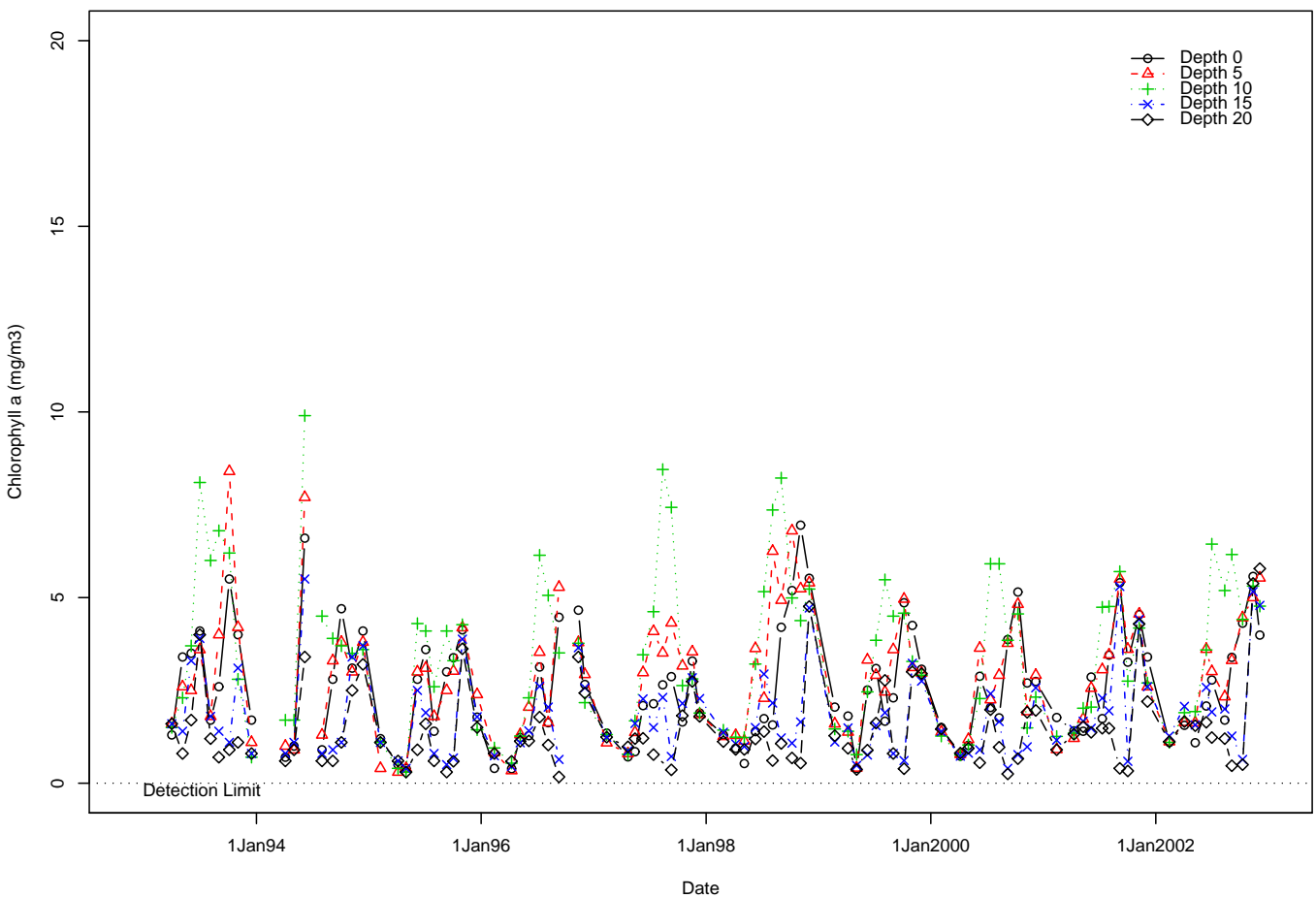


Figure 121: Lake Whatcom chlorophyll a data for Site 1.

Lake Whatcom chlorophyll a data for Site 2, December 1992 through December 2002.

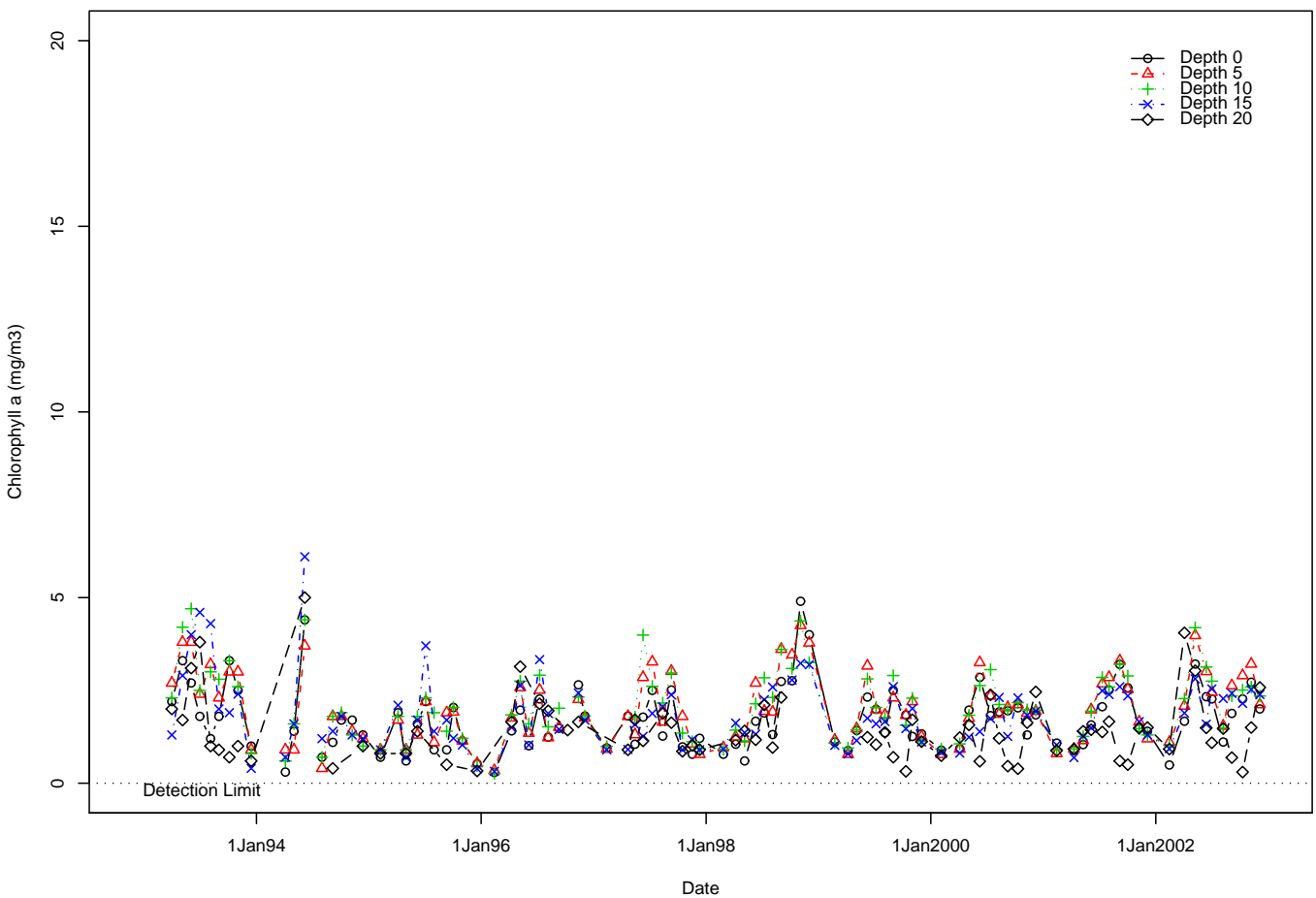


Figure 122: Lake Whatcom chlorophyll a data for Site 2.

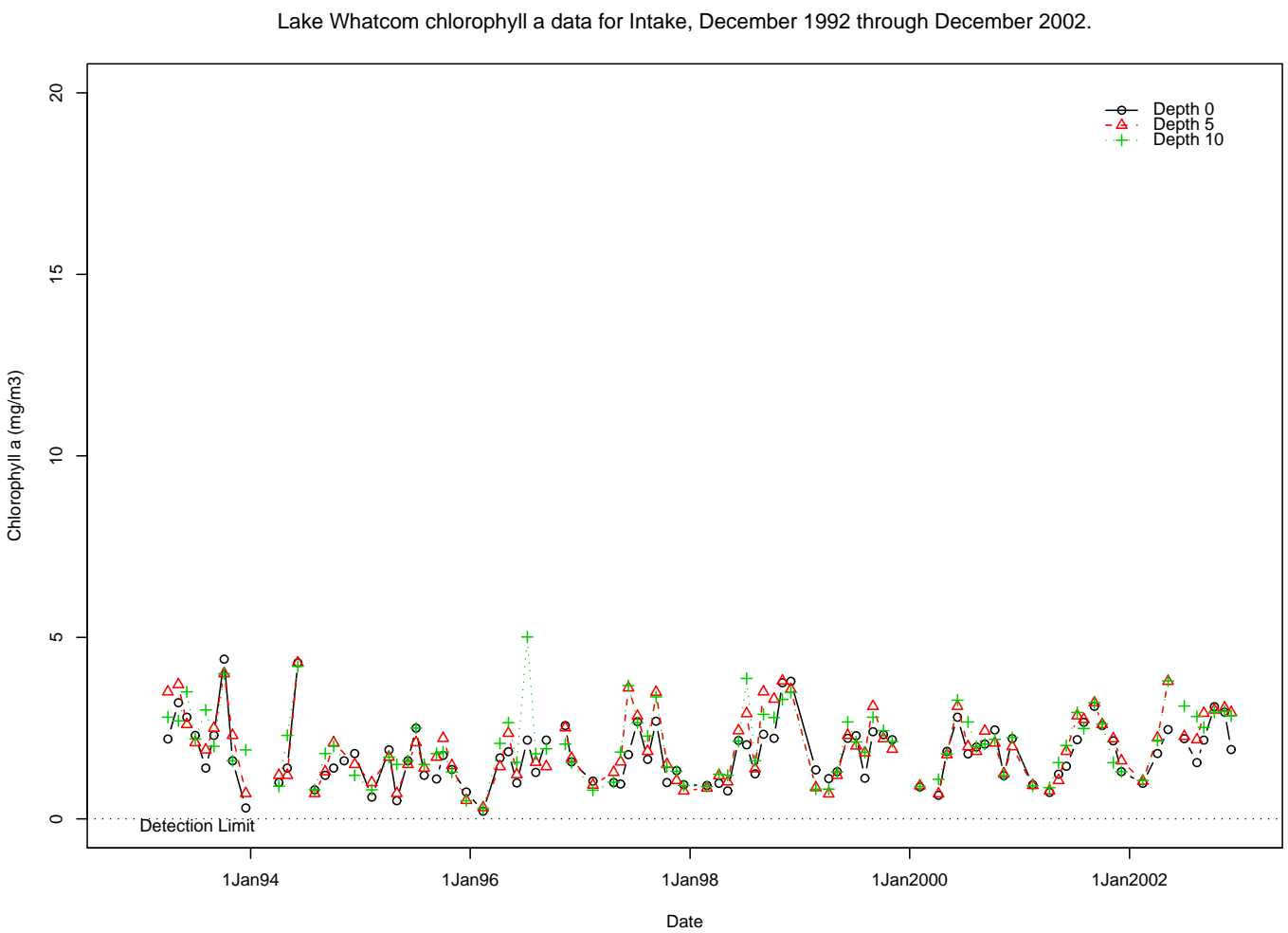


Figure 123: Lake Whatcom chlorophyll data for the Intake.



Lake Whatcom chlorophyll a data for Site 3, December 1992 through December 2002.

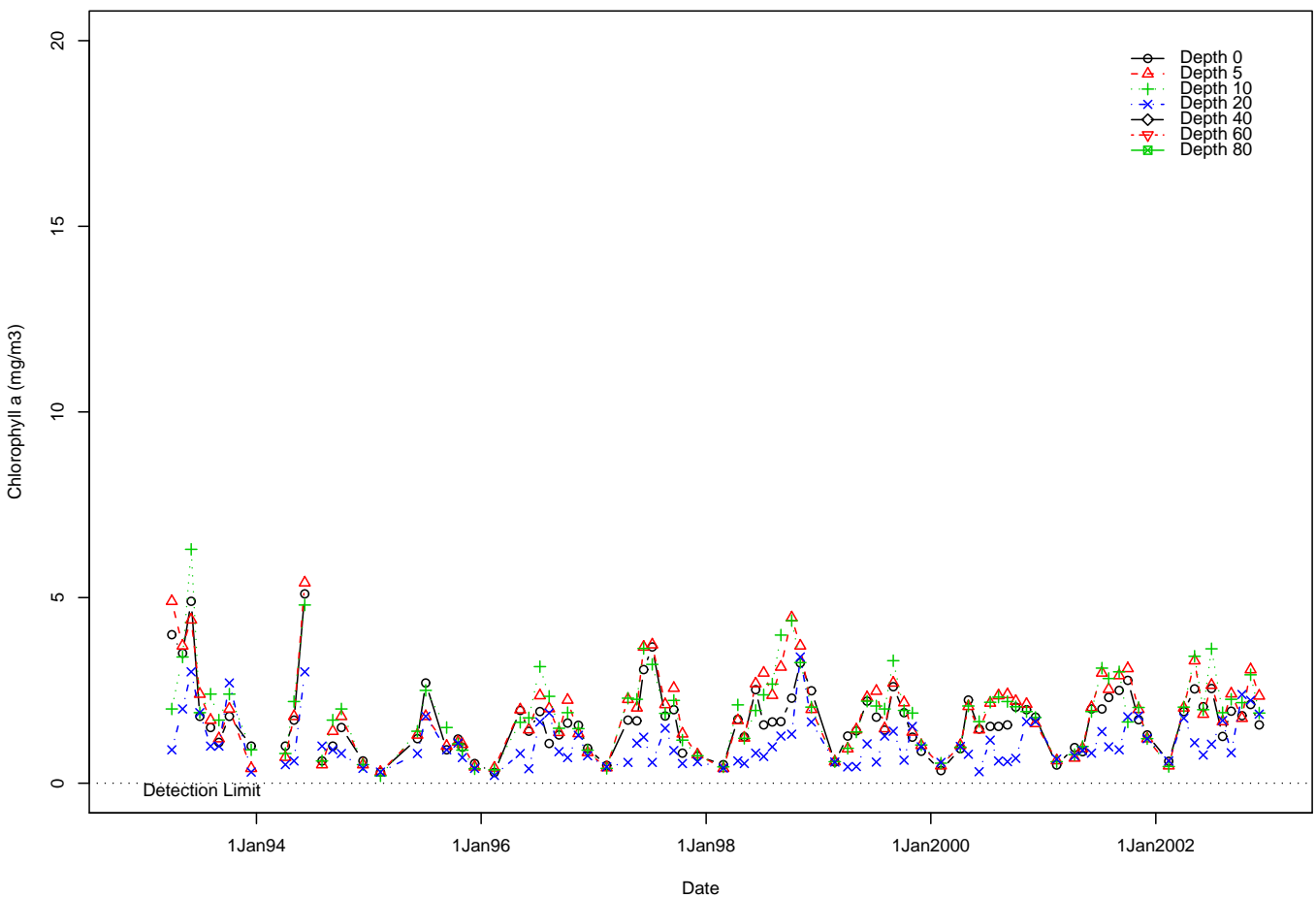


Figure 124: Lake Whatcom chlorophyll a data for Site 3.

Lake Whatcom chlorophyll a data for Site 4, December 1992 through December 2002.

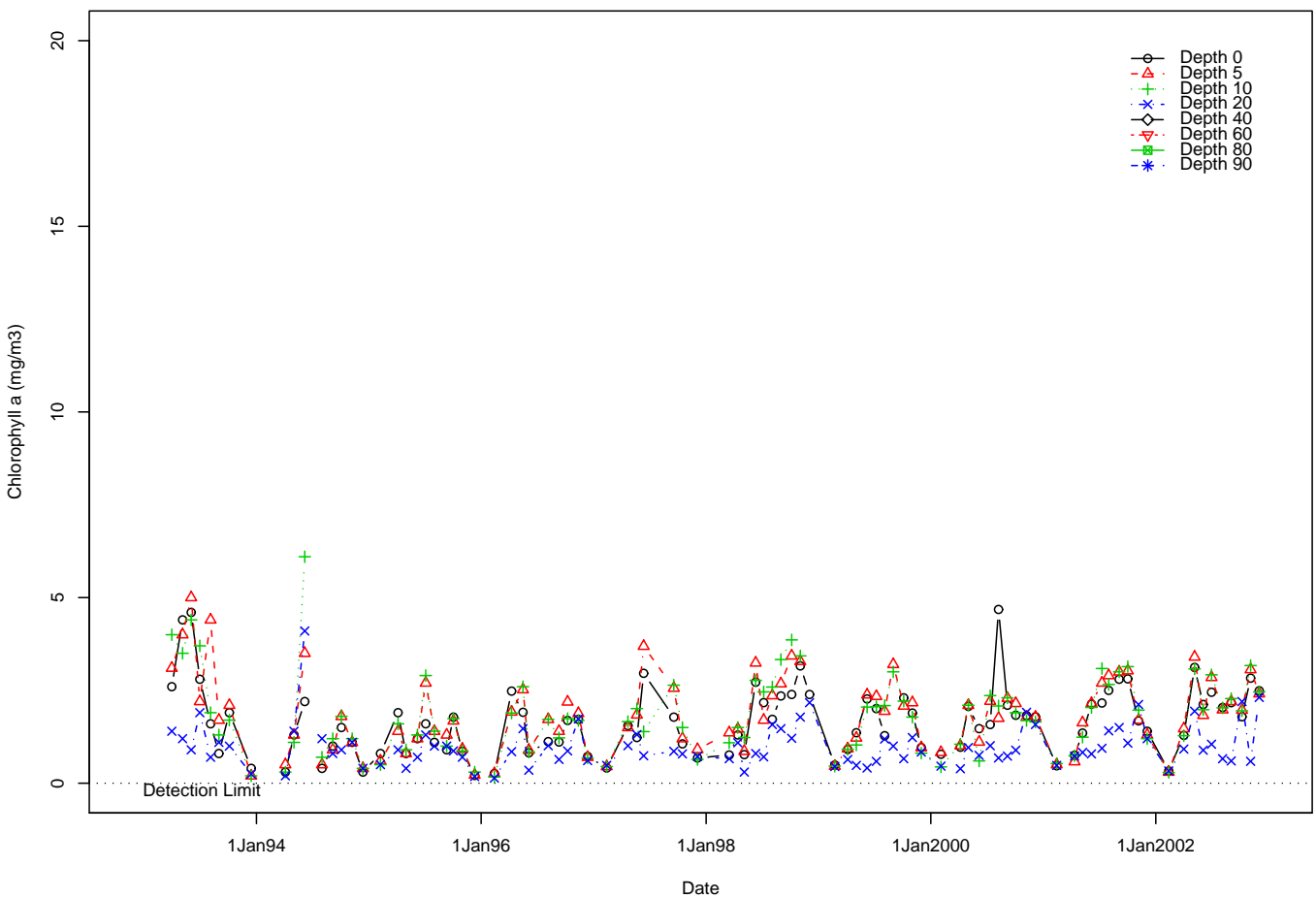


Figure 125: Lake Whatcom chlorophyll a data for Site 4.

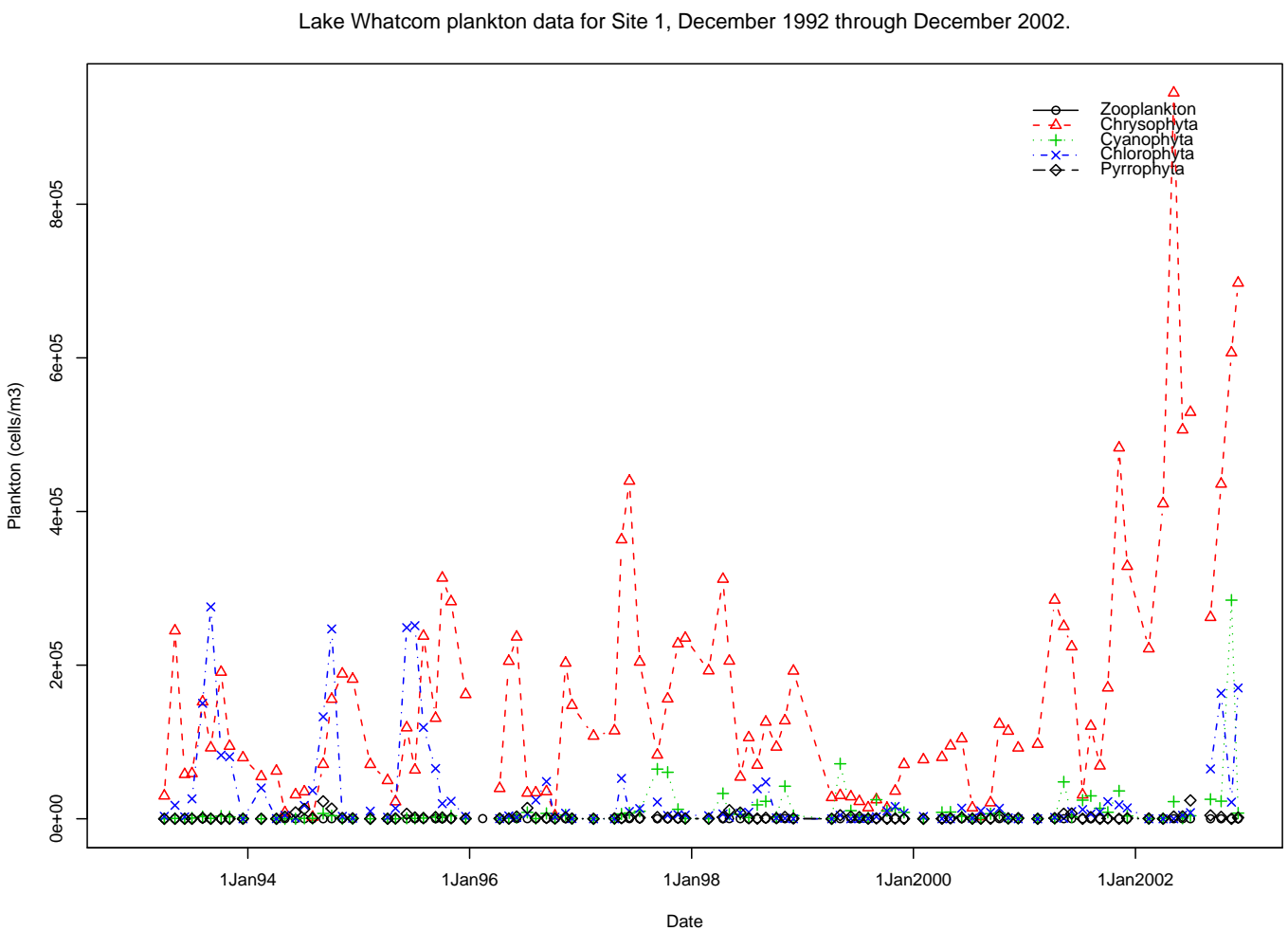


Figure 126: Lake Whatcom plankton data for Site 1.

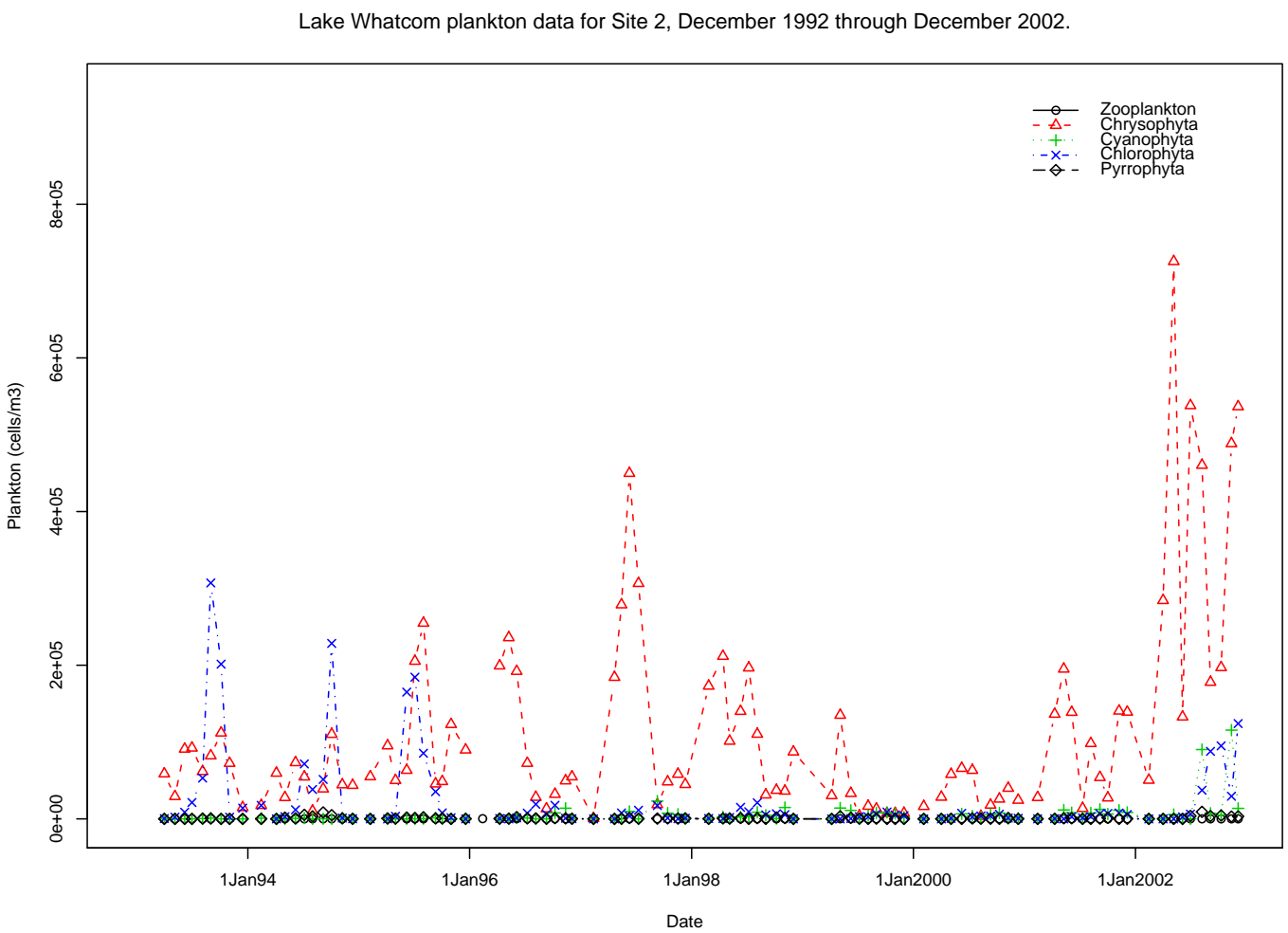


Figure 127: Lake Whatcom plankton data for Site 2.

Lake Whatcom plankton data for Intake, December 1992 through December 2002.

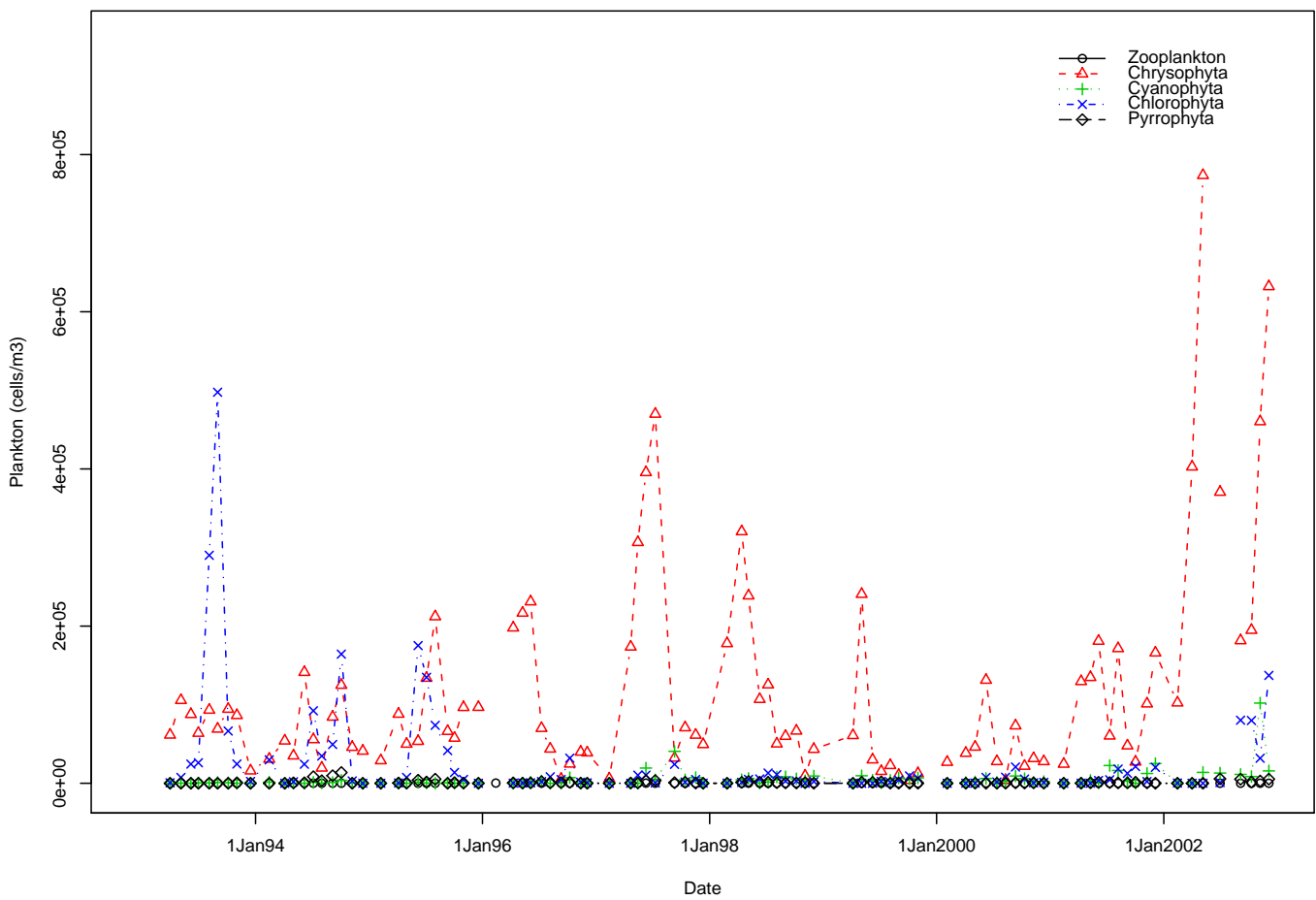


Figure 128: Lake Whatcom plankton data for the Intake.

Lake Whatcom plankton data for Site 3, December 1992 through December 2002.

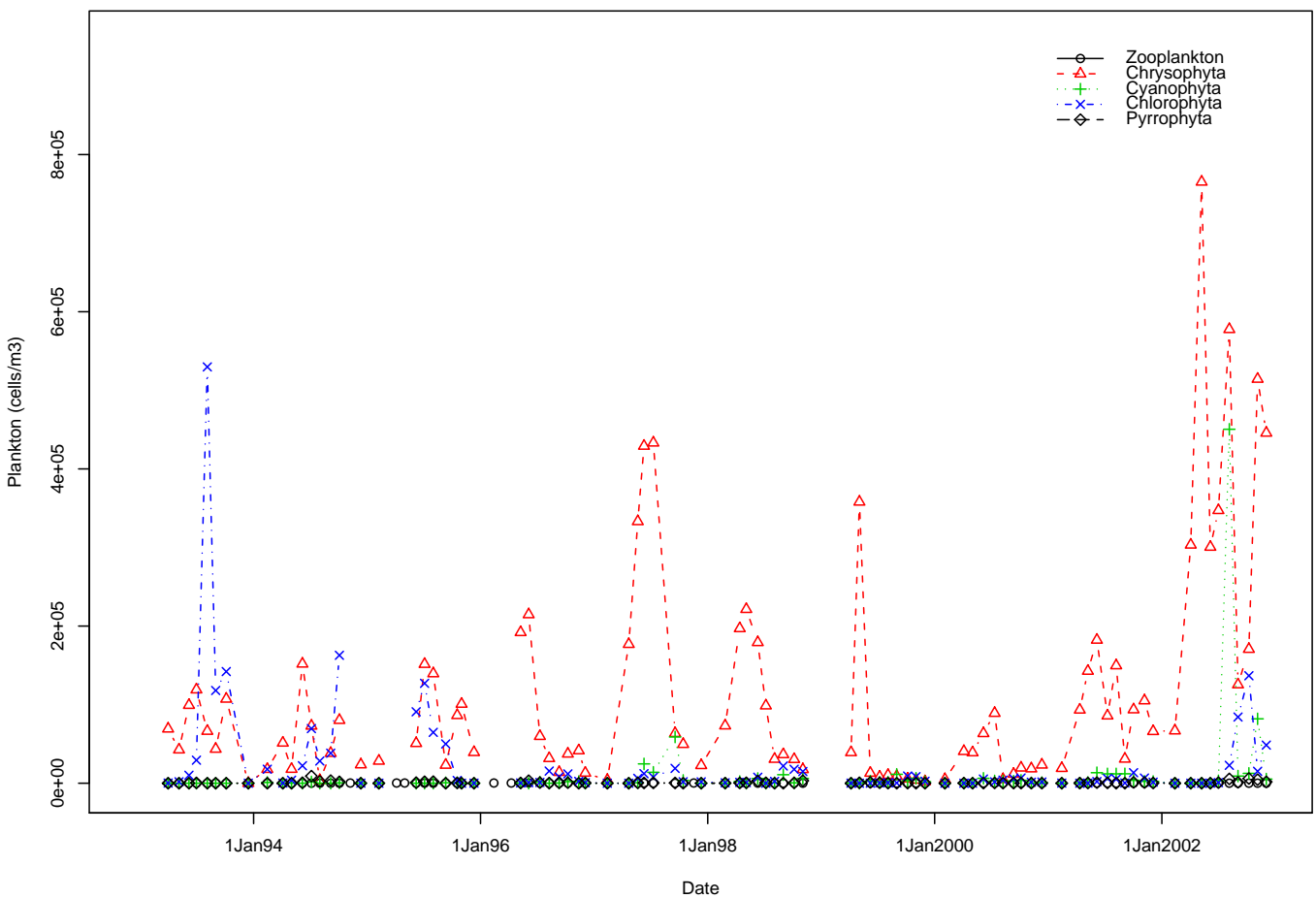


Figure 129: Lake Whatcom plankton data for Site 3.

Lake Whatcom plankton data for Site 4, December 1992 through December 2002.

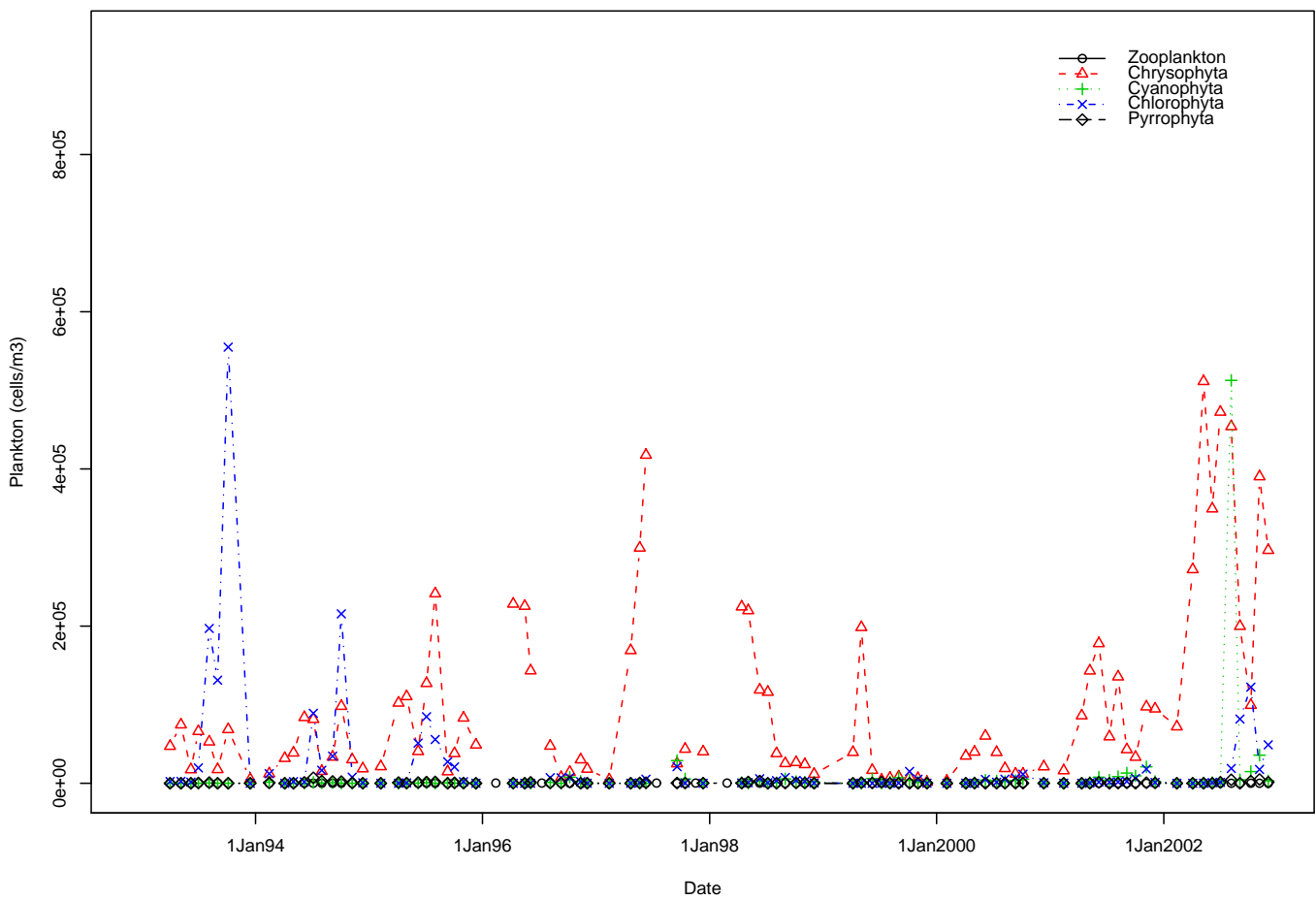


Figure 130: Lake Whatcom plankton data for Site 4.

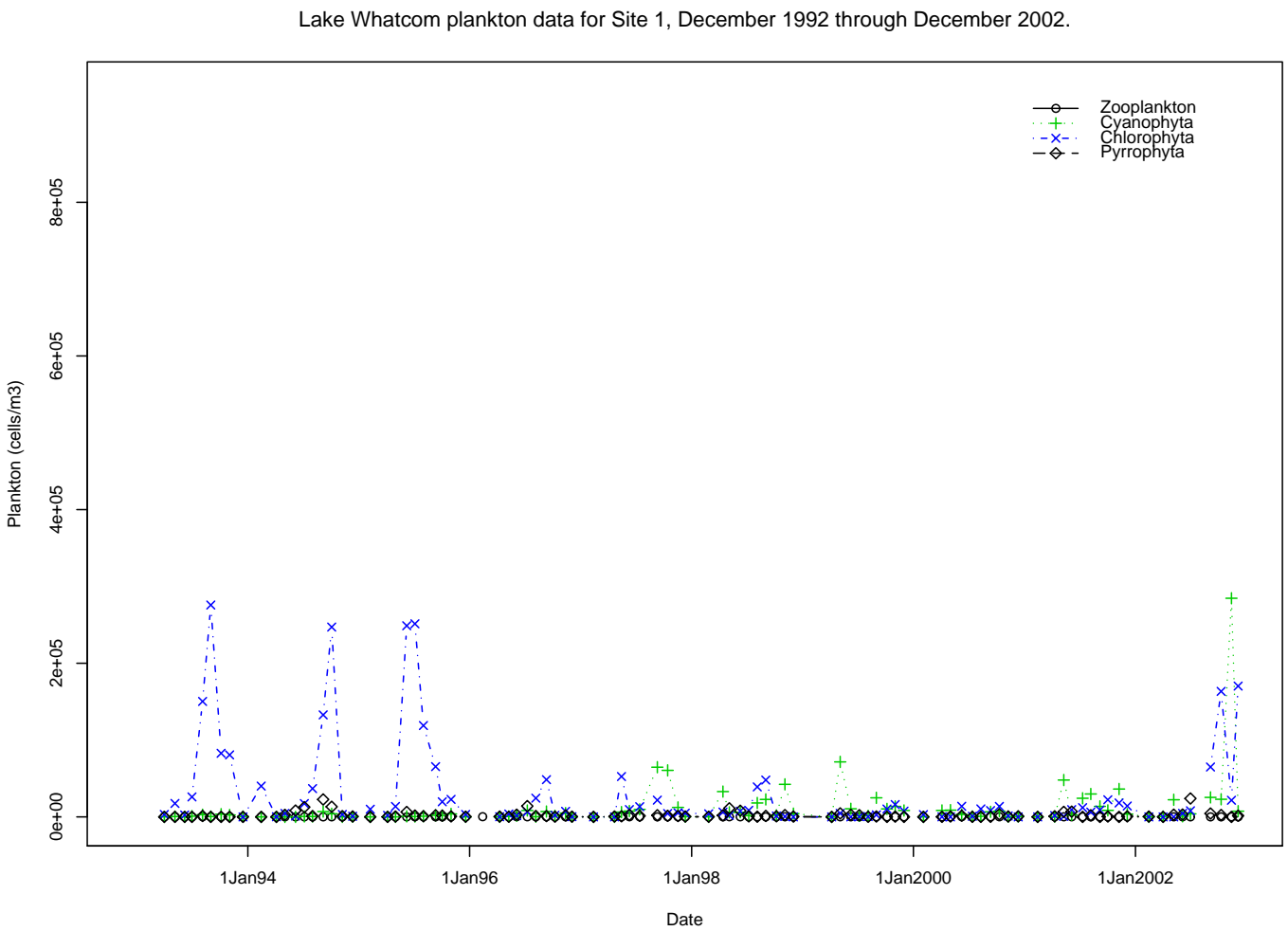


Figure 131: Lake Whatcom plankton data for Site 1, low range plot.



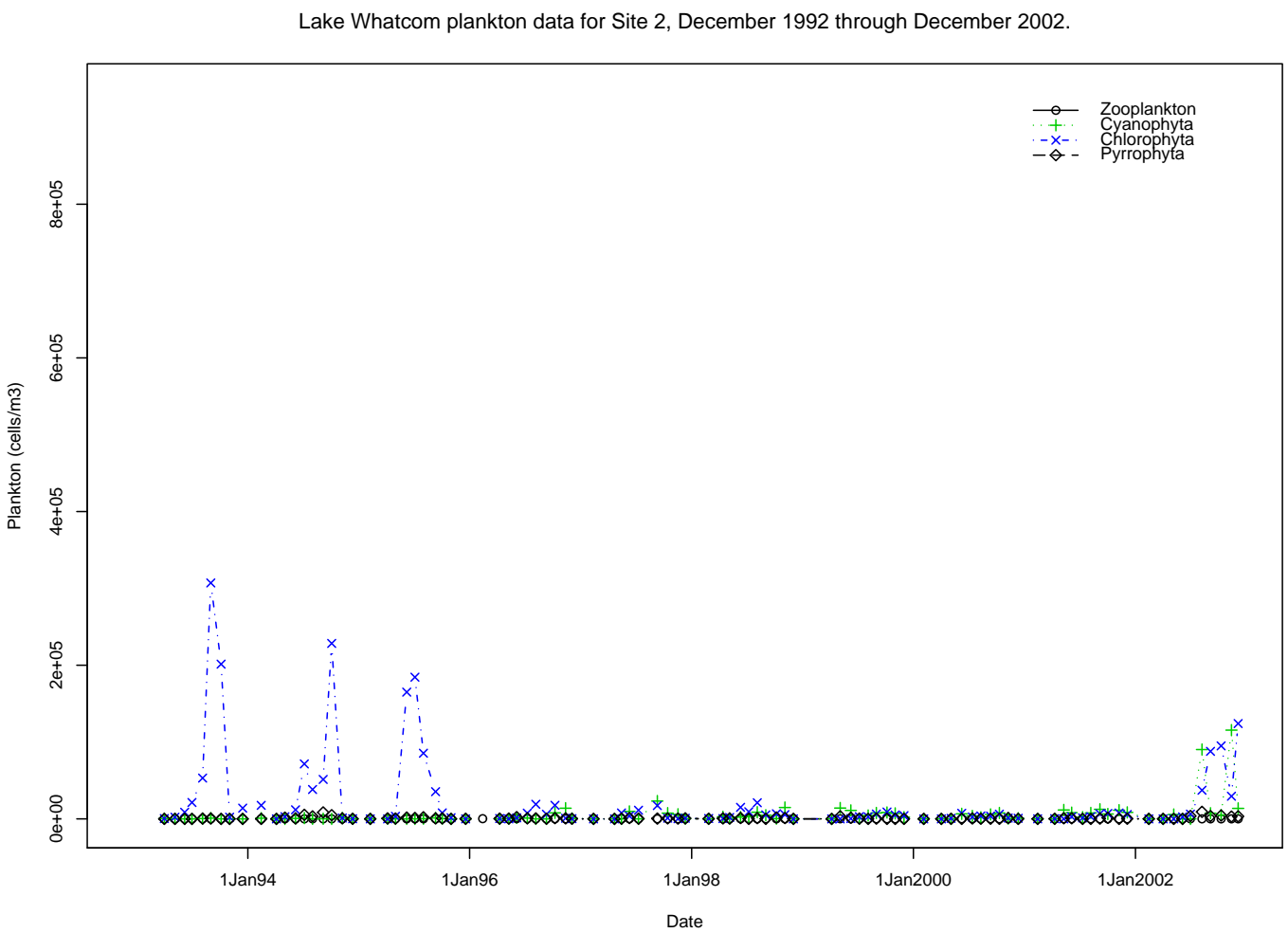


Figure 132: Lake Whatcom plankton data for Site 2, low range plot.

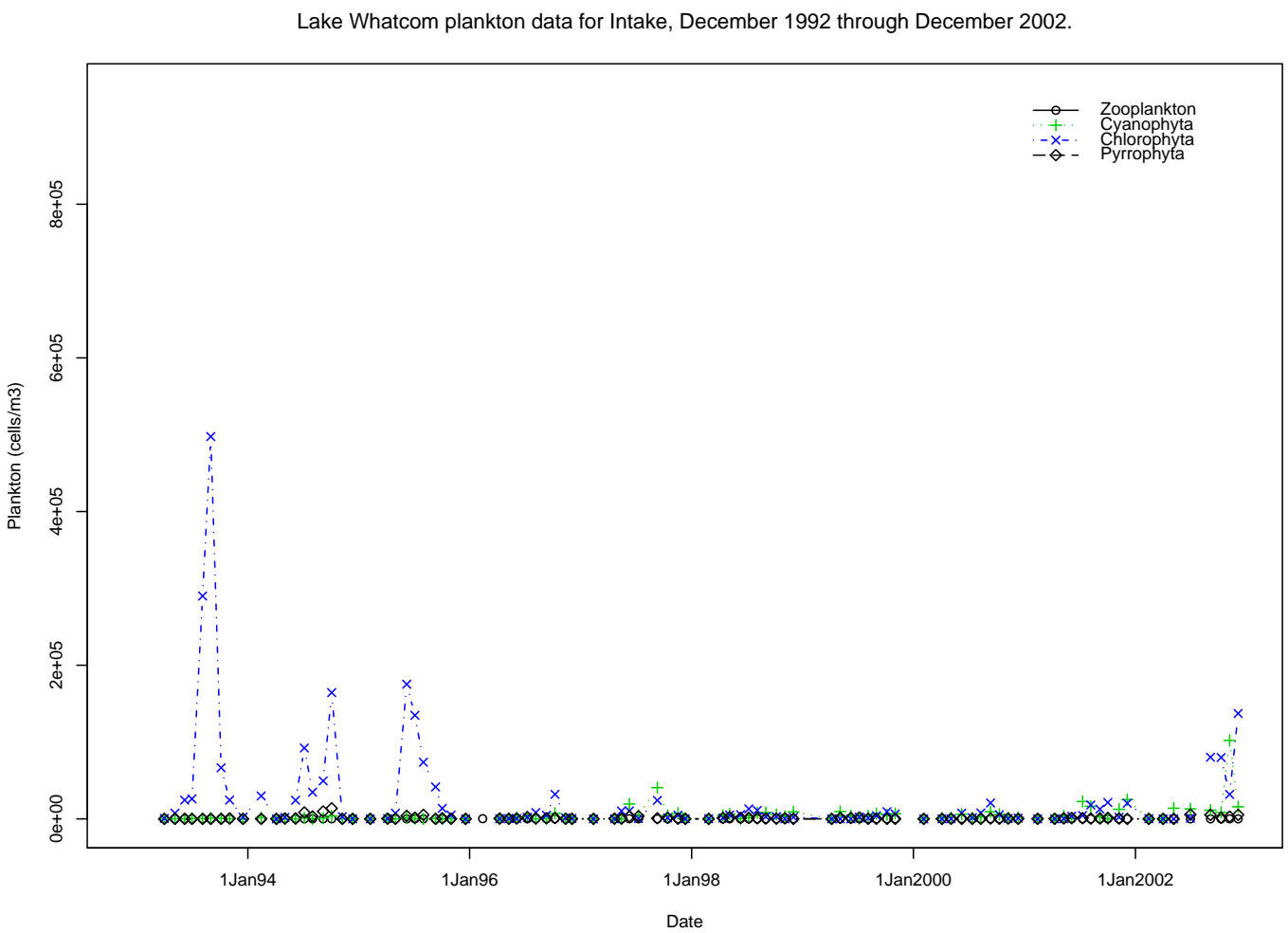


Figure 133: Lake Whatcom plankton data for the Intake, low range plot.

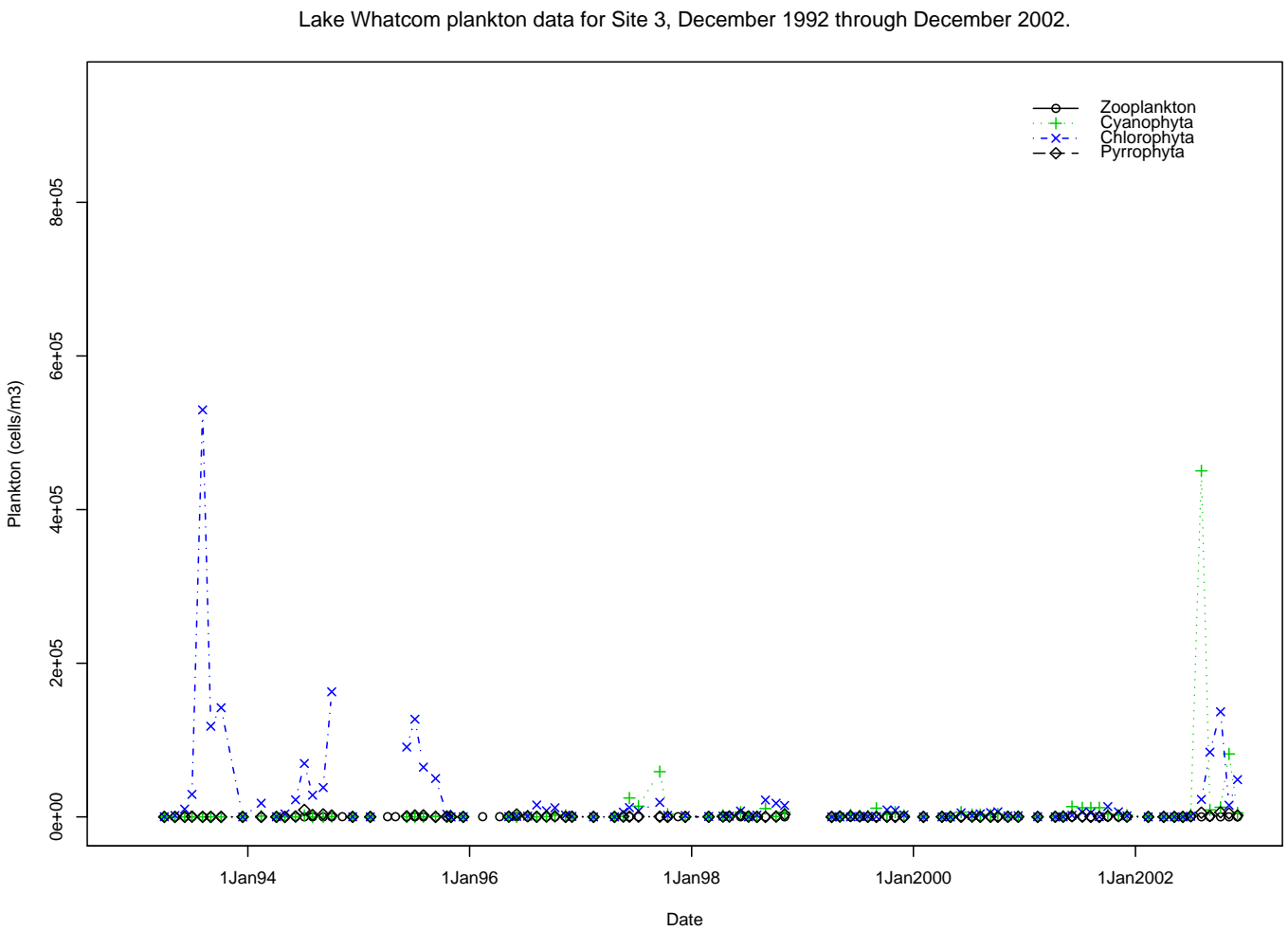


Figure 134: Lake Whatcom plankton data for Site 3, low range plot.

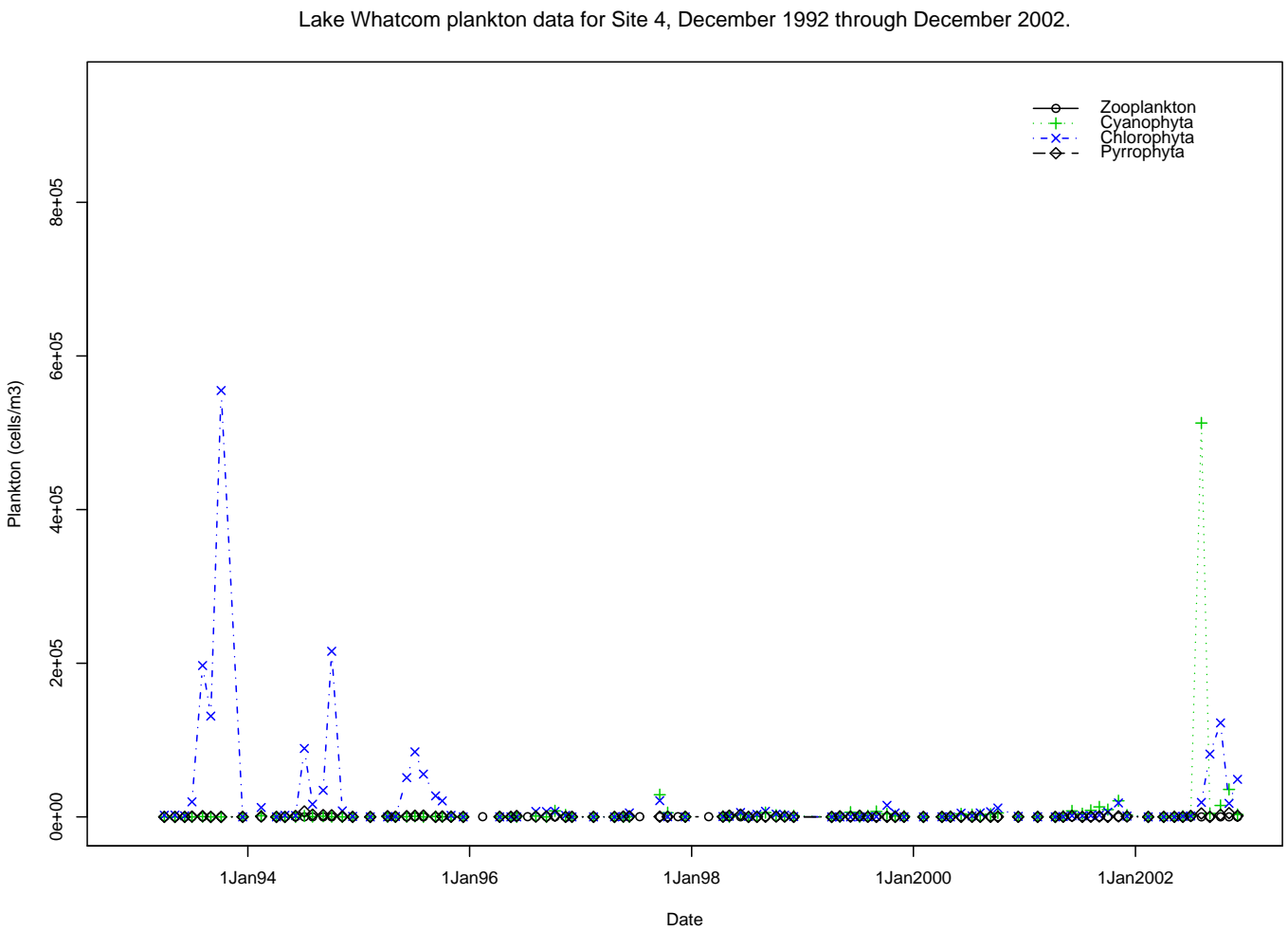


Figure 135: Lake Whatcom plankton data for Site 4, low range plot.

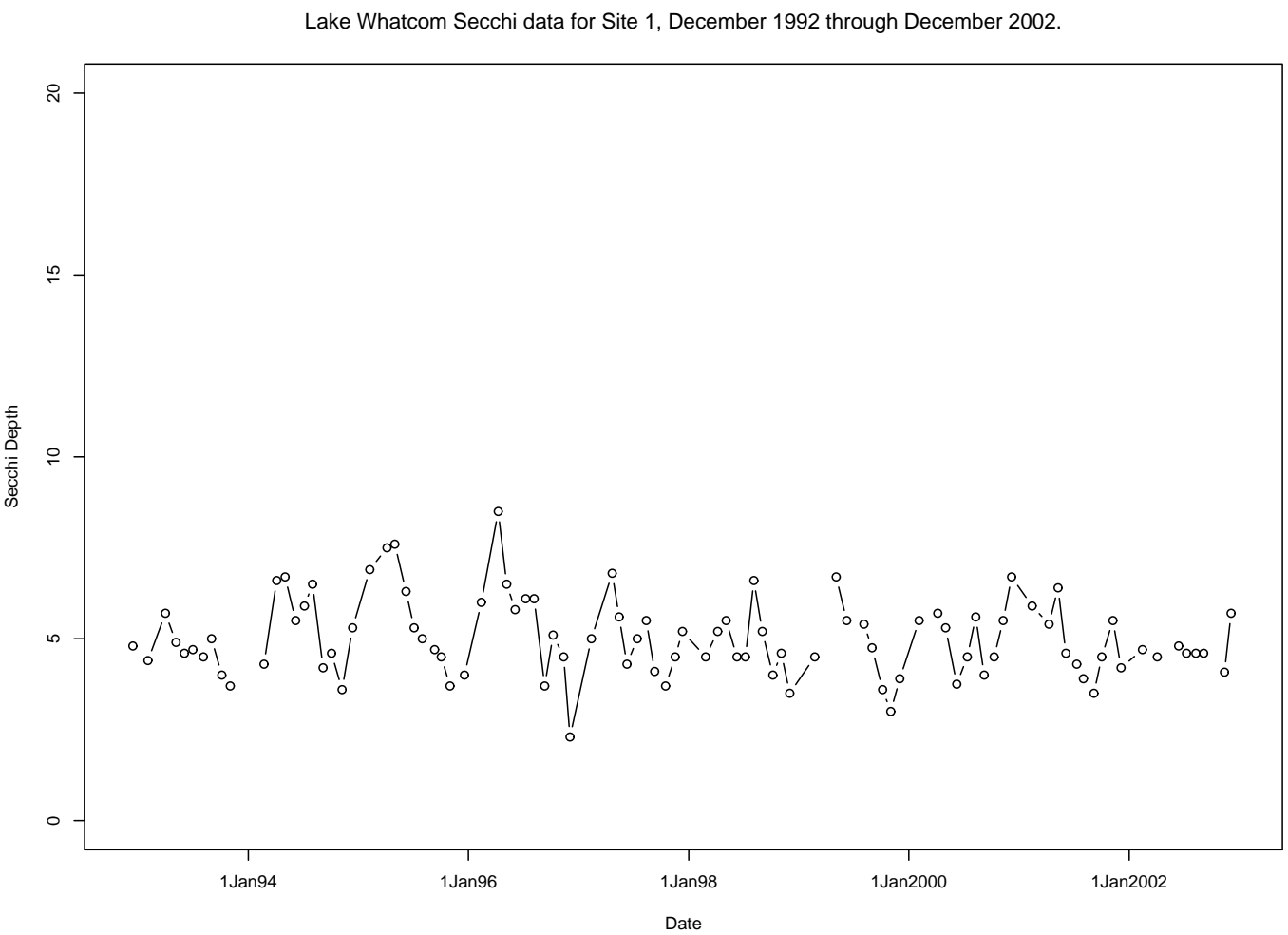


Figure 136: Lake Whatcom Secchi depths for Site 1.

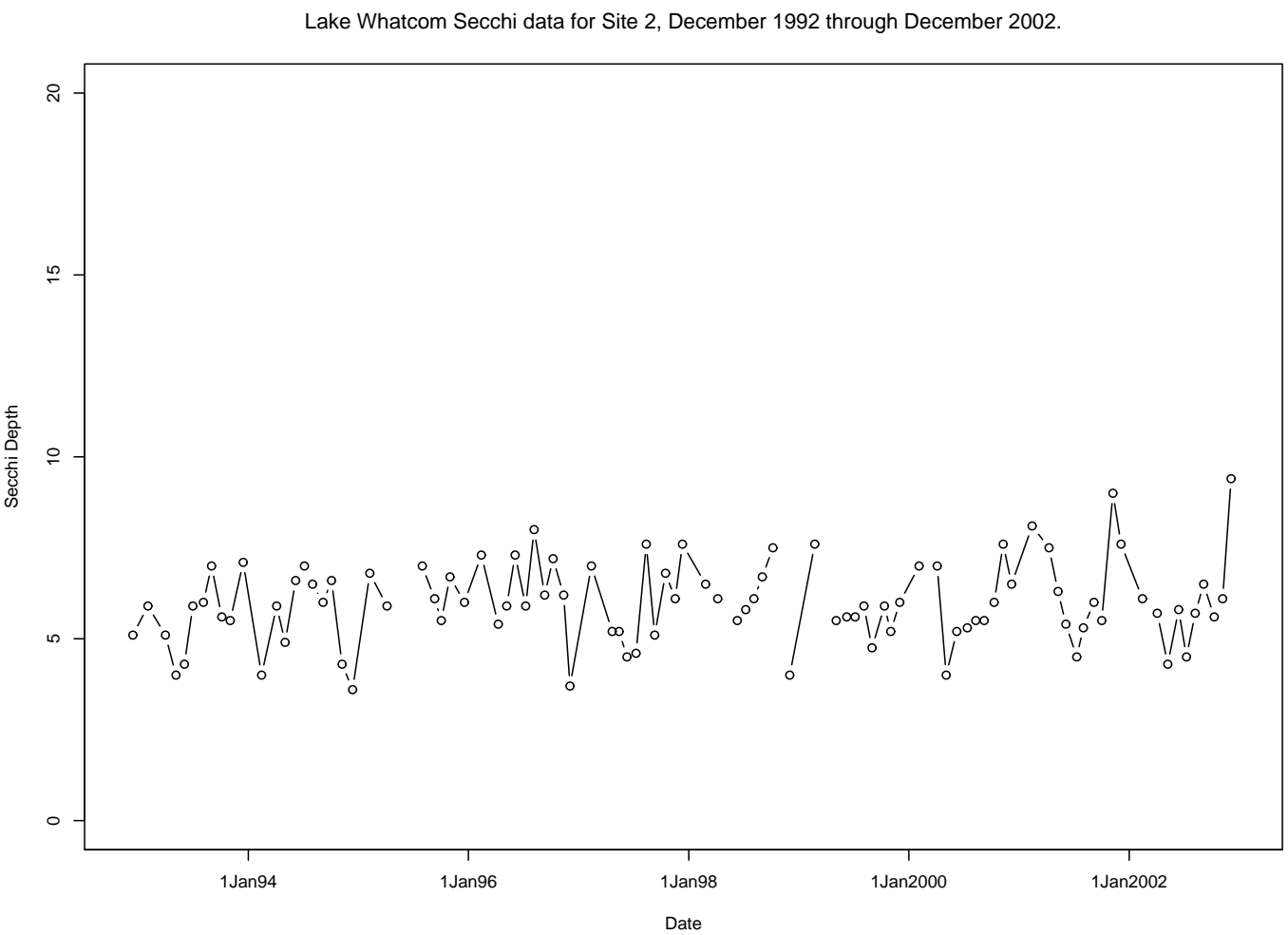


Figure 137: Lake Whatcom Secchi depths for Site 2.

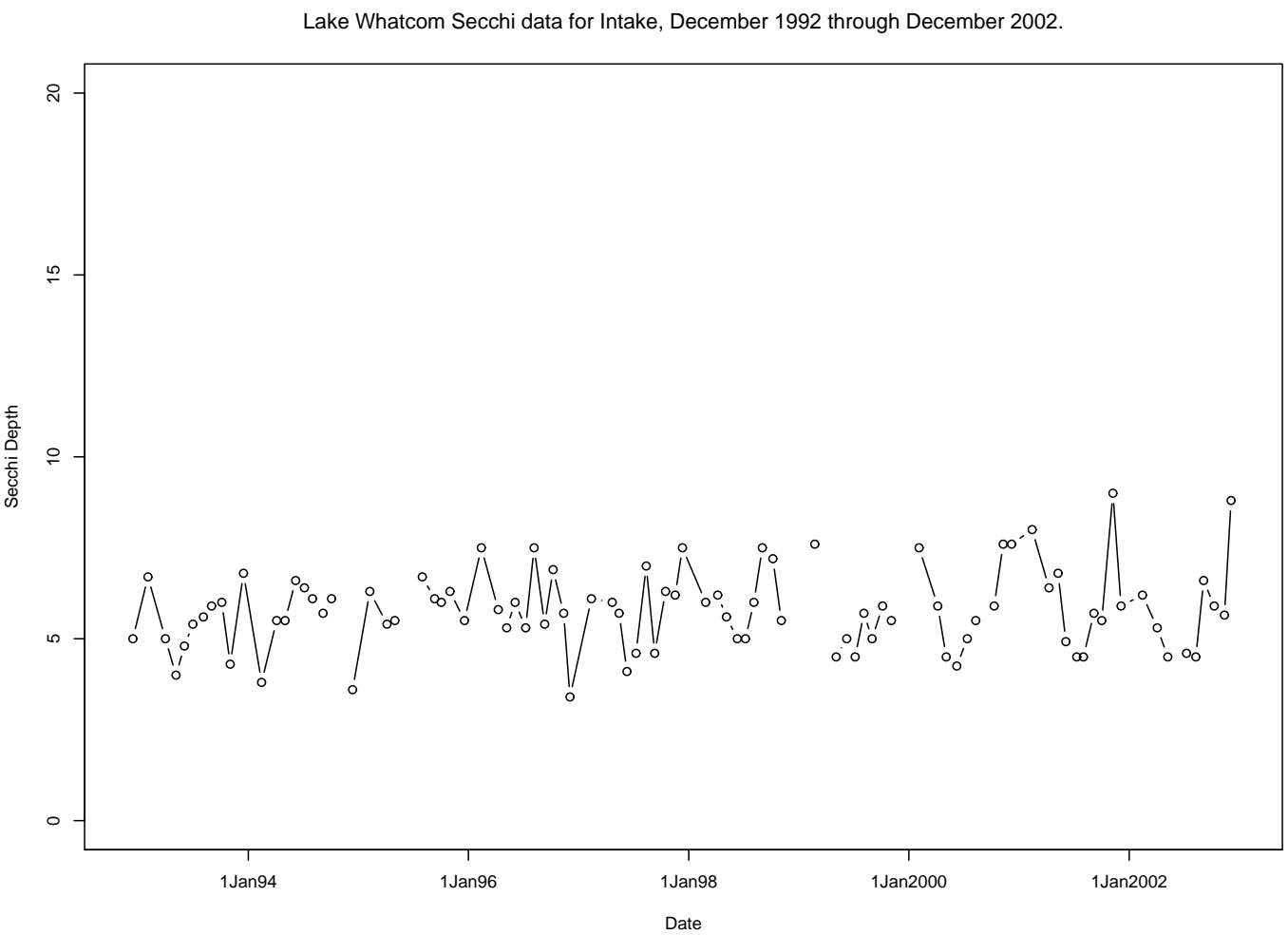


Figure 138: Lake Whatcom Secchi depths for the Intake.

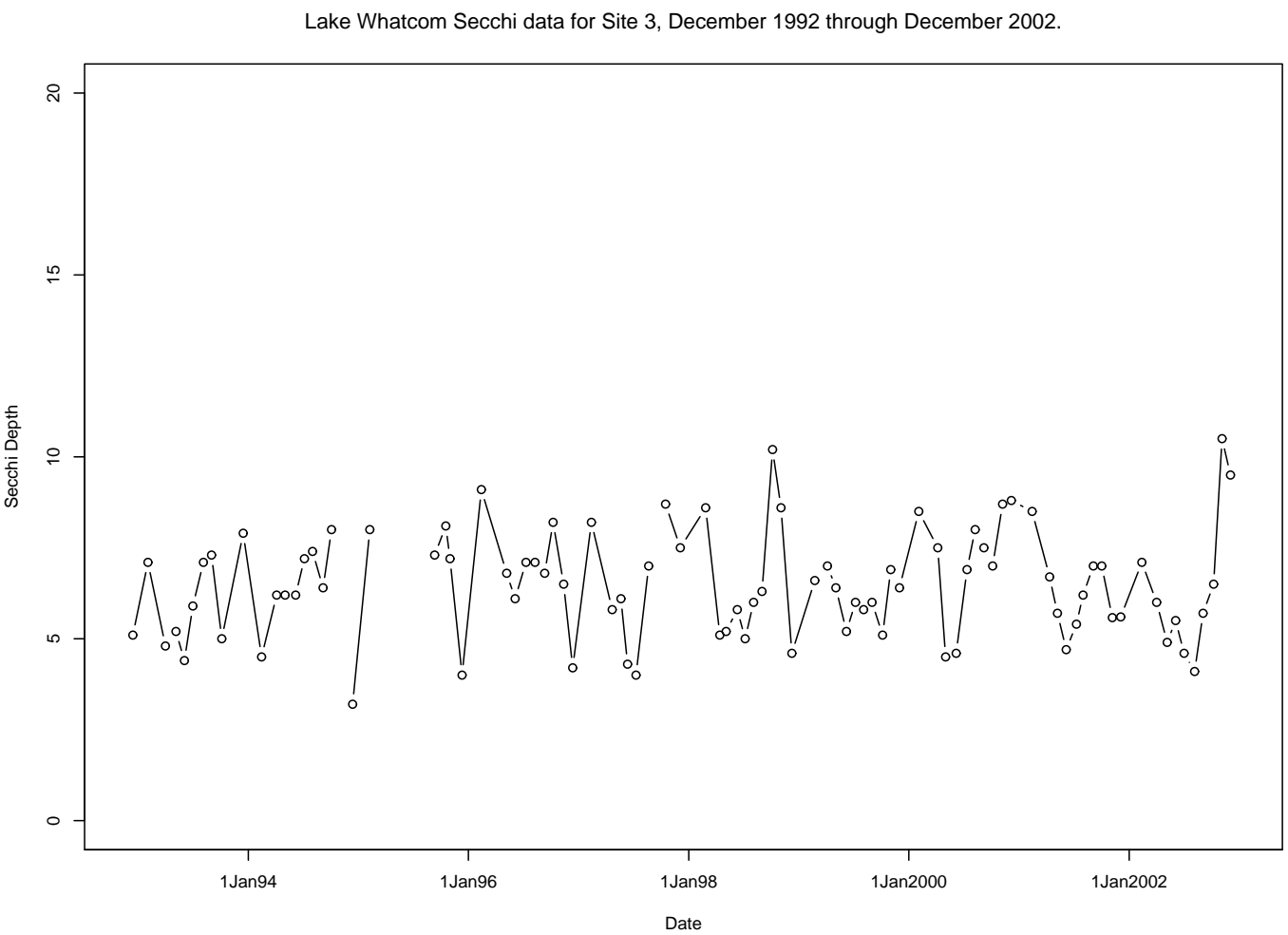


Figure 139: Lake Whatcom Secchi depths for Site 3.



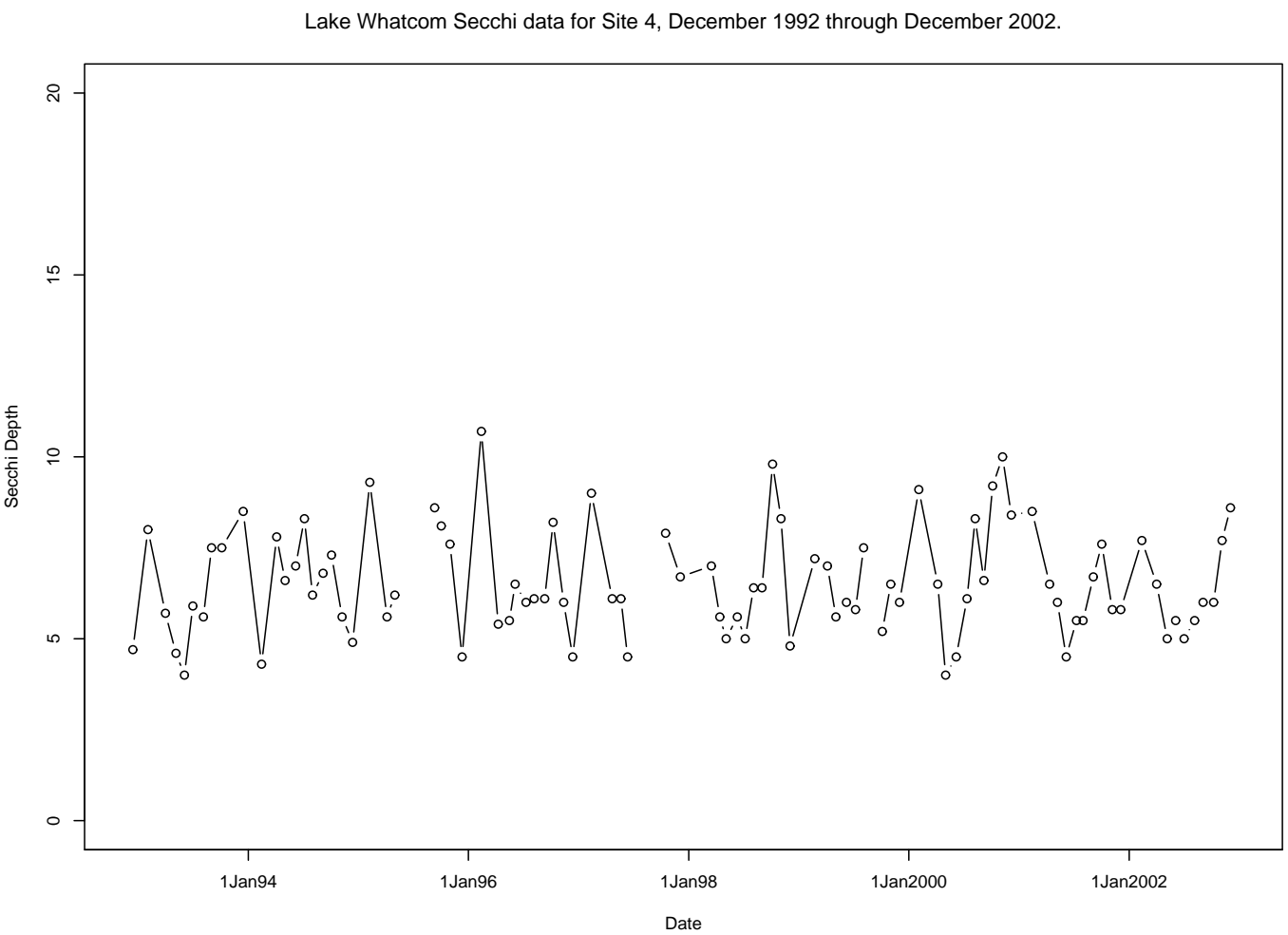


Figure 140: Lake Whatcom Secchi depths for Site 4.

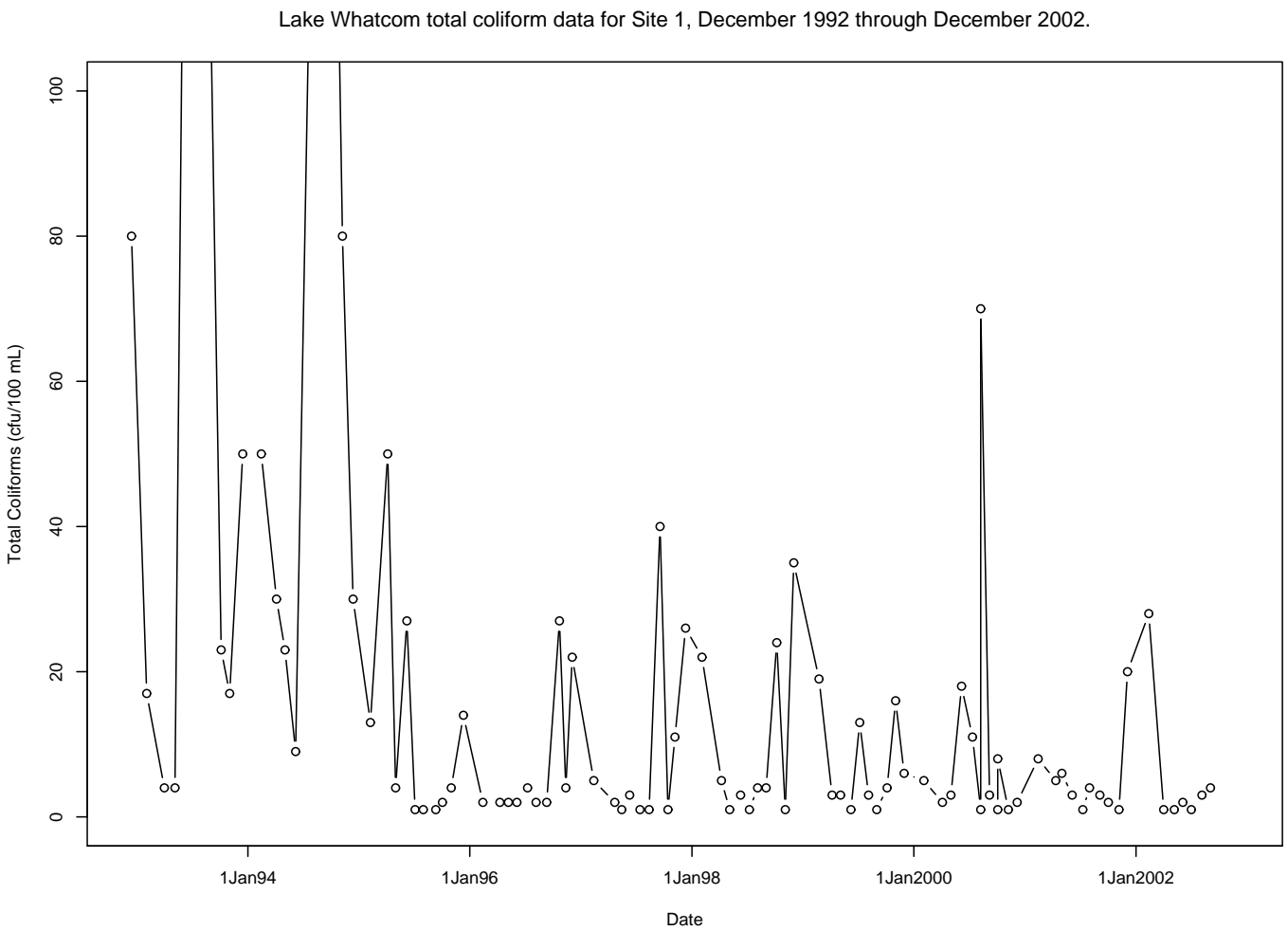


Figure 141: Lake Whatcom total coliform data for Site 1.

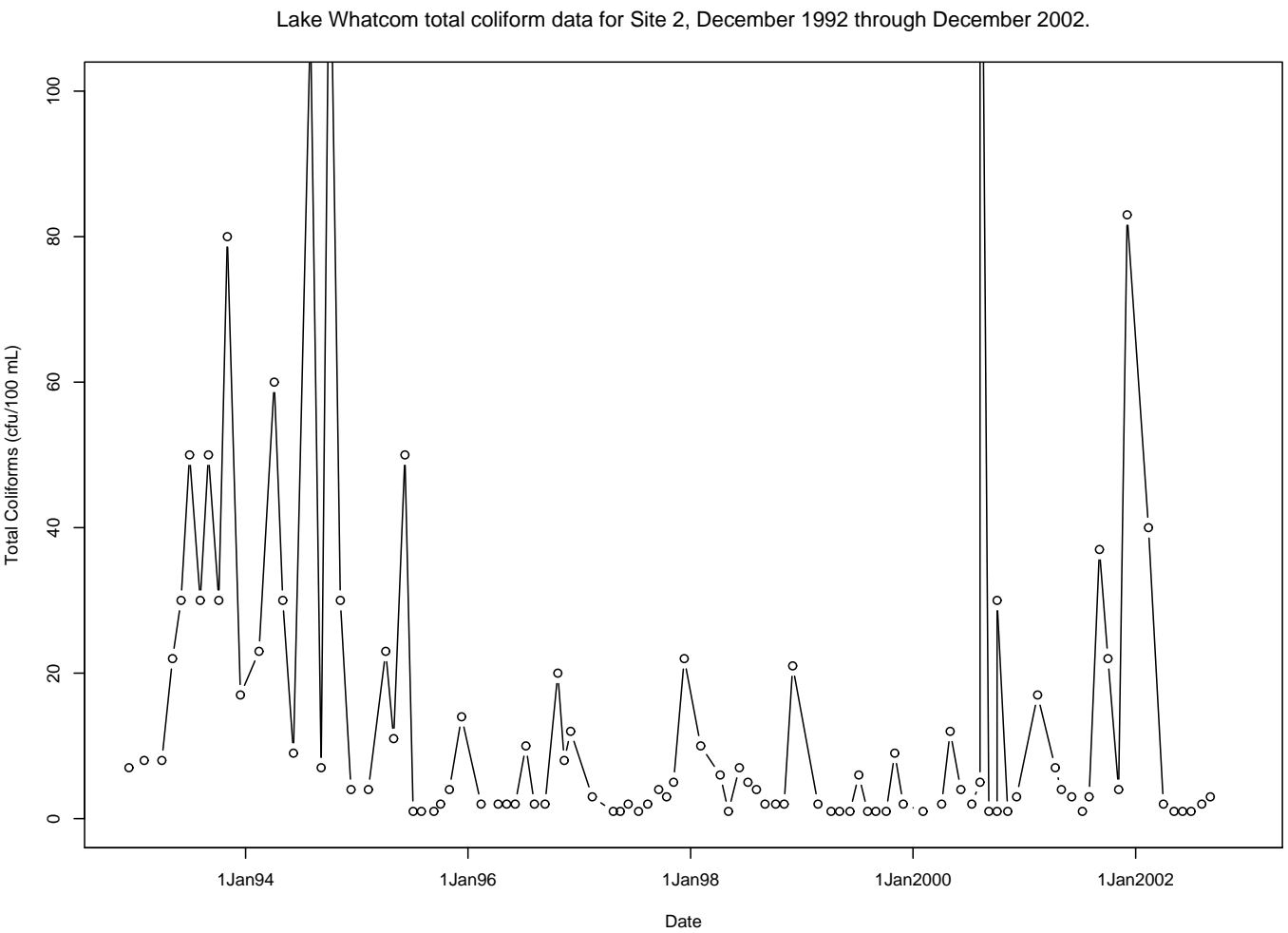


Figure 142: Lake Whatcom total coliform data for Site 2.

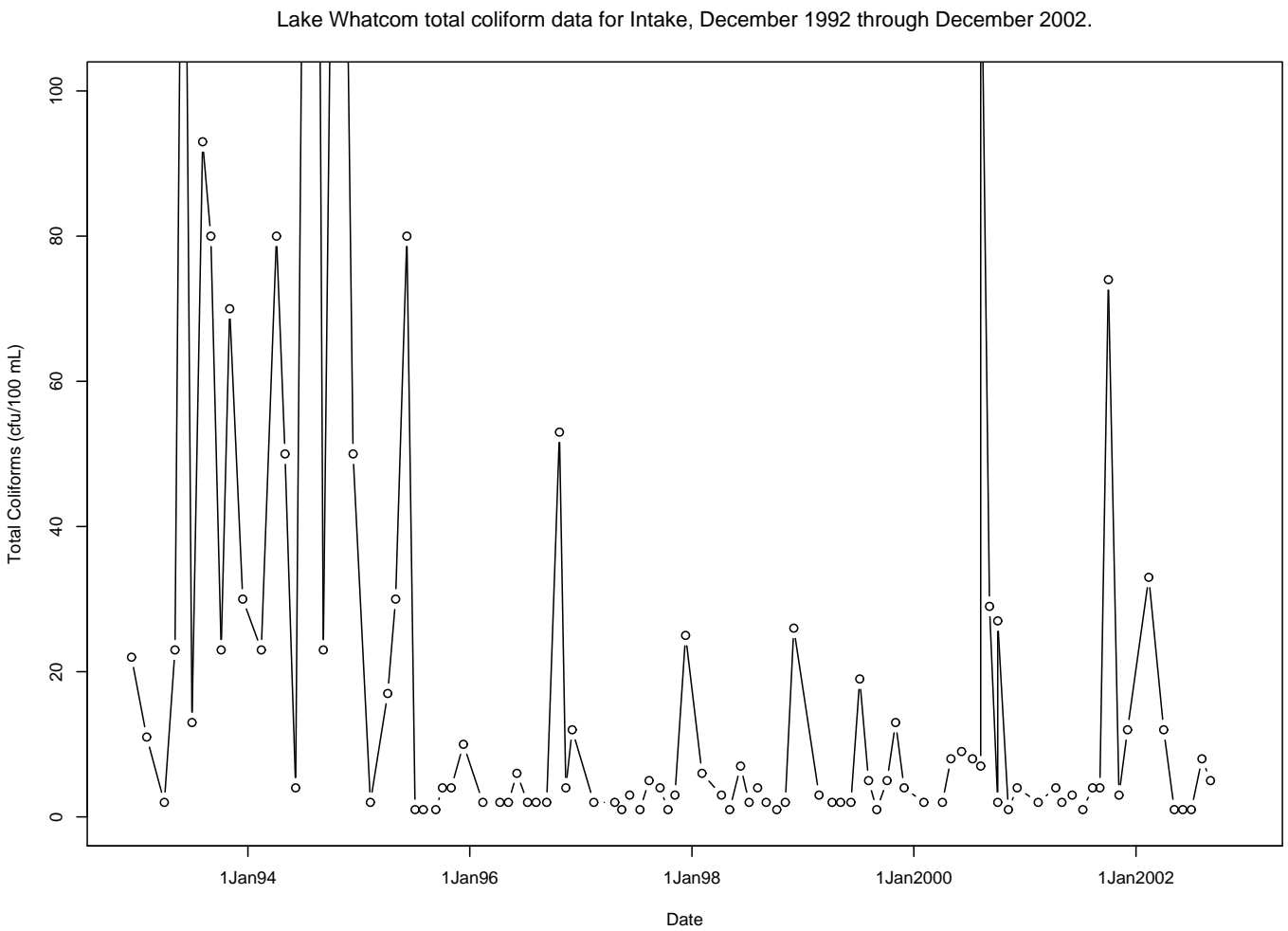


Figure 143: Lake Whatcom total coliform data for the Intake.

Lake Whatcom total coliform data for Site 3, December 1992 through December 2002.

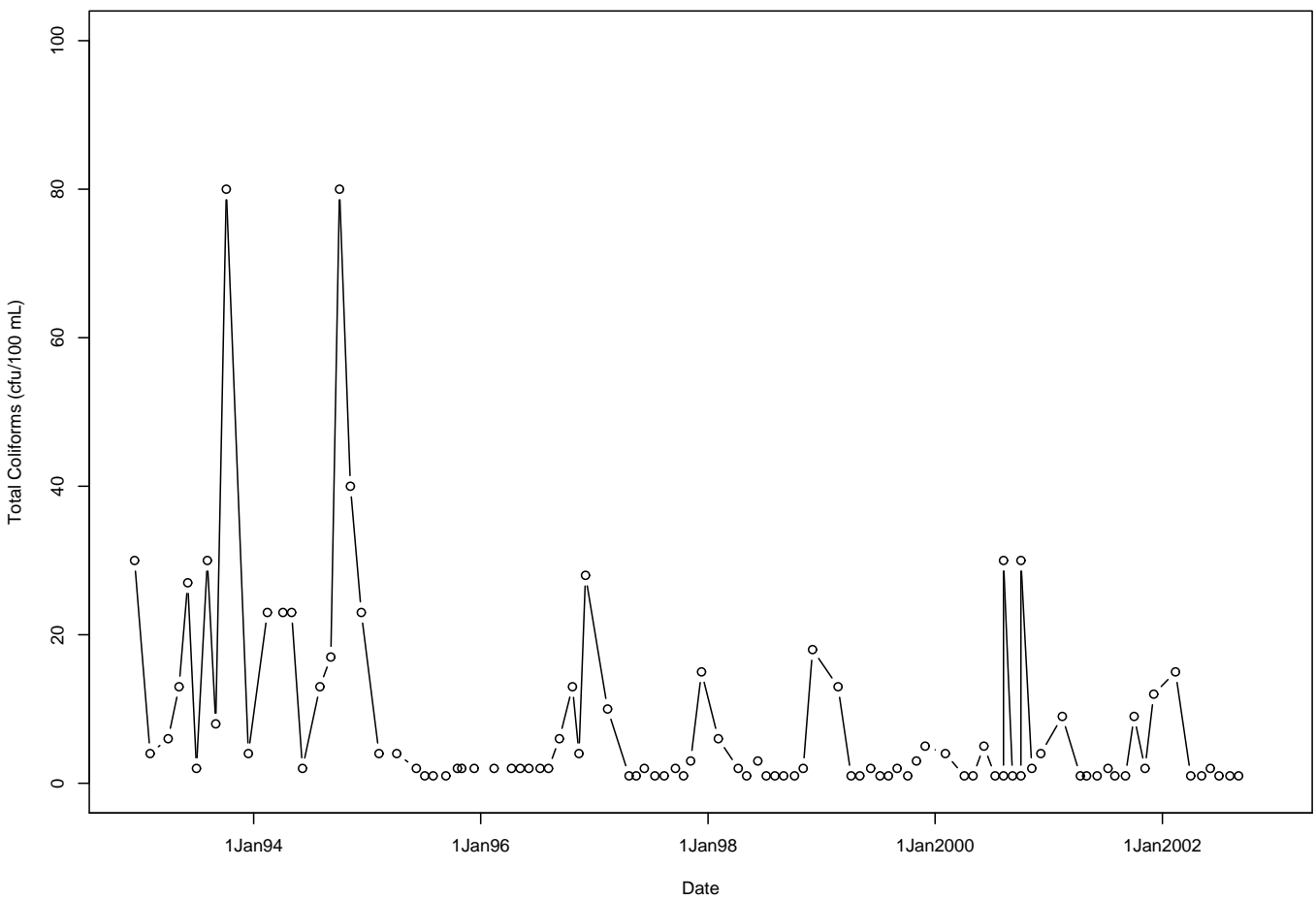


Figure 144: Lake Whatcom total coliform data for Site 3.

Lake Whatcom total coliform data for Site 4, December 1992 through December 2002.

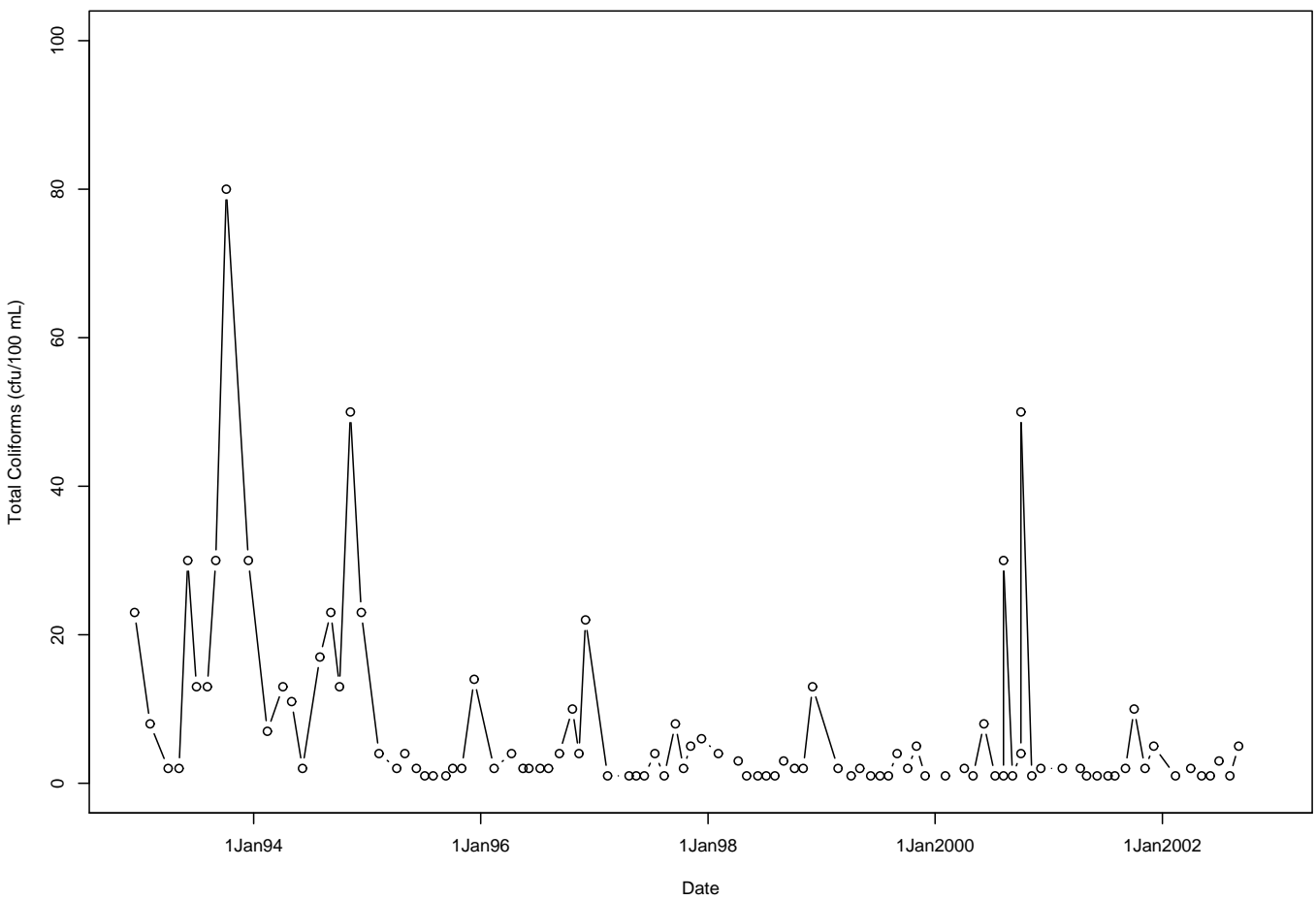


Figure 145: Lake Whatcom total coliform data for Site 4.

Lake Whatcom fecal coliform data for Site 1, December 1992 through December 2002.

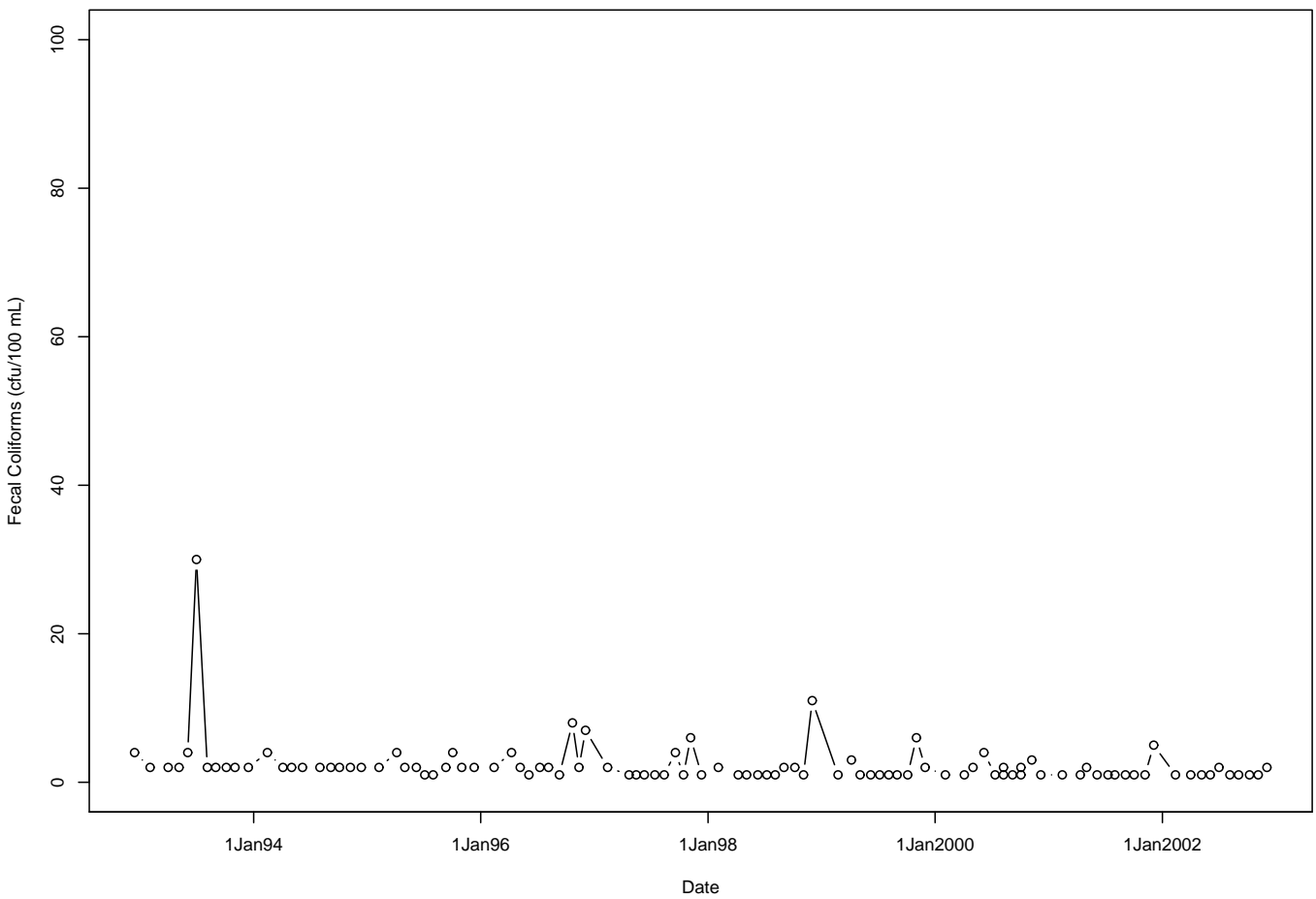


Figure 146: Lake Whatcom fecal coliform data for Site 1.

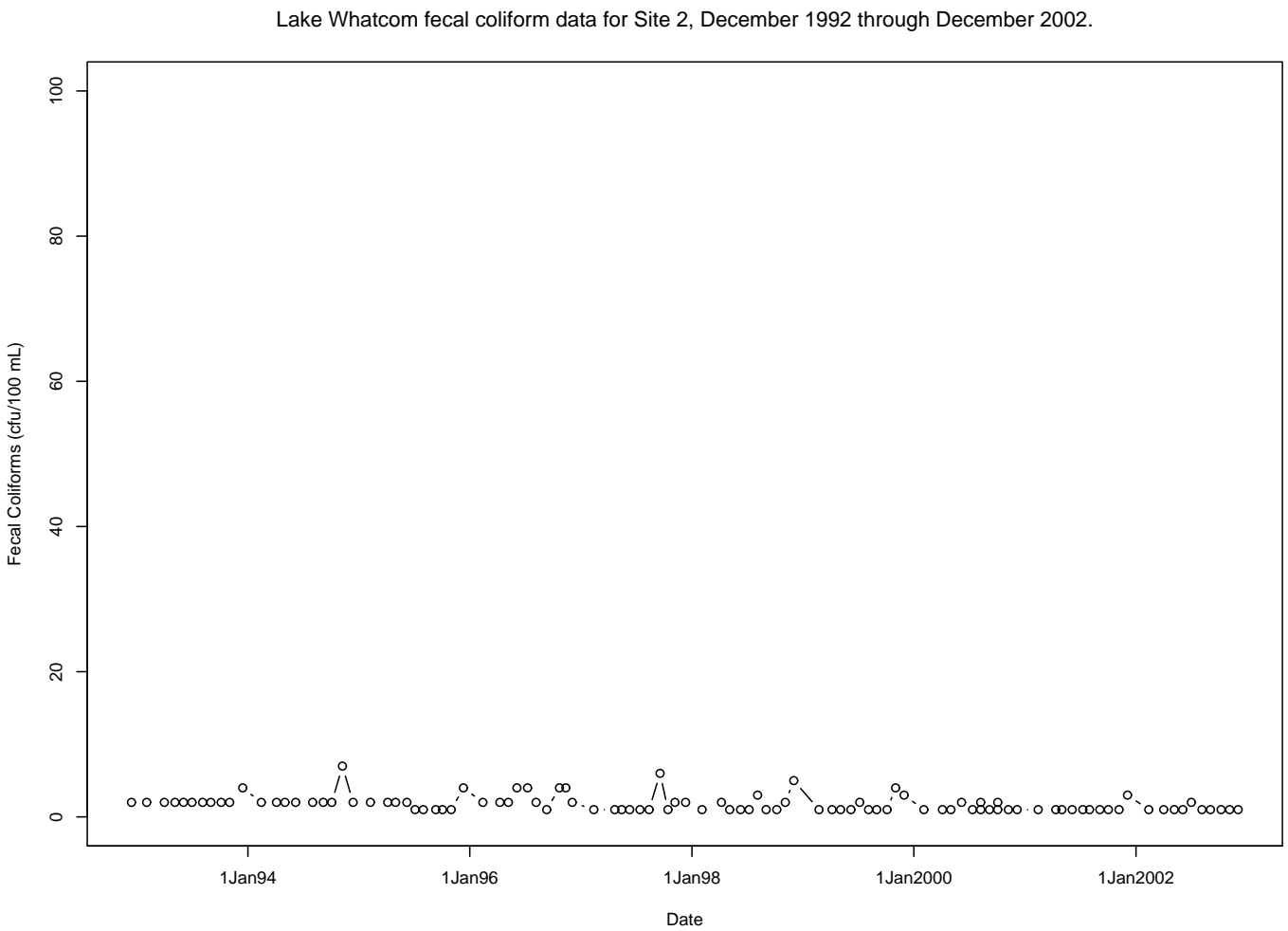


Figure 147: Lake Whatcom fecal coliform data for Site 2.



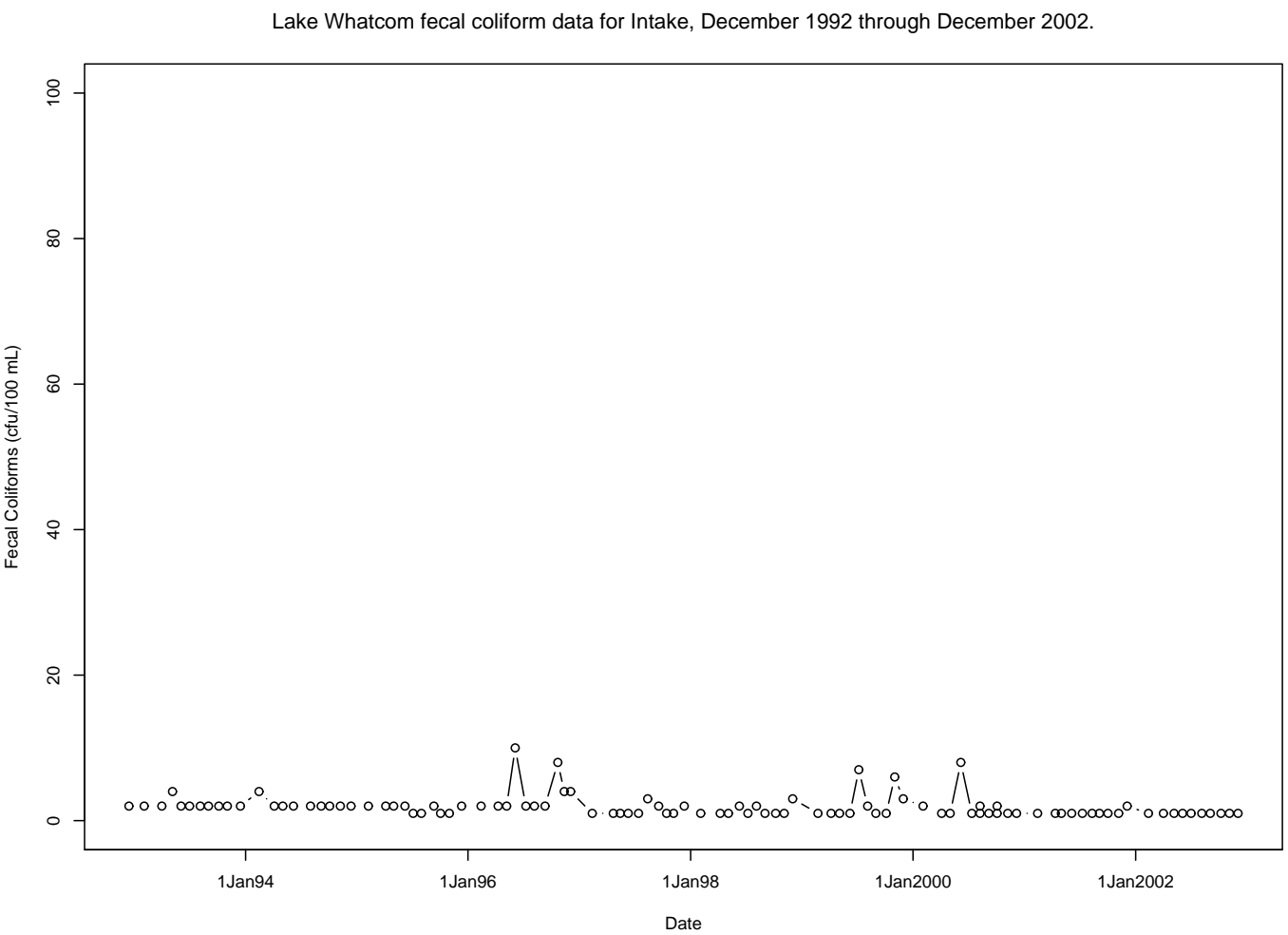


Figure 148: Lake Whatcom fecal coliform data for the Intake.

Lake Whatcom fecal coliform data for Site 3, December 1992 through December 2002.

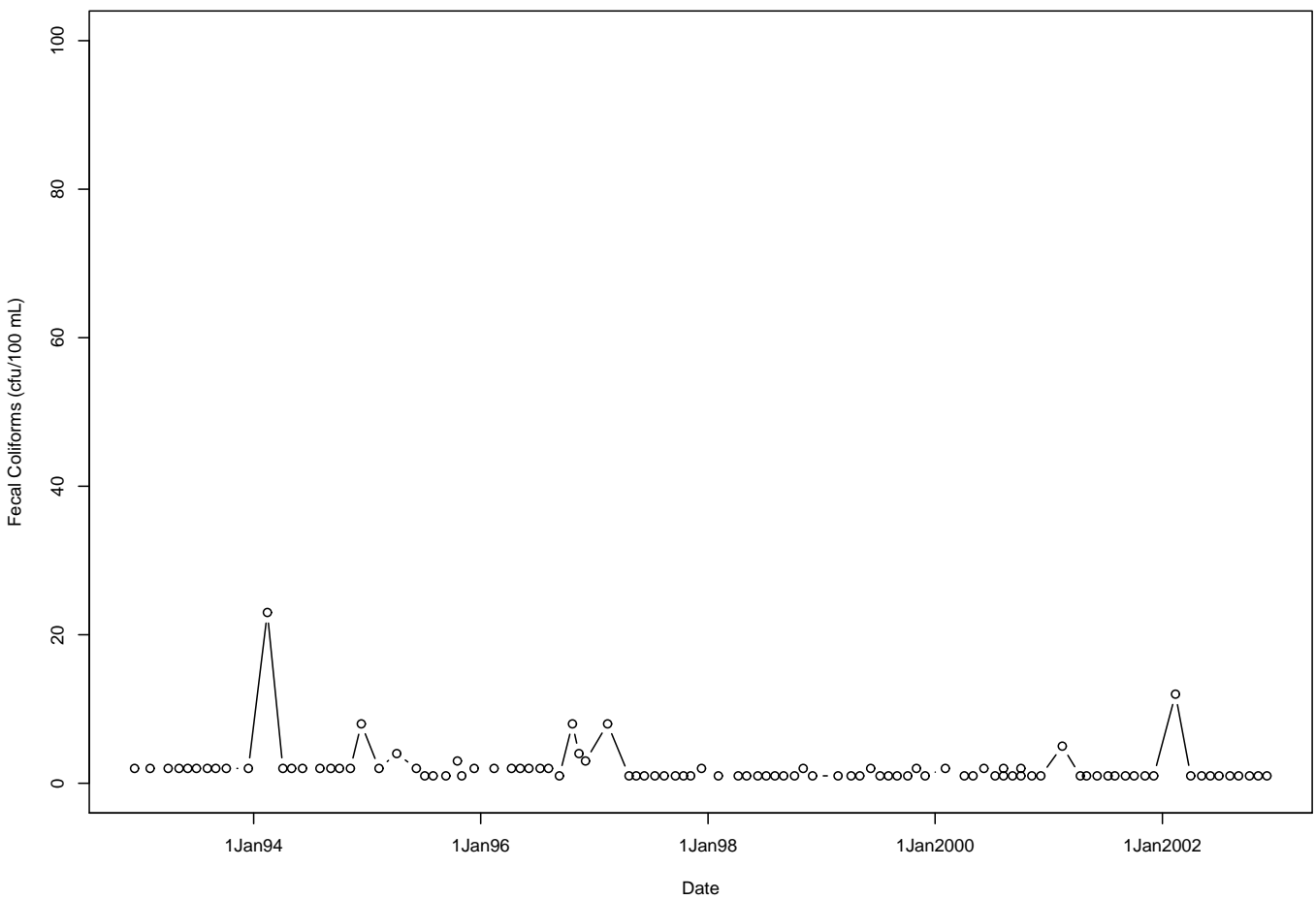


Figure 149: Lake Whatcom fecal coliform data for Site 3.

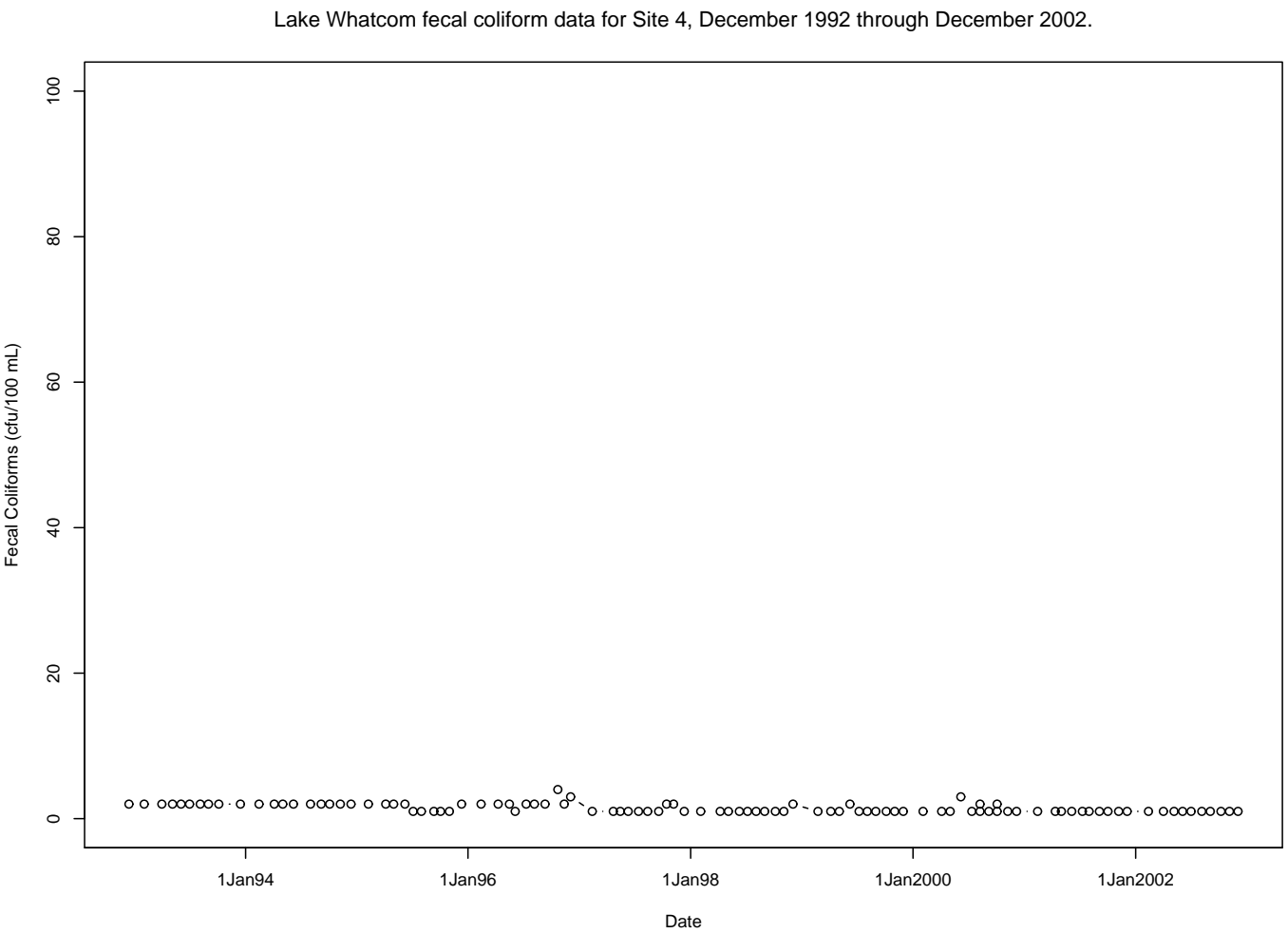
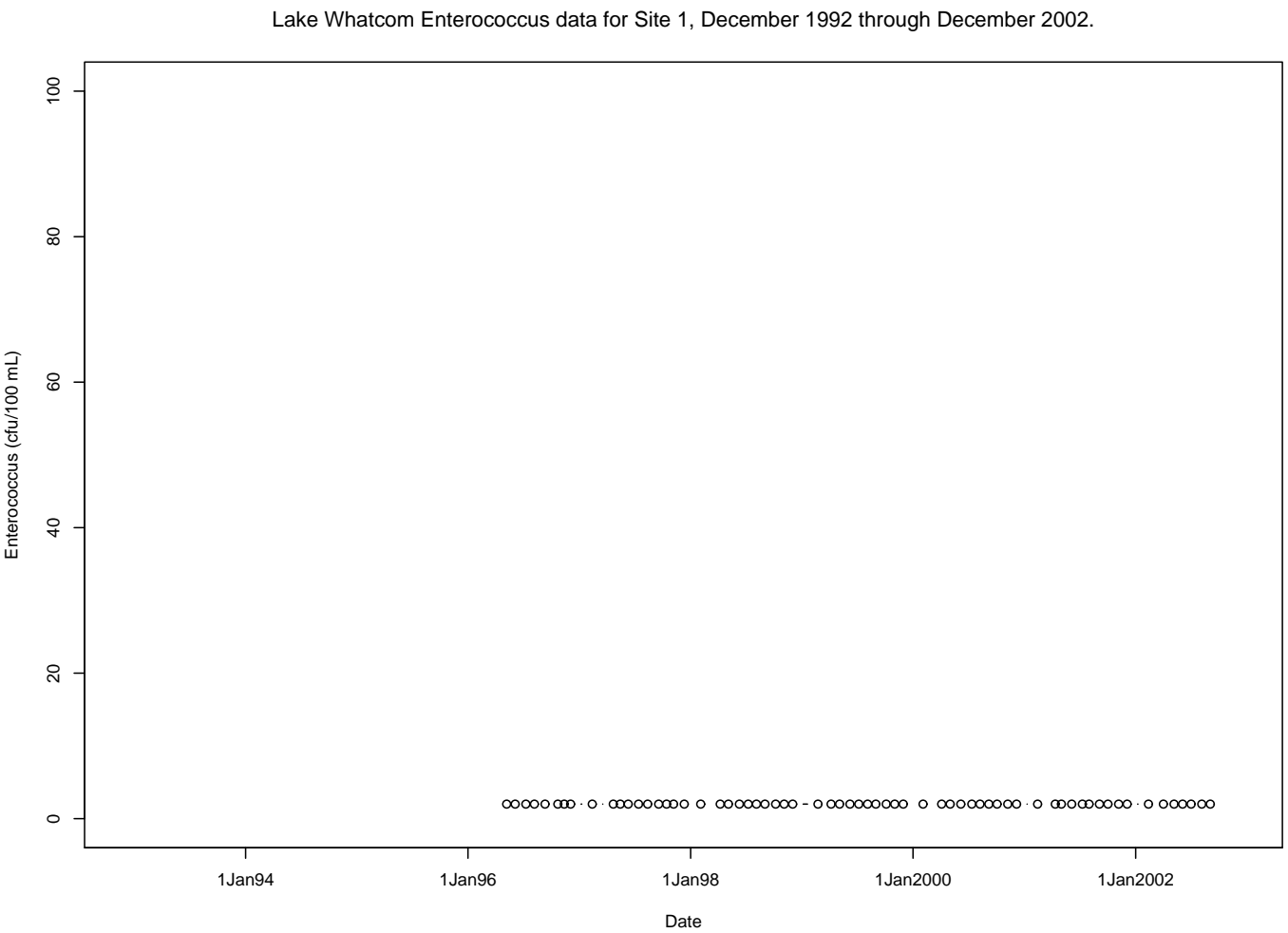
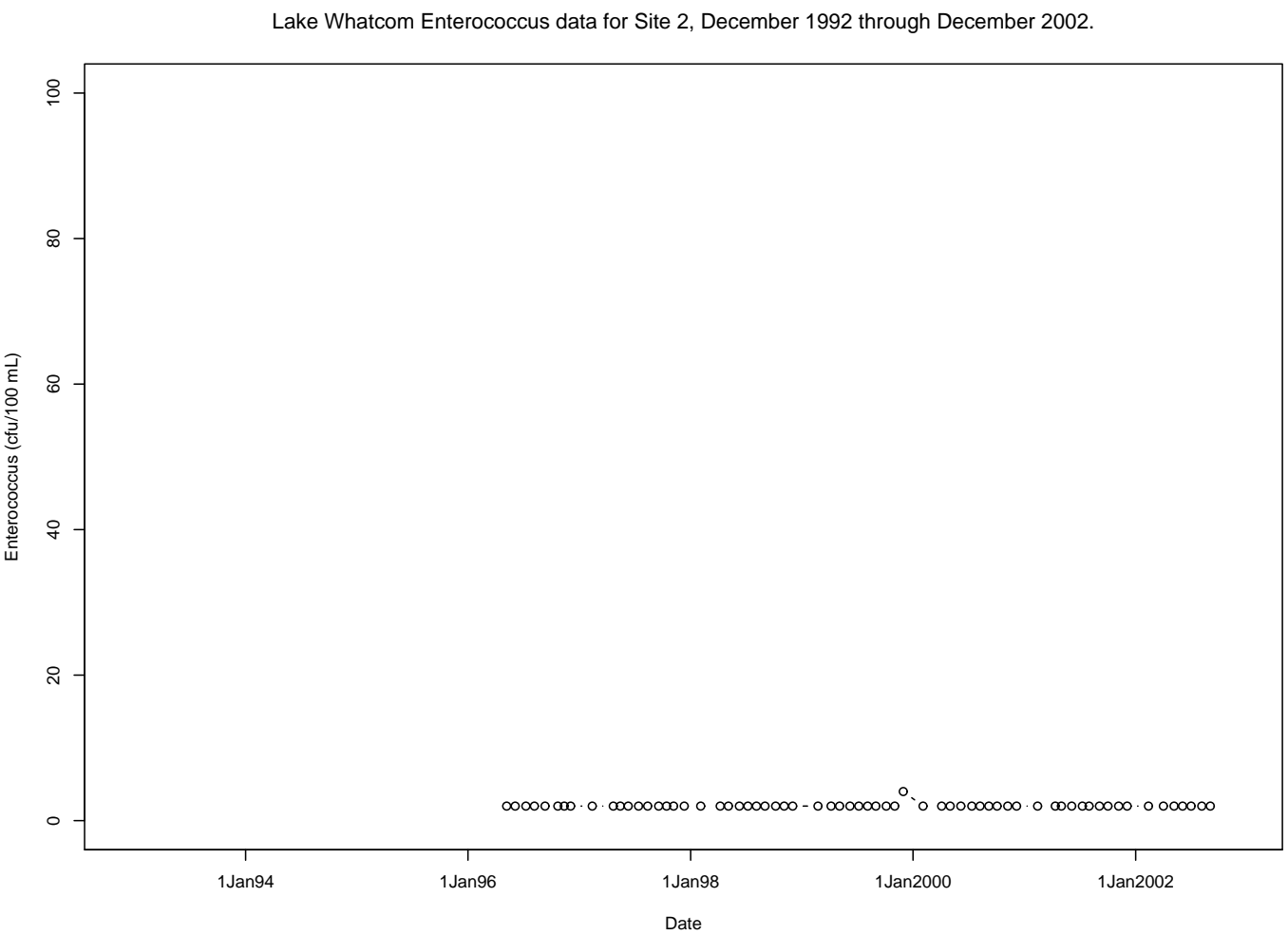


Figure 150: Lake Whatcom fecal coliform data for Site 4.

Figure 151: Lake Whatcom *Enterococcus* data for Site 1.

Figure 152: Lake Whatcom *Enterococcus* data for Site 2.

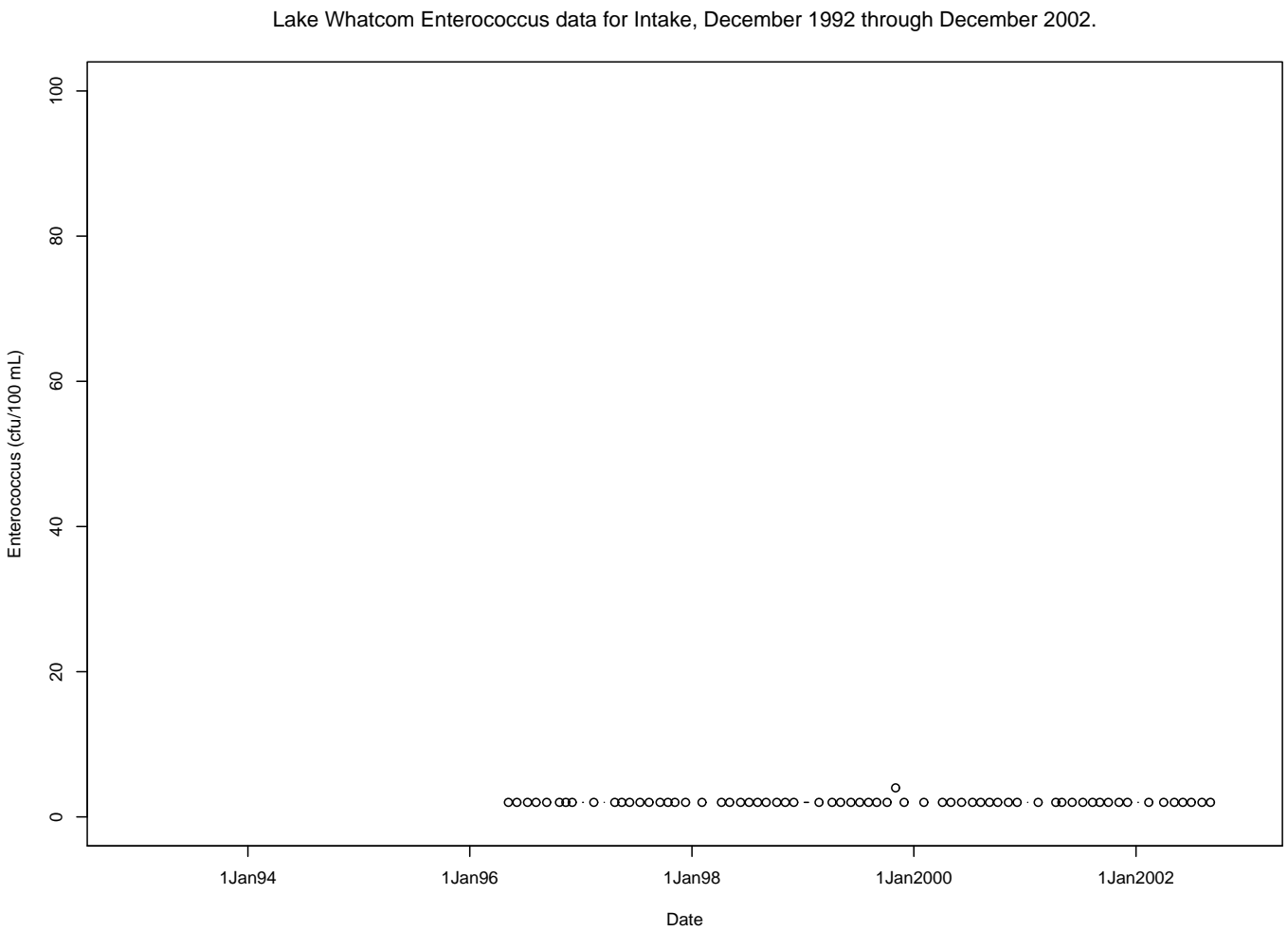


Figure 153: Lake Whatcom *Enterococcus* data for the Intake.

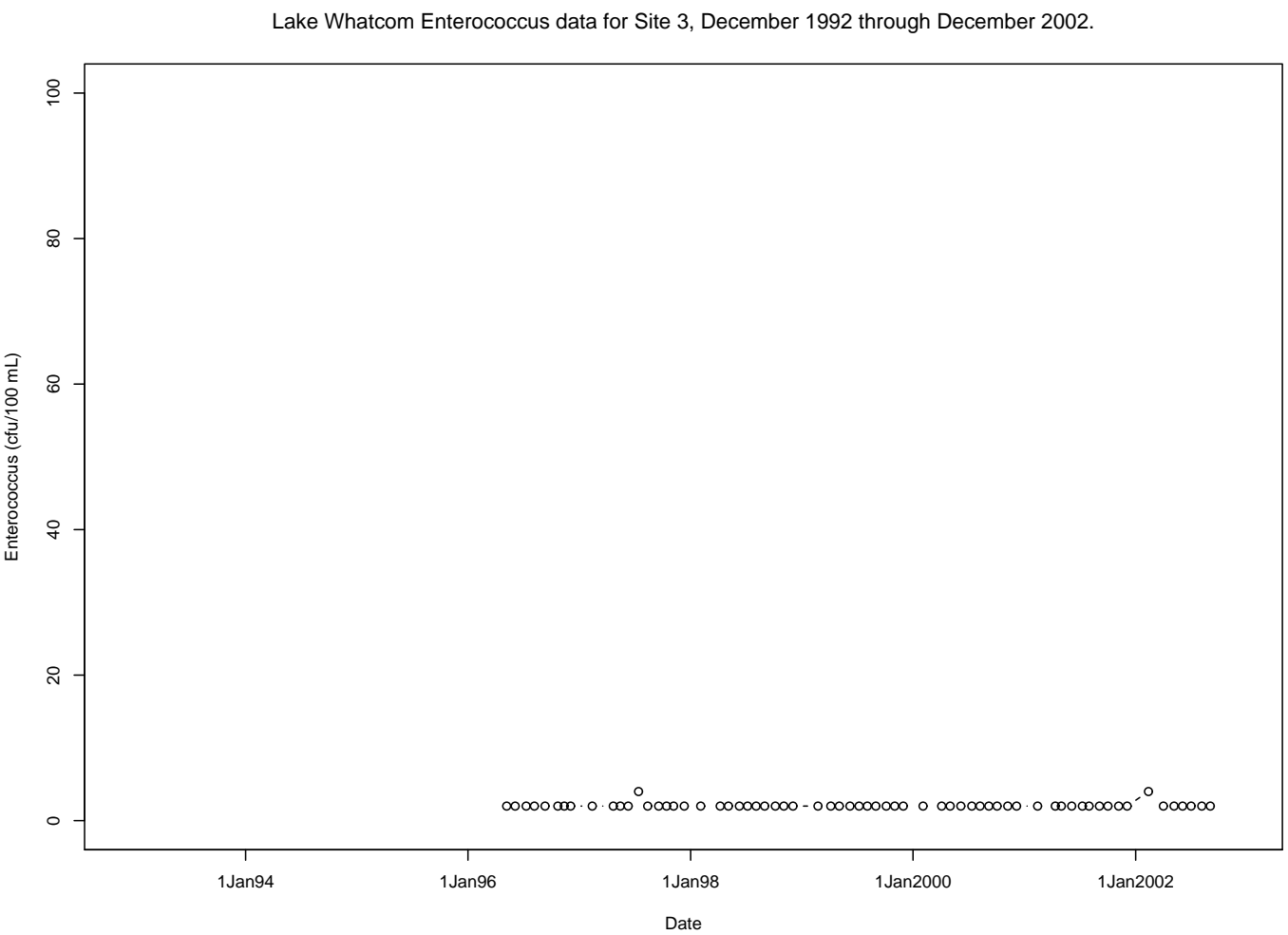


Figure 154: Lake Whatcom *Enterococcus* data for Site 3.

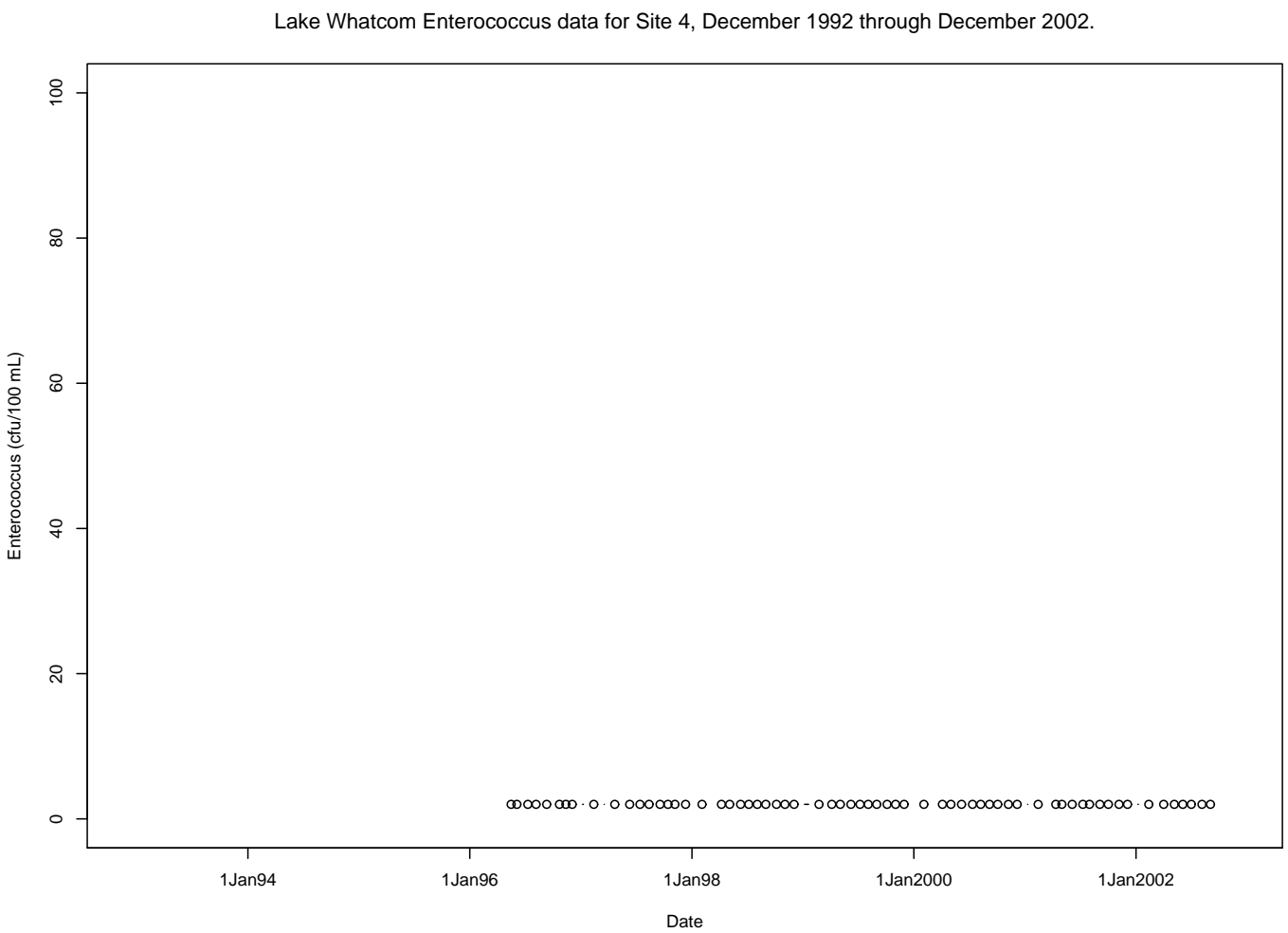


Figure 155: Lake Whatcom *Enterococcus* for Site 4.



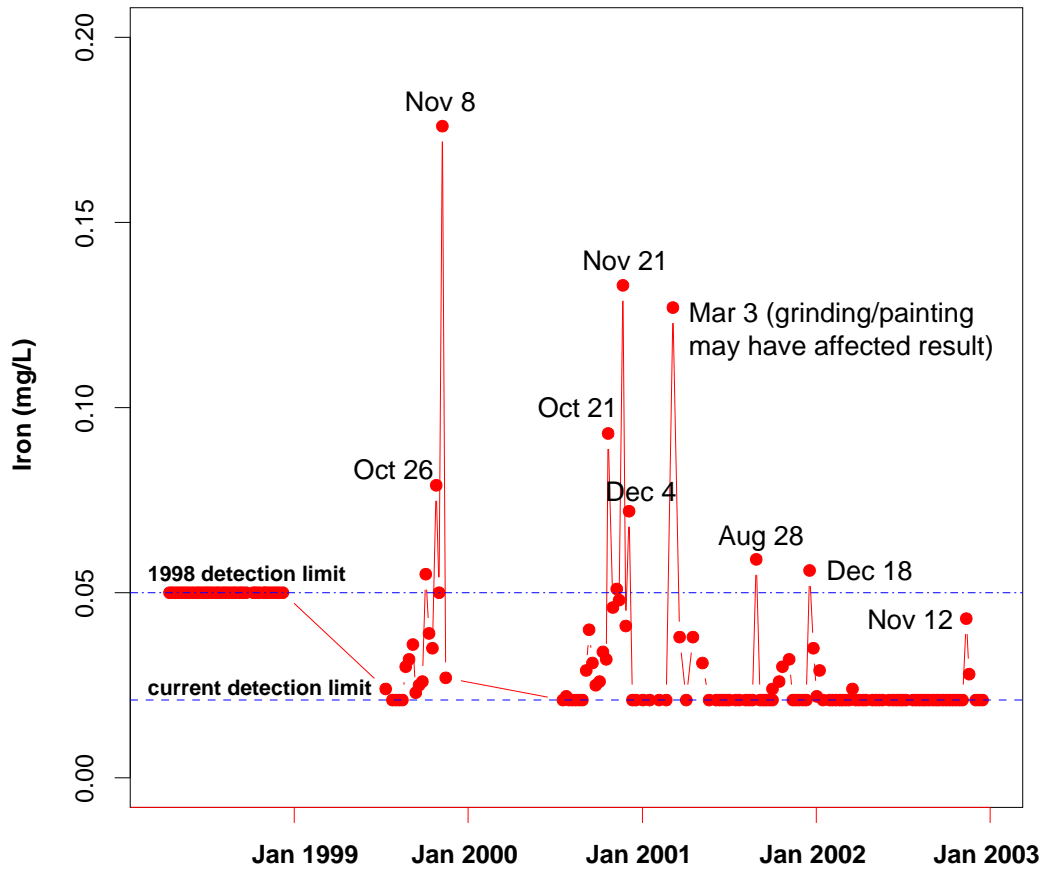


Figure 156: Iron concentration in untreated drinking water measured at the Lake Whatcom gatehouse, 1998–2002. Data were provided by the City of Bellingham Public Works Department.

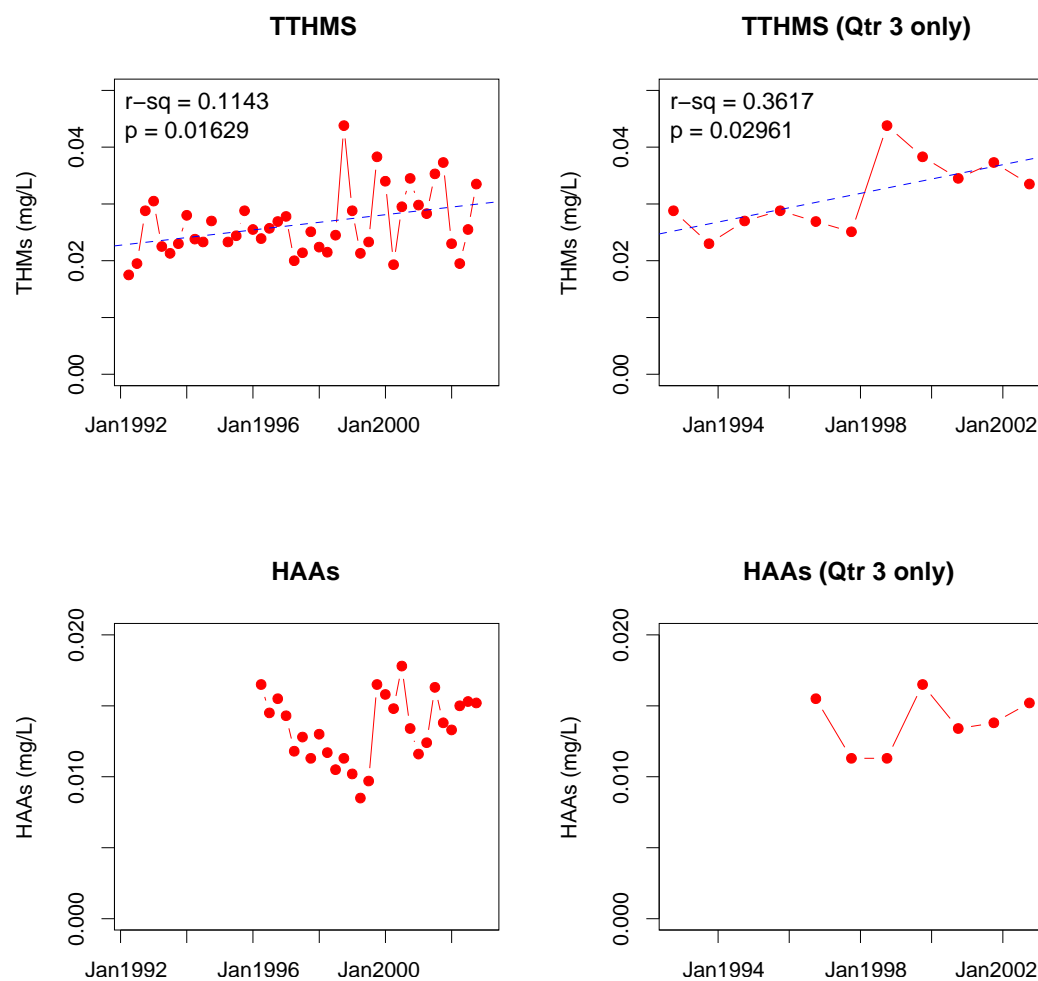


Figure 157: Total trihalomethanes (TTHMs) and haloacetic acids (HAA5) concentrations in the Bellingham water distribution system, 1992–2002 (fall). Regressions for TTHMs and TTHMs (Qtr 3) were statistically significant. Data were provided by the City of Bellingham Public Works Department.

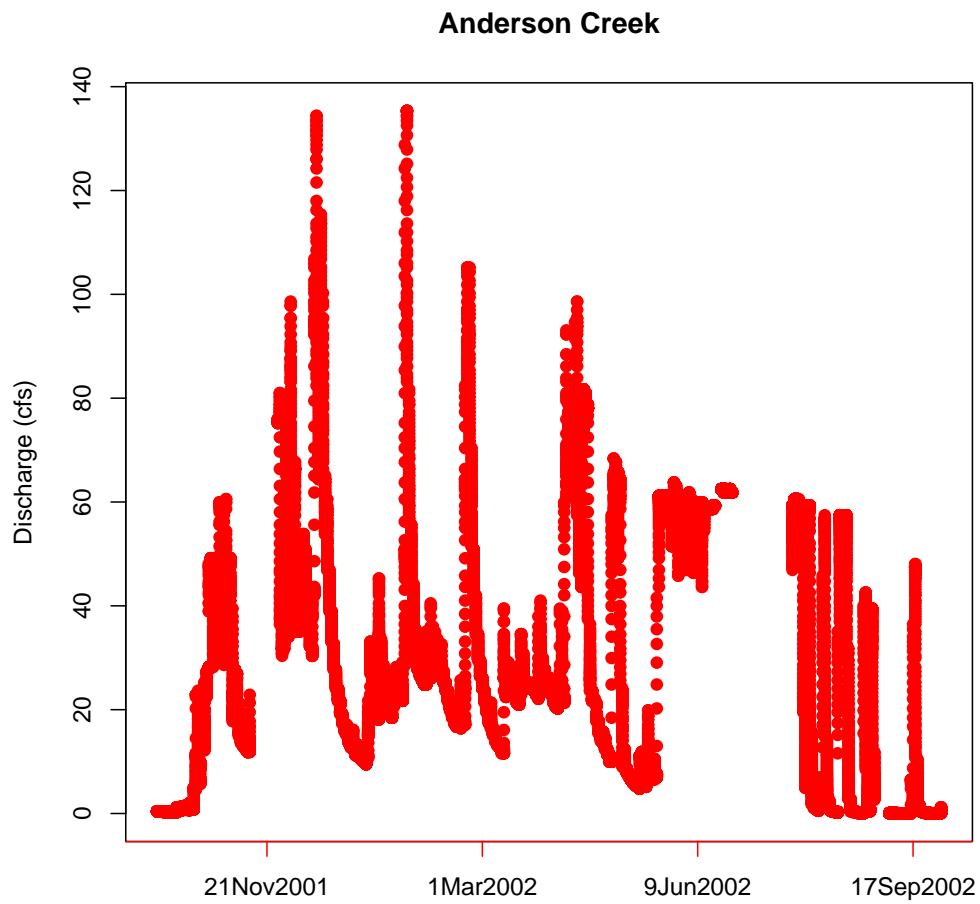


Figure 158: Anderson Creek hydrograph, October 1, 2001–September 30, 2002. Data recording frequency was changed from 30 minute intervals to 15 minute intervals on June 20, 2002.

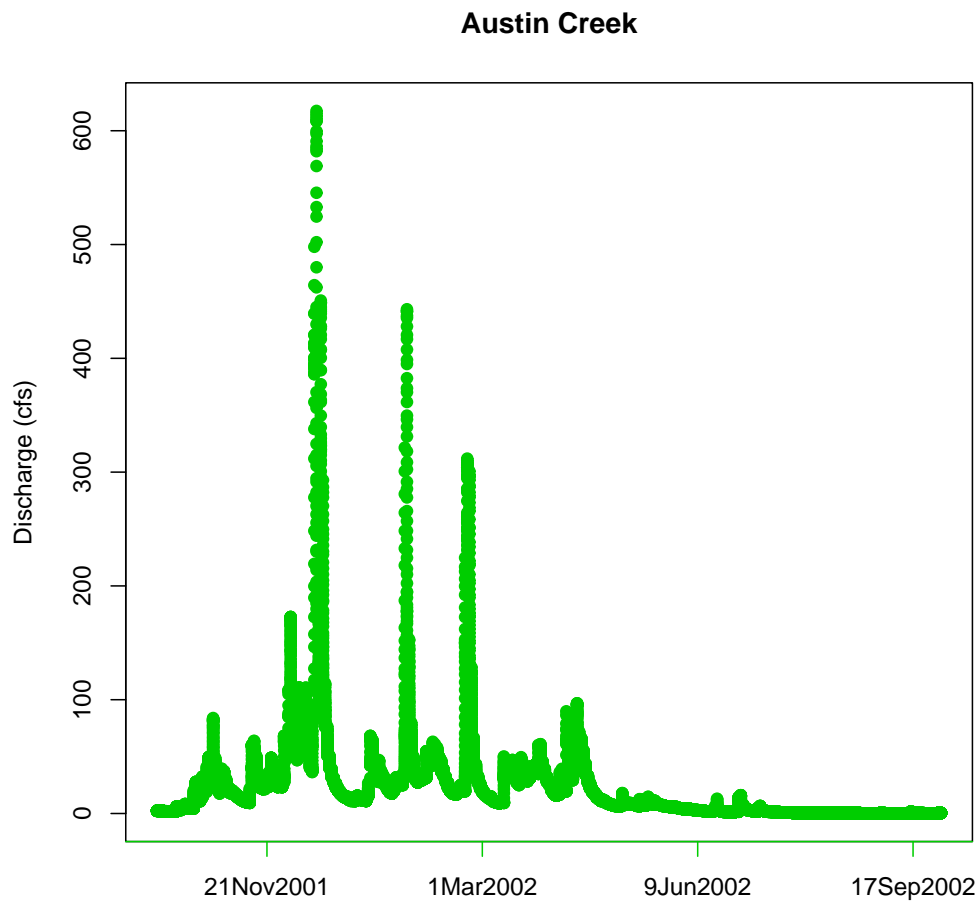


Figure 159: Austin Creek hydrograph, October 1, 2001–September 30, 2002. Data recording frequency was changed from 30 minute intervals to 15 minute intervals on June 20, 2002.

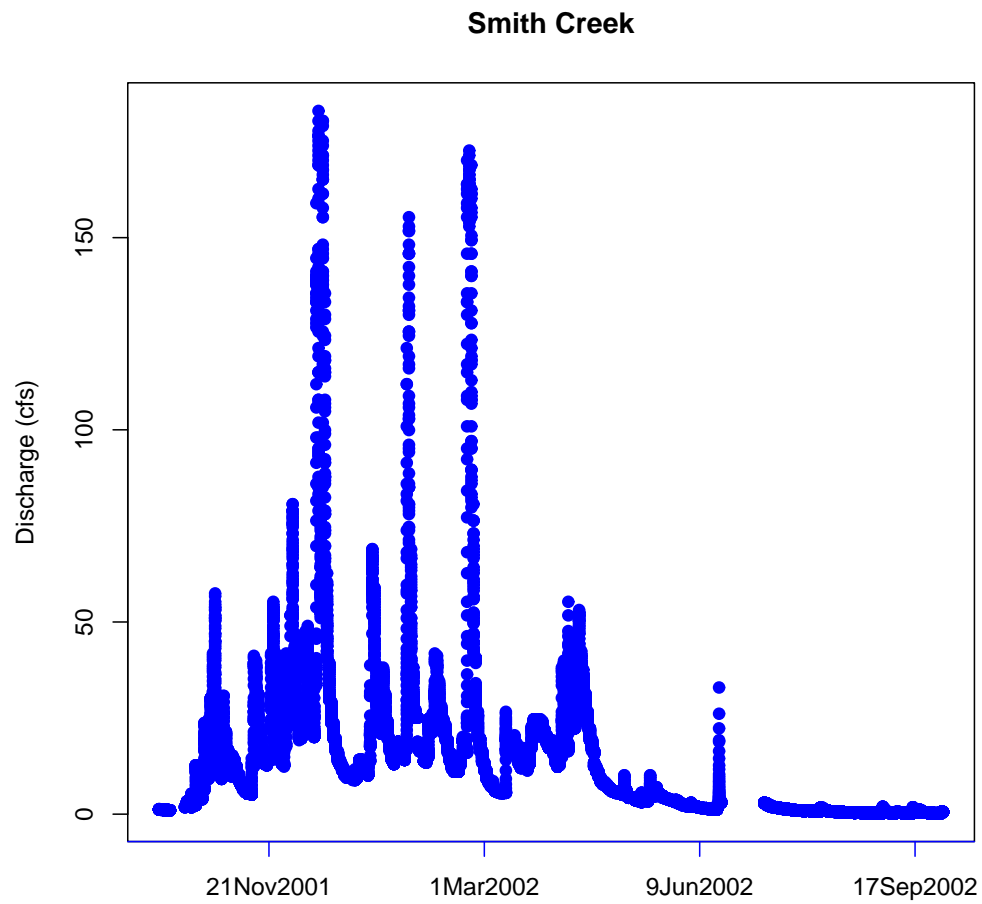


Figure 160: Smith Creek hydrograph, October 1, 2001–September 30, 2002. Data recording frequency was changed from 30 minute intervals to 15 minute intervals on June 20, 2002.

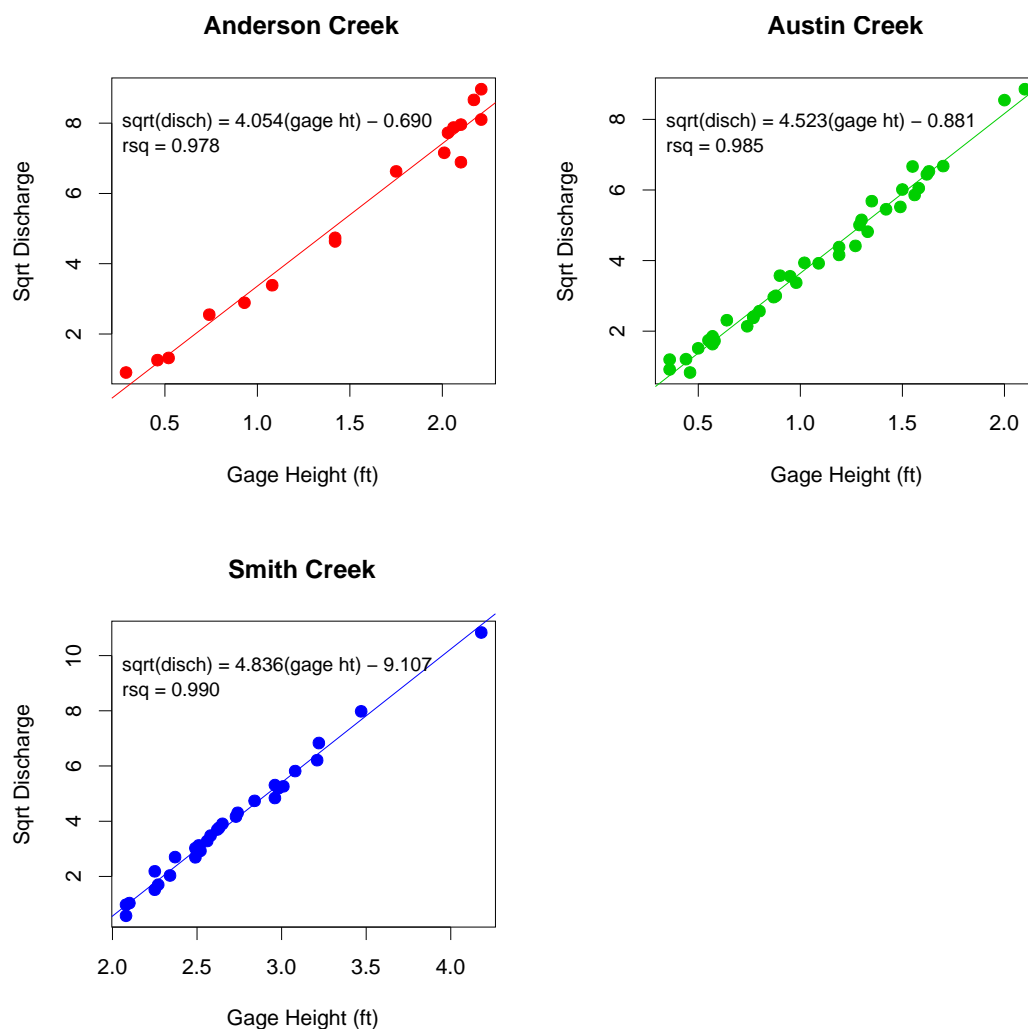


Figure 161: Anderson Creek, Austin Creek, and Smith Creek rating curves, October 1, 2001–September 30, 2002. Regressions show the relationship between gauge height (x) and square root of discharge (y).

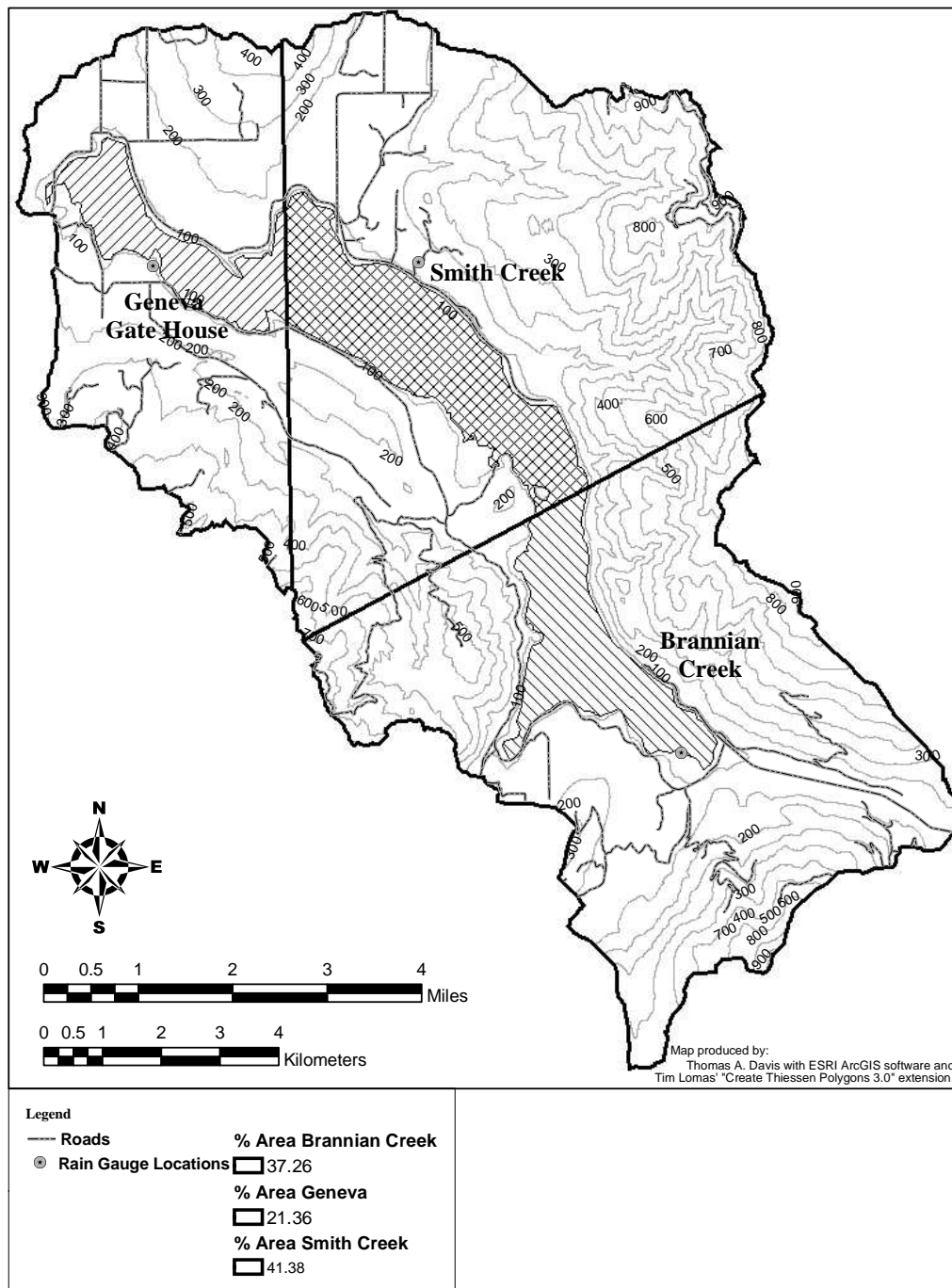


Figure 162: Lake Whatcom watershed precipitation groups and weighted areas, October 1, 2001–September 30, 2002.

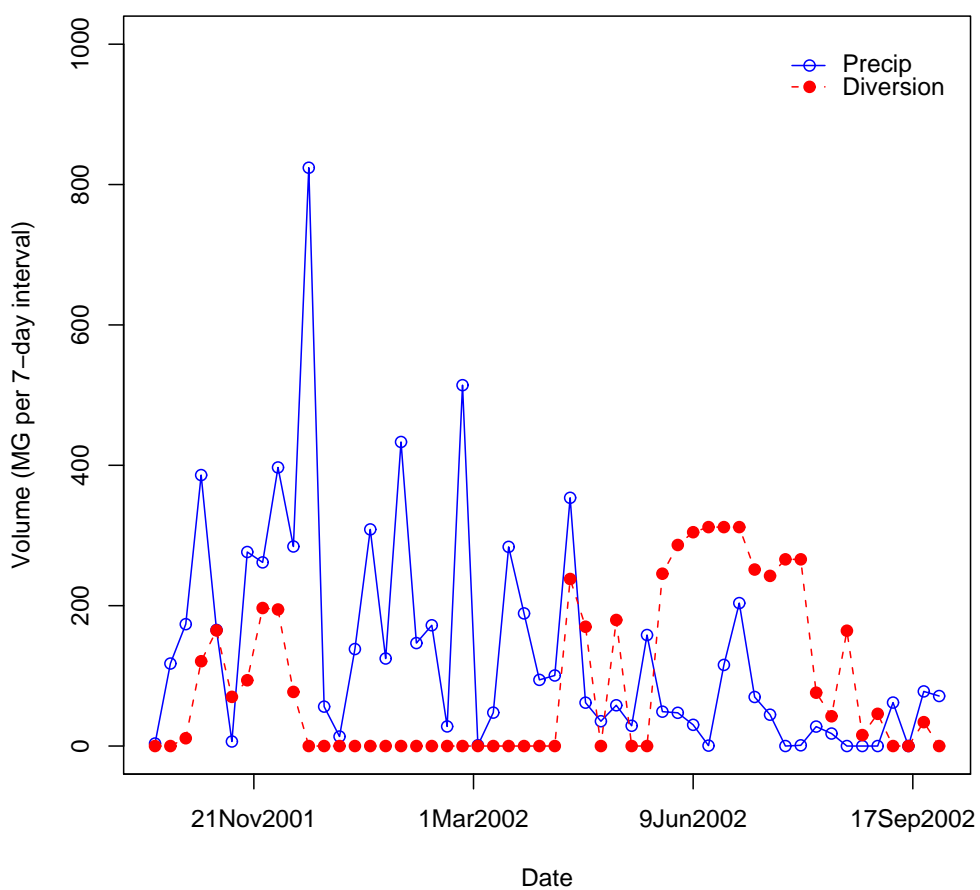


Figure 163: Lake Whatcom watershed direct hydrologic inputs, October 1, 2001–September 30, 2002.



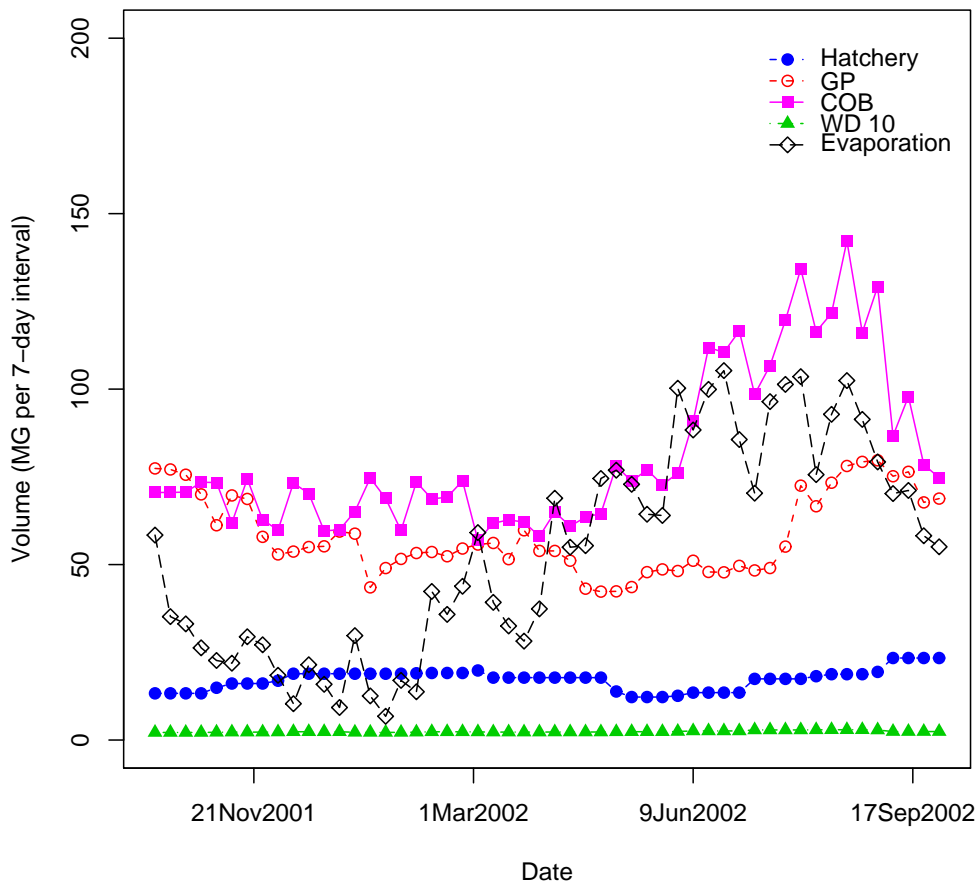


Figure 164: Lake Whatcom watershed hydrologic withdrawals, October 1, 2001–September 30, 2002.

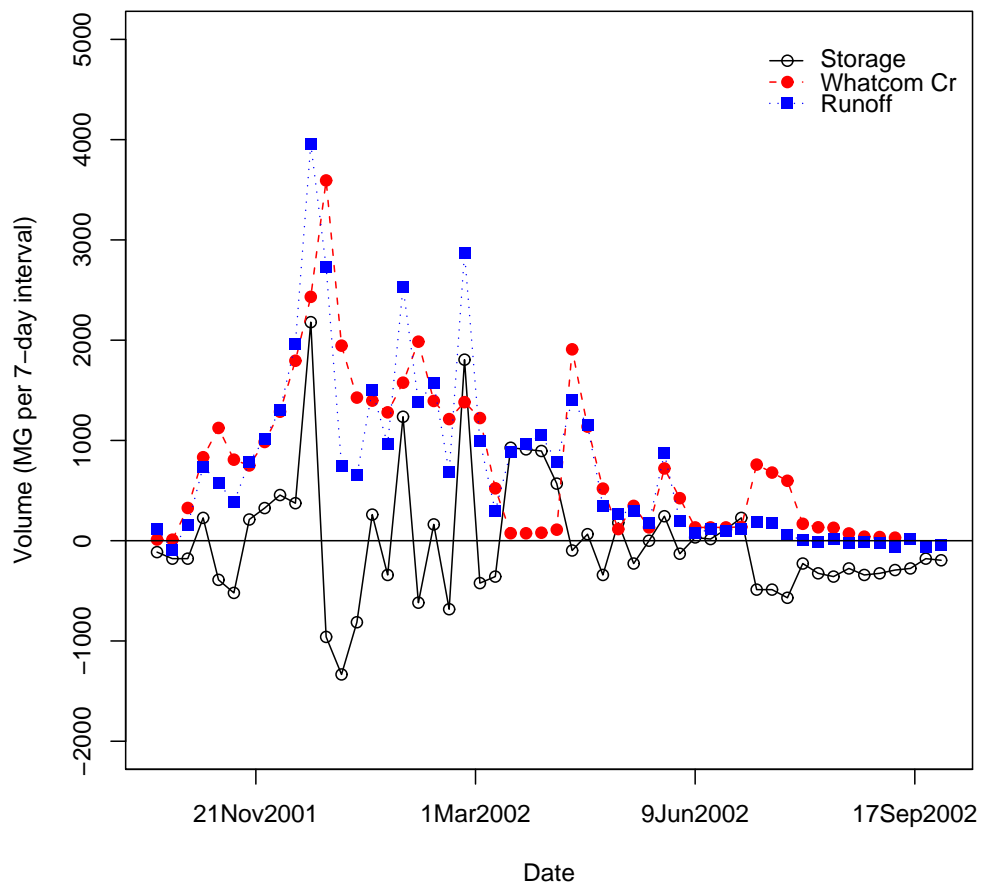


Figure 165: Change in Lake Whatcom storage, October 1, 2001–September 30, 2002.

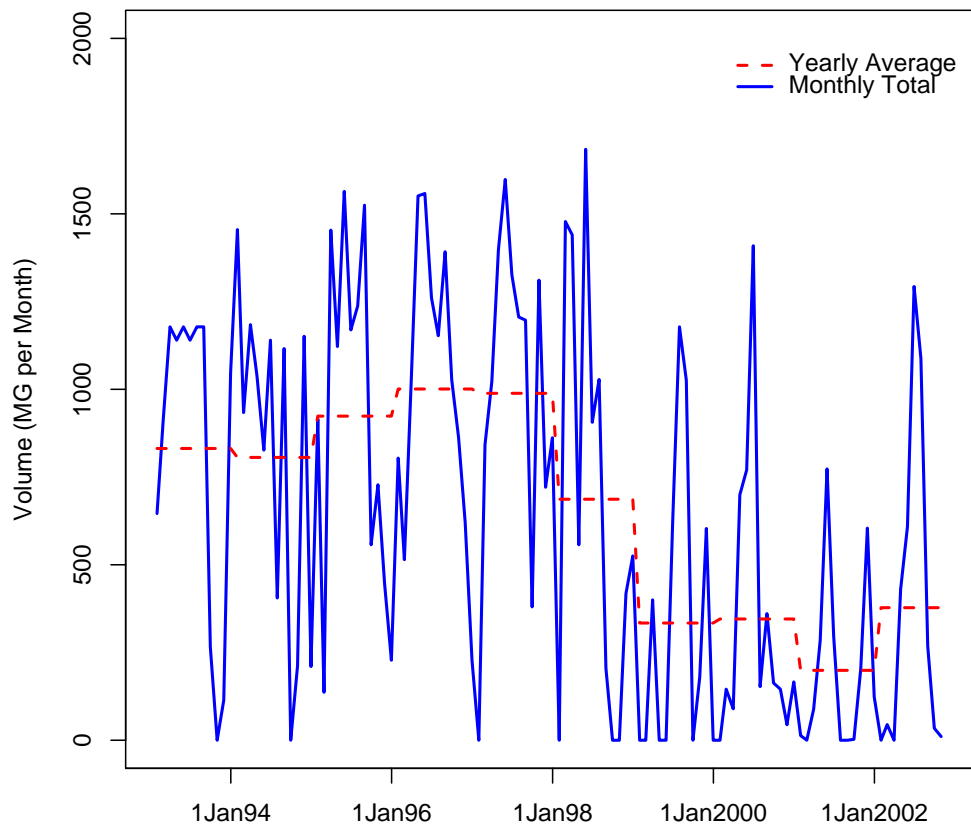


Figure 166: Middle Fork diversion flow into Lake Whatcom, 1993–2002.

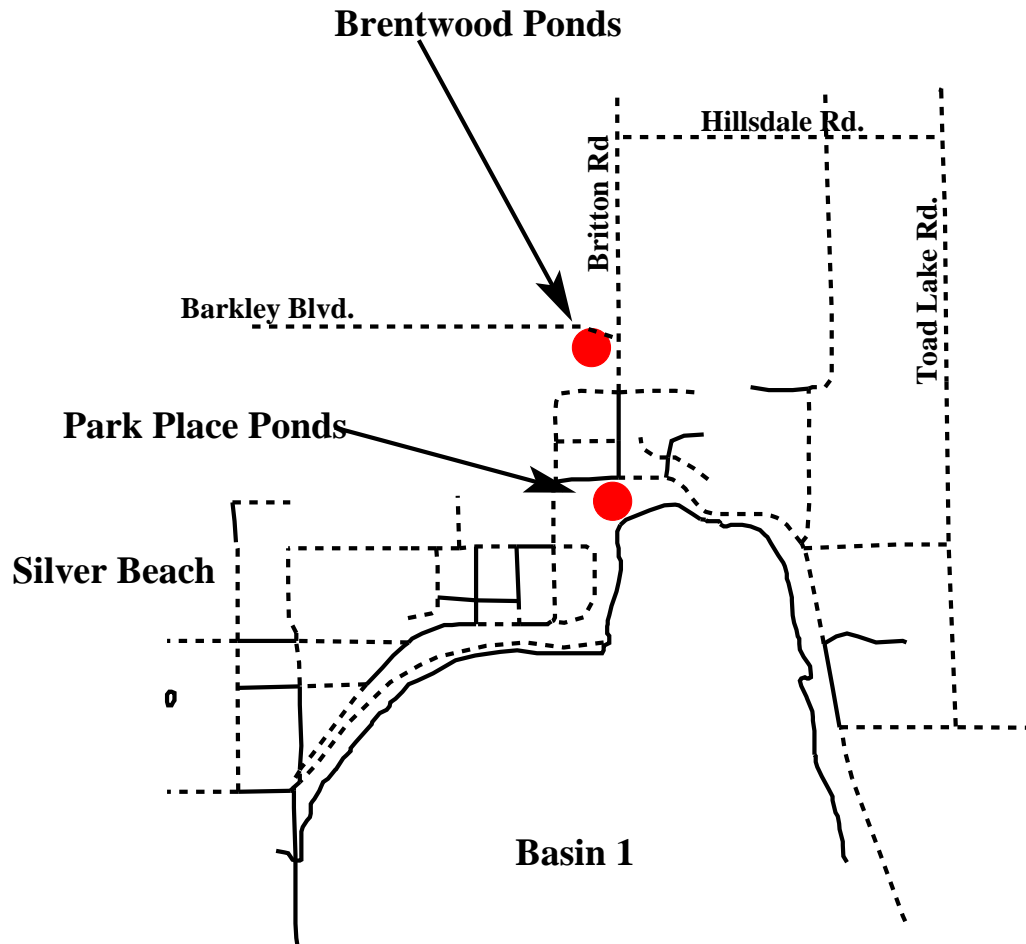


Figure 167: Locations of the sampling sites for the Park Place and Brentwood wet ponds.

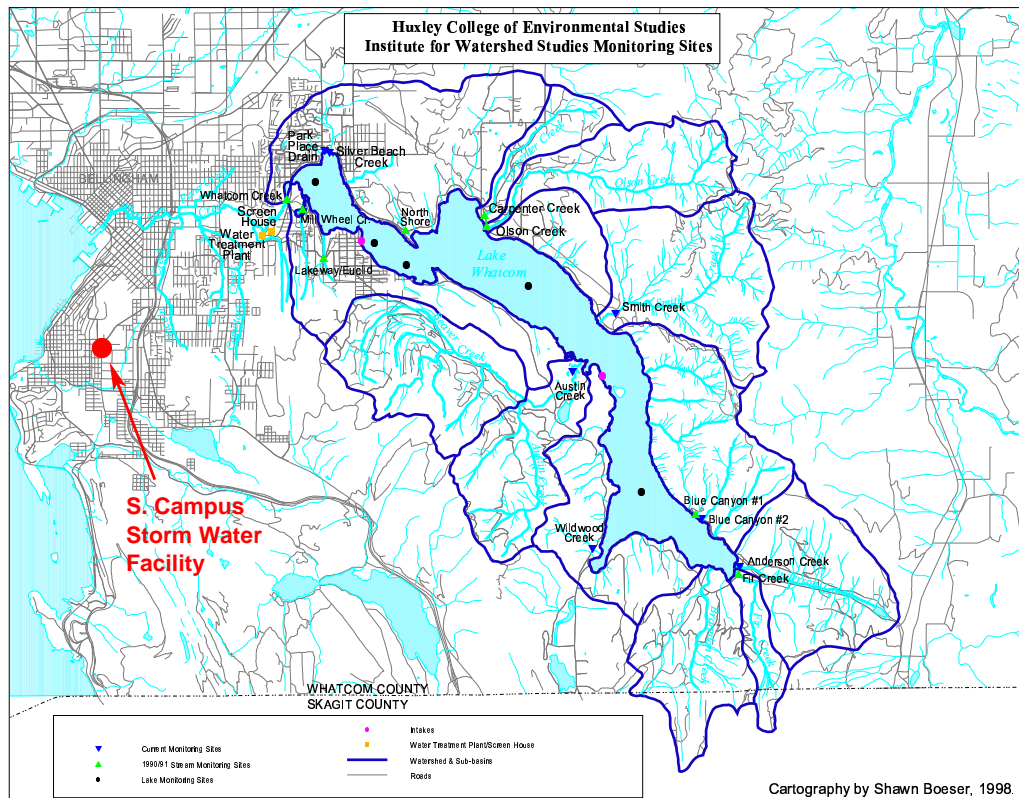


Figure 168: Locations of the South Campus storm water treatment facility.



Figure 169: Brentwood wet pond, December 17, 2001, cell 3.



Figure 170: Park Place wet pond, July 16, 2002.





Figure 171: South Campus storm water treatment facility, January 10 2002.



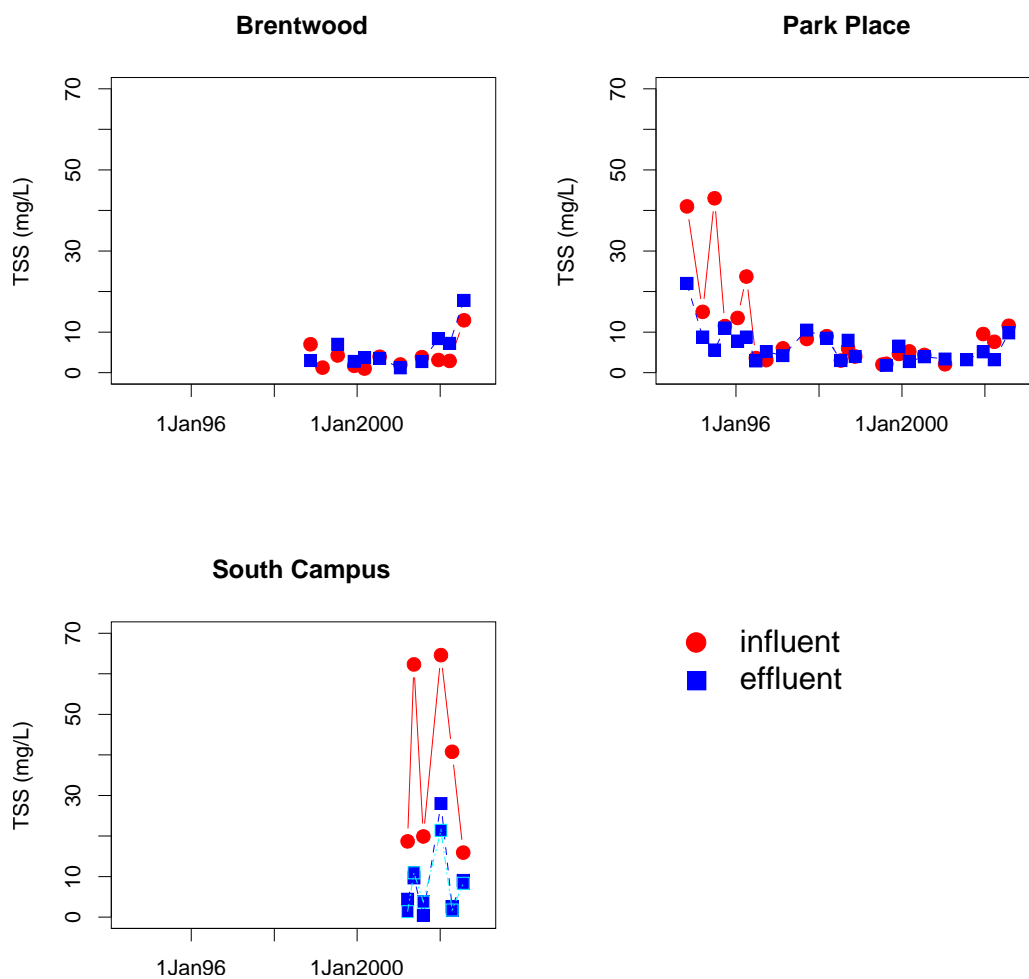


Figure 172: Total suspended solids concentrations in the influent and effluent from the Park Place and Brentwood wet ponds and the South Campus rock/plant filter.

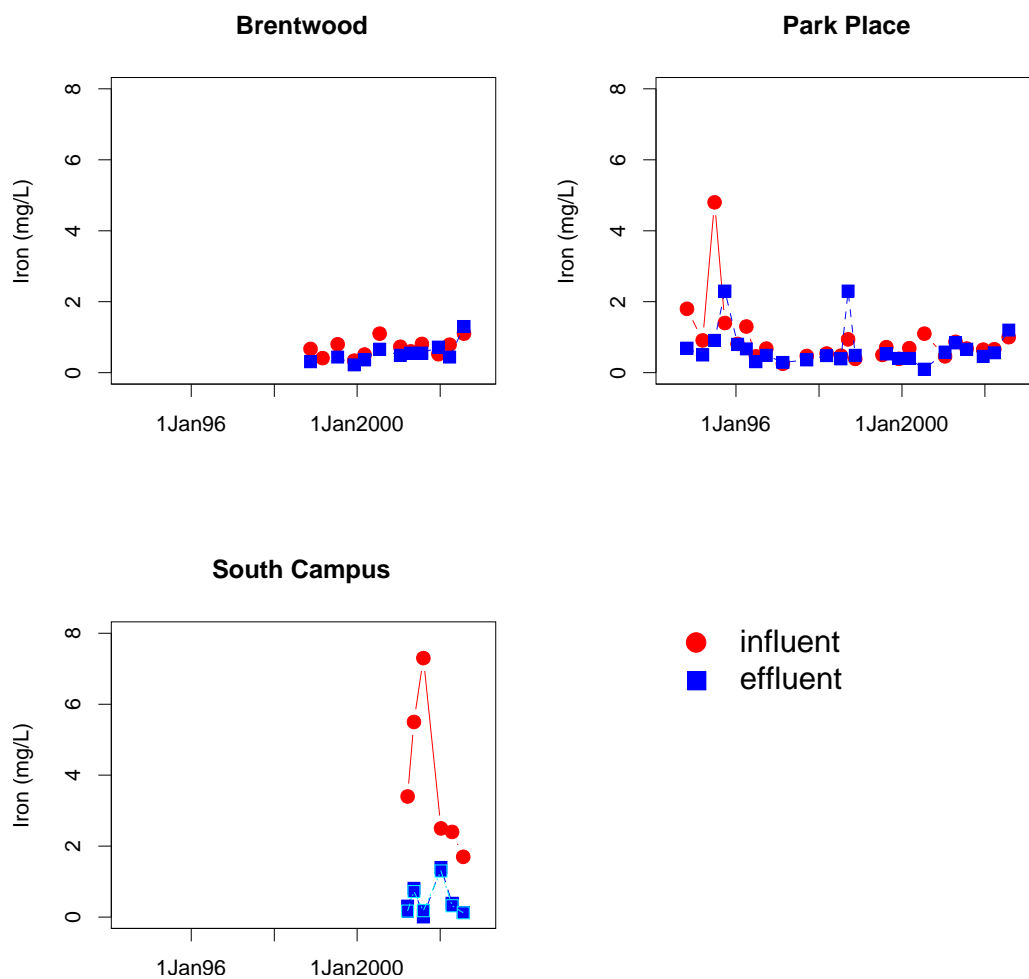


Figure 173: Total iron concentrations in the influent and effluent from the Park Place and Brentwood wet ponds and the South Campus rock/plant filter.

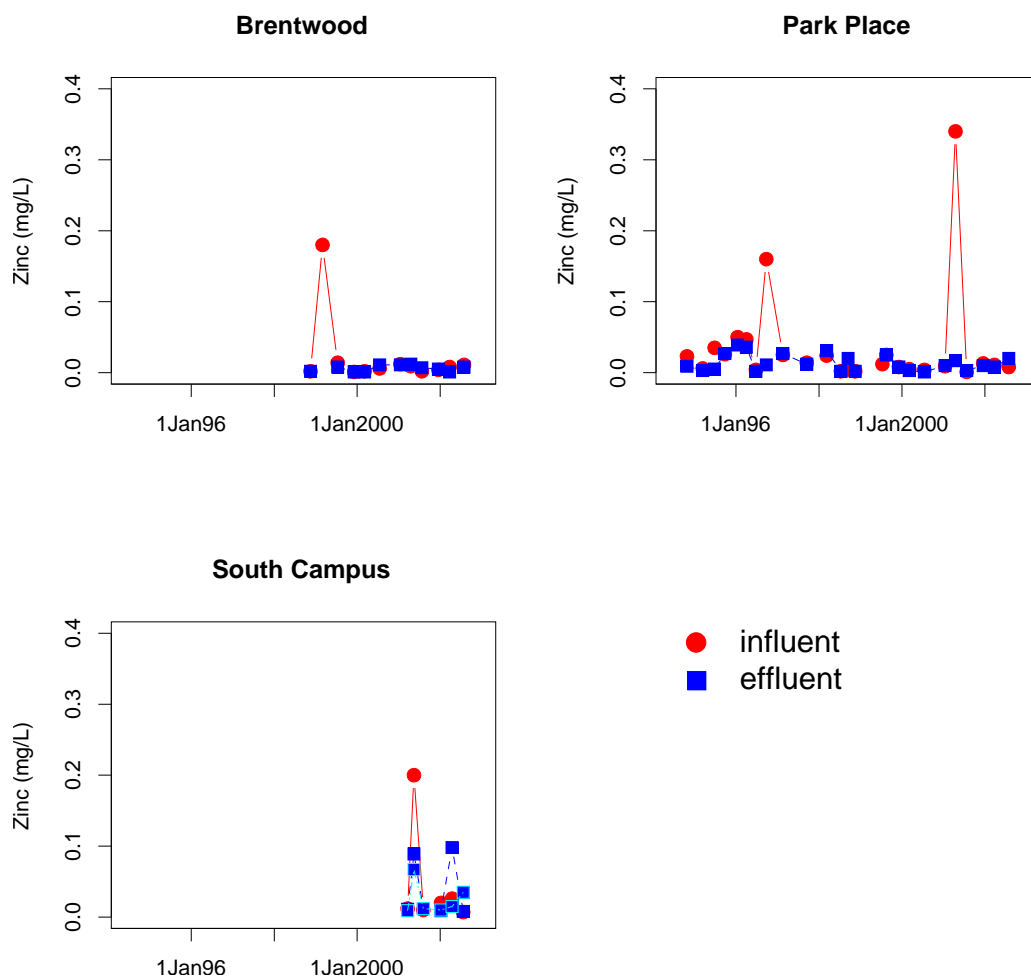
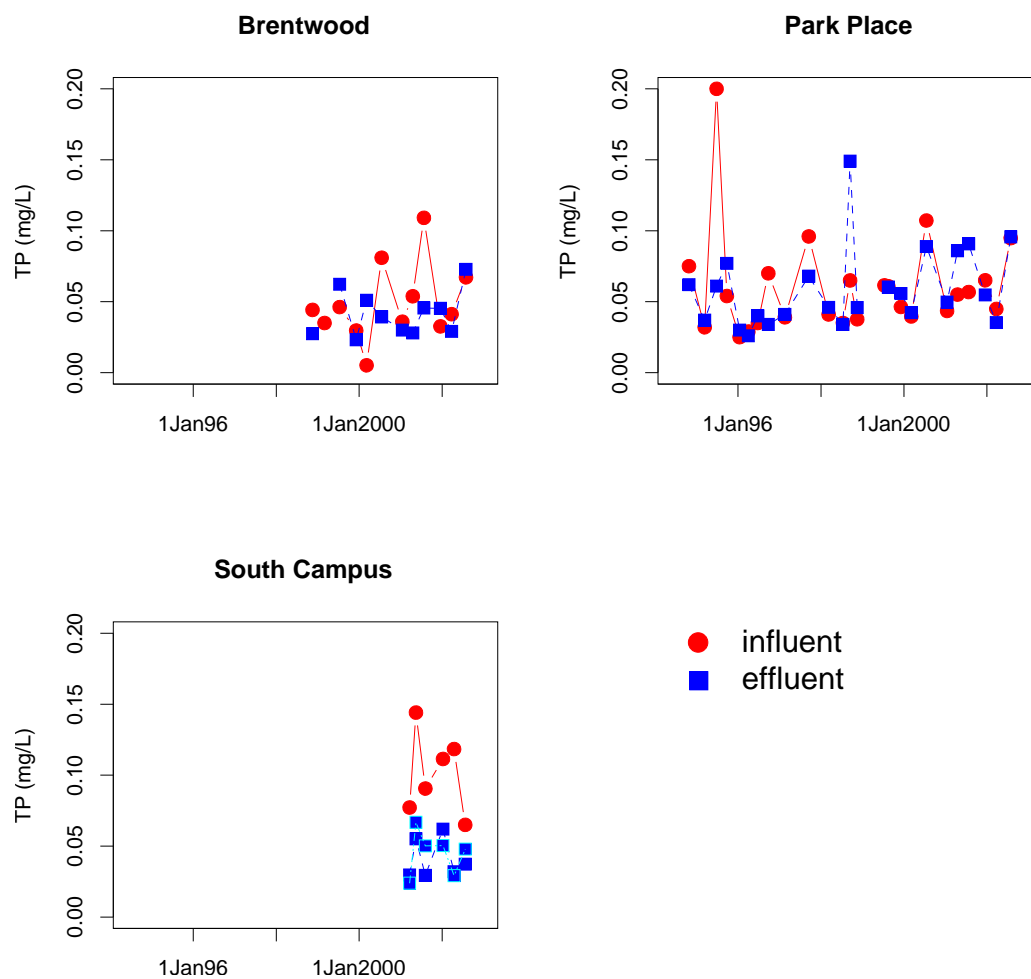


Figure 174: Total zinc concentrations in the influent and effluent from the Park Place and Brentwood wet ponds and the South Campus rock/plant filter.



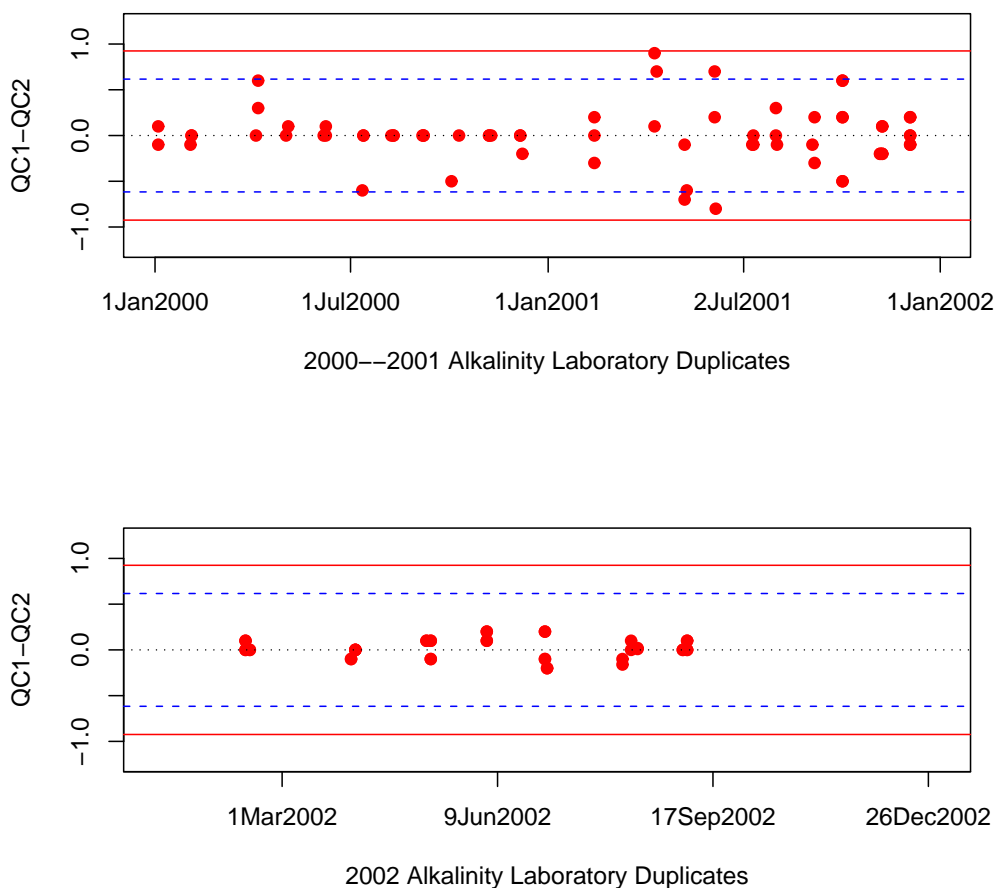


Figure 176: Alkalinity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

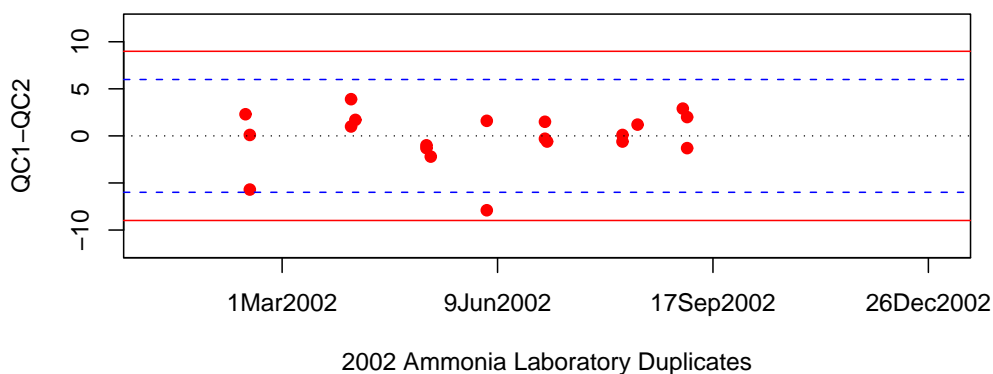
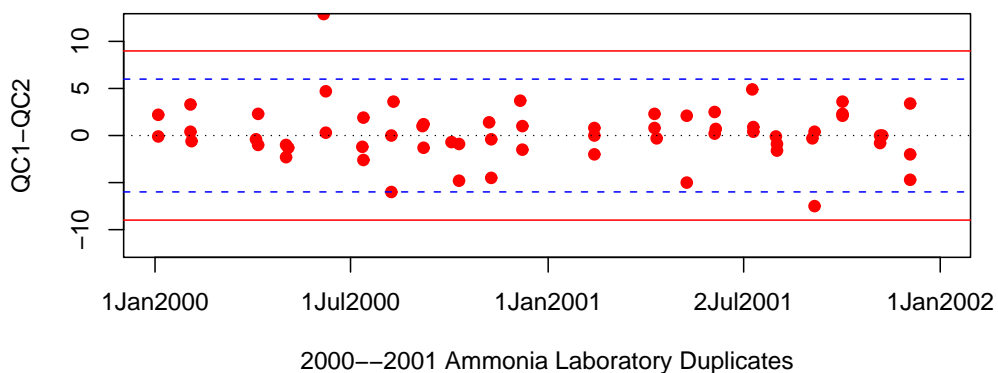


Figure 177: Ammonia laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceeding two years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

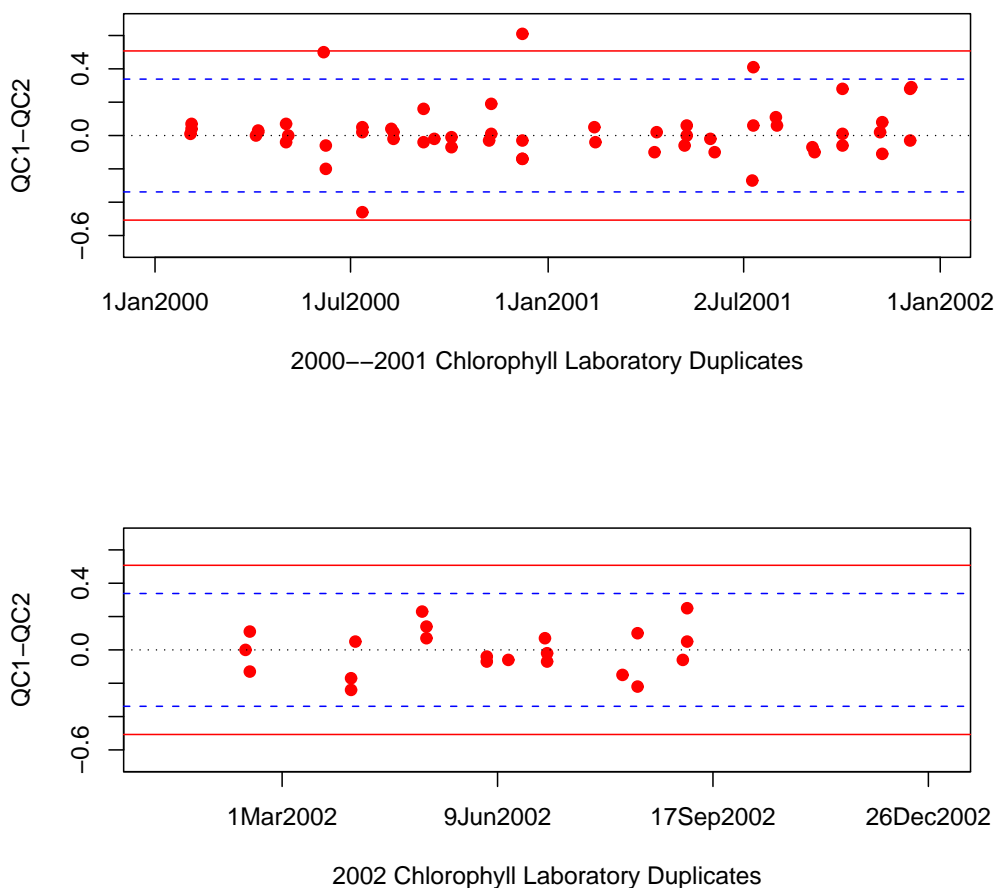


Figure 178: Chlorophyll laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceeding two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

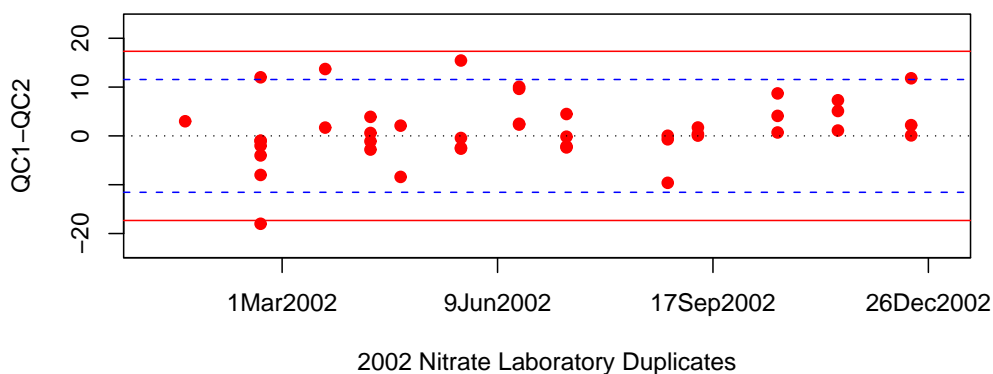
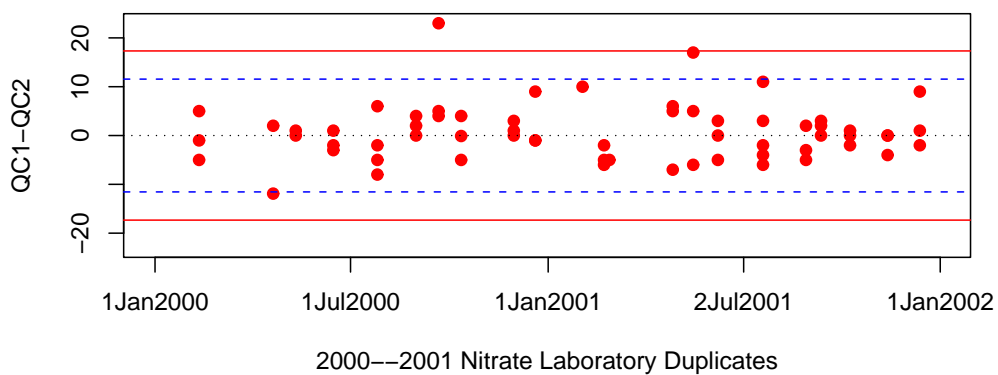


Figure 179: Nitrate/nitrite laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceeding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



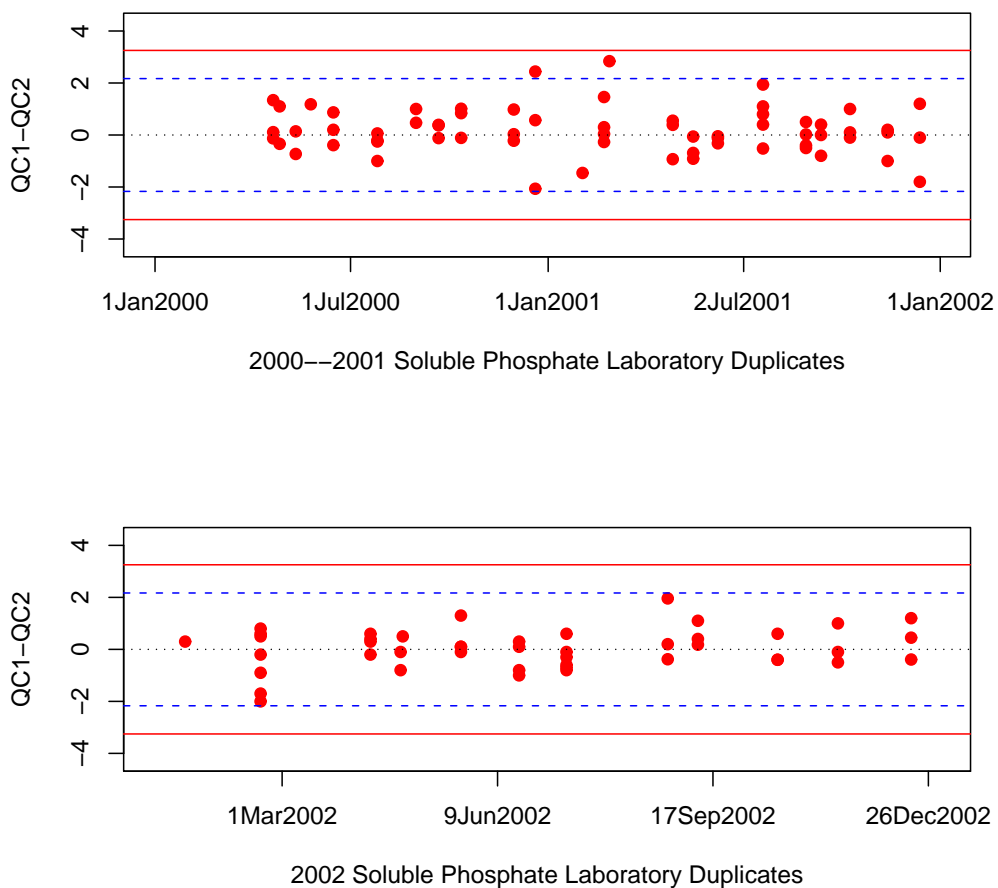


Figure 180: Soluble reactive phosphate laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the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

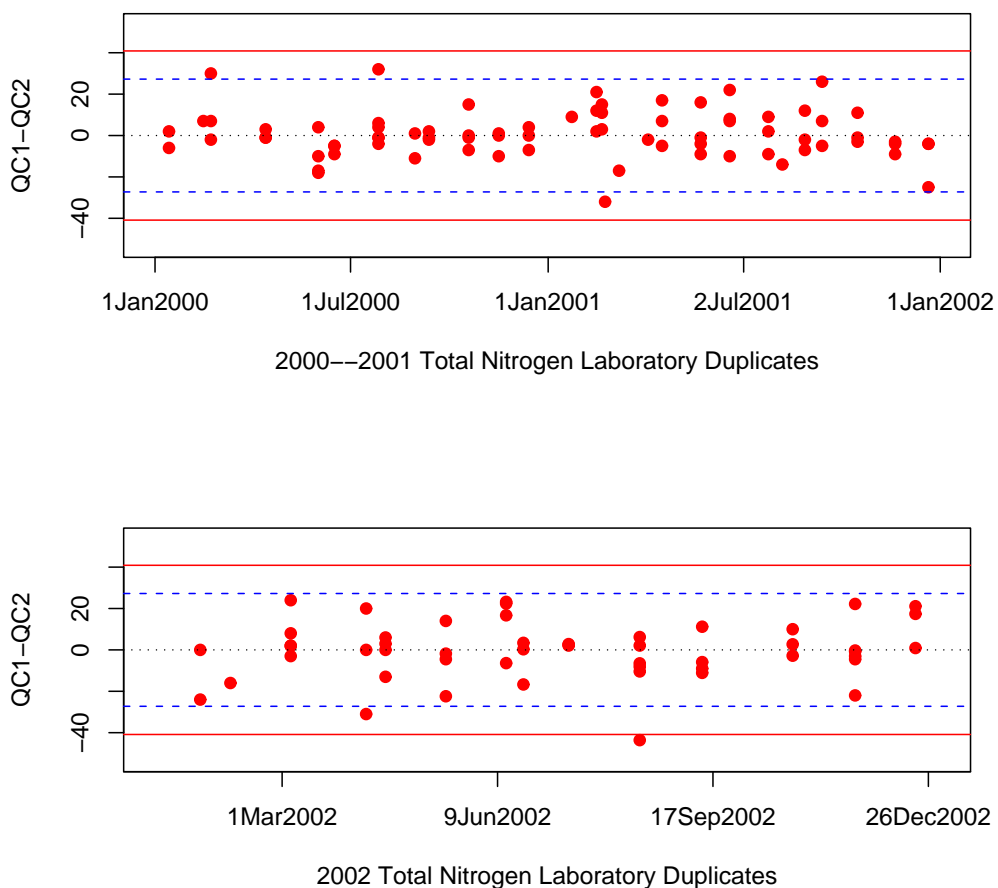


Figure 181: Total nitrogen laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceeding two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

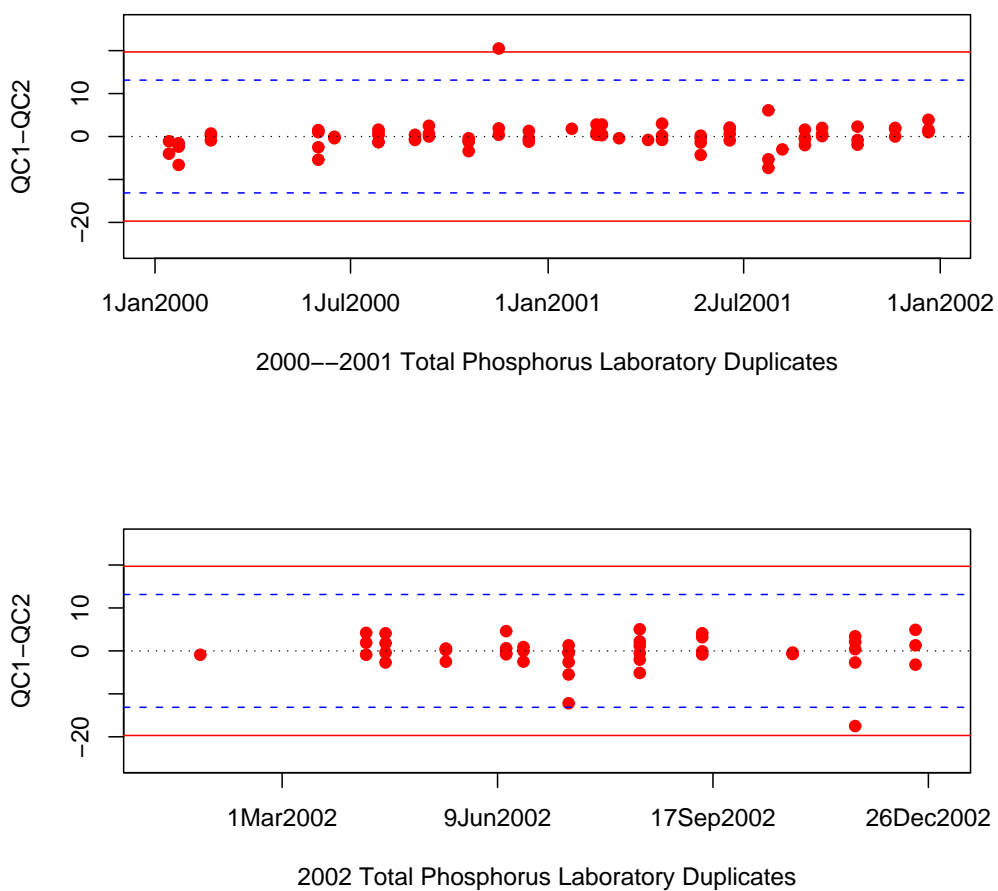


Figure 182: Total phosphorus laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceeding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

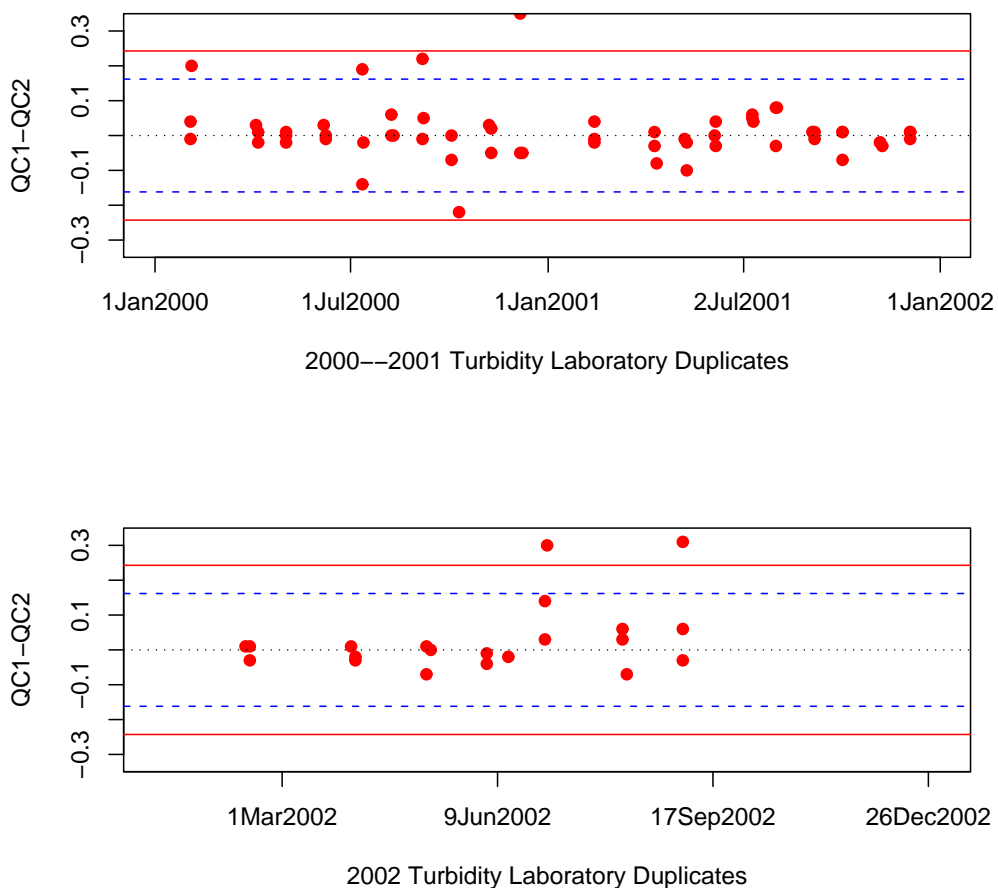


Figure 183: Turbidity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceeding two years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

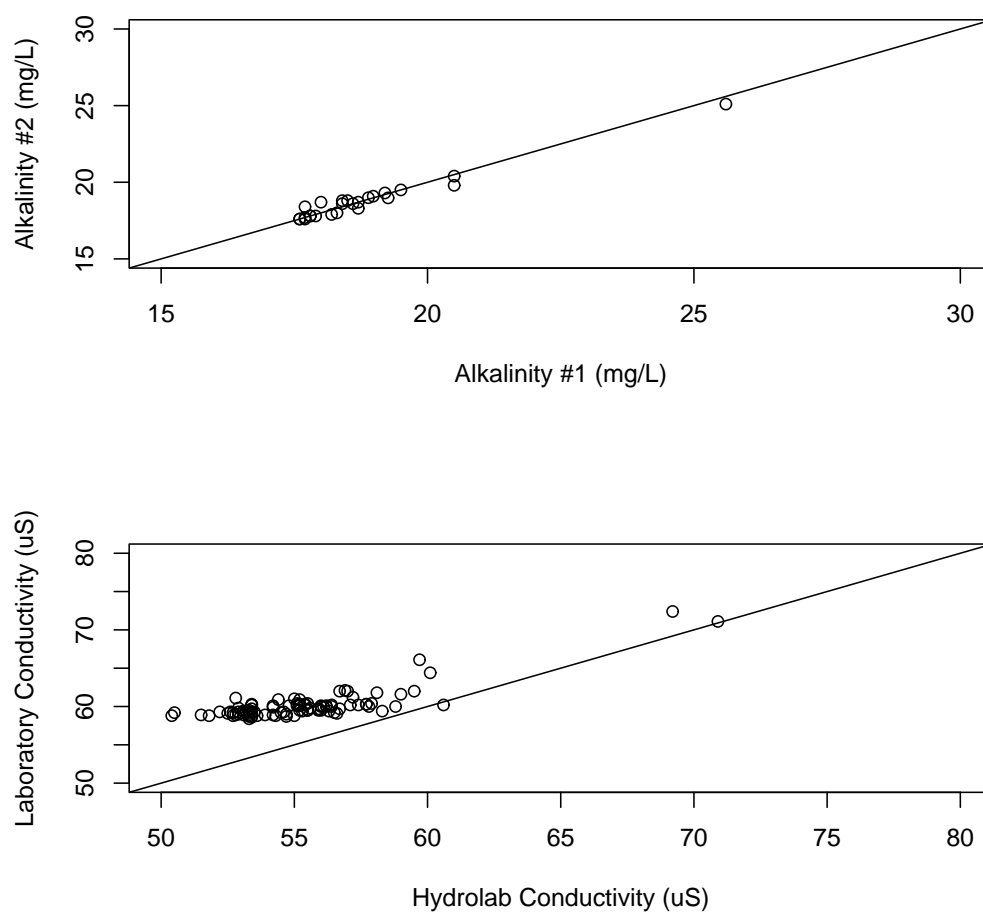


Figure 184: Alkalinity and conductivity field duplicates.

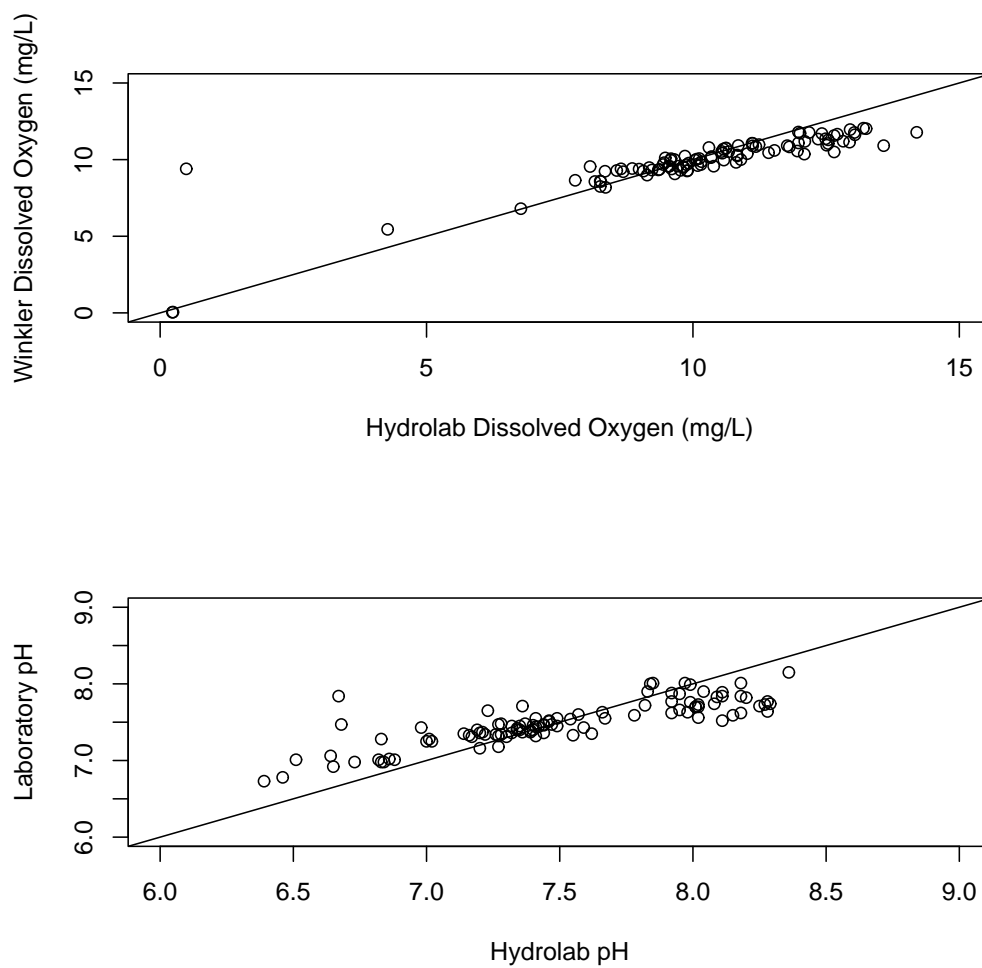


Figure 185: Dissolved oxygen and pH field duplicates.

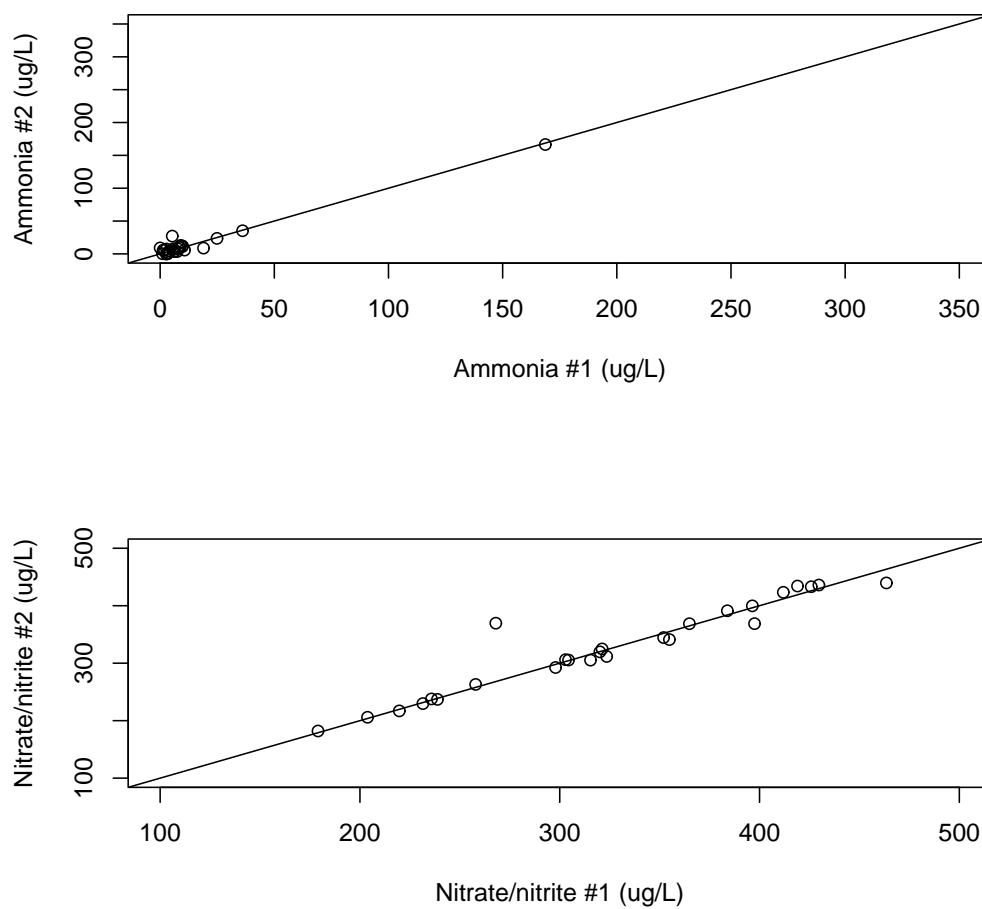


Figure 186: Ammonia and nitrate/nitrite field duplicates.

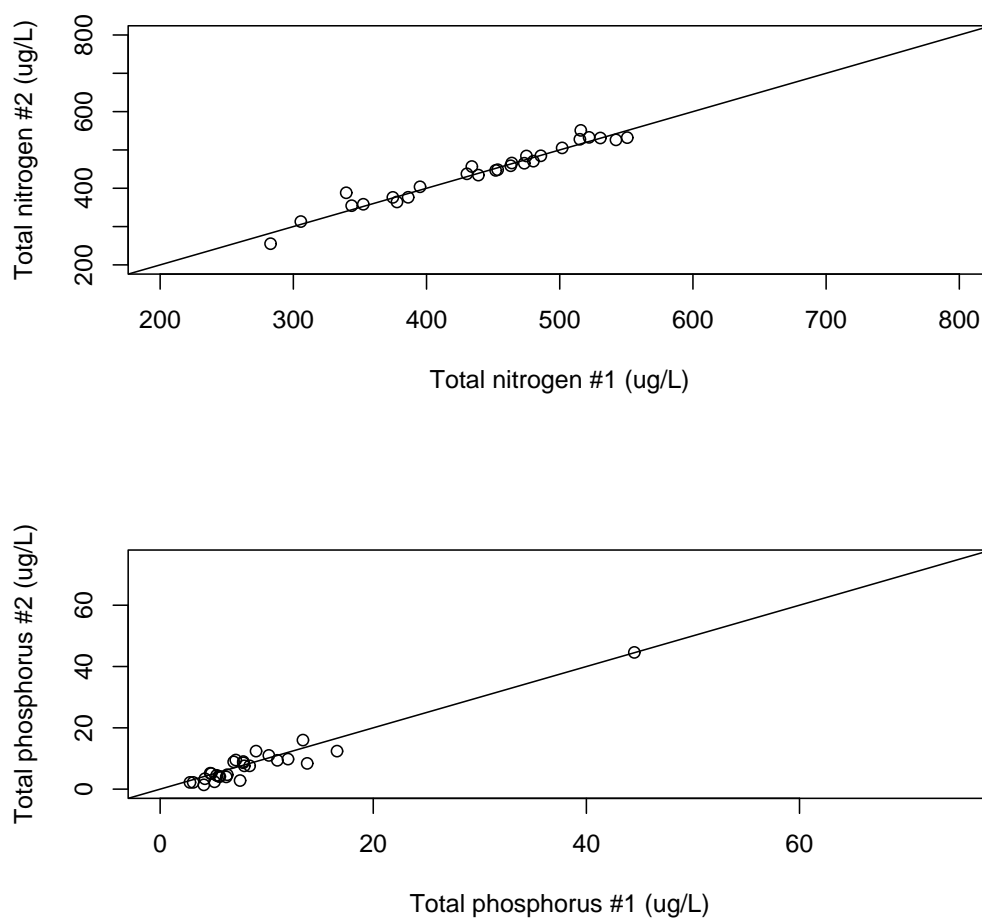


Figure 187: Total nitrogen and total phosphorus field duplicates.



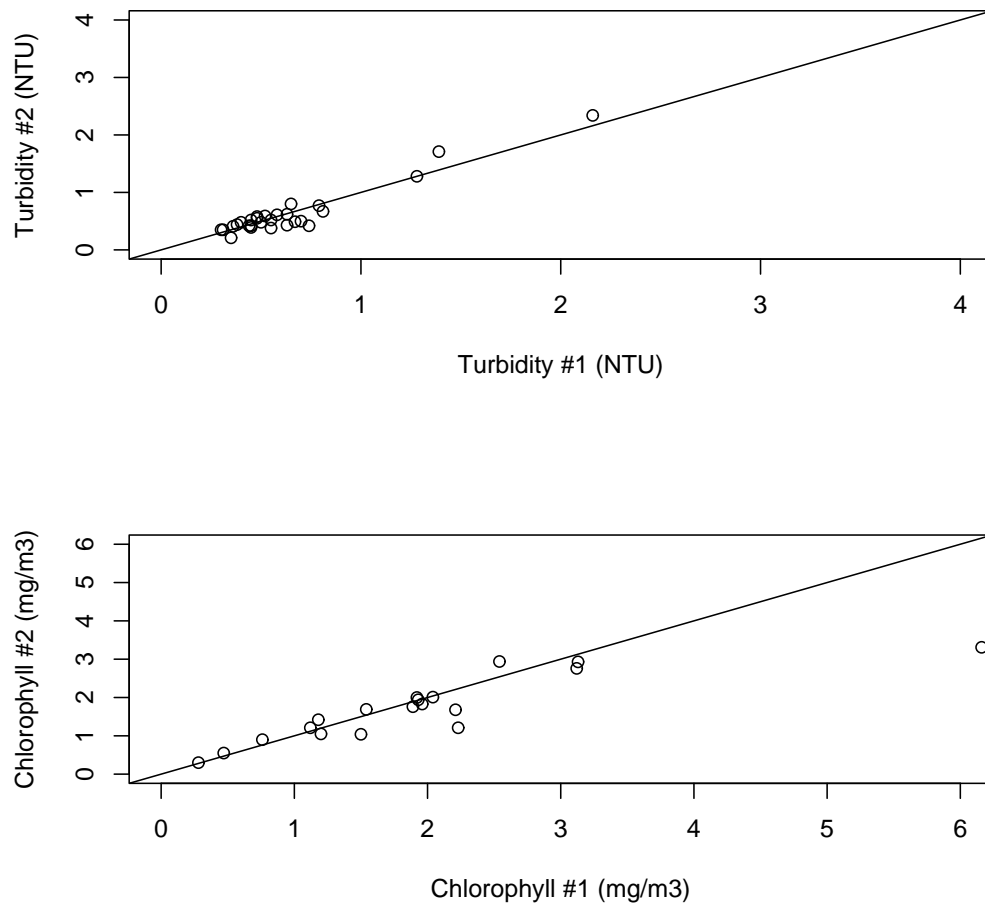


Figure 188: Turbidity and chlorophyll field duplicates.

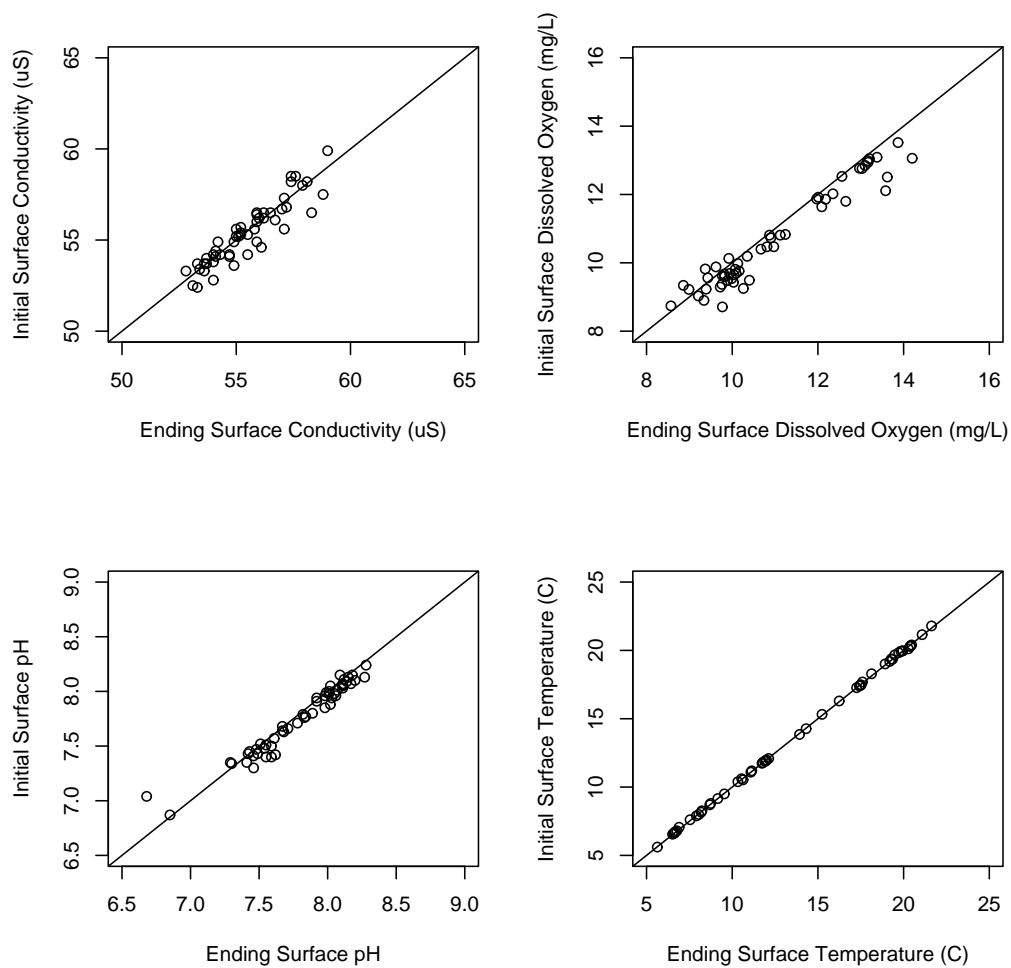


Figure 189: Comparison between initial and ending surface Hydrolab readings.

## A Site Descriptions

### A.1 Lake Whatcom Monitoring Sites

Please refer to Figures 190–192 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 37 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 locator. 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 192. There are no permanent buoys at these sites; depth is determined at each site using an electronic depth finder. At present, water samples are only collected at site s2.

**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 gate-house. This site is one of the more difficult sites to locate because the marker buoy is frequently missing. The depth at the Intake site should be at least 13 m deep. The GPS coordinates for the Intake site on August 5, 1993 were: 48° 44.89 N, 122° 23.47 W.

**Site 3** is located mid-basin just north of a line between the old railroad bridge and Lakewood. The depth at Site 3 should be at least 80 m deep. The GPS coordinates for Site 3 on August 5, 1993 were: 48° 44.27 N, 122° 20.25 W.

**Site 4** is located at the intersection of a line between two points of land and a line parallel to the north edge of an inlet (see Figure A2). The depth at Site 4 should be at least 90 m deep. The GPS coordinates for Site 4 on August 5, 1993 were: 48° 41.53 N, 122° 18.01 W.

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

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

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

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

Table 37: Summary of site codes for Lake Whatcom water quality sampling.

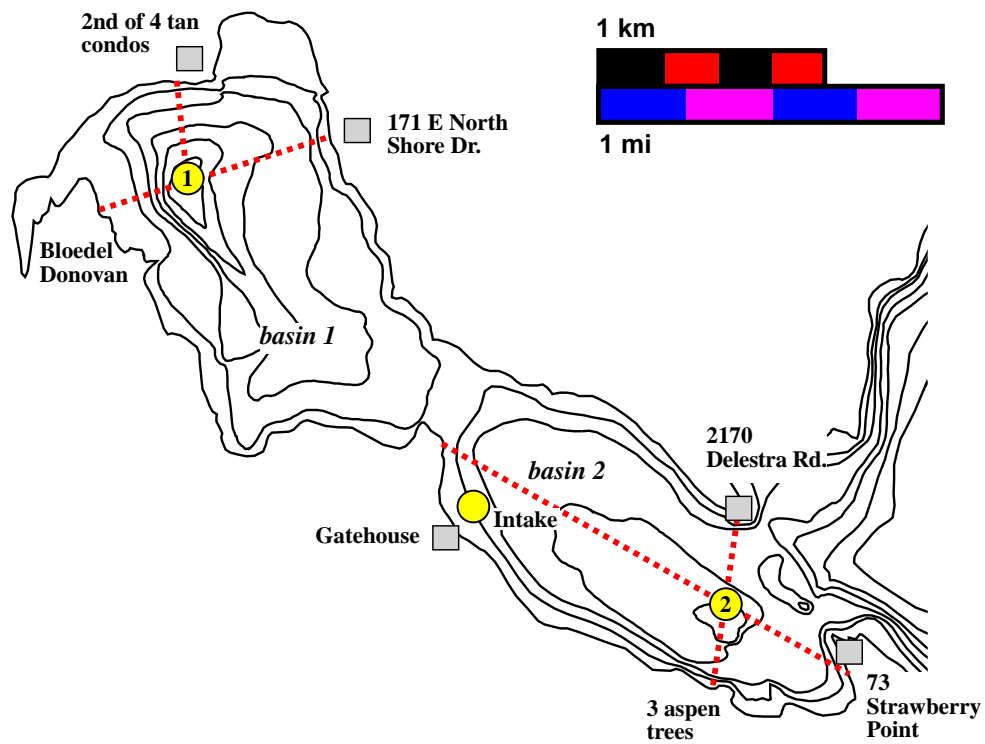


Figure 190: Lake Whatcom sampling sites, basins 1–2.

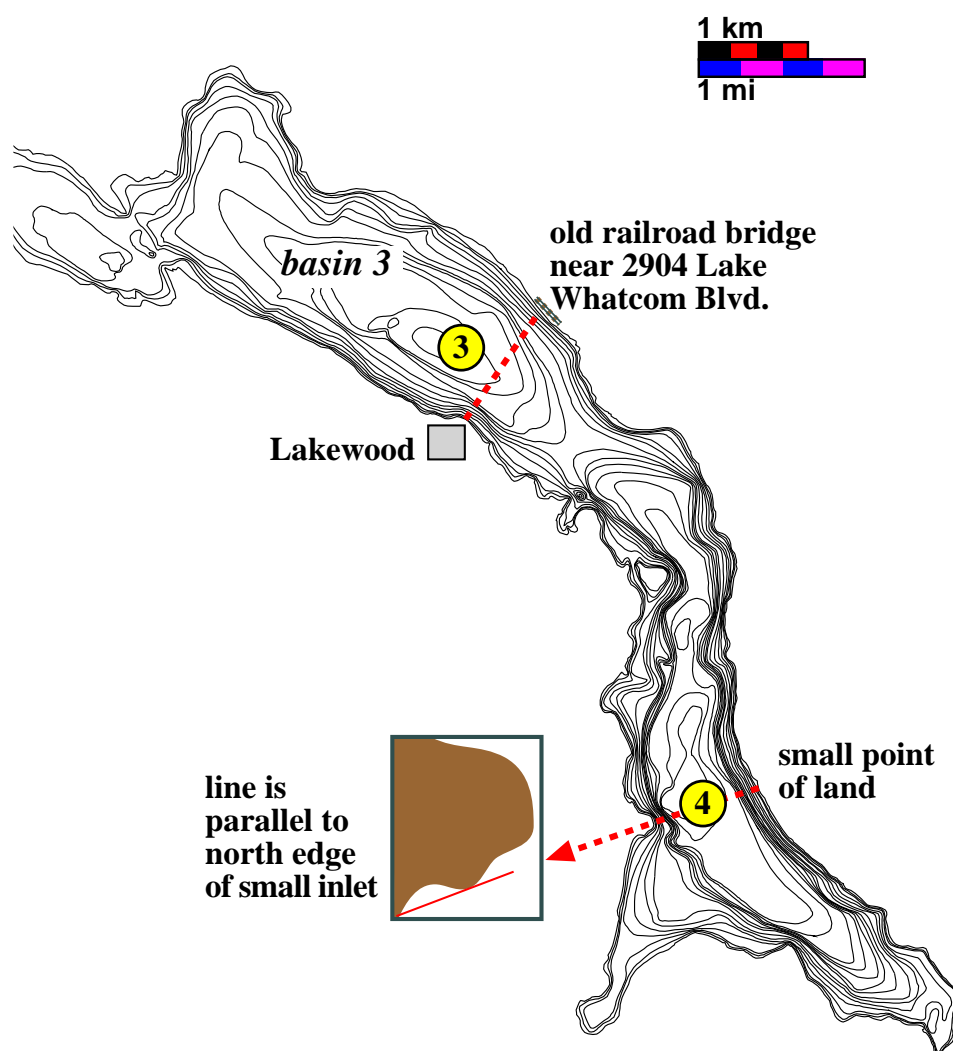


Figure 191: Lake Whatcom sampling sites, basin 3.

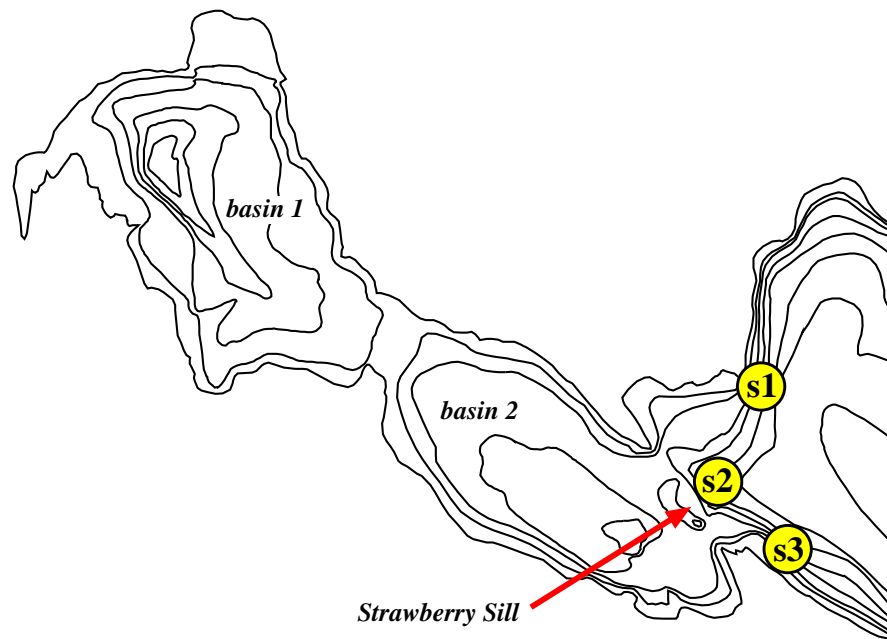


Figure 192: Strawberry sill sampling sites. (Only site s2 is currently sampled.)



## **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. The GPS coordinates for Smith Creek at the dead end of North Shore Road are 48° 43' 46.3" N; 122° 18' 51.1" W.

### **Silver Beach Creek:**

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

### **Park Place storm drain:**

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

### **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. The GPS coordinates for Austin Creek at the bridge are 48° 42' 46.8" N; 122° 19' 52.2" W.

### **Wildwood Creek:**

The site is located approximately 30 feet south of the entrance to the Wildwood Resort at the culvert where South Lake Whatcom Boulevard crosses the creek. The GPS coordinates for Wildwood Creek at the culvert are 48° 40' 41.1" N; 122° 19' 04.9" W.

**Anderson Creek:**

The site is located at the bridge where South Bay Drive crosses the creek. Water samples and discharge measurements are collected upstream from the bridge. The Anderson Creek hydrograph is mounted in the existing stilling well on the east side of Anderson Creek, directly adjacent to the bridge over Anderson Creek (South Bay Drive), approximately 0.5 km from the mouth of the creek. The GPS coordinates for Anderson Creek at the bridge are 48° 40' 24.3" N; 122° 16' 02.8" W.

**Blue Canyon Creek:**

This small creek is not shown on the USGS topographic map for the area. However, it is located just north of the two major Blue Canyon streams pictured on the USGS Lake Whatcom 7.5 min. quadrangle (Sect. 22, T 37N, R 4E). Samples are collected upstream from the culvert crossing the Blue Canyon road. The GPS coordinates for Blue Canyon Creek on Blue Canyon Road are 48° 41' 06.3" N; 122° 17' 00.7" W.

## **B Lake Whatcom Data**

The 2001/2002 Lake Whatcom water quality data, including data from special sampling projects, are included on the following pages. The historic detection limits and abbreviations for each parameter are listed in Table 38. The historic detection limits for each parameter were estimated based on recommended lower detection ranges (APHA, 1998; Ebina, et al., 1983; Hydrolab, 1997; Lind, 1985) instrument limitations, and analyst judgement on the lowest repeatable concentration for each test. Over time, some analytical techniques have improved so that current detection limits are lower than defined below (see, for example, current detection limits in Table 2, page 30). 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 38.

Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity ( $\pm$ )	Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity ( $\pm$ )
alk	Alkalinity	$\pm 0.5$ mg/L	As	arsenic, total	dl = 0.03/0.01/0.001 mg/L
toc	Carbon, total organic	dl = 1.0 mg/L	Cd	cadmium, total	dl = 0.002/0.0005 mg/L
chl	Chlorophyll <i>a</i>	$\pm 0.1$ mg/m <sup>3</sup>	Cr	chromium, total	dl = 0.006/0.001 mg/L
fc	Coliforms, fecal	dl $\leq 2$ col/100 mL	Cu	copper, total	dl = 0.002/0.001 mg/L
tc	Coliforms, total	dl $\leq 2$ col/100 mL	Fe	iron, total	dl = 0.01/0.005 mg/L
cond	Conductivity, Hydrolab	$\pm 2$ $\mu$ S/cm	Pb	lead, total	dl = 0.001 mg/L
cond	Conductivity, lab	$\pm 2$ $\mu$ S/cm	Hg	mercury, total	dl = 0.01 mg/L
ec	<i>Enterococcus</i>	dl $\leq 2$ col/100 mL	Hg	mercury, total	
nh3	Nitrogen, ammonia	dl = 10 $\mu$ g-N/L	Hg	mercury, total, low	
no3	Nitrogen, nitrate/nitrite	dl = 20 $\mu$ g-N/L		AmTest	dl = 0.0002 mg/L
tn	Nitrogen, total nitrogen	dl = 100 $\mu$ g-N/L		Env. Canada	dl = 0.00005 mg/L
do	Oxygen, Hydrolab	$\pm 0.1$ mg/L		Frontier	dl = 0.00000015 mg/L
do	Oxygen, Winkler	$\pm 0.1$ mg/L	Hg	mercury, methyl, low	
pH	pH, Hydrolab	$\pm 0.1$ pH unit		Frontier	dl = 0.00000002 mg/L
pH	pH, lab	$\pm 0.1$ pH unit	Ni	nickel, total	dl = 0.01/0.005 mg/L
srp	Phosphate, soluble reactive	dl = 5 $\mu$ g-P/L	Zn	zinc, total	dl = 0.002/0.001 mg/L
tp	Phosphorus, total	dl = 5 $\mu$ g-P/L			
secchi	Secchi depth	$\pm 0.1$ m			
temp	Temperature	$\pm 0.1^\circ$ C			
tss	Total suspended solids	dl = 2 mg/L			
turb	Turbidity	$\pm 0.2$ NTU			

Historic detection limits listed in this table are conservative estimates designed to permit comparisons with historic data.

The AmTest detection limits for metals decreased in 1999 and 2002 (arsenic only); the older detection limits are listed first in this table.

Table 2 lists the current IWS detection limits for selected analyses; Appendix B.7 includes the the current AmTest reports and detection limits.

Table 38: Summary of analyses in the Lake Whatcom monitoring project.

## **B.1 Lake Whatcom Hydrolab Data**

Hydrolab data from the 2001/2002 sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the 1988–2002 Lake Whatcom hydrolab data are available on the CD that accompanies the printed report or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

## **B.2 Lake Whatcom Water Quality Data**

Water quality data from the 2001/2002 sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the 1988–2002 Lake Whatcom water quality data are available on the CD that accompanies the printed report or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

### **B.3 Lake Whatcom Plankton Data**

Lake Whatcom plankton data from the 2001/2002 sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the 1991–2002 Lake Whatcom plankton data are available on the CD that accompanies the printed report or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

## **B.4 Strawberry Sill Hydrolab and Water Quality Data**

Strawberry Sill data from the 2001/2002 sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the historic data from the sill are not available.



## **B.5 Storm Water Treatment Monitoring Data**

Brentwood, Park Place, and South Campus storm water treatment data from the 2001/2002 sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the 1994–2002 storm water treatment data are available on the CD that accompanies the printed report or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

## **B.6 City of Bellingham Coliform Data**

Coliform data from the 2001/2002 sampling period are included in hardcopy format in the printed version of this report. Electronic copies of the data may be obtained by contacting the City of Bellingham Public Works Department, Bellingham, WA, 98225.

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

The following AmTest data reports are included in hardcopy format in the printed version of this report (filed by collection date). Electronic copies of these data are not available.

Sample location	Date	Analyses
Lake Whatcom, surface and bottom	October 23, 2001	metals (low-level mercury only)
	December 22, 2001	metals (low-level mercury only)
	March 1, 2002	metals (regular + low-level mercury); total organic carbon
	April 19, 2002	metals (low-level mercury only)
	May 22, 2002	metals (low-level mercury only)
	October 2, 2002	metals (regular); total organic carbon
Strawberry sill, surface and 35 m	October 23, 2001	metals; total organic carbon
	February 4, 2002	metals; total organic carbon
Park Place/Brentwood wet ponds	January 17, 2002	metals; total organic carbon
	April 15, 2002	metals; total organic carbon
	August 29, 2002	metals; total organic carbon
South Campus storm drain	February 4, 2002	metals, total organic carbon
	May 15, 2002	metals, total organic carbon
	August 29, 2002	metals, total organic carbon
Watershed creeks	March 20, 2002	metals; total organic carbon
	August 1, 2002	metals (low-level mercury only); total organic carbon

Sites Codes for the AmTest reports are as follows:

Lake Sites	Creek Sites	Storm Water Treatment Sites
11-O Site 1, surface (0.3 m)	CW1 Smith Creek	BW1 Brentwood inlet
11-B Site 1, bottom (20 m)	CW2 Silver Beach Creek	BW2 Brentwood outlet
21-O Intake, surface (0.3 m)	CW3 Park Place Drain	PP4 Park Place inlet
21-B Intake, bottom (10 m)	CW4 Blue Canyon Creek	PP5 Park Place outlet
22-O Site 2, surface (0.3 m)	CW5 Anderson Creek	NSCSD South Campus inlet
22-B Site 2, bottom (20 m)	CW6 Wildwood Creek	ESCSD South Campus east outlet
31-O Site 3, surface (0.3 m)	CW7 Austin Creek	WSCSD South Campus west outlet
31-B Site 3, bottom (80 m)		
32-O Site 4, surface (0.3 m)		
32-B Site 4, bottom (90 m)		
SS-O Strawberry Sill, surface (0.3 m)		
SS-B Strawberry Sill, bottom (35 m)		

## **B.8 Low Level Mercury Data (Environment Canada and Frontier Geosciences)**

Low-level mercury data from Environment Canada and Exponent are included in hardcopy format in the printed version of this report (filed by collection date). Electronic copies of these data are not available.

## B.9 Lake Whatcom Electronic Data

The annual Lake Whatcom reports include a CD containing historic Hydrolab and water quality data (1988–2002); Austin Creek, Anderson Creek, and Smith Creek hydrograph data (1998–2002); historic plankton data (1991–2002); and historic storm water treatment monitoring data (1994–2002). The data files included on the CD are described in the readme.txt file on the CD.

The electronic data files have **NOT** been censored to identify below detection and above detection values. Refer to Tables 2 and 38 (pages 30 and 264) for applicable detection limits and abbreviations. It is essential that any statistical or analytical results that are generated using these data be reviewed by someone familiar with statistical uncertainty associated with uncensored data.

### Readme.txt:

```
*****
README FILE - LAKE WHATCOM DATA
*****
```

The CD included with this report included the following data files:

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

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

The water quality data files contain the following variables: site, depth (m), month, day, year, alkalinity (mg/L), turbidity (NTU), ammonia (ug-N/L), total persulfate nitrogen (ug-N/L), nitrate/nitrite (ug-N/L), soluble reactive phosphate (ug-P/L), total phosphorus (ug-P/L), chlorophyll (mg/m3).

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

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

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

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

The site codes in the data are as follows:

- 11 = Lake Whatcom Site 1
- 21 = Lake Whatcom Intake site
- 22 = Lake Whatcom Site 2
- 31 = Lake Whatcom Site 3
- 32 = Lake Whatcom Site 4
- 33 = Strawberry Sill site S1 (discontinued)
- 34 = Strawberry Sill site S2
- 35 = Strawberry Sill site S3 (discontinued)

- BW1 (BW\_in) = Brentwood wet pond inlet
- BW2 (BW\_out) = Brentwood wet pond outlet
- PP1 (PP\_cell1) = Park Place wet pond cell 1 (discontinued)
- PP2 (PP\_cell2) = Park Place wet pond cell 2 (discontinued)
- PP3 (PP\_cell3) = Park Place wet pond cell 3 (discontinued)
- PP4 (PP\_in) = Park Place wet pond inlet
- PP5 (PP\_out) = Park Place wet pond outlet
- SC1 (SC\_in) = South Campus storm water facility inlet
- SC2 (SC\_outE) = South Campus storm water facility east outlet
- SC3 (SC\_outW) = South Campus storm water facility west outlet
- WL = Grace Lane wetland (discontinued)

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

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VERIFICATION PROCESS FOR THE 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 bench sheets and field notebooks. If an error was found, the entire set of values for that analysis were reviewed for the sampling period containing the error. Corrections were noted in the printed copy and entered into the electronic file; all entries were dated and initialed in the archive copy.

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

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

Specific Deletions: 1) Rows containing only missing values were deleted. 2) All lab conductivity for February 1993 were deleted for cause: meter inadequate for low conductivity readings (borrowed Huxley's student meter). 3) All Hydrolab conductivity from April - December 1993 were deleted for cause: Hydrolab probe slowly lost sensitivity. Probe was replaced and Hydrolab was reconditioned prior to the February 1994 sampling. 4) All 1993 Hydrolab dissolved oxygen data less than or equal to 2.6 mg/L were deleted for cause: Hydrolab probe lost sensitivity at low oxygen concentrations. Probe was replaced and Hydrolab was reconditioned prior to February 1994 sampling. 5) All srp and tp data were deleted (entered as "missing" in 1989) from the July 10, 1989 wq data due to sample contamination in at least three samples. 6) December 2, 1991, Site 3, 0 m conductivity point deleted due to inconsistency with adjacent points. 7) December 15, 1993, Site 4, 80 m lab conductivity point deleted because matching field conductivity data are absent and point is inconsistent with all other lab conductivity points. 8) November 4, 1991, Site 2, 17-20 m, conductivity points deleted due to evidence of equipment problems related to depth. 9) February 2, 1990, Site 1, 20 m, soluble phosphate and total phosphorus points deleted due to evidence of sample contamination. 10) August 6, 1990, Site 1, 0 m, soluble phosphate and total phosphorus points deleted due to evidence of sample contamination. 11) October 5, 1992, Site 3, 80 m, all data deleted

due to evidence of sample contamination in turbidity, ammonia, and total phosphorus results. 12) August 31, 1992, Site 3, 5 m, soluble phosphate and total phosphorus data deleted due to probable coding error. 13) All total Kjeldahl nitrogen data were removed from the historic record. This was not due to errors with the data but rather on-going confusion over which records contained total persulfate nitrogen and which contained total Kjeldahl nitrogen. The current historic record contains only total persulfate nitrogen. Total Kjeldahl nitrogen data were retained in the IWS data base, but not in the long-term Lake Whatcom data files.

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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.