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Lake Whatcom Monitoring Project 2022/2023 Report

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Background for the Lake Whatcom Annual Reports

- This report describes the results from the 2022/2023 Lake Whatcom monitoring program conducted by the Institute for Watershed Studies at Western Washington University (https://iws.wwu.edu/).

- The major objectives in 2022/2023 were to continue long-term baseline water quality monitoring in Lake Whatcom and its major tributaries; collect storm runoff water quality data from representative streams in the watershed; and continue collection of hydrologic data from Austin and Smith Creeks.

- Each section in this report contains a brief discussion of the water quality parameters that are measured as part of the monitoring effort. For additional help with understanding the relationship between water quality data and lake, stream, or watershed ecology, we recommend the USGS Water Science School website (https://www.usgs.gov/special-topics/water-science-school/science).

- The online pdf copy of this report contains red hyperlinks that will open online citations, and blue hyperlinks that will jump to referenced tables and figures or to the section that contains additional information about a specific topic. These hyperlinks are active if the report is opened using Adobe Reader, which can be downloaded free from www.adobe.com/products/reader.html.

- This report is part of an on-going series of annual reports and special project reports that provide a complete documentation of the monitoring program over time. A summary of the Institute for Watershed Studies Lake Whatcom reports, including special project reports, is included in Section 5.2, beginning on page 94, and many of the reports are available online through Western CEDAR, the WWU repository for open access scholarship, under the Institute for Watershed Studies Lake Whatcom collection (http://cedar.wwu.edu/iws_lakewhatcom).

Summary of 2022/2023 Monitoring Project

- During the summer the lake's water column was thermally stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). Most of the 2022/2023 temperature profiles fell within historical ranges, with stable stratification present at Sites 1–4 by mid-late May (Section 2.3.1, page 4).[1]

- The hypolimnetic oxygen concentrations have declined over time at Site 1 (Section 2.3.2, page 5), causing the lake to be listed by the Department of Ecology on the 1998 303d list of impaired waterbodies in the state of Washington. Hypolimnetic oxygen was higher at Site 1 compared to previous years, with oxygen concentrations above 2 mg/L from 12 meters to the bottom through July and August sampling. Concentrations dipped below 2 mg/L from 12 meters to the bottom in September.

- Nitrate depletion was evident at all sites in the photosynthetic zone during the summer due to algal uptake of this essential nutrient (Section 2.3.5, page 10). Unlike the other indicators of phytoplankton productivity, the dissolved inorganic nitrogen (DIN = nitrate + nitrite + ammonium) trend has not stabilized in recent years. A month-by-month analysis of near-surface DIN showed that water column concentrations have declined in general, not just in the summer. Nitrate depletion also occurred in the hypolimnion at Site 2 due to nitrate reduction by bacteria. Anaerobic conditions in the hypolimnion at Sites 1 and 2 resulted in elevated concentrations of ammonium by the end of the summer.

- The summer near-surface total phosphorus concentrations continued to follow erratic patterns, with no significant correlations with year (Section 2.3.5, page 12), reflecting the complicated nature of phosphorus movement in the water column. Hypolimnetic phosphorus remains elevated in the summer at Sites 1 and 2 when dissolved oxygen is low.

- The summer near-surface chlorophyll concentrations have increased significantly over time at all sites (Section 2.3.6, page 13). Despite being quite variable, the concentrations appear to have stabilized since 2004, ranging from 3.3–6.7 μg/L at Site 1 and 2.6–4.6 μg/L at Sites 2–4.

[1] These links direct the reader to sections with additional information on the summary topic.

- All of the mid-basin *E. coli* counts were less than 5 cfu/100 mL (Section 2.3.7, page 15). The *E. coli* counts at the Bloedel-Donovan recreational area (collected offshore from the swimming area) were slightly higher than mid-basin counts, but passed the freshwater *Primary Contact Recreational* bacteria standard for Washington in place since 2021 (see Section 2.3.7, page 15 for discussion of changes in standards).

- The concentrations of trihalomethanes and haloacetic acids (THMs and HAAs) in Bellingham's treated drinking water have increased over time, but have been declining in recent years. The concentrations of both types of disinfection by-products remained below the maximum contaminant levels of 0.080 mg/L and 0.060 mg/L, respectively (Section 2.3.8, page 17).

- Monthly tributary samples were collected at 12 locations in the Lake Whatcom watershed (Section 3, page 58). Most of the tributaries had low concentrations of total suspended solids, low alkalinities and conductivities, and low levels of nutrients (phosphorus and nitrogen). The residential streams had higher concentrations of total suspended solids, higher alkalinities and conductivities, higher *E. coli* counts, and higher nutrient concentrations.

- Hydrograph data were collected at Austin and Smith Creeks using rating curves to calculate discharge (Section 4.1, page 79).

- Storm runoff samples were collected in Carpenter Creek, Olsen Creek, and Smith Creek (three storm events each) using time-paced automated samplers (Section 4, page 79). The water quality data are sent to the City of Bellingham for use in watershed modeling.

1 Background

This report is part of an on-going series of annual reports and special project reports that document the Lake Whatcom monitoring program over time. Many of the reports are available online through Western CEDAR, the WWU repository for open access scholarship, under the Institute for Watershed Studies Lake Whatcom collection (http://cedar.wwu.edu/iws_lakewhatcom). Reports that are not available on CEDAR may be available in the Institute for Watershed Studies (IWS) library or through the City of Bellingham Public Works Department. A summary of the Lake Whatcom annual and special project reports is included in Section 5.2, beginning on page 94.

Each section in this report contains a brief discussion of the water quality parameters that are measured as part of the monitoring effort. For additional help with understanding the relationship between water quality data and lake, stream, or watershed ecology, we recommend the USGS Water Science School website.[2]

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. It also serves as a primary or supplemental water source to various water systems adjacent to the City of Bellingham.

The lake and its watershed provide recreational opportunities, as well as important habitats for fish and wildlife. The lake is used as a storage reservoir to buffer peak storm water flows in Whatcom Creek. Because of its aesthetic appeal, the watershed is highly valued for residential development. Historically, most of the nonresidential portion of the watershed was zoned for forestry and was managed by state or private timber companies.

Through a land acquisition program initiated in 2001, the city has purchased over 2,700 acres to set aside for preservation.[3] Additionally, approximately 7,800 acres of forest lands formerly managed by the Department of Natural Resources was reconveyed to Whatcom County in January 2014 to be managed as low impact park lands. The Lake Whatcom reconveyance planning process is summarized online.[4]

[2] https://www.usgs.gov/special-topics/water-science-school/science

[3] https://cob.org/services/environment/lake-whatcom/lw-property-acquisition-program

[4] www.whatcomcounty.us/625/Lake-Whatcom-Reconveyance

1.1 Objectives

The City of Bellingham and Western Washington University have collaborated on water quality studies in Lake Whatcom since the early 1960s. Beginning in 1988, a monitoring program was initiated by the City and WWU that was designed to provide long-term lake data for 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.

The major objectives of the 2022/2023 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom and its major tributaries; collect storm runoff water quality data from representative streams in the watershed; and continue collection of hydrologic data from Austin and Smith Creeks.

Detailed site descriptions can be found in Appendix A. The historical lake data are plotted in Appendix B. The current quality control results are in Appendix C. The monitoring data are available online at `https://iws.wwu.edu/` as described in Appendix D (page 347). Table 2.1 (page 19) lists abbreviations and units used to describe water quality analyses; Tables 2.2 & 3.1 (pages 20 & 63) list the locations, depths, and frequency for lake and tributary sampling.

2 Lake Whatcom Monitoring

2.1 Site Descriptions

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (Figure A1, page 103 in Appendix A.1). Sites 1–2 are located at the deepest points in their respective basins. The Intake site is located adjacent to the underwater intake point where the City of Bellingham withdraws lake water from basin 2. Site 3 is located at the deepest point in the northern sub-basin of basin 3 and Site 4 is located at the deepest point in the southern sub-basin of basin 3. Water samples were also collected at the City of Bellingham Lake Whatcom Gatehouse, which is located onshore and west of the Intake site.

2.2 Field Sampling and Analytical Methods

The lake was sampled on October 3 & 5, November 9 & 14 and December 6 & 13, 2022; and February 2 & 14, April 13 & 25, May 9 & 11, June 6 & 8, July 11 & 13, August 1 & 3 and September 5 & 7, 2023. Each sampling event is a multi-day task; all samples were collected during daylight hours, typically between 10:00 am and 3:00 pm. The analytical and sampling procedures are summarized in Tables 2.1 & 2.2 (pages 19 & 20). Table 2.3 (page 21) summarizes missing data from the 2022/2023 sampling season.

A YSI EXO1 multiparameter field meter was used to measure temperature, pH, dissolved oxygen, and conductivity in the field. Raw water samples were collected using a Van Dorn sampler and plankton samples were collected using a 30-L Schindler trap equipped with a 20 μm mesh plankton net. Bacteriological samples were collected with a surface grab sample. The water and bacteriological samples were stored on ice and in the dark until they reached the laboratory. 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. Total organic carbon analyses were done by AmTest[5] and by IWS. The bacteria samples were analyzed by the City of Bellingham.

2.3 Results and Discussion

The lake monitoring data include monthly field measurements (conductivity, dissolved oxygen, pH, Secchi depth, and water temperature); laboratory analyses for ambient water quality parameters (ammonium,[6] nitrate/nitrite,[7] total nitrogen, soluble phosphate, total phosphorus, alkalinity, turbidity, chlorophyll); plankton and bacteria counts; and total organic carbon measurements.

The 2022/2023 temperature, dissolved oxygen, pH, and conductivity profiles are shown in Figures B1–B50 (Appendix B, pages 107–156). Tables 2.4–2.8 (pages

[5] AmTest, 13600 Northeast 126th Place, Suite C, Kirkland, WA, 98034–8720.

[6] Nearly all ammonia (NH_4^+) is ionized to ammonium (NH_3) in surface water. Earlier IWS reports used "ammonia" and "ammonium" interchangeably; we now use "ammonium" to indicate that the data represent the concentration of ionized ammonia.

[7] Nitrate and nitrite were analyzed together because nitrite concentrations are very low in surface water. For simplicity, nitrate/nitrite will be referred to as "nitrate" in this document.

22–26) summarize the current field measurements, ambient water quality, and *E. coli*[8] data, and all of the current data are plotted in comparison with historic data in Figures B66–B140 (Appendix B, pages 173–248). These figures are scaled to plot the full range of Lake Whatcom water quality data including minimum, maximum, and outlier values, and do not provide the best illustration of trends that occur in the lake. Separate tables and figures are provided to show trends and illustrate specific patterns in the data. The raw data are available online at https://iws.wwu.edu/ as described in Appendix D (page 347).

2.3.1 Water temperature

The 2022/2023 monthly temperature profiles for Sites 1–4 were plotted as overlay points on shaded polygons that summarize the 1988–2023 historic temperature ranges (Figures 2.1–2.13, pages 29–41). The monthly YSI profiles for temperature, dissolved oxygen, pH, and conductivity at Sites 1–4 and the Intake were included in Appendix B (Figures B1–B50, pages 107–156).

The summer temperature profiles (e.g., Figure 2.7, page 35) show how the lake stratifies into a warm surface layer (*epilimnion*), and cool bottom layer (*hypolimnion*). The transition zone between the epilimnion and hypolimnion (*metalimnion*) is a region of rapidly changing water temperature. When stratified, the temperature profiles show distinct differences between the surface and bottom of the water column. Stratification develops gradually, and once stable, persists until fall or winter, depending on location in the lake. Seasonal weather differences alter the timing of lake stratification; if the spring is cool, cloudy, and windy, the lake may stratify later than when it has been hot and sunny.

In Lake Whatcom, all sites except the Intake[9] are usually stratified by late spring or early summer. Stratification may begin as early as April, but is often not stable until May or June. The stability of stratification is determined in part by the temperature differences in the water column, but also by water circulation and local weather patterns. Once the water column temperature differs by at least 5°C (ΔT $\geq$5°C), it is unlikely that the lake will destratify.[10]

[8] The switch from fecal coliform to *E. coli* as the bacterial indicator species happened in January 2023, thus some results from the 2022/2023 water year include fecal coliform data. We refer to *E. coli* as the primary indicator throughout this report.

[9] The Intake is too shallow to develop stable stratification (see Appendix B, Figures B1–B46).

[10] The ΔT is the difference between the epilimnion and hypolimnion temperatures.

As the weather becomes colder and days shorten, the lake cools and the surface and bottom water temperatures become more similar. Eventually the water column will start to mix from the surface to the bottom and the lake will destratify. Basins 1 and 2 (Sites 1–2) usually destratify by the end of October or early November, but basin 3 (Sites 3–4) is usually still stratified in November (Figure 2.2, page 30). Complete destratification of basin 3 occurs in December or early January, so by February the temperatures are uniform throughout the water column at all sites (Figure 2.4, page 32).

Although destratification is relatively abrupt, the process of mixing the entire water column is not instantaneous. When the lake begins to destratify, water temperatures may be uniform from the surface to the bottom, but the rate of water circulation may not be sufficient to replenish hypolimnetic oxygen concentrations. This phenomenon, where temperature is uniform, but dissolved compounds (e.g., dissolved oxygen) remain partially stratified, is common in the early stages of destratification, when the basin is starting to mix (see November 2013 temperature and oxygen profiles from Site 2; Figure B.7 in Matthews, et al., 2015).

The lake was still stratified at all sites in October 2022 (Figure 2.1, page 29). Sites 1–2 were completely destratified by November (Figure 2.2, page 30), whereas Sites 3–4 were destratified by December 2022 ($\Delta T \leq 1^\circ$ C)(Figure 2.3, page 31).

The water column was starting to stratify in early May 2023 ($\Delta T = 2.3$–3.9° C). Sites 1 and 3 had developed stable stratification ($\Delta T > 4^\circ$ C) at the May sampling event (Figure 2.6, pages 34), whereas Sites 2 and 4 did not fully stratify until June sampling (Figure 2.7, pages 35). All sites remained stratified through October, with temperatures falling within typical historical ranges (Figures 2.7–2.10, pages 35–38).

2.3.2 Dissolved oxygen

The 2022/2023 monthly oxygen profiles for Sites 1–4 were plotted as overlay points on shaded polygons that summarize the 1988–2023 historic temperature ranges (Figures 2.1–2.13, pages 29–41).[11] The monthly YSI profiles for temperature, dissolved oxygen, pH, and conductivity at Sites 1–4 and the Intake were included in Appendix B (Figures B1–B50, pages 107–156).

[11] October–December 2023 are not part of the 2022/2023 sampling period, but the temperature/oxygen profiles were included to provide information on the timing of destratification.

As in past years, Sites 1–2 developed severe hypolimnetic oxygen deficits during the summer (Figures 2.8–2.10, pages 36–38). Hypolimnetic oxygen depletion only becomes apparent after stratification, when the lower waters of the basin are isolated from the lake's surface and biological respiration consumes the oxygen dissolved in the water. Biological respiration usually increases when there is an abundant supply of organic matter (e.g., decomposing algae). In basin 3, which has a very large, well-oxygenated hypolimnion, respiration has relatively little influence on hypolimnetic oxygen concentrations.

In contrast, there is rapid depletion of the hypolimnetic oxygen concentrations at Sites 1–2. These two sites are in shallow basins that have small hypolimnions compared to their photic zones[12] so decomposition of algae and other organic matter causes a significant drop in hypolimnetic oxygen over the summer. This oxygen depletion may be apparent in May if the lake stratifies early in the spring, but is more commonly observed beginning in June (Figure 2.7, page 35). Site 1 had relatively high dissolved oxygen concentrations in June and July compared to prior sampling years.

Low oxygen conditions are associated with a number of unappealing water quality problems in lakes, including loss of aquatic habitat; release of phosphorus from the sediments; increased rates of algal production due to release of phosphorus; unpleasant odors during lake destratification; fish kills, particularly during lake destratification; release of metals and organics from the sediments; increased mercury methylation; increased drinking water treatment costs; increased taste and odor problems in drinking water; and increased risks associated with disinfection by-products created during the drinking water treatment process.

The levels of hypolimnetic oxygen have declined over time at Site 1, causing the lake to be listed by the Department of Ecology as an "impaired" waterbody (Pelletier, 1998).[13] The increasing rate of oxygen loss is most apparent during July and August, after the lake develops stable stratification but before oxygen levels drop near zero. To illustrate this trend we fitted the dissolved oxygen data using an exponential function (see discussion by Matthews, et al., 2004). As indicated

[12] The photic zone is the region with enough light to support algal photosynthesis, which extends to about 10 m below the surface in Lake Whatcom. Assuming a photic zone of 0–10 m, the photic zones for basins 1, 2, and 3 would be 75%, 70%, and 17% of the basin's volume, respectively (Mitchell, et al., 2010).

[13] `www.ecy.wa.gov/programs/wq/303d`.

in Figures 2.14–2.17 (pages 42–45), there were significant negative correlations[14] between dissolved oxygen and time for all hypolimnetic samples collected between July and September. The July hypolimnetic oxygen concentrations were >4 mg/L at all depths and in August the oxygen concentrations were between 2–4 mg/L. By September, dissolved oxygen concentrations were near 0 mg/L.

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in June, July, and August (Figures 2.7–2.9, pages 35–37). This was caused by the accumulation of phytoplankton along the density gradient between the epilimnion and hypolimnion where light and nutrients are sufficient to support very high levels of photosynthesis. Chlorophyll concentrations within the metalimnetic oxygen peak may be 4–5 times higher than those measured near the surface of the lake (Matthews and DeLuna, 2008). Metalimnetic oxygen peaks are common at Site 1 during the summer, and may occur at Sites 2–4, but will usually be at different depths because the metalimnions are at different depths. When present, the metalimnions form at approximately 5–10 m at Site 1, 10–15 m at Site 2, and 15–20 m at Sites 3–4.

Hypolimnetic oxygen loss is much less obvious in basin 3, in part due to the much larger hypolimnetic volume. Sites 3 and 4 often develop small oxygen sags near the thermocline during late summer. These are caused by respiration of heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (e.g., Figure 2.1, page 29; Figure B4, page 110; Matthews and DeLuna, 2008). From October through December, which is usually the last month of stratification in basin 3, the hypolimnetic oxygen concentrations at Sites 3–4 are often lower than in the epilimnion, which likely reflects continued biological respiration in the isolated hypolimnion (e.g., Figures 2.3 & B14, pages 31 & 120). However, the hypolimnion in basin 3 rarely drops below 5–6 mg/L of dissolved oxygen.[15]

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[14] Correlation analyses examine the relationships between two variables. The test statistic ranges from –1 to +1; the closer to ±1, the stronger the correlation. The significance is measured using the p-value; significant correlations have p-values <0.05.

[15] From 1998–2019, the deep sample from Site 3 was taken at 80 m; however, this depth is very close to the lake bottom and was frequently contaminated by the bottom sediments. Starting in the 2019–2020 report, we no longer sample at 80 m and instead use 75 m as the deepest measurement.

Hypolimnetic hydrogen sulfide: Bacteria require an energy source (e.g., organic carbon) and an electron acceptor (e.g., oxygen) for basic growth and metabolism. Under anaerobic conditions, when oxygen is not available, there is a predictable sequence whereby different types of anaerobic bacteria use alternate electron acceptors.[16] First, bacteria will use nitrate as an alternate to oxygen, converting nitrate to nitrite and nitrogen gas. Next, bacteria use manganese and ferrous ions. When these compounds are exhausted, bacteria use sulfate, converting it to hydrogen sulfide, a colorless gas with a strong, rotten-egg smell. If the electron acceptors listed above are unavailable, bacteria can use carbon dioxide, converting it to methane.

Hydrogen sulfide is commonly present in anaerobic lake sediments, but if the overlying water contains oxygen the sulfide will be converted into sulfates or other compounds. If the overlying water is anaerobic, hydrogen sulfide can build up to detectable levels during stratification. Hydrogen sulfide is an indicator of the degree of anoxia in the hypolimnion because it will not persist in oxygenated waters and is formed after the nitrate, manganese, and ferrous ions are exhausted.

The hypolimnion at Sites 1–2 usually contain detectable concentrations of hydrogen sulfide by October (Table 2.9, page 27). Hydrogen sulfide concentrations are measured in October because that is the latest month that is consistently stratified at Sites 1–2, so the hydrogen sulfide concentrations should be near their highest levels. The value of hydrogen sulfide obtained from Site 1 was below detection limits; however, the value in Site 2 was quite high. The hydrogen sulfide values in Site 2 correspond with elevated concentrations of ammonium in the hypolimnion (Figure B97, page 205) – see Section 2.3.5 for a discussion (page 10).

2.3.3 Conductivity and pH

The pH and conductivity data followed trends that were fairly typical for Lake Whatcom (Figures B1–B50 and B76–B85, pages 107–156 and 183–192). Epilimnetic pH values increased during the summer due to photosynthetic activity and hypolimnetic pH values decreased due to decomposition and the release of dissolved compounds from the sediments (Figures B31–B45, pages 137–151).

The conductivity concentrations were elevated in hypolimnetic samples at Sites 1–2, coinciding with periods of low oxygen near the bottom (e.g., Figures B46 –

[16] For a more complete discussion of anaerobic decomposition in lakes, see Jones and Smol, 2024.

B47, pages 152 –153). The historical data show what appears to be a decreasing trend in the conductivity values from 1988–2002, but this was caused by using increasingly sensitive equipment during the past three decades and does not indicate any actual change in the conductivity in the lake (Matthews, et al., 2004). Occasional spikes in conductivity at Site 3 are associated with low oxygen in samples collected very close to the bottom sediments.

2.3.4 Alkalinity and turbidity

Lake Whatcom is a soft water lake so most alkalinity values were low (≤25 mg/L; Figures B86–B90, pages 194–198). During the summer the alkalinity values at the bottom of Sites 1–2 increased due to decomposition and the release of dissolved compounds from the sediments into the lower portion of the water column.

Turbidity values in the lake were usually low (1–3 NTU) except during late summer in samples from near the bottom of the lake. The high turbidity levels during this time are an indication of increasing turbulence in the lower hypolimnion as the lake begins to destratify. The highest turbidity peaks were measured at Sites 1–2, followed by Sites 3 and 4 (Figures B91–B95, pages 199–203).

Suspended sediments from storm events can also cause elevated turbidity levels in the lake. Major storm events usually occur during winter or early spring when the lake is destratified, so the turbidity levels will be high throughout the water column. Storm-related turbidity peaks are easier to see in samples from the Intake and Site 4 where there are fewer distracting late summer hypolimnetic turbidity peaks.

2.3.5 Nitrogen and phosphorus

The nitrogen and phosphorus data are illustrated in Figures B96–B120 (pages 204–228). Nitrogen and phosphorus are important nutrients that influence the amount and type of microbiota (e.g., algae) that grow in the lake. We measured inorganic forms of nitrogen and phosphorus (nitrite, nitrate, ammonium, and soluble phosphate) as well as total nitrogen and total phosphorus, which includes inorganic and organic compounds.[17]

[17]Organic nitrogen and phosphorus comes from living or decomposing plants and animals, and may include bacteria, algae, leaf fragments, and other organic particles.

Nitrogen: Most algae use dissolved inorganic nitrogen (DIN)[18] for growth. Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B101–B105, pages 209–213), particularly at Site 1, where the epilimnetic nitrate concentrations usually drop below 20 μg-N/L by the end of the summer. Because nitrogen is required for algal growth, depletion of epilimnetic DIN concentrations is an indirect way to measure phytoplankton productivity. And, because algal densities have been increasing throughout the lake, it is not surprising to find that the DIN concentrations have declined over time (Figure 2.18, page 46). But, unlike the other indicators of phytoplankton productivity (see **Indications of eutrophication**, beginning on page 14), the DIN trend has not stabilized in recent years.

A month-by-month analysis of near-surface DIN showed that water column concentrations have declined in general, not just in the summer (Figure 2.19, page 47). Summer DIN concentrations are most likely declining because of higher lake productivity, with phytoplankton depleting DIN through uptake into their cells. When the summer DIN concentrations were adjusted by subtracting them from the median spring DIN values (ΔDIN = $\text{DIN}_{\text{spring}} - \text{DIN}_{\text{summer}}$), the trend with year was only marginally significant or not statistically significant, depending on site (Figure 2.20, page 48). Because phytoplankton uptake of DIN would be lower in the spring, this weak trend observed when comparing spring and summer DIN suggests that the overall decline in DIN is not wholly the result of phytoplankton uptake.

The reason for the lake-wide drop in DIN is not known, but similar trends have been reported for lakes in the midwestern and northeastern region of the USA (Oliver, et al., 2017), lakes in the Sierra Nevadas (Sickman, et al., 2003), lakes in the Adirondacks (Waller, et al., 2012), Swedish lakes (Isles et al., 2018), as well as lakes and rivers in northern Italy (Rogora, et al., 2012). Most of these studies attribute the declining DIN concentrations to decreasing amounts of nitrogen entering lakes from atmospheric deposition, but without a detailed nitrogen budget analysis for Lake Whatcom, it would be premature to attribute the declining DIN to a specific cause.

[18] Dissolved inorganic nitrogen includes ammonium, nitrate, and nitrite. Usually, epilimnetic concentrations of ammonium and nitrite are low, so DIN is nearly equivalent to nitrate. When DIN is not available, some algae can use organic nitrogen and some Cyanobacteria, and a few uncommon species of diatoms, can convert dissolved nitrogen gas to ammonia (not ammonium) via nitrogen fixation.

The implication, however, is that Lake Whatcom water quality conditions may become increasingly favorable for the growth of nitrogen-fixing Cyanobacteria, many of which are capable of releasing toxins. Recent summer algal counts from Lake Whatcom revealed that the lake contained many species of Cyanobacteria (Matthews, et al., 2012), but the nitrogen-fixing species were not abundant. It will be important to continue tracking the densities of Cyanobacteria in the lake and to watch for increases in the densities of nitrogen-fixing species.

Hypolimnetic nitrate concentrations dropped below 20 μg-N/L at Site 2 in late summer, but remained high in Site 1 (Figures B101–B102, pages 209–210). In anaerobic environments, bacteria reduce nitrate (NO_3^-) to nitrite (NO_2^-) and nitrogen gas (N_2). The historical data indicate that nitrate reduction has been common in the hypolimnion at Site 1, but was not common at Site 2 until the summer of 1999 (Figure B102, page 210). Since then, the only year that Site 2 hypolimnetic nitrate concentrations did not drop below 20 μg-N/L was 2007. Matthews, et al. (2008) hypothesized that the 2007 results were caused by a combination of late spring stratification and early fall destratification, which shortened the period of anoxia in the hypolimnion. The relatively high nitrate values in the hypolimnion of Site 1 may be the result of the more dissolved oxygen present during the summer months in 2023.

Ammonium, along with hydrogen sulfide, is often an indicator of hypolimnetic anoxia.[19] Ammonium is readily taken up by plants as a growth nutrient. In oxygenated environments, ammonium is rarely present in high concentrations because it is rapidly converted to nitrate through biological and chemical processes. In low oxygen environments, like the hypolimnion at Sites 1–2, ammonium concentrations increase during late summer, reaching maximum concentrations just prior to destratification (Figures B96 & B97, pages 204 & 205).

Elevated hypolimnetic ammonium concentrations have been common at both sites throughout the monitoring period, but beginning in 1999 the concentrations increased noticeably at Site 2 (Figure B97, page 205). The hypolimnion in Site 2 tends to be smaller than Site 1, potentially concentrating ammonium in a smaller volume of water.

[19] Ammonium is produced during decomposition of organic matter; hydrogen sulfide is produced by bacteria that use sulfate (SO_4^{2-}) instead of oxygen, creating sulfide (S^{2-}) that reacts with hydrogen ions to form hydrogen sulfide (H_2S). See hydrogen sulfide discussion on page 8.

The October 2022 ammonium concentrations near the bottom of Site 1 (310 μg-N/L at 20 meters) were consistent with previous years, but were comparatively lower at the bottom of Site 2 (167 μg-N/L at 20 meters). This is consistent with the relatively low hydrogen sulfide concentrations at the bottom of Site 2 in 2022. By contrast, Site 1 had relatively low ammonium concentrations at 20 meters in October 2023 (96 μg-N/L), but ammonium values were higher at the bottom of Site 2 (367 μg-N/L at 20 meters), corresponding with elevated hydrogen sulfide concentrations at the latter site. Both sites are usually destratified by November, which causes the ammonium concentrations to drop through winter and spring (see annual patterns in Figures B96 & B97, pages 204 & 205).

Sites 3–4 often have slightly elevated ammonium concentrations in the metalimnion at 20 m, or near the bottom at 80–90 m (Figures B99–B100, pages 207–208). This is caused by bacterial decomposition of organic matter, but the concentrations never approach the levels found in the hypolimnion at Sites 1–2.

Phosphorus: Although the Lake Whatcom microbiota require nitrogen, phosphorus is usually what limits microbial growth (Bittner, 1993; Liang, 1994; Matthews, et al., 2002a; McDonald, 1994). The total phosphorus concentration in the water column is a complex mixture of soluble and insoluble phosphorus compounds, only some of which can be used by algae to sustain growth. Soluble forms of phosphorus (e.g., orthophosphate) are easily taken up by algae and other microbiota, and, as a result, are rarely found in high concentrations in the water column. Insoluble phosphorus can be present in the water column bound to the surface of tiny particles or as suspended organic matter (e.g., live or dead algae). Some microbiota produce enzymes that release phosphorus from the surface of suspended soil particles. Liang (1994) and Groce (2011) demonstrated that $\geq$50% of the total phosphorus associated with soils in the Lake Whatcom watershed was potentially "bioavailable" through enzyme action. Algal growth tests revealed that 37–92% (median=78%) of the total phosphorus in storm runoff from Anderson, Austin, and Smith Creeks was bioavailable (Deacon, 2015).

Prior to 2000, the median epilimnetic phosphorus concentrations in Lake Whatcom were $<$5 μg-P/L at Sites 2–4 and approximately 5–8 μg-P/L at Site 1 (Figure 2.21, page 49). Since 2000, the median epilimnetic phosphorus concentrations have often been in the detectable range ($\geq$5 μg-P/L), but the pattern is quite erratic, reflecting the complicated nature of phosphorus movement in the water column (Figure 2.21, page 49).

Total phosphorus and soluble phosphate concentrations were usually low except in the hypolimnion at Sites 1–2 just prior to destratification (Figures B111–B115, pages 219–223 and B116–B120, pages 224–228). When hypolimnetic oxygen concentrations are low, sediment-bound phosphorus becomes soluble and leaches into the overlying water. Although median summer phosphorus at the bottom of the hypolimnion has been relatively stable at all sites (with the exception of increases over time in Site 2; Figure 2.22, page 50), it is worth noting that phosphorus concentrations at the bottom of the hypolimnion are substantially higher than in the epilimnion (note difference in scale between Figure 2.21 & 2.22).

Prior to destratification, hypolimnetic phosphorus may be taken up by microbiota in the hypolimnion or metalimnion (see Section 2.3.2 and Matthews and DeLuna, 2008). When the lake mixes in the fall, the hypolimnetic phosphorus will be distributed throughout the water column. As oxygen concentrations increase during mixing, any soluble phosphorus that has not been taken up by biota will usually be converted back into insoluble phosphorus. Because phosphorus moves back and forth between soluble and insoluble forms and between organic and inorganic compounds, it can be difficult to interpret total phosphorus trends. For example, when algal densities increase, their growth usually results in the reduction of soluble and bioavailable fractions of phosphorus in the epilimnion. This uptake moves the phosphorus into the "live-algae" fraction of organic phosphorus, which should show up in total phosphorus measurements. But algae are not distributed homogeneously in the water column (Matthews and Deluna, 2008), making it difficult to estimate the amount of phosphorus that is incorporated into algal biomass.

2.3.6 Chlorophyll, plankton, and Secchi depth

Site 1 continued to have the highest overall chlorophyll concentrations of all the sites (Figures B121–B125, pages 229–233). Peak chlorophyll concentrations were usually collected at 0–15 m, while samples from 20 m had relatively low chlorophyll concentrations because light levels are not optimal for algal growth at this depth.

The plankton counts (Figures B131–B140, pages 239–248) were usually dominated by golden algae (Chrysophyta).[20] Substantial numbers of green algae

[20] Several algal taxonomic groups are combined to ease interpretation; details on algal taxonomy can be found in Matthews (2022).

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

Secchi depths (Figures B126–B130, pages 234–238) showed no clear seasonal pattern because transparency in Lake Whatcom is affected by particulates from storm events as well as algal blooms.

Indications of eutrophication: Eutrophication is the term used to describe a lake that is becoming more biologically productive. It can apply to an unproductive lake that is becoming slightly more eutrophic, or a productive lake that is becoming extremely eutrophic (see Wetzel, 2001, for more about eutrophication and Matthews, et al., 2005, for a description of the chemical and biological indicators of eutrophication in Lake Whatcom).

Chlorophyll is a direct measure of algal biomass and generally provides a better indication of changes in the lake's biological productivity than phosphorus. Similarly, although algal counts are useful for looking at trends within the same type of algae (e.g., are the numbers of Cyanobacteria increasing?), cell counts are not as good as chlorophyll for estimating algal biomass. The actual relationship between chlorophyll and algae cell counts is complex. The amount of chlorophyll in a cell is influenced by the physiological age and condition of the cell, light intensity, nutrient availability, and many other factors. In addition, while most types of algae are counted by individual cells, a few types must be counted by colonies because the cells are too difficult to see.

The median near-surface summer chlorophyll concentrations have increased significantly at all sites since 1994 (Figure 2.23, page 51). Site 1 has shown the most year-to-year variability, which is reflected by a slightly lower correlation statistic compared to Sites 2–4 (Site 1 Kendall's τ = 0.334; Sites 2–4 Kendalls τ = 0.492, 0.559, 0.514, respectively).[21] Although the annual chlorophyll concentrations are quite variable, the median near-surface summer concentrations seem to have stabilized since 2004, ranging from 3.3–6.7 μg/L at Site 1 and 2.6–4.6 μg/L at Sites 2–4 (Figures B121–B125, pages 229–233).

[21] See discussion of correlation in footnote on page 7.

It is notable that the near-surface summer chlorophyll medians in Sites 2–4 are now roughly even with the chlorophyll medians in Site 1 (Site 1 = 3.6 μg/L, Site 2 = 3.9 μg/L, Site 3 = 4.2 μg/L, Site 4 = 3.8 μg/L).

Under certain conditions and in certain lakes, a thin layer of algae can form deep in the water column (i.e., not at the surface) – this is known as a deep chlorophyll maximum. Deep chlorophyll maxima are thought to be a product of lake depth, stratification, and light, with deeper, relatively clear stratified lakes frequently observing this pattern (Fee, 1976). These deep chlorophyll maxima occur frequently in Lake Whatcom, with the highest values of chlorophyll often observed at 10 or 15 m (Figures B121–B125, pages 229–233). For example, the very high chlorophyll value at Site 1 in July 2010 was at 10 m. These layers can be thin (from a few centimeters to a few meters) and may not be observed with discrete sampling. Another way to detect them is to examine dissolved oxygen profiles, which will spike near the deep chlorophyll layer because of increased algal photosynthesis (Figures 2.7–2.10, pages 35–38). For further discussion, see page 7.

Except for the dinoflagellates,[22] the algae counts have increased significantly since 1994 (Figure 2.24, page 52). However, as with chlorophyll, the algae counts appear to have stabilized since 2004. Cyanobacteria, which are often used as bioindicators of eutrophication, have increased at all sites (Figure 2.25, page 53). The Cyanobacteria counts are dominated by *Aphanothece*, *Aphanocapsa*, *Cyanodictyon*, and *Snowella*, genera that are not usually associated with toxic blooms, but some of which have led to filter clogging incidences at the water treatment plant.[23]

2.3.7 Coliform bacteria

This sampling period (2022–2023) follows a change in the surface water standards based on freshwater "designated use" categories, which for Lake Whatcom is "Primary Contact Recreation," described in Chapter 173–201A–200 of the Washington Administrative Code, Water Quality Standards for Surface Waters of the state of Washington.

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[22] Dinoflagellates are small single-cell algae that are common in Lake Whatcom, but rarely have high densities in the plankton counts.

[23] P. Wendling, pers. comm., City of Bellingham Public Works Dept.

The standard for bacteria prior to (and including) December 31, 2020 was:

> *Fecal coliform organism levels within an averaging period must not exceed a geometric mean value of 100 CFU or MPN per 100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained within an averaging period exceeding 200 CFU or MPN per 100 mL.*

The standard for bacteria after December 31, 2020 is:

> E. coli *organism levels within an averaging period must not exceed a geometric mean value of 100 CFU or MPN per 100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained within the averaging period exceeding 320 CFU or MPN per 100 mL.*

The city, in collaboration with the Washington Department of Ecology, examined whether fecal coliform data can transfer to the new *E. coli* standard.[24] The Dept. of Ecology utilized a linear regression approach with paired sampling data on fecal coliform and *E. coli* in Whatcom Creek and found sufficient agreement between the two measures to apply a translator to *E. coli* data to allow for trend analysis. A similar approach was utilized for Lake Whatcom, with a transition to *E. coli* as the sole indicator species in January 2023. To maintain the long-term data record, both *E. coli* and fecal coliform data are plotted together in Appendix B (Figures B141–B145, pages 249–253).

All of the mid-basin (Sites 1–4) and Intake values for *E. coli* were less than 5 cfu[25]/100 mL (Tables 2.4–2.8, pages 22–26, Figures B141–B145, pages 249–253) and passed the freshwater *Primary Contact Recreation* bacteria standard in place since 2021.

Bacteria samples collected offshore from the Bloedel-Donovan swimming area had slightly higher *E. coli* counts than at Site 1 (mid-basin) (Figure B146, page 254). None of the Bloedel-Donovan *E. coli* counts exceeded 100 cfu/100 mL and the geometric mean was 2.1 cfu/100 mL, so this site passed both parts of the freshwater *Primary Contact Recreation* bacteria standard in place since 2021.

[24] P. Wendling, pers. comm., City of Bellingham Public Works Dept.
[25] Colony forming unit/100 mL; cfu/100 mL is sometimes labeled "colonies/100 mL."

2.3.8 Total organic carbon and disinfection by-products

Total organic carbon concentrations, along with plankton and chlorophyll data, are used to help assess the likelihood of developing potentially harmful disinfection by-products through the reaction of chlorine with organic compounds during the drinking water treatment process. Algae excrete dissolved organic carbon into water, which can react with chlorine to form disinfection by-products, predominately chloroform and other trihalomethanes (THMs). When algal densities (or total organic carbon concentrations) increase, we expect to see an increase in THMs. To minimize risk, limits are set on the levels of disinfection by-products allowed in treated drinking water through the Safe Drinking Water Act's Disinfection Byproduct Rule. This Rule was adopted in 1979 and has undergone two major revisions (Phase I in 1998; Phase II in 2005). The sampling requirement doubled under Phase II; currently the City samples eight locations in the water distribution system.[26]

The 2022/2023 total organic carbon concentrations ranged from 1.2–2.1 mg/L (AmTest) and 1.7–2.0 mg/L (IWS; Table 2.10, page 28). The samples were split and analyzed by AmTest and the IWS laboratory to compare results. The median difference between AmTest and IWS concentrations was ± 0.25 mg/L. Larger differences could have been caused by small particulates that were unevenly distributed in the split samples or differences in the analytical methodologies.

The 2022/2023 THMs and HAAs remained below the maximum contaminant levels of 0.080 mg/L and 0.060 mg/L, respectively, described in Chapter 246–290–310 of Washington Administrative Code, Water Quality Standards for Public Water Supplies. The THMs concentrations have showed a significant increase over time (Figures 2.26–2.27, pages 54–55). Concentrations are greatest during spring and summer (Quarters 2–3) when algal densities are higher. However, in recent years THMs concentrations appear to be declining, likely due to operational changes by the City of Bellingham.[27]

Haloacetic acids (HAAs), another type of disinfection by-product, also increased until $\sim$2014, but have declined in recent years, resulting in an overall non-significant trend over time (Figure 2.28, page 56). Seasonal HAA data followed this trend and were not significantly correlated with time (Figure 2.29, page 57). According to Sung, et al. (2000), HAAs are not as closely linked to algal con-

[26] P. Wendling, pers. comm., City of Bellingham Public Works Dept.
[27] P. Wendling, pers. comm., City of Bellingham Public Works Dept.

centrations and chlorine dose as THMs. In addition, HAAs can be degraded by the microbial biofilm that grows on the surface of water treatment filtration media (Baribeau, et al., 2005). Although microbial biofilm on filtration media can be a major site of HAA degradation (Grigorescu and Hozalski, 2010), bioremediation is thought to be occurring in the City of Bellingham's distribution system by pipe and reservoir biofilm.[28]

[28]P. Wendling, pers. comm., City of Bellingham Public Works Dept.

Abbrev.	Parameter	Method	Historic DL[†]	2022/2023 MDL[†]	Sensitivity or Confidence limit
IWS field measurements:					
cond	Conductivity	YSI (2017)	–	–	$\pm$ 2 μS/cm
do	Dissolved oxygen	YSI (2017)	–	–	$\pm$ 0.1 mg/L
ph	pH	YSI (2017)	–	–	$\pm$ 0.1 pH unit
temp	Temperature	YSI (2017)	–	–	$\pm$ 0.1° C
disch	Discharge	Rantz et al. (1982); SOP-IWS-6	–	–	–
secchi	Secchi depth	Lind (1985)	–	–	$\pm$ 0.1 m
IWS laboratory analyses:					
alk	Alkalinity	APHA (2017) #2320; SOP-IWS-8	–	–	$\pm$ 0.4 mg/L
cond	Conductivity	APHA (2017) #2510; SOP-IWS-8	–	–	$\pm$ 2.1 μS/cm
do	Dissolved oxygen	APHA (2017) #4500-O.C.; SOP-IWS-8	–	–	$\pm$ 0.1 mg/L
ph	pH-lab	APHA (2017) #4500-H^+; SOP-IWS-8	–	–	$\pm$ 0.1 pH unit
tss	T. suspended solids	APHA (2017) #2540 D; SOP-IWS-13	2 mg/L	2.1 mg/L	$\pm$ 3.2 mg/L
turb	Turbidity	APHA (2017) #2130; SOP-IWS-8	–	–	$\pm$ 0.2 NTU
nh4	Ammonium (auto)	APHA (2017) #4500-NH_3 H; SOP-IWS-19	10 μg-N/L	5.9 μg-N/L	$\pm$ 5.3 μg-N/L
no3	Nitrite/nitrate (auto)	APHA (2017) #4500-NO_3 I; SOP-IWS-22	20 μg-N/L	19.8 μg-N/L	$\pm$ 22.9 μg-N/L
tn	T. nitrogen (auto)	APHA (2017) #4500-N C; SOP-IWS-22	100 μg-N/L	38.7 μg-N/L	$\pm$ 38.3 μg-N/L
srp	Sol. phosphate (auto)	APHA (2017) #4500-P G; SOP-IWS-22	5 μg-P/L	1.4 μg-P/L	$\pm$ 0.7 μg-P/L
tp	T. phosphorus (auto)	APHA (2017) #4500-P J; SOP-IWS-22	5 μg-P/L	1.3 μg-P/L	$\pm$ 2.2 μg-P/L
toc[‡]	T. organic carbon	APHA (2017) #5310 B; SOP-IWS-23	1.0 mg/L	0.17 mg/L	$\pm$ 0.18 mg/L
IWS plankton analyses:					
chl	Chlorophyll	APHA (2017) #10200 H; SOP-LW-16	–	–	$\pm$ 0.1 μg/L
chlo	Chlorophyta	Lind (1985), Schindler trap	–	–	–
cyan	Cyanobacteria	Lind (1985), Schindler trap	–	–	–
chry	Chrysophyta	Lind (1985), Schindler trap	–	–	–
pyrr	Pyrrophyta	Lind (1985), Schindler trap	–	–	–
City coliform analyses:					
ec	*E. coli*	EPA (2014) #1603	1 cfu/100 mL	1 cfu/100 mL	–
Edge Analytical analyses:					
H_2S	Hydrogen sulfide	APHA (2017) #4500-S2 F	–	0.044 mg/L	–
AmTest analyses:					
toc[‡]	T. organic carbon	APHA (2017) #5310 B	1.0 mg/L	0.5 mg/L	–

[†]Historic detection limits (DL) are usually higher than current method detection limits (MDL).
[‡]Total organic carbon analyses are run in duplicate by IWS and AmTest to evaluate analytical equivalence.

Table 2.1: Summary of IWS, AmTest, Edge Analytical, and City of Bellingham analytical methods and parameter abbreviations.

Parameter	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct†	Nov†	Dec†	Locations‡
DO - field	•	•	•	•	•	•	•	•	•	•	Sites 1, 2, Intake - every 1 m;
pH - field	•	•	•	•	•	•	•	•	•	•	Sites 3, 4 - every 1 m to 10 m
Temp - field	•	•	•	•	•	•	•	•	•	•	then every 5 m; Gatehouse - 0.3 m
Cond - field	•	•	•	•	•	•	•	•	•	•	
Secchi depth	•	•	•	•	•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake
Alkalinity	•	•	•	•	•	•	•	•	•	•	Sites 1, 2 - 0.3, 5, 10, 15, 20 m;
Ammonium	•	•	•	•	•	•	•	•	•	•	Intake - 0.3, 5, 10 m;
Nitrate/nitrite	•	•	•	•	•	•	•	•	•	•	Site 3 - 0.3, 5, 10, 20, 40, 60,
T. nitrogen	•	•	•	•	•	•	•	•	•	•	75 m; Site 4 - 0.3, 5, 10, 20, 40
Sol. phosphate	•	•	•	•	•	•	•	•	•	•	60, 80, 90 m; Gatehouse - 0.3 m
T. phosphorus	•	•	•	•	•	•	•	•	•	•	
Turbidity	•	•	•	•	•	•	•	•	•	•	
T. organic carbon	•			•							Sites 1, 2, 3, 4, Intake - 0.3 m and bottom only
Chlorophyll	•	•	•	•	•	•	•	•	•	•	Sites 1, 2, 3, 4 - 0.3, 5, 10, 15, 20 m; Intake - 0.3, 5, 10 m
Plankton	•	•	•	•	•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake; 5 m
Bacteria (City)	•	•	•	•	•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake, Bloedel-Donovan; 0.3 m
H_2S - opt								•			Sites 1, 2 - 10, 15, 20 m

†Samples will be collected Feb-Dec in 2022 and 2023; field work will end in September 2024 to allow time to complete all analyses unless the monitoring contract is extended past December 2024.
‡Samples within each parameter subgroup are collected at all locations listed in this column.

Table 2.2: Lake Whatcom lake monitoring schedule. All field and laboratory methods are summarized in Table 2.1; missing data resulting from sampling and laboratory issues are summarized in Table 2.3.

Month	Missing Sample Summary	Comments
October 2022	No missing data	
November 2022	Site 3: No alkalinity at 0m Gatehouse: No turbidity	Sample spilled Lab error
December 2022	No missing data	
February 2023	No missing data	
April 2023	Site 3: No nitrate data from 10, 20, 40, 60m Site 4: No nitrate data from 0, 40, 60, 80, 90m	Unacceptable lab variability Unacceptable lab variability
May 2023	No missing data	
June 2023	Site 4: No samples taken at 5m Intake: No soluble reactive phosphorus data from 5m	Sample not collected Lab error
July 2023	No missing data	
August 2023	No missing data	
September 2023	No missing data	

Table 2.3: Summary of missing lake data due to sampling or laboratory issues.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	19.5	21.0	21.1	26.1
Conductivity (μS/cm)	58.7	60.2	60.9	73.7
Dissolved oxygen (mg/L)	0.0	9.9	8.7	12.2
pH	6.1	7.3	7.2	8.8
Temperature (°C)	5.7	9.8	11.2	22.2
Turbidity (NTU)	0.5	0.7	0.9	4.6
Nitrogen, ammonium (μg-N/L)	<10	<10	23.5	310.2
Nitrogen, nitrate/nitrite (μg-N/L)	<20	175.9	127.4	274.2
Nitrogen, total (μg-N/L)	<100	329.1	307.7	450.7
Phosphorus, soluble (μg-P/L)	<5	<5	<5	51.0
Phosphorus, total (μg-P/L)	<5	6.2	9.3	77.9
Chlorophyll (μg/L)	0.3	3.5	3.7	17.7
Secchi depth (m)	3.5	4.8	4.6	6.5
E. coli (cfu/100 mL)‡	<1	1.0	1.1	2.0

†Uncensored arithmetic means except coliforms (geometric mean)
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1)

Table 2.4: Summary of Site 1 water quality data, Oct. 2022 – Sept. 2023.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	18.2	20.4	20.2	21.1
Conductivity (μS/cm)	56.7	58.1	58.4	60.3
Dissolved oxygen (mg/L)	8.9	10.2	10.4	12.0
pH	7.2	7.6	7.7	8.6
Temperature (°C)	6.3	12.9	14.0	21.5
Turbidity (NTU)	0.4	0.5	0.5	0.8
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	15.2
Nitrogen, nitrate/nitrite (μg-N/L)	<20	137.8	138.8	284.6
Nitrogen, total (μg-N/L)	<100	285.1	279.3	394.2
Phosphorus, soluble (μg-P/L)	<5	<5	<5	5.3
Phosphorus, total (μg-P/L)	<5	<5	<5	7.9
Chlorophyll (μg/L)	1.1	3.0	3.1	8.0
Secchi depth (m)	4.0	5.5	5.4	7.5
E. coli (cfu/100 mL)‡	<1	1.0	1.2	4.0

†Uncensored arithmetic means except coliforms (geometric mean)
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$)

Table 2.5: Summary of Intake water quality data, Oct. 2022– Sept. 2023.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	18.6	20.2	20.4	26.4
Conductivity (μS/cm)	56.7	58.1	58.8	73
Dissolved oxygen (mg/L)	0.1	10.1	9.3	12.0
pH	6.0	7.3	7.4	8.6
Temperature (°C)	6.3	11.0	12.3	21.5
Turbidity (NTU)	0.4	0.5	0.7	4.4
Nitrogen, ammonium (μg-N/L)	$<$10	$<$10	17.3	259.1
Nitrogen, nitrate/nitrite (μg-N/L)	$<$20	174.4	161.2	285.7
Nitrogen, total (μg-N/L)	$<$100	321.0	318.0	507.8
Phosphorus, soluble (μg-P/L)	$<$5	$<$5	$<$5	32.3
Phosphorus, total (μg-P/L)	$<$5	5.3	6.7	84.8
Chlorophyll (μg/L)	0.5	2.7	3.0	8.3
Secchi depth (m)	3.4	5.8	5.5	7.0
E. coli (cfu/100 mL)‡	$<$1	1.0	1.0	1.0

†Uncensored arithmetic means except coliforms (geometric mean)
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$)

Table 2.6: Summary of Site 2 water quality data, Oct. 2022– Sept. 2023.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	18.1	19.3	19.4	20.9
Conductivity (μS/cm)	56.4	57.8	57.8	59.9
Dissolved oxygen (mg/L)	6.6	9.8	9.9	12.1
pH	6.2	7.1	7.2	8.4
Temperature (°C)	6.3	7.4	10.4	20.9
Turbidity (NTU)	0.2	0.4	0.4	1.4
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	29.4
Nitrogen, nitrate/nitrite (μg-N/L)	<20	294.8	249.2	371.3
Nitrogen, total (μg-N/L)	<100	388.6	357.9	468.4
Phosphorus, soluble (μg-P/L)	<5	<5	<5	<5
Phosphorus, total (μg-P/L)	<5	<5	<5	17.5
Chlorophyll (μg/L)	1.0	2.4	2.9	6.1
Secchi depth (m)	4.0	6.2	6.2	8.5
E. coli (cfu/100 mL)‡	<1	1.0	1.0	1.0

†Uncensored arithmetic means except coliforms (geometric mean)
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1)

Table 2.7: Summary of Site 3 water quality data, Oct. 2022– Sept. 2023.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	18.1	19.2	19.2	20.9
Conductivity (μS/cm)	56.2	57.8	57.7	59.8
Dissolved oxygen (mg/L)	7.8	10.1	10.1	12.3
pH	6.4	7.1	7.2	8.5
Temperature (°C)	6.2	7.0	10.0	20.9
Turbidity (NTU)	0.2	0.4	0.4	0.7
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	46.0
Nitrogen, nitrate/nitrite (μg-N/L)	<20	299.1	259.4	468.4
Nitrogen, total (μg-N/L)	<100	385.0	358.0	442.9
Phosphorus, soluble (μg-P/L)	<5	<5	<5	13.1
Phosphorus, total (μg-P/L)	<5	<5	<5	29.1
Chlorophyll (μg/L)	0.6	2.8	2.8	5.9
Secchi depth (m)	4.0	6.2	6.2	8.5
E. coli (cfu/100 mL)‡	<1	1.0	1.0	1.0

†Uncensored arithmetic means except coliforms (geometric mean)
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1)

Table 2.8: Summary of Site 4 water quality data, Oct. 2022– Sept. 2023.

	H_2S (mg/L)			H_2S (mg/L)	
Year	Site 1	Site 2	Year	Site 1	Site 2
1999†	0.03–0.04	0.40	2012	na	na
2000†	0.27	0.53	2013	0.20§	0.16
2001†	0.42	0.76	2014	0.28	0.66
2002†	0.09	0.32	2015	0.51	0.41
2003†	0.05	0.05	2016	0.64	0.51
2004†	0.25	0.25	2017	0.68*	<0.05
2005‡	0.13, 0.12	0.25, 0.42	2018	0.32	0.39
2006	0.20	0.42	2019	0.10	0.22
2007	0.40	0.20	2020	0.29	0.51
2008	0.28	0.38	2021	0.25	0.51
2009	0.15	0.47	2022	0.09	<0.05
2010	0.38	0.40	2023	<0.05	0.54
2011	0.12	0.16			

†H_2S samples analyzed by HACH test kit.
‡HACH (first value) vs. Edge Analytical (second value)
§Corrected value (1.20 in Matthews, et al., 2015)
*Sample collected at 15 meters; sample from 20 m contained sediment.

Table 2.9: October hypolimnetic hydrogen sulfide concentrations at Sites 1 and 2 (20 m). The H_2S samples have been analyzed by Edge Analytical since 2005; earlier samples were analyzed using a HACH field test kit.

Site	Depth (m)	Date	AmTest TOC (mg/L)	IWS TOC (mg/L)	Date	AmTest TOC (mg/L)	IWS TOC (mg/L)
Site 1	0	Feb 14, 2023	2.0	1.9	Jun 6, 2023	2.0	2.0
	20	Feb 14, 2023	2.1	1.8	Jun 6, 2023	2.0	2.0
Intake	0	Feb 14, 2023	1.8	1.8	Jun 6, 2023	1.6	2.0
	10	Feb 14, 2023	1.9	1.7	Jun 6, 2023	1.7	1.9
Site 2	0	Feb 14, 2023	1.8	1.8	Jun 6, 2023	1.5	1.8
	20	Feb 14, 2023	1.8	1.7	Jun 6, 2023	1.3	1.8
Site 3	0	Feb 2, 2023	2.0	1.7	Jun 8, 2023	1.6	1.9
	75	Feb 2, 2023	2.0	1.8	Jun 8, 2023	1.3	1.7
Site 4	0	Feb 2, 2023	2.0	1.7	Jun 8, 2023	1.6	1.9
	90	Feb 2, 2023	2.0	1.8	Jun 8, 2023	1.2	1.7

Table 2.10: Lake Whatcom 2022/2023 total organic carbon data. February and Aug samples were split and analyzed by AmTest (TOC-AM) and IWS (TOC-IWS). Differences can be expected when concentrations are low and if there are particles present in one sample but not the other.

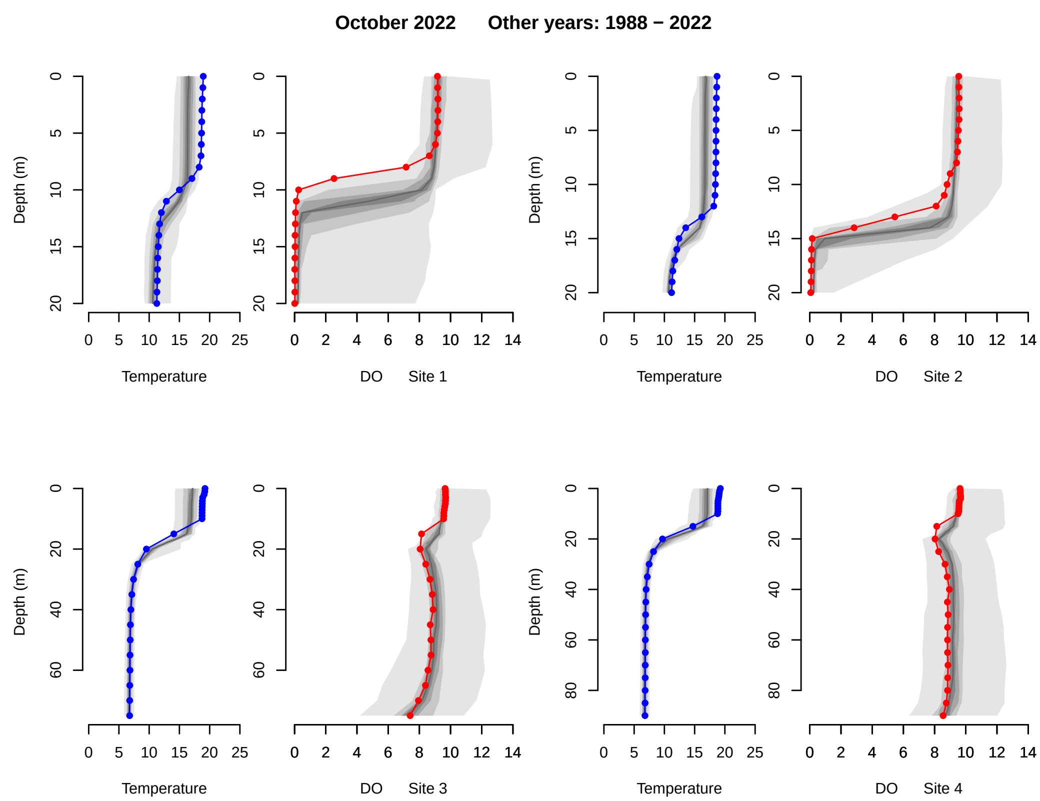


Figure 2.1: October 2022 temperature (-•-) and dissolved oxygen (-•-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2022 data.

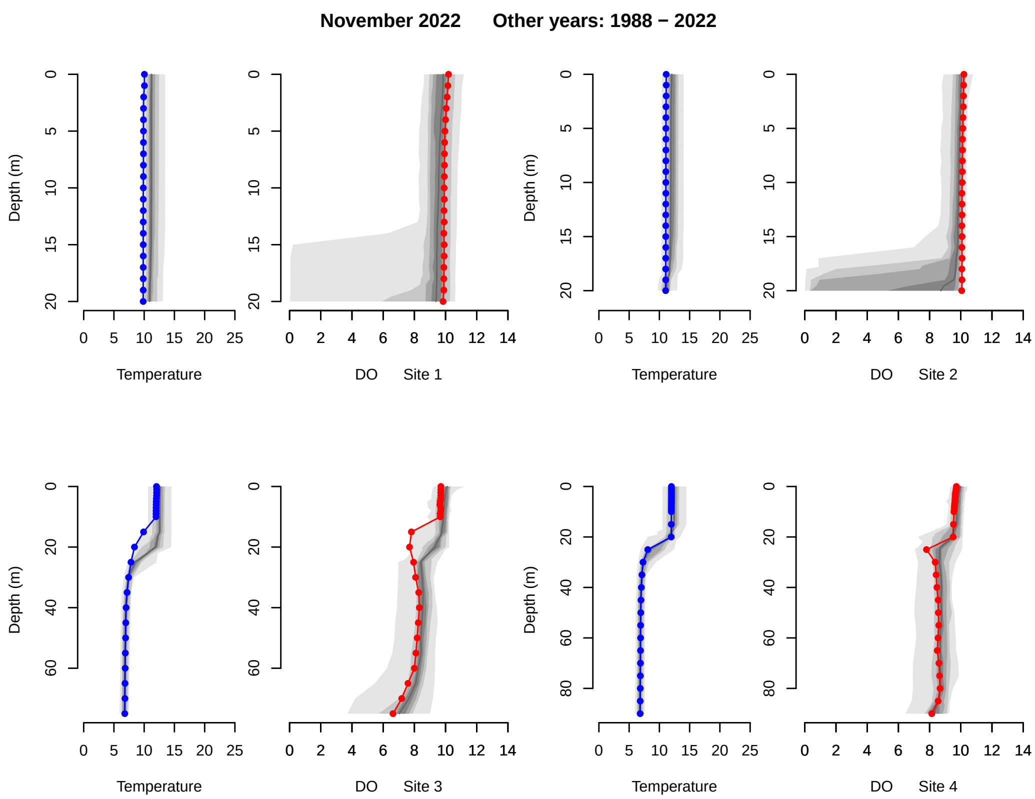


Figure 2.2: November 2022 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2022 data.

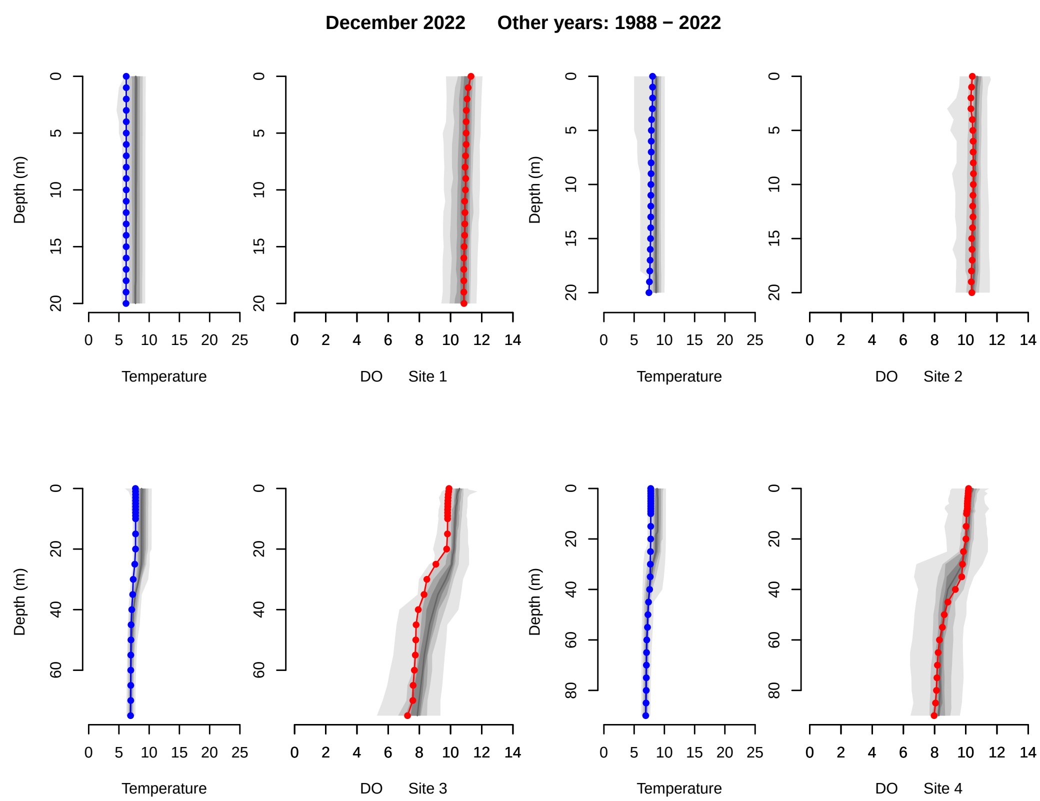


Figure 2.3: December 2022 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2022 data.

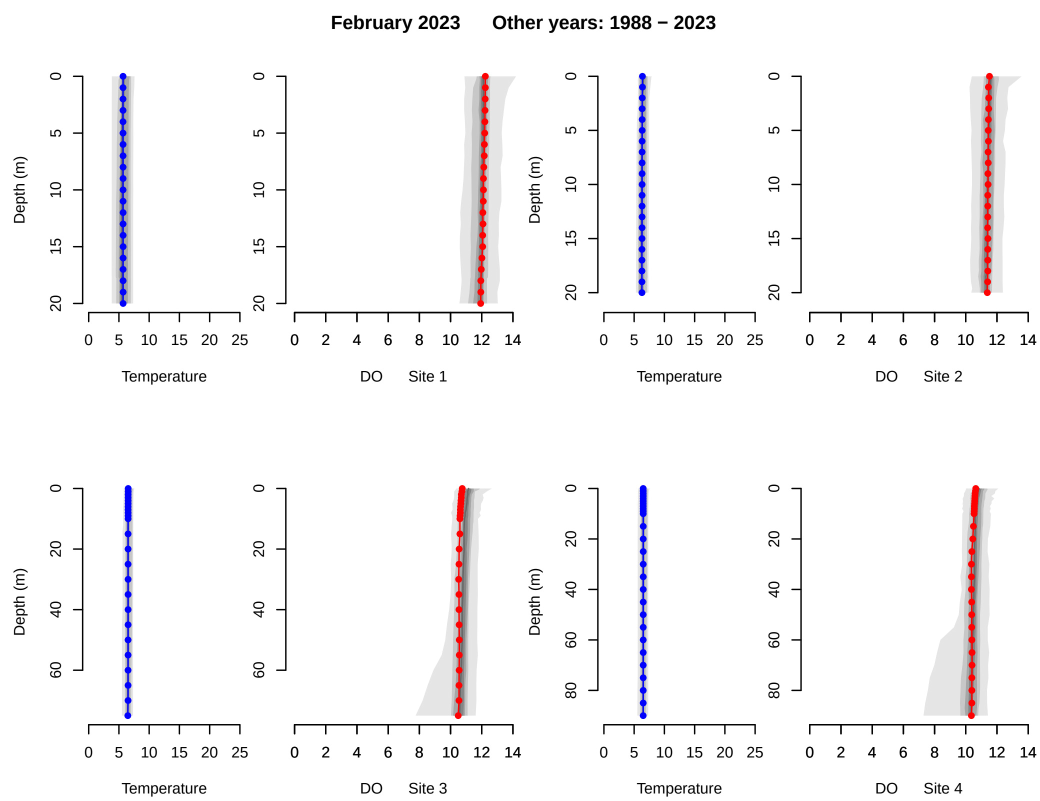


Figure 2.4: February 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data.

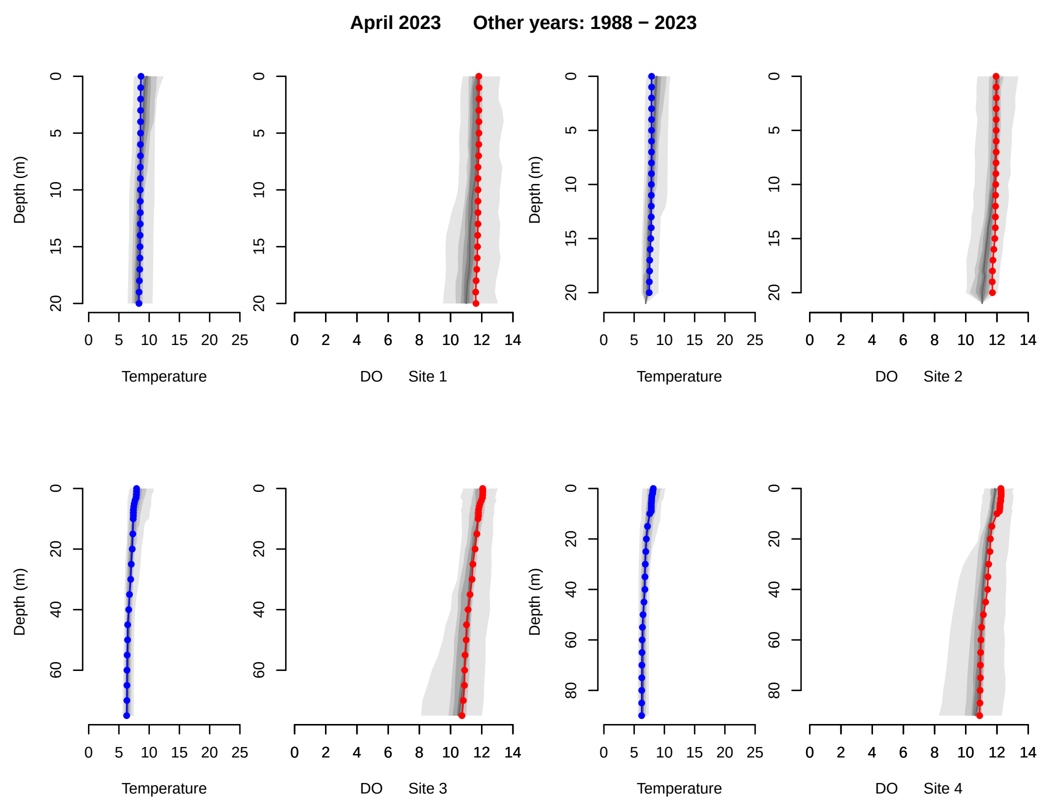


Figure 2.5: April 2023 temperature (-•-) and dissolved oxygen (-•-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data.

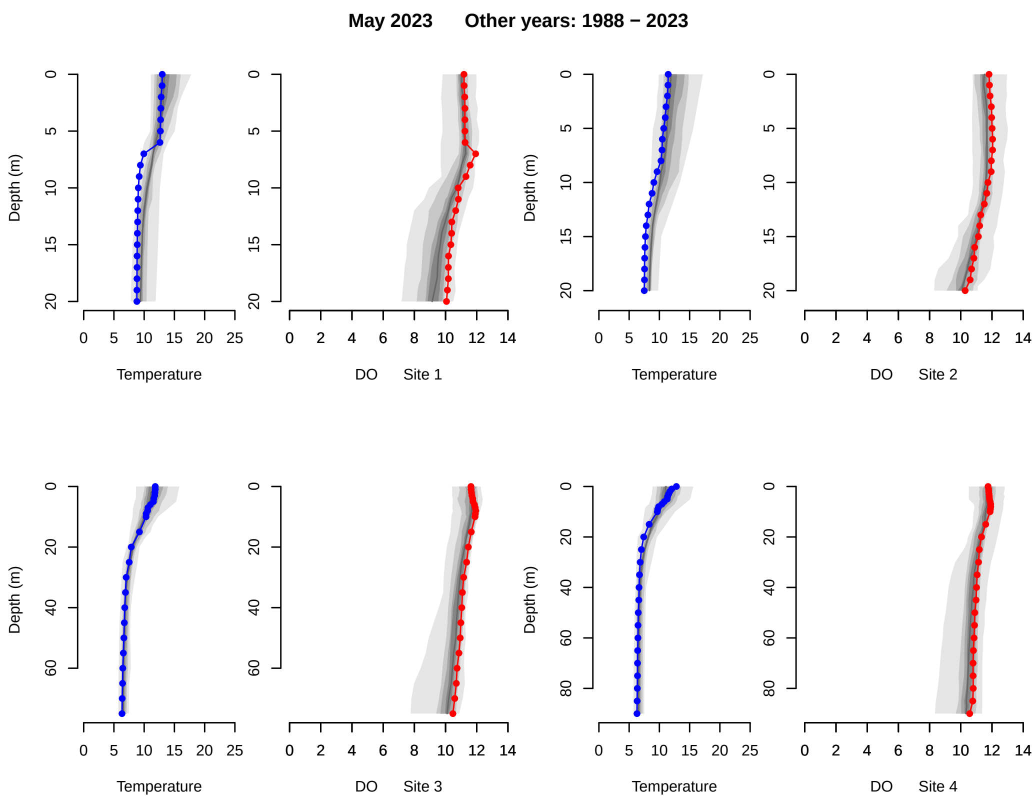


Figure 2.6: May 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data.

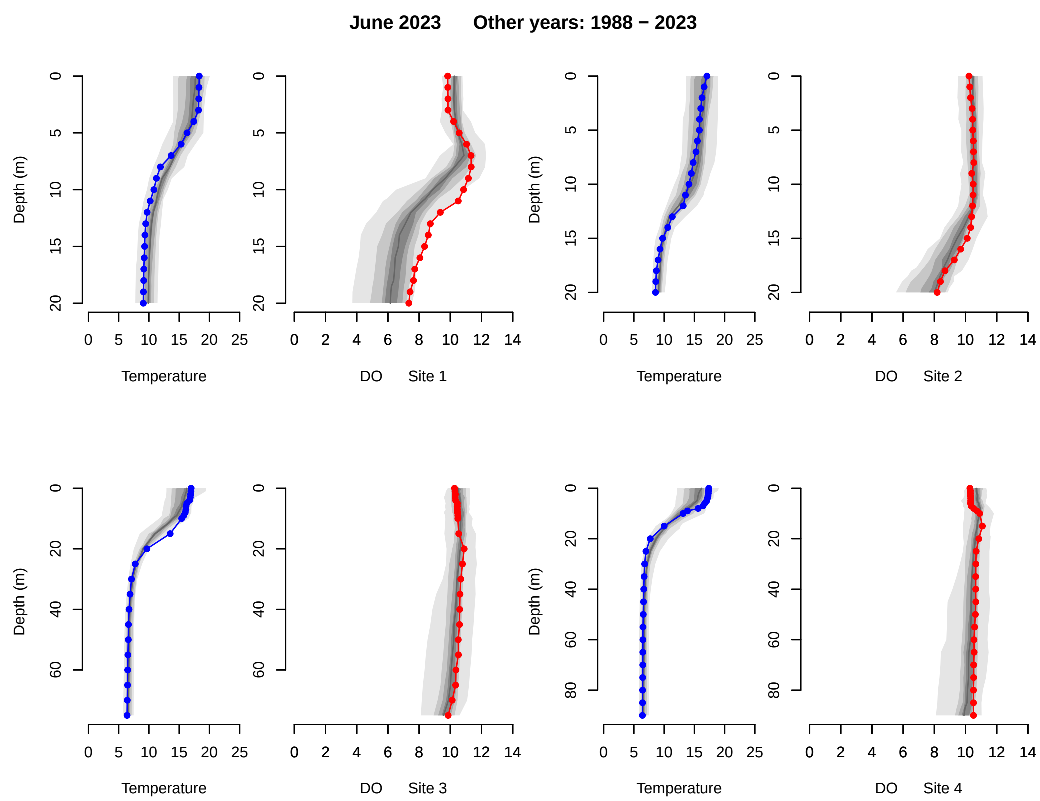


Figure 2.7: June 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data.

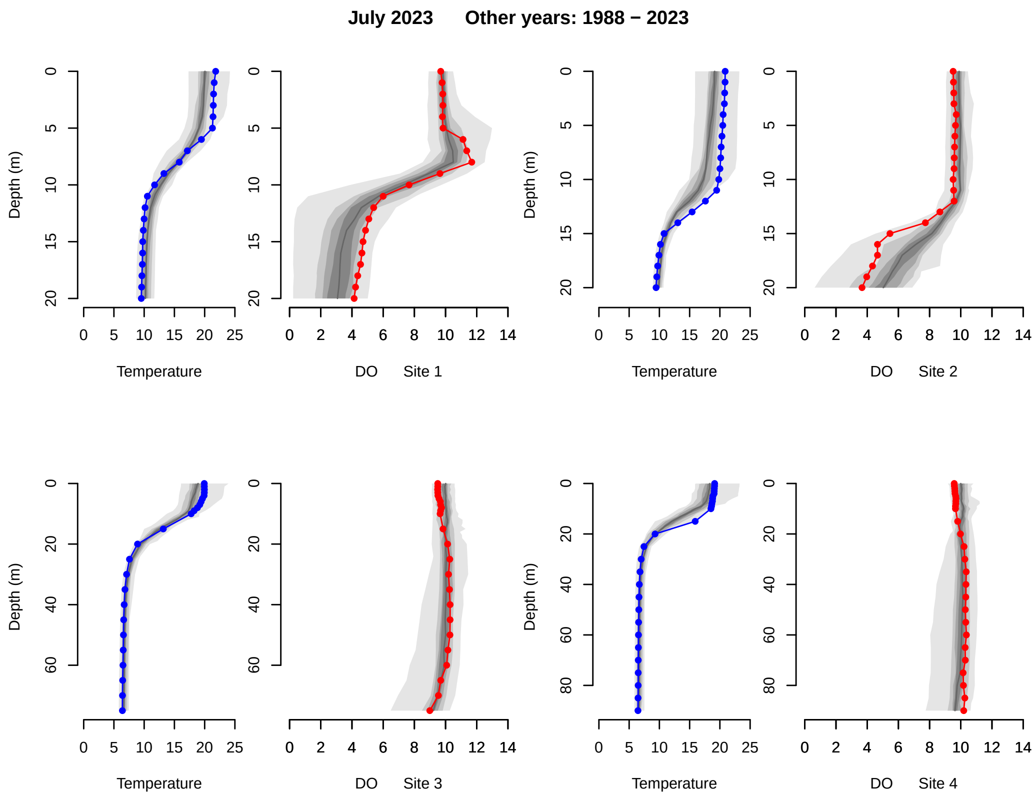


Figure 2.8: July 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data.

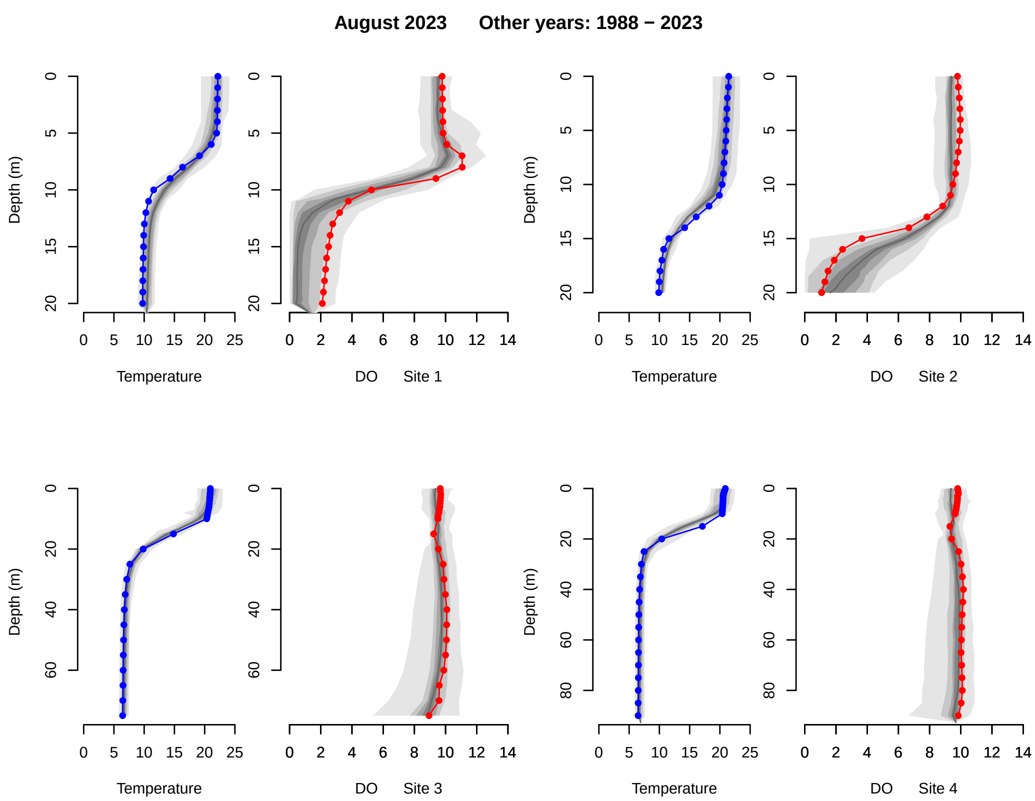


Figure 2.9: August 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data.

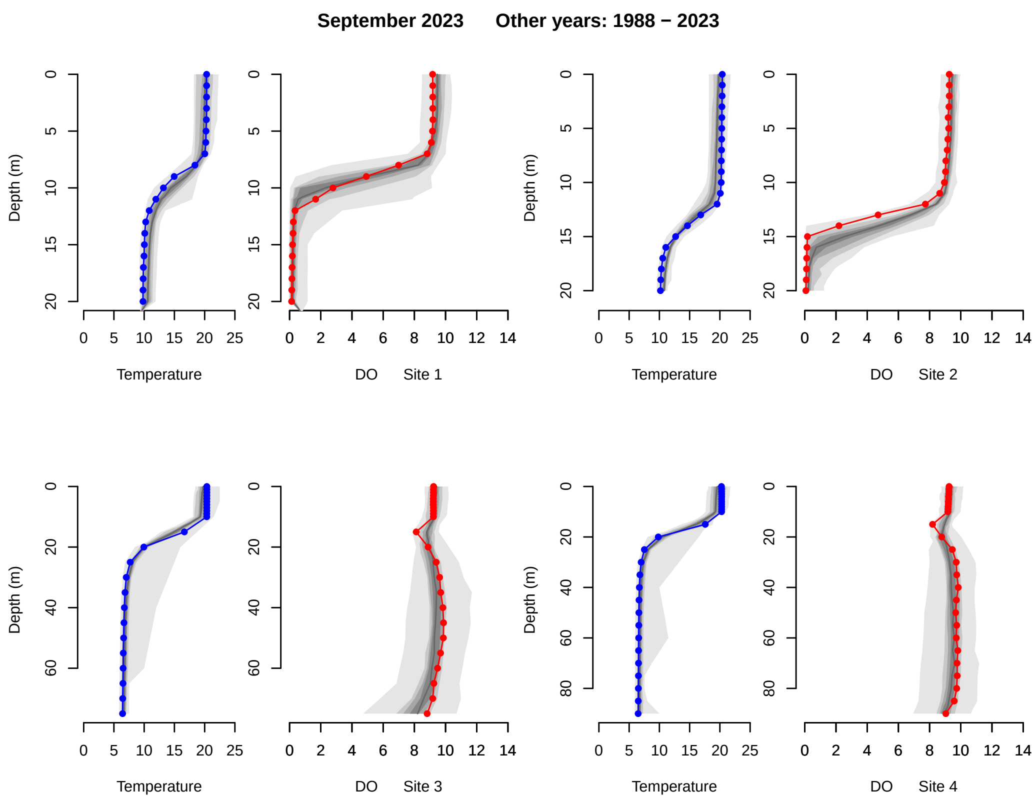


Figure 2.10: September 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data.

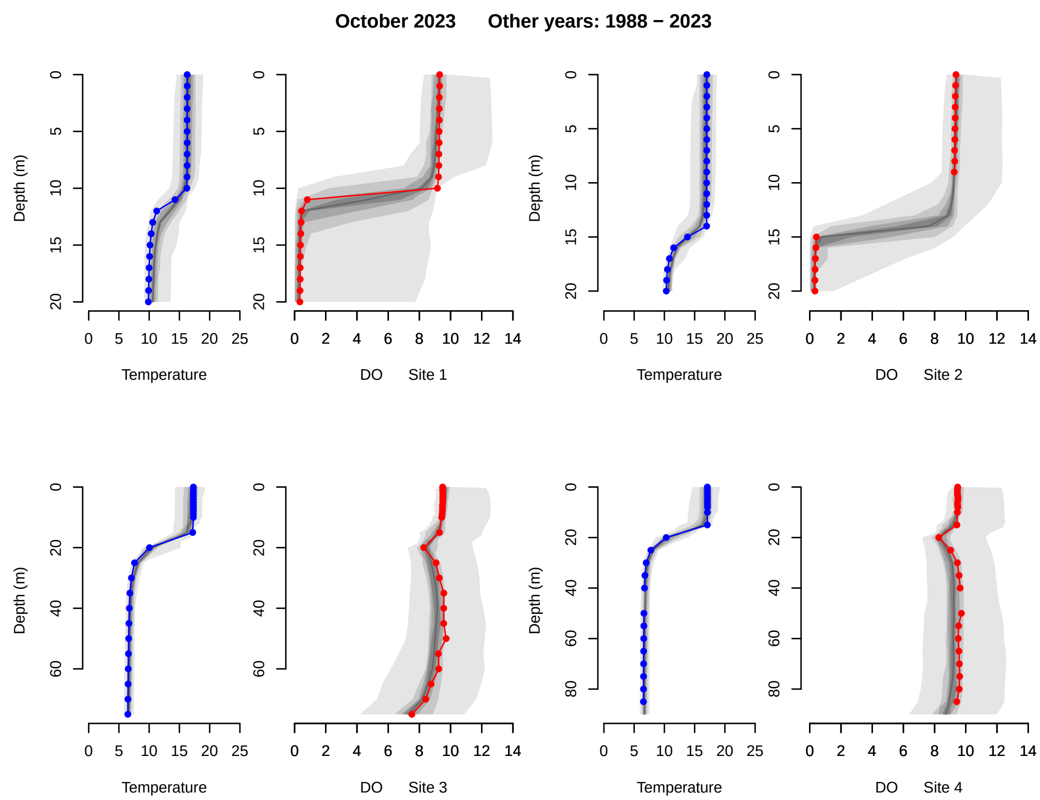


Figure 2.11: October 2023 temperature (-•-) and dissolved oxygen (-•-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data. October 2023 is not part of the 2022/2023 sampling period, but were included to to provide information on the timing of destratification.

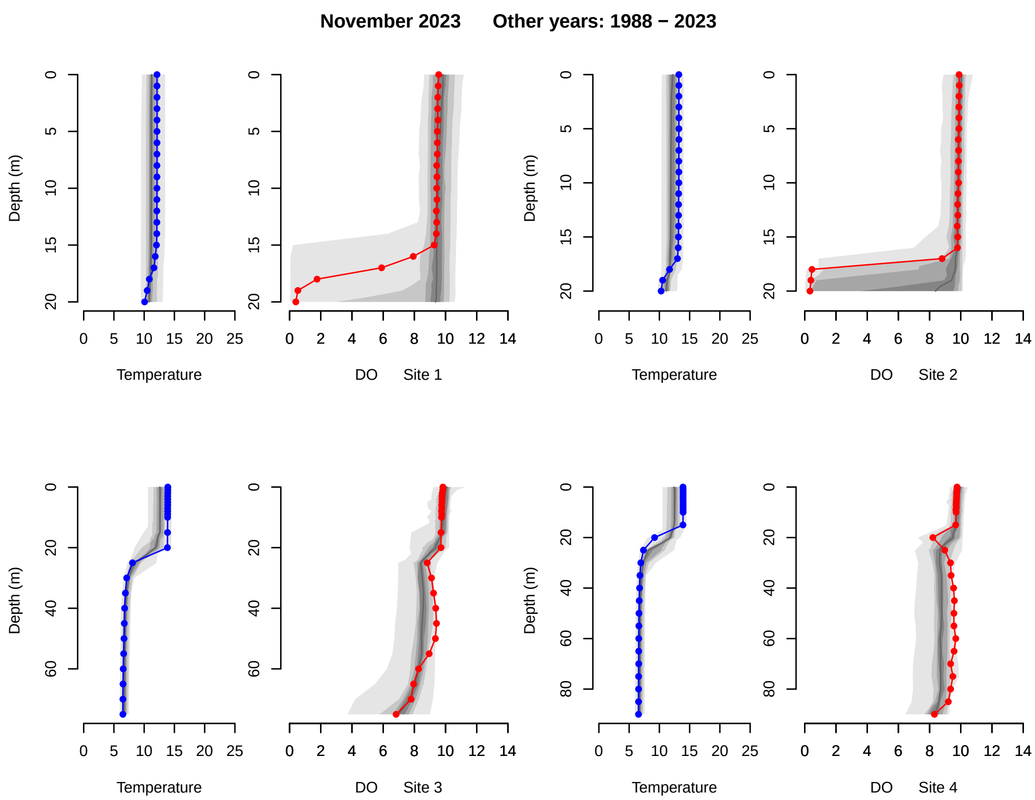


Figure 2.12: November 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data. November 2023 is not part of the 2022/2023 sampling period, but were included to to provide information on the timing of destratification.

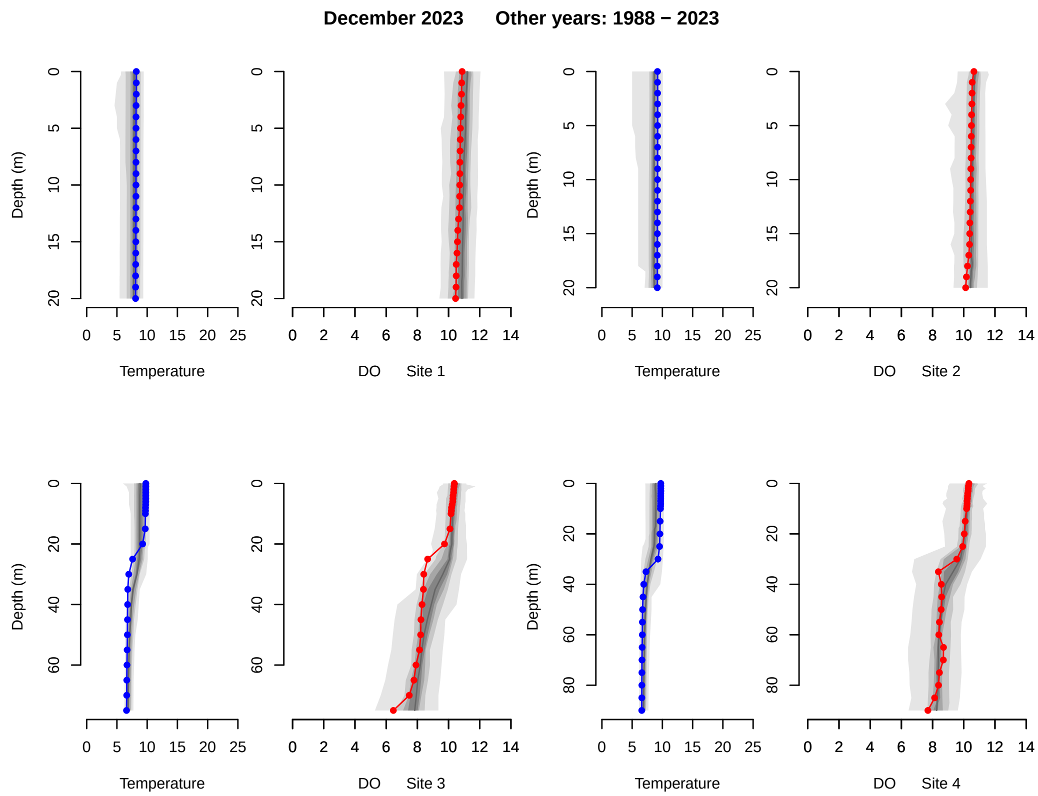


Figure 2.13: December 2023 temperature (-●-) and dissolved oxygen (-●-) profiles compared to historic ranges. The gradation in shading shows the approximate frequency of the 1988–2023 data. December 2023 is not part of the 2022/2023 sampling period, but were included to to provide information on the timing of destratification.

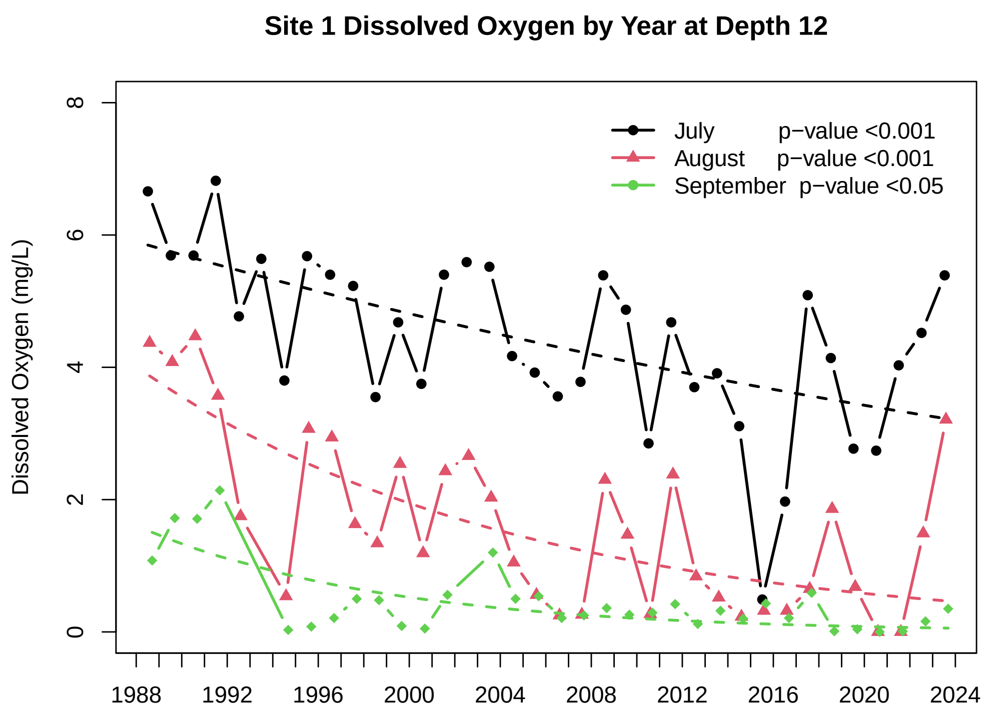


Figure 2.14: Relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

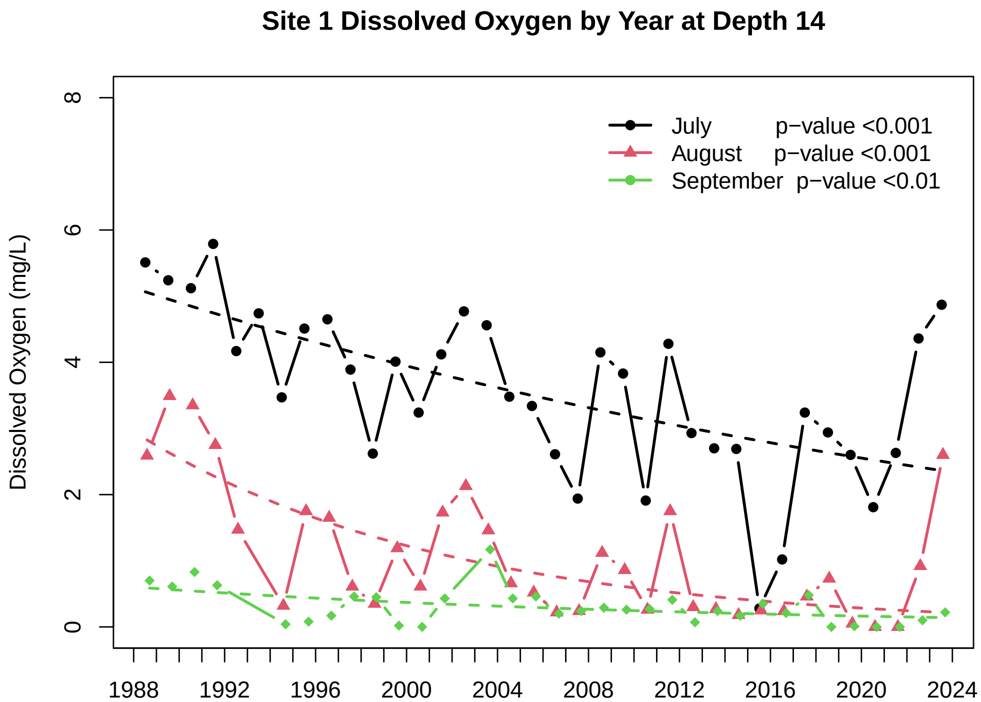


Figure 2.15: Relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

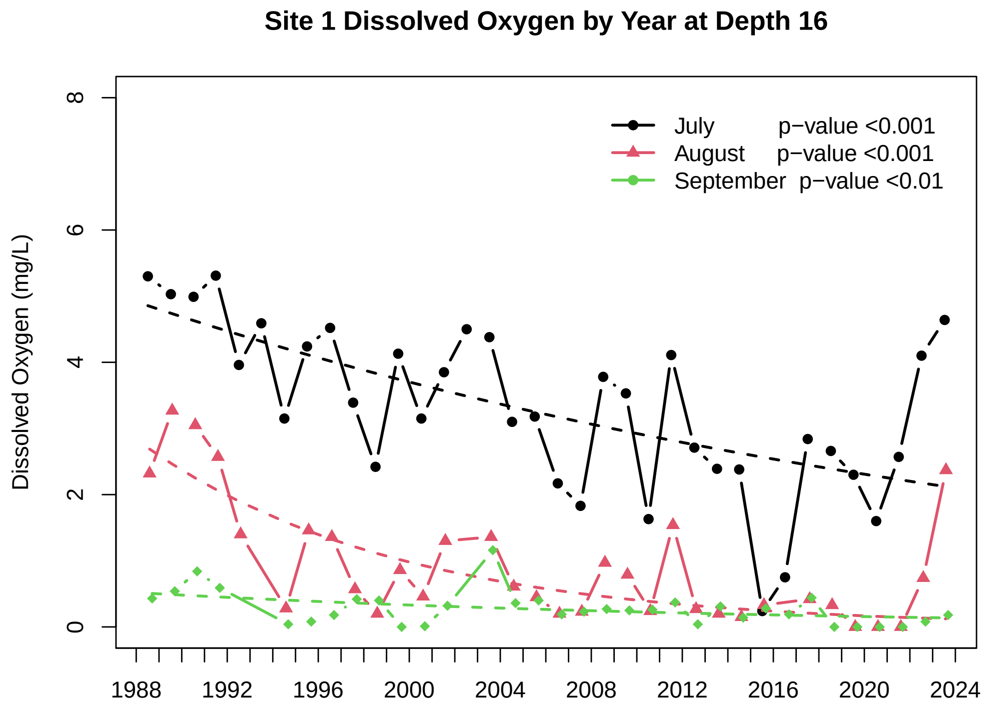


Figure 2.16: Relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

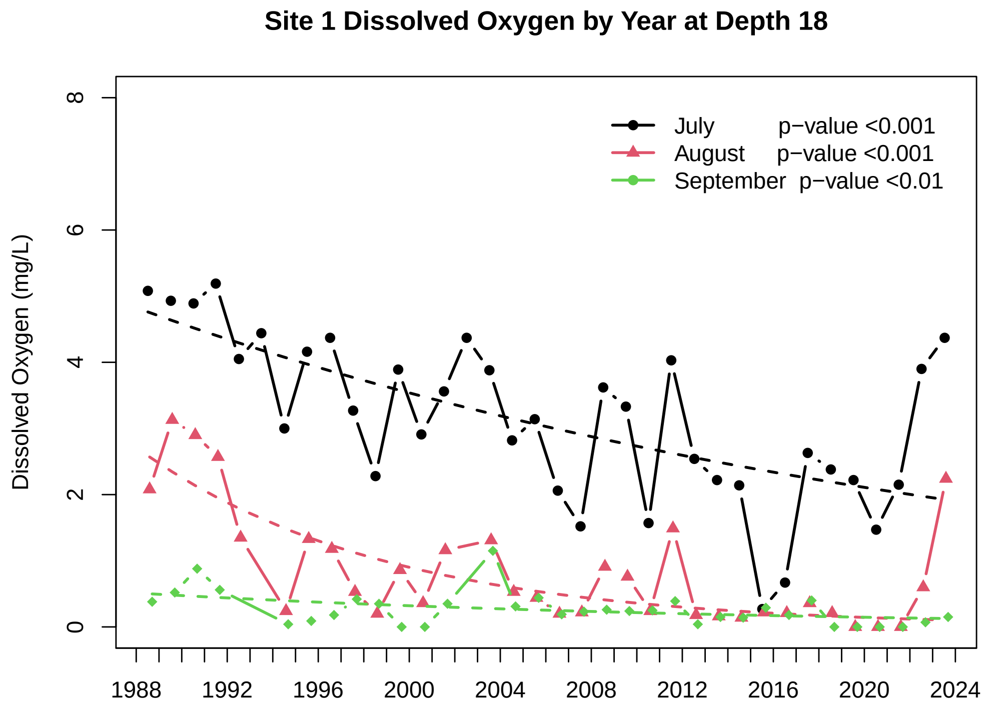


Figure 2.17: Relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

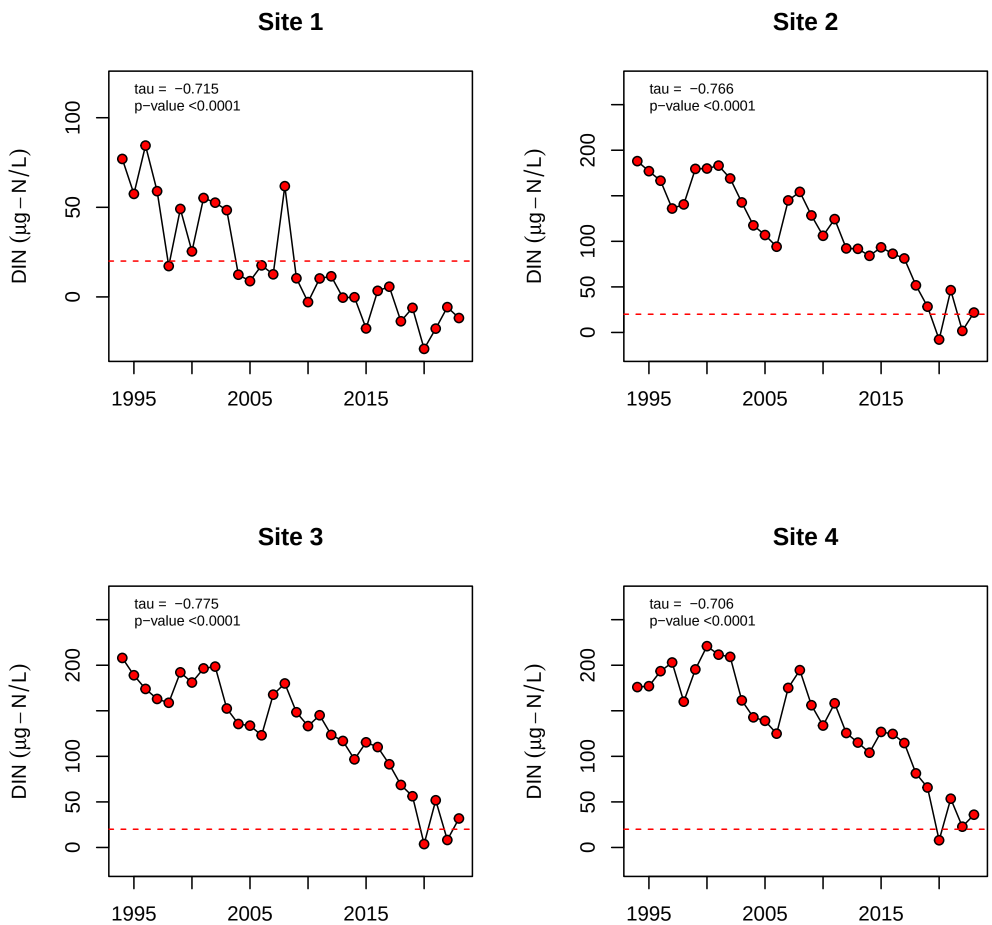


Figure 2.18: Minimum summer, near-surface dissolved inorganic nitrogen (DIN) concentrations (1994–2023 June-Oct, depths ≤5 m). Uncensored (raw) data were used to illustrate that minimum values are dropping below analytical detection limits (dashed red line); negative values represent regression results for concentrations below the detection limit. Note differences in y-axis scale between Site 1 and Sites 2–4. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

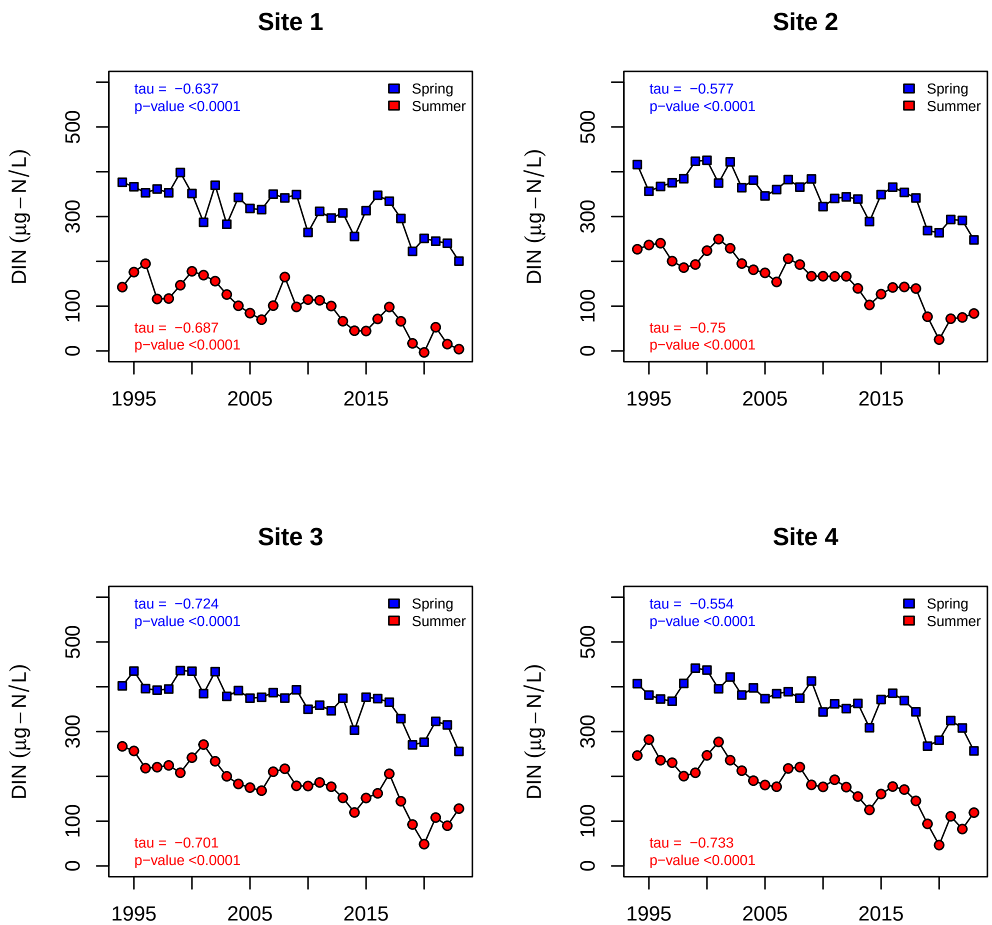


Figure 2.19: Comparison of median spring (Feb-May) vs. summer (June-Oct) near-surface dissolved inorganic nitrogen (DIN) concentrations (1994–2023, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

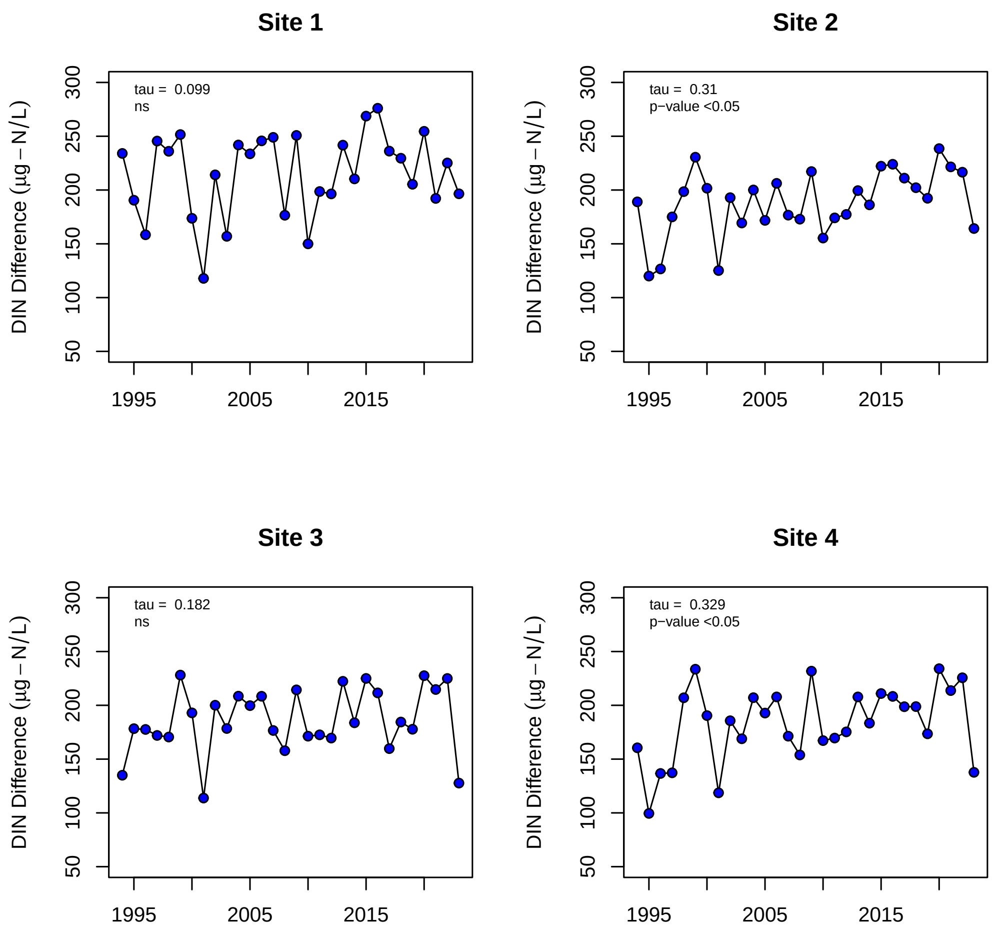


Figure 2.20: Differences between median spring (Feb-May) and summer (June-Oct) near-surface dissolved inorganic nitrogen (DIN) concentrations (1994–2023, depths $\leq$5 m; DIN difference = DIN_{spring}-DIN_{summer}). Kendall's τ correlations were used because the data were not monotonic-linear; correlations were marginally significant (p-value $<$0.05) or not significant (ns; p-value $>$0.05).

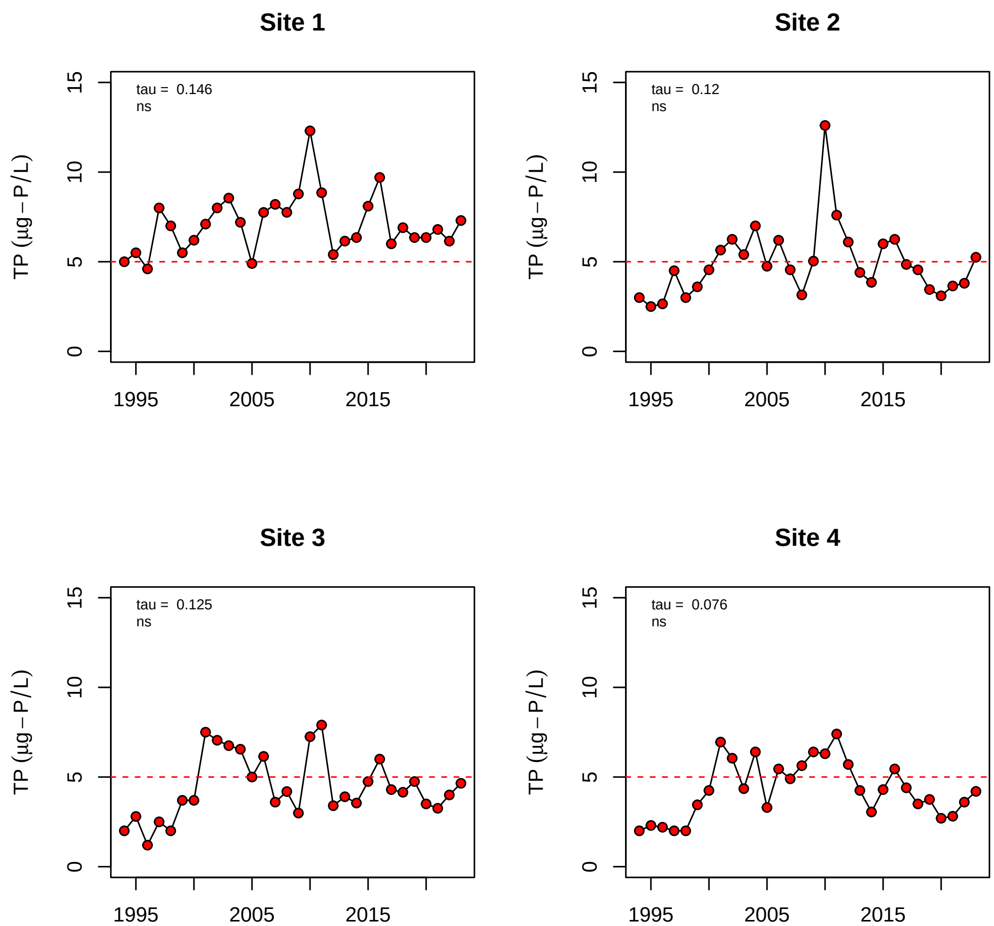


Figure 2.21: Median summer, near-surface total phosphorus concentrations (1994–2023, June-Oct, depths ≤5 m). Uncensored (raw) data were used to illustrate when median values are below analytical detection limits (dashed red line). Kendall's τ correlations were used because the data were not monotonic-linear; none of the correlations were significant.

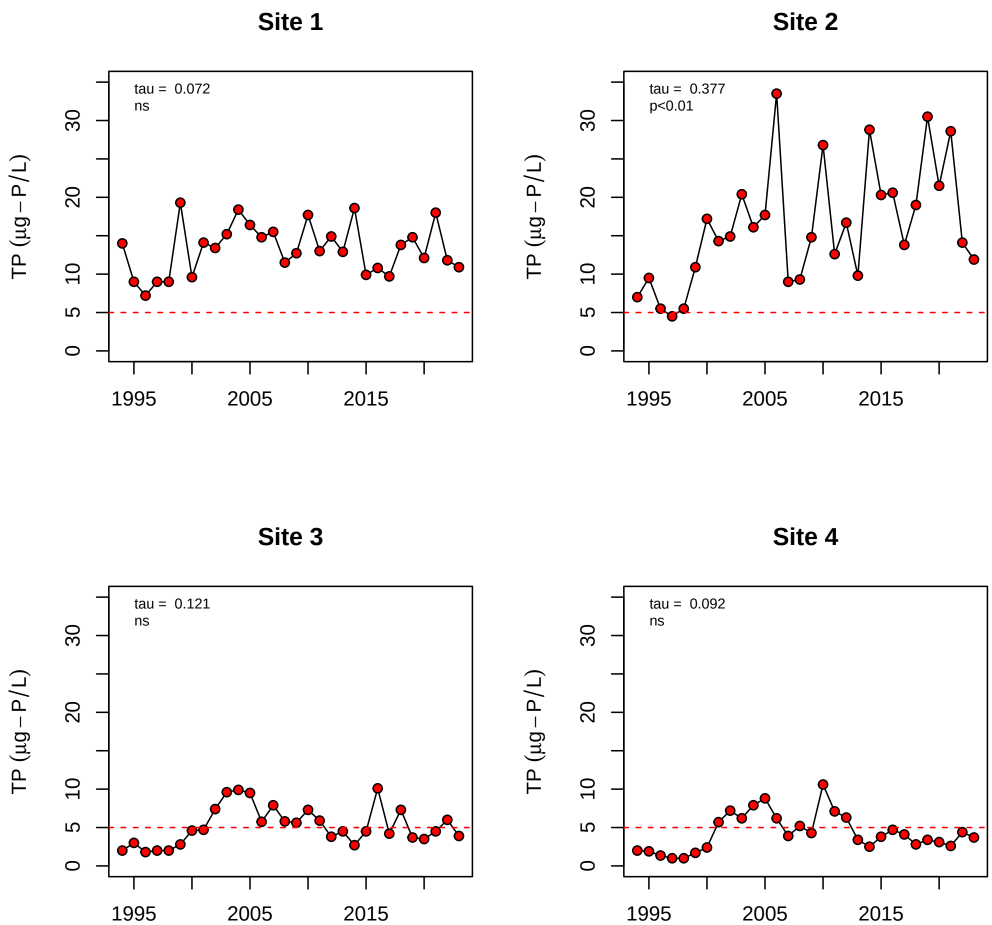


Figure 2.22: Median summer, near-bottom total phosphorus concentrations (1994–2023, June-Oct). Depths are specific to site, where Site 1 and 2 depth ≥20 m, Site 3 depth ≥75 m, and Site 4 depth ≥90 m. Between 1994–1998, 1-3 samples were missing during this June-Oct sampling period at these specific depths. Uncensored (raw) data were used to illustrate when median values are below analytical detection limits (dashed red line). Kendall's τ correlations were used because the data were not monotonic-linear; correlations were significant (p-value <0.01, Site 2) or not significant (ns; p-value >0.05).

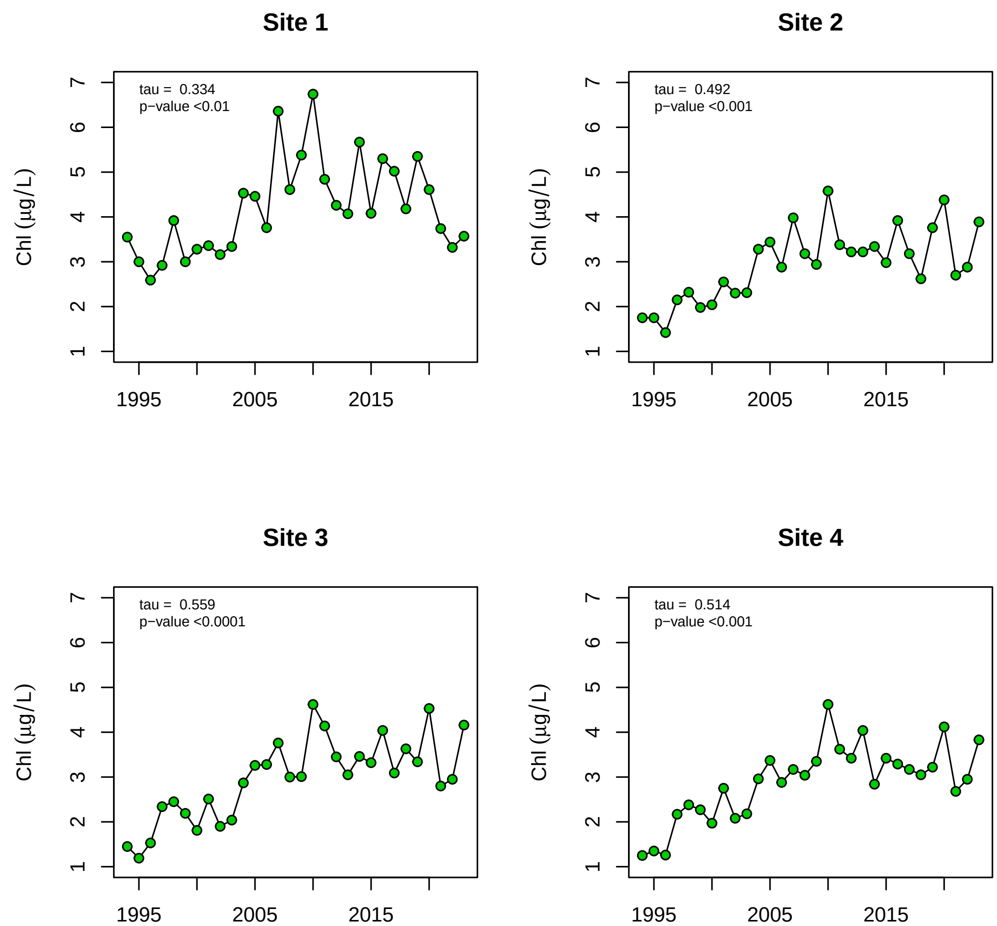


Figure 2.23: Median summer near-surface chlorophyll concentrations (1994–2023, June-October, depths ≤5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

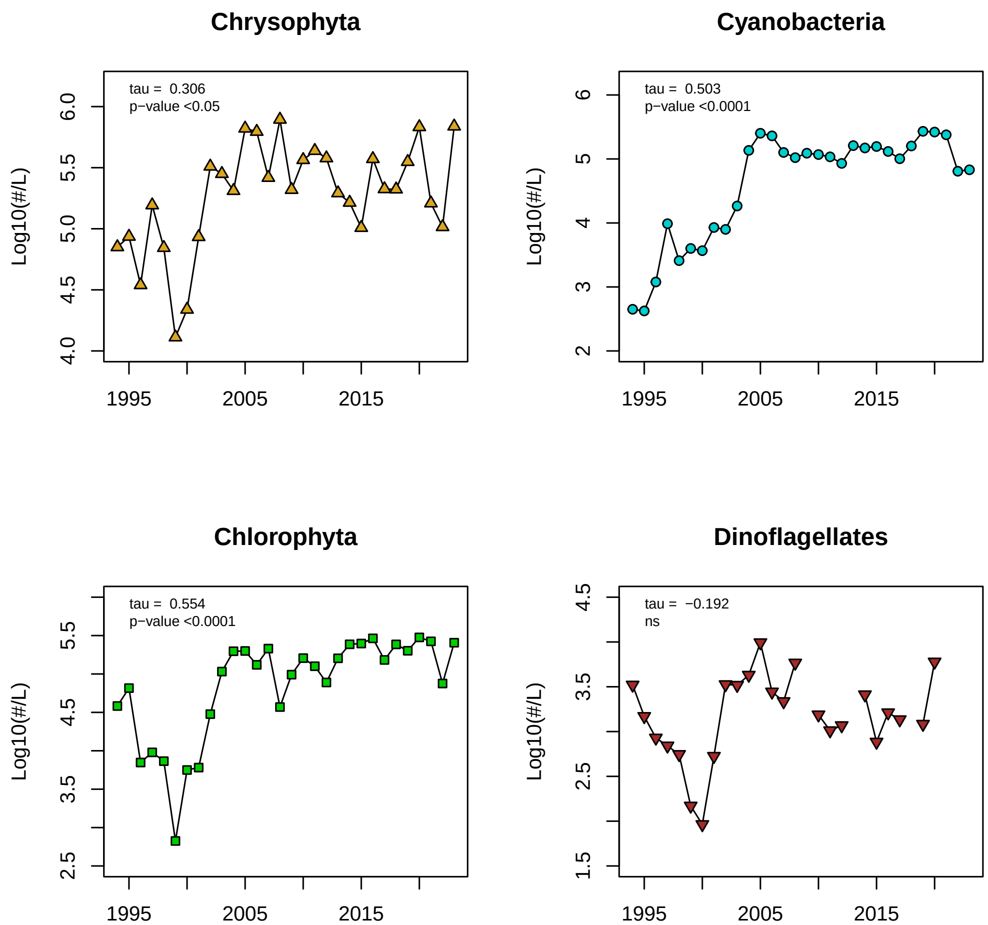


Figure 2.24: Log_{10} plots of median summer, near-surface algae counts (1994-2023, June-October, all sites and depths). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations except Dinoflagellates were significant. Note difference in vertical axis scales.

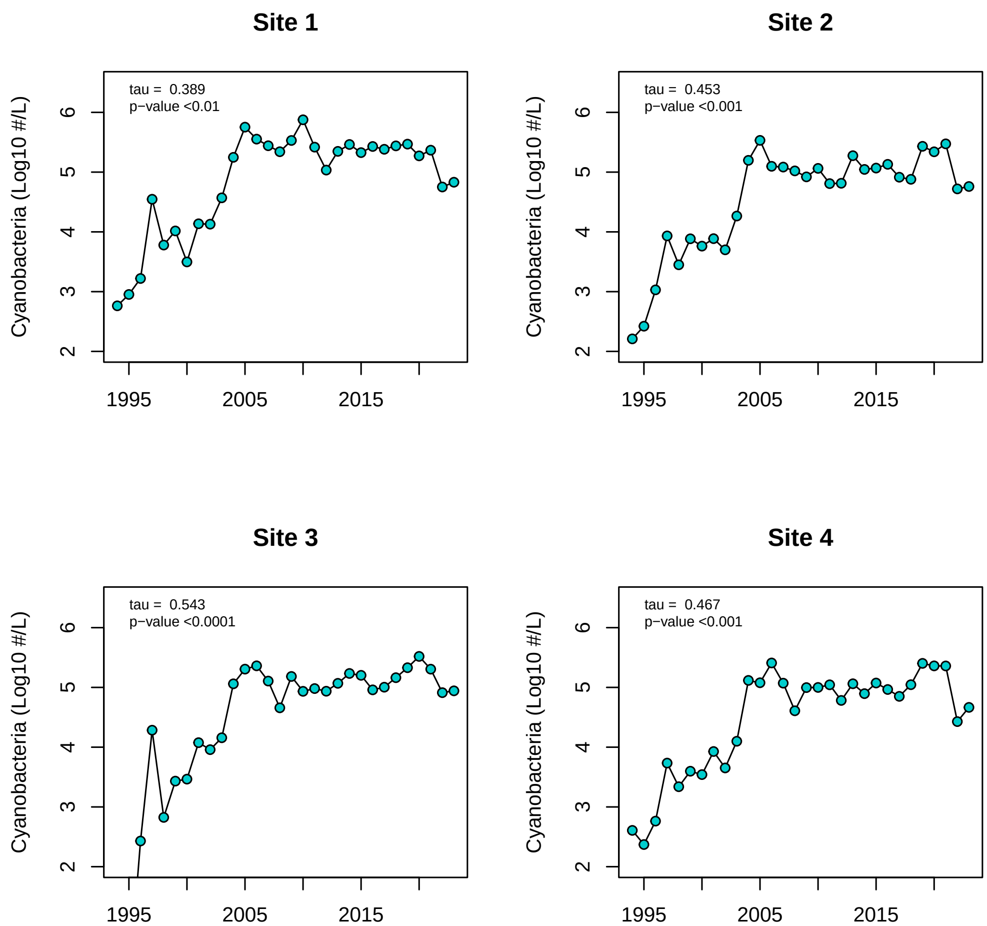


Figure 2.25: Log_{10} plots of median summer, near-surface Cyanobacteria counts (1994–2023, June-October, depths $\leq$5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

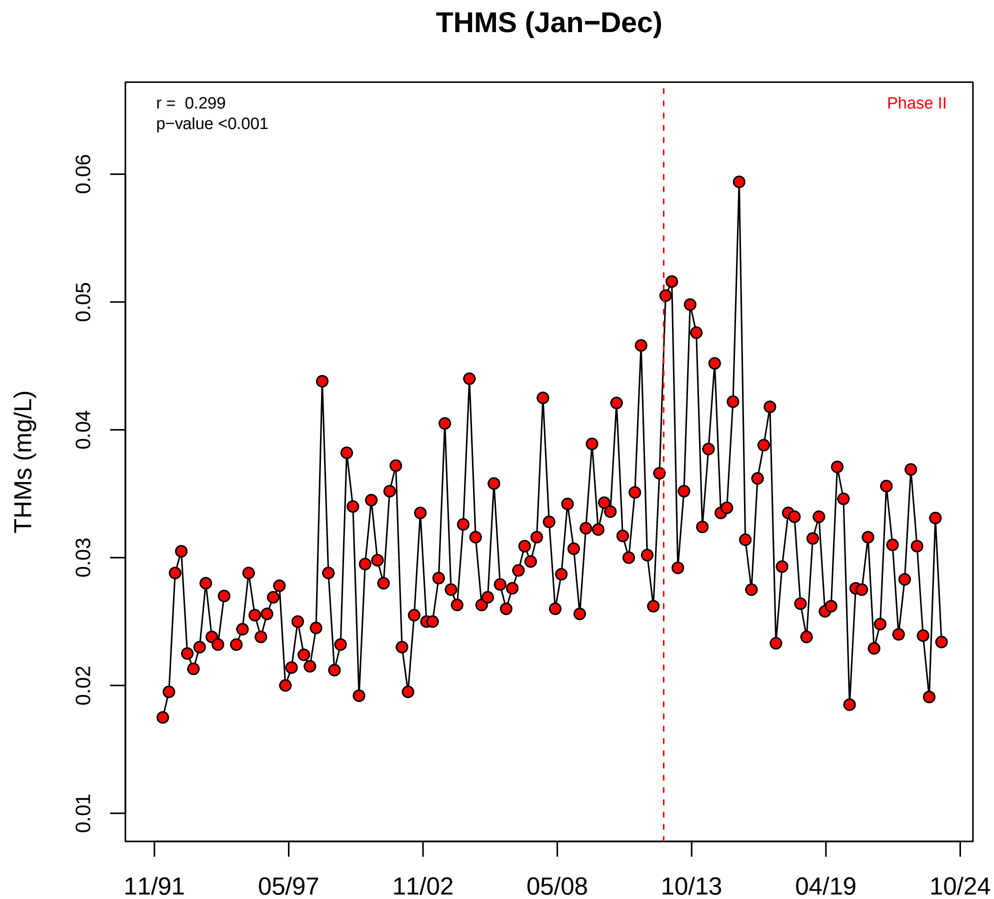


Figure 2.26: Total trihalomethanes (THMs) quarterly average concentrations in the Bellingham water distribution system (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for total THMs is 0.080 mg/l; all samples were below the level. The number of sites used to calculate the quarterly averages increased from four to eight in the fourth quarter of 2012 (vertical red line). Kendall's τ correlation was used because the data were not monotonic-linear; the correlation was significant.

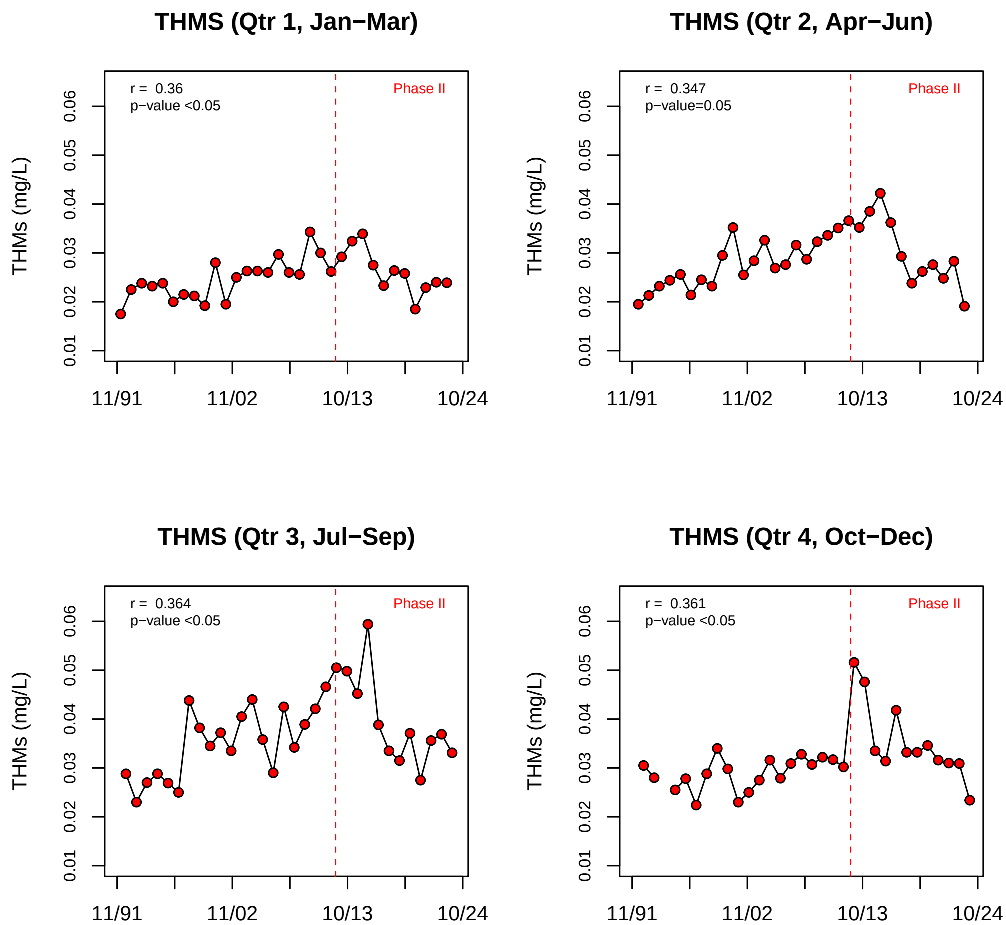


Figure 2.27: Total trihalomethanes (THMs) quarterly average concentrations in the Bellingham water distribution system plotted by quarter (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for total THMs is 0.080 mg/l; all samples were below the level. The number of sites used to calculate the quarterly averages increased from four to eight in the fourth quarter of 2012 (vertical red line). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations of total THMs with time were significant.

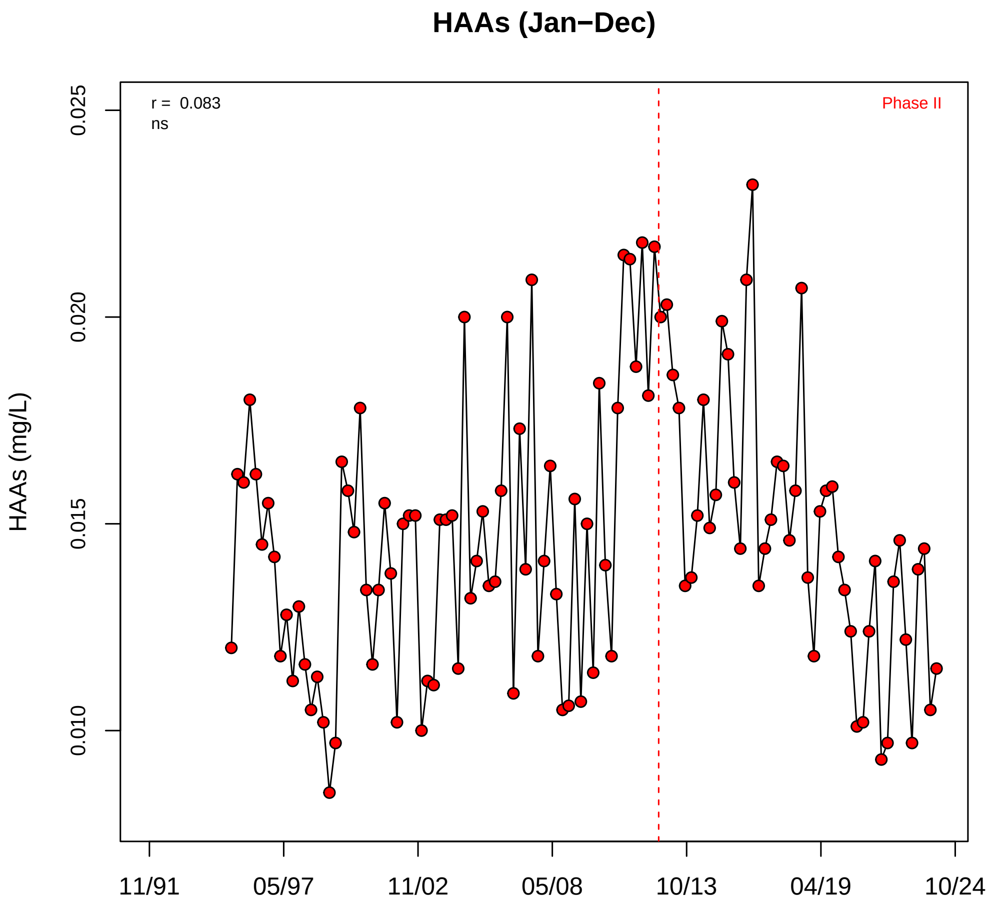


Figure 2.28: Haloacetic acids (HAAs) quarterly average concentrations in the Bellingham water distribution system (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for HAAs is 0.060 mg/l; all samples were below the level. The number of sites used to calculate the quarterly averages increased from four to eight in the fourth quarter of 2012 (vertical red line). Kendall's τ correlation was used because the data were not monotonic-linear; the correlation was not significant.

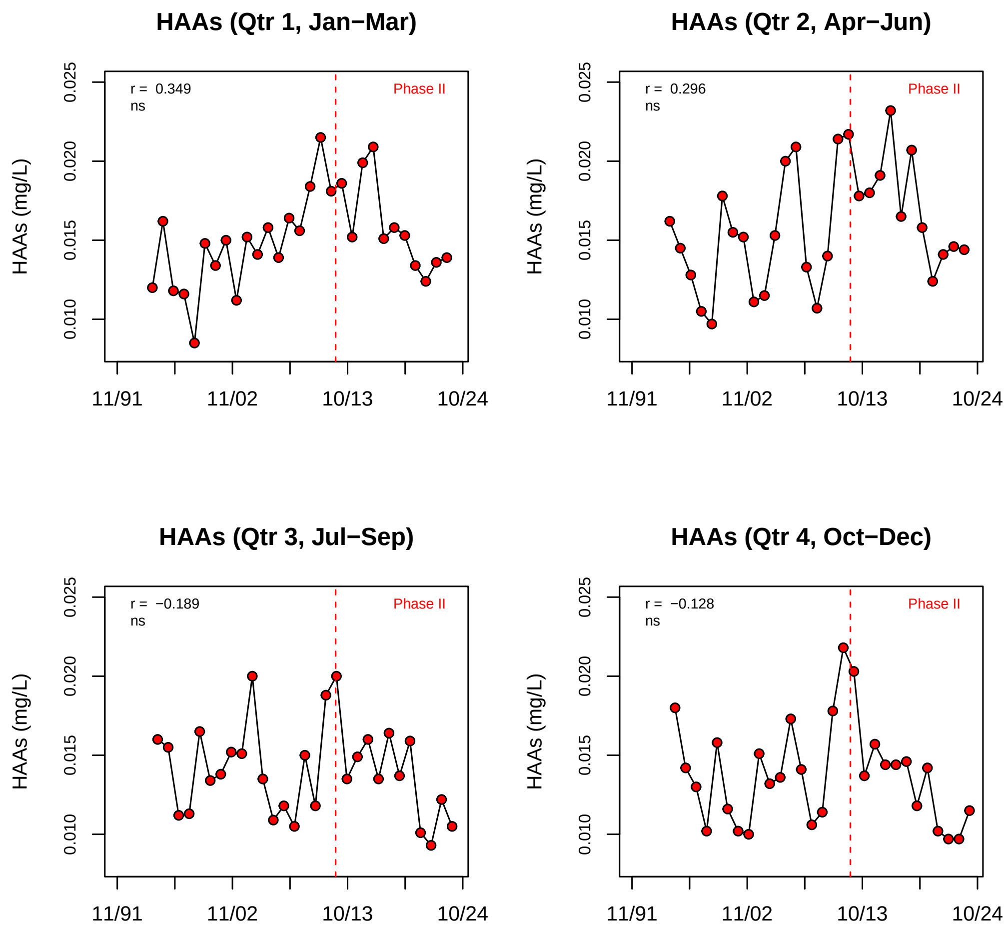


Figure 2.29: Haloacetic acids (HAAs) quarterly average concentrations in the Bellingham water distribution system plotted by quarter (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for HAAs is 0.060 mg/l; all samples were below the level. The number of sites used to calculate the quarterly averages increased from four to eight in the fourth quarter of 2012 (vertical red line). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations of HAAs with time were not significant.

3 Tributary Monitoring

The major objective for the tributary monitoring was to provide baseline water quality data for the tributaries that flow into Lake Whatcom. Whatcom Creek was also sampled to provide baseline data for the lake's outlet. Monthly samples were collected in 2004–2006, 2010–2012, and 2014. The level of effort was reduced in 2007–2009, with samples collected twice each year. Monthly sampling was re-initiated in January 2016 and has continued through 2023.

3.1 Site Descriptions

Samples were collected from Anderson, Austin, Blue Canyon, Brannian, Carpenter, Euclid, Millwheel, Olsen, Silver Beach, Smith, and Whatcom Creeks and the Park Place drain. The sampling locations for these sites are described in Appendix A.2 and shown on Figure A2, page 104.

3.2 Field Sampling and Analytical Methods

The tributaries were sampled on October 10, November 7, and December 13, 2022; and January 10, February 7, March 7, April 4, May 2, June 14, July 18, August 8, and September 12, 2023. All samples were collected during daylight hours, typically between 10:00 am and 3:00 pm. The analytical and sampling procedures are summarized in Tables 2.1 & 3.1 (pages 19 & 63). Table 3.2 (page 64) summarizes missing data from the 2022/2023 sampling season.

A YSI ProDSS field meter was used to measure temperature, dissolved oxygen, pH, and conductivity in the field. Raw water and bacteriological samples were stored on ice and in the dark until they reached the laboratory. The bacteria samples were analyzed by the City of Bellingham and total organic carbon analyses were analyzed by AmTest[29] and by IWS.

[29] AmTest, 13600 Northeast 126th Place, Suite C, Kirkland, WA, 98034–8720.

3.3 Results and Discussion

The tributary data include field measurements (dissolved oxygen, temperature, pH, conductivity); laboratory analyses for ambient water quality parameters (ammonium,[30] nitrate/nitrite,[31] total nitrogen, soluble phosphate, total phosphorus, alkalinity, total suspended solids, and turbidity); bacteria counts; and total organic carbon measurements.

The 2022/2023 tributary data are summarized in Table 3.3 (page 65), with descriptive statistics for each site listed in Tables 3.4–3.15 (pages 66–77). The total organic carbon data are listed in Table 3.16 (page 78). Because of missing samples during the 2022/2023 field season due to insufficient flow in creeks to sample (see Table 3.2, page 64), the summary statistics for these sites are biased toward water quality conditions present during spring, fall, and winter, with less representation of summer conditions.

Historical tributary data from 2004 to the present are plotted in Appendix B.4 (Figures B147–B185, pages 257–295). These figures include a dashed (blue) horizontal line that shows the median value for Smith Creek and a solid (red) horizontal line that shows the median value for each site. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted.

In Table 3.3, the "typical ranges" for alkalinity, conductivity, total suspended solids, ammonium, and soluble phosphate were derived from historic water quality data for Lake Whatcom tributaries that flow through predominantly forested portions of the watershed (Anderson, Brannian, Olsen, and Smith Creeks). The temperature, dissolved oxygen, and pH ranges were based on WAC 173-201A, Tables 200 (1)(c), 200(1)(d), and 200 (1)(g) for salmonid spawning, rearing, and migration, with the qualification that the single monthly grab samples from the Lake Whatcom tributaries may not show the lowest 1-day minimum dissolved oxygen or the maximum 7-day temperature. The turbidity range was based on historical watershed data and WAC 173-201A Table 200 (1)(e), which limits anthropogenic contributions to no more than 5 NTU over background. The *E. coli*

[30] Nearly all ammonia (NH_4^+) is ionized to ammonium (NH_3) in surface water. Earlier IWS reports used "ammonia" and "ammonium" interchangeably; we now use "ammonium" to indicate that the data represent the concentration of ionized ammonia.

[31] Nitrate and nitrite were analyzed together because nitrite concentrations are very low in surface water. For simplicity, nitrate/nitrite will be referred to as "nitrate" in this document.

range was based on the WAC 173-201A Table 200 (2)(b) standard for *Primary Contact Recreation* in place since 2021.[32] The total phosphorus range was based on the lake nutrient criteria action value for the Coast Range, Puget Lowlands, and Northern Rockies Ecoregions listed from WAC 173-201A-230, Table 230(1). The lake nutrient criteria require collecting multiple samples from the epilimnion during summer, so the total phosphorus range in Table 3.3 can only be used as a general reference.

Water temperatures and dissolved oxygen concentrations followed typical seasonal cycles, with most sites having colder temperatures and higher oxygen concentrations during the winter, and warmer temperatures and lower oxygen concentrations during the summer (Figures B147–B152, pages 257–262). Whatcom Creek had higher temperatures and slightly lower oxygen concentrations than most other sites, reflecting the influence of Lake Whatcom (Figures B147 and B150, pages 257 and 260).

The residential tributaries (Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) often have slightly elevated temperatures and lower dissolved oxygen concentrations (Figures B149 and B152, pages 259 and 262). But the dry conditions meant that some of the residential sites could not be sampled during late summer when high temperatures and low oxygen concentrations are most common (Table 3.2).

Most of the tributaries in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by conductivities $\leq$100 μS/cm and alkalinities $\leq$30 mg/L (Table 3.3, page 65; Figures B153–B161, pages 263–271). Sites that did not match this description included some residential tributaries (Silver Beach Creek and the Park Place drain) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$5 mg/L) and low turbidities ($\leq$5 NTU) except during periods of high precipitation and runoff (Figures B162–B167, pages 272–277). The only site that had consistently high solids and turbidity values was Millwheel Creek, which is often turbid due to disturbed sediments in an upstream pond.

[32] See Section 2.3.7, page 15 for discussion.

The median ammonium concentrations were generally low ($\leq$10 μg-N/L) except in Park Place and Millwheel (Table 3.3; Figures B168–B170, pages 278–280). Ammonium does not persist long in oxygenated surface waters. When present in streams, it usually indicates a near-by source such as an upstream wetland with anaerobic soils or a pollution source.

Most of the tributaries had lower total nitrogen and nitrate concentrations than Smith Creek (Figures B171– B176, pages 281– 286). The relatively high nitrate and total nitrogen concentrations in Smith Creek are probably due to the presence of nitrogen-fixing alders (*Alnus rubra*) in the riparian zone upstream from the sampling site. High nitrate and total nitrogen concentrations are not necessarily an indication of water pollution, and low nitrate concentrations actually favor the growth of nuisance Cyanobacteria. The exceptionally low nitrate concentrations in Whatcom Creek (Figure B171, page 281) reflect algal uptake of nitrogen in the lake.

Soluble inorganic phosphate is quickly removed from surface water by biota, so high concentrations of soluble phosphate usually indicate a nearby source such as an anaerobic wetland or a pollution source. The median 2022/2023 soluble phosphate concentrations were $\leq$10 μg-P/L at all sites except Silver Beach Creek and the Park Place drain (Table 3.3). The historical data indicate that although soluble phosphate concentrations were generally low, nearly all sites have had a few high peaks, and high concentrations were common in residential streams.

Total phosphorus concentrations were higher than soluble phosphate concentrations (Figures B177–B182, pages 287–292). The median 2022/2023 concentrations were $\leq$20 μg-P/L at all sites except Millwheel Creek and Silver Beach Creek (Table 3.3). As with soluble phosphate, nearly all sites have had occasional high total phosphorus peaks.

High *E. coli* counts are an indicator of residential pollution (Table 3.3; Figures B183–B185, pages 293–295). Although most of the sites had relatively low *E. coli* counts during 2022/2023, Millwheel Creek exceeded a geometric mean of 100 cfu/100 mL. Three sites (Olsen, Millwheel, and Carpenter Creeks) had more than 10% of the samples that exceeded 320 cfu/100 mL. Several of the small residential tributaries could not be sampled during the late summer (see Table 3.2), when *E. coli* counts are often higher, so these sites may have exceeded the *E. coli* criteria by a greater margin than what is indicated in the summary tables.

The total organic carbon concentrations from February and June 2023 are included in Table 3.16 (page 78). Several of the residential sites (Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) had slightly elevated ($\geq$3 mg/L) total organic carbon concentrations in summer. Several sites had elevated total organic carbon concentrations in winter, likely reflecting precipitation events. The paired samples analyzed by IWS and AmTest were very similar, with a median difference of $\pm$0.20 mg/L. Larger differences could have been caused by small particulates that were unevenly distributed in the split samples or differences in analytical methodologies.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
DO - field	•	•	•	•	•	•	•	•	•	•	•	•
pH - field	•	•	•	•	•	•	•	•	•	•	•	•
Temp - field	•	•	•	•	•	•	•	•	•	•	•	•
Cond - field	•	•	•	•	•	•	•	•	•	•	•	•
Alkalinity	•	•	•	•	•	•	•	•	•	•	•	•
Ammonium	•	•	•	•	•	•	•	•	•	•	•	•
Nitrate/nitrite	•	•	•	•	•	•	•	•	•	•	•	•
T. nitrogen	•	•	•	•	•	•	•	•	•	•	•	•
Sol. phosphate	•	•	•	•	•	•	•	•	•	•	•	•
T. phosphorus	•	•	•	•	•	•	•	•	•	•	•	•
T. susp. solids	•	•	•	•	•	•	•	•	•	•	•	•
Turbidity	•	•	•	•	•	•	•	•	•	•	•	•
T. organic carbon	•	•	•	•	•	•	•	•	•	•	•	•
Bacteria (City)	•	•	•	•	•	•	•	•	•	•	•	•

Table 3.1: Lake Whatcom tributary monitoring schedule. All field and laboratory methods are summarized in Table 2.1.

Month	Sample Summary	Comments
October 2022	No field and laboratory data for Blue Canyon, Brannian, Carpenter, Euclid, Millwheel, Silver Beach Creeks	Insufficient flow
	No nitrate or soluble reactive phosphorus data for Smith Creek†	Lab error
November 2022	No missing data	
December 2022	No missing data	
January 2023	No missing data	
February 2022	No missing data	
March 2023	No total phosphorus or total nitrogen for Olsen Creek	Broken sample vial
April 2023	No nitrate data for Anderson, Blue Canyon, Brannian, Carpenter, Millwheel, Olsen, Park Place, and Silver Beach Creeks	Unacceptable lab variability
May 2023	No missing data	
June 2023	No missing data	
July 2023	No missing data	
August 2023	No field and laboratory data for Brannian, Euclid, and Millwheel Creeks	Insufficient flow
September 2023	No field and laboratory data for Blue Canyon, Brannian, Carpenter, Euclid, and Millwheel Creeks	Insufficient flow

†Sample taken 7 days after other tributaries from upper creek sampling location.

Table 3.2: Summary of missing tributary data due to sampling or laboratory issues.

	Typical range	Anderson	Austin	Brannian	Olsen	Smith	Whatcom
Alkalinity	med. $\leq$30 mg/L	yes	yes	yes	yes	yes	yes
Conductivity	med. $\leq$100 μS/cm	yes	yes	yes	yes	yes	yes
D. oxygen†	min. $\geq$8.0 mg/L	no	yes	yes	yes	yes	yes
pH	6.5–8.5	no	yes	yes	yes	yes	no
Temperature†	max. $\leq$17.5 °C	yes	yes	yes	yes	yes	no
T. susp. solids	med. $\leq$5 mg/L	yes	yes	yes	yes	yes	yes
Turbidity	med. $\leq$5 NTU	yes	yes	yes	yes	yes	yes
Ammonium	med. $\leq$10 μg-N/L	yes	yes	yes	yes	yes	yes
Sol. phosphate	med. $\leq$10 μg-P/L	yes	yes	yes	yes	yes	yes
T. phosphorus	med. $\leq$20 μg-P/L	yes	yes	yes	yes	yes	yes
E. coli	gmean $\leq$100 cfu/mL	yes	yes	yes	yes	yes	yes
	max. 10% $>$320 cfu/mL	yes	yes	yes	no	yes	yes

	Typical range	Blue Canyon	Carpenter	Euclid	Mill-wheel	Park Place	Silver Beach
Alkalinity	med. $\leq$30 mg/L	no	yes	yes	yes	no	no
Conductivity	med. $\leq$100 μS/cm	no	yes	yes	yes	no	no
D. oxygen†	min. $\geq$8.0 mg/L	yes	yes	no	no	no	yes
pH	6.5–8.5	yes	yes	yes	yes	yes	yes
Temperature†	max. $\leq$17.5 °C	yes	yes	yes	no	no	yes
T. susp. solids	med. $\leq$5 mg/L	yes	yes	yes	no	yes	yes
Turbidity	med. $\leq$5 NTU	yes	yes	yes	no	yes	yes
Ammonium	med. $\leq$10 μg-N/L	yes	yes	yes	no	no	yes
Sol. phosphate	med. $\leq$10 μg-P/L	yes	yes	yes	yes	no	no
T. phosphorus	med. $\leq$20 μg-P/L	yes	yes	yes	no	yes	no
E. coli	gmean $\leq$100 cfu/mL	yes	yes	yes	no	yes	yes
	max. 10% $>$320 cfu/mL	yes	no	yes	no	yes	yes‡

†Many of the residential creeks were not sampled during part of the summer due to low flow, which is when water temperatures are usually high and dissolved oxygen concentrations low.
‡Exactly 10%.

Table 3.3: Comparison of October 2022-September 2023 water quality in Lake Whatcom tributaries ("no" indicates that the site does not fall within the water quality ranges or meet the criteria described on page 59).

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	14.0	16.4	17.4	25.5
Conductivity (μS/cm)	50.0	56.2	58.0	79.7
Dissolved oxygen (mg/L)	7.7	9.9	9.8	11.7
pH	6.3	6.7	6.7	7.0
Temperature (°C)	4.5	8.5	8.8	13.2
Total suspended solids (mg/L)	$<$2	$<$2	2.3	10.0
Turbidity (NTU)	0.2	0.7	0.9	2.5
Nitrogen, ammonium (μg-N/L)	$<$10	$<$10	$<$10	43.1
Nitrogen, nitrate/nitrite (μg-N/L)	258.1	336.5	328.2	409.9
Nitrogen, total (μg-N/L)	270.0	468.1	452.8	649.8
Phosphorus, soluble (μg-P/L)	$<$5	6.3	7.4	11.8
Phosphorus, total (μg-P/L)	$<$5	12.9	14.1	26.1
Total organic carbon (mg/L)	$<$1	2.5	2.3	4.8
E. coli (cfu/100 mL)‡	$<$1	28.0	15.2	190
(Percent of samples $>$320 cfu/100 mL = 0)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3.4: Summary of Anderson Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean[†]	Max.
Alkalinity (mg/L $CaCO_3$)	12.6	18.2	26.6	44.4
Conductivity (μS/cm)	55.1	67.1	100.1	175.8
Dissolved oxygen (mg/L)	9.0	11.4	11.2	13.0
pH	6.9	7.1	7.1	7.8
Temperature (°C)	3.1	7.8	9.0	16.4
Total suspended solids (mg/L)	<2	<2	<2	10.3
Turbidity (NTU)	0.3	0.9	1.2	5.5
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	94.6	399.0	361.6	587.8
Nitrogen, total (μg-N/L)	<100	503.8	454.8	708
Phosphorus, soluble (μg-P/L)	<5	5.4	5.4	7.4
Phosphorus, total (μg-P/L)	<5	10.0	9.5	14
Total organic carbon (mg/L)	1.5	2.0	2.2	3.5
E. coli (cfu/100 mL)[‡]	7	20.0	28.6	110
(Percent of samples $>$320 cfu/100 mL = 0)				

[†]Uncensored arithmetic means except coliforms (geometric mean);
[‡]Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3.5: Summary of Austin Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	65.4	137.9	137.7	190.5
Conductivity (μS/cm)	263.4	304.4	310.4	365.6
Dissolved oxygen (mg/L)	9.8	11.9	11.5	12.6
pH	8.1	8.2	8.2	8.3
Temperature (°C)	4.4	7.0	7.8	13.8
Total suspended solids (mg/L)	<2	4.3	4.3	11.1
Turbidity (NTU)	0.4	2.1	2.1	6.2
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	226.6	459.4	714.9	1896.9
Nitrogen, total (μg-N/L)	319.3	573.3	654.2	1560.7
Phosphorus, soluble (μg-P/L)	<5	7.0	6.9	10.8
Phosphorus, total (μg-P/L)	<5	6.6	8.8	24.3
Total organic carbon (mg/L)	1.5	2.2	2.4	4.2
E. coli (cfu/100 mL)‡	<1	2.0	3.7	84
(Percent of samples >320 cfu/100 mL = 0)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3.6: Summary of Blue Canyon Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	8.2	8.6	9.9	17.7
Conductivity (μS/cm)	36.9	38.6	40.8	49.6
Dissolved oxygen (mg/L)	8.7	11.7	11.3	12.3
pH	6.8	6.9	6.9	7.0
Temperature (°C)	4.1	6.2	6.7	11.8
Total suspended solids (mg/L)	<2	<2	<2	6.5
Turbidity (NTU)	0.6	0.9	1.9	5.8
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	266.4	750.1	692.1	1174.2
Nitrogen, total (μg-N/L)	339.0	761.8	778.6	1337.6
Phosphorus, soluble (μg-P/L)	<5	<5	<5	6.5
Phosphorus, total (μg-P/L)	<5	6.9	8.6	27.8
Total organic carbon (mg/L)	1.6	2.1	2.2	3.4
E. coli (cfu/100 mL)‡	<1	4.0	4.9	110
(Percent of samples >320 cfu/100 mL = 0)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 3.7: Summary of Brannian Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	15.9	18.2	27.6	51.4
Conductivity (μS/cm)	59.0	66.8	80.9	121.6
Dissolved oxygen (mg/L)	8.3	11.9	11.3	13.1
pH	7.2	7.4	7.4	7.7
Temperature (°C)	2.7	6.2	8.6	17.4
Total suspended solids (mg/L)	<2	<2	<2	4.8
Turbidity (NTU)	0.8	2.0	2.1	3.1
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	11.3
Nitrogen, nitrate/nitrite (μg-N/L)	78.8	695.9	644.6	1076.9
Nitrogen, total (μg-N/L)	259.5	997.6	868.6	1340.8
Phosphorus, soluble (μg-P/L)	<5	7.8	7.7	15.7
Phosphorus, total (μg-P/L)	<5	12.5	13.7	25.5
Total organic carbon (mg/L)	2.6	3.6	4.0	7.3
E. coli (cfu/100 mL)‡	6	44.0	57.6	940
(Percent of samples >320 cfu/100 mL = 22)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 3.8: Summary of Carpenter Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	21.5	23.3	25.8	42.5
Conductivity (μS/cm)	81.6	99.2	102.6	134.3
Dissolved oxygen (mg/L)	6.6	10.7	10.5	12.2
pH	6.7	7.0	7.0	7.2
Temperature (°C)	4.5	6.7	7.3	12.7
Total suspended solids (mg/L)	$<$2	$<$2	$<$2	6
Turbidity (NTU)	0.5	0.9	1.5	5.5
Nitrogen, ammonium (μg-N/L)	$<$10	$<$10	$<$10	16.1
Nitrogen, nitrate/nitrite (μg-N/L)	48.2	598.5	632.6	1177.5
Nitrogen, total (μg-N/L)	181.3	713.3	700.0	1362.5
Phosphorus, soluble (μg-P/L)	$<$5	6.0	6.2	9.4
Phosphorus, total (μg-P/L)	$<$5	10.9	9.4	14.5
Total organic carbon (mg/L)	2.5	2.9	3.1	4.5
E. coli (cfu/100 mL)‡	14	32.0	38.6	130
(Percent of samples $>$320 cfu/100 mL = 0)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3.9: Summary of Euclid Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	22.7	25.9	29.9	58
Conductivity (μS/cm)	80.2	90.1	96.8	139.5
Dissolved oxygen (mg/L)	4.1	10.8	10.0	12.0
pH	7.0	7.1	7.1	7.2
Temperature (°C)	3.7	6.5	8.1	17.9
Total suspended solids (mg/L)	<2	5.1	7.7	18.3
Turbidity (NTU)	3.8	6.8	7.4	14.2
Nitrogen, ammonium (μg-N/L)	<10	15.3	29.3	117.2
Nitrogen, nitrate/nitrite (μg-N/L)	<20	380.4	442.3	1067.1
Nitrogen, total (μg-N/L)	491.9	742.3	849.6	1616.0
Phosphorus, soluble (μg-P/L)	<5	8.4	9.6	18.1
Phosphorus, total (μg-P/L)	19.4	26.8	58.1	254.0
Total organic carbon (mg/L)	3.2	4.0	4.5	7.5
E. coli (cfu/100 mL)‡	72	135.0	188.5	960
(Percent of samples >320 cfu/100 mL = 17)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3.10: Summary of Millwheel Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	14.9	21.5	31.7	56.6
Conductivity (μS/cm)	52.0	63.4	87.7	143.1
Dissolved oxygen (mg/L)	9.3	11.4	11.3	13.2
pH	7.2	7.5	7.5	7.9
Temperature (°C)	2.2	8.0	9.1	17
Total suspended solids (mg/L)	<2	<2	5.5	49.4
Turbidity (NTU)	0.2	1.0	1.3	3.9
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	12
Nitrogen, nitrate/nitrite (μg-N/L)	32.1	618.1	507.4	941.9
Nitrogen, total (μg-N/L)	<100	778.4	630.6	1006.7
Phosphorus, soluble (μg-P/L)	<5	6.6	6.9	10.3
Phosphorus, total (μg-P/L)	<5	9.9	10.1	15.6
Total organic carbon (mg/L)	1.8	2.4	2.6	3.7
E. coli (cfu/100 mL)‡	1	108.0	51.6	530
(Percent of samples >320 cfu/100 mL = 20)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 3.11: Summary of Olsen Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	37.9	83.4	93.3	143.2
Conductivity (μS/cm)	133.5	270.1	277.7	370.0
Dissolved oxygen (mg/L)	6.2	9.7	9.1	11.4
pH	7.2	7.3	7.3	7.7
Temperature (°C)	6.2	10.7	12.4	20.2
Total suspended solids (mg/L)	<2	<2	2.0	11.2
Turbidity (NTU)	1.1	2.1	3.2	14.2
Nitrogen, ammonium (μg-N/L)	<10	17.8	18.9	56.4
Nitrogen, nitrate/nitrite (μg-N/L)	263.6	645.8	767.2	2261.4
Nitrogen, total (μg-N/L)	335.3	857.0	833.0	1264.7
Phosphorus, soluble (μg-P/L)	6.0	10.2	10.4	18.0
Phosphorus, total (μg-P/L)	5.1	19.2	22.2	59.5
Total organic carbon (mg/L)	2.8	3.0	3.2	4.0
E. coli (cfu/100 mL)‡	<1	13.0	11.6	130
(Percent of samples >320 cfu/100 mL = 0)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 3.12: Summary of Park Place outlet water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	44.7	64.2	75.1	120.9
Conductivity (μS/cm)	148.2	170.8	210.1	311.1
Dissolved oxygen (mg/L)	9.0	11.5	11.0	12.9
pH	7.7	7.8	7.8	8.0
Temperature (°C)	3.2	7.0	9.9	17.2
Total suspended solids (mg/L)	<2	<2	3.9	14.4
Turbidity (NTU)	1.2	1.9	2.4	6.6
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	24.3
Nitrogen, nitrate/nitrite (μg-N/L)	250.3	583.7	714.8	1678.0
Nitrogen, total (μg-N/L)	477.8	842.9	870.3	1487.0
Phosphorus, soluble (μg-P/L)	6.7	15.6	15.8	33.3
Phosphorus, total (μg-P/L)	7.3	21.0	23.7	53.2
Total organic carbon (mg/L)	3.9	4.5	4.5	5.4
E. coli (cfu/100 mL)‡	12	56.5	86.1	3300
(Percent of samples $>$320 cfu/100 mL = 10)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3.13: Summary of Silver Beach Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	13.6	16.7	24.0	40.9
Conductivity (μS/cm)	49.6	56.7	74.8	122.7
Dissolved oxygen (mg/L)	9.2	11.5	11.3	13.1
pH	7.0	7.4	7.4	7.8
Temperature (°C)	3.0	7.8	9.1	17.1
Total suspended solids (mg/L)	<2	<2	<2	2.8
Turbidity (NTU)	0.1	0.4	0.6	2.0
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	377.8	869.7	793.3	1180.9
Nitrogen, total (μg-N/L)	<100	985.8	842.9	1461.9
Phosphorus, soluble (μg-P/L)	<5	<5	5.7	11.7
Phosphorus, total (μg-P/L)	<5	6.3	6.5	11.5
Total organic carbon (mg/L)	1.7	2.3	2.4	3.8
E. coli (cfu/100 mL)‡	4	39.5	28.3	140
(Percent of samples >320 cfu/100 mL = 0)				

†Uncensored arithmetic means except coliforms (geometric mean);
‡Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 3.14: Summary of Smith Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Variable	Min.	Med.	Mean[†]	Max.
Alkalinity (mg/L $CaCO_3$)	20.4	21.7	22.1	27.1
Conductivity (μS/cm)	58.9	62.0	63.3	71.2
Dissolved oxygen (mg/L)	8.8	10.6	10.6	12.1
pH	7.4	7.5	7.7	8.6
Temperature (°C)	5.1	11.9	13.3	24.7
Total suspended solids (mg/L)	<2	<2	<2	2.2
Turbidity (NTU)	0.5	0.8	0.8	1.3
Nitrogen, ammonium (μg-N/L)	<10	<10	10.6	51.5
Nitrogen, nitrate/nitrite (μg-N/L)	<20	88.2	116.4	310.9
Nitrogen, total (μg-N/L)	<100	301.8	298.7	404.4
Phosphorus, soluble (μg-P/L)	<5	<5	<5	<5
Phosphorus, total (μg-P/L)	<5	9.1	8.8	14.5
Total organic carbon (mg/L)	1.9	2.2	2.3	3.2
E. coli (cfu/100 mL)[‡]	<1	3.5	5.3	140
(Percent of samples >320 cfu/100 mL = 0)				

[†]Uncensored arithmetic means except coliforms (geometric mean);
[‡]Censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 3.15: Summary of Whatcom Creek water quality data, October 2022-September 2023. *E. coli* data available from January to September 2023 only.

Site	Date	TOC-AM (mg/L)	TOC-IWS (mg/L)	Date	TOC-AM (mg/L)	TOC-IWS (mg/L)
Anderson	Feb 7, 2023	4.5	3.8	Jun 14, 2023	2.7	2.5
Austin (lower)	Feb 7, 2023	2.9	2.5	Jun 14, 2023	2.1	2.0
Blue Canyon	Feb 7, 2023	3.4	2.9	Jun 14, 2023	2.1	2.1
Brannian	Feb 7, 2023	2.7	2.4	Jun 14, 2023	2.5	2.5
Carpenter	Feb 7, 2023	4.4	4.2	Jun 14, 2023	2.6	2.6
Euclid	Feb 7, 2023	3.1	2.8	Jun 14, 2023	3.5	3.4
Millwheel	Feb 7, 2023	3.8	3.4	Jun 14, 2023	11.0	7.5
Olsen	Feb 7, 2023	3.1	3.1	Jun 14, 2023	2.4	2.3
Park Place	Feb 7, 2023	3.3	2.9	Jun 14, 2023	3.4	3.2
Silver Beach	Feb 7, 2023	4.9	4.4	Jun 14, 2023	4.4	4.5
Smith	Feb 7, 2023	2.9	2.9	Jun 14, 2023	2.2	2.1
Whatcom	Feb 7, 2023	2.5	1.9	Jun 14, 2023	2.4	2.4

Table 3.16: Lake Whatcom 2023 tributary total organic carbon data. February and August samples were split and analyzed by AmTest (TOC-AM) and IWS (TOC-IWS).

4 Storm Water Monitoring

4.1 Hydrograph Monitoring

Creek stage values collected from digital recorders installed in Austin Creek and Smith Creek and field measured creek discharges are used to develop rating curves and discharge hydrographs. The hydrographs are shown in Figures 4.1–4.2 (pages 84–85). The location of each stage recorder is described in Appendix A.2 (page 99). All hydrograph data, including data from previous years, are online at `https://iws.wwu.edu/`. All results are reported as Pacific Standard Time, without Daylight Saving Time adjustment. Field notes, comments on missing data, and rating curves for each water year are available upon request to the City of Bellingham or the Institute for Watershed Studies.

Stage-discharge values in Austin Creek collected between the 2018 and 2023 water years were used to develop a rating curve (Figure 4.3, page 86). Two rating curves were developed for Smith. A storm event caused a change in channel morphology that resulted in a shift in the measured stage-discharge relationship in Smith creek that was noticeable at low flows starting on 12/24/2022. As such, a rating curve was developed for Smith Creek using stage-discharge values collected between the 2018 and November 2022 (Figure 4.4, page 87) that was used to estimate discharge based on measured stage values ranging from 10/1/2022 through 12/23/2022 (Smith 2022 in Table 4.1). A second rating curve was developed for Smith using stage-discharge values collected in 2023 (Figure 4.5, page 88) that was used to estimate discharge based on measured stage values ranging from 12/24/2022 through 9/30/2023 (Smith 2023 in Table 4.1). Both rating curves contain some targeted high-flow measurements collected from Smith Creek ranging back to 2013.

Rating curves for Smith and Austin Creeks were generated in MS Excel® using a standard power curve given by the following equation (Kennedy, 1984; Rantz et al., 1982; WMO, 2010):

(1) $$Q_e = a(s - b)^c$$

where Q_e is the estimated stream discharge at a respective stage height; s is the creek stage height and coefficients *a, b*, and *c* are empirical fitting parameters.

The power equation is suitable when the system is relatively stable, which is assumed for Smith and Austin Creeks. The empirical constants *a*, *b*, and *c* are determined by iterative approximations to obtain the best fit between measured discharges and estimated (Q_e) at the respective stages.

The measured stage-discharge values for each creek were broken up in segments based on changes in flow magnitude. The Q_e values were estimated for each segment using a generalized reduced gradient (GRD) nonlinear solver in Excel®. The GRD solver iteratively adjusts the *a*, *b*, and *c* values to optimize the Q_e discharge estimate by minimizing the sum of the square of the error between the measured and estimated (Q_e) at a respective stage. The Excel® technique was validated by producing statistically similar discharge values produced by Aquarius in both Smith and Austin Creek for the 2021 water year ($R^2 \approx 1$)[33].

The 15-minute stage data (*s*) recorded at the Smith and Austin creek-gauging stations were used along with the values in Table 4.1 and Equation (1) to estimate the discharge time series for the 2023 water year. The resulting 15-minute discharge values were aggregated into 1-hour averages (Figures 4.1–4.2, pages 84–85). Due to equipment malfunctions, Smith had a stage-data gap between 4/25/2023 and 5/8/2023 and Austin had gaps between 5/11/2023 and 6/15/2023 and between 6/19/2023 and 7/20/2023. The gaps were filled with estimated discharge values using rainfall and weather variables from COB gauges in the Lake Whatcom watershed and the Distributed-Hydrology-Soils-Vegetation Model (DHSVM) that is calibrated to the Smith Creek and Austin Creek basins (Wigmosta, et al., 1994; Kelleher, 2006).

4.2 Site Descriptions

The 2022/2023 storm water sampling focused on Carpenter, Olsen, and Smith Creeks (Figure A2, page 104). Earlier storm water sampling in the Lake Whatcom watershed summarized in previous annual reports (see Section 5.2, page 94).

[33] Prior to 2022, the software Aquarius was used.

4.3 Field Sampling and Analytical Methods

Three storm events were sampled in each of Carpenter, Olsen, and Smith Creeks (Table 4.2, page 83). The samples were collected using time-paced ISCO samplers provided by the City of Bellingham and analyzed for total suspended solids, total phosphorus, soluble reactive phosphorus, total nitrogen, and nitrate/nitrite[34] as described in Table 2.1 (page 19).

Dry summers have a direct impact on stream flow (base flow), which is supported by soil water and groundwater. As illustrated in the hydrographs for the Lake Whatcom watershed (Figures 4.1–4.2, pages 84–85), stream discharge decreased over the course of the summer as soils dried out and groundwater levels declined due to low rainfall and high levels of evapotranspiration from vegetation. Moreover, most late summer rainfall goes into replenishing soil water (storage) rather than direct runoff into streams. Lower summer stream flows and groundwater levels will also reduce runoff into the lake. When coupled with higher summer lake withdrawals and lake evaporation, the lake level will usually drop over the course of the summer, reaching a minimum in late fall.

As indicated in Table 3.2 (page 64), many of the smaller tributaries to Lake Whatcom were dry, or nearly dry during late summer. Storm water data are used by the City as part of their watershed modeling program and will be reported directly to the City to be incorporated into the model. Storm water data are available upon request to the City of Bellingham or the Institute for Watershed Studies.

[34]Nitrate and nitrite were analyzed together because nitrite concentrations are very low in surface water and require low level analytical techniques to measure accurately. For simplicity, nitrate/nitrite will be referred to as "nitrate" in this document.

Creek	Segment	a	b	c
Austin	$0 < s < 1.0$	12.5563	0.0000	2.7831
Austin	$1.0 \leq s < 1.8$	28.2450	0.3328	1.9560
Austin	$s \geq 1.8$	92.7596	1.1153	1.2449
Smith 2022	$0 < s < 2.0$	0.0190	0.2754	8.8740
Smith 2022	$2.0 \leq s < 2.8$	0.0156	0.0000	7.4095
Smith 2022	$s \geq 2.8$	1.0465	0.0000	3.5361
Smith 2023	$0 < s < 2.4$	12.5243	1.3731	1.8918
Smith 2023	$s \geq 2.4$	31.4409	1.7896	1.9232

Table 4.1: Rating curve values used in Equation (1) for Austin and Smith Creeks, where s is the measured stage height and a, b, and c are empirical constants.

Carpenter Creek			
Start Date	Start Time	End Date	End Time
Jan 13, 2023	12:24	Jan 15, 2023	03:24
Mar 12, 2023	13:14	Mar 14, 2023	07:14
Mar 23, 2023	20:00	Mar 26, 2023	05:00

Olsen Creek			
Start Date	Start Time	End Date	End Time
Nov 3, 2022	21:49	Nov 5, 2022	09:49
Feb 19, 2023	22:12	Feb 21, 2023	10:12
Apr 9, 2023	07:00	Apr 12, 2023	07:00

Smith Creek			
Start Date	Start Time	End Date	End Time
Jan 13, 2023	10:08	Jan 15, 2023	07:08
Feb 19, 2023	22:29	Feb 21, 2023	10:29
Mar 12, 2023	14:09	Mar 14, 2023	05:09

Table 4.2: Summary of 2022-2023 storm event sampling dates for Carpenter, Olsen, and Smith Creeks. Time is Pacific Standard.

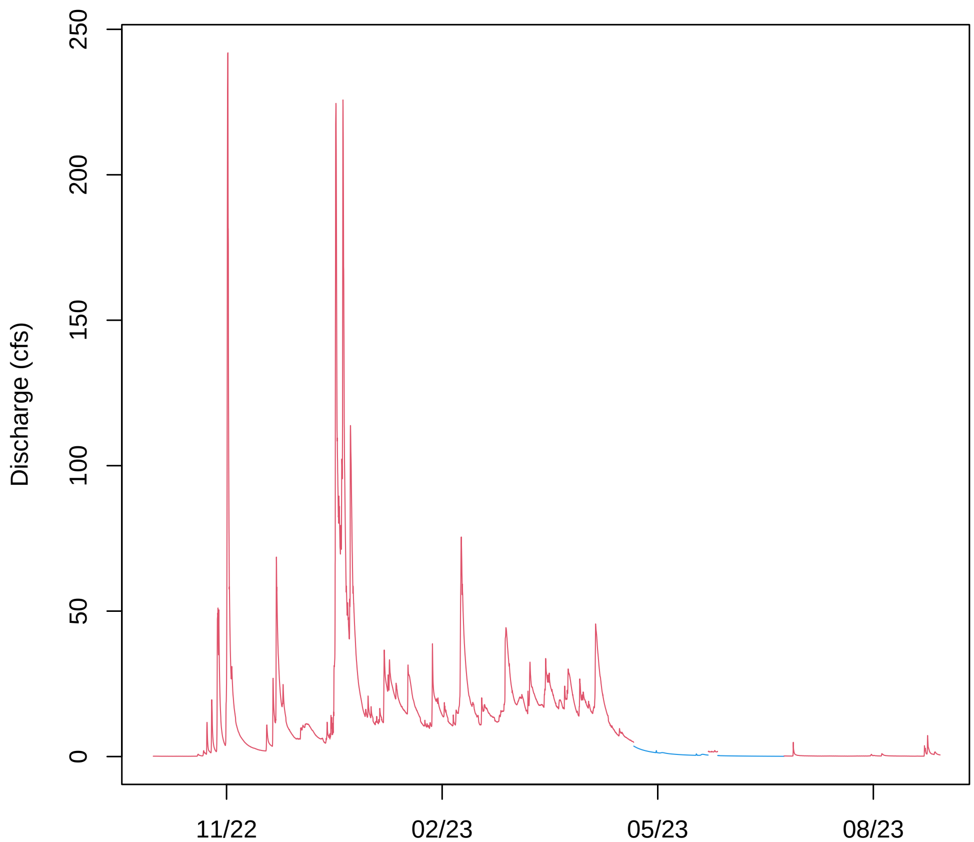


Figure 4.1: Austin Creek hydrograph for WY2023 (October 1, 2022–September 30, 2023). The red line represents field-collected data, whereas the blue line represents model-simulated data during the period when the gauge was out of commission (see Section 4 for details). Gauge data were recorded at 15 minute intervals, but were plotted at 1 hour intervals to match the model-simulated data.

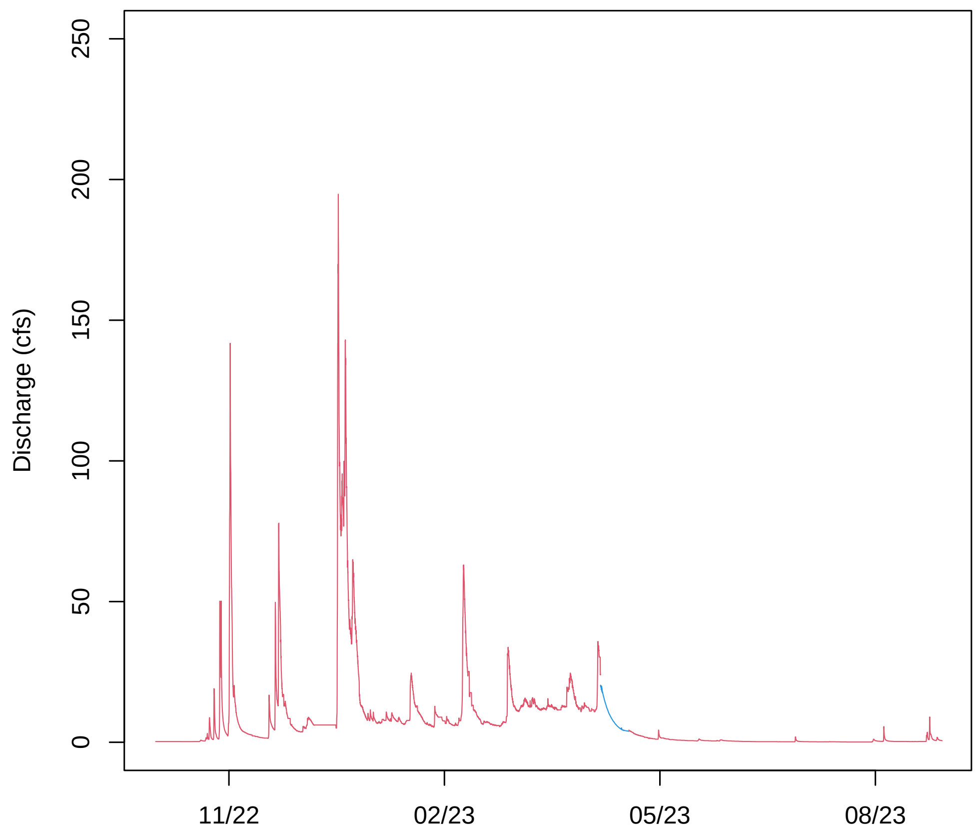


Figure 4.2: Smith Creek hydrograph for WY2023 (October 1, 2022–September 30, 2023). The red line represents field-collected data, whereas the blue line represents model-simulated data during the period when the gauge was out of commission (see Section 4 for details). Gauge data were recorded at 15 minute intervals, but were plotted at 1 hour intervals to match the model-simulated data.

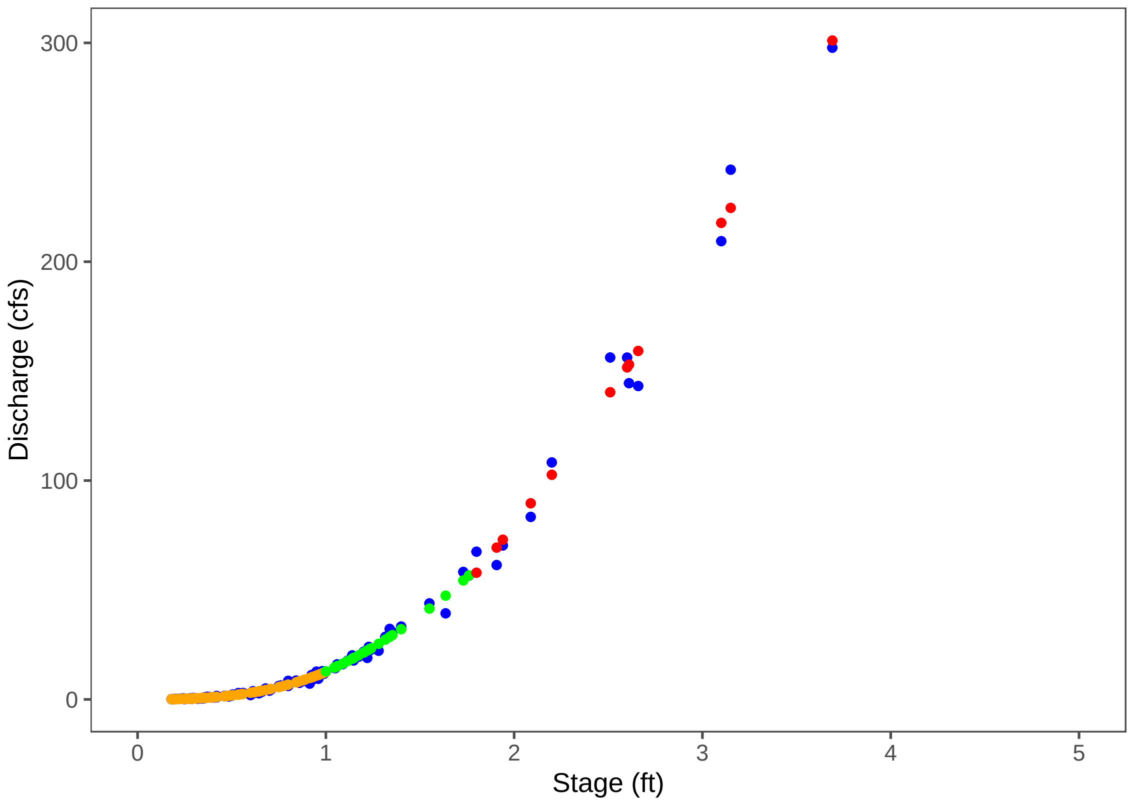


Figure 4.3: Austin Creek measured stage-discharge values (blue symbols) and rating curve values estimated using Equation (1). The orange is for segment $0 < s < 1.0$, green is for $1.0 \leq s < 1.8$, and red is for $s \geq 1.8$ (see Table 4.1).

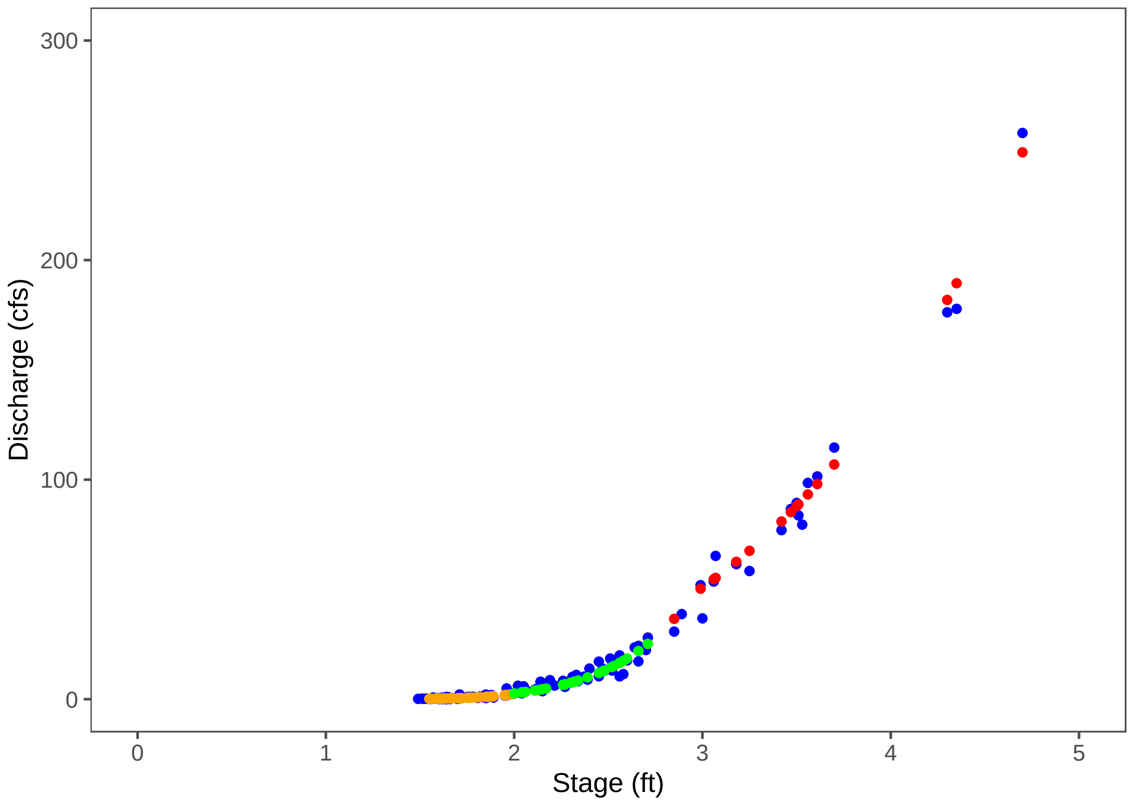


Figure 4.4: Smith Creek measured stage-discharge values (blue symbols) and rating curve values estimated using Equation (1) for 2022. The orange is for segment $0 < s < 2.0$, green is for $2.0 \leq s < 2.8$, and red is for $s \geq 2.8$ (see Table 4.1).

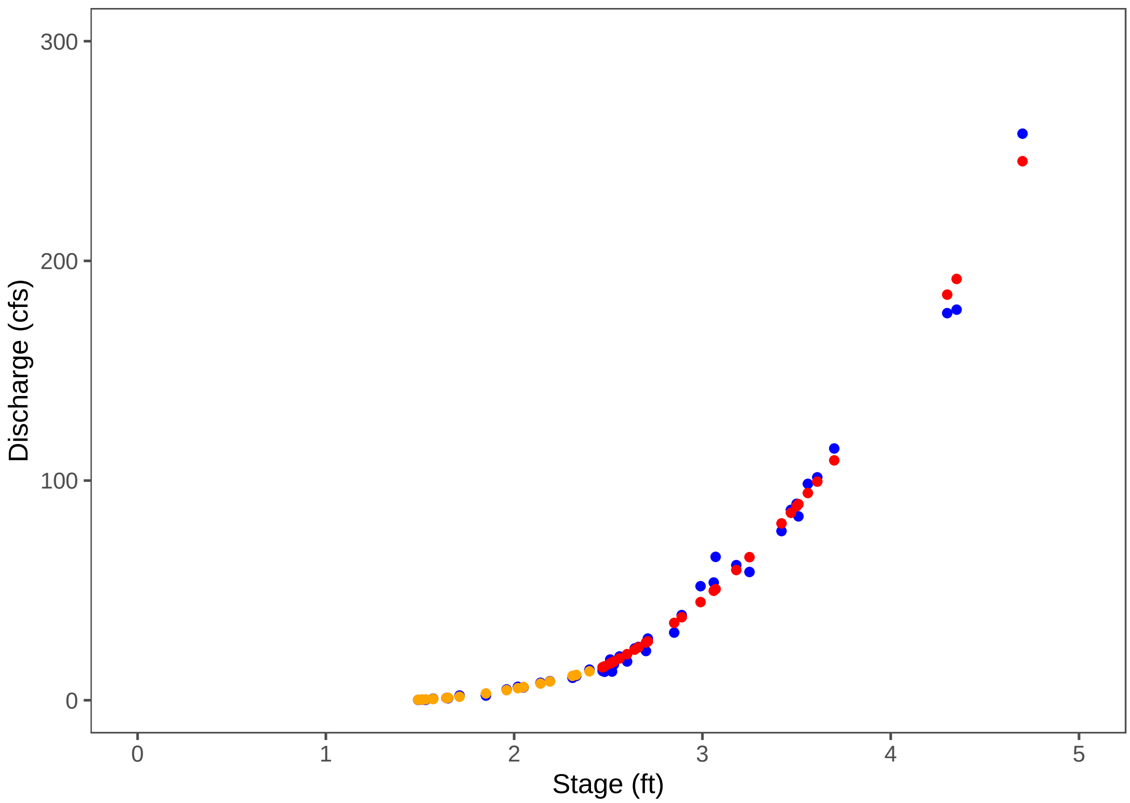


Figure 4.5: Smith Creek measured stage-discharge values (blue symbols) and rating curve values estimated using Equation (1) for 2023. The orange is for segment $0 < s < 2.4$ and red is for $s \geq 2.4$ (see Table 4.1).

5 References and Related Reports

5.1 Cited References

APHA. 2017. Standard Methods for the Examination of Water and Wastewater, 23rd Edition. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, D. C.

Ashurst, S. 2003. Microcosm study of the accumulation of benzo(a)pyrene by Lake Whatcom phytoplankton. M. S. Thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA. https://cedar.wwu.edu/lakewhat_theses/8

Baribeau, H., S. Krasner, R. Chinn, and P. Singer. 2005. Impact of biomass on the stability of HAAs and THMs in a simulated distribution system. Journal of the American Water Works Association 97:69–81

Bittner, C. W. 1993. The response of Lake Whatcom bacterioplankton to nutrient enrichment. M. S. Thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.

Deacon, J. 2015. Determining biologically available phosphorus in storm water entering Lake Whatcom, WA using the dual culture diffusion apparatus. M. S. Thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA. https://cedar.wwu.edu/wwuet/397

EPA. 2014. Method 1603: *Escherichia coli* (*E. coli*) in Water by Membrane Filtration Using Modified membrane-Thermotolerant *Escherichia coli* Agar (Modified mTEC). US Environmental Protection Agency, Washington, D. C.

Fee, E. 1976. The vertical and seasonal distribution of chlorophyll in lakes of the Experimental Lakes Area, northwestern Ontario: Implications for primary production estimates. Limnology and Oceanography 21: 767-783.

Grigorescu, A., R. Hozalski. 2010. Modeling HAA biodegradation in biofilters and distribution systems. Journal of the American Water Works Association 102: 67–80.

Groce, S. 2011. Soils as a Source of Bioavailable Phosphorus in the Lake Whatcom Watershed. M. S. Thesis, Huxley College of the Environment, Western Washington University, Bellingham, WA. https://cedar.wwu.edu/wwuet/142

Isles, P. D. F., I. F. Creed, A-K. Bergström. 2018. Recent synchronous declines in DIN:TP in Swedish lakes. Global Biogeochemical Cycles 32: 208-–225.

Johengen, T., G. Smith, D. Schar, H. Purcel, D. Loewensteiner, Z. Epperson, M. Tamburri, G. Meadows, S. Green, F. Yousef, J. Anderson. 2016. Performance verification statement for Hach Hydrolab DS5X and HL4 dissolved oxygen sensor. Alliance for Coastal Technologies, Alliance for Coastal Technologies, ACT VS16-05. DOI: http://dx.doi.org/10.25607/OBP-298.

Jones, I. D. and J. P. Smol. 2024. Wetzel's Limnology: Lake and River Ecosystems, Fourth Edition. Academic Press, San Diego, CA.

Kelleher, K. D. 2006. Streamflow Calibration of Two Sub-basins in the Lake Whatcom Watershed, Washington Using a Distributed Hydrology Model. WWU Graduate School Collection. 439. https://cedar.wwu.edu/wwuet/439

Kennedy, E. J. 1984. Discharge ratings at gaging stations. Techniques of Water-Resources Investigations Book 3, Chapter A 10, U. S. Geological Survey, 58 p.

Liang, C-W. 1994. Impact of Soil and Phosphorus Enrichment on Lake Whatcom Periphytic Algae. M. S. Thesis, Huxley College of the Environment, Western Washington University, Bellingham, WA.

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

Matthews, R. A., 2021. Summary of Lake Whatcom Algal Research, 1987–2021. A Collection of Open Access Books and Monographs. 13. Institute for Watershed Studies, Western, Washington University. https://cedar.wwu.edu/cedarbooks/13

Matthews, R. A. and E. DeLuna, 2008. Metalimnetic oxygen and ammonium maxima in Lake Whatcom, Washington (USA). Northwest Science 82:18–29.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, K. Beeler, and G. B. Matthews. 2015. Lake Whatcom Monitoring Project, 2013/2014 Final Report, February 26, 2015. Report to the City of Bellingham, WA. https://cedar.wwu.edu/lakewhat_annualreps/3

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. 2012. Lake Whatcom Monitoring Project, 2010/2011 Final Report, February 24, 2012. Report to the City of Bellingham, WA. https://cedar.wwu.edu/lakewhat_annualreps/4

Matthews, R. A., M. Hilles, J. Vandersypen, R. J. Mitchell, and G. B. Matthews. 2008. Lake Whatcom Monitoring Project 2006–2007 Final Report. Final Report prepared for the City of Bellingham Public Works Department, April, 2008, Bellingham, WA. https://cedar.wwu.edu/lakewhat_annualreps/8

Matthews, R. A., M. Hilles, J. Vandersypen, R. J. Mitchell, and G. B. Matthews. 2005. Lake Whatcom Monitoring Project 2003–2004 Final Report. Final Report prepared for the City of Bellingham Public Works Department, March, 2005, Bellingham, WA. https://cedar.wwu.edu/lakewhat_annualreps/13

Matthews, R. A., M. Hilles, J. Vandersypen, R. J. Mitchell, and G. B. Matthews. 2004. Lake Whatcom Monitoring Project 2002–2003 Final Report. Final Report prepared for the City of Bellingham Public Works Department, March, 2004, Bellingham, WA. https://cedar.wwu.edu/lakewhat_annualreps/12

Matthews, R., M. Hilles, and G. Pelletier. 2002a. Determining trophic state in Lake Whatcom, Washington (USA), a soft water lake exhibiting seasonal nitrogen limitation. Hydrobiologia 468:107–121.

Matthews, R. A., M. Hilles, J. Vandersypen, R. J. Mitchell, and G. B. Matthews. 2002b. Lake Whatcom Monitoring Project 2000–2001 Final Report. Final Report prepared for the City of Bellingham Public Works Department, March, 2002, Bellingham, WA. https://cedar.wwu.edu/lakewhat_annualreps/15

McDonald, K. R. 1994. Nutrient limitation of phytoplankton in Lake Whatcom. M. S. Thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.

Mitchell, R., G. Gabrisch, and R. Matthews. 2010. Lake Whatcom Bathymetry and Morphology. Report prepared for the City of Bellingham Public Works Department, December 2, 2010, Bellingham, WA. https://cedar.wwu.edu/bathymetry/1

Oliver, S. K., S. M. Colling, P. A. Soranno, T. Wagner, E. H. Stanley, J. R. Jones, C. A. Stow, and N. R. Lottig. 2017. Unexpected stasis in a changing world: lake nutrient and chlorophyll trends since 1990. Global Change Biology 23(12): 5455–5467.

Pelletier, G. 1998. Dissolved oxygen in Lake Whatcom. Trend in the depletion of hypolimnetic oxygen in basin I, 1983–1997. Washington State Department of Ecology Report #98–313, Olympia, WA.

Rantz, S.E., et al. 1982. Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge. Geological Survey Water-Supply Paper #2175, U. S. Government Printing Office, Washington, D. C.

Rogora, M., S. Arisci, and A. Marchetto. 2012. The role of nitrogen deposition in the recent nitrate decline in lakes and rivers in Northern Italy. Science of the Total Environment 417–418: 214–223.

Sickman, J. O., J. M. Melack, and D. W. Clow. 2003. Evidence for nutrient enrichment of high-elevation lakes in the Sierra Nevada, California. Limnology and Oceanography 48(5):1885–1892

Sung, W., B. Reilly-Matthews, D. K. O'Day, and K. Horrigan. 2000. Modeling DBP Formation. Journal of the American Water Works Association 92:5–53.

Waller, K., D. Driscoll, J. Lynch, D. Newcomb, and K. Roy. 2012. Long-term recovery of lakes in the Adirondack region of New York to decreases in acid deposition. Atmospheric Environment 46:56–64.

Wigmosta, M. S., Vail, L. W., and Lettenmaier, D. P. 1994. A distributed hydrology-vegetation model for complex terrain. Water Resources Research 30: 1665–1679, https://doi.org/10.1029/94WR00436

World Meteorological Organization. 2010. Manual on stream gauging. Computation of discharge WMO-No. 1044, II, 195.

YSI. 2017. EXO User Manual, Revision G, April 2017. YSI Incorporated, Yellow Springs, OH.

5.2 Related Reports

The following is a list of annual reports and special project reports produced by the Institute for Watershed Studies since 1987 as part of the Lake Whatcom monitoring program sponsored by the City of Bellingham and Western Washington University. Many of the reports are available online at https://iws.wwu.edu/ (follow links to the Lake Whatcom project); older reports are available in the IWS library and through the city of Bellingham Public Works Department. This list does not include research reports, student projects, or publications that were not prepared specifically for the City of Bellingham. Contact IWS for information about additional Lake Whatcom publications.

Annual monitoring reports (listed reverse chronological):

Strecker, A., M. Hilles, J. Pickens, K. Queen, E. Flarry, R. Mitchell, R. A. Matthews, and G. B. Matthews. 2023. Lake Whatcom Monitoring Project, 2021/2022 Final Report, February 13, 2023. Report to the City of Bellingham, WA.

Strecker, A., M. Hilles, J. Pickens, R. Mitchell, R. A. Matthews, and G. B. Matthews. 2022. Lake Whatcom Monitoring Project, 2020/2021 Final Report, February 28, 2022. Report to the City of Bellingham, WA.

Strecker, A., M. Hilles, J. Pickens, R. Mitchell, R. A. Matthews, and G. B. Matthews. 2021. Lake Whatcom Monitoring Project, 2019/2020 Final Report, February 24, 2021. Report to the City of Bellingham, WA.

Matthews, R. A., A. Strecker, M. Hilles, J. Pickens, R. Mitchell, and G. B. Matthews. 2020. Lake Whatcom Monitoring Project, 2018/2019 Final Report, February 6, 2020. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Pickens, R. Mitchell, and G. B. Matthews. 2019. Lake Whatcom Monitoring Project, 2017/2018 Final Report, February 26, 2019. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Pickens, R. Mitchell, K.Beeler, and G. B. Matthews. 2018. Lake Whatcom Monitoring Project, 2016/2017 Final Report, February 23, 2018. Report to the City of Bellingham, WA. 0

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, K.Beeler, and G. B. Matthews. 2017. Lake Whatcom Monitoring Project, 2015/2016 Final Report, February 21, 2017. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, K.Beeler, and G. B. Matthews. 2016. Lake Whatcom Monitoring Project, 2014/2015 Final Report, February 23, 2016. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, K.Beeler, and G. B. Matthews. 2015. Lake Whatcom Monitoring Project, 2013/2014 Final Report, February 26, 2015. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. 2014. Lake Whatcom Monitoring Project, 2012/2013 Final Report, March 6, 2014. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. 2013. Lake Whatcom Monitoring Project, 2011/2012 Final Report, March 8, 2013. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. 2012. Lake Whatcom Monitoring Project, 2010/2011 Final Report, February 24, 2012. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2009/2010 Final Report, March 1, 2011. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2008/2009 Final Report, March 10, 2010. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2007/2008 Final Report, March 19, 2009. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2006/2007 Final Report, April 2, 2008. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2005/2006 Final Report, April 11, 2007. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2004/2005 Final Report, March 30, 2006. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2003/2004 Final Report, March 15, 2005. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2002/2003 Final Report, April 5, 2004. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2001/2002 Final Report, April 21, 2003. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 2000/2001 Final Report, March 15, 2002. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 1999/2000 Final Report, March 23, 2001. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles, J. Vandersypen, R. Mitchell, and G. B. Matthews. Lake Whatcom Monitoring Project, 1998/99 Final Report, March 15, 2000. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1997/98 Final Report, April 12, 1999. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1996/97 Final Report, February 10, 1998. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1995/96 Final Report, March 24, 1997. Report to the City of Bellingham, WA.

Matthews, R. A., M. Hilles and G. B. Matthews. Lake Whatcom Monitoring Project, 1994/95 Final Report, February 9, 1996. Report to the City of Bellingham, WA.

Matthews, R. A. and G. B. Matthews. Lake Whatcom Monitoring Project, 1993–1994 Final Report, March 2, 1995. Report to the City of Bellingham, WA.

Matthews, R. and G. Matthews. Lake Whatcom Monitoring Project, 1992–1993 Final Report, January 31, 1994. Report to the City of Bellingham, WA.

Matthews, R. and G. Matthews. Lake Whatcom Monitoring Project, 1991–1992 Final Report, March 19, 1993. Report to the City of Bellingham, WA.

Rector, J. M. and R. A. Matthews. Lake Whatcom Monitoring Program, August 1987 Final Report. Institute for Watershed Studies Report, Western Washington University, Bellingham, WA.

Other Lake Whatcom reports (listed reverse chronological):

Matthews, R. A., M. Hilles and J. Vandersypen. Austin Creek and Beaver Creek Sampling Project, October 11, 2005. Report to the City of Bellingham, WA.

Matthews, R. A. Relationship between Drinking Water Treatment Chemical Usage and Lake Whatcom water Quality and Algal Data, October 4, 2004. Report to the City of Bellingham, WA.

Matthews, R. A. Strawberry Sill Water Quality Analysis, March 19, 2004. Report to the City of Bellingham, WA.

Matthews, R. A., M. Saunders, M A. Hilles, and J. Vandersypen. Park Place Wet Pond Monitoring Project, 1994–2000 Summary Report, February 2, 2001. Report to the City of Bellingham, WA.

Carpenter, M. R., C. A. Suczek, and R. A. Matthews. Mirror Lake Sedimentation Study Summary Report, February, 1992. Report to the City of Bellingham, WA.

Walker, S., R. Matthews, and G. Matthews. Lake Whatcom Storm Runoff Project, Final Report, January 13, 1992. Report to the City of Bellingham, WA.

Creahan, K., T. Loranger, B. Gall, D. Brakke, and R. Matthews. Lake Whatcom Watershed Management Plan, December, 1986, revised July, 1987. Institute for Watershed Studies Report, Western Washington University, Bellingham, WA.

A Site Descriptions

Figures A1–A2 (pages 103–104) show the locations of the current monitoring sites and Table A1 (page 102) lists the approximate GPS coordinates for the lake and creek sites. All site descriptions, including text descriptions and GPS coordinates, are approximate. For detailed information about sampling locations, contact IWS.

A.1 Lake Whatcom Monitoring Sites

Site 1 is located in the north central portion of basin 1 along a straight line from the Bloedel Donovan boat launch to the house located at 171 E. North Shore Rd. The depth at Site 1 should be at least 25 meters; samples are collected from the surface to 20 m.

Site 2 is located in the south central portion of basin 2 just west of the intersection of a line joining the boat house at 73 Strawberry Point and the point of Geneva sill. The depth at Site 2 should be at least 23 meters; samples are collected from the surface to 20 m.

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

Site 3 is located in the northern portion of basin 3, 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; samples are collected from the surface to 75 m.

Site 4 is located in the southern portion of basin 3, mid-basin, and just north of South Bay. The depth at Site 4 should be at least 90 m; samples are collected from the surface to 90 m.

A.2 Tributary Monitoring Sites

Anderson Creek samples are collected using a sampling pole from the upstream side of the South Bay Rd. bridge. The Anderson Creek hydrograph[35] is mounted

[35] This hydrograph is no longer maintained by IWS; data are available on the USGS web site at http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=12201950.

in the stilling well on the east side of Anderson Creek, directly adjacent to the bridge over Anderson Creek (South Bay Rd.), approximately 0.5 km from the mouth of the creek.

The **Austin Creek** hydrograph gauge and sampling site is located approximately 15 m downstream from Lake Whatcom Blvd. From October 2004 through September 2006, three additional sampling sites were sampled in the Austin Creek watershed, so for clarification, the gauged site has been renamed **Lower Austin Creek**.

Blue Canyon Creek samples are collected upstream from the culvert under Blue Canyon Rd. in the second of three small streams that cross the road. During conditions of low flow or high lake levels, samples are collected, if possible, approximately 7 m upstream from the road crossing.

Brannian Creek samples are collected using a sampling pole from the downstream side of South Bay Rd., approximately 40 m upstream from the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

Carpenter Creek samples are collected approximately 7 m upstream from North Shore Dr. near the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

Euclid Creek samples are collected from a small tributary off Euclid Avenue near the USGS hydrograph gauge. The site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

Millwheel Creek samples are collected approximately 8 m upstream from Flynn St. near the USGS hydrograph gauge. The creek is unnamed on most topographic maps, but has been called "Millwheel Creek" by residents of the watershed due to its proximity to the old mill pond. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

Olsen Creek samples are collected upstream from North Shore Dr., approximately 3 meters upstream from the bridge. This site was added in October 2004 as part of the 2004–2006 monthly creek monitoring project.

Park Place samples are collected from the storm drain that empties into Lake Whatcom at Park Place Ln. Samples from this site include outlet flow from the Park Place storm water treatment facility.

Silver Beach Creek samples are collected approximately 75 m upstream from the culvert under North Shore Rd., just upstream from the USGS hydrograph gauge.

The **Smith Creek** hydrograph is mounted on the south wall of a sandstone bluff directly underneath the bridge over Smith Creek (North Shore Rd.) approximately 1 km upstream from the mouth of the creek. Water samples are collected near the old bridge site, at the end of North Shore Rd. approximately 500 m downstream from the IWS hydrograph gauge. During periods of low flow, Smith Creek is sampled approximately 15 m downstream from the IWS hydrograph gauge.

Whatcom Creek samples are collected approximately 2 m downstream from the foot bridge below the Lake Whatcom outlet spillway. This site was added in October 2004 as part of the monthly 2004–2006 creek monitoring project.

A.3 Storm Water Monitoring Sites

The 2022/2023 storm water monitoring program focused on collecting storm runoff data from Carpenter, Olsen, and Smith Creeks. Carpenter Creek samples are collected approximately 7 m upstream from North Shore Dr. near the USGS hydrograph gauge. Olsen Creek samples are collected upstream from North Shore Dr., approximately 3 meters upstream from the bridge. Smith Creek samples are collected near the old bridge site, at the end of North Shore Rd. approximately 500 m downstream from the IWS hydrograph gauge.

For information about other storm water sites that have been monitored by IWS, refer to the annual reports listed in Section 5.2 (page 94).

Lake Sites	Latitude (°N)	Longitude (°W)
Site 1	48.760	-122.411
Intake	(GPS omitted)	
Site 2	48.743	-122.382
Site 3	48.738	-122.336
Site 4	48.695	-122.304

Tributary/Stormwater Sites	Latitude (°N)	Longitude (°W)
Anderson	48.673	-122.268
Austin (lower)	48.713	-122.331
Blue Canyon	48.685	-122.283
Brannian	48.669	-122.279
Carpenter	48.754	-122.354
Euclid	48.748	-122.410
Millwheel	48.755	-122.416
Olsen	48.751	-122.354
Park Place	48.769	-122.409
Silver Beach	48.769	-122.407
Smith	48.732	-122.309
Whatcom	48.757	-122.422

Table A1: Approximate GPS coordinates for Lake Whatcom sampling sites.

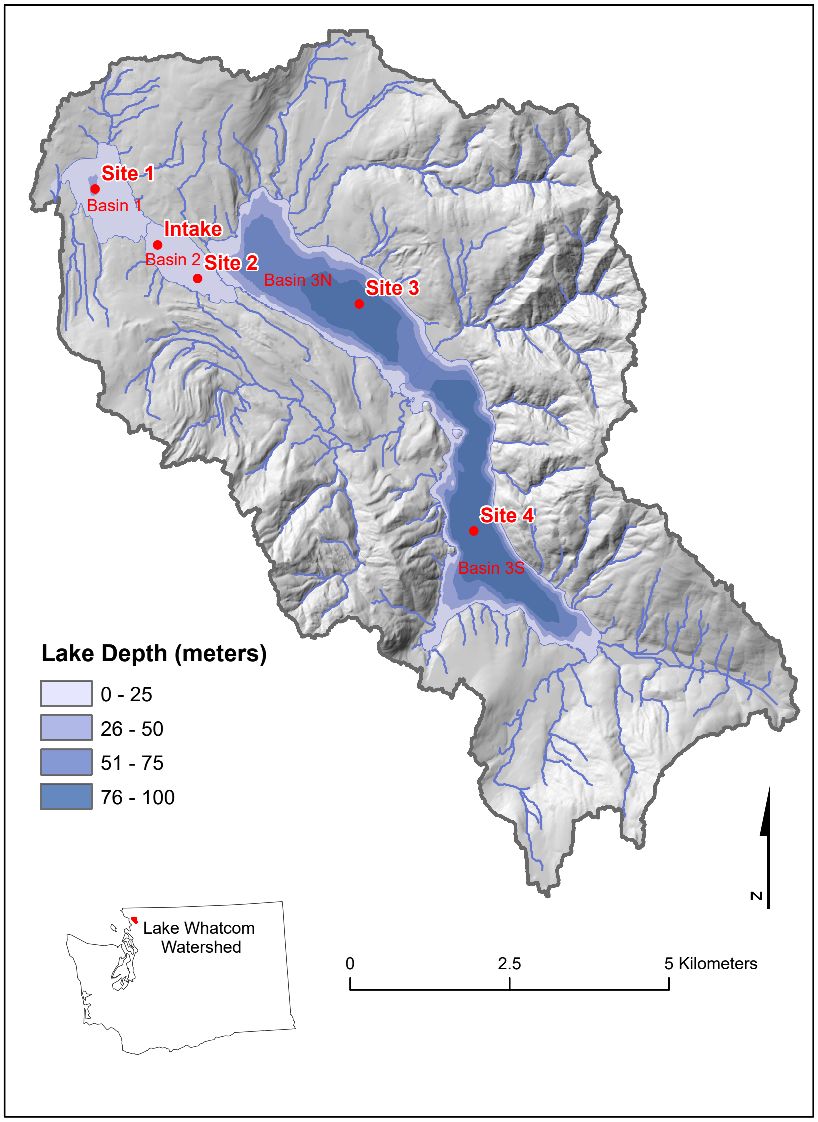


Figure A1: Lake Whatcom lake sampling sites. Basemap created using data from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

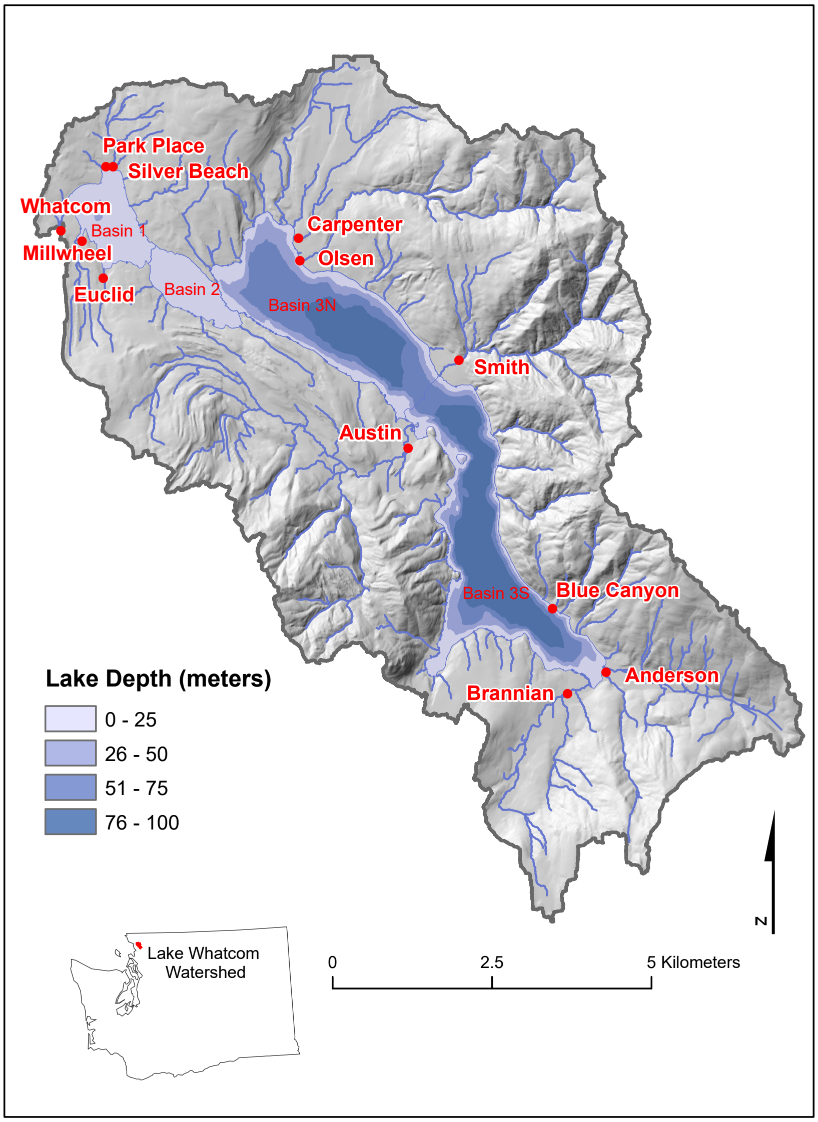


Figure A2: Lake Whatcom tributary and storm water sampling sites. Basemap created using data from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

B Long-Term Water Quality Figures

The current and historic Lake Whatcom water quality data are plotted on the following pages. Detection limits and abbreviations for each parameter are listed in Table 2.1 (page 19).

The historic detection limits for each parameter were estimated based on an analysis of historic detection ranges, instrument limitations, and analyst judgment on the lowest repeatable concentration for each test. Over time, some analytical techniques have improved so that current detection limits are lower than the historic limits listed in Table 2.1, page 19). Because the Lake Whatcom data set includes long-term monitoring data that have been collected using a variety of analytical techniques, this report sets conservative historic detection limits to allow comparisons between all years.

In the Lake Whatcom report, unless indicated, no data substitutions are used for below detection values ("bdl" data). Instead, we identify summary statistics that include bdl values, and, if appropriate, discuss the implications of including these values in the analysis.

Because of the length of the data record, many of the figures reflect trends related to improvements in analytical techniques over time and the introduction of increasingly sensitive field equipment (see, for example, Figures B81–B85, pages 188–192, which show the effect of using increasingly sensitive conductivity probes). These changes generally result in a reduction in analytical variability, and sometimes result in lower detection limits.

B.1 Monthly YSI Profiles

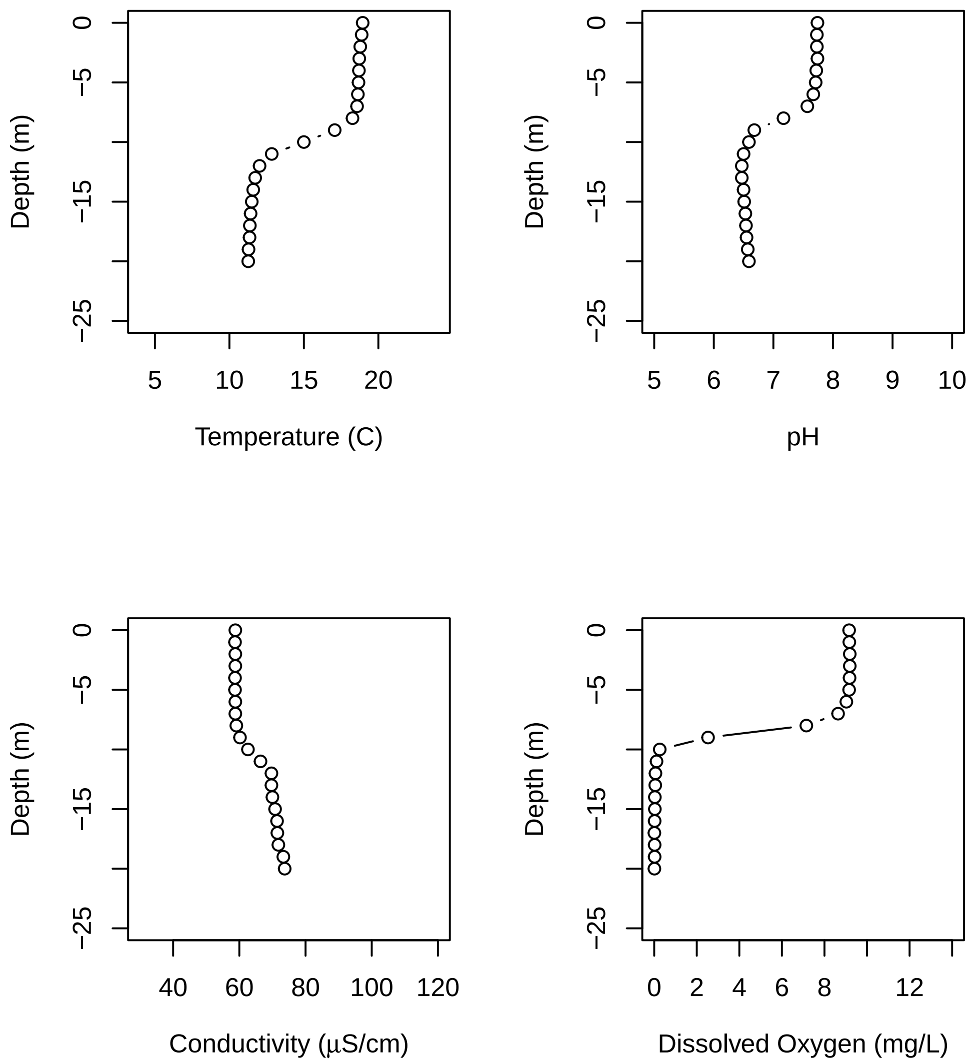


Figure B1: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, October 5, 2022.

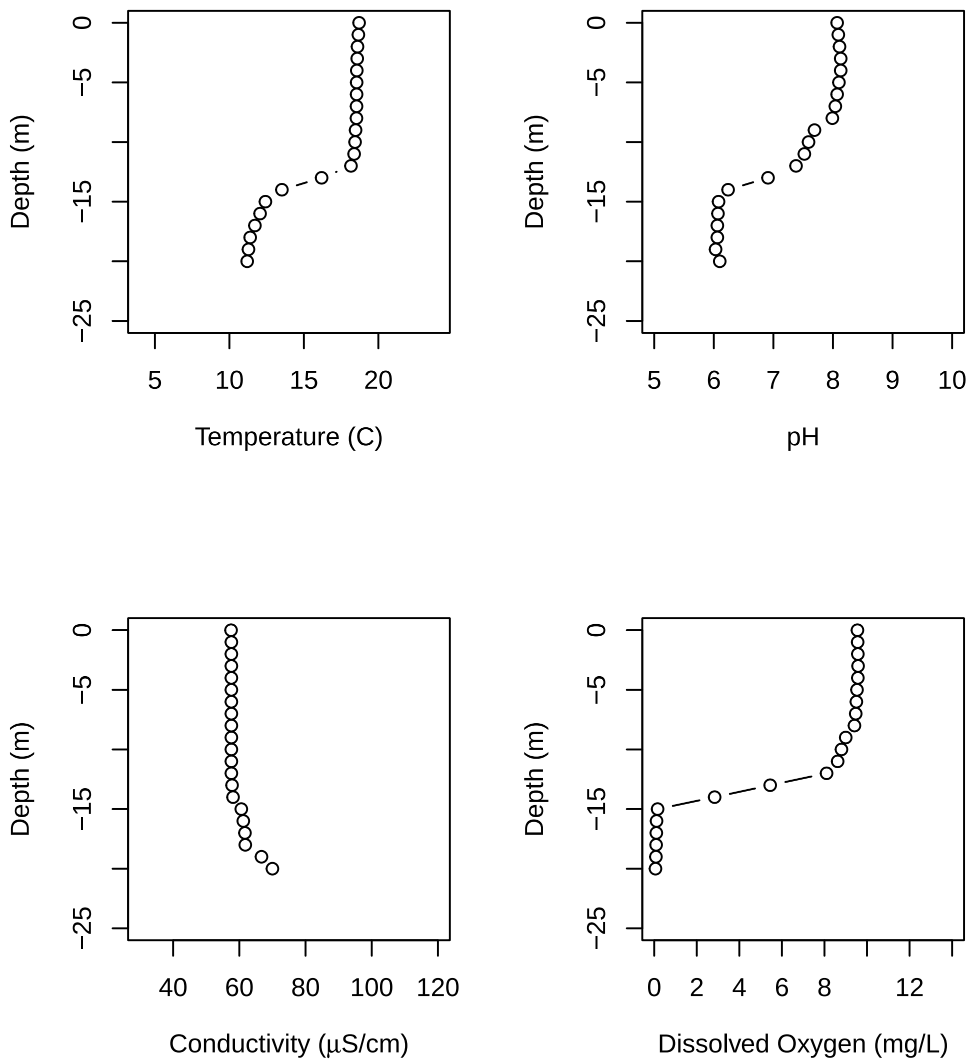


Figure B2: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, October 5, 2022.

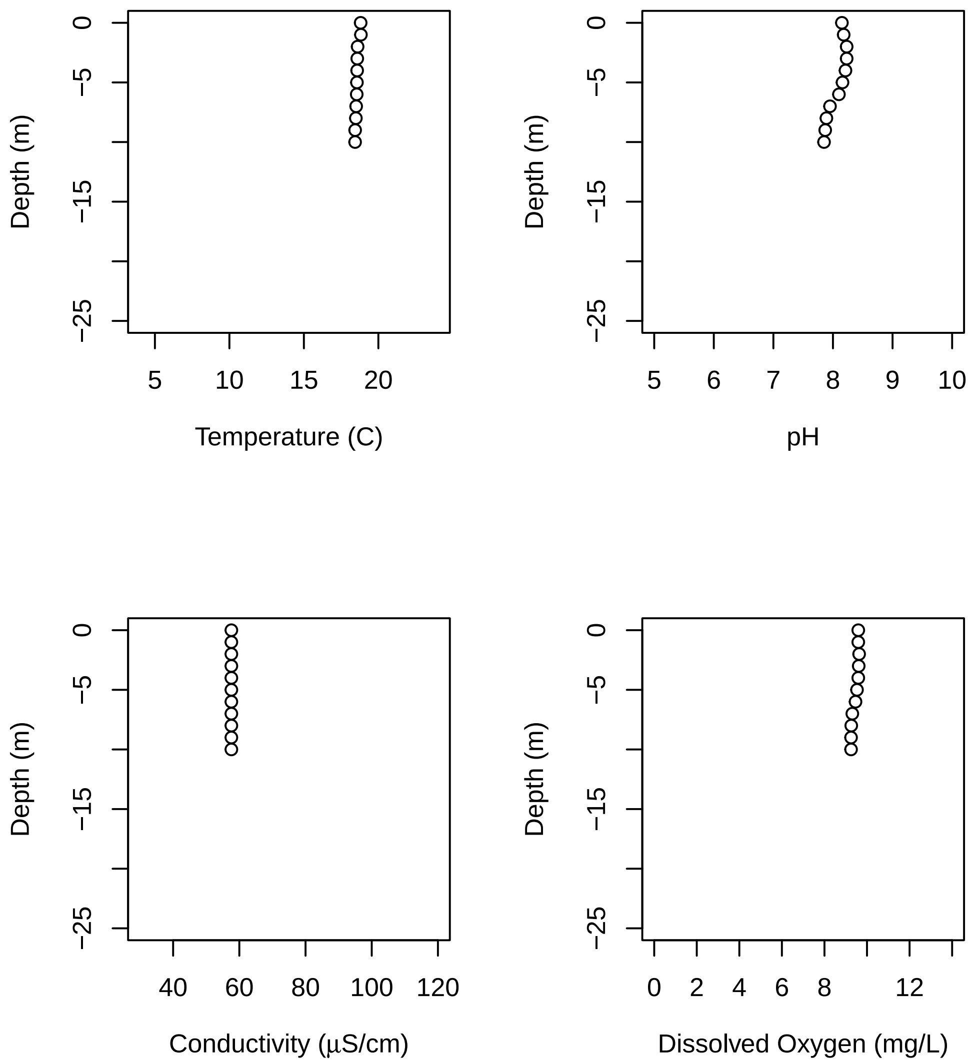


Figure B3: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, October 5, 2022.

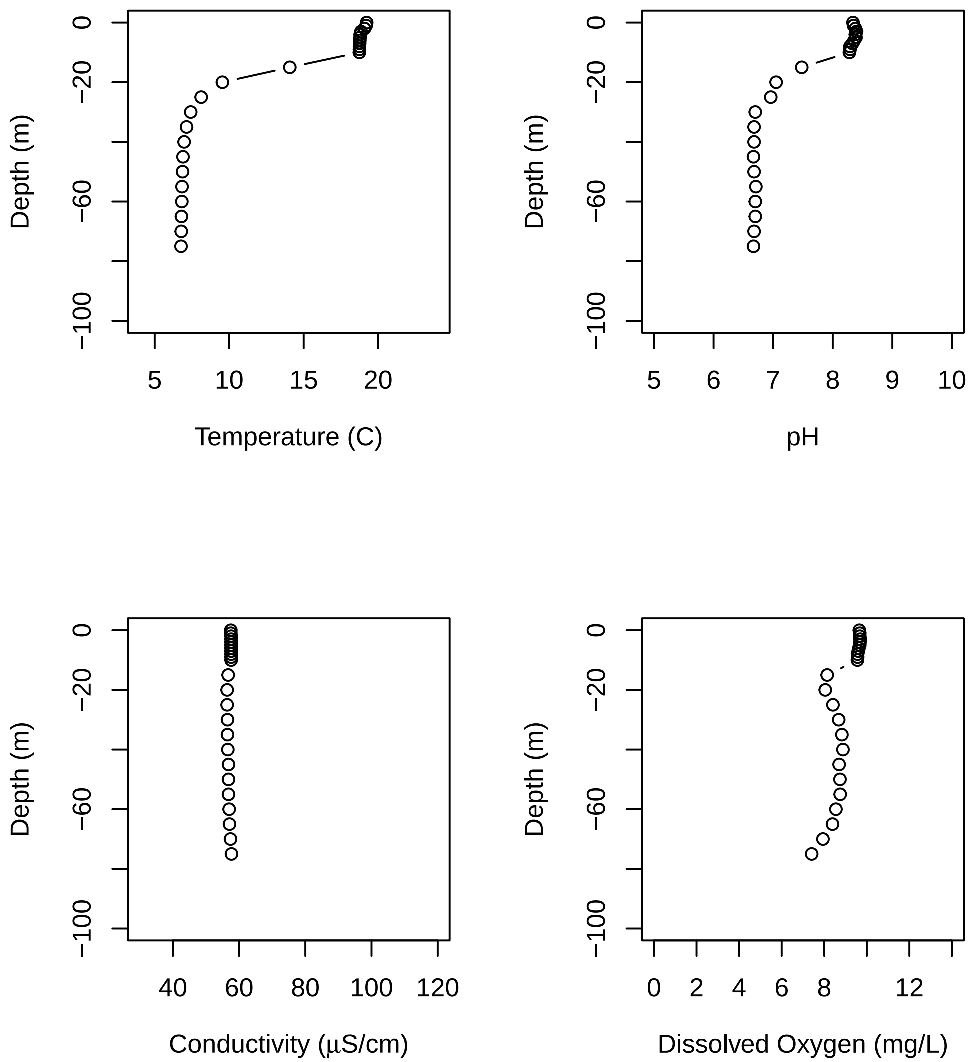


Figure B4: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, October 3, 2022.

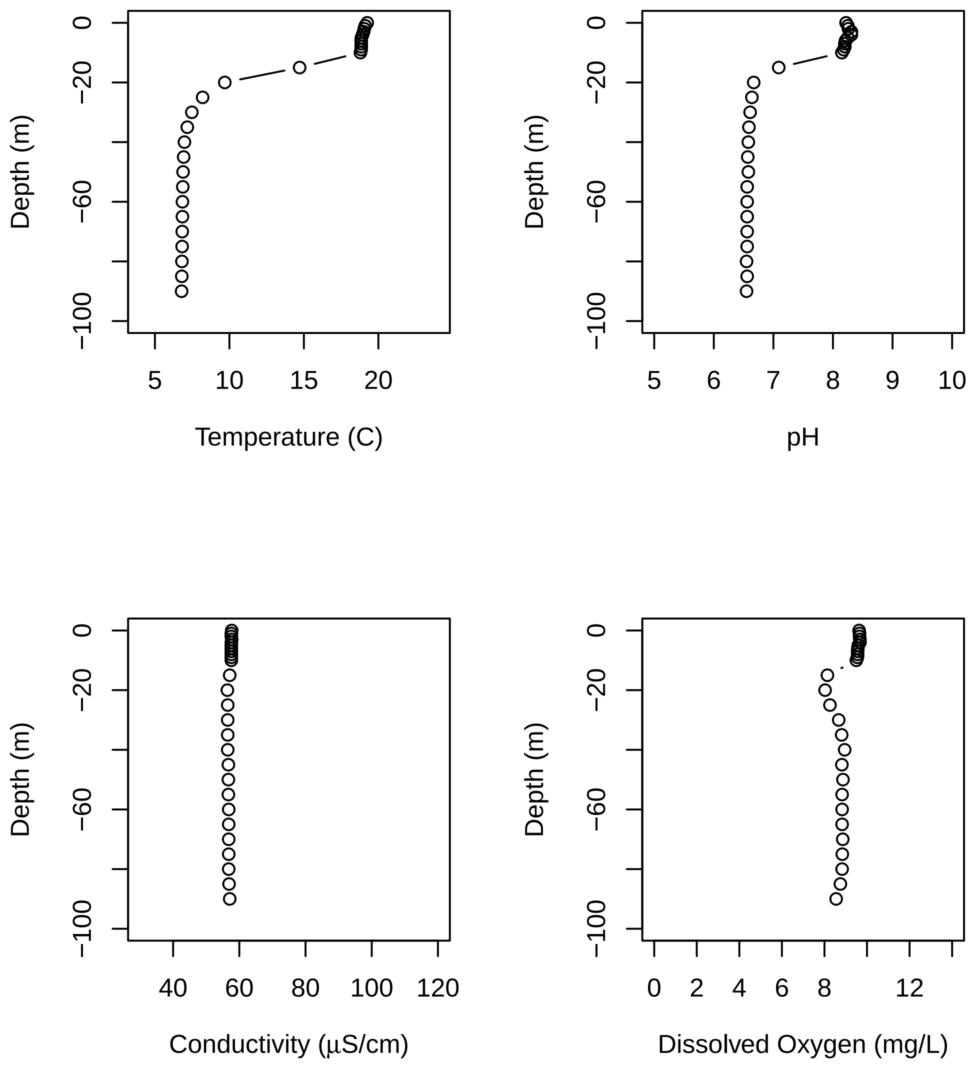


Figure B5: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, October 3, 2022.

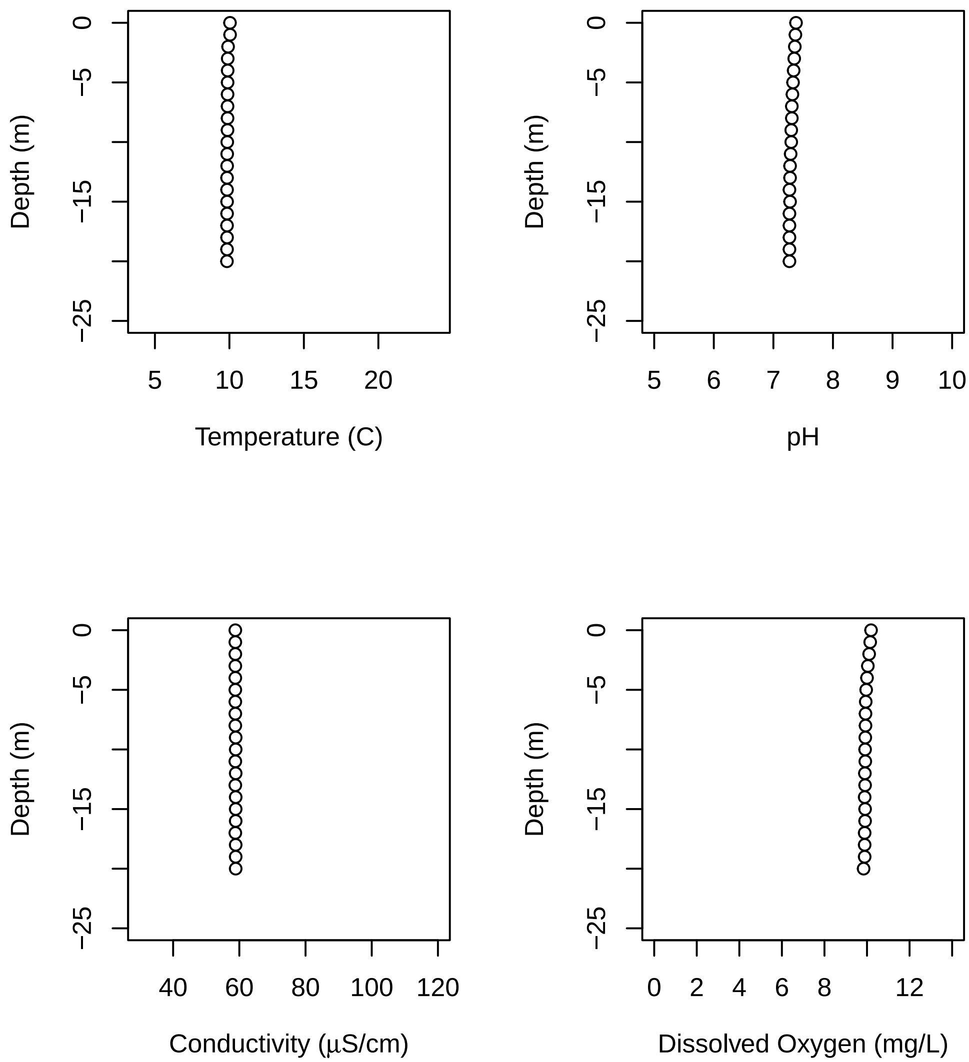


Figure B6: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, November 14, 2022.

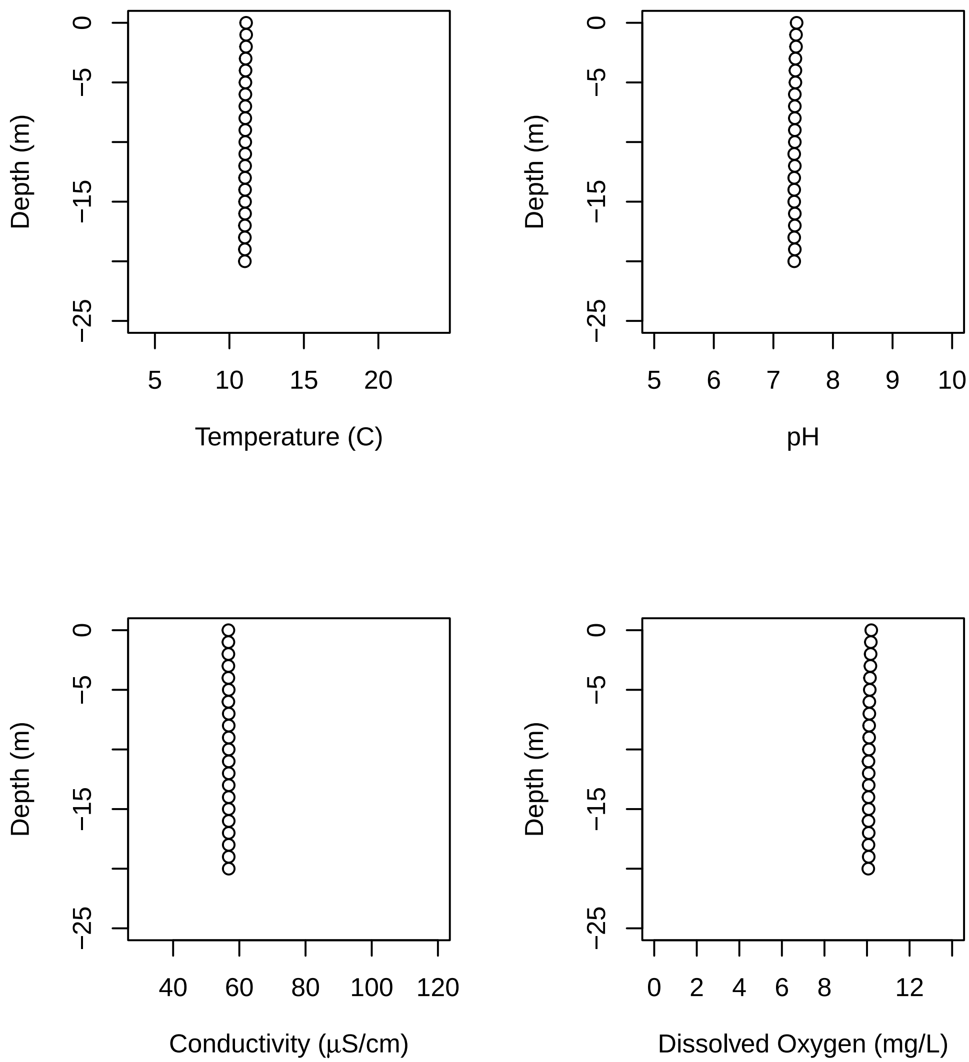


Figure B7: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, November 14, 2022.

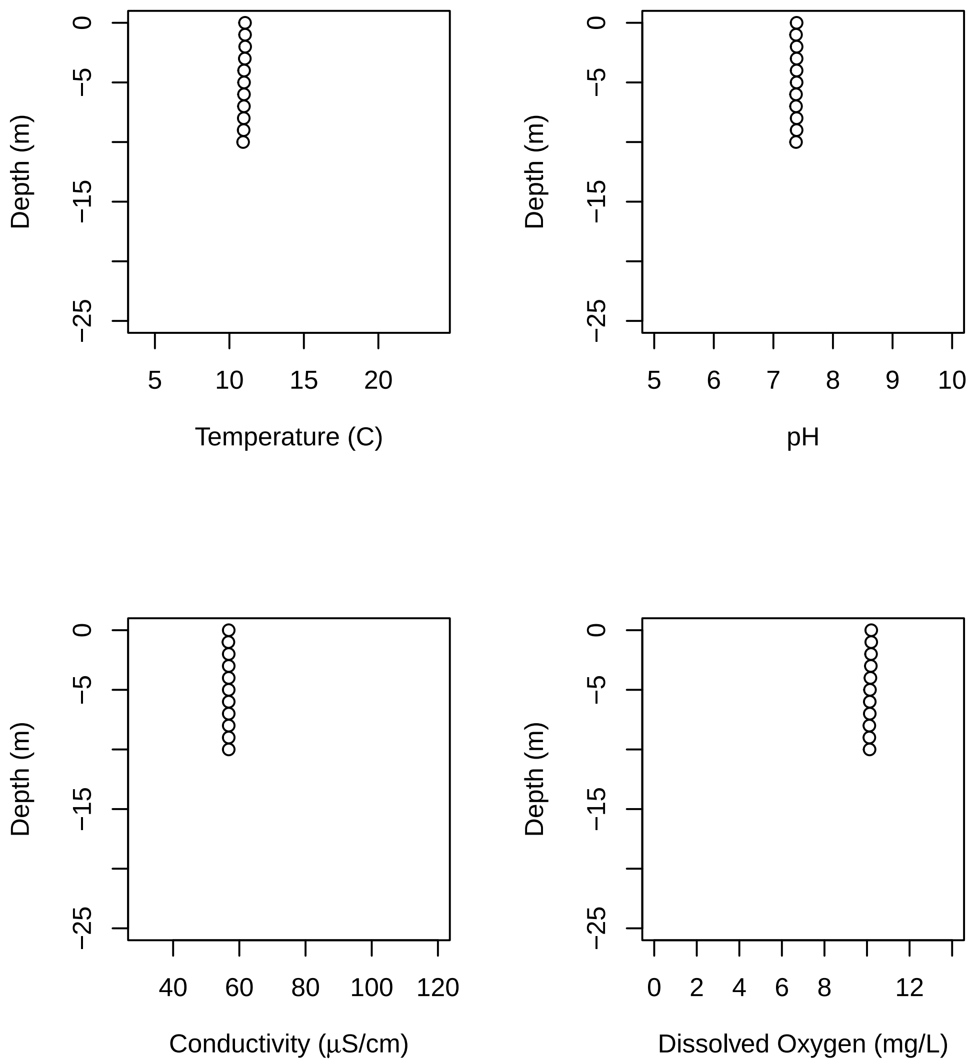


Figure B8: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, November 14, 2022.

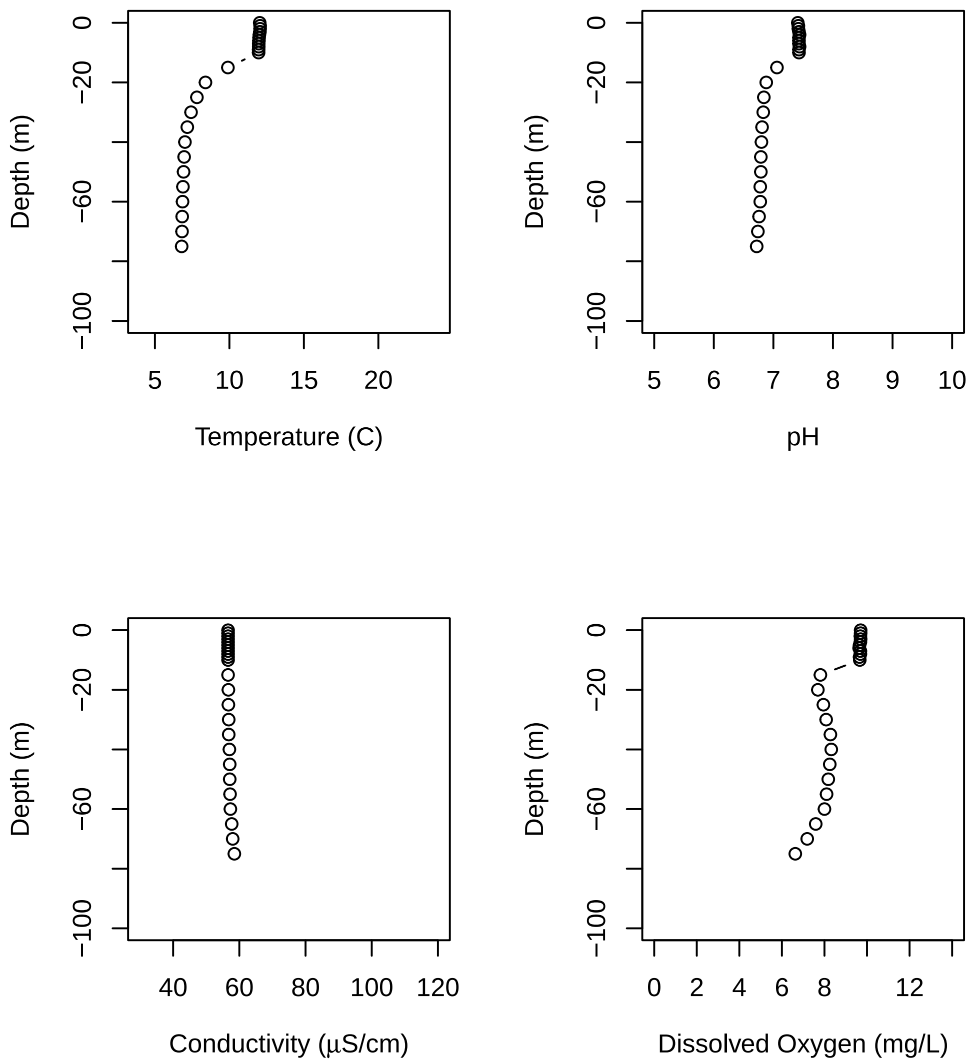


Figure B9: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, November 9, 2022.

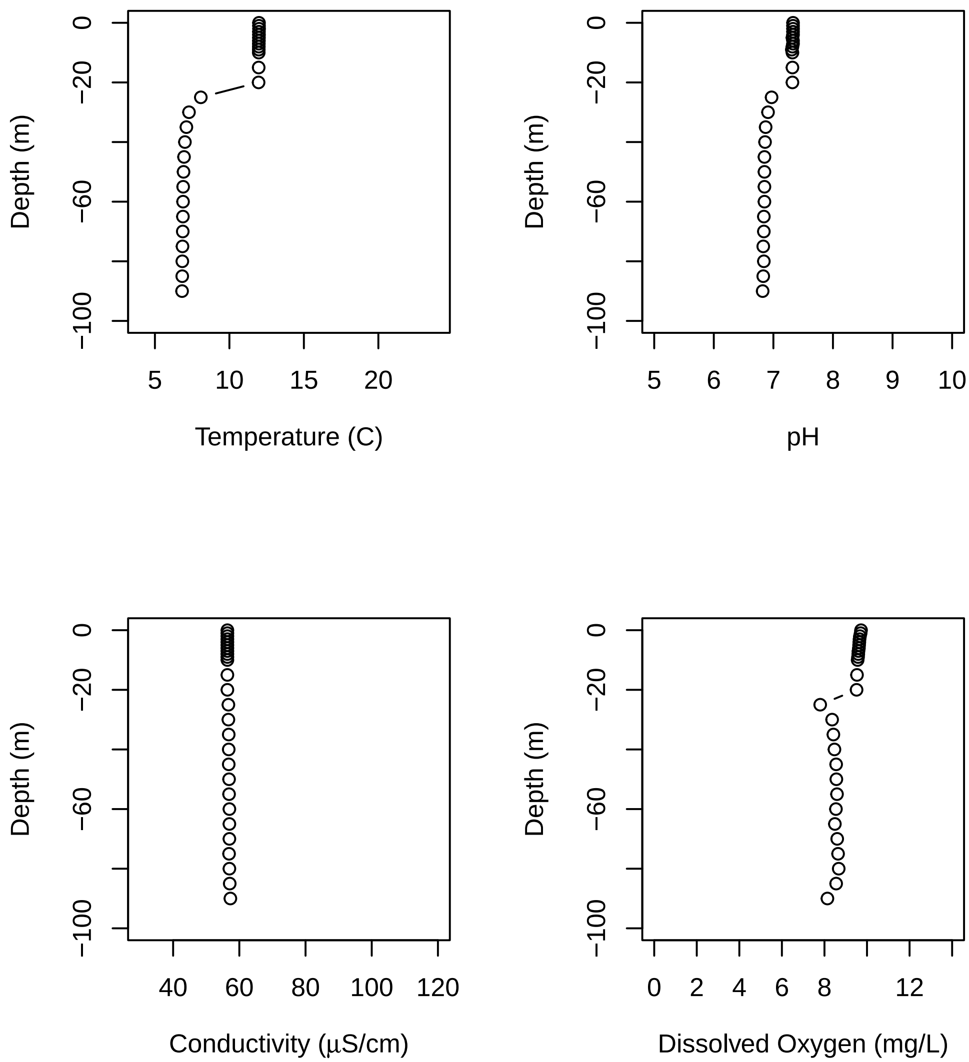


Figure B10: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, November 9, 2022.

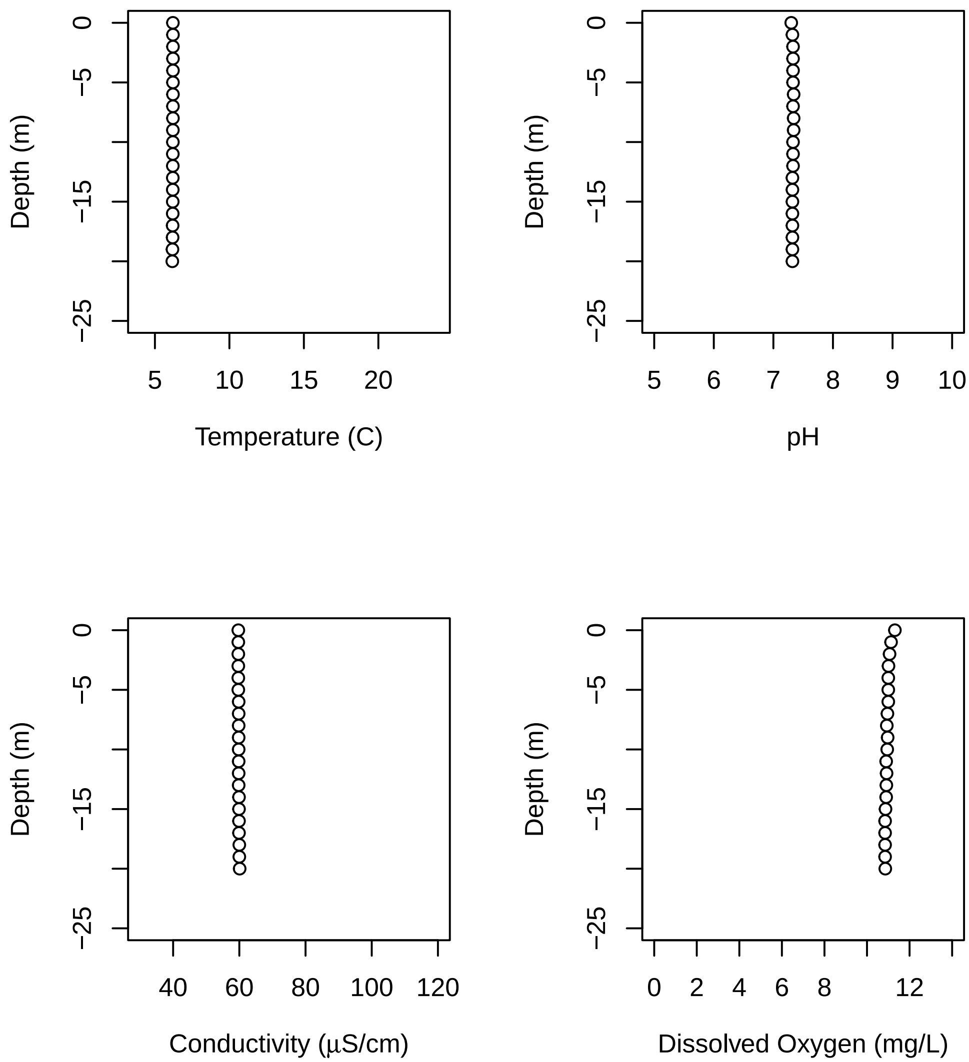


Figure B11: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, December 6, 2022.

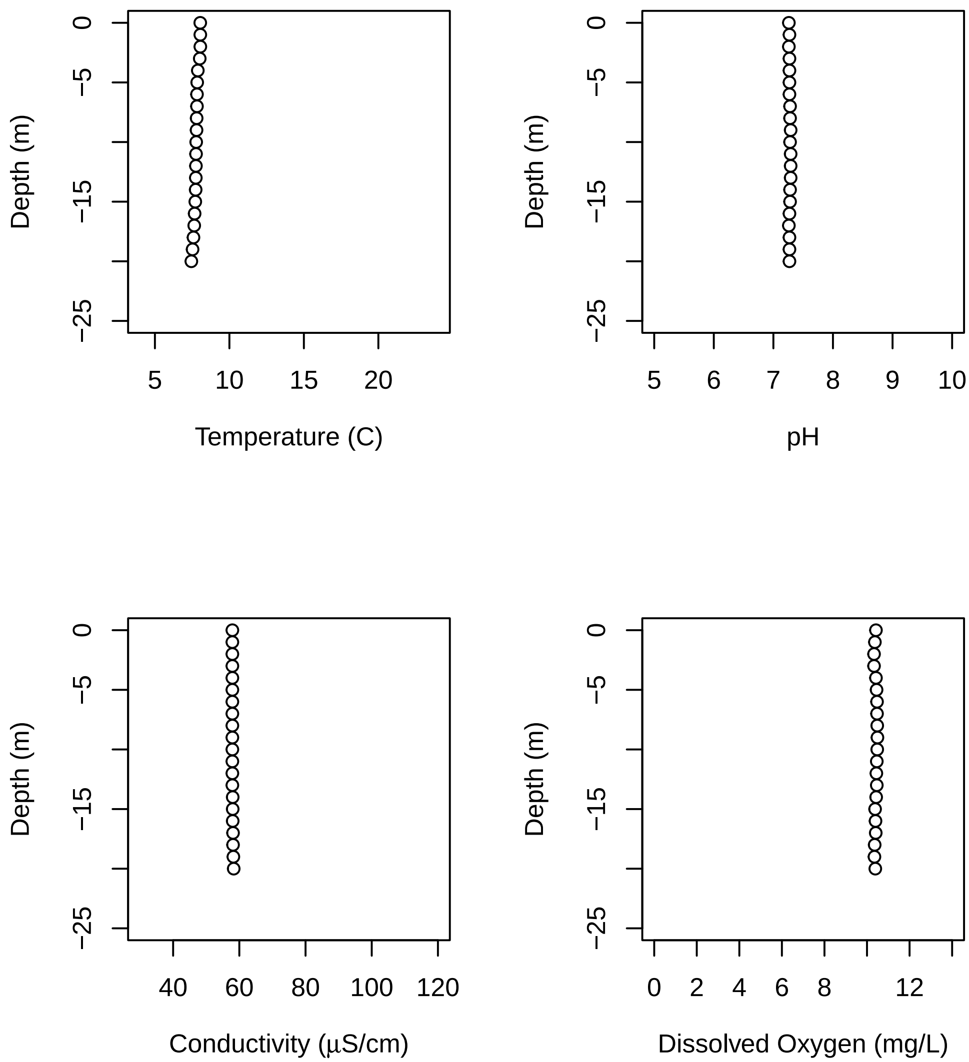


Figure B12: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, December 6, 2022.

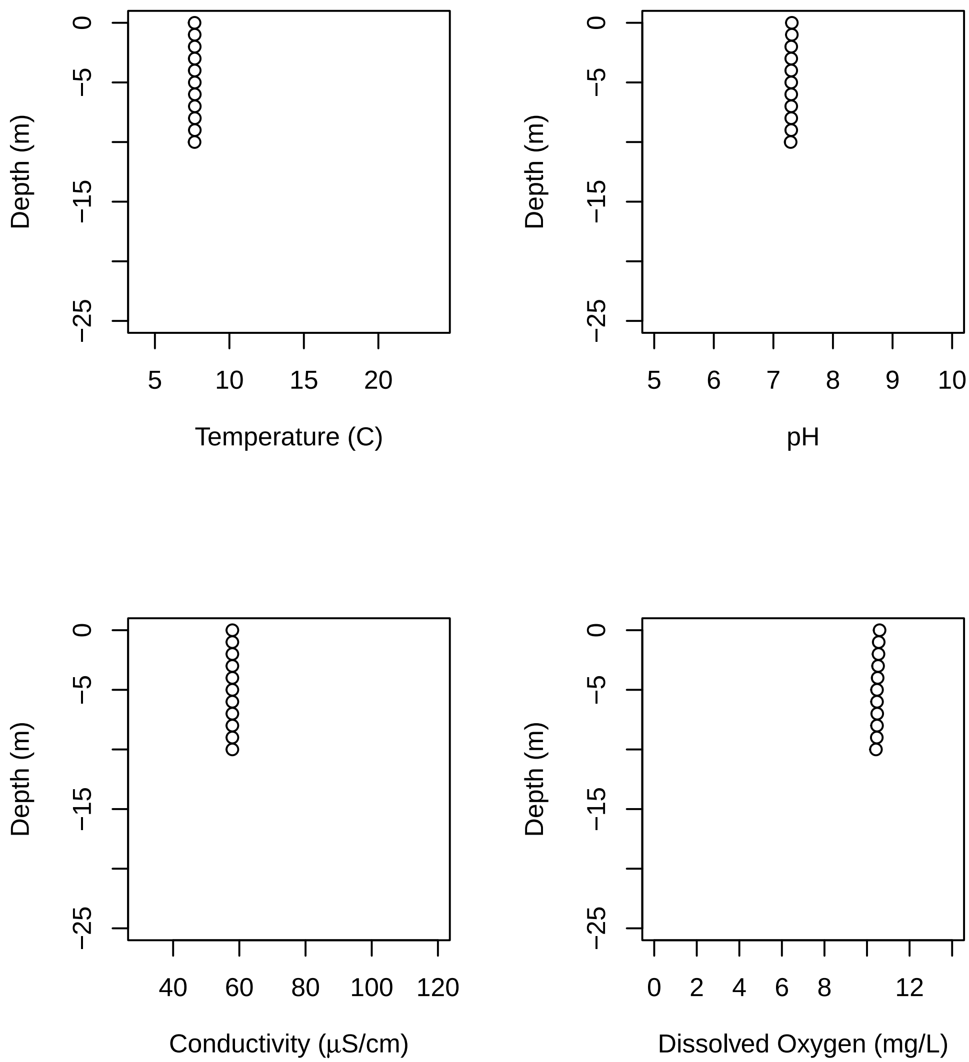


Figure B13: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, December 6, 2022.

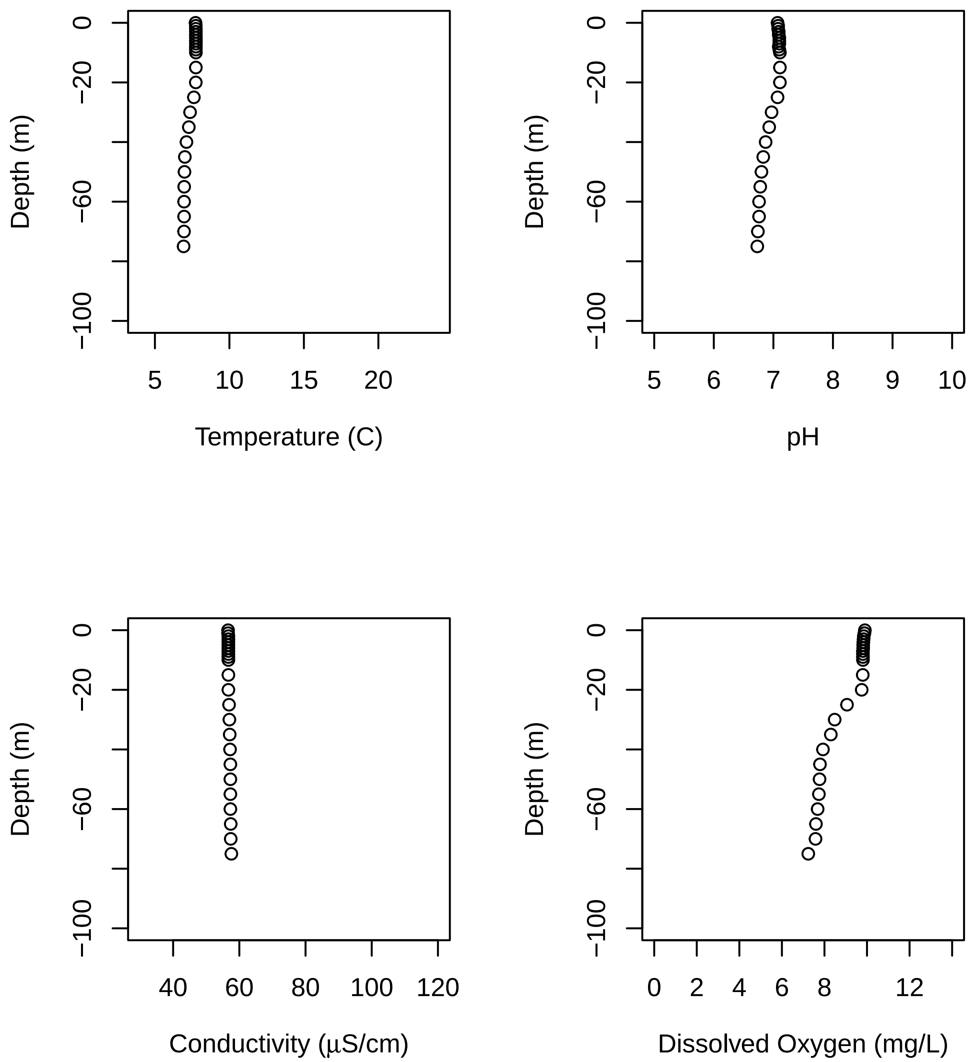


Figure B14: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, December 13, 2022.

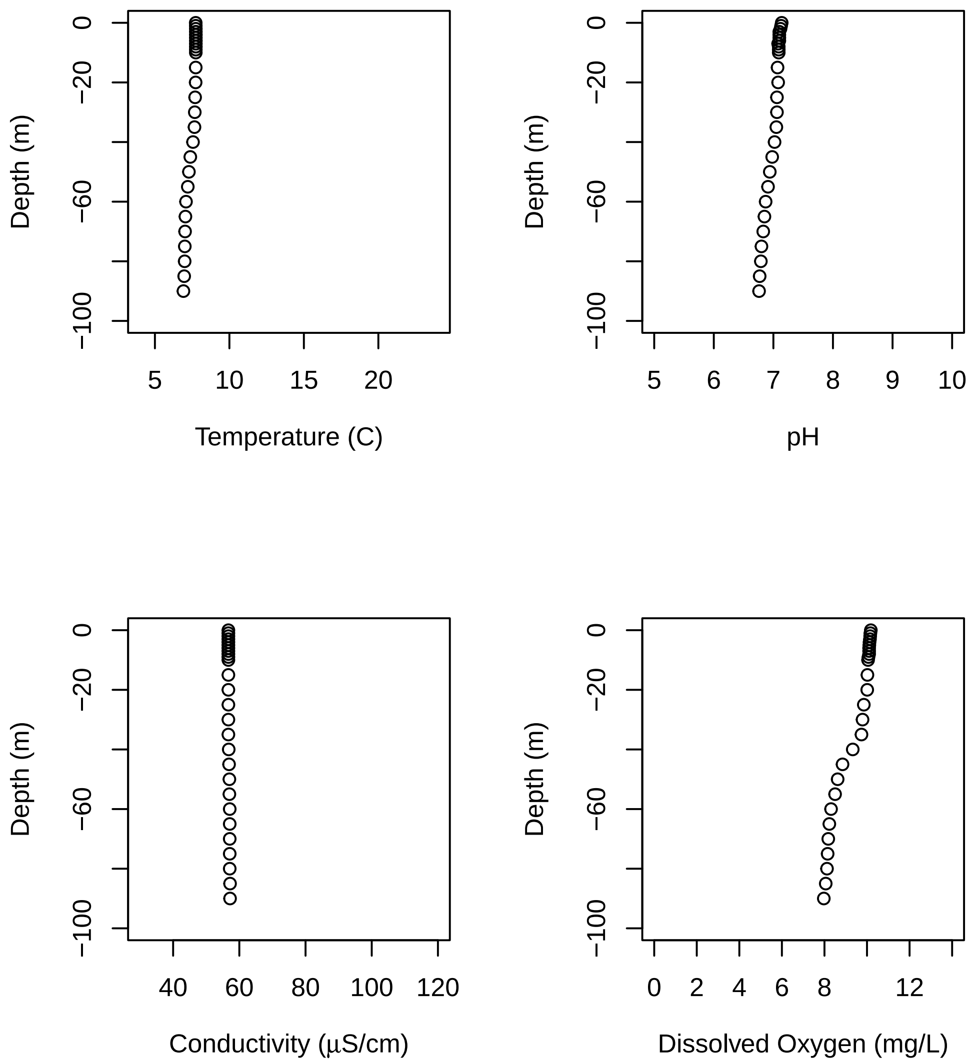


Figure B15: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, December 13, 2022.

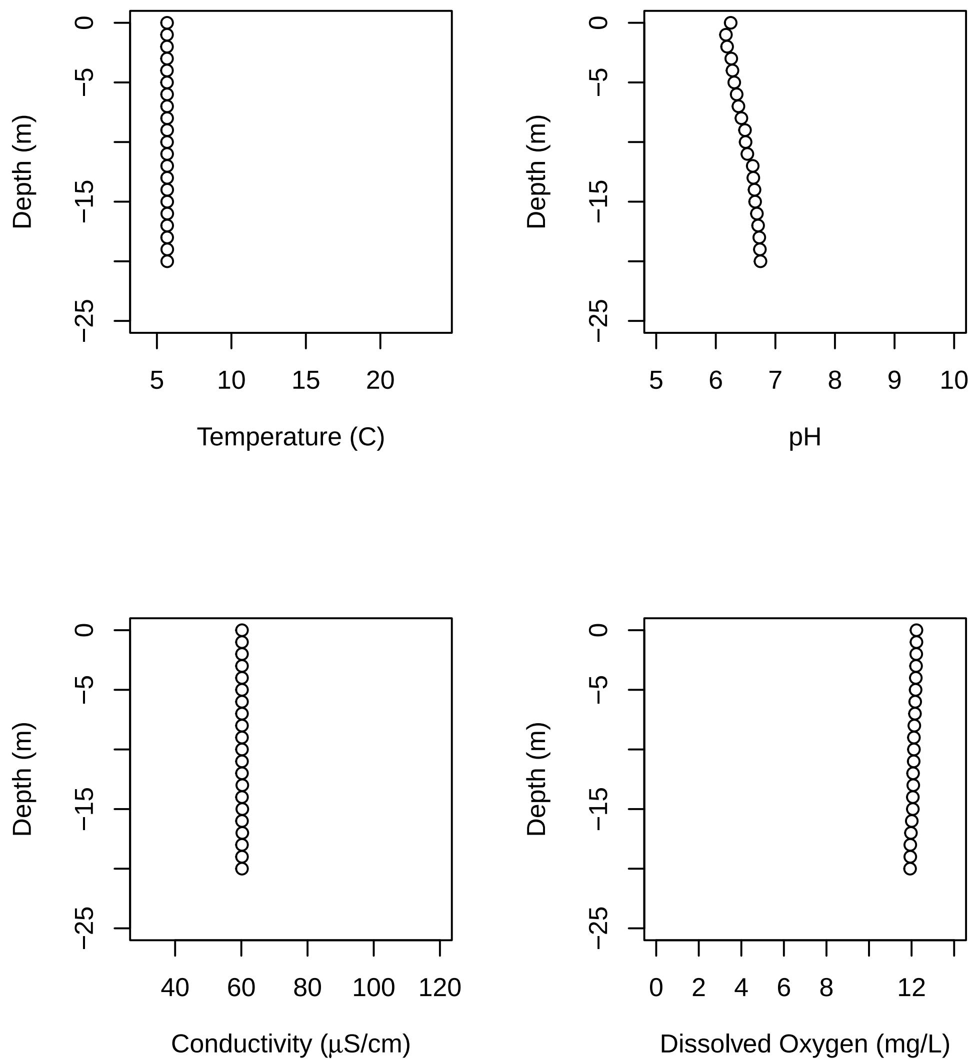


Figure B16: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, February 14, 2023.

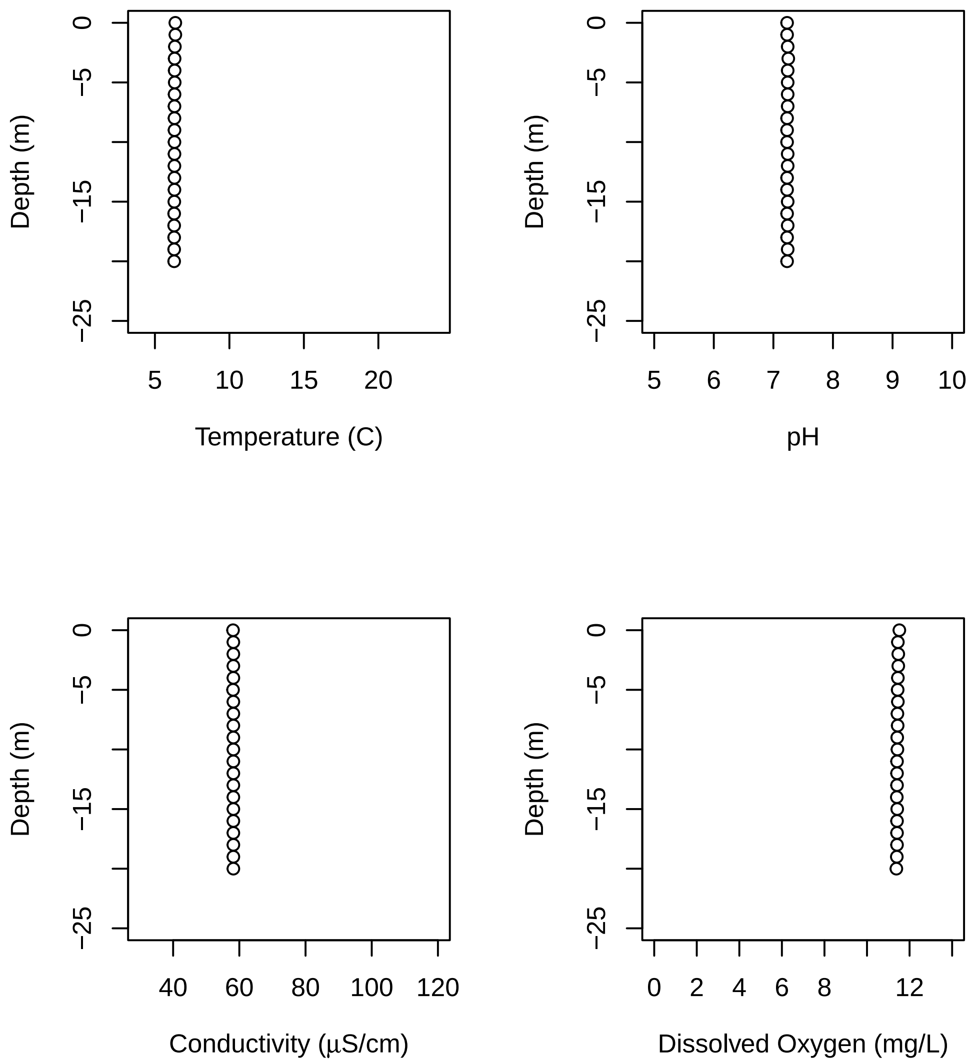


Figure B17: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, February 14, 2023.

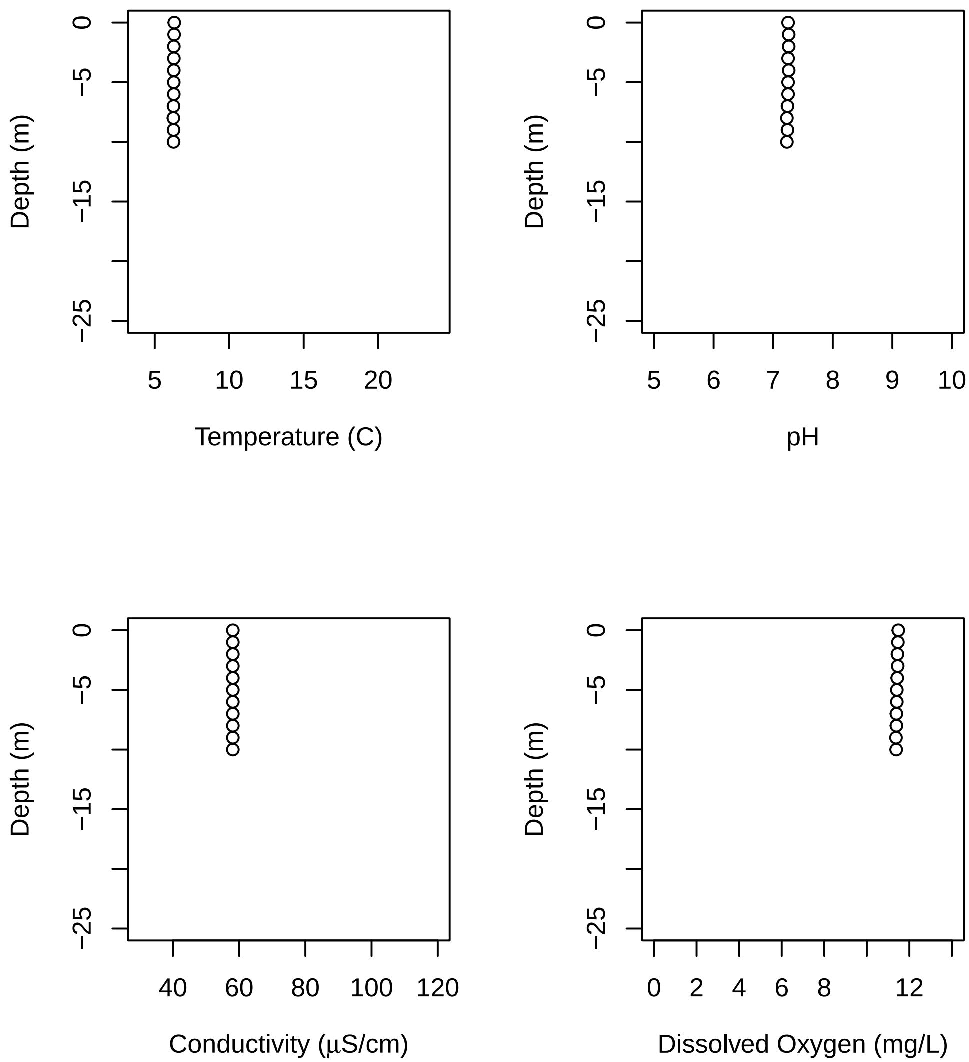


Figure B18: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, February 14, 2023.

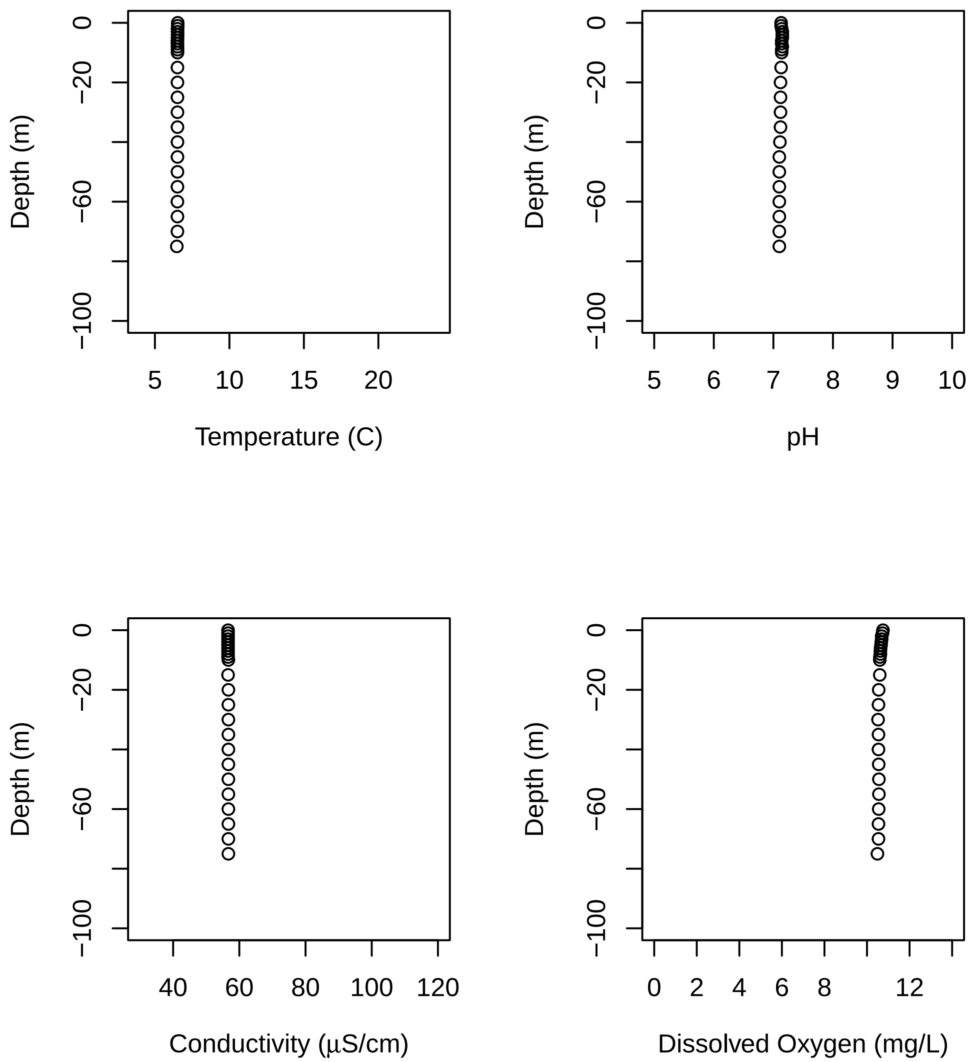


Figure B19: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, February 2, 2023.

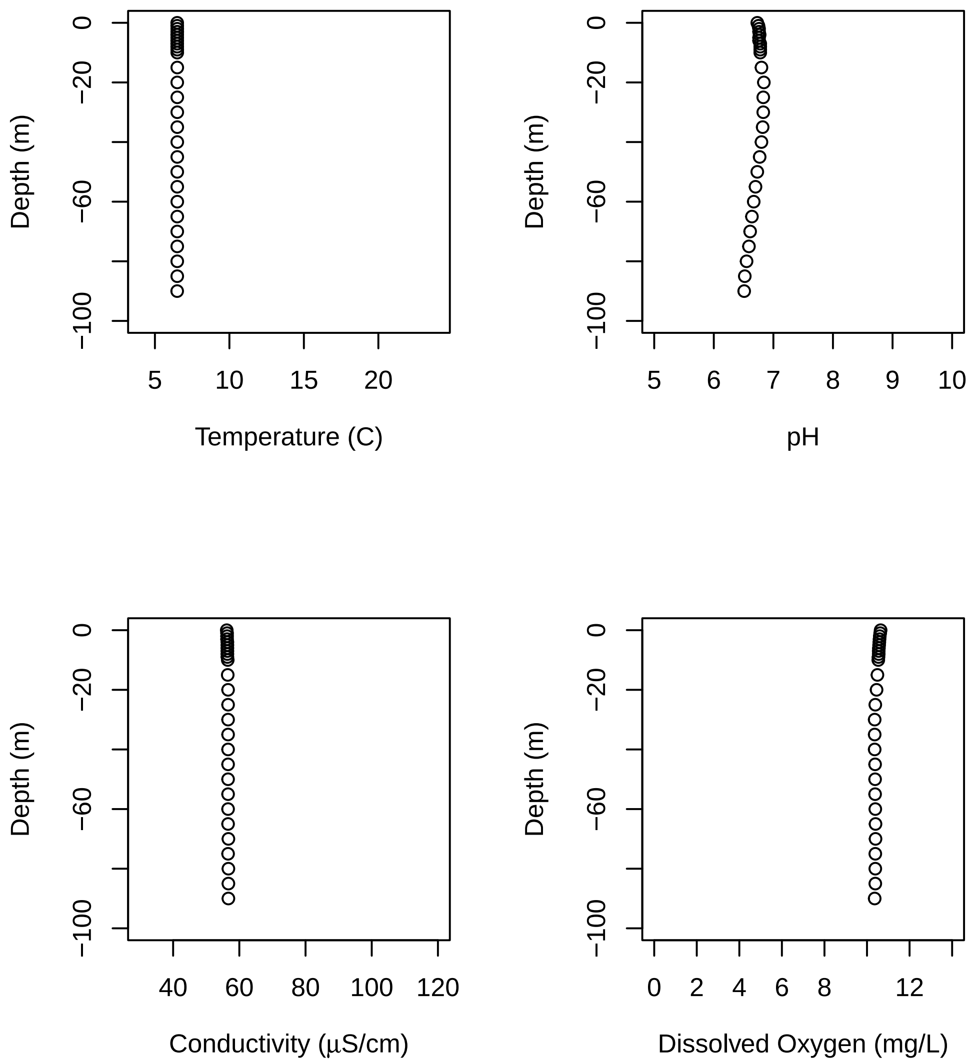


Figure B20: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, February 2, 2023.

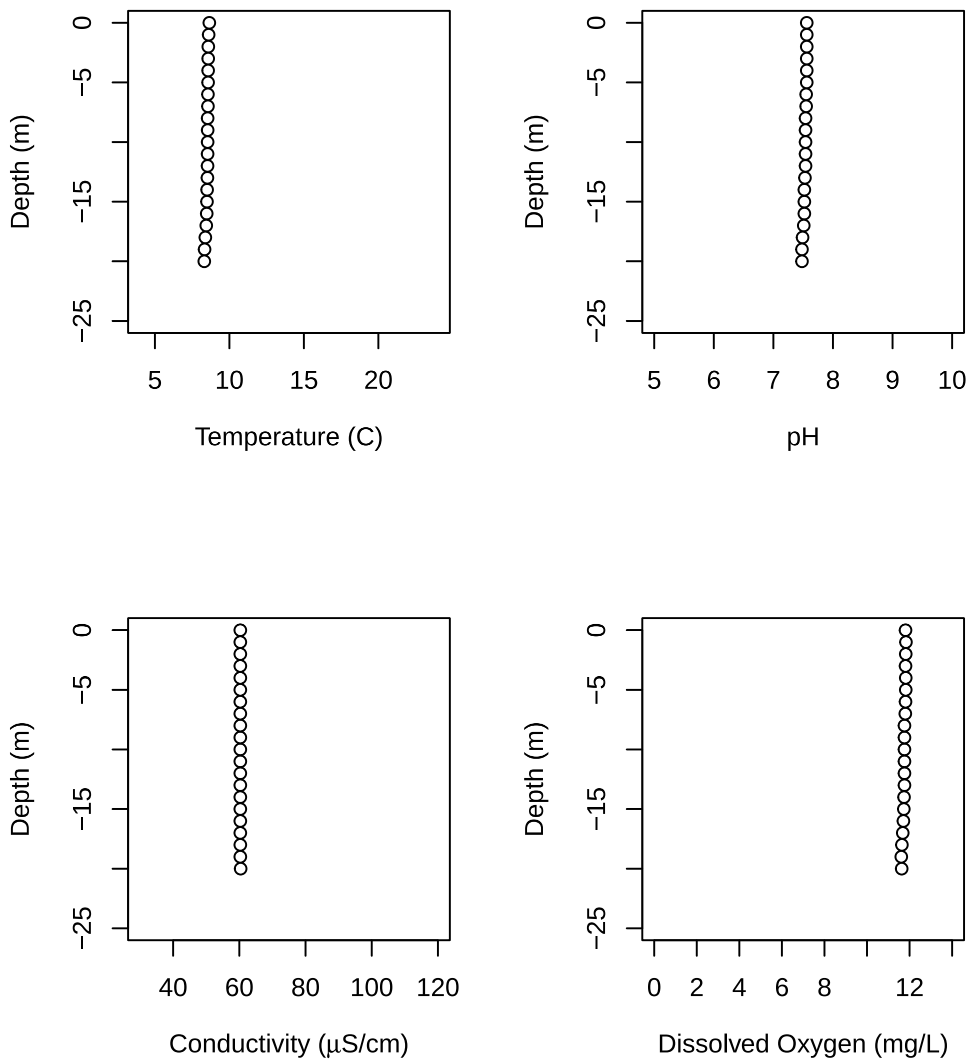


Figure B21: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, April 13, 2023.

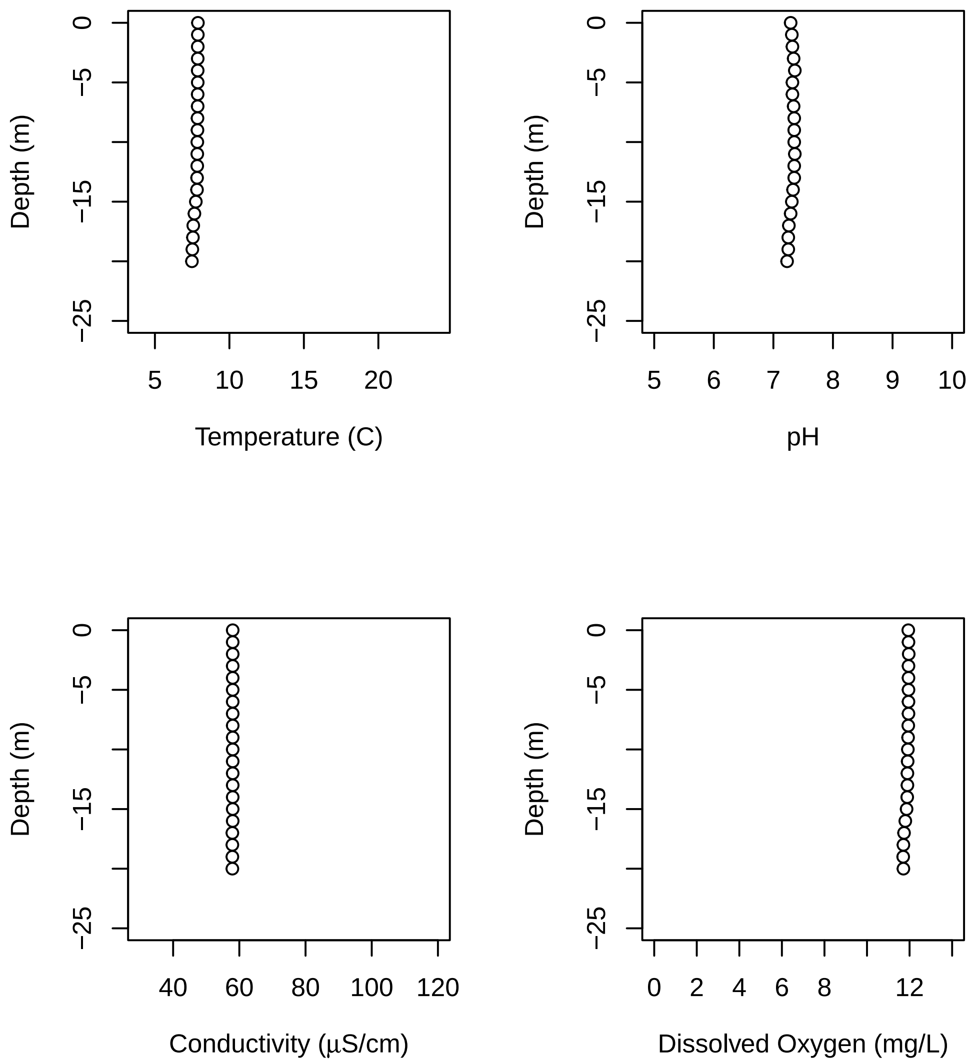


Figure B22: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, April 13, 2023.

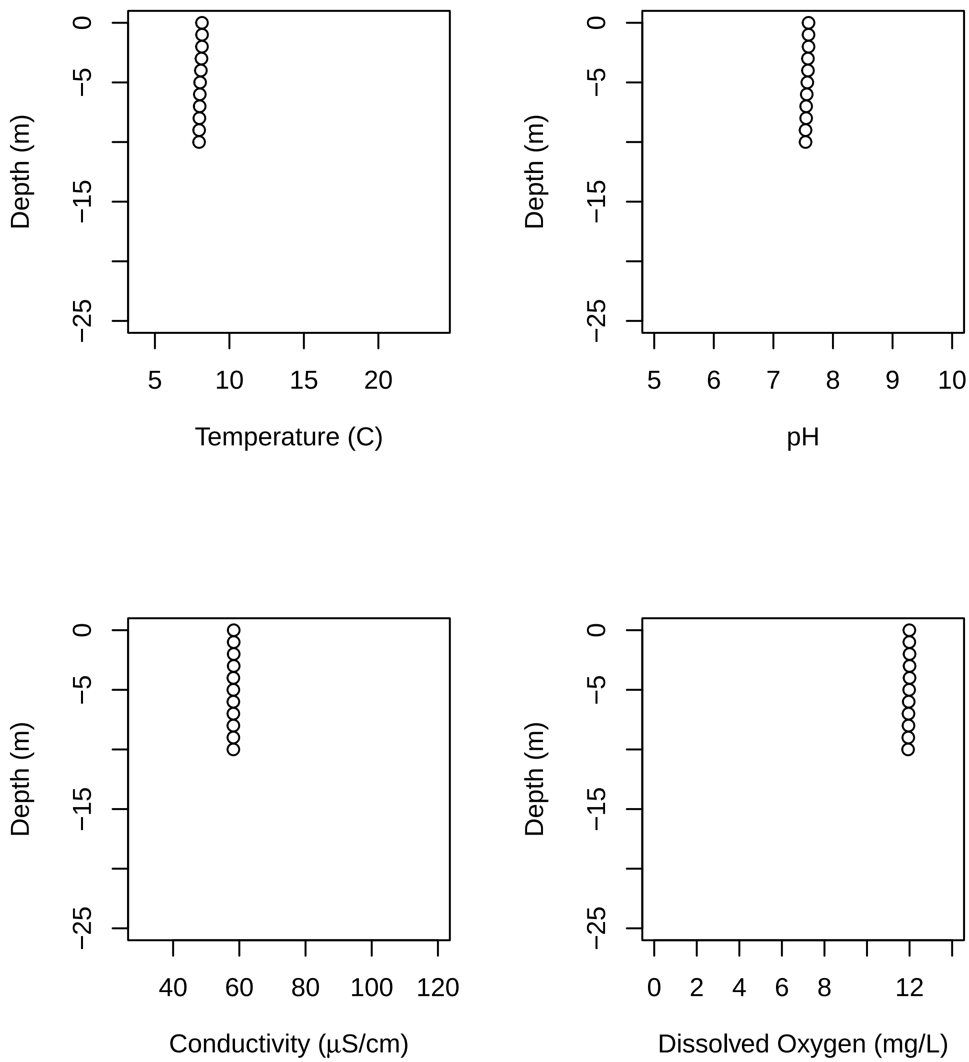


Figure B23: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, April 13, 2023.

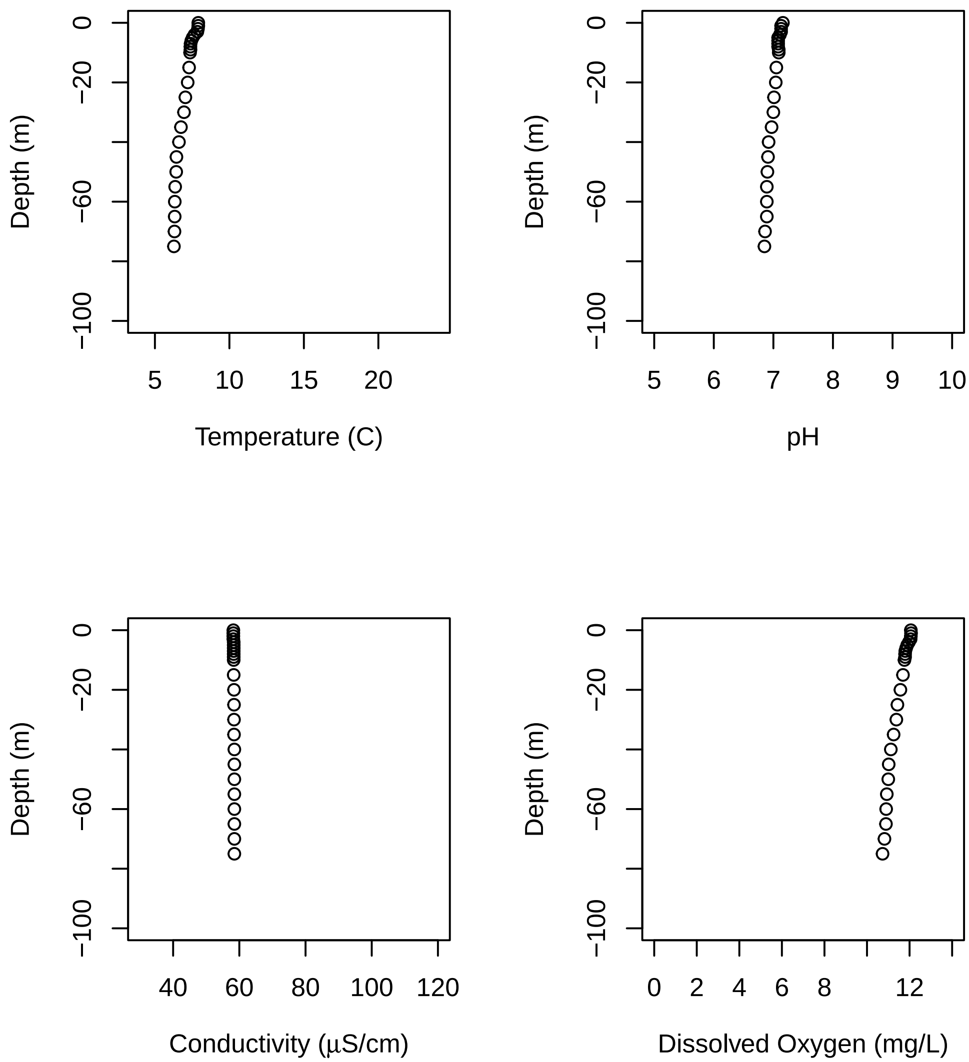


Figure B24: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, April 25, 2023.

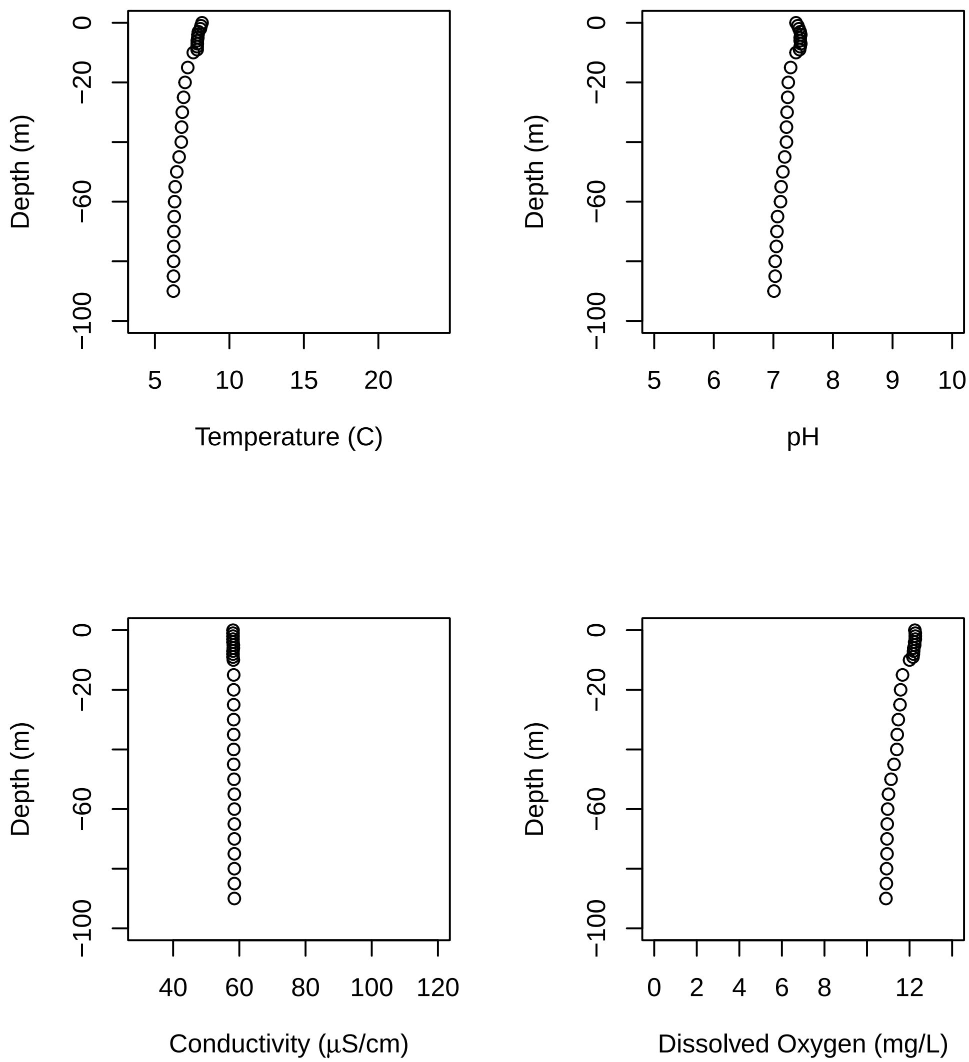


Figure B25: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, April 25, 2023.

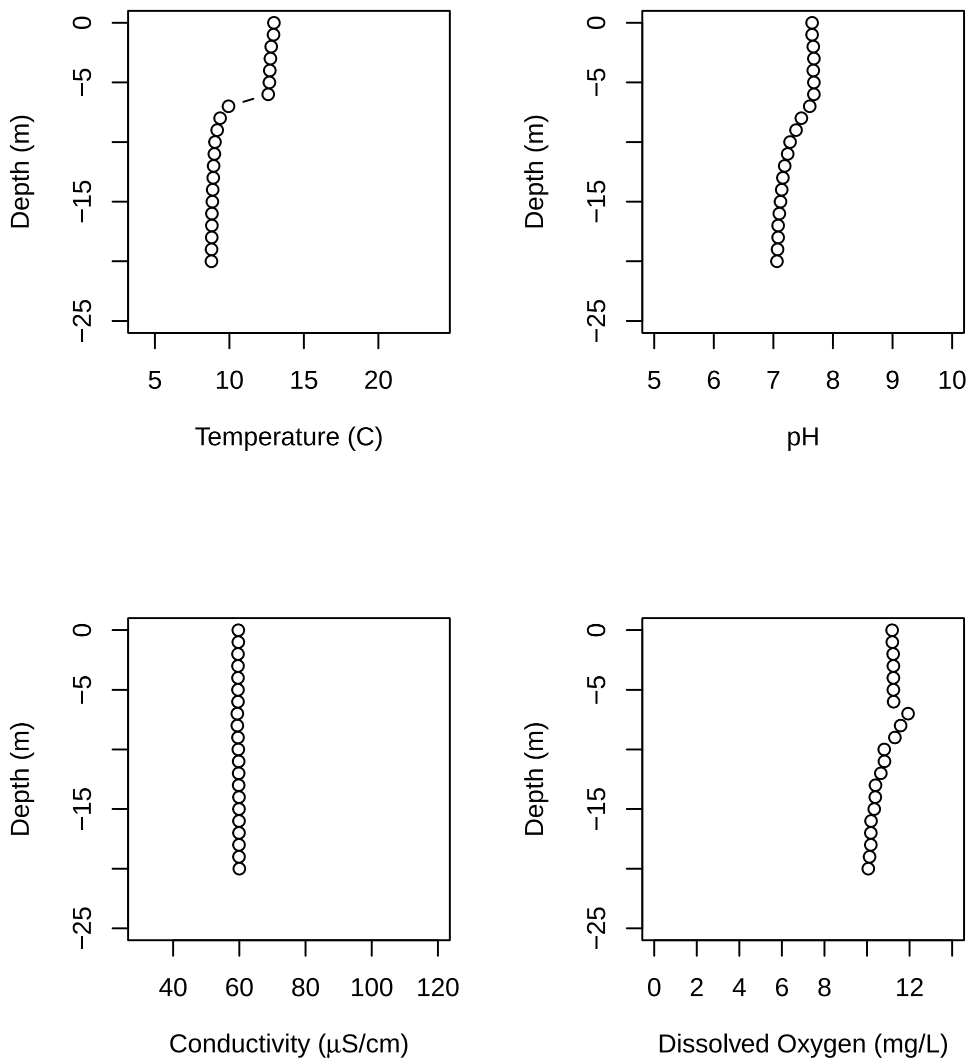


Figure B26: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, May 9, 2023.

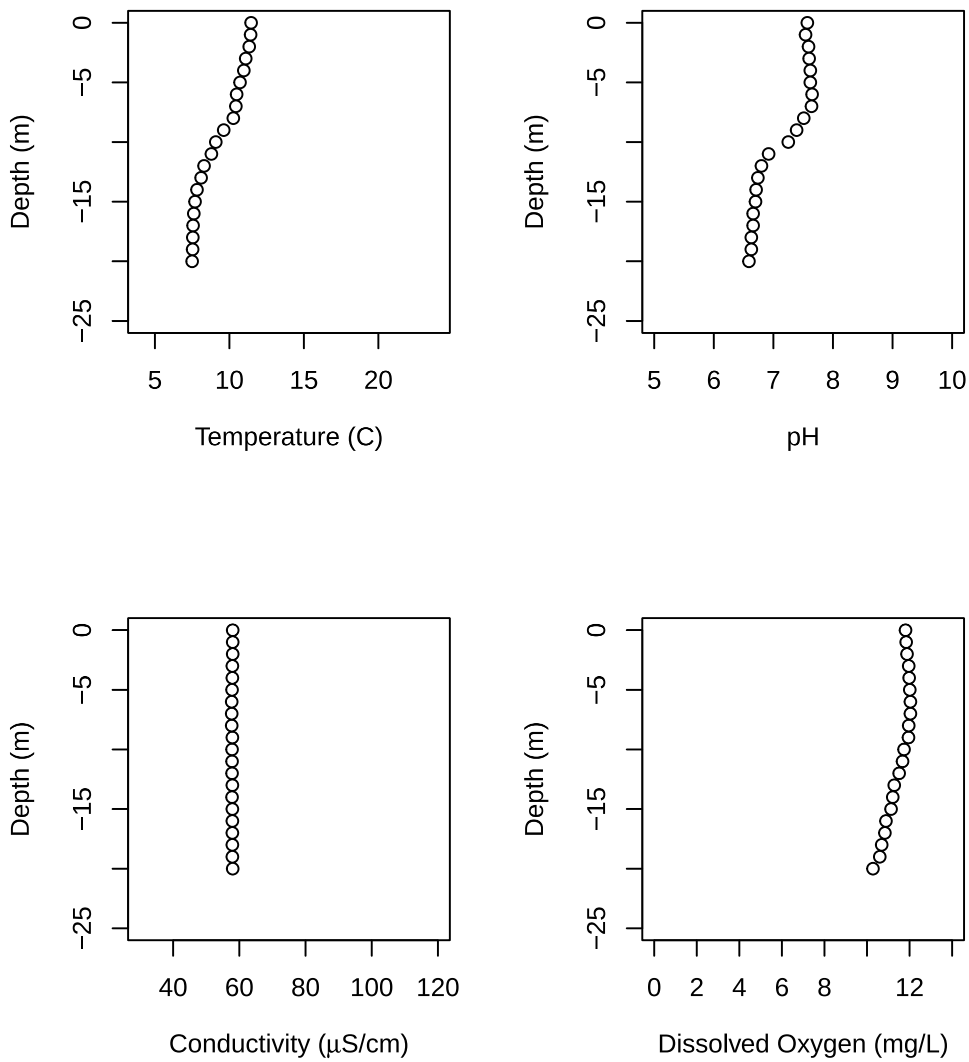


Figure B27: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, May 9, 2023.

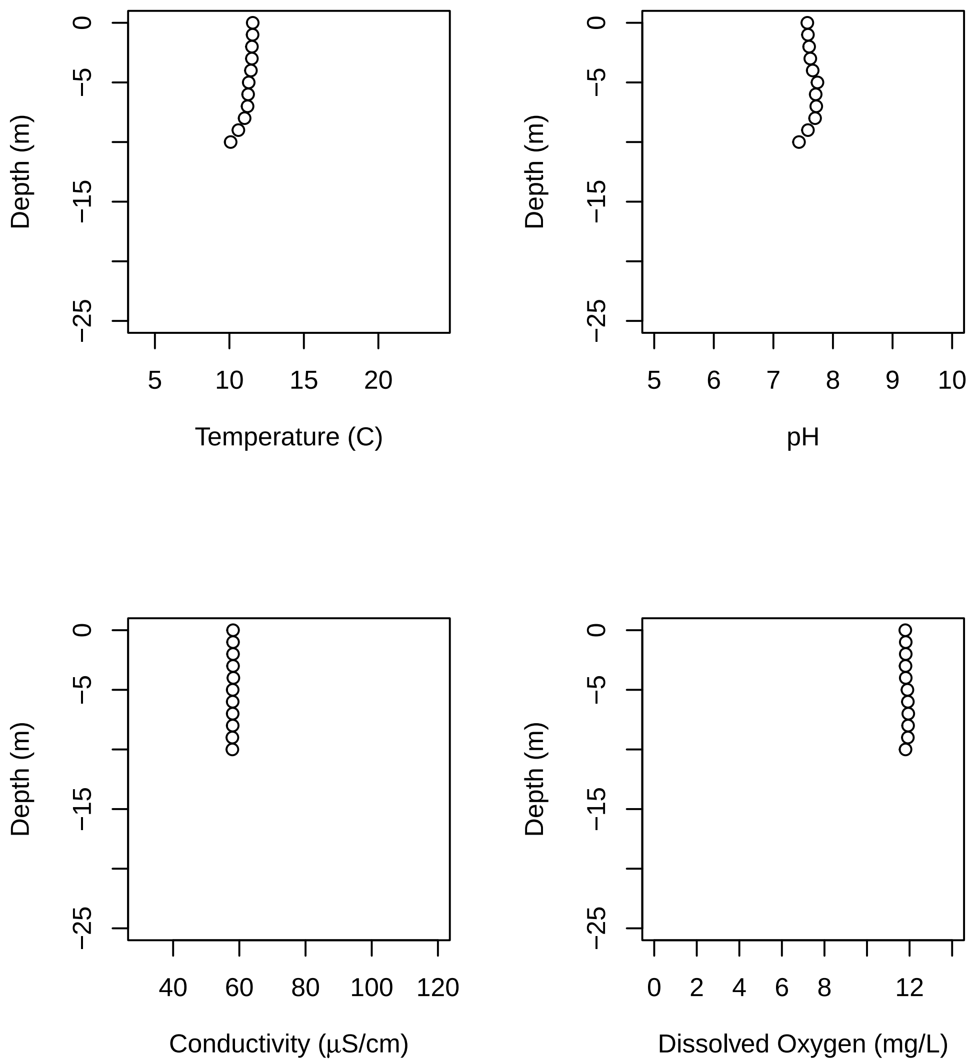


Figure B28: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, May 9, 2023.

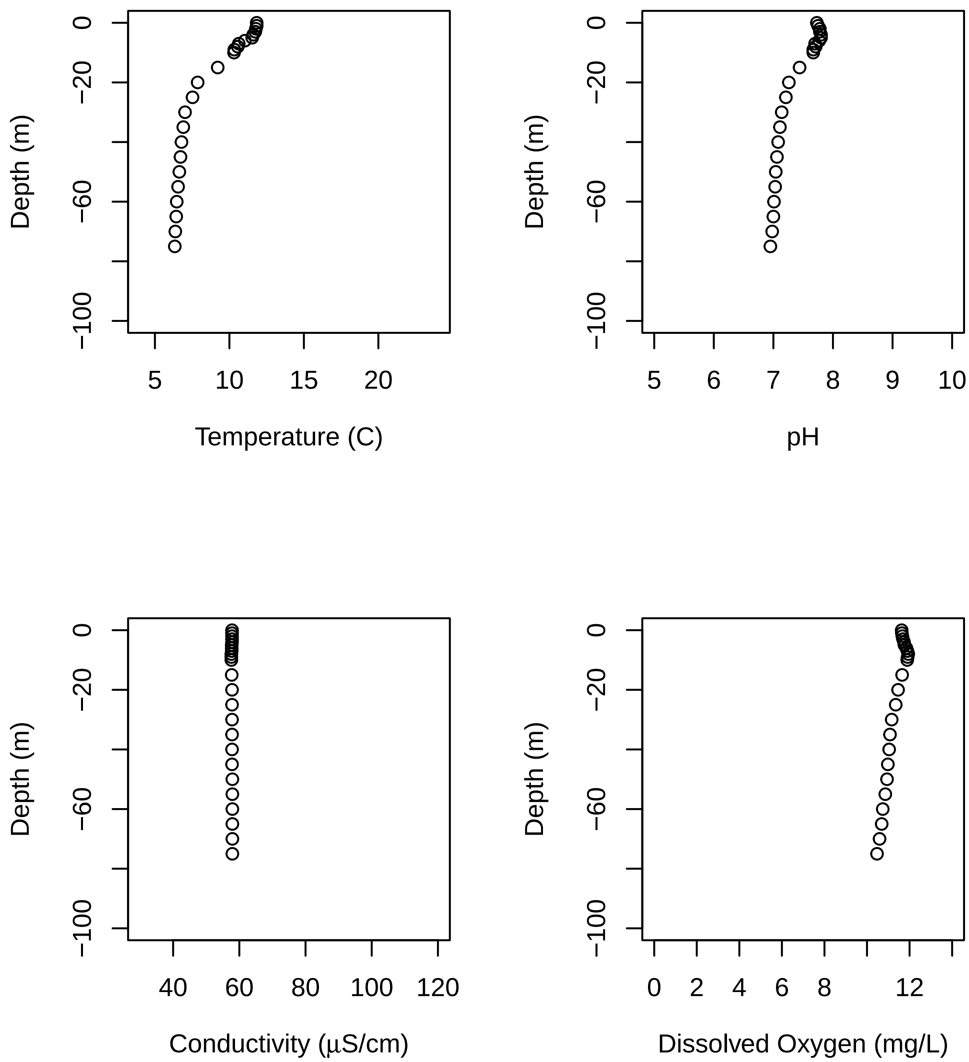


Figure B29: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, May 1, 2023.

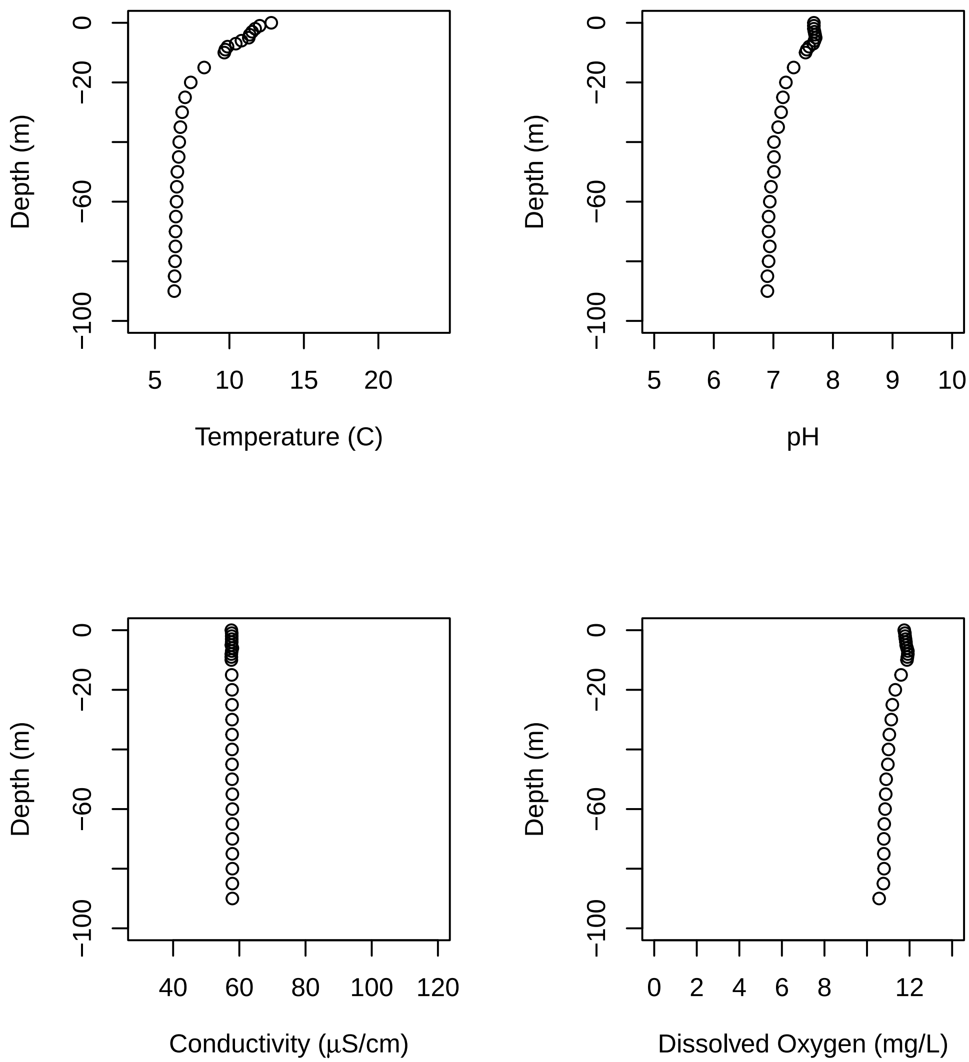


Figure B30: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, May 11, 2023.

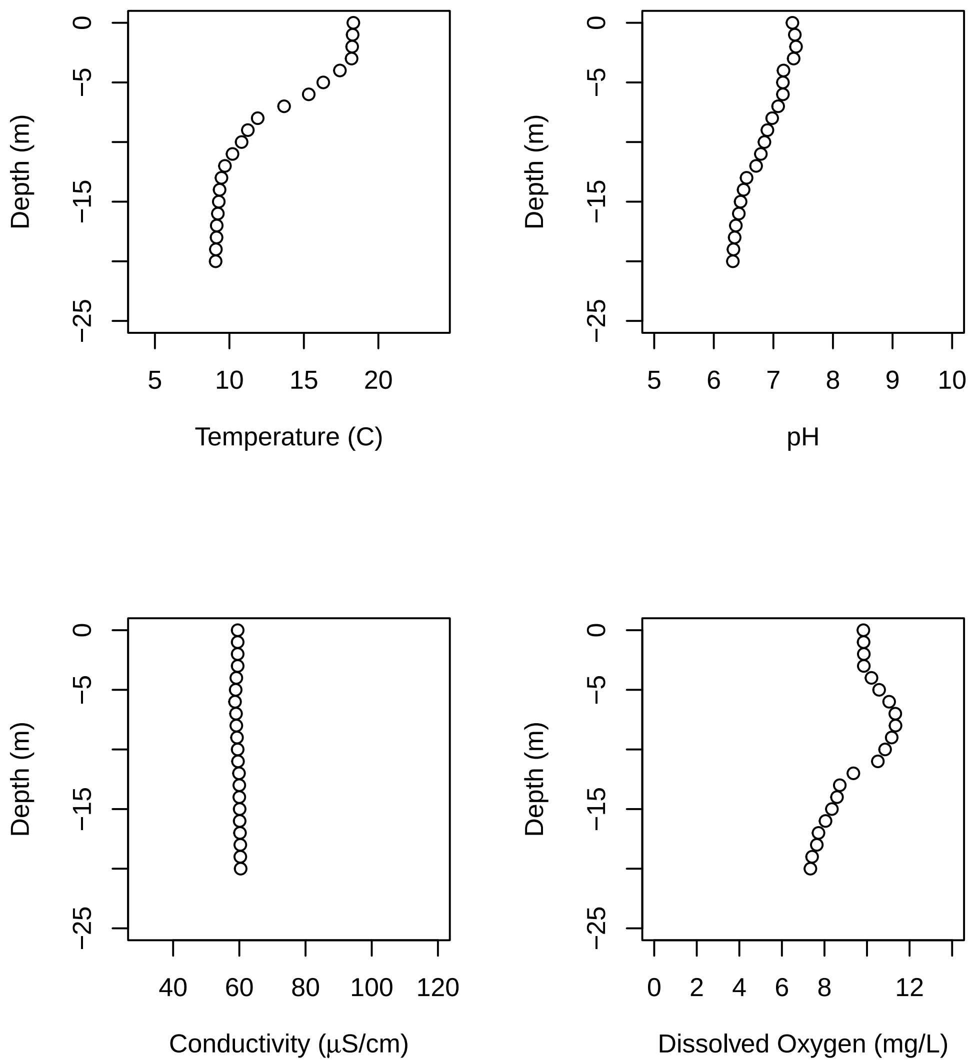


Figure B31: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, June 6, 2023.

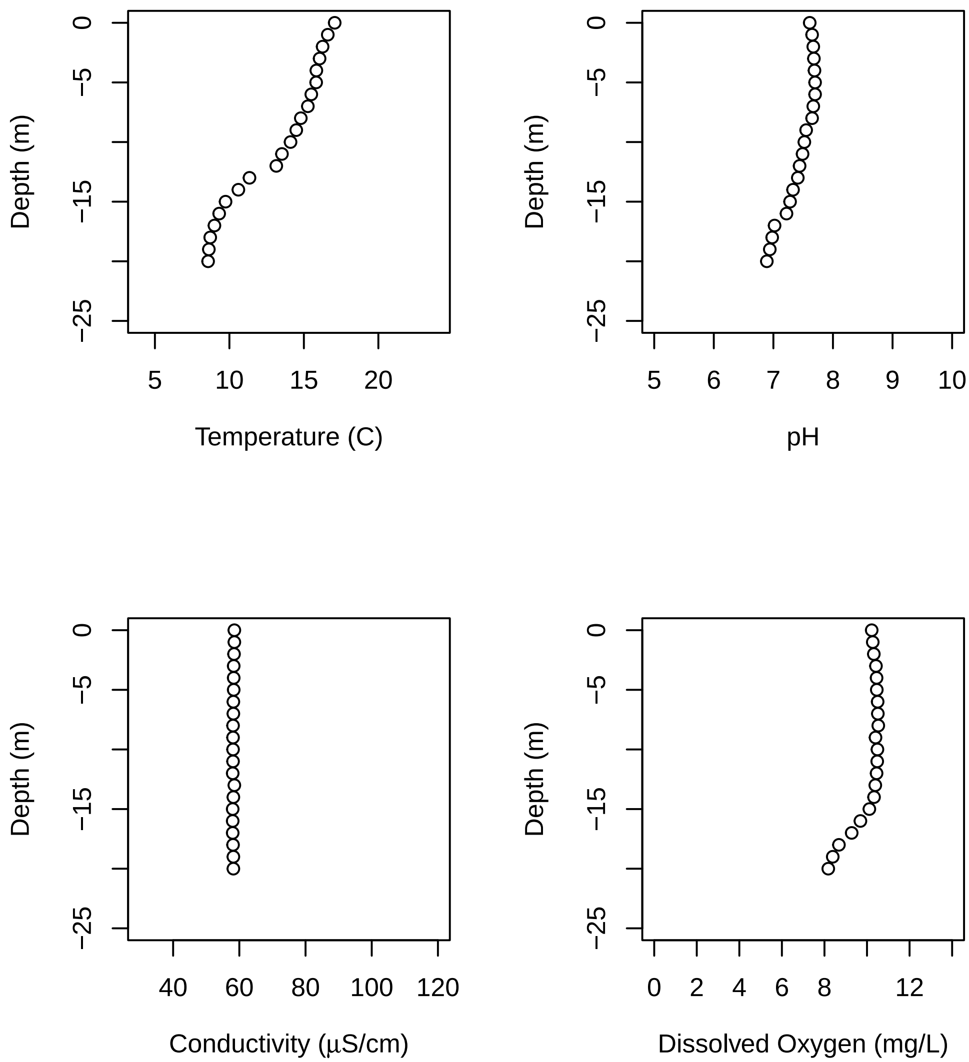


Figure B32: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, June 6, 2023.

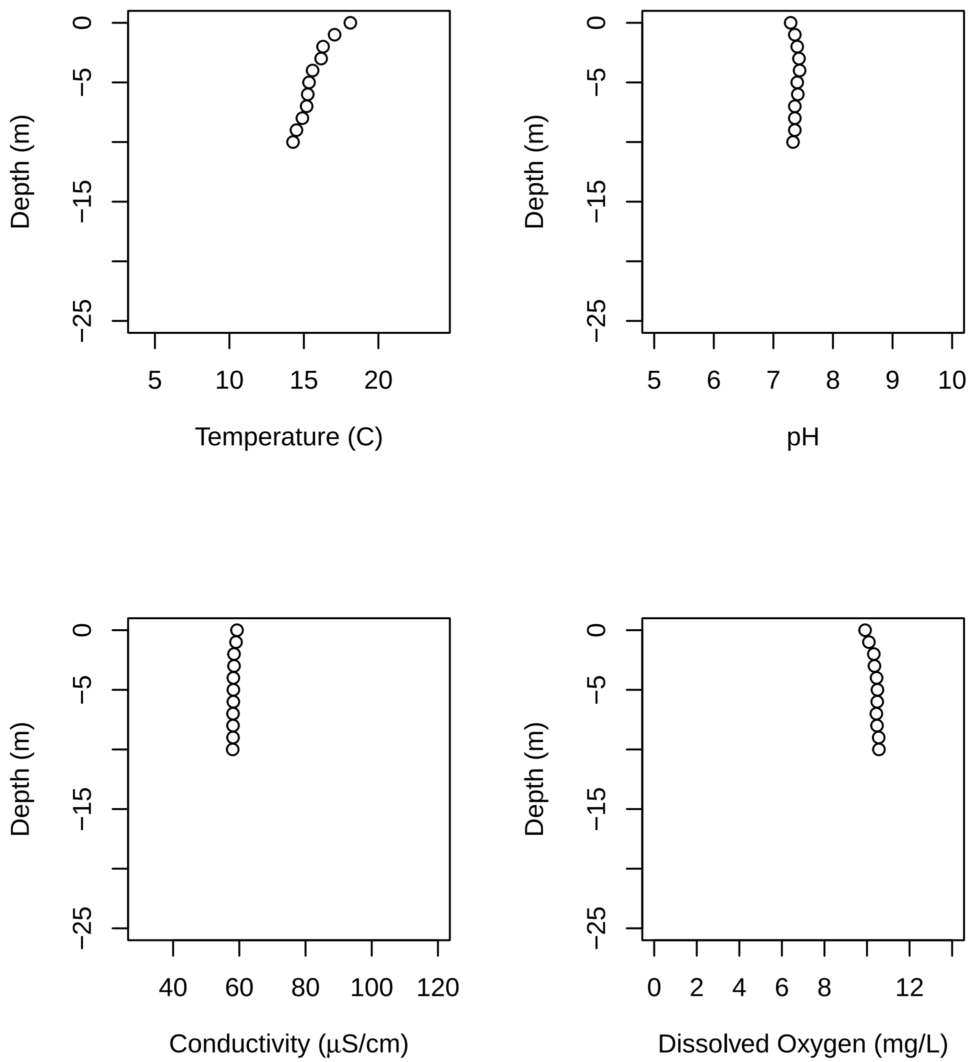


Figure B33: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, June 6, 2023.

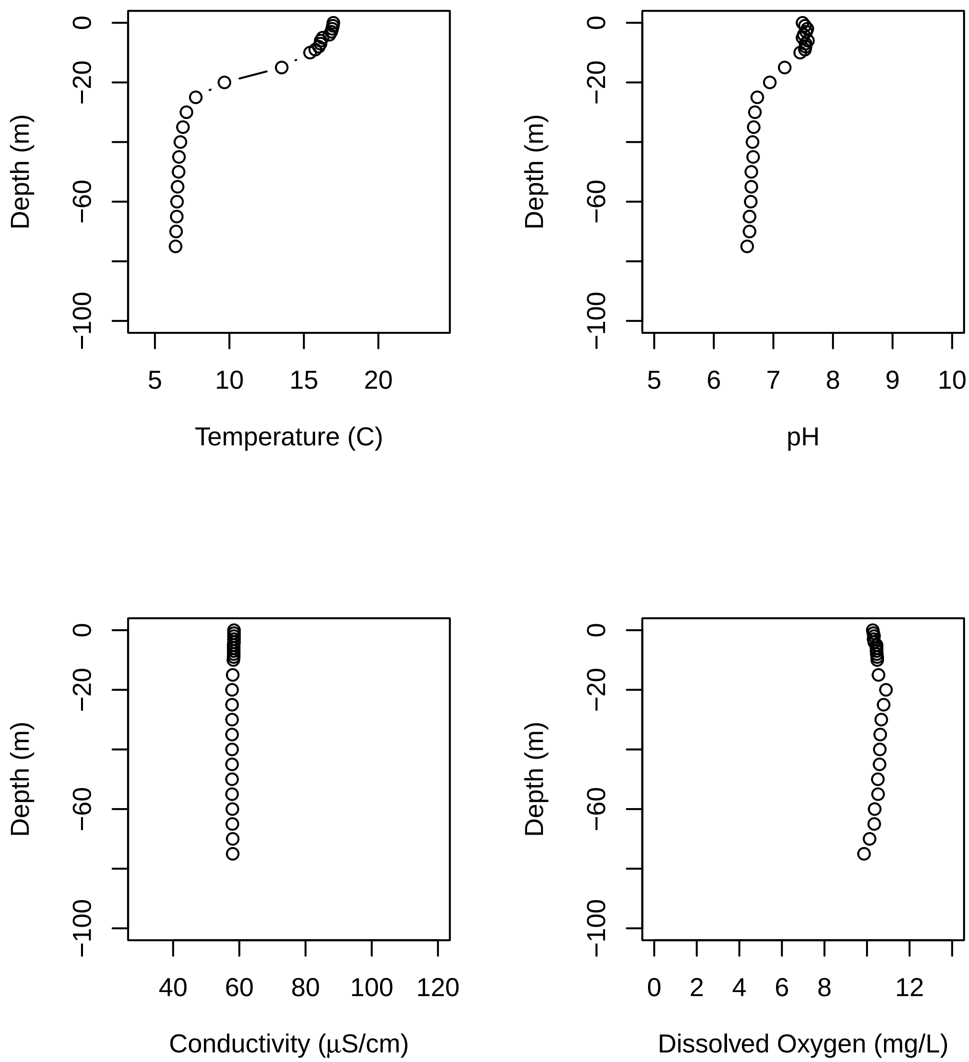


Figure B34: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, June 8, 2023.

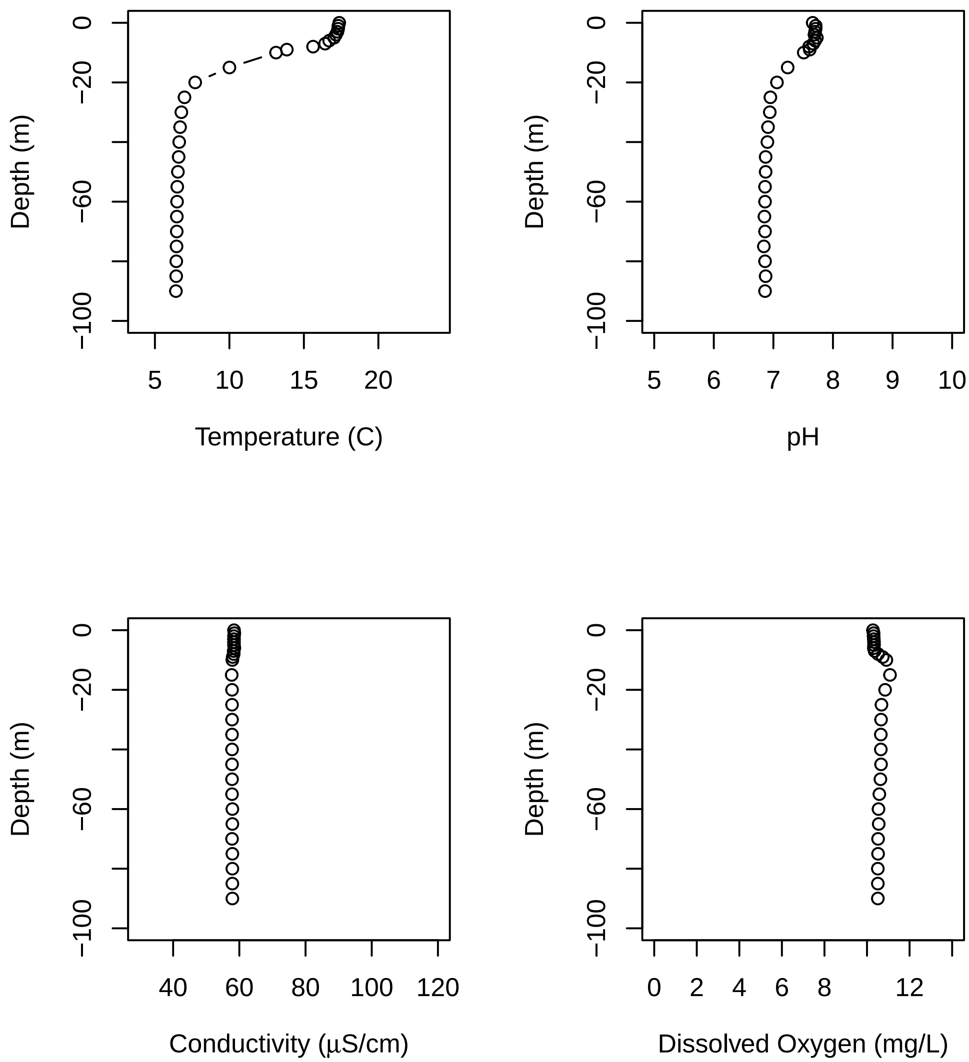


Figure B35: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, June 8, 2023.

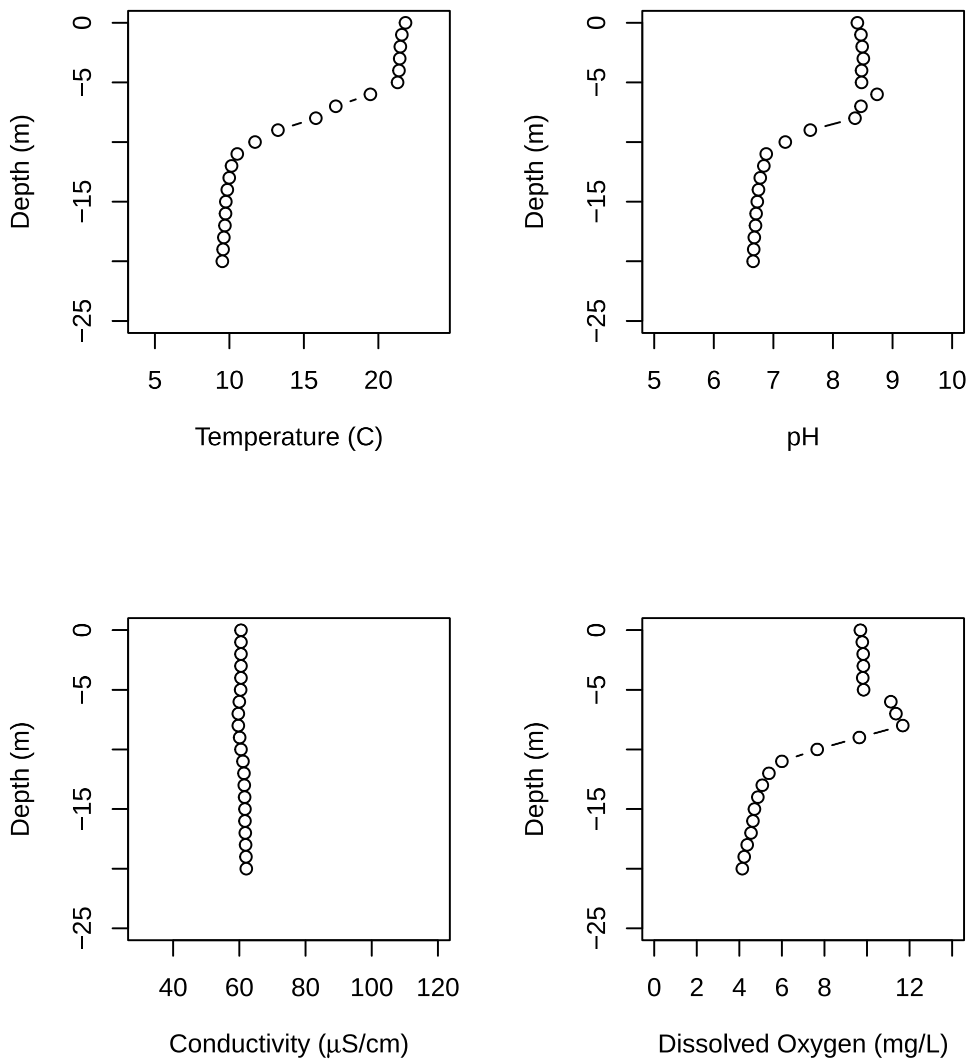


Figure B36: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, July 13, 2023.

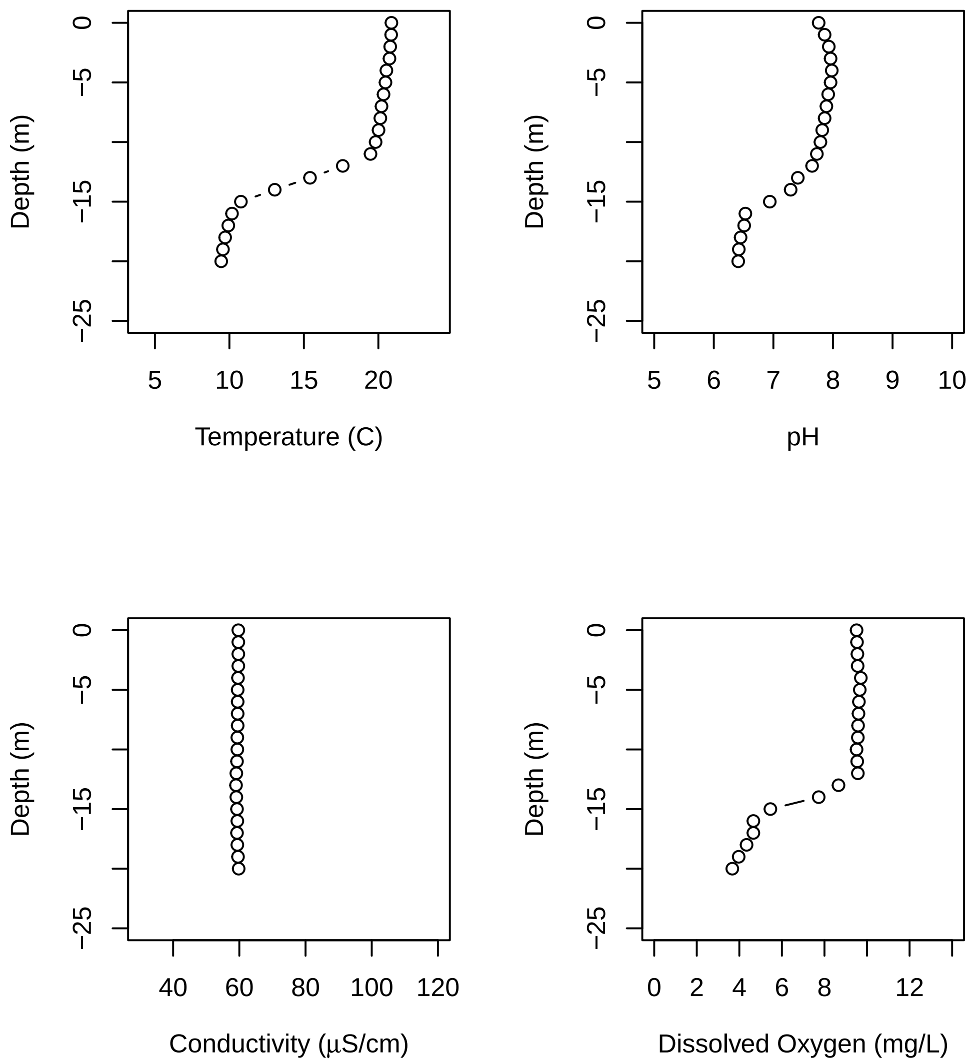


Figure B37: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, July 13, 2023.

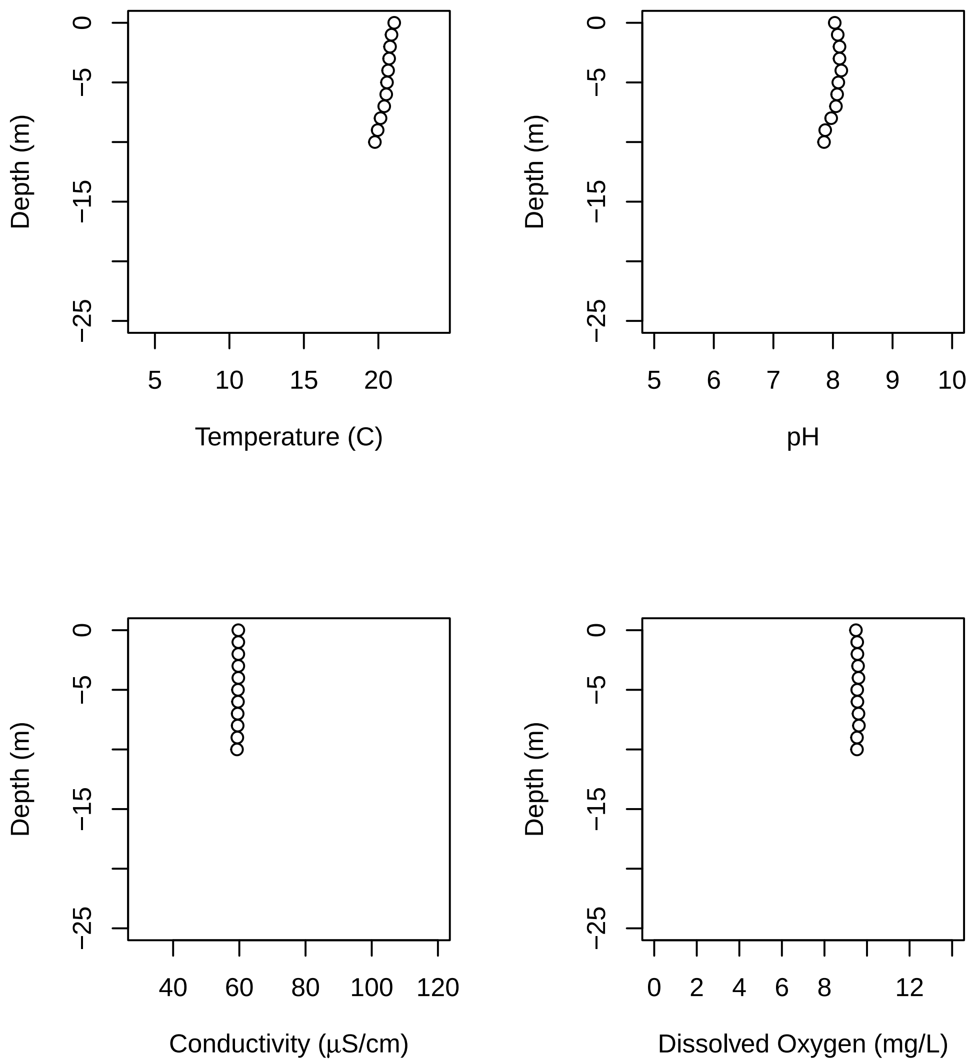


Figure B38: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, July 13, 2023.

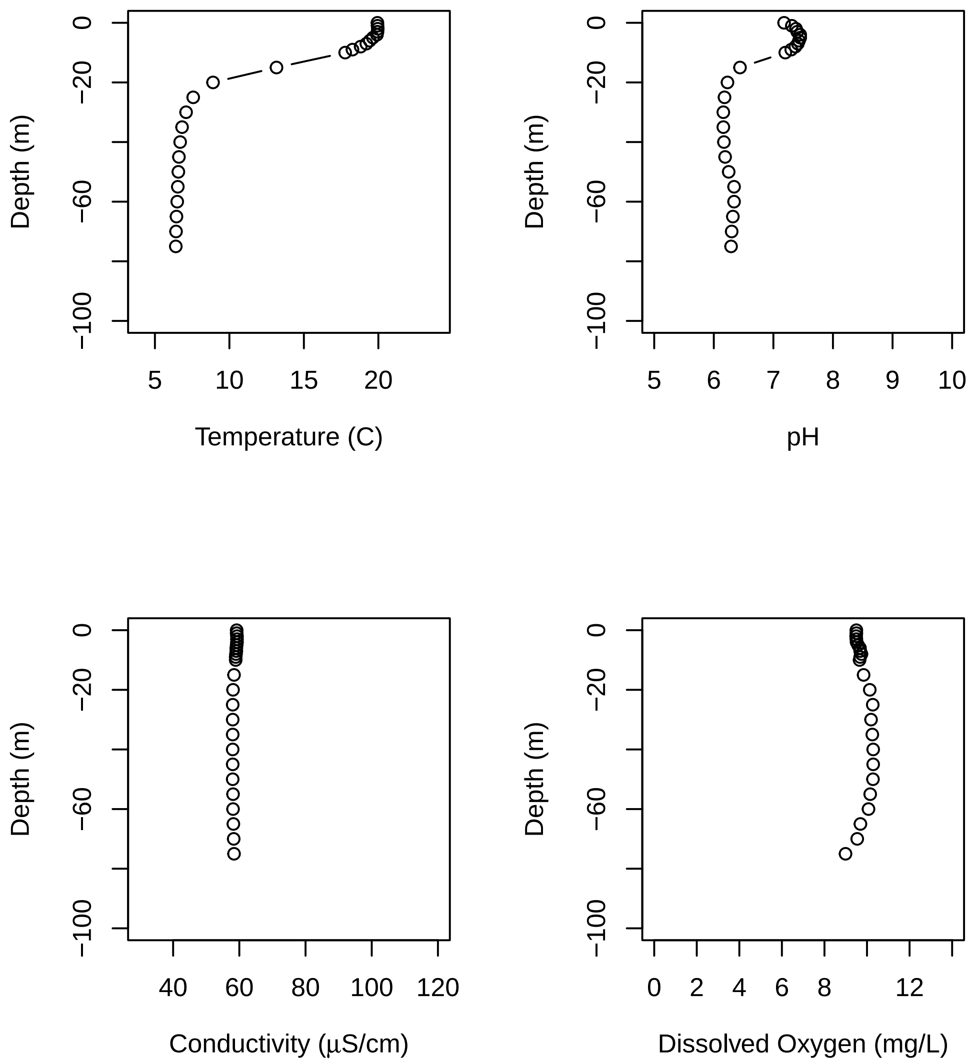


Figure B39: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, July 11, 2023.

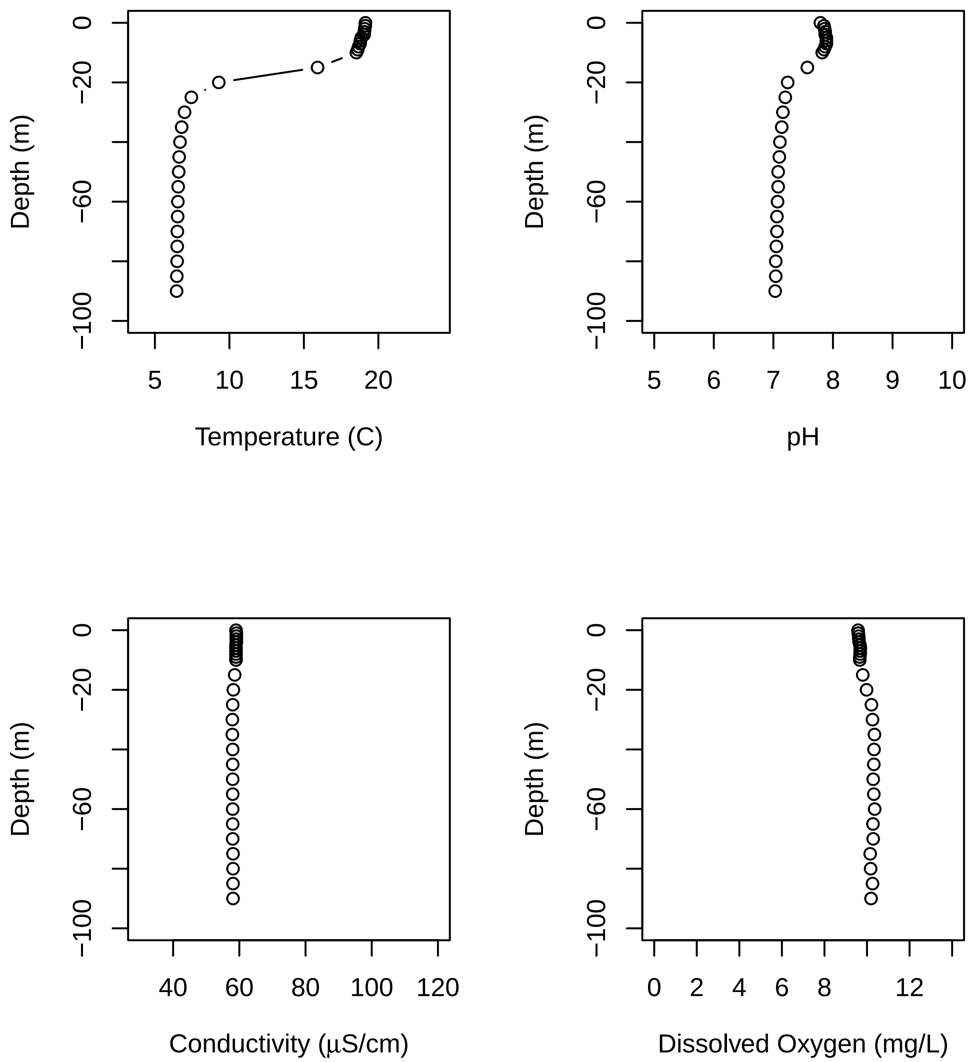


Figure B40: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, July 11, 2023.

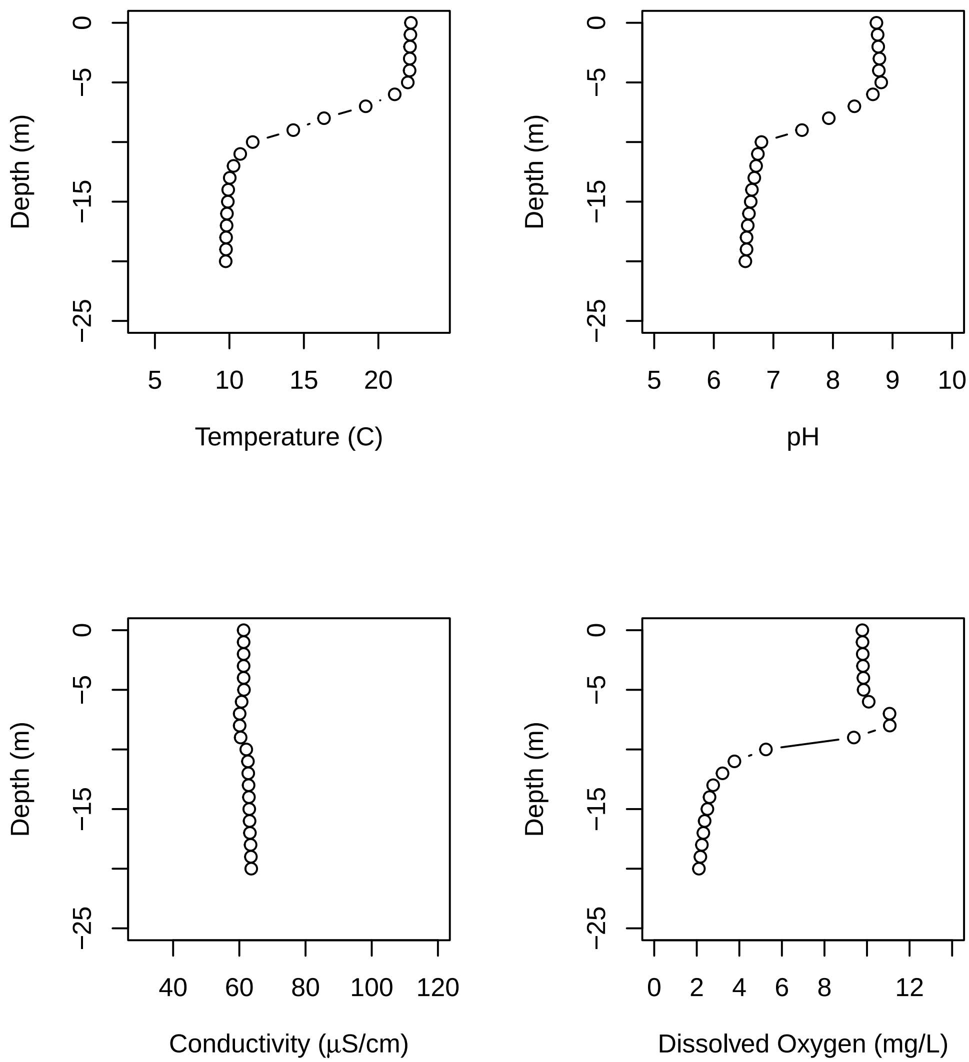


Figure B41: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, August 3, 2023.

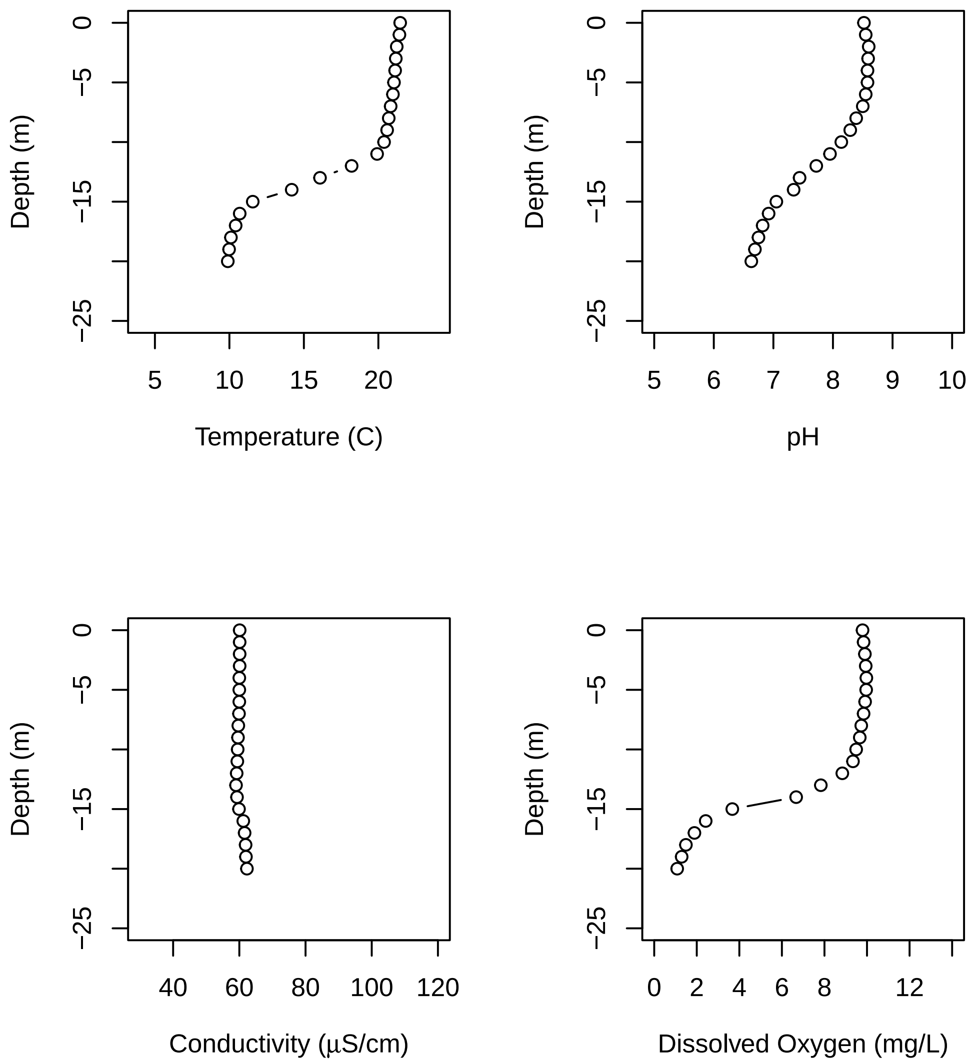


Figure B42: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, August 3, 2023.

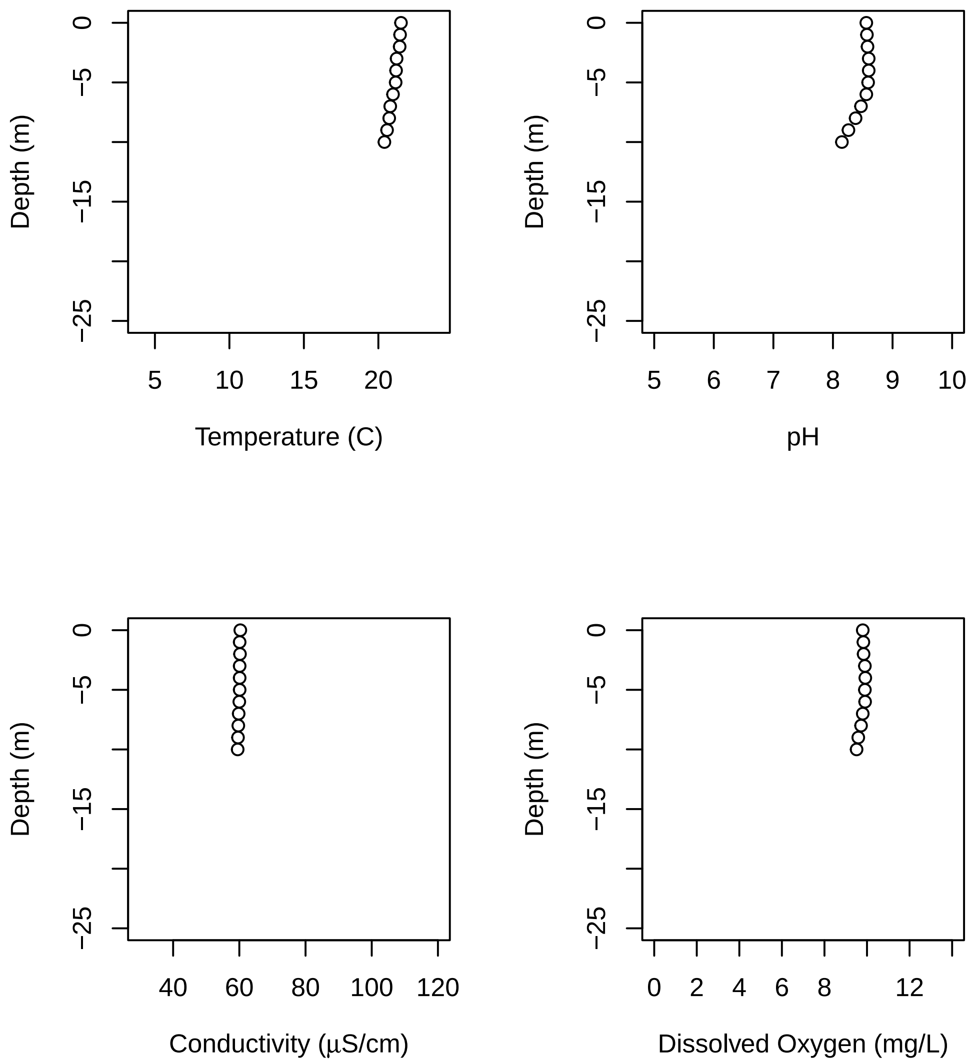


Figure B43: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, August 3, 2023.

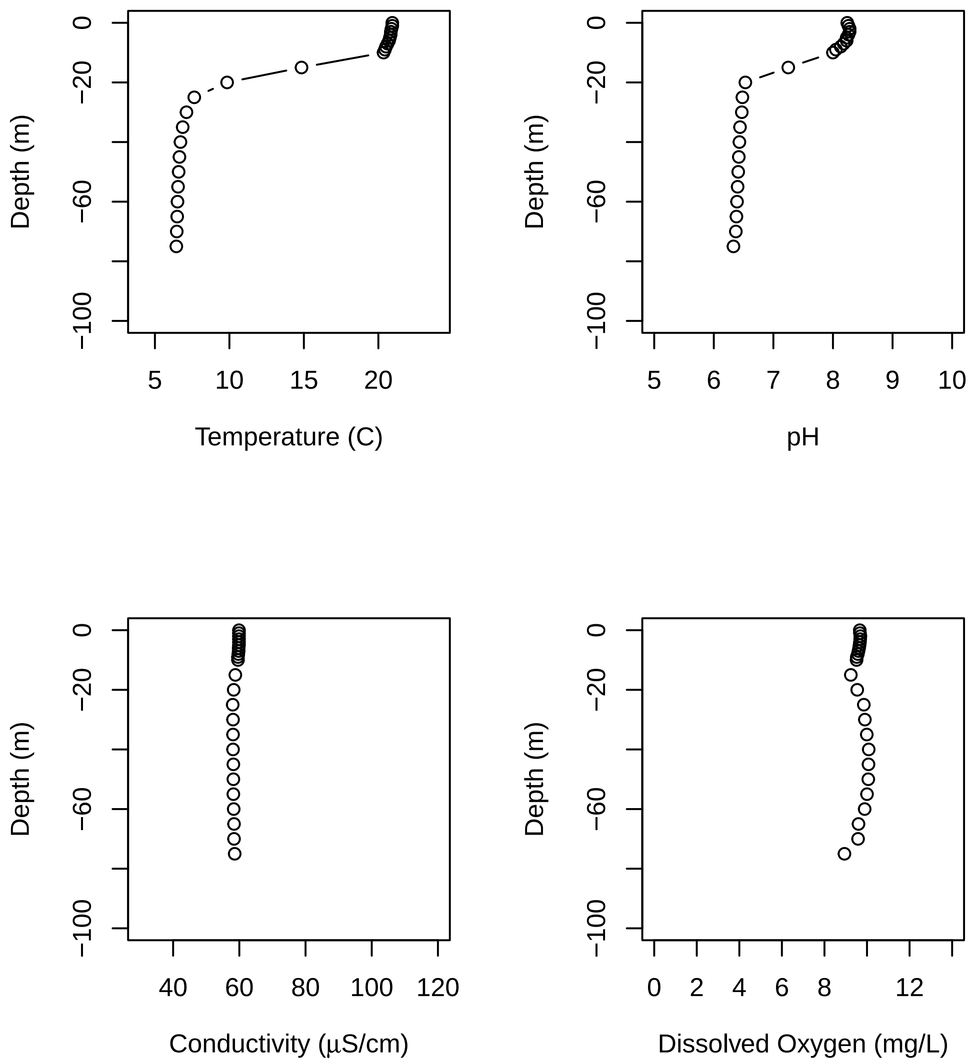


Figure B44: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, August 1, 2023.

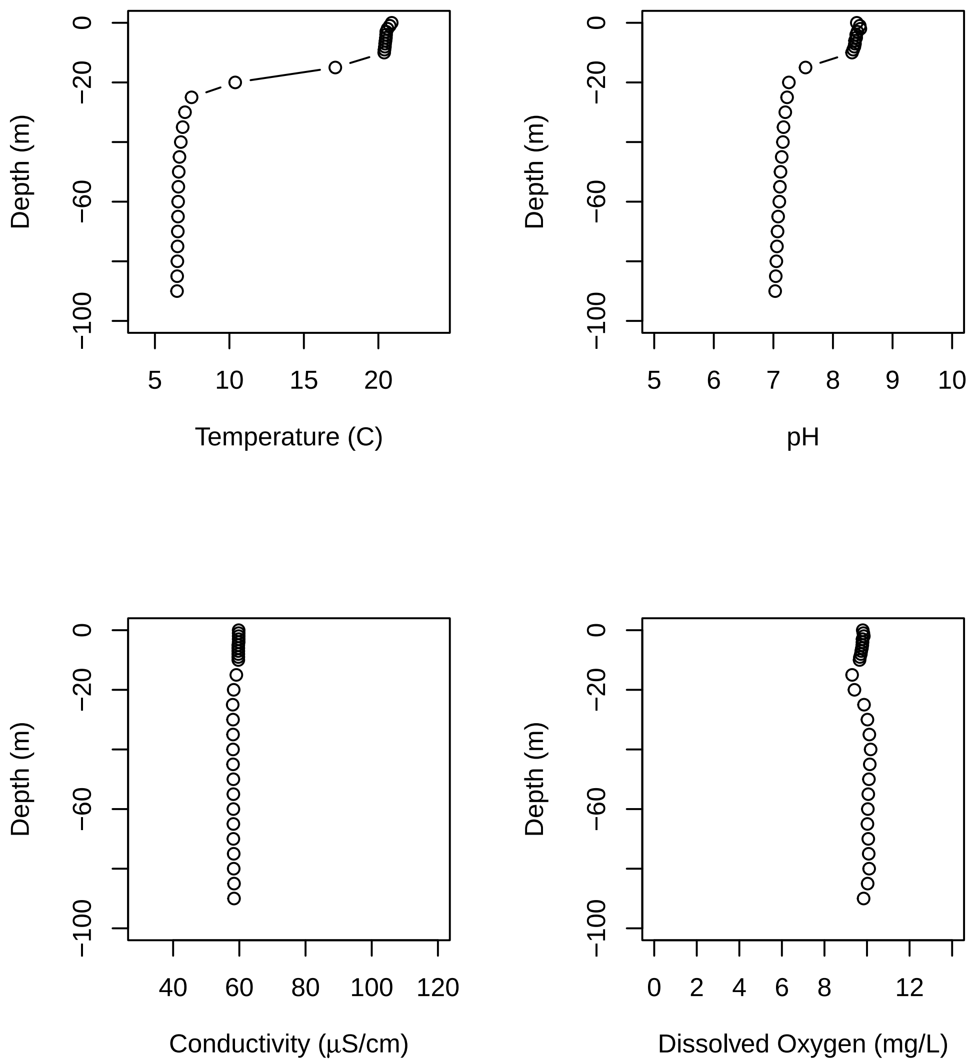


Figure B45: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, August 1, 2023.

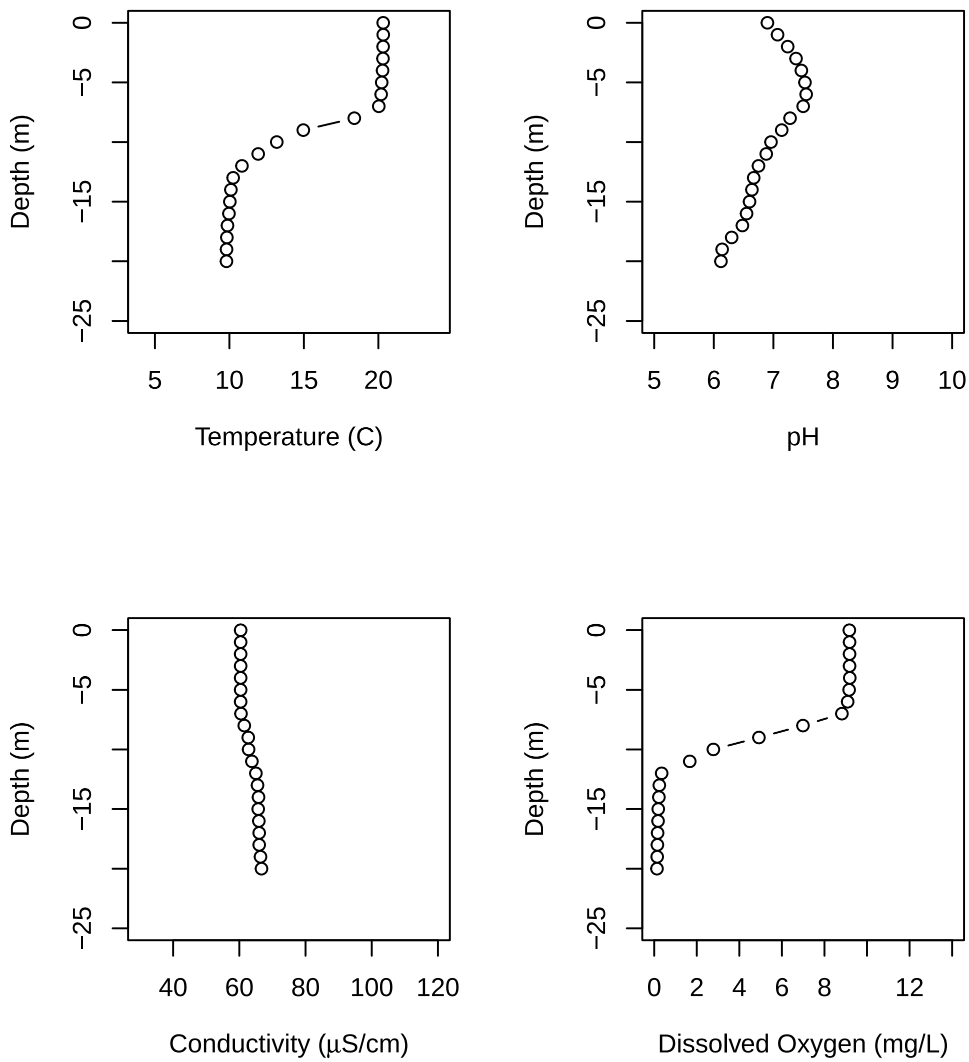


Figure B46: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, September 7, 2023.

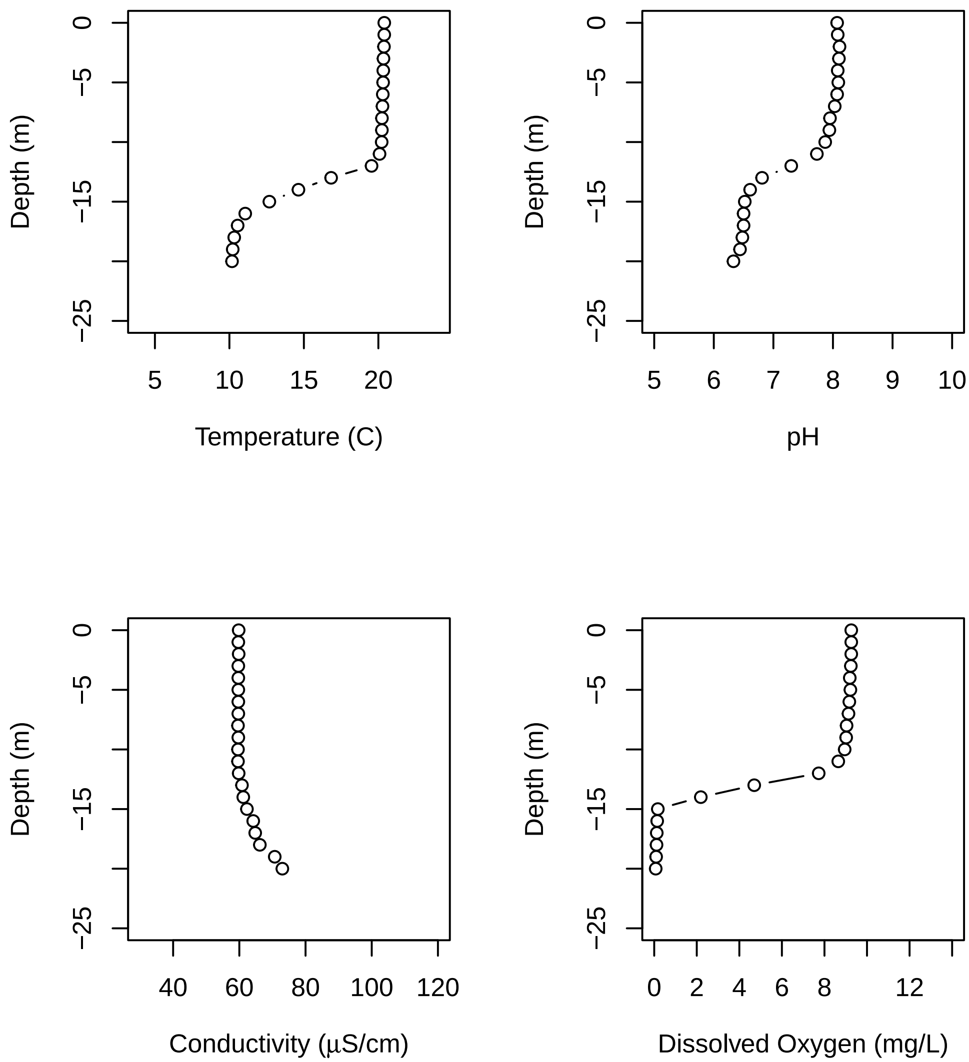


Figure B47: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, September 7, 2023.

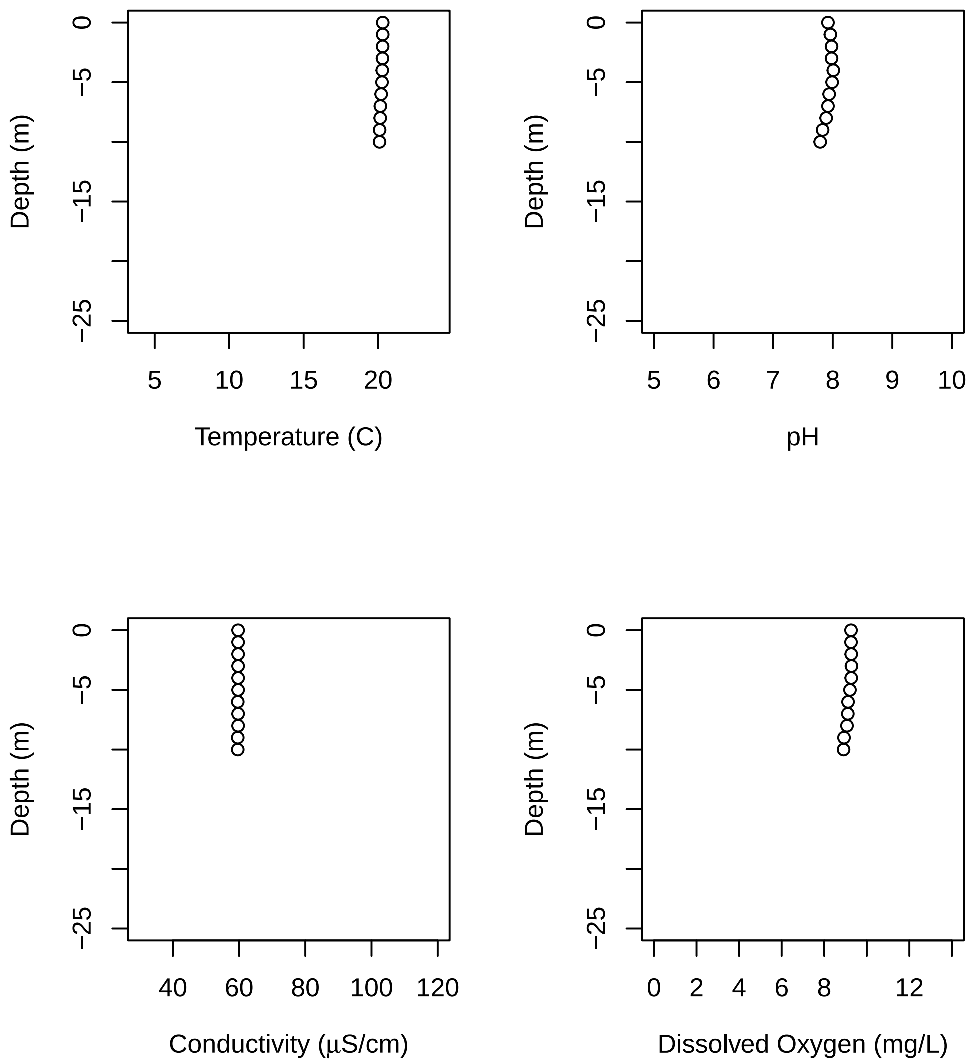


Figure B48: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, September 7, 2023.

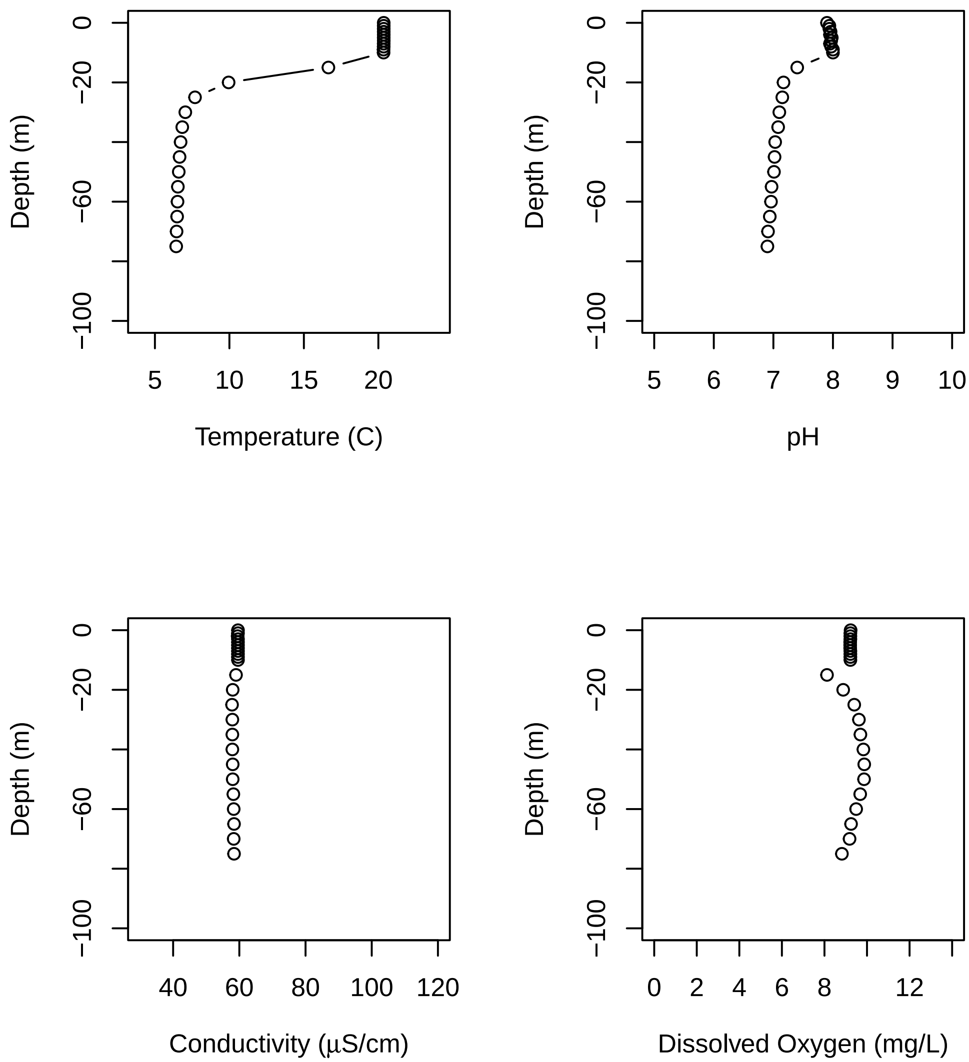


Figure B49: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, September 5, 2023.

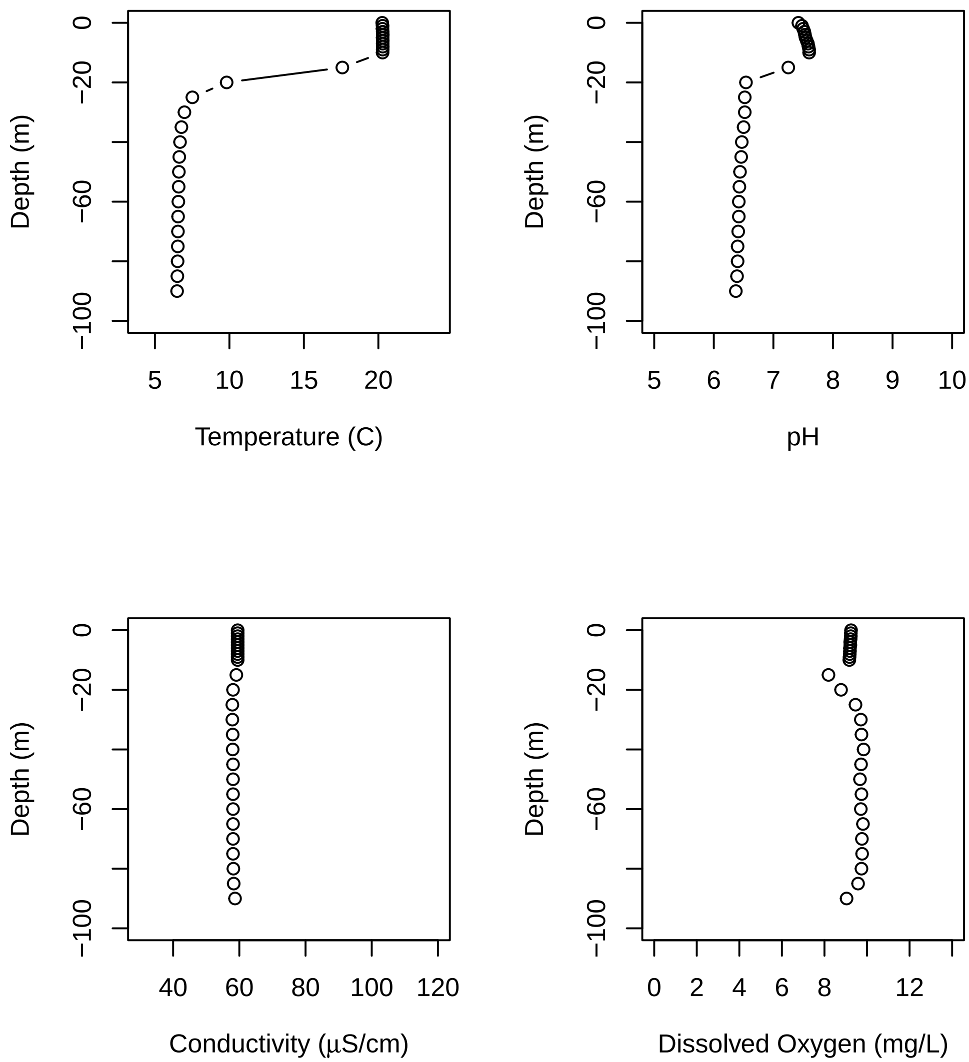


Figure B50: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, September 5, 2023.

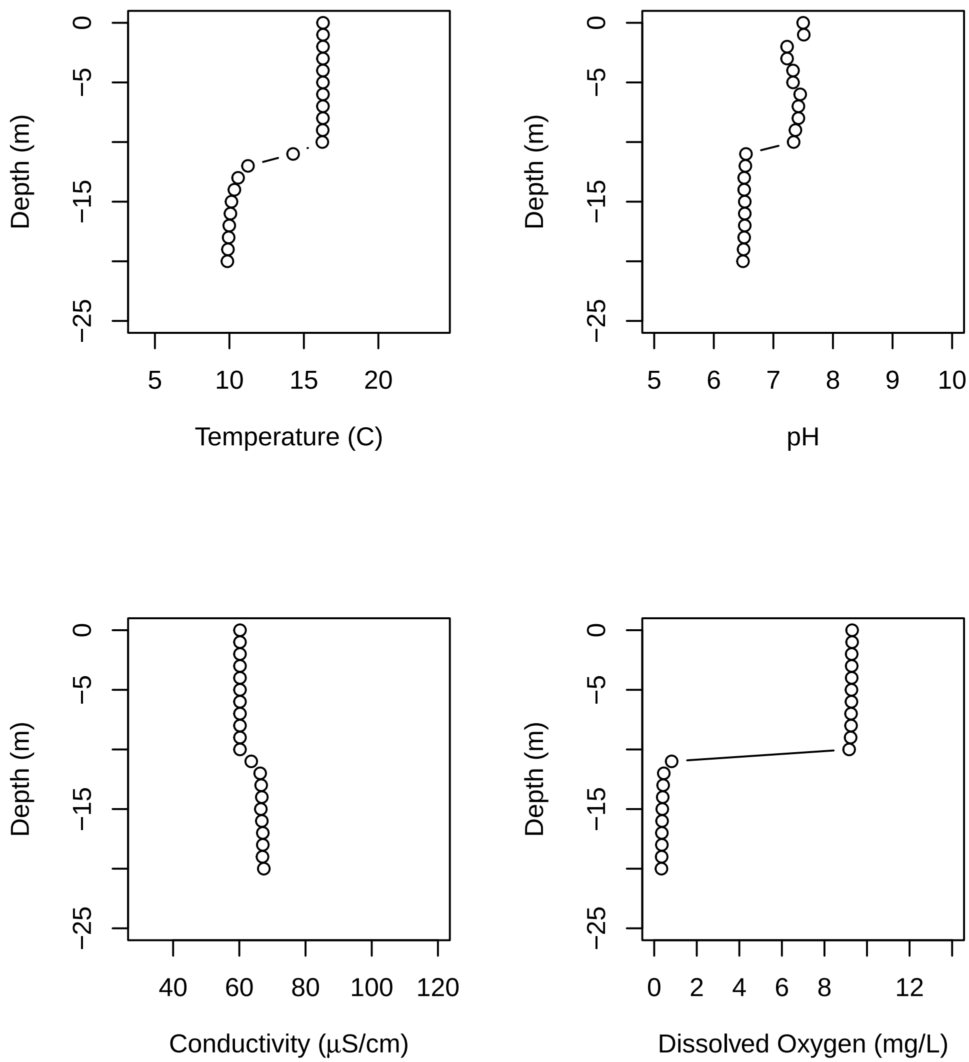


Figure B51: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, October 4, 2023.

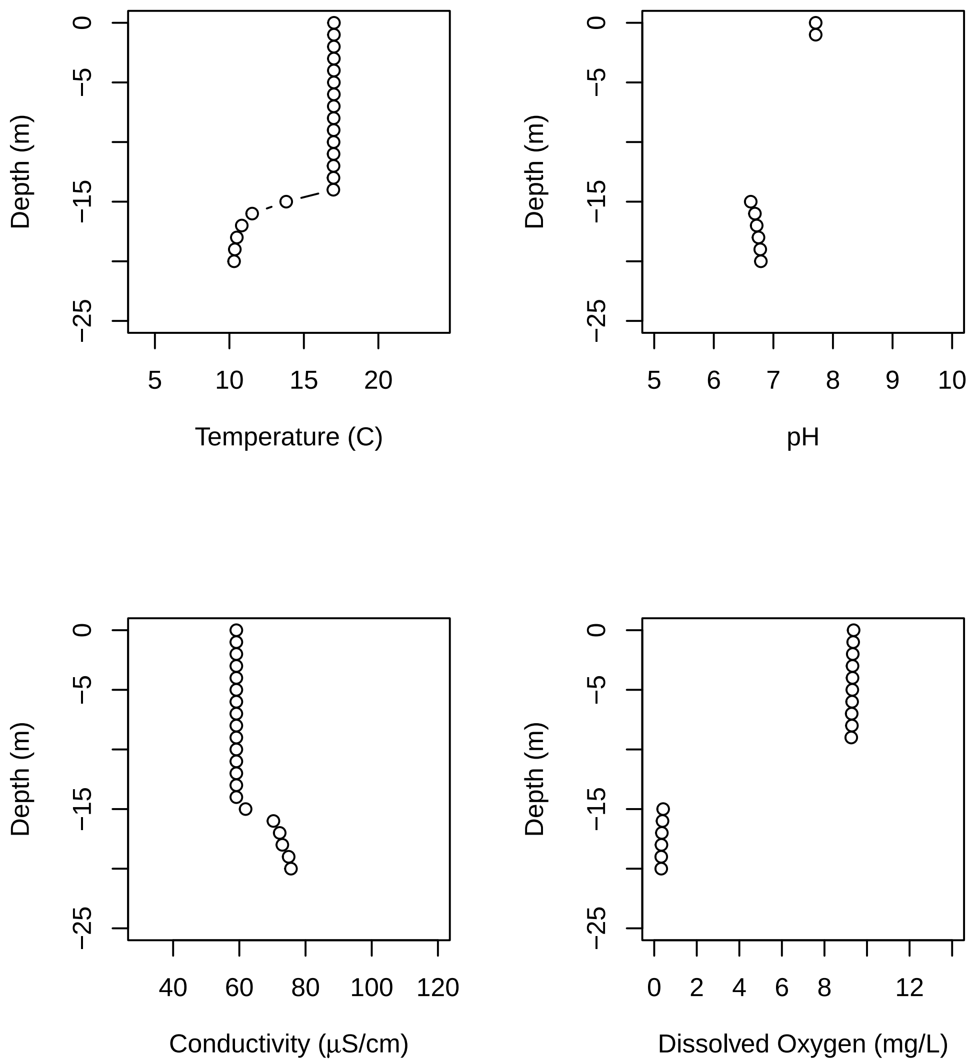


Figure B52: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, October 4, 2023.

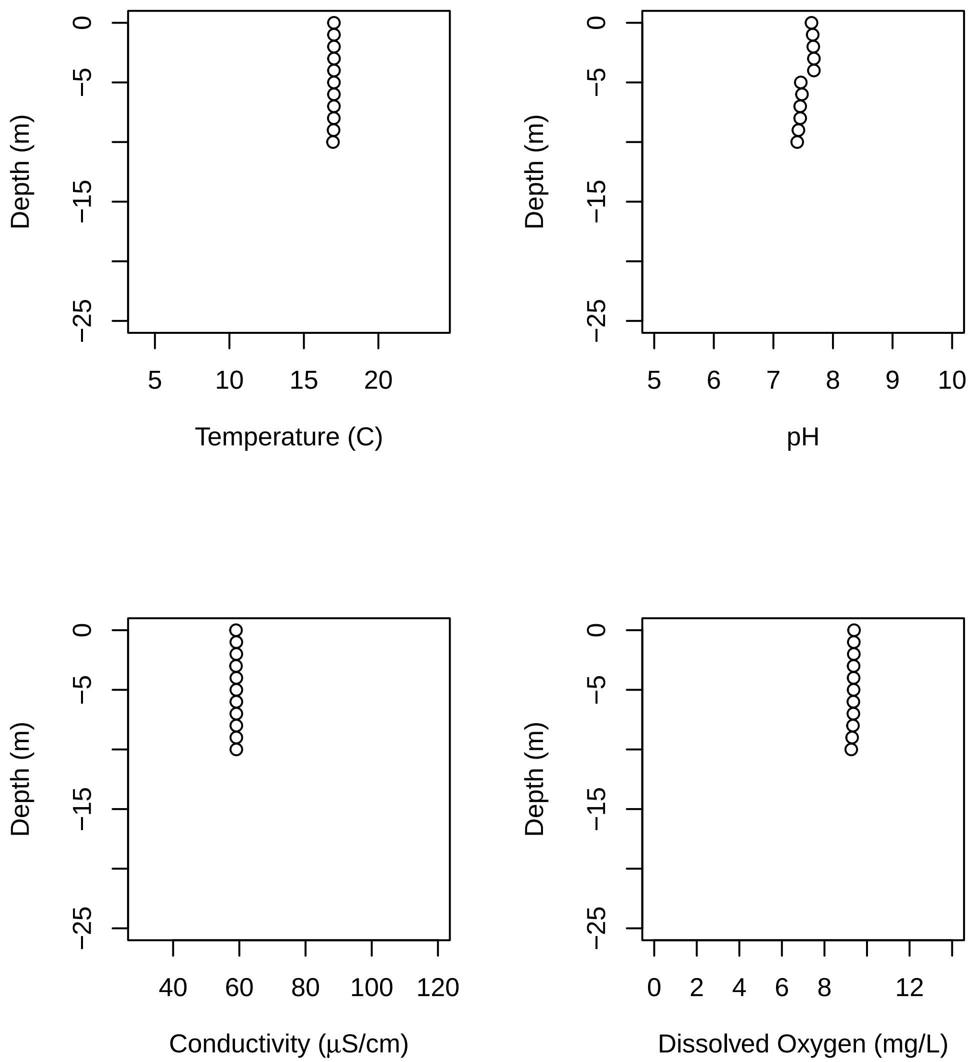


Figure B53: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, October 4, 2023.

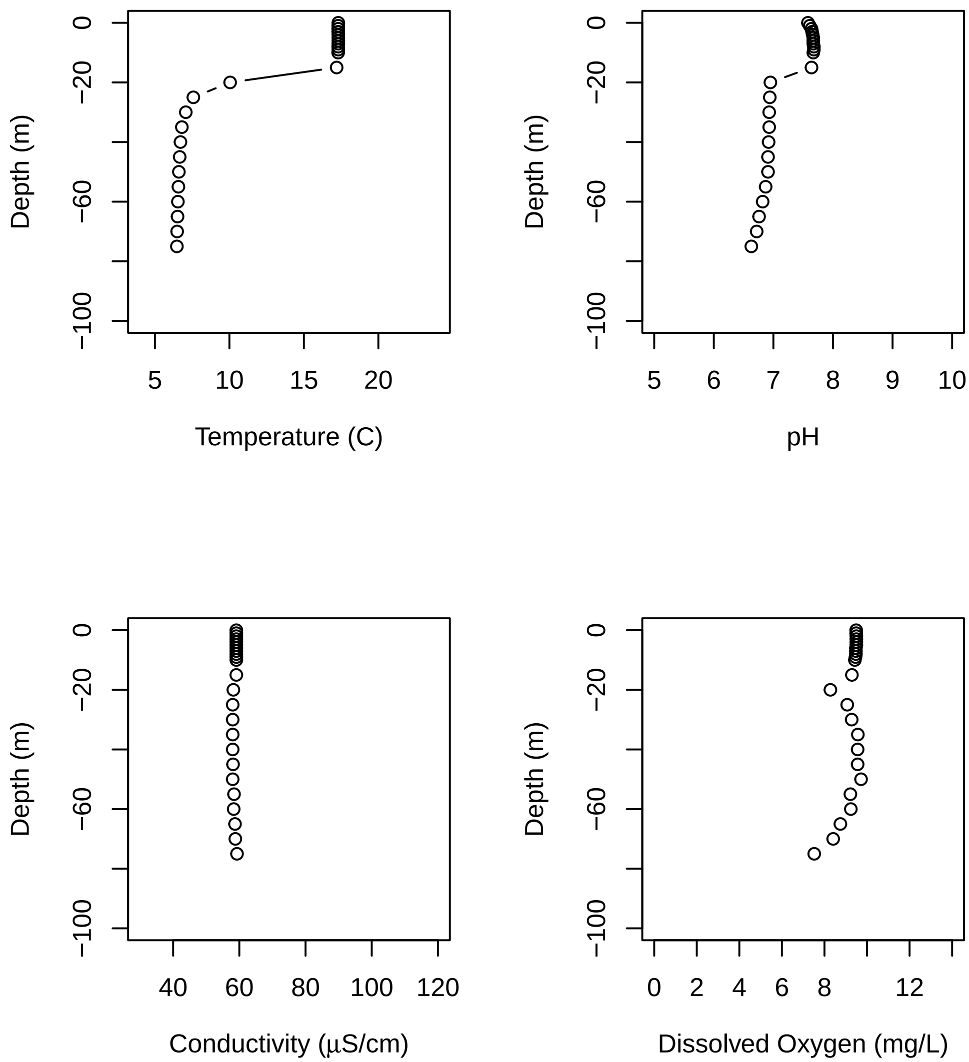


Figure B54: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, October 2, 2023.

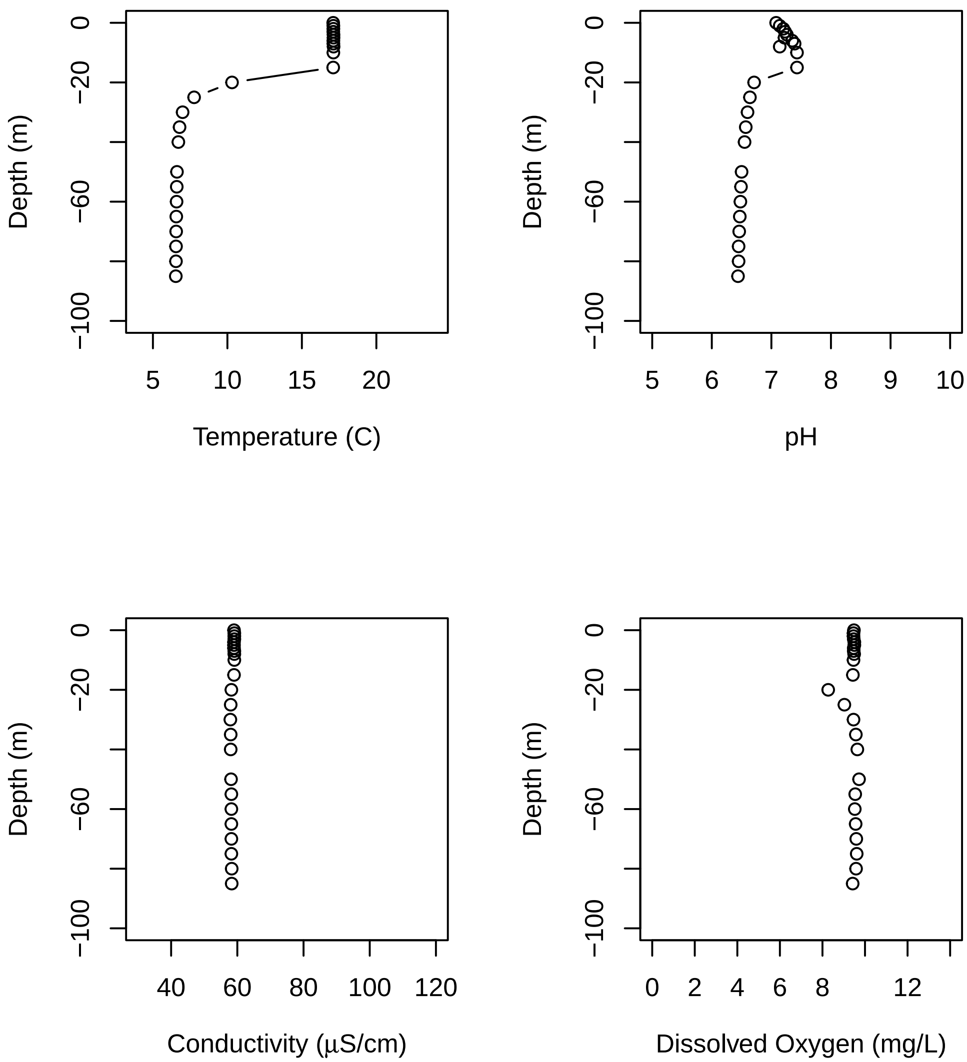


Figure B55: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, October 2, 2023.

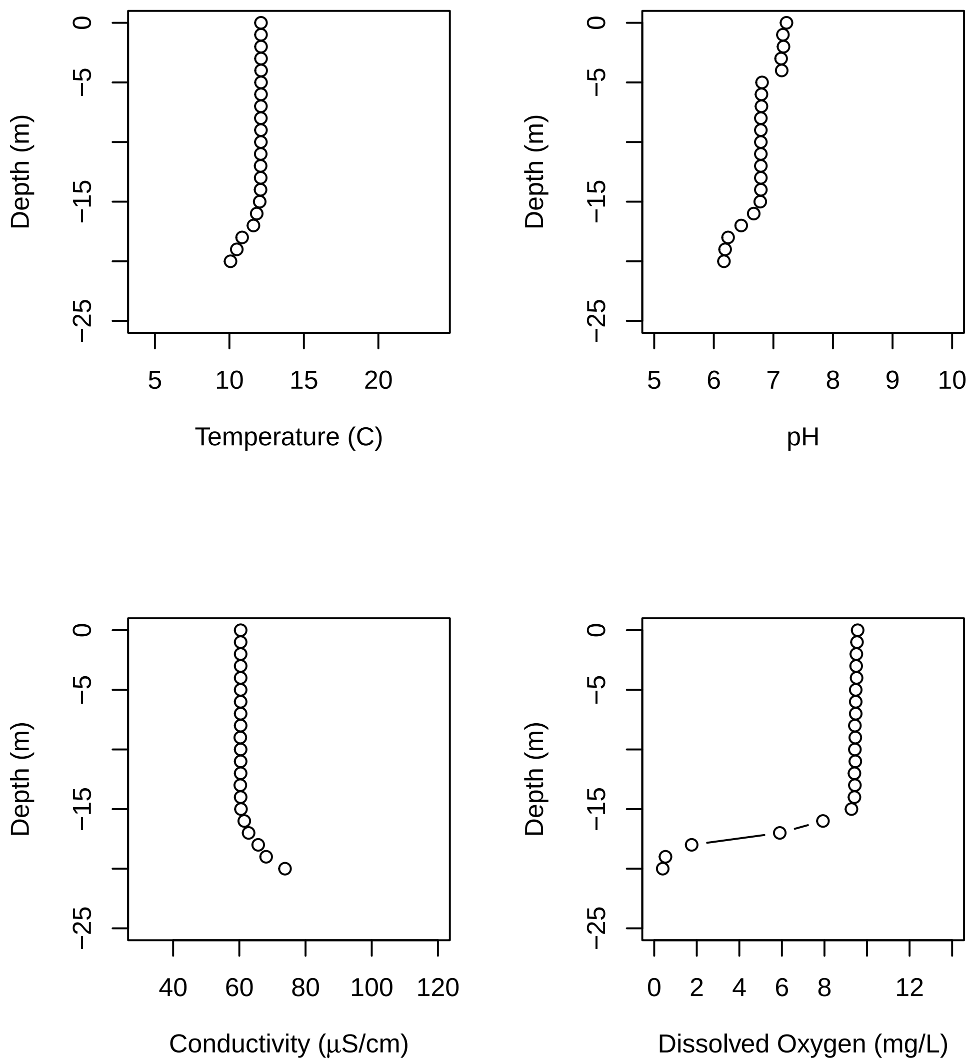


Figure B56: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, November 8, 2023.

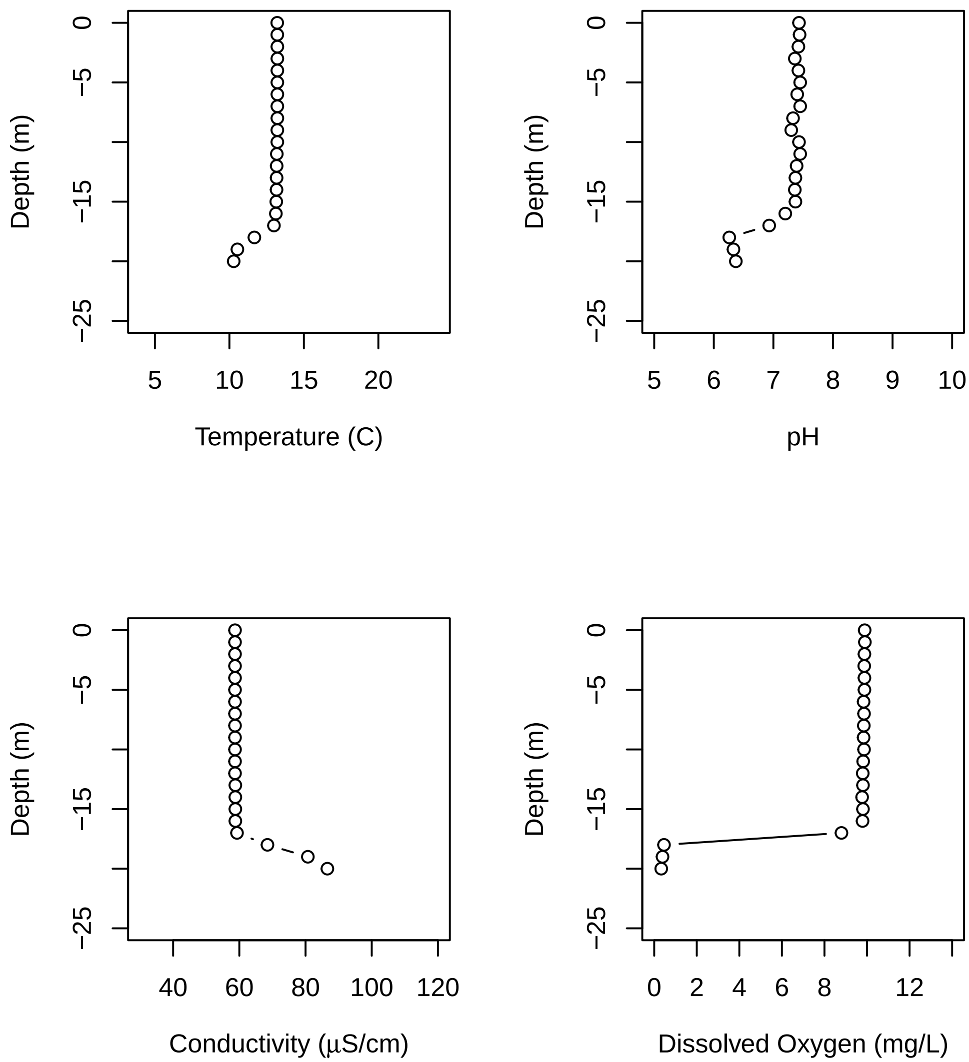


Figure B57: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, November 8, 2023.

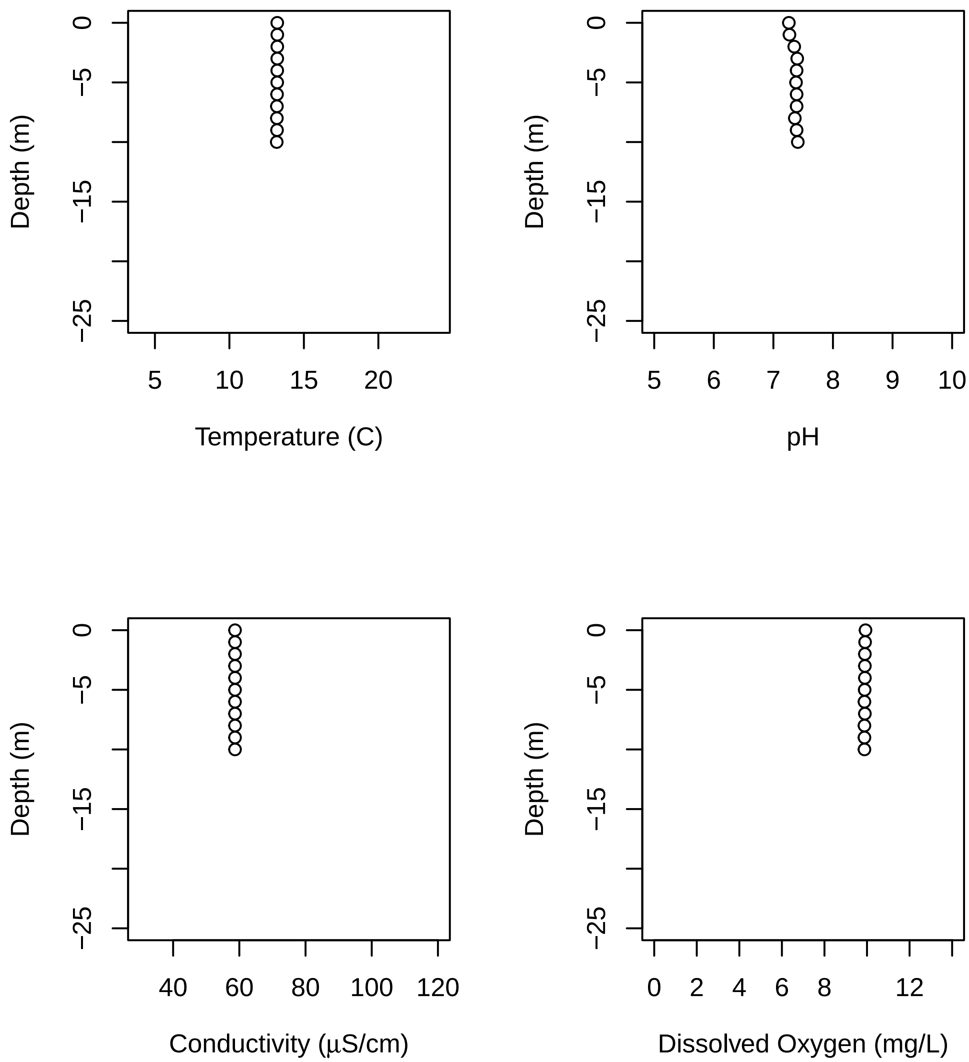


Figure B58: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, November 8, 2023.

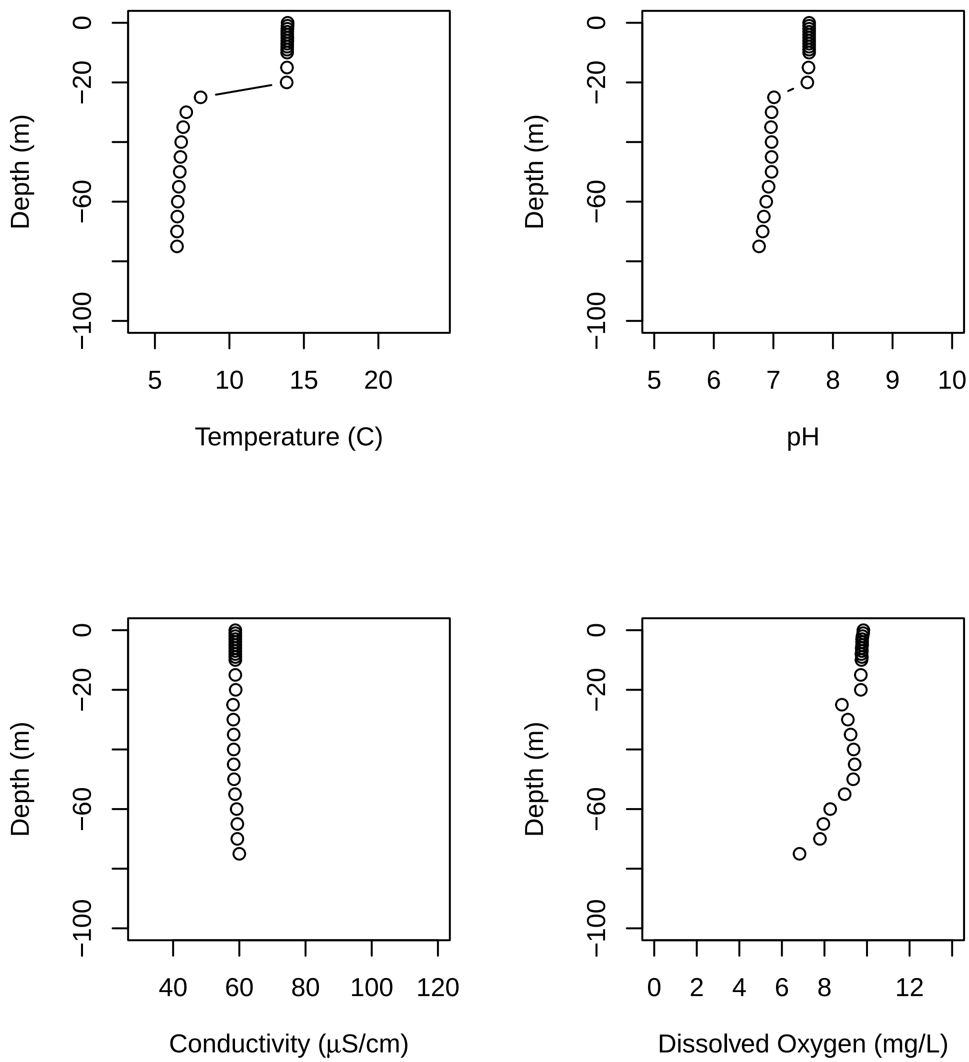


Figure B59: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, November 1, 2023.

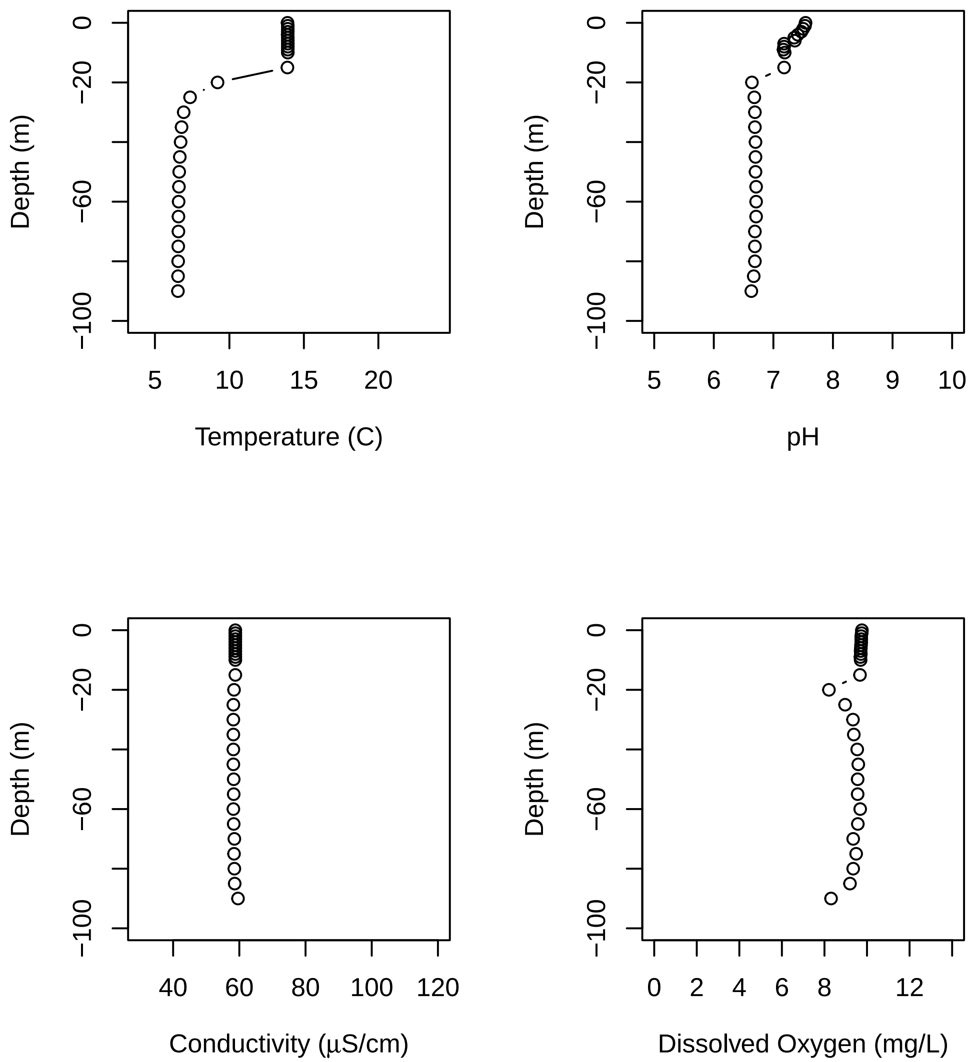


Figure B60: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, November 1, 2023.

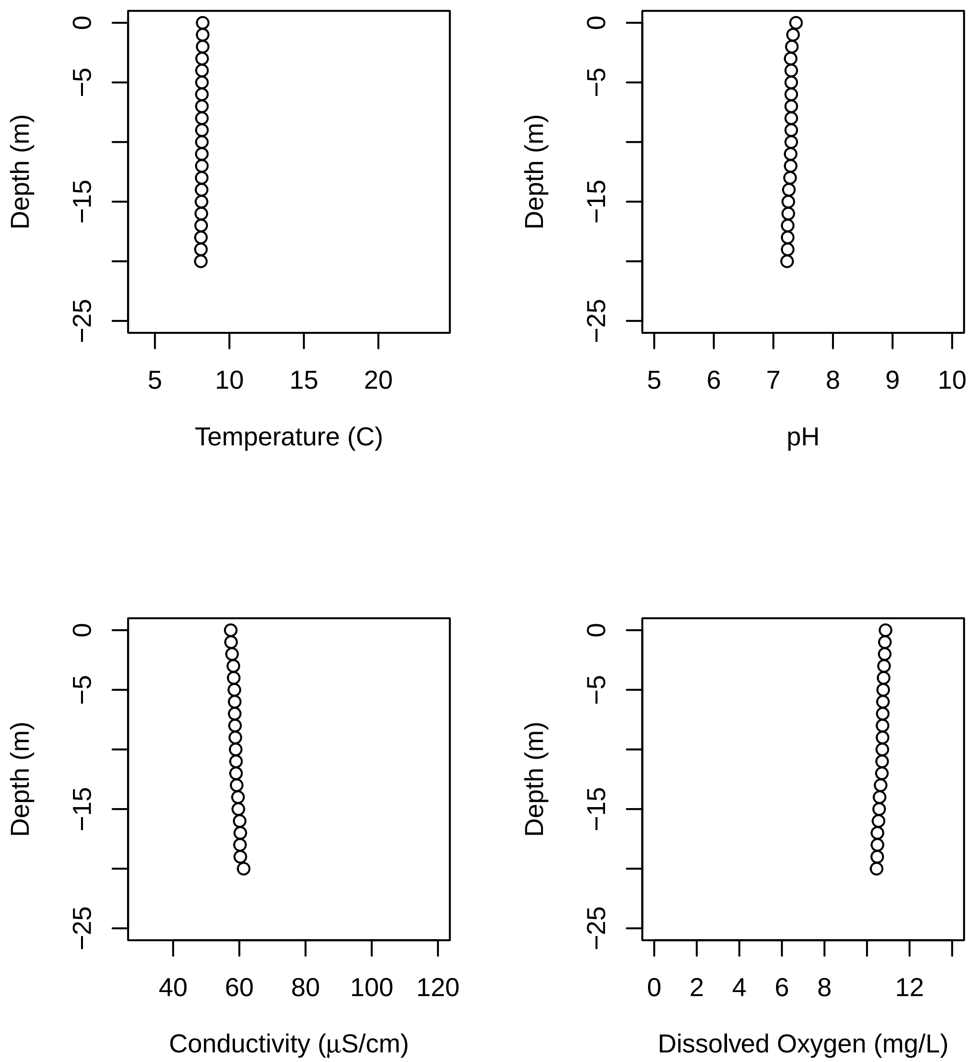


Figure B61: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, December 12, 2023.

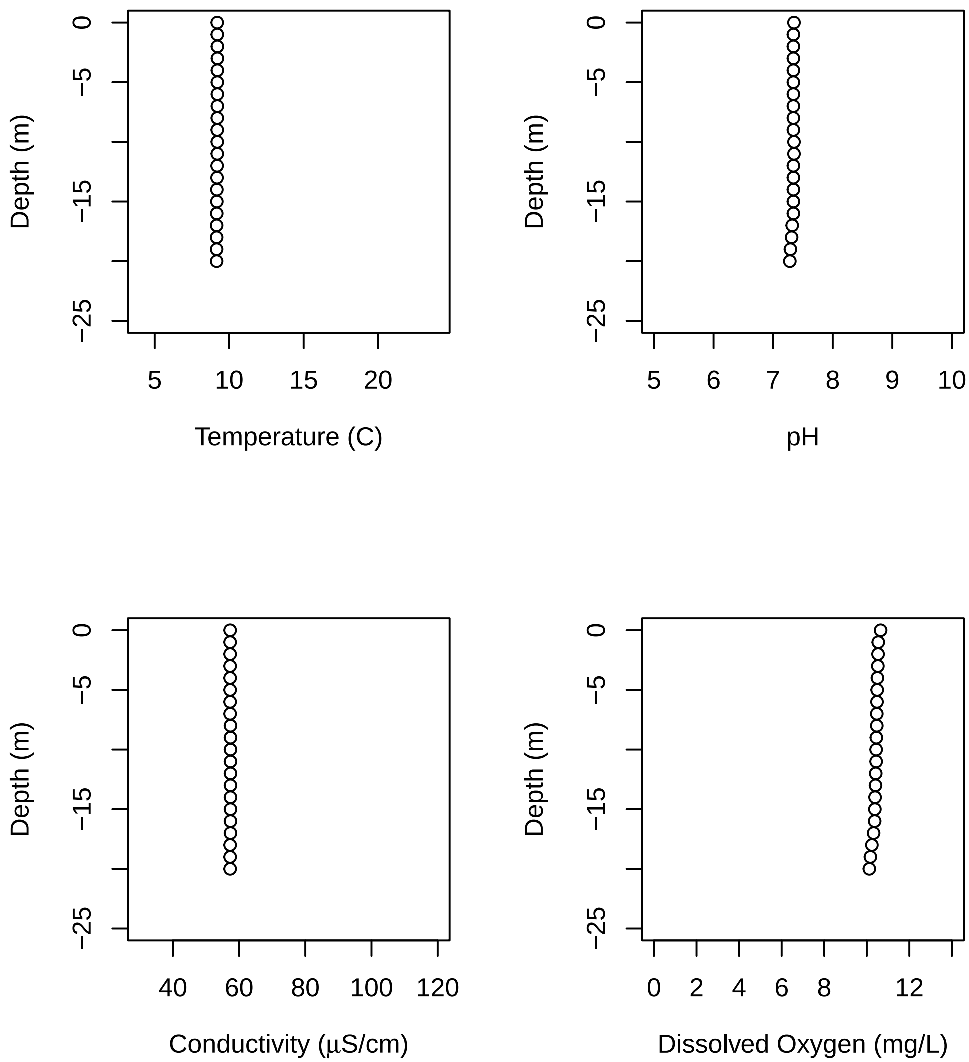


Figure B62: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, December 12, 2023.

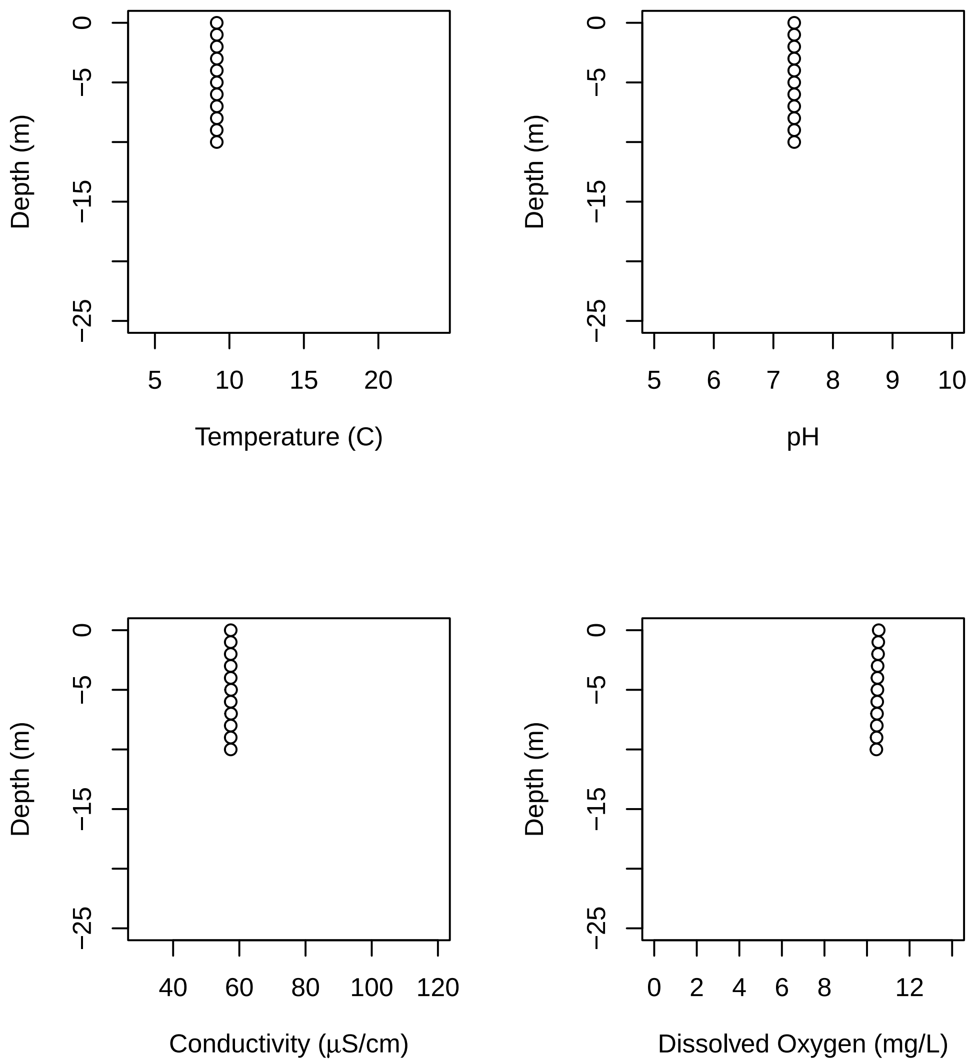


Figure B63: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, December 12, 2023.

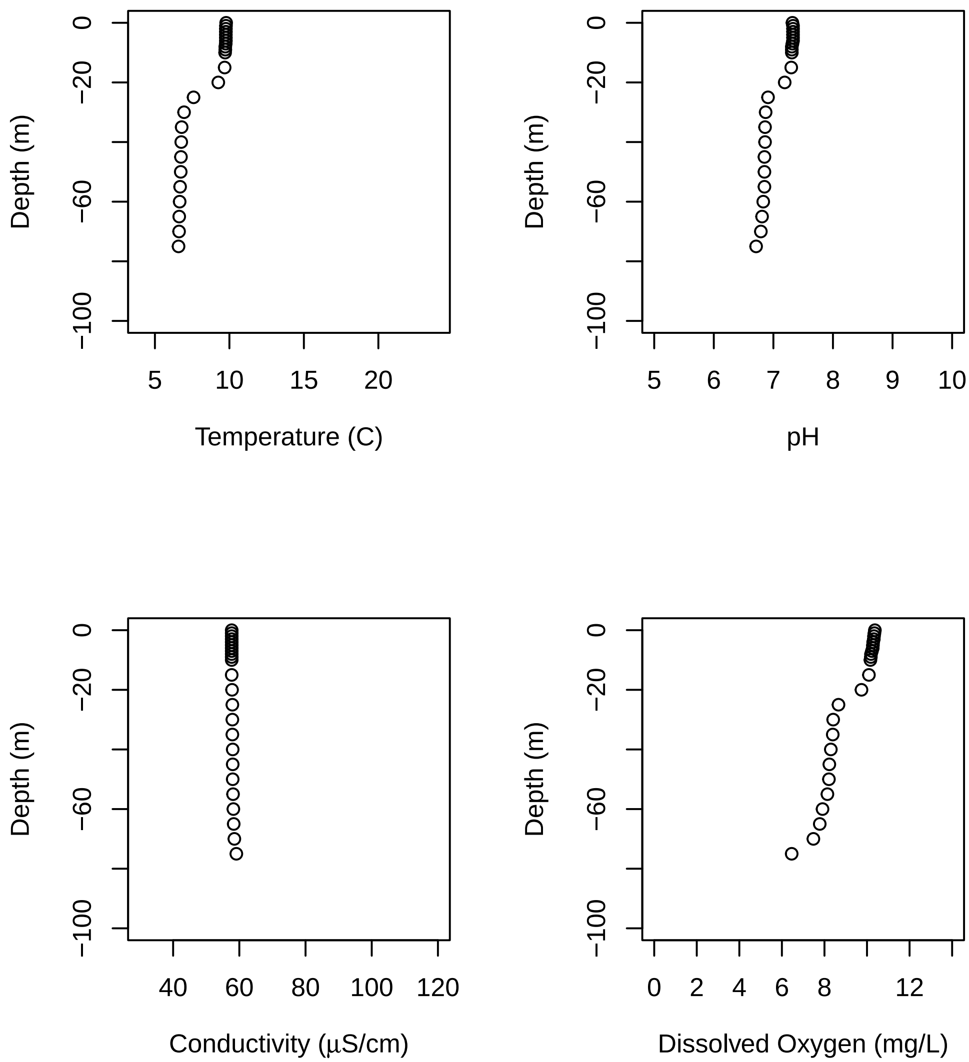


Figure B64: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, December 6, 2023.

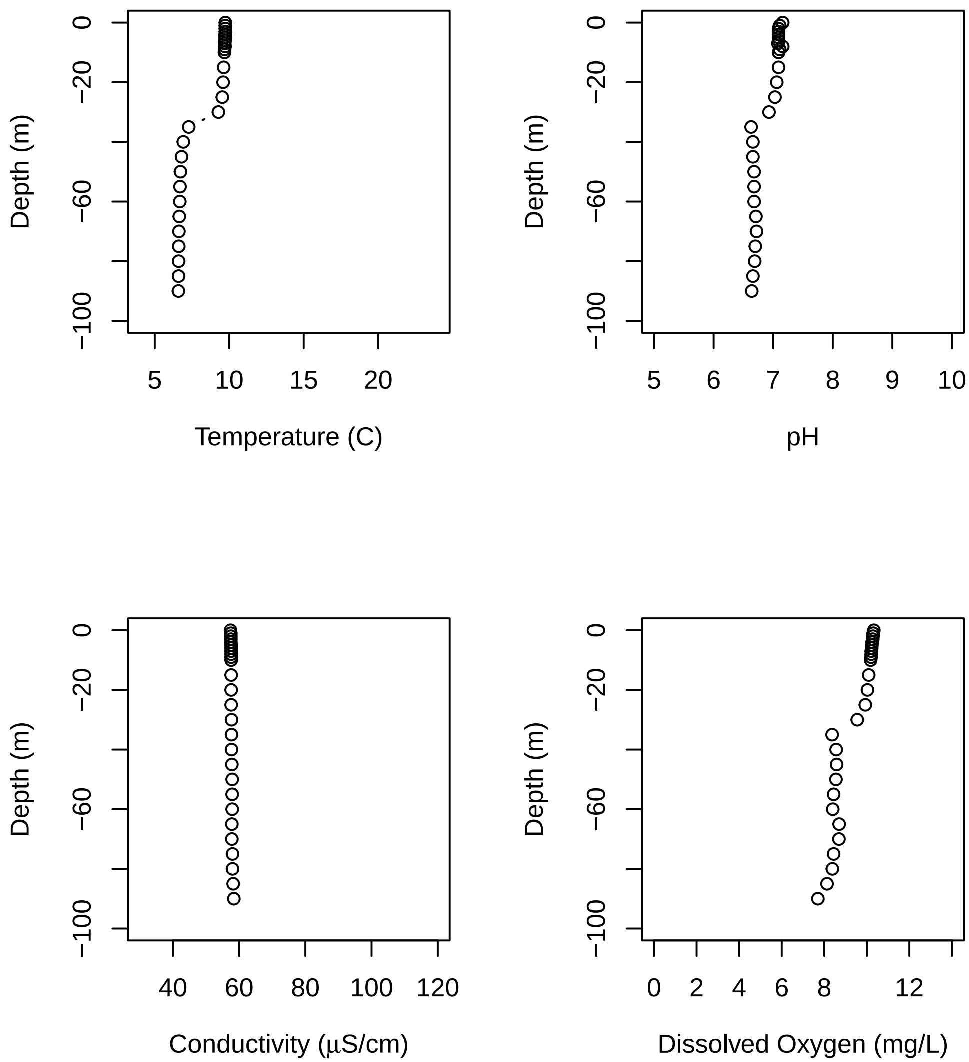


Figure B65: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, December 6, 2023.

B.2 Long-term YSI/Hydrolab Data (1988-present)

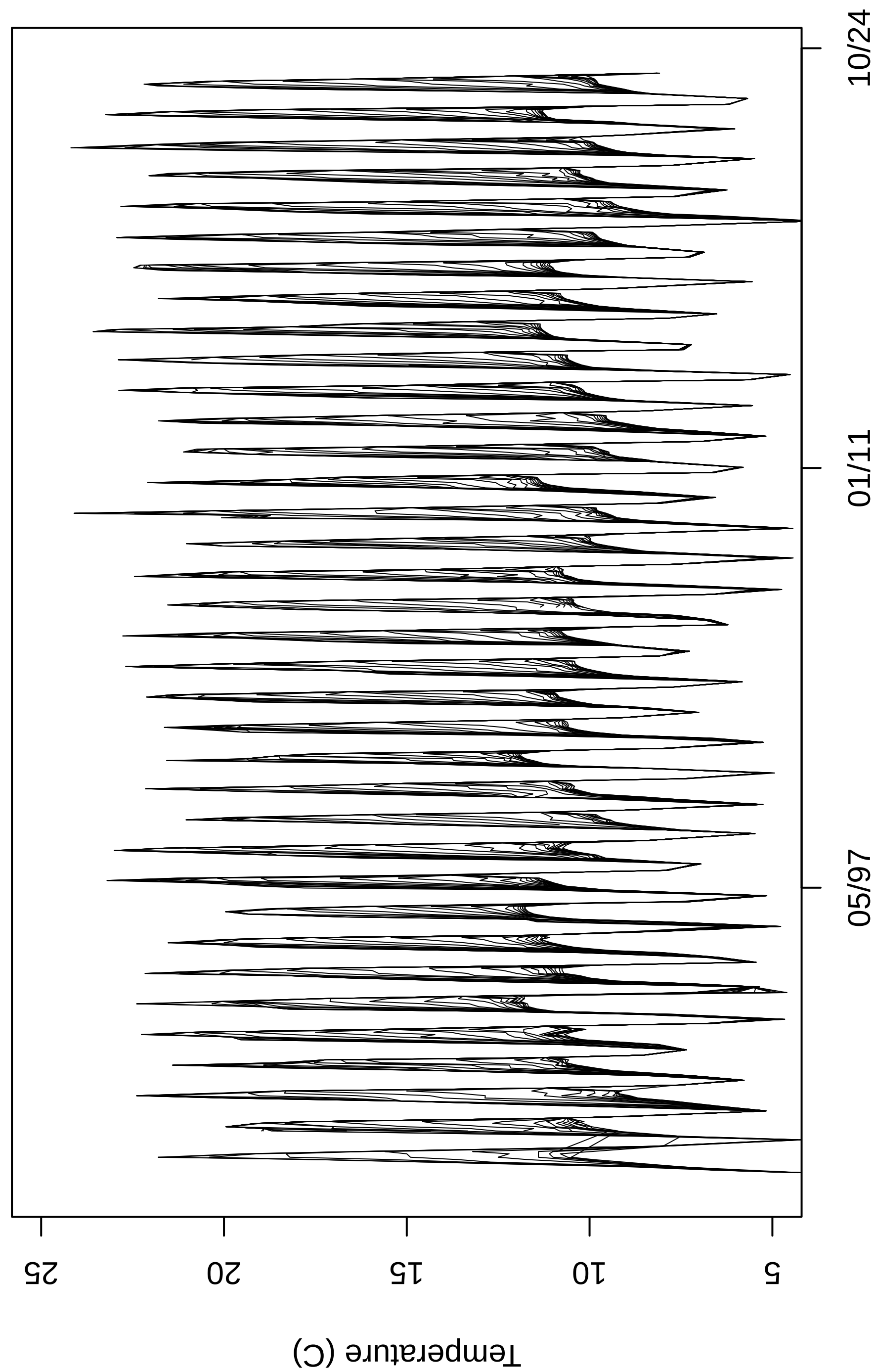


Figure B66: Lake Whatcom historic temperature data for Site 1.

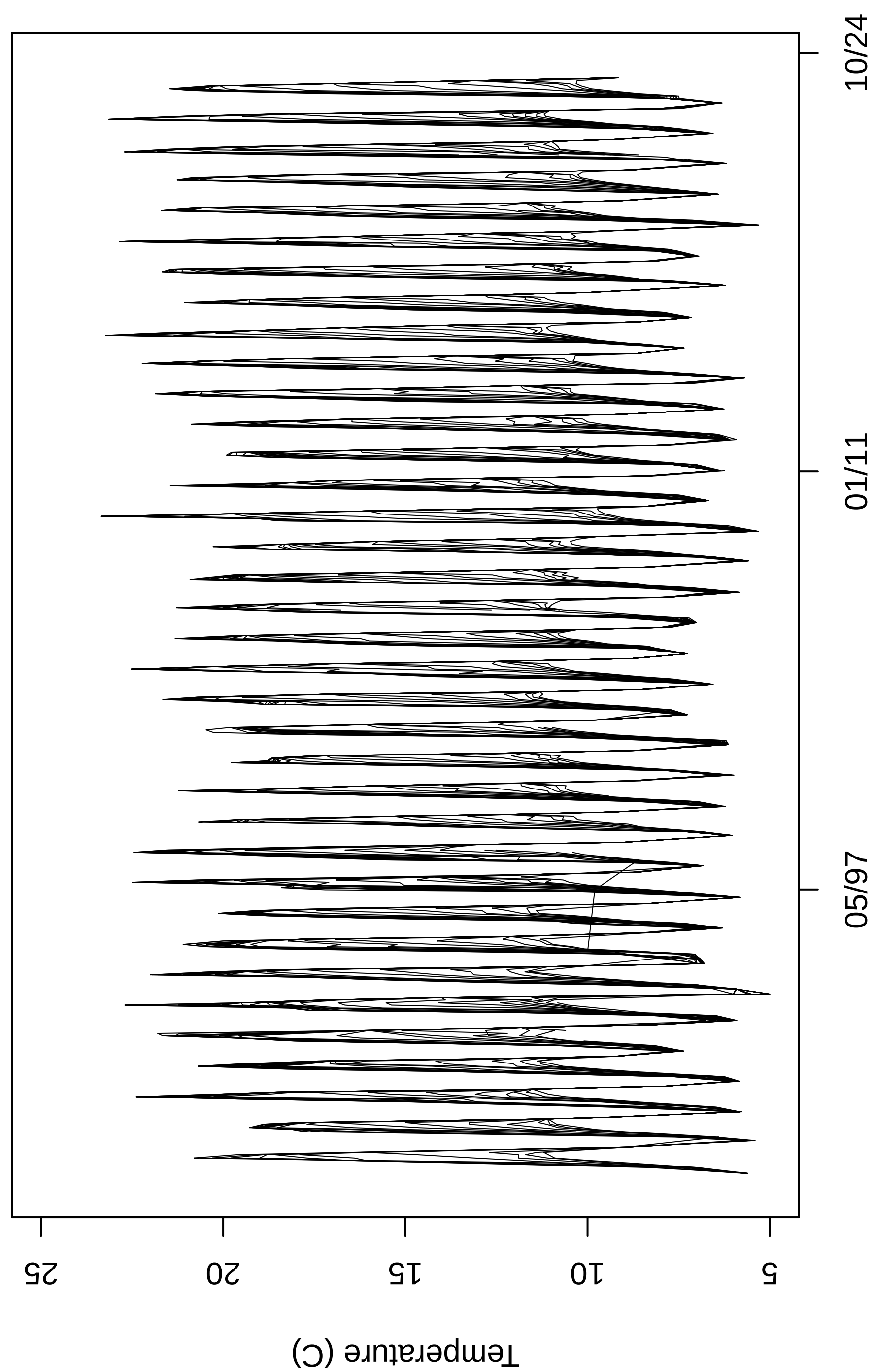


Figure B67: Lake Whatcom historic temperature data for Site 2.

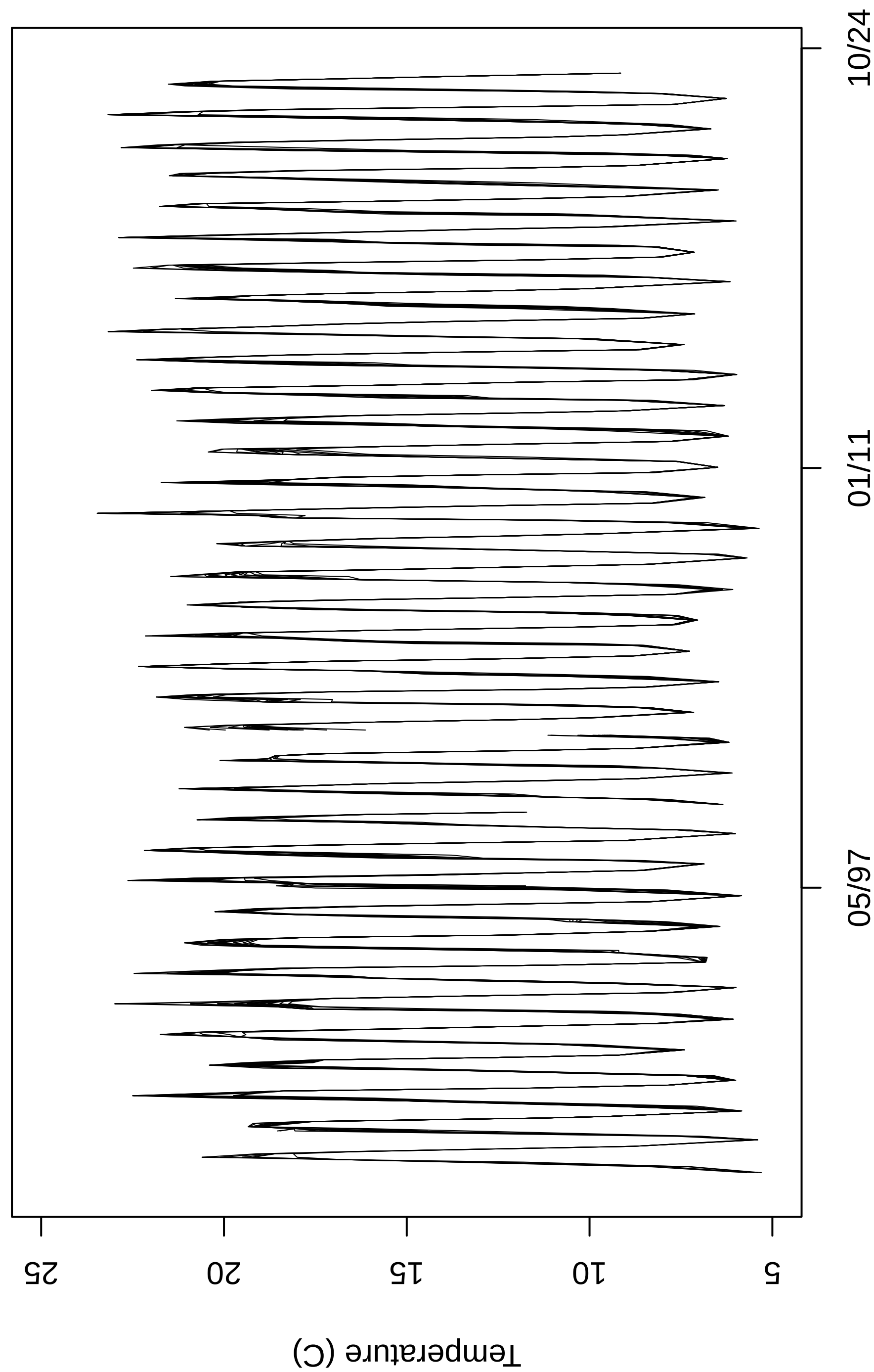


Figure B68: Lake Whatcom historic temperature data for the Intake.

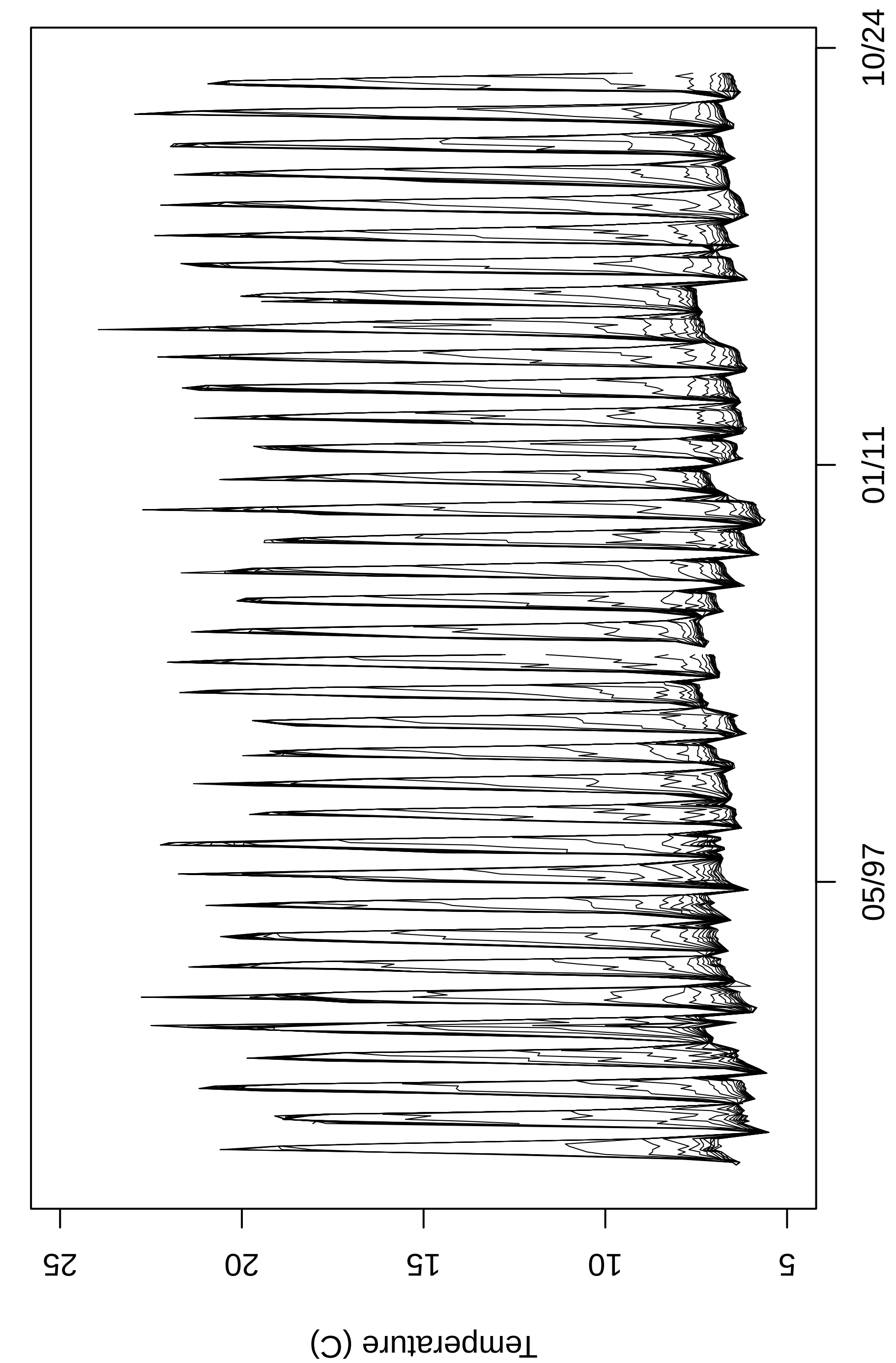


Figure B69: Lake Whatcom historic temperature data for Site 3.

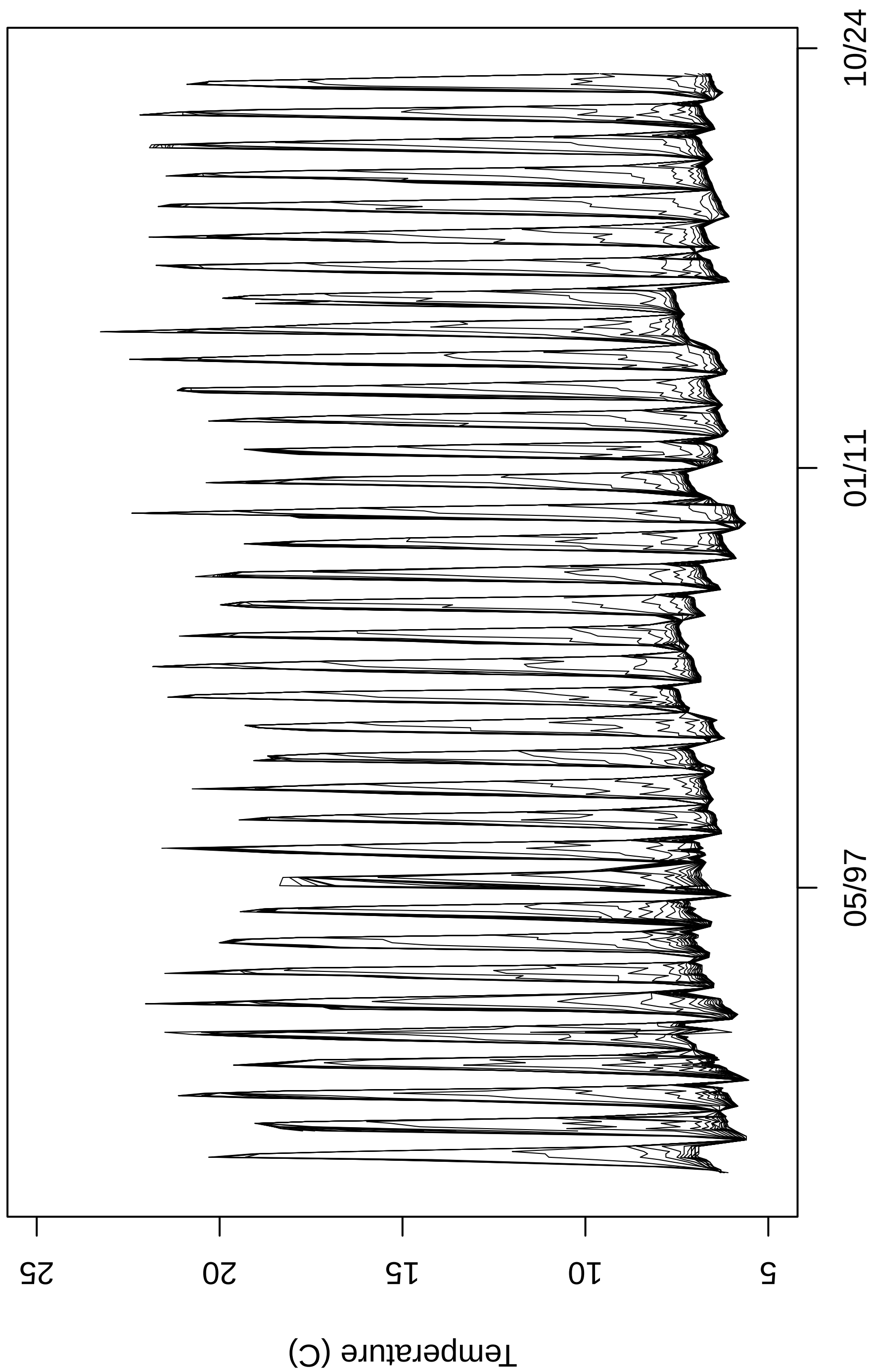


Figure B70: Lake Whatcom historic temperature data for Site 4.

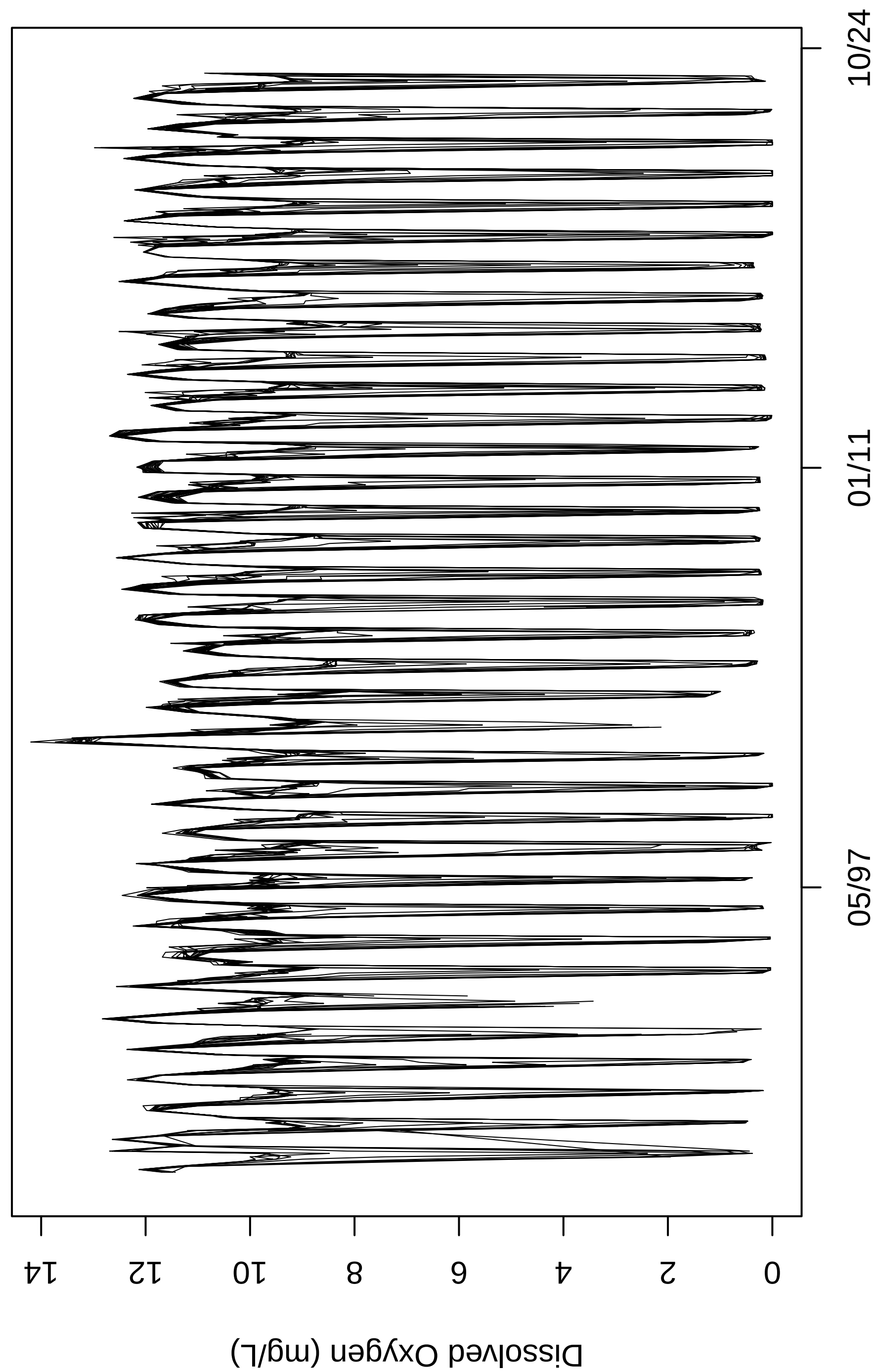


Figure B71: Lake Whatcom historic dissolved oxygen data for Site 1.

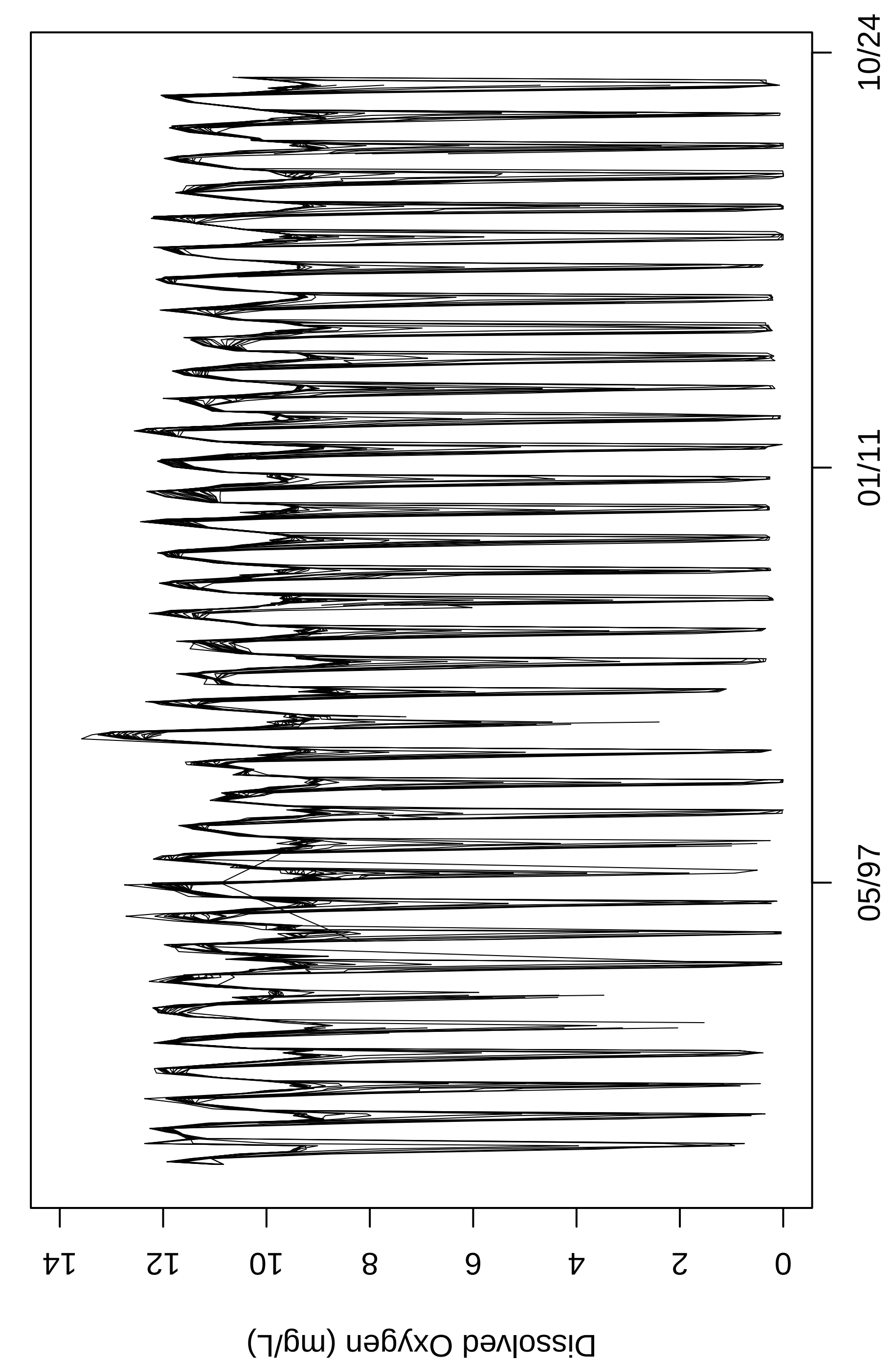


Figure B72: Lake Whatcom historic dissolved oxygen data for Site 2.

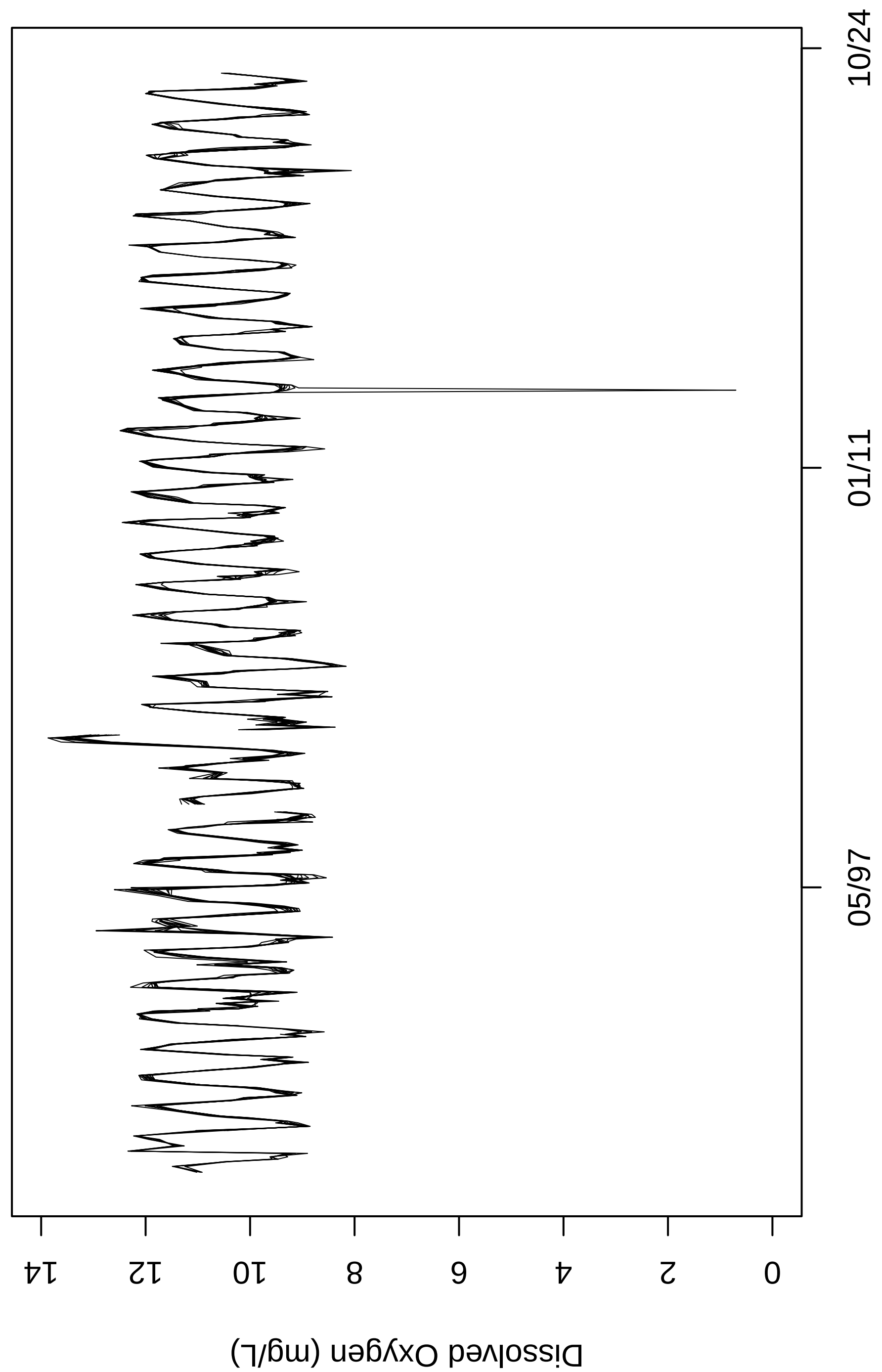


Figure B73: Lake Whatcom historic dissolved oxygen data for the Intake. See discussion of the low dissolved oxygen value in Matthews et al. (2014).

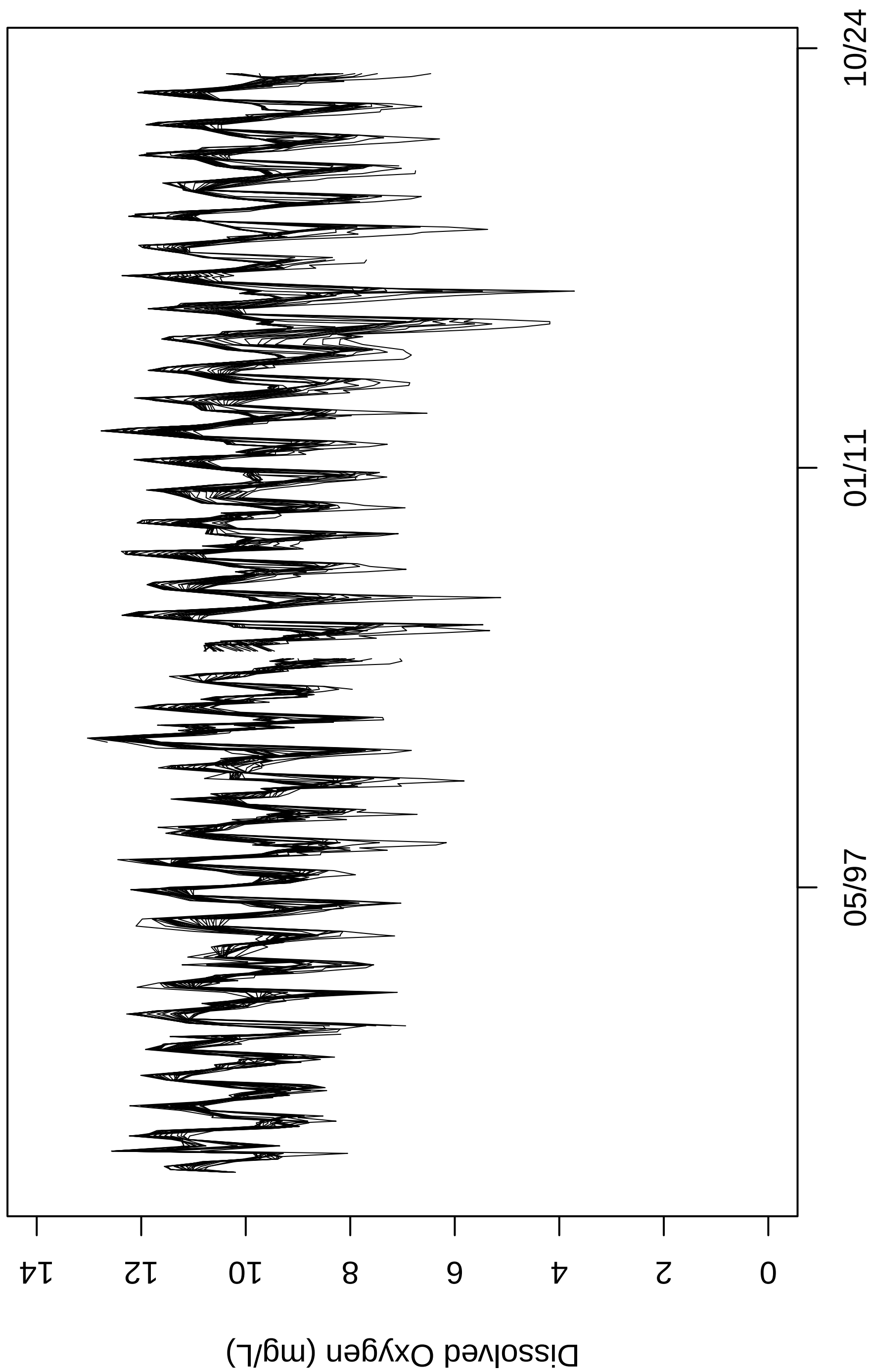


Figure B74: Lake Whatcom historic dissolved oxygen data for Site 3.

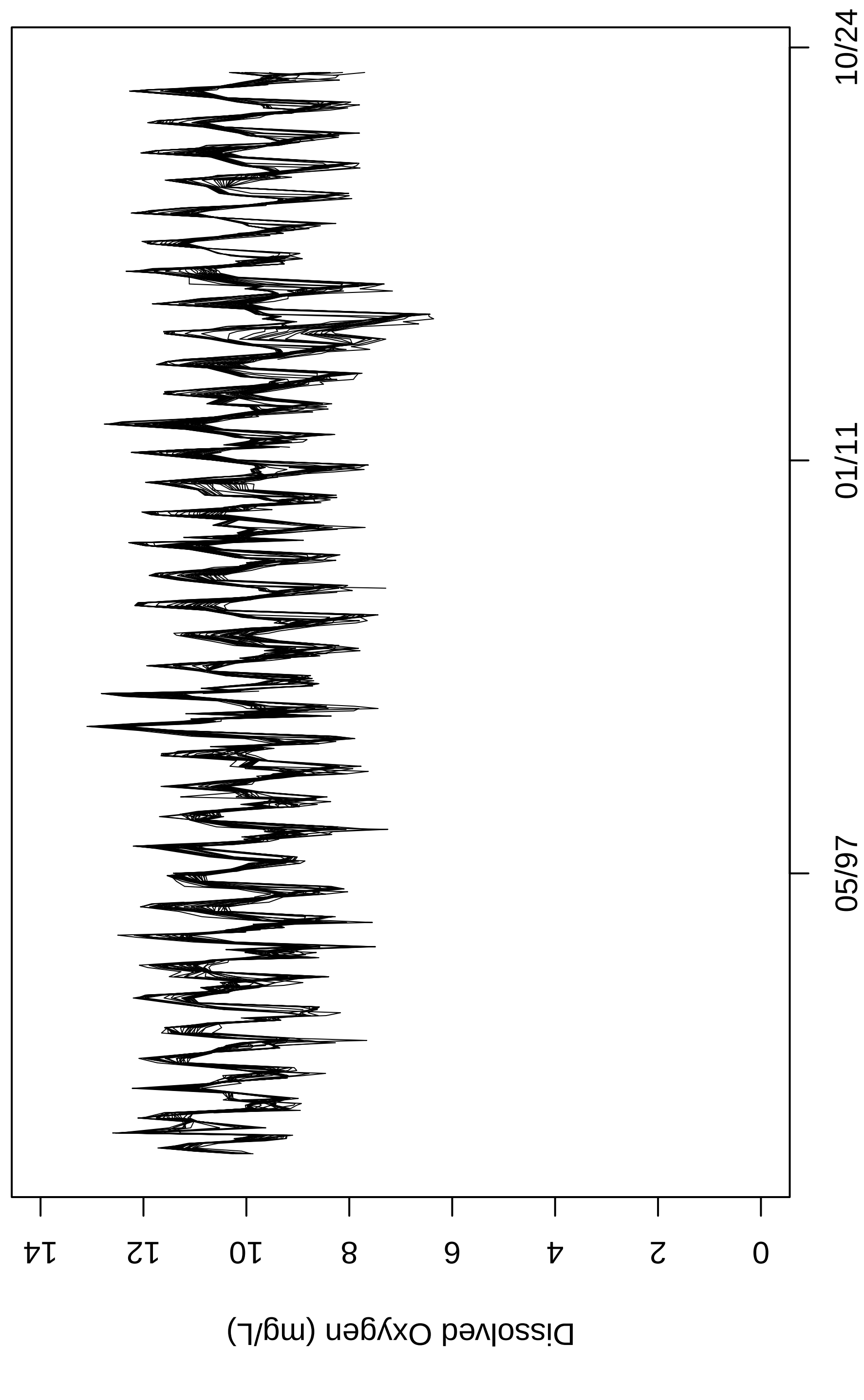


Figure B75: Lake Whatcom historic dissolved oxygen data for Site 4.

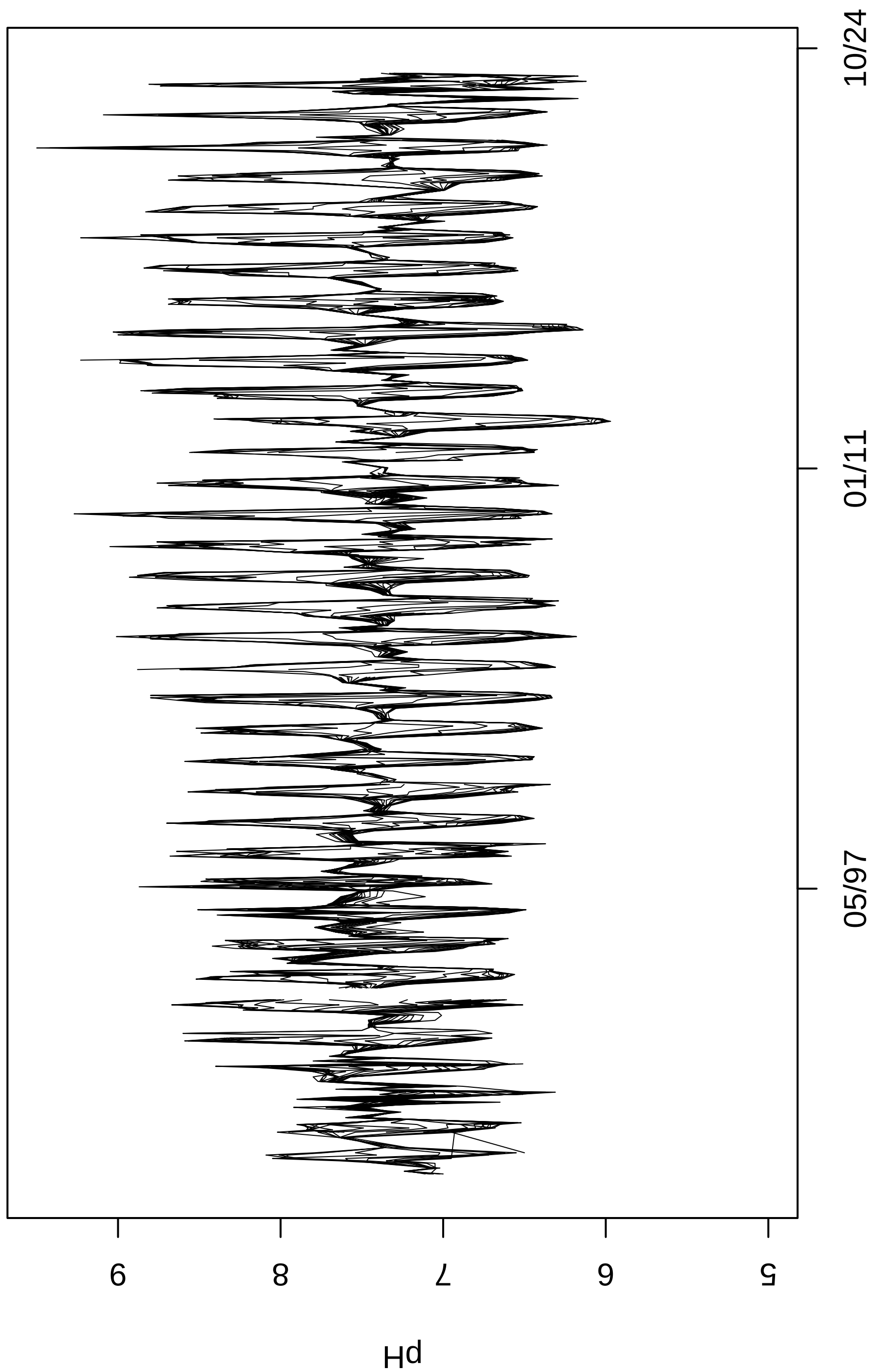


Figure B76: Lake Whatcom historic pH data for Site 1.

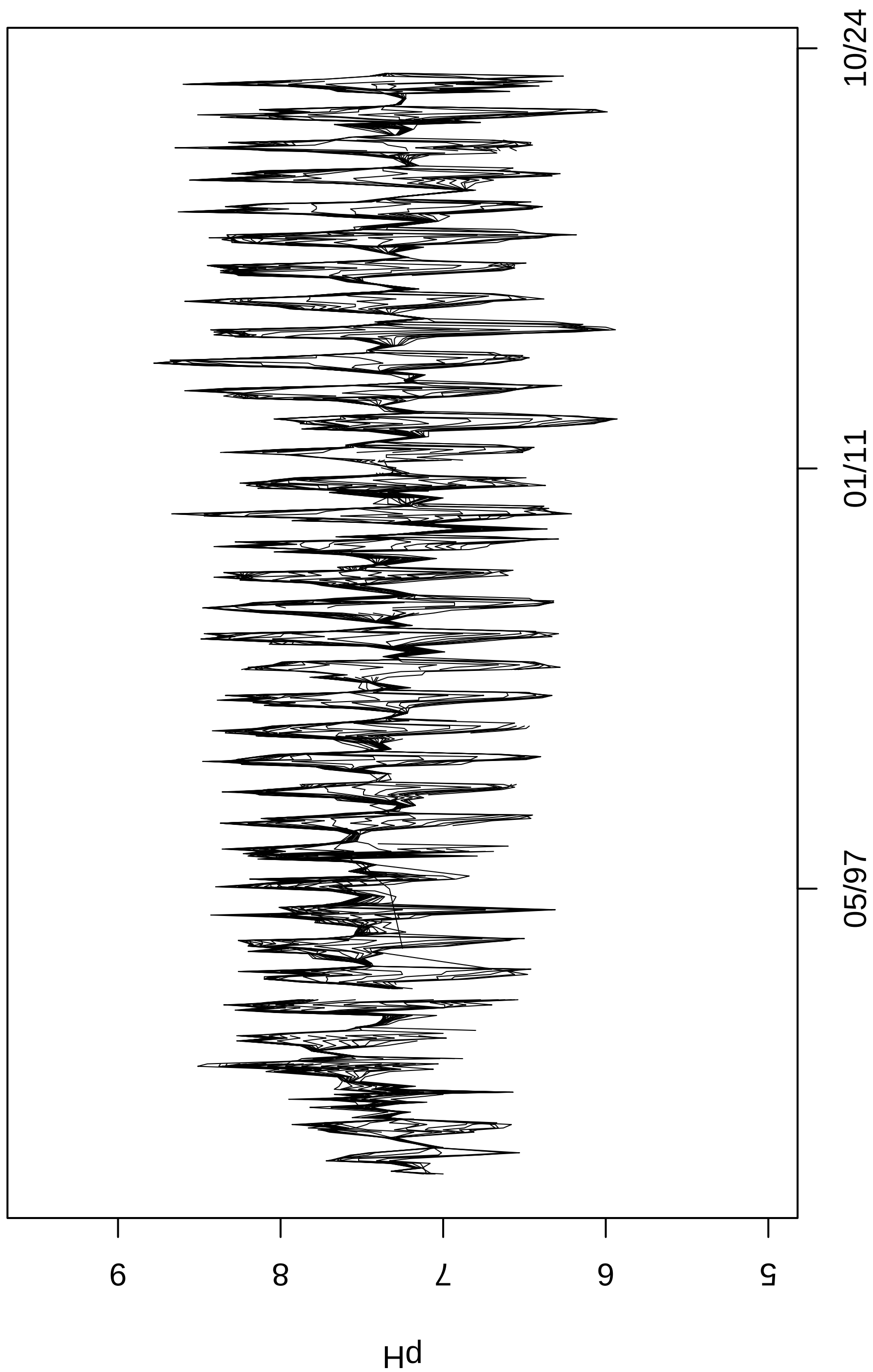


Figure B77: Lake Whatcom historic pH data for Site 2.

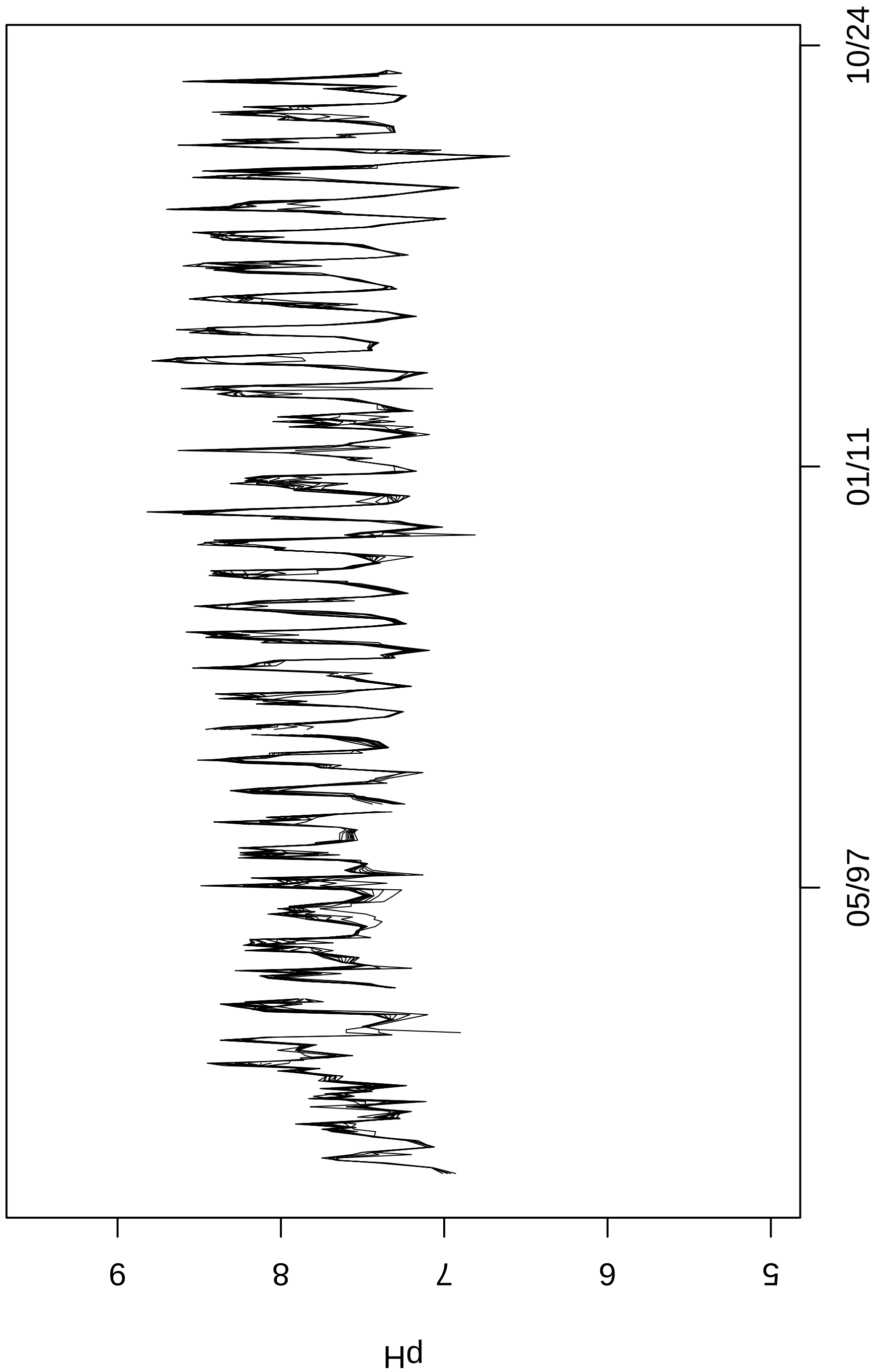


Figure B78: Lake Whatcom historic pH data for the Intake.

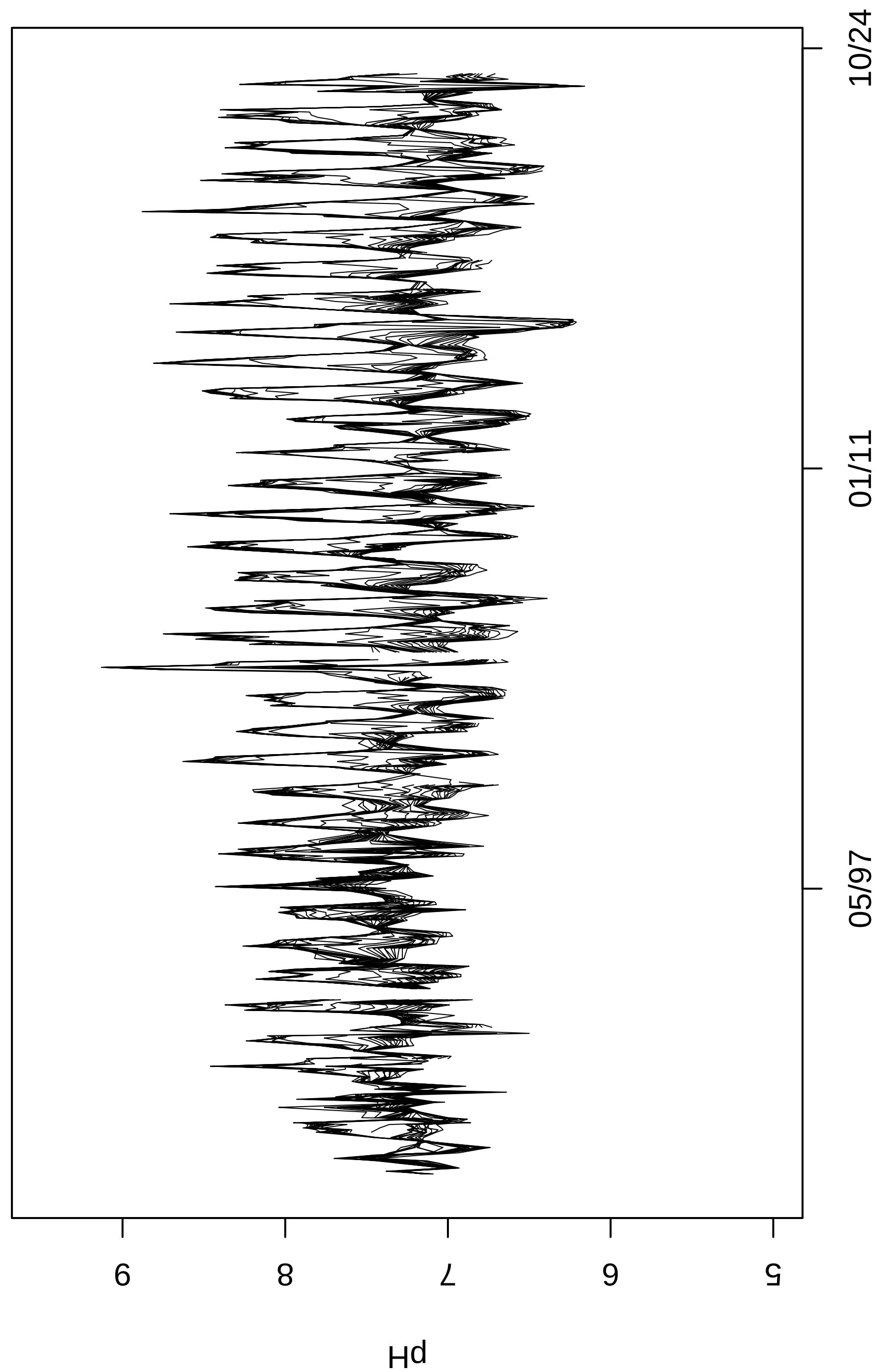


Figure B79: Lake Whatcom historic pH data for Site 3.

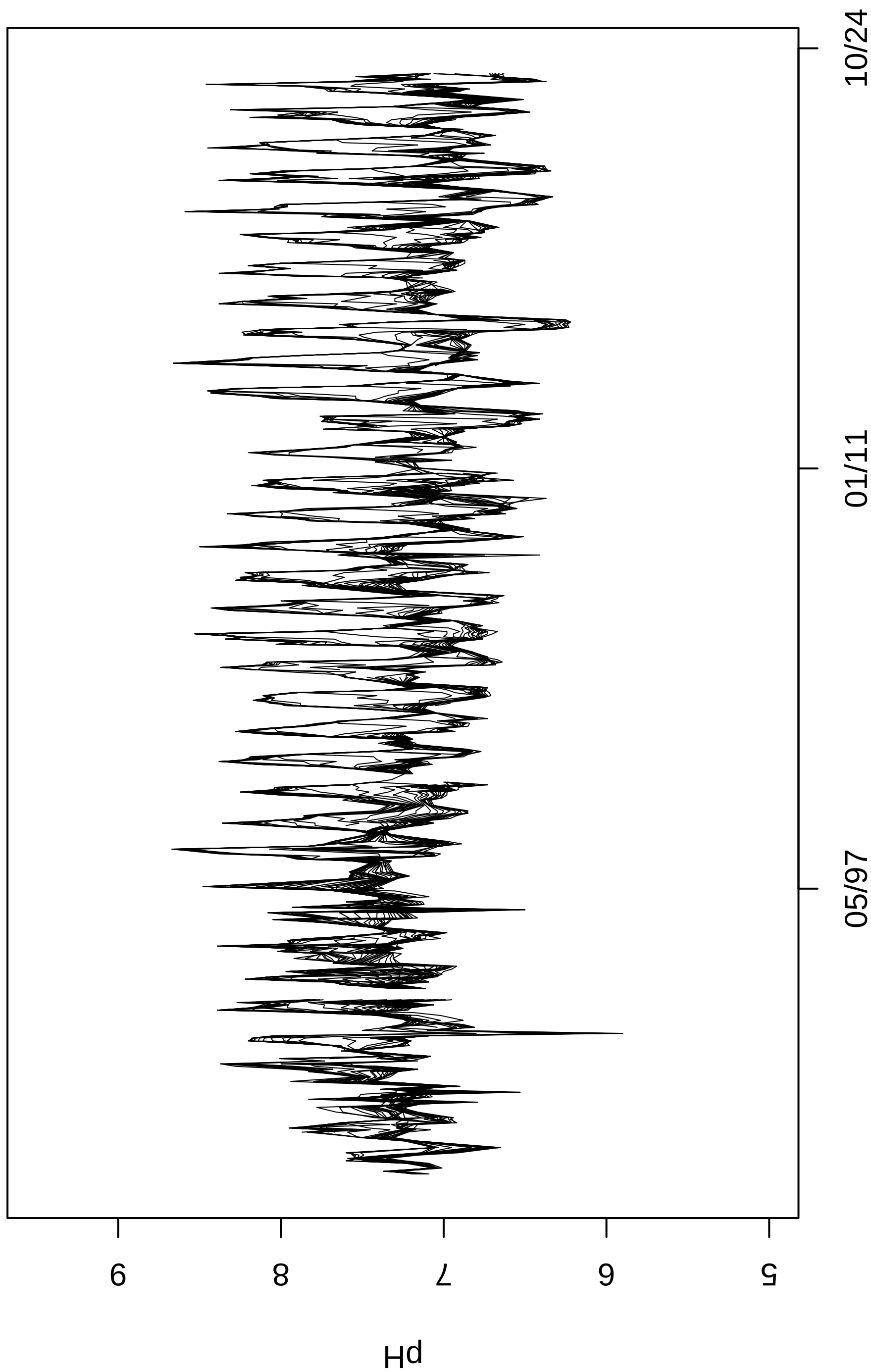


Figure B80: Lake Whatcom historic pH data for Site 4.

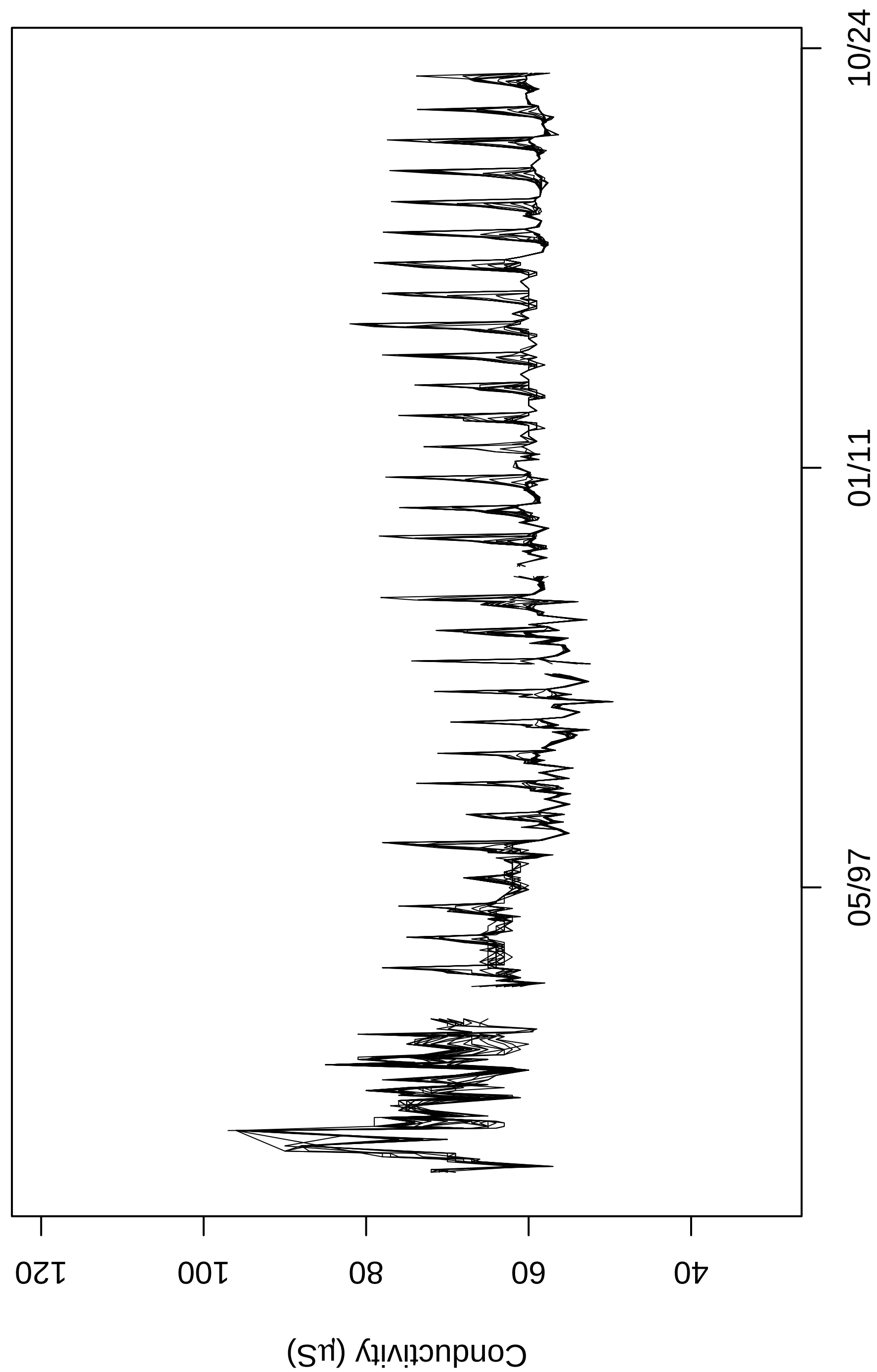


Figure B81: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to more sensitive equipment.

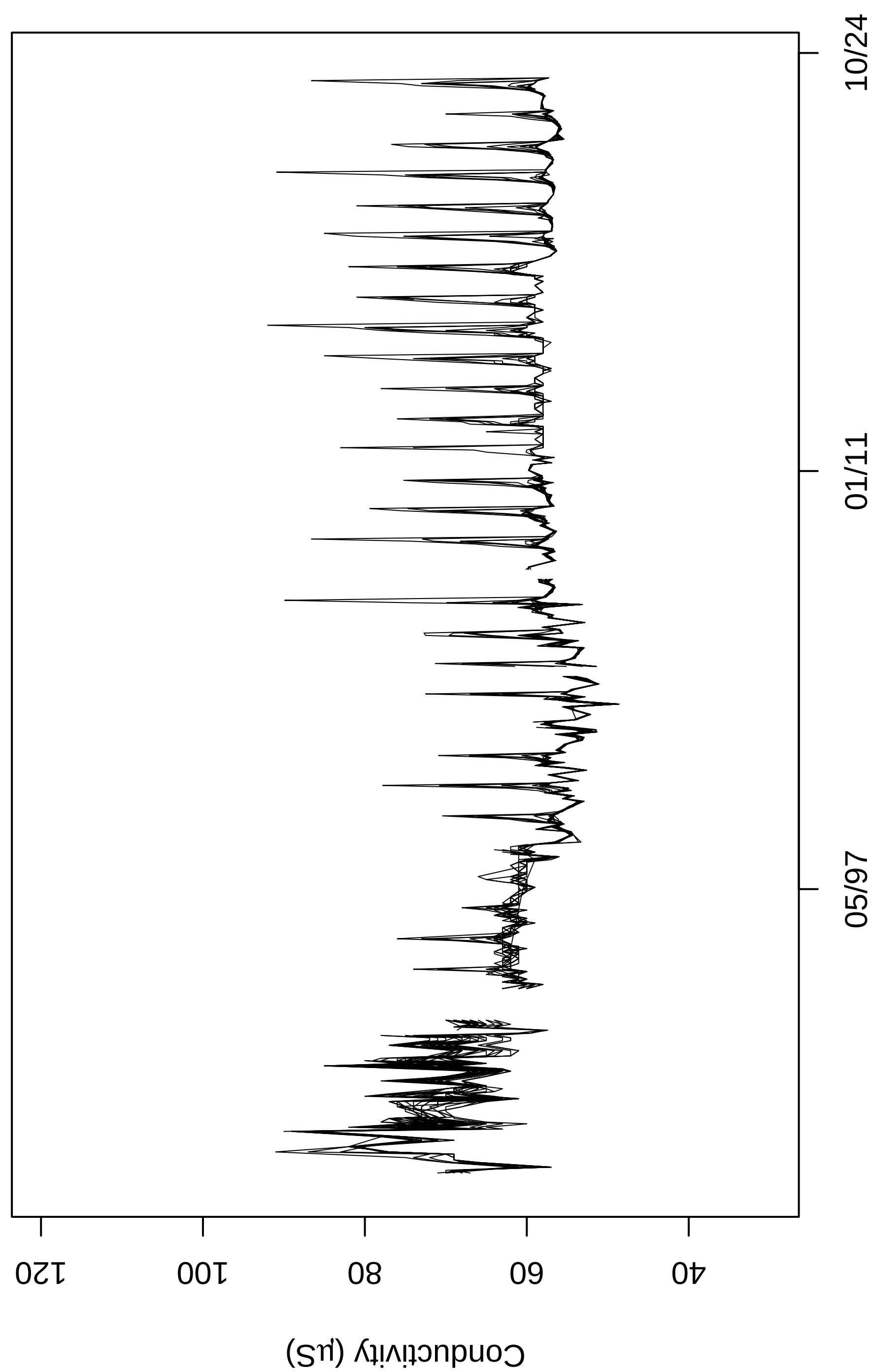


Figure B82: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to more sensitive equipment.

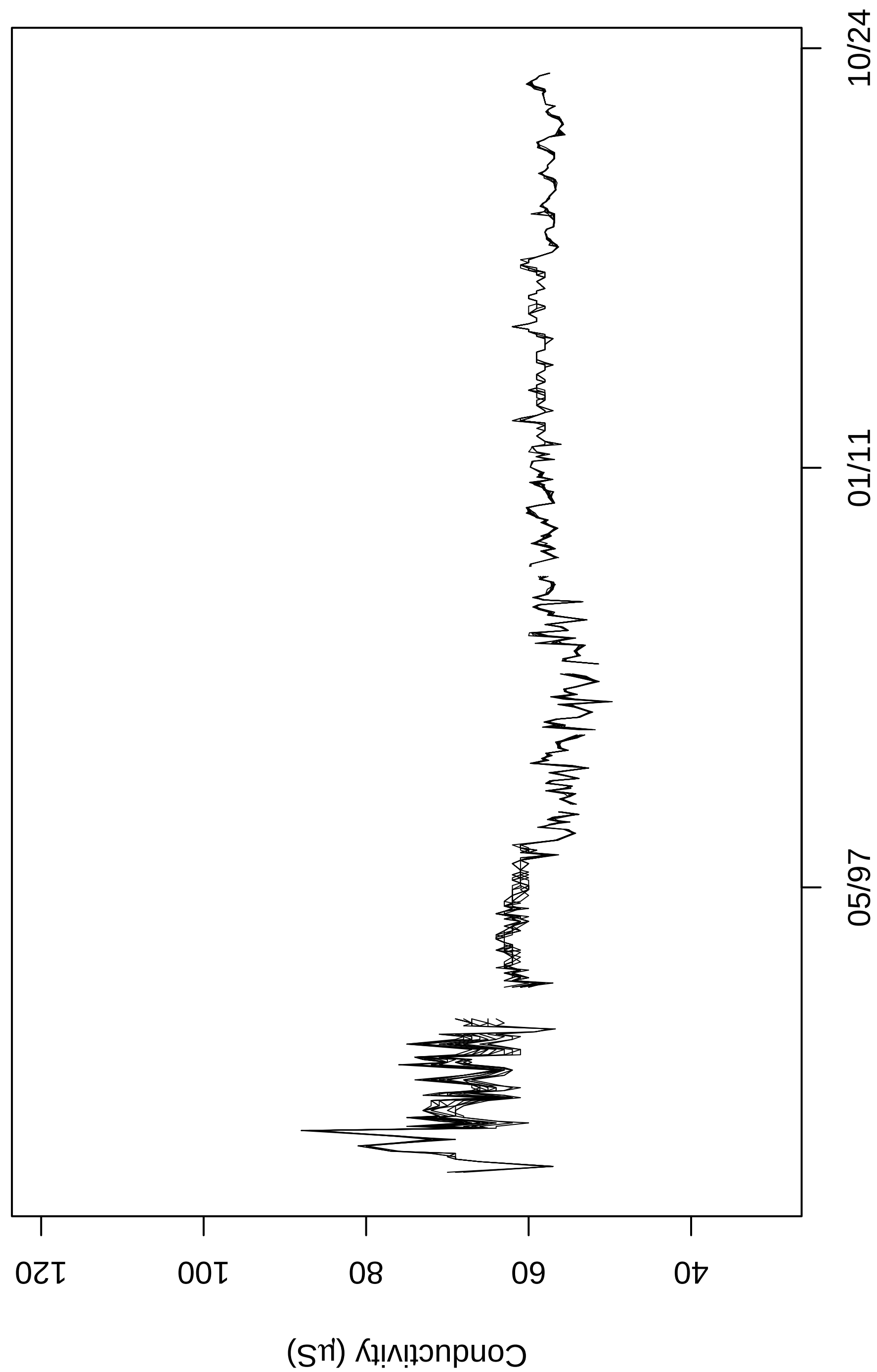


Figure B83: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to more sensitive equipment.

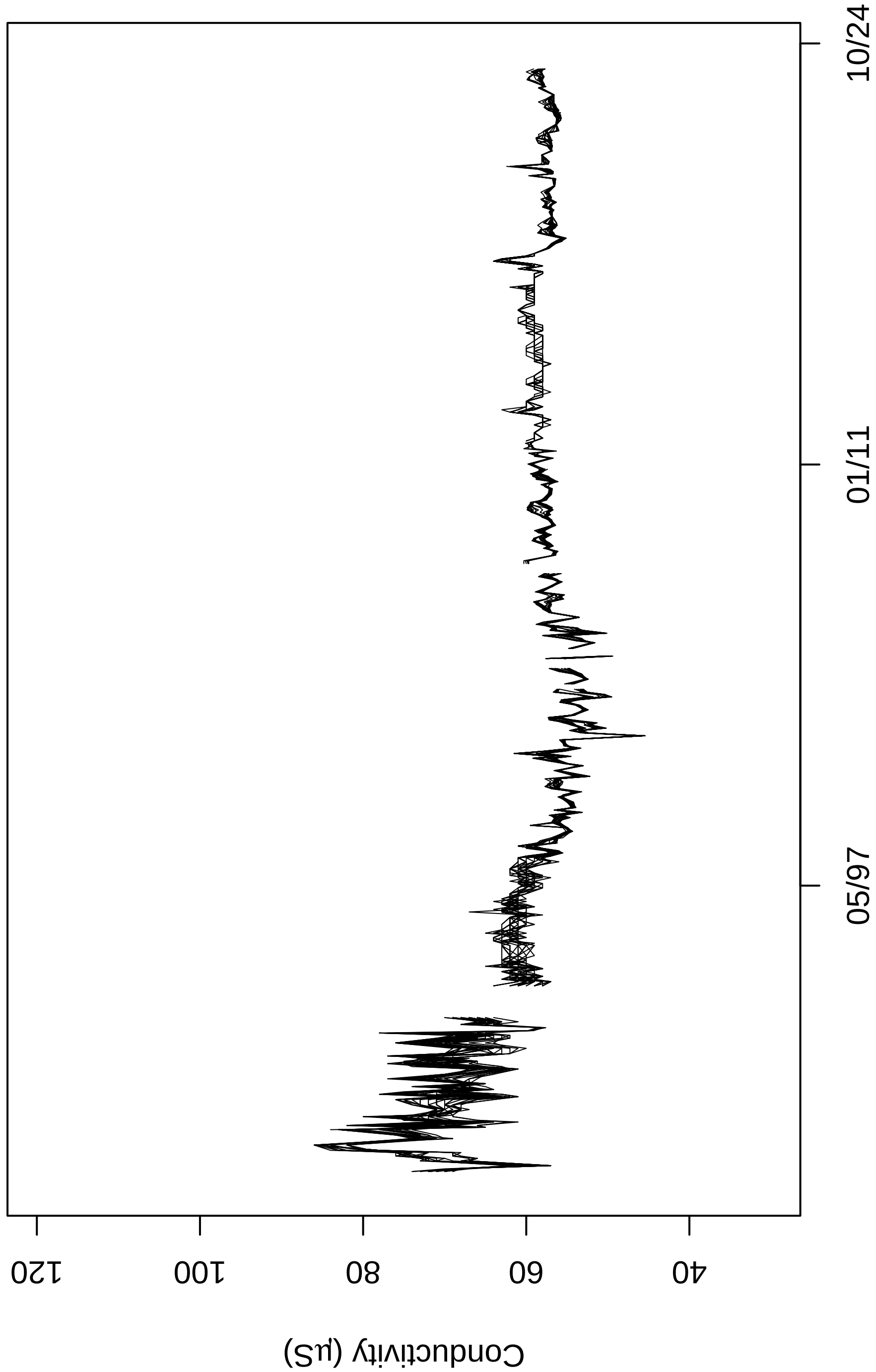


Figure B84: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to more sensitive equipment.

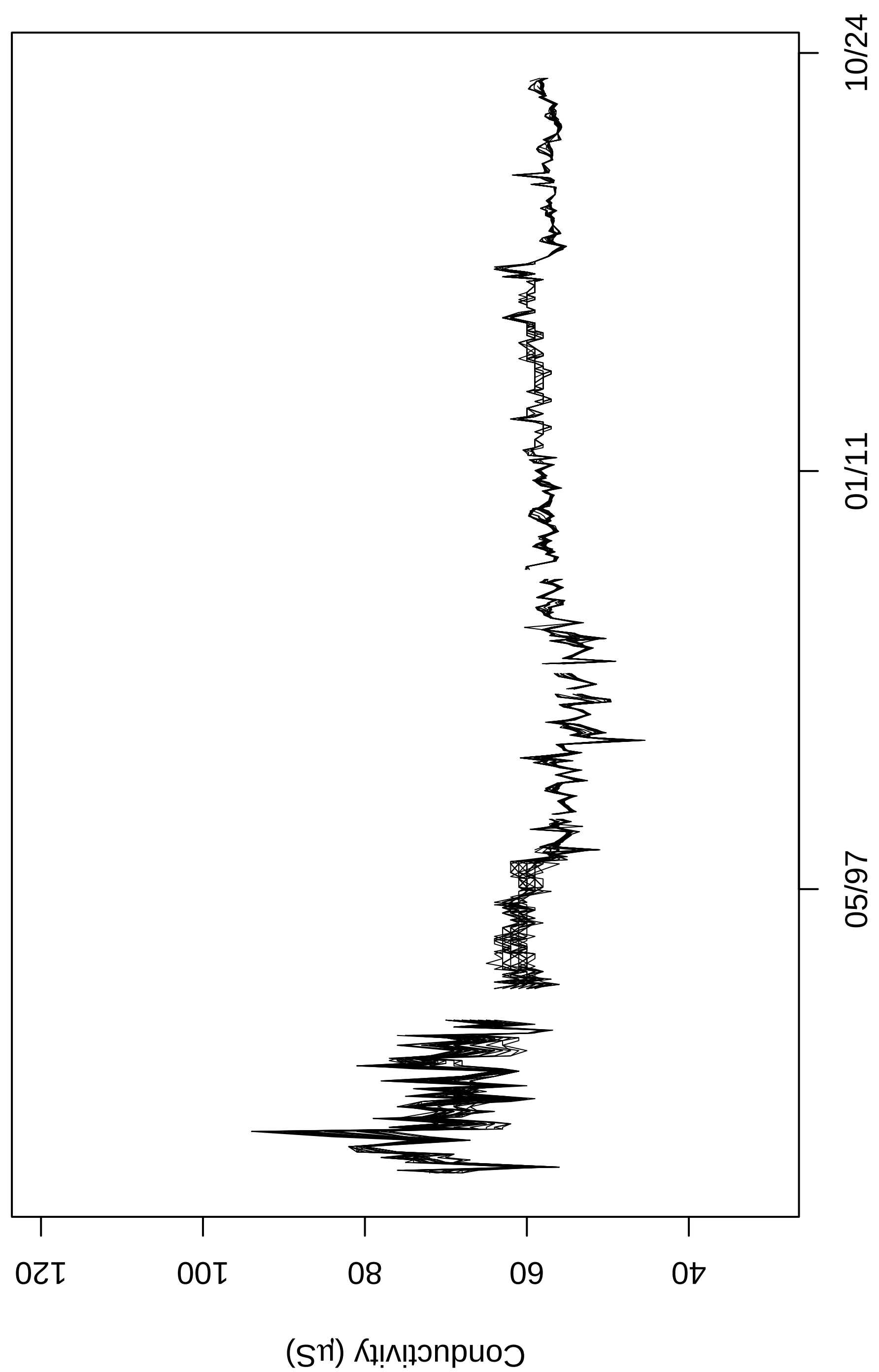


Figure B85: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to more sensitive equipment.

B.3 Long-term Water Quality Data (1988-present)

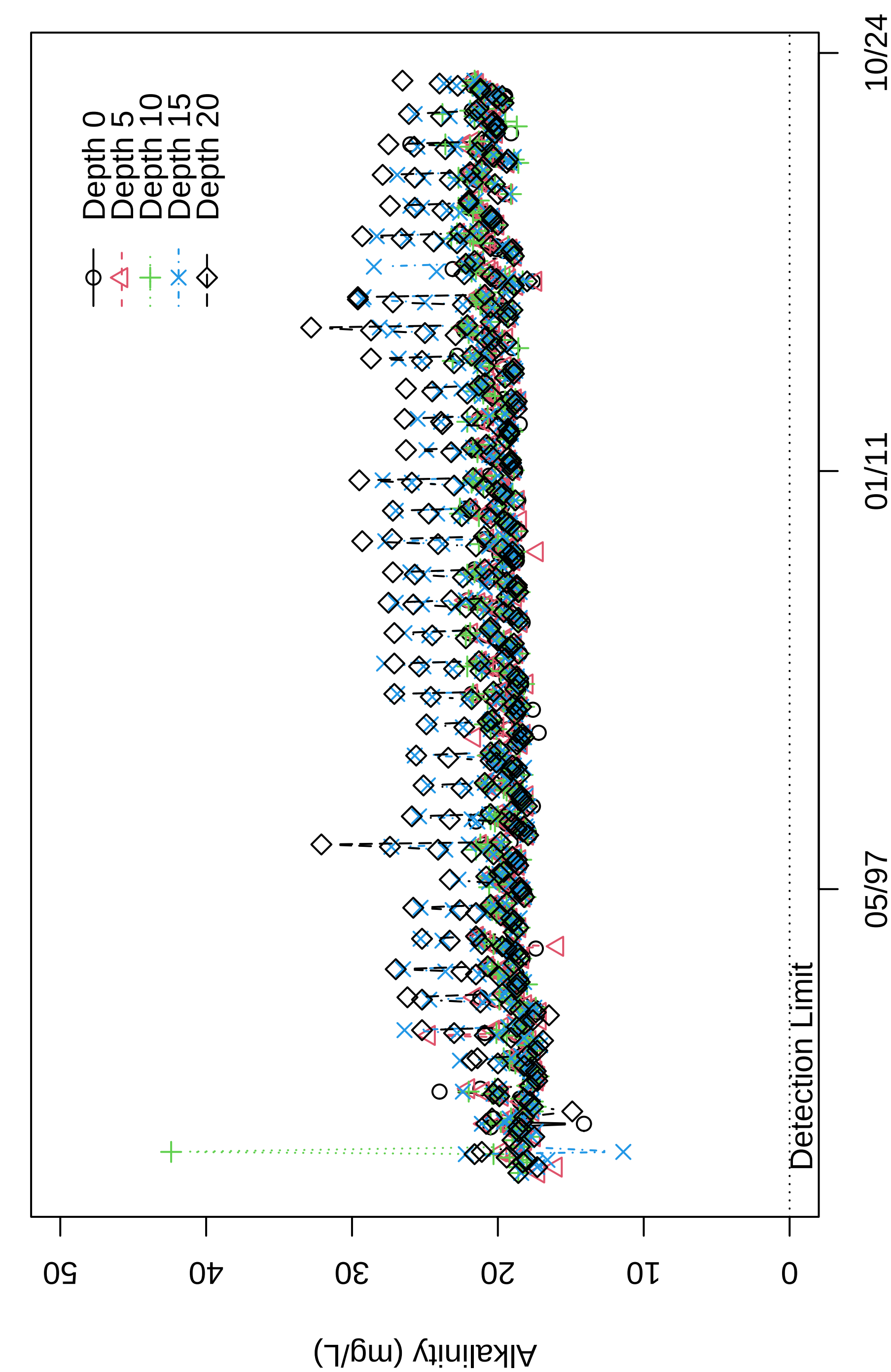


Figure B86: Lake Whatcom alkalinity data for Site 1.

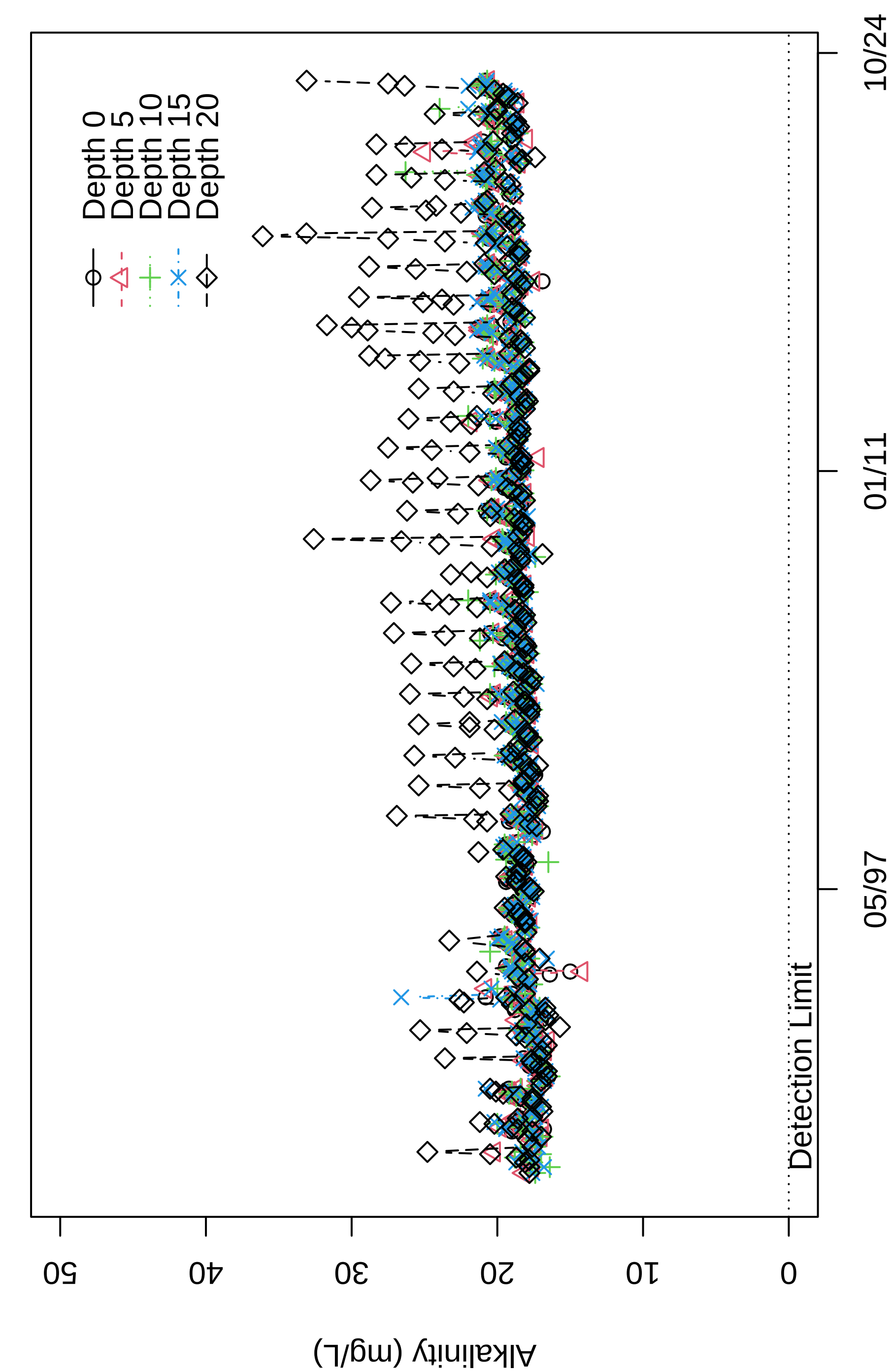


Figure B87: Lake Whatcom alkalinity data for Site 2.

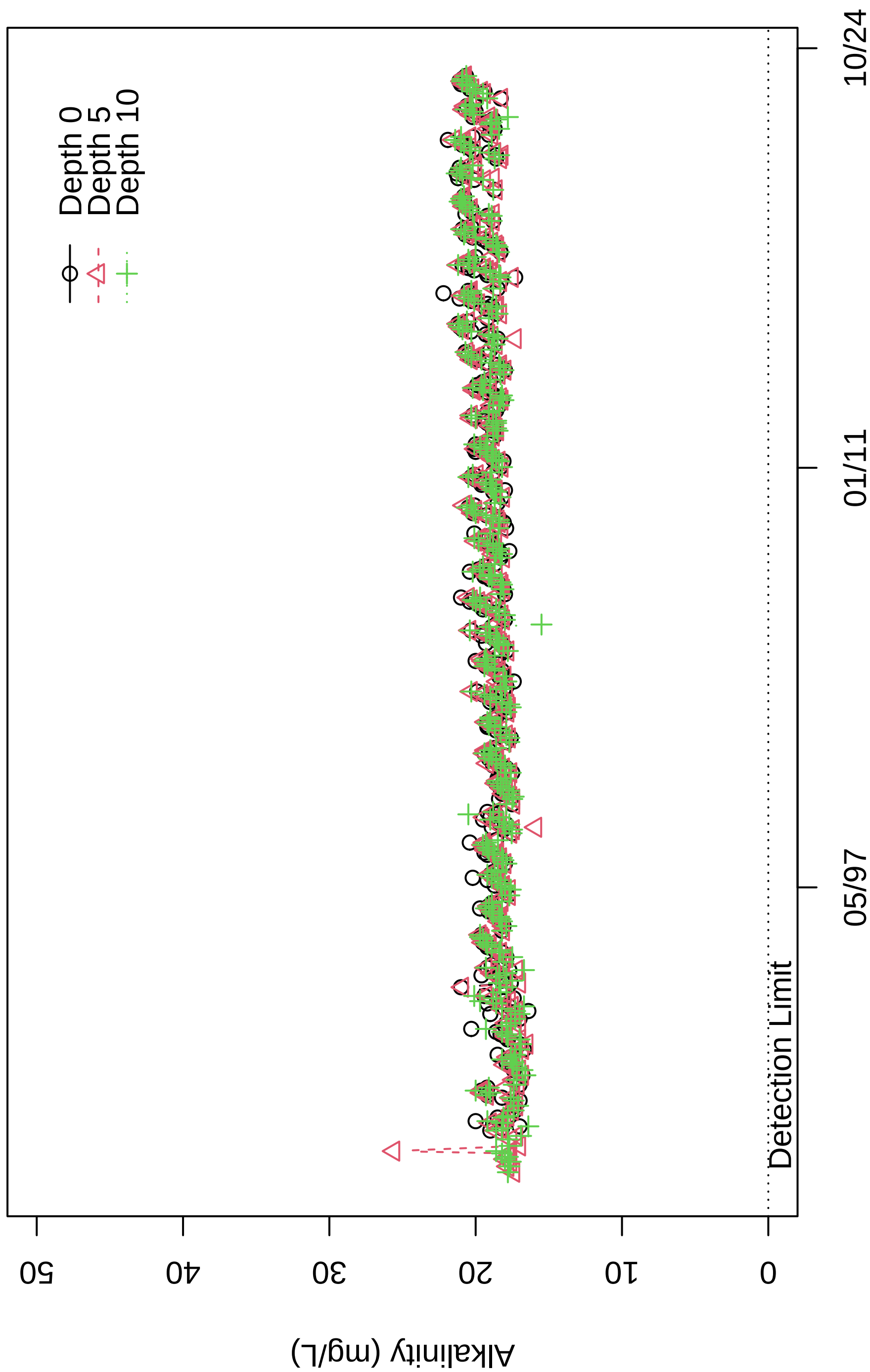


Figure B88: Lake Whatcom alkalinity data for the Intake site.

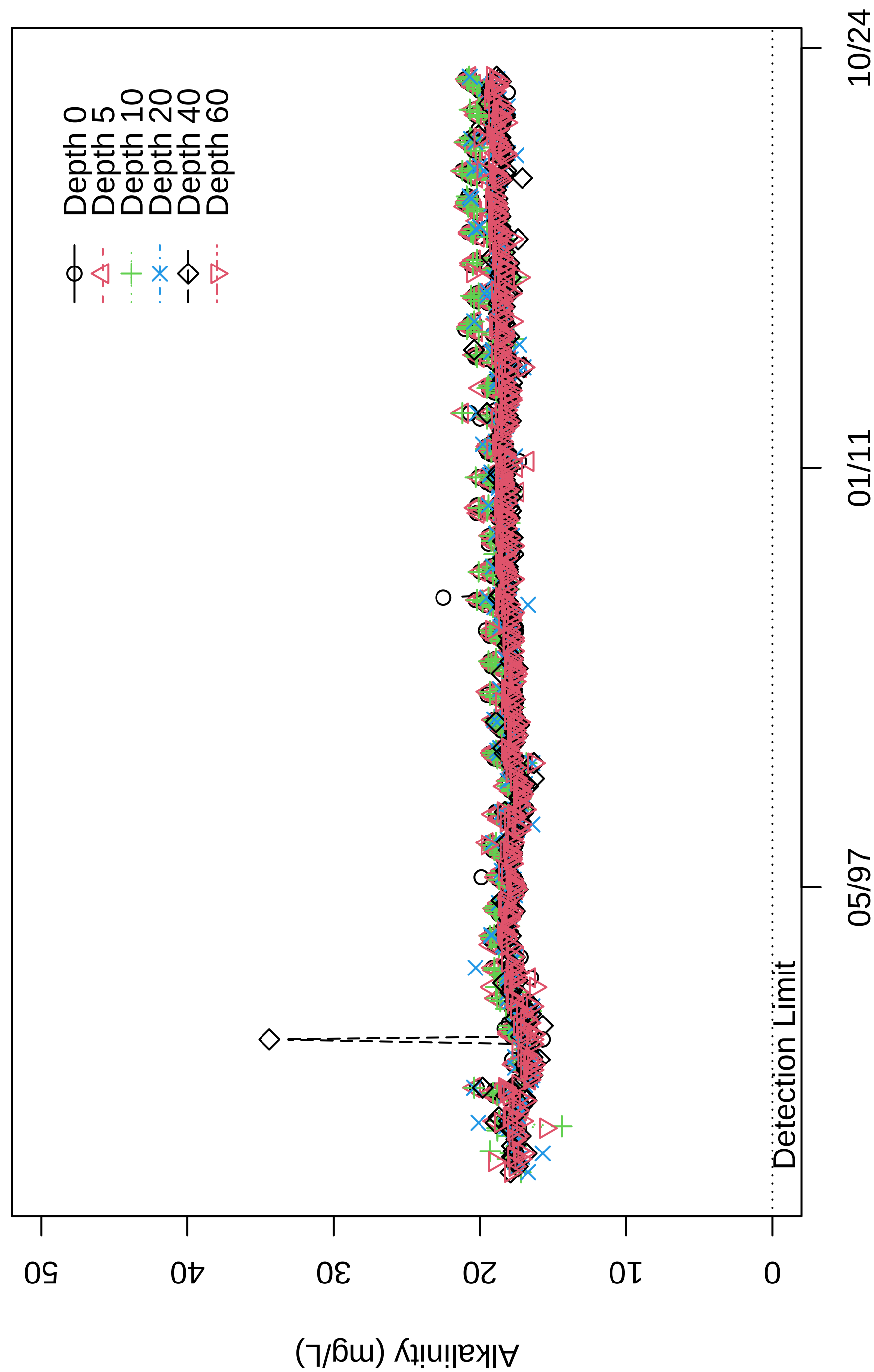


Figure B89: Lake Whatcom alkalinity data for Site 3.

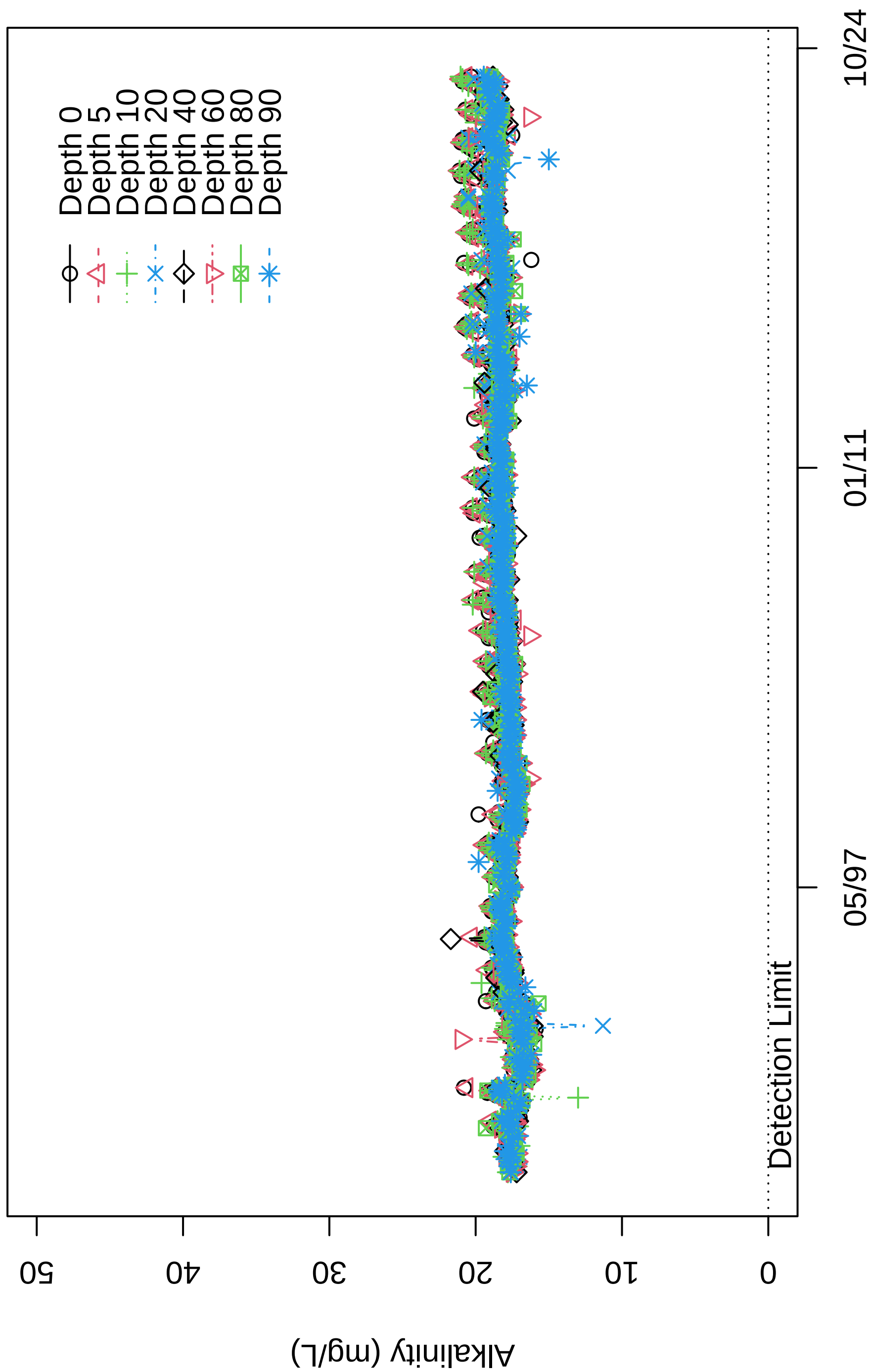


Figure B90: Lake Whatcom alkalinity data for Site 4.

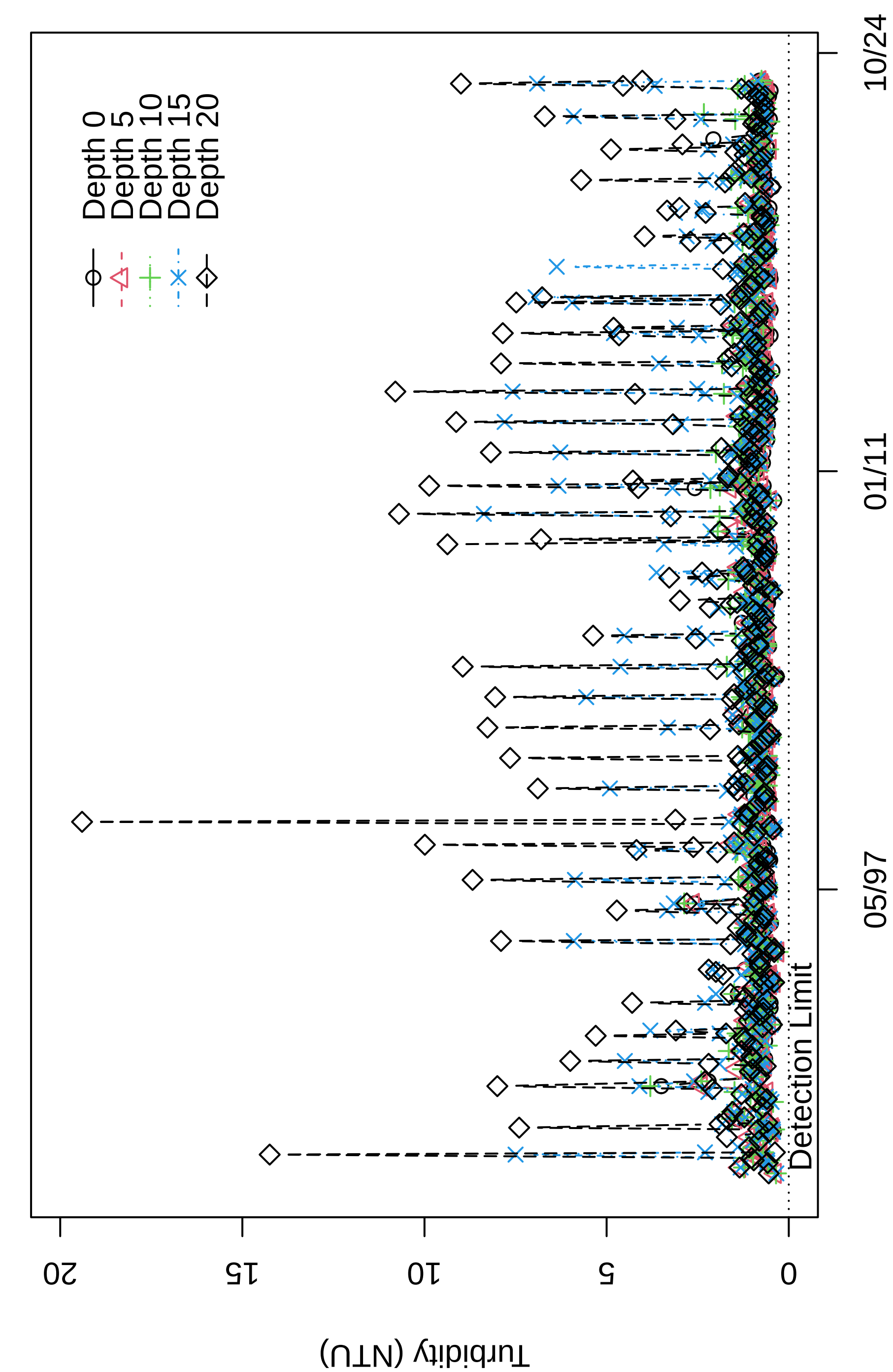


Figure B91: Lake Whatcom turbidity data for Site 1.

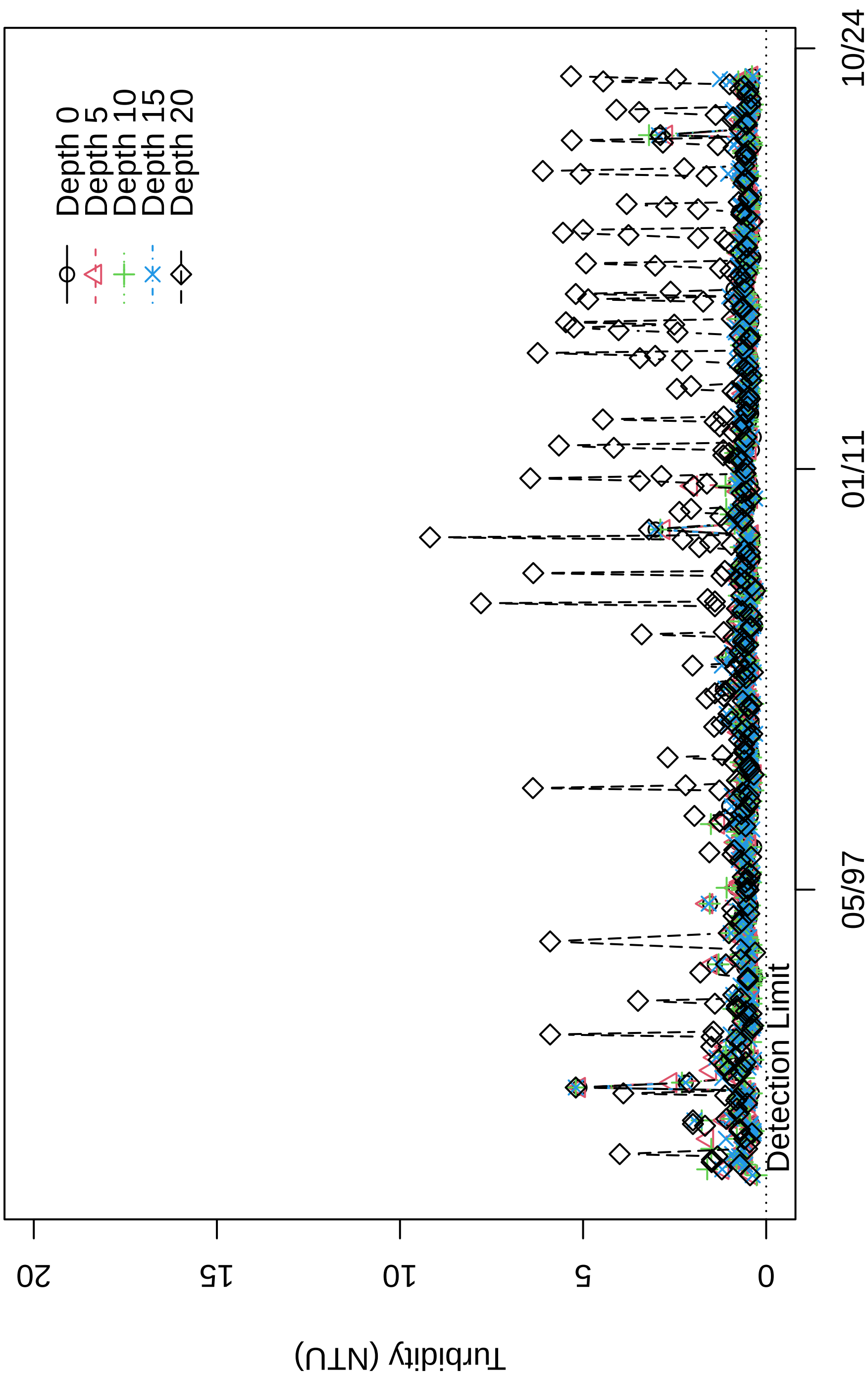


Figure B92: Lake Whatcom turbidity data for Site 2.

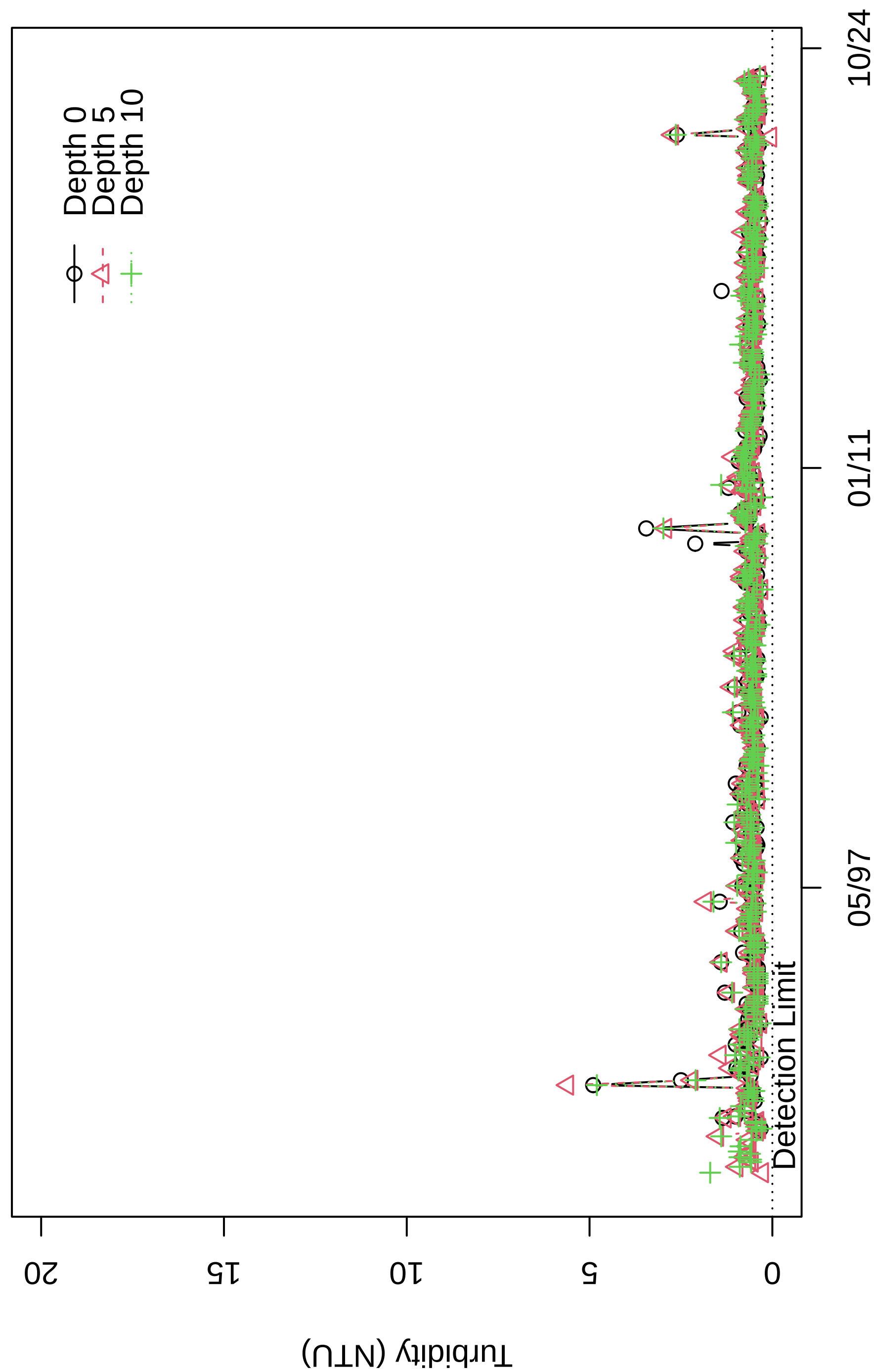


Figure B93: Lake Whatcom turbidity data for the Intake site.

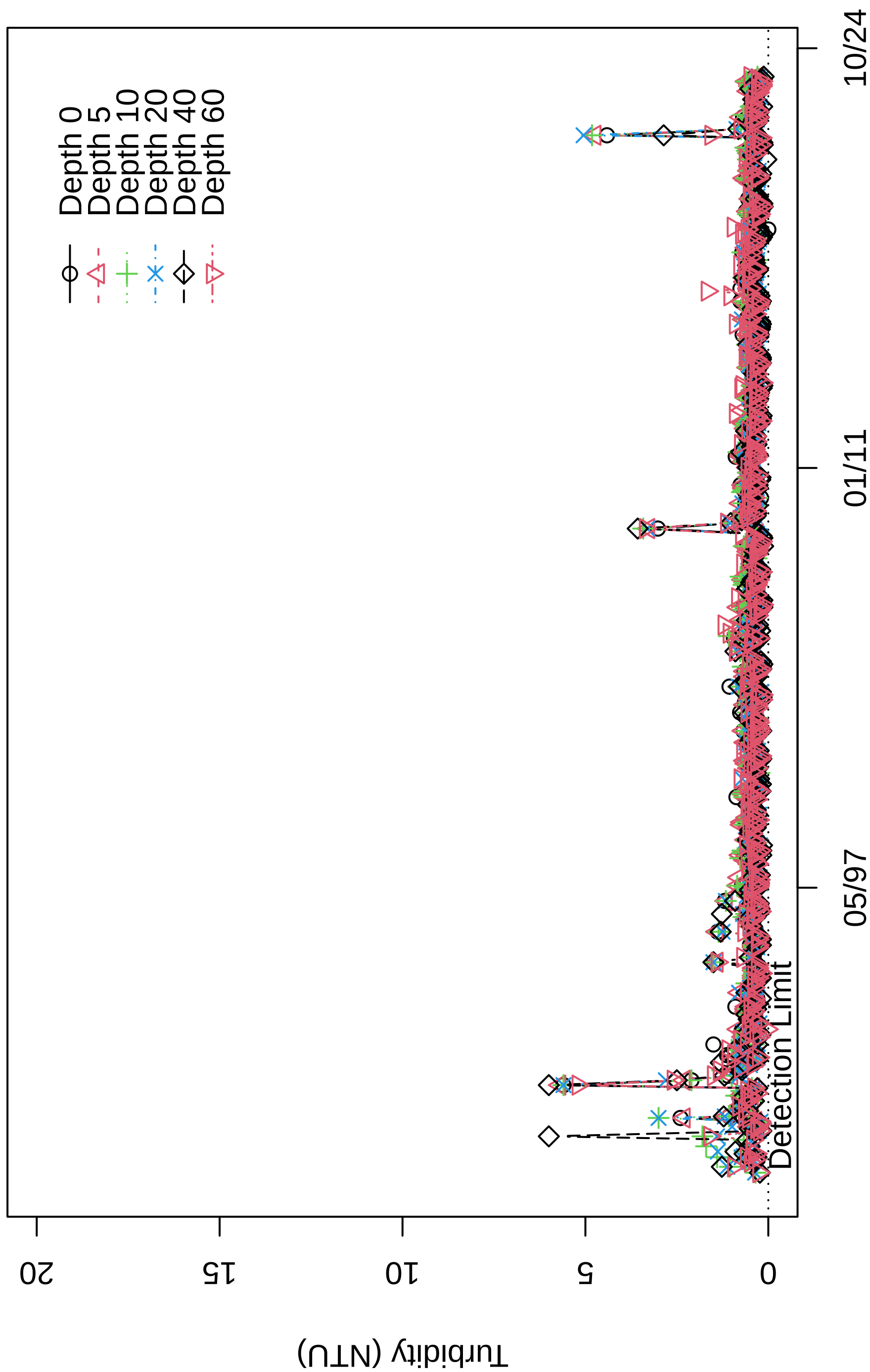


Figure B94: Lake Whatcom turbidity data for Site 3.

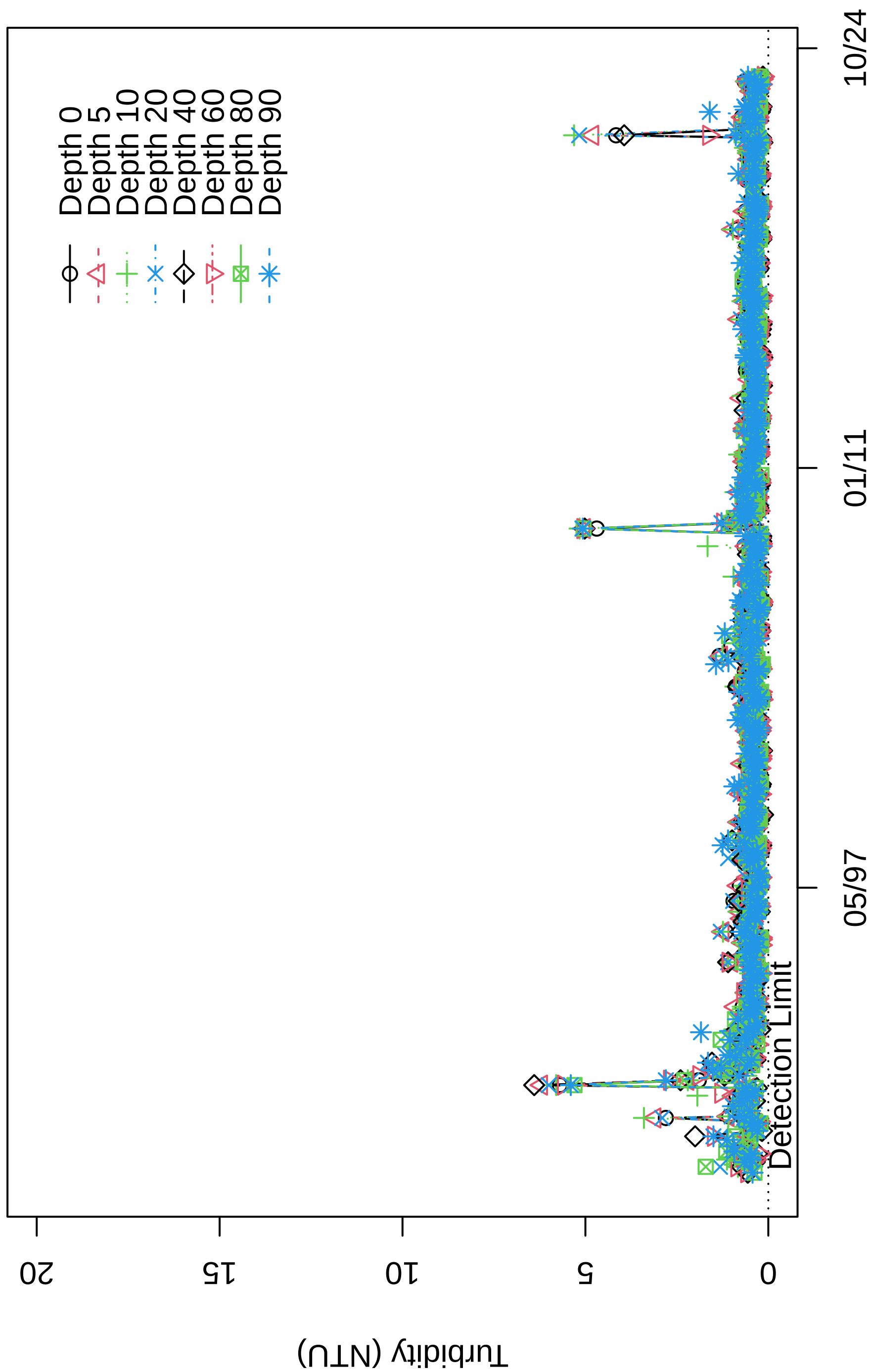


Figure B95: Lake Whatcom turbidity data for Site 4.

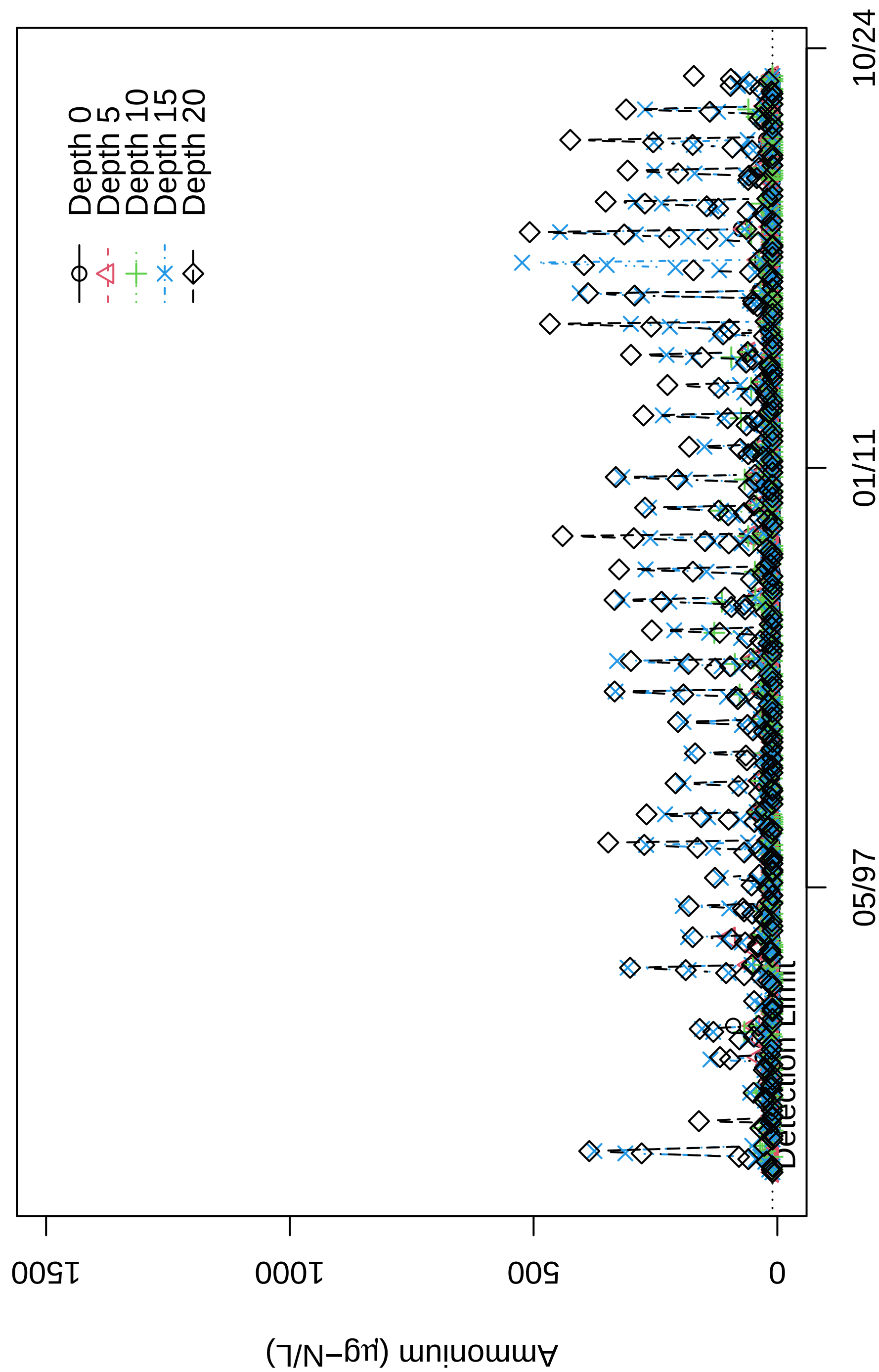


Figure B96: Lake Whatcom ammonium data for Site 1.

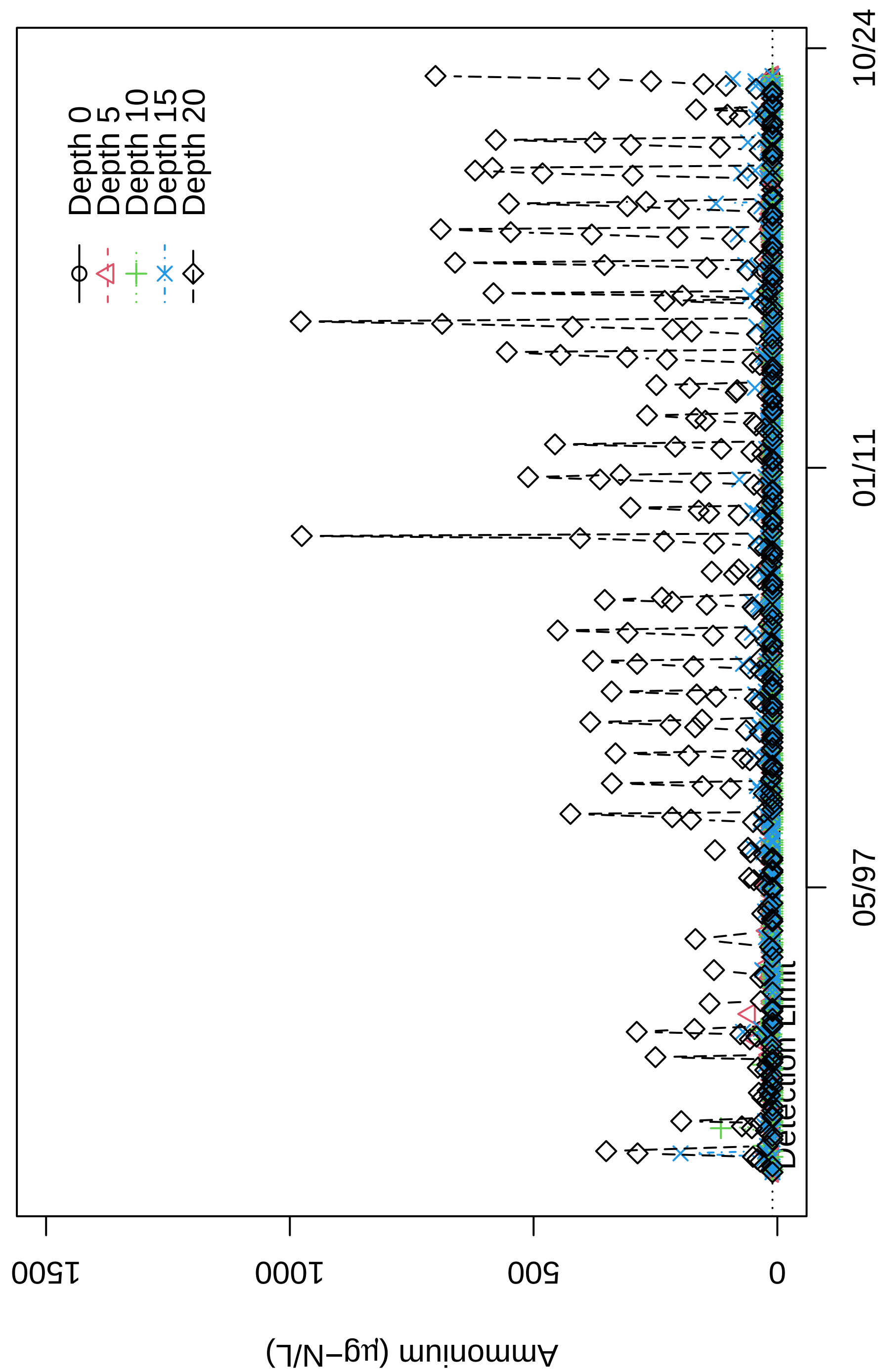


Figure B97: Lake Whatcom ammonium data for Site 2.

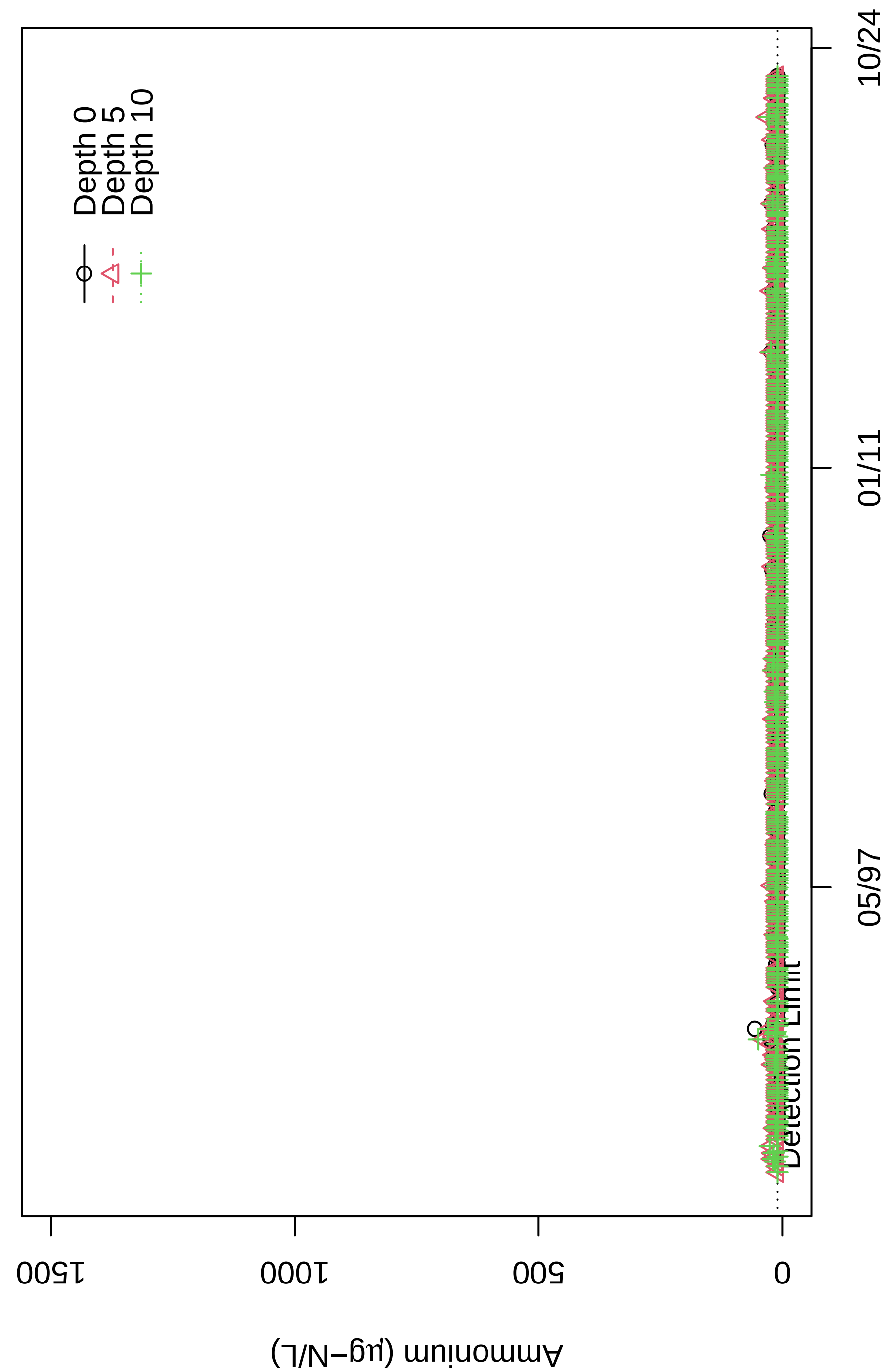


Figure B98: Lake Whatcom ammonium data for the Intake site.

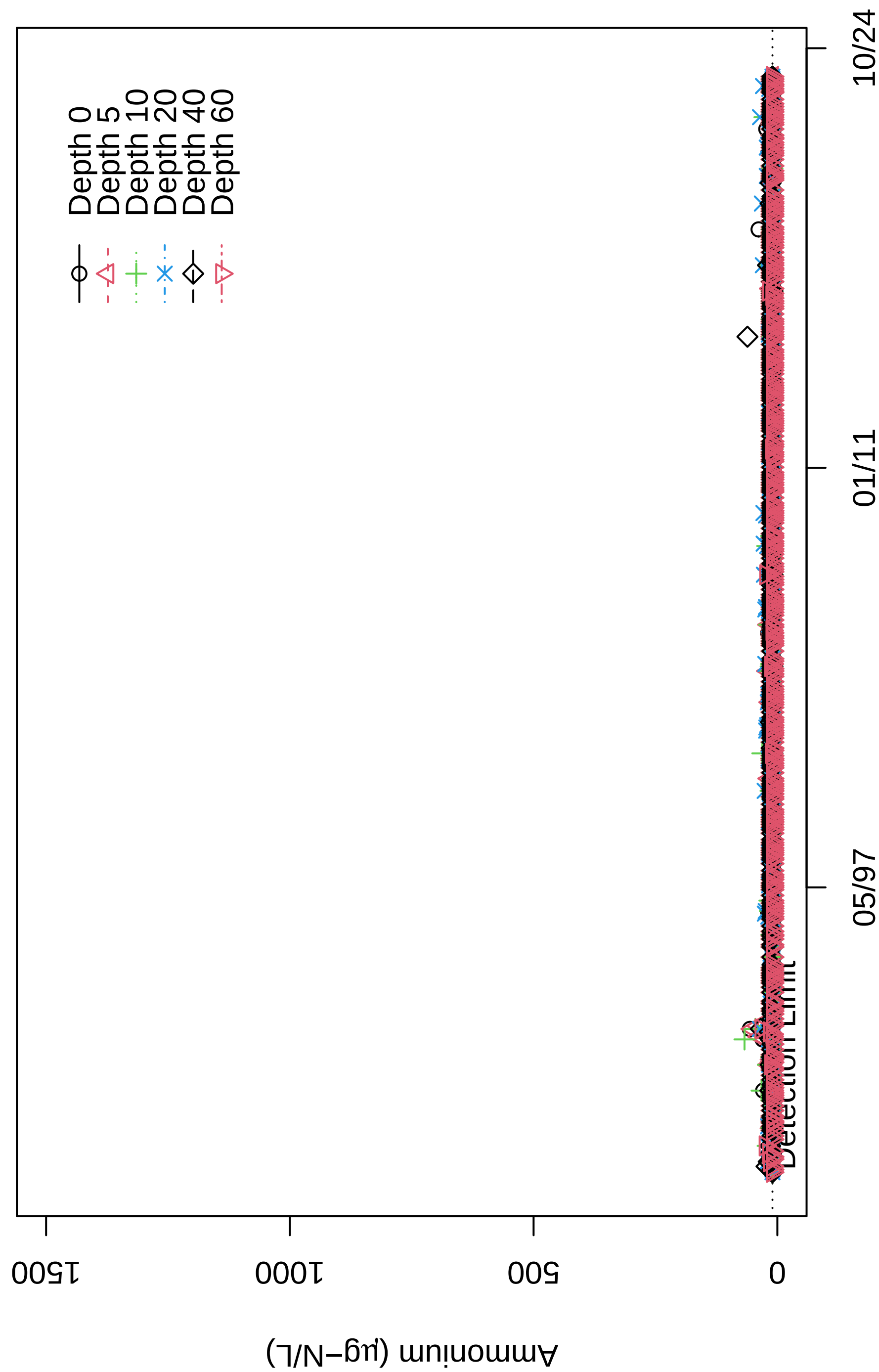


Figure B99: Lake Whatcom ammonium data for Site 3.

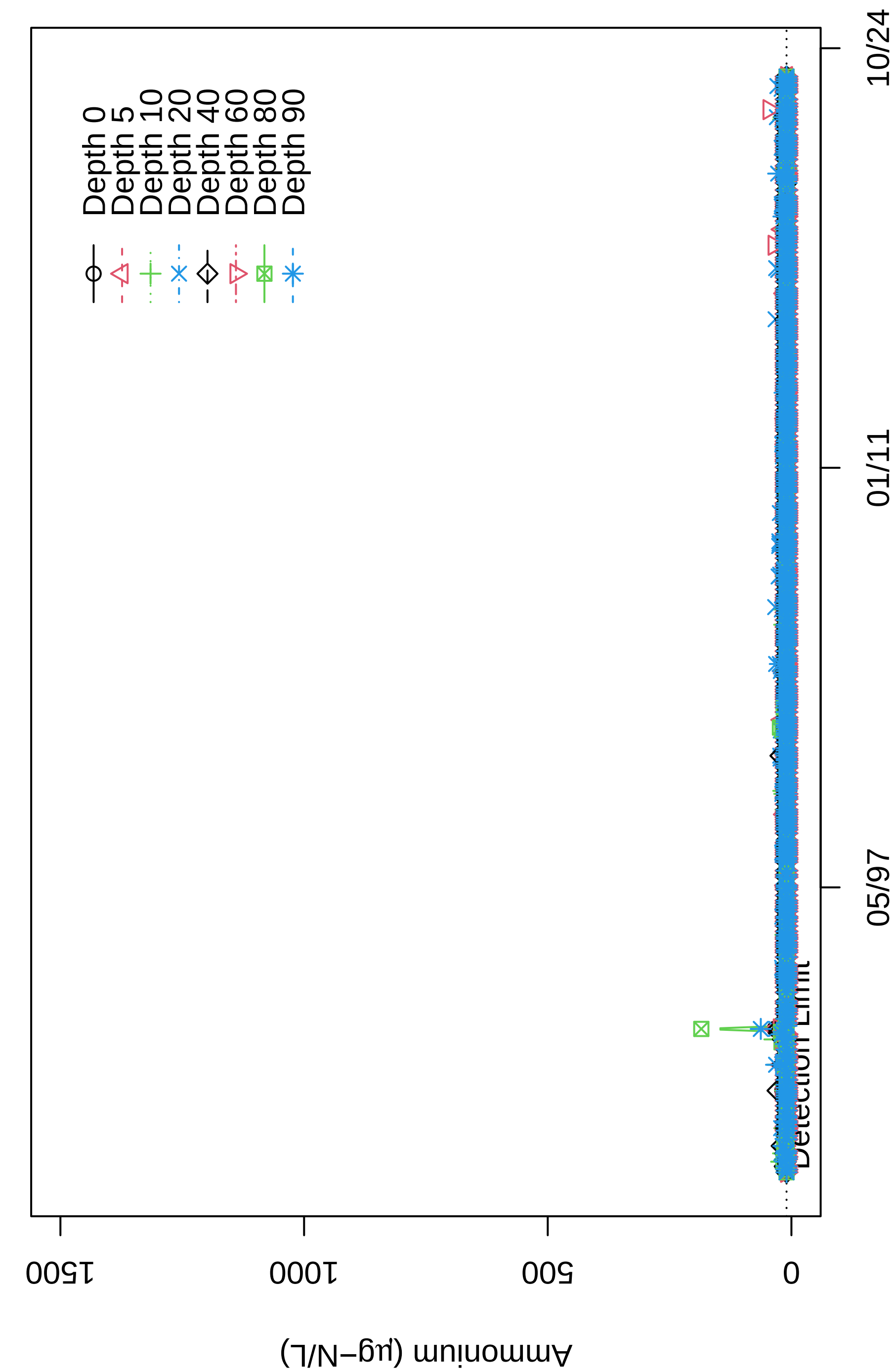


Figure B100: Lake Whatcom ammonium data for Site 4.

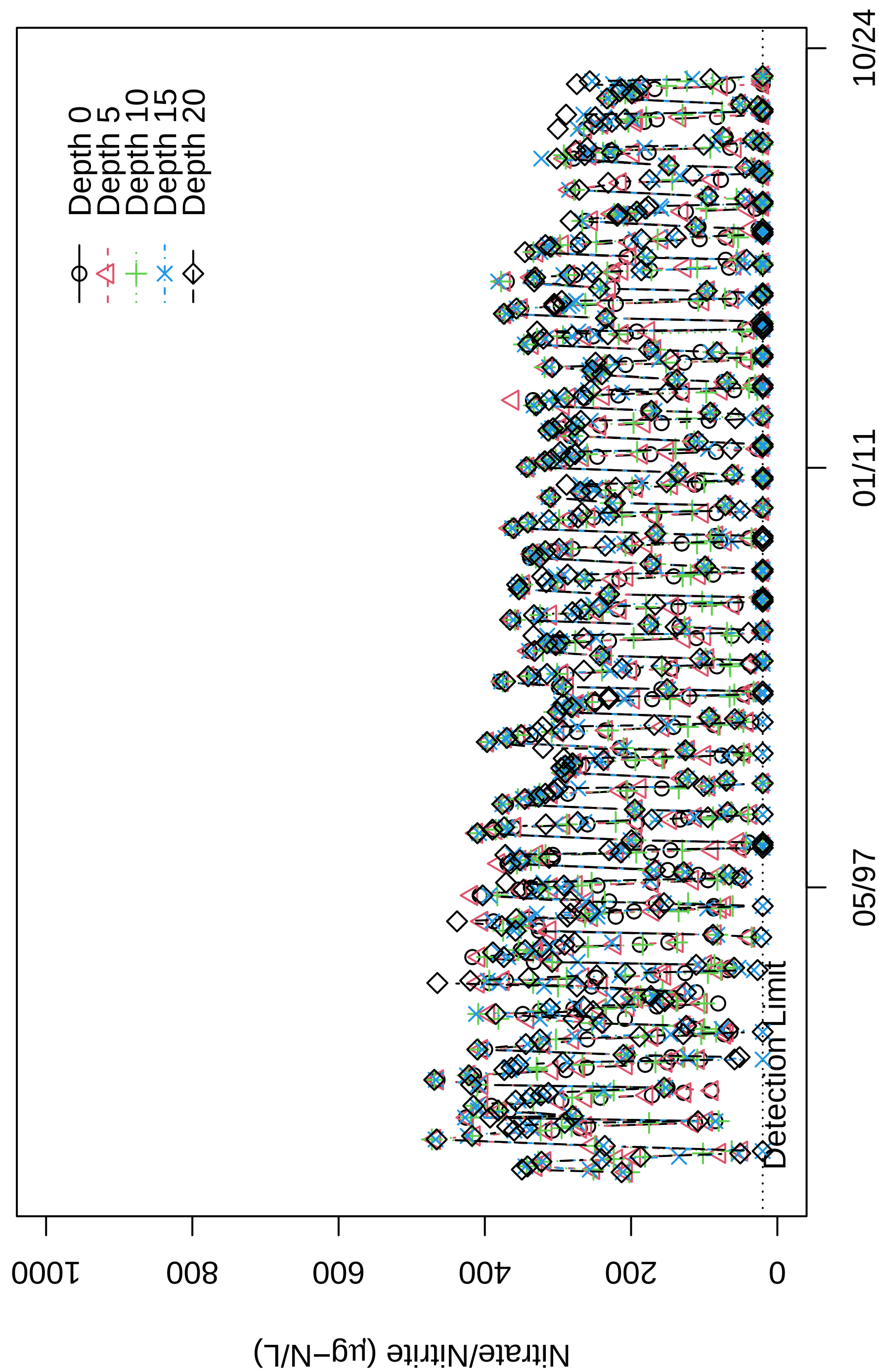


Figure B101: Lake Whatcom nitrate/nitrite data for Site 1.

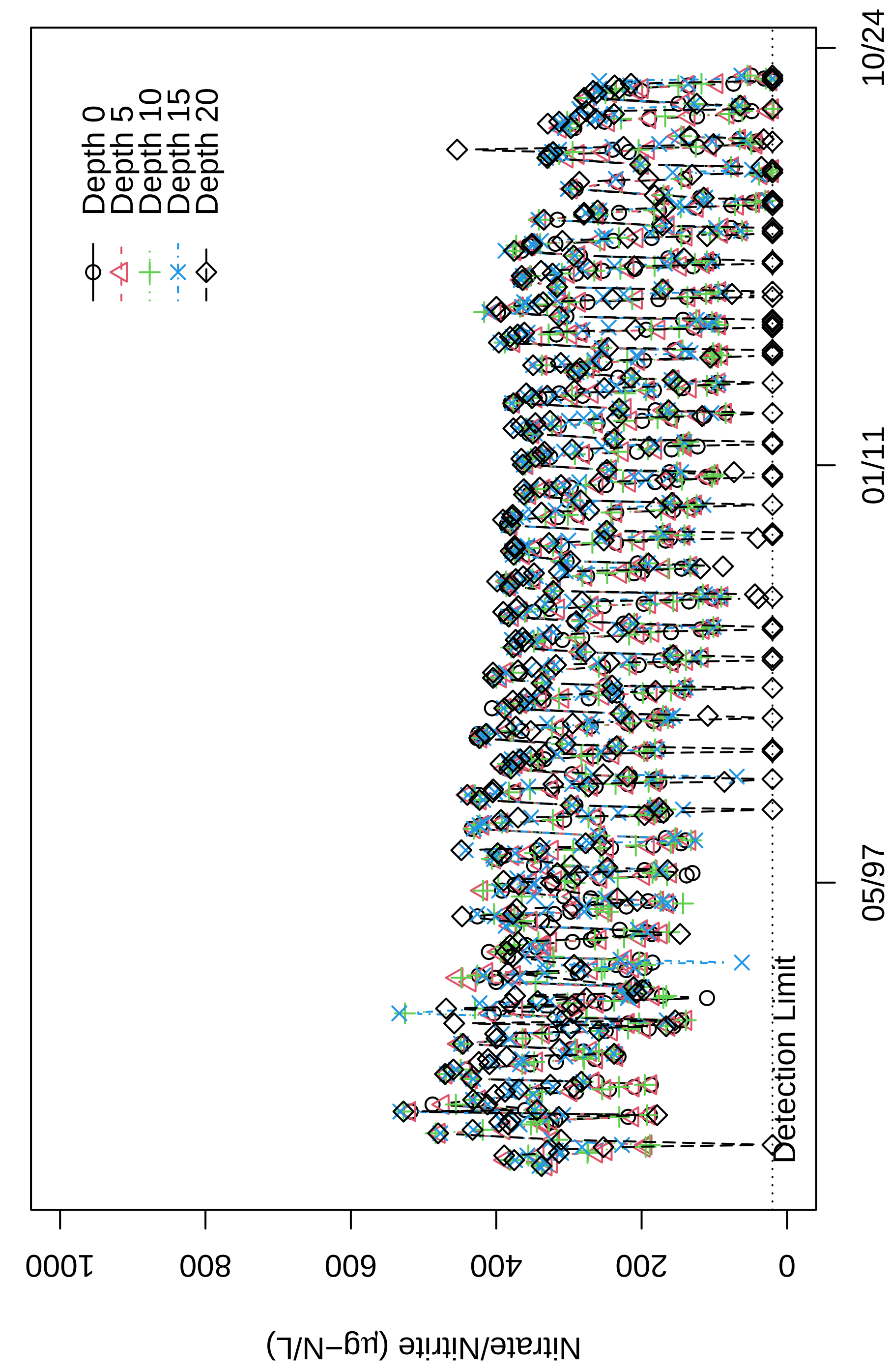


Figure B102: Lake Whatcom nitrate/nitrite data for Site 2.

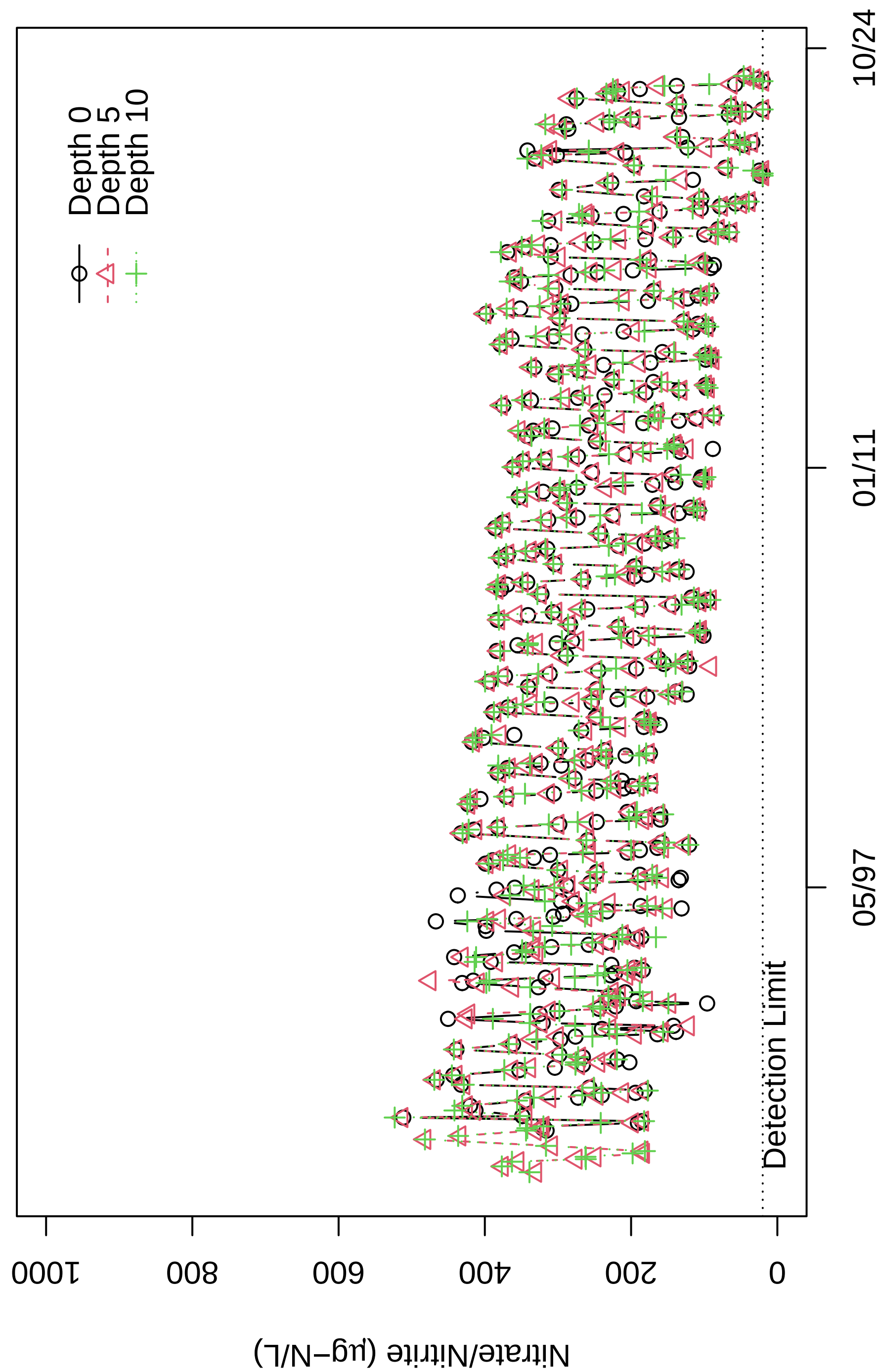


Figure B103: Lake Whatcom nitrate/nitrite data for the Intake site.

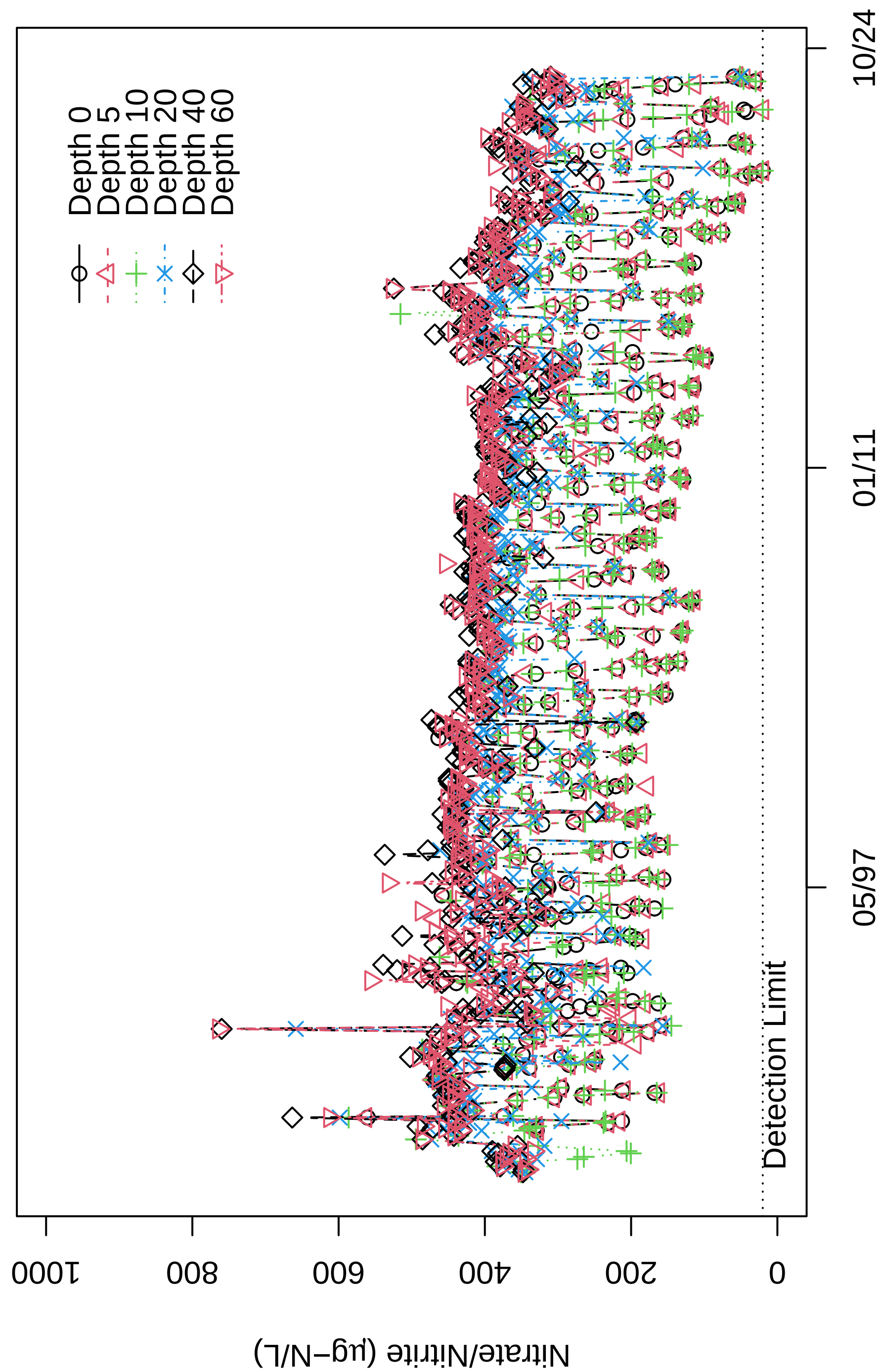


Figure B104: Lake Whatcom nitrate/nitrite data for Site 3.

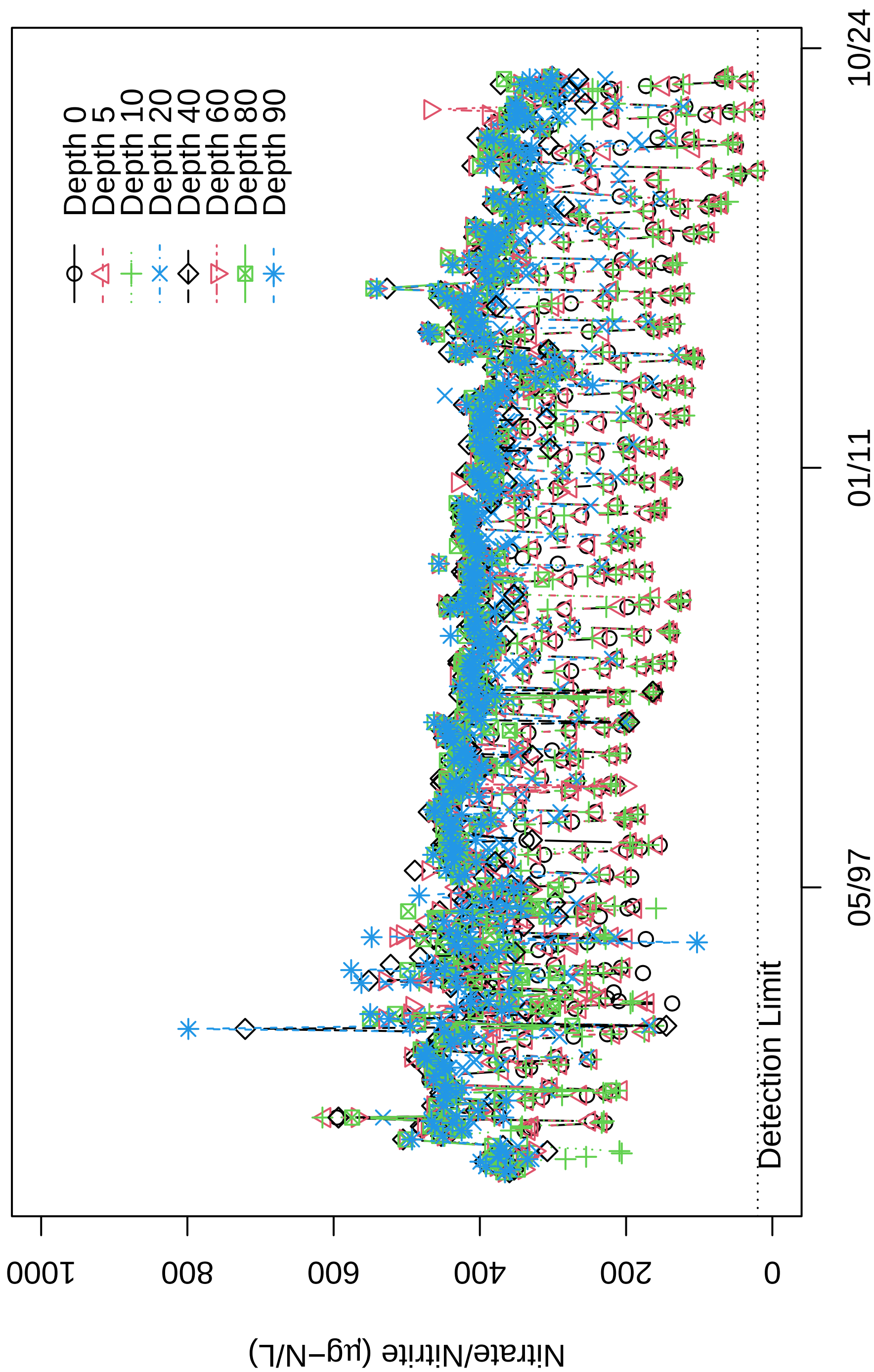


Figure B105: Lake Whatcom nitrate/nitrite data for Site 4.

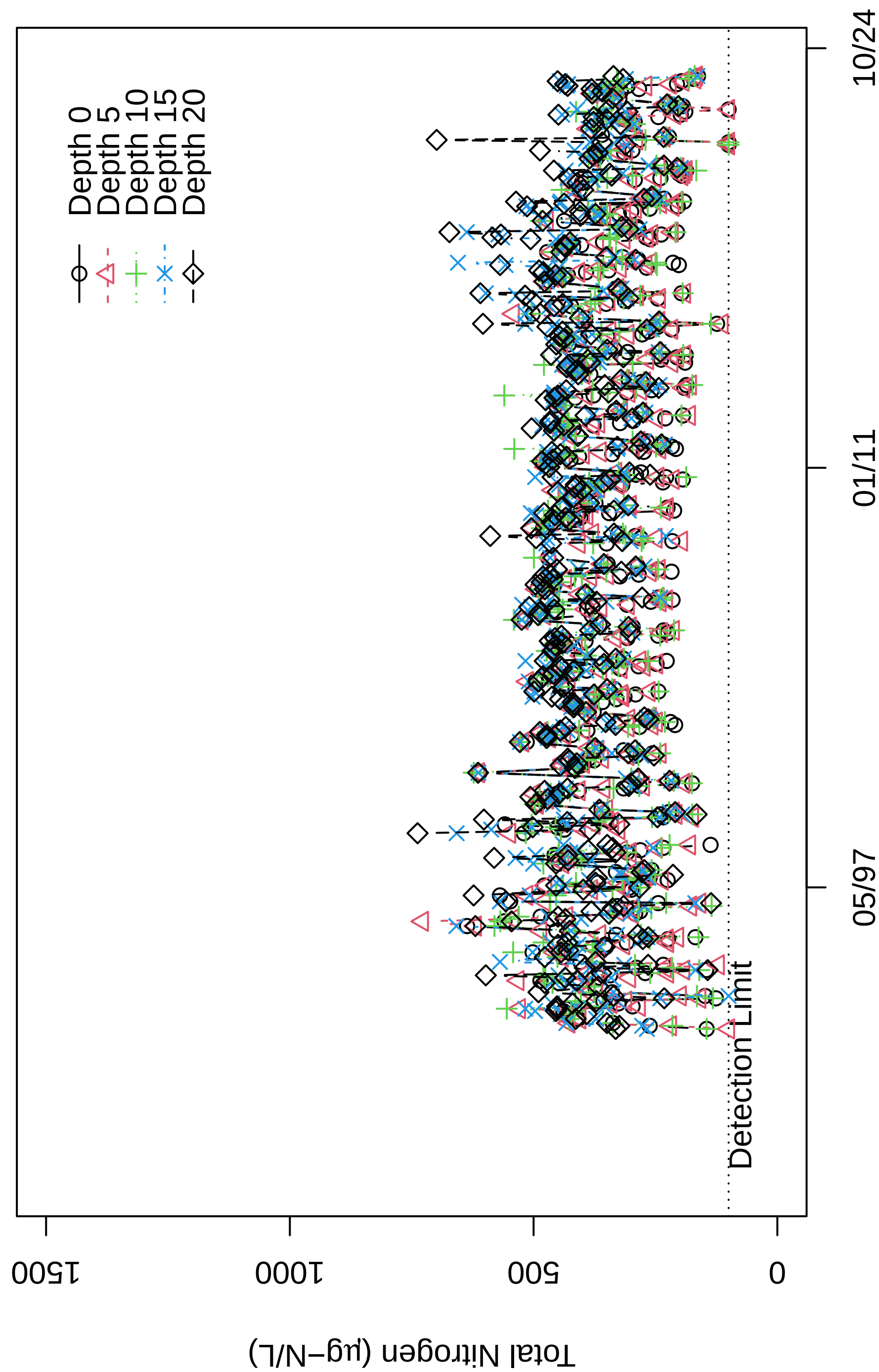


Figure B106: Lake Whatcom total nitrogen data for Site 1.

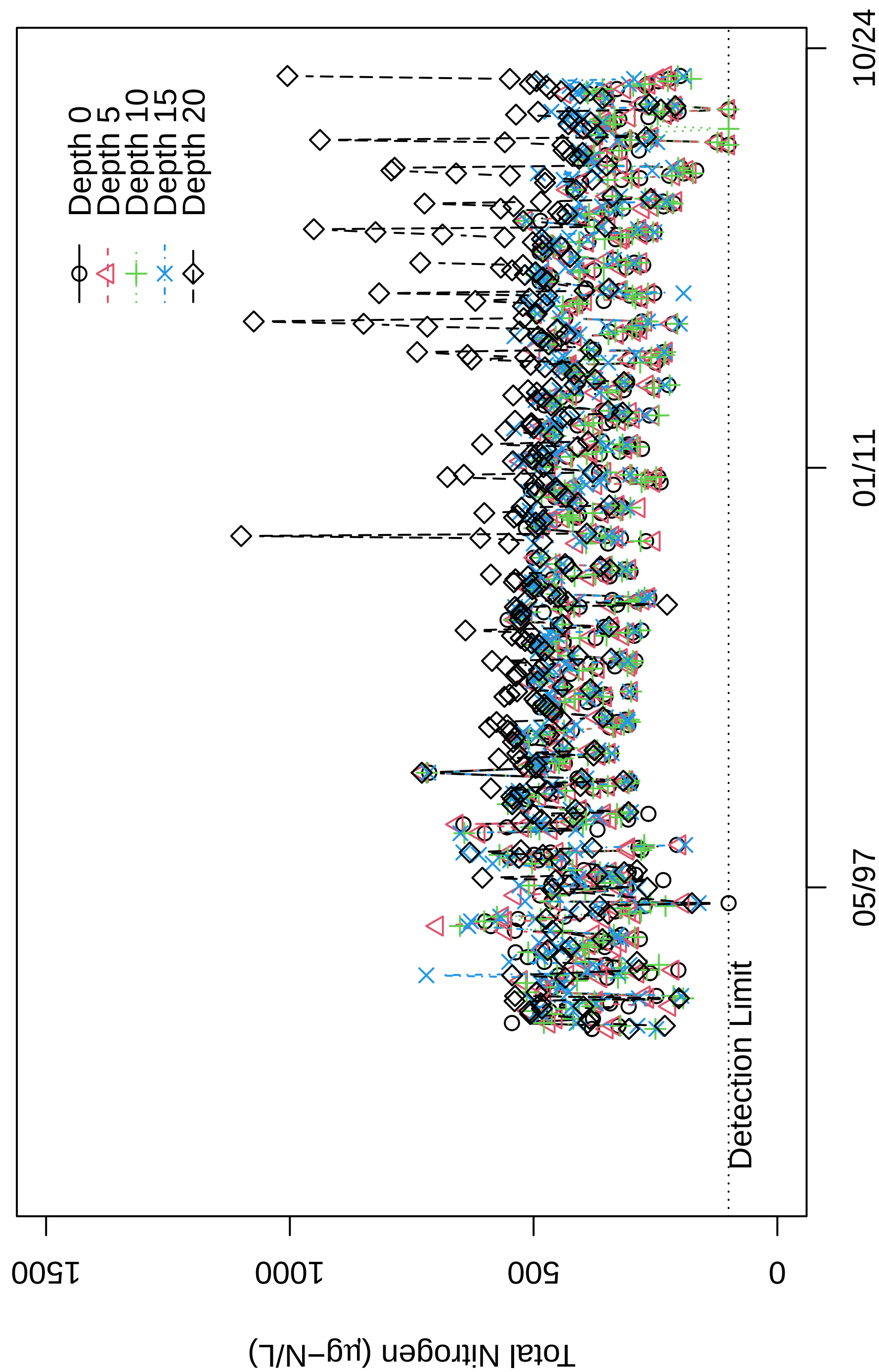


Figure B107: Lake Whatcom total nitrogen data for Site 2.

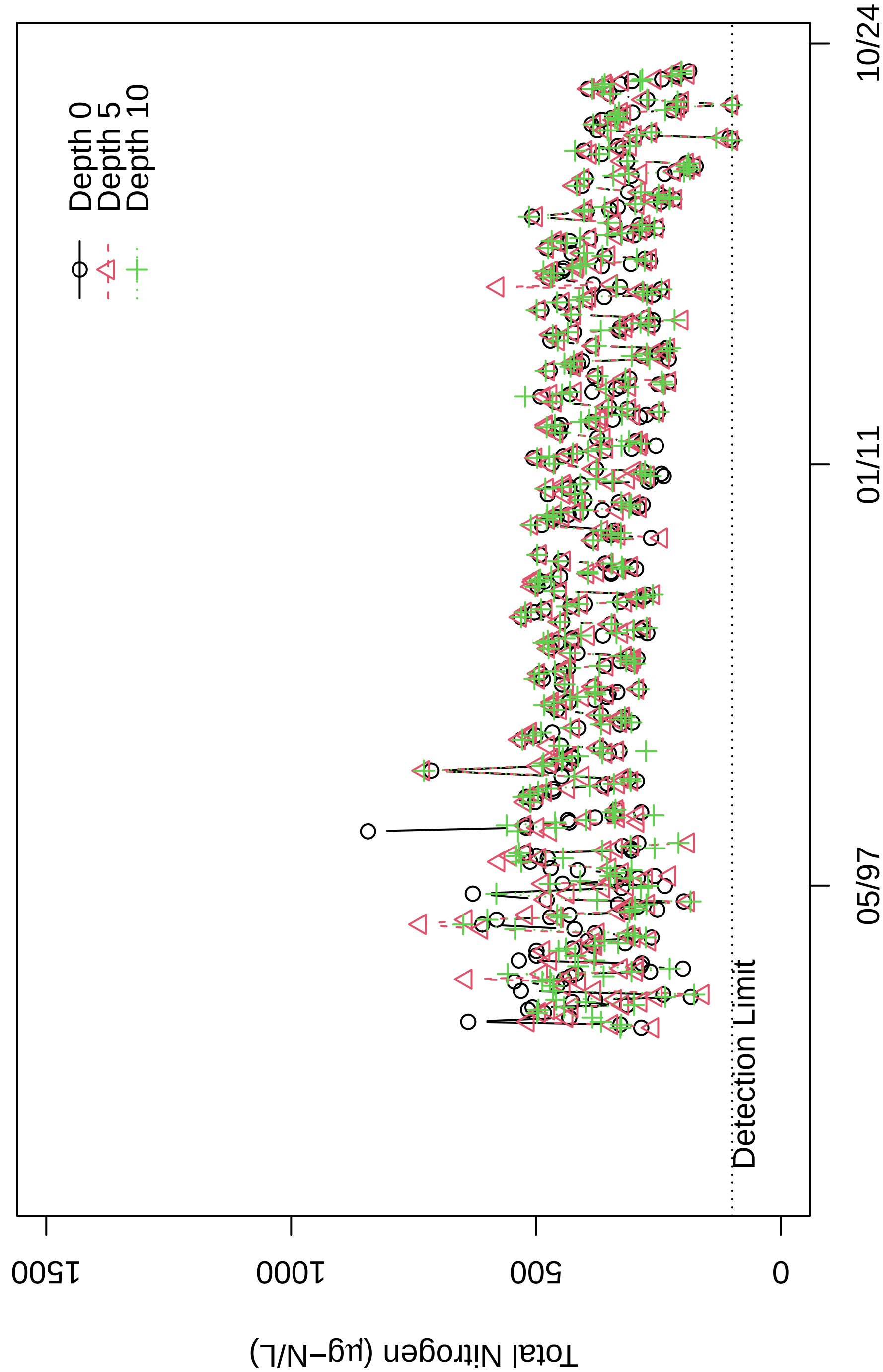


Figure B108: Lake Whatcom total nitrogen data for the Intake site.

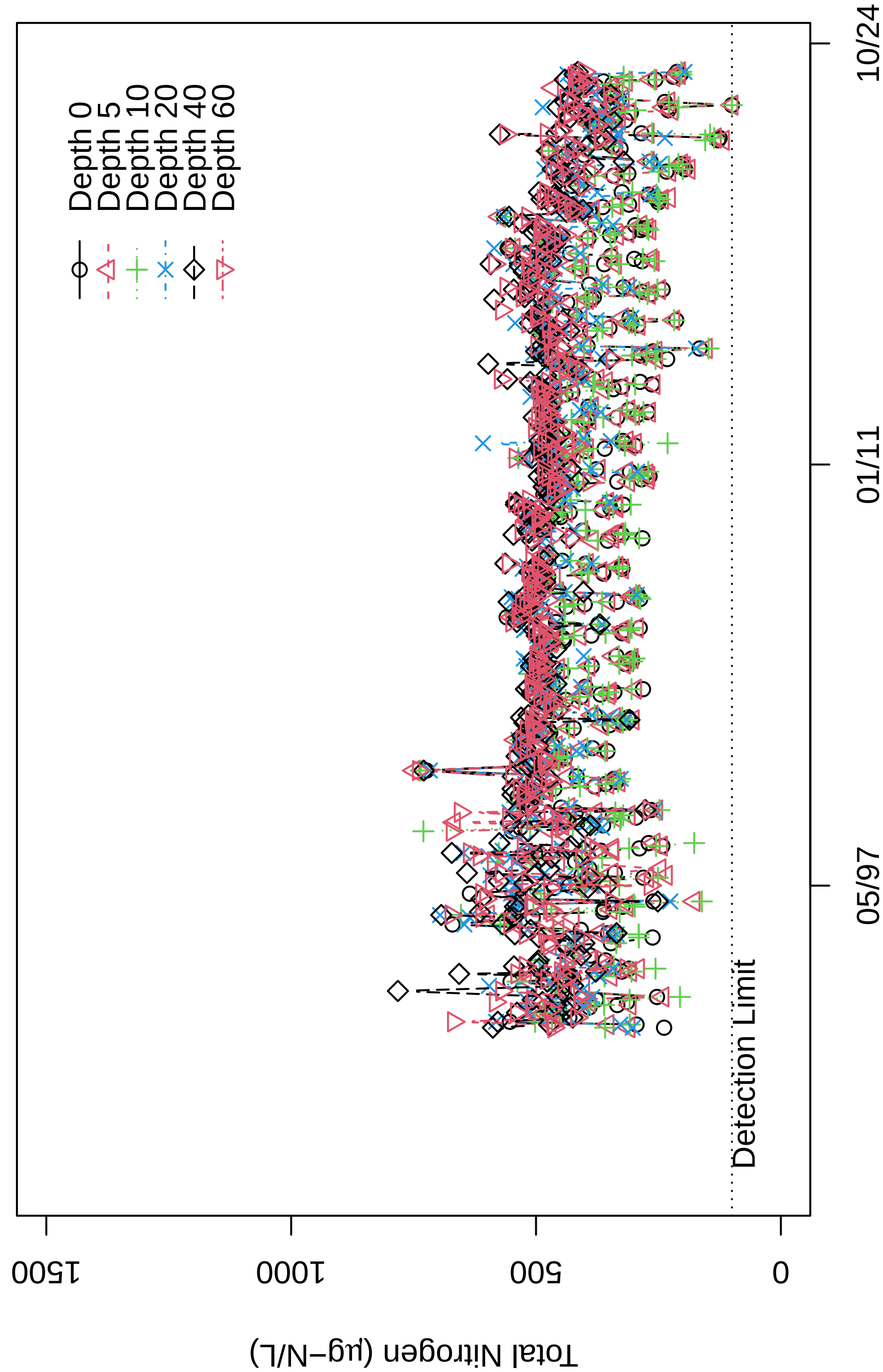


Figure B109: Lake Whatcom total nitrogen data for Site 3.

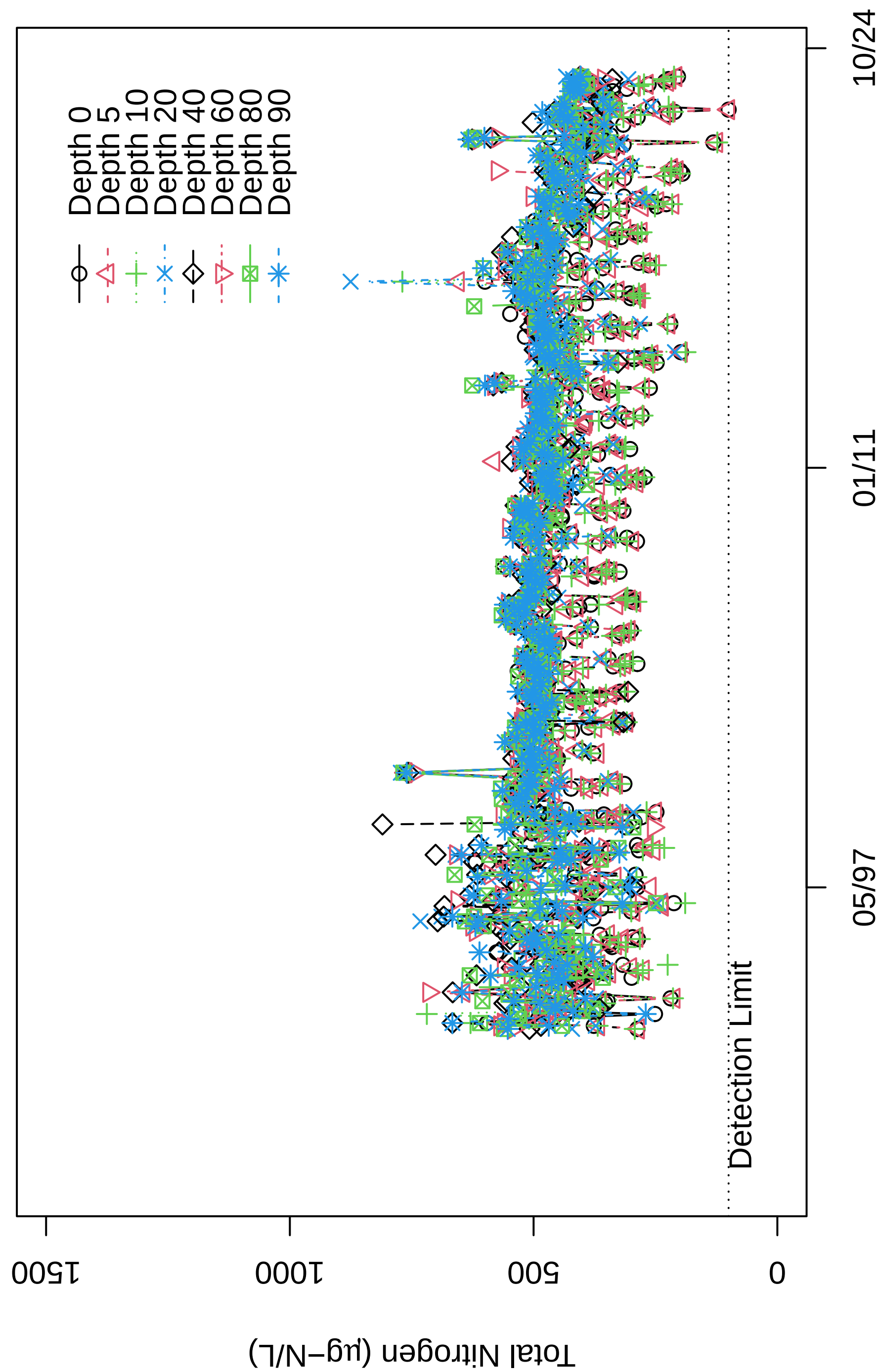


Figure B110: Lake Whatcom total nitrogen data for Site 4.

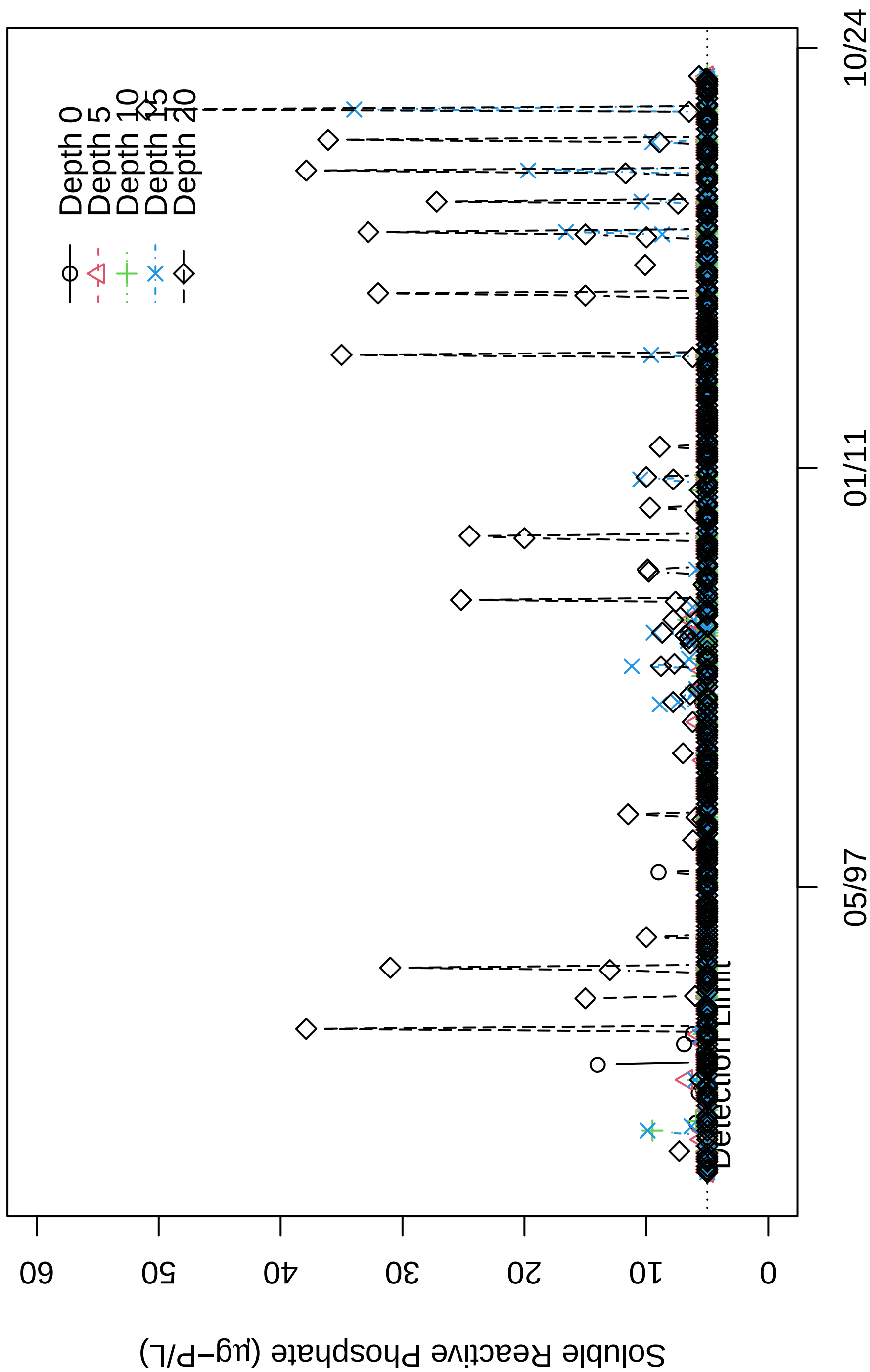


Figure B111: Lake Whatcom soluble phosphate data for Site 1.

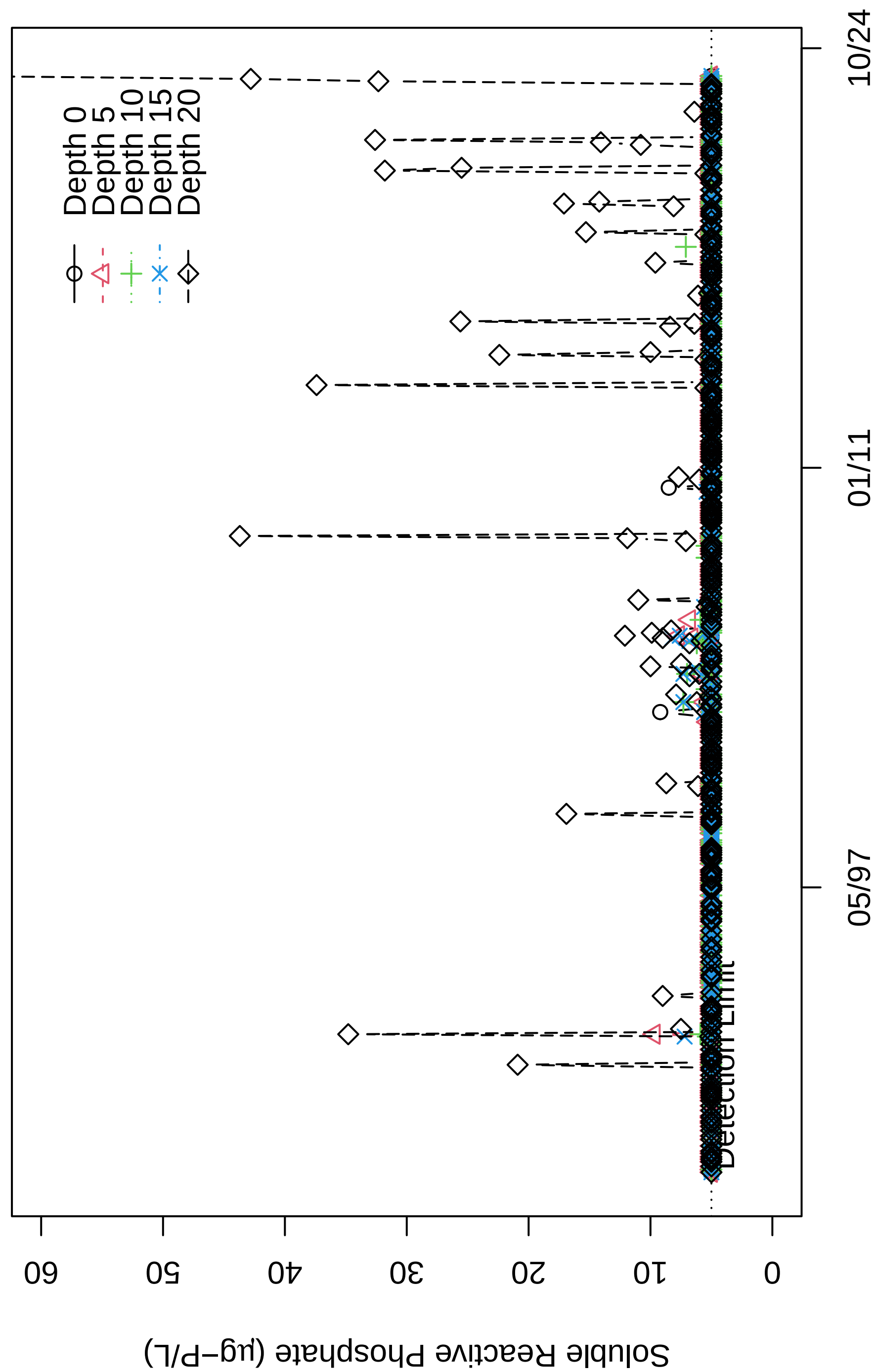


Figure B112: Lake Whatcom soluble phosphate data for Site 2. One data point is outside of the plot range: September 2023, 84.8 μg/L.

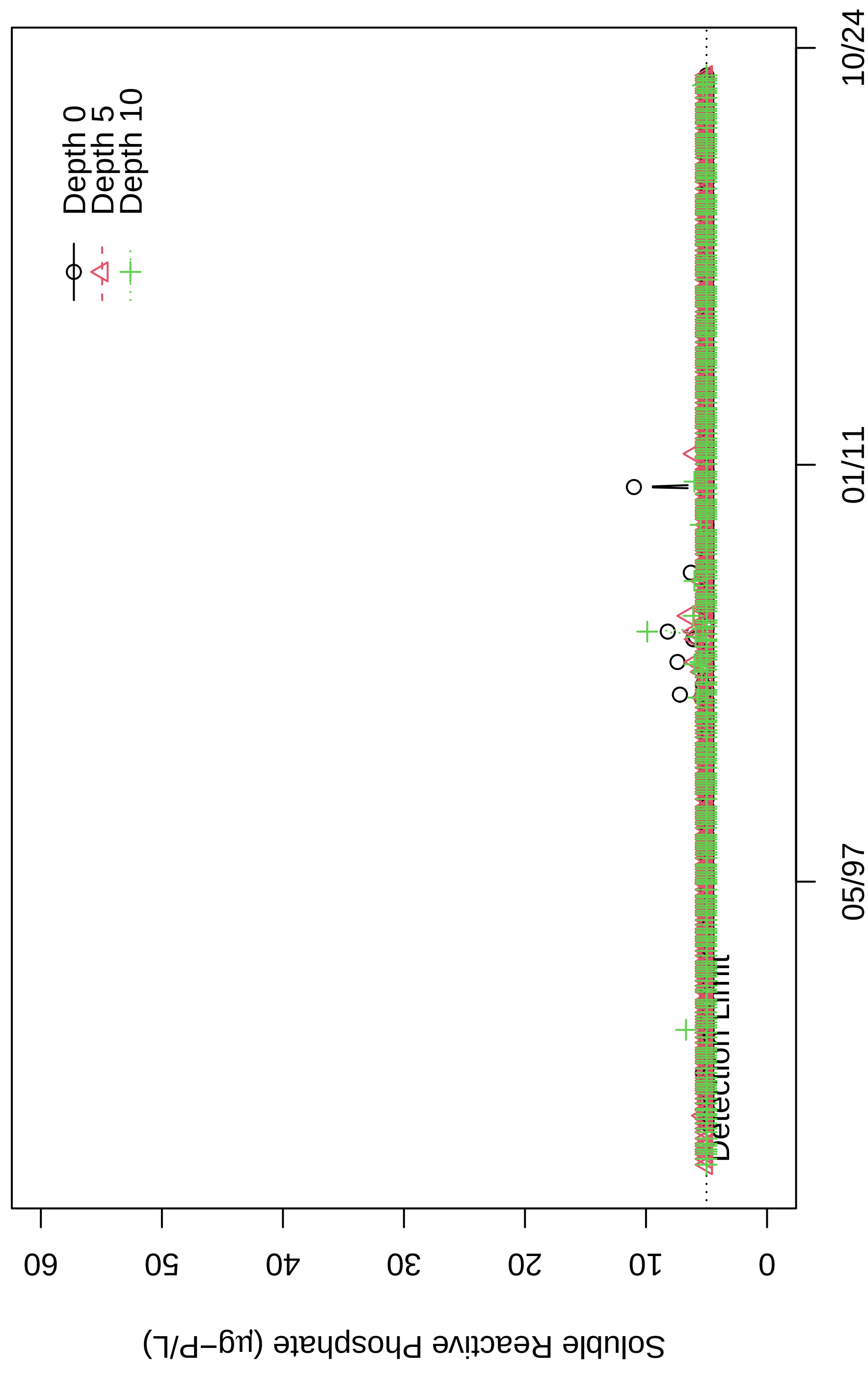


Figure B113: Lake Whatcom soluble phosphate data for the Intake site.

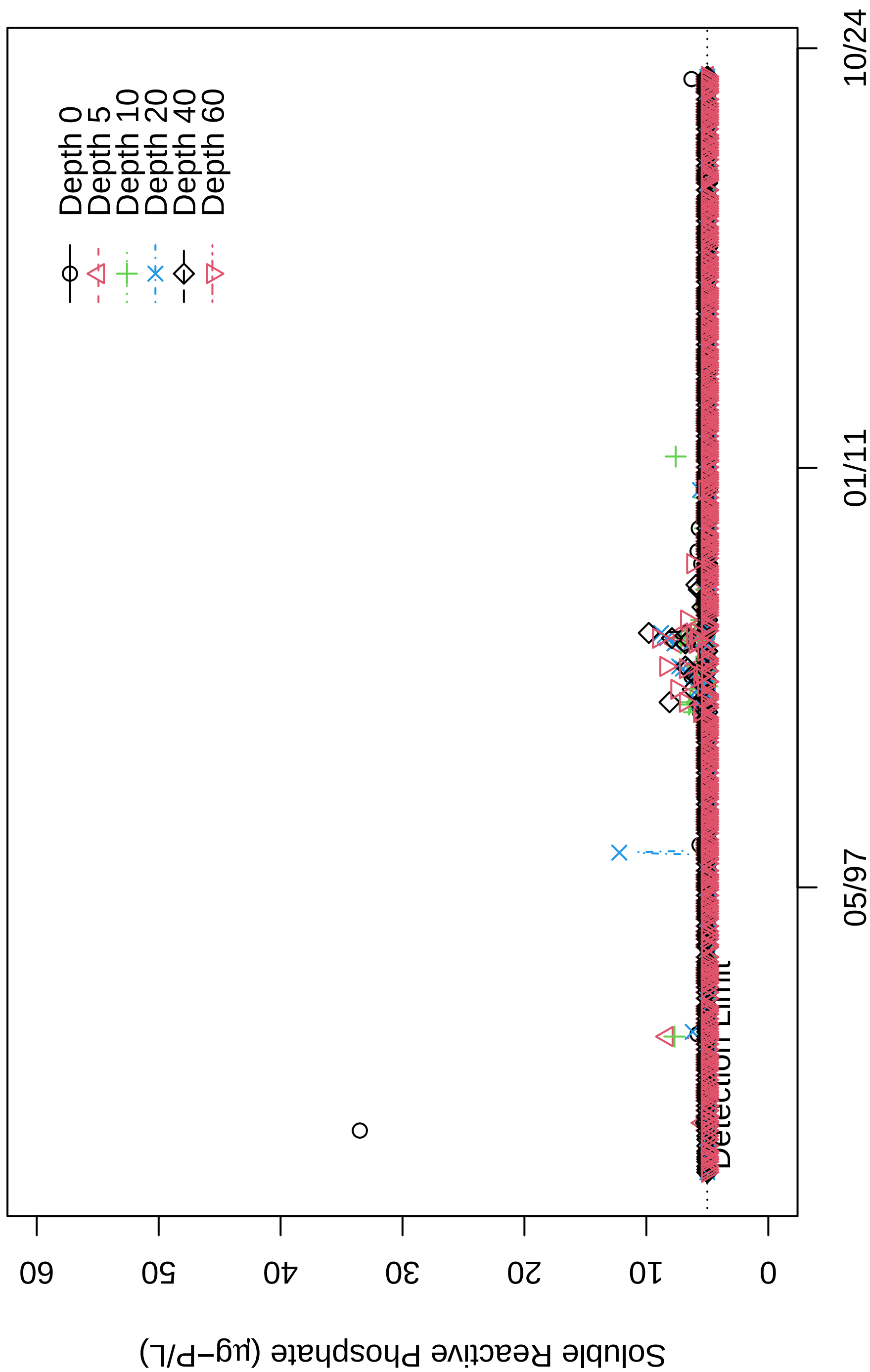


Figure B114: Lake Whatcom soluble phosphate data for Site 3.

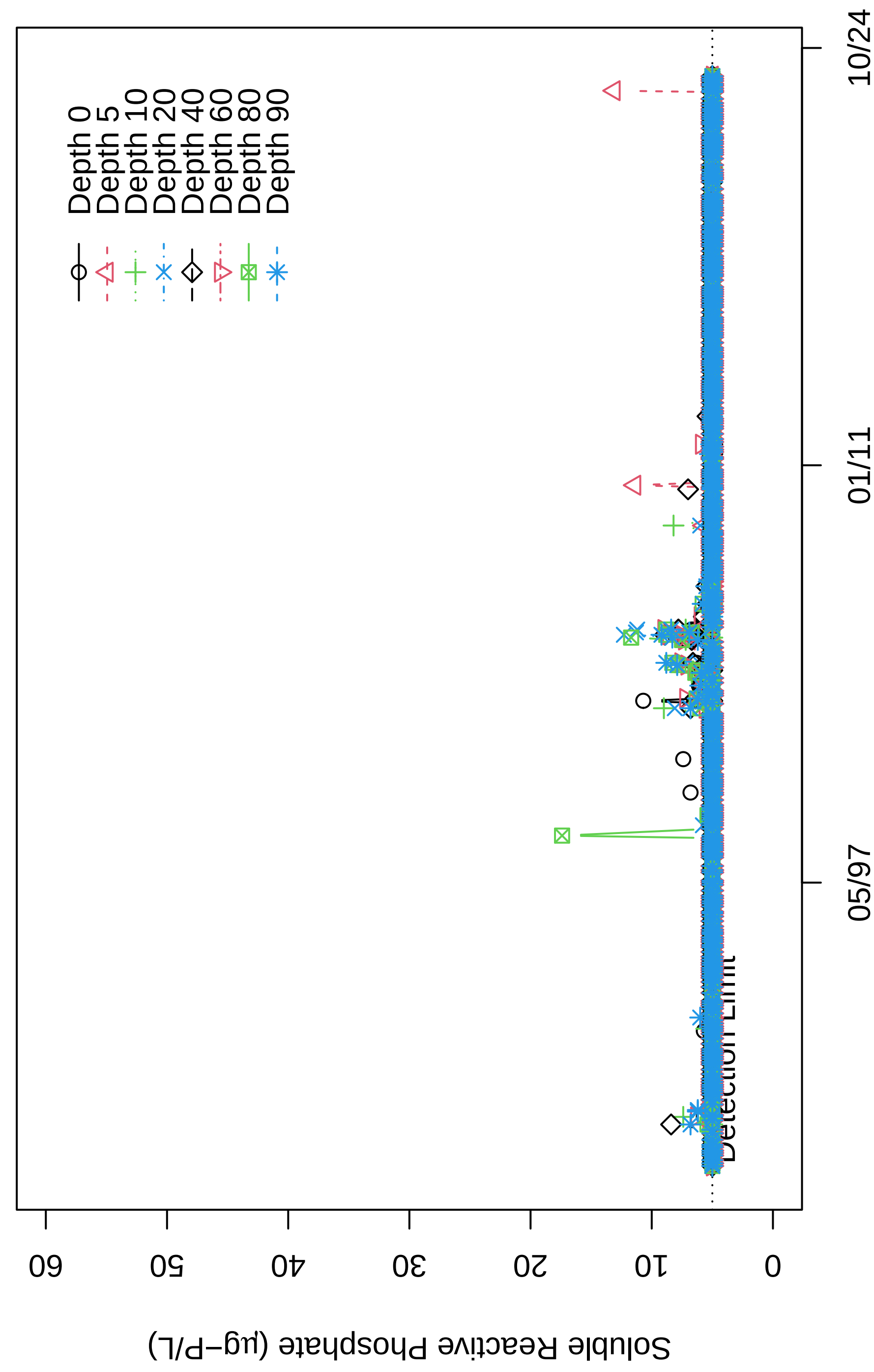


Figure B115: Lake Whatcom soluble phosphate data for Site 4.

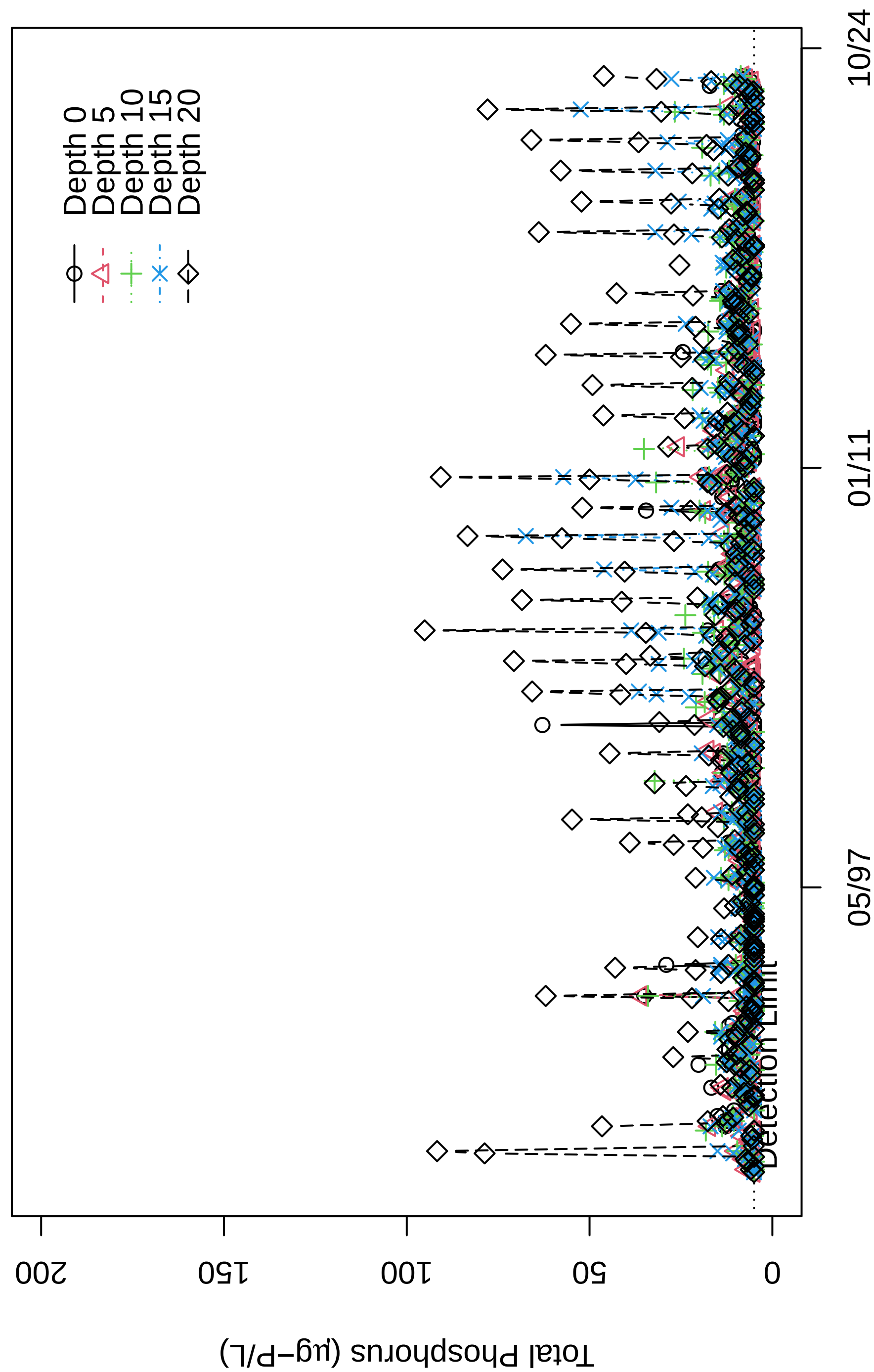


Figure B116: Lake Whatcom total phosphorus data for Site 1.

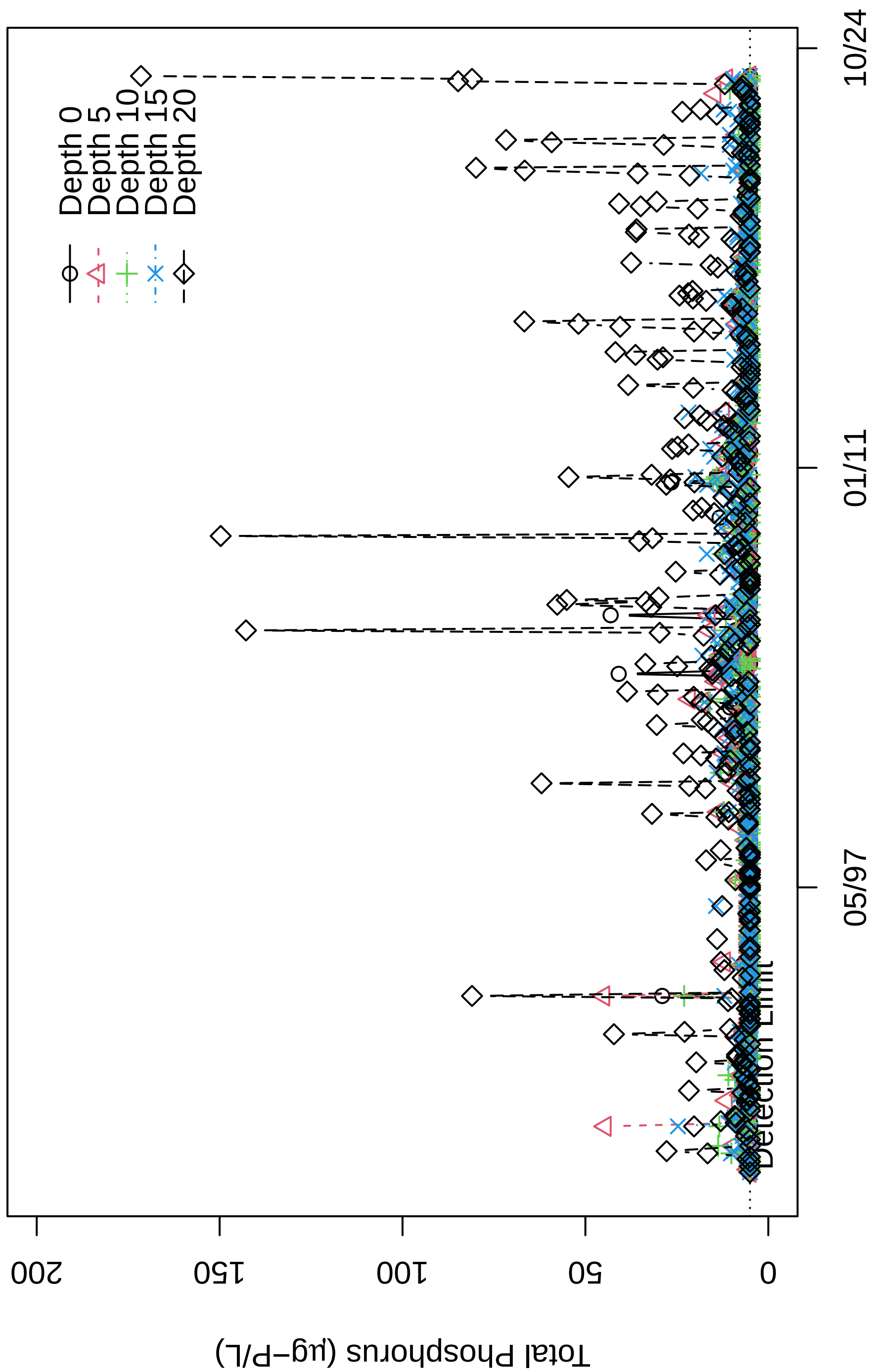


Figure B117: Lake Whatcom total phosphorus data for Site 2.

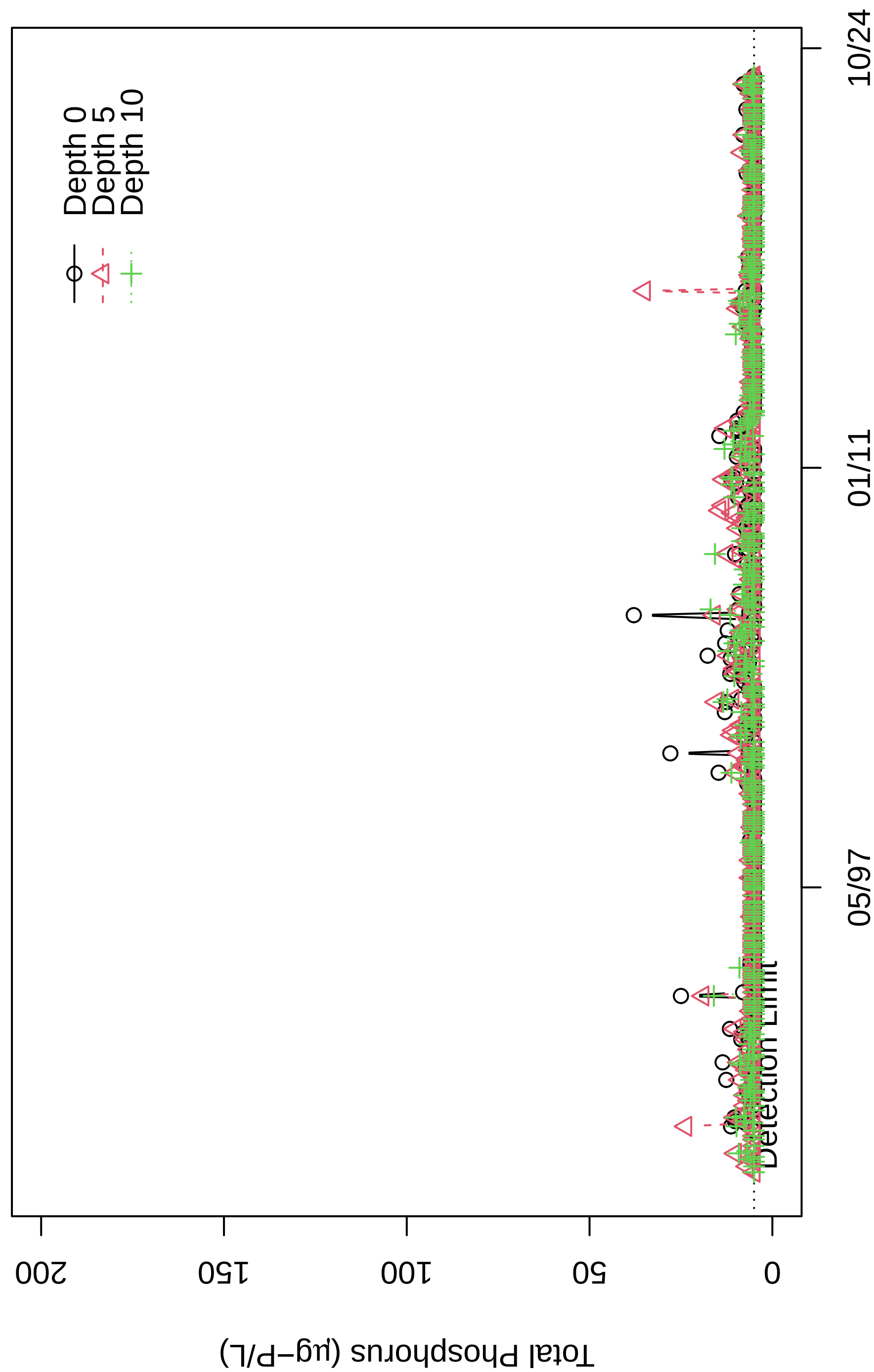


Figure B118: Lake Whatcom total phosphorus data for the Intake site.

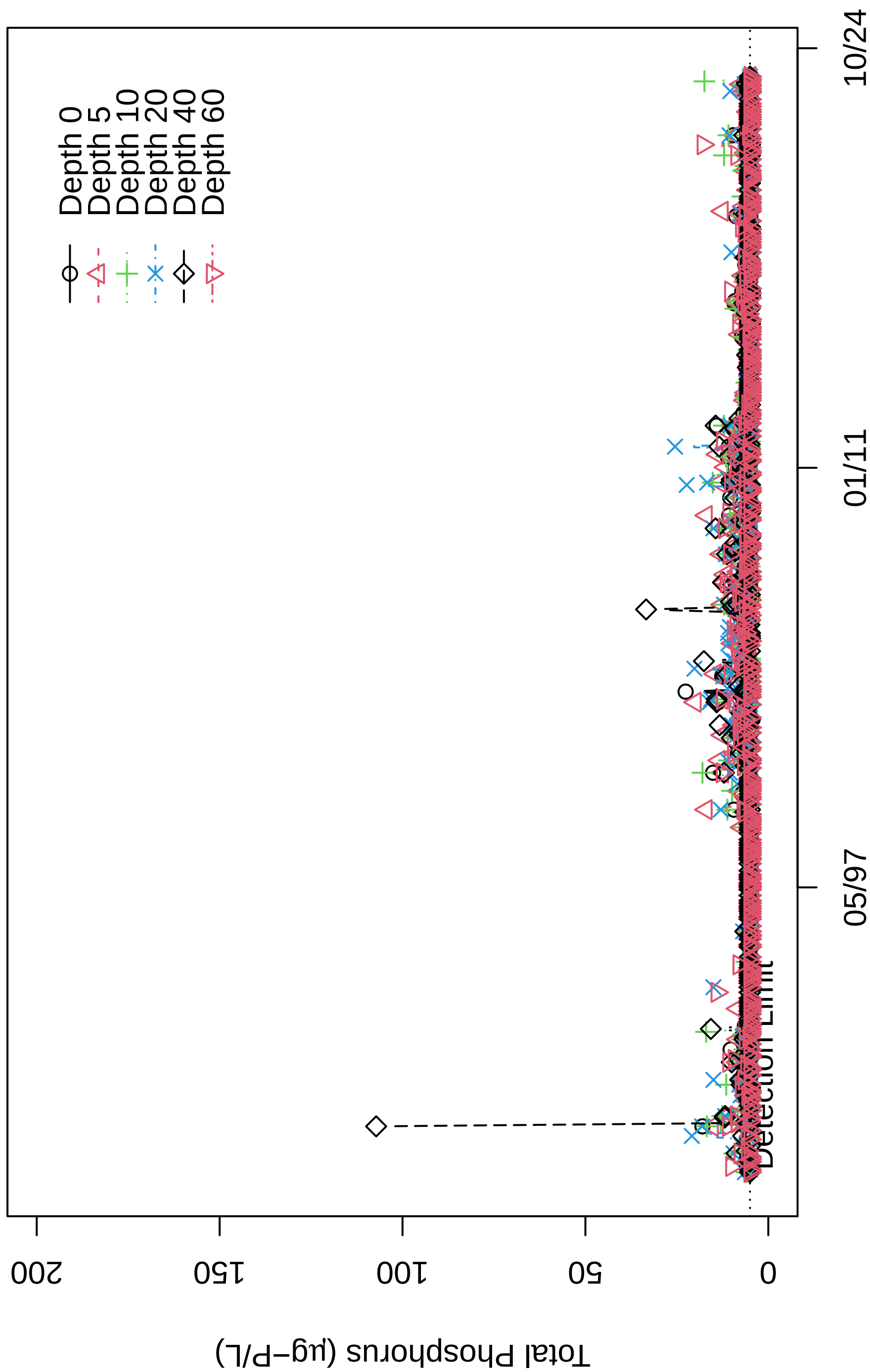


Figure B119: Lake Whatcom total phosphorus data for Site 3.

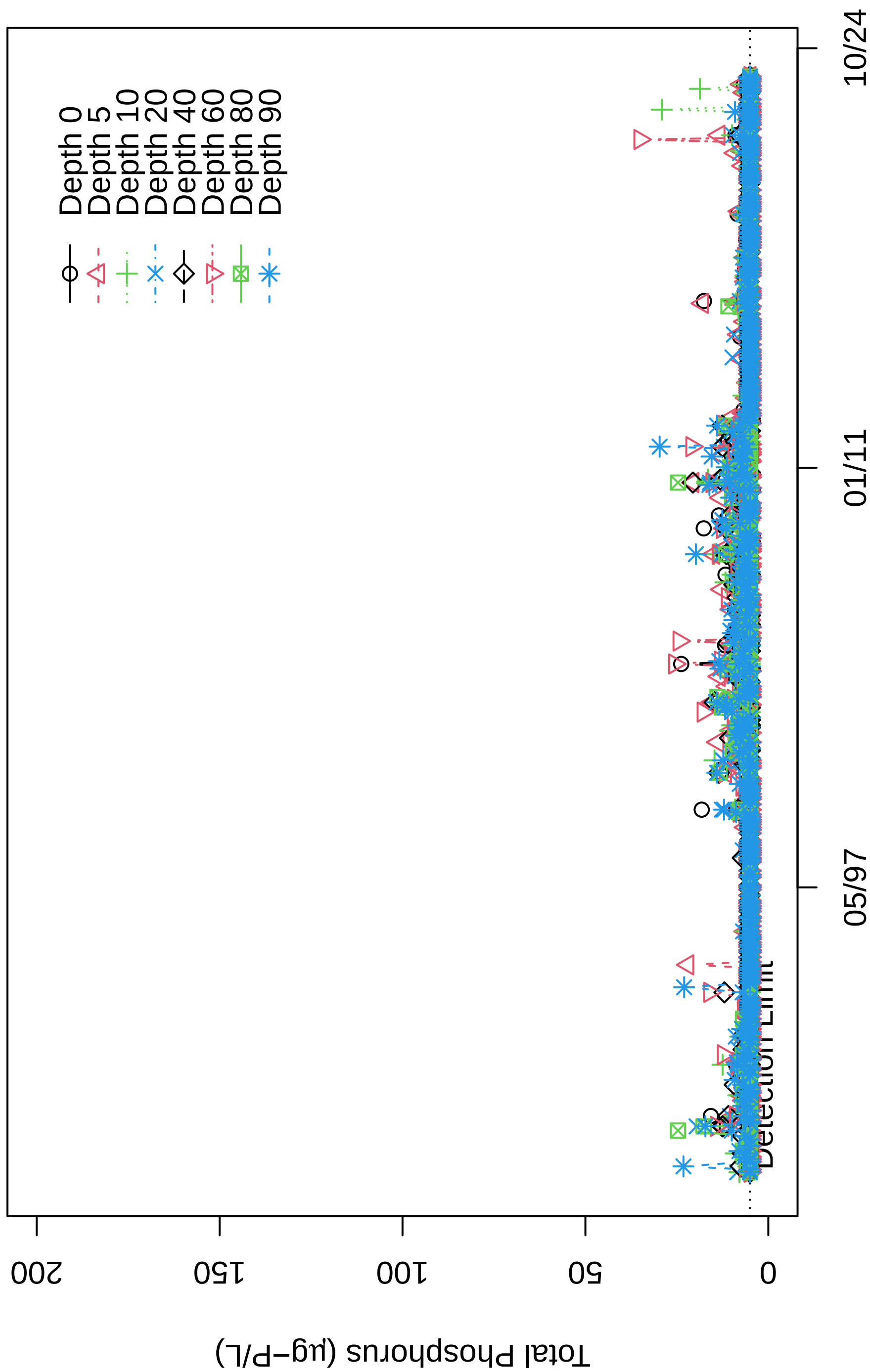


Figure B120: Lake Whatcom total phosphorus data for Site 4.

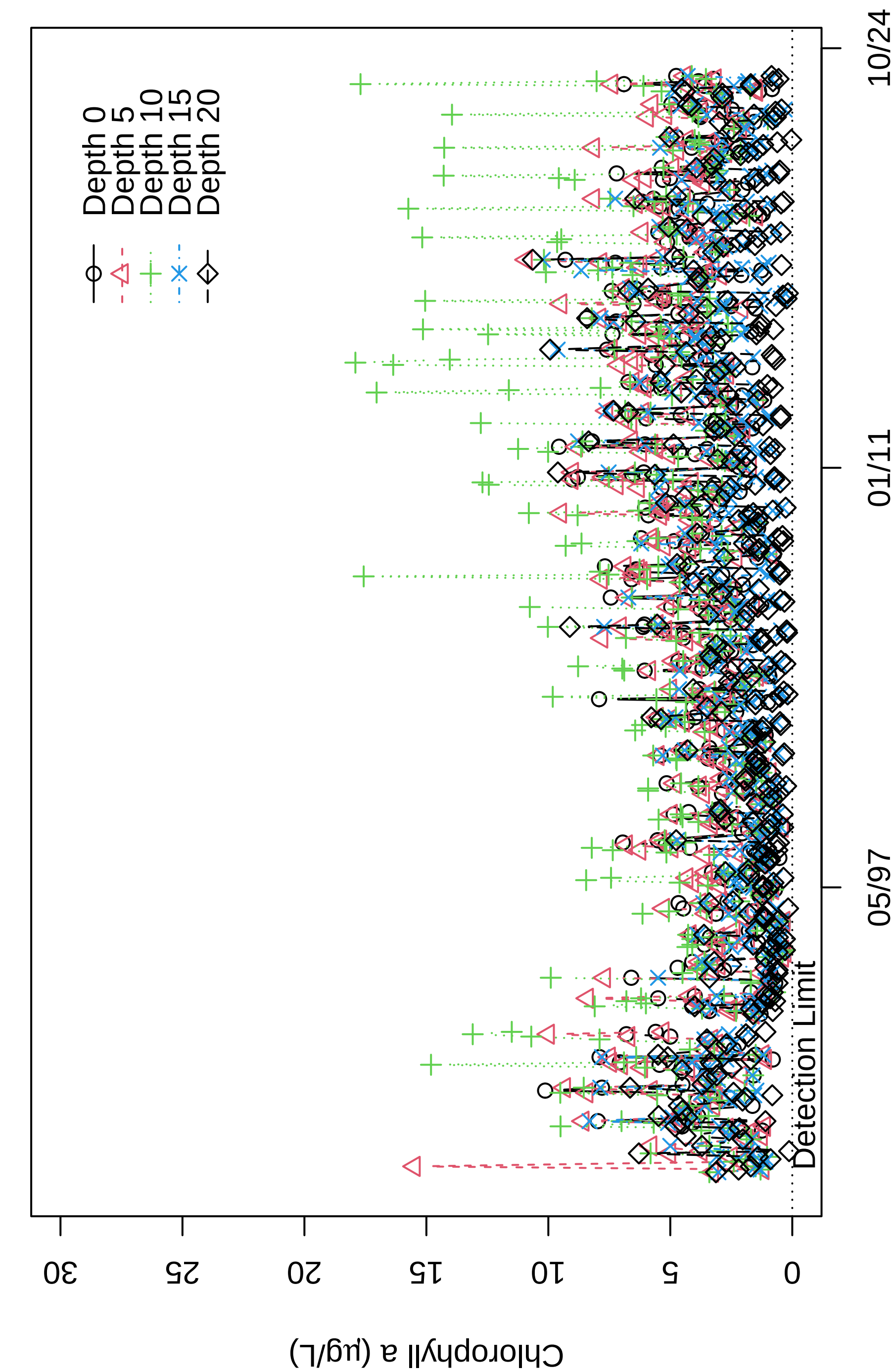


Figure B121: Lake Whatcom chlorophyll data for Site 1.

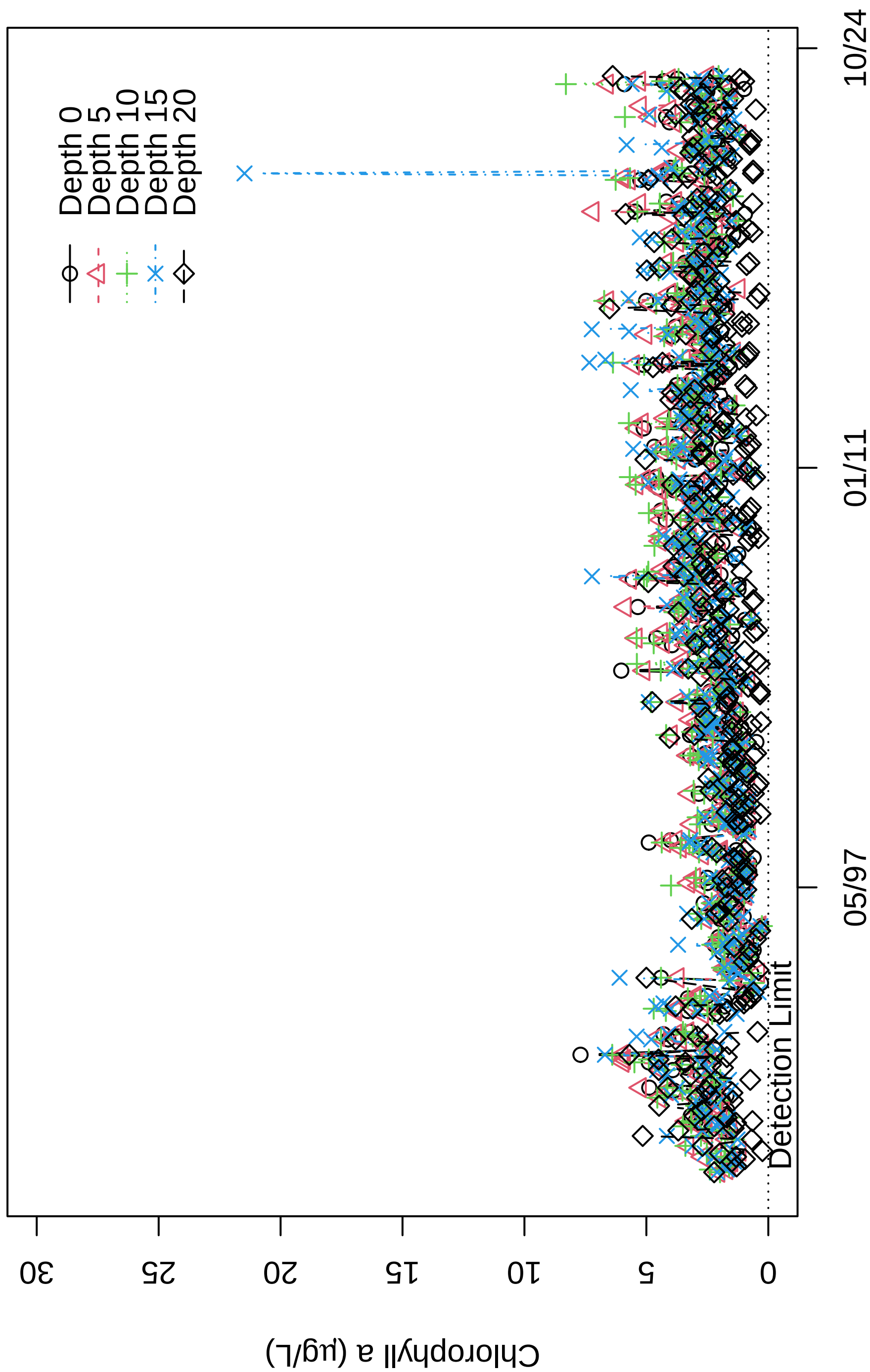


Figure B122: Lake Whatcom chlorophyll data for Site 2.

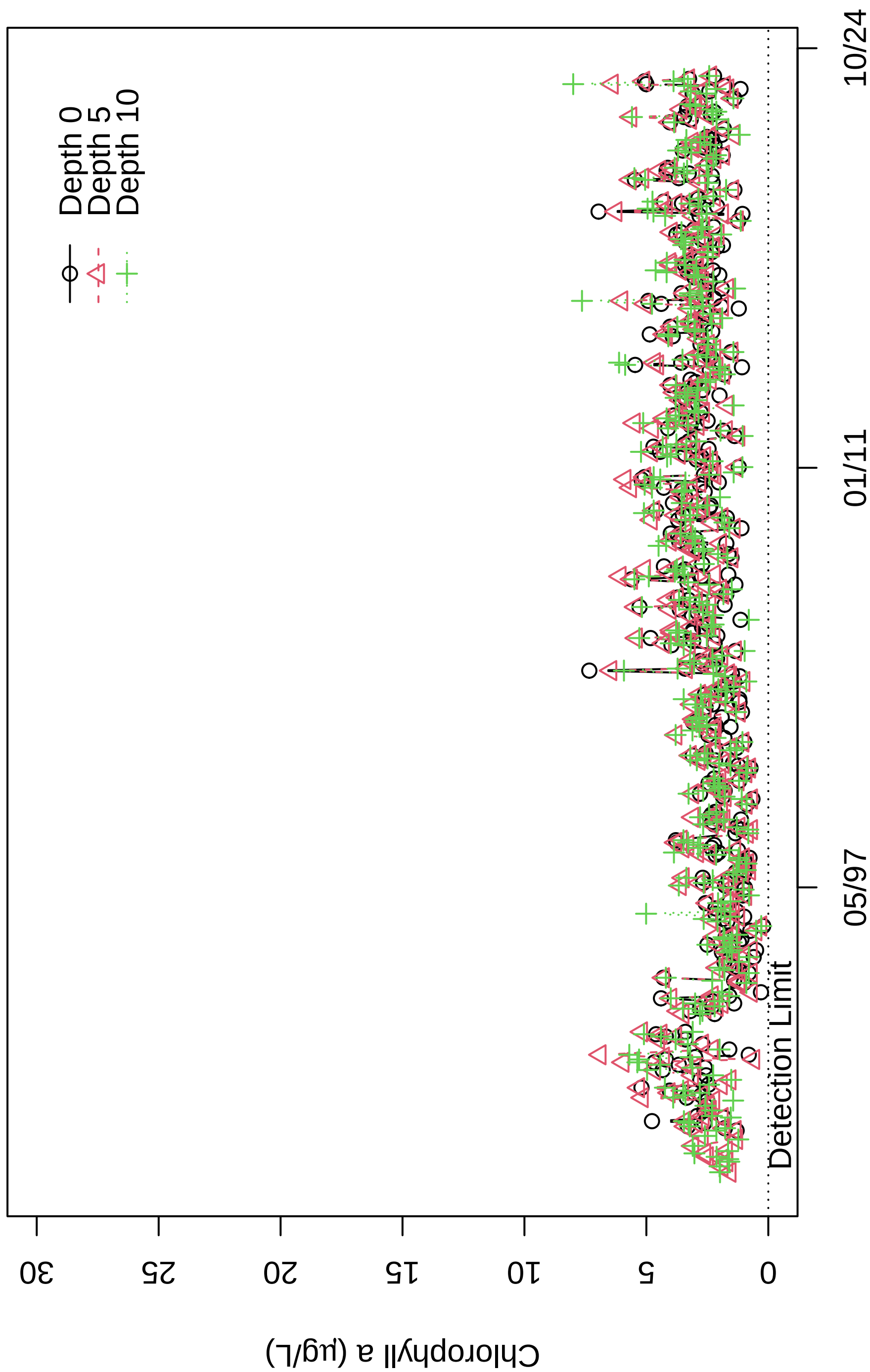


Figure B123: Lake Whatcom chlorophyll data for the Intake site.

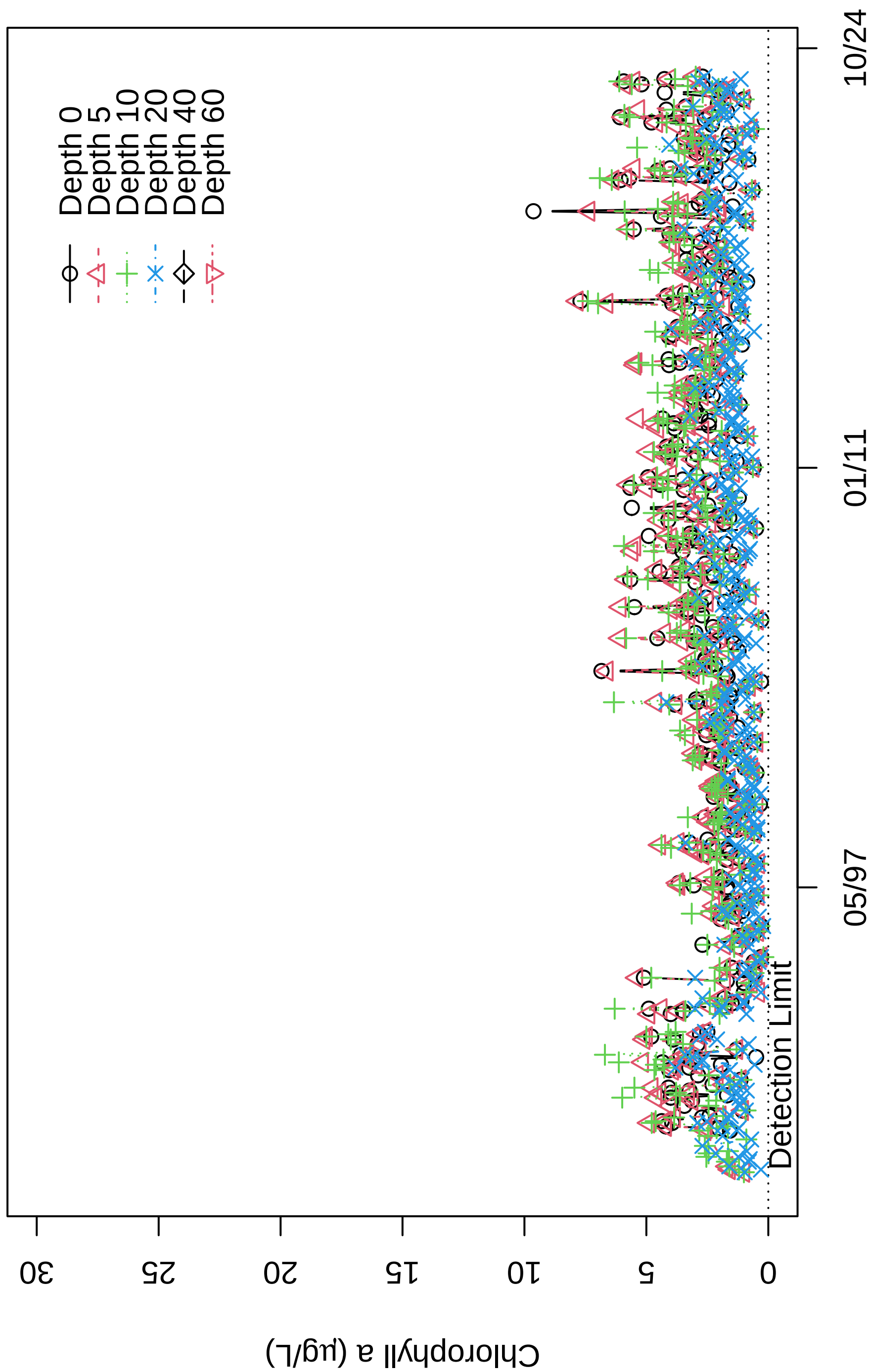


Figure B124: Lake Whatcom chlorophyll data for Site 3. Note that samples are not taken at all depths; see Table 2.2 for details.

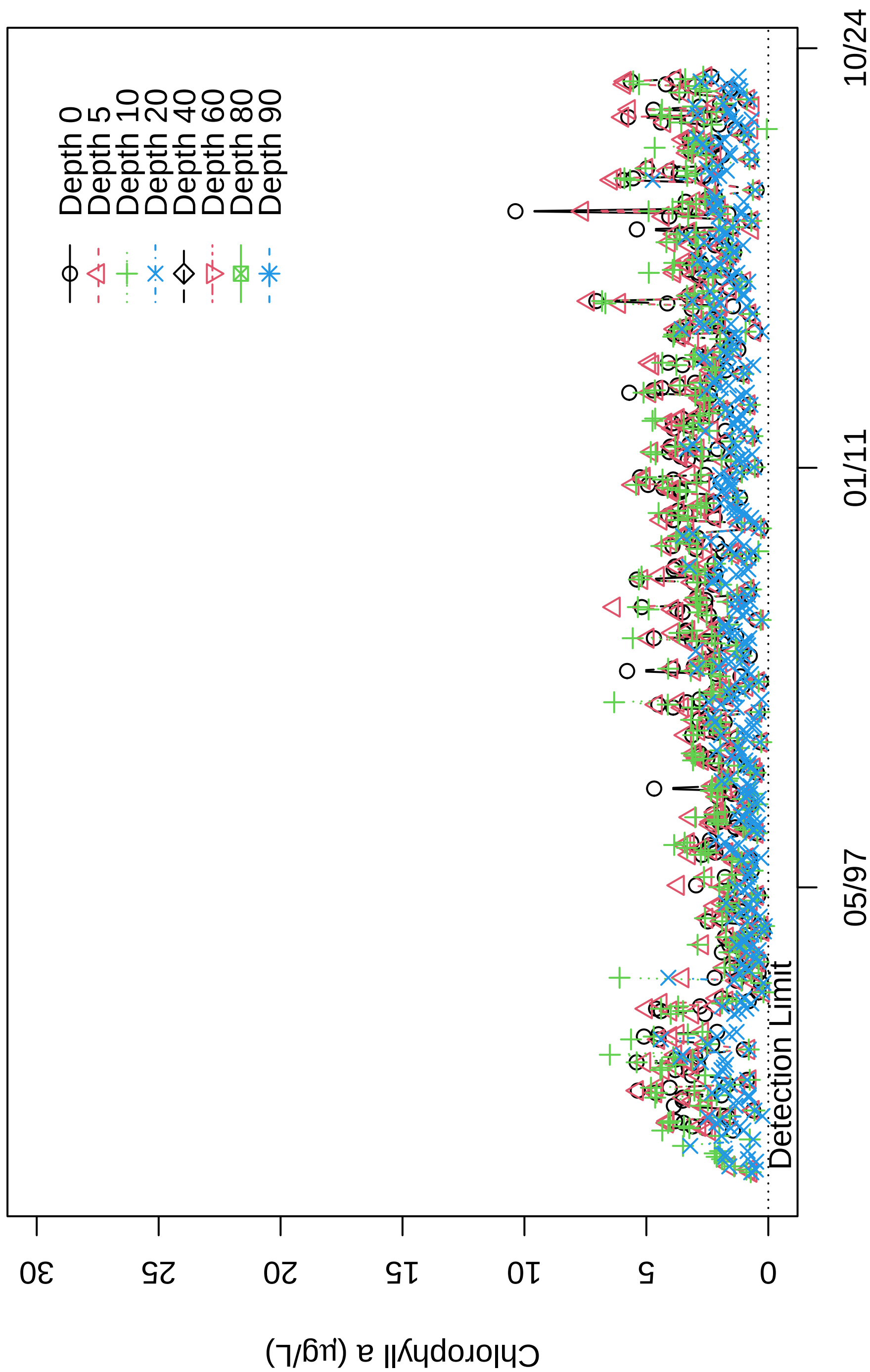


Figure B125: Lake Whatcom chlorophyll data for Site 4. Note that samples are not taken at all depths; see Table 2.2 for details.

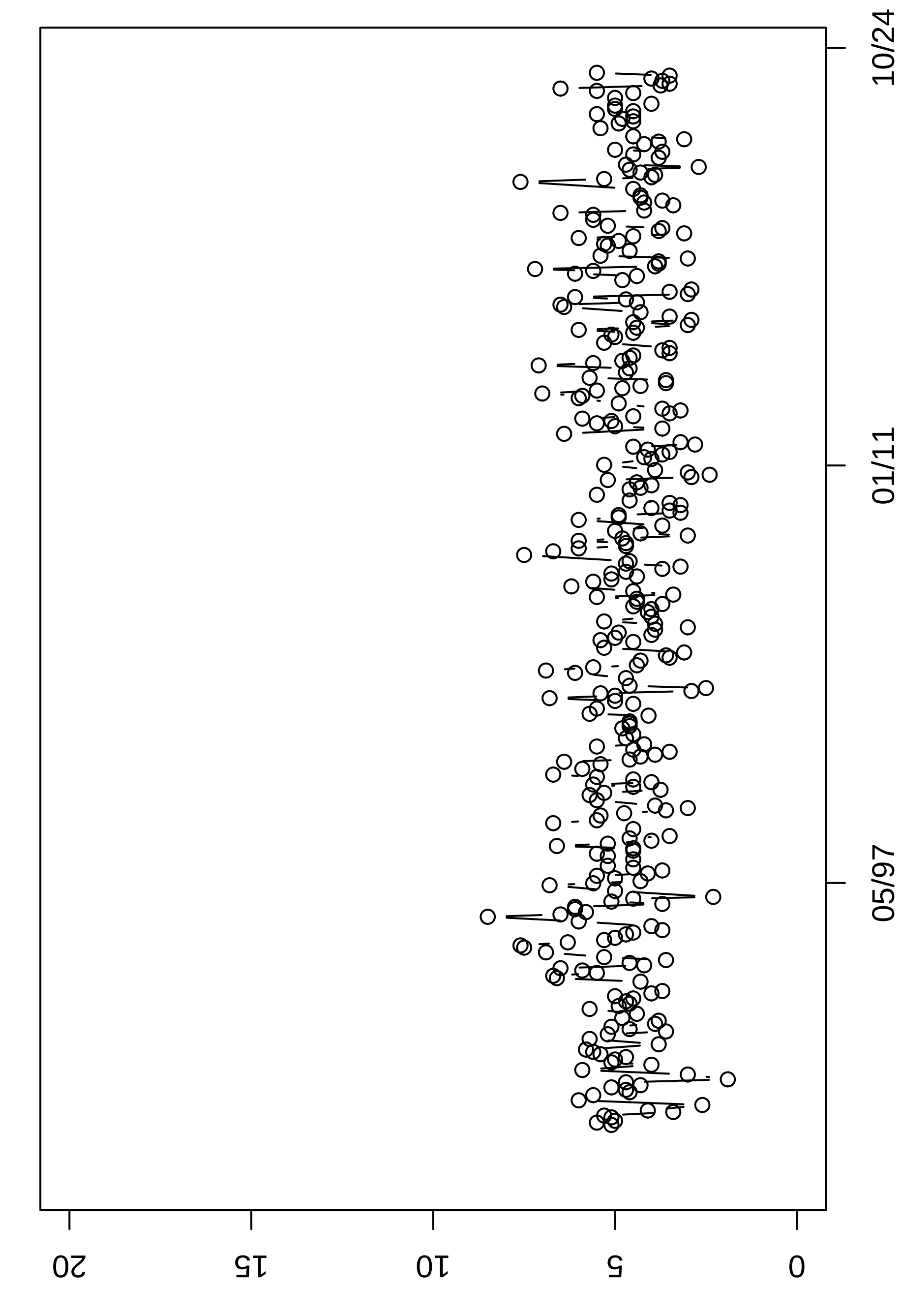


Figure B126: Lake Whatcom Secchi depths for Site 1.

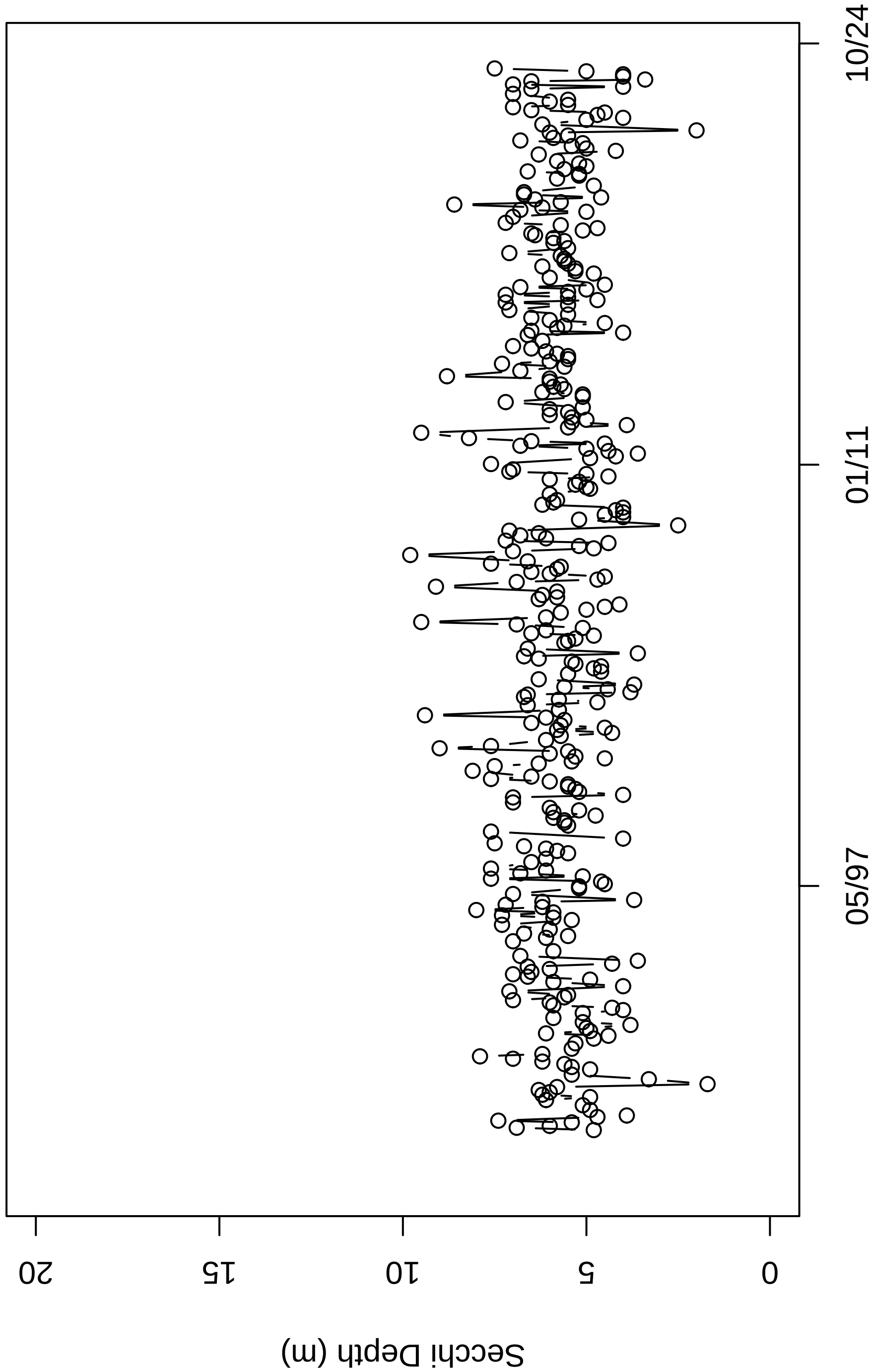


Figure B127: Lake Whatcom Secchi depths for Site 2.

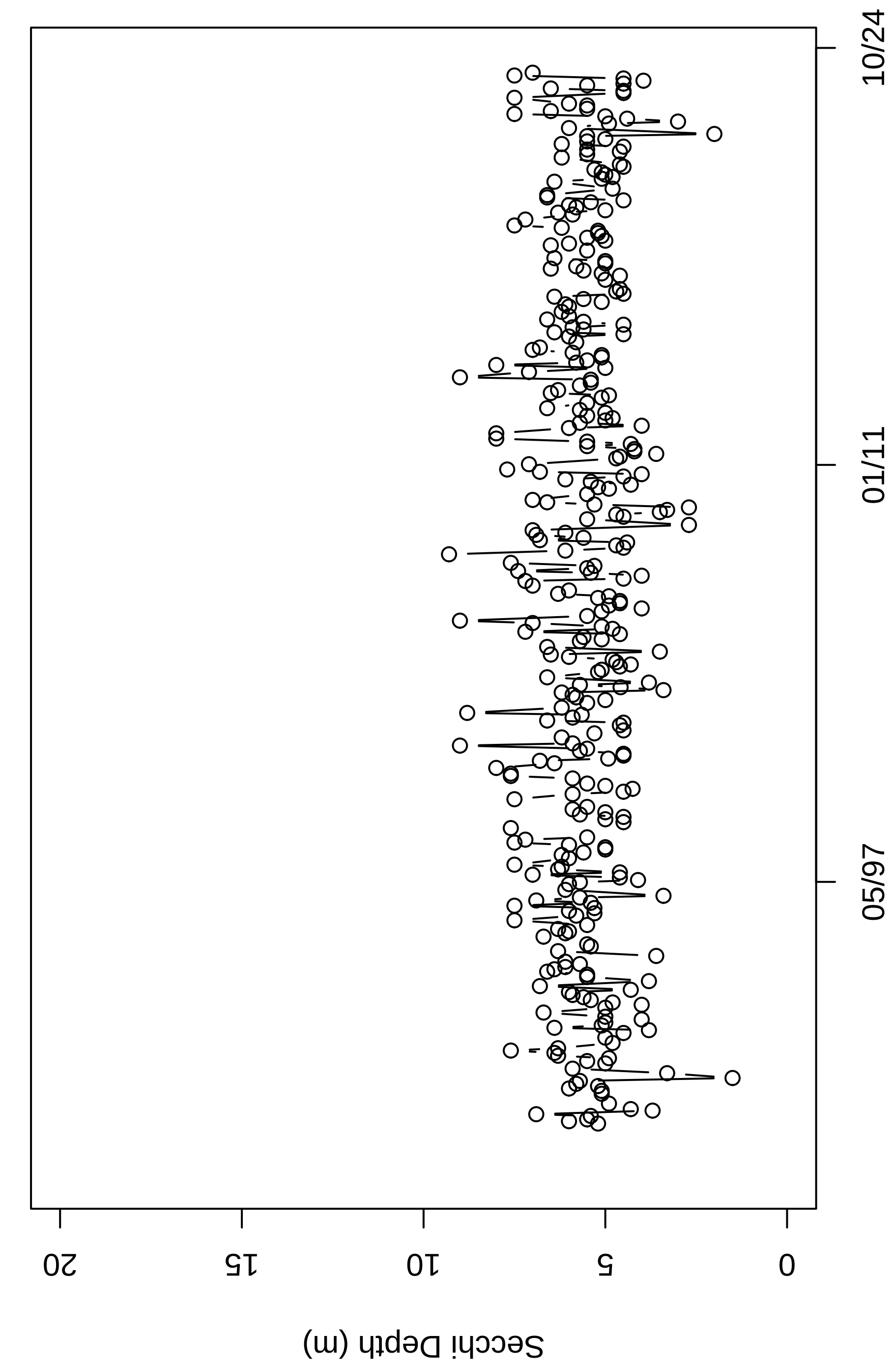


Figure B128: Lake Whatcom Secchi depths for the Intake site.

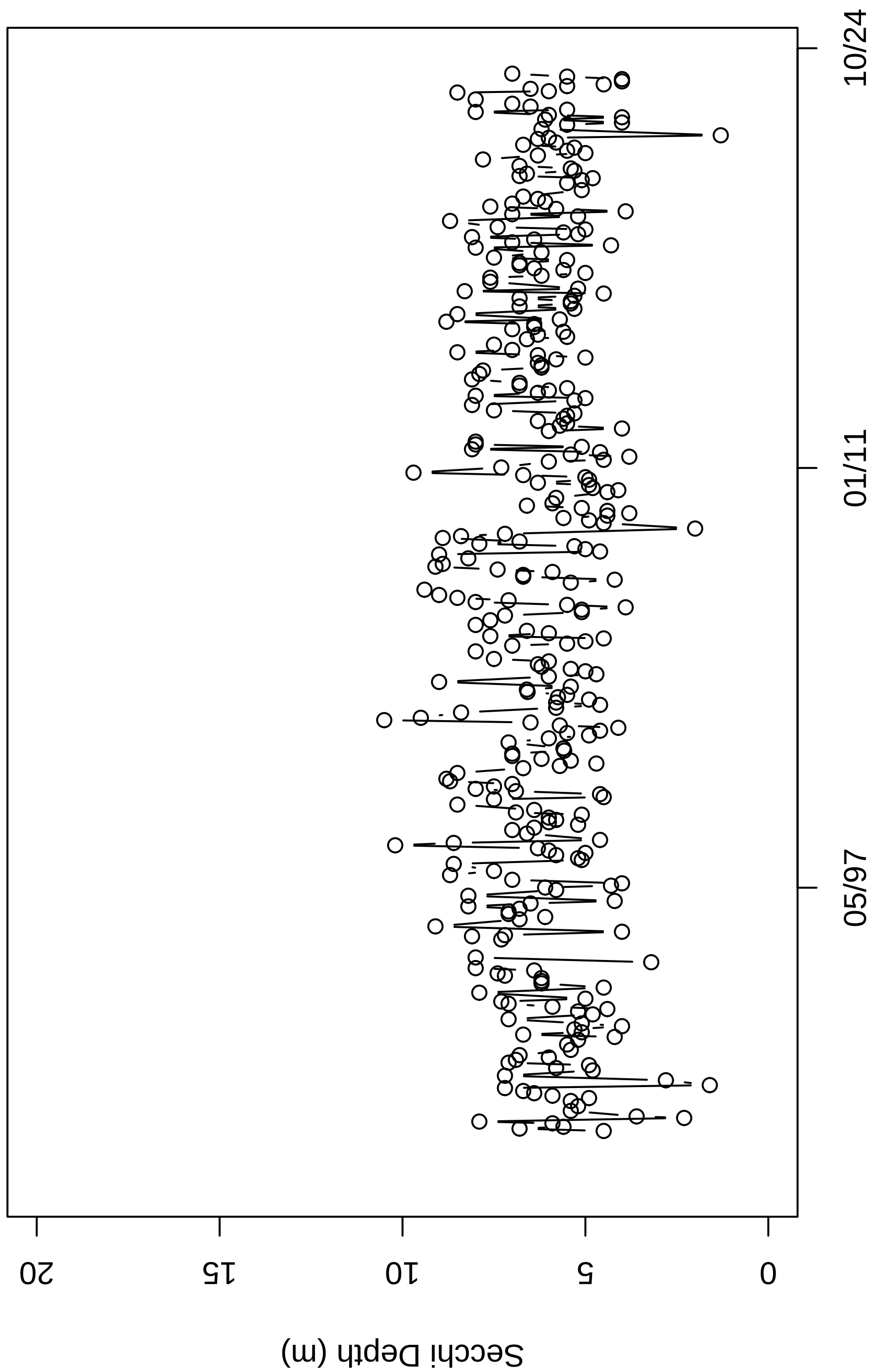


Figure B129: Lake Whatcom Secchi depths for Site 3.

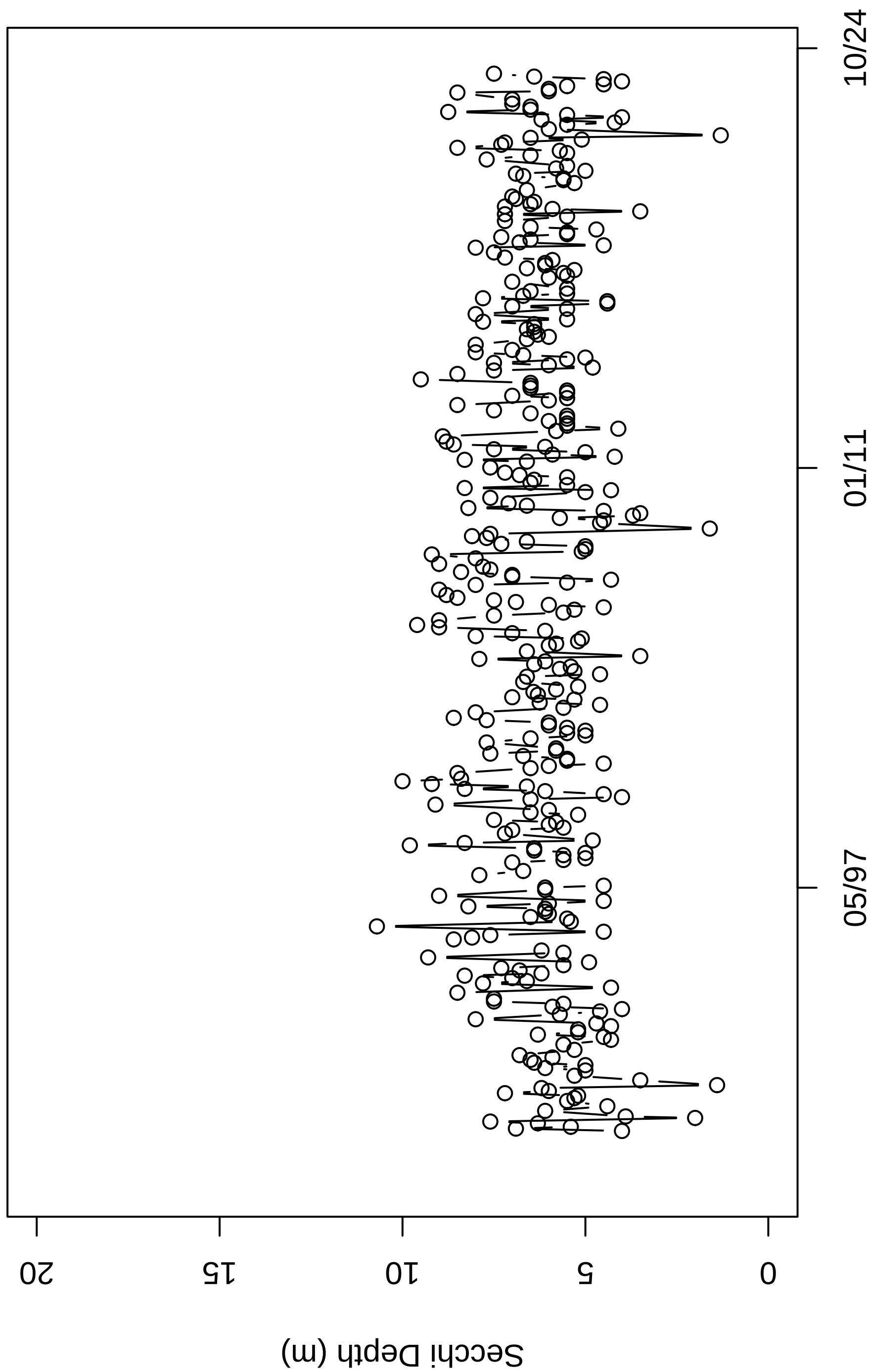


Figure B130: Lake Whatcom Secchi depths for Site 4.

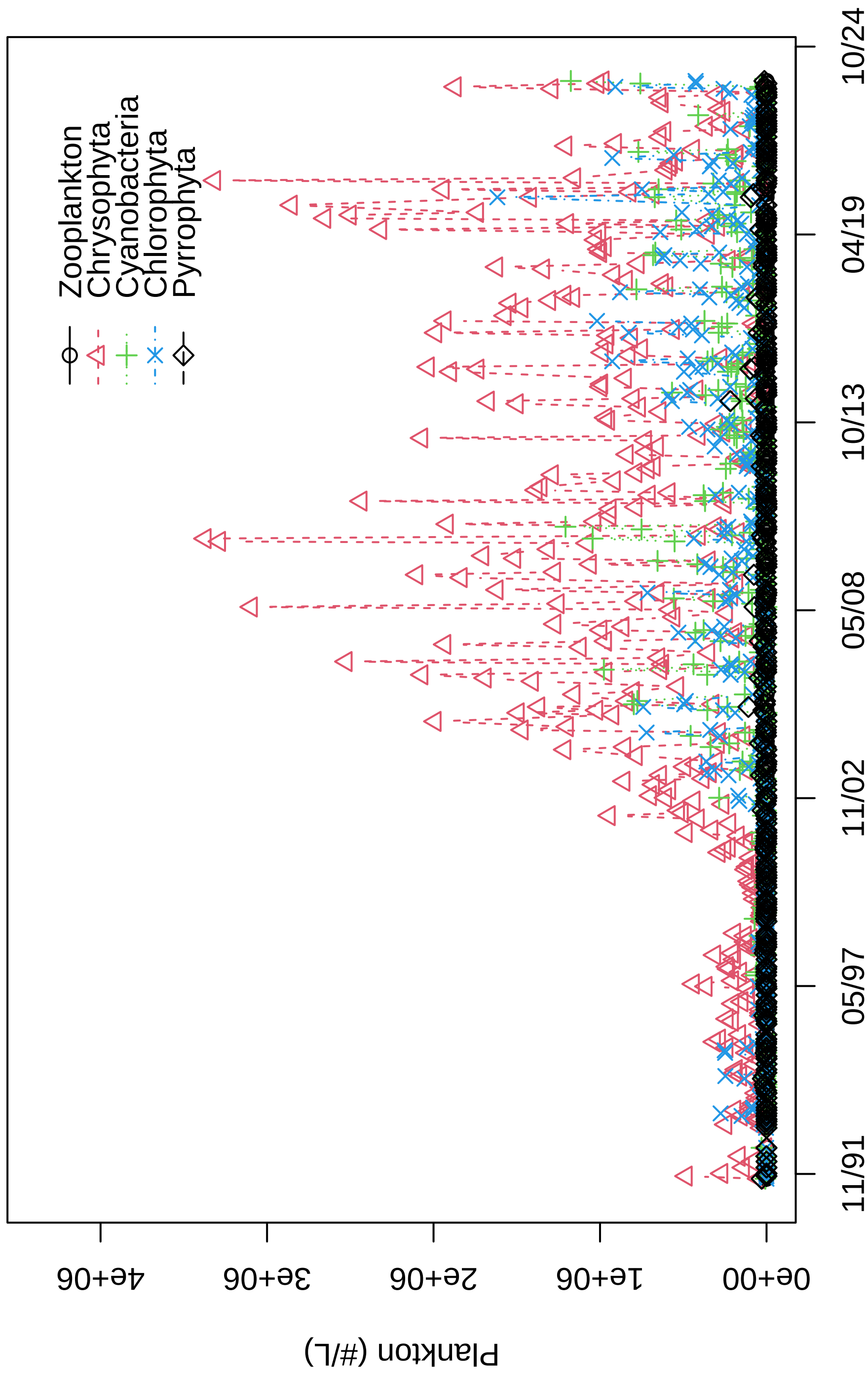


Figure B131: Lake Whatcom plankton data for Site 1.

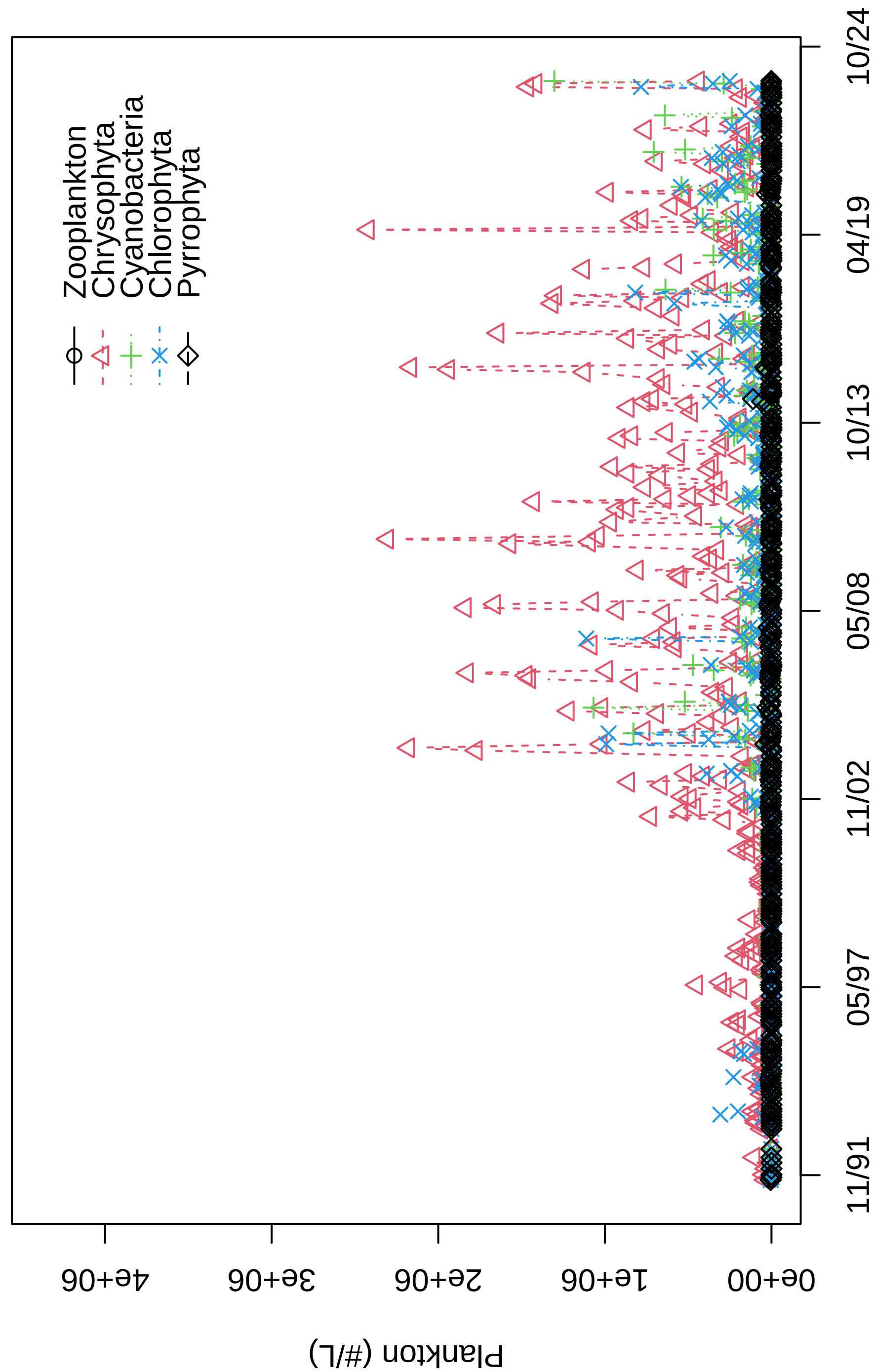


Figure B132: Lake Whatcom plankton data for Site 2.

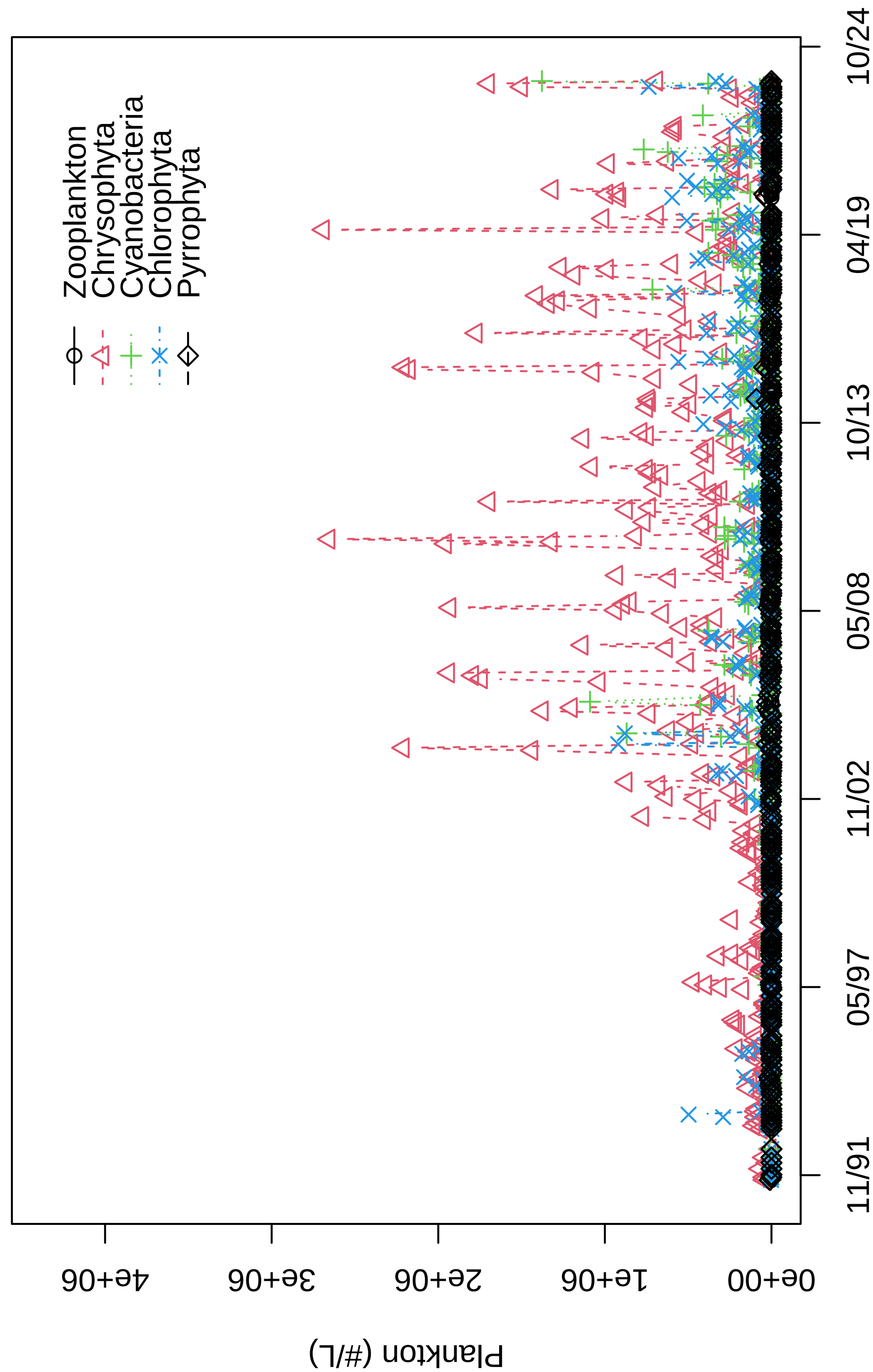


Figure B133: Lake Whatcom plankton data for the Intake Site.

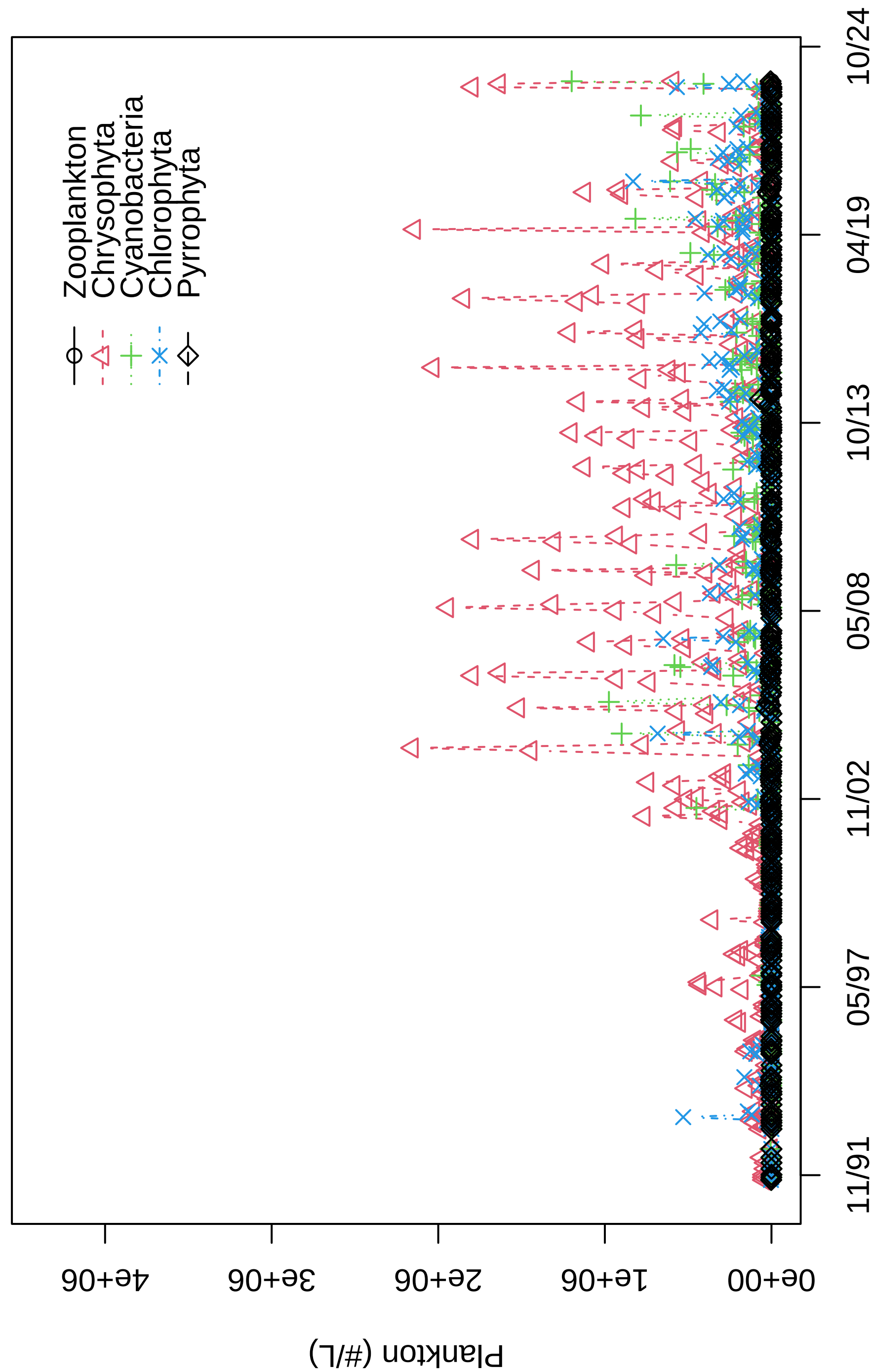


Figure B134: Lake Whatcom plankton data for Site 3.

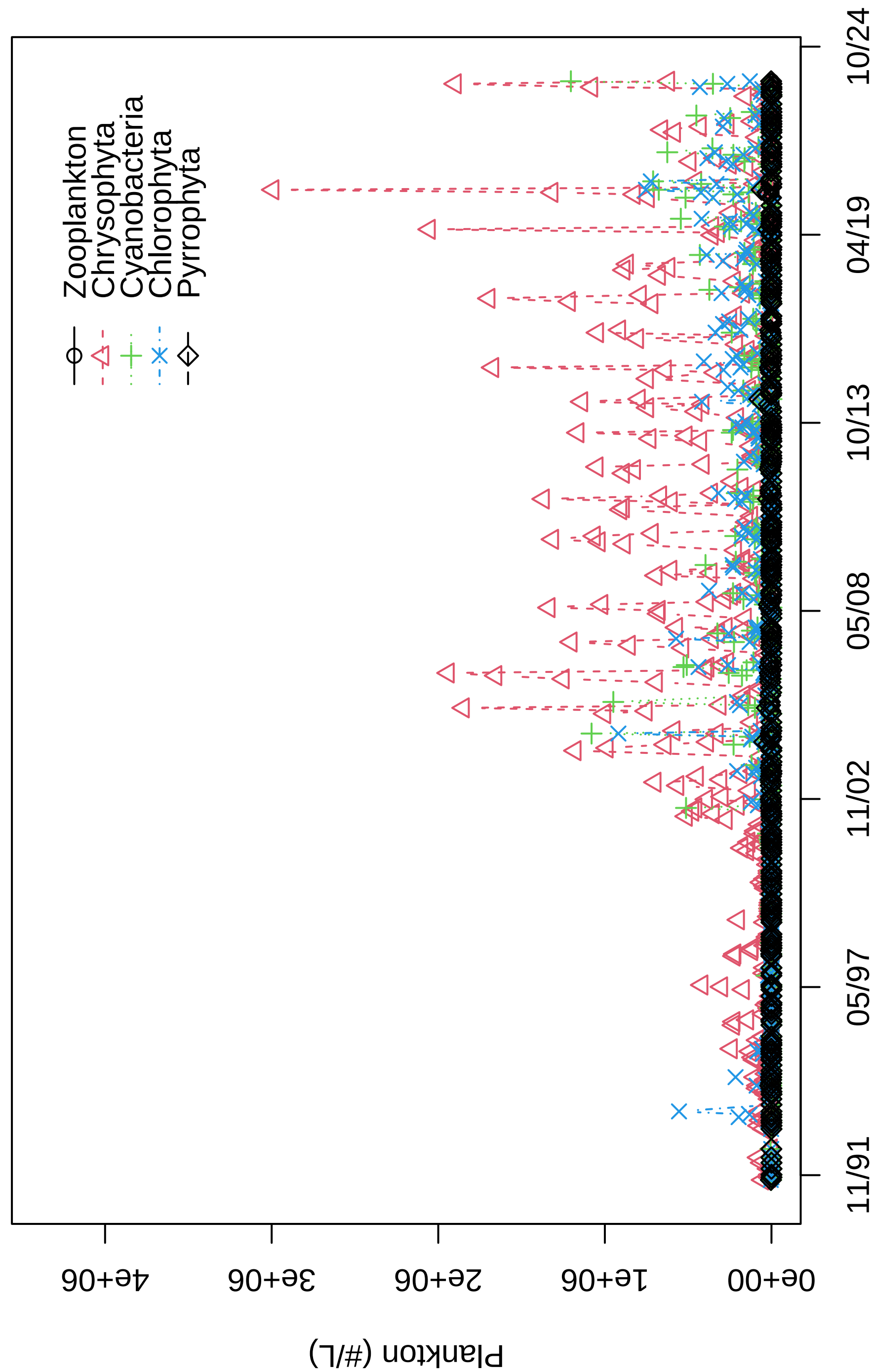


Figure B135: Lake Whatcom plankton data for Site 4.

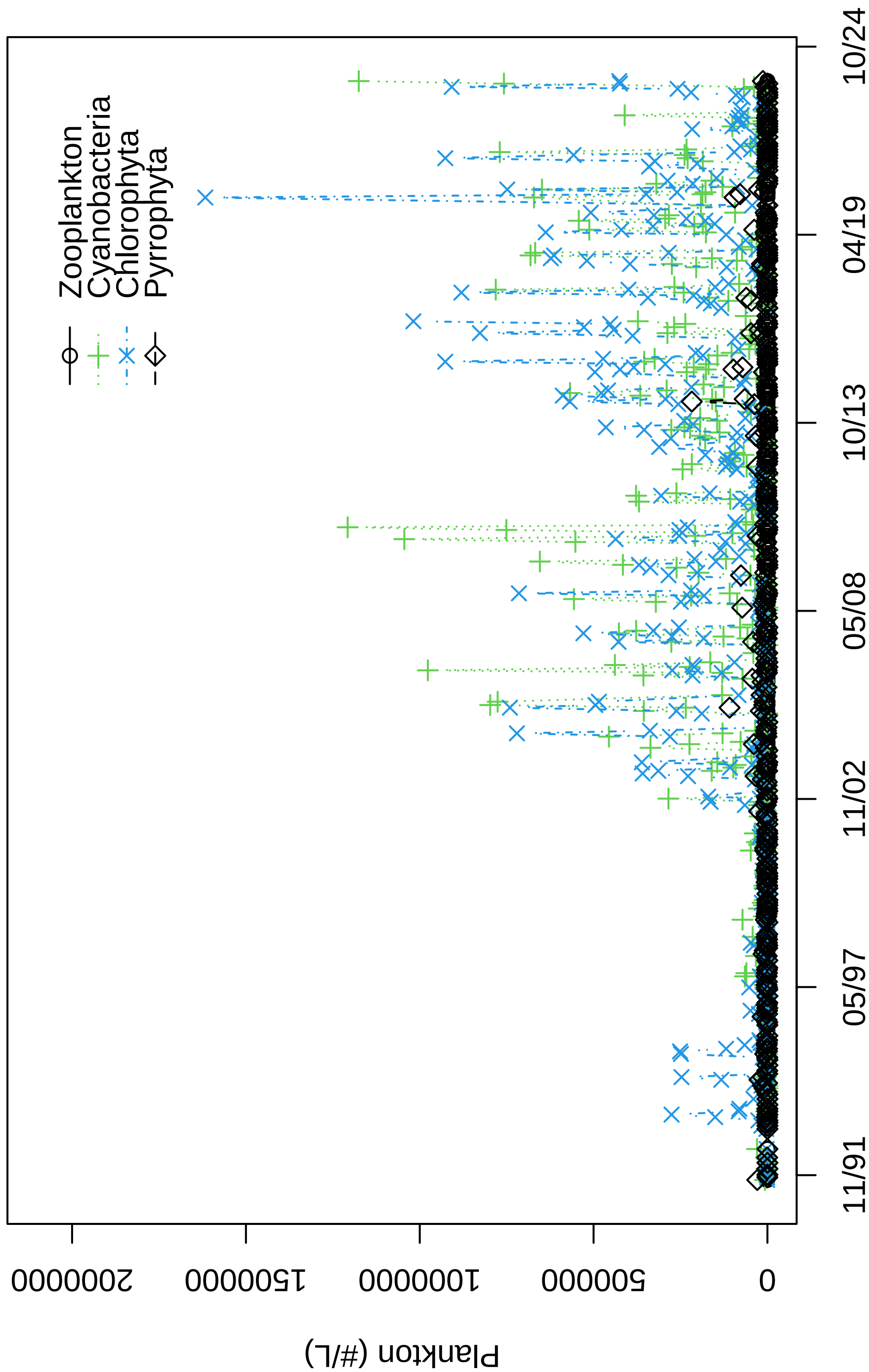


Figure B136: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

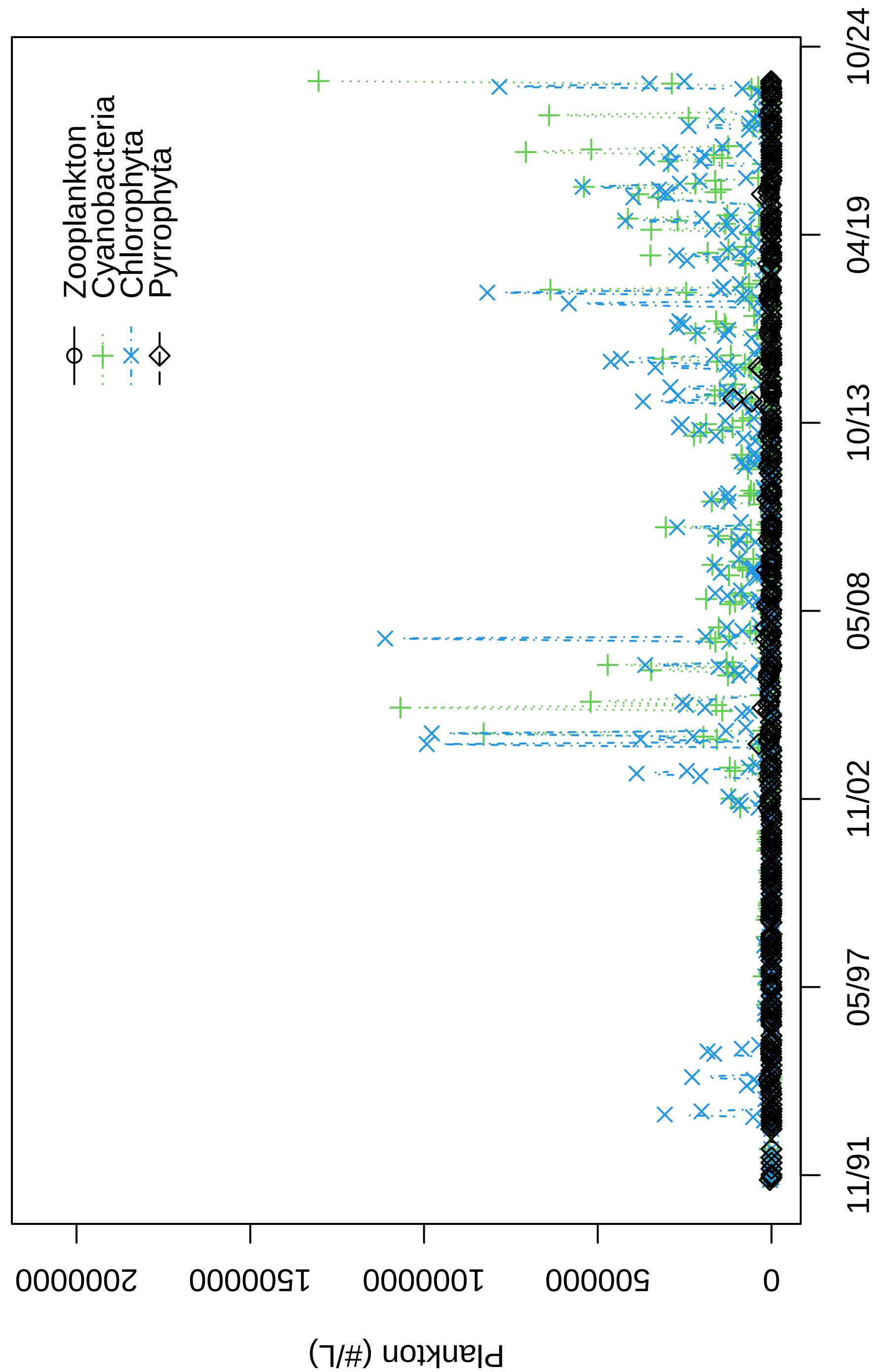


Figure B137: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

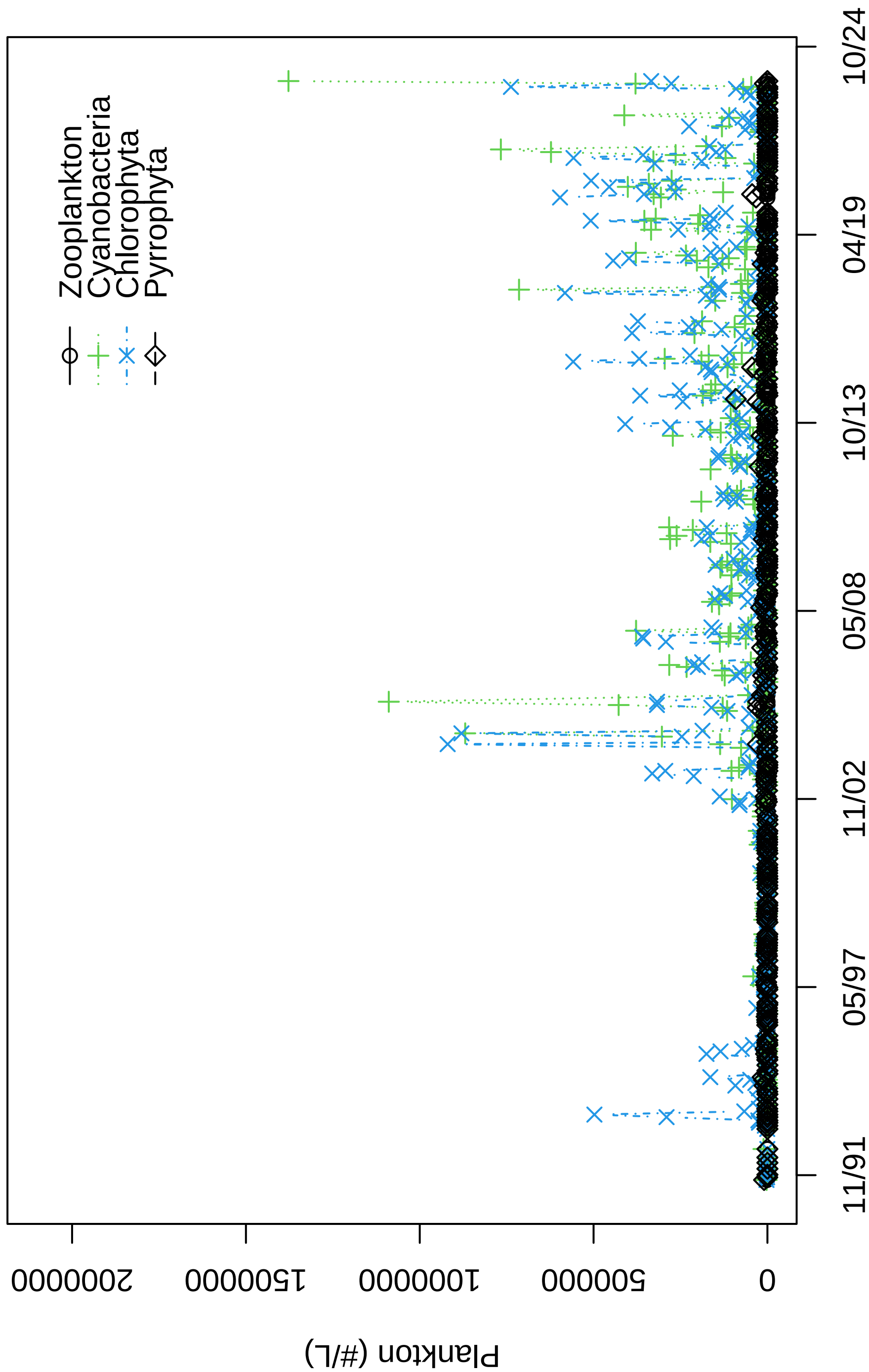


Figure B138: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

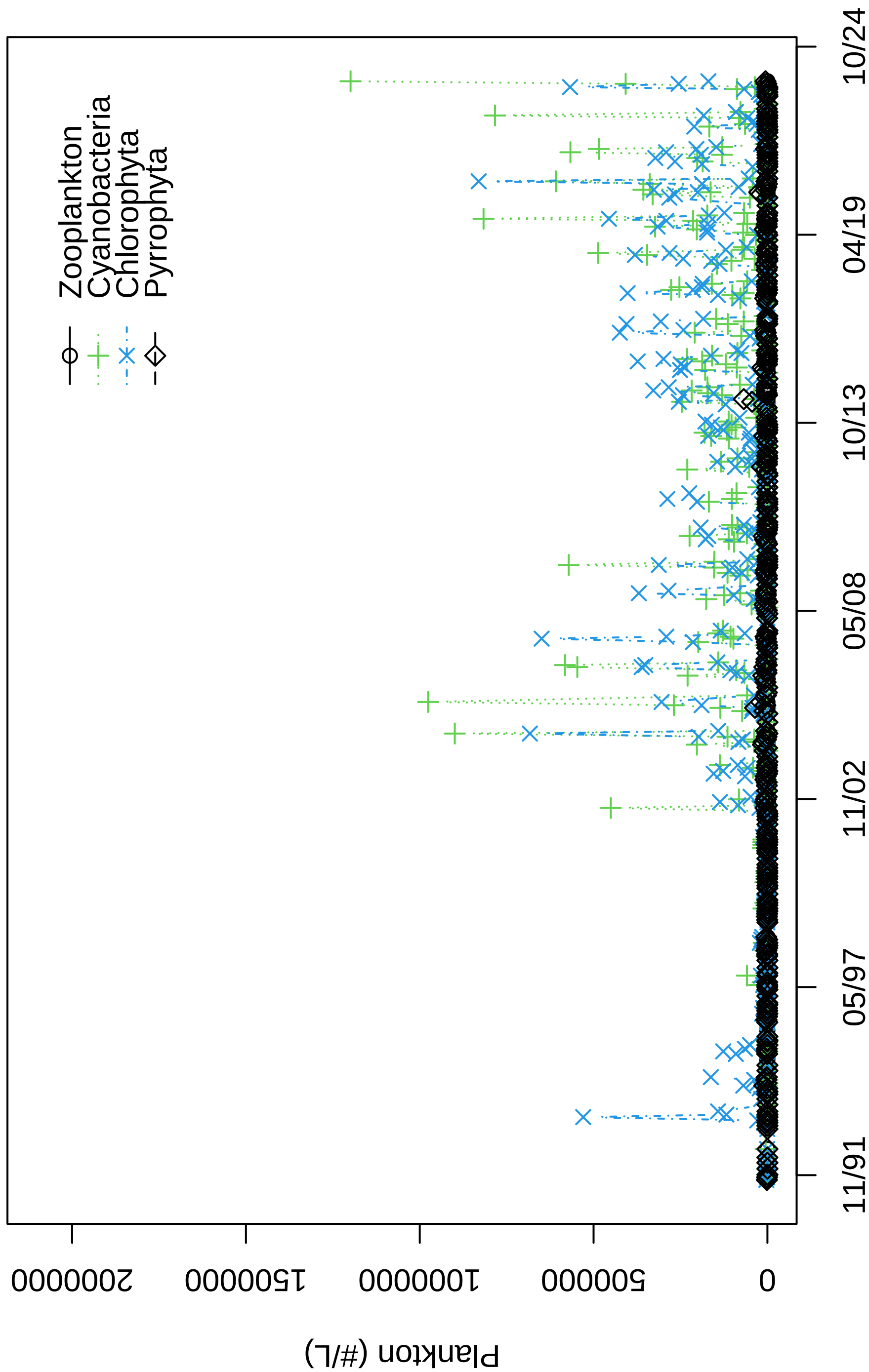


Figure B139: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

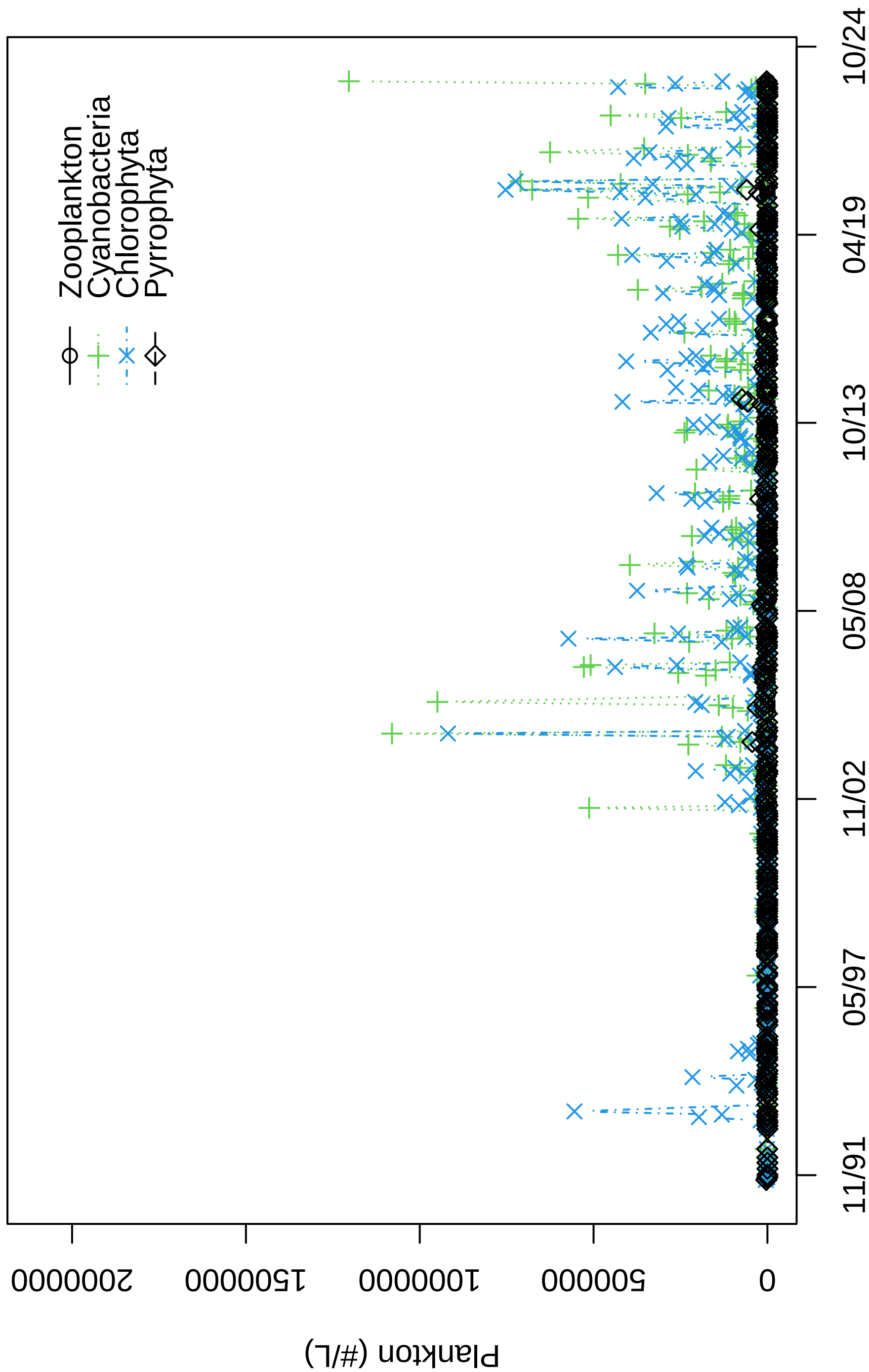


Figure B140: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

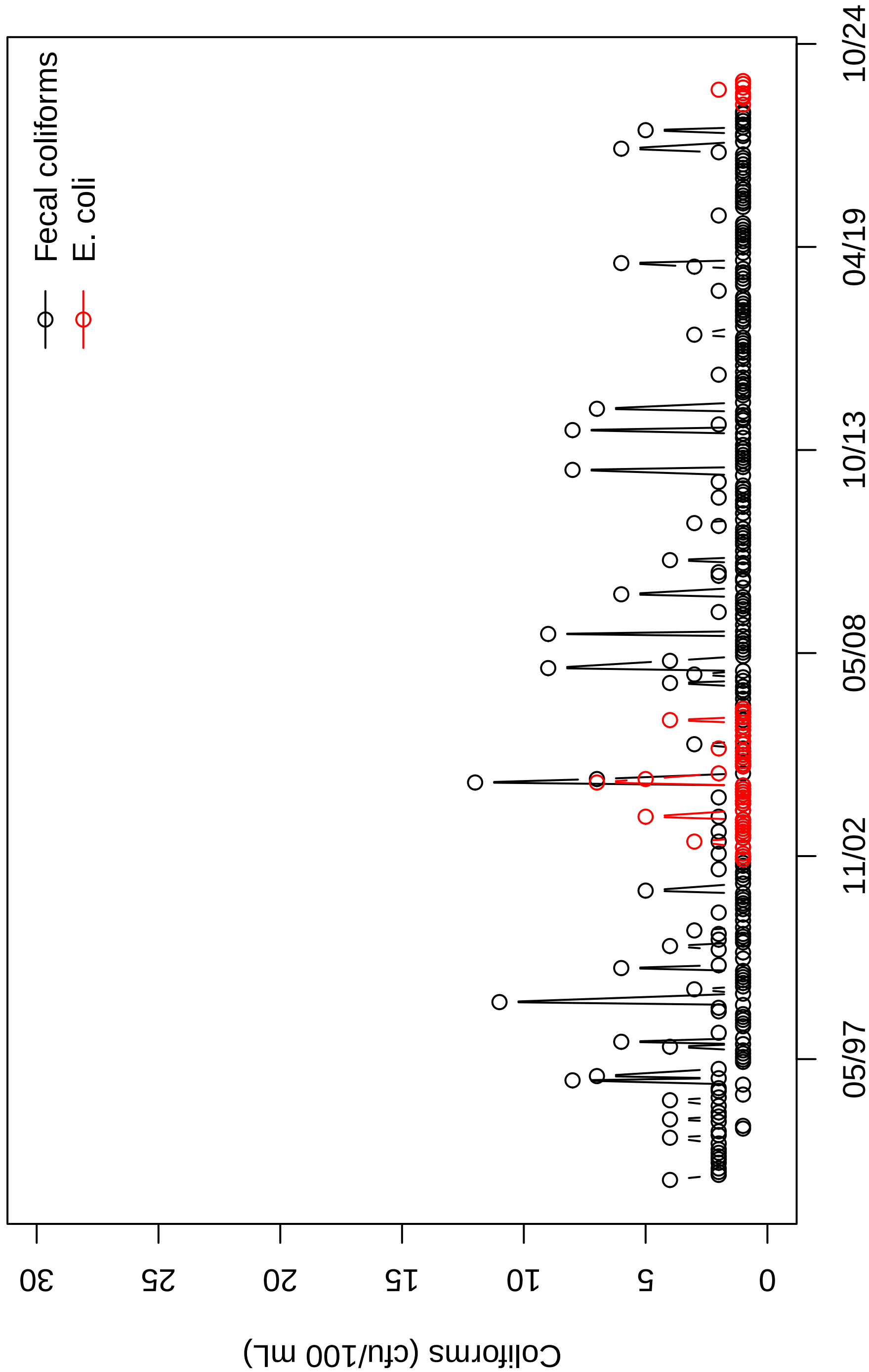


Figure B141: Lake Whatcom coliform data for Site 1, with fecal coliforms in black and *E. coli* in red. See text for more details.

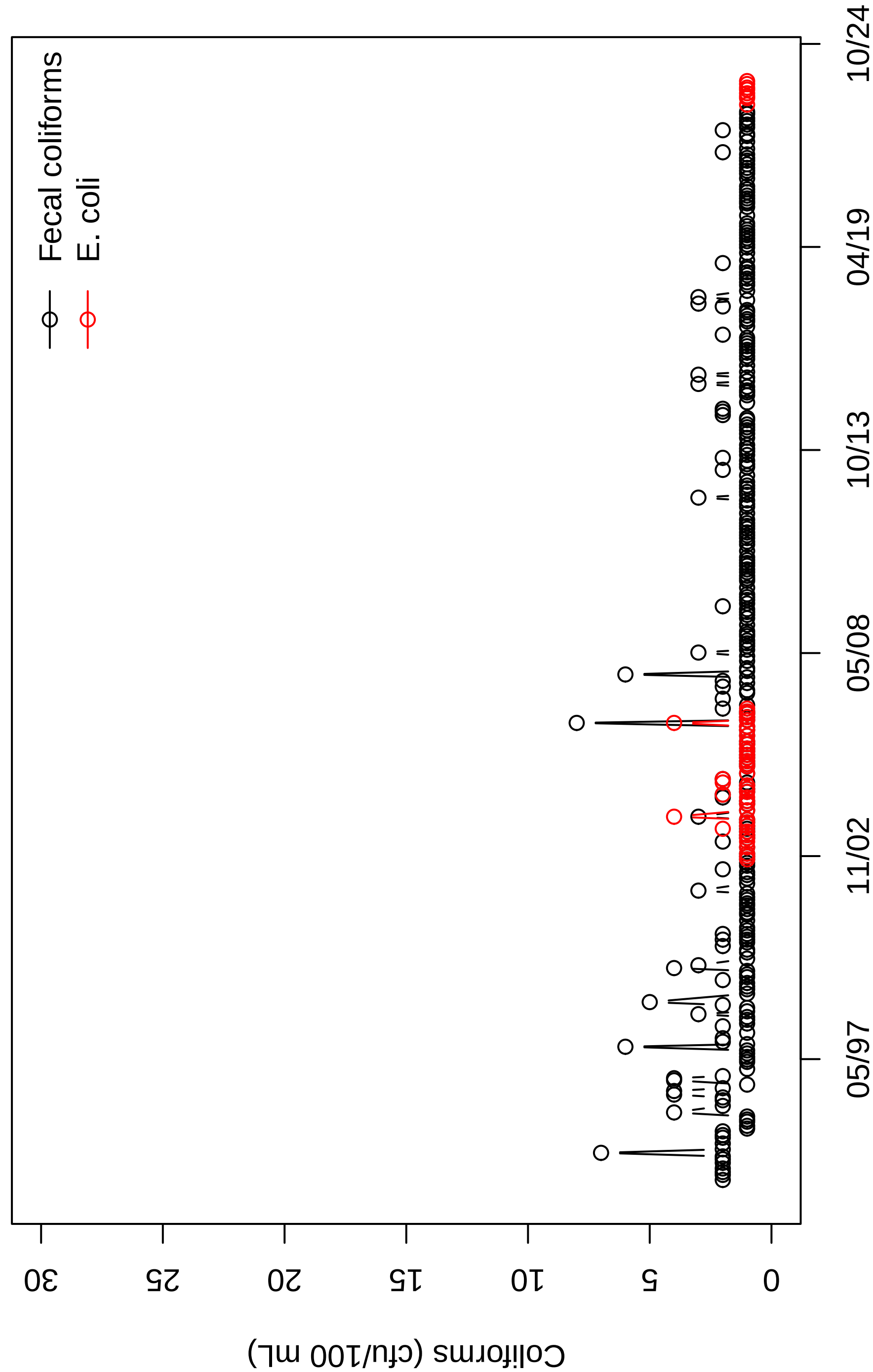


Figure B142: Lake Whatcom coliform data for Site 2, with fecal coliforms in black and *E. coli* in red.

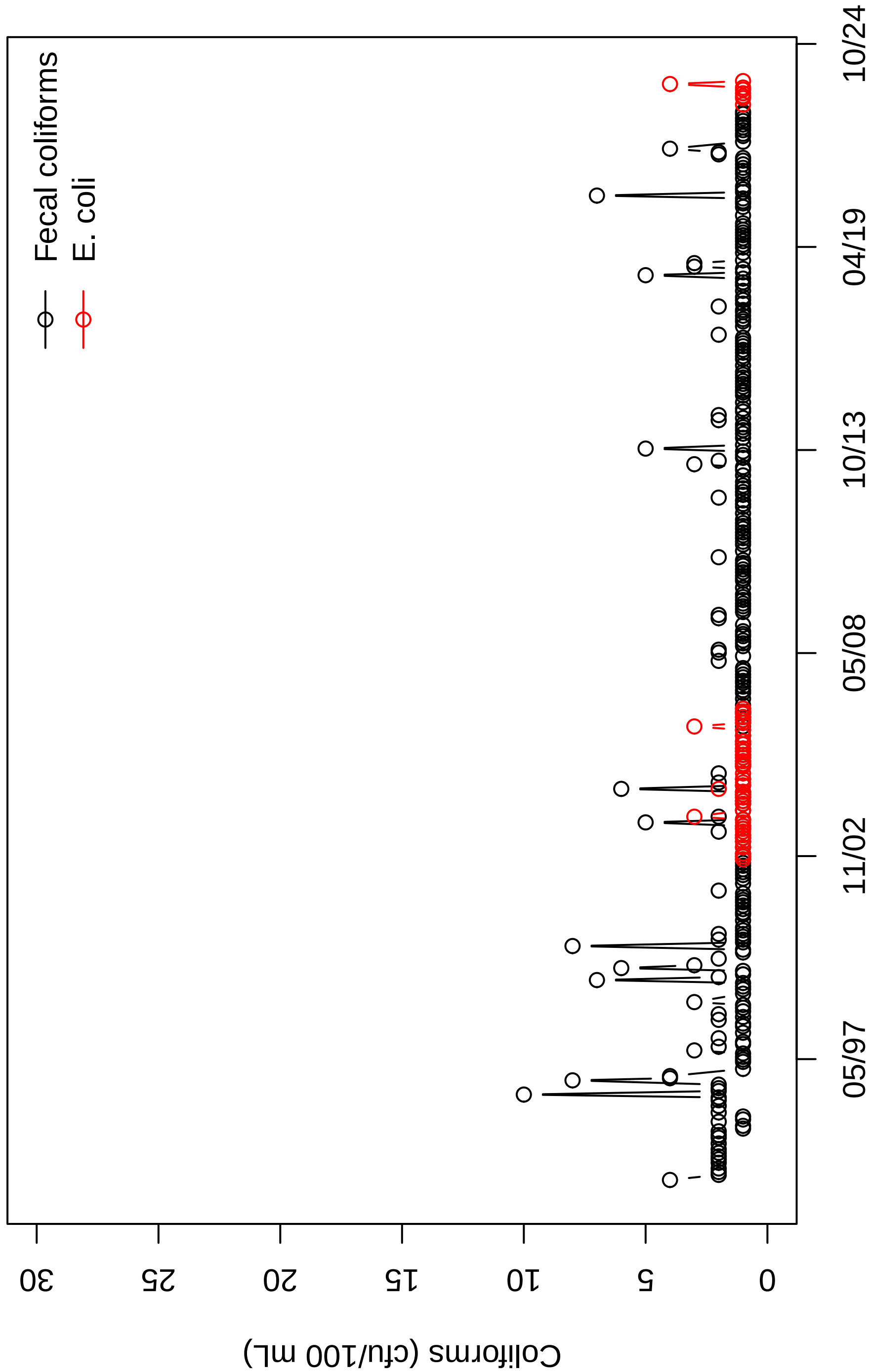


Figure B143: Lake Whatcom coliform data for the Intake site, with fecal coliforms in black and *E. coli* in red.

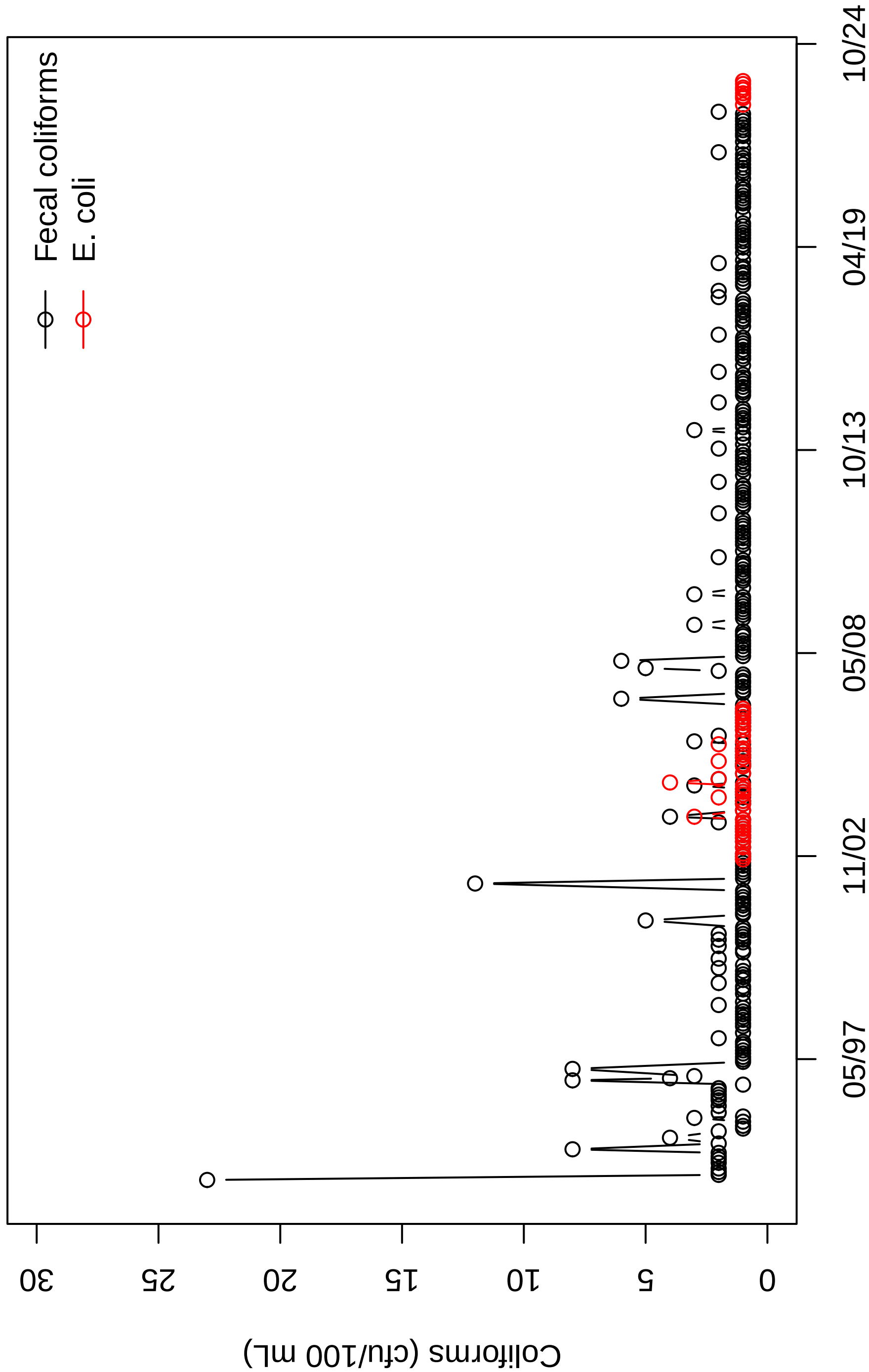


Figure B144: Lake Whatcom coliform data for Site 3, with fecal coliforms in black and *E. coli* in red.

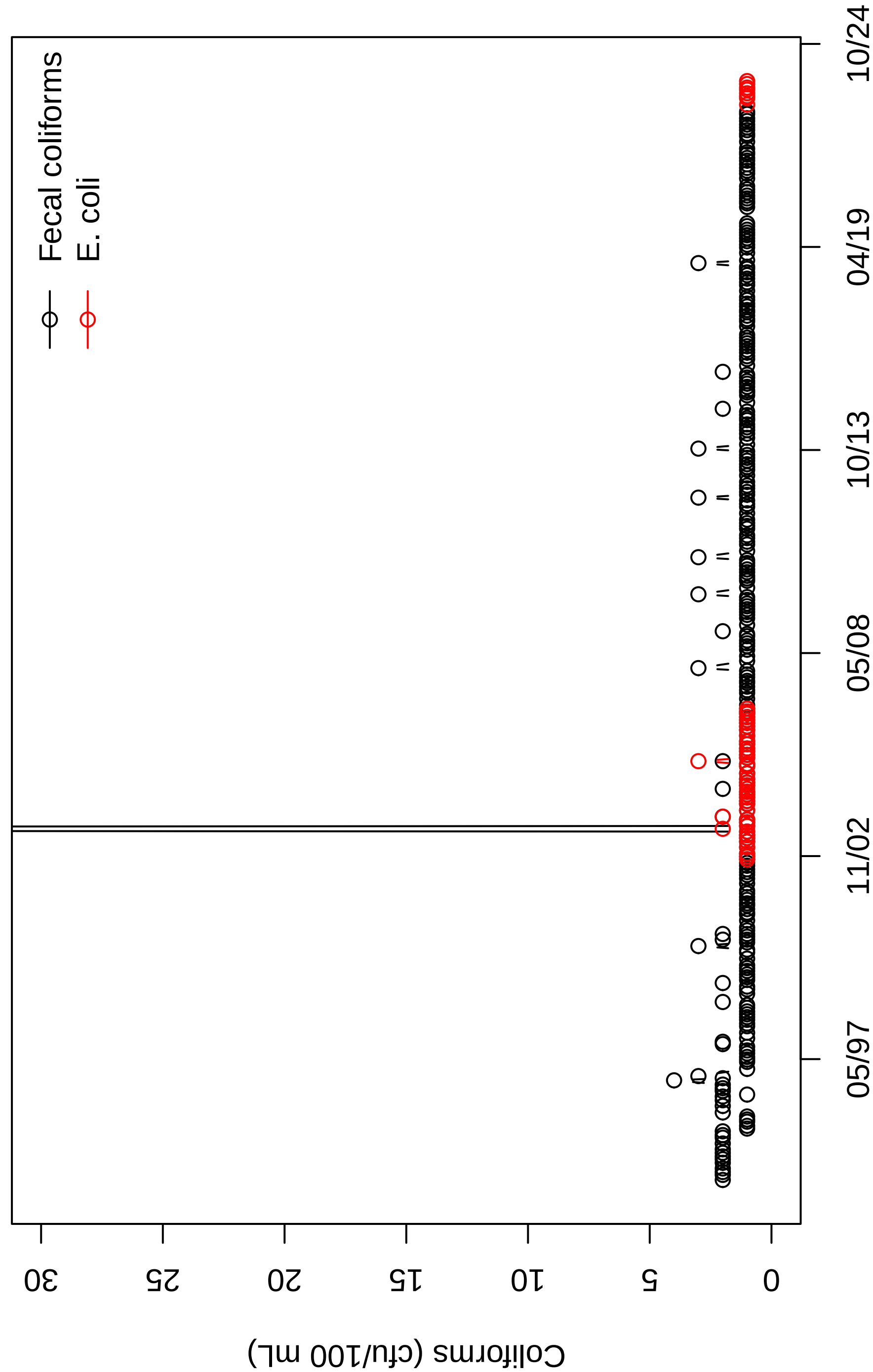


Figure B145: Lake Whatcom coliform data for Site 4, with fecal coliforms in black and *E. coli* in red. One data point is outside of the plot range: August 2003, 160 cfu/100 mL (fecal coliforms).

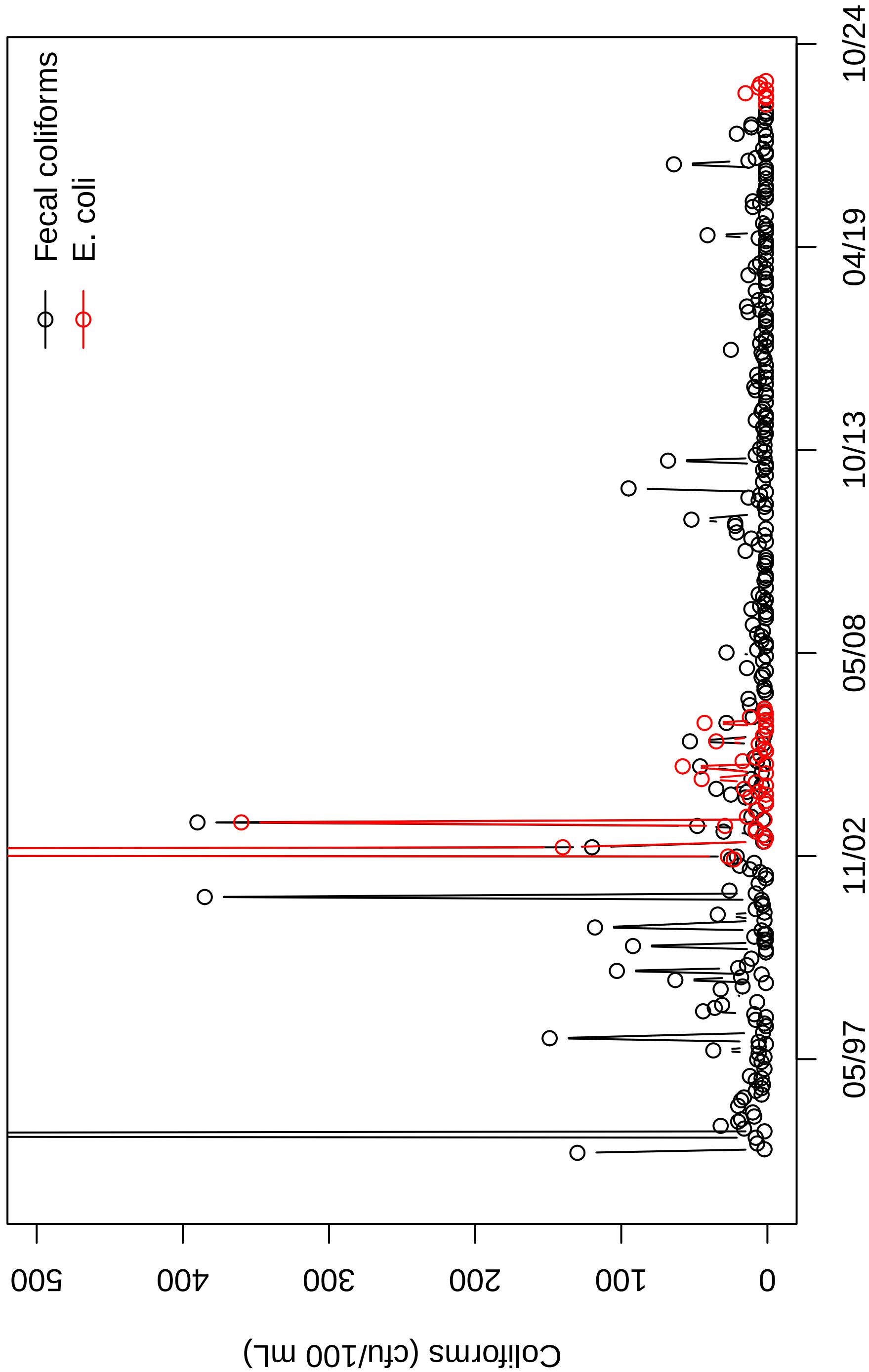


Figure B146: Lake Whatcom coliform data for Bloedel Donovan, with fecal coliforms in black and *E. coli* in red. Note difference in y-axis scaling compared to Sites 1-4. Three data points are outside of the plot range: May 1995, 1600 cfu/100 mL (fecal coliforms); December 2002, 2700 cfu/100 mL (fecal coliforms and *E. coli*).

B.4 Lake Whatcom Tributary Data (2004-present)

The figures in this appendix include the monthly or biannual baseline data collected from 2004 through the current monitoring period. Each figure includes a dashed (blue) horizontal line that shows the median value for Smith Creek and a solid (red) horizontal line that shows the median value for each creek. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted. The figures were scaled to include all but extreme outliers; off-scale outliers are listed in Table B1 (page 256).

Site	Date	Parameter	Concentration
Anderson	January 10, 2006	Total susp. solids	168.8 mg/L
Austin	January 10, 2006	Total susp. solids	166.5 mg/L
Brannian	March 3, 2014	Total phosphorus	349.8 μg-P/L
	March 3, 2014	Total susp. solids	328.5 mg/L
	January 12, 2022	Total phosphorus	259.4μg-P/L
Millwheel	February 8, 2005	Ammonium	569.4 μg-N/L
	February 8, 2005	Soluble phosphate	116.5 μg-P/L
	July 11, 2011	Ammonium	291.7 μg-N/L
	October 12, 2011	Total phosphorus	521.8 μg-P/L
	September 12, 2012	Ammonium	837.7 μg-N/L
	September 12, 2012	Total phosphorus	452.2 μg-P/L
	July 8, 2014	Total phosphorus	788.2 μg-P/L
	July 8, 2014	Soluble phosphate	165.1 μg-P/L
	July 8, 2014	Ammonium	1956.4 μg-N/L
	September 9, 2014	Total phosphorus	263.5 μg-P/L
	October 9, 2018	Total phosphorus	1,342 μg-P/L
	July 12, 2019	Total phosphorus	292.0 μg-P/L
	July 12, 2019	Ammonium	291.0 μg-N/L
	July 12, 2022	Total phosphorus	300.3 μg-P/L
	July 12, 2022	Soluble phosphate	116.3 μg-P/L
	July 12, 2022	Ammonium	411.4 μg-N/L
	June 14, 2023	Total phosphorus	254.0 μg-P/L
Olsen	January 10, 2006	Total susp. solids	166.9 mg/L
	January 12, 2022	Total phosphorus	257.8 μg-P/L
	January 12, 2022	Total susp. solids	332 mg/L
Park Place	August 1, 2006	F. coliforms	18,000 cfu/100 mL
	July 18, 2017	F. coliforms	19,000 cfu/100 mL
	May 14, 2019	Ammonium	693.3 μg-N/L
	May 14, 2019	Soluble phosphate	111.8 μg-P/L
	September 13, 2022	Ammonium	266.5 μg-N/L
Silver Beach	August 1, 2006	F. coliforms	12,000 cfu/100 mL

Table B1: List of outliers omitted from Figures B147–B185 to preserve scale.

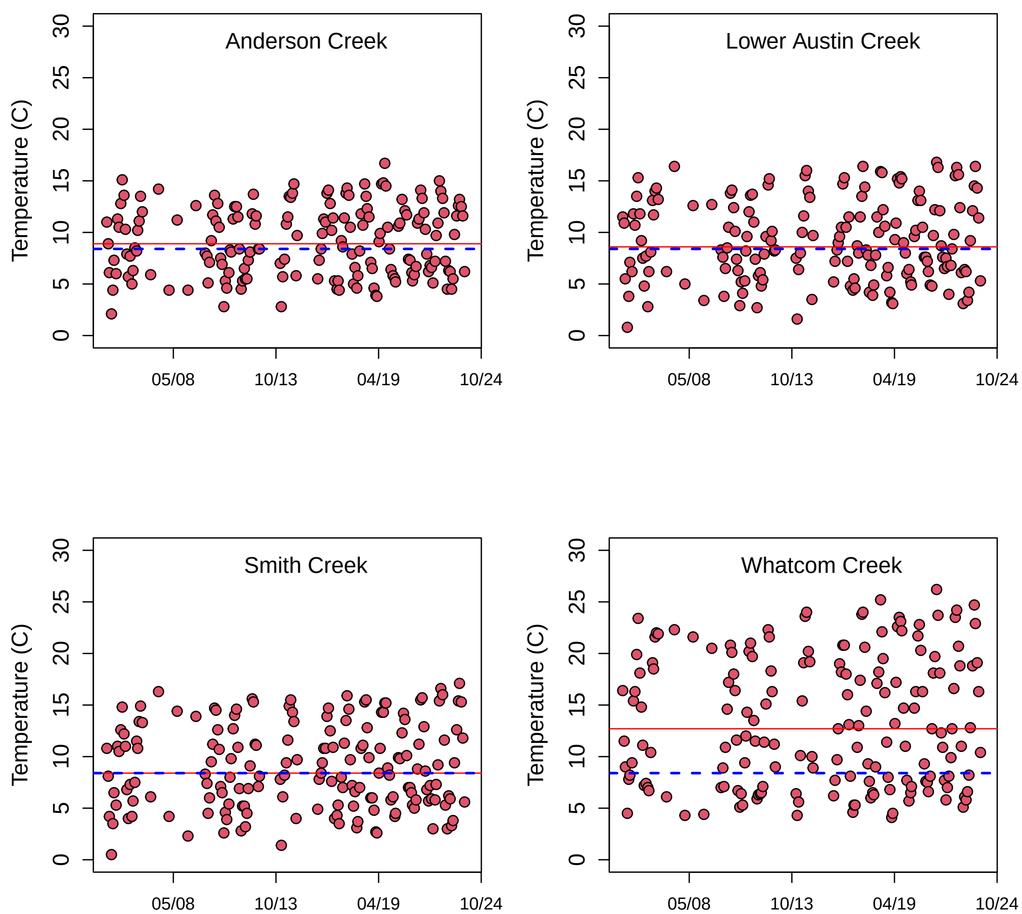


Figure B147: Temperature data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

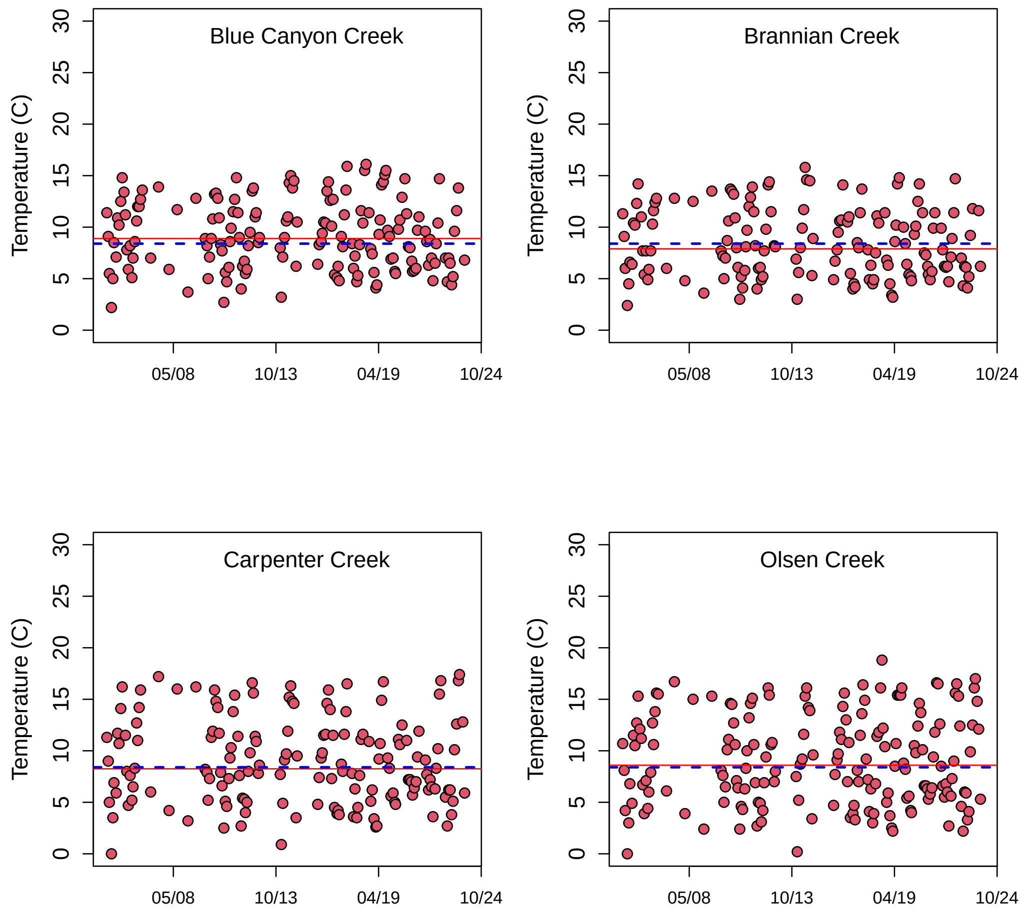


Figure B148: Temperature data Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

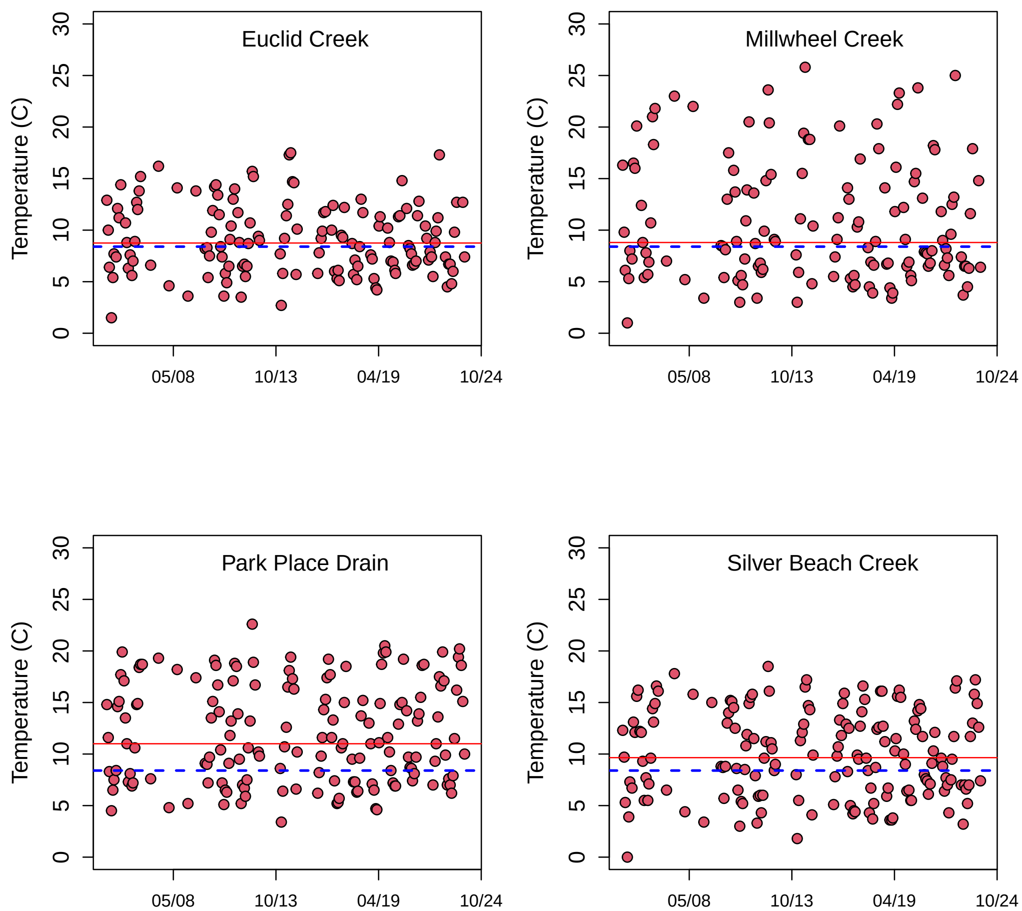


Figure B149: Temperature data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

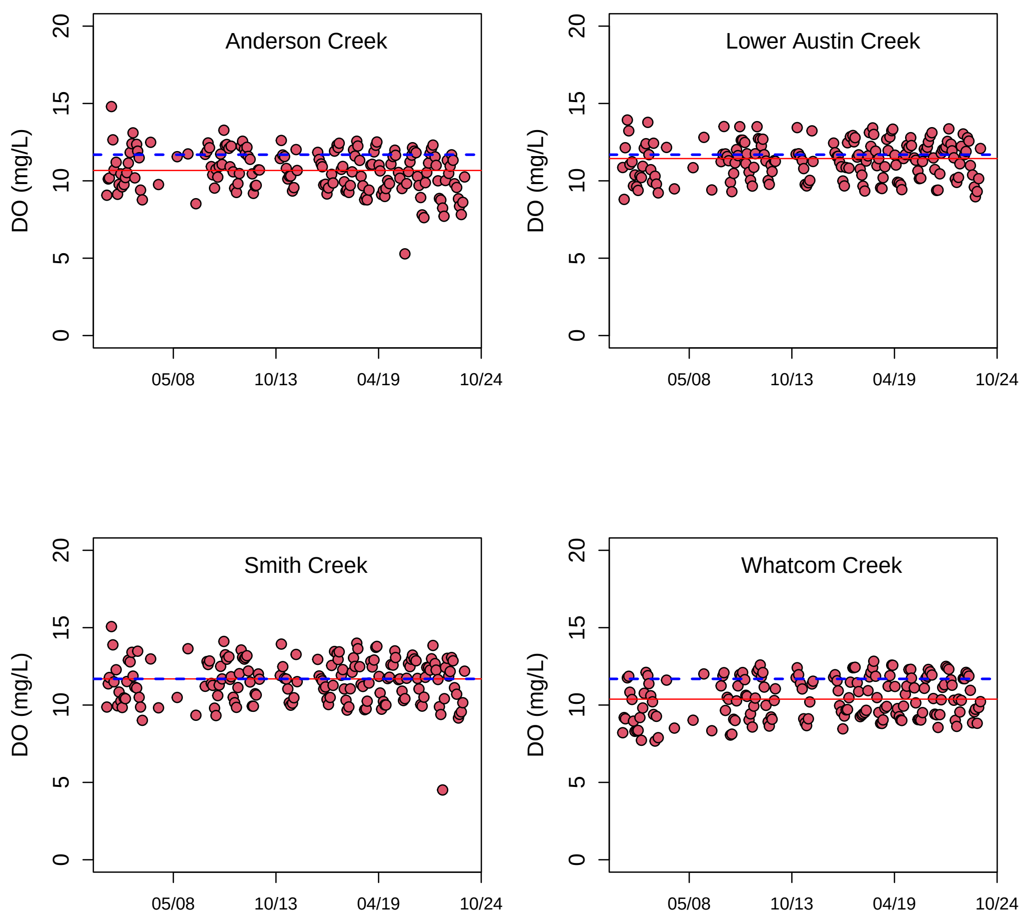


Figure B150: Dissolved oxygen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

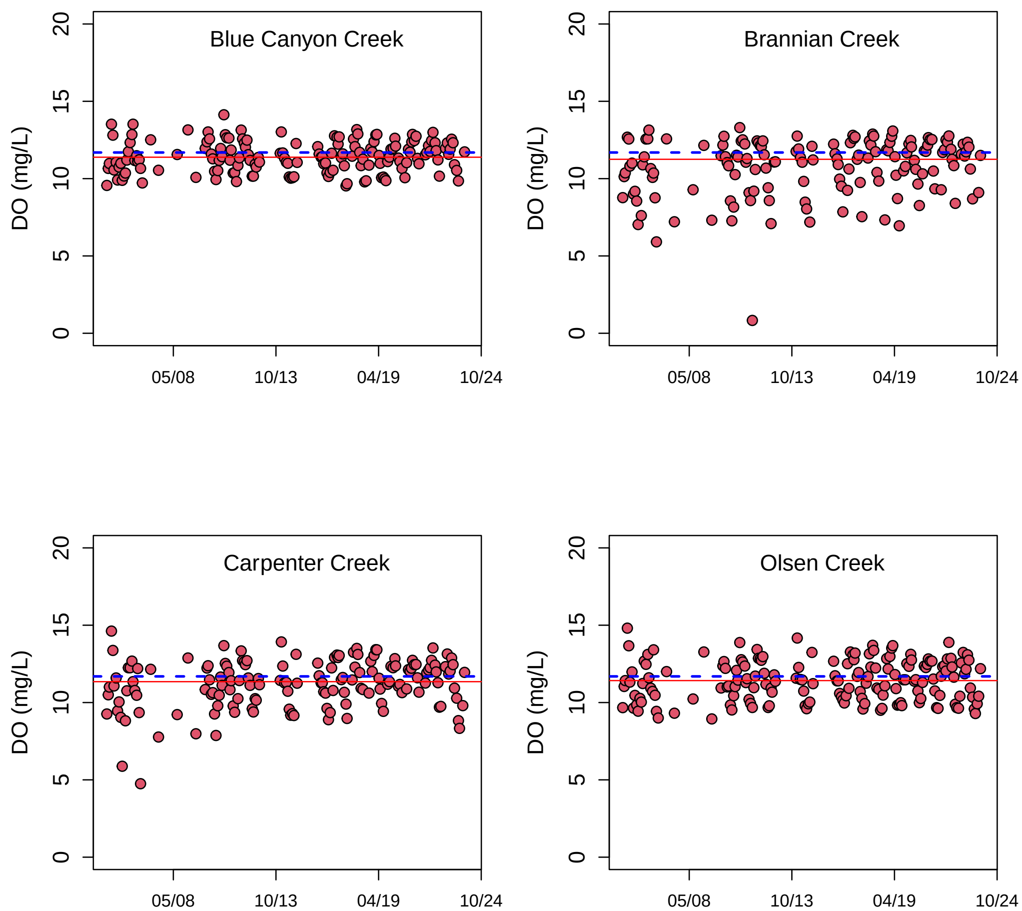


Figure B151: Dissolved oxygen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

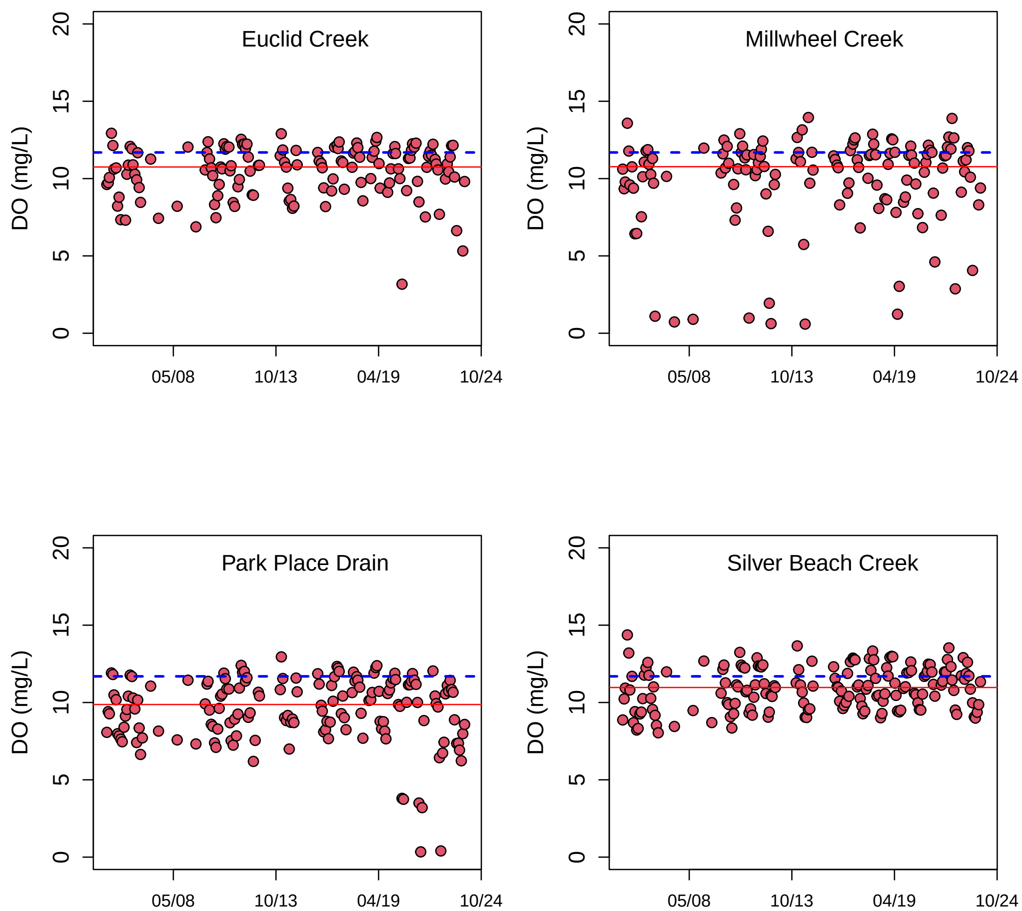


Figure B152: Dissolved oxygen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

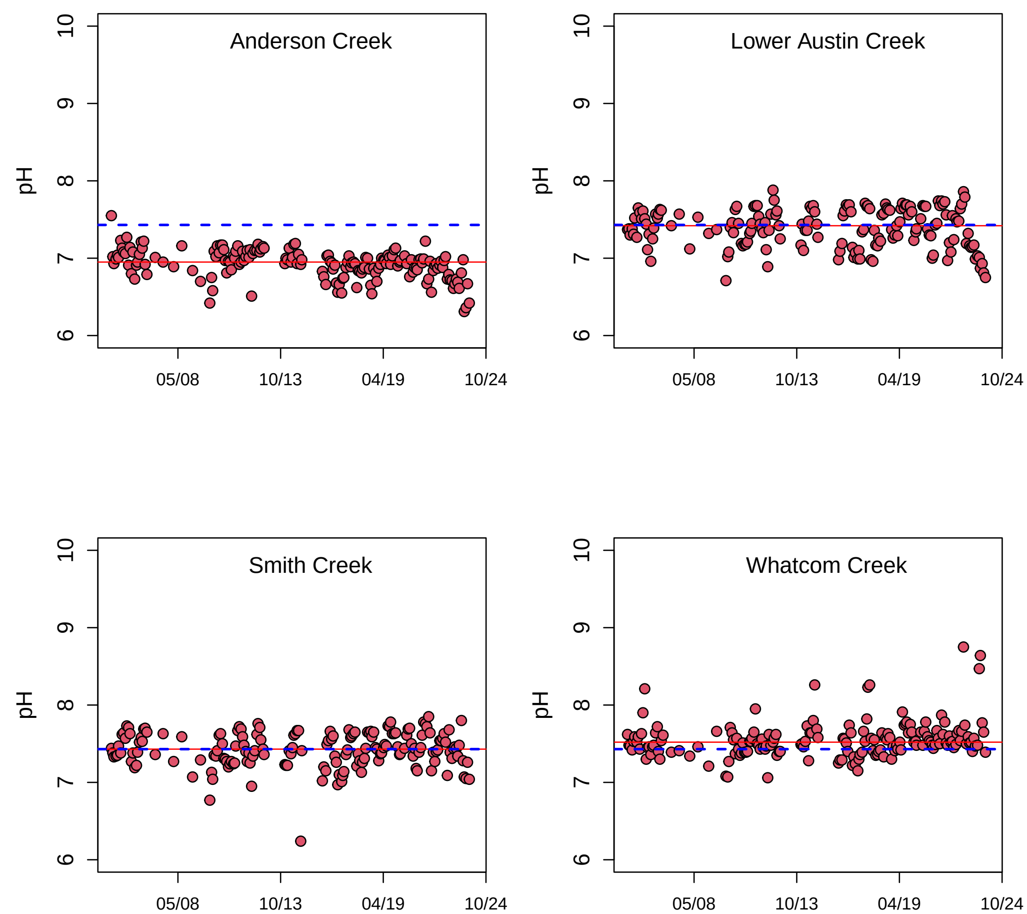


Figure B153: Tributary pH data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

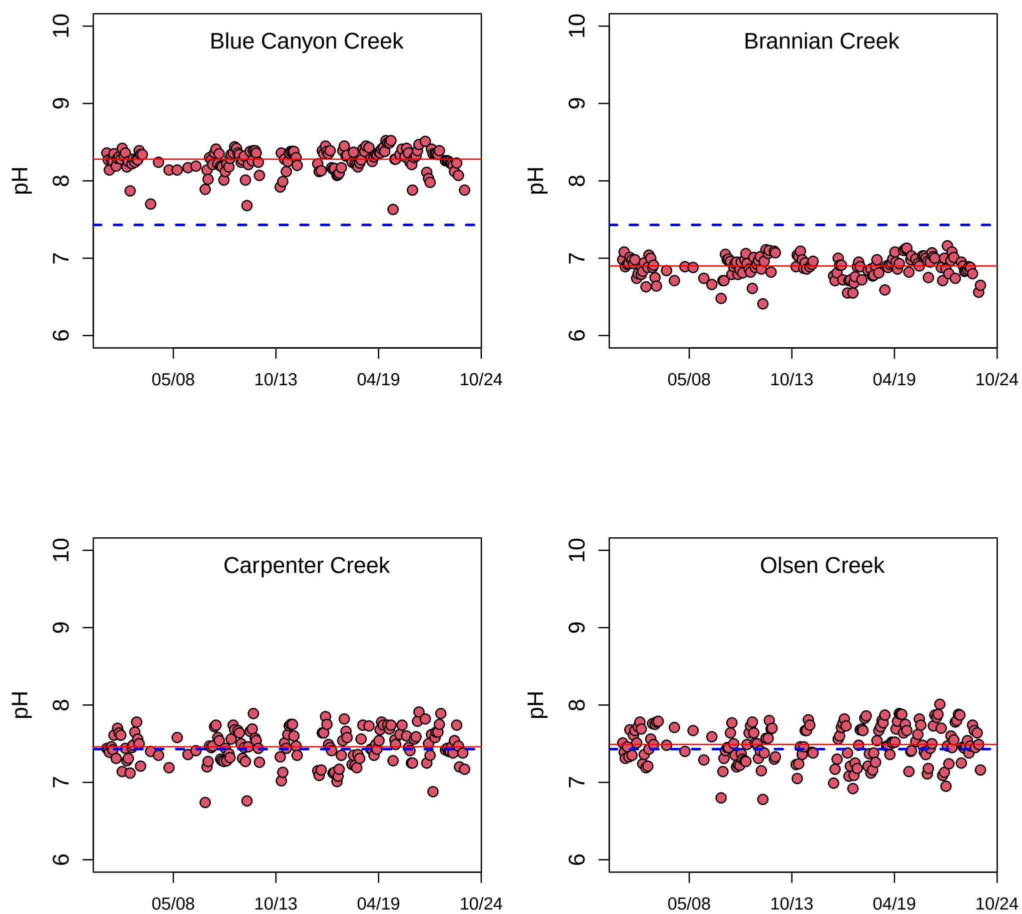


Figure B154: Tributary pH data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

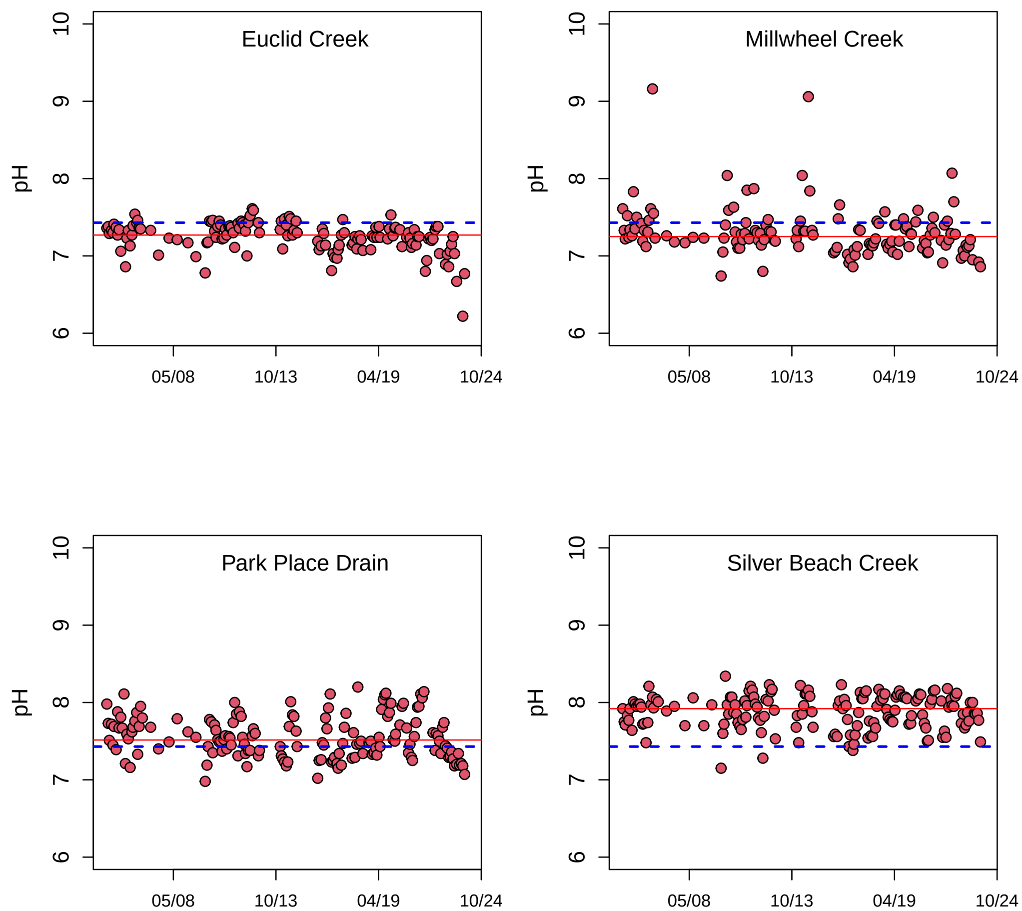


Figure B155: Tributary pH data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

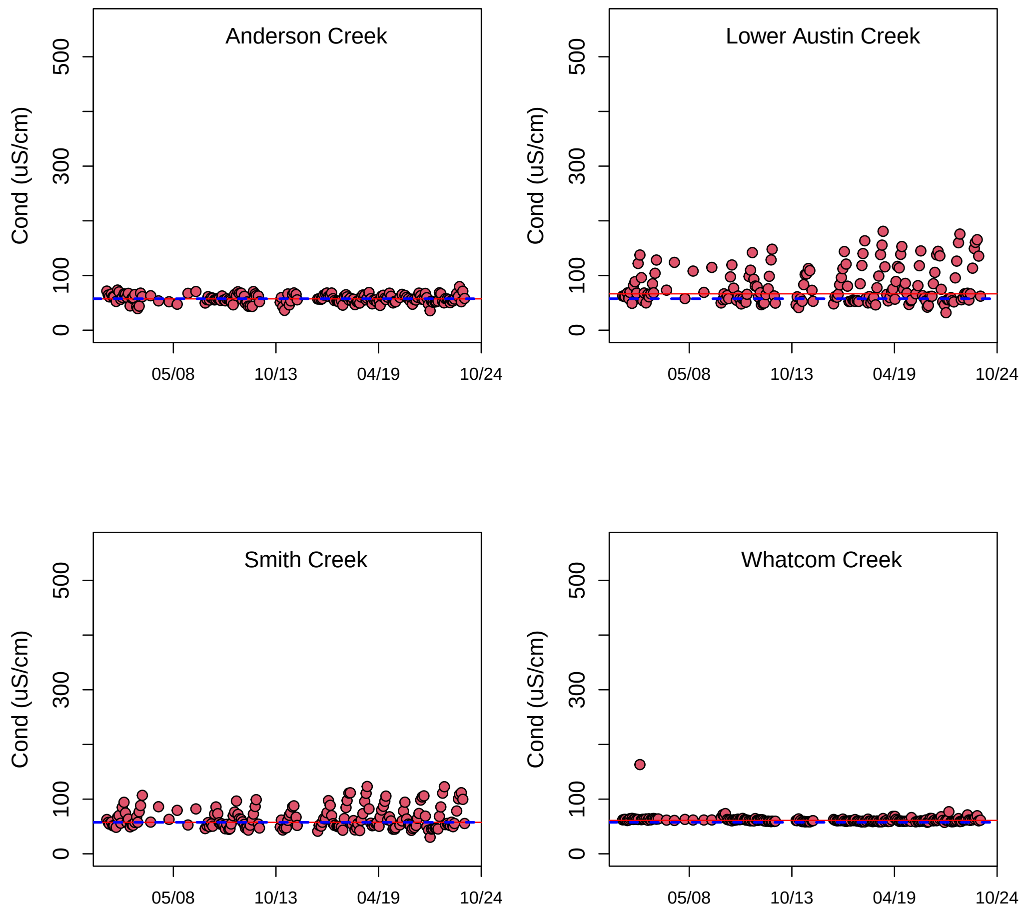


Figure B156: Conductivity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

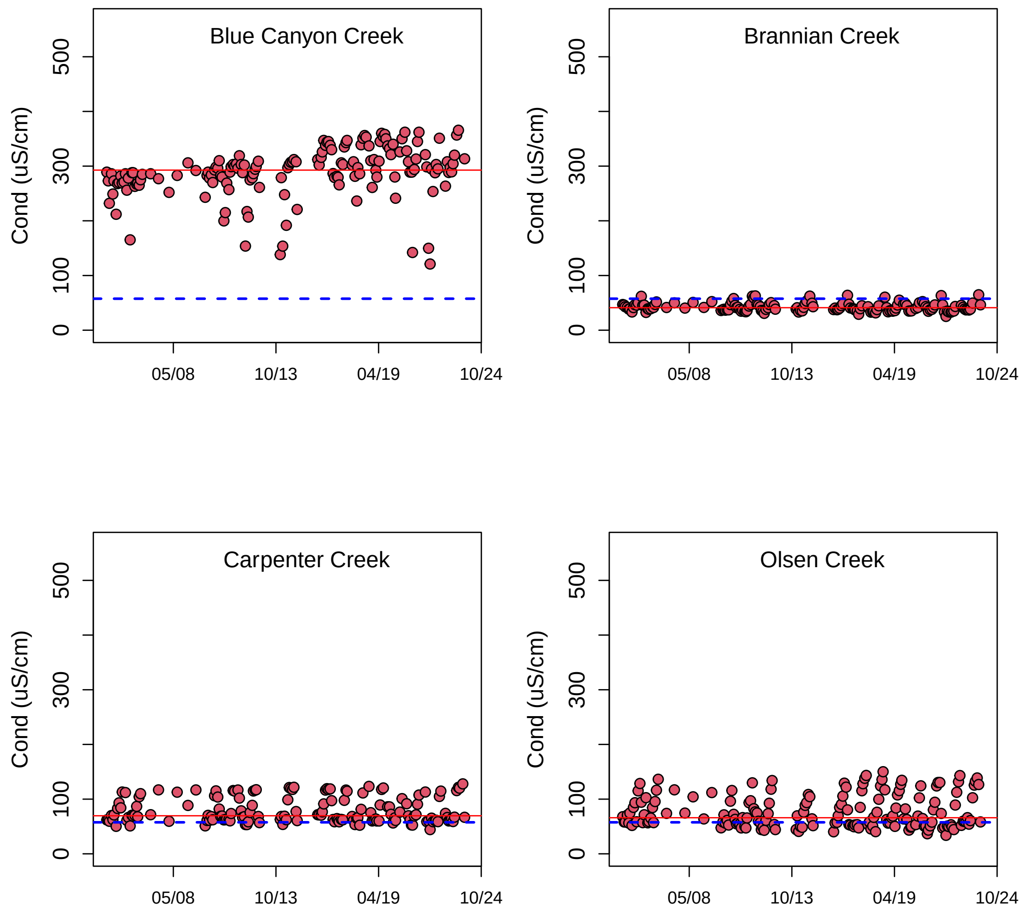


Figure B157: Conductivity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

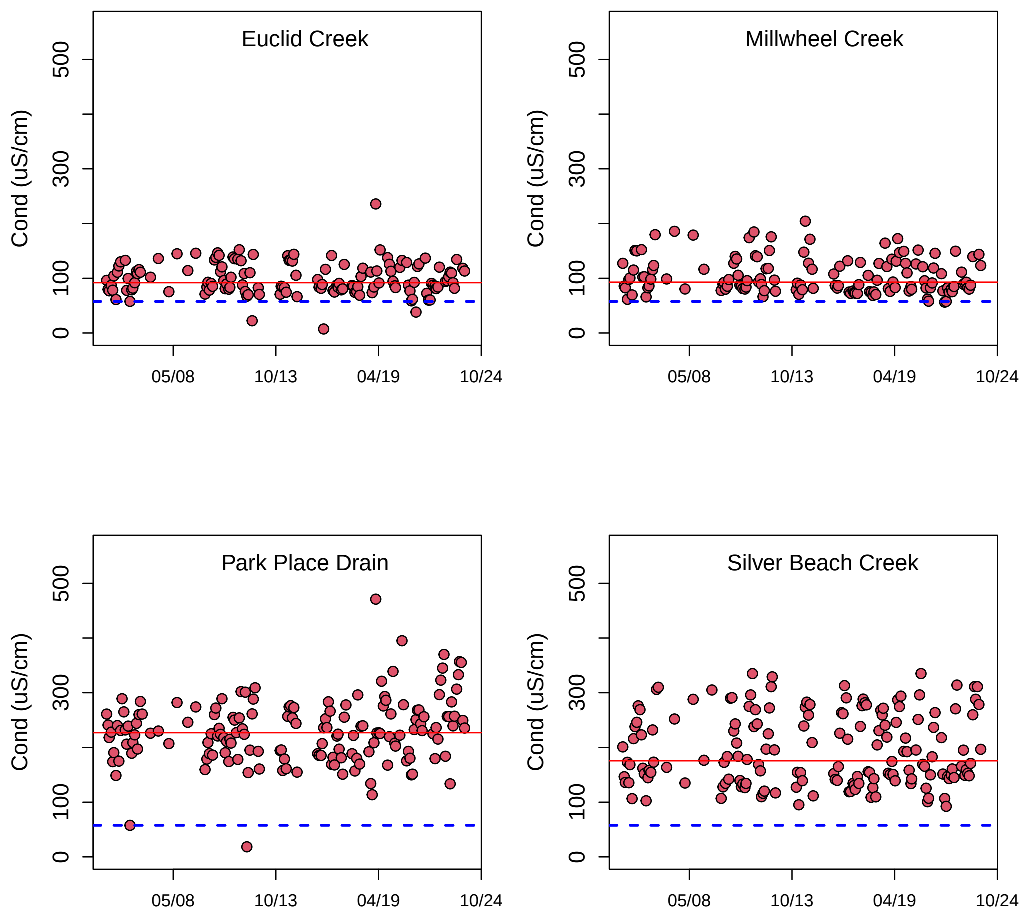


Figure B158: Conductivity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

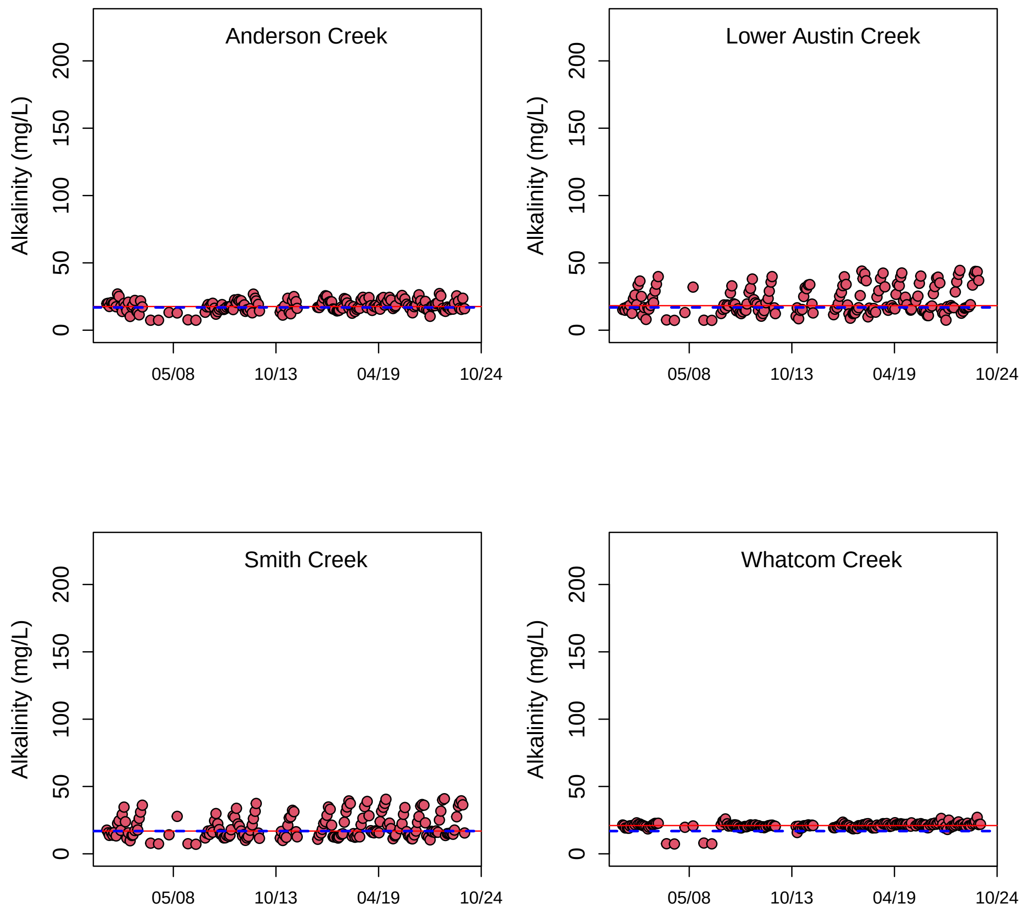


Figure B159: Alkalinity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

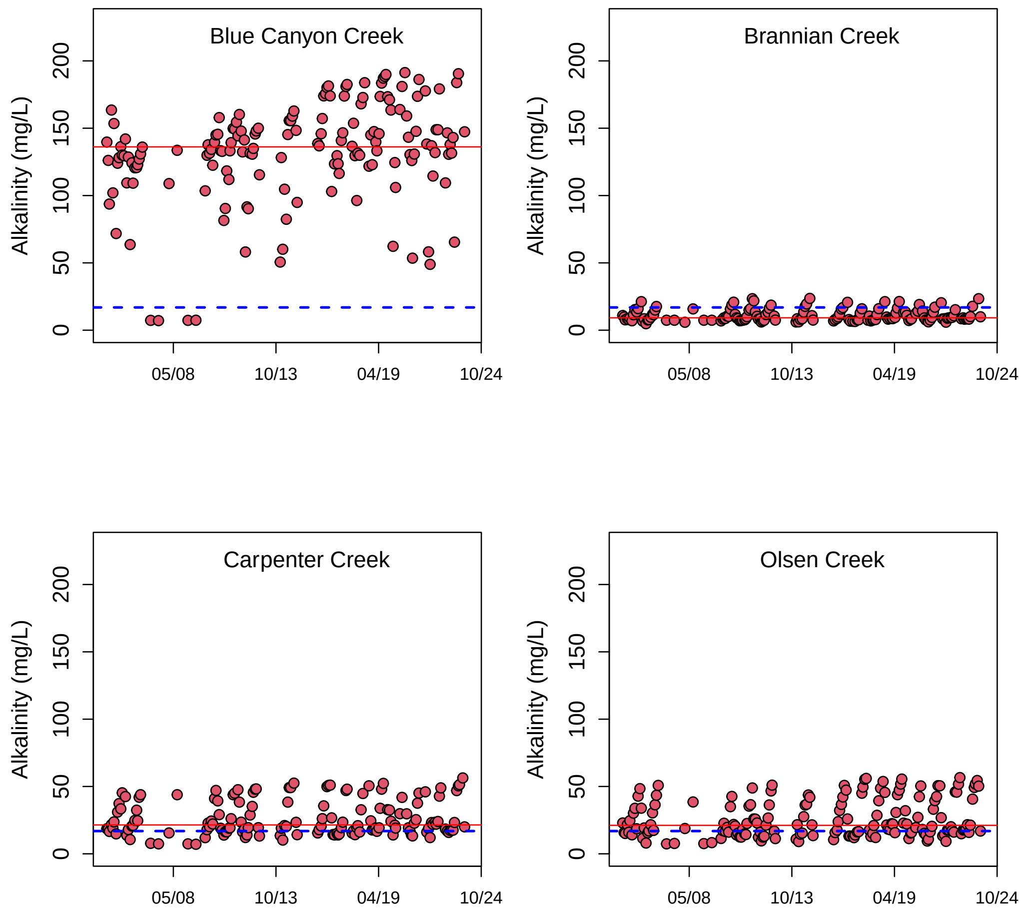


Figure B160: Alkalinity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

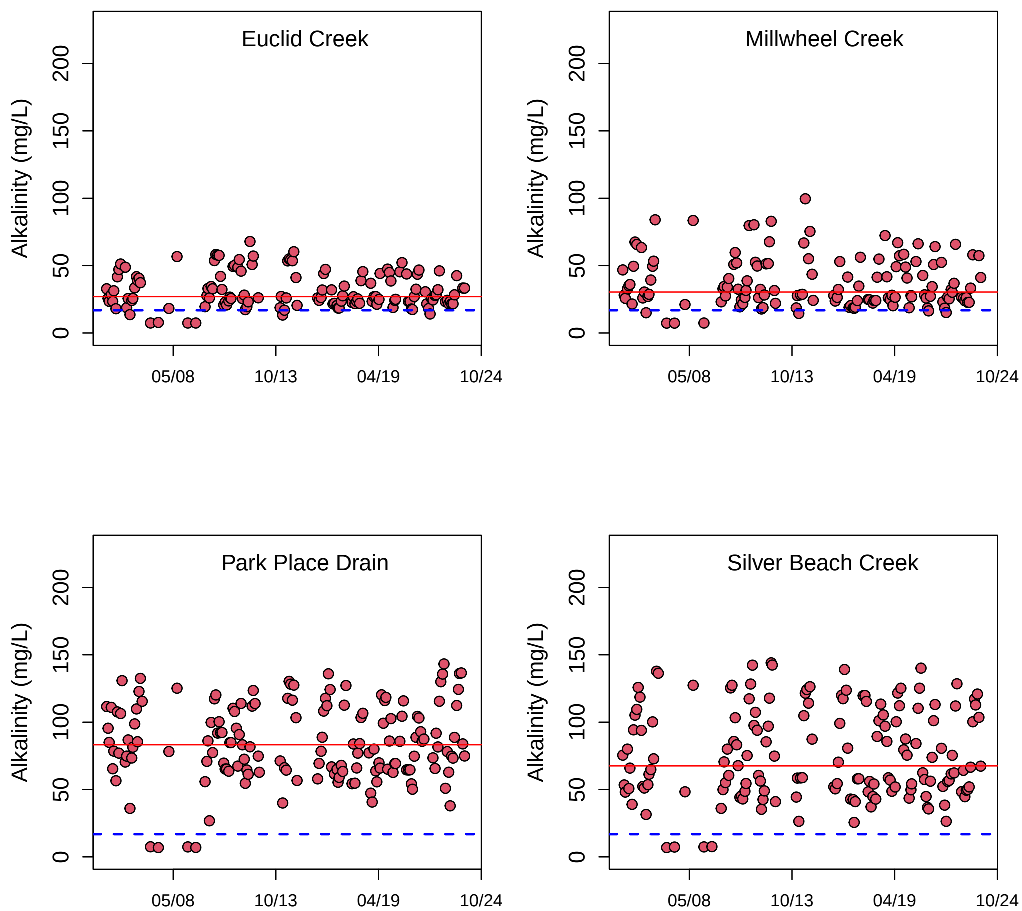


Figure B161: Alkalinity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

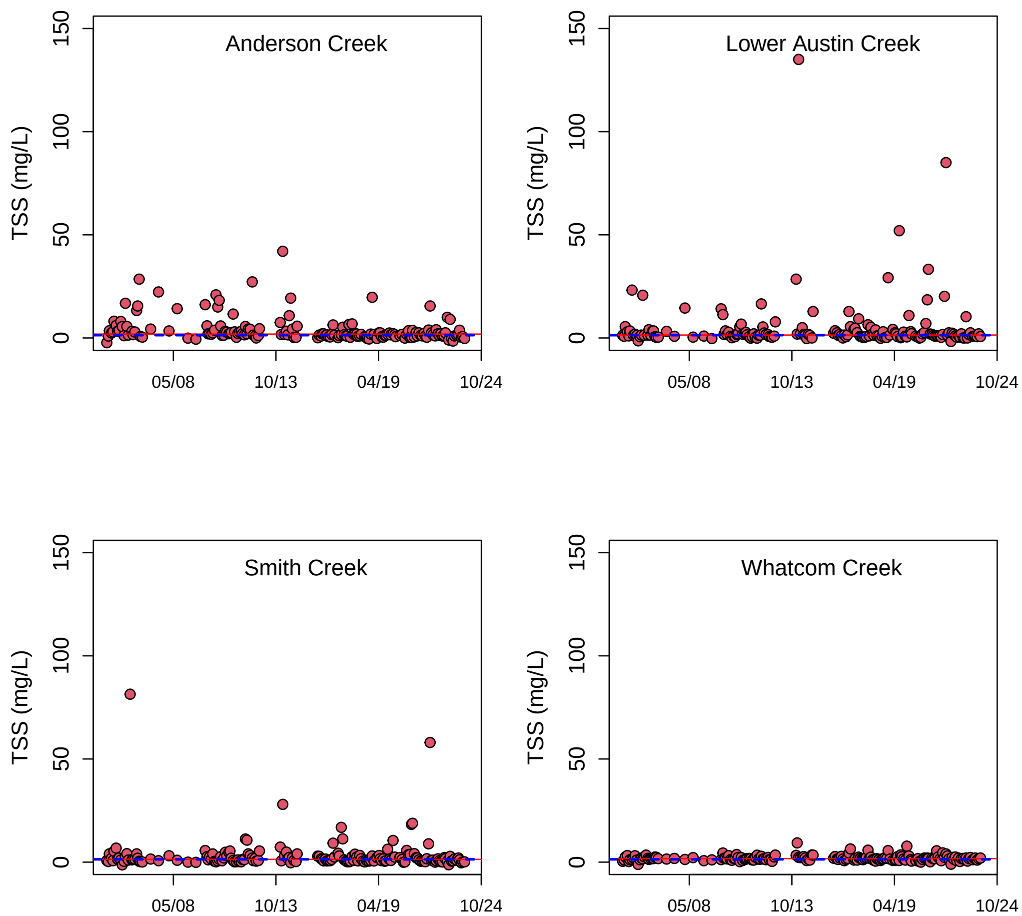


Figure B162: Total suspended solids data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

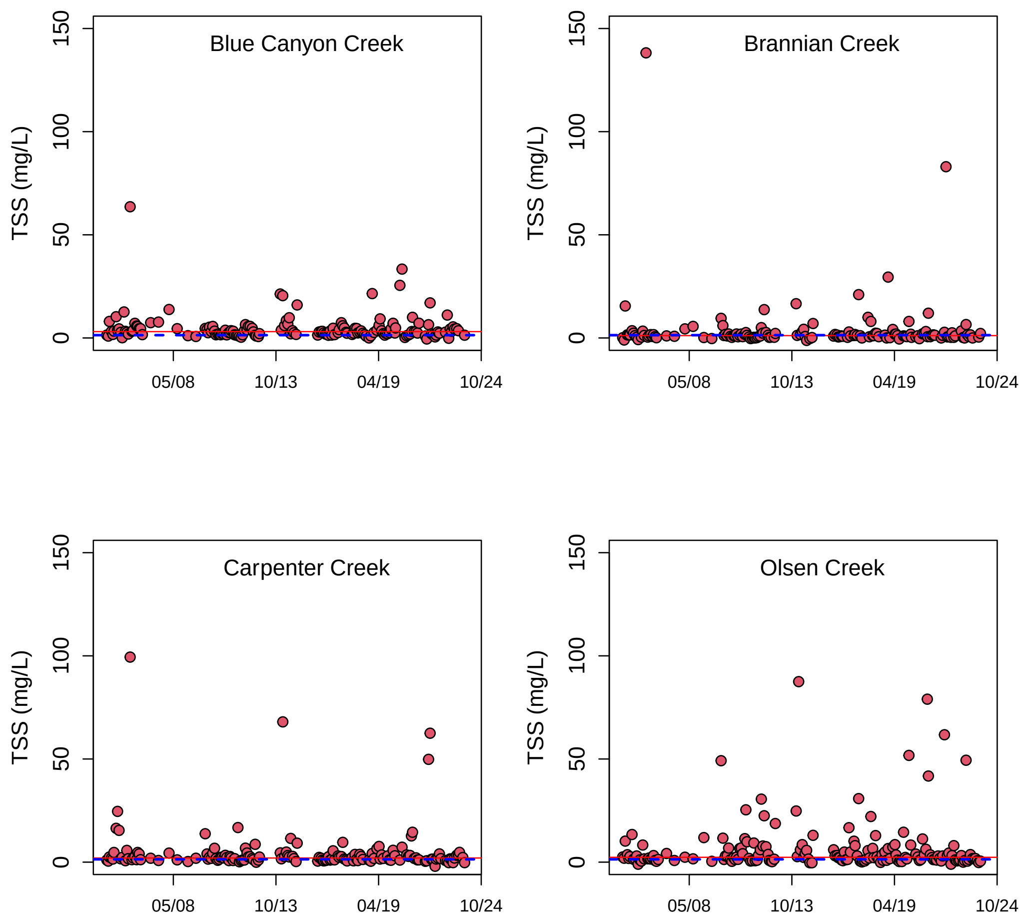


Figure B163: Total suspended solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

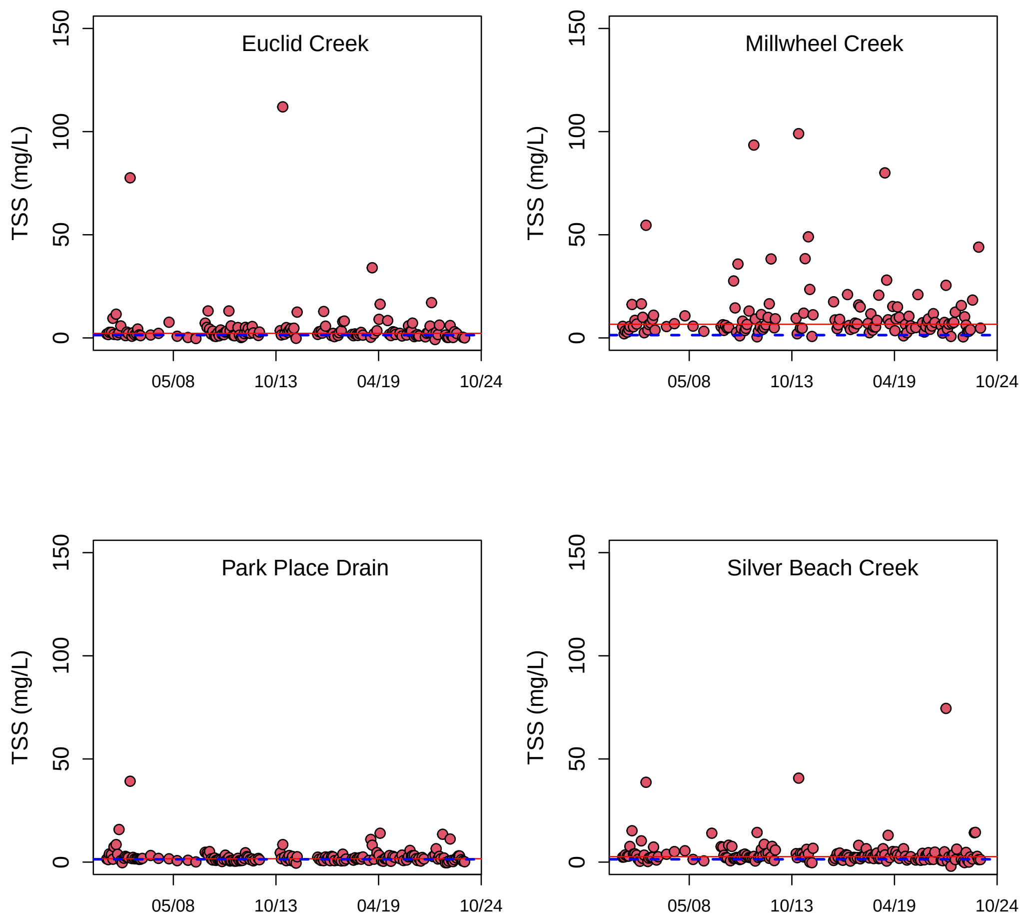


Figure B164: Total suspended solids data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

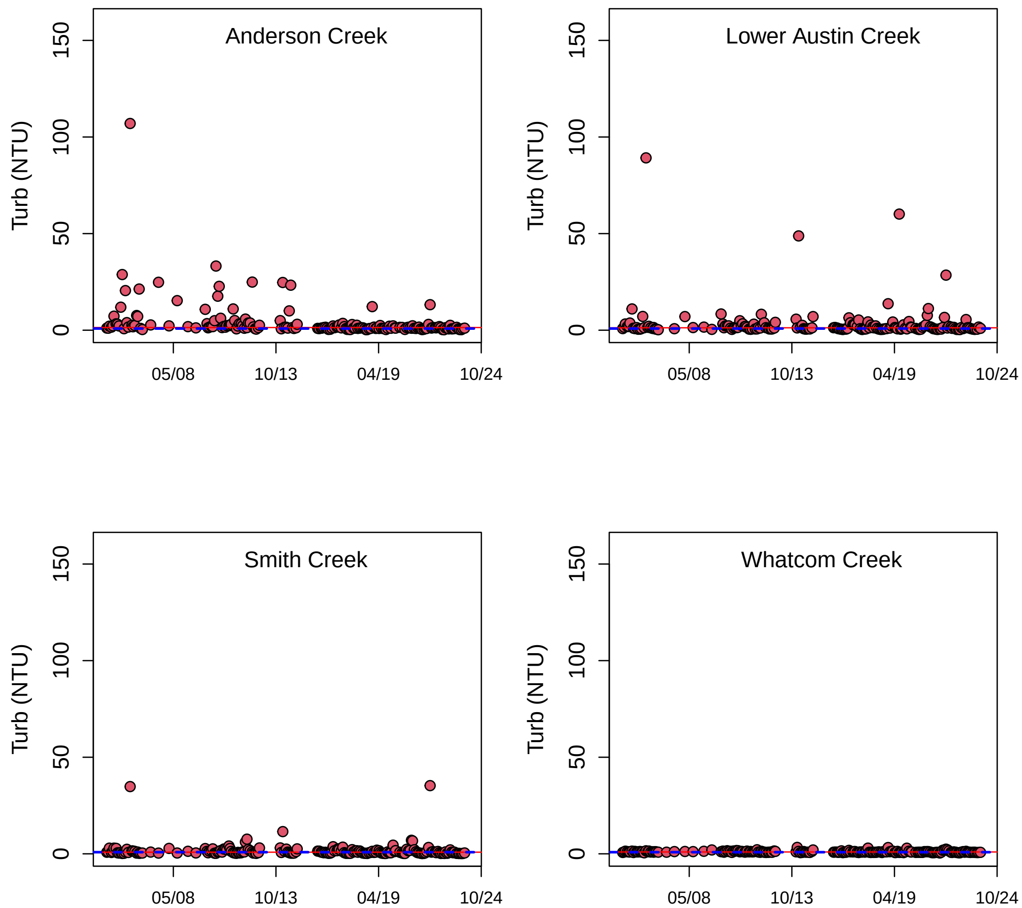


Figure B165: Turbidity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

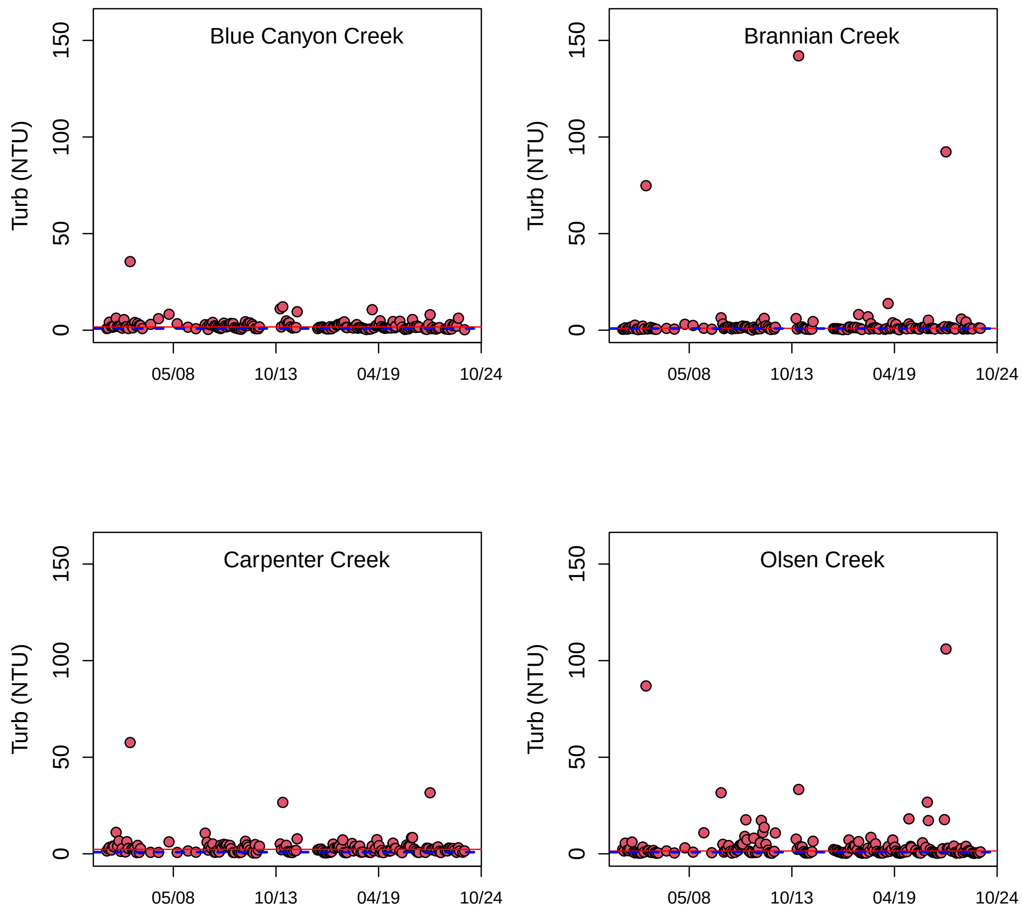


Figure B166: Turbidity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

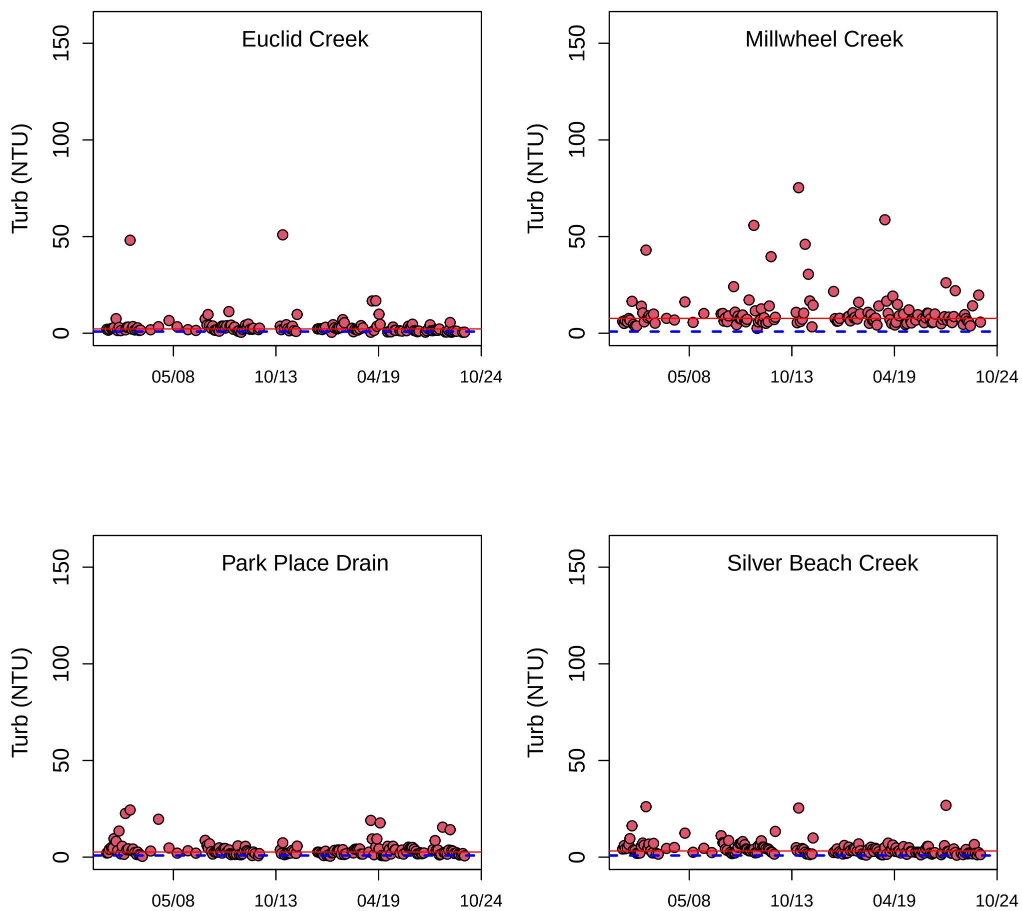


Figure B167: Turbidity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

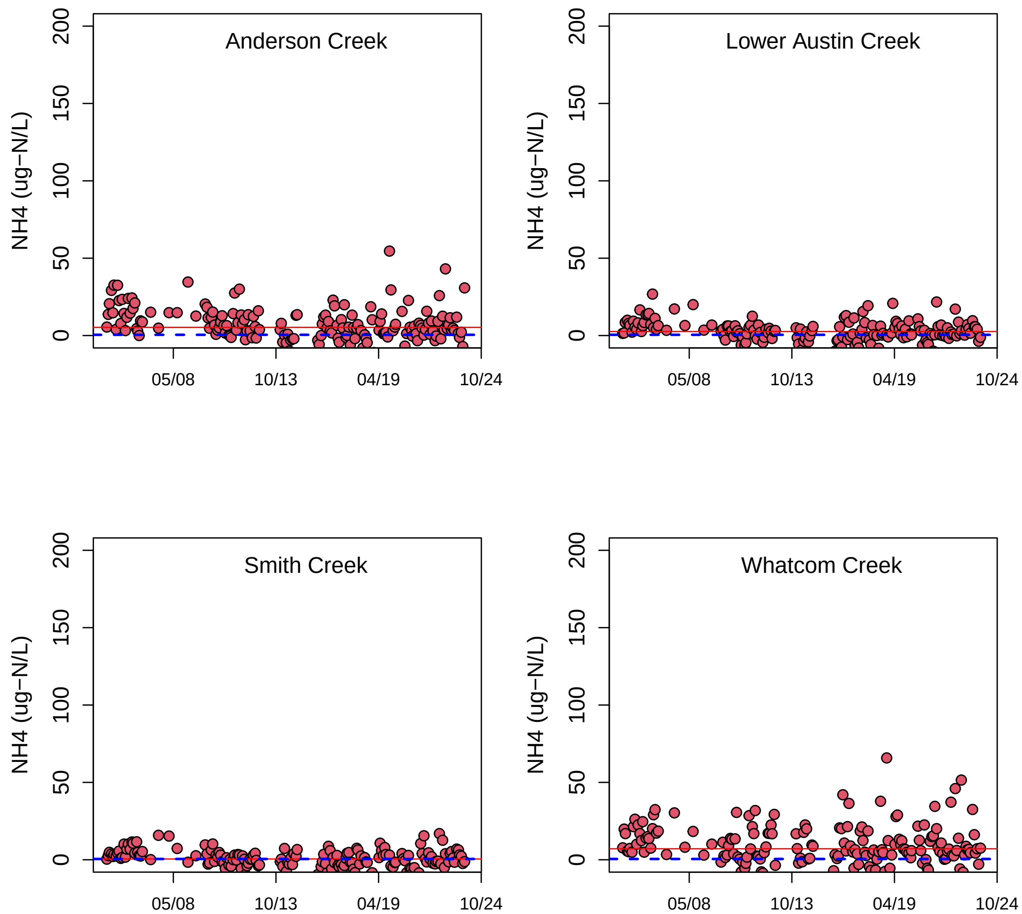


Figure B168: Ammonium data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

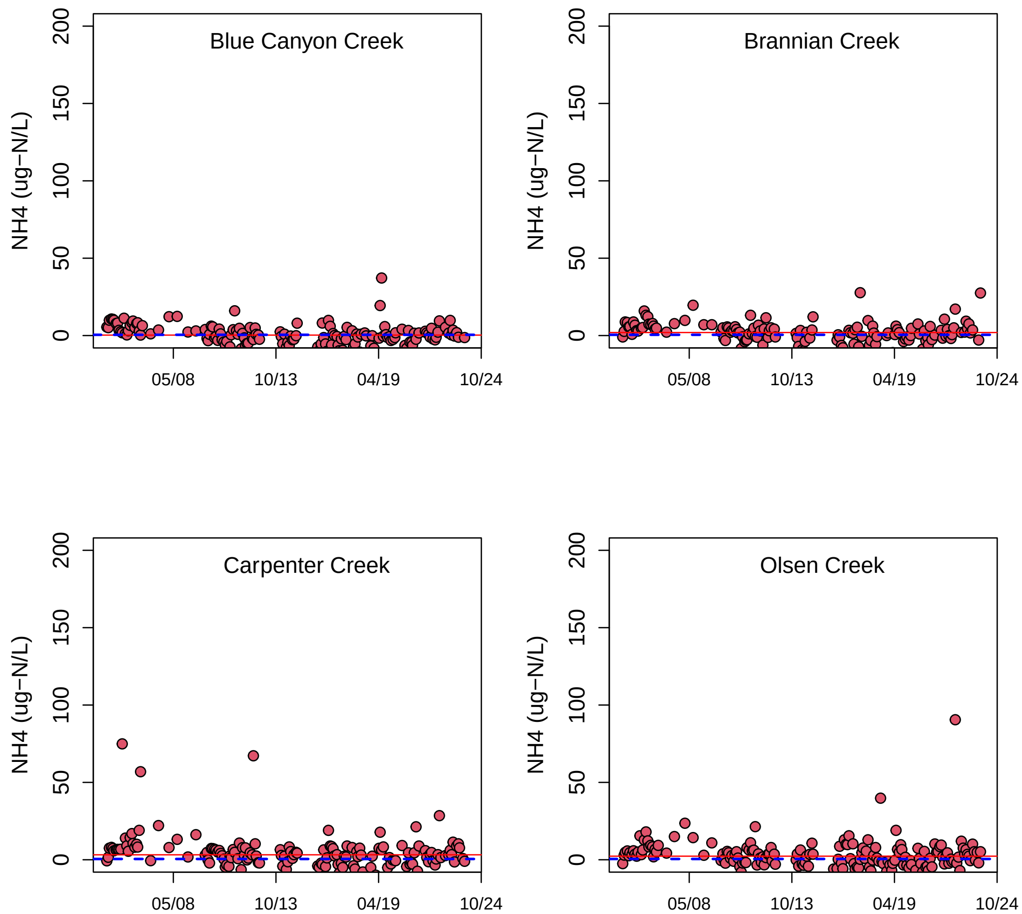


Figure B169: Ammonium data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

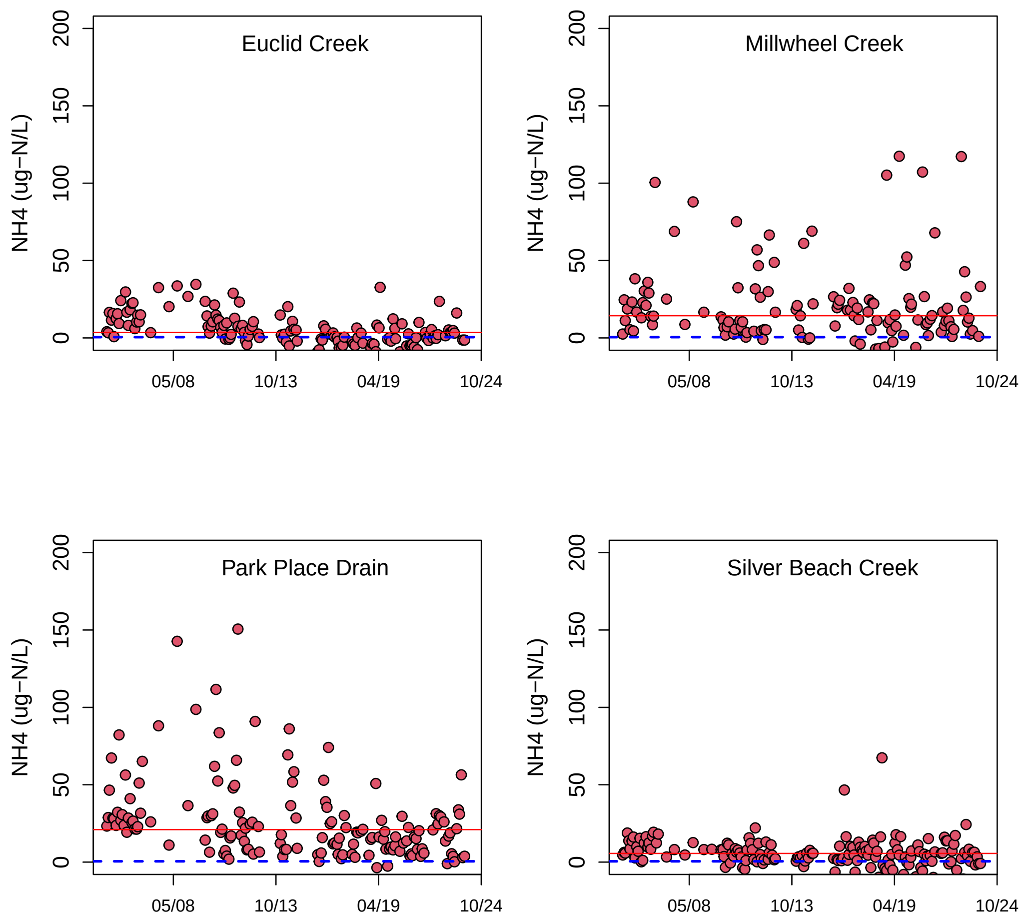


Figure B170: Ammonium data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

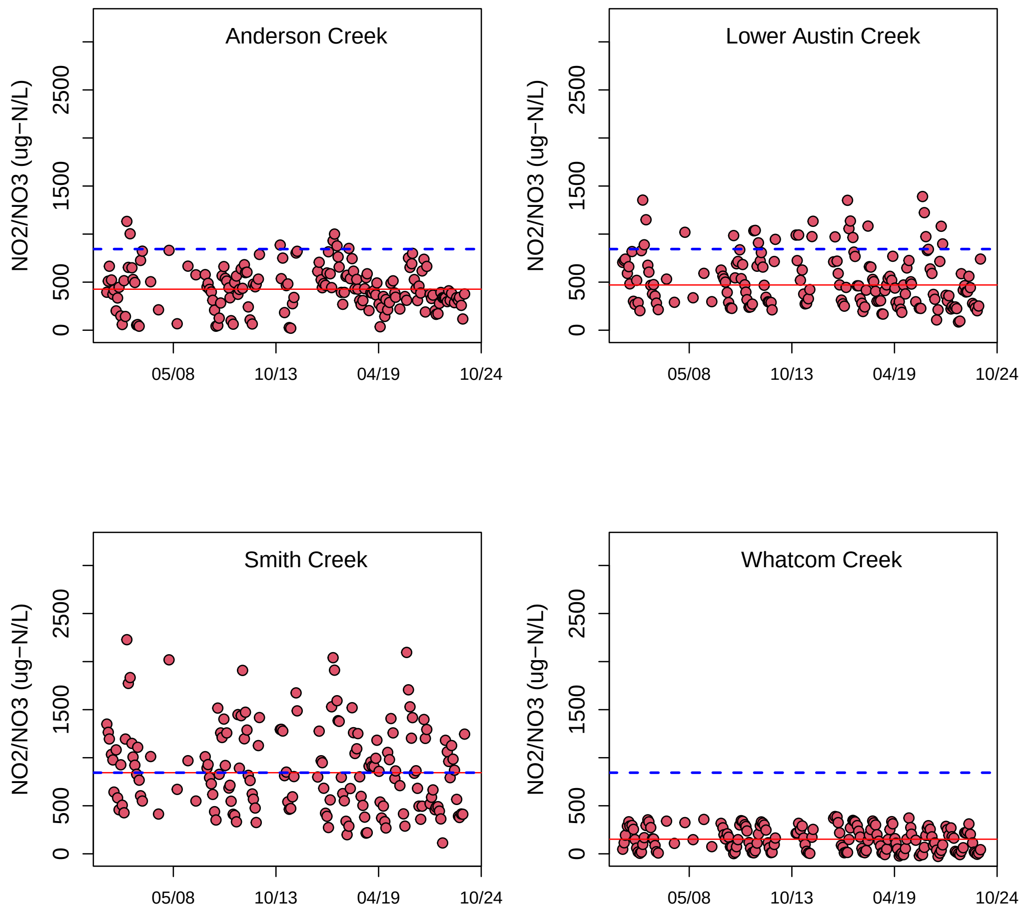


Figure B171: Nitrate/nitrite data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

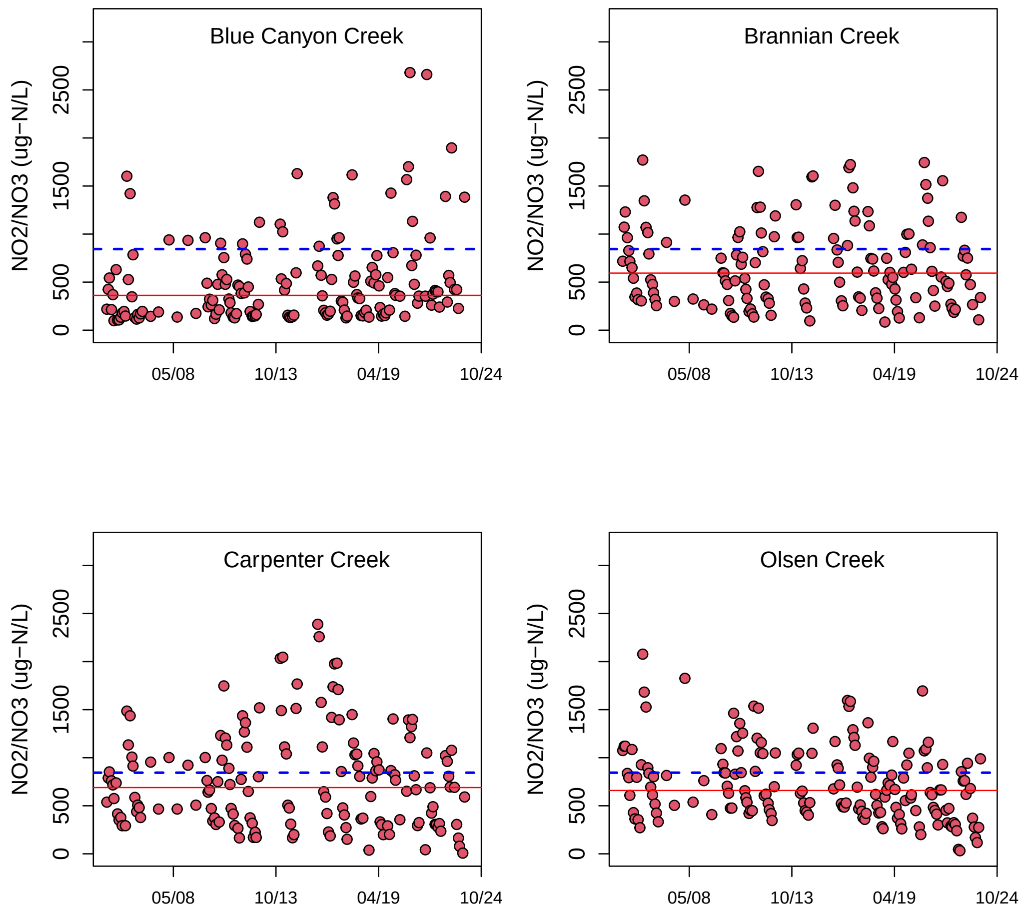


Figure B172: Nitrate/nitrite data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

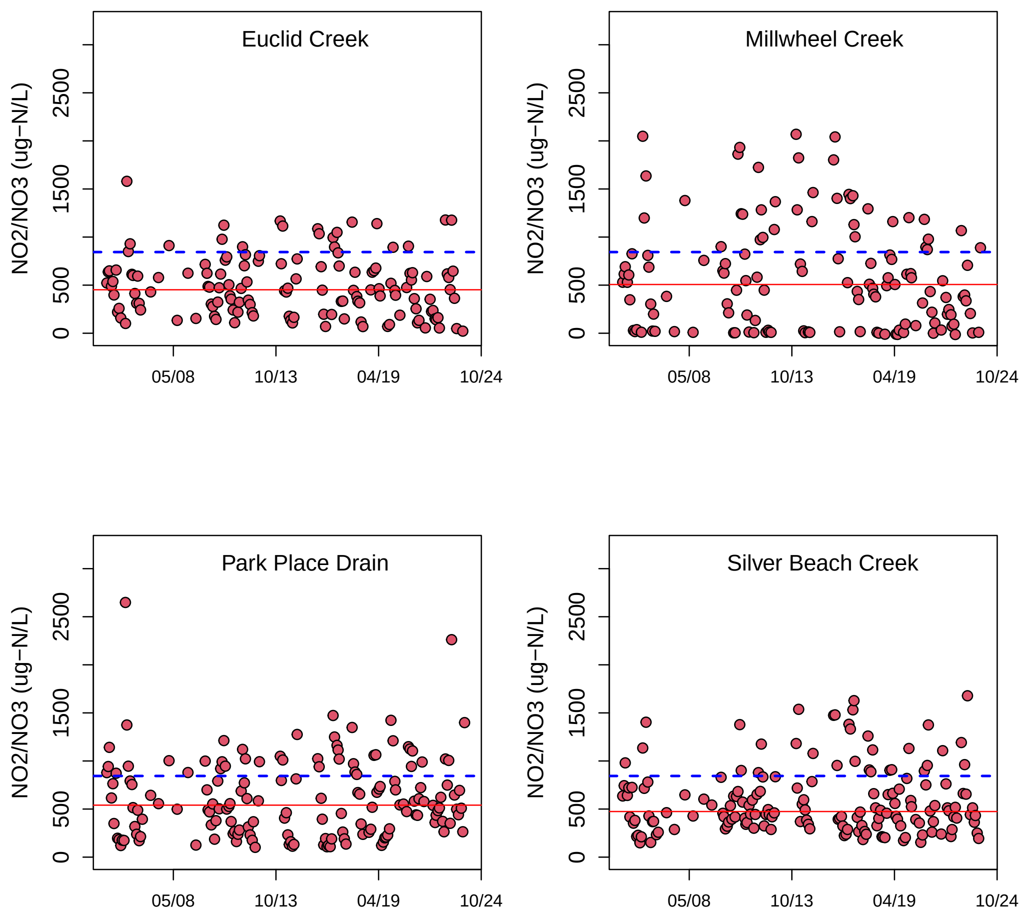


Figure B173: Nitrate/nitrite data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

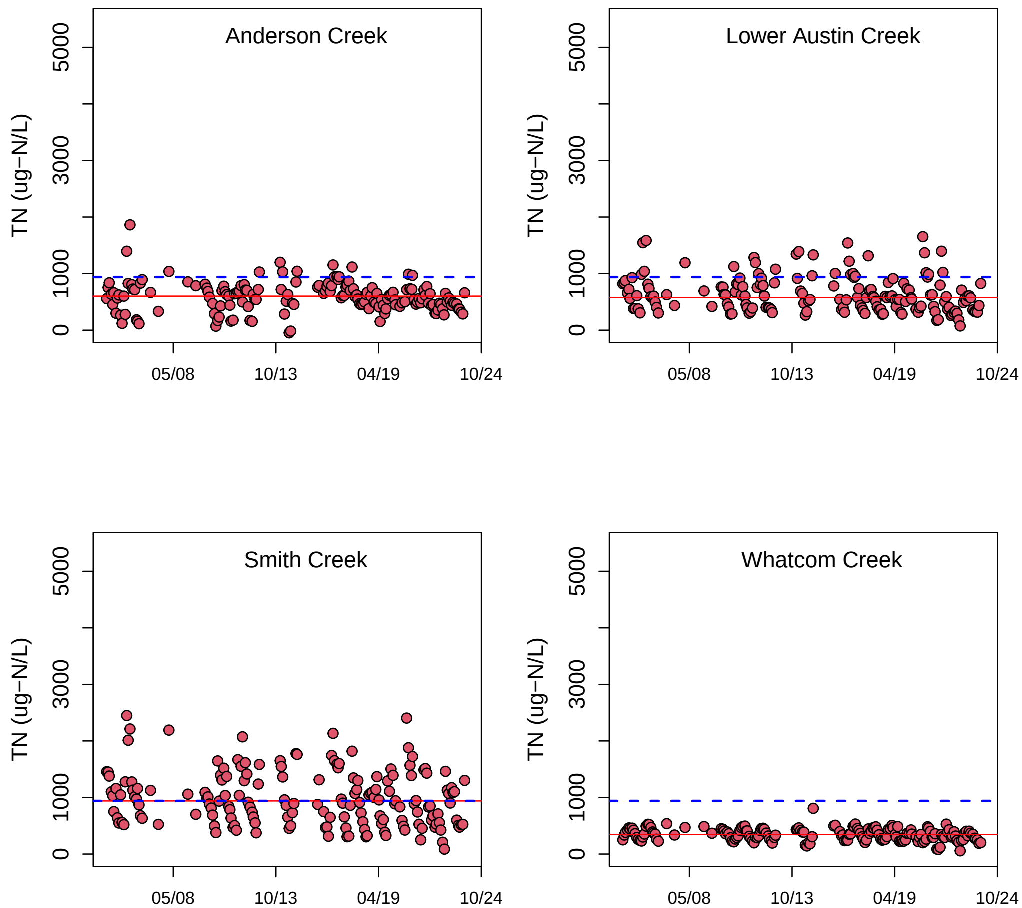


Figure B174: Total nitrogen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

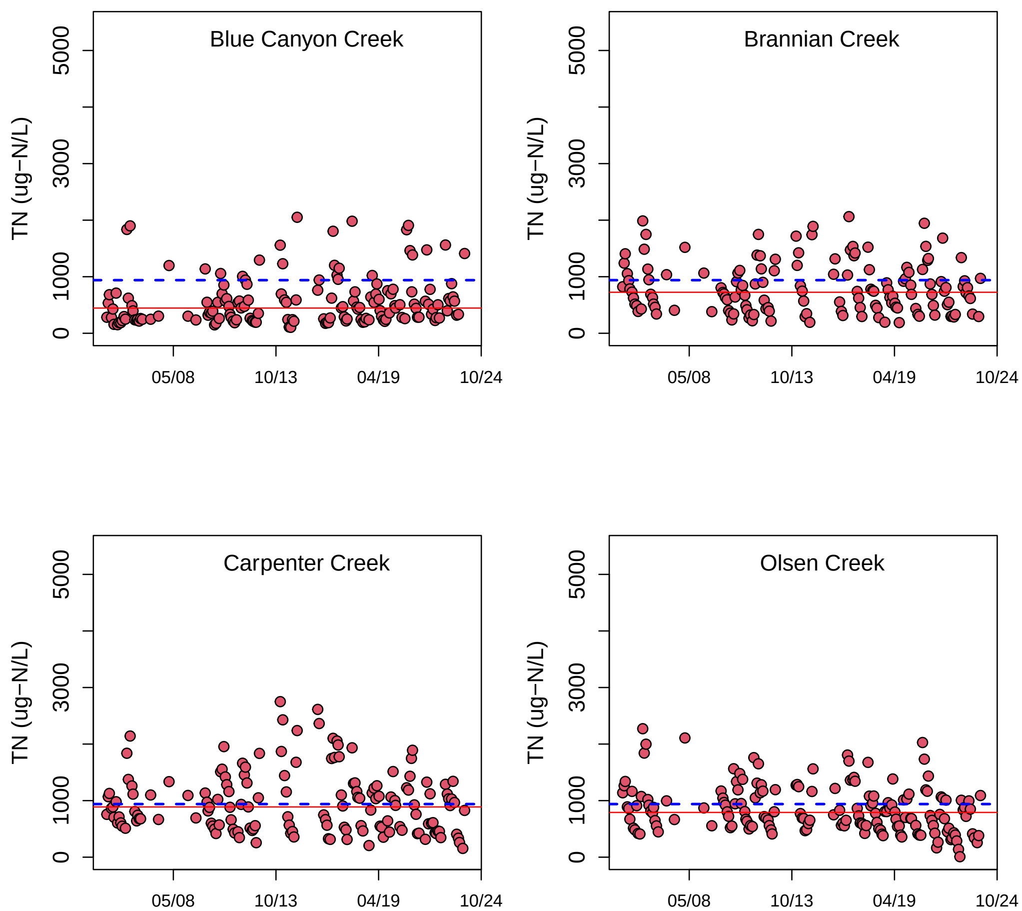


Figure B175: Total nitrogen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

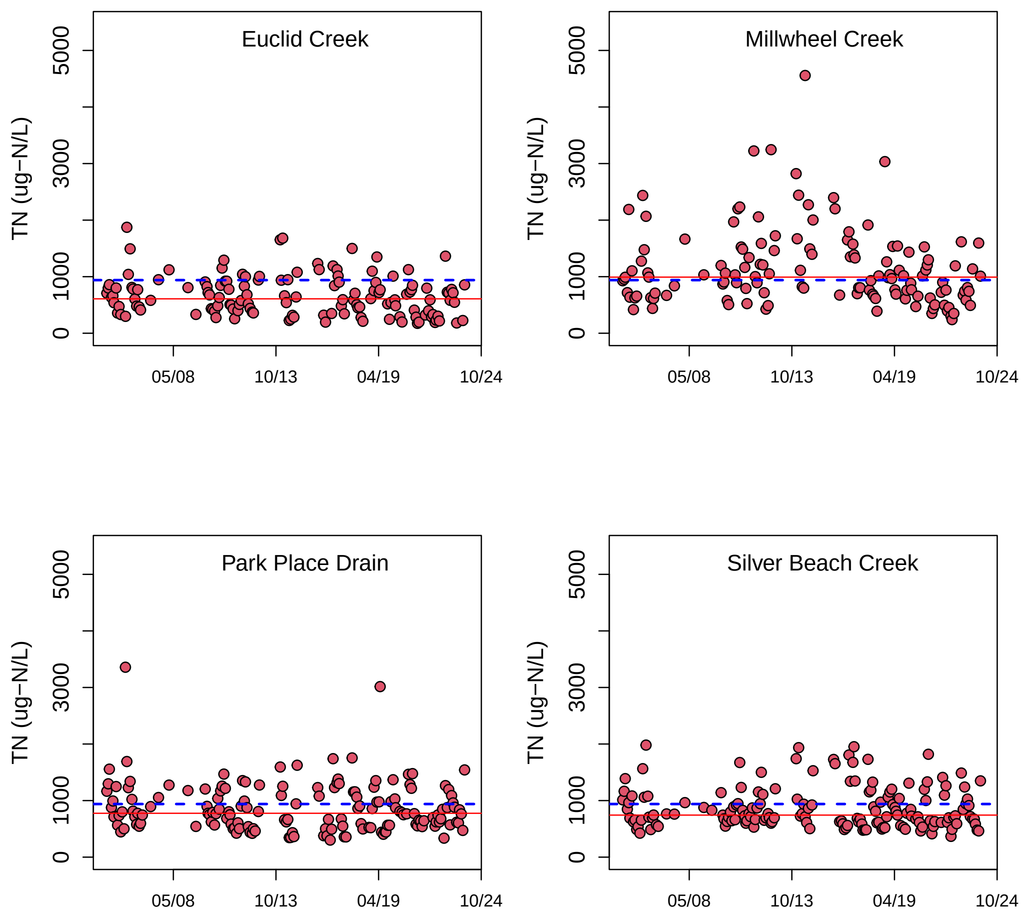


Figure B176: Total nitrogen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

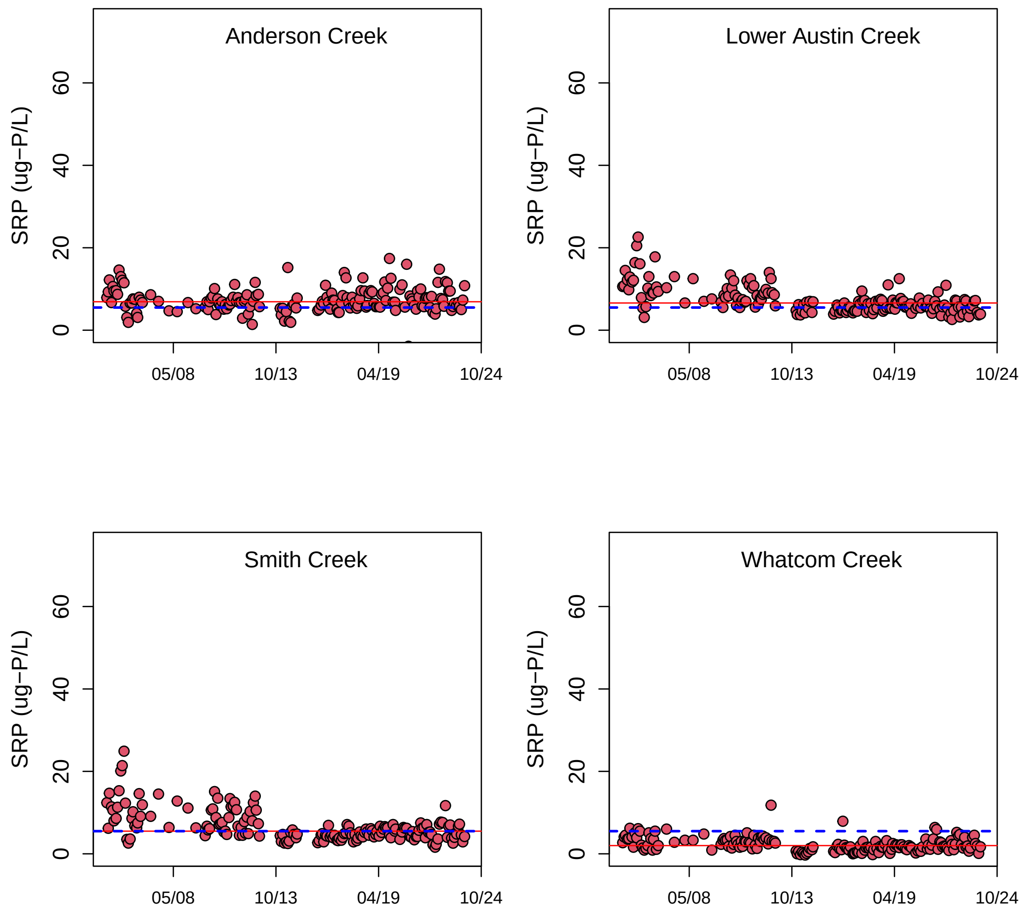


Figure B177: Soluble phosphate data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

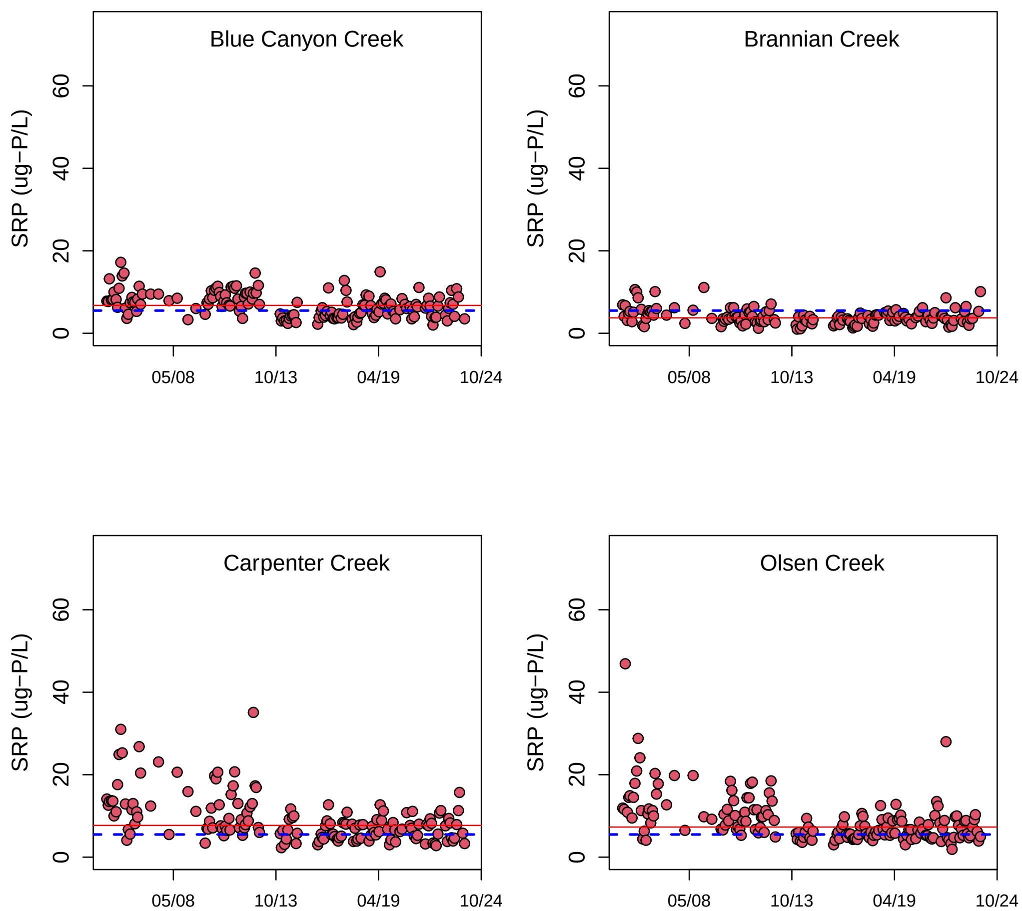


Figure B178: Soluble phosphate data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

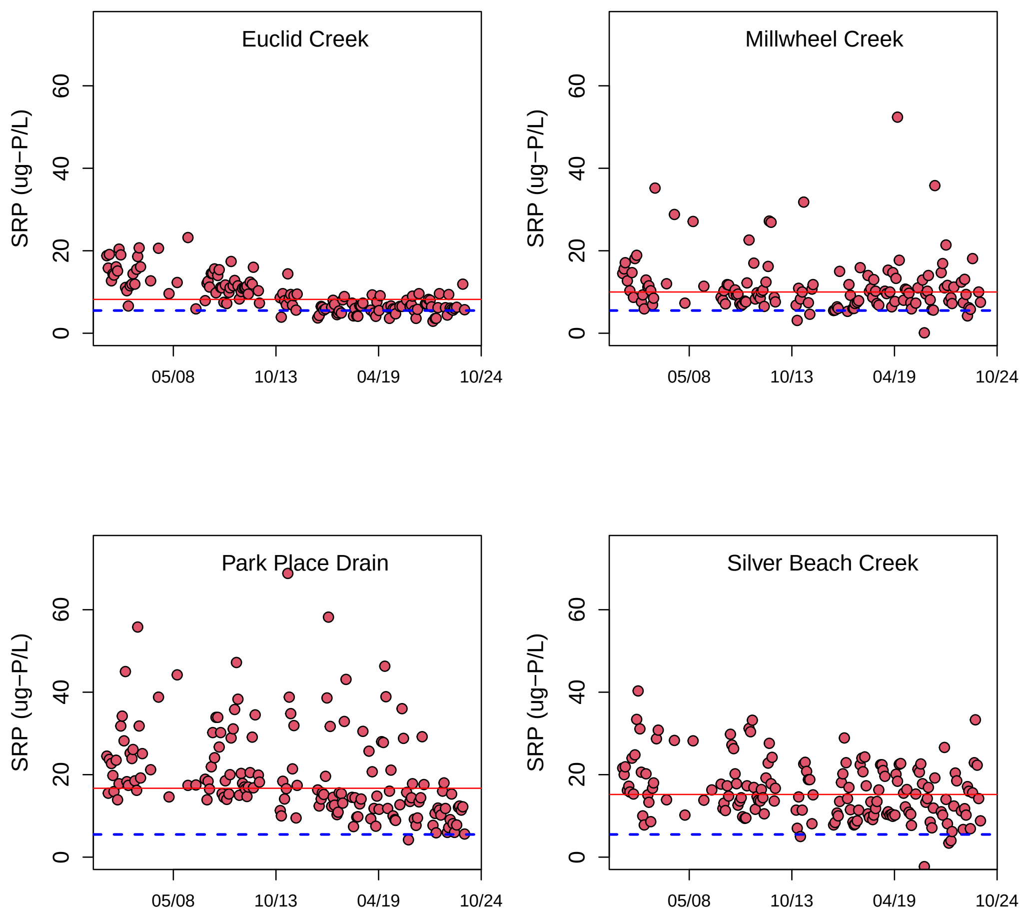


Figure B179: Soluble phosphate data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

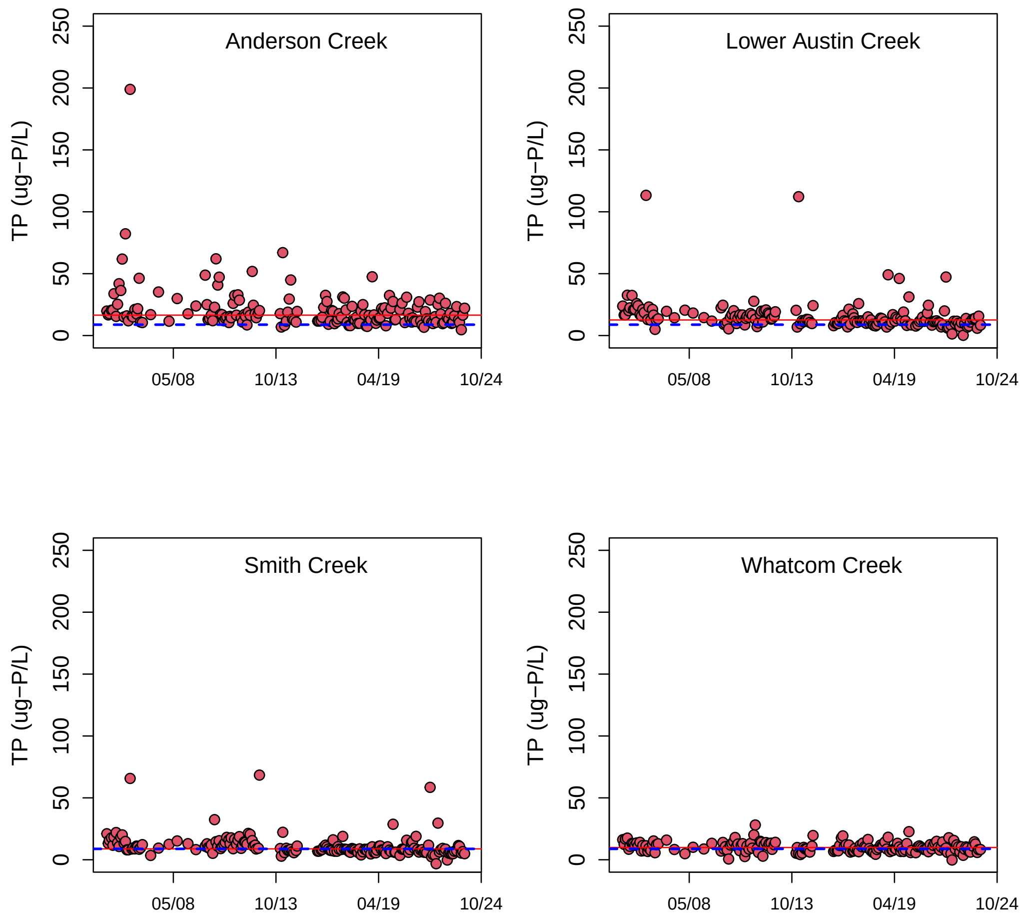


Figure B180: Total phosphorus data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

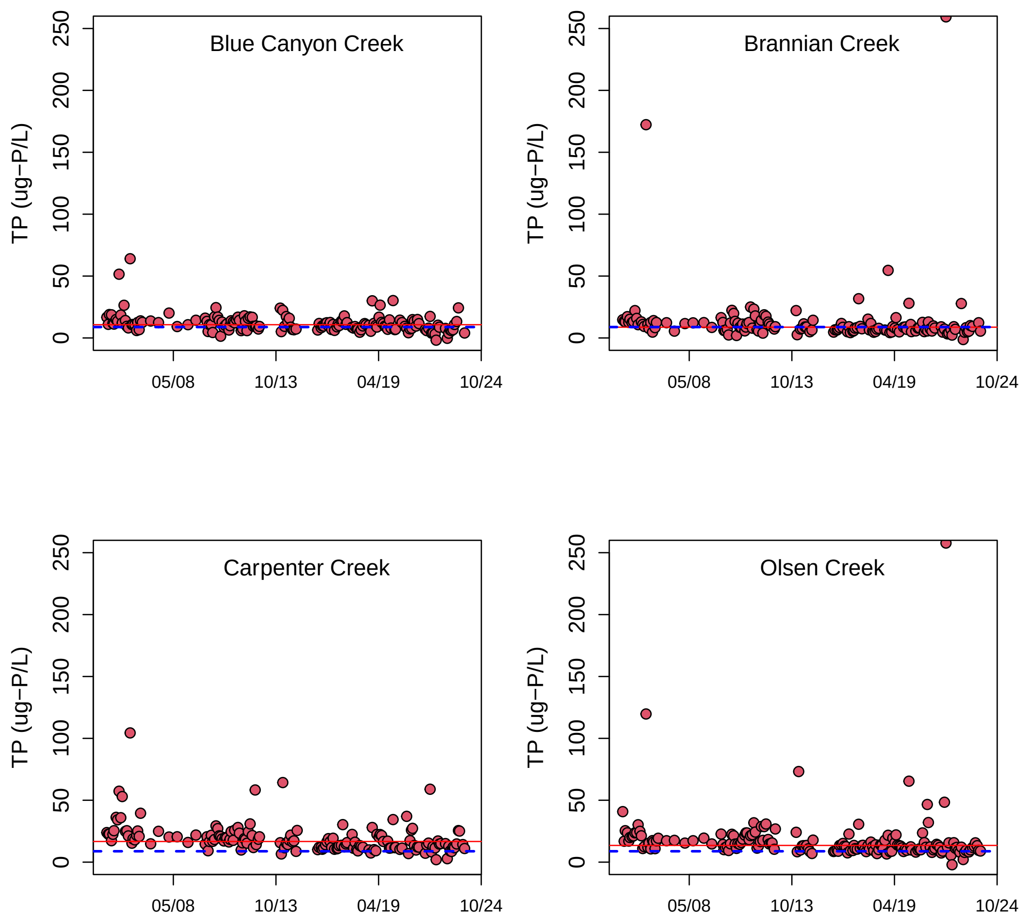


Figure B181: Total phosphorus data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

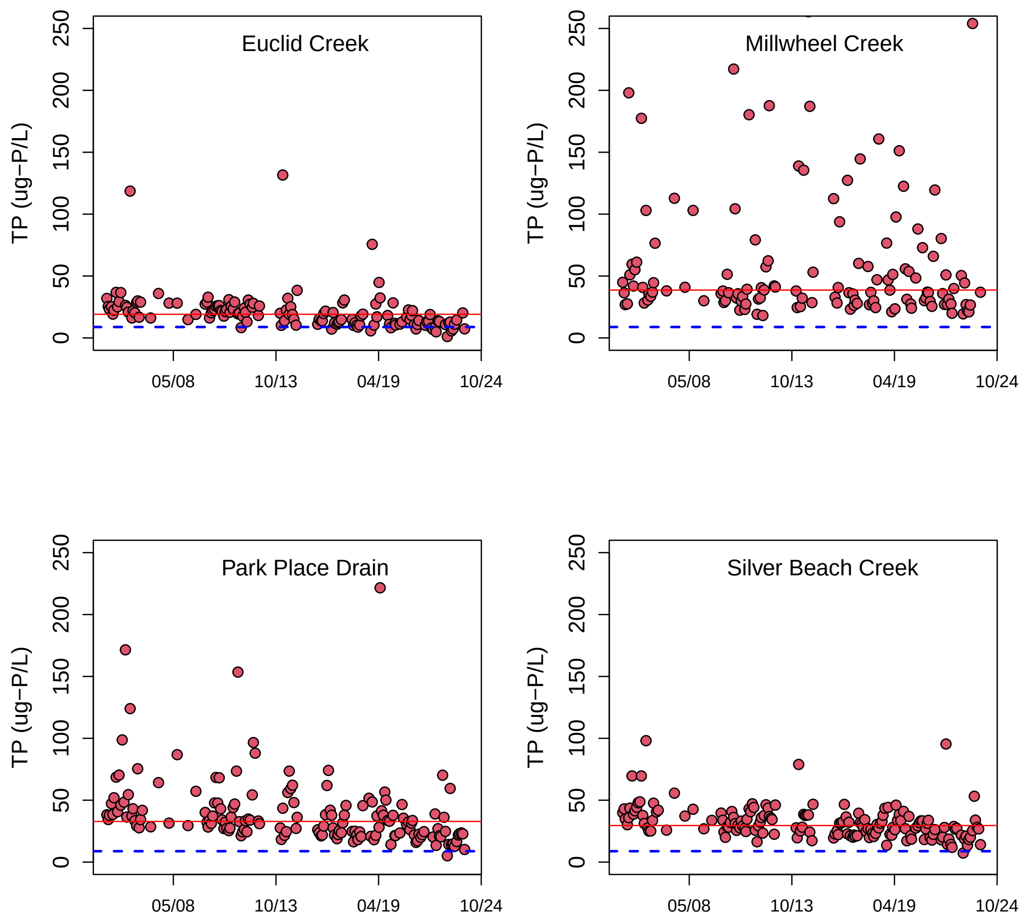


Figure B182: Total phosphorus data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

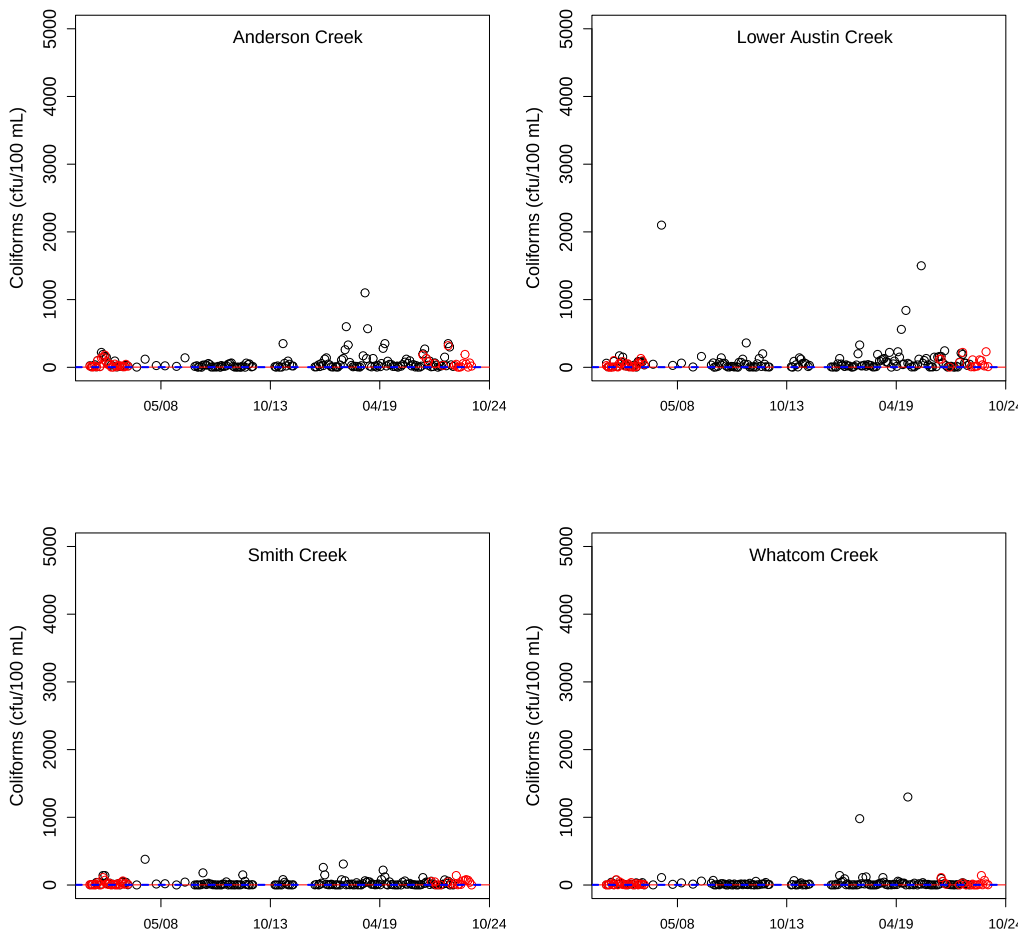


Figure B183: Coliform data for Anderson, Austin, Smith, and Whatcom Creeks, with fecal coliforms in black and *E. coli* in red. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

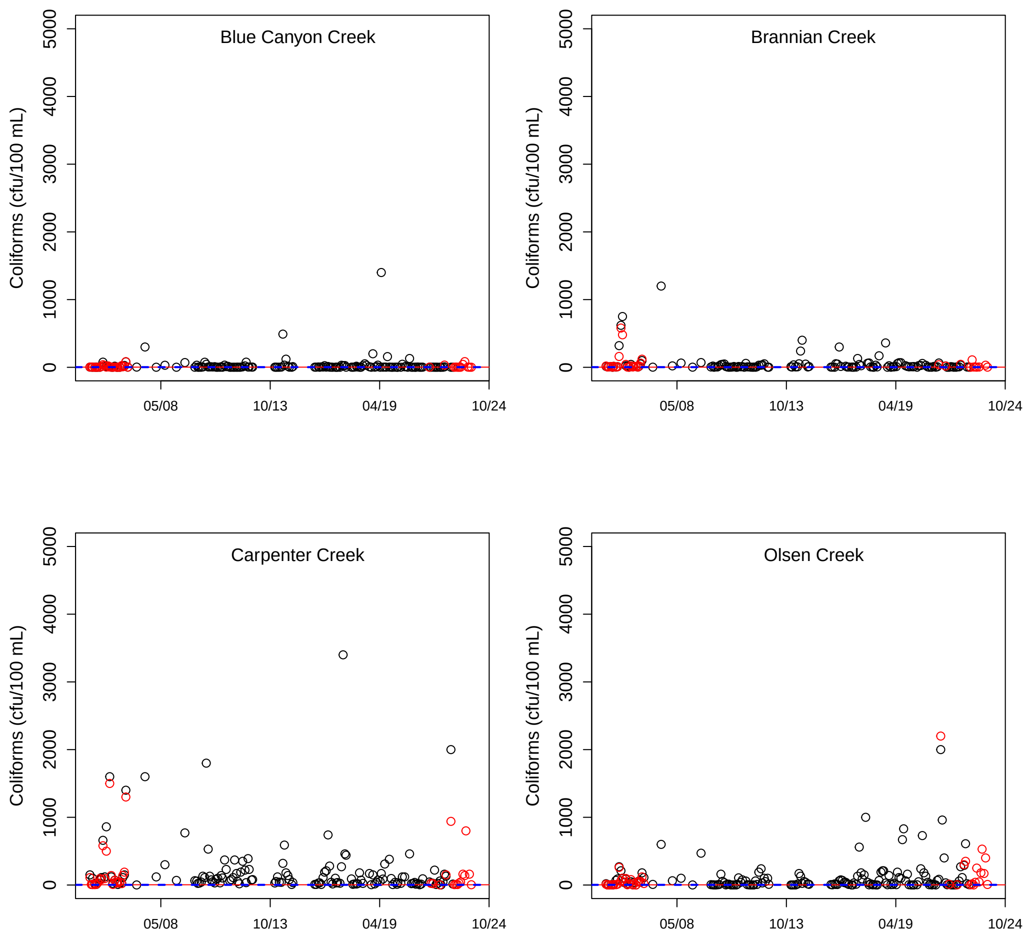


Figure B184: Coliform data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks, with fecal coliforms in black and *E. coli* in red. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

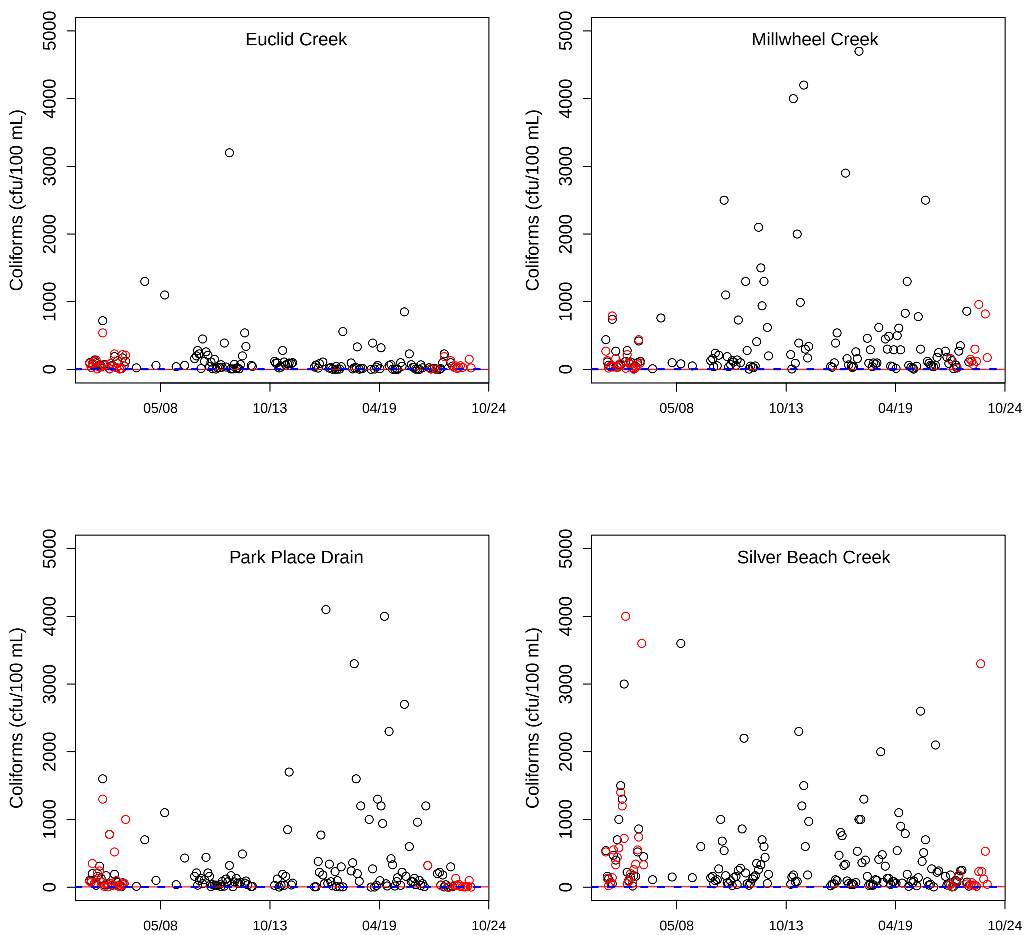


Figure B185: Coliform data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain, with fecal coliforms in black and *E. coli* in red. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

C Quality Control

C.1 Performance Evaluation Reports

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 2.1 (page 19). Single-blind quality control tests were conducted as part of the IWS laboratory certification process (Table C1).

C.2 Laboratory Duplicates, Spikes, and Check Standards

Ten percent of all samples analyzed in the laboratory were duplicated to measure analytical precision. Sample matrix spikes were analyzed during each analytical run to evaluate analyte recovery for the nutrient analyses (ammonium, nitrate/nitrite, total nitrogen, soluble reactive phosphate, and total phosphorus). Check standards were analyzed during each analytical run to evaluate measurement precision and accuracy.[36] The quality control results for laboratory duplicates, matrix spikes, and check standards are plotted in control charts (Figures C1–C30, pages 299–328). Data that exceed the plotting range of the control charts are in Table C2, page 298.

C.3 Field Duplicates

Ten percent of all samples collected in the field were duplicated to measure sample replication (Figures C31–C47, pages 329–345). Samples collected using field meters (conductivity, dissolved oxygen, and pH) were evaluated using water samples collected from the same depth as the field meter measurement. The absolute mean difference for the field duplicates was calculated as follows:

$$\text{Absolute mean difference} = \frac{\sum |\text{Original Sample} - \text{Duplicate Sample}|}{\text{number of duplicate pairs}}$$

[36]External check standards are not available for all analytes.

	Reported Value	Assigned Value	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	382	370	333–407	accept
Total alkalinity (mg/L as $CaCO_3$)	71.9	72.7	61.8–83.6	accept
Ammonium nitrogen, auto (mg-N/L)†	12.6	11.2	8.94–13.4	accept
Nitrate/nitrite nitrogen, auto (mg-N/L)	23.4	23.8	19.9–27.5	accept
Nitrite nitrogen, auto (mg-N/L)	2.02	2.00	1.70–2.30	accept
Organic carbon, dissolved (mg/L)	6.57	6.57	5.83–7.23	accept
Organic carbon, total (mg/L)	32.6	33.8	27.9–39.6	accept
	6.56	6.57	5.26–7.88	accept
Orthophosphate, manual (mg-P/L)	1.27	1.28	1.09–1.47	accept
Orthophosphate, auto (mg-P/L)	1.28	1.28	1.09–1.47	accept
Total phosphorus, manual (mg-P/L)	4.69	4.80	3.97–5.58	accept
Total phosphorus, auto (mg-P/L)	4.68	4.80	3.97–5.58	accept
pH	7.64	7.60	7.40–7.80	accept
Total solids, non-filterable (mg/L)	69.0	75.2	61.0–84.0	accept
Turbidity (NTU)	18.9	16.7	13.9–19.6	accept

†The manual method is no longer used and has been removed from quality control testing

Table C1: Single-blind quality control results, WP–290 (4/19/2023); all results were within acceptance limits. Dissolved organic carbon and second set of values for total organic carbon from WS–134 (5/19/2023). IWS applied for and was given interim accreditation for total and dissolved organic carbon analyses.

Year	Month	Analyte	Type	Testing or Training	Value
2020	November	orthophosphate	lab duplicate	training	6.37
	December	nitrate/nitrite	check	training	34
2021	January	alkalinity	lab duplicate	training	-1
	January	total nitrogen	lab duplicate	training	-129.43
	January	total phosphorus	spike	training	146
	February	alkalinity	lab duplicate	training	-2
	February	total suspended solids	lab duplicate	training	-8.25
	April	alkalinity	check	training	0.09
	April	conductivity	lab duplicate	training	-2.8
	May	dissolved oxygen	lab duplicate	training	0.34
	July	nitrate/nitrite	spike	training	67
	July	nitrate/nitrite	spike	training	63
	September	total nitrogen	lab duplicate	training	-152.35
	November	alkalinity	lab duplicate	training	-2.1
	November	orthophosphate	lab duplicate	training	5.91
	December	pH	lab duplicate	training	-0.8
2022	January	turbidity	lab duplicate	training	1.2
	February	total phosphorus	check	training	-4.34
	February	total phosphorus	check	training	-5.3
	February	turbidity	lab duplicate	training	-0.46
	March	turbidity	lab duplicate	training	0.51
	March	alkalinity	lab duplicate	training	1.3
	March	pH	lab duplicate	training	-0.55
	March	total nitrogen	lab duplicate	training	235.95
	April	total nitrogen	check	training	77.92
	May	total phosphorus	check	training	5.6
	May	alkalinity	lab duplicate	training	7.5
	May	conductivity	lab duplicate	training	-15.3
	June	pH	lab duplicate	training	0.3
	July	nitrate/nitrite	lab duplicate	training	-158.19
	October	chlorophyll	lab duplicate	testing	1.33
2023	February	orthophosphate	check	testing	-4.35
	February	orthophosphate	check	testing	-5.09
	April	nitrate/nitrite	lab duplicate	testing	128.3
	April	dissolved oxygen	lab duplicate	testing	-0.93
	May	nitrate/nitrite	lab duplicate	testing	167.75
	May	total nitrogen	spike	testing	153
	May	total phosphorus	lab duplicate	testing	-14.82
	August	chlorophyll	lab duplicate	testing	1.78

Table C2: Data in this table denote quality control values that exceeded ± 4 std. dev. from the training mean. Unplotted points were included in QC calculations, but were not plotted to preserve plotting scale (Figures C1–C30).

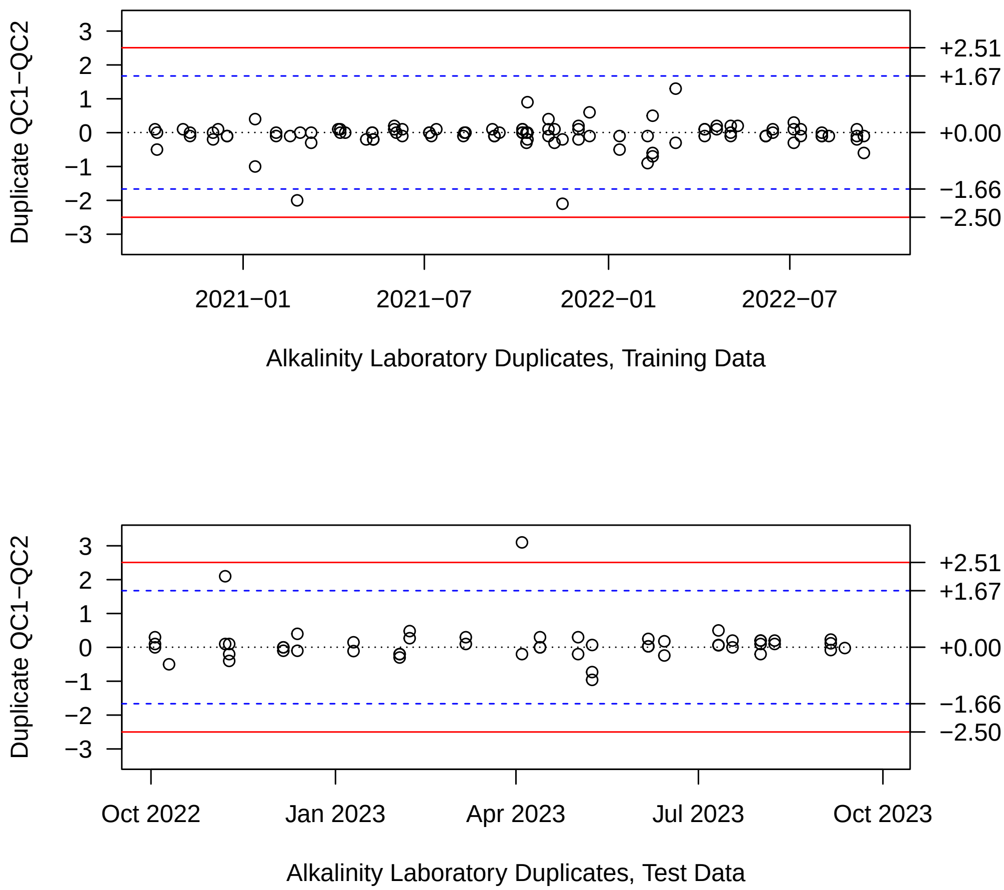
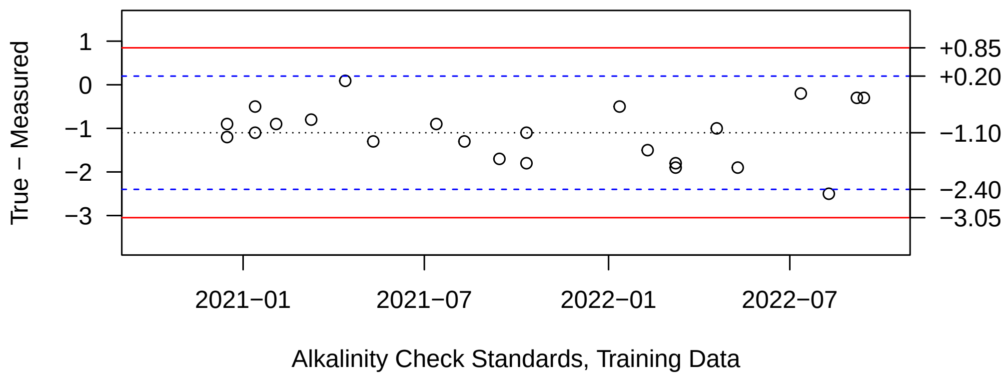


Figure C1: Alkalinity laboratory duplicates (mg/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



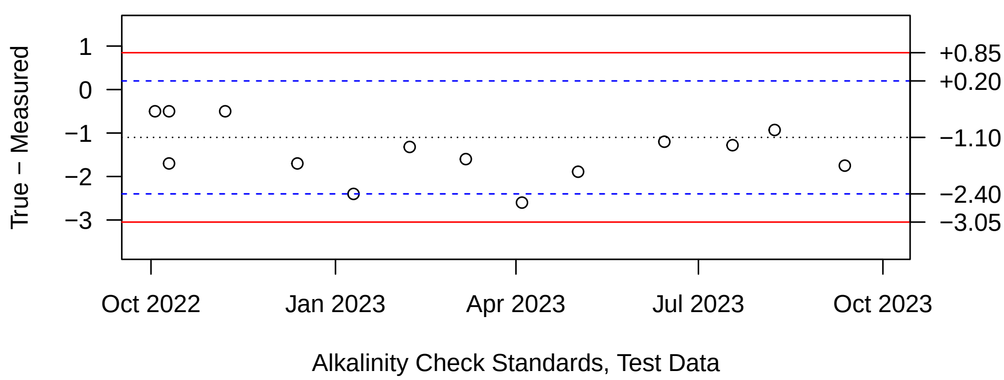
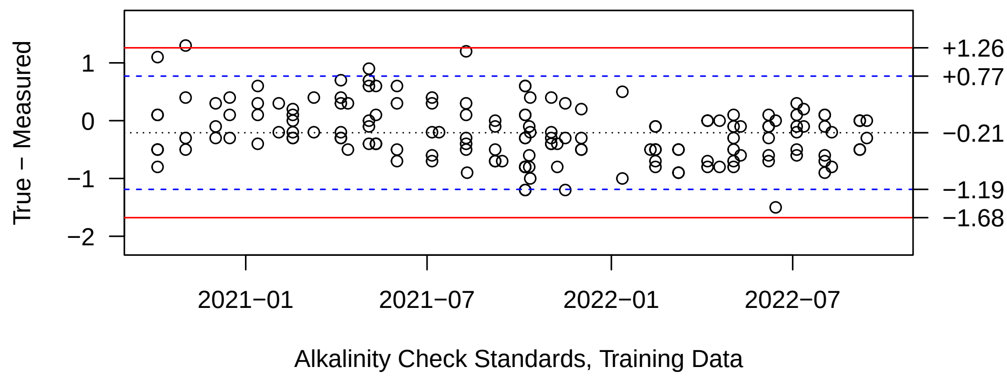


Figure C2: Alkalinity high-range check standards (mg/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



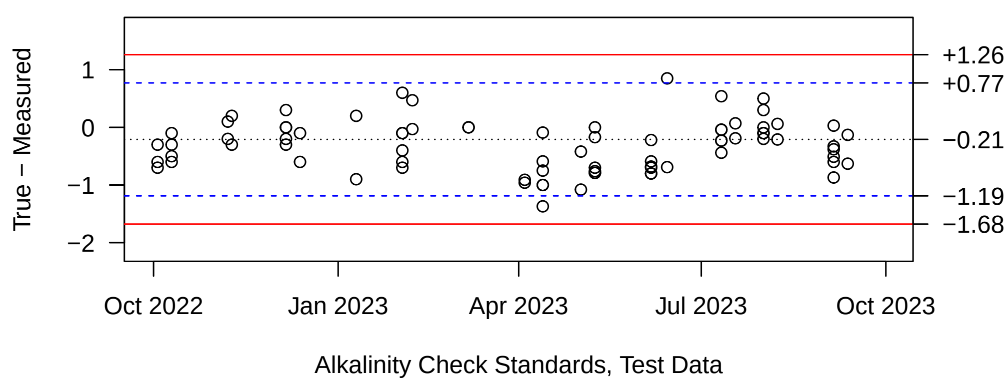
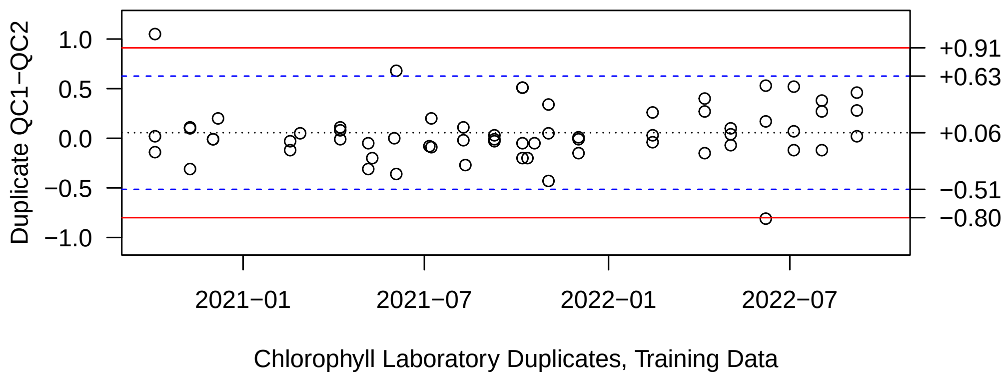


Figure C3: Alkalinity low-range check standards (mg/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



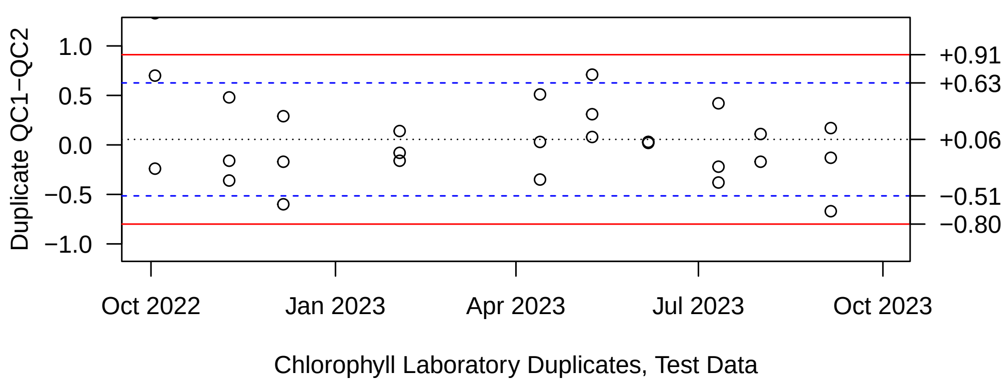
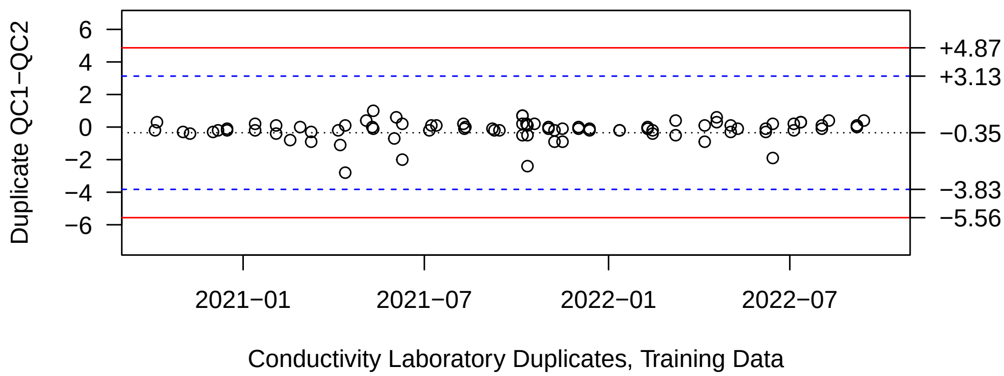


Figure C4: Chlorophyll laboratory duplicates (μg/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits ($\pm$2 std. dev. from mean pair difference) and upper/lower warning limits ($\pm$3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



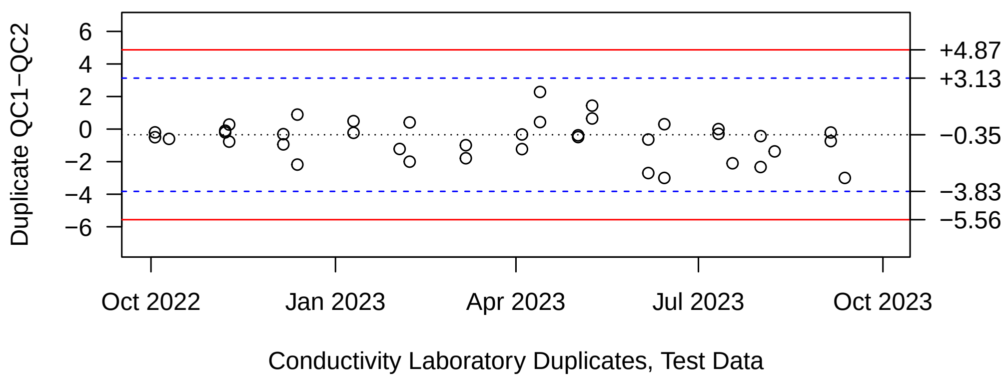
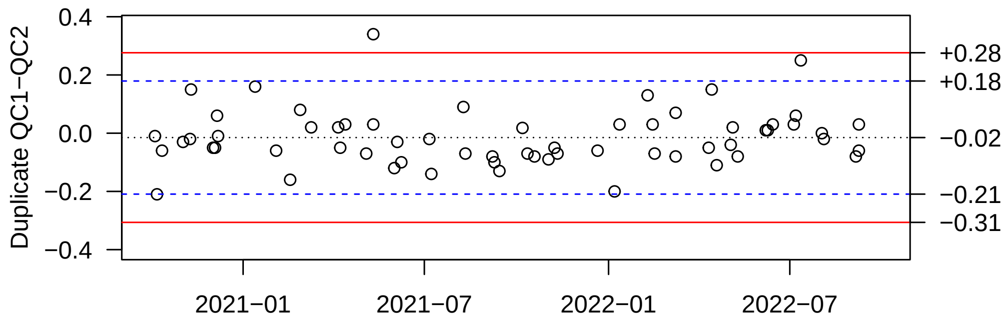
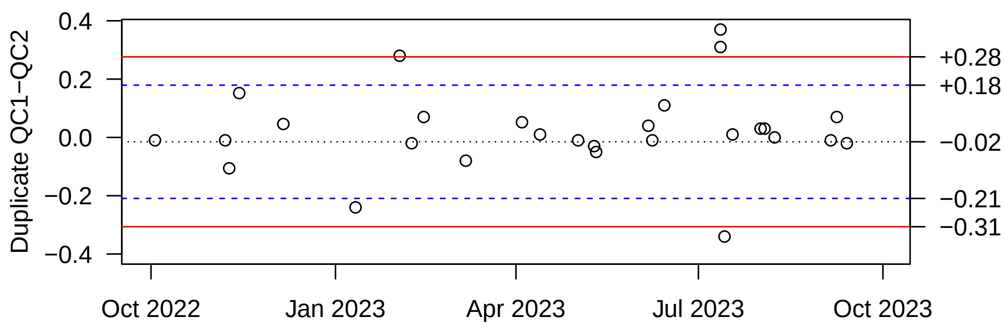


Figure C5: Conductivity laboratory duplicates (μS/cm) for the Lake Whatcom monitoring program. Upper/lower acceptance limits ($\pm$2 std. dev. from mean pair difference) and upper/lower warning limits ($\pm$3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

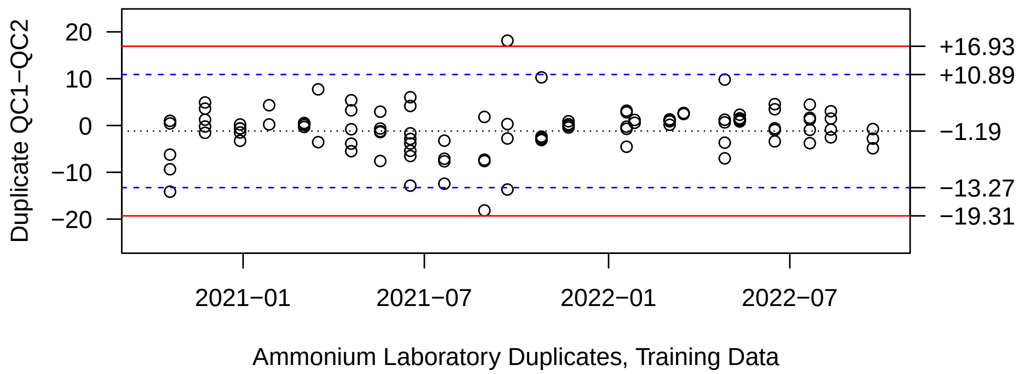


Dissolved Oxygen Laboratory Duplicates, Training Data



Dissolved Oxygen Laboratory Duplicates, Test Data

Figure C6: Dissolved oxygen laboratory duplicates (mg/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



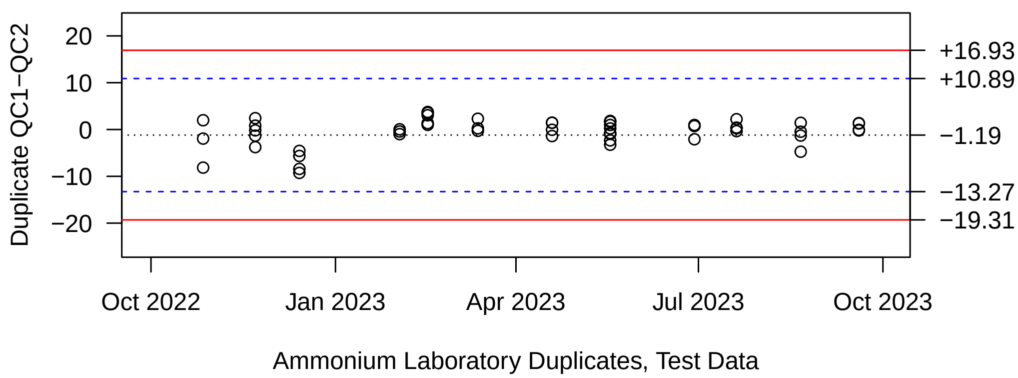
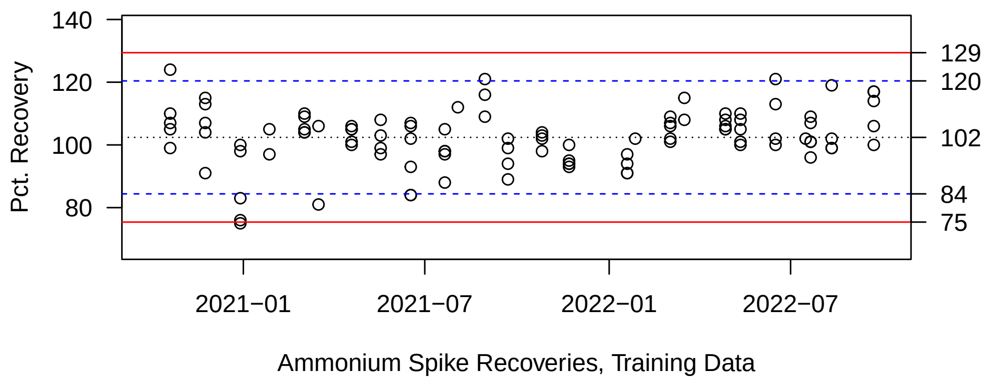


Figure C7: Nitrogen (ammonium) laboratory duplicates (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



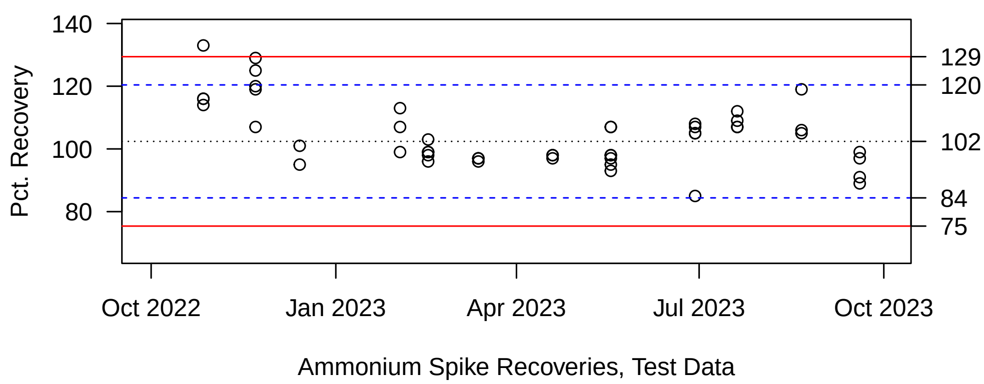
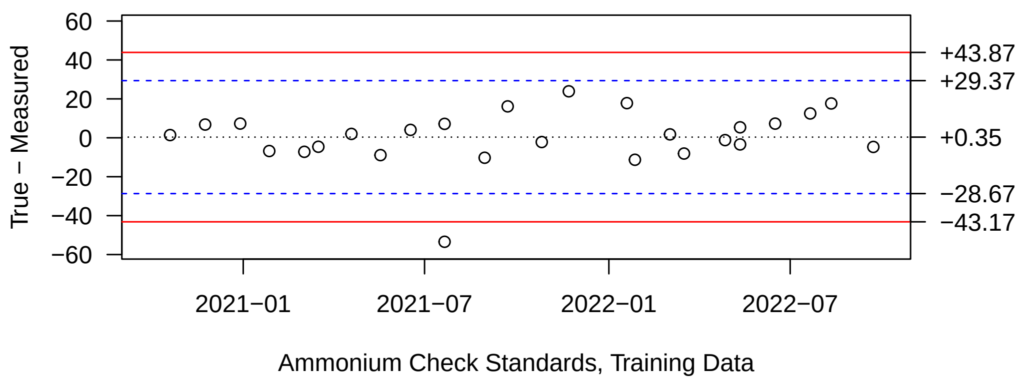


Figure C8: Nitrogen (ammonium) spike recoveries (%) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of spike data.



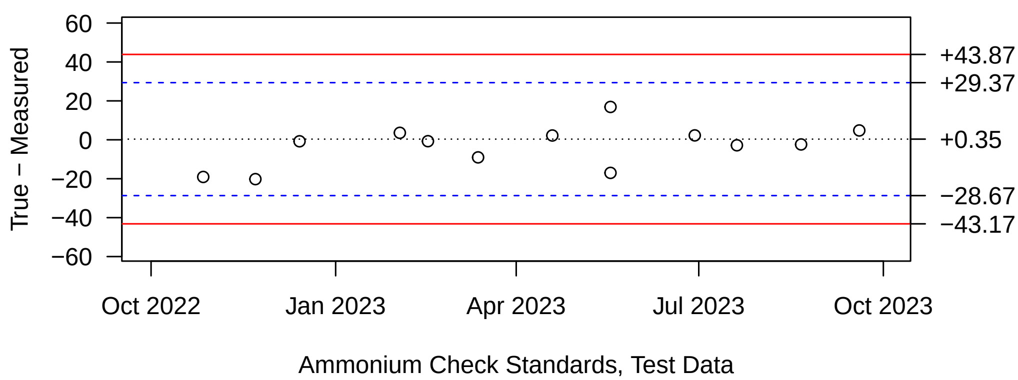
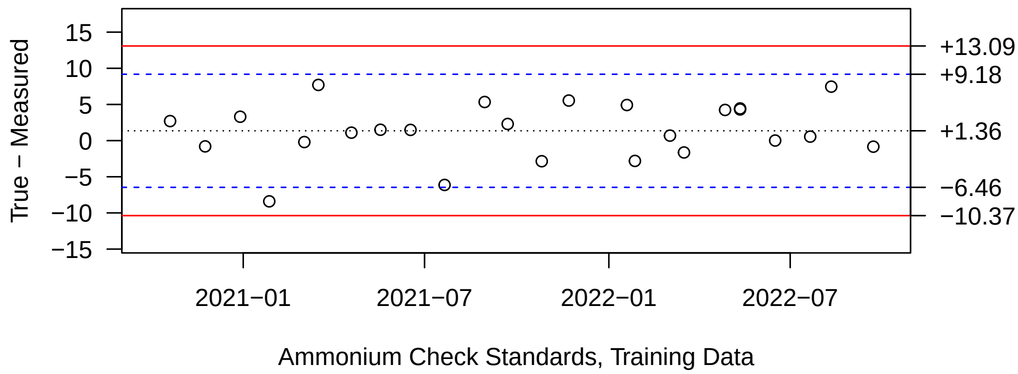


Figure C9: Nitrogen (ammonium) high-range check standards (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



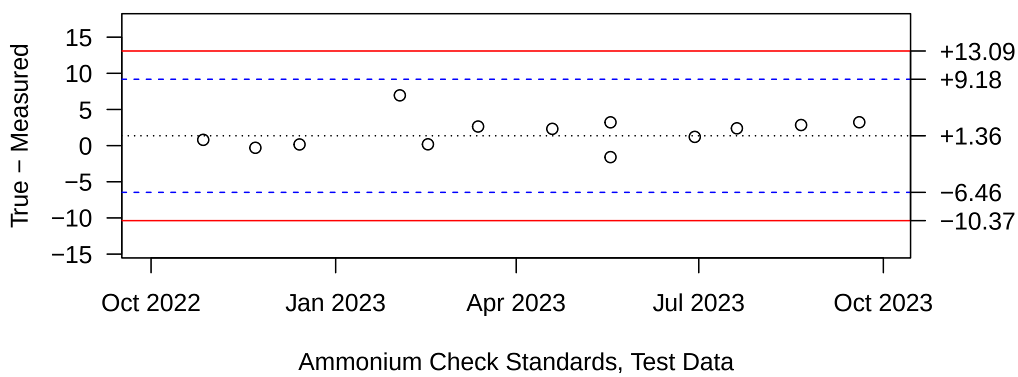
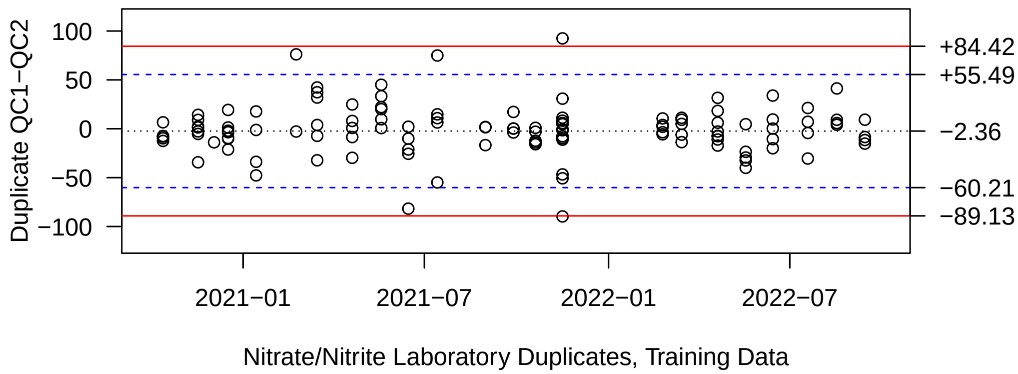


Figure C10: Nitrogen (ammonium) low-range check standards (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



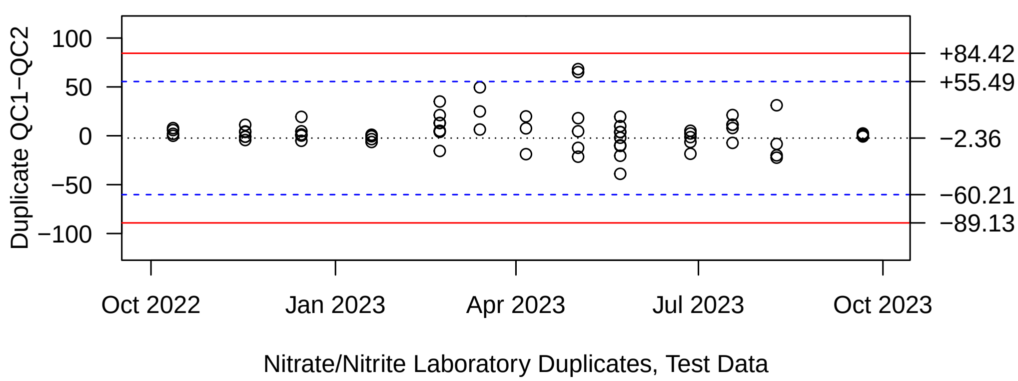
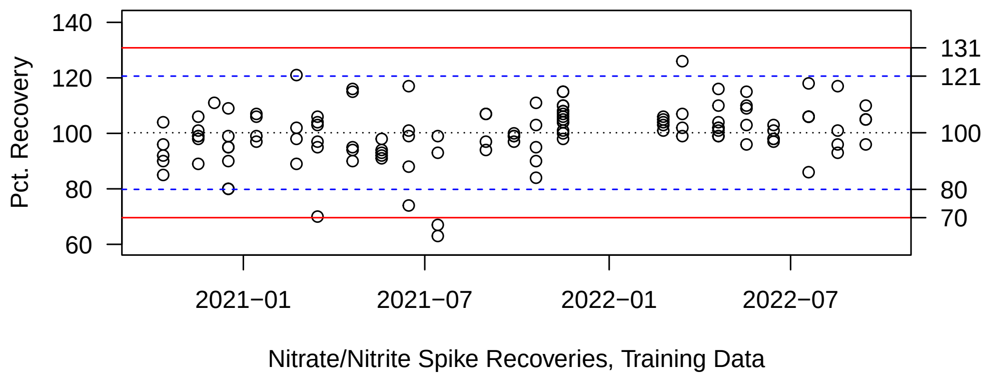


Figure C11: Nitrogen (nitrate/nitrite) laboratory duplicates (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



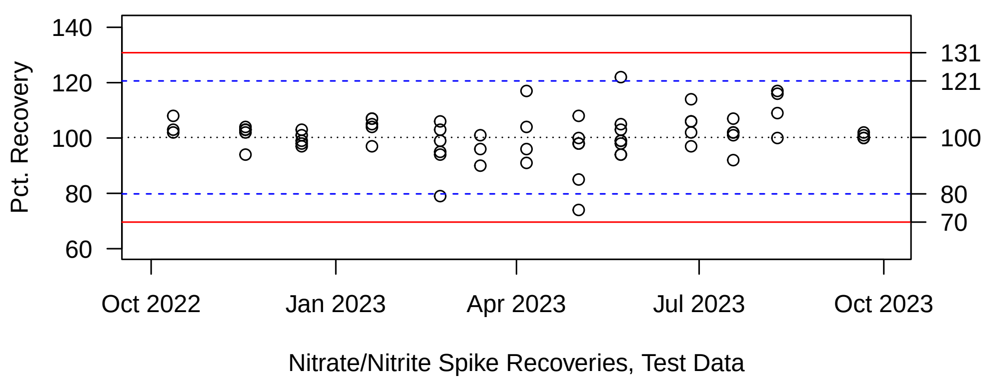
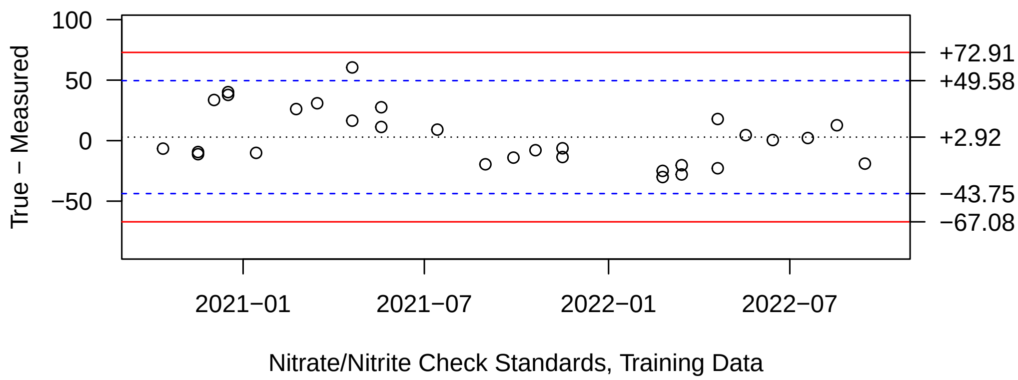


Figure C12: Nitrogen (nitrate/nitrite) spike recoveries (%) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of spike data.



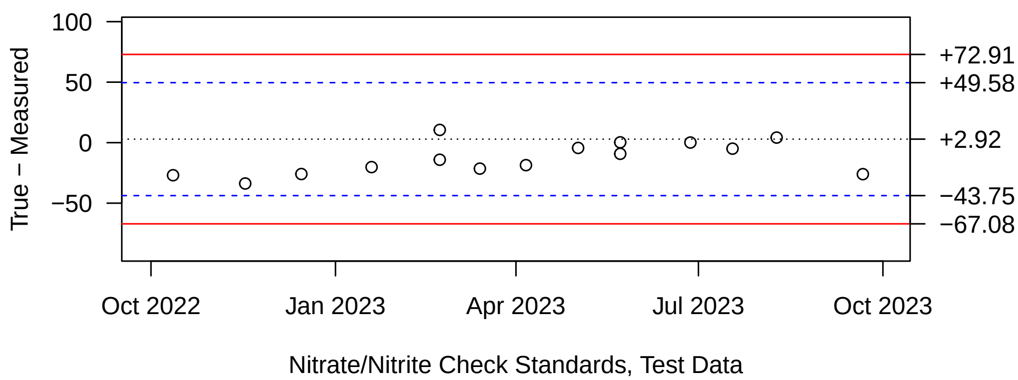
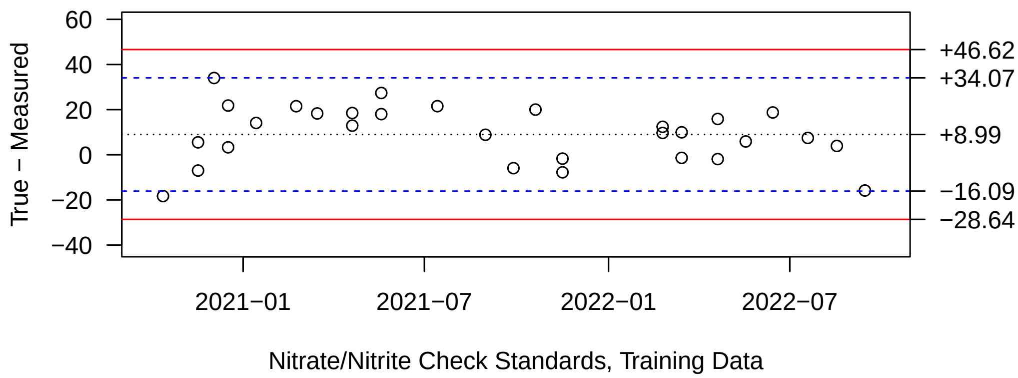


Figure C13: Nitrogen (nitrate/nitrite) high-range check standards (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



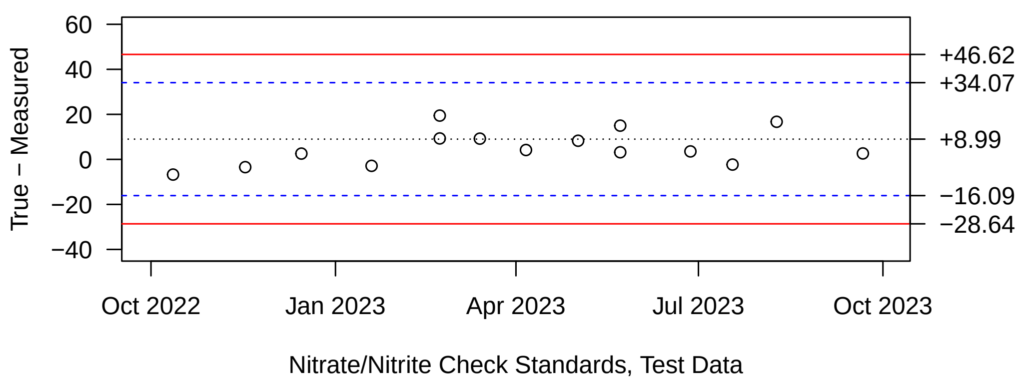
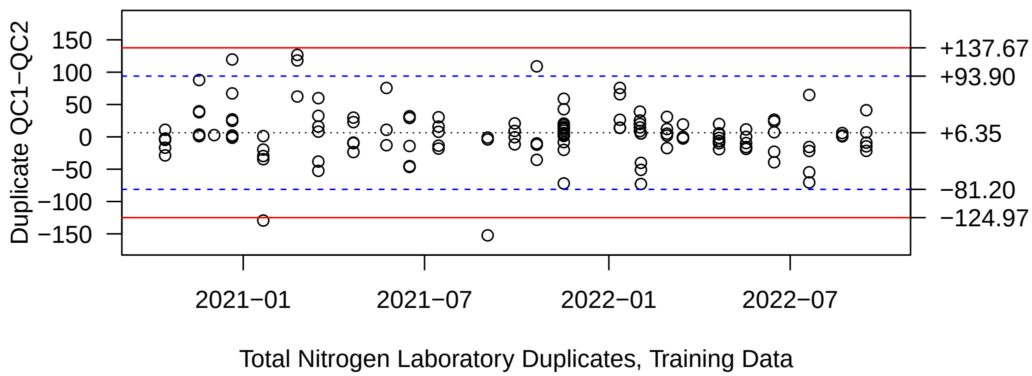


Figure C14: Nitrogen (nitrate/nitrite) low-range check standards (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits ($\pm$2 std. dev. from mean pair difference) and upper/lower warning limits ($\pm$3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



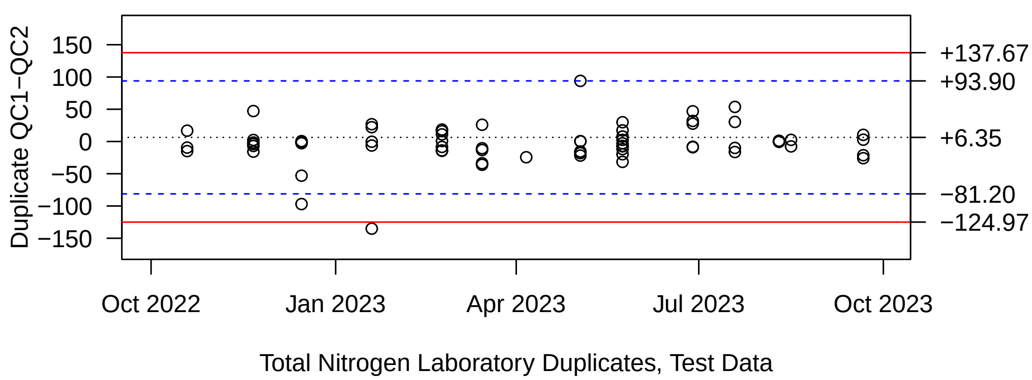
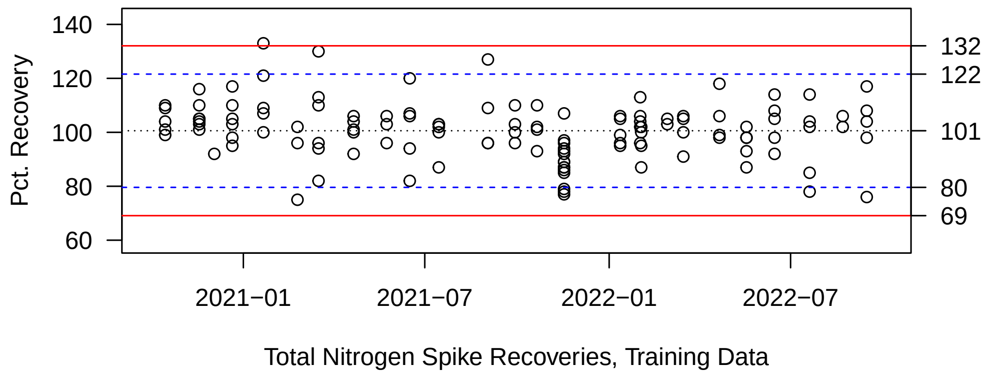


Figure C15: Nitrogen (total) laboratory duplicates (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



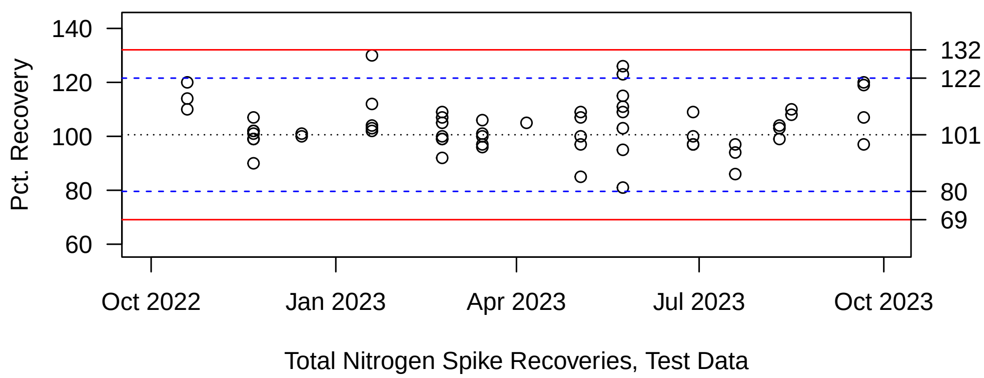
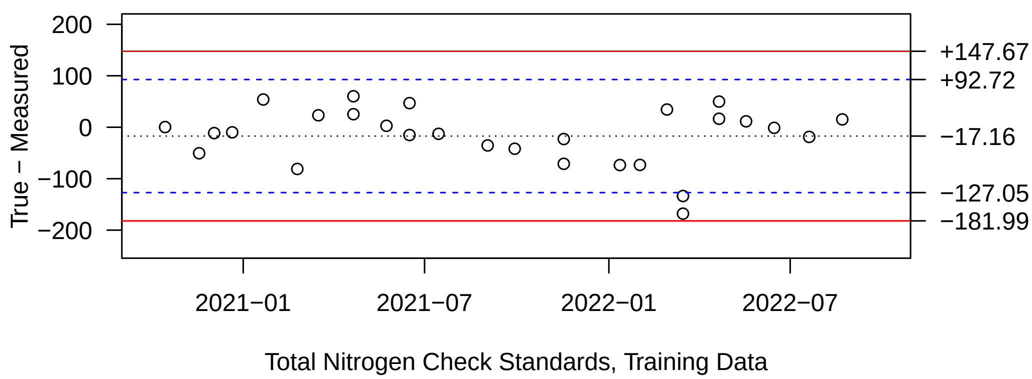


Figure C16: Nitrogen (total) spike recoveries (%) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of spike data.



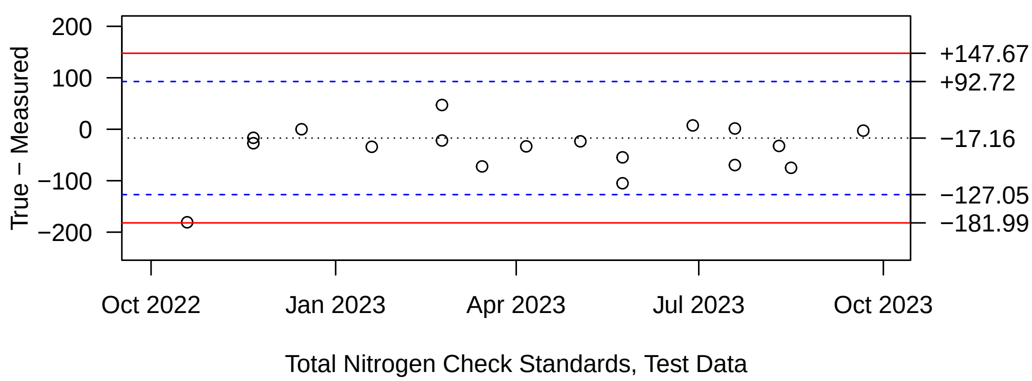
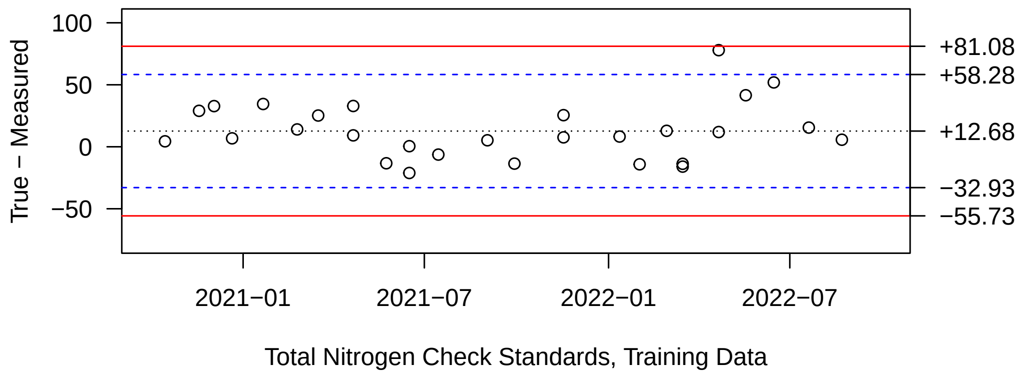


Figure C17: Nitrogen (total) high-range check standards (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



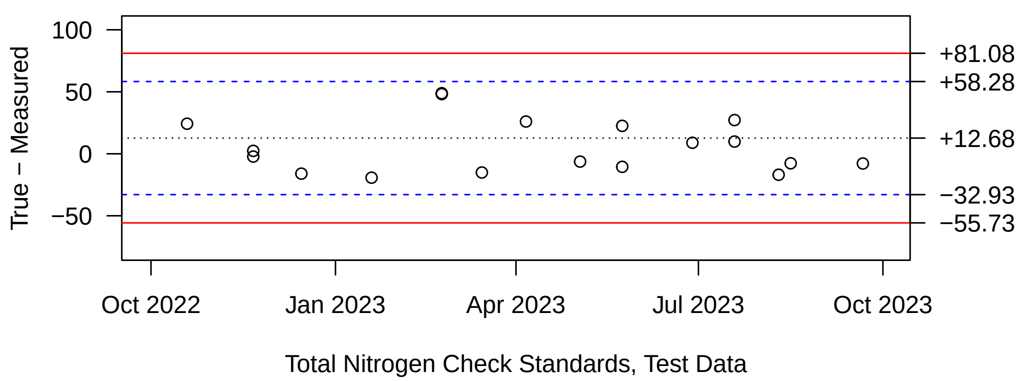
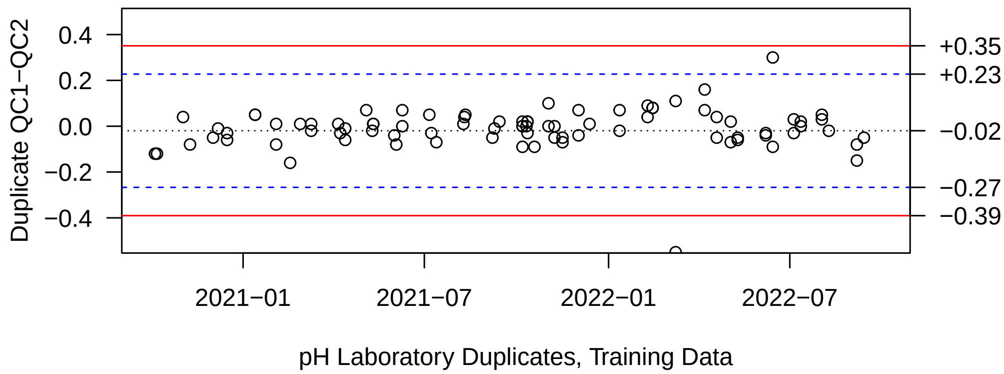


Figure C18: Nitrogen (total) low-range check standards (μg-N/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



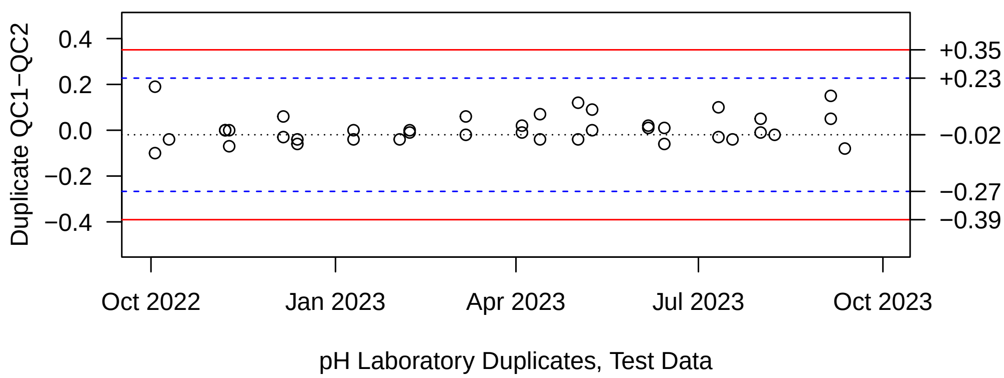
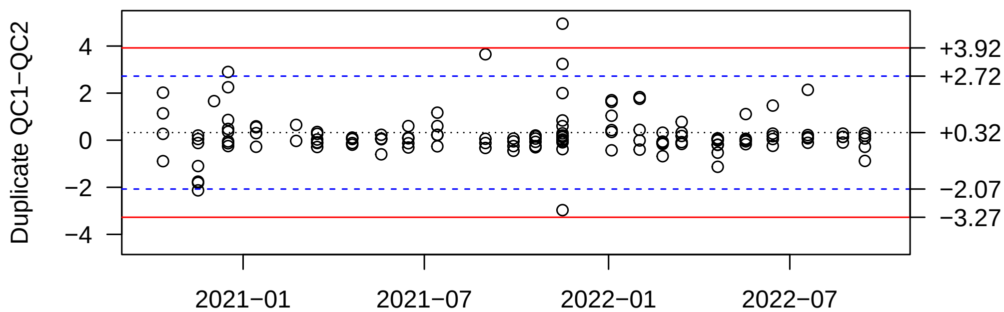
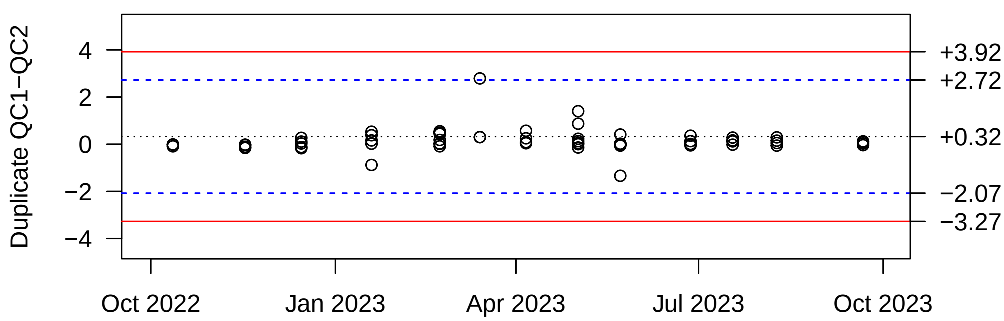


Figure C19: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

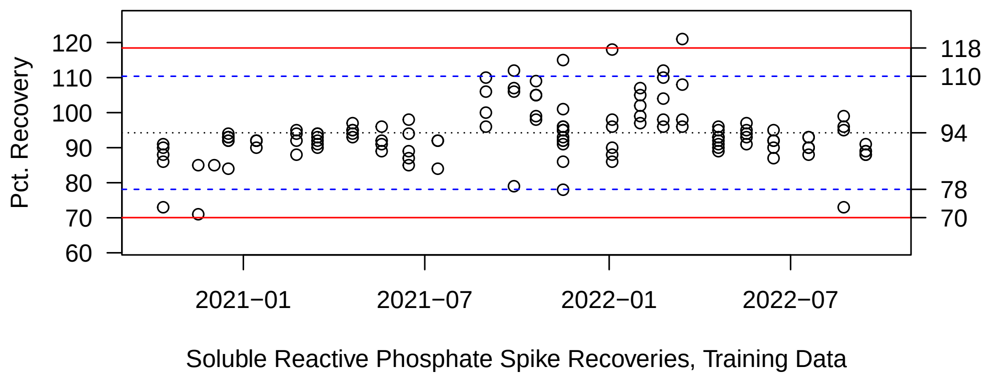


Soluble Reactive Phosphate Laboratory Duplicates, Training Data



Soluble Reactive Phosphate Laboratory Duplicates, Test Data

Figure C20: Phosphorus (soluble reactive phosphate) laboratory duplicates (μg-P/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



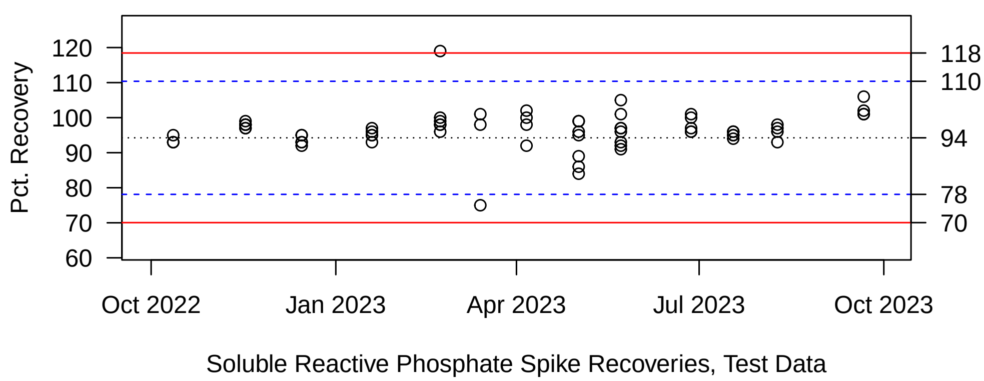
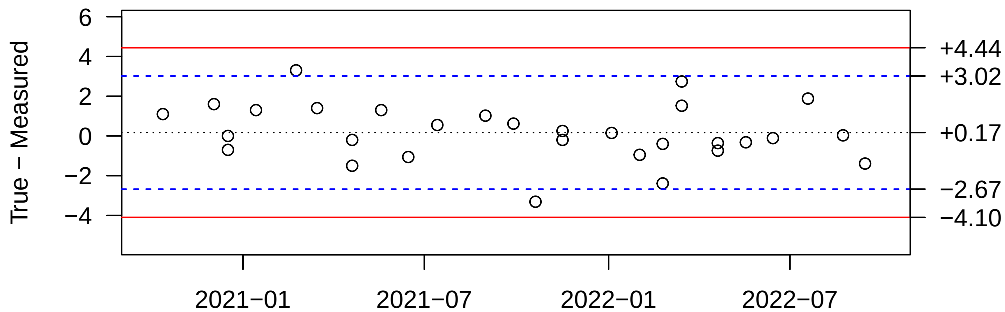
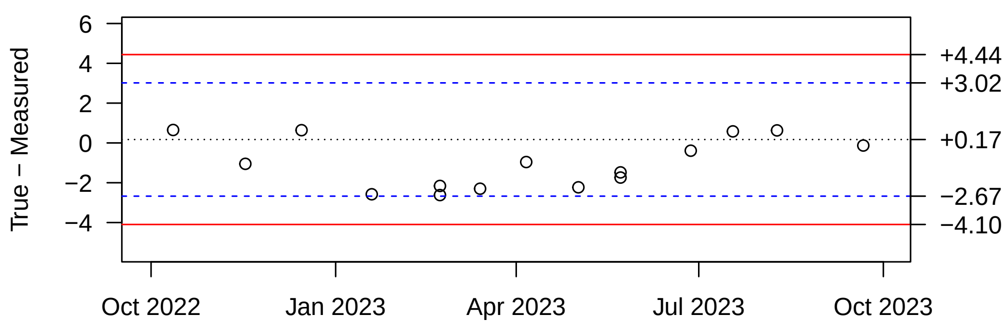


Figure C21: Phosphorus (soluble reactive phosphate) spike recoveries (%) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of spike data.

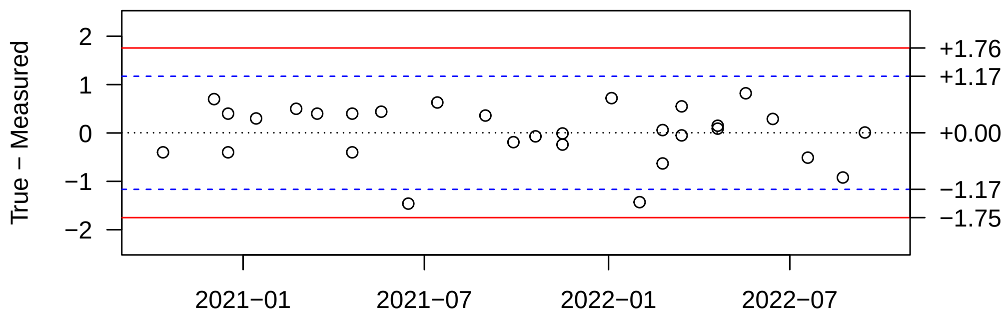


Soluble Reactive Phosphate Check Standards, Training Data

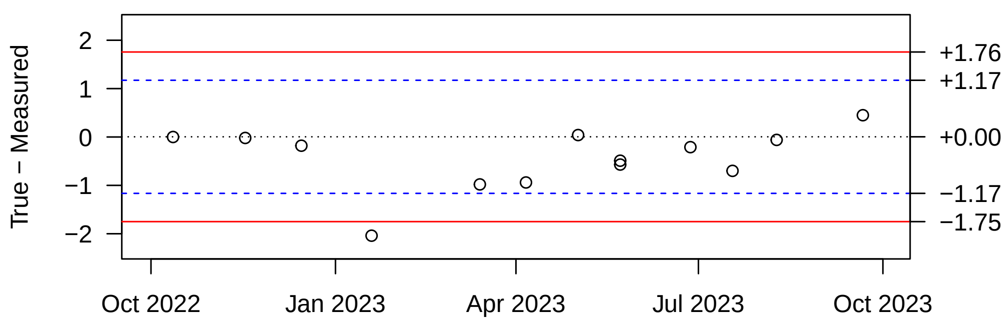


Soluble Reactive Phosphate Check Standards, Test Data

Figure C22: Phosphorus (soluble reactive phosphate) high-range check standards (μg-P/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.

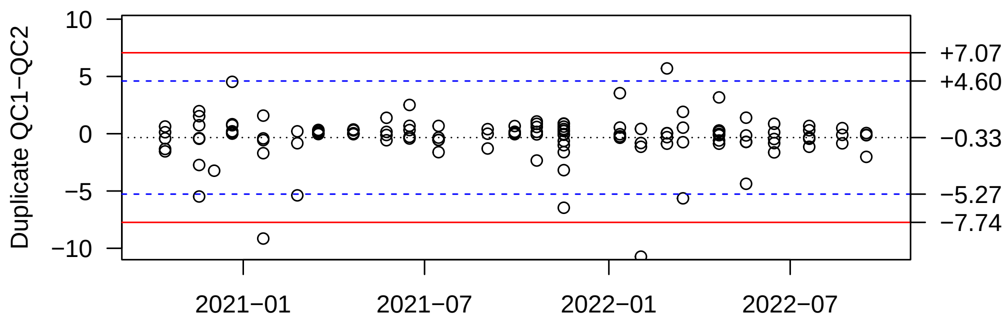


Soluble Reactive Phosphate Check Standards, Training Data

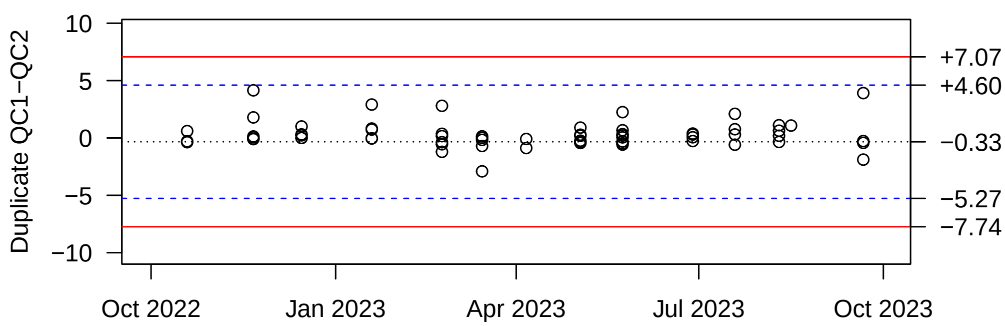


Soluble Reactive Phosphate Check Standards, Test Data

Figure C23: Phosphorus (soluble reactive phosphate) low-range check standards (μg-P/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.

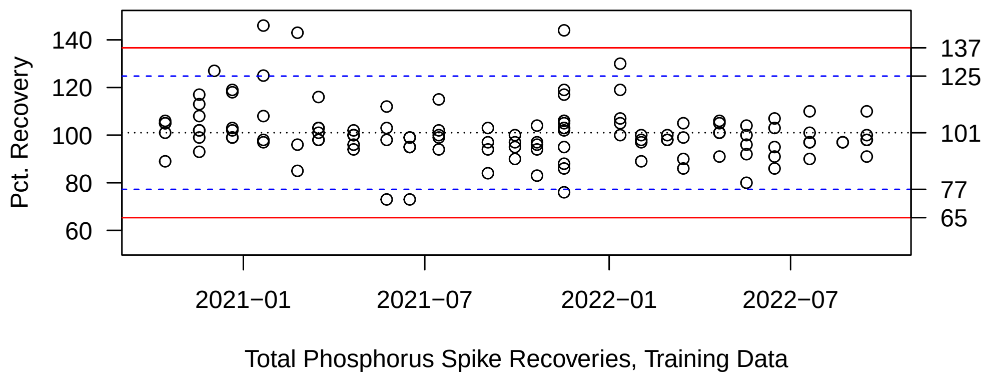


Total Phosphorus Laboratory Duplicates, Training Data



Total Phosphorus Laboratory Duplicates, Test Data

Figure C24: Phosphorus (total) laboratory duplicates (μg-P/L) 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 preceding two years of lab duplicate data.



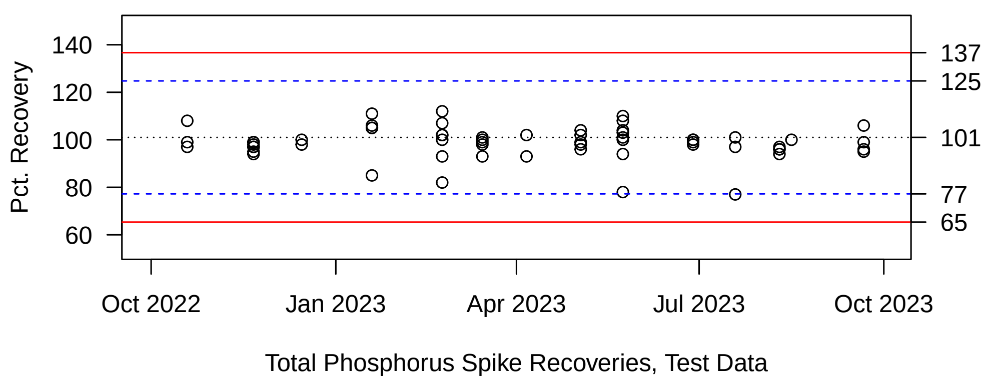
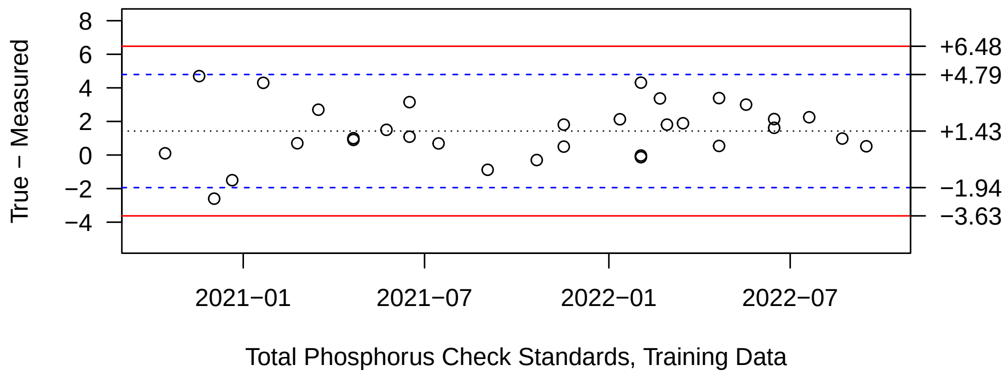


Figure C25: Phosphorus (total) spike recoveries (%) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of spike data.



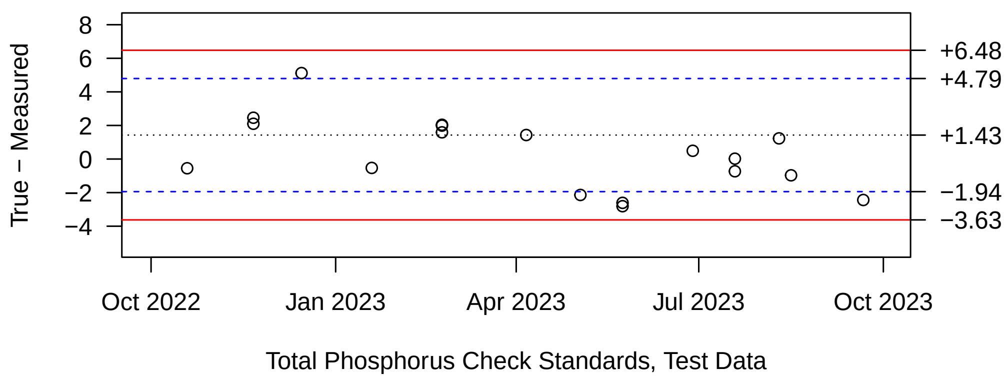
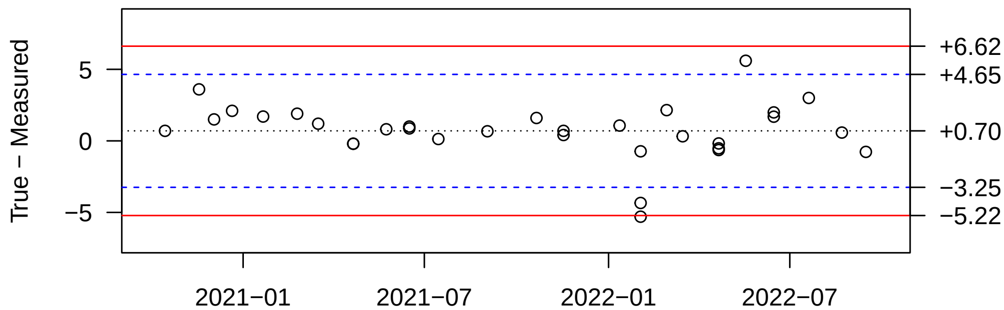
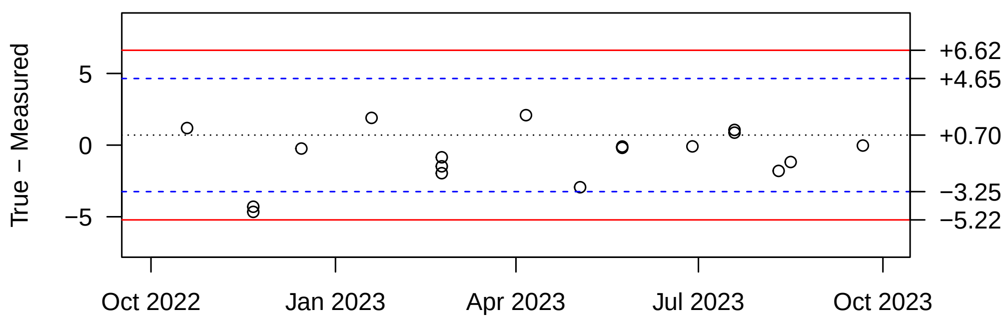


Figure C26: Phosphorus (total) high-range check standards (μg-P/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.

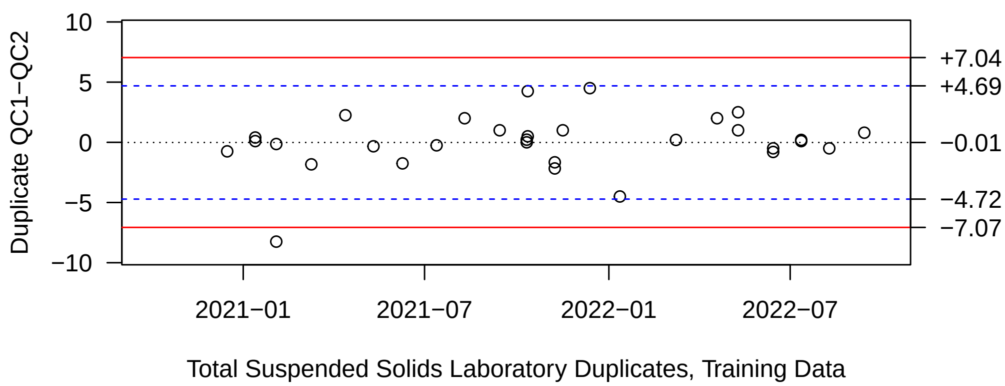


Total Phosphorus Check Standards, Training Data



Total Phosphorus Check Standards, Test Data

Figure C27: Phosphorus (total) low-range check standards (μg-P/L) for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



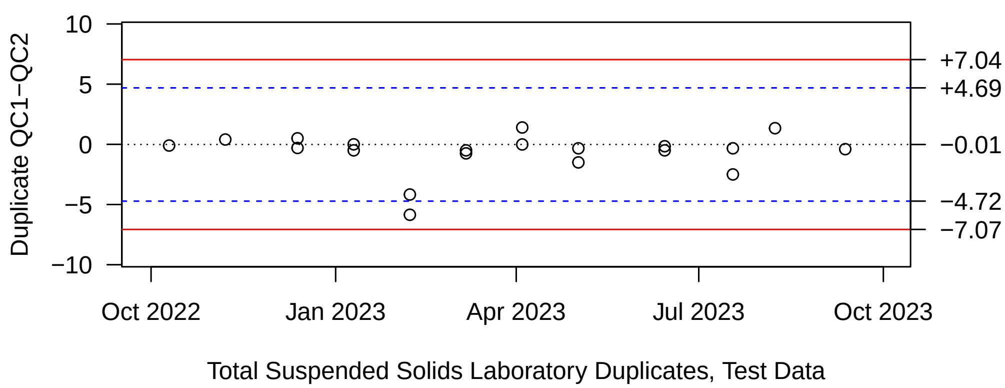
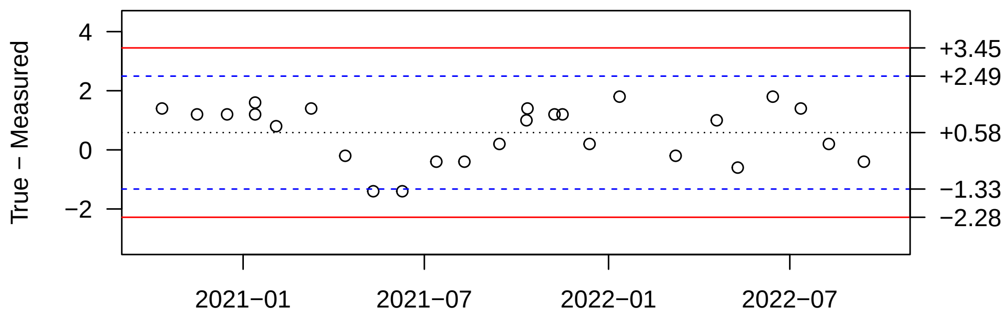
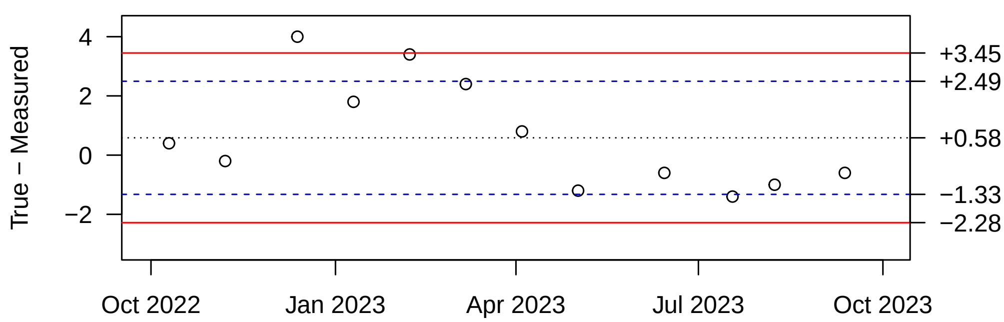


Figure C28: Total suspended solids laboratory duplicates (mg/L) for the Lake Whatcom monitoring program (tributary and storm water samples). Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

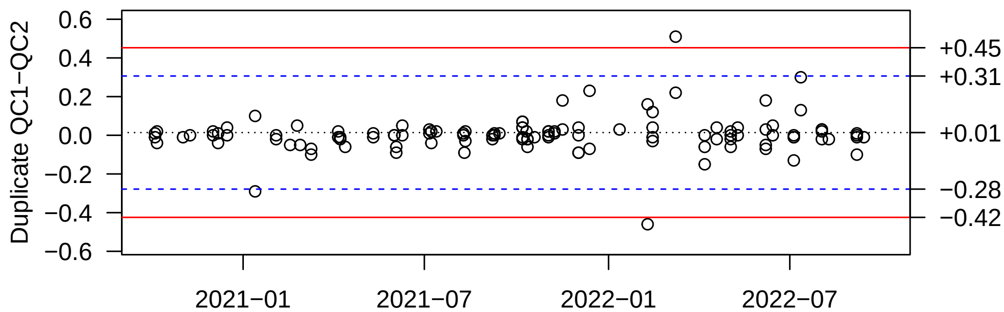


Total Suspended Solids Check Standards, Training Data

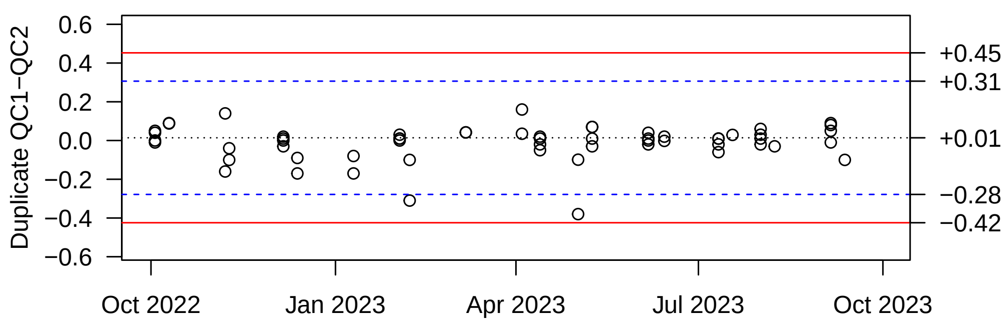


Total Suspended Solids Check Standards, Test Data

Figure C29: Total suspended solids check standards (mg/L) for the Lake Whatcom monitoring program (tributary and storm water samples). Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of check standard data.



Turbidity Laboratory Duplicates, Training Data



Turbidity Laboratory Duplicates, Test Data

Figure C30: Turbidity laboratory duplicates (NTU) 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 preceding two years of lab duplicate data.

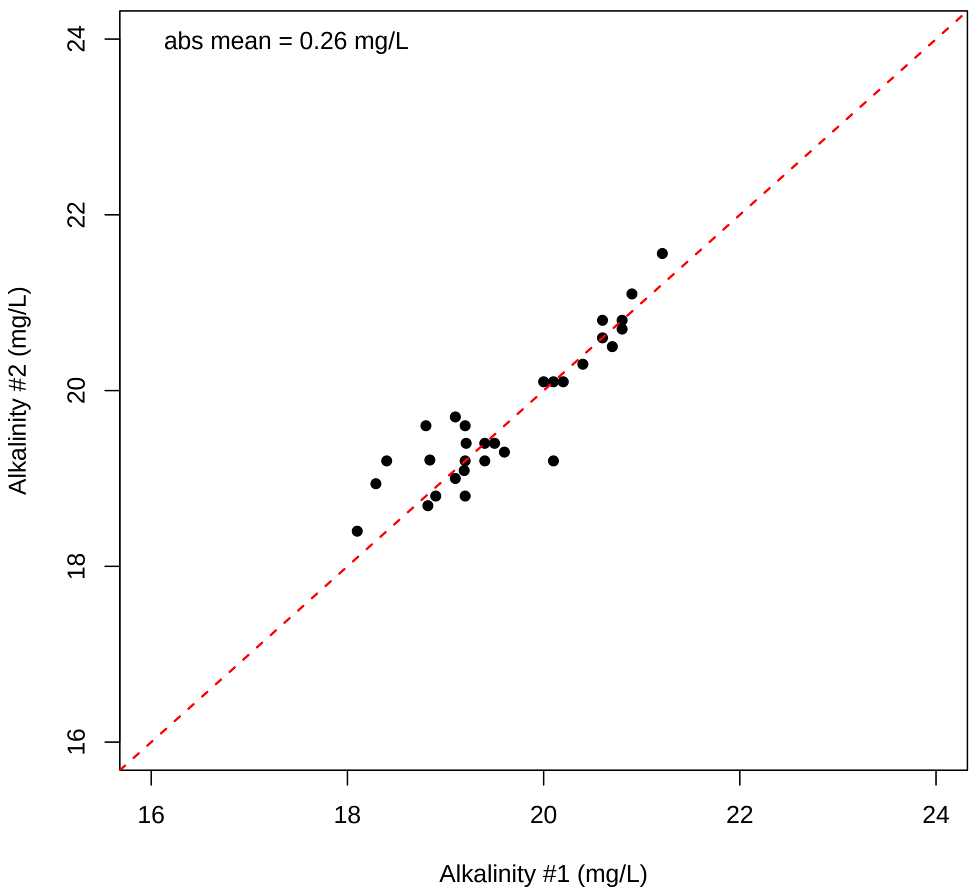


Figure C31: Alkalinity field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

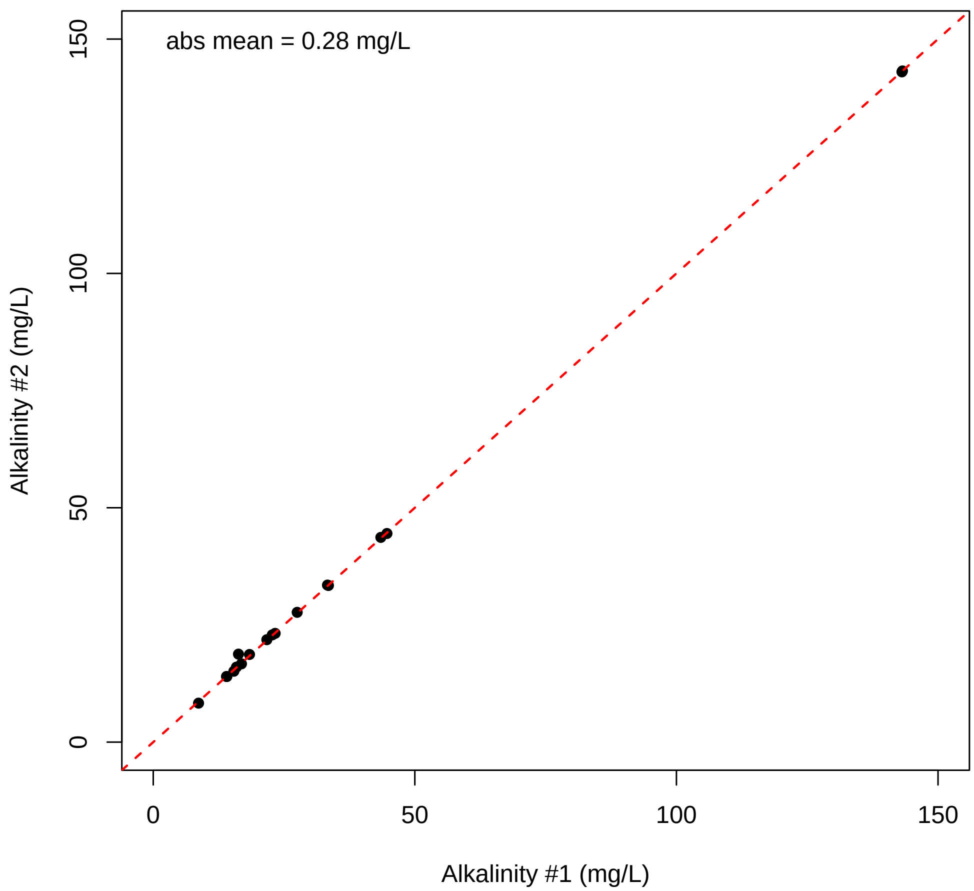


Figure C32: Alkalinity field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship.

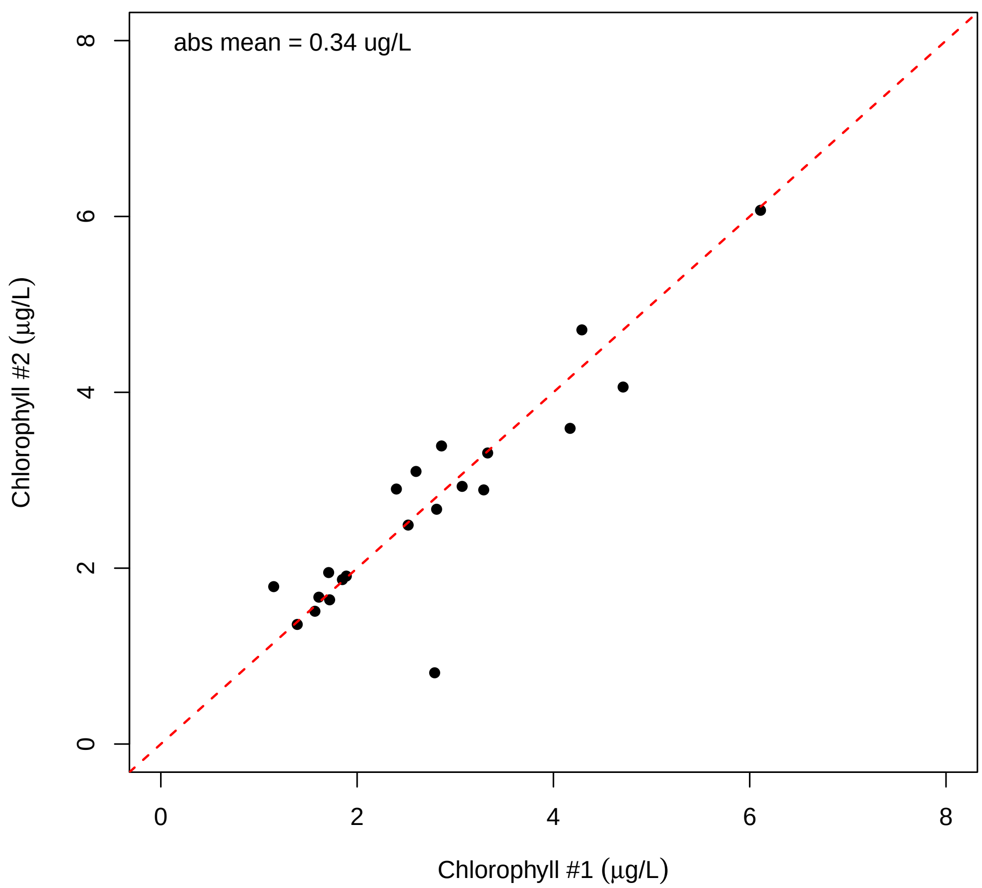


Figure C33: Chlorophyll field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

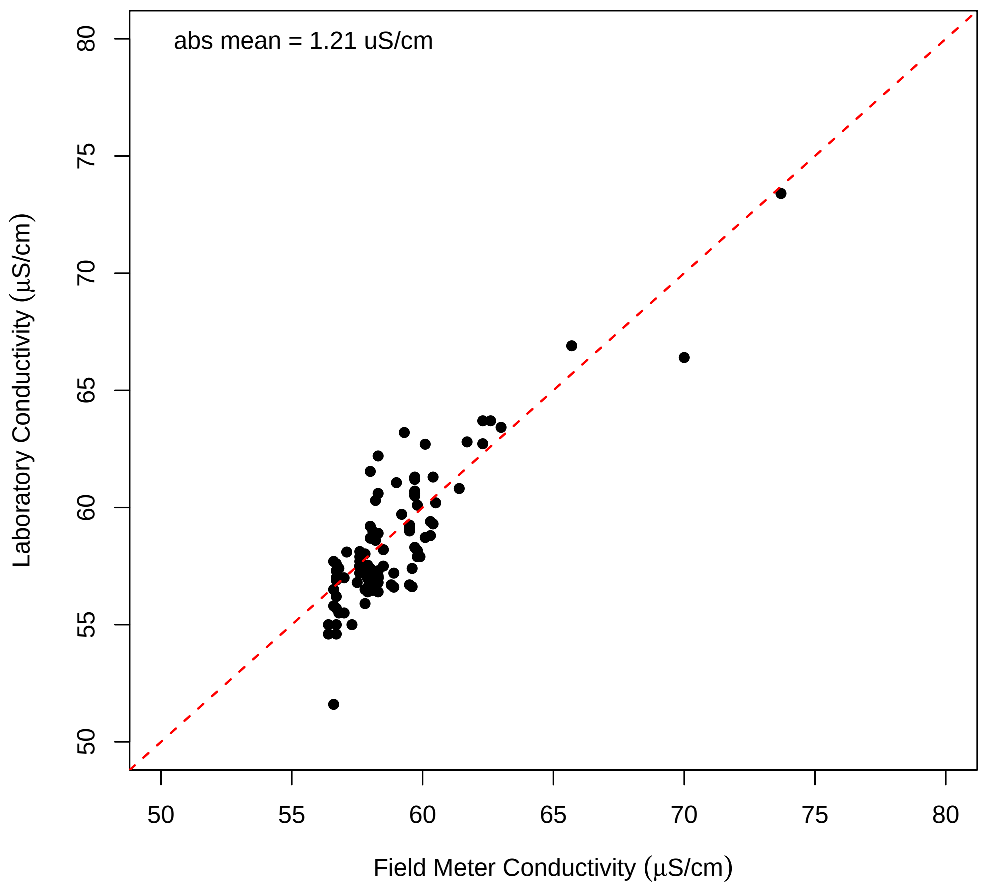


Figure C34: Conductivity field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

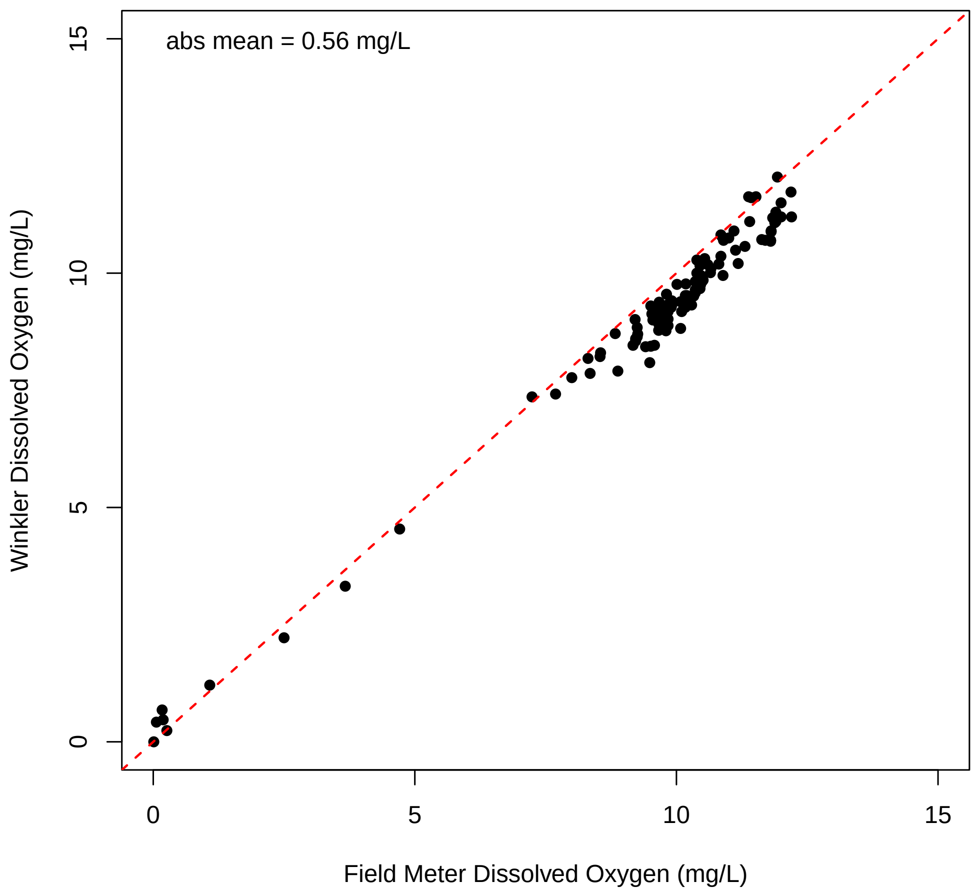


Figure C35: Dissolved oxygen field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship. There was a systematic bias between the Winkler and field meter results, with the Winkler results ∼0.5 mg/L lower than the field meter. This is within typical ranges for Winkler vs. field meter comparisons (Johengen, et al., 2016).

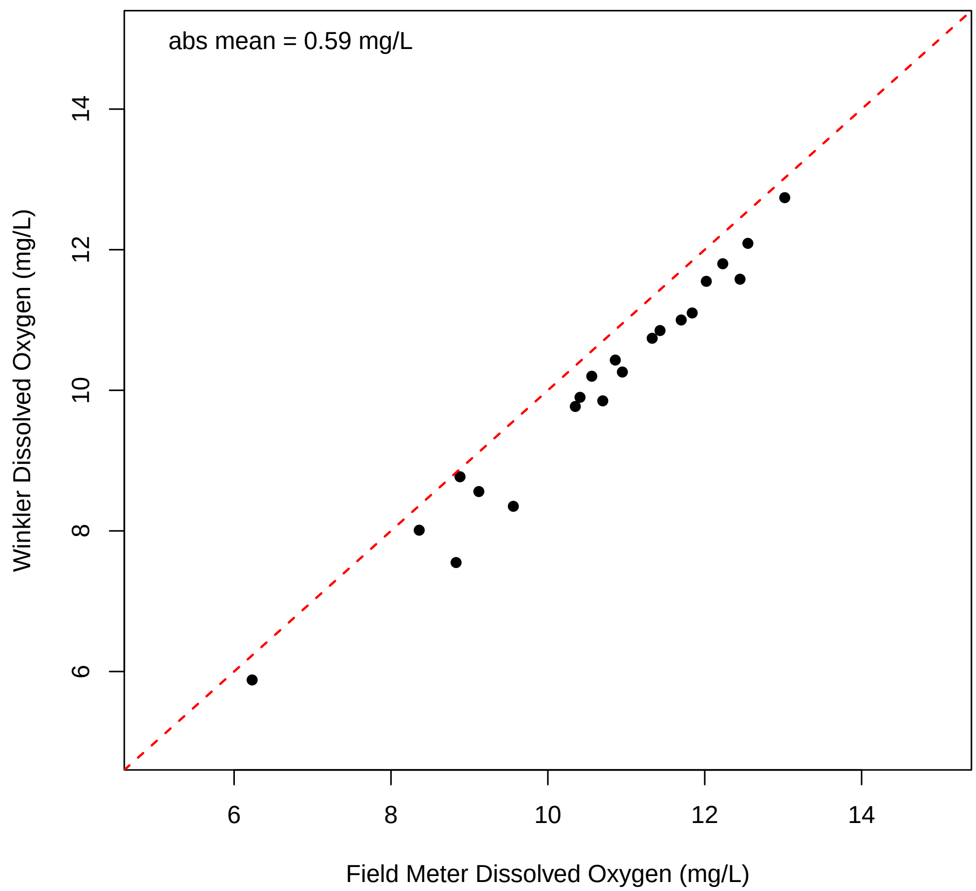


Figure C36: Dissolved oxygen field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship. There was a systematic bias between the Winkler and field meter results, with the Winkler results ∼0.5 mg/L lower than the field meter. This is within typical ranges for Winkler vs. field meter comparisons (Johengen, et al., 2016).

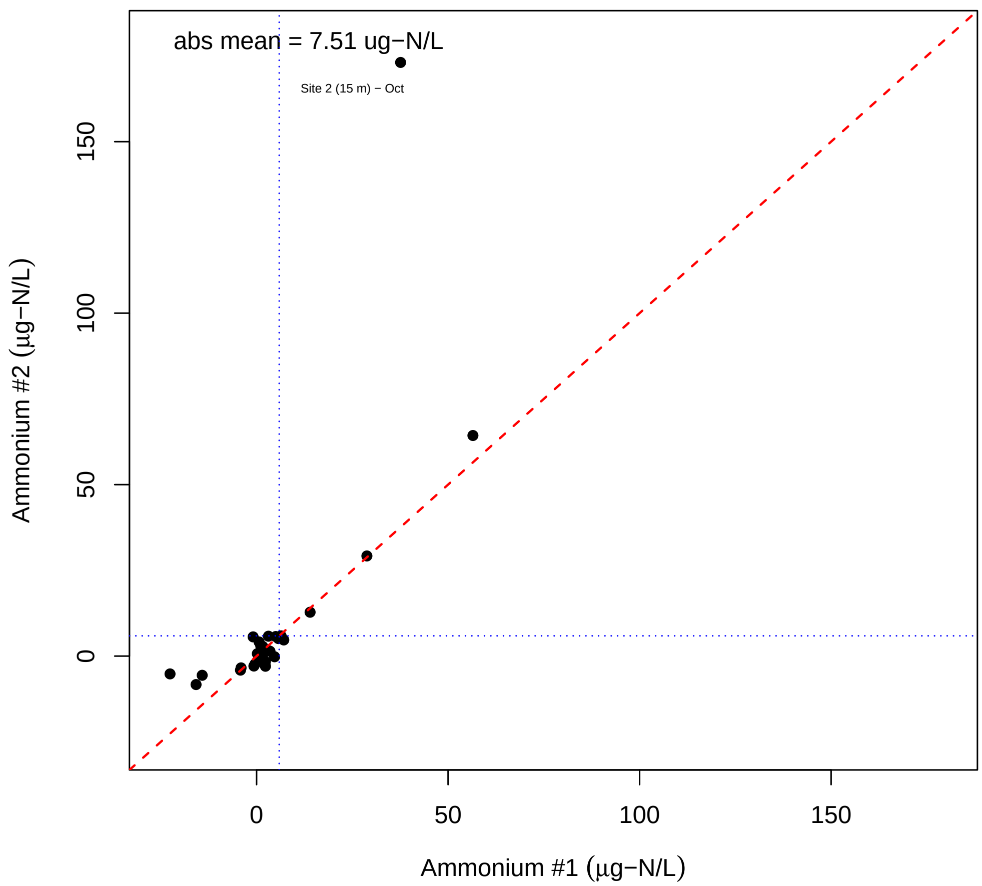


Figure C37: Nitrogen (ammonium) field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable. The labeled outlier likely reflects slight differences in sampling depth at the boundary between anoxic and oxic conditions.

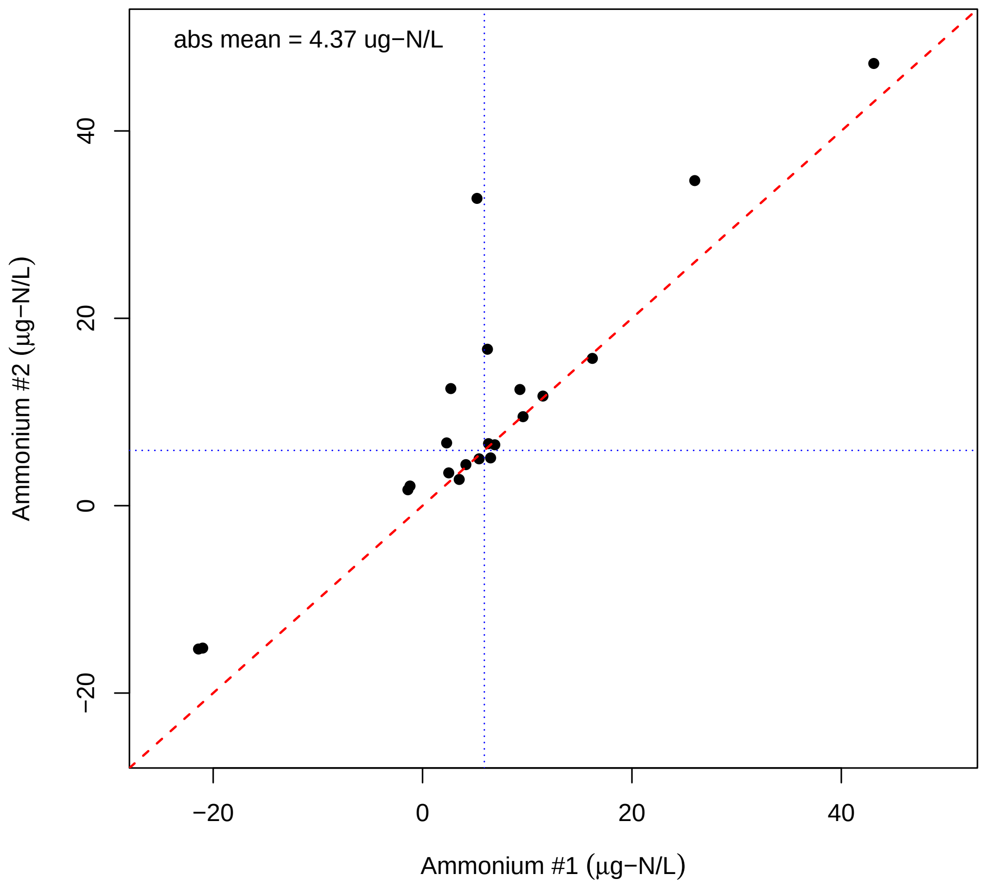


Figure C38: Nitrogen (ammonium) field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable.

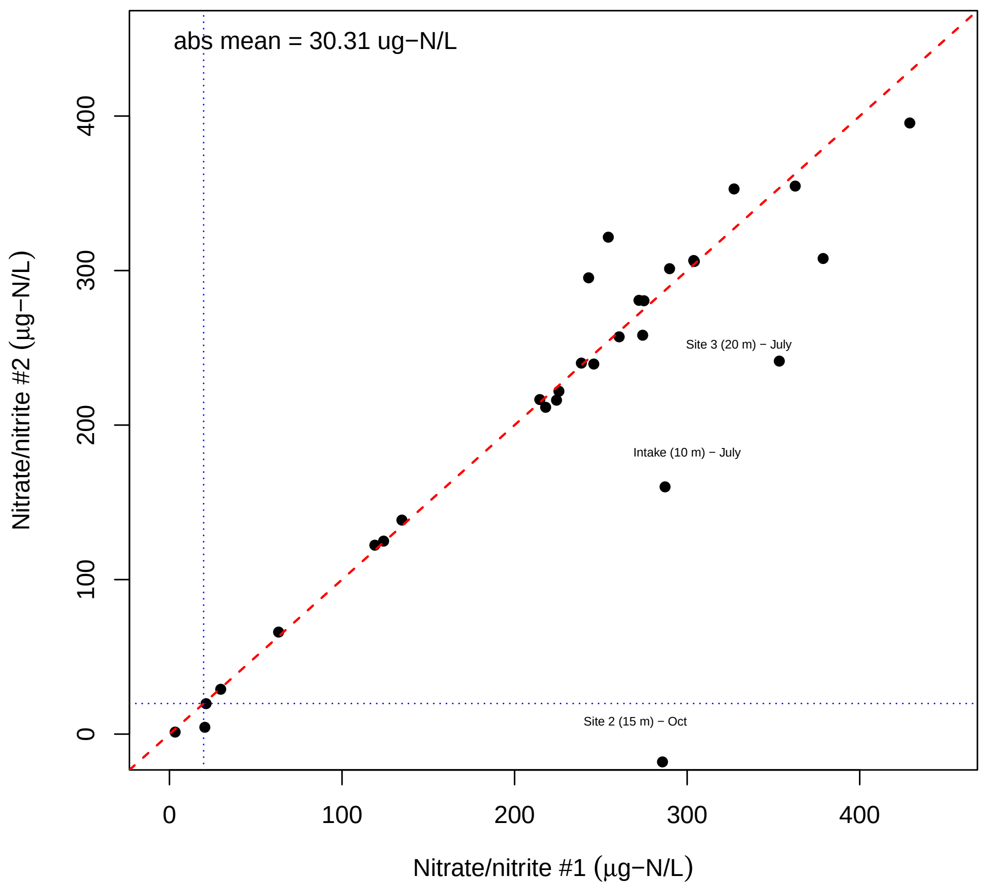


Figure C39: Nitrogen (nitrate/nitrite) field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable. The labeled outliers likely reflect slight differences in sampling depth.

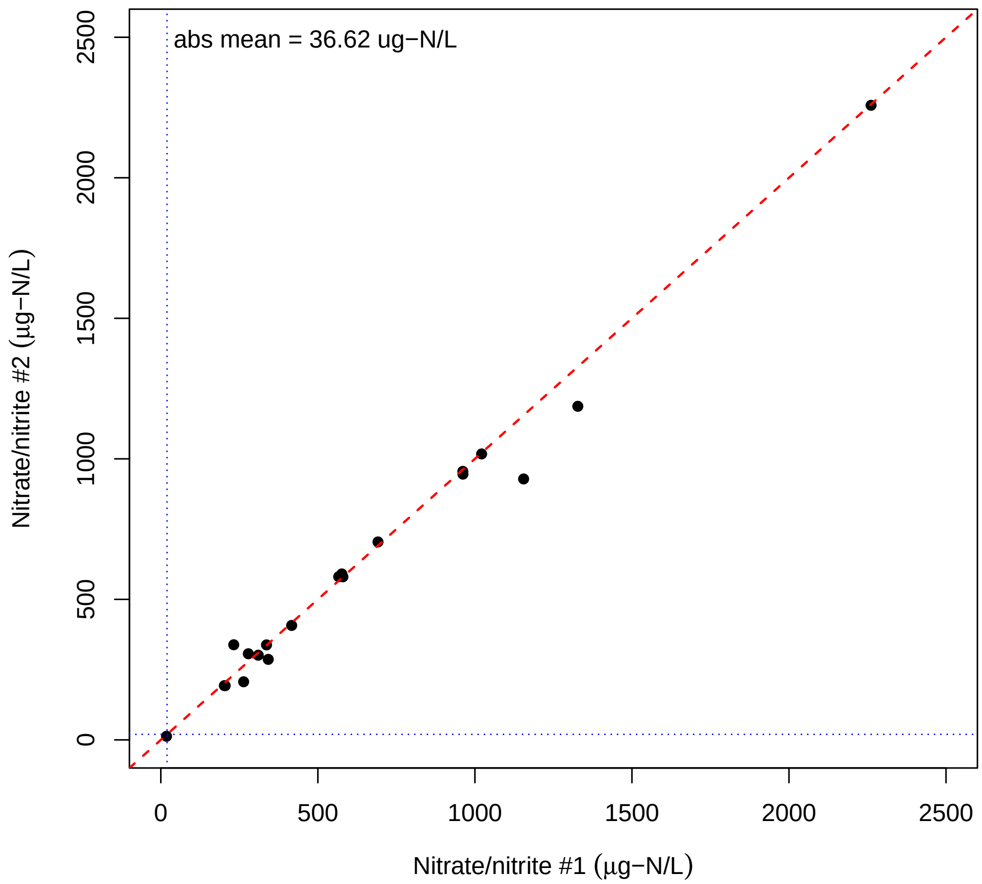


Figure C40: Nitrogen (nitrate/nitrite) field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable.

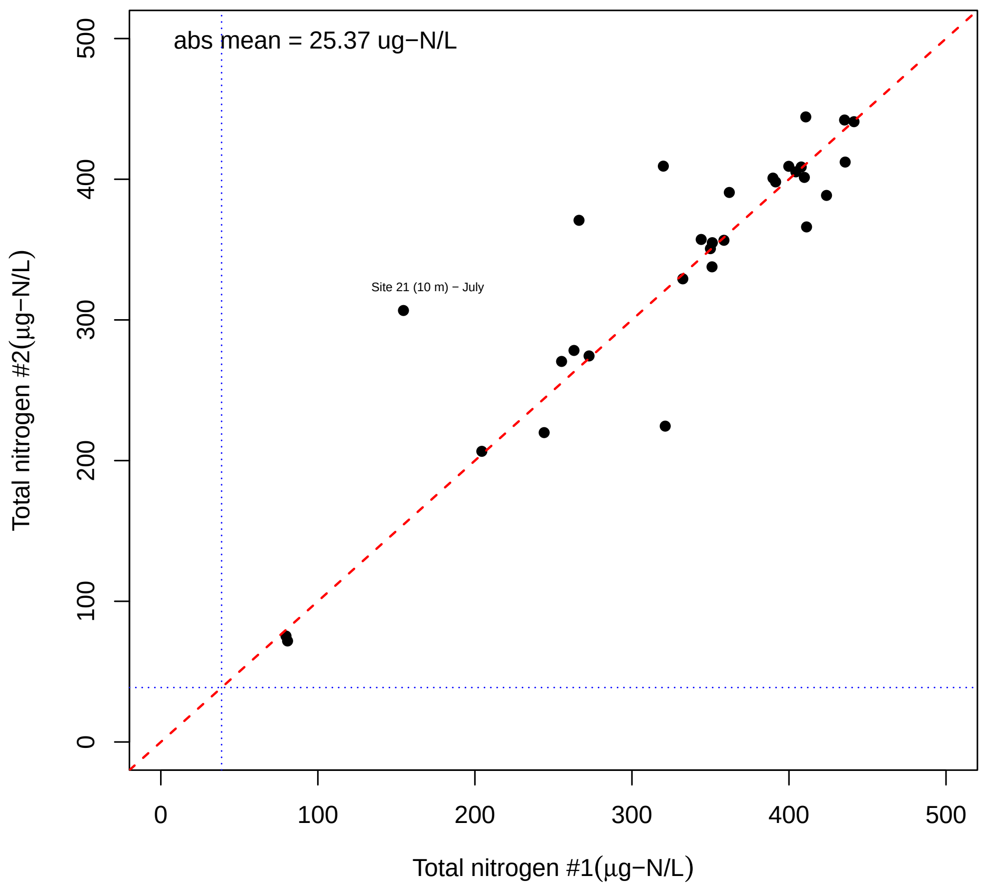


Figure C41: Nitrogen (total) field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable. The labeled outlier likely reflects slight differences in sampling depth. The scatter around the line is within the range of the laboratory QC standards (Figure C15).

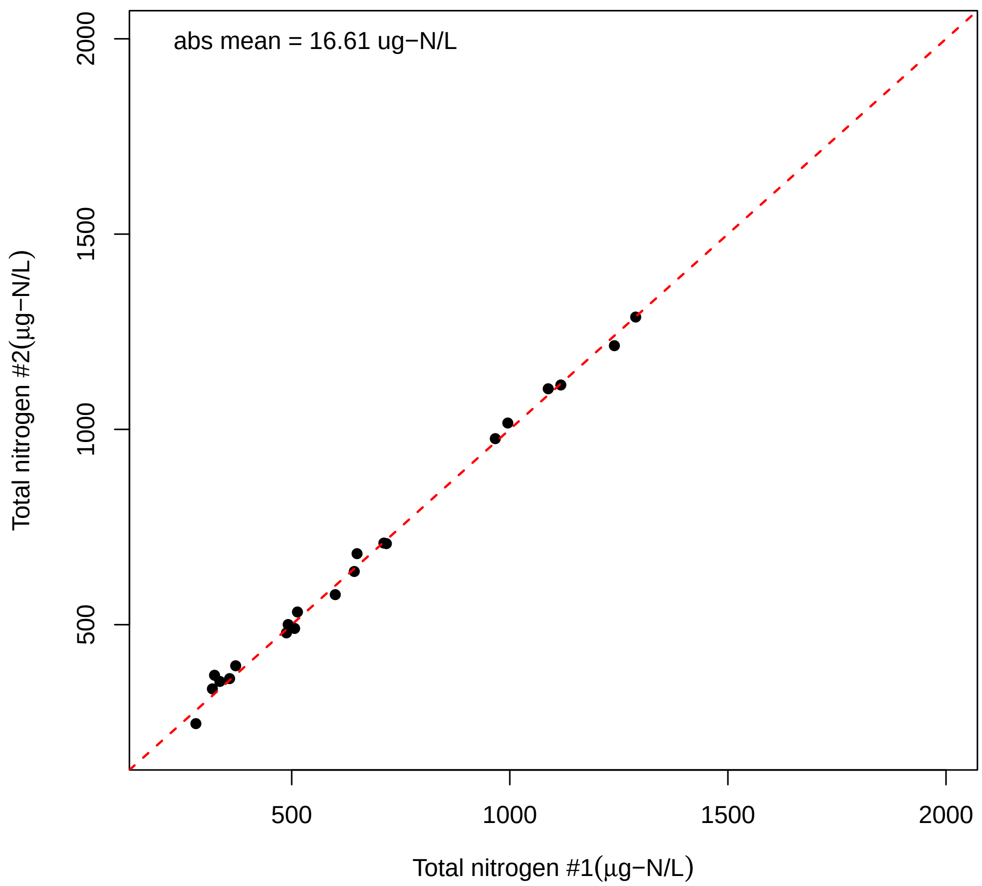


Figure C42: Nitrogen (total) field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship.

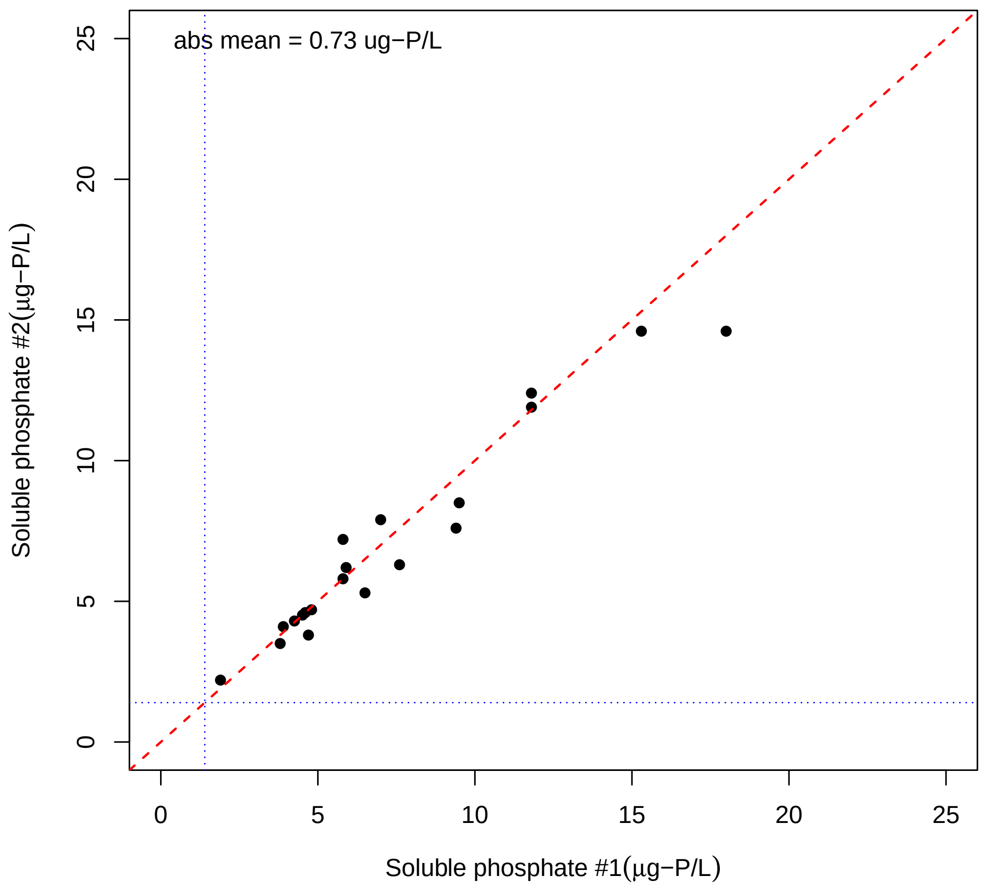


Figure C43: Phosphorus (soluble reactive phosphate) field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable.

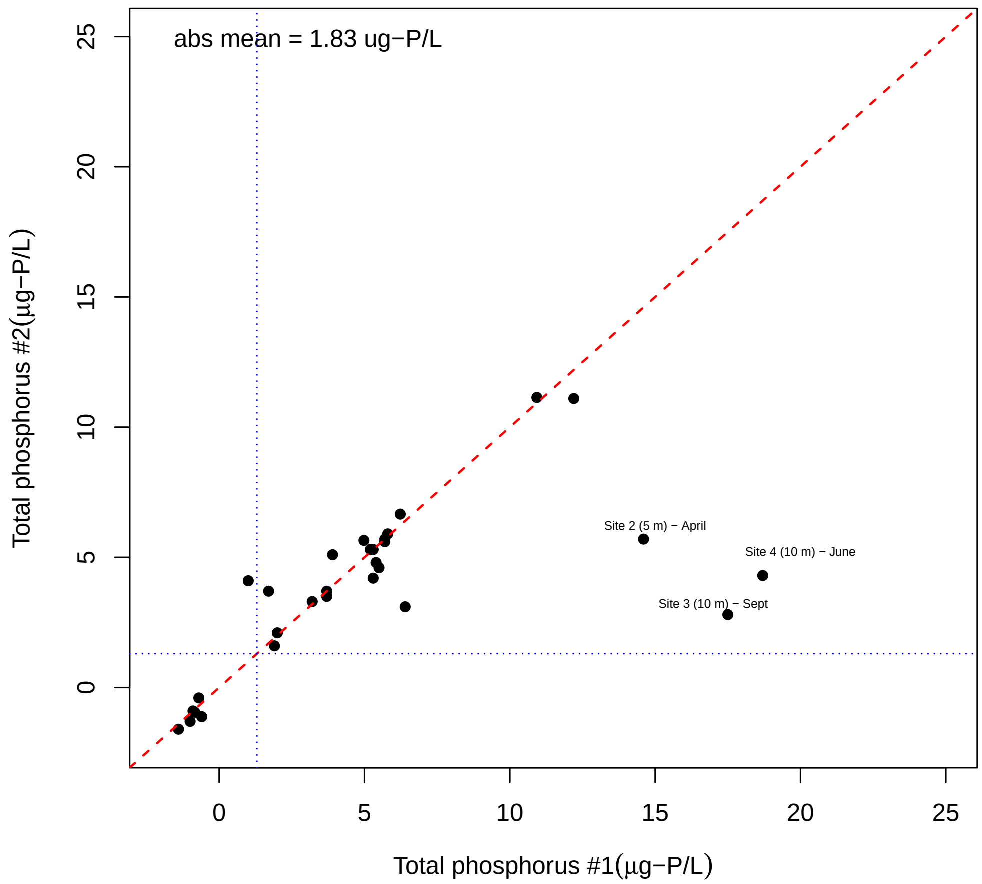


Figure C44: Phosphorus (total) field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable. The labeled outliers likely reflect slight differences in sampling depth and/or natural variability in particulate matter distribution.

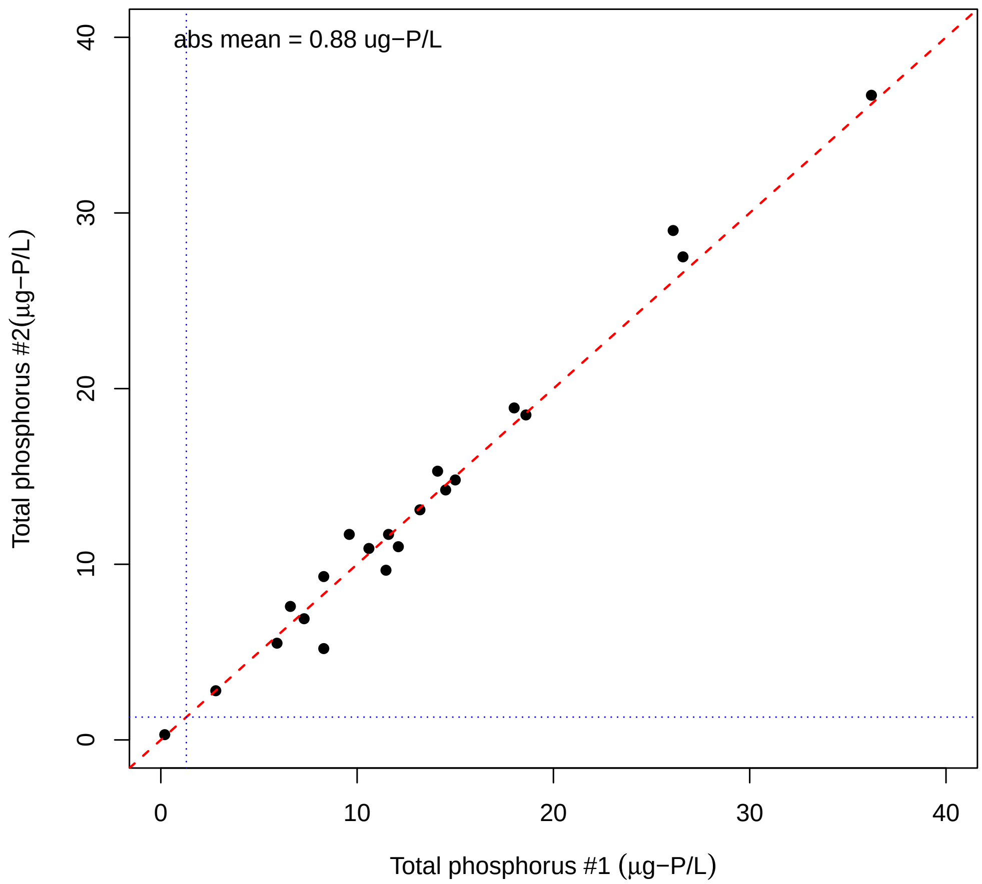


Figure C45: Phosphorus (total) field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable.

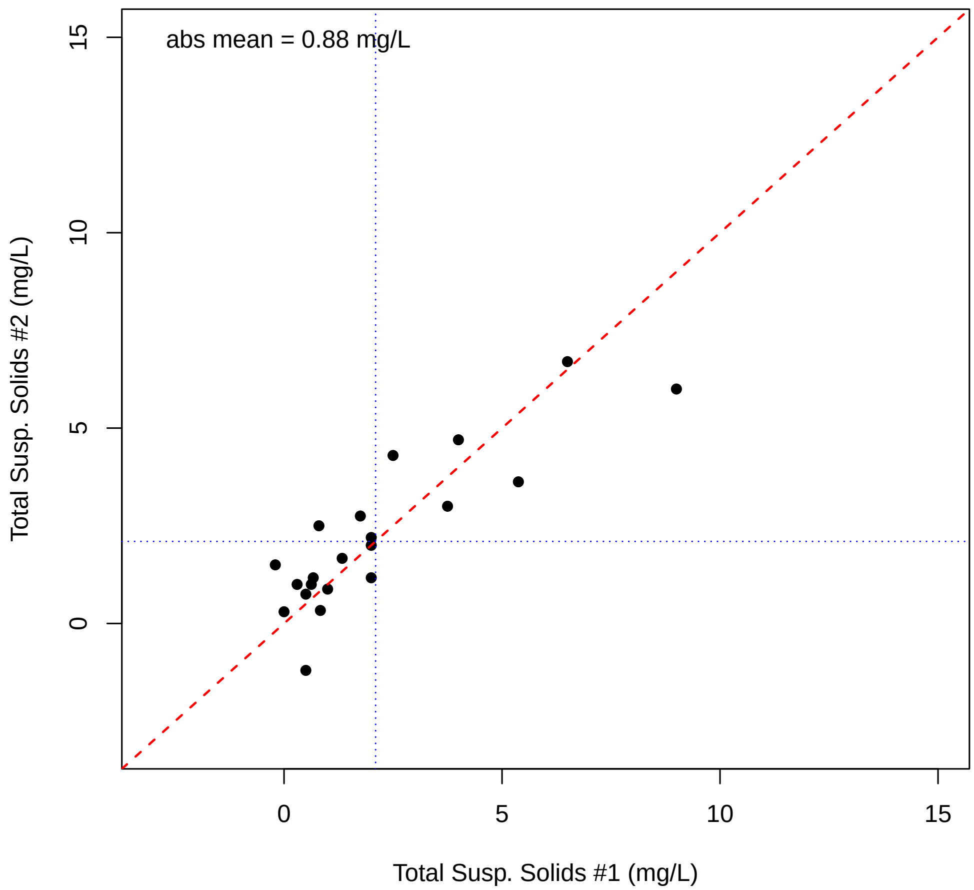


Figure C46: Total suspended solids field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; blue reference lines show current detection limit. Sample values below detection limits can be unreliable.

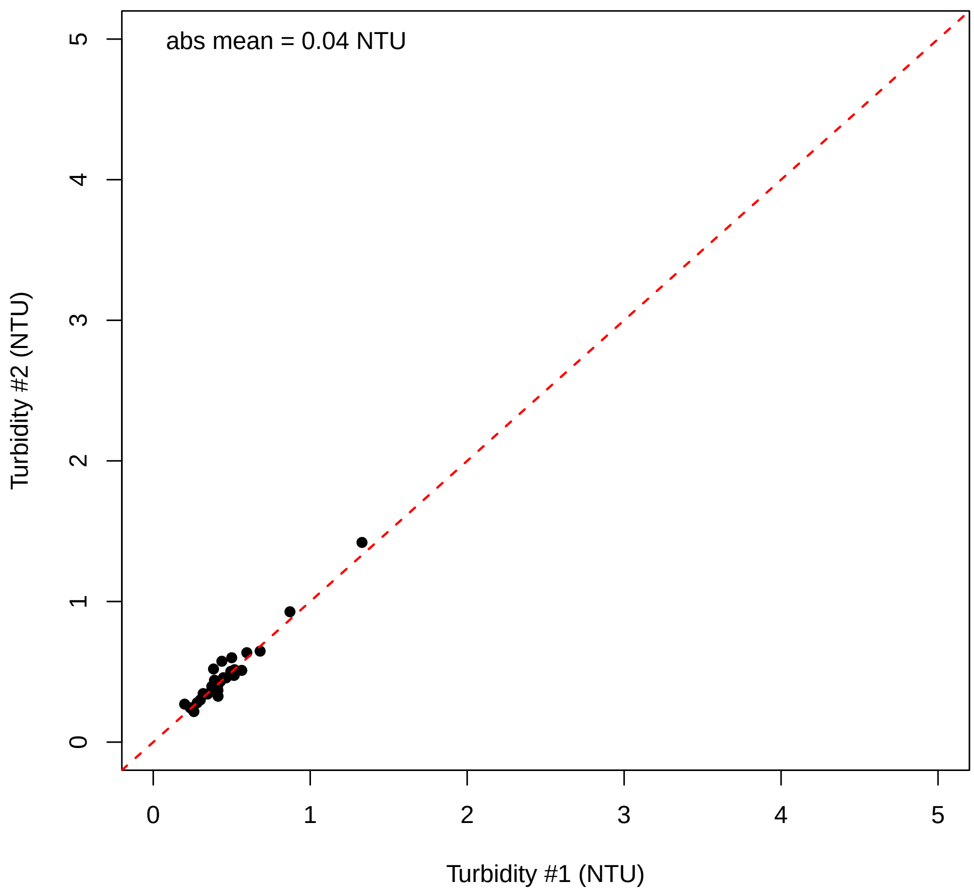


Figure C47: Turbidity field duplicates for the 2022/2023 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

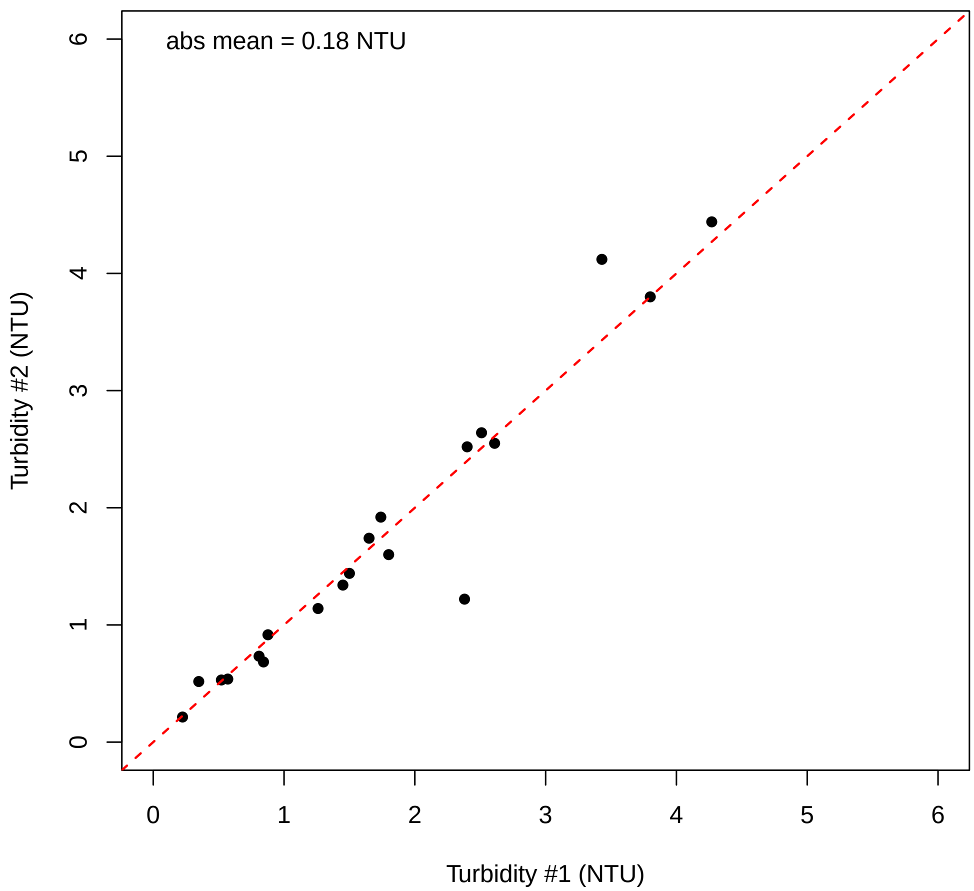


Figure C48: Turbidity field duplicates for the 2022/2023 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship.

D Lake Whatcom Online Data

The following **readme** file describes the electronic data posted at the IWS web site (https://iws.wwu.edu/) and additional data available from IWS. Please contact the Director of the Institute for Watershed Studies if you have questions or trouble accessing the online data.

```
**************************************************************
* README FILE - LAKE WHATCOM ONLINE DATA
* THIS FILE WAS UPDATED JANUARY 4, 2024
**************************************************************
Most of the Lake Whatcom water quality data are available in
electronic format at the IWS website (https://iws.wwu.edu/) or from
the IWS Director.

The historic and current detection limits and abbreviations for each
parameter are listed in the annual reports.  The historic detection
limits for each parameter were estimated based on recommended lower
detection ranges, instrument limitations, and analyst judgment on the
lowest repeatable concentration for each test.  Over time, some
analytical techniques have improved so that current detection limits
are usually lower than historic detection limits.  Because the Lake
Whatcom data set includes long-term monitoring data, which have been
collected using a variety of analytical techniques, this report sets
conservative detection limits to allow comparisons between years.

All files are comma-separated ascii data files.  The code "NA" has
been entered into all empty cells in the ascii data files to fill in
unsampled dates and depths, missing data, etc.  Questions about
missing data should be directed to the IWS Director.

Unless otherwise indicated, the electronic data files have NOT been
censored to flag or otherwise identify below detection and above
detection values.  As a result, the ascii files may contain negative
values due to linear extrapolation of the standards regression curve
for below detection data.  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.
```

```
*************************************************************
* ONLINE LAKE DATA FILES:
*************************************************************
Hydrolab/YSI data
1988_hl.csv, 1989_hl.csv, 1990_hl.csv, 1991_hl.csv, 1992_hl.csv
1993_hl.csv, 1994_hl.csv, 1995_hl.csv, 1996_hl.csv, 1997_hl.csv
1998_hl.csv, 1999_hl.csv, 2000_hl.csv, 2001_hl.csv, 2002_hl.csv
2003_hl.csv, 2004_hl.csv, 2005_hl.csv, 2006_hl.csv, 2007_hl.csv
2008_hl.csv, 2009_hl.csv, 2010_hl.csv, 2011_hl.csv, 2012_hl.csv
2013_hl.csv, 2014_hl.csv, 2015_hl.csv, 2016_hl.csv, 2017_hl.csv
2018_hl.csv, 2019_hl.csv, 2020_hl.csv, 2021_hl.csv, 2022_hl.csv
2023_hl.csv

Water quality data
1988_wq.csv, 1989_wq.csv, 1990_wq.csv, 1991_wq.csv, 1992_wq.csv
1993_wq.csv, 1994_wq.csv, 1995_wq.csv, 1996_wq.csv, 1997_wq.csv
1998_wq.csv, 1999_wq.csv, 2000_wq.csv, 2001_wq.csv, 2002_wq.csv
2003_wq.csv, 2004_wq.csv, 2005_wq.csv, 2006_wq.csv, 2007_wq.csv
2008_wq.csv, 2009_wq.csv, 2010_wq.csv, 2011_wq.csv, 2012_wq.csv
2013_wq.csv, 2014_wq.csv, 2015_wq.csv, 2016_wq.csv, 2017_wq.csv
2018_wq.csv, 2019_wq.csv, 2020_wq.csv, 2021_wq.csv, 2022_wq.csv
2023_wq.csv

Plankton counts
plankton.csv

The *_hl.csv files include: site, depth (m), month, day, year, temp
(temperature, C), pH, cond (conductivity, uS/cm), do (dissolved
oxygen, mg/L), lcond (lab conductivity qc, uS/cm), secchi (secchi
depth, m).

The *_wq.csv files include: site, depth (m), month, day, year, alk
(alkalinity, mg/L as CaCO3), turb (turbidity. NTU), nh3 (ammonium,
ug-N/L), tn (total persulfate nitrogen, ug-N/L), nos (nitrate/
nitrite, ug-N/L), srp (soluble reactive phosphate, ug-P/L), tp (total
persulfate phosphorus, ug-P/L), chl (chlorophyll, ug/L).

The plankton.csv file includes: site, depth (m), month, day, year,
zoop (zooplankton, #/L), chry (chrysophyta, #/L), cyan (cyano-
bacteria, #/L), chlo (chlorophyta, #/L), pyrr (pyrrophyta, #/L). The
plankton file was updated in fall 2023 to correct a calculation error in
zooplankton density that occurred from July 2022-June 2023.
```

```
***********************************************************
* ONLINE HYDROGRAPH DATA FILES:
***********************************************************
WY1998.csv, WY1999.csv, WY2000_rev.csv (rev. 3/8/2012), WY2001.csv,
WY2002.csv, WY2003.csv, WY2004_rev.csv (rev. 6/21/2006), WY2005.csv,
WY2006.csv, WY2007.csv (rev. July 31, 2008), WY2008.csv, WY2009.csv,
WY2010.csv, WY2011.csv, WY2012.csv, WY2013.csv, WY2014.csv, WY2015.csv
WY2016.csv, WY2017.csv, WY2018.csv, WY2019.csv, WY2020.csv, WY2021.csv,
WY2022.csv, WY2023.csv

The WY*.csv files include: month, day, year, hour, min, sec, ander.g
(anderson gauge height, ft), ander.cfs(anderson discharge, cfs),
austin.g (austin gauge height, ft), austin.cfs (austin discharge,
cfs), smith.g (smith gauge height, ft), smith.cfs (smith discharge,
cfs).  Anderson Creek hydrograph data were deleted in WY2000_rev.csv
due to uncertainty about the gauge height; Anderson Creek data are
available for WY1998, WY1999, and WY2001-WY2007. Beginning with
WY2002, the variable "time" replaced "hour, min, sec," with time
reported daily on a 24-hr basis. Data are reported as Pacific
Standard Time without Daylight Saving Time adjustment. In WY2022.csv
and WY2023.csv, there are additional columns for DHSVM modeled data
(e.g., smith.dhsvm.cfs) - these data are provided for the period of time
when the gauges were not operational. See Section 4
for further detail.

***********************************************************
* STORM WATER AND TRIBUTARY DATA FILES
***********************************************************
The storm water and tributary data include composite and grab samples
from numerous sites in the Lake Whatcom watershed (1994--present),
representing a variety of study objectives and sampling intensities
over time.  The electronic data files are not posted online, but may
be obtained by contacting the Institute for Watershed Studies.

***********************************************************
* SITE CODES
* ALL FILES - INCLUDES DISCONTINUED SITES AND OFF-LINE DATA
***********************************************************
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
34  = Strawberry Sill site S2
35  = Strawberry Sill site S3

AlabamaVault inlet     = Alabama canister vault inlet
AlabamaVault outlet    = Alabama canister vault outlet
Brentwood inlet        = Brentwood wet pond inlet
Brentwood outlet       = Brentwood wet pond outlet
ParkPlace cell1        = Park Place wet pond cell 1
ParkPlace cell2        = Park Place wet pond cell 2
ParkPlace cell3        = Park Place wet pond cell 3
ParkPlace inlet        = Park Place wet pond inlet
ParkPlace outlet       = Park Place wet pond outlet
Parkstone_swale inlet  = Parkstone grass swale inlet
Parkstone_swale outlet = Parkstone grass swale outlet
Parkstone_pond inlet   = Parkstone wet pond inlet
Parkstone_pond outlet  = Parkstone wet pond outlet
SouthCampus inlet      = South Campus storm water facility inlet
SouthCampus outletE    = South Campus storm water facility east outlet
SouthCampus outletW    = South Campus storm water facility west outlet
Sylvan inlet           = Sylvan storm drain inlet
Sylvan outlet          = Sylvan storm drain outlet
Wetland outlet         = Grace Lane wetland

CW1 = Smith Creek (see alternate code below)
CW2 = Silver Beach Creek (see alternate code below)
CW3 = Park Place drain (see alternate code below)
CW4 = Blue Canyon Creek (see alternate code below)
CW5 = Anderson Creek (see alternate code below)
CW6 = Wildwood Creek (discontinued in 2004)
CW7 = Austin Creek (see alternate code below)
```

The following tributary site codes were used for the expanded 2004-2006 tributary monitoring project

```
AND  = Anderson Creek (same location as CW5 above)
BEA1 = Austin.Beaver.confluence
AUS = Austin.lower (same location as CW7 above)
BEA2 = Austin.upper
BEA3 = Beaver.upper
BLU = BlueCanyon (same location as CW4 above)
BRA = Brannian
CAR = Carpenter
EUC = Euclid
MIL = Millwheel
```

OLS = Olsen
PAR = ParkPlace (same location as CW3 above)
SIL = SilverBeach (same location as CW2 above)
SMI = Smith (same location as CW1 above)
WHA = Whatcom

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

During the summer of 1998 the Institute for Watershed Studies began creating an electronic data file that would contain long term data records for Lake Whatcom. These data were to be 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 re-verification process was done.

The re-verification started with printing a 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 IWS 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 reactive phosphate and total phosphorus points deleted due to evidence of sample contamination. 10) August 6, 1990, Site 1, 0 m, soluble reactive 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, ammonium, and total phosphorus results. 12) August 31, 1992, Site 3, 5 m, soluble reactive phosphate and total phosphorus data deleted due to probable coding error. 13) All total Kjeldahl nitrogen data were removed from the historic record. This was not due to errors with the data but rather on-going confusion over which records contained total persulfate nitrogen and which contained total Kjeldahl nitrogen. The current historic record contains only total persulfate nitrogen. Total Kjeldahl nitrogen data were retained in the IWS data base, but not in the long-term Lake Whatcom data files.

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

1994-present: The Lake Whatcom data are verified using a four step method: 1) The results are reviewed as they are generated. Outliers are checked for possible analytical or computational errors. This step is completed by the Laboratory Analyst and IWS Laboratory Supervisor. 2) The results are reviewed monthly or quarterly 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.

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.