2-23-2018

Lake Whatcom Monitoring Project 2016/2017 Report

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

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

Joan Pickens
Western Washington University, joan.pickens@wwu.edu

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

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

Lake Whatcom Monitoring Project
2016/2017 Report

Dr. Robin A. Matthews
Michael Hilles
Joan Pickens
Institute for Watershed Studies,
Huxley College of the Environment

Dr. Robert J. Mitchell
Geology Department,
College of Science and Engineering

Dr. Geoffrey B. Matthews
Computer Science Department,
College of Science and Engineering

Western Washington University
Bellingham, Washington 98225

February 23, 2018

Funding for this project was provided by the City of Bellingham, as part of their long-term commitment to environmental education and their concern for maintaining the water quality of Lake Whatcom. We thank Marilyn Desmul, Ahmed Ali, Bobbi Bevacqua, Charlie Christenson, Kayla Galicia, Connor Kitzen, Michael Lawlor, Miles Mayer, Bailey McCurdy, Ian Moran, Sam Rabb, Kris Staples-Weyrauch, and Jocelyn Wensloff for assistance with the project.

(This page blank)

Contents

List of Figures

List of Tables

(This page blank)

Executive Summary

Background for the Lake Whatcom Annual Reports

- This report describes the results from the 2016/2017 Lake Whatcom monitoring program conducted by the Institute for Watershed Studies at Western Washington University (www.wwu.edu/iws).

- The major objectives in 2016/2017 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 online resource "Water on the Web" (WOW, 2004; www.waterontheweb.org).

- 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 addition 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 107, 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 2016/2017 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 2016/2017 temperature profiles fell within historic ranges; however, the lake was still destratified in April, and only weakly stratified by May; stable stratification was present all Sites 1–4 by early June. (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. The hypolimnetic oxygen loss at Site 1 started later in the summer of 2017 than most years because the lake was not fully stratified until June. As a result, the July hypolimnetic oxygen concentrations were relatively high, but by August the oxygen concentrations were <2 mg/L from 12 meters to the bottom.

- 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). Nitrate depletion also occurred in the hypolimnion at Sites 1 and 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 have increased significantly over time at most sites (Section 2.3.5, page 12), but the patterns are erratic, reflecting the complicated nature of phosphorus movement in the water column.

- 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 3.8–6.7 μg/L at Site 1 and 2.9–4.6 μg/L at Sites 2–4.

- All of the mid-basin fecal coliforms counts were less than 10 cfu/100 mL (Section 2.3.7, page 14). The coliform counts at the Bloedel-Donovan recreational area (collected offshore from the swimming area) were slightly

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

higher than mid-basin counts, but passed the freshwater *Extraordinary Primary Contact Recreational* bacteria standard for Washington.

- The concentrations of trihalomethanes and haloacetic acids (TTHMs and HAAs) in Bellingham's treated drinking water have been increasing over time, but 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 15).

- Monthly tributary samples were collected at 12 locations in the Lake Whatcom watershed (Section 3, page 51). Due to an unusually dry spring and summer, five of the sites could not be sampled on one or more of the sampling trips.

- 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 coliform counts, and higher nutrient concentrations.

- Hydrograph data were collected at Austin and Smith Creeks using rating curves developed with Aquarius software to calculate discharge (Section 4.1, page 69).

- Storm runoff samples were collected in Austin Creek (two storm events), Olsen Creek (three storm events), and Silver Beach Creek (eight storm events) using time-paced automated samplers (Section 4, page 69). The storm runoff contained elevated levels of total suspended solids and total phosphorus.

(This page blank)

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 107.

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 online resource "Water on the Web" (www.waterontheweb.org; WOW, 2004).

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 consecutive water systems 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.

In January 22, 2014, approximately 8,800 acres of forest lands formerly managed by the Department of Natural Resources was reconveyed to Whatcom County to be managed as low impact park lands. The Lake Whatcom reconveyance planning process is summarized online at 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 1981, 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 2016/2017 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 historic lake data are plotted in Appendix B. The current quality control results are in Appendix C. The monitoring data are available online at `www.wwu.edu/iws` as described in Appendix D (page 344). Table 2.1 (page 17) lists abbreviations and units used to describe water quality analyses in this document.

2 Lake Whatcom Monitoring

2.1 Site Descriptions

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (Figure A1, page 115 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 4 & 6, November 1 & 3, and December 1 & 14 2016; and February 21 & 23, April 11 & 13, May 4 & 11, June 6 & 13, July 6 & 11, August 1, 3, & 7, and September 5 & 7 2017. Each sampling event is a multi-day task; all samples were collected during daylight hours, typically between 10:00 am and 3:00 pm.

A YSI multiparameter field meter was used to measure temperature, pH, dissolved oxygen, and conductivity. Raw water samples were collected using a VanDorn sampler. All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory, and were analyzed as described in Table 2.1 (page 17). Total organic carbon analyses were done by AmTest[2] or by IWS. Plankton samples were placed in a cooler and returned to the laboratory unpreserved. The plankton sample volumes were measured in the laboratory and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham.

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,[3] nitrate/nitrite,[4] total nitrogen, soluble phosphate, total phosphorus, alkalinity, turbidity, chlorophyll); plankton and bacteria counts; and total organic carbon measurements.

The 2016/2017 temperature, dissolved oxygen, pH, and conductivity profiles are shown in Figures B1–B50 (Appendix B, pages 120–169). Tables 2.2–2.6 (pages 18–22) summarize the current field measurements, ambient water quality, and

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

[3] Ammonium (NH_4^+) is ionized ammonia (NH_3). Nearly all ammonia is ionized in surface water. Earlier IWS reports used the term ammonia and ammonium interchangeably to describe ammonium concentrations because it is generally understood that ammonia is usually ionized. To improve clarity, IWS has switched to the term "ammonium" to indicate that we are reporting the concentration of ionized ammonia. This does not represent any change in analytical methods.

[4] 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.

coliform data, and all of the current data are plotted in comparison with historic data in Figures B51–B130 (Appendix B, pages 171–251). 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 `www.wwu.edu/iws` as described in Appendix D (page 344).

2.3.1 Water temperature

The 2016/2017 monthly temperature profiles for Sites 1–4 were plotted as overlay points on shaded polygons showing the historic 1988–2014 temperature ranges (Figures 2.1–2.10, pages 25–34).[5] 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 120–169).

The spring and summer temperature profiles (Figures 2.5–2.10, pages 29–34) 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[6] 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.[7]

[5] The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

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

[7] 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 often still stratified in November or early December (Figures 2.2–2.3, pages 26–27). Complete destratification of basin 3 usually occurs in December or early January, so by February the temperatures are uniform throughout the water column at all sites (Figure 2.4, page 28).

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 2016 (Figure 2.1, page 25), but Sites 1–2 were destratified by November (Figure 2.2, page 26). Sites 3–4 were weakly stratified in December 2016; the entire lake was destratified in February 2017 (Figures 2.3–2.4, pages 27–28).

The lake was destratified in April 2017, and was only weakly stratified by May (Figures 2.5–2.6, pages 29–30). The water temperatures fell within historic ranges, but temperatures in the deep portion of basin three (Sites 3–4, ≥30 m) were near the low range for lake temperatures at that time of year. All sites were stratified by early June (ΔT ≥5°C), and remained stratified through September, with temperatures falling within typical historic ranges. (Figures 2.7–2.10, pages 31–2.10).

2.3.2 Dissolved oxygen

The 2016/2017 monthly oxygen profiles for Sites 1–4 were plotted as overlay points on shaded polygons showing the 1988–2014 historic temperature ranges (Figures 2.1–2.10, pages 25–34). 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 120–169). Provisional October and November 2017 temperature and oxygen data were included in this report (Figures 2.11–2.12, pages 35–36)[8] to help with the discussion of October–December 2016 dissolved oxygen results (see Matthews, et al., 2017)

As in past years, Sites 1–2 developed severe hypolimnetic oxygen deficits during the summer (Figures 2.7–2.10, pages 31–34). 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, biological respiration has relatively little influence on hypolimnetic oxygen concentrations except in the deepest samples from Site 3 (e.g., Figures 2.1, page 25). In contrast, there is rapid depletion of the hypolimnetic oxygen concentrations at Sites 1–2, typically (but not always) beginning in May when the lake is stratified (Figure 2.6, page 30). These two sites are in shallow basins that have small hypolimnions compared to their photic zones, so decomposition of algae and other organic matter causes a measurable drop in hypolimnetic oxygen over the summer.[9]

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).[10] The increasing rate of oxygen loss is most apparent during July and August, after the lake develops stable stratification but before oxygen levels drops near zero. To illustrate this trend we fitted the July and August data using

---

[8]October–December 2017 data are not part of the 2016/2017 sampling period.

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

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

an exponential function (see discussion by Matthews, et al., 2004). As indicated in Figures 2.13–2.16 (pages 37–40), there were significant negative correlations between dissolved oxygen and time for all hypolimnetic samples collected during July and August.[11]

The hypolimnetic oxygen loss at Site 1 started later in the summer of 2017 than most years because the lake was not fully stratified until June. As a result, the July hypolimnetic oxygen concentrations were relatively high. By August, however, the oxygen concentrations had dropped to levels similar to the past five years. The oxygen loss was particularly rapid at 12 meters (Figure 2.13, page 37), where the oxygen concentrations dropped from 5.09 mg/L in July to 0.65 mg/L in August, which was a loss of 4.4 mg/L. Previously, the greatest oxygen loss at this depth was 3.4 mg/L, which occurred in 2009 and 2013.

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in June and July, and smaller peaks were evident at Sites 2 and 4 in June (Figures 2.7–2.8, pages 31–32; Figures B31–B40, pages 150–159). 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).

Hypolimnetic oxygen loss is much less obvious in basin three, 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 25; Figures B4 and B5, pages 123 and 124; Matthews and DeLuna, 2008). From October through December, which is usually the last month of stratification in basin three, the hypolimnetic oxygen concentrations at Sites 3–4 are often lower than in the epilimnion (e.g., Figures 2.1–2.3, pages 25–27). But it is uncommon for the hypolimnion in basin three to contain <5–6 mg/L of dissolved oxygen, with the exception of the 80 meter sample from Site 3, which is very close to the sediments, and occasionally drops into the 0–4 mg/L range.

[11] 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.

In both 2015 and 2016, the oxygen concentrations in the lower portion of the hypolimnion at Site 3 were unusually low during the months leading up to destratification, often falling outside the historic ranges (Figure 2.2, page 26; Matthews et al., 2017). Unlike the oxygen trend occurring at Site 1, which is related to biological oxygen consumption of increasing amounts of organic matter, the low oxygen concentrations in the hypolimnion at Site 3 appear to be related to water temperature. In the absence of oxygen-depleting factors (like decomposition), dissolved oxygen and water temperature are inversely correlated, so warm water will contain less oxygen than cold water. Figure 2.17 (page 41) shows this inverse correlation using dissolved oxygen concentrations and water temperature data in the samples collected from 1988–2017 in November at 60–75 meters.[12] The unusually low oxygen concentrations in November 2015 and 2016 were paired with relatively high water temperatures. By comparison, hypolimnetic temperature and oxygen data for October and November 2017 were within typical ranges (Figures 2.11–2.12 and Figure 2.17; pages 35–36 and 41).

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.[13] First, bacteria will use nitrate as an alternate to oxygen, converting nitrate to ammonium or 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.

[12] The 80 m data were not used for the reason described previously. Samples collected at that depth are sometimes influenced by bottom sediments, so they are not always representative of the water quality in the hypolimnion.

[13] For a more complete discussion of anaerobic decomposition in lakes, see Wetzel, 2001.

The hypolimnion at Sites 1–2 usually contain detectable concentrations of hydrogen sulfide by October (Table 2.7, page 23). 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. In 2017, stable stratification didn't develop until about June, and the hypolimnion at Sites 1–2 still contained $\geq$2 mg/L of oxygen in July. The hypolimnetic oxygen concentrations were $<$2 mg/L from August through October at Site 1, which resulted in measurable hydrogen sulfide concentrations (0.68 mg/L). At Site 2, however, the hypolimnetic oxygen concentrations did not drop below 2 mg/L until September, and the hydrogen sulfide concentrations were still below detection in October ($<$0.05 mg/L).

2.3.3 Conductivity and pH

The pH and conductivity data followed trends that were fairly typical for Lake Whatcom (Figures B1–B50 and B61–B70, pages 120–169 and 181–190). Surface pH values increased during the summer due to photosynthetic activity. Hypolimnetic pH values decreased and conductivities increased due to decomposition and the release of dissolved compounds from the sediments.

The conductivity concentrations were elevated in deep samples at Sites 1–2, and periodically at Site 3, coinciding with periods of low oxygen near the bottom (Figures B66, B67, and B69, pages 186, 187, and 189). The historic data from 1988–2002 show what appears to be a decreasing trend in the conductivity values, 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 (80 m).

2.3.4 Alkalinity and turbidity

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures B71–B75, pages 192–196). During the summer the alkalinity values at the bottom of Sites 1–2, and occasionally Site 3, increased due to decomposition and the release of dissolved compounds in the lower waters.

Turbidity values in the lake were usually low (1–3 NTU) except during late summer in samples from 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 Site 3 (Figures B76–B80, pages 197–201).

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 basin 3 because there are fewer distracting late summer hypolimnetic turbidity peaks (see February 2009 storm-related turbidity peaks in Figures B78 and B79–B80; pages 199 and 200–201).

2.3.5 Nitrogen and phosphorus

The nitrogen and phosphorus data for Lake Whatcom are illustrated in Figures B81–B105 (pages 202–226). 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.[14]

Nitrogen: Most algae use inorganic nitrogen in the form of nitrate or ammonium for growth.[15] Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 207–211), particularly at Site 1, where the epilimnetic nitrate concentrations usually drop below 20 μg-N/L by the end of the summer. Epilimnetic nitrogen depletion is an indirect, but fairly sensitive measure of phytoplankton productivity, and because algal densities have been increasing throughout the lake, epilimnetic dissolved inorganic nitrogen concentrations (DIN)[16] have been declining over time (Figure 2.18, page 42).

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

[15] Many types of algae can also use organic nitrogen, and some Cyanobacteria and a few uncommon species of diatoms can use dissolved nitrogen gas.

[16] Dissolved inorganic nitrogen includes ammonium, nitrate, and nitrite. Usually, epilimnetic concentrations of ammonium and nitrite are low, so DIN is nearly equivalent to nitrate.

Hypolimnetic nitrate concentrations dropped below 20 μg-N/L at Sites 1–2 (Figures B86–B87, pages 207–208). In anaerobic environments, bacteria reduce nitrate (NO_3^-) to nitrite (NO_2^-) and nitrogen gas (N_2). The historic 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 B87, page 208). 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.

Ammonium, along with hydrogen sulfide, is often an indicator of hypolimnetic anoxia.[17] 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 B81 & B82, pages 202 & 203). 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 B82, page 203). Despite the late stratification in 2017, the October samples from Sites 1–2 contained extremely high ammonium concentrations near the bottom of the water column, reaching 523.5 μg-N/L at Site 1 (15 m) and 661.1 μg-N/L at Site 2 (20 m).[18] Both sites usually destratify by November, which causes the ammonium concentrations to drop to the lower concentrations, which persist through winter and spring (see annual patterns in Figures B81 & B82, pages 202 & 203).

Sites 3–4 often have slightly elevated ammonium concentrations in the metalimnion at 20 m, or near the bottom at 80–90 m (Figures B84–B85, pages 205–206). This is caused by bacterial decomposition of organic matter, but the concentrations never approach the levels found in the hypolimnion at Sites 1–2.

[17] 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.

[18] The Site 1 sample from 20 meters was lost during processing.

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).

When hypolimnetic oxygen concentrations are low, sediment-bound phosphorus becomes soluble and leaches into the overlying water. 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, similar to the epilimnetic DIN reduction that was described for nitrogen. 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 (Deluna and Matthews, 2008), making it difficult to estimate the amount of phosphorus that is incorporated into algal biomass.

In Lake Whatcom, total phosphorus and soluble phosphate concentrations were usually low except in the hypolimnion at Sites 1–2 just prior to destratification (Figures B96–B100, pages 217–221 and B101–B105, pages 222–226). Epilimnetic total phosphorus concentrations are usually lower than late-summer hypolimnetic peaks. Prior to 2000, the median epilimnetic phosphorus concentrations were <5 μg-P/L at Sites 2–4 and approximately 5–8 μg-P/L at Site 1 (Figure 2.19, page 43). The epilimnetic phosphorus levels have increased significantly at most sites (Figure 2.19, page 43); however, the pattern is quite erratic, reflecting the complicated nature of phosphorus movement in the water column. In 2017, the epilimnetic phosphorus concentrations were below detection at Sites 2–4 and near the detection limit at Site 1.

2.3.6 Chlorophyll, plankton, and Secchi depth

Site 1 continued to have the highest chlorophyll concentrations of all the sites (Figures B106–B110, pages 227–231). 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 Lake Whatcom plankton counts were usually dominated by Chrysophyta, primarily *Dinobryon*, *Mallomonas*, and diatoms (Figures B121–B130, pages 242–251). Substantial blooms of green algae (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 B111–B115, pages 232–236) 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).

The median near-surface summer chlorophyll concentrations have increased significantly at all sites since 1994 (Figure 2.20, page 44). 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 = 0.548; Sites 2–4 Kendalls τ = 0.584, 0.645, 0.633, respectively).[19] Although the annual chlorophyll concentrations are quite variable, they seem to have stabilized since 2004, ranging from 3.8–6.7 μg/L at Site 1 and 2.9–4.6 μg/L at Sites 2–4.

Chlorophyll is a direct measure of algal biomass and generally provides a better indication of changes in the lake's biological productivity than phosphorus. But we use algal counts rather than chlorophyll to look for trends within the same type of algae (e.g., are the numbers of Cyanobacteria increasing?). The actual relationship between chlorophyll concentration and the algae cell count is complex. The amount of chlorophyll in an algal 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. Even if the amount of chlorophyll was constant in each cell, it would take many tiny cells to equal the chlorophyll biomass in one large colony.

Except for the dinoflagellates,[20] the algae counts have increased significantly since 1994 (Figure 2.21, page 45). Cyanobacteria, which are often used as bioindicators of eutrophication, have increased at all sites (Figure 2.22, page 46). The Cyanobacteria counts are dominated by *Aphanothece*, *Aphanocapsa*, *Cyanodictyon*, and *Snowella*. These genera not typically associated with toxic blooms (Granéli and Turner, 2006; Matthews, et al., 2012). As with chlorophyll, the algae and Cyanobacteria counts appear to have stabilized around 2004.

2.3.7 Coliform bacteria

The current surface water standards are based on "designated use" categories, which for Lake Whatcom is "Extraordinary Primary Contact Recreation." The standard for bacteria is described in Chapter 173–201A–200 of the Washington Administrative Code, Water Quality Standards for Surface Waters of the state of Washington:

[19] See discussion of correlation in footnote on page 7

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

> *Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.*

All of the mid-basin (Sites 1–4) and Intake values for fecal coliforms were less than 10 cfu[21]/100 mL (Figures B116–B120, pages 237–241) and passed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

Coliform samples collected offshore from the Bloedel-Donovan swimming area had slightly higher counts than at Site 1 (mid-basin). None of the Bloedel-Donovan counts exceeded 100 cfu/100 mL and the geometric mean was 2 cfu/100 mL, so this site passed both parts of the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

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).

The 2016/2017 total organic carbon concentrations ranged from 1.7–5.2 mg/L, with most samples $\leq$2.5 mg/L (Table 2.8, page 24). The August samples were split and analyzed by AmTest and the IWS laboratory to compare results. With the exception of Site 1 (surface), the samples differed by at most $\pm$0.3 mg/L. The difference between Site 1 surface samples could have been caused by small particulates that were present in the AmTest sample but not in the IWS sample.

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

[21]Colony forming unit/100 mL; cfu/100 mL is sometimes labeled "colonies/100 mL."

requirement doubled under Phase II; currently the City samples eight locations in the water distribution system.[22]

The THMs have increased in Bellingham's treated drinking water, particularly during the summer and fall (second and third quarters; Figures 2.23–2.24, pages 47–48), when algal densities are higher. Haloacetic acids (HAAs), another type of disinfection by-product, also show a significant increase over time (Figure 2.25, page 49). This trend is confined to winter and spring quarters (Quarters 1–2); the summer and fall data were not significantly correlated with year (Figure 2.26, page 50). According to Sung, et al. (2000), HAAs are not as closely linked to algal concentrations 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). As a result, the HAAs trend is not easily explained, and is not a simple response to increasing summer/fall algae.

The total 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.

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

Abbrev.	Parameter	Method	Historic DL†	2016/2017 MDL†	Sensitivity or Confidence limit
IWS field measurements:					
cond	Conductivity	YSI (2010)	–	–	± 2 μS/cm
do	Dissolved oxygen	YSI (2010)	–	–	± 0.1 mg/L
ph	pH	YSI (2010)	–	–	± 0.1 pH unit
temp	Temperature	YSI (2010)	–	–	± 0.1° C
disch	Discharge	Rantz et al. (1982); SOP-IWS-6	–	–	–
secchi	Secchi depth	Lind (1985)	–	–	± 0.1 m
IWS laboratory analyses:					
alk	Alkalinity	APHA (2012) #2320; SOP-IWS-8	–	–	± 0.6 mg/L
cond	Conductivity	APHA (2012) #2510; SOP-IWS-8	–	–	± 2.1 μS/cm
do	Dissolved oxygen	APHA (2012) #4500-O.C.; SOP-IWS-8	–	–	± 0.1 mg/L
ph	pH-lab	APHA (2012) #4500-H^+; SOP-IWS-8	–	–	± 0.1 pH unit
tss	T. suspended solids	APHA (2012) #2540 D; SOP-IWS-13	2 mg/L	1.4 mg/L	± 2.8 mg/L
turb	Turbidity	APHA (2012) #2130; SOP-IWS-8	–	–	± 0.2 NTU
nh4	Ammonium (auto)	APHA (2012) #4500-NH_3 H; SOP-IWS-19	10 μg-N/L	6.0 μg-N/L	± 16.0 μg-N/L
no3	Nitrite/nitrate (auto)	APHA (2012) #4500-NO_3 I; SOP-IWS-22	20 μg-N/L	5.7 μg-N/L	± 26.3 μg-N/L
tn	T. nitrogen (auto)	APHA (2012) #4500-N C; SOP-IWS-22	100 μg-N/L	23.5 μg-N/L	± 22.8 μg-N/L
srp	Sol. phosphate (auto)	APHA (2012) #4500-P G; SOP-IWS-22	5 μg-P/L	1.5 μg-P/L	± 1.3 μg-P/L
tp	T. phosphorus (auto)	APHA (2012) #4500-P J; SOP-IWS-22	5 μg-P/L	1.9 μg-P/L	± 4.3 μg-P/L
toc‡	T. organic carbon	Potter and Wimsatt (2009)	1.0 mg/L	0.5 mg/L	–
IWS plankton analyses:					
chl	Chlorophyll	APHA (2012) #10200 H; SOP-LW-16	–	–	± 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:					
fc	Fecal coliform	APHA (2012) #9222 D	1 cfu/100 mL	1 cfu/100 mL	–
Edge Analytical analyses:					
H_2S	Hydrogen sulfide	APHA (2012) #4500-S^2	–	0.100 mg/L	–
AmTest analyses:					
toc‡	T. organic carbon	APHA (2012) #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.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	17.4	20.2	20.5	29.6
Conductivity (μS/cm)	59.0	60.0	62.5	78.0
Dissolved oxygen (mg/L)	0.2	9.9	8.5	12.5
pH	6.5	7.4	7.5	8.8
Temperature (°C)	5.5	11.3	12.3	22.5
Turbidity (NTU)	0.5	0.9	1.2	7.0
Nitrogen, ammonium (μg-N/L)	<10	<10	49.4	405.4
Nitrogen, nitrate/nitrite (μg-N/L)	<20	223.8	187.2	381.6
Nitrogen, total (μg-N/L)	190.3	429.8	396.7	609.2
Phosphorus, soluble (μg-P/L)	<5	<5	<5	32.0
Phosphorus, total (μg-P/L)	<5	6.9	8.8	42.6
Chlorophyll (μg/L)	0.2	4.0	4.5	10.1
Secchi depth (m)	2.9	4.4	4.7	7.2
Coliforms, fecal (cfu/100 mL)‡	<1	1	1	3

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

Table 2.2: Summary of Site 1 water quality data, Oct. 2016 – Sept. 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	17.3	19.2	19.4	22.2
Conductivity (μS/cm)	58.0	59.0	59.1	61.0
Dissolved oxygen (mg/L)	9.1	10.3	10.4	12.1
pH	7.3	7.7	7.9	8.6
Temperature (°C)	6.2	15.0	14.4	22.5
Turbidity (NTU)	0.4	0.6	0.6	1.4
Nitrogen, ammonium (μg-N/L)	$<$10	$<$10	$<$10	22.5
Nitrogen, nitrate/nitrite (μg-N/L)	86.8	241.2	230.4	366.1
Nitrogen, total (μg-N/L)	239.3	409.9	389.8	578.0
Phosphorus, soluble (μg-P/L)	$<$5	$<$5	$<$5	$<$5
Phosphorus, total (μg-P/L)	$<$5	5.2	6.0	35.0
Chlorophyll (μg/L)	1.4	2.9	2.9	4.6
Secchi depth (m)	4.6	5.0	5.2	6.5
Coliforms, fecal (cfu/100 mL)‡	$<$1	1	1	2

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

Table 2.3: Summary of Intake water quality data, Oct. 2016– Sept. 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	16.9	19.1	19.6	29.5
Conductivity (μS/cm)	58.0	59.0	60.4	81.0
Dissolved oxygen (mg/L)	0.2	10.2	9.6	12.1
pH	6.6	7.5	7.6	8.4
Temperature (°C)	6.2	11.4	12.7	21.7
Turbidity (NTU)	0.4	0.6	0.8	5.2
Nitrogen, ammonium (μg-N/L)	<10	<10	28.9	582.3
Nitrogen, nitrate/nitrite (μg-N/L)	<20	264.2	240.8	367.6
Nitrogen, total (μg-N/L)	192.5	407.7	413.7	816.9
Phosphorus, soluble (μg-P/L)	<5	<5	<5	5.2
Phosphorus, total (μg-P/L)	<5	5.7	6.4	21.9
Chlorophyll (μg/L)	0.4	2.8	2.9	5.1
Secchi depth (m)	4.5	5.4	5.5	6.8
Coliforms, fecal (cfu/100 mL)‡	<1	1	1	2

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

Table 2.4: Summary of Site 2 water quality data, Oct. 2016 – Sept. 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	17.3	18.6	18.7	20.6
Conductivity (μS/cm)	58.0	59.0	59.6	88.0
Dissolved oxygen (mg/L)	2.3	10.2	10.0	12.4
pH	6.8	7.3	7.5	8.5
Temperature (°C)	6.1	7.7	10.5	21.7
Turbidity (NTU)	0.3	0.5	0.6	2.5
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	29.8
Nitrogen, nitrate/nitrite (μg-N/L)	112.5	363.9	333.9	533.5
Nitrogen, total (μg-N/L)	241.5	473.9	451.7	626.0
Phosphorus, soluble (μg-P/L)	<5	<5	<5	8.6
Phosphorus, total (μg-P/L)	<5	<5	5.0	14.9
Chlorophyll (μg/L)	0.9	2.5	2.5	6.5
Secchi depth (m)	4.5	6.4	11.1	58.9
Coliforms, fecal (cfu/100 mL)‡	<1	1	1	2

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

Table 2.5: Summary of Site 3 water quality data, Oct. 2016 – Sept. 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	17.3	18.4	18.6	20.6
Conductivity (μS/cm)	58.0	60.0	60.0	64.0
Dissolved oxygen (mg/L)	7.3	10.1	10.1	12.3
pH	6.9	7.2	7.4	8.4
Temperature (°C)	6.1	7.6	10.1	21.7
Turbidity (NTU)	0.2	0.4	0.4	0.7
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	31.3
Nitrogen, nitrate/nitrite (μg-N/L)	120.4	373.9	345.8	545.7
Nitrogen, total (μg-N/L)	248.8	479.3	470.5	875.3
Phosphorus, soluble (μg-P/L)	<5	<5	<5	<5
Phosphorus, total (μg-P/L)	<5	<5	<5	7.0
Chlorophyll (μg/L)	0.8	2.5	2.4	4.9
Secchi depth (m)	5.3	6.1	18.1	58.9
Coliforms, fecal (cfu/100 mL)‡	<1	1	1	1

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

Table 2.6: Summary of Site 4 water quality data, Oct. 2016 – Sept. 2017.

	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	2009	0.15	0.47
2000†	0.27	0.53	2010	0.38	0.40
2001†	0.42	0.76	2011	0.12	0.16
2002†	0.09	0.32	2012	na	na
2003†	0.05	0.05	2013	0.20§	0.16
2004†	0.25	0.25	2014	0.28	0.66
2005‡	0.13, 0.12	0.25, 0.42	2015	0.51	0.41
2006	0.20	0.42	2016	0.64	0.51
2007	0.40	0.20	2017	0.68*	<0.05
2008	0.28	0.38			

†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 2.7: 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. The 2012 samples were lost during processing.

Site	Depth (m)	Date	TOC-AM (mg/L)	Date	TOC-AM (mg/L)	TOC-IWS (mg/L)
Site 1	0	Feb 23, 2017	1.8	Aug 3, 2017	5.2	2.2
	20	Feb 23, 2017	1.9	Aug 3, 2017	2.5	2.3
Intake	0	Feb 23, 2017	1.7	Aug 3, 2017	NA†	2.3
	10	Feb 23, 2017	3.0	Aug 3, 2017	2.3	2.1
Site 2	0	Feb 23, 2017	1.7	Aug 3, 2017	2.5	2.2
	20	Feb 23, 2017	1.7	Aug 3, 2017	2.5	2.3
Site 3	0	Feb 21, 2017	1.7	Aug 1, 2017	2.2	2.1
	80	Feb 21, 2017	1.7	Aug 1, 2017	1.9	1.7
Site 4	0	Feb 21, 2017	1.6	Aug 1, 2017	2.2	2.0
	90	Feb 21, 2017	1.6	Aug 1, 2017	1.9	1.7

†Sample lost during collection.

Table 2.8: Lake Whatcom 2016/2017 total organic carbon data. February samples were analyzed by AmTest; August samples were split and analyzed by Amtest (TOC-AM) and IWS (TOC-IWS).

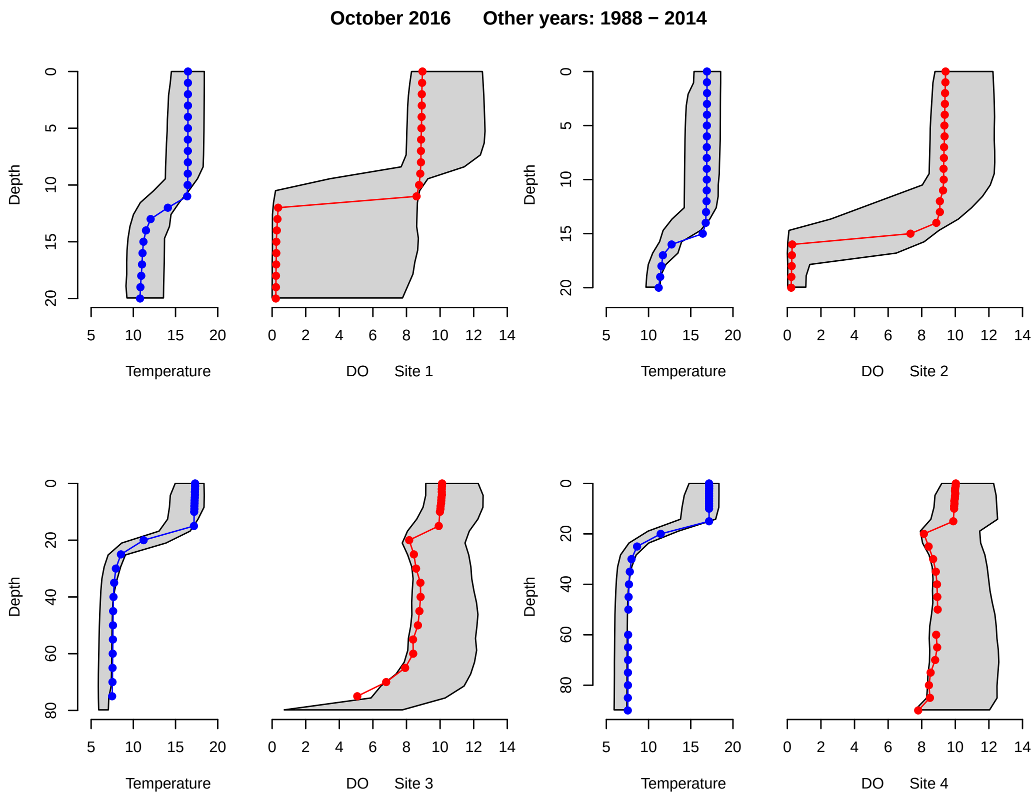


Figure 2.1: October 2016 temperature (-•-) and dissolved oxygen (-•-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

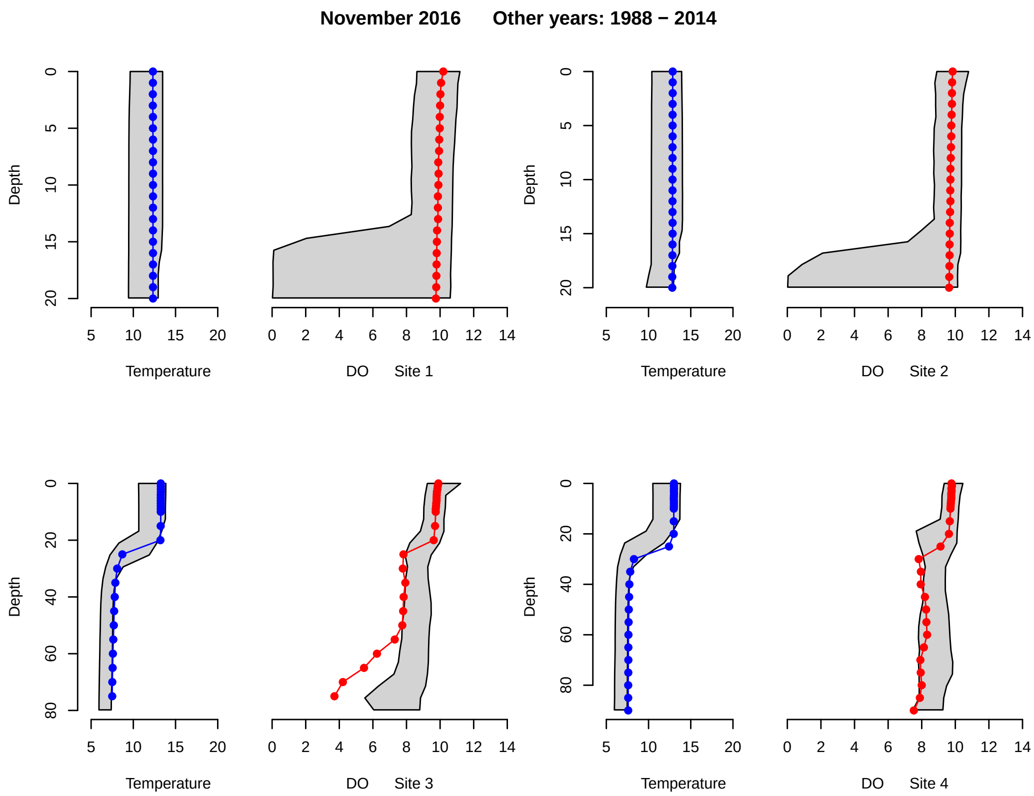


Figure 2.2: November 2016 temperature (-•-) and dissolved oxygen (-•-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

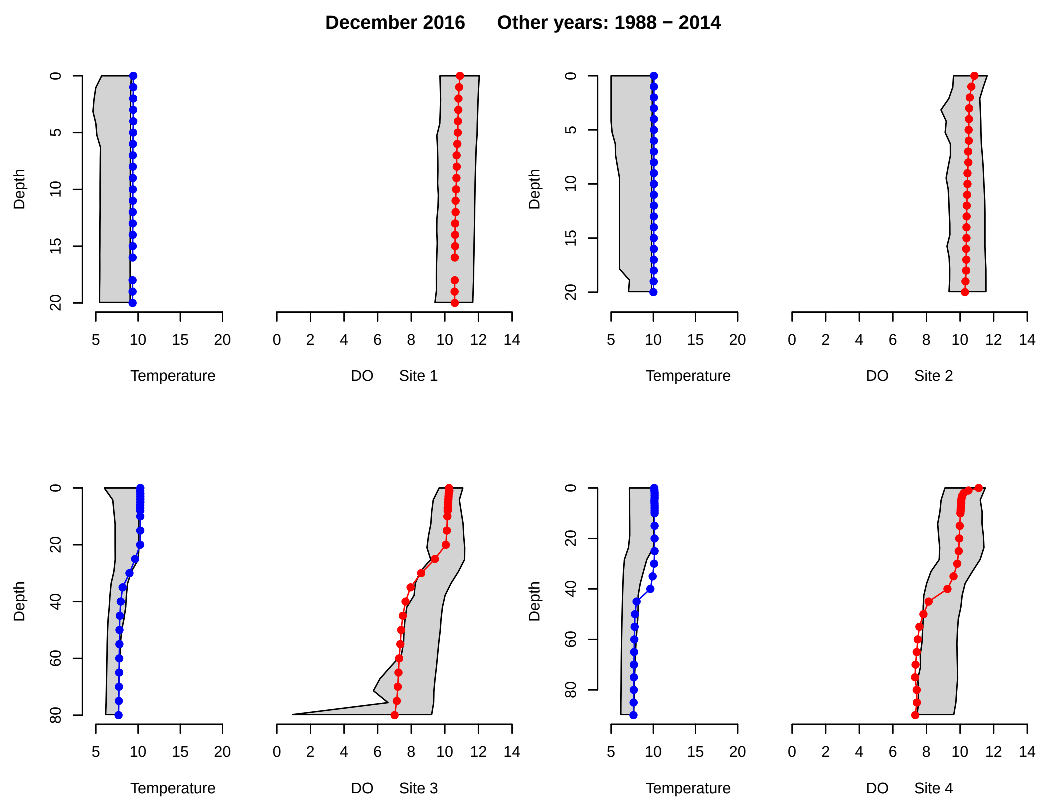


Figure 2.3: December 2016 temperature (-•-) and dissolved oxygen (-•-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

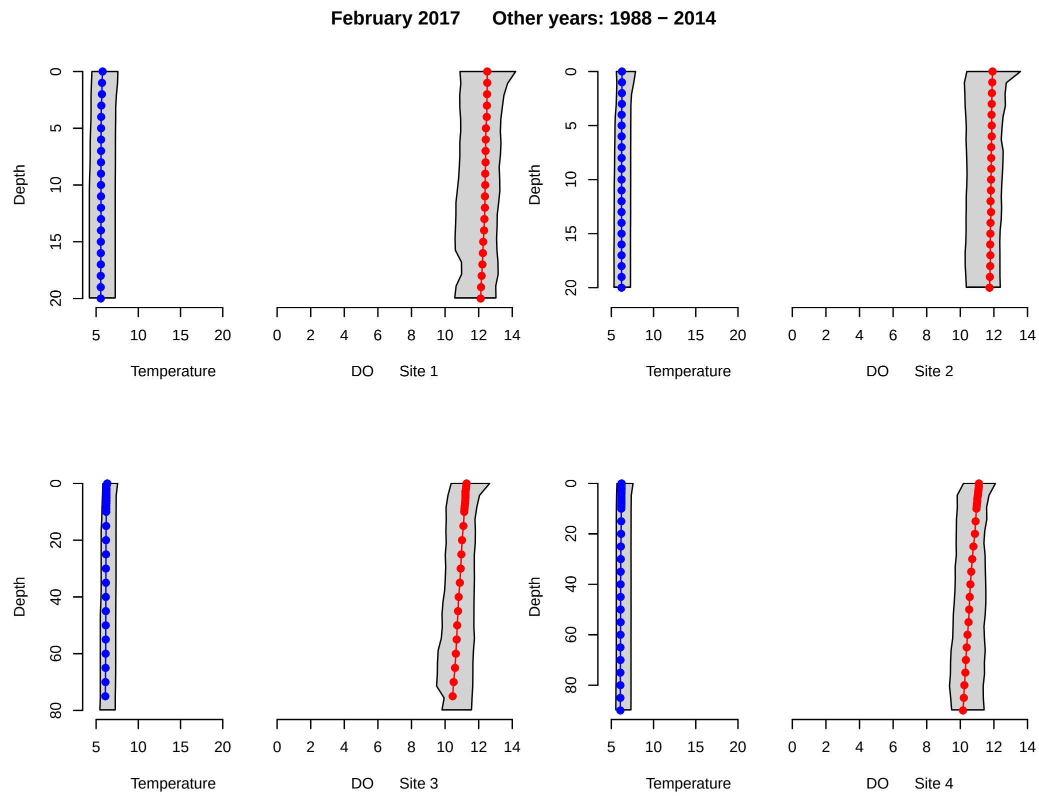


Figure 2.4: February 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

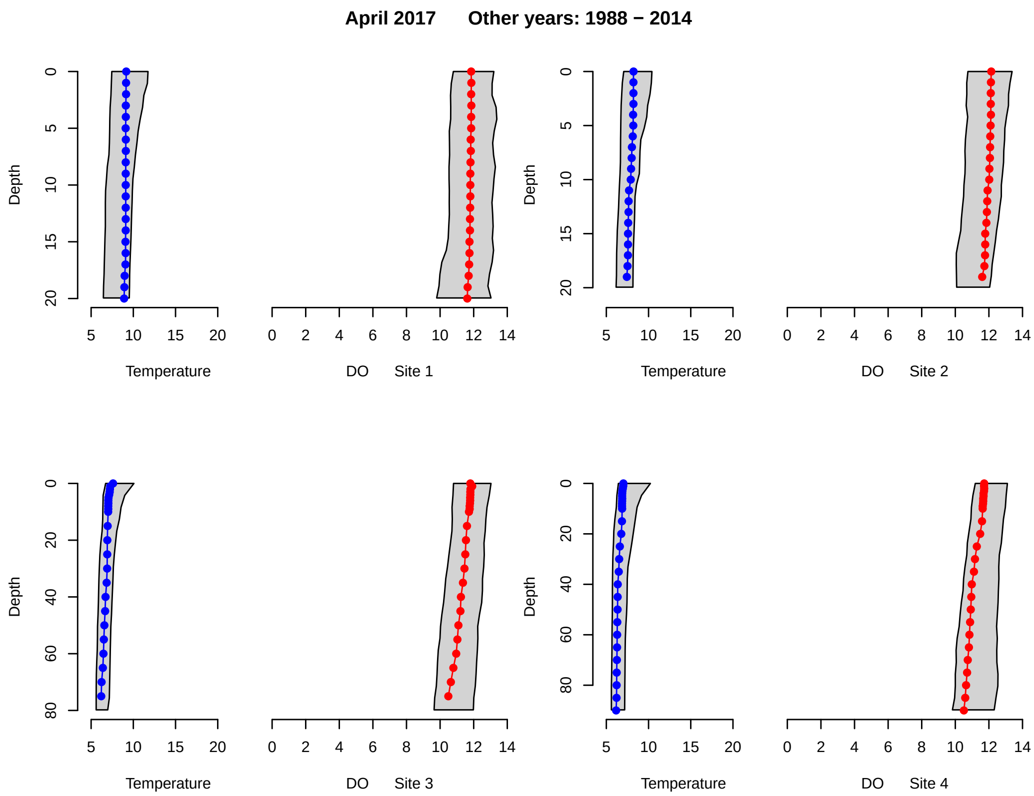


Figure 2.5: April 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

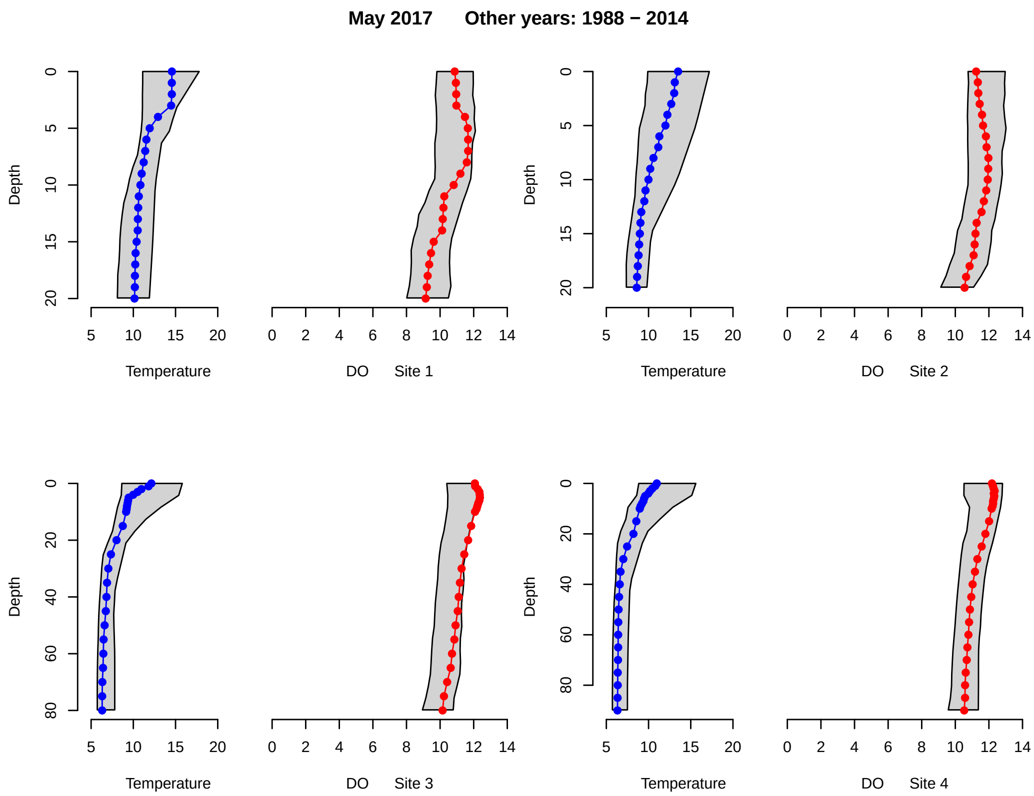


Figure 2.6: May 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

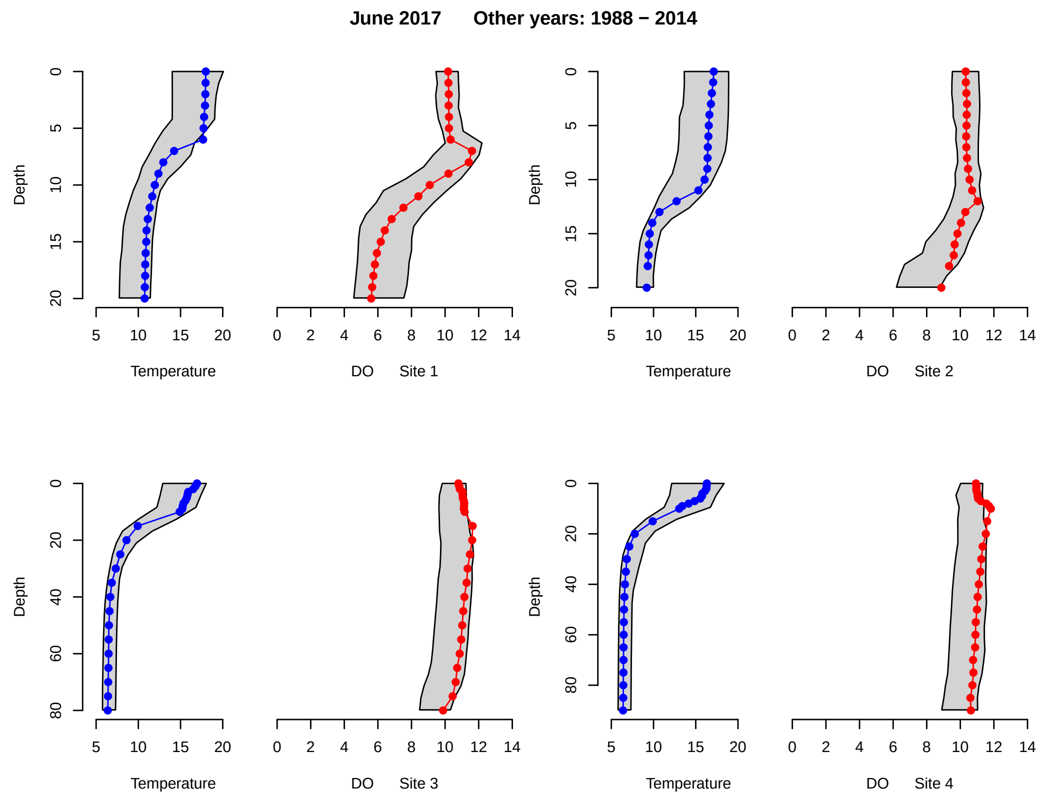


Figure 2.7: June 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

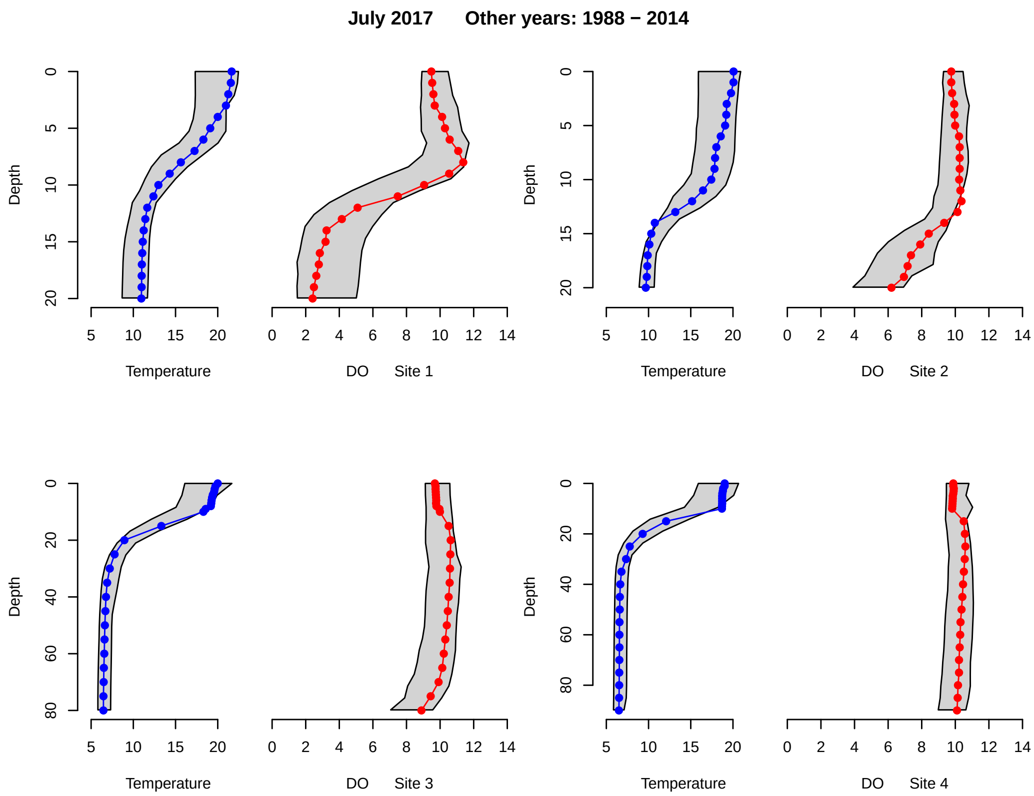


Figure 2.8: July 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

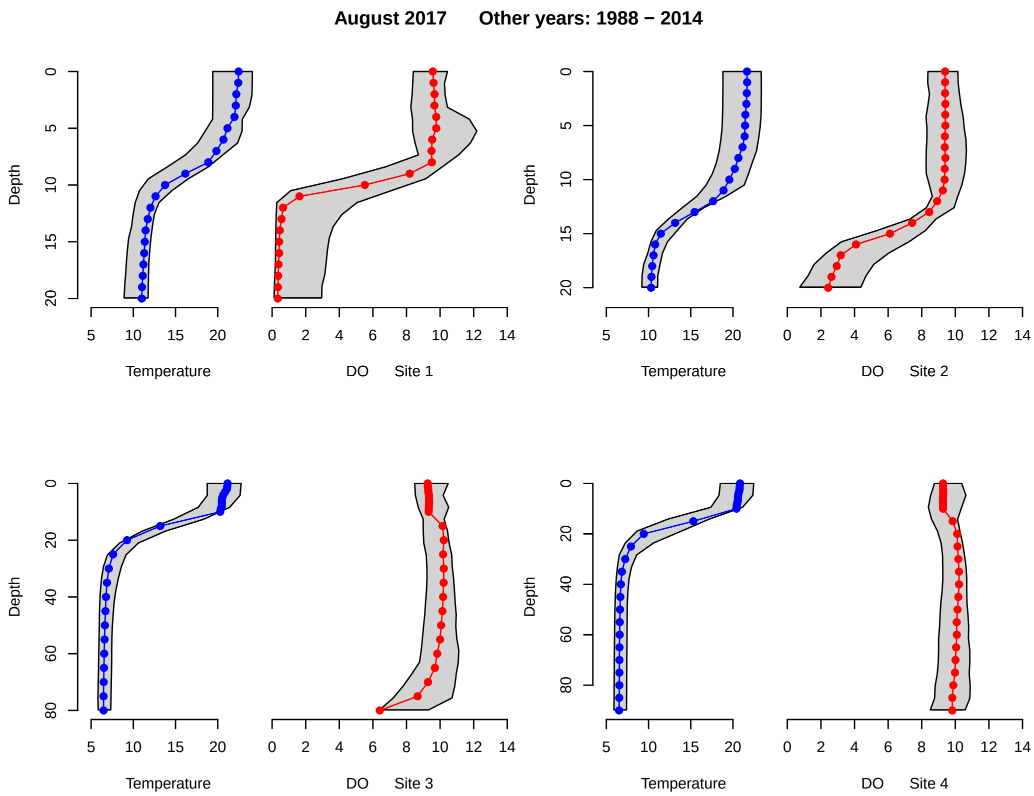


Figure 2.9: August 2017 temperature (-•-) and dissolved oxygen (-•-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

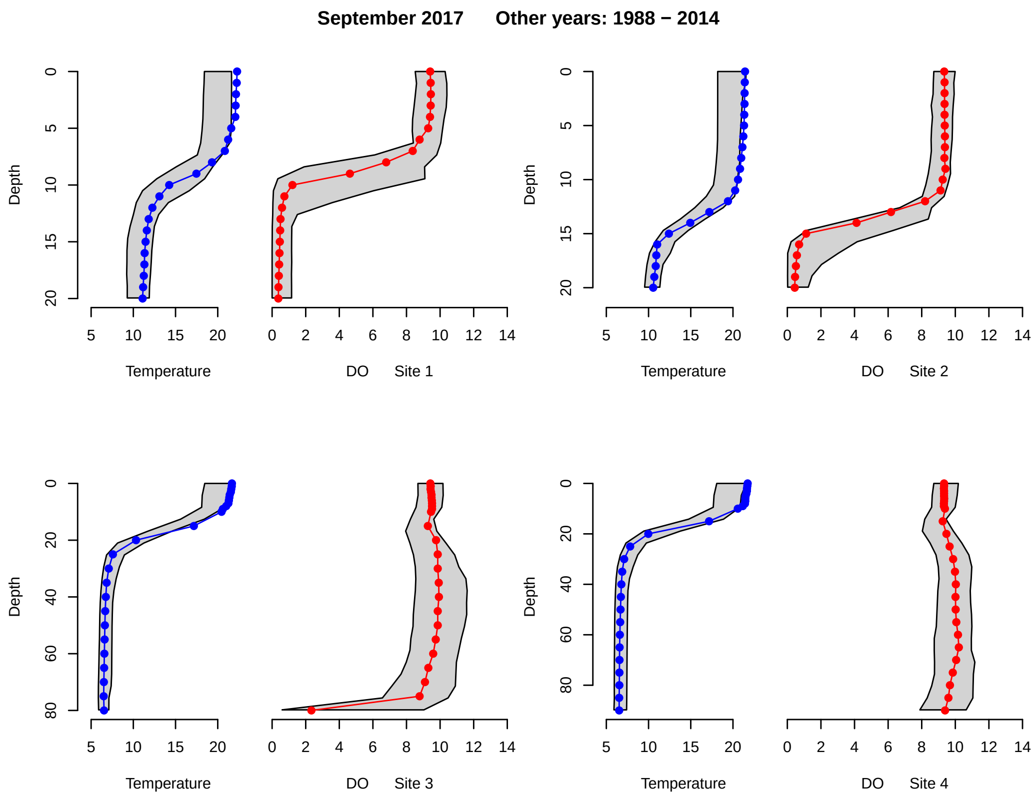


Figure 2.10: September 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017).

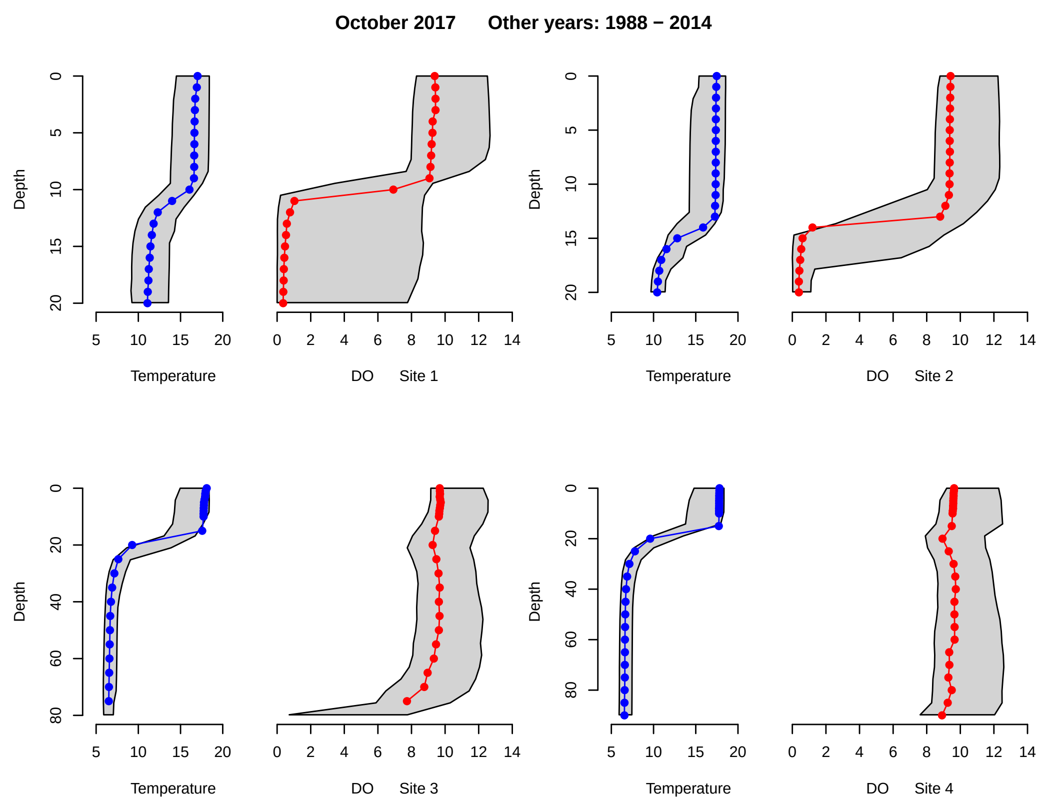


Figure 2.11: October 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017). October 2017 is not part of the 2016/2017 sampling period; preliminary October results were included to provide information for the temperature and oxygen discussion.

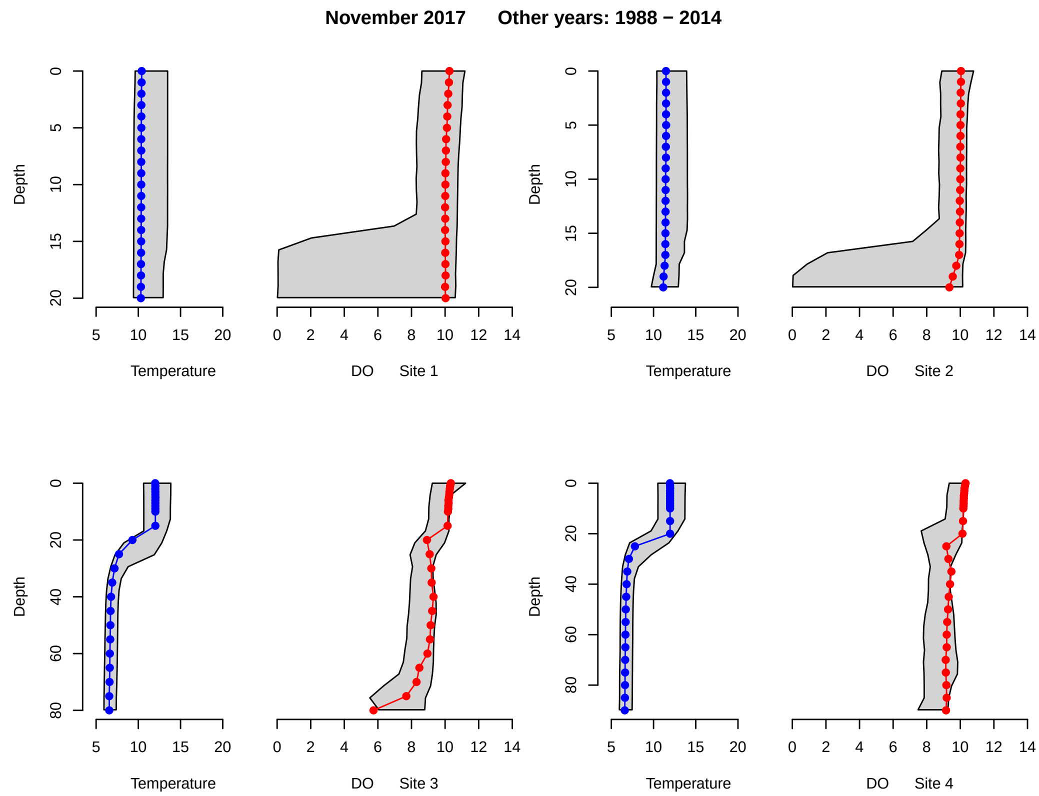


Figure 2.12: November 2017 temperature (-●-) and dissolved oxygen (-●-) profiles compared to 1988-2014 minimum/maximum ranges (gray shaded polygons). The 2015 and 2016 data were excluded from the historic ranges because of atypical patterns (see Matthews et al., 2016; 2017). November 2017 is not part of the 2016/2017 sampling period; preliminary November results were included to provide information for the temperature and oxygen discussion.

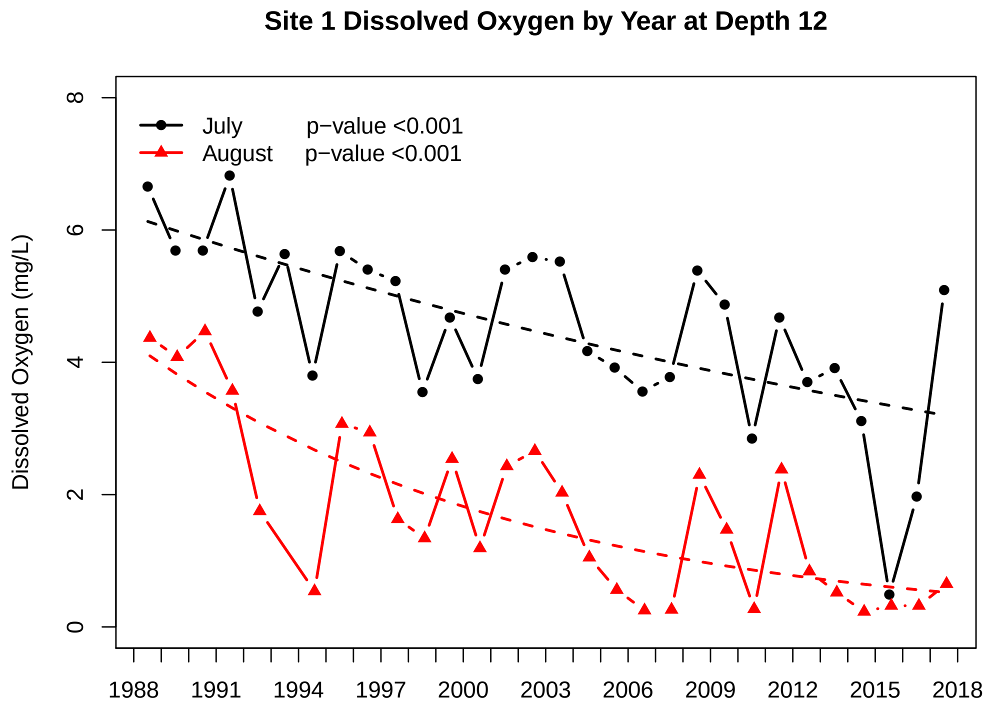


Figure 2.13: Relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

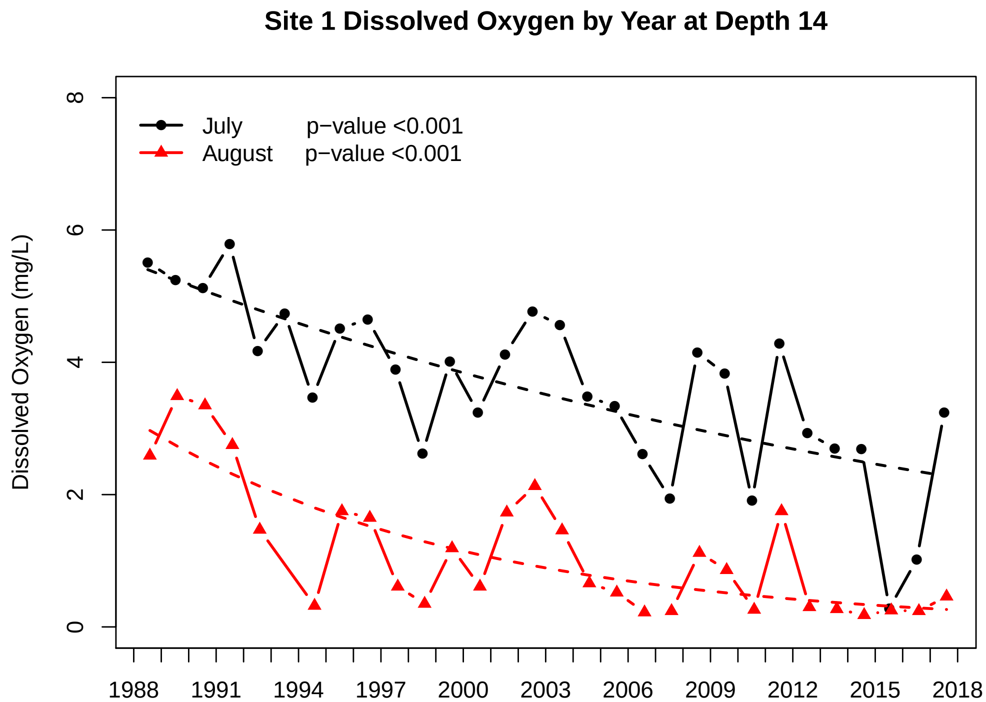


Figure 2.14: Relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

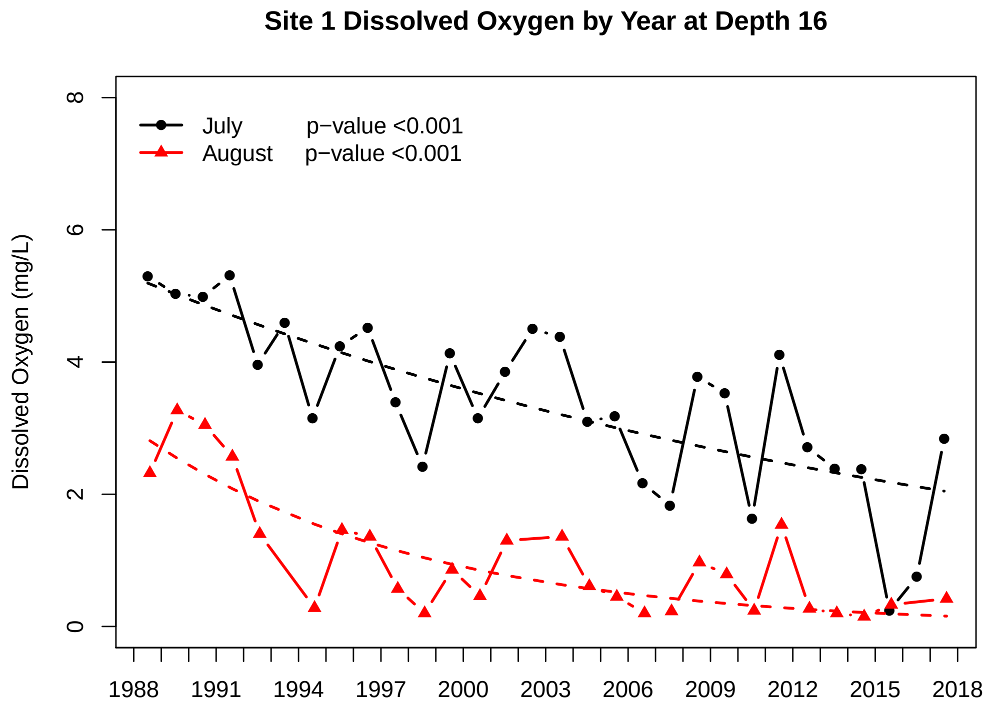


Figure 2.15: Relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

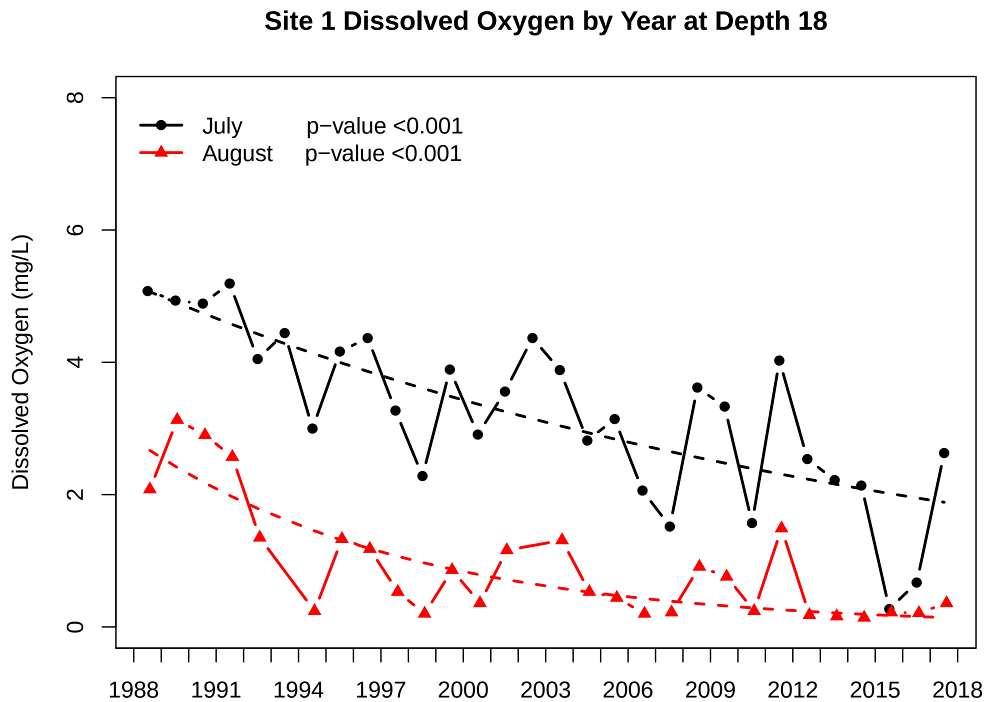


Figure 2.16: Relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

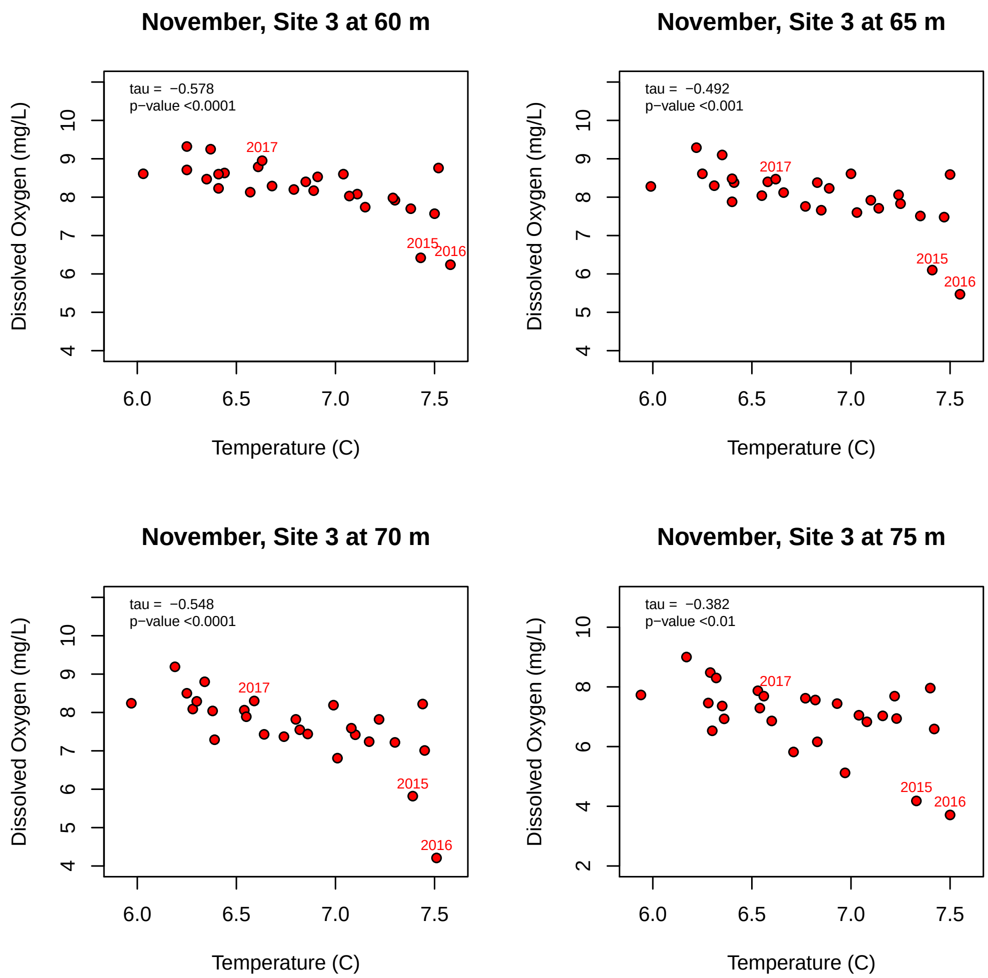


Figure 2.17: Relationship between dissolved oxygen and water temperature at Site 3, 60–75 m. Kendall's τ correlations were used because the data were not monotonic-linear; all of the correlations were significant.

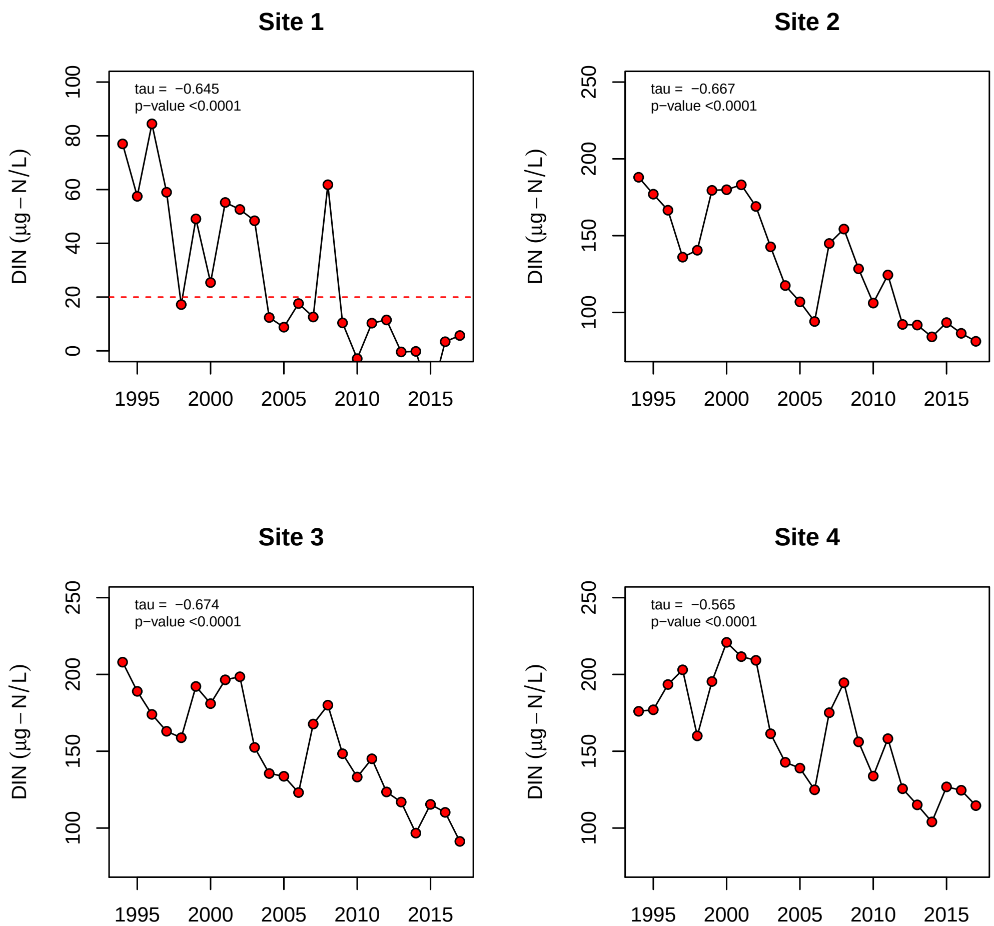


Figure 2.18: Minimum summer, near-surface dissolved inorganic nitrogen (DIN) concentrations (1994–2017 June-Oct, depths ≤5 m). Uncensored (raw) data were used to illustrate that minimum values are dropping below analytical detection limits (dashed red line). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

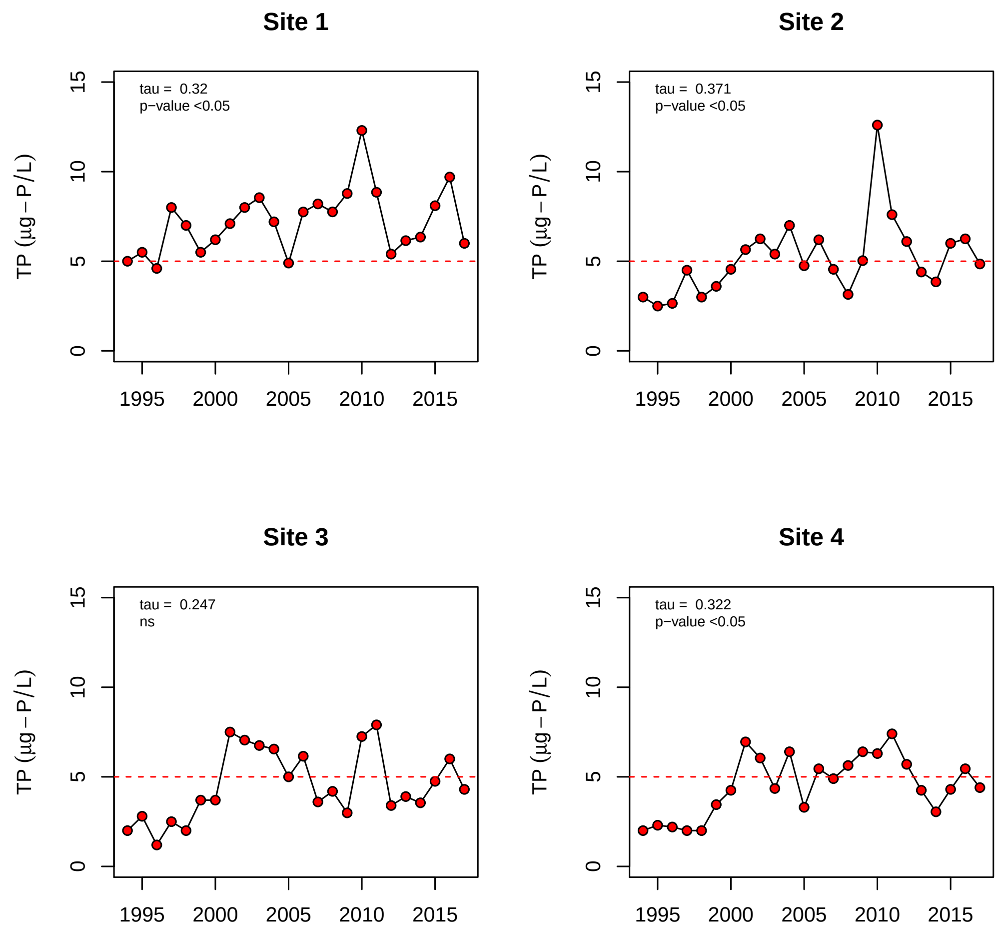


Figure 2.19: Median summer, near-surface total phosphorus concentrations (1994–2017, June-Oct, depths $\leq$5 m). Uncensored (raw) data were used to illustrate that median values are increasingly above analytical detection limits (dashed red line). Kendall's τ correlations were used because the data were not monotonic-linear; the correlations were significant at Sites 1, 2, and 4.

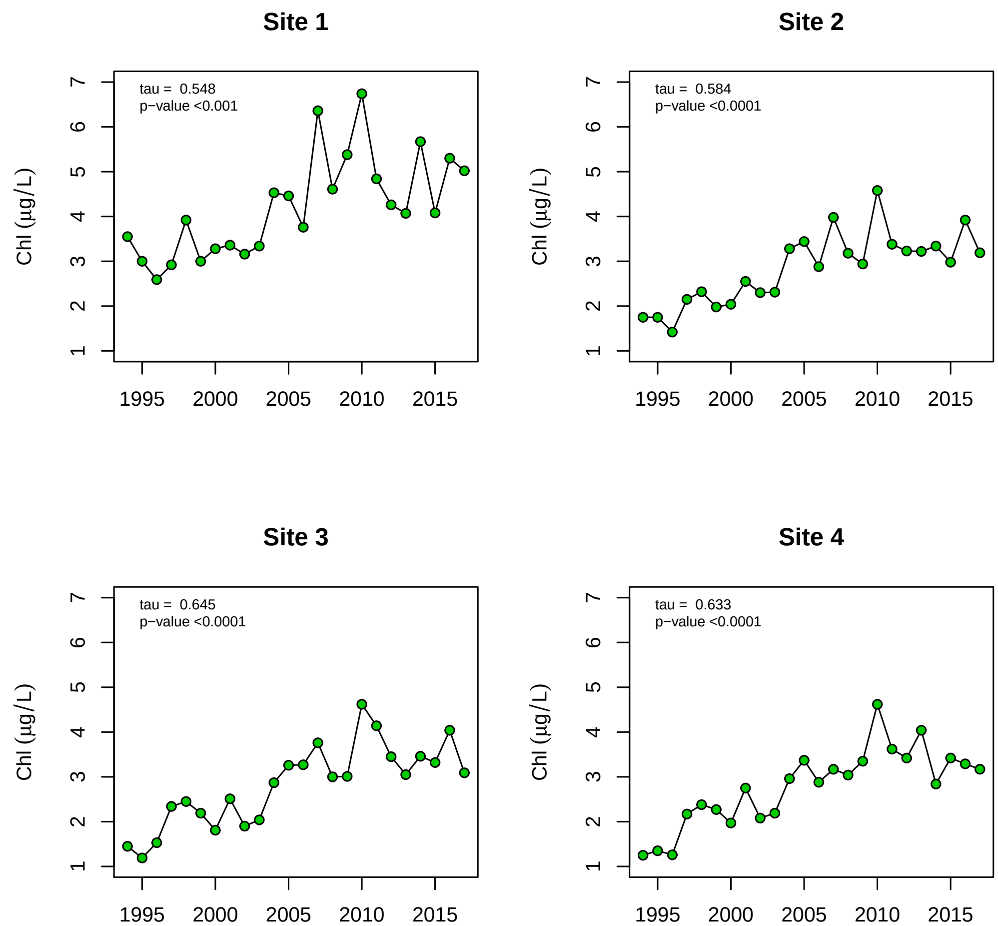


Figure 2.20: Median summer near-surface chlorophyll concentrations (1994–2017, June-October, depths ≤5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

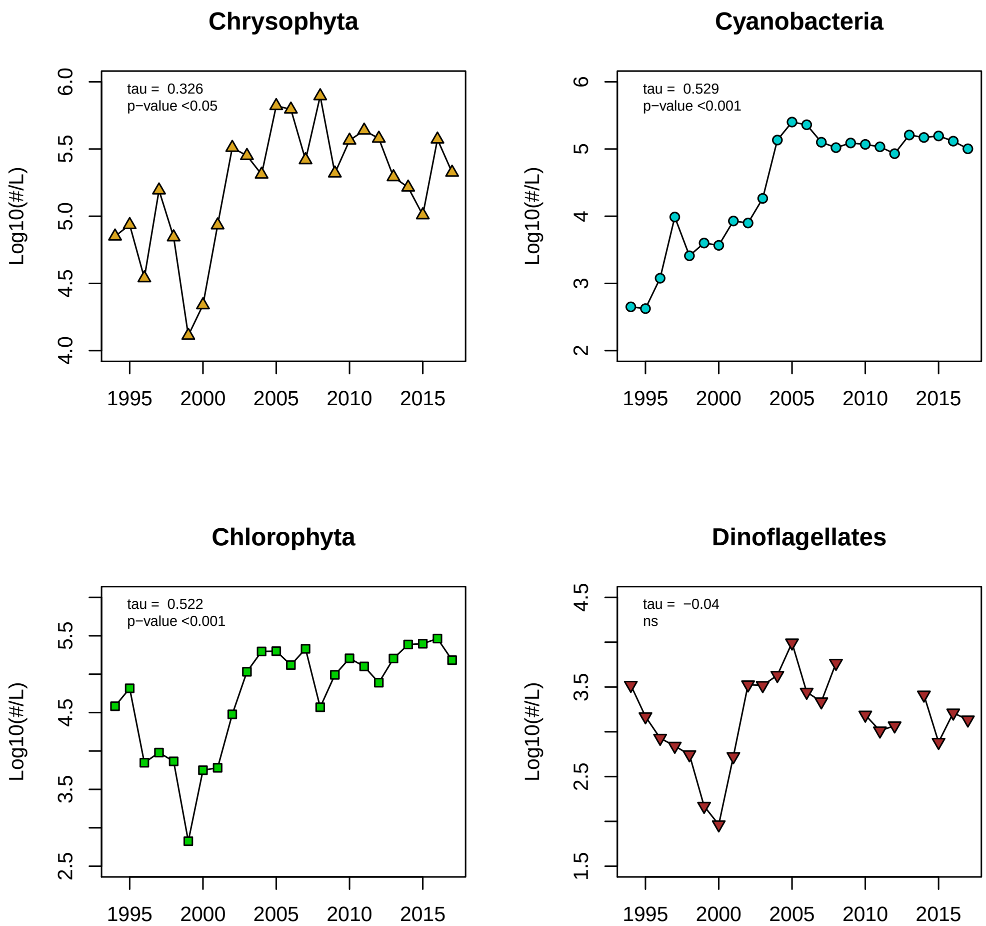


Figure 2.21: Log_{10} plots of median summer, near-surface algae counts (1994-2017, June-October, all sites and depths). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations except Dinoflagellates were significant. Note difference in vertical axis scales.

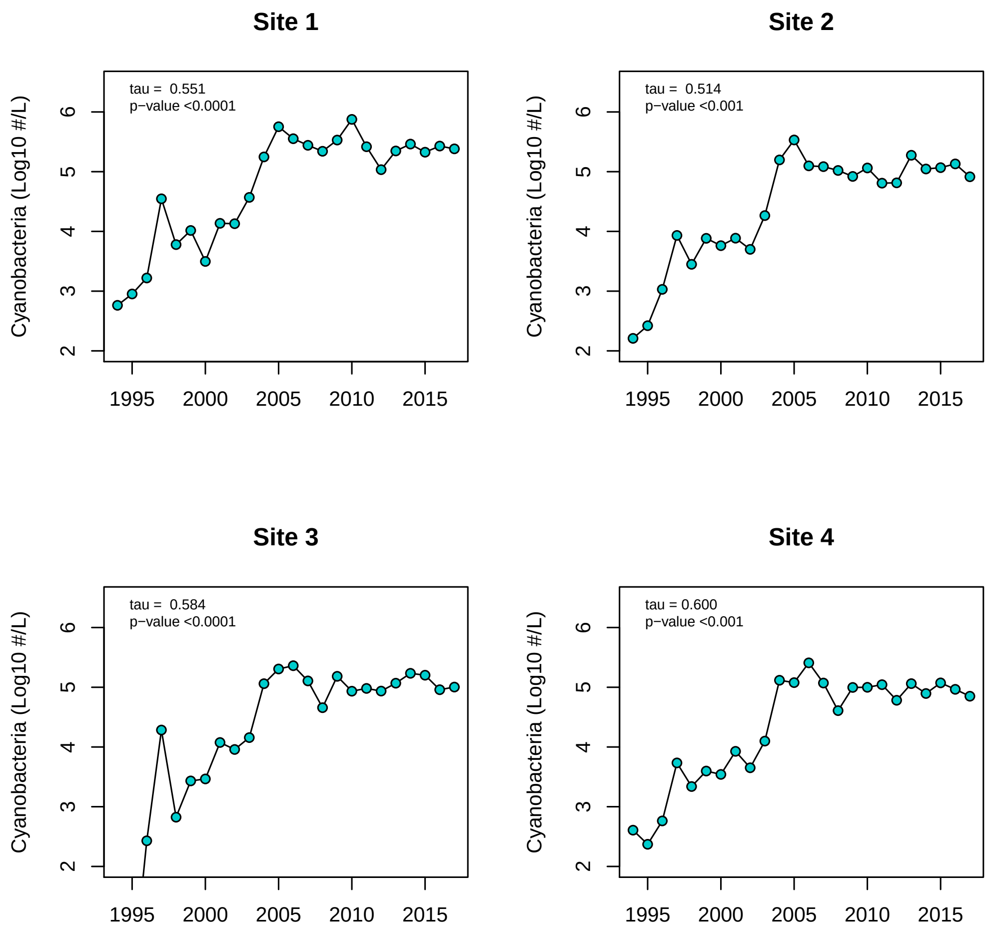


Figure 2.22: Log_{10} plots of median summer, near-surface Cyanobacteria counts (1994–2017, June-October, depths ≤ 5 m). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant.

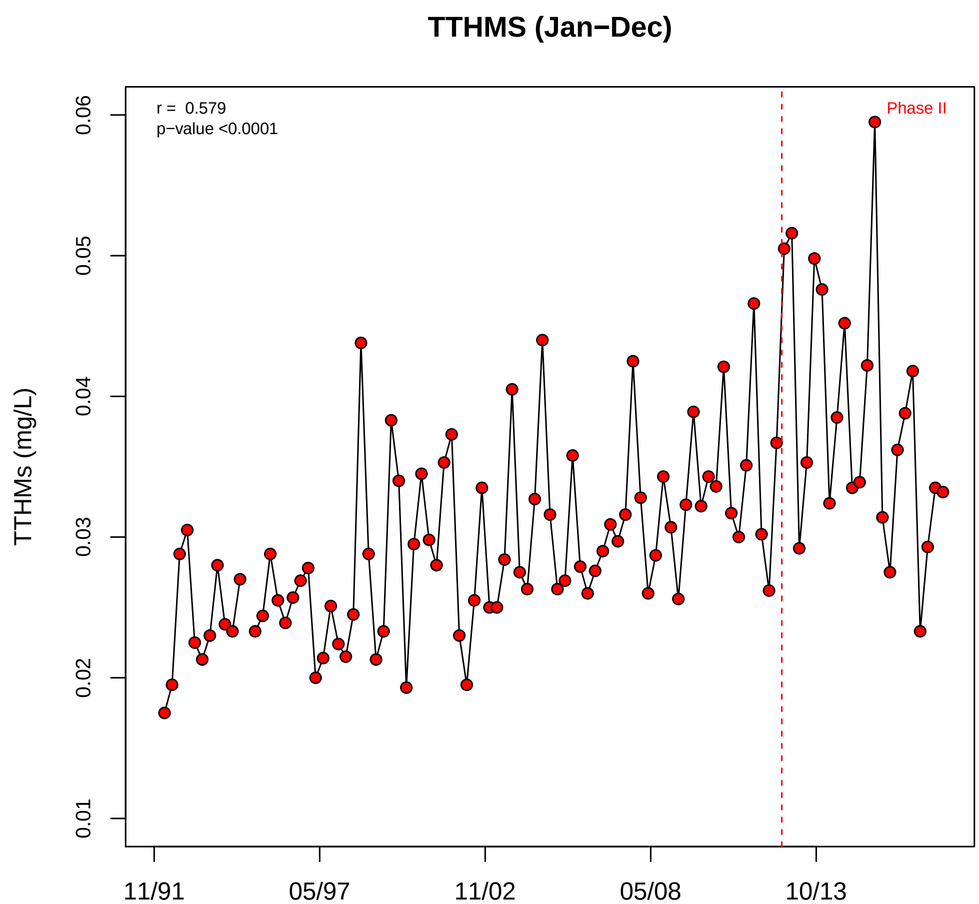


Figure 2.23: Total trihalomethanes (TTHMs) concentrations in the Bellingham water distribution system (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for TTHMs is 0.080 mg/l; all samples were below the level. The number of sites used to calculate 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.

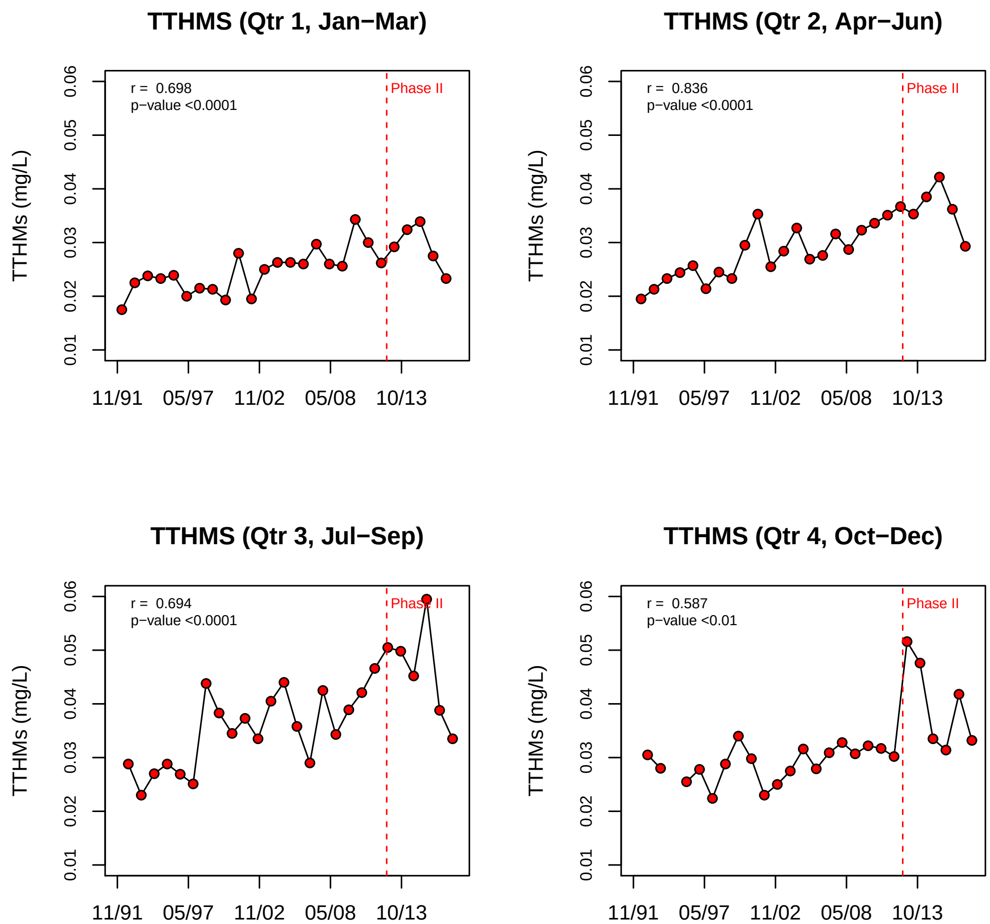


Figure 2.24: Quarterly total trihalomethanes (TTHMs) concentrations in the Bellingham water distribution system (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for TTHMs is 0.080 mg/l; all samples were below the level. The number of sites used 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 were significant.

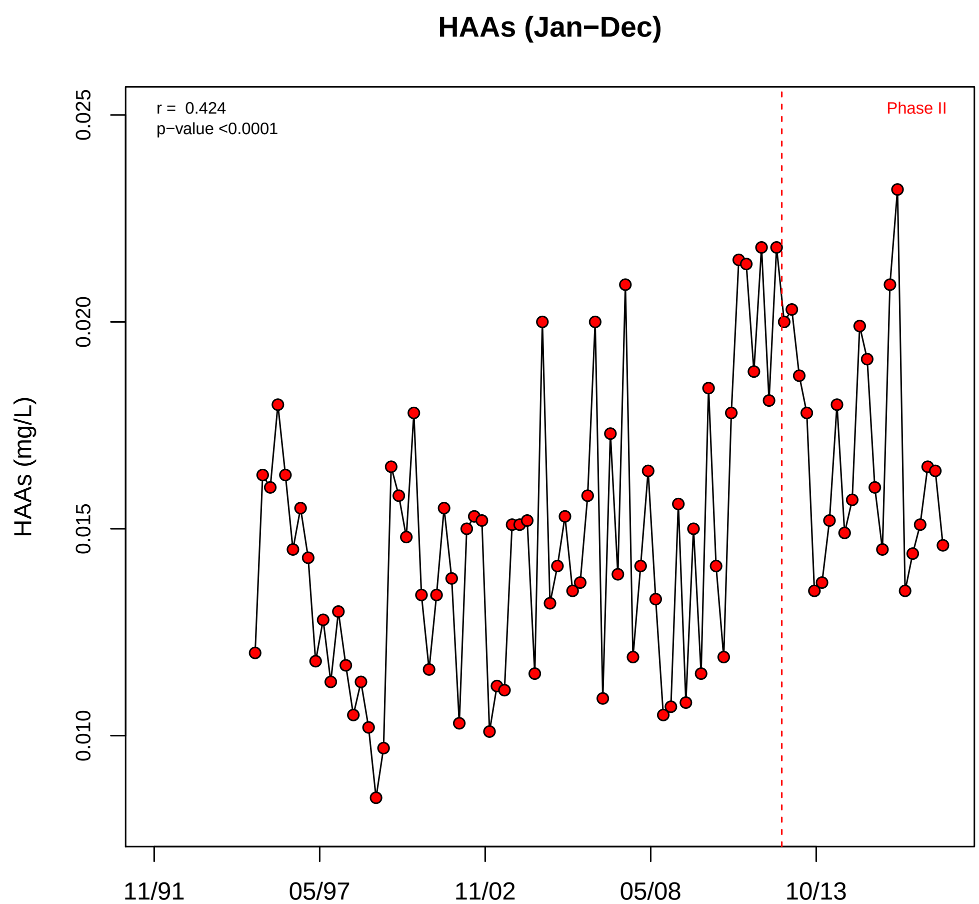


Figure 2.25: Haloacetic acids (HAAs) concentrations in the Bellingham water distribution system (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for HAAs is 0.060 mg/l; all samples were below the level. The number of sites used to calculate 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 significant.

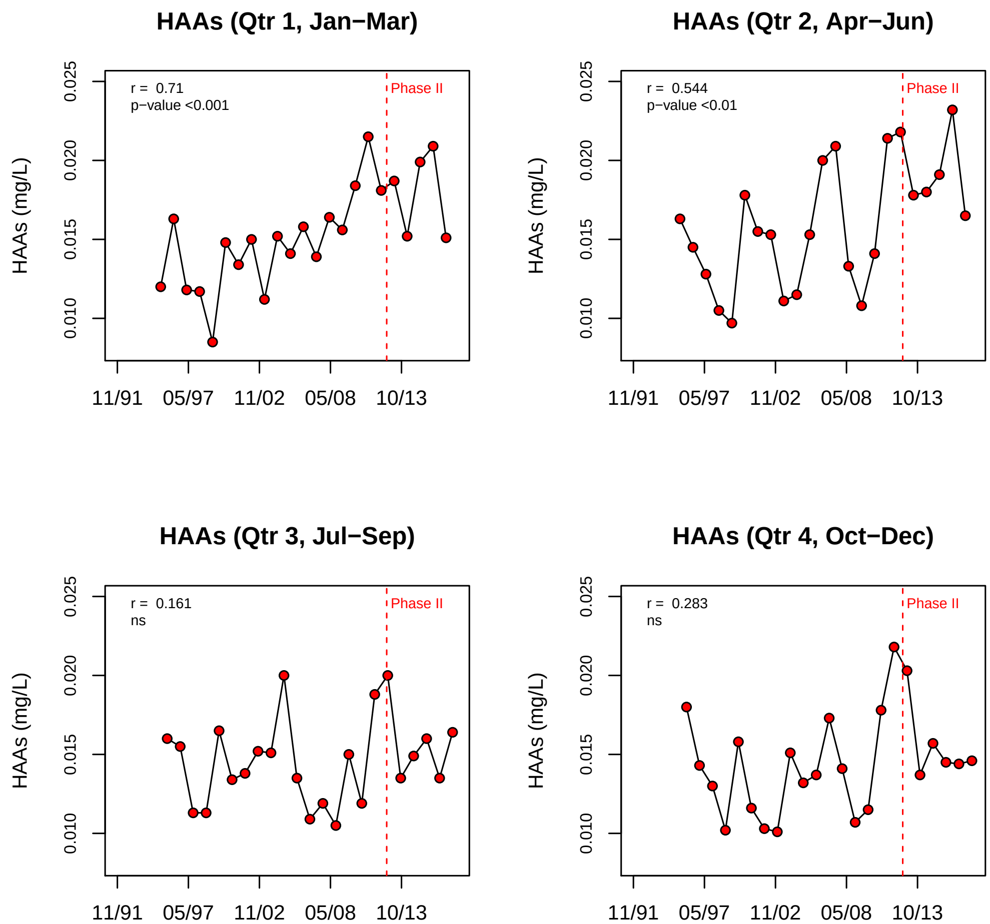


Figure 2.26: Quarterly haloacetic acids (HAAs) concentrations in the Bellingham water distribution system (data provided by the City of Bellingham Public Works Department). The recommended maximum contaminant level for HAAs is 0.060 mg/l; all samples were below the level. The number of sites used to calculate the quarterly averages increased from four to eight in the fourth quarter of 2012 (vertical red line). Kendall's τ correlations were used because the data were not monotonic-linear; the Quarter 1 and Quarter 2 correlations were 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 from 2004–2006, 2010–2012, and in 2014. The level of effort was reduced from 2007–2009, with samples collected twice each year. Monthly sampling was re-initiated in January 2016 and will continue through 2018.

3.1 Site Descriptions

Samples were collected from Anderson, Austin, Blue Canyon, Brannian, Carpenter, Euclid, Mill Wheel, 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 116.

3.2 Field Sampling and Analytical Methods

The tributaries were sampled on October 11, November 8, and December 6, 2016; and January 24, February 14, March 7, April 18, May 16, June 15, July 18, August 8, and September 12, 2017. A YSI ProODO field meter was used to measure temperature and dissolved oxygen in the field. The analytical procedures for sampling the tributaries are summarized in Table 2.1 (page 17). All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory. Once in the laboratory the handling procedures that were relevant for each analysis were followed (see Table 2.1). The bacteria samples were analyzed by the City of Bellingham and total organic carbon analyses were done by AmTest[23] or by IWS. All other analyses were done by WWU.

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

3.3 Results and Discussion

The tributary data include field measurements (dissolved oxygen and temperature); laboratory analyses for ambient water quality parameters (ammonium,[24] nitrate/nitrite,[25] total nitrogen, soluble phosphate, total phosphorus, alkalinity, total suspended solids, and turbidity); bacteria counts; and total organic carbon measurements.

The 2016–2017 tributary data are summarized in Table 3.1 (page 55), with descriptive statistics for each site listed in Tables 3.2–3.13 (pages 56–67). The total organic carbon data are listed in Table 3.14 (page 68). During the summer the stream flow was too low to collect samples at five sites: Blue Canyon and Carpenter Creeks were not sampled in September; Brannian Creek was not sampled in August and September; Euclid and Millwheel Creeks were not sampled in July, August, and September. As a result, the summary statistics for these sites are biased toward water quality conditions present during spring, fall, and winter.

Historic tributary data from 2004 to the present are plotted in Appendix B.4 (Figures B131–B169, pages 254–292). 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 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.

In Table 3.1, 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) 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

[24] Ammonium (NH_4^+) is ionized ammonia (NH_3). Nearly all ammonia is ionized in surface water. Earlier IWS reports used the term ammonia and ammonium interchangeably to describe ammonium concentrations because it is generally understood that ammonia is usually ionized. To improve clarity, IWS has switched to the term "ammonium" to indicate that we are reporting the concentration of ionized ammonia. This does not represent any change in analytical methods.

[25] 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.

maximum 7-day temperature. The turbidity range was based on historic watershed data and WAC 173-201A Table 200 (1)(e), which limits anthropogenic contributions to no more than 5 NTU over background. The coliform range was based on WAC 173-201A Table 200 (2)(b) for extraordinary primary contact recreation. 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 3.1 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 B131–B136). Whatcom Creek had higher temperatures and slightly lower oxygen concentrations than most other sites, reflecting the influence of Lake Whatcom (Figures B131 and B134). The residential tributaries (Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) often had elevated temperatures and lower dissolved oxygen concentrations (Figures B133 and B136), which is typical for streams in developed watersheds.

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by conductivities $\leq$100 μS and alkalinities $\leq$25 mg/L (Table 3.1; Figures B137–B145). Sites that did not match this description included the residential tributaries (Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$5 mg/L) and low turbidities ($\leq$5 NTU) except during periods of high precipitation and runoff (Figures B146–B151). The only site that had consistently high solids and turbidity values was Mill Wheel Creek, which is often turbid due to disturbed sediments in an upstream pond.

Ammonium concentrations were generally low ($\leq$10 μg-N/L) except in the residential streams (Table 3.1; Figures B152–B154). 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 creeks had lower total nitrogen and nitrate concentrations than Smith Creek (Figures B155– B160). 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 B155) 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 near-by source such as an anaerobic wetland or a pollution source. The median 2016–2017 soluble phosphate concentrations were $\leq$10 μg-P/L at all sites except Silver Beach Creek and the Park Place drain (Table 3.1). The historic 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 B161–B166). The median 2016–2017 concentrations were $\leq$20 μg-P/L at all sites except Millwheel and Silver Beach Creeks and the Park Place drain (Table 3.1). As with soluble phosphate, nearly all sites have had occasional high total phosphorus peaks.

High coliform counts are an indicator of residential pollution (Table 3.1; Figures B167–B169). Although most of the sites had relatively low coliform counts during 2016–2017, four sites exceeded a geometric mean of 50 cfu/100 mL (Carpenter, Millwheel, and Silver Beach Creeks and the Park Place drain) and only three sites (Blue Canyon, Brannian, and Smith Creeks) has fewer than 10% of the samples with >100 cfu/100 mL Several of the small residential tributaries could not be sampled during the summer, and coliform counts are often higher during the summer, so these sites may have exceeded the coliform criteria by a greater margin than what is indicated in the summary tables.

The total organic carbon concentrations from February and July 2017 are included in Table 3.14 (page 68). The residential sites (Carpenter, Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain) had slightly elevated ($\geq$3 mg/L) total organic carbon concentrations. The paired samples analyzed by IWS and Amtest were similar except in Carpenter Creek. The variation may have been caused by variation in the density of suspended organic particulates.

	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	yes	yes	yes	yes	yes	yes
D. oxygen†	min. $\geq$8.0 mg/L	yes	yes	no	yes	yes	yes
pH	6.5–8.5	yes	yes	yes	yes	yes	yes
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
F. coliforms	gmean $\leq$50 cfu	yes	yes	yes	yes	yes	yes
	max. 10% >100 cfu	no	no	yes	no	yes	no

	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	no	yes	yes	yes	no	no
D. oxygen†	min. $\geq$8.0 mg/L	yes	yes	yes	no	yes	yes
pH	6.5–8.5	yes	yes	yes	yes	yes	yes
Temperature†	max. $\leq$17.5 C	yes	yes	yes	yes	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	no	no
F. coliforms	gmean $\leq$50 cfu	yes	no	yes	no	no	no
	Max. 10% >100 cfu	yes	no	no	no	no	no

†Many of the residential creeks can't be sampled during part of the summer due to low flow, which is when water temperatures are usually high and dissolved oxygen concentrations low.

Table 3.1: Comparison of October 2016-September 2017 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 52).

Variable	Min.	Med.	Mean[†]	Max.
Alkalinity (mg/L $CaCO_3$)	14.3	16.3	17.2	22.9
Conductivity (μS/cm)	45.8	54.9	56.7	68.0
Dissolved oxygen (mg/L)	9.2	10.6	10.7	12.4
pH	6.5	6.8	6.8	7.0
Temperature (°C)	4.4	9.7	9.3	14.3
Total suspended solids (mg/L)	<2	<2	2.5	6.5
Turbidity (NTU)	0.4	1.5	1.6	3.5
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	22.9
Nitrogen, nitrate/nitrite (μg-N/L)	269.4	614.4	642.4	1000.4
Nitrogen, total (μg-N/L)	572.0	832.3	824.0	1152.6
Phosphorus, soluble (μg-P/L)	<5	7.2	7.8	14.0
Phosphorus, total (μg-P/L)	8.1	16.3	17.3	31.2
Coliforms, fecal (cfu/100 mL)[‡]	3	33	34	600
(Percent of samples >100 cfu/100 mL = 42)				

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

Table 3.2: Summary of Anderson Creek water quality data, October 2016-September 2017.

Variable	Min.	Med.	Mean[†]	Max.
Alkalinity (mg/L $CaCO_3$)	8.9	15.1	21.2	43.9
Conductivity (μS/cm)	52.4	54.8	80.1	163.5
Dissolved oxygen (mg/L)	9.3	11.6	11.5	12.9
pH	7.0	7.2	7.3	7.7
Temperature (°C)	4.4	8.3	9.2	16.4
Total suspended solids (mg/L)	$<$2	2.6	3.9	12.8
Turbidity (NTU)	0.4	2.3	2.4	6.4
Nitrogen, ammonium (μg-N/L)	$<$10	$<$10	$<$10	15.5
Nitrogen, nitrate/nitrite (μg-N/L)	194.3	614.8	671.4	1351.5
Nitrogen, total (μg-N/L)	295.0	833.1	784.5	1541.5
Phosphorus, soluble (μg-P/L)	$<$5	5.5	5.9	9.5
Phosphorus, total (μg-P/L)	7.0	11.8	13.7	25.8
Coliforms, fecal (cfu/100 mL)[‡]	2	22	25	330
(Percent of samples $>$100 cfu/100 mL = 17)				

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

Table 3.3: Summary of Austin Creek water quality data, October 2016-September 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	103.0	129.6	138.6	182.5
Conductivity (μS/cm)	265.7	303.0	305.1	347.0
Dissolved oxygen (mg/L)	9.5	11.6	11.4	12.8
pH	8.1	8.2	8.2	8.4
Temperature (°C)	4.8	9.1	9.3	15.9
Total suspended solids (mg/L)	<2	3.4	3.7	7.4
Turbidity (NTU)	0.7	2.5	2.4	4.3
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	128.2	528.0	635.5	1379.7
Nitrogen, total (μg-N/L)	217.6	621.1	766.7	1803.8
Phosphorus, soluble (μg-P/L)	<5	4.6	5.8	12.8
Phosphorus, total (μg-P/L)	6.1	11.0	11.1	17.8
Coliforms, fecal (cfu/100 mL)‡	<1	2	3	30
(Percent of samples >100 cfu/100 mL = 0)				

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

Table 3.4: Summary of Blue Canyon Creek water quality data, October 2016-September 2017. This site was not sampled in September 2017 due to low flow.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	6.5	137.7	10.0	20.7
Conductivity (μS/cm)	29.1	39.4	41.5	63.8
Dissolved oxygen (mg/L)	7.5	11.4	11.0	12.8
pH	6.5	6.7	6.7	7.0
Temperature (°C)	4.0	8.2	8.1	13.7
Total suspended solids (mg/L)	<2	<2	3.4	21.0
Turbidity (NTU)	0.4	1.4	1.8	8.1
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	27.7
Nitrogen, nitrate/nitrite (μg-N/L)	205.9	1008.8	964.1	1723.2
Nitrogen, total (μg-N/L)	296.2	1200.4	1100.3	2062.4
Phosphorus, soluble (μg-P/L)	<5	<5	<5	<5
Phosphorus, total (μg-P/L)	<5	7.7	9.5	31.7
Coliforms, fecal (cfu/100 mL)‡	<1	4	8	130
(Percent of samples >100 cfu/100 mL = 10)				

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

Table 3.5: Summary of Brannian Creek water quality data, October 2016-September 2017. This site was not sampled in August and September 2017 due to low flow.

Variable	Min.	Med.	Mean[†]	Max.
Alkalinity (mg/L $CaCO_3$)	14.0	17.2	23.7	48.0
Conductivity (μS/cm)	58.5	62.9	77.9	116.6
Dissolved oxygen (mg/L)	9.0	11.6	11.6	13.1
pH	7.0	7.3	7.4	7.8
Temperature (°C)	3.8	8.0	8.5	16.5
Total suspended solids (mg/L)	<2	<2	2.9	9.6
Turbidity (NTU)	0.6	3.0	2.9	7.2
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	151.1	1394.4	1125.6	1983.9
Nitrogen, total (μg-N/L)	313.5	1745.1	1341.3	2101.5
Phosphorus, soluble (μg-P/L)	<5	5.4	6.3	10.9
Phosphorus, total (μg-P/L)	10.4	13.3	14.9	30.3
Coliforms, fecal (cfu/100 mL)[‡]	16	100	123	3400
(Percent of samples >100 cfu/1l0 mL = 45)				

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

Table 3.6: Summary of Carpenter Creek water quality data, October 2016-September 2017. This site was not sampled in September 2017 due to low flow.

Variable	Min.	Med.	Mean[†]	Max.
Alkalinity (mg/L $CaCO_3$)	18.5	21.8	23.0	32.0
Conductivity (μS/cm)	74.8	83.7	93.4	141.6
Dissolved oxygen (mg/L)	9.2	11.1	11.0	12.4
pH	6.8	7.1	7.1	7.5
Temperature (°C)	5.1	9.3	8.4	12.4
Total suspended solids (mg/L)	<2	2.4	3.4	8.2
Turbidity (NTU)	0.5	2.8	3.4	7.0
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	148.9	698.6	609.3	1048.7
Nitrogen, total (μg-N/L)	343.3	841.8	759.9	1189.5
Phosphorus, soluble (μg-P/L)	<5	6.3	6.4	8.9
Phosphorus, total (μg-P/L)	7.1	13.2	16.6	30.6
Coliforms, fecal (cfu/100 mL)[‡]	2	20	17	560
(Percent of samples >100 cfu/100 mL = 11)				

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

Table 3.7: Summary of Euclid Creek water quality data, October 2016-September 2017. This site was not sampled in July, August, and September 2017 due to low flow.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	18.3	19.7	24.5	41.5
Conductivity (μS/cm)	72.2	74.8	88.0	131.9
Dissolved oxygen (mg/L)	6.8	11.2	10.7	12.6
pH	6.9	7.0	7.1	7.3
Temperature (°C)	4.5	10.3	9.5	16.9
Total suspended solids (mg/L)	4.1	7.0	10.1	21.0
Turbidity (NTU)	6.4	8.3	9.3	16.0
Nitrogen, ammonium (μg-N/L)	<10	17.9	14.5	32.0
Nitrogen, nitrate/nitrite (μg-N/L)	<100	1003.0	859.3	1443.7
Nitrogen, total (μg-N/L)	698.8	1352.0	1266.1	1793.2
Phosphorus, soluble (μg-P/L)	5.3	7.5	8.5	15.9
Phosphorus, total (μg-P/L)	23.2	35.5	56.9	144.6
Coliforms, fecal (cfu/100 mL)‡	28	160	191	4700
(Percent of samples >100 cfu/100 mL = 56)				

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

Table 3.8: Summary of Millwheel Creek water quality data, October 2016-September 2017. This site was not sampled in July, August, and September 2017 due to low flow.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	12.0	16.2	24.9	55.3
Conductivity (μS/cm)	47.4	53.3	75.6	138.1
Dissolved oxygen (mg/L)	9.6	11.8	11.7	13.3
pH	6.9	7.3	7.4	7.8
Temperature (°C)	3.3	7.5	8.7	16.4
Total suspended solids (mg/L)	<2	3.0	7.0	30.8
Turbidity (NTU)	0.3	2.4	2.7	7.2
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	15.5
Nitrogen, nitrate/nitrite (μg-N/L)	358.1	911.2	932.6	1596.1
Nitrogen, total (μg-N/L)	420.3	1103.0	1064.7	1806.4
Phosphorus, soluble (μg-P/L)	<5	5.5	6.2	10.6
Phosphorus, total (μg-P/L)	7.5	11.2	13.6	30.6
Coliforms, fecal (cfu/100 mL)‡	<1	35	29	560
(Percent of samples >100 cfu/100 mL = 33)				

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

Table 3.9: Summary of Olsen Creek water quality data, October 2016-September 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	55.4	64.2	70.8	127.2
Conductivity (μS/cm)	151.1	189.4	202.6	277.7
Dissolved oxygen (mg/L)	8.2	10.8	10.6	12.3
pH	7.2	7.3	7.4	7.9
Temperature (°C)	5.2	10.8	10.4	18.5
Total suspended solids (mg/L)	<2	<2	<2	3.9
Turbidity (NTU)	1.4	2.6	2.7	3.9
Nitrogen, ammonium (μg-N/L)	<10	12.1	14.2	30.1
Nitrogen, nitrate/nitrite (μg-N/L)	135.9	736.9	724.9	1472.8
Nitrogen, total (μg-N/L)	357.3	952.6	940.3	1740.5
Phosphorus, soluble (μg-P/L)	10.3	13.8	18.1	43.1
Phosphorus, total (μg-P/L)	18.9	26.5	29.3	45.8
Coliforms, fecal (cfu/100 mL)‡	4	88	80	19000
(Percent of samples >100 cfu/100 mL = 40)				

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

Table 3.10: Summary of Park Place outlet water quality data, October 2016-September 2017. This site was not sampled in August and September 2017 due to low flow.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	25.6	57.9	65.3	119.8
Conductivity (μS/cm)	119.1	140.7	184.0	288.4
Dissolved oxygen (mg/L)	9.3	11.1	11.2	12.9
pH	7.4	7.7	7.8	8.1
Temperature (°C)	4.2	9.7	9.8	16.6
Total suspended solids (mg/L)	<2	2.3	2.8	8.1
Turbidity (NTU)	1.3	3.4	3.4	6.8
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	12.9
Nitrogen, nitrate/nitrite (μg-N/L)	182.9	441.1	757.0	1627.5
Nitrogen, total (μg-N/L)	475.9	678.1	1017.0	1952.3
Phosphorus, soluble (μg-P/L)	7.8	12.8	14.9	24.3
Phosphorus, total (μg-P/L)	20.1	25.8	27.1	39.5
Coliforms, fecal (cfu/100 mL)‡	36	216	189	1300
(Percent of samples $>$100 cfu/100 mL = 50)				

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

Table 3.11: Summary of Silver Beach Creek water quality data, October 2016-September 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	11.7	14.5	19.8	39.3
Conductivity (μS/cm)	43.1	53.5	64.7	111.0
Dissolved oxygen (mg/L)	9.7	12.1	11.8	13.5
pH	7.0	7.3	7.3	7.7
Temperature (°C)	3.5	7.8	8.8	15.9
Total suspended solids (mg/L)	<2	2.5	4.6	16.9
Turbidity (NTU)	0.3	1.6	1.6	3.7
Nitrogen, ammonium (μg-N/L)	<10	<10	<10	<10
Nitrogen, nitrate/nitrite (μg-N/L)	198.6	1086.8	1052.9	2040.6
Nitrogen, total (μg-N/L)	306.3	1248.2	1154.6	2134.6
Phosphorus, soluble (μg-P/L)	<5	<5	<5	7.1
Phosphorus, total (μg-P/L)	6.7	8.4	9.6	18.9
Coliforms, fecal (cfu/100 mL)‡	<1	6	8	310
(Percent of samples >100 cfu/100 mL = 8)				

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

Table 3.12: Summary of Smith Creek water quality data, October 2016-September 2017.

Variable	Min.	Med.	Mean†	Max.
Alkalinity (mg/L $CaCO_3$)	18.6	20.8	20.2	21.6
Conductivity (μS/cm)	58.3	60.0	60.0	62.6
Dissolved oxygen (mg/L)	9.2	10.7	10.7	12.4
pH	7.2	7.4	7.5	8.3
Temperature (°C)	4.6	13.1	13.5	24.0
Total suspended solids (mg/L)	<2	<2	2.3	6.4
Turbidity (NTU)	0.7	1.0	1.1	1.8
Nitrogen, ammonium (μg-N/L)	<10	<10	10.9	36.4
Nitrogen, nitrate/nitrite (μg-N/L)	<100	204.9	186.9	347.9
Nitrogen, total (μg-N/L)	203.5	361.1	371.7	530.7
Phosphorus, soluble (μg-P/L)	<5	<5	<5	<5
Phosphorus, total (μg-P/L)	6.2	8.9	9.2	13.5
Coliforms, fecal (cfu/100 mL)‡	<1	5	10	980
(Percent of samples >100 cfu/100 mL = 17)				

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

Table 3.13: Summary of Whatcom Creek water quality data, October 2016-September 2017.

Site	Date	TOC-AM (mg/L)	Date	TOC-AM (mg/L)	TOC-IWS (mg/L)
Anderson	February 14, 2017	2.0	July 18, 2017	1.8	1.6
Austin (lower)	February 14, 2017	2.0	July 18, 2017	1.9	1.6
Blue Canyon	February 14, 2017	2.8	July 18, 2017	2.2	1.5
Brannian	February 14, 2017	1.5	July 18, 2017	1.6	1.4
Carpenter	February 14, 2017	3.8	July 18, 2017	7.0	2.6
Euclid	February 14, 2017	3.0	July 18, 2017	(dry)	(dry)
Millwheel	February 14, 2017	3.5	July 18, 2017	(dry)	(dry)
Olsen	February 14, 2017	2.8	July 18, 2017	2.3	NA
Park Place	February 14, 2017	3.9	July 18, 2017	4.5	4.1
Silver Beach	February 14, 2017	4.6	July 18, 2017	5.2	4.7
Smith	February 14, 2017	2.3	July 18, 2017	2.1	1.9
Whatcom	February 14, 2017	2.1	July 18, 2017	2.6	2.6

Table 3.14: Lake Whatcom 2017 tributary total organic carbon data. February samples were analyzed by AmTest; August samples were split and analyzed by Amtest (TOC-AM) and IWS (TOC-IWS).

4 Storm Water Monitoring

4.1 Hydrograph Monitoring

Recording hydrographs are installed in Austin Creek and Smith Creek; the data are plotted in Figures 4.1–4.2 (pages 75–76). The location of each hydrograph is described in Appendix A.2 (page 111). All hydrograph data, including data from previous years, are online at www.wwu.edu/iws. Field notes and rating curves for each water year are available from the Institute for Watershed Studies. The rating curves were generated using Aquarius rating curve software (Aquatic Informatics, 2014). The field discharge and stage height measurements are plotted in Figures 4.3–4.4 (pages 77–78) and the Aquarius rating curve equations are listed in Tables 4.1–4.2 (pages 72–73). All results are reported as Pacific Standard Time, without Daylight Saving Time adjustment.

Between March 4 and June 22 the Smith Creek hydrograph sporadically stopped logging data (Figure 4.2). The equipment was repaired repeatedly, which did not resolve the issue, so the data logger was replaced on September 6, 2017.

4.2 Site Descriptions

The current storm water sampling has focused on Austin, Olsen, and Silver Beach Creeks (Figure A3, page 117). Olsen Creek is a relatively new storm water sampling sites (sampling started in 2016); earlier storm water sampling in Austin and Silver Beach Creeks was summarized in previous annual reports (see Section 5.2, page 107).

4.3 Field Sampling and Analytical Methods

Two storm events were sampled in Austin Creek, three events were sampled in Olsen Creek, and eight events were sampled in Silver Beach Creek (Table 4.3, page 74; Figures 4.5–4.29, pages 79–103). The storm event data in this report includes events from November 2016 through November 2017; the 2016 events were also described in the 2016/2017 annual report (Matthews et al., 2017).

The samples were collected using time-paced ISCO automated samplers provided by the City of Bellingham and were analyzed for total suspended solids, total phosphorus, soluble reactive phosphorus, total nitrogen, and nitrate/nitrite[26] as described in Table 2.1 (page 17).

4.4 Results and Discussion

4.4.1 Precipitation

The unusually dry spring and summer of 2017 resulted in extremely low water levels in many of the streams in the Lake Whatcom watershed, making it difficult to collect storm water samples. According to the Bellingham 3 SSW weather station (WRCC, 2017) located at the Post Point Waste-Water Treatment Plant in Fairhaven, July was the driest summer in the past 30 years. The July, August, and September total rainfall in 2017 was tied with 2002 as the lowest three-month total in the last 30 years (1.83 inches compared to the 30-year average of 4.0 inches). Dry summers have a direct impact on stream flow (base flow) in the Lake Whatcom watershed, which is supported by soil water and groundwater. As illustrated in the hydrographs (Figures 4.1–4.2, pages 75–76), stream discharge decreases over the course of the summer as soils dry out and groundwater levels decline due to high levels of evapotranspiration from vegetation and low rainfall. Moreover, most late summer rainfall goes into replenishing soil water (storage) rather than into direct runoff to streams. Lower summer stream flows and groundwater levels also reduce runoff into the lake. When coupled with higher summer lake withdrawals and lake evaporation, the lake level will drop over the course of the summer, reaching a minimum in late fall. The average September 30 lake level during the past 30 years is 312.28 ft relative to City of Bellingham vertical datum. On September 30, 2017, the lake level was 311.34 ft, which is the third lowest level in 30 years.[27]

[26]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.

[27]The lowest lake level, 310.88 ft, occurred in 1998. The summer of 1998 was nearly as dry as 2017, but lake withdrawals were over two-times higher due to Georgia Pacific operations. The 2017 lake level (311.34 feet) is the lowest since Georgia Pacific started scaling back their withdrawals in 2001.

4.4.2 Water quality

Total suspended solids and total phosphorus usually increased with stage height,[28] with maximum concentrations occurring near the hydrograph peaks (Figures 4.5–4.14, pages 79–88). This relationship was evident at most sites, but was clearly demonstrated in Austin Creek Event 15, where the total suspended solids and total phosphorus concentrations peaked twice in response to separate rising portions of the hydrograph (Figures 4.5 and 4.10). Some of the events contained outliers (e.g., Figure 4.6); outliers such as these are common during storm events, and can be caused by bank erosion or other types of upstream disturbance.

Nitrate and soluble phosphate are soluble compounds that can be leached from soils and transported in storm runoff. If the leached compounds have built up for a period of time, the concentrations in the runoff increase, following the hydrograph curve (e.g., Silver Beach Creek Event 30; Figure 4.17). But the leaching process is not instantaneous, so the concentrations in runoff may show no increase in response to precipitation, or may decrease due to dilution by precipitation.

Total nitrogen consists of both organic and inorganic compounds (see Section 2.3.5, page 10), but in streams, it is usually mostly in the form of nitrate unless there is a nearby source of organic nitrogen or ammonium (e.g., sewage contamination, anaerobic soils, upstream swamps or bogs). As with nitrate, the total nitrogen concentrations in storm runoff may follow the hydrograph curve (e.g., Austin Creek Event 15; Figure 4.20) or respond like a soluble compound and be diluted or constant during the storm event (e.g., Silver Beach Creek Event 37; Figure 4.24).

[28]Stage height is used rather than estimated stream flow because stage height is measured directly by the ISCO sampler so it is a more accurate indicator of the rise and fall of the water level during sample collection.

Stage Height (ft)	Discharge Equations
0.16–0.24	discharge = 5.714 $\times$ stage$^{1.918}$
0.24–0.35	discharge = 10.676 $\times$ stage$^{2.356}$
0.35–0.48	discharge = 13.663 $\times$ stage$^{2.591}$
0.48–0.68	discharge = 13.663 $\times$ stage$^{2.591}$
0.68–0.95	discharge = 13.699 $\times$ stage$^{2.598}$
0.95–1.33	discharge = 13.700 $\times$ stage$^{2.598}$
1.33–1.86	discharge = 13.704 $\times$ stage$^{2.597}$
1.86–2.60	discharge = 13.705 $\times$ stage$^{2.597}$
2.60–4.75	discharge = 20.768 $\times$ stage$^{2.162}$

Table 4.1: Austin Creek rating curves for WY2017 (October 1, 2016-September 30, 2017); equations generated by Aquarius software (Aquatic Informatics, 2014).

Stage Height (ft)	Discharge Equations
1.42–1.59	discharge = 0.002 $\times$ stage$^{11.883}$
1.59–1.82	discharge = 0.009 $\times$ stage$^{8.549}$
1.82–2.10	discharge = 0.012 $\times$ stage$^{8.065}$
2.10–2.44	discharge = 0.011 $\times$ stage$^{8.112}$
2.44–3.07	discharge = 0.226 $\times$ stage$^{4.752}$
3.07–4.03	discharge = 0.467 $\times$ stage$^{4.103}$
4.03–5.00	discharge = 0.562 $\times$ stage$^{3.970}$

Table 4.2: Smith Creek rating curves for WY2017 (October 1, 2016-September 30, 2017); equations generated by Aquarius software (Aquatic Informatics, 2014).

	Event Duration	Event Precip
Austin Creek		
Event 14	04:30 Nov 15 to 01:30 Nov 16, 2017	0.61 in (1.54 cm)§
Event 15	11:30 Nov 30 to 10:00 Dec 2, 2017	1.11 in (2.82 cm)§
Olsen Creek		
Event 1	08:45 Nov 2 to 11:45 Nov 3, 2016	0.85 in (2.16 cm)†
Event 2	07:00 Nov 24 to 13:00 Nov 26, 2016	1.86 in (4.72 cm)†
Event 3	02:30 Feb 15 to 11:30 Feb 16, 2017	0.57 in (1.45 cm)†
Silver Beach Creek		
Event 30	02:00 Oct 13 to 08:00 Oct 14, 2016	1.61 in (4.09 cm)‡
Event 31	17:30 Nov 2 to 11:30 Nov 3, 2016	0.66 in (1.68 cm)‡
Event 32	06:30 Nov 24 to 12:30 Nov 25, 2016	0.78 in (1.98 cm)‡
Event 33	02:30 Feb 15 to 05:30 Feb 16, 2017	0.46 in (1.17 cm)‡
Event 34	11:00 Nov 2 to 03:30 Nov 3, 2017	0.60 in (1.52 cm)‡
Event 35	03:00 Nov 15 to 00:00 Nov 16, 2017	0.81 in (2.06 cm)‡
Event 36	07:30 Nov 21 to 10:30 Nov 22, 2017	0.40 in (1.02 cm)‡
Event 37	11:30 Nov 30 to 10:00 Dec 2, 2017	0.93 in (2.36 cm)‡

†Northshore rain gage; ‡Bloedel-Donovan rain gage; §Geneva.

Table 4.3: Summary of storm events for Austin, Olsen, and Silver Beach Creeks and event precipitation totals. Precipitation data were provided by the City of Bellingham. Austin Creek Events 1–13 and Silver Beach Creek Events 1–24 were discussed in earlier reports (Section 5.2, page 107).

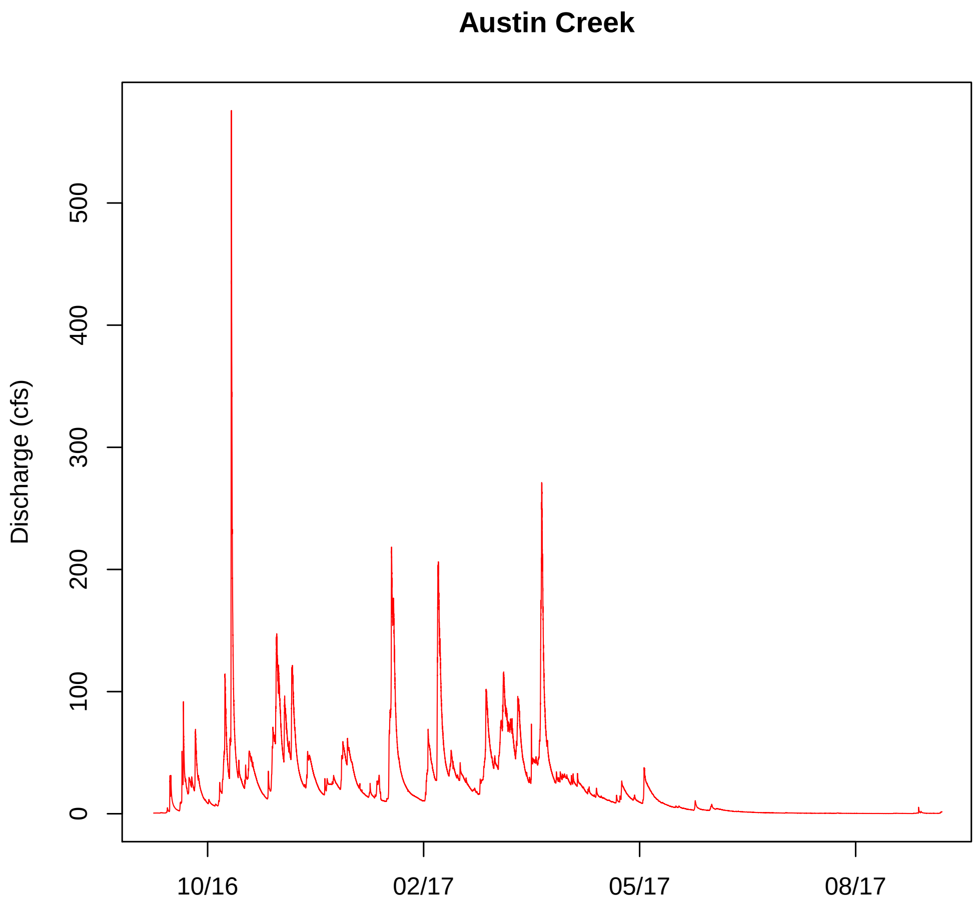


Figure 4.1: Austin Creek hydrograph for WY2017 (October 1, 2016–September 30, 2017). Data were recorded at 15 minute intervals. The data gaps were caused by equipment damage from storms.

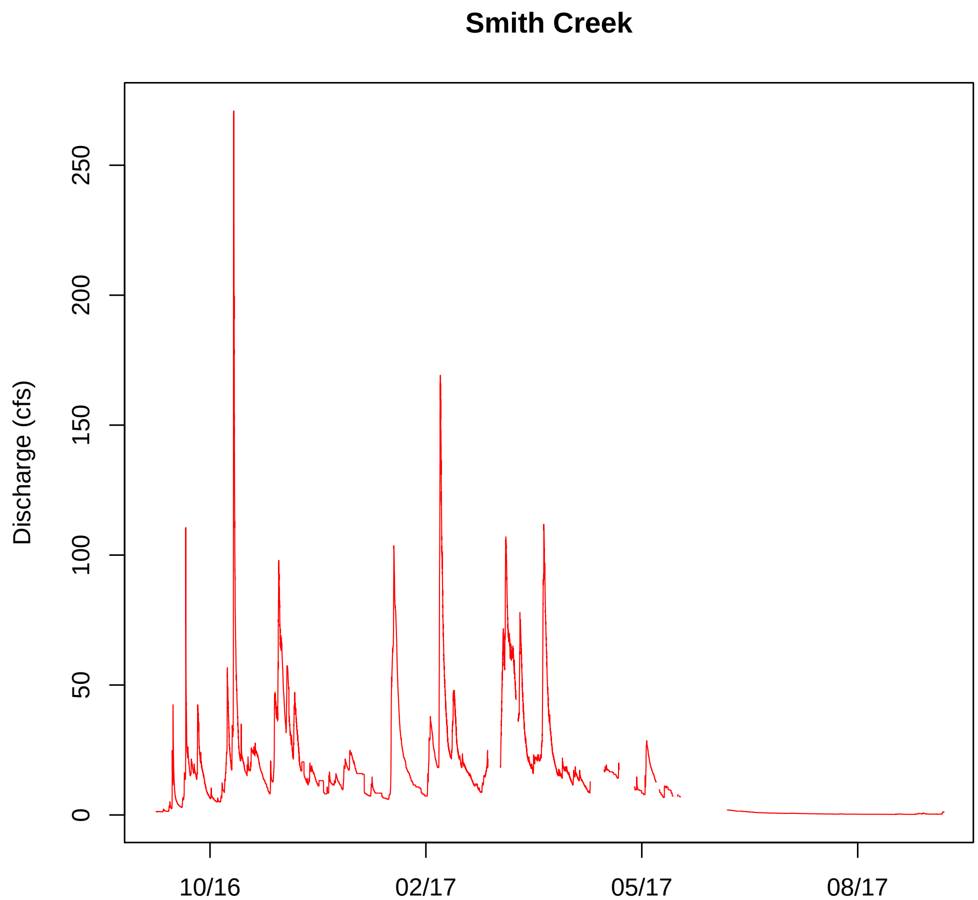


Figure 4.2: Smith Creek hydrograph for WY2017 (October 1, 2016–September 30, 2017). Data were recorded at 15 minute intervals.

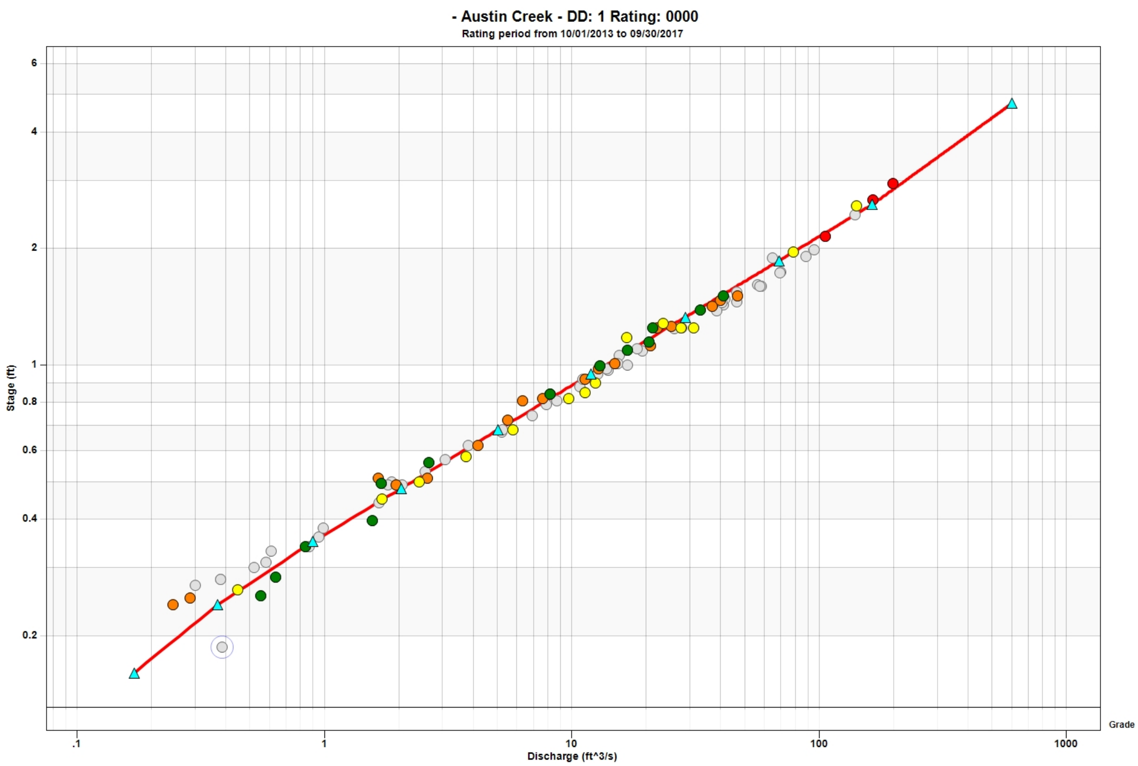


Figure 4.3: Aquarius rating curve for Austin Creek. The triangles (△) show the fitted rating curve for WY2017. The circles show data collected in WY2017 (●), WY2016 (●), WY2015 (●). The gray-shaded circles (●) show data collected prior to WY2015 that were not used to build the rating curve but were plotted to help track drift in the rating equation. The red circles (●) show data collected prior to WY2015 that were used for the rating curve because they help define the high end of the rating curve.

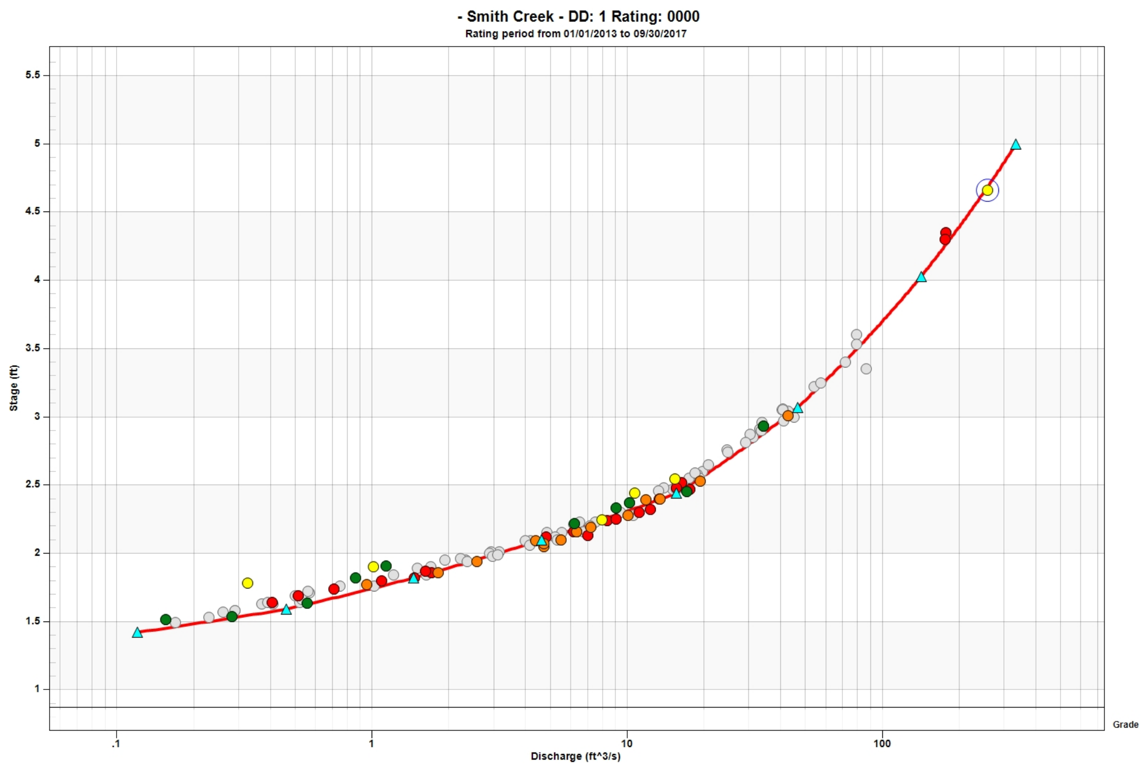


Figure 4.4: Aquarius rating curve for Smith Creek. The triangles (△) show the fitted rating curve for WY2017. The circles show data collected in WY2017 (●), WY2016 (○), WY2015 (●). The gray-shaded circles (○) show data collected prior to WY2015 that were not used to build the rating curve but were plotted to help track drift in the rating equation. The red circles (●) show data collected prior to WY2015 that were used for the rating curve because they help define the high end of the rating curve.

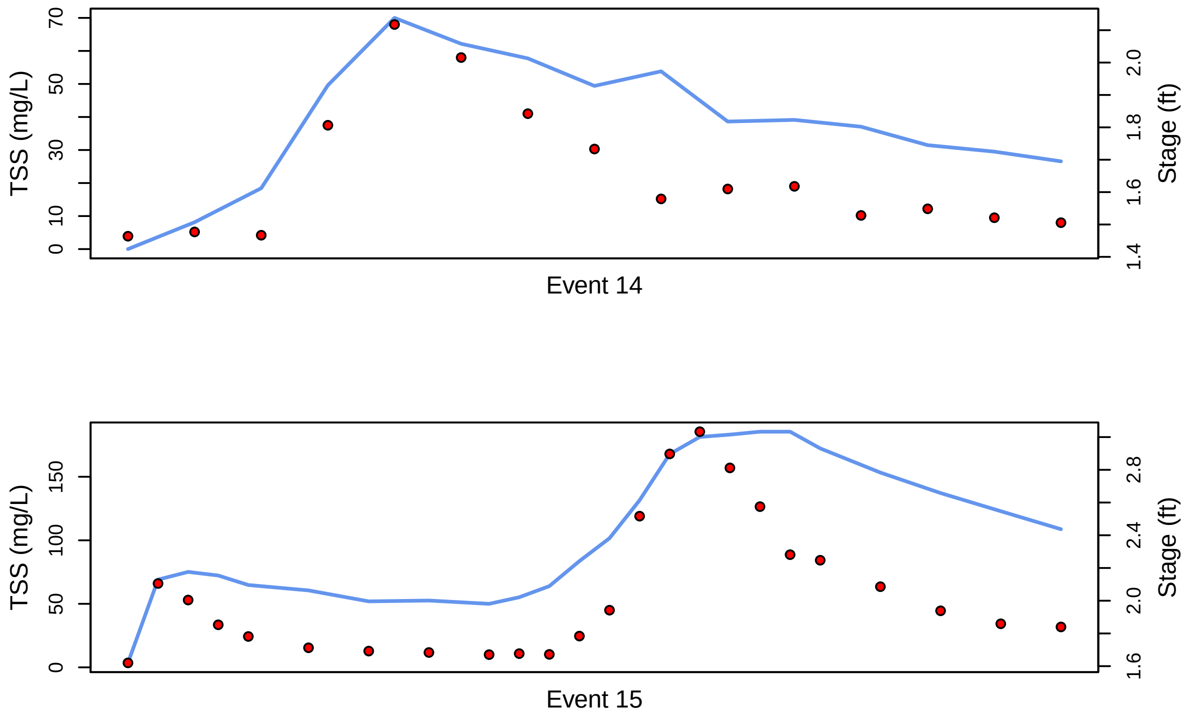


Figure 4.5: Austin Creek storm water monitoring results for Events 14–15: total suspended solids (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

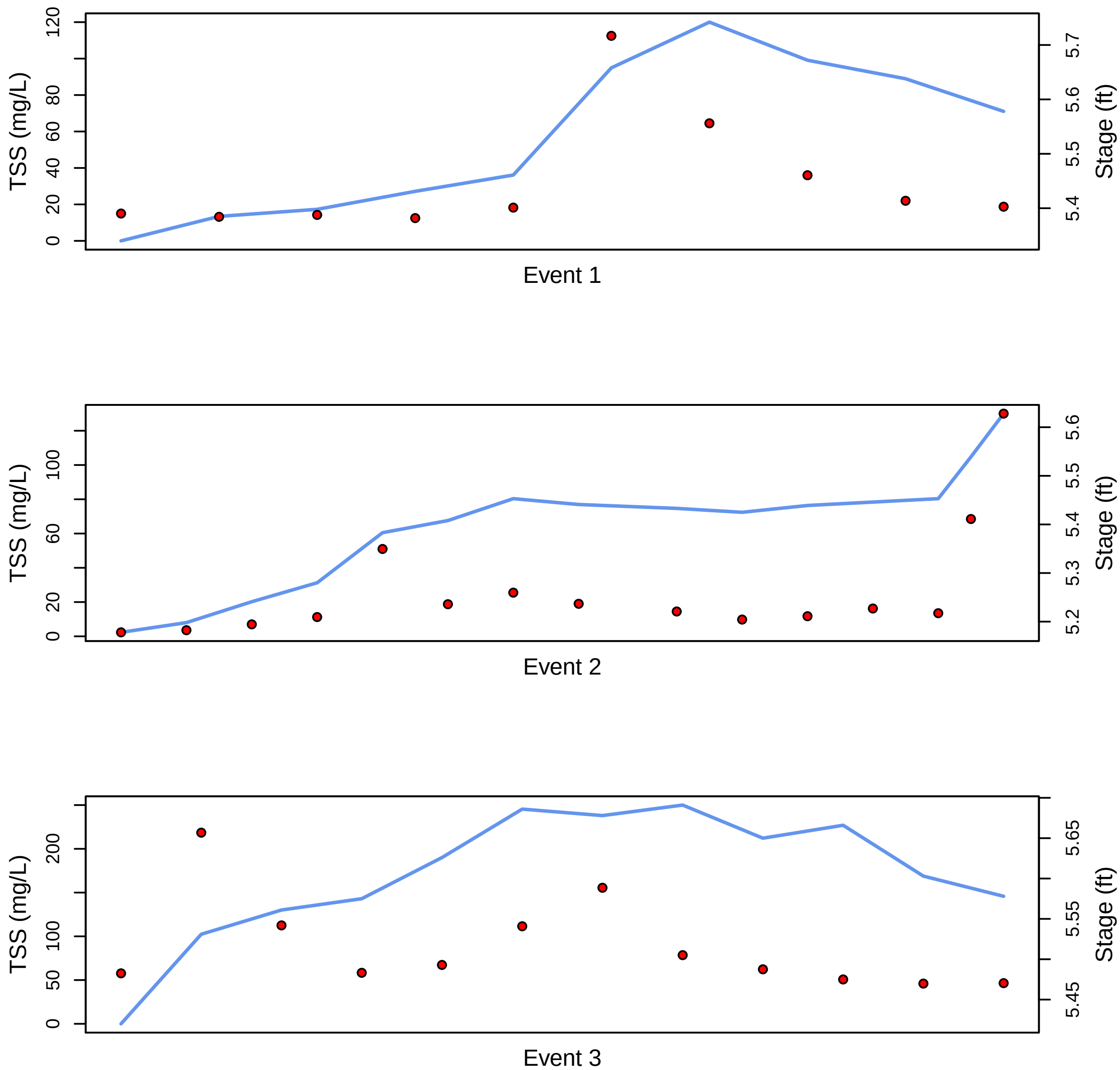


Figure 4.6: Olsen Creek storm water monitoring results for Events 1–3: total suspended solids (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

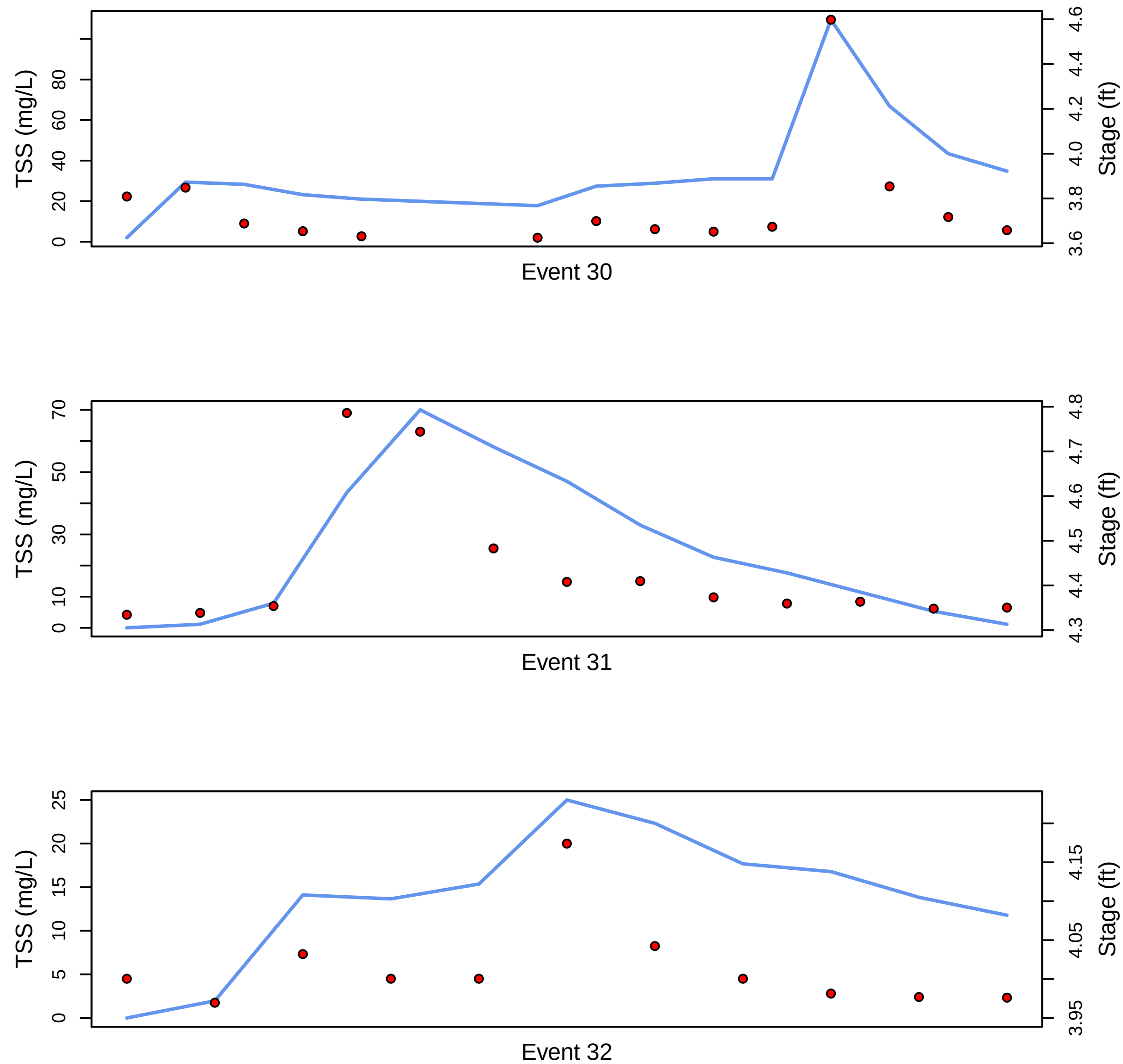


Figure 4.7: Silver Beach Creek storm water monitoring results for Events 30–32: total suspended solids (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

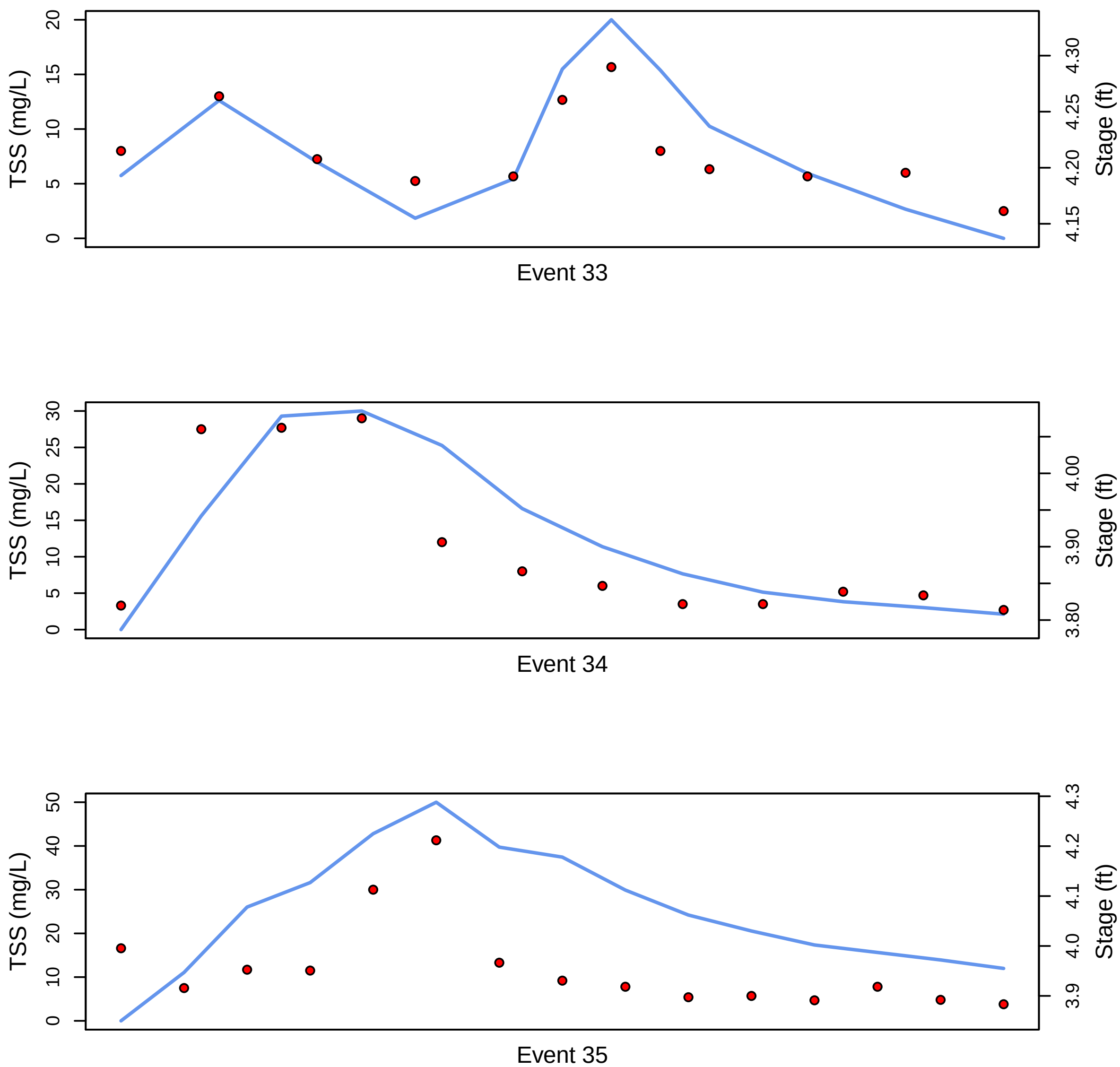


Figure 4.8: Silver Beach Creek storm water monitoring results for Events 33–35: total suspended solids (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

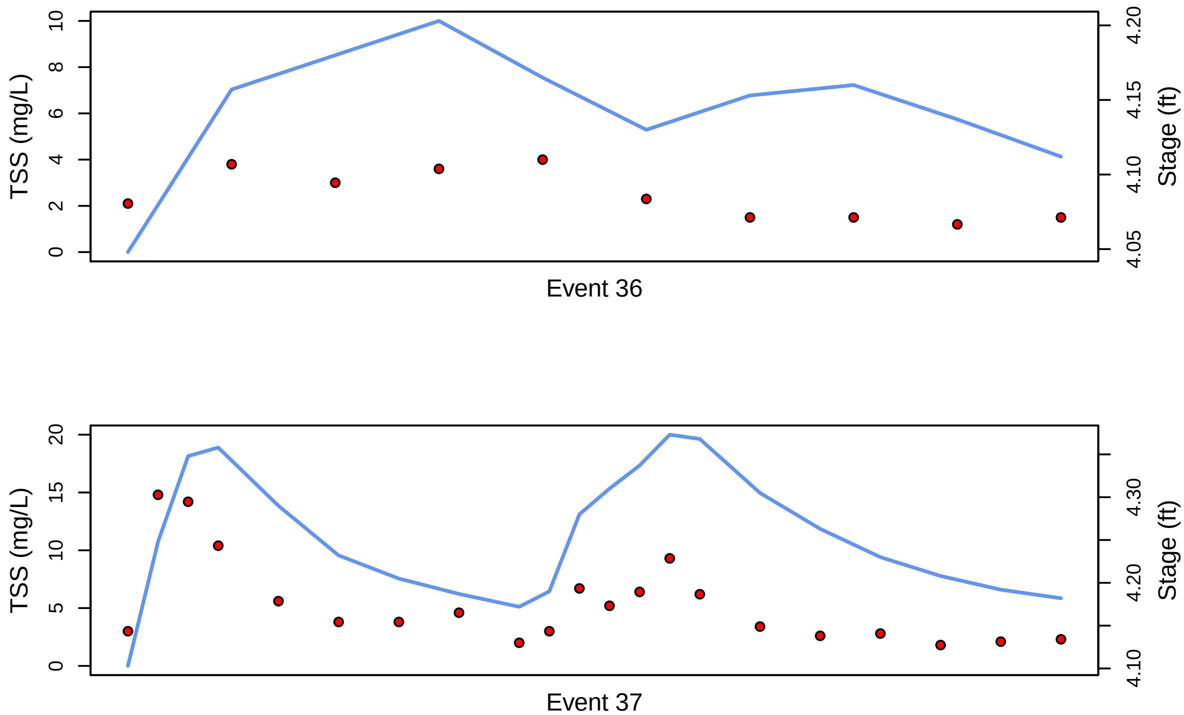


Figure 4.9: Silver Beach Creek storm water monitoring results for Events 36–37: total suspended solids (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

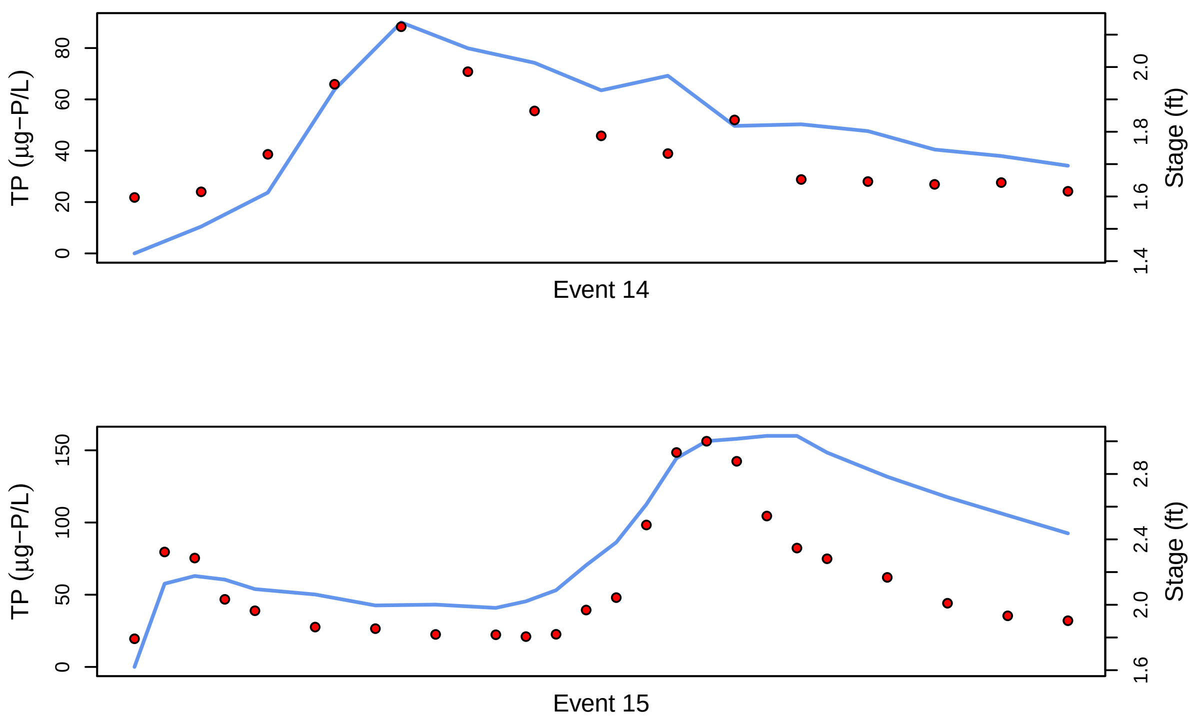


Figure 4.10: Austin Creek storm water monitoring results for Events 14–15: total phosphorus (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

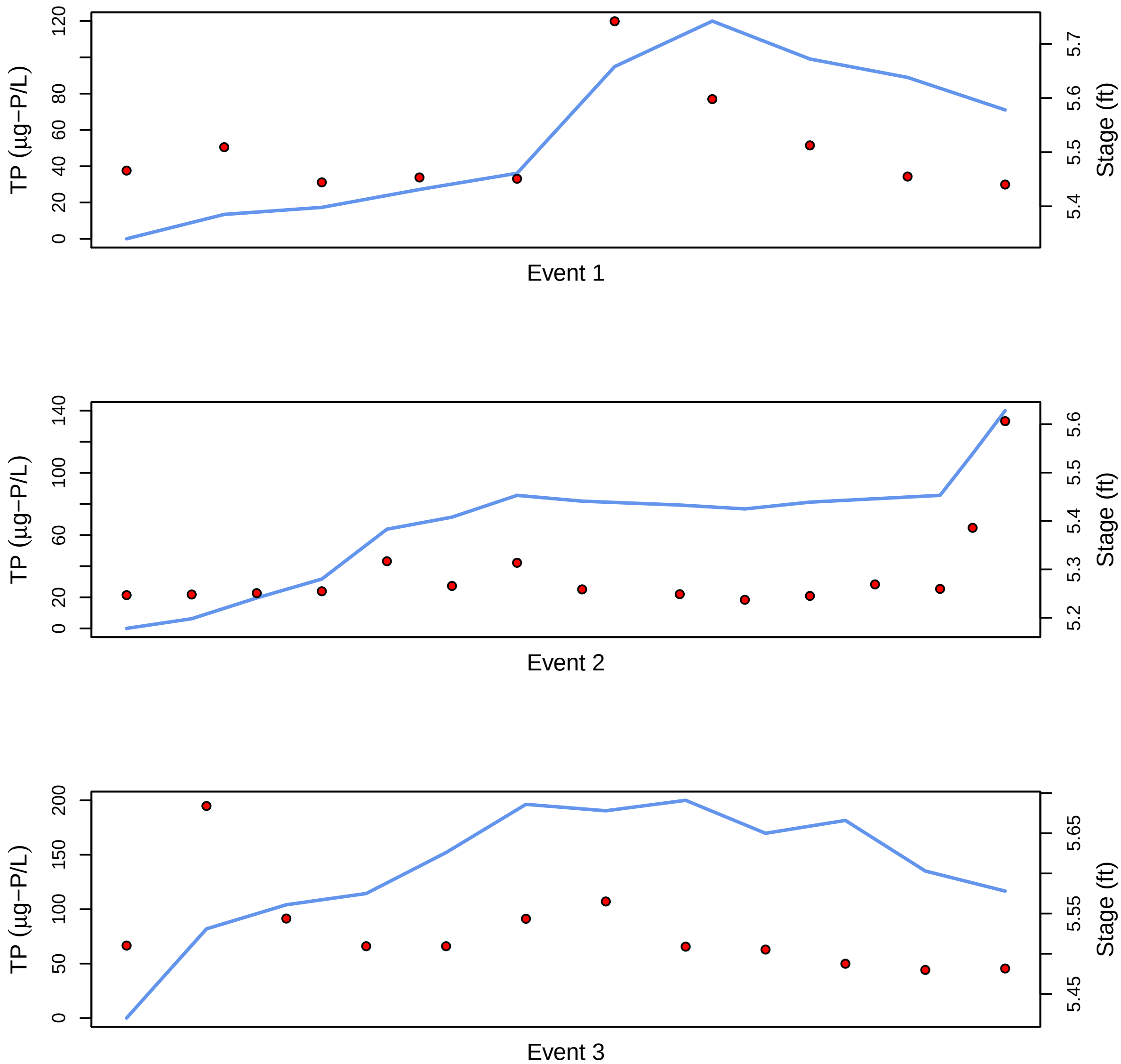


Figure 4.11: Olsen Creek storm water monitoring results for Events 1–3: total phosphorus (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

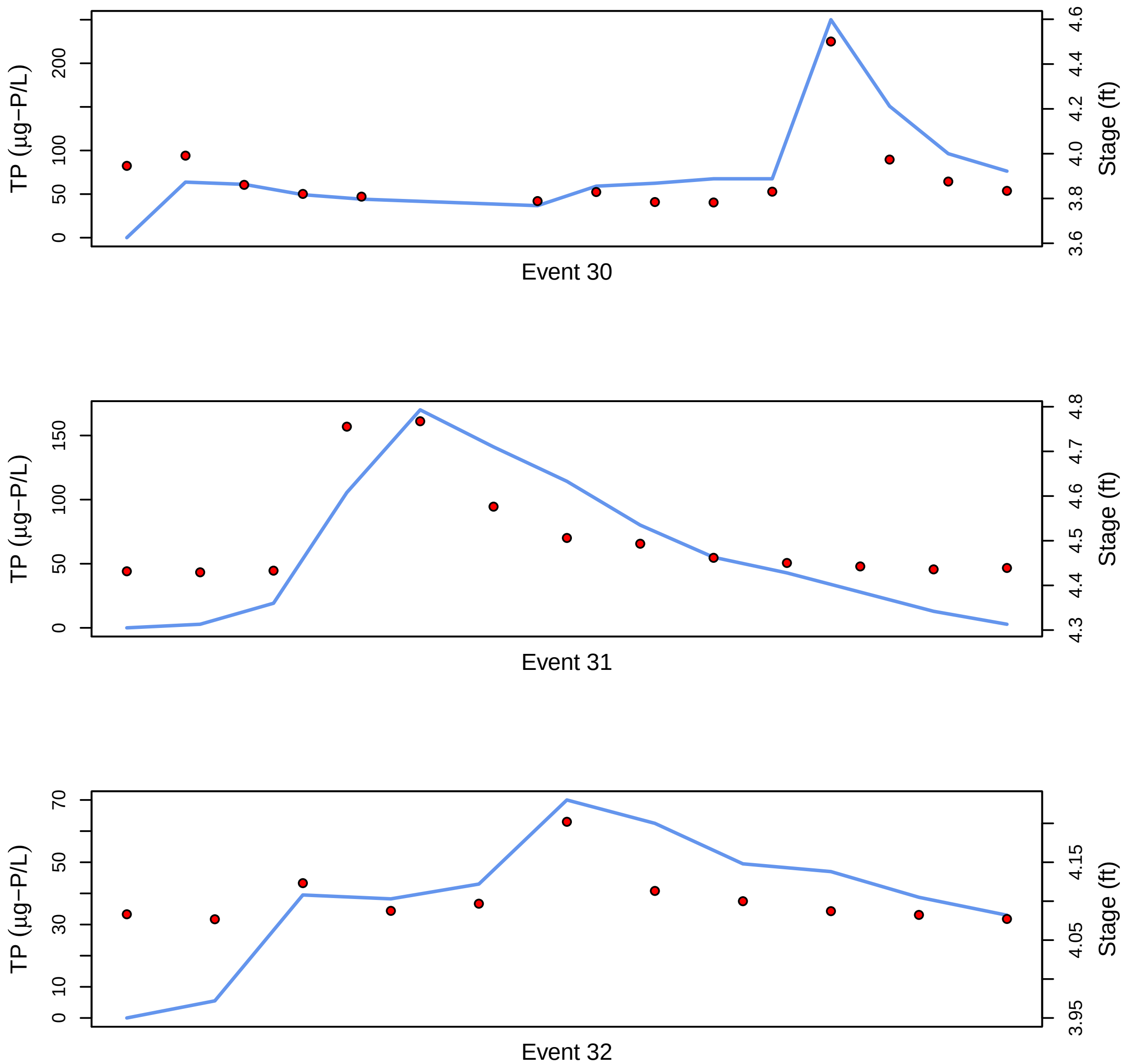


Figure 4.12: Silver Beach Creek storm water monitoring results for Events 30–32: total phosphorus (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

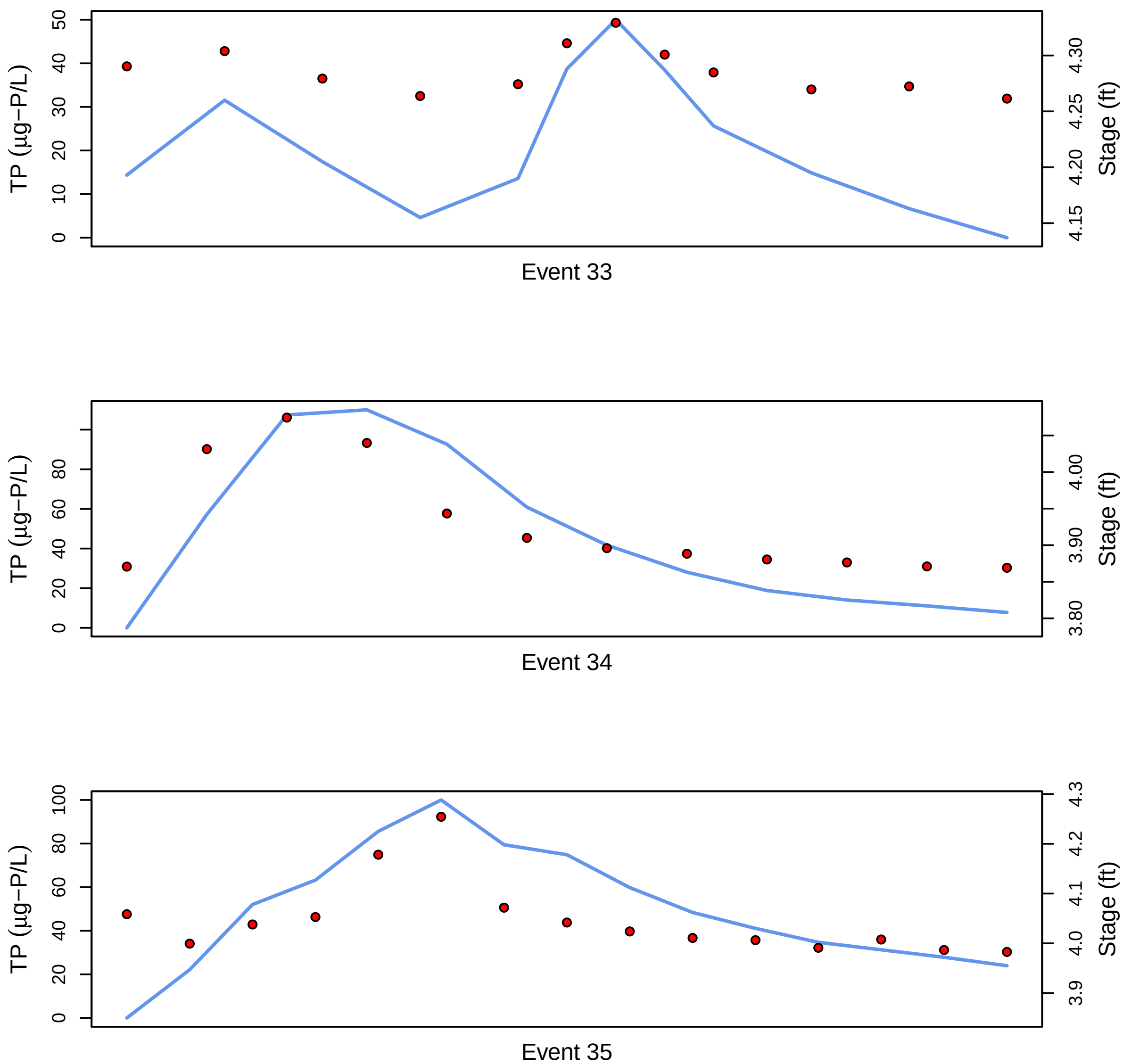


Figure 4.13: Silver Beach Creek storm water monitoring results for Events 33–35: total phosphorus (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

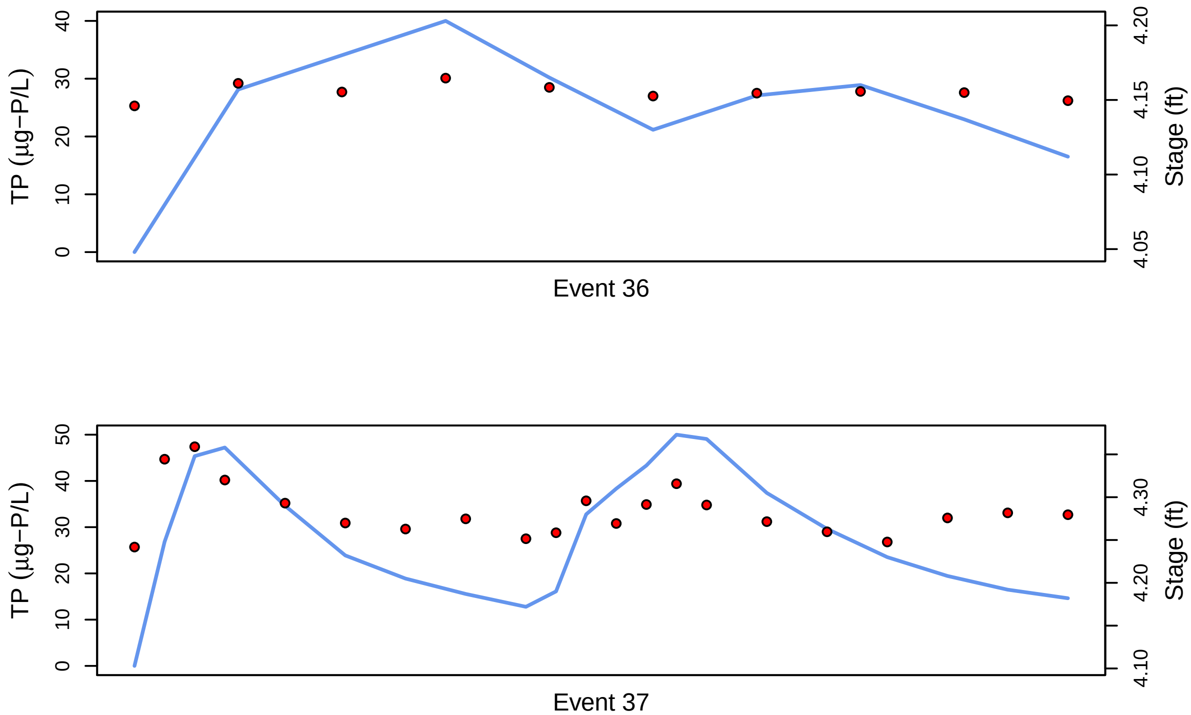
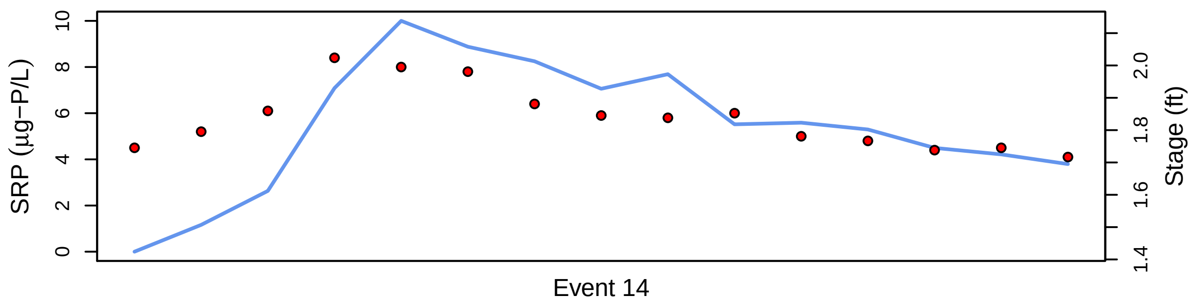


Figure 4.14: Silver Beach Creek storm water monitoring results for Events 36–37: total phosphorus (●) vs. ISCO stage height (—). Note differences in vertical axis scales.



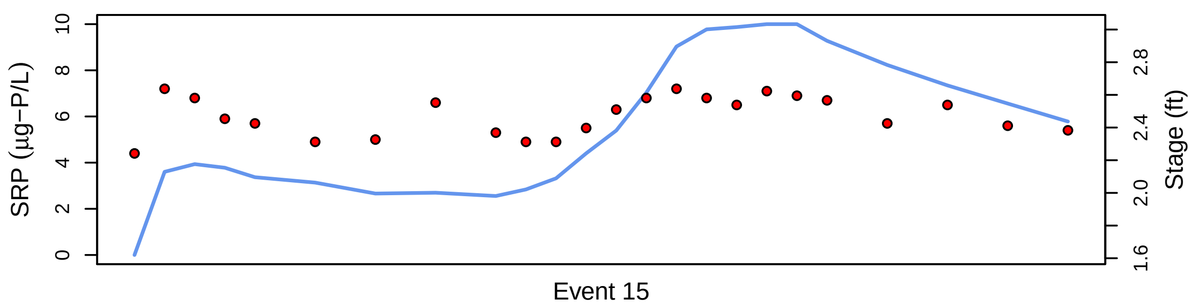


Figure 4.15: Austin Creek storm water monitoring results for Events 14-15: soluble phosphate (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

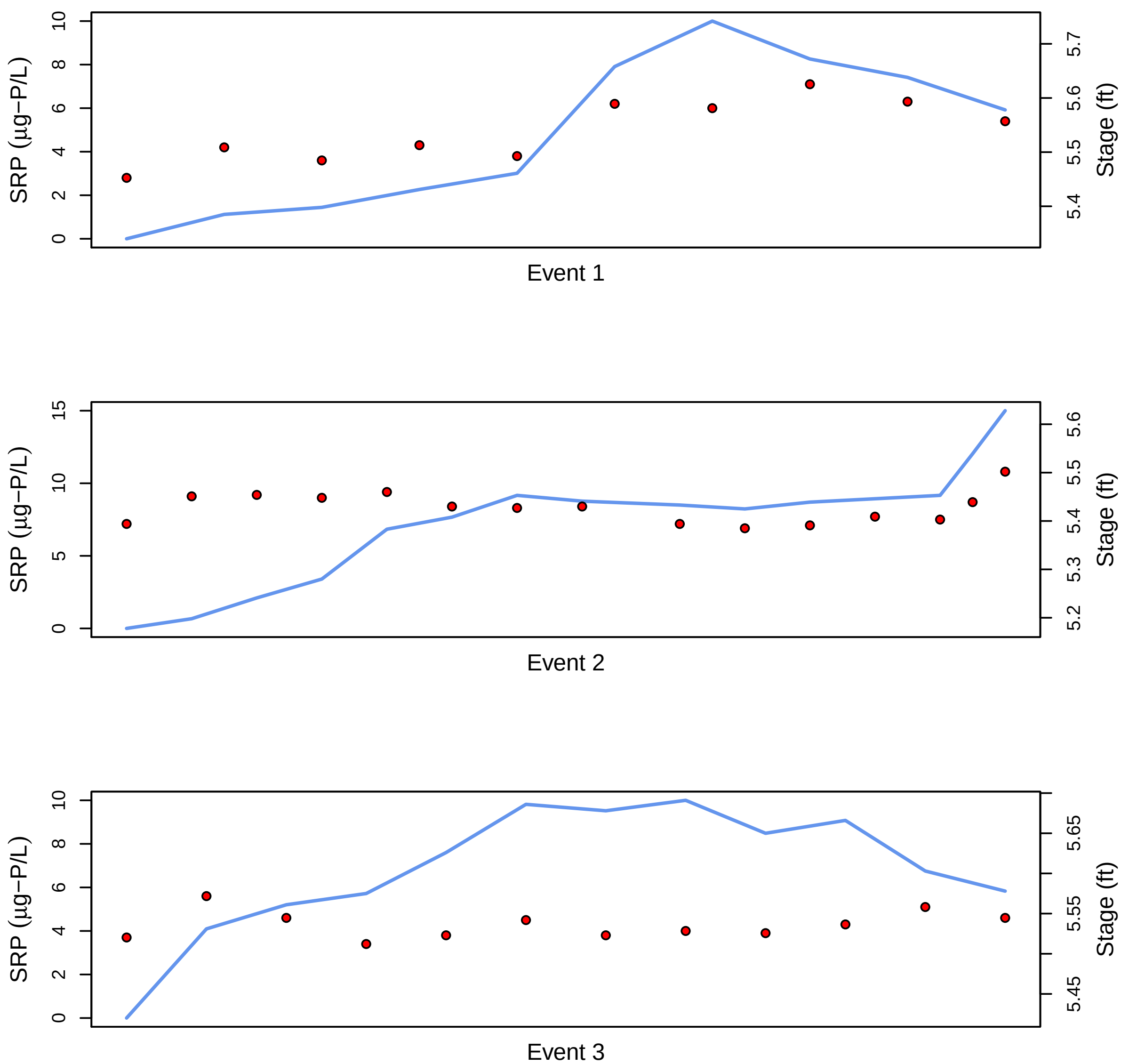


Figure 4.16: Olsen Creek storm water monitoring results for Events 1–3: soluble phosphate (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

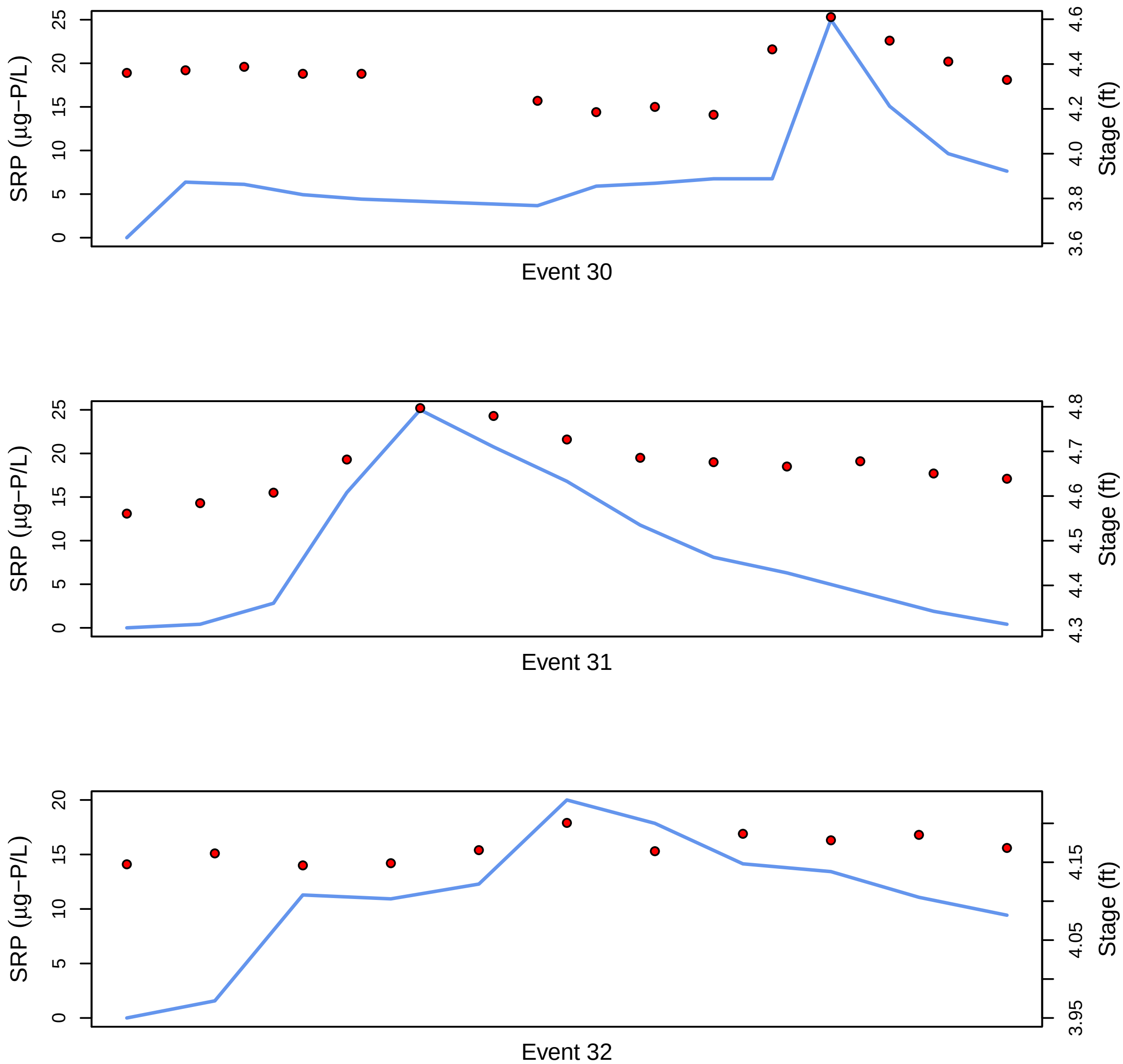


Figure 4.17: Silver Beach Creek storm water monitoring results for Events 30–32: soluble phosphate (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

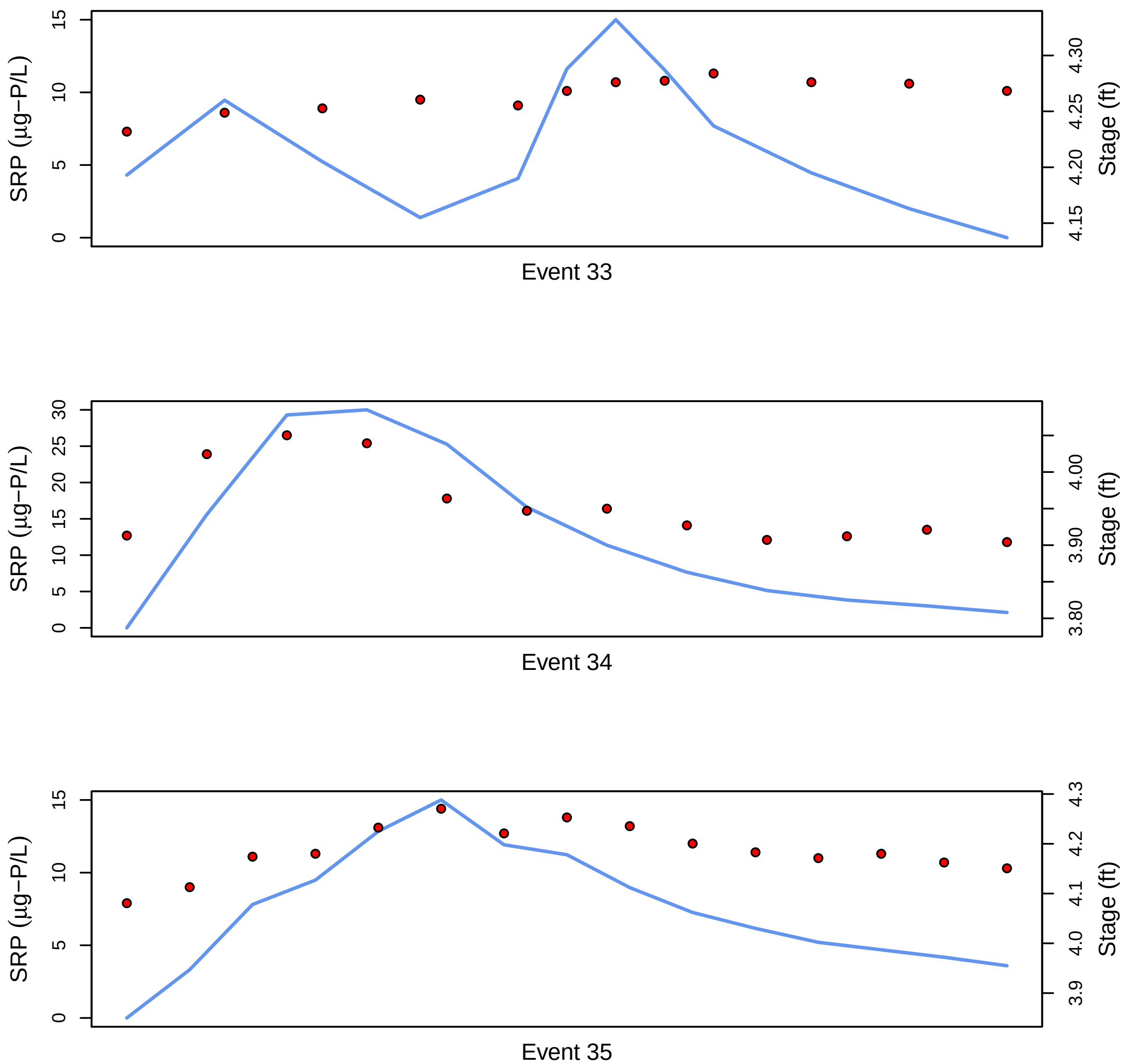
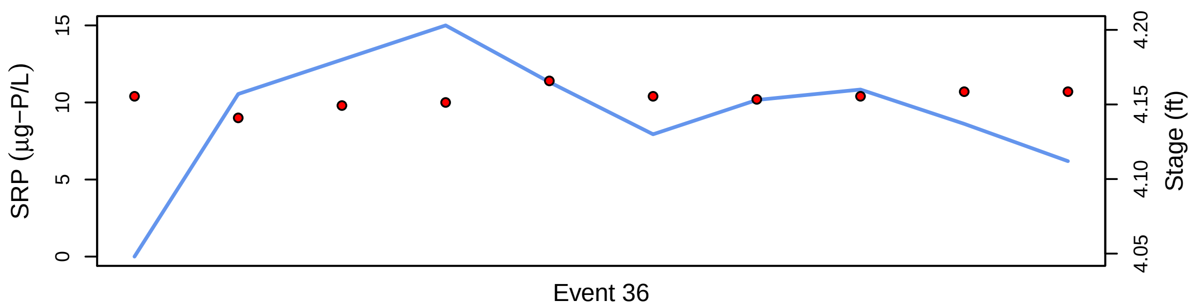


Figure 4.18: Silver Beach Creek storm water monitoring results for Events 33–35: soluble phosphate (●) vs. ISCO stage height (—). Note differences in vertical axis scales.



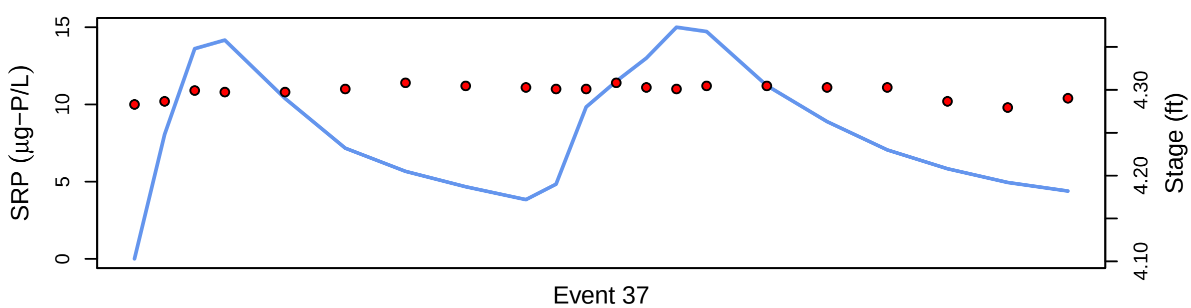
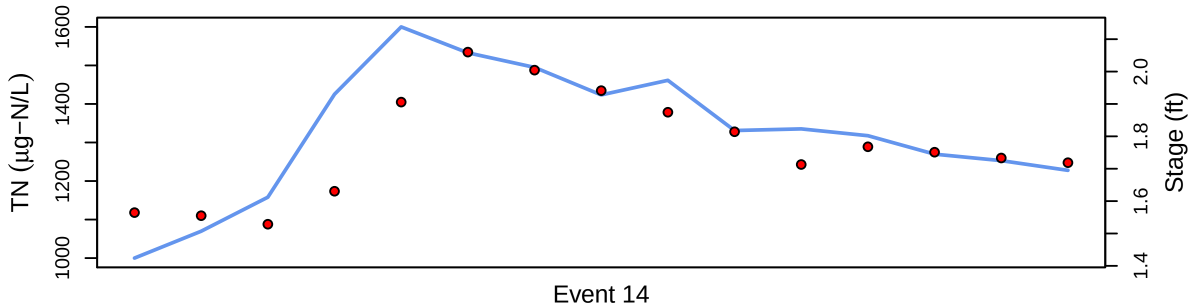


Figure 4.19: Silver Beach Creek storm water monitoring results for Events 36–37: soluble phosphate (•) vs. ISCO stage height (—). Note differences in vertical axis scales.



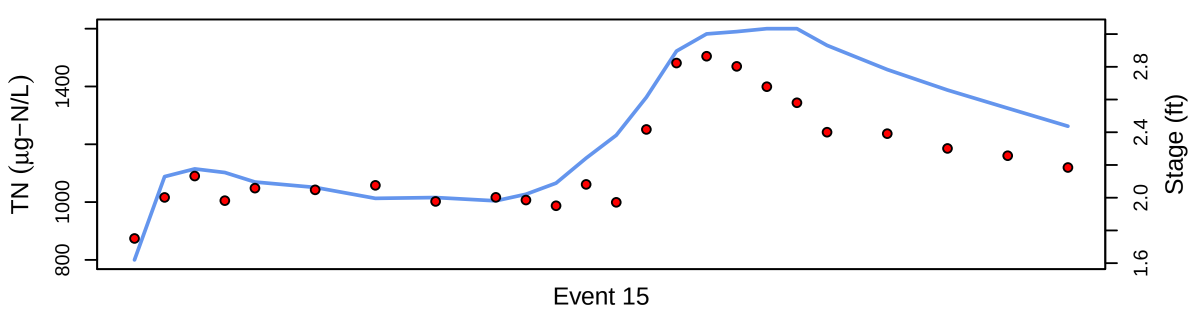


Figure 4.20: Austin Creek storm water monitoring results for Events 14–15: total nitrogen (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

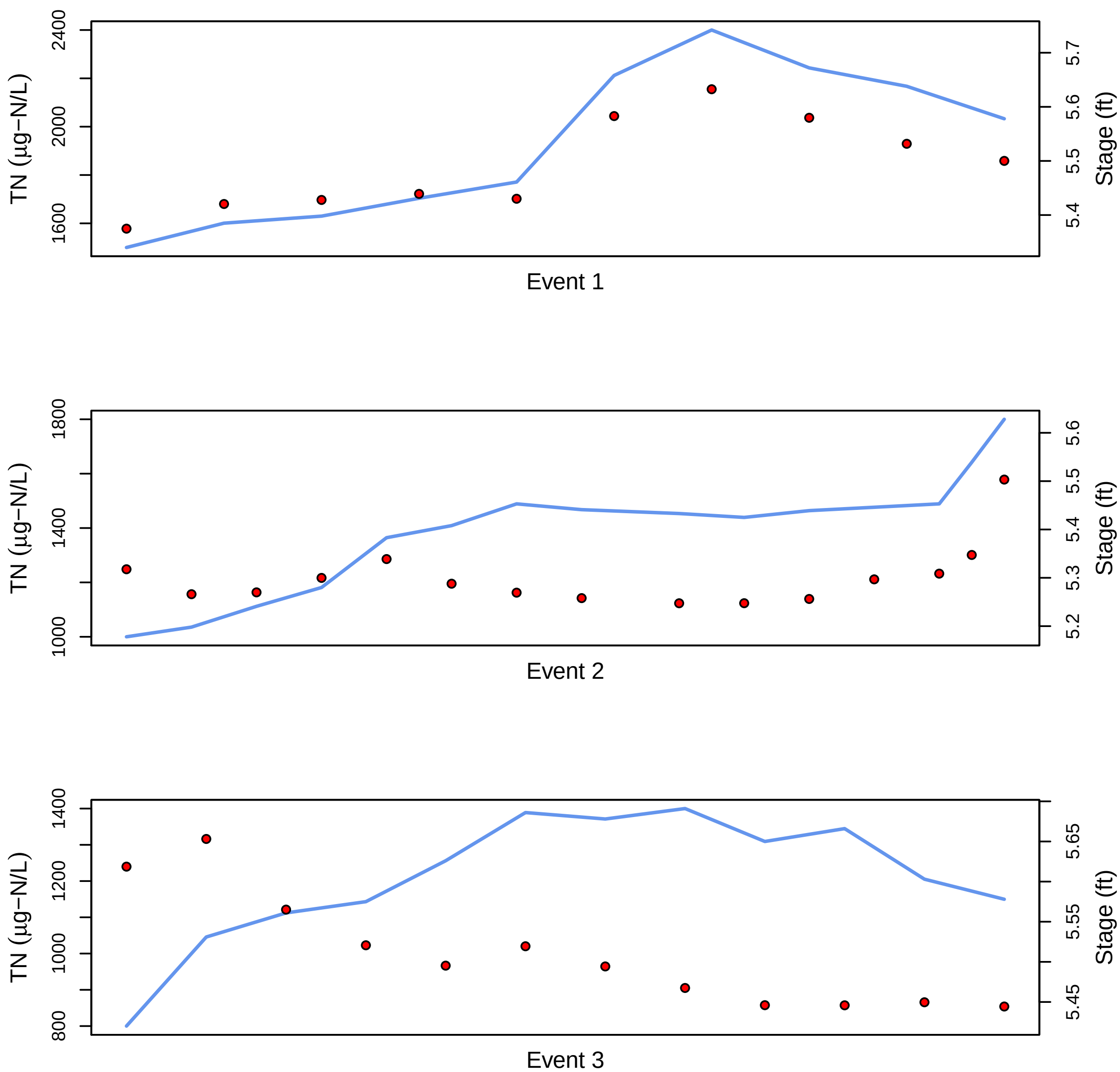


Figure 4.21: Olsen Creek storm water monitoring results for Events 1–3: total nitrogen (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

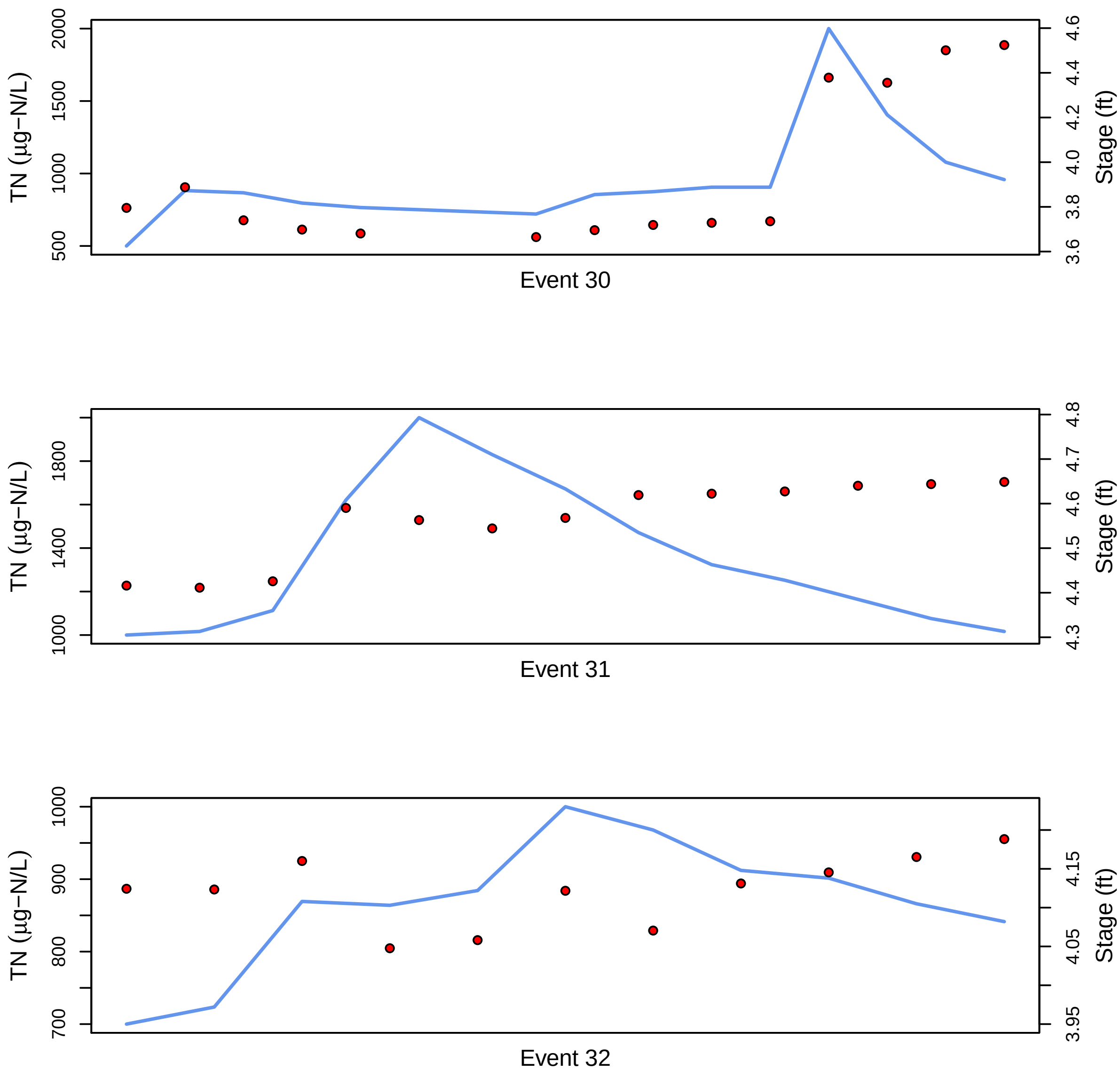


Figure 4.22: Silver Beach Creek storm water monitoring results for Events 30–32: total nitrogen (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

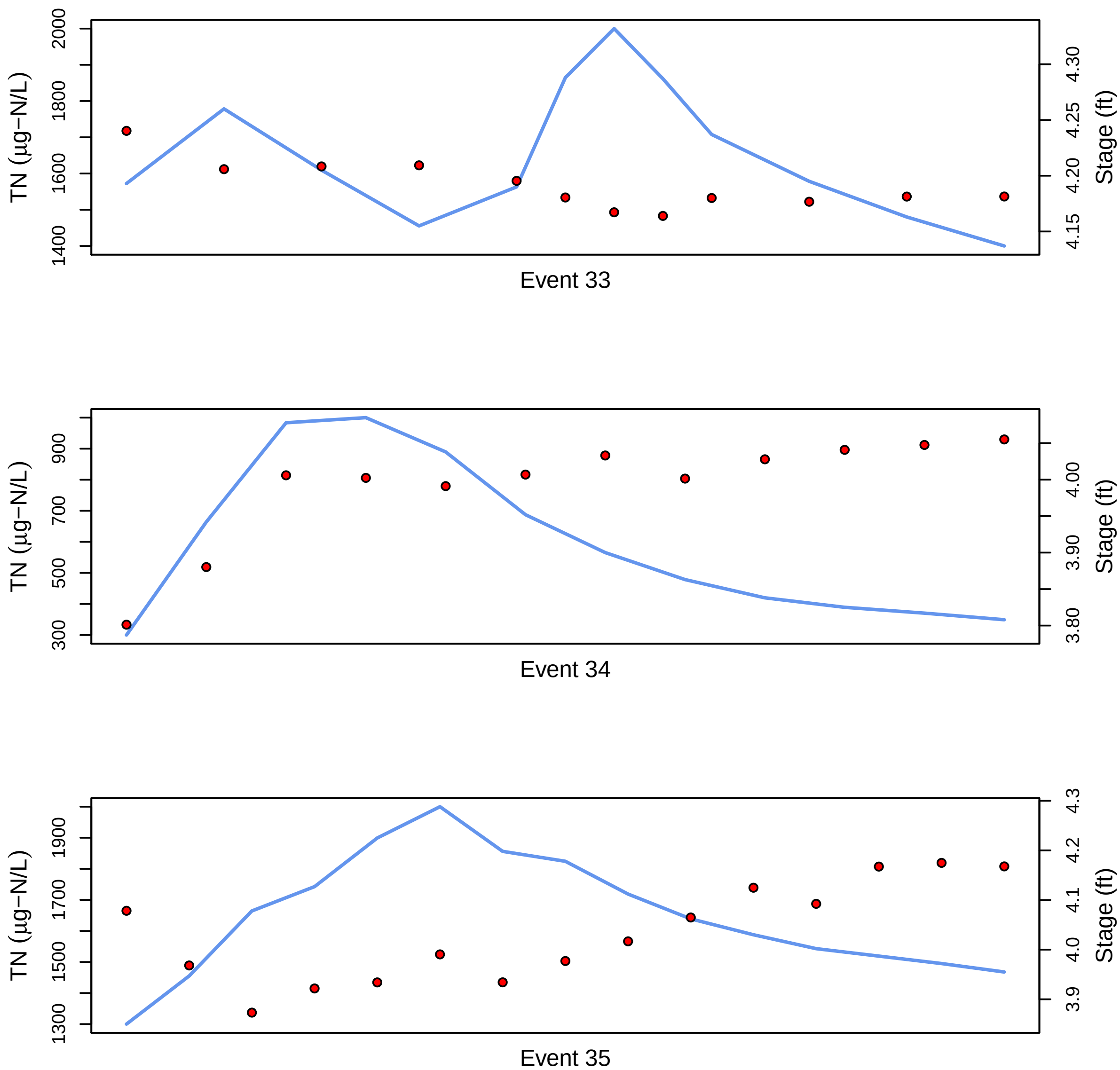


Figure 4.23: Silver Beach Creek storm water monitoring results for Events 33–35: total nitrogen (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

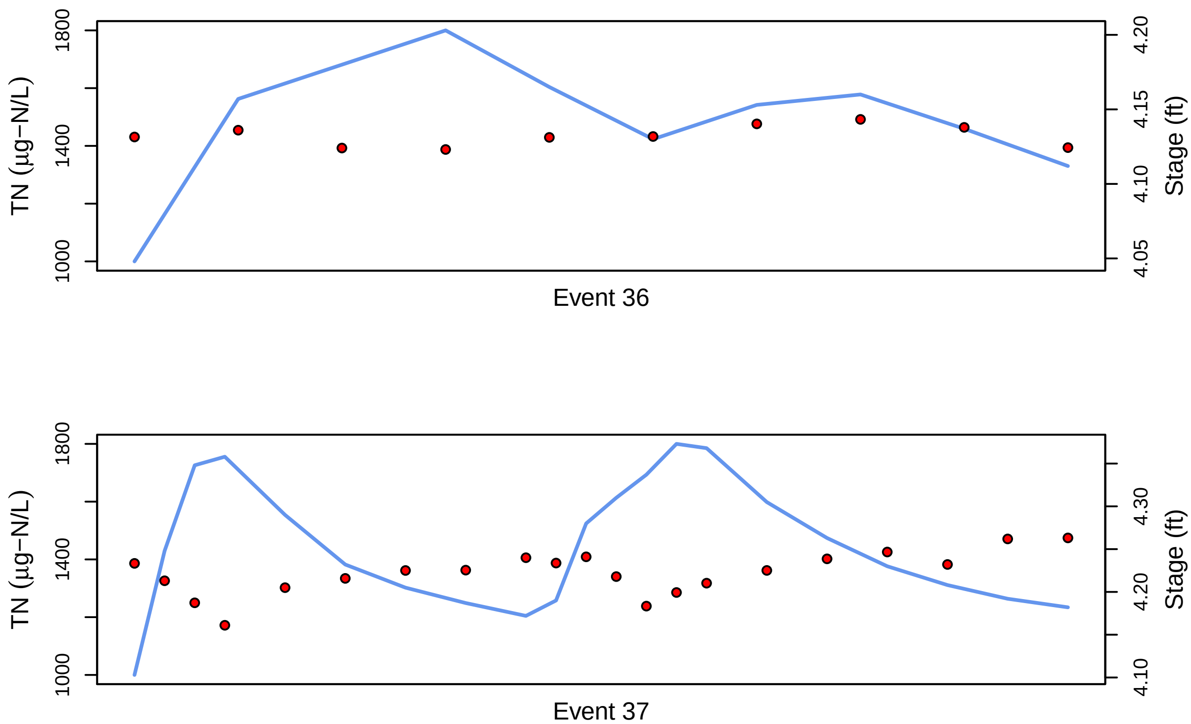


Figure 4.24: Silver Beach Creek storm water monitoring results for Events 36–37: total nitrogen (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

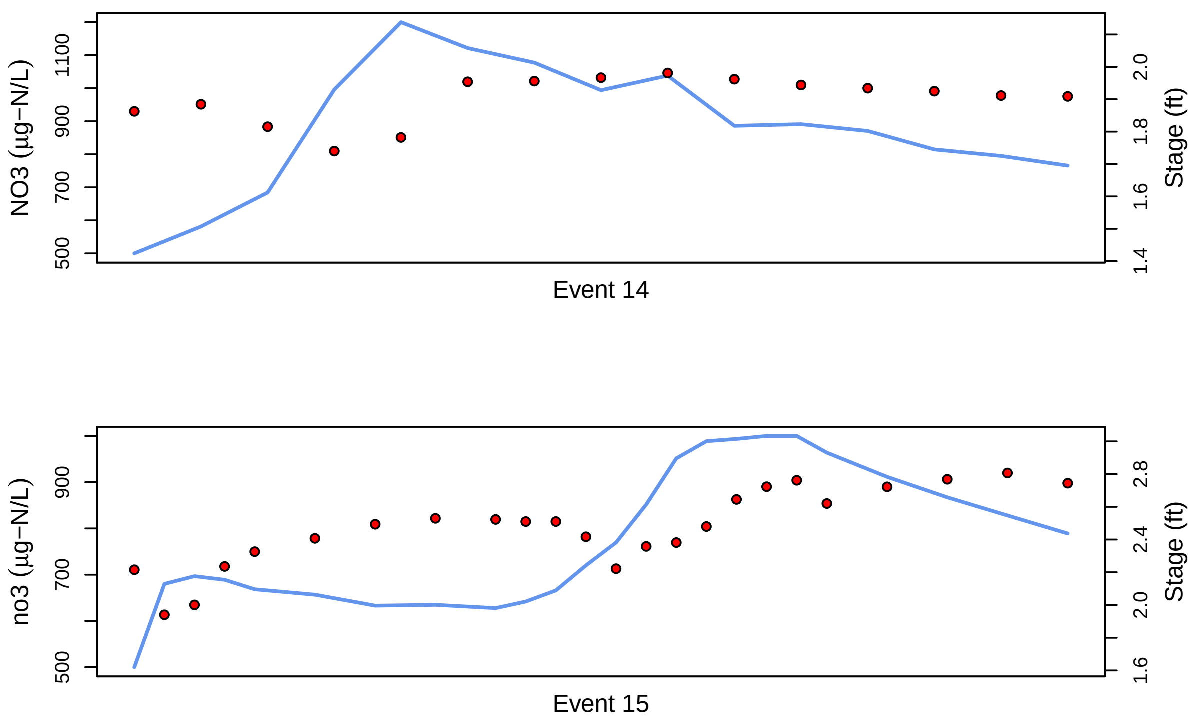


Figure 4.25: Austin Creek storm water monitoring results for Events 14–15: nitrate/nitrite (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

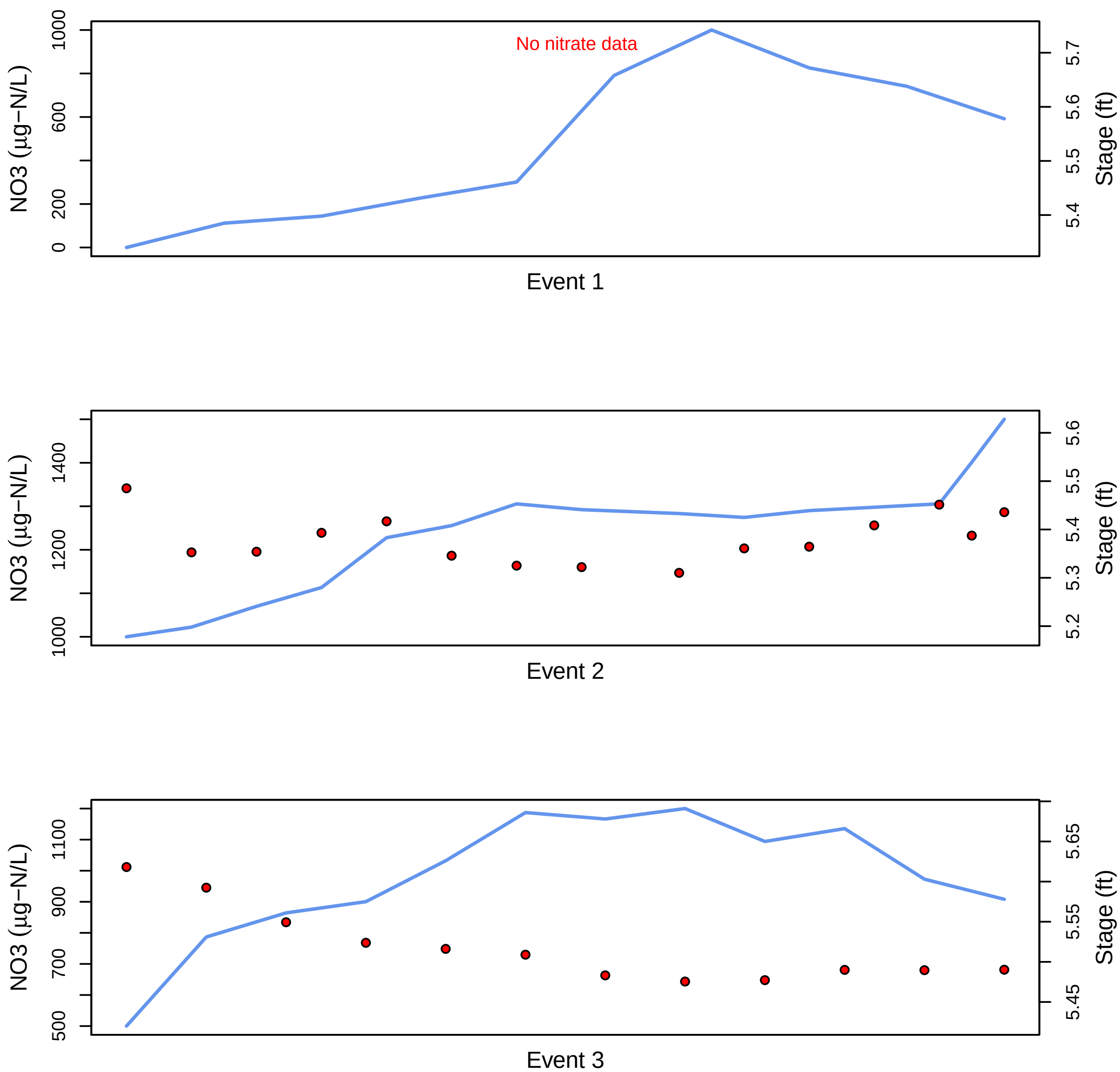


Figure 4.26: Olsen Creek storm water monitoring results for Events 1–3: nitrate/nitrite (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

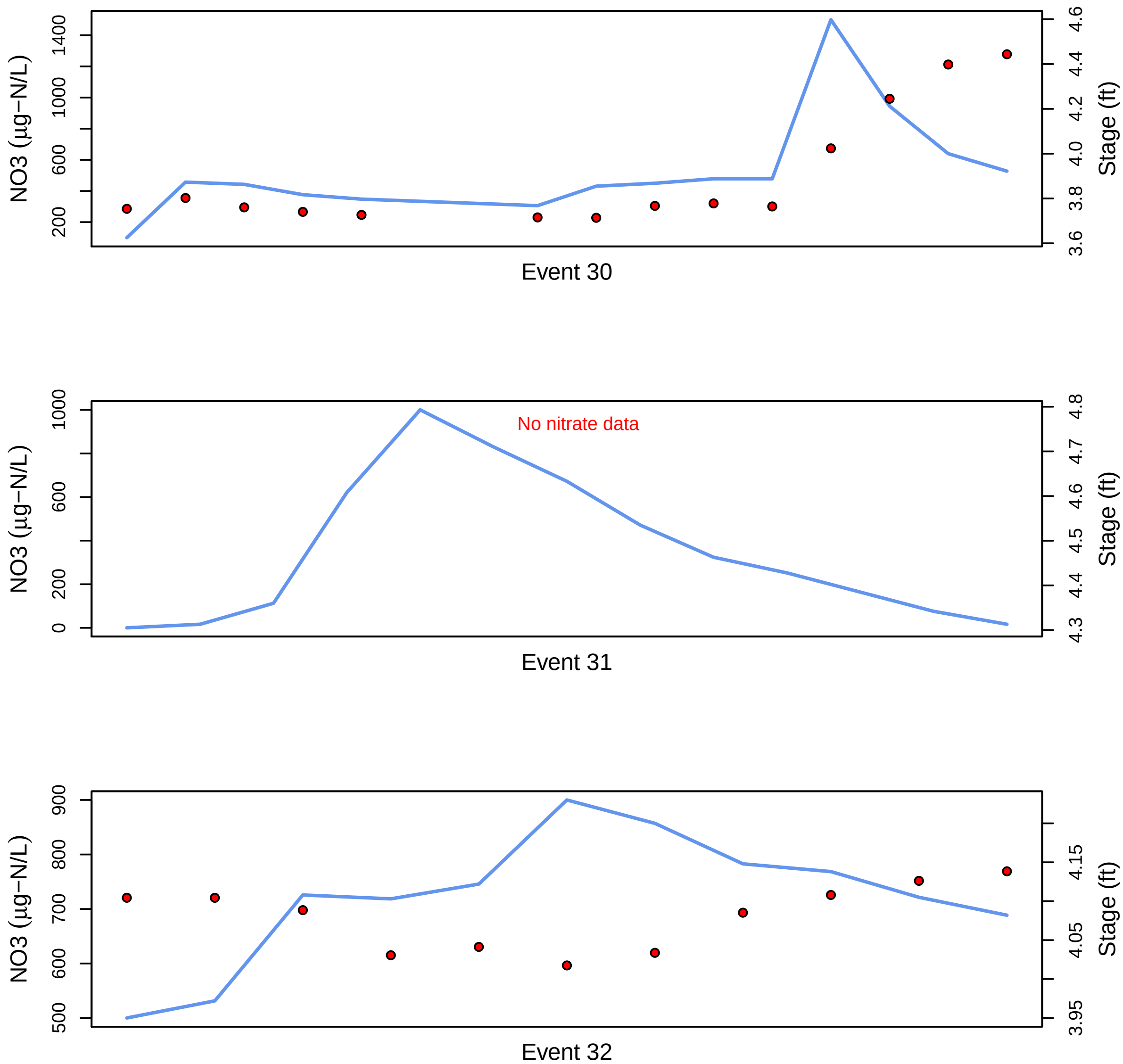


Figure 4.27: Silver Beach Creek storm water monitoring results for Events 30–32: nitrate/nitrite (●) vs. ISCO stage height (—). Note differences in vertical axis scales.

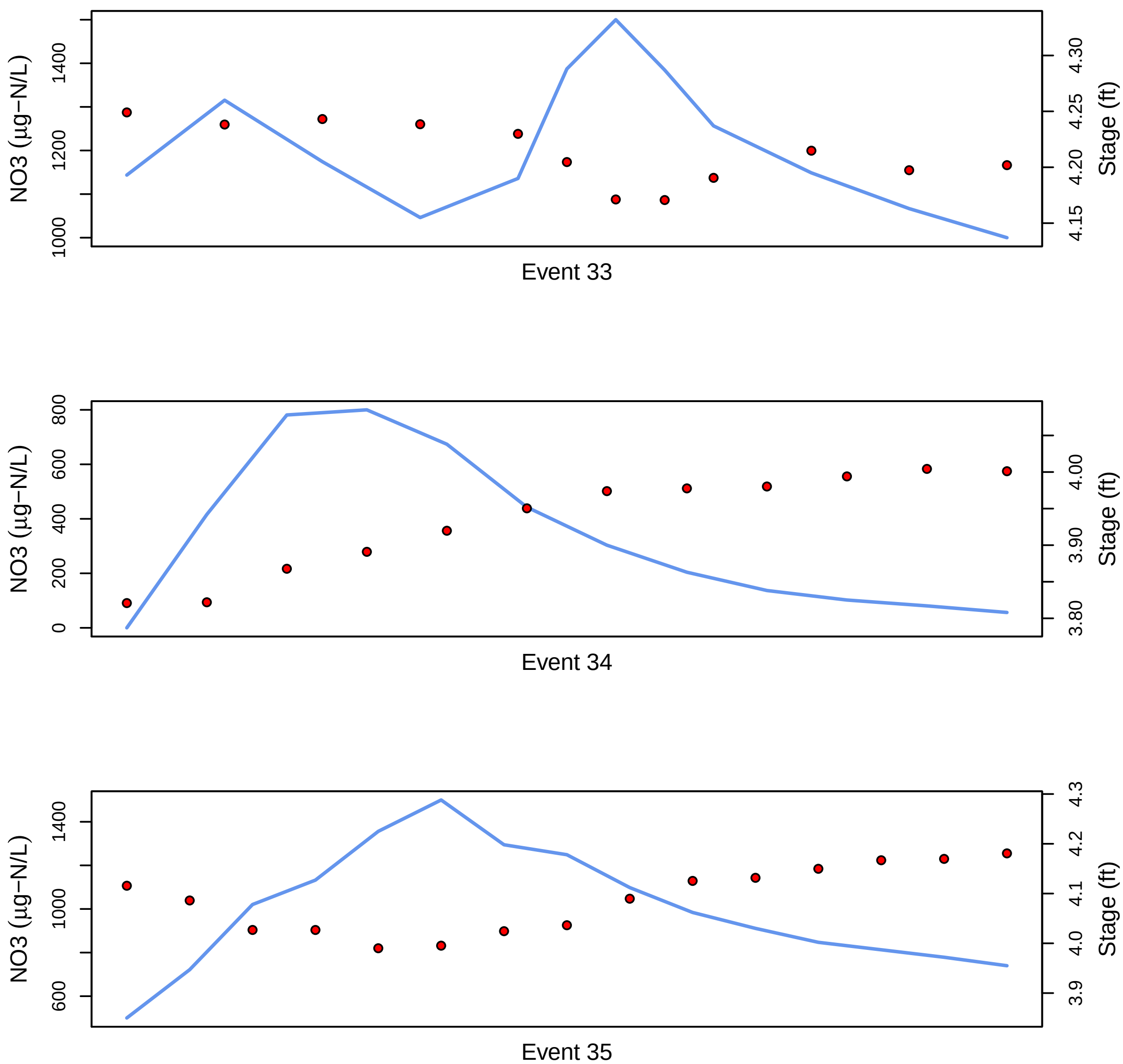


Figure 4.28: Silver Beach Creek storm water monitoring results for Events 33–35: nitrate/nitrite (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

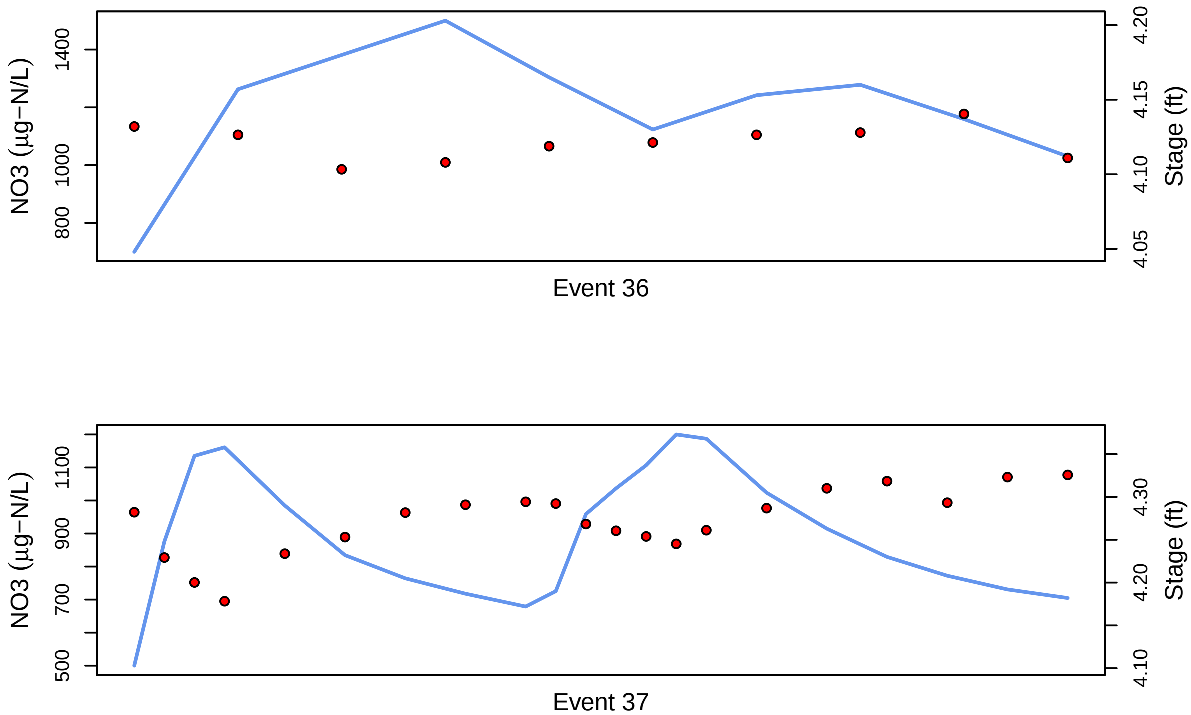


Figure 4.29: Silver Beach Creek storm water monitoring results for Events 36–37: nitrate/nitrite (•) vs. ISCO stage height (—). Note differences in vertical axis scales.

5 References and Related Reports

5.1 References

Aquatic Informatics. 2014. AQUARIUS rating curve software. Aquatic Informatics, Vancouver, British Columbia, Canada.

APHA. 2012. Standard Methods for the Examination of Water and Wastewater, 22nd Edition. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

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.

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. J. Amer. Water Works Assoc. 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.

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.

Granéli, E. and J. T. Turner (Eds). 2006. Ecology of Harmful Algae. Springer-Verlag, Berlin, Germany.

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. 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, 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, 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. 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. 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.

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.

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.

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.

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.

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.

Potter, B. and F. Wimsatt. 2009. Method 415.3, Rev. 1.2: Determination of Total Organic Carbon and Specific UV Absorbance at 254 nm in Source Water and Drinking Water. U. S. Environmental Protection Agency, Washington, DC.

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.

Sung, W., B. Reilly-Matthews, D. K. O'Day, and K. Horrigan. 2000. Modeling DBP Formation. J. Amer. Water Works Assoc. 92:5–53.

Wetzel, R. G. 2001. Limnology, Third Edition. Academic Press, San Diego, CA.

WOW. 2004. Water on the Web - Monitoring Minnesota Lakes on the Internet and Training Water Science Technicians for the Future - a National On-line Curriculum using Advanced Technologies and Real-Time Data (www.waterontheweb.org). University of Minnesota-Duluth, Duluth, MN.

WRCC, Western Regional Climate Center. [cited 10 Dec 2017]. Available from https://wrcc.dri.edu/Climate/summaries.php

YSI. 2010. YSI 6-Series Multiparameter Water Quality Sondes User Manual, Revision G, November 2012. 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 www.wwu.edu/iws (follow links to the Lake Whatcom project under Lake Studies); 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:

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:

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–A3 (pages 115–117) show the locations of the current monitoring sites and Table A1 (page 114) 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 at 20 m 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.

Site 2 is located at 18–20 m 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 **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.

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.

A.2 Tributary Monitoring Sites

Anderson Creek samples are collected 15 m upstream from South Bay Rd. Water samples and discharge measurements are collected upstream from the bridge. The Anderson Creek hydrograph[29] is mounted 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.

[29]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.

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 downstream from the culvert under Blue Canyon Rd. in the second of three small streams that cross the road. This site can be difficult to locate and may be dry or have minimal flow during drought conditions; contact IWS for detailed information about the site location.

Brannian Creek samples are collected approximately 40 m downstream from South Bay Rd. near 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 Ave. samples are collected from an unnamed tributary located off Decator Rd. near the USGS hydrograph gauge. The site is named for its proximity to Euclid Ave., and 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 at the gaging station approximately 15 m downstream from North Shore Dr.

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 2016/2017 storm water monitoring program focused on collecting storm runoff data from Carpenter, Olsen, and Silver Beach 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; and Silver Beach Creek samples are collected approximately 75 m upstream from the culvert under North Shore Rd., just upstream from the USGS 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 107).

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.

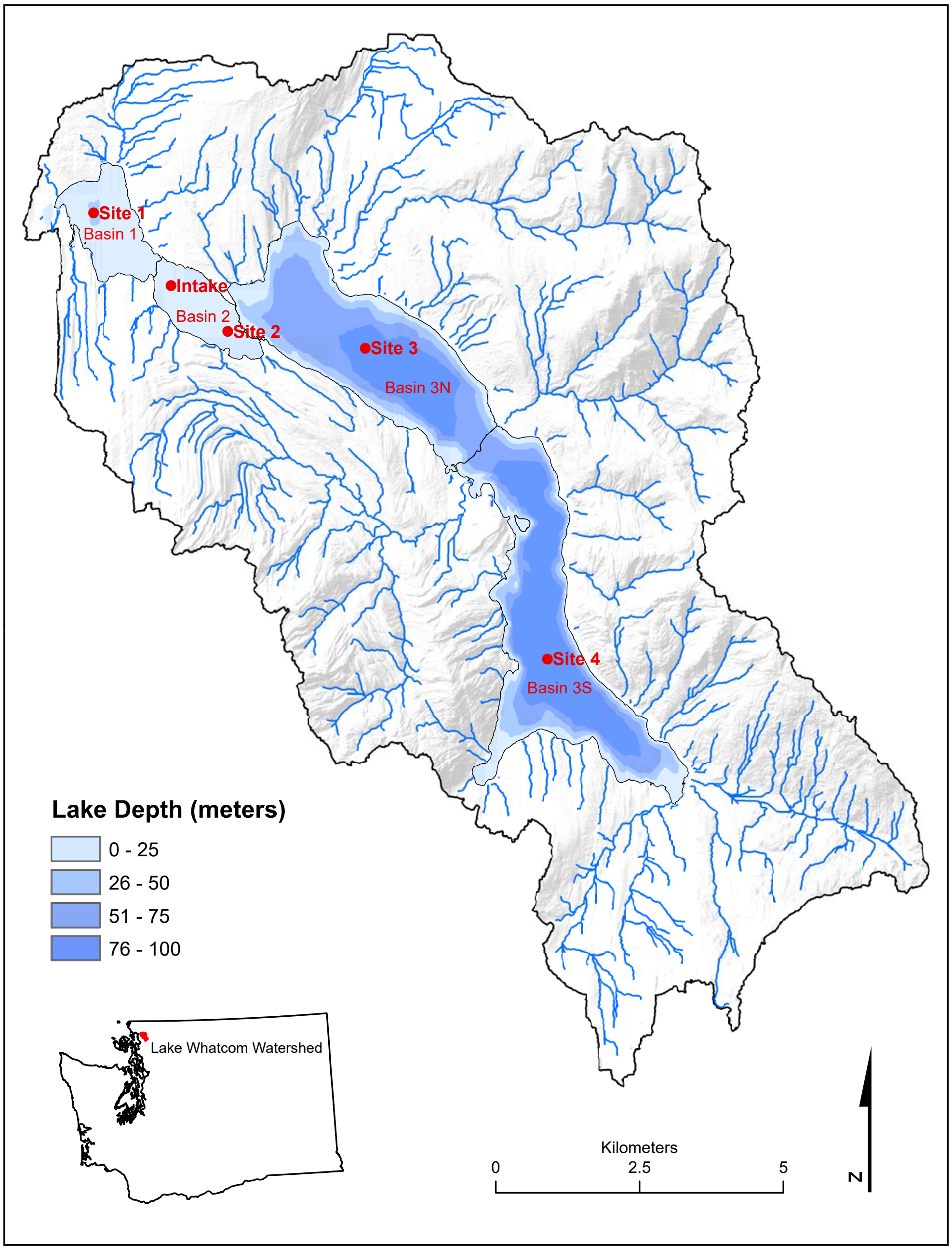


Figure A1: Lake Whatcom lake sampling sites. Basemap created using data from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

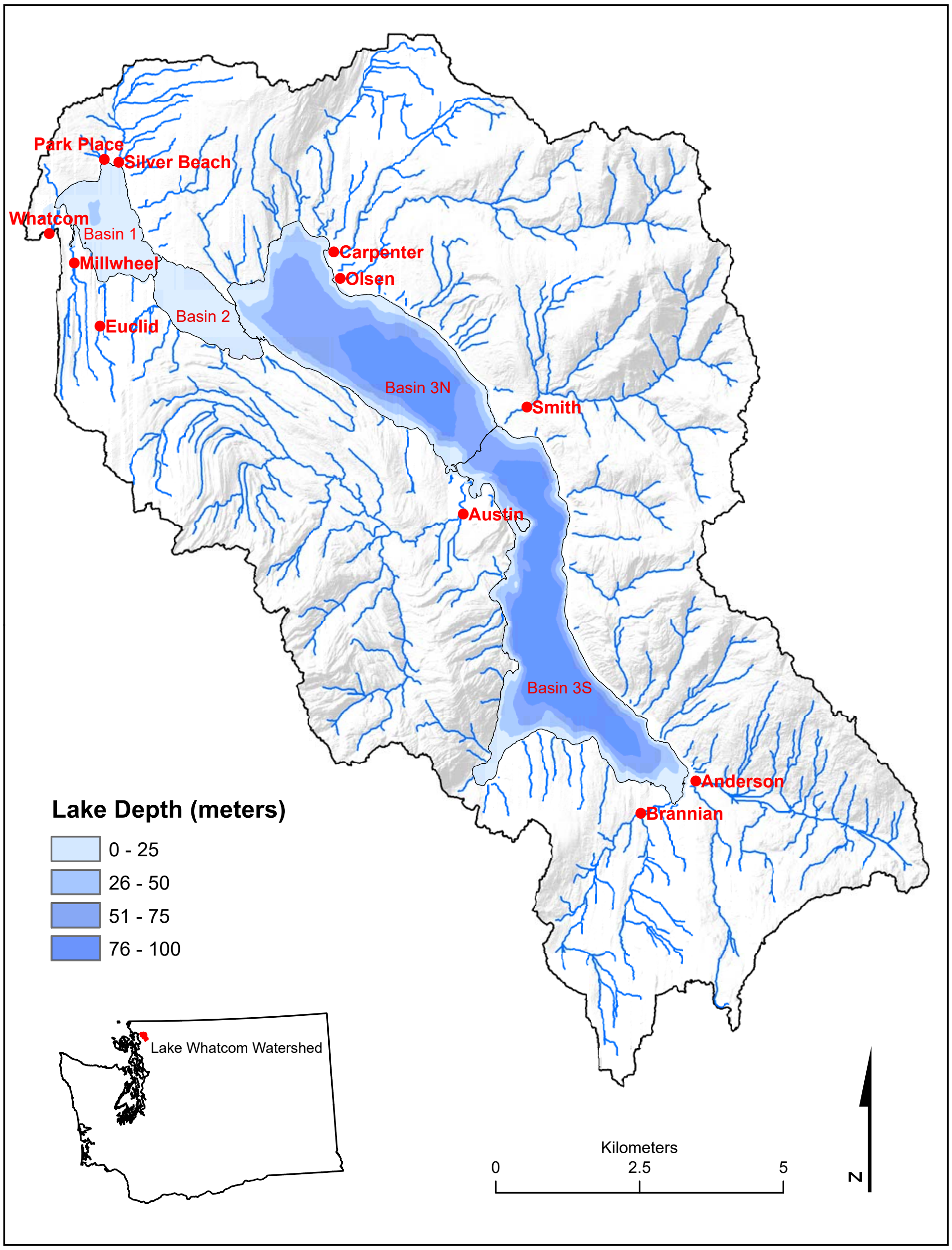


Figure A2: Lake Whatcom tributary and outlet sampling sites. Basemap created using data from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

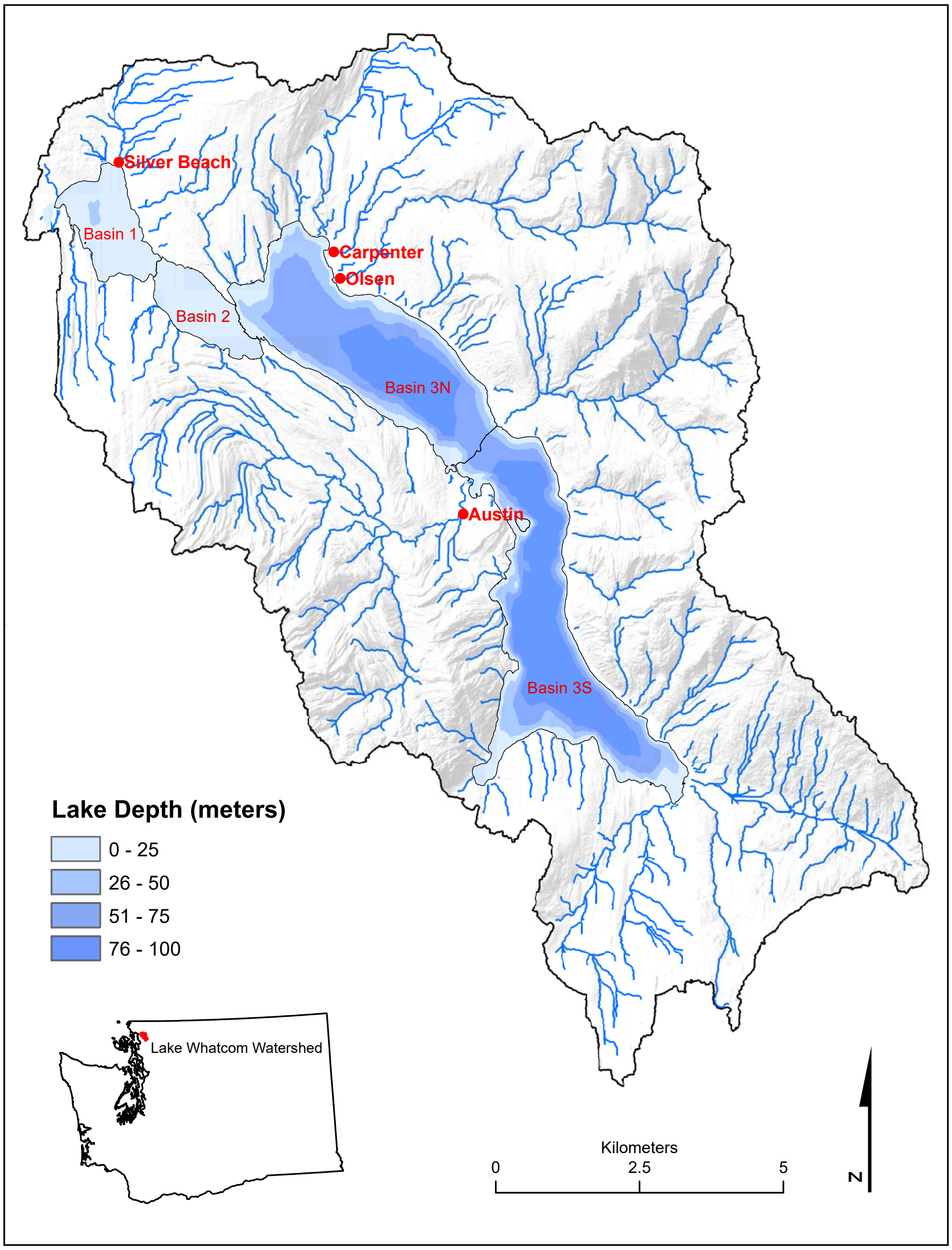


Figure A3: Lake Whatcom hydrograph and storm water sampling sites. Basemap created using data from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

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 17).

The historic detection limits for each parameter were estimated based on recommended lower detection ranges (APHA, 1998; Hydrolab, 1997; Lind, 1985), instrument limitations, and analyst judgment on the lowest repeatable concentration for each test. Over time, some analytical techniques have improved so that current detection limits are lower than defined below (see current detection limits in Table 2.1, page 17). 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 introduction of increasingly sensitive field equipment (see, for example, Figures B66–B70, pages 186–190, 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

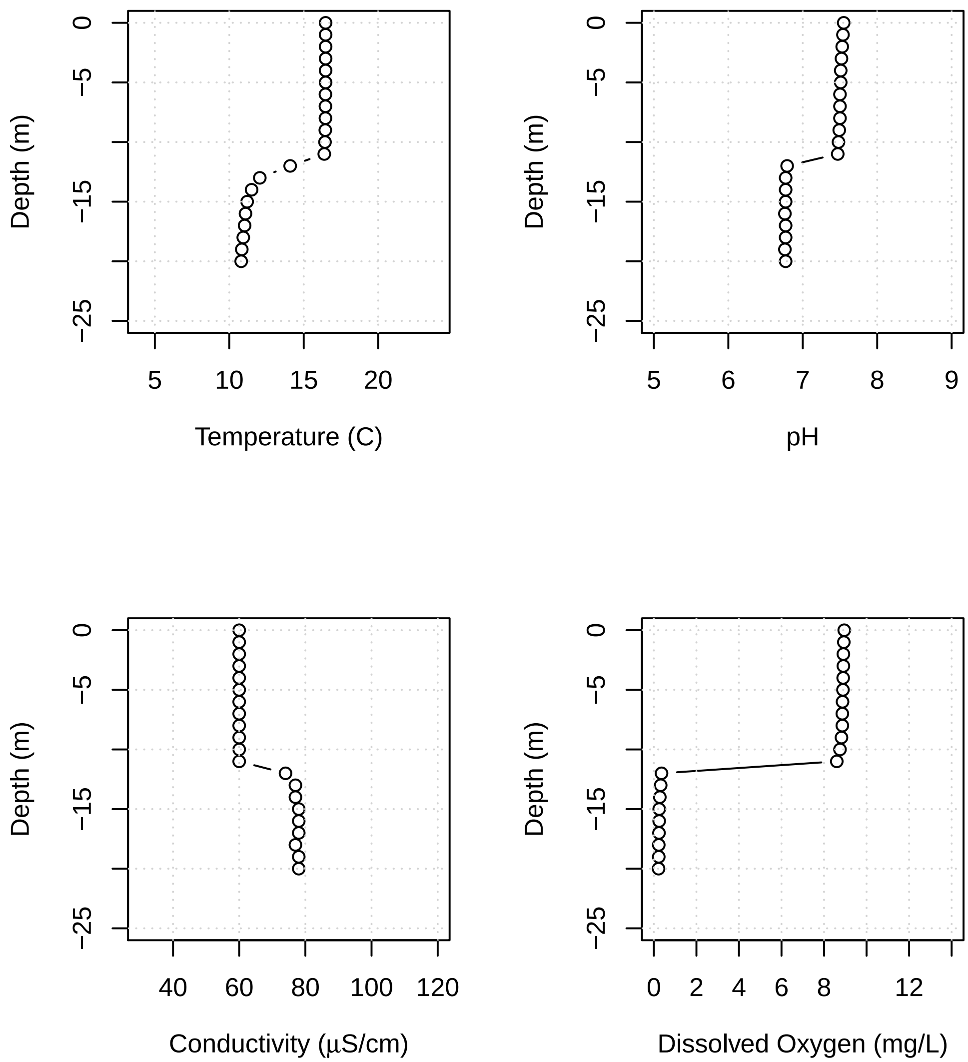


Figure B1: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, October 6, 2016.

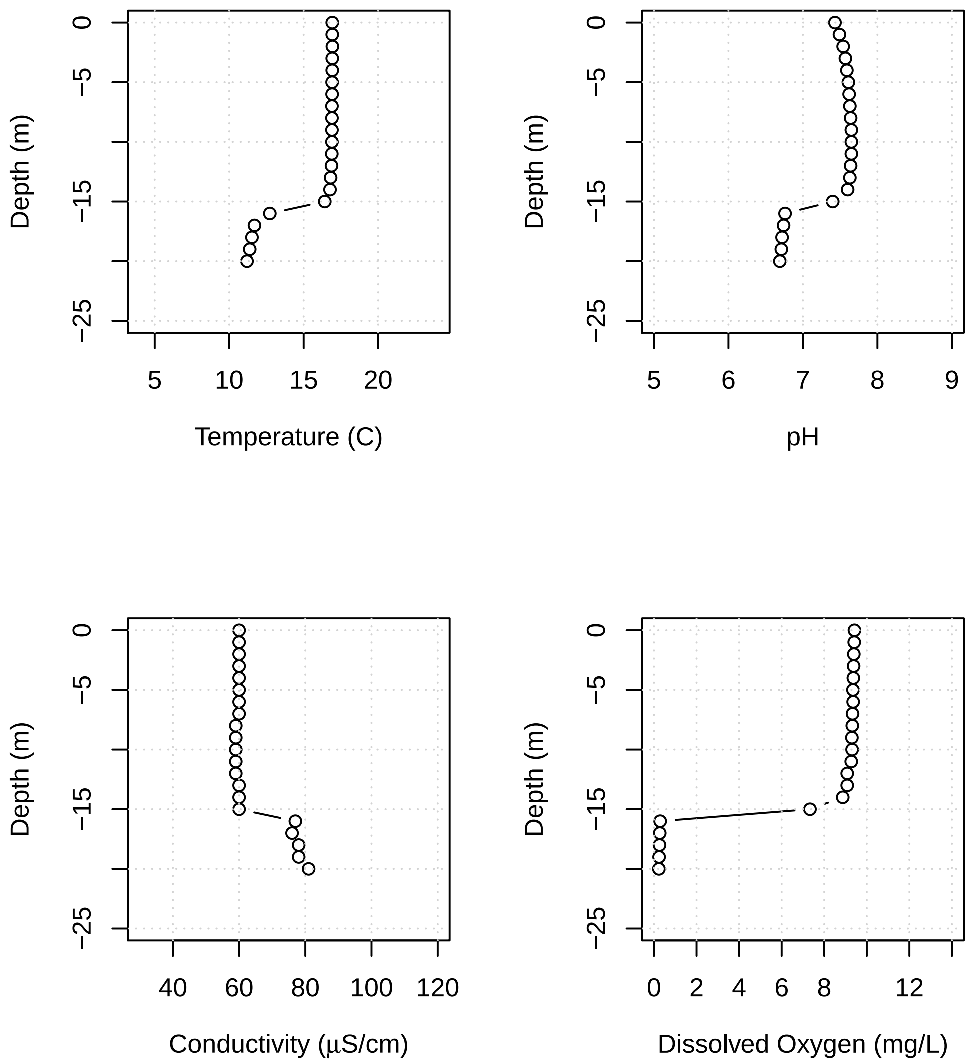


Figure B2: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, October 6, 2016.

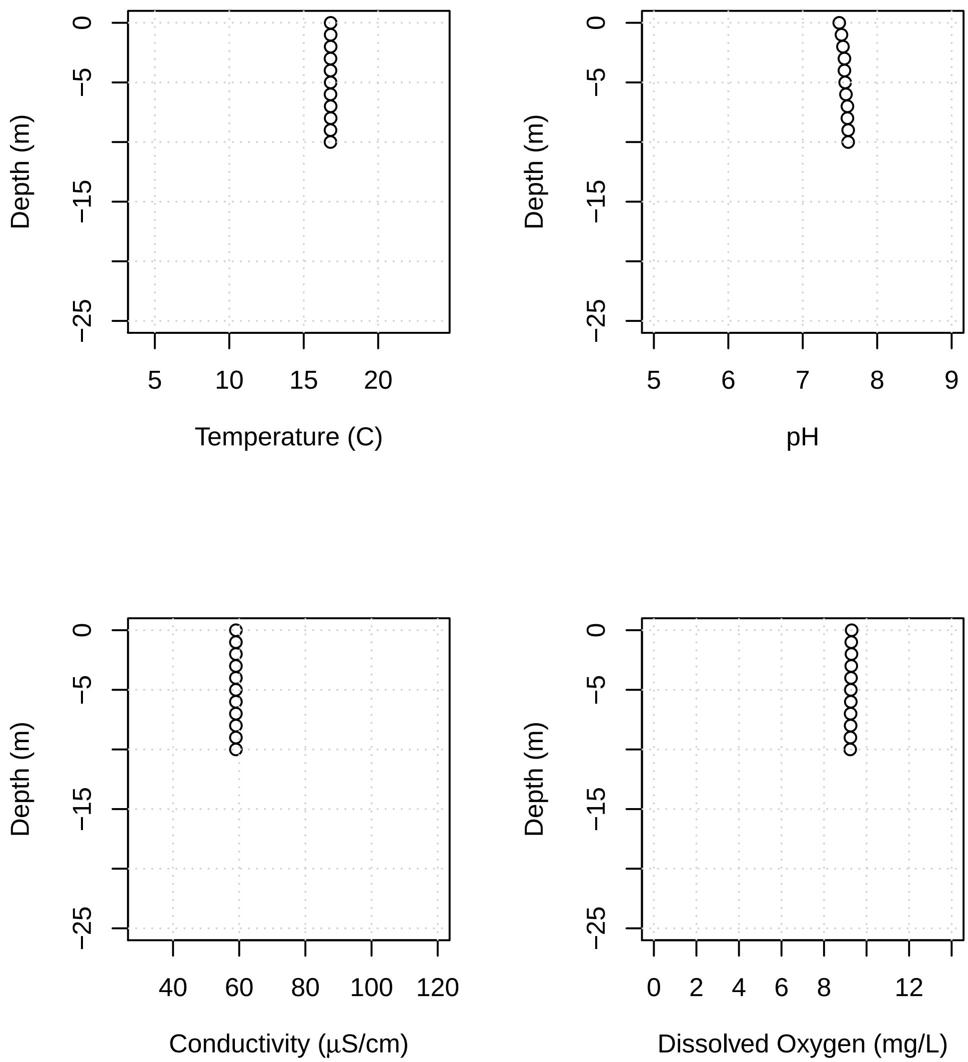


Figure B3: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, October 6, 2016.

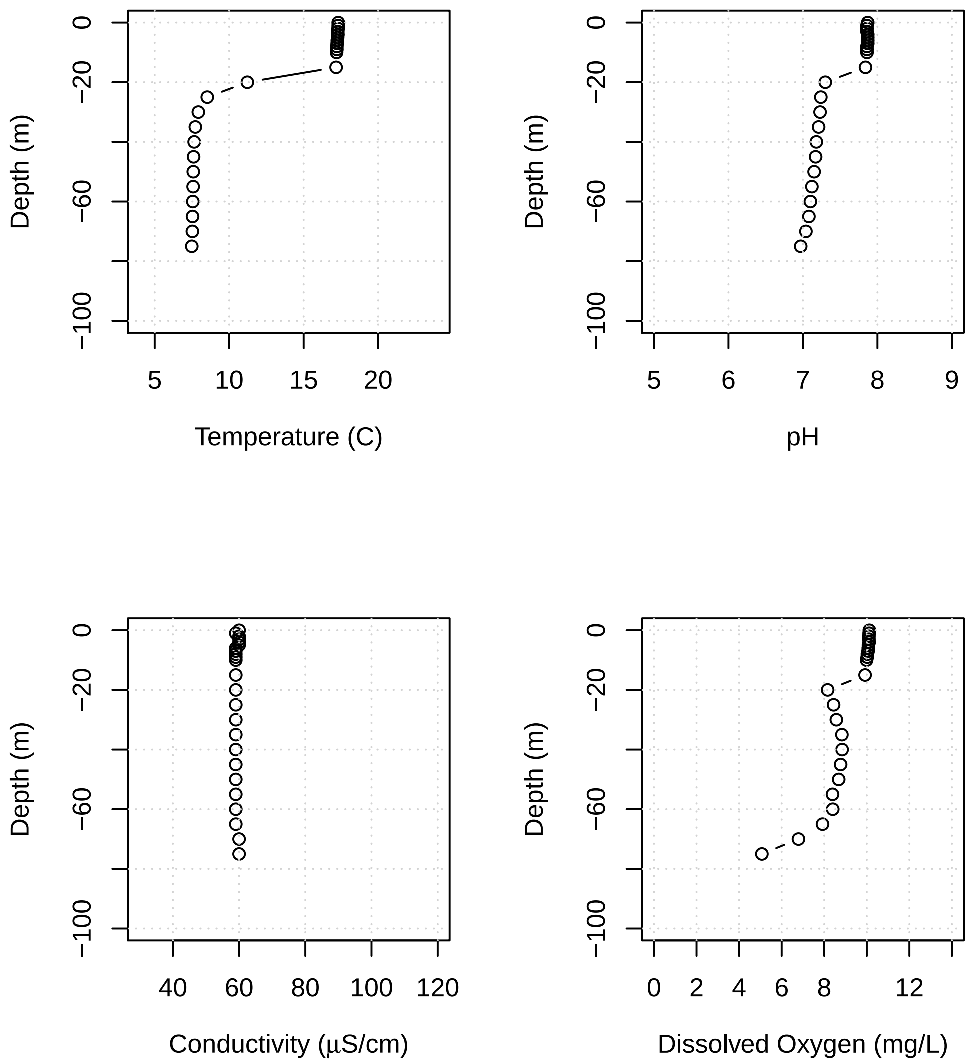


Figure B4: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, October 4, 2016.

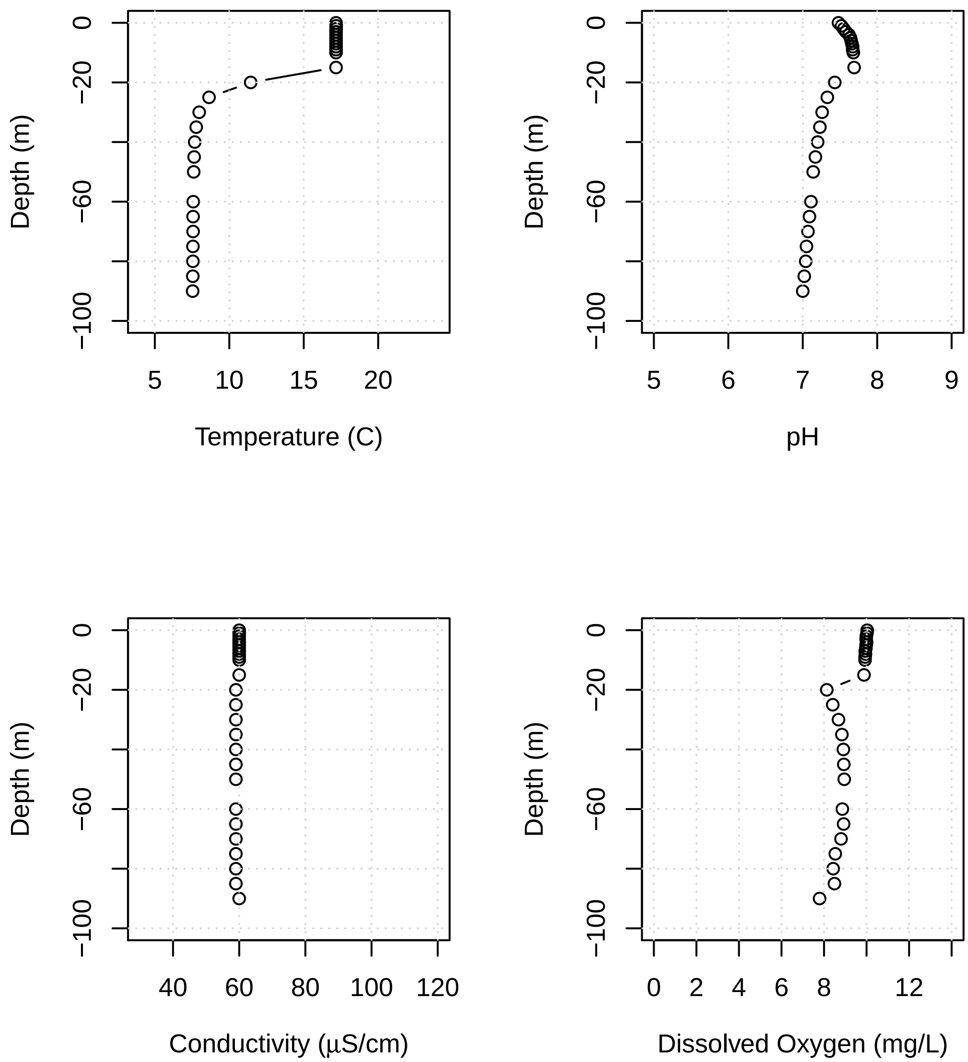


Figure B5: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, October 4, 2016.

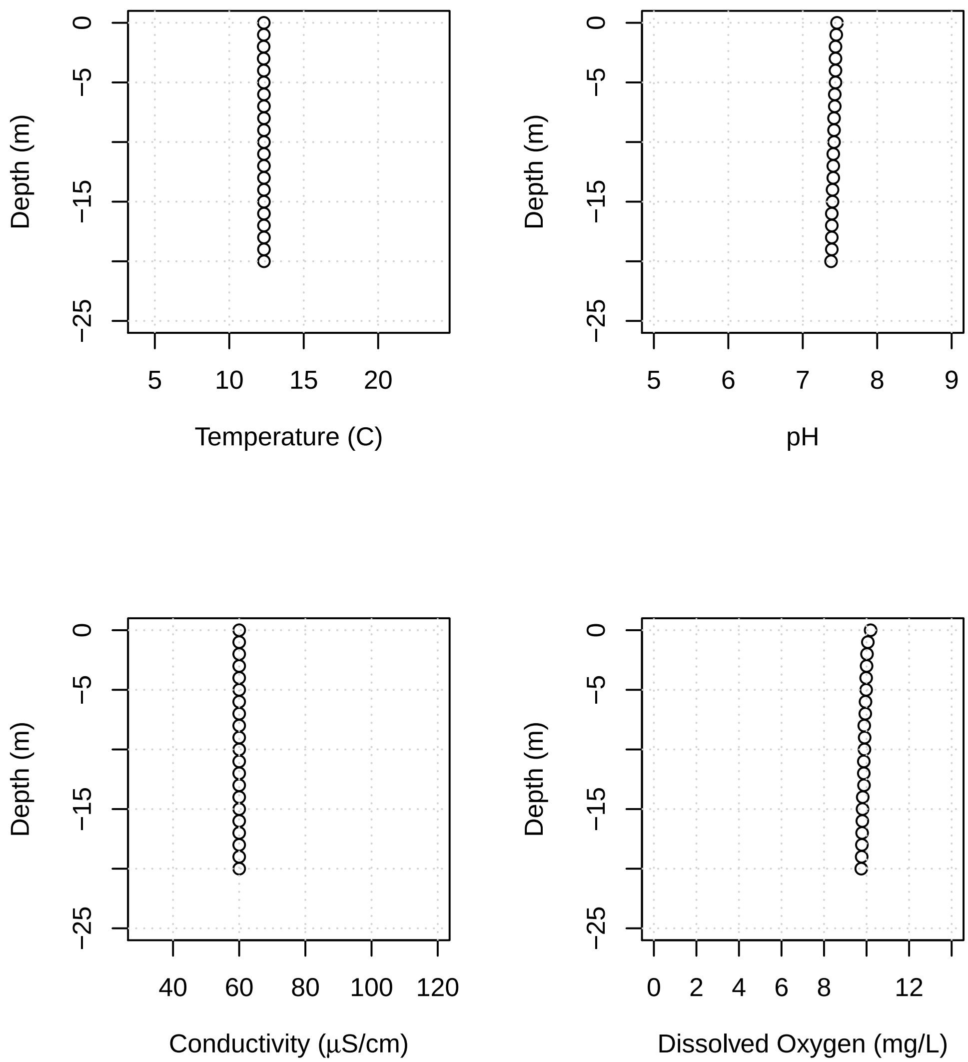


Figure B6: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, November 3, 2016.

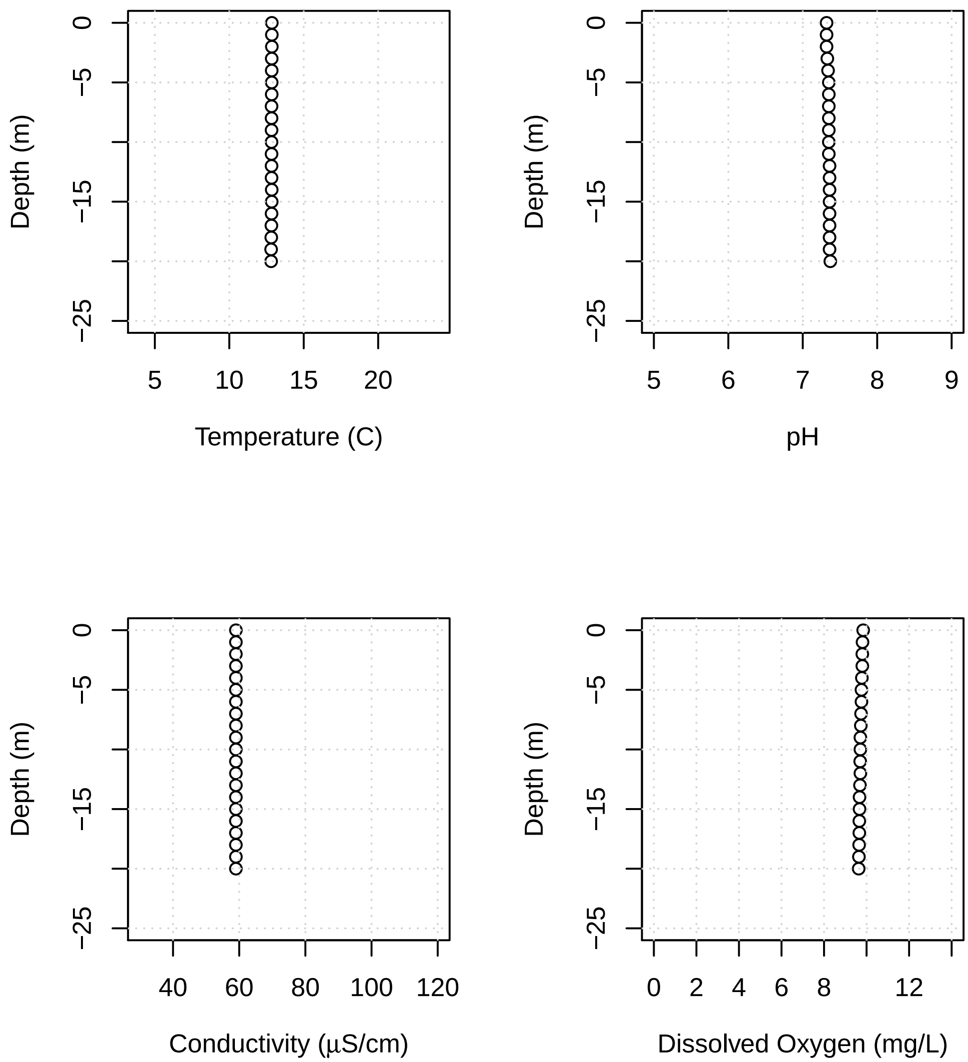


Figure B7: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, November 3, 2016.

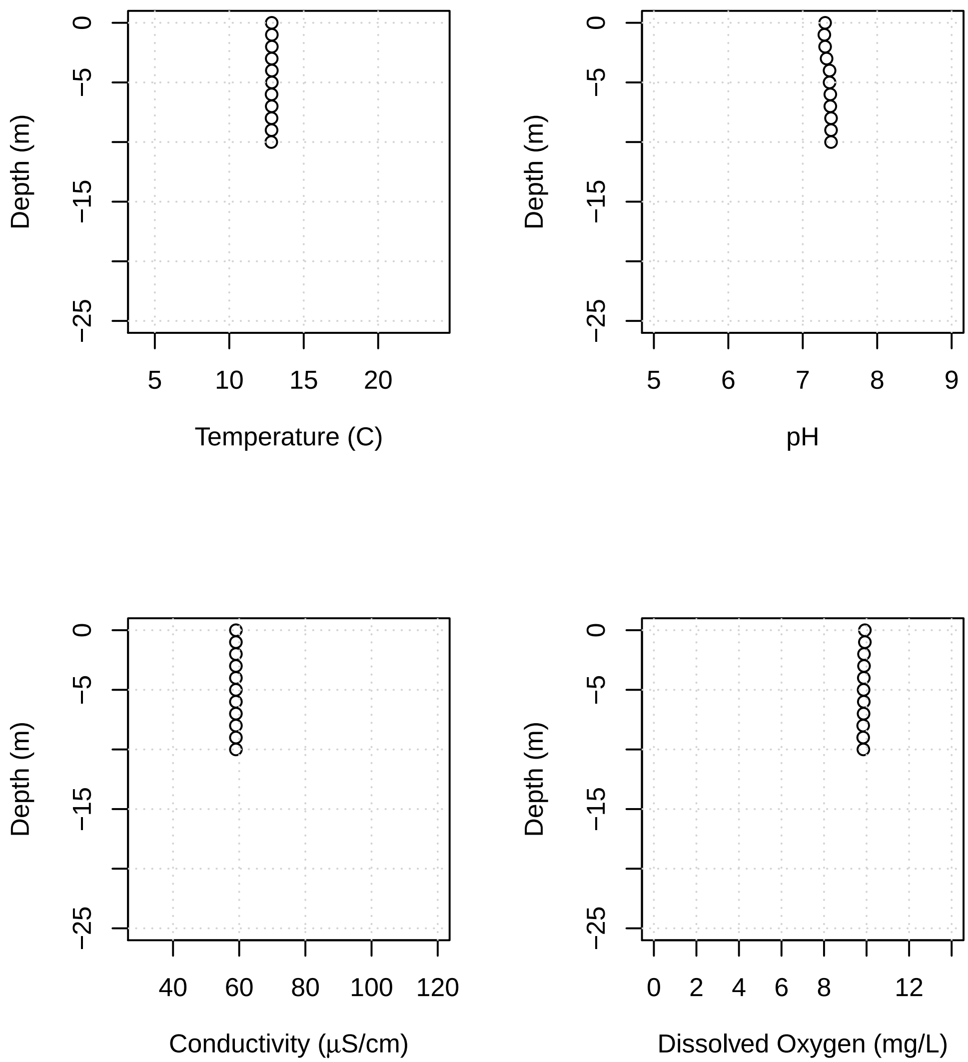


Figure B8: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, November 3, 2016.

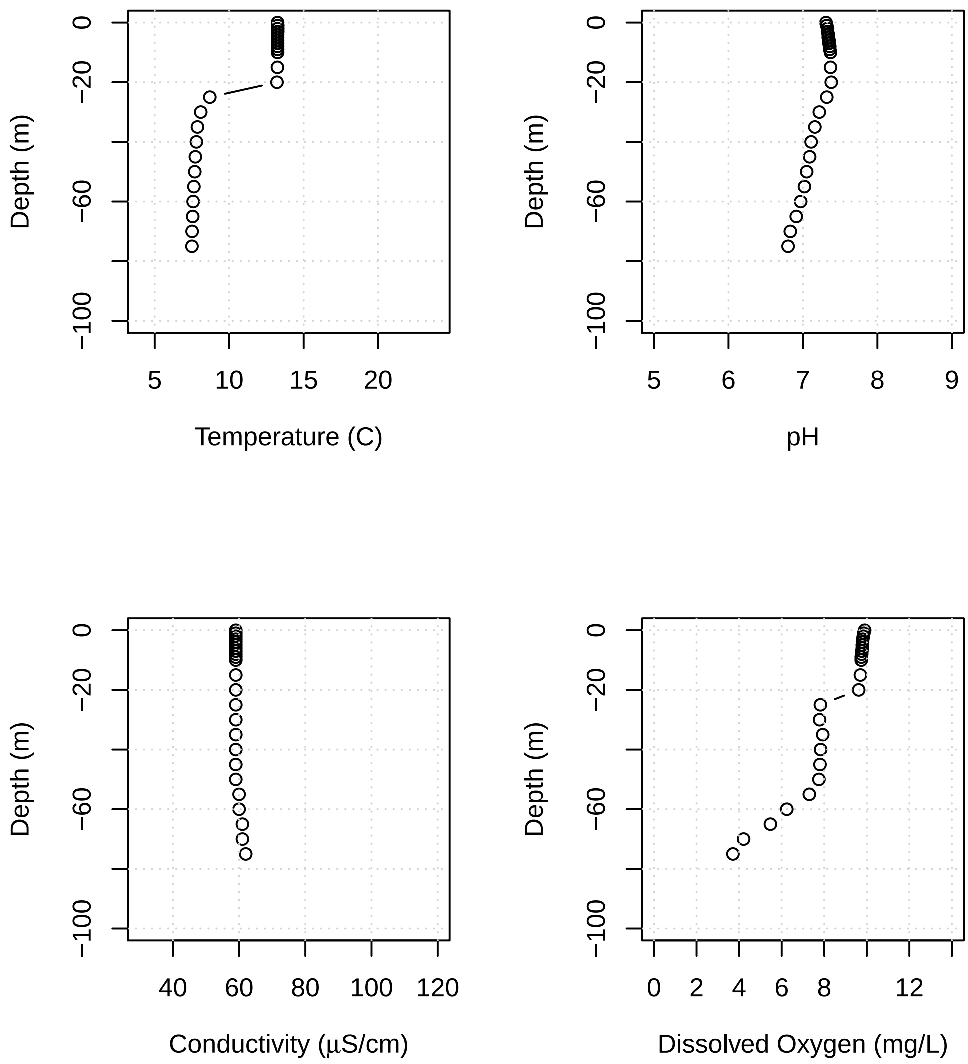


Figure B9: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, November 1, 2016.

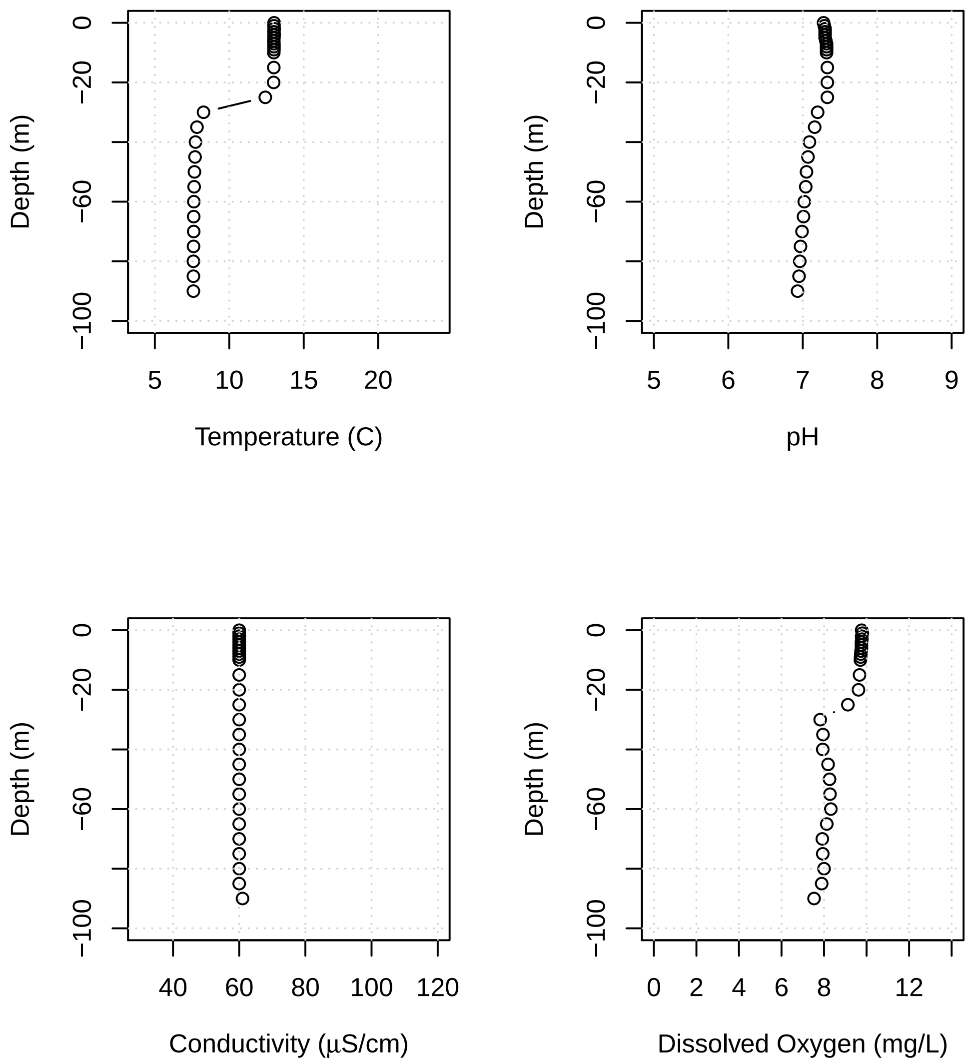


Figure B10: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, November 1, 2016.

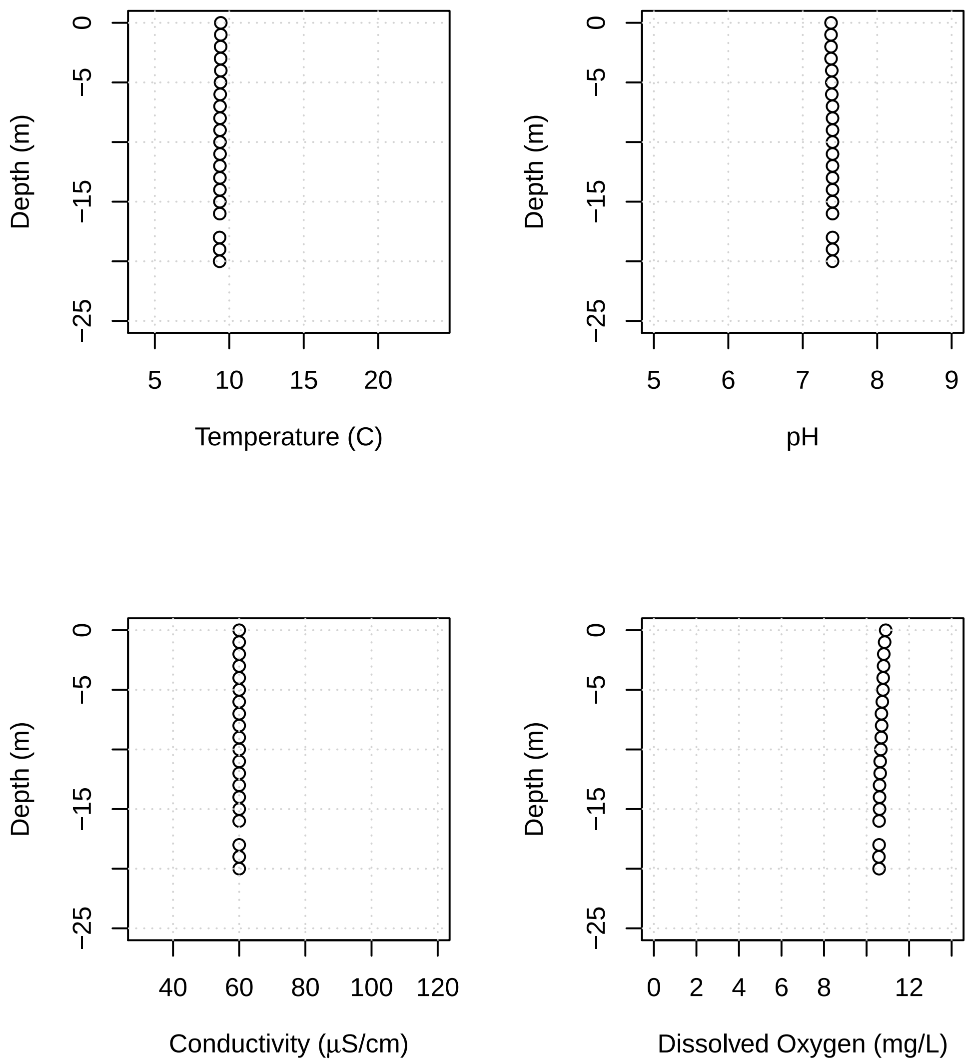


Figure B11: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, December 1, 2016.

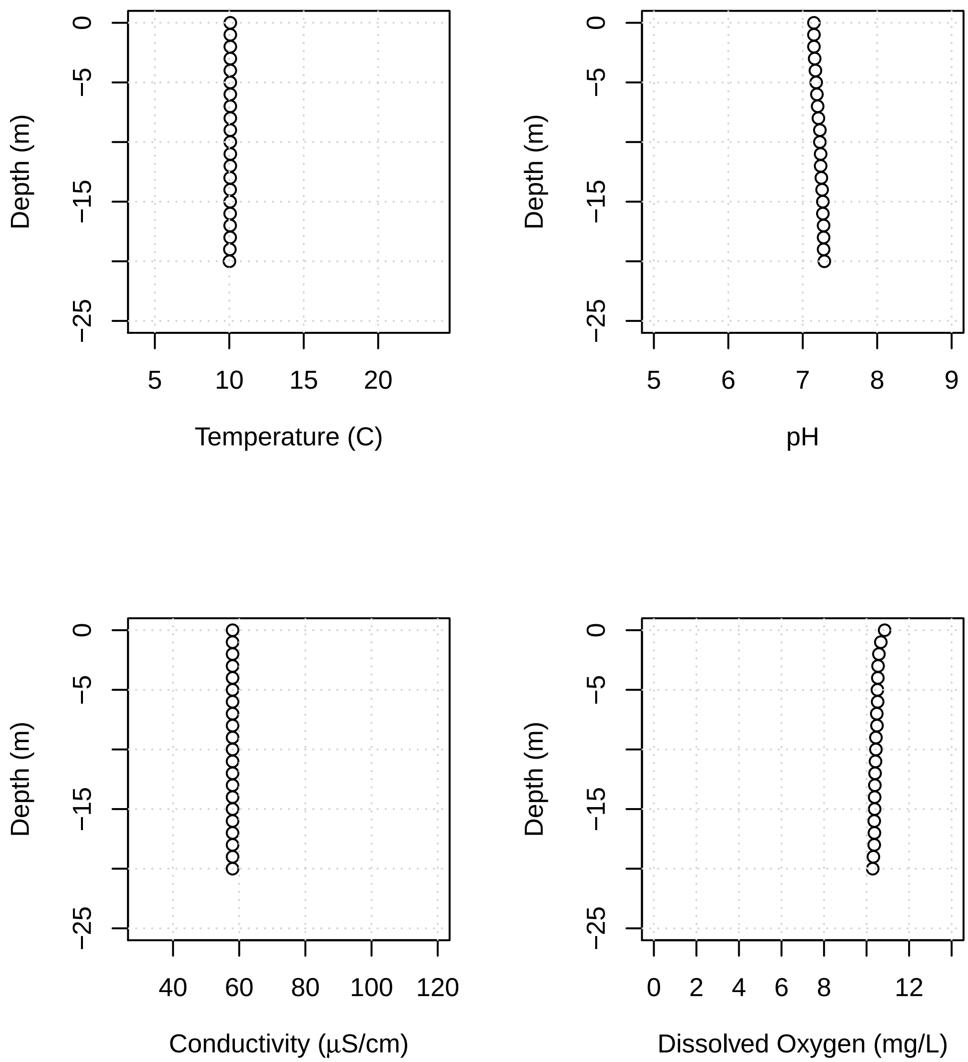


Figure B12: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, December 1, 2016.

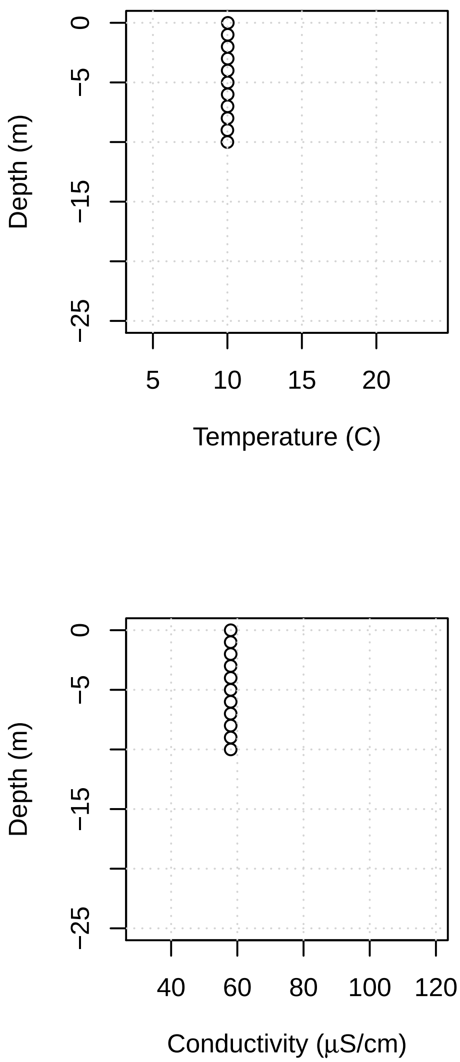


Figure B13: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, December 1, 2016.

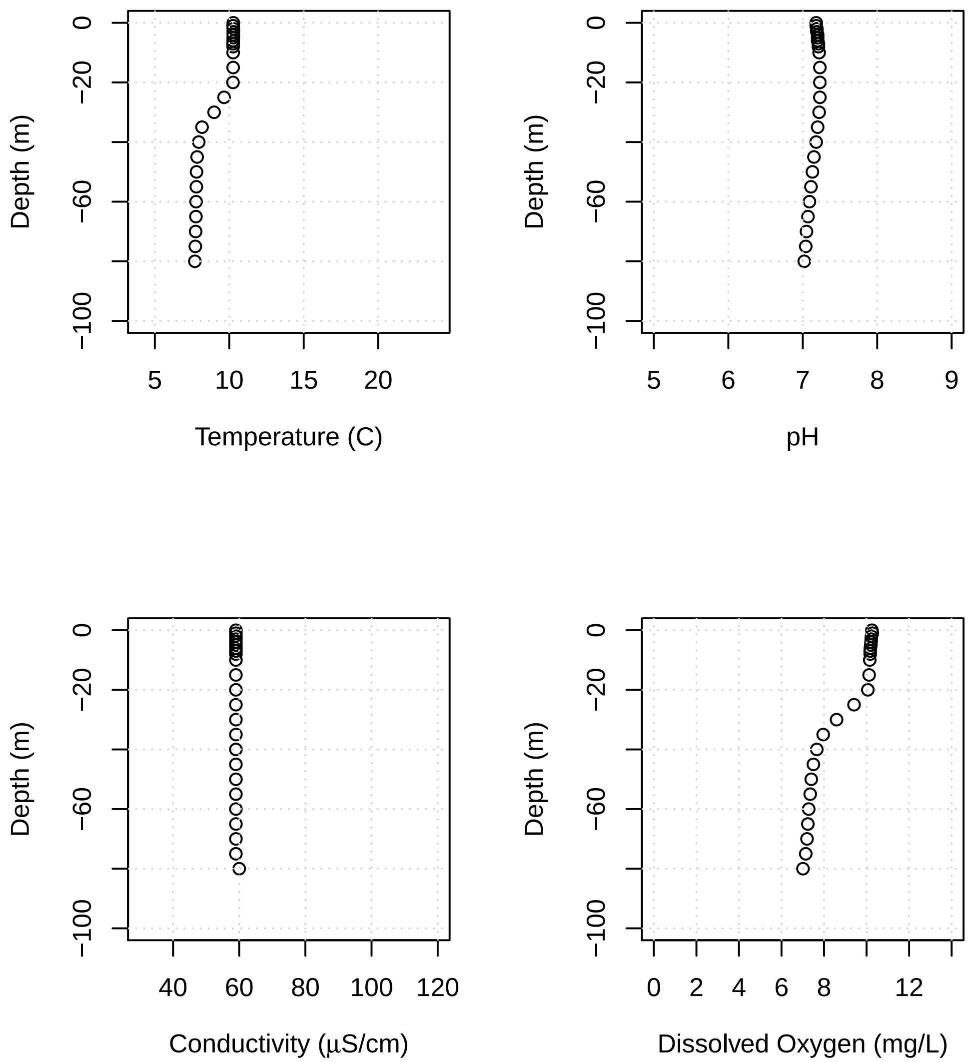


Figure B14: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, December 1, 2016.

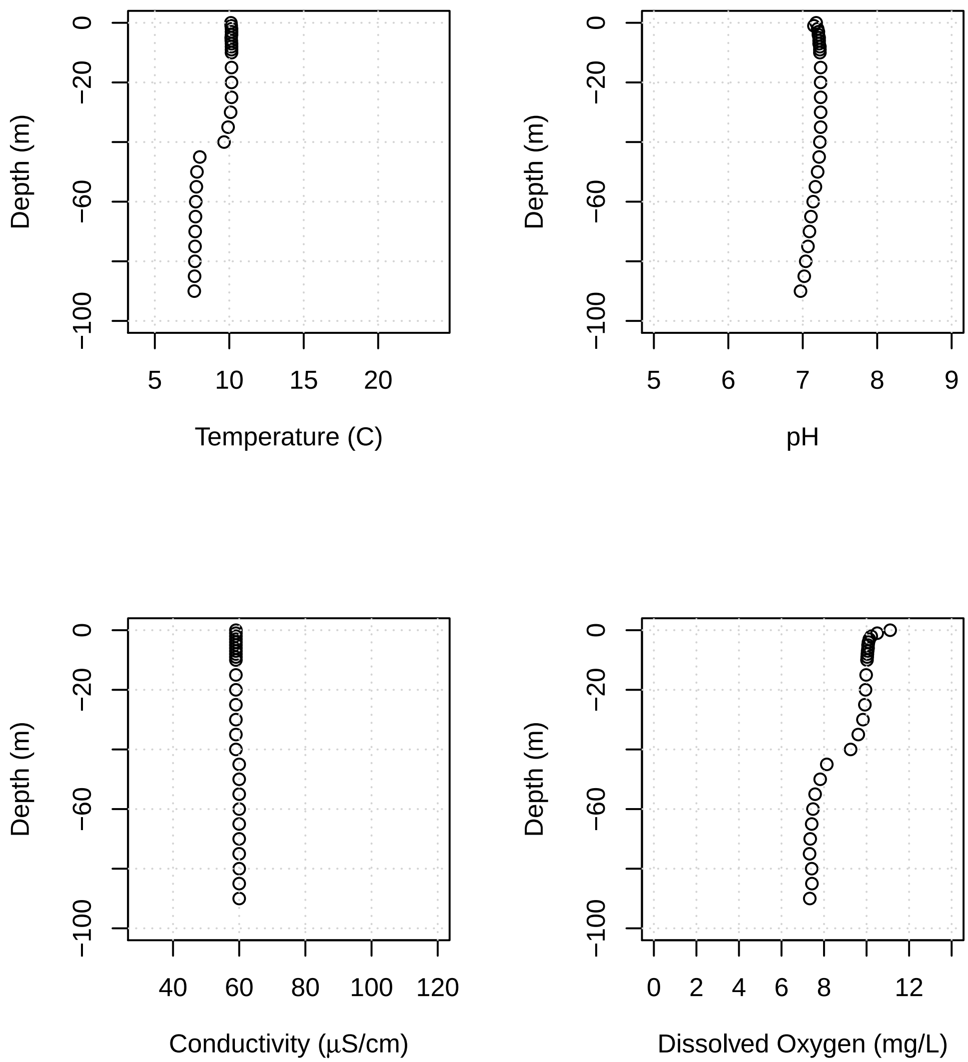


Figure B15: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, December 1, 2016.

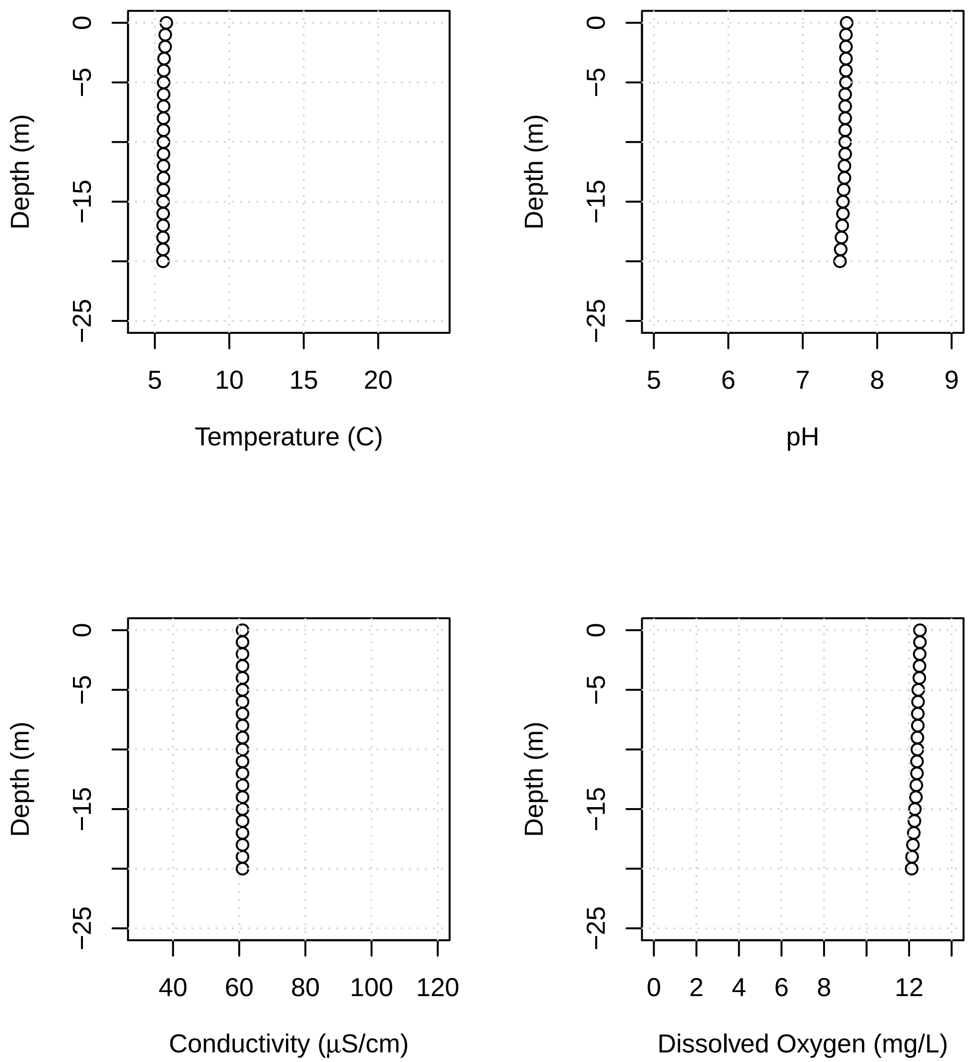


Figure B16: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, February 23, 2017.

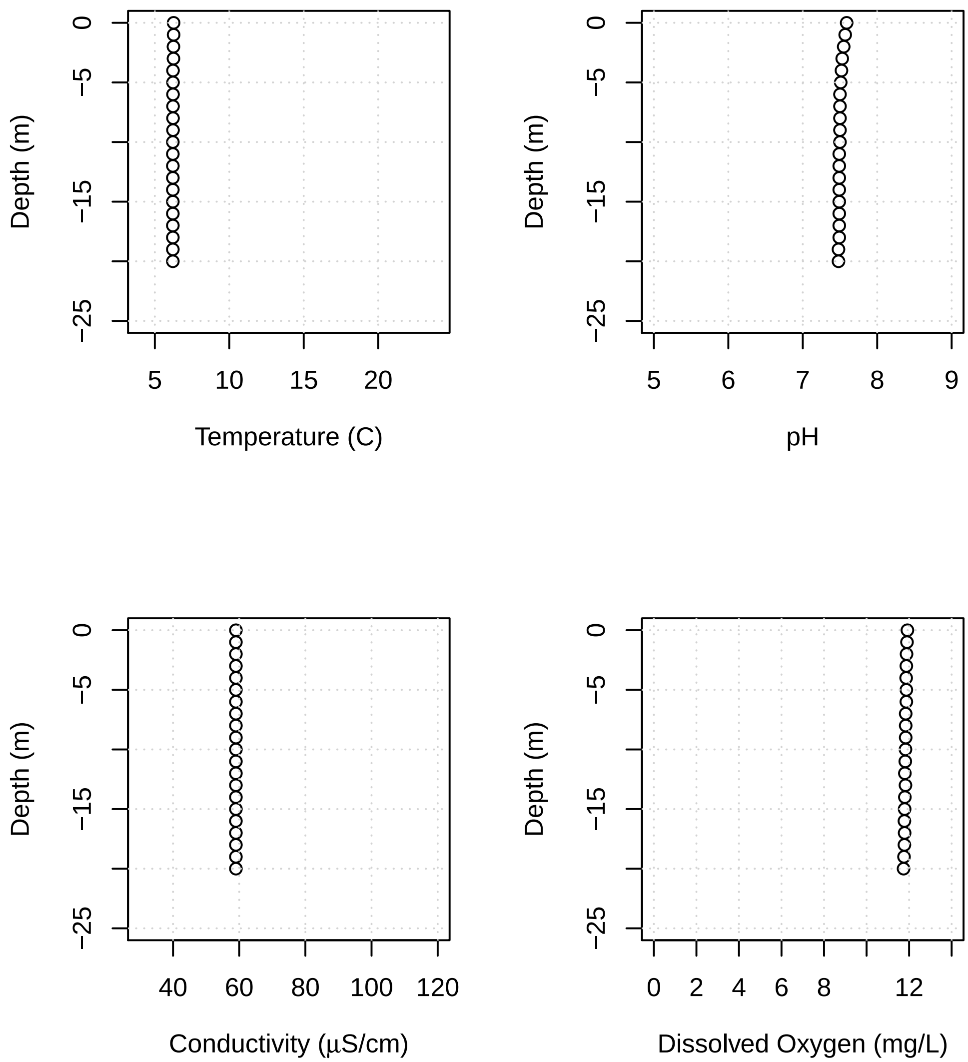


Figure B17: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, February 23, 2017.

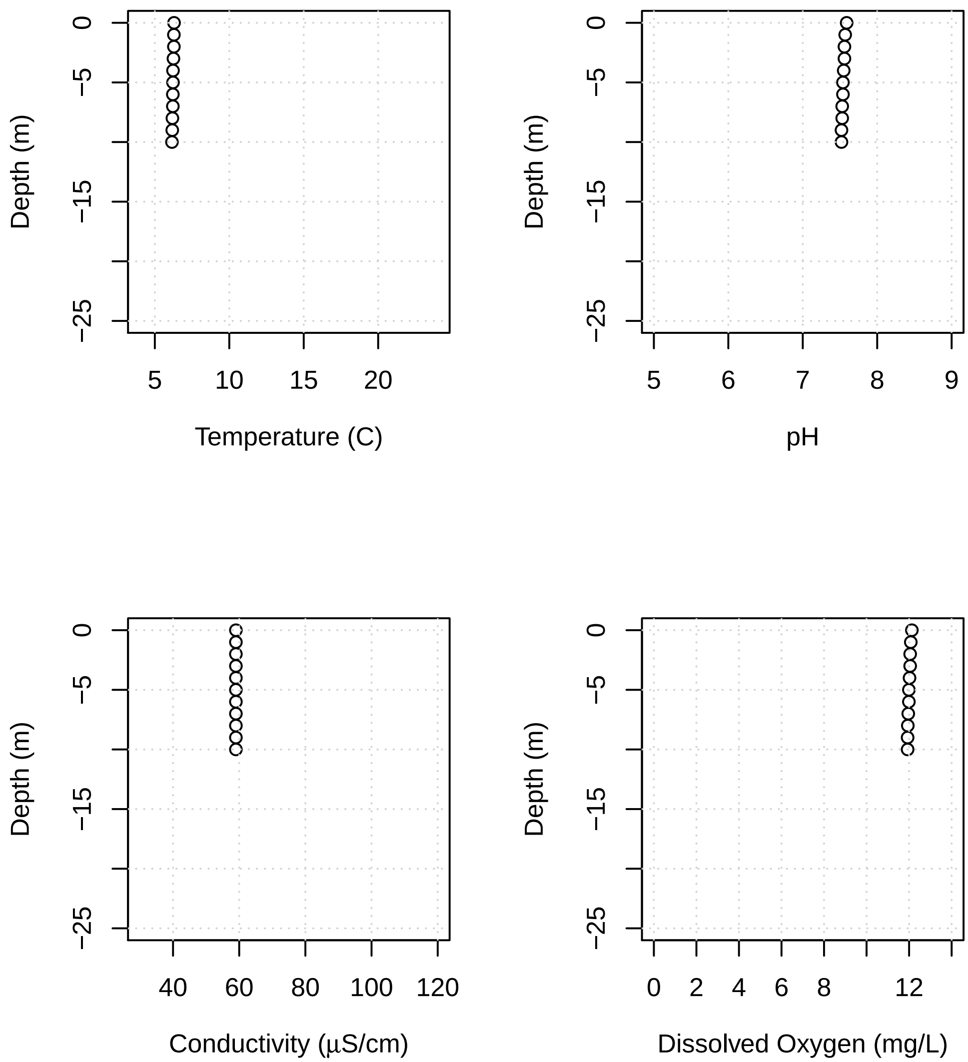


Figure B18: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, February 23, 2017.

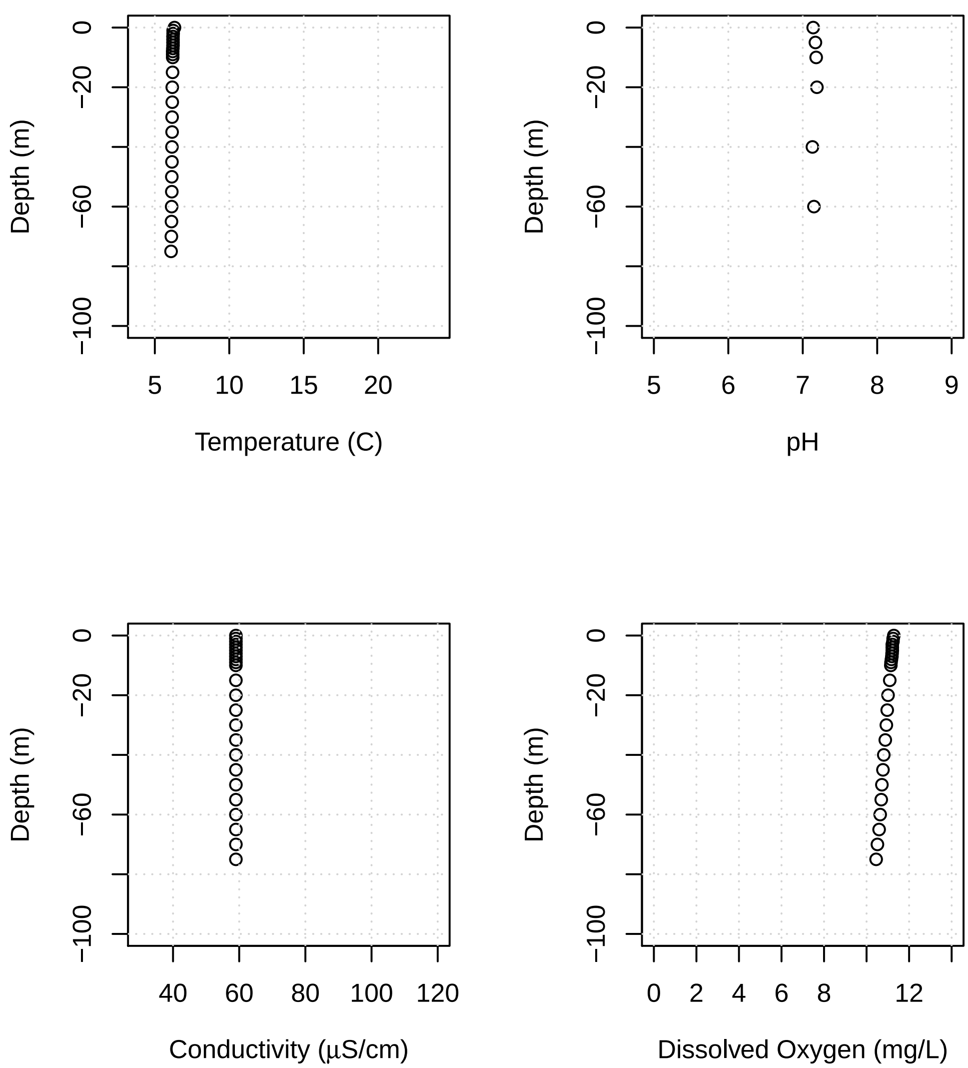


Figure B19: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, February 21, 2017. Due to equipment failure, the pH values were measured in the laboratory.

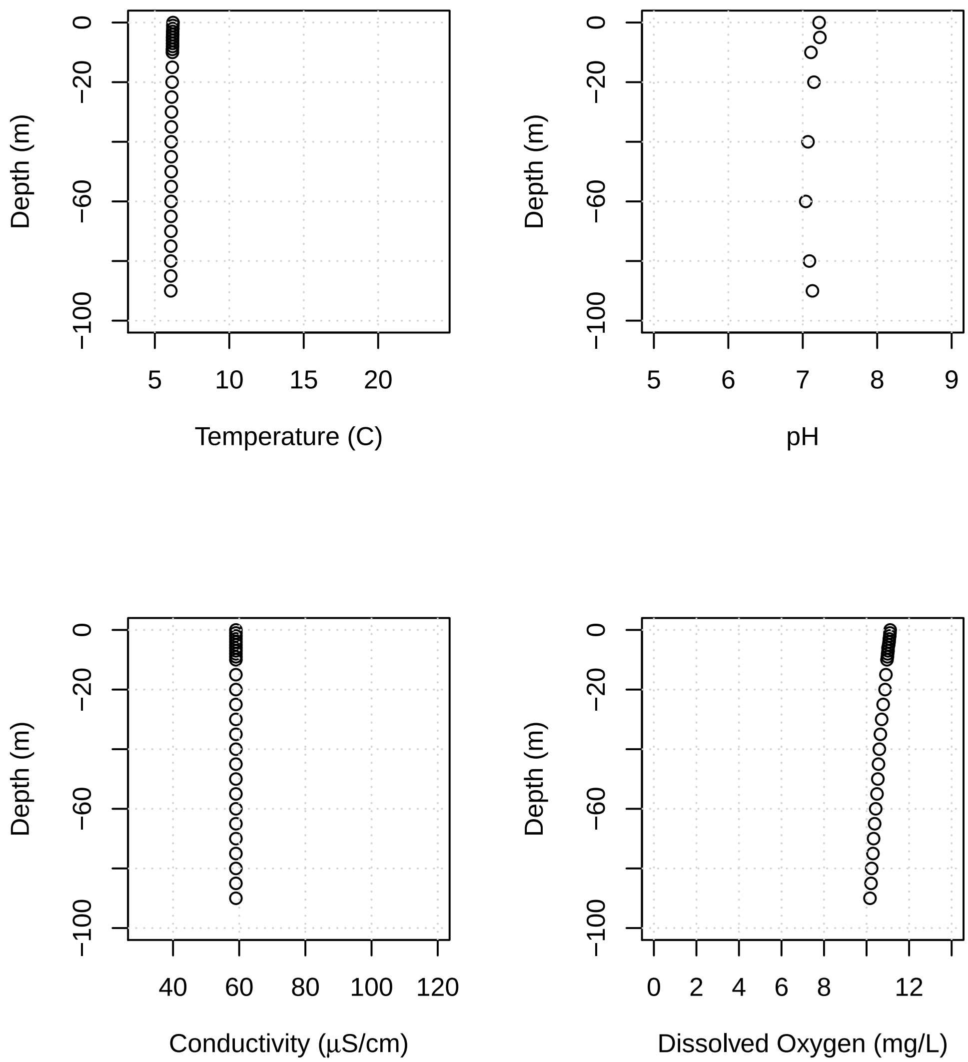


Figure B20: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, February 21, 2017. Due to equipment failure, the pH values were measured in the laboratory.

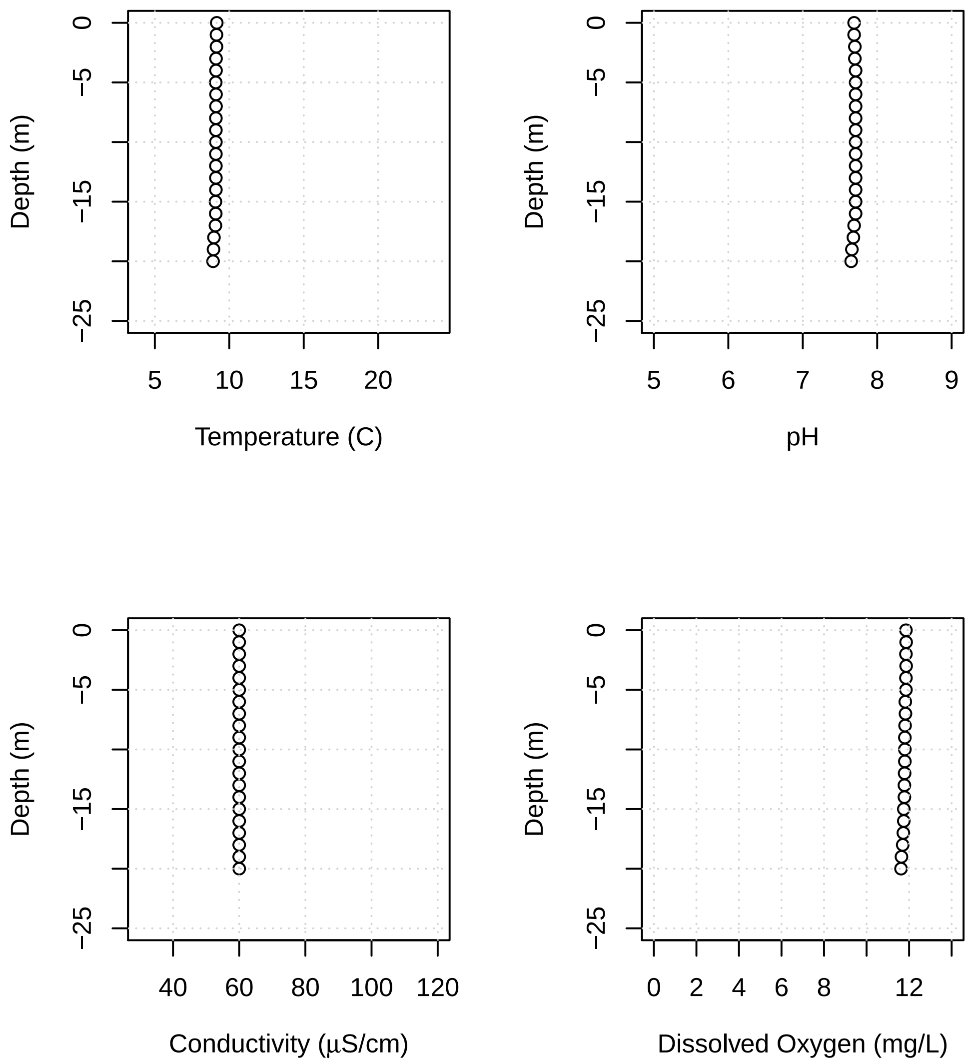


Figure B21: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, April 13, 2017.

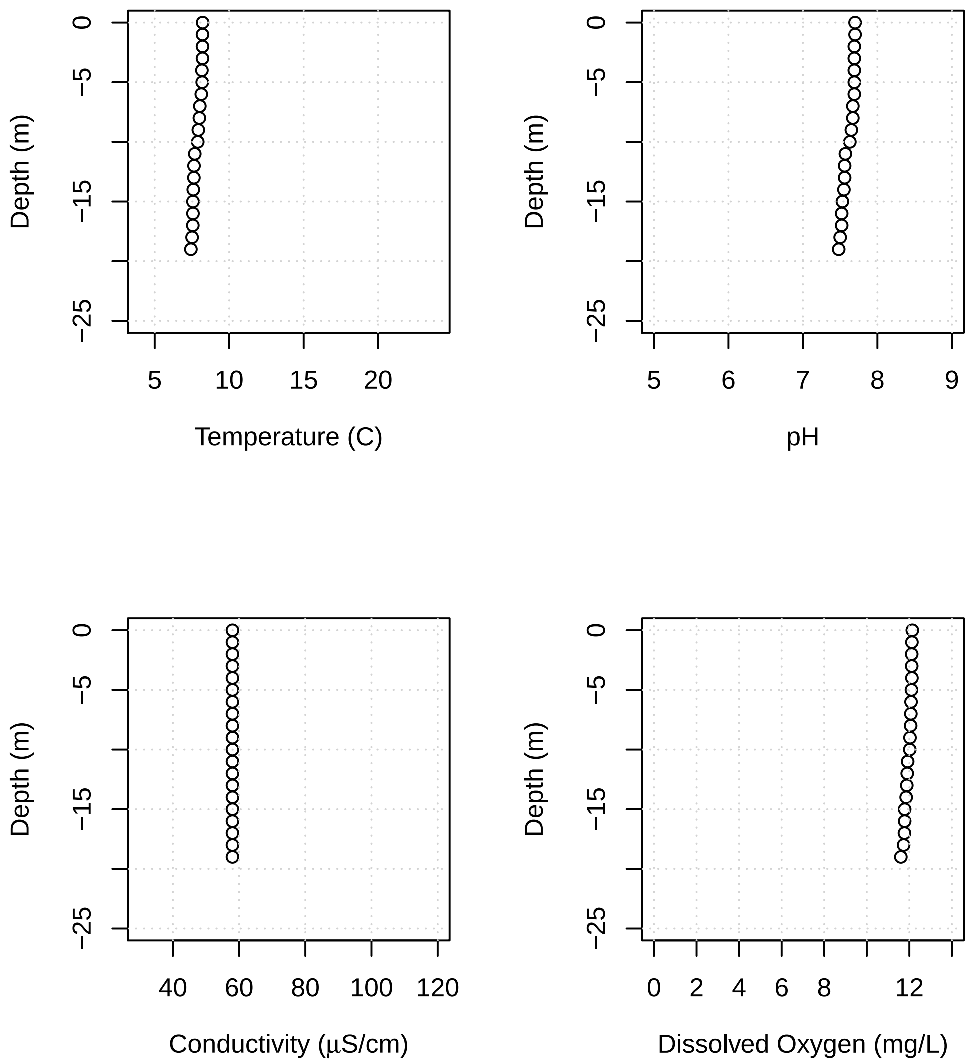


Figure B22: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, April 13, 2017.

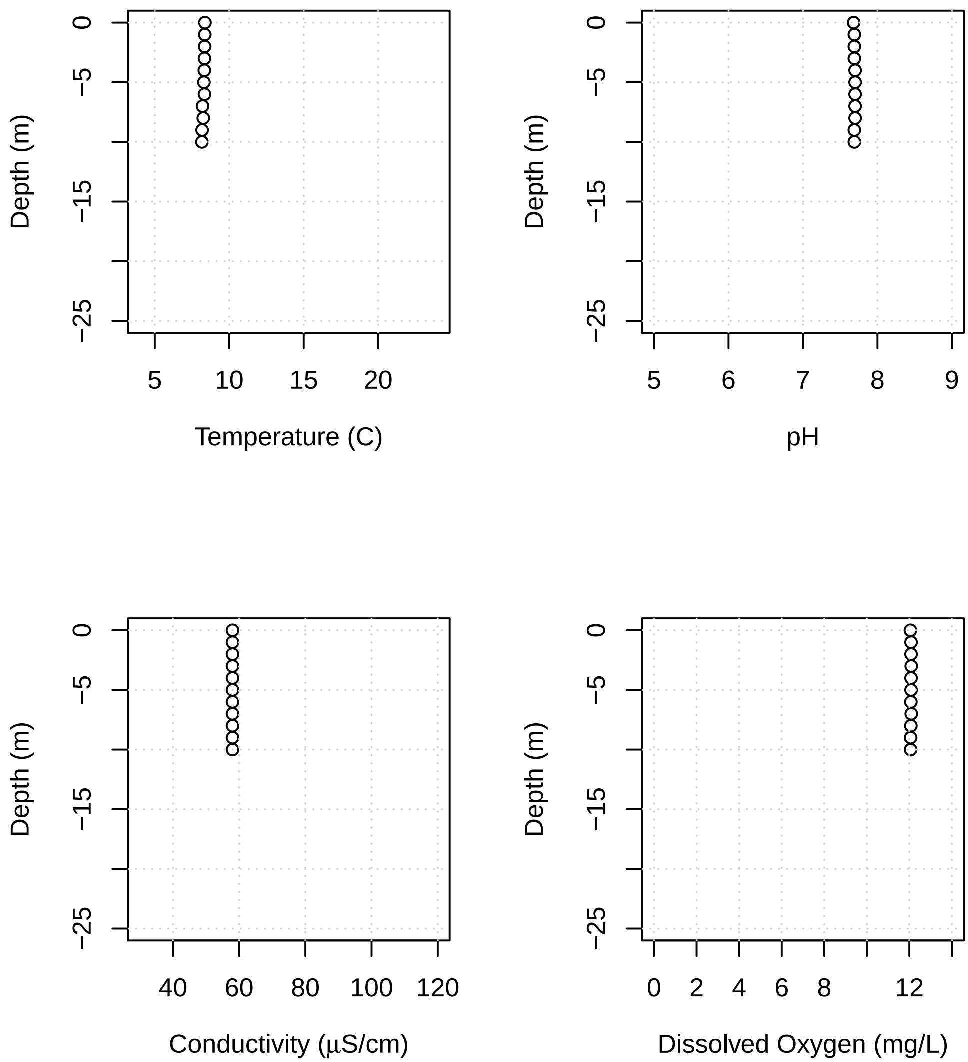


Figure B23: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, April 13, 2017.

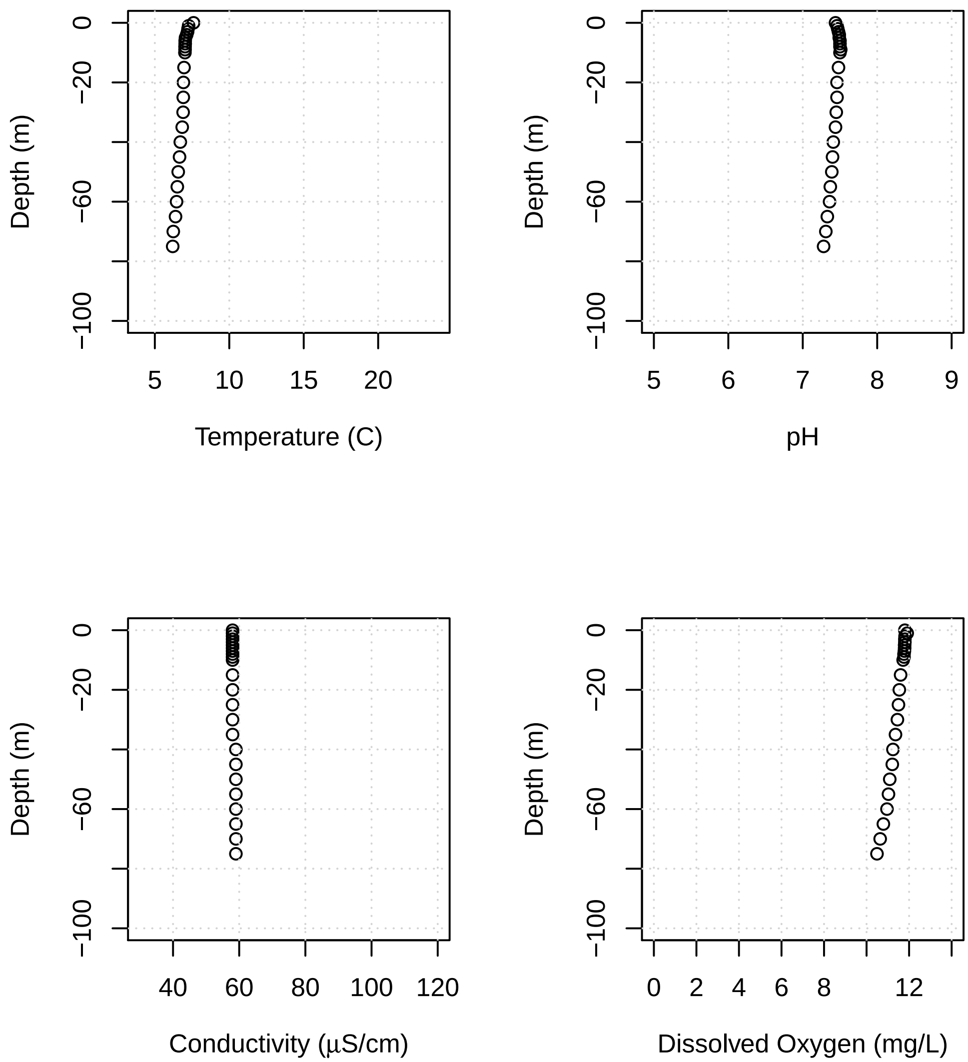


Figure B24: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, April 11, 2017.

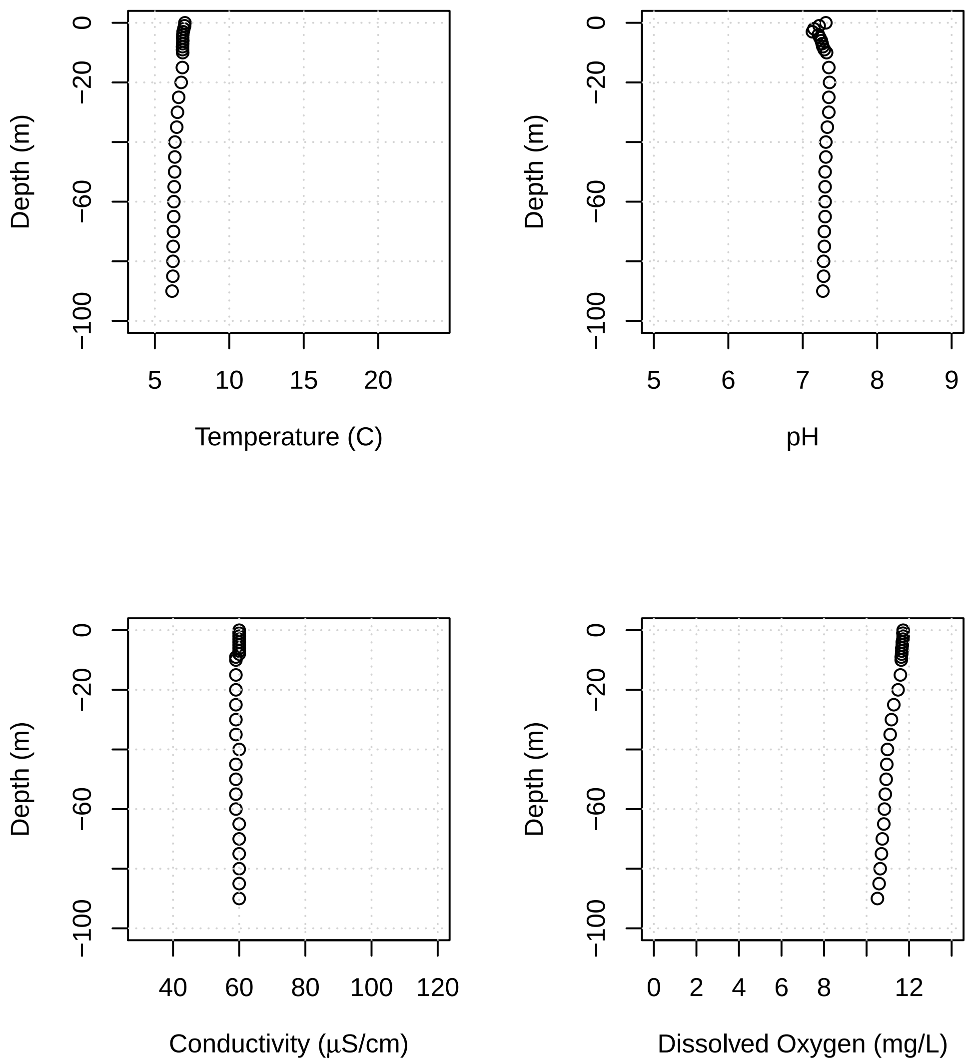


Figure B25: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, April 11, 2017.

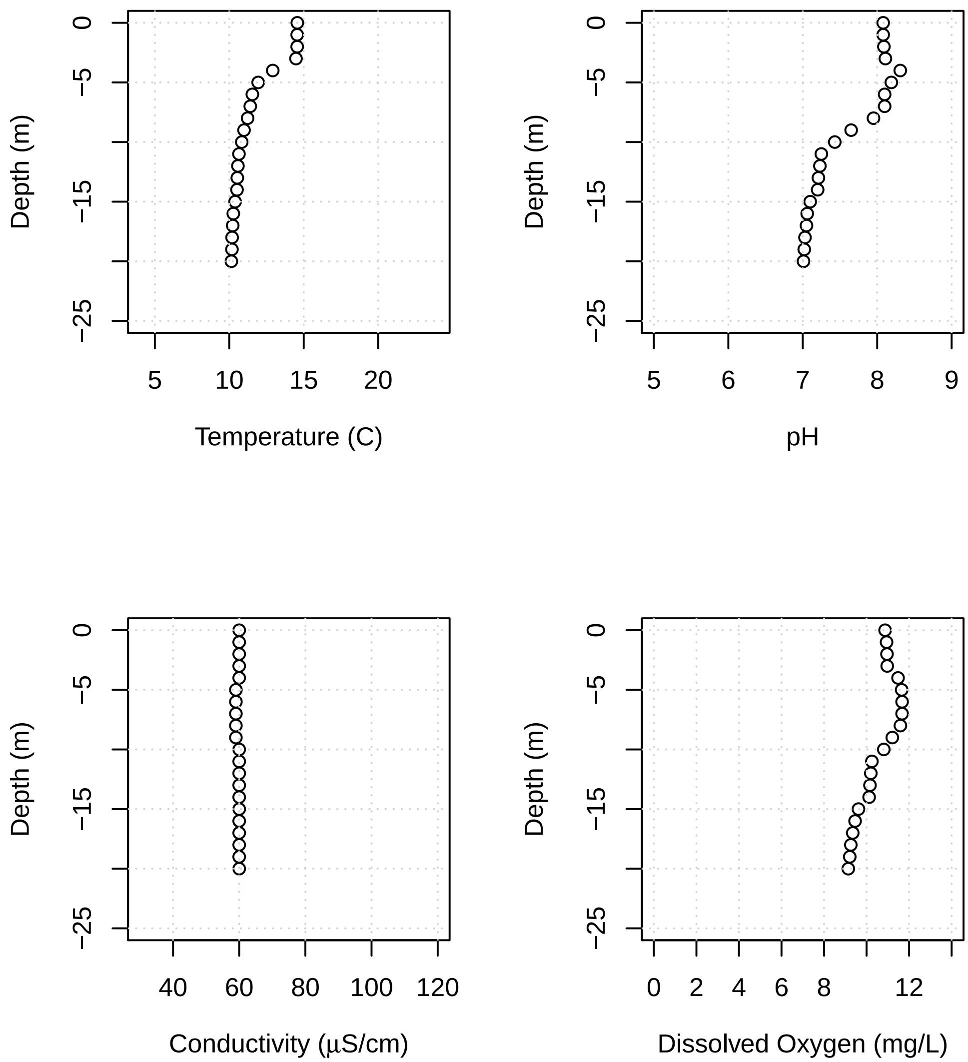


Figure B26: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, May 11, 2017.

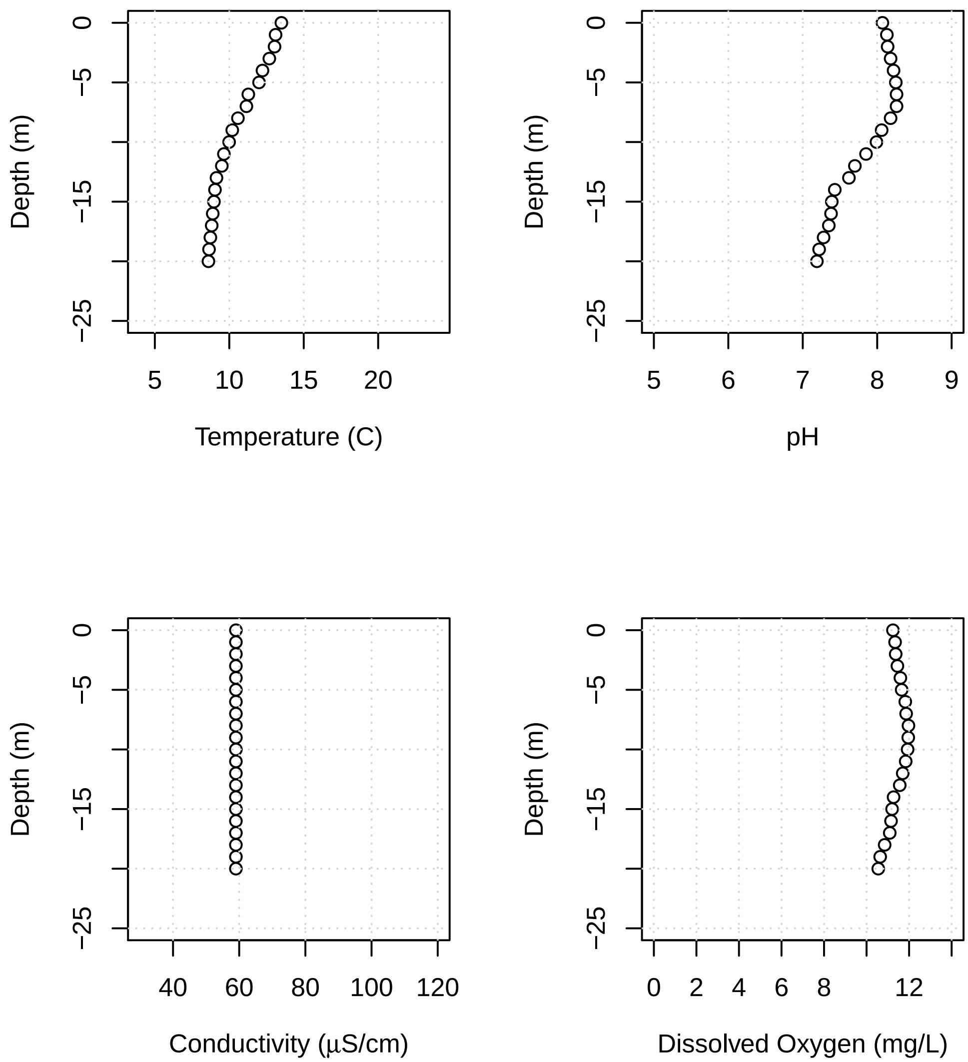


Figure B27: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, May 11, 2017.

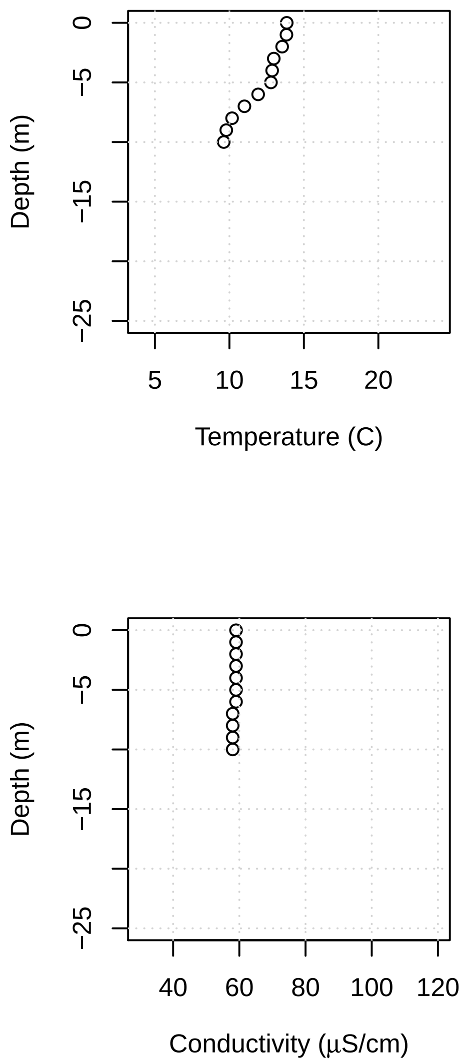


Figure B28: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, May 11, 2017.

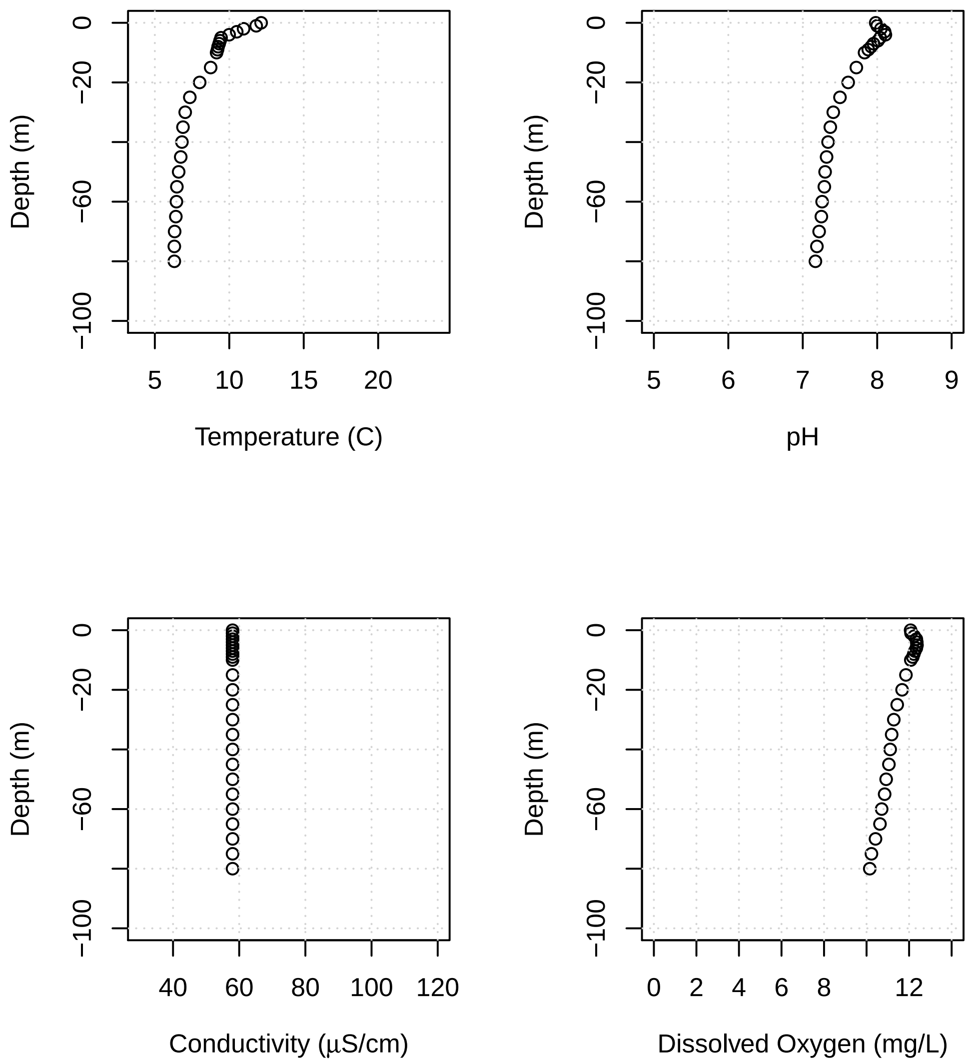


Figure B29: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, May 4, 2017.

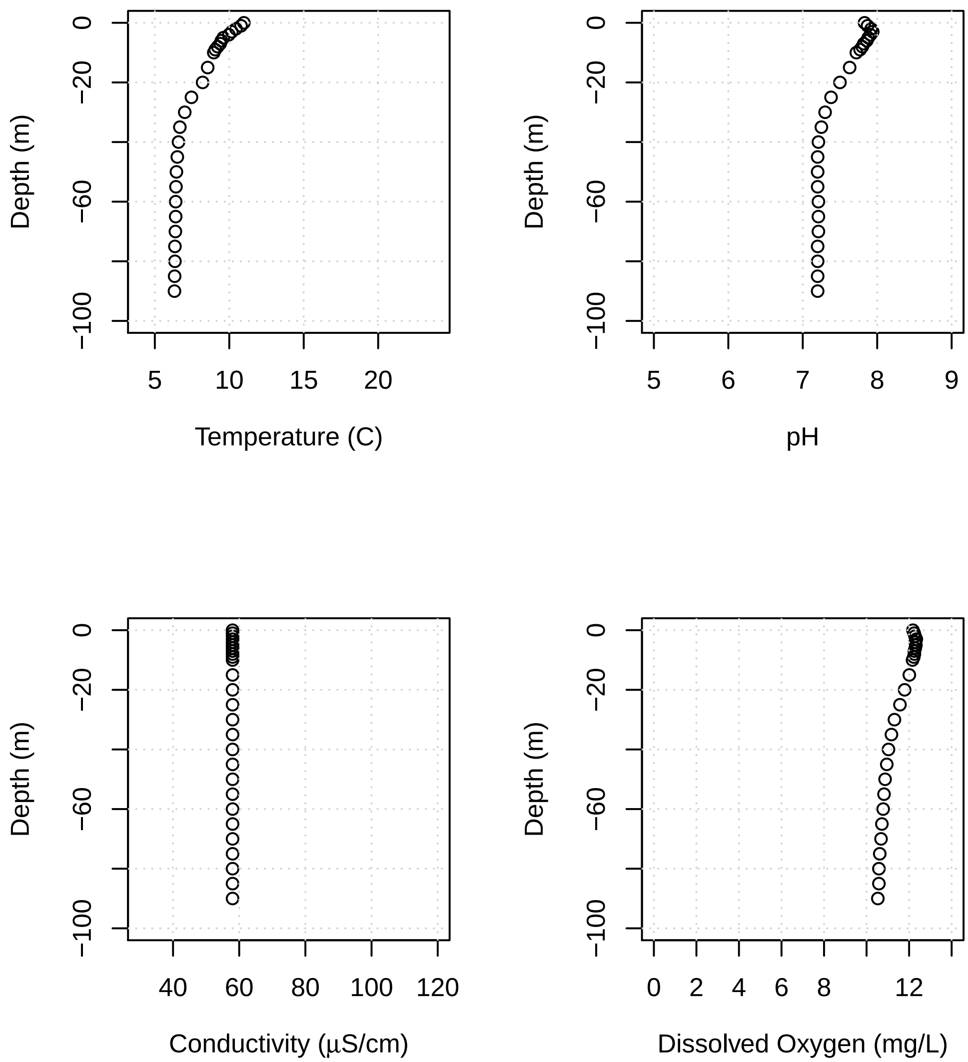


Figure B30: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, May 4, 2017.

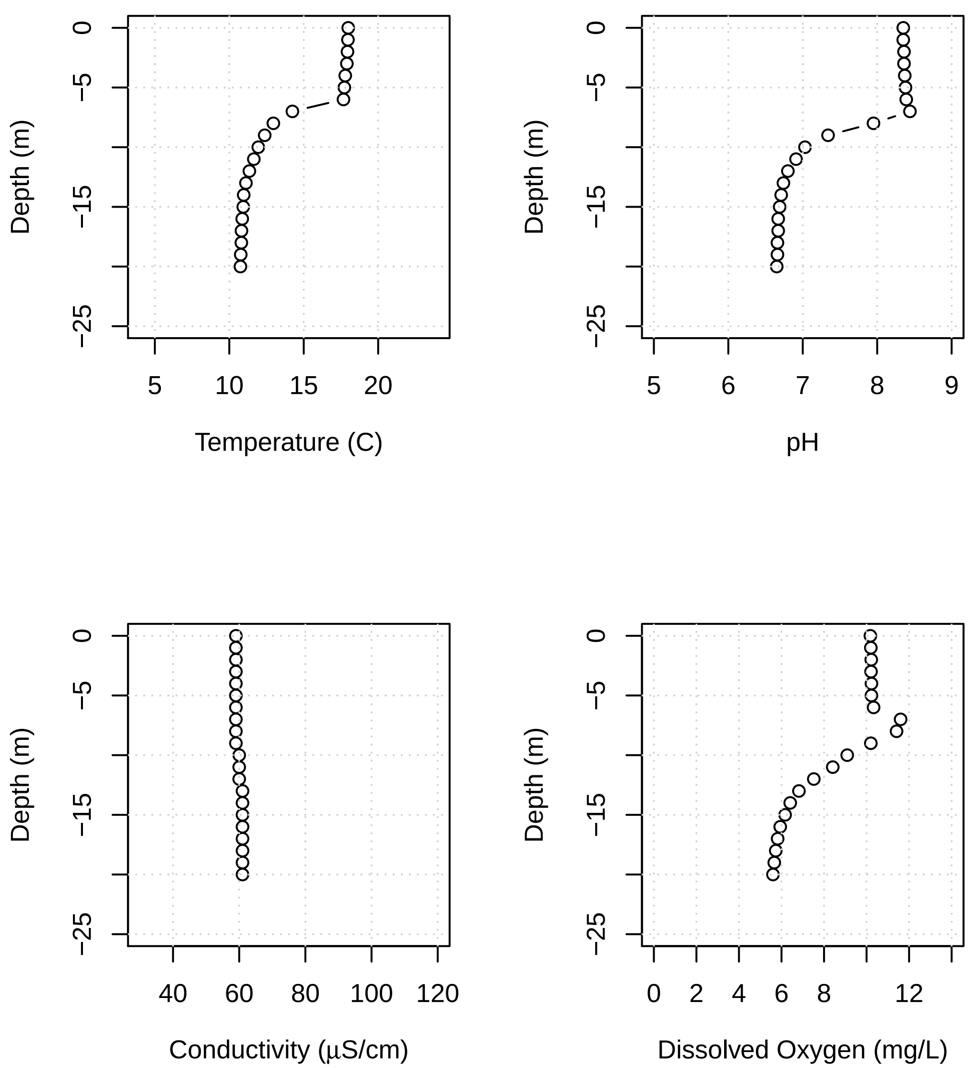


Figure B31: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, June 13, 2017.

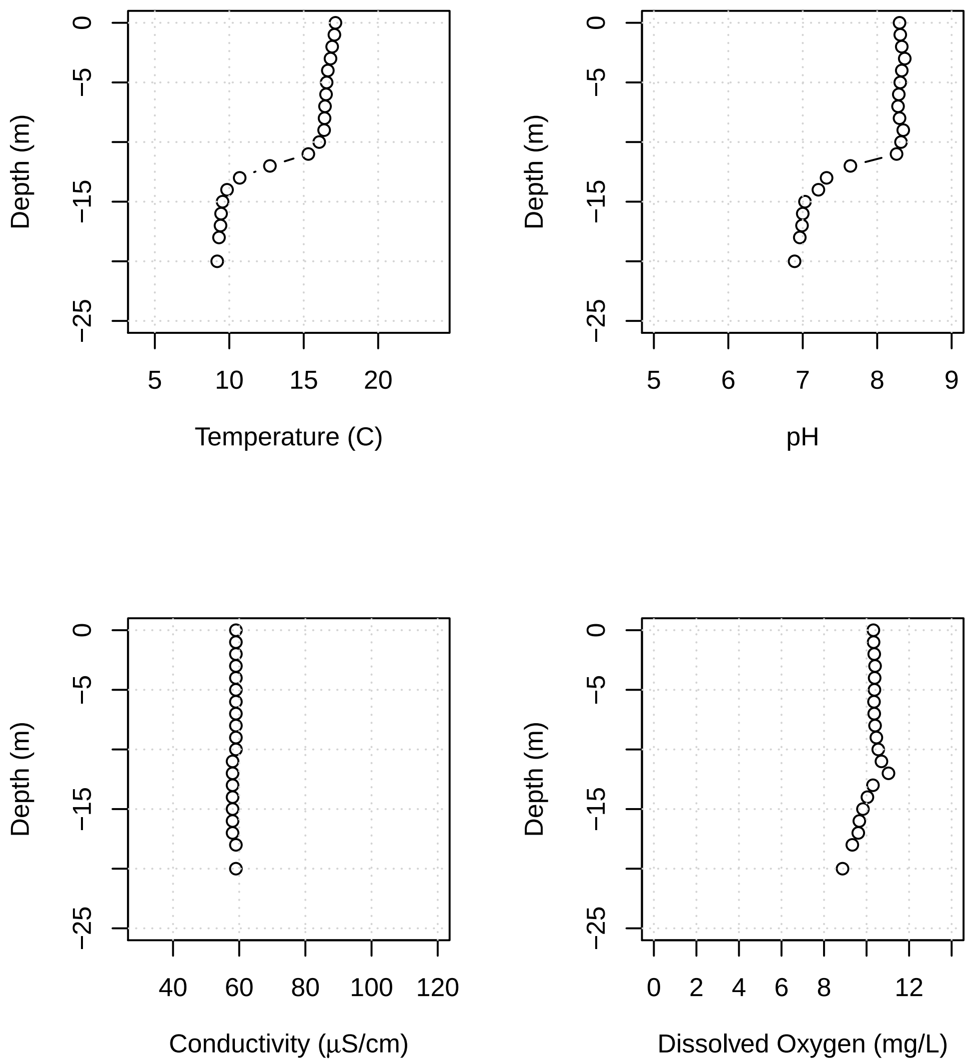


Figure B32: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, June 13, 2017.

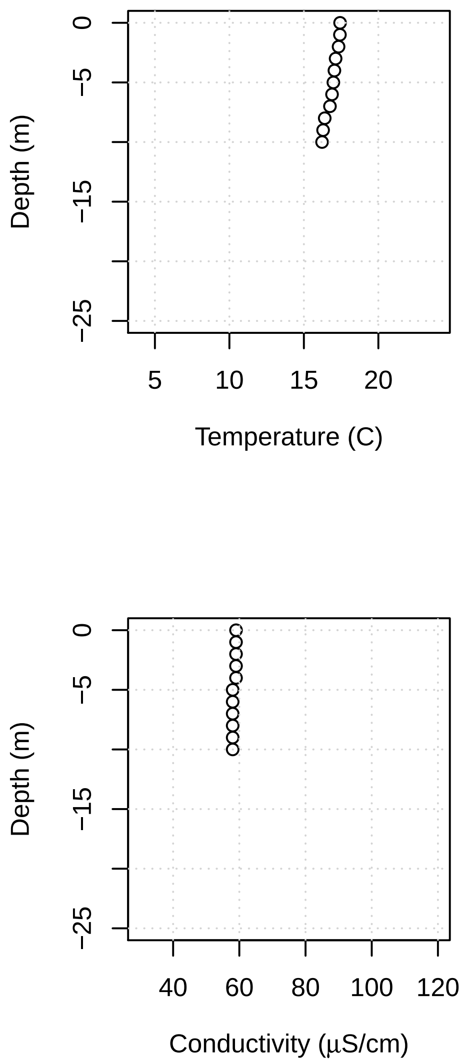


Figure B33: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, June 13, 2017.

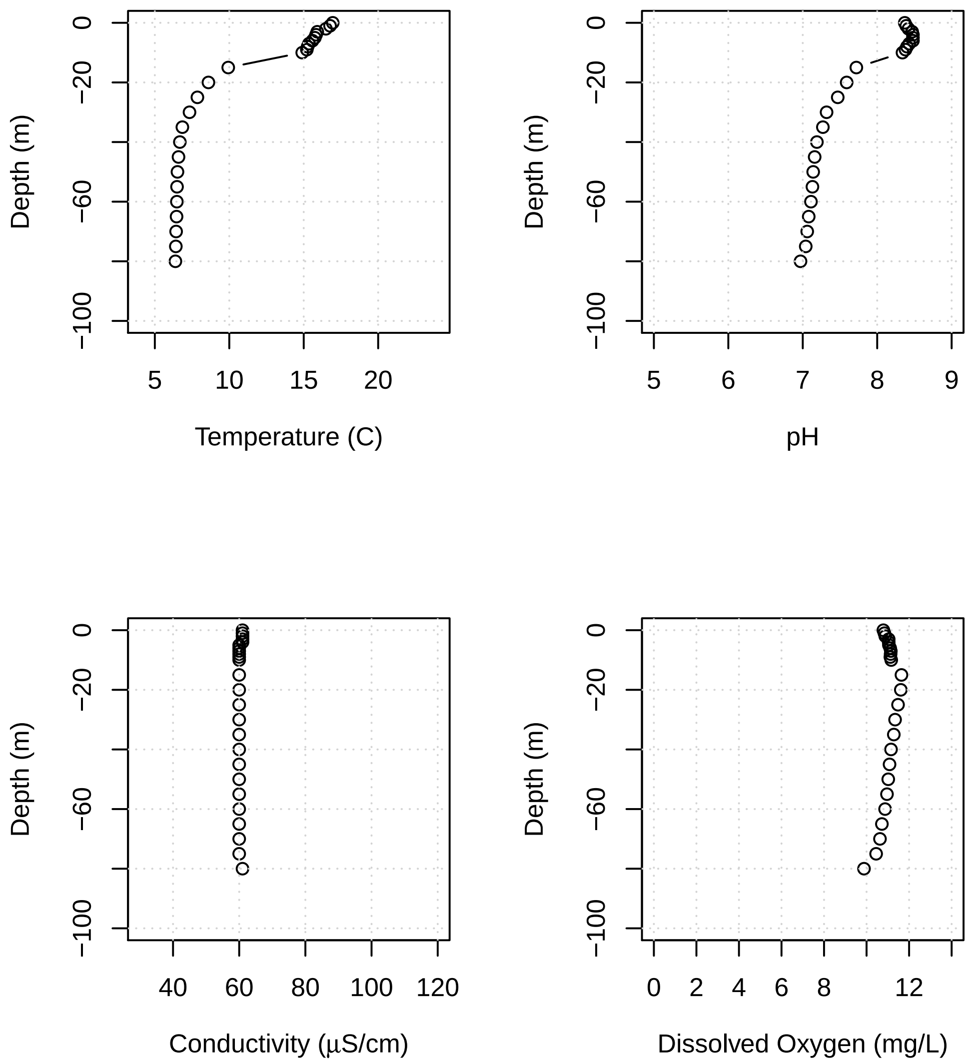


Figure B34: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, June 6, 2017.

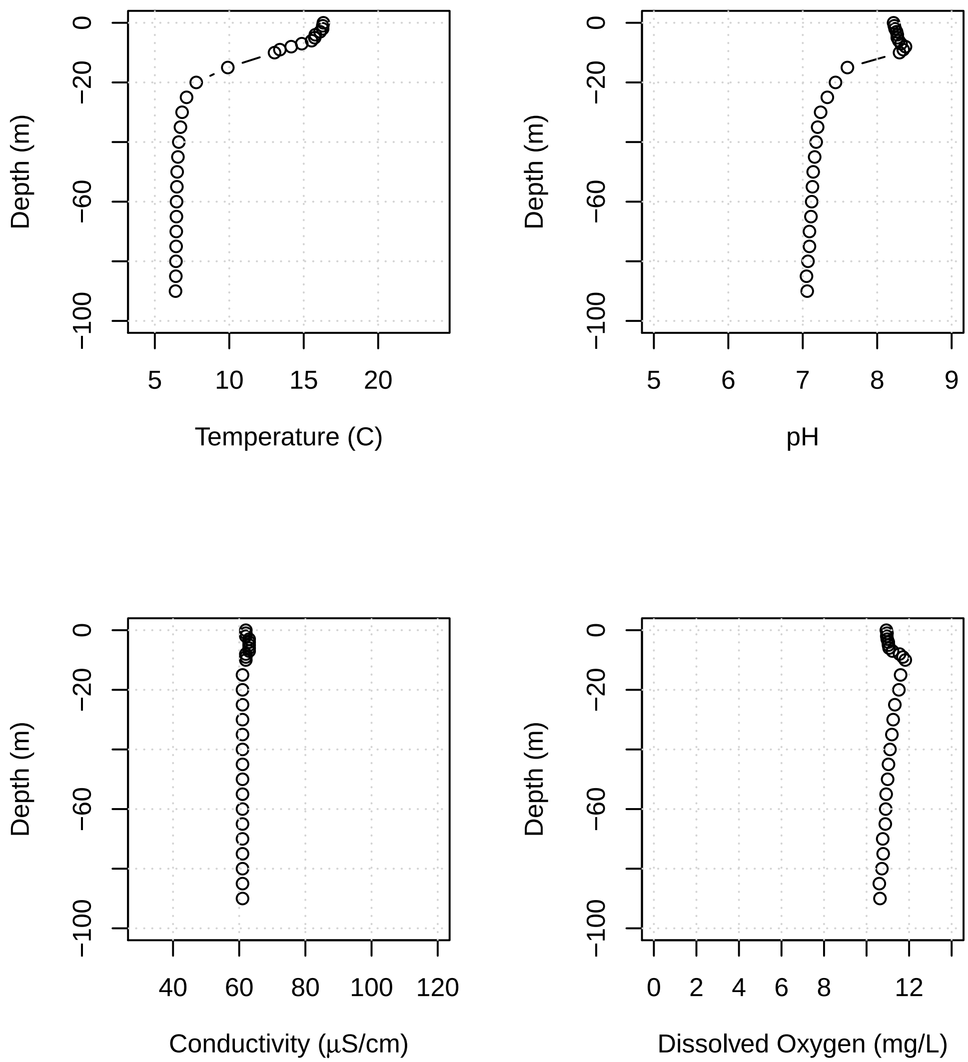


Figure B35: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, June 6, 2017.

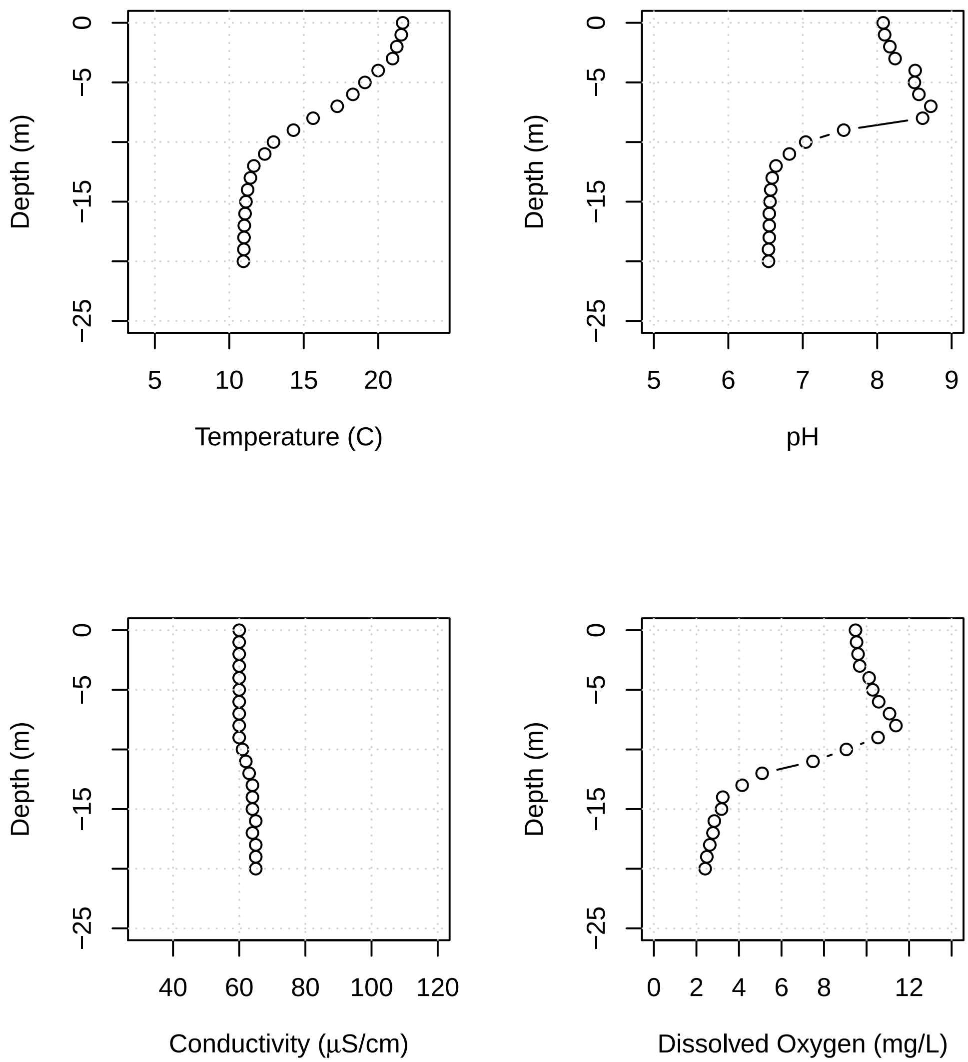


Figure B36: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, July 6, 2017.

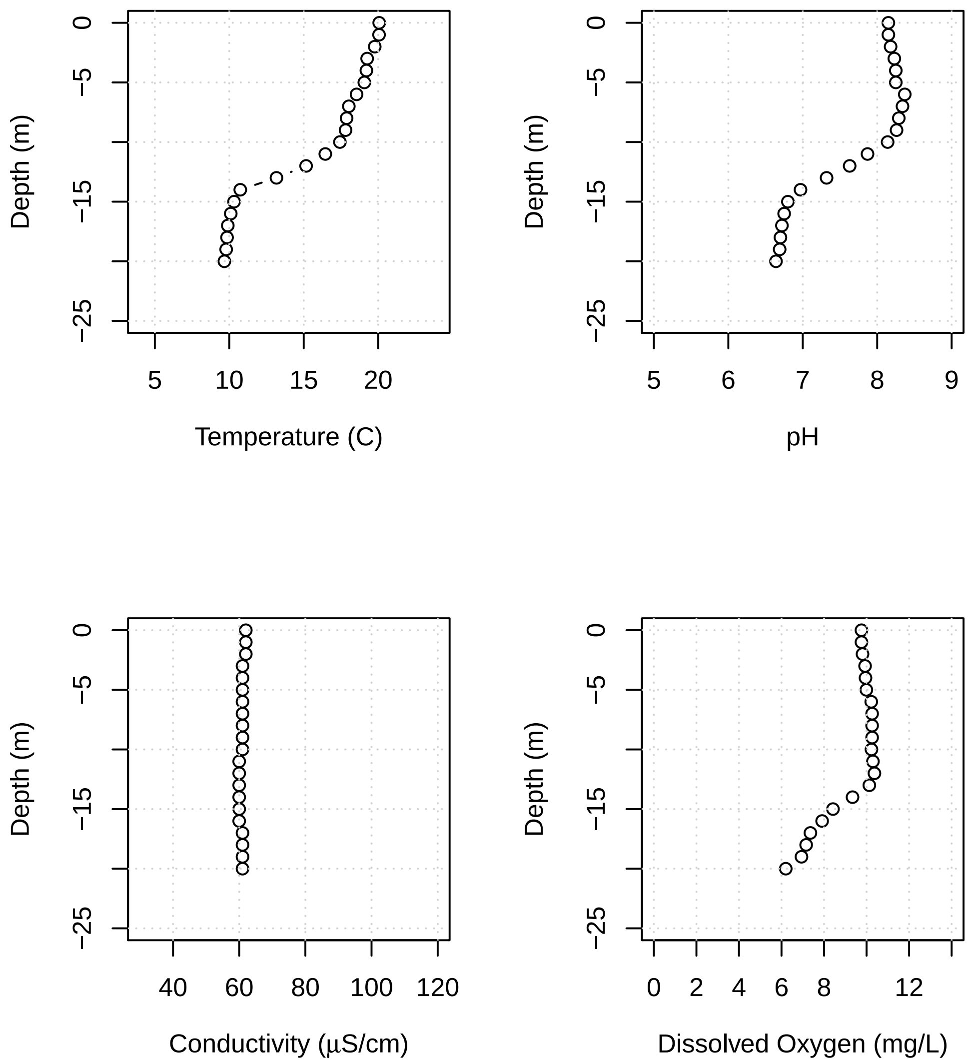


Figure B37: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, July 6, 2017.

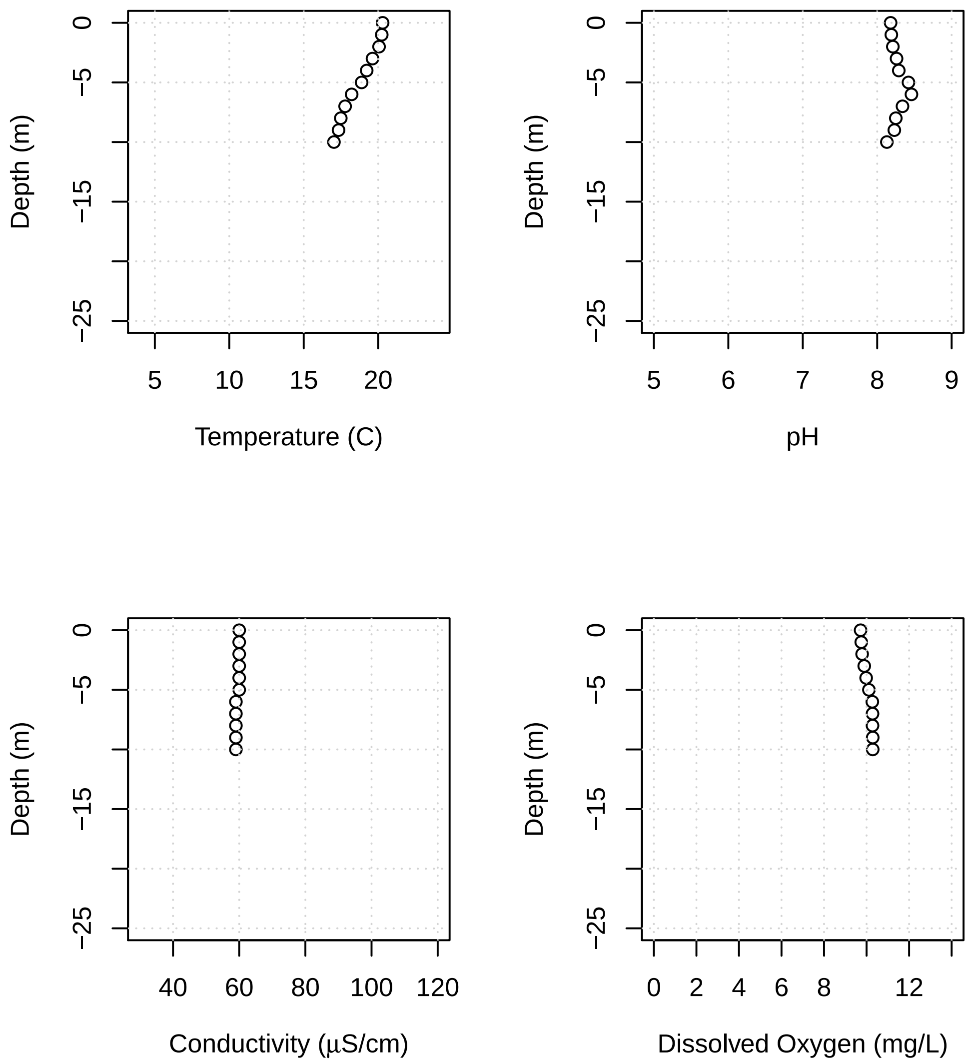


Figure B38: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, July 6, 2017.

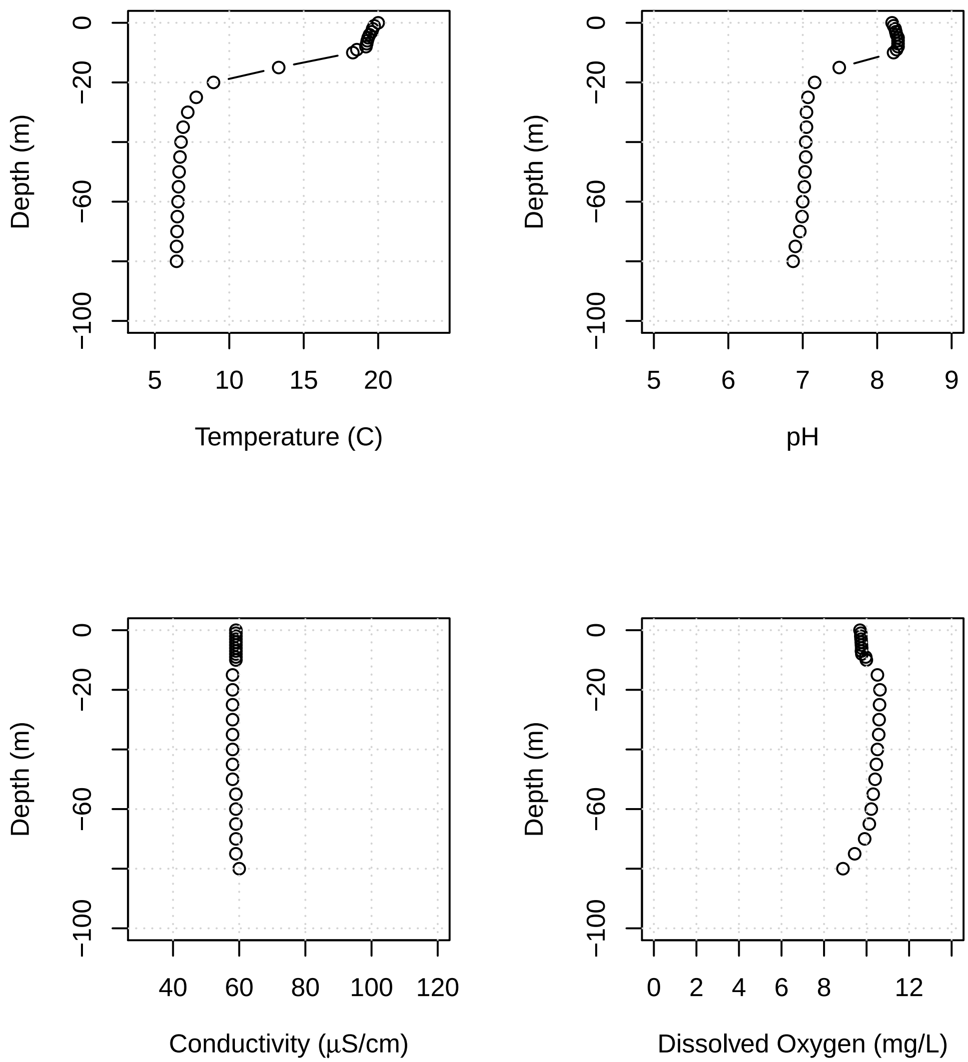


Figure B39: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, July 11, 2017.

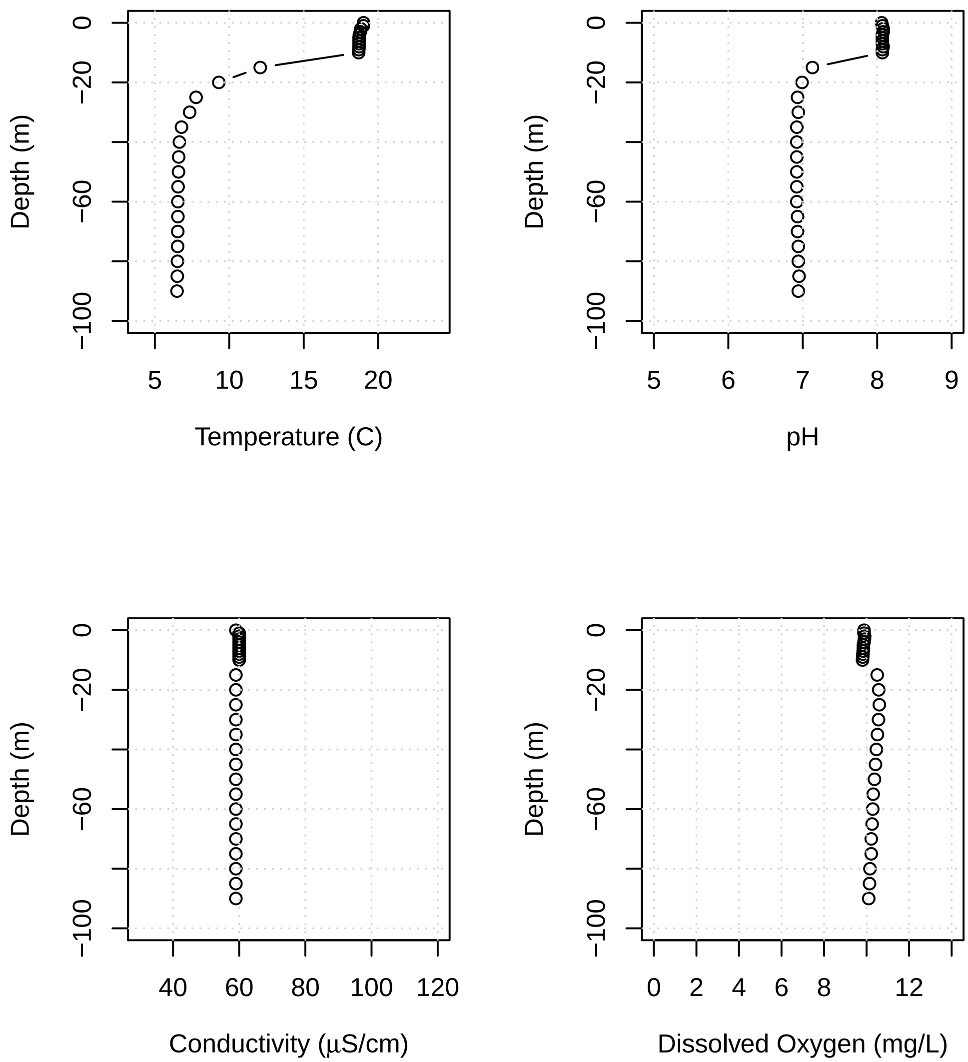


Figure B40: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, July 11, 2017.

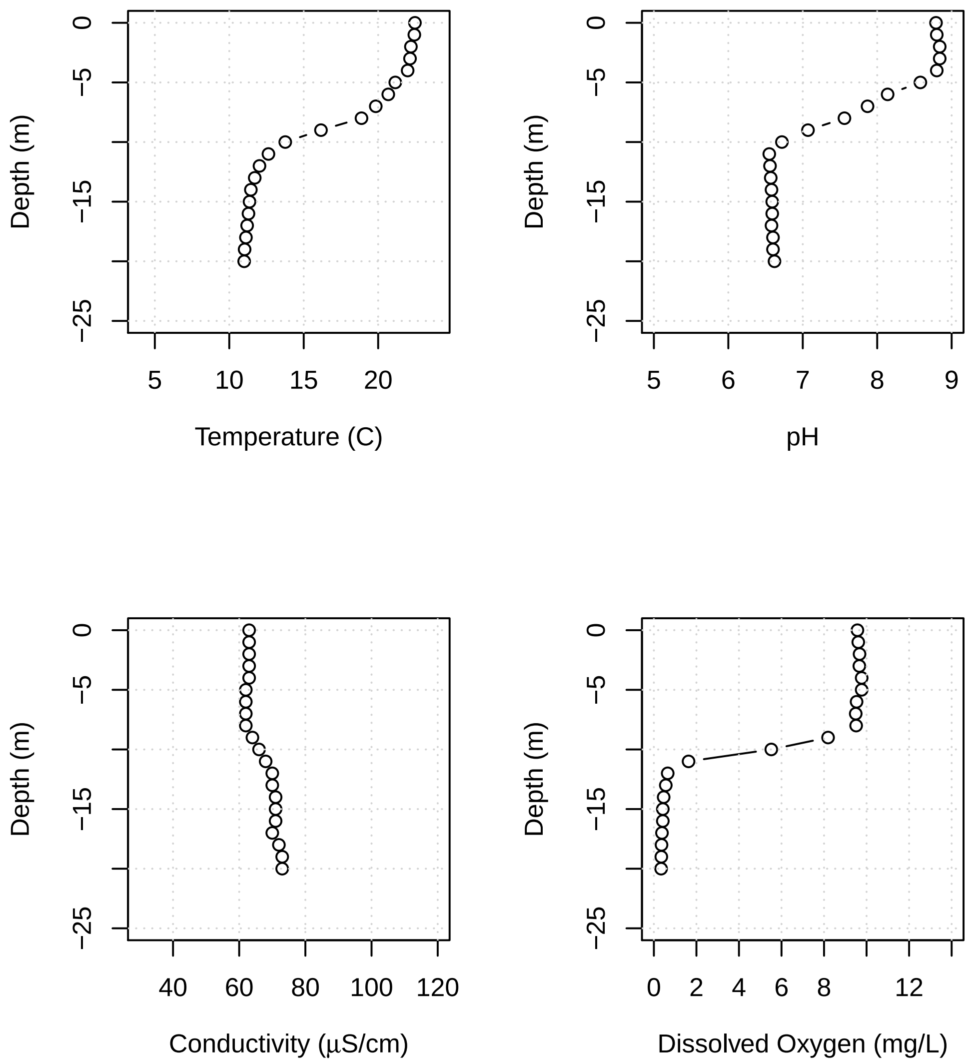


Figure B41: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, August 7, 2017.

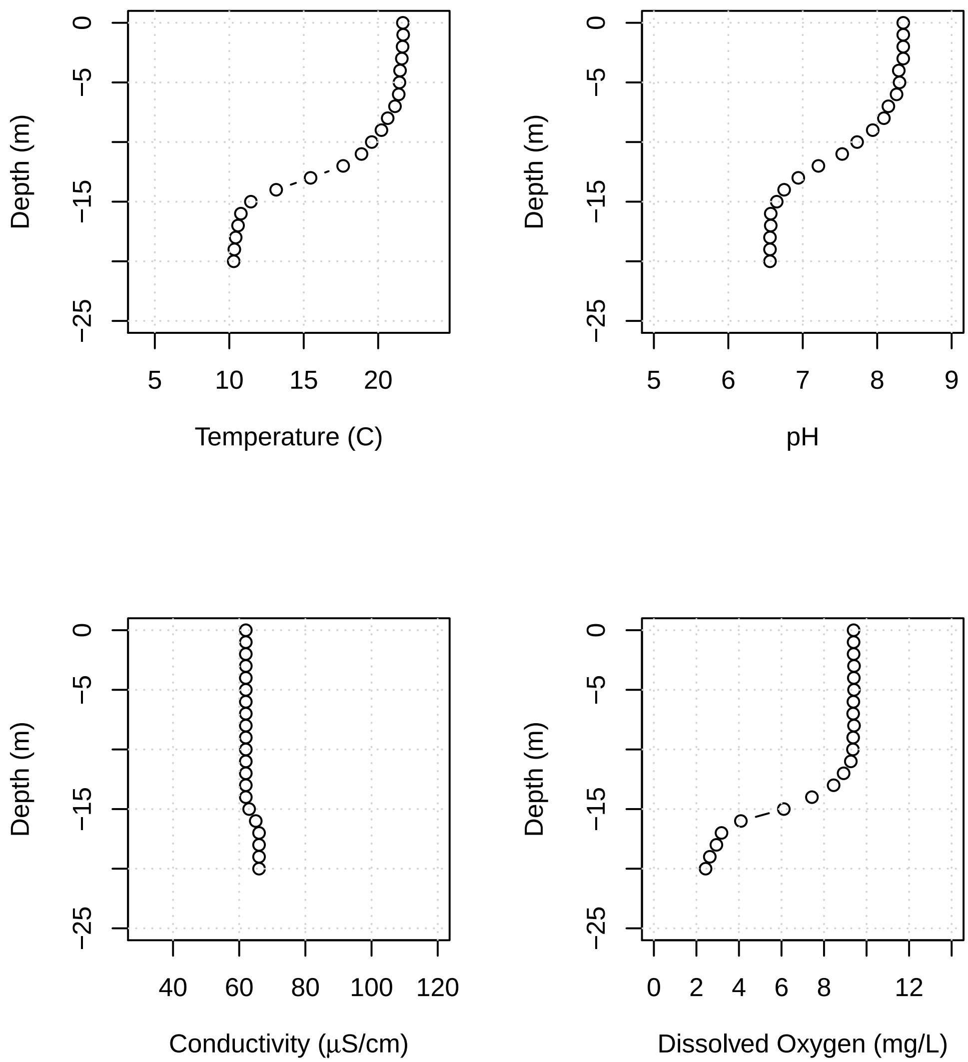


Figure B42: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, August 7, 2017.

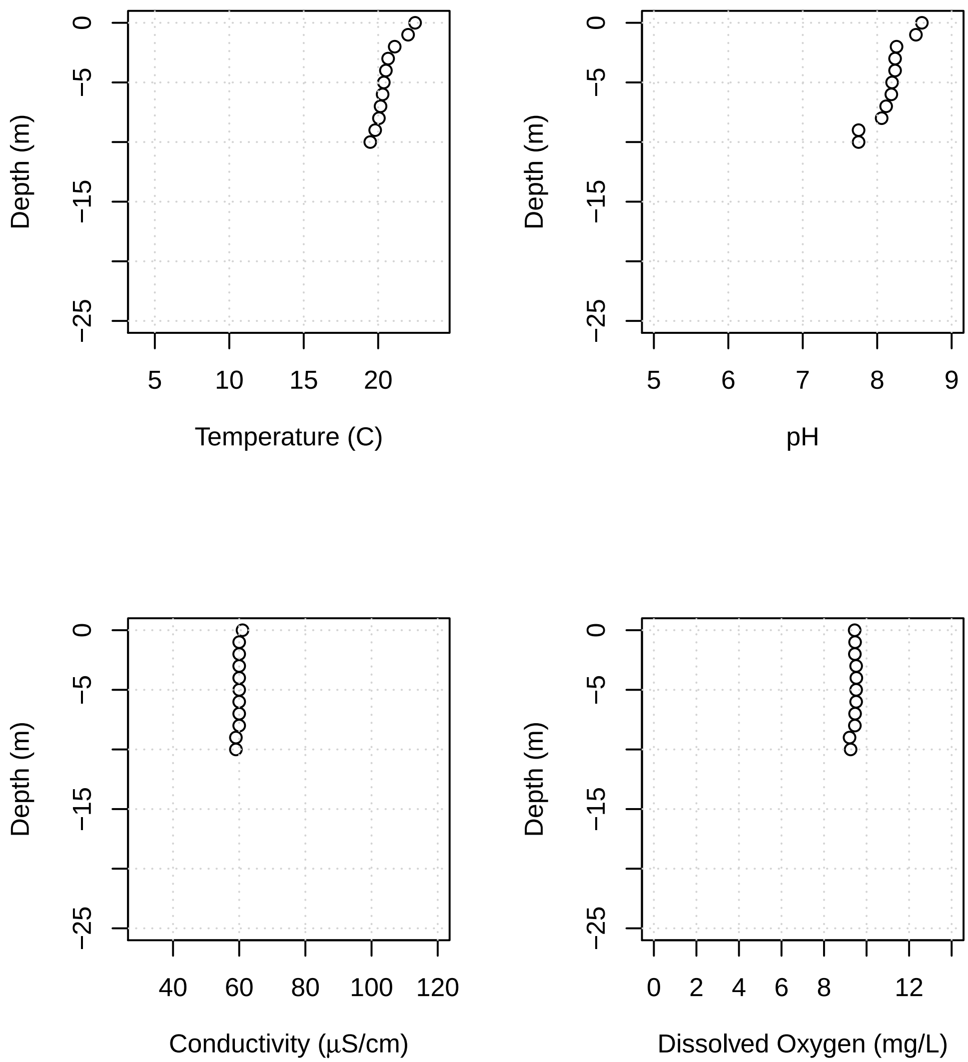


Figure B43: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, August 3, 2017.

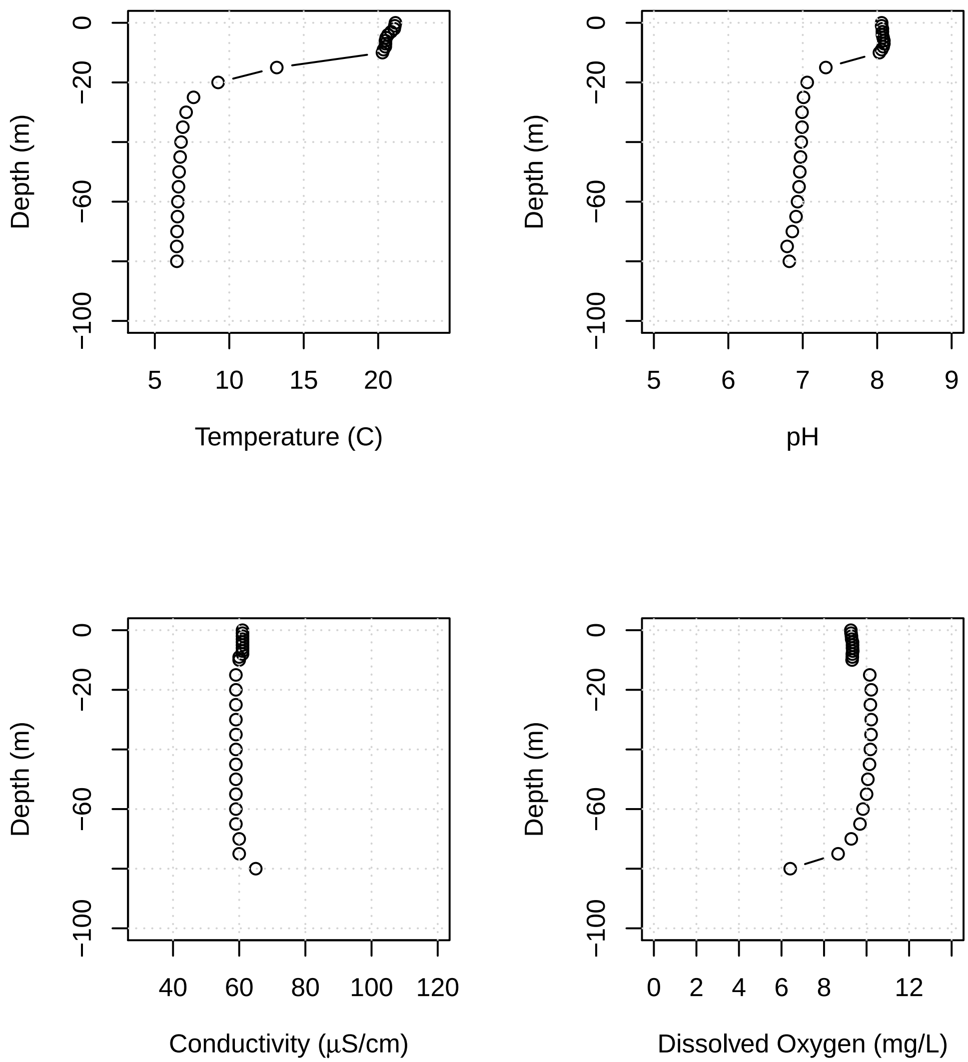


Figure B44: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, August 1, 2017.

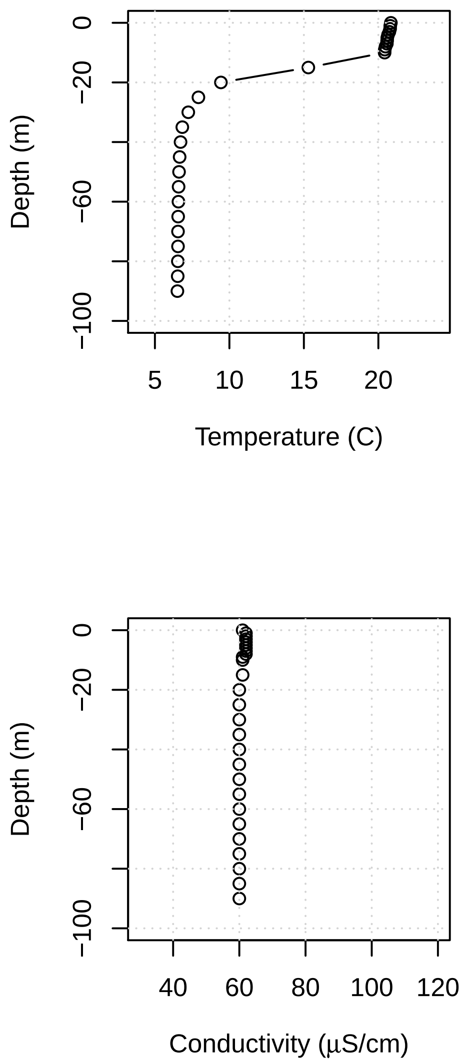


Figure B45: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, August 1, 2017.

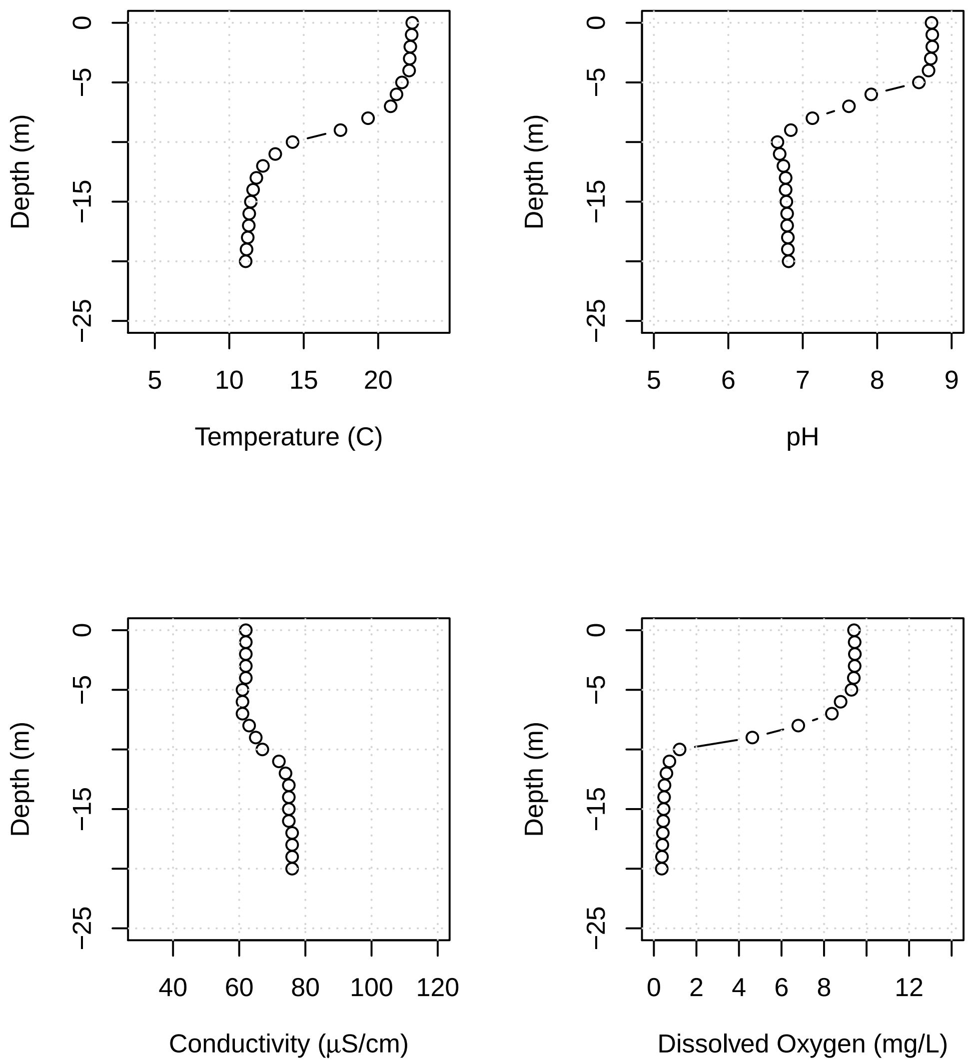


Figure B46: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 1, September 7, 2017.

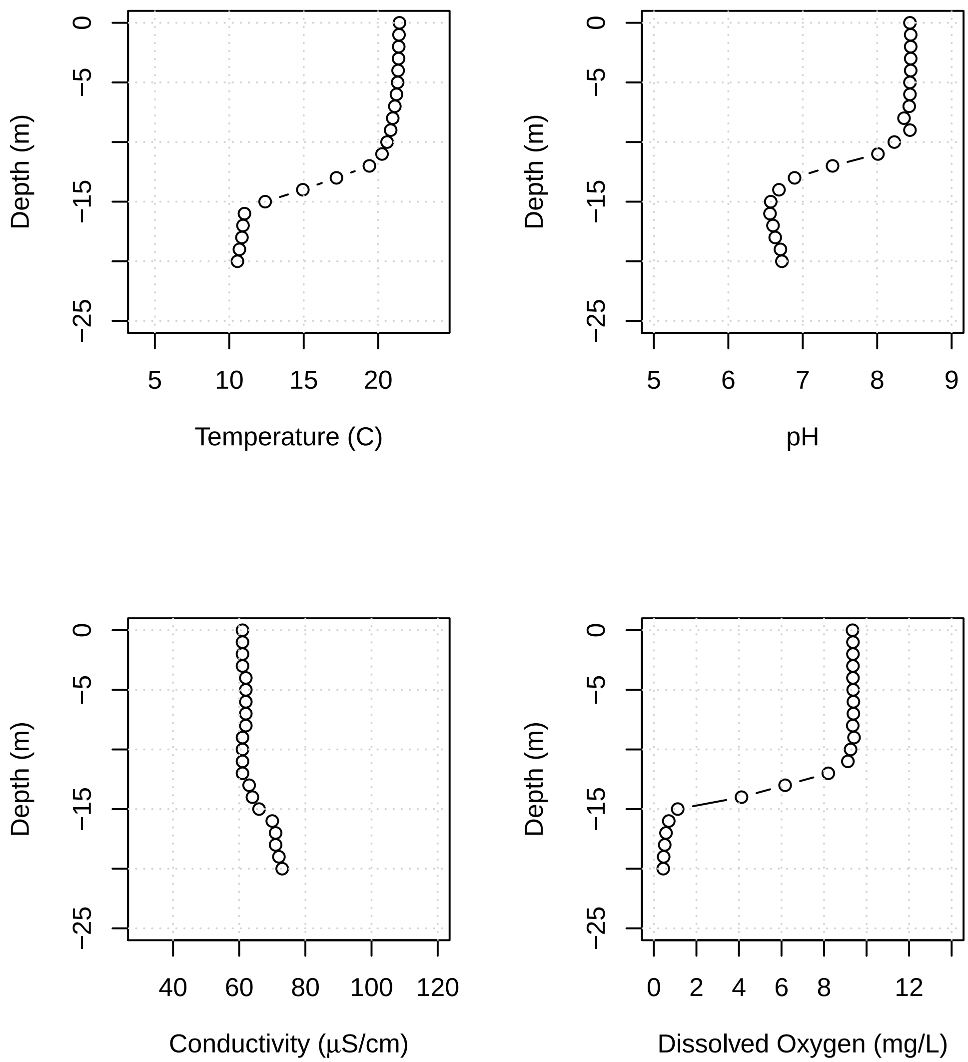


Figure B47: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 2, September 7, 2017.

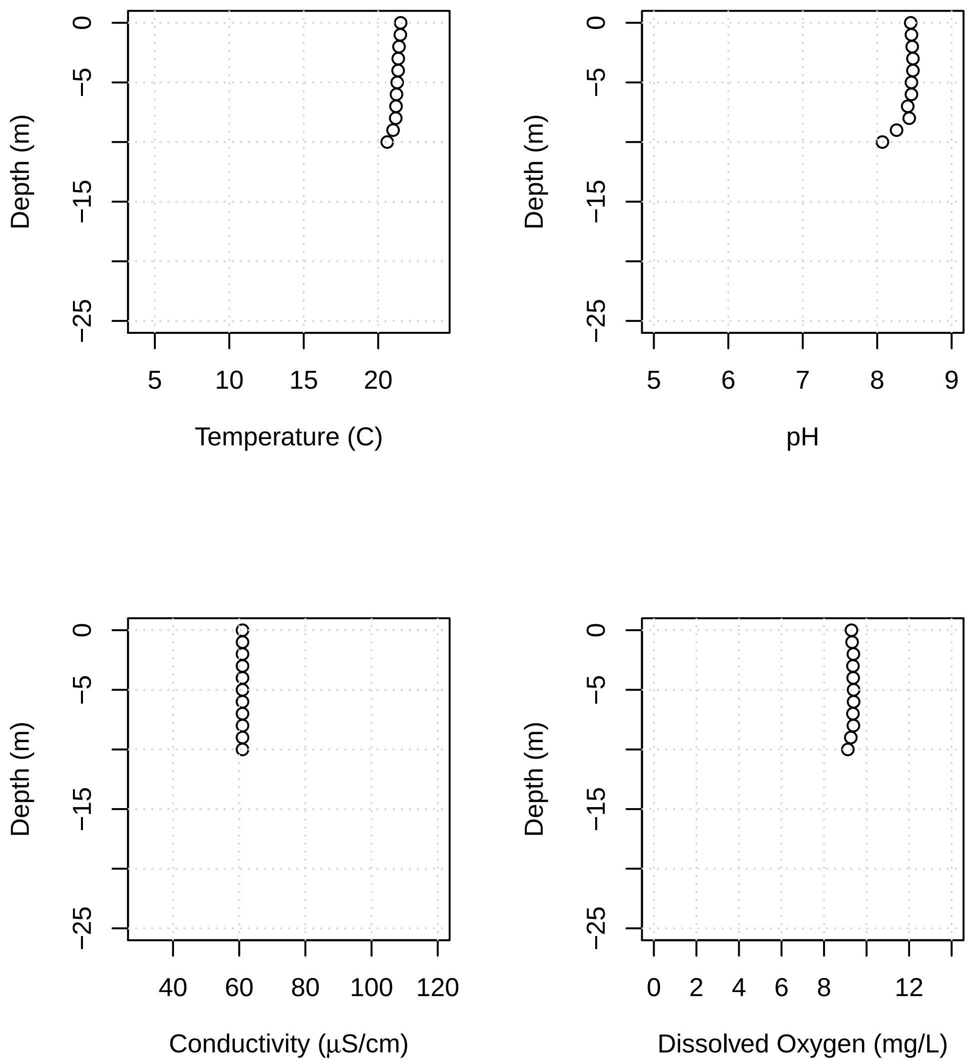


Figure B48: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for the Intake, September 7, 2017.

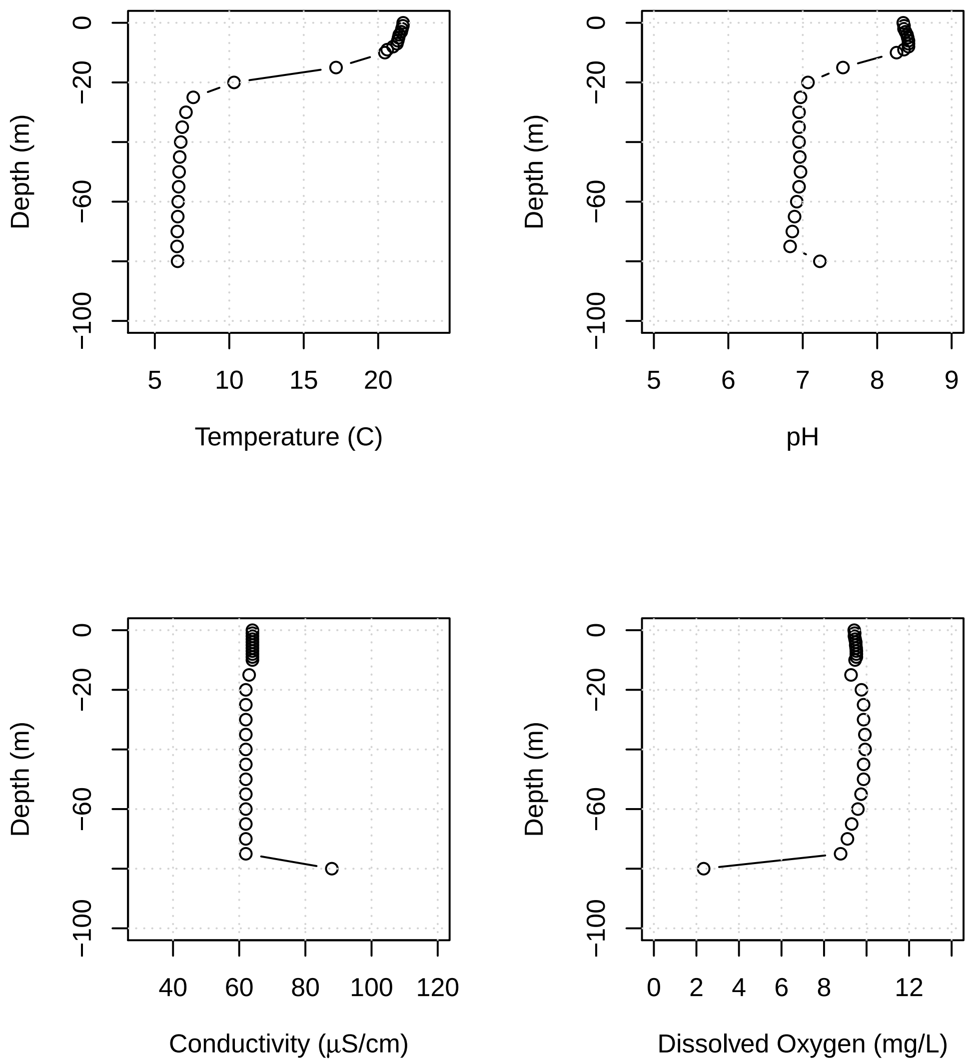


Figure B49: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 3, September 5, 2017.

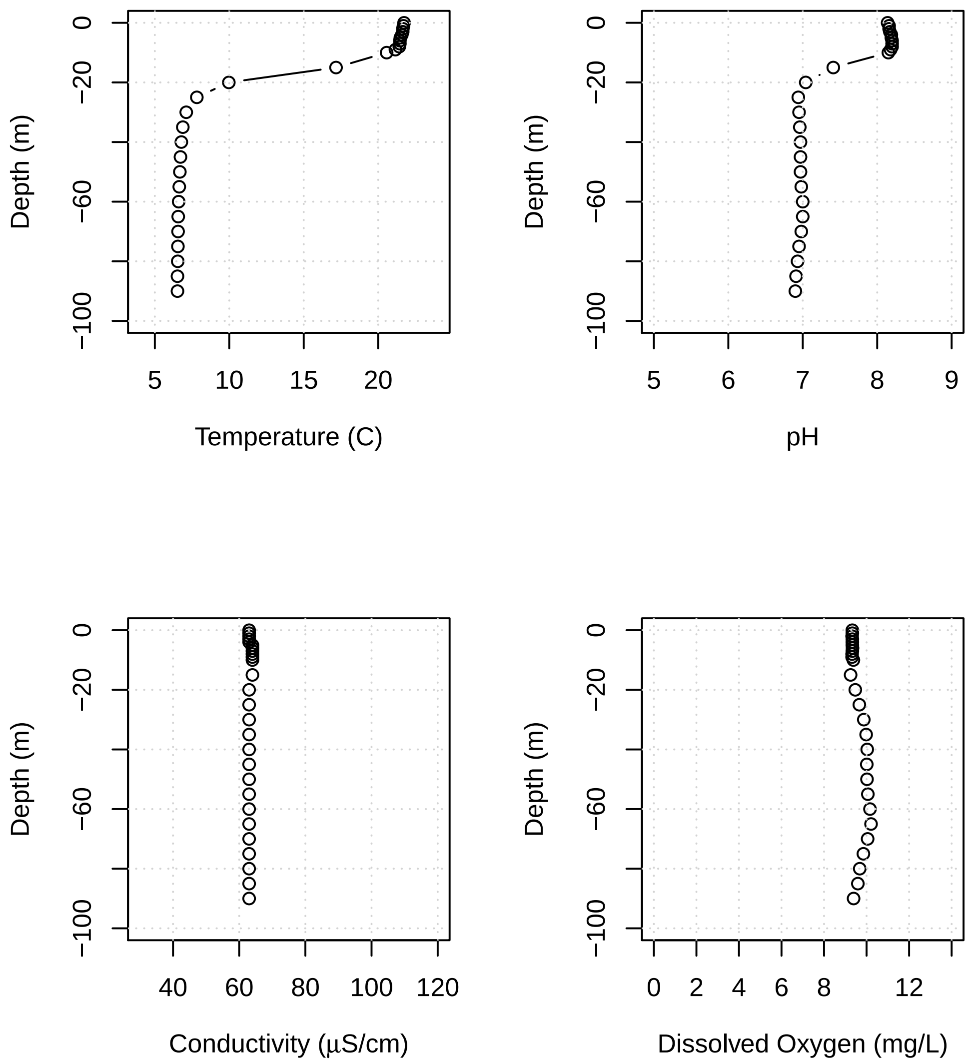


Figure B50: Lake Whatcom water column profiles showing temperature, pH, conductivity, and dissolved oxygen for Site 4, September 5, 2017.

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

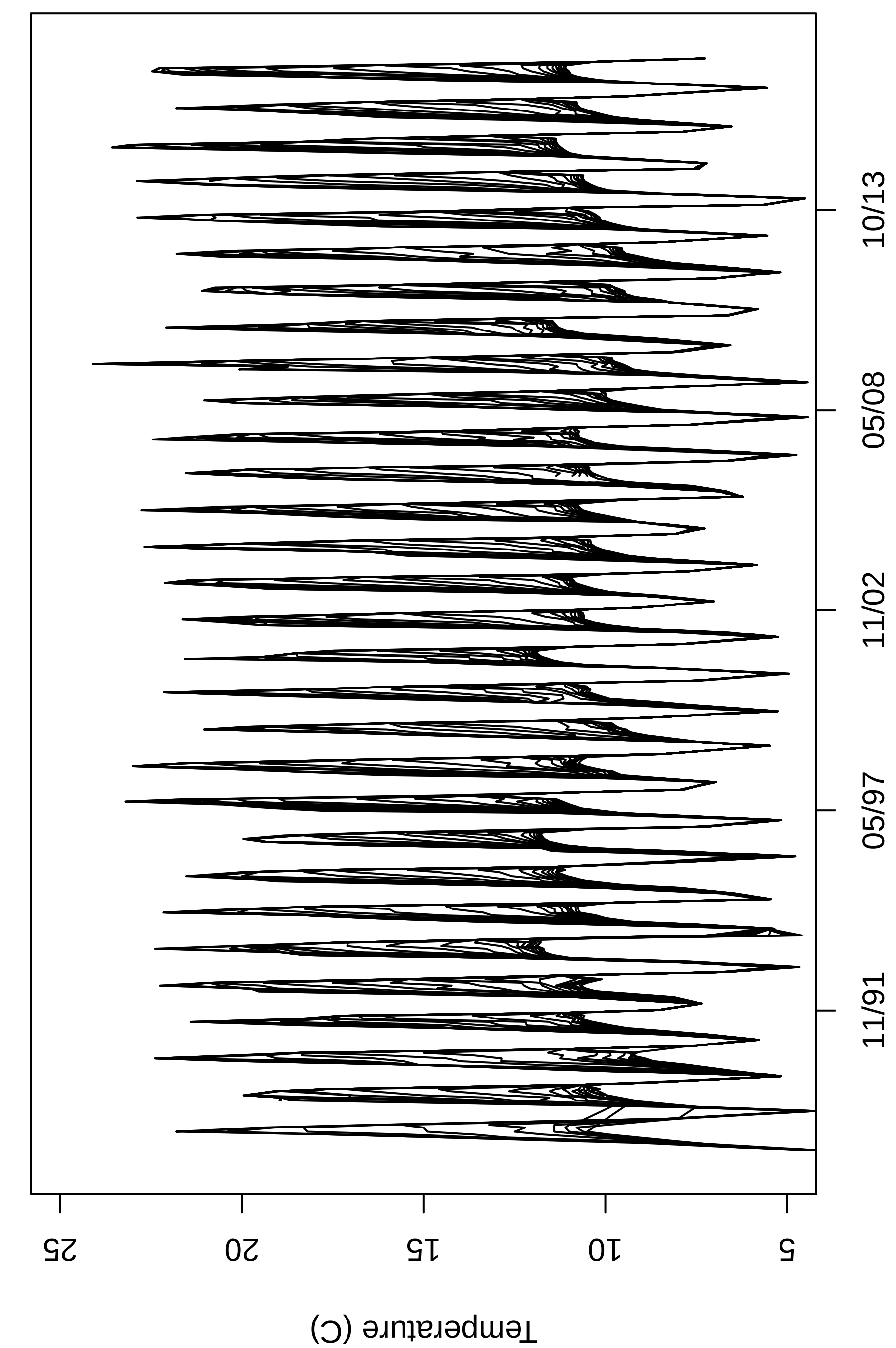


Figure B51: Lake Whatcom historic temperature data for Site 1.

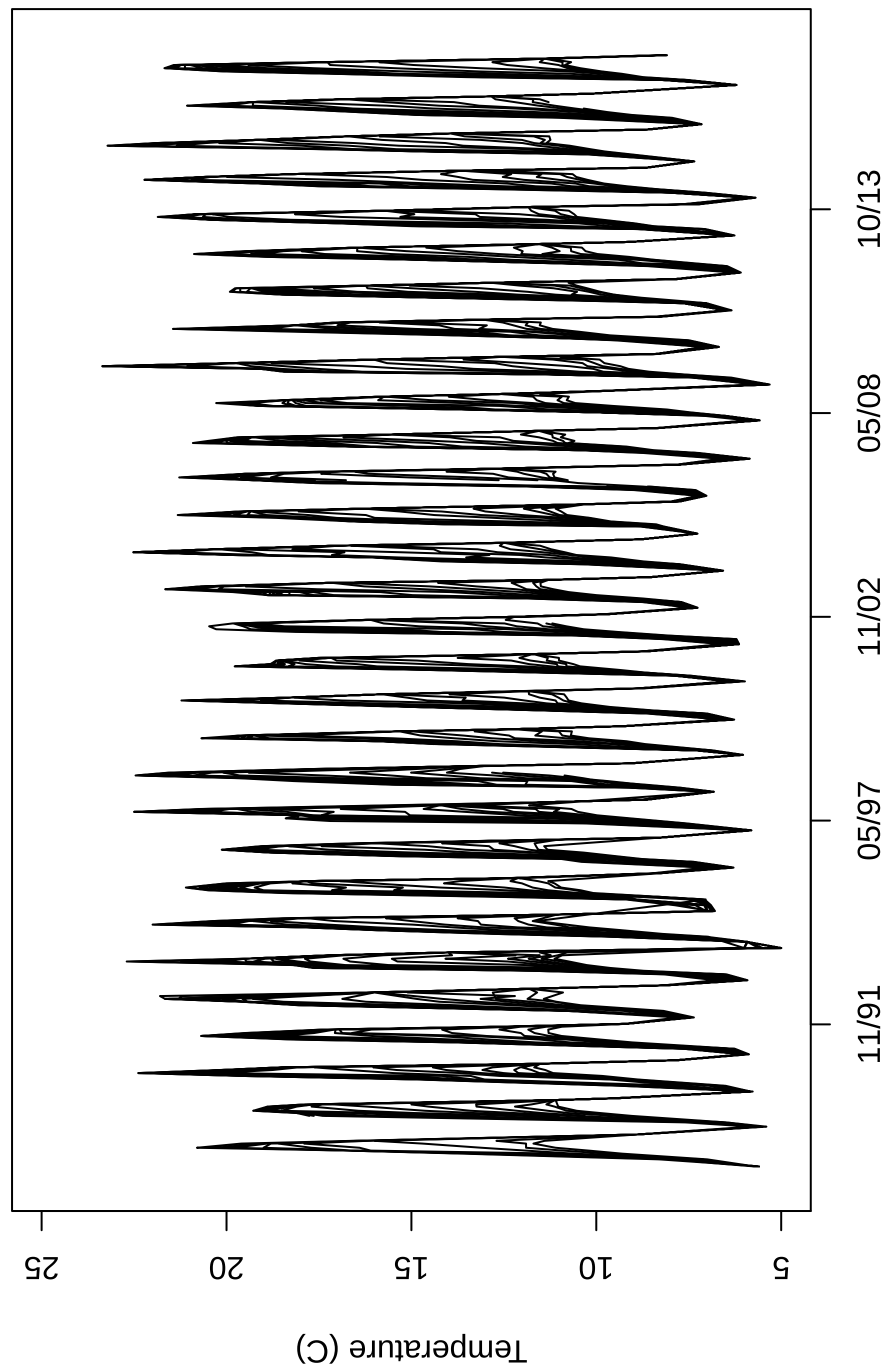


Figure B52: Lake Whatcom historic temperature data for Site 2.

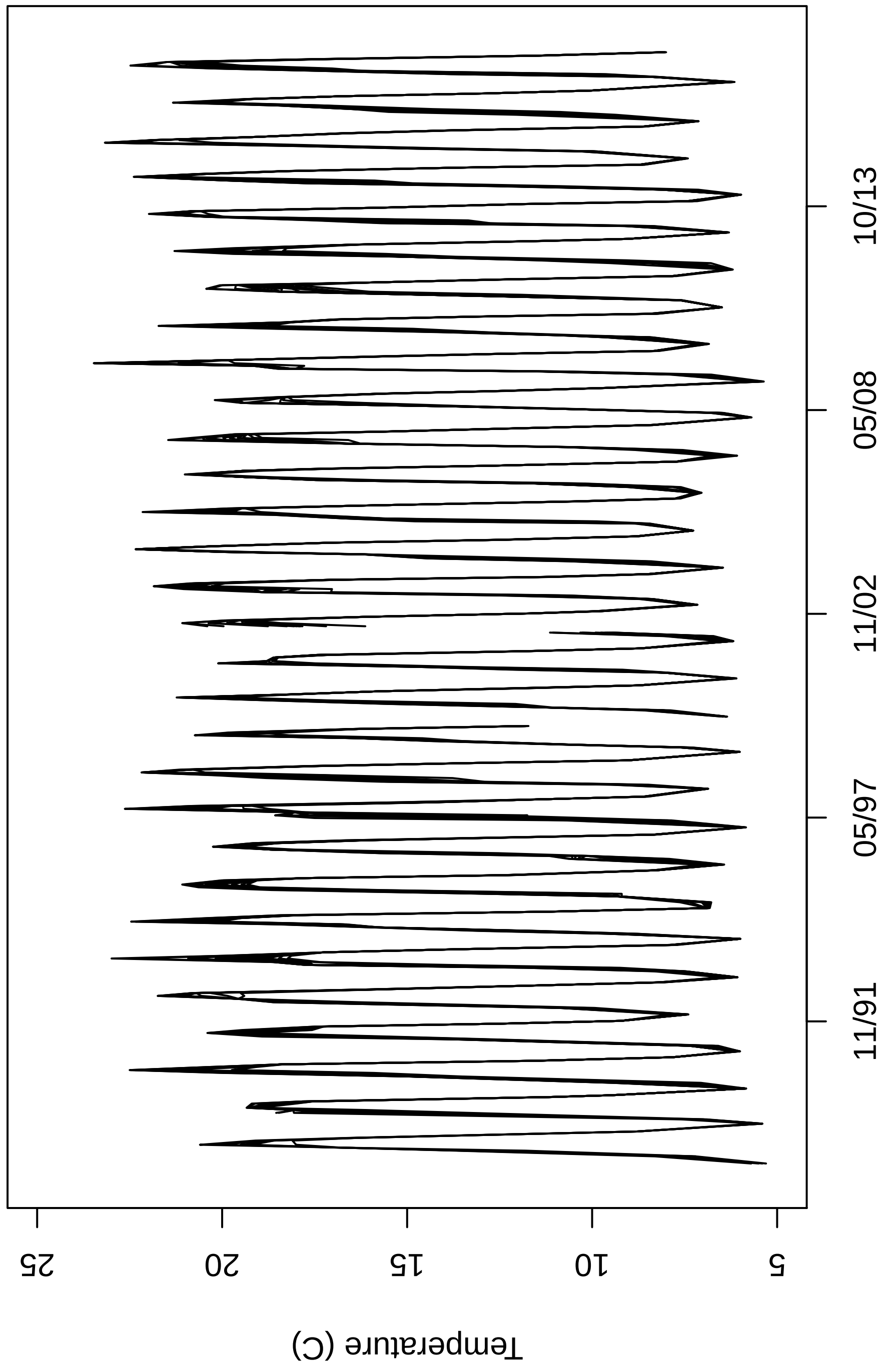


Figure B53: Lake Whatcom historic temperature data for the Intake.

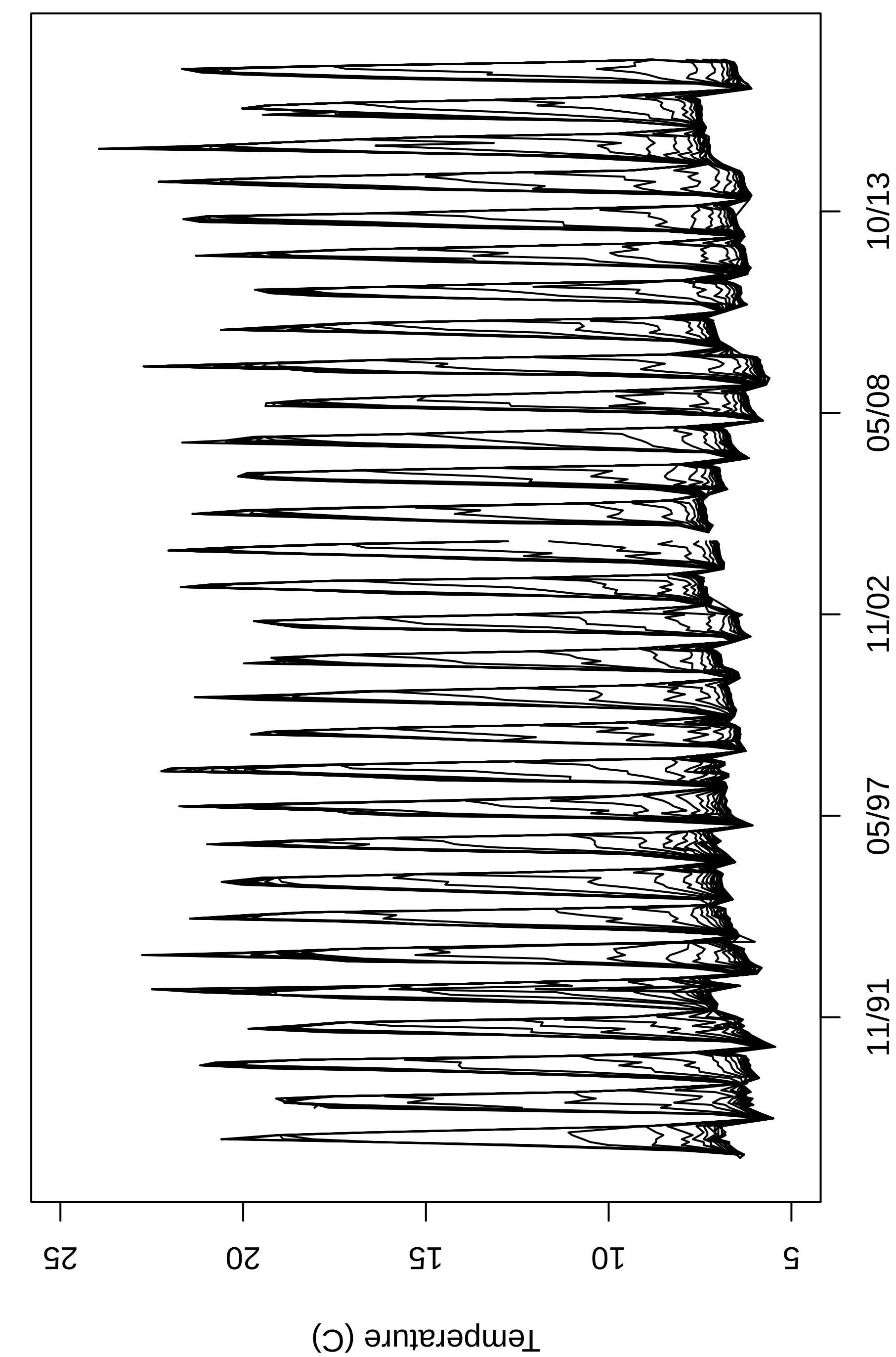


Figure B54: Lake Whatcom historic temperature data for Site 3.

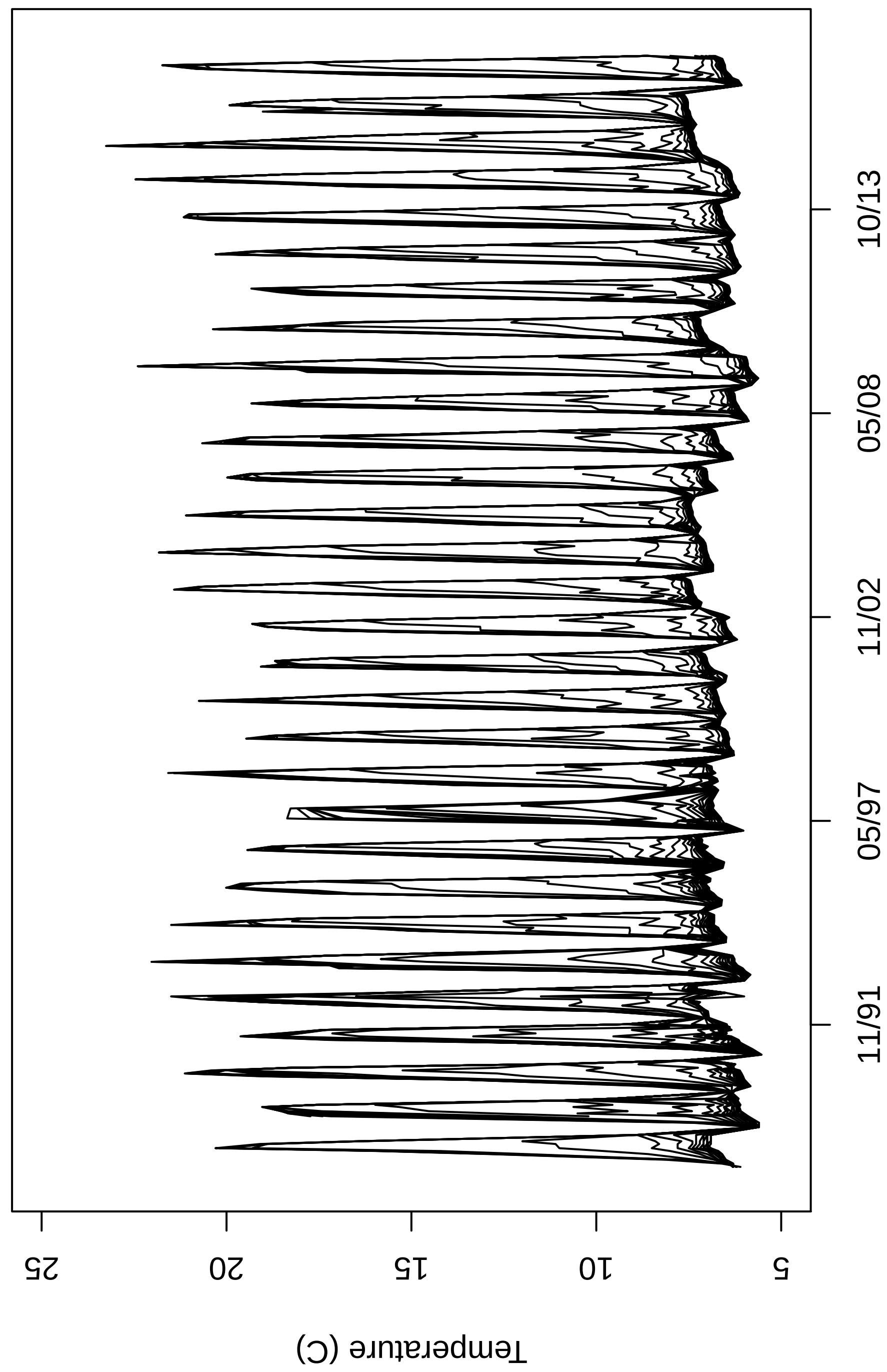


Figure B55: Lake Whatcom historic temperature data for Site 4.

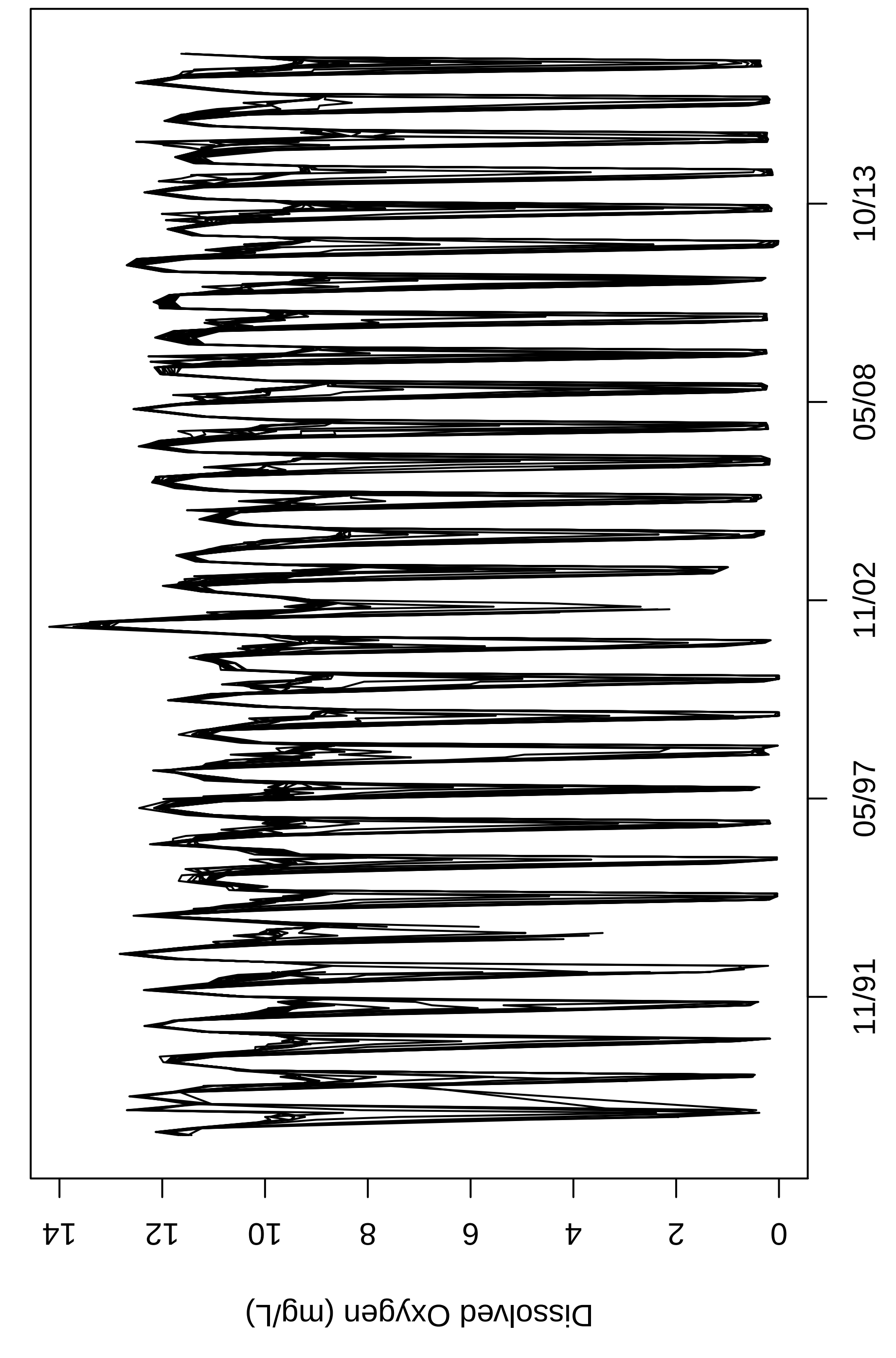


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

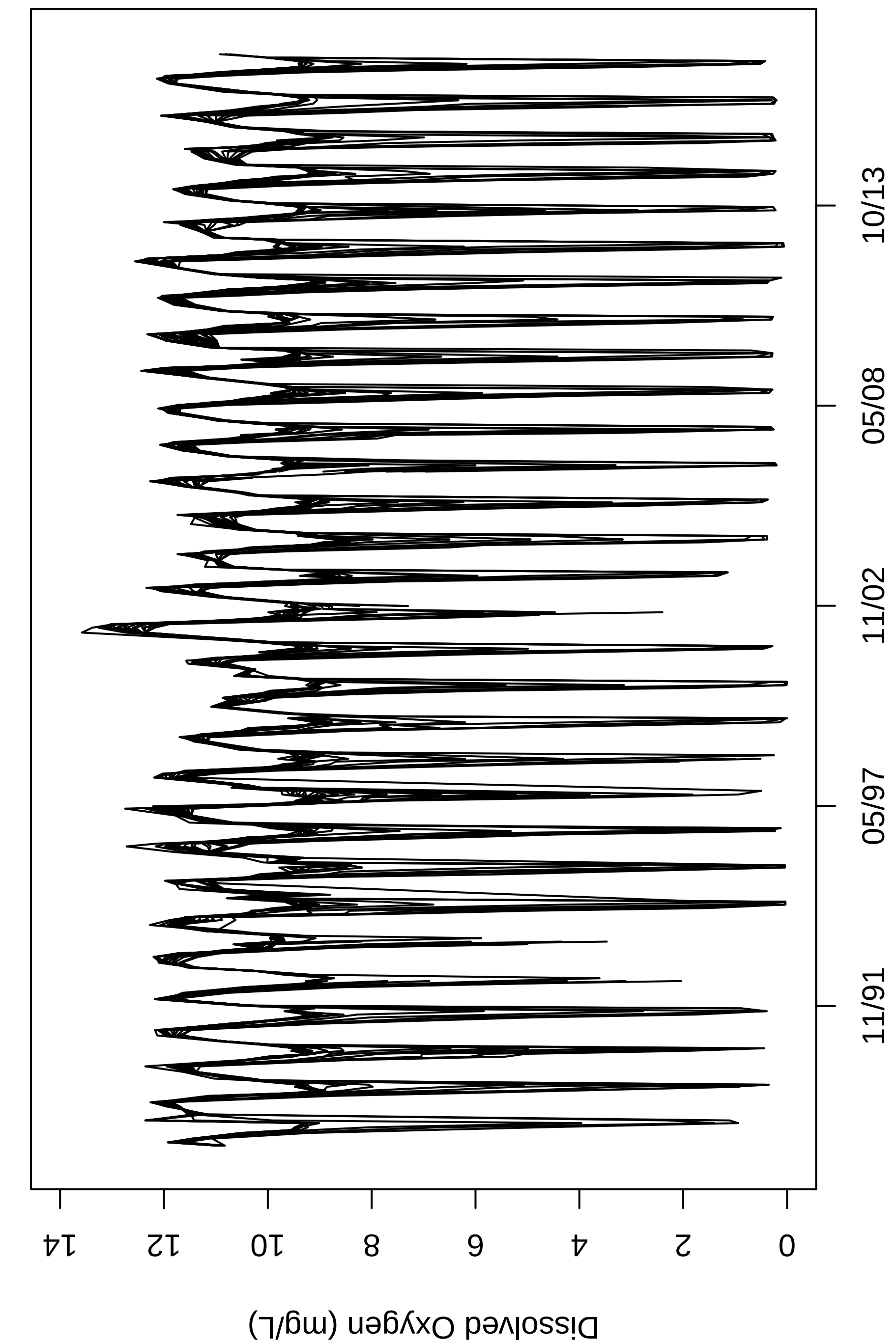


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

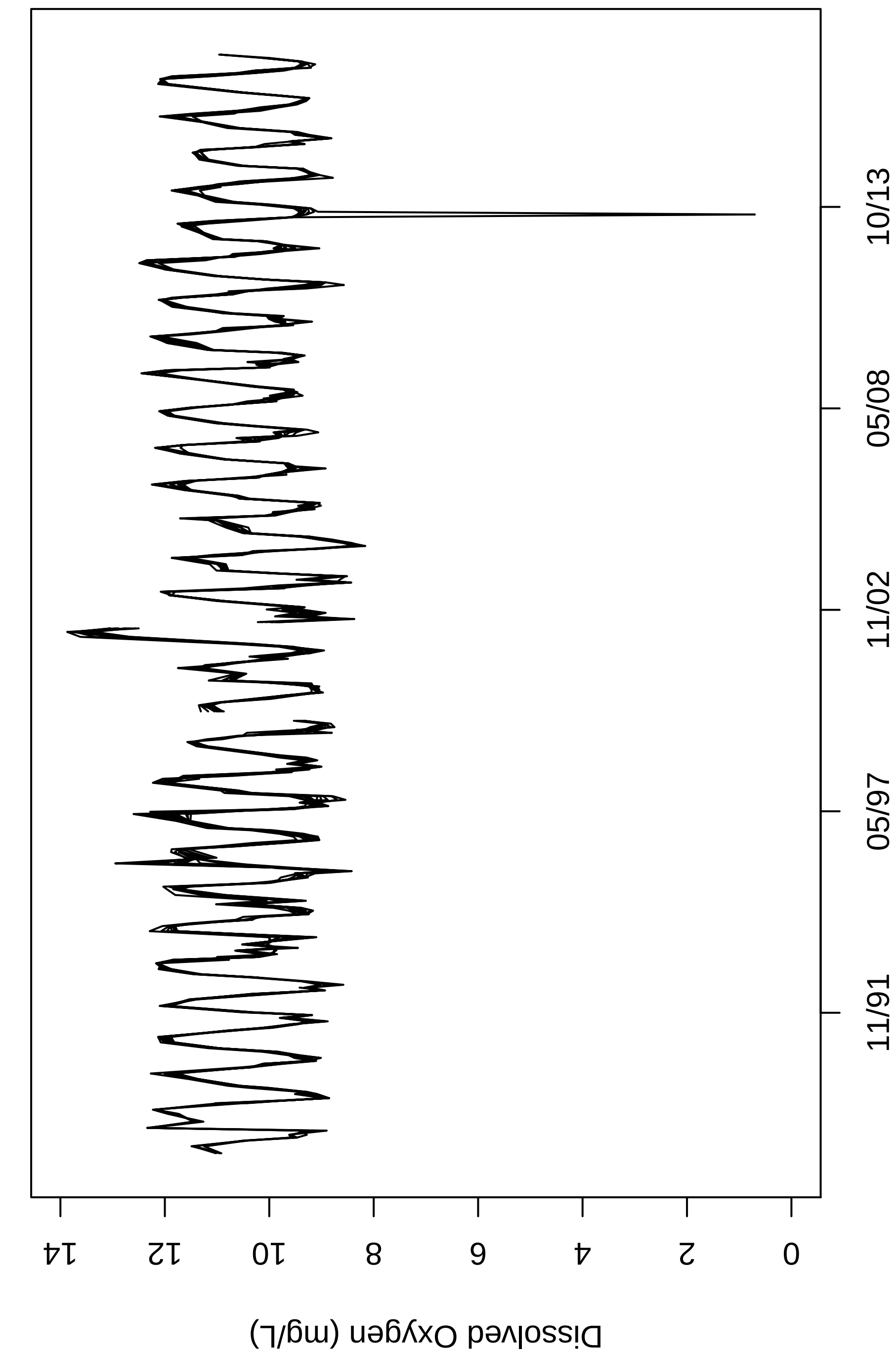


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake. See discussion of the low dissolved oxygen value in Matthews et al. (2014).

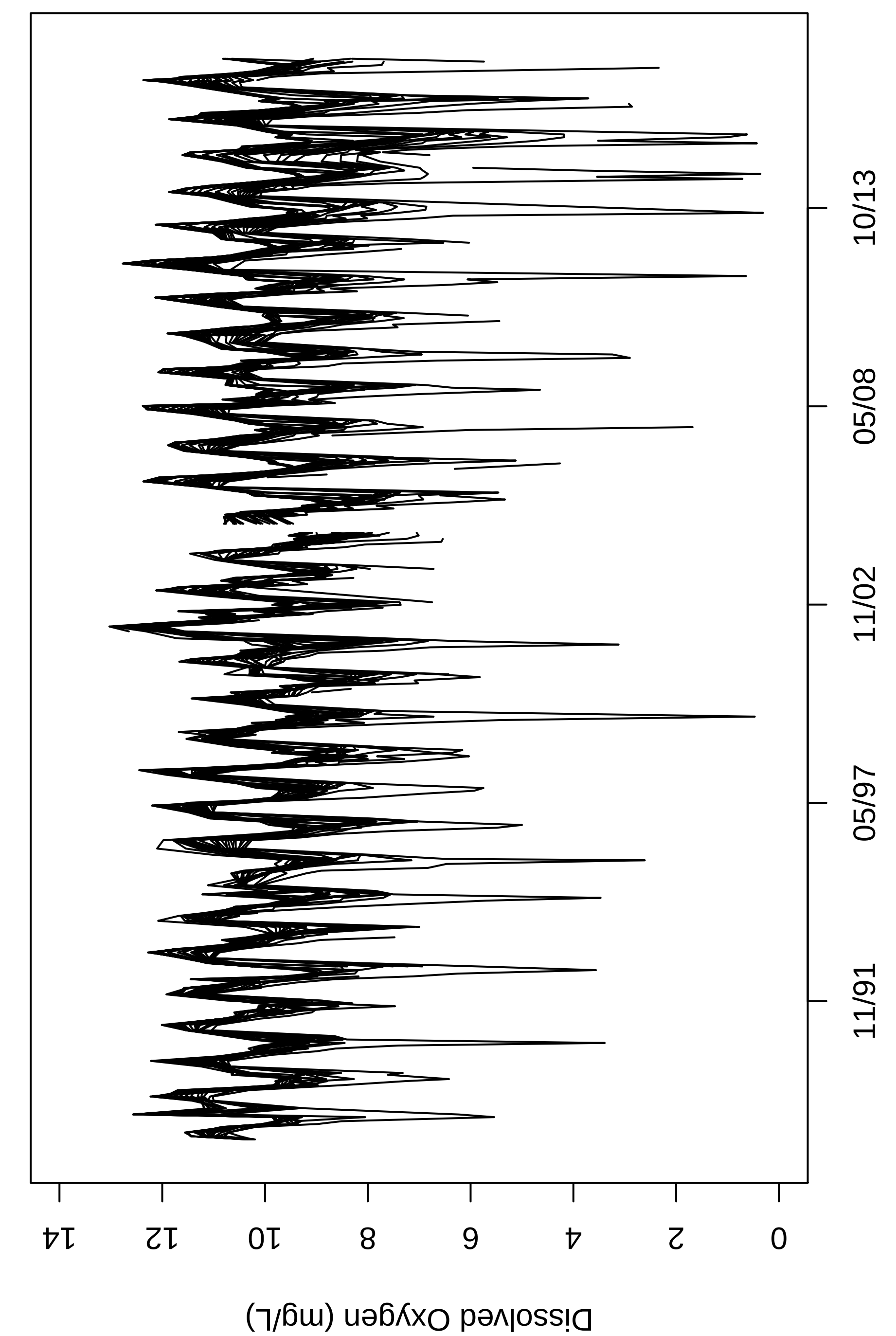


Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.

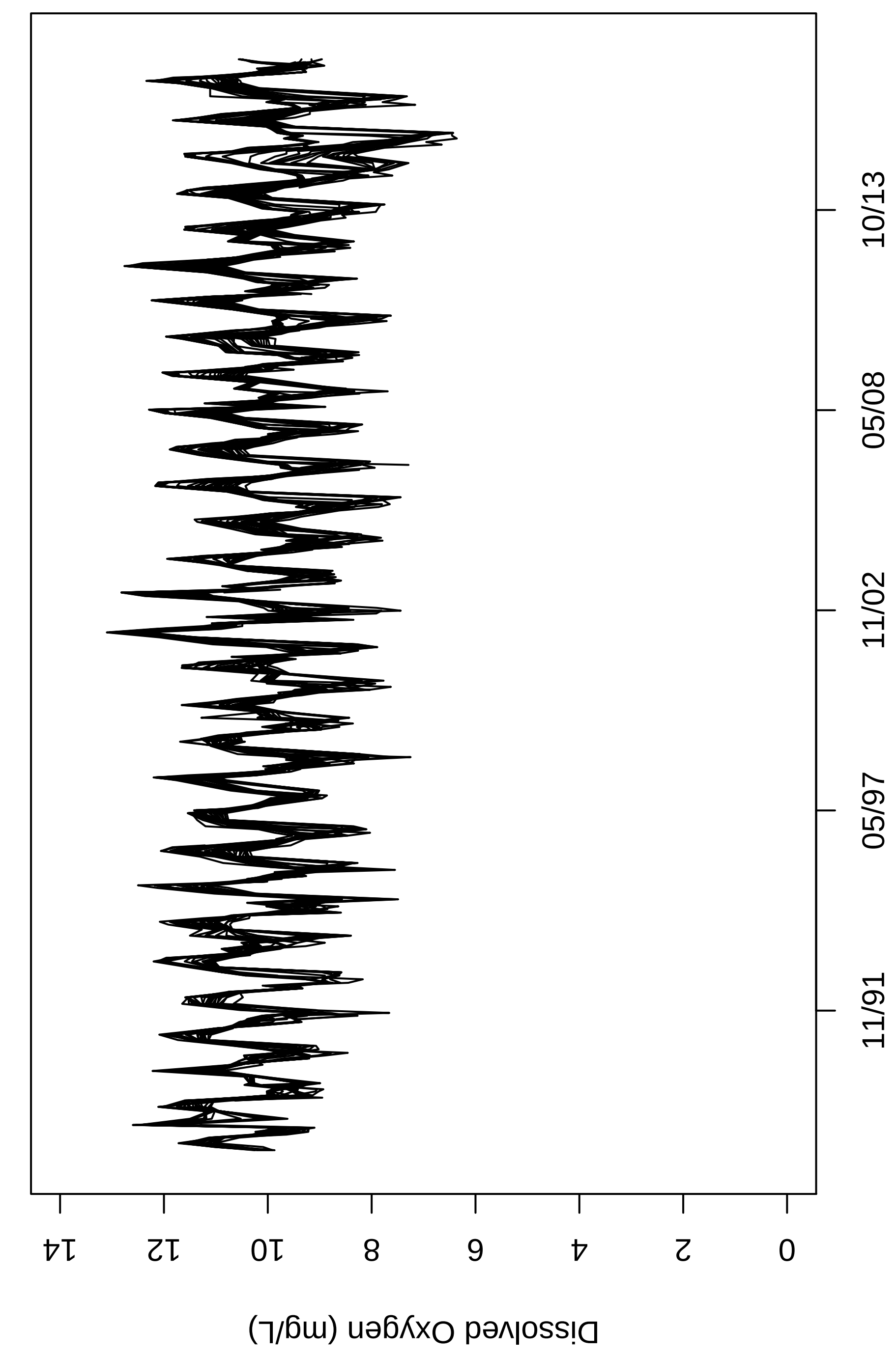


Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

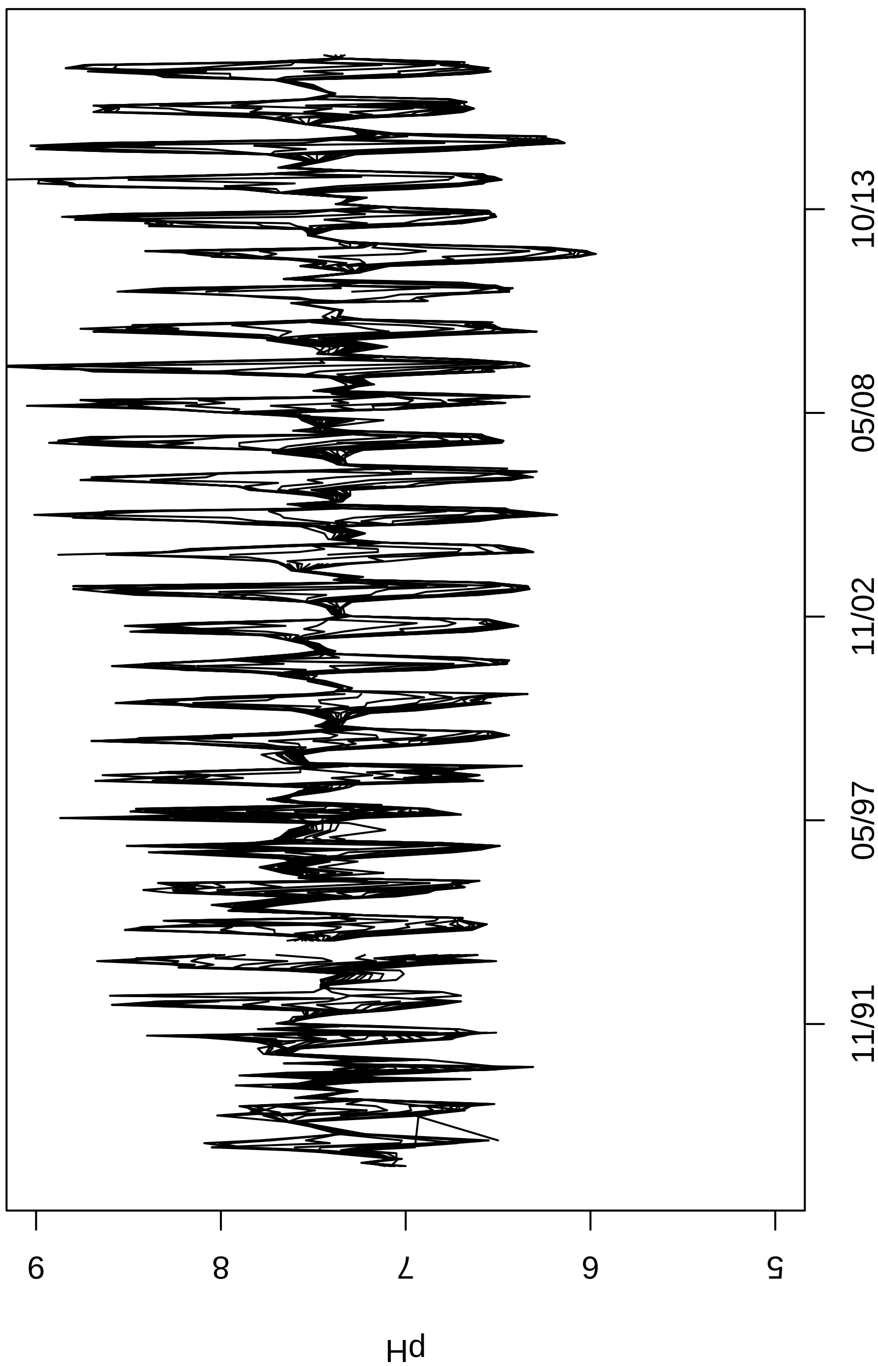


Figure B61: Lake Whatcom historic pH data for Site 1.

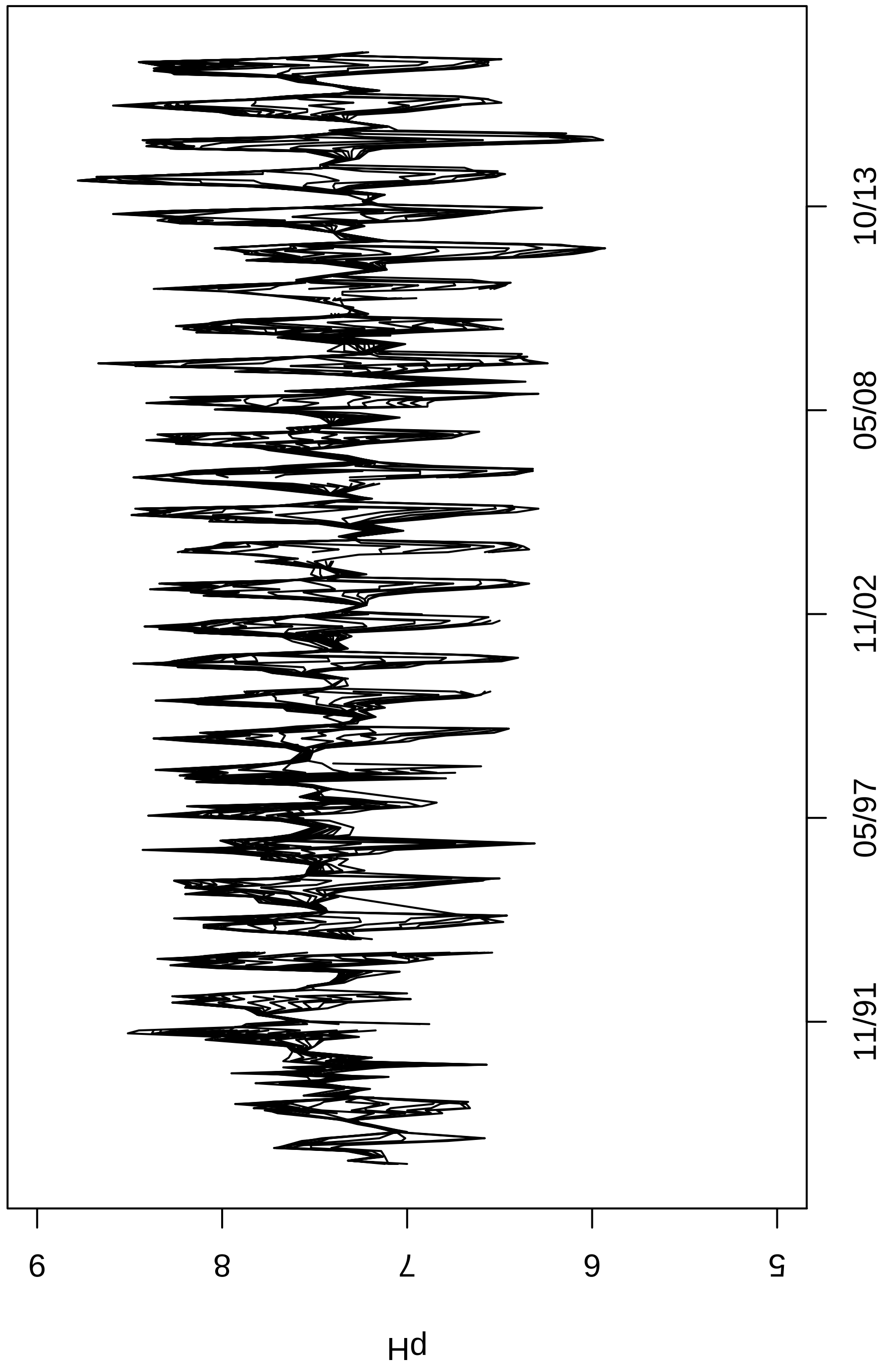


Figure B62: Lake Whatcom historic pH data for Site 2.

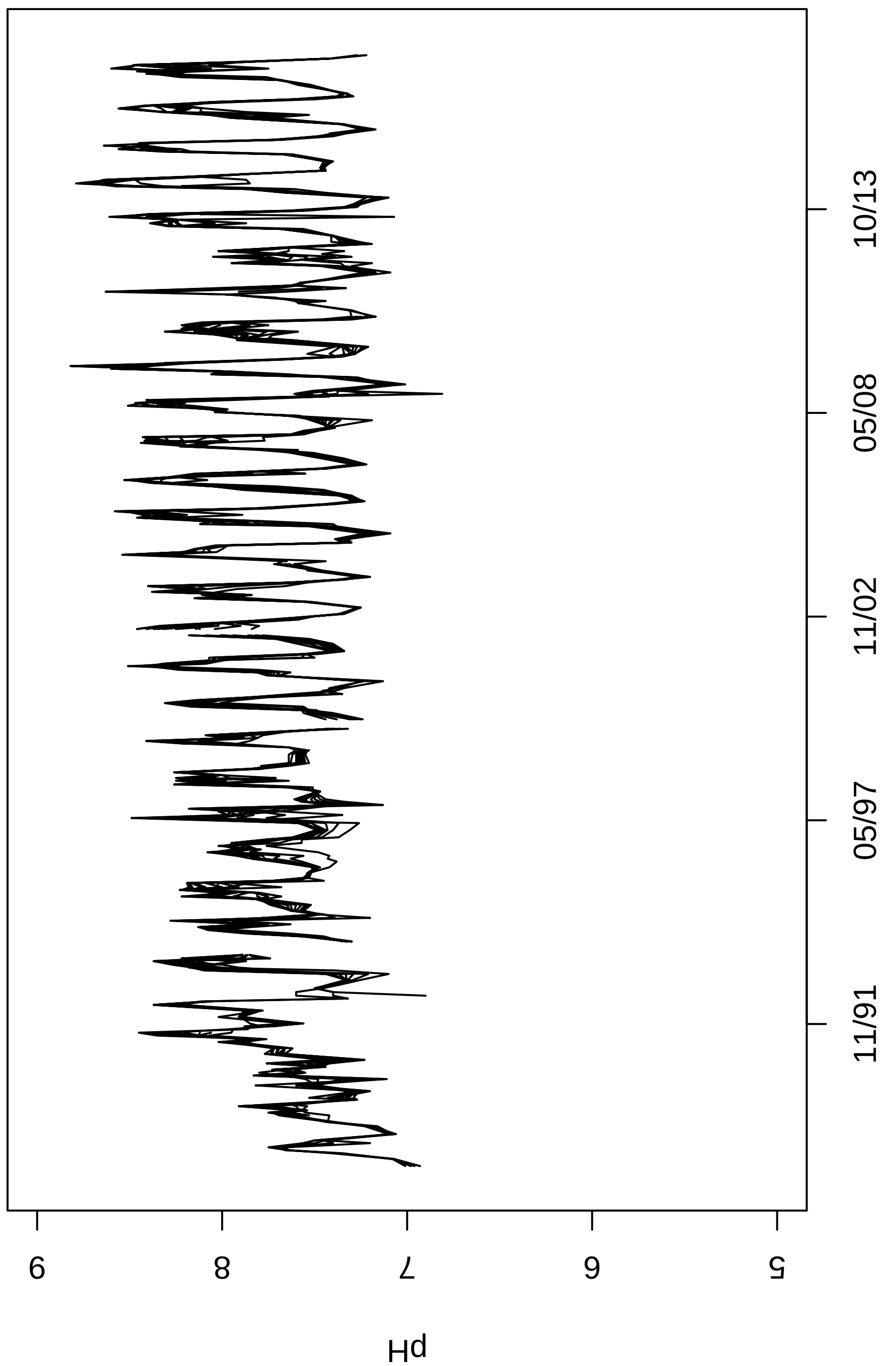


Figure B63: Lake Whatcom historic pH data for the Intake.

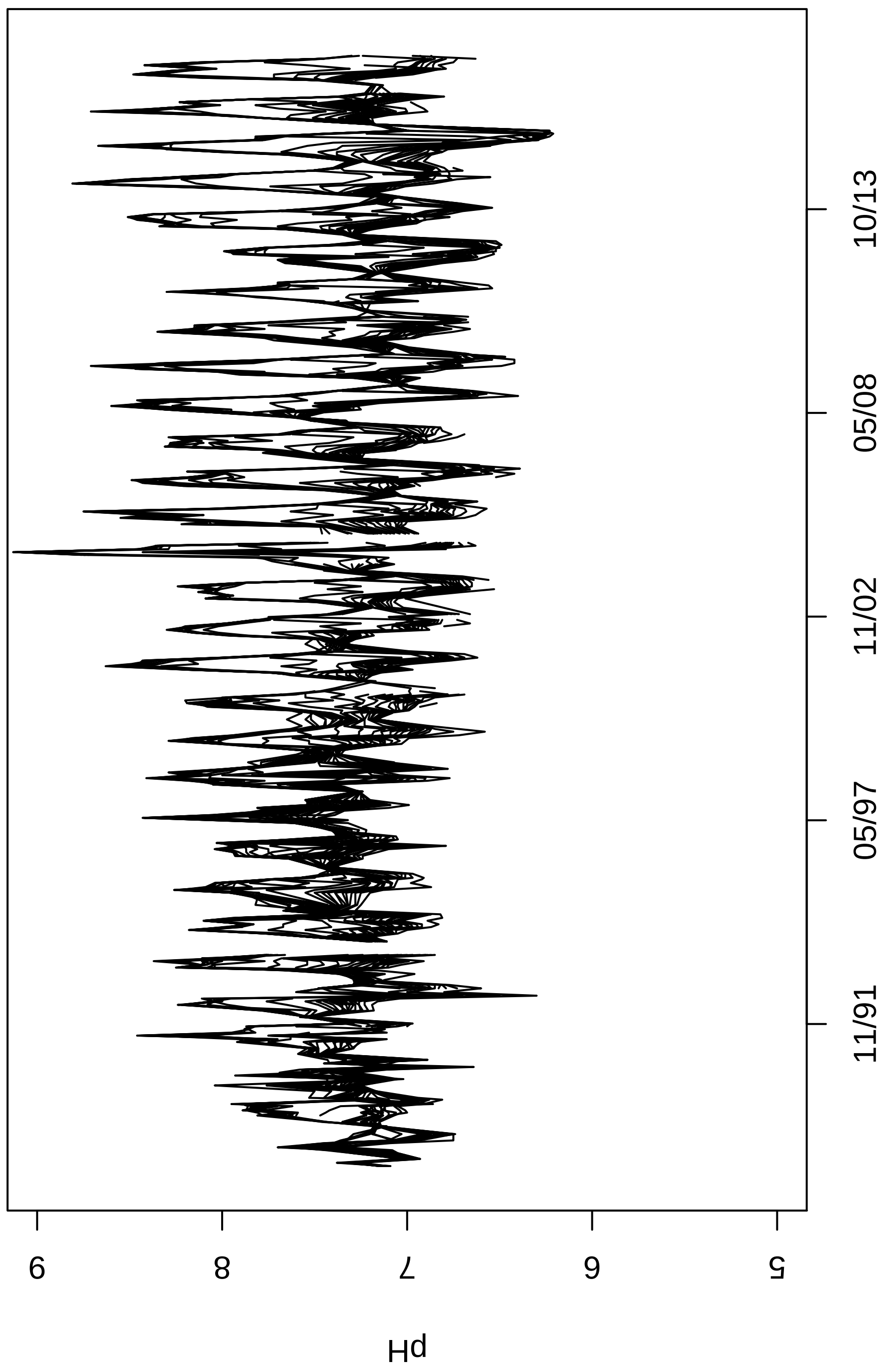


Figure B64: Lake Whatcom historic pH data for Site 3.

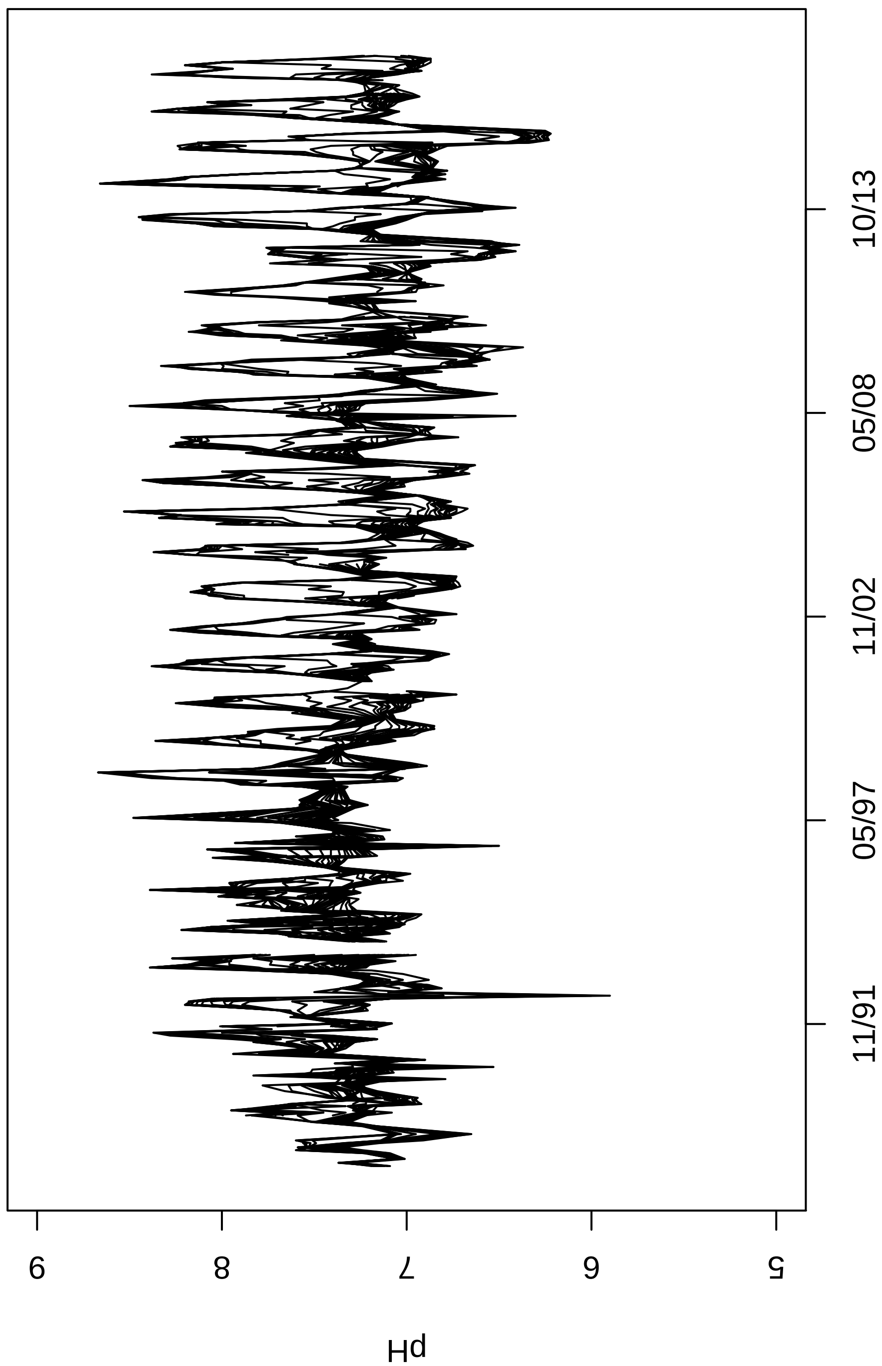


Figure B65: Lake Whatcom historic pH data for Site 4.

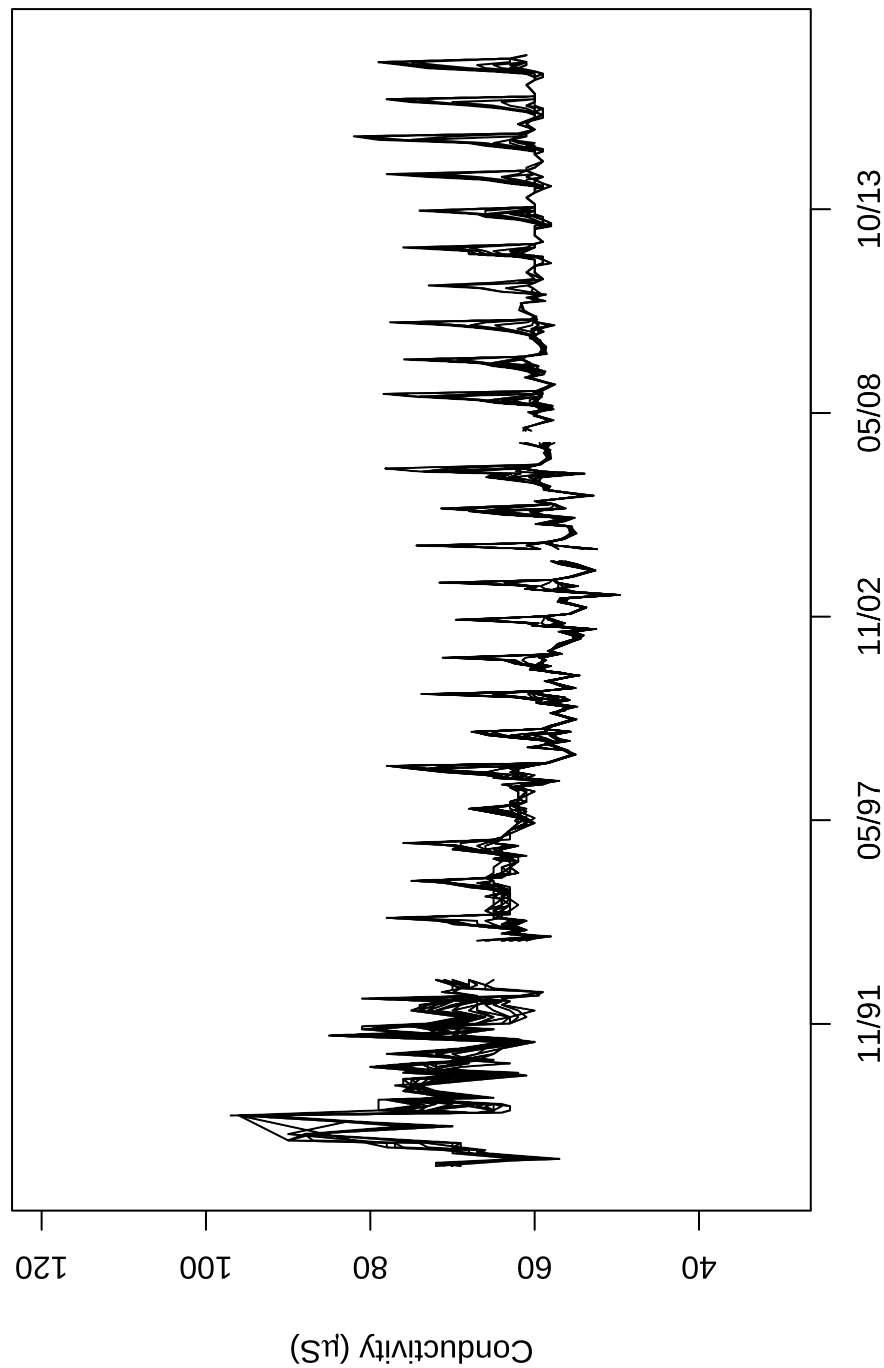


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to more sensitive equipment.

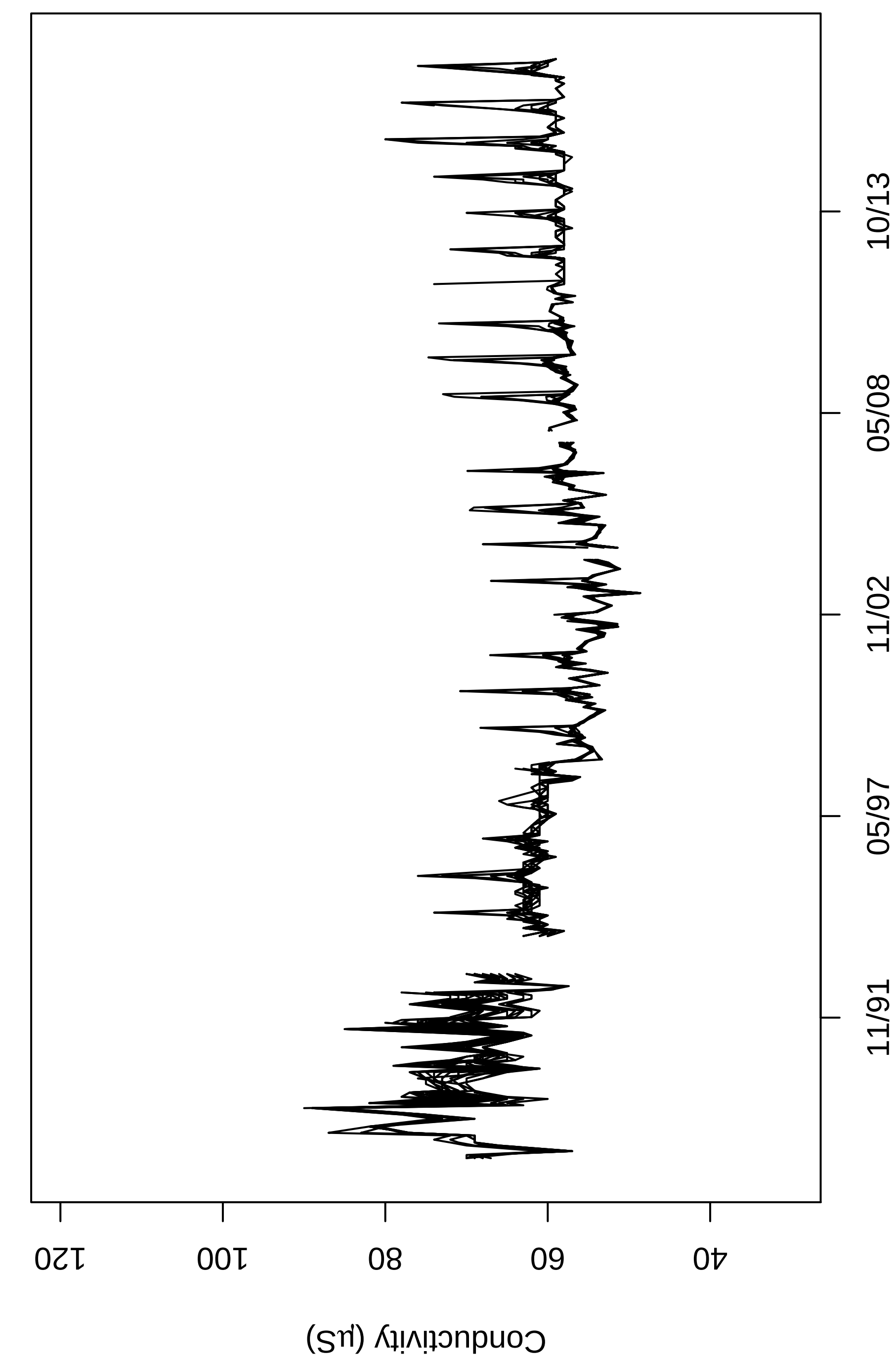


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to more sensitive equipment.

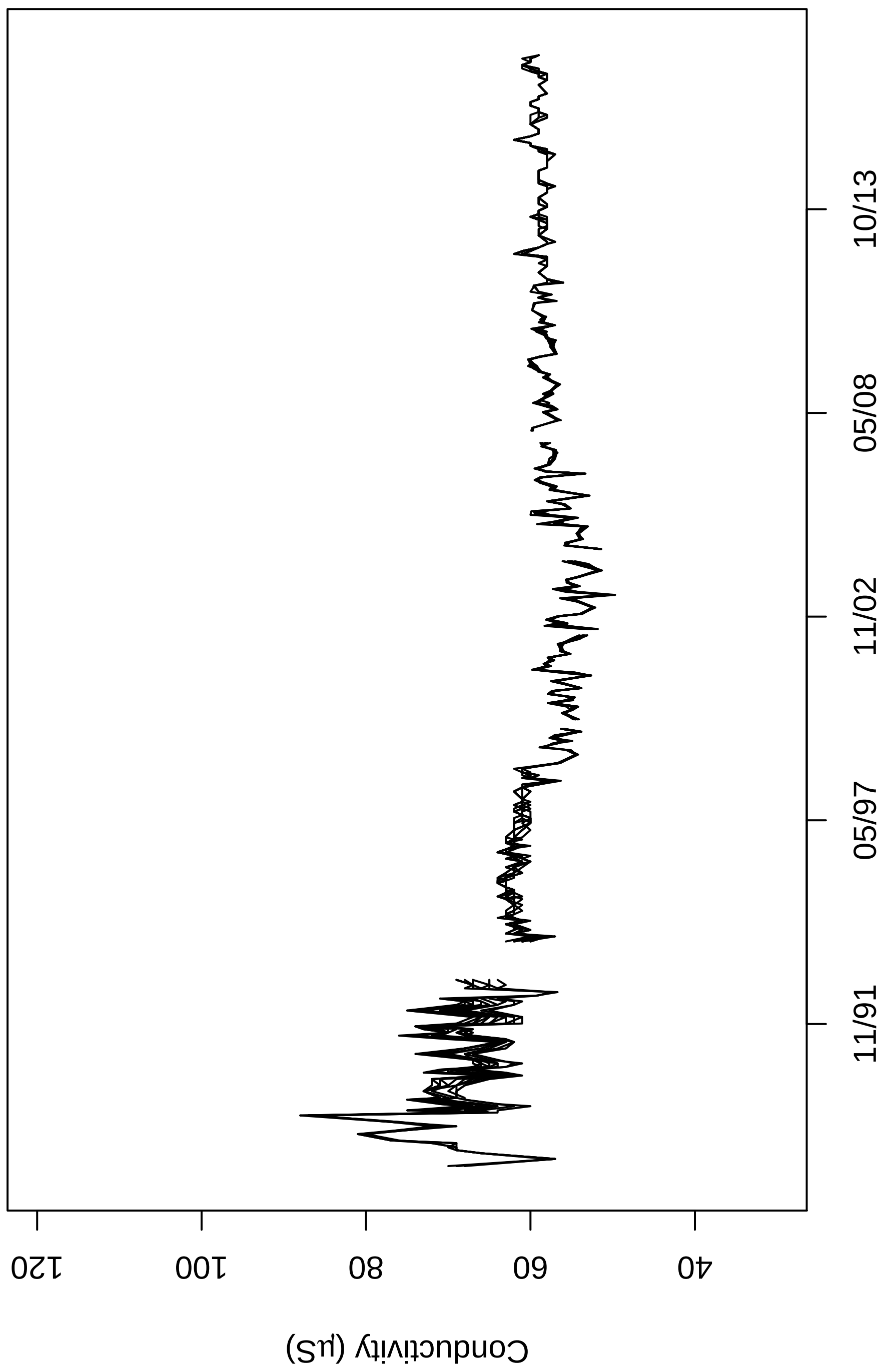


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to more sensitive equipment.

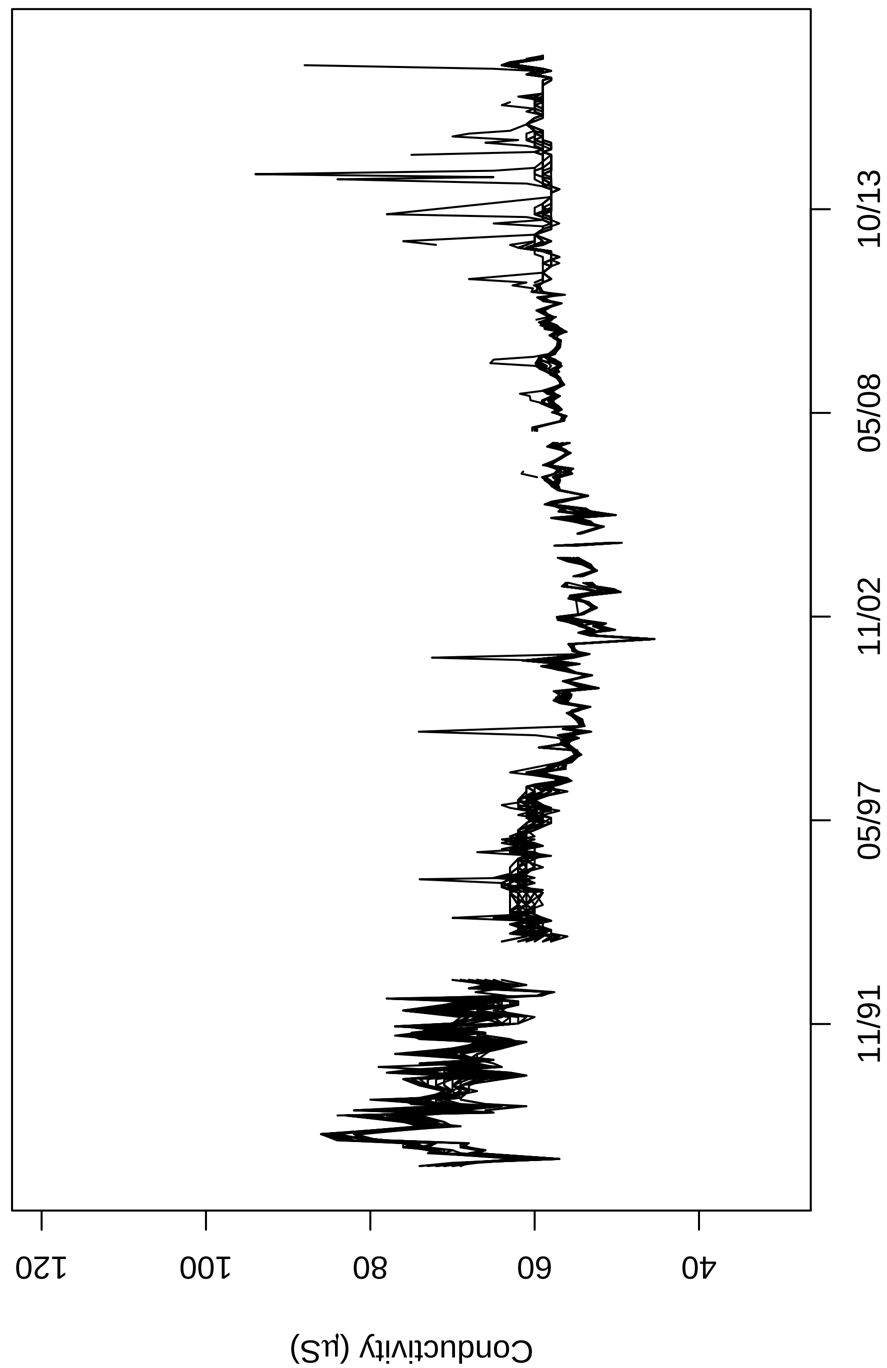


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to more sensitive equipment.

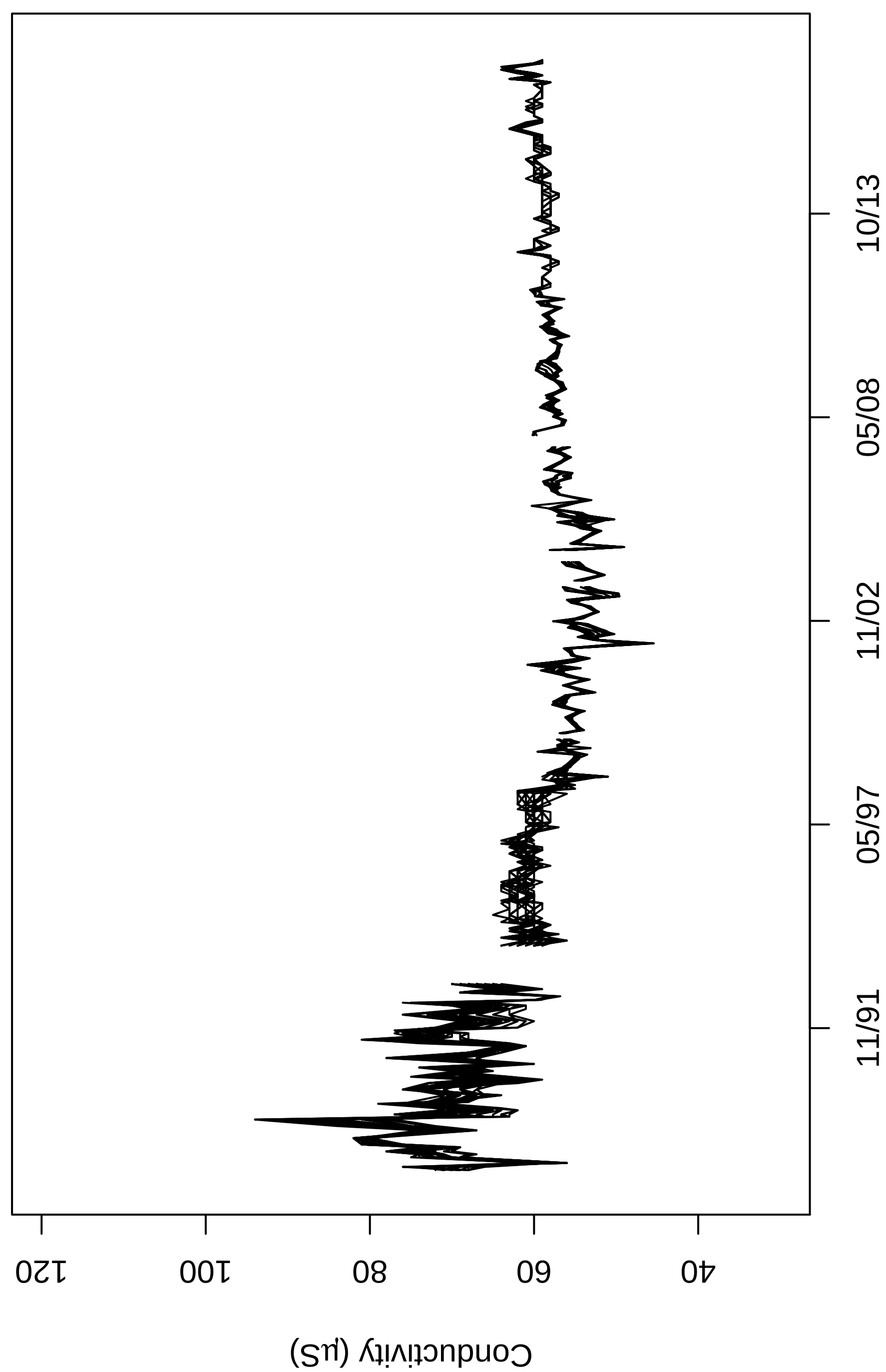


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to more sensitive equipment.

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

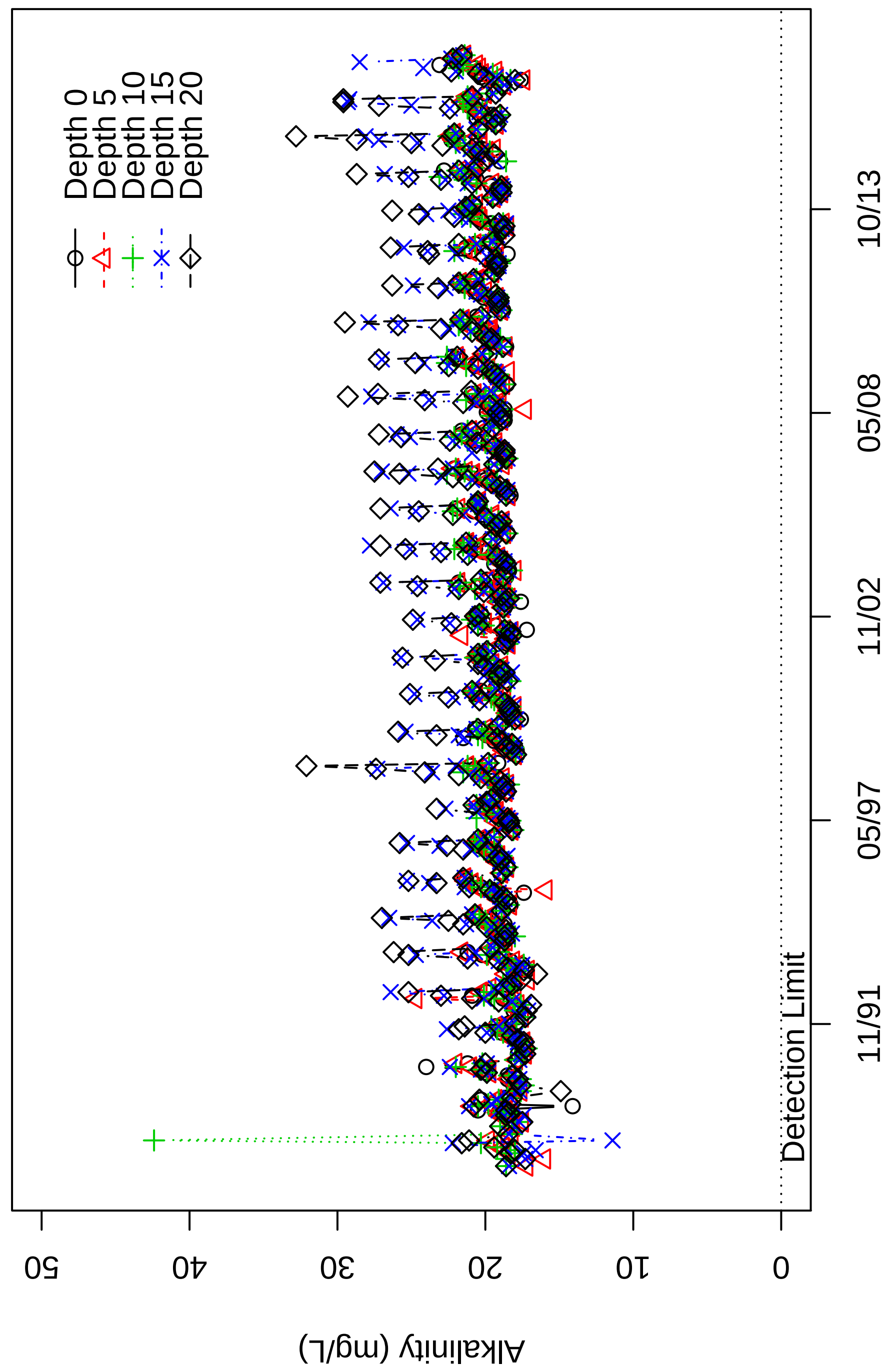


Figure B71: Lake Whatcom alkalinity data for Site 1.

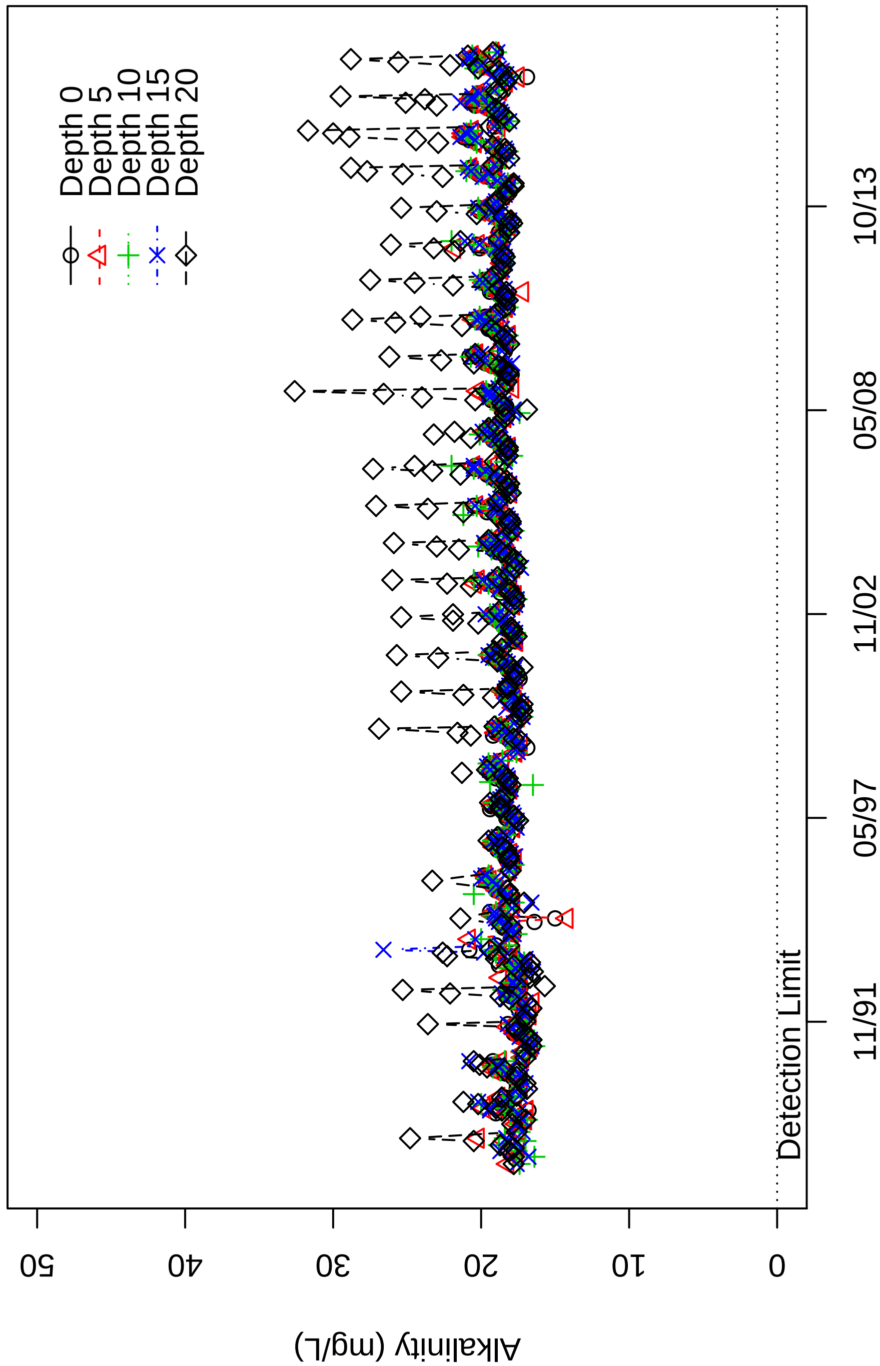


Figure B72: Lake Whatcom alkalinity data for Site 2.

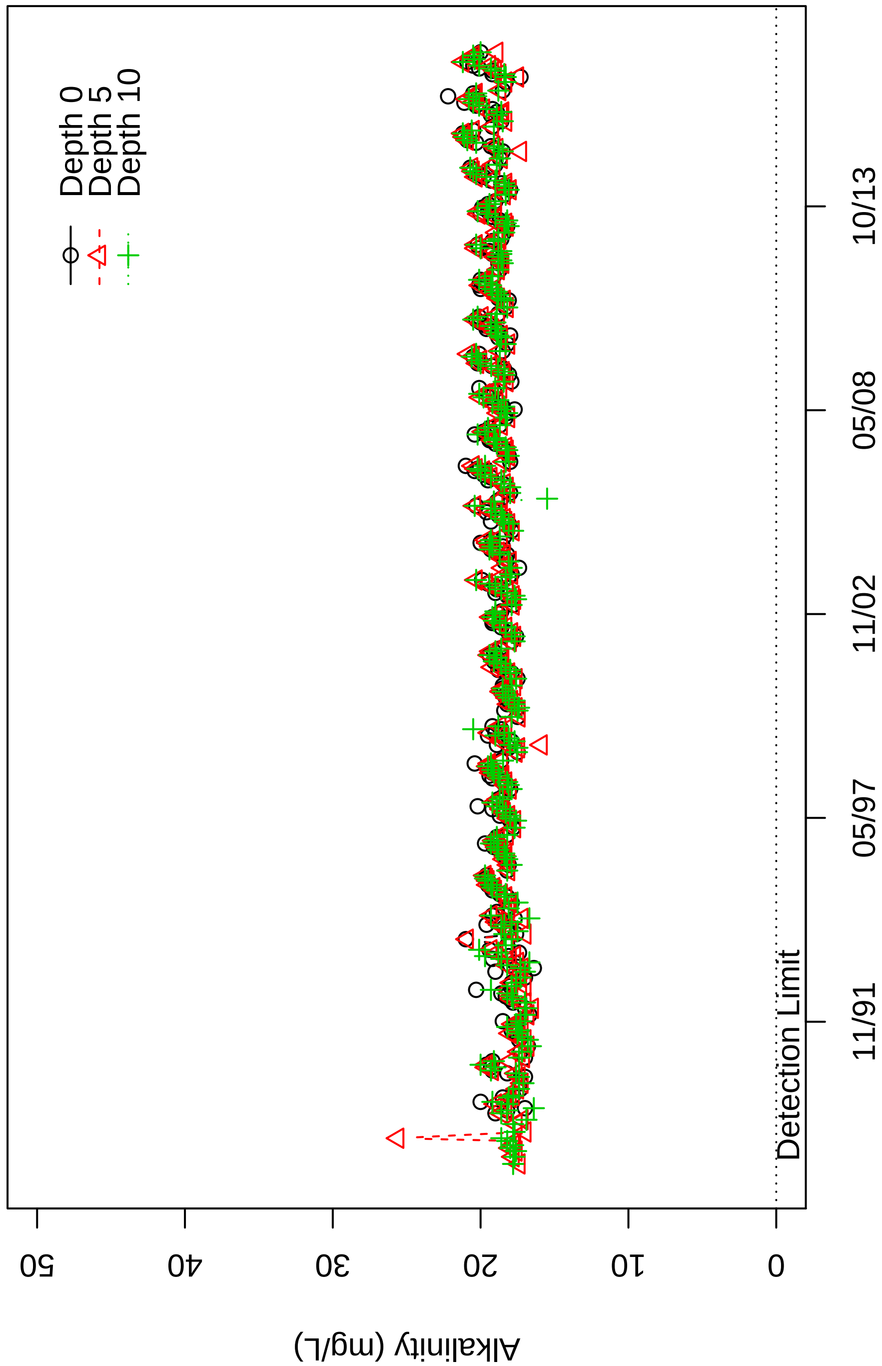


Figure B73: Lake Whatcom alkalinity data for the Intake site.

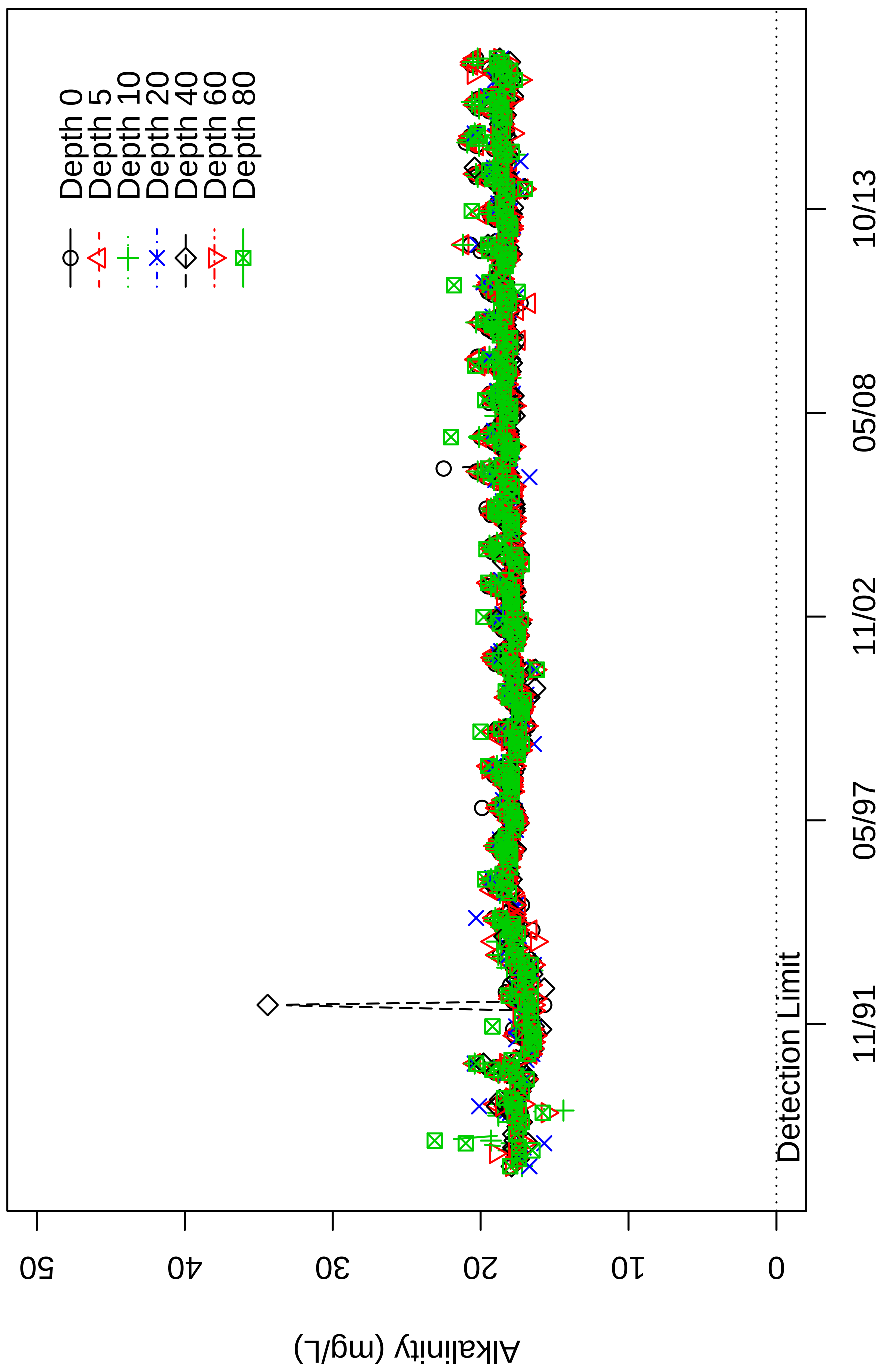


Figure B74: Lake Whatcom alkalinity data for Site 3.

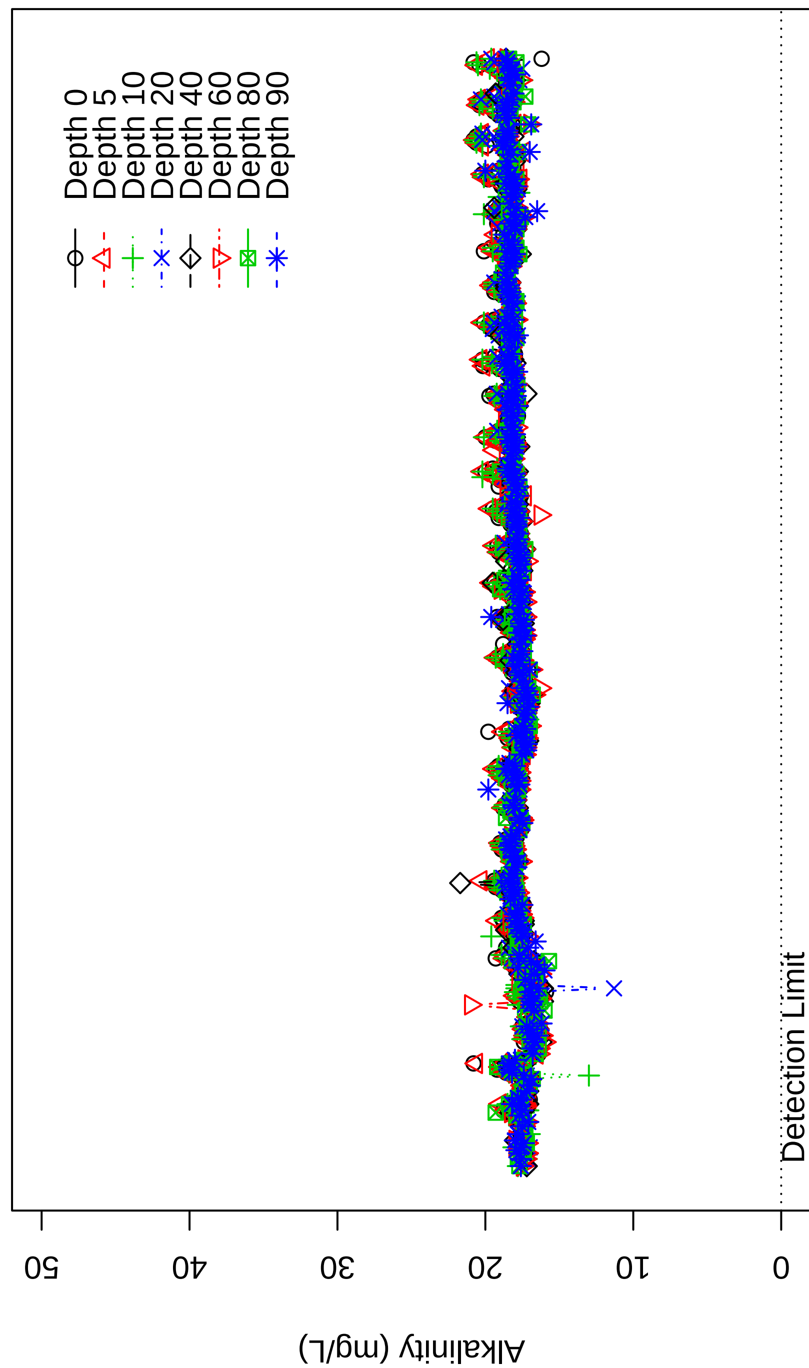


Figure B75: Lake Whatcom alkalinity data for Site 4.

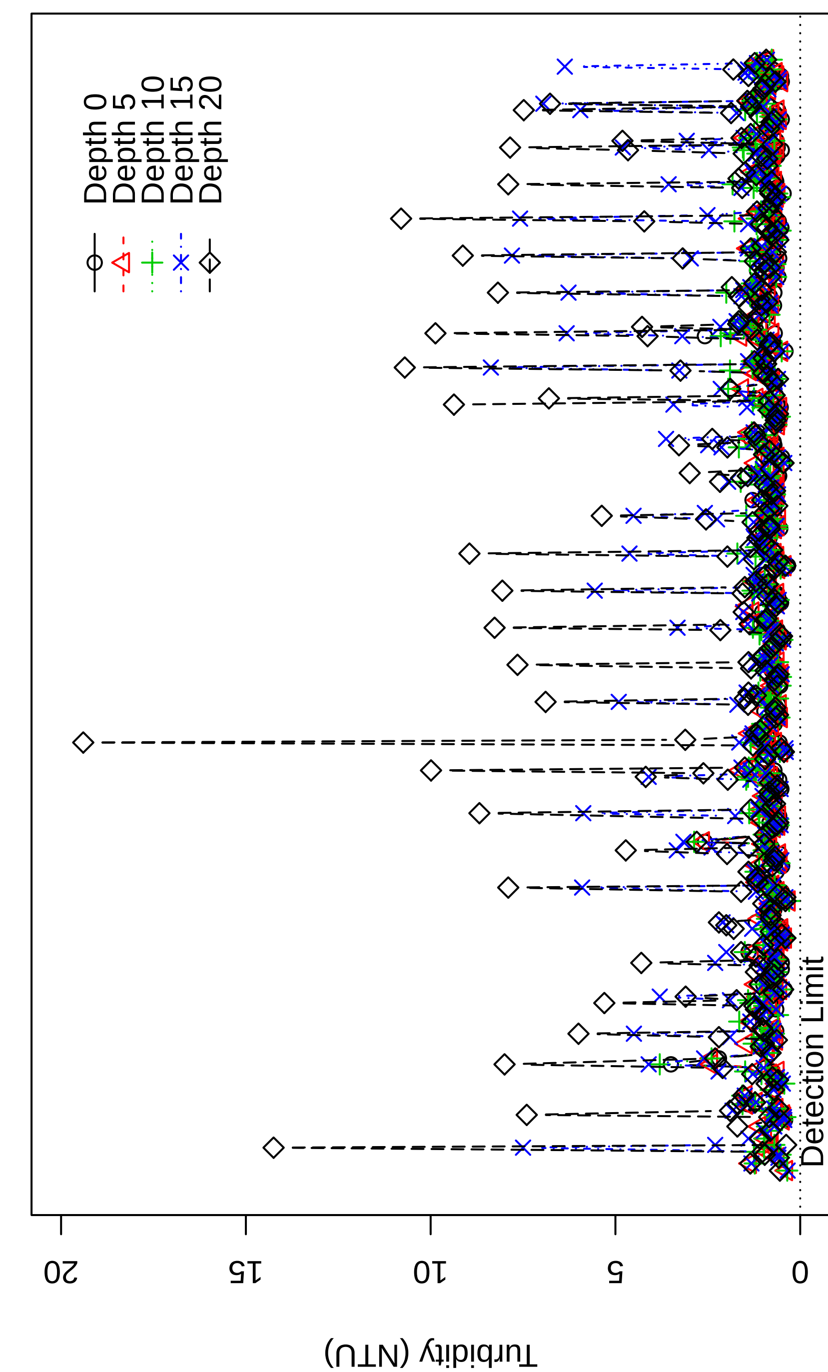


Figure B76: Lake Whatcom turbidity data for Site 1.

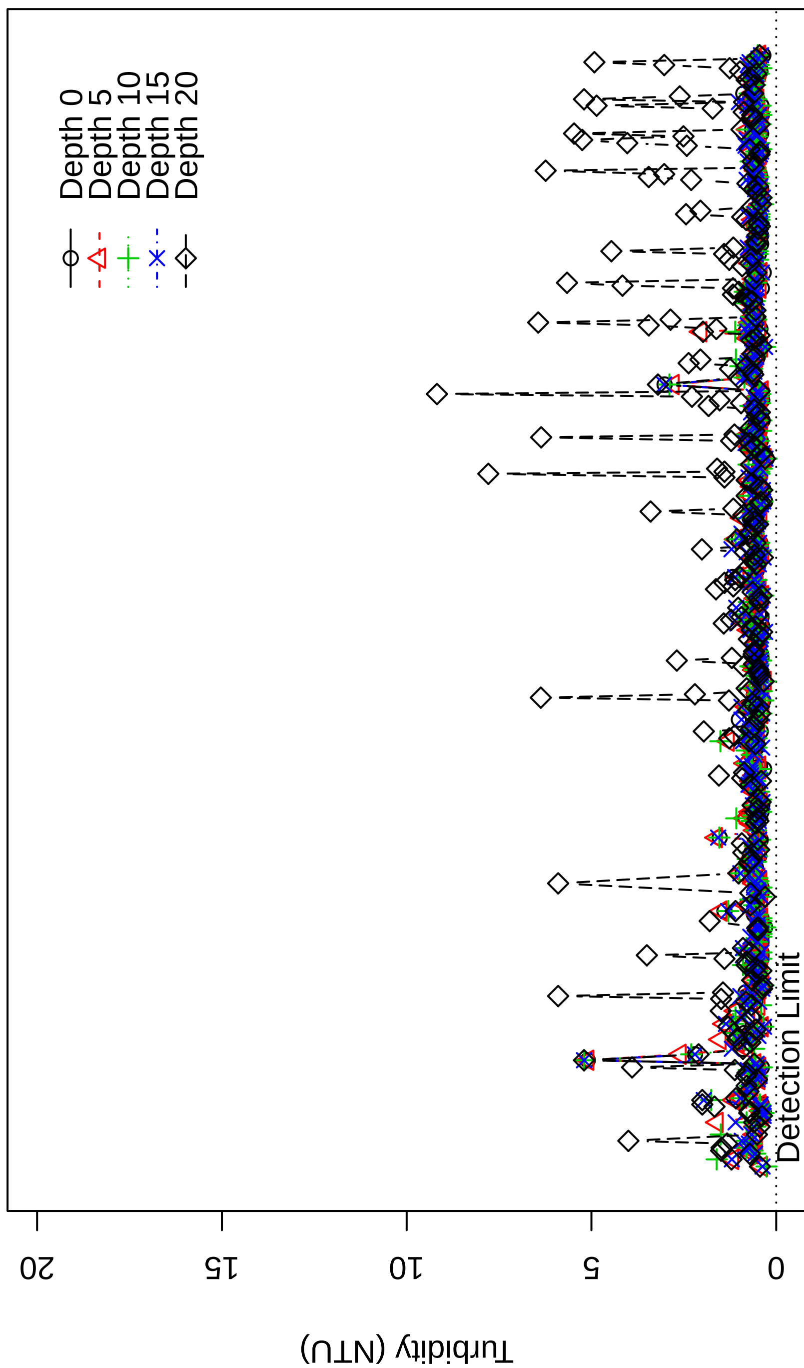


Figure B77: Lake Whatcom turbidity data for Site 2.

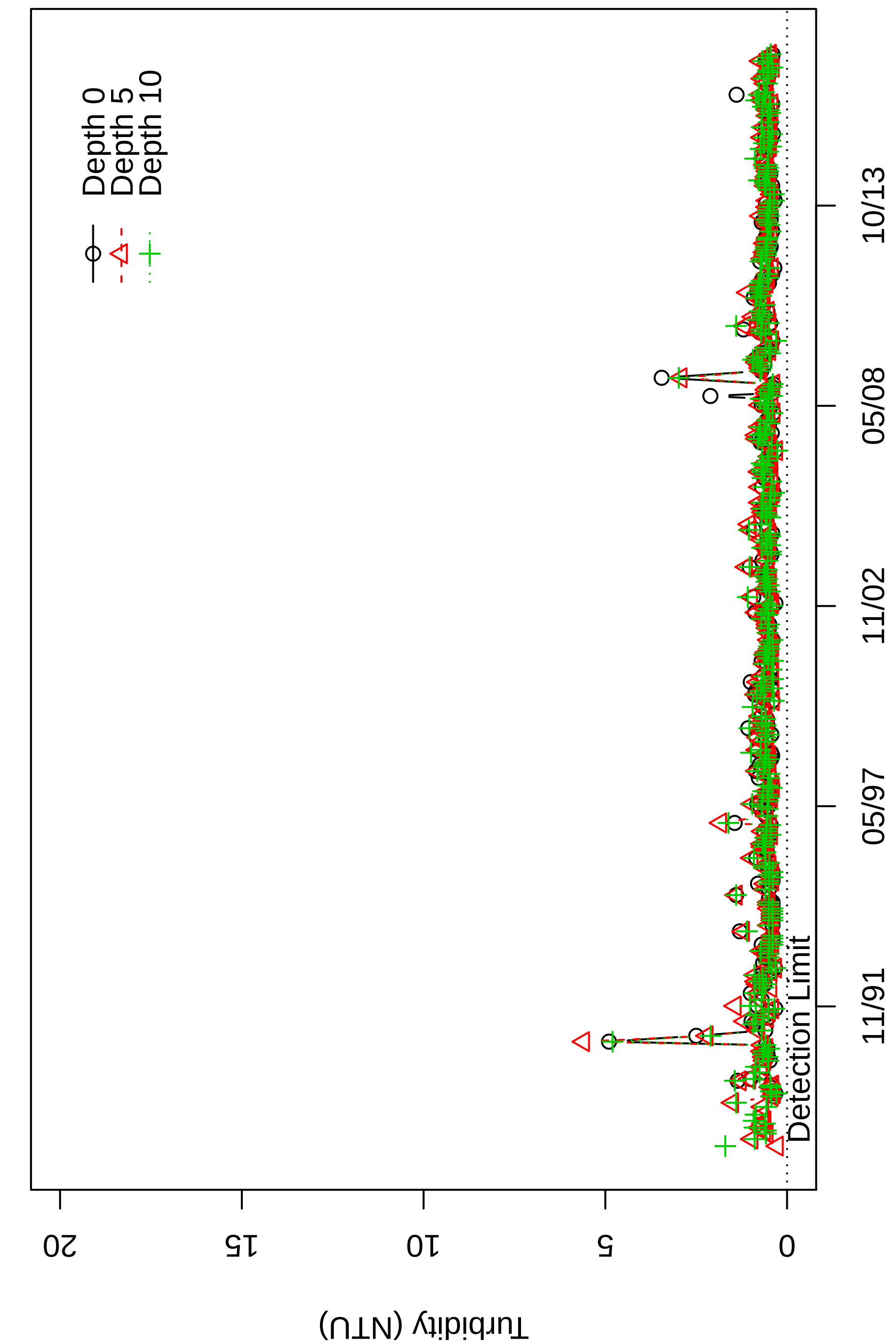


Figure B78: Lake Whatcom turbidity data for the Intake site.

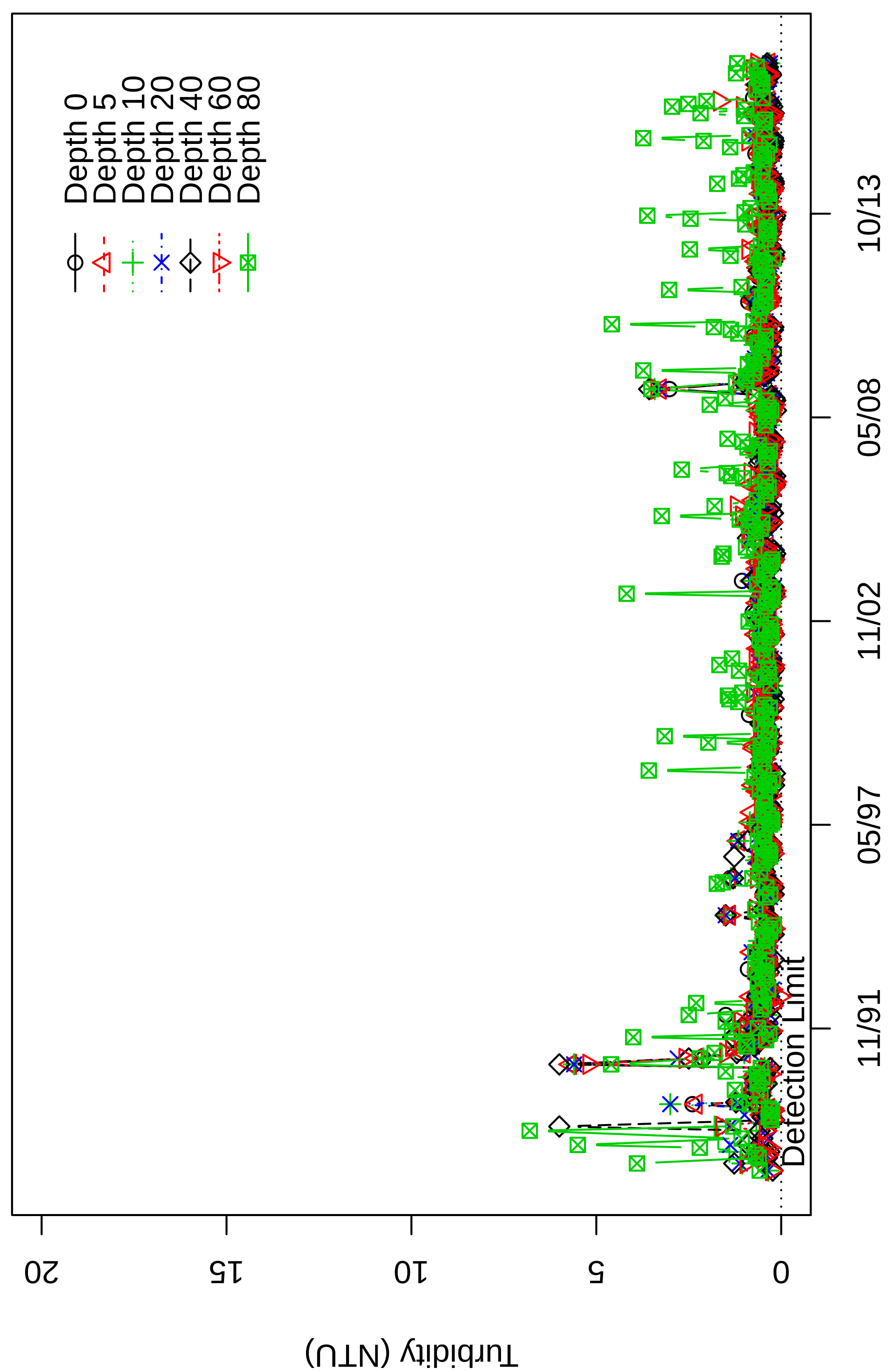


Figure B79: Lake Whatcom turbidity data for Site 3.

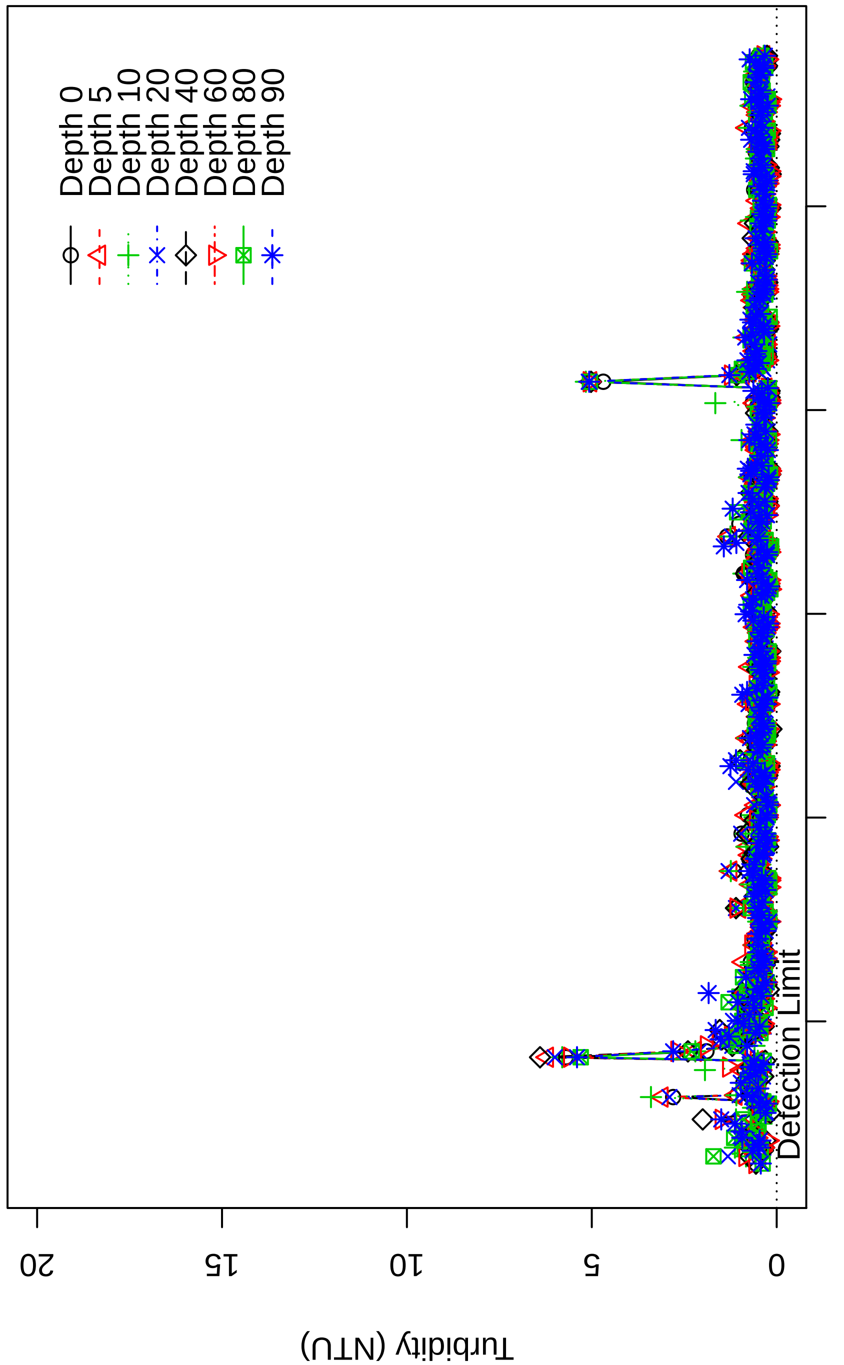


Figure B80: Lake Whatcom turbidity data for Site 4.

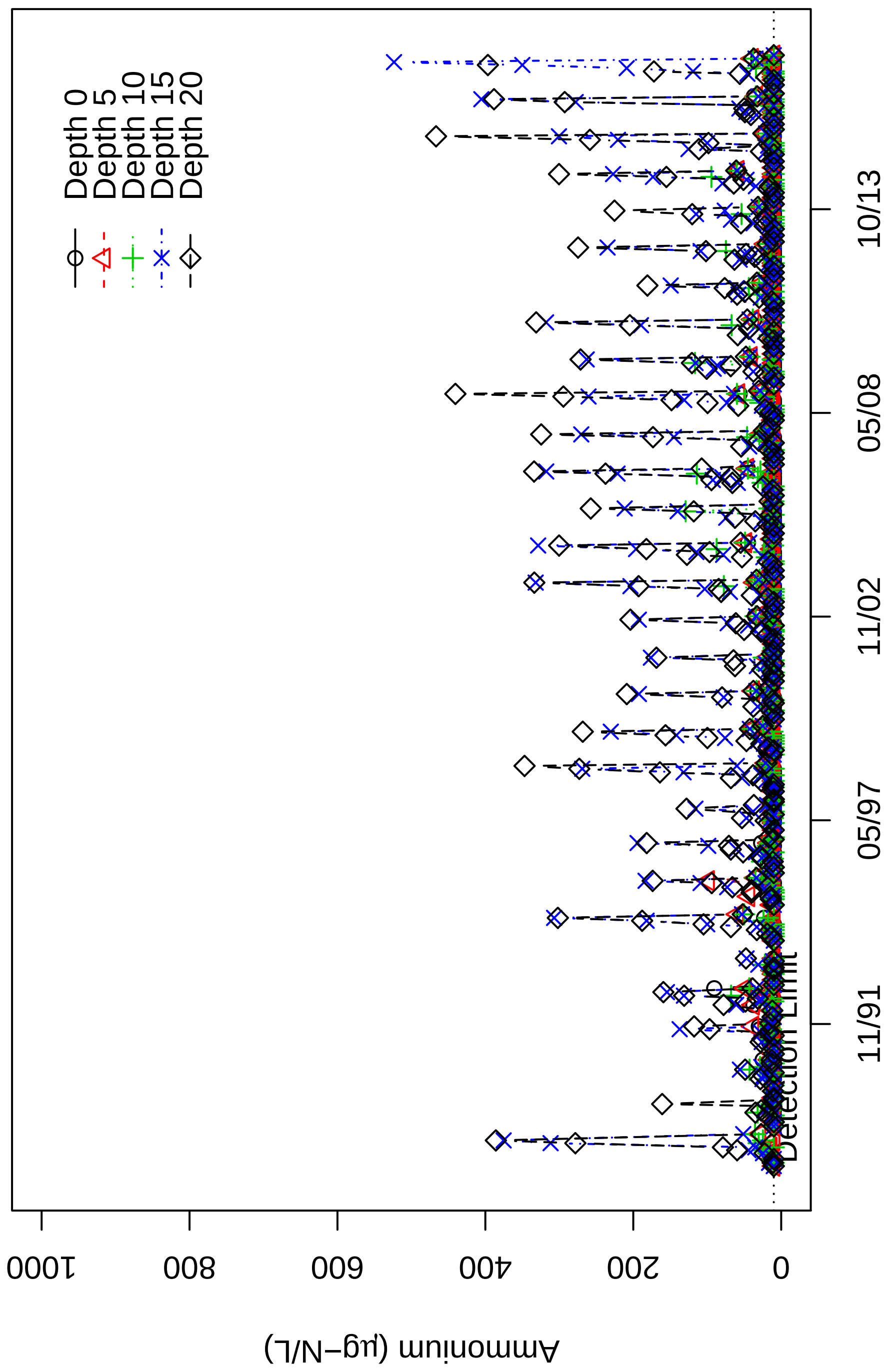


Figure B81: Lake Whatcom ammonium data for Site 1.

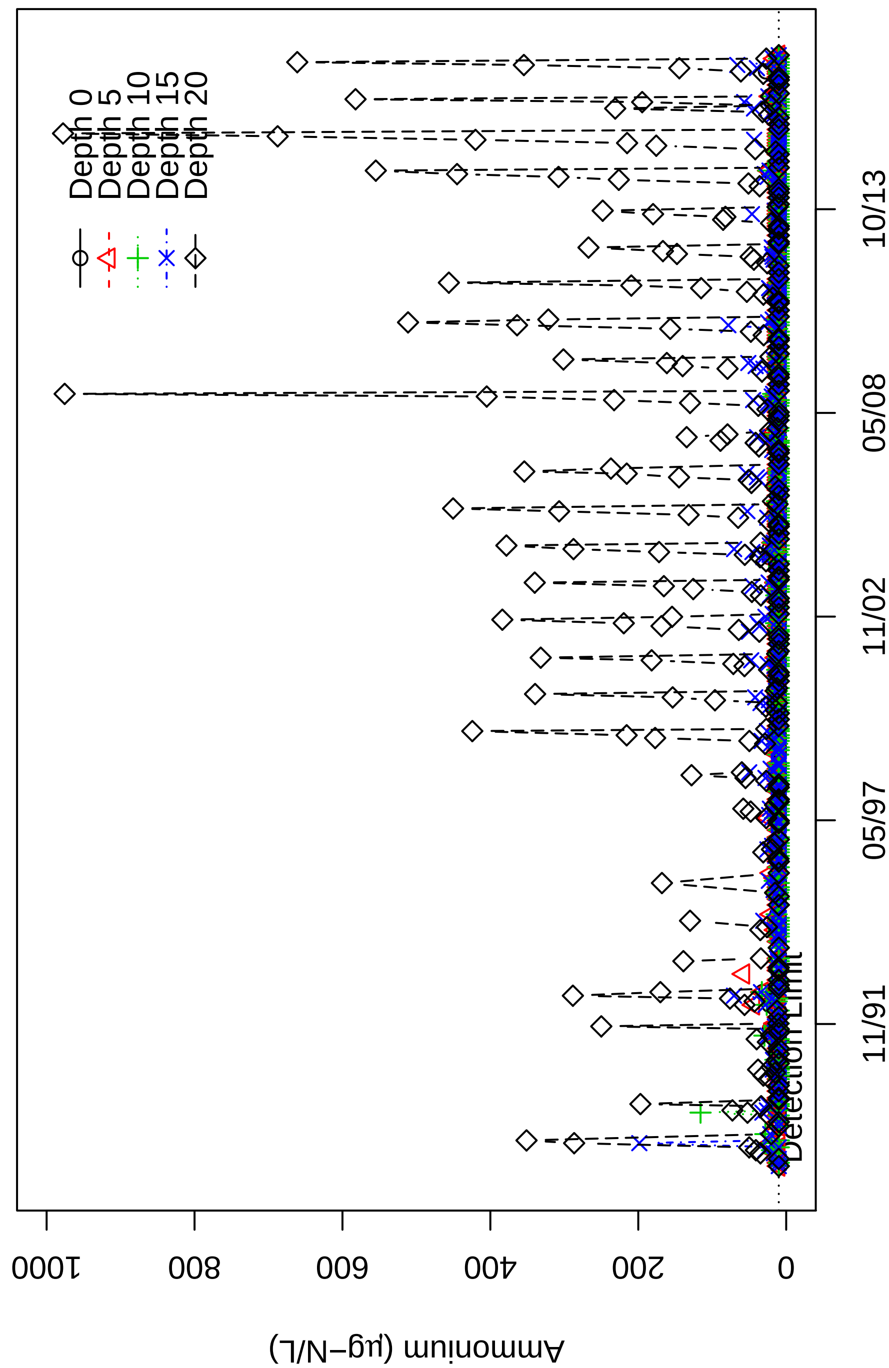


Figure B82: Lake Whatcom ammonium data for Site 2.

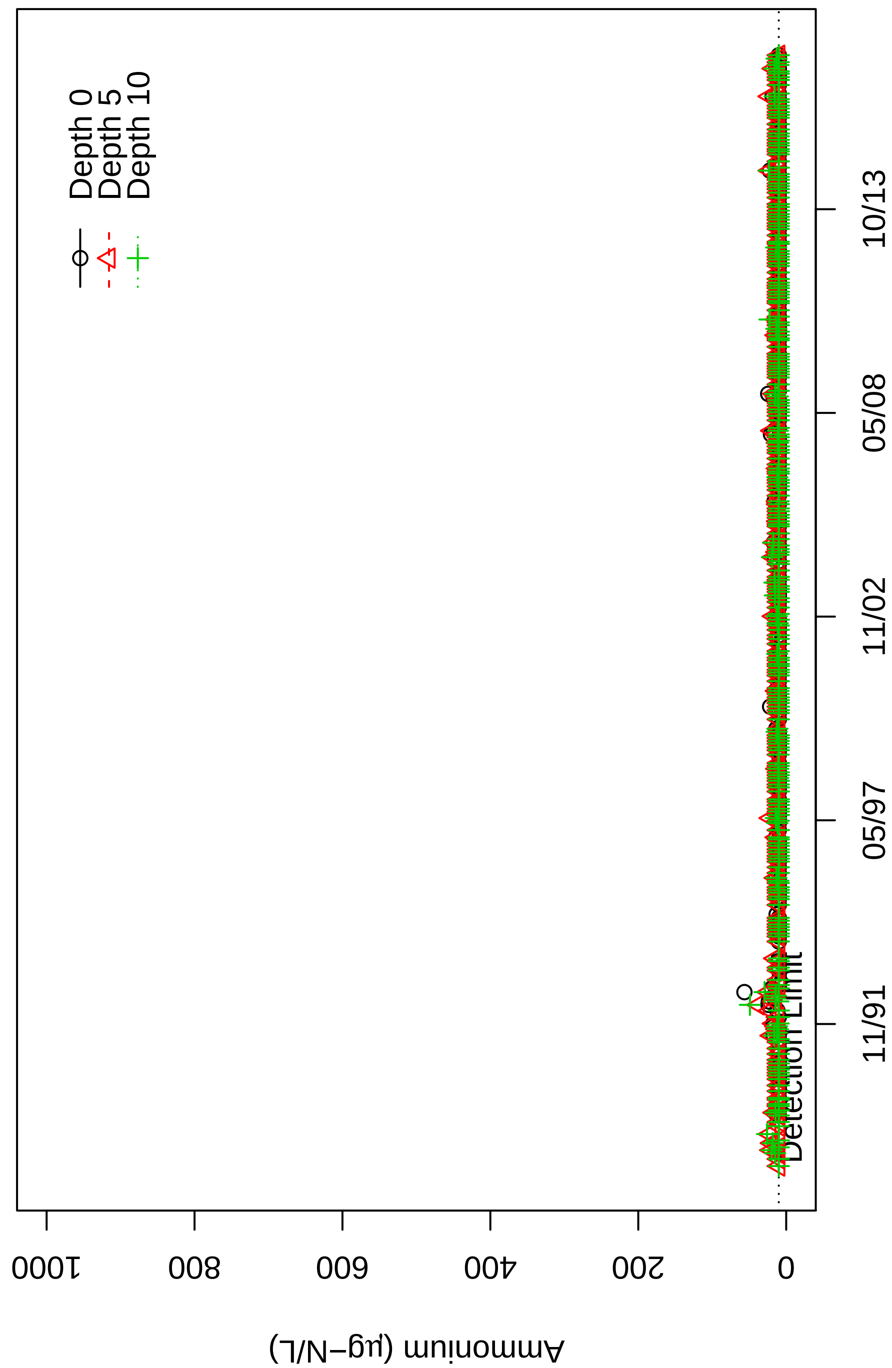


Figure B83: Lake Whatcom ammonium data for the Intake site.

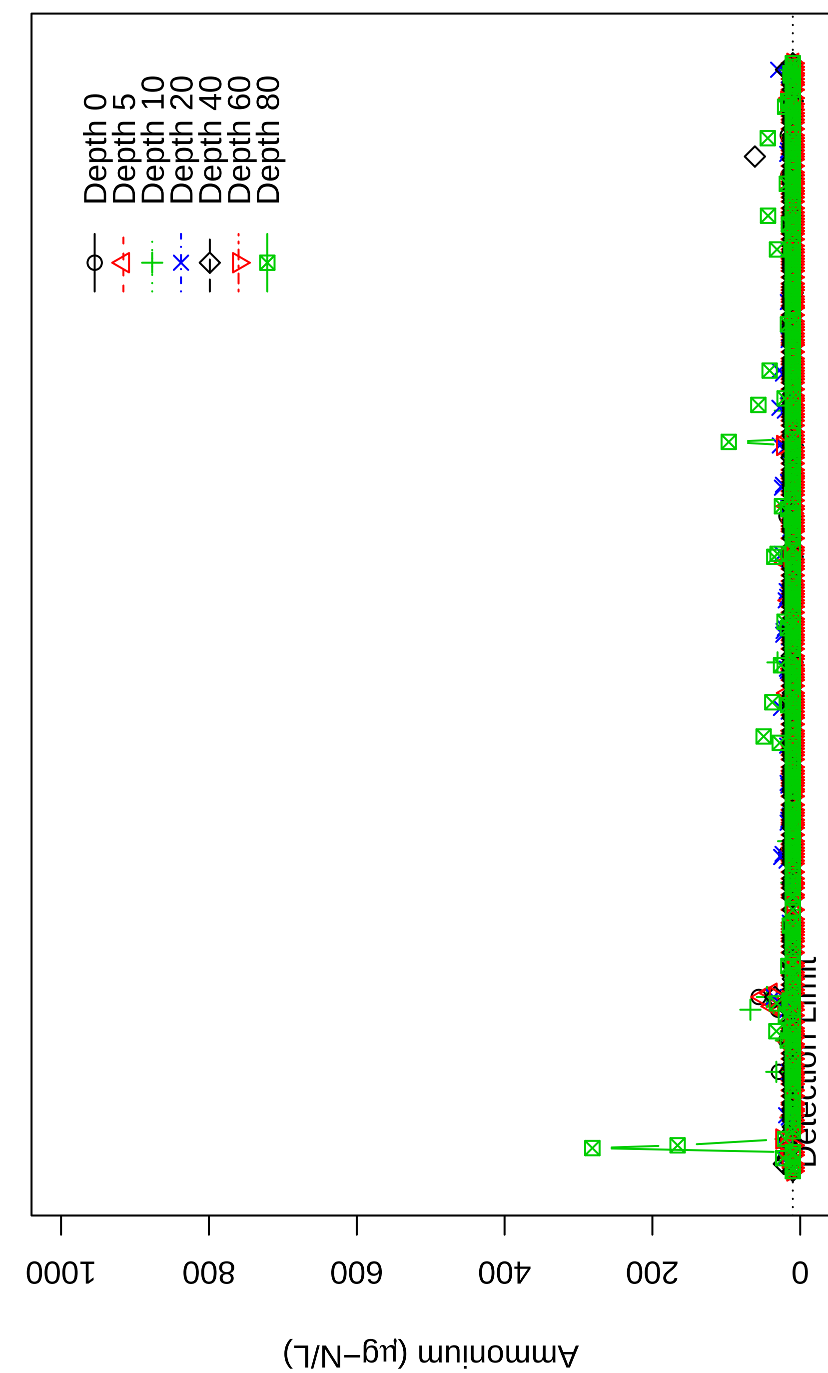


Figure B84: Lake Whatcom ammonium data for Site 3.

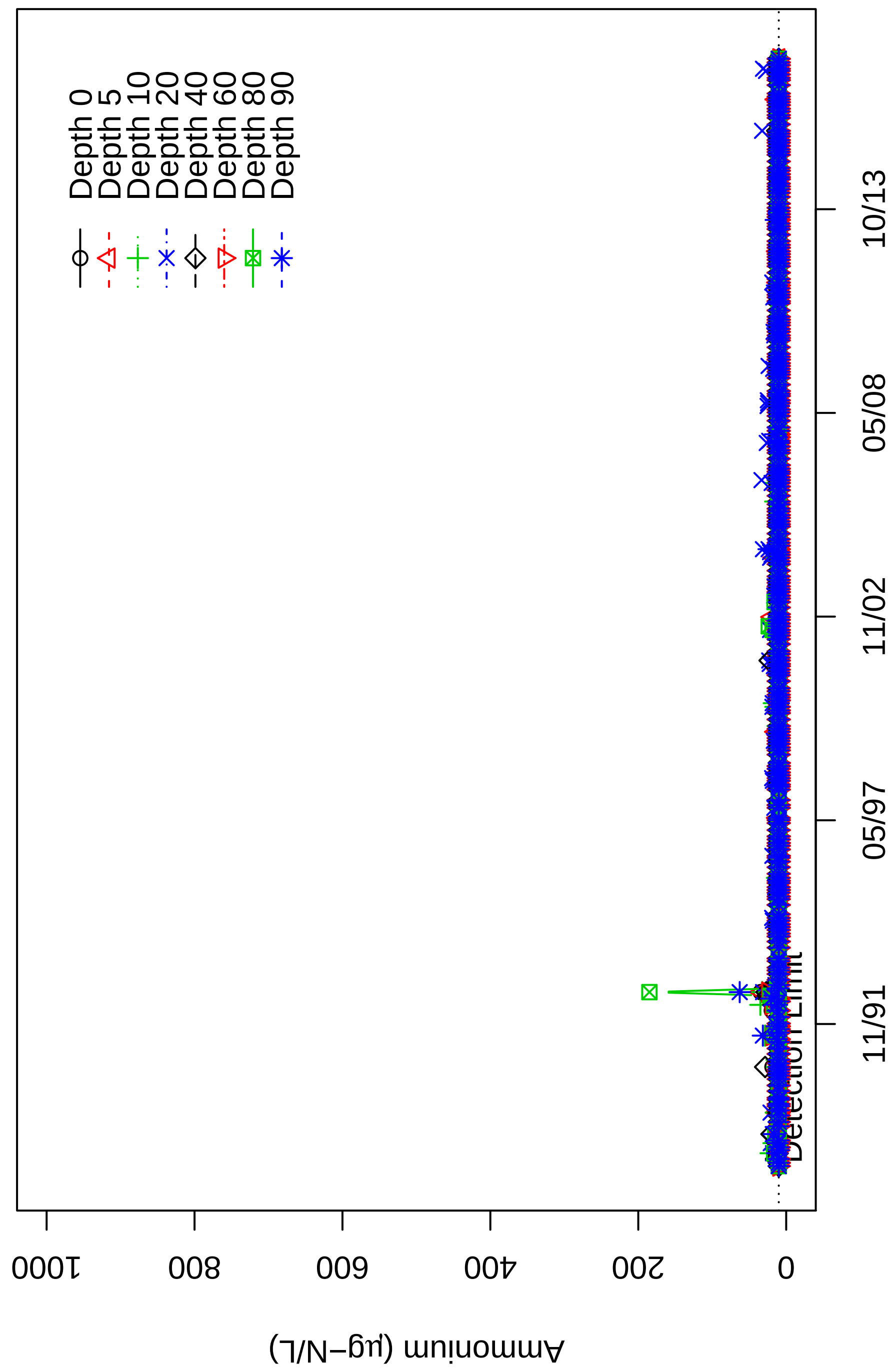


Figure B85: Lake Whatcom ammonium data for Site 4.

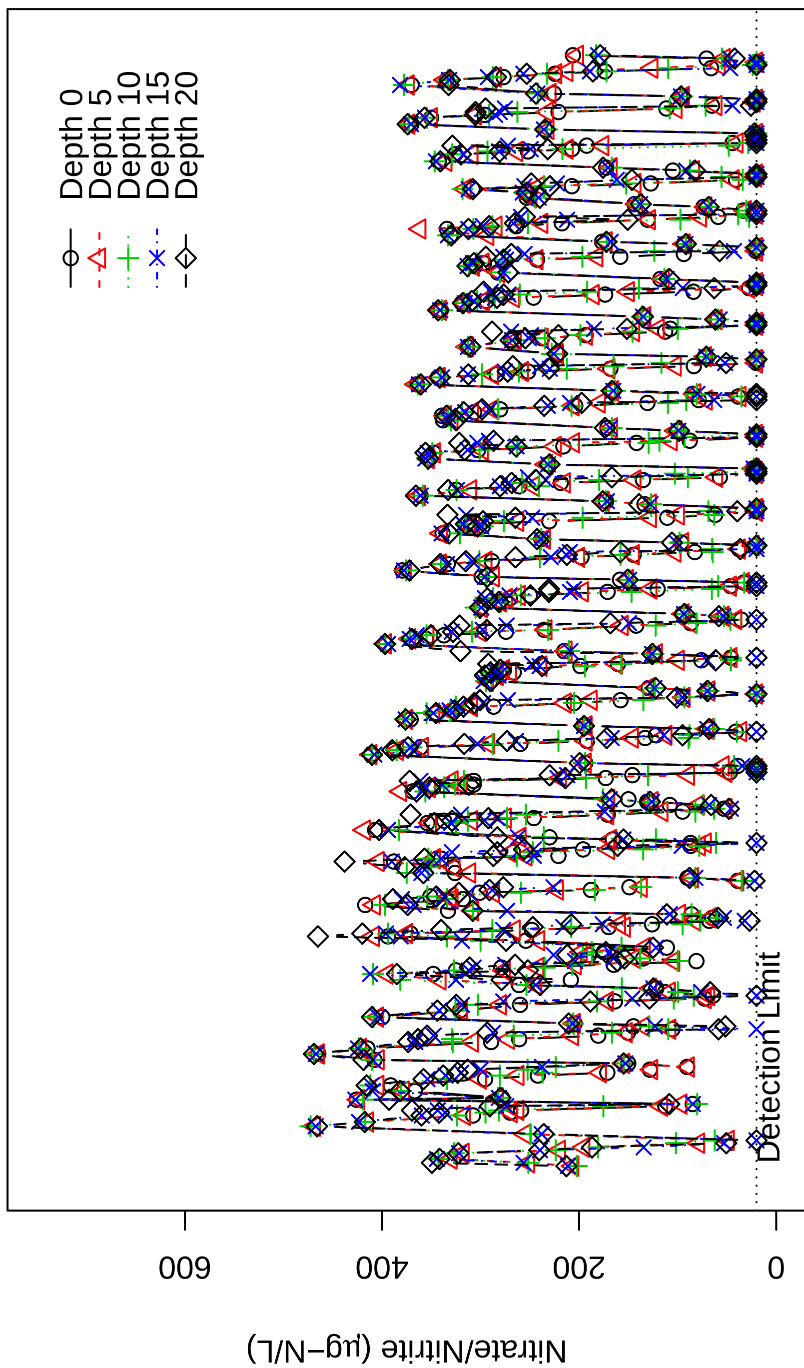


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.

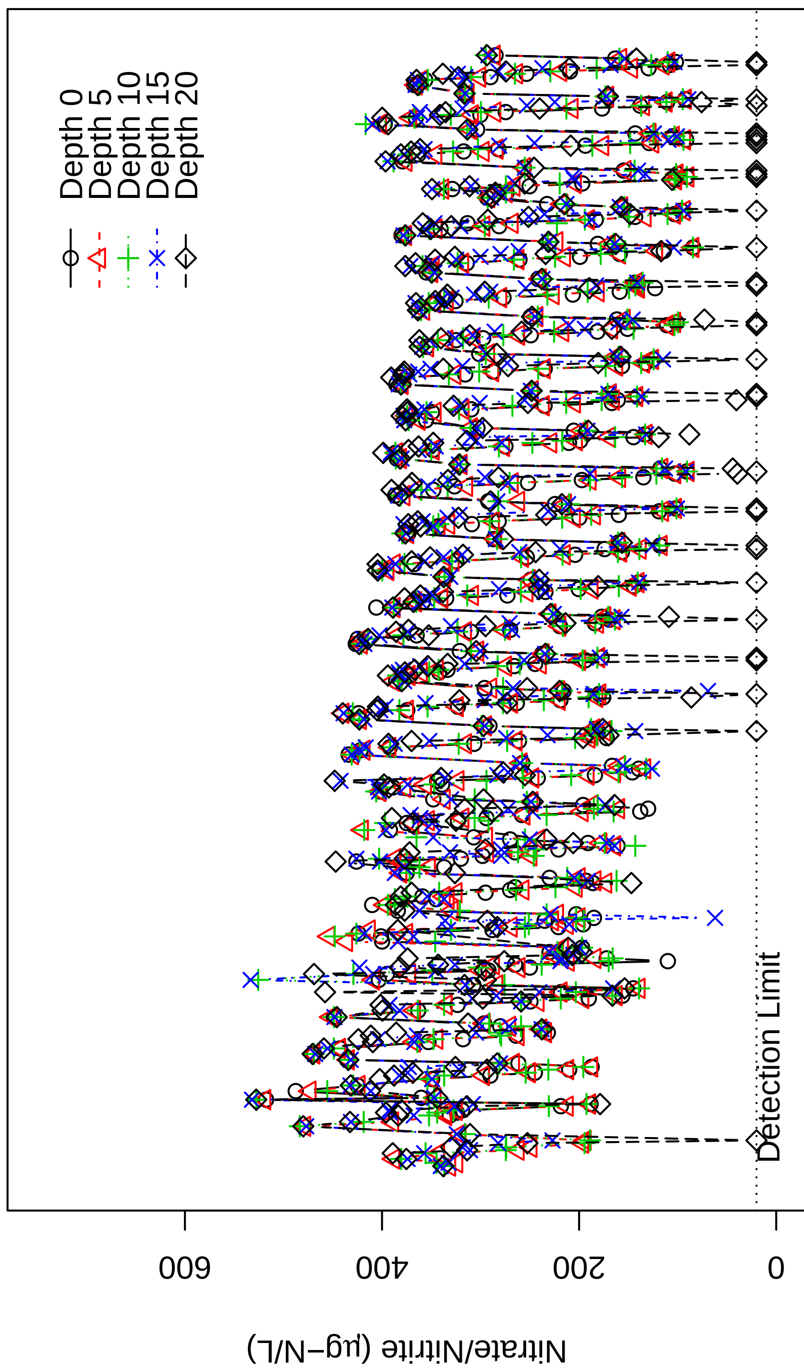


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

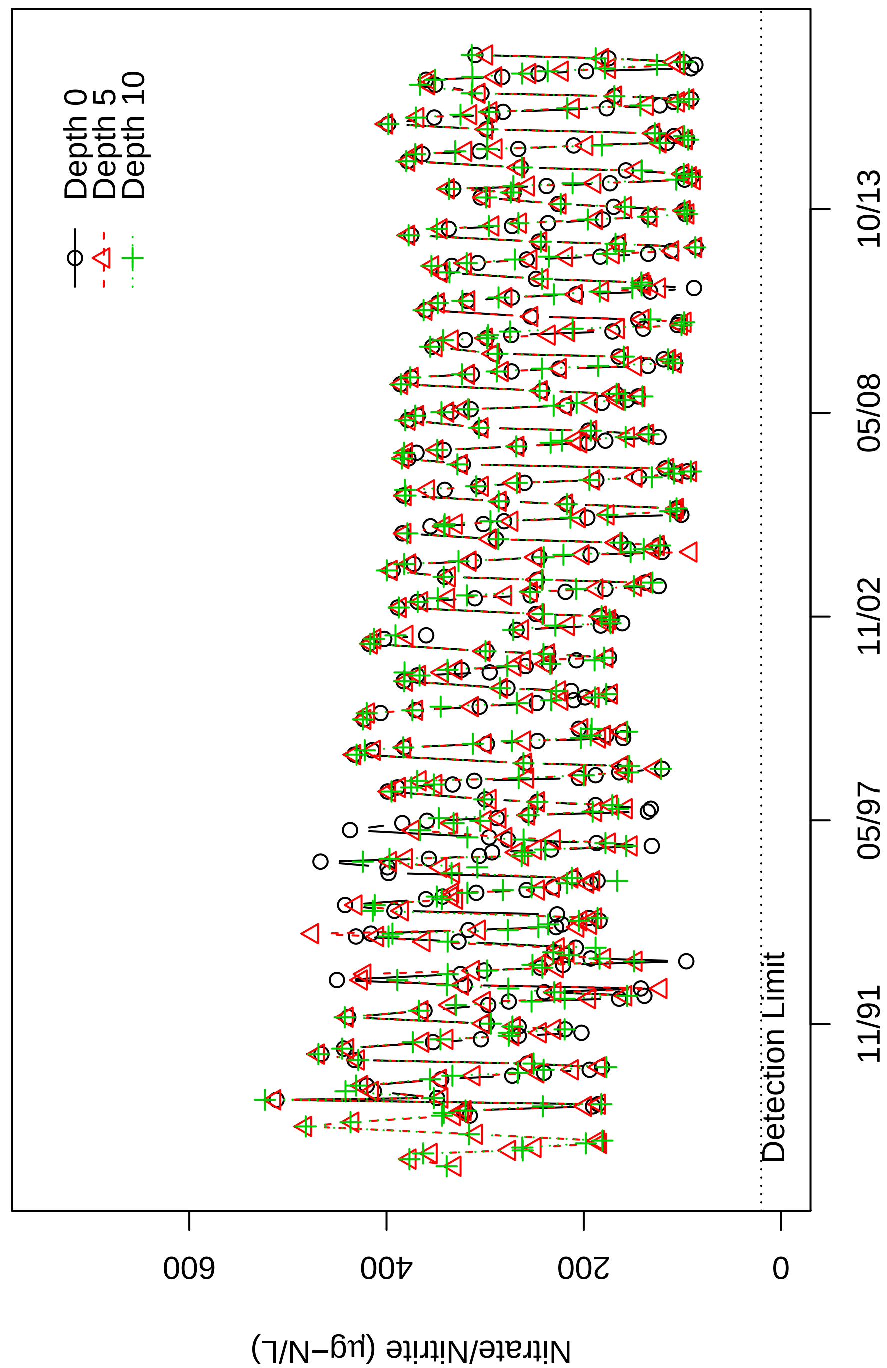


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

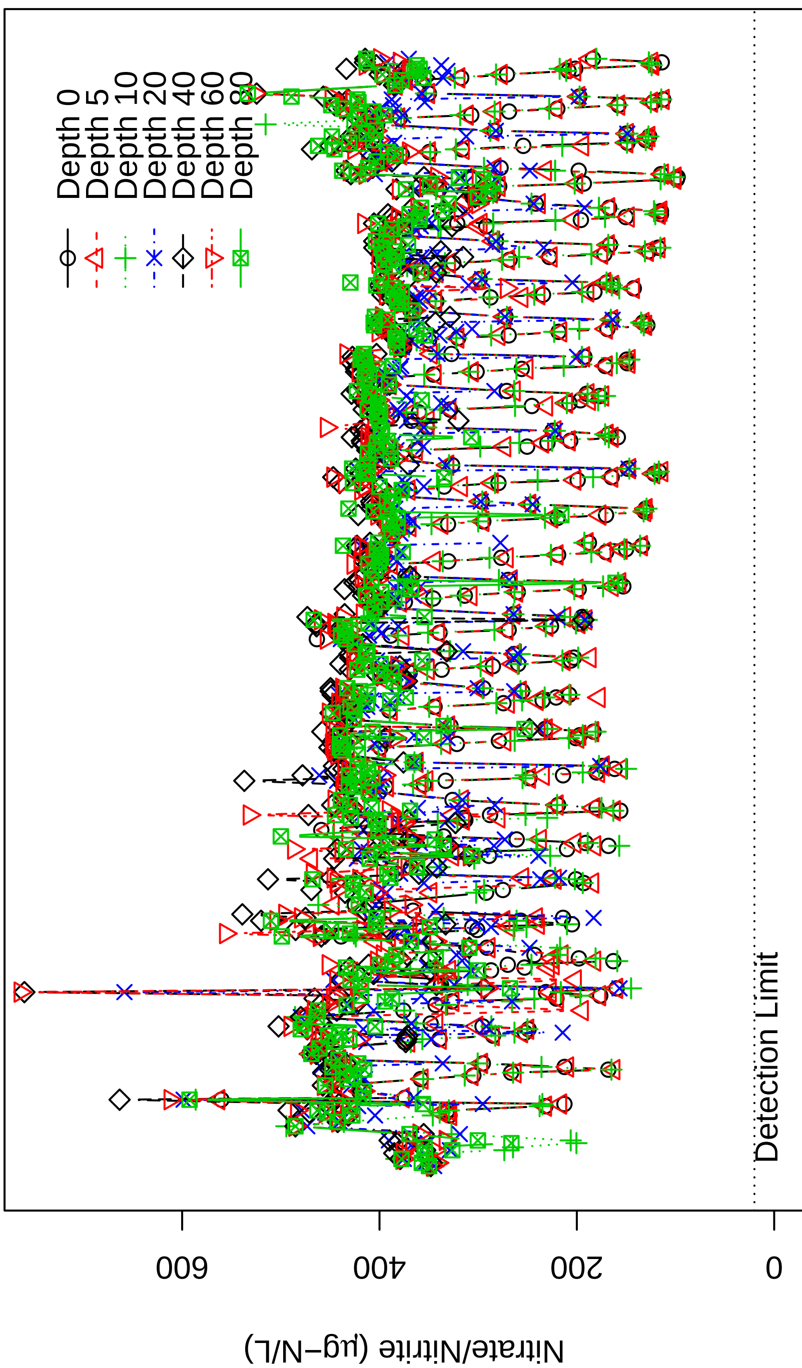


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

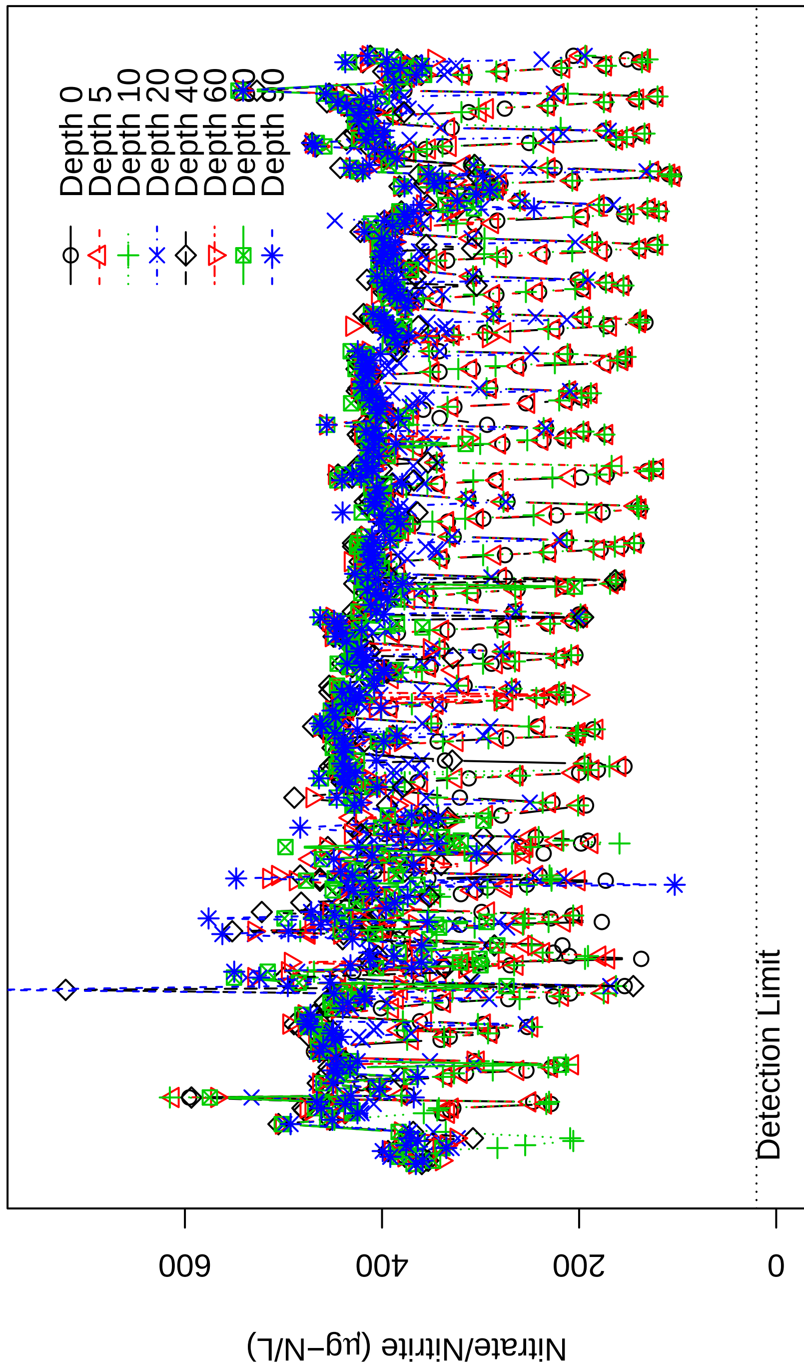


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4.

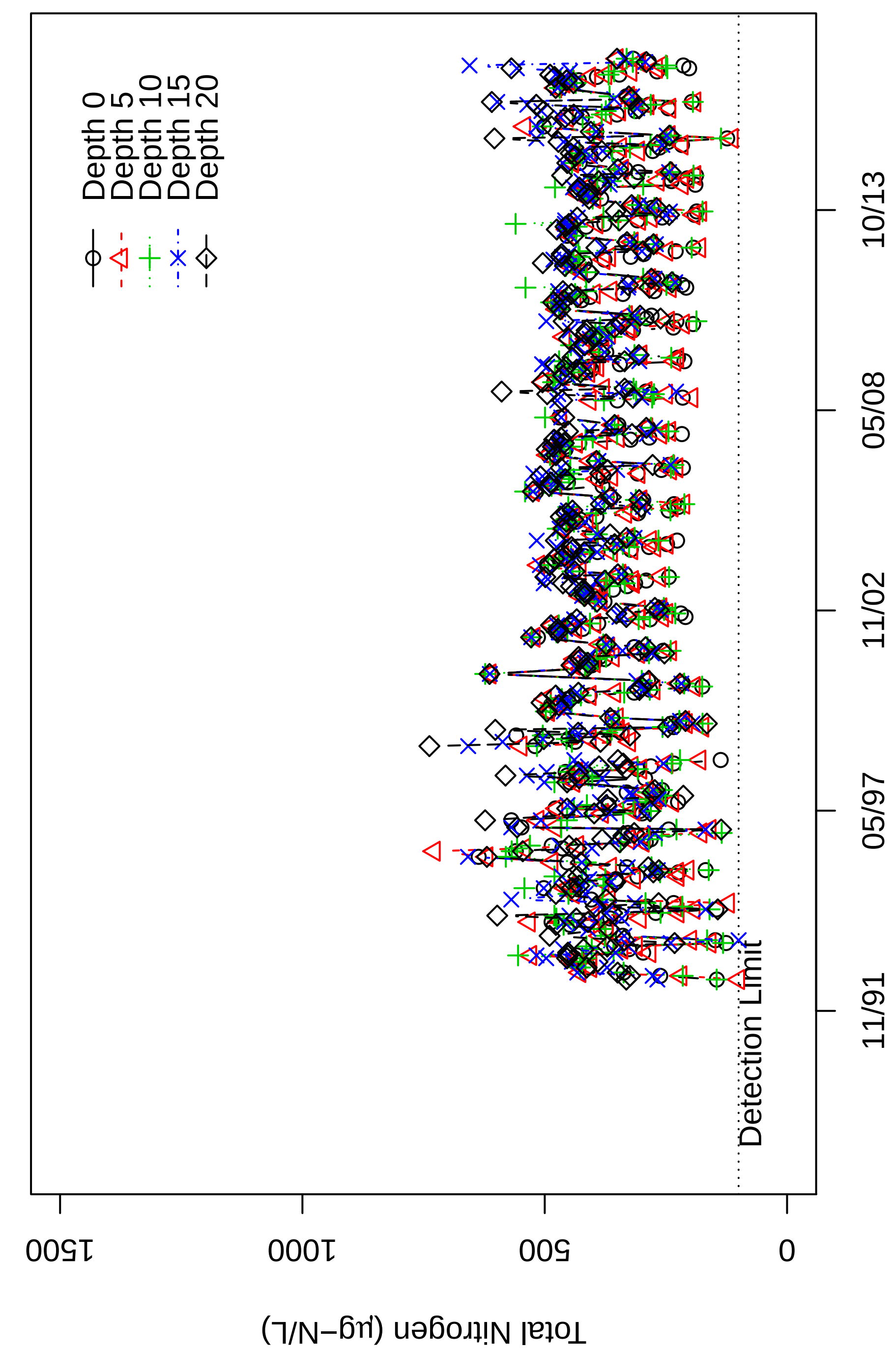


Figure B91: Lake Whatcom total nitrogen data for Site 1.

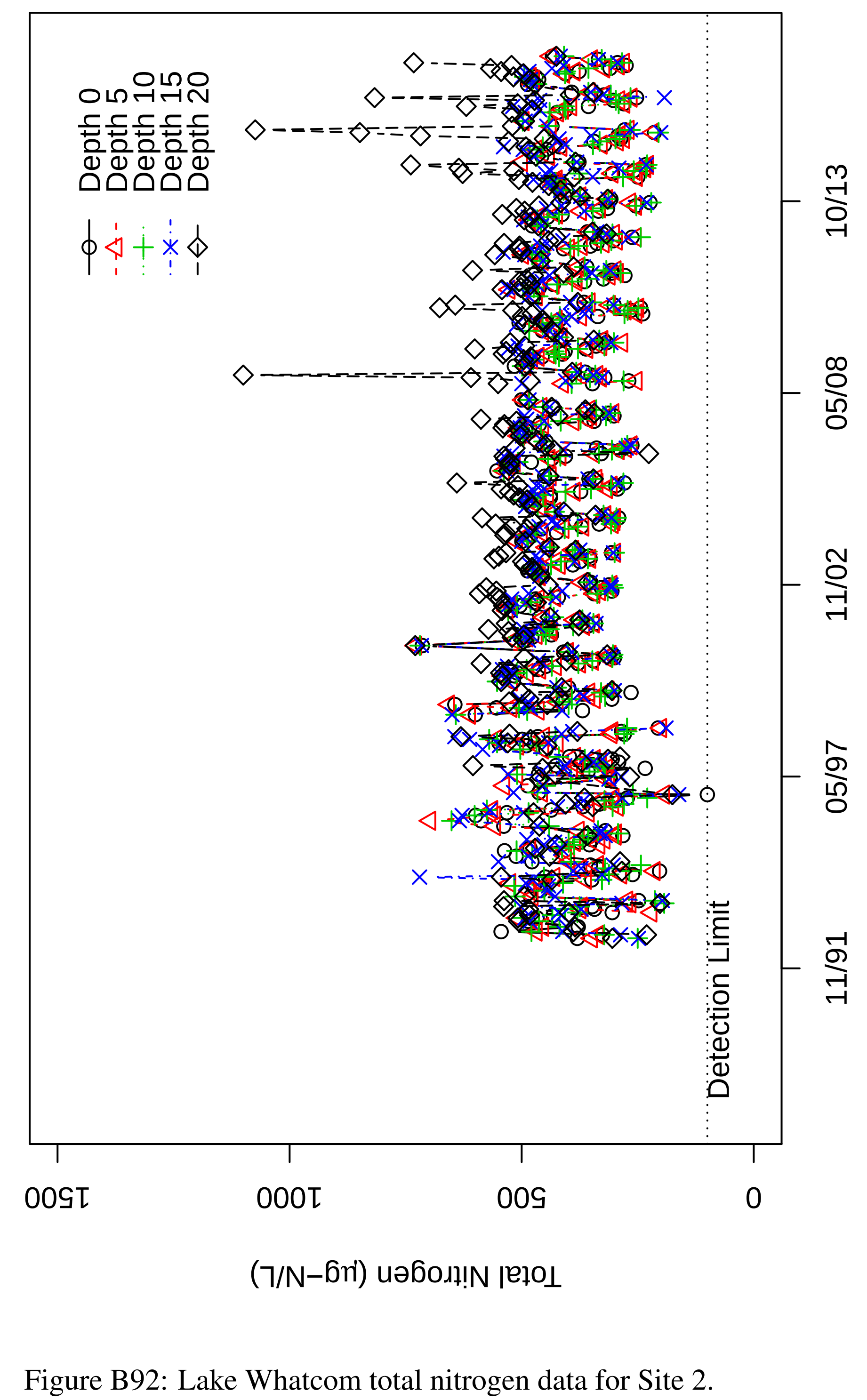


Figure B92: Lake Whatcom total nitrogen data for Site 2.

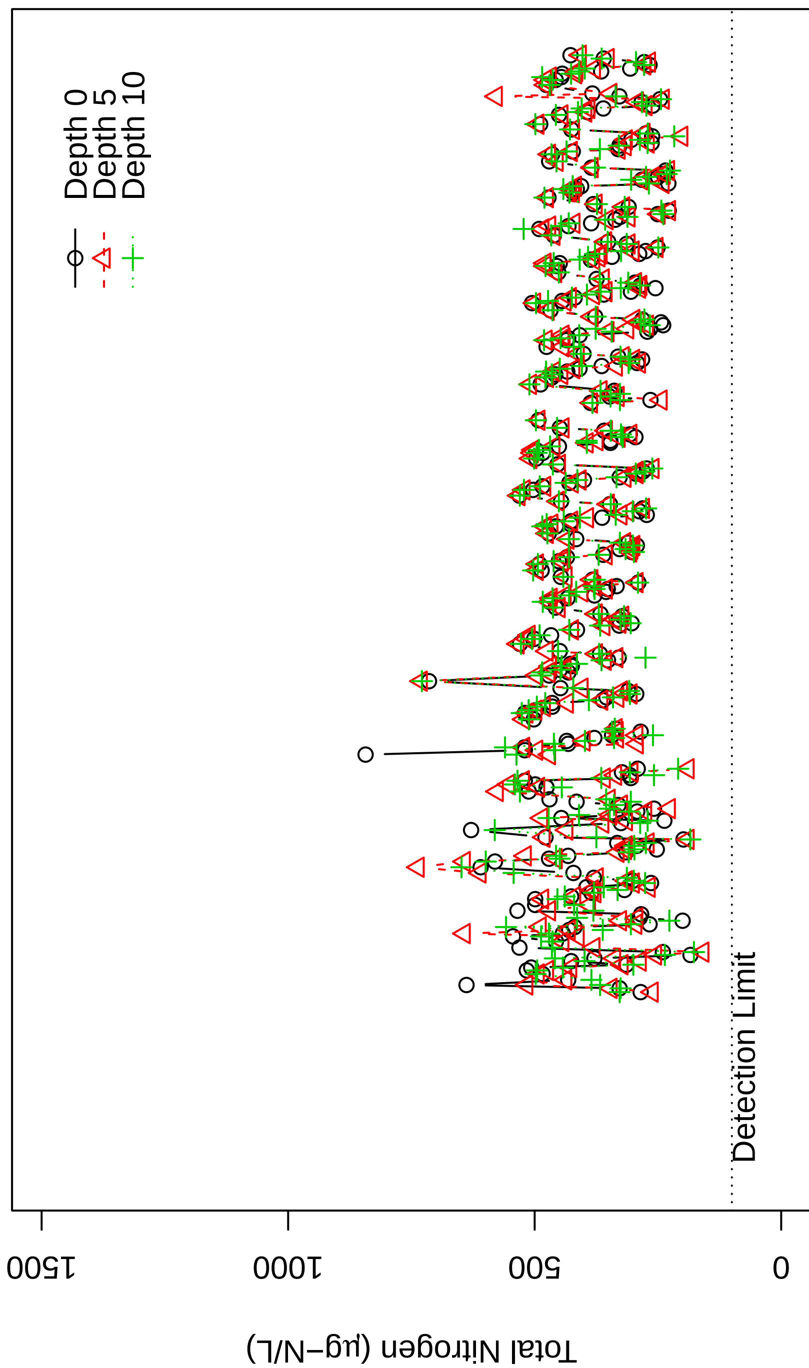


Figure B93: Lake Whatcom total nitrogen data for the Intake site.

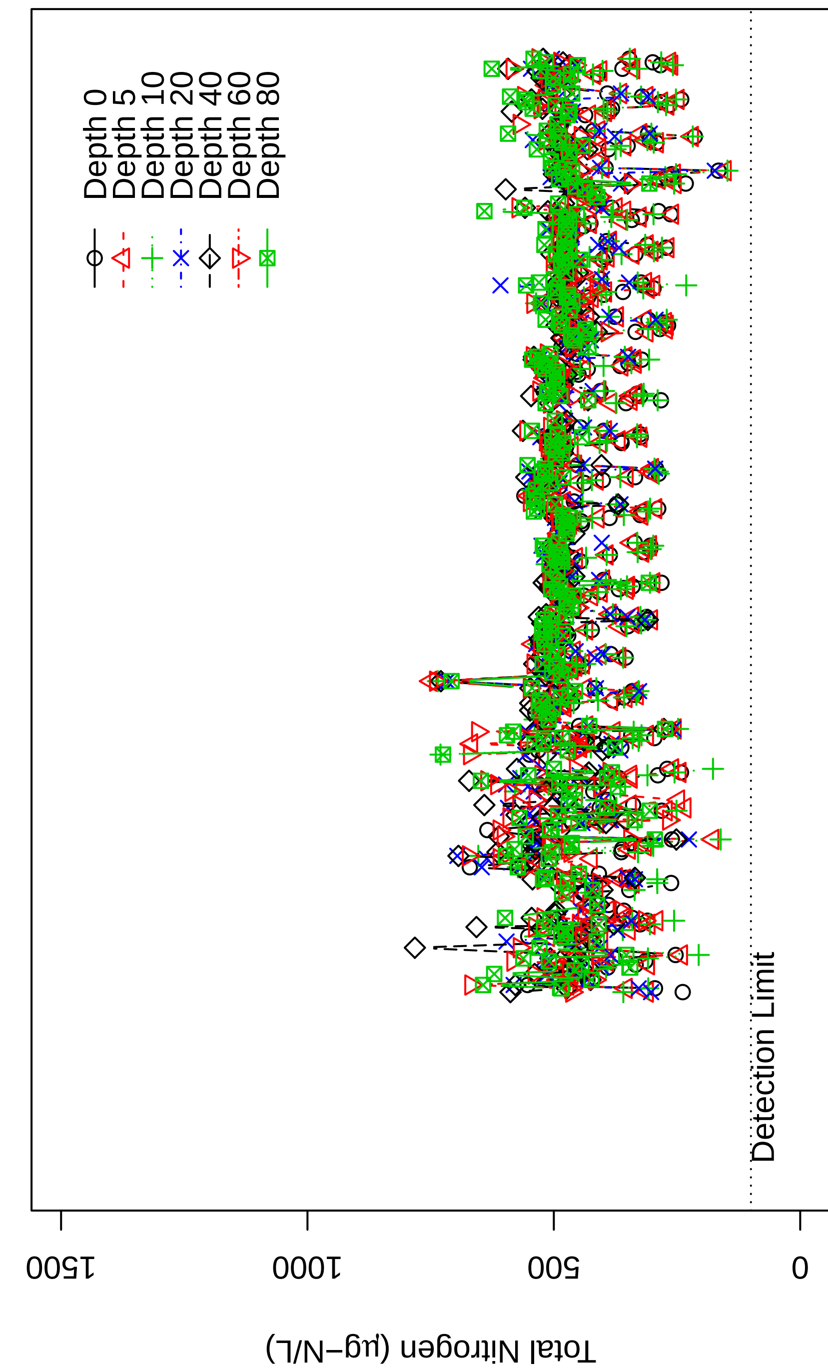


Figure B94: Lake Whatcom total nitrogen data for Site 3.

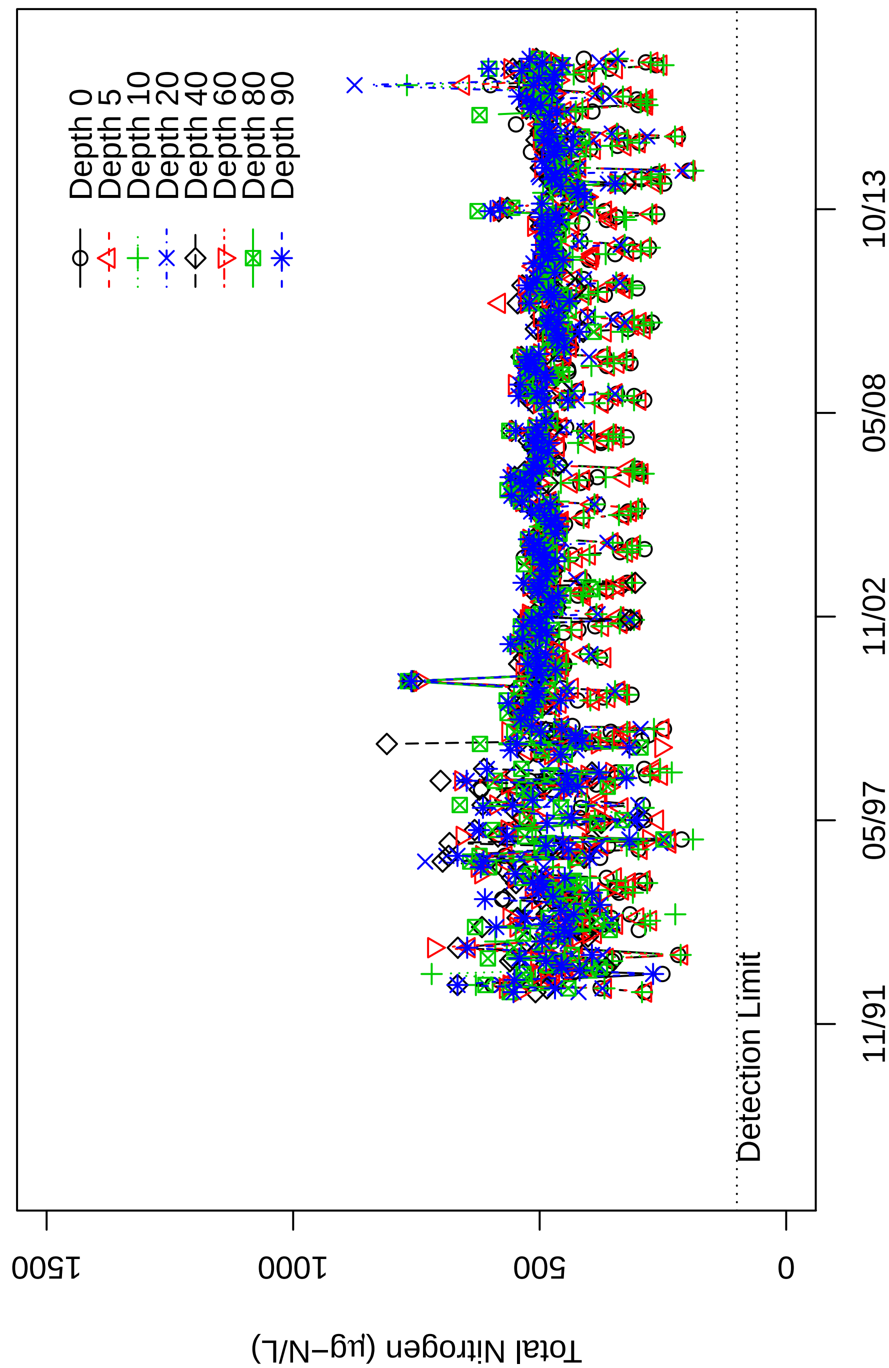


Figure B95: Lake Whatcom total nitrogen data for Site 4.

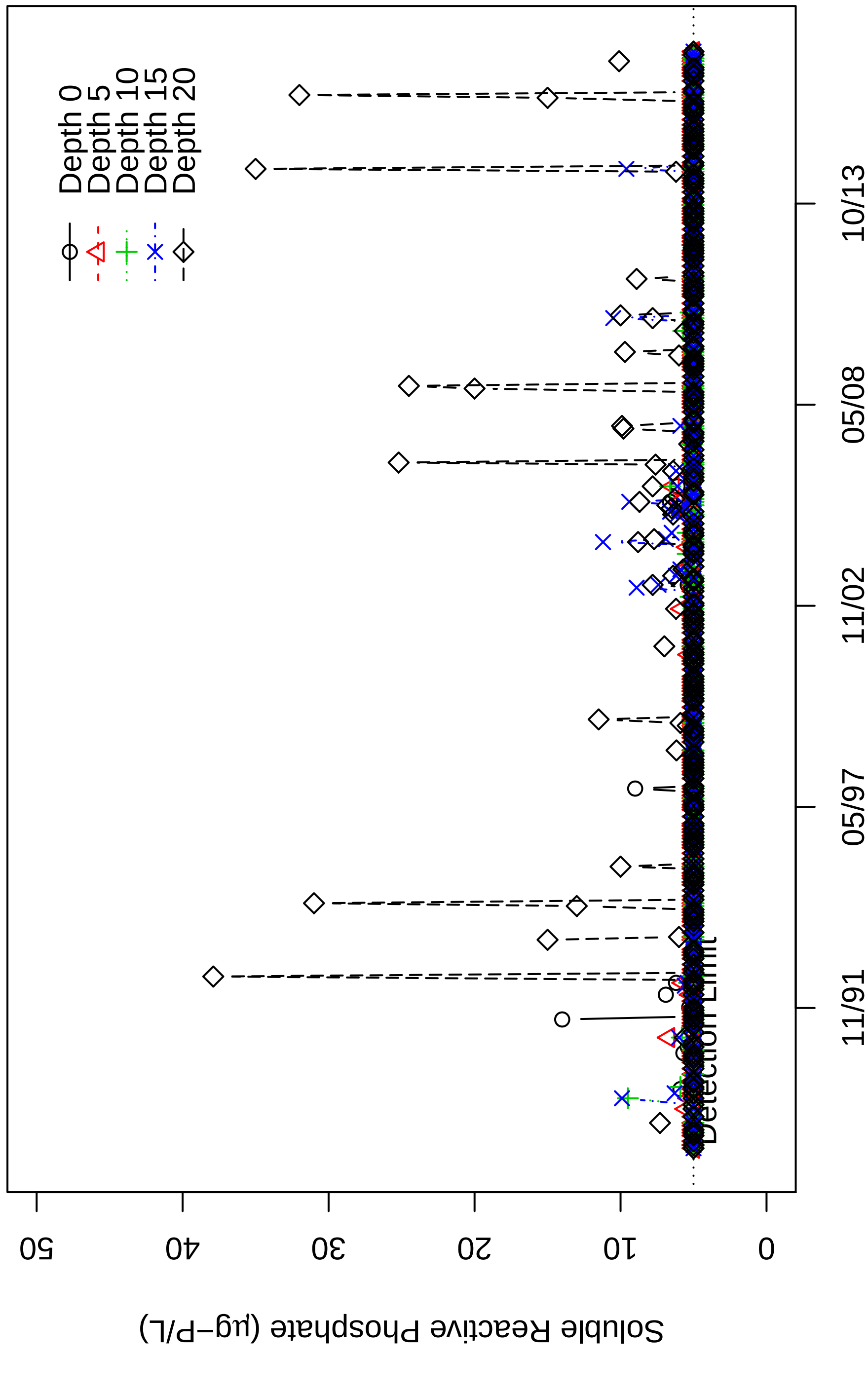


Figure B96: Lake Whatcom soluble phosphate data for Site 1.

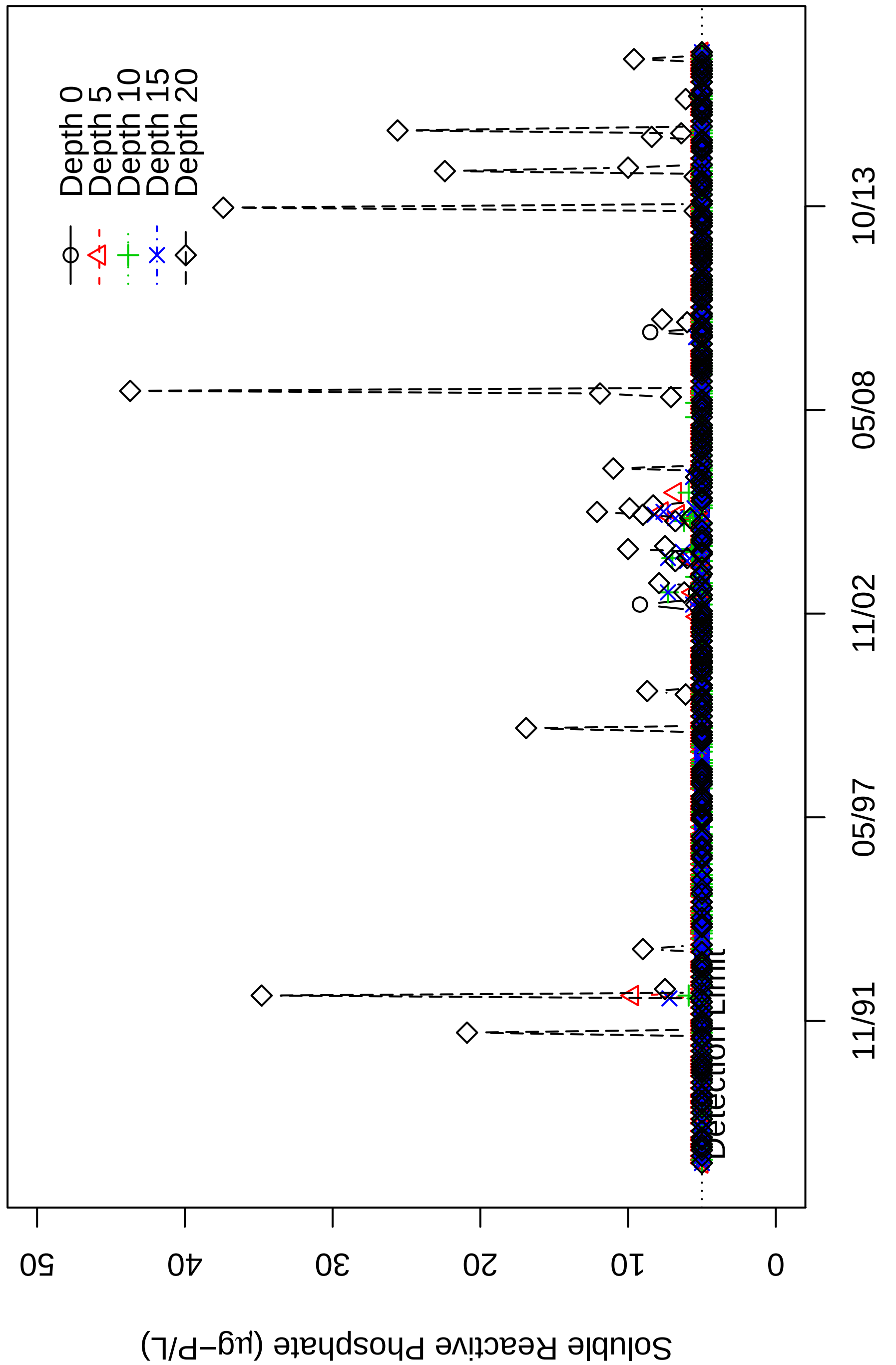


Figure B97: Lake Whatcom soluble phosphate data for Site 2.

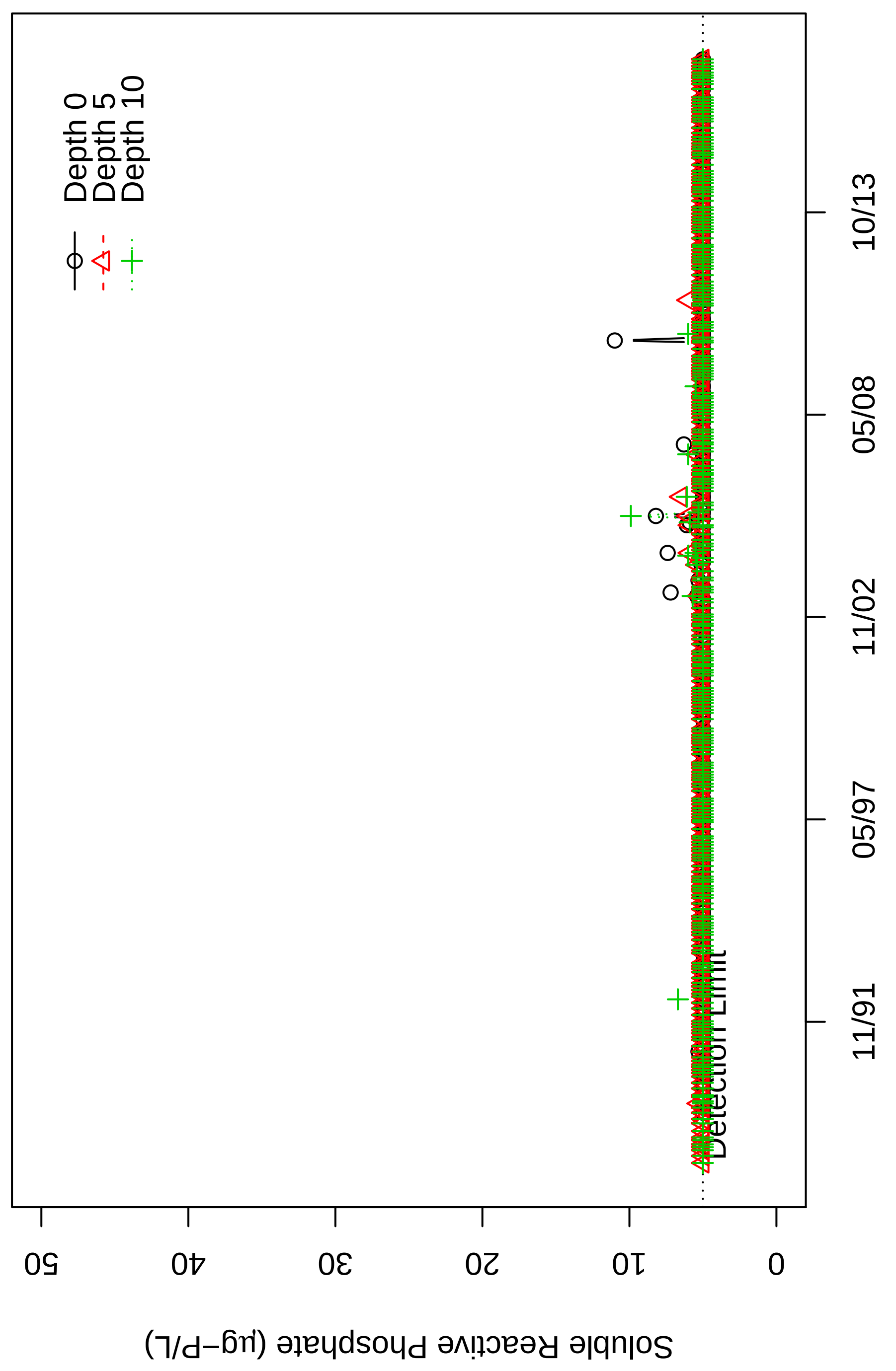


Figure B98: Lake Whatcom soluble phosphate data for the Intake site.

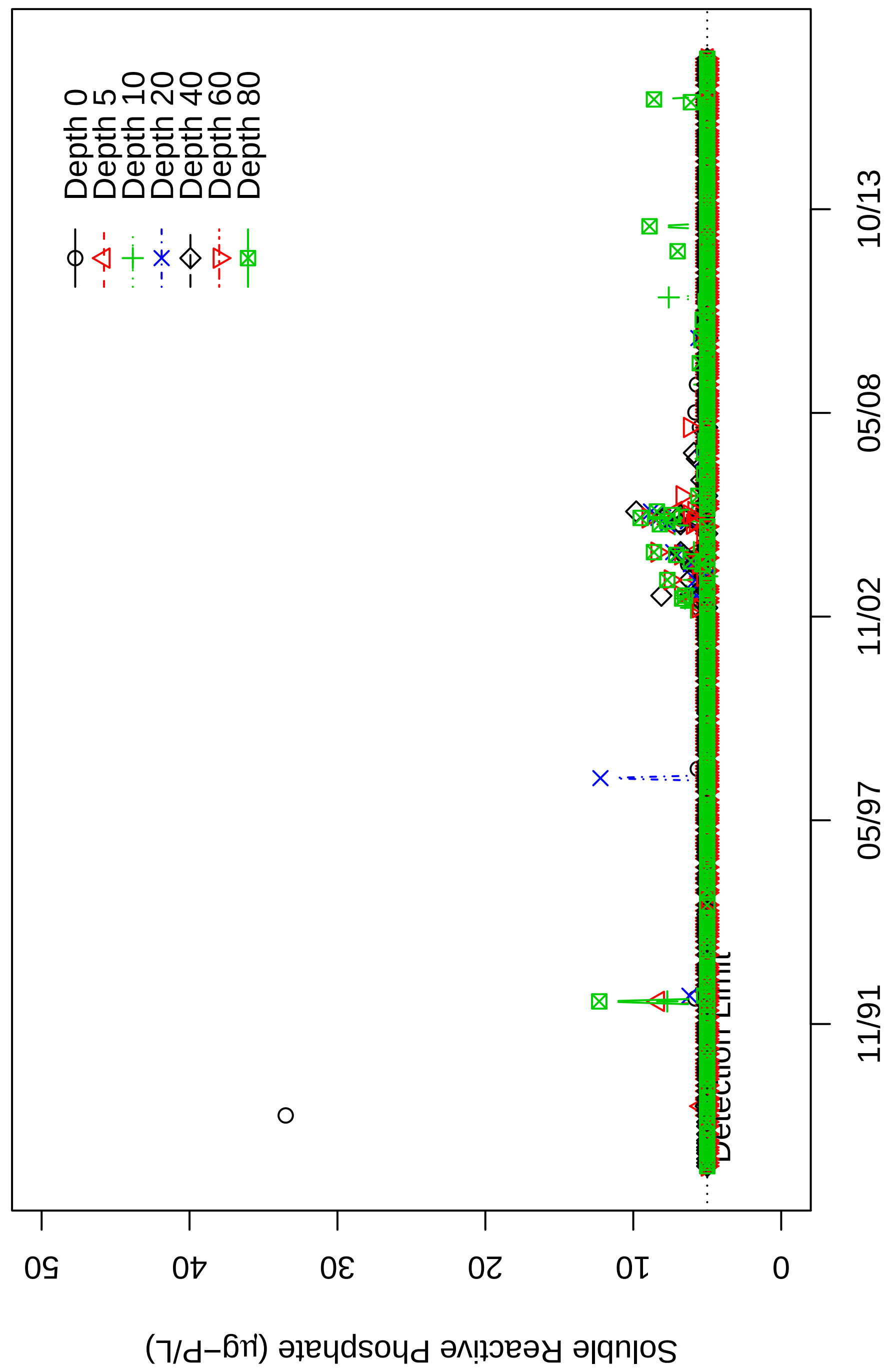


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

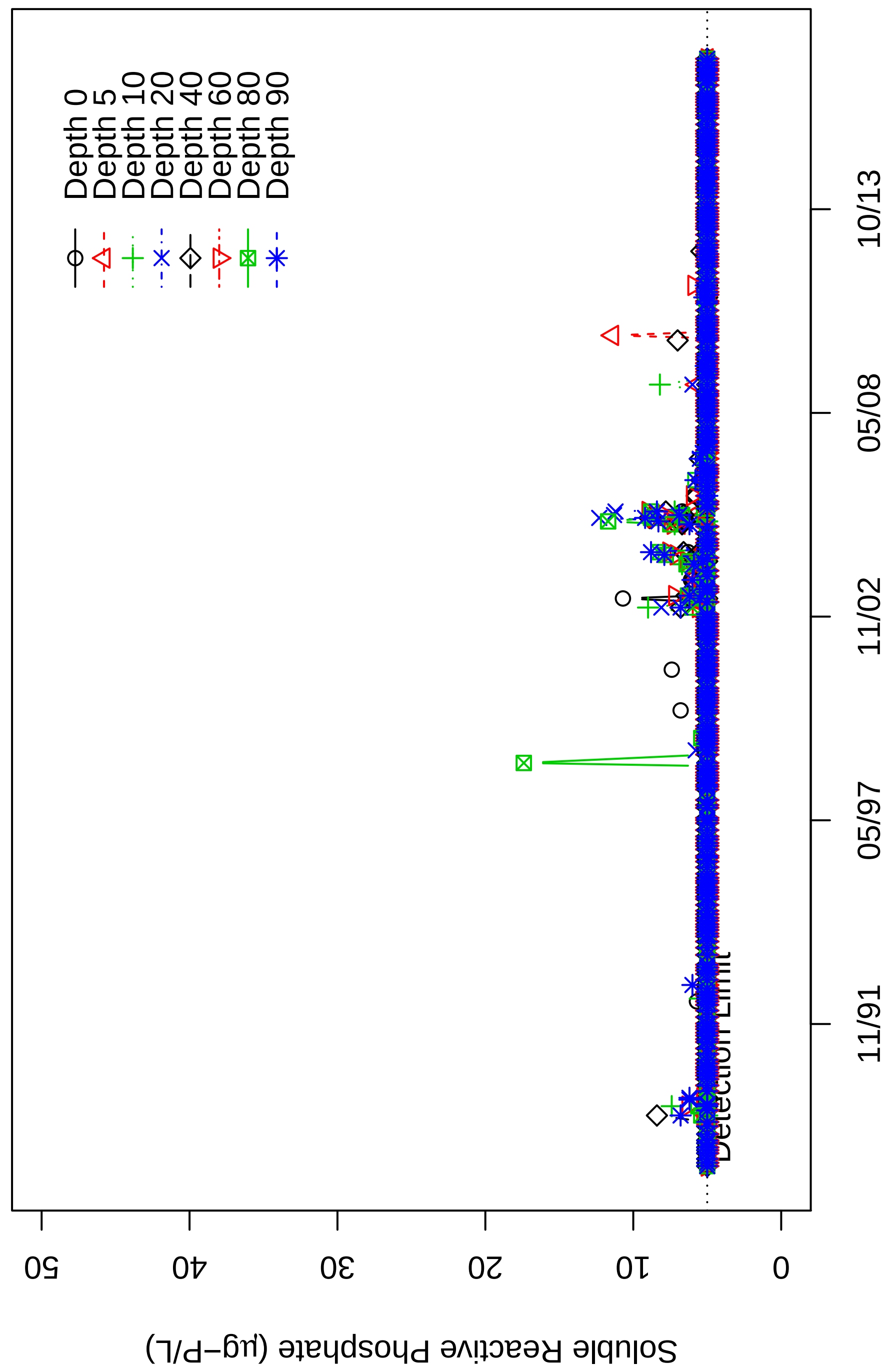


Figure B100: Lake Whatcom soluble phosphate data for Site 4.

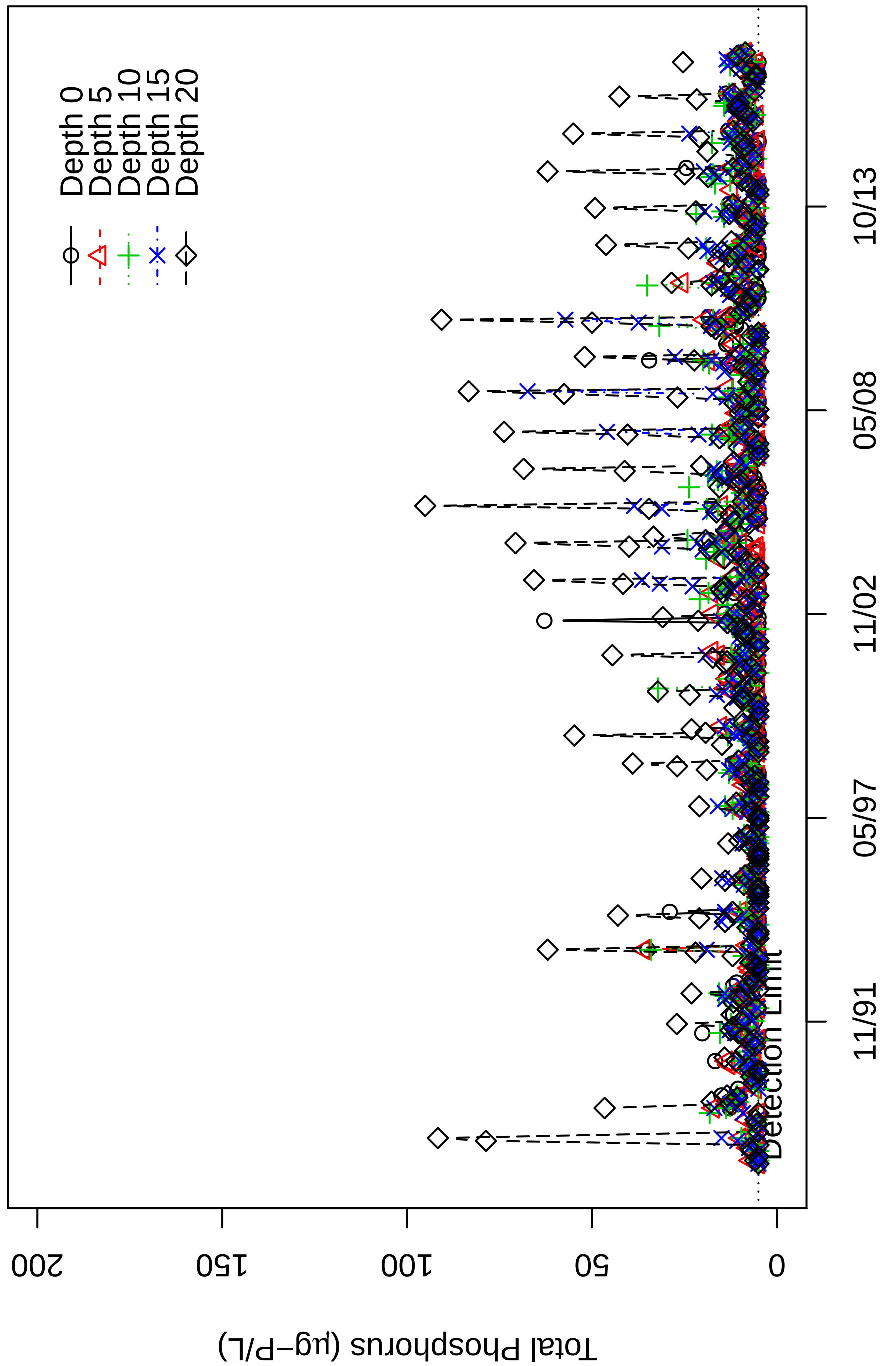


Figure B101: Lake Whatcom total phosphorus data for Site 1.

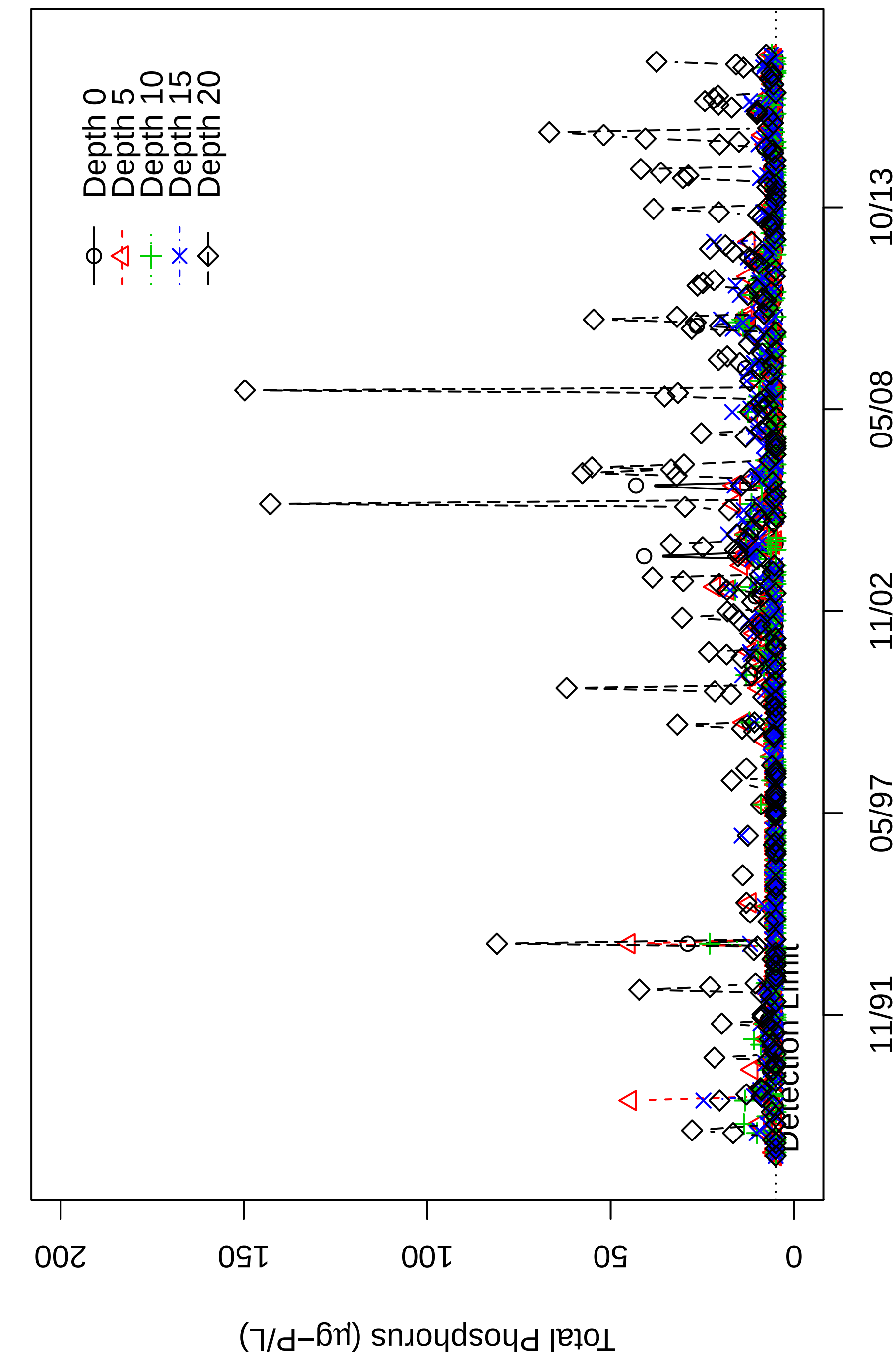


Figure B102: Lake Whatcom total phosphorus data for Site 2.

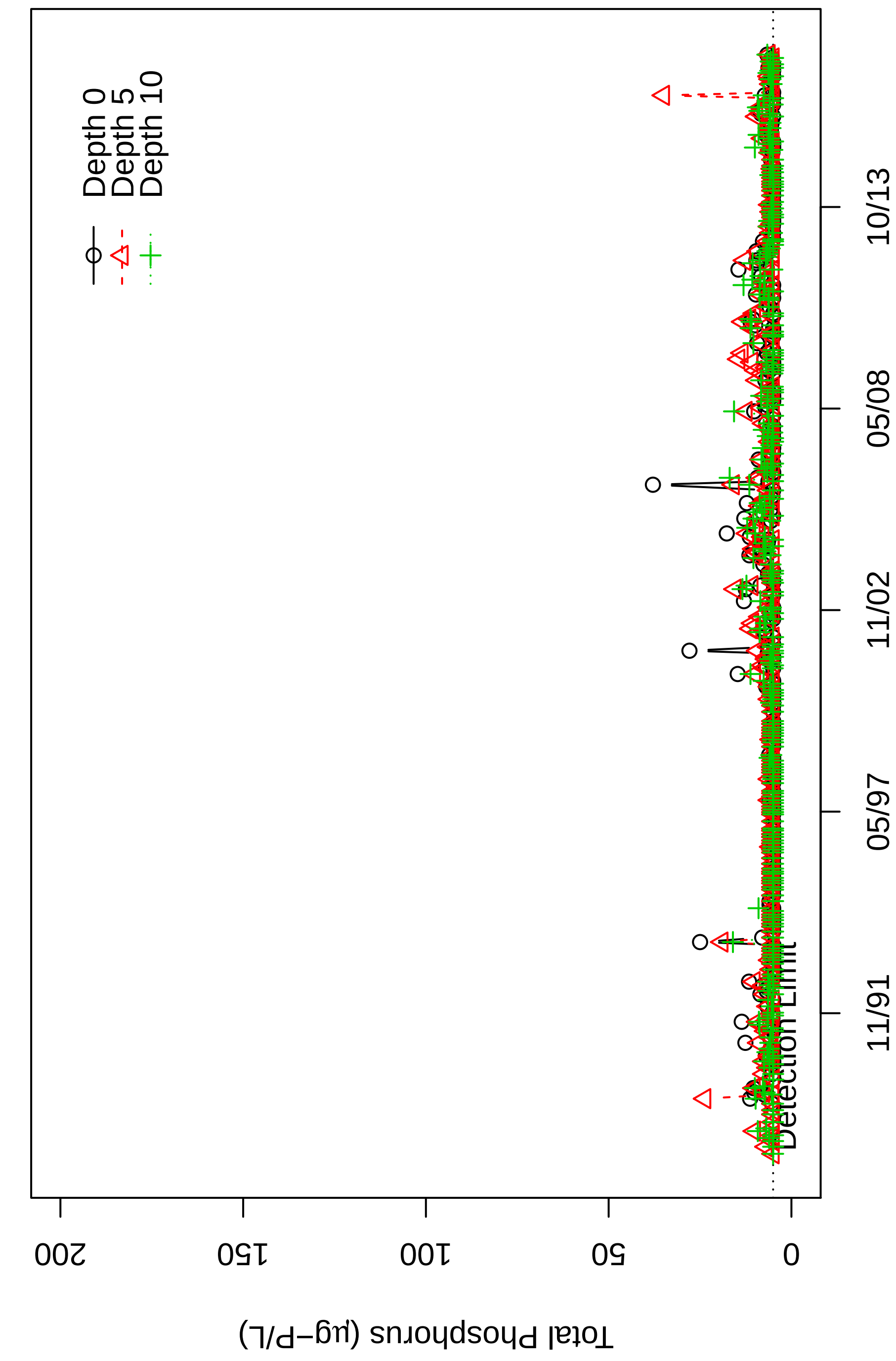


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

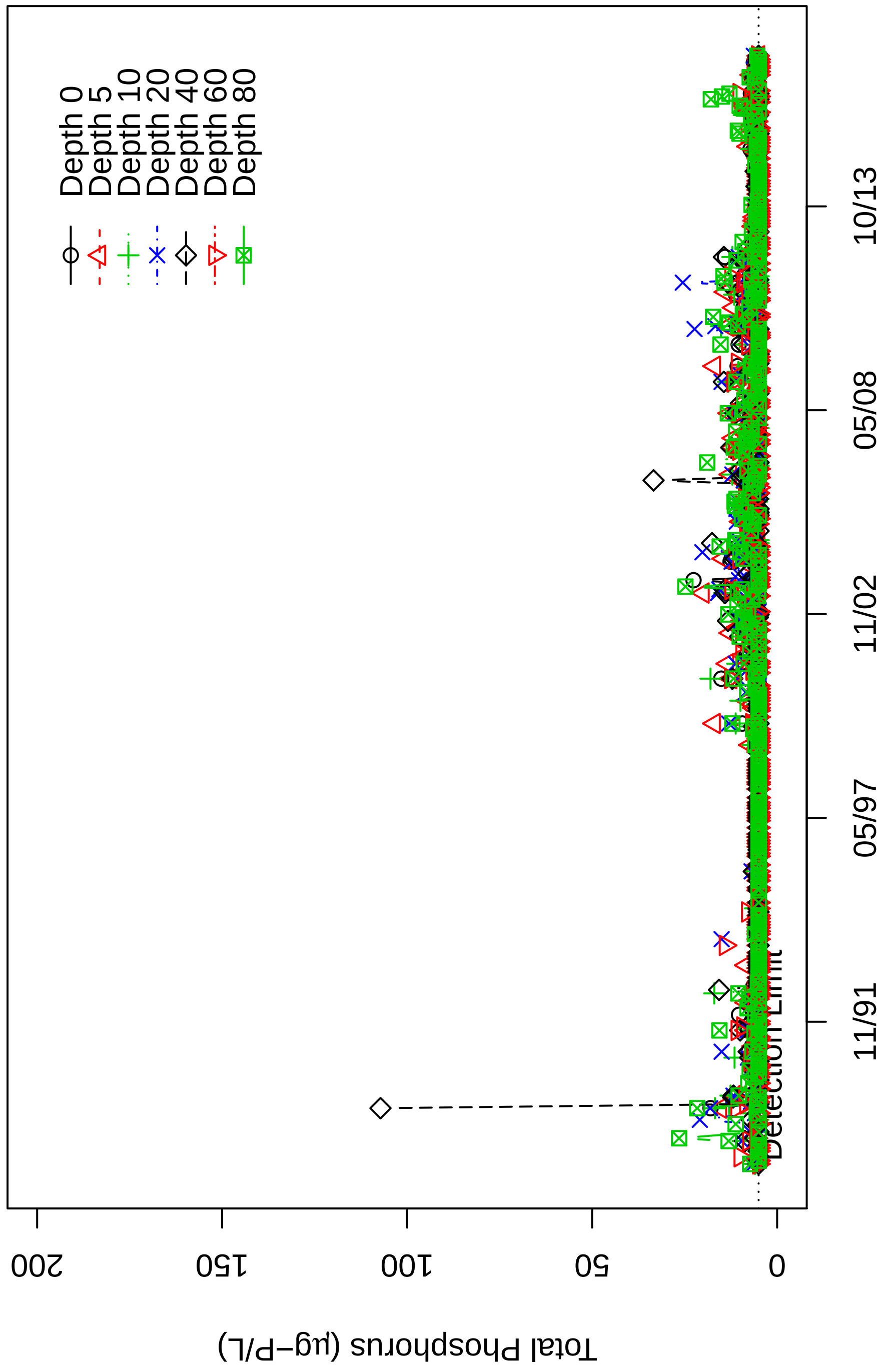


Figure B104: Lake Whatcom total phosphorus data for Site 3.

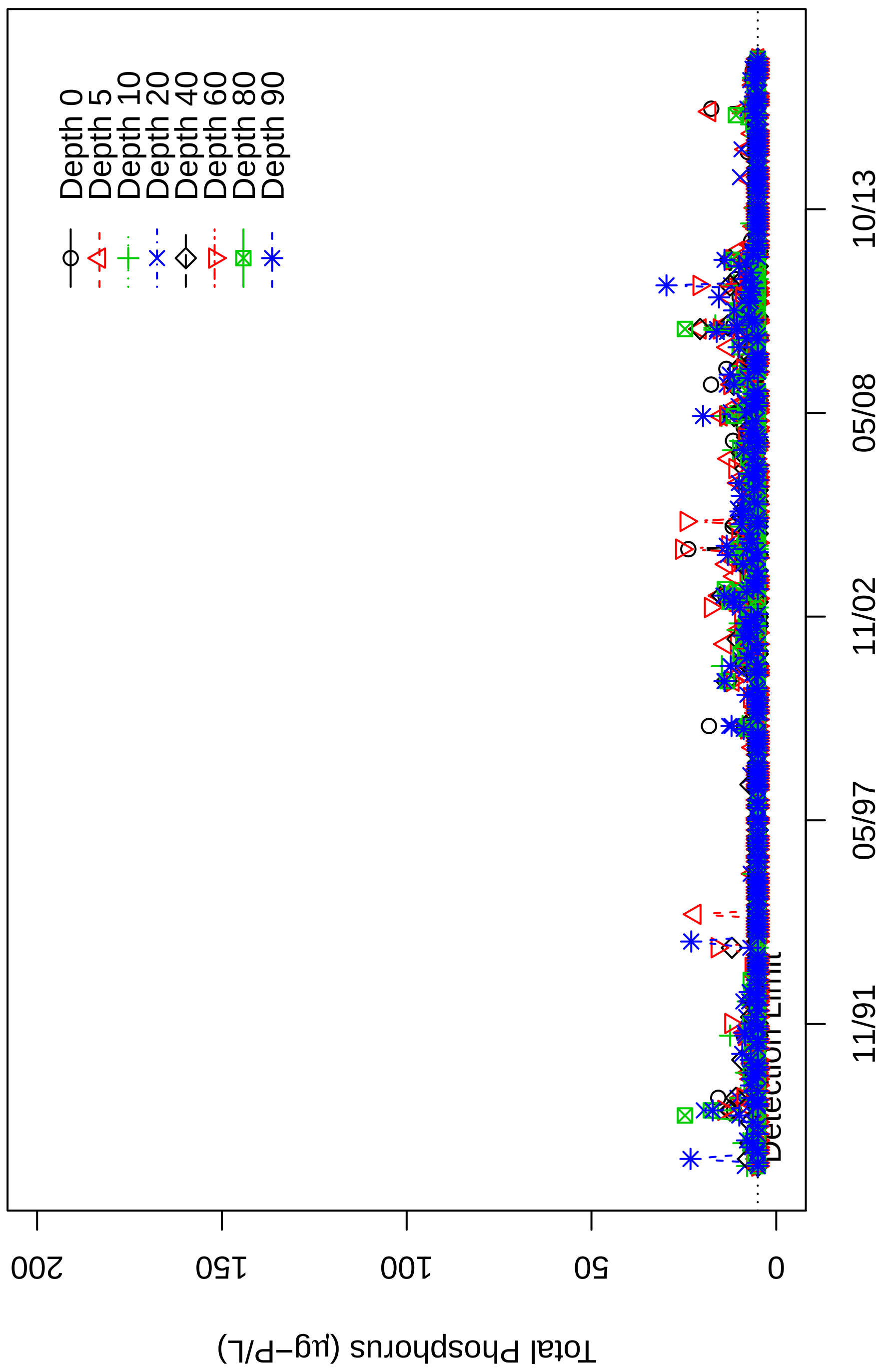


Figure B105: Lake Whatcom total phosphorus data for Site 4.

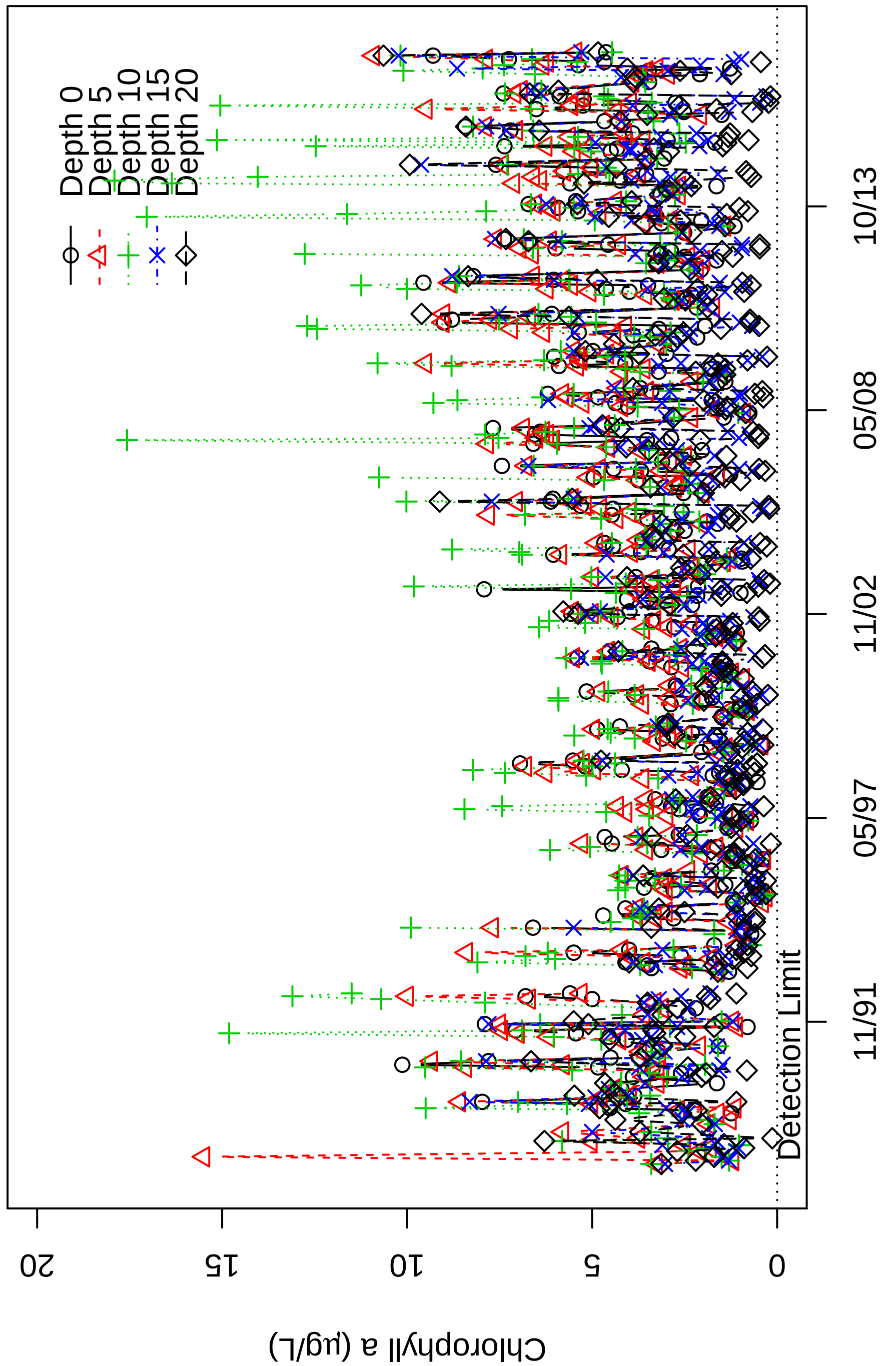


Figure B106: Lake Whatcom chlorophyll data for Site 1.

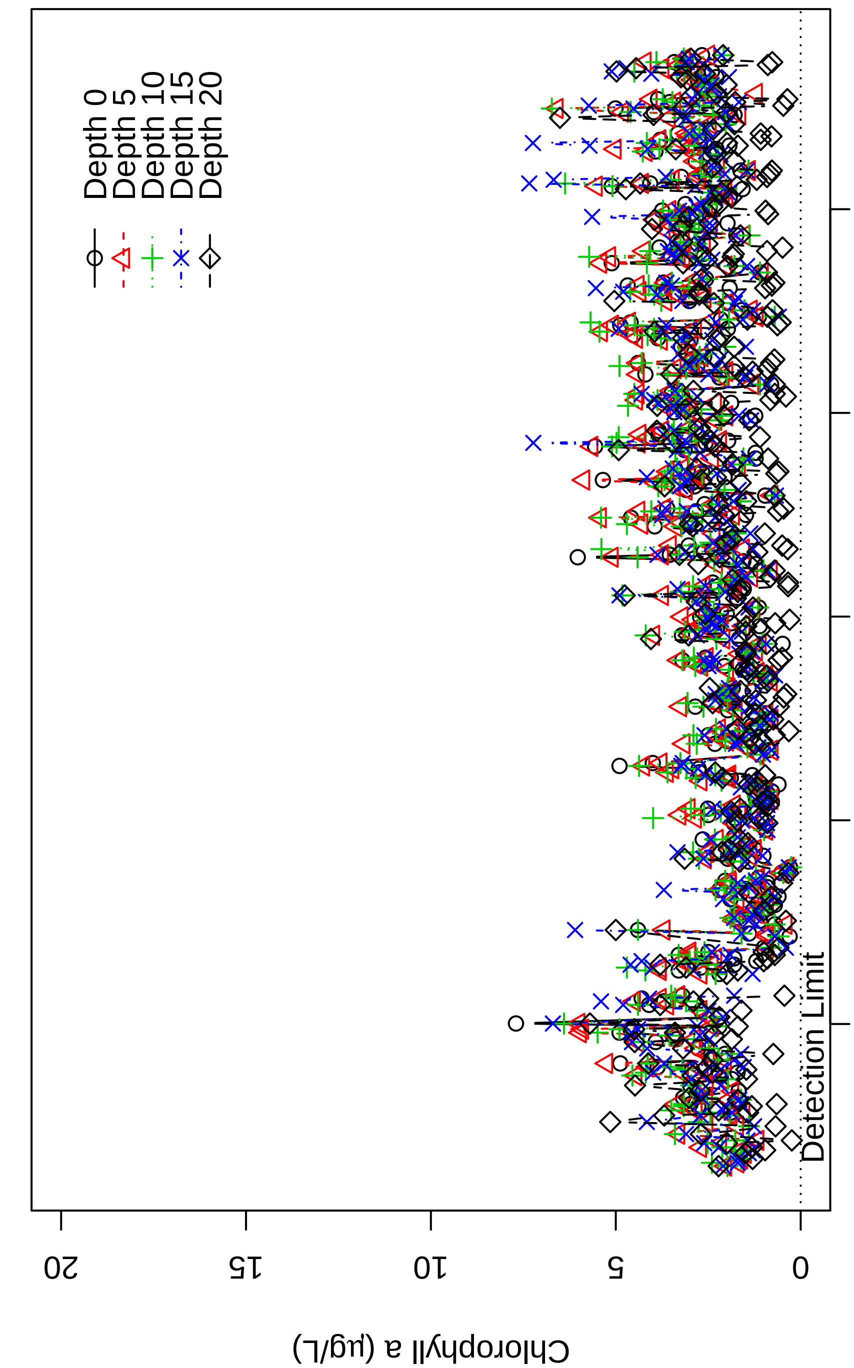


Figure B107: Lake Whatcom chlorophyll data for Site 2.

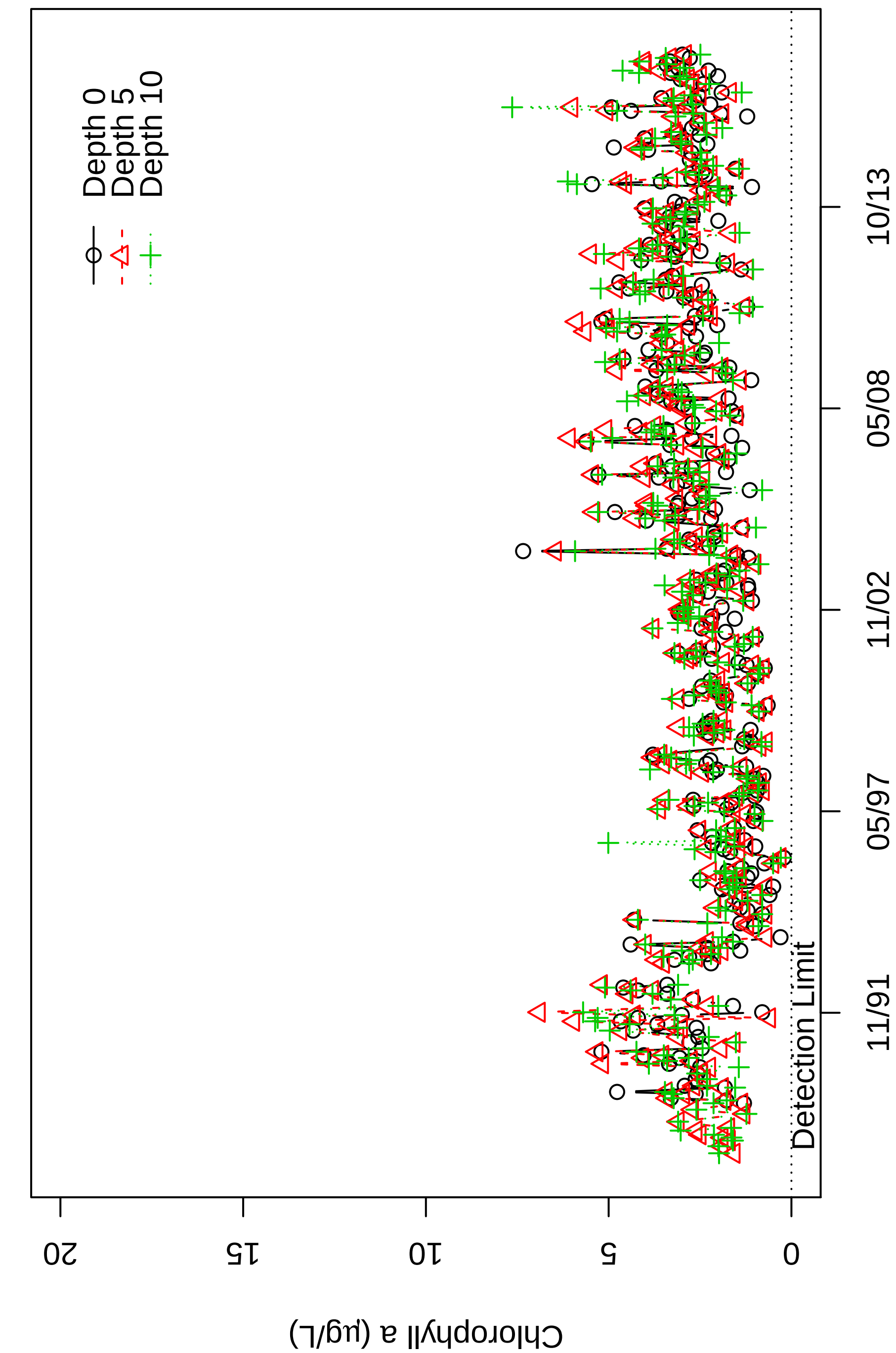


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

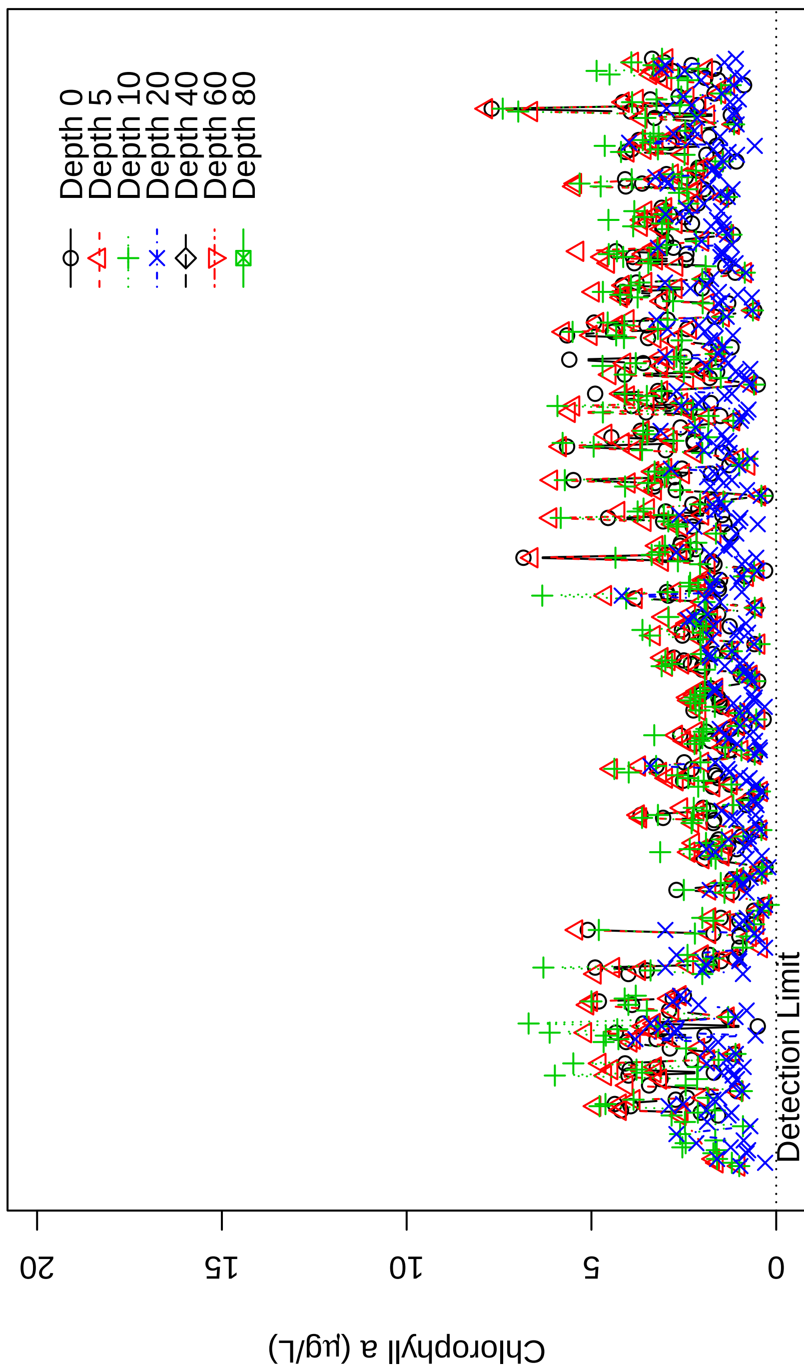


Figure B109: Lake Whatcom chlorophyll data for Site 3.

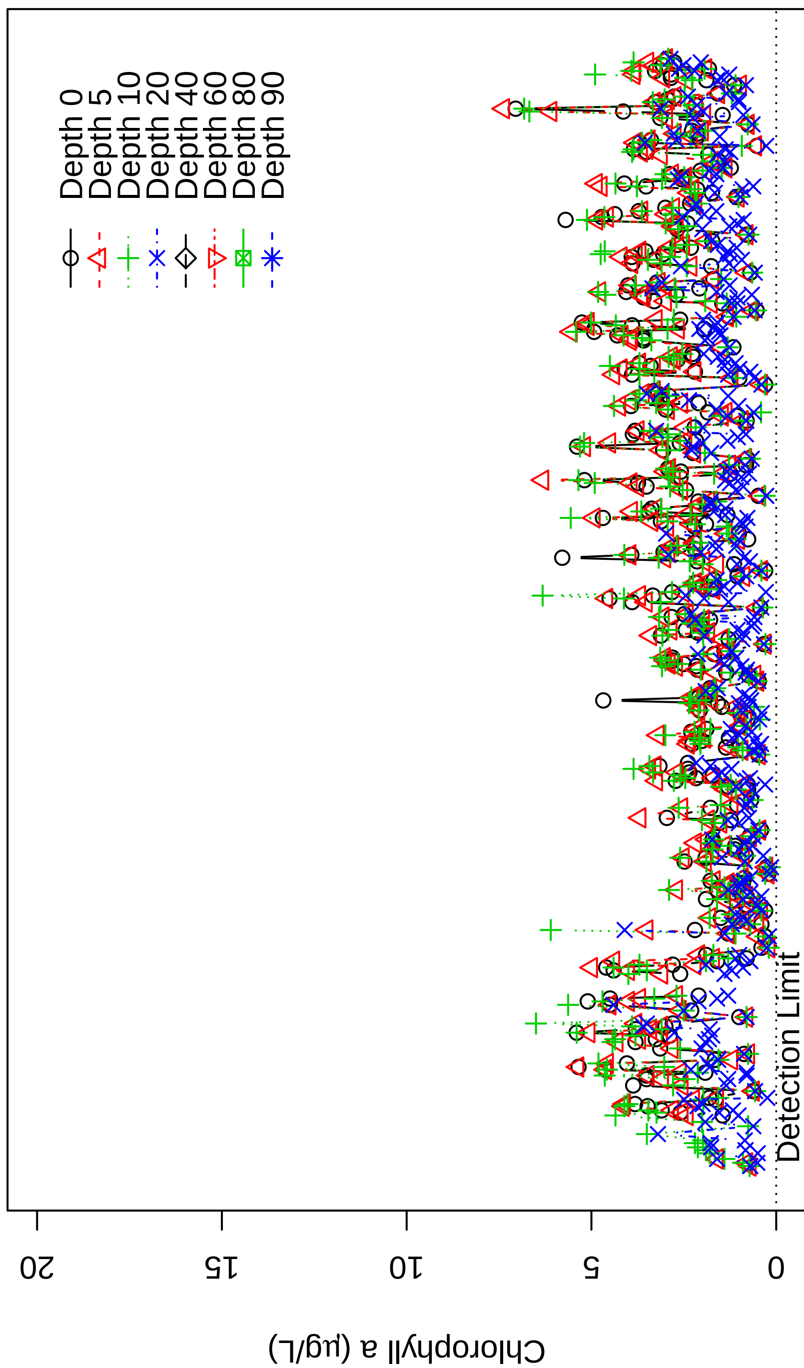


Figure B110: Lake Whatcom chlorophyll data for Site 4.

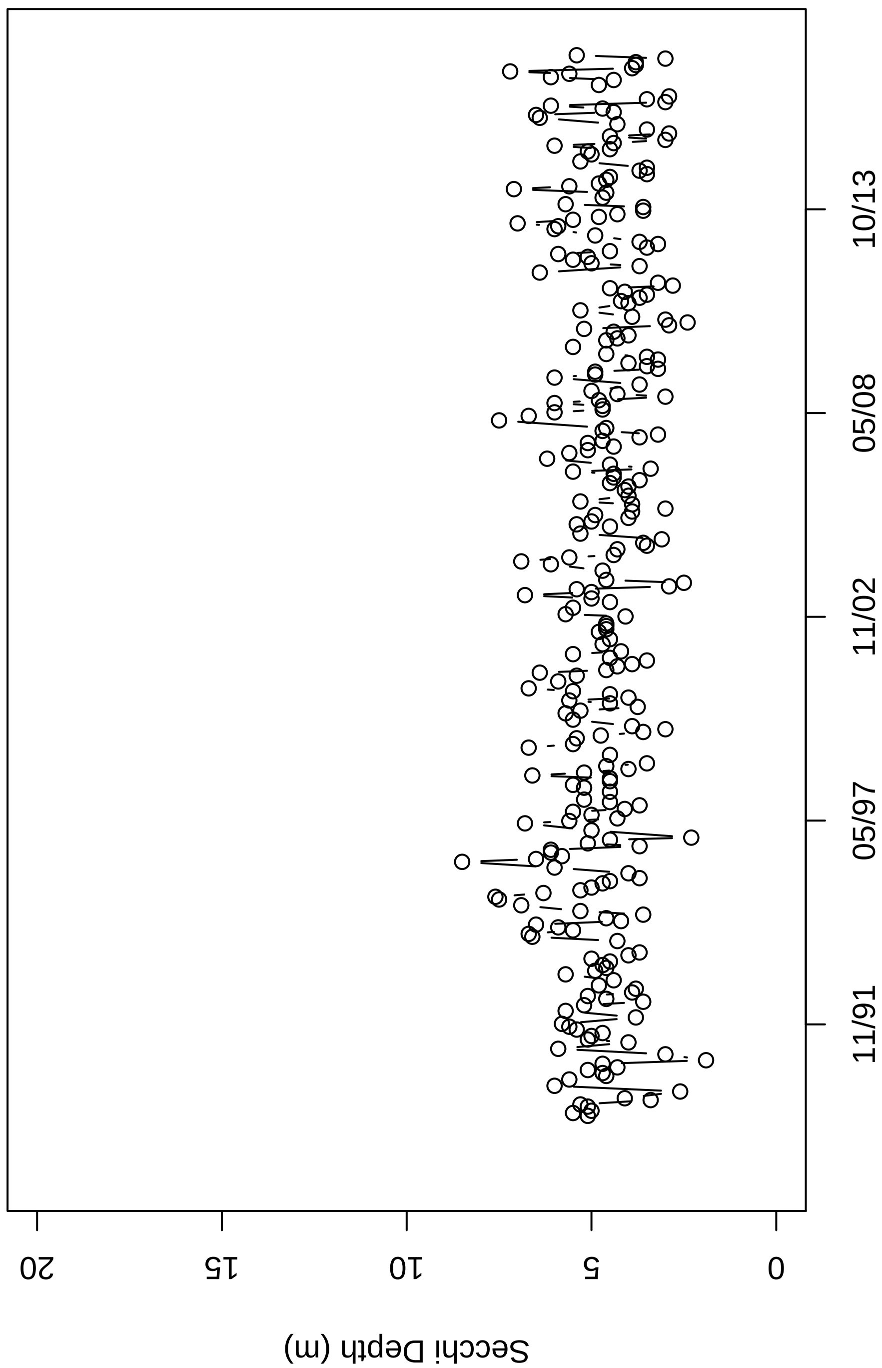


Figure B111: Lake Whatcom Secchi depths for Site 1.

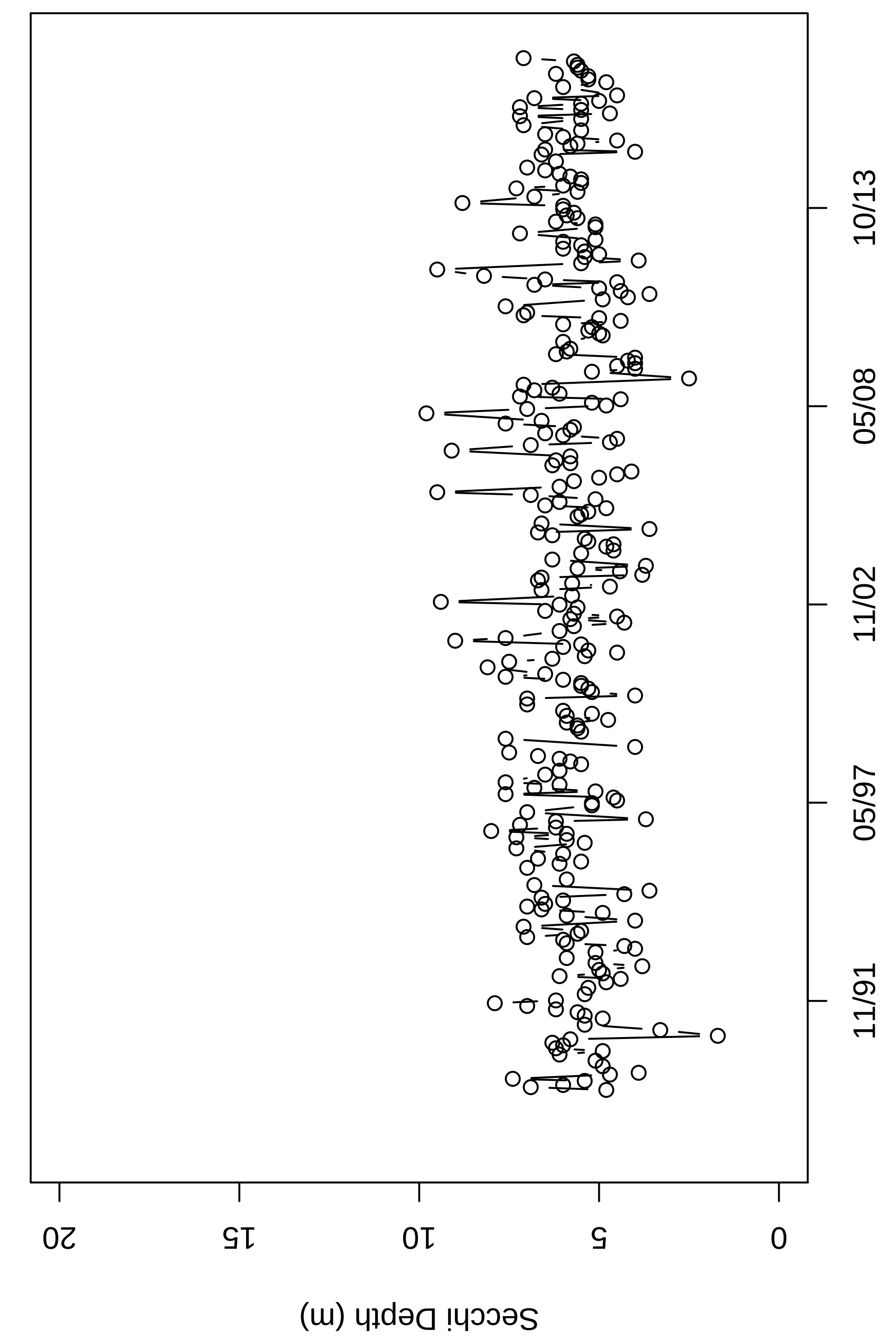


Figure B112: Lake Whatcom Secchi depths for Site 2.

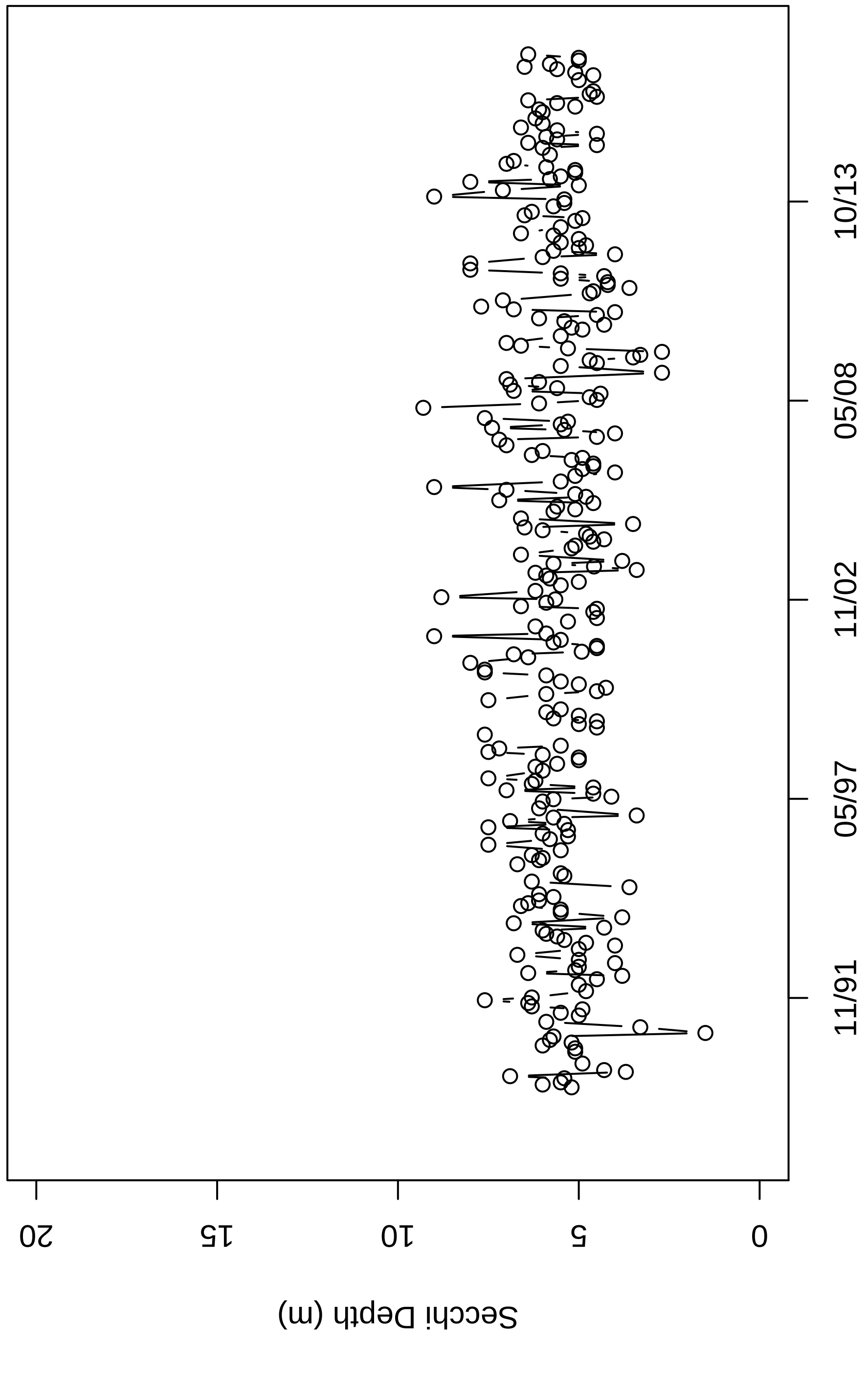


Figure B113: Lake Whatcom Secchi depths for the Intake site.

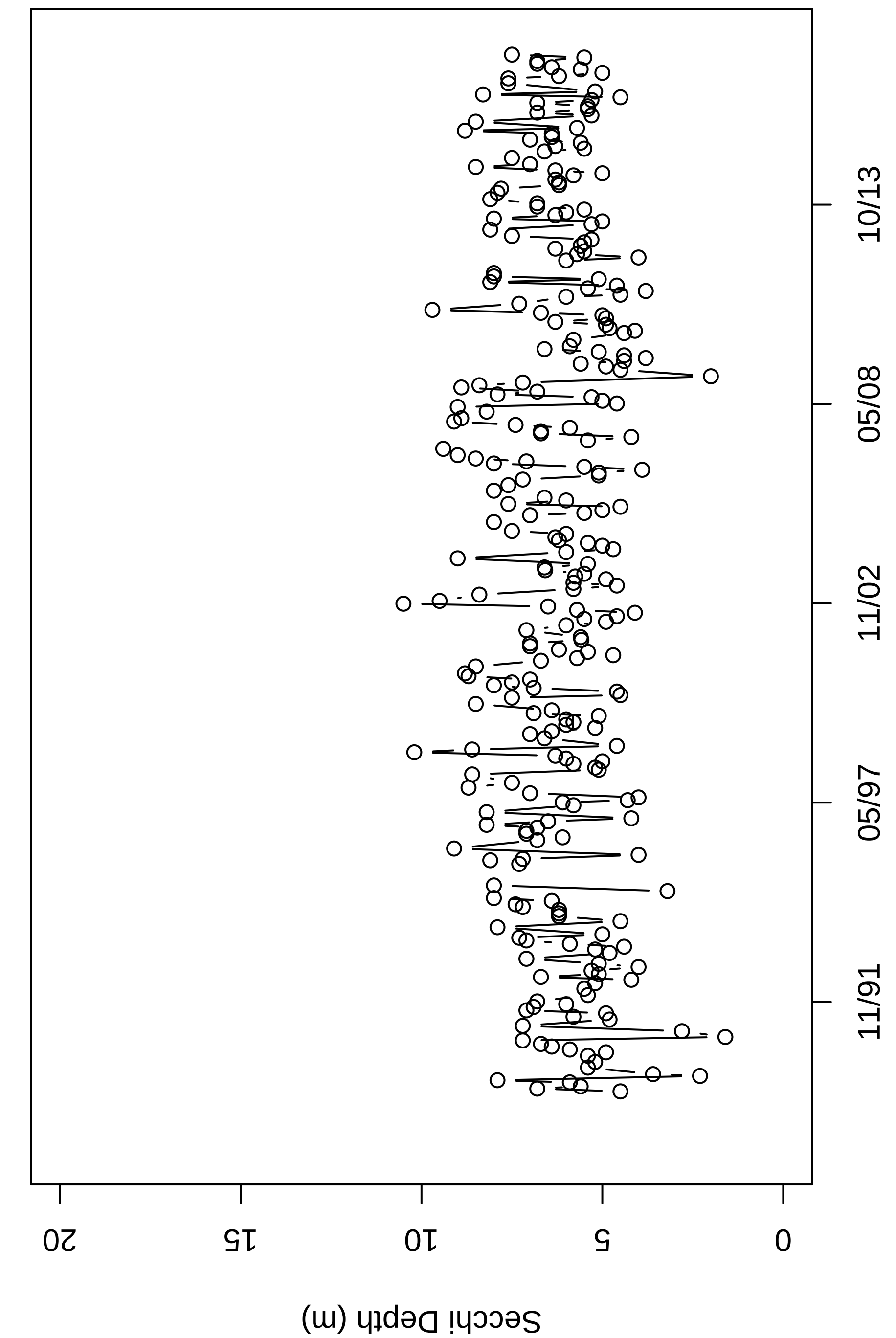


Figure B114: Lake Whatcom Secchi depths for Site 3.

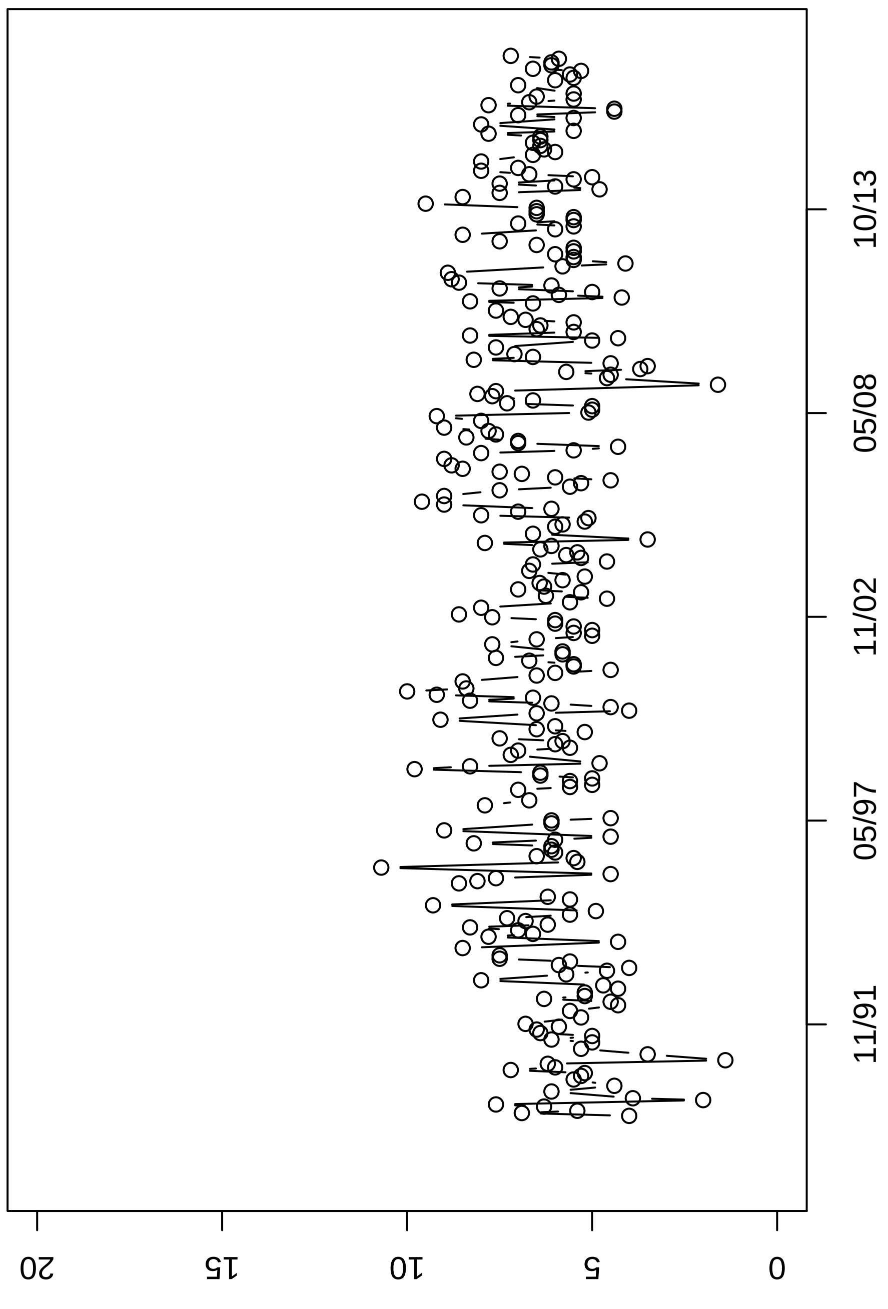


Figure B115: Lake Whatcom Secchi depths for Site 4.

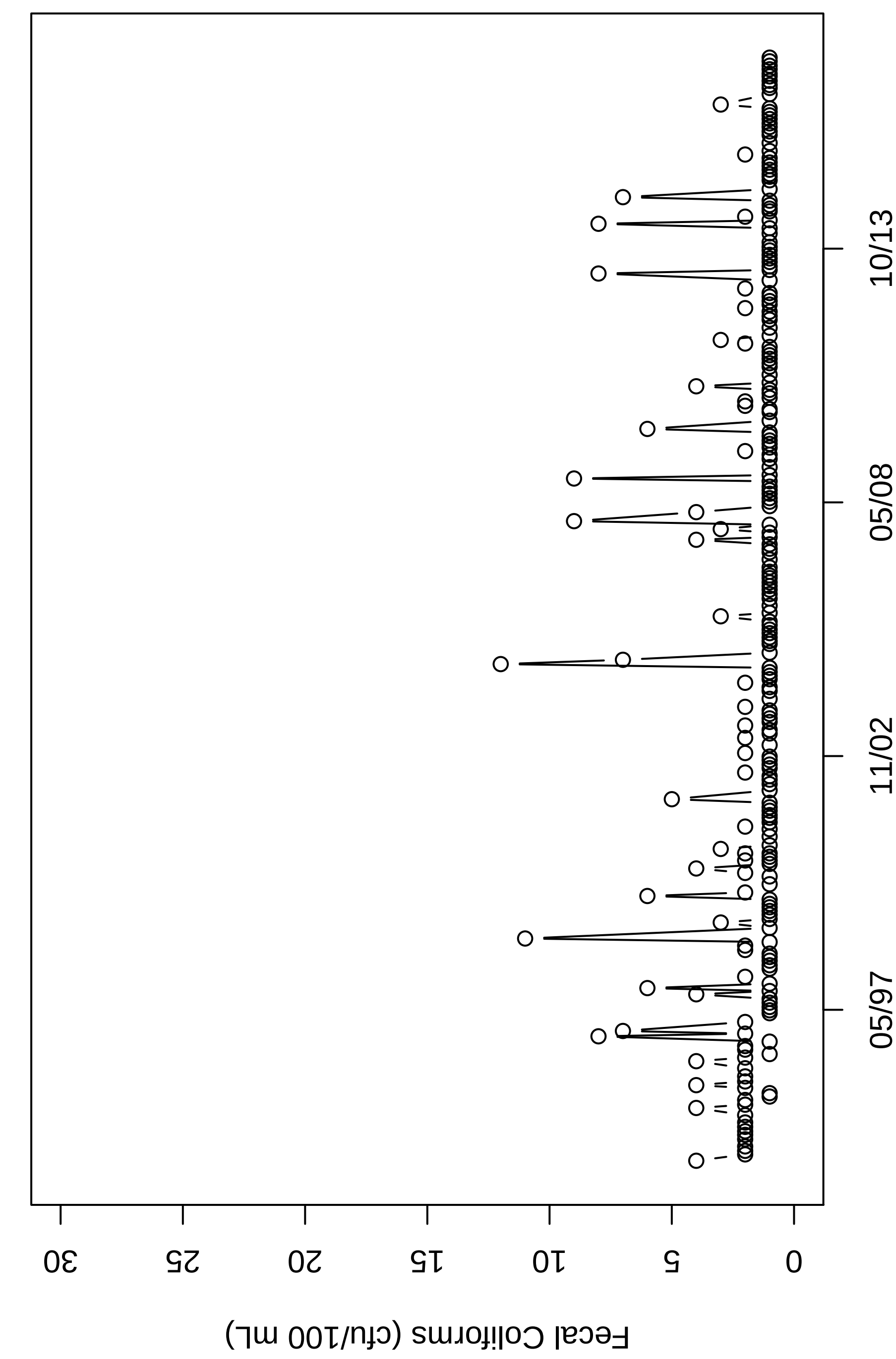


Figure B116: Lake Whatcom fecal coliform data for Site 1.

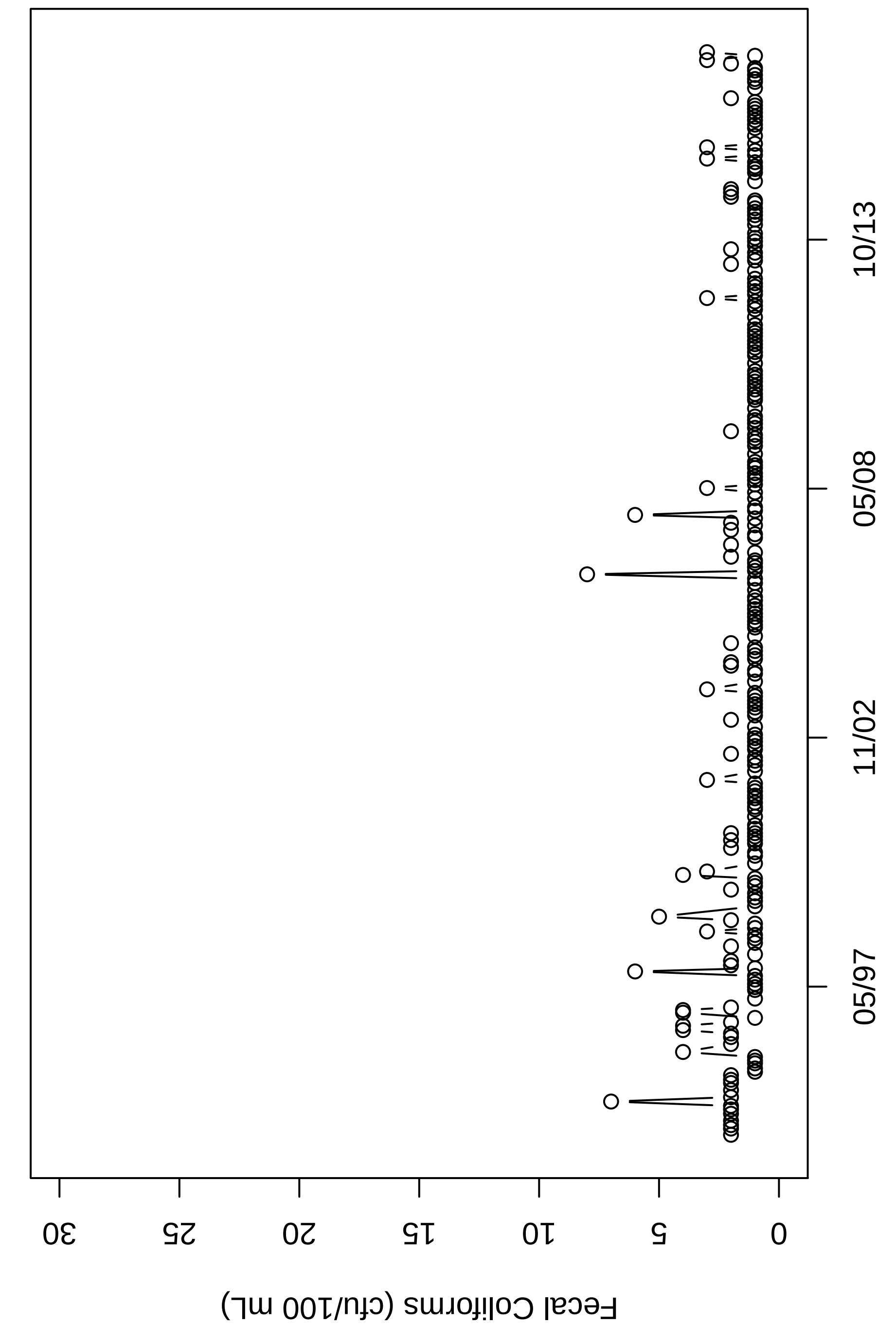


Figure B117: Lake Whatcom fecal coliform data for Site 2.

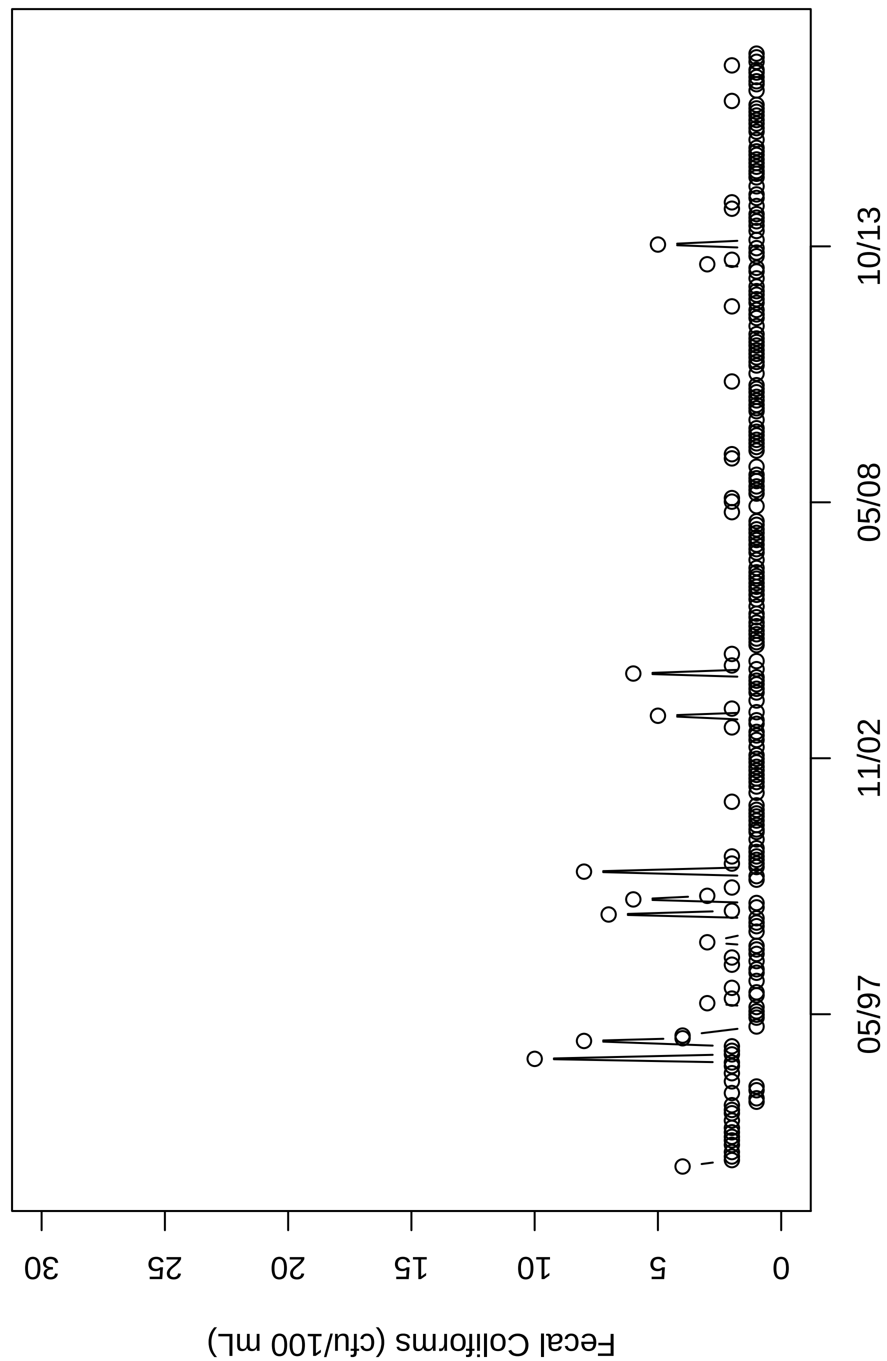


Figure B118: Lake Whatcom fecal coliform data for the Intake site.

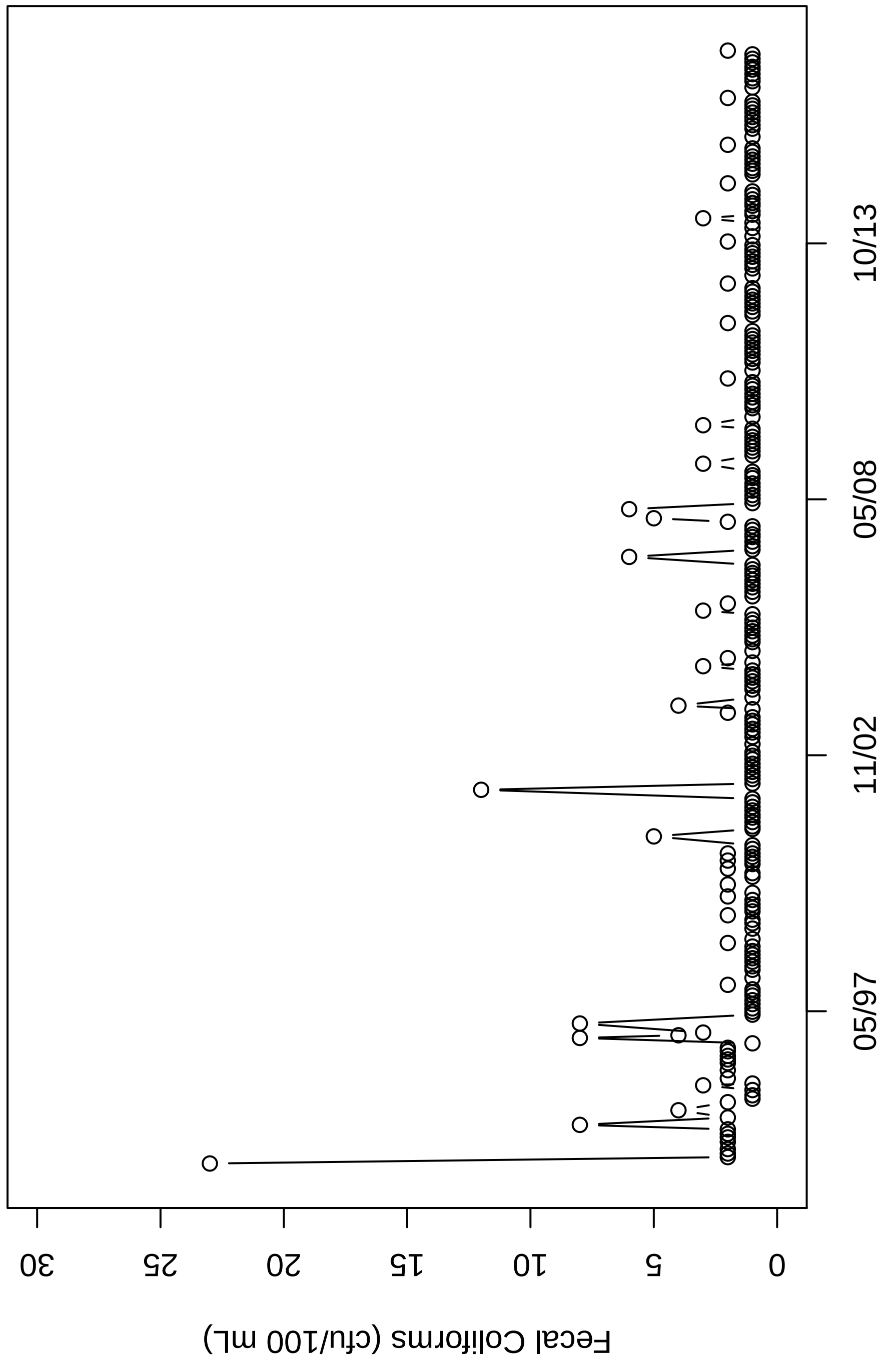


Figure B119: Lake Whatcom fecal coliform data for Site 3.

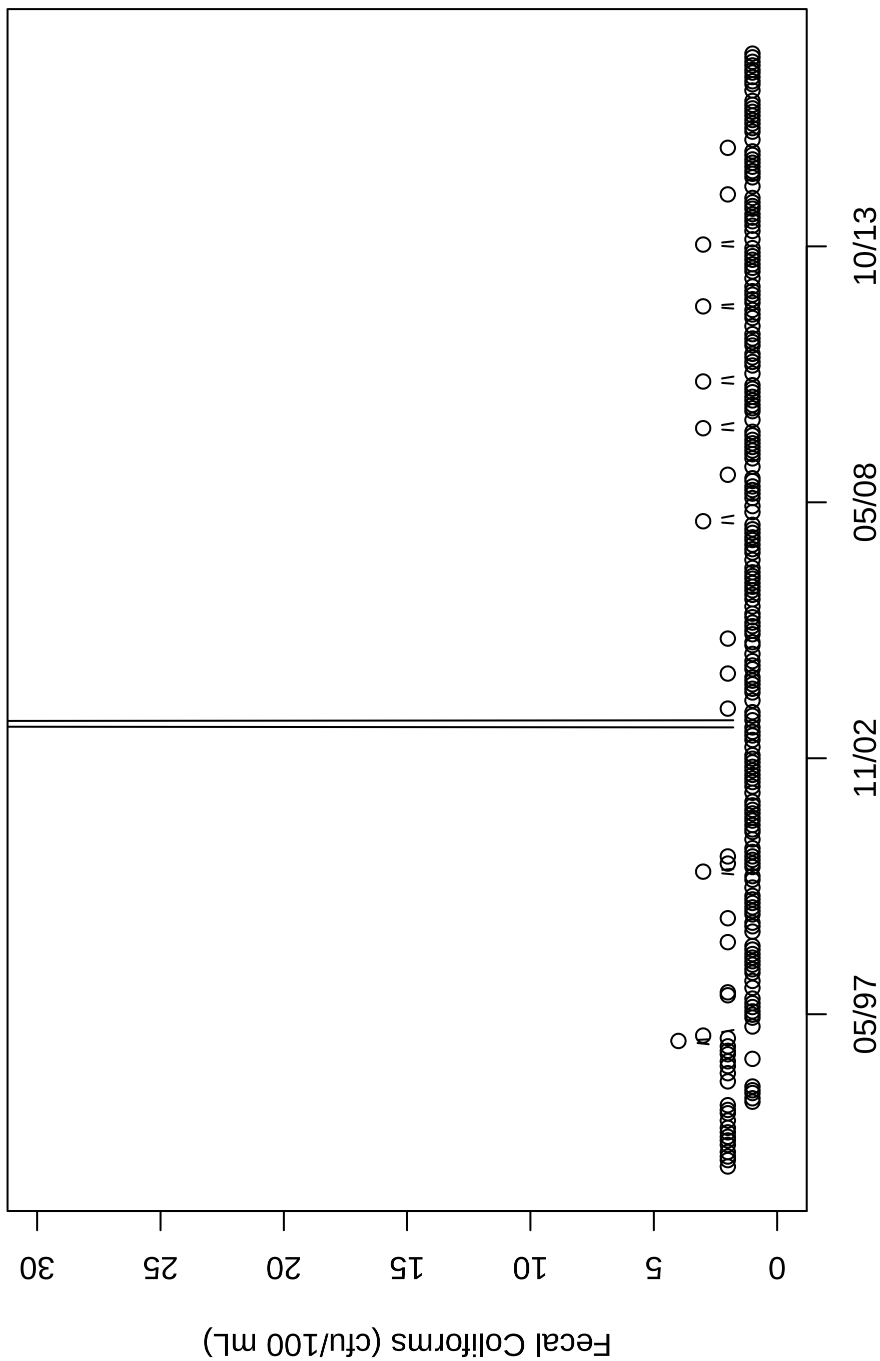


Figure B120: Lake Whatcom fecal coliform data for Site 4.

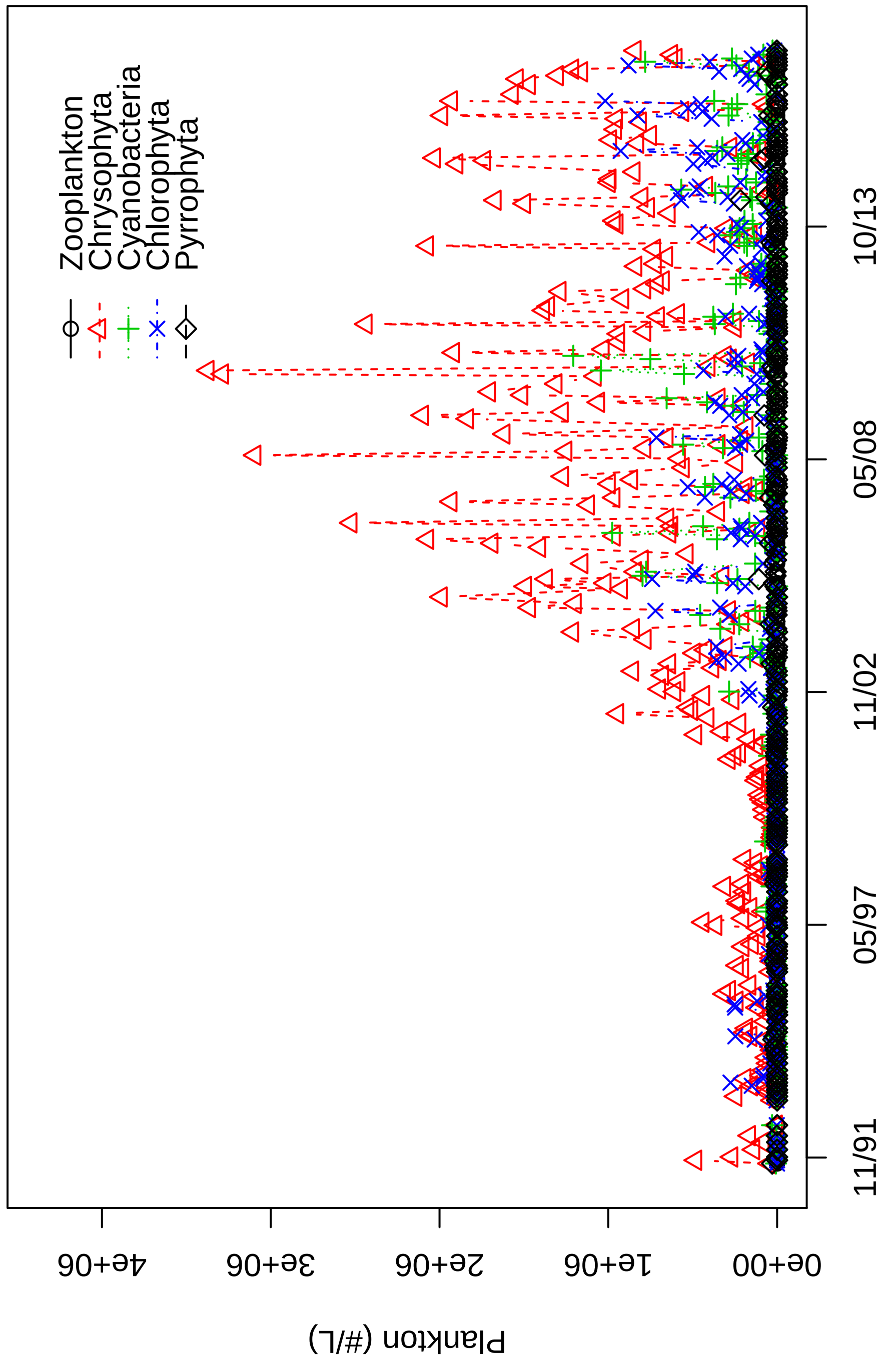


Figure B121: Lake Whatcom plankton data for Site 1.

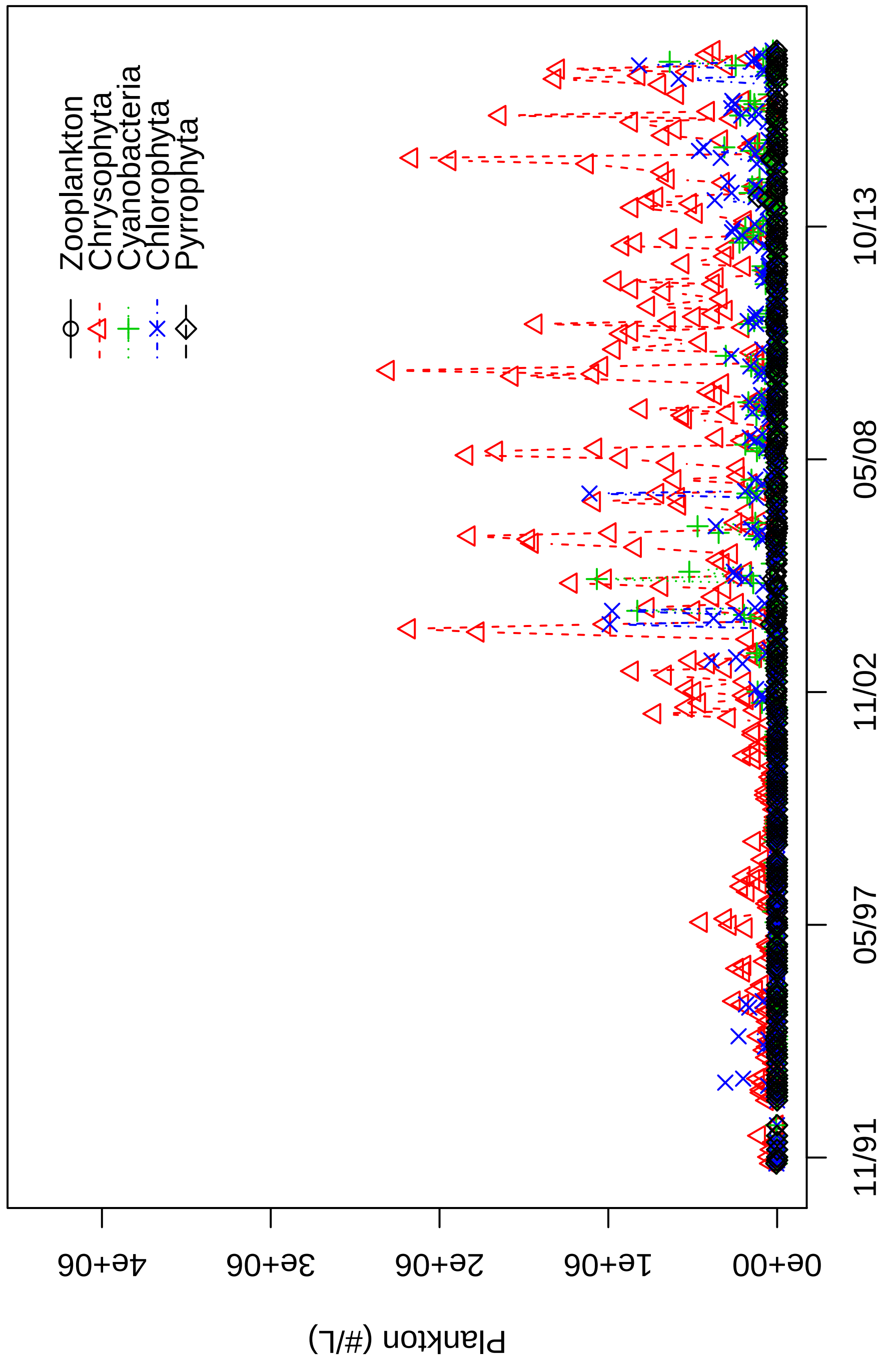


Figure B122: Lake Whatcom plankton data for Site 2.

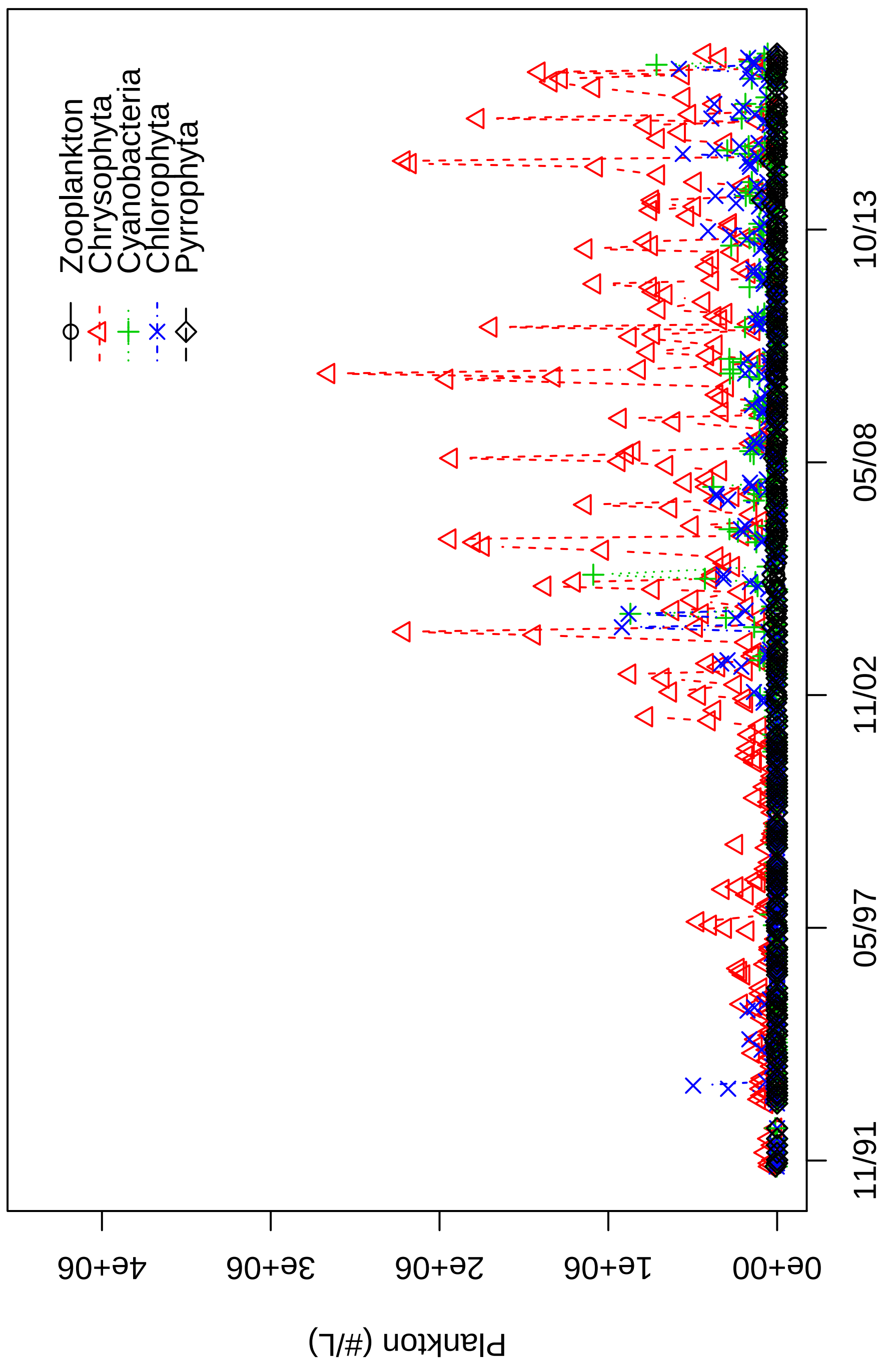


Figure B123: Lake Whatcom plankton data for the Intake Site.

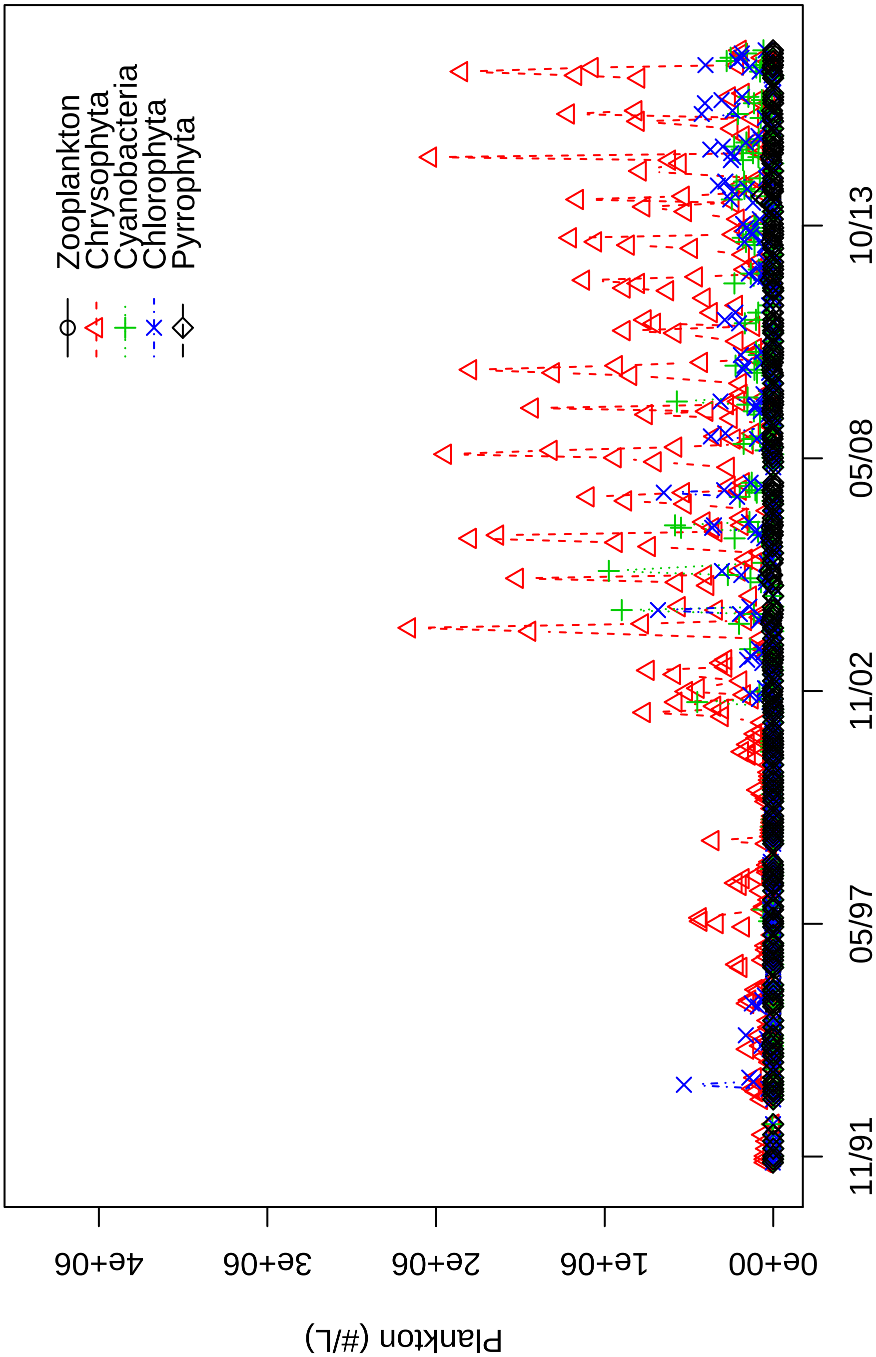


Figure B124: Lake Whatcom plankton data for Site 3.

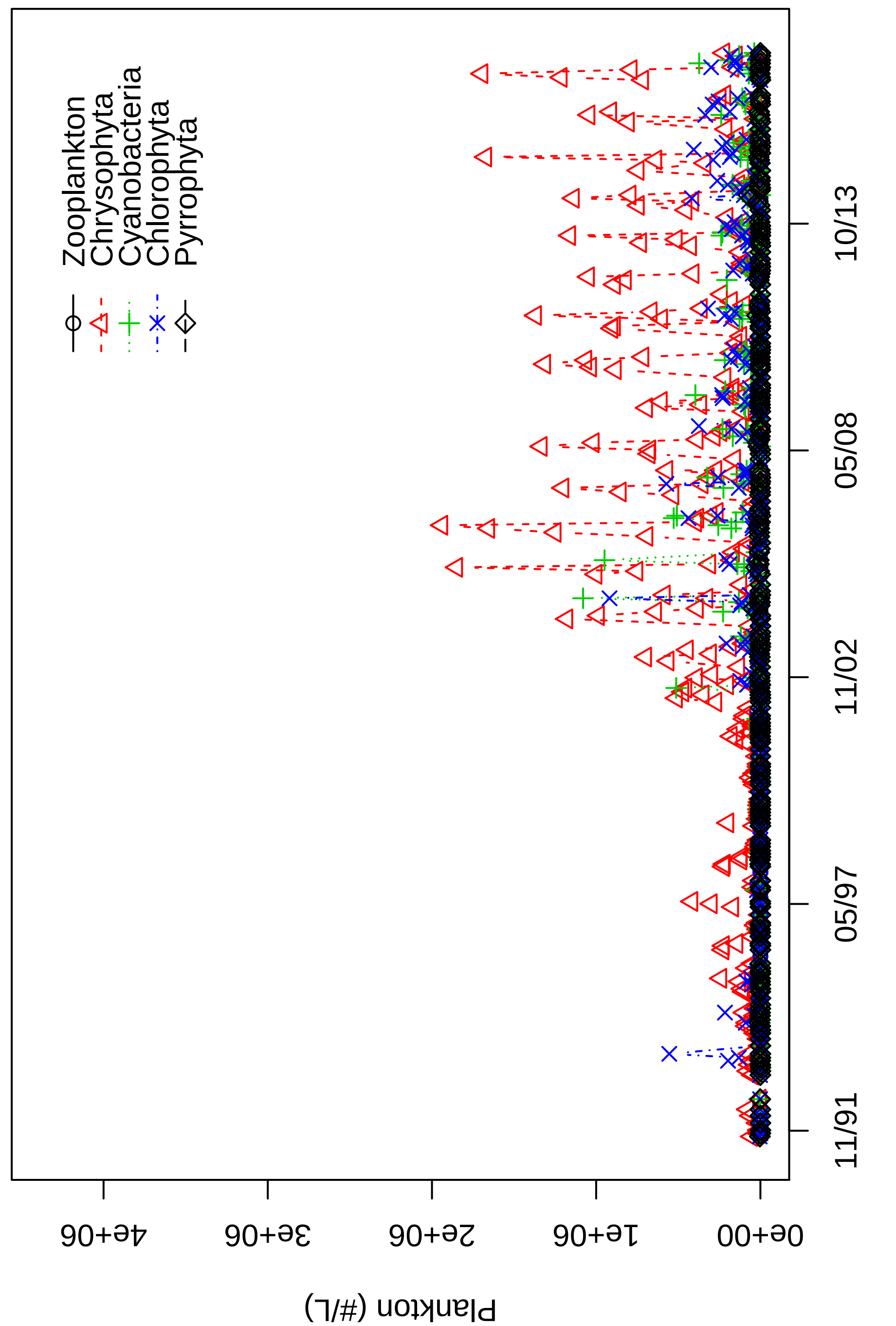


Figure B125: Lake Whatcom plankton data for Site 4.

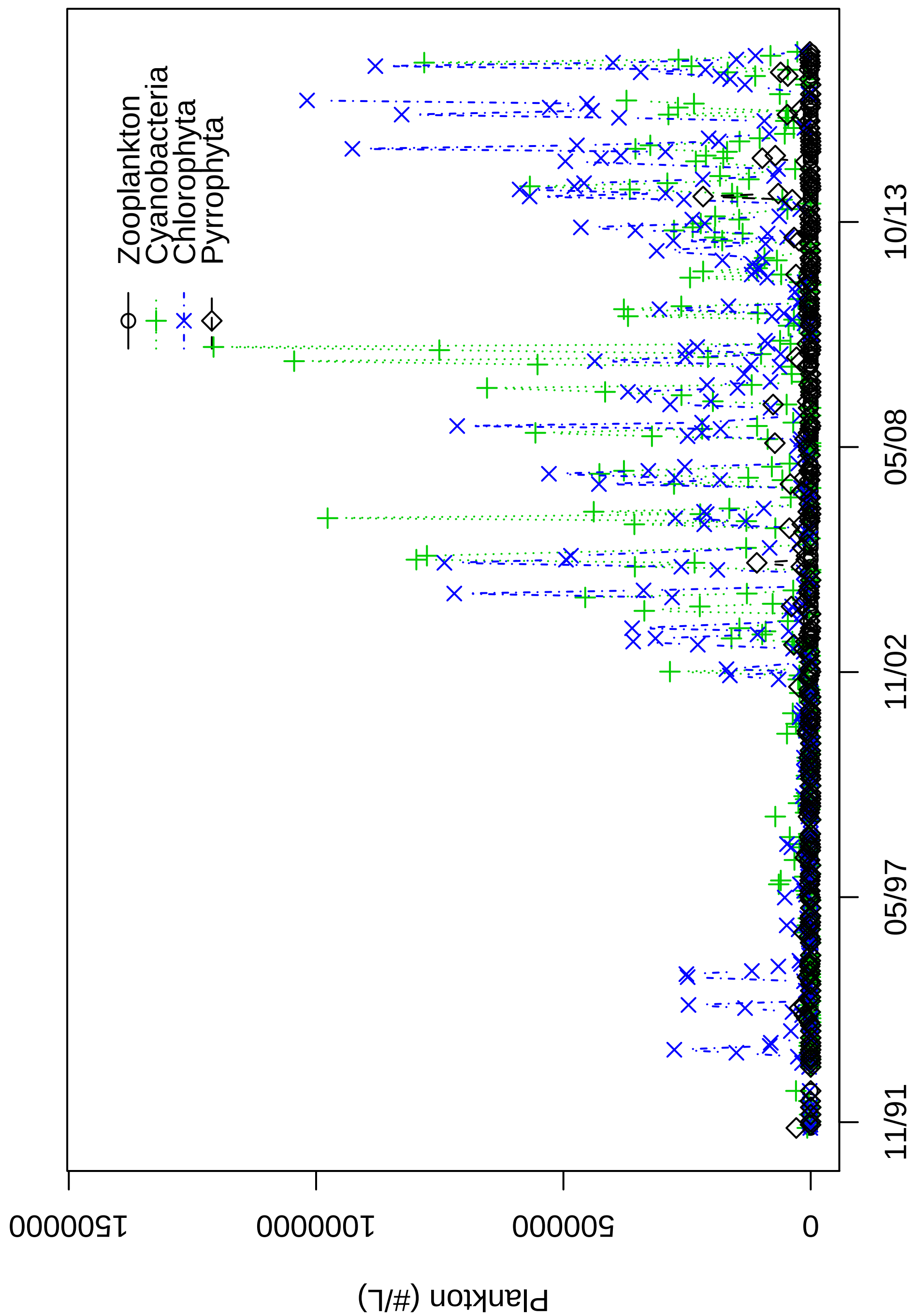


Figure B126: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

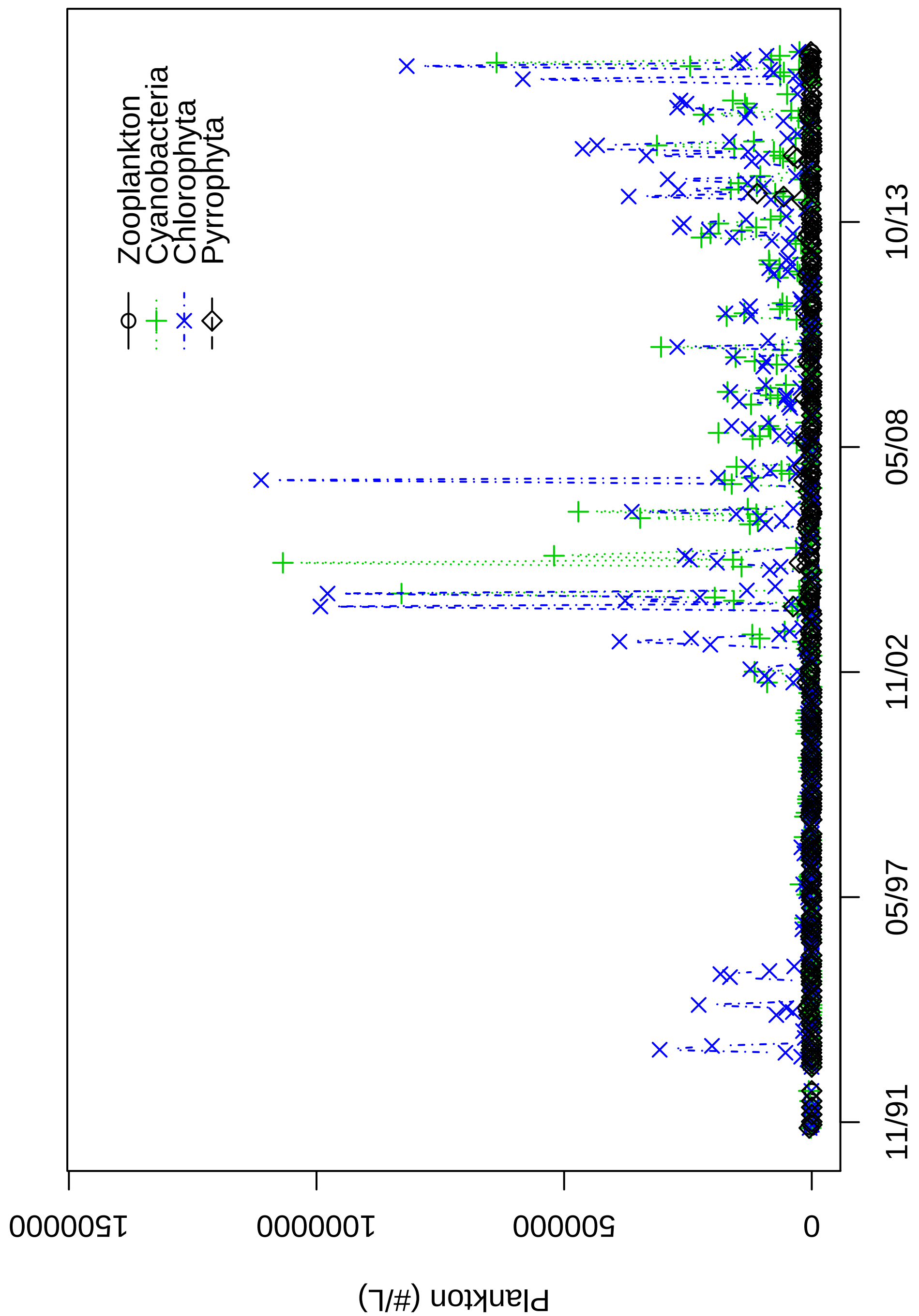


Figure B127: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

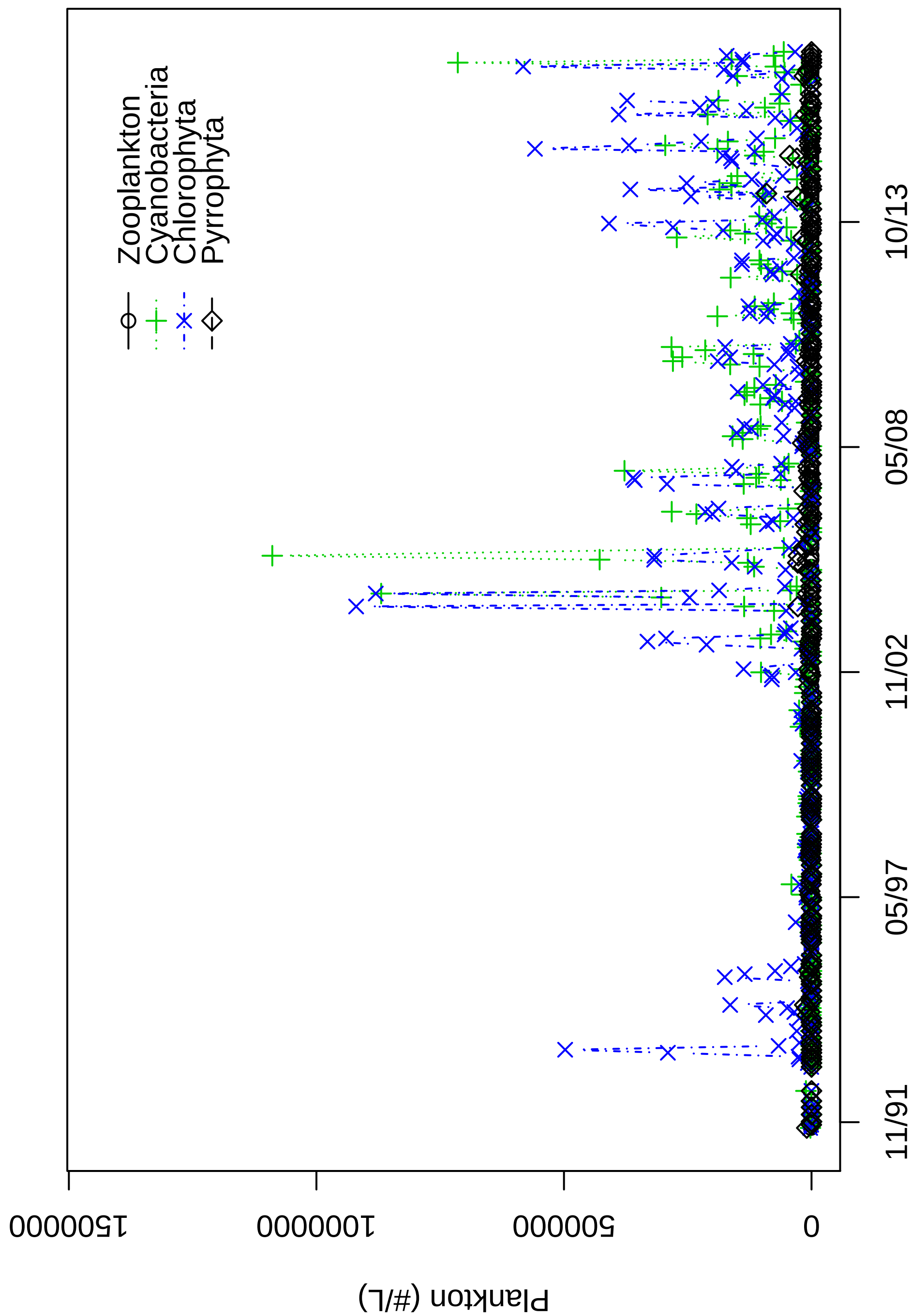


Figure B128: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

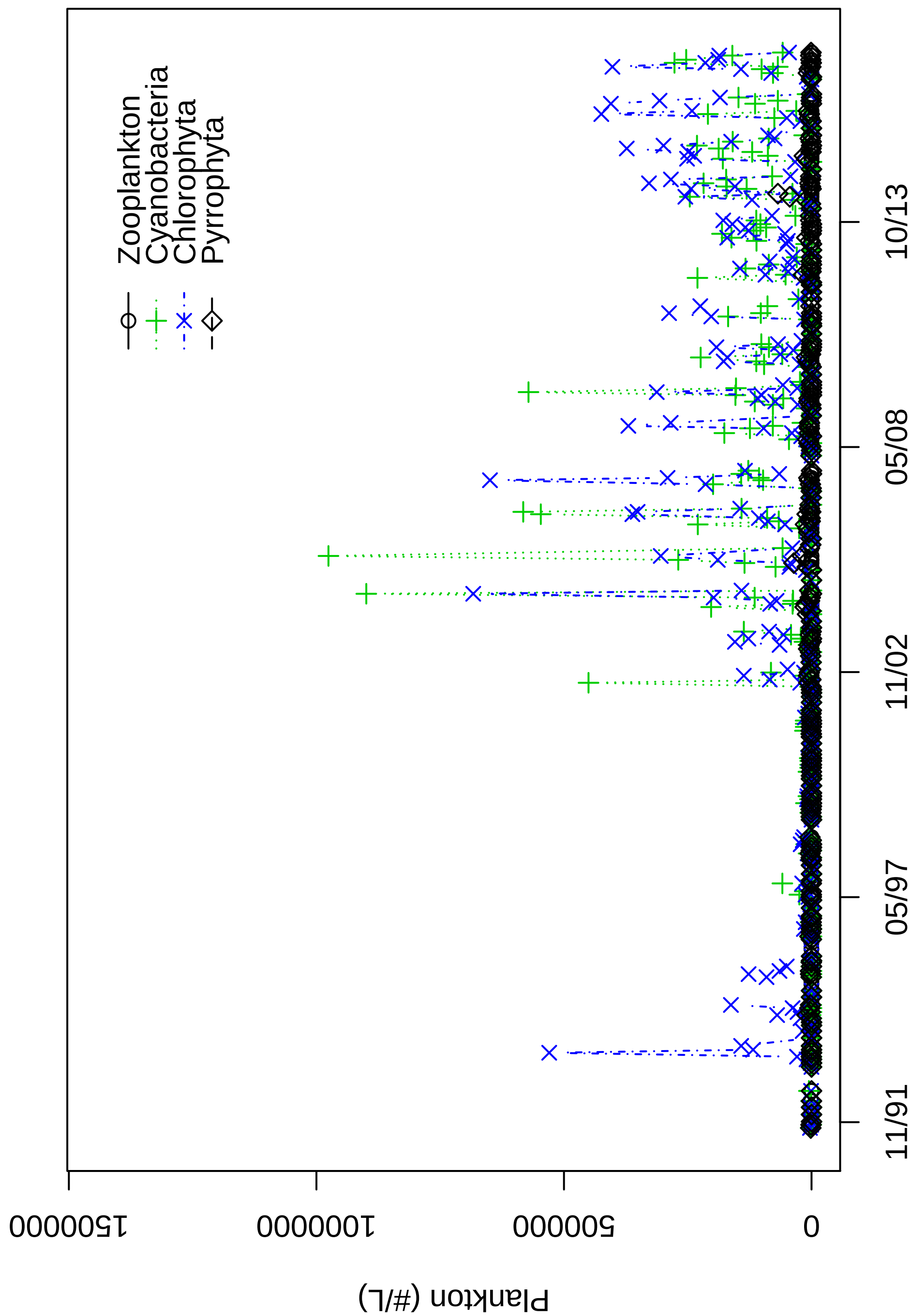


Figure B129: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

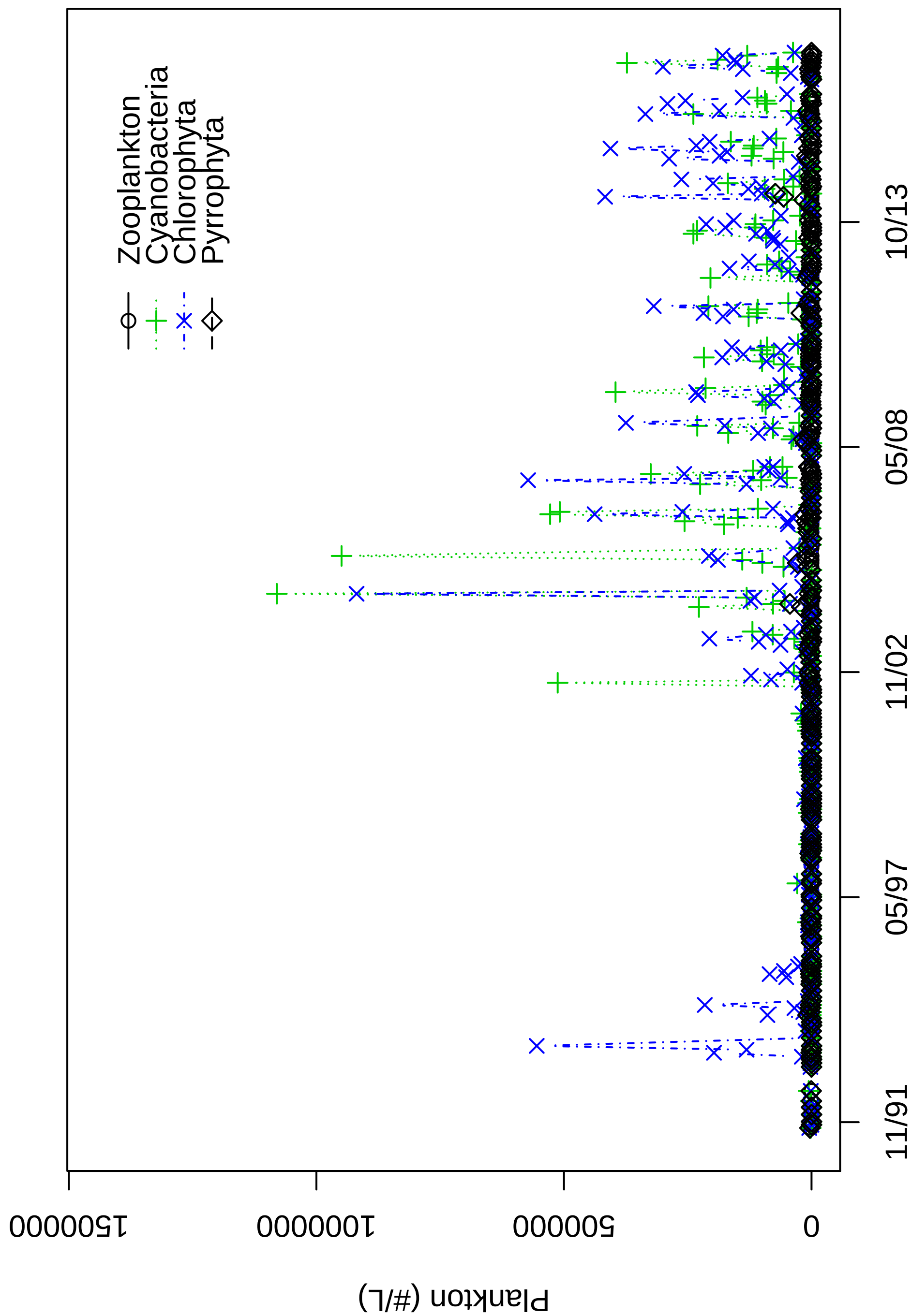


Figure B130: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

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 253).

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
Carpenter	June 15, 2017	F. coliforms	3,400 cfu/100 mL
Euclid	October 12, 2011	F. coliforms	3,200 cfu/100 mL
Millwheel	February 8, 2005	Ammonium	569.4 μg-N/L
	February 8, 2005	Soluble phosphate	116.5 μg-P/L
	September 14, 2010	Total phosphorus	217.2 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
	March 3, 2014	F.coliforms	4,000 cfu/100 mL
	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	F. coliforms	4,200 cfu/100 mL
	September 9, 2014	Total phosphorus	263.5 μg-P/L
	June 15, 2017	F. coliforms	4,700 cfu/100 mL
Olsen	January 10, 2006	Total susp. solids	166.9 mg/L
Park Place	August 1, 2006	F. coliforms	18,000 cfu/100 mL
	October 12, 2011	Ammonium	150.6 μg-N/L
	August 10, 2016	F. coliforms	4,100 cfu/100 mL
	July 18, 2017	F. coliforms	19,100 cfu/100 mL
Silver Beach	October 10, 2005	F. coliforms	5,800 cfu/100 mL
	August 1, 2006	F. coliforms	12,000 cfu/100 mL
	July 17, 2007	F. coliforms	5,300 cfu/100 mL
	July 15, 2008	F. coliforms	3,600 cfu/100 mL
	July 8, 2014	F. coliforms	5,700 cfu/100 mL

Table B1: List of outliers omitted from Figures B131–B169 to preserve scale.

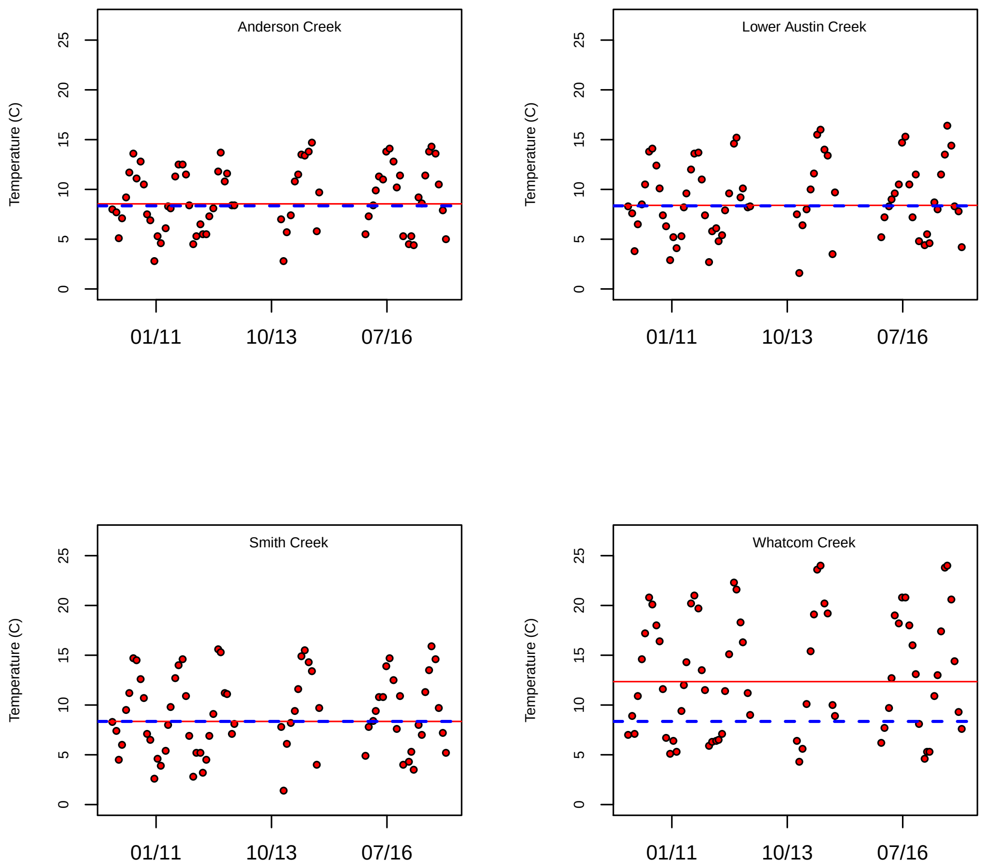


Figure B131: Temperature data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

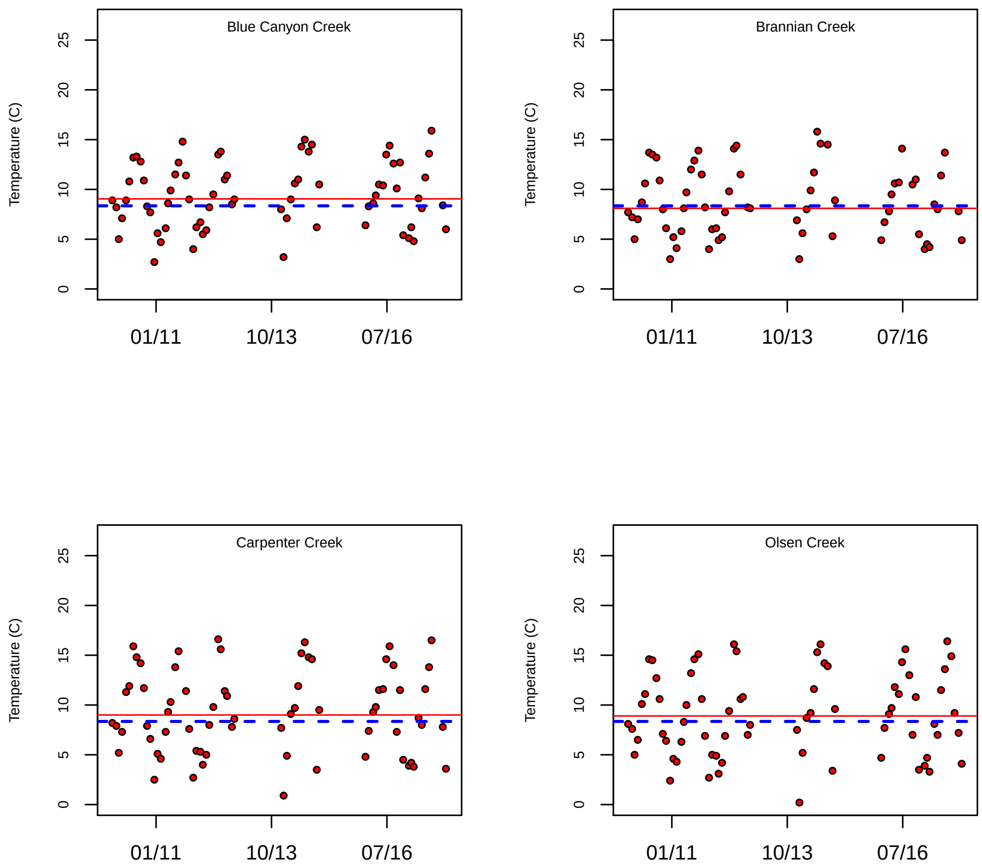


Figure B132: Temperature data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

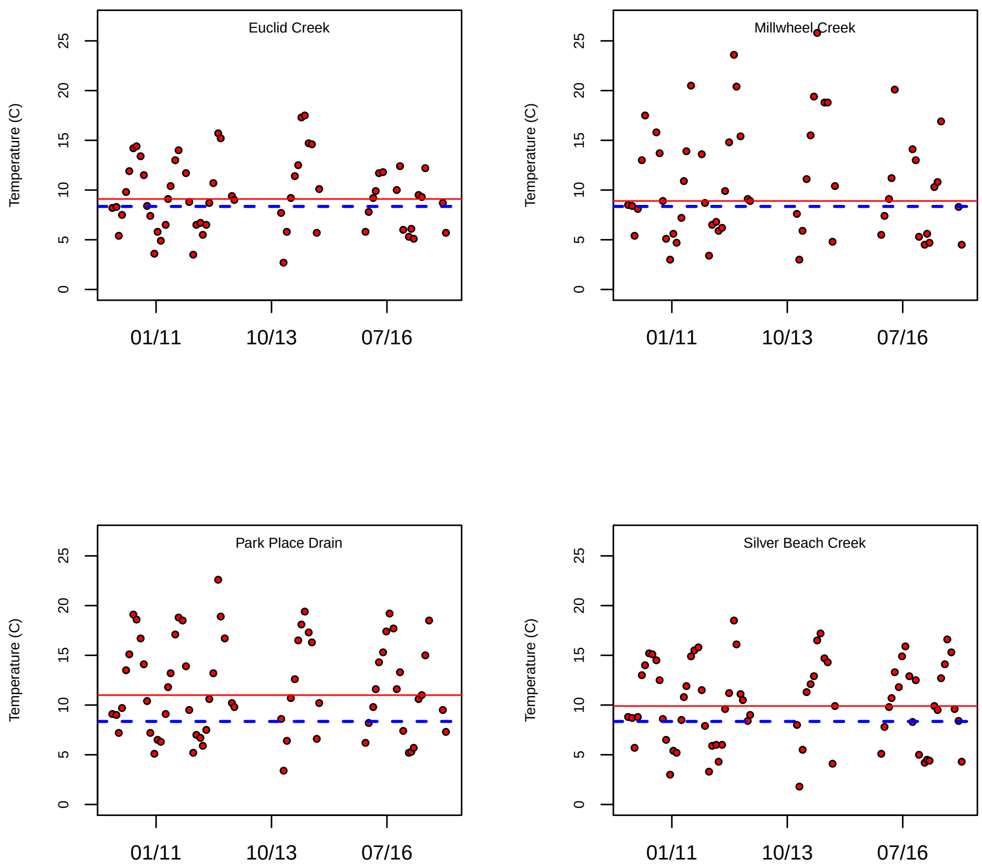


Figure B133: Temperature data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

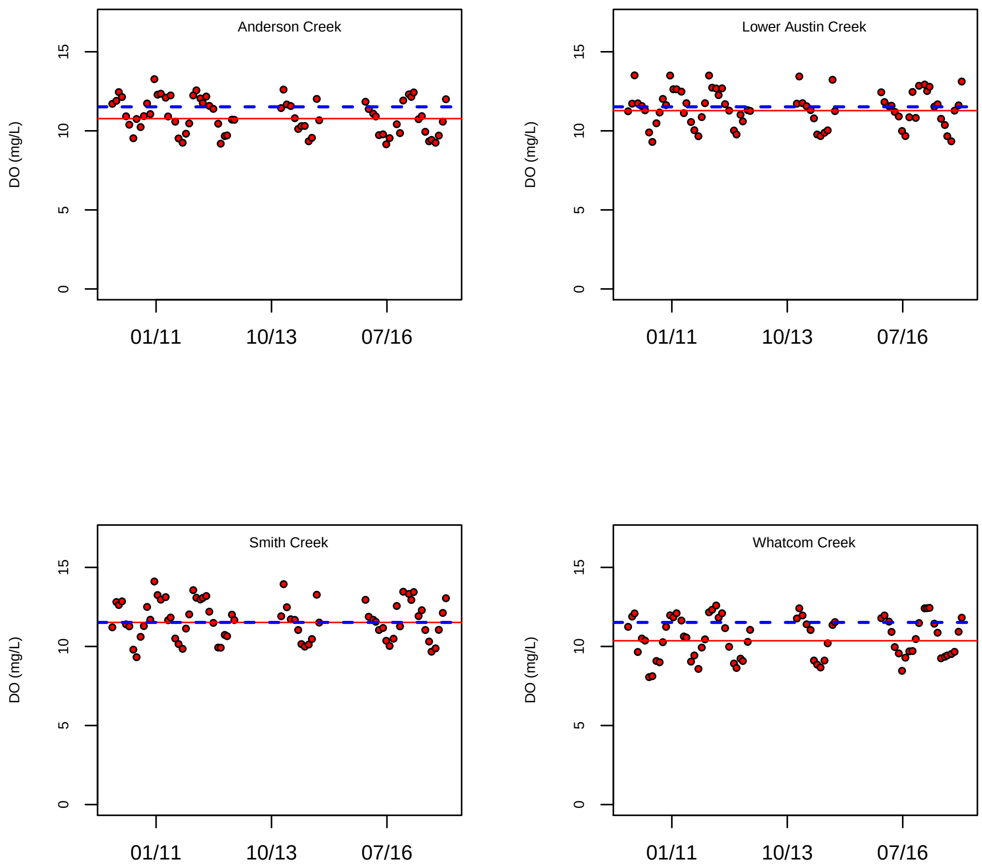


Figure B134: Dissolved oxygen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

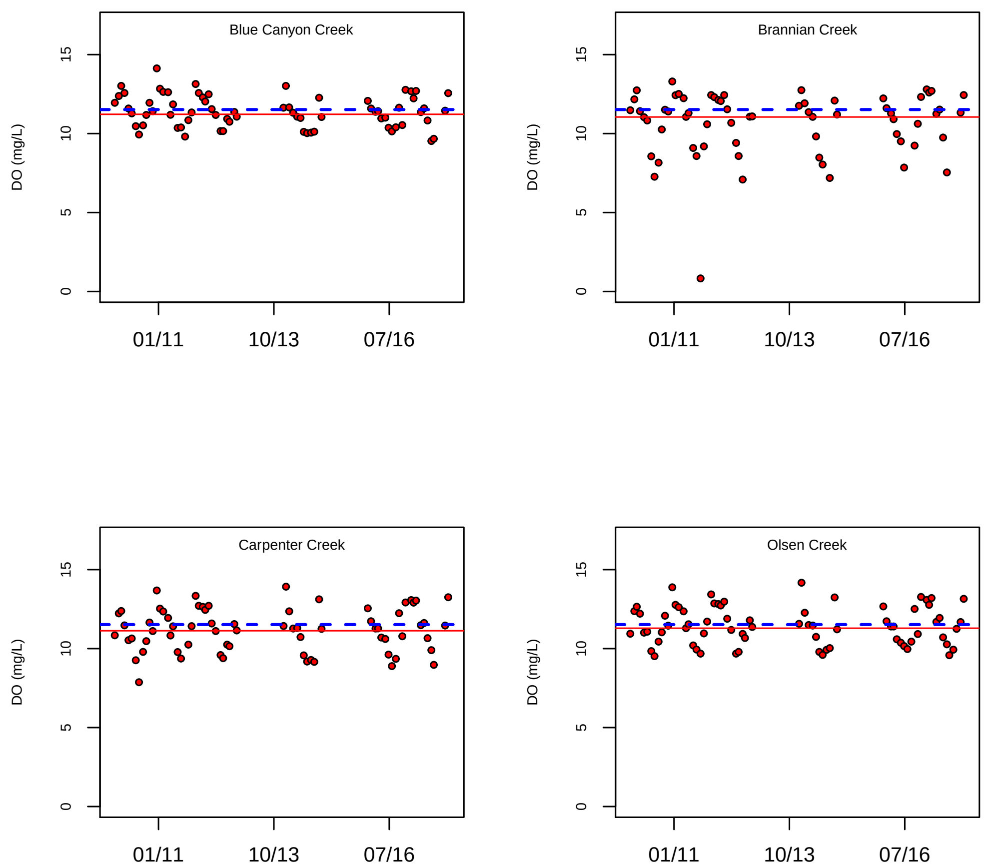


Figure B135: Dissolved oxygen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

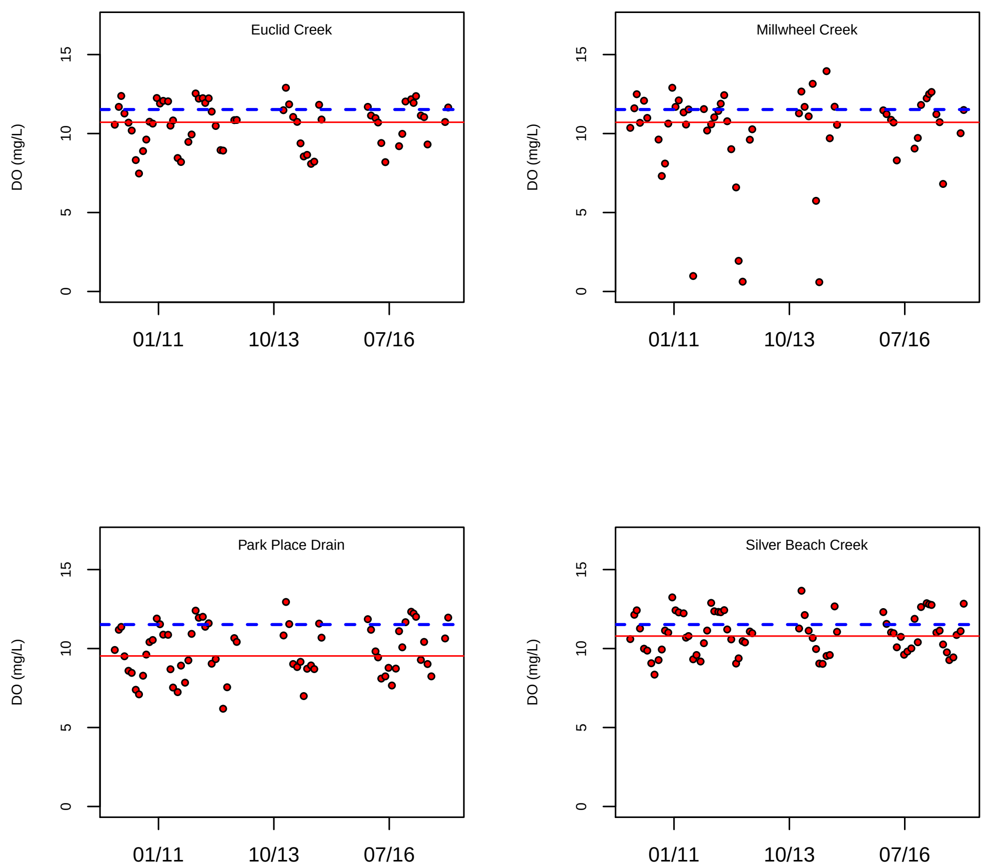


Figure B136: Dissolved oxygen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

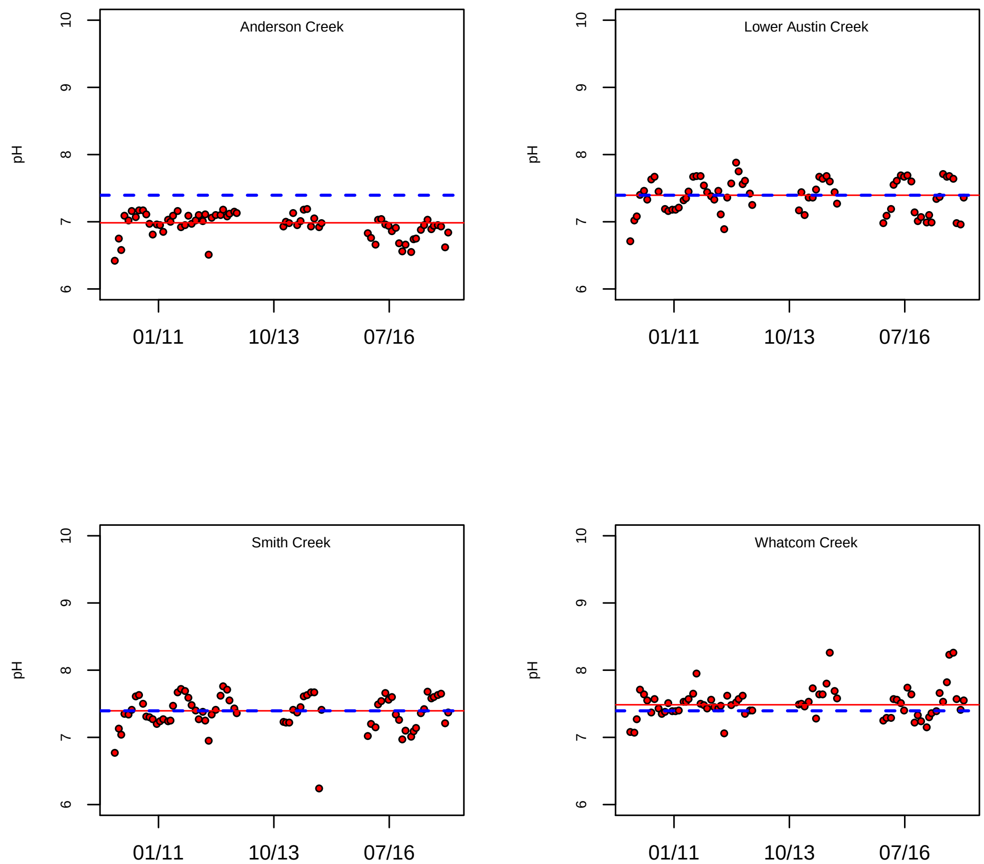


Figure B137: Tributary pH data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

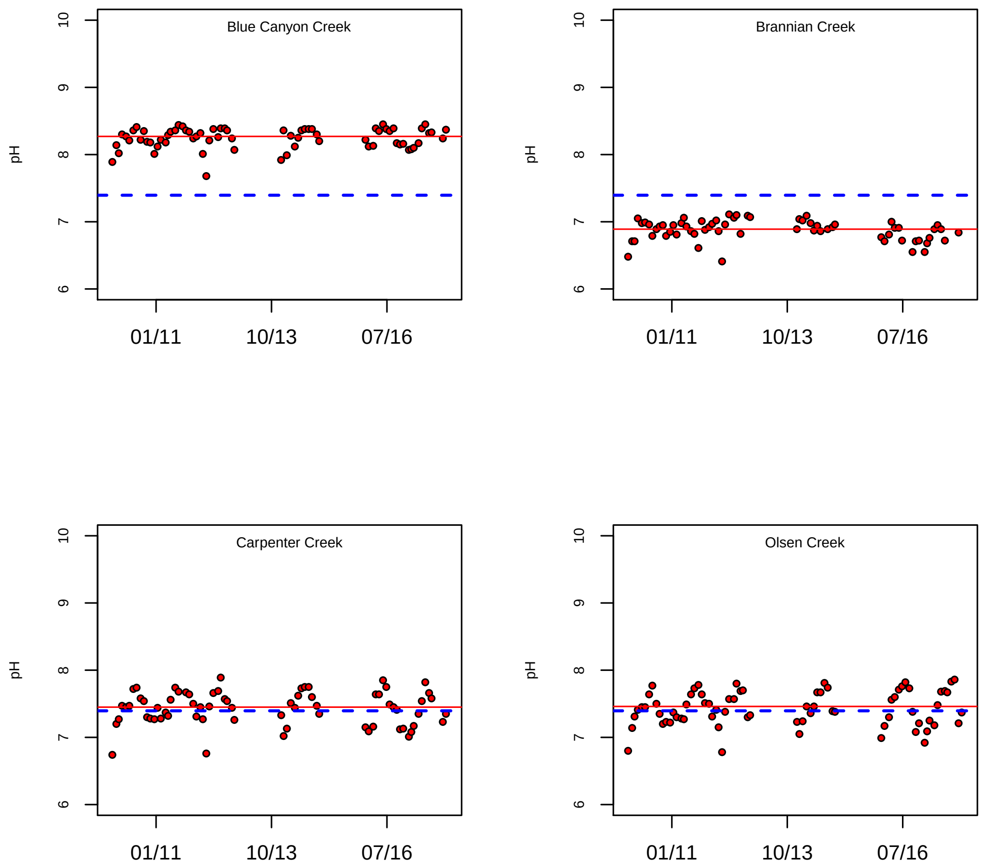


Figure B138: Tributary pH data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

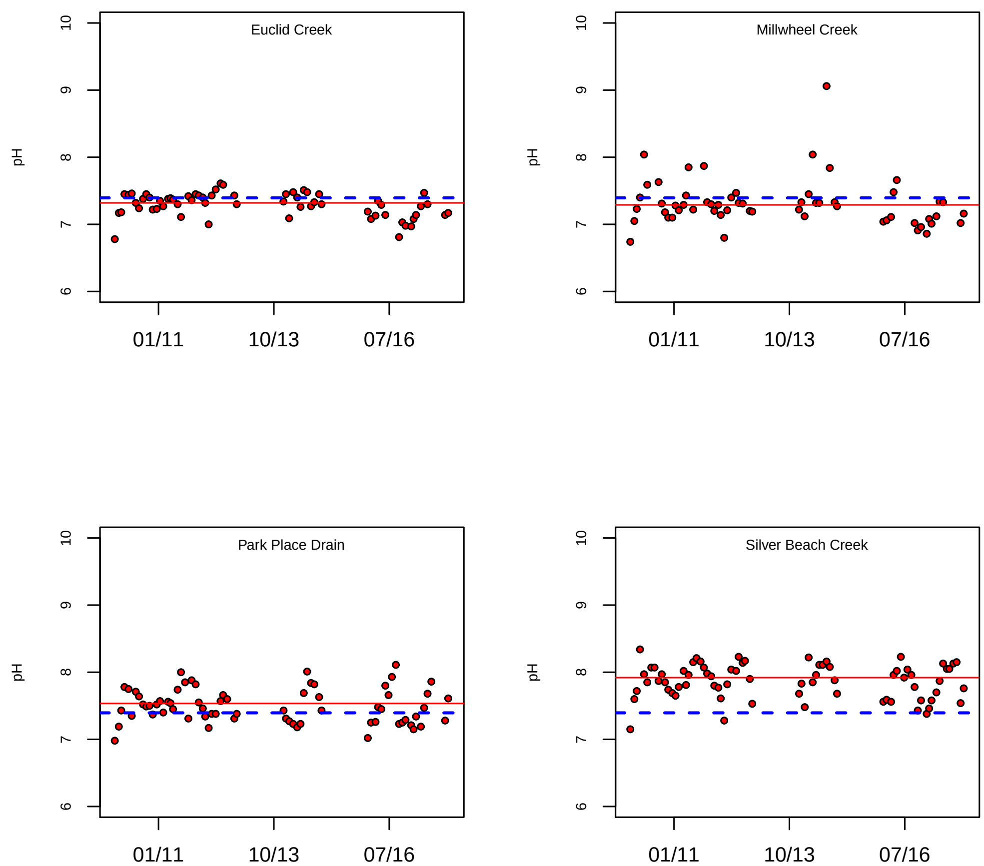


Figure B139: Tributary pH data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

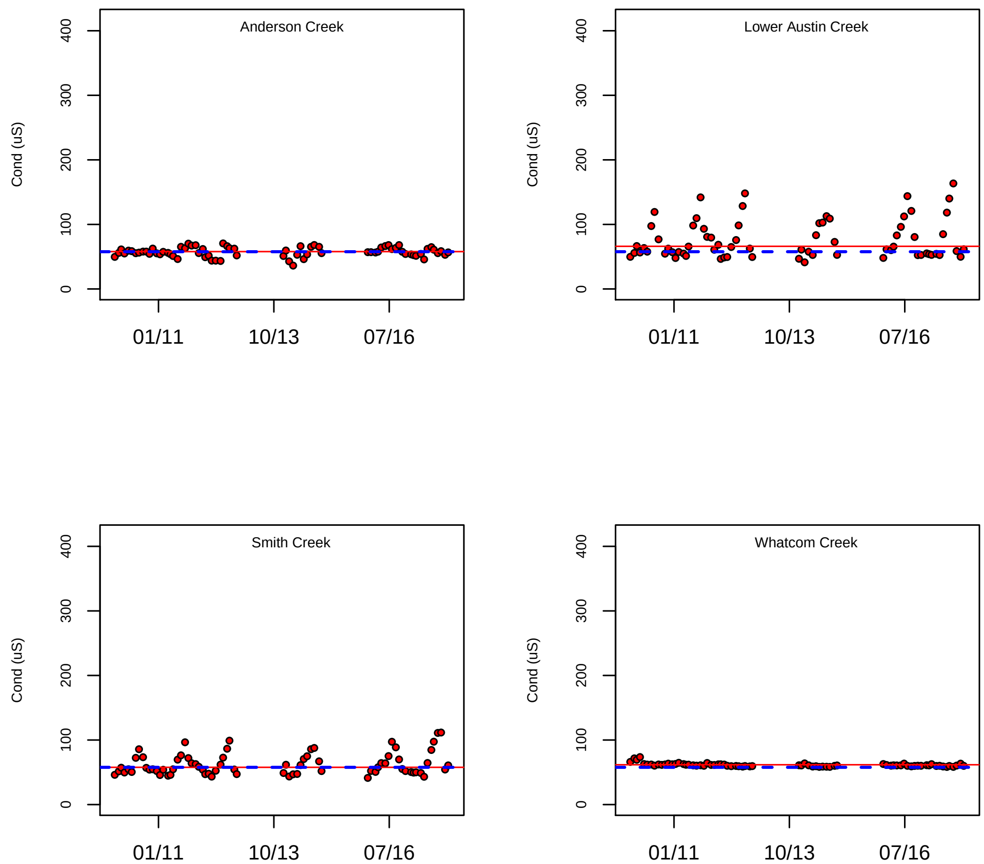


Figure B140: Conductivity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

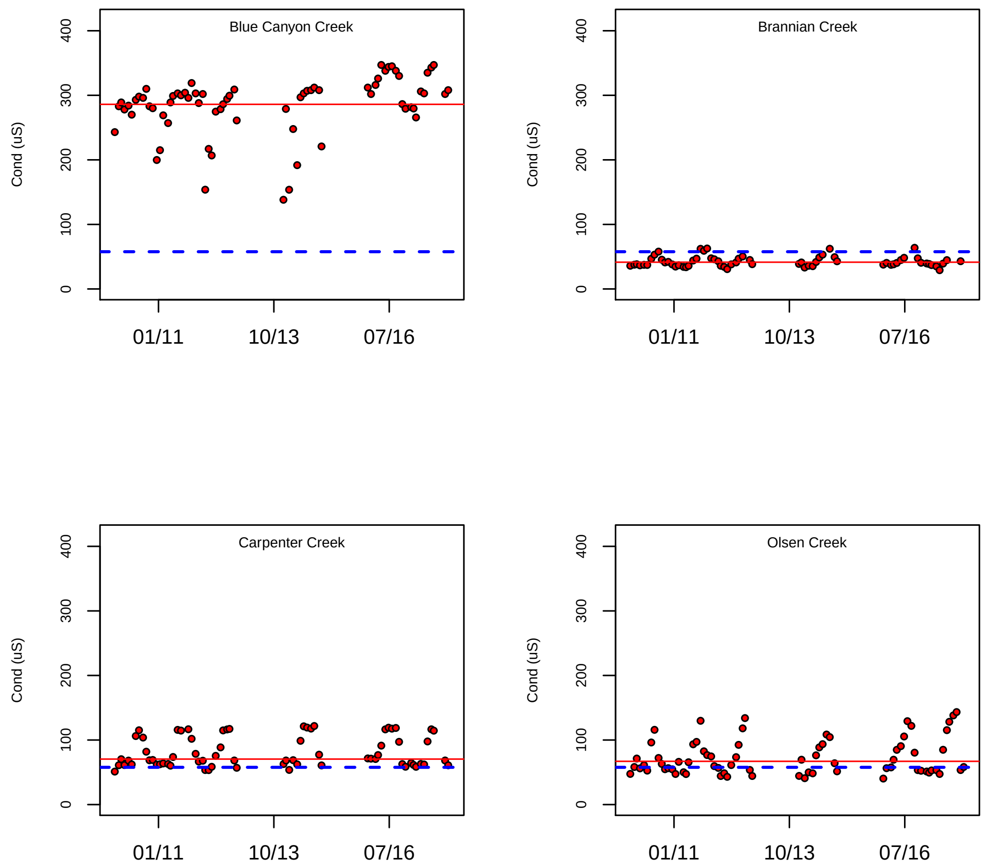


Figure B141: Conductivity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

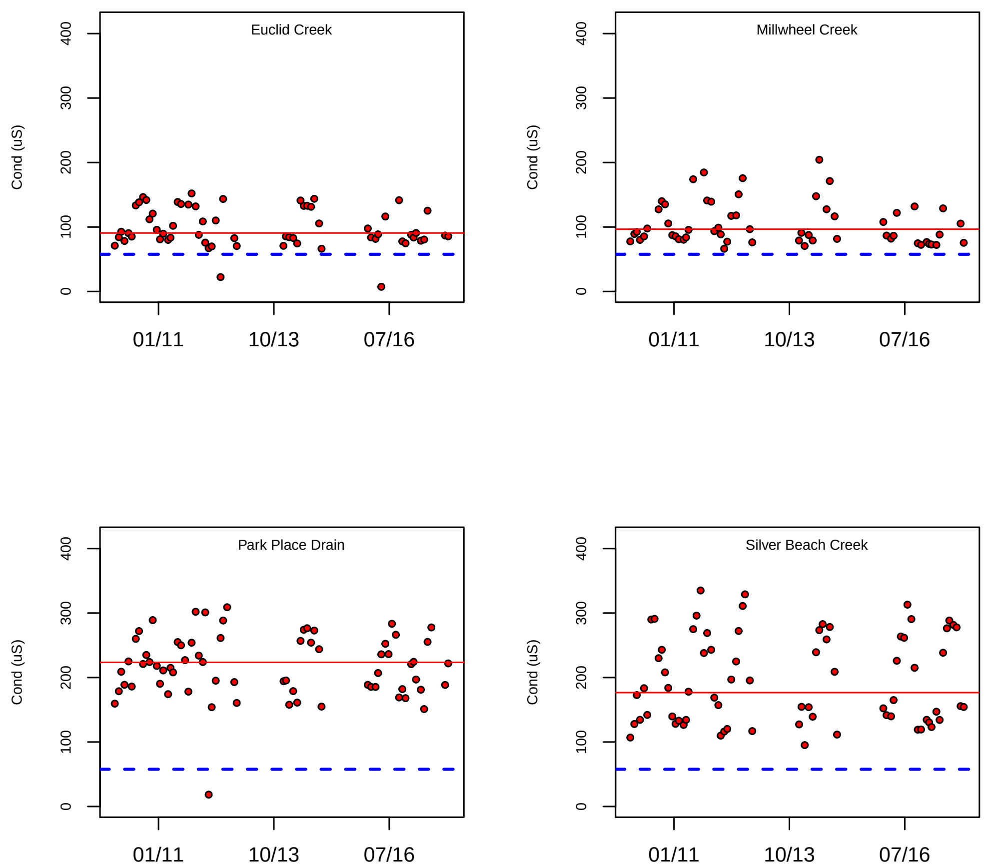


Figure B142: Conductivity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

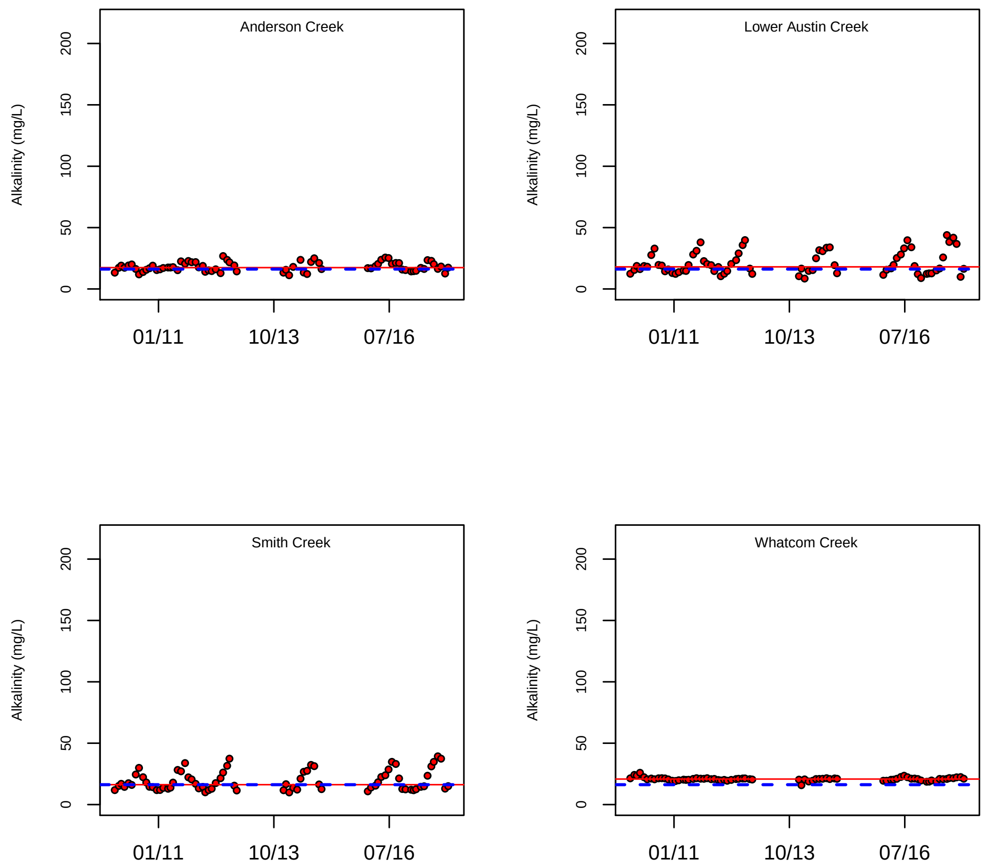


Figure B143: Alkalinity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

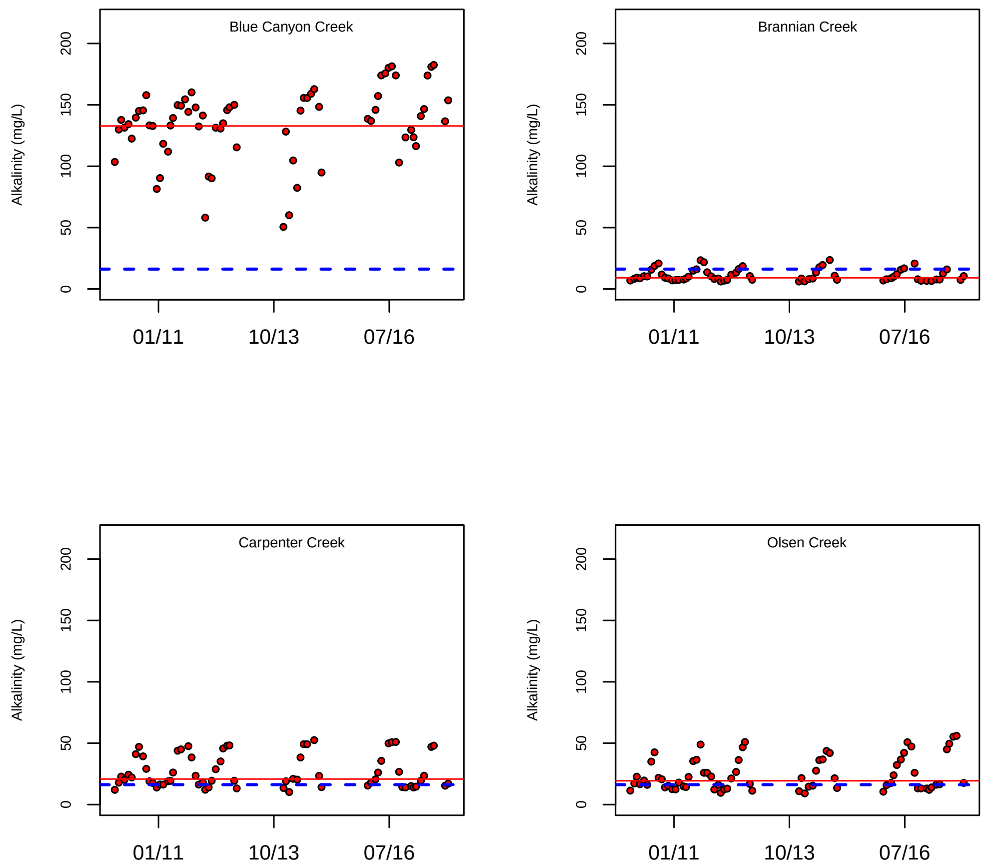


Figure B144: Alkalinity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

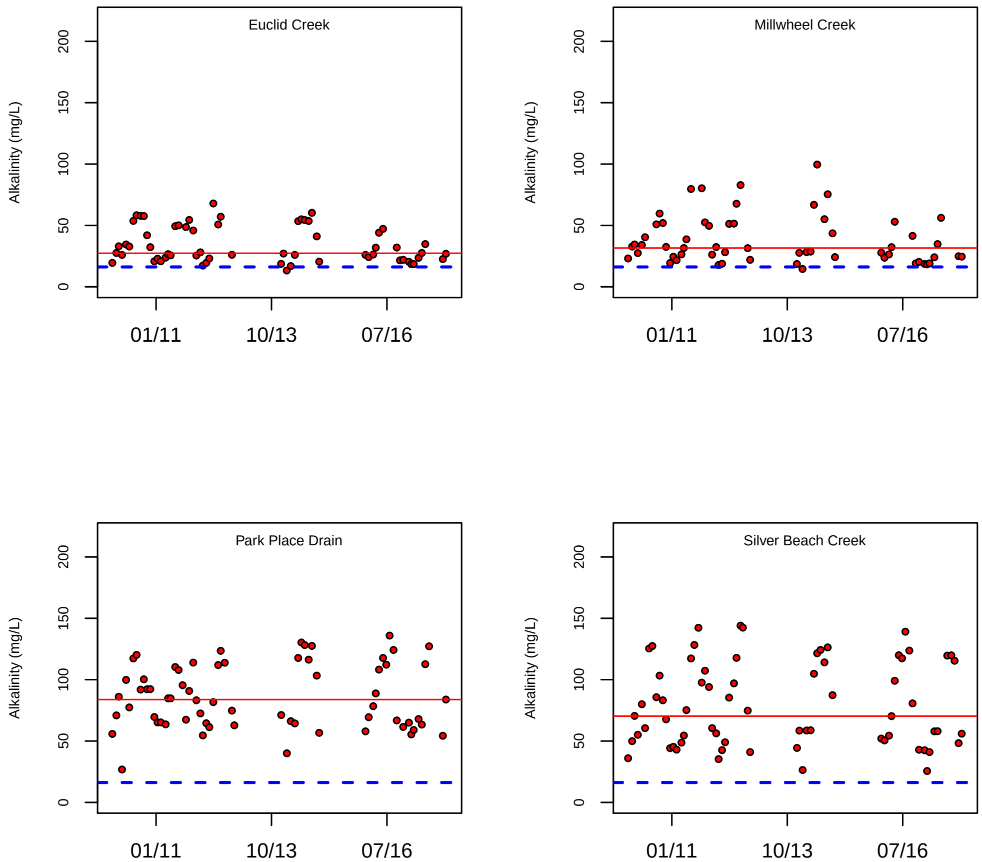


Figure B145: Alkalinity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

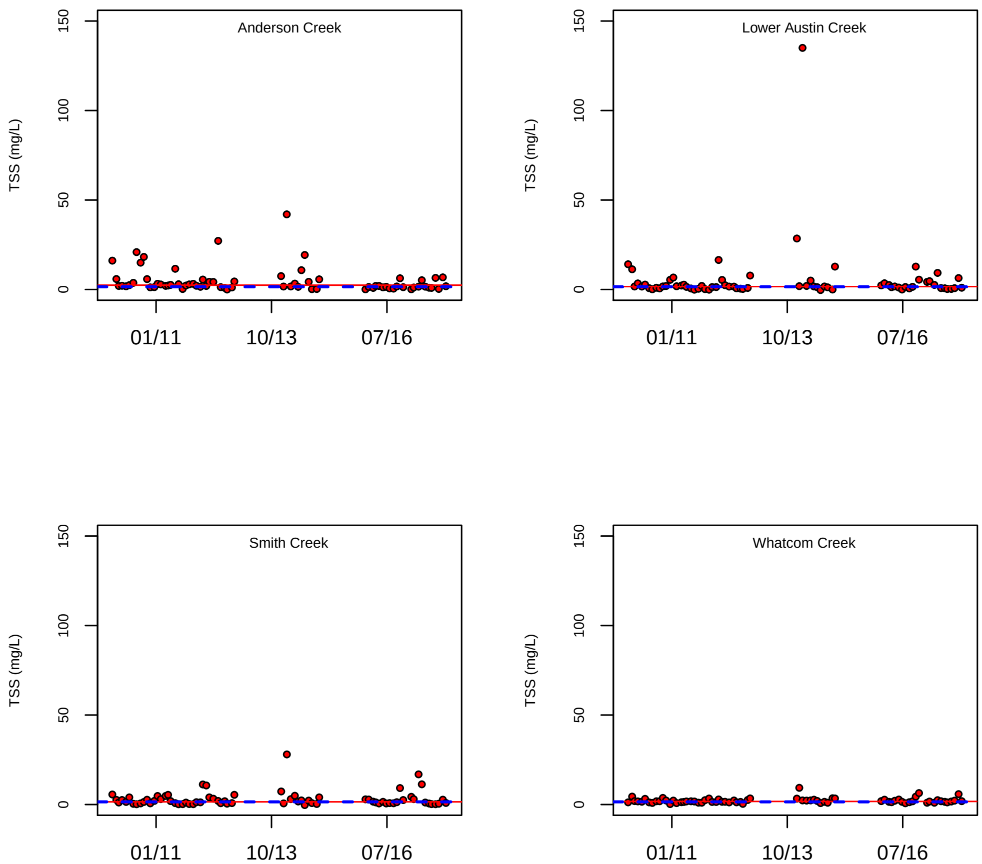


Figure B146: Total suspended solids data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

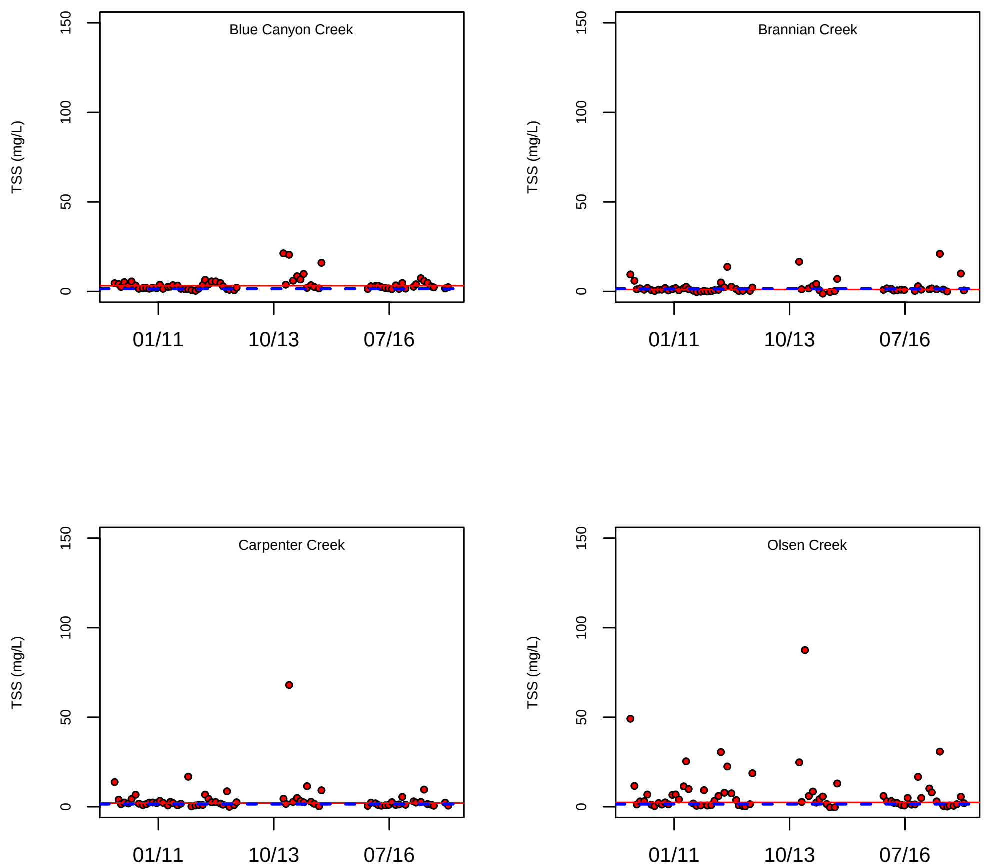


Figure B147: Total suspended solids data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

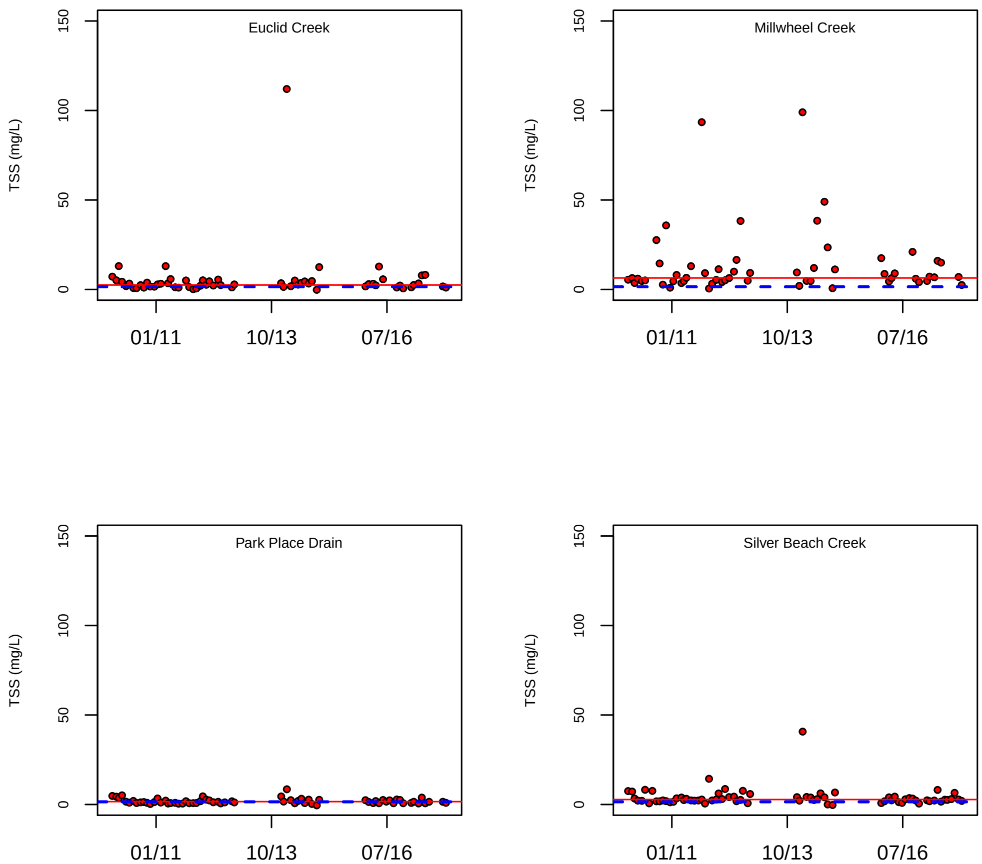


Figure B148: Total suspended solids data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

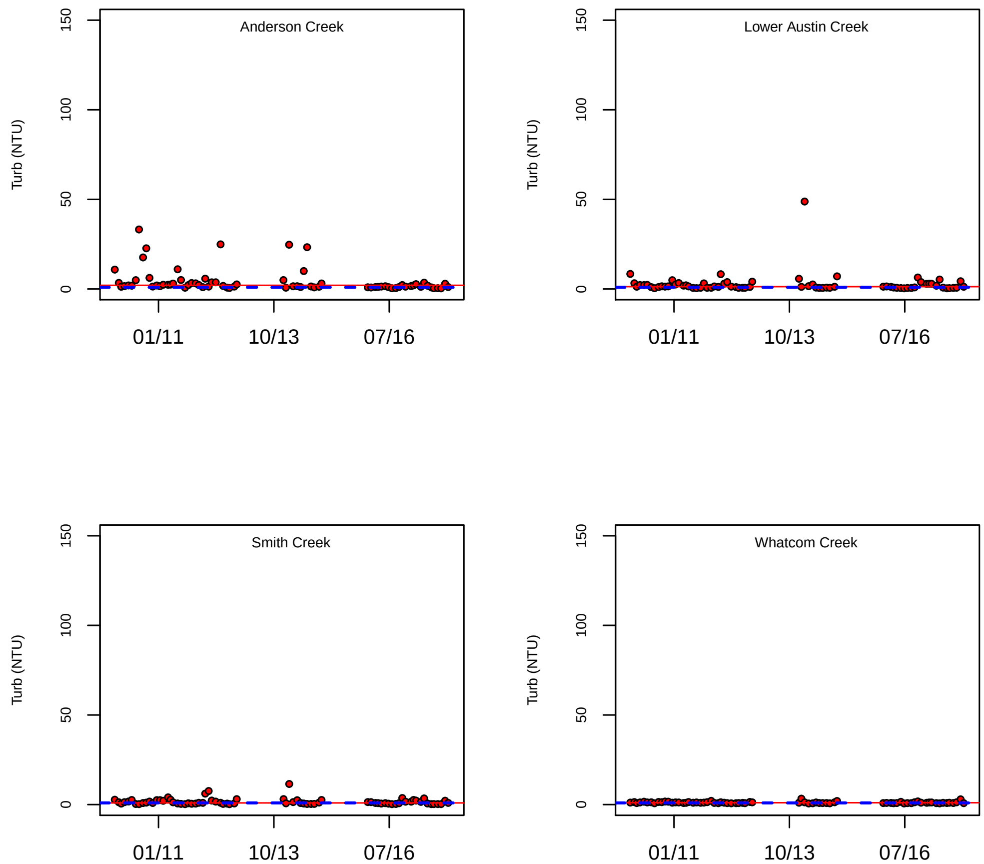


Figure B149: Turbidity data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

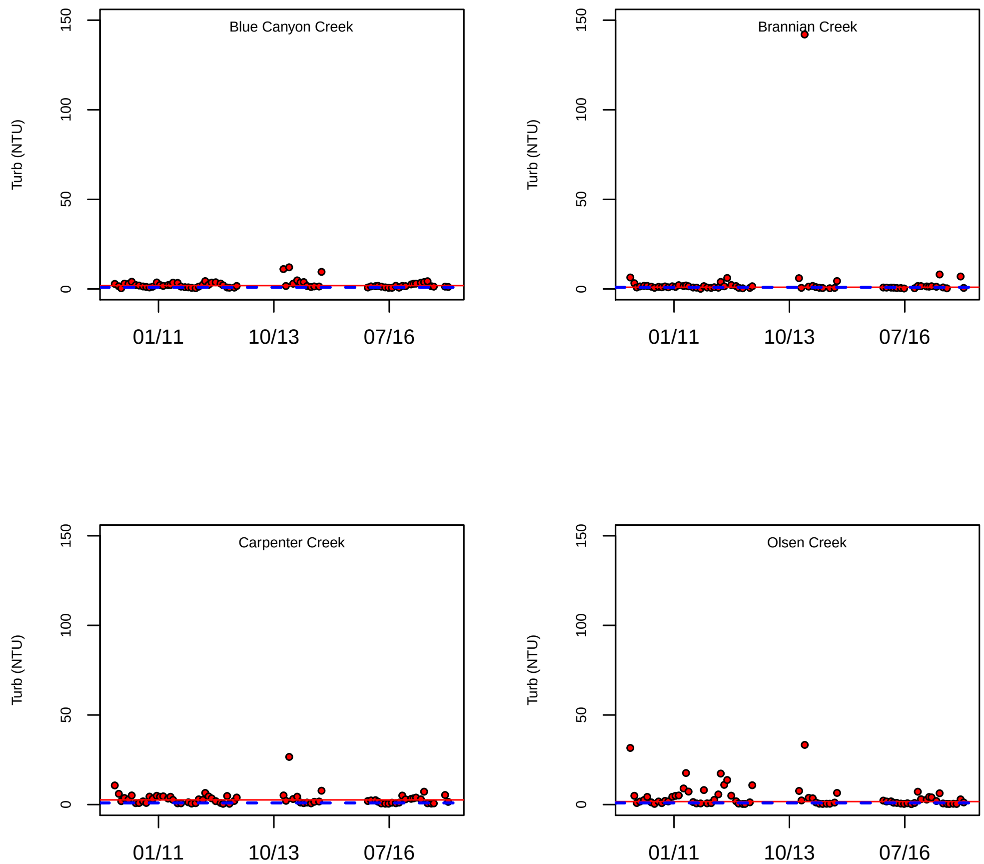


Figure B150: Turbidity data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

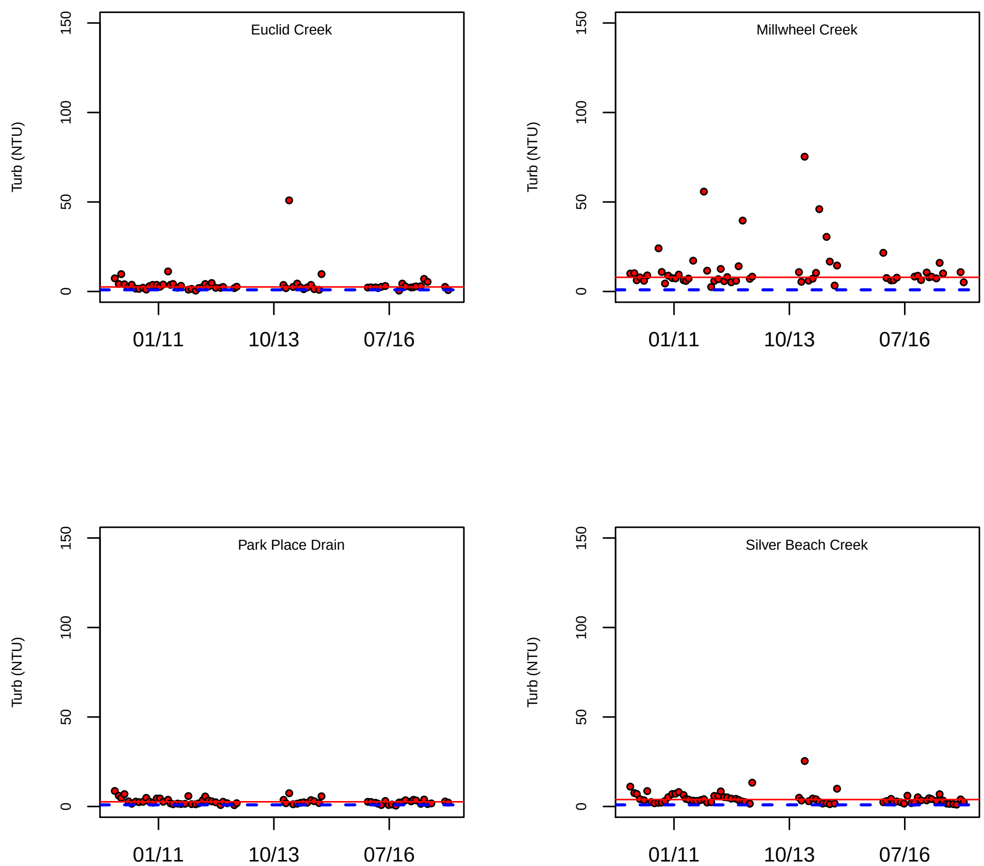


Figure B151: Turbidity data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

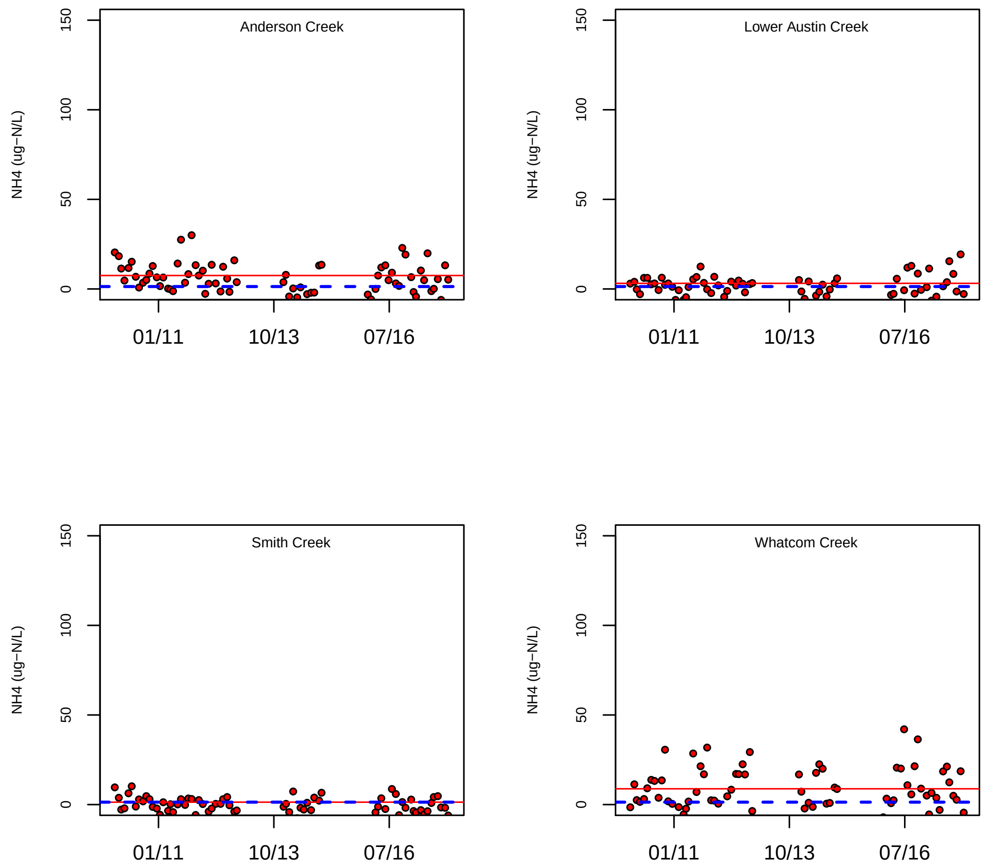


Figure B152: Ammonium data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

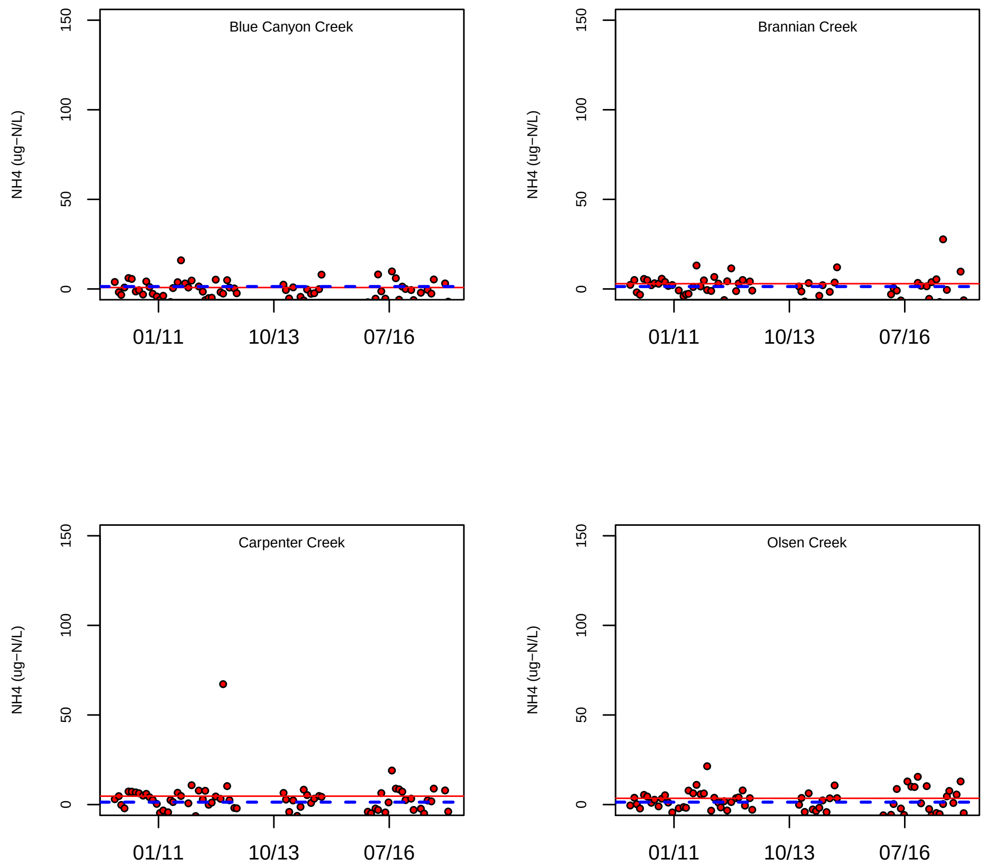


Figure B153: Ammonium data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

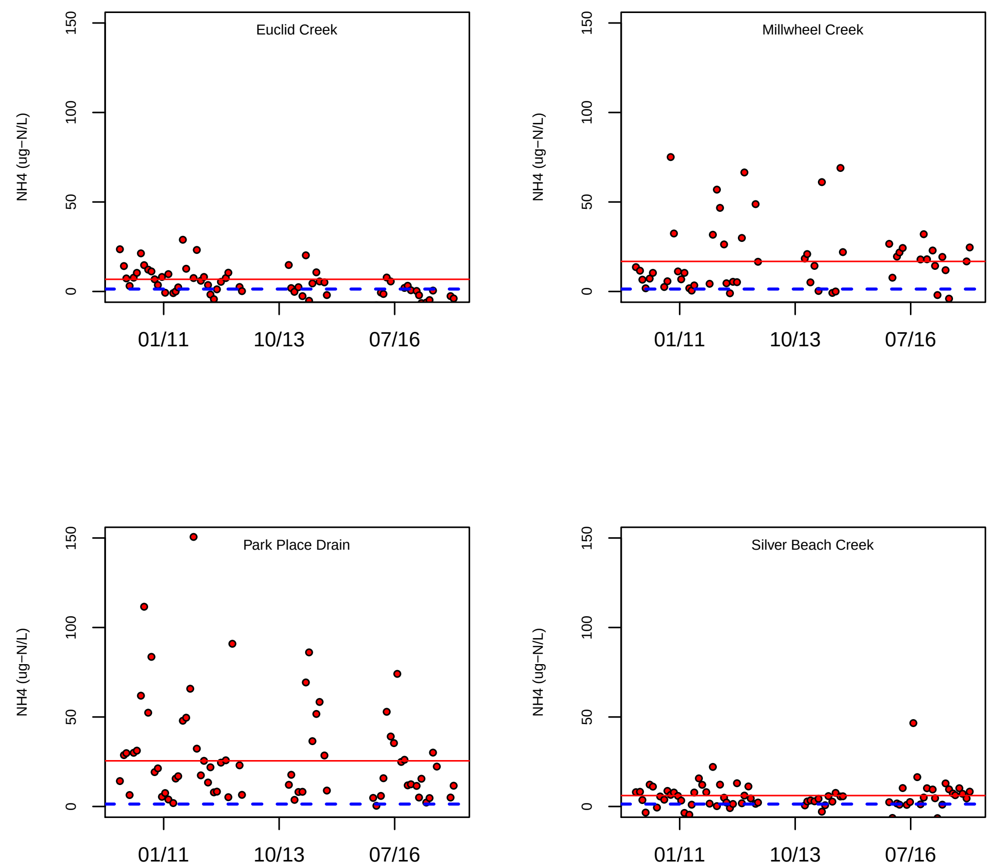


Figure B154: Ammonium data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

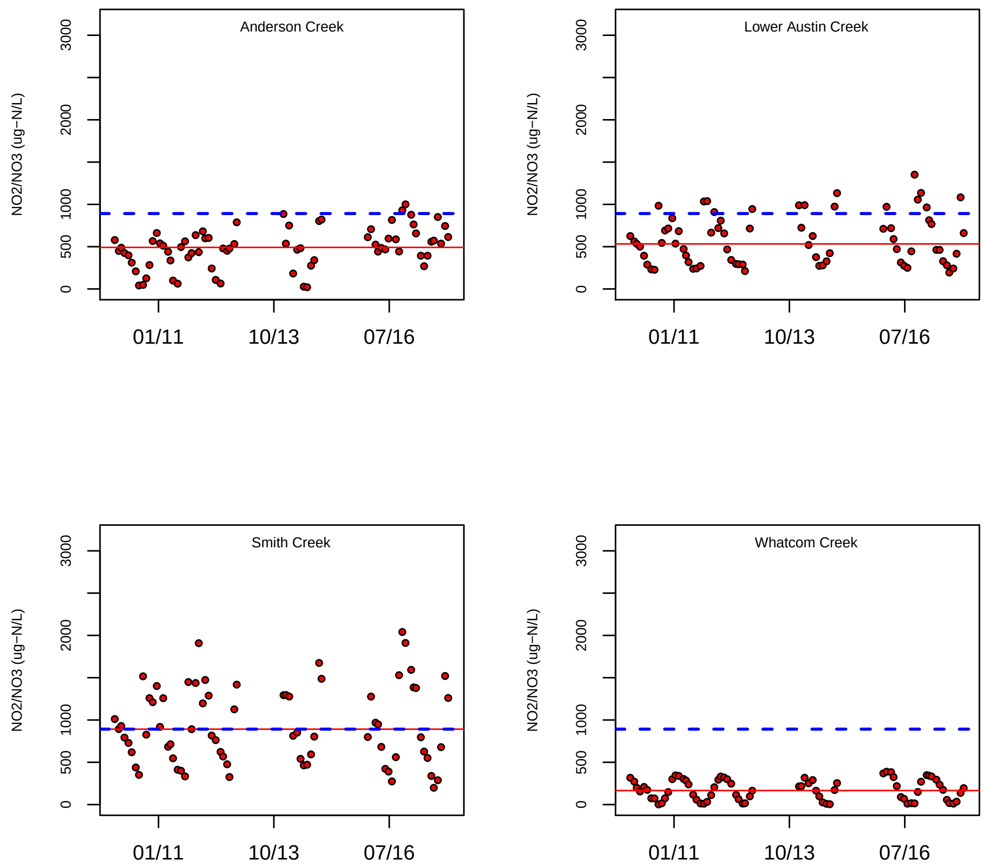


Figure B155: Nitrate/nitrite data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

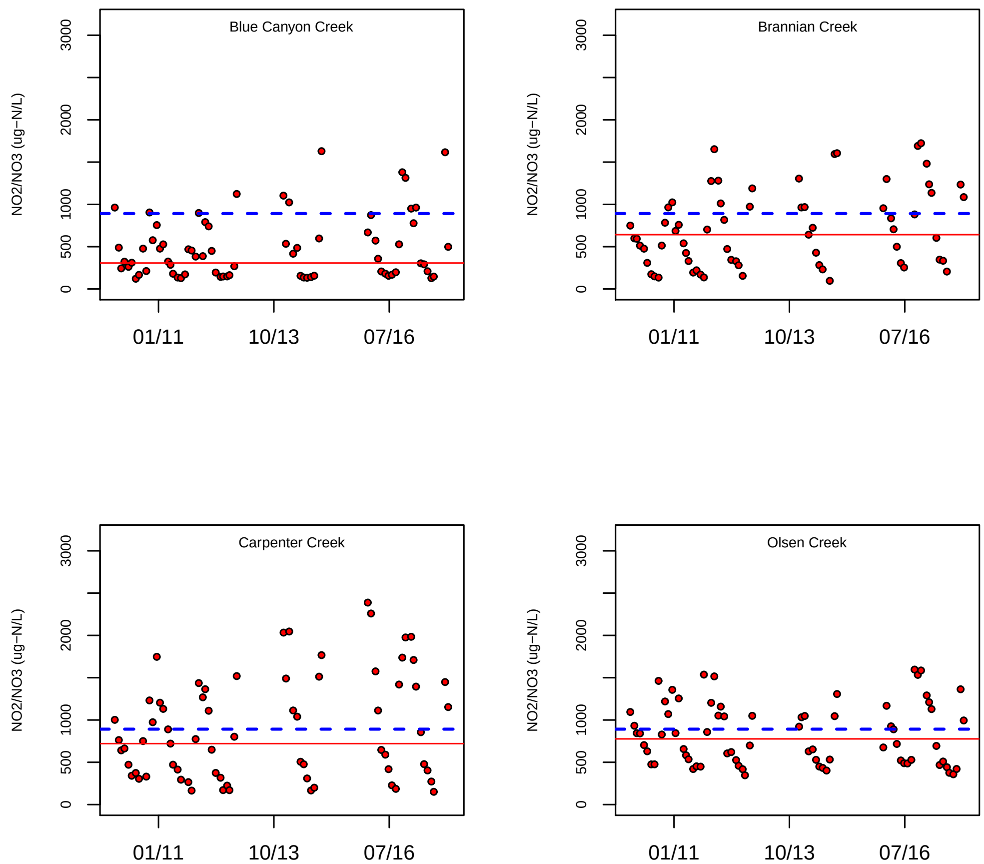


Figure B156: Nitrate/nitrite data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

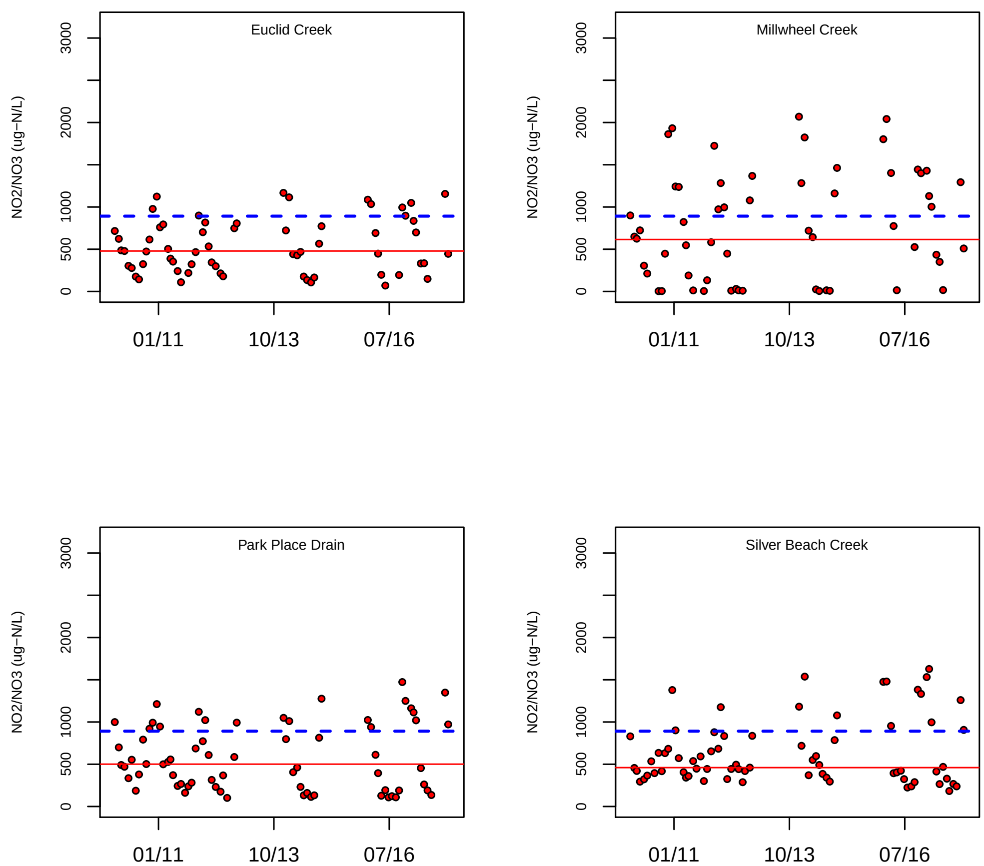


Figure B157: Nitrate/nitrite data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

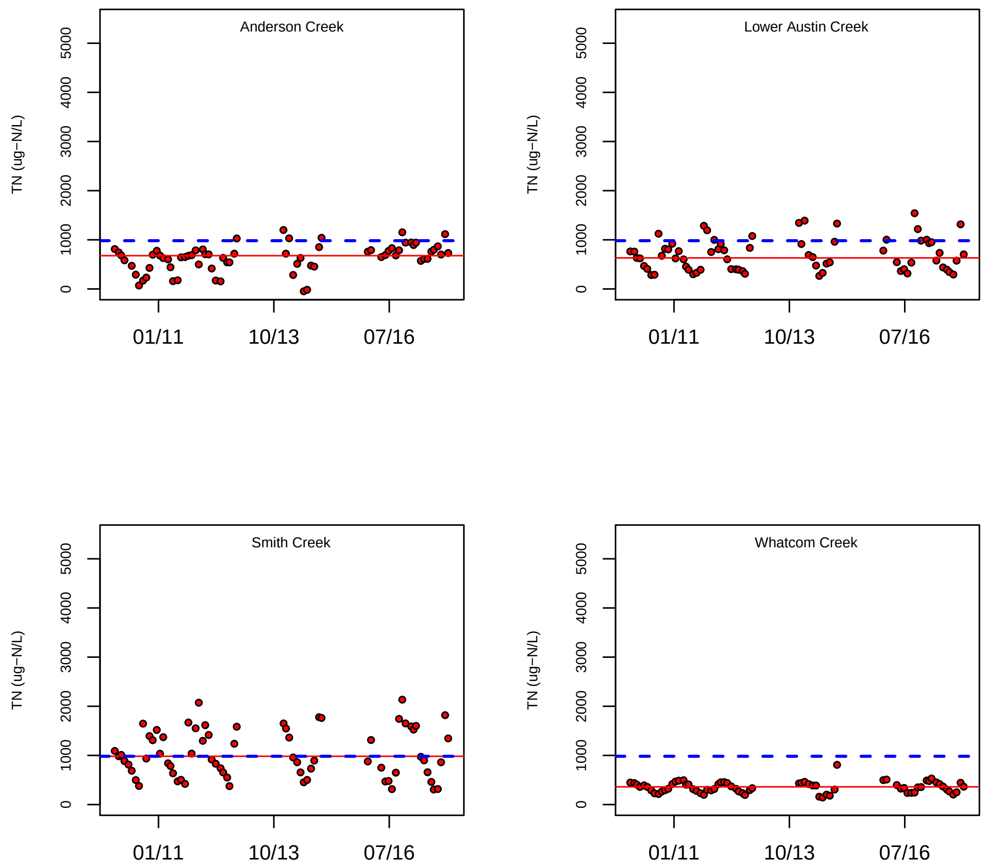


Figure B158: Total nitrogen data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

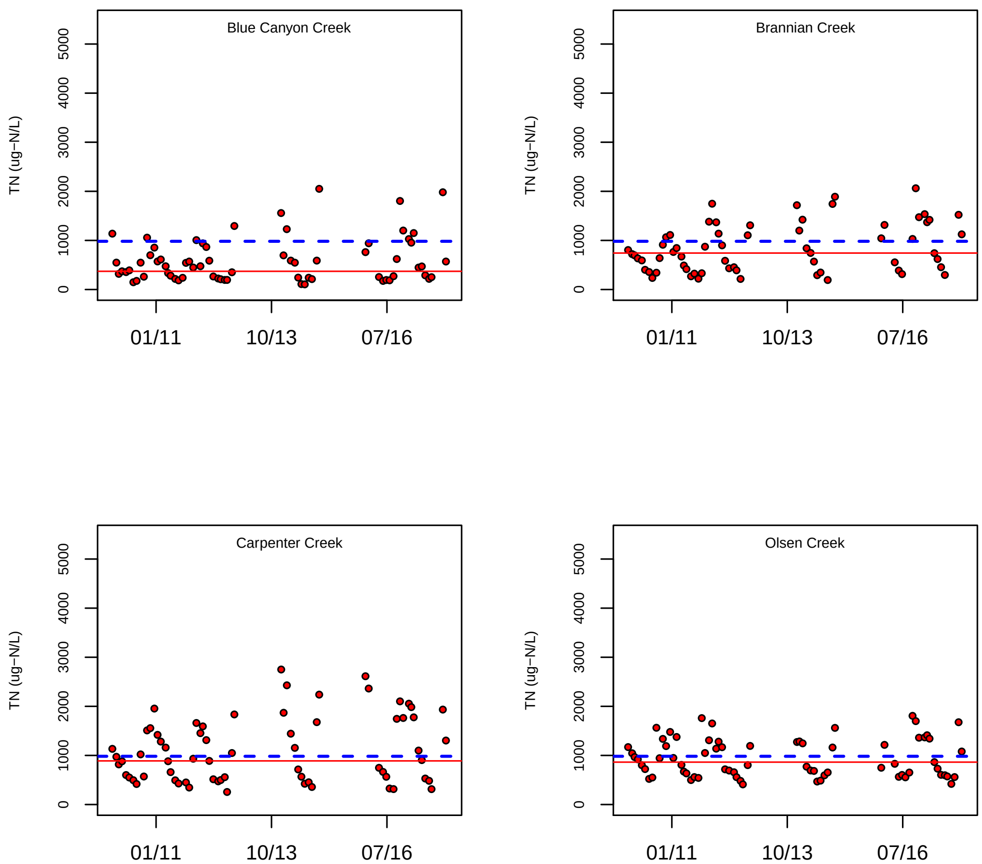


Figure B159: Total nitrogen data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

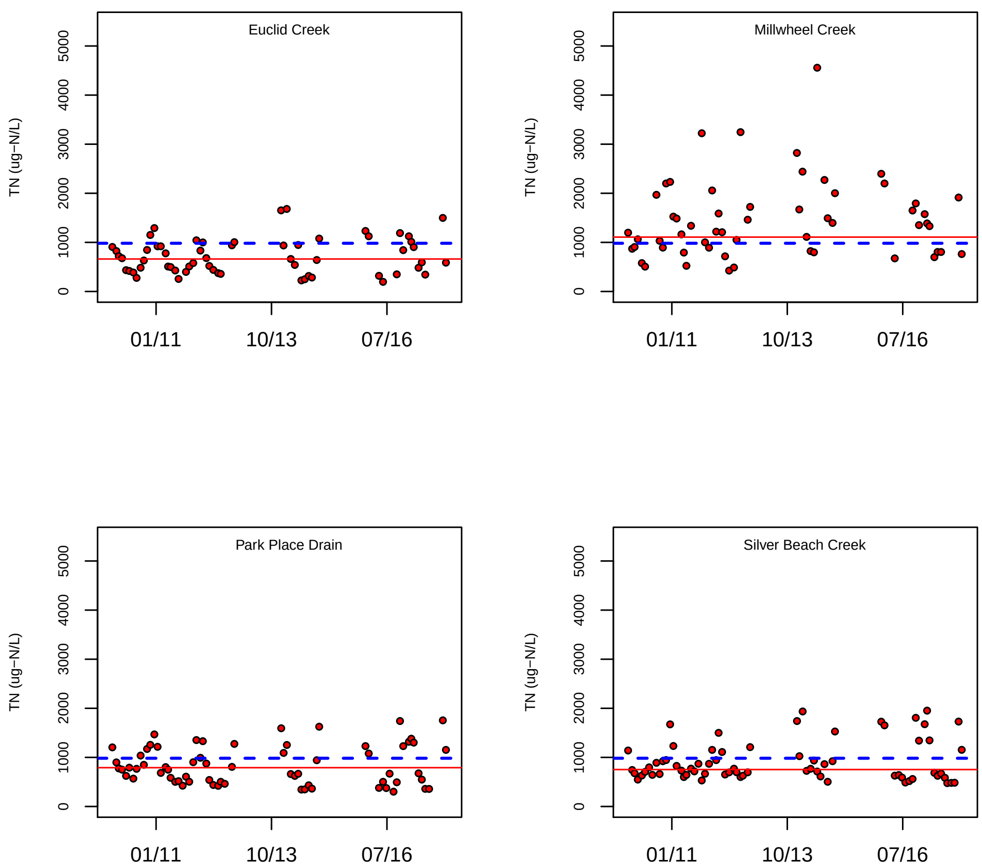


Figure B160: Total nitrogen data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

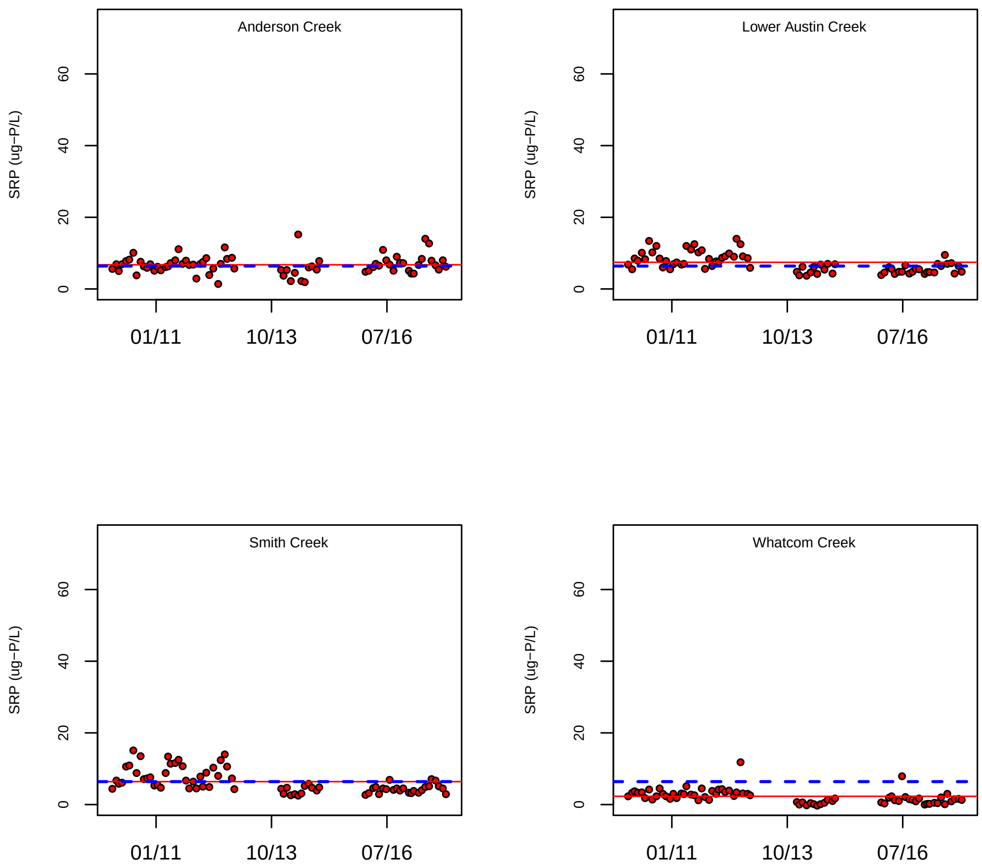


Figure B161: Soluble phosphate data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

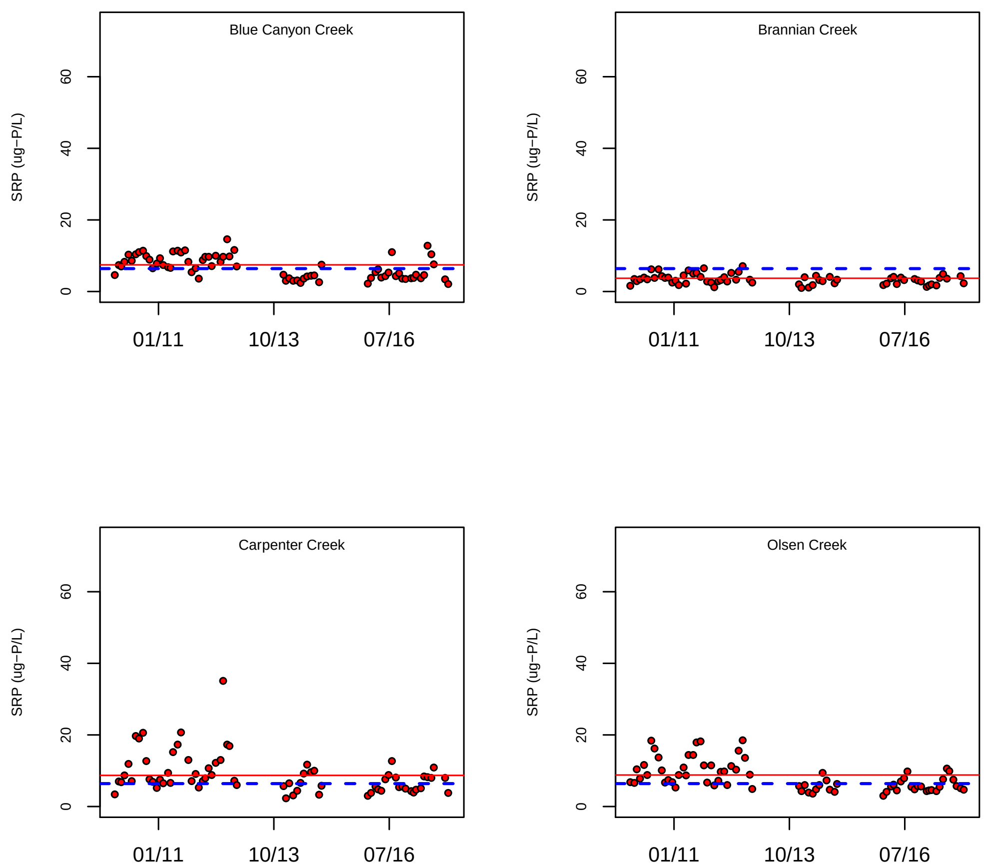


Figure B162: Soluble phosphate data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

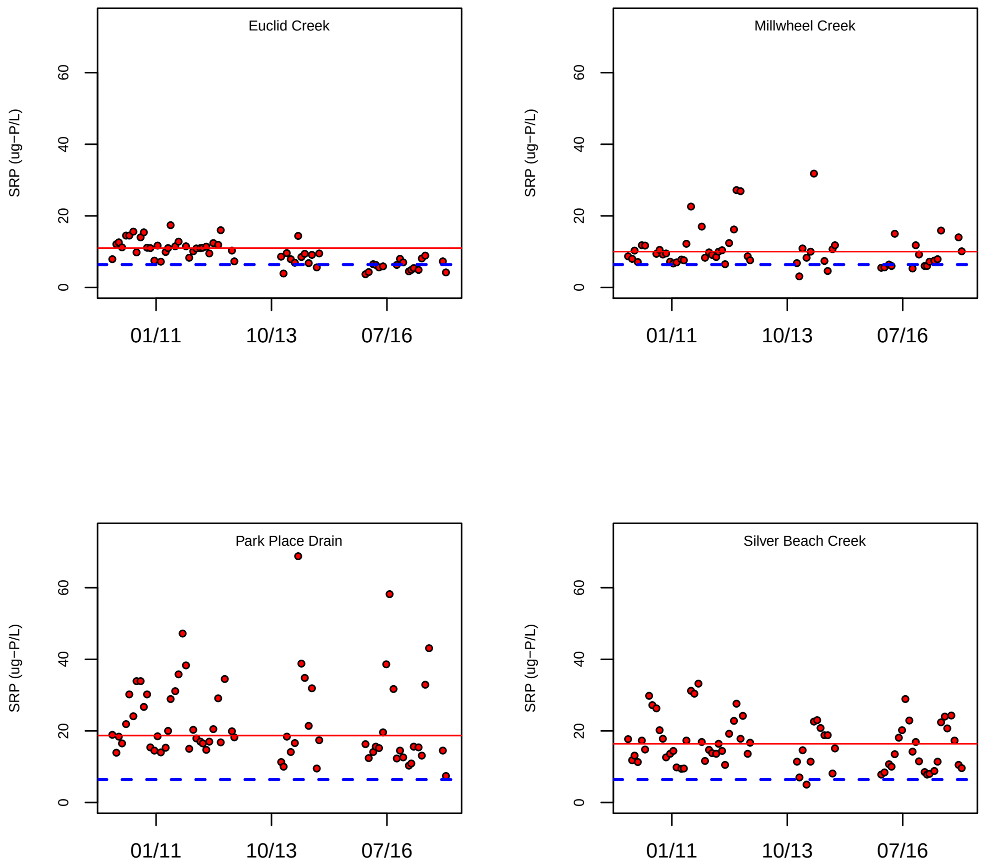


Figure B163: Soluble phosphate data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

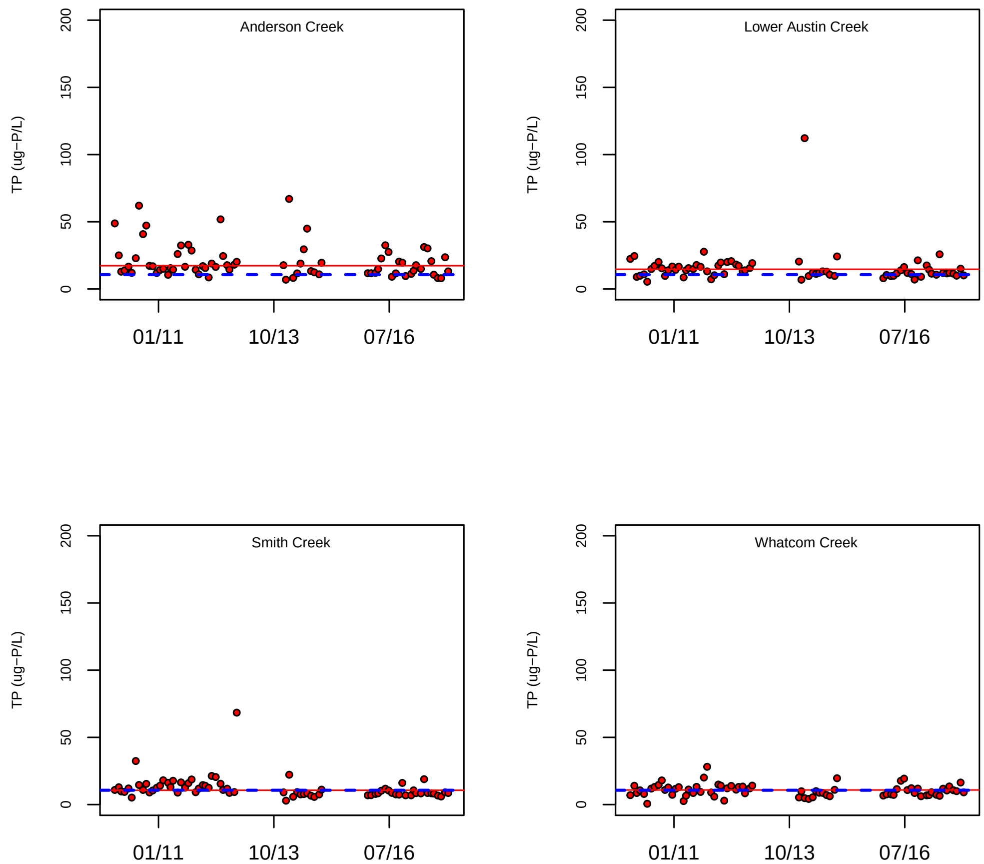


Figure B164: Total phosphorus data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

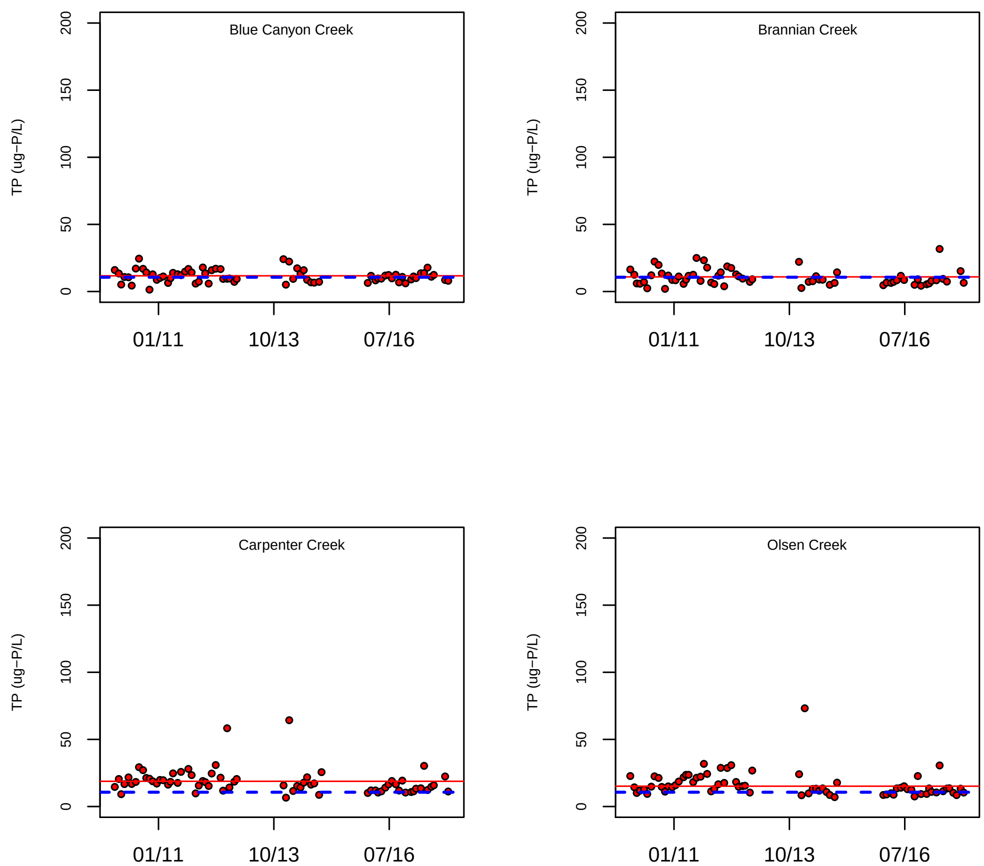


Figure B165: Total phosphorus data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

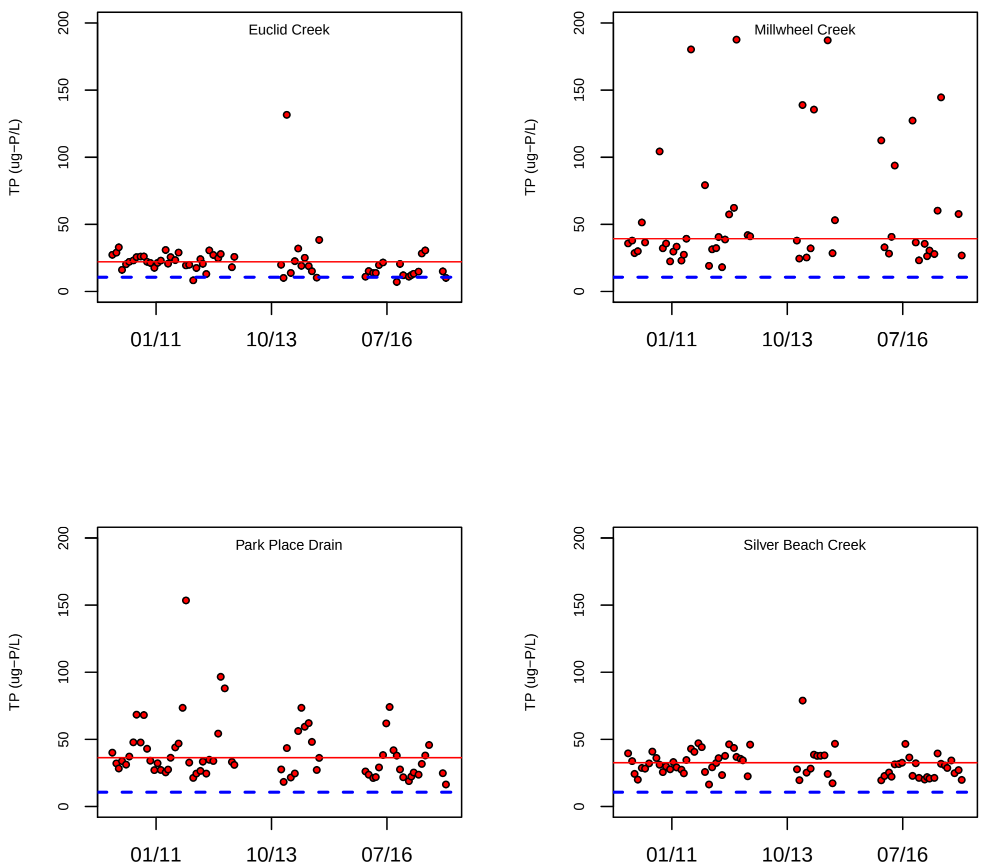


Figure B166: Total phosphorus data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

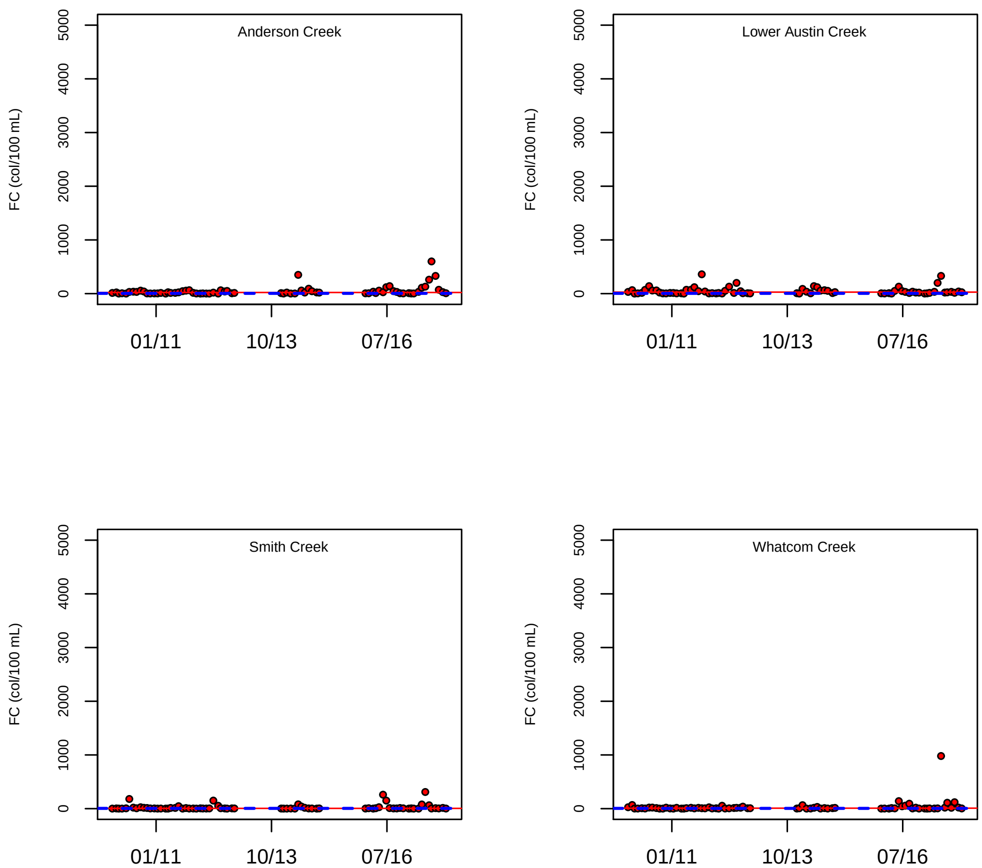


Figure B167: Fecal coliform data for Anderson, Austin, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

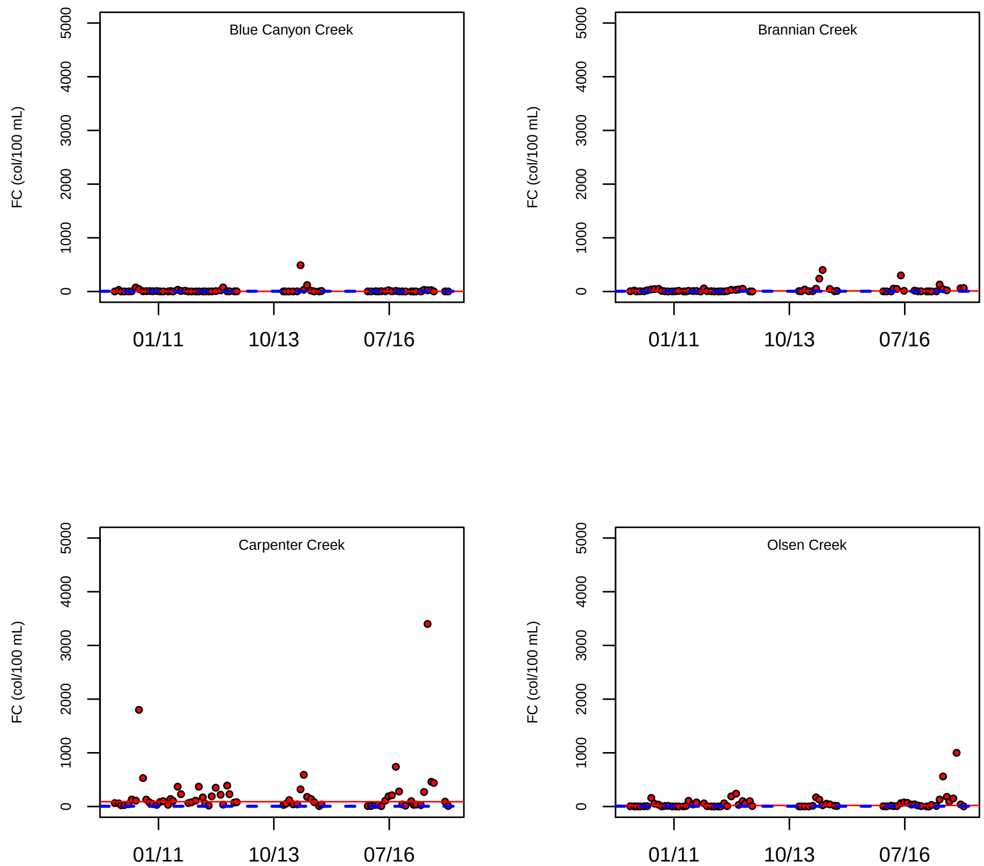


Figure B168: Fecal coliform data for Blue Canyon, Brannian, Carpenter, and Olsen Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

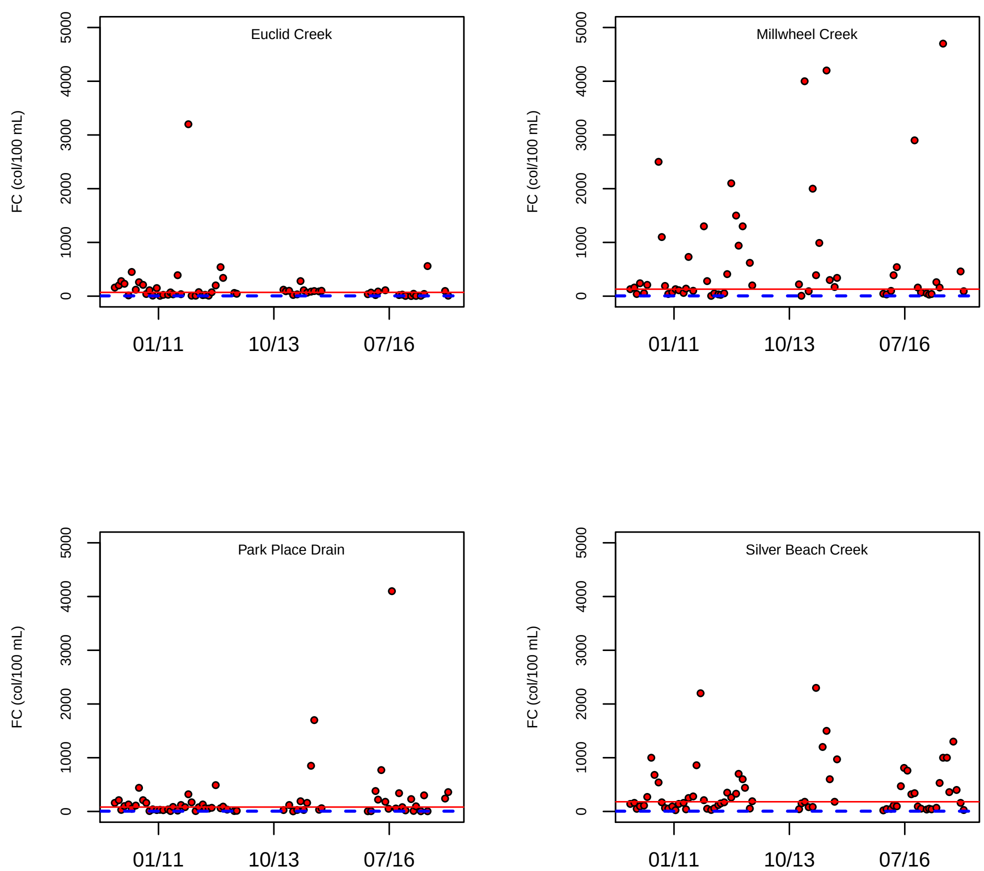


Figure B169: Fecal coliform data for Euclid, Millwheel, and Silver Beach Creeks and the Park Place drain. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

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 17). 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). External check standards were analyzed during each analytical run to evaluate measurement precision and accuracy.[30] The quality control results for laboratory duplicates, matrix spikes, and check standards are plotted in control charts (Figures C1–C30, pages 295–324).

C.3 Field Duplicates

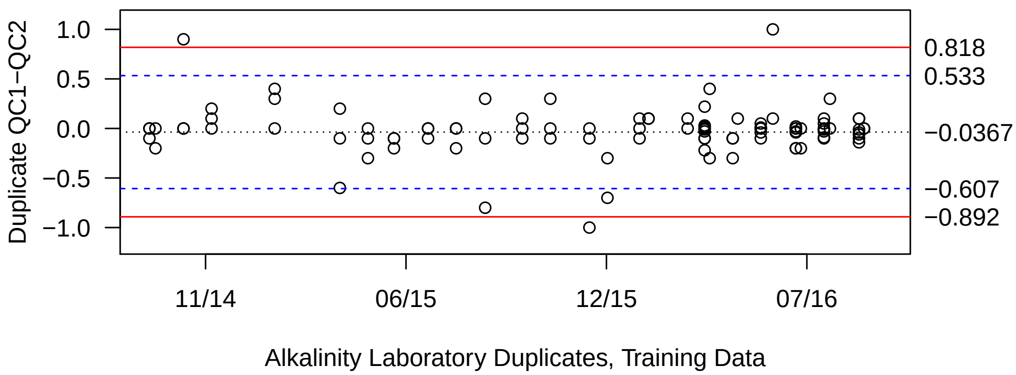
Ten percent of all samples collected in the field were duplicated to measure sample replication (Figures C31–C48, pages 325–342). Samples collected using field meters (conductivity, dissolved oxygen, and pH) were evaluated using water samples collected from the same depth as the field meter measurement. The absolute mean difference for the field duplicates was calculated as follows:

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

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

	Reported Value	Assigned Value	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)	402	398	358–438	accept
Total alkalinity (mg/L as $CaCO_3$)	102	104	88.4–120	accept
Ammonium nitrogen, manual (mg-N/L)	5.63	5.75	4.48–7.04	accept
Ammonium nitrogen, auto (mg-N/L)	4.98	5.75	4.48–7.04	accept
Nitrate/nitrite nitrogen, auto (mg-N/L)	8.67 14.5†	10.5 14.2†	8.73–12.2 11.8–16.4†	not accept accept†
Nitrite nitrogen, auto (mg-N/L)	2.62	2.64	2.27–3.02	accept
Orthophosphate, manual (mg-P/L)	3.61	3.58	3.04–4.12	accept
Orthophosphate, auto (mg-P/L)	3.60	3.58	3.04–4.12	accept
Total phosphorus, manual (mg-P/L)	1.58	1.48	1.18–1.78	accept
Total phosphorus, auto (mg-P/L)	1.49	1.48	1.18–1.78	accept
pH	6.33	6.39	6.19–6.59	accept
Solids, non-filterable (mg/L)	54.9	58.4	46.2–66.2	accept
Turbidity (NTU)	15.3	16.5	13.7–19.4	accept

Table C1: Single-blind quality control results, WP–238 (07/12/2017); all results were within acceptance limits except WP–238 nitrate/nitrite. Analysis for nitrate/nitrite was repeated following method correction (WP–239, 08/02/2017)†; result was within acceptance limits. Nitrate/nitrite single-blind quality control results will be repeated twice during the 2017/2018 sampling period to confirm that method correction was successful.



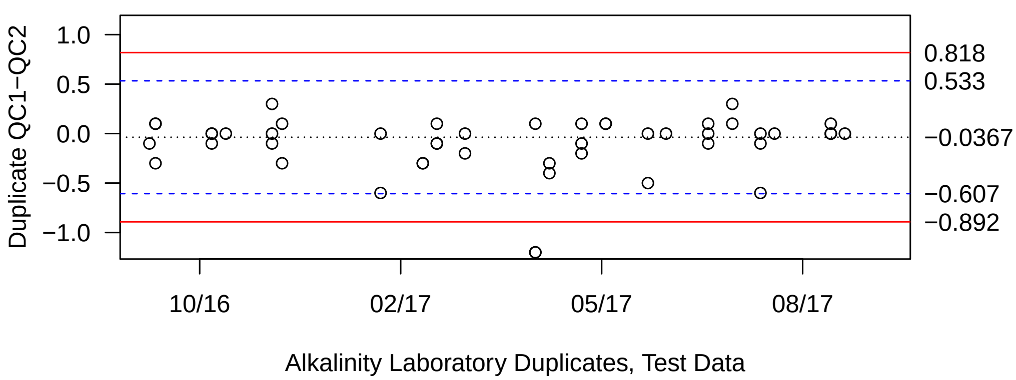
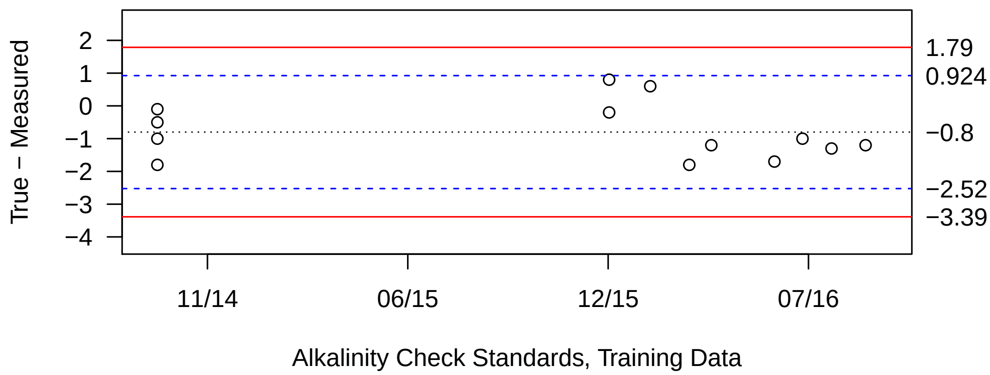


Figure C1: Alkalinity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



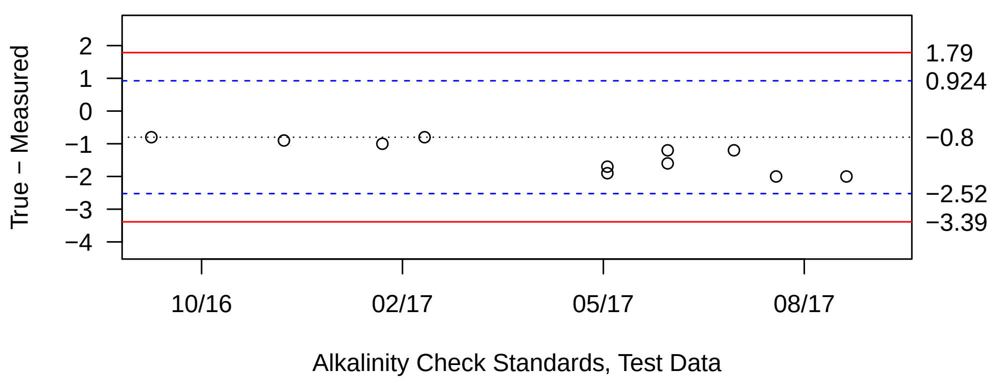
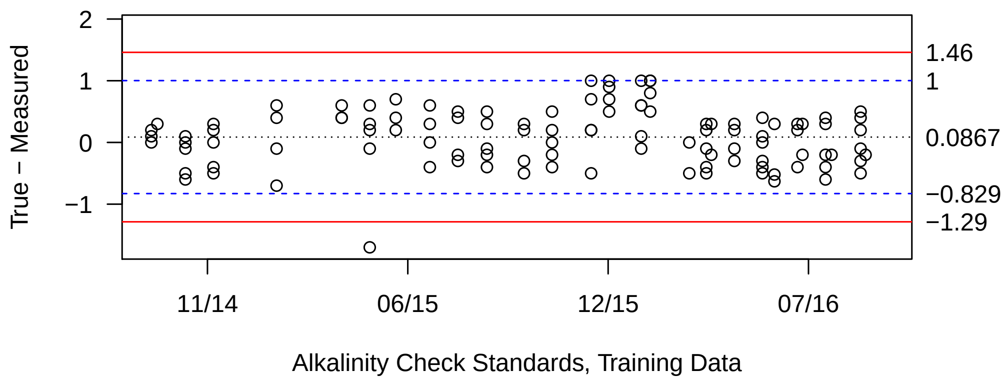


Figure C2: Alkalinity high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



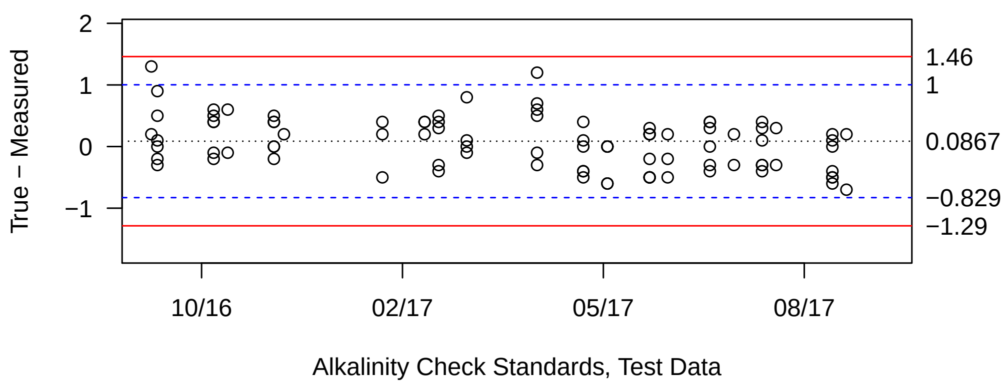
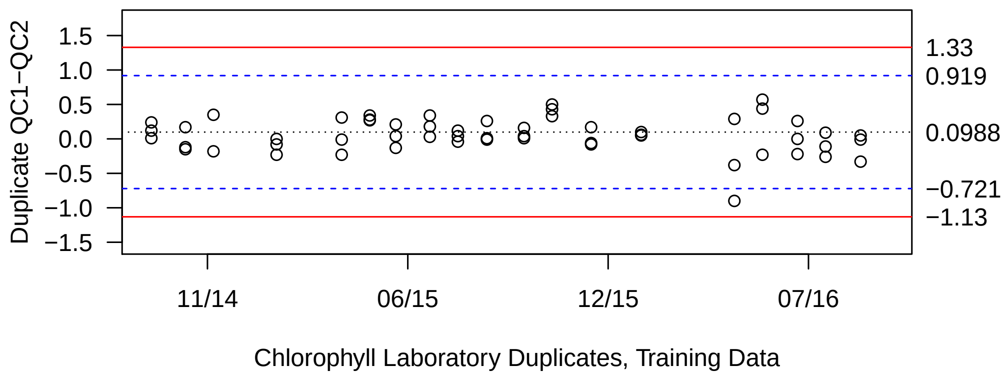


Figure C3: Alkalinity low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



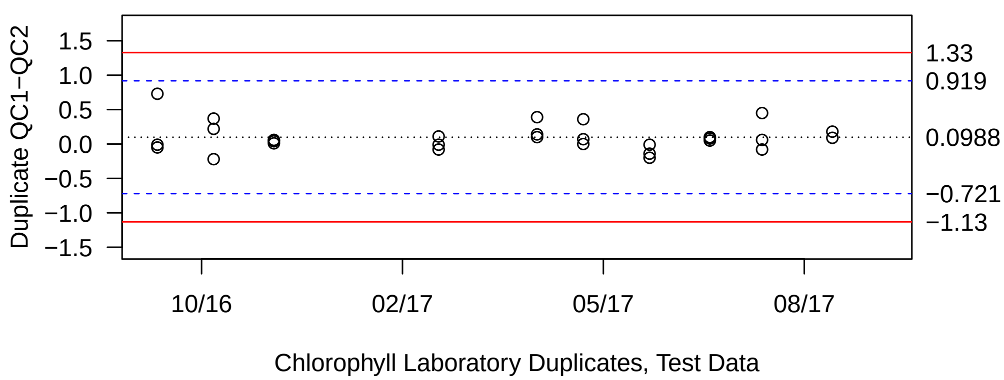


Figure C4: Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

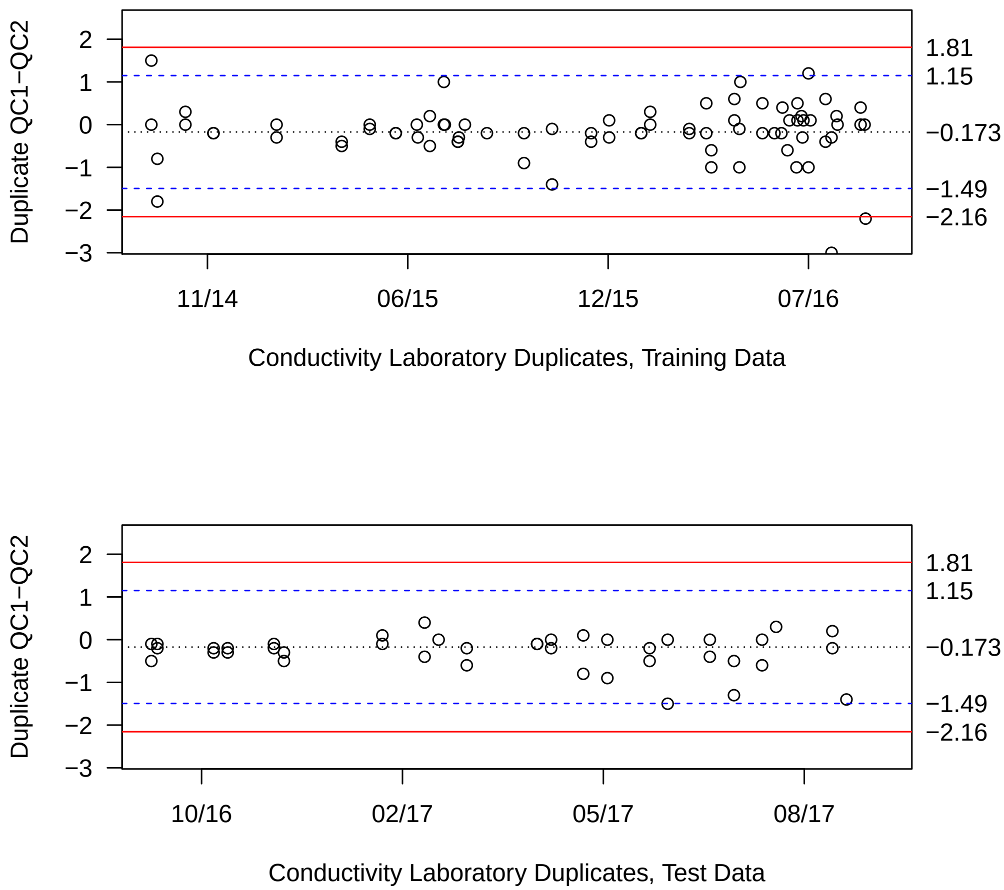
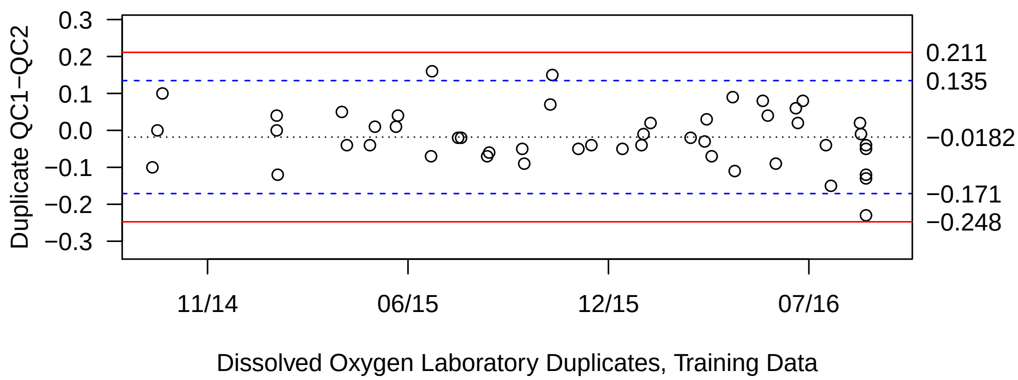


Figure C5: Conductivity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



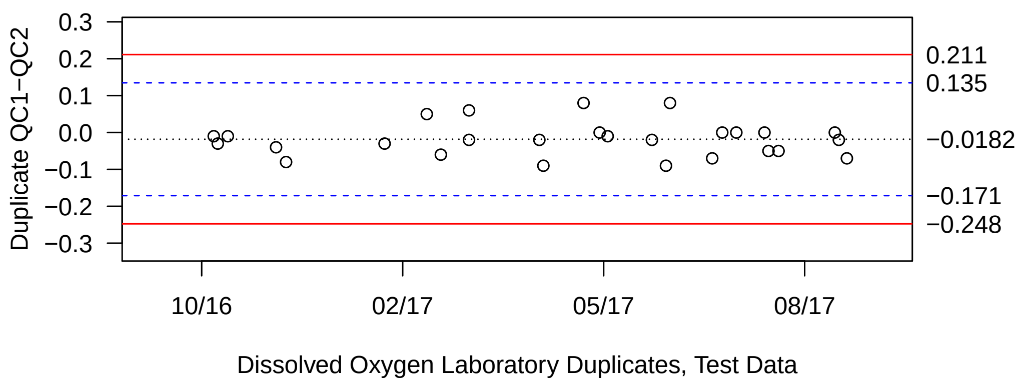
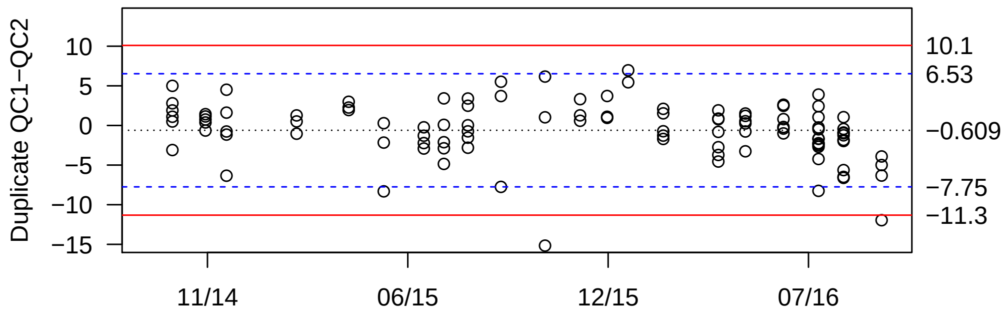
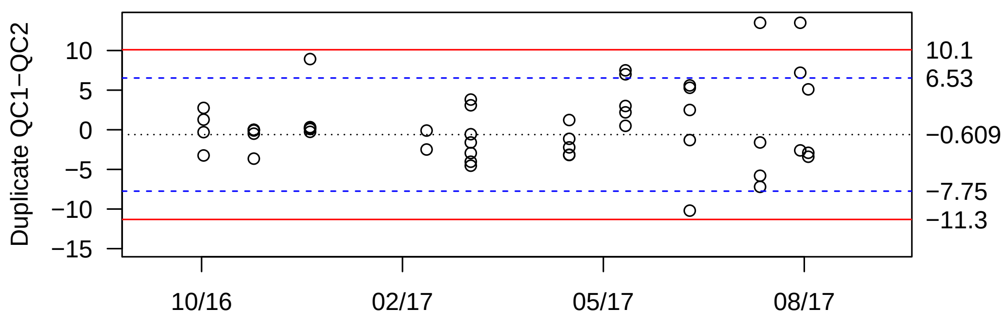


Figure C6: Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

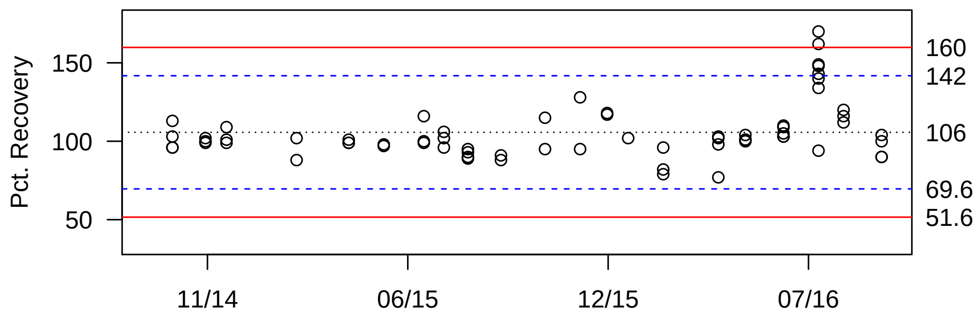


Ammonium Laboratory Duplicates, Training Data

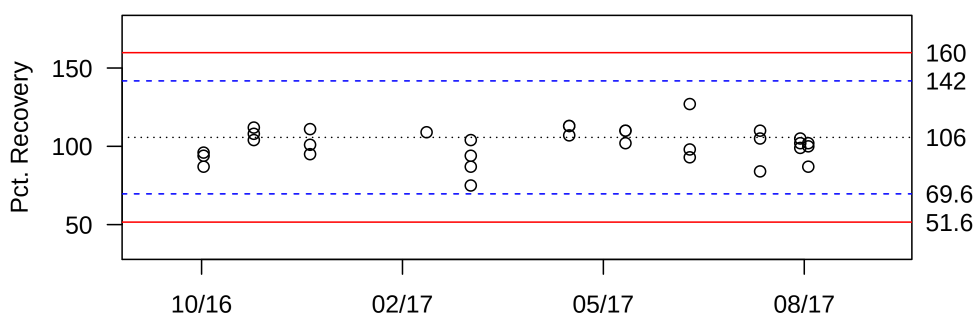


Ammonium Laboratory Duplicates, Test Data

Figure C7: Nitrogen (ammonium) laboratory 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.

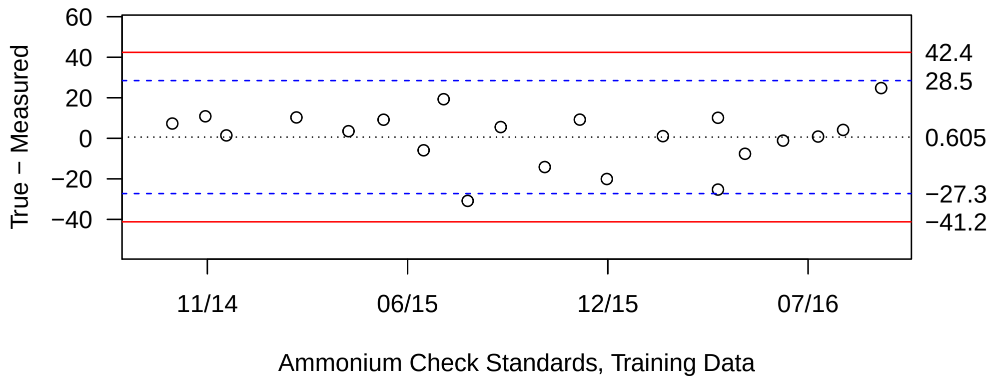


Ammonium Spike Recoveries, Training Data



Ammonium Spike Recoveries, Test 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 lab duplicate data.



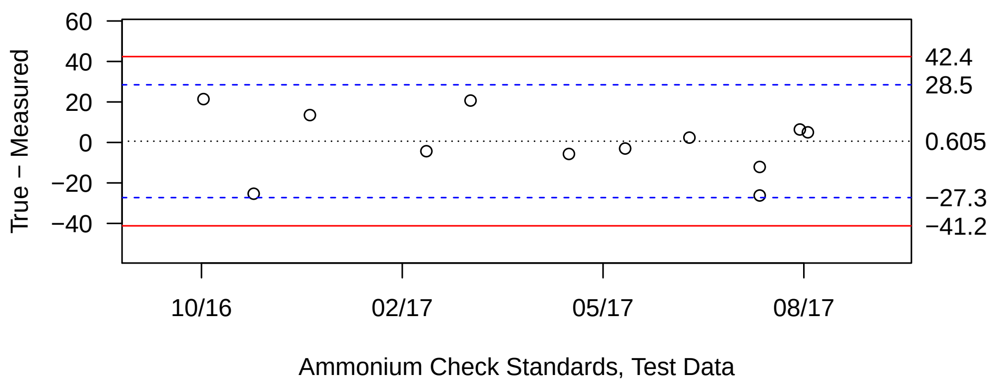
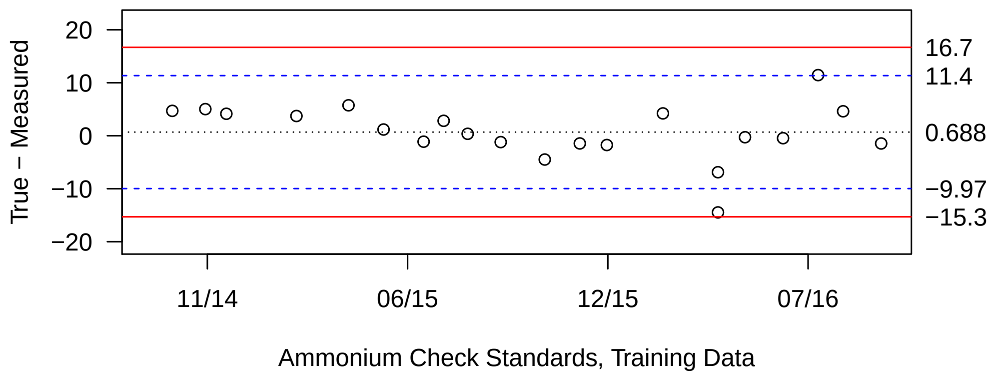


Figure C9: Nitrogen (ammonium) high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



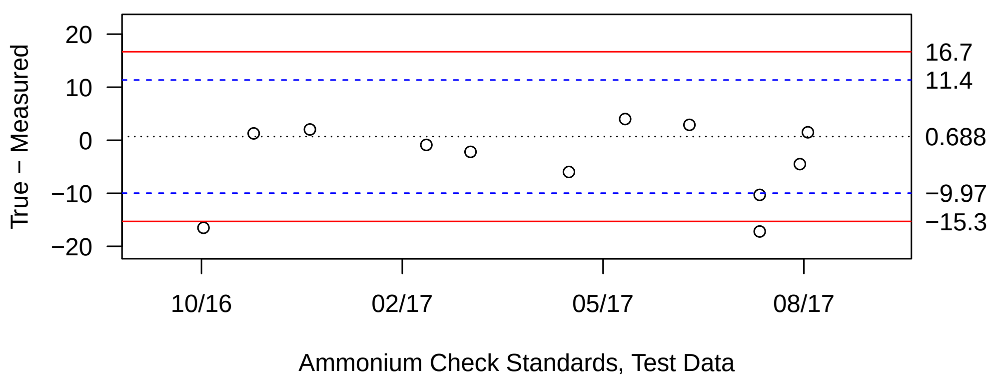
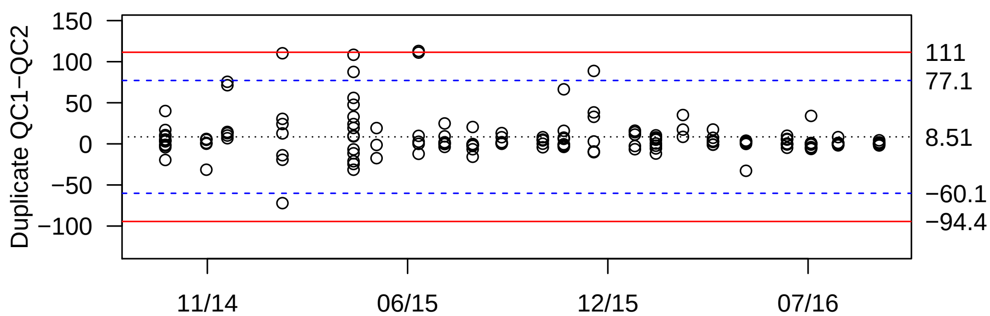
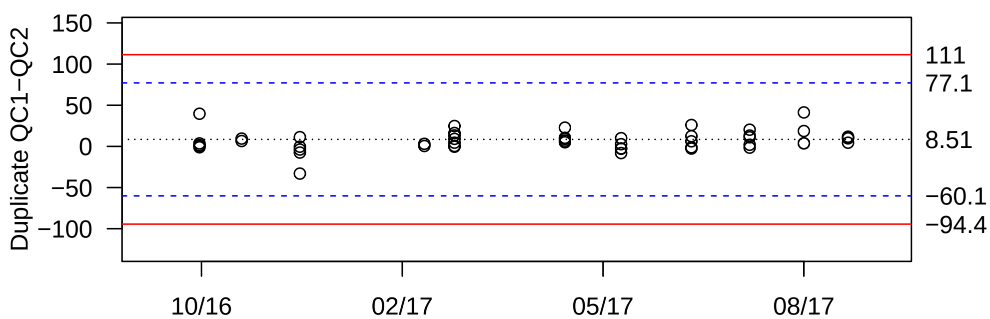


Figure C10: Nitrogen (ammonium) low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



Nitrate/Nitrite Laboratory Duplicates, Training Data



Nitrate/Nitrite Laboratory Duplicates, Test Data

Figure C11: Nitrogen (nitrate/nitrite) laboratory 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.

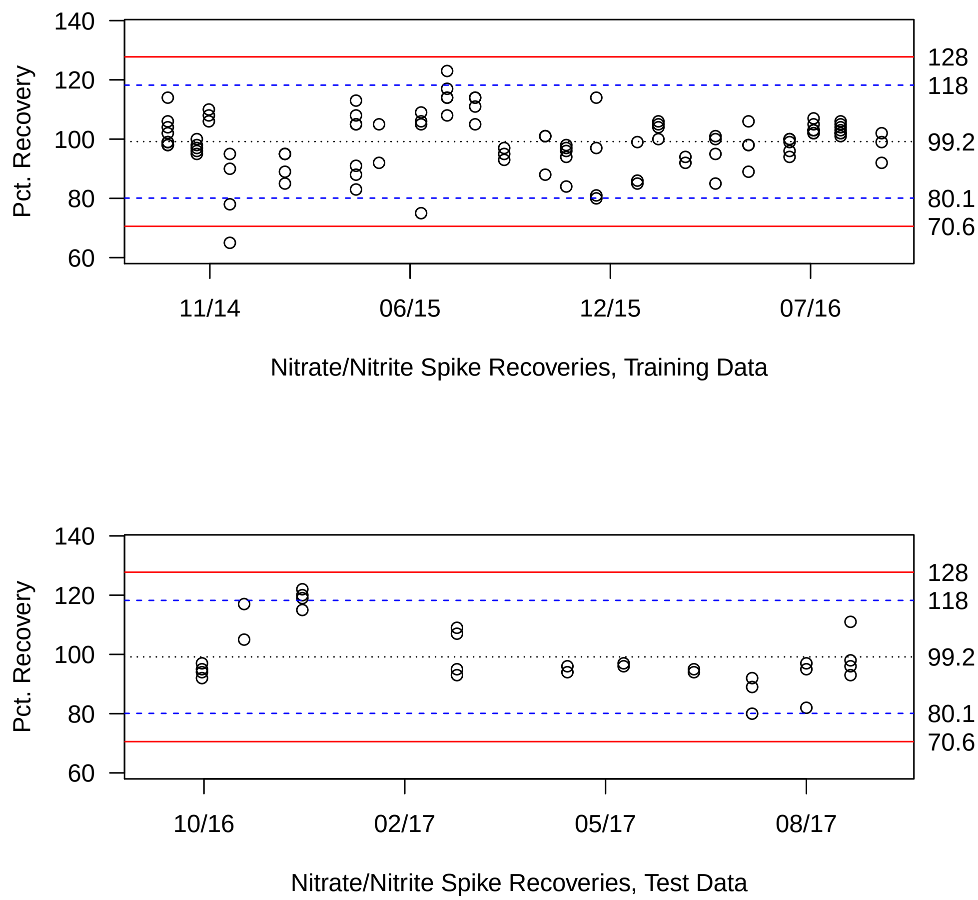
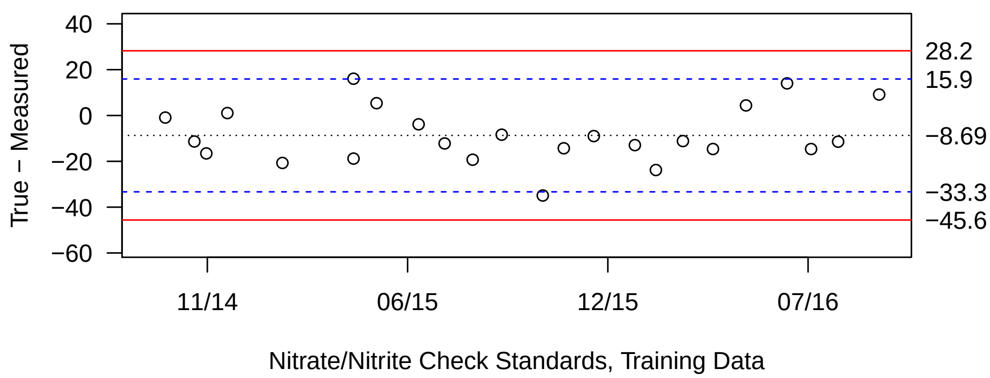


Figure C12: Nitrogen (nitrate/nitrite) spike recoveries for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



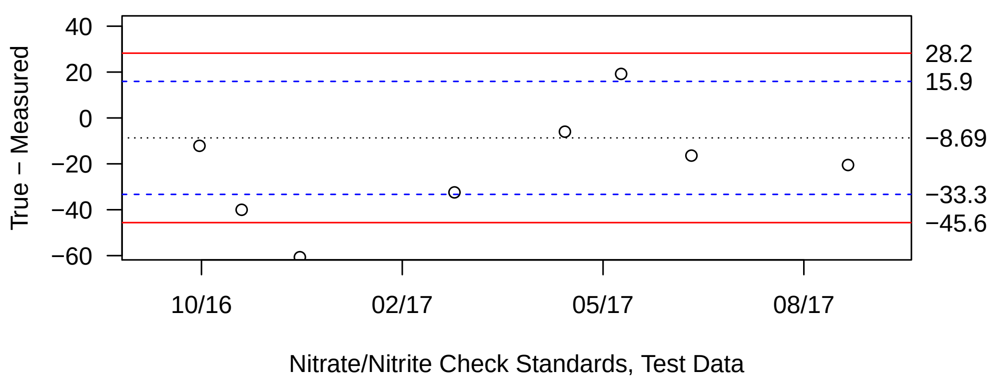
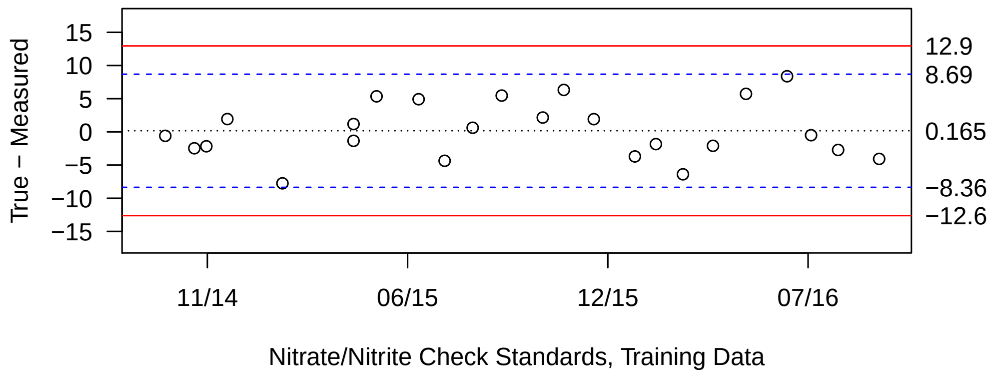


Figure C13: Nitrogen (nitrate/nitrite) high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years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



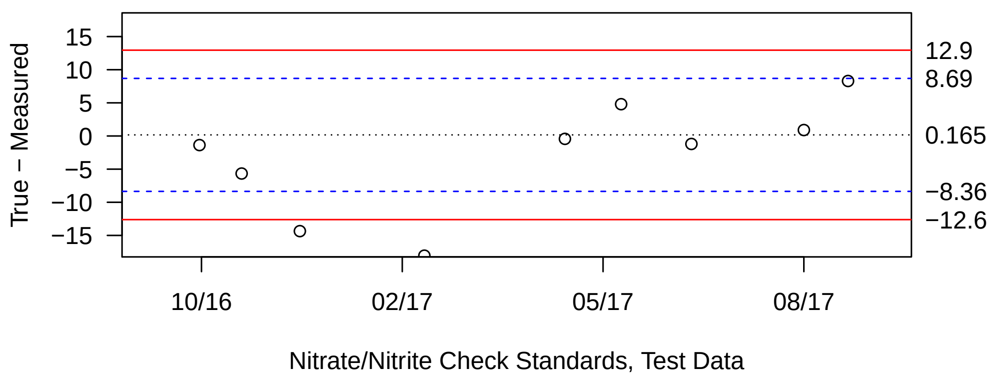
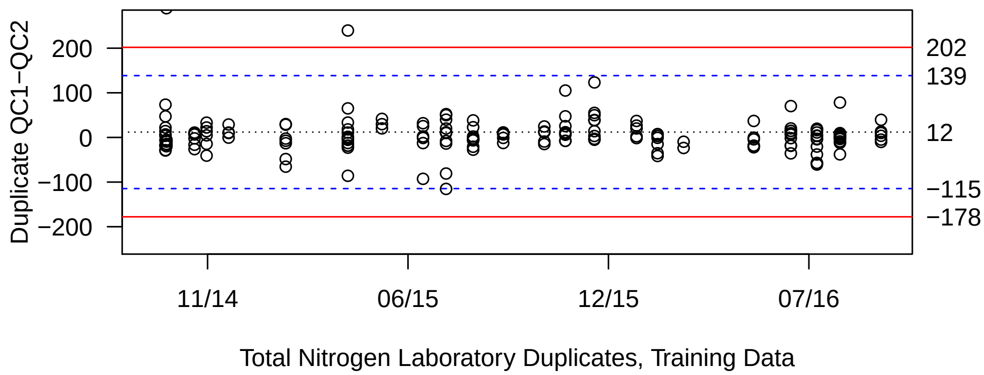


Figure C14: Nitrogen (nitrate/nitrite) low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of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



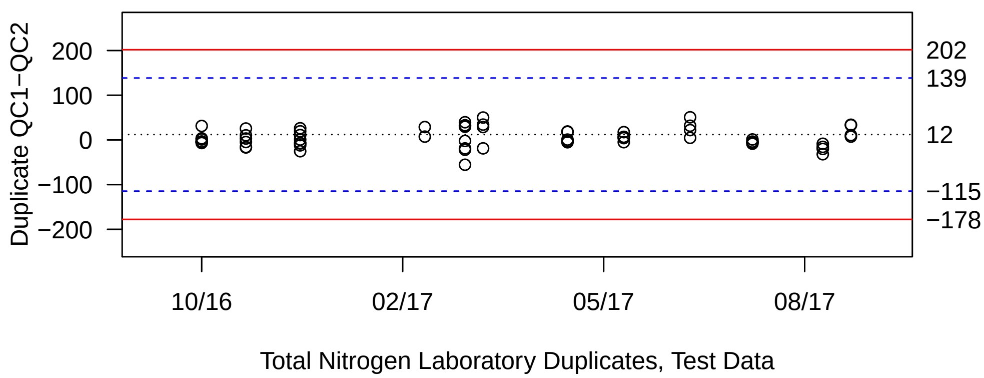
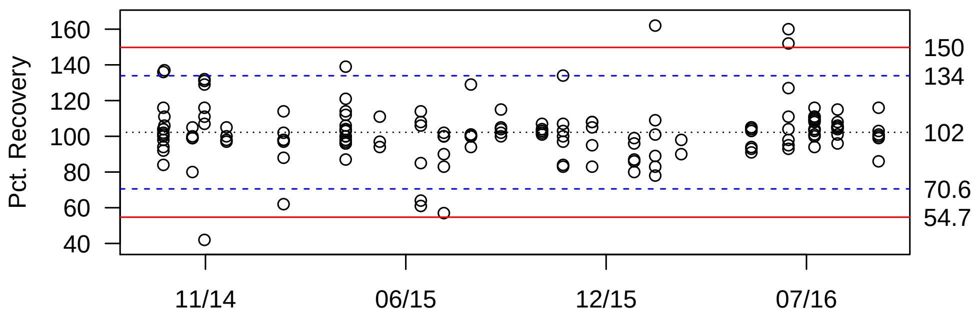
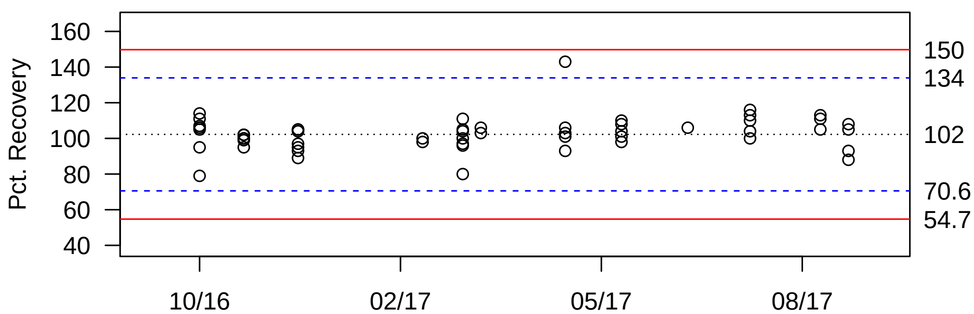


Figure C15: Nitrogen (total) laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

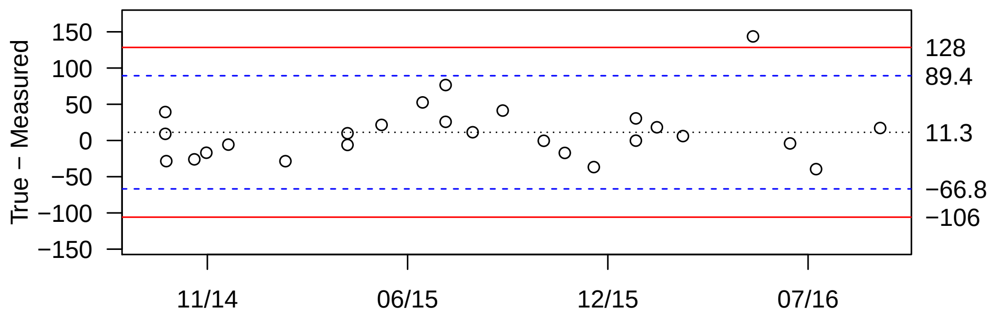


Total Nitrogen Spike Recoveries, Training Data

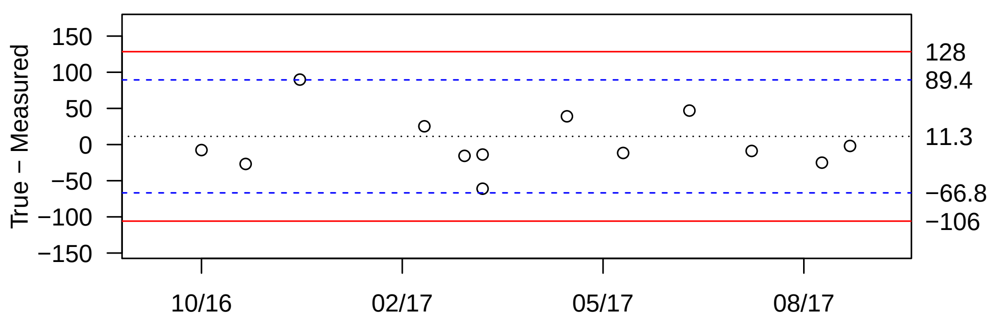


Total Nitrogen Spike Recoveries, Test Data

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 lab duplicate data.

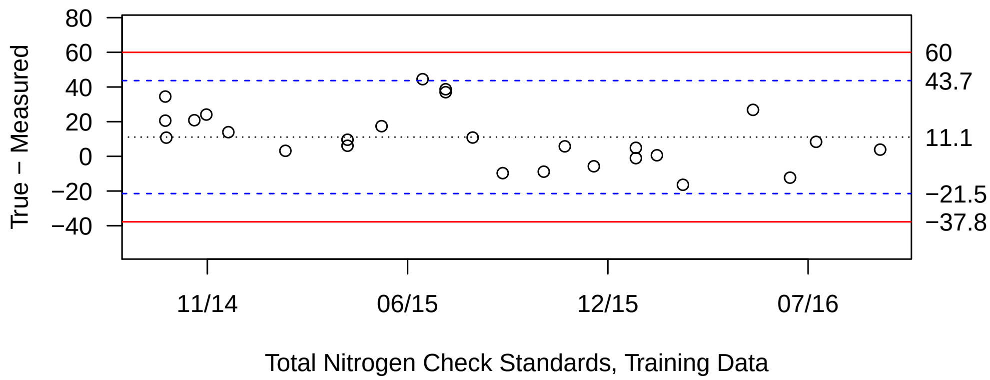


Total Nitrogen Check Standards, Training Data



Total Nitrogen Check Standards, Test Data

Figure C17: Nitrogen (total) high-range check standards 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.



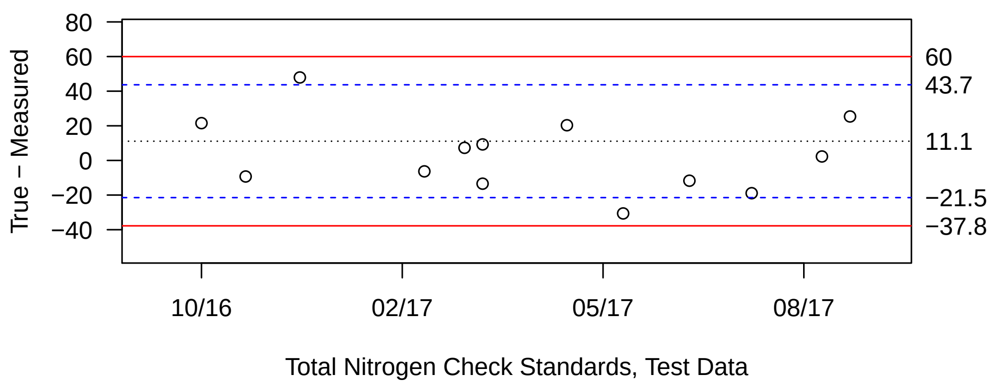
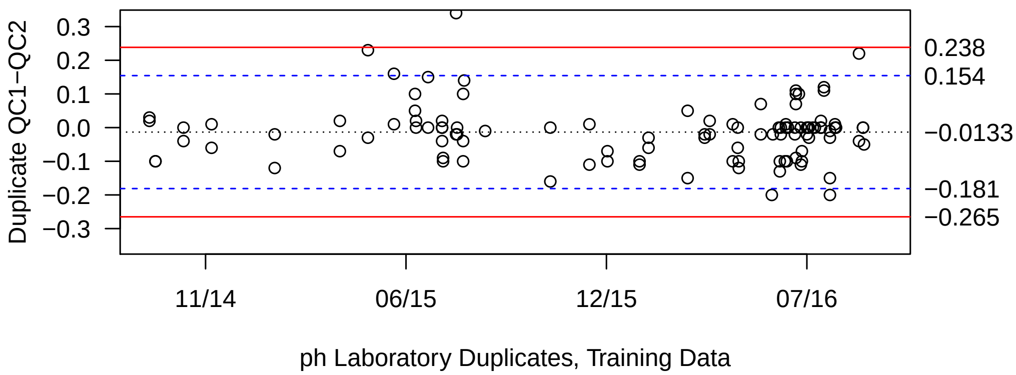


Figure C18: Nitrogen (total) low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



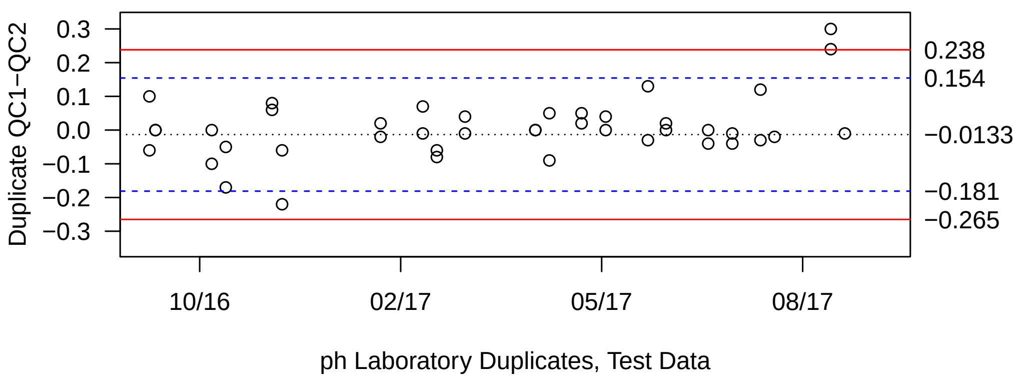
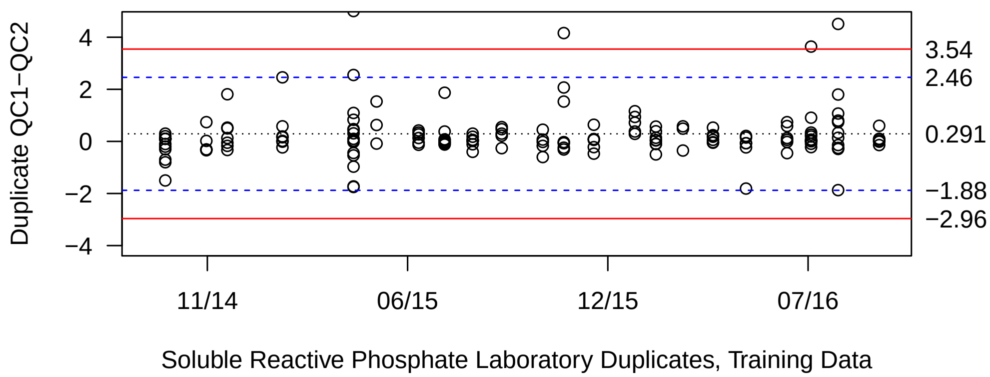


Figure C19: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



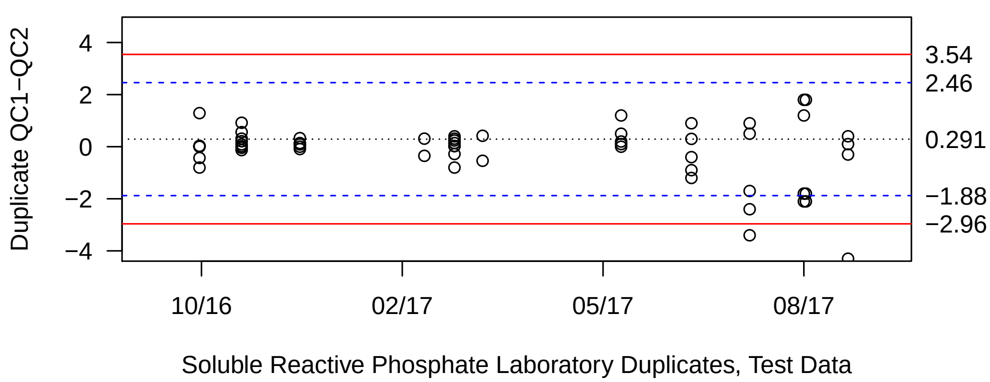
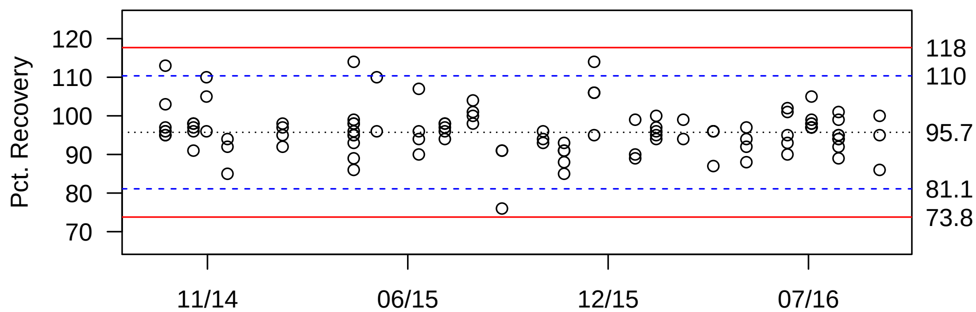
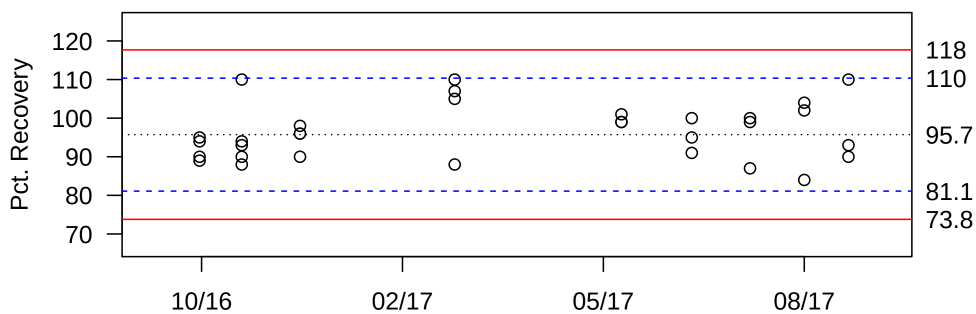


Figure C20: Phosphorus (soluble reactive phosphate) laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two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

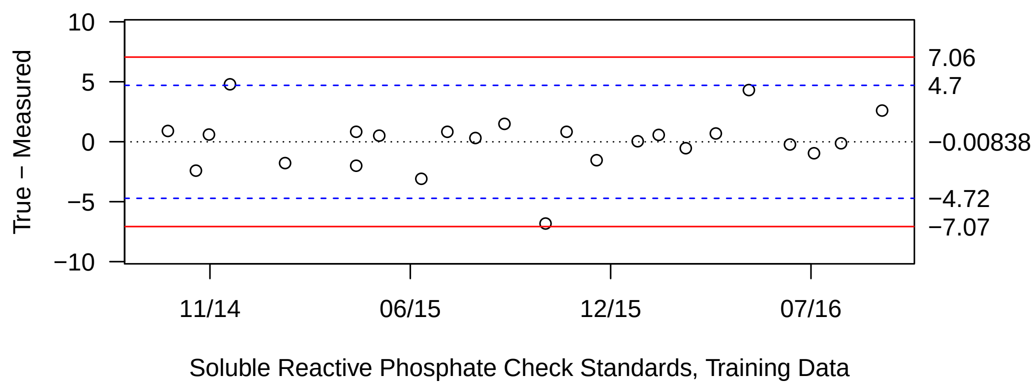


Soluble Reactive Phosphate Spike Recoveries, Training Data



Soluble Reactive Phosphate Spike Recoveries, Test 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 lab duplicate data.



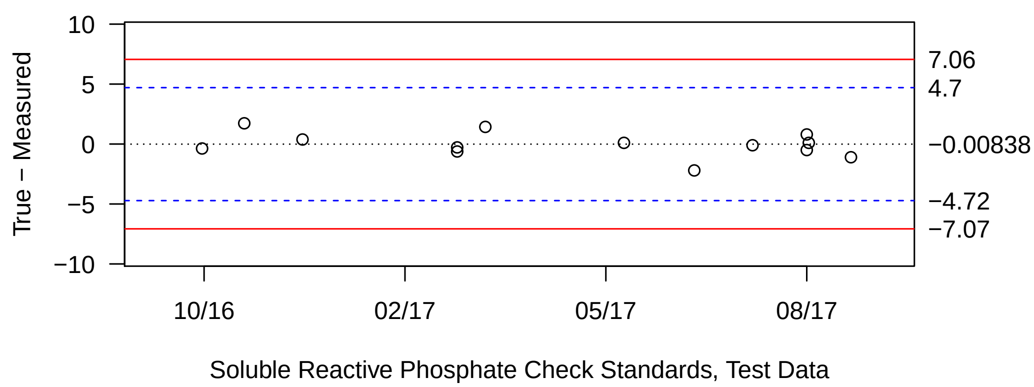
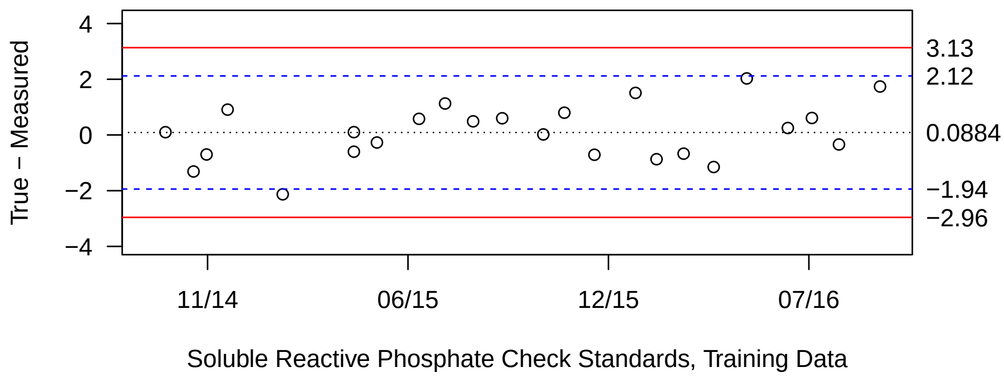


Figure C22: Phosphorus (soluble reactive phosphate) high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding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



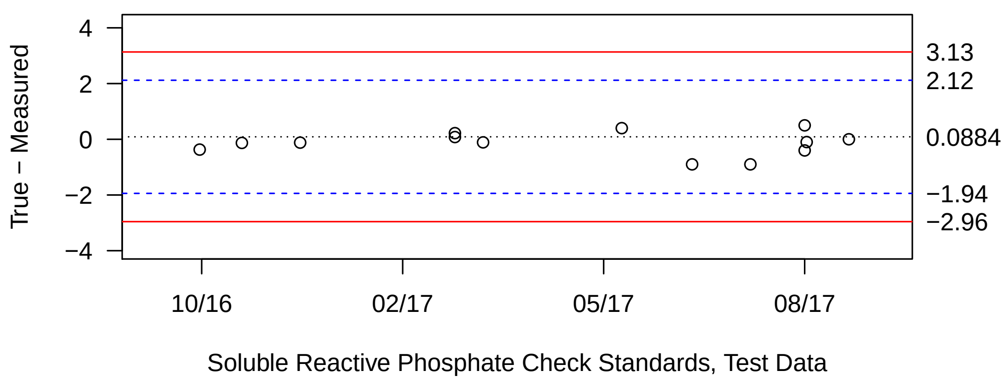
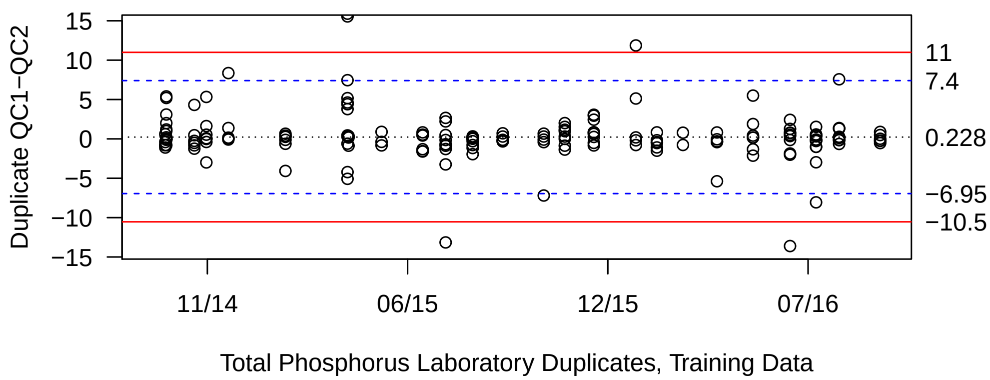


Figure C23: Phosphorus (soluble reactive phosphate) low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding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



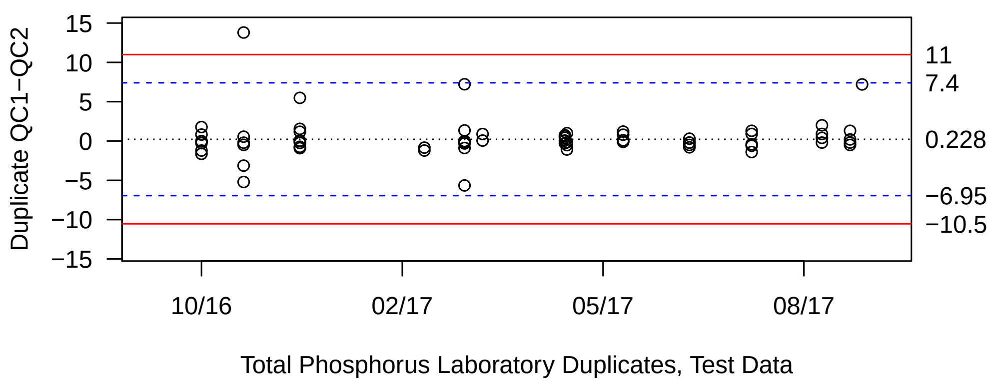


Figure C24: Phosphorus (total) laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

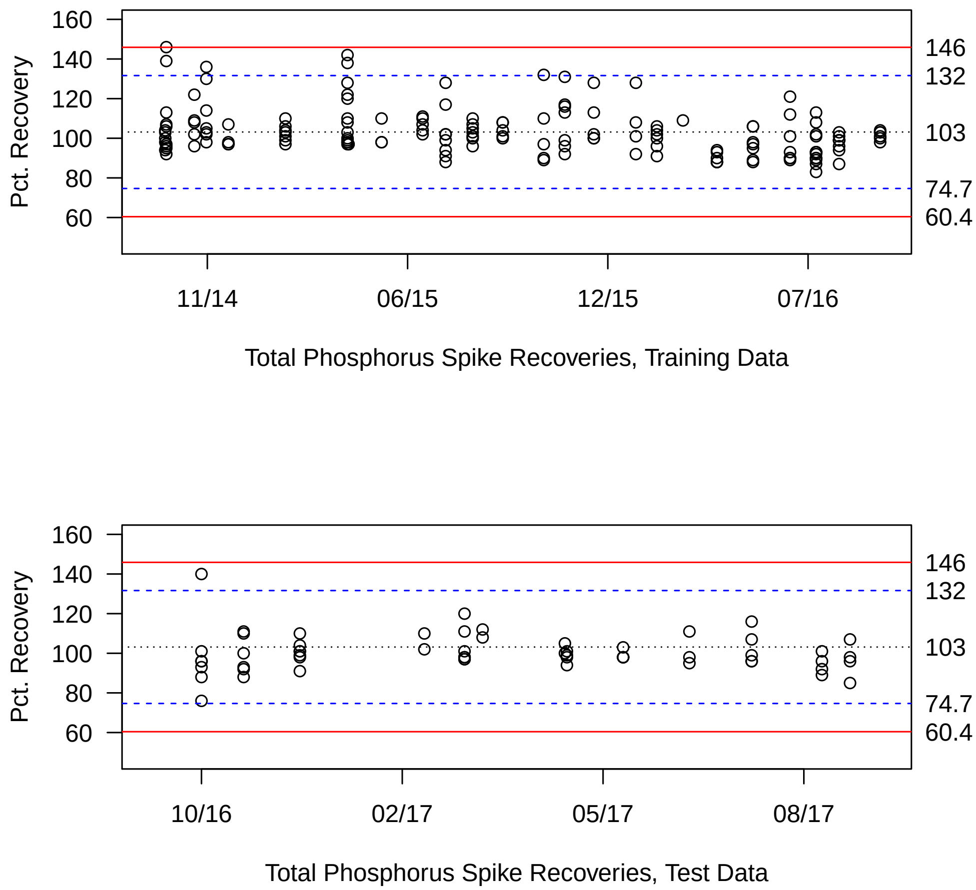


Figure C25: Phosphorus (total) spike recoveries for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

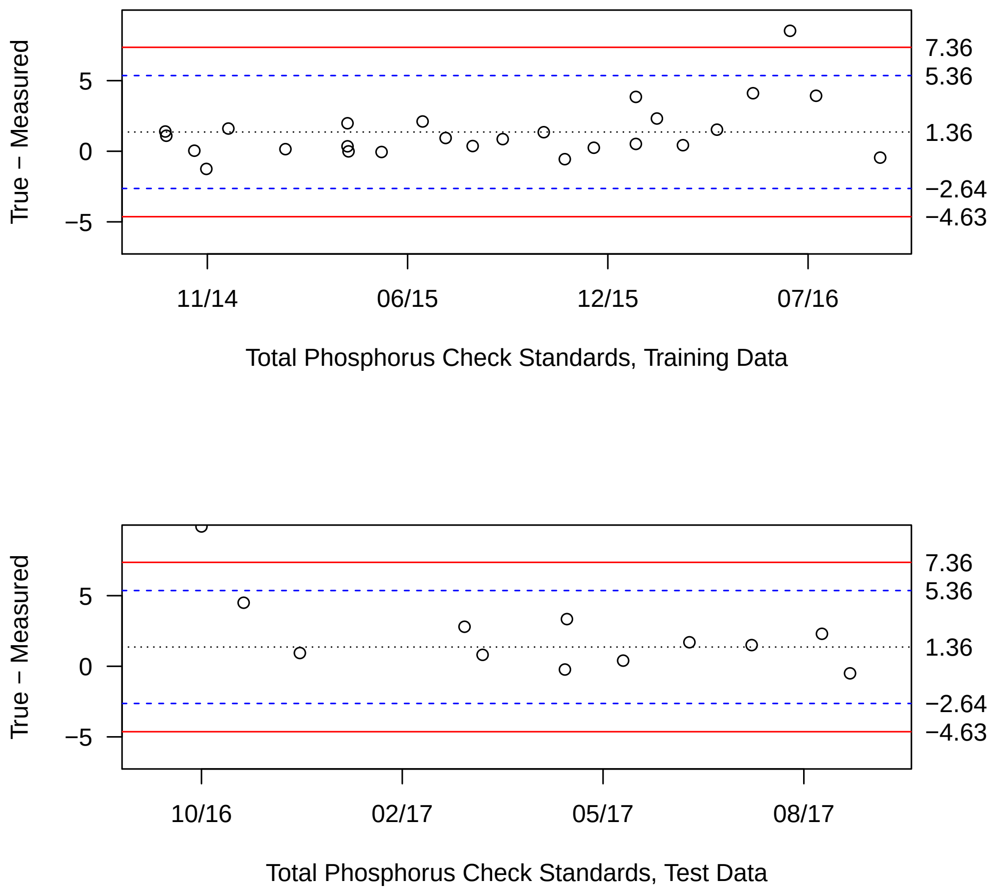
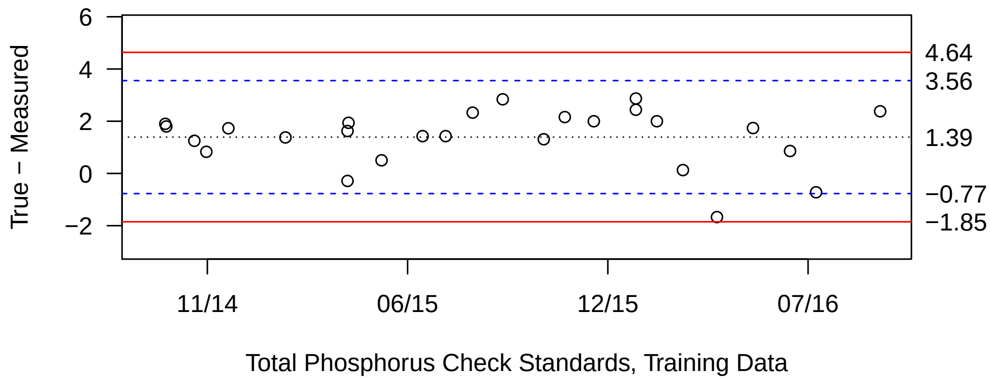


Figure C26: Phosphorus (total) high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



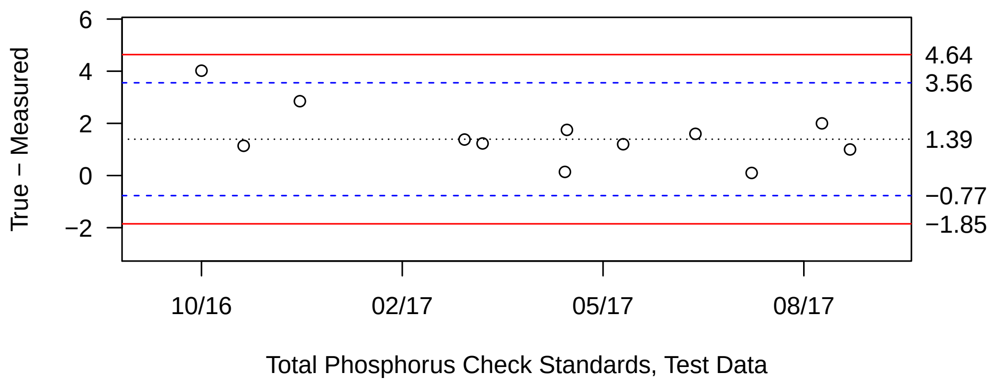
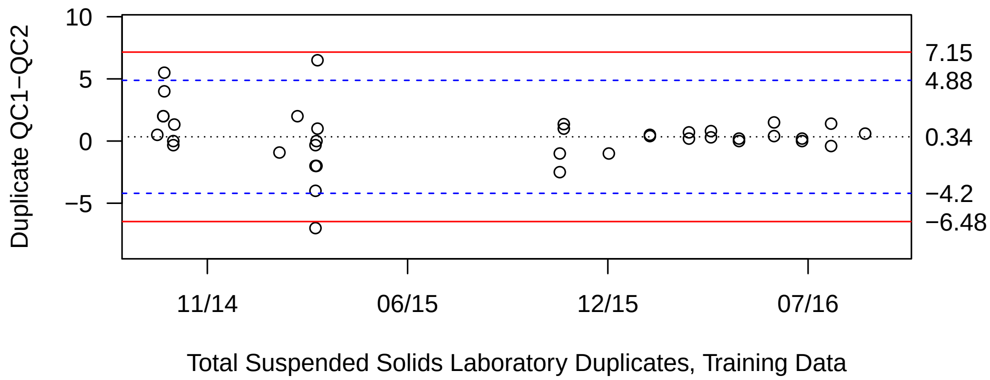


Figure C27: Phosphorus (total) low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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



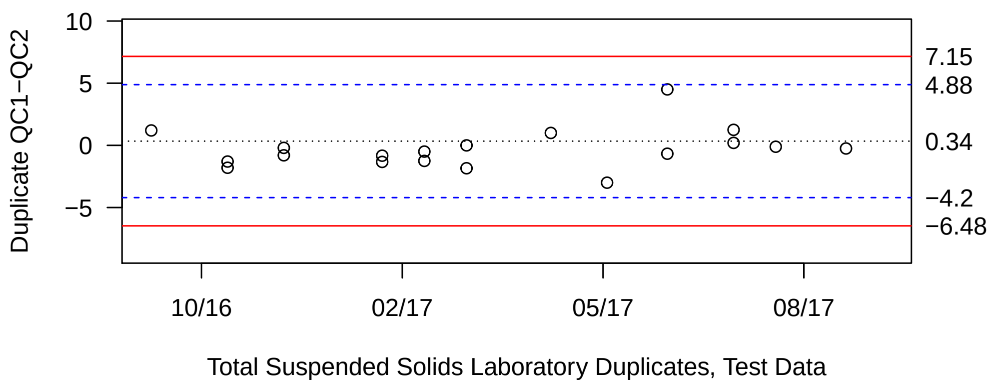
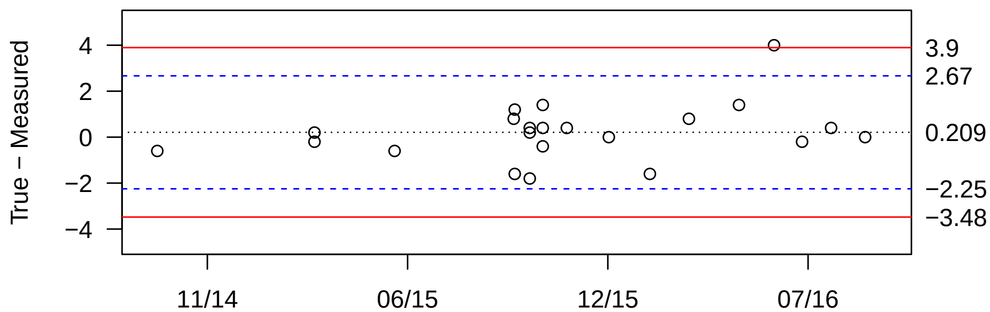
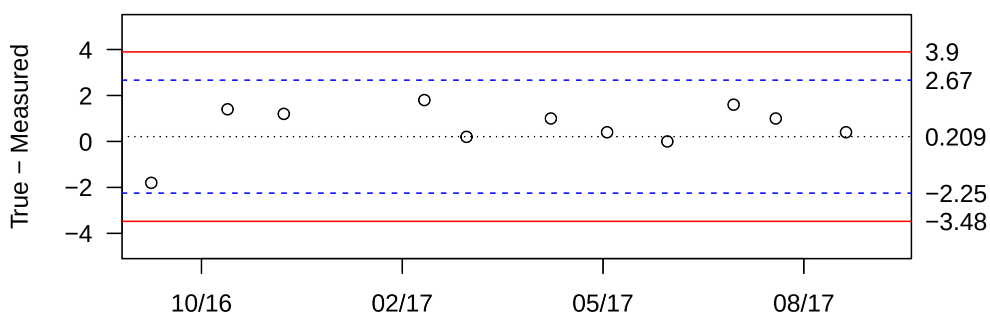


Figure C28: Total suspended solids laboratory duplicates for the Lake Whatcom monitoring program (tributary and storm water samples). Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on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

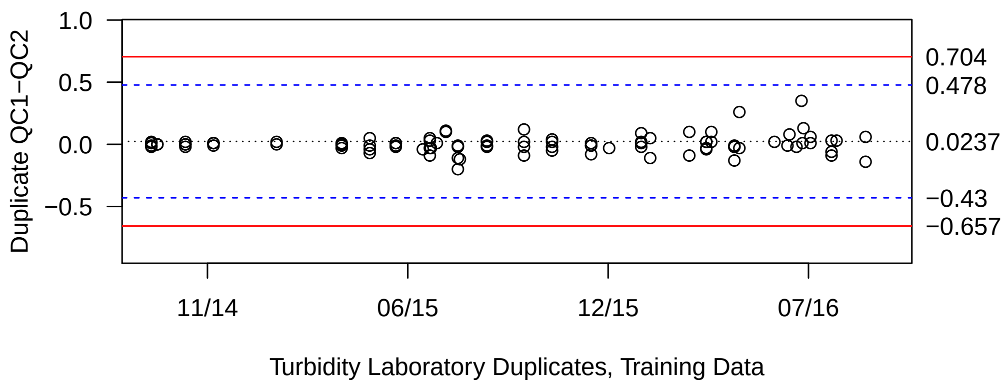


Total Suspended Solids Check Standards, Training Data



Total Suspended Solids Check Standards, Test Data

Figure C29: Total suspended solids check standards 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.



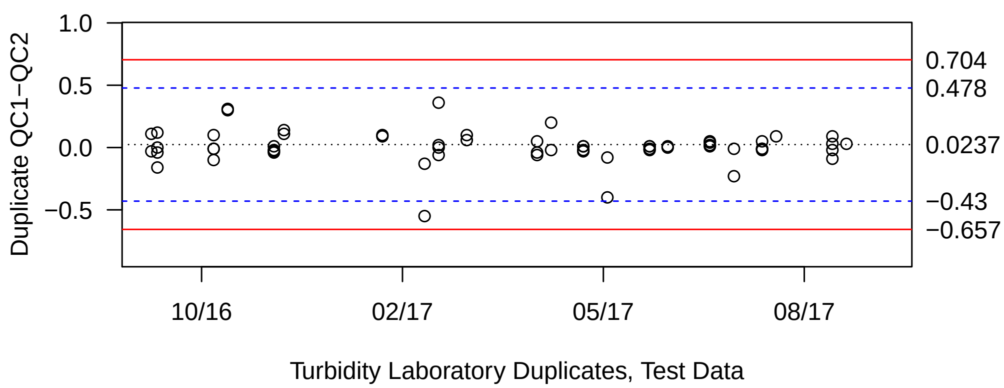


Figure C30: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

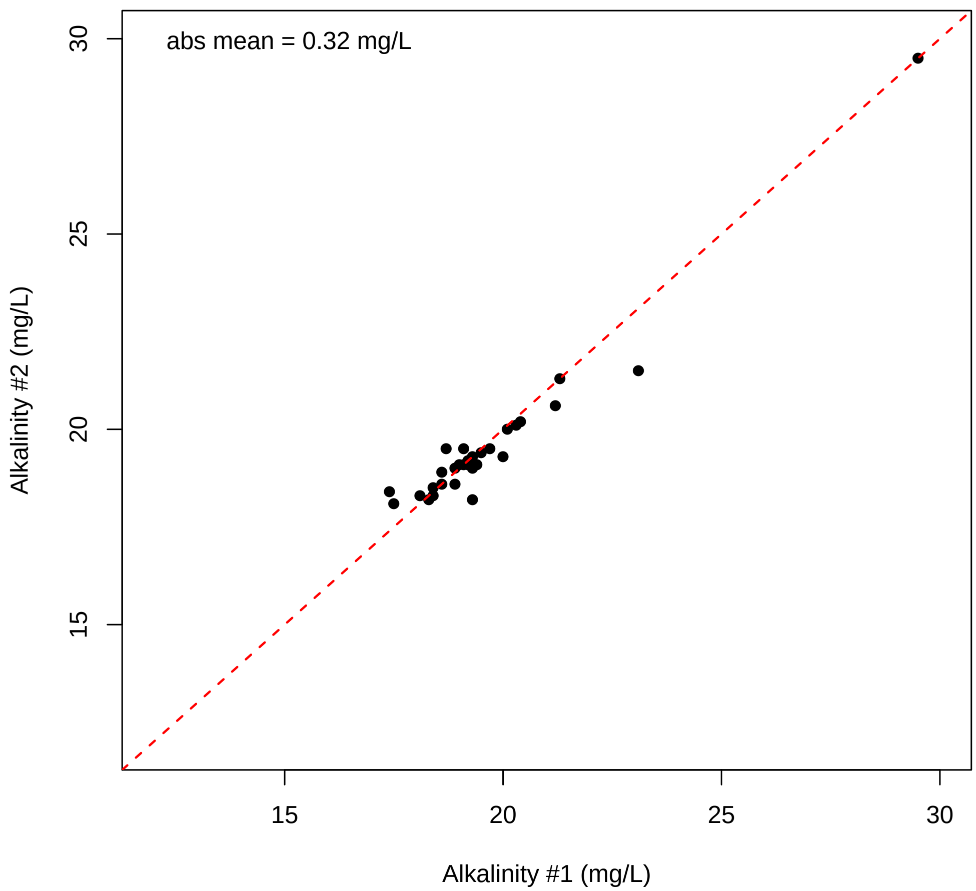


Figure C31: Alkalinity field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

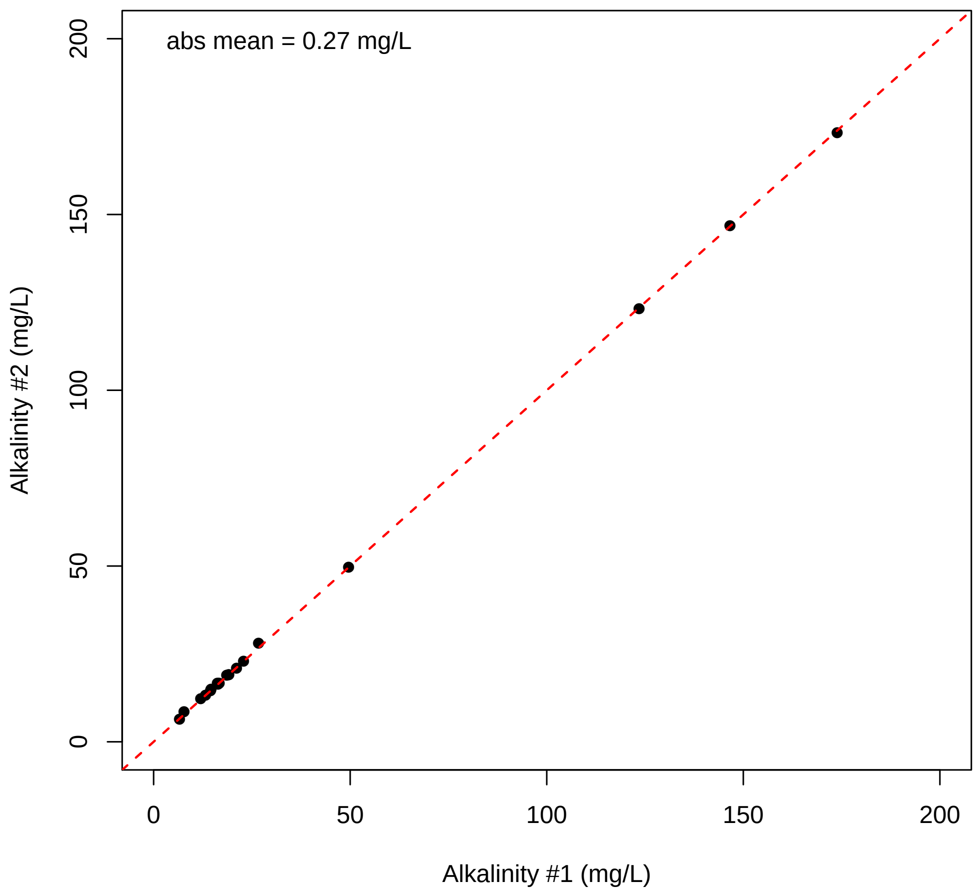


Figure C32: Alkalinity field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship.

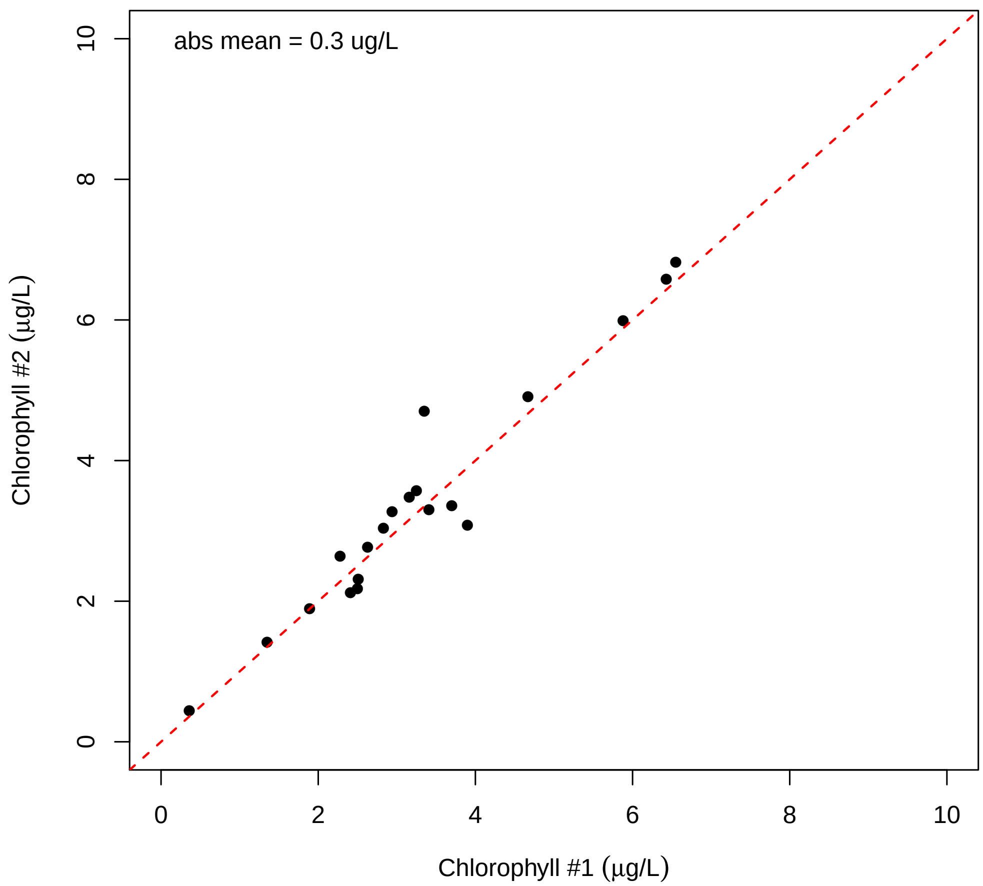


Figure C33: Chlorophyll field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

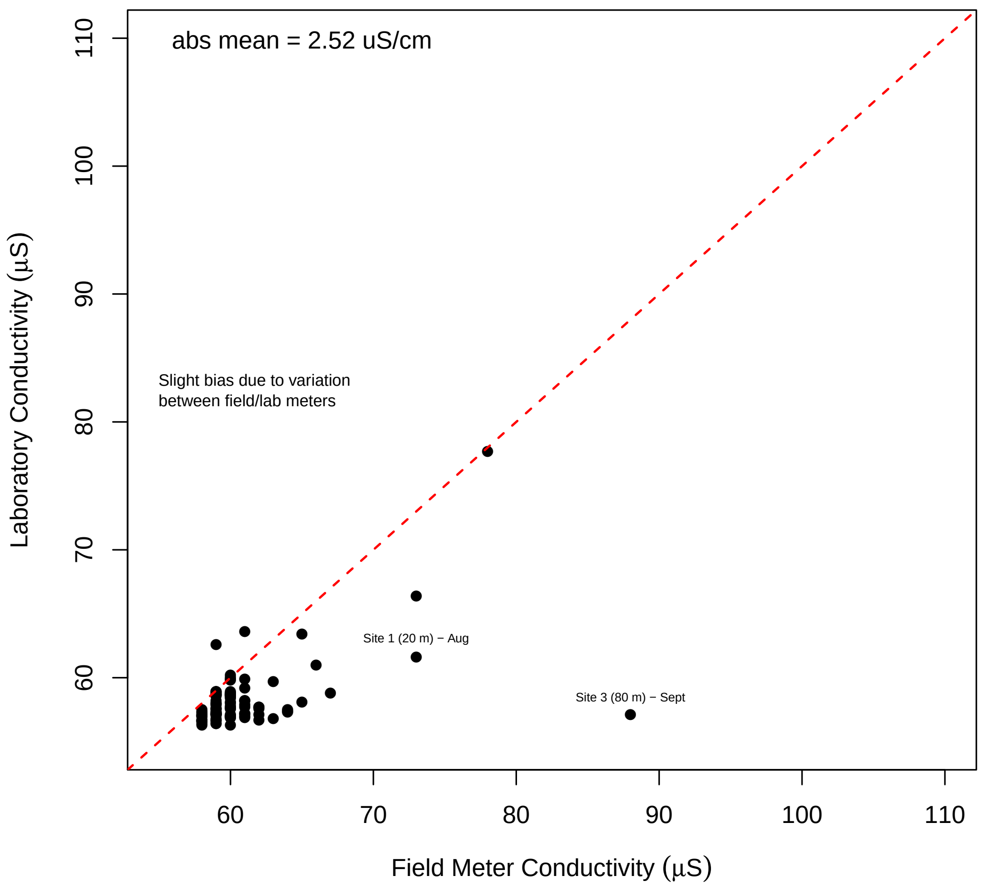


Figure C34: Conductivity field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship. The labeled outliers were collected when extreme gradients were present. Field meter samples were collected at true depth; field duplicate samples were measured in the laboratory from samples collected using a marked line, which will be slightly shallower than true depth.

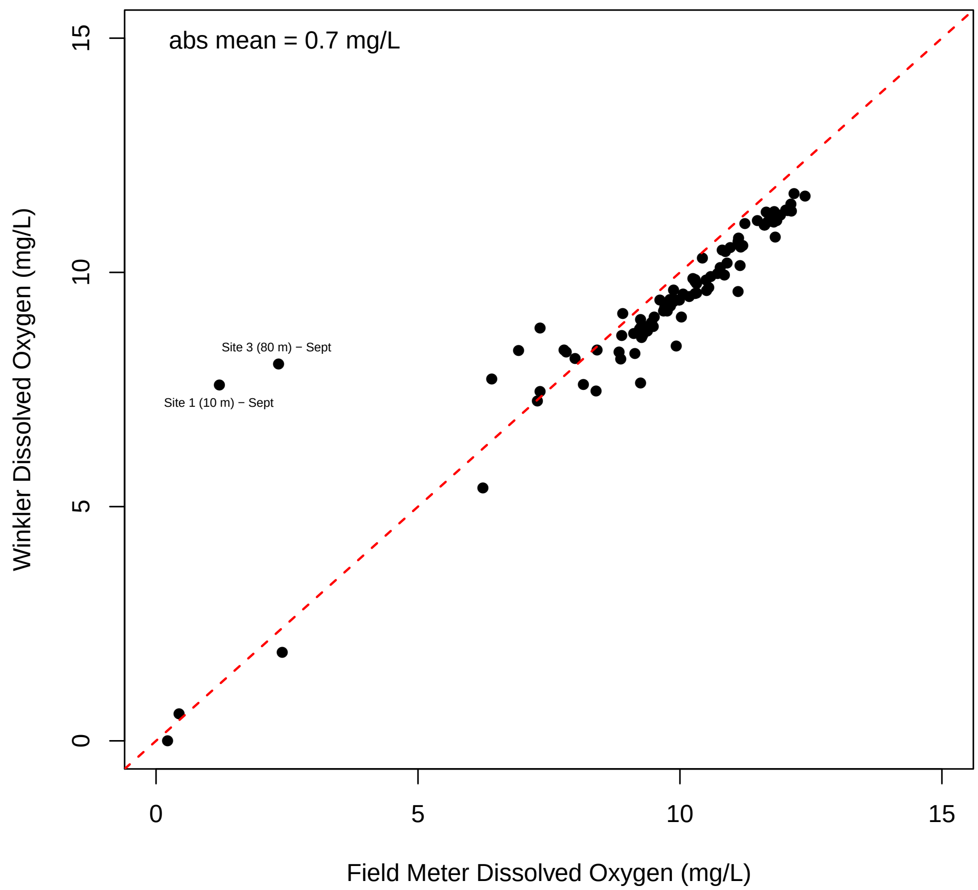


Figure C35: Dissolved oxygen field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship. The labeled outliers were collected when extreme gradients were present. Field meter samples were collected at true depth; Winkler samples were measured in the laboratory from samples collected using a marked line, which will be slightly shallower than true depth.

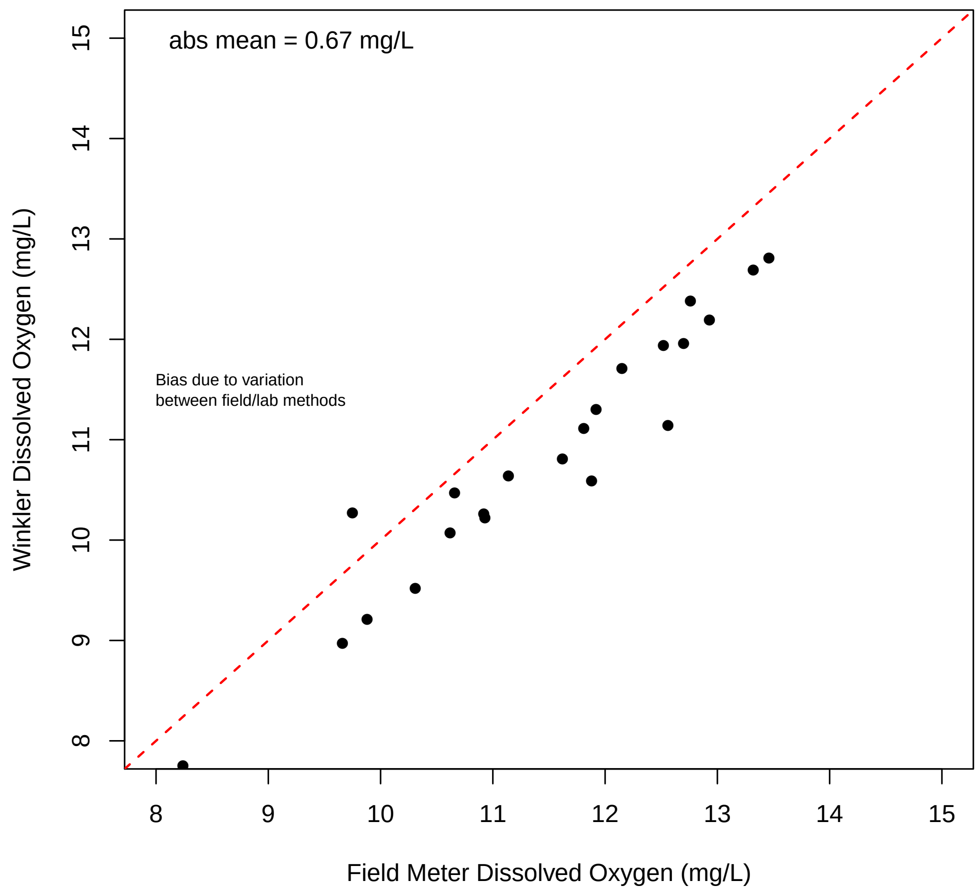


Figure C36: Dissolved oxygen field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship. Systematic bias was present in the field meter results. The meter used for tributary monitoring is not the same as the one used for lake samples; a new field meter has been ordered that is similar in design as the meter used to collect lake samples.

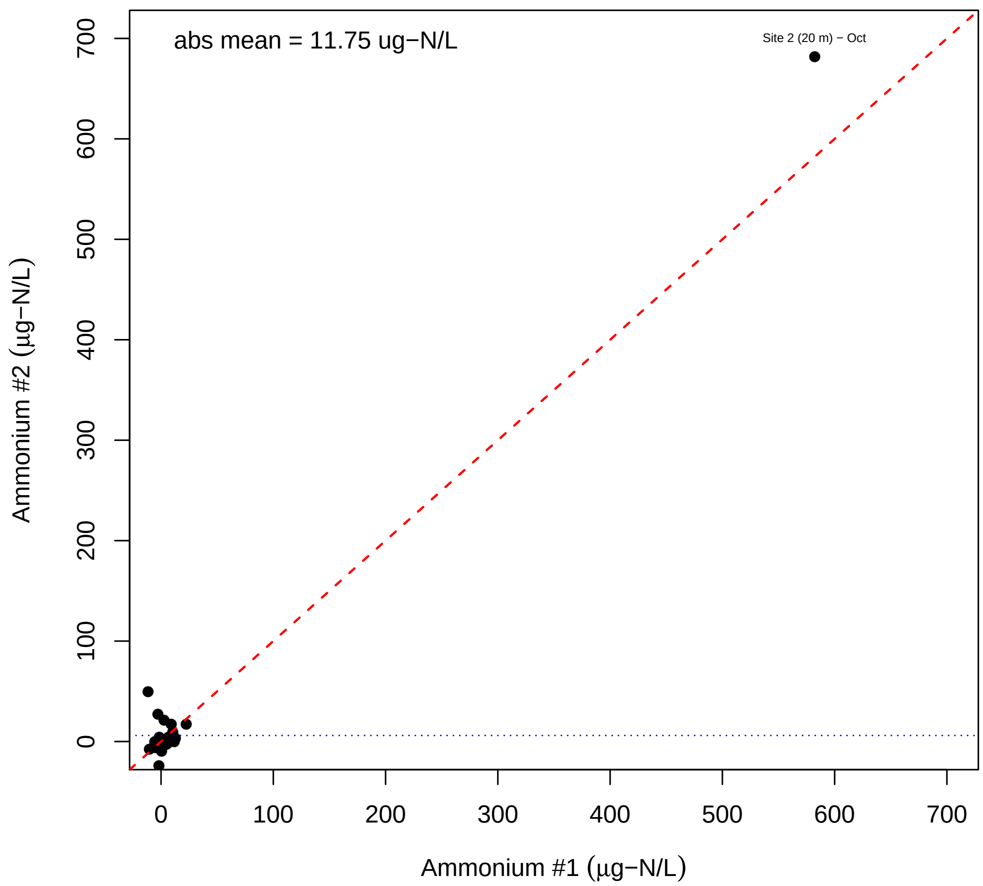


Figure C37: Nitrogen (ammonium) field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit. The high degree of scatter is due to the low concentrations of the samples; the labeled outlier was collected when extreme gradients were present.

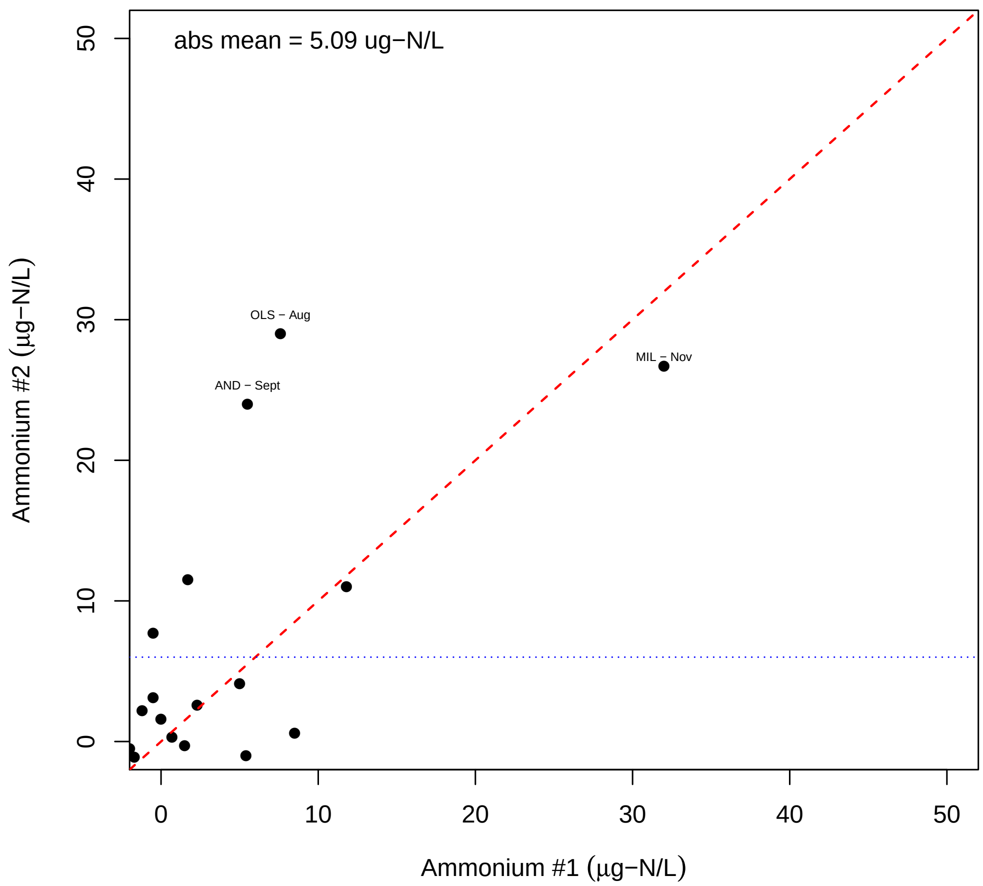


Figure C38: Nitrogen (ammonium) field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit. The high degree of scatter is due to the low concentrations of the samples; the labeled outliers were collected from residential streams or during low flow conditions.

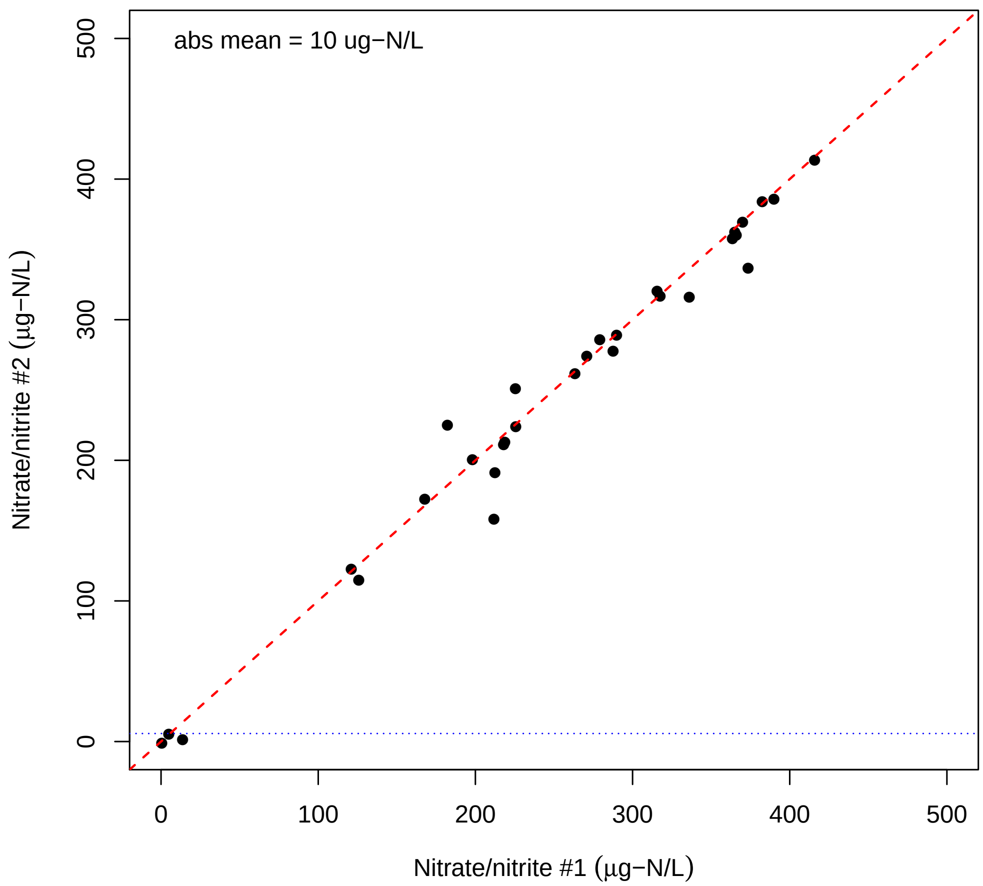


Figure C39: Nitrogen (nitrate/nitrite) field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit.

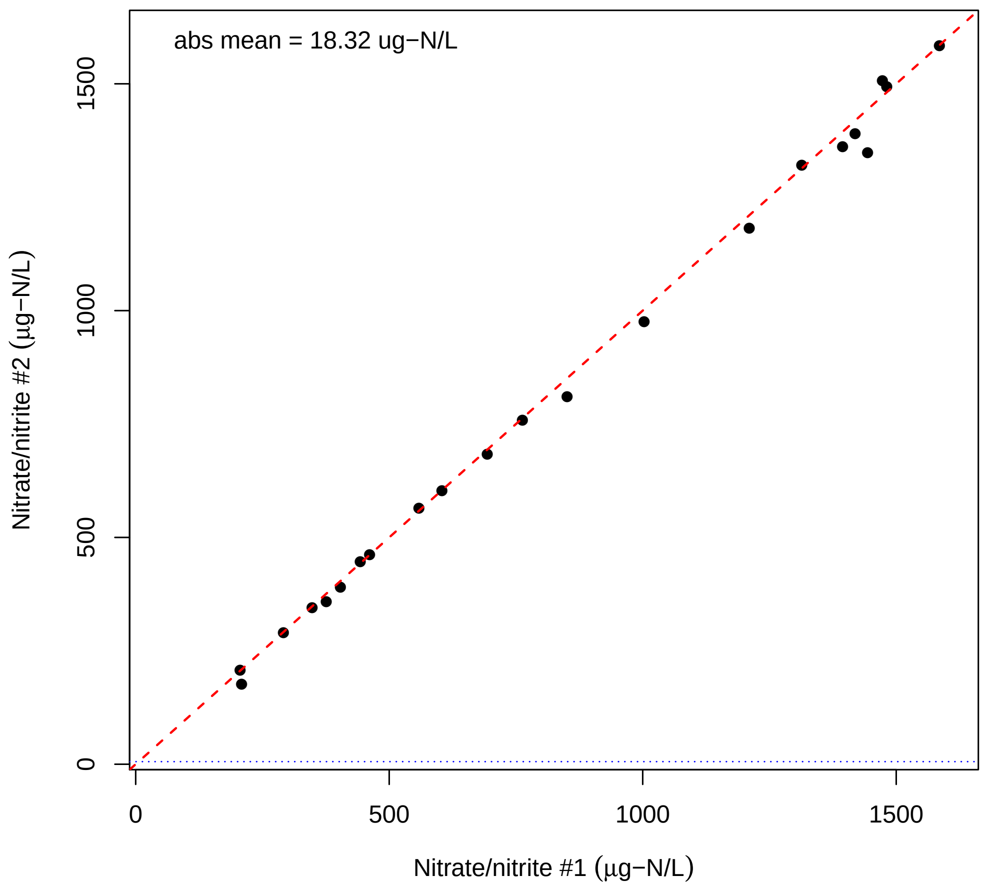


Figure C40: Nitrogen (nitrate/nitrite) field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit.

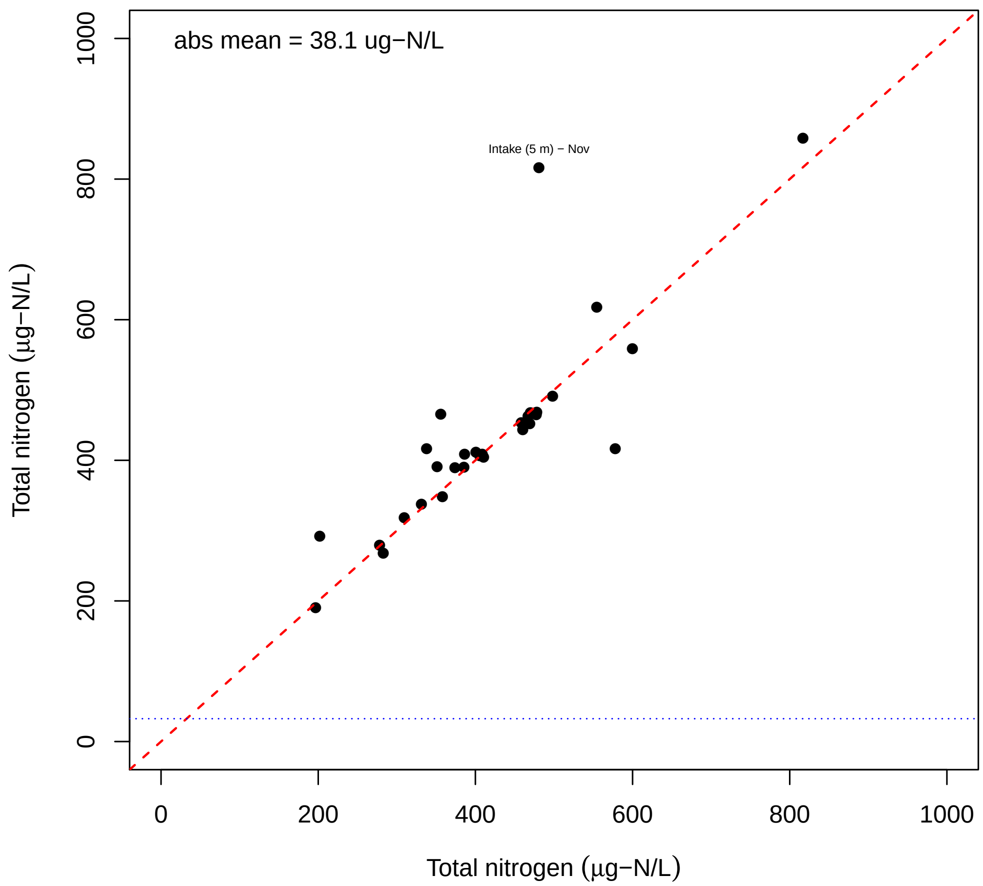


Figure C41: Nitrogen (total) field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship. The variation in the labeled outlier may be due to particulate contamination.

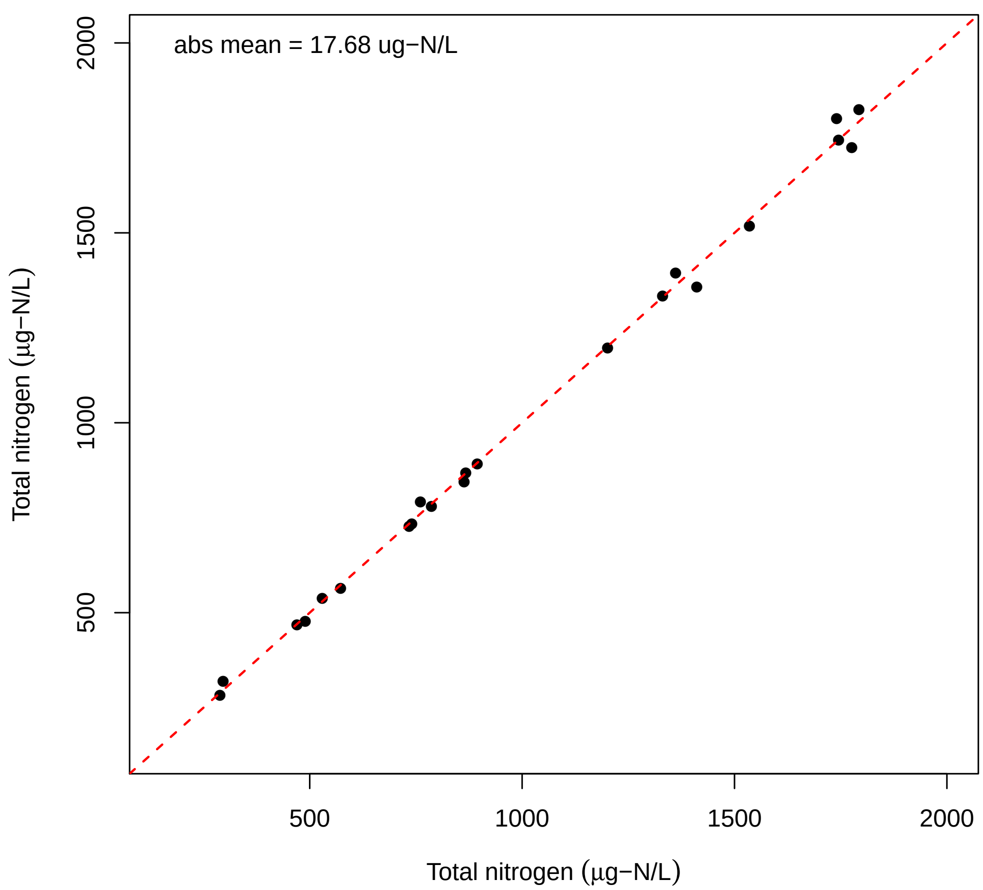


Figure C42: Nitrogen (total) field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship.

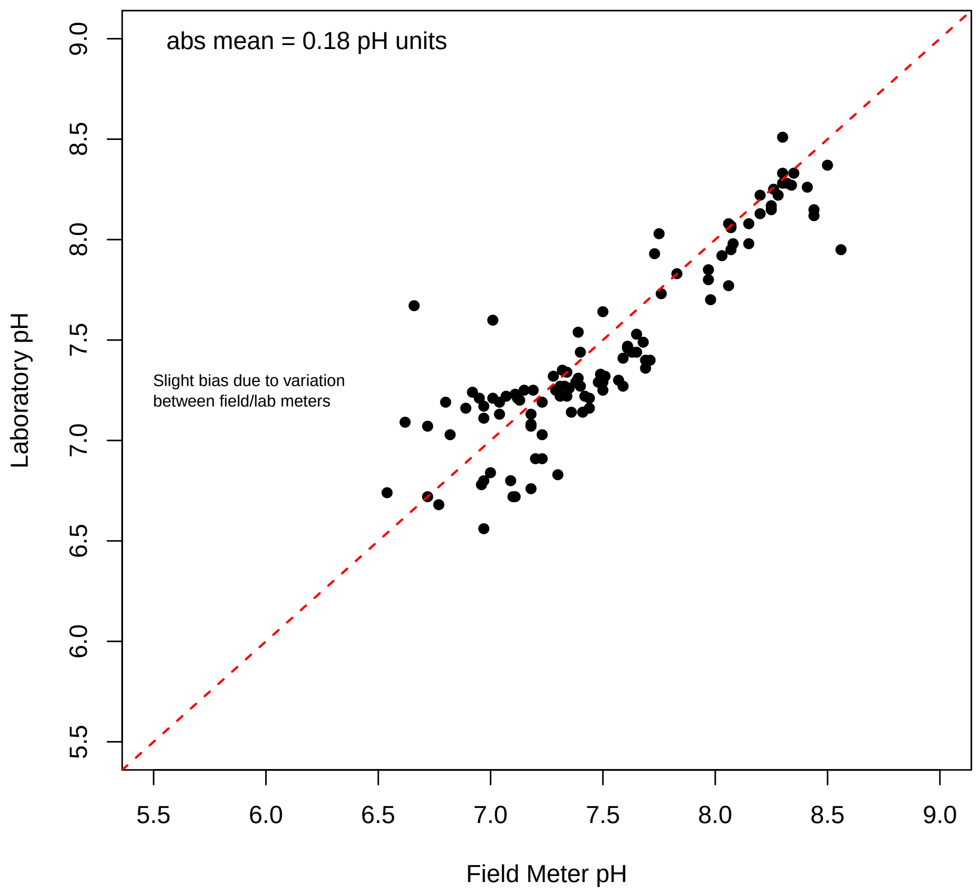


Figure C43: Field duplicates for pH from the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

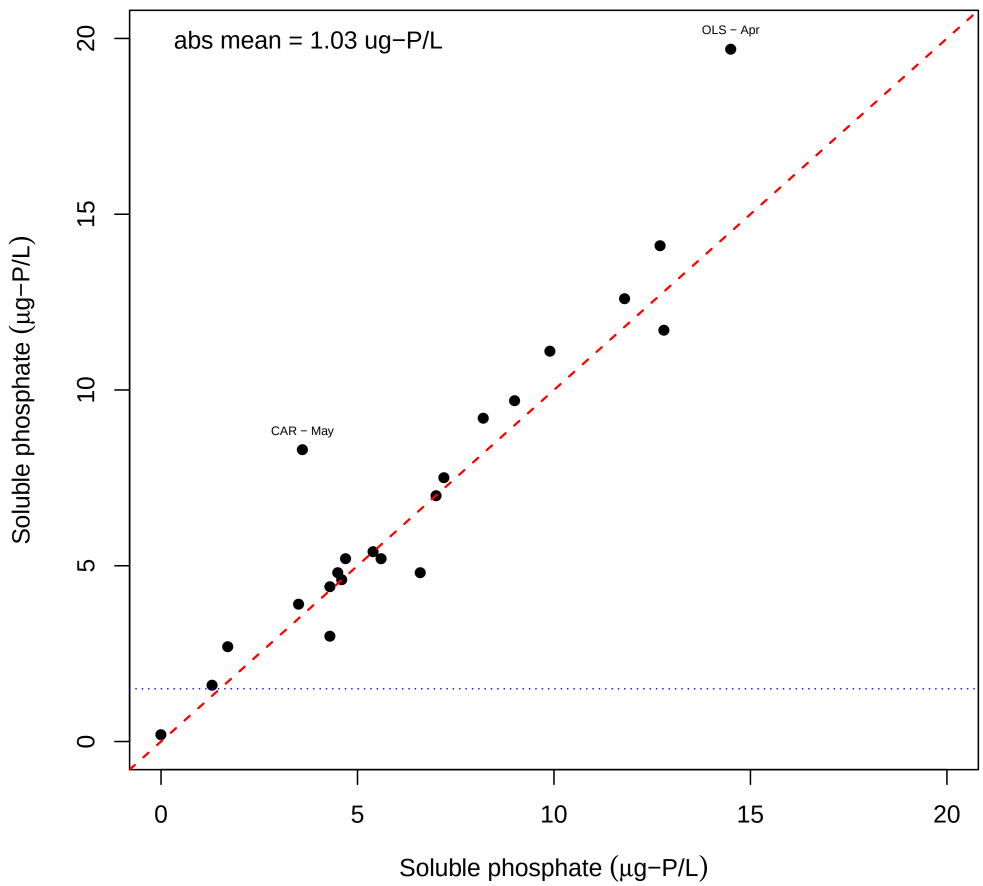


Figure C44: Phosphorus (soluble reactive phosphate) field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit. the high degree of scatter is due to the low concentrations of the samples.

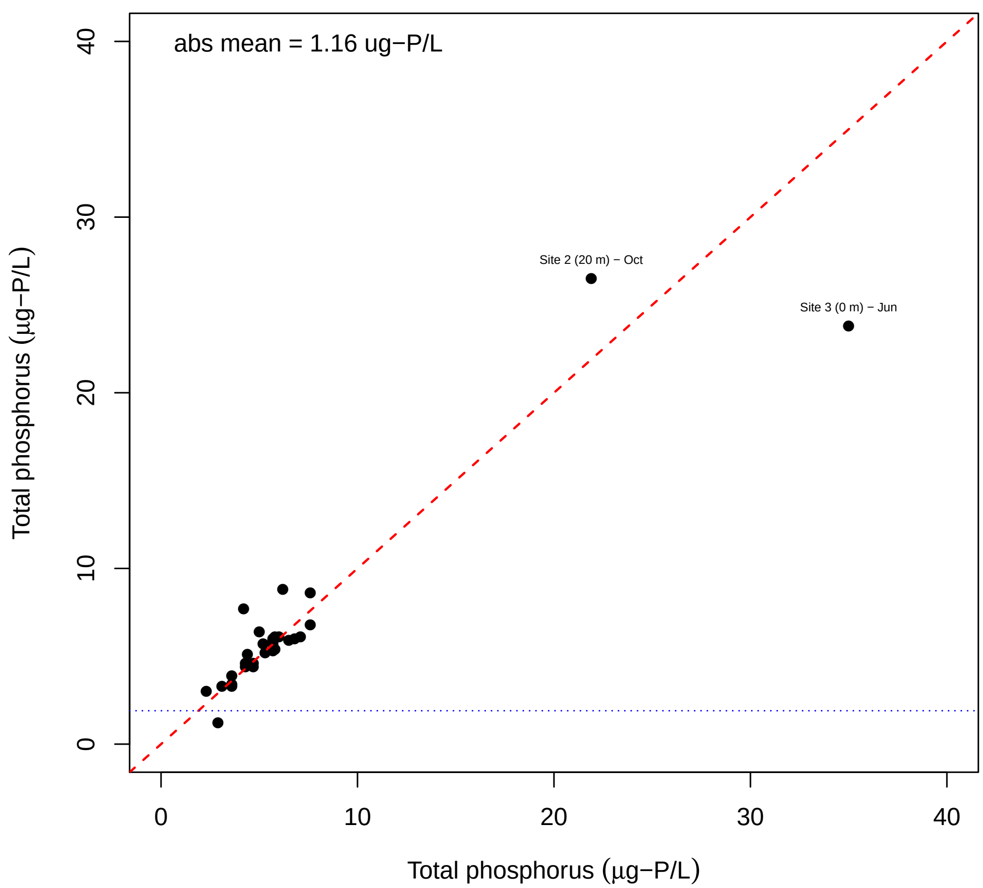


Figure C45: Phosphorus (total) field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit. The high degree of scatter is due to the low concentrations of the samples; the labeled outliers were collected when extreme gradients were present or at the surface where particulate contamination is common.

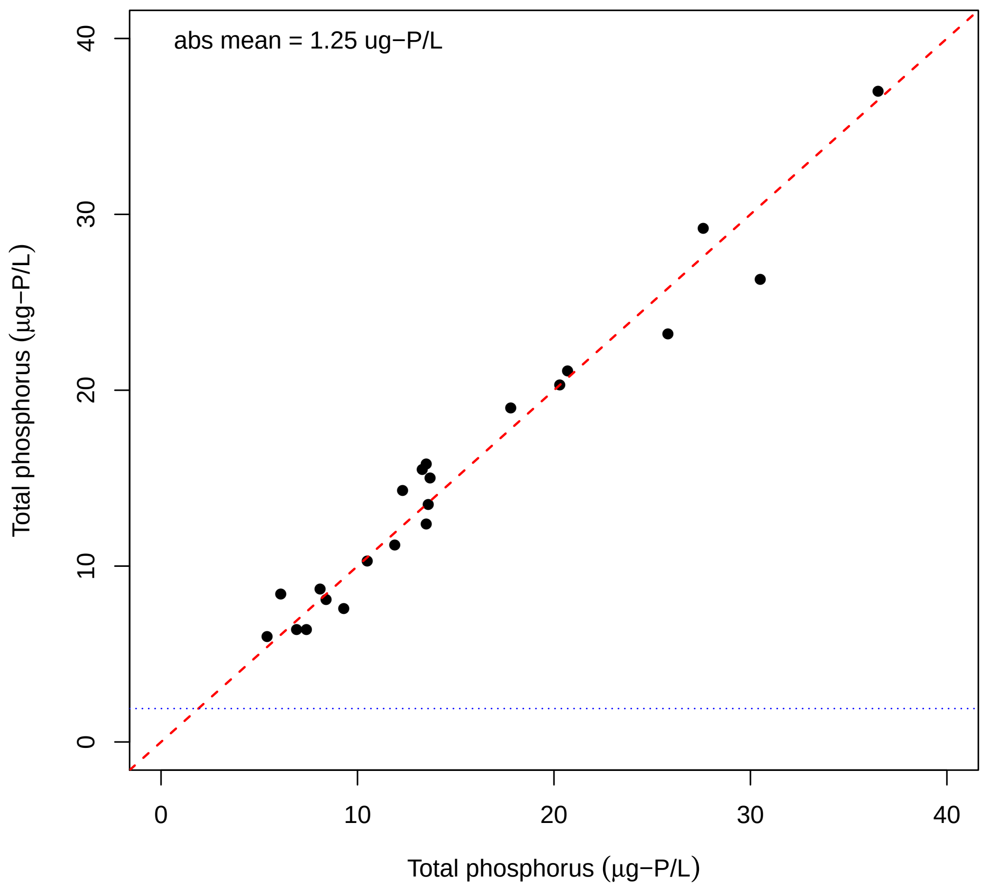


Figure C46: Phosphorus (total) field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit.

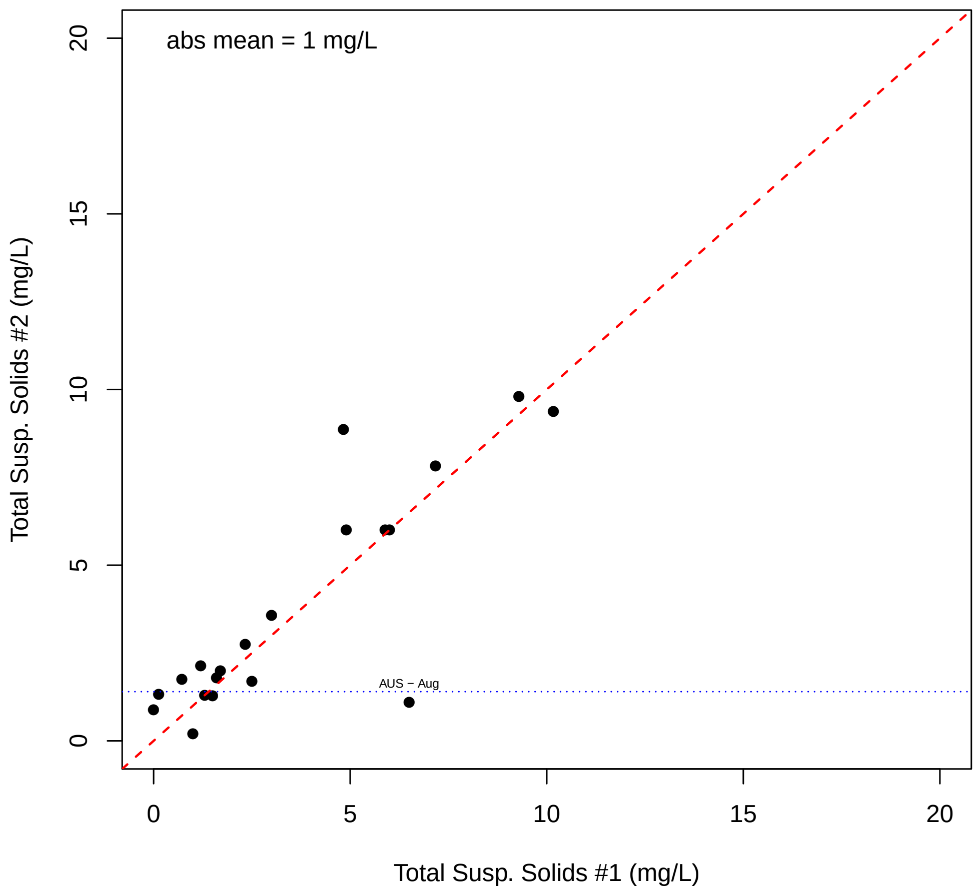


Figure C47: Total suspended solids field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship; horizontal reference line shows current detection limit. The high degree of scatter is due to the low concentrations of the samples.

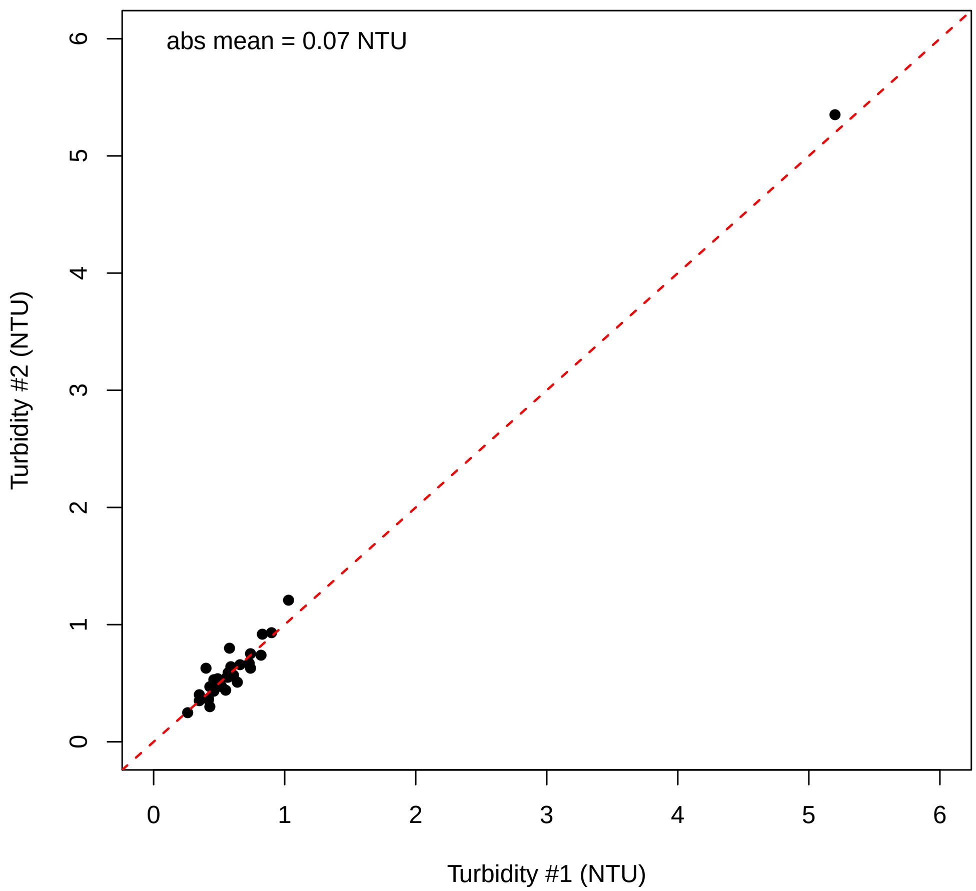


Figure C48: Turbidity field duplicates for the 2016/2017 Lake Whatcom monitoring program (lake samples). Diagonal reference line shows 1:1 relationship.

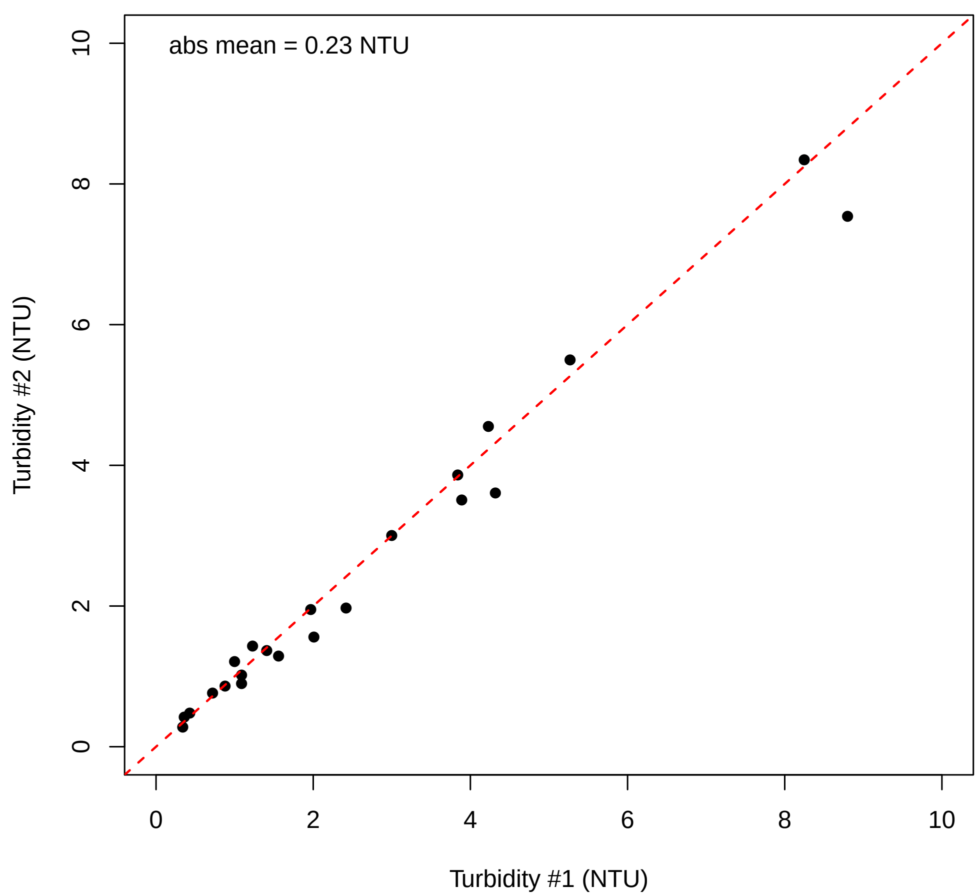


Figure C49: Turbidity field duplicates for the 2016/2017 Lake Whatcom monitoring program (tributary samples). Diagonal reference line shows 1:1 relationship.

D Lake Whatcom Online Data

The following **readme** file describes the electronic data posted at the IWS web site (www.wwu.edu/iws) 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 FEBRUARY 22, 2018
**************************************************************
Most of the Lake Whatcom water quality data are available in
electronic format at the IWS website (http://www.wwu.edu/iws) 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

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

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).

************************************************************
* 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
```

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.

```
*************************************************************
* 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.