

3-6-2014

# Lake Whatcom Monitoring Project 2012/2013 Report

Robin A. Matthews

*Western Washington University, robin.matthews@wwu.edu*

Michael Hilles

*Western Washington University, michael.hilles@wwu.edu*

Joan Vandersypen

*Western Washington University, joan.vandersypen@wwu.edu*

Robert J. Mitchell

*Western Washington University, robert.mitchell@wwu.edu*

Geoffrey B. Matthews

*Western Washington University, geoffrey.matthews@wwu.edu*

*See next page for additional authors*

Follow this and additional works at: [https://cedar.wwu.edu/lakewhat\\_annualreps](https://cedar.wwu.edu/lakewhat_annualreps)



Part of the [Environmental Monitoring Commons](#)

---

## Recommended Citation

Matthews, Robin A.; Hilles, Michael; Vandersypen, Joan; Mitchell, Robert J.; Matthews, Geoffrey B.; and Beeler, Katherine, "Lake Whatcom Monitoring Project 2012/2013 Report" (2014). *Lake Whatcom Annual Reports*. 1.

[https://cedar.wwu.edu/lakewhat\\_annualreps/1](https://cedar.wwu.edu/lakewhat_annualreps/1)

This Report is brought to you for free and open access by the Lake Whatcom at Western CEDAR. It has been accepted for inclusion in Lake Whatcom Annual Reports by an authorized administrator of Western CEDAR. For more information, please contact [westerncedar@wwu.edu](mailto:westerncedar@wwu.edu).

---

**Authors**

Robin A. Matthews, Michael Hilles, Joan Vandersypen, Robert J. Mitchell, Geoffrey B. Matthews, and Katherine Beeler

# Lake Whatcom Monitoring Project 2012/2013 Report

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

Dr. Robert J. Mitchell  
Katherine Beeler  
*Geology Department,  
College of Sciences and Technology*

Dr. Geoffrey B. Matthews  
*Computer Science Department,  
College of Sciences and Technology*

Western Washington University  
Bellingham, Washington 98225

March 6, 2014

---

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, Cassie Castrejon, Sean Cooper, Tommy Craig, Miette Dahlgren, Jonnel Deacon, Erin Donahou, Ariel Edwards, Olivia Edwards, Chad Elofson, Laura Junge, Rosa Sanchez, Alice Scott, and Niki Thane for assistance with the project.

(This page blank)

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>Lake Whatcom Monitoring</b>	<b>2</b>
2.1	Site Descriptions . . . . .	2
2.2	Field Sampling and Analytical Methods . . . . .	2
2.3	Results and Discussion . . . . .	3
2.3.1	Water temperature . . . . .	3
2.3.2	Dissolved oxygen . . . . .	6
2.3.3	Conductivity and pH . . . . .	8
2.3.4	Alkalinity and turbidity . . . . .	9
2.3.5	Nitrogen and phosphorus . . . . .	9
2.3.6	Chlorophyll, plankton, and Secchi depth . . . . .	12
2.3.7	Coliform bacteria . . . . .	14
2.3.8	Total organic carbon and disinfection by-products . . . . .	14
<b>3</b>	<b>Hydrograph Data</b>	<b>36</b>
3.1	Rating Curves Comparison . . . . .	36
<b>4</b>	<b>Storm Water Monitoring</b>	<b>50</b>
4.1	Site Descriptions . . . . .	50
4.2	Field Sampling and Analytical Methods . . . . .	50
4.3	Results and Discussion . . . . .	51
<b>5</b>	<b>References and Related Reports</b>	<b>82</b>
5.1	References . . . . .	82

5.2	Related Reports . . . . .	85
<b>A</b>	<b>Site Descriptions</b>	<b>89</b>
A.1	Lake Whatcom Monitoring Sites . . . . .	89
A.2	Storm Water Monitoring Sites . . . . .	89
<b>B</b>	<b>Long-Term Water Quality Figures</b>	<b>93</b>
B.1	Monthly YSI Profiles . . . . .	94
B.2	Long-term Hydrolab Data (1988-present) . . . . .	145
B.3	Long-term Water Quality Data (1988-present) . . . . .	166
<b>C</b>	<b>Quality Control</b>	<b>227</b>
C.1	Performance Evaluation Reports . . . . .	227
C.2	Laboratory Duplicates, Spikes, and Check Standards . . . . .	227
C.3	Field Duplicates . . . . .	227
<b>D</b>	<b>Lake Whatcom Online Data</b>	<b>269</b>

## List of Figures

1	Boxplots showing 1988-2013 surface water temperatures . . . . .	24
2	Relationship between dissolved oxygen and time at Site 1, 12 m .	25
3	Relationship between dissolved oxygen and time at Site 1, 14 m .	26
4	Relationship between dissolved oxygen and time at Site 1, 16 m .	27
5	Relationship between dissolved oxygen and time at Site 1, 18 m .	28
6	Minimum summer, near-surface dissolved inorganic nitrogen concentrations	29
7	Median summer, near-surface total phosphorus concentrations . .	30
8	Median summer near-surface chlorophyll concentrations . . . . .	31
9	Log <sub>10</sub> plots of median summer, near-surface algae counts . . . . .	32
10	Log <sub>10</sub> plots of median summer, near-surface Cyanobacteria counts	33
11	Median annual total organic carbon concentrations. . . . .	34
12	Total trihalomethanes and haloacetic acids concentrations in the Bellingham water distribution	
13	Comparison between observed staff heights and sensor stage readings at Austin Creek.	40
14	Austin Creek hydrograph, October 1, 2012–September 30, 2013. .	41
15	Smith Creek hydrograph, October 1, 2012–September 30, 2013. .	42
16	Austin Creek rating curve developed using Excel. . . . .	43
17	Smith Creek rating curve developed for low flows (stage <2.3 ft) using Excel.	44
18	Smith Creek rating curve developed for high flows (stage ≥2.3 ft) using Excel.	45
19	Austin Creek rating curve developed using Aquarius. . . . .	46
20	Smith Creek rating curve developed using Aquarius. . . . .	47
21	Comparison between Austin Creek hydrographs generated using Excel and Aquarius rating cur	
22	Comparison between Smith Creek hydrographs generated using Excel and Aquarius rating curv	
23	Anderson Creek precipitation and stream flow for Events 1–6 and 8.	55

24	Anderson Creek storm water monitoring results for Events 1–6 and 8: total suspended solids vs.
25	Anderson Creek storm water monitoring results for Events 1–6 and 8: total phosphorus vs. stream
26	Anderson Creek storm water monitoring results for Events 2–6 and 8: soluble phosphate vs. stream
27	Anderson Creek storm water monitoring results for Events 1–6 and 8: total nitrogen vs. stream
28	Anderson Creek storm water monitoring results for Events 2–6 and 8: nitrate/nitrite vs. stream
29	Austin Creek precipitation and stream flow for Events 2–4 and 7–8. 61
30	Austin Creek storm water monitoring results for Events 2–4 and 7–8: total suspended solids vs.
31	Austin Creek storm water monitoring results for Events 2–4 and 7–8: total phosphorus vs. stream
32	Austin Creek storm water monitoring results for Events 2–4 and 7–8: soluble phosphate vs. stream
33	Austin Creek storm water monitoring results for Events 2–4 and 7–8: total nitrogen vs. stream
34	Austin Creek storm water monitoring results for Events 2–4 and 7–8: nitrate/nitrite vs. stream
35	Brannian Creek precipitation and stream flow for Events 1–4, 6, and 8. 67
36	Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: total suspended solids
37	Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: total phosphorus vs. stream
38	Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: soluble phosphate vs.
39	Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: total nitrogen vs. stream
40	Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: nitrate/nitrite vs. stream
41	Correlation between stage height and total suspended solids in Anderson, Austin, and Brannian
42	Correlation between stream flow or stage height and total phosphorus in Anderson, Austin, and
43	Correlation between stage height and soluble phosphate in Anderson, Austin, and Brannian Cree
44	Correlation between stage height and total nitrogen in Anderson, Austin and Brannian Creeks.
45	Correlation between stage height and nitrate in Anderson, Austin, and Brannian Creeks. 77
46	Correlation between total suspended solids and total phosphorus in Anderson, Austin, and Bran
47	Correlation between stream flow and total phosphorus by storm event in Anderson Creek. 79
48	Correlation between stream flow and total phosphorus by storm event in Austin Creek. 80



49	Correlation between stream flow and total phosphorus by storm event in Brannian Creek.	81
A1	Lake Whatcom lake sampling sites . . . . .	91
A2	Lake Whatcom storm water sampling sites . . . . .	92
B1	Lake Whatcom YSI profiles for Site 1, October 11, 2012. . . . .	95
B2	Lake Whatcom YSI profiles for Site 2, October 11, 2012. . . . .	96
B3	Lake Whatcom YSI profiles for the Intake, October 11, 2012. . . . .	97
B4	Lake Whatcom YSI profiles for Site 3, October 9, 2012. . . . .	98
B5	Lake Whatcom YSI profiles for Site 4, October 9, 2012. . . . .	99
B6	Lake Whatcom YSI profiles for Site 1, November 15, 2012. . . . .	100
B7	Lake Whatcom YSI profiles for Site 2, November 15, 2012. . . . .	101
B8	Lake Whatcom YSI profiles for the Intake, November 15, 2012. . . . .	102
B9	Lake Whatcom YSI profiles for Site 3, November 6, 2012. . . . .	103
B10	Lake Whatcom YSI profiles for Site 4, November 6, 2012. . . . .	104
B11	Lake Whatcom YSI profiles for Site 1, December 6, 2012. . . . .	105
B12	Lake Whatcom YSI profiles for Site 2, December 6, 2012. . . . .	106
B13	Lake Whatcom YSI profiles for the Intake, December 6, 2012. . . . .	107
B14	Lake Whatcom YSI profiles for Site 3, December 12, 2012. . . . .	108
B15	Lake Whatcom YSI profiles for Site 4, December 12, 2012. . . . .	109
B16	Lake Whatcom YSI profiles for Site 1, February 7, 2013. . . . .	110
B17	Lake Whatcom YSI profiles for Site 2, February 7, 2013. . . . .	111
B18	Lake Whatcom YSI profiles for the Intake, February 7, 2013. . . . .	112
B19	Lake Whatcom YSI profiles for Site 3, February 14, 2013. . . . .	113
B20	Lake Whatcom YSI profiles for Site 4, February 14, 2013. . . . .	114
B21	Lake Whatcom YSI profiles for Site 1, April 11, 2013. . . . .	115
B22	Lake Whatcom YSI profiles for Site 2, April 11, 2013. . . . .	116

B23	Lake Whatcom YSI profiles for the Intake, April 11, 2013. . . . .	117
B24	Lake Whatcom YSI profiles for Site 3, April 9, 2013. . . . .	118
B25	Lake Whatcom YSI profiles for Site 4, April 9, 2013. . . . .	119
B26	Lake Whatcom YSI profiles for Site 1, May 9, 2013. . . . .	120
B27	Lake Whatcom YSI profiles for Site 2, May 9, 2013. . . . .	121
B28	Lake Whatcom YSI profiles for the Intake, May 9, 2013. . . . .	122
B29	Lake Whatcom YSI profiles for Site 3, May 7, 2013. . . . .	123
B30	Lake Whatcom YSI profiles for Site 4, May 7, 2013. . . . .	124
B31	Lake Whatcom YSI profiles for Site 1, June 6, 2013. . . . .	125
B32	Lake Whatcom YSI profiles for Site 2, June 6, 2013. . . . .	126
B33	Lake Whatcom YSI profiles for the Intake, June 6, 2013. . . . .	127
B34	Lake Whatcom YSI profiles for Site 3, June 4, 2013. . . . .	128
B35	Lake Whatcom YSI profiles for Site 4, June 4, 2013. . . . .	129
B36	Lake Whatcom YSI profiles for Site 1, July 11, 2013. . . . .	130
B37	Lake Whatcom YSI profiles for Site 2, July 11, 2013. . . . .	131
B38	Lake Whatcom YSI profiles for the Intake, July 11, 2013. . . . .	132
B39	Lake Whatcom YSI profiles for Site 3, July 9, 2013. . . . .	133
B40	Lake Whatcom YSI profiles for Site 4, July 9, 2013. . . . .	134
B41	Lake Whatcom YSI profiles for Site 1, August 8, 2013. . . . .	135
B42	Lake Whatcom YSI profiles for Site 2, August 8, 2013. . . . .	136
B43	Lake Whatcom YSI profiles for the Intake, August 8, 2013. . . . .	137
B44	Lake Whatcom YSI profiles for Site 3, August 6, 2013. . . . .	138
B45	Lake Whatcom YSI profiles for Site 4, August 6, 2013. . . . .	139
B46	Lake Whatcom YSI profiles for Site 1, September 4, 2013. . . . .	140
B47	Lake Whatcom YSI profiles for Site 2, September 4, 2013. . . . .	141

B48	Lake Whatcom YSI profiles for the Intake, September 4, 2013. . . . .	142
B49	Lake Whatcom YSI profiles for Site 3, September 3, 2013. . . . .	143
B50	Lake Whatcom YSI profiles for Site 4, September 3, 2013. . . . .	144
B51	Lake Whatcom historic temperature data for Site 1. . . . .	146
B52	Lake Whatcom historic temperature data for Site 2. . . . .	147
B53	Lake Whatcom historic temperature data for the Intake. . . . .	148
B54	Lake Whatcom historic temperature data for Site 3. . . . .	149
B55	Lake Whatcom historic temperature data for Site 4. . . . .	150
B56	Lake Whatcom historic dissolved oxygen data for Site 1. . . . .	151
B57	Lake Whatcom historic dissolved oxygen data for Site 2. . . . .	152
B58	Lake Whatcom historic dissolved oxygen data for the Intake. . . . .	153
B59	Lake Whatcom historic dissolved oxygen data for Site 3. . . . .	154
B60	Lake Whatcom historic dissolved oxygen data for Site 4. . . . .	155
B61	Lake Whatcom historic pH data for Site 1. . . . .	156
B62	Lake Whatcom historic pH data for Site 2. . . . .	157
B63	Lake Whatcom historic pH data for the Intake. . . . .	158
B64	Lake Whatcom historic pH data for Site 3. . . . .	159
B65	Lake Whatcom historic pH data for Site 4. . . . .	160
B66	Lake Whatcom historic conductivity data for Site 1. . . . .	161
B67	Lake Whatcom historic conductivity data for Site 2. . . . .	162
B68	Lake Whatcom historic conductivity data for the Intake. . . . .	163
B69	Lake Whatcom historic conductivity data for Site 3. . . . .	164
B70	Lake Whatcom historic conductivity data for Site 4. . . . .	165
B71	Lake Whatcom alkalinity data for Site 1. . . . .	167
B72	Lake Whatcom alkalinity data for Site 2. . . . .	168

B73	Lake Whatcom alkalinity data for the Intake site. . . . .	169
B74	Lake Whatcom alkalinity data for Site 3. . . . .	170
B75	Lake Whatcom alkalinity data for Site 4. . . . .	171
B76	Lake Whatcom turbidity data for Site 1. . . . .	172
B77	Lake Whatcom turbidity data for Site 2. . . . .	173
B78	Lake Whatcom turbidity data for the Intake site. . . . .	174
B79	Lake Whatcom turbidity data for Site 3. . . . .	175
B80	Lake Whatcom turbidity data for Site 4. . . . .	176
B81	Lake Whatcom ammonium data for Site 1. . . . .	177
B82	Lake Whatcom ammonium data for Site 2. . . . .	178
B83	Lake Whatcom ammonium data for the Intake site. . . . .	179
B84	Lake Whatcom ammonium data for Site 3. . . . .	180
B85	Lake Whatcom ammonium data for Site 4. . . . .	181
B86	Lake Whatcom nitrate/nitrite data for Site 1. . . . .	182
B87	Lake Whatcom nitrate/nitrite data for Site 2. . . . .	183
B88	Lake Whatcom nitrate/nitrite data for the Intake site. . . . .	184
B89	Lake Whatcom nitrate/nitrite data for Site 3. . . . .	185
B90	Lake Whatcom nitrate/nitrite data for Site 4. . . . .	186
B91	Lake Whatcom total nitrogen data for Site 1. . . . .	187
B92	Lake Whatcom total nitrogen data for Site 2. . . . .	188
B93	Lake Whatcom total nitrogen data for the Intake site. . . . .	189
B94	Lake Whatcom total nitrogen data for Site 3. . . . .	190
B95	Lake Whatcom total nitrogen data for Site 4. . . . .	191
B96	Lake Whatcom soluble phosphate data for Site 1. . . . .	192
B97	Lake Whatcom soluble phosphate data for Site 2. . . . .	193

B98	Lake Whatcom soluble phosphate data for the Intake site. . . . .	194
B99	Lake Whatcom soluble phosphate data for Site 3. . . . .	195
B100	Lake Whatcom soluble phosphate data for Site 4. . . . .	196
B101	Lake Whatcom total phosphorus data for Site 1. . . . .	197
B102	Lake Whatcom total phosphorus data for Site 2. . . . .	198
B103	Lake Whatcom total phosphorus data for the Intake site. . . . .	199
B104	Lake Whatcom total phosphorus data for Site 3. . . . .	200
B105	Lake Whatcom total phosphorus data for Site 4. . . . .	201
B106	Lake Whatcom chlorophyll data for Site 1. . . . .	202
B107	Lake Whatcom chlorophyll data for Site 2. . . . .	203
B108	Lake Whatcom chlorophyll data for the Intake site. . . . .	204
B109	Lake Whatcom chlorophyll data for Site 3. . . . .	205
B110	Lake Whatcom chlorophyll data for Site 4. . . . .	206
B111	Lake Whatcom Secchi depths for Site 1. . . . .	207
B112	Lake Whatcom Secchi depths for Site 2. . . . .	208
B113	Lake Whatcom Secchi depths for the Intake site. . . . .	209
B114	Lake Whatcom Secchi depths for Site 3. . . . .	210
B115	Lake Whatcom Secchi depths for Site 4. . . . .	211
B116	Lake Whatcom fecal coliform data for Site 1. . . . .	212
B117	Lake Whatcom fecal coliform data for Site 2. . . . .	213
B118	Lake Whatcom fecal coliform data for the Intake site. . . . .	214
B119	Lake Whatcom fecal coliform data for Site 3. . . . .	215
B120	Lake Whatcom fecal coliform data for Site 4. . . . .	216
B121	Lake Whatcom plankton data for Site 1. . . . .	217
B122	Lake Whatcom plankton data for Site 2. . . . .	218

B123	Lake Whatcom plankton data for the Intake Site. . . . .	219
B124	Lake Whatcom plankton data for Site 3. . . . .	220
B125	Lake Whatcom plankton data for Site 4. . . . .	221
B126	Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton	
B127	Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton	
B128	Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining	
B129	Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton	
B130	Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton	
C1	Alkalinity laboratory duplicates for the Lake Whatcom monitoring program.	229
C2	Alkalinity low-range check standards for the Lake Whatcom monitoring program.	230
C3	Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program.	231
C4	Conductivity laboratory duplicates for the Lake Whatcom monitoring program.	232
C5	Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program.	233
C6	Ammonium laboratory duplicates for the Lake Whatcom monitoring program.	234
C7	Ammonium spike recoveries for the Lake Whatcom monitoring program.	235
C8	Ammonium high-range check standards for the Lake Whatcom monitoring program.	236
C9	Ammonium low-range check standards for the Lake Whatcom monitoring program.	237
C10	Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program.	238
C11	Nitrate/nitrite spike recoveries for the Lake Whatcom monitoring program.	239
C12	Nitrate/nitrite high-range check standards for the Lake Whatcom monitoring program.	240
C13	Nitrate/nitrite low-range check standards for the Lake Whatcom monitoring program.	241
C14	Total nitrogen laboratory duplicates for the Lake Whatcom monitoring program.	242
C15	Total nitrogen spike recoveries for the Lake Whatcom monitoring program.	243
C16	Total nitrogen high-range check standards for the Lake Whatcom monitoring program.	244
C17	Total nitrogen low-range check standards for the Lake Whatcom monitoring program.	245

- C18 Laboratory pH duplicates for the Lake Whatcom monitoring program.246
- C19 Soluble reactive phosphate laboratory duplicates for the Lake Whatcom monitoring program.248
- C20 Soluble reactive phosphate spike recoveries for the Lake Whatcom monitoring program.248
- C21 Soluble reactive phosphate high-range check standards for the Lake Whatcom monitoring program.248
- C22 Soluble reactive phosphate low-range check standards for the Lake Whatcom monitoring program.248
- C23 Total phosphorus laboratory duplicates for the Lake Whatcom monitoring program.251
- C24 Total phosphorus spike recoveries for the Lake Whatcom monitoring program.252
- C25 Total phosphorus high-range check standards for the Lake Whatcom monitoring program.253
- C26 Total phosphorus low-range check standards for the Lake Whatcom monitoring program.254
- C27 Total suspended solids laboratory duplicates for the Lake Whatcom monitoring program.255
- C28 Total suspended solids check standards for the Lake Whatcom monitoring program.256
- C29 Turbidity laboratory duplicates for the Lake Whatcom monitoring program.257
- C30 Alkalinity field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C31 Chlorophyll field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C32 Conductivity field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C33 Dissolved oxygen field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C34 Ammonium field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C35 Nitrate/nitrite field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C36 Total nitrogen field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C37 Field duplicates for pH from the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C38 Total phosphorus field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257
- C39 Turbidity field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples).257

## List of Tables

1	Summary of IWS, AmTest, Edge Analytical, and City of Bellingham analytical methods and pa	
2	Summary of Site 1 water quality data, Oct. 2012 – Sept. 2013. . .	17
3	Summary of Intake water quality data, Oct. 2012– Sept. 2013. . .	18
4	Summary of Site 2 water quality data, Oct. 2012 – Sept. 2013. . .	19
5	Summary of Site 3 water quality data, Oct. 2012 – Sept. 2013. . .	20
6	Summary of Site 4 water quality data, Oct. 2012 – Sept. 2013. . .	21
7	October hypolimnetic hydrogen sulfide concentrations at Sites 1 and 2	22
8	Lake Whatcom 2012/2013 total organic carbon data . . . . .	23
9	Austin Creek rating curves, October 1, 2012–May 31, 2013. . . .	38
10	Smith Creek rating curves, October 1, 2012–May 31, 2013. . . . .	39
11	Summary of Anderson Creek storm events and precipitation at the Brannian Creek precipitation	
12	Summary of Austin Creek storm events and precipitation at the North Shore weather station. 5	
13	Summary of Brannian Creek storm events and precipitation at the Brannian Creek precipitation	
A1	Approximate GPS coordinates for Lake Whatcom sampling sites.	90
C1	Single-blind quality control results . . . . .	228



## Executive Summary

- This report describes the results from the 2012/2013 Lake Whatcom monitoring program. The major objectives were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; collect storm runoff water quality data from Anderson, Austin, and Bran-nian Creeks; and continue collection of hydrologic data from Austin and Smith Creeks.
- 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 85.
- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The surface water temperatures were slightly warmer than historic medians during most of the spring and early summer, but cooled rapidly in the fall.
- The levels of hypolimnetic oxygen have declined over time at Site 1, causing the lake to be listed by the Department of Ecology on the 1998 303d list of impaired waterbodies in the State of Washington. Following the onset of stratification, the hypolimnetic oxygen concentrations dropped rapidly. By August 8, 2013, the oxygen concentration was  $<1$  mg/L from 12 meters to the bottom. Temporary stratification resulted in atypically low dissolved oxygen near the bottom at the Intake during August 2013, but the water column was well-mixed at this site by September.
- Nitrate depletion was evident at all sites in the photosynthetic zone during the summer due to algal uptake of this essential nutrient. Low nitrate in the photosynthetic zone favors the growth of Cyanobacteria. 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 and chlorophyll concentrations have increased significantly over time at most sites. The patterns continue to be somewhat variable, but it appears that the chlorophyll concentrations

have stabilized since 2004, with medians ranging from 3.8–6.7  $\mu\text{g/L}$  at Site 1 and 2.9–4.6  $\mu\text{g/L}$  at Sites 2–4.

- The concentrations of trihalomethanes in Bellingham’s treated drinking water have been increasing over time, particularly during the late summer/fall (third quarter). The total THMS and HAAS remained below the recommended maximum contaminant levels of 0.080 mg/L and 0.060 mg/L, respectively.
- All of the mid-basin fecal coliforms counts were less than 10 cfu/100 mL. The coliform counts at the Bloedel-Donovan recreational area (collected offshore from the swimming area) were slightly higher than mid-basin counts, but passed the freshwater *Extraordinary Primary Contact Recreational* bacteria standard for Washington State.
- Hydrograph data were collected at Austin and Smith Creeks using stage-discharge rating curves developed using Aquarius software. Prior to this year, stage-discharge rating curves were developed using Excel. A comparison between Austin Creek and Smith Creek rating curves using both Excel and Aquarius software showed that the hydrographs matched each other closely.
- Eight storm events were monitored in Anderson, Austin, and Brannian Creeks using automated samplers to collect flow-paced or time-paced discrete samples. The storm runoff contained elevated levels of total suspended solids, total phosphorus, and soluble phosphate that were significantly correlated with stage height. In addition, total suspended solids and total phosphorus concentrations were highly correlated with each other.

## 1 Introduction

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 at <http://www.wvu.edu/iws>. Older reports are available in the Institute for Watershed Studies (IWS) library and through the City of Bellingham Public Works Department. A summary of the Lake Whatcom reports, including special project reports, is included in Section 5.2, beginning on page 85.

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom also serves as a water source for the Puget Sound Energy Co-Generation Plant, which is located at the former Georgia-Pacific Corporation site on Bellingham Bay.<sup>1</sup> The lake and parts of the watershed provide recreational opportunities, as well as providing important habitats for fish and wildlife. The lake is used as a storage reservoir to buffer peak storm water flows in Whatcom Creek. Much of the watershed is zoned for forestry and is managed by state or private timber companies. Because of its aesthetic appeal, much of the watershed is highly valued for residential development.

The City of Bellingham and Western Washington University have collaborated on investigations of the water quality in Lake Whatcom since the early 1960s. Beginning in 1981, a monitoring program was initiated by the City and WWU that was designed to provide long-term data for Lake Whatcom for basic parameters such as temperature, pH, dissolved oxygen, conductivity, turbidity, nutrients (nitrogen and phosphorus), and other representative water quality measurements. The major goal of the long-term monitoring effort is to provide a record of Lake Whatcom's water quality over time.

The major objectives of the 2012/2013 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom; collect storm runoff water quality data from Anderson, Austin, and Brannian Creeks; and continue collection of hydrologic data from Austin and Smith Creeks.

---

<sup>1</sup>The Georgia-Pacific Corporation closed its Bellingham pulp mill operations in 2001, reducing its water requirements from 30–35 MGD to 7–12 MGD. By 2007 the water requirements had been reduced to 0.6–3.88 MGD; the mill closed its operations in December 2007.

Detailed site descriptions can be found in Appendix A. The historic lake data are plotted in Appendix B. The current quality control results can be found in Appendix C. The monitoring data are available online at <http://www.wvu.edu/iws> as described in Appendix D (page 269). Table 1 (page 16) 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 91 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 (north of the Sunnyside sill), and Site 4 is located at the deepest point in the southern sub-basin of basin 3 (south of the Sunnyside sill). 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 9 & 11, November 6 & 15, and December 6 & 12 2012; and February 7 & 14, April 9 & 11, May 7 & 9, June 4 & 6, July 9 & 11, August 6 & 8, and September 3 & 4 2013. 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<sup>2</sup> was used to measure temperature, pH, dissolved oxygen, and conductivity. Raw water samples were collected using a Van-Dorn 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 1 (page 16). Total organic carbon analyses

---

<sup>2</sup>YSI Inc., Yellow Springs, Ohio

were done by AmTest.<sup>3</sup> Plankton samples were placed in a cooler and returned to the laboratory unpreserved. The plankton sample volumes were measured in the laboratory and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham.

## 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<sup>4</sup>, nitrate/nitrite, total nitrogen, soluble phosphate, total phosphorus, alkalinity, turbidity, chlorophyll); plankton and bacteria counts; and total organic carbon measurements.

Tables 2–6 (pages 17–21) summarize the current field measurements, ambient water quality, and coliform data. The raw data are available online at <http://www.wvu.edu/iws> as described in Appendix D (page 269). The monthly profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 95–144).

The 2012/2013 lake data are plotted with historic lake data in Figures B51–B130 (pages 146–226). 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.

### 2.3.1 Water temperature

The mid-winter temperature profiles (e.g., Figures B16–B20, pages 110–114) and the multi-year temperature profiles (Figures B51–B55, pages 146–150) show that the water column mixes during the fall, winter, and early spring. During this time, water temperatures, dissolved oxygen concentrations, pH levels, and conductivi-

---

<sup>3</sup>AmTest, 13600 Northeast 126th Place, Suite C, Kirkland, WA, 98034–8720.

<sup>4</sup>Ammonium ( $\text{NH}_4^+$ ) is ionized ammonia ( $\text{NH}_3$ ). 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.

ties are fairly uniform from the surface to the bottom of the lake, even at Site 4, which is over 300 ft (100 m) deep.

The summer temperature profiles (e.g., Figures B46–B50, pages 140–144) show how the lake stratifies into a warm surface layer (*epilimnion*), and cool bottom layer (*hypolimnion*). The transition zone between the epilimnion and hypolimnion (the *metalimnion*), is a region of rapidly changing water temperature. When stratified, the profiles show distinct differences between surface and bottom temperatures.

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 are usually stratified by late spring or early summer. (The Intake is too shallow to develop a stable stratification.) 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 ( $\Delta T \geq 5^\circ\text{C}$ ), it is unlikely that the lake will destratify.<sup>5</sup>

The lake cools as the weather becomes colder and days shorten. As the lake cools, the surface and bottom water temperatures become more similar, and eventually the lake will destratify and the water column will mix from the surface to the bottom. Although destratification is relatively abrupt, the process is not instantaneous. In addition, 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 (see November 2006 temperature and oxygen profiles from Sites 1–2: Figures B6 and B7 in Matthews, et al., 2008). Basins 1 and 2 (Sites 1–2) usually destratify by the end of October but basin 3 (Sites 3–4) is often still stratified in November or early December. Complete destratification of basin 3 usually occurs in December or early January, so by February the temperatures are relatively uniform throughout the water column at all sites.

---

<sup>5</sup>The  $\Delta T$  is the difference between the epilimnion and hypolimnion temperatures.

Historic data reveal that water temperatures in basin 3 are generally cooler than in basins 1 and 2, but the two shallow basins experience more extreme temperature variations. The lowest and highest temperatures measured in the lake since 1988 were at Site 1 (4.2° C on February 1, 1988 and February 26, 1989; 24.1° C on August 4, 2009). The large water volume in basin 3 moderates temperature fluctuations, so water temperatures in basin 3 change slower in response to weather conditions compared to the shallow basins.

The surface water temperatures during 2013 were slightly warmer than the historic median values during most of the spring and early summer, but cooled rapidly in the fall. As a result, by October 2013 the surface temperatures were slightly cooler than historic medians (Figure 1, page 24).

All sites except the Intake were stratified during the October 2012 sampling period (Figures B1–B5, pages 95–99). Sites 1–2 were destratified on November 15, 2012 (Figures B6 and B7, pages 100 and 101) and the dissolved oxygen concentrations were homogeneous throughout the water column at Site 1. At Site 2 the dissolved oxygen concentrations were homogeneous at all depths except 20 meters, indicating that the water column was not yet completely mixed.

Sites 3–4 were still stratified on November 6, 2012 and very weakly stratified on December 12, 2012 (Figures B9, B10, B14, and B15; pages 103, B10, 108, and 109). The entire lake was destratified by the February 2013 sampling period (Figures B16–B20, pages 110–B20).

The lake had not developed stable stratification by the April 2013 sampling period, but all sites (except the Intake) were stratified by early May (Figures B21–B30, pages 115–124). Although the Intake does not develop stable (persistent) stratification, the water column can form temporary stratification during periods of calm weather, which is characterized by incomplete mixing. This condition was present on August 8, 2013, as can be seen by the low oxygen concentrations and pH levels at 10 meters (Figure B43, page 137). By the following month, although the other sites were still stratified, the water column at the Intake was well mixed (Figure B48, page 142).



### 2.3.2 Dissolved oxygen

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.

As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures B41–B42 and B56–B57, pages 135–136 and 151–152). 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, occasionally, in the deepest sample from Site 3 (Figures B49–B50 and B59–B60, pages 143–144 and 154–155).

In contrast, there is rapid depletion of the hypolimnetic oxygen concentrations at Sites 1–2 (Figures B46–B47, and B56–B57, pages 140–141 and 151–152). 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.<sup>6</sup>

As discussed on page 5, temporary stratification resulted in an atypically low dissolved oxygen concentration at 10 meters at the Intake site on August 8, 2013 (Figure B43, page 137). This was probably due to slow water column circulation, which can occur during periods of calm weather, even at sites that do not develop stable stratification. By the following month, although the other sites were still stratified, the water column at the Intake was well mixed (Figure B48, page 142)

---

<sup>6</sup>The photic zone is the portion of the lake with enough light to support algal photosynthesis. In Lake Whatcom, peak chlorophyll levels are usually at 5–10 meters, so photic zone volumes will be defined as the percent volume  $\leq 10$  meters. Using this definition, the photic zones for basins 1, 2, and 3 occupy 75%, 70%, and 17%, respectively (Mitchell, et al., 2010).



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).<sup>7</sup> The increasing rate of oxygen loss is most apparent during July and August, after the lake develops a stable thermal stratification but before oxygen levels drop near zero. To illustrate this trend we fitted the July and August data using an exponential function (see discussion by Matthews, et al., 2004). As indicated in Figures 2–5 (pages 25–28), there were significant negative correlations between dissolved oxygen and time for all hypolimnetic samples collected during July and August.<sup>8</sup> By August 8, 2013 the oxygen concentrations were <1 mg/L from 12 meters to the bottom.

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in July (Figure B36, page 130). 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).

Site 3 developed an oxygen sag near the bottom prior to destratification (e.g., September 2013; Figure B49, page 143). This is fairly common at Site 3, as illustrated in the historic data (Figure B59, page 154). Sites 3 and 4 developed small oxygen sags near the thermocline (e.g., Figures B4 and B5, pages 98 and 99), which are caused by respiration of heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (Matthews and DeLuna, 2008).

**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.<sup>9</sup> First, bacteria will use nitrate as an alternate to oxygen, converting nitrate to ammonium or nitrogen gas. Next, bacteria use manganese

---

<sup>7</sup><http://www.ecy.wa.gov/programs/wq/303d>.

<sup>8</sup>Correlation analyses examine the relationships between two variables. The test statistic ranges from -1 to +1; the closer to  $\pm 1$ , the stronger the correlation. The significance is measured using the p-value; significant correlations have p-values <0.05.

<sup>9</sup>For a more complete discussion of anaerobic decomposition in lakes, see Wetzel, 2001.

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 all of the above electron acceptors 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 indirect indicator of the degree of anoxia in the hypolimnion because it will not persist in oxygenated waters and is formed after the nitrate, manganese, and ferrous ions are exhausted.

The hypolimnion at Sites 1–2 usually contain detectable concentrations of hydrogen sulfide by October (Table 7, page 22). 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 at their highest levels. When the lake stratifies late or is unusually cool, the October hydrogen sulfide levels will not be as high as in warmer years.

### **2.3.3 Conductivity and pH**

The pH and conductivity data followed trends that were typical for Lake Whatcom (Figures B1–B50 and B61–B70, pages 95–144 and 156–165). 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.

There was a significant long-term trend in the conductivity data that 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).

### 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 167–171). 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 (Figures B76–B80, pages 172–176).

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).

### 2.3.5 Nitrogen and phosphorus

Figures B81–B105 (pages 177–201) show the nitrogen and phosphorus data for Lake Whatcom. 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.<sup>10</sup>

**Nitrogen:** Most algae require inorganic nitrogen in the form of nitrate or ammonium for growth, but some types of algae can use organic nitrogen or even dissolved nitrogen gas.<sup>11</sup> Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 182–186), particu-

---

<sup>10</sup>Organic nitrogen and phosphorus comes from living or decomposing plants and animals, and may include bacteria, algae, leaf fragments, and other organic particles.

<sup>11</sup>Only Cyanobacteria and a few uncommon species of diatoms can use nitrogen gas.

larly at Site 1, where the epilimnetic nitrate concentrations often drop below 20  $\mu\text{g-N/L}$  by the end of the summer. Epilimnetic nitrogen depletion is an indirect measure of phytoplankton productivity, and because algal densities have been increasing throughout the lake, epilimnetic dissolved inorganic nitrogen concentrations (DIN)<sup>12</sup> have been declining over time (Figure 6, page 29). Low epilimnetic DIN concentrations favor the growth of Cyanobacteria because many types of Cyanobacteria can use dissolved  $\text{N}_2$  gas as a nitrogen source.

Hypolimnetic nitrate concentrations dropped below 20  $\mu\text{g-N/L}$  at Sites 1 and 2 (Figures B86–B87, pages 182–B87). In anaerobic environments, bacteria reduce nitrate ( $\text{NO}_3^-$ ) to nitrite ( $\text{NO}_2^-$ ) and nitrogen gas ( $\text{N}_2$ ). 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. At Site 2 the hypolimnetic nitrate concentrations dropped below 20  $\mu\text{g-N/L}$  from 1999–2006 and 2008–2013, but not in 2007. Matthews, et al. (2008) hypothesized that the higher levels in 2007 were the result of late stratification, which shortened the period of anoxia in the hypolimnion and resulted in less nitrate reduction. The onset of stratification is only one factor involved in hypolimnetic nitrate depletion; the duration of stratification is also important. In 2007, not only did the lake stratify late, Site 2 was nearly destratified by early October and completely mixed by November. The entire period of anoxia was short compared to most years.

Ammonium, along with hydrogen sulfide, is often an indicator of hypolimnetic anoxia.<sup>13</sup> 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 nitrite and nitrate through biological and chemical processes. In low oxygen environments, ammonium accumulates until the lake destratifies. High levels of ammonium (and hydrogen sulfide) are often detected in the hypolimnion at Sites 1 and 2 just before destratification (Figures B81 & B82, pages 177 & 178). 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 178).

---

<sup>12</sup>Dissolved inorganic nitrogen includes ammonium, nitrate, and nitrite. Under most conditions, epilimnetic concentrations of ammonium and nitrite are very low, so epilimnetic DIN is nearly equivalent to nitrate.

<sup>13</sup>Ammonium is produced during decomposition of organic matter; hydrogen sulfide is produced by bacteria that use sulfate ( $\text{SO}_4^{2-}$ ) instead of oxygen, creating sulfide ( $\text{S}^{2-}$ ) that reacts with hydrogen ions to form hydrogen sulfide ( $\text{H}_2\text{S}$ ). See hydrogen sulfide discussion on page 7.

Sites 3 and 4 often have slightly elevated ammonium concentrations at 20 m (metalimnion) or near the bottom at 80–90 m (Figures B84–B85, pages 180–181). This is caused by bacterial decomposition of organic matter, but the concentrations never approach the levels found in the hypolimnion at Sites 1–2.

**Phosphorus:** Although the Lake Whatcom microbiota require nitrogen, phosphorus is usually what limits microbial growth (Bittner, 1993; Liang, 1994; Matthews, et al., 2002a; McDonald, 1994). The total phosphorus concentration in the water column is a complex mixture of soluble and insoluble phosphorus compounds, only some of which can be used by algae to sustain growth. Soluble forms of phosphorus (e.g., orthophosphate) are easily taken up by algae and other microbiota, and, as a result, are rarely found in high concentrations in the water column. Insoluble phosphorus can be present in the water column bound to the surface of tiny particles or as suspended organic matter (e.g., live or dead algae). Because competition for phosphorus is so intense, microbiota have developed many mechanisms for obtaining phosphorus from the surface of particles or from decomposing organic matter. Liang (1994) and Groce (2011) found that ~50% of the total phosphorus in soils in the Lake Whatcom watershed was potentially “bioavailable” for algal growth.

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 mixed 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. But, since this uptake simply moves the phosphorus into the “live-algae” fraction of organic phosphorus, total phosphorus concentrations may actually increase in the epilimnion.

In Lake Whatcom, total phosphorus and soluble phosphate concentrations were usually low except in the hypolimnion at Sites 1 and 2 just prior to destratification (Figures B96–B100, pages 192–196 and B101–B105, pages 197–201). Epilimnetic total phosphorus concentrations are usually lower than late-summer hypolimnetic peaks. Prior to 2000, the median epilimnetic phosphorus concentrations were  $<5 \mu\text{g-P/L}$  at Sites 2–4 and approximately  $5\text{--}8 \mu\text{g-P/L}$  at Site 1 (Figure 7, page 30). The epilimnetic phosphorus levels have increased significantly at most sites (Figure 7, page 30); however, the pattern is quite erratic, reflecting the complicated nature of phosphorus movement in the water column. It is important to note that low water column phosphorus concentrations do not always predict low algal densities, and may instead indicate rapid and efficient cycling of phosphorus among the lake biota.

### 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 202–206). 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, consisting primarily *Dinobryon*, *Mallomonas*, and diatoms (Figures B121–B130, pages 217–226). Substantial blooms of bluegreen bacteria (Cyanobacteria) and green algae (Chlorophyta) 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, Cyanobacteria and Chlorophyta often dominate the plankton biomass, particularly in late summer and early fall (Ashurst, 2003; Matthews, et al., 2002b). In addition, most of the Cyanobacteria in these samples are counted by colony rather than as individual cells because of the tiny cell size. When the Cyanobacteria density is estimated using settled algae counts (Matthews, et al. 2012), the plankton counts are dominated by tiny Cyanobacteria.

Secchi depths (Figures B111–B115, pages 207–211) showed no clear seasonal pattern because transparency in Lake Whatcom is affected by particulates from storm events and the Nooksack River diversion 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 8, page 31). Site 1 has shown the least amount of change and Sites 3–4 have shown greatest change. In 2013, the median near-surface summer chlorophyll concentrations at Sites 1 and 4 were nearly identical (4.07 and 4.04  $\mu\text{g/L}$ , respectively). Although the annual chlorophyll concentrations are quite variable, they seem to have stabilized since 2004, ranging from 3.8–6.7  $\mu\text{g/L}$  at Site 1 and 2.9–4.6  $\mu\text{g/L}$  at Sites 2–4.

Chlorophyll is a direct measure of algal biomass and is best used to evaluate trophic changes in the lake (e.g., is the lake becoming more biologically productive?). We used 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<sup>14</sup> the algae counts have also increased significantly since 1994 (Figure 9, page 32). Similarly, there has been a steady increase in the numbers of Cyanobacteria at all sites (Figure 10, page 33). As with the chlorophyll concentrations, the algae and Cyanobacteria counts appear to have stabilized around 2004.

---

<sup>14</sup>Dinoflagellates are small single-cell algae that are common in Lake Whatcom, but rarely have high densities in the plankton counts.



### 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:

*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<sup>15</sup>/100 mL (Figures B116–B120, pages 212–216) 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 5 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 2012/2013 total organic carbon concentrations ranged from 1.4–5.0 mg/L, and were higher in the February samples than in August (Table 8, page 23). The long-term data show that the median total organic carbon concentrations have increased over time (Figure 11, page 34).

---

<sup>15</sup>Colony forming unit/100 mL; cfu/100 mL is sometimes labeled “colonies/100 mL.”



When algal densities or total organic carbon concentrations increase, we expect to see an increase in THMs. To minimize risk, limits are set on the levels of disinfection by-products allowed in treated drinking water through the Safe Drinking Water Act's Disinfection Byproduct Rule. This Rule was adopted in 1979 and has undergone two major revisions (Phase I in 1998; Phase II in 2005). The sampling requirement doubled under Phase II; currently the City samples eight locations in the water distribution system.<sup>16</sup>

The THMs have been increasing in Bellingham's treated drinking water, particularly during the late summer/fall (third quarter; Figure 12, page 35). Haloacetic acids, another disinfection by-product, are not as closely linked to algal concentrations and chlorine dose (Sung, et al., 2000). The Jan-Dec HAAs results were marginally correlated with time due to the large sample size, but the third quarter data were not correlated with time. The total THMs and HAAs remained below the recommended 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.

---

<sup>16</sup>P. Wendling, pers. comm., City of Bellingham Public Works Dept.

Abbrev.	Parameter	Method	Historic DL <sup>†</sup>	2012/2013 MDL <sup>†</sup>	Sensitivity or Confidence limit
<b>IWS field measurements:</b>					
cond	Conductivity	Hydrolab (1997) or YSI (2010)	–	–	± 2 µS/cm
do	Dissolved oxygen	Hydrolab (1997) or YSI (2010)	–	–	± 0.1 mg/L
ph	pH	Hydrolab (1997) or YSI (2010)	–	–	± 0.1 pH unit
temp	Temperature	Hydrolab (1997) or YSI (2010)	–	–	± 0.1° C
disch	Discharge	Rantz et al. (1982); SOP-IWS-6	–	–	–
secchi	Secchi depth	Lind (1985)	–	–	± 0.1 m
<b>IWS laboratory analyses:</b>					
alk	Alkalinity	APHA (2012) #2320; SOP-IWS-8	–	–	± 0.9 mg/L
cond	Conductivity	APHA (2012) #2510; SOP-IWS-8	–	–	± 1.4 µS/cm
do	Dissolved oxygen	APHA (2012) #4500-O.C.; SOP-IWS-8	–	–	± 0.1 mg/L
ph	pH-lab	APHA (2012) #4500-H <sup>+</sup> ; SOP-IWS-8	–	–	± 0.1 pH unit
tss	T. suspended solids	APHA (2012) #2540 D; SOP-IWS-13	2 mg/L	0.9 mg/L	± 2.5 mg/L
turb	Turbidity	APHA (2012) #2130; SOP-IWS-8	–	–	± 0.2 NTU
nh4	Ammonium (auto)	APHA (2012) #4500-NH <sub>3</sub> H; SOP-IWS-19	10 µg-N/L	7.2 µg-N/L	± 5.0 µg-N/L
no3	Nitrite/nitrate (auto)	APHA (2012) #4500-NO <sub>3</sub> I; SOP-IWS-19	20 µg-N/L	6.1 µg-N/L	± 8.9 µg-N/L
tn	T. nitrogen (auto)	APHA (2012) #4500-N C; SOP-IWS-19	100 µg-N/L	35.9 µg-N/L	± 39.1 µg-N/L
srp	Sol. phosphate (auto)	APHA (2012) #4500-P G; SOP-IWS-19	5 µg-P/L	1.4 µg-P/L	± 2.0 µg-P/L
tp	T. phosphorus (auto)	APHA (2012) #4500-P J; SOP-IWS-19	5 µg-P/L	0.7 µg-P/L	± 1.5 µg-P/L
<b>IWS plankton analyses:</b>					
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	–	–	–
<b>City coliform analyses:</b>					
fc	Fecal coliform	APHA (2012) #9222 D	1 cfu/100 mL	1 cfu/100 mL	–
<b>Edge Analytical analyses:</b>					
H <sub>2</sub> S	Hydrogen sulfide	APHA (2012) #4500-S <sup>2</sup>	–	0.100 mg/L	–
<b>AmTest analyses:<sup>‡</sup></b>					
TOC	T. organic carbon	APHA (2012) #5310 B	1.0 mg/L	0.5 mg/L	–

<sup>†</sup> Historic detection limits (DL) are usually higher than current method detection limits (MDL).

<sup>‡</sup> Changes reflect recalculation of detection limits or change in methods.

Table 1: Summary of IWS, AmTest, Edge Analytical, and City of Bellingham analytical methods and parameter abbreviations.

Variable	Min.	Med.	Mean <sup>†</sup>	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	18.5	20.0	20.4	26.4
Conductivity (μS/cm)	58.0	60.0	61.0	76.0
Dissolved oxygen (mg/L)	0.0	9.7	8.3	12.0
pH	6.2	7.3	7.3	8.9
Temperature (°C)	5.5	10.3	11.6	22.9
Turbidity (NTU)	0.5	0.8	1.3	10.8
Nitrogen ammonium (μg-N/L)	<10	<10	23.8	274.6
Nitrogen nitrate/nitrite (μg-N/L)	<20	172.5	174.5	361.6
Nitrogen total (μg-N/L)	180.3	378.0	360.2	560.1
Phosphorus soluble (μg-P/L)	<5	<5	<5	<5
Phosphorus total (μg-P/L)	<5	7.4	9.6	46.2
Chlorophyll (μg/L)	0.5	3.3	4.2	17.0
Secchi depth (m)	3.2	4.9	4.9	7.0
Coliforms fecal (cfu/100 mL) <sup>‡</sup>	<1	1	1	8

<sup>†</sup>Uncensored arithmetic means except coliforms (geometric mean);

<sup>‡</sup>Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 2: Summary of Site 1 water quality data, Oct. 2012 – Sept. 2013.

Variable	Min.	Med.	Mean <sup>†</sup>	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	18.1	19.0	19.1	20.3
Conductivity ( $\mu$ S/cm)	57.0	58.5	58.5	60.0
Dissolved oxygen (mg/L)	0.7	10.3	10.4	11.8
pH	7.1	7.7	7.9	8.6
Temperature ( $^{\circ}$ C)	6.3	14.5	14.4	22.0
Turbidity (NTU)	0.4	0.5	0.5	0.7
Nitrogen ammonium ( $\mu$ g-N/L)	<10	<10	<10	14.1
Nitrogen nitrate/nitrite ( $\mu$ g-N/L)	86.3	216.1	217.6	377.6
Nitrogen total ( $\mu$ g-N/L)	239.3	352.6	365.0	522.5
Phosphorus soluble ( $\mu$ g-P/L)	<5	<5	<5	<5
Phosphorus total ( $\mu$ g-P/L)	<5	<5	<5	7.8
Chlorophyll ( $\mu$ g/L)	1.4	3.2	3.1	3.9
Secchi depth (m)	4.9	5.7	5.7	6.6
Coliforms fecal (cfu/100 mL) <sup>‡</sup>	<1	1	1	3

<sup>†</sup>Uncensored arithmetic means except coliforms (geometric mean);

<sup>‡</sup>Censored values replaced with closest integer (i.e., <1  $\Rightarrow$  1).

Table 3: Summary of Intake water quality data, Oct. 2012– Sept. 2013.

Variable	Min.	Med.	Mean <sup>†</sup>	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	17.9	18.8	19.3	26.1
Conductivity (μS/cm)	57.0	58.5	59.1	76.0
Dissolved oxygen (mg/L)	0.1	9.9	9.4	12.0
pH	6.2	7.4	7.5	8.6
Temperature (°C)	6.3	11.4	12.5	21.9
Turbidity (NTU)	0.4	0.5	0.6	2.4
Nitrogen ammonium (μg-N/L)	<10	<10	14.5	267.3
Nitrogen nitrate/nitrite (μg-N/L)	<20	230.9	233.9	380.3
Nitrogen total (μg-N/L)	243.7	413.5	391.4	541.7
Phosphorus soluble (μg-P/L)	<5	<5	<5	5.5
Phosphorus total (μg-P/L)	<5	5.4	6.5	21.8
Chlorophyll (μg/L)	0.5	3.2	2.9	5.6
Secchi depth (m)	5.1	5.7	5.7	7.2
Coliforms fecal (cfu/100 mL) <sup>‡</sup>	<1	1	1	2

<sup>†</sup>Uncensored arithmetic means except coliforms (geometric mean);

<sup>‡</sup>Censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 4: Summary of Site 2 water quality data, Oct. 2012 – Sept. 2013.

Variable	Min.	Med.	Mean <sup>†</sup>	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	17.8	18.3	18.6	21.2
Conductivity ( $\mu$ S/cm)	57.0	59.0	59.3	78.0
Dissolved oxygen (mg/L)	0.3	9.9	9.9	12.1
pH	6.5	7.3	7.4	8.5
Temperature ( $^{\circ}$ C)	6.3	7.4	10.2	21.6
Turbidity (NTU)	0.2	0.4	0.5	2.5
Nitrogen ammonium ( $\mu$ g-N/L)	<10	<10	<10	31.4
Nitrogen nitrate/nitrite ( $\mu$ g-N/L)	114.8	360.8	316.3	416.0
Nitrogen total ( $\mu$ g-N/L)	259.1	464.0	431.9	519.1
Phosphorus soluble ( $\mu$ g-P/L)	<5	<5	<5	<5
Phosphorus total ( $\mu$ g-P/L)	<5	<5	<5	9.3
Chlorophyll ( $\mu$ g/L)	1.2	3.0	2.7	4.7
Secchi depth (m)	5.0	5.8	6.3	8.1
Coliforms fecal (cfu/100 mL) <sup>‡</sup>	<1	1	1	2

<sup>†</sup>Uncensored arithmetic means except coliforms (geometric mean);

<sup>‡</sup>Censored values replaced with closest integer (i.e., <1  $\Rightarrow$  1).

Table 5: Summary of Site 3 water quality data, Oct. 2012 – Sept. 2013.

Variable	Min.	Med.	Mean <sup>†</sup>	Max.
Alkalinity (mg/L CaCO <sub>3</sub> )	17.3	18.3	18.4	20.1
Conductivity ( $\mu$ S/cm)	57.0	59.0	58.9	62.0
Dissolved oxygen (mg/L)	8.3	9.8	9.9	11.6
pH	6.4	7.2	7.3	8.5
Temperature ( $^{\circ}$ C)	6.3	6.9	9.9	21.2
Turbidity (NTU)	0.2	0.4	0.4	0.7
Nitrogen ammonium ( $\mu$ g-N/L)	<10	<10	<10	14.1
Nitrogen nitrate/nitrite ( $\mu$ g-N/L)	117.6	377.2	332.5	447.9
Nitrogen total ( $\mu$ g-N/L)	261.6	474.5	443.0	512.2
Phosphorus soluble ( $\mu$ g-P/L)	<5	<5	<5	<5
Phosphorus total ( $\mu$ g-P/L)	<5	<5	<5	6.8
Chlorophyll ( $\mu$ g/L)	0.7	2.5	2.6	5.7
Secchi depth (m)	5.5	6.3	6.4	8.5
Coliforms fecal (cfu/100 mL) <sup>‡</sup>	<1	1	1	1

<sup>†</sup>Uncensored arithmetic means except coliforms (geometric mean);

<sup>‡</sup>Censored values replaced with closest integer (i.e., <1  $\Rightarrow$  1).

Table 6: Summary of Site 4 water quality data, Oct. 2012 – Sept. 2013.

Year	H <sub>2</sub> S (mg/L)		Year	H <sub>2</sub> S (mg/L)	
	Site 1	Site 2		Site 1	Site 2
1999 <sup>†</sup>	0.03–0.04	0.40	2006	0.20	0.42
2000 <sup>†</sup>	0.27	0.53	2007	0.40	0.20
2001 <sup>†</sup>	0.42	0.76	2008	0.28	0.38
2002 <sup>†</sup>	0.09	0.32	2009	0.15	0.47
2003 <sup>†</sup>	0.05	0.05	2010	0.38	0.40
2004 <sup>†</sup>	0.25	0.25	2011	0.12	0.16
2005 <sup>‡</sup>	0.13	0.25	2012	na	na
2005 <sup>‡</sup>	0.12	0.42	2013	0.20	0.16

<sup>†</sup>H<sub>2</sub>S samples analyzed by HACH test kit.

<sup>‡</sup>HACH (first value) vs. Edge Analytical (second value)

Table 7: October hypolimnetic hydrogen sulfide concentrations at Sites 1 and 2 (20 m). The H<sub>2</sub>S 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	Date	Depth (m)	TOC (mg/L)	Date	Depth (m)	TOC (mg/L)
Site 1	Feb 7, 2013	0	5.0	Aug 8, 2013	0	2.2
	Feb 7, 2013	20	5.3	Aug 8, 2013	20	1.9
Intake	Feb 7, 2013	0	4.6	Aug 8, 2013	0	1.9
	Feb 7, 2013	10	4.4	Aug 8, 2013	10	1.9
Site 2	Feb 7, 2013	0	4.5	Aug 8, 2013	0	1.9
	Feb 7, 2013	20	4.8	Aug 8, 2013	20	2.0
Site 3	Feb 14, 2013	0	NA	Aug 6, 2013	0	2.1
	Feb 14, 2013	80	5.1	Aug 6, 2013	80	1.5
Site 4	Feb 14, 2013	0	4.8	Aug 6, 2013	0	4.9
	Feb 14, 2013	90	4.5	Aug 6, 2013	90	1.4

Table 8: Lake Whatcom 2012/2013 total organic carbon data. February 7, 2013 Site 3 surface sample was lost during processing.

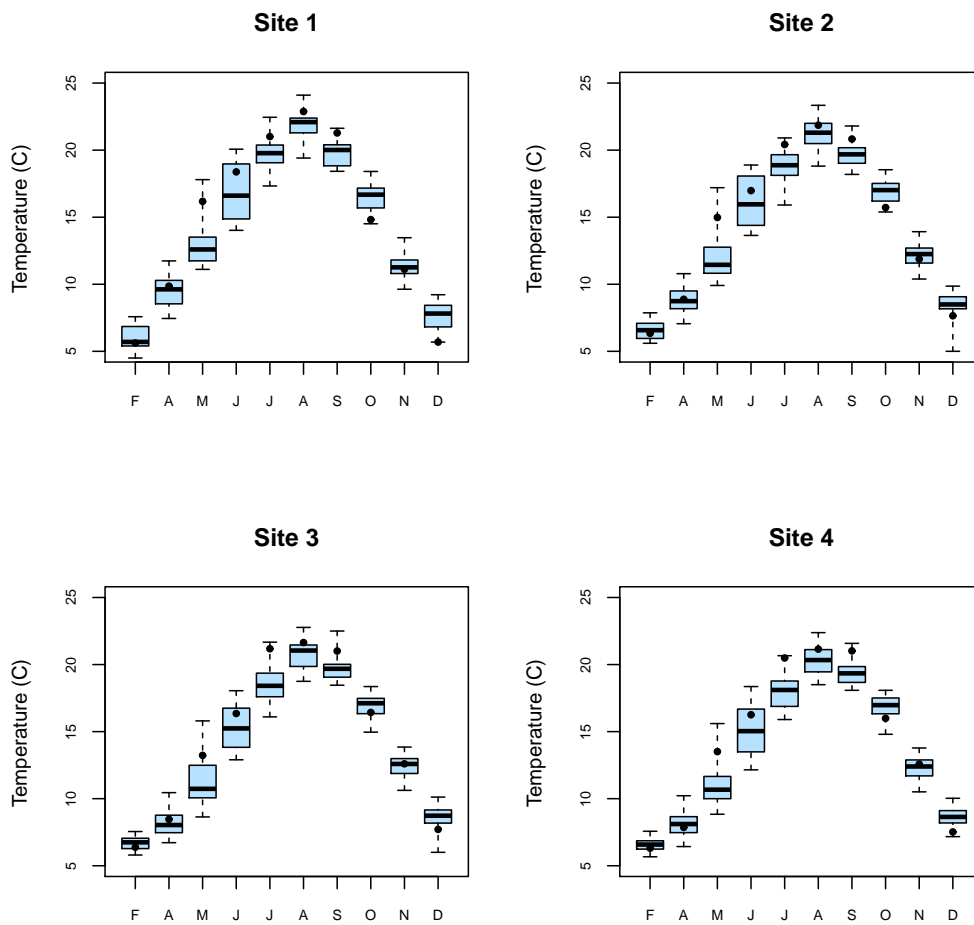


Figure 1: Boxplots showing 1988–2013 surface water temperatures (depth <1 m, all sites and years) with monthly 2013 data (●). Boxplots show medians and upper/lower quartiles; whiskers extend to maximum/minimum values.

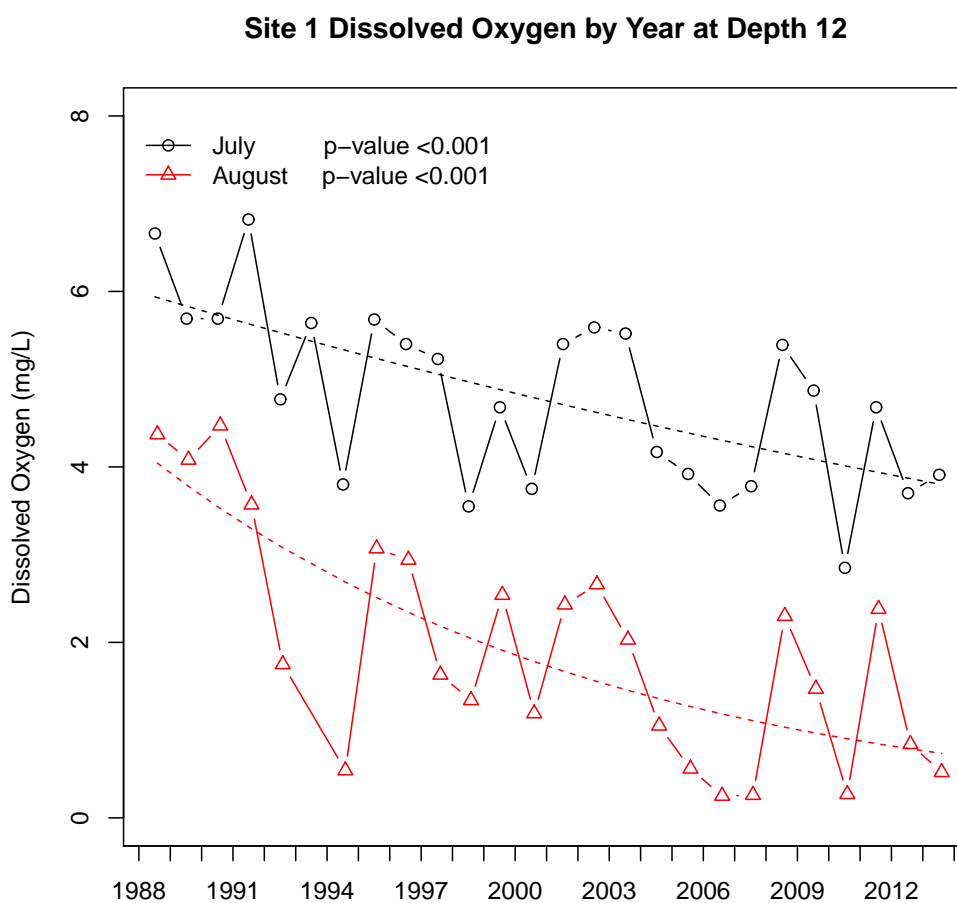


Figure 2: Relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

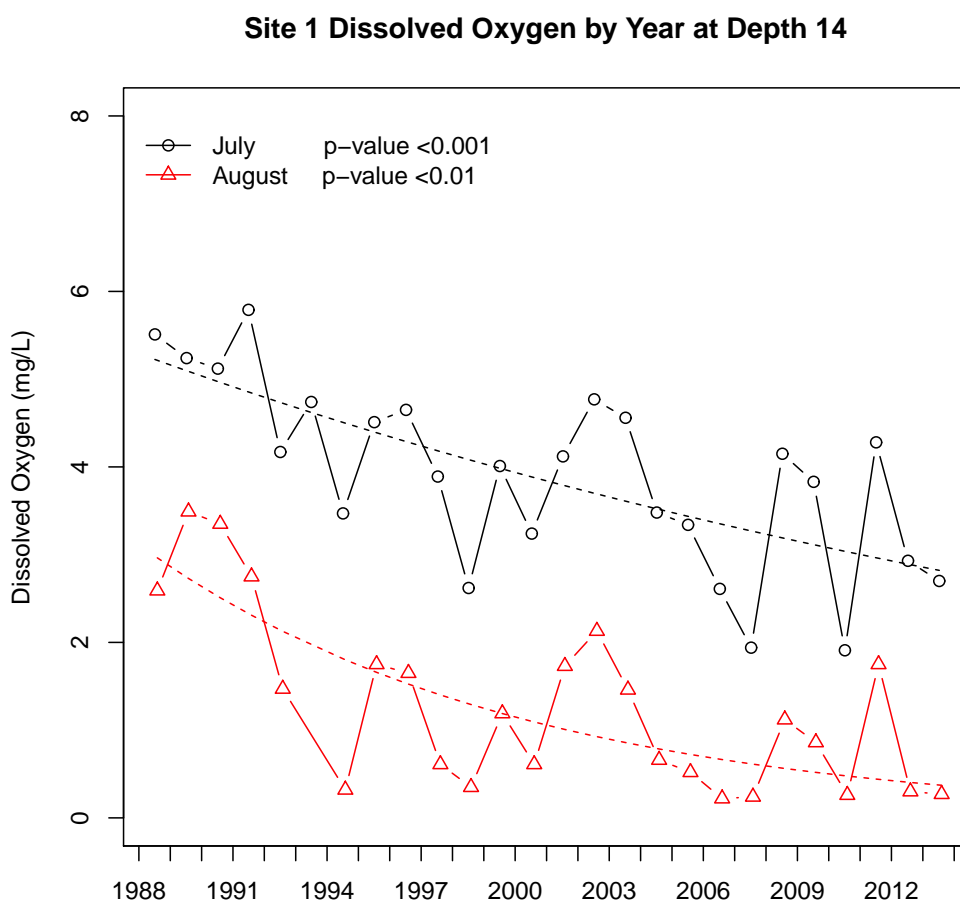


Figure 3: Relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

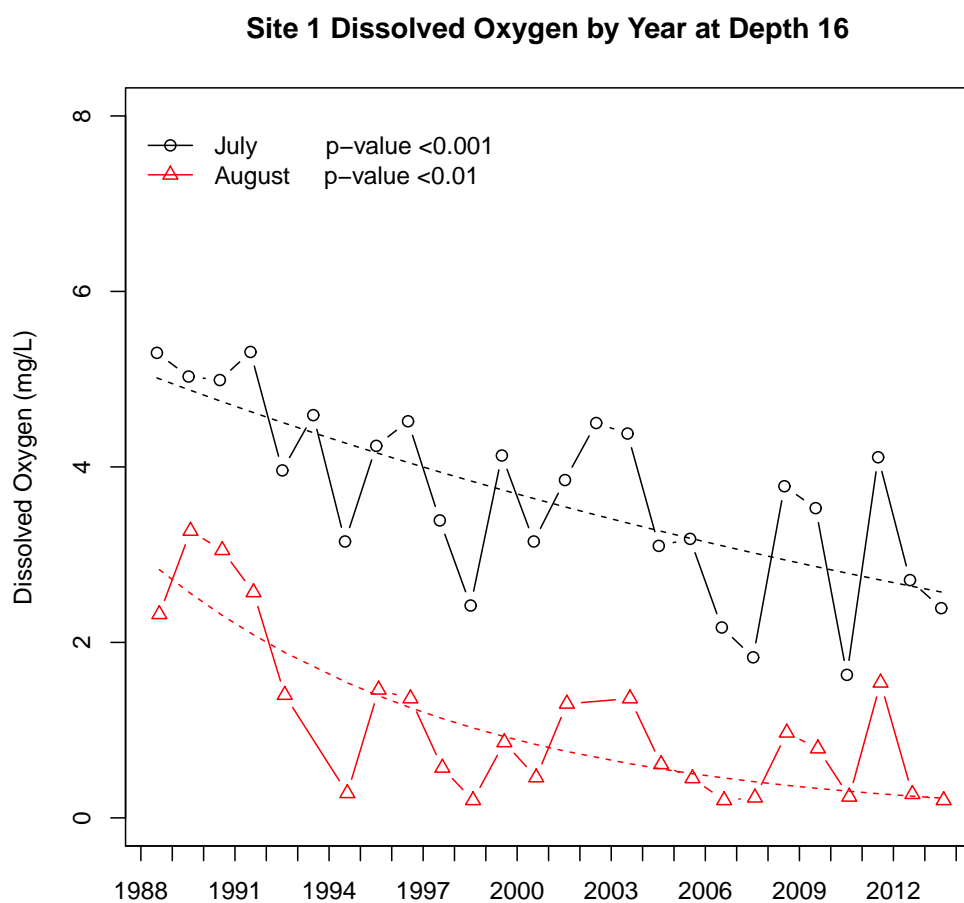


Figure 4: Relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

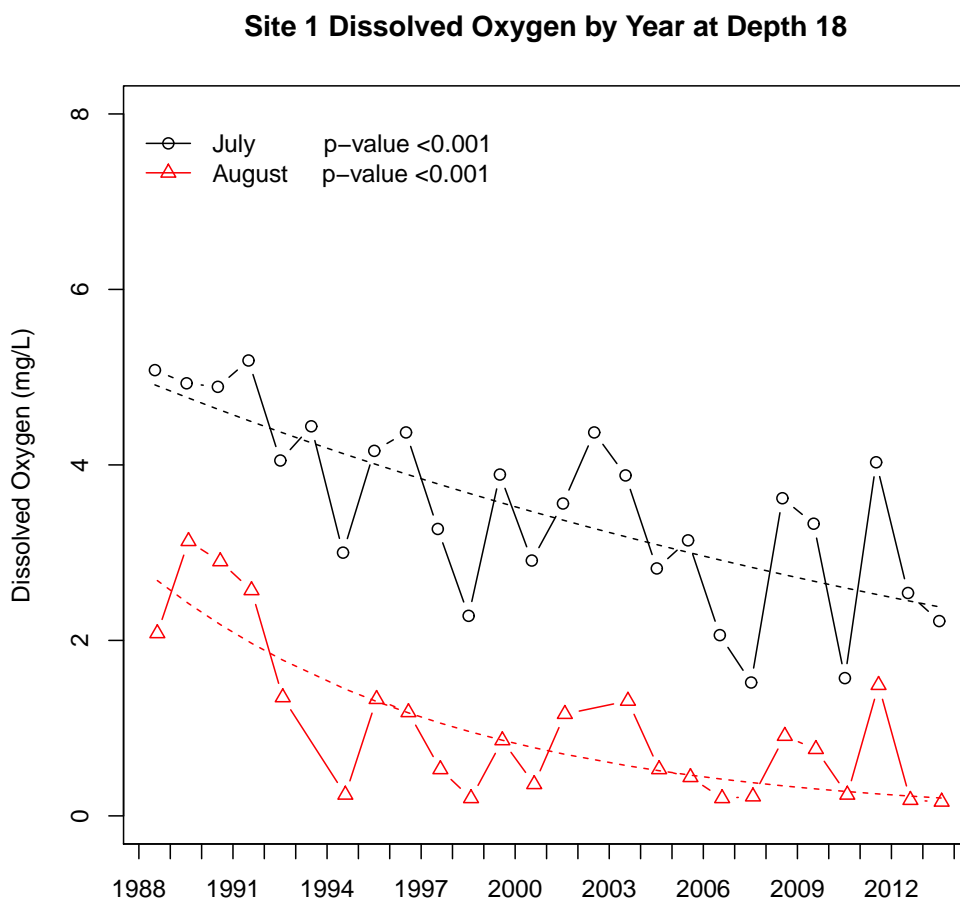


Figure 5: Relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

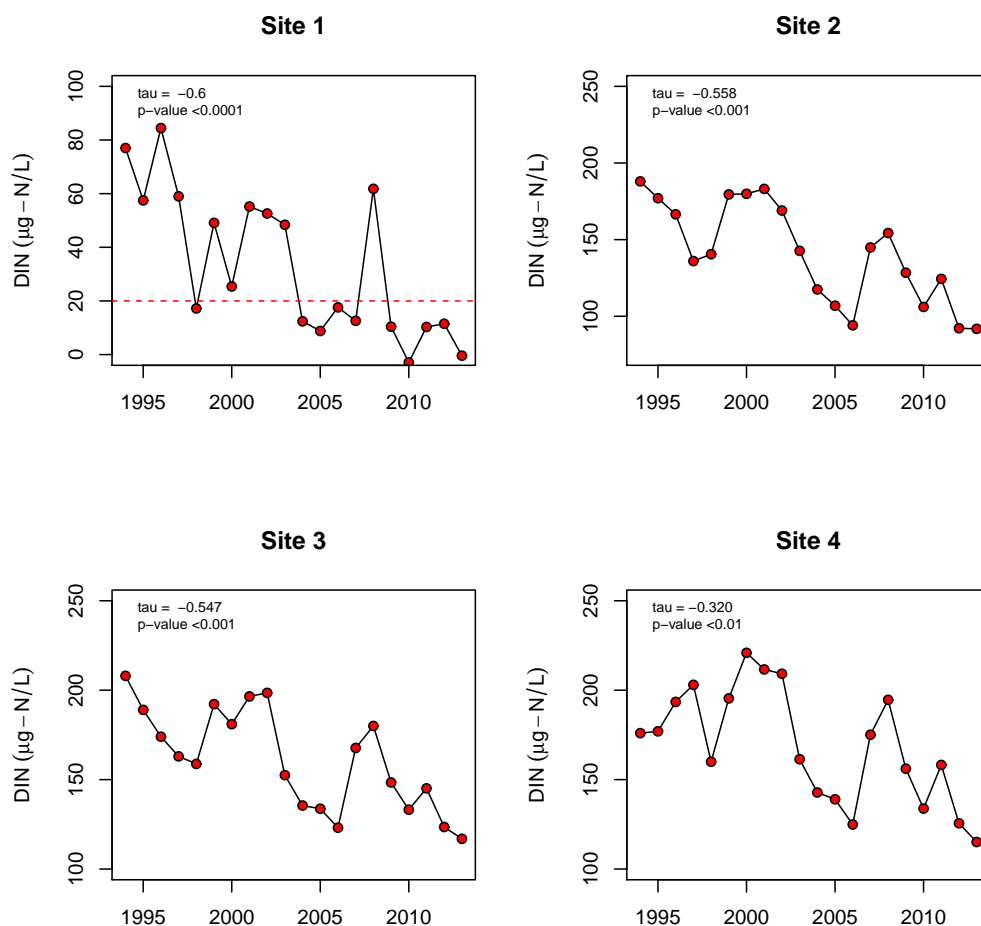


Figure 6: Minimum summer, near-surface dissolved inorganic nitrogen concentrations (1994–2013, June–Oct, depths  $\leq 5$  m). Uncensored (raw) data were used to illustrate that minimum values are dropping below analytical detection limits (dashed red line). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

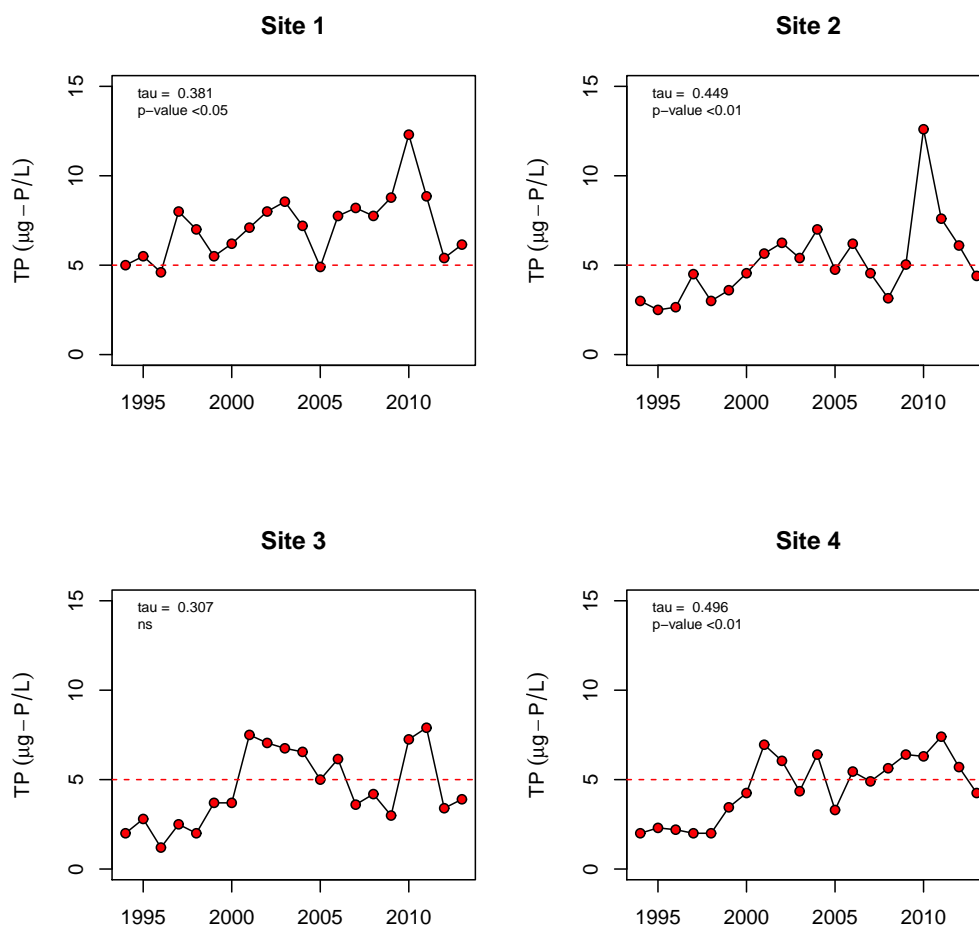


Figure 7: Median summer, near-surface total phosphorus concentrations (1994–2013, June–Oct, depths  $\leq 5$  m). Uncensored (raw) data were used to illustrate that median values are increasingly above analytical detection limits (dashed red line). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; the correlations were significant at Sites 1, 2, and 4.



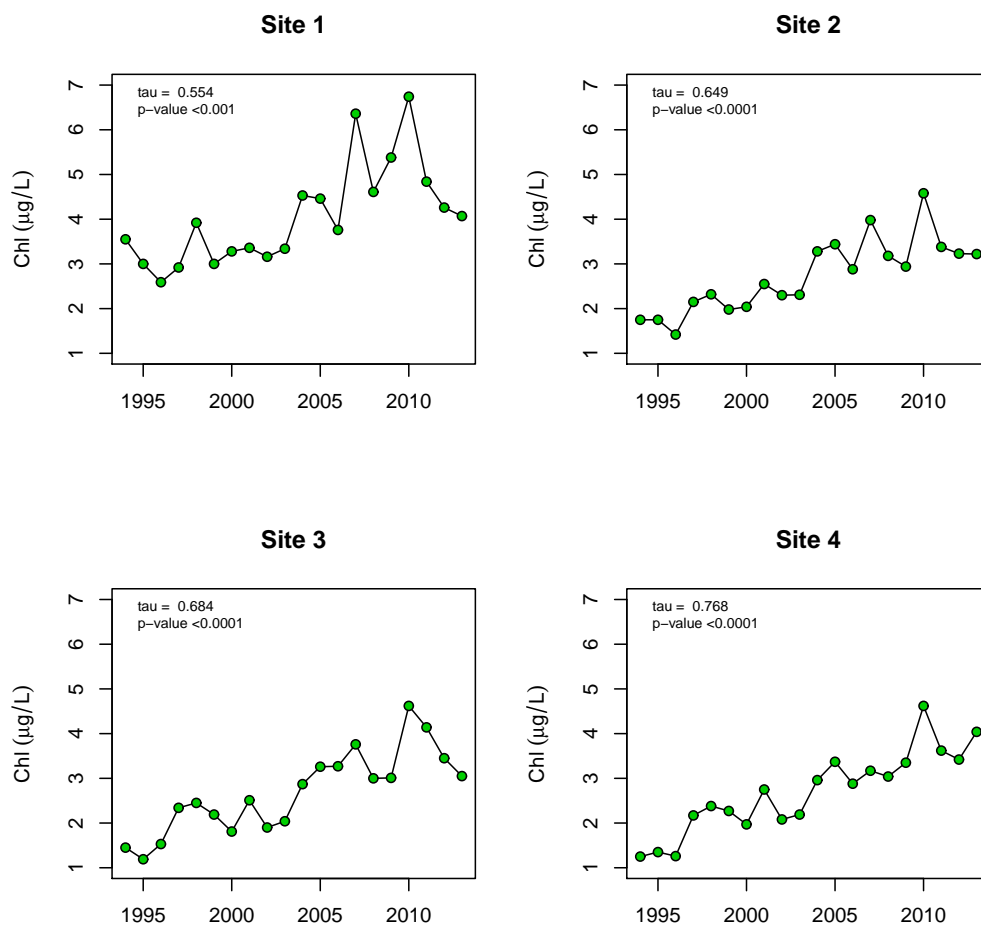


Figure 8: Median summer near-surface chlorophyll concentrations (1994–2013, June–October, depths  $\leq 5$  m). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

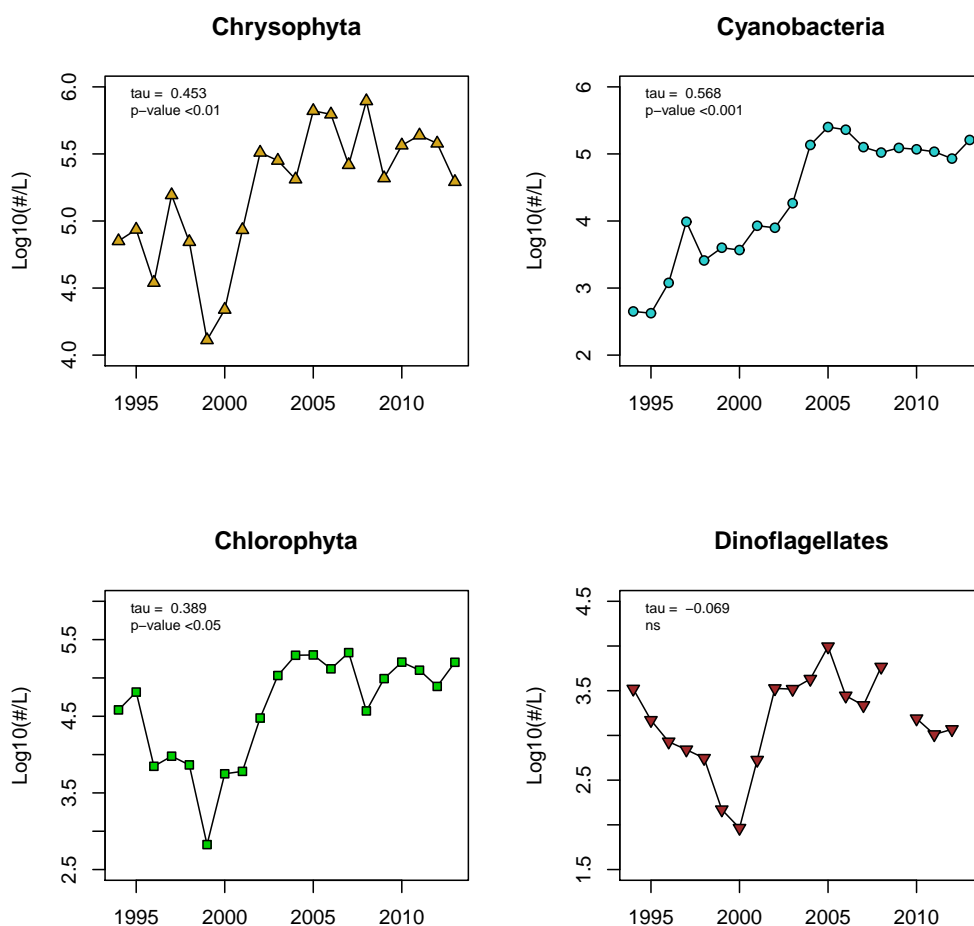


Figure 9:  $\text{Log}_{10}$  plots of median summer, near-surface algae counts (1994-2013, June-October, all sites and depths). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations except Dinoflagellates were significant.

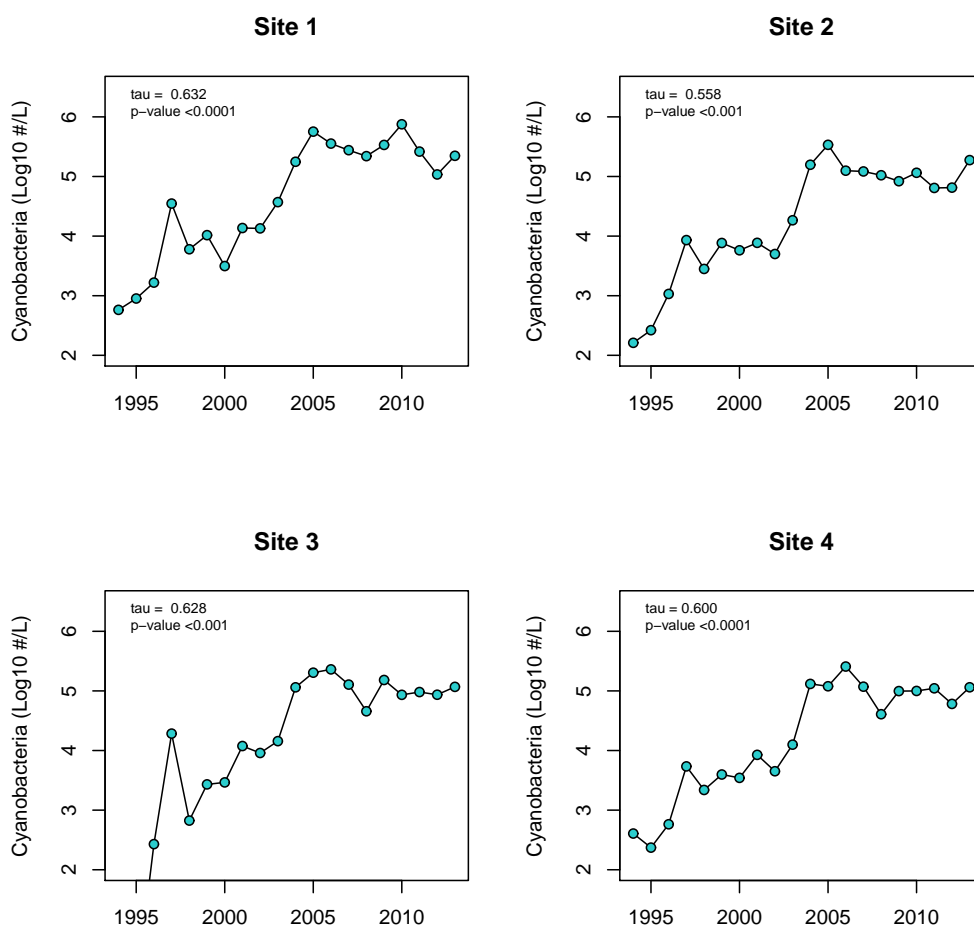


Figure 10: Log<sub>10</sub> plots of median summer, near-surface Cyanobacteria counts (1994–2013, June–October, depths  $\leq 5$  m). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

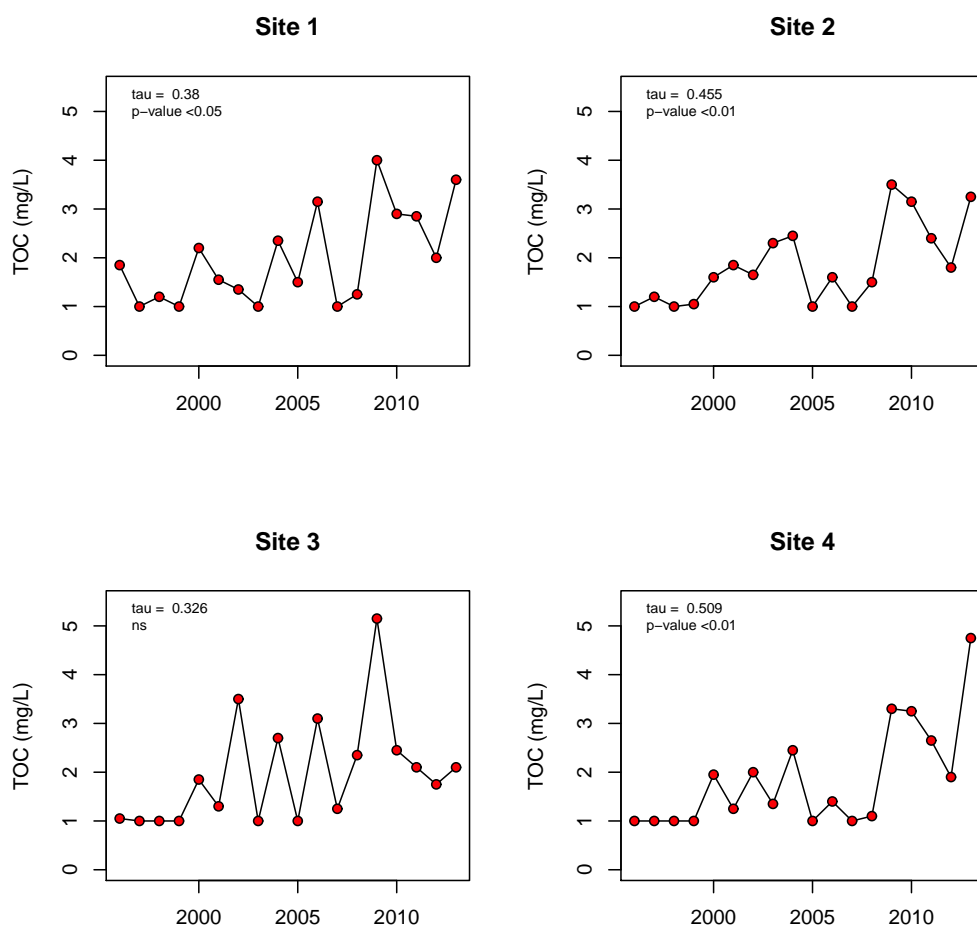


Figure 11: Median annual total organic carbon concentrations (surface/bottom, winter/summer, 1996–2013). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

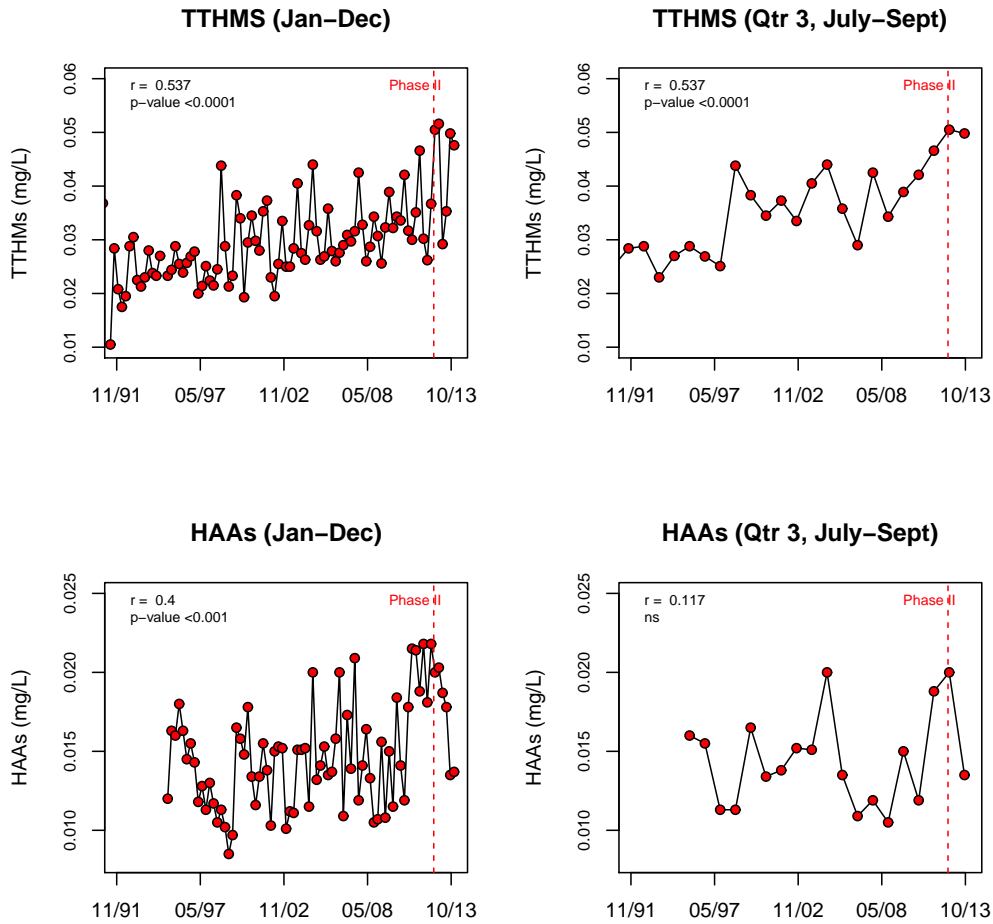


Figure 12: Quarterly average total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2013. Data were provided by the City of Bellingham Public Works Department. Kendall’s  $\tau$  correlations were used because the data were not monotonic-linear; correlations for THMS (Jan-Dec and Qtr 3) and Jan-Dec HAAs were significant. The number of sites used to calculate the quarterly averages increased from four to eight in the fourth quarter of 2012 (vertical red line).

### 3 Hydrograph Data

Recording hydrographs are installed in Austin Creek and Smith Creek; the data are plotted in Figures 14–15 (pages 41–42). The location of each hydrograph is described in Appendix A.2. All hydrograph data, including data from previous years, are online at <http://www.wvu.edu/iws>. Field notes and rating curves for each water year are available from the Institute for Watershed Studies. All results are reported as Pacific Standard Time, without Daylight Saving Time adjustment.

At the Austin Creek site, there was a discrepancy between the sensor stage and staff gauge height at high flows (Figure 13, page 40). The problem may be due to a leak in the system, which will be corrected if possible. For the 2013 water year, stage readings above 1.42 ft were adjusted using the following equation to provide a better match with the observed staff height:

$$\text{adjusted stage (ft)} = 1.3975 \times \text{recorded stage} - 0.5$$

The Austin Creek and Smith Creek discharge values presented in this report were calculated from the original staff heights ( $\leq 1.4$  ft) or adjusted staff heights ( $> 1.4$  ft) using the Aquarius rating curve software (Aquatic Informatics, 2013). Prior to this year, stage-discharge rating curves were developed and applied using Excel. A comparison of the two methods is provided below.

#### 3.1 Rating Curves Comparison

Rating curves were developed for Austin and Smith Creeks using both Excel and Aquarius software and were used to calculate discharge for the period of October 1, 2012–May 31, 2013. For the Excel rating curves, stage measurements were plotted against either the logarithm or the square root of measured discharge (Figures 16–18, pages 43–45). One rating curve was generated for Austin Creek (Figure 16, page 43), and two rating curves (low and high flows) were developed for Smith Creek (Figures 17–18, pages 44–45). The Aquarius curves were plotted on a logarithmic scale using multiple stage height segments (Tables 9–10, pages 38–39; Figures 19–20, pages 46–47).

The two methods produced similar results (Figures 21–22, pages 48–49). The most noticeable difference was that the Aquarius rating curves predicted higher discharges than Excel during the highest flows at Smith Creek (Figure 22). For

Austin Creek, the Aquarius curves produced lower values than Excel for many of the moderate peaks (50–100 cfs; Figure 21). In general, however, the hydrographs matched each other closely. The Nash-Sutcliffe (1970) efficiency (E) was 0.995 for Austin Creek and 0.994 for Smith Creek, and the coefficient of determination ( $r^2$ ; Krause, et al., 2005) was 0.996 for both creeks.

There are advantages with both rating curve methods. The advantages of the Excel method include simplicity and transparency. The Excel software can be programmed to update rating curves and hydrographs automatically when new data are added to the spreadsheet, and the rating curves can be communicated in one or two equations. The benefit of using the Aquarius software is that the rating curves can easily be set up to include many discharge segments, accounting for variations in the stage-discharge relationship at different levels of flow. In addition, the Aquarius software is used by USGS, so the IWS results are more comparable to other streams in the Lake Whatcom watershed that are monitored by USGS.

## Aquarius Rating Curves

Stage Height (ft)	Discharge Equations
0.27–0.32	discharge = $36.836 \times \text{stage}^{3.674}$
0.32–0.37	discharge = $38.507 \times \text{stage}^{3.713}$
0.37–0.49	discharge = $18.656 \times \text{stage}^{2.984}$
0.49–0.72	discharge = $16.870 \times \text{stage}^{2.843}$
0.72–1.00	discharge = $15.690 \times \text{stage}^{2.622}$
1.00–1.39	discharge = $15.691 \times \text{stage}^{2.661}$
1.39–2.06	discharge = $17.035 \times \text{stage}^{2.411}$
2.06–2.64	discharge = $21.449 \times \text{stage}^{2.092}$
2.64–3.17	discharge = $23.159 \times \text{stage}^{2.013}$
3.17–3.91	discharge = $25.020 \times \text{stage}^{1.946}$

## Excel Rating Curve

$$\text{stage} = 0.1871 \times \sqrt{\text{discharge}} + 0.2245$$

Table 9: Austin Creek rating curves, October 1, 2012–May 31, 2013. The Aquarius and Excel rating curves were applied to the original ( $\leq 1.42$  ft) or adjusted ( $> 1.42$  ft) stage heights to calculate discharge as described on page 36.



## Aquarius Rating Curves

Stage Height (ft)	Discharge Equations
1.46–1.49	discharge = 0.004 × stage <sup>9.546</sup>
1.49–1.51	discharge = 0.006 × stage <sup>8.342</sup>
1.51–1.57	discharge = 0.003 × stage <sup>9.951</sup>
1.57–1.64	discharge = 0.003 × stage <sup>10.362</sup>
1.64–1.70	discharge = 0.003 × stage <sup>10.428</sup>
1.70–1.77	discharge = 0.003 × stage <sup>10.305</sup>
1.77–1.84	discharge = 0.003 × stage <sup>10.187</sup>
1.84–1.92	discharge = 0.003 × stage <sup>10.171</sup>
1.92–1.99	discharge = 0.003 × stage <sup>10.298</sup>
1.99–2.05	discharge = 0.012 × stage <sup>8.156</sup>
2.05–2.07	discharge = 0.001 × stage <sup>16.487</sup>
2.07–2.25	discharge = 0.043 × stage <sup>6.481</sup>
2.25–2.57	discharge = 0.059 × stage <sup>6.098</sup>
2.57–2.98	discharge = 0.140 × stage <sup>5.176</sup>
2.98–3.40	discharge = 0.616 × stage <sup>3.820</sup>
3.40–3.81	discharge = 0.511 × stage <sup>3.973</sup>
3.81–4.33	discharge = 0.328 × stage <sup>4.303</sup>
4.33–4.60	discharge = 0.209 × stage <sup>4.612</sup>

## Excel Rating Curves

stage (<2.3 ft) = 0.4352 × log(discharge) + 1.8185
stage (≥2.3 ft) = 0.1983 × sqrt(discharge) + 1.7373

Table 10: Smith Creek rating curves, October 1, 2012–May 31, 2013.

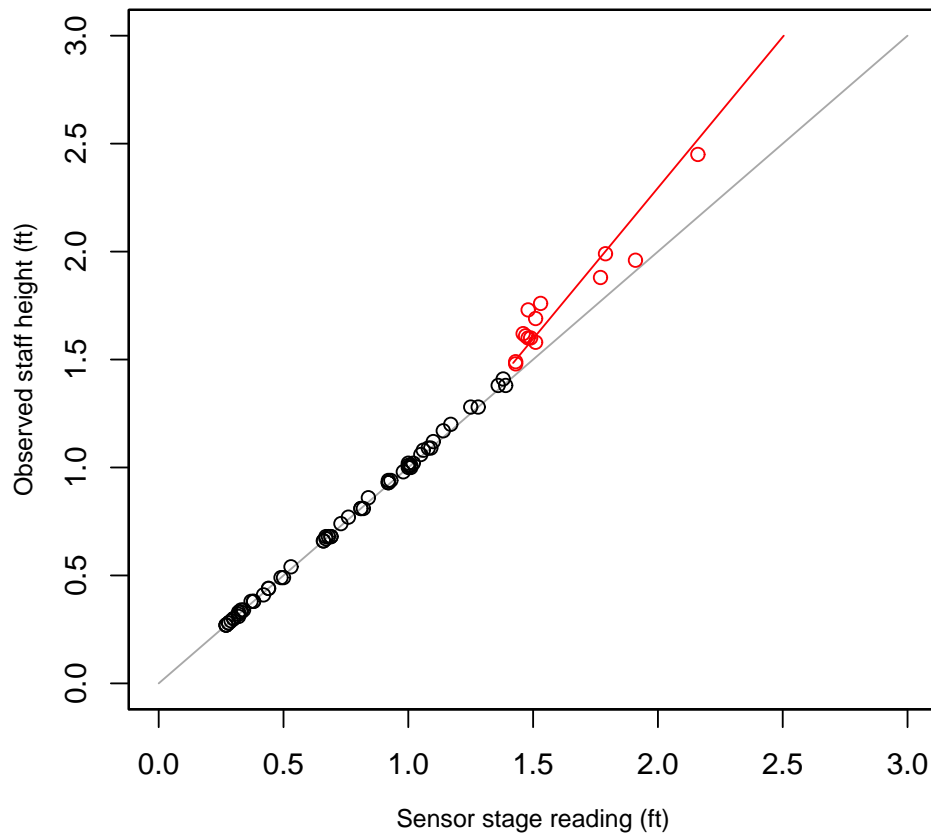


Figure 13: Comparison between observed staff heights and sensor stage readings at Austin Creek. The gray line represents equal staff height and sensor stage. There is a discrepancy between the two measurements for stages above 1.42 ft (red markers). Stage data above this level were adjusted as described on page 36.

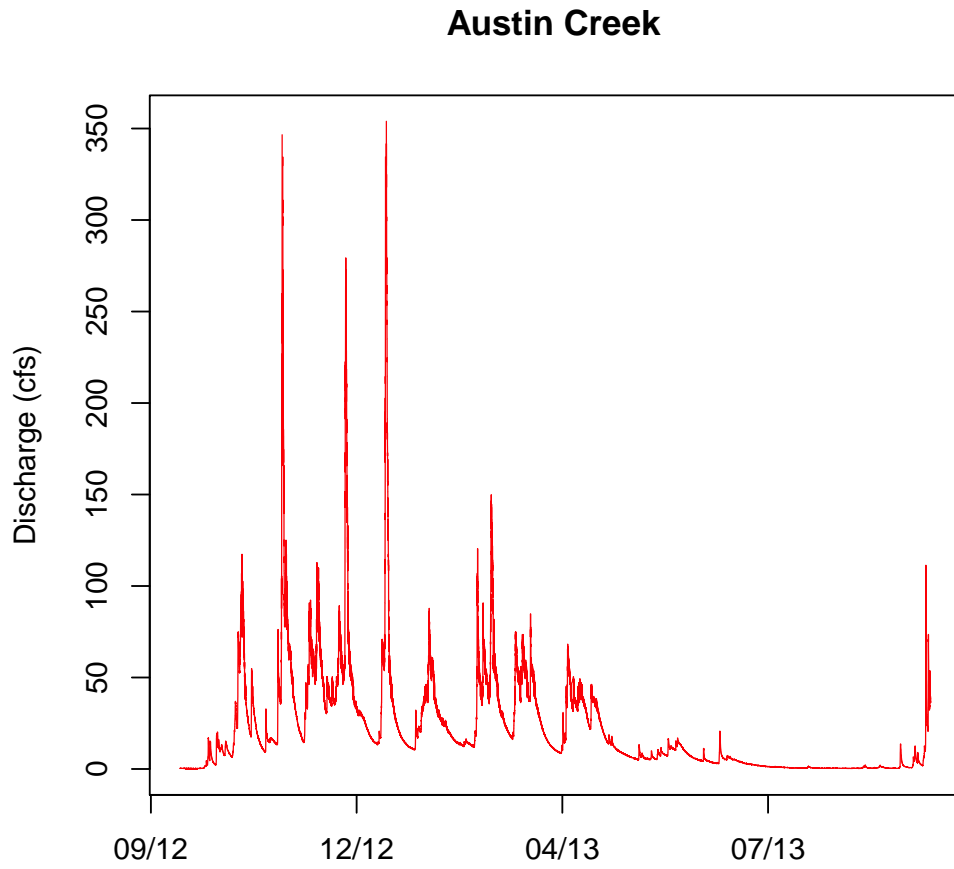


Figure 14: Austin Creek hydrograph, October 1, 2012–September 30, 2013. Data were recorded at 15 minute intervals.

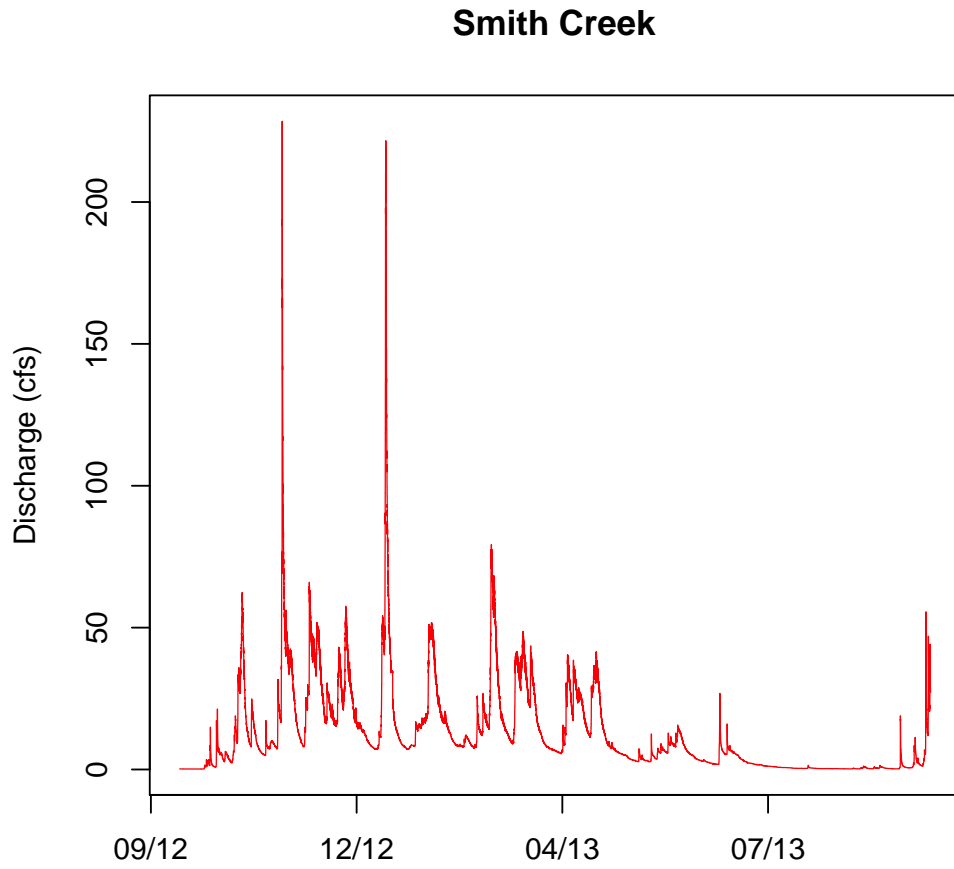


Figure 15: Smith Creek hydrograph, October 1, 2012–September 30, 2013. Data were recorded at 15 minute intervals.

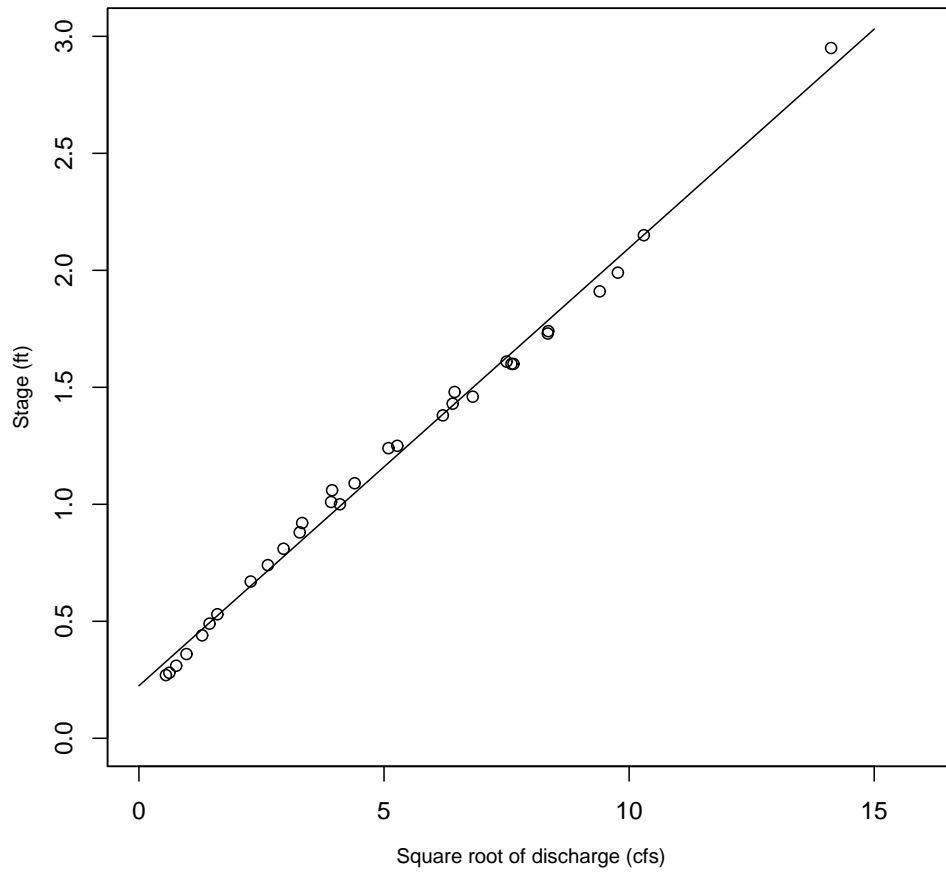


Figure 16: Austin Creek rating curve developed using Excel.

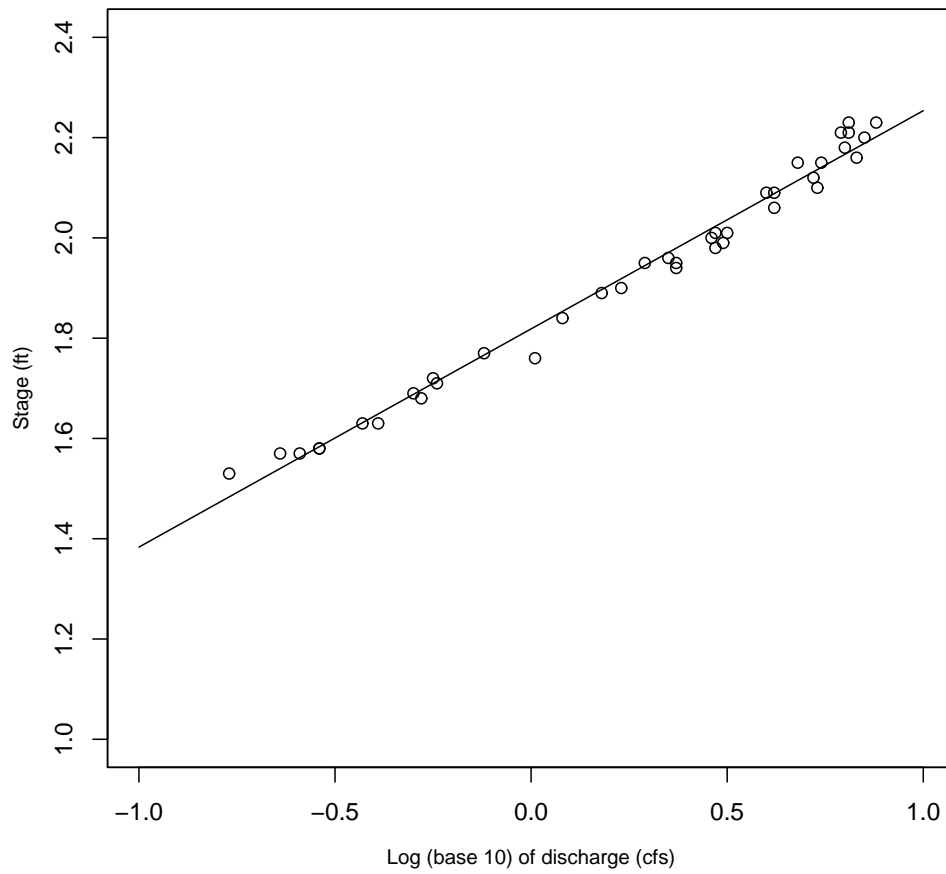


Figure 17: Smith Creek rating curve developed for low flows (stage <2.3 ft) using Excel.

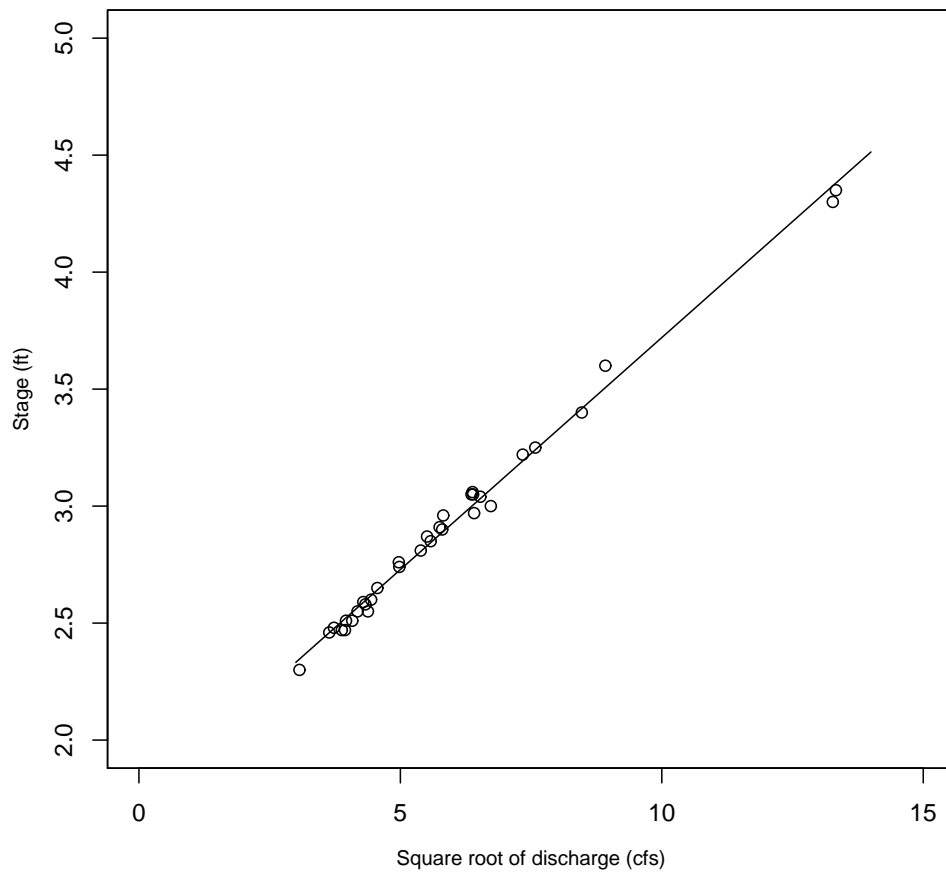


Figure 18: Smith Creek rating curve developed for high flows (stage  $\geq 2.3$  ft) using Excel.

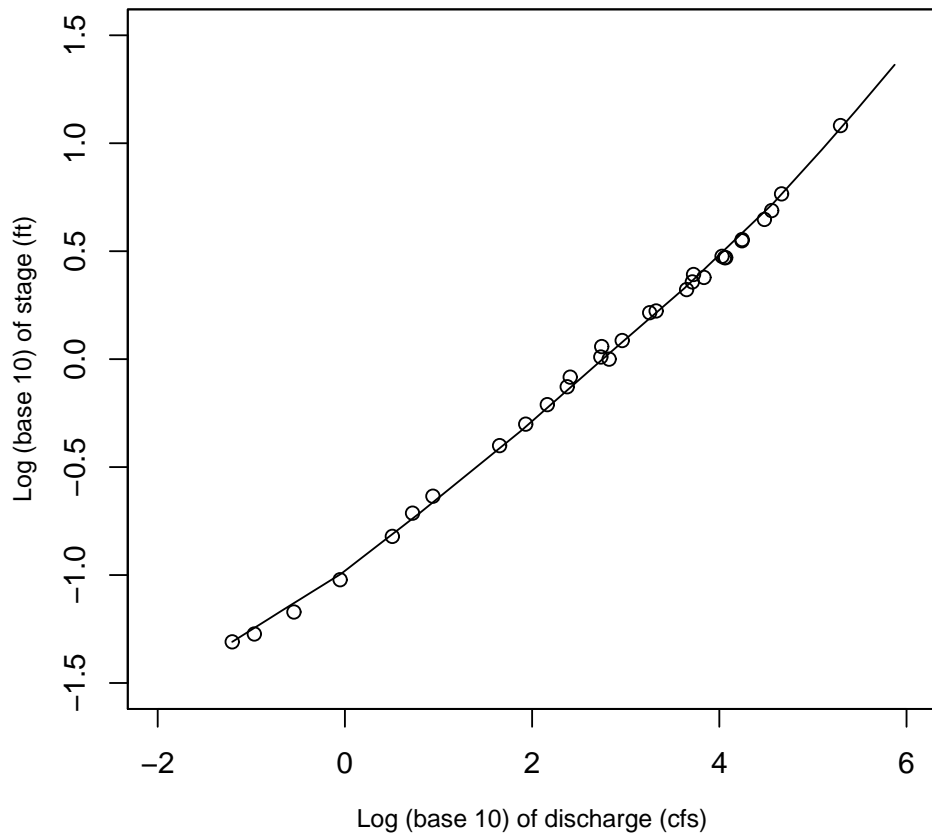


Figure 19: Austin Creek rating curve developed using Aquarius.



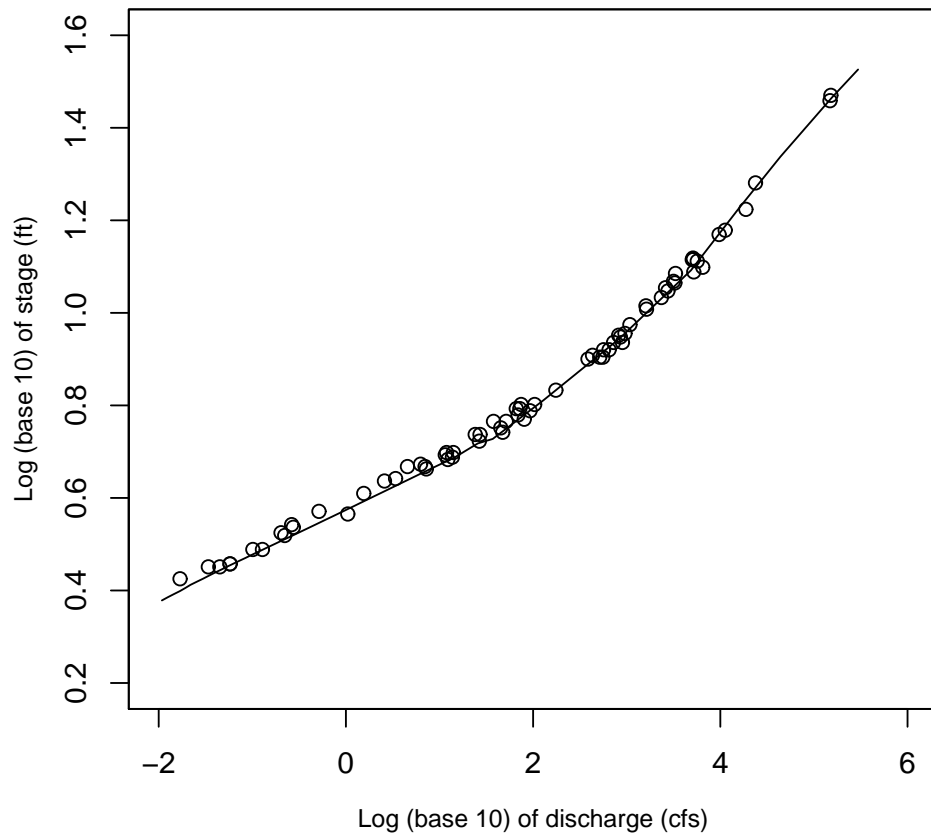


Figure 20: Smith Creek rating curve developed using Aquarius.

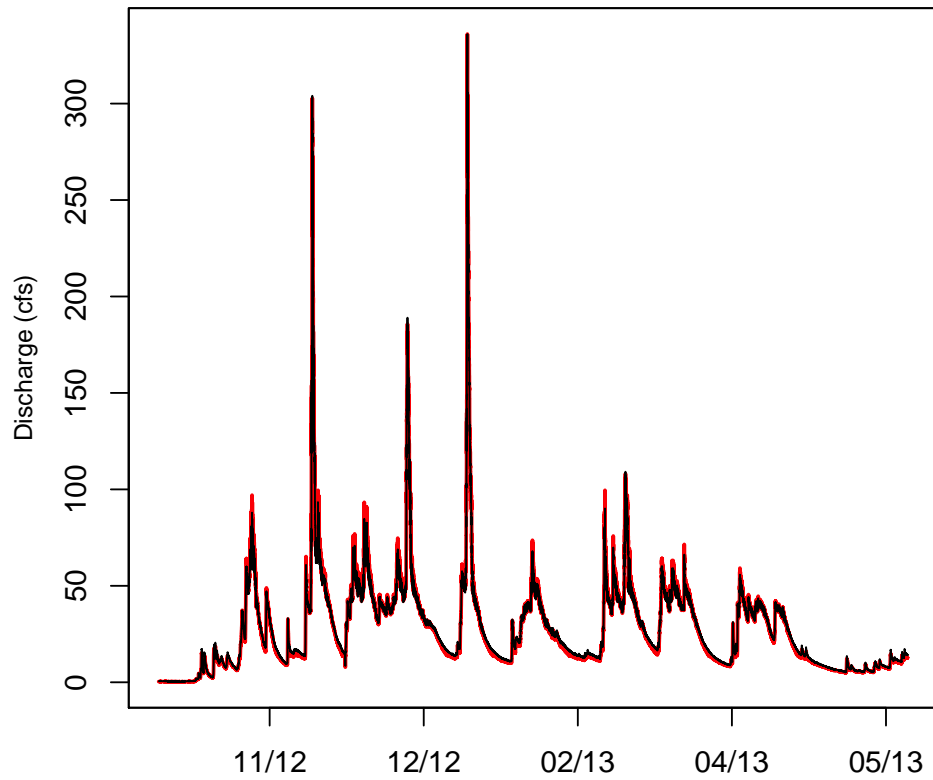


Figure 21: Comparison between Austin Creek hydrographs generated using the Excel (—) and Aquarius (—) rating curves, October 1, 2012 – May 31, 2013.

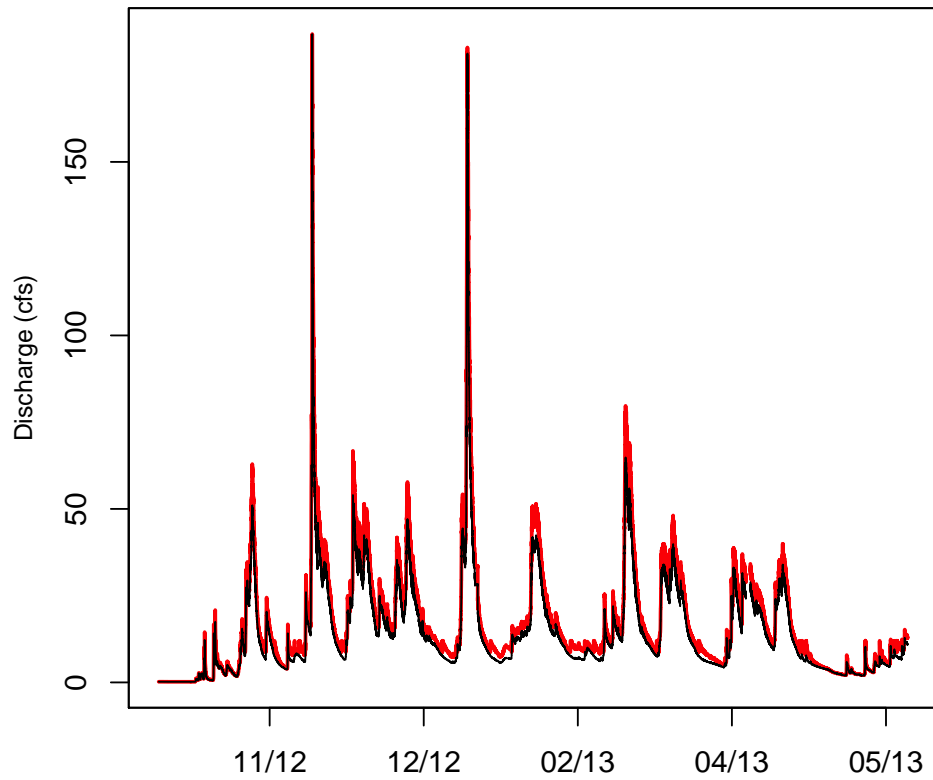


Figure 22: Comparison between Smith Creek hydrographs generated using the Excel (—) and Aquarius (—) rating curves, October 1, 2012–May 31, 2013.

## 4 Storm Water Monitoring

### 4.1 Site Descriptions

Beginning in 2013, storm water monitoring has emphasized sampling in Anderson, Austin, and Brannian Creeks (Figure A2, page 92). For information about other storm water sites that have been monitored by IWS, refer to the annual reports listed in Section 5.2 (page 85).

### 4.2 Field Sampling and Analytical Methods

Eight storm events were sampled between January and November 2013 (Tables 11–13, pages 52–54). Flow-paced or time-paced discrete samples were collected at the gauging sites in Anderson, Austin, and Brannian Creeks using ISCO automated samplers provided by the City of Bellingham. Seven of the eight events (Events 1–6, 8) were sampled at Anderson Creek, six of the eight (Events 1–4, 6, 8) were sampled at Brannian Creek, and five of the eight (Events 2–4, 7–8) were sampled at Austin Creek. With the exception of Event 2 at Austin Creek, all events met the precipitation guidance of  $\geq 1$  cm in 24 hours and included samples from the rising and falling legs of the hydrograph.

For Events 1–4, the ISCO samplers collected flow-paced samples. For Events 5–8 the samplers collected time-paced samples. The change to time-paced sampling was made to provide better representation of the rising leg of the hydrograph. The ISCO samplers recorded stream elevation (stage height) at 15 minute intervals during each storm event and when a water sample was collected.<sup>17</sup>

The samples were analyzed for total suspended solids, total phosphorus, soluble reactive phosphorus, total nitrogen, and nitrate/nitrite following the methods summarized in Table 1 (page 16).

---

<sup>17</sup>The flow-paced water samples were collected at irregular intervals based on stream flow, so the sampling time rarely coincided with the automatic 15-min stage height measurements.

### 4.3 Results and Discussion

The amount and intensity of precipitation varied between storm events (Tables 11–13; Figures 23, 29, and 35, pages 55, 61, and 67). The 24-hour maximum precipitation totals ranged from 0.6–4.2 cm. Precipitation totals recorded at the Brannian Creek rain gauge were consistently higher than those recorded at the North Shore station for the same events.

Total suspended solids and total phosphorus increased with stream flow for all events (Figures 24–25, 30–31, and 36–37). Soluble phosphate and total nitrogen sometimes increased with flow, but often showed little relationship to the hydrograph (Figures 26–27, 32–33, and 38–39). Nitrate concentrations were usually diluted by precipitation, although both total nitrogen and nitrate tended to increase with flow during Events 6 and 8 (Figures 28, 34, and 40).

Correlation analysis was used to show relationships between stream elevation (stage height), and water quality (Figures 41–45, pages 73–77).<sup>18</sup> Stage height was used rather than discharge because discharge is estimated from a rating curve and contains more uncertainty than stage height.

Total suspended solids, total phosphorus, and soluble phosphate were significantly correlated with stage height at all three sites (Figures 41–43). Total nitrogen and nitrate were weakly correlated with stage height at Anderson Creek and were not correlated at Austin and Brannian Creeks (Figures 44–45). Total suspended solids and total phosphorus were correlated at all three sites (Figure 46;  $\tau = 0.56$ – $0.768$ ). The correlation was strongest at Brannian Creek and weakest at Austin Creek. Total phosphorus is often adsorbed to the surface of sediment particles and is transported with sediments in storm runoff.

Part of the variability in Figures 41–45 came from within-storm differences, which can be seen by plotting the storm events separately. For example, Figures 47–49 show the correlations between total phosphorus and stage height by event. The results varied considerably, with correlation statistics ranging from insignificant to highly significant (e.g., Event 1 at Anderson Creek  $\tau = 0.854$ ). In theory, the “best” statistical approach would be to evaluate all data separately by storm event. But this is not always feasible, or even desirable, especially if the goal is to develop a simple model of pollutant transport as a function of stream flow.

---

<sup>18</sup>See footnote on page 7 for a short description of correlation analysis.

Event	Sampling Period	Event Duration (hr)	Max. 24-hr Precip
1	01:45 Jan 23 to 18:30 Jan 24, 2013	40.75	0.74 in (1.9 cm)
2	12:30 Jan 29 to 15:30 Jan 30, 2013	27	0.77 in (2.0 cm)
3	16:45 Feb 27 to 05:45 Mar 03, 2013	85	1.17 in (3.0 cm)
4	01:15 Mar 11 to 16:15 Mar 15, 2013	111	0.99 in (2.5 cm)
5	17:15 Jun 19 to 15:00 Jun 21, 2013	45.75	0.89 in (2.3 cm)
6	15:15 Nov 1 to 9:30 Nov 4	66.25	1.67 in (4.2 cm)
7	Not sampled	—	—
8	14:45 Nov 14 to 9:45 Nov 17	67	1.28 in (3.3 cm)

Table 11: Summary of Anderson Creek storm events and maximum 24-hr precipitation total at the Brannian Creek precipitation gauge. Precipitation data were provided by the City of Bellingham.

Event	Sampling Period	Event Duration (hr)	Max. 24-hr Precip
1	Not sampled	–	–
2	22:30 Jan 27 to 13:00 Jan 31, 2013	86.5	0.24 in (0.6 cm)
3	15:30 Feb 27 to 11:30 Mar 04, 2013	116	0.84 in (2.1 cm)
4	22:15 Mar 10 to 18:00 Mar 15, 2013	115.75	0.84 in (2.1 cm)
5	Not sampled	–	–
6	Not sampled	–	–
7	15:00 Nov 6 to 9:15 Nov 9	66.25	0.72 in (1.8 cm)
8	15:30 Nov 14 to 10:15 Nov 17	66.75	0.72 in (1.8 cm)

Table 12: Summary of Austin Creek storm events and maximum 24-hr precipitation total at the North Shore weather station. Precipitation data were provided by the City of Bellingham.

Event	Sampling Period	Event Duration (hr)	Max. 24-hr Precip
1	00:45 Jan 23 to 18:00 Jan 24, 2013	41.25	0.74 in (1.9 cm)
2	18:00 Jan 28 to 00:45 Feb 02, 2013	102.75	0.77 in (2.0 cm)
3	23:45 Feb 26 to 05:15 Mar 03, 2013	101.5	1.17 in (3.0 cm)
4	22:30 Mar 10 to 07:30 Mar 15, 2013	105	0.99 in (2.5 cm)
5	Not sampled	–	–
6	0:00 Nov 2 to 9:45 Nov 4	57.75	1.67 in (4.2 cm)
7	Not sampled	–	–
8	15:15 Nov 14 to 9:45 Nov 17	66.5	1.28 in (3.3 cm)

Table 13: Summary of Brannian Creek storm events and maximum 24-hr precipitation total at the Brannian Creek precipitation gauge. Precipitation data were provided by the City of Bellingham.



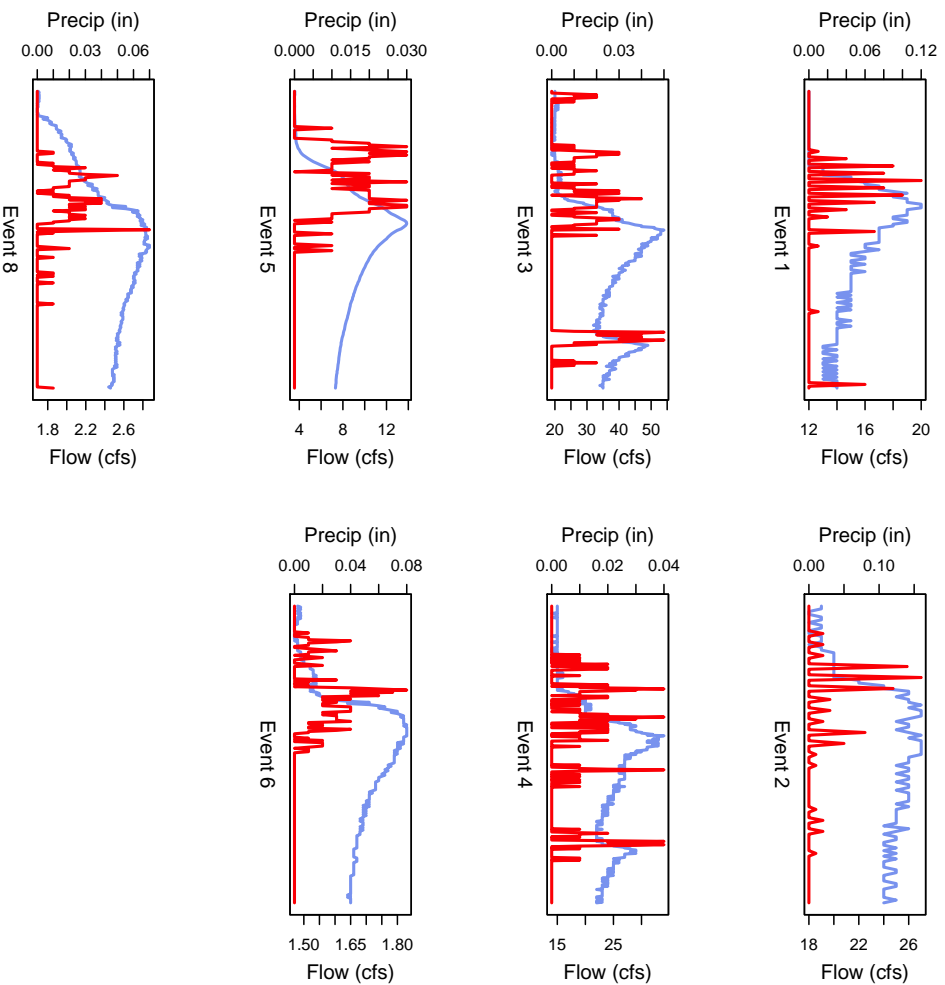


Figure 23: Anderson Creek precipitation (—) and stream flow (—) for Events 1–6 and 8. Flow data are from the USGS gauging station. Note scale for each event. Precipitation data are from the Brannian Creek rain gauge. Missing values (1/23/2013 7:00 to 2/7/2013 6:45) were replaced by hourly data from the Plantation rain gauge.

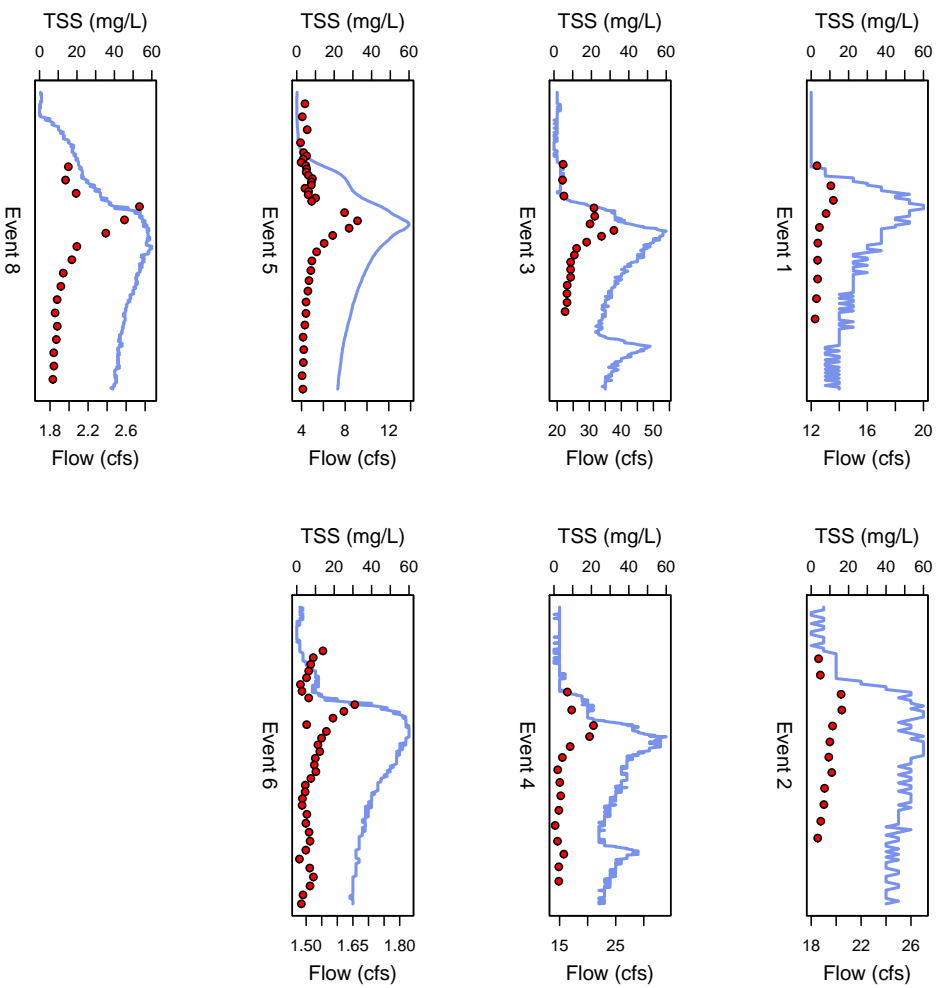


Figure 24: Anderson Creek storm water monitoring results for Events 1–6 and 8: total suspended solids (●) vs. stream flow (—). Flow data are from the USGS gauging station. Note scale for each event.

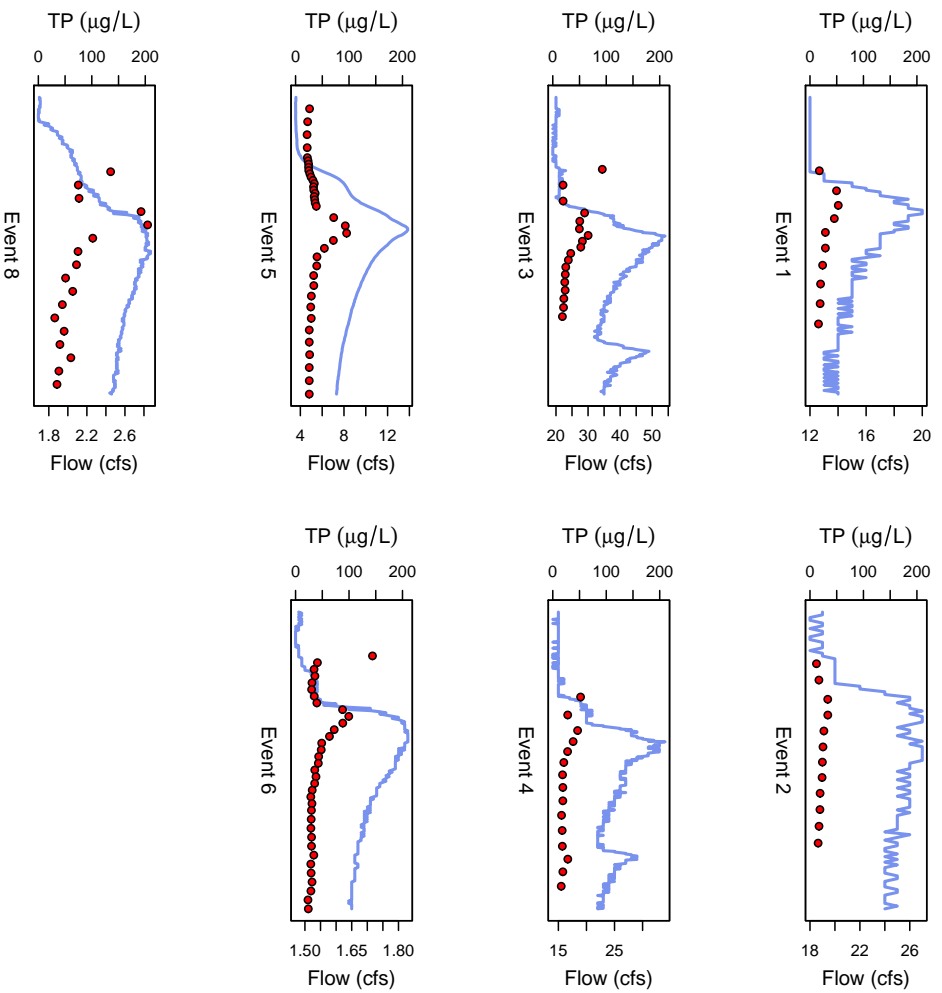


Figure 25: Anderson Creek storm water monitoring results for Events 1–6 and 8: total phosphorus (●) vs. stream flow (—). Flow data are from the USGS gauging station. Note scale for each event.

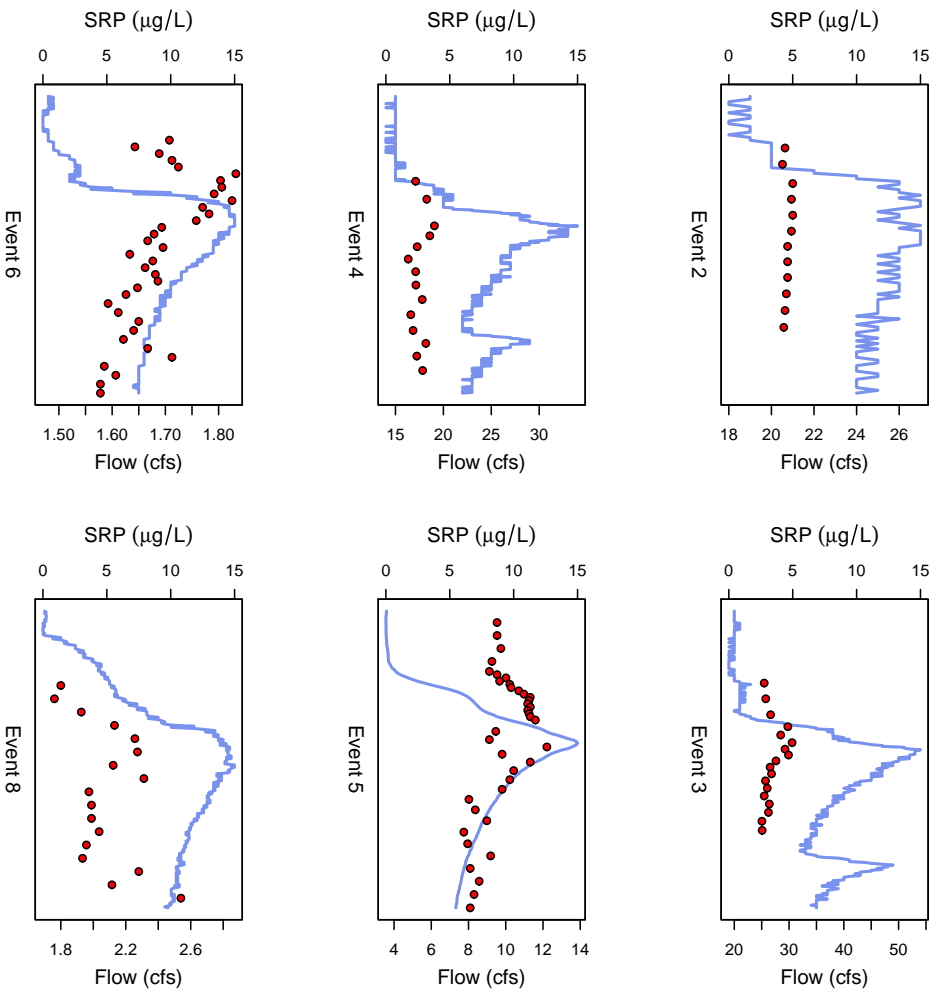


Figure 26: Anderson Creek storm water monitoring results for Events 2–6 and 8: soluble phosphate (●) vs. stream flow (—). Flow data are from the USGS gauging station. Note scale for each event. Event 1 samples from Anderson Creek were not analyzed for soluble phosphate.

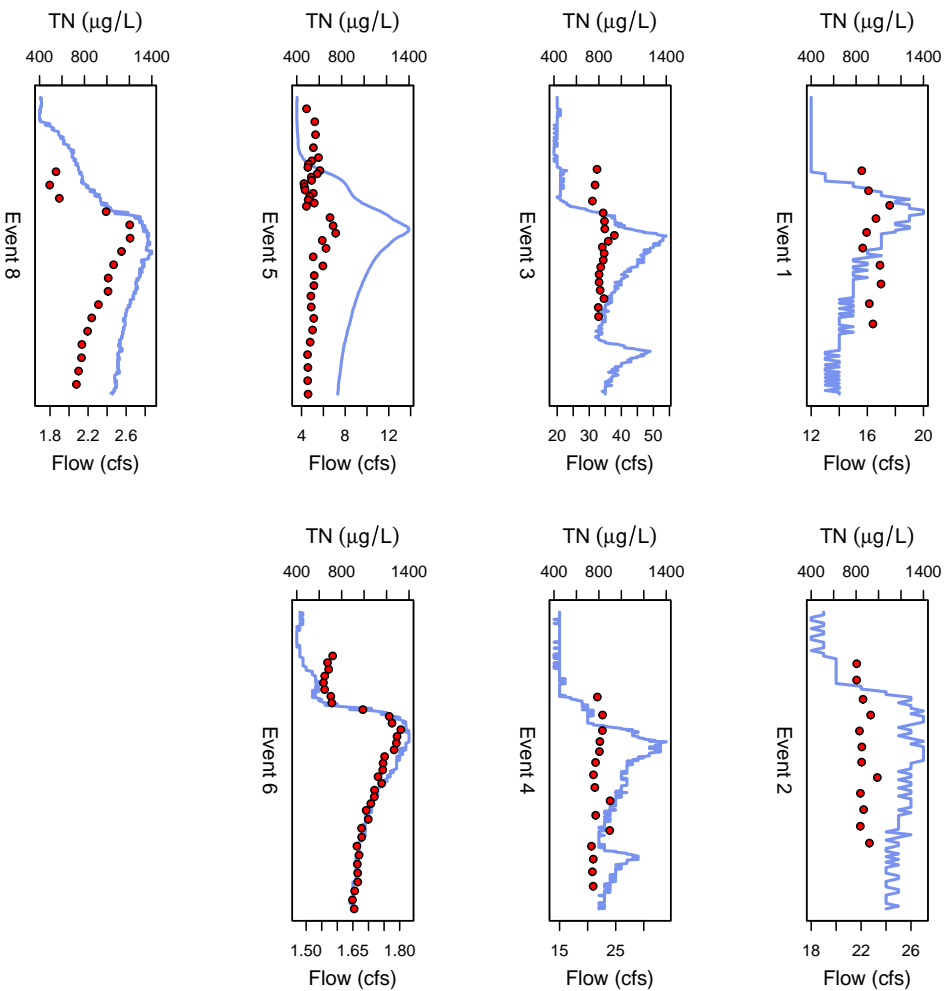


Figure 27: Anderson Creek storm water monitoring results for Events 1–6 and 8: total nitrogen (●) vs. stream flow (—). Flow data are from the USGS gauging station. Note scale for each event. Flow data are from the USGS gauging station.

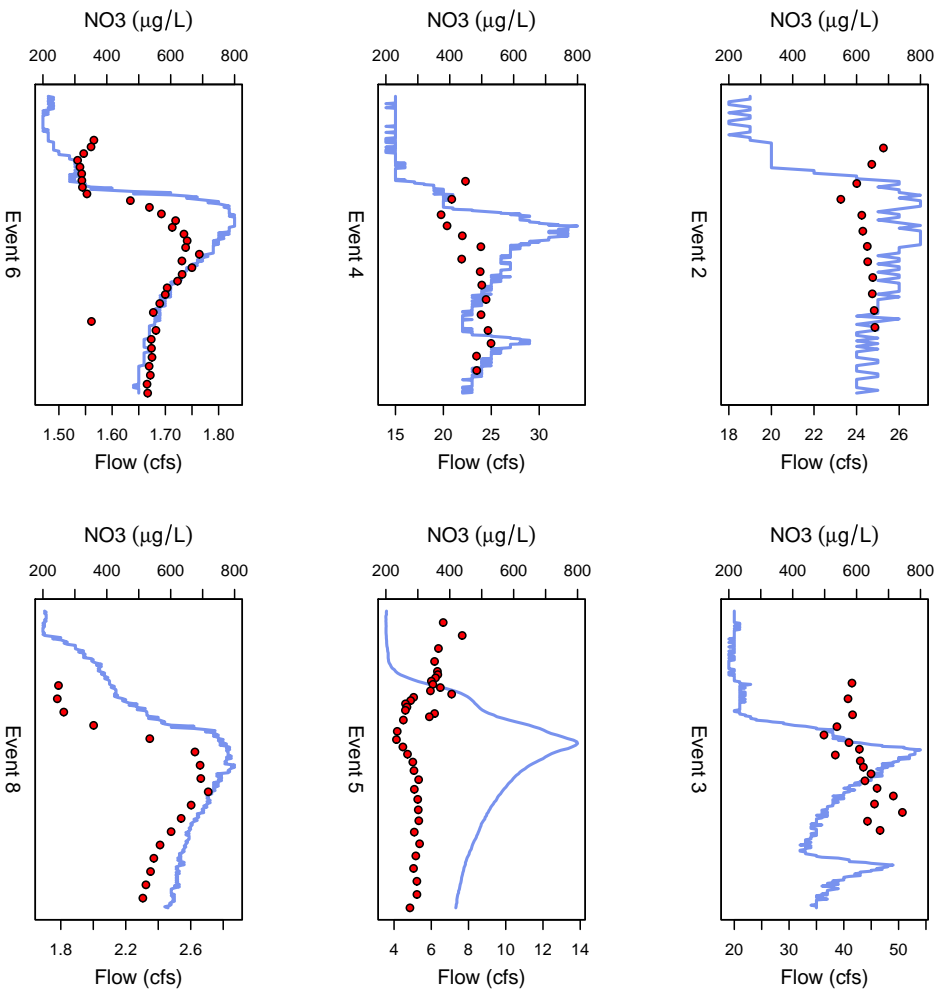


Figure 28: Anderson Creek storm water monitoring results for Events 2–6 and 8: nitrate/nitrite (●) vs. stream flow (—). Flow data are from the USGS gauging station. Note scale for each event. Event 1 samples from Anderson Creek were not analyzed for nitrate/nitrite.

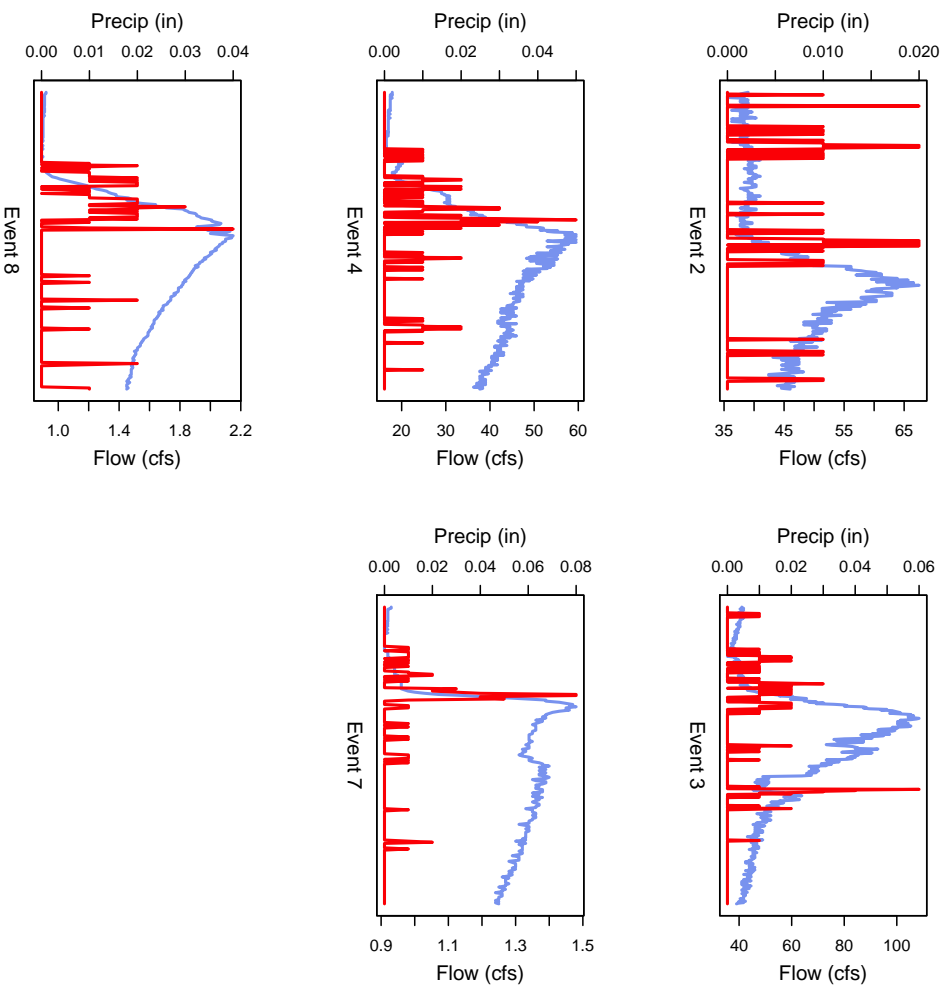


Figure 29: Austin Creek precipitation (—) and stream flow (—) for Events 2–4 and 7–8. Flow data are provisional after 9/30/2013 23:45. Note scale for each event.

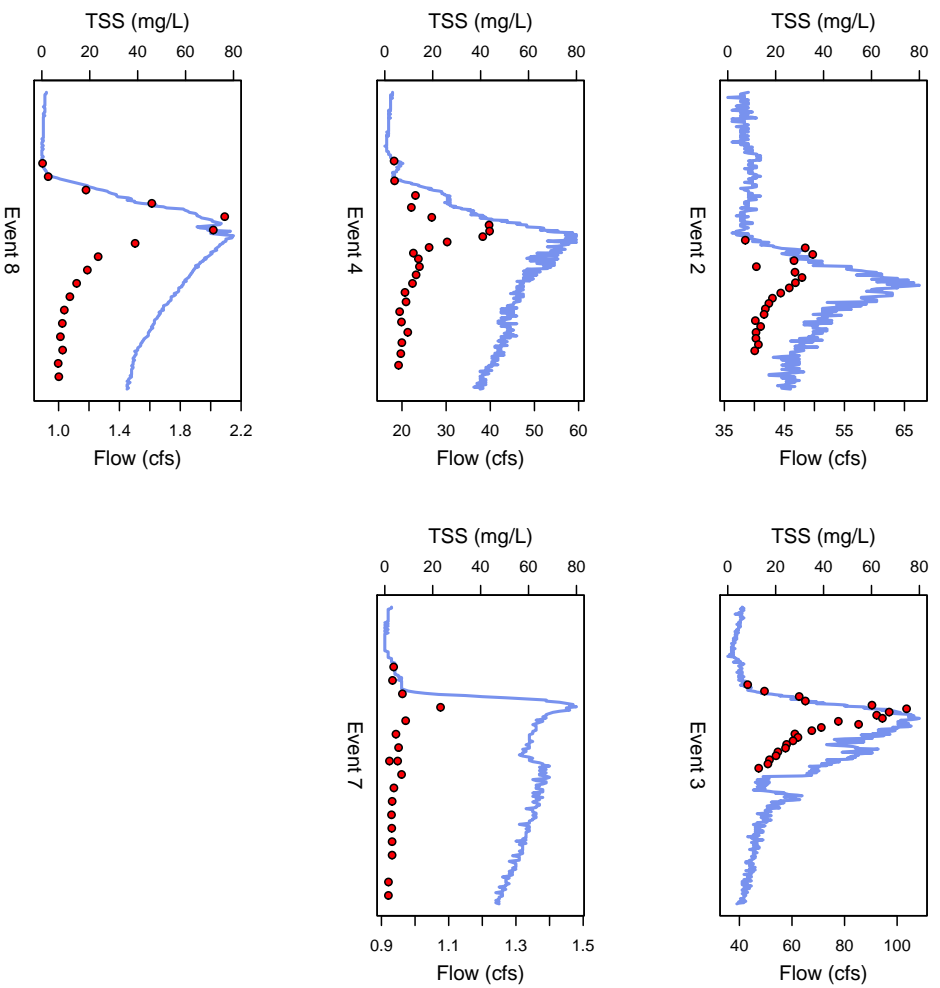


Figure 30: Austin Creek storm water monitoring results for Events 2–4 and 7–8: total suspended solids (●) vs. stream flow (—). Flow data are provisional after 9/30/2013 23:45. Note scale for each event.



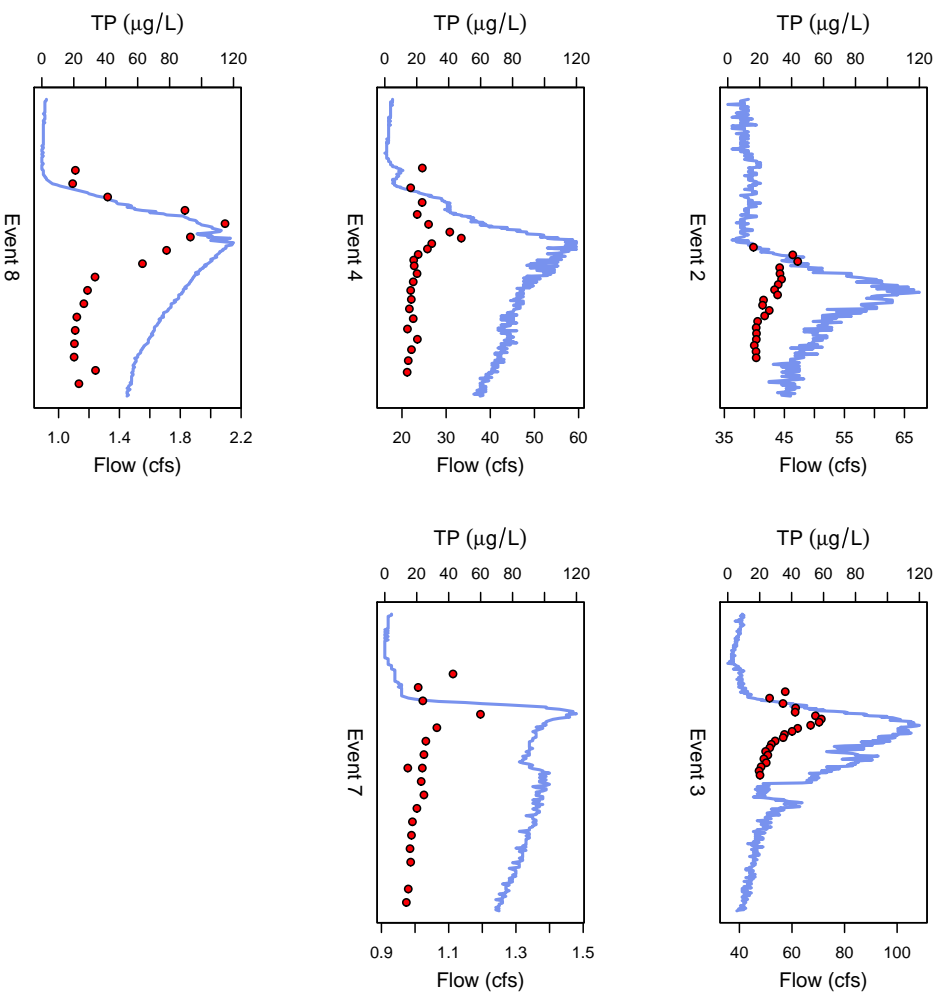


Figure 31: Austin Creek storm water monitoring results for Events 2–4 and 7–8: total phosphorus (●) vs. stream flow (—). Flow data are provisional after 9/30/2013 23:45. Note scale for each event.

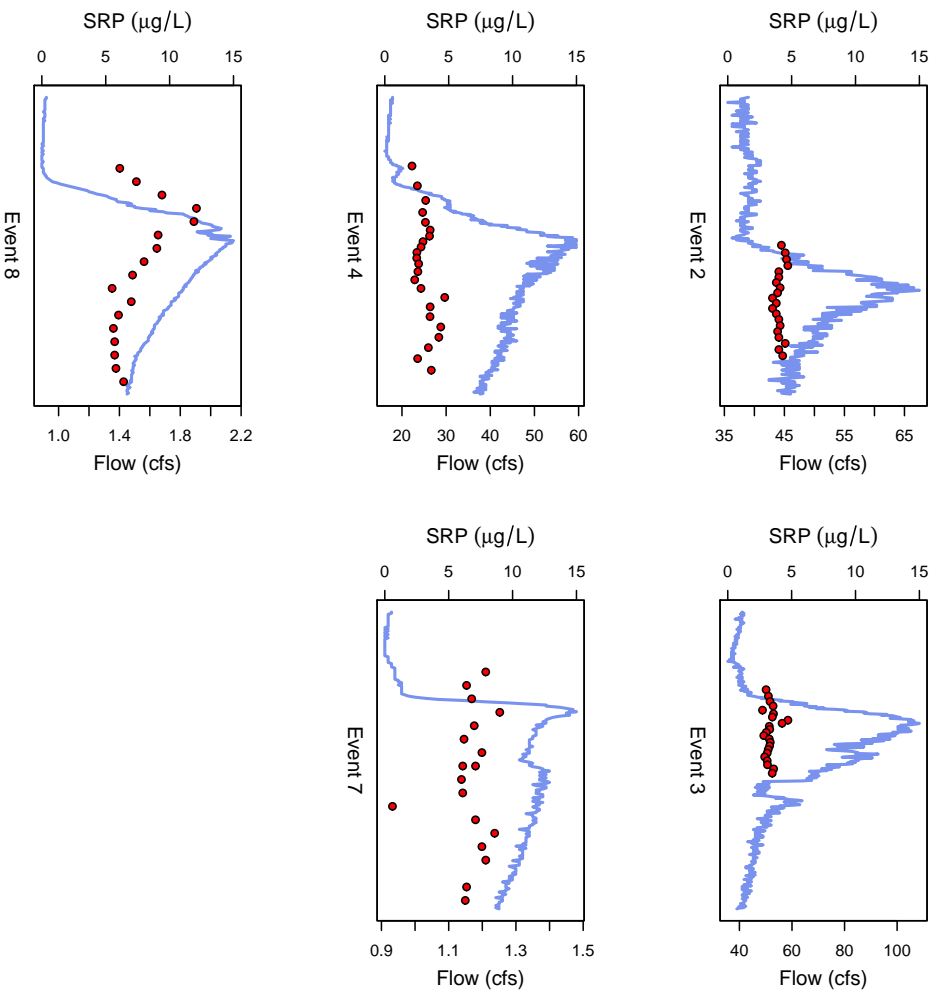


Figure 32: Austin Creek storm water monitoring results for Events 2–4 and 7–8: soluble phosphate (●) vs. stream flow (—). Flow data are provisional after 9/30/2013 23:45. Note scale for each event.

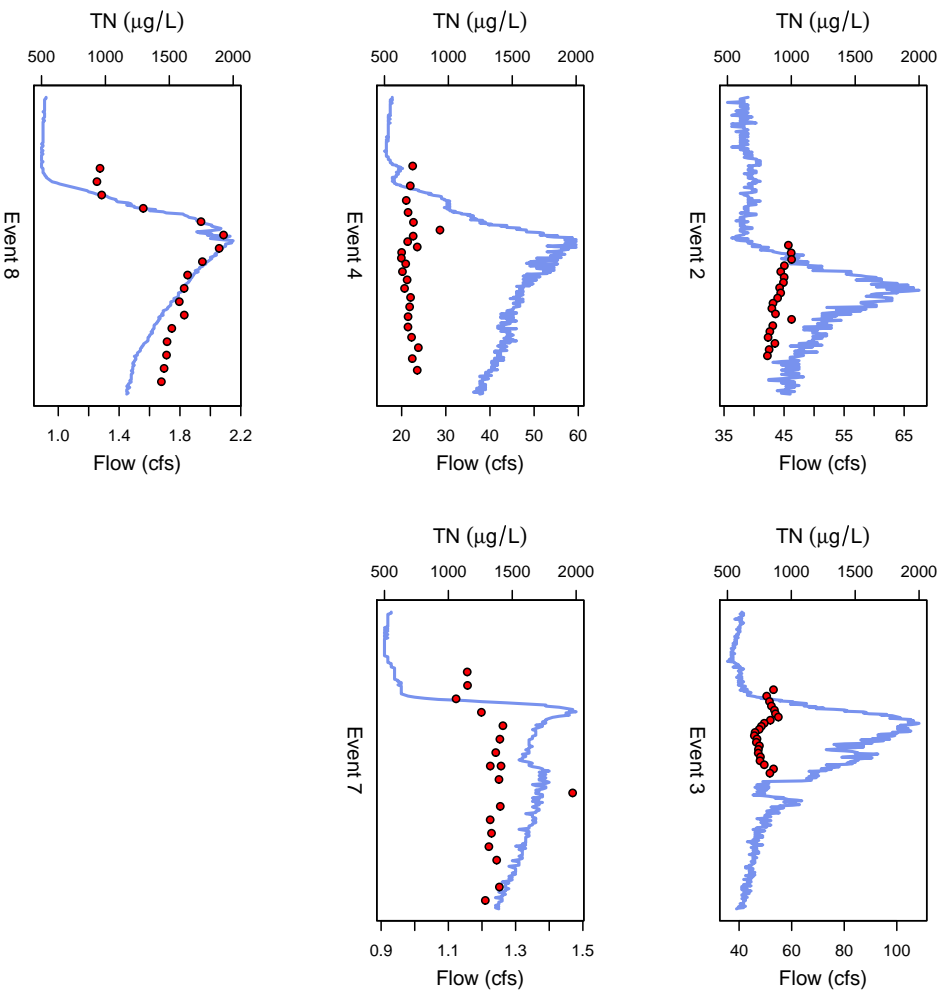


Figure 33: Austin Creek storm water monitoring results for Events 2–4 and 7–8: total nitrogen (●) vs. stream flow (—). Flow data are provisional after 9/30/2013 23:45. Note scale for each event.

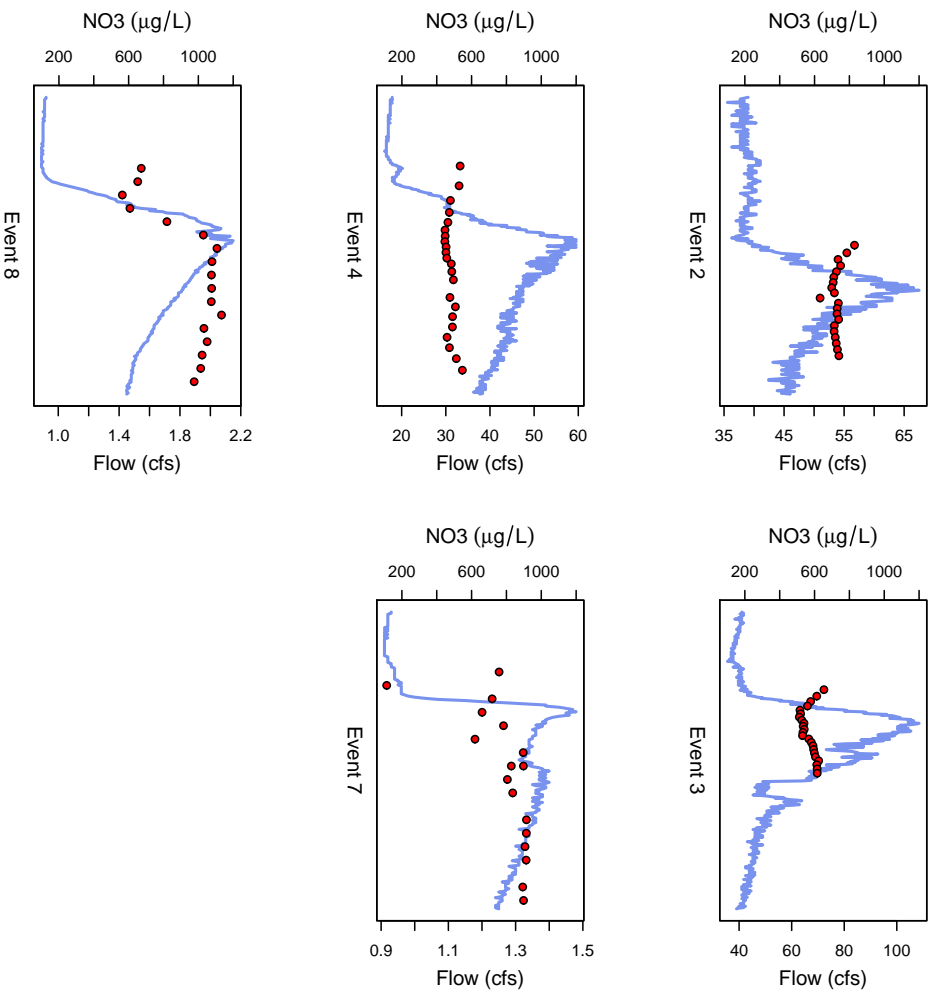


Figure 34: Austin Creek storm water monitoring results for Events 2–4 and 7–8: nitrate/nitrite (●) vs. stream flow (—). Flow data are provisional after 9/30/2013 23:45. Note scale for each event.

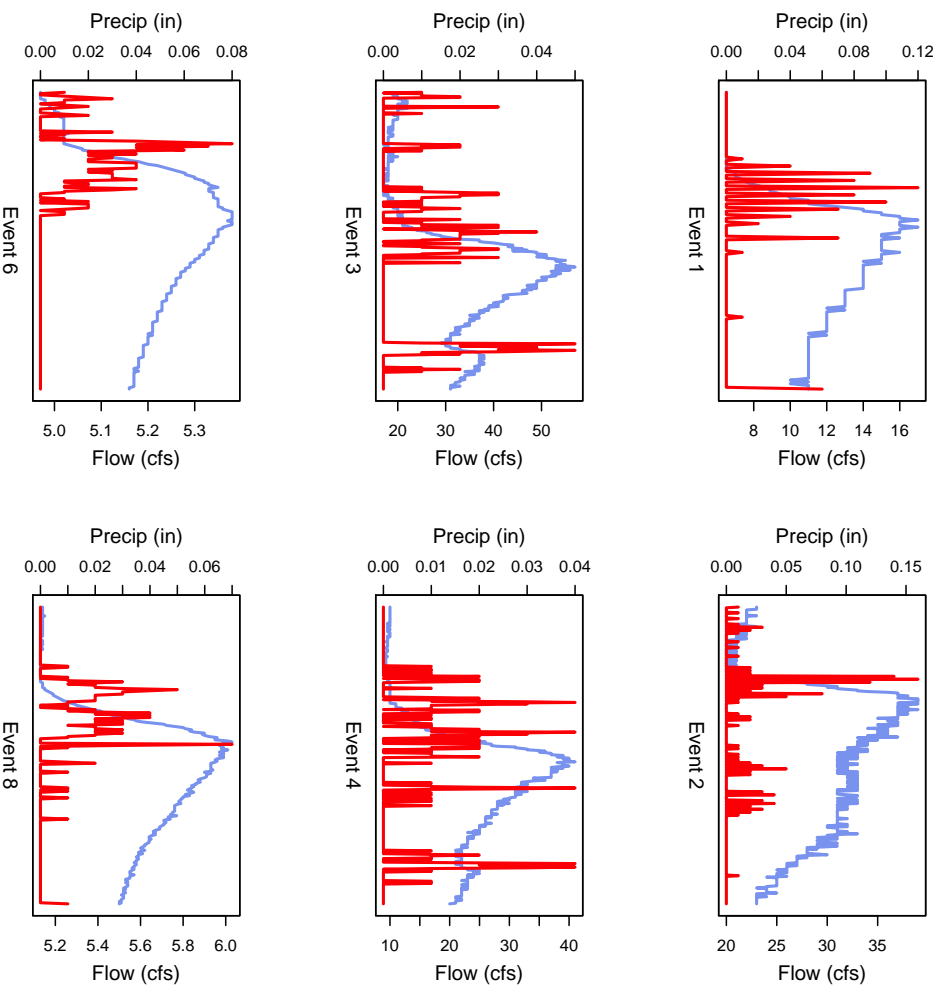


Figure 35: Brannian Creek precipitation (—) and stream flow (—) for Events 1–4, 6, and 8. Flow data are from the USGS gauging station and are provisional after 2/5/2013 23:45. Note scale for each event. Precipitation data are from the Brannian Creek rain gauge. Missing values (1/23/2013 7:00 to 2/7/2013 6:45) were replaced by hourly data from the Plantation rain gauge.

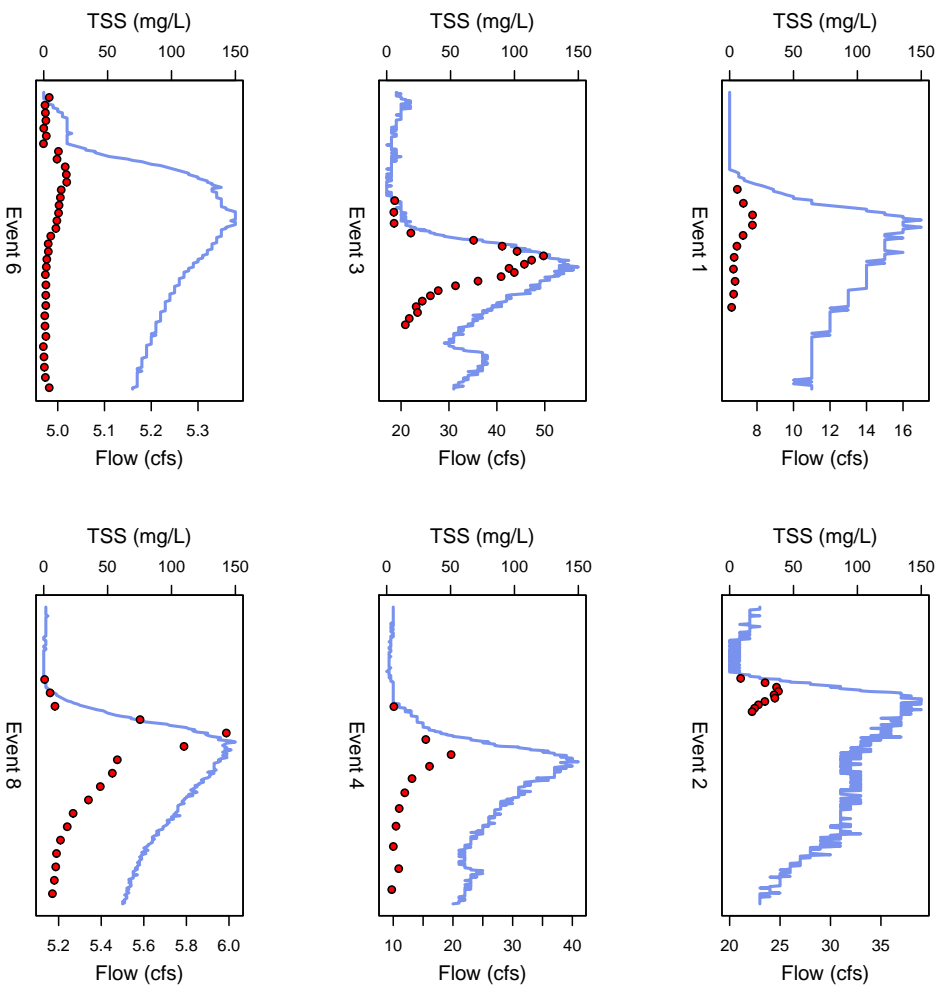


Figure 36: Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: total suspended solids (●) vs. stream flow (—). Flow data are from the USGS gauging station and are provisional after 2/5/2013 23:45. Note scale for each event.

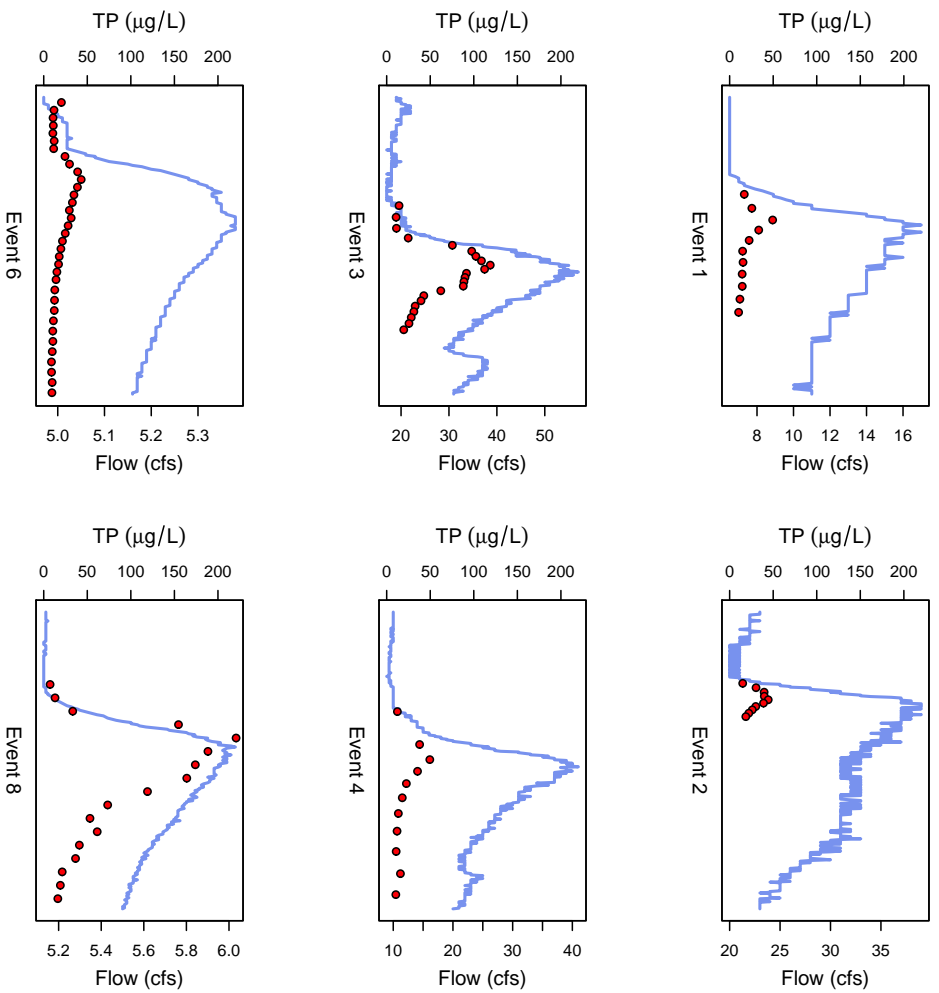


Figure 37: Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: total phosphorus (●) vs. stream flow (—). Flow data are from the USGS gauging station and are provisional after 2/5/2013 23:45. Note scale for each event.

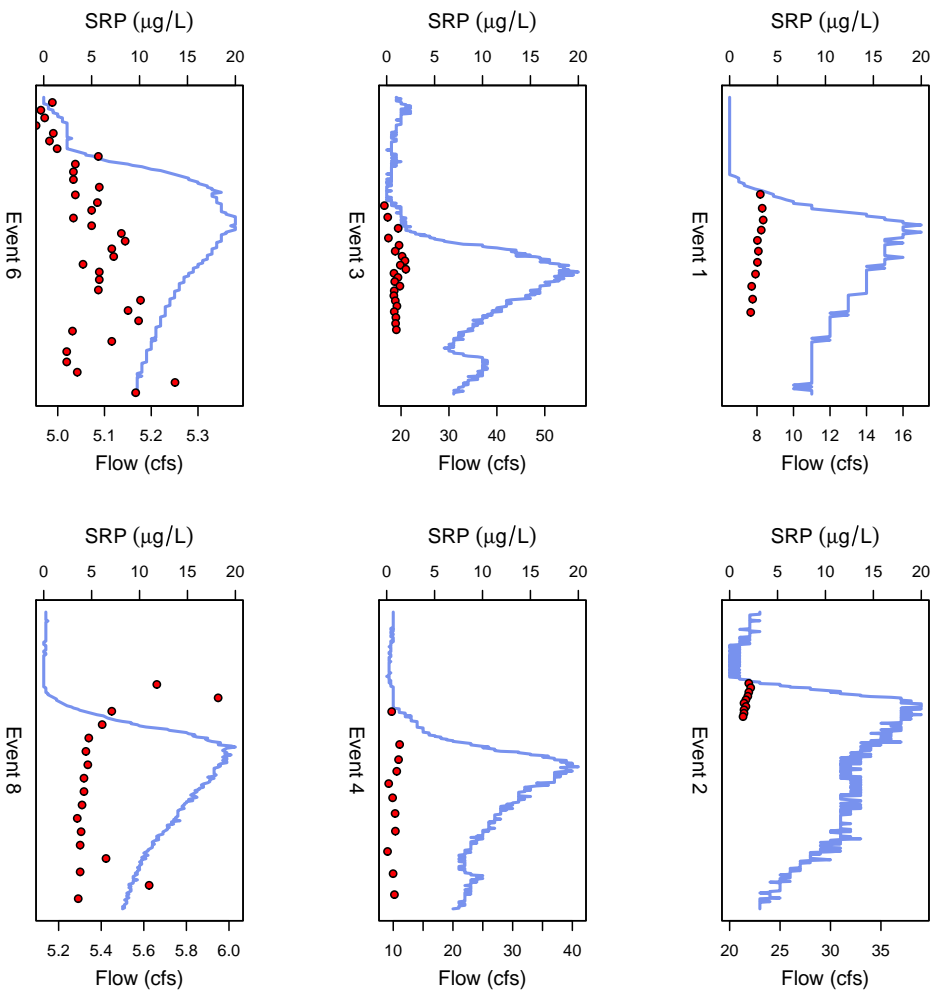


Figure 38: Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: soluble phosphate (●) vs. stream flow (—). Flow data are from the USGS gauging station and are provisional after 2/5/2013 23:45. Note scale for each event.



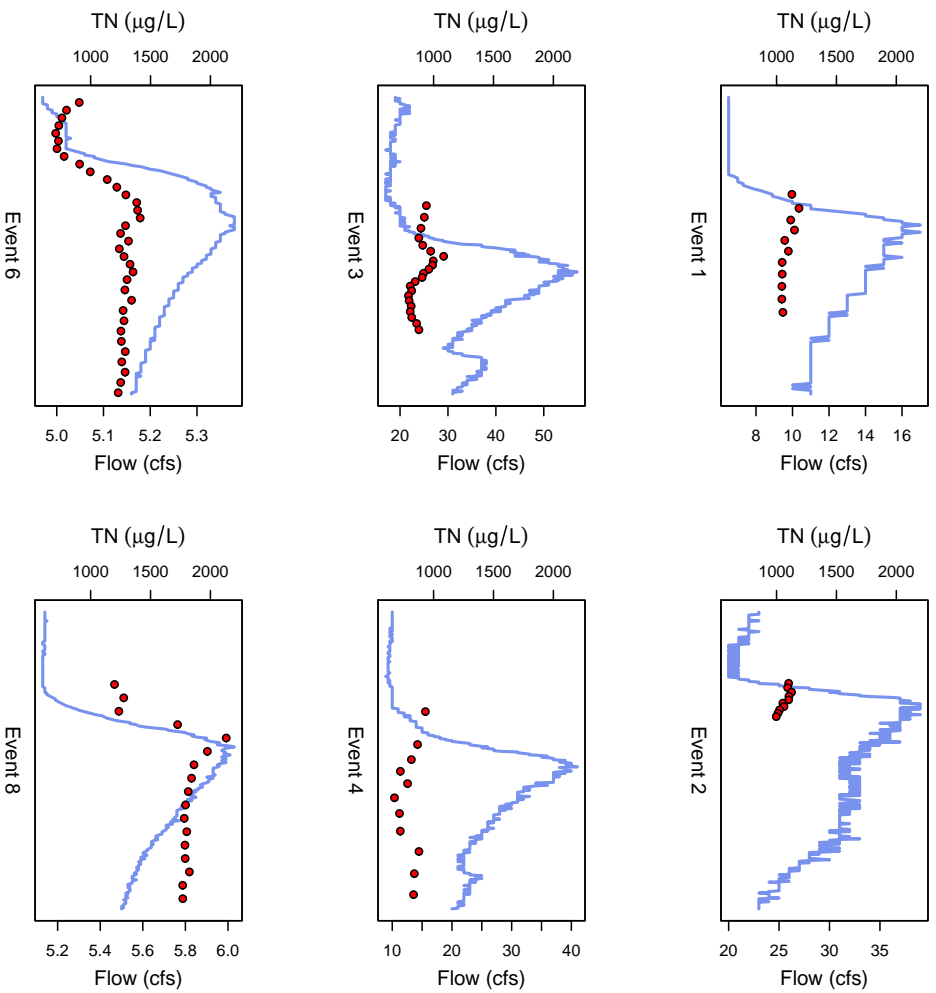


Figure 39: Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: total nitrogen (●) vs. stream flow (—). Flow data are from the USGS gauging station and are provisional after 2/5/2013 23:45. Note scale for each event.

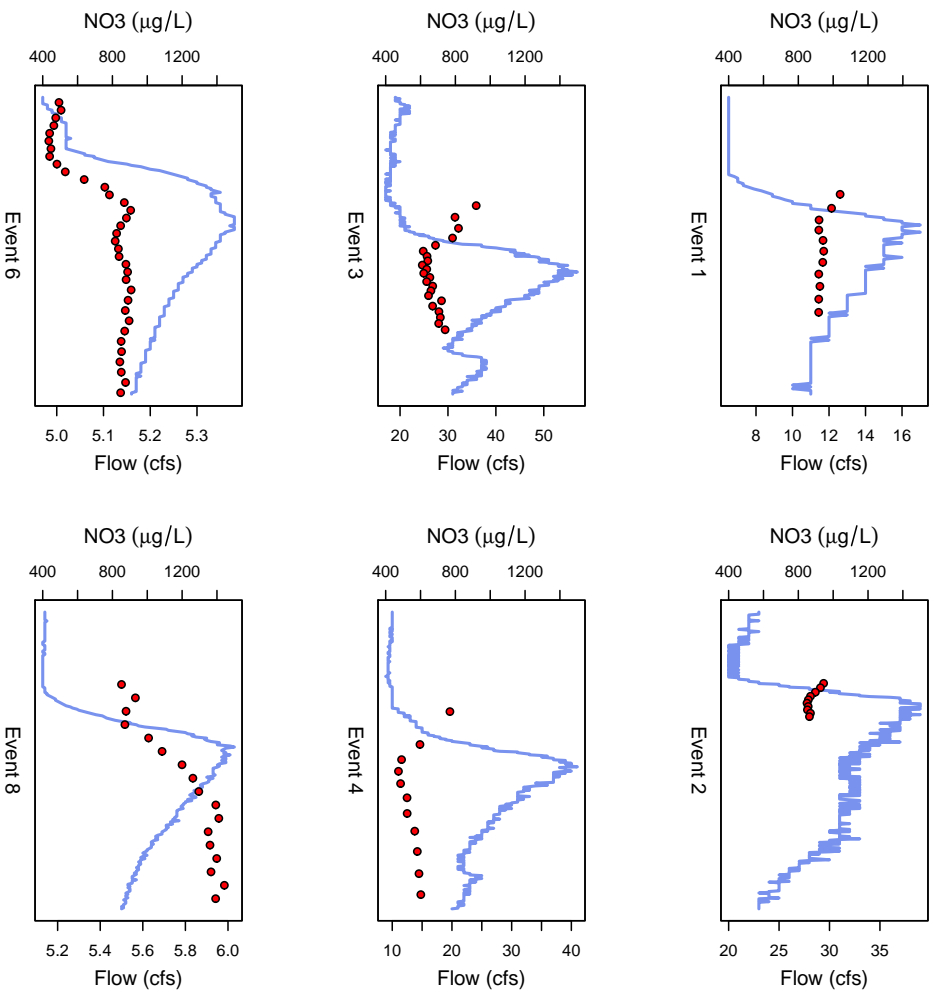


Figure 40: Brannian Creek storm water monitoring results for Events 1–4, 6, and 8: nitrate/nitrite (●) vs. stream flow (—). Flow data are from the USGS gauging station and are provisional after 2/5/2013 23:45. Note scale for each event.

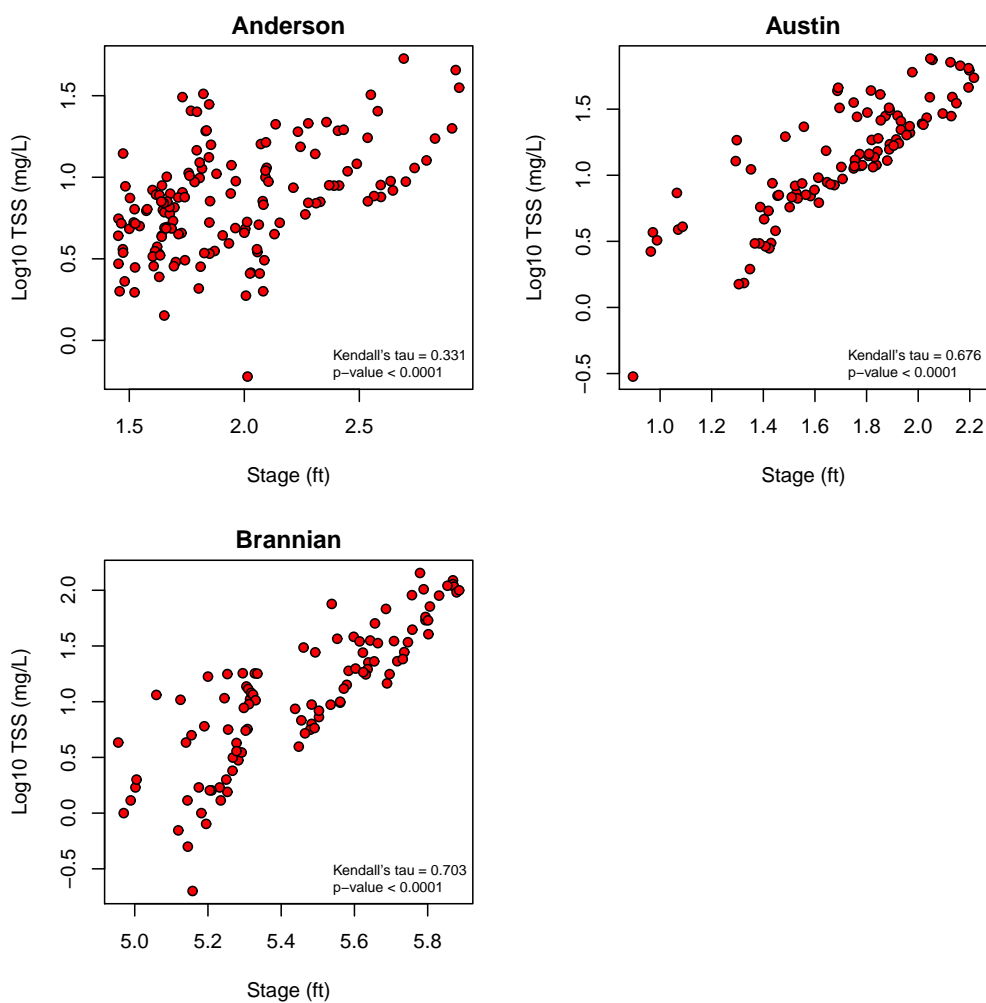


Figure 41: Correlation between stage height and total suspended solids in Anderson, Austin, and Brannian Creeks (Events 1–8). Austin Event 2 was excluded because it did not meet the precipitation goal. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

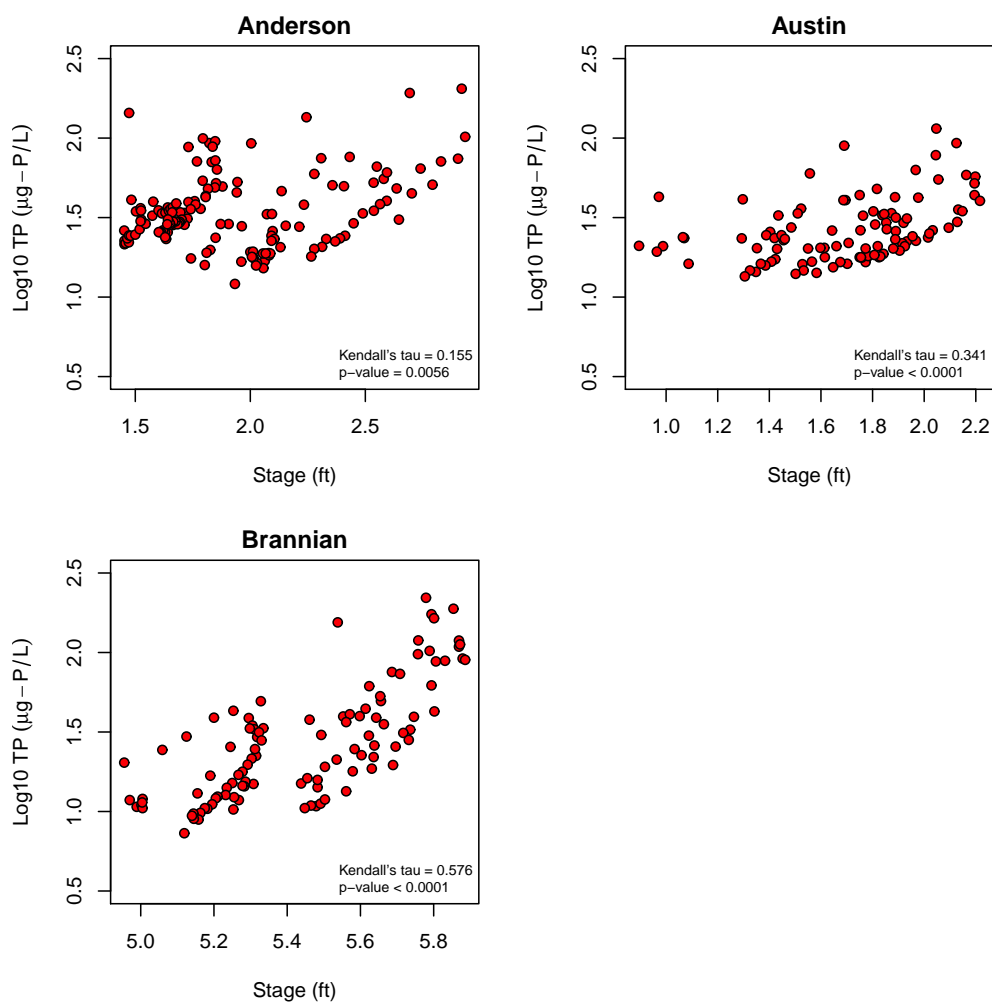


Figure 42: Correlation between stage height and total phosphorus in Anderson, Austin, and Brannian Creeks (Events 1–8). Austin Event 2 was excluded because it did not meet the precipitation goal. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

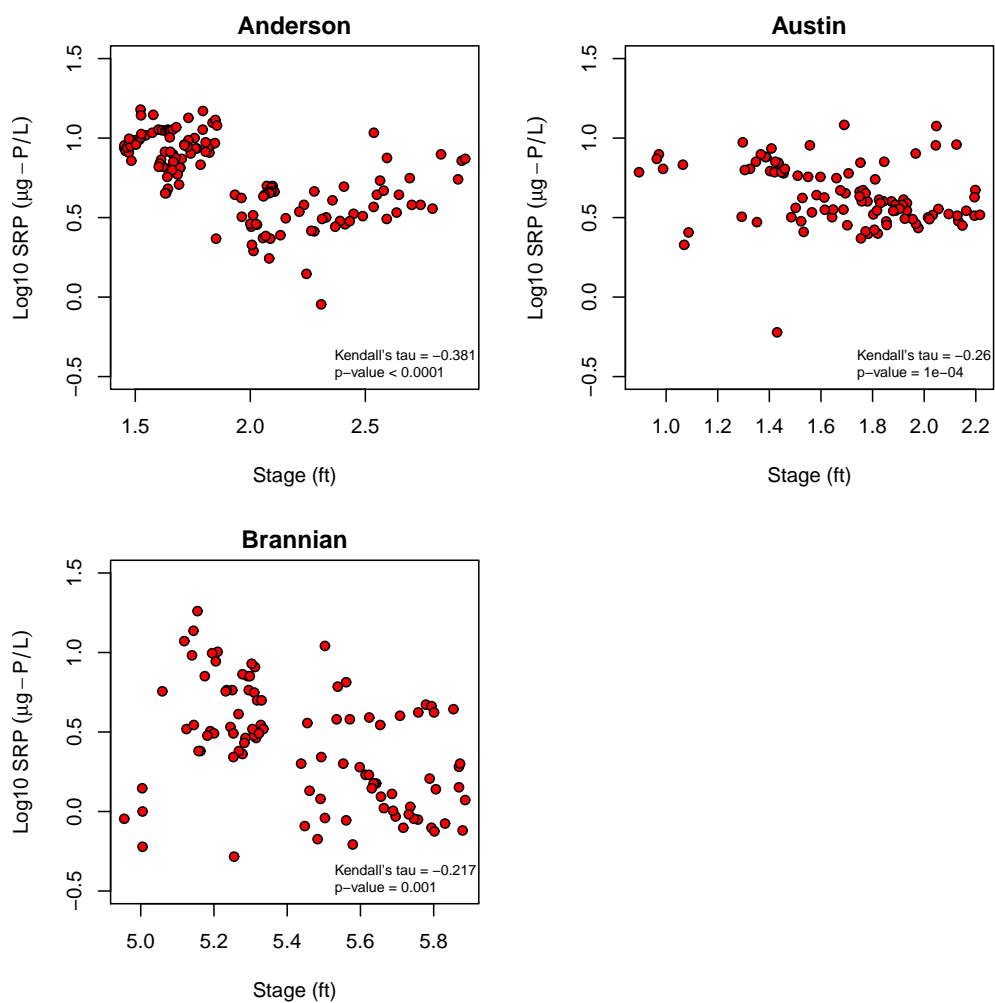


Figure 43: Correlation between stage height and soluble phosphate in Anderson, Austin, and Brannian Creeks (Events 1–8). Austin Event 2 was excluded because it did not meet the precipitation goal. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.

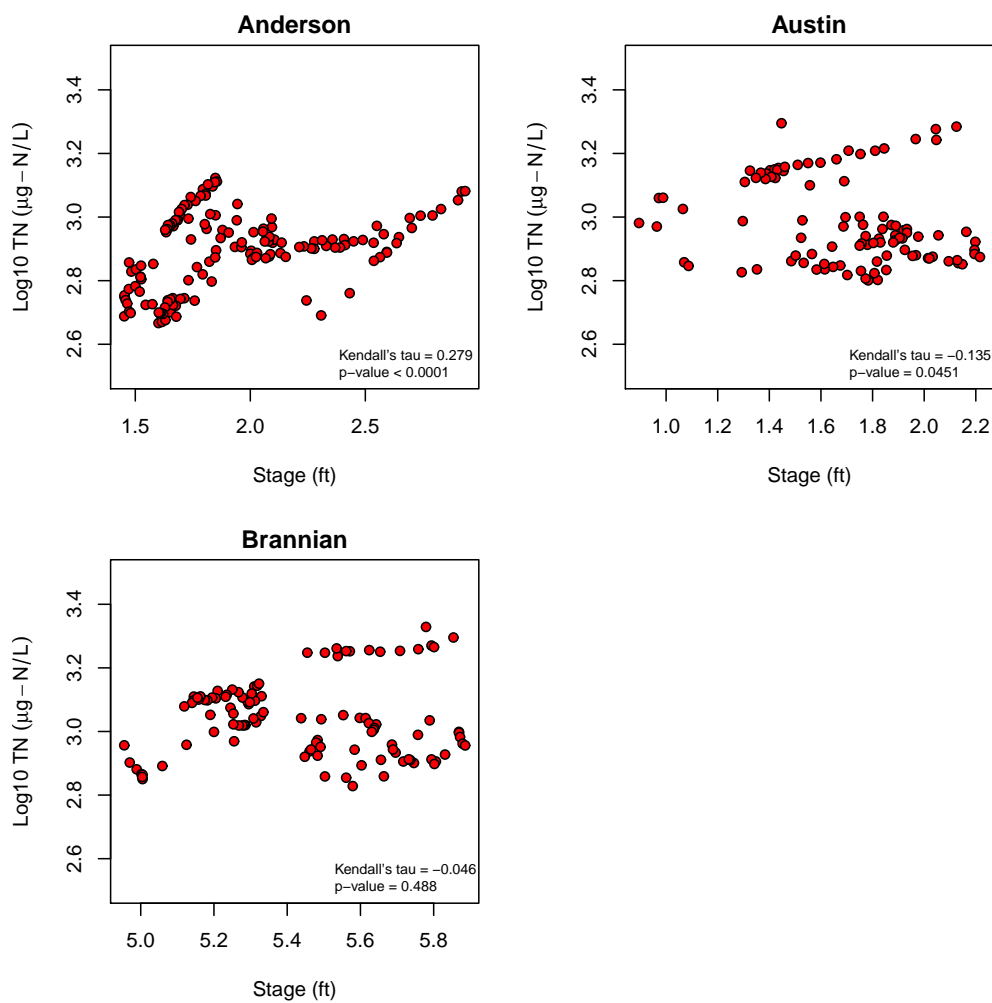


Figure 44: Correlation between stage height and total nitrogen in Anderson, Austin, and Brannian Creeks (Events 1–8). Austin Event 2 was excluded because it did not meet the precipitation goal. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; the correlations for Anderson and Austin Creeks were significant.

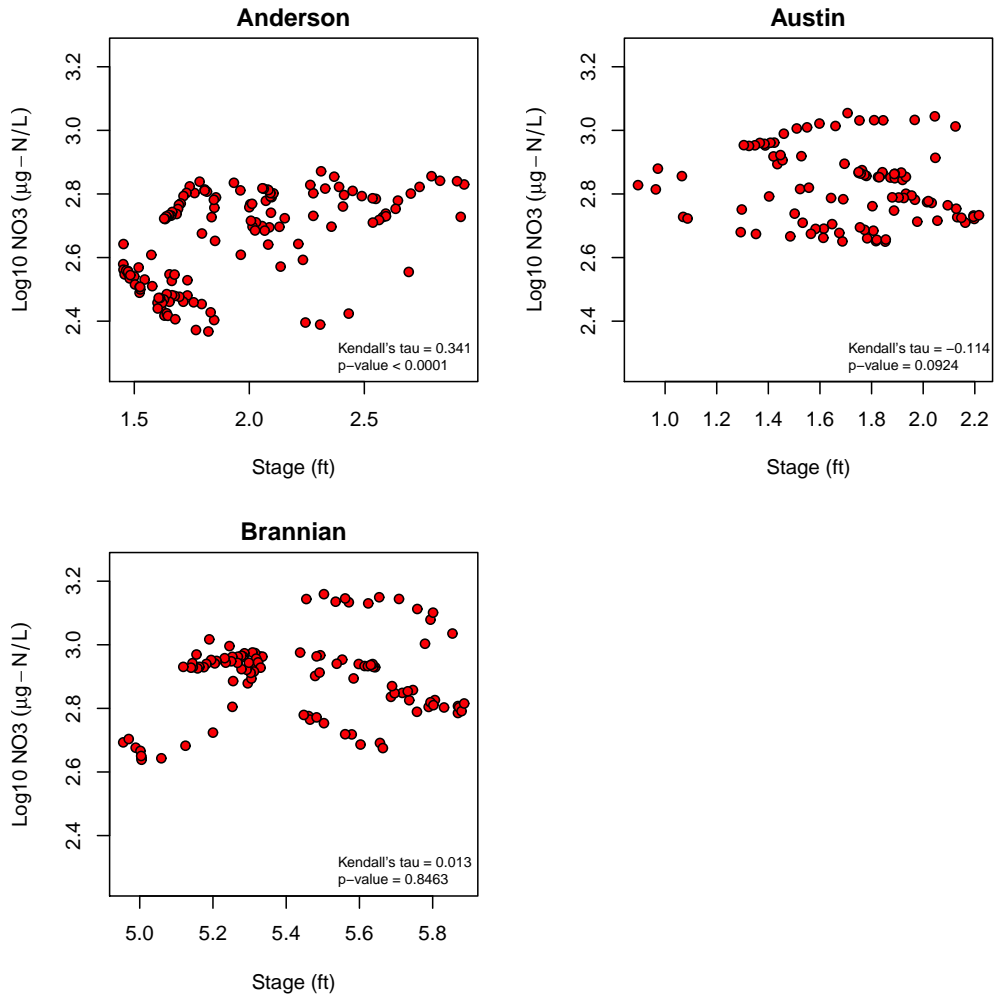


Figure 45: Correlation between stage height and nitrate in Anderson, Austin, and Brannian Creeks (Events 1–8). Austin Event 2 was excluded because it did not meet the precipitation goal. Two low values (<200 μg-N/L) were not plotted to improve plotting scale for the remaining points. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; the correlation for Anderson Creek was significant.

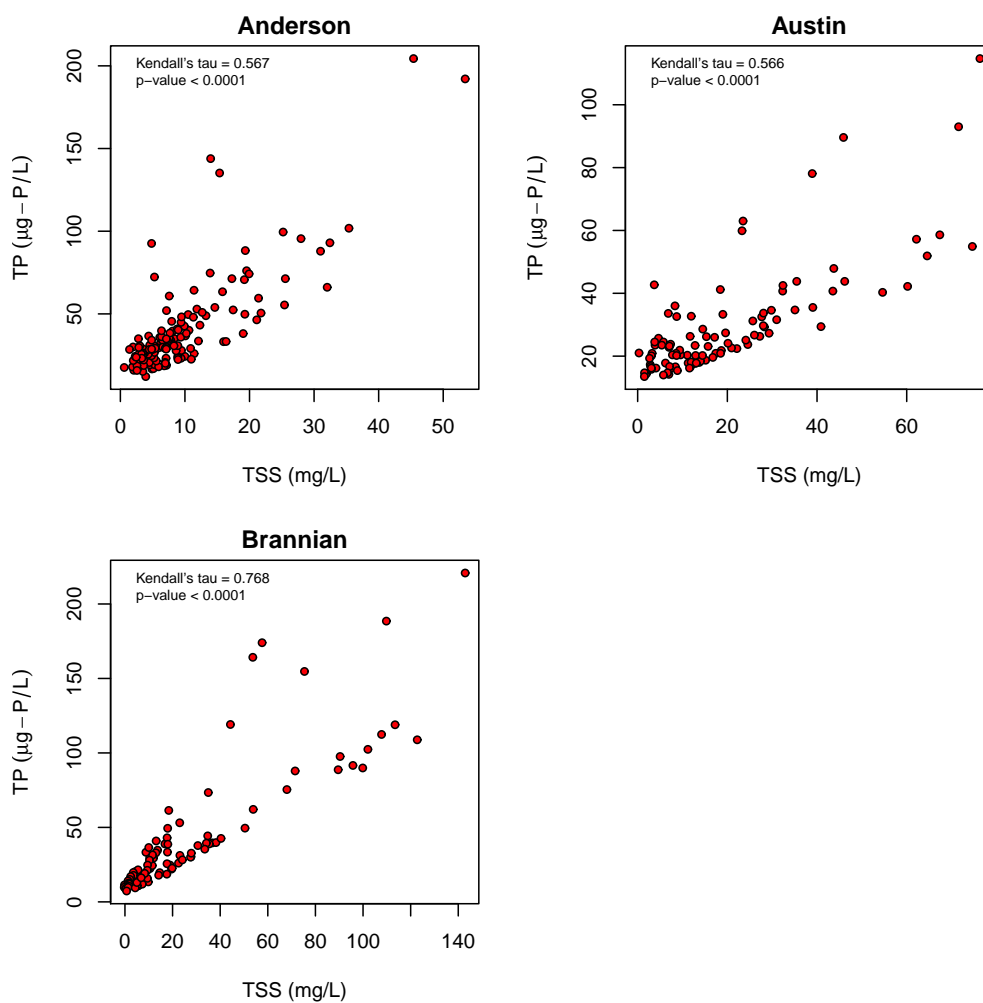


Figure 46: Correlation between total suspended solids and total phosphorus in Anderson, Austin, and Brannian Creeks (Events 1–8). Austin Event 2 was excluded because it did not meet the precipitation goal. Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; all correlations were significant.



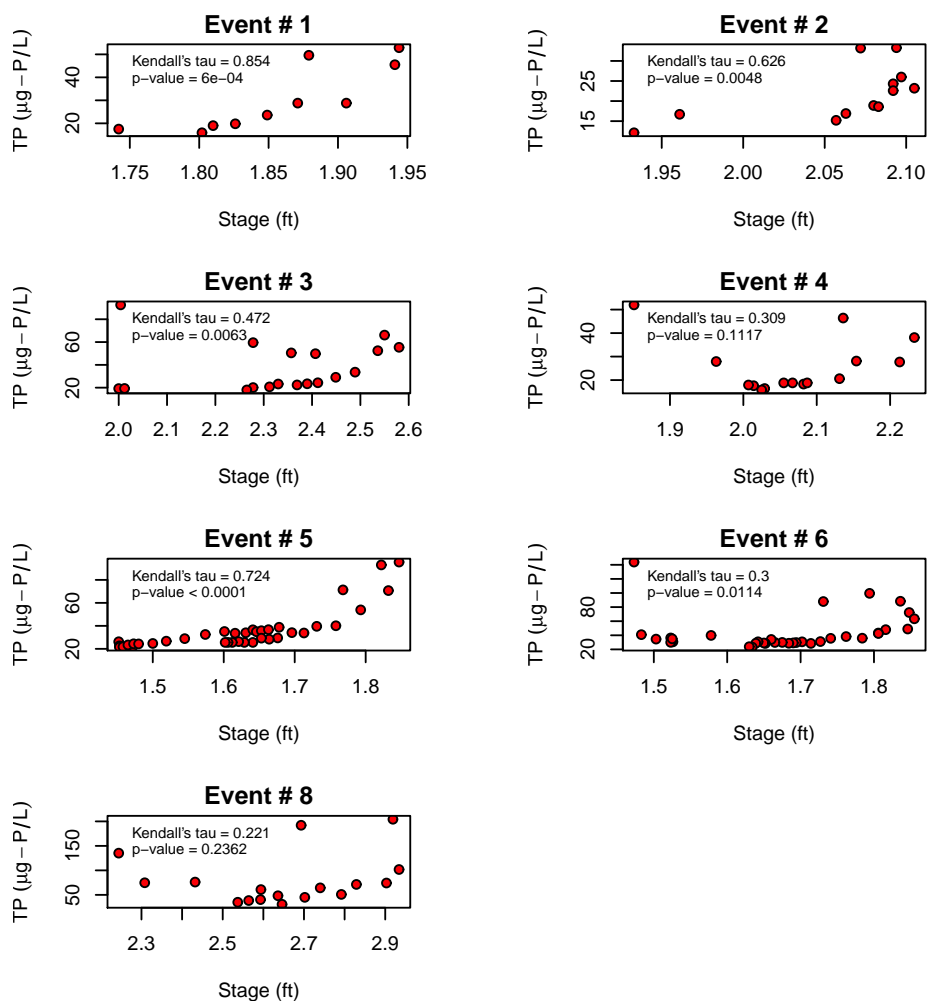


Figure 47: Correlation between stage height and total phosphorus by storm event in Anderson Creek (Events 1–6 and 8). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; correlations for Events 1, 2, 3, 5, and 6 were significant.

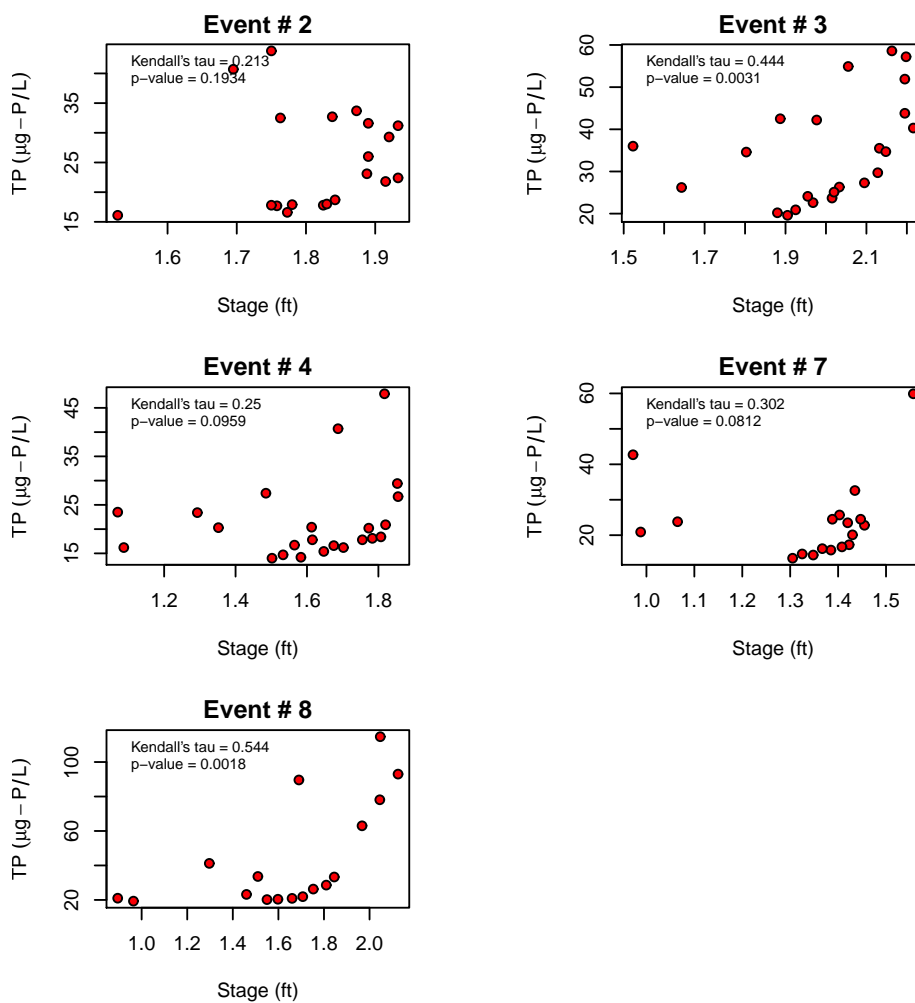


Figure 48: Correlation between stage height and total phosphorus by storm event in Austin Creek (Events 2–4 and 7–8). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; correlations for Events 3 and 8 were significant.

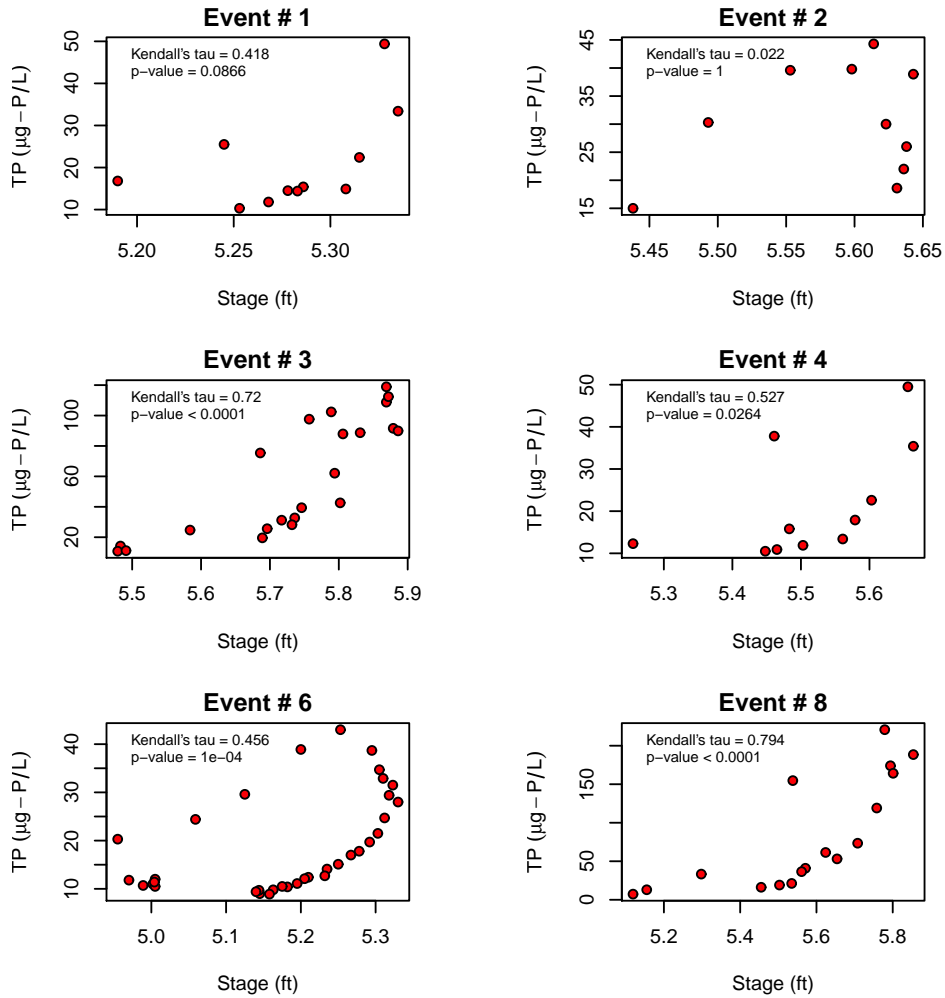


Figure 49: Correlation between stage height and total phosphorus by storm event in Brannian Creek (Events 1–4, 6, and 8). Kendall's  $\tau$  correlations were used because the data were not monotonic-linear; correlations for Events 3, 4, 6, and 8 were significant.

## 5 References and Related Reports

### 5.1 References

- Aquatic Informatics. 2013. 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.
- 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.
- EPA. 1994. Method 200.7: Determination of Metals and Trace Elements in Water and Wastes by Inductively Coupled Plasma-Atomic Emission Spectrometry, Revision 4.4, U. S. Environmental Protection Agency, Washington DC.
- 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.
- Hydrolab. 1997. Data Sonde 4 Water Quality Multiprobes User Manual, Revision D., August 1997. Hydrolab Corporation, Austin, TX.
- Krause, P., D. P. Boyle, and F. Bäse. 2005. Comparison of different efficiency criteria for hydrological model assessment. *Advances in Geosciences* 5: 89–97.
- 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. 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. 2011. 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. 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.

- Nash, J. E. and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models; Part I, A discussion of principles. *Journal of Hydrology* 10(3): 282–290.
- Pelletier, G. 1998. Dissolved oxygen in Lake Whatcom. Trend in the depletion of hypolimnetic oxygen in basin I, 1983–1997. Washington State Department of Ecology Report #98–313, Olympia, WA.
- Rantz, S.E., et al. (1982). *Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge.* Geological Survey Water-Supply Paper #2175, U. S. Government Printing Office, Washington, D. C.
- 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.
- 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 <http://www.wvu.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, 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 and A2 (pages 91 and 92) show the locations of the current monitoring sites and Table A1 (page 90) lists the approximate GPS coordinates for the lake and creek sites. All site descriptions, including text descriptions and GPS coordinates, are approximate because of variability in satellite coverage, GPS unit sensitivity, boat movement, stream bank or channel alterations, stream flow rates, weather conditions, and other factors that affect sampling location. Text descriptions contain references to local landmarks that may change over time. For detailed information about exact 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 Storm Water Monitoring Sites

The 2012/2013 storm water monitoring program focused on collecting storm runoff data from Anderson, Austin, and Brannian Creeks. For information about other storm water sites that have been monitored by IWS, refer to the annual reports listed in Section 5.2 (page 85).

**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<sup>19</sup> 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.

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**.

**Brannian Creek** samples are collected approximately 40 m downstream from South Bay Rd. near the USGS hydrograph gauge.

Lake Sites	Latitude (°N)	Longitude (°W)
Site 1	48.4536	122.2438
Intake	(GPS omitted)	
Site 2	48.4436	122.2254
Site 3	48.4416	122.2009
Site 4	48.4141	122.1815

Storm Water Sites	Latitude (°N)	Longitude (°W)
Anderson	48.67335	122.26751
Austin (lower)	48.71312	122.33076
Brannian	48.66910	122.27949

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

<sup>19</sup>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](http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=12201950).

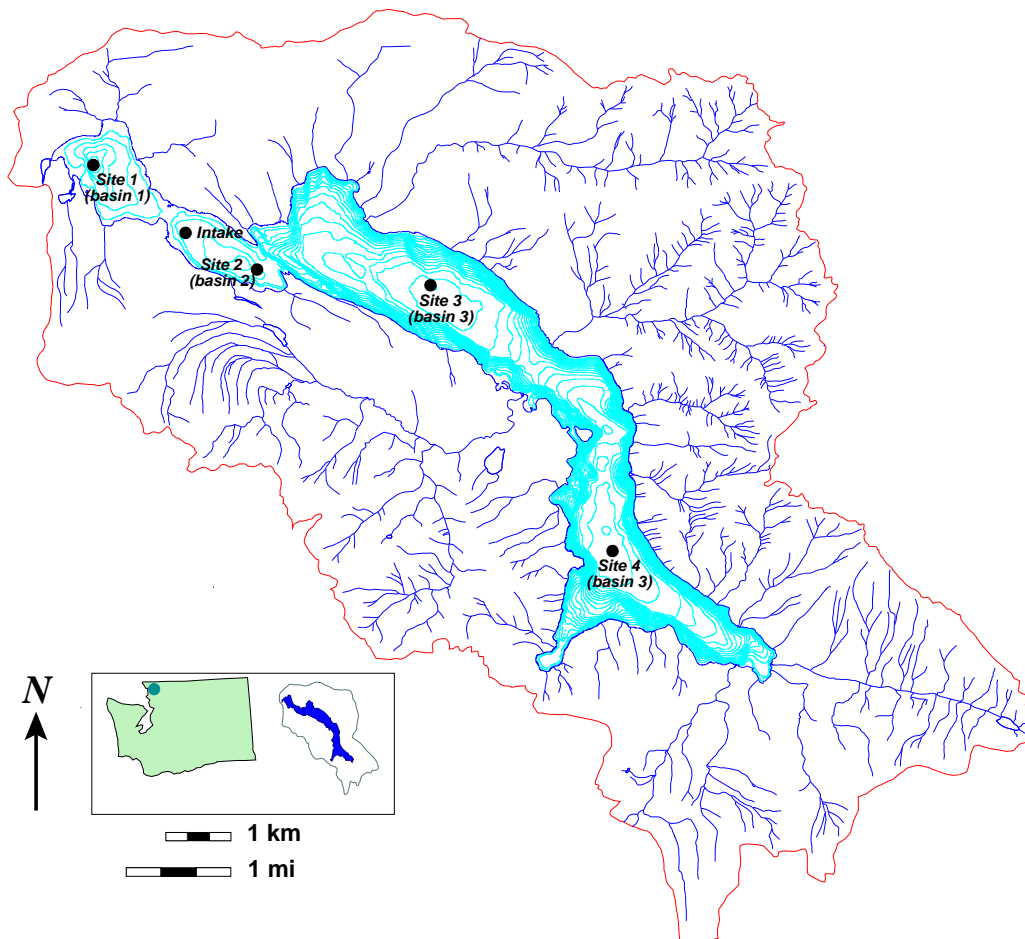


Figure A1: Lake Whatcom lake sampling sites. Basemap created using source files provided by G. Gabrisch and data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

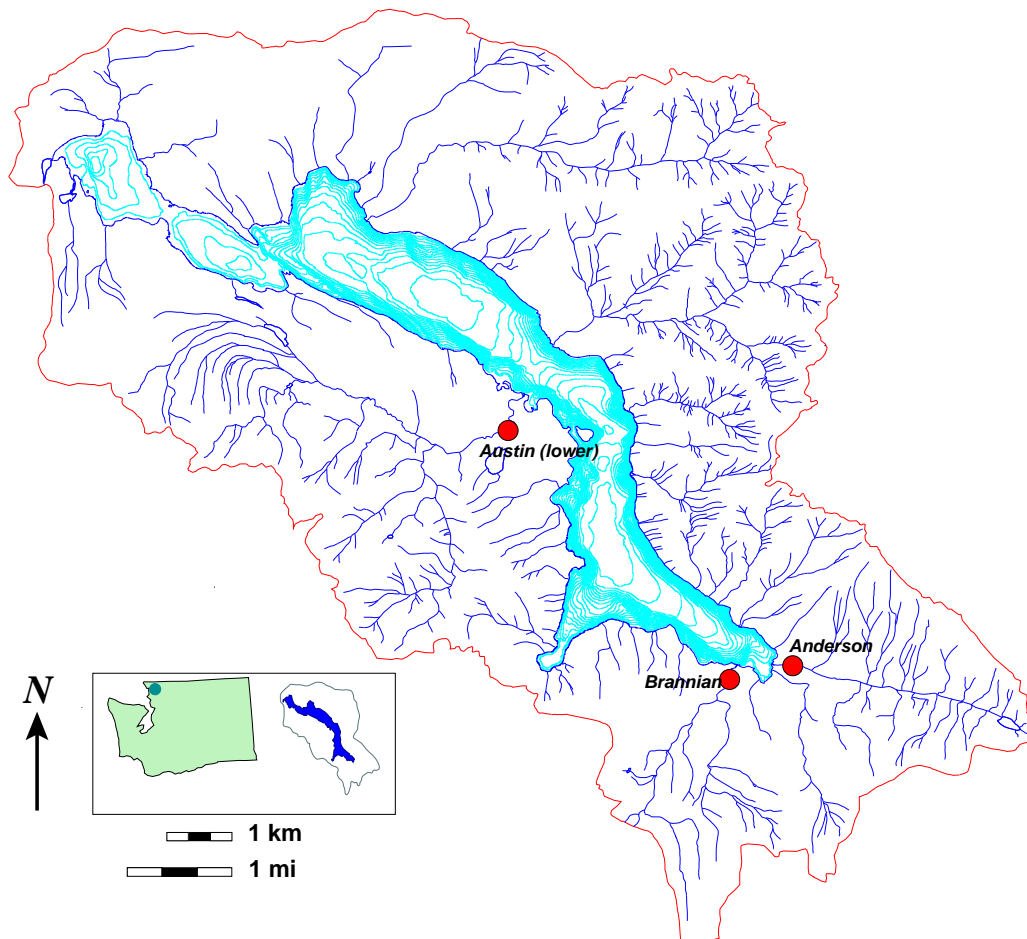


Figure A2: Lake Whatcom storm water sampling sites. Basemap created using source files provided by G. Gabrisch and data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

## **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 1 (page 16).

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 1, page 16). 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 161–165, 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**



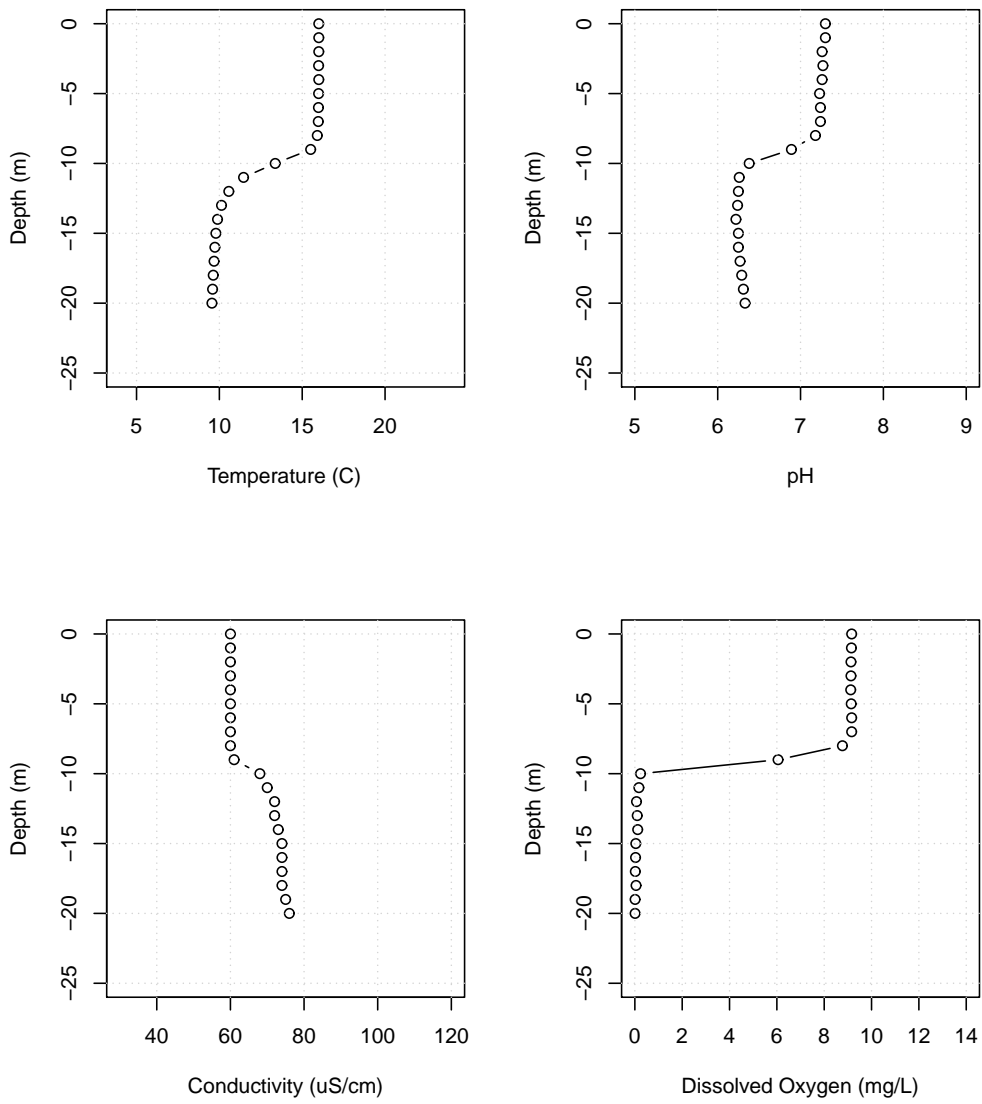


Figure B1: Lake Whatcom YSI profiles for Site 1, October 11, 2012.

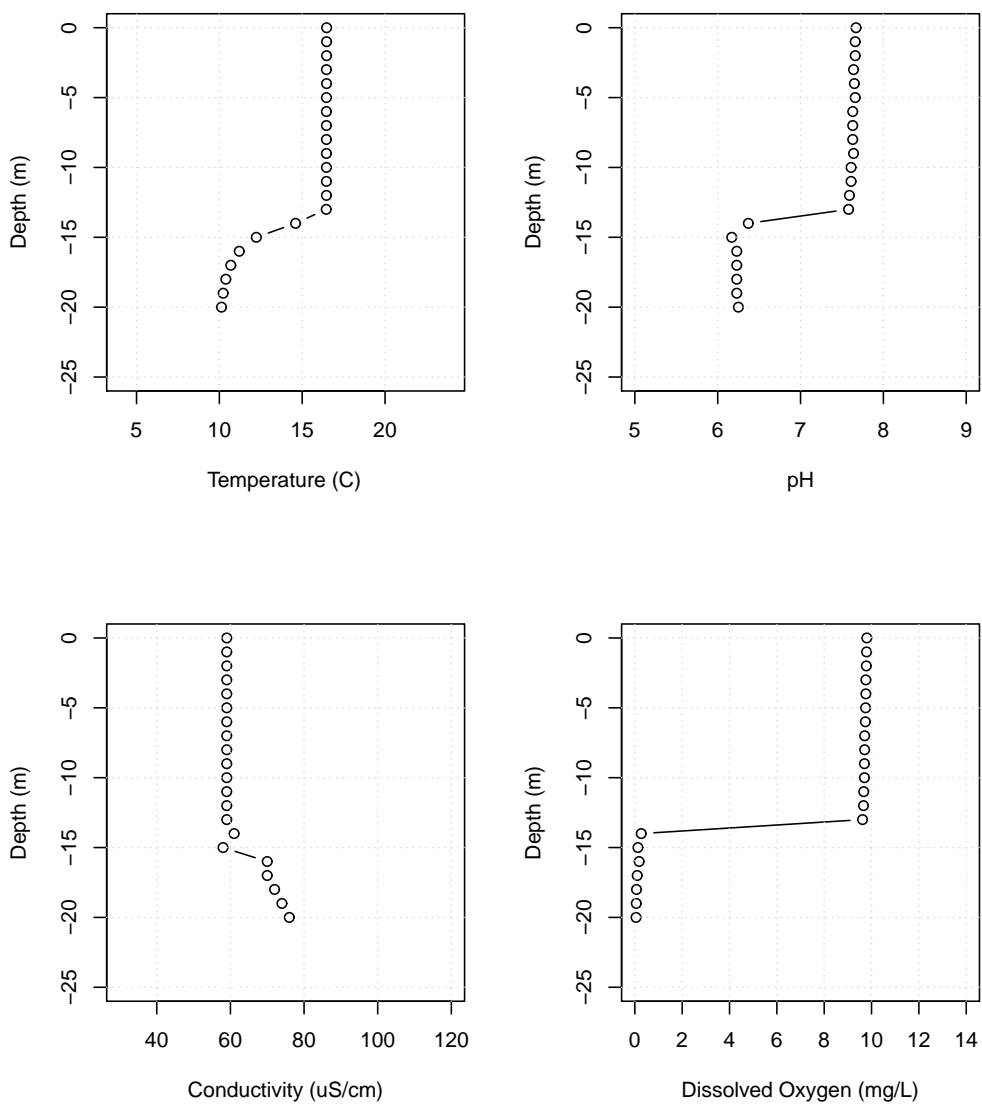


Figure B2: Lake Whatcom YSI profiles for Site 2, October 11, 2012.

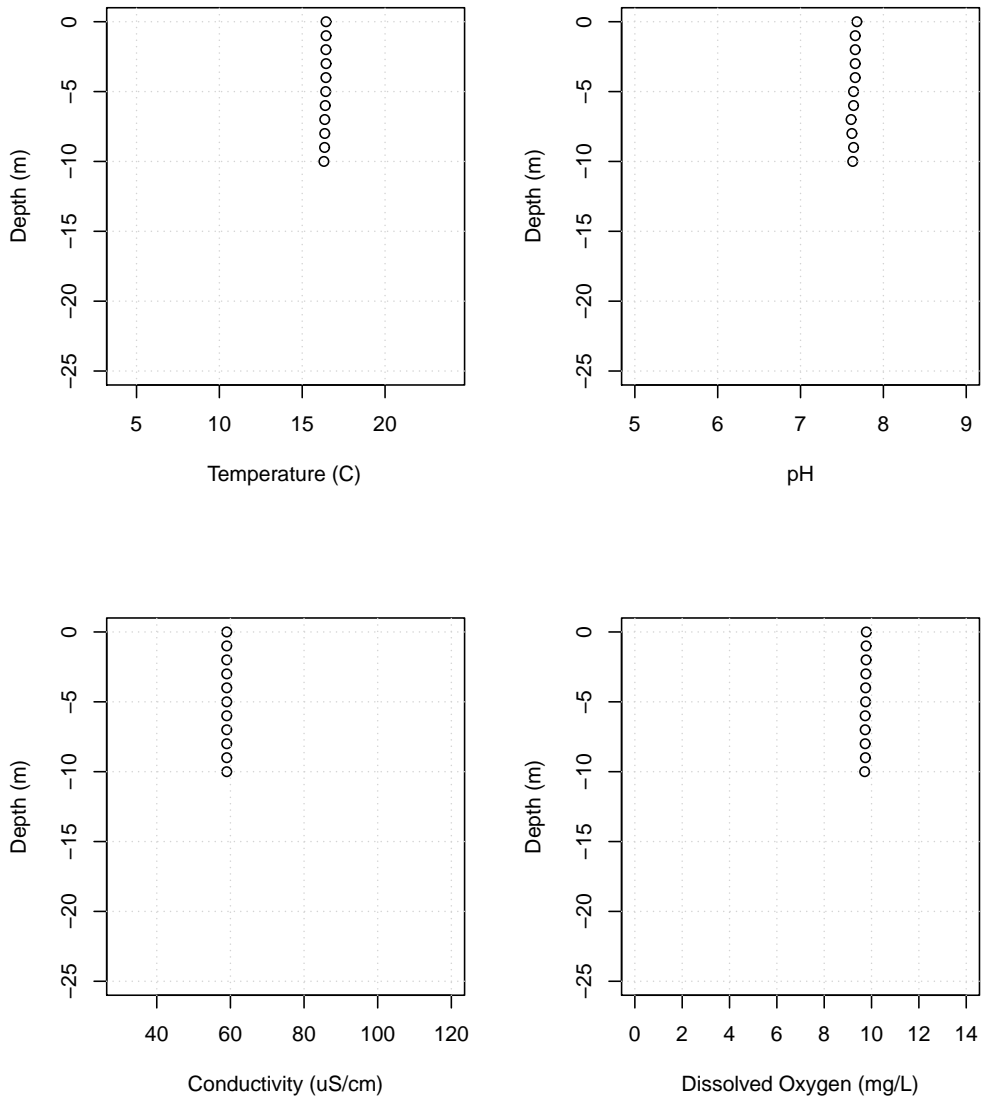


Figure B3: Lake Whatcom YSI profiles for the Intake, October 11, 2012.

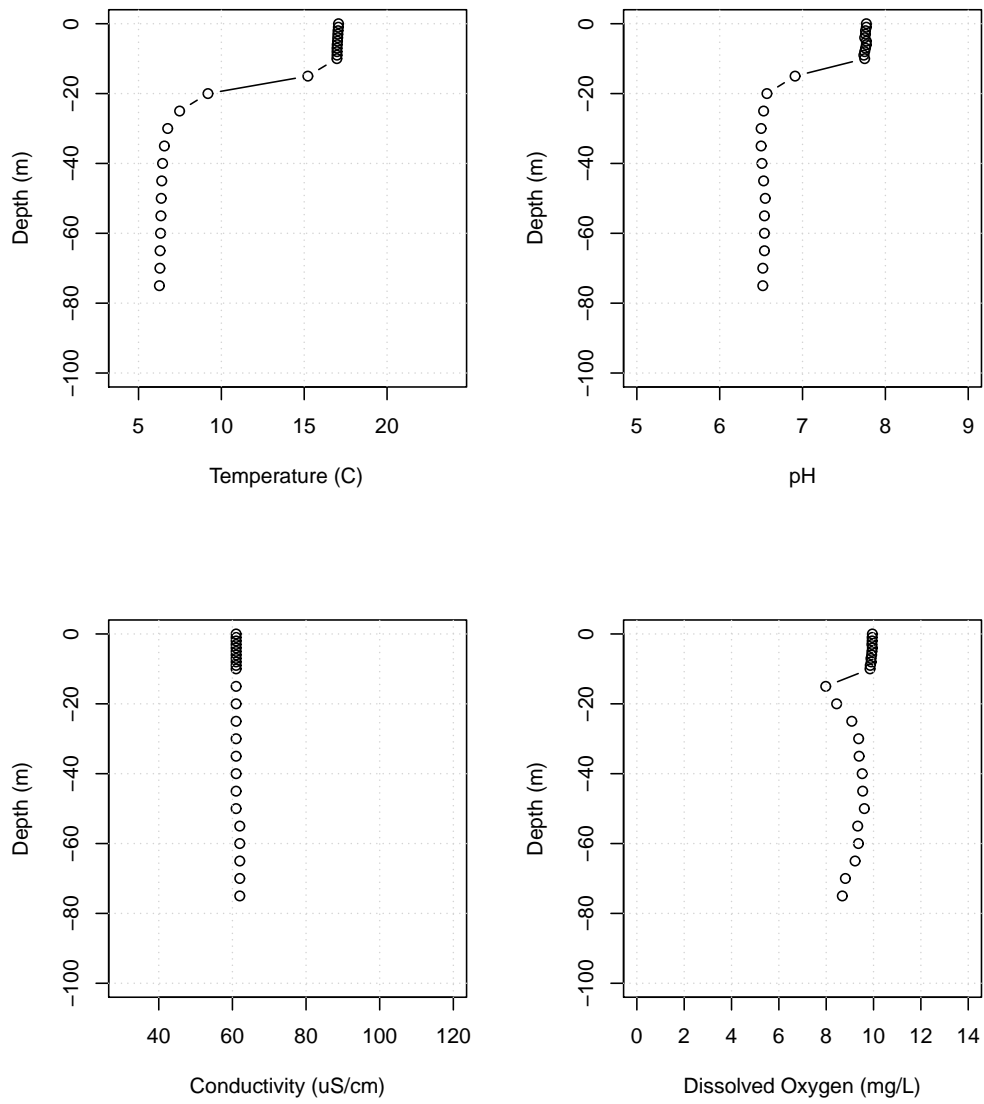


Figure B4: Lake Whatcom YSI profiles for Site 3, October 9, 2012.

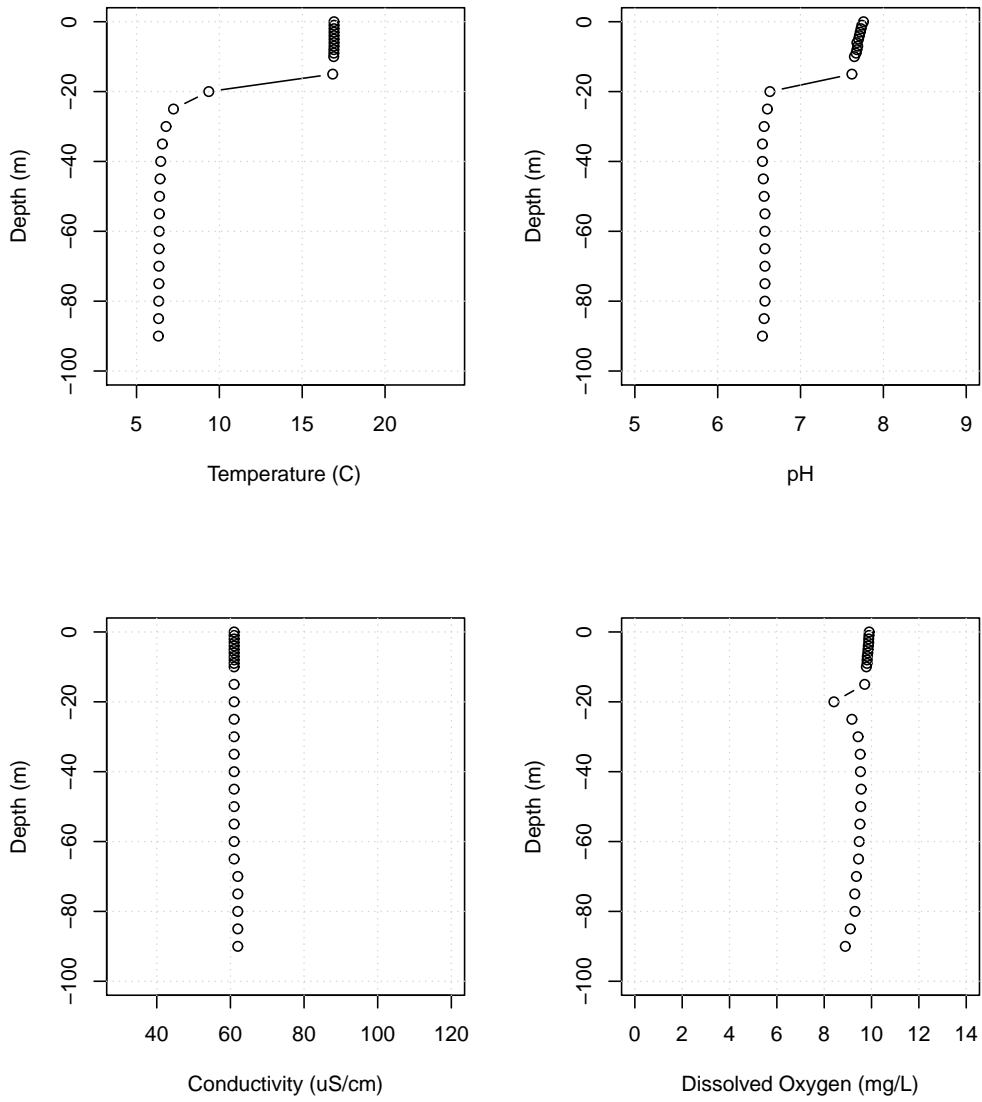


Figure B5: Lake Whatcom YSI profiles for Site 4, October 9, 2012.

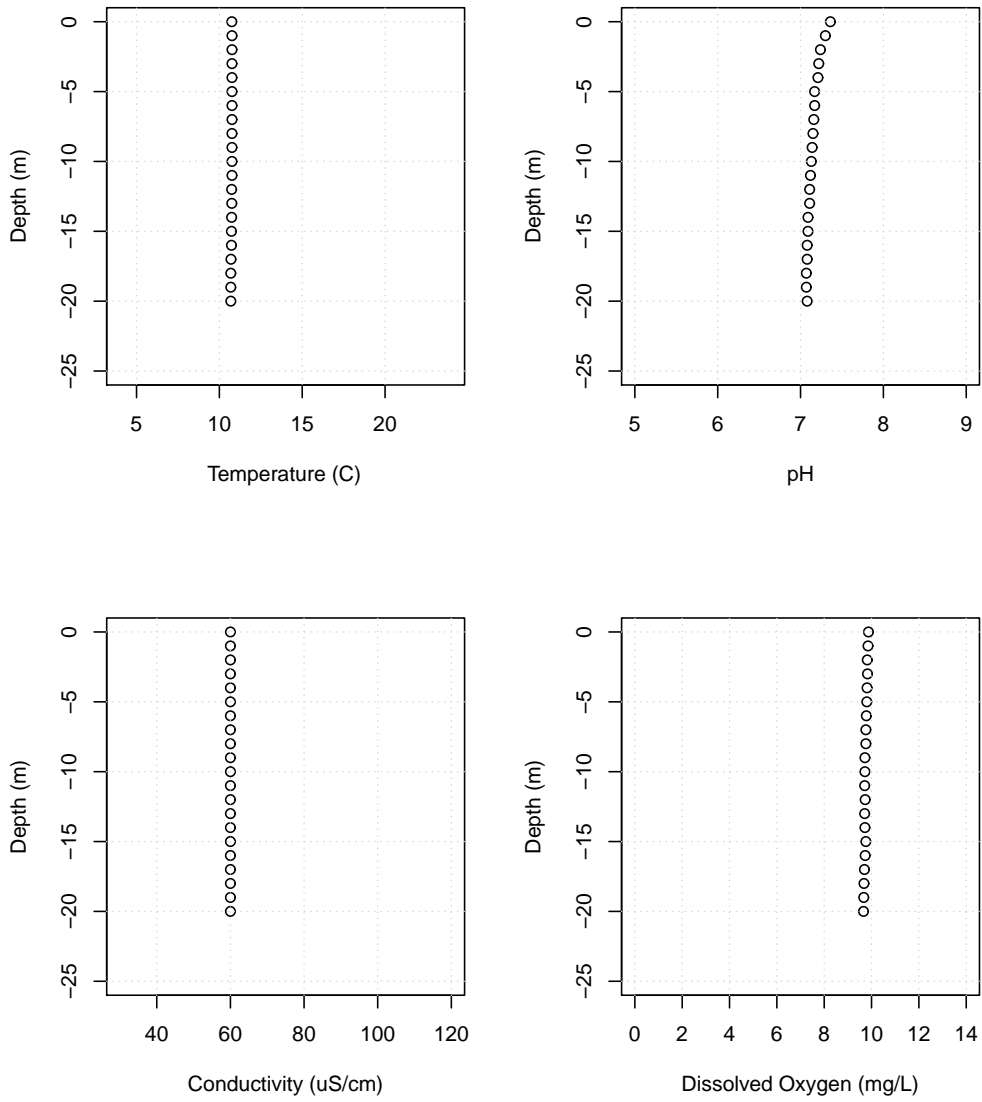


Figure B6: Lake Whatcom YSI profiles for Site 1, November 15, 2012.

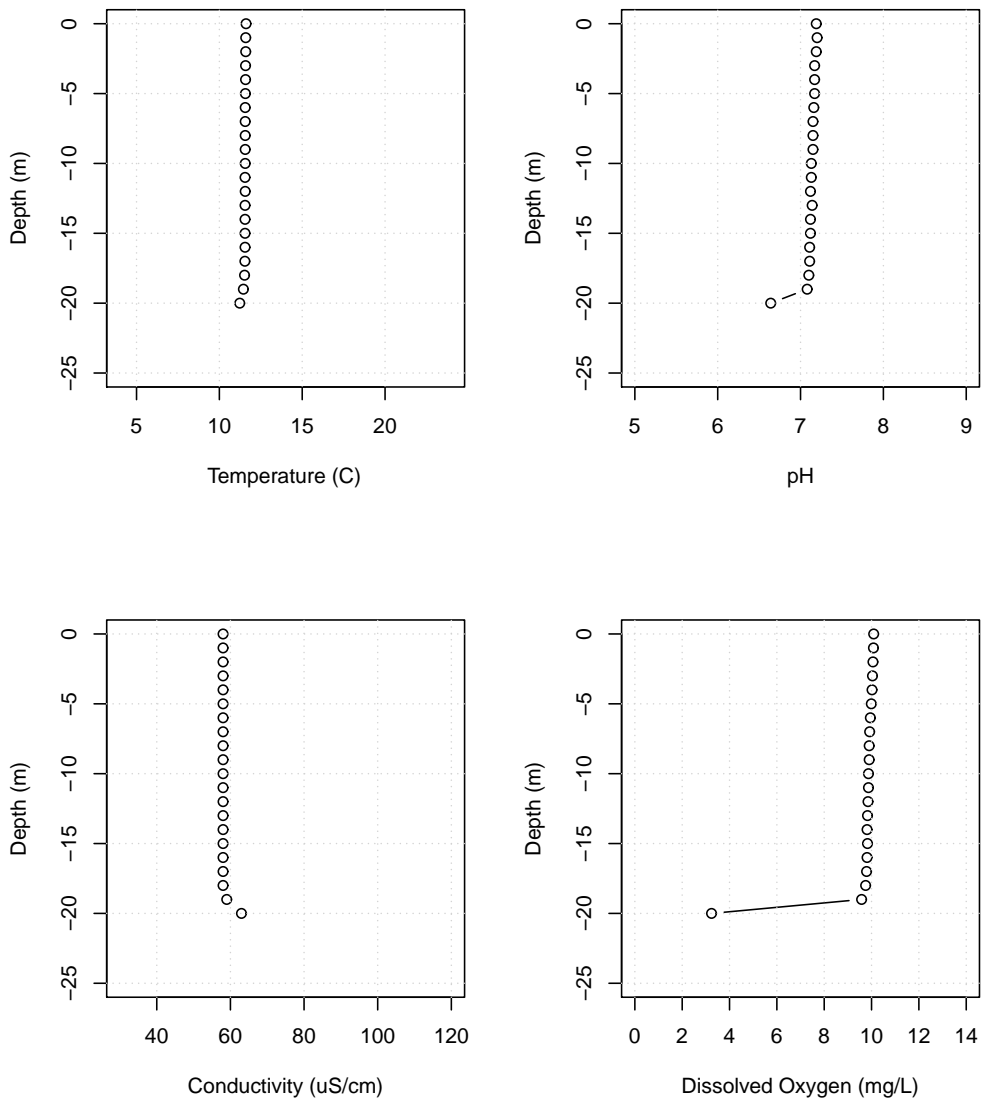


Figure B7: Lake Whatcom YSI profiles for Site 2, November 15, 2012.

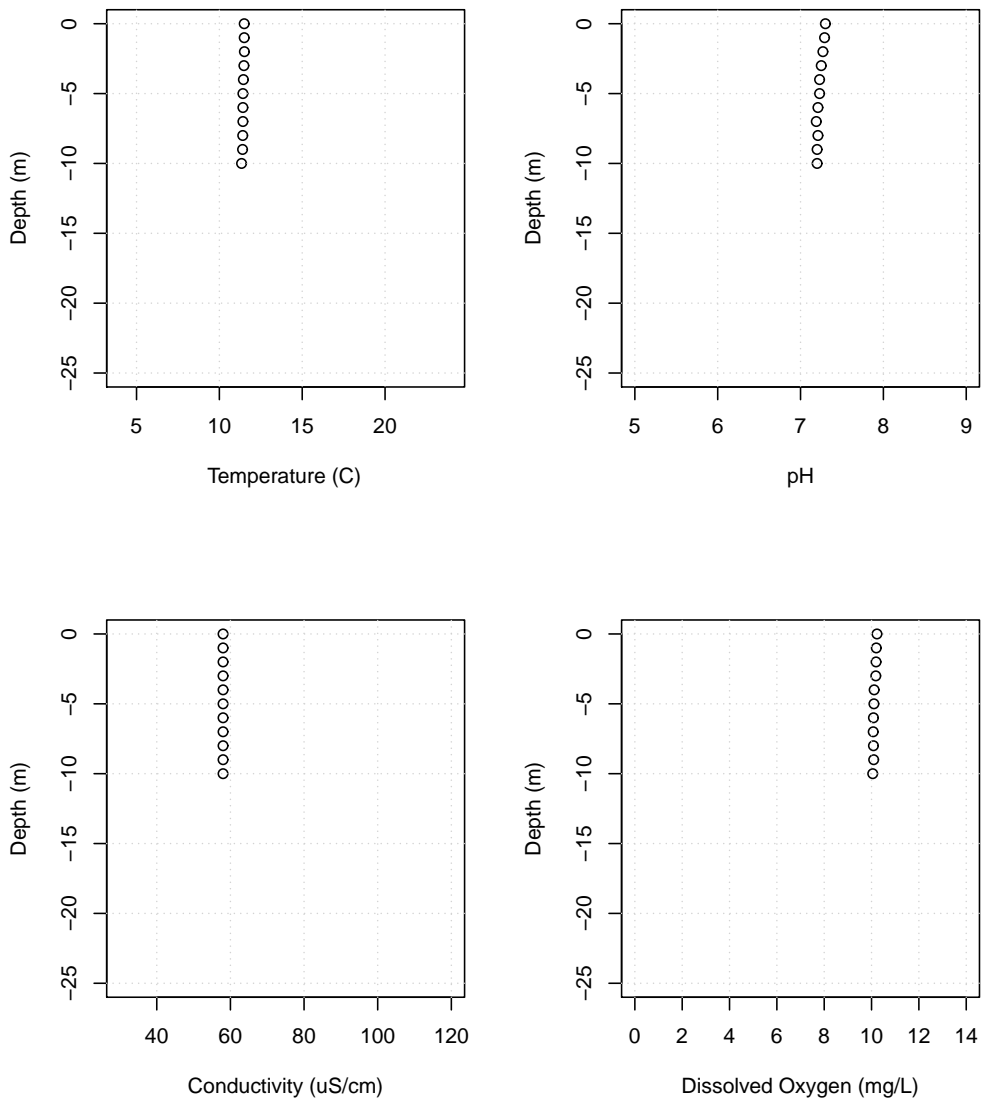


Figure B8: Lake Whatcom YSI profiles for the Intake, November 15, 2012.



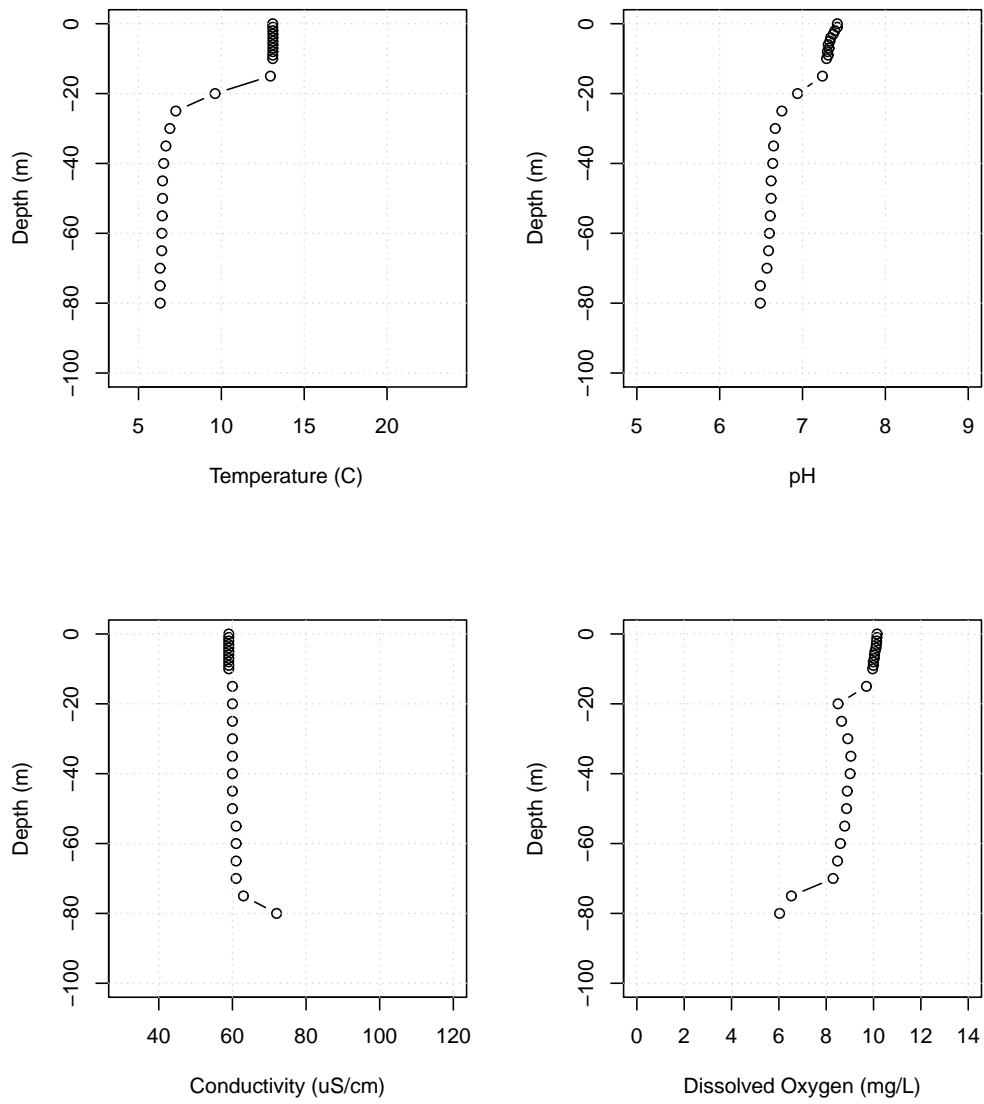


Figure B9: Lake Whatcom YSI profiles for Site 3, November 6, 2012.

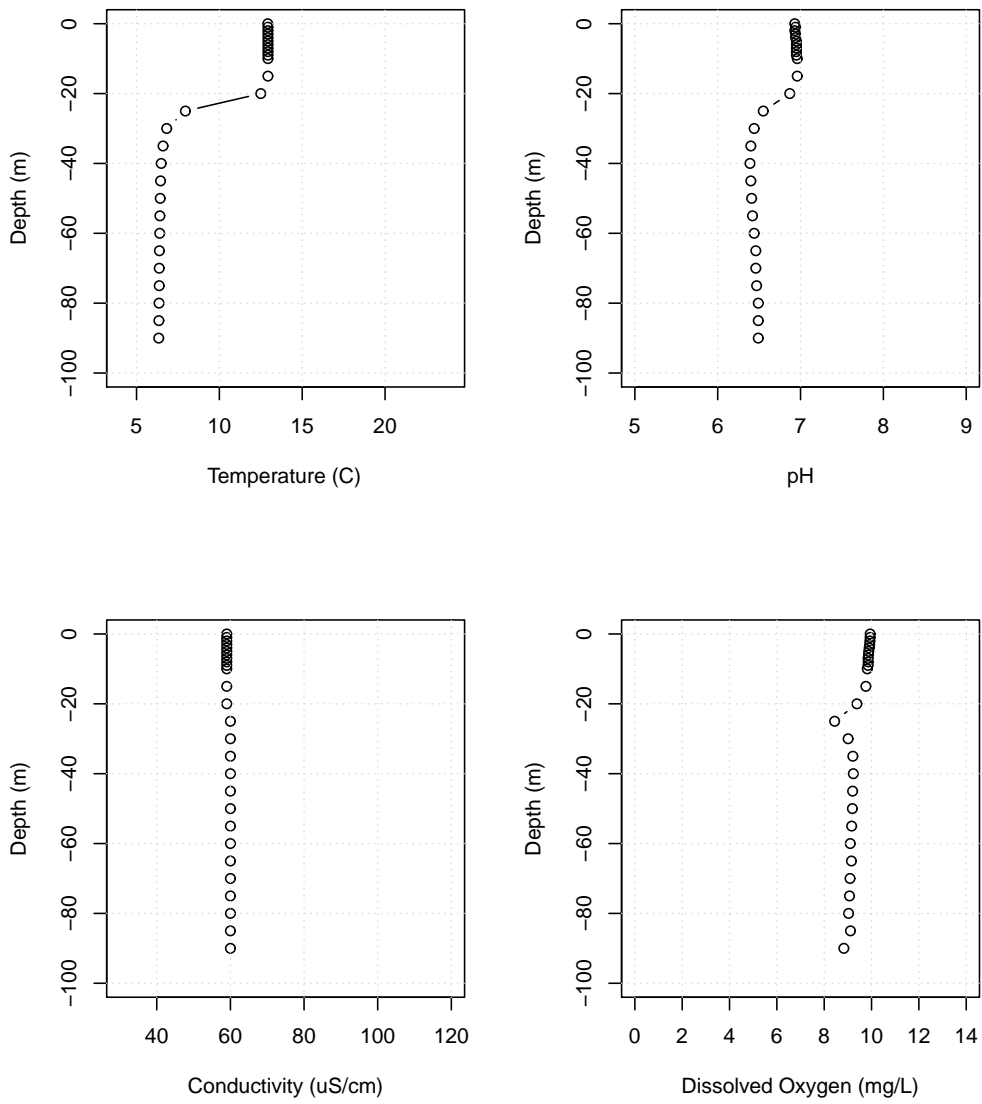


Figure B10: Lake Whatcom YSI profiles for Site 4, November 6, 2012.

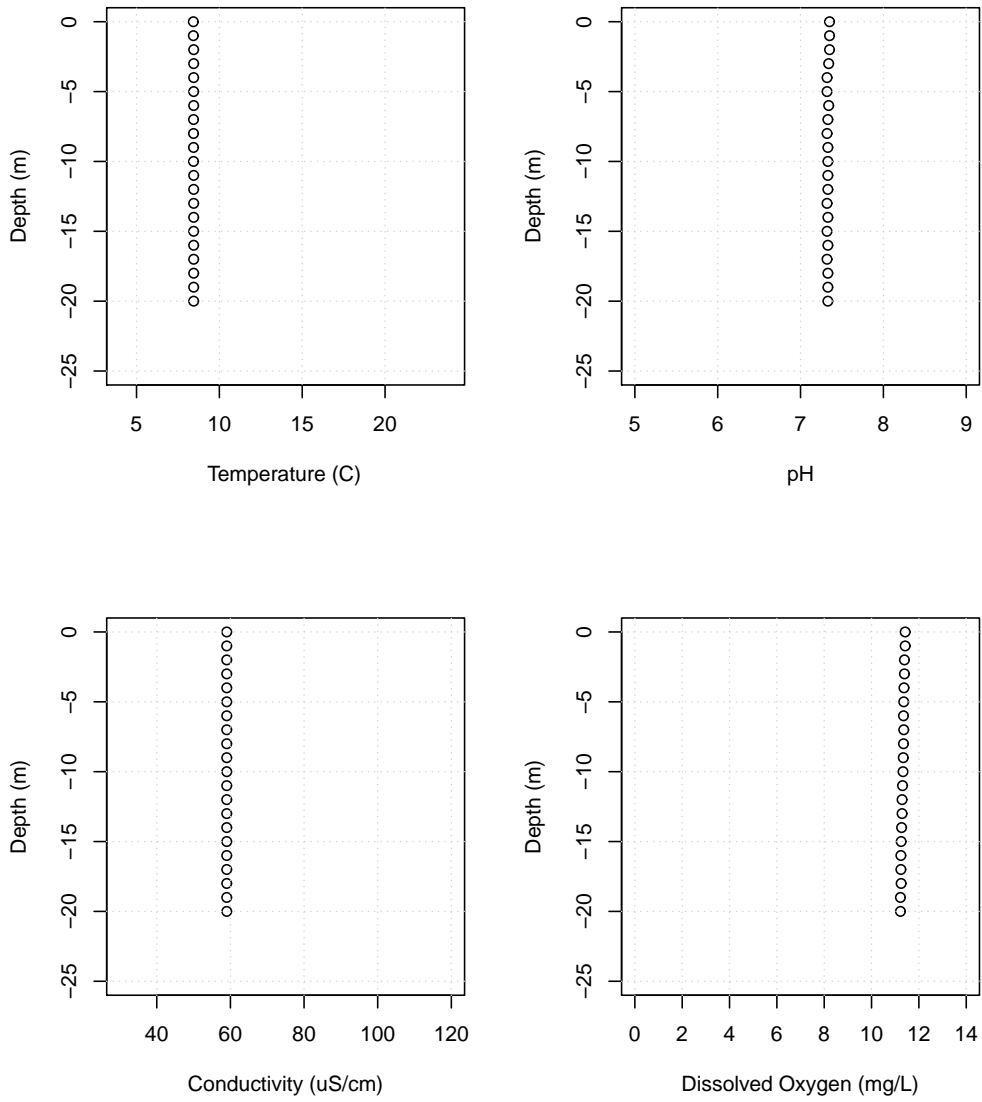


Figure B11: Lake Whatcom YSI profiles for Site 1, December 6, 2012.

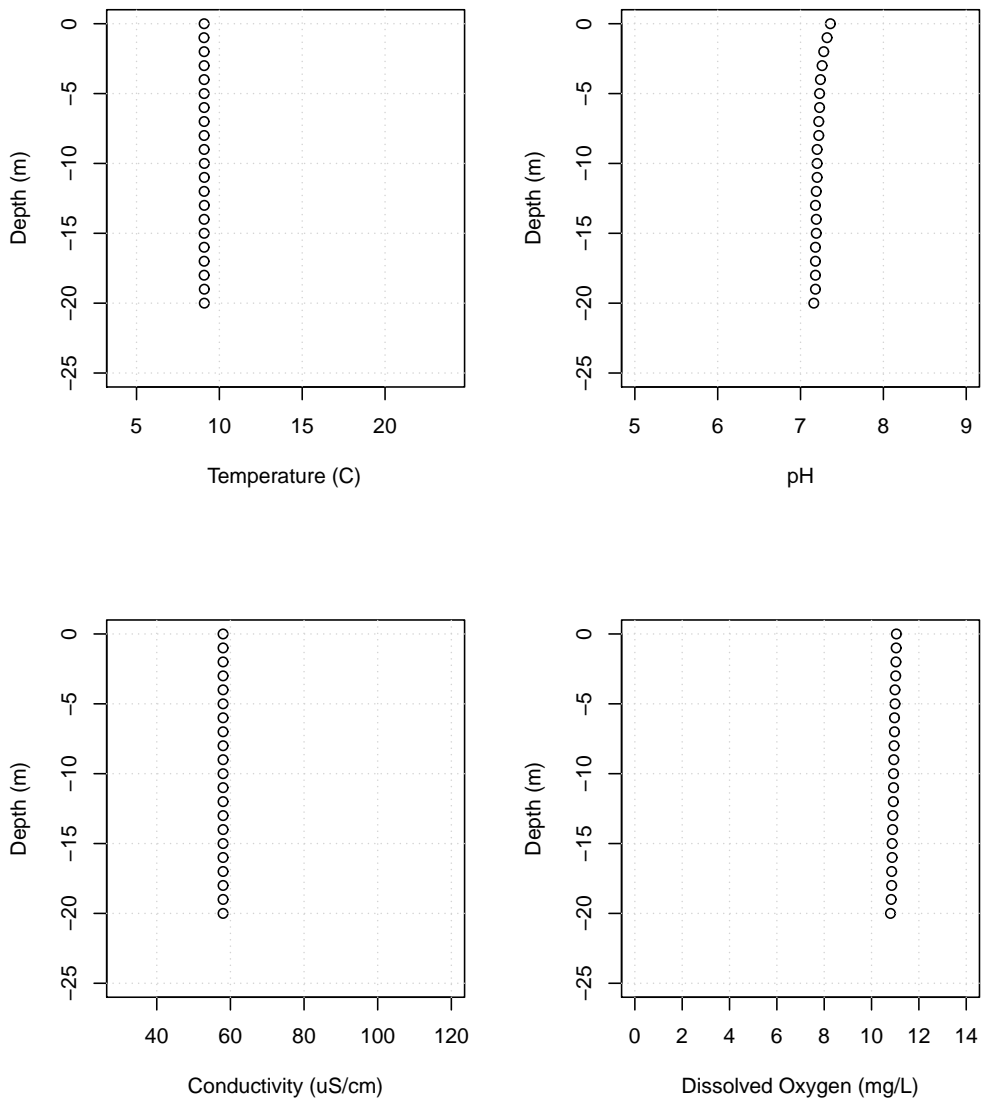


Figure B12: Lake Whatcom YSI profiles for Site 2, December 6, 2012.

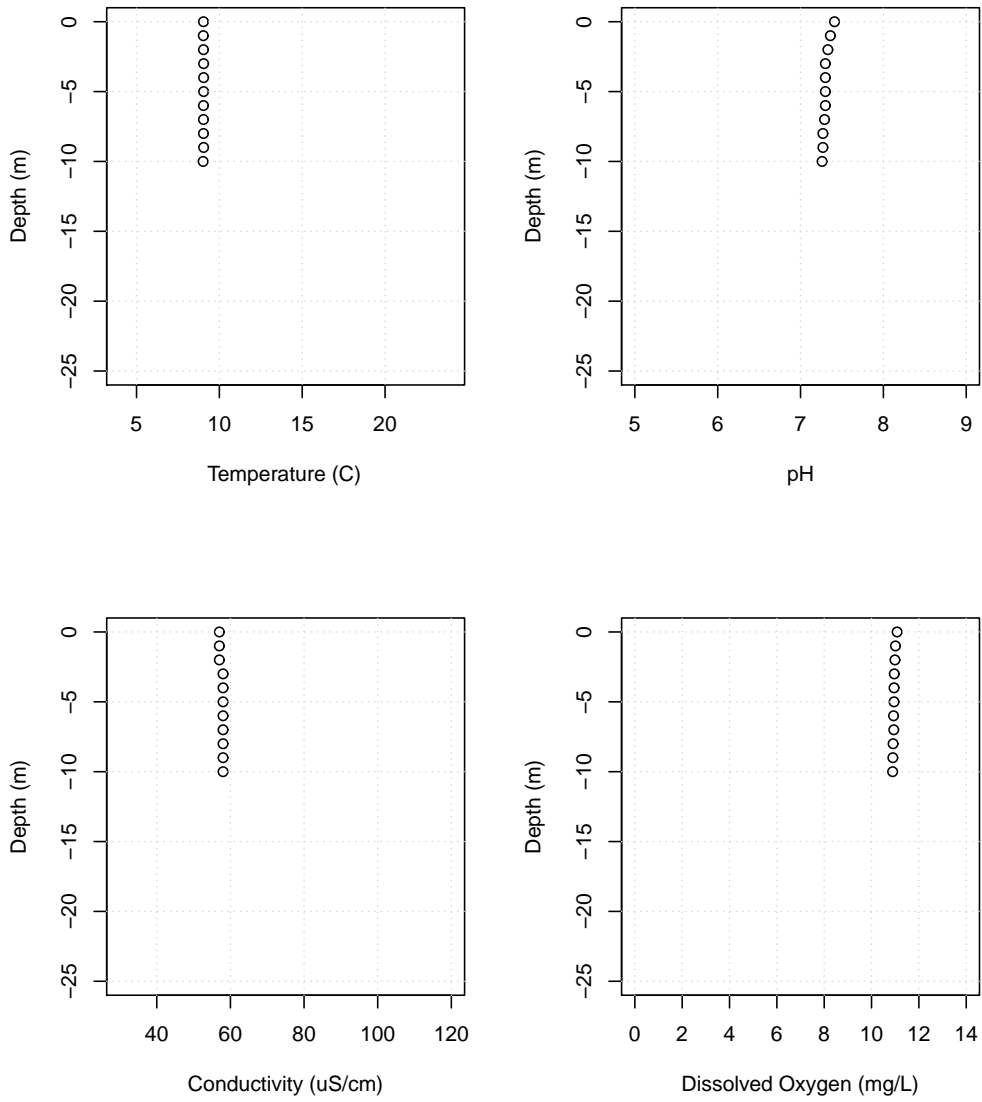


Figure B13: Lake Whatcom YSI profiles for the Intake, December 6, 2012.

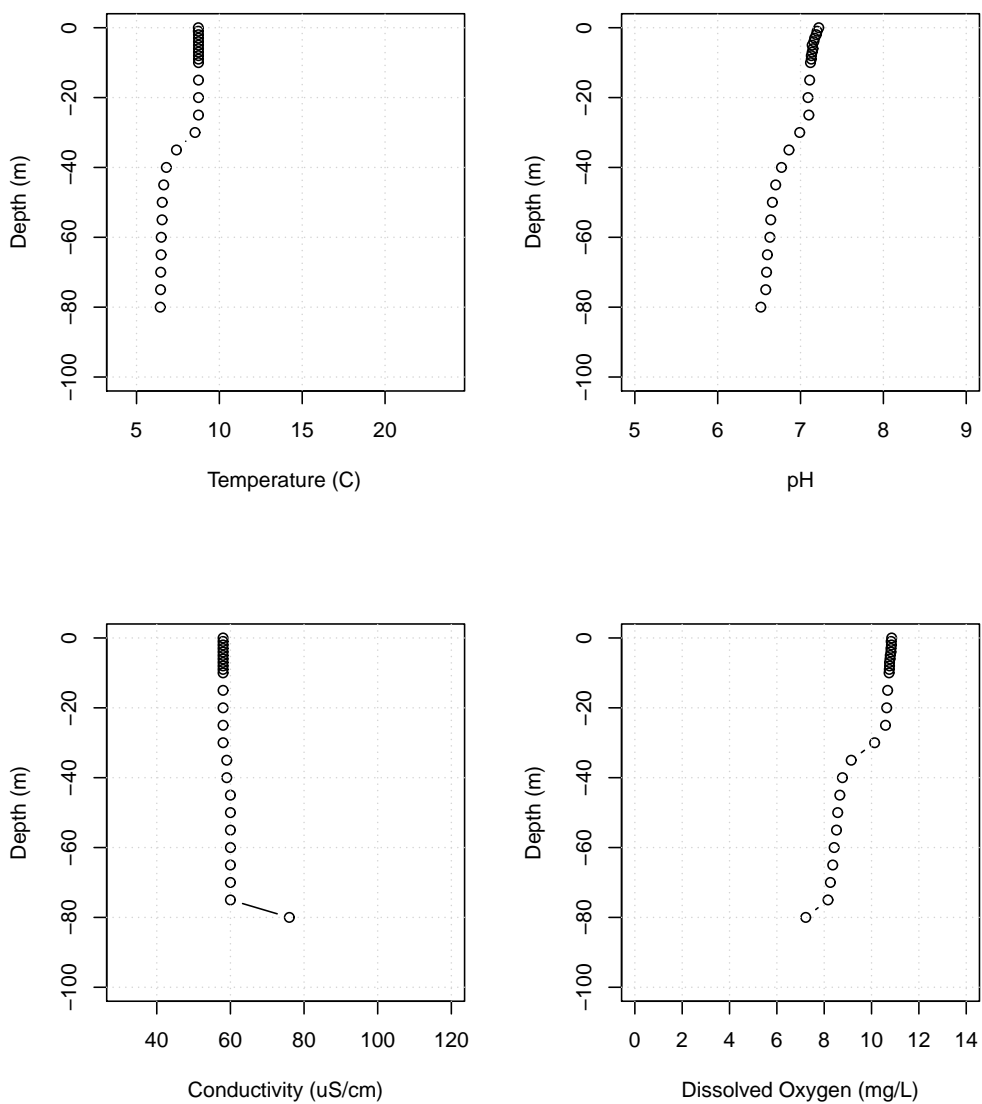


Figure B14: Lake Whatcom YSI profiles for Site 3, December 12, 2012.

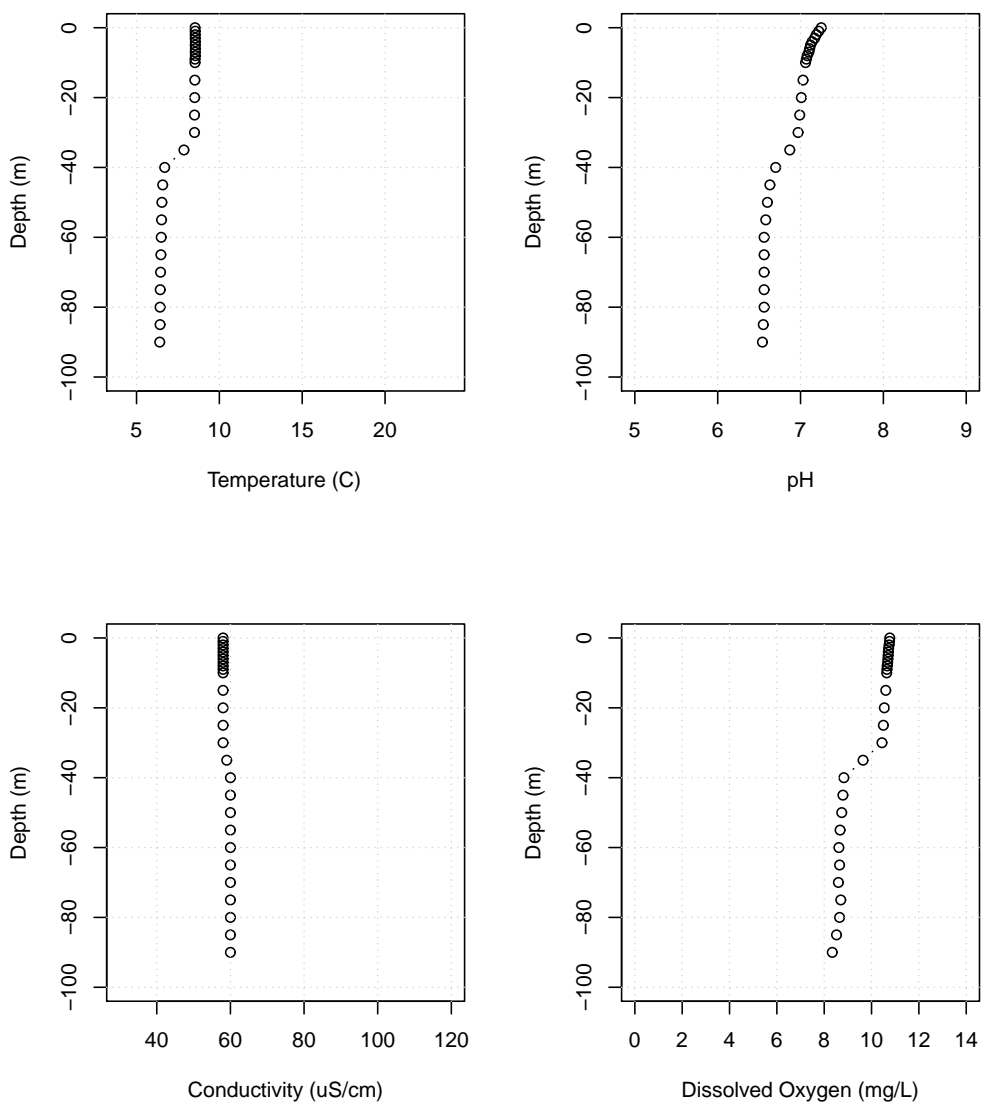


Figure B15: Lake Whatcom YSI profiles for Site 4, December 12, 2012.

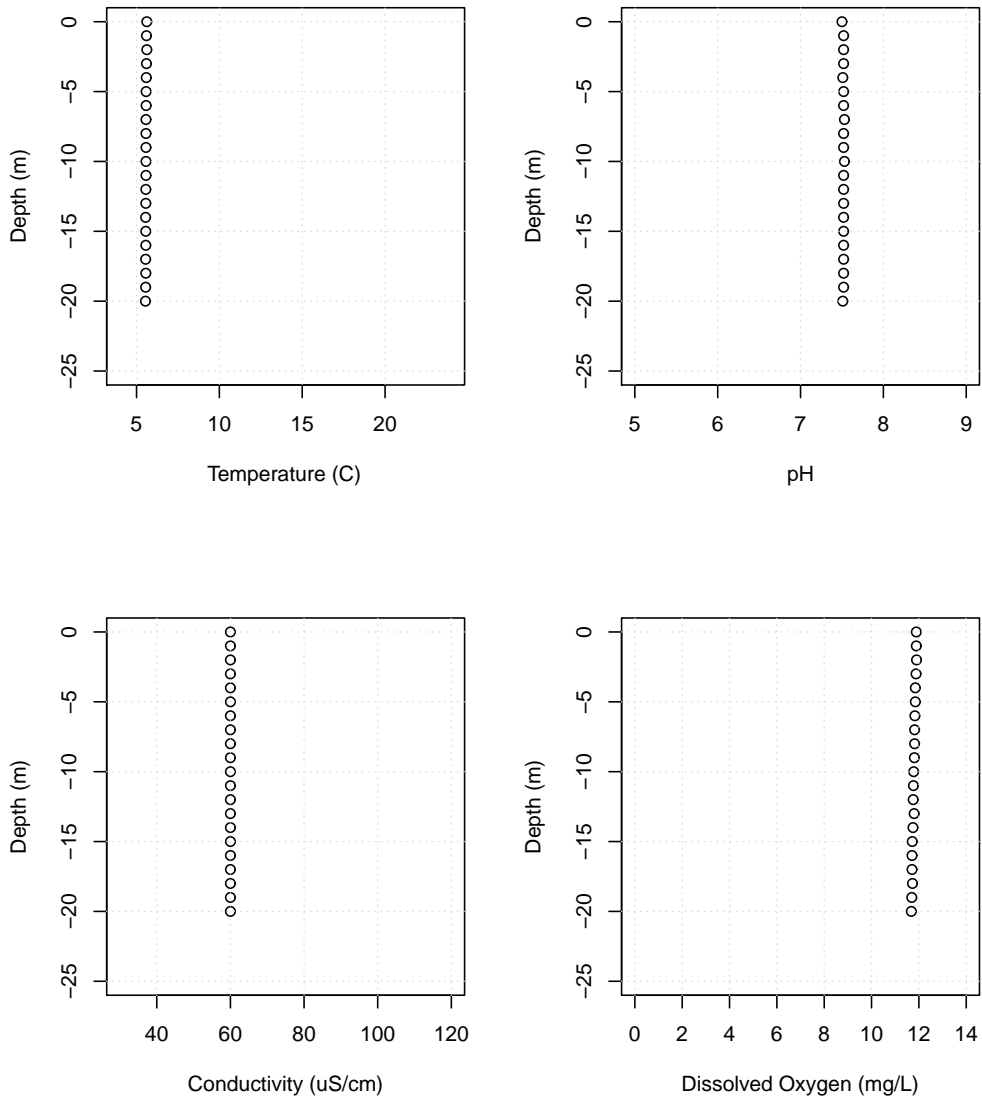


Figure B16: Lake Whatcom YSI profiles for Site 1, February 7, 2013.



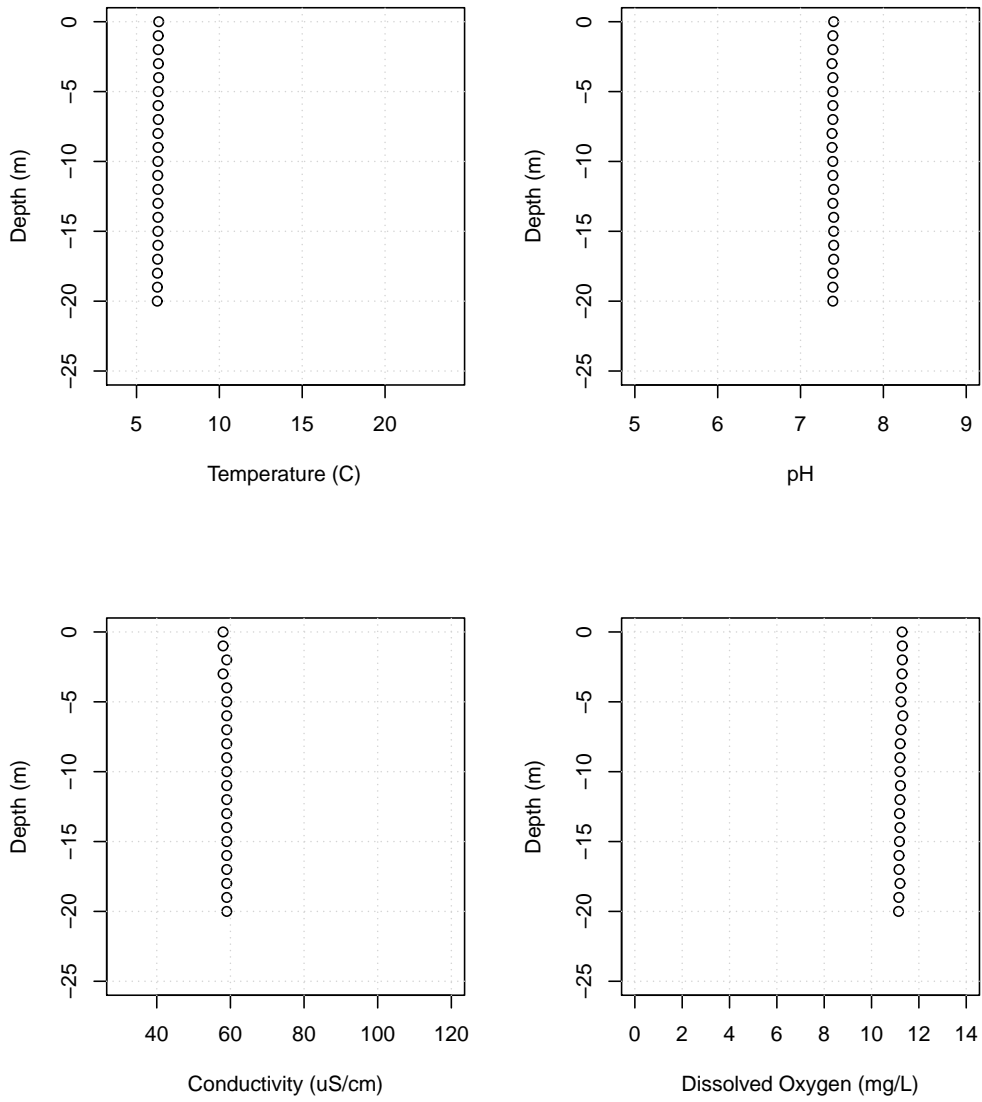


Figure B17: Lake Whatcom YSI profiles for Site 2, February 7, 2013.

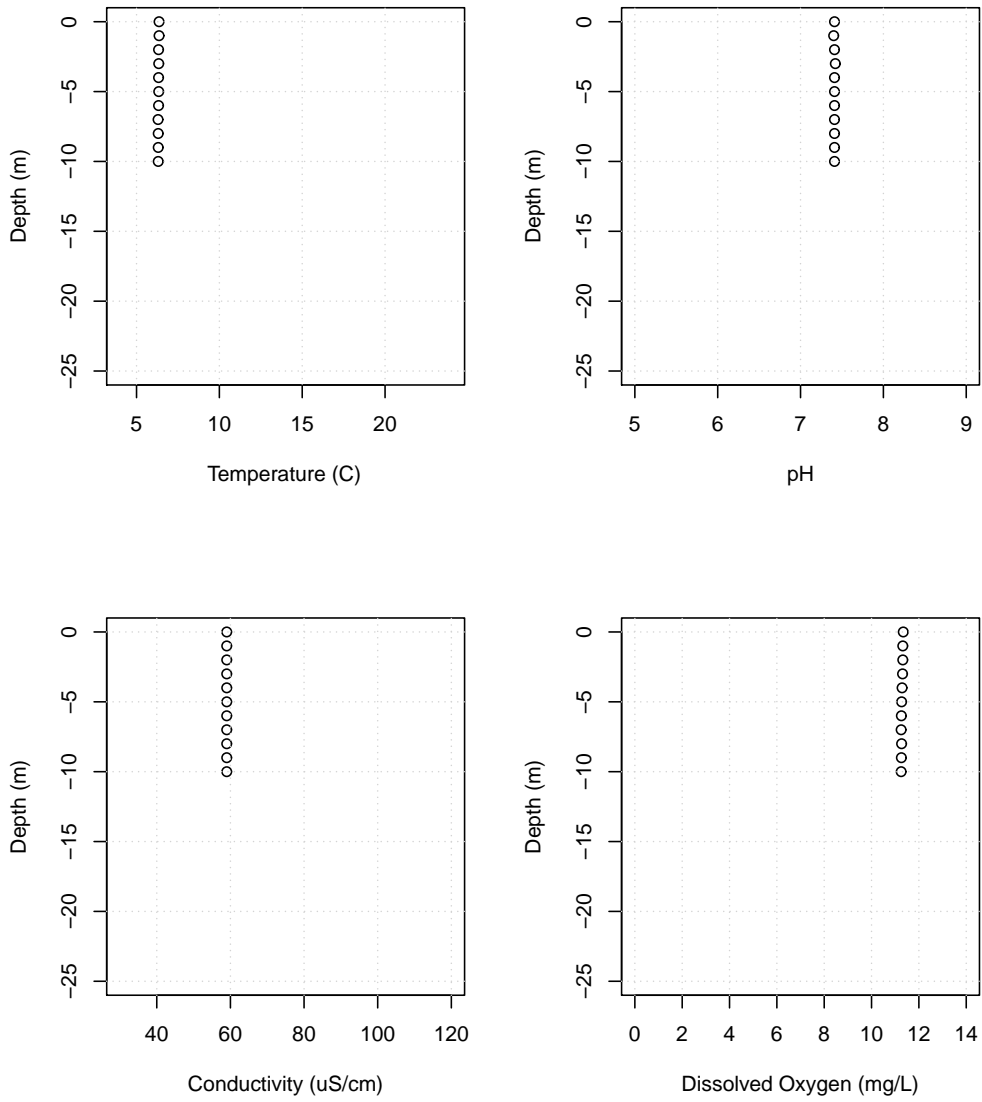


Figure B18: Lake Whatcom YSI profiles for the Intake, February 7, 2013.

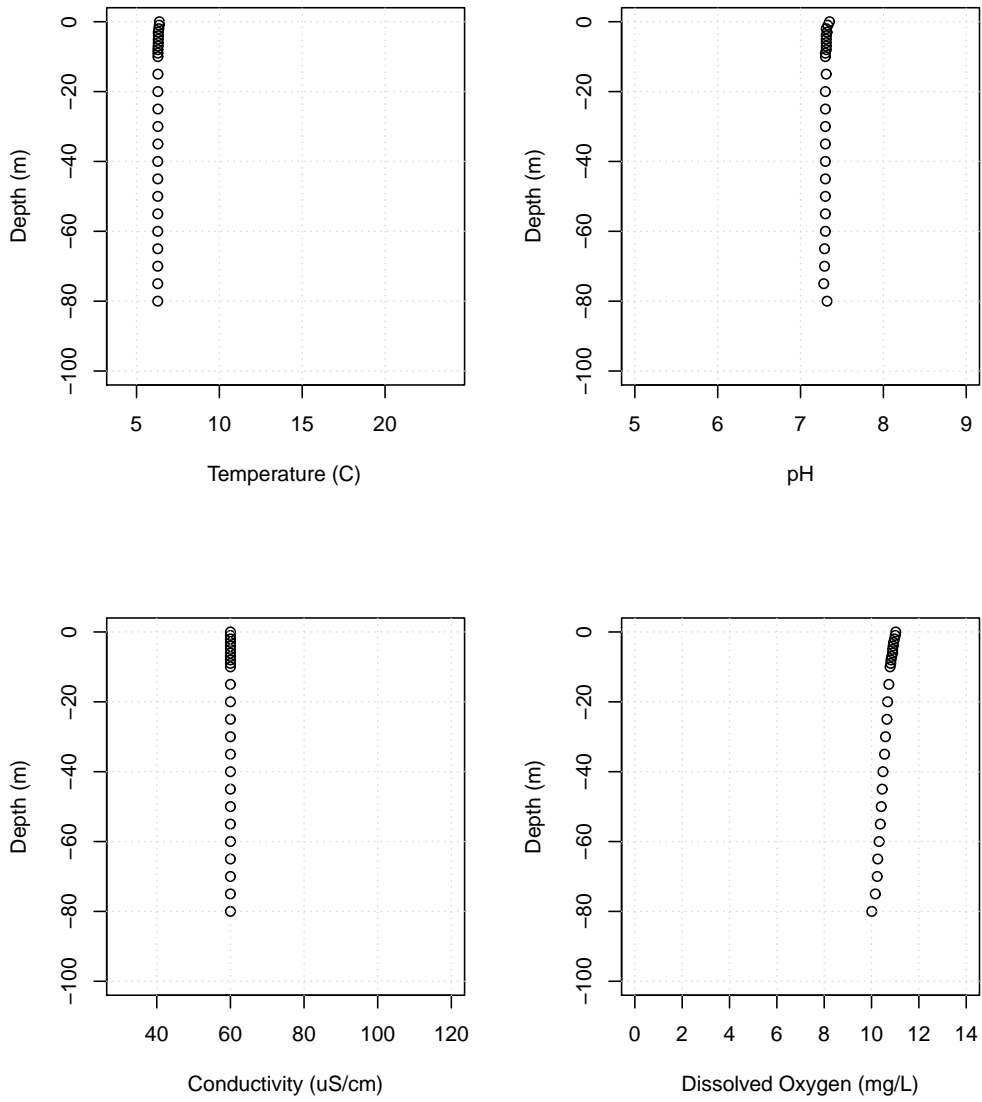


Figure B19: Lake Whatcom YSI profiles for Site 3, February 14, 2013.

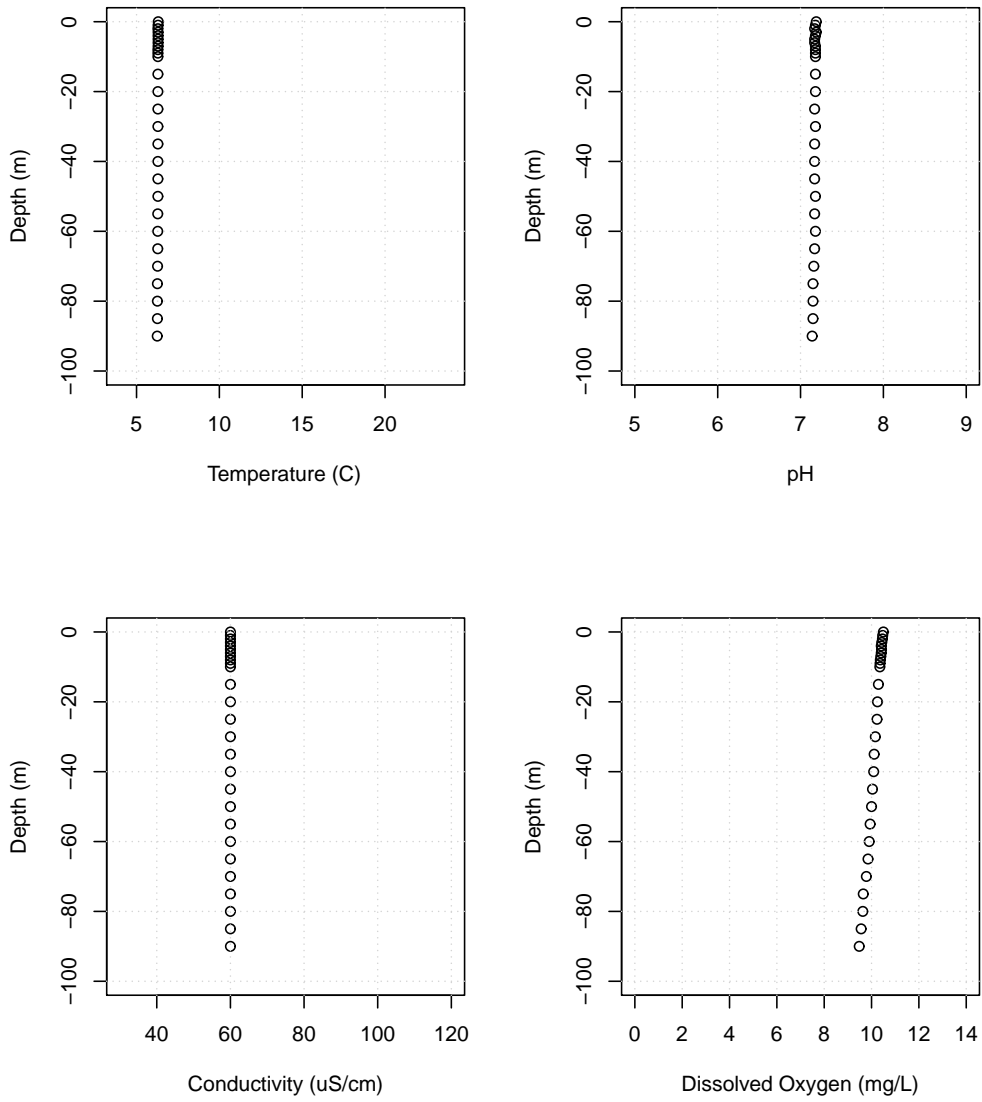


Figure B20: Lake Whatcom YSI profiles for Site 4, February 14, 2013.

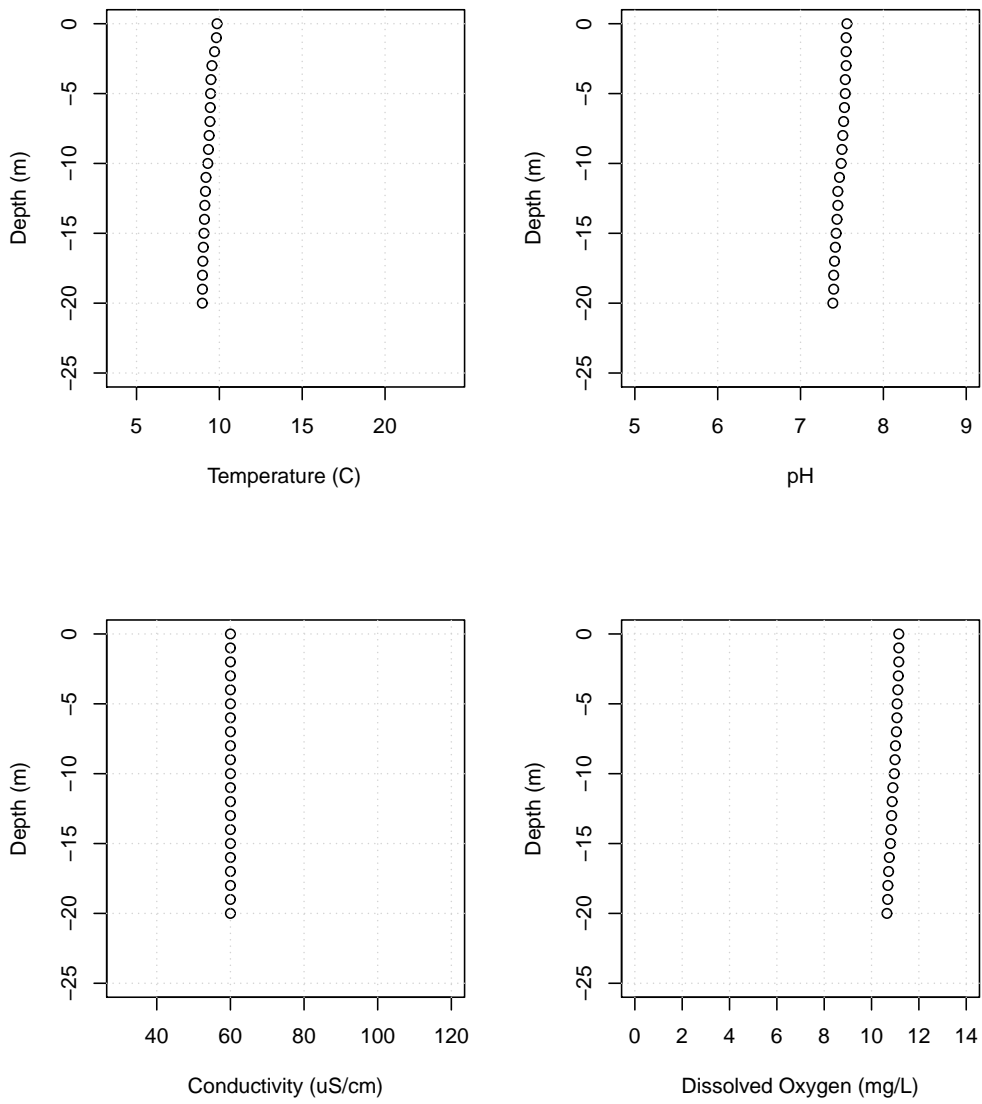


Figure B21: Lake Whatcom YSI profiles for Site 1, April 11, 2013.

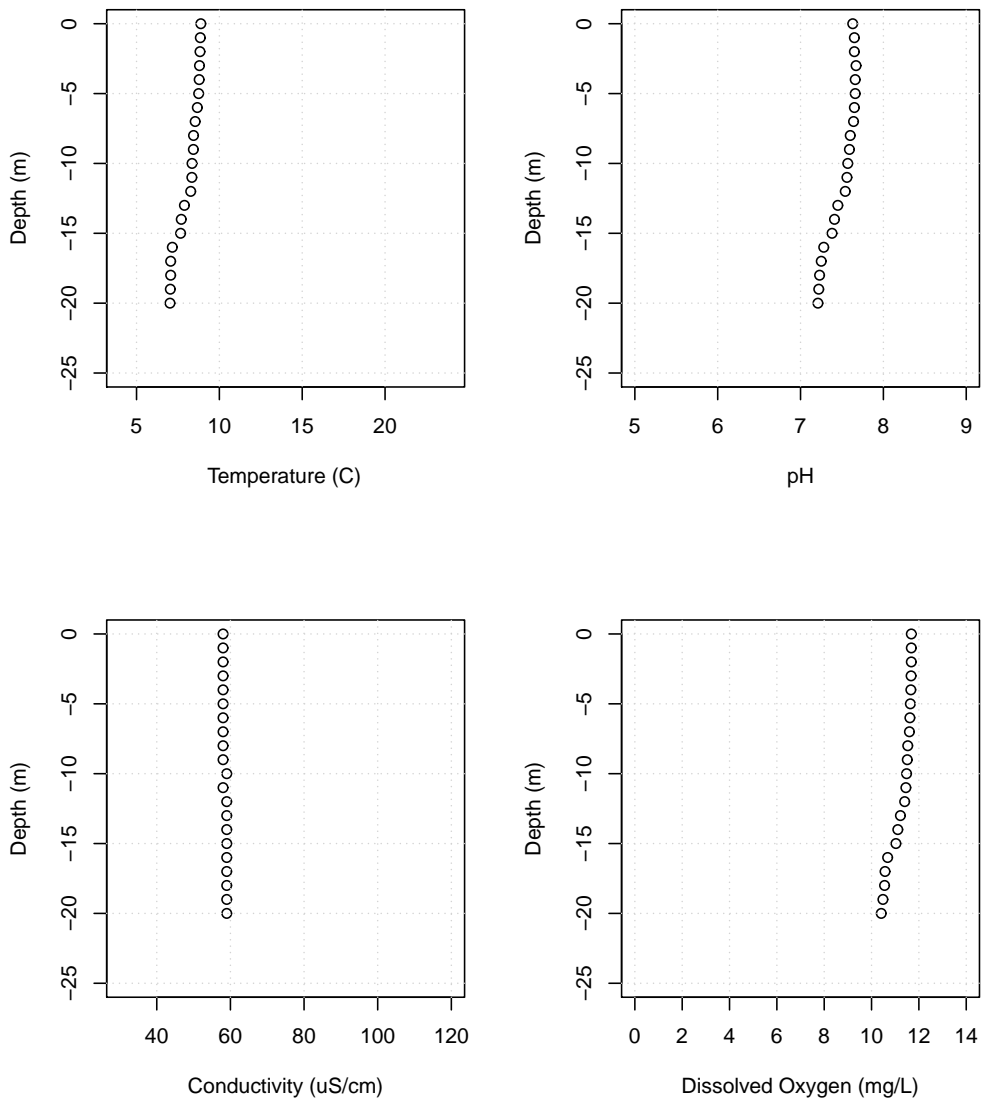


Figure B22: Lake Whatcom YSI profiles for Site 2, April 11, 2013.

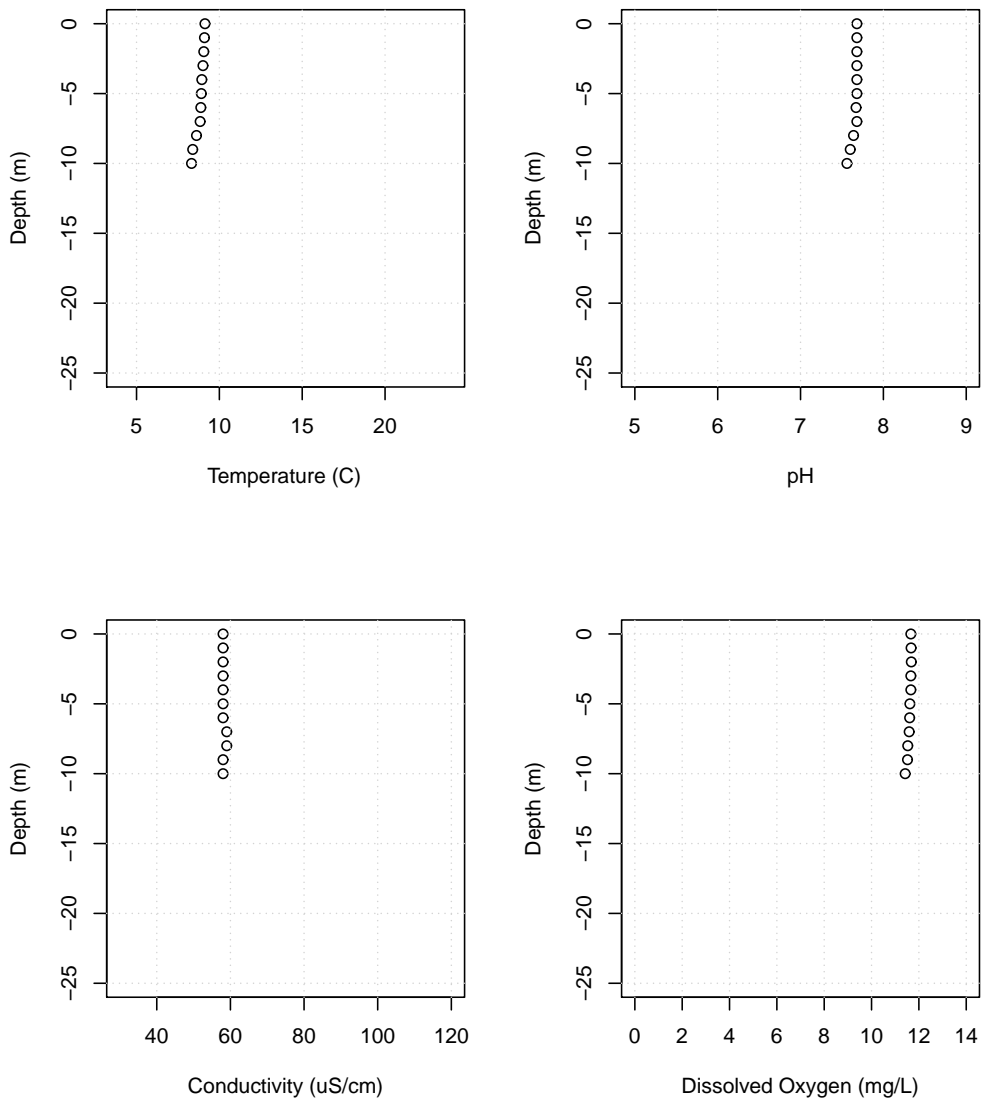


Figure B23: Lake Whatcom YSI profiles for the Intake, April 11, 2013.

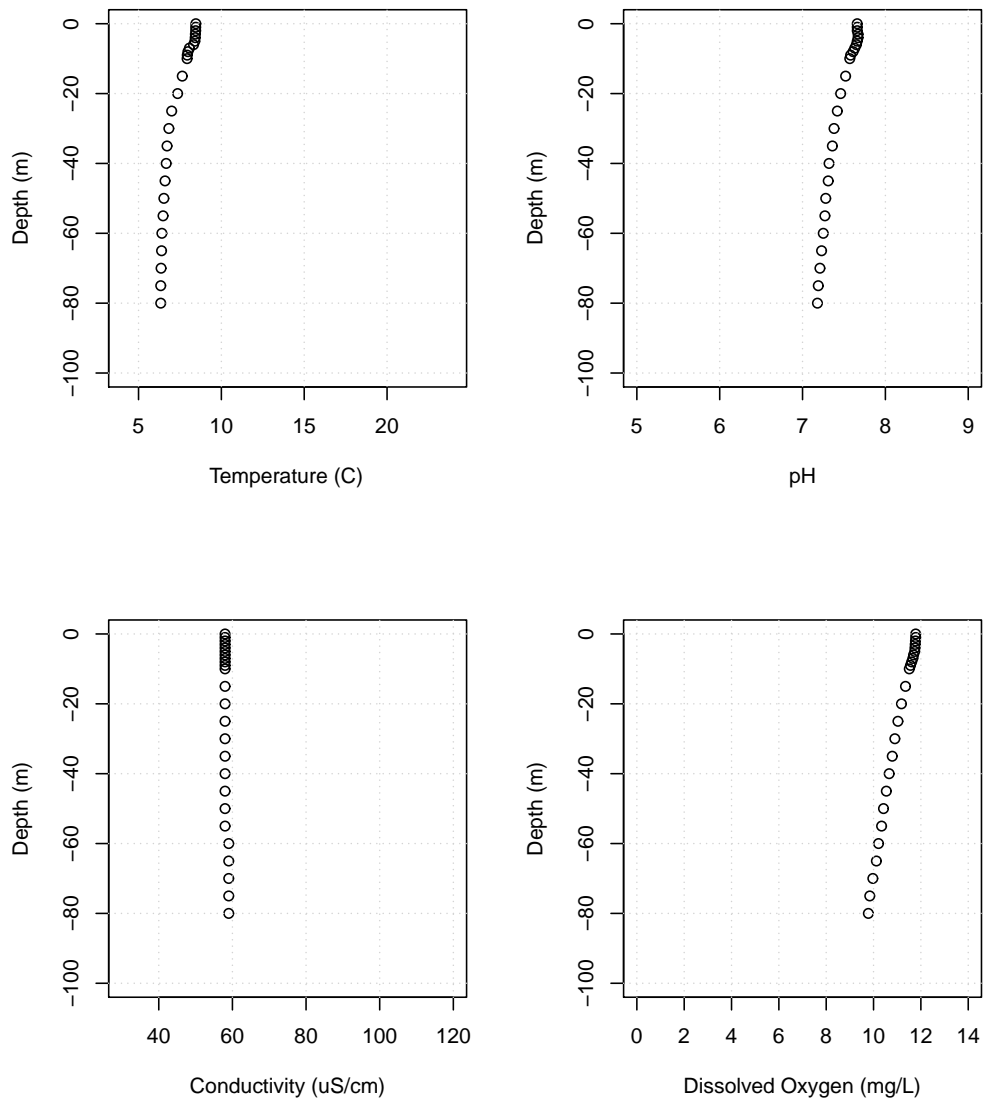


Figure B24: Lake Whatcom YSI profiles for Site 3, April 9, 2013.



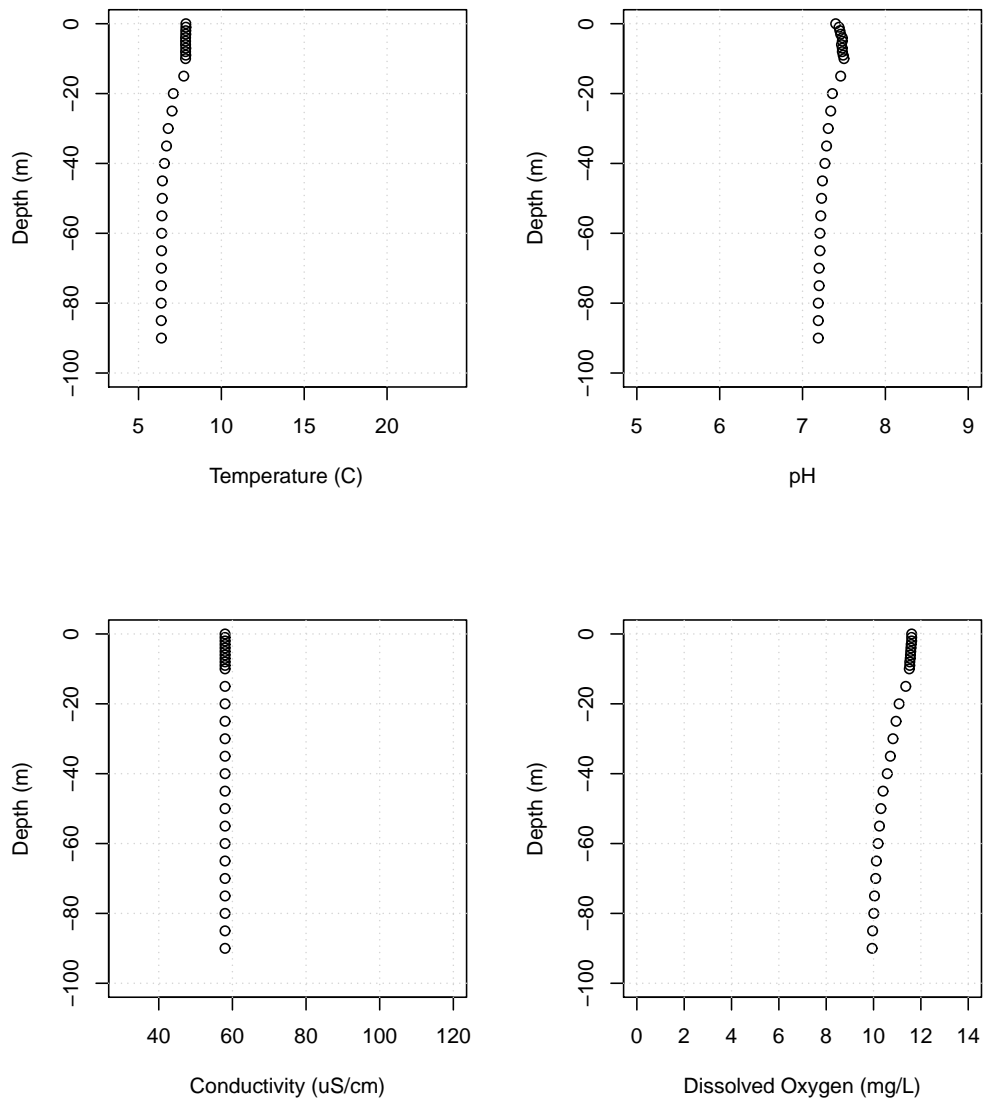


Figure B25: Lake Whatcom YSI profiles for Site 4, April 9, 2013.

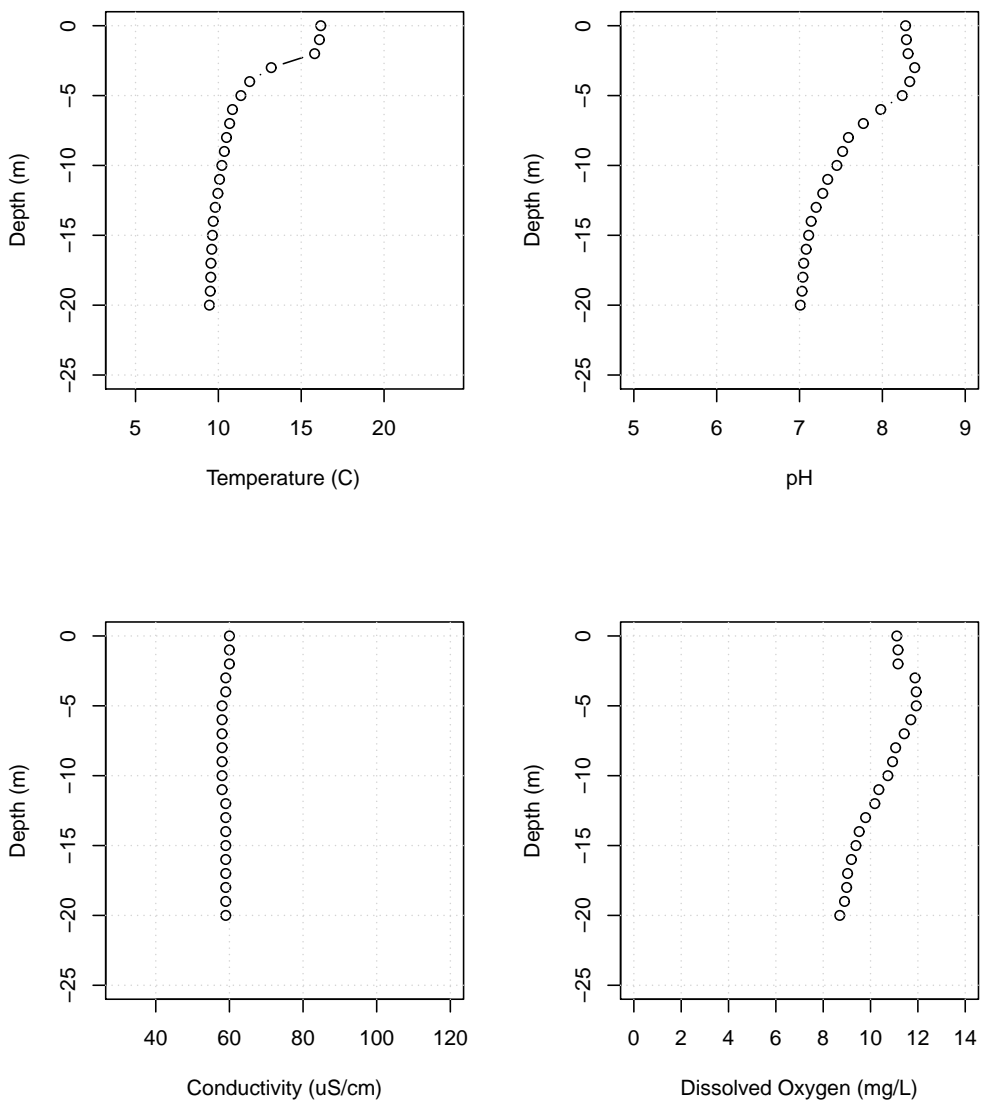


Figure B26: Lake Whatcom YSI profiles for Site 1, May 9, 2013.

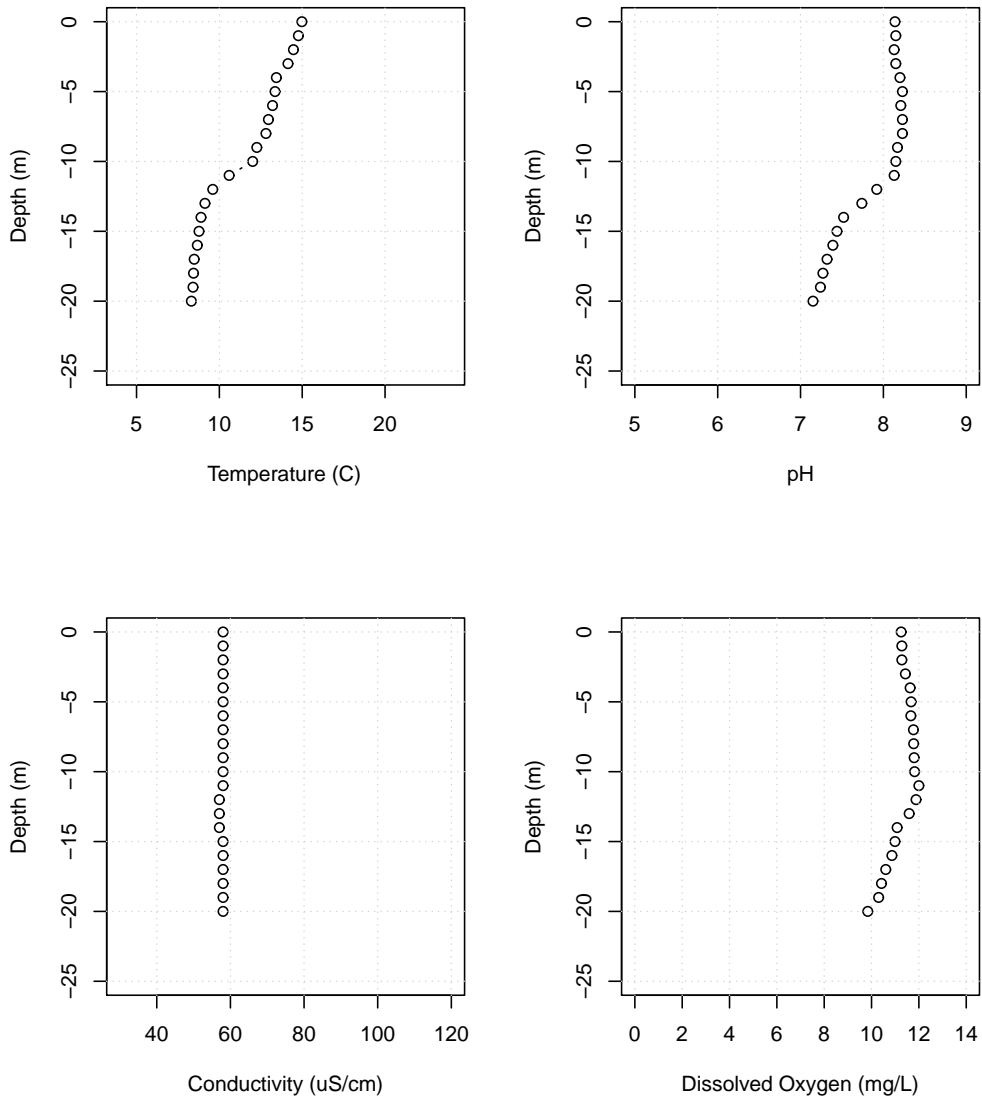


Figure B27: Lake Whatcom YSI profiles for Site 2, May 9, 2013.

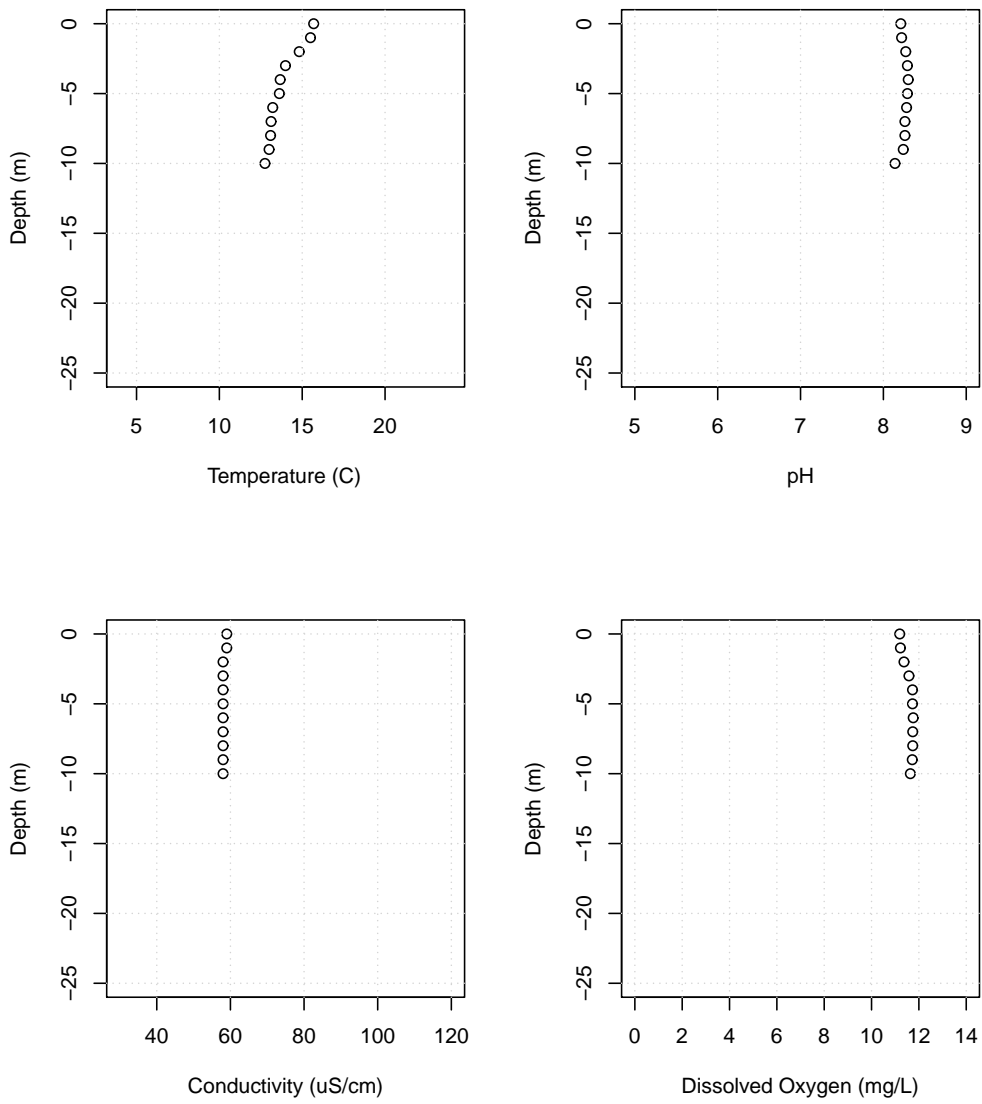


Figure B28: Lake Whatcom YSI profiles for the Intake, May 9, 2013.

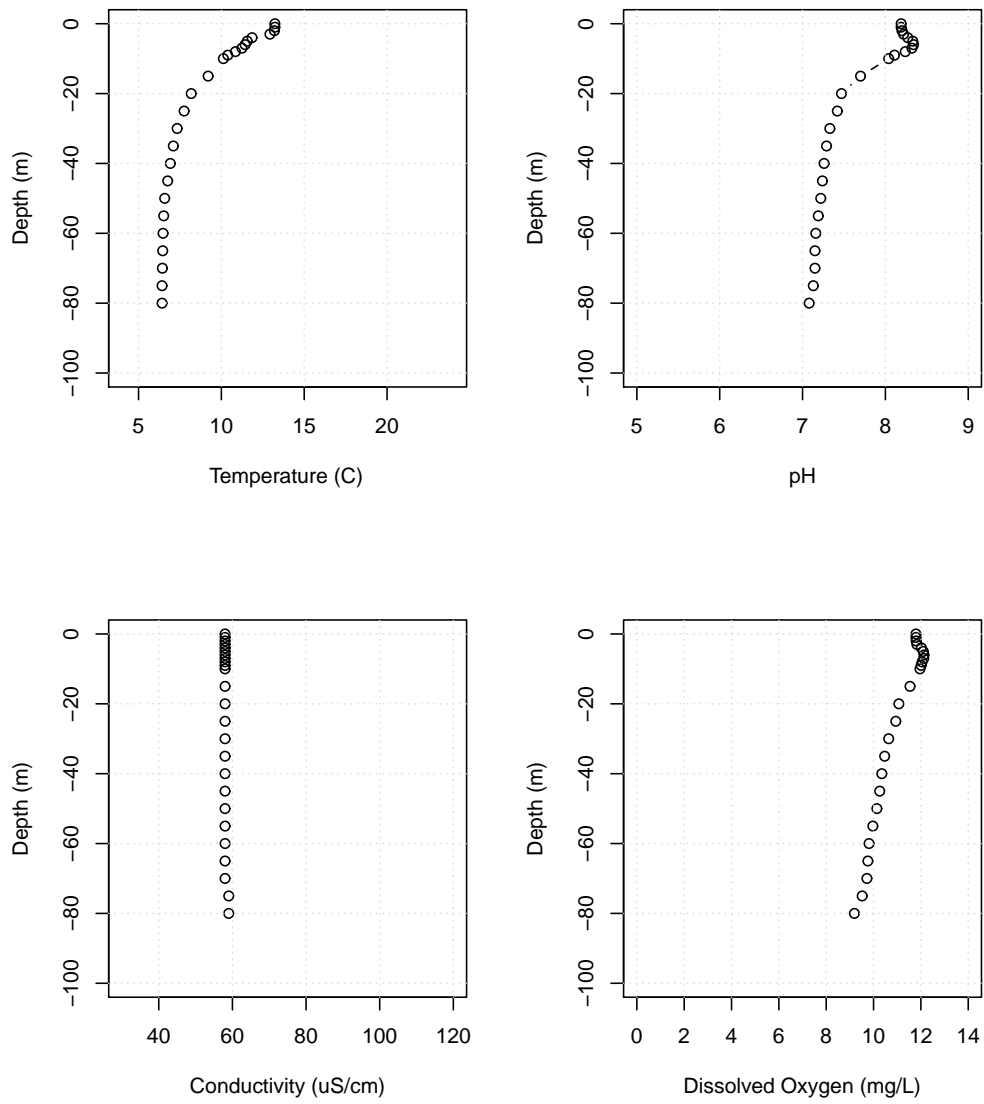


Figure B29: Lake Whatcom YSI profiles for Site 3, May 7, 2013.

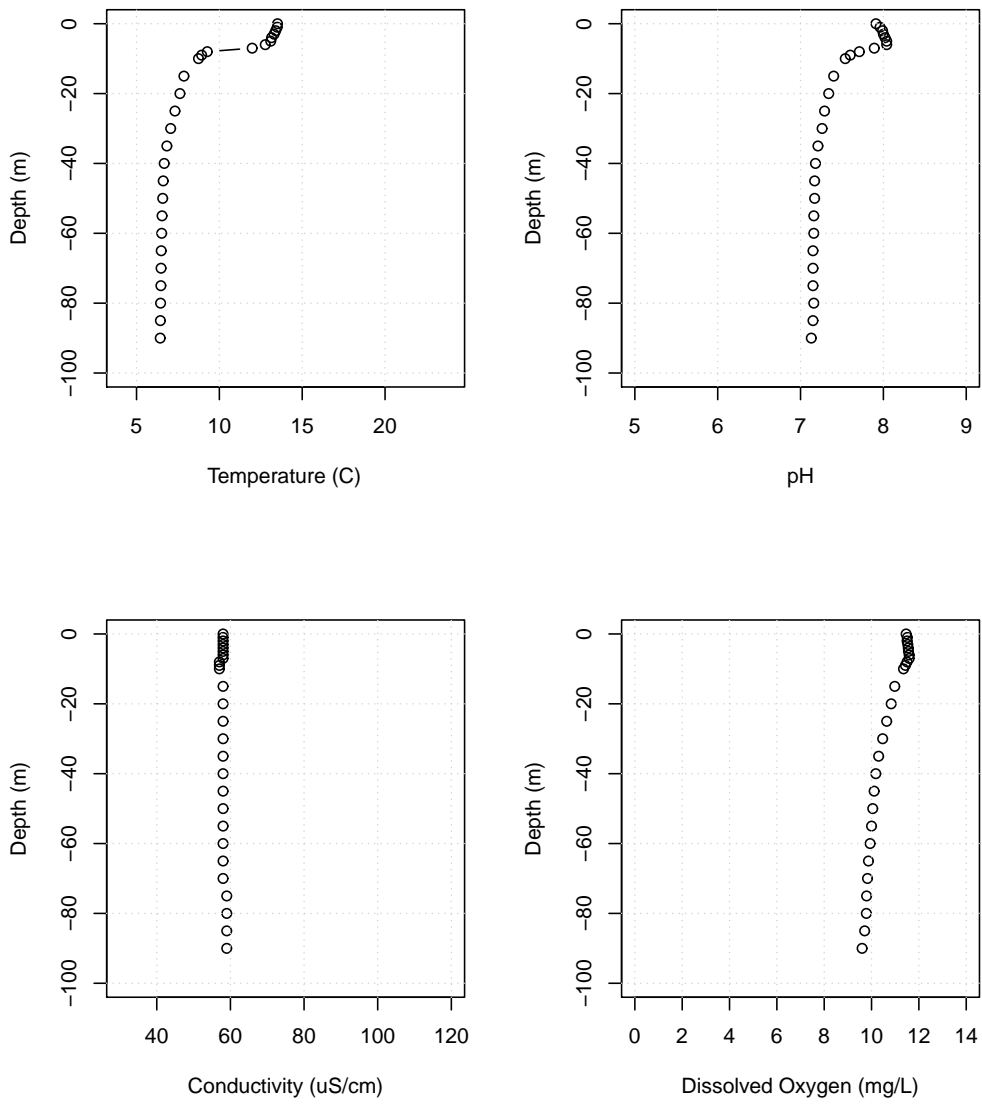


Figure B30: Lake Whatcom YSI profiles for Site 4, May 7, 2013.

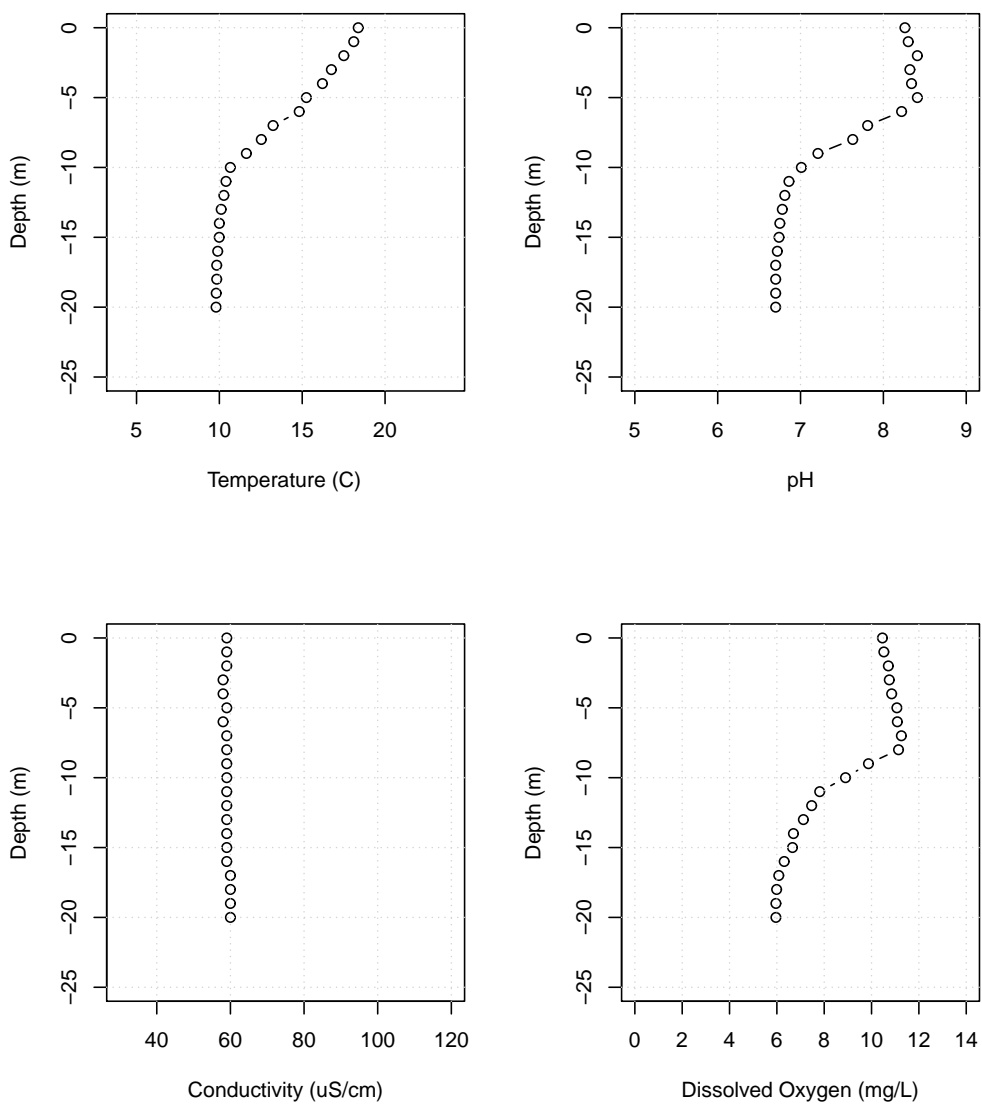


Figure B31: Lake Whatcom YSI profiles for Site 1, June 6, 2013.

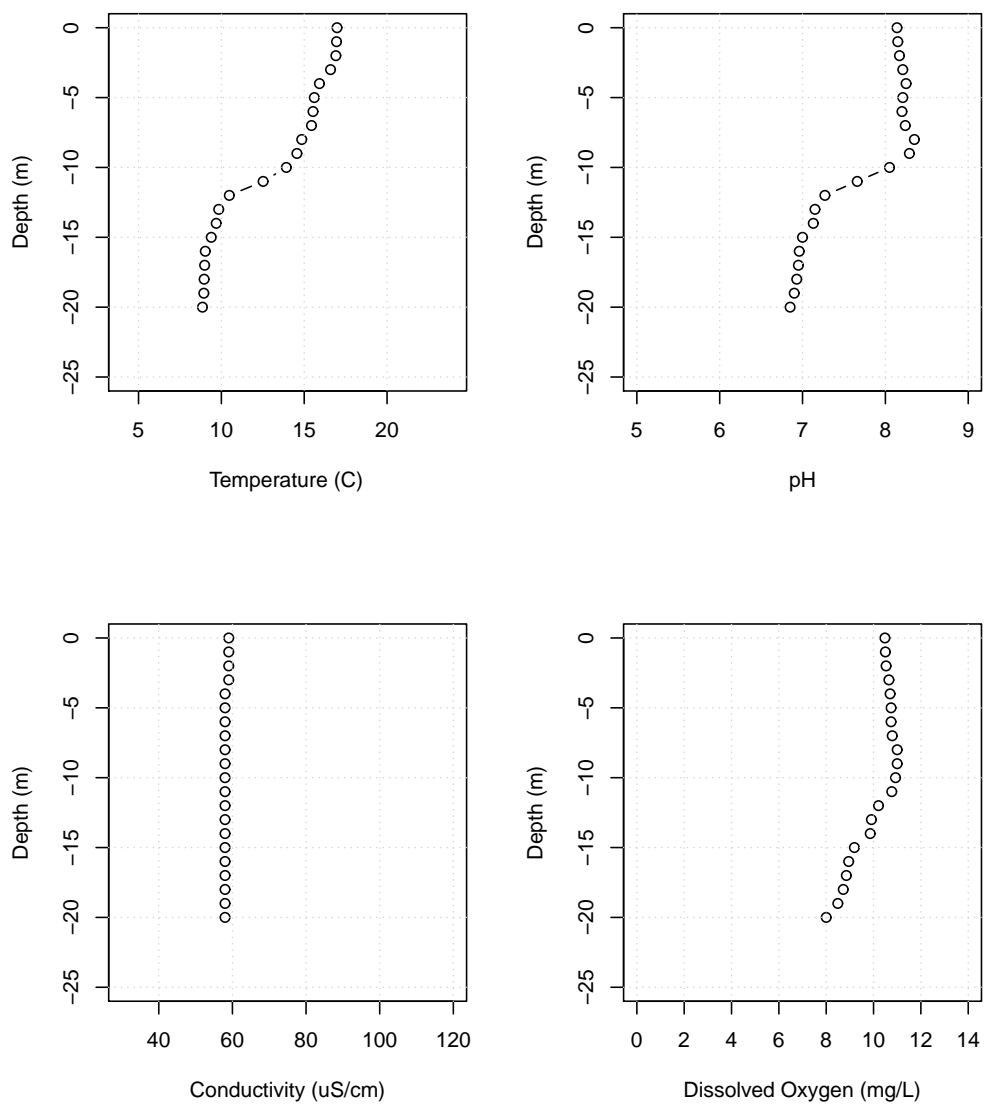


Figure B32: Lake Whatcom YSI profiles for Site 2, June 6, 2013.



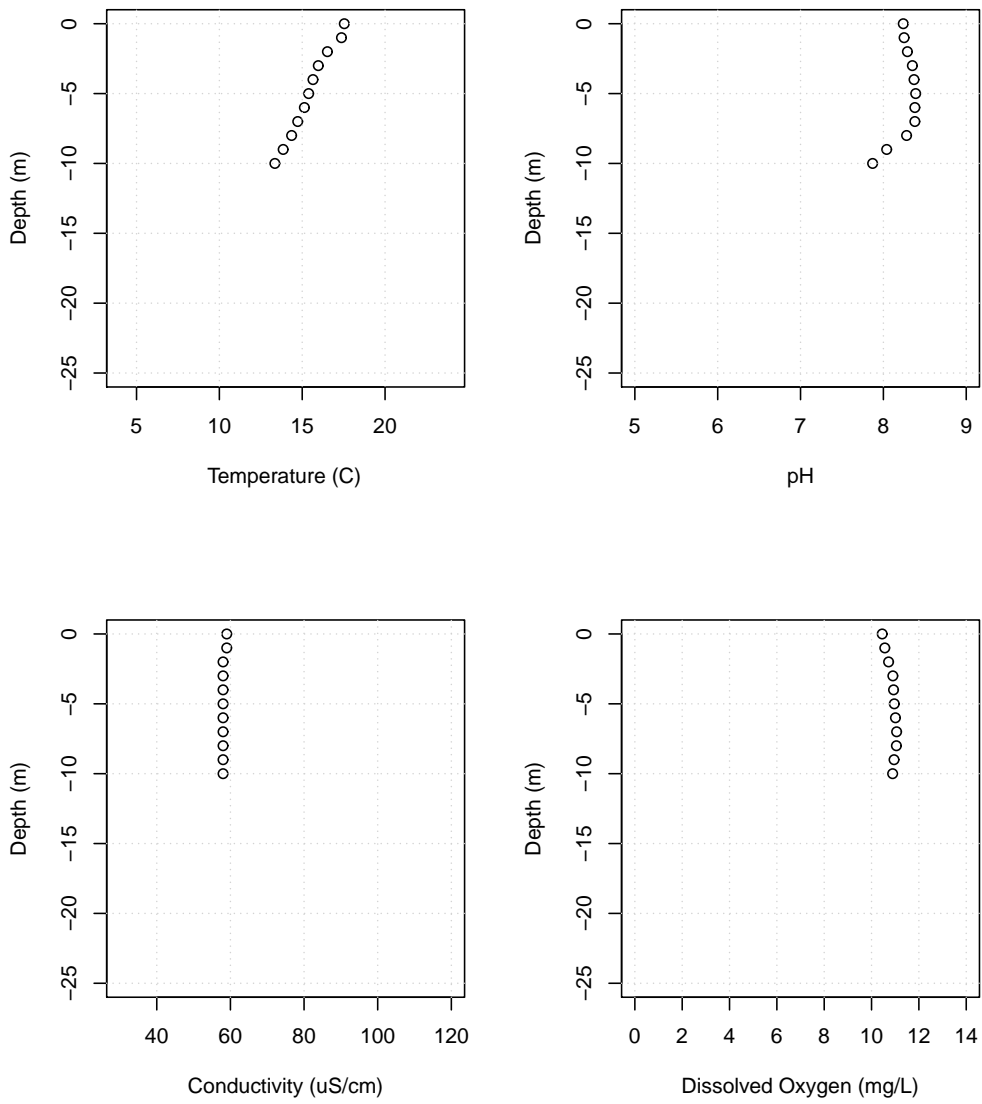


Figure B33: Lake Whatcom YSI profiles for the Intake, June 6, 2013.

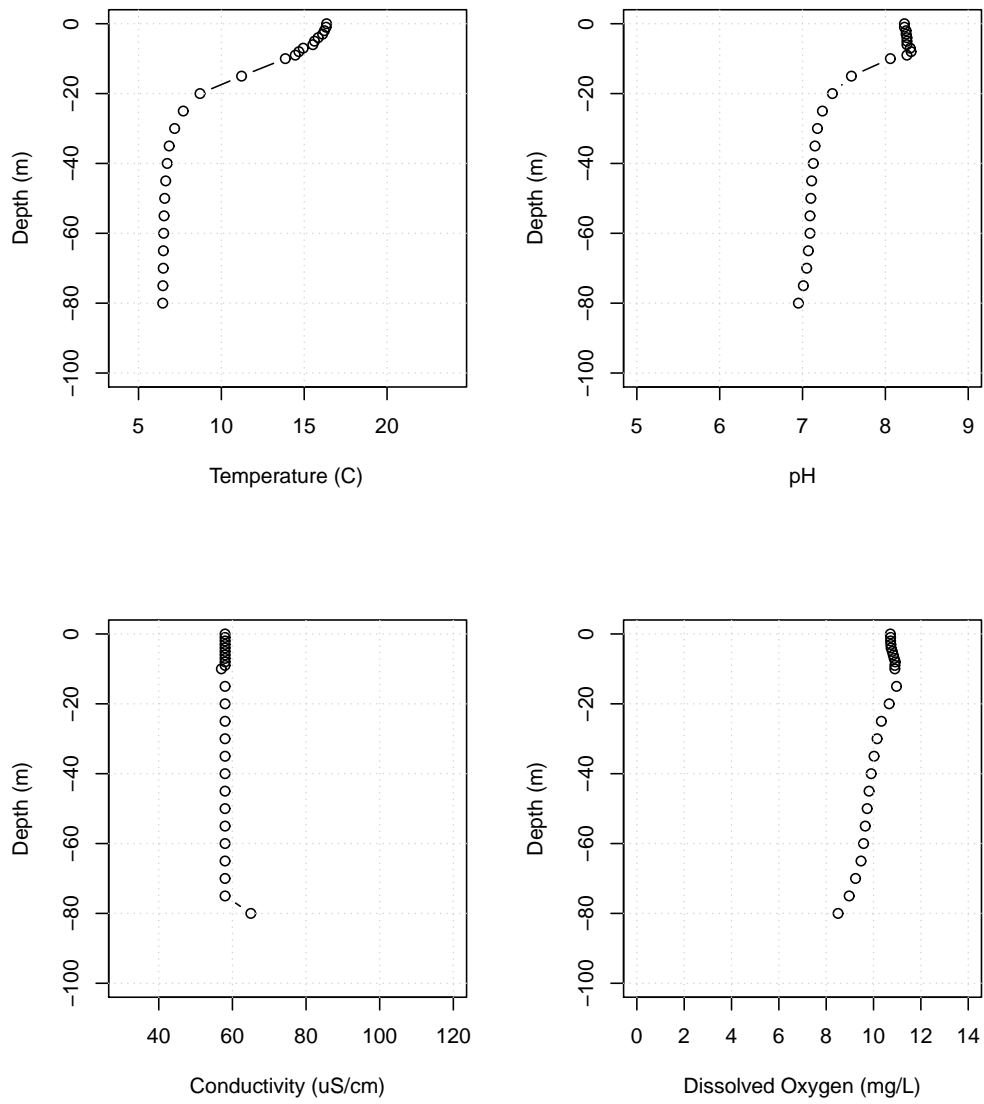


Figure B34: Lake Whatcom YSI profiles for Site 3, June 4, 2013.

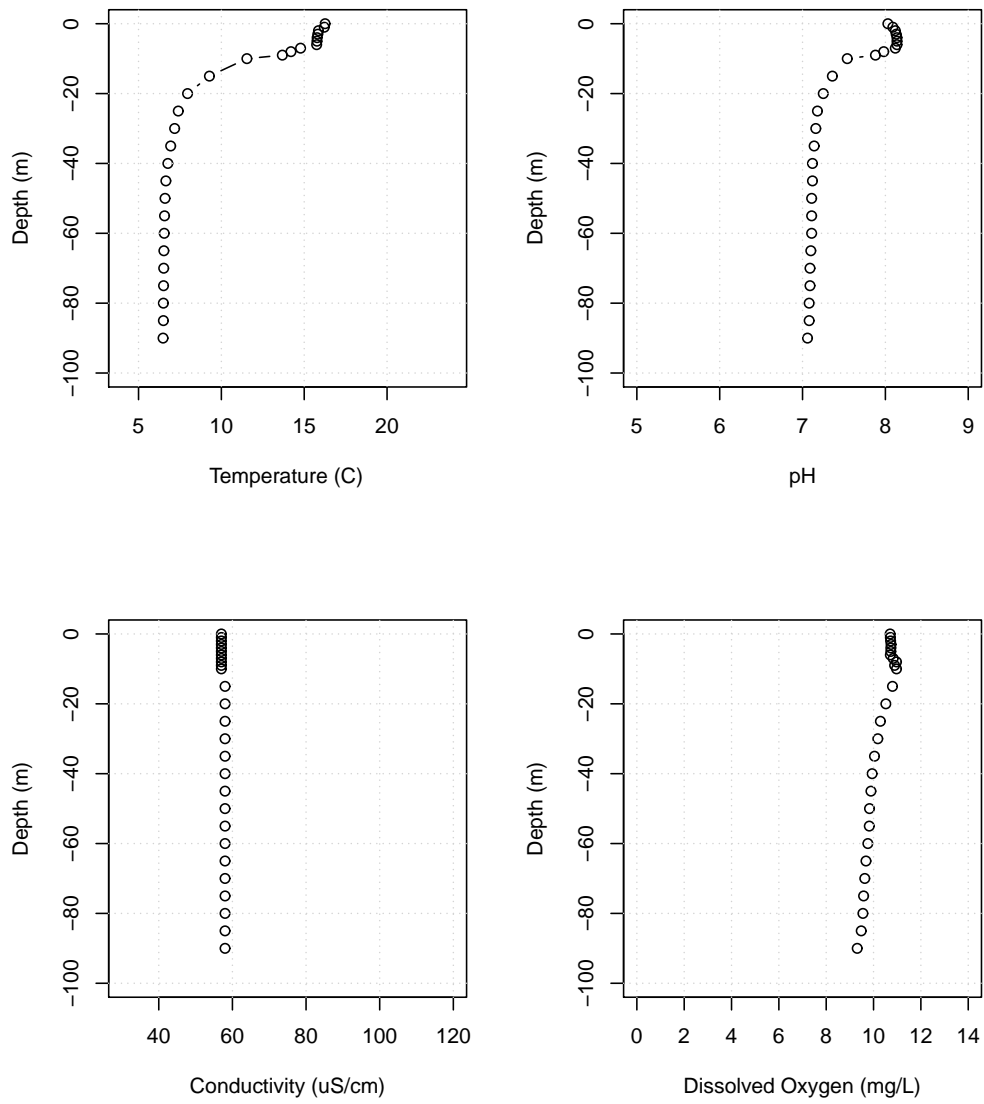


Figure B35: Lake Whatcom YSI profiles for Site 4, June 4, 2013.

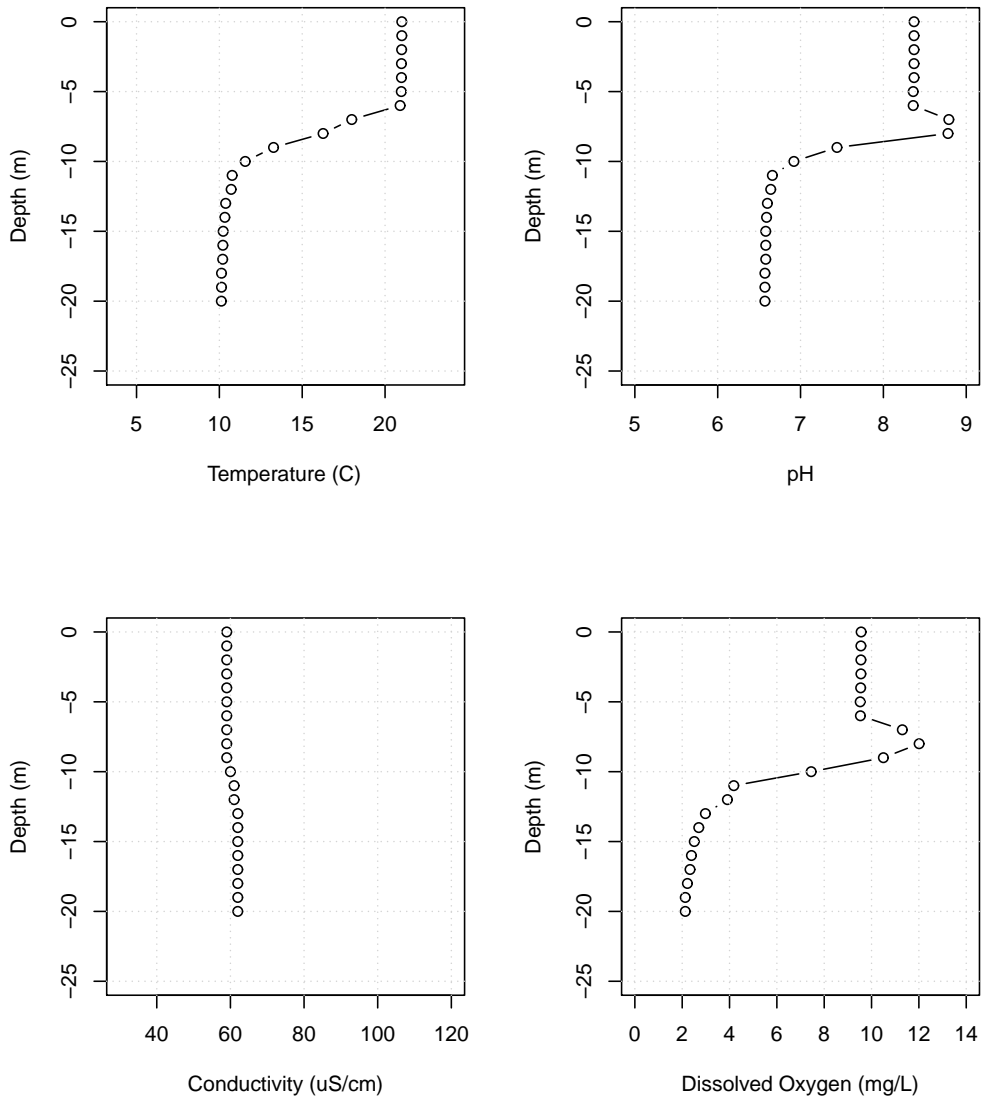


Figure B36: Lake Whatcom YSI profiles for Site 1, July 11, 2013.

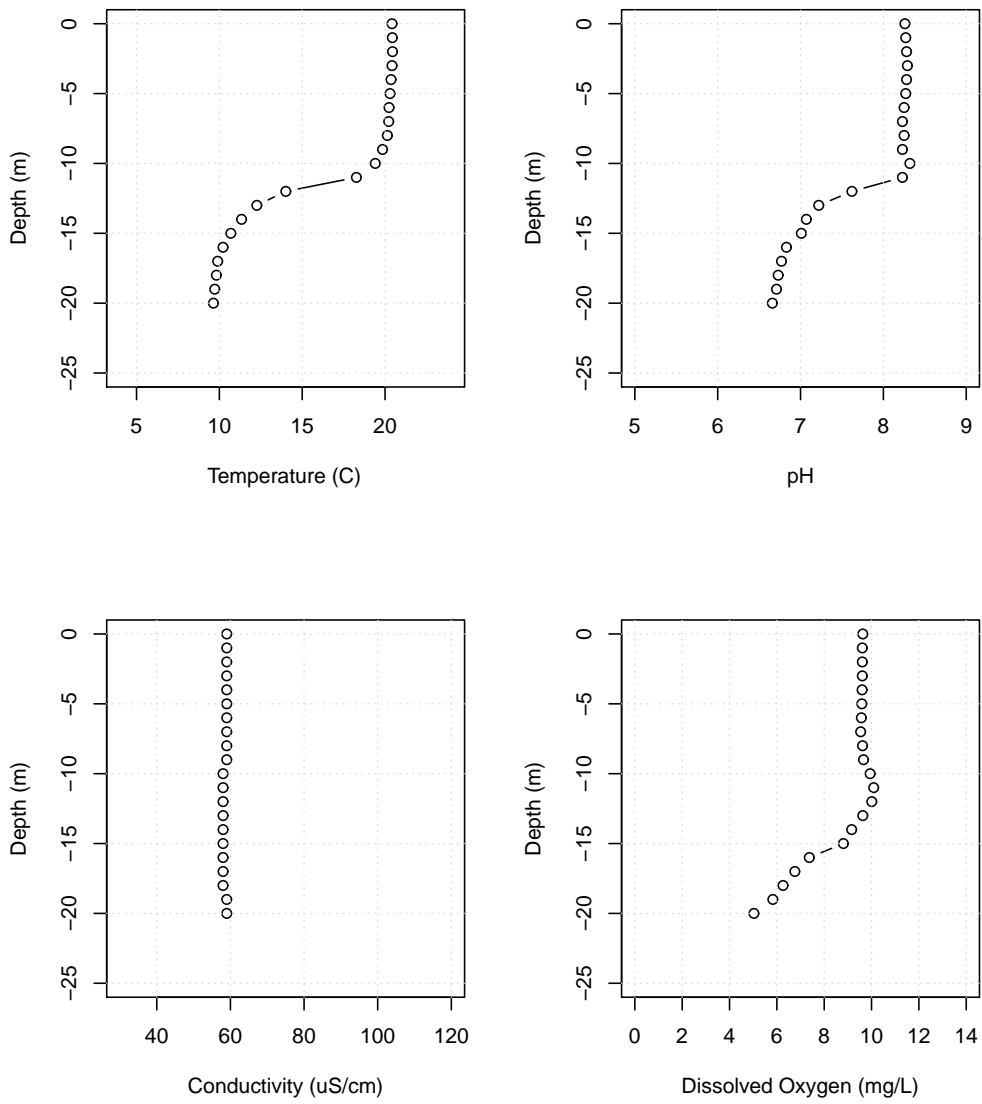


Figure B37: Lake Whatcom YSI profiles for Site 2, July 11, 2013.

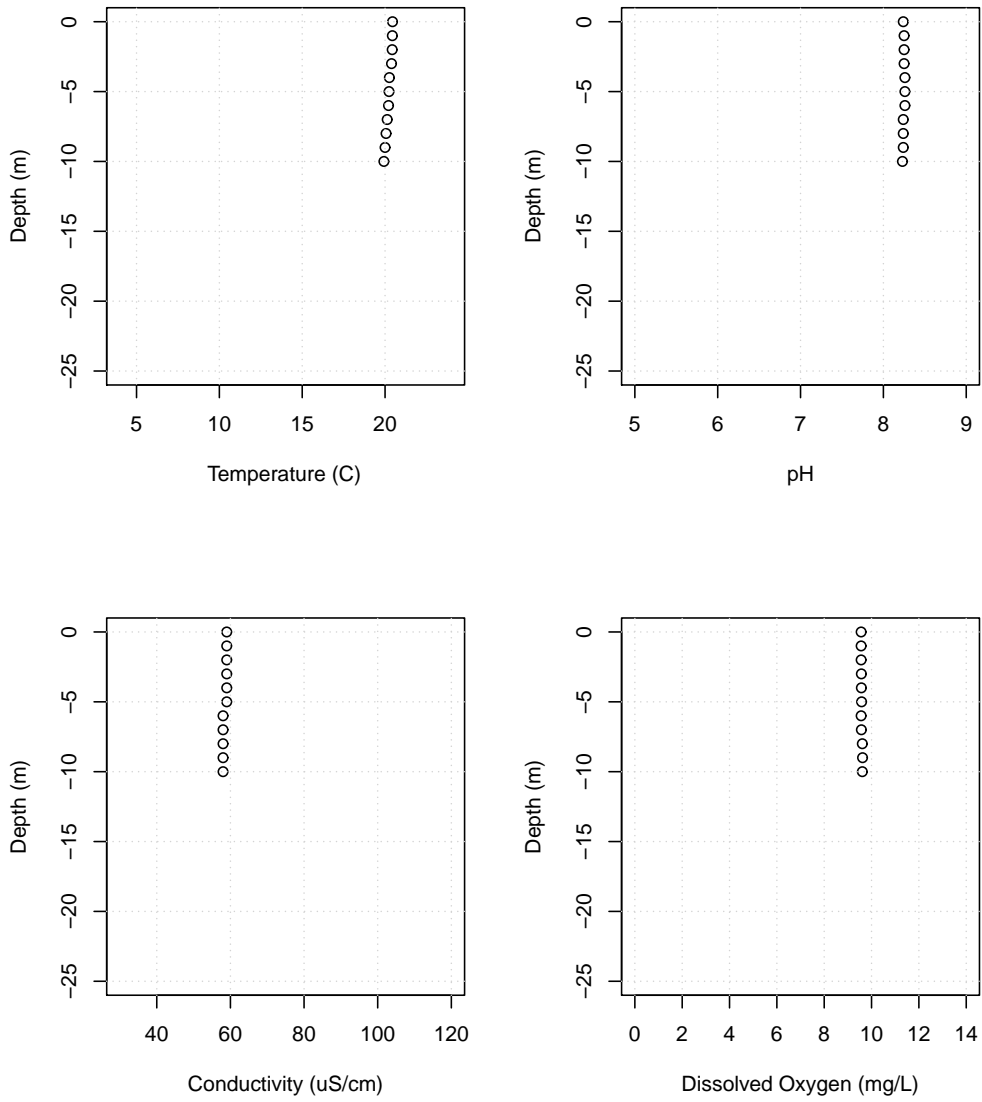


Figure B38: Lake Whatcom YSI profiles for the Intake, July 11, 2013.

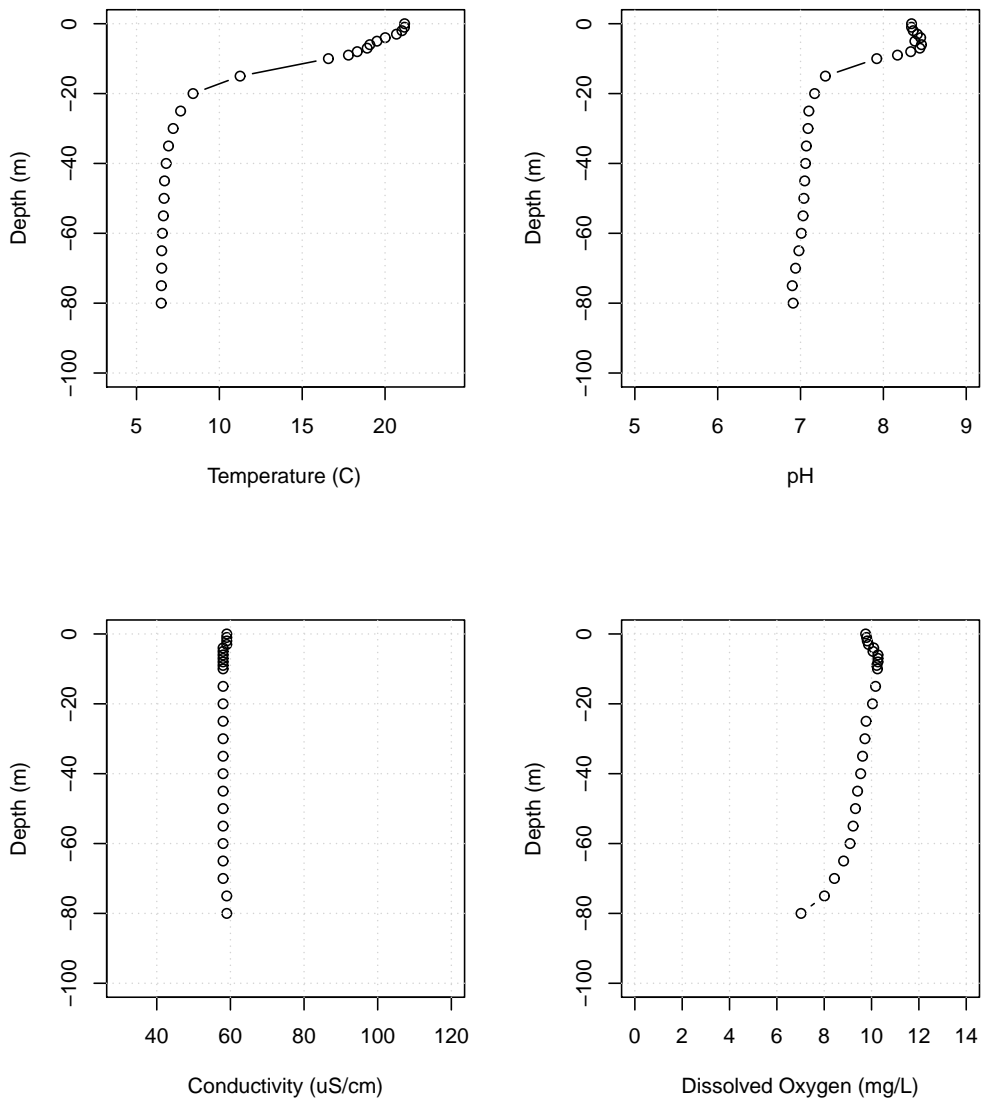


Figure B39: Lake Whatcom YSI profiles for Site 3, July 9, 2013.

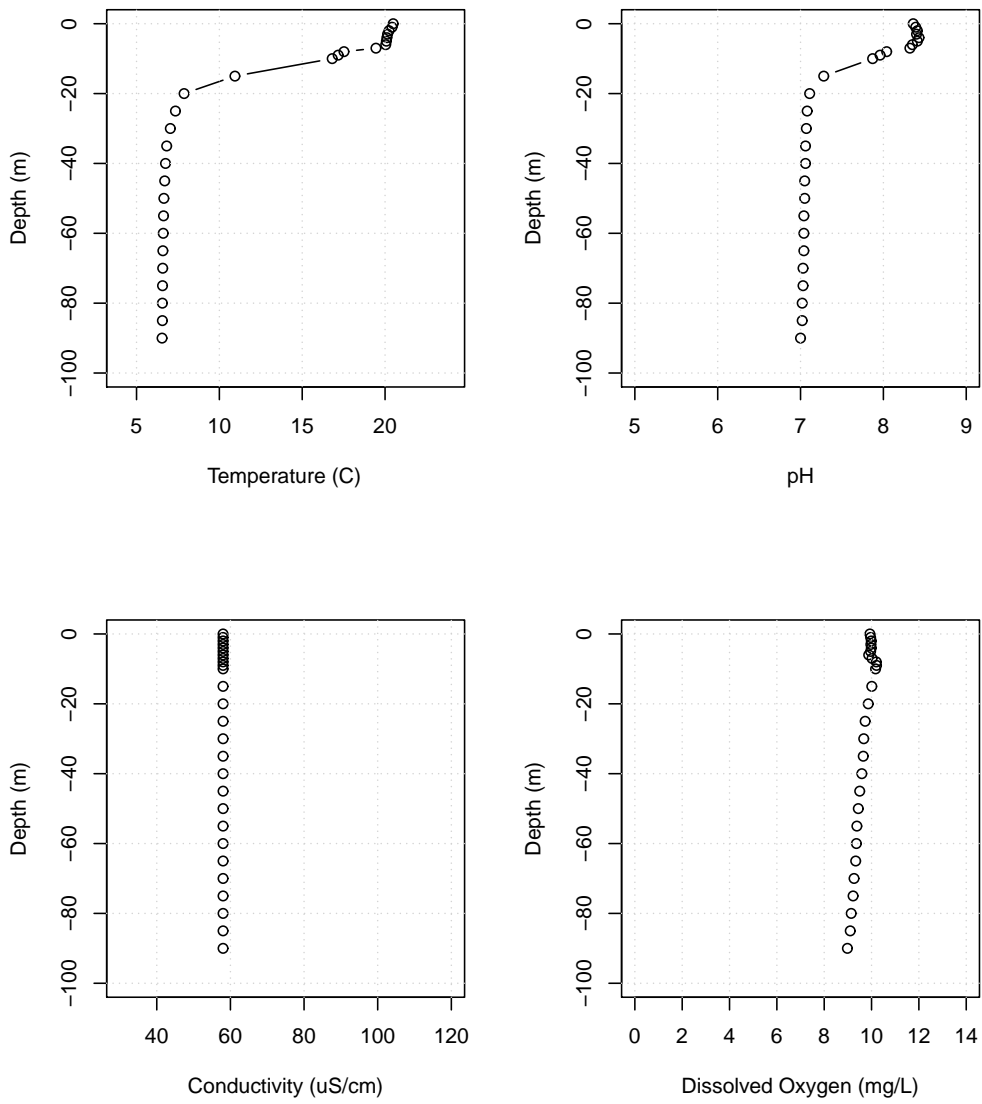


Figure B40: Lake Whatcom YSI profiles for Site 4, July 9, 2013.



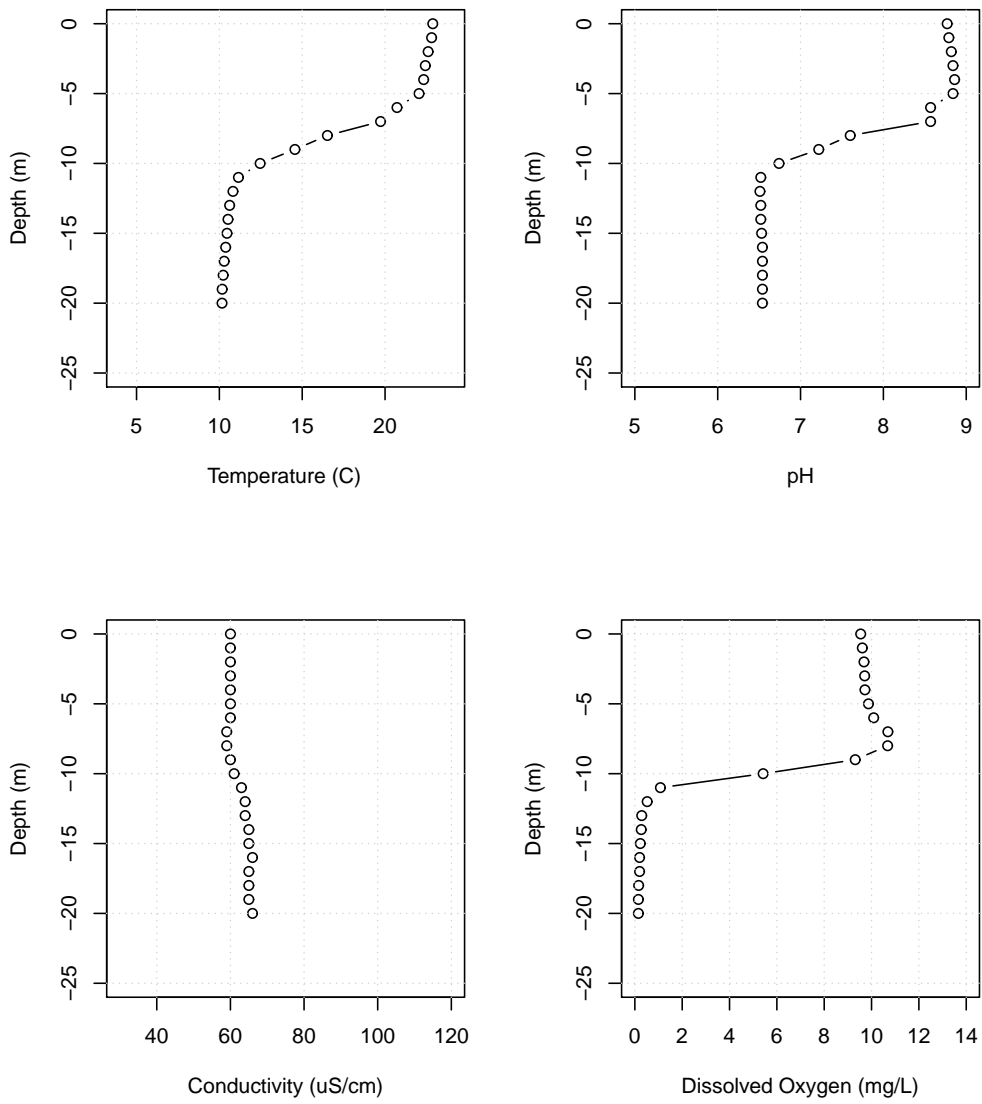


Figure B41: Lake Whatcom YSI profiles for Site 1, August 8, 2013.

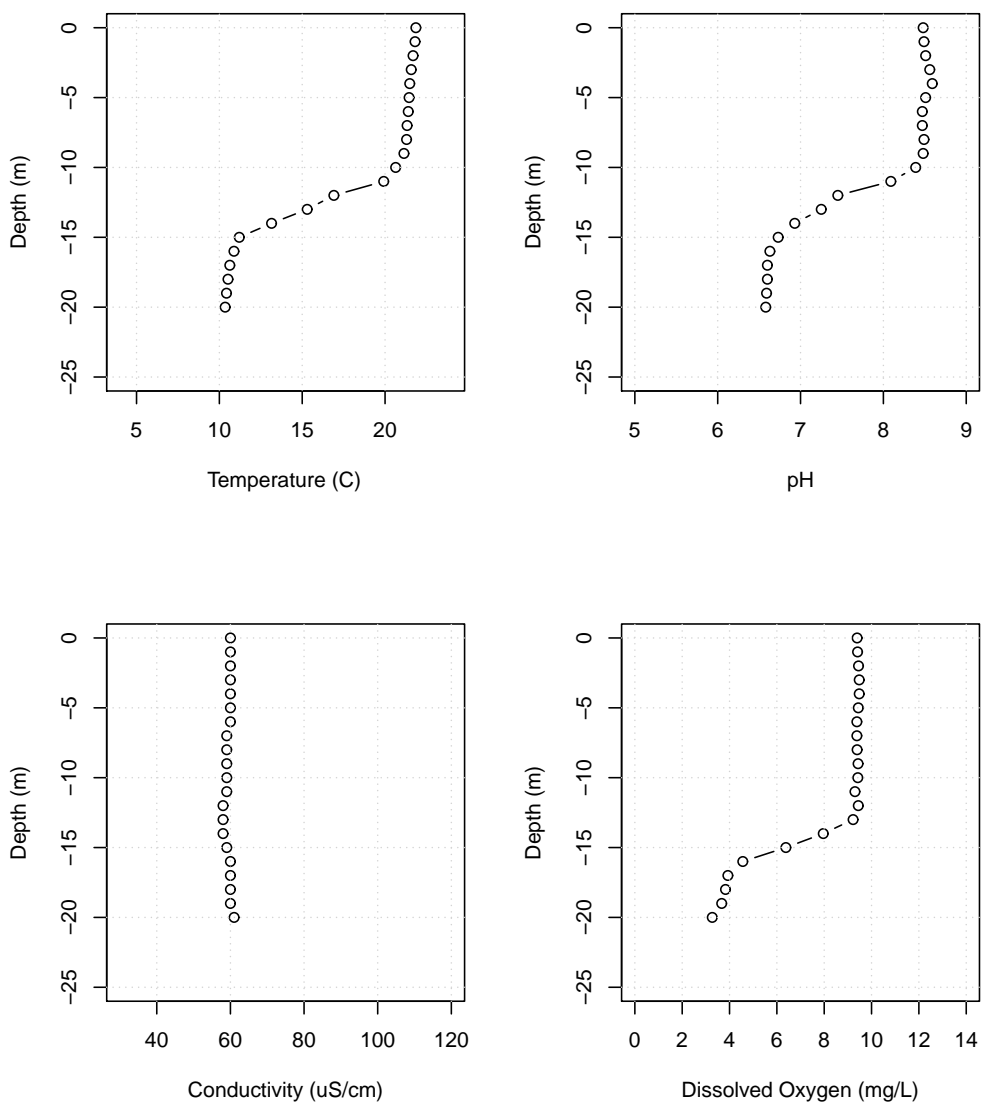


Figure B42: Lake Whatcom YSI profiles for Site 2, August 8, 2013.

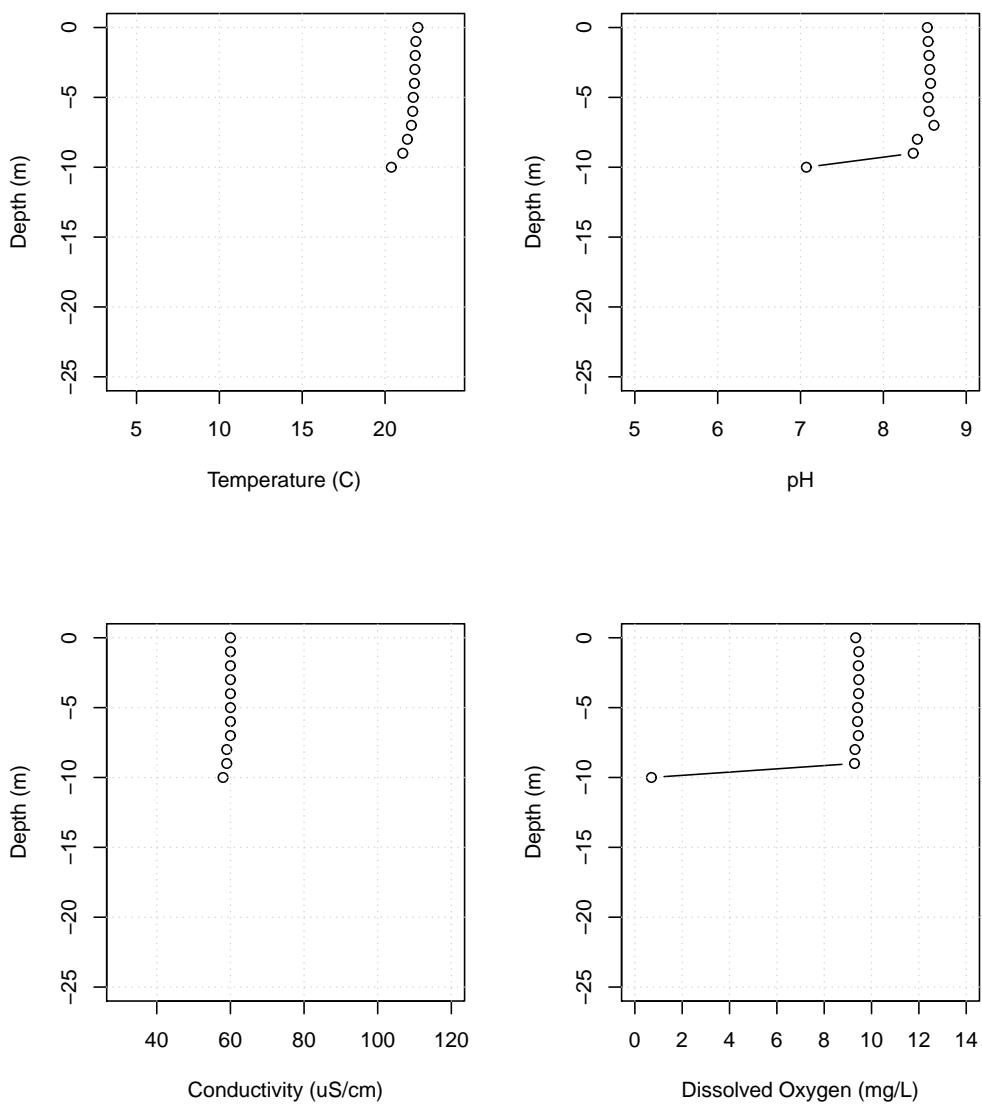


Figure B43: Lake Whatcom YSI profiles for the Intake, August 8, 2013. See discussion of low oxygen value on page 5.

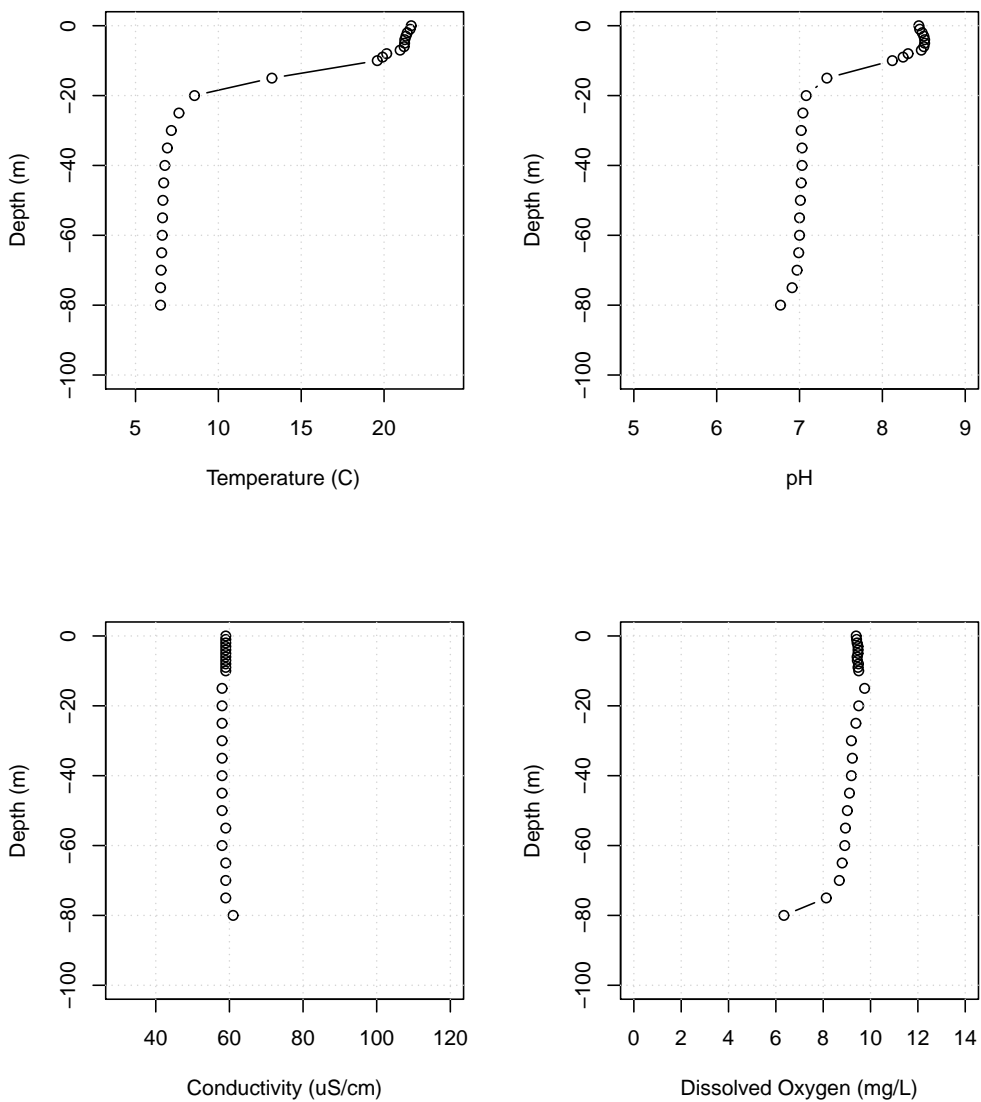


Figure B44: Lake Whatcom YSI profiles for Site 3, August 6, 2013.

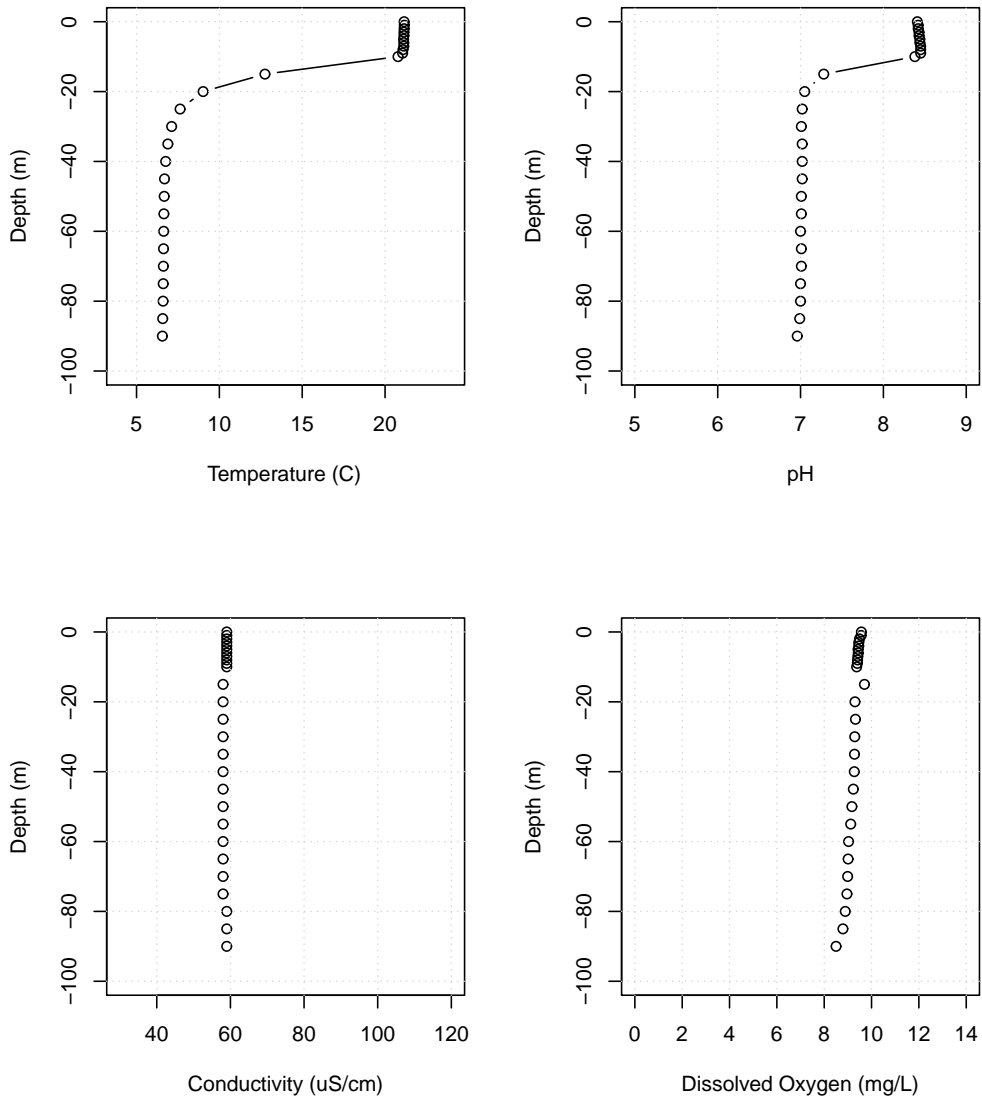


Figure B45: Lake Whatcom YSI profiles for Site 4, August 6, 2013.

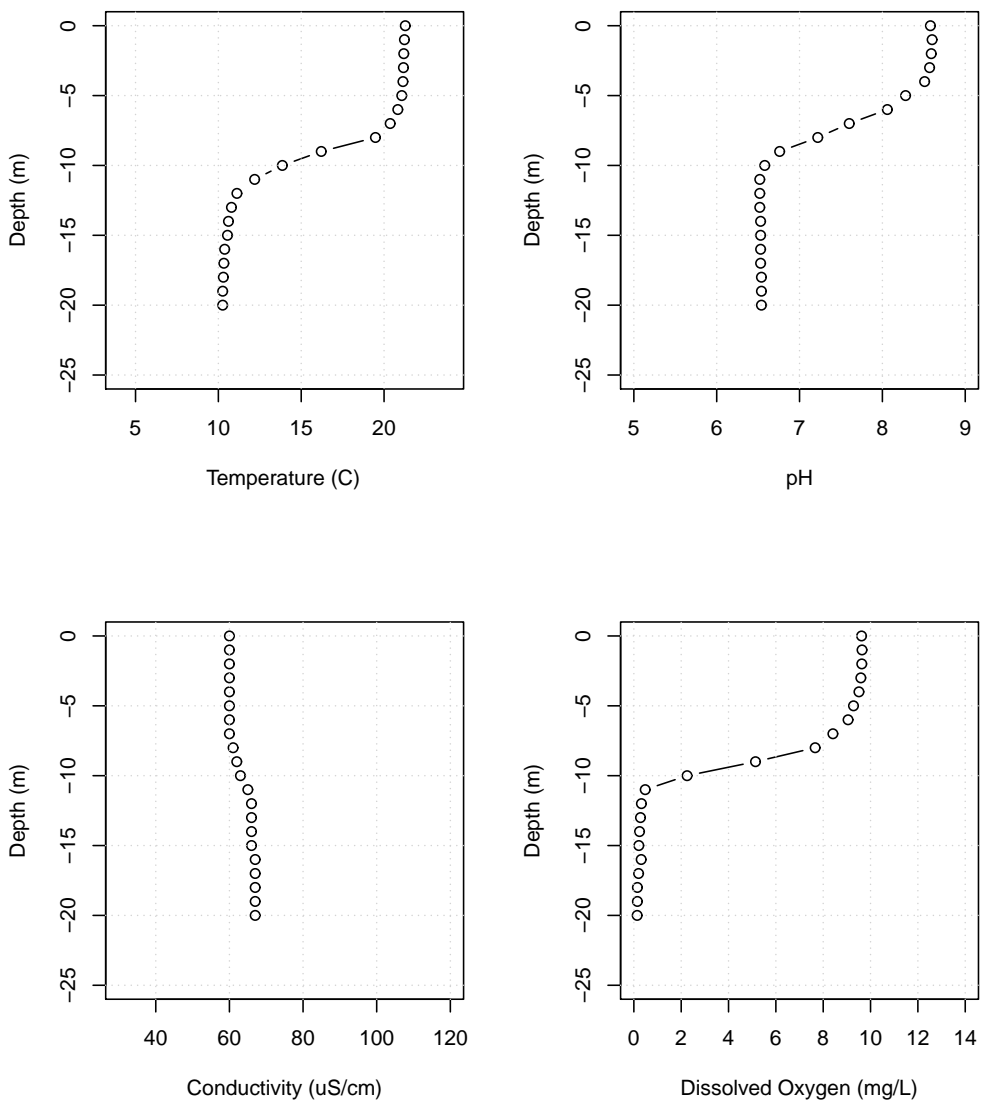


Figure B46: Lake Whatcom YSI profiles for Site 1, September 4, 2013.

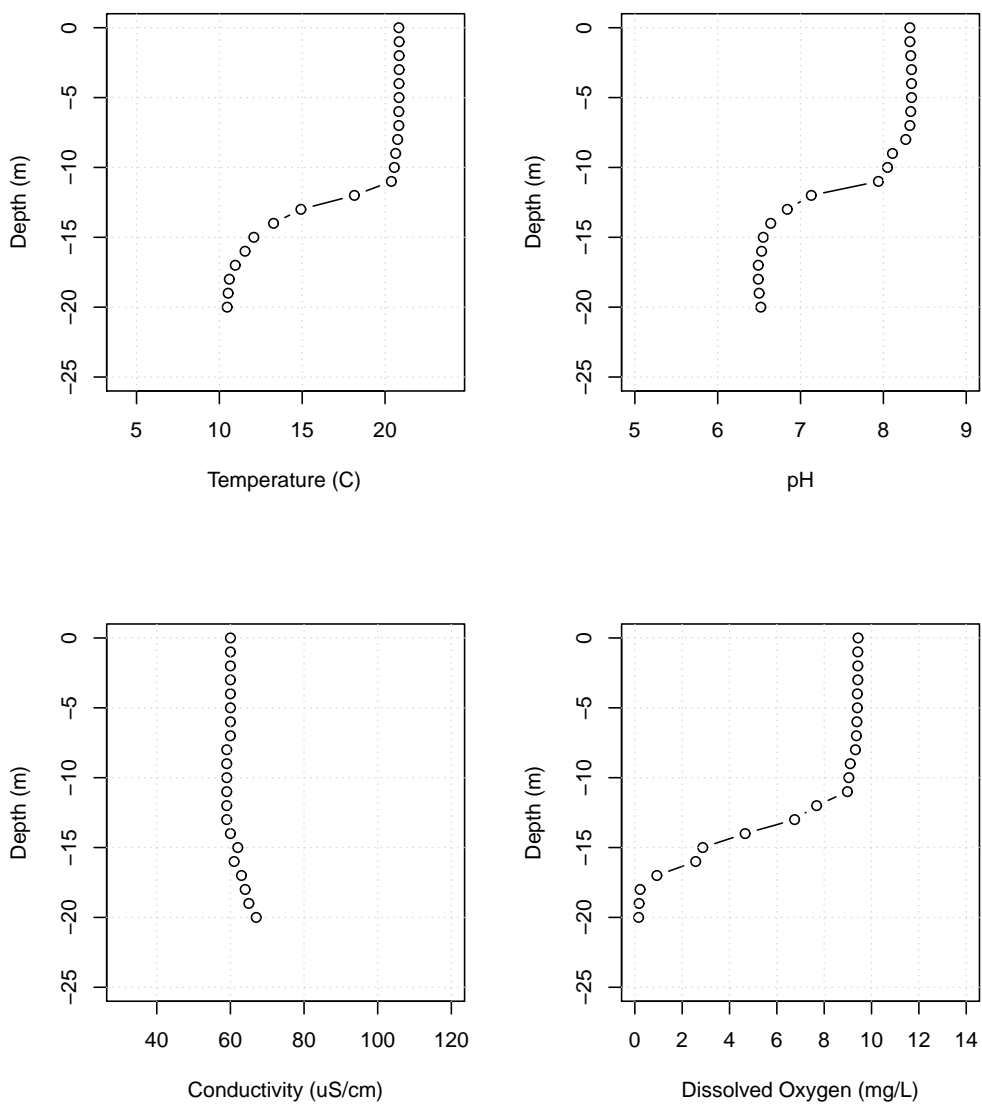


Figure B47: Lake Whatcom YSI profiles for Site 2, September 4, 2013.

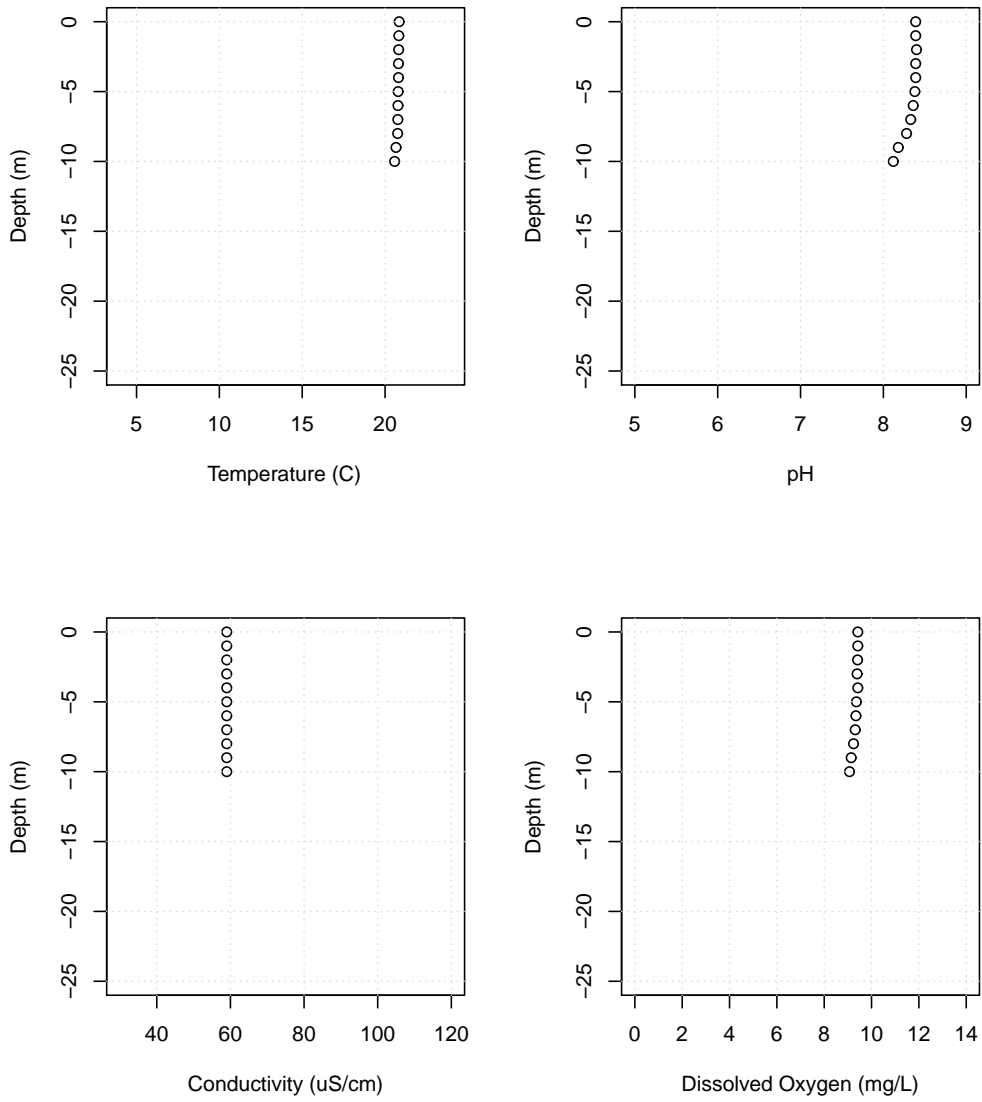


Figure B48: Lake Whatcom YSI profiles for the Intake, September 4, 2013.



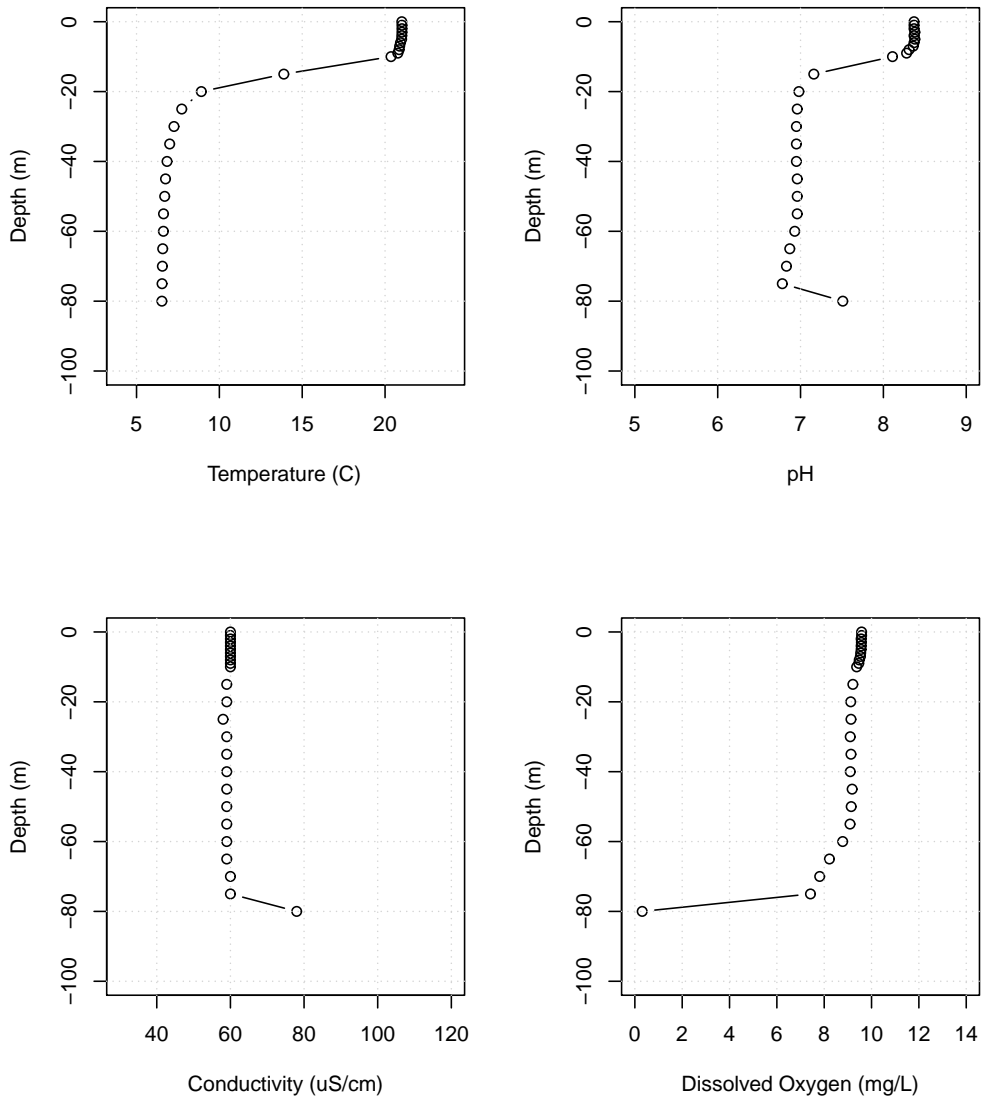


Figure B49: Lake Whatcom YSI profiles for Site 3, September 3, 2013.

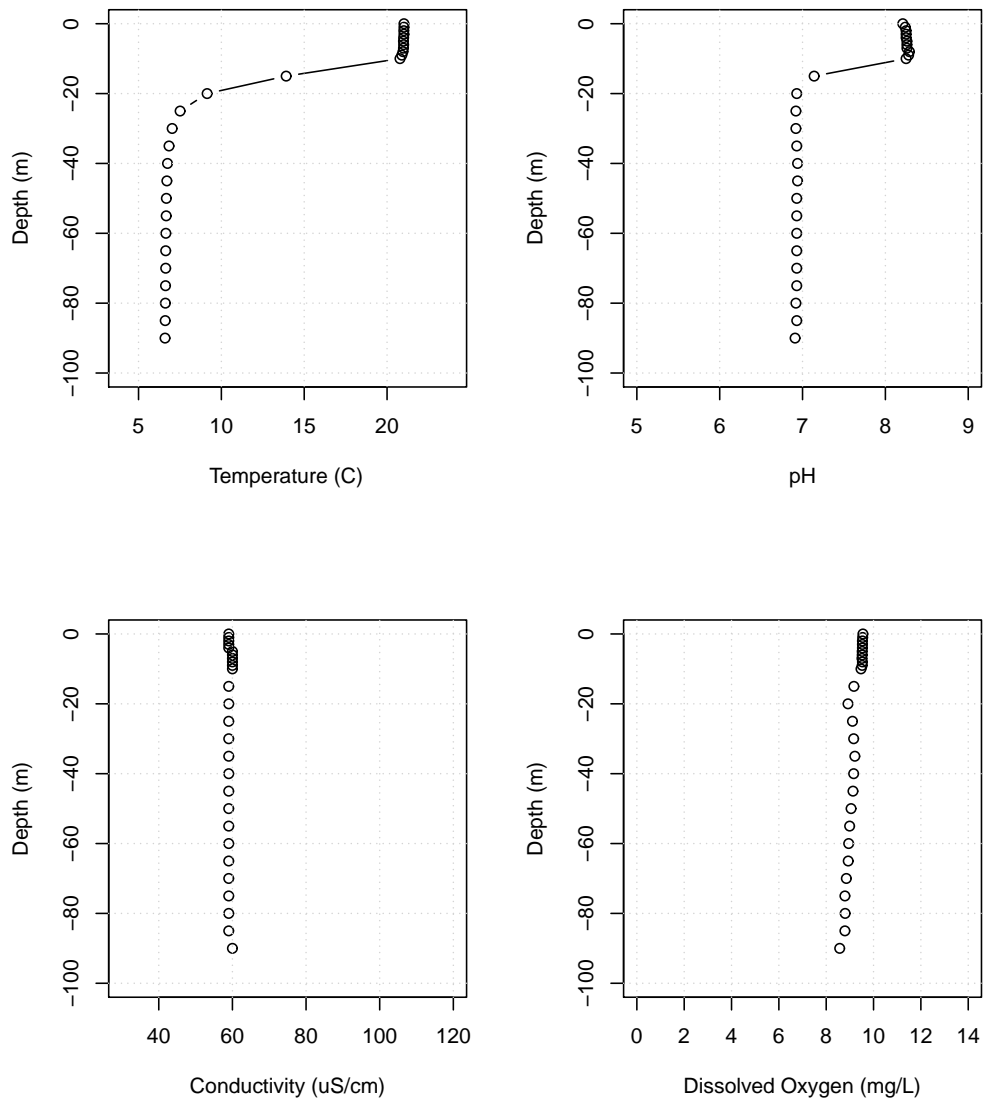


Figure B50: Lake Whatcom YSI profiles for Site 4, September 3, 2013.

## **B.2 Long-term Hydrolab Data (1988-present)**

Lake Whatcom temperature data for Site 1, February 1988 through December 2013.

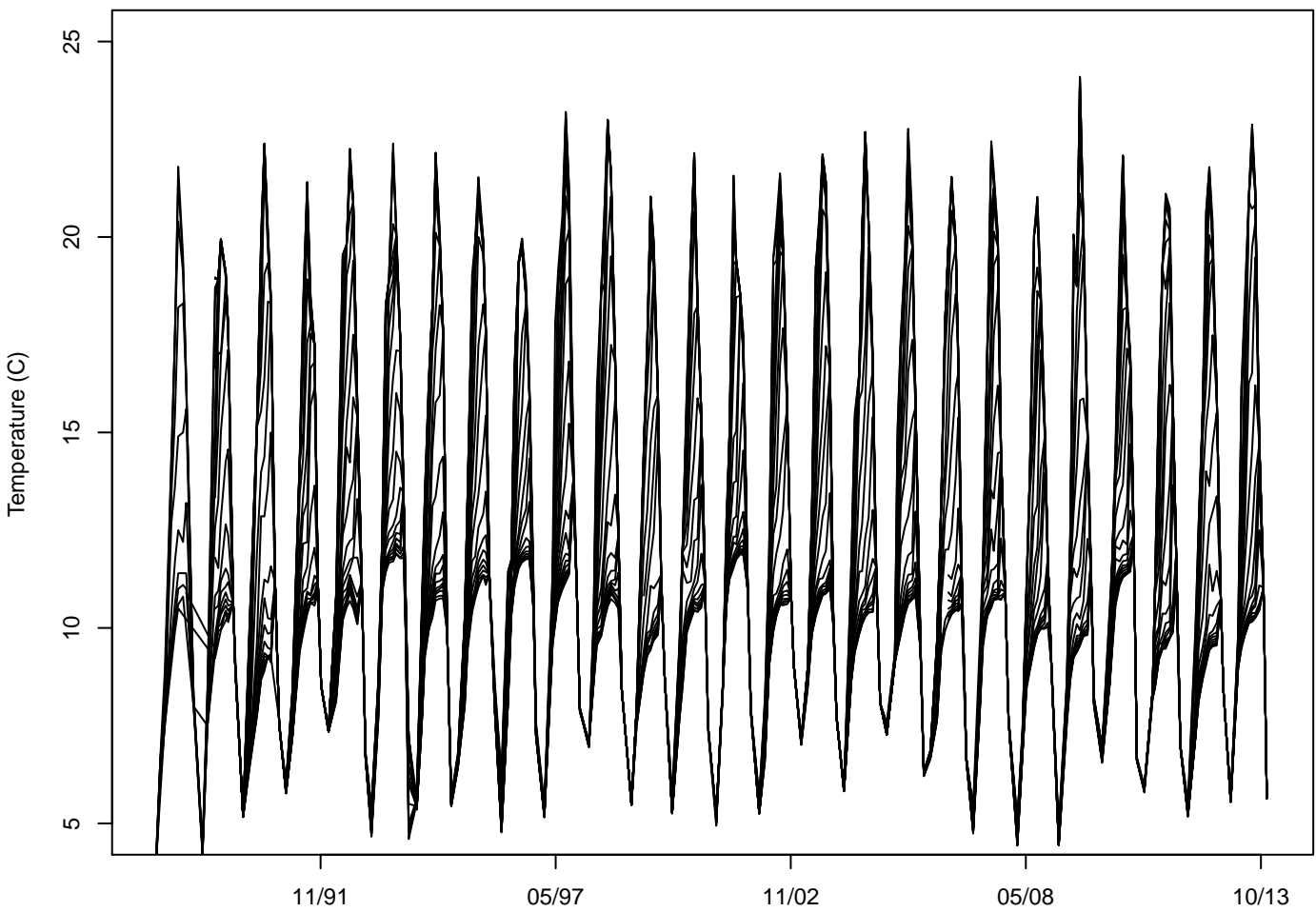


Figure B51: Lake Whatcom historic temperature data for Site 1.

Lake Whatcom temperature data for Site 2, February 1988 through December 2013.

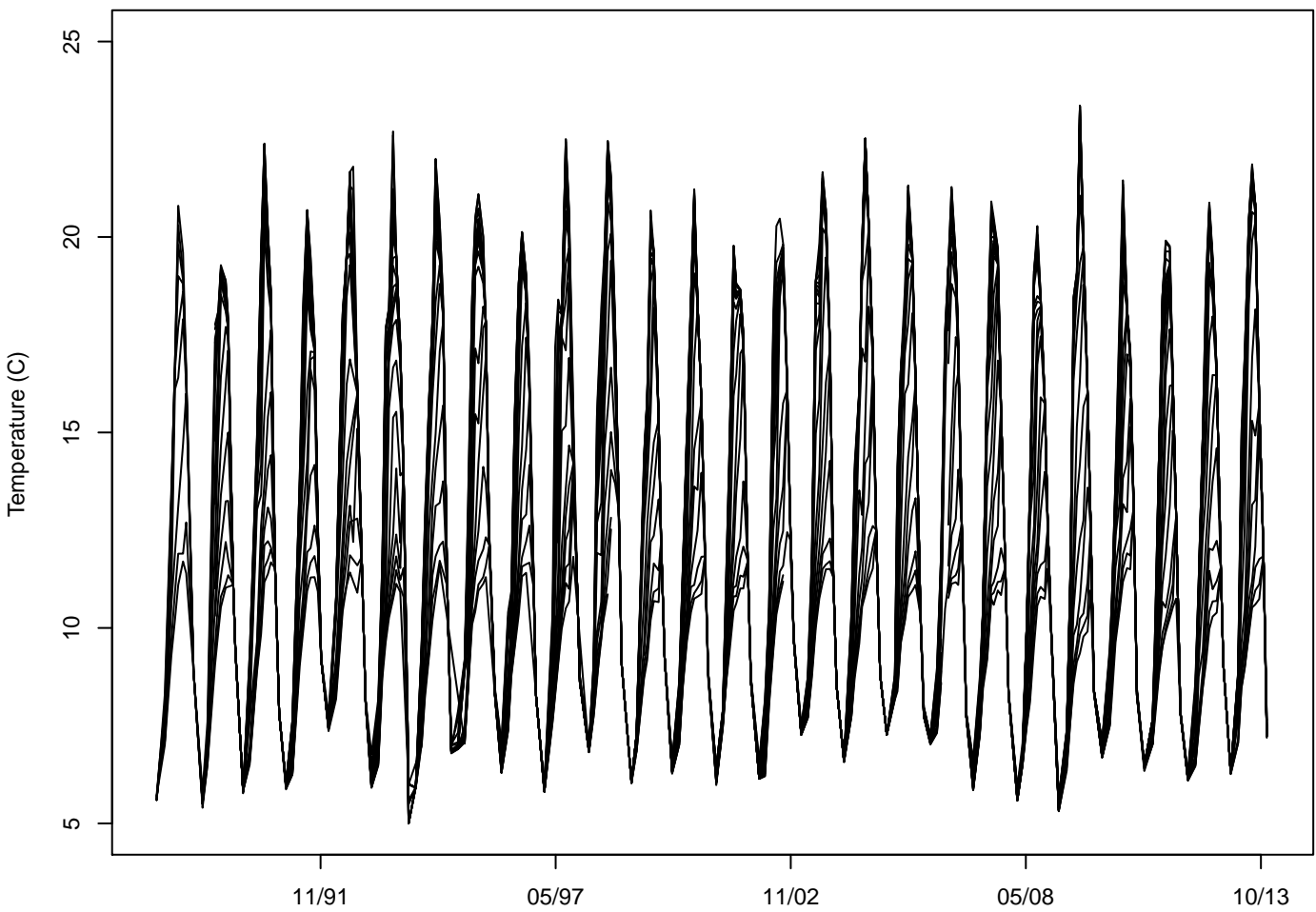


Figure B52: Lake Whatcom historic temperature data for Site 2.

Lake Whatcom temperature data for Intake, February 1988 through December 2013.

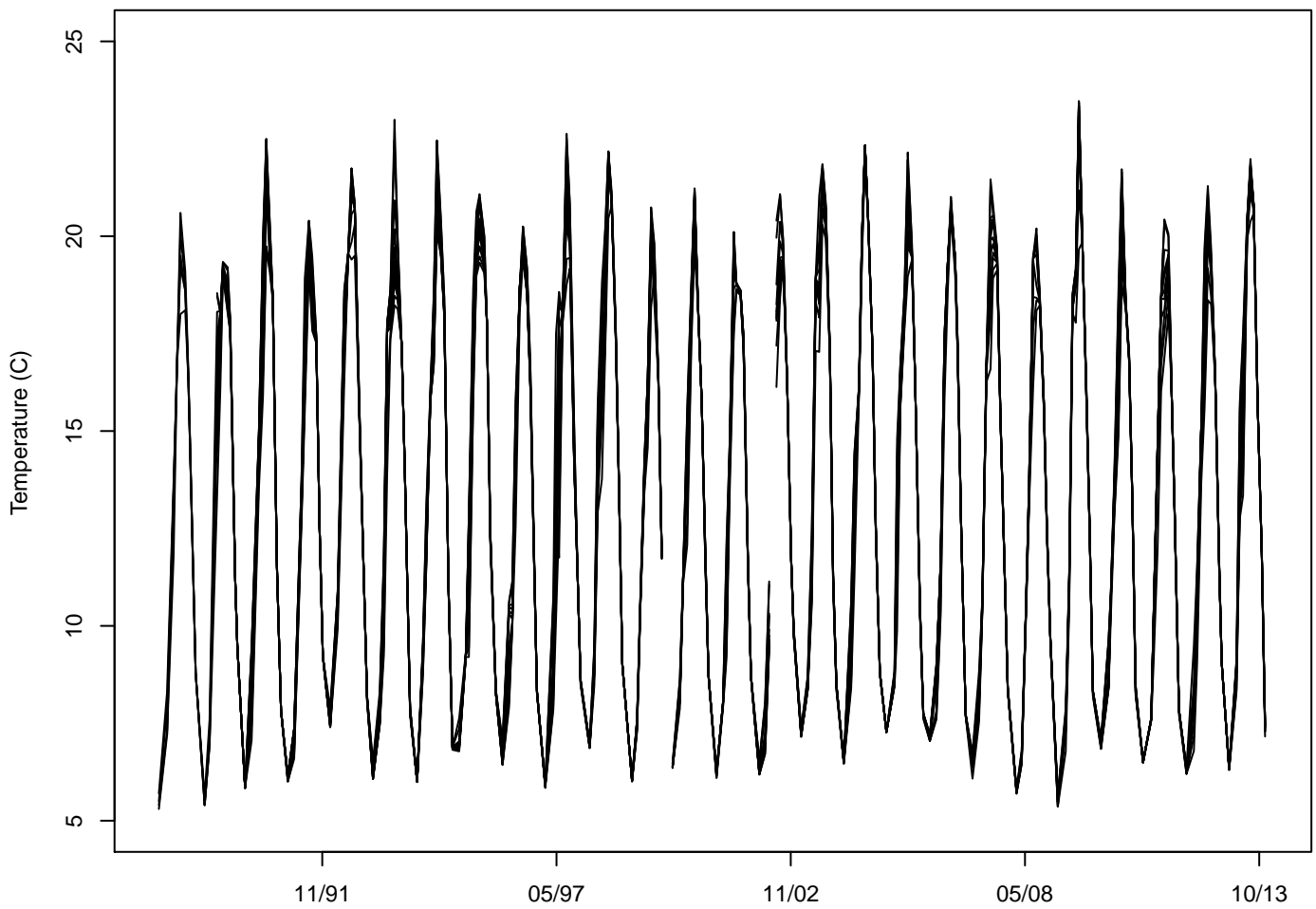


Figure B53: Lake Whatcom historic temperature data for the Intake.

Lake Whatcom temperature data for Site 3, February 1988 through December 2013.

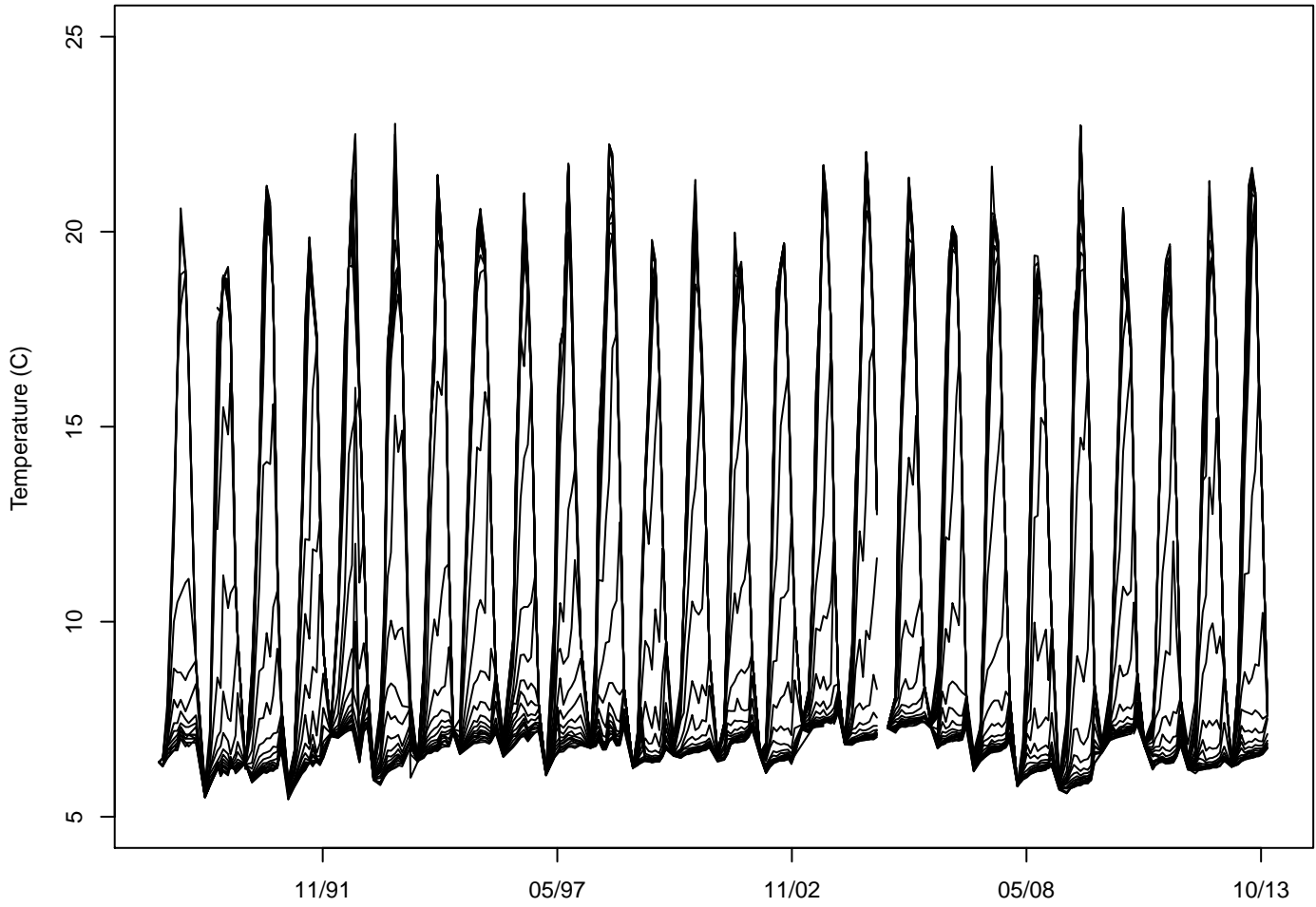


Figure B54: Lake Whatcom historic temperature data for Site 3.

Lake Whatcom temperature data for Site 4, February 1988 through December 2013.

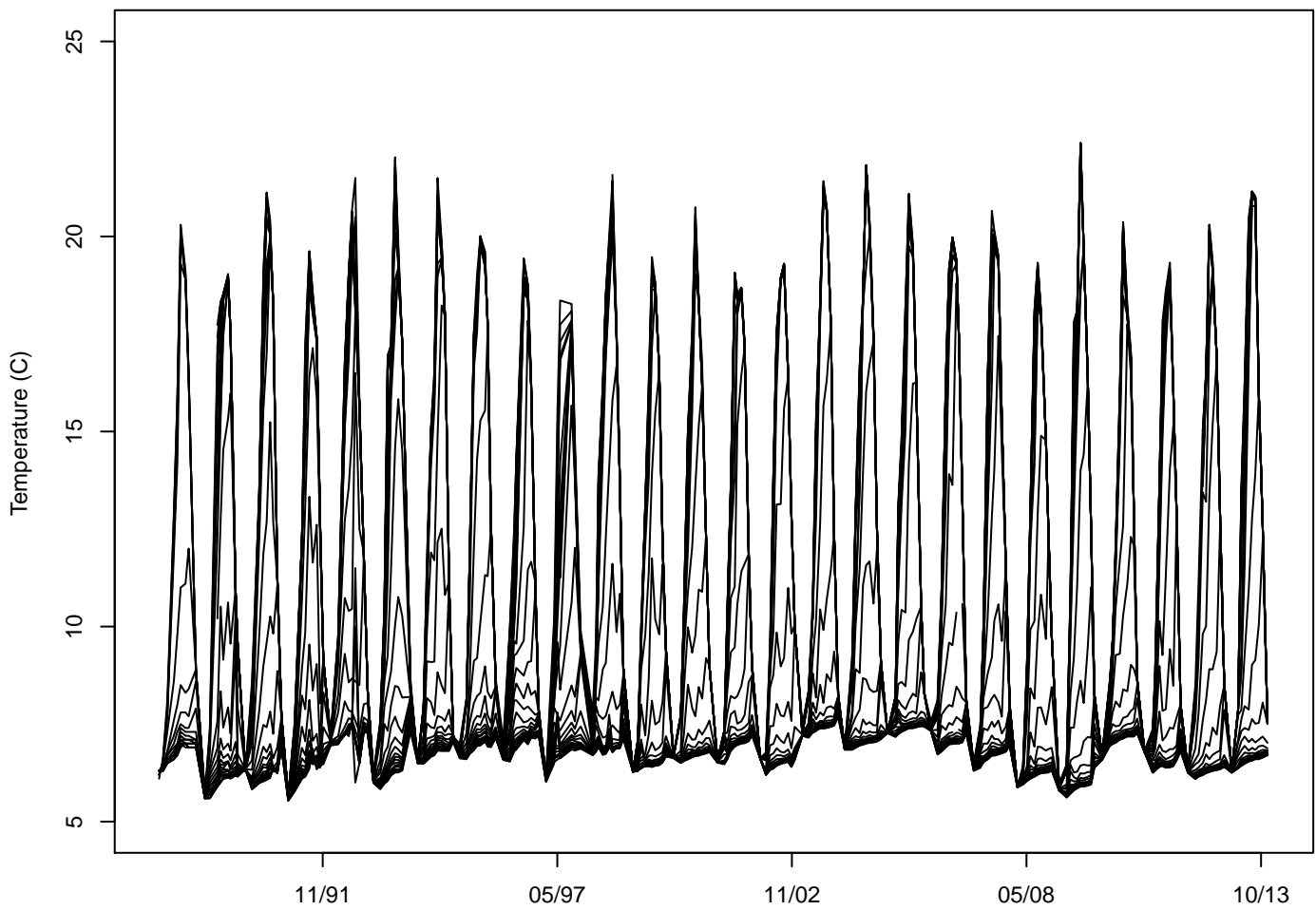


Figure B55: Lake Whatcom historic temperature data for Site 4.



Lake Whatcom dissolved oxygen data for Site 1, February 1988 through December 2013.

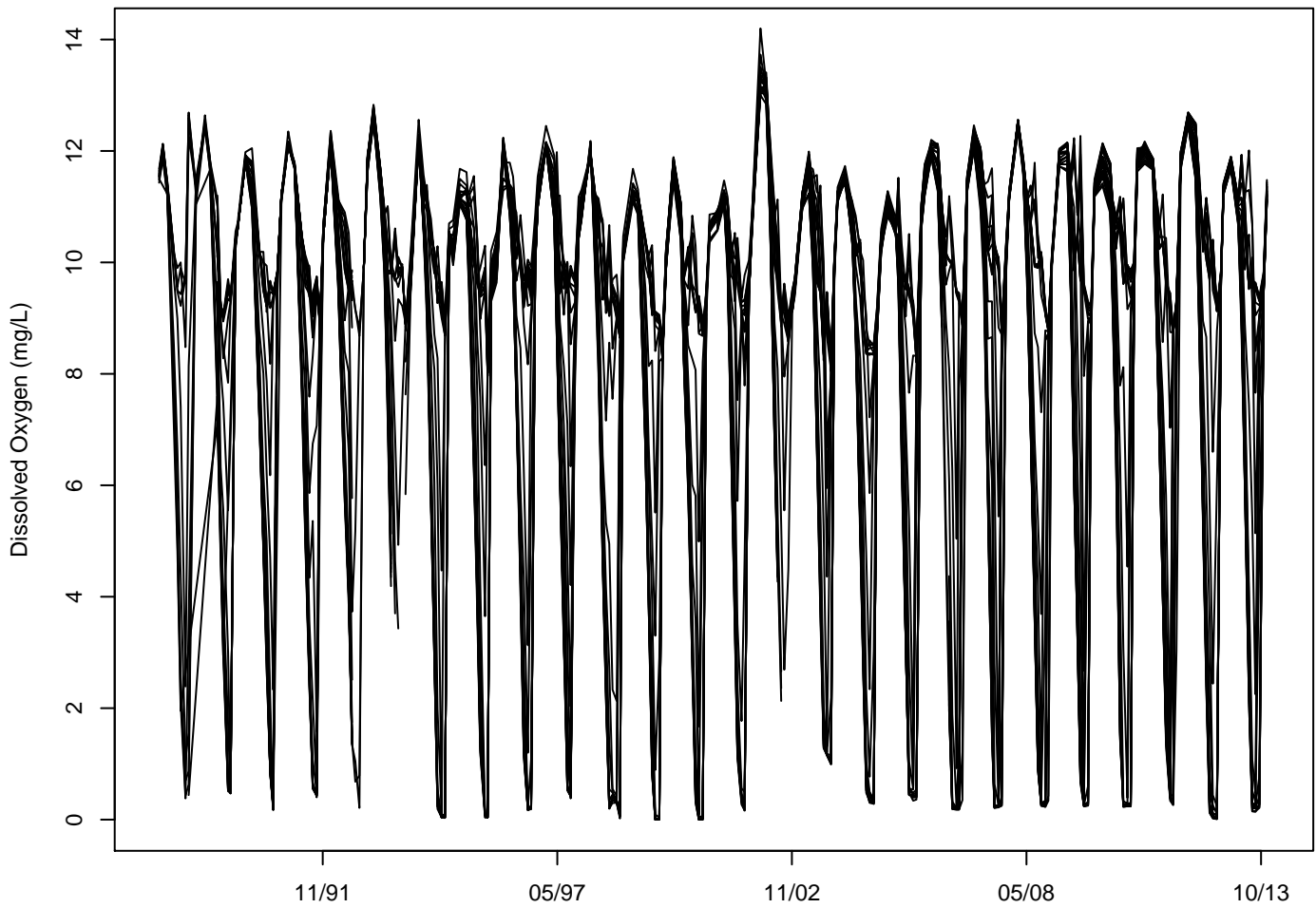


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

Lake Whatcom dissolved oxygen data for Site 2, February 1988 through December 2013.

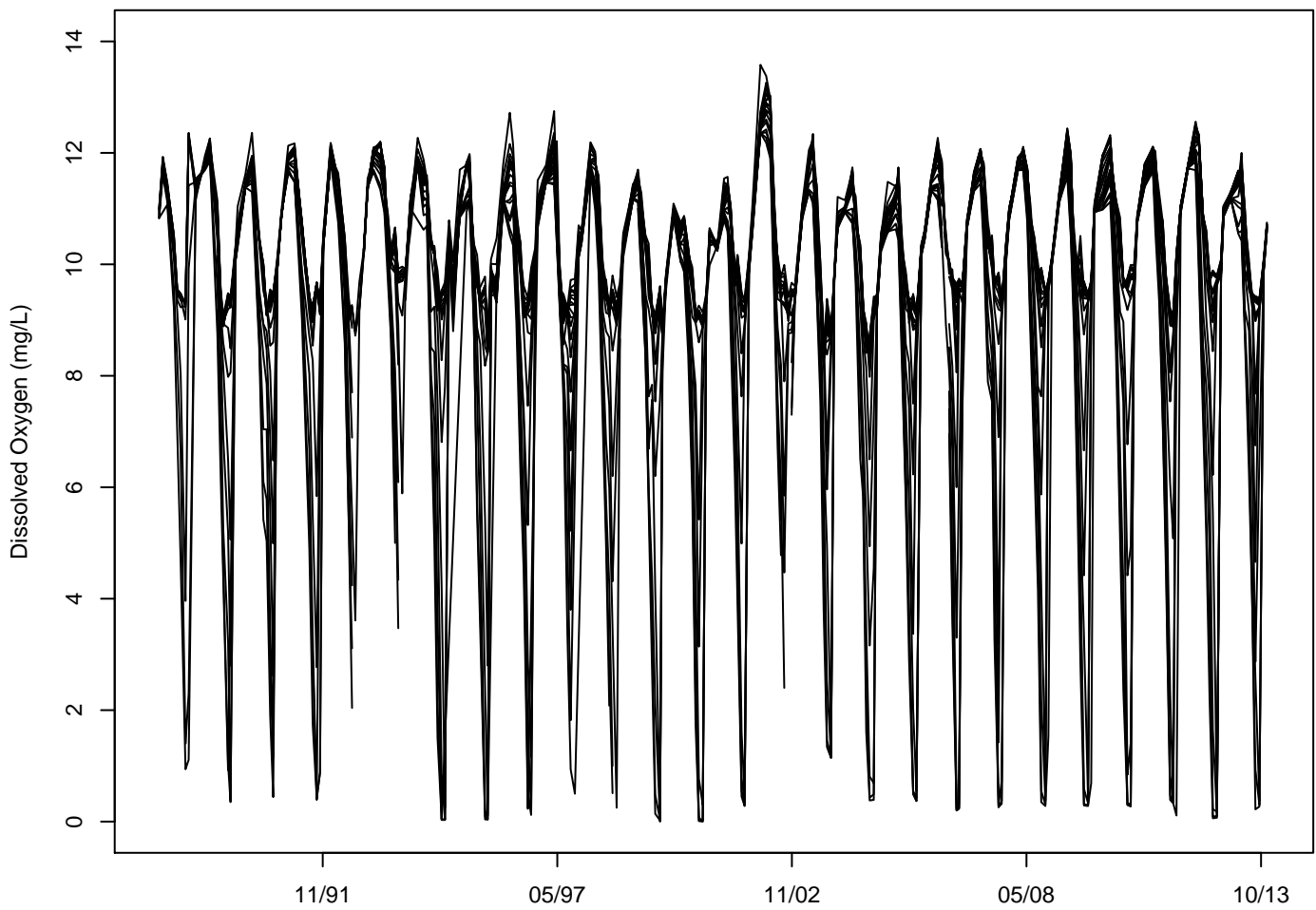


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

Lake Whatcom dissolved oxygen data for Intake, February 1988 through December 2013.

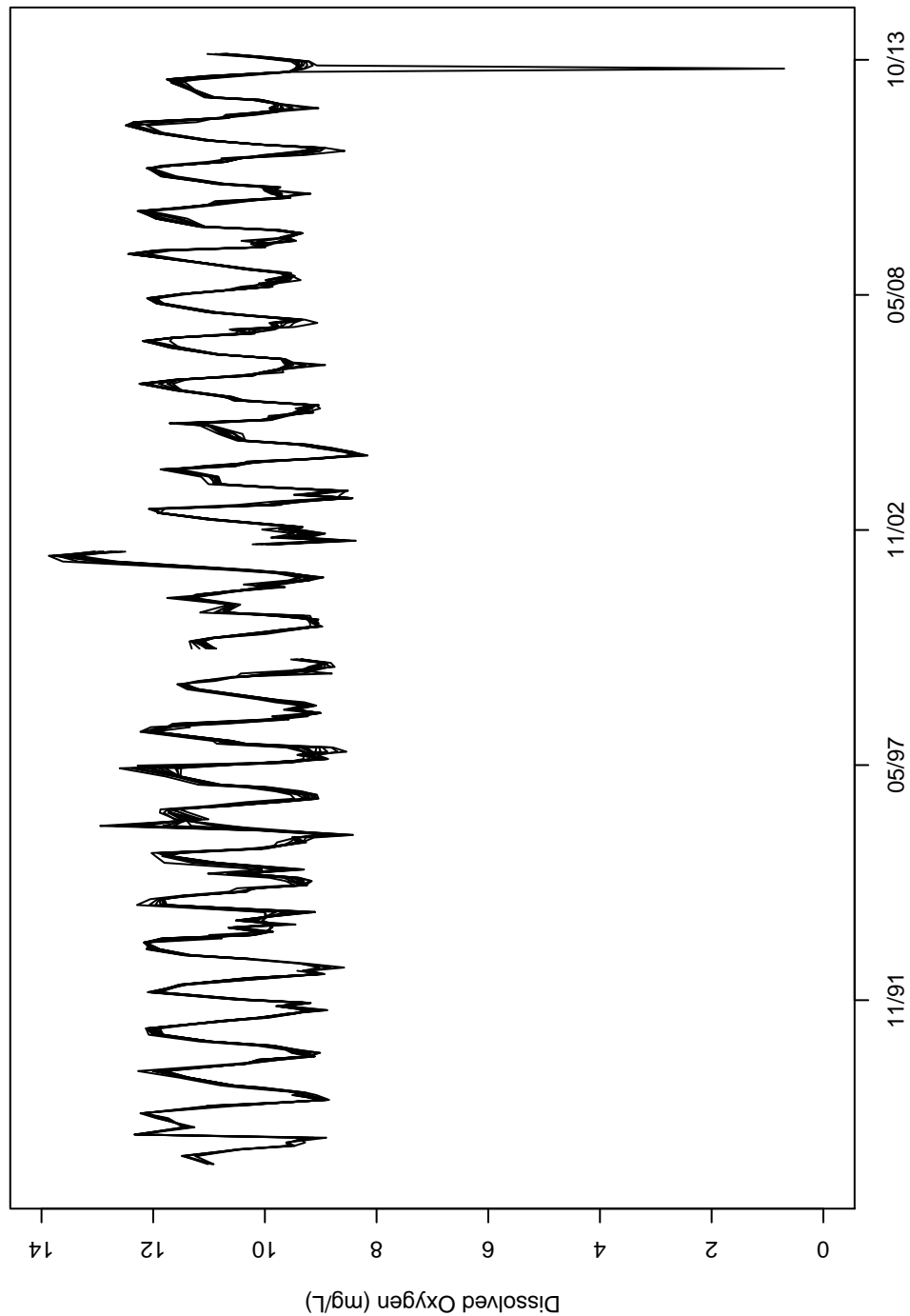


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake. See discussion of the low dissolved oxygen value on page 5.

Lake Whatcom dissolved oxygen data for Site 3, February 1988 through December 2013.

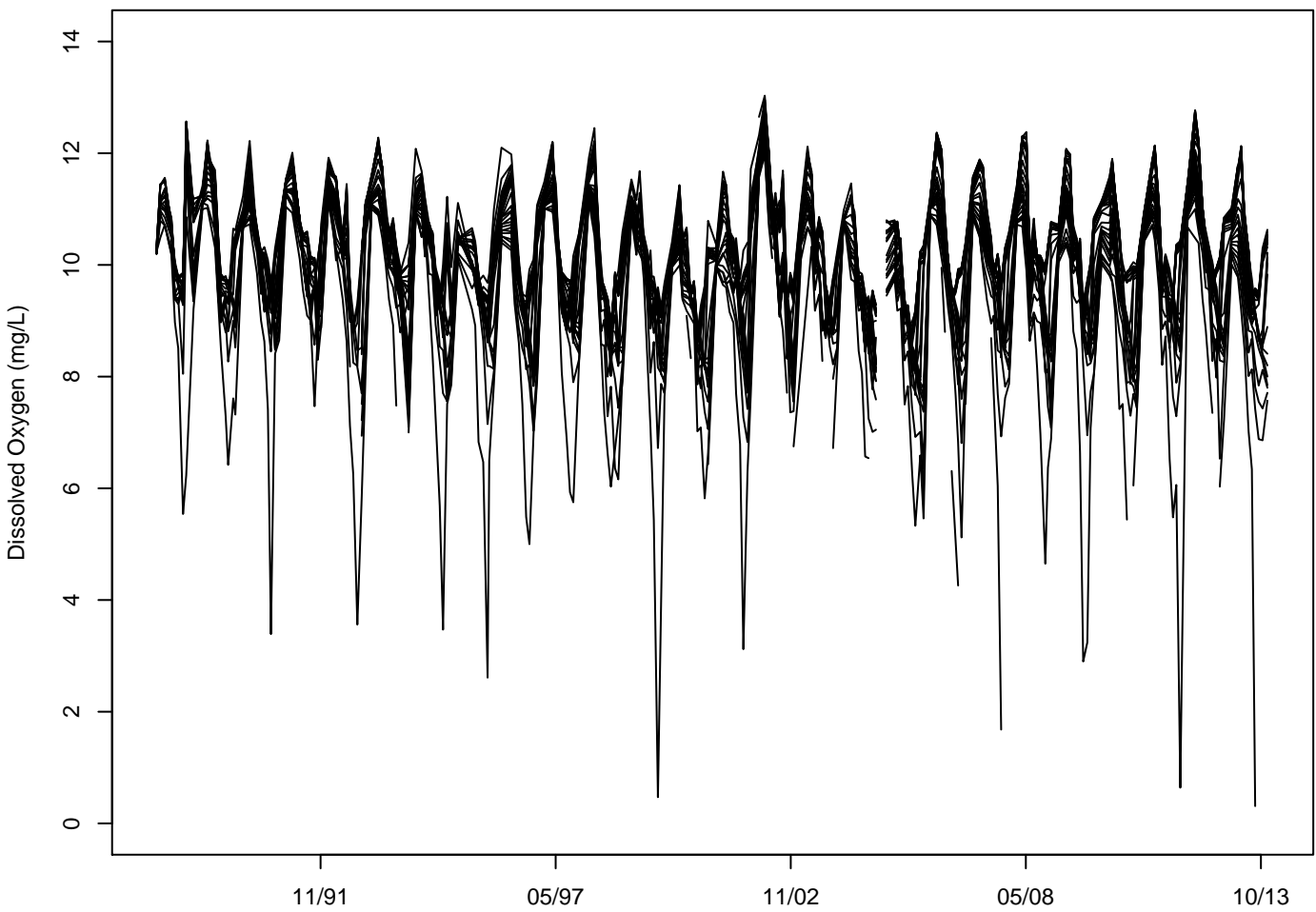


Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.

Lake Whatcom dissolved oxygen data for Site 4, February 1988 through December 2013.

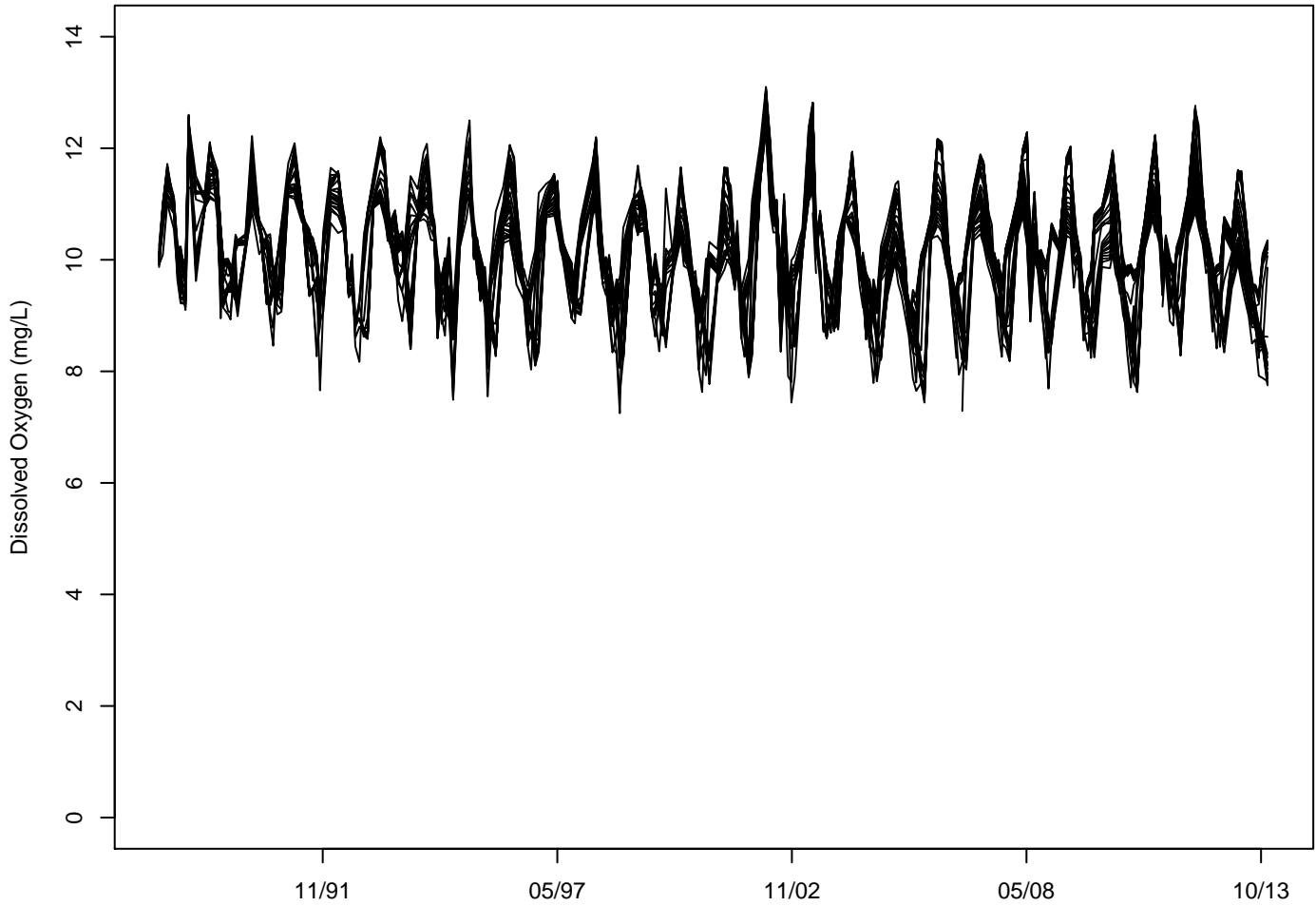


Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

Lake Whatcom pH data for Site 1, February 1988 through December 2013.

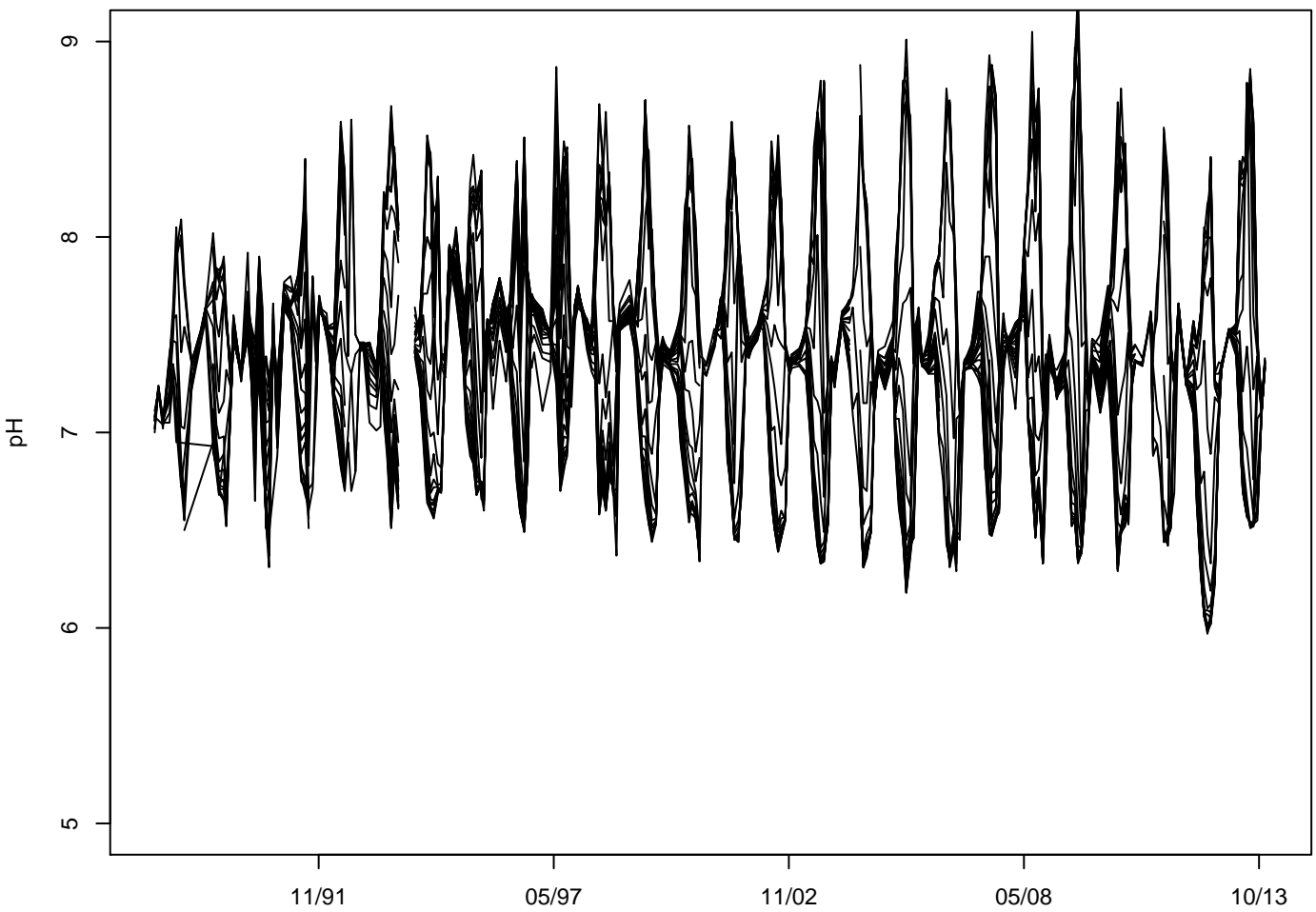


Figure B61: Lake Whatcom historic pH data for Site 1.

Lake Whatcom pH data for Site 2, February 1988 through December 2013.

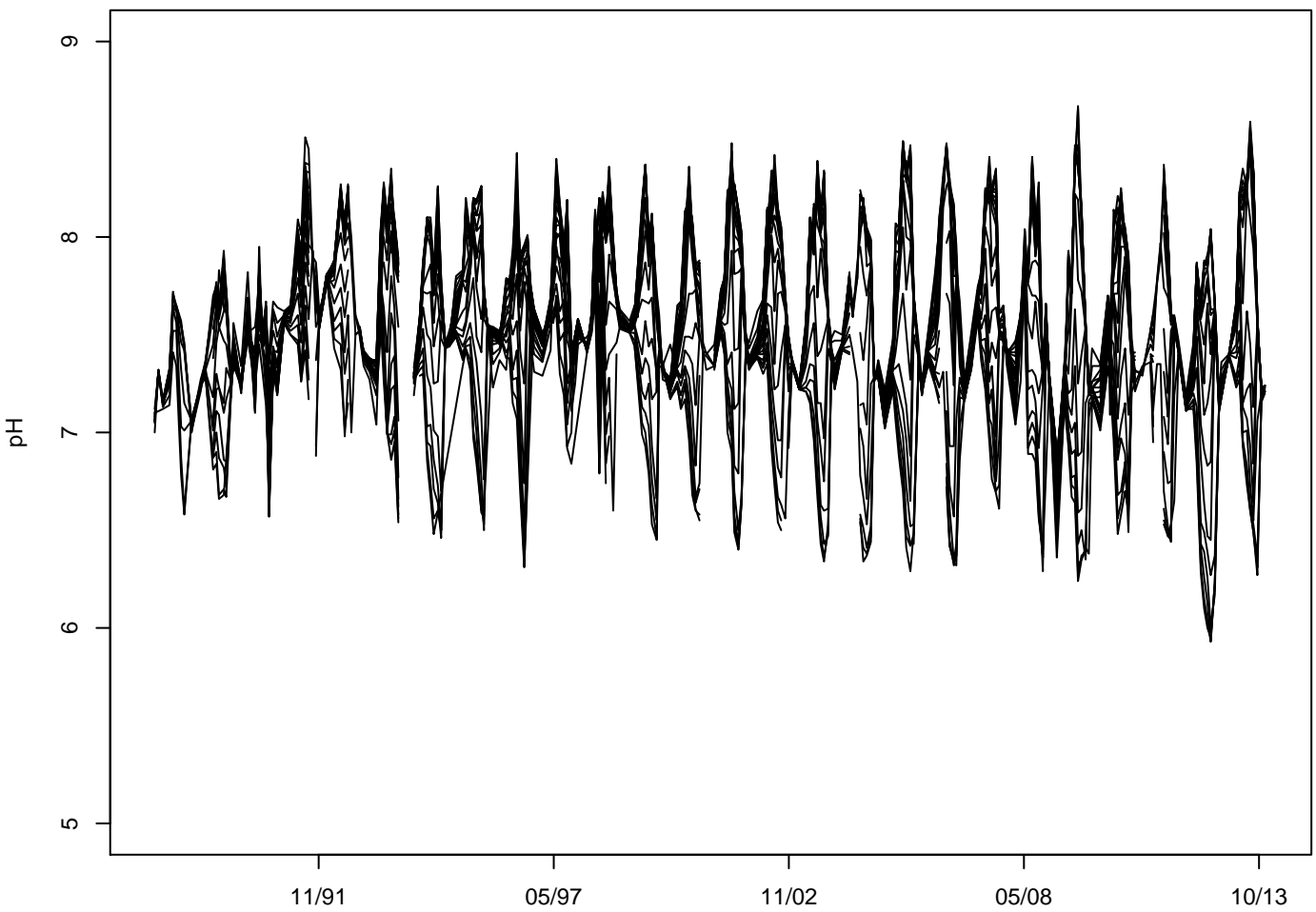


Figure B62: Lake Whatcom historic pH data for Site 2.

Lake Whatcom pH data for Intake, February 1988 through December 2013.

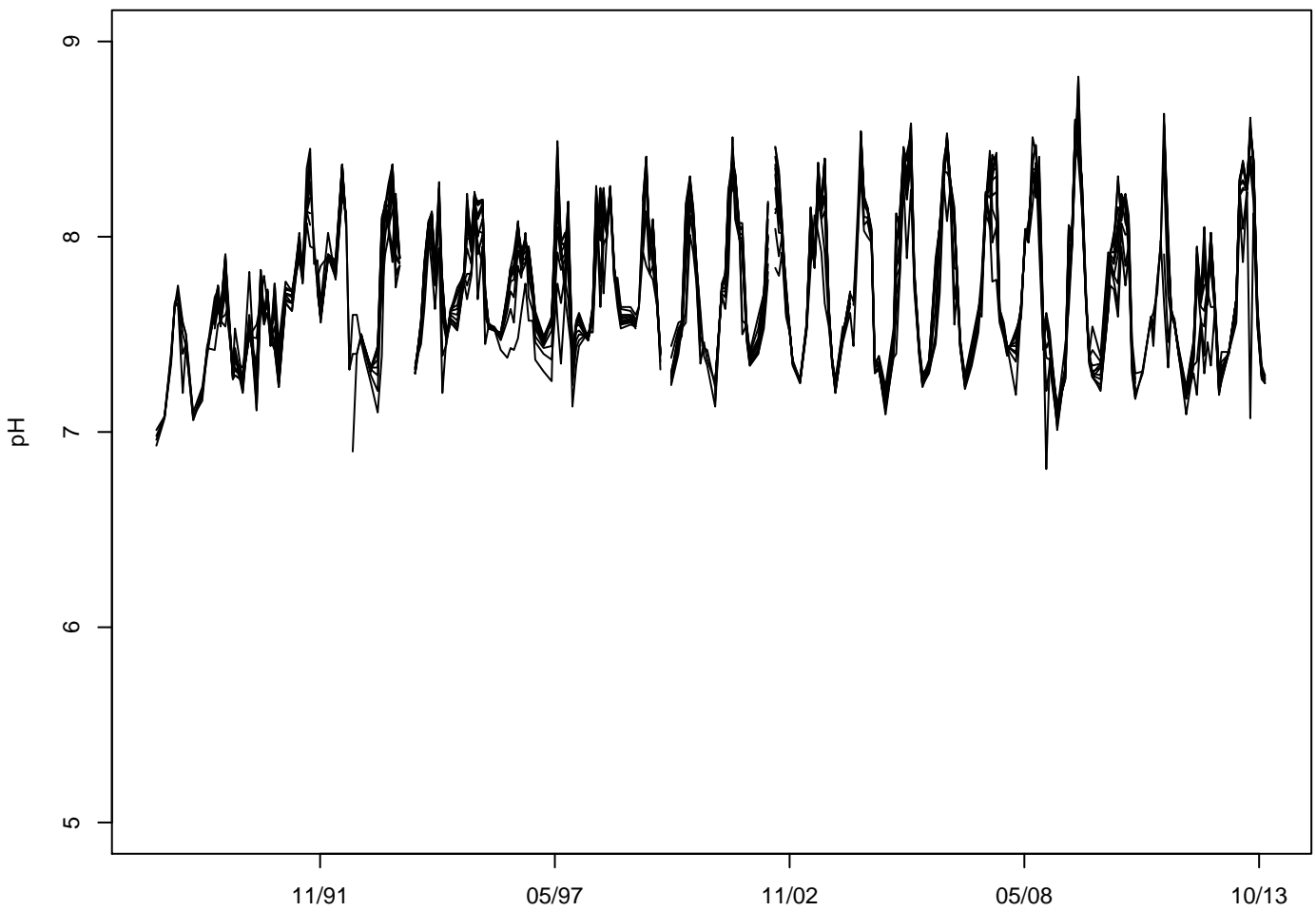


Figure B63: Lake Whatcom historic pH data for the Intake.



Lake Whatcom pH data for Site 3, February 1988 through December 2013.

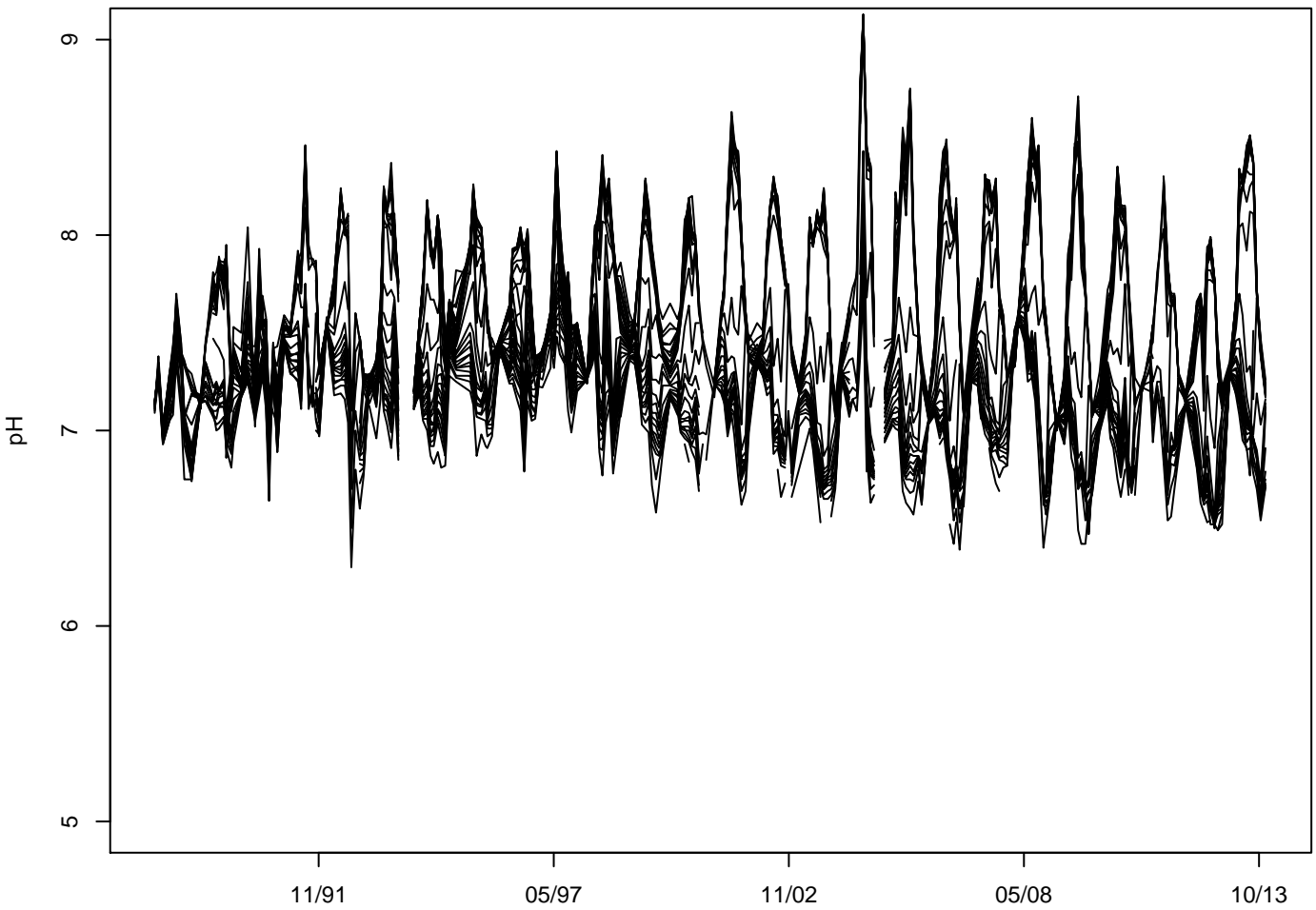


Figure B64: Lake Whatcom historic pH data for Site 3.

Lake Whatcom pH data for Site 4, February 1988 through December 2013.

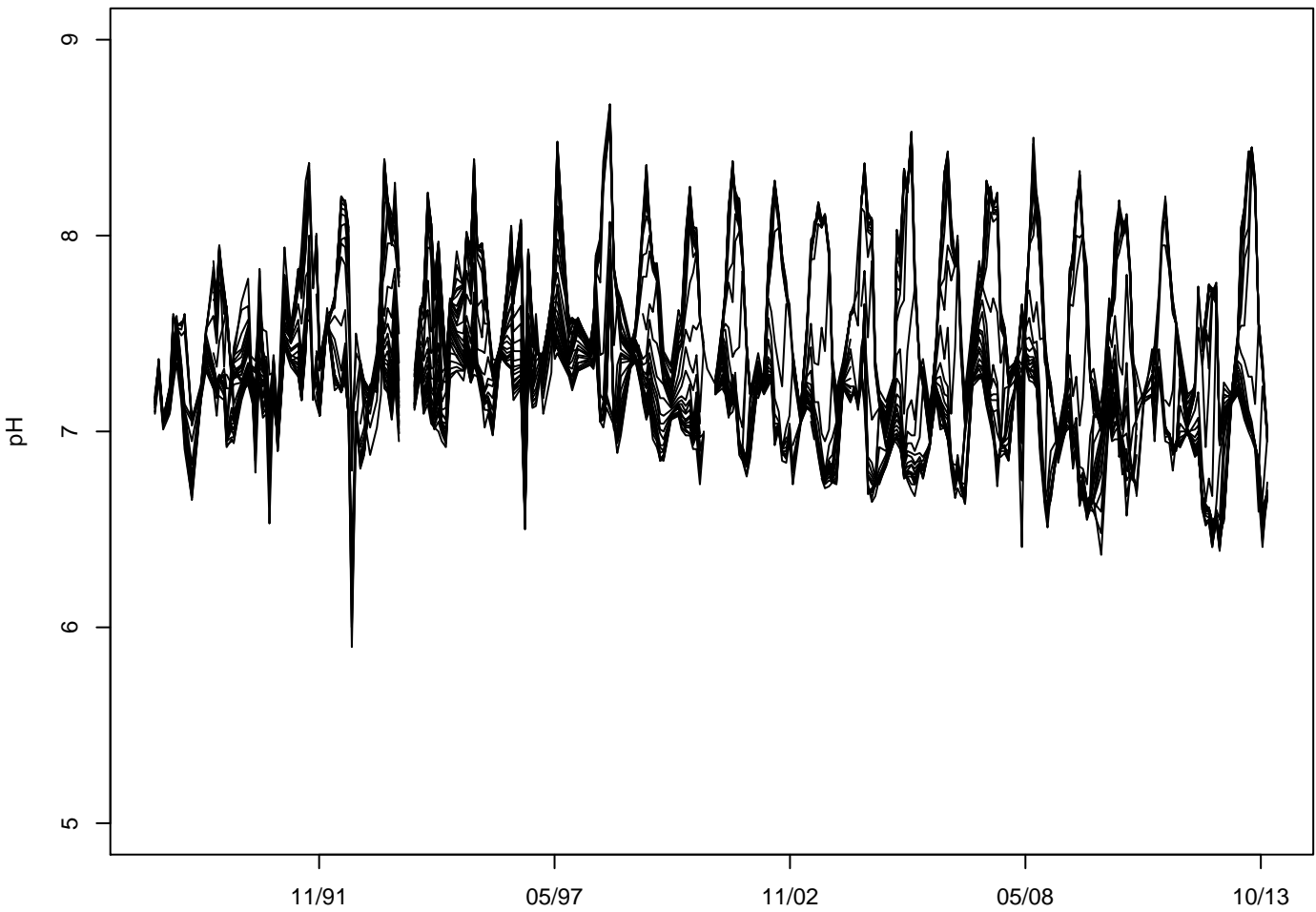


Figure B65: Lake Whatcom historic pH data for Site 4.

Lake Whatcom conductivity data for Site 1, February 1988 through December 2013.

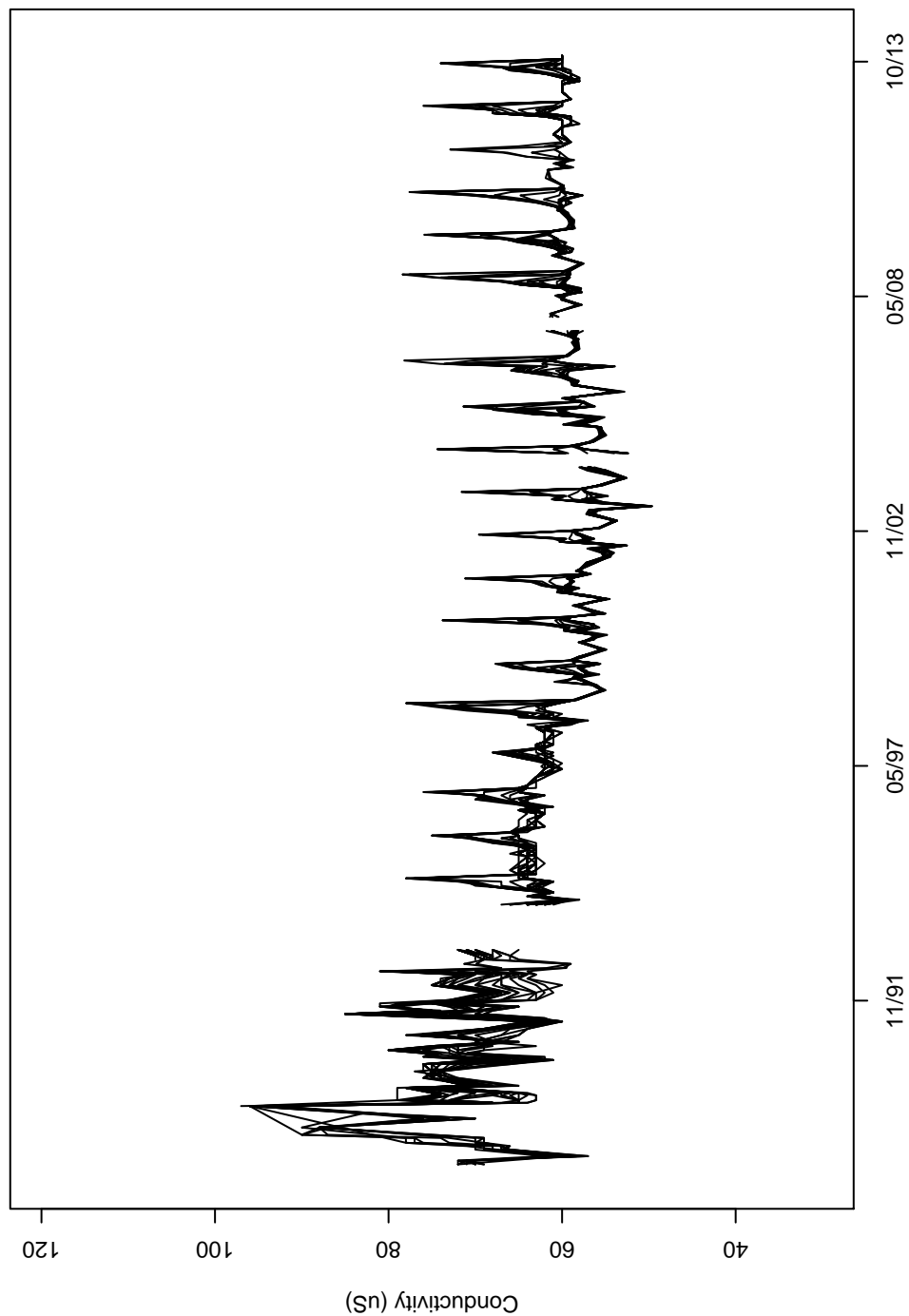


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to more sensitive equipment.

Lake Whatcom conductivity data for Site 2, February 1988 through December 2013.

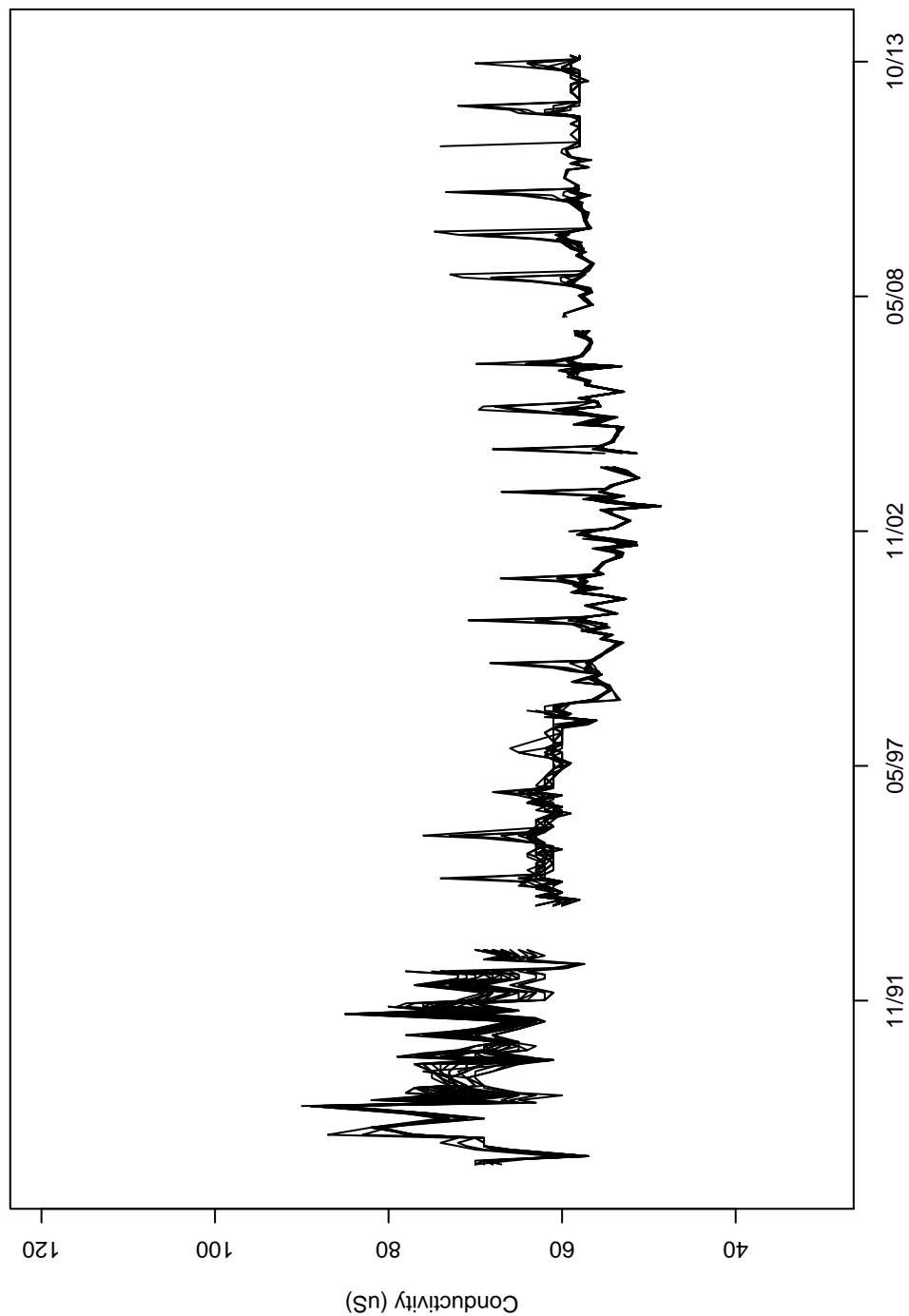


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to more sensitive equipment.

Lake Whatcom conductivity data for Intake, February 1988 through December 2013.

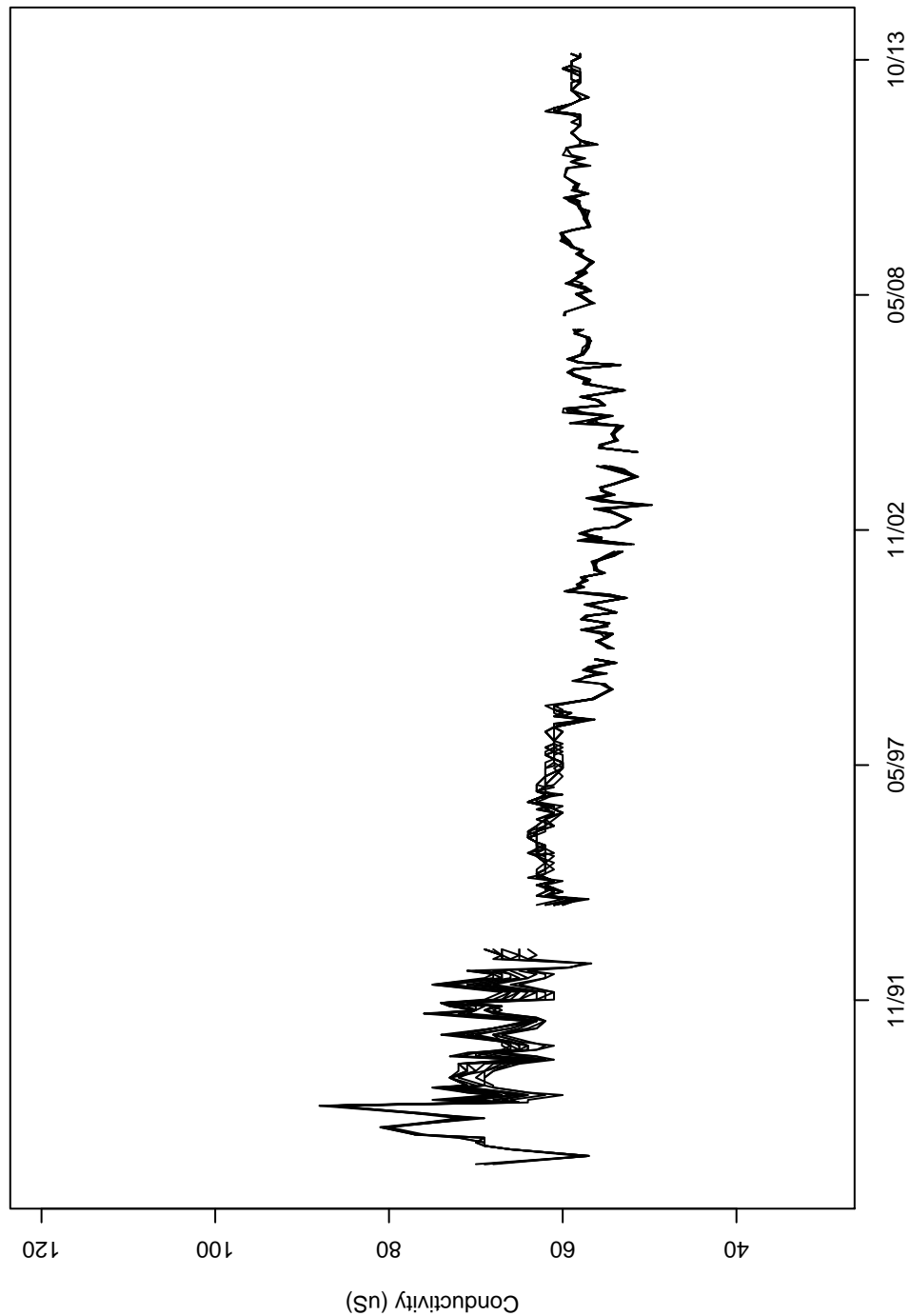


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to more sensitive equipment.

Lake Whatcom conductivity data for Site 3, February 1988 through December 2013.

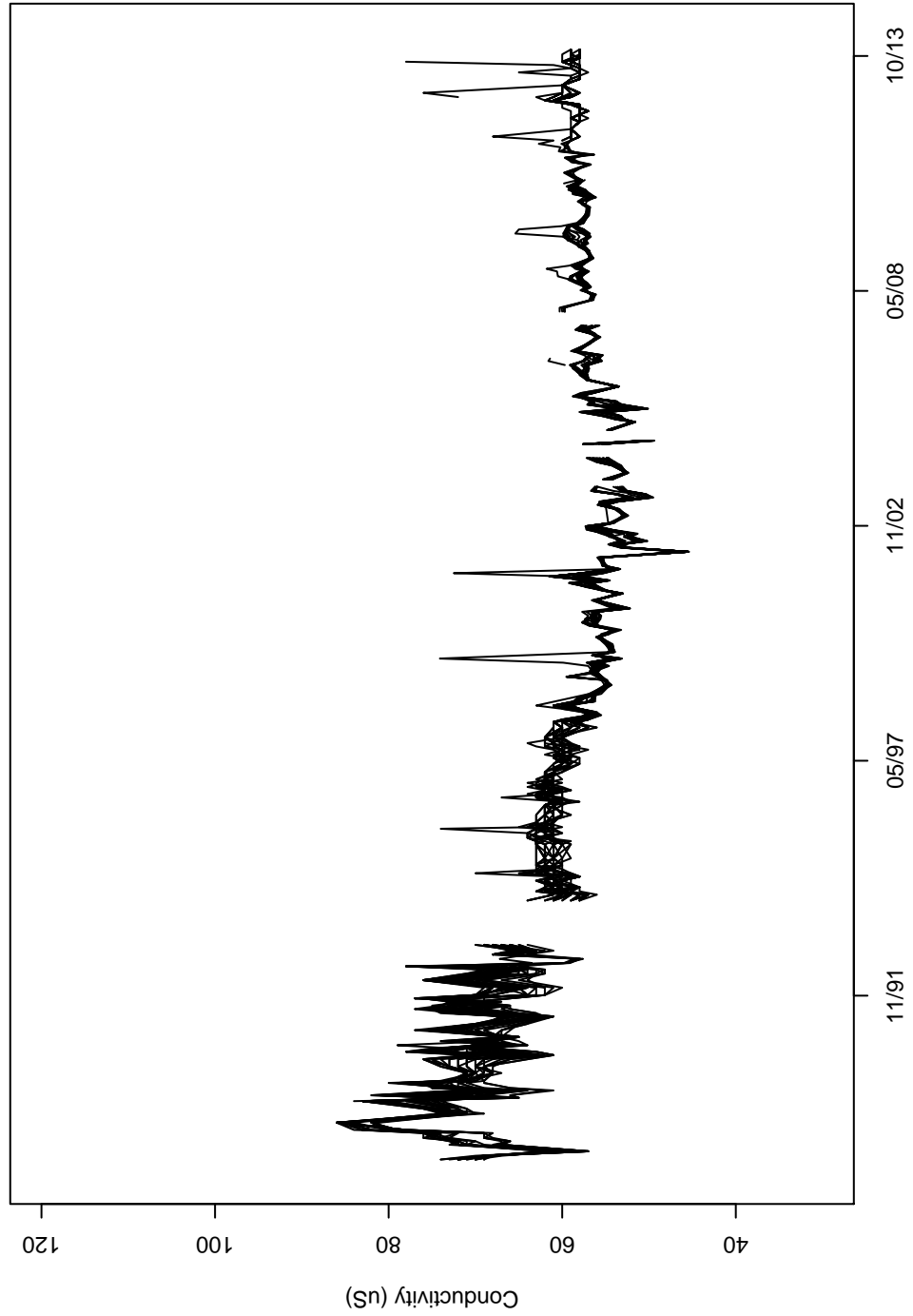


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to more sensitive equipment.

Lake Whatcom conductivity data for Site 4, February 1988 through December 2013.

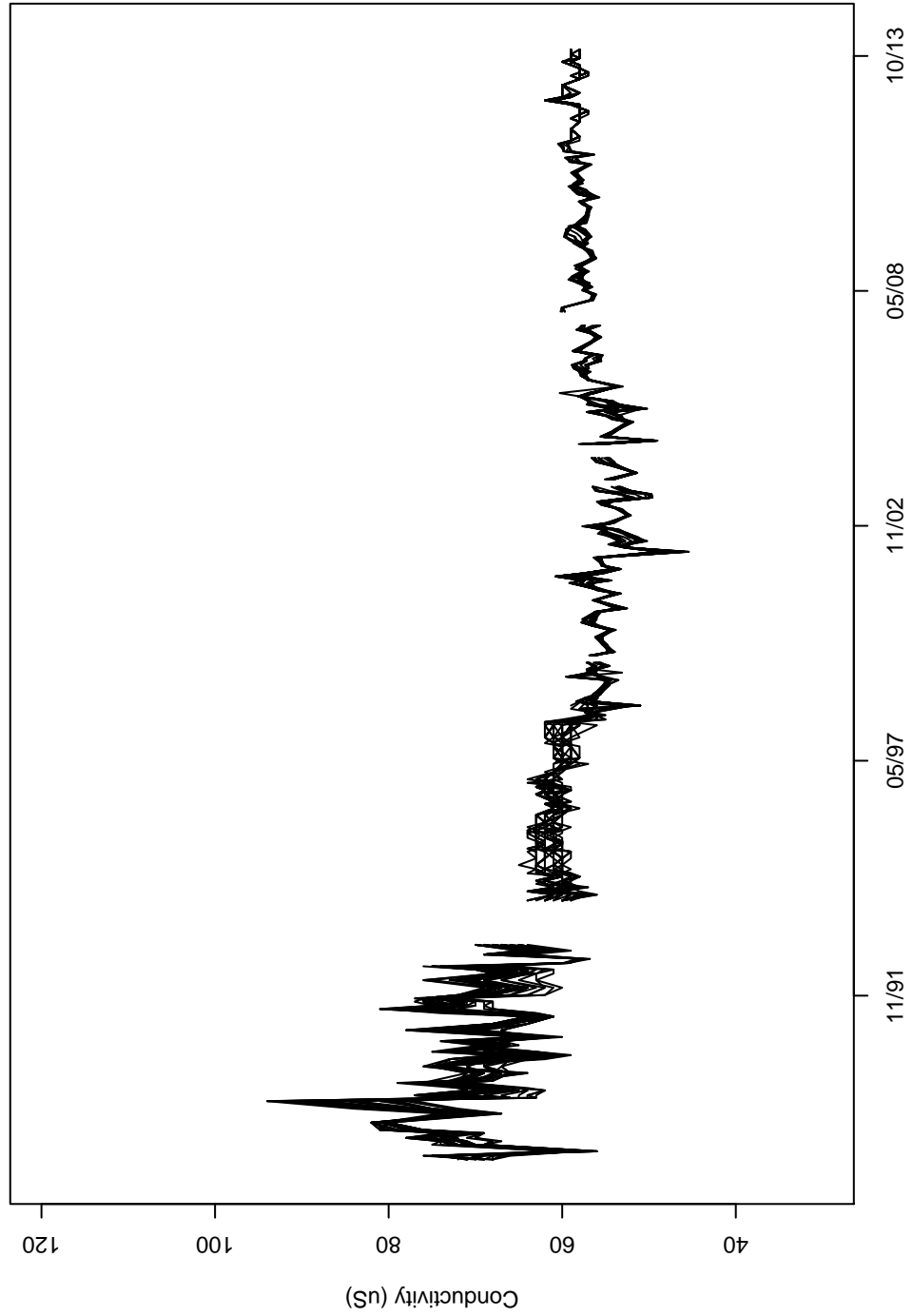


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to more sensitive equipment.

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



Lake Whatcom alkalinity data for Site 1, February 1988 through December 2013.

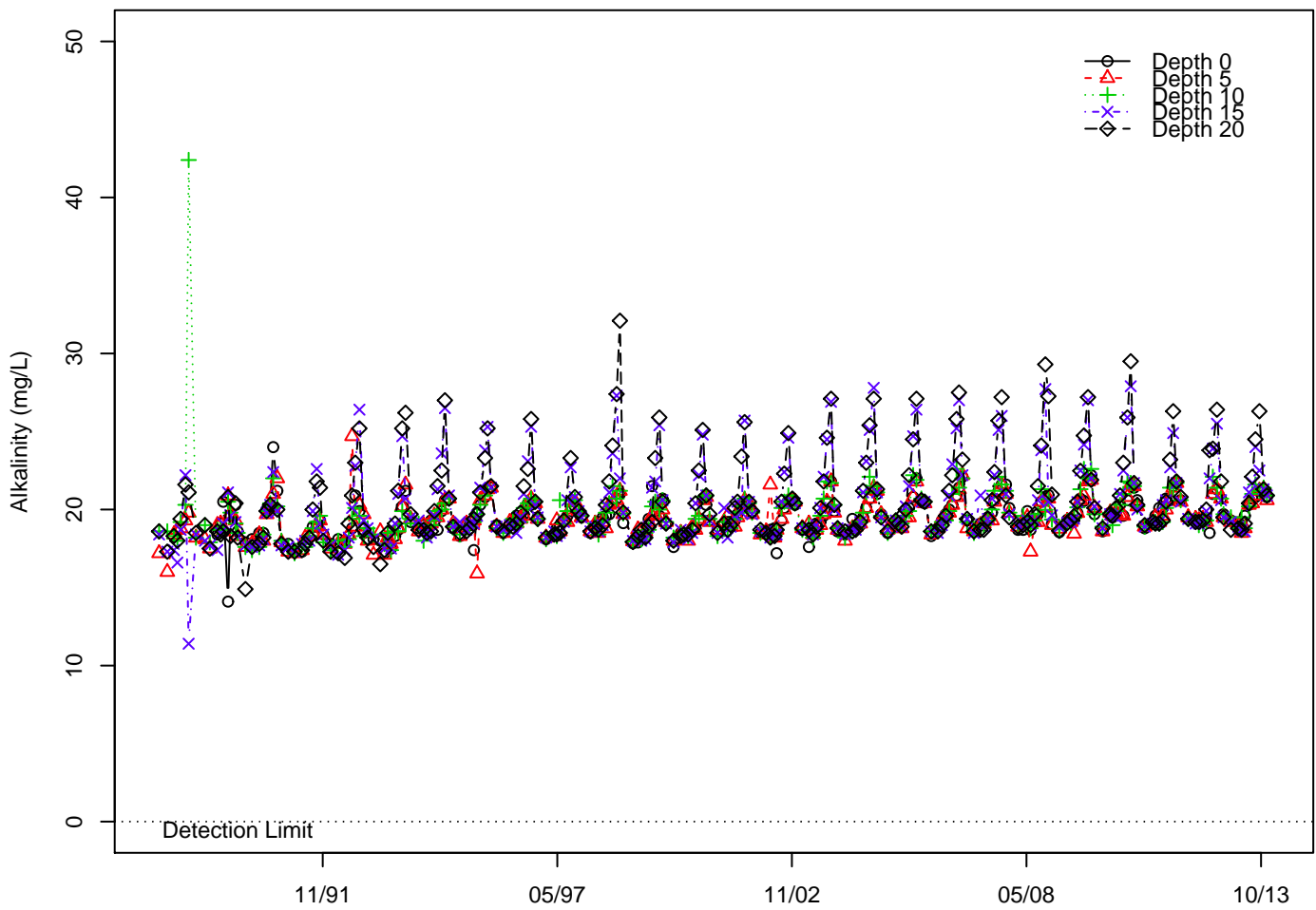


Figure B71: Lake Whatcom alkalinity data for Site 1.

Lake Whatcom alkalinity data for Site 2, February 1988 through December 2013.

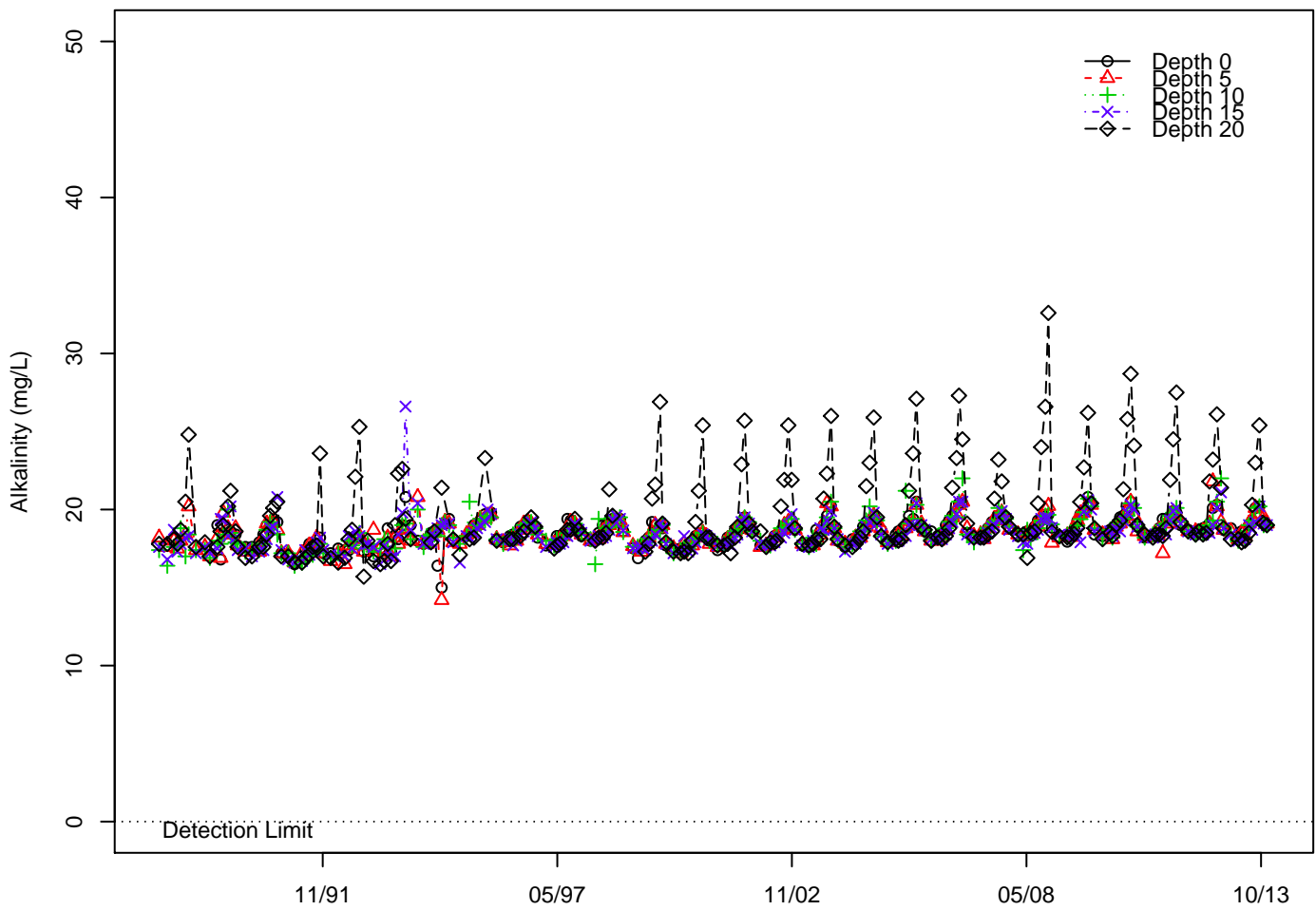


Figure B72: Lake Whatcom alkalinity data for Site 2.

Lake Whatcom alkalinity data for Intake, February 1988 through December 2013.

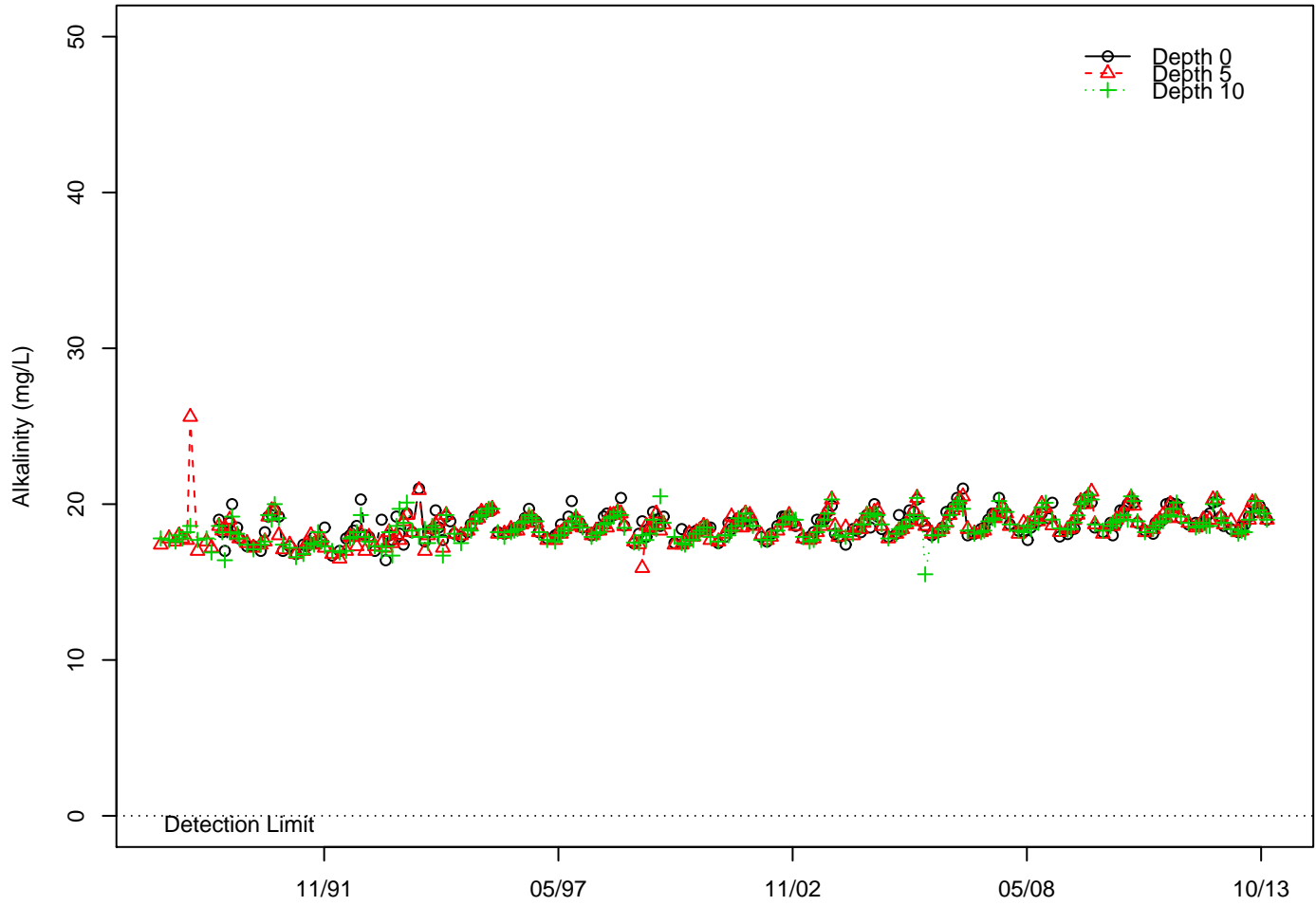


Figure B73: Lake Whatcom alkalinity data for the Intake site.

Lake Whatcom alkalinity data for Site 3, February 1988 through December 2013.

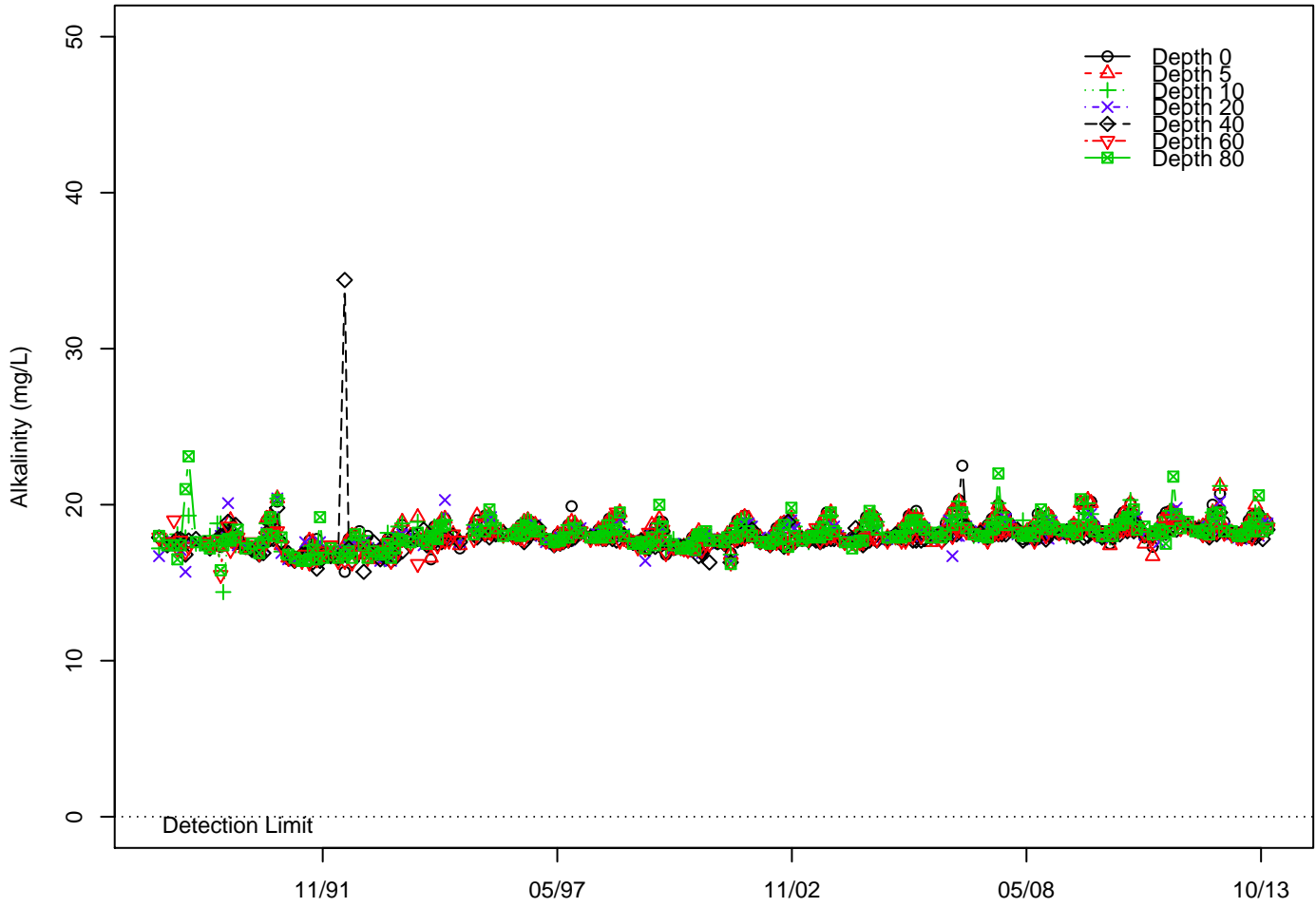


Figure B74: Lake Whatcom alkalinity data for Site 3.

Lake Whatcom alkalinity data for Site 4, February 1988 through December 2013.

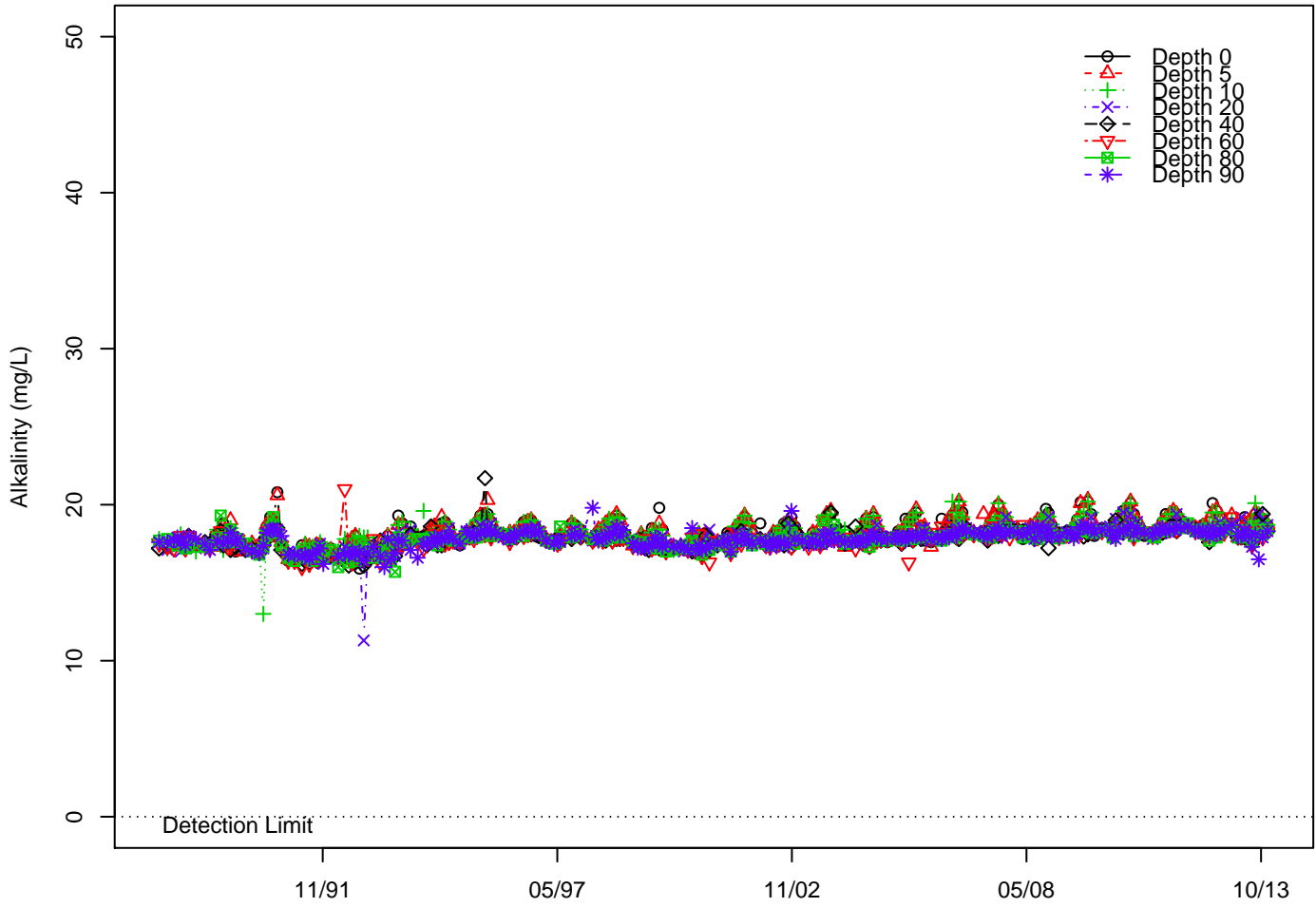


Figure B75: Lake Whatcom alkalinity data for Site 4.

Lake Whatcom turbidity data for Site 1, February 1988 through December 2013.

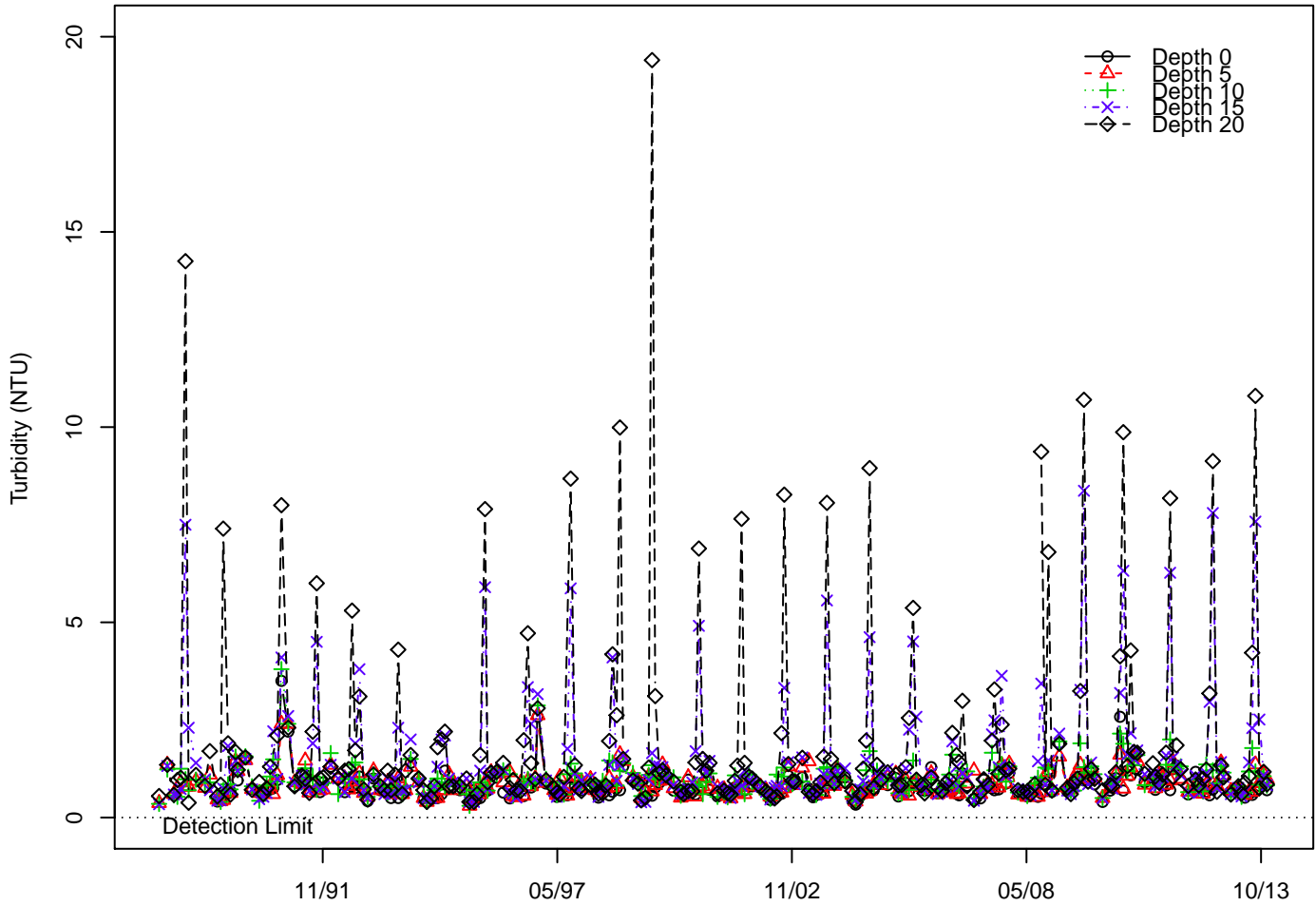


Figure B76: Lake Whatcom turbidity data for Site 1.

Lake Whatcom turbidity data for Site 2, February 1988 through December 2013.

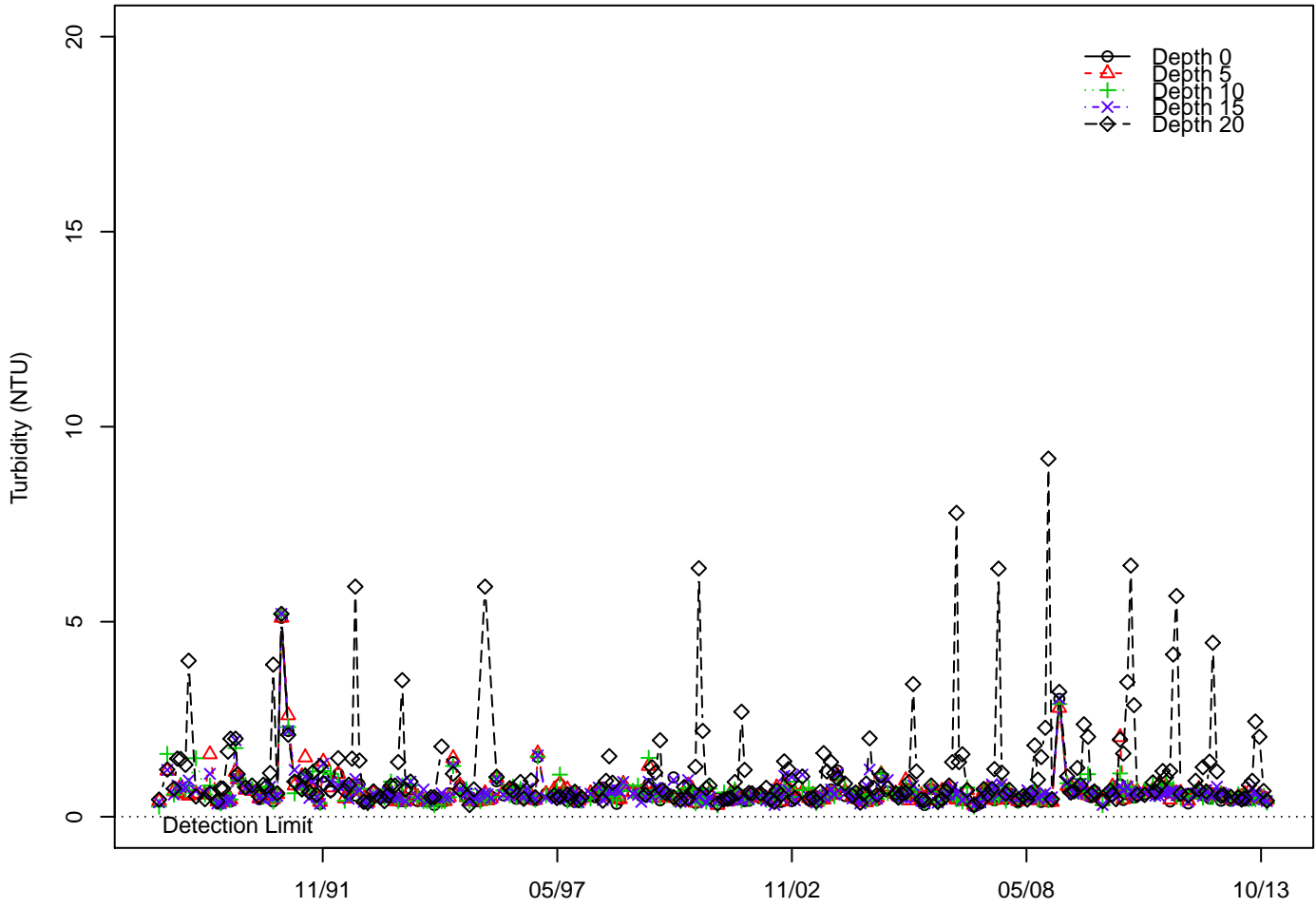


Figure B77: Lake Whatcom turbidity data for Site 2.

Lake Whatcom turbidity data for Intake, February 1988 through December 2013.

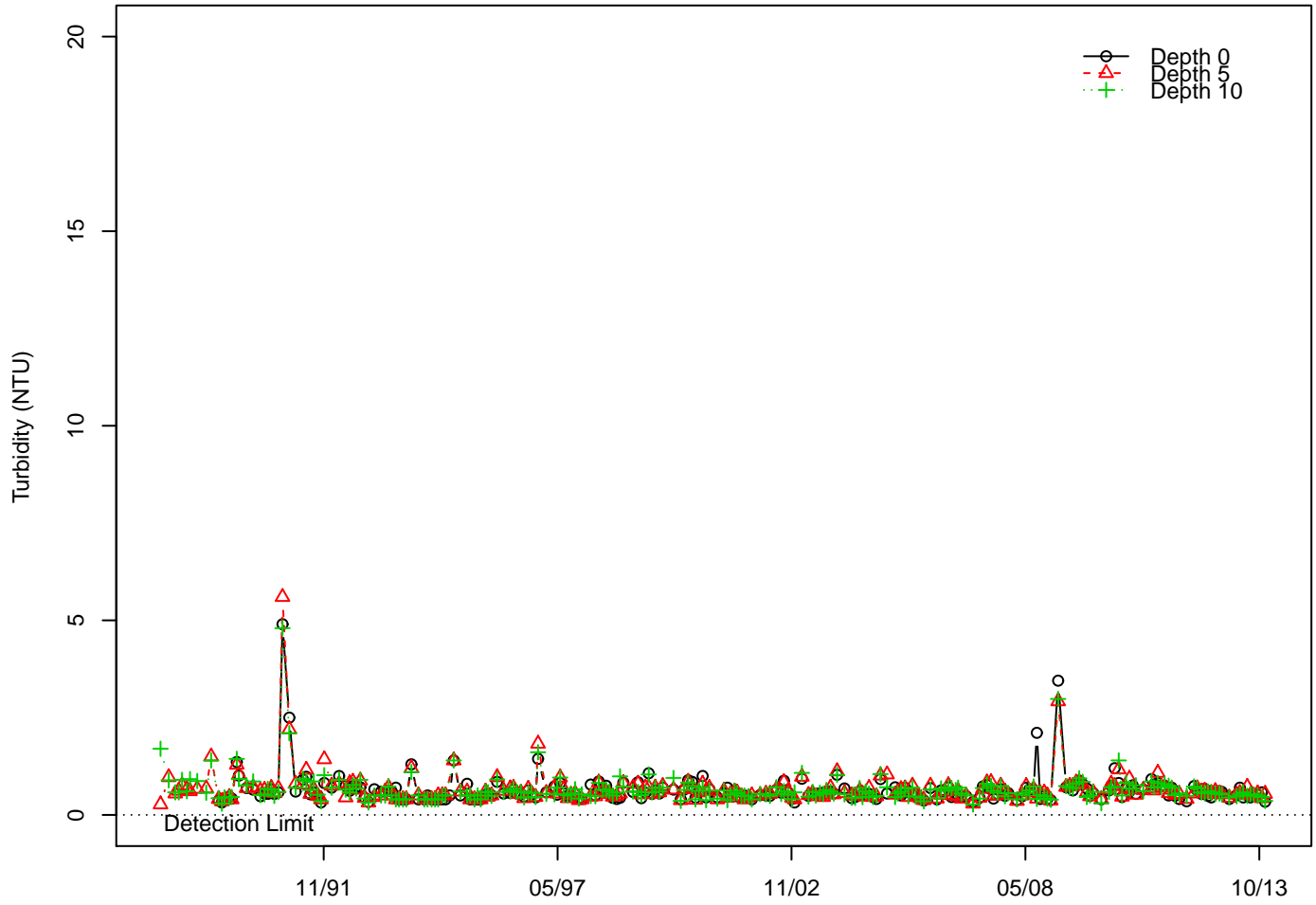


Figure B78: Lake Whatcom turbidity data for the Intake site.



Lake Whatcom turbidity data for Site 3, February 1988 through December 2013.

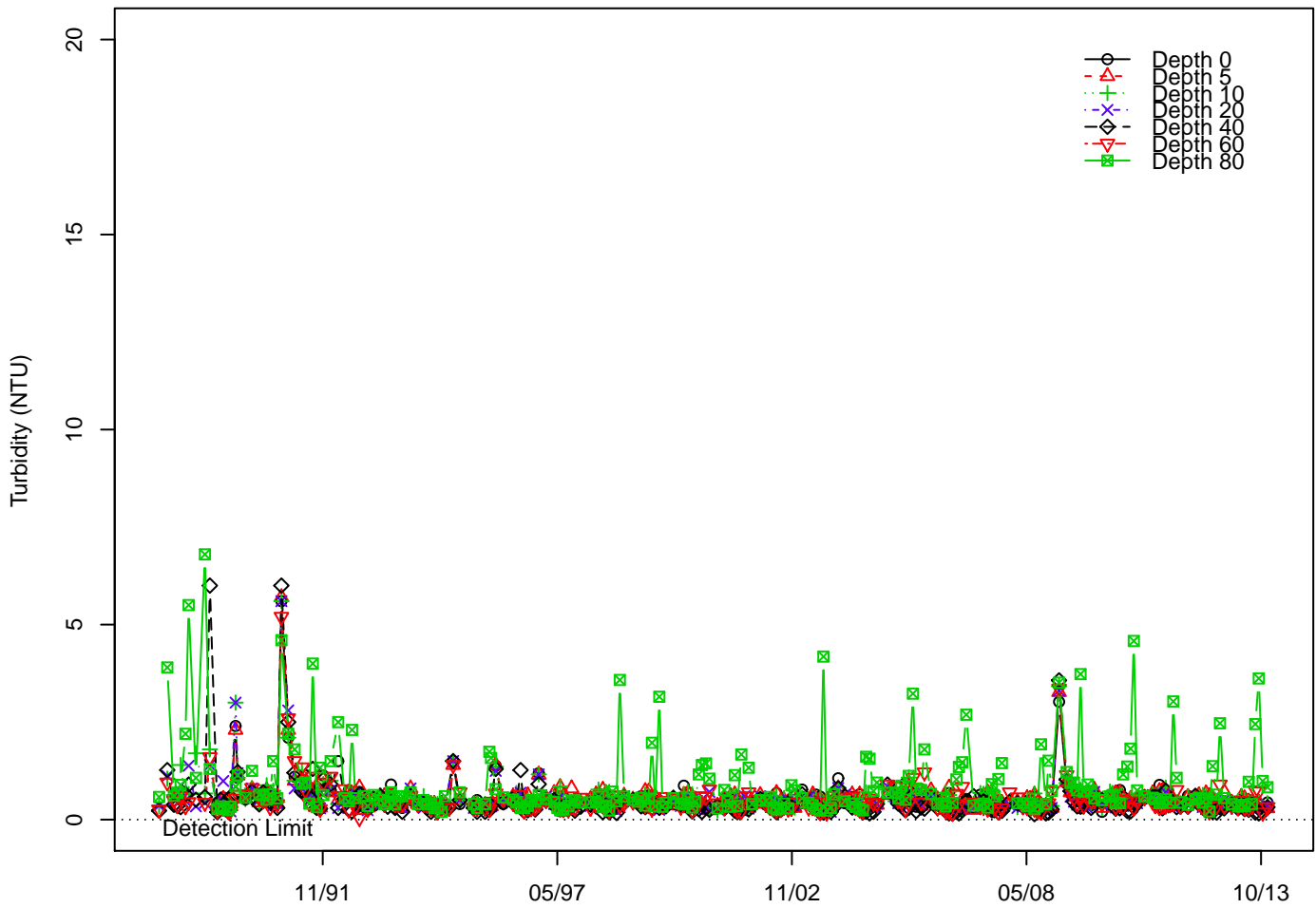


Figure B79: Lake Whatcom turbidity data for Site 3.

Lake Whatcom turbidity data for Site 4, February 1988 through December 2013.

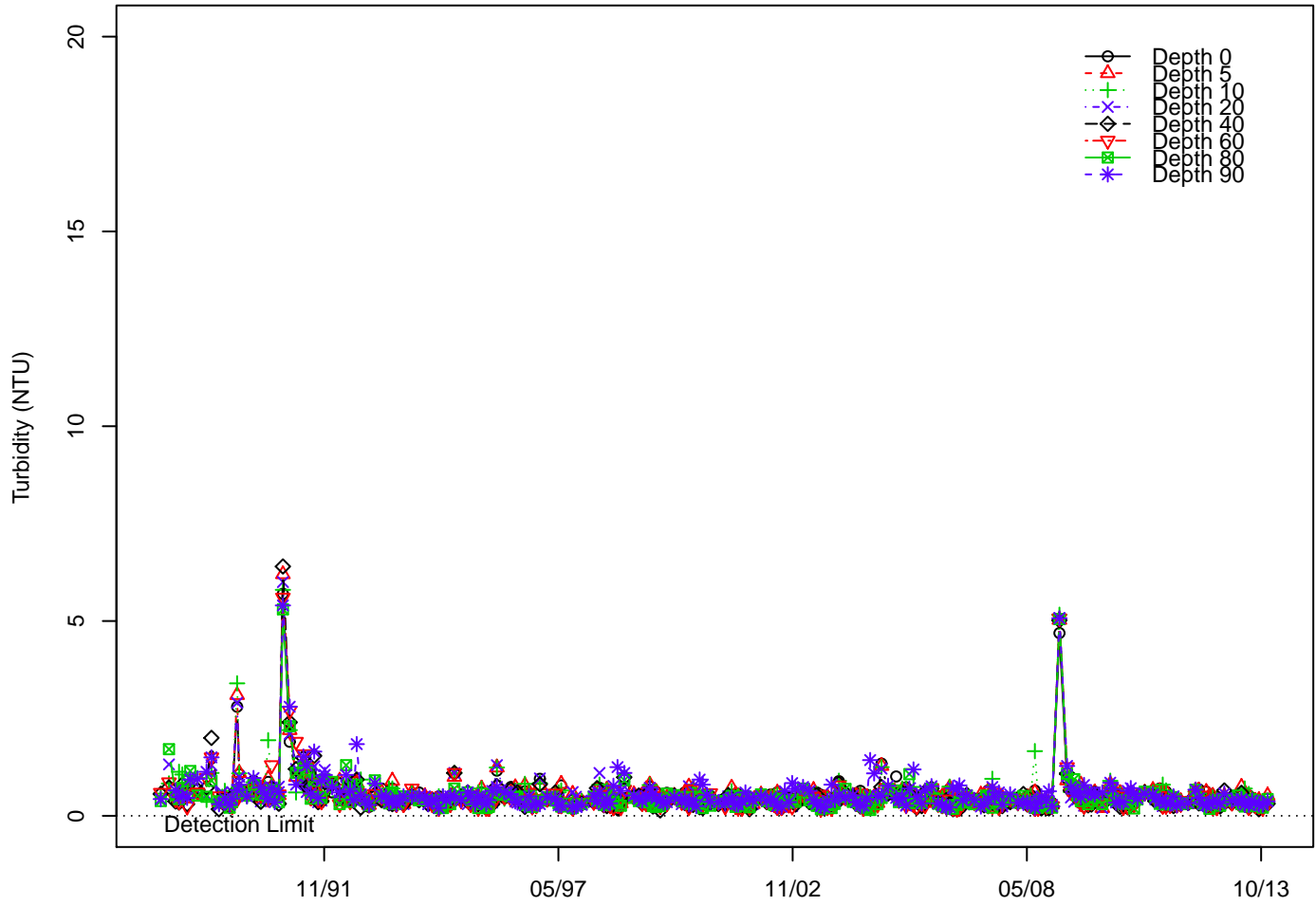


Figure B80: Lake Whatcom turbidity data for Site 4.

Lake Whatcom ammonium data for Site 1, February 1988 through December 2013.

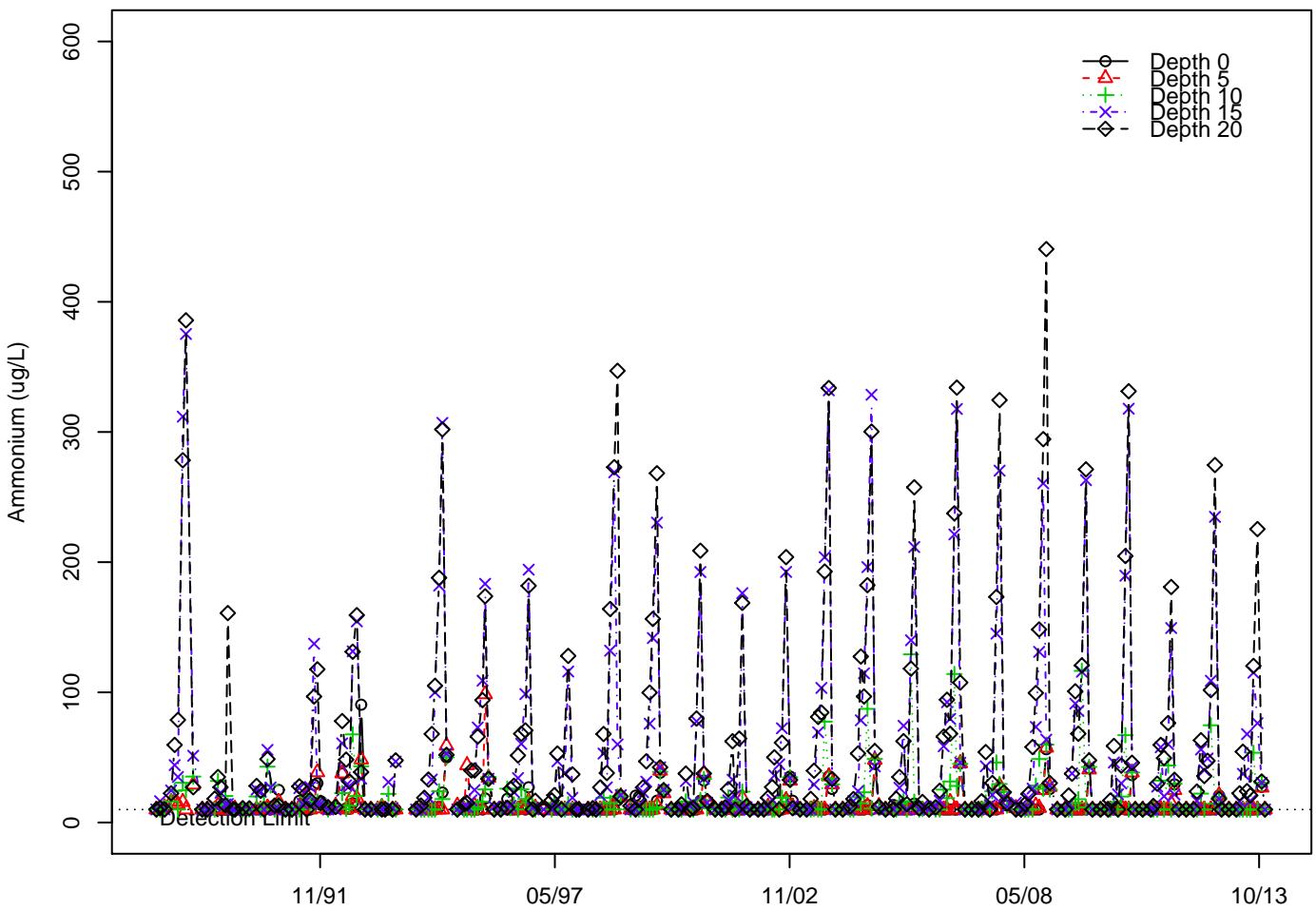


Figure B81: Lake Whatcom ammonium data for Site 1.

Lake Whatcom ammonium data for Site 2, February 1988 through December 2013.

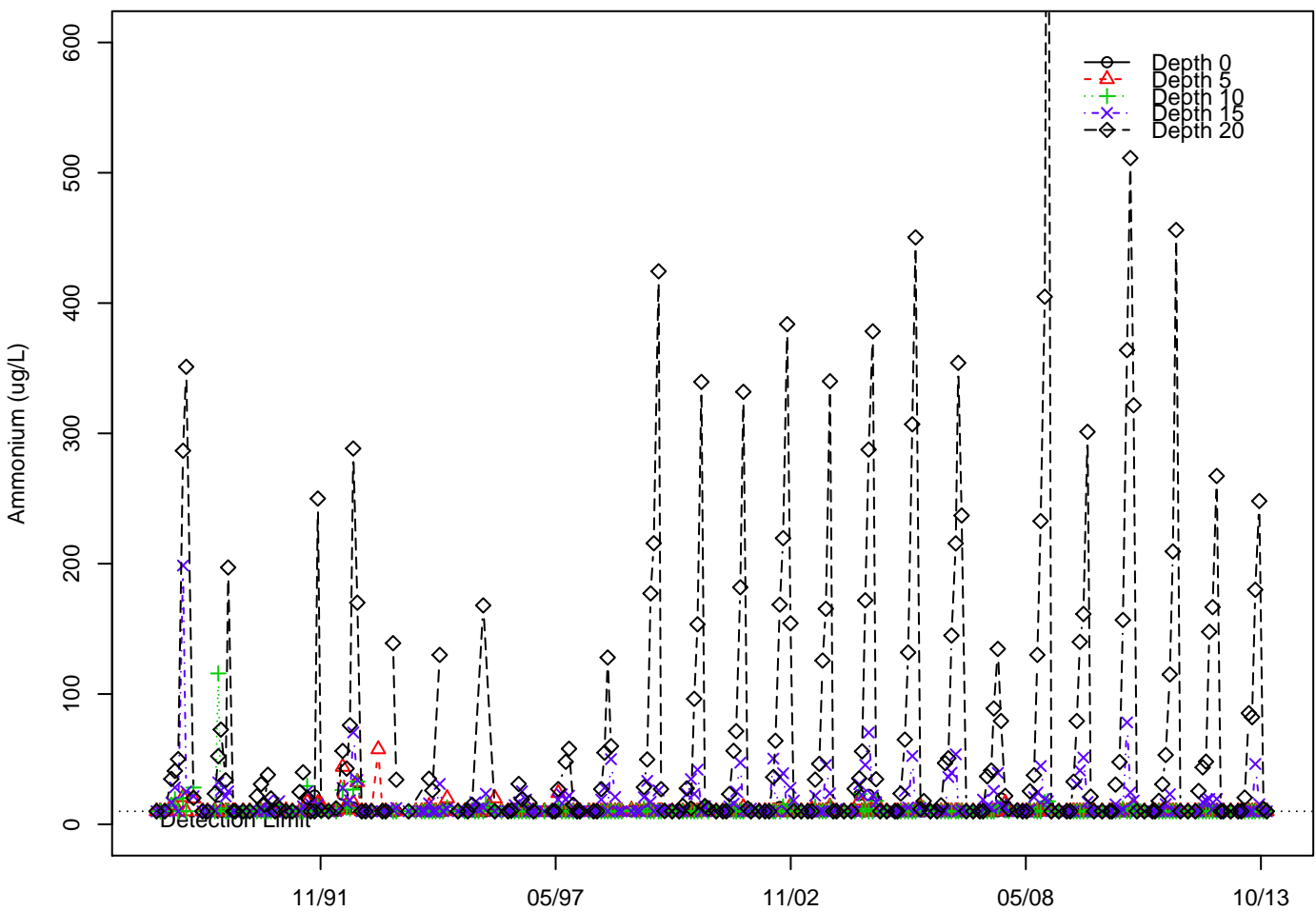


Figure B82: Lake Whatcom ammonium data for Site 2.

Lake Whatcom ammonium data for Intake, February 1988 through December 2013.

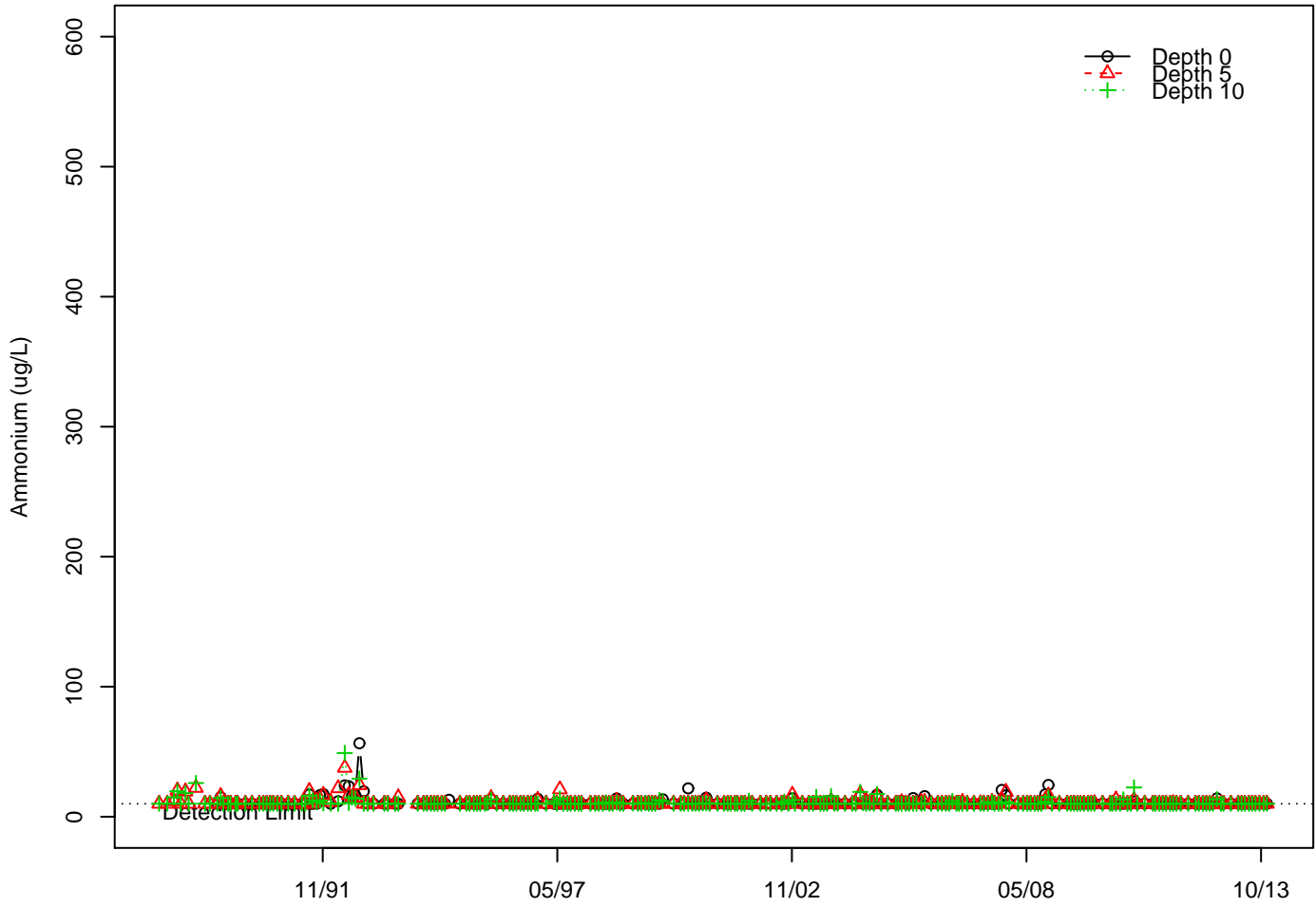


Figure B83: Lake Whatcom ammonium data for the Intake site.

Lake Whatcom ammonium data for Site 3, February 1988 through December 2013.

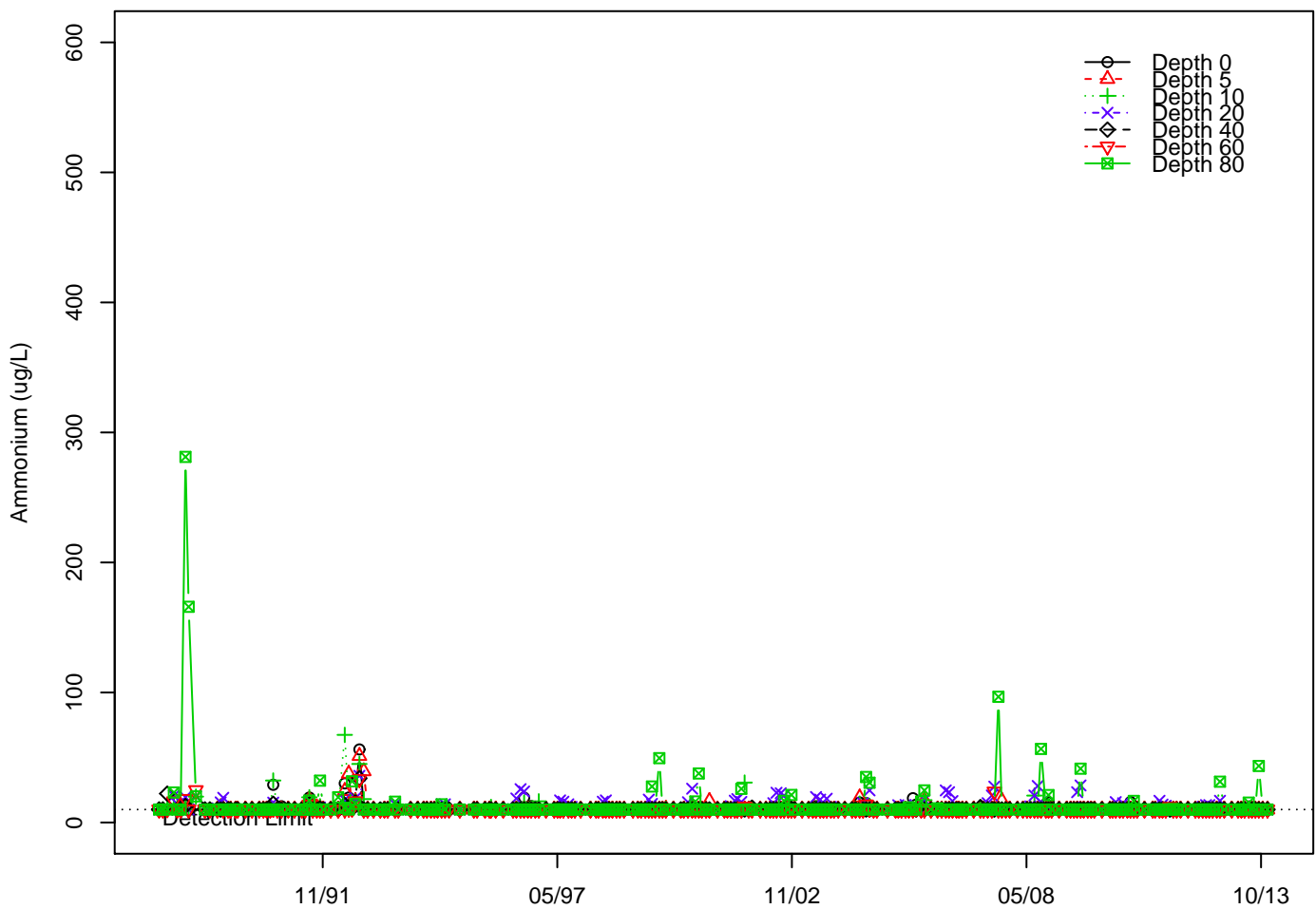


Figure B84: Lake Whatcom ammonium data for Site 3.

Lake Whatcom ammonium data for Site 4, February 1988 through December 2013.

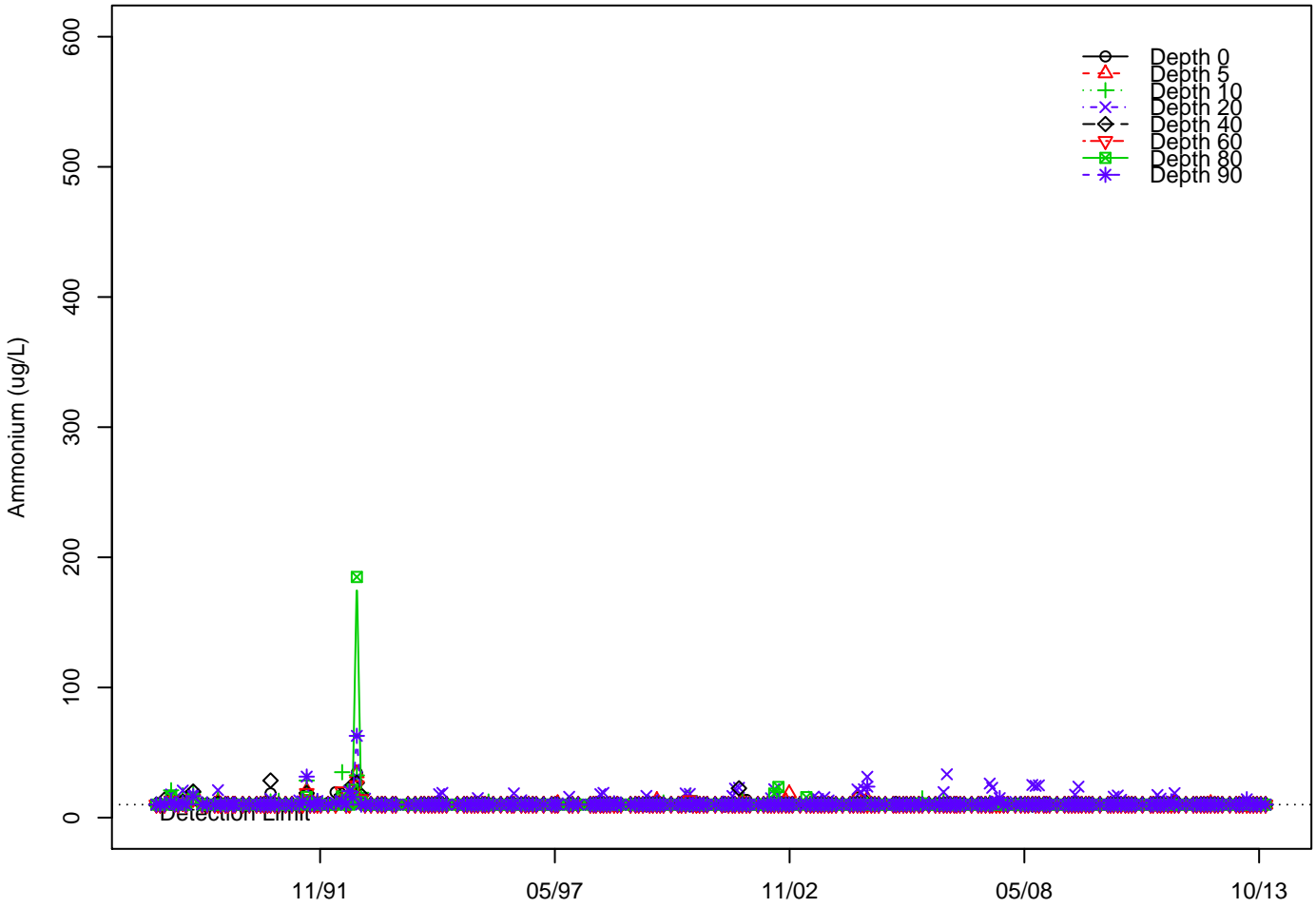


Figure B85: Lake Whatcom ammonium data for Site 4.

Lake Whatcom nitrate/nitrite data for Site 1, February 1988 through December 2013.

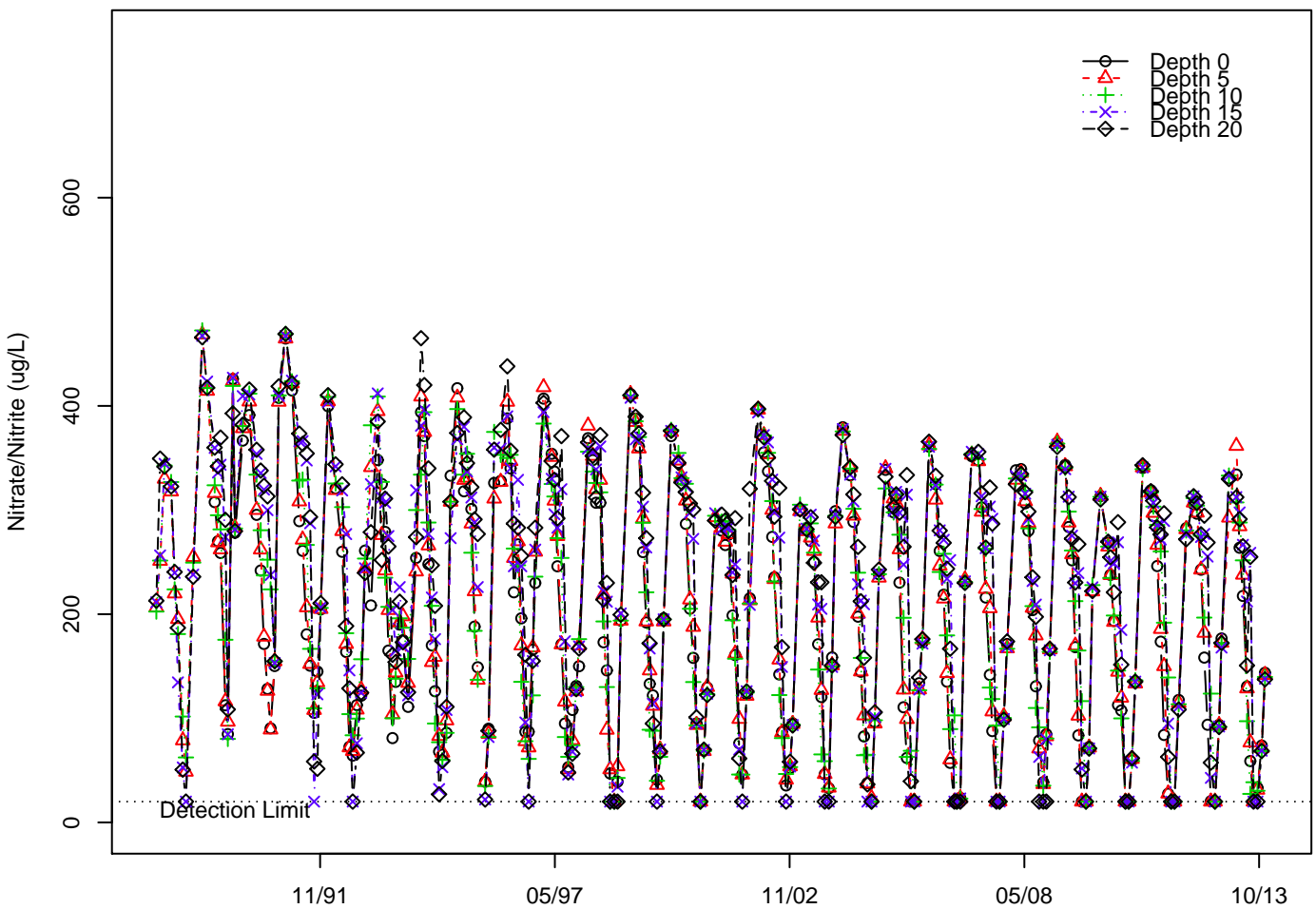


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.



Lake Whatcom nitrate/nitrite data for Site 2, February 1988 through December 2013.

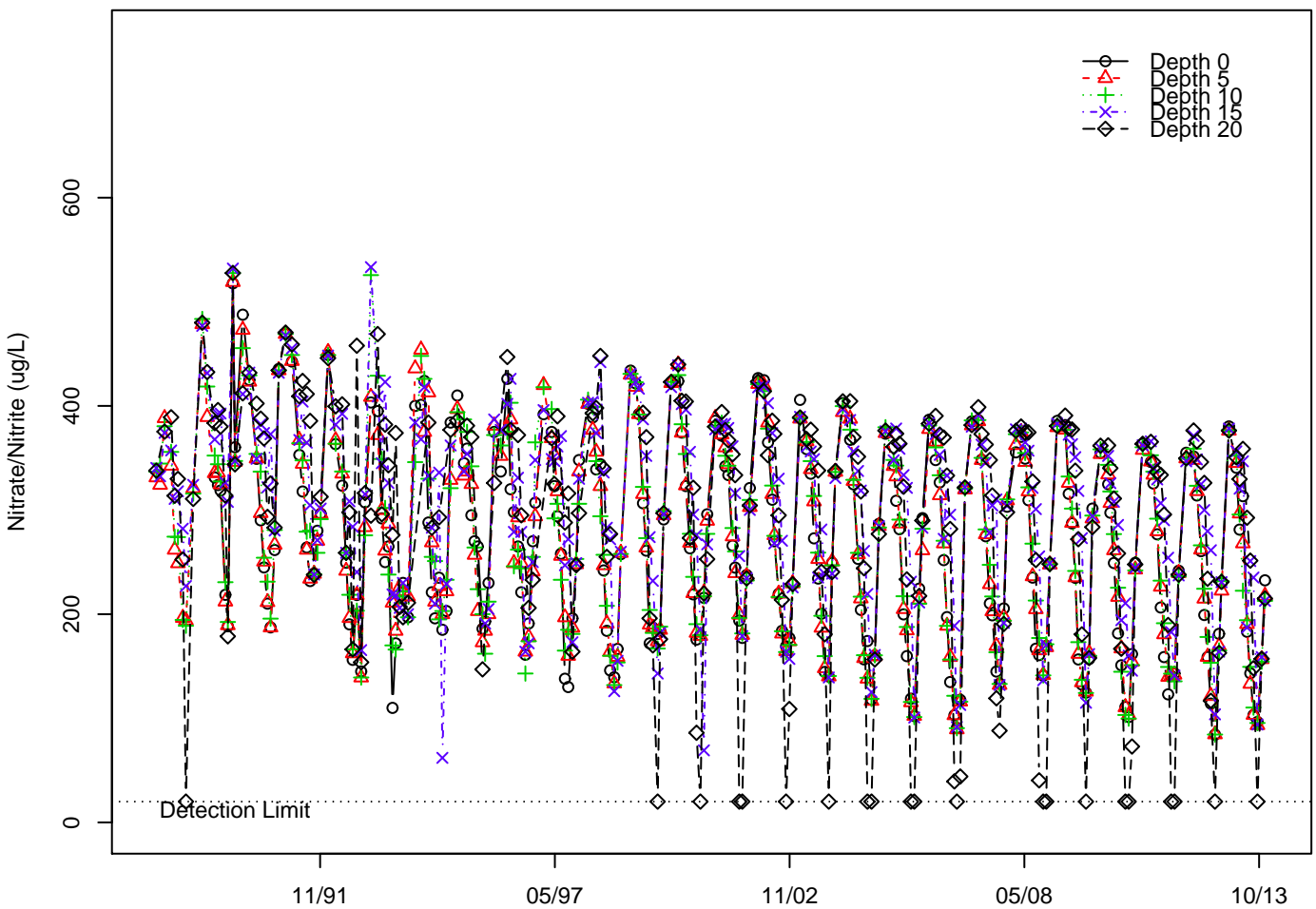


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

Lake Whatcom nitrate/nitrite data for Intake, February 1988 through December 2013.

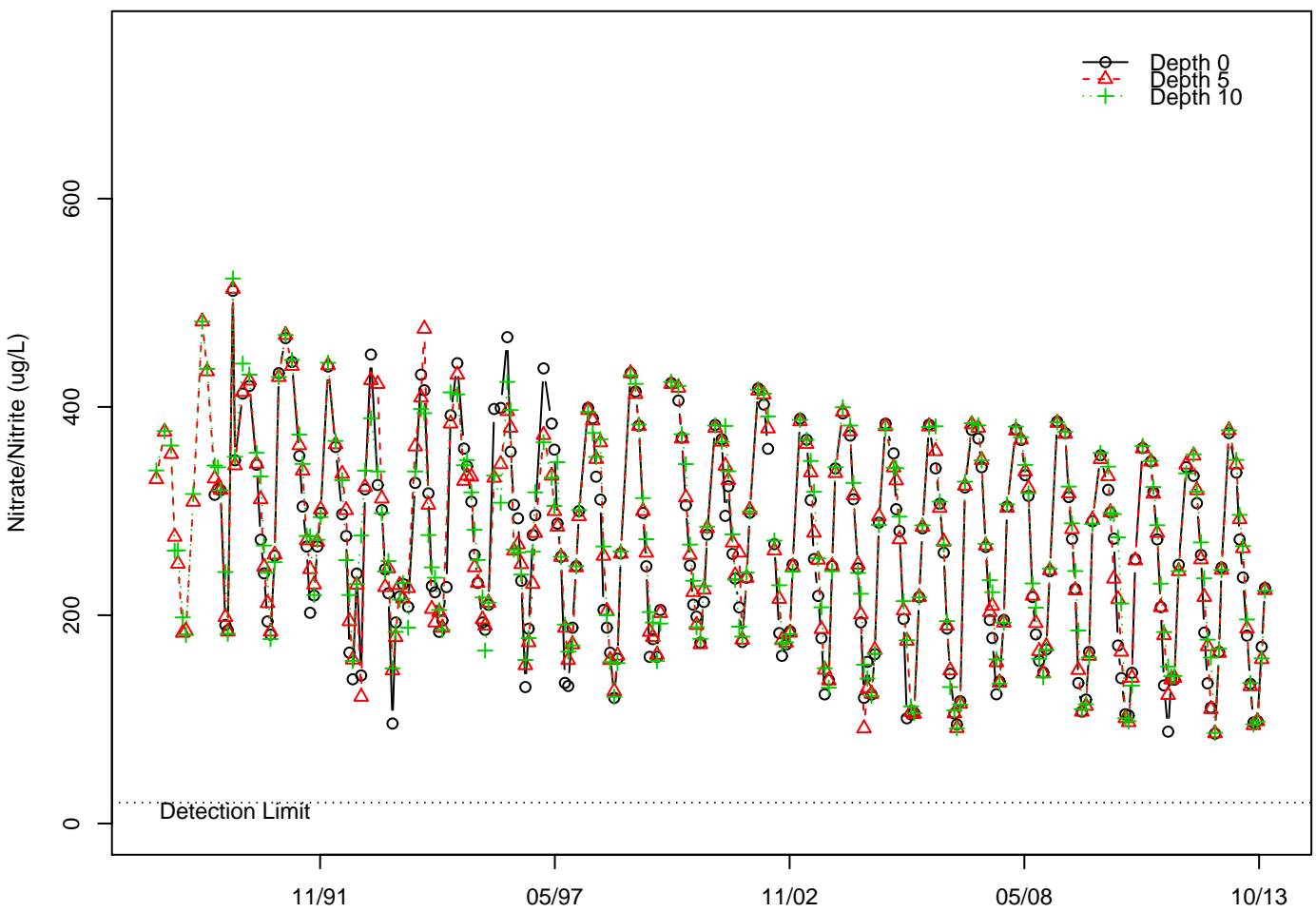


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

Lake Whatcom nitrate/nitrite data for Site 3, February 1988 through December 2013.

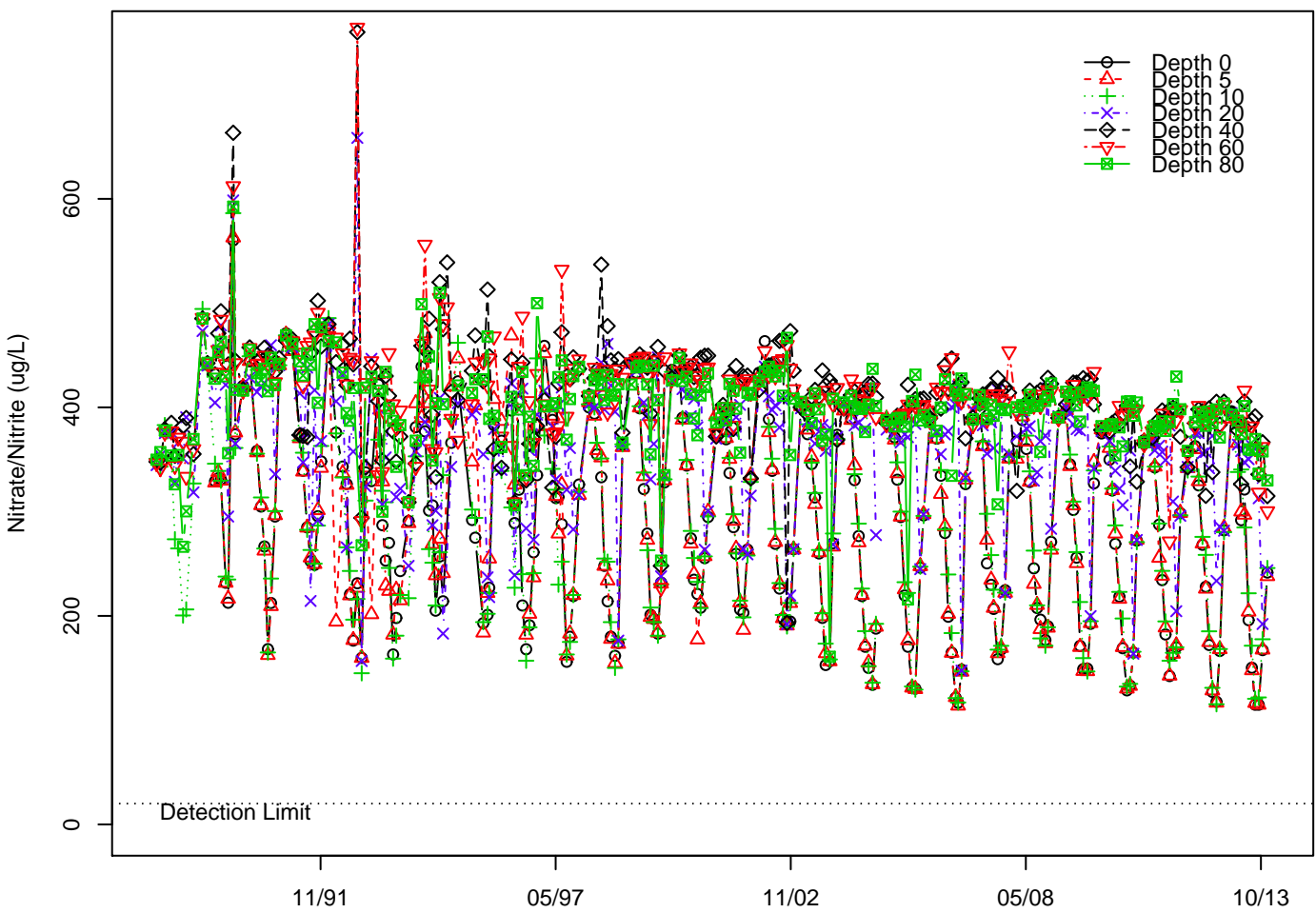


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

Lake Whatcom nitrate/nitrite data for Site 4, February 1988 through December 2013.

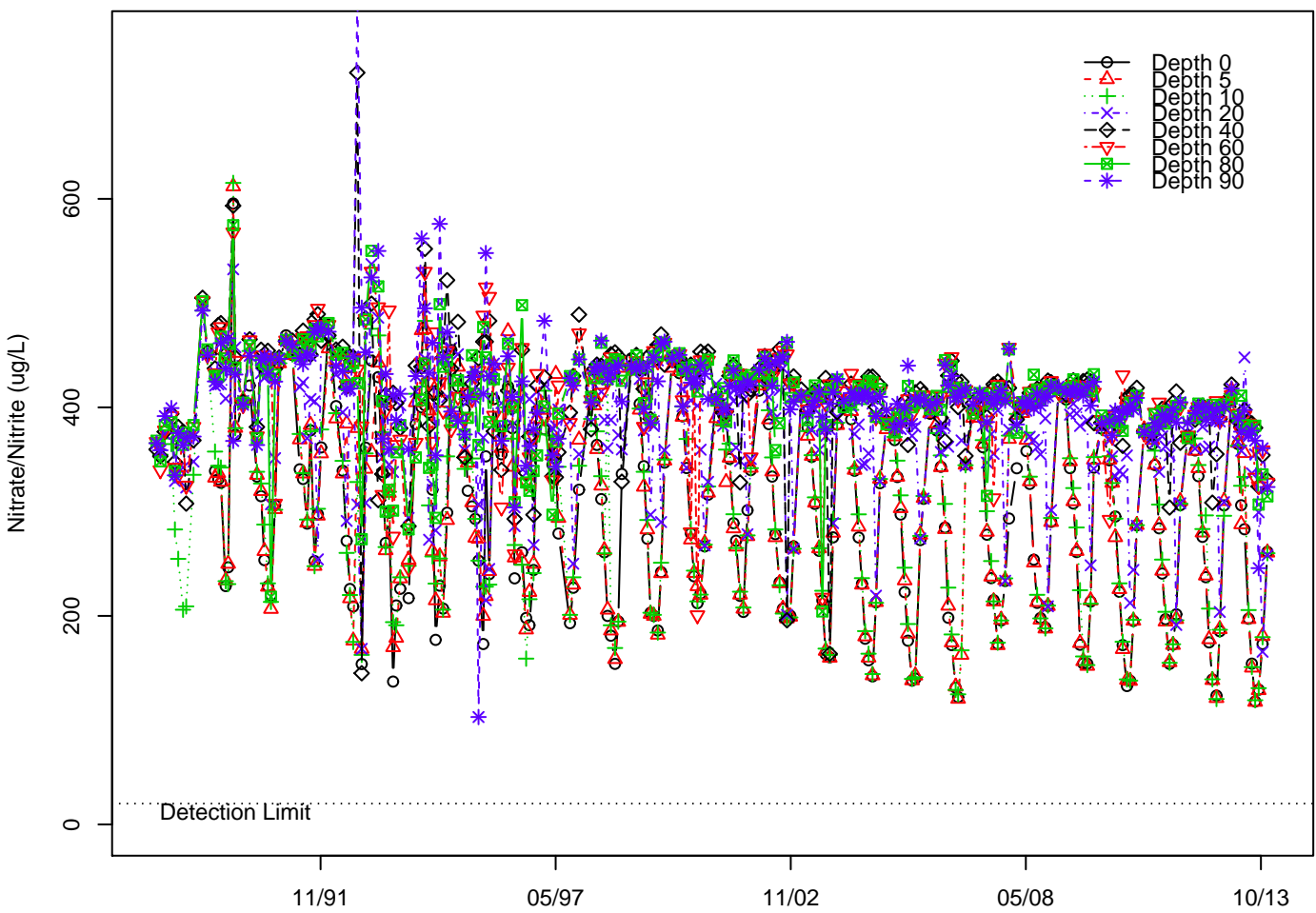


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4.

Lake Whatcom total nitrogen data for Site 1, February 1988 through December 2013.

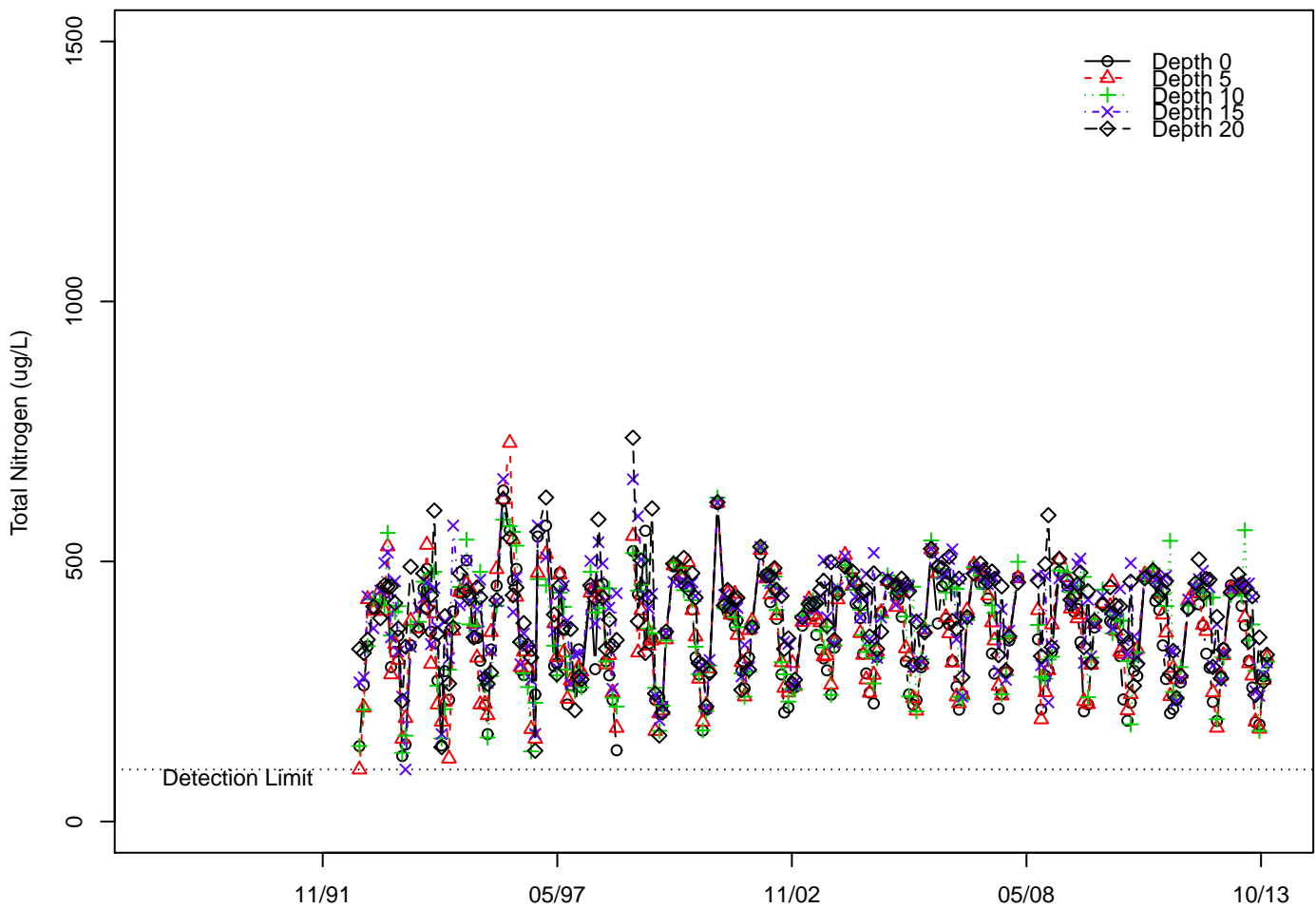


Figure B91: Lake Whatcom total nitrogen data for Site 1.

Lake Whatcom total nitrogen data for Site 2, February 1988 through December 2013.

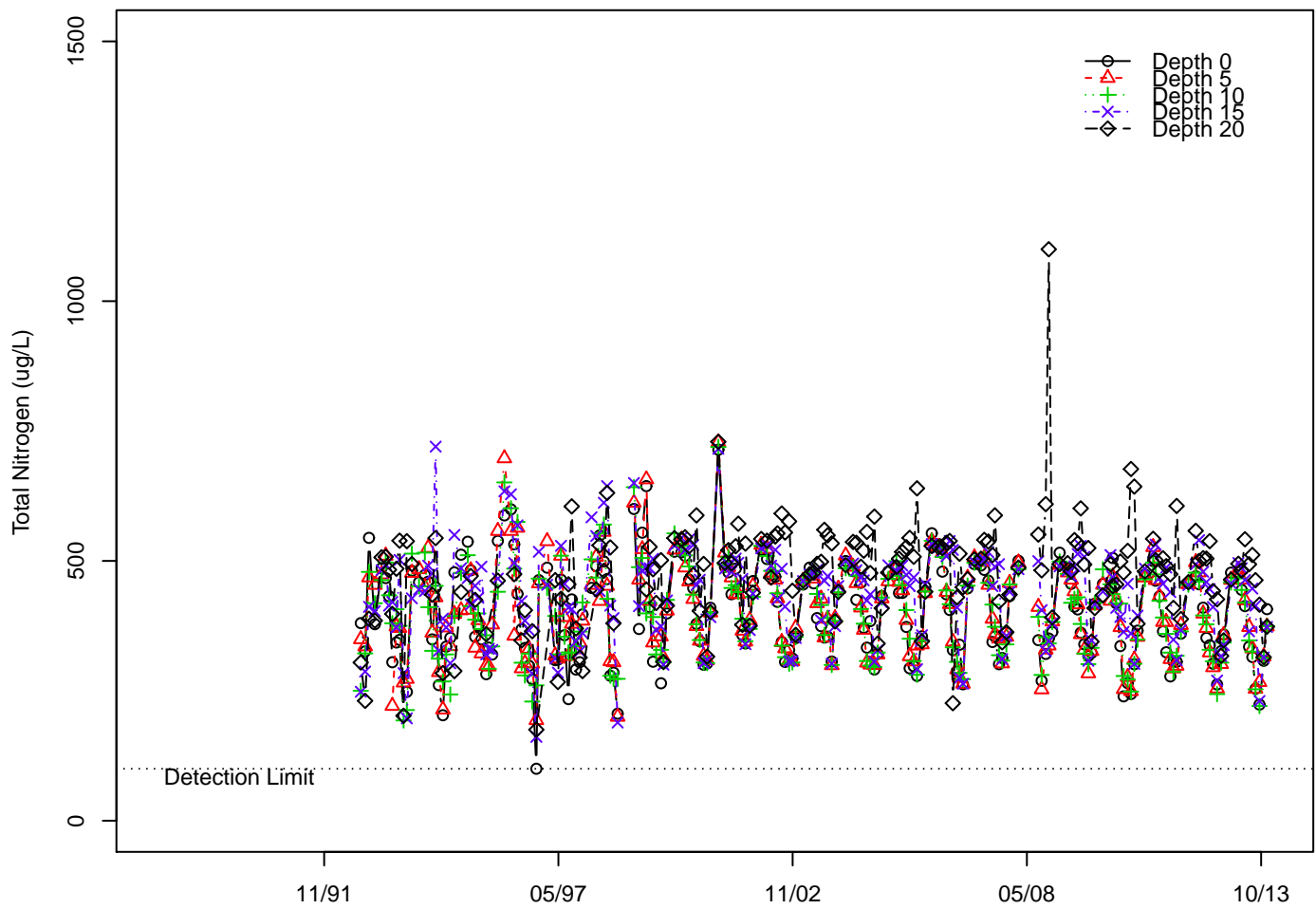


Figure B92: Lake Whatcom total nitrogen data for Site 2.

Lake Whatcom total nitrogen data for Intake, February 1988 through December 2013.

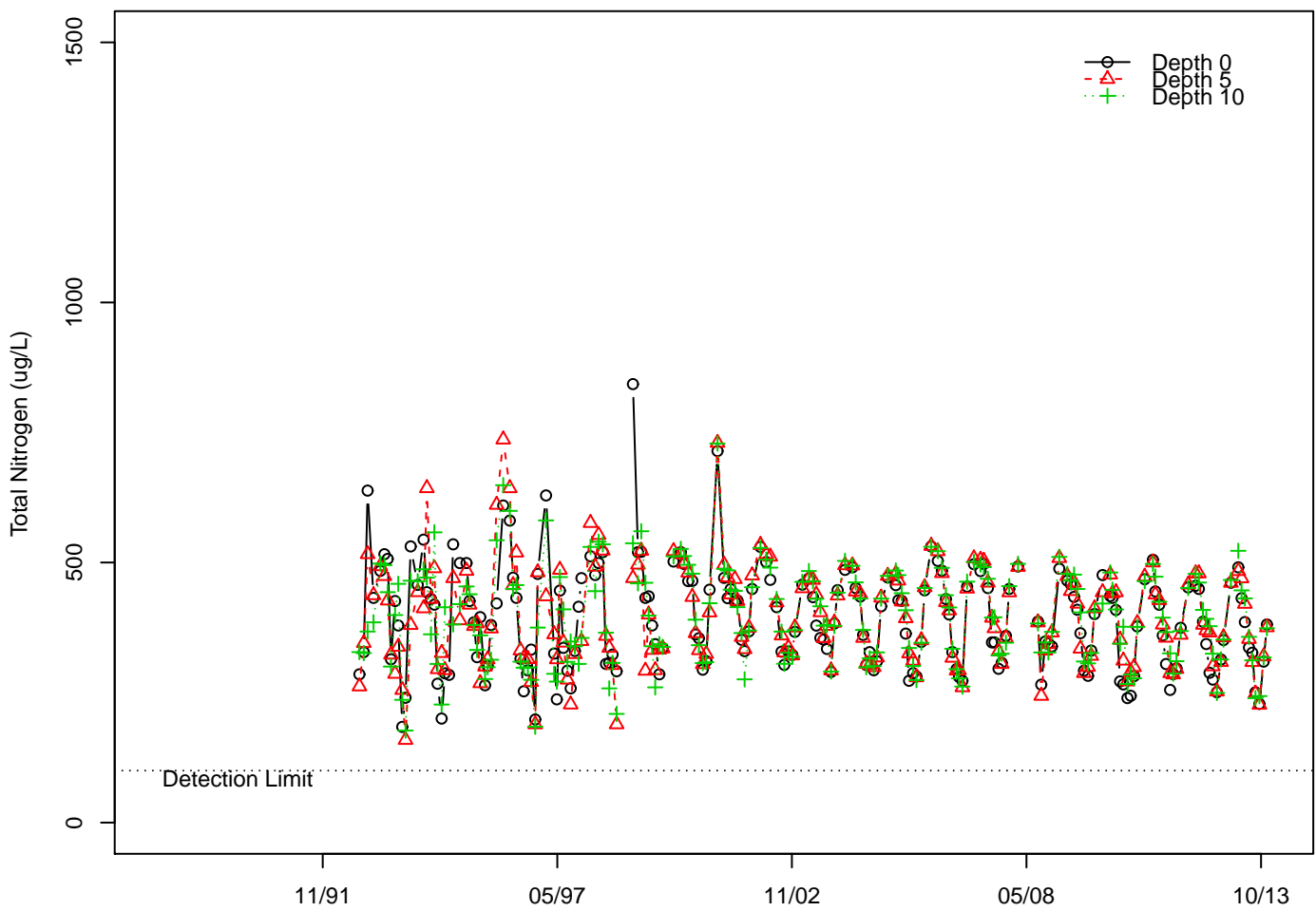


Figure B93: Lake Whatcom total nitrogen data for the Intake site.

Lake Whatcom total nitrogen data for Site 3, February 1988 through December 2013.

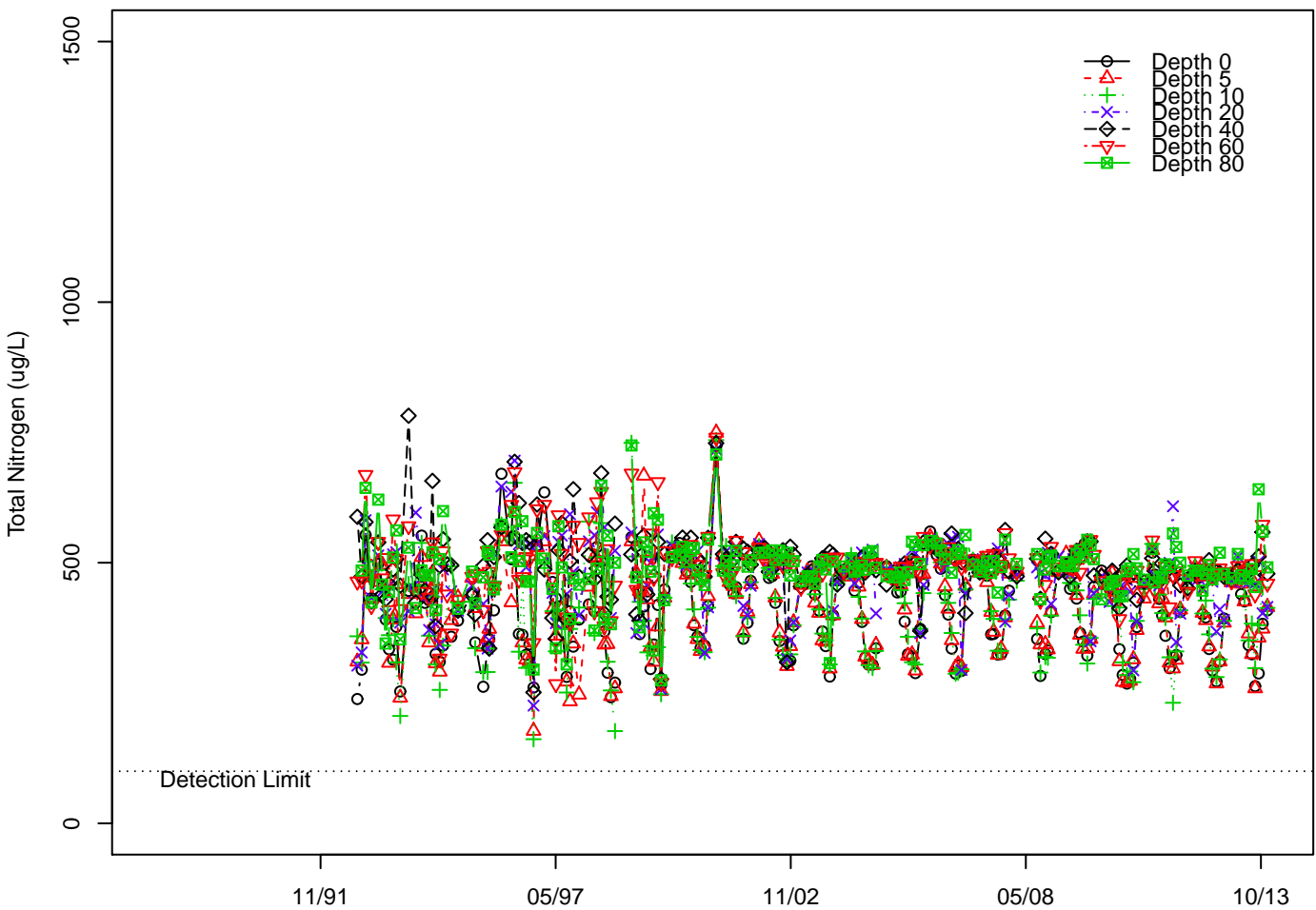


Figure B94: Lake Whatcom total nitrogen data for Site 3.



Lake Whatcom total nitrogen data for Site 4, February 1988 through December 2013.

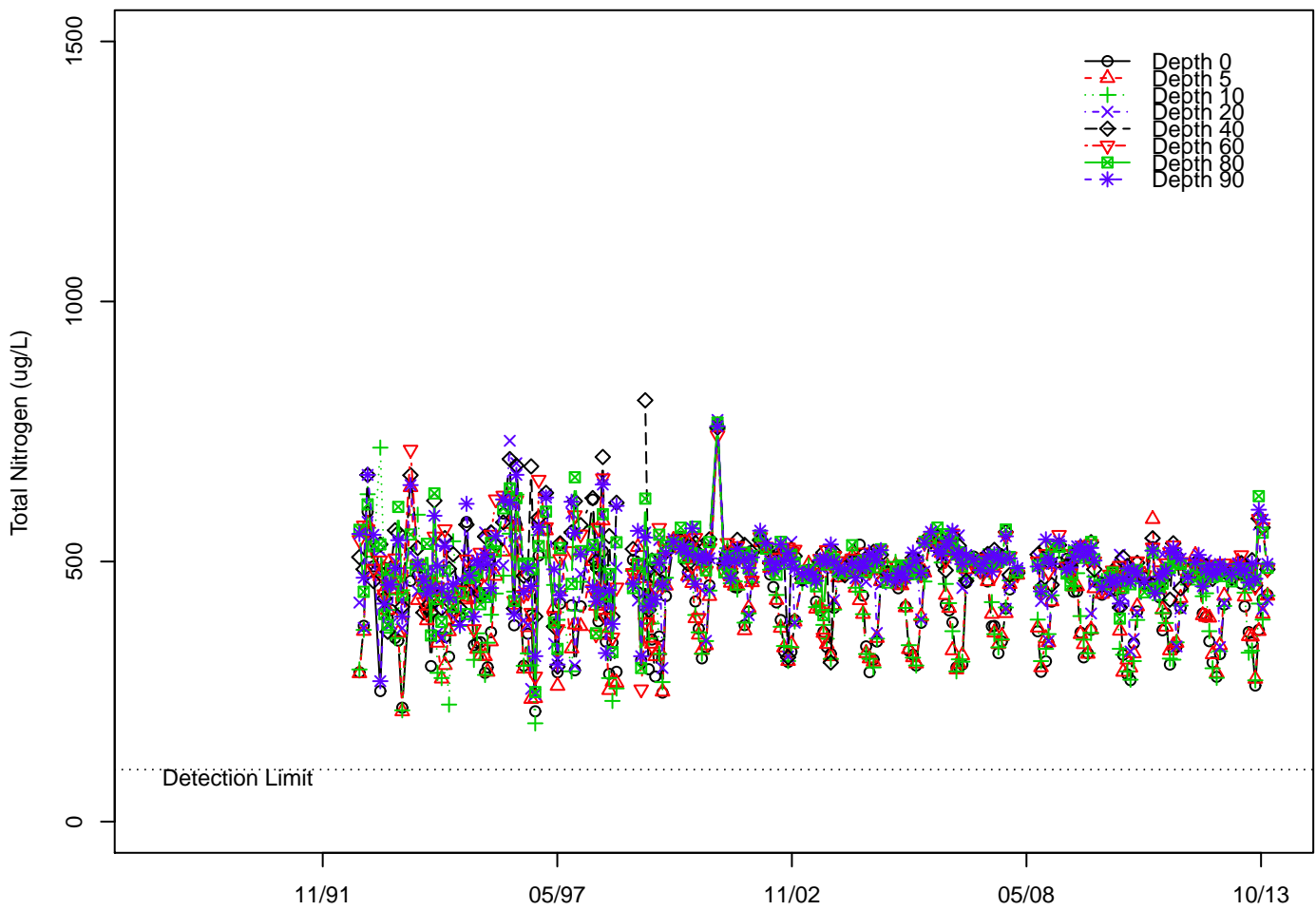


Figure B95: Lake Whatcom total nitrogen data for Site 4.

Lake Whatcom soluble reactive phosphate data for Site 1, February 1988 through December 2013.

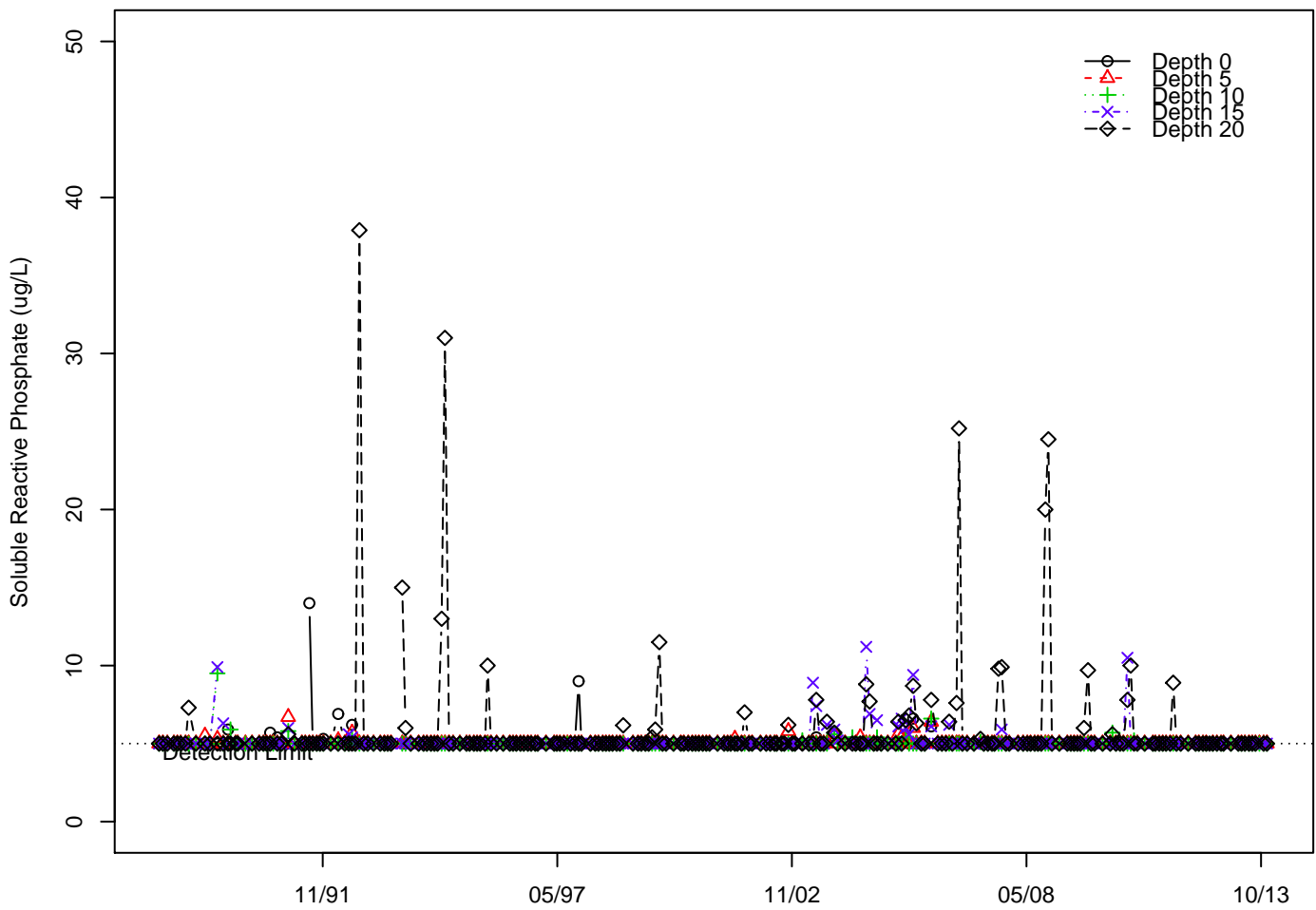


Figure B96: Lake Whatcom soluble phosphate data for Site 1.

Lake Whatcom soluble reactive phosphate data for Site 2, February 1988 through December 2013.

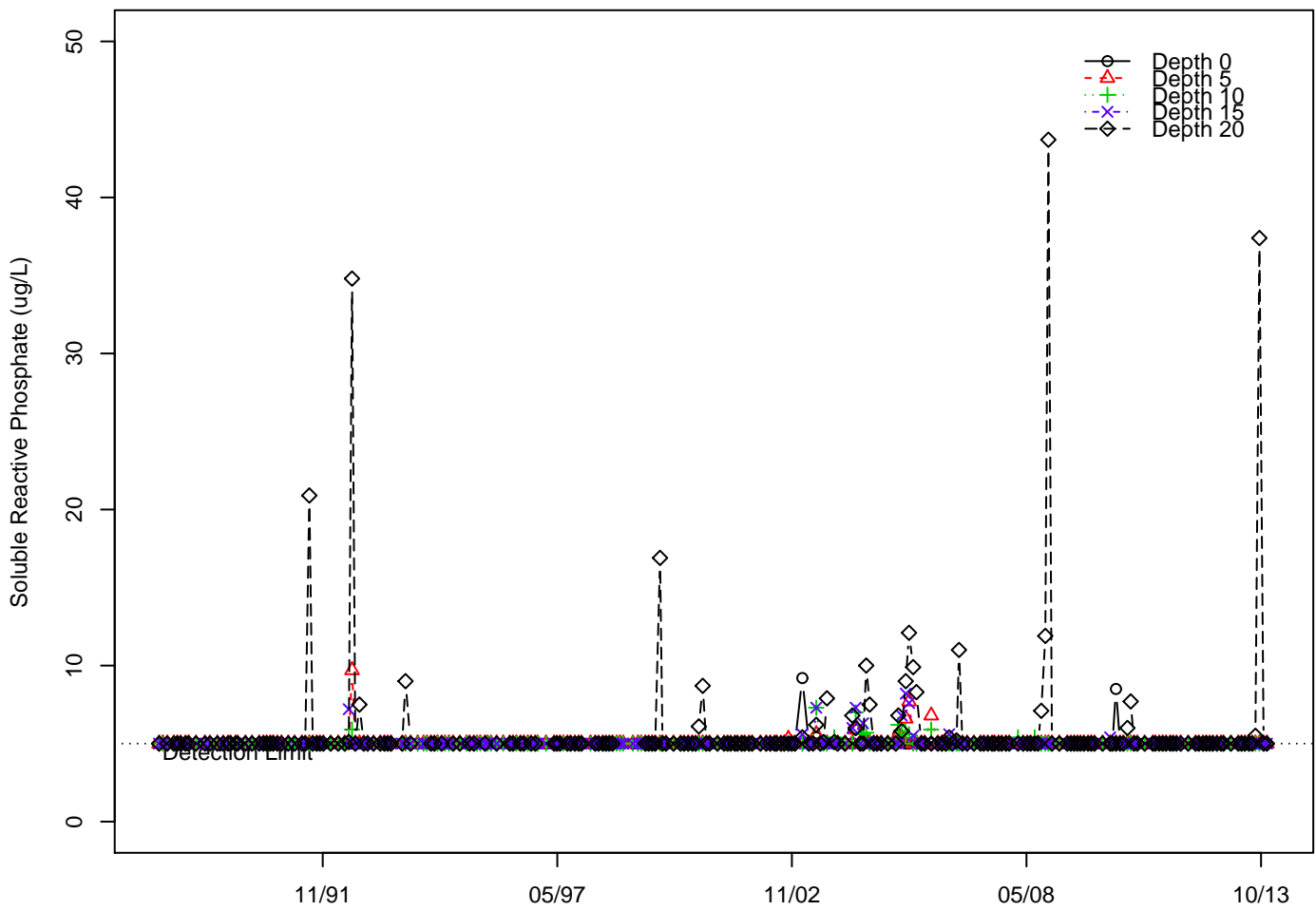


Figure B97: Lake Whatcom soluble phosphate data for Site 2.

Lake Whatcom soluble reactive phosphate data for Intake, February 1988 through December 2013.

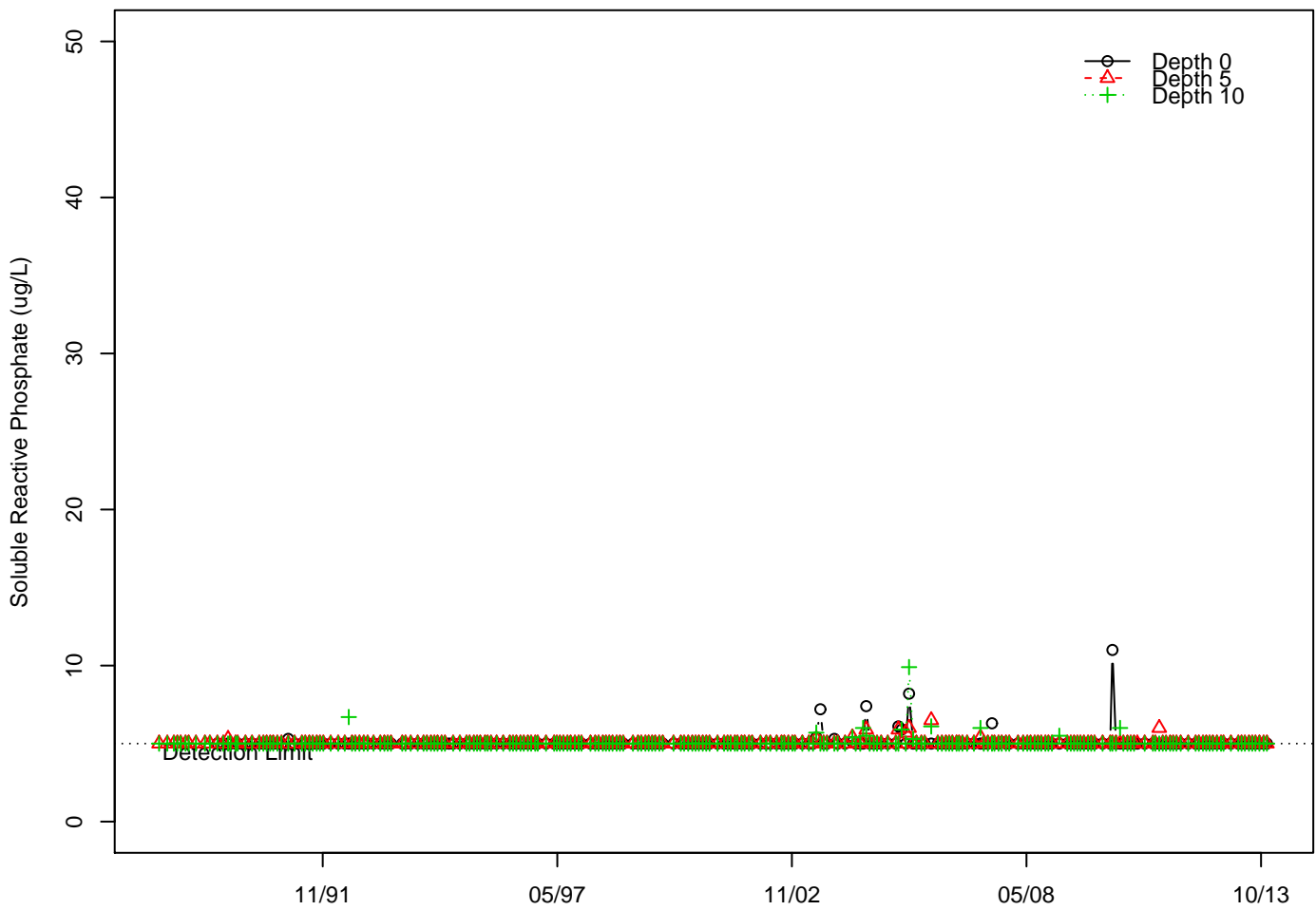


Figure B98: Lake Whatcom soluble phosphate data for the Intake site.

Lake Whatcom soluble reactive phosphate data for Site 3, February 1988 through December 2013.

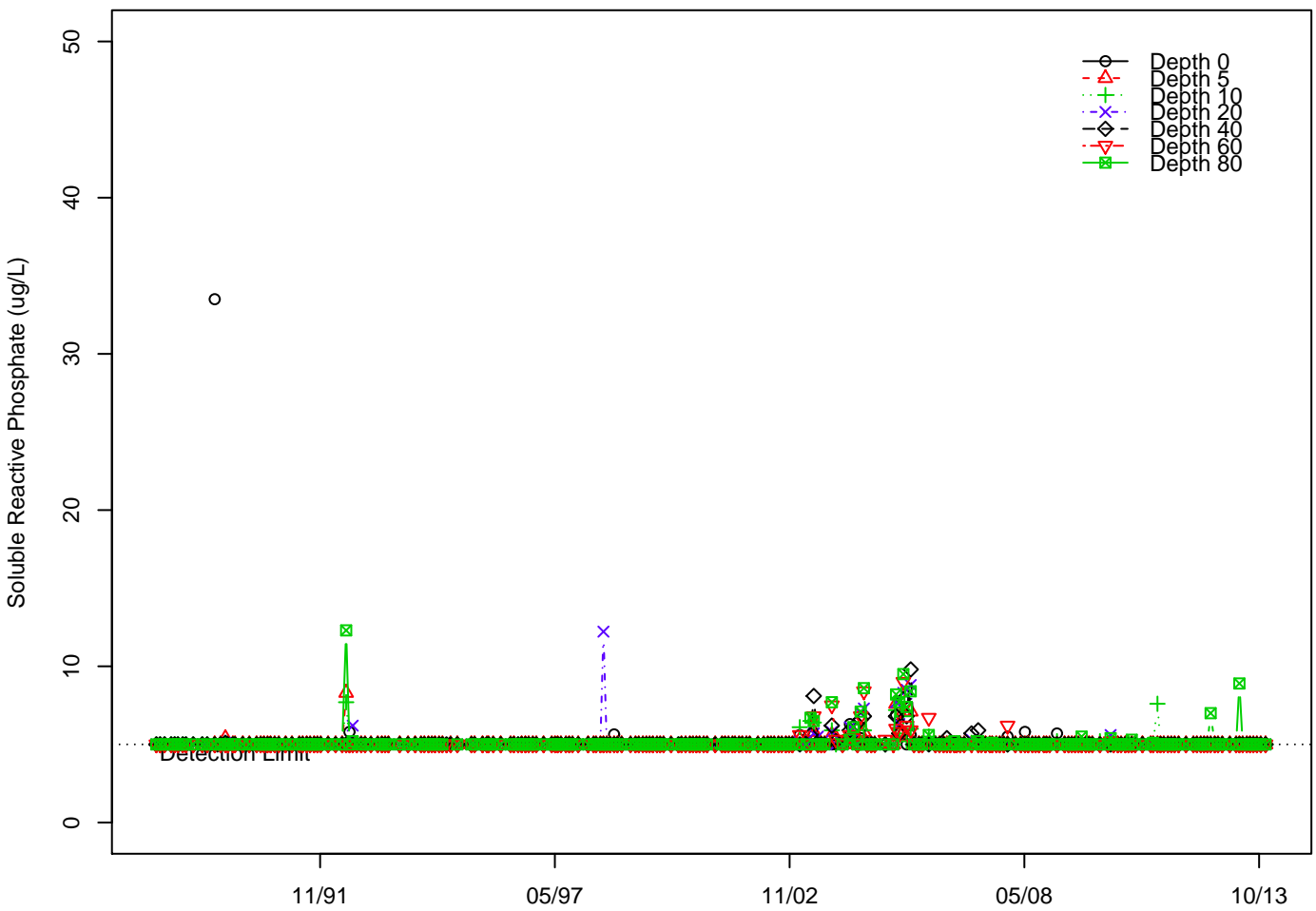


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

Lake Whatcom soluble reactive phosphate data for Site 4, February 1988 through December 2013.

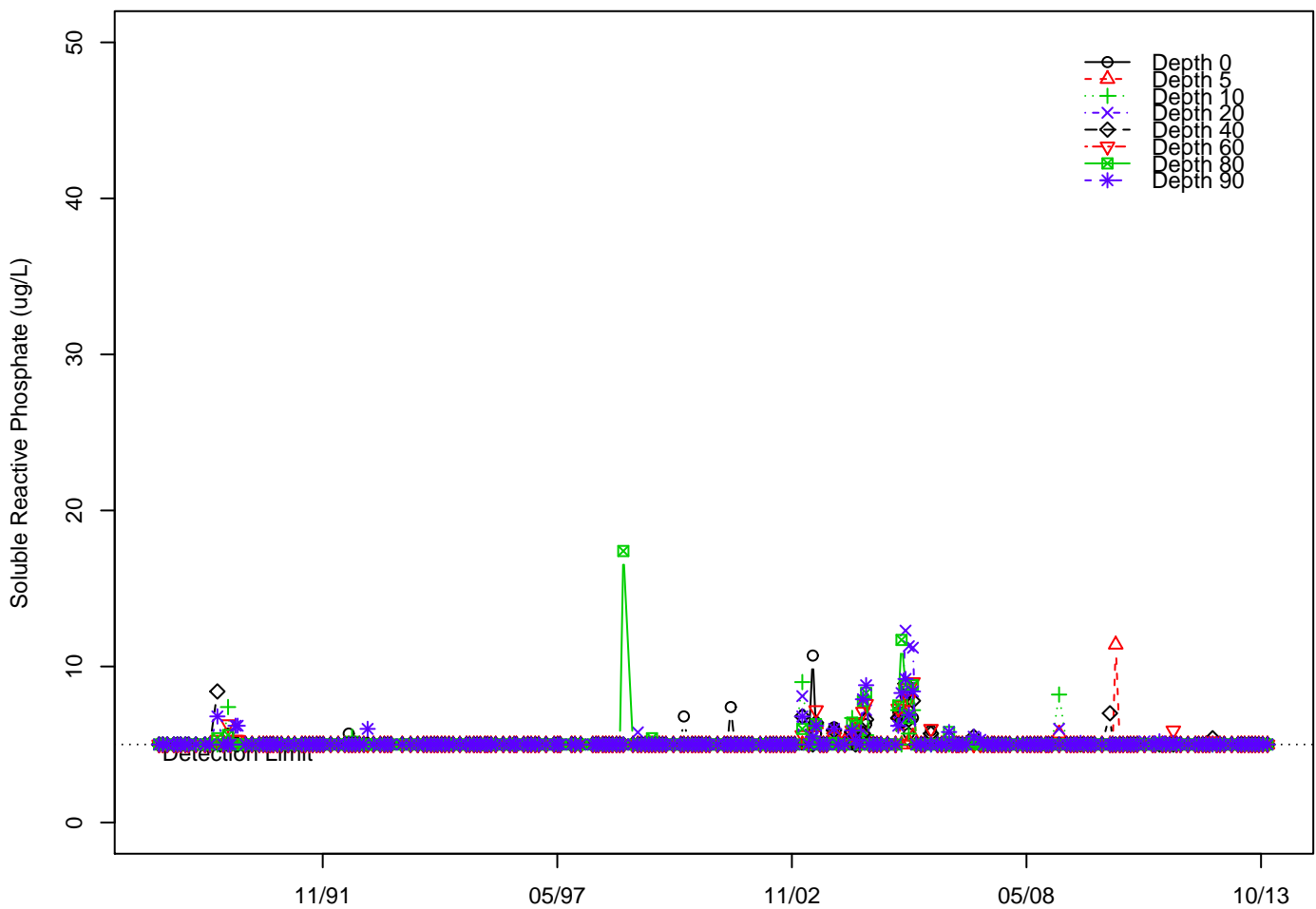


Figure B100: Lake Whatcom soluble phosphate data for Site 4.

Lake Whatcom total phosphorus data for Site 1, February 1988 through December 2013.

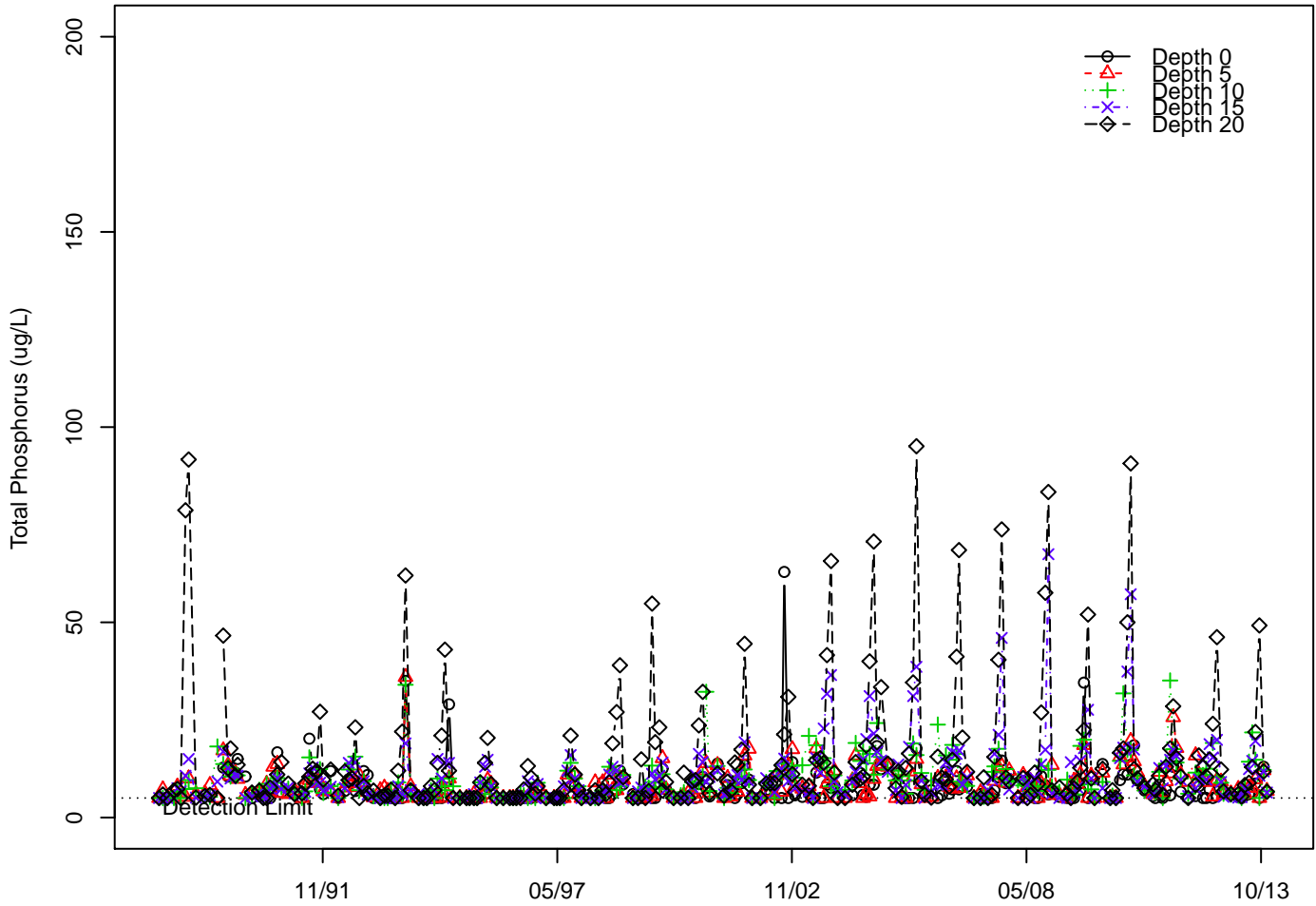


Figure B101: Lake Whatcom total phosphorus data for Site 1.

Lake Whatcom total phosphorus data for Site 2, February 1988 through December 2013.

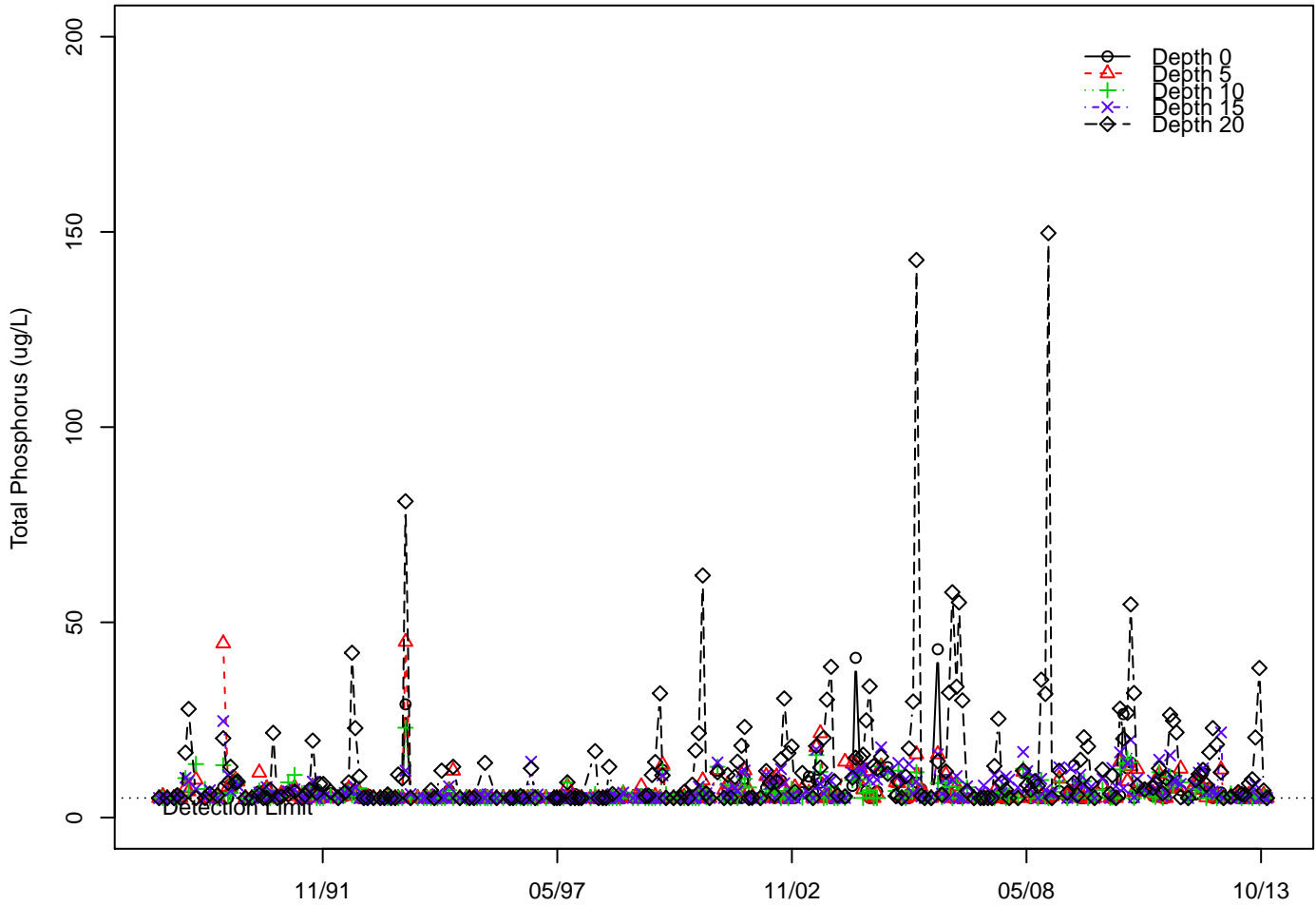


Figure B102: Lake Whatcom total phosphorus data for Site 2.



Lake Whatcom total phosphorus data for Intake, February 1988 through December 2013.

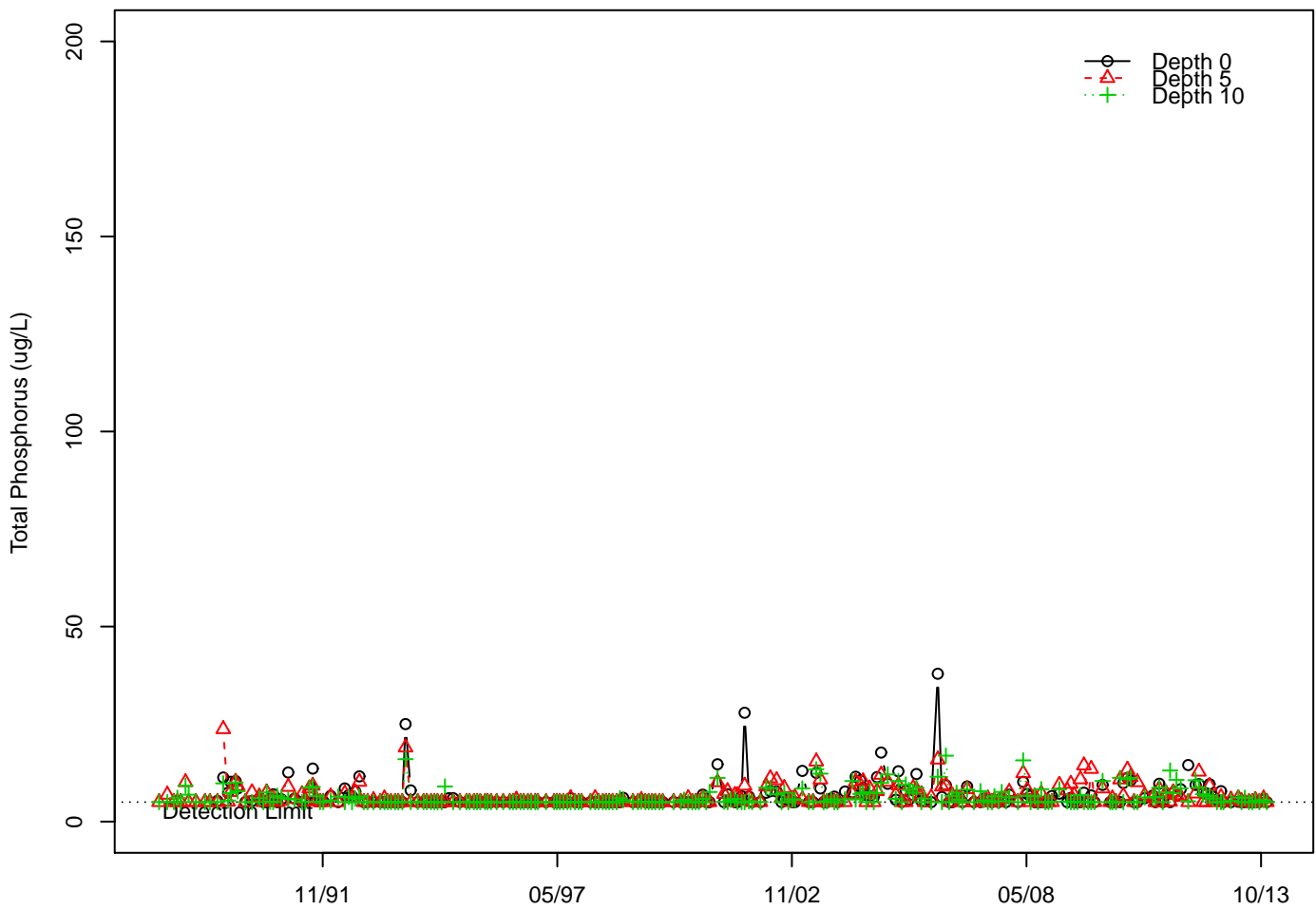


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

Lake Whatcom total phosphorus data for Site 3, February 1988 through December 2013.

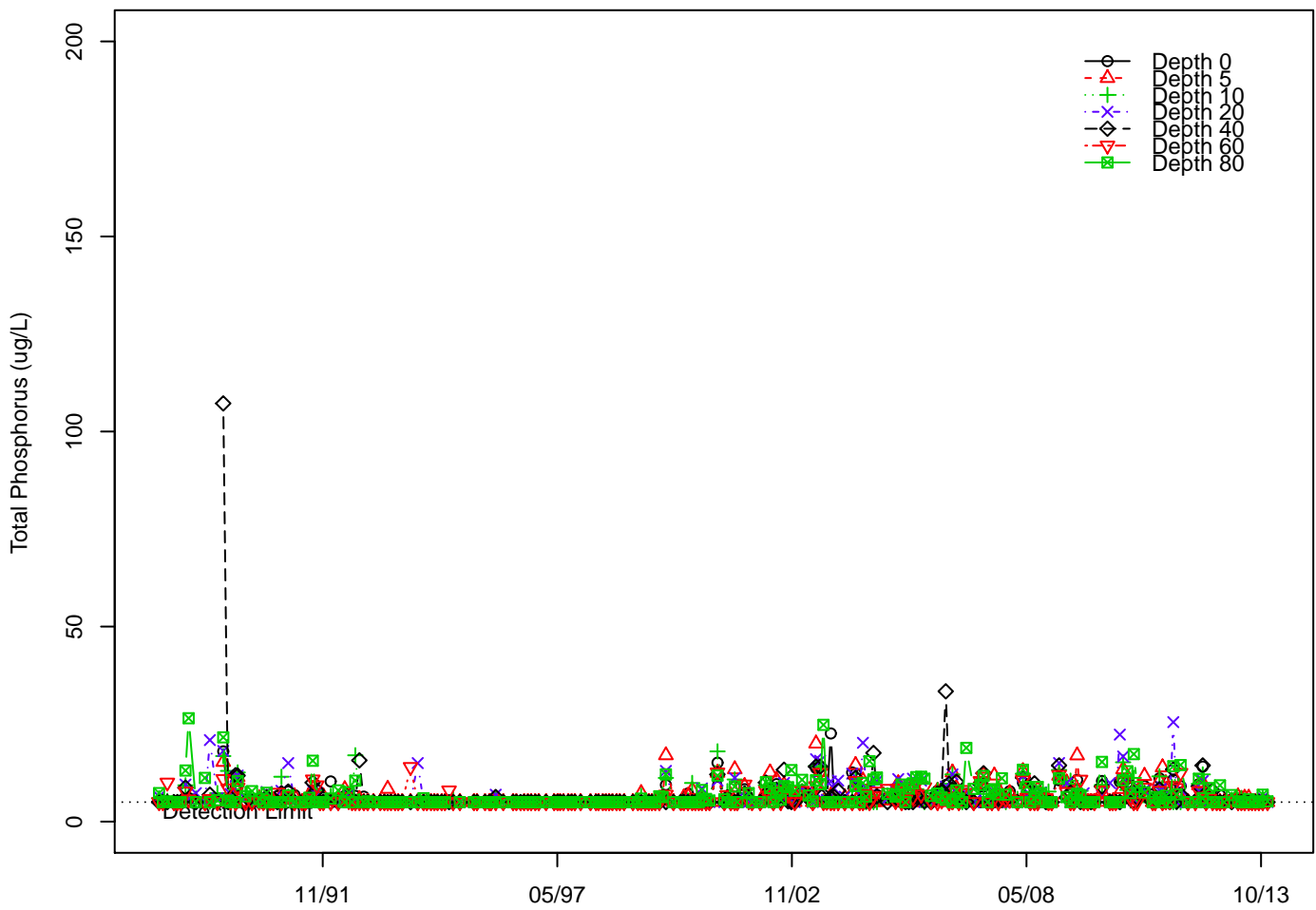


Figure B104: Lake Whatcom total phosphorus data for Site 3.

Lake Whatcom total phosphorus data for Site 4, February 1988 through December 2013.

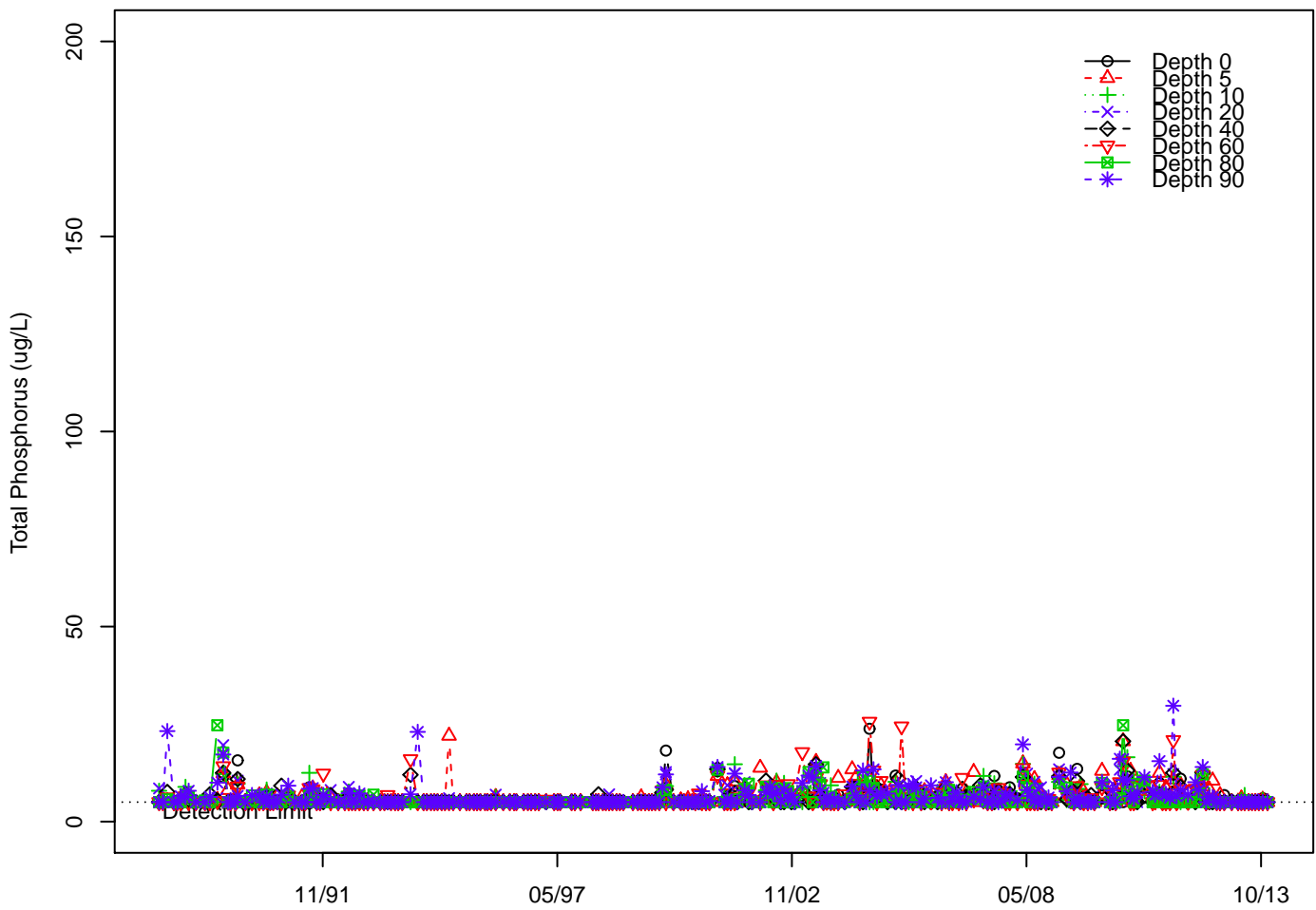


Figure B105: Lake Whatcom total phosphorus data for Site 4.

Lake Whatcom chlorophyll a data for Site 1, February 1988 through December 2013.

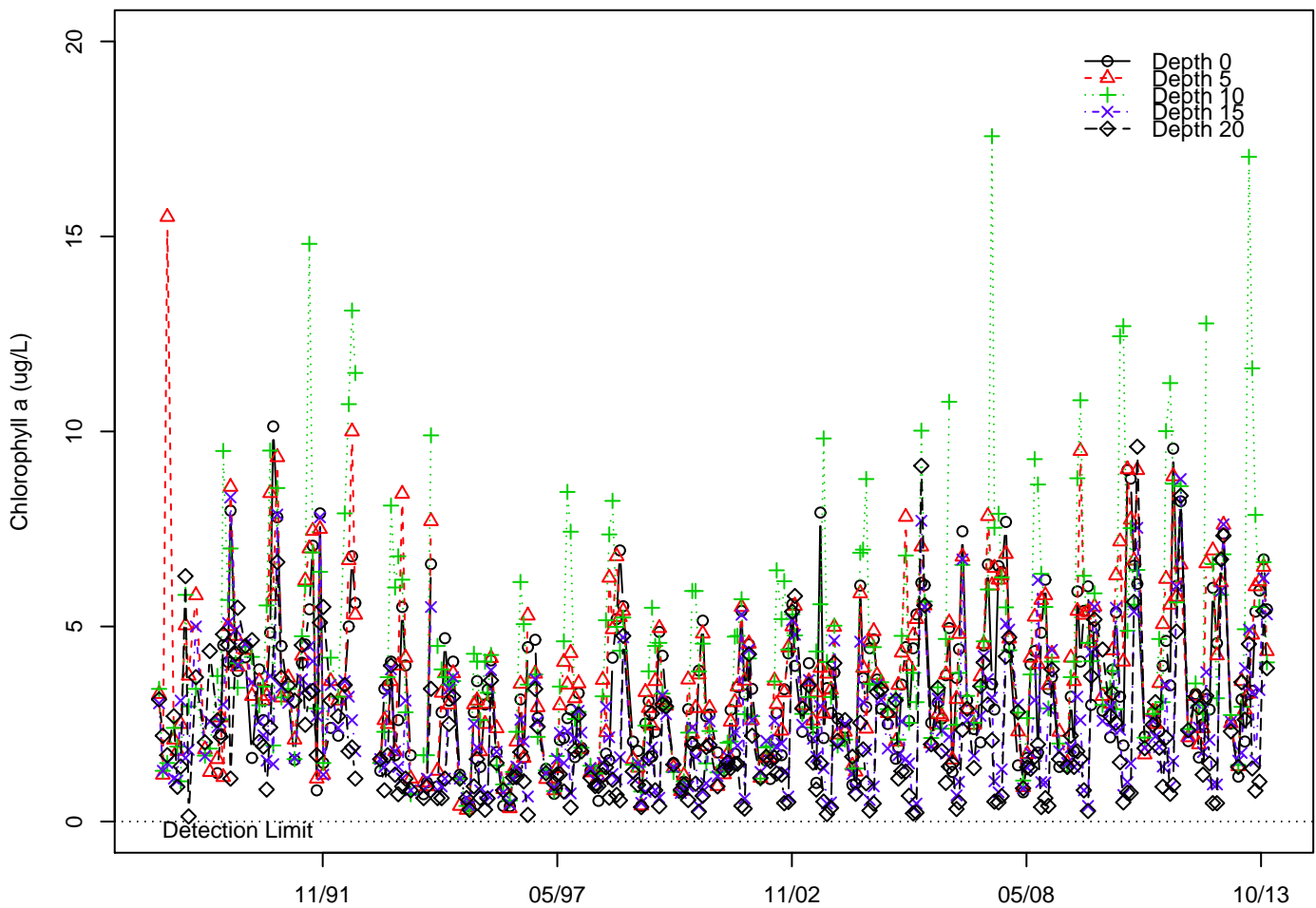


Figure B106: Lake Whatcom chlorophyll a data for Site 1.

Lake Whatcom chlorophyll a data for Site 2, February 1988 through December 2013.

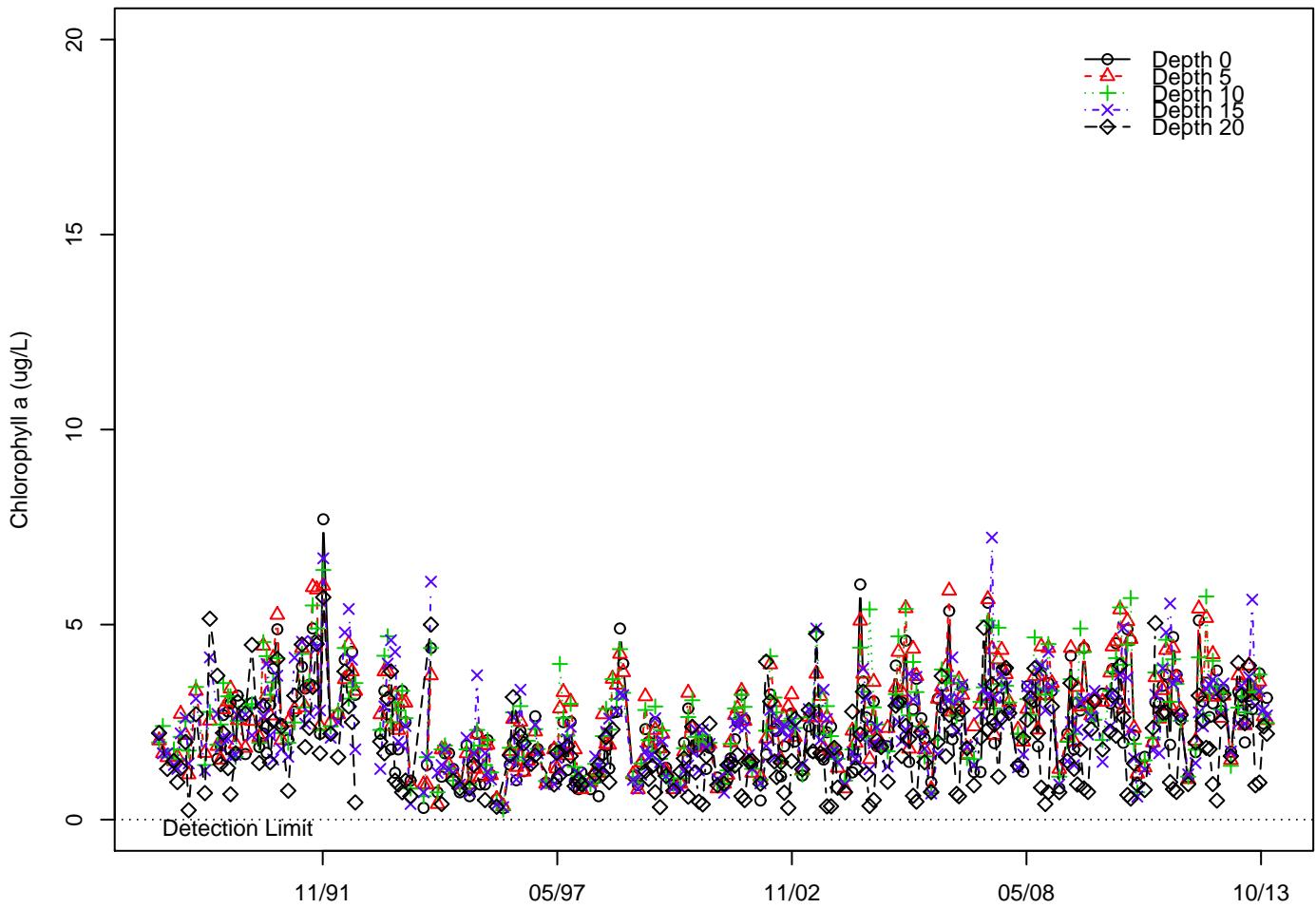


Figure B107: Lake Whatcom chlorophyll data for Site 2.

Lake Whatcom chlorophyll a data for Intake, February 1988 through December 2013.

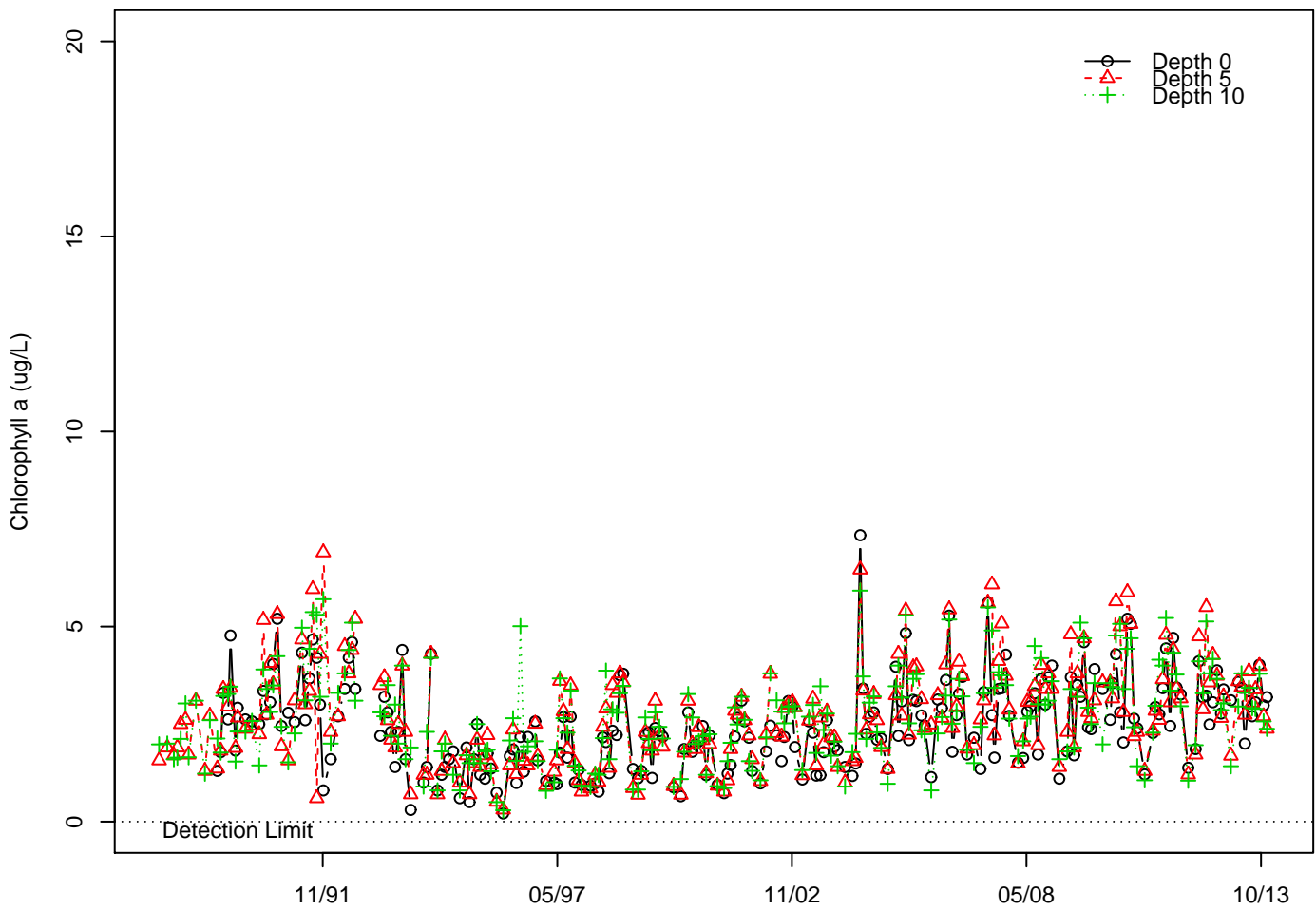


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

Lake Whatcom chlorophyll a data for Site 3, February 1988 through December 2013.

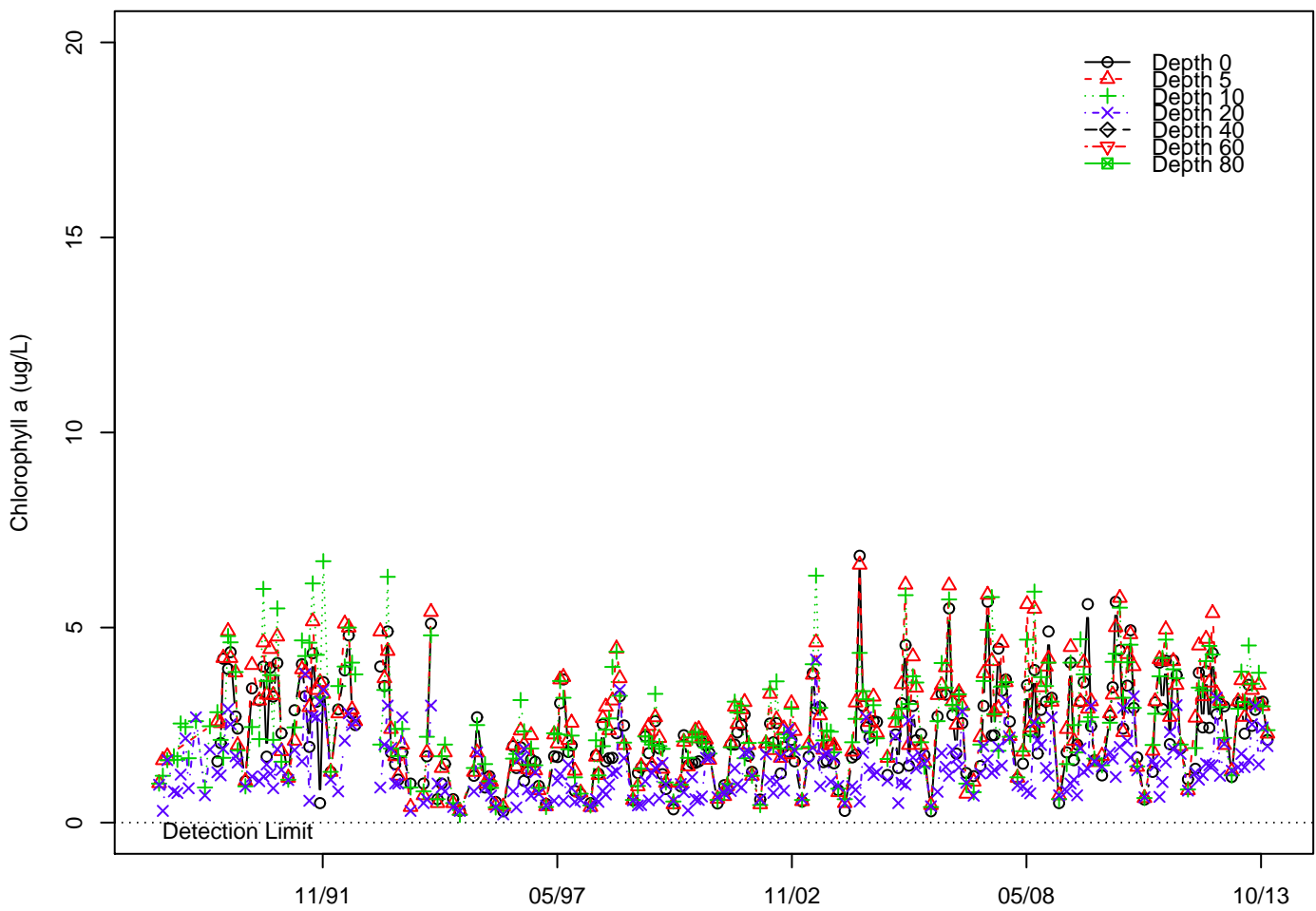


Figure B109: Lake Whatcom chlorophyll data for Site 3.

Lake Whatcom chlorophyll a data for Site 4, February 1988 through December 2013.

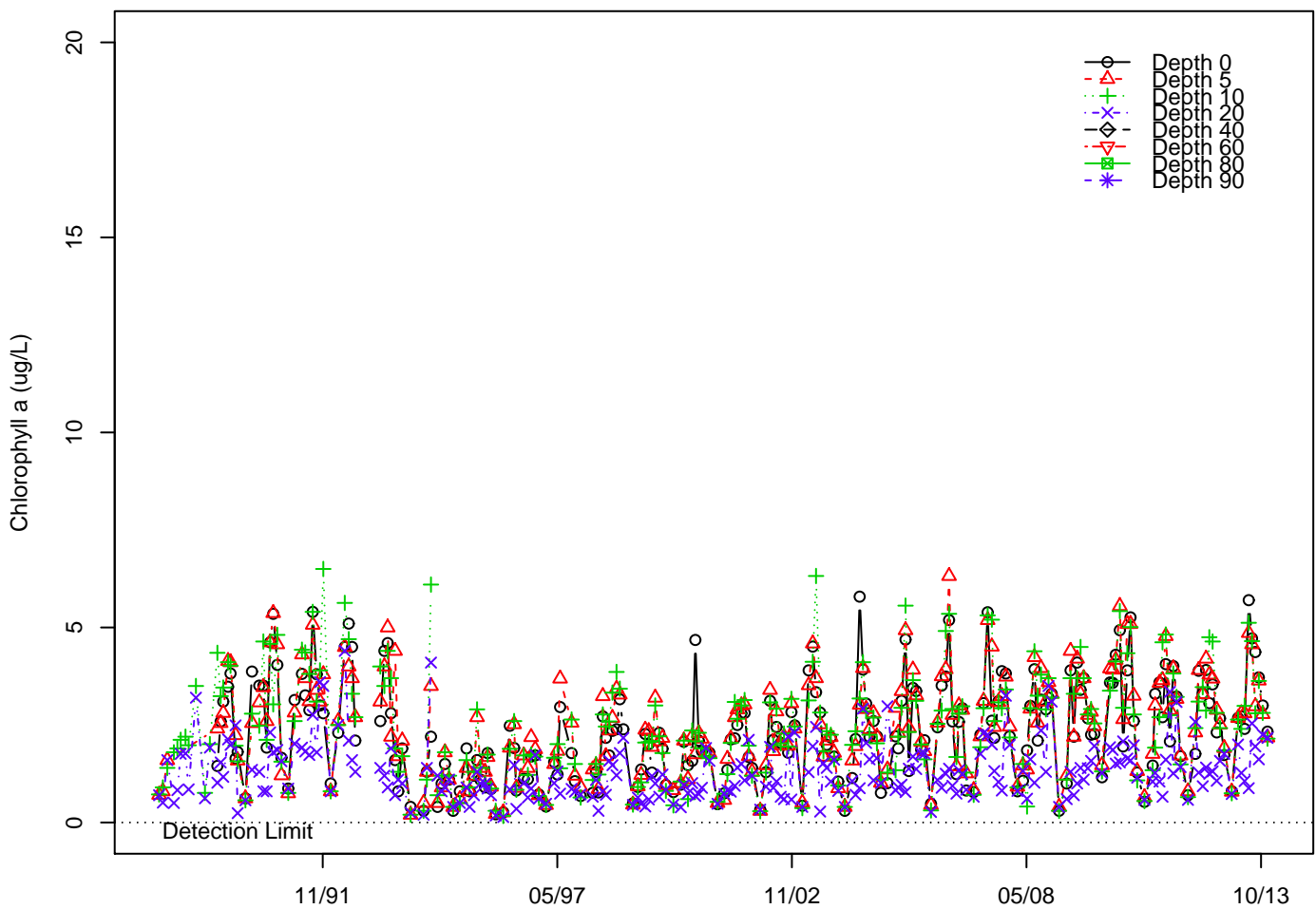


Figure B110: Lake Whatcom chlorophyll data for Site 4.



Lake Whatcom Secchi data for Site 1, February 1988 through December 2013.

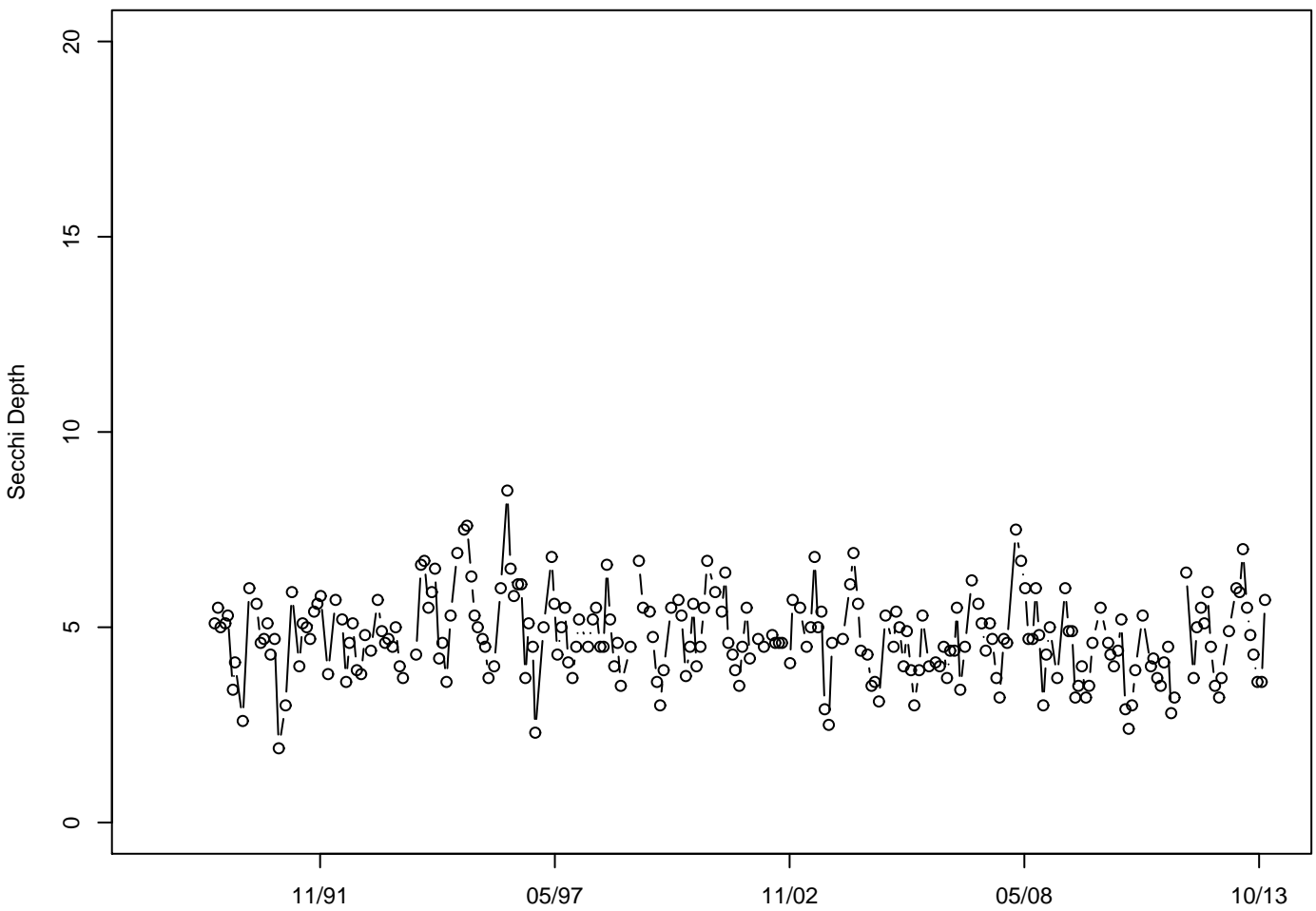


Figure B111: Lake Whatcom Secchi depths for Site 1.

Lake Whatcom Secchi data for Site 2, February 1988 through December 2013.

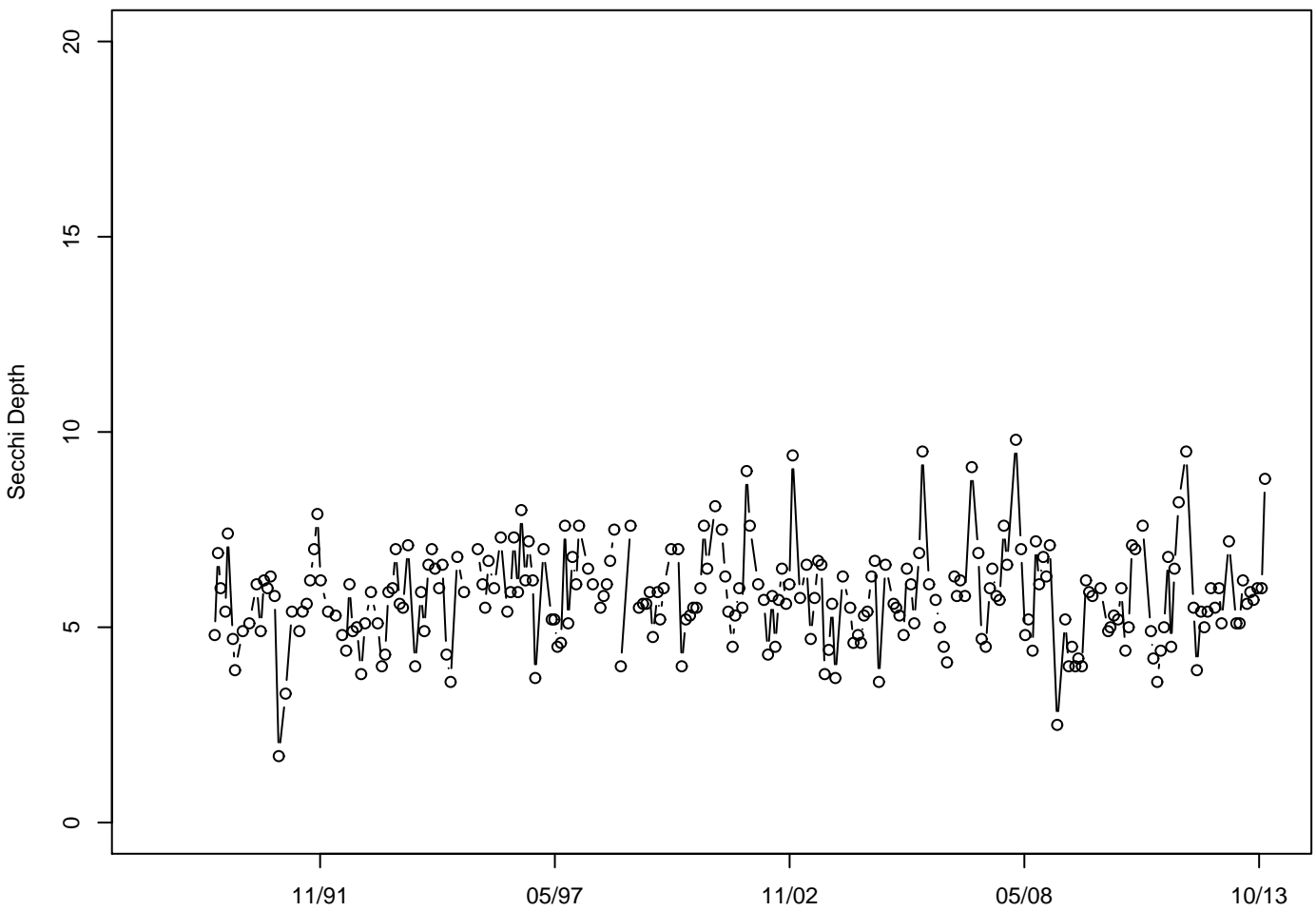


Figure B112: Lake Whatcom Secchi depths for Site 2.

Lake Whatcom Secchi data for Intake, February 1988 through December 2013.

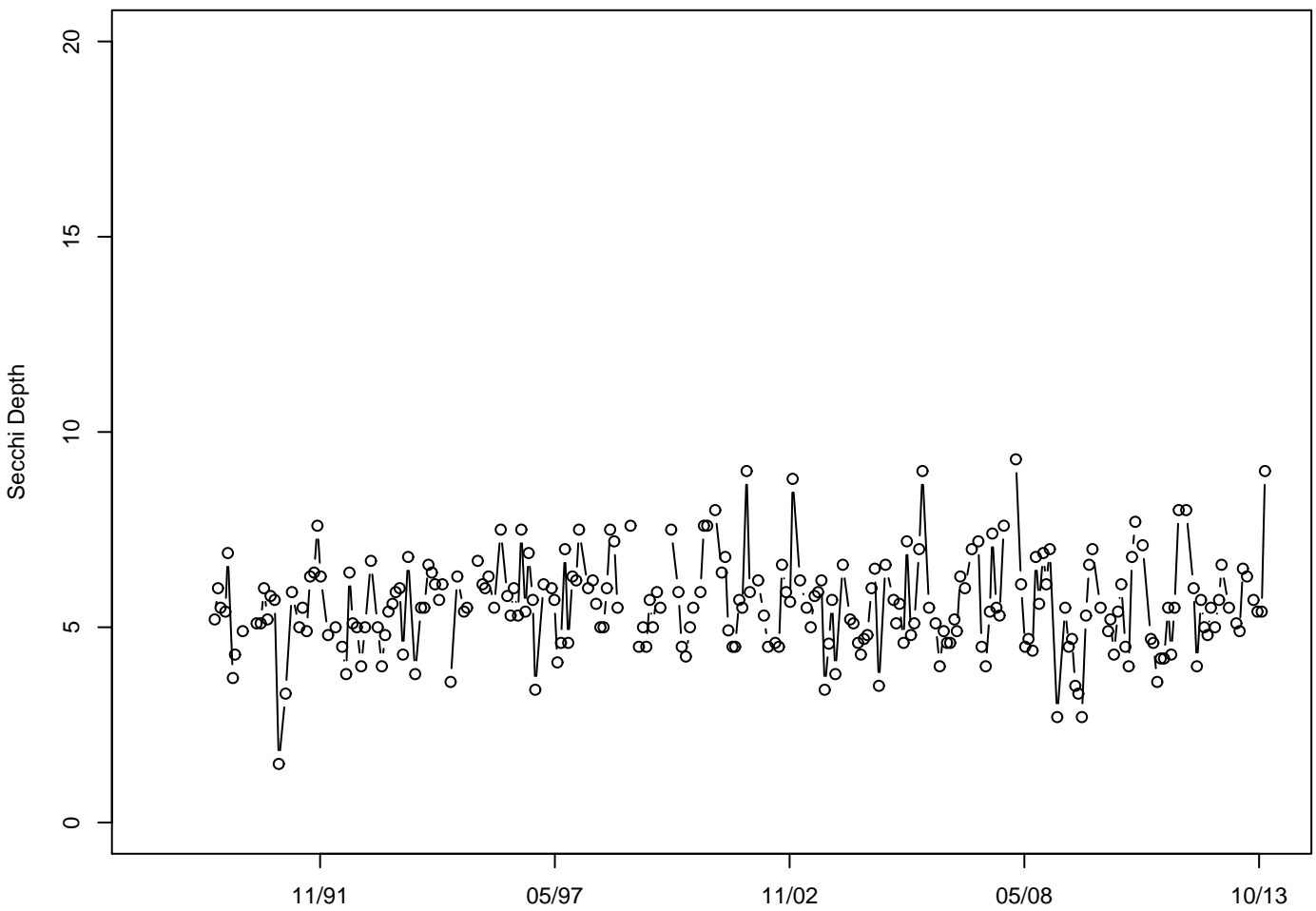


Figure B113: Lake Whatcom Secchi depths for the Intake site.

Lake Whatcom Secchi data for Site 3, February 1988 through December 2013.

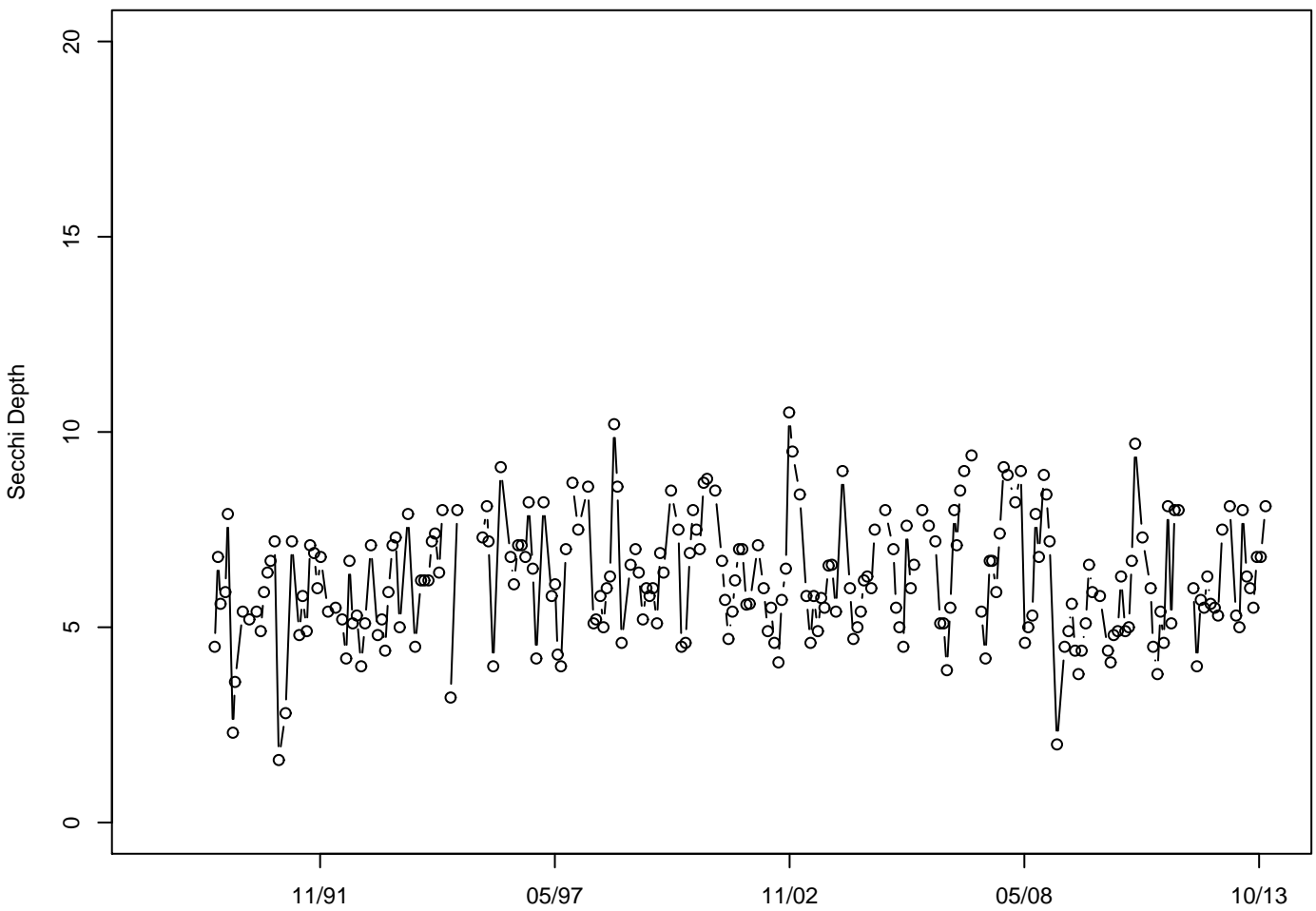


Figure B114: Lake Whatcom Secchi depths for Site 3.

Lake Whatcom Secchi data for Site 4, February 1988 through December 2013.

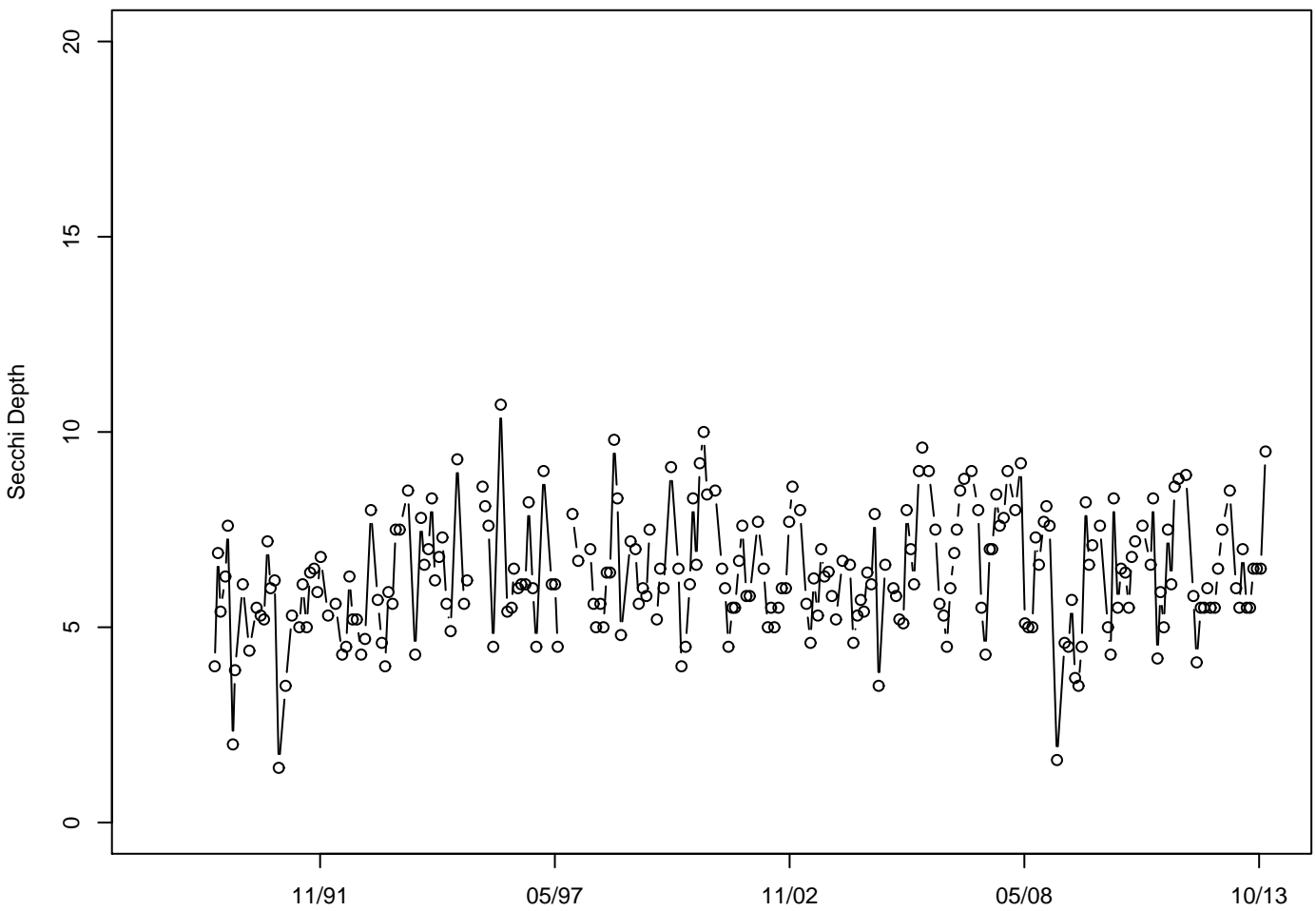


Figure B115: Lake Whatcom Secchi depths for Site 4.

Lake Whatcom fecal coliform data for Site 1, February 1988 through December 2013.

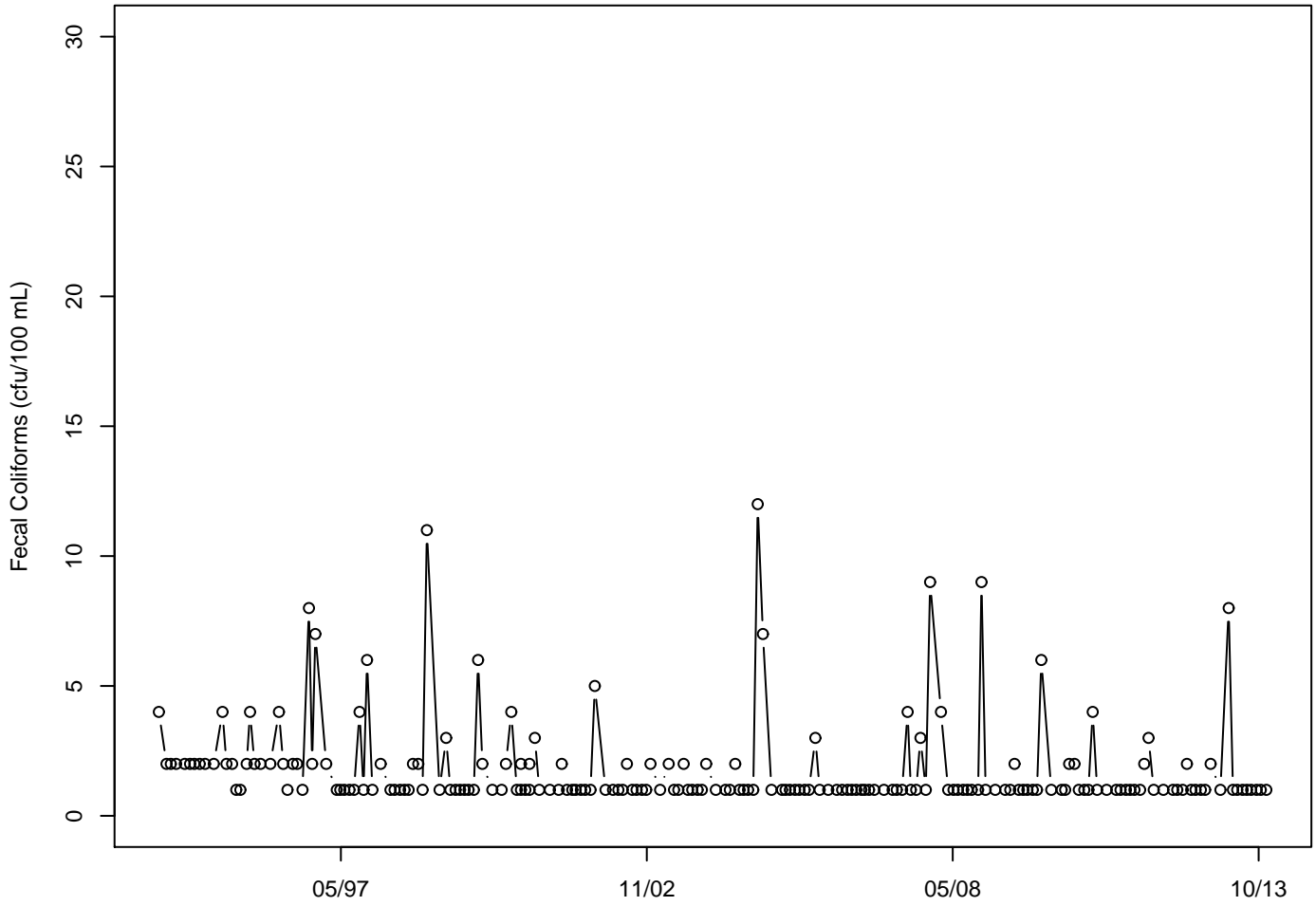


Figure B116: Lake Whatcom fecal coliform data for Site 1.

Lake Whatcom fecal coliform data for Site 2, February 1988 through December 2013.

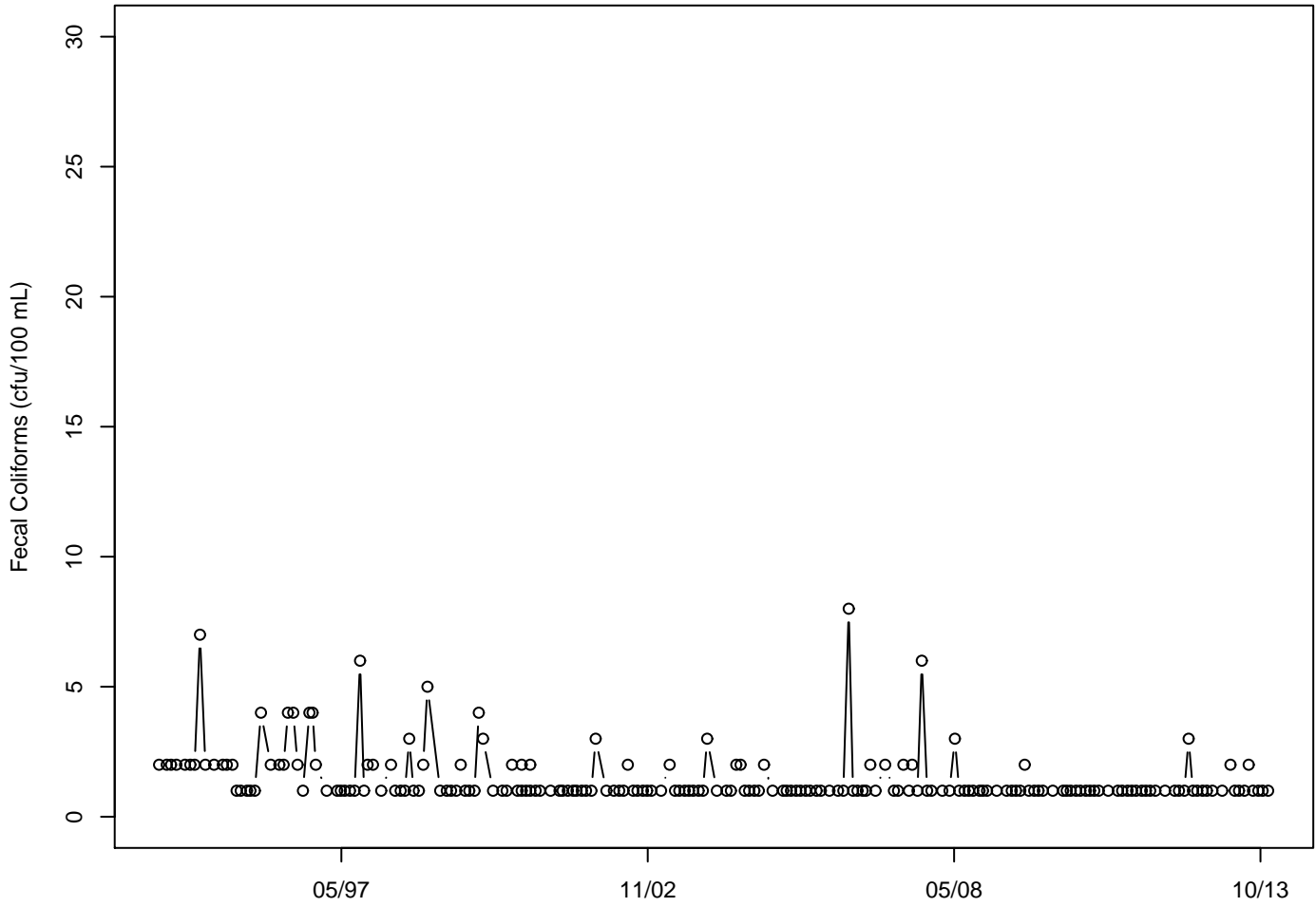


Figure B117: Lake Whatcom fecal coliform data for Site 2.

Lake Whatcom fecal coliform data for Intake, February 1988 through December 2013.

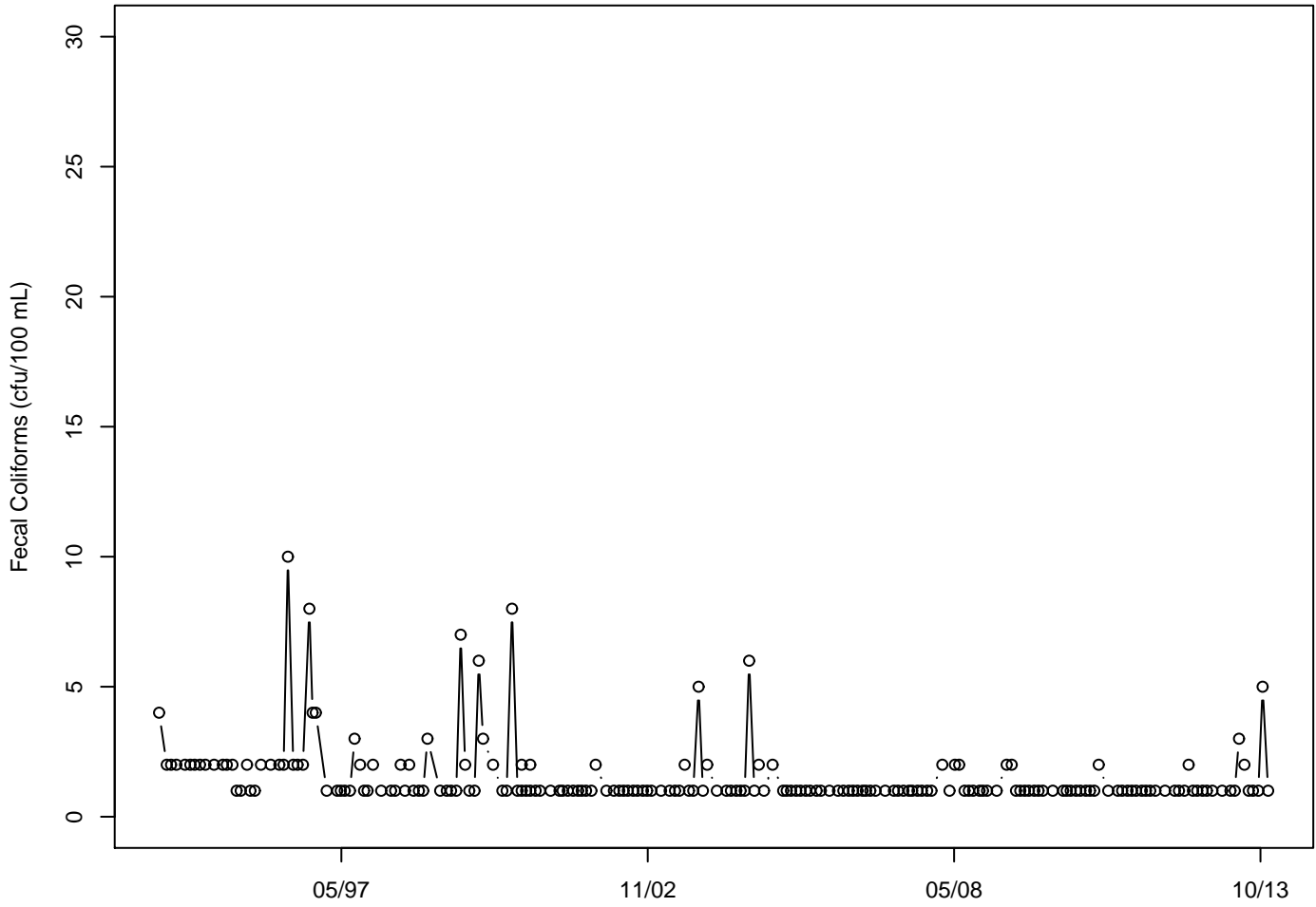


Figure B118: Lake Whatcom fecal coliform data for the Intake site.



Lake Whatcom fecal coliform data for Site 3, February 1988 through December 2013.

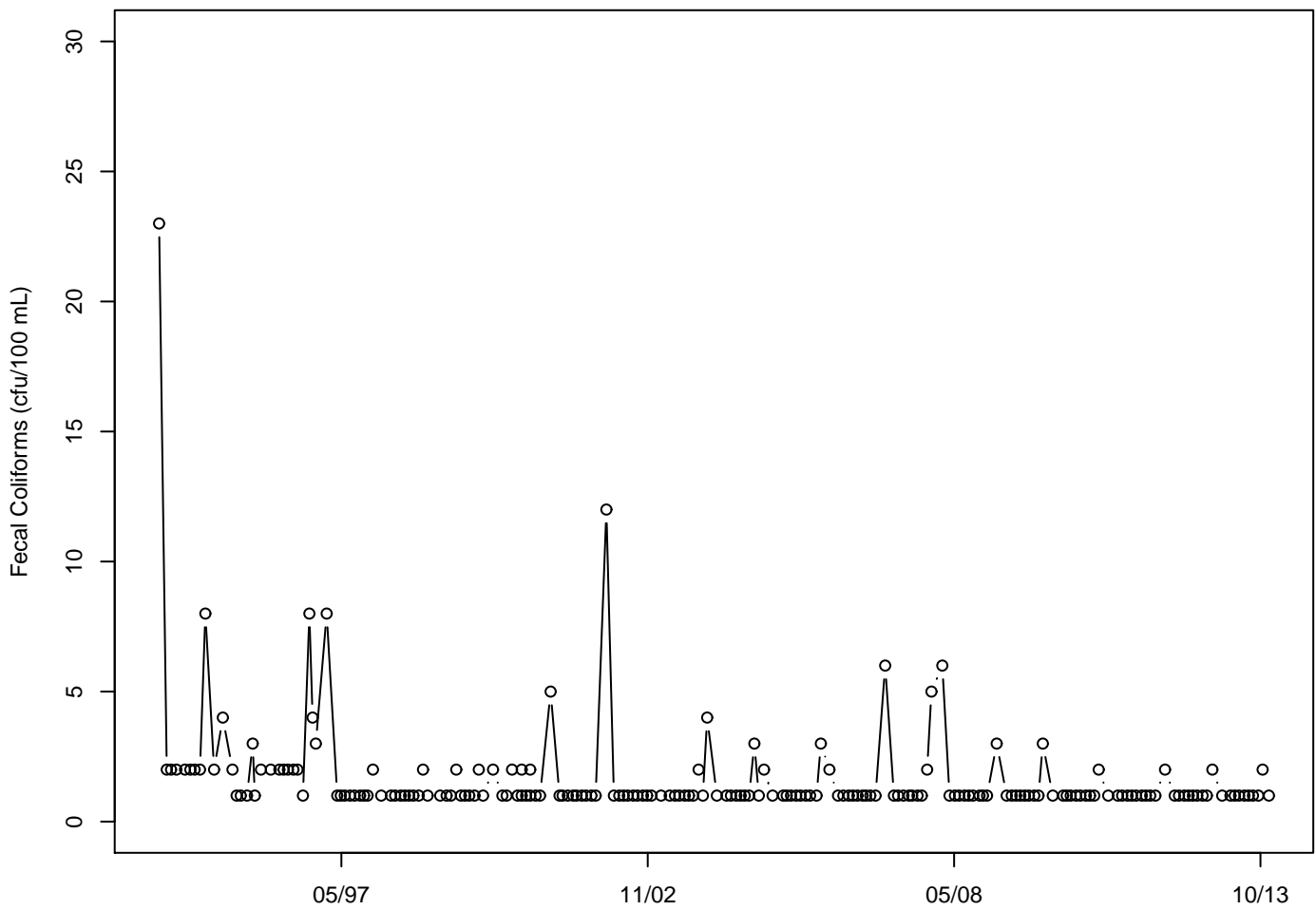


Figure B119: Lake Whatcom fecal coliform data for Site 3.

Lake Whatcom fecal coliform data for Site 4, February 1988 through December 2013.

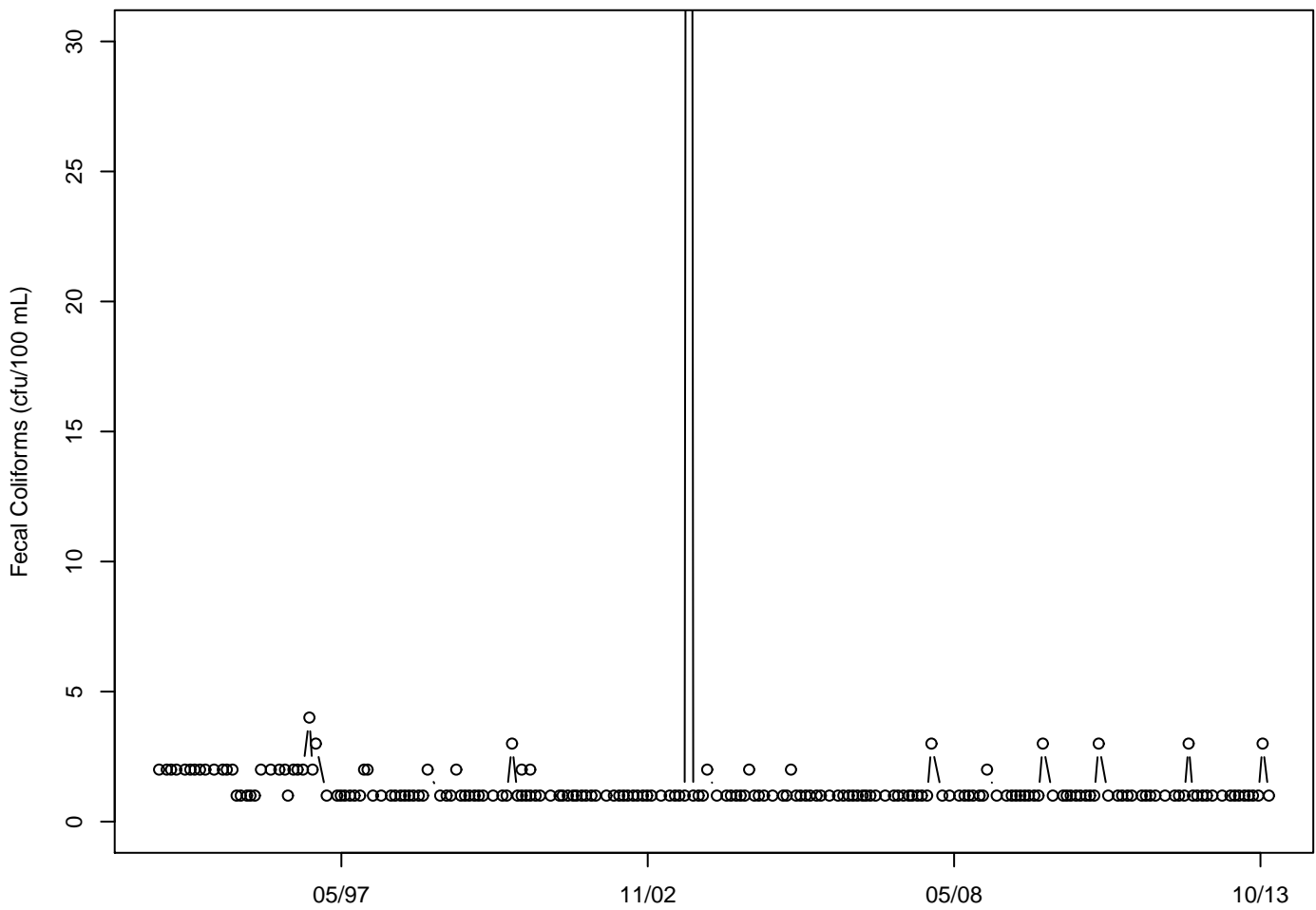


Figure B120: Lake Whatcom fecal coliform data for Site 4.

Lake Whatcom plankton data for Site 1, February 1988 through December 2013.

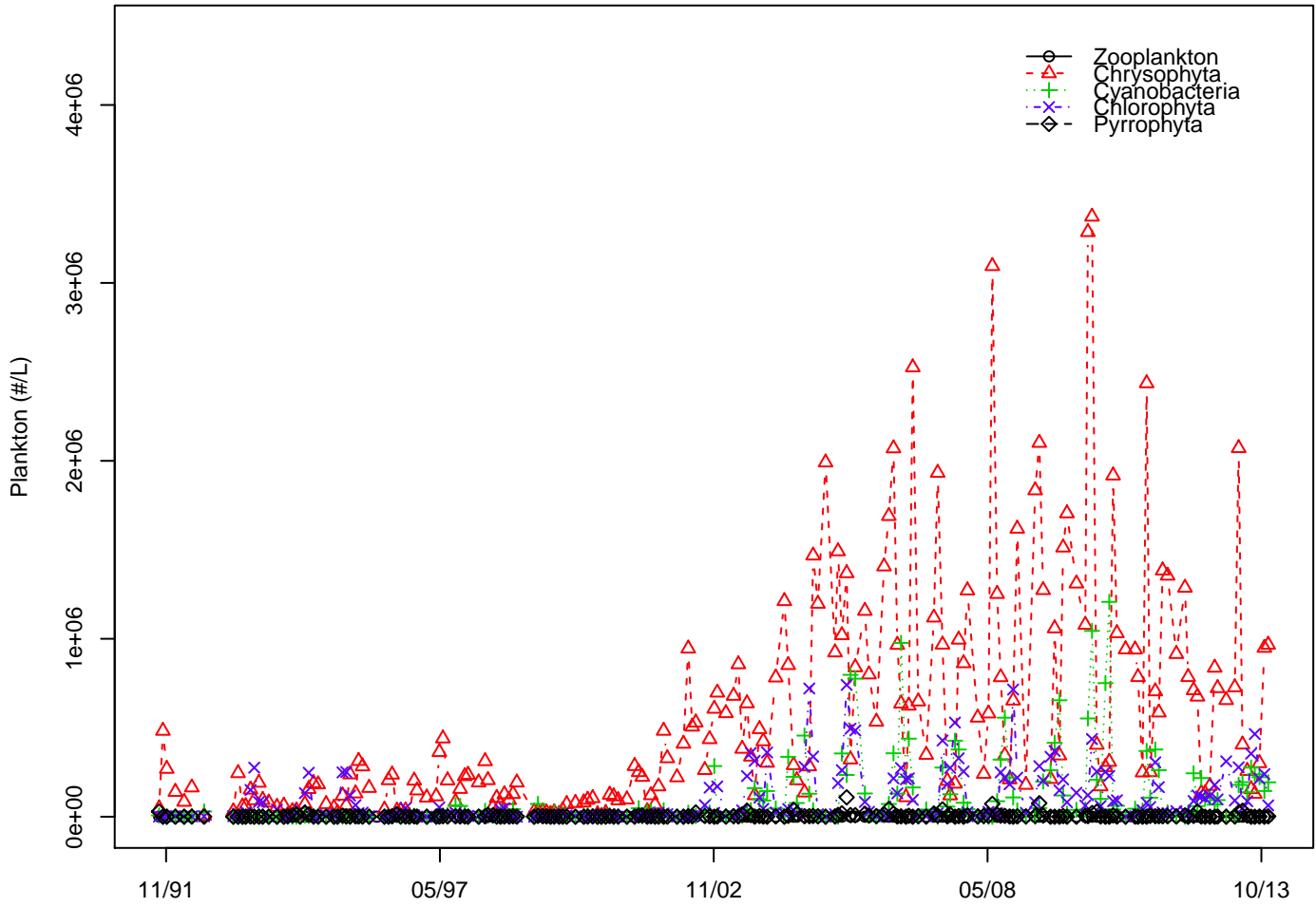


Figure B121: Lake Whatcom plankton data for Site 1.

Lake Whatcom plankton data for Site 2, February 1988 through December 2013.

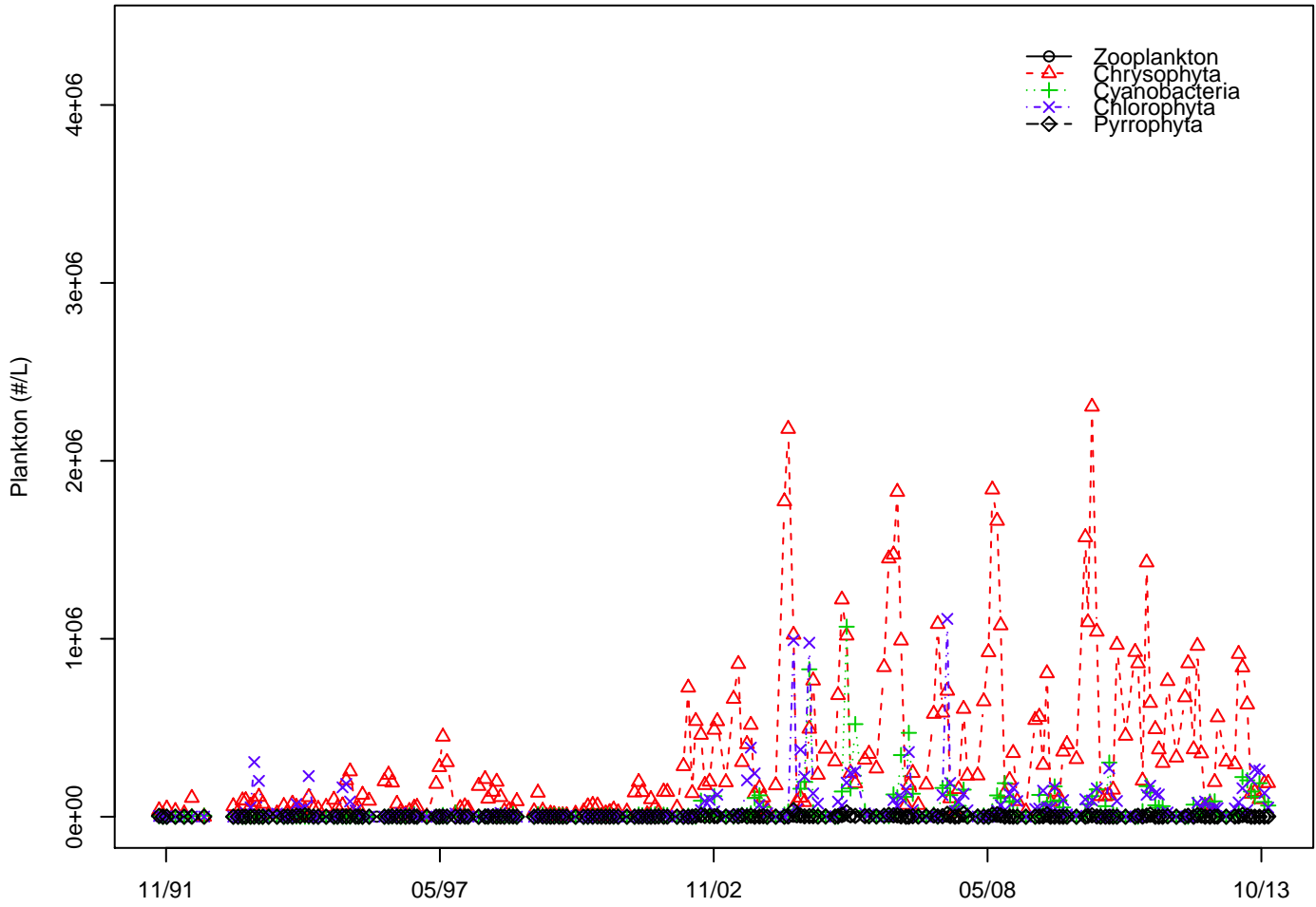


Figure B122: Lake Whatcom plankton data for Site 2.

Lake Whatcom plankton data for Intake, February 1988 through December 2013.

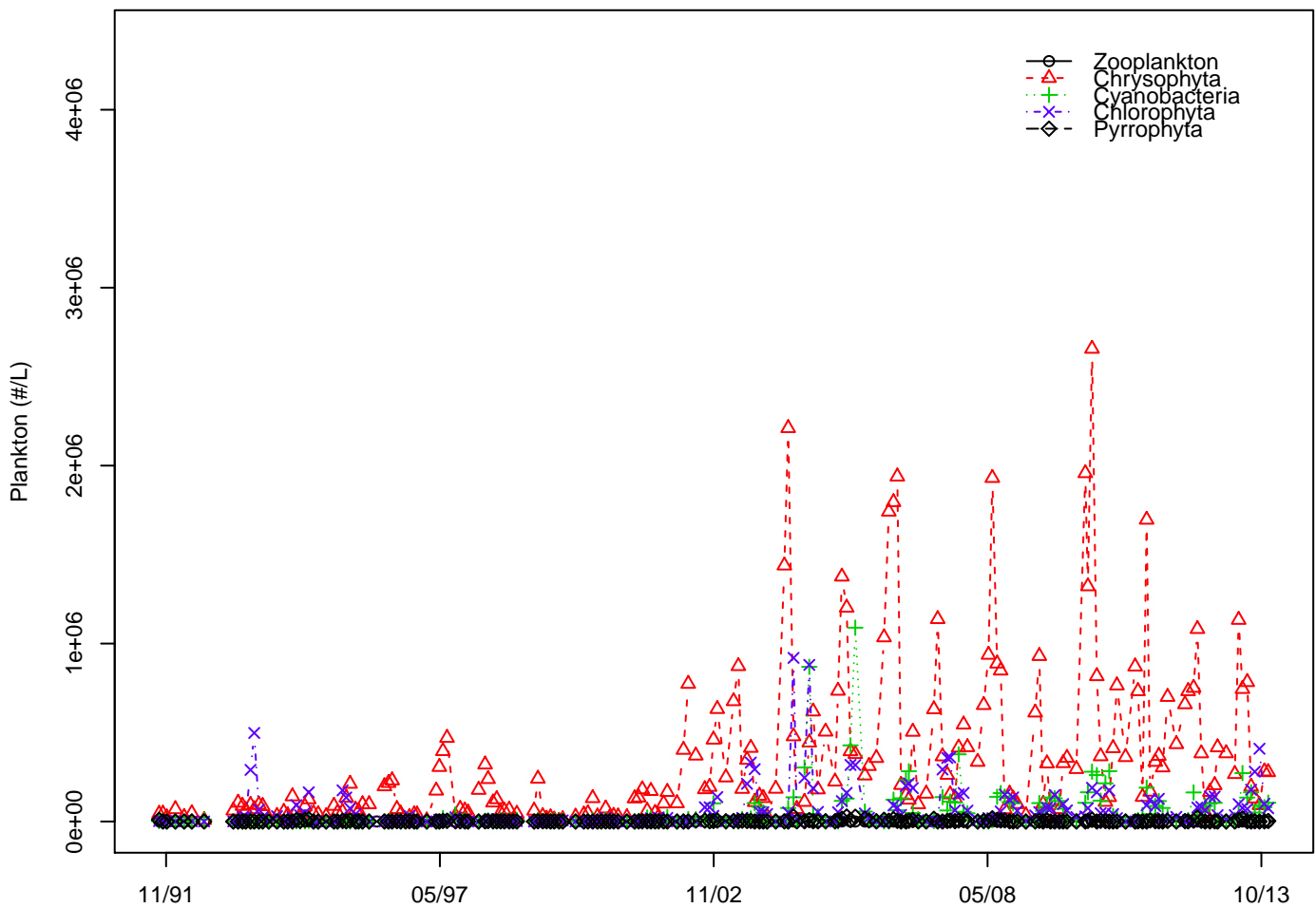


Figure B123: Lake Whatcom plankton data for the Intake Site.

Lake Whatcom plankton data for Site 3, February 1988 through December 2013.

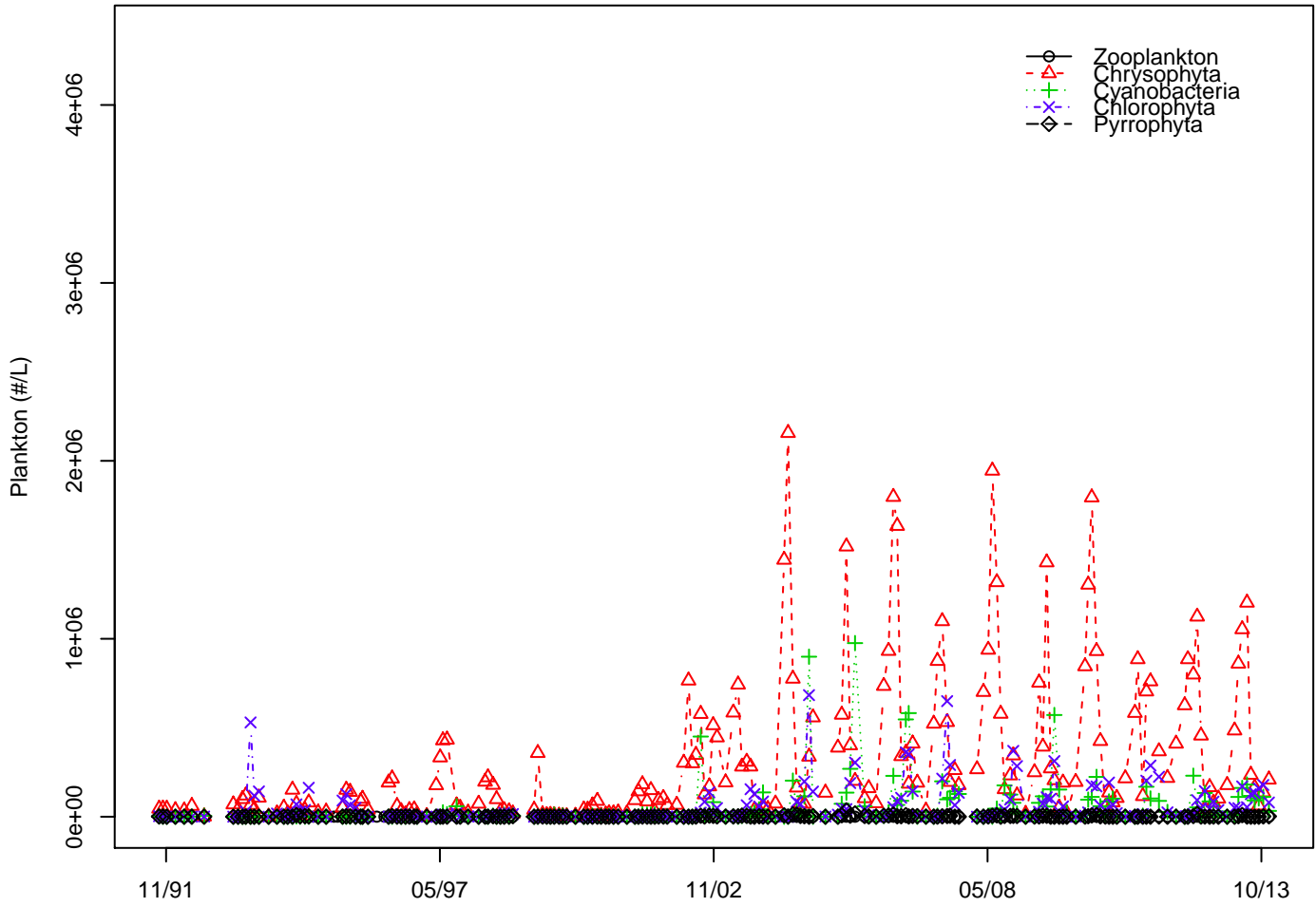


Figure B124: Lake Whatcom plankton data for Site 3.

Lake Whatcom plankton data for Site 4, February 1988 through December 2013.

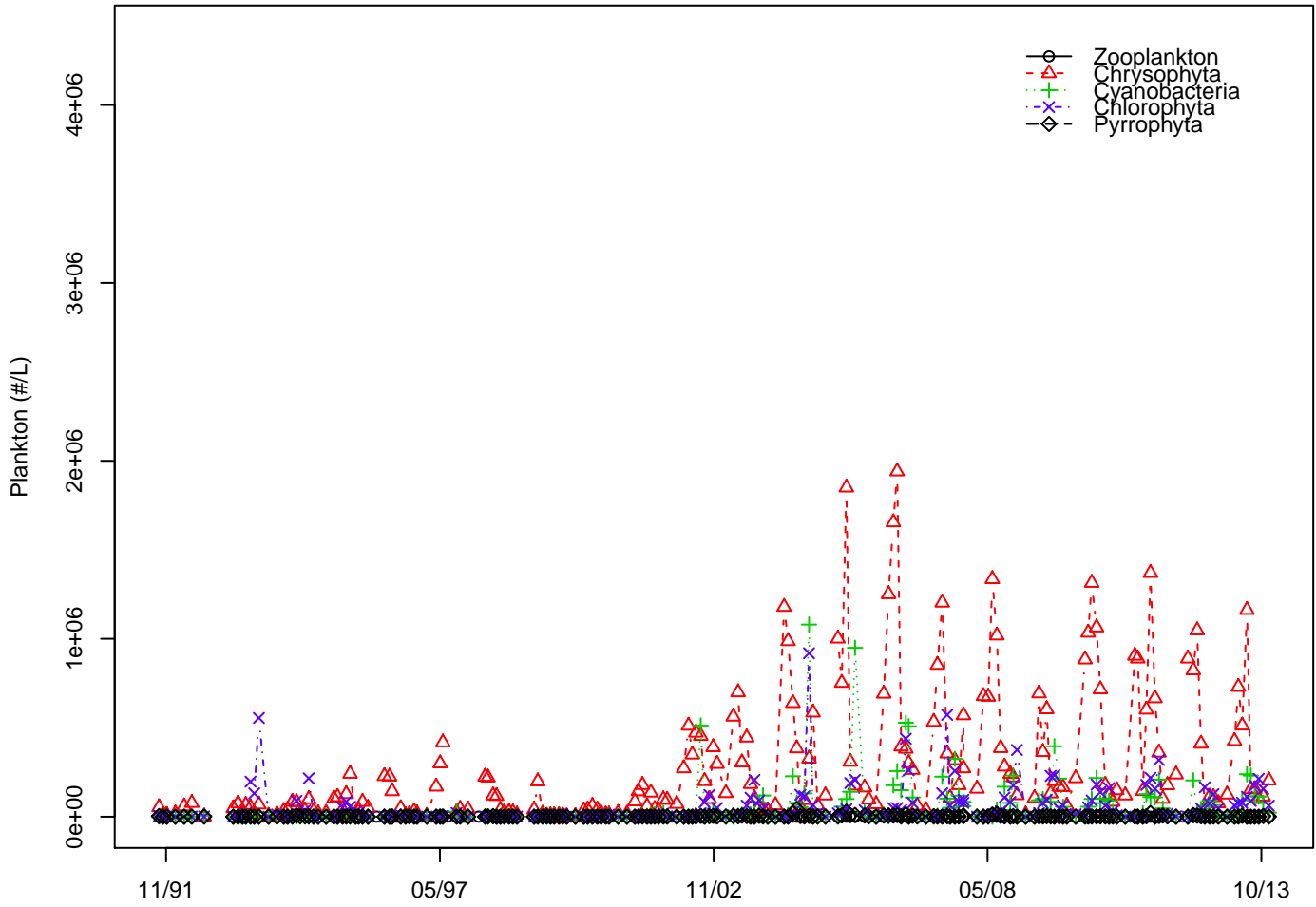


Figure B125: Lake Whatcom plankton data for Site 4.

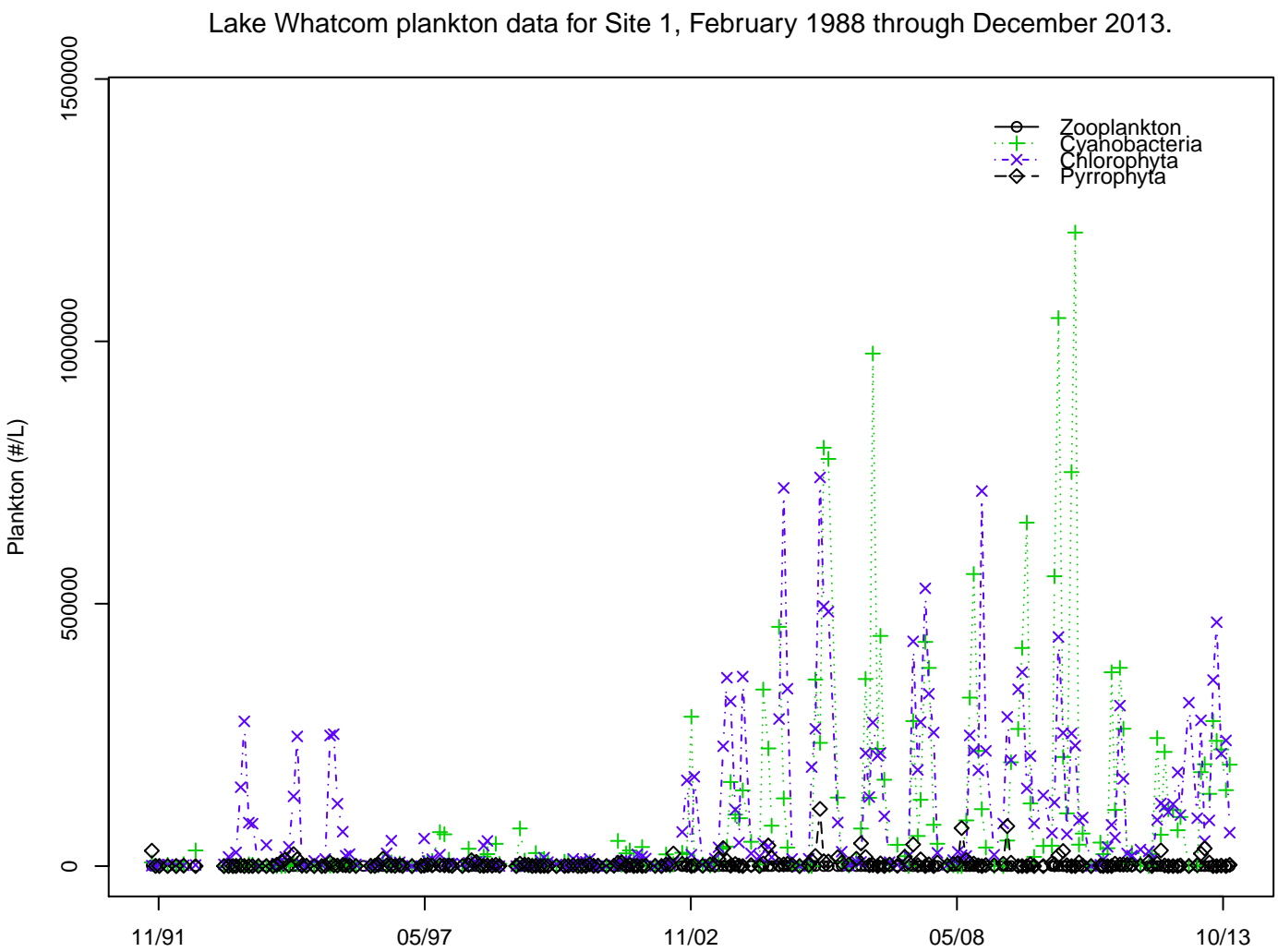


Figure B126: Lake Whatcom plankton data for Site 1, with Chrysochyta omitted to show remaining plankton groups.



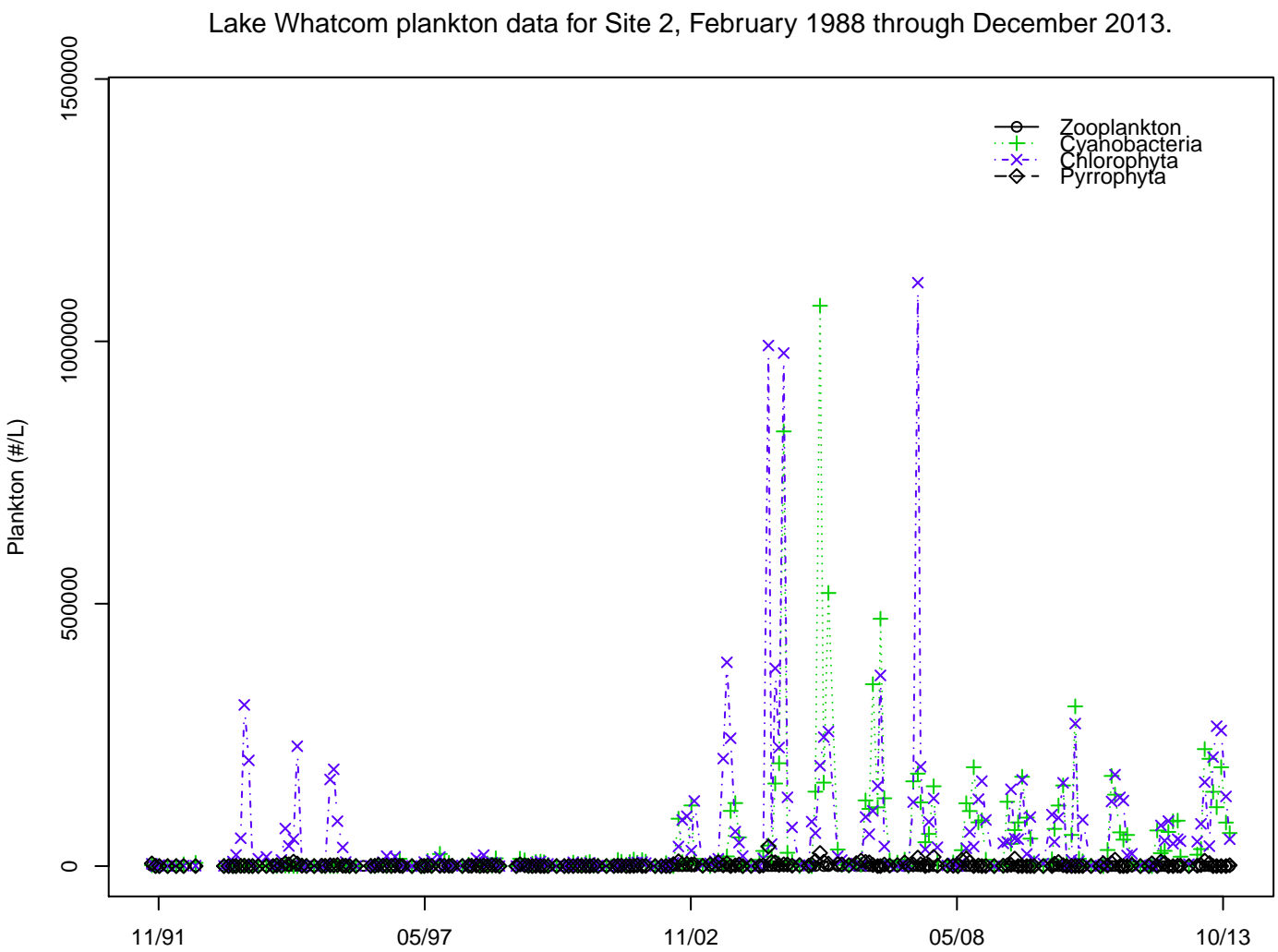


Figure B127: Lake Whatcom plankton data for Site 2, with Chrysochyta omitted to show remaining plankton groups.

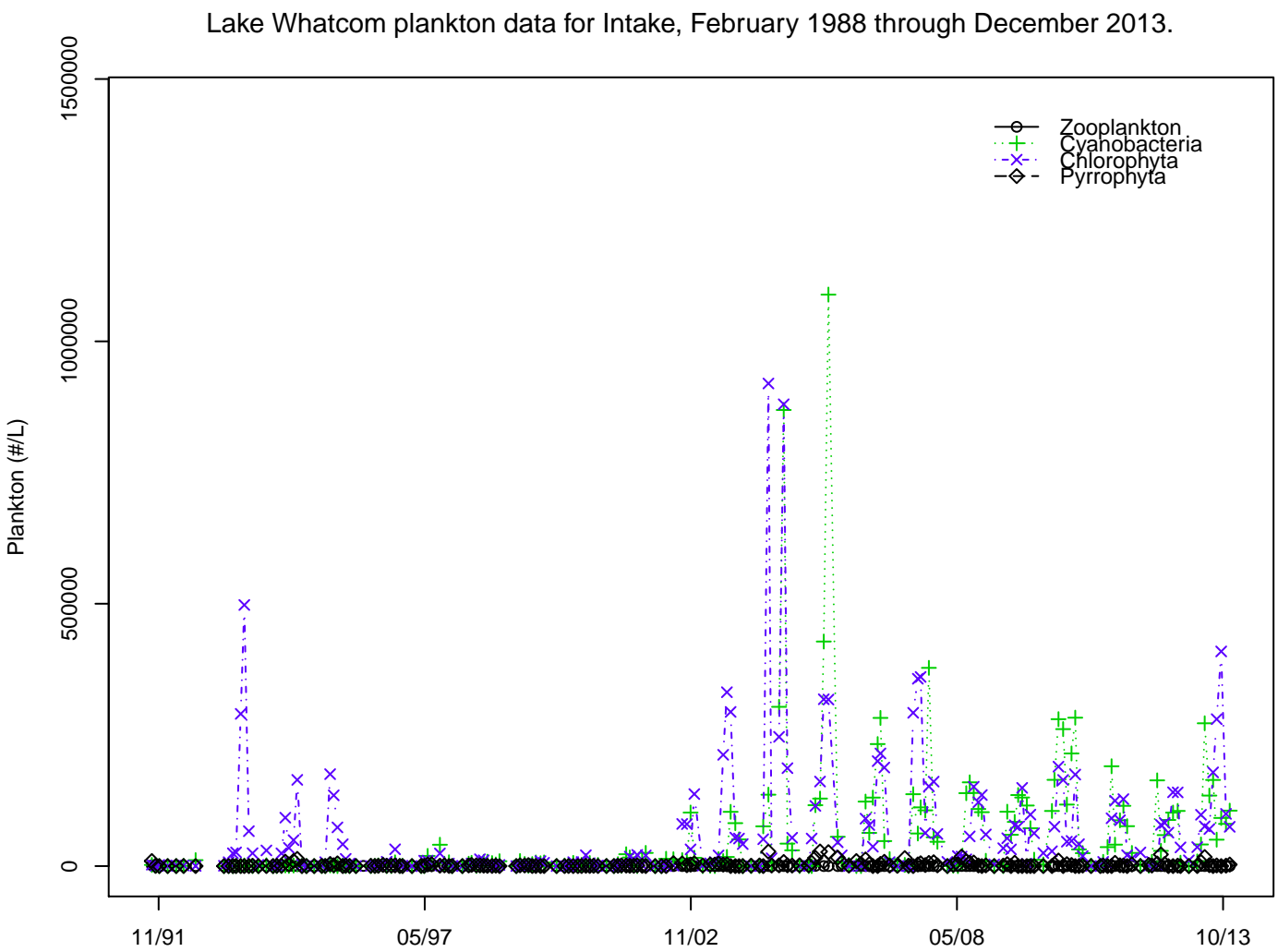


Figure B128: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

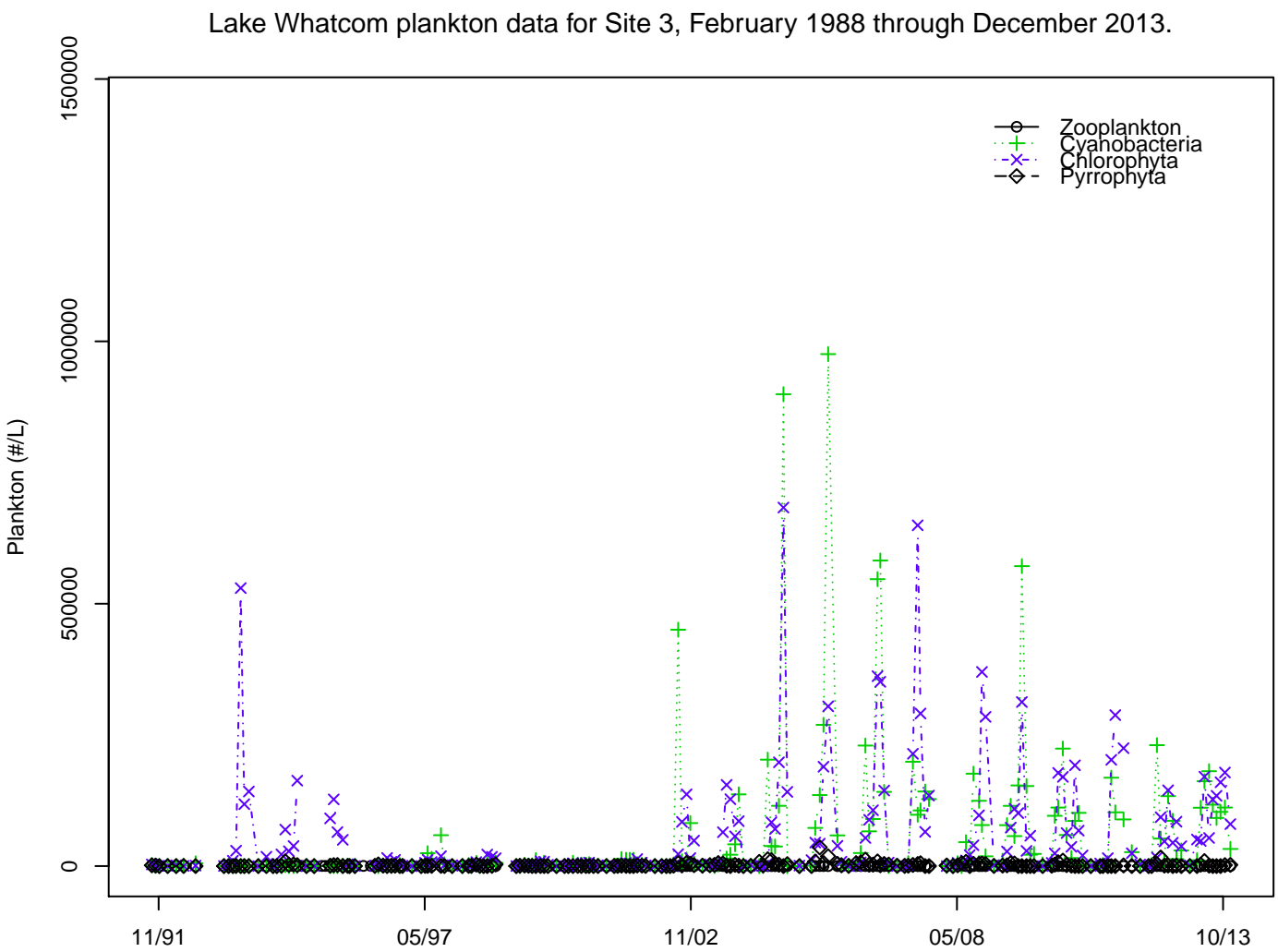


Figure B129: Lake Whatcom plankton data for Site 3, with Chrysochyta omitted to show remaining plankton groups.

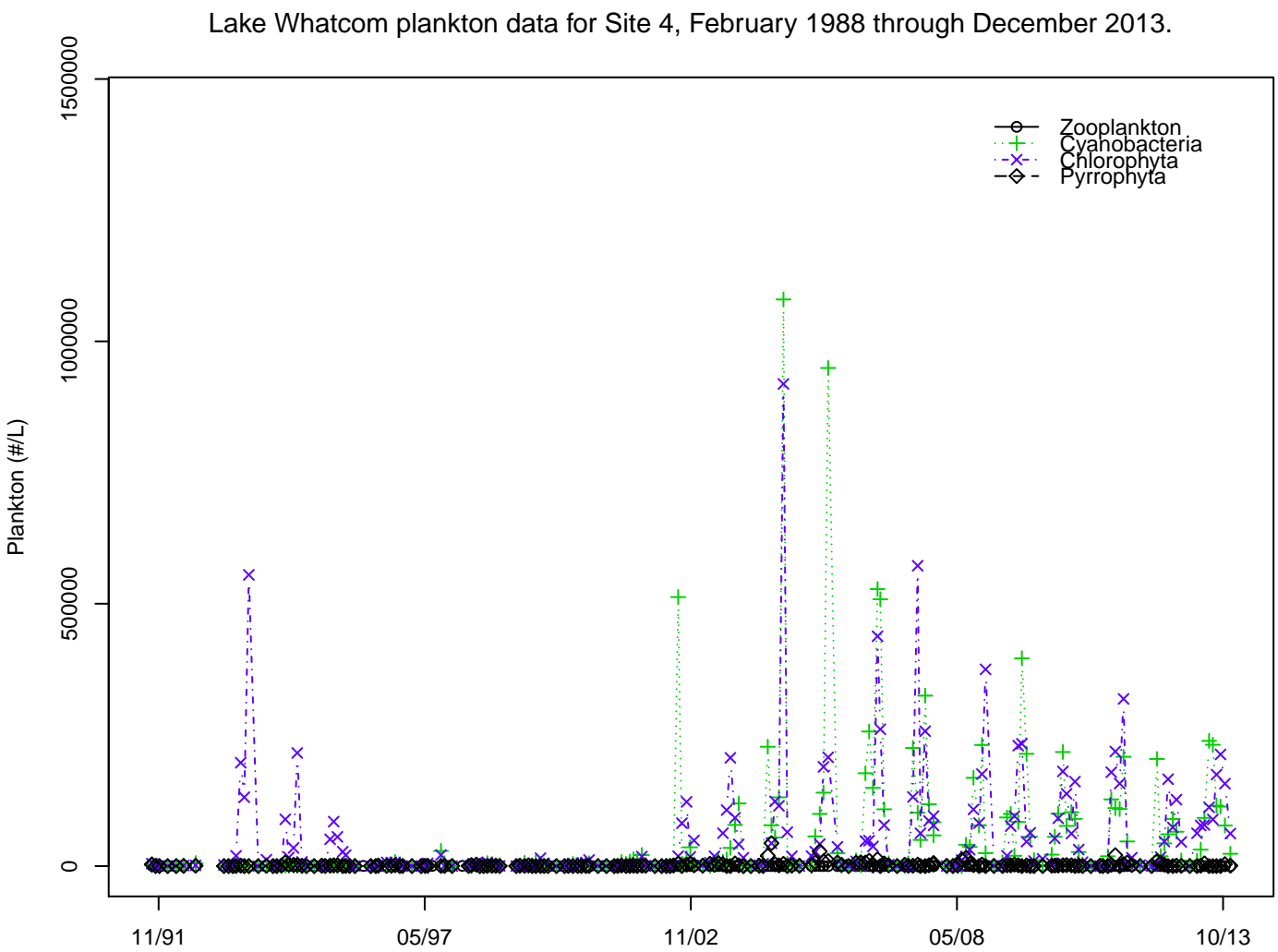


Figure B130: Lake Whatcom plankton data for Site 4, with Chrysochyta omitted to show remaining plankton groups.

## 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 1 (page 16). 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.<sup>20</sup> The quality control results for laboratory duplicates, matrix spikes, and check standards are plotted in control charts (Figures C1–C29, pages 229–257).

### C.3 Field Duplicates

Ten percent of all samples collected in the field were duplicated to measure sample replication (Figures C30–C39, pages 258–267). 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 using the following equation:

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

---

<sup>20</sup>External check standards are not available for all analytes.

	Reported Value	Assigned Value	Acceptance Limits	Test Result
Specific conductivity ( $\mu\text{S}/\text{cm}$ at $25^\circ\text{C}$ )	372	373	333–413	accept
Total alkalinity (mg/L as $\text{CaCO}_3$ )	109	113	100–1243	accept
Ammonium nitrogen, manual (mg-N/L)	14.1	14.3	10.6–17.7	accept
Ammonium nitrogen, auto (mg-N/L)	15.1	14.3	10.6–17.7	accept
Nitrate/nitrite nitrogen, auto (mg-N/L)	38.2	39.0	31.8–45.3	accept
Nitrite nitrogen, auto (mg-N/L)	0.723	0.723	0.561–0.877	accept
Orthophosphate, manual (mg-P/L)	1.49	1.49	1.18–1.82	accept
Orthophosphate, auto (mg-P/L)	1.53	1.49	1.18–1.82	accept
Total phosphorus, manual (mg-P/L)	4.52	4.50	3.69–5.37	accept
Total phosphorus, auto (mg-P/L)	4.53	4.50	3.69–5.37	accept
pH	7.91	7.77	7.57–7.97	accept
Solids, non-filterable (mg/L), WP–195	67.5	83.0	67.9–92.3	too low
Repeat after methods revision, WP–197	93.1	86.0	70.5–95.5	accept
Turbidity (NTU)	10.2	9.78	7.92–11.6	accept

Table C1: Single-blind quality control results, WP–195 (06/05/2013) and WP–197 (08/06/2013; total suspended solids). All results were within acceptance limits except non-filterable solids, which was repeated after adopting a methodological change to address higher turbidity levels present in the performance standards. The repeated test was within acceptance limits.

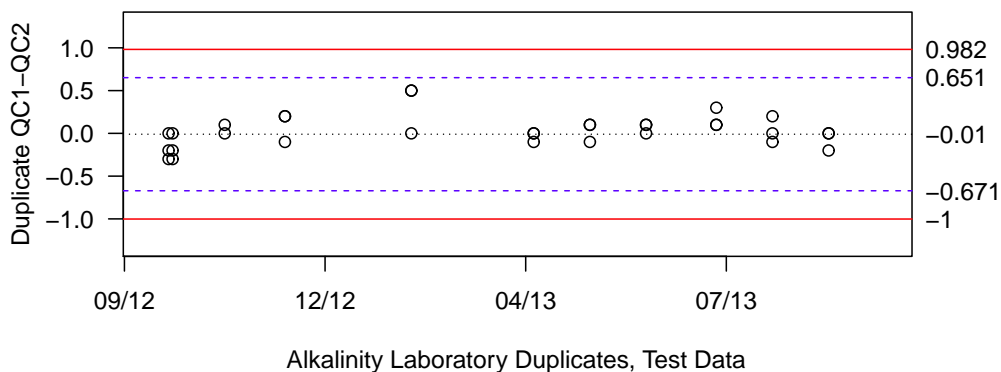
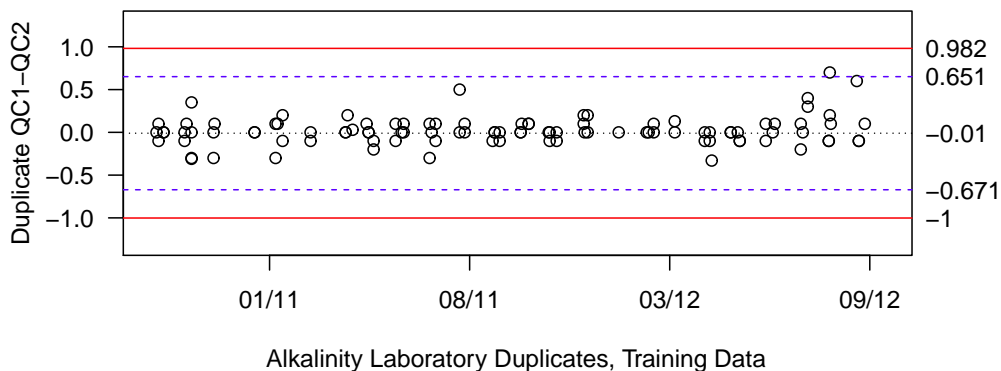


Figure C1: Alkalinity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

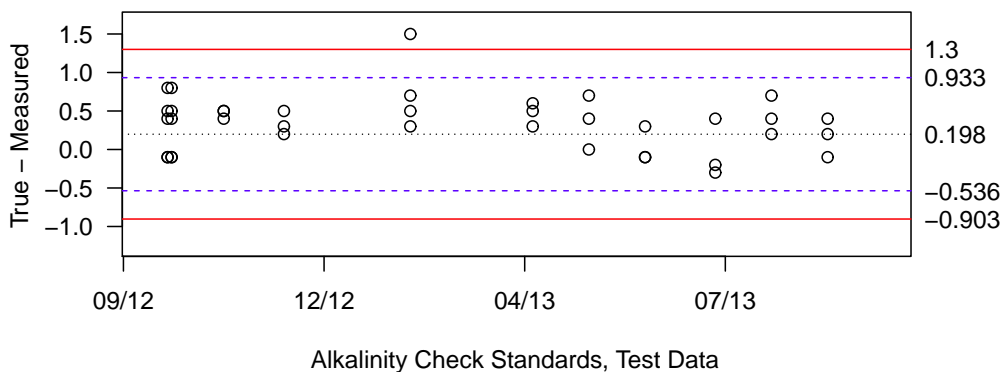
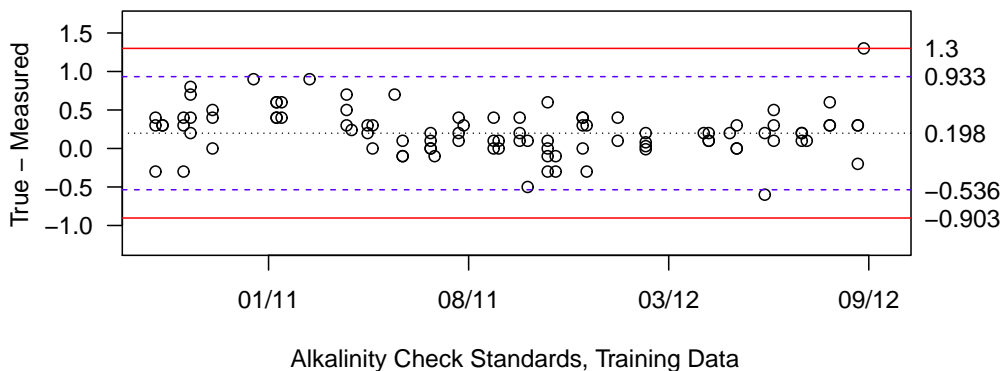


Figure C2: Alkalinity low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab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



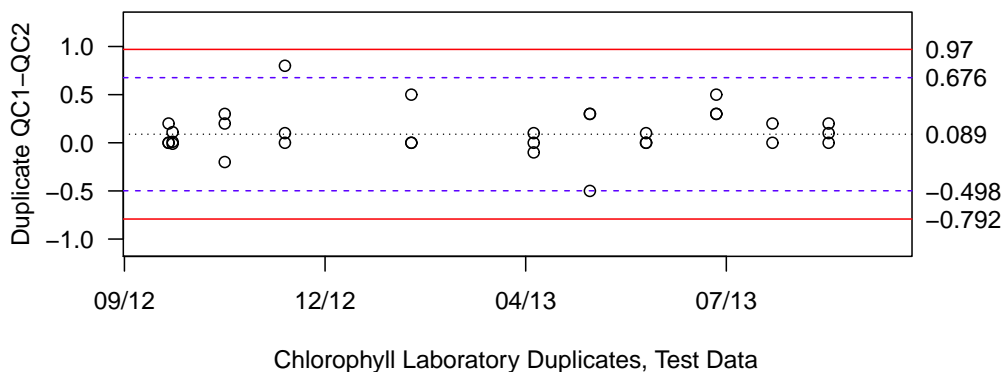
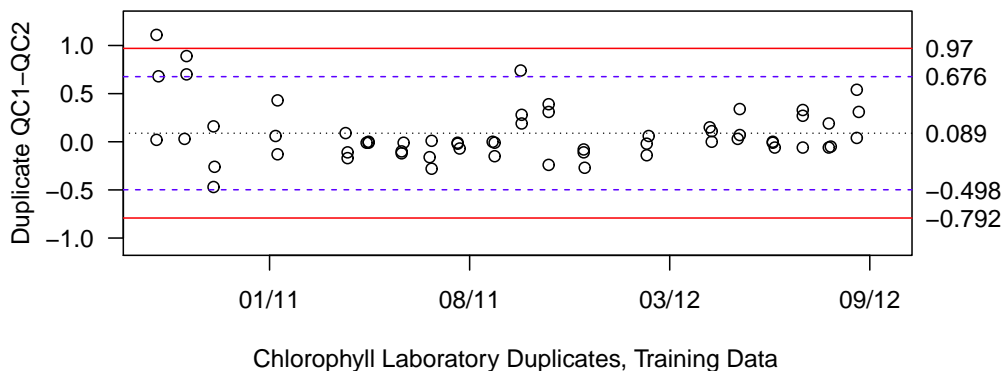


Figure C3: Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program (lake samples). Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

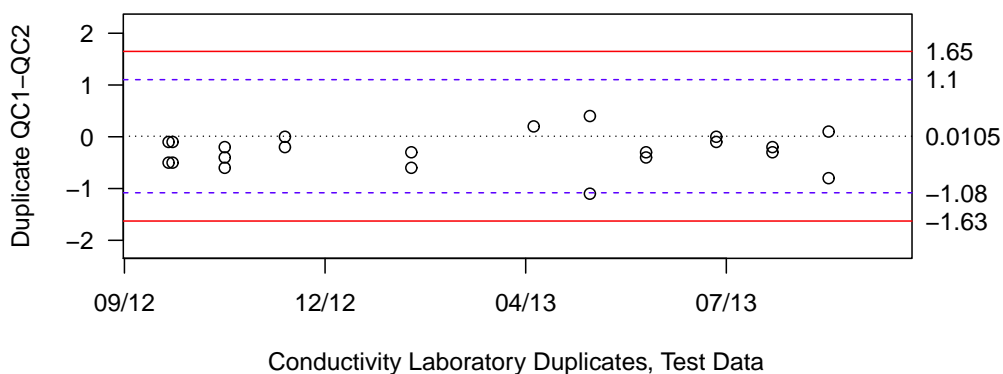
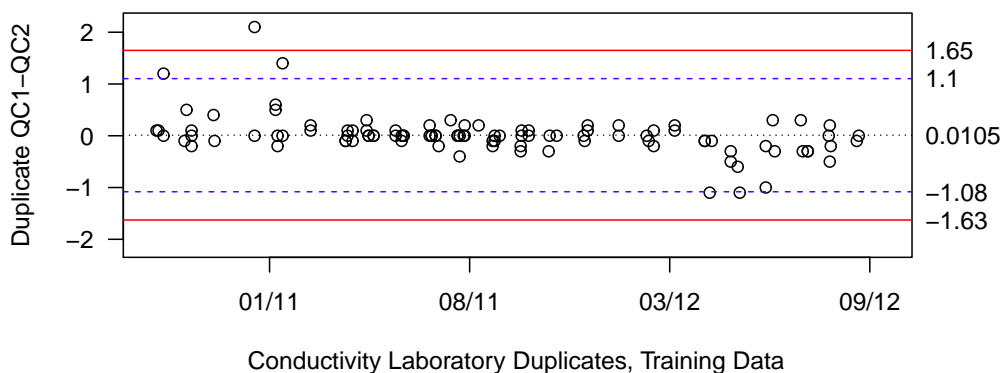


Figure C4: Conductivity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

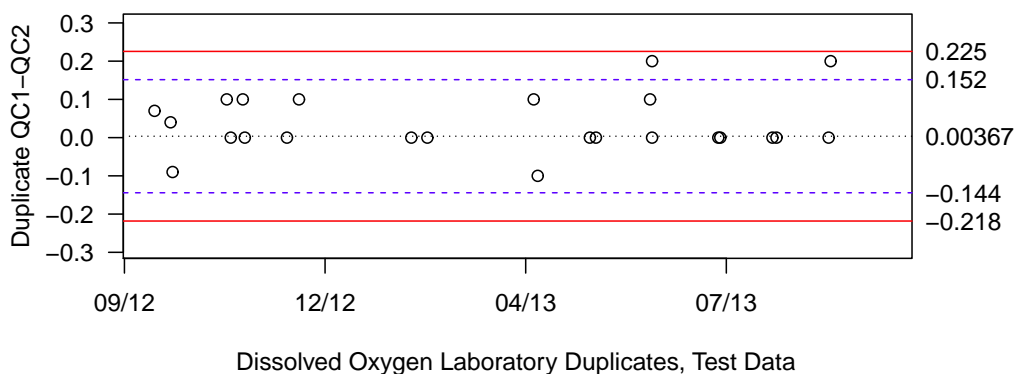
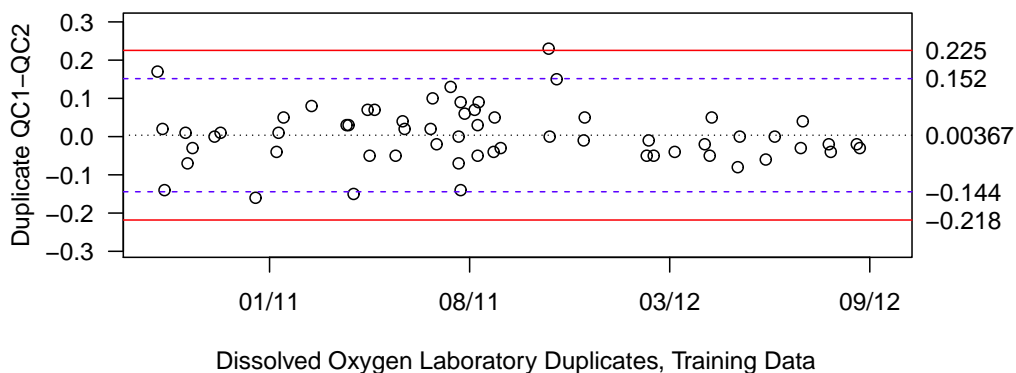


Figure C5: Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab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

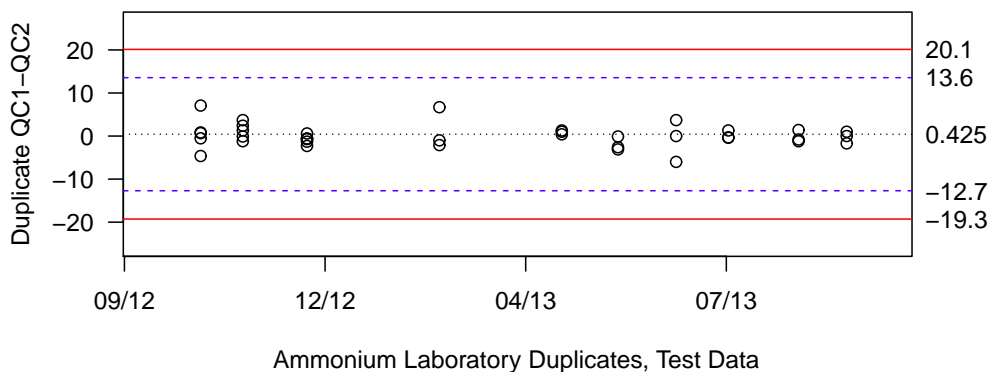
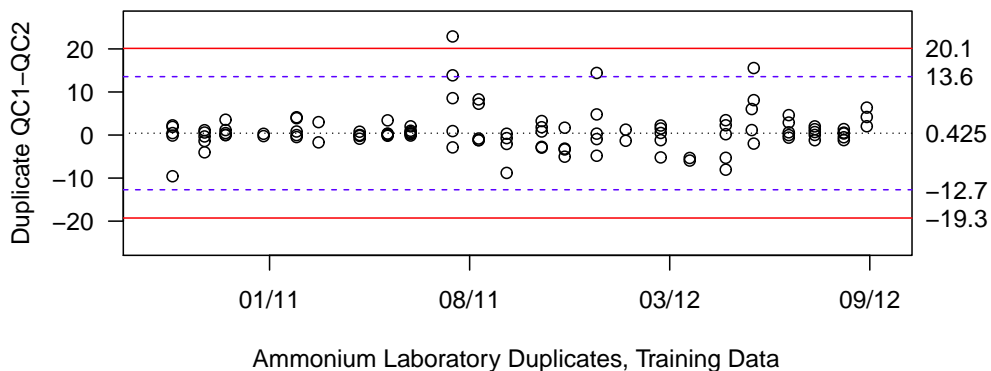


Figure C6: Ammonium laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

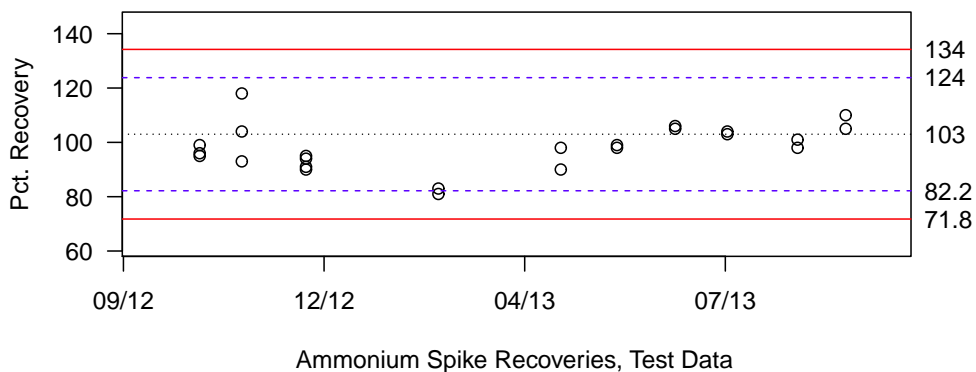
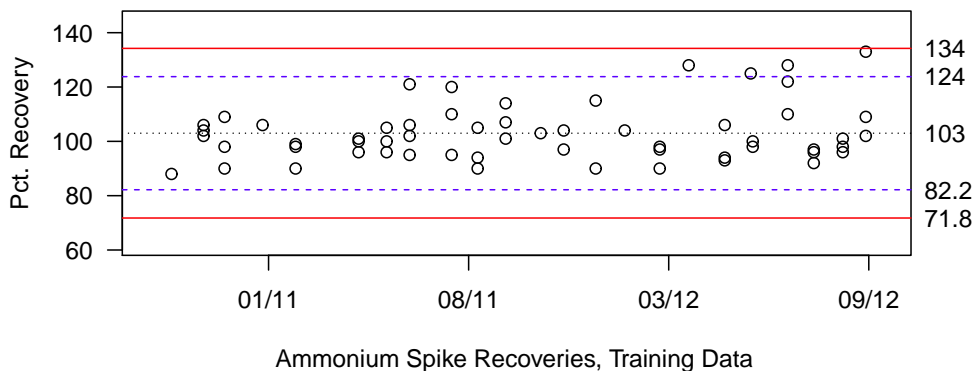


Figure C7: Ammonium spike recoveries for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

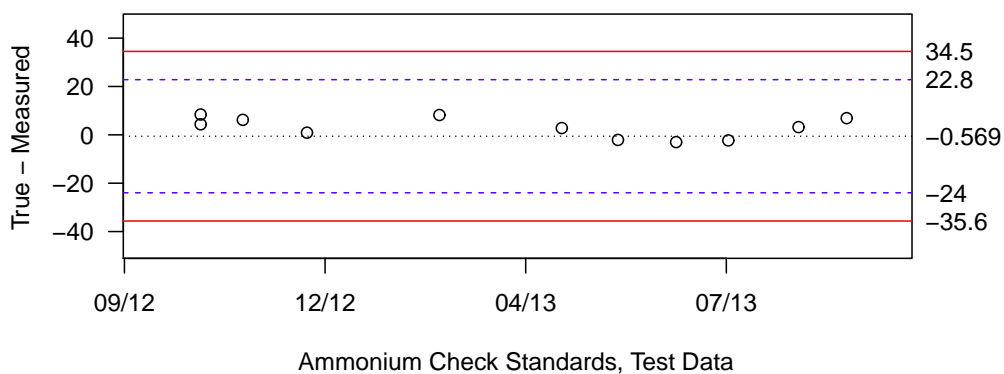
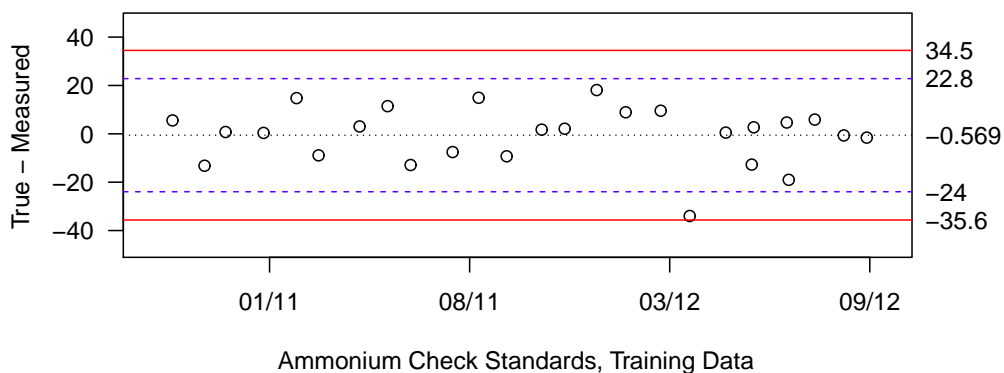


Figure C8: Ammonium high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

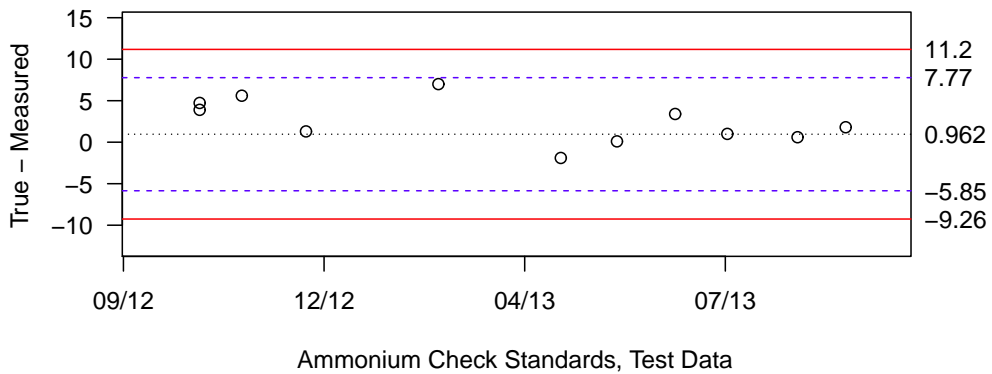
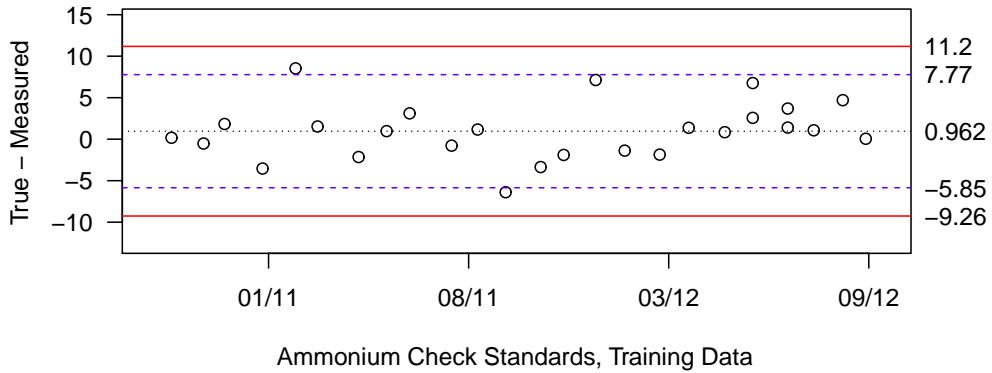


Figure C9: Ammonium low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

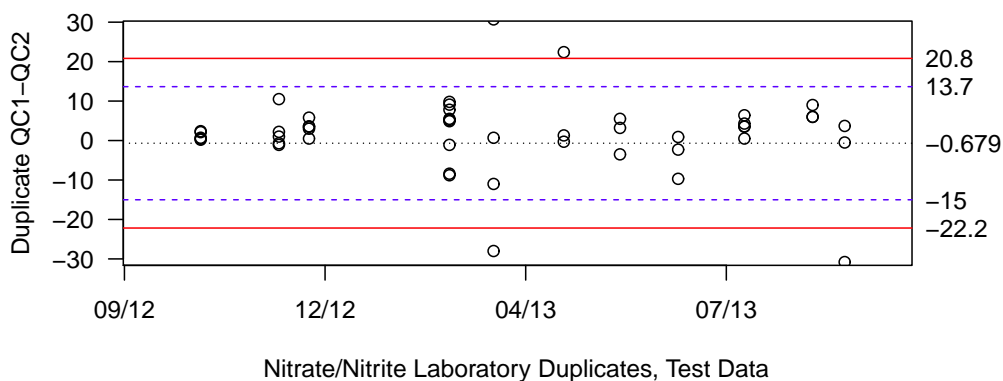
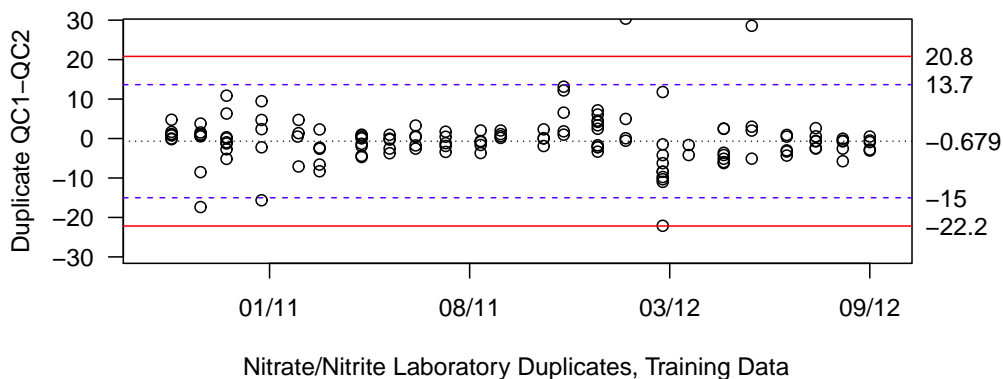


Figure C10: Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



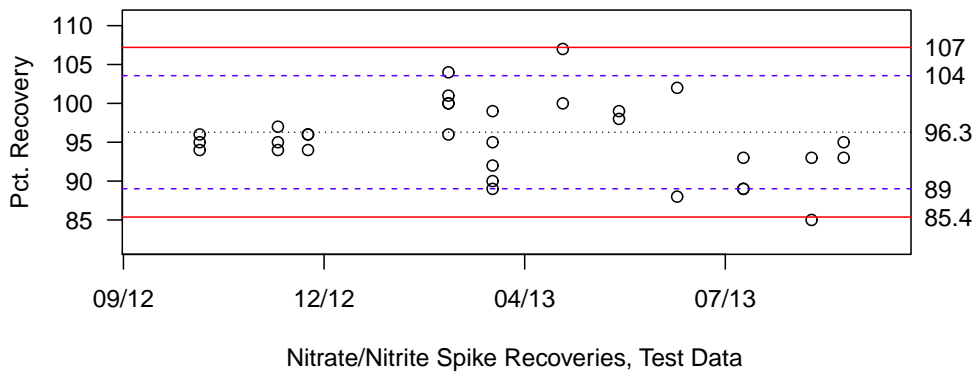
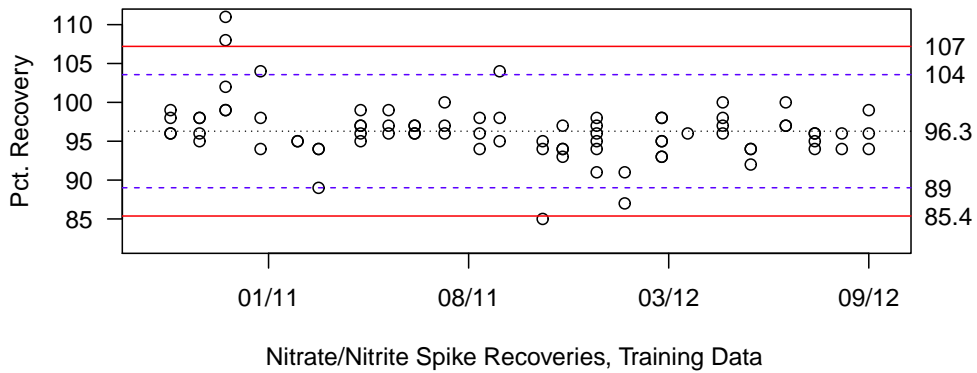


Figure C11: Nitrate/nitrite spike recoveries for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

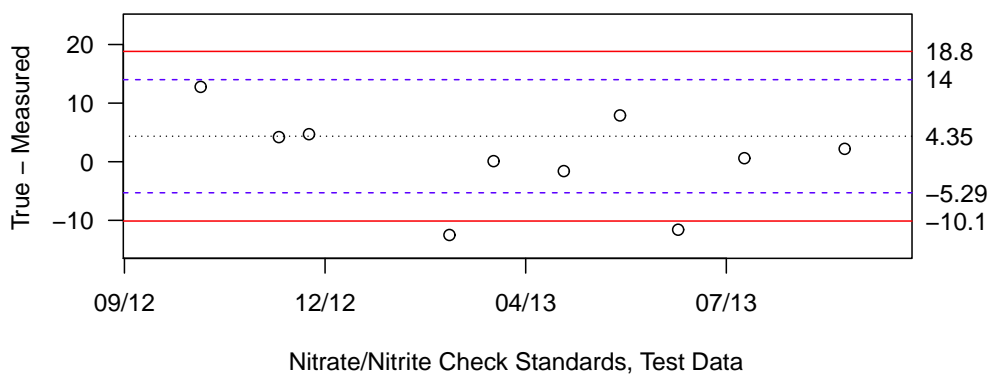
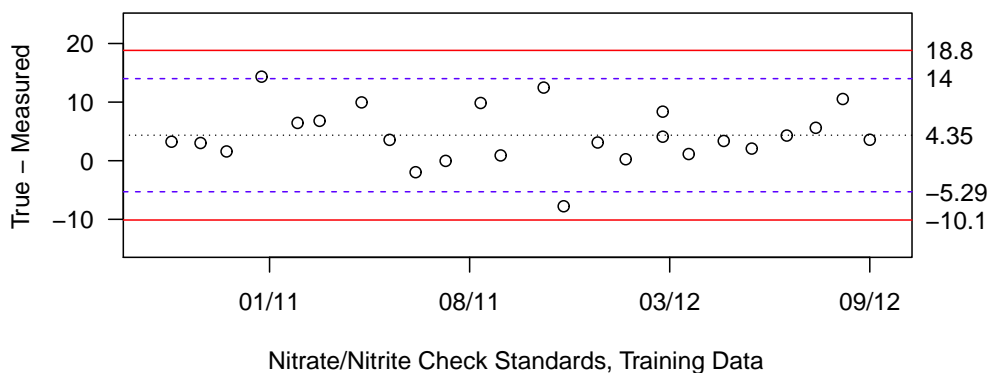


Figure C12: Nitrate/nitrite high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

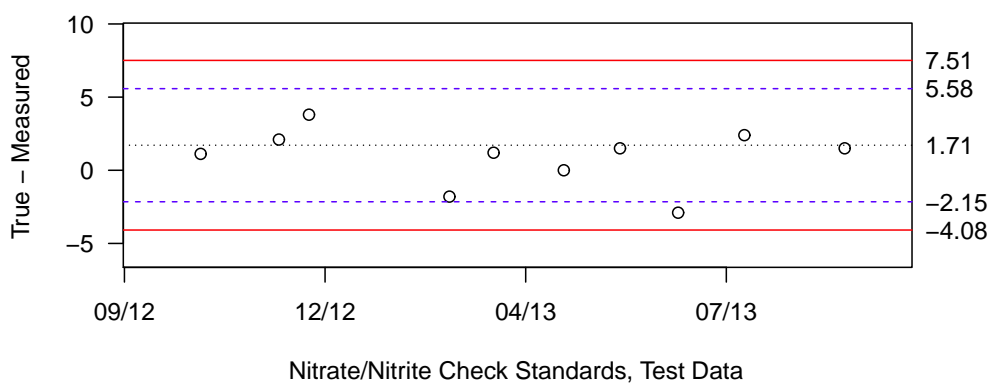
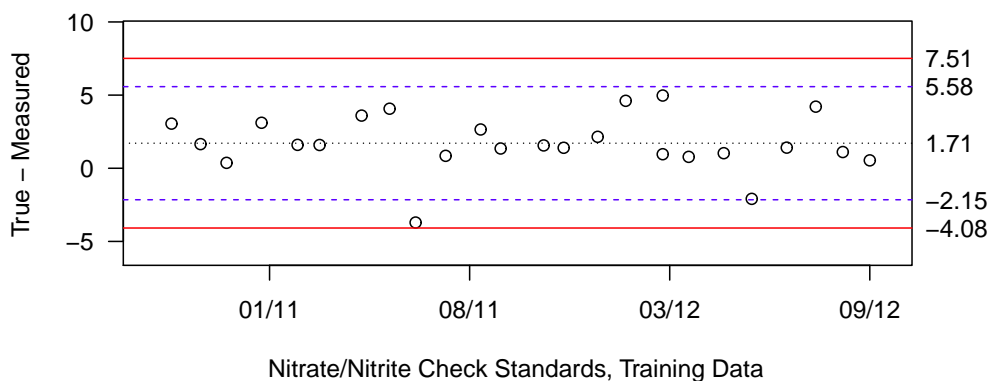


Figure C13: Nitrate/nitrite low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years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

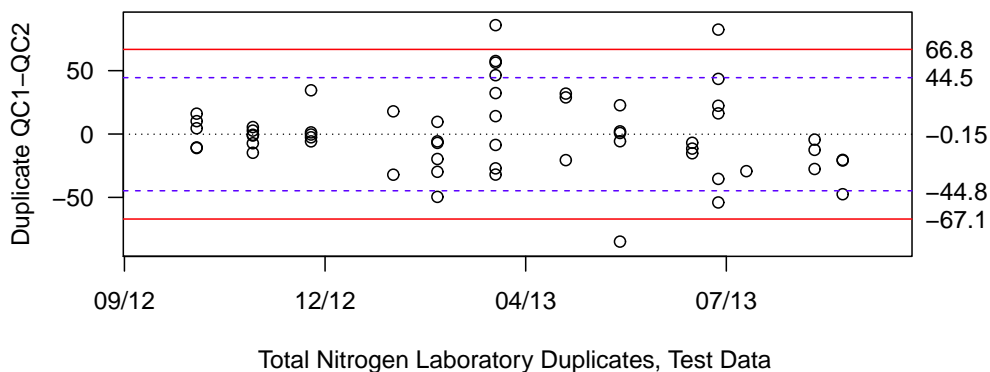
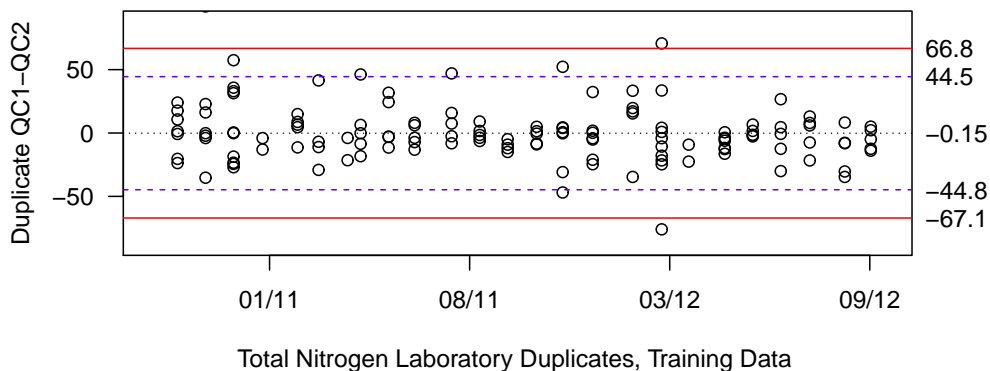


Figure C14: Total nitrogen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

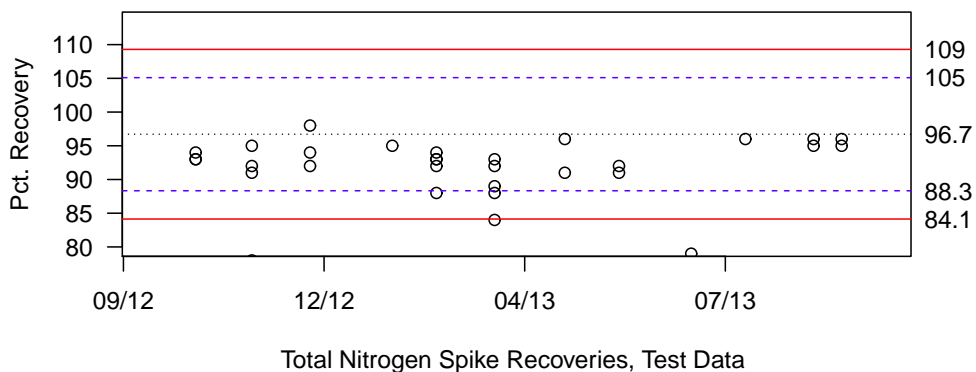
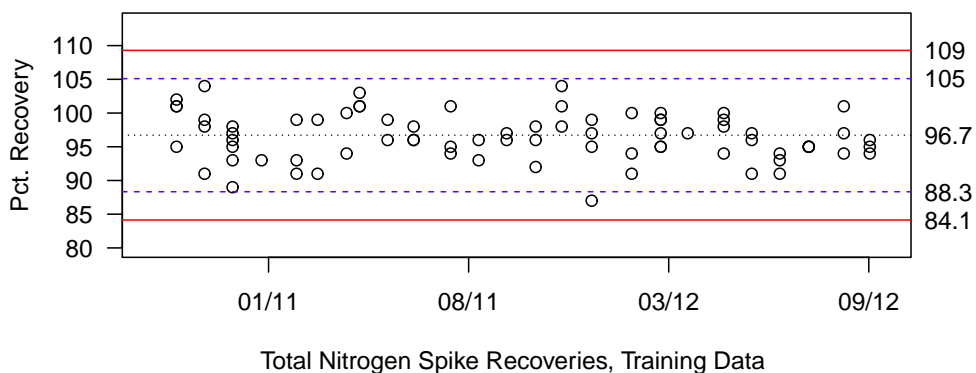


Figure C15: Total nitrogen spike recoveries for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

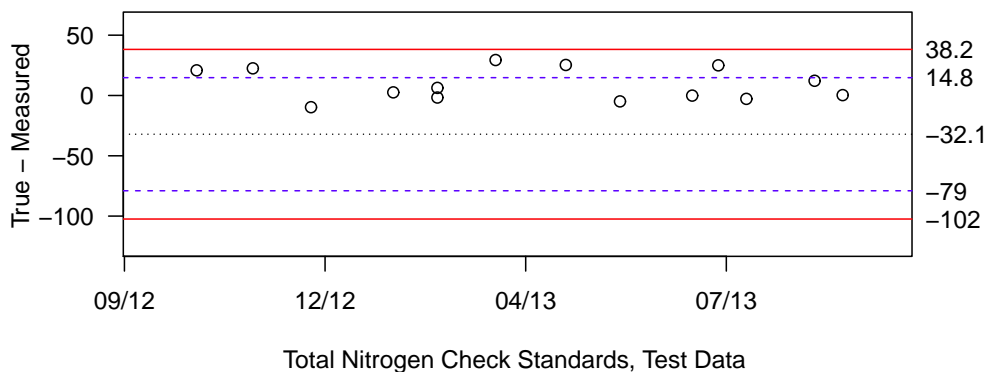
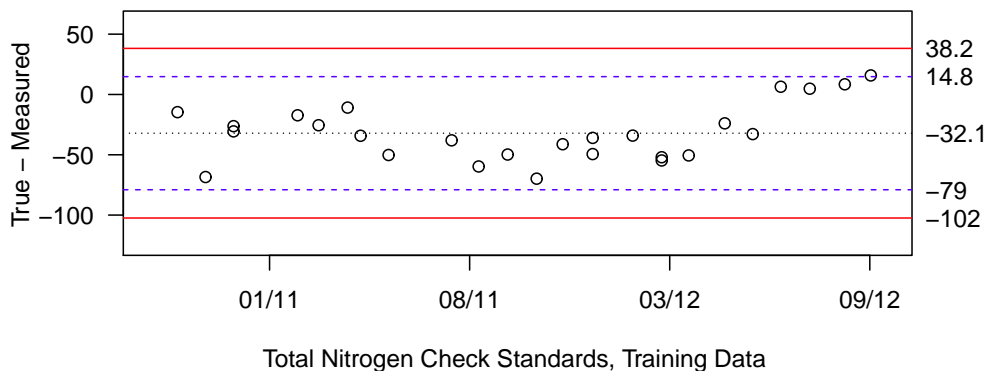


Figure C16: Total nitrogen high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

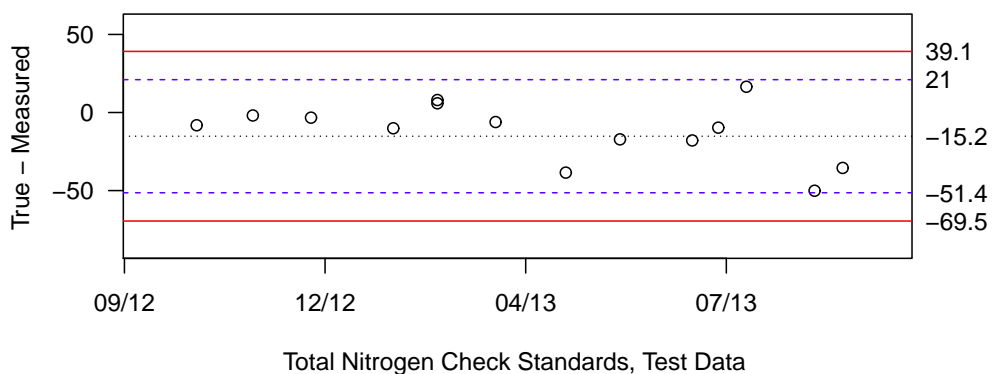
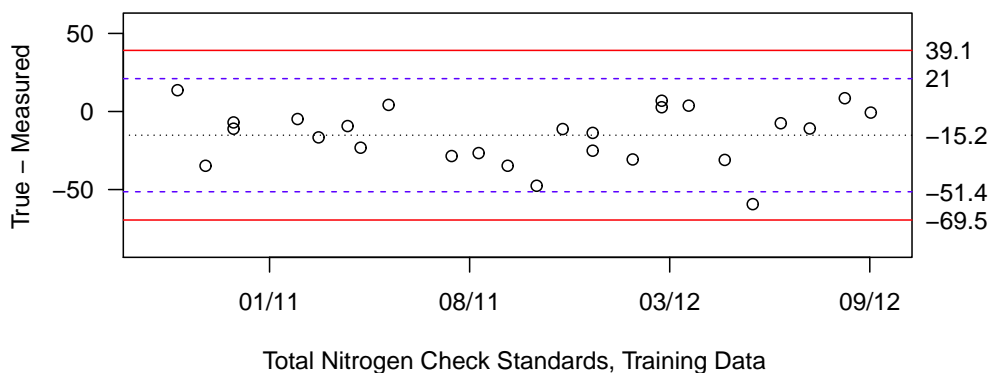


Figure C17: Total nitrogen low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

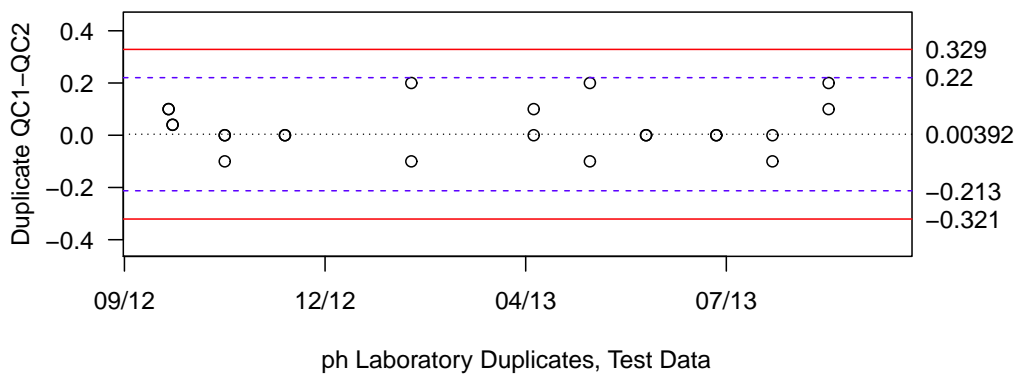
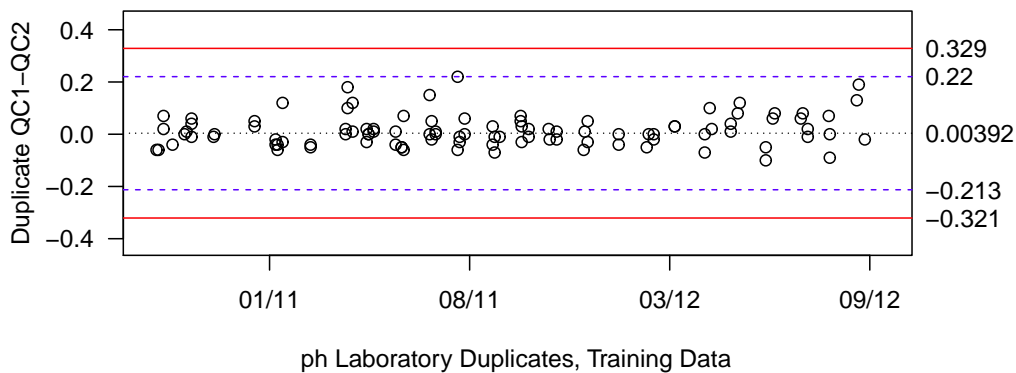


Figure C18: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.



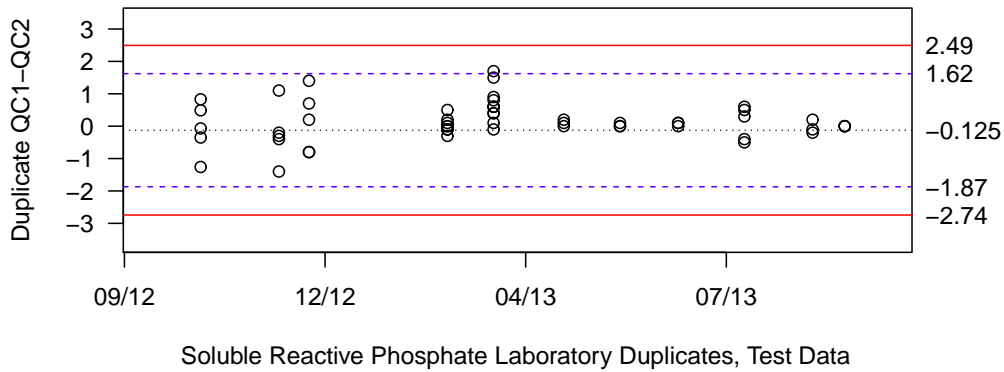
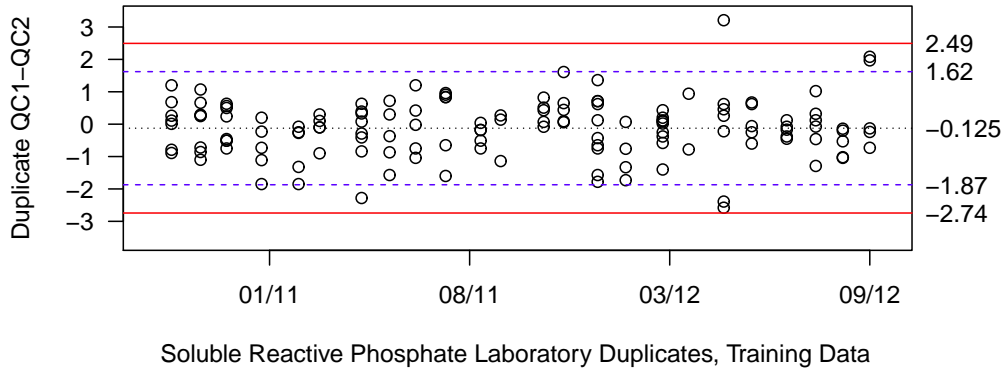


Figure C19: Soluble reactive phosphate laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two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



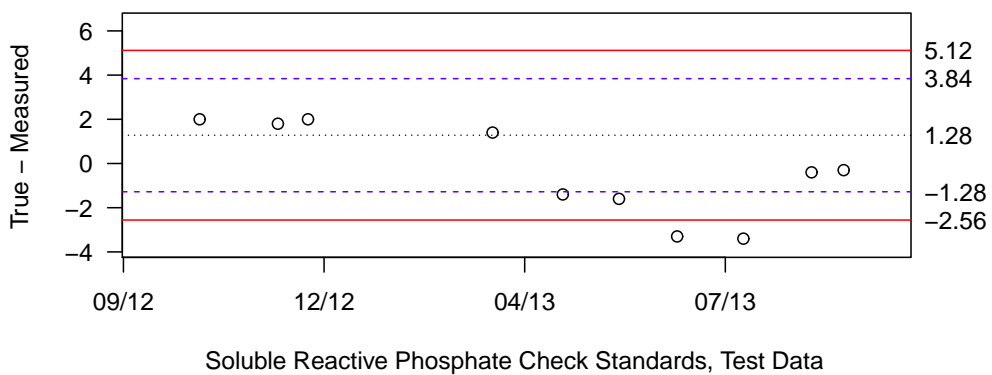
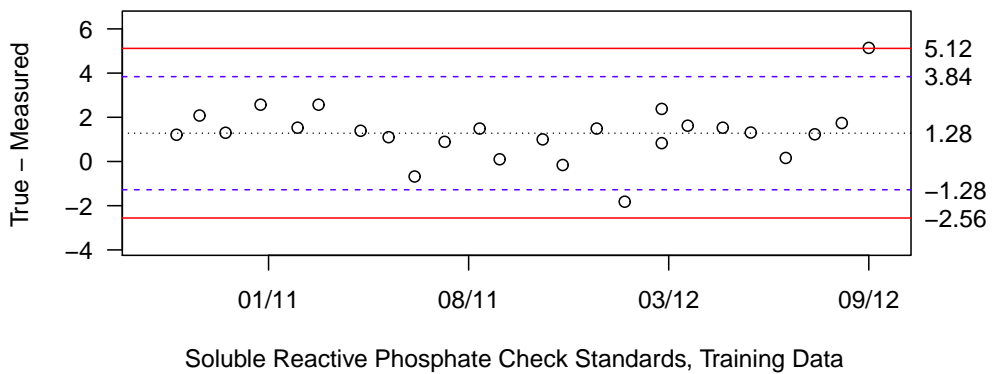


Figure C21: Soluble reactive phosphate high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

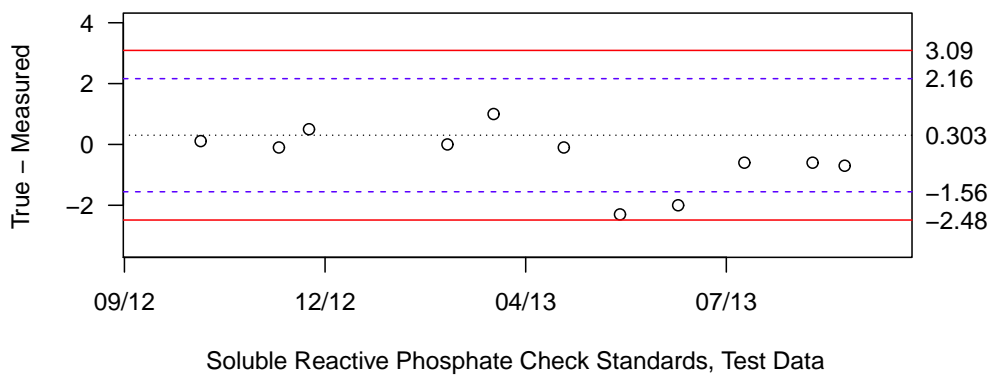
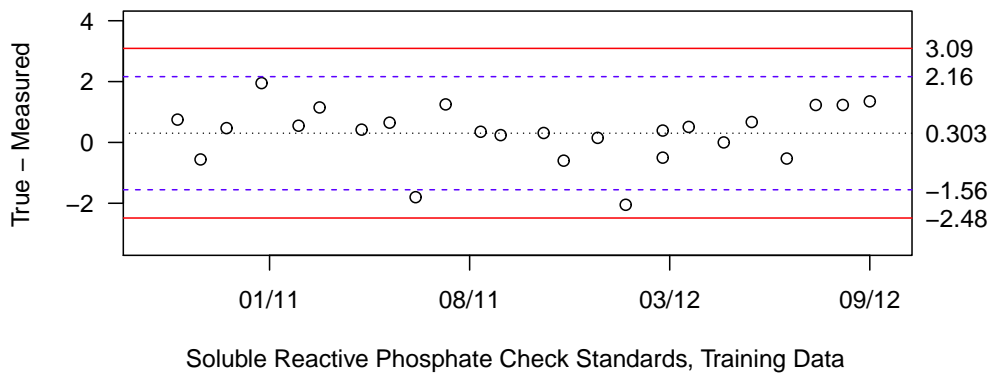


Figure C22: Soluble reactive phosphate low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding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

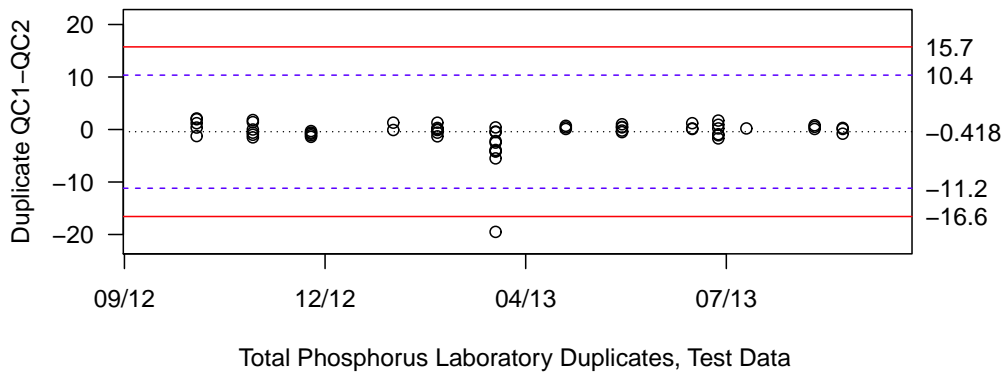
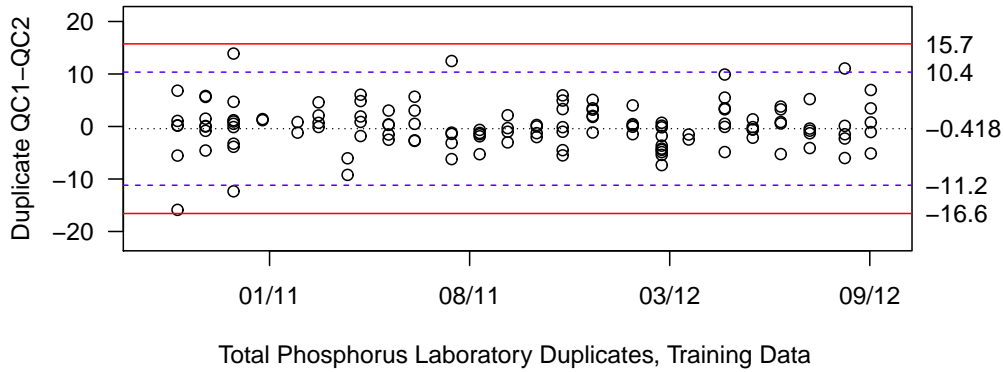


Figure C23: Total phosphorus laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data. Slight increase in variability may be due to insufficient persulfate concentration; method revised to increase concentration.

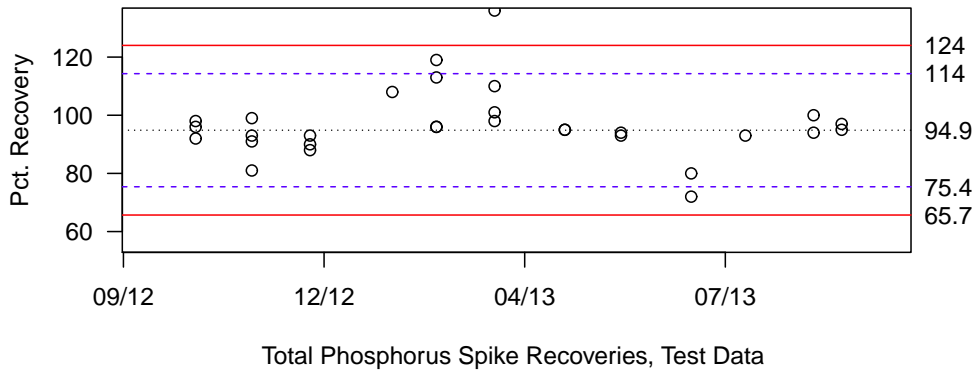
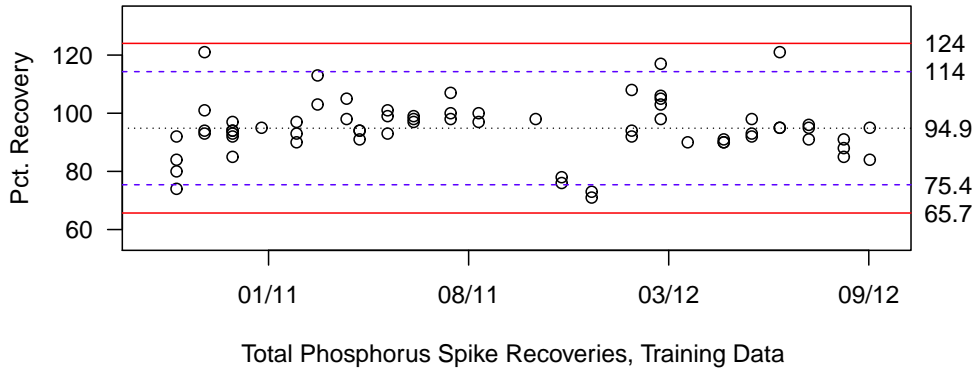


Figure C24: Total phosphorus spike recoveries for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

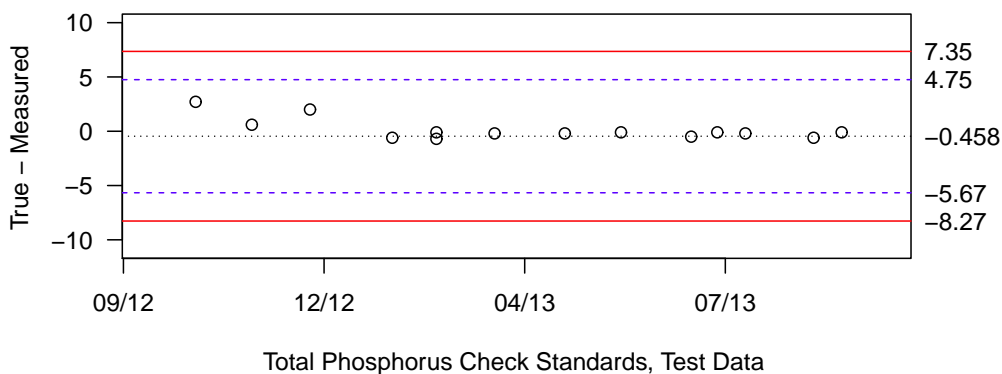
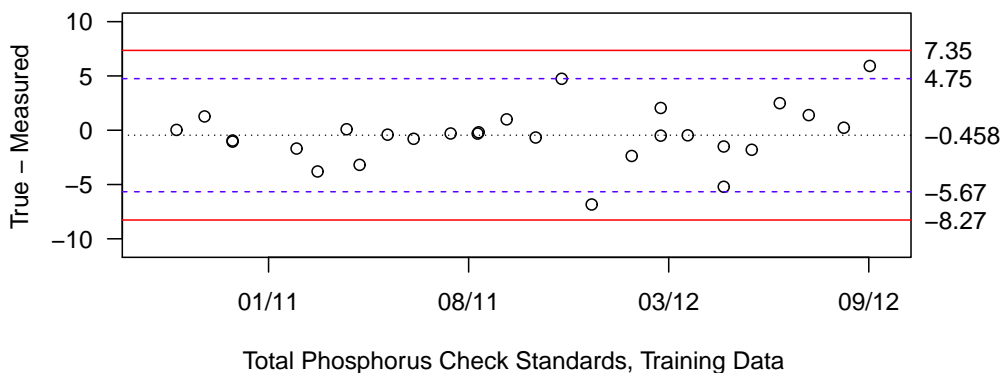


Figure C25: Total phosphorus high-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

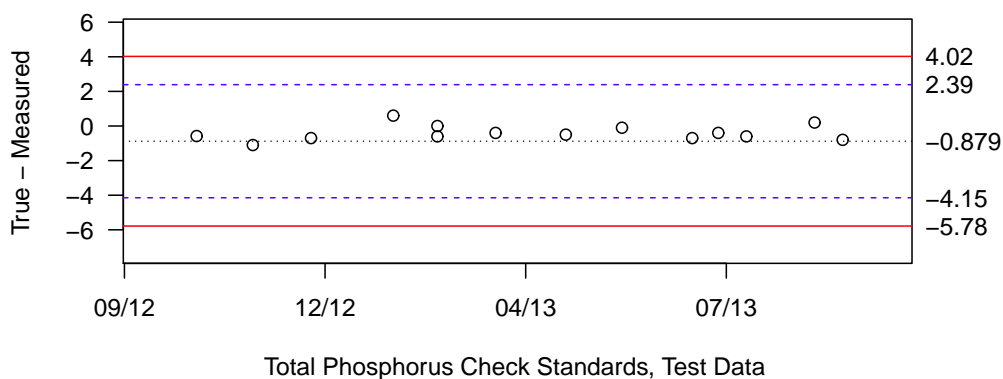
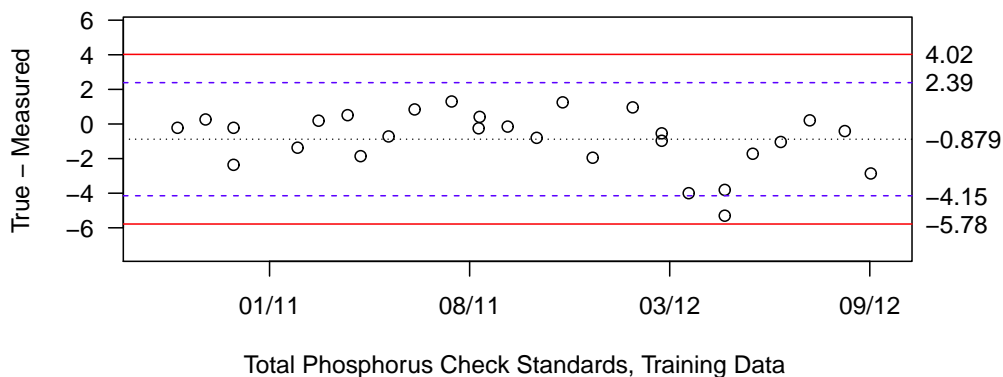


Figure C26: Total phosphorus low-range check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years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



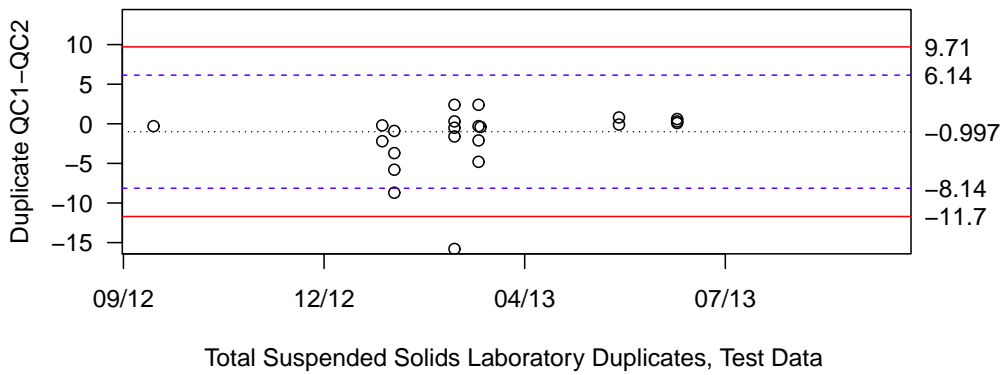
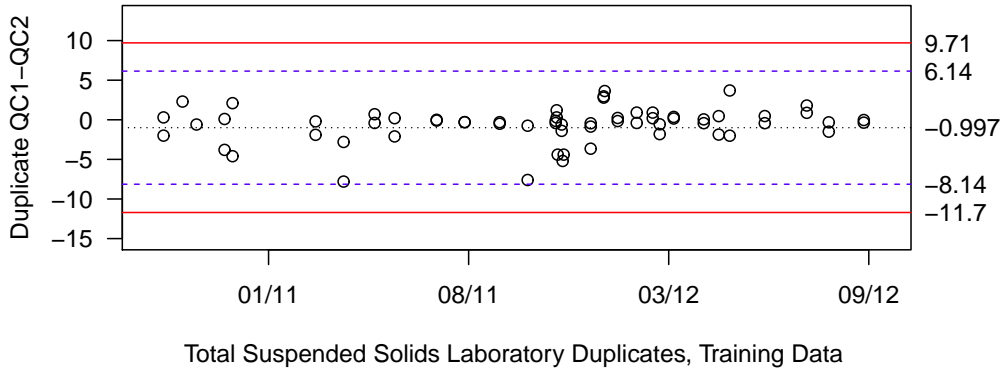


Figure C27: Total suspended solids laboratory duplicates for the Lake Whatcom monitoring program (creek and storm water samples). Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

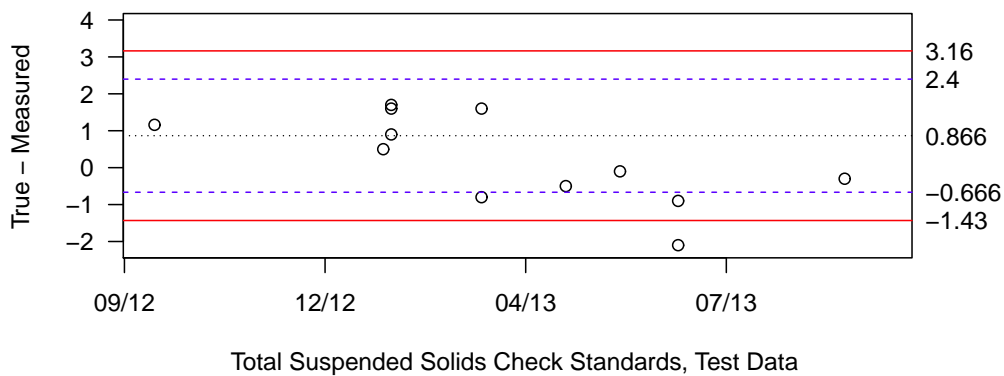
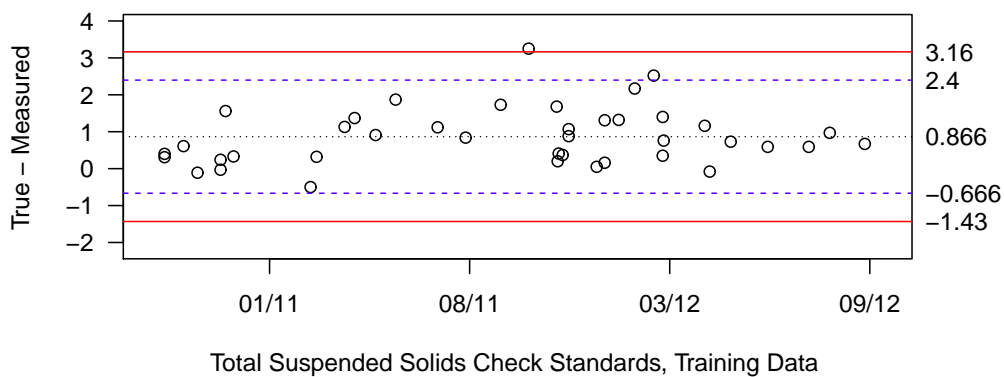


Figure C28: Total suspended solids check standards for the Lake Whatcom monitoring program (creek and storm water samples). Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based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

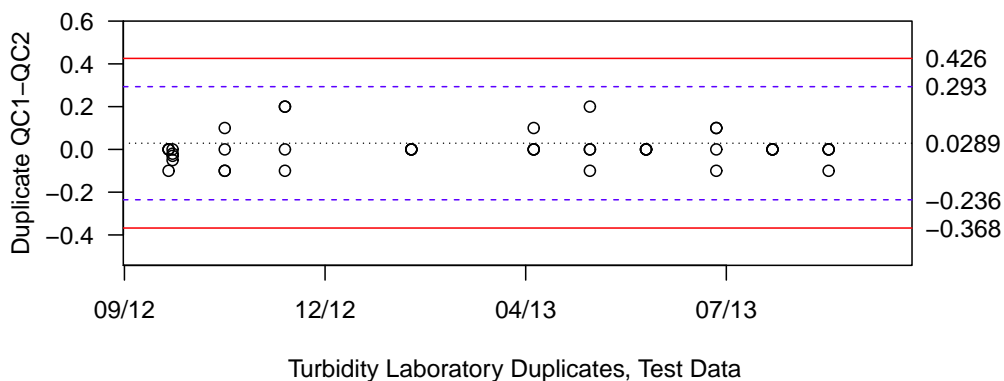
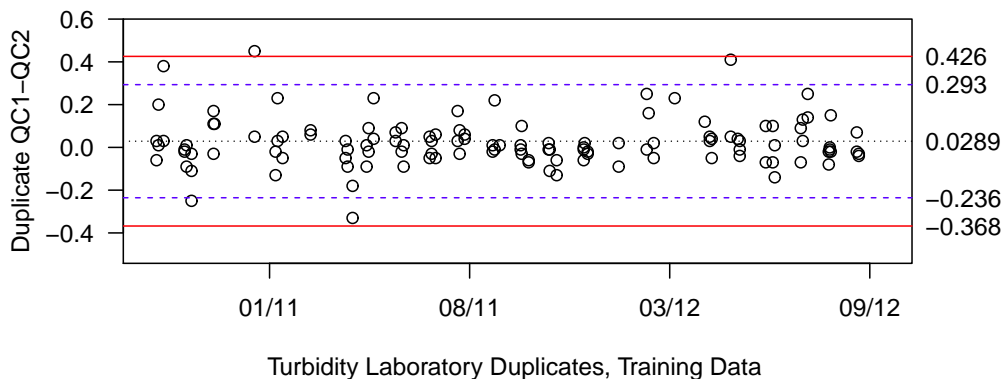


Figure C29: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits ( $\pm 2$  std. dev. from mean pair difference) and upper/lower warning limits ( $\pm 3$  std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

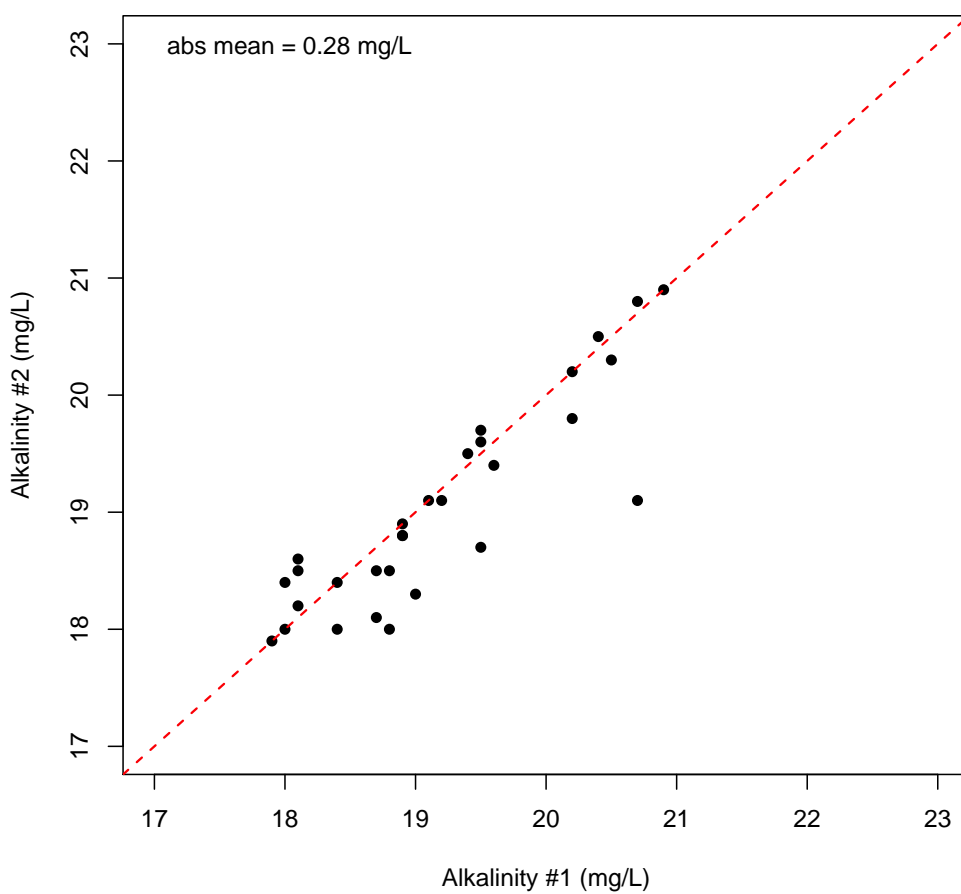


Figure C30: Alkalinity field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

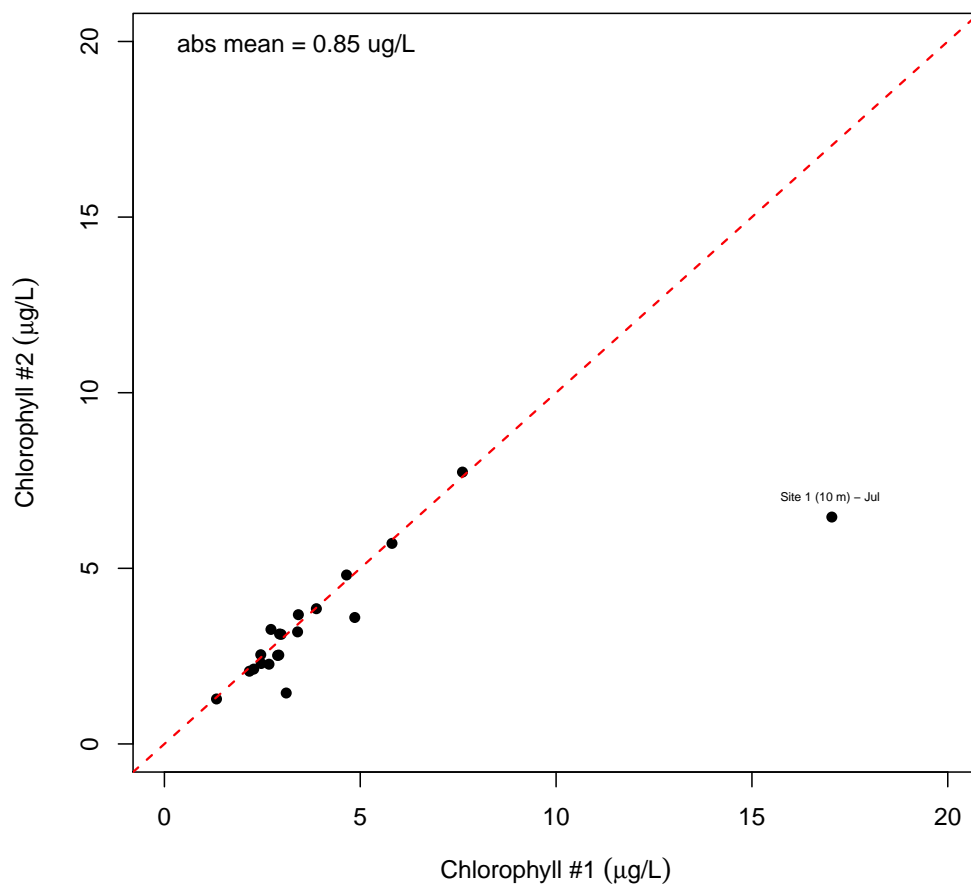


Figure C31: Chlorophyll field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. The labeled outlier was collected from the portion of the water column exhibiting a metalimnetic oxygen maximum (see discussion on page 7).

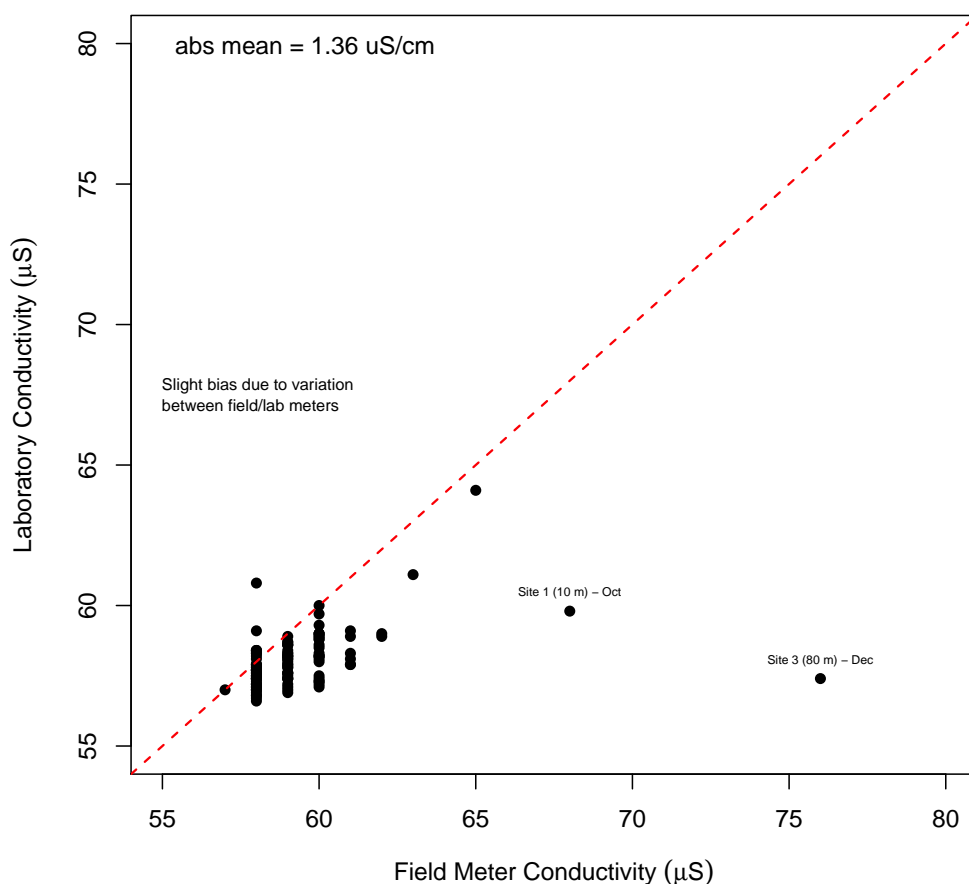


Figure C32: Conductivity field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. The high degree of scatter is due to the low concentration of the samples. The labeled outliers were collected when the lake was stratified, or recently destratified and incompletely mixed, at depths where extreme gradients were present. Field meter samples were collected at true depth; laboratory samples were collected using a marked line, which is slightly shallower than true depth.

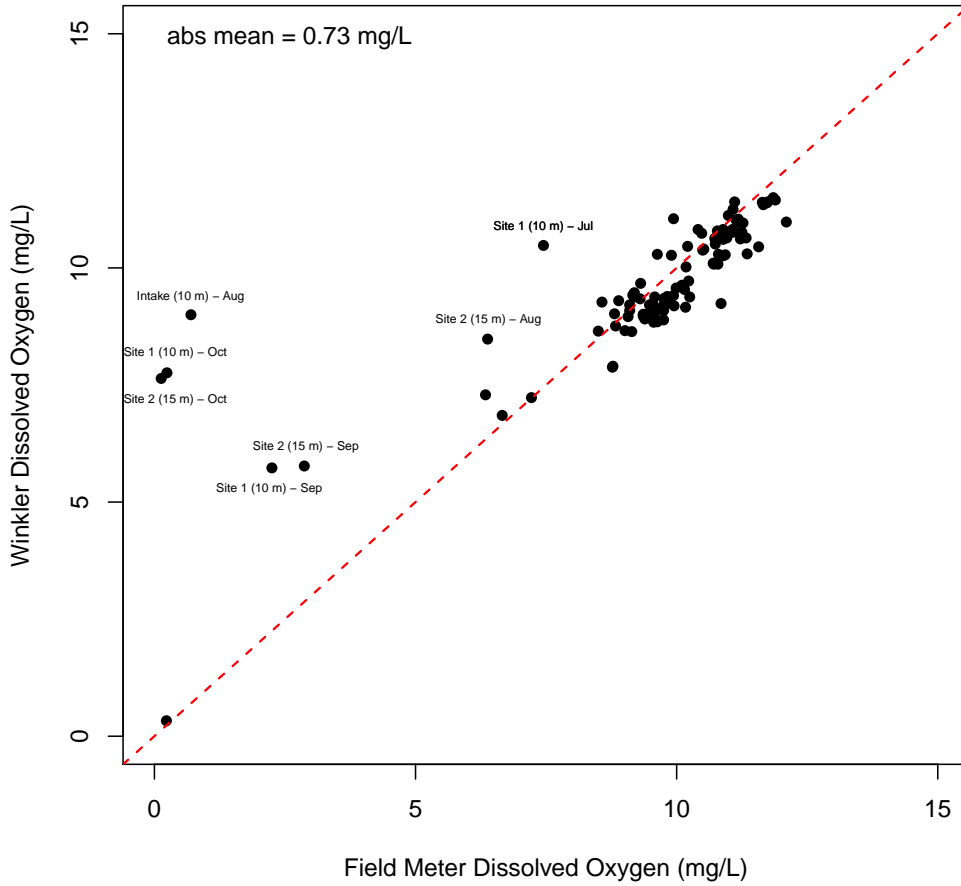


Figure C33: Dissolved oxygen field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. The labeled outliers were collected when the lake was stratified, or recently destratified and incompletely mixed, at depths where extreme gradients were present. Field meter samples were collected at true depth; Winkler samples were collected using a marked line, which is slightly shallower than true depth.

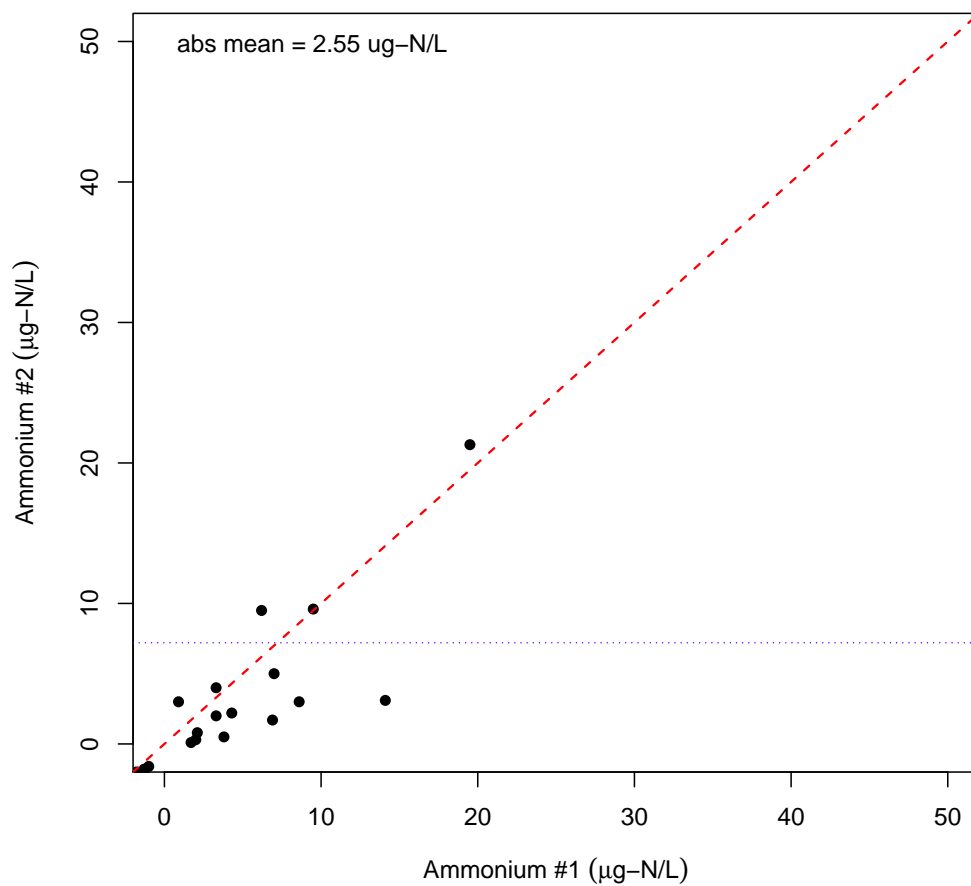


Figure C34: Ammonium field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.



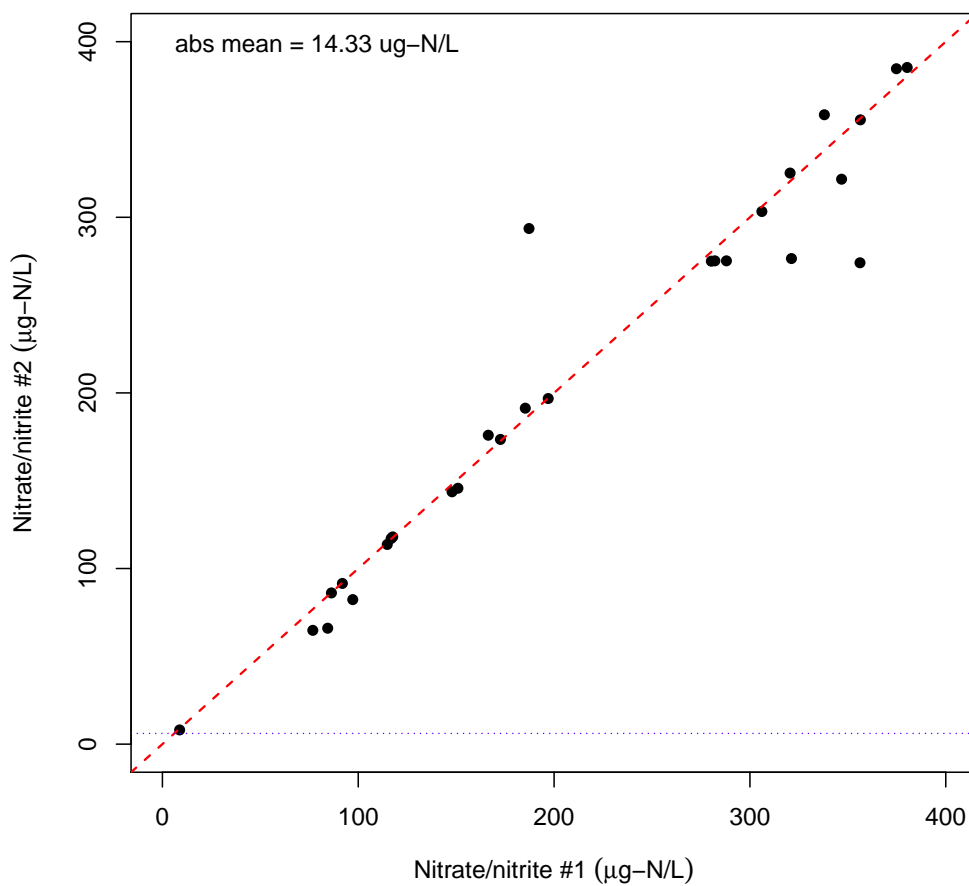


Figure C35: Nitrate/nitrite field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

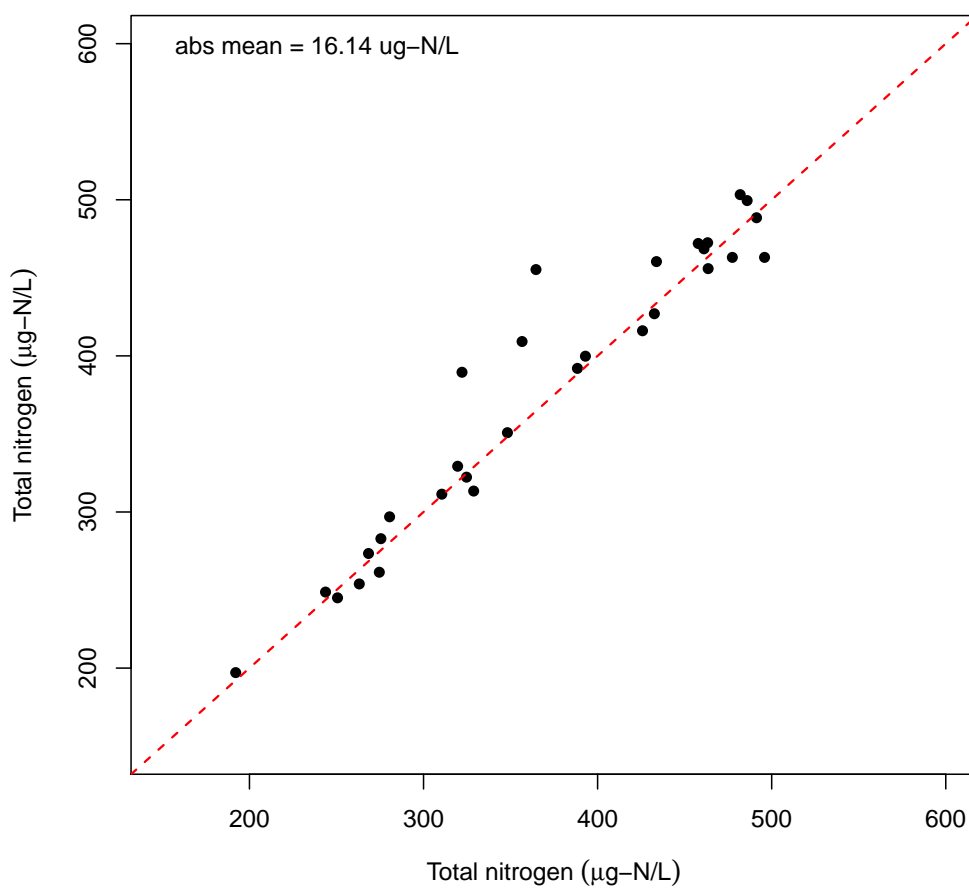


Figure C36: Total nitrogen field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.

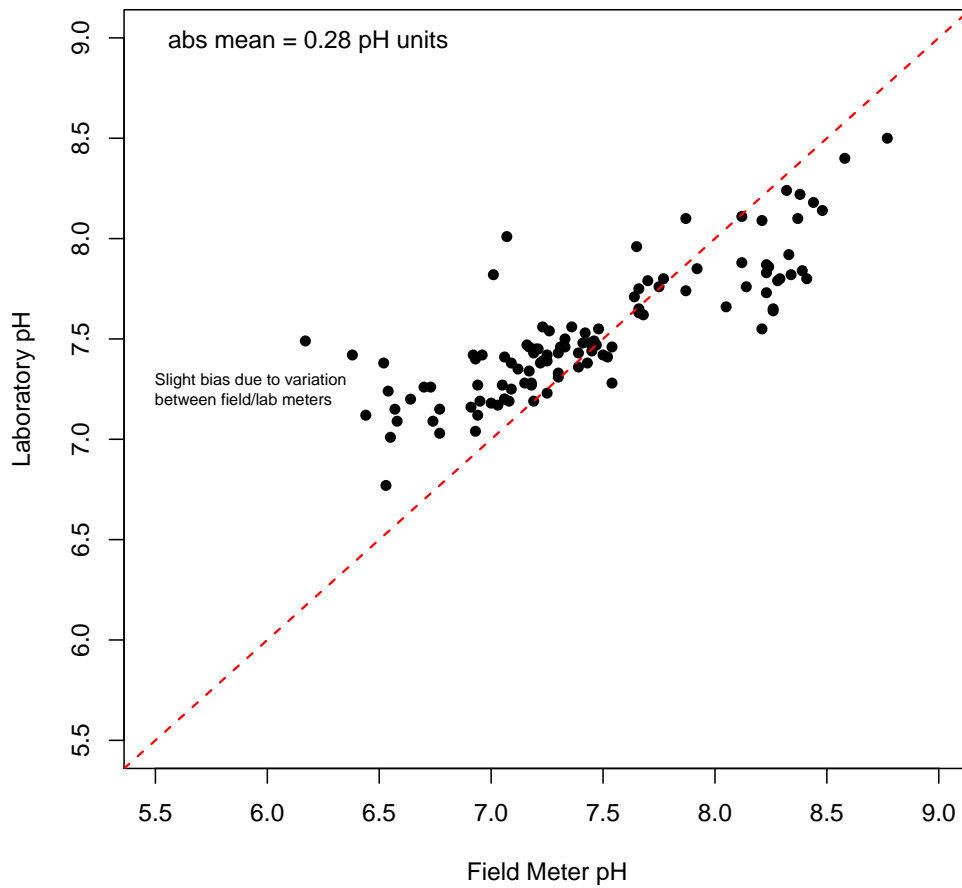


Figure C37: Field duplicates for pH from the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship.

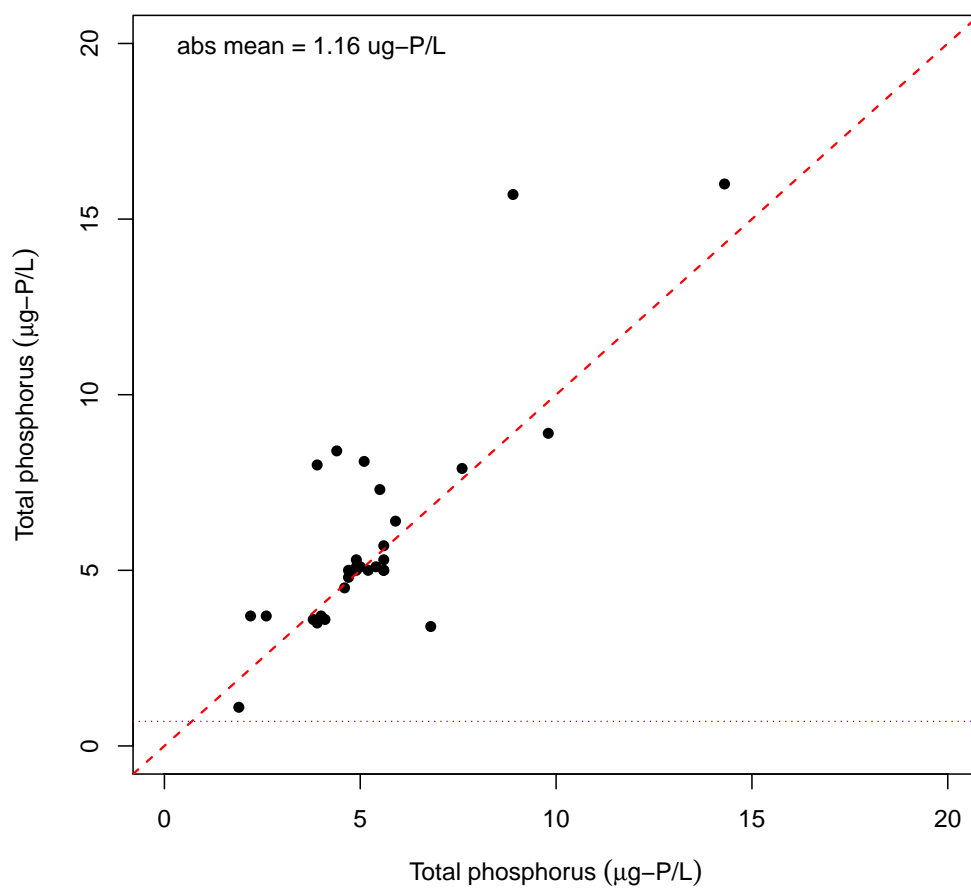


Figure C38: Total phosphorus field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. The high degree of scatter is due to the low concentrations of the samples.

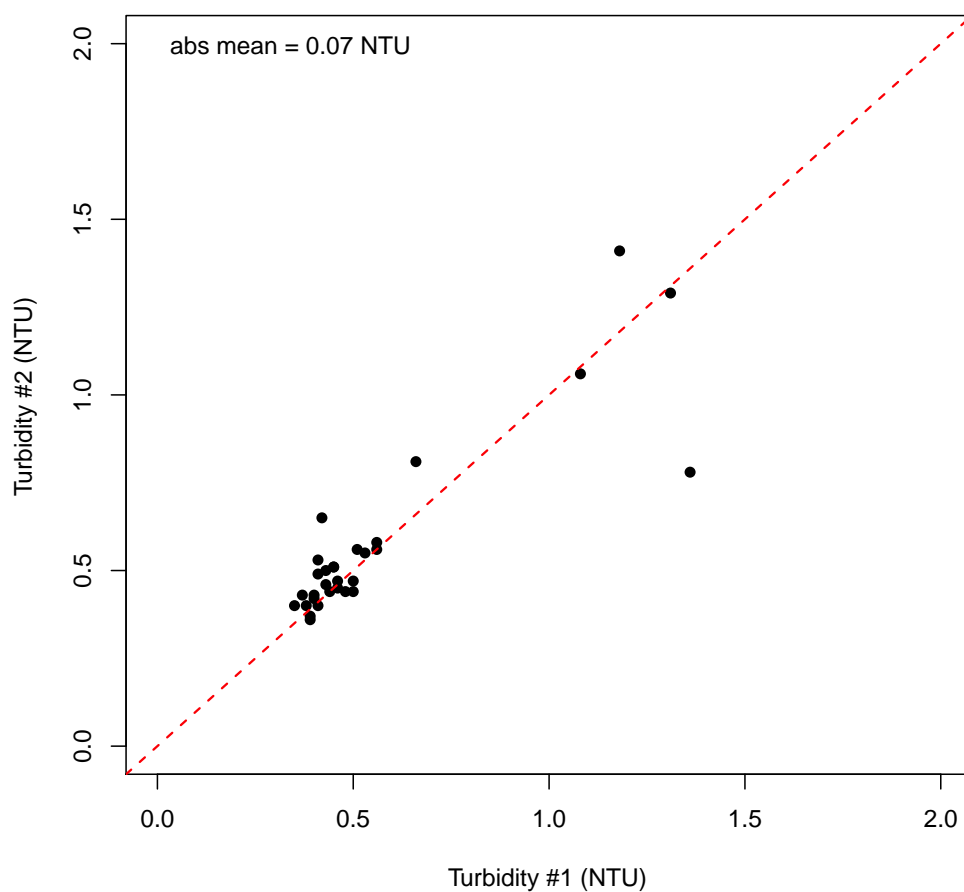


Figure C39: Turbidity field duplicates for the 2012/2013 Lake Whatcom Monitoring Project (lake samples). Diagonal reference line shows a 1:1 relationship. The high degree of scatter is due to the low concentrations of the samples.

(This page blank)

## D Lake Whatcom Online Data

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

```
*****
* README FILE - LAKE WHATCOM ONLINE DATA
* THIS FILE WAS UPDATED JANUARY 3, 2014
*****
Most of the Lake Whatcom water quality data are available in
electronic format at the IWS website (http://www.wvu.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      Water quality data    Plankton data
1988_hl.csv           1988_wq.csv           plankton.csv
1989_hl.csv           1989_wq.csv
1990_hl.csv           1990_wq.csv
1991_hl.csv           1991_wq.csv
1992_hl.csv           1992_wq.csv
1993_hl.csv           1993_wq.csv
1994_hl.csv           1994_wq.csv
1995_hl.csv           1995_wq.csv
1996_hl.csv           1996_wq.csv
1997_hl.csv           1997_wq.csv
1998_hl.csv           1998_wq.csv
1999_hl.csv           1999_wq.csv
2000_hl.csv           2000_wq.csv
2001_hl.csv           2001_wq.csv
2002_hl.csv           2002_wq.csv
2003_hl.csv           2003_wq.csv
2004_hl.csv           2004_wq.csv
2005_hl.csv           2005_wq.csv
2006_hl.csv           2006_wq.csv
2007_hl.csv           2007_wq.csv
2008_hl.csv           2008_wq.csv
2009_hl.csv           2009_wq.csv
2010_hl.csv           2010_wq.csv
2011_hl.csv           2011_wq.csv
2012_hl.csv           2012_wq.csv
2013_hl.csv           2013_wq.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 (revised March 8, 2012)  
WY2001.csv  
WY2002.csv  
WY2003.csv  
WY2004\_rev.csv (revised June 21, 2006)  
WY2005.csv  
WY2006.csv  
WY2007.csv (revised July 31, 2008)  
WY2008.csv  
WY2009.csv  
WY2010.csv  
WY2011.csv  
WY2012.csv  
WY2013.csv

The WY\*.csv files include: month, day, year, hour, min, sec, ander.g (anderson gage height, ft), ander.cfs (anderson discharge, cfs), austin.g (austin gage height, ft), austin.cfs (austin discharge, cfs), smith.g (smith gage height, ft), smith.cfs (smith discharge, cfs). Anderson Creek hydrograph data were deleted in WY2000\_rev.csv due to uncertainty about the gage 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 and sent to the City. Unusual results are identified. This step is completed by the IWS Director. 3) The results are reviewed on an annual basis and discussed in the Lake Whatcom Monitoring Program Final Report. Unusual results are identified, and explained, if possible. This step is completed by the IWS Director, IWS Laboratory Supervisor, and Laboratory Analyst. 4) Single-blind quality control samples, laboratory duplicates, and field duplicates are analyzed as specified in the Lake Whatcom Monitoring Program contract and in the IWS Laboratory Certification requirements. Unusual results that suggest instrumentation or analytical problems are reported to the IWS Director and City. The results from these analyses are summarized in the annual report.

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

Prior to 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.