



3-30-2006

Lake Whatcom Monitoring Project 2004/2005 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

Follow this and additional works at: https://cedar.wwu.edu/lakewhat_annualreps



Part of the [Environmental Monitoring Commons](#)

Recommended Citation

Matthews, Robin A.; Hilles, Michael; Vandersypen, Joan; Mitchell, Robert J.; and Matthews, Geoffrey B., "Lake Whatcom Monitoring Project 2004/2005 Report" (2006). *Lake Whatcom Annual Reports*. 10.

https://cedar.wwu.edu/lakewhat_annualreps/10

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.

Lake Whatcom Monitoring Project 2004/2005 Final Report

Dr. Robin A. Matthews,
Mr. Mike Hilles
Ms. Joan Vandersypen
Institute for Watershed Studies,
Western Washington University

Dr. Robert J. Mitchell
Geology Department
Western Washington University

Dr. Geoffrey B. Matthews
Computer Science Department
College of Arts & Sciences
Western Washington University*

March 30, 2006

*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, Stephen Backholm, Stephen Bond, Ryan Bradley, Allison Daniels, Gerald Gabrisch, Alexander Hansen, Kara Hitchko, Alexandra Karpoff, Michael LeMoine, Jason Mahr, Lisa Marko, Nicholas Marlatt, Deka Olson, Rebecca Rowland, Jordan Sly, Ryan Vasak, Dan Whealdon-Haught, Deborah Wilson, Melinda Woodard, and Golnar Zandpoor for their assistance with the project

Contents

1	Introduction	1
2	Lake Whatcom Monitoring	2
2.1	Site Descriptions	2
2.2	Field Sampling and Analytical Methods	2
2.3	Results and Discussion	3
2.3.1	Water temperature	4
2.3.2	Dissolved oxygen	5
2.3.3	Conductivity and pH	7
2.3.4	Alkalinity and turbidity	7
2.3.5	Nitrogen and phosphorus	7
2.3.6	Chlorophyll, plankton, and Secchi depth	9
2.3.7	Coliform bacteria	11
2.3.8	Metals	12
2.3.9	Total organic carbon and disinfection by-products	13
3	Creek Monitoring	39
3.1	Site Descriptions	39
3.2	Field Sampling and Analytical Methods	39
3.3	Results and Discussion	40
3.3.1	Monthly creek monitoring	40
3.3.2	Comparison to Smith Creek	42
3.3.3	48-hr sampling	42
3.3.4	Austin Creek and Beaver Creek intensive sampling	43

4	Lake Whatcom Hydrology	86
4.1	Hydrograph Data	86
4.2	Watershed Modeling	86
4.3	Water Budget	87
5	Storm Water Treatment Monitoring	106
5.1	Sampling procedures	106
5.2	Results and Discussion	107
6	References	120
6.1	Lake Whatcom Reports	124
A	Site Descriptions	127
A.1	Lake Whatcom Monitoring Sites	127
A.2	Creek Monitoring Sites	127
A.3	Storm Water Monitoring Sites	129
B	Lake Whatcom Historic Water Quality Figures	143
B.1	Monthly Hydrolab Profiles	144
B.2	Temperature, Dissolved Oxygen, pH, Conductivity	195
B.3	Alkalinity and Turbidity	216
B.4	Nitrogen and Phosphorus	227
B.5	Plankton, Chlorophyll, Secchi Depth	253
B.6	Coliform Bacteria	274
C	Quality Control	285
C.1	Laboratory Duplicates	286

C.2	Field Duplicate Results	295
D	Lake Whatcom Data	301
D.1	Lake Whatcom Hydrolab Data	303
D.2	Lake Whatcom Water Quality Data	320
D.3	Lake Whatcom Tributary Data	325
D.4	Lake Whatcom Plankton Data	334
D.5	Storm Water Treatment Monitoring Data	336
D.6	City of Bellingham Coliform Data	340
D.7	Lake Whatcom Electronic Data	357
D.8	AmTest Metals and TOC (Lake, Creeks, Storm Water)	358

List of Figures

1	Comparison of 2005 surface water temperatures (●) to boxplots showing 1988–2004 surface temperature medians and ranges (depth <1 m for all sites and years).	25
2	Correlation between fecal coliforms and <i>E. coli</i> counts in surface water samples (lake, stream, storm water treatment facility) in the Lake Whatcom watershed, October 2004 – September 2005. . . .	26
3	Iron concentration in untreated drinking water measured at the Lake Whatcom gatehouse, 1998–2005.	27
4	Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 12 m.	28
5	Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 14 m.	29
6	Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 16 m.	30
7	Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 18 m.	31
8	Distribution of summer (May–Sept) algal counts by year (Sites 1–4 combined).	32
9	Distribution of summer (May–Sept) Cyanophyta counts at Sites 1–4 by year.	33
10	Median Cyanophyta annual and summer (May–Sept) densities at Sites 1–4, 1992–2005.	34
11	Lake Whatcom annual chlorophyll densities, 1994–2004.	35
12	Lake Whatcom total organic carbon concentrations from surface and bottom samples at Sites 1–4 and the Intake.	36
13	Lake Whatcom total organic carbon concentrations at Site 2 (mid-basin, surface/bottom), the Intake (off-shore, surface/bottom), and the raw water gatehouse (data provided by the City of Bellingham Public Works Department).	37

14	Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2005.	38
15	Summary of the 2004/2005 alkalinity data for all creeks.	64
16	Summary of the 2004/2005 conductivity data for all creeks.	65
17	Summary of the 2004/2005 dissolved oxygen data for all creeks.	66
18	Summary of the 2004/2005 pH data for all creeks.	67
19	Summary of the 2004/2005 temperature data for all creeks.	68
20	Summary of the 2004/2005 total solids data for all creeks.	69
21	Summary of the 2004/2005 total suspended solids data for all creeks.	70
22	Summary of the 2004/2005 turbidity data for all creeks.	71
23	Summary of the 2004/2005 total nitrogen data for all creeks.	72
24	Summary of the 2004/2005 nitrate/nitrite data for all creeks.	73
25	Summary of the 2004/2005 ammonia data for all creeks.	74
26	Summary of the 2004/2005 total phosphorus data for all creeks.	75
27	Summary of the 2004/2005 soluble reactive phosphate data for all creeks.	76
28	Summary of the 2004/2005 fecal coliform data for all creeks.	77
29	Summary of the 2004/2005 <i>E. coli</i> data for all creeks.	78
30	Monthly and 48-hr temperature and dissolved oxygen data from Lower Austin and Smith Creeks.	79
31	Monthly and 48-hr conductivity and pH data from Lower Austin and Smith Creeks.	80
32	Monthly and 48-hr alkalinity and turbidity data from Lower Austin and Smith Creeks.	81
33	Monthly and 48-hr ammonia and nitrate/nitrite data from Lower Austin and Smith Creeks.	82

34	Monthly and 48-hr soluble phosphate and coliform data from Lower Austin and Smith Creeks.	83
35	Monthly and 48-hr total nitrogen and total phosphorus data from Anderson, Lower Austin and Smith Creeks.	84
36	Monthly and 48-hr total suspended solids and total solids data from Anderson, Lower Austin and Smith Creeks.	85
37	Anderson Creek hydrograph, October 1, 2004–September 30, 2005.	93
38	Austin Creek hydrograph, October 1, 2004–September 30, 2005. .	94
39	Smith Creek hydrograph, October 1, 2004–September 30, 2005. .	95
40	Anderson Creek, Austin Creek, and Smith Creek rating curves. . .	96
41	Lake Whatcom watershed precipitation groups and weighted areas.	97
42	Lake Whatcom watershed direct hydrologic inputs, October 1, 2004–September 30, 2005.	98
43	Lake Whatcom watershed hydrologic withdrawals, October 1, 2004–September 30, 2005.	99
44	Summary of 7-day changes in Lake Whatcom storage, watershed runoff, and Whatcom Creek flows, October 1, 2004–September 30, 2005.	100
45	Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2004–September 30, 2005.	101
46	Comparison of Lake Whatcom daily lake volumes for 2000–2005.	102
47	Anderson Creek hydrograph showing recorded and simulated values, October 1, 2004–September 30, 2005.	103
48	Austin Creek hydrograph showing recorded and simulated values, October 1, 2004–September 30, 2005.	104
49	Smith Creek hydrograph showing recorded and simulated values, October 1, 2004–September 30, 2005.	105

50	Comparison of inlet and outlet total suspended solids concentrations relative to the median 2004/2005 concentration in Smith Creek (dashed reference line) and Silver Beach Creek (dotted reference line).	117
51	Comparison of inlet and outlet total phosphorus concentrations relative to the median 2004/2005 concentration in Smith Creek (dashed reference line) and Silver Beach Creek (dotted reference line).	118
52	Inlet and outlet total phosphorus concentrations compared to the 2004/2005 minimum/maximum total phosphorus concentrations in Silver Beach Creek.	119
A1	Lake Whatcom 2004/2005 lake sampling sites.	132
A2	Lake Whatcom 2004/2005 creek sampling sites.	133
A3	Sampling sites in the Austin Creek and Beaver Creek watersheds, November 20, 2004.	134
A4	Locations of the Park Place and Brentwood wet ponds, the Parkstone swale/pond, and the Alabama Hill and Silvern vaults.	135
A5	Locations of the South Campus storm water treatment facility.	136
A6	Photograph of the Alabama Hill vault, November 2005.	137
A7	Photograph of the Brentwood wet pond, July 2004.	138
A8	Photograph of the Park Place wet pond, March 2005.	139
A9	Photograph of the Parkstone wet pond and swale, November 2003.	140
A10	Photograph of the Silvern storm water treatment vault, May 2004.	141
A11	Photograph of the South Campus storm water treatment facility, January 2005.	142
B1	Lake Whatcom Hydrolab profile for Site 1, October 7, 2004.	145
B2	Lake Whatcom Hydrolab profile for Site 2, October 7, 2004.	146
B3	Lake Whatcom Hydrolab profile for the Intake, October 7, 2004.	147

B4	Lake Whatcom Hydrolab profile for Site 3, October 5, 2004. . . .	148
B5	Lake Whatcom Hydrolab profile for Site 4, October 5, 2004. . . .	149
B6	Lake Whatcom Hydrolab profile for Site 1, November 4, 2004. . . .	150
B7	Lake Whatcom Hydrolab profile for Site 2, November 4, 2004. . . .	151
B8	Lake Whatcom Hydrolab profile for the Intake, November 4, 2004. . . .	152
B9	Lake Whatcom Hydrolab profile for Site 3, November 3, 2004. . . .	153
B10	Lake Whatcom Hydrolab profile for Site 4, November 3, 2004. . . .	154
B11	Lake Whatcom Hydrolab profile for Site 1, December 9, 2004. . . .	155
B12	Lake Whatcom Hydrolab profile for Site 2, December 9, 2004. . . .	156
B13	Lake Whatcom Hydrolab profile for the Intake, December 9, 2004. . . .	157
B14	Lake Whatcom Hydrolab profile for Site 3, December 7, 2004. . . .	158
B15	Lake Whatcom Hydrolab profile for Site 4, December 7, 2004. . . .	159
B16	Lake Whatcom Hydrolab profile for Site 1, February 3, 2005. . . .	160
B17	Lake Whatcom Hydrolab profile for Site 2, February 3, 2005. . . .	161
B18	Lake Whatcom Hydrolab profile for the Intake, February 3, 2005. . . .	162
B19	Lake Whatcom Hydrolab profile for Site 3, February 1, 2005. . . .	163
B20	Lake Whatcom Hydrolab profile for Site 4, February 1, 2005. . . .	164
B21	Lake Whatcom Hydrolab profile for Site 1, April 13, 2005. . . .	165
B22	Lake Whatcom Hydrolab profile for Site 2, April 13, 2005. . . .	166
B23	Lake Whatcom Hydrolab profile for the Intake, April 13, 2005. . . .	167
B24	Lake Whatcom Hydrolab profile for Site 3, April 11, 2005. . . .	168
B25	Lake Whatcom Hydrolab profile for Site 4, April 11, 2005. . . .	169
B26	Lake Whatcom Hydrolab profile for Site 1, May 5, 2005. . . .	170
B27	Lake Whatcom Hydrolab profile for Site 2, May 5, 2005. . . .	171
B28	Lake Whatcom Hydrolab profile for the Intake, May 5, 2005. . . .	172

B29	Lake Whatcom Hydrolab profile for Site 3, May 4, 2005.	173
B30	Lake Whatcom Hydrolab profile for Site 4, May 4, 2005.	174
B31	Lake Whatcom Hydrolab profile for Site 1, June 2, 2005.	175
B32	Lake Whatcom Hydrolab profile for Site 2, June 2, 2005.	176
B33	Lake Whatcom Hydrolab profile for the Intake, June 2, 2005.	177
B34	Lake Whatcom Hydrolab profile for Site 3, June 1, 2005.	178
B35	Lake Whatcom Hydrolab profile for Site 4, June 1, 2005.	179
B36	Lake Whatcom Hydrolab profile for Site 1, July 7, 2005.	180
B37	Lake Whatcom Hydrolab profile for Site 2, July 7, 2005.	181
B38	Lake Whatcom Hydrolab profile for the Intake, July 7, 2005.	182
B39	Lake Whatcom Hydrolab profile for Site 3, July 5, 2005.	183
B40	Lake Whatcom Hydrolab profile for Site 4, July 5, 2005.	184
B41	Lake Whatcom Hydrolab profile for Site 1, August 4, 2005.	185
B42	Lake Whatcom Hydrolab profile for Site 2, August 4, 2005.	186
B43	Lake Whatcom Hydrolab profile for the Intake, August 4, 2005.	187
B44	Lake Whatcom Hydrolab profile for Site 3, August 2, 2005.	188
B45	Lake Whatcom Hydrolab profile for Site 4, August 2, 2005.	189
B46	Lake Whatcom Hydrolab profile for Site 1, September 8, 2005.	190
B47	Lake Whatcom Hydrolab profile for Site 2, September 8, 2005.	191
B48	Lake Whatcom Hydrolab profile for the Intake, September 8, 2005.	192
B49	Lake Whatcom Hydrolab profile for Site 3, September 6, 2005.	193
B50	Lake Whatcom Hydrolab profile for Site 4, September 6, 2005.	194
B51	Lake Whatcom temperature data for Site 1 (1988–2005).	196
B52	Lake Whatcom temperature data for Site 2 (1988–2005).	197
B53	Lake Whatcom temperature data for the Intake (1988–2005).	198

B54	Lake Whatcom temperature data for Site 3 (1988–2005).	199
B55	Lake Whatcom temperature data for Site 4 (1988–2005).	200
B56	Lake Whatcom dissolved oxygen data for Site 1 (1988–2005).	201
B57	Lake Whatcom dissolved oxygen data for Site 2 (1988–2005).	202
B58	Lake Whatcom dissolved oxygen data for the Intake (1988–2005).	203
B59	Lake Whatcom dissolved oxygen data for Site 3 (1988–2005).	204
B60	Lake Whatcom dissolved oxygen data for Site 4 (1988–2005).	205
B61	Lake Whatcom pH data for Site 1 (1988–2005).	206
B62	Lake Whatcom pH data for Site 2 (1988–2005).	207
B63	Lake Whatcom pH data for the Intake (1988–2005).	208
B64	Lake Whatcom pH data for Site 3 (1988–2005).	209
B65	Lake Whatcom pH data for Site 4 (1988–2005).	210
B66	Lake Whatcom conductivity data for Site 1 (1988–2005).	211
B67	Lake Whatcom conductivity data for Site 2 (1988–2005).	212
B68	Lake Whatcom conductivity data for the Intake (1988–2005).	213
B69	Lake Whatcom conductivity data for Site 3 (1988–2005).	214
B70	Lake Whatcom conductivity data for Site 4 (1988–2005).	215
B71	Lake Whatcom alkalinity data for Site 1 (1988–2005).	217
B72	Lake Whatcom alkalinity data for Site 2 (1988–2005).	218
B73	Lake Whatcom alkalinity data for the Intake (1988–2005).	219
B74	Lake Whatcom alkalinity data for Site 3 (1988–2005).	220
B75	Lake Whatcom alkalinity data for Site 4 (1988–2005).	221
B76	Lake Whatcom turbidity data for Site 1 (1988–2005).	222
B77	Lake Whatcom turbidity data for Site 2 (1988–2005).	223
B78	Lake Whatcom turbidity data for the Intake (1988–2005).	224

B79	Lake Whatcom turbidity data for Site 3 (1988–2005).	225
B80	Lake Whatcom turbidity data for Site 4 (1988–2005).	226
B81	Lake Whatcom ammonia data for Site 1 (1988–2005).	228
B82	Lake Whatcom ammonia data for Site 2 (1988–2005).	229
B83	Lake Whatcom ammonia data for the Intake (1988–2005).	230
B84	Lake Whatcom ammonia data for Site 3 (1988–2005).	231
B85	Lake Whatcom ammonia data for Site 4 (1988–2005).	232
B86	Lake Whatcom nitrate/nitrite data for Site 1 (1988–2005).	233
B87	Lake Whatcom nitrate/nitrite data for Site 2 (1988–2005).	234
B88	Lake Whatcom nitrate/nitrite data for the Intake (1988–2005).	235
B89	Lake Whatcom nitrate/nitrite data for Site 3 (1988–2005).	236
B90	Lake Whatcom nitrate/nitrite data for Site 4 (1988–2005).	237
B91	Lake Whatcom total nitrogen data for Site 1 (1988–2005).	238
B92	Lake Whatcom total nitrogen data for Site 2 (1988–2005).	239
B93	Lake Whatcom total nitrogen data for the Intake (1988–2005).	240
B94	Lake Whatcom total nitrogen data for Site 3 (1988–2005).	241
B95	Lake Whatcom total nitrogen data for Site 4 (1988–2005).	242
B96	Lake Whatcom soluble phosphate data for Site 1 (1988–2005).	243
B97	Lake Whatcom soluble phosphate data for Site 2 (1988–2005).	244
B98	Lake Whatcom soluble phosphate data for the Intake (1988–2005).	245
B99	Lake Whatcom soluble phosphate data for Site 3 (1988–2005).	246
B100	Lake Whatcom soluble phosphate data for Site 4 (1988–2005).	247
B101	Lake Whatcom total phosphorus data for Site 1 (1988–2005).	248
B102	Lake Whatcom total phosphorus data for Site 2 (1988–2005).	249
B103	Lake Whatcom total phosphorus data for the Intake (1988–2005).	250

B104	Lake Whatcom total phosphorus data for Site 3 (1988–2005).	251
B105	Lake Whatcom total phosphorus data for Site 4 (1988–2005).	252
B106	Lake Whatcom chlorophyll data for Site 1 (1988–2005).	254
B107	Lake Whatcom chlorophyll data for Site 2 (1988–2005).	255
B108	Lake Whatcom chlorophyll data for the Intake (1988–2005).	256
B109	Lake Whatcom chlorophyll data for Site 3 (1988–2005).	257
B110	Lake Whatcom chlorophyll data for Site 4 (1988–2005).	258
B111	Lake Whatcom plankton data for Site 1 (1992–2005).	259
B112	Lake Whatcom plankton data for Site 2 (1992–2005).	260
B113	Lake Whatcom plankton data for the Intake (1992–2005).	261
B114	Lake Whatcom plankton data for Site 3 (1992–2005).	262
B115	Lake Whatcom plankton data for Site 4 (1992–2005).	263
B116	Lake Whatcom plankton data for Site 1, plotted to show Cyanophyta and Chlorophyta (1992–2005).	264
B117	Lake Whatcom plankton data for Site 2, plotted to show Cyanophyta and Chlorophyta (1992–2005).	265
B118	Lake Whatcom plankton data for the Intake, plotted to show Cyanophyta and Chlorophyta (1992–2005).	266
B119	Lake Whatcom plankton data for Site 3, plotted to show Cyanophyta and Chlorophyta (1992–2005).	267
B120	Lake Whatcom plankton data for Site 4, plotted to show Cyanophyta and Chlorophyta (1992–2005).	268
B121	Lake Whatcom Secchi depths for Site 1.	269
B122	Lake Whatcom Secchi depths for Site 2.	270
B123	Lake Whatcom Secchi depths for the Intake.	271
B124	Lake Whatcom Secchi depths for Site 3.	272

B125	Lake Whatcom Secchi depths for Site 4.	273
B126	Lake Whatcom fecal coliform data for Site 1 (1994–2005).	275
B127	Lake Whatcom fecal coliform data for Site 2 (1994–2005).	276
B128	Lake Whatcom fecal coliform data for the Intake (1994–2005).	277
B129	Lake Whatcom fecal coliform data for Site 3 (1994–2005).	278
B130	Lake Whatcom fecal coliform data for Site 4 (1994–2005).	279
B131	Lake Whatcom <i>E. coli</i> data for Site 1.	280
B132	Lake Whatcom <i>E. coli</i> data for Site 2.	281
B133	Lake Whatcom <i>E. coli</i> data for the Intake.	282
B134	Lake Whatcom <i>E. coli</i> data for Site 3.	283
B135	Lake Whatcom <i>E. coli</i> for Site 4.	284
C1	Alkalinity laboratory duplicate control chart for the Lake Whatcom monitoring program.	287
C2	Ammonia laboratory duplicate control chart for the Lake Whatcom monitoring program.	288
C3	Chlorophyll laboratory duplicate control chart for the Lake Whatcom monitoring program.	289
C4	Nitrate/nitrite laboratory duplicate control chart for the Lake Whatcom monitoring program.	290
C5	Soluble reactive phosphate laboratory duplicate control chart for the Lake Whatcom monitoring program.	291
C6	Total nitrogen laboratory duplicate control chart for the Lake Whatcom monitoring program.	292
C7	Total phosphorus laboratory duplicate control chart for the Lake Whatcom monitoring program.	293
C8	Turbidity laboratory duplicate control chart for the Lake Whatcom monitoring program.	294

C9 Alkalinity and conductivity field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. 296

C10 Dissolved oxygen and pH field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. 297

C11 Ammonia and nitrate/nitrite field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. 298

C12 Total nitrogen and total phosphorus field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. 299

C13 Turbidity and chlorophyll field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. 300

List of Tables

1	Lake Whatcom 2004/2005 lake monitoring schedule.	15
2	Summary of IWS and City of Bellingham analytical methods. . .	16
3	Summary of Site 1 ambient water quality data, Oct. 2004 – Sept. 2005.	17
4	Summary of Intake ambient water quality data, Oct. 2004 – Sept. 2005.	18
5	Summary of Site 2 ambient water quality data, Oct. 2004 – Sept. 2005.	19
6	Summary of Site 3 ambient water quality data, Oct. 2004 – Sept. 2005.	20
7	Summary of Site 4 ambient water quality data, Oct. 2004 – Sept. 2005.	21
8	Lake Whatcom 2004/2005 total metals data.	22
9	Lake Whatcom 2004/2005 total organic carbon data.	23
10	October hypolimnetic ammonia and hydrogen sulfide concentra- tions at Sites 1 and 2 (1999–2005).	24
11	Lake Whatcom 2004/2005 creek monitoring schedule.	44
12	Summary of Anderson Creek monthly water quality data, Oct. 2004 – Sept. 2005.	45
13	Summary of upper Austin Creek monthly water quality data, Oct. 2004 – Sept. 2005.	46
14	Summary of upper Beaver Creek monthly water quality data, Oct. 2004 – Sept. 2005.	47
15	Summary of water quality data collected at the confluence of Austin Creek and Beaver Creek, Oct. 2004 – Sept. 2005.	48

16	Summary of lower Austin Creek (downstream from confluence with Beaver Creek) monthly water quality data, Oct. 2004 – Sept. 2005.	49
17	Summary of Blue Canyon Creek monthly water quality data, Oct. 2004 – Sept. 2005.	50
18	Summary of Brannian Creek monthly water quality data, Oct. 2004 – Sept. 2005.	51
19	Summary of Carpenter Creek monthly water quality data, Oct. 2004 – Sept. 2005.	52
20	Summary of Euclid Creek monthly water quality data, Oct. 2004 – Sept. 2005.	53
21	Summary of Millwheel Creek monthly water quality data, Oct. 2004 – Sept. 2005.	54
22	Summary of Olsen Creek monthly water quality data, Oct. 2004 – Sept. 2005.	55
23	Summary of Park Place outlet monthly water quality data, Oct. 2004 – Sept. 2005.	56
24	Summary of Silver Beach Creek monthly water quality data, Oct. 2004 – Sept. 2005.	57
25	Summary of Smith Creek monthly water quality data, Oct. 2004 – Sept. 2005.	58
26	Summary of Whatcom Creek monthly water quality data, Oct. 2004 – Sept. 2005.	59
27	Comparison of fecal coliform data from Lake Whatcom tributaries to WAC 173–201A surface water standards.	60
28	Summary of creek water quality differences based on similarity to Smith Creek.	61
29	Total metals and total organic carbon results for 48-hr composite samples collected in selected creeks in the Lake Whatcom watershed.	62

30	Abbreviations for creek sampling sites in Figures 15 – 29.	63
31	Annual water balance quantities for the Lake Whatcom watershed, WY2000–WY2005.	90
32	Monthly input water balance quantities for the Lake Whatcom watershed, October 2004–September 2005.	91
33	Monthly output water balance quantities for the Lake Whatcom watershed, October 2004–September 2005.	92
34	Storm water treatment systems monitoring schedule (2004/2005).	112
35	Park Place wet pond, South Campus rock/plant filter, and Alabama Hill vault composite samples and average percent reductions between inlet and outlet samples.	113
36	Alabama vault grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D.	114
37	Park Place wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D.	115
38	South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D.	116
A1	Approximate GPS coordinates for the current Lake Whatcom Monitoring Project sampling sites.	131
C1	Summary of 2004/2005 single-blind quality control results.	285
D1	Summary of analyses in the Lake Whatcom monitoring project.	302

Executive Summary

- This report describes the results from the 2004/2005 Lake Whatcom monitoring program. The objectives of this program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; monitor the effectiveness of storm water treatment systems; continue collection of hydrologic data from Anderson, Austin, and Smith Creeks; and update the hydrologic model for Lake Whatcom.
- 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 Lake Whatcom reports, including special project reports, is included in Section 6.1, beginning on page 124.
- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The lake was warmer during February and May, but close to historic median temperatures during most other months. The lake was stratified by the first week in May.
- 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.
- Nitrate depletion was evident at all sites in the photosynthetic zone during the summer. At Site 1 the epilimnetic nitrate concentrations fell below 20 $\mu\text{g-N/L}$, creating an environment favorable for cyanobacteria. Hypolimnetic nitrate concentrations dropped below 10 $\mu\text{g-N/L}$ at both Sites 1 and 2, indicating prolonged anaerobic conditions. High hypolimnetic concentrations of ammonia and phosphorus were present at Sites 1 and 2, which is also consistent with anaerobic conditions.
- Chlorophyll concentrations have increased significantly throughout the lake since 1994. Cell counts for all four of the major algal types, Chrysophyta (diatoms), Chlorophyta (green algae), Cyanophyta (cyanobacteria), and Pyrrophyta (dinoflagellates), have also increased throughout the lake. Cyanophyta counts have increased to where they are now at levels similar to the Chrysophyta and Chlorophyta.

- Although the 2004/2005 total organic carbon concentrations were below detection at most sites, the long-term data suggest that the concentrations may actually be increasing all sites except Site 1. Concurrently, there has been a significant increase in the concentrations of trihalomethanes in Bellingham's treated water.
- Most of the mid-basin fecal coliforms and *E. coli* counts were less than 10 cfu/100 mL. The coliform counts at the Bloedel-Donovan recreational area (collected near the dock 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.
- Zinc and iron were detected at most sites, but were within normal ranges for the lake. Chromium, copper, and nickel were detected in many of the samples, but the concentrations were near the limit of detection, so it is not clear whether this represents an actual increase in metals concentrations in the lake or just variation in low level analytical analysis. Mercury and lead were detected in a few samples, but because the concentrations were at or near detection levels, it is unlikely that these detections represent an increase in metals concentrations in the lake.
- The creeks were monitored more intensively in 2004/2005 to provide baseline data for most of the tributaries that flow into Lake Whatcom. Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of total and dissolved solids, low alkalinities and conductivities, low levels of nitrate and ammonia, and relatively low coliform counts. Residential streams had higher concentrations of total and dissolved solids, higher alkalinities and conductivities, higher nutrient concentrations, and much higher coliform counts. Blue Canyon Creek, which drains a mineral-rich portion of the watershed, had unusually high concentrations of dissolved solids, higher alkalinities, and much higher conductivities, but low nutrient and coliform levels.
- Most of the creeks failed to meet Part B of the surface water standards for coliforms (WAC 173-201A); Carpenter, Euclid, Millwheel, Park Place, and Silver Beach Creeks failed both parts of the surface water standards. Only upper Beaver Creek, Blue Canyon Creek, and Whatcom Creek passed both parts of the standard.

- Water quality in Austin Creek, Beaver Creek, and Olsen Creek was similar to Smith Creek, which was selected as a reference site. Silver Beach Creek and the Park Place wet pond outlet had the worst water quality compared to Smith Creek, with significantly higher concentrations for many of the water quality parameters. Carpenter Creek, Euclid Creek, and Millwheel Creek had high concentrations of total solids and total phosphorus, but were otherwise similar to Smith Creek.
- A water balance was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage. The major inputs into the lake during WY2005¹ included surface and subsurface runoff (74.1%), direct precipitation (16.2%), and water diverted from the Middle Fork of the Nooksack River (9.6%). Outputs included Whatcom Creek (74.0%), the City of Bellingham (9.8%), Georgia Pacific (5.3%), evaporation (7.2%), the Whatcom Falls Hatchery (3.1%), and the Lake Whatcom Water and Sewer District (0.6%).²
- The Distributed Hydrology-Soils-Vegetation Model (DHSVM) was applied to the Anderson, Austin, and Smith Creek basins in the Lake Whatcom watershed to predict surface-water runoff into the lake. The simulated stream flow results are displayed with the recorded data for each site. Calibration refinement will continue as more stream flow and weather data become available.
- Three storm water treatment systems were monitored in 2004/2005: the Park Place wet pond; the Alabama Hill underground storm water treatment vault; and the South Campus storm water treatment facility, which is outside the Lake Whatcom watershed, but is used as a reference site because it often provides better pollutant removal than systems inside the watershed.
- Of the three storm water treatment systems that were monitored in 2004/2005, only the South Campus system provided consistent phosphorus and sediment removal. The Park Place wet pond and Alabama Hill vault provided virtually no phosphorus removal and minimal or inconsistent removal of solids. The City is currently redesigning the Park Place treatment system, which should improve pollutant removal in the future.

¹Water Year 2005 covers the period from October 1, 2004 through September 30, 2005

²Formerly Water District #10

- Over the past 10 years, IWS has monitored the performance of five storm water treatment systems inside the Lake Whatcom watershed (Alabama vault, Brentwood wet pond, Park Place wet pond, Parkstone swale/pond, and Sylvan vault). The data suggest that although most of the storm water treatment systems provided some degree of sediment removal, none have provided significant or consistent reductions in phosphorus.

1 Introduction

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. Many of the reports are available online at <http://www.ac.wvu.edu/~iws> (follow links to the Lake Whatcom Watershed Project – online reports); older reports are available in the 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 6.1, beginning on page 124.

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom also provides high quality water for the Georgia-Pacific Corporation mill³, which, prior to 2001, was the largest user of Lake Whatcom water. The lake and parts of the watershed provide recreational opportunities, as well as providing important habitats for fish and wildlife. The lake is used as a storage reservoir to buffer peak storm water flows in Whatcom Creek. Much of the watershed is zoned for forestry and is managed by state or private timber companies. Because of its aesthetic appeal, much of the 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. In addition, since the City and WWU review the scope of work for the monitoring program each year, short-term water quality questions can be addressed as needed.

³The Georgia-Pacific Corporation closed its pulp mill operations in 2001, reducing its water requirements from 30–35 MGD to 7–12 MGD. The water requirements were further reduced in 2003 to 5–9 MGD when Georgia-Pacific closed all but its tissue production facility. In 2005, the water requirements were even lower, ranging from 3.5–8.5 MGD, with an average of 5 MGD for the year (City of Bellingham Public Works Dept.).

The major objectives of the 2004/2005 Lake Whatcom monitoring program were to continue long-term baseline water quality monitoring in Lake Whatcom and selected tributary streams; monitor the effectiveness of storm water treatment systems; continue collection of hydrologic data from Anderson, Austin, and Smith Creeks; and update the hydrologic model for Lake Whatcom.

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 2004/2005 monitoring data are printed in hardcopy version of this report in Appendix D and included in electronic format in the online version of this report. Table D1 on page 302 (at the beginning of Appendix D) lists all abbreviations and units used to describe water quality analyses in this document.

2 Lake Whatcom Monitoring

2.1 Site Descriptions

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (Figure A1, page 132, 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 Water Treatment Plant gatehouse, which is located onshore and west of the intake site.

2.2 Field Sampling and Analytical Methods

The lake was sampled ten times during the 2004/2005 monitoring program to measure the parameters listed in Table 1. Each sampling event is a multi-day task; all samples are collected during daylight hours, typically between 10:00 am and 3:00 pm. The sampling dates were: October 5 & 7, November 3 & 4 and December 7 & 9, 2004; and February 1 & 3, April 11 & 13, May 4 & 5, June 1 & 2, July 5 & 7, August 2 & 4, and September 6 & 8, 2005.

A Surveyor IVa Hydrolab was used to measure temperature, pH, dissolved oxygen, and conductivity. All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory, and were analyzed as described in Table 2 on page 16 (APHA, 1998; Hydrolab, 1997; Lind, 1985). Total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest.⁴ Plankton samples were placed in a cooler and returned to the laboratory unpreserved. The plankton sample volumes were measured in the laboratory and the samples were preserved with Lugol's solution. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. Unless otherwise noted, all other analyses were done by WWU personnel.

2.3 Results and Discussion

The lake monitoring data include field measurements (conductivity, dissolved oxygen, pH, Secchi depth, and water temperature); monthly or bimonthly laboratory analyses for ambient water quality parameters (ammonia, nitrate+nitrite, total nitrogen, soluble phosphate, total phosphorus, alkalinity, turbidity, chlorophyll); monthly or bimonthly plankton and bacteria; and biannual metals and total organic carbon measurements.

Tables 3–7 (pages 17–21) summarize the 2004/2005 field measurements, ambient water quality, and coliform data. The raw data are included in Appendix D, beginning on page 301, and in electronic format on the CD that accompanies this report. The monthly 2004/2005 Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 145–194).

The historic lake data are also plotted in Figures B51–B70 (pages 196–215) and Figures B71–B135 (pages 217–284). These figures are scaled to plot the full range of Lake Whatcom water quality data including minimum, maximum, and outlier values. As a result, they usually do not provide the best illustration of trends that occur in the lake. Separate tables and figures are provided for trend discussions.

⁴AmTest, 14603 N.E. 87th St., Redmond, WA, 98052.

2.3.1 Water temperature

The mid-winter Hydrolab profiles (e.g., Figures B16–B20, pages 160–164) and the multi-year temperature profiles (Figures B51–B55, pages 196–200) show that the water column mixes during the fall, winter, and early spring. During this time, water temperatures, dissolved oxygen concentrations, pH levels, and conductivities are fairly uniform from the surface to the bottom of the lake, even at Site 4, which is over 300 ft (100 m) deep.

The summer Hydrolab profiles (e.g., Figures B46–B50, pages 190–194) illustrate how the lake stratifies into a warm surface layer (the *epilimnion*) and a cool bottom layer (the *hypolimnion*). The transition zone between the epilimnion and hypolimnion, the *metalimnion*, is a region of rapidly changing water temperature. When stratified, the Hydrolab profiles show distinct differences between surface and bottom temperatures. Climatic differences alter the timing of lake stratification; if the spring is cool, cloudy, and windy, the lake will stratify later than when it has been hot and sunny.

Stratification develops gradually, and once stable, persists until fall or winter, depending on location in the lake. In Lake Whatcom, all sites except the Intake, which is too shallow to develop a stable stratification, are usually stratified by June. Stratification may begin as early as April, but is often not stable until May or early June. The actual stability of stratification is determined in part by the temperature differences in the water column, but also by water circulation and local weather patterns. However, once the water column temperature differs by at least 5° C, it is unlikely that the lake will destratify. Typically, all three basins reach a 5° C difference by early June (see summary of monthly water column temperature differences in Matthews, et al., 2005).

Destratification occurs abruptly in basins 1 and 2, and more gradually in basin 3. The lake cools as the weather becomes colder and day length shortens. Basins 1 and 2 (Sites 1–2) destratify by the end of October, while basin 3 (Sites 3–4) is often still stratified in November or early December. Complete destratification probably occurs in late December or early January in basin 3, so that by February, the temperatures are relatively uniform throughout the water column.

The historic water temperature data indicate that the annual median temperatures in basin 3 are cooler than basins 1 and 2, and 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; 23.2 °C on August 5, 1998). The large water volume in basin 3 moderates temperature fluctuations, so it will be less susceptible than the shallow basins to temperature changes in response to weather conditions.

The 2005 surface water temperatures were warmer than usual during February and May (Figure 1, page 25), but most other months were close to historic median temperatures. The lake was stratified by the first week in May (Figures B26–B30, pages 170–174).

2.3.2 Dissolved oxygen

As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures B41–B42 and B56–B57, pages 185–186 and 201–202). Hypolimnetic oxygen depletion only becomes apparent after stratification, at which time the lower waters of the basin are isolated from the lake's surface and biological respiration consumes the oxygen dissolved in the water. Biological productivity and respiration are increased when there is an abundant supply of nutrients, as well as by other environmental factors such as warm water temperatures. In basin 3, which has comparatively low concentrations of essential nutrients such as phosphorus, biological respiration has less influence on hypolimnetic oxygen concentrations (e.g., Figures B50 and B60, pages 194 and 205). In contrast, Site 1 shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures B46 and B56, pages 190 and 201).

During October 2004, the oxygen concentrations at Site 3 dropped from 9.5 mg/L at the surface to 2.9 mg/L at 80 m (Figure B4, page 148). The difference between surface and bottom oxygen concentrations was smaller in November (9.3 mg/L at the surface vs. 6.4 mg/L at 79 m), and by December, basin 3 was beginning to destratify. Site 4 had a very small oxygen sag ($\Delta T \sim 1.5$ mg/L) near the bottom during October and November. Both sites also had small oxygen sags near the thermocline. This was probably caused by respiration of heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (DeLuna, 2004).

Low oxygen conditions are associated with a number of unappealing water quality problems in lakes, including loss of aquatic habitat; release of nutrients (phosphorus and nitrogen) from the sediments; increased rates of algal production due to release of nutrients; unpleasant odors during lake overturn; fish kills, particularly during lake overturn; release of metals and organics from the sediments; increased 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.

Site 1 oxygen trends: 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 (Pelletier, 1998).⁵ 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 4–7 (pages 28–31), there were significant negative correlations between dissolved oxygen and time for all samples collected from the hypolimnion during July and August (see footnote on page 11 for a description of correlation analysis).

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in May, June, and August (Figures B26, B31, and B41, pages 170, 175, and 185).⁶ DeLuna (2004) described this phenomenon, which is caused by the accumulation of phytoplankton along the density gradient between the epilimnion and hypolimnion in basin 1, 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 (DeLuna, 2004).

⁵Information about the 303(d) list is available at <http://www.ecy.wa.gov/programs/wq/303d>.

⁶Although supersaturation can occur in other portions of the lake, particularly the epilimnion, supersaturation in the metalimnion is much more persistent over time, and changes the classification of the lake's oxygen profile from "heterograde" to "orthograde." Refer to Wetzel (1986) and DeLuna (2004) for a more complete discussion.

2.3.3 Conductivity and pH

The Hydrolab pH and conductivity data followed trends that were typical for Lake Whatcom, with only small differences between sites and depths (Figures B61–B70, pages 206–215). Surface pH increased during the summer due to photosynthetic activity. Hypolimnetic pH values decreased and conductivity values increased due to decomposition and the release of dissolved compounds from the sediments. A significant long-term trend was apparent in the conductivity data (Matthews, et al., 2004). This trend is the result of changing to increasingly sensitive equipment during the past two decades, resulting in lower values over time, and does not indicate any change in the actual conductivity in the lake.

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 217–221). During the summer the alkalinity and conductivity values at the bottom of Sites 1–2 increased due to decomposition and the release of dissolved compounds in the lower waters.

The turbidity values were mostly less than 1–2 NTU except during late summer in samples from the lower depths at Sites 1–2, and occasionally Site 3 (Figures B76–B80, pages 222–226). The high turbidity levels near the bottom are an indication of increasing turbulence in the lower hypolimnion as the lake nears turnover. The influence of winter storms on turbidity can be seen in the samples from December 1996. At that time, the water column was thoroughly mixed at Sites 1 and 2, so higher turbidities were measured at all depths. Basin 3, however, was still stratified below 40–50 m so higher turbidities were measured only in the epilimnion.

2.3.5 Nitrogen and phosphorus

Figures B81–B105 (pages 228–252) 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 grows in the lake. In Lake Whatcom, most algae use inorganic nitrogen in the form of nitrate for growth. Under some conditions, ammonia or dissolved nitrogen gas can be used.⁷

⁷Only cyanobacteria and a few uncommon species of diatoms can use nitrogen gas.

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 233–237), particularly at Site 1, where the epilimnetic nitrate concentrations fell below 20 $\mu\text{g-N/L}$. Epilimnetic nitrogen depletion is an indirect measure of phytoplankton productivity. Coincident with low nitrate concentrations, late summer is when we usually find the highest densities of nitrogen-fixing Cyanophyta (bluegreen bacteria or cyanobacteria) in the plankton samples. Epilimnetic nitrate concentrations decrease at Sites 3–4, but rarely fall below 150 $\mu\text{g-N/L}$, making nitrogen co-limitation unlikely.

The hypolimnetic nitrate concentrations dropped below 10 $\mu\text{g-N/L}$ at both Sites 1 and 2. In anaerobic environments, bacteria reduce nitrate (NO_3^-) to nitrite (NO_2^-) and nitrogen gas (N_2). The historic data indicate that nitrate reduction has been common at Site 1, but was not common at Site 2 until the summer of 1999.

High ammonia concentrations were measured just prior to overturn in the hypolimnion at Sites 1 and 2 (Figures B81 & B82, pages 228 & 229). Elevated hypolimnetic ammonia concentrations have been common at both sites throughout the monitoring period, but beginning in 1999 the concentrations increased noticeably at Site 2.

Ammonia, along with hydrogen sulfide, is often an indicator of hypolimnetic anoxia. Ammonia is produced during decomposition of organic matter. Ammonia is readily taken up by plants as a growth nutrient. In oxygenated environments, ammonia is rarely present in high concentrations because it is rapidly converted to nitrite and nitrate through biological and chemical processes. In low oxygen environments, such as the hypolimnion at Sites 1 and 2, ammonia accumulates until the lake destratifies. Currently, the ammonia and hydrogen sulfide concentrations are higher at Site 2 than at Site 1 (Table 10, page 24).

Sites 3 and 4 often have slightly elevated ammonia concentrations at 20 m (Figures B84–B85, pages 231–232). This is due to bacterial decomposition of organic matter in the metalimnion (DeLuna, 2004), but the concentrations never approach the levels found in the hypolimnion at Sites 1–2. A similar metalimnetic accumulation of ammonia was observed by McNair (1995) in Lake Samish. Sites 3 and 4 occasionally have slightly elevated ammonia concentrations at 80–90 m during late summer, which is probably also caused by decomposition of organic matter.

Although the Lake Whatcom microbiota require nitrogen, phosphorus is usually what limits microbial growth (Bittner, 1993; Liang, 1994; Matthews, et al., 2002a; McDonald, 1994). Soluble forms of phosphorus (e.g., soluble phosphate) are easily taken up by 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. 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) found that 50% of the total phosphorus bound to the surface of soil collected from a construction site in the Lake Whatcom watershed was “bioavailable” and could be extracted by algae and microbiota.

Soluble phosphate concentrations were usually low ($\leq 10 \mu\text{g-P/L}$) at all sites and depths except in the hypolimnion at Sites 1 and 2 just prior to overturn (Figures B96–B100, pages 243–247). Elevated total phosphorus levels were present in the hypolimnion at Sites 1 and 2 during stratification (Figures B101–B105, pages 248–252). When hypolimnetic oxygen concentrations are low, sediment-bound phosphorus becomes soluble and leaches into the overlying water. Prior to turnover, hypolimnetic phosphorus may be taken up by microbiota in the metalimnion (see Section 2.3.2 and DeLuna, 2004). 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 convert into insoluble forms.

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 254–258). Samples from 20 m at Sites 1 and 2 usually had lower chlorophyll concentrations than samples nearer the surface. Twenty meters is near the lower limit of the photic zone, so the low light intensity is not optimal for algal growth. Also, most algae are aerobic organisms, so the low oxygen conditions in the late summer hypolimnion would not be favorable for growth.⁸ Peak chlorophyll concentrations were usually at 0–15 m.

⁸Many cyanobacteria can photosynthesize under aerobic or anaerobic conditions (Lee, 1989).

The Lake Whatcom plankton counts were usually dominated by Chrysophyta⁹ (Figures B111–B120, pages 259–268), consisting primarily of diatoms, *Dinobryon*, and *Mallomonas*. Substantial blooms of cyanobacteria (Cyanophyta) and green algae (Chlorophyta) were also measured at all sites during summer and late fall. Previous analyses of algal biovolume in Lake Whatcom indicated that although Chrysophyta dominate the numerical plankton counts, Cyanophyta and Chlorophyta often dominate the plankton biovolume, particularly in late summer and early fall (Ashurst, 2003; Matthews, et al., 2002b).

Secchi depths (Figures B121–B125, pages 269–273) showed no clear seasonal pattern because transparency in Lake Whatcom is affected by particulates from storm events and the diversion as well as algal blooms

Indications of eutrophication: Matthews, et al. (2005) describe trends in chemical and biological indicators of eutrophication apparent in the historic water quality data from Lake Whatcom. 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. Most of Lake Whatcom is relatively unproductive, which makes it particularly vulnerable to eutrophication from phosphorus loading. See Wetzel (1983) for a discussion of the effects of eutrophication on lakes.

One of the most important indicators of eutrophication in Lake Whatcom is the increasing algal densities that are apparent at all sites in the lake (Figure 8, page 32). Cell counts for all four of the major algal types, Chrysophyta (diatoms), Chlorophyta (green algae), Cyanophyta (cyanobacteria), and Pyrrophyta (dinoflagellates), are increasing significantly in the lake. The Cyanophyta increase is disturbing because cyanobacteria are often indicators of water quality deterioration (Wetzel, 1983). Cyanophyta usually reach peak densities in late summer or early fall, just prior to turnover. In Lake Whatcom, the summer/fall Cyanophyta counts have increased significantly at all sites (Figures 9–10, pages 33–34), and are now at levels similar to the Chrysophyta and Chlorophyta.

⁹The Chrysophyta phylum name has been changed to Heterokontophyta in many taxonomies.

Concurrent with the increase in algal densities, there has been a significant increase in chlorophyll concentrations at all sites since 1994 (Figure 11, page 35). Prior to 1994, chlorophyll was sampled using a slightly less accurate method, resulting in more within-sample variation. If these earlier data are included, the correlations are not significant because the pattern is masked by sample variance.

2.3.7 Coliform bacteria

Beginning in October 2002, the coliform monitoring was changed to include *Escherichia coli* (*E. coli*), along with fecal coliform counts. This change was made to reflect potential revisions in the Washington State Department of Ecology's approach to defining bacterial pollution in surface water. Total coliforms and *Enterococcus* counts were discontinued. For information about historic total coliform and *Enterococcus* levels in Lake Whatcom, refer to previous annual reports (e.g., Matthews, et al., 2005).

The current surface water standards are based on "designated use" categories, which for Lake Whatcom is likely to be "Extraordinary Primary Contact Recreation." The standard for bacteria is described in Chapter 173-201A of the Washington Administrative Code, Water Quality Standards for Surface Waters of the State of Washington (online version available at <http://www.ecy.wa.gov/biblio/wac173201a.html>):

Fecal coliform organisms 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.

The standard is based on fecal coliform counts, but allows the use of alternate methods (e.g., *E. coli* counts) when there is evidence that most of the coliform contamination is not from warm-blooded animals. In surface water samples from the Lake Whatcom watershed, there is a very close correlation between fecal coliform counts and *E. coli* counts (Figure 2, page 26), so fecal coliform counts appear to be a reliable tool for determining compliance.¹⁰

¹⁰Correlation analyses were used to examine the strength of relationships between two vari-

All but one of the mid-basin (Sites 1–4) and Intake values for fecal coliforms and *E. coli* counts were less than 10 cfu¹¹/100 mL (Figures B126–B135, pages 275–284) and passed the freshwater *Extraordinary Primary Contact Recreation* bacteria standard. The single outlier occurred at Site 1 on November 3, when the fecal coliform count was 12 cfu/100 mL (the *E. coli* count was 7 cfu/100 mL).

The Bloedel-Donovan counts, which were collected near the dock offshore from the swimming area, were higher than Site 1 (mid-basin) counts, but the geometric means of 6 and 5 cfu/100 mL for fecal coliforms and *E. coli*, respectively, passed both parts of the freshwater *Extraordinary Primary Contact Recreation* bacteria standard.

2.3.8 Metals

The metals data for Lake Whatcom are included in Table 8 (page 22). This table includes only the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); Appendix D.8 (beginning on page 358) lists concentrations for an additional 24 metals that are included as part of the analytical procedure used by AmTest. In 1999, AmTest upgraded their equipment and analytical procedures for most metals. As a result, many of the analyses now have lower detection limits, resulting in fewer “below detection” data (bdl). These newly detectable metals probably do not represent increases in the metals concentrations in the lake.

Most of the metals concentrations were near or below detection limits, or were within normal concentration ranges for the lake. Zinc was detected at all sites during February, but was below detection during September. Iron was detectable at most sites and depths in February and September. The highest iron concentrations, 0.860 mg/L and 1.300 mg/L, were measured in September at the bottom of Sites 1 and 2, respectively. The elevated iron concentrations at Sites 1 and 2 were the result of sediment-bound iron converting to soluble forms under anaerobic conditions and leaching into the overlying water. Chromium, copper, and nickel were detected in many of the samples, which is unusual. Most of the detections

ables (e.g., fecal coliforms and *E. coli*). Correlation test statistics range from –1 to +1; the closer to ± 1 , the stronger the correlation. The significance is measured using the p-value; significant correlations have p-values <0.05. Monotonic linear correlations were measured using Pearson’s r ; nonlinear (e.g., exponential) correlations were measured using Kendall’s τ .

¹¹Colony forming unit/100 mL; cfu/100 mL is sometimes labeled “colonies/100 mL.”

were near the limit of detection, so it is not clear whether this represents an actual increase in metals concentrations in the lake or just variation in low level analytical analysis. Mercury and lead were detected in a few samples, but because the concentrations were at or near detection levels, it is unlikely that these detections represent an increase in metals concentrations in the lake.

Elevated concentrations of iron have been detected in raw water at the Lake Whatcom gatehouse¹² during late summer and fall (Figure 3, page 27), particularly during the first few weeks after the lake destratifies (see Figure 3, October–November peaks). The March 3, 2001 sample may have been contaminated with iron from renovations occurring inside the gatehouse during that time (Figure 3). Following lake turnover, most soluble iron is converted to insoluble iron, which slowly settles to the bottom. As a result, gatehouse iron concentrations were usually ≤ 0.05 mg/L during the rest of the year.

2.3.9 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, along with other decaying organic material, can react with chlorine to form disinfection by-products, predominately chloroform and other trihalomethanes (THMs). As algal densities increase, we expect to see an increase in THMs. The major concern with THMs is their potential carcinogenicity. It can be difficult and expensive to remove THMs from drinking water (Viessman & Hammer, 1985).

Although the 2004/2005 total organic carbon concentrations were below detection at most sites (Table 9, page 23), the long-term data suggest that the concentrations may actually be increasing over time (Figure 12, page 36). Data provided by the City of Bellingham Public Works Department suggest that the total organic carbon concentrations may also be increasing at the raw water gatehouse. The total organic carbon concentrations at the gatehouse usually fall within the same concentration ranges measured at Site 2 and the Intake, (Figure 13, page 37).

¹²The gatehouse is the structure that connects the intake in Lake Whatcom with an underground pipe that transports the water to the City's water treatment plant.

As illustrated in Figure 14 (page 38), THMs are increasing in Bellingham's treated drinking water, particularly during the fall (third quarter). Haloacetic acids (another important disinfection by-product) do not appear to be increasing with time (Figure 14) and do not have a statistically significant regression with time. Unlike THMs, which are predictable based on algal concentration and chlorine dose, the formation of HAAs is not well correlated with algal concentration or chlorine dose (Sung, et al., 2000).

Parameter	2004			2005									Location
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
DO - Hydrolab	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, Intake - every 1 m;
pH - Hydrolab	•	•	•		•		•	•	•	•	•	•	Sites 3, 4 - every 1 m to 10 m
Temp - Hydrolab	•	•	•		•		•	•	•	•	•	•	then every 5 m;
Cond - Hydrolab	•	•	•		•		•	•	•	•	•	•	Gatehouse
Secchi depth	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake
Alkalinity	•	•	•		•		•	•	•	•	•	•	Sites 1, 2 - 0.3, 5, 10, 15, 20 m;
Ammonia	•	•	•		•		•	•	•	•	•	•	Intake - 0.3, 5, 10 m;
Nitrate/nitrite	•	•	•		•		•	•	•	•	•	•	Site 3 - 0.3, 5, 10, 20, 40, 60,
T. nitrogen	•	•	•		•		•	•	•	•	•	•	80 m;
Sol. phosphate	•	•	•		•		•	•	•	•	•	•	Site 4 - 0.3, 5, 10, 20, 40, 60,
T. phosphorus	•	•	•		•		•	•	•	•	•	•	80, 90 m;
Turbidity	•	•	•		•		•	•	•	•	•	•	Gatehouse
T. metals (As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Zn)					•							•	Sites 1, 2, 3, 4, Intake -
T. organic carbon					•							•	0.3 m and bottom only
Chlorophyll	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4 - 0.3, 5, 10,
Plankton	•	•	•		•		•	•	•	•	•	•	15, 20 m; Intake - 0.3, 5, 10 m
Bacteria	•	•	•		•		•	•	•	•	•	•	Sites 1, 2, 3, 4, Intake;
													5 m
													Sites 1, 2, 3, 4, Intake,
													Bloedel-Donovan; 0.3 m
H ₂ S - opt	•										•	•	Sites 1, 2 - 10, 15, 20 m

Table 1: Lake Whatcom 2004/2005 lake monitoring schedule.

Parameter	Method	Historic DL [†]	2004/2005 MDL [†]	Sensitivity or Confidence limit
Conductivity-field	Hydrolab (1997), field meter	–	–	± 2 µS/cm
Conductivity-lab	APHA (1998) #2510, low-level, SOP-LW-9	–	–	± 1.9 µS/cm
Dissolved oxygen-field	Hydrolab (1997), field meter	–	–	± 0.1 mg/L
Dissolved oxygen-lab	APHA (1998) #4500-O.C., Winkler, SOP-LW-12	–	–	± 0.1 mg/L
pH-field	Hydrolab (1997), field meter	–	–	± 0.1 pH unit
pH-lab	APHA (1998) #4500-H ⁺ , low-ionic, SOP-LW-8	–	–	± 0.04 pH unit
Temperature	Hydrolab (1997), field meter	–	–	± 0.1° C
Alkalinity	APHA (1998) #2320, low level, SOP-IWS-15	–	–	± 0.5 mg/L
Discharge	Rantz et al. (1982), rating curve, SOP-IWS-6	–	–	–
Secchi disk	Lind (1985)	–	–	± 0.1 m
T. solids	APHA (1998) #2540 B, gravimetric, SOP-LW-22	2 mg/L	6.2 mg/L	± 2.0 mg/L
T. suspended solids	APHA (1998) #2540 D, gravimetric, SOP-LW-22	2 mg/L	1.8 mg/L	± 2.0 mg/L
Turbidity	APHA (1998) #2130, nephelometric, SOP-LW-11	–	–	± 0.2 NTUs
Ammonia (bench)	APHA (1998) #4500-NH ₃ F., phenate, SOP-LW-21	10 µg-N/L	2.0 µg-N/L	± 3.2 µg-N/L
Ammonia (auto)	APHA (1998) #4500-NH ₃ H., phenate, SOP-LW-19	10 µg-N/L	3.8 µg-N/L	± 6.7 µg-N/L
Nitrite/nitrate (auto)	APHA (1998) #4500-NO ₃ I., Cd reduction, SOP-IWS-19	20 µg-N/L	2.8 µg-N/L	± 5.6 µg-N/L
T. nitrogen (auto)	APHA (1998) #4500-N C., persulfate digestion, SOP-IWS-19	100 µg-N/L	7.6 µg-N/L	± 9.2 µg-N/L
Sol. phosphate (auto)	APHA (1998) #4500-P G., ascorbic acid, SOP-IWS-19	5 µg-P/L	1.3 µg-P/L	± 2.7 µg-P/L
T. phosphorus (auto)	APHA (1998) #4500-P H., persulfate digestion, SOP-IWS-19	5 µg-P/L	3.0 µg-P/L	± 3.5 µg-P/L
Chlorophyll	APHA (1998) #10200 H, acetone, SOP-IWS-16	–	–	± 0.1 mg/m ³
Plankton	Lind (1985), Schindler trap	–	–	–
E. coli (City)	EPA (2005) 1603, mod. m-Tec membrane filtration	2 cfu/100 mL	–	–
Fecal coliform (City)	APHA (1998) #9222 D, membrane filter	2 cfu/100 mL	–	–

[†] Historic detection limits (DL) are usually higher than current method detection limits (MDL). See Appendix D for additional information.

Table 2: Summary of IWS and City of Bellingham analytical methods.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	18.5	19.6	20.4	27.8	2.0	50
Conductivity (μS/cm)	54.9	57.6	58.8	74.4	4.2	210
Dissolved oxygen (mg/L)	0.3	9.5	8.0	11.5	3.6	210
pH	6.2	7.3	7.3	9.0	0.7	210
Temperature (°C)	7.3	10.9	12.1	22.8	4.0	210
Turbidity (NTU)	0.5	0.9	1.1	5.4	0.9	50
Nitrogen - ammonia (μg-N/L)	<10	10.6	35.1	328.6	65.9	50
Nitrogen - nitrate/nitrite (μg-N/L)	<20	238.7	195.7	340.0	122.3	50
Nitrogen - total (μg-N/L)	224.6	414.6	387.8	516.6	80.4	50
Phosphorus - soluble (μg-P/L)	<5	<5	<5	9.4	1.9	50
Phosphorus - total (μg-P/L)	<5	11.9	13.6	70.7	11.1	50
Chlorophyll (mg/m ³)	0.2	3.1	3.0	7.8	1.5	50
Secchi depth (m)	3.1	4.3	4.3	5.4	0.8	10
Coliforms - fecal (cfu/100 mL) [‡]	<1	1	3	12	na	10
Coliforms - E. coli (cfu/100 mL) [‡]	<1	1	2	7	na	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 3: Summary of Site 1 ambient water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	17.8	18.7	18.8	20.0	0.6	30
Conductivity (μS/cm)	53.0	55.6	55.8	60.0	1.9	110
Dissolved oxygen (mg/L)	8.8	9.9	10.0	11.7	0.8	109
pH	7.1	7.9	7.8	8.6	0.5	110
Temperature (°C)	7.3	15.2	14.1	22.2	4.7	110
Turbidity (NTU)	0.4	0.6	0.6	1.1	0.2	30
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	17.5	4.8	30
Nitrogen - nitrate/nitrite (μg-N/L)	101.0	243.2	237.6	383.9	96.6	30
Nitrogen - total (μg-N/L)	272.7	412.1	387.5	484.6	72.7	30
Phosphorus - soluble (μg-P/L)	<5	<5	<5	9.9	2.2	30
Phosphorus - total (μg-P/L)	<5	7.6	7.6	17.7	3.8	30
Chlorophyll (mg/m ³)	1.0	2.9	3.0	5.4	1.1	30
Secchi depth (m)	3.5	5.7	5.6	7.2	1.1	10
Coliforms - fecal (cfu/100 mL) [‡]	<1	1	1	2	na	10
Coliforms - E. coli (cfu/100 mL) [‡]	<1	1	1	1	na	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 4: Summary of Intake ambient water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	17.8	18.8	19.0	25.9	1.4	50
Conductivity (μS/cm)	52.9	55.4	56.3	72.5	3.4	210
Dissolved oxygen (mg/L)	0.3	9.7	9.1	11.7	2.6	210
pH	6.3	7.3	7.4	8.5	0.6	210
Temperature (°C)	7.3	12.1	12.6	21.3	4.2	210
Turbidity (NTU)	0.4	0.6	0.7	3.4	0.4	50
Nitrogen - ammonia (μg-N/L)	<10	<10	25.8	378.3	69.0	50
Nitrogen - nitrate/nitrite (μg-N/L)	<20	283.9	251.7	379.5	104.6	50
Nitrogen - total (μg-N/L)	291.1	441.0	421.0	585.3	80.5	50
Phosphorus - soluble (μg-P/L)	<5	<5	<5	12.1	2.5	50
Phosphorus - total (μg-P/L)	<5	8.8	8.7	29.7	5.5	49
Chlorophyll (mg/m ³)	0.5	2.5	2.7	5.4	1.1	50
Secchi depth (m)	3.6	5.9	5.7	6.7	1.0	10
Coliforms - fecal (cfu/100 mL) [‡]	<1	1	1	2	na	10
Coliforms - E. coli (cfu/100 mL) [‡]	<1	1	1	2	na	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 5: Summary of Site 2 ambient water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	17.7	18.0	18.3	19.4	0.5	63
Conductivity (μS/cm)	49.4	53.5	53.8	67.0	2.4	221
Dissolved oxygen (mg/L)	2.9	9.3	9.4	10.8	1.0	220
pH	6.6	7.3	7.5	8.8	0.6	221
Temperature (°C)	7.0	7.9	10.9	21.4	4.7	222
Turbidity (NTU)	0.2	0.6	0.6	3.2	0.4	63
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	18.7	3.7	63
Nitrogen - nitrate/nitrite (μg-N/L)	131.2	380.2	327.2	437.0	96.0	62
Nitrogen - total (μg-N/L)	298.2	474.1	448.0	540.4	67.8	62
Phosphorus - soluble (μg-P/L)	<5	5.7	5.1	9.8	2.4	62
Phosphorus - total (μg-P/L)	<5	6.5	6.5	17.6	3.1	62
Chlorophyll (mg/m ³)	0.5	2.6	2.5	6.1	1.2	45
Secchi depth (m)	4.5	6.0	6.3	8.0	1.2	9
Coliforms - fecal (cfu/100 mL) [‡]	<1	1	1	3	na	10
Coliforms - E. coli (cfu/100 mL) [‡]	<1	1	2	4	na	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 6: Summary of Site 3 ambient water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	16.3	17.9	18.1	19.4	0.5	80
Conductivity (μS/cm)	49.0	53.8	53.7	58.1	2.1	270
Dissolved oxygen (mg/L)	7.8	9.5	9.6	11.4	0.8	270
pH	6.6	7.0	7.3	8.5	0.5	270
Temperature (°C)	7.0	7.7	10.3	21.1	4.3	270
Turbidity (NTU)	0.3	0.5	0.6	1.3	0.2	80
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	10.5	2.6	80
Nitrogen - nitrate/nitrite (μg-N/L)	138.0	383.8	343.2	440.0	86.4	79
Nitrogen - total (μg-N/L)	296.4	476.8	456.5	523.6	61.0	80
Phosphorus - soluble (μg-P/L)	<5	<5	<5	12.3	3.0	79
Phosphorus - total (μg-P/L)	<5	5.9	6.0	24.4	3.7	80
Chlorophyll (mg/m ³)	0.8	2.2	2.2	5.6	1.1	50
Secchi depth (m)	3.5	6.1	6.1	8.0	1.4	10
Coliforms - fecal (cfu/100 mL) [‡]	<1	1	1	2	na	10
Coliforms - E. coli (cfu/100 mL) [‡]	<1	1	1	3	na	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 7: Summary of Site 4 ambient water quality data, Oct. 2004 – Sept. 2005.

Site	Depth (m)	Date	T. As (mg/L)	T. Cd (mg/L)	T. Cr (mg/L)	T. Cu (mg/L)	T. Fe (mg/L)	T. Hg (mg/L)	T. Ni (mg/L)	T. Pb (mg/L)	T. Zn (mg/L)
Site 1	0	Feb 3, 2005	<0.01	<0.0005	0.016	0.017	0.048	<0.0002	0.015	<0.001	0.020
Site 1	20	Feb 3, 2005	<0.01	<0.0005	<0.001	0.004	0.010	<0.0002	<0.005	<0.001	0.009
Intake	0	Feb 3, 2005	<0.01	<0.0005	<0.001	0.004	<0.005	<0.0002	<0.005	<0.001	0.008
Intake	10	Feb 3, 2005	<0.01	<0.0005	<0.001	0.004	0.010	<0.0002	<0.005	<0.001	0.010
Site 2	0	Feb 3, 2005	<0.01	<0.0005	0.002	0.003	<0.005	<0.0002	<0.005	<0.001	0.007
Site 2	20	Feb 3, 2005	<0.01	<0.0005	<0.001	0.004	<0.005	<0.0002	<0.005	<0.001	0.009
Site 3	0	Feb 1, 2005	<0.01	<0.0005	0.002	0.004	0.015	<0.0002	<0.005	<0.001	0.046
Site 3	80	Feb 1, 2005	<0.01	<0.0005	<0.001	0.005	0.300	<0.0002	<0.005	0.002	0.012
Site 4	0	Feb 1, 2005	<0.01	<0.0005	<0.001	0.004	<0.005	<0.0002	<0.005	<0.001	0.007
Site 4	90	Feb 1, 2005	<0.01	<0.0005	<0.001	0.007	<0.005	<0.0002	<0.005	<0.001	0.011
Site 1	0	Sept 8, 2005	<0.01	<0.0005	0.005	<0.001	0.044	<0.0002	0.020	<0.001	<0.001
Site 1	20	Sept 8, 2005	<0.01	<0.0005	0.006	<0.001	0.860	<0.0002	0.018	<0.001	<0.001
Intake	0	Sept 8, 2005	<0.01	<0.0005	0.011	<0.001	0.019	<0.0002	0.020	<0.001	<0.001
Intake	10	Sept 8, 2005	<0.01	<0.0005	0.008	<0.001	0.019	0.0004	0.200	<0.001	<0.001
Site 2	0	Sept 8, 2005	<0.01	<0.0005	0.008	<0.001	0.031	<0.0002	0.020	<0.001	<0.001
Site 2	20	Sept 8, 2005	<0.01	<0.0005	0.004	<0.001	1.300	<0.0002	0.018	<0.001	<0.001
Site 3	0	Sept 6, 2005	<0.01	<0.0005	0.006	<0.001	0.150	<0.0002	0.020	<0.001	<0.001
Site 3	80	Sept 6, 2005	<0.01	<0.0005	0.008	<0.001	0.110	<0.0002	0.018	<0.001	<0.001
Site 4	0	Sept 6, 2005	<0.01	<0.0005	0.008	<0.001	0.017	<0.0002	0.020	<0.001	<0.001
Site 4	90	Sept 6, 2005	<0.01	<0.0005	0.010	<0.001	0.130	<0.0002	0.018	<0.001	<0.001

Table 8: Lake Whatcom 2004/2005 total metals data. Only the metals specified in the 2004/2005 monitoring plan are included in this table; the results for 24 additional metals are included in Appendix D.8.

Site	Date	Depth	TOC		Date	Depth	TOC
			(mg/L)	(mg/L)			
Site 1	Feb 3, 2005	0	<1		Sept 8, 2005	0	2.2
	Feb 3, 2005	20	<1		Sept 8, 2005	20	2.0
Intake	Feb 3, 2005	0	<1		Sept 8, 2005	0	<1
	Feb 3, 2005	10	<1		Sept 8, 2005	10	<1
Site 2	Feb 3, 2005	0	<1		Sept 8, 2005	0	<1
	Feb 3, 2005	20	<1		Sept 8, 2005	15	<1
Site 3	Feb 1, 2005	0	<1		Sept 6, 2005	0	9.2
	Feb 1, 2005	80	<1		Sept 6, 2005	80	<1
Site 4	Feb 1, 2005	0	<1		Sept 6, 2005	0	<1
	Feb 1, 2005	90	<1		Sept 6, 2005	90	<1

Table 9: Lake Whatcom 2004/2005 total organic carbon data.

Date		H ₂ S (mg/L)	NH ₃ (μg-N/L)
October 1999	Site 1 (bottom)	0.03–0.04	268.3
	Site 2 (bottom)	0.40	424.4
October 2000	Site 1 (bottom)	0.27	208.8
	Site 2 (bottom)	0.53	339.5
October 2001	Site 1 (bottom)	0.42	168.7
	Site 2 (bottom)	0.76	331.9
October 2002	Site 1 (bottom)	0.09	203.9
	Site 2 (bottom)	0.32	383.8
October 2003	Site 1 (bottom)	0.05	333.8
	Site 2 (bottom)	0.05	340.0
October 2004	Site 1 (bottom)	0.25	300.3
	Site 2 (bottom)	0.25	378.3
October 2005	Site 1 (bottom)	0.12	257.5
	Site 2 (bottom)	0.42	450.4

Table 10: October hypolimnetic ammonia and hydrogen sulfide concentrations at Sites 1 and 2 (1999–2005).

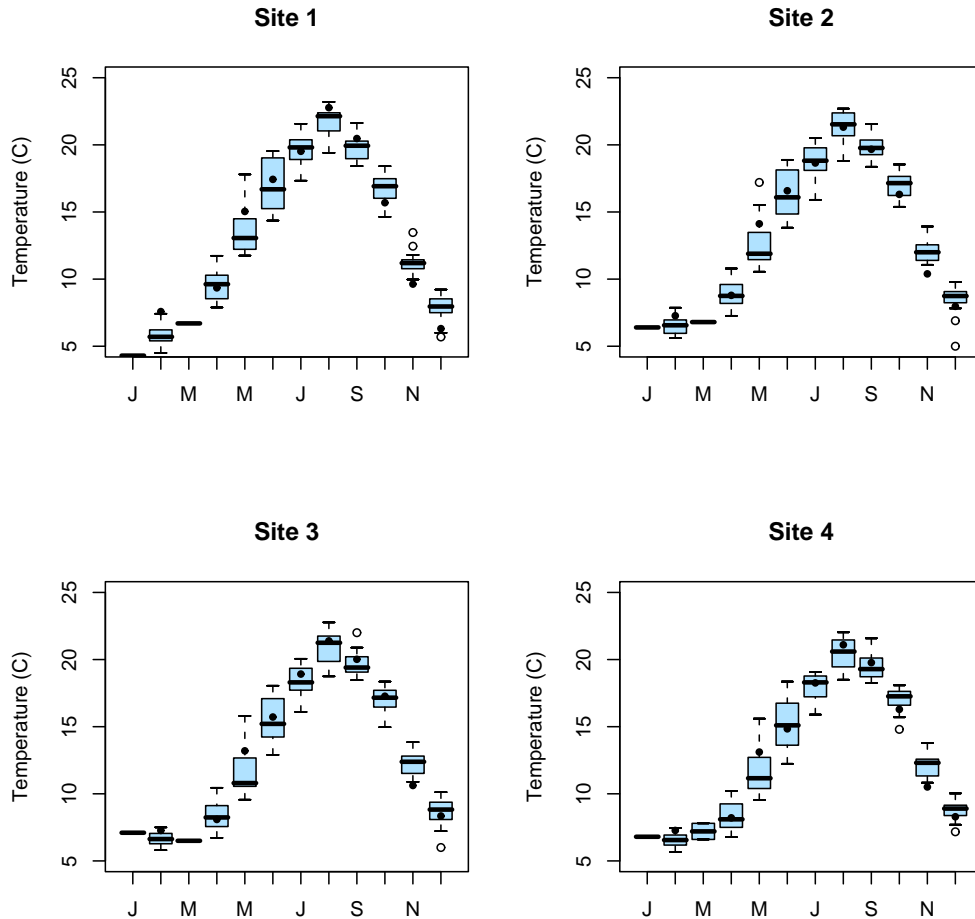


Figure 1: Comparison of 2005 surface water temperatures (●) to boxplots showing 1988–2004 surface temperature medians and ranges (depth <1 m for all sites and years). Boxplots show medians and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values; outliers lie outside $1.5 \times$ IQR.

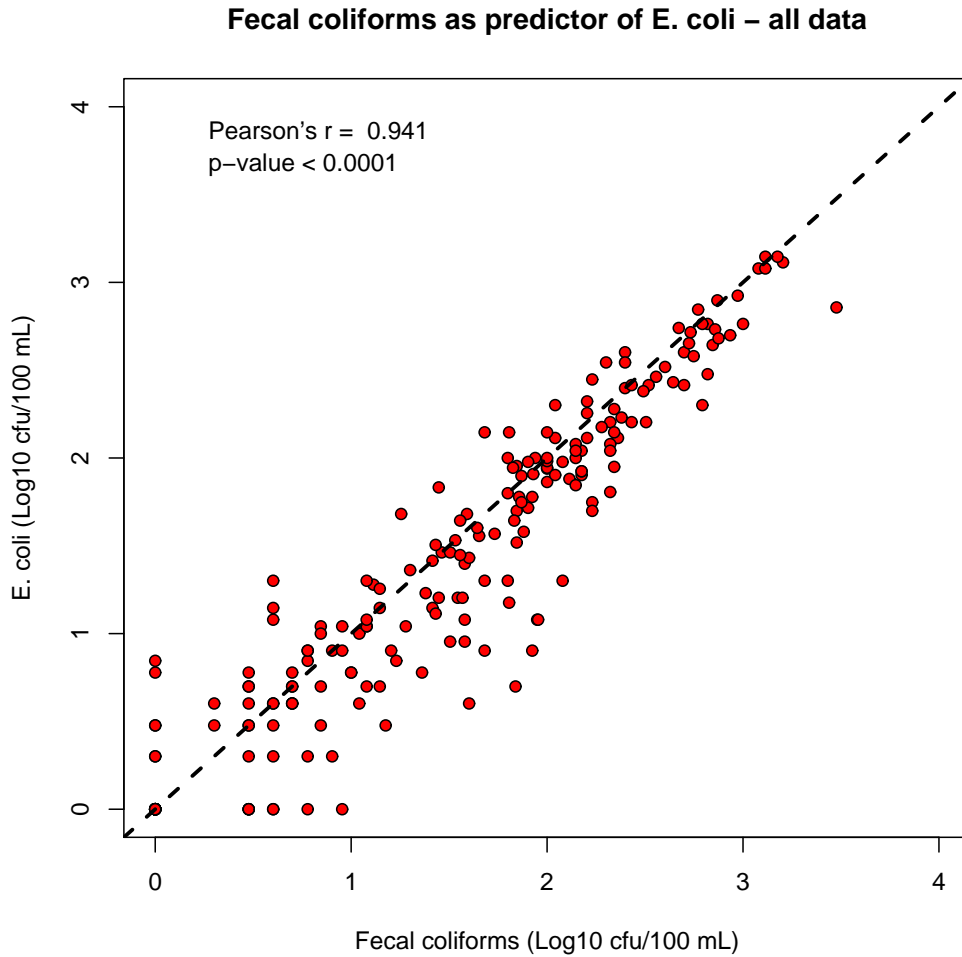


Figure 2: Correlation between fecal coliforms and *E. coli* counts in surface water samples (lake, stream, storm water treatment facility) in the Lake Whatcom watershed, October 2004 – September 2005. Pearson's r correlation was used because the log-transformed data were nearly monotonic-linear and the residuals were homogeneous. The diagonal line was added for reference to show a 1:1 relationship.

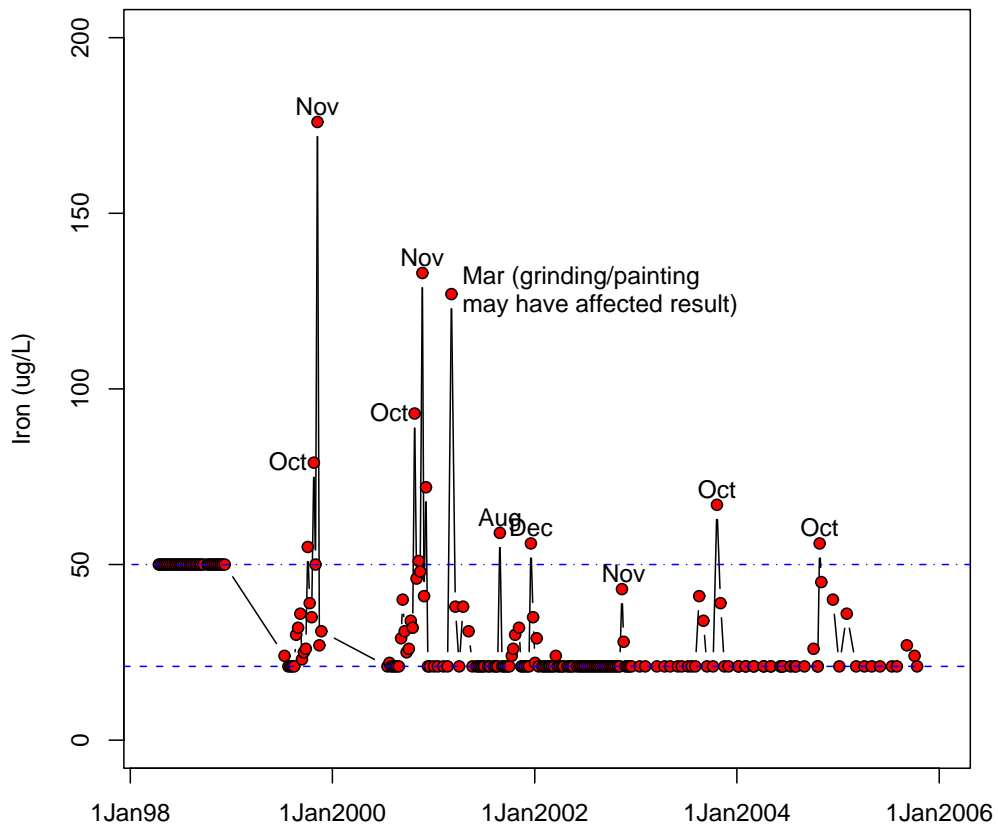


Figure 3: Iron concentration in untreated drinking water measured at the Lake Whatcom gatehouse, 1998–2005. Data were provided by the City of Bellingham Public Works Department.

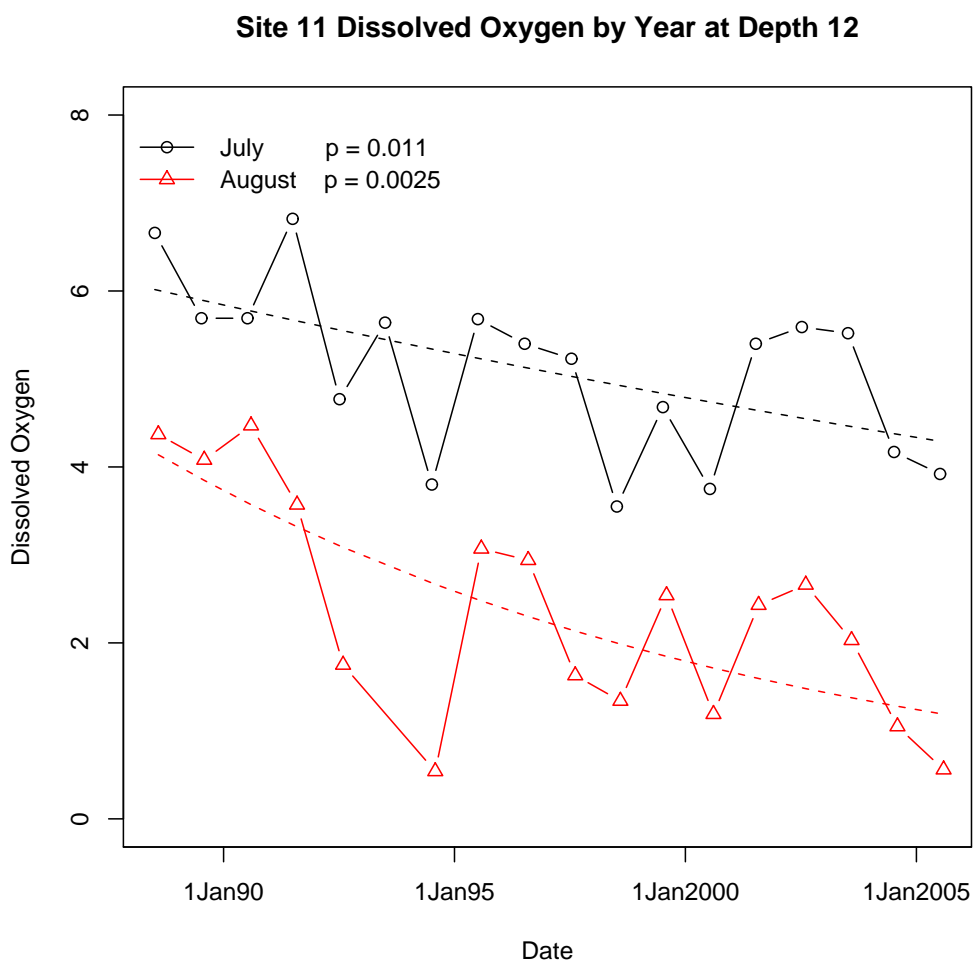


Figure 4: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

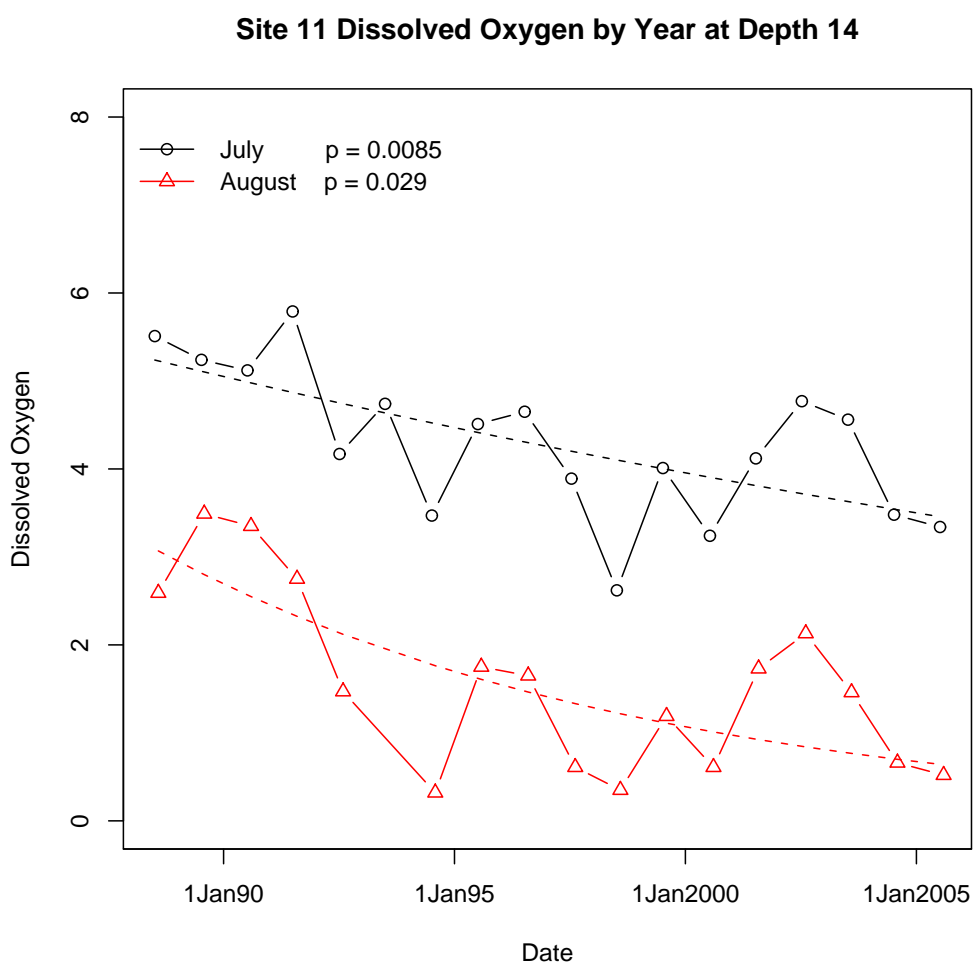


Figure 5: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

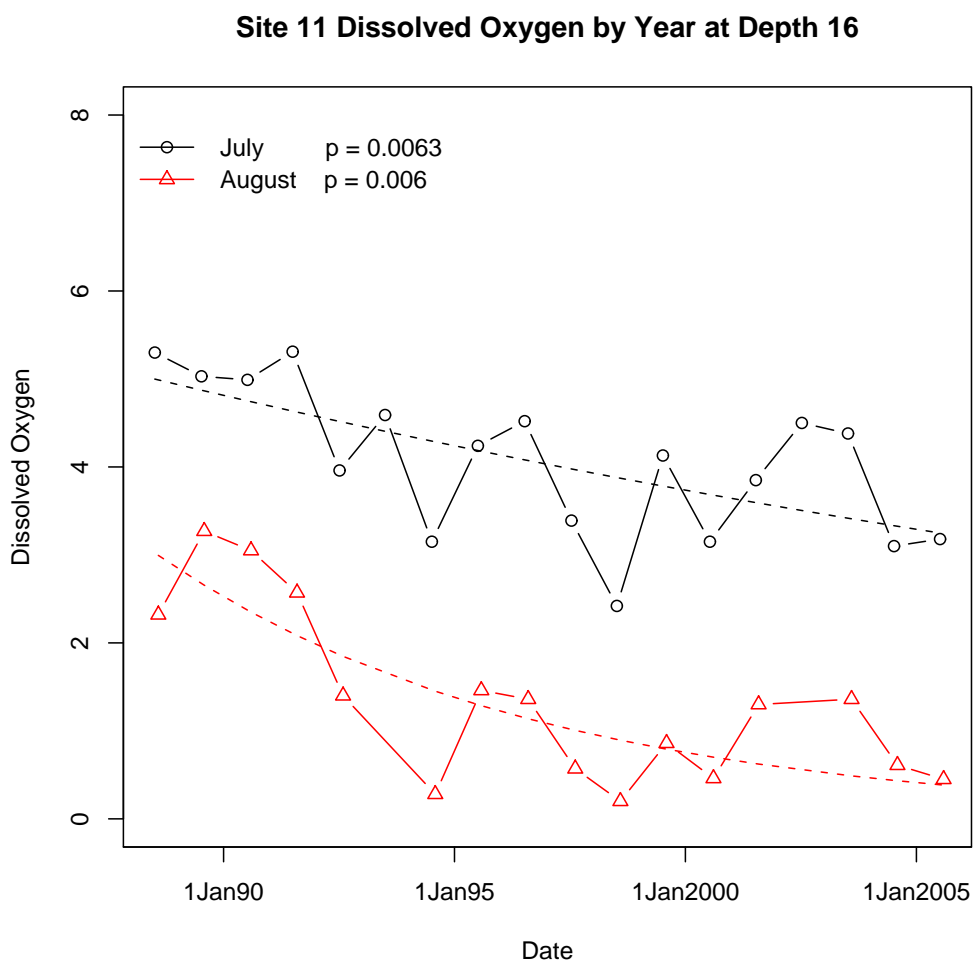


Figure 6: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

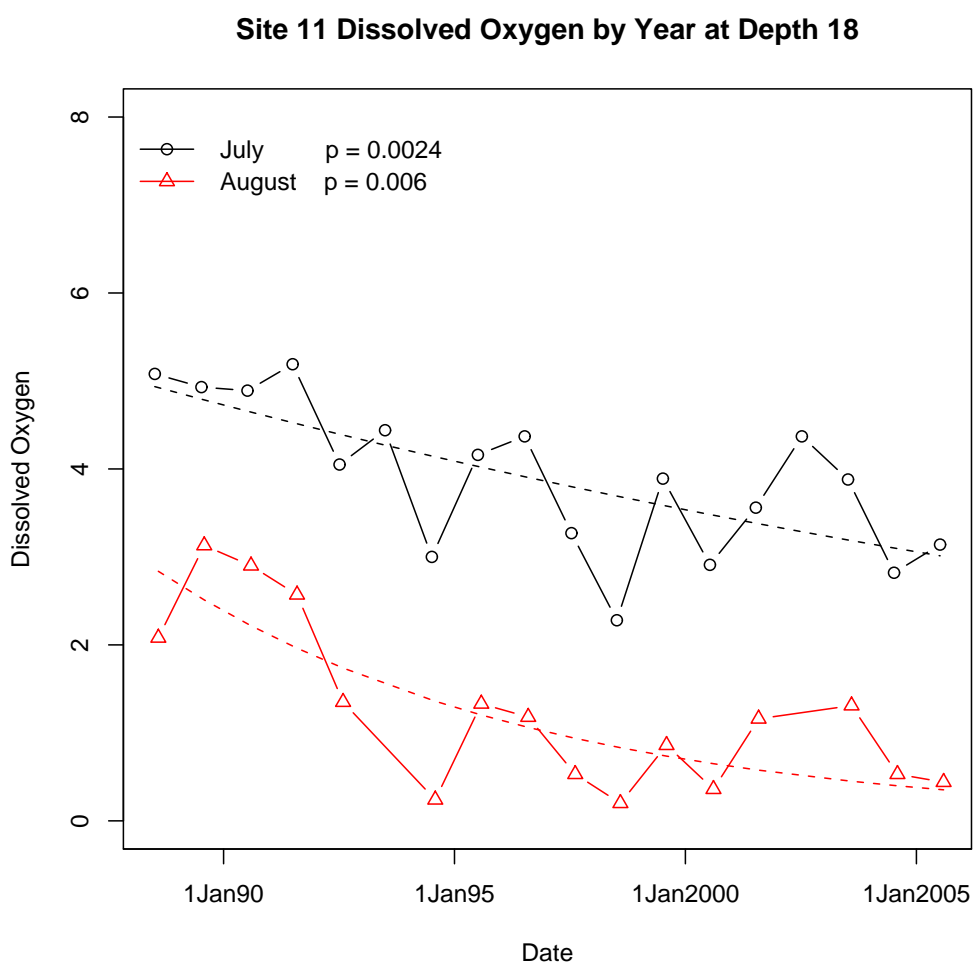


Figure 7: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were significant at $p < 0.05$.

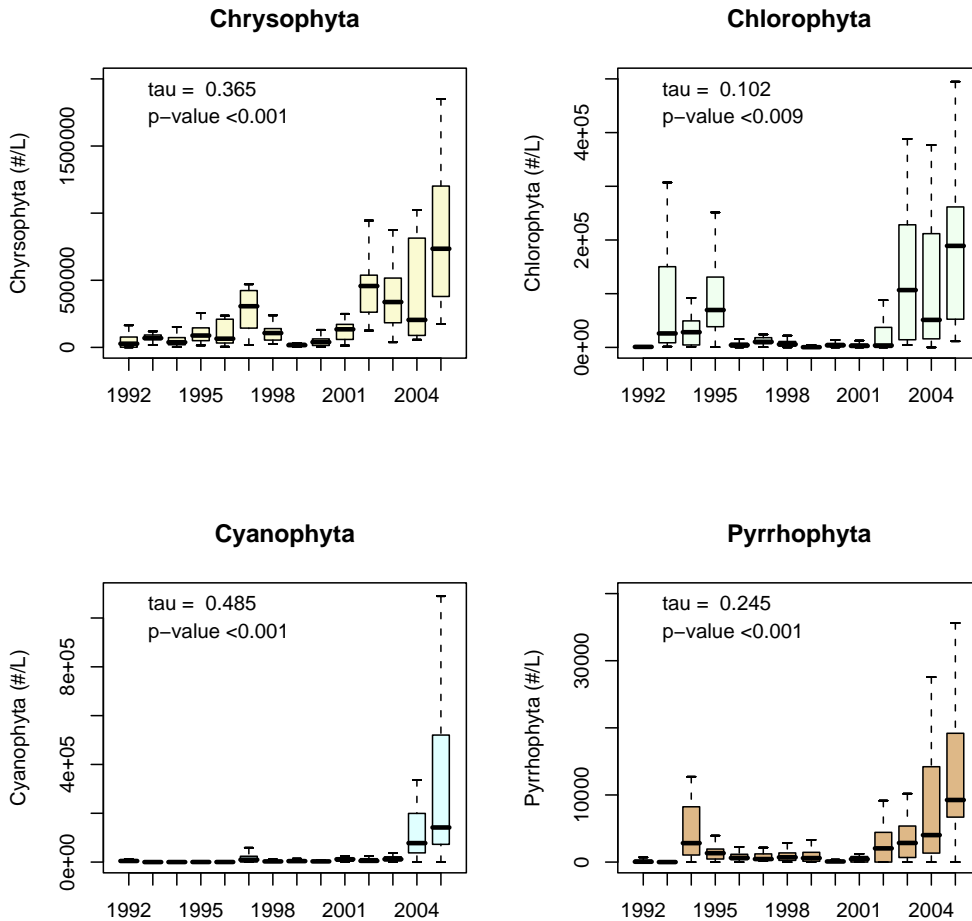


Figure 8: Distribution of summer (May–Sept) algal counts by year (Sites 1–4 combined). Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values; outliers were not plotted, but were included in the correlation analysis (see text for discussion). Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

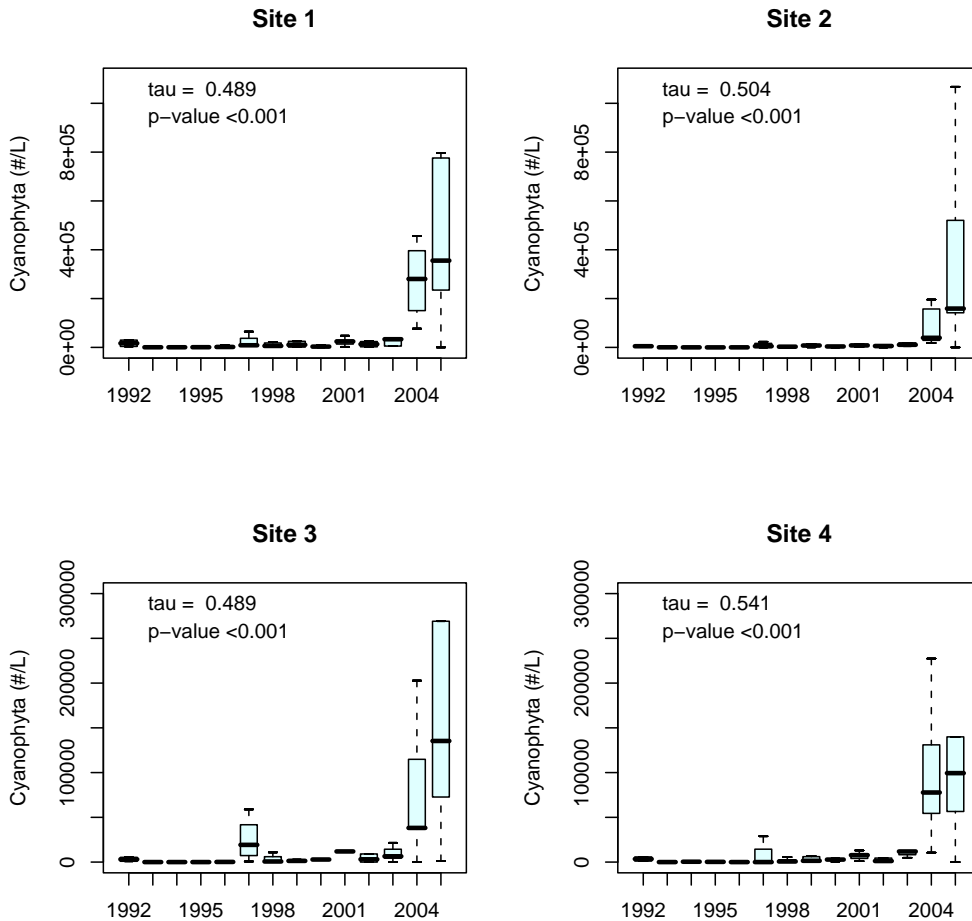


Figure 9: Distribution of summer (May–Sept) Cyanophyta counts at Sites 1–4 by year. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values; outliers were not plotted, but were included in the correlation analysis (see text for discussion). Kendall’s τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

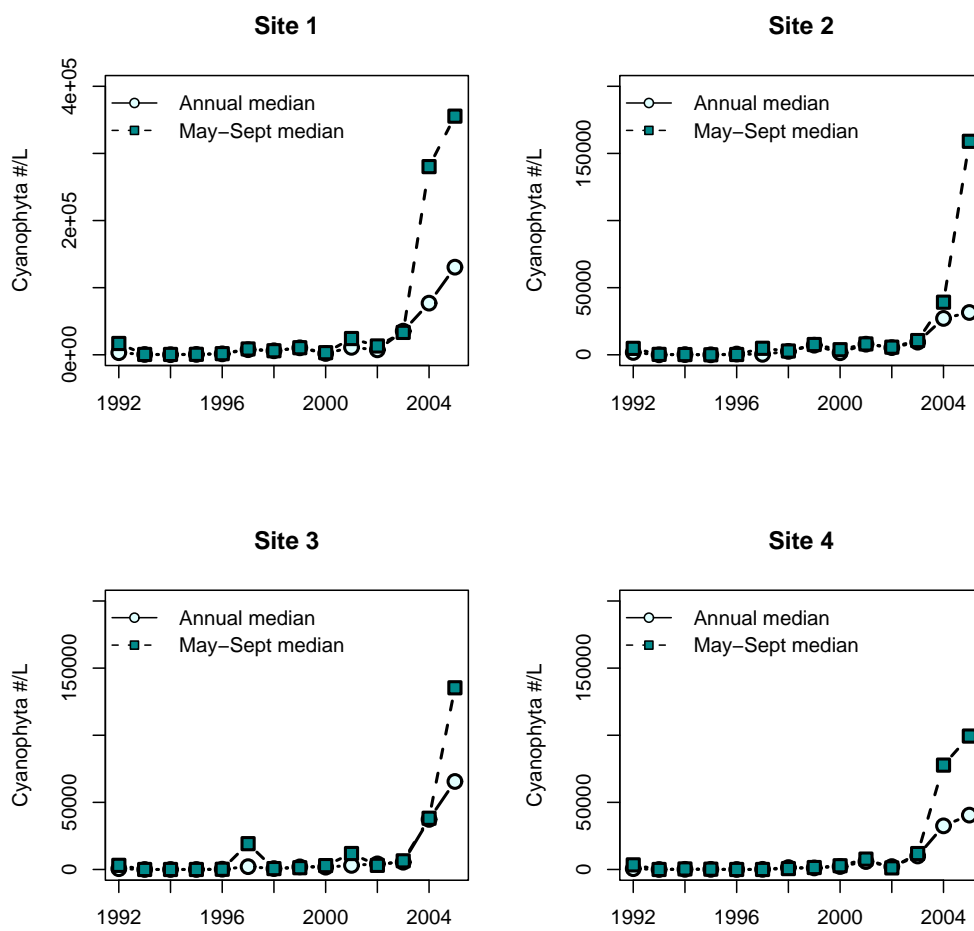


Figure 10: Median Cyanophyta annual and summer (May–Sept) densities at Sites 1–4, 1992–2005.

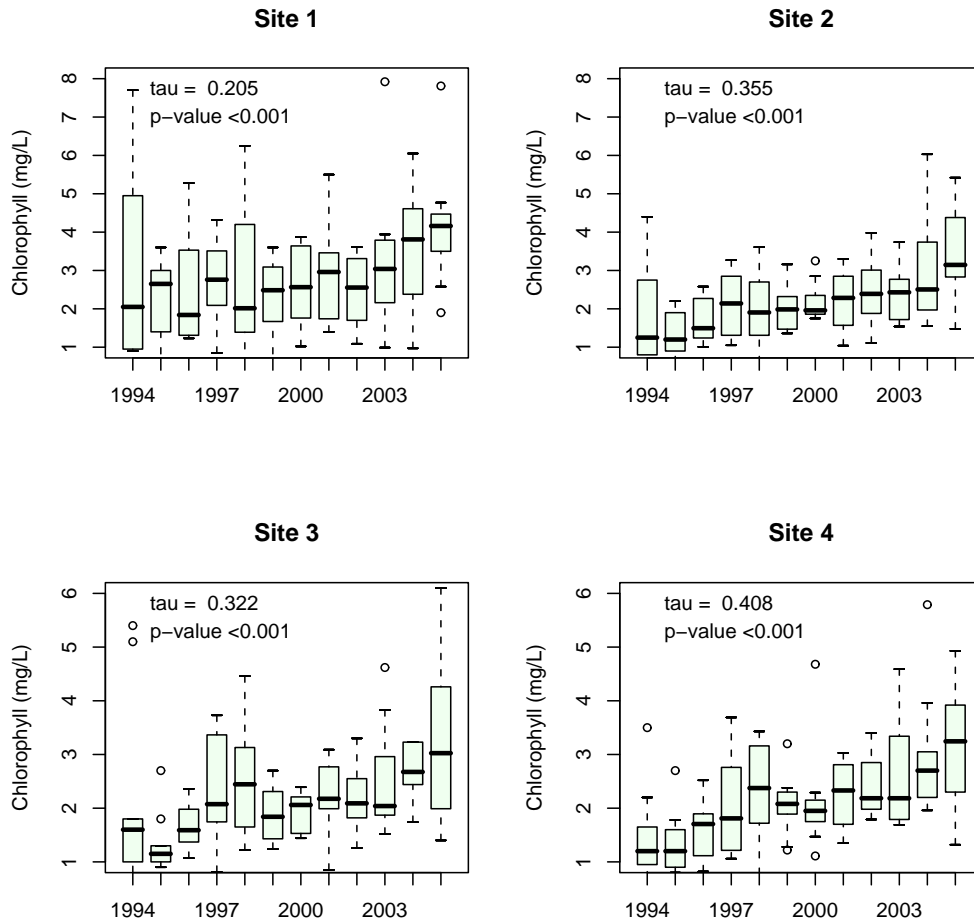


Figure 11: Lake Whatcom annual chlorophyll densities, 1994–2004. A different plotting scale is used for Sites 1 and 2 because of the higher chlorophyll concentration at this site. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values; extreme outliers were not plotted, but were included in the correlation analysis (see text for discussion). Kendall’s τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

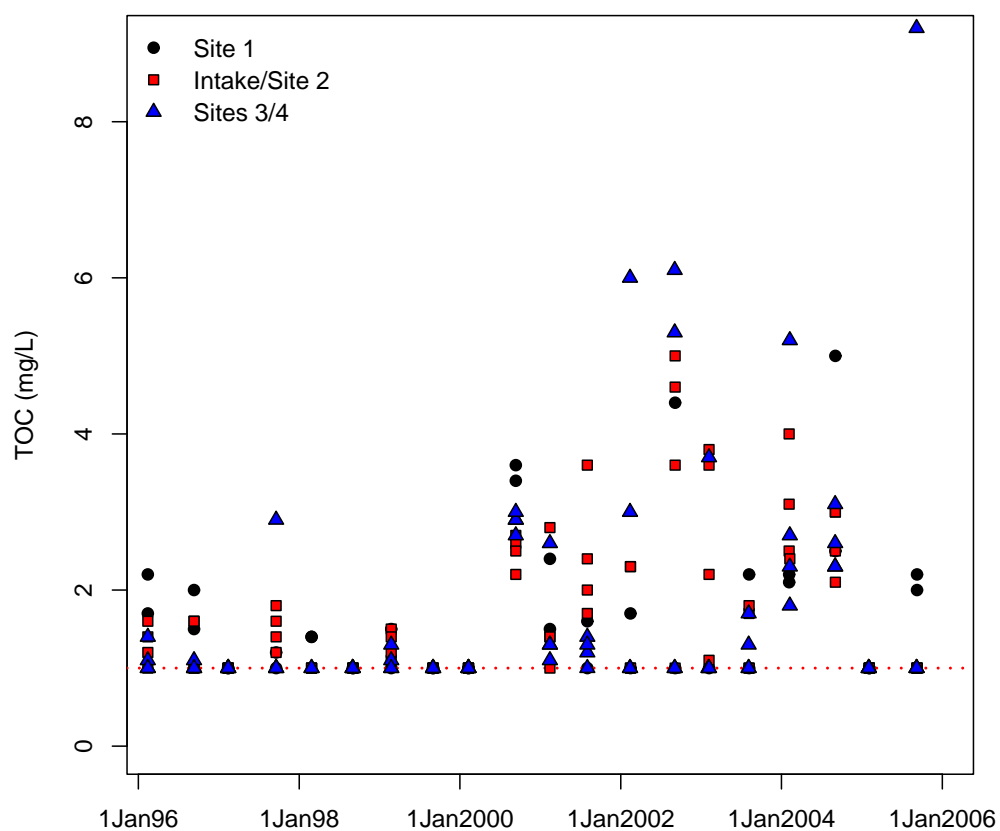


Figure 12: Lake Whatcom total organic carbon concentrations from surface and bottom samples at Sites 1–4 and the Intake. Note that multiple plotted points at the detection limit (red dotted line) may not be visible.

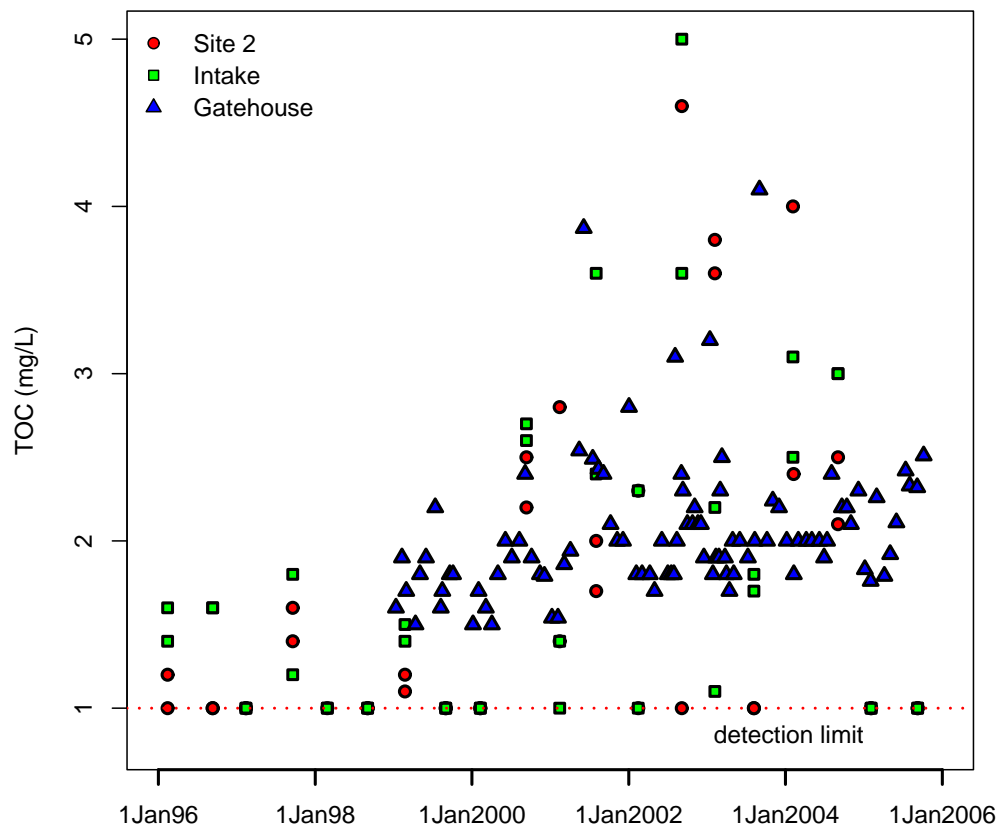


Figure 13: Lake Whatcom total organic carbon concentrations at Site 2 (mid-basin, surface/bottom), the Intake (off-shore, surface/bottom), and the raw water gatehouse (data provided by the City of Bellingham Public Works Department). Note that multiple plotted points at the detection limit (red dotted line) may not be visible.

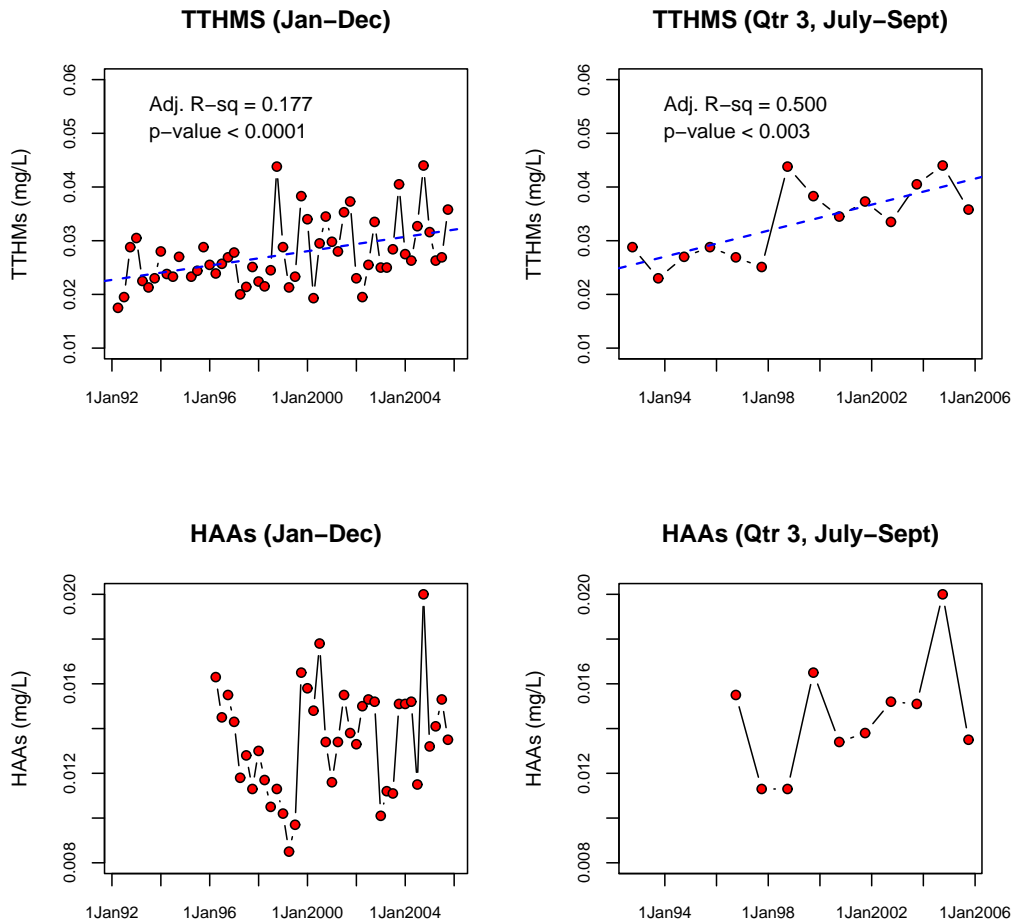


Figure 14: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2005. Regressions for Jan-Dec and Qtr 3 THMs vs. time were significant. Data were provided by the City of Bellingham Public Works Department.

3 Creek Monitoring

3.1 Site Descriptions

Fifteen sites were sampled monthly during 2004/2005 (Figure A2, page 133), which represents a substantial increase in the level of effort directed toward collecting tributary data in the Lake Whatcom watershed. Monthly samples were collected from Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, Euclid, Mill Wheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks to measure the parameters listed in Table 11. The sampling locations for these sites are described in Appendix A.2 (beginning on page 127).

In addition to monthly monitoring, Anderson, Austin, and Smith Creeks were sampled twice to collect 48-hr composite samples using automatic samplers provided by the City, and the Austin Creek and Beaver Creek watersheds were sampled intensively during a 1-day “creek walk.” The findings from the creek walk are summarized briefly in this report, and the full data report is available online at <http://www.ac.wvu.edu/iws>.

3.2 Field Sampling and Analytical Methods

The creeks were sampled on October 13, November 10, December 1, 2004, and January 11, February 8, March 1, April 12, May 10, June 8, July 12, August 9, and September 13, 2005. The water quality measurements are summarized in Table 11 (page 44). The analytical procedures are summarized in Table 2 (page 16). All water samples (including bacteriological samples) collected in the field were stored on ice and in the dark until they reached the laboratory. Once in the laboratory the handling procedures that were relevant for each analysis were followed (see Table 2). The total metals analyses (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc) and total organic carbon analyses were done by AmTest. The bacteria samples were analyzed by the City of Bellingham at their water treatment plant. All other analyses were done by WWU personnel. Creek discharge measurements were collected during the monthly sampling period at Blue Canyon Creek using the transect procedure described by USGS (Rantz, et al., 1982). All other sites have USGS or IWS gauges that provide discharge data to the City.

3.3 Results and Discussion

3.3.1 Monthly creek monitoring

The major objective for the 2004/2005 creek monitoring was to provide baseline data for most of the tributaries that flow into Lake Whatcom. Whatcom Creek was also sampled to provide baseline data for the lake's outlet. The monthly data are summarized in Tables 12–26 (pages 45–59) and on boxplots that show medians and data ranges for each creek (Figures 15–29, pages 64–78). The figures include horizontal reference lines that show the median value for Smith Creek. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted. The figures also show which creeks had significantly higher or lower concentrations relative to Smith Creek.¹³

Temperature and dissolved oxygen concentrations were similar at all sites (Figures 17 and 19). The Park Place wet pond outlet, Silver Beach Creek, and Whatcom Creek had slightly lower median dissolved oxygen concentrations and slightly higher median temperatures, which is typical for residential streams and streams that are formed by lake outlets.

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by low concentrations for alkalinity (≤ 50 mg/L), conductivity (≤ 100 μ S), and total solids (≤ 100 mg/L), with pH levels only slightly above neutral (Figures 15–16, 18, and 20). Sites that did not match this description included the residential streams (e.g., the Park Place outlet and Silver Beach Creek) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations (≤ 10 mg/L) and low turbidities (≤ 5 NTU) except for outliers that were probably related to precipitation events (Figures 21–22)

Total nitrogen includes both inorganic nitrogen (ammonia, nitrite, and nitrate) and organic nitrogen. In the Lake Whatcom tributaries, total nitrogen and nitrate/nitrite concentrations were nearly identical, indicating that very little organic nitrogen was present in the streams (Figures 23 and 24). Total nitrogen and nitrate concentrations were low in Anderson, Blue Canyon, and Whatcom Creeks. The low levels in Whatcom Creek, and possible Anderson Creek, reflect algal uptake

¹³Significance was determined at p-value ≤ 0.050 using the pairwise Wilcoxon rank sum test, corrected for repeated measured (Hollander & Wolfe, 1999).

of nitrogen in upstream lakes. The low level in Blue Canyon Creek is probably due to the unusual soils in its watershed. Ammonia concentrations were elevated in residential streams (e.g., the Park Place outlet), as well as in Anderson and Whatcom Creeks (Figure 25). Ammonia does not persist long in oxygenated surface waters. When present in streams, it usually indicates a near-by source such as an upstream wetland with anaerobic soils or a pollution source. The elevated ammonia at Park Place probably reflects residential pollution. In Whatcom Creek, it may be coming from basin 1. The ammonia source in Anderson Creek is unknown; there is a wetland, a small lake, and hobby farms located upstream from our sampling site.

Total phosphorus, like total nitrogen, includes inorganic and organic forms of phosphorus. Soluble inorganic phosphate, is quickly removed from surface water by biota, so high concentrations of soluble phosphorus usually indicate a near-by source such as an anaerobic wetland or a pollution source. In the Lake Whatcom tributaries, total phosphorus concentrations were usually much higher than soluble phosphate concentrations (Figures 26 and 27). None of the creeks had significantly higher soluble phosphate concentrations compared to Smith Creek, but Whatcom Creek had significantly lower concentrations. This probably reflects algal uptake in basin 1. Carpenter, Euclid, Millwheel, Park Place, and Silver Beach Creeks had significantly higher total phosphorus concentrations compared to Smith Creek.

High coliform counts are a good indicator of residential pollution. Only Silver Beach Creek had significantly higher coliform counts relative to Smith Creek. However, most of the sites, including Smith Creek, failed to meet the coliform surface water standards set by WAC 173–201A (Table 27, page 60). Most of the sites failed Part B, which states that no more than 10% of the samples may exceed 100 cfu/100 mL, but passed Part A, which requires a geometric mean count of less than 50 cfu/100 mL. Notably, the same creeks that had elevated total phosphorus levels (Carpenter, Euclid, Millwheel, Park Place, and Silver Beach Creeks) failed both parts of the surface water standards for coliforms. Only upper Beaver Creek, Blue Canyon Creek, and Whatcom Creek passed both parts of the standard.

3.3.2 Comparison to Smith Creek

In general, the water quality in Austin Creek, Beaver Creek, and Olsen Creek was similar to Smith Creek (Table 28, page 61). Silver Beach Creek had the worst water quality, with significantly higher values for alkalinity, conductivity, pH, turbidity, total solids, total phosphorus and coliforms compared to Smith Creek. The Park Place wet pond outlet also had poor water quality, with higher values for alkalinity, conductivity, total solids, ammonia, and total phosphorus. Carpenter Creek, Euclid Creek, and Millwheel Creek had high concentrations of total solids and total phosphorus. The water quality in Whatcom Creek reflected the effects of Lake Whatcom by having significantly lower levels for total solids (sediments settle in lakes) and nutrients. Nitrate, total nitrogen (which is predominantly nitrate), and soluble phosphate concentrations were significantly lower due to algal uptake in basin 1. Ammonia was higher, probably from the accumulation of ammonia in anaerobic portions of the lake. The other two sites that had significantly higher ammonia concentrations were Anderson Creek and the Park Place wet pond outlet, both of which have standing water upstream from the sampling sites. Millwheel Creek has a pond upstream from the sampling location that attracts waterfowl, which may contribute to the higher levels of turbidity, total solids, and total phosphorus in the creek.

3.3.3 48-hr sampling

Because streams are constantly moving, water samples collected from stream only capture a brief snapshot of the water quality changes that typically occur on a daily basis. The objective of the 48-hr sampling was to provide information about variability in stream water quality. Composite samples were collected at 90 minute intervals for 48 hours from Anderson, Lower Austin, and Smith Creeks in January and March, 2005. During the composite sampling period, 4 grab samples were collected from Lower Austin and Smith Creeks. The composite and grab samples were analyzed for the parameters listed in Table 11 (page 44).

The stream flows were considerably higher in January (see Section 4) than in March. The January 18–20 sampling period was preceded by a cold, dry period, with snow falling on January 11; during sampling there was heavy precipitation (2 in. at the Bellingham airport). The March 9–11 sampling period was relatively dry (0.1 in.), but stream discharge was relatively high (wet-season base flow).

The grab samples reveal some of the variation that can occur in streams during 48 hours (Figures 30–34 (pages 79–83)). Grab sample data were plotted along with monthly data from the same site. Although some parameters were reasonably stable during 48 hours (e.g., conductivity; Figure 31), most showed considerable variation. In some cases, there was at least as much variation within 48 hours as during the entire 12 month sampling period (e.g., turbidity; Figure 32).

The composite samples represent “average” concentrations within the 48-hr period and were quite similar to the monthly data (Figures 35–36, pages 84–84). This suggests that the monthly monitoring results are good indicators of average water quality conditions, but may not characterize the full range of water quality conditions, and in particular, may underestimate the minimum and maximum values that can occur in the stream.

Total metals and total organic carbon concentrations were measured in the composite samples (Table 29, page 62). Total organic carbon concentrations were very low or below detection. Most metals concentrations were near or below detection. Low levels of copper were present in samples from Anderson and Smith Creeks; low levels of zinc were present at all sites. Iron was present in all samples, but the levels were within typical ranges for the Lake Whatcom watershed.

3.3.4 Austin Creek and Beaver Creek intensive sampling

Beaver Creek and Austin Creek were sampled intensively on November 20, 2004 to measure temperature, dissolved oxygen, turbidity, total nitrogen, total phosphorus, total suspended solids, and fecal coliforms. The objective was to assess the amount of variability that can be expected for water quality measurements collected from these creeks at different times during the day and in different locations within the Austin Creek and Beaver Creek watersheds.

Water quality data were collected every 30 minutes at three stationary or “fixed” sites in upper and lower Austin Creek and Beaver Creek, beginning at 8:00 am and ending at 16:00 (4 pm). During this same period, individual samples were collected at 24 additional “creek walk” sites within the Austin Creek and Beaver Creek watersheds (Figure A3, page 134). The creek walk sites included 8 sites in Austin Creek, 8 sites in Beaver Creek, 5 small tributaries to Austin Creek, and 3 small tributary to Beaver Creek. The full creek walk report is available online at <http://www.ac.wvu.edu/iws>.

Parameter	2004			2005								
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
DO	●	●	●	○	●	○	●	●	●	●	●	●
pH	●	●	●	○	●	○	●	●	●	●	●	●
Temp	●	●	●	○	●	○	●	●	●	●	●	●
Cond	●	●	●	○	●	○	●	●	●	●	●	●
Alkalinity	●	●	●	○	●	○	●	●	●	●	●	●
Ammonia	●	●	●	○	●	○	●	●	●	●	●	●
Nitrite/nitrate	●	●	●	○	●	○	●	●	●	●	●	●
T. nitrogen	●	●	●	★	●	★	●	●	●	●	●	●
Sol. phosphate	●	●	●	○	●	○	●	●	●	●	●	●
T. phosphorus	●	●	●	★	●	★	●	●	●	●	●	●
T. solids	●	●	●	★	●	★	●	●	●	●	●	●
T. susp. solids	●	●	●	★	●	★	●	●	●	●	●	●
Turbidity	●	●	●	○	●	○	●	●	●	●	●	●
T. metals (As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Zn)				†		†						
T. organic carbon				†		†						
Discharge (Blue Canyon only)	●	●	●	●	●	●	●	●	●	●	●	●
Bacteria	●	●	●	●	●	●	●	●	●	●	●	●

● = monthly grab

○ = monthly grab + 4× grab (during composite)

† = 48-hr composite sample

★ = monthly grab + 4× grab + 48-hr composite

Table 11: Lake Whatcom 2004/2005 creek monitoring schedule.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	13.9	19.8	19.8	26.9	3.4	12
Conductivity (μS/cm)	52.5	62.8	63.6	73.4	6.2	12
Dissolved oxygen (mg/L)	9.1	10.2	10.6	14.8	1.6	12
pH	6.9	7.1	7.1	7.6	0.2	12
Temperature (°C)	2.1	9.7	9.1	15.1	4.0	12
Turbidity (NTU)	0.8	2.2	5.4	28.8	8.0	12
Total solids (mg/L)	46.6	52.5	54.0	63.4	5.9	11
Total suspended solids (mg/L)	<1.8	3.3	3.6	8.1	3.0	12
Nitrogen - ammonia (μg-N/L)	4.0	17.7	18.4	32.6	10.0	12
Nitrogen - nitrate/nitrite (μg-N/L)	58.8	406.4	382.4	665.4	174.3	12
Nitrogen - total (μg-N/L)	120.2	580.0	508.9	837.1	220.0	12
Phosphorus - soluble (μg-P/L)	6.7	10.1	10.5	14.6	2.3	12
Phosphorus - total (μg-P/L)	15.0	20.2	26.3	61.8	14.5	12
Discharge (cfs)	1.30	6.14	14.81	109.71	31.63	11
Coliforms - fecal (cfu/100 mL) [‡]	5	41	38	220	NA	12
Coliforms - E. coli (cfu/100 mL) [‡]	4	29	32	180	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 12: Summary of Anderson Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	9.6	13.9	16.5	34.2	7.2	12
Conductivity (μS/cm)	37.6	54.5	65.6	126.0	29.6	12
Dissolved oxygen (mg/L)	9.3	11.0	11.1	13.7	1.4	12
pH	7.1	7.4	7.4	7.6	0.2	12
Temperature (°C)	1.6	9.3	8.8	15.5	4.1	12
Turbidity (NTU)	0.3	0.8	1.0	4.2	1.0	12
Total solids (mg/L)	36.3	43.5	49.6	77.3	14.4	11
Total suspended solids (mg/L)	<1.8	<1.8	<1.8	6.9	2.2	12
Nitrogen - ammonia (μg-N/L)	<2.0	5.2	5.7	16.1	5.0	12
Nitrogen - nitrate/nitrite (μg-N/L)	255.2	425.4	448.3	724.7	141.4	12
Nitrogen - total (μg-N/L)	361.6	543.4	534.4	783.2	122.3	12
Phosphorus - soluble (μg-P/L)	5.2	11.3	12.1	21.6	5.0	12
Phosphorus - total (μg-P/L)	12.1	18.4	22.9	74.3	16.6	12
Discharge (cfs)	0.16	4.04	6.46	32.43	8.65	12
Coliforms - fecal (cfu/100 mL)	<1	3	5	240	NA	12
Coliforms - E. coli (cfu/100 mL)	<1	3	4	200	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 13: Summary of upper Austin Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	9.9	18.0	18.4	33.6	7.1	12
Conductivity (μS/cm)	45.5	60.8	70.3	127.7	24.0	12
Dissolved oxygen (mg/L)	8.5	10.2	10.4	13.5	1.5	12
pH	7.0	7.1	7.1	7.6	0.2	12
Temperature (°C)	1.3	9.7	8.9	14.5	3.9	12
Turbidity (NTU)	0.3	1.7	2.2	9.6	2.4	12
Total solids (mg/L)	45.7	54.7	58.5	83.1	10.8	11
Total suspended solids (mg/L)	<1.8	<1.8	2.6	18.0	5.0	12
Nitrogen - ammonia (μg-N/L)	<2.0	9.6	17.5	108.1	29.1	12
Nitrogen - nitrate/nitrite (μg-N/L)	212.5	635.0	607.3	941.5	250.2	12
Nitrogen - total (μg-N/L)	370.6	803.9	783.2	1082.6	263.6	12
Phosphorus - soluble (μg-P/L)	7.0	12.9	13.8	22.4	4.3	12
Phosphorus - total (μg-P/L)	14.1	27.3	30.4	66.8	13.6	12
Discharge (cfs)	0.04	3.06	6.95	40.39	11.14	12
Coliforms - fecal (cfu/100 mL)	1	4	7	90	NA	12
Coliforms - E. coli (cfu/100 mL)	<1	6	5	81	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 14: Summary of upper Beaver Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	11.7	17.0	19.9	37.4	7.4	12
Conductivity (μS/cm)	45.3	67.4	74.9	140.6	27.5	12
Dissolved oxygen (mg/L)	8.4	10.7	10.8	13.7	1.4	12
pH	7.0	7.3	7.3	7.6	0.2	12
Temperature (°C)	0.9	9.8	9.1	15.0	4.0	12
Turbidity (NTU)	0.4	1.7	3.2	17.6	4.7	12
Total solids (mg/L)	36.0	59.3	62.2	85.2	14.6	11
Total suspended solids (mg/L)	<1.8	<1.8	5.1	35.0	10.2	11
Nitrogen - ammonia (μg-N/L)	2.3	6.9	7.9	14.7	4.2	12
Nitrogen - nitrate/nitrite (μg-N/L)	227.9	596.2	554.2	892.7	234.7	12
Nitrogen - total (μg-N/L)	318.3	755.0	725.2	1073.1	260.2	12
Phosphorus - soluble (μg-P/L)	9.3	12.2	12.9	18.1	3.0	12
Phosphorus - total (μg-P/L)	18.6	26.2	27.5	44.0	8.7	12
Discharge (cfs)	0.20	10.04	17.12	92.83	25.20	12
Coliforms - fecal (cfu/100 mL)	3	20	22	250	NA	12
Coliforms - E. coli (cfu/100 mL)	<1	17	14	350	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 15: Summary of water quality data collected at the confluence of Austin Creek and Beaver Creek, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	4.6	17.9	19.8	36.5	8.9	12
Conductivity (μS/cm)	49.1	68.0	77.3	137.5	26.8	12
Dissolved oxygen (mg/L)	8.8	10.7	10.9	13.9	1.6	12
pH	7.3	7.4	7.5	7.7	0.1	12
Temperature (°C)	0.8	10.8	9.1	15.3	4.3	12
Turbidity (NTU)	0.5	1.4	2.4	11.0	2.9	12
Total solids (mg/L)	44.5	57.0	60.0	84.7	12.9	11
Total suspended solids (mg/L)	<1.8	<1.8	3.5	23.2	6.4	12
Nitrogen - ammonia (μg-N/L)	<2.0	7.3	6.8	16.6	4.3	12
Nitrogen - nitrate/nitrite (μg-N/L)	202.6	554.7	525.1	818.3	214.5	12
Nitrogen - total (μg-N/L)	305.6	690.5	666.9	927.5	222.4	12
Phosphorus - soluble (μg-P/L)	9.8	12.6	14.2	22.6	4.0	12
Phosphorus - total (μg-P/L)	16.6	23.1	23.8	32.6	6.0	12
Discharge (cfs)	0.25	4.18	10.91	50.29	19.44	6
Coliforms - fecal (cfu/100 mL)	3	30	23	170	NA	12
Coliforms - E. coli (cfu/100 mL)	1	16	13	100	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 16: Summary of lower Austin Creek (downstream from confluence with Beaver Creek) monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	71.8	128.8	124.8	163.5	25.3	12
Conductivity (μS/cm)	212.0	270.5	264.5	289.0	22.7	12
Dissolved oxygen (mg/L)	9.6	10.6	10.8	13.5	1.2	12
pH	8.1	8.3	8.3	8.4	0.1	12
Temperature (°C)	2.2	9.8	9.4	14.8	3.7	12
Turbidity (NTU)	0.8	2.0	2.5	6.2	1.8	12
Total solids (mg/L)	142.6	162.1	160.7	173.3	9.4	11
Total suspended solids (mg/L)	<1.8	3.2	4.4	12.6	3.9	12
Nitrogen - ammonia (μg-N/L)	<2.0	8.0	7.2	11.2	3.4	12
Nitrogen - nitrate/nitrite (μg-N/L)	99.0	204.9	268.6	629.9	180.4	12
Nitrogen - total (μg-N/L)	157.4	289.0	389.8	710.3	215.2	12
Phosphorus - soluble (μg-P/L)	6.3	9.1	10.5	17.2	3.4	12
Phosphorus - total (μg-P/L)	11.0	15.8	18.9	51.5	11.2	12
Discharge (cfs)	0.03	0.19	0.20	0.38	0.12	10
Coliforms - fecal (cfu/100 mL)	<1	3	4	76	NA	12
Coliforms - E. coli (cfu/100 mL)	<1	3	4	38	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 17: Summary of Blue Canyon Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	7.0	9.8	10.7	16.0	3.1	11
Conductivity (μS/cm)	33.3	42.9	42.9	50.0	4.8	11
Dissolved oxygen (mg/L)	7.0	10.1	10.0	12.7	1.7	11
pH	6.7	6.9	6.9	7.1	0.1	11
Temperature (°C)	2.4	9.1	8.5	14.2	3.6	11
Turbidity (NTU)	0.3	0.8	1.0	2.6	0.7	11
Total solids (mg/L)	30.1	35.8	36.9	51.6	6.0	10
Total suspended solids (mg/L)	<1.8	<1.8	2.3	15.5	4.6	11
Nitrogen - ammonia (μg-N/L)	<2.0	5.6	4.8	8.8	3.3	11
Nitrogen - nitrate/nitrite (μg-N/L)	317.0	715.6	706.1	1230.4	300.7	11
Nitrogen - total (μg-N/L)	385.5	784.3	825.6	1405.2	315.5	11
Phosphorus - soluble (μg-P/L)	2.8	5.3	6.2	10.6	2.6	11
Phosphorus - total (μg-P/L)	10.7	13.5	14.5	22.1	3.1	11
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	1	12	20	750	NA	11
Coliforms - E. coli (cfu/100 mL)	2	11	21	580	NA	11

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 18: Summary of Brannian Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	14.8	21.7	25.5	45.3	9.9	11
Conductivity (μS/cm)	50.3	70.0	74.2	113.0	17.8	11
Dissolved oxygen (mg/L)	5.9	10.5	10.5	14.6	2.3	11
pH	7.1	7.5	7.5	7.7	0.2	11
Temperature (°C)	0.0	9.0	8.6	16.2	4.8	11
Turbidity (NTU)	1.3	3.3	3.9	11.1	2.8	11
Total solids (mg/L)	52.6	67.3	71.6	100.8	16.5	10
Total suspended solids (mg/L)	<1.8	2.3	6.6	24.6	8.2	11
Nitrogen - ammonia (μg-N/L)	<2.0	6.7	11.9	74.9	21.1	11
Nitrogen - nitrate/nitrite (μg-N/L)	292.3	574.8	582.4	852.5	199.6	11
Nitrogen - total (μg-N/L)	547.9	864.0	839.7	1127.0	189.3	11
Phosphorus - soluble (μg-P/L)	10.0	13.7	17.0	31.0	6.9	11
Phosphorus - total (μg-P/L)	17.3	25.4	32.1	57.3	13.1	11
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	8	100	76	860	NA	11
Coliforms - E. coli (cfu/100 mL)	6	80	46	580	NA	11

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 19: Summary of Carpenter Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	18.0	29.9	32.3	51.2	11.0	10
Conductivity (μS/cm)	61.1	91.7	94.7	130.0	22.0	10
Dissolved oxygen (mg/L)	7.3	9.9	10.0	12.9	1.7	10
pH	7.1	7.3	7.3	7.4	0.1	10
Temperature (°C)	1.5	8.9	8.9	14.4	3.9	10
Turbidity (NTU)	1.3	2.2	2.7	7.5	1.8	10
Total solids (mg/L)	62.2	68.3	74.3	91.3	10.3	9
Total suspended solids (mg/L)	<1.8	2.6	4.1	11.5	3.6	10
Nitrogen - ammonia (μg-N/L)	<2.0	12.0	11.3	24.1	7.2	10
Nitrogen - nitrate/nitrite (μg-N/L)	158.3	505.4	452.7	657.0	185.5	10
Nitrogen - total (μg-N/L)	330.7	684.4	660.2	858.5	169.7	10
Phosphorus - soluble (μg-P/L)	12.6	16.0	16.5	20.4	2.6	10
Phosphorus - total (μg-P/L)	19.2	27.4	28.7	36.8	6.6	10
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	29	79	93	720	NA	10
Coliforms - E. coli (cfu/100 mL)	8	72	64	540	NA	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 20: Summary of Euclid Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	21.5	35.5	40.9	67.5	16.1	10
Conductivity (μS/cm)	61.5	99.2	104.1	150.9	31.3	10
Dissolved oxygen (mg/L)	6.4	9.7	9.8	13.6	2.2	10
pH	7.2	7.3	7.4	7.8	0.2	10
Temperature (°C)	1.0	8.9	10.6	20.1	6.2	10
Turbidity (NTU)	3.7	5.9	6.6	16.5	3.7	10
Total solids (mg/L)	71.6	85.8	88.2	112.8	14.7	9
Total suspended solids (mg/L)	2.0	5.5	6.0	16.2	4.1	10
Nitrogen - ammonia (μg-N/L)	2.5	17.7	71.4	569.4	175.3	10
Nitrogen - nitrate/nitrite (μg-N/L)	17.0	529.7	422.9	826.0	298.6	10
Nitrogen - total (μg-N/L)	624.4	941.3	990.3	2188.6	460.9	10
Phosphorus - soluble (μg-P/L)	8.7	15.1	24.7	116.5	32.4	10
Phosphorus - total (μg-P/L)	27.5	53.0	62.8	198.0	48.9	10
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	36	69	106	740	NA	10
Coliforms - E. coli (cfu/100 mL)	20	69	85	790	NA	10

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 21: Summary of Millwheel Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	14.1	22.3	25.3	48.4	11.3	12
Conductivity (μS/cm)	51.9	66.4	76.0	128.6	24.9	12
Dissolved oxygen (mg/L)	9.4	10.8	11.1	14.8	1.7	12
pH	7.3	7.5	7.5	7.8	0.2	12
Temperature (°C)	0.0	9.3	8.3	15.3	4.6	12
Turbidity (NTU)	0.3	1.5	2.0	6.1	1.9	12
Total solids (mg/L)	48.7	60.3	63.2	86.1	10.6	11
Total suspended solids (mg/L)	<1.8	2.2	3.5	13.4	4.1	12
Nitrogen - ammonia (μg-N/L)	<2.0	4.0	4.5	15.5	4.1	12
Nitrogen - nitrate/nitrite (μg-N/L)	271.6	794.0	737.4	1119.8	324.6	12
Nitrogen - total (μg-N/L)	409.8	900.1	892.4	1338.7	332.9	12
Phosphorus - soluble (μg-P/L)	9.5	14.7	18.9	46.9	10.5	12
Phosphorus - total (μg-P/L)	16.9	23.7	24.0	40.8	6.5	12
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	1	28	17	270	NA	12
Coliforms - E. coli (cfu/100 mL)	1	9	11	260	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 22: Summary of Olsen Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	56.5	95.5	93.2	130.8	22.6	11
Conductivity (μS/cm)	9.0	229.5	208.0	289.0	74.0	12
Dissolved oxygen (mg/L)	7.5	8.8	9.2	11.9	1.6	12
pH	7.4	7.7	7.7	8.1	0.2	12
Temperature (°C)	4.5	13.1	12.2	19.9	5.0	12
Turbidity (NTU)	1.4	4.4	5.1	13.5	3.6	12
Total solids (mg/L)	112.7	144.8	142.5	185.8	24.1	11
Total suspended solids (mg/L)	<1.8	2.8	4.1	15.8	4.5	12
Nitrogen - ammonia (μg-N/L)	23.3	28.6	36.8	82.2	19.0	12
Nitrogen - nitrate/nitrite (μg-N/L)	120.6	482.4	534.4	1141.6	372.9	12
Nitrogen - total (μg-N/L)	446.5	934.7	964.9	1555.7	343.1	12
Phosphorus - soluble (μg-P/L)	13.9	23.1	22.6	34.2	6.5	12
Phosphorus - total (μg-P/L)	34.4	47.8	54.1	98.7	19.0	12
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	28	115	119	1600	NA	12
Coliforms - E. coli (cfu/100 mL)	4	75	81	1300	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 23: Summary of Park Place outlet monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	39.0	77.8	80.5	125.8	29.8	12
Conductivity (μS/cm)	106.4	187.0	192.7	276.0	56.7	12
Dissolved oxygen (mg/L)	8.2	9.8	10.3	14.4	2.0	12
pH	7.6	7.9	7.9	8.0	0.1	12
Temperature (°C)	0.0	10.9	9.5	16.2	4.9	12
Turbidity (NTU)	2.0	4.3	5.4	16.2	4.0	12
Total solids (mg/L)	99.7	137.4	132.8	170.3	25.0	11
Total suspended solids (mg/L)	<1.8	3.2	4.2	15.2	3.9	12
Nitrogen - ammonia (μg-N/L)	2.7	9.2	10.2	18.8	5.2	12
Nitrogen - nitrate/nitrite (μg-N/L)	149.0	527.0	515.9	980.2	260.5	12
Nitrogen - total (μg-N/L)	423.5	905.5	861.4	1388.1	302.4	12
Phosphorus - soluble (μg-P/L)	15.3	21.8	23.5	40.3	7.9	12
Phosphorus - total (μg-P/L)	30.2	43.3	45.7	69.6	12.4	12
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	48	505	417	3000	NA	12
Coliforms - E. coli (cfu/100 mL)	20	480	305	1400	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 24: Summary of Silver Beach Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	13.3	16.6	19.5	34.7	6.9	12
Conductivity (μS/cm)	48.5	57.8	63.0	94.2	14.1	12
Dissolved oxygen (mg/L)	9.8	11.1	11.4	15.1	1.7	12
pH	7.3	7.5	7.5	7.7	0.1	12
Temperature (°C)	0.5	9.3	8.3	14.8	4.3	12
Turbidity (NTU)	0.2	0.8	1.2	2.9	1.1	12
Total solids (mg/L)	43.3	51.7	51.0	60.4	5.2	11
Total suspended solids (mg/L)	<1.8	<1.8	2.0	6.8	2.3	12
Nitrogen - ammonia (μg-N/L)	<2.0	3.0	3.5	10.1	2.6	12
Nitrogen - nitrate/nitrite (μg-N/L)	427.0	951.5	870.2	1349.7	331.7	12
Nitrogen - total (μg-N/L)	519.6	1073.8	1013.1	1456.1	344.7	12
Phosphorus - soluble (μg-P/L)	6.2	11.9	13.7	24.8	5.8	12
Phosphorus - total (μg-P/L)	10.7	18.3	17.4	22.0	4.1	12
Discharge (cfs)	0.41	7.55	10.17	34.28	9.87	11
Coliforms - fecal (cfu/100 mL)	1	15	13	140	NA	12
Coliforms - E. coli (cfu/100 mL)	1	7	8	110	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 25: Summary of Smith Creek monthly water quality data, Oct. 2004 – Sept. 2005.

Variable	Min.	Med.	Mean [†]	Max.	SD	N
Alkalinity (mg/L CaCO ₃)	19.0	21.0	20.9	23.0	1.3	12
Conductivity (μS/cm)	60.8	63.0	80.6	173.7	41.1	12
Dissolved oxygen (mg/L)	8.2	9.2	9.5	11.9	1.3	12
pH	7.4	7.6	7.6	8.2	0.2	12
Temperature (°C)	4.5	13.5	13.3	23.4	5.7	12
Turbidity (NTU)	0.7	1.0	1.0	1.4	0.2	12
Total solids (mg/L)	35.2	40.7	42.2	47.7	4.4	11
Total suspended solids (mg/L)	<1.8	<1.8	<1.8	3.2	1.2	12
Nitrogen - ammonia (μg-N/L)	4.9	13.5	13.7	26.2	7.7	12
Nitrogen - nitrate/nitrite (μg-N/L)	5.1	171.1	170.7	333.3	120.2	12
Nitrogen - total (μg-N/L)	239.6	371.9	364.4	462.3	87.5	12
Phosphorus - soluble (μg-P/L)	1.6	4.1	4.3	6.2	1.3	12
Phosphorus - total (μg-P/L)	8.5	13.2	13.3	17.5	2.6	12
Discharge (cfs)	Data from USGS gages available from City					
Coliforms - fecal (cfu/100 mL)	2	9	11	74	NA	12
Coliforms - E. coli (cfu/100 mL)	2	6	9	79	NA	12

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.

[‡]Geometric means; all censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 26: Summary of Whatcom Creek monthly water quality data, Oct. 2004 – Sept. 2005.

	Part A		Part B	
	Geom.Mean (GM) ≤50 cfu/100 mL		Max 10% >100 cfu/100 mL	
Anderson Creek	GM = 38	pass	42% >100	fail
Austin Creek, upper	GM = 5	pass	17% >100	fail
Beaver Creek, upper	GM = 7	pass	0% >100	pass
Austin/Beaver confluence	GM = 22	pass	17% >100	fail
Austin Creek, lower	GM = 23	pass	17% >100	fail
Blue Canyon Creek	GM = 4	pass	0% >100	pass
Brannian Creek	GM = 20	pass	27% >100	fail
Carpenter Creek	GM = 76	fail	55% >100	fail
Euclid Creek	GM = 93	fail	20% >100	fail
Millwheel Creek	GM = 106	fail	40% >100	fail
Olsen Creek	GM = 17	pass	18% >100	fail
Park Place outlet	GM = 119	fail	50% >100	fail
Silver Beach Creek	GM = 417	fail	83% >100	fail
Smith Creek	GM = 13	pass	17% >100	fail
Whatcom Creek	GM = 11	pass	0% >100	pass

‡All censored values replaced with closest integer (i.e., <1 ⇒ 1).

Table 27: Comparison of fecal coliform data from Lake Whatcom tributaries to WAC 173–201A surface water standards.

	Alk	Cond	DO	pH	Temp	Turb	TS	TSS
Anderson Creek	ns	ns	ns	L	ns	ns	ns	ns
Austin Creek, upper	ns	ns	ns	ns	ns	ns	ns	ns
Beaver Creek, upper	ns	ns	ns	L	ns	ns	ns	ns
Austin/Beaver confluence	ns	ns	ns	ns	ns	ns	ns	ns
Austin Creek, lower	ns	ns	ns	ns	ns	ns	ns	ns
Blue Canyon Creek	H	H	ns	H	ns	ns	H	ns
Brannian Creek	L	L	ns	L	ns	ns	L	ns
Carpenter Creek	ns	ns	ns	ns	ns	ns	H	ns
Euclid Creek	ns	ns	ns	ns	ns	ns	H	ns
Millwheel Creek	H	ns	ns	ns	ns	H	H	ns
Olsen Creek	ns	ns	ns	ns	ns	ns	ns	ns
Park Place outlet	H	H	ns	ns	ns	ns	H	ns
Silver Beach Creek	H	H	ns	H	ns	H	H	ns
Whatcom Creek	ns	ns	ns	ns	ns	ns	L	ns

	NH3	NO3	TN	SRP	TP	FC	E.coli
Anderson Creek	H	L	ns	ns	ns	ns	ns
Austin Creek, upper	ns	ns	ns	ns	ns	ns	ns
Beaver Creek, upper	ns	ns	ns	ns	ns	ns	ns
Austin/Beaver confluence	ns	ns	ns	ns	ns	ns	ns
Austin Creek, lower	ns	ns	ns	ns	ns	ns	ns
Blue Canyon Creek	ns	L	L	ns	ns	ns	ns
Brannian Creek	ns	ns	ns	ns	ns	ns	ns
Carpenter Creek	ns	ns	ns	ns	H	ns	ns
Euclid Creek	ns	ns	ns	ns	H	ns	ns
Millwheel Creek	ns	ns	ns	ns	H	ns	ns
Olsen Creek	ns	ns	ns	ns	ns	ns	ns
Park Place outlet	H	ns	ns	ns	H	ns	ns
Silver Beach Creek	ns	ns	ns	ns	H	H	H
Whatcom Creek	H	L	L	L	ns	ns	ns

Table 28: Summary of creek water quality differences based on similarity to Smith Creek. Sites are identified as being not different (ns), significantly higher (H), or significantly lower (L) than Smith Creek. Significance differences were determined at p-value ≤ 0.050 using the pairwise Wilcoxon rank sum test.

	Date	TOC (mg/L)	T. As (mg/L)	T. Cd (mg/L)	T. Cr (mg/L)	T. Cu (mg/L)
Anderson	Jan 20, 2005	1.8	<0.01	<0.0005	<0.001	0.010
Anderson	Mar 11, 2005	<1	<0.01	<0.0005	<0.001	0.002
Austin, lower	Mar 11, 2005	<1	<0.01	<0.0005	<0.001	<0.001
Smith	Mar 11, 2005	<1	<0.01	<0.0005	<0.001	0.001

	Date	T. Fe (mg/L)	T. Hg (mg/L)	T. Ni (mg/L)	T. Pb (mg/L)	T. Zn (mg/L)
Anderson	Jan 20, 2005	0.410	<0.0002	<0.005	<0.001	0.011
Anderson	Mar 11, 2005	0.220	<0.0002	<0.005	<0.001	0.002
Austin, lower	Mar 11, 2005	0.130	<0.0002	<0.005	<0.001	0.003
Smith	Mar 11, 2005	0.024	<0.0002	<0.005	<0.001	0.002

Table 29: Total metals and total organic carbon results for 48-hr composite samples collected in selected creeks in the Lake Whatcom watershed.

Abbr.	Site	Abbr.	Site
AND	Anderson Creek	EUC	Euclid Creek
AUS1	Austin Creek, upper	MIL	Millwheel Creek
AUS2	Austin Creek/Beaver Creek	OLS	Olsen Creek
AUS3	Austin Creek, lower	PAR	Park Place Creek
BEA	Beaver Creek, upper	SIL	Silver Beach Creek
BLU	Blue Canyon Creek	SMI	Smith Creek
BRA	Brannian Creek	WHA	Whatcom Creek
CAR	Carpenter Creek		

Table 30: Abbreviations for creek sampling sites in Figures 15 – 29.

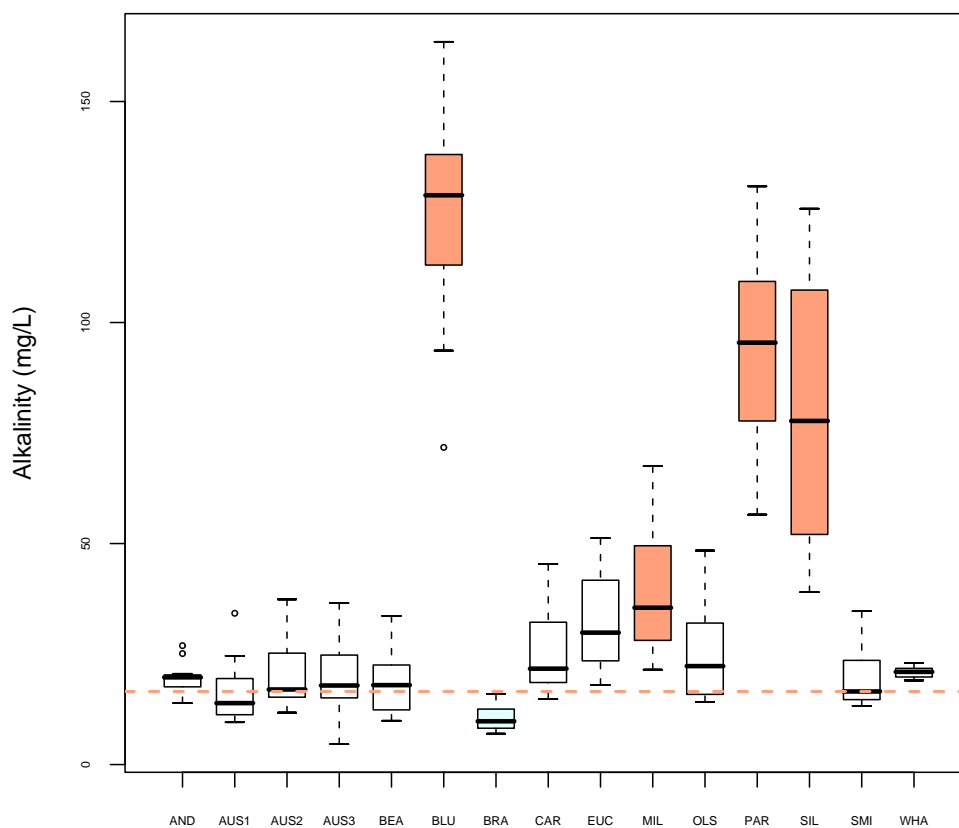


Figure 15: Summary of the 2004/2005 alkalinity data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

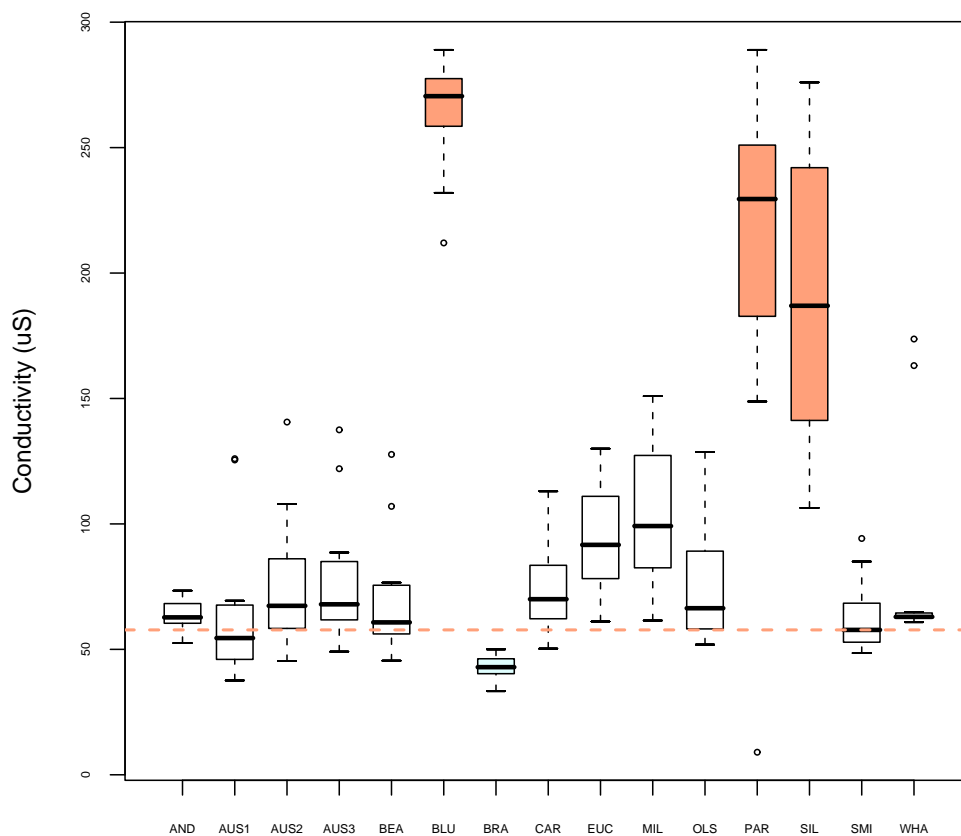


Figure 16: Summary of the 2004/2005 conductivity data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

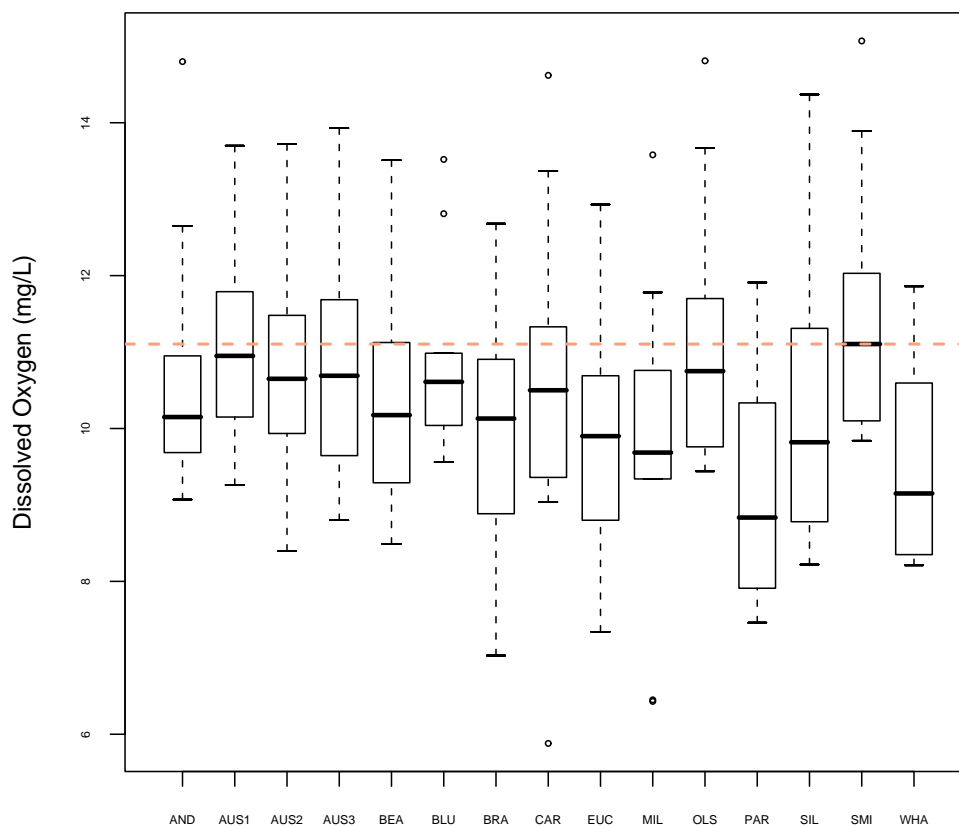


Figure 17: Summary of the 2004/2005 dissolved oxygen data for all creeks. Box-plots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. None of the creeks were significantly different than Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

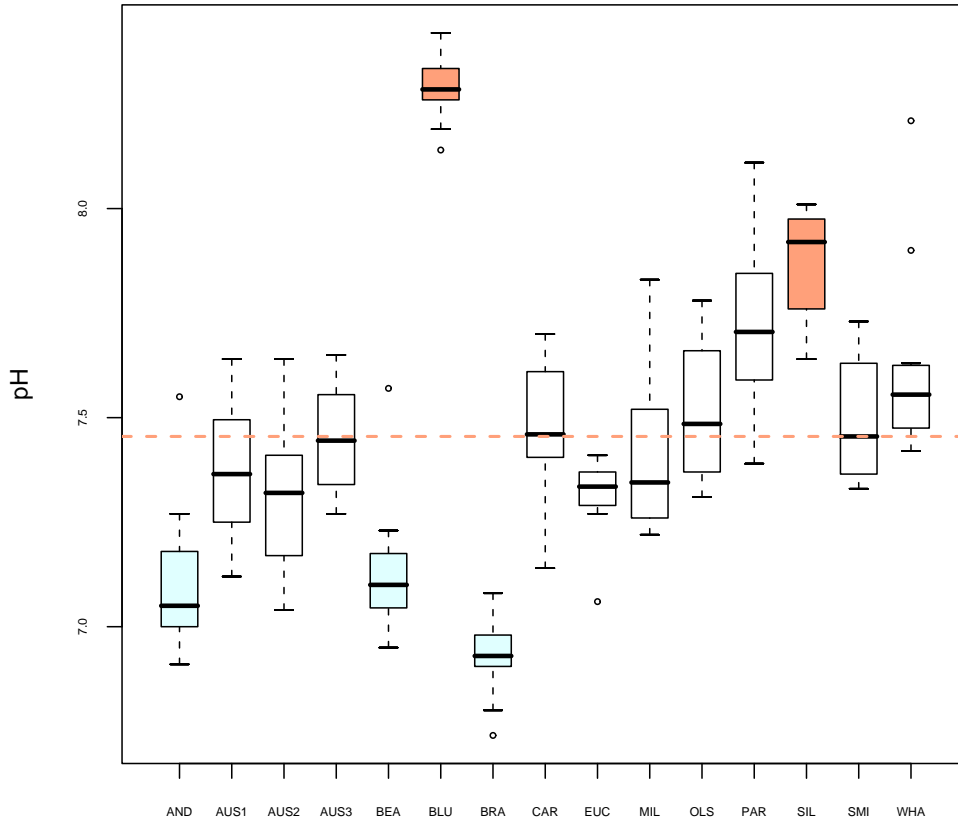


Figure 18: Summary of the 2004/2005 pH data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

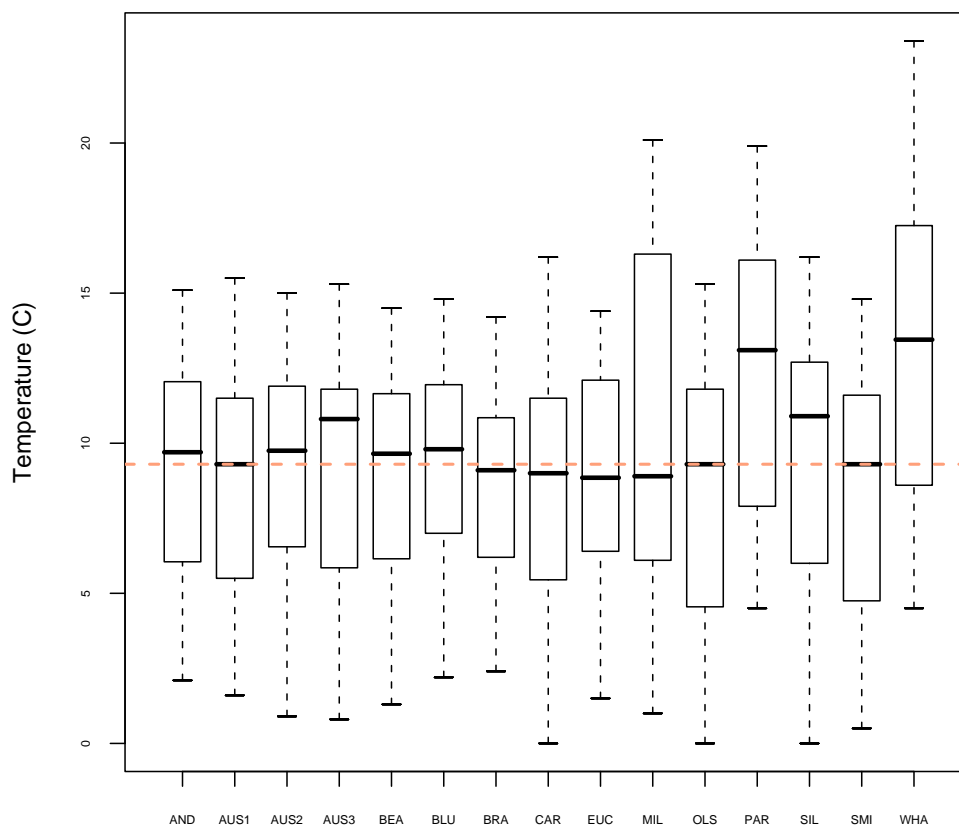


Figure 19: Summary of the 2004/2005 temperature data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. None of the creeks were significantly different than Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

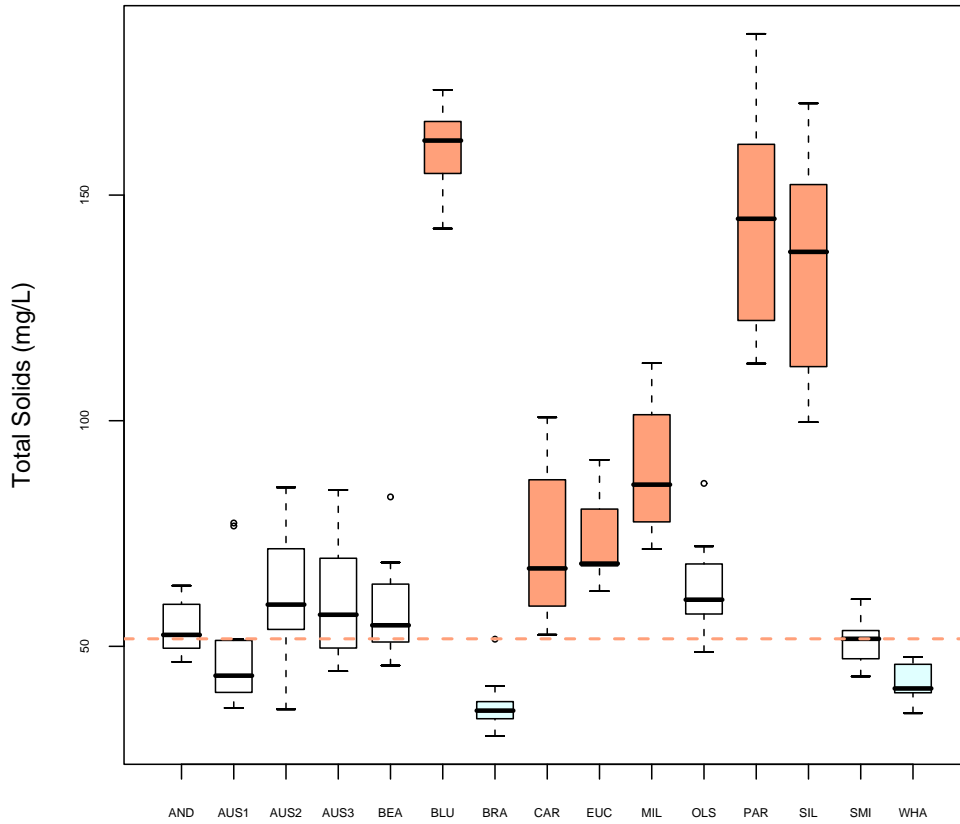


Figure 20: Summary of the 2004/2005 total solids data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

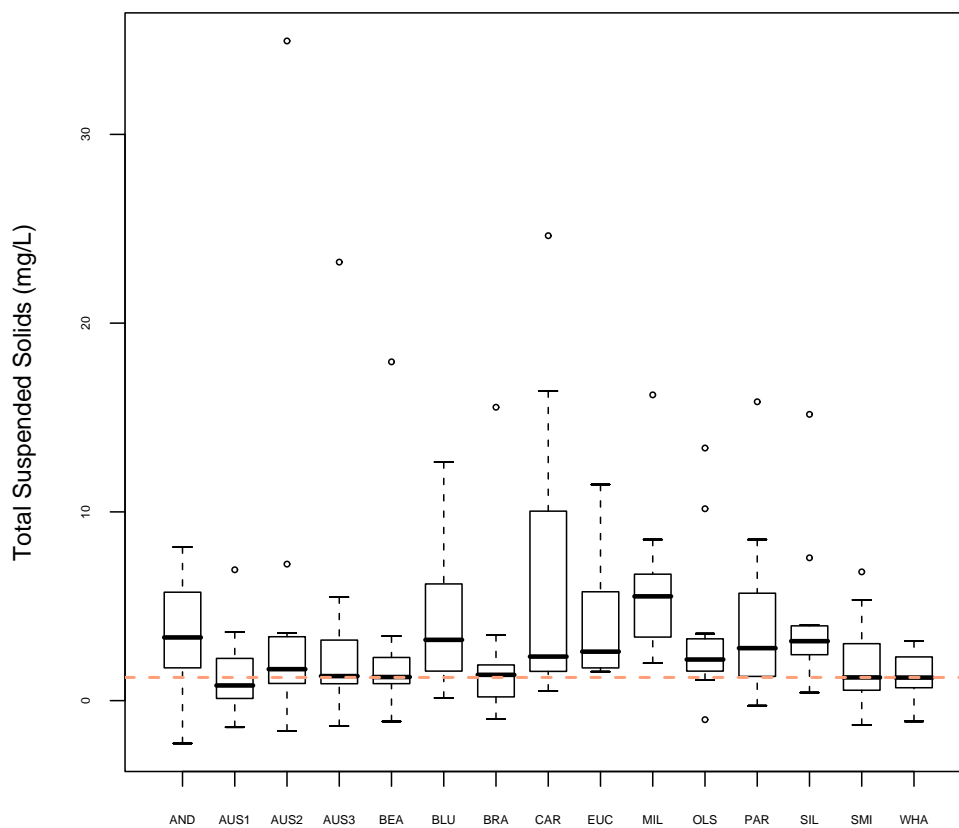


Figure 21: Summary of the 2004/2005 total suspended solids data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. None of the creeks were significantly different than Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

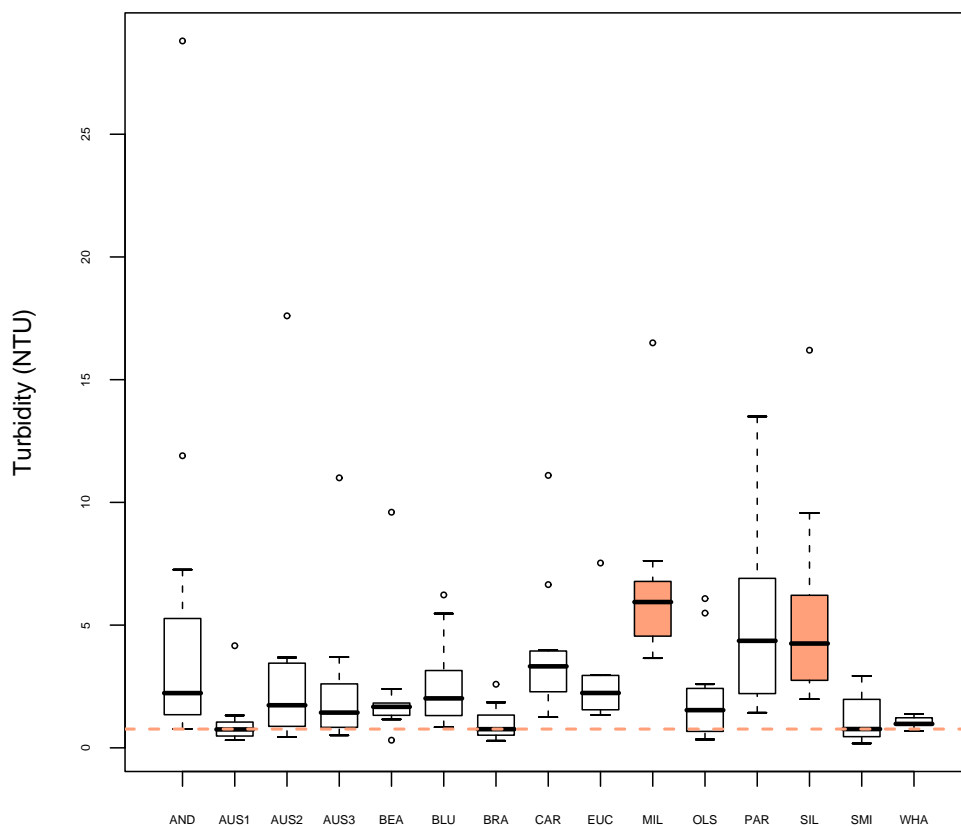


Figure 22: Summary of the 2004/2005 turbidity data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

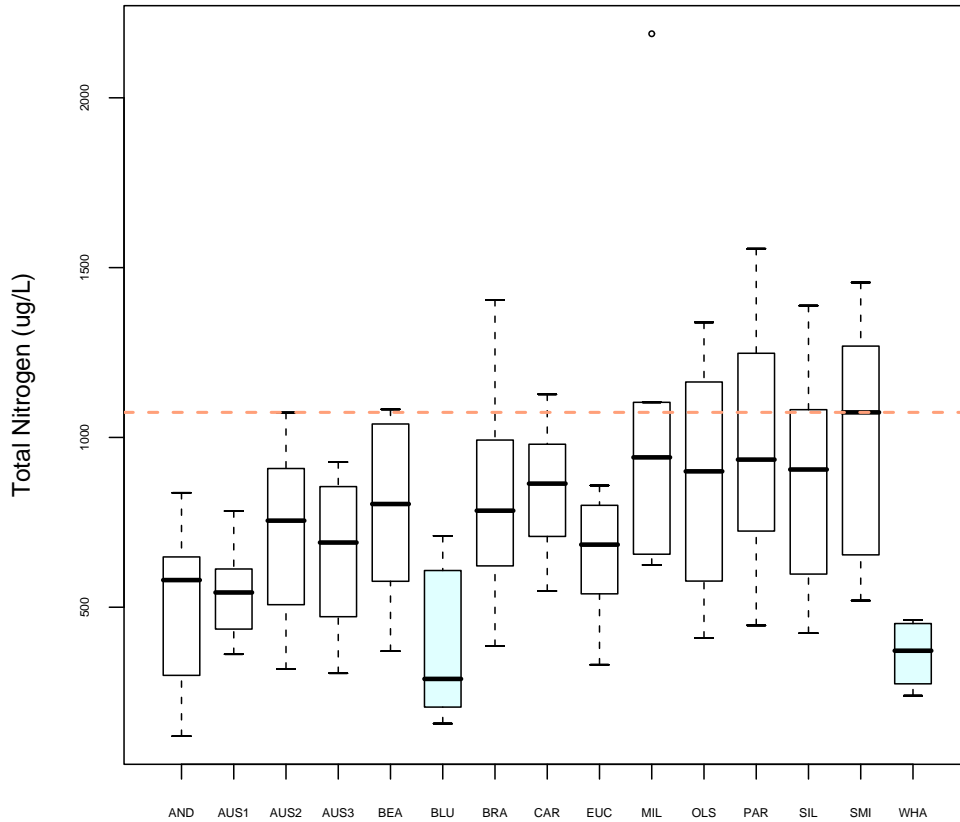


Figure 23: Summary of the 2004/2005 total nitrogen data for all creeks. Box-plots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

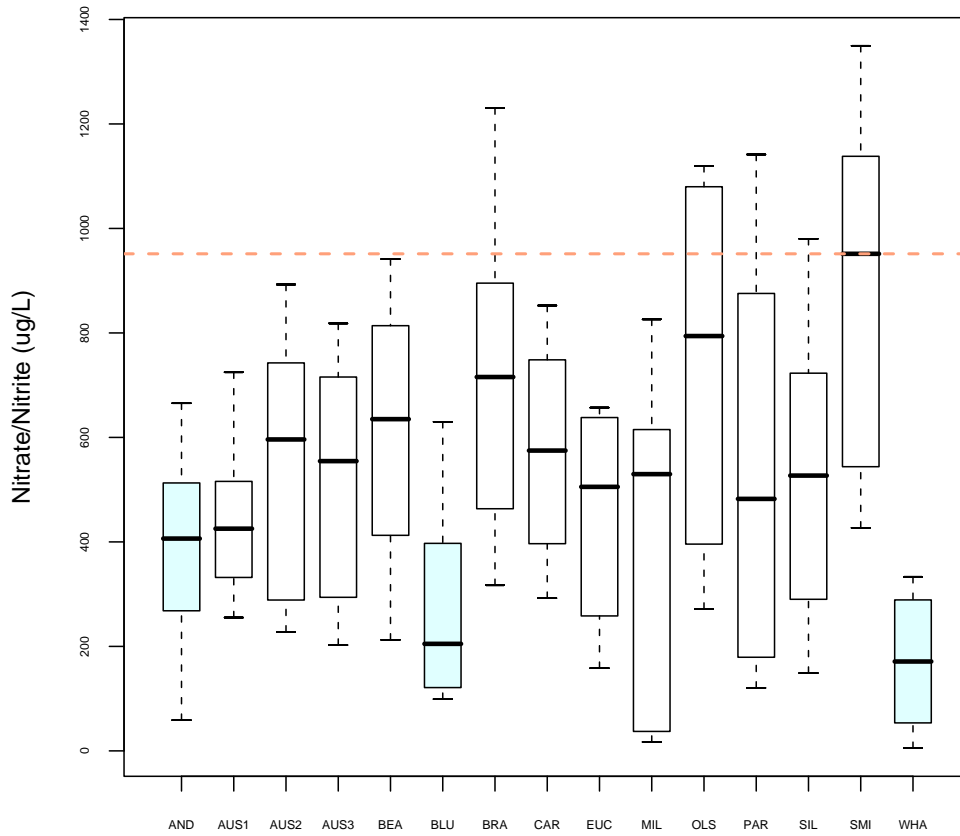


Figure 24: Summary of the 2004/2005 nitrate/nitrite data for all creeks. Box-plots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

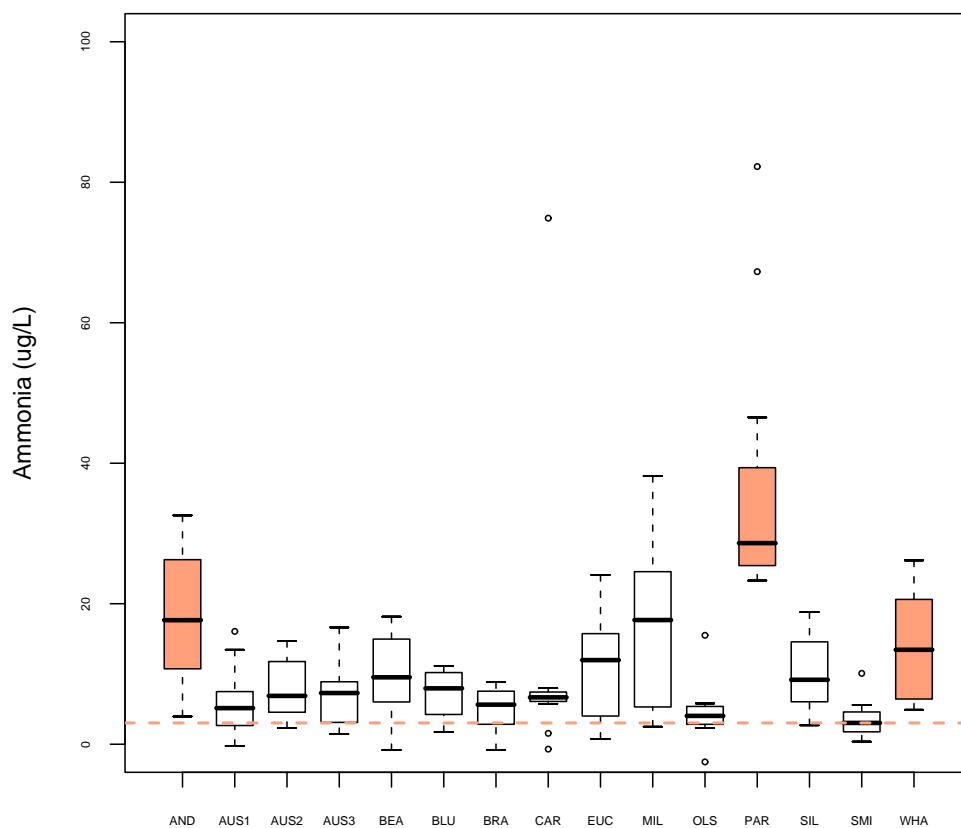


Figure 25: Summary of the 2004/2005 ammonia data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

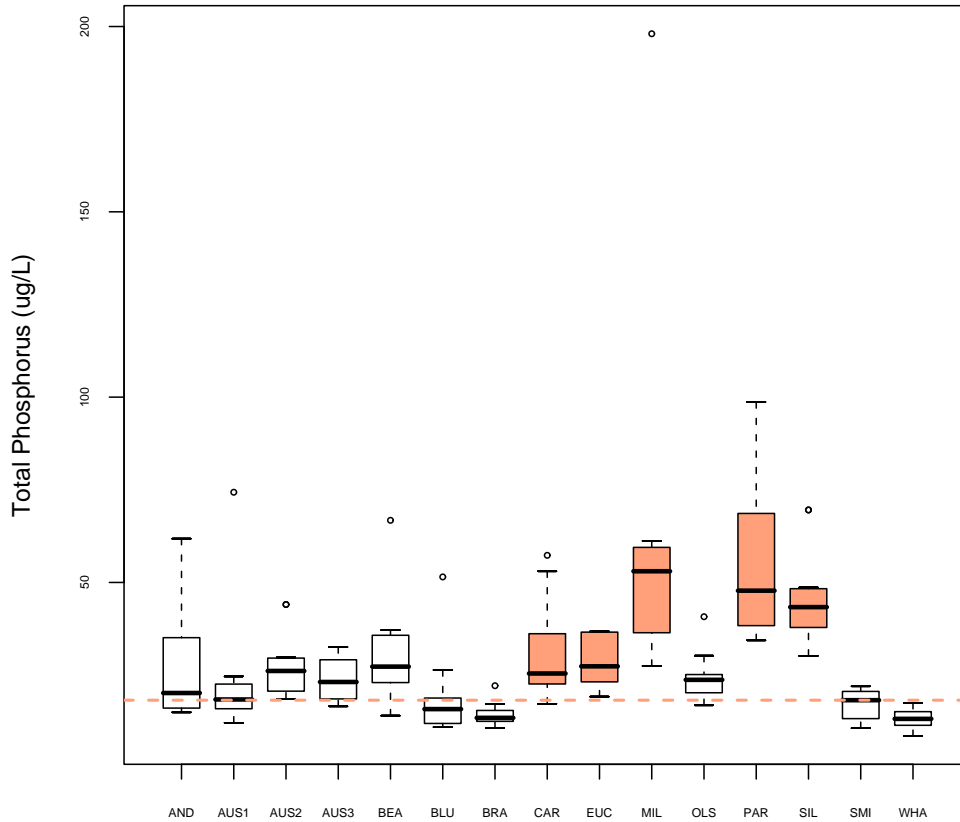


Figure 26: Summary of the 2004/2005 total phosphorus data for all creeks. Box-plots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

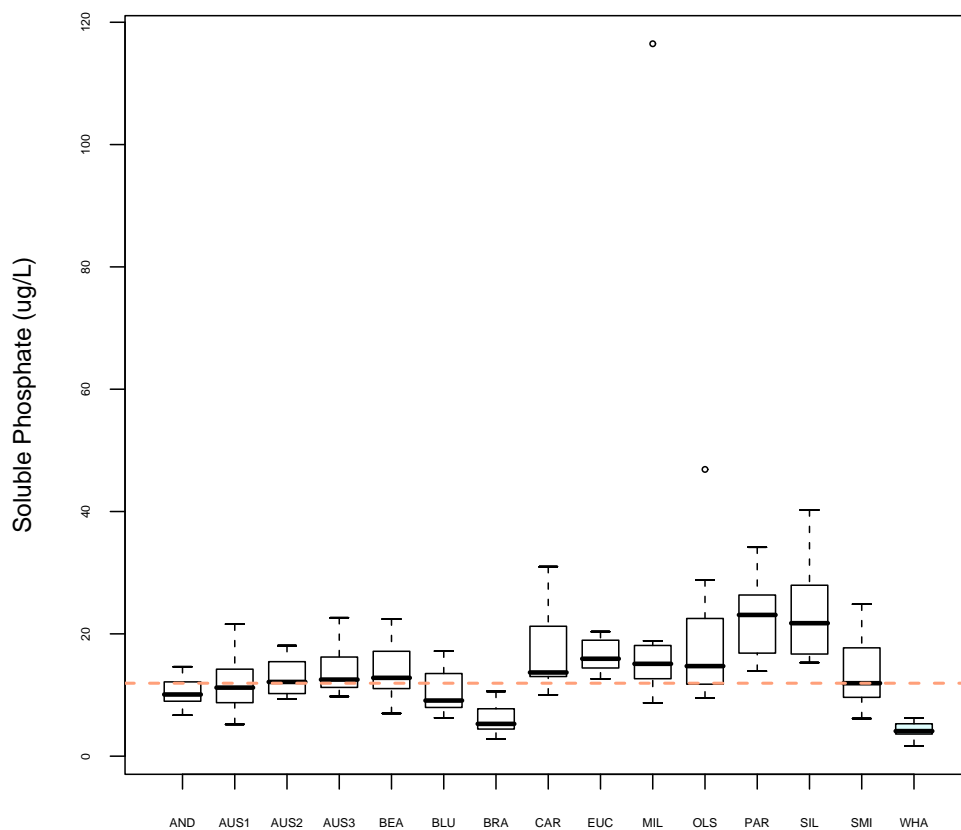


Figure 27: Summary of the 2004/2005 soluble reactive phosphate data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

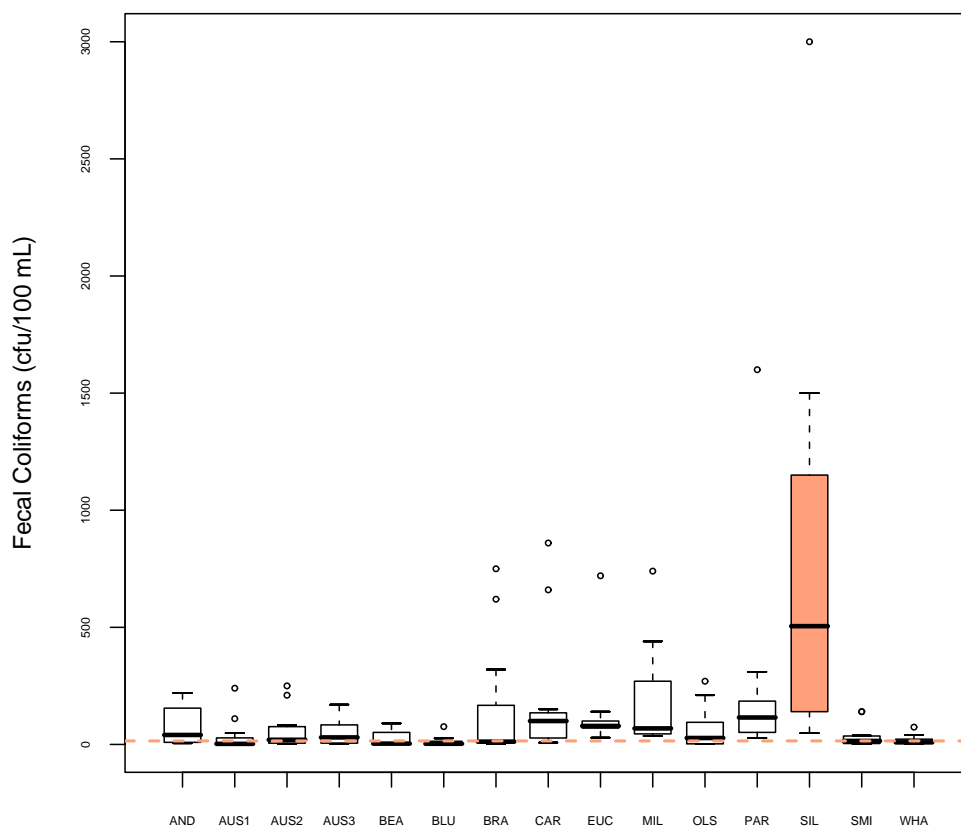


Figure 28: Summary of the 2004/2005 fecal coliform data for all creeks. Box-plots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

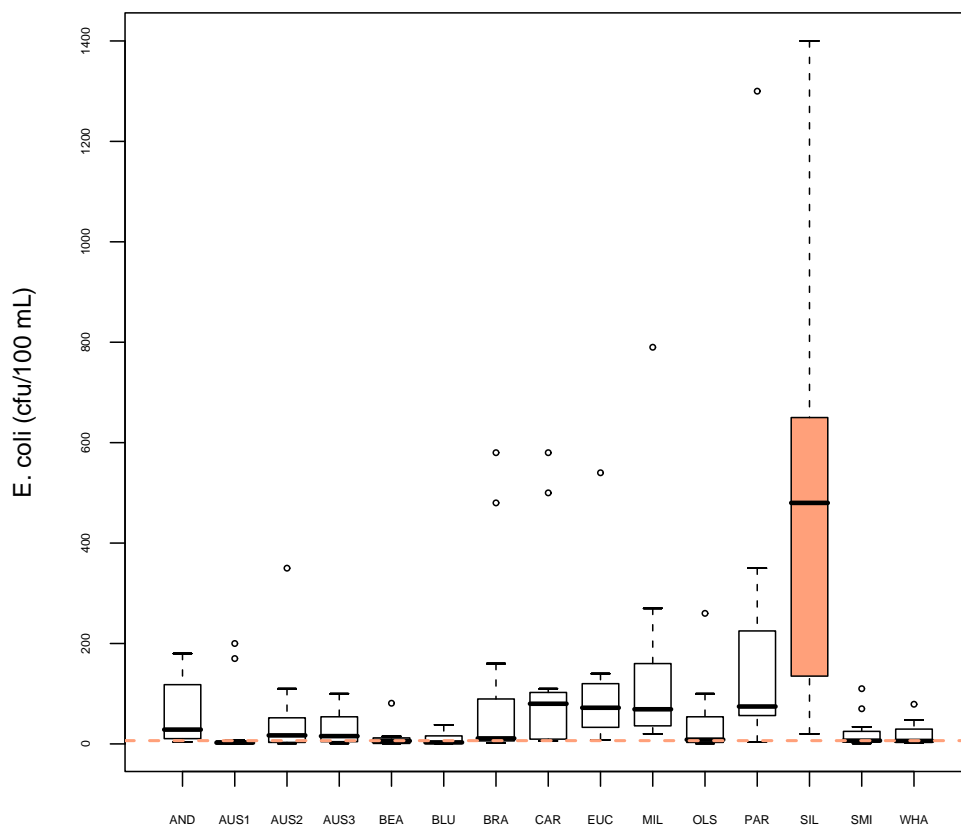


Figure 29: Summary of the 2004/2005 *E. coli* data for all creeks. Boxplots show median and upper/lower quartiles; whiskers extend $1.5 \times$ interquartile range or to maximum/minimum values. Horizontal reference line shows median value for Smith Creek. Shaded boxes indicate creeks with significant higher or lower median values compared to Smith Creek. Refer to Table 30 on page 63 for sampling site abbreviations.

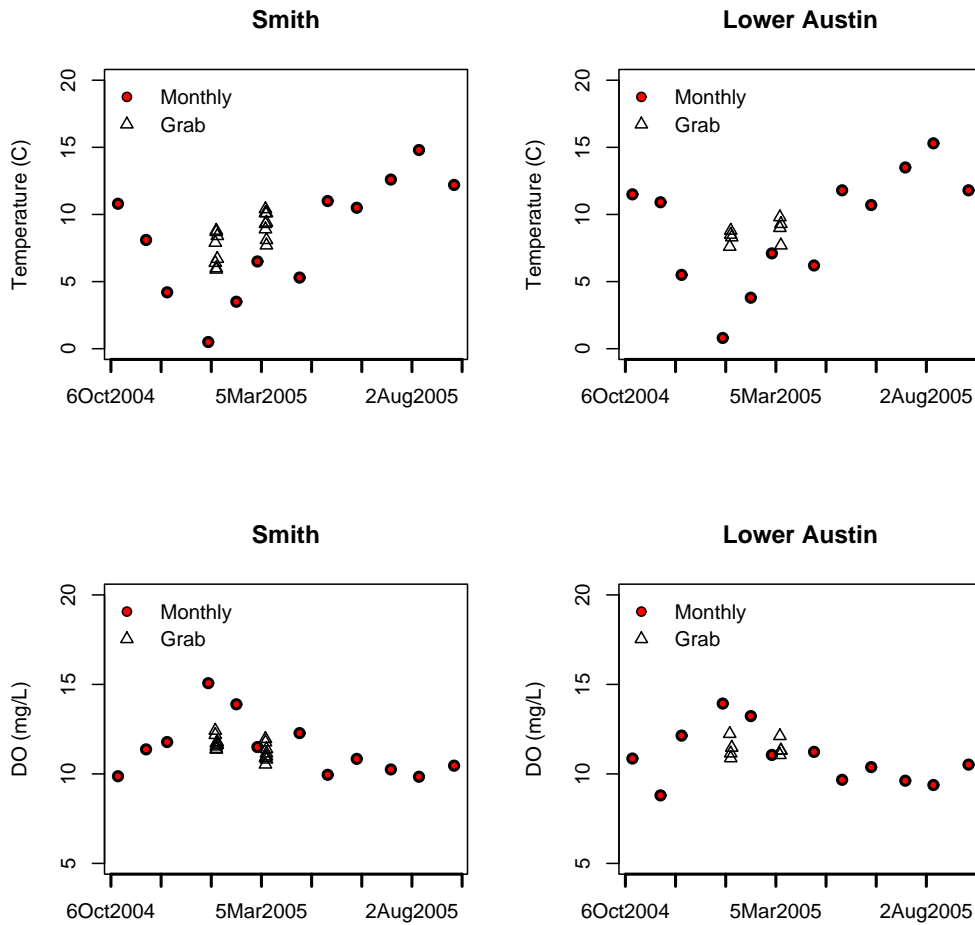


Figure 30: Monthly and 48-hr temperature and dissolved oxygen data from Lower Austin and Smith Creeks.

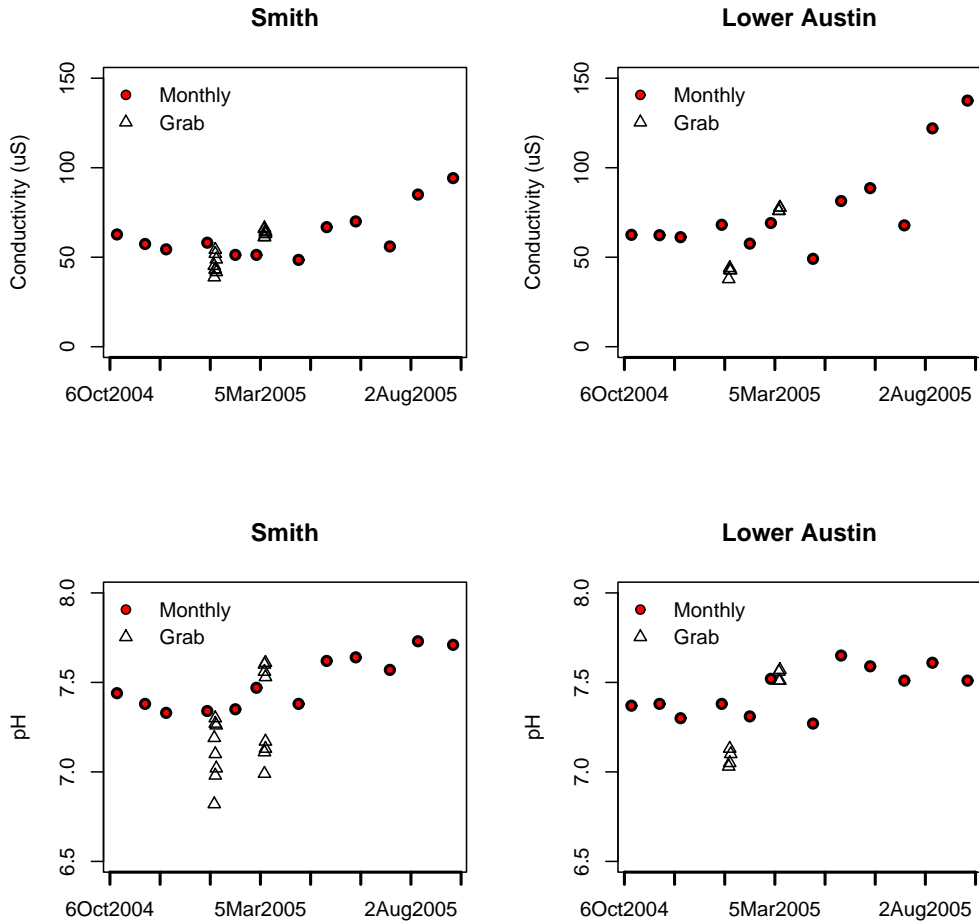


Figure 31: Monthly and 48-hr conductivity and pH data from Lower Austin and Smith Creeks.

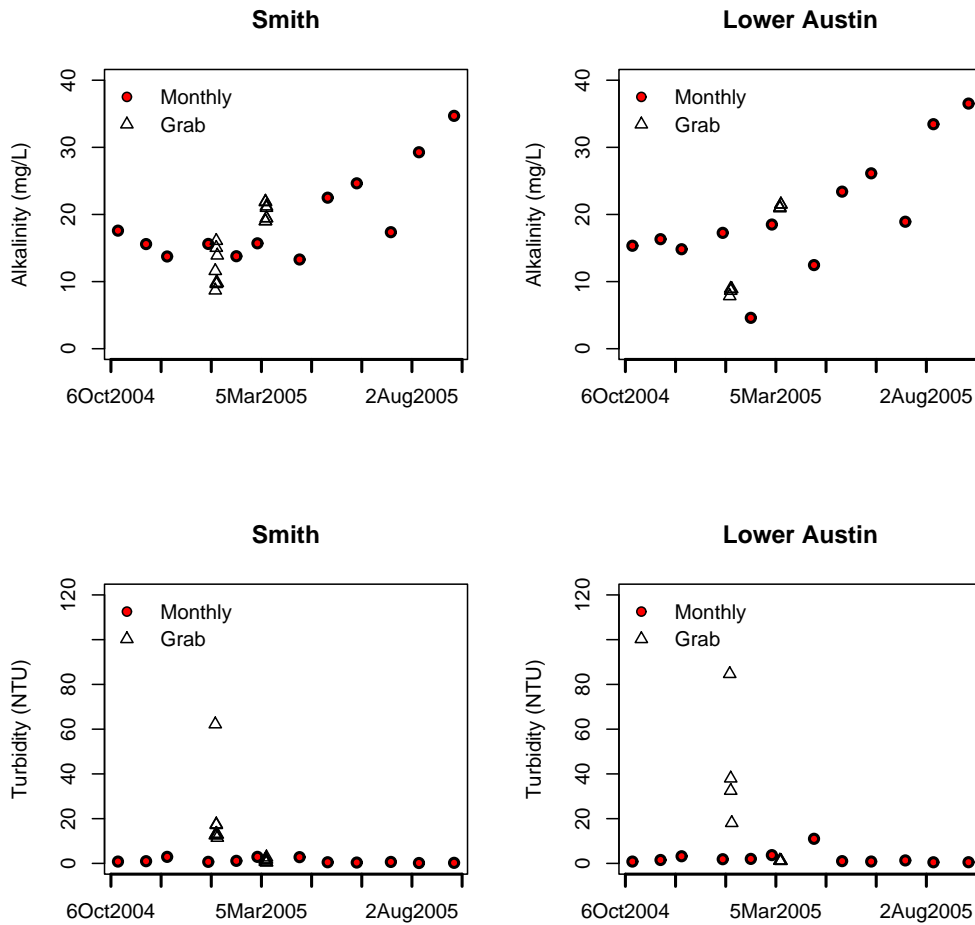


Figure 32: Monthly and 48-hr alkalinity and turbidity data from Lower Austin and Smith Creeks.

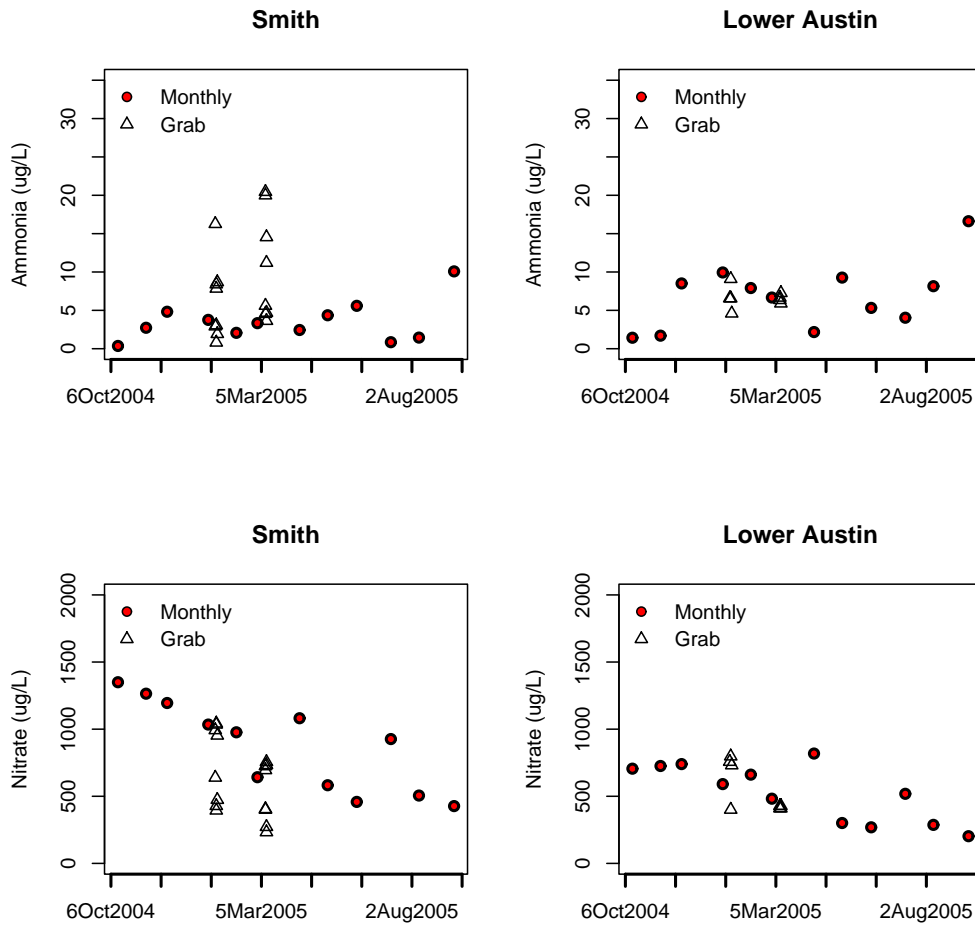


Figure 33: Monthly and 48-hr ammonia and nitrate/nitrite data from Lower Austin and Smith Creeks.

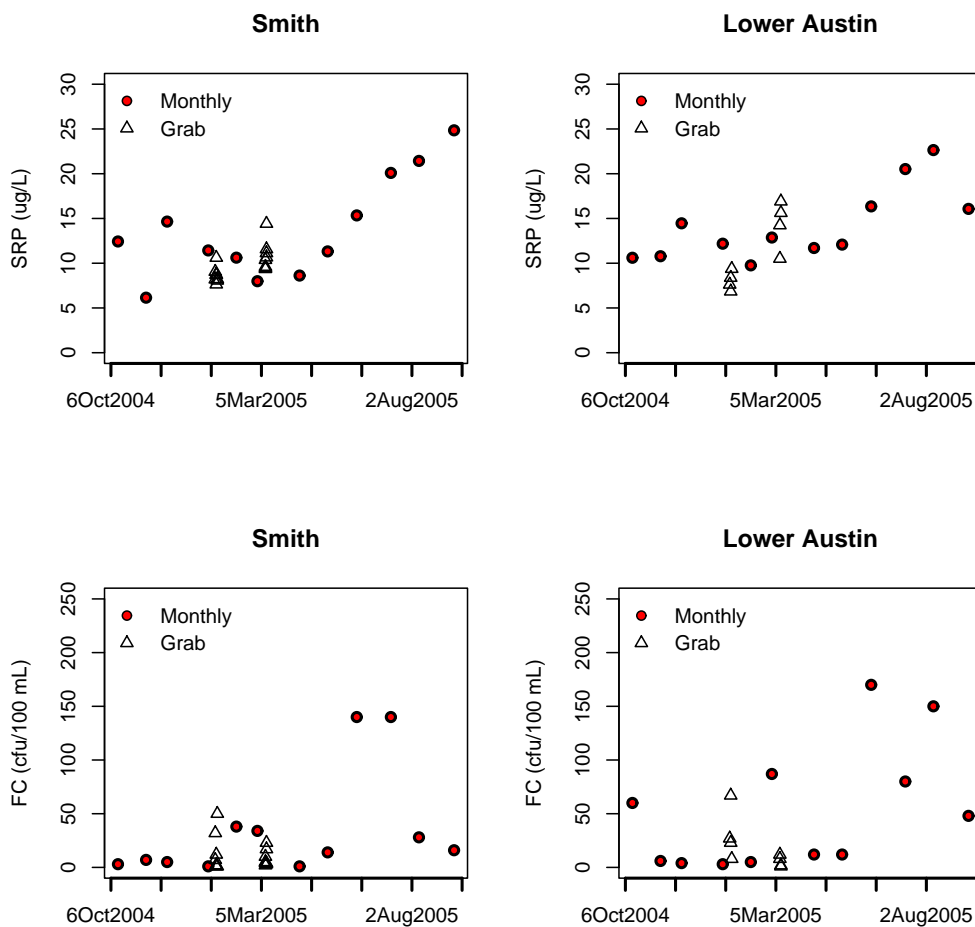


Figure 34: Monthly and 48-hr soluble phosphate and coliform data from Lower Austin and Smith Creeks.

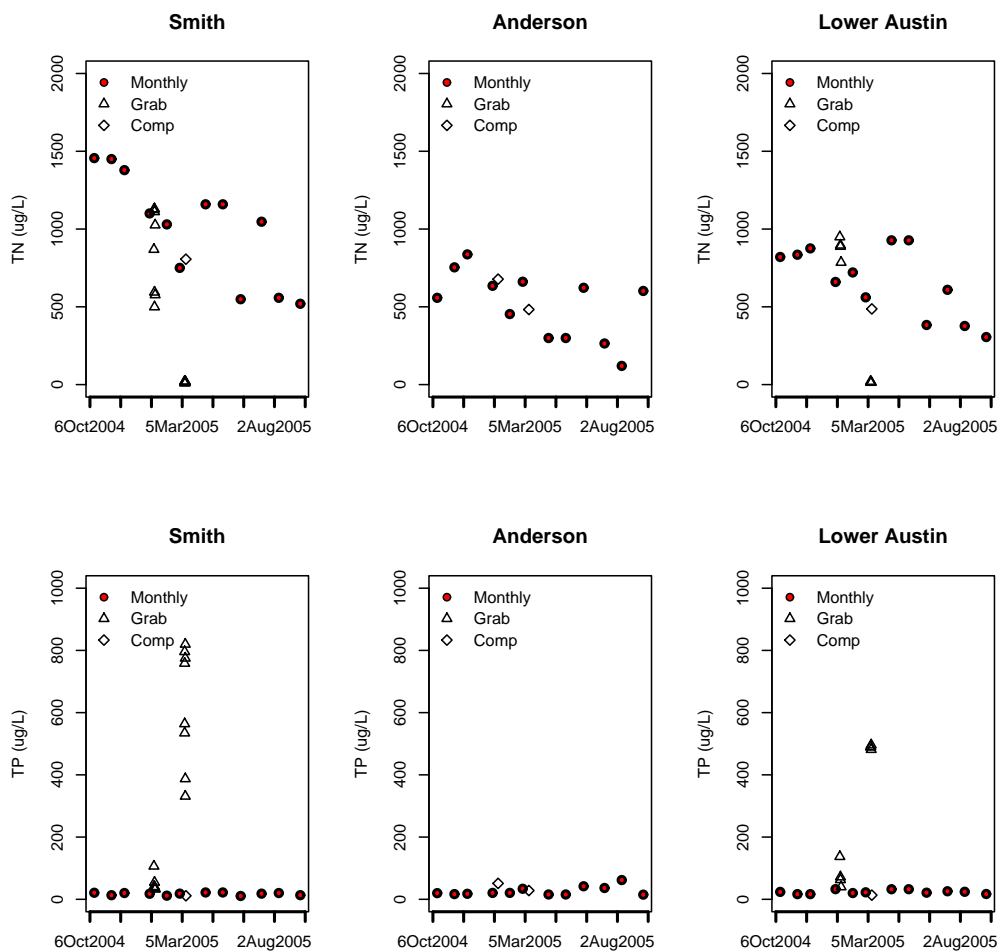


Figure 35: Monthly and 48-hr total nitrogen and total phosphorus data from Anderson, Lower Austin and Smith Creeks.

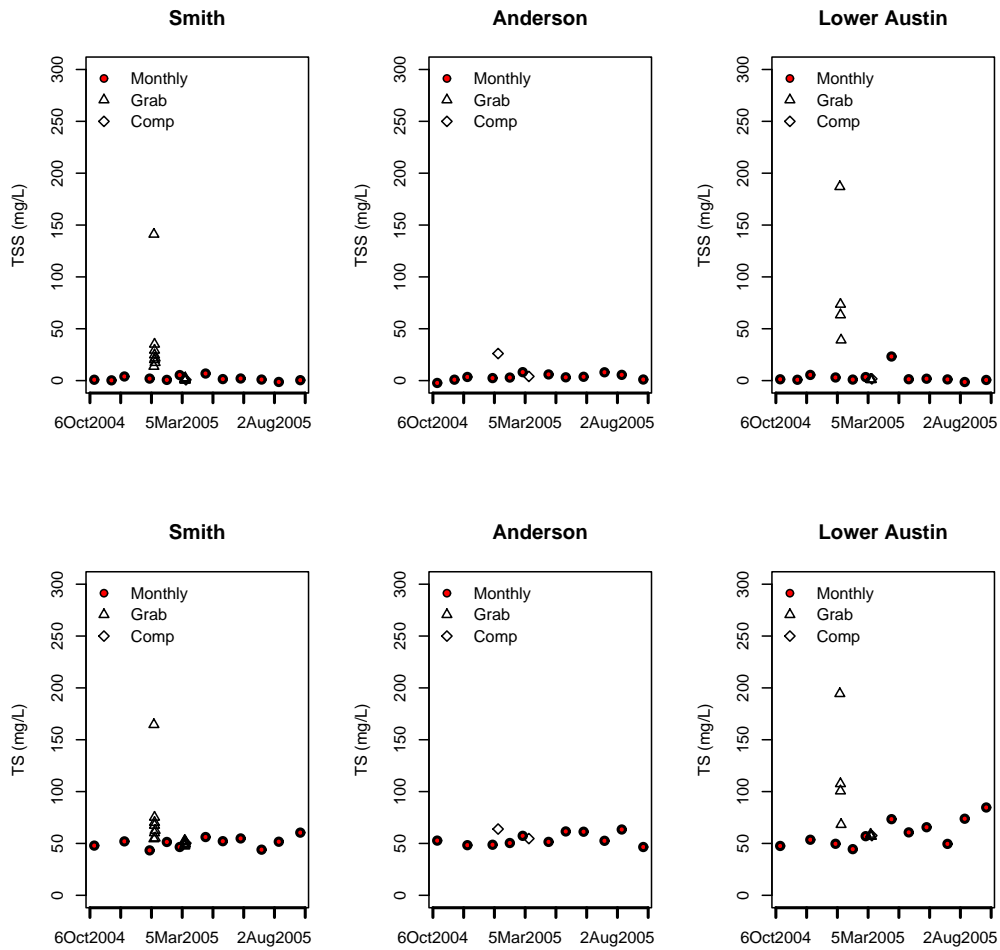


Figure 36: Monthly and 48-hr total suspended solids and total solids data from Anderson, Lower Austin and Smith Creeks.

4 Lake Whatcom Hydrology

4.1 Hydrograph Data

Recording hydrographs have been installed in Anderson, Austin, and Smith Creeks; the data are plotted in Figures 37–39 (pages 93–95). The location of each hydrograph is described in Appendix A.2, beginning on page 127. All hydrograph data, including data from previous years, are included on the CD that accompanies this report. Detailed field notes 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.

The historic hydrograph data were recorded at 30 minute intervals until summer of 2003, when new recorders were installed at all sites. The new recorders log data at 15 minute intervals. The primary reason for changing the logging interval was to conform with USGS hydrograph data that are being collected at six additional sites in the Lake Whatcom watershed (Brannian, Carpenter, Euclid, Mill Wheel, Olsen, and Silver Beach Creeks). Figure 40 (page 96) shows the rating curves for each hydrograph. New rating curves need to be generated whenever the creek channel is significantly altered due to storm runoff or construction activities. Starting dates for each rating curve are indicated in Figure 40. Rating curves for earlier water years are available from the Institute for Watershed Studies.

4.2 Watershed Modeling

The Distributed Hydrology-Soils-Vegetation Model (DHSVM) was applied to the Anderson, Austin, and Smith Creek basins in the Lake Whatcom watershed to predict surface-water runoff into the lake. The DHSVM is a physically based numerical model developed at the University of Washington and Pacific Northwest National Laboratory (Wigmosta et al., 1994). Its primary application has been in mountainous watersheds in the Pacific Northwest (e.g., Storck et al., 1998; Bowling et al., 2000; VanSharr et al., 2002).

Watershed attributes in the DHSVM are defined by geographic information system (GIS) grids including a DEM, watershed boundary, soil type, soil thickness, vegetation, and stream flow network. The input grids for the basins were developed in ArcInfo using a 30-meter grid spacing. The model simulates a water and

energy balance at the grid cell scale given input values for air temperature, humidity, wind speed, incoming short wave radiation, incoming long wave radiation, and precipitation. The meteorological input data were collected from the Smith Creek weather station in the watershed or were estimated using predictive models (e.g., longwave radiation). The data were formatted into one-hour time steps.

Calibration of the DHSVM to the basins requires the modification of the basin attributes and meteorological data until the simulated stream flow adequately matches the actual recorded stream flow (within about 5%). To date, the DHSVM has been sufficiently calibrated to the Austin and Smith Creek basins (by Katie Kelleher a WWU geology graduate student) and the Anderson Creek basin (by Robert Mitchell). Calibration refinement will continue as more stream flow and weather data become available. The simulated stream flow for Anderson, Austin, and Smith Creeks for the 2004/2005 water year are shown in Figures 47–49 (pages 103–105). Note that the simulated stream flow for Anderson Creek does not contain diversion flow from the Middle Fork. The difference between the recorded and simulated stream flow in Austin Creek is likely due to errors in the new rating curve for Austin Creek which has not yet been developed for higher flows. The simulated stream flow in Austin Creek matches the recorded very well for previous years using the old rating curve (2001 through 2004).

4.3 Water Budget

A water balance was applied to Lake Whatcom to identify its major water inputs and outputs and to examine runoff and storage. The traditional method of estimating a water balance (i.e., inputs - outputs = change in storage) was employed. Inputs into the lake include direct precipitation, water diverted from the Middle Fork of the Nooksack River (diversion), runoff (surface runoff + groundwater). Outputs include evaporation, Whatcom Creek, the Hatchery, City of Bellingham, Georgia Pacific, and the Lake Whatcom Water and Sewer District.¹⁴ The change in storage is estimated from daily lake-level changes. All of these are measured quantities provided by the City of Bellingham except for evaporation, and runoff.

Daily direct-precipitation magnitudes were estimated using the precipitation data recorded at the Geneva gatehouse, Smith Creek, and Brannian Creek gauges. The Thiessen polygon method (Dingman, 1994) was used to estimate the direct-

¹⁴Formerly Water District #10

precipitation areal average over the lake by weighting the precipitation at each gauge by a respective lake-area percentage. The weighted areas were determined by a Thiessen Polygon extension in ArcGIS (Figure 41, page 97). The average direct-precipitation depth (inches) for a given day was converted to a volume in millions of gallons (MG) via a rating curve generated from the lake level-area data developed by Ferrari and Nuanes (2001). The rating curve accounts for changes in surface area of the lake due to lake level changes. The annual direct rainfall to the lake for the water year 2004/2005 was 47.9 inches (6501 MG).

Daily lake evaporation was estimated using a model based on the Penman method (Dingman, 1994). The Penman method is a theoretically based model that estimates free-water evaporation using both energy-balance and mass transfer concepts. The method requires daily average incident solar radiation, air temperature, dew point temperature, and wind speed. Hourly data from the Smith Creek weather station in the watershed were used to estimate daily averages. The daily evaporation depths (inches) predicted by the model were converted to volumes (MG) via a rating curve generated from the lake level-area data developed by Ferrari and Nuanes (2001). The estimated yearly evaporation from the lake for the water year 2004/2005 was 21.9 inches (2990 MG), most of which occurs between June and September.

Daily change in storage was determined by subtracting each day's lake level by the subsequent day's level. This resulted in negative values when the lake level was decreasing and positive values when the lake level was increasing. The daily net change in lake level (inches) was converted to a volume (MG) via a rating curve generated from the lake level-capacity data developed by Ferrari and Nuanes (2001). The rating curve accounts for changes in volume of the lake due to lake level changes. The median total lake volume in 2004/2005 was 252,970 MG. Figure 46 (page 102) shows daily lake-volume values for the past five years. The dramatic changes throughout the course of a year are due primarily to rainfall-runoff events and the Whatcom Creek discharges that are controlled by the COB.

Surface runoff and groundwater were combined into a single runoff component that is determined by adding the outputs to the change in storage and subtracting the precipitation and diversion magnitudes. The runoff values are rough estimates.

Yearly water balance totals are listed in Table 31 (page 90) along with the yearly total values for the four previous water years. The total inputs and outputs were estimated to be 40,026 MG and 41,738 MG, respectively. The total volume of

outputs correspond to 16.5% of the median total volume of the lake. Under the assumption that the lake is completely mixed and flow is steady state (inputs = outputs)¹⁵, this would correspond to a 6.1 year residence time. Using these assumptions, the residence times for the past 5 years ranged from 5.1–10.7 years. Tables 32 and 33 (pages 91–92) show the 2004/2005 total input and output volumes along with the corresponding monthly percentage of each total.

The daily water balance quantities were summed into 7-day totals, which were used to generate plots of the input, output, change in storage, and estimated runoff volumes (Figures 42–45, pages 98–100). All the inputs, except for runoff, are shown in Figure 42 and all the outputs, except for Whatcom Creek, are shown in Figure 43. The input, runoff, and output to Whatcom Creek are shown along with the change in lake storage on Figure 44 because they have similar magnitudes. Figure 45 shows 7-day summed totals for inputs, outputs, and change in storage.

¹⁵Although the lake is not completely mixed and the flow is not steady state, these assumptions are commonly used to provide a simple estimate of residence time for water in lakes.

	2004–2005	2003–2004	2002–2003	2001–2002	2000–2001
Inputs (MG)					
Direct Precipitation	6,501 (16.2%)	7,612 (18.6%)	4,859 (19.5%)	7,078 (14.5%)	4,811 (19.3%)
Diversion	3,852 (9.6%)	5,095 (12.4%)	4,442 (17.8%)	4,693 (9.6%)	1,783 (7.1%)
Runoff*	29,673 (74.1%)	28,288 (69.0%)	15,589 (62.6%)	36,920(75.8%)	18,345 (73.6%)
Total	40,026 (100%)	40,955 (100%)	24,890 (100%)	48,691(100%)	24,938 (100%)
Outputs (MG)					
Whatcom Creek	30,899 (74.0%)	26,948 (71.2%)	13,361 (53.5%)	38,223 (77.5%)	10,508 (44.5%)
Hatchery	1,288 (3.1%)	1,278 (3.4%)	1,124 (4.5%)	901 (1.8%)	1,074 (4.5%)
Georgia Pacific	2,198 (5.3%)	2,053 (5.4%)	2,988 (12.0%)	3,046 (6.2%)	4,851 (20.5%)
City of Bellingham	4,111 (9.8%)	4,449 (11.8%)	4,342 (17.4%)	4,234 (8.6%)	4,076 (17.3%)
LW Water/Sewer Distr.	252 (0.6%)	204 (0.5%)	136 (0.6%)	126 (0.3%)	140 (0.6%)
Evaporation	2,990 (7.2%)	2,924 (7.7%)	3,016 (12.1%)	2,812 (5.7%)	2,971 (12.6%)
Total	41,738 (100%)	37,855 (100%)	24,971 (100%)	49,341 (100%)	23,621 (100%)
Net change in storage	-1,692	3,139	-81	-651	1,318
Median lake volume (MG)	252,856	252,970	252,075	252,368	251,978
Outflow percent of volume	16.5%	15.0%	9.9%	19.6%	9.4%
Residence time (years)**	6.1	6.7	10.1	5.1	10.7

*Runoff = surface runoff + groundwater

**Based on the assumption that water in the lake is completely mixed and flow is steady state (i. e., inputs = outputs)

Table 31: Annual water balance quantities for the Lake Whatcom watershed, WY2000–WY2005.

Month	Input Percents			Total
	Diver	Precip	Runoff*	
Oct	2.09	9.44	5.56	5.84
Nov	0.00	19.65	22.73	20.04
Dec	11.38	15.21	17.70	16.64
Jan	18.29	10.94	17.25	16.25
Feb	7.18	4.23	6.93	6.48
Mar	9.49	10.03	6.55	7.36
Apr	30.12	11.83	16.41	16.86
May	9.38	4.21	3.09	3.84
Jun	0.04	3.65	1.28	1.55
Jul	5.18	4.04	2.30	2.84
Aug	6.72	3.04	0.07	1.16
Sep	0.14	3.74	0.14	0.72
Input Volume (MG)				
Total	3,852	6,501	29,673	40,026

*Runoff = surface runoff + groundwater

Table 32: Monthly input water balance quantities for the Lake Whatcom watershed, October 2004–September 2005.

Month	Output Percents						Total
	WC	Hatch	GP	COB	WSD	Evap	
Oct	14.83	8.22	9.99	7.83	7.72	3.84	12.85
Nov	17.70	7.36	9.82	7.17	7.67	1.30	14.70
Dec	24.76	7.99	10.55	7.18	8.15	0.39	19.92
Jan	17.86	5.90	11.46	7.61	8.55	1.58	14.92
Feb	7.28	8.89	10.63	6.43	7.55	2.95	7.11
Mar	0.93	7.01	8.15	7.02	8.22	6.42	2.54
Apr	11.83	11.95	7.46	7.18	8.06	12.07	11.14
May	2.26	6.80	7.65	8.45	8.50	13.15	4.11
Jun	0.42	7.87	6.01	8.71	8.77	13.25	2.73
Jul	0.86	9.70	6.27	11.47	9.83	18.39	3.77
Aug	0.67	8.43	5.79	12.00	9.70	16.59	3.49
Sep	0.60	9.89	6.21	8.95	7.27	10.08	2.72
Output Volume (MG)							
Total	30,899	1,288	2,198	4,111	252	2,990	41,738

Table 33: Monthly output water balance quantities for the Lake Whatcom watershed, October 2004–September 2005.

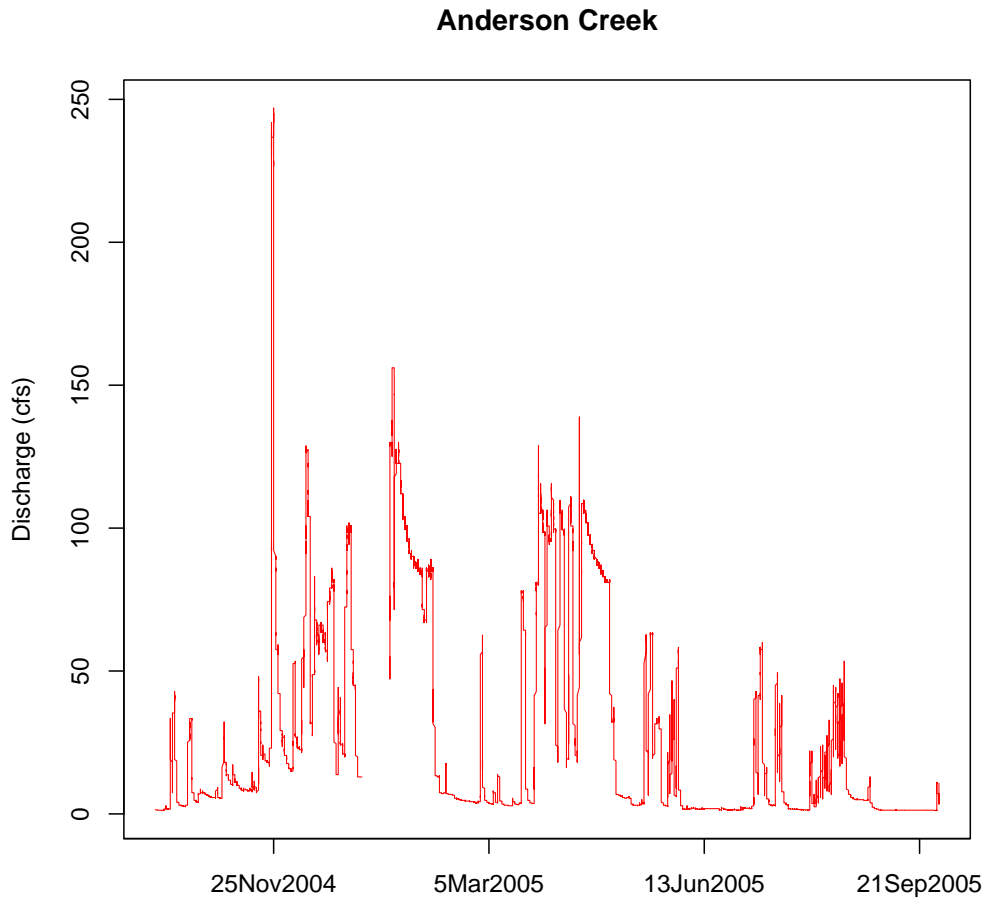


Figure 37: Anderson Creek hydrograph, October 1, 2004–September 30, 2005. Data were recorded at 15 minute intervals.

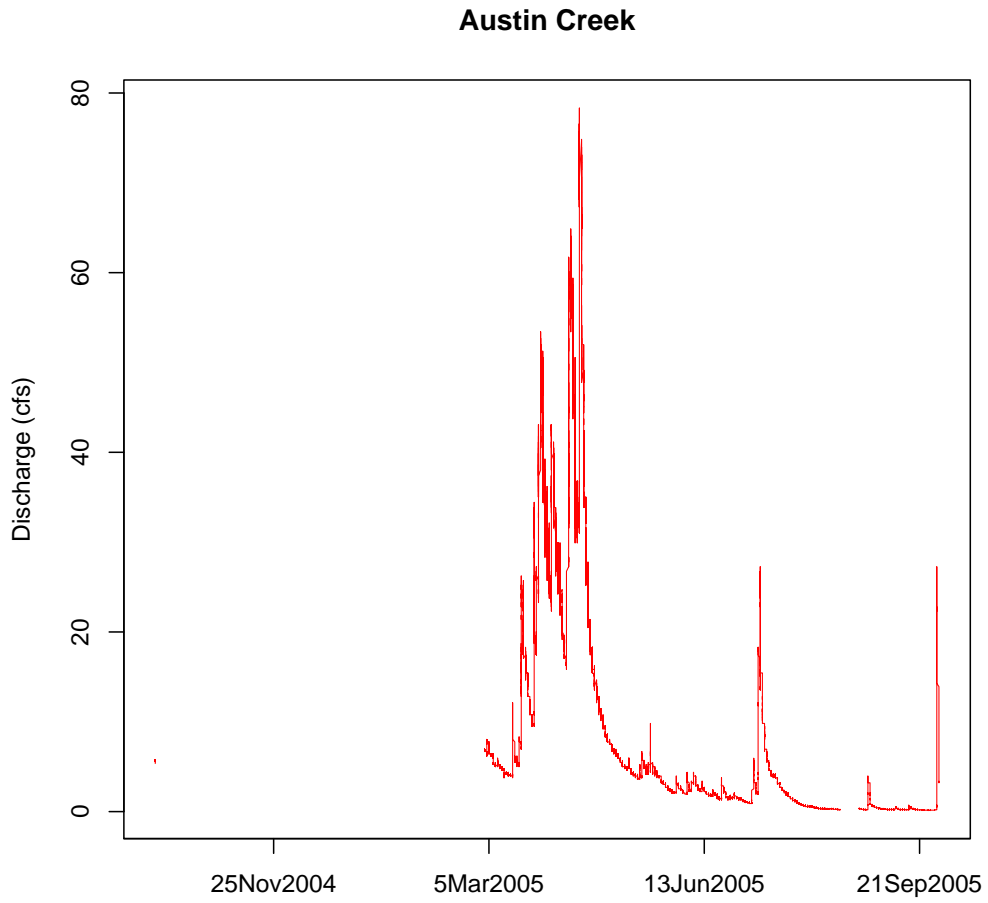


Figure 38: Austin Creek hydrograph, October 1, 2004–September 30, 2005. Data were recorded at 15 minute intervals.

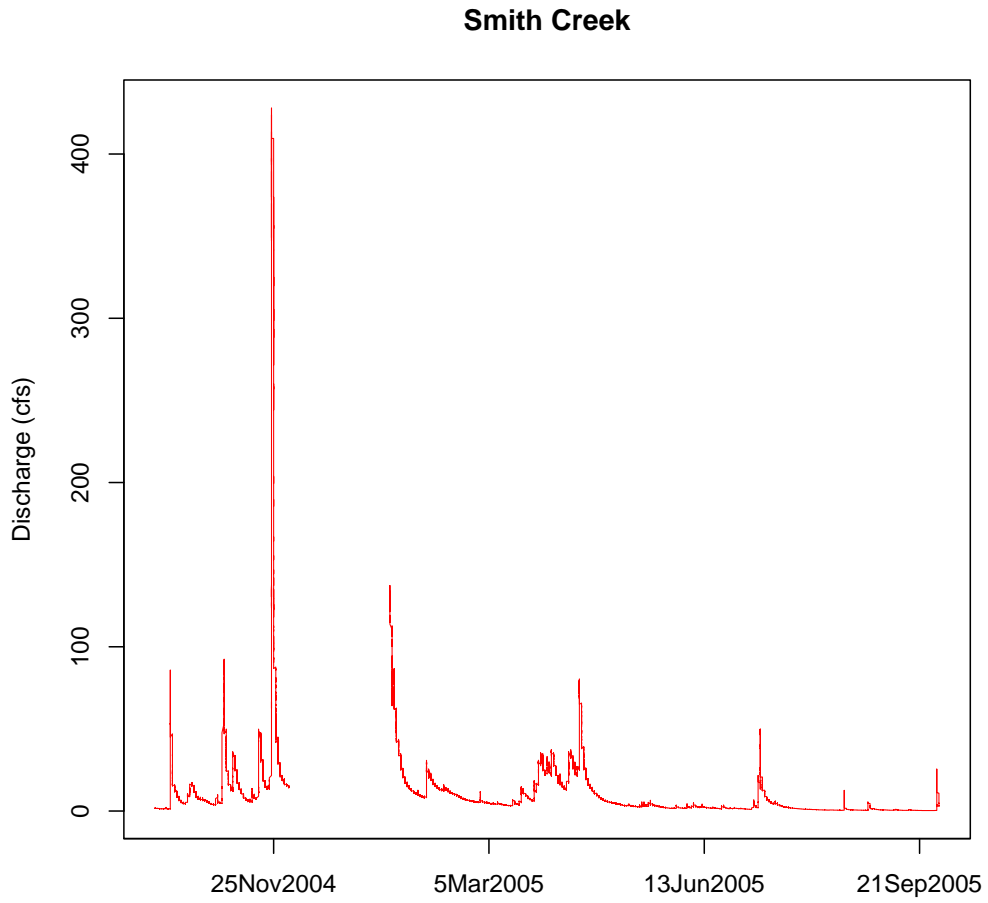


Figure 39: Smith Creek hydrograph, October 1, 2004–September 30, 2005. Data were recorded at 15 minute intervals.

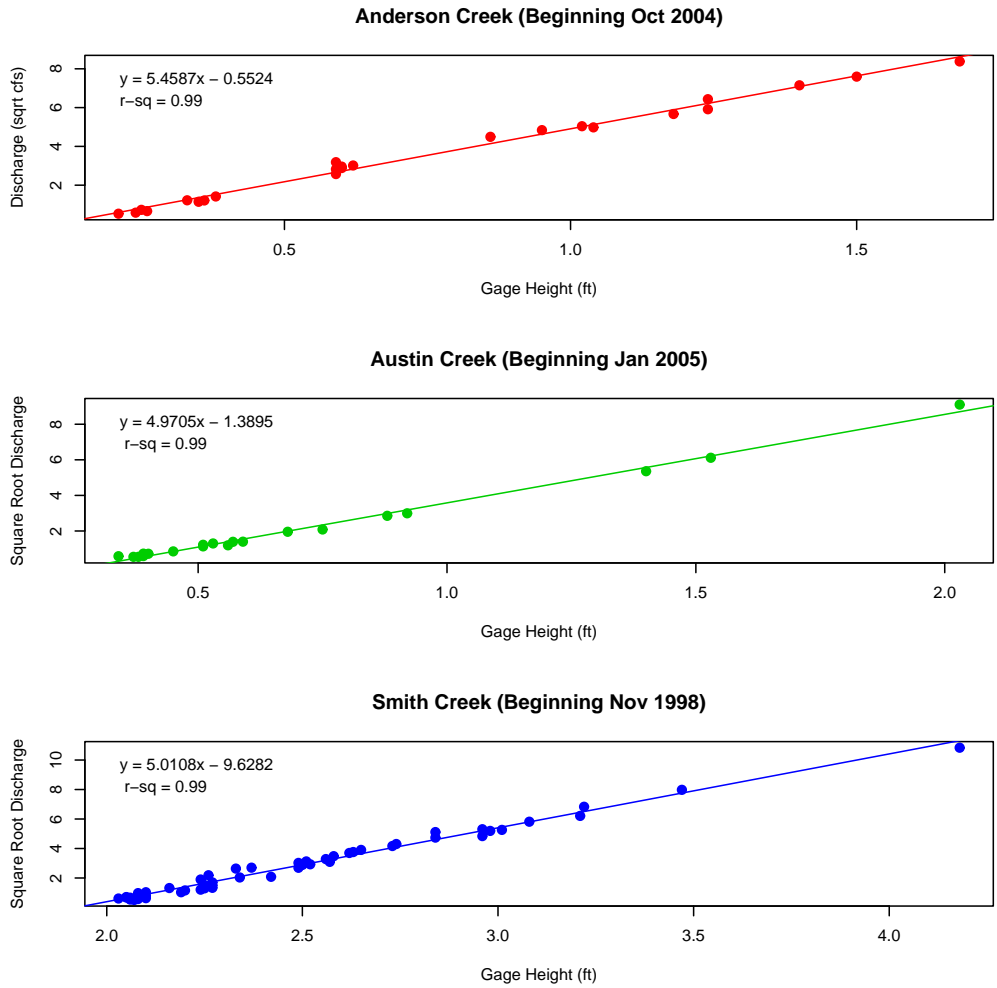


Figure 40: Anderson Creek, Austin Creek, and Smith Creek rating curves. Regressions show the relationship between gauge height (x) and square root transformed discharge (y), beginning from the date listed on each figure. For earlier rating curves, contact the Institute for Watershed Studies.

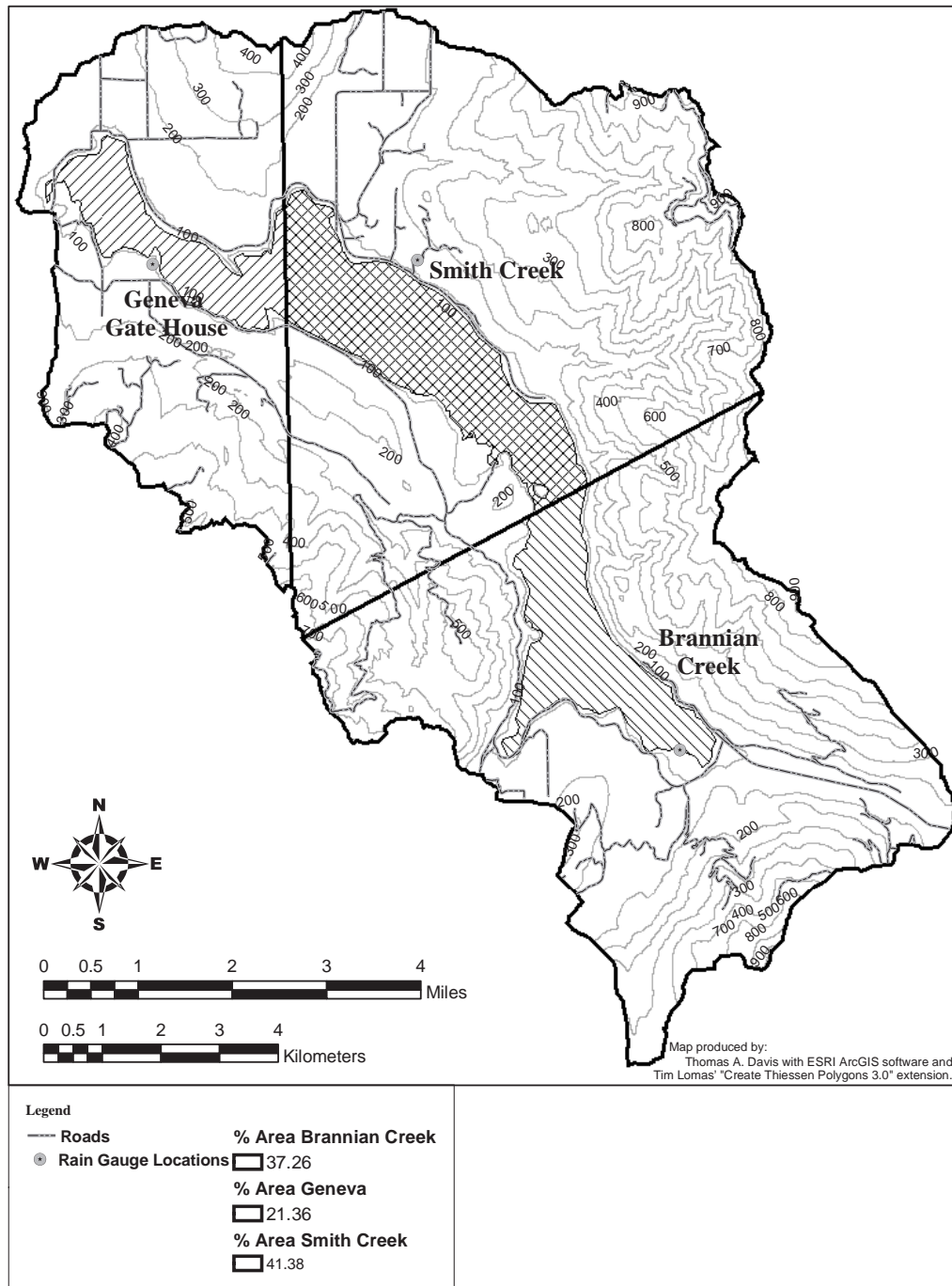


Figure 41: Lake Whatcom watershed precipitation groups and weighted areas.

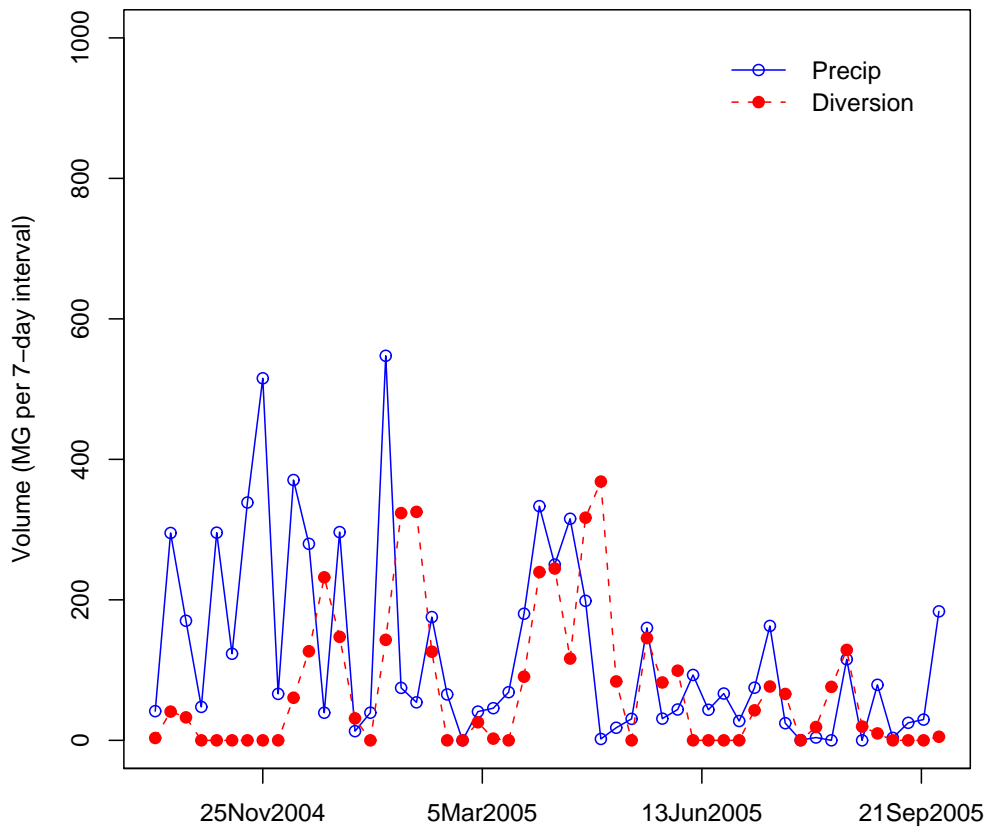


Figure 42: Lake Whatcom watershed direct hydrologic inputs, October 1, 2004–September 30, 2005.

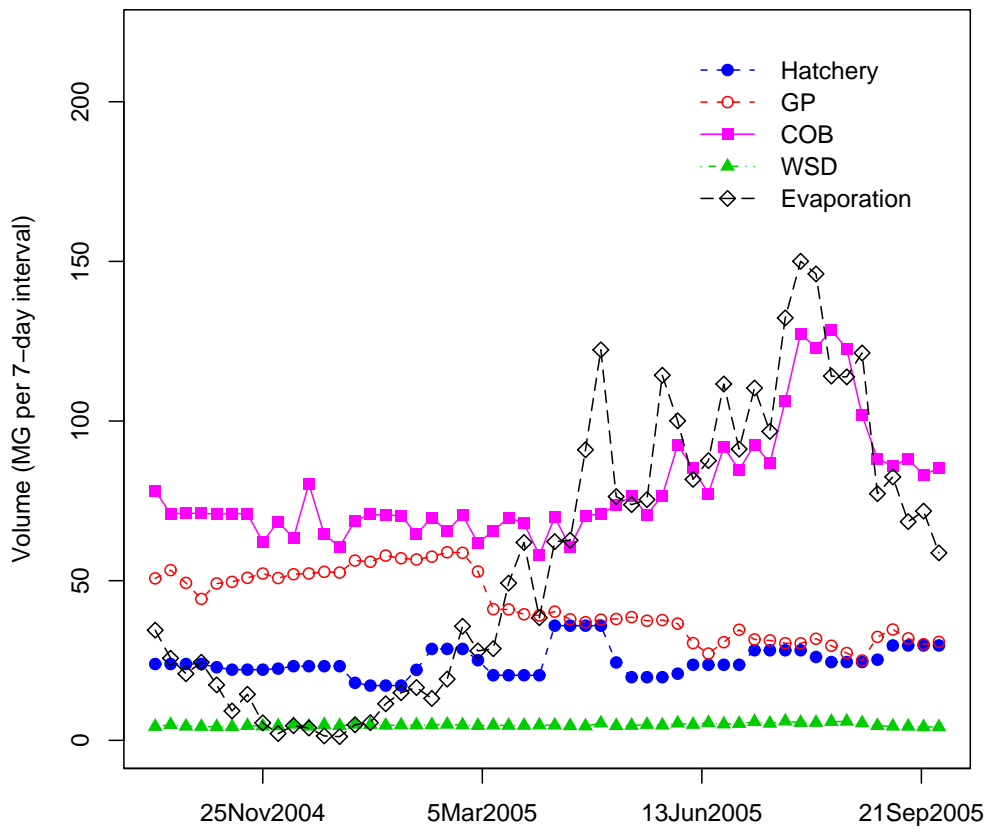


Figure 43: Lake Whatcom watershed hydrologic withdrawals, October 1, 2004–September 30, 2005.

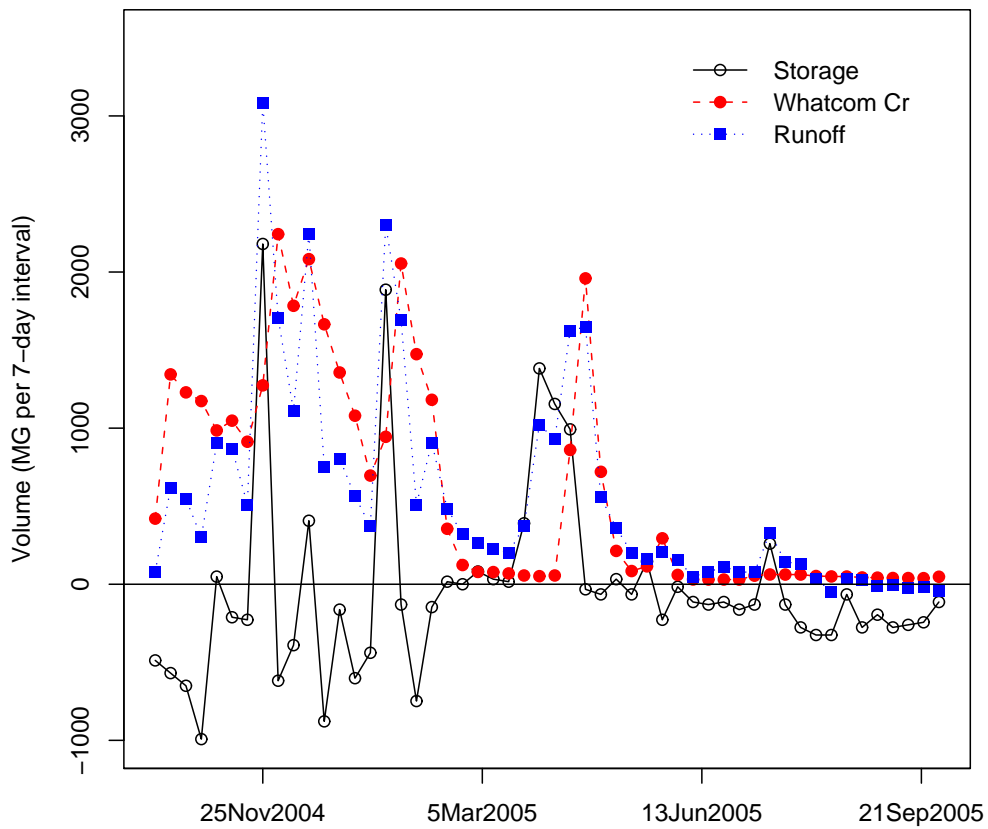


Figure 44: Summary of 7-day changes in Lake Whatcom storage, watershed runoff, and Whatcom Creek flows, October 1, 2004–September 30, 2005.

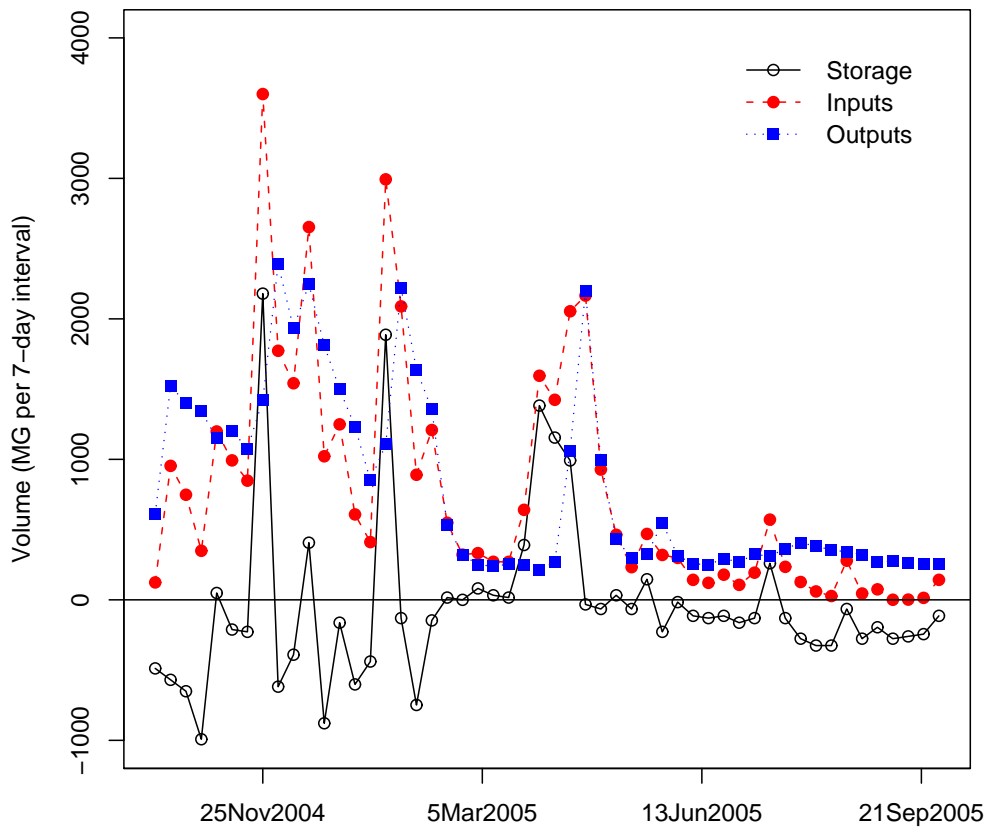


Figure 45: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2004–September 30, 2005.

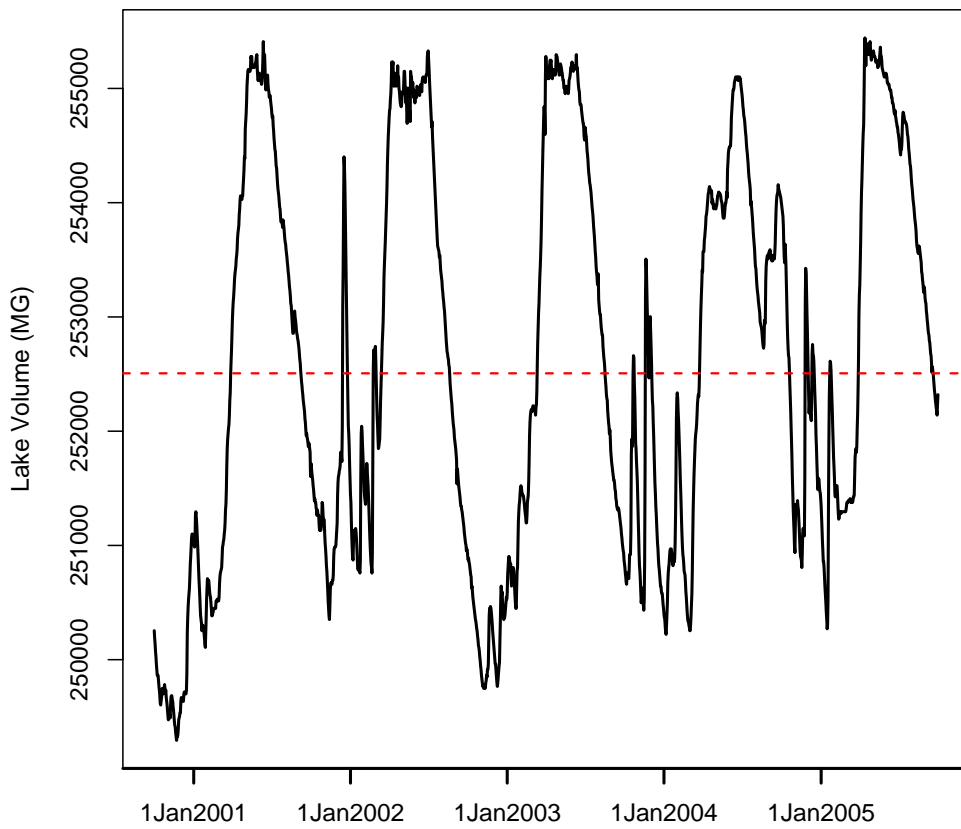


Figure 46: Comparison of Lake Whatcom daily lake volumes for 2000–2005. Horizontal line represents median lake volume for the period plotted.

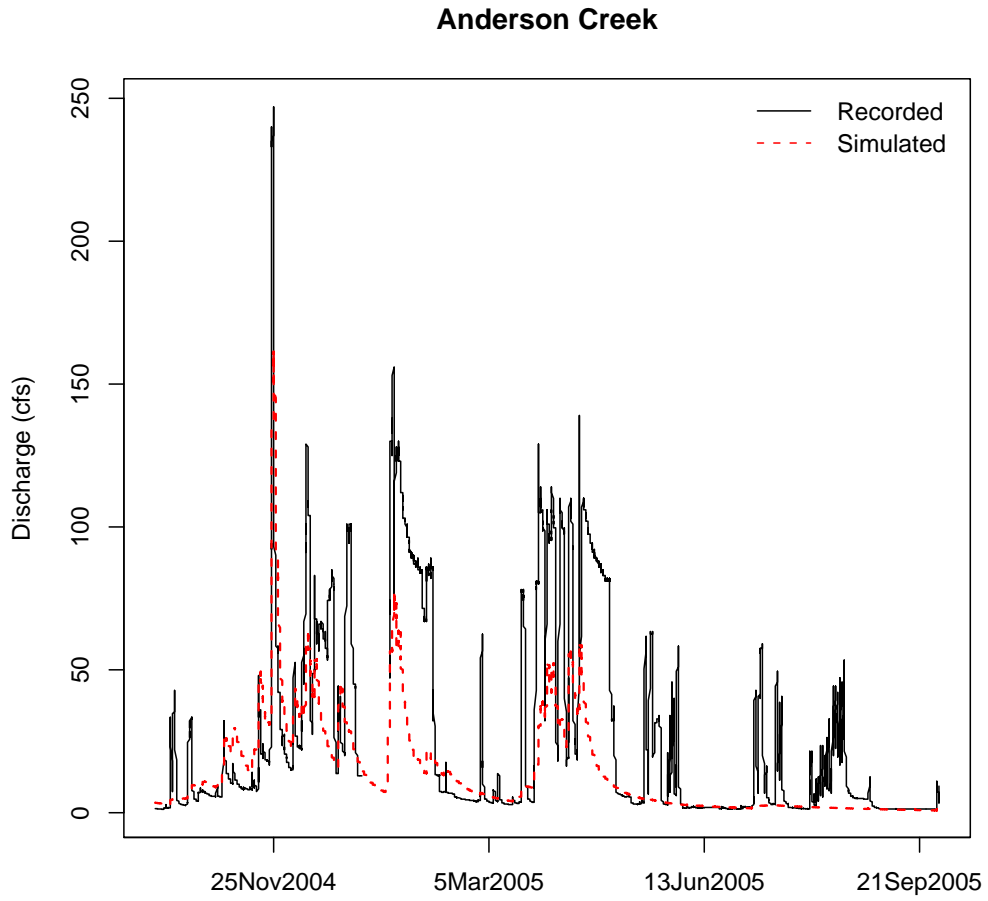


Figure 47: Anderson Creek hydrograph showing recorded and simulated values, October 1, 2004–September 30, 2005.

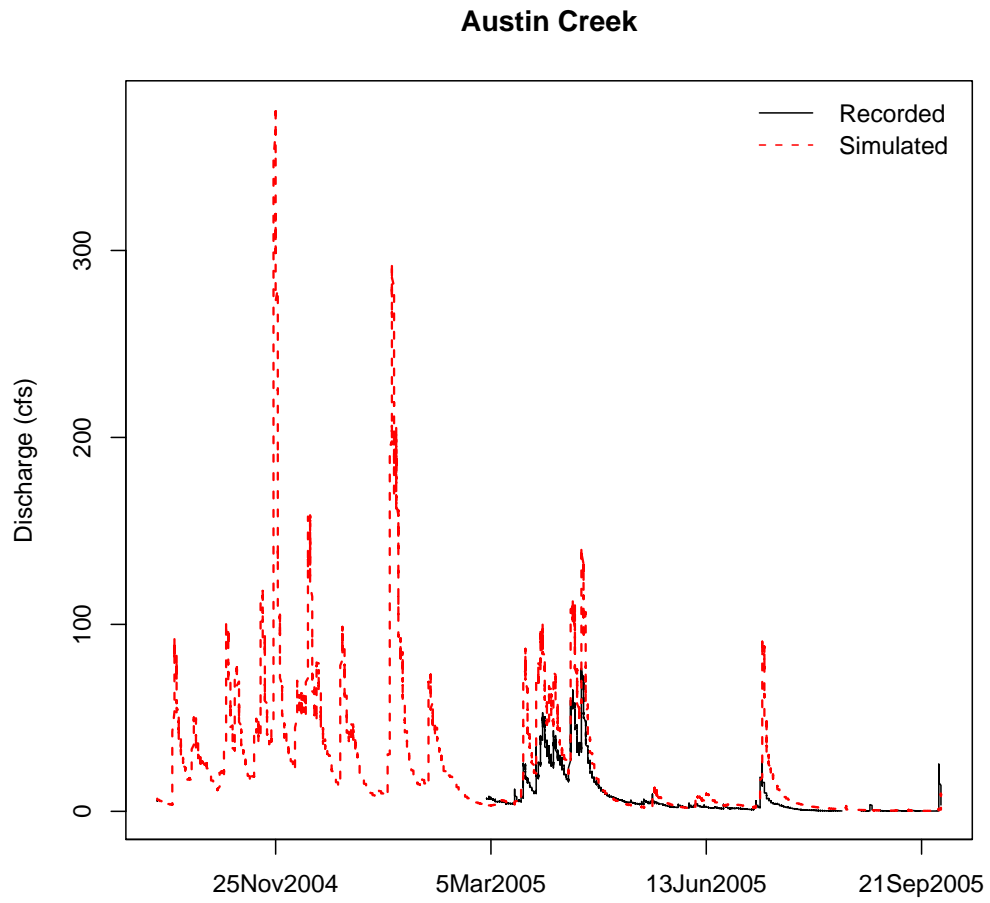


Figure 48: Austin Creek hydrograph showing recorded and simulated values, October 1, 2004–September 30, 2005.

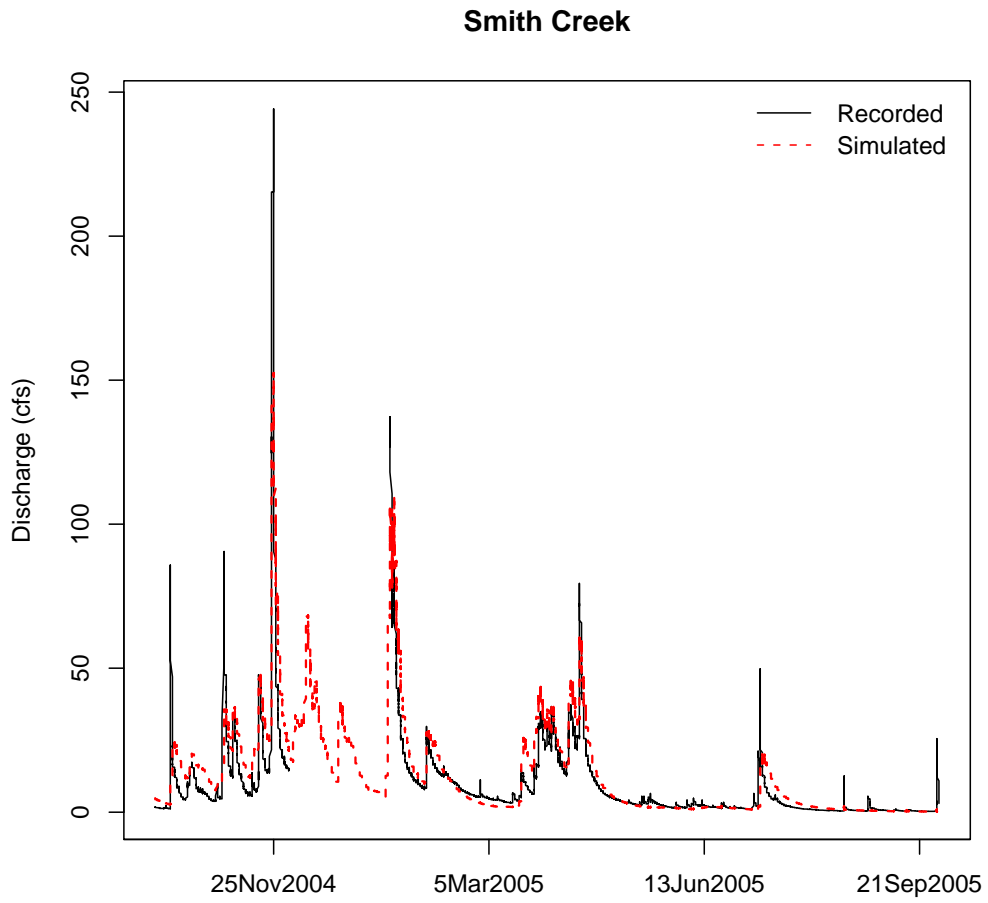


Figure 49: Smith Creek hydrograph showing recorded and simulated values, October 1, 2004–September 30, 2005.

5 Storm Water Treatment Monitoring

The objective of this portion of the lake monitoring project was to evaluate the storm water treatment efficiencies of representative treatment facilities in the vicinity of the Lake Whatcom watershed. During the 2004/2005 monitoring period, samples were collected from the Park Place wet pond, one underground storm water vault (Alabama Hill vault), and the South Campus storm water treatment facility.¹⁶ This report also includes a summary of the results collected in previous years from the Brentwood wet pond, the Silvern vault, and the Parkstone grass swale/wet pond. The locations of all current and previous monitoring sites are described in Appendix A, beginning on page 127, and illustrated in Figures A4 and A5 (pages 135 and 136). Photographs of the monitoring sites are included in Figures A6–A11 (pages 137–142).

5.1 Sampling procedures

Due to construction activities, weather conditions, and low flows, none of the sites could be sampled three times within the October 2004 – September 2005 monitoring period (Table 34 on page 112 shows the proposed monitoring schedule). In order to include three collections from as many sites as possible, we extended sampling into November 2005.

Park Place was sampled on March 21–23, 2005, but construction activities prevented sampling during the rest of the monitoring period. The South Campus storm water treatment facility, which was sampled on January 24–26, May 24–26, and November 9–11, 2005. The Alabama Hill vault was sampled on November 1–2, 2004 and March 28–29 and November 1–2, 2005.

Where possible, composite and grab samples were collected at inflow and outflow points for each site. Automatic composite samplers (ISCO type, supplied by the City of Bellingham) were placed at the inlet and outlet and composite water samples were collected at 90 minute intervals over a 48 hour period. The composite samples were analyzed for total solids, total suspended solids, heavy metals (arsenic, cadmium, chromium, copper, iron, nickel, lead, and zinc), total organic

¹⁶The South Campus storm water treatment facility is a state-of-the-art combination of grass swales and rock/plant filters. Although outside the Lake Whatcom watershed, it is included in the monitoring effort as an indicator of potential treatment effectiveness.

carbon, total nitrogen, and total phosphorus. Grab samples were collected four times during the 48 hour period at the inflow(s) and outflow(s) at each site. The Hydrolab Surveyor IV was used to measure pH, temperature, dissolved oxygen, and conductivity in the field. Bacteria samples (fecal coliforms and *E. coli*) were analyzed by the City of Bellingham. Due to flow constraints, composite sampling was not always possible in the Alabama Hill vault. When flows were too low for obtaining composites, grab samples were used to measure total solids, total suspended solids, total nitrogen, and total phosphorus.

5.2 Results and Discussion

The Park Place wet pond has been monitored since 1994 and annual water quality data are summarized by Matthews, et al. (2001). Monitoring at the South Campus facility began in 2001 and monitoring at the Alabama Hill vault began in 2004. Additional storm water treatment sites that have been monitored in the past include the Brentwood wet pond (1998–2004), the Parkstone swale/wet pond (2004) and the Silvern vault (2004).

Both the Brentwood and Park Place storm water treatment facilities consist of a series of wet ponds that develop extensive macrophyte growth during the summer (Figures A7 and A8, pages 138 and 139). The South Campus storm water treatment facility was constructed during the fall and winter of 2000. The rock/plant filters were planted with cattails (*Typha latifolia*), but only minimal growth had occurred by the end of summer, 2001. Due to excessive sediment loading from campus construction activities during 2001–2002, the gravel was replaced and the vegetation was replanted in the fall of 2002. The facility now supports a dense growth of emergent macrophytes (Figure A11, page 142).

The Alabama Hill and Silvern vaults are underground canister systems that can be filled with special materials designed to remove specific pollutants from surface runoff (Figures A6 and A10, pages 137 and 141). The Silvern vault is very small, containing only 6 canisters. Sampling at that site was discontinued after one year because the vault was usually dry or contained standing water that was not representative of storm runoff. The Alabama vault is considerably larger, consisting of 26 canisters, and while it is easier to sample than the Silvern vault, it is still difficult to collect composite samples. One set of composite samples were collected in the Alabama vault in 2004, but only grab samples were collected in 2005.

The Parkstone treatment system is a complex sequence of grass swales and small wet ponds (Figure A9, page 140) with multiple inlets and outlets. The upper portion of the Parkstone system is a grass swale that receives water from a small wetland (Parkstone swale inlet #1) and paved roadway (Parkstone swale inlet #2). Partially treated water from the swale outlet mixes with untreated street runoff to form the Parkstone pond inlet. The water is discharged from the Parkstone pond outlet into Mill Wheel Creek, which flows into Lake Whatcom. Because of the numerous source of runoff into this system, it was not considered to be a good site to assess pollutant removal, and was not sampled during the 2004/2005 monitoring period.

Tables 35–38 (pages 113–116) show the raw data from the storm water treatment systems that were monitored in 2004/2005. The tables also show the percent analyte reduction between the inflow and outflow, calculated as follows:

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

For the 48-hr composite samples, the above equation produces the “Event Mean Concentration Efficiency Percent” (Winer, 2000) based on the composited inlet and outlet samples; for the grab samples; the above equation produces the EMC efficiency percent from the average of the four inlet or outlet grab samples.

Most of the sites had slight differences between inlet and outlet values for temperature, pH, dissolved oxygen, and conductivity (Tables 36–38, pages 114–116). These differences were most likely the result of surface water enters a standing water environment (e.g., vault, pond, or constructed wetland)

The Alabama Hill vault provided virtually no phosphorus removal, ranging from a maximum of 2.9–3.3% reduction to an *increase* of 38.4% during the November 2005 sampling period (Tables 35 and 36, pages 113 and 114). Similarly, the vault provided minimal and inconsistent removal of suspended solids (8.1–32.8% reduction, with an *increase* of 6.7% in November 2004).

The structure of the Alabama Hill vault made it very difficult to obtain composite samples because the outlet flow was irregular, resulting in “dry” samples for some of the composites. To avoid this problem, only grab samples were collected from the vault in 2005. Both composite and grab samples were collected in November 2004, which allowed us to compare the total nitrogen, total phosphorus, and total suspended solids results for both types of samples. The percent reductions

were very similar for total phosphorus (grab = 2.9%, composite = 3.3%), but less similar for total nitrogen (grab = 18.9%, composite = 2.3%) and total suspended solids (grab = -6.7%, composite = 18.6%).

Due to construction activities, we were only able to sample the Park Place wet pond once. As in previous years, the Park Place wet pond provided virtually no phosphorus removal (0.4% *increase* in total phosphorus at the outlet), a minimal reduction in total solids (9%), and a relatively small (38%) reduction in total suspended solids (Table 37, page 115). The City is currently redesigning the Park Place treatment system, which should improve pollutant removal.

As in previous years, the South Campus system provided the best phosphorus and sediment removal, with seasonal percent reductions of 51.0–82.1% for total suspended solids and 12.6–61.5% for total phosphorus (Table 38, page 116). The South Campus system also provided the best coliform reduction, ranging from 54.3–86.0% for fecal coliforms and 42.0–84.7% for *E. coli*.

Over the past 10 years, IWS has monitored the performance of five storm water treatment systems inside the Lake Whatcom watershed (Alabama vault, Brentwood wet pond, Park Place wet pond, Parkstone swale/pond, and Sylvan vault). During this time the data suggest that none of these treatment systems have provided significant or consistent reductions in sediment or phosphorus in the runoff. Figures 50 and 51 (pages 117 and 118) show the inlet (open symbols) and outlet (shaded symbols) concentrations for total suspended solids and total phosphorus for all of the sites inside the Lake Whatcom watershed. Horizontal reference lines were added to show the 2004/2005 median total suspended solids and total phosphorus concentrations for Smith Creek (dashed line) and Silver Beach Creek (dotted line). Smith Creek was chosen as a reference because it is relatively unpolluted. Silver Beach Creek was chosen because it is one of the most polluted natural streams in the watershed.

Although most of the storm water treatment systems provided some degree of sediment removal, they rarely reduced sediment concentrations to levels approaching Smith Creek, or even Silver Beach Creek (Figure 50). The lack of phosphorus removal is more important, particularly in light of the increasing algal densities in the lake. It is clear from Figure 50 that the phosphorus concentrations at the outlets for all of the storm water treatment systems was higher than median value for Smith Creek. The vaults performed particularly poorly, routinely exceeding the Silver Beach Creek median and maximum (Figure 52, (page 119). Storm water

vaults are being installed throughout the watershed, with the intention of reducing pollutant loading into the lake. The City is currently testing canister media to determine which is effective at removing pollutants, especially phosphorus, from runoff. It is clear from other studies of storm water treatment systems that maintenance and design choices play an important part in the effectiveness of pollutant removal (Debo and Reese, 2003; Winer, 2000). It will be essential that the performance of storm water vaults be monitored to determine whether pollution removal is occurring, and under what conditions.

It should be noted that phosphorus reduction is a difficult problem and low removal efficiencies are commonly reported for nearly all types of storm water treatment systems, including wet ponds, grass swales, and filter systems. A recent study of the effectiveness of storm water treatment Best Management Practices (BMPs) revealed that there were no significant differences between mean influent and effluent phosphorus concentrations for most BMP categories, including media filters, retention ponds, and wetland basins (GeoSyntec Consultants and Wright Water Engineers, Inc., 2006).¹⁷ The authors reported similar statistical issues for other pollutants:

“In many instances, no significant difference between influent and effluent medians was determined. Therefore, it is not possible to determine with any certainty whether the BMP had an effect or simply that the characteristics of the runoff treated (for example, low influence concentrations) govern the distribution of effluent values.” (GeoSyntec Consultants and Wright Water Engineers, Inc., 2006)

Although this should not be taken as a broad statement that storm water treatment BMPs *never* reduce pollutants in runoff, it does illustrate the difficulty of both storm water treatment and performance assessment. In the Lake Whatcom watershed, storm water treatment is particularly difficult because the pollutant concentrations usually fall below the “irreducible concentration” (Winer, 2000; Schueler 1996) for total phosphorus ($\sim 150\text{--}200 \mu\text{g-P/L}$) and total suspended

¹⁷The GeoSyntec report analyzed BMP performance using two approaches: analysis of mean effluent concentrations by BMP category (one value per BMP study) and analysis of each effluent concentration by BMP category (all individual values included in analysis). The first approach (one value per BMP study) provides a better assessment of cross-site BMP performance because it weighs each BMP equally rather than giving greater weight to studies with a large number of single-site results.

solids ($\sim 20\text{--}40$ mg/L). When pollutant concentrations fall below the irreducible level, we may not be able to achieve significant pollutant removal using conventional approaches, and may actually see increased concentrations in the effluent. Unfortunately, the irreducible concentration for phosphorus is much higher than background concentrations found in forested streams such as Smith Creek, and is not a realistic water quality goal for protecting the lake. The field of storm water treatment is rapidly advancing and many new treatment technologies and “low impact development” approaches are being developed. As these new systems are introduced, it remains critically important that the performance of the treatment systems be monitored, despite the statistical and technological difficulties that this represents.

Parameter	2004 Oct-Dec wet, low flow	2005 Jan-Apr wet, high flow	2005 Jul-Sept dry, low flow	Location
DO	•	•	•	inflow, outflow; 4 grab samples in 48 hrs
pH	•	•	•	
Temp	•	•	•	
Cond	•	•	•	
Bacteria	•	•	•	
T. solids	•	•	•	inflow, outflow; 48-hr composite sample
T. susp. solids	•	•	•	
T. nitrogen	•	•	•	
T. phosphorus	•	•	•	
T. metals (As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Zn)	•	•	•	
T. organic carbon	•	•	•	
Photos			•	all sites
Nuisance checklist	•	•	•	

[†]Twenty-four additional metals are included as part of the standard AmTest analytical procedure.

Table 34: Storm water treatment systems monitoring schedule (2004/2005).

Site	Date	TSS (mg/L)	TS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
Alabama vault inlet	Nov 1–2, 2004	13.97	126.50	9.4	2.92	0.21
Alabama vault outlet	Nov 1–2, 2004	11.37	126.50	9.4	2.86	0.20
Percent reduction		18.6	0.0	0.0	2.3	3.3
Park Place inlet	Mar 21–23, 2005	5.73	123.83	2.1	0.849	0.05
Park Place outlet	Mar 21–23, 2005	3.55	112.75	6.0	0.841	0.05
Percent reduction		38.0	9.0	-185.7	0.9	-0.4
South Campus inlet	Jan 24–26, 2005	4.08	252.08	<1	1.28	0.05
South Campus outletE	Jan 24–26, 2005	<2*	241.33	<1	1.23	0.03
South Campus outletW	Jan 24–26, 2005	<2*	240.78	<1	1.3	0.04
Percent reduction		51.0	4.4	0.0	1.4	33.3
South Campus inlet	May 24–26, 2005	<2	177.75	3.6	0.96	0.09
South Campus outletE	May 24–26, 2005	<2	225.17	7.7	0.20	0.13
South Campus outletW	May 24–26, 2005	<2	218.50	4.4	0.23	0.02
Percent reduction		NA	-24.8	-68.1	77.6	12.6
South Campus inlet	Nov 9–11, 2005	32.67	236.11	8.3	1.25	0.08
South Campus outletE	Nov 9–11, 2005	9.48	197.67	8.1	0.96	0.04
South Campus outletW	Nov 9–11, 2005	2.20	190.11	9.6	0.65	0.03
Percent reduction		82.1	17.9	-6.6	35.6	61.5

*Value replaced with detection limit to calculate percent reduction.

Site	Date	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)
Alabama vault inlet	Nov 1–2, 2004	<0.01	<0.0005	0.0010	0.016	0.380	<0.0002	<0.005	0.012	0.051
Alabama vault outlet	Nov 1–2, 2004	<0.01	<0.0005	<0.001	0.016	0.280	<0.0002	<0.005	0.009	0.050
Percent reduction		NA	NA	NA	0.0	26.3	NA	NA	25.0	2.0
Park Place inlet	Mar 21–23, 2005	<0.01	<0.0005	<0.001	0.004	0.430	<0.0002	<0.005	<0.001	0.010
Park Place outlet	Mar 21–23, 2005	<0.01	<0.0005	<0.001	0.006	0.390	0.0003	<0.005	0.003	0.009
Percent reduction		NA	NA	NA	-50.0	9.3	NA	NA	NA	10.0
South Campus inlet	Jan 24–26, 2005	<0.01	<0.0005	<0.001	0.029	1.200	<0.0002	<0.005	0.003	0.053
South Campus outletE	Jan 24–26, 2005	<0.01	<0.0005	0.001	0.030	0.098	<0.0002	<0.005	<0.001	0.049
South Campus outletW	Jan 24–26, 2005	<0.01	<0.0005	<0.001	0.028	0.230	<0.0002	<0.005	<0.001	0.160
Percent reduction		NA	NA	NA	0.0	86.3	NA	NA	NA	-97.2
South Campus inlet	May 24–26, 2005	<0.01	<0.0005	<0.001	0.005	1.800	<0.0002	<0.005	0.007	0.021
South Campus outletE	May 24–26, 2005	<0.01	<0.0005	<0.001	0.004	<0.005*	<0.0002	<0.005	0.002	0.012
South Campus outletW	May 24–26, 2005	<0.01	<0.0005	<0.001	0.004	<0.005*	<0.0002	<0.005	0.001	0.010
Percent reduction		NA	NA	NA	20.0	99.7	NA	NA	78.6	47.6
South Campus inlet	Nov 9–11, 2005	<0.01	<0.0005	0.001*	0.007	2.20	<0.0002	<0.005	<0.001	0.024
South Campus outletE	Nov 9–11, 2005	<0.01	<0.0005	0.005	0.008	0.55	<0.0002	<0.005	<0.001	0.016
South Campus outletW	Nov 9–11, 2005	<0.01	<0.0005	0.004	0.007	0.14	<0.0002	<0.005	<0.001	0.012
Percent reduction		NA	NA	-350.0	-7.1	84.3	NA	NA	NA	41.7

*Value replaced with detection limit to calculate percent reduction.

Table 35: Park Place wet pond, South Campus rock/plant filter, and Alabama Hill vault composite samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (µS/cm)	TSS (mg/L)	TS (mg/L)	NH3 (mg/L)	NO3 (mg/L)	TN (mg/L)	SRP (mg/L)	TP (mg/L)
inlet	Nov 1-2, 2004 (A)	9.0	7.62	10.29	97.9	10.43	NA	NA	NA	0.83	NA	0.13
inlet	Nov 1-2, 2004 (B)	9.5	7.50	9.97	78.8	31.27	NA	NA	NA	0.88	NA	0.17
inlet	Nov 1-2, 2004 (C)	11.2	7.48	10.15	252.0	6.35	NA	NA	NA	5.04	NA	0.20
inlet	Nov 1-2, 2004 (D)	11.5	7.53	9.48	259.0	3.07	NA	NA	NA	4.55	NA	0.15
outlet	Nov 1-2, 2004 (A)	9.0	7.54	10.03	98.5	21.97	NA	NA	NA	0.93	NA	0.15
outlet	Nov 1-2, 2004 (B)	9.5	7.44	9.71	81.2	26.30	NA	NA	NA	0.81	NA	0.15
outlet	Nov 1-2, 2004 (C)	11.2	7.44	10.08	251.0	4.00	NA	NA	NA	4.51	NA	0.18
outlet	Nov 1-2, 2004 (D)	11.5	7.49	9.51	259.0	2.28	NA	NA	NA	2.92	NA	0.14
Seasonal % reduction		0.0	0.7	1.4	-0.3	-6.7	NA	NA	NA	18.9	NA	2.9
inlet	Mar 28-29, 2005 (A)	8.3	7.48	9.53	77.8	71.50	114.17	0.07	0.34	0.96	0.04	0.20
inlet	Mar 28-29, 2005 (B)	9.3	7.74	10.19	181.0	21.13	137.75	0.09	0.94	1.46	0.07	0.12
inlet	Mar 28-29, 2005 (C)	8.2	7.74	10.06	214.0	9.50	146.67	0.03	1.02	1.44	0.08	0.12
outlet	Mar 28-29, 2005 (A)	8.2	7.52	10.10	85.4	83.47	128.83	0.08	0.36	1.07	0.05	0.21
outlet	Mar 28-29, 2005 (B)	9.4	7.51	9.25	184.4	8.43	131.67	0.04	0.97	1.36	0.09	0.13
outlet	Mar 28-29, 2005 (C)	8.2	7.45	8.77	193.0	2.00*	128.33	0.01	0.91	1.24	0.12	0.13
Seasonal % reduction		0.0	2.1	5.6	2.1	8.1	2.4	31.4	2.6	4.8	-38.2	-5.2
inlet	Nov 1-2, 2005 (A)	11.0	7.24	NA	134.0	10.23	101.75	NA	NA	2.41	NA	0.15
inlet	Nov 1-2, 2005 (B)	11.6	7.29	9.64	204.0	4.23	148.08	NA	NA	4.50	NA	0.15
inlet	Nov 1-2, 2005 (C)	11.5	7.49	9.28	254.0	2.63	175.58	NA	NA	4.49	NA	0.11
outlet	Nov 1-2, 2005 (A)	10.9	7.40	NA	135.0	6.42	100.42	NA	NA	2.36	NA	0.18
outlet	Nov 1-2, 2005 (B)	11.5	7.41	9.62	203.0	3.07	144.33	NA	NA	4.38	NA	0.18
outlet	Nov 1-2, 2005 (C)	11.5	7.51	8.53	261.0	2.00*	176.75	NA	NA	4.38	NA	0.20
Seasonal % reduction		0.6	-1.4	4.1	-1.2	32.8	0.9	NA	NA	2.5	NA	-38.4

*Value replaced with detection limit to calculate percent reduction.

Site	Date (Time)	TOC (mg/L)	FC (100 mL)	E. coli (100 mL)	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Hg (mg/L)	Ni (mg/L)	Zn (mg/L)
inlet	Nov 1-2, 2004 (A)	NA	660	300	NA	NA	NA	NA	NA	NA	NA	NA
inlet	Nov 1-2, 2004 (B)	NA	500	400	NA	NA	NA	NA	NA	NA	NA	NA
inlet	Nov 1-2, 2004 (C)	NA	1300	1400	NA	NA	NA	NA	NA	NA	NA	NA
inlet	Nov 1-2, 2004 (D)	NA	250	250	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Nov 1-2, 2004 (A)	NA	1200	1200	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Nov 1-2, 2004 (B)	NA	360	290	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Nov 1-2, 2004 (C)	NA	940	840	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Nov 1-2, 2004 (D)	NA	330	260	NA	NA	NA	NA	NA	NA	NA	NA
Seasonal % reduction		NA	-4.4	-10.2	NA	NA	NA	NA	NA	NA	NA	NA
inlet	Mar 28-29, 2005 (A)	4.1	560	380	<0.01	<0.0005	<0.001	0.007	0.69	<0.0002	<0.005	0.036
inlet	Mar 28-29, 2005 (B)	NA	220	190	NA	NA	NA	NA	NA	NA	NA	NA
inlet	Mar 28-29, 2005 (C)	<1*	140	100	<0.01	<0.0005	<0.001	0.004	0.22	<0.0002	<0.005	0.015
outlet	Mar 28-29, 2005 (A)	11	530	450	<0.01	0.0007	<0.001	0.010	0.88	<0.0002	<0.005	0.066
outlet	Mar 28-29, 2005 (B)	NA	220	89	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Mar 28-29, 2005 (C)	5.5	20	23	<0.01	<0.0005	<0.001	0.003	0.08	<0.0002	<0.005	0.012
Seasonal % reduction		-223.5	16.3	16.1	NA	NA	NA	-18.2	-5.6	NA	NA	-52.9
inlet	Nov 1-2, 2005 (A)	NA	1200	720	NA	NA	NA	NA	NA	NA	NA	NA
inlet	Nov 1-2, 2005 (B)	NA	1000	720	NA	NA	NA	NA	NA	NA	NA	NA
inlet	Nov 1-2, 2005 (C)	NA	530	400	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Nov 1-2, 2005 (A)	NA	620	960	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Nov 1-2, 2005 (B)	NA	530	1000	NA	NA	NA	NA	NA	NA	NA	NA
outlet	Nov 1-2, 2005 (C)	NA	110	210	NA	NA	NA	NA	NA	NA	NA	NA
Seasonal % reduction		NA	53.8	-17.9	NA	NA	NA	NA	NA	NA	NA	NA

Table 36: Alabama vault grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A-D. Negative values indicate an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μ S/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
inlet	Mar 21–23, 2005 (A)	9.5	7.36	11.80	168.8	590	700
inlet	Mar 21–23, 2005 (B)	8.0	7.49	11.39	177.7	500	260
inlet	Mar 21–23, 2005 (C)	8.9	7.62	10.94	179.2	170	280
inlet	Mar 21–23, 2005 (D)	7.5	7.58	10.51	175.8	63	100
outlet	Mar 21–23, 2005 (A)	8.4	7.41	11.88	129.1	620	120
outlet	Mar 21–23, 2005 (B)	8.4	7.32	10.88	166.8	210	160
outlet	Mar 21–23, 2005 (C)	11.8	7.63	12.33	170.4	27	14
outlet	Mar 21–23, 2005 (D)	7.6	7.51	10.23	175.5	64	140
Seasonal % reduction		-6.8	0.6	-1.5	8.5	30.4	67.6

Table 37: Park Place wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D. Negative values indicate an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
inlet	Jan 24–26, 2005 (A)	10.9	7.47	10.47	373.0	33	23
inlet	Jan 24–26, 2005 (B)	10.8	7.46	10.55	385.0	11	12
inlet	Jan 24–26, 2005 (C)	10.9	7.43	9.48	392.0	8	9
inlet	Jan 24–26, 2005 (D)	10.8	7.49	9.84	402.0	5	3
outletE	Jan 24–26, 2005 (A)	10.7	7.42	7.88	369.0	5	8
outletE	Jan 24–26, 2005 (B)	9.5	7.42	8.17	384.0	1	1
outletE	Jan 24–26, 2005 (C)	10.1	7.39	7.00	390.0	1	1
outletE	Jan 24–26, 2005 (D)	9.5	7.45	7.37	399.0	1	1
outletW	Jan 24–26, 2005 (A)	10.8	7.52	8.21	364.0	10	8
outletW	Jan 24–26, 2005 (B)	9.6	7.51	8.66	381.0	1	1
outletW	Jan 24–26, 2005 (C)	10.3	7.49	7.38	386.0	1	1
outletW	Jan 24–26, 2005 (D)	9.5	7.55	7.81	396.0	1	1
Seasonal % reduction		7.8	-0.1	22.6	1.1	81.6	76.6
inlet	May 24–26, 2005 (A)	12.9	7.36	7.85	363.0	25	12
inlet	May 24–26, 2005 (B)	13.0	7.26	8.63	368.0	24	16
inlet	May 24–26, 2005 (C)	12.7	7.43	7.46	377.0	12	4
inlet	May 24–26, 2005 (D)	13.0	7.32	7.70	380.0	14	4
outletE	May 24–26, 2005 (A)	12.8	7.37	4.47	356.0	6	1
outletE	May 24–26, 2005 (B)	12.7	7.35	5.03	360.0	4	1
outletE	May 24–26, 2005 (C)	12.6	7.41	4.39	367.0	6	1
outletE	May 24–26, 2005 (D)	12.6	7.40	4.71	370.0	1	4
outletW	May 24–26, 2005 (A)	12.9	7.28	3.68	351.0	1	1
outletW	May 24–26, 2005 (B)	12.8	7.29	4.08	353.0	1	1
outletW	May 24–26, 2005 (C)	12.7	7.39	3.59	361.0	1	1
outletW	May 24–26, 2005 (D)	12.7	7.34	3.78	363.0	1	1
Seasonal % reduction		1.4	-0.2	46.7	3.2	86.0	84.7
inlet	Nov 9–11, 2005 (A)	12.9	7.48	8.97	391.0	10	7
inlet	Nov 9–11, 2005 (B)	12.9	7.53	8.47	393.0	8	5
inlet	Nov 9–11, 2005 (C)	13.0	7.46	8.42	411.0	NA	2
inlet	Nov 9–11, 2005 (D)	11.8	7.62	9.81	195.0	580	490
outletE	Nov 9–11, 2005 (A)	11.3	7.48	6.86	374.0	34	17
outletE	Nov 9–11, 2005 (B)	11.7	7.49	6.41	385.0	27	35
outletE	Nov 9–11, 2005 (C)	11.7	7.45	6.16	402.0	NA	15
outletE	Nov 9–11, 2005 (D)	12.2	7.46	7.78	321.0	300	290
outletW	Nov 9–11, 2005 (A)	10.0	7.44	5.02	335.0	3	3
outletW	Nov 9–11, 2005 (B)	10.0	7.44	4.80	339.0	2	1
outletW	Nov 9–11, 2005 (C)	10.1	7.40	4.92	402.0	NA	4
outletW	Nov 9–11, 2005 (D)	10.3	7.51	7.06	366.0	180	220
Seasonal % reduction		13.7	0.8	31.3	-5.2	54.3	42.0

Table 38: South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential from A–D. Negative values indicate an increase in concentration at the outlet.

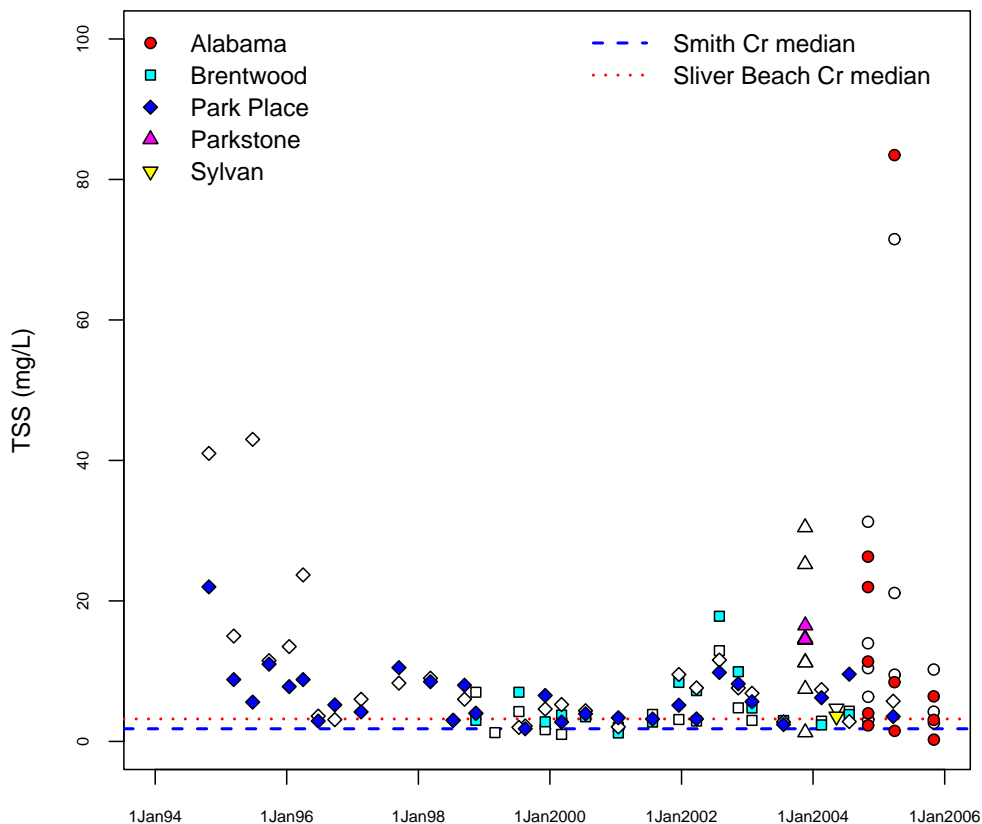


Figure 50: Comparison of inlet and outlet total suspended solids concentrations relative to the median 2004/2005 concentration in Smith Creek (dashed reference line) and Silver Beach Creek (dotted reference line). Open symbols show inlet concentrations and shaded symbols show outlet concentrations. Two outlier points from Parkstone inlet samples were omitted to facilitate plotting.

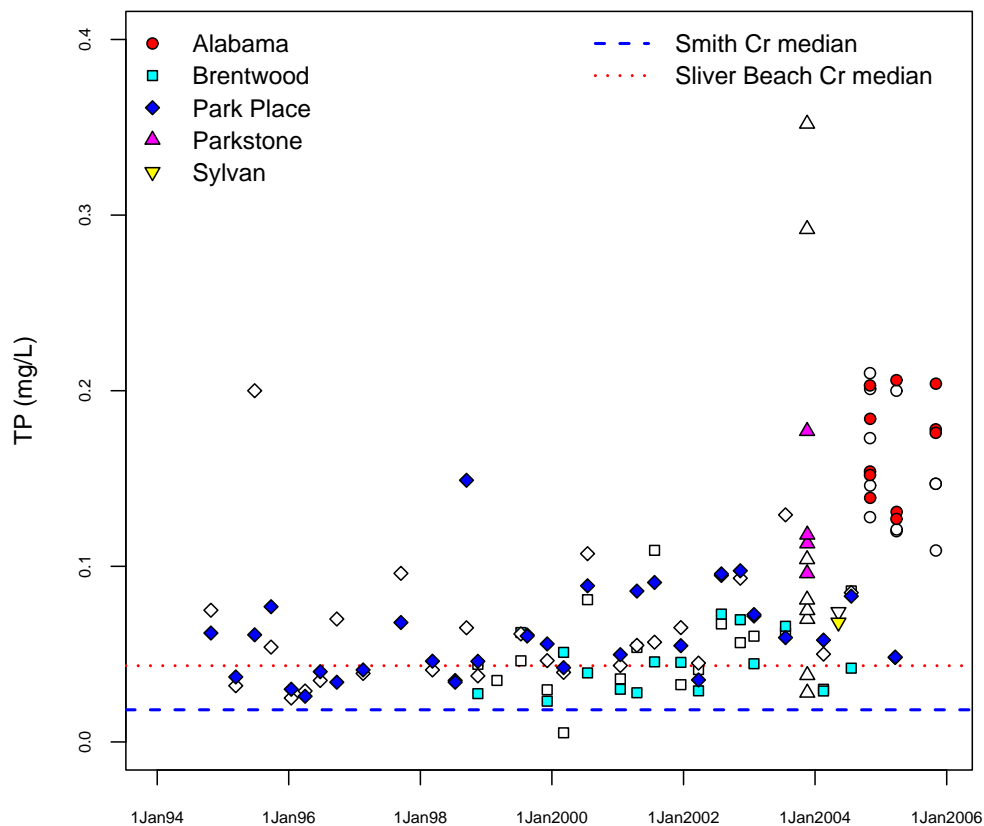


Figure 51: Comparison of inlet and outlet total phosphorus concentrations relative to the median 2004/2005 concentration in Smith Creek (dashed reference line) and Silver Beach Creek (dotted reference line). Open symbols show inlet concentrations and shaded symbols show outlet concentrations.

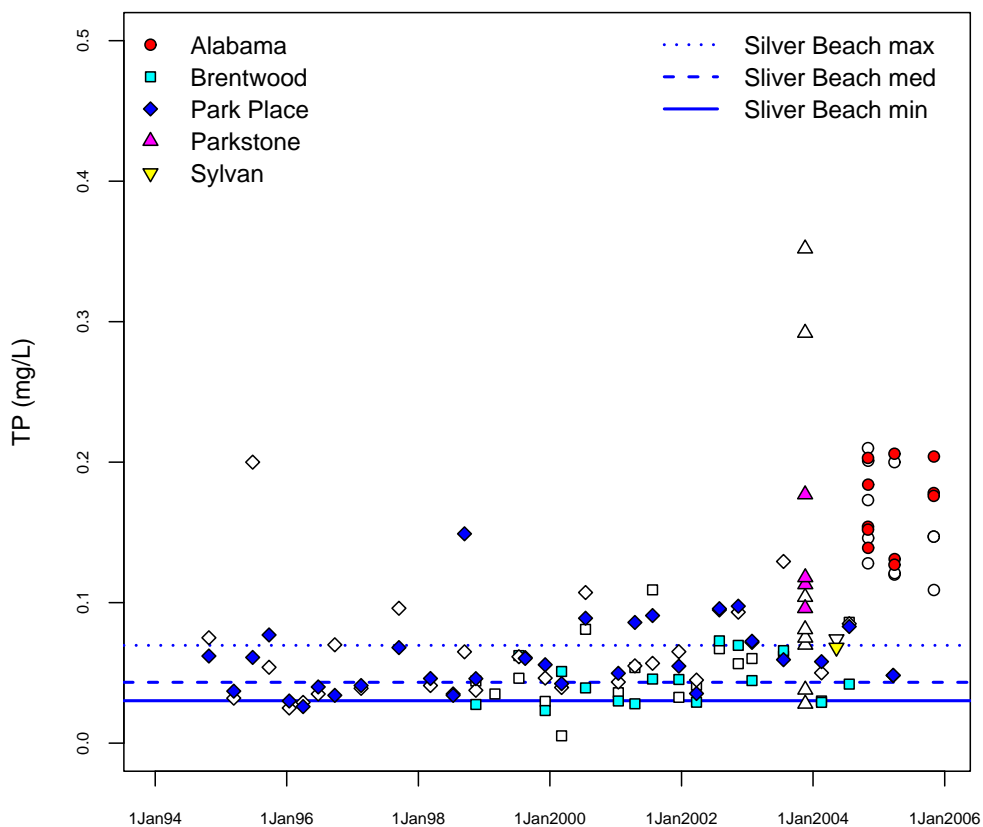


Figure 52: Inlet and outlet total phosphorus concentrations compared to the 2004/2005 minimum/maximum total phosphorus concentrations in Silver Beach Creek. Open symbols show inlet concentrations and shaded symbols show outlet concentrations.

6 References

- APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th 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.
- Bowling, L. C., P. Storck and D. P. Lettenmaier. 2000. Hydrologic effects of logging in Western Washington, United States. *Wat. Resour. Res.* 36:3223–3240.
- Debo, T. N. and A. J. Reese. 2003. Municipal Stormwater Management, Second Edition. Lewis Publishers, New York, NY.
- DeLuna, E. 2004. Microbial patterns in the metalimnion of Lake Whatcom, Washington. M. S. thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.
- Dingman, S. L. 1994. Physical Hydrology. Macmillan College Publishing Co., New York, NY.
- EPA. 2005. Method 1603: *Escherichia coli* (E. coli) in Water by Membrane Filtration Using Modified Membrane-Thermotolerant *Escherichia coli* Agar (Modified mTEC), U. S. Environmental Protection Agency, Office of Water (4303T), 1200 Pennsylvania Avenue, NW, Washington, DS, 20460, April 2005.
- Ferrari, R. L. and S. Nuanes. 2001. Lake Whatcom 1999–2000 Area and Capacity Survey. U.S. Department of the Interior, Bureau of Reclamation. No. 0704–0188.

- GeoSyntec Consultants and Wright Water Engineers, Inc. 2006. Analysis of Treatment System Performance, International Stormwater Best Management Practices (BMP) Database [1999–2005]. Report to the Water Environmental Research Foundation, American Society of Civil Engineers, U. S. Environmental Protection Agency, Federal Highway Administration, and American Public Works Association, February 2006. Online at <http://www.bmpdatabase.org>
- Hollander, M. and D. A. Wolfe, 1999. Nonparametric Statistical Methods, Second Edition. John Wiley & Sons, New York, NY.
- Hydrolab. 1997. Data Sonde 4 Water Quality Multiprobes User Manual, Revision D., August 1997. Hydrolab Corporation, Austin, TX.
- Lee, R. E. 1989. Phycology, Second Edition. Cambridge University Press, New York, NY.
- Liang, C-W. 1994. Impact of soil and phosphorus enrichment on Lake Whatcom periphytic algae. M. S. thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.
- Lind, O. T.. 1985. Handbook of Common Methods in Limnology, 2nd Edition. Kendall/Hunt Publishing Co., Dubuque, IA.
- Matthews, R. A., 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.

- Matthews, R. A., M. Saunders, M. A. Hilles, and J. Vandersypen. 2001. Park Place Wet Pond Monitoring Project 1994–2000 Summary Report. Final Report prepared for the City of Bellingham Public Works Department, February, 2001, 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.
- McNair, C. M. 1995. Dynamic chlorophyll maxima and their association with environmental gradients: a multivariate analysis. M. S. thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.
- Pelletier, G. 1998. Dissolved oxygen in Lake Whatcom. Trend in the depletion of hypolimnetic oxygen in basin I, 1983–1997. Washington State Department of Ecology Report #98–313, Olympia, WA.
- 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.
- Storck, P., L. Bowling, P. Wetherbee and D. Lettenmaie. 1998. Application of a GIS-based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest. *Hydrol. Process.* 12:889–904.
- Sung, W., B. Reilly-Matthews, D. K. O’Day, and K. Horrigan. 2000. Modeling DBP Formation. *J. Amer. Water Works Assoc.* 92:5–53.
- VanShaar, J. R., I. Haddeland, and D. P. Lettenmaier. 2002. Effects of land cover changes on the hydrologic response of interior Columbia River Basin forested catchments. *Hydrol. Process.* 16:2499–2520.
- W. Viessman, Jr., and M. J. Hammer. 1985. *Water Supply and Pollution Control*, 4th Edition. Harper & Row Publishers, New York, NY.
- Wetzel, R. G. 1983. *Limnology*, Second Edition. Saunders College Publishing, New York, NY.

- Wigmosta, M. S., L. Vail, and D. P. Lettenmaier. 1994. A distributed hydrology-vegetation model for complex terrain. *Wat. Resour. Res.* 30:1665–1679.
- Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices, Second Edition. Center for Watershed Protection, 8391 Main Street, Ellicott City, MD.

6.1 Lake Whatcom 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.ac.wvu.edu/~iws> (follow links to the Lake Whatcom Watershed Project – online reports); 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.

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., 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. 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., 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. Strawberry Sill Water Quality Analysis, March 19, 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. 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.
- 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.
- 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.

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.

A Site Descriptions

Figures A1–A5 (pages 132–136) show the locations of the current monitoring sites and Table A1 (page 131) 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 the IWS Director.

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 Creek Monitoring Sites

Anderson Creek samples are collected 15 m upstream from South Bay Rd. Water samples and discharge measurements are collected upstream from the bridge. The Anderson Creek hydrograph 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. Beginning in October 2004, three additional sampling sites were added in the Austin Creek watershed, so for clarification, the gauged site was renamed **Lower Austin Creek**. **Upper Austin Creek** samples are collected approximately 20 m upstream from Tumbling Water Ln. **Upper Beaver Creek** samples are collected approximately 15 m downstream from the confluence of Beaver Creek and an unnamed tributary and is accessed from Gate 13 in Sudden Valley. Samples from the **Austin Creek/Beaver Creek confluence** are collected approximately 60 m downstream from the confluence of Austin and Beaver Creeks.

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

Brannian Creek samples are collected approximately 40 m downstream from South Bay Rd. near the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly creek monitoring project.

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

Euclid Ave. samples are collected from an unnamed tributary located off Decator Rd. near the USGS hydrograph gauge. The site is named for its proximity to Euclid Ave., and was added in October 2004 as part of the monthly creek monitoring project.

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

Olsen Creek samples are collected just downstream from North Shore Dr. near the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly creek monitoring project.

Park Place samples are collected from the outlet of the Park Place storm water treatment system. Currently, samples are collected by accessing a manhole located approximately 7 m from Park Place Ln. Construction activities in the vicinity of the storm water treatment system can affect the sampling location; contact the IWS Director for detailed information about the current site location.

Silver Beach Creek samples are collected approximately 15 m upstream from the culvert under North Shore Rd.

The **Smith Creek** hydrograph is mounted on the south wall of a sandstone bluff directly underneath the bridge over Smith Creek (North Shore Rd.) approximately 1 km upstream from the mouth of the creek. Water samples are collected at the gaging station approximately 15 m downstream from North Shore Dr.

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

A.3 Storm Water Monitoring Sites

The **Alabama Hill storm water treatment vault** is located on the east side of a 3-way intersection of Alabama St., Electric Ave., and North Shore Drive. The vault drains directly into Lake Whatcom.

The **Brentwood wet pond** is located at the southwest corner of the intersection between Britton Rd. and Barkley Blvd. The facility treats residential runoff from north of Barkley Blvd. and west of Britton Rd. Treated water flows from the facility into an underground drain that flows directly into Lake Whatcom, bypassing the Park Place storm water treatment system.

The **Park Place wet pond** is located on Park Place, south of North Shore Dr. and east of the intersection with Britton Rd. The facility treats residential runoff from south of Barkley Blvd. and west of Britton Rd. Treated water flows from the facility directly into Lake Whatcom.

The **Parkstone storm water treatment facility** is located on the northwest corner of Parkstone Ln. and Lakeway Dr. The facility is a complex system of grass swales, natural wetlands, and constructed ponds, with numerous inlets and outlets. The pond outlet flows into Millwheel Creek, a tributary to Lake Whatcom.

The **South Campus storm water treatment facility** is located south of the intersection between Bill McDonald Pky. and South College Dr. The facility treats runoff from the southern portion of Western Washington University. The campus runoff flows into a large underground concrete settling vault located on the northwest corner of the intersection, then flows into a series of grass swales and gravel beds planted with aquatic vegetation. This facility lies outside the Lake Whatcom watershed.

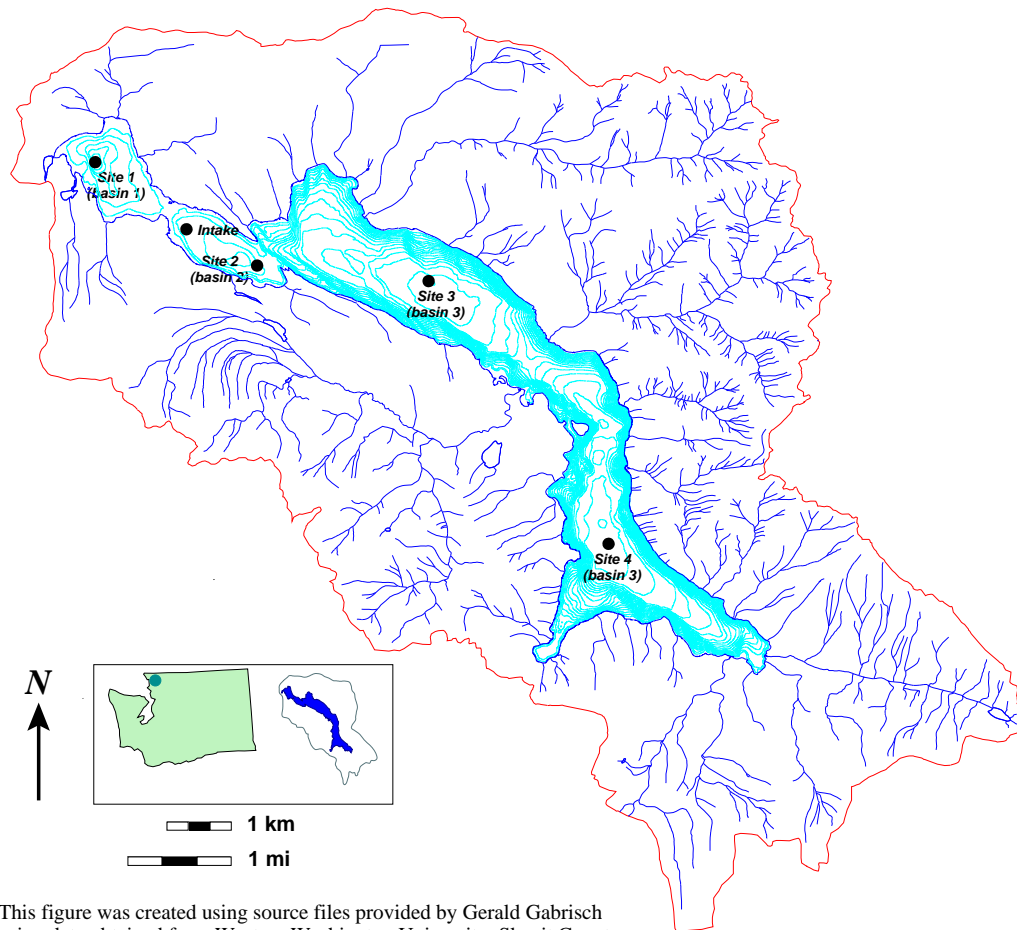
The **Silvern storm water treatment vault** is located at the bottom of the cul de sac on the southwest side of Silvern Ln., north of North Shore Dr. and opposite the Park Place wet pond. The vault drains into the storm water connector that ties into the Park Place outlet.

Lake Sites	Latitude	Longitude
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

Creek Sites	Latitude	Longitude
Anderson	48.67335	122.26751
Austin (lower)	48.71312	122.33076
Austin/Beaver (confluence)	48.71163	122.34035
Austin (upper)	48.70870	122.34310
Beaver (upper)	48.72284	122.36551
Blue Canyon	48.68532	122.28295
Brannian	48.66910	122.27949
Carpenter	48.75432	122.35449
Euclid	48.74844	122.41005
Millwheel	48.75507	122.41635
Olsen	48.75129	122.35353
Park Place	48.76894	122.40915
Silver Beach	48.76859	122.40700
Smith	48.73191	122.30864
Whatcom	48.75715	122.42229

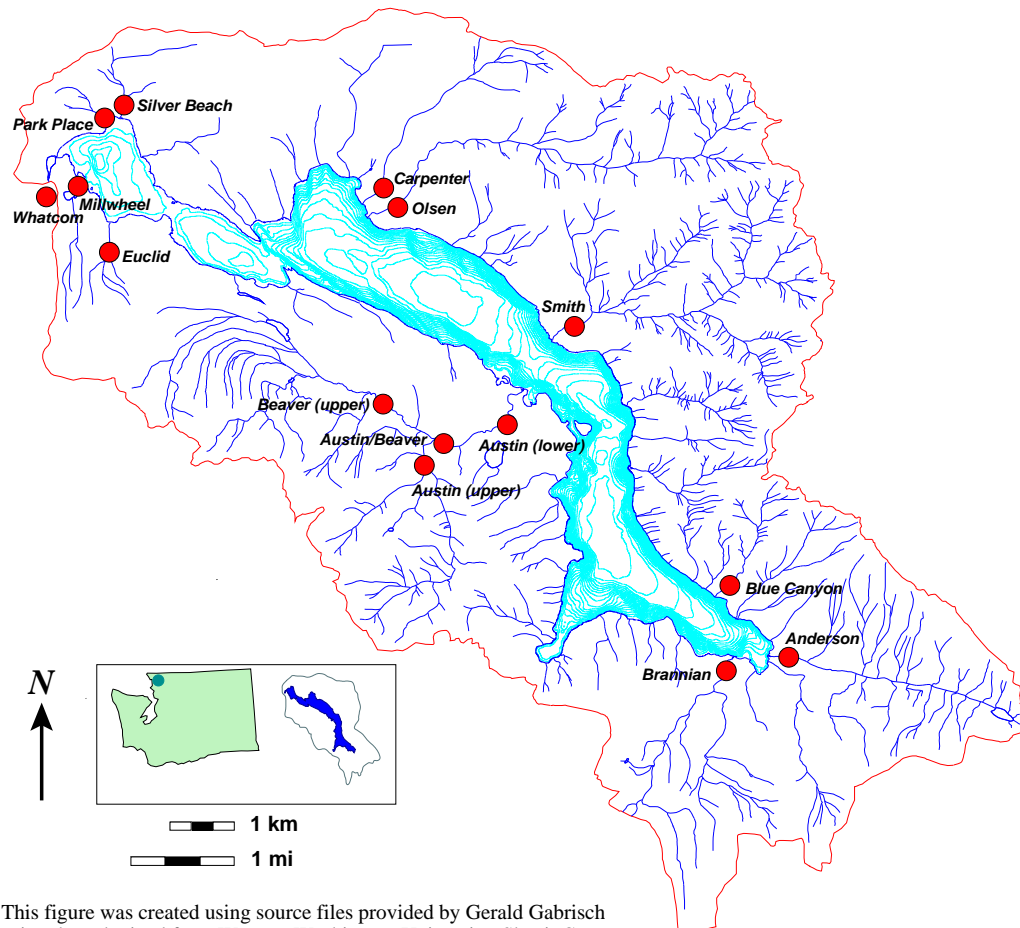
Storm Water Sites	Latitude	Longitude
Alabama Hill	no GPS data available	
Brentwood	no GPS data available	
Park Place	48.4608	122.2433
Parkstone	48.4450	122.2505
Silvern	48.4609	122.2434
South Campus	no GPS data available	

Table A1: Approximate GPS coordinates for the current Lake Whatcom Monitoring Project sampling sites.



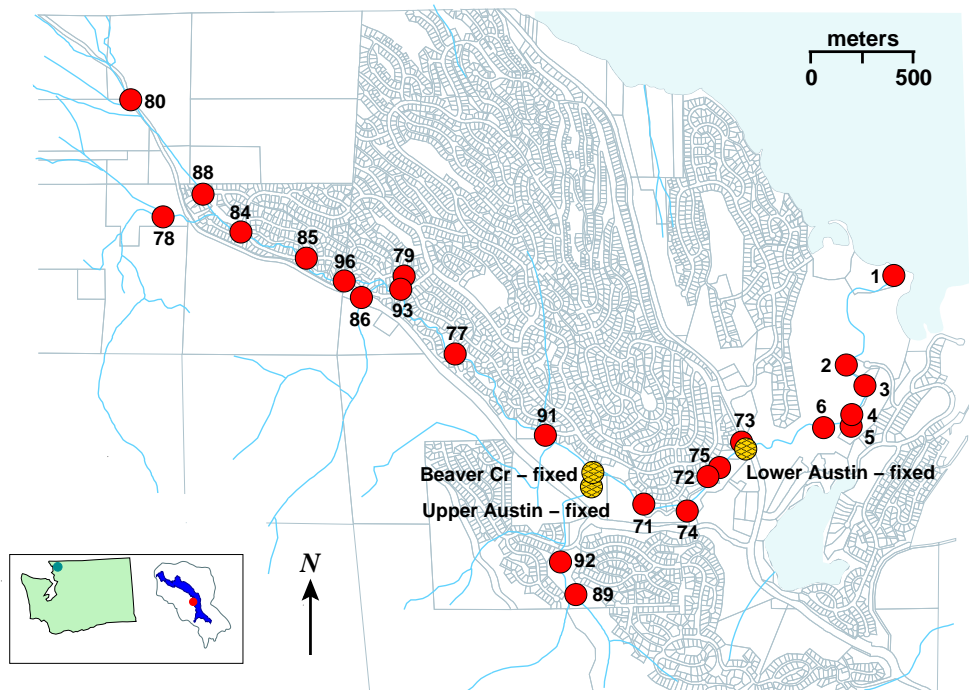
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A1: Lake Whatcom 2004/2005 lake sampling sites.



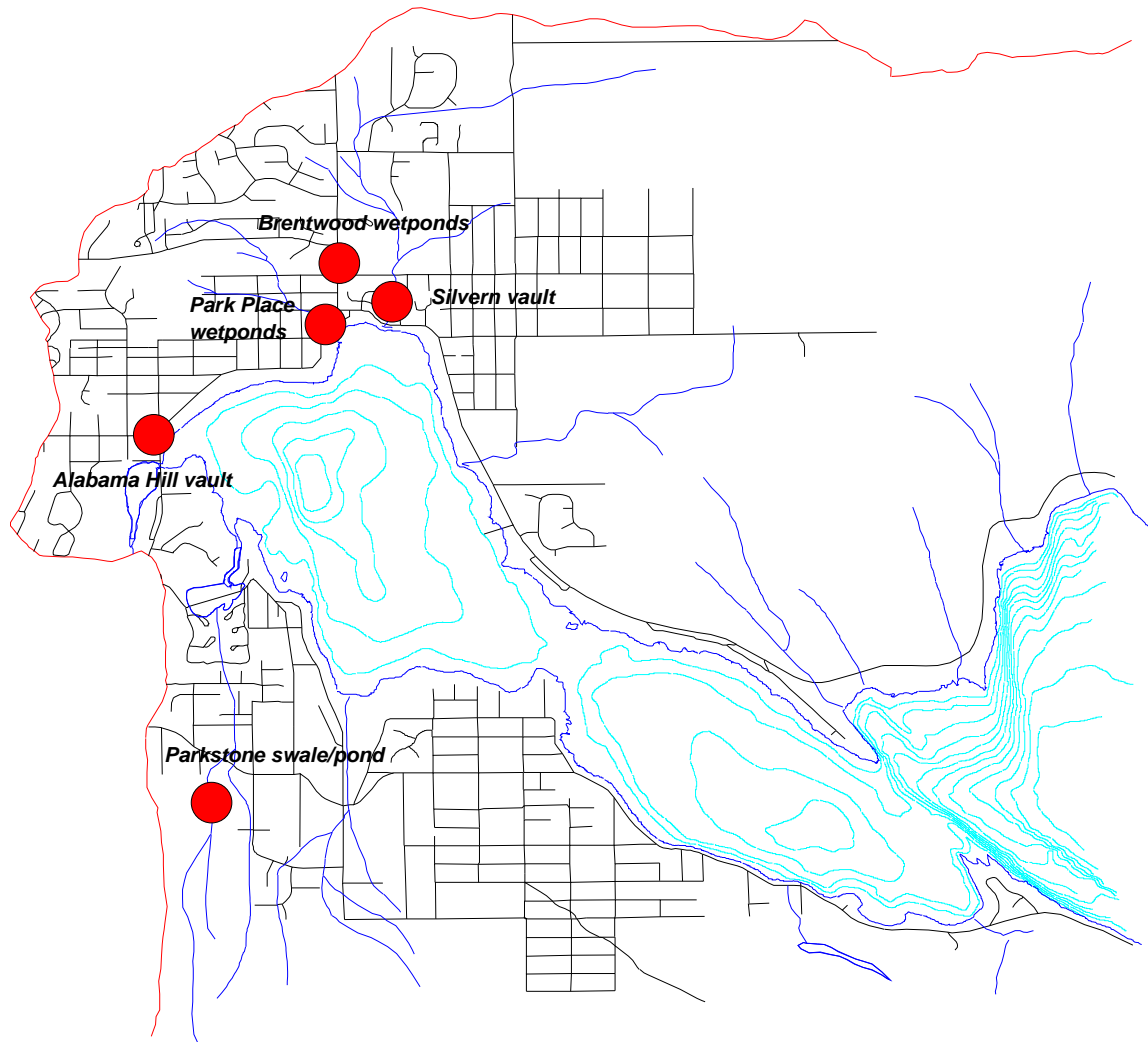
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A2: Lake Whatcom 2004/2005 creek sampling sites.



This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A3: Sampling sites in the Austin Creek and Beaver Creek watersheds, November 20, 2004.



This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A4: Locations of the Park Place and Brentwood wet ponds, the Parkstone swale/pond, and the Alabama Hill and Silvern vaults.

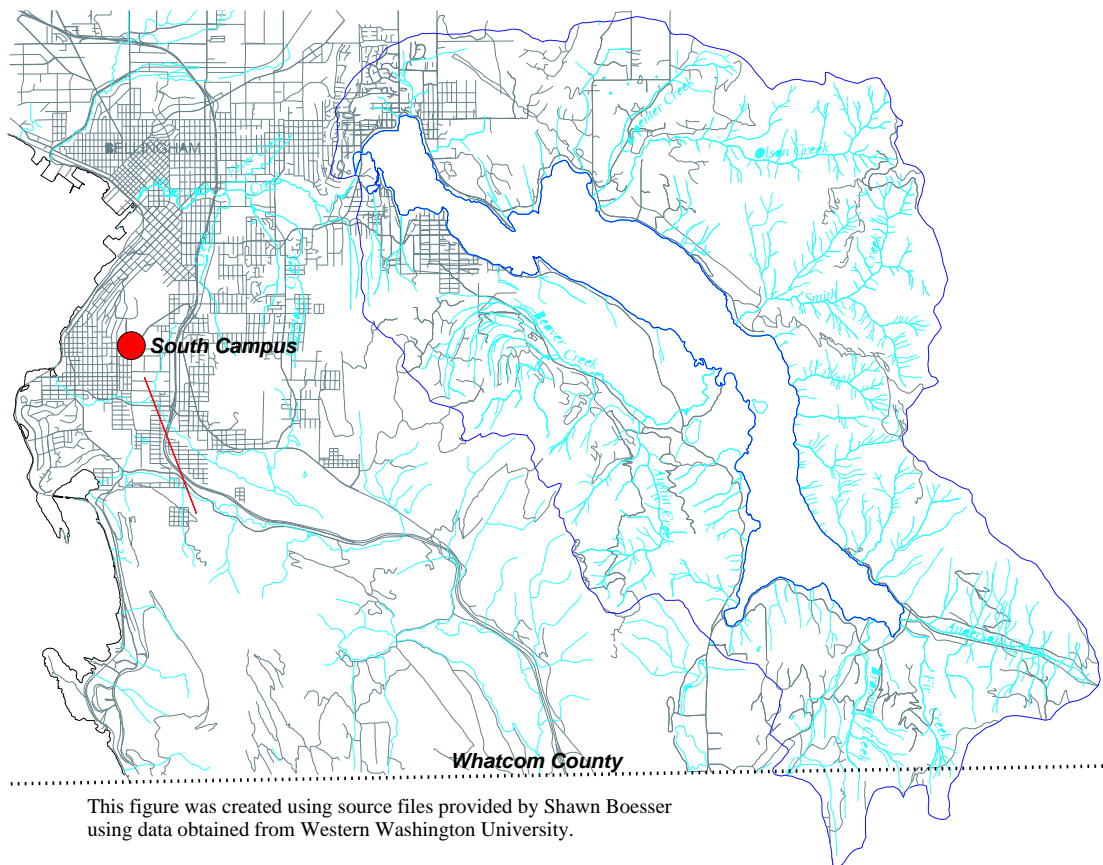


Figure A5: Locations of the South Campus storm water treatment facility.



Figure A6: Photograph of the Alabama Hill vault, November 2005.



Figure A7: Photograph of the Brentwood wet pond, July 2004. This site was not sampled in 2005.



Figure A8: Photograph of the Park Place wet pond, March 2005.



Figure A9: Photograph of the Parkstone wet pond and swale, November 2003. This site was not sampled in 2005.



Figure A10: Photograph of the Silvern storm water treatment vault, May 2004. This site was not sampled in 2005.



Figure A11: Photograph of the South Campus storm water treatment facility, January 2005.

B Lake Whatcom Historic 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 D1. Table D1 includes abbreviations and detection limits for all analytes measured during the current year's monitoring program, as well as any other analyses included in the verified historic data set included on the CD with this report.

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, for example, current detection limits in Table 2, page 16). 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 historic detection limits in order 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 211–215, 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. Refer to Matthews, et al. (2005) for a discussion of historic trends in Lake Whatcom.

B.1 Monthly Hydrolab Profiles

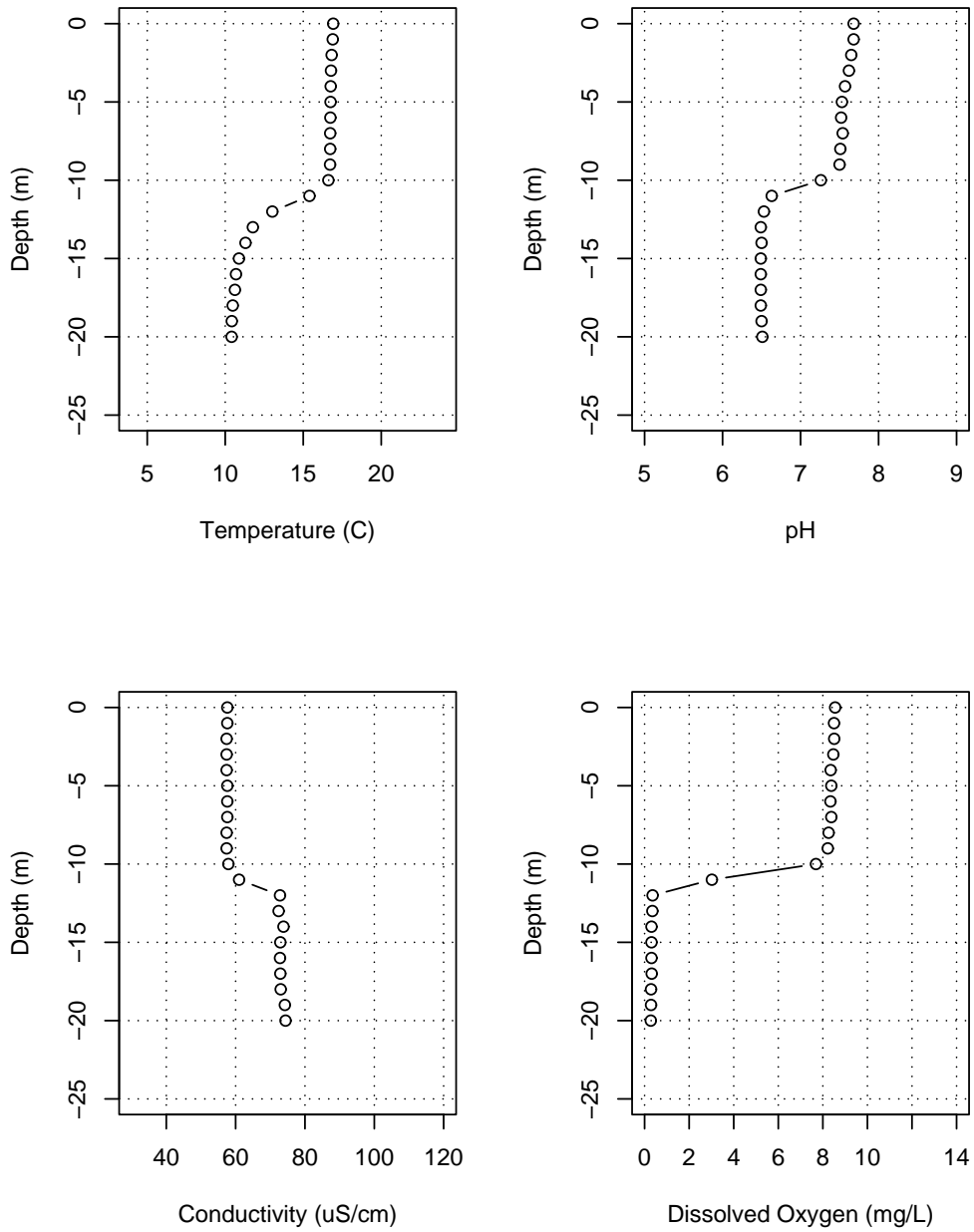


Figure B1: Lake Whatcom Hydrolab profile for Site 1, October 7, 2004.

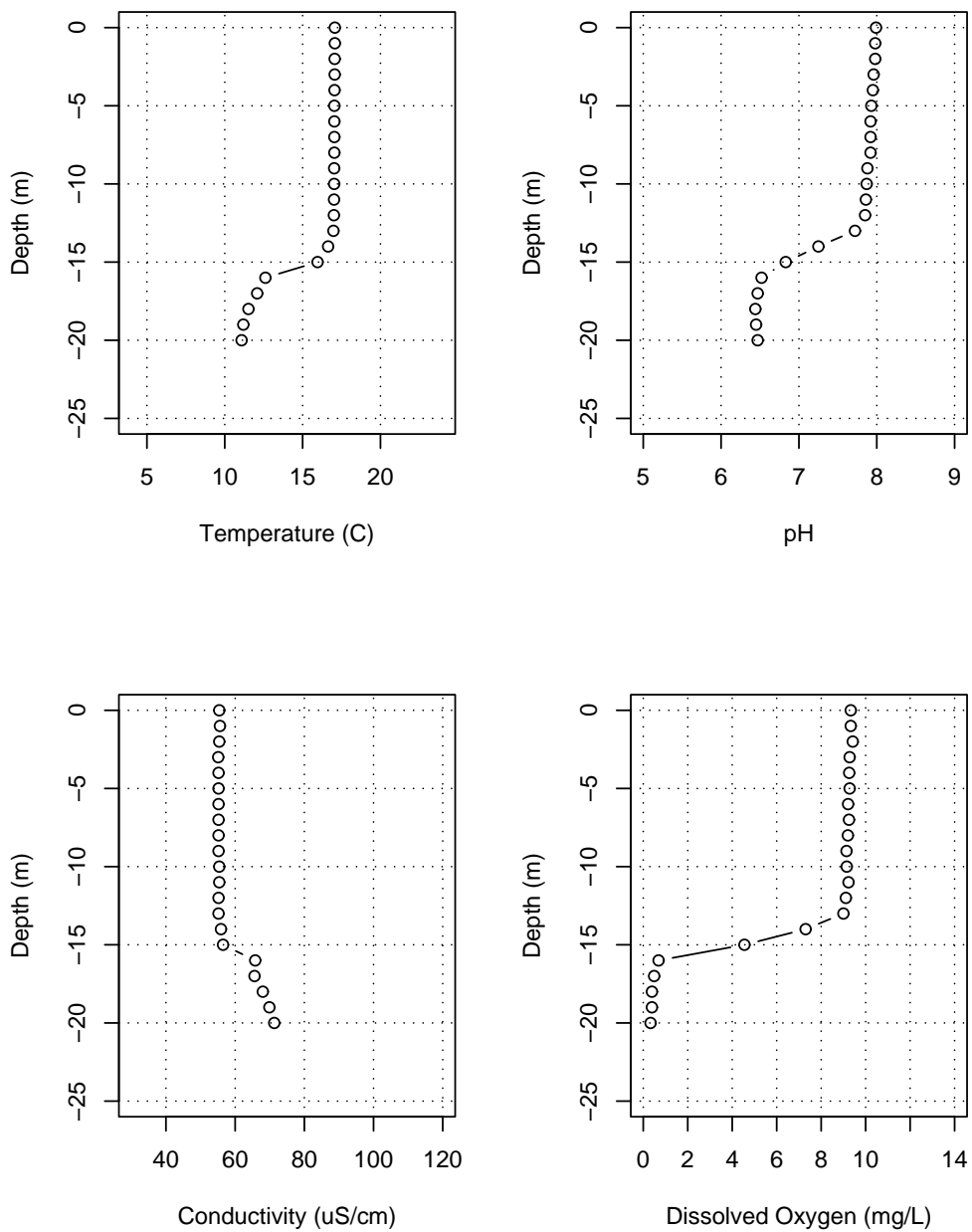


Figure B2: Lake Whatcom Hydrolab profile for Site 2, October 7, 2004.

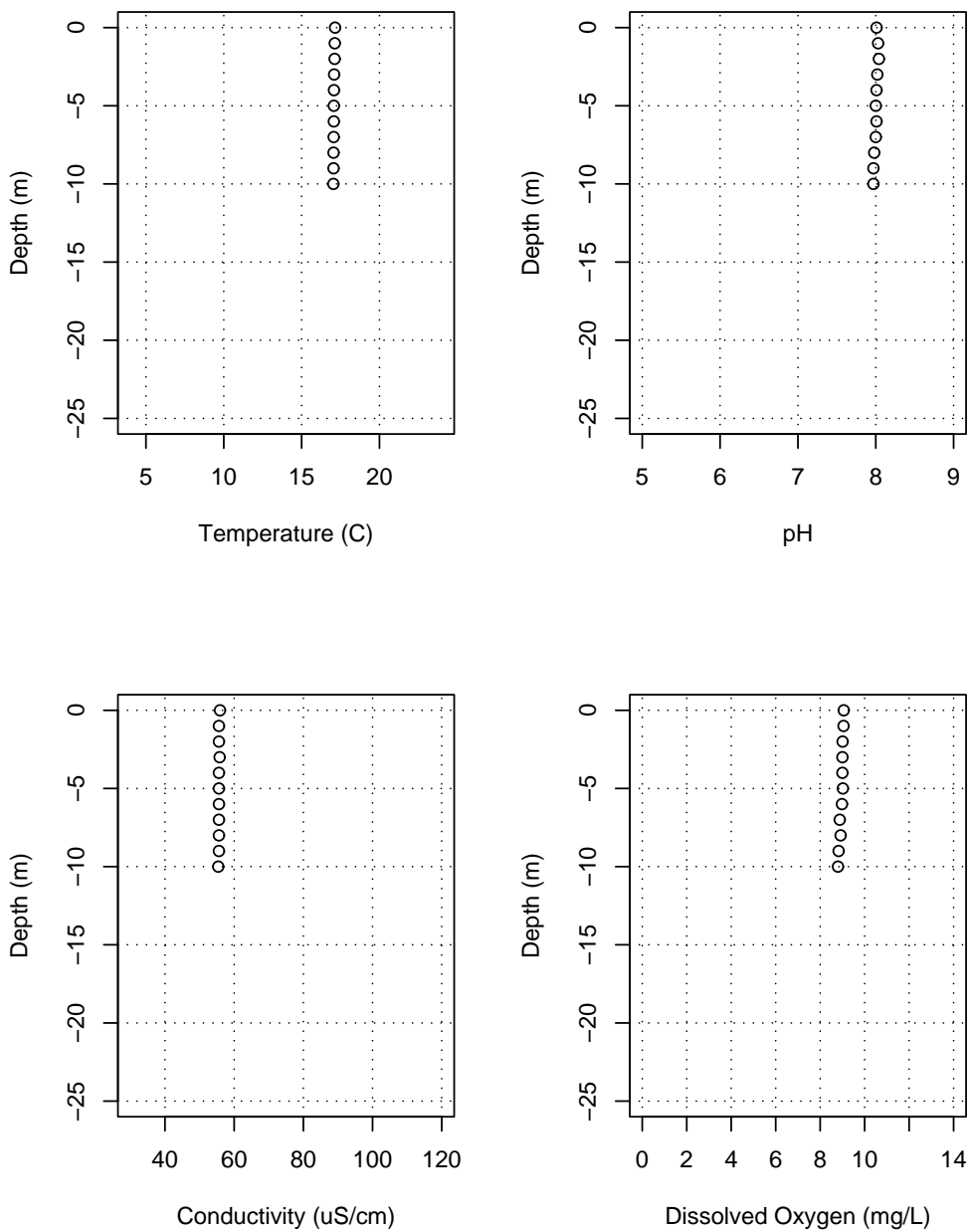


Figure B3: Lake Whatcom Hydrolab profile for the Intake, October 7, 2004.

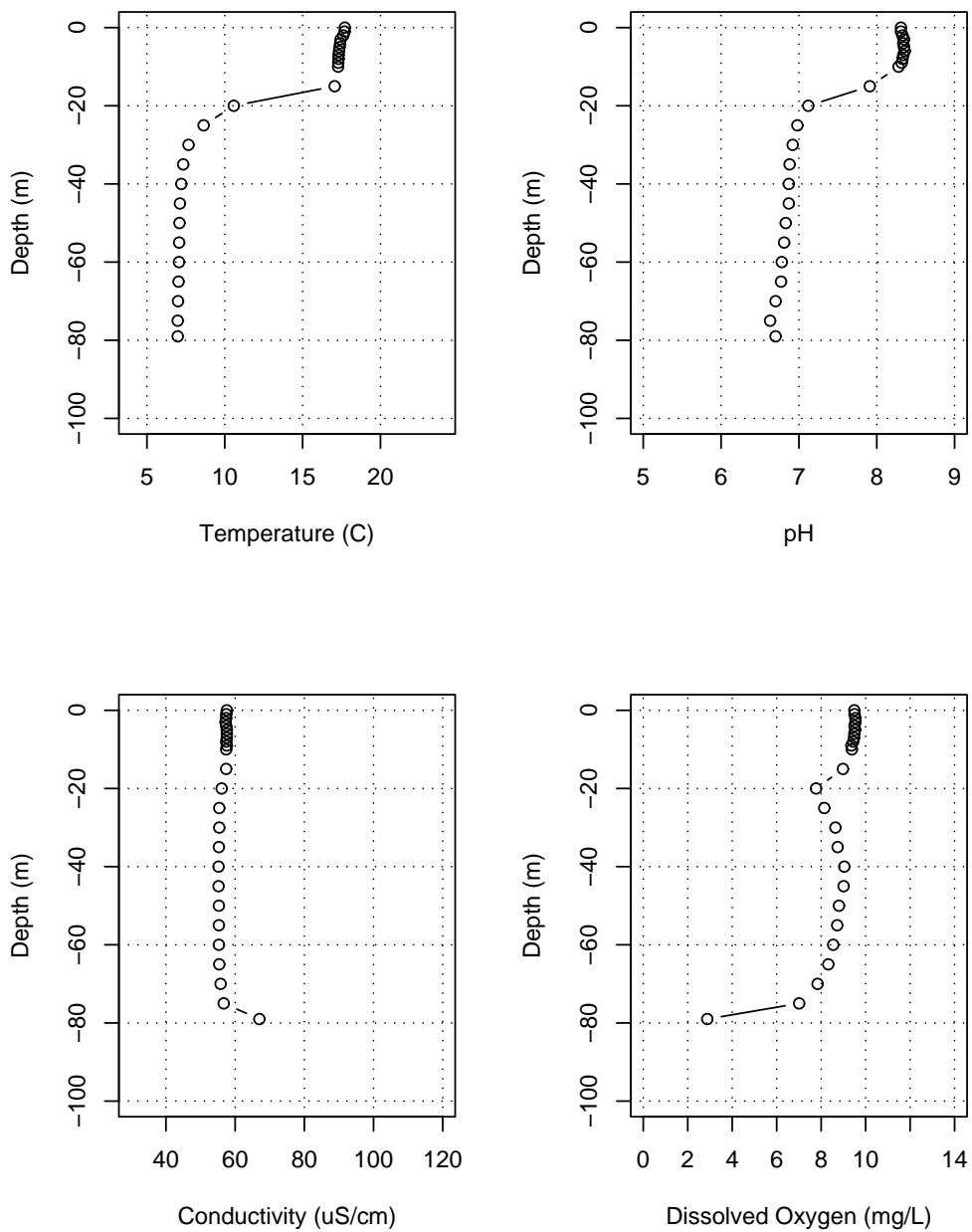


Figure B4: Lake Whatcom Hydrolab profile for Site 3, October 5, 2004.

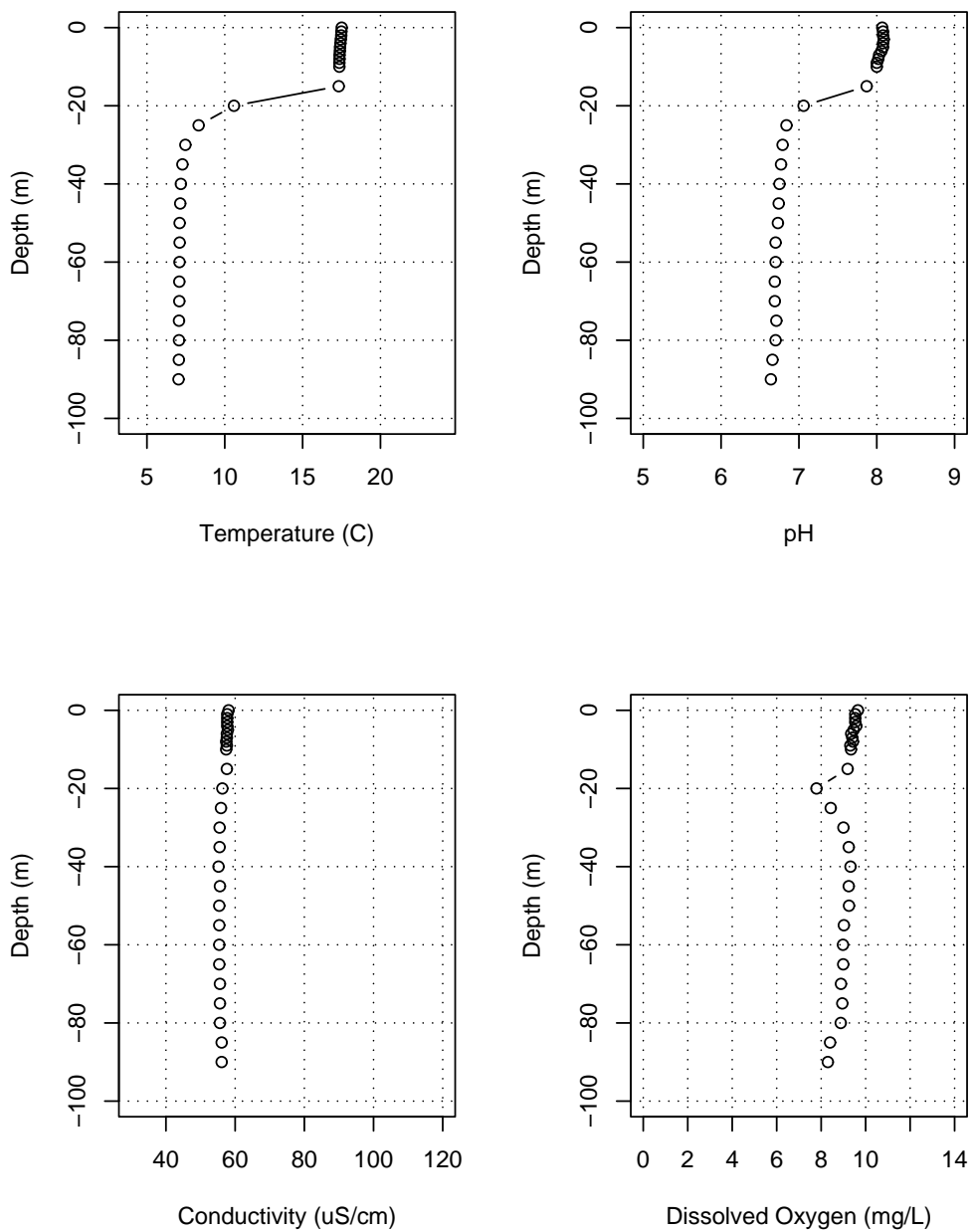


Figure B5: Lake Whatcom Hydrolab profile for Site 4, October 5, 2004.

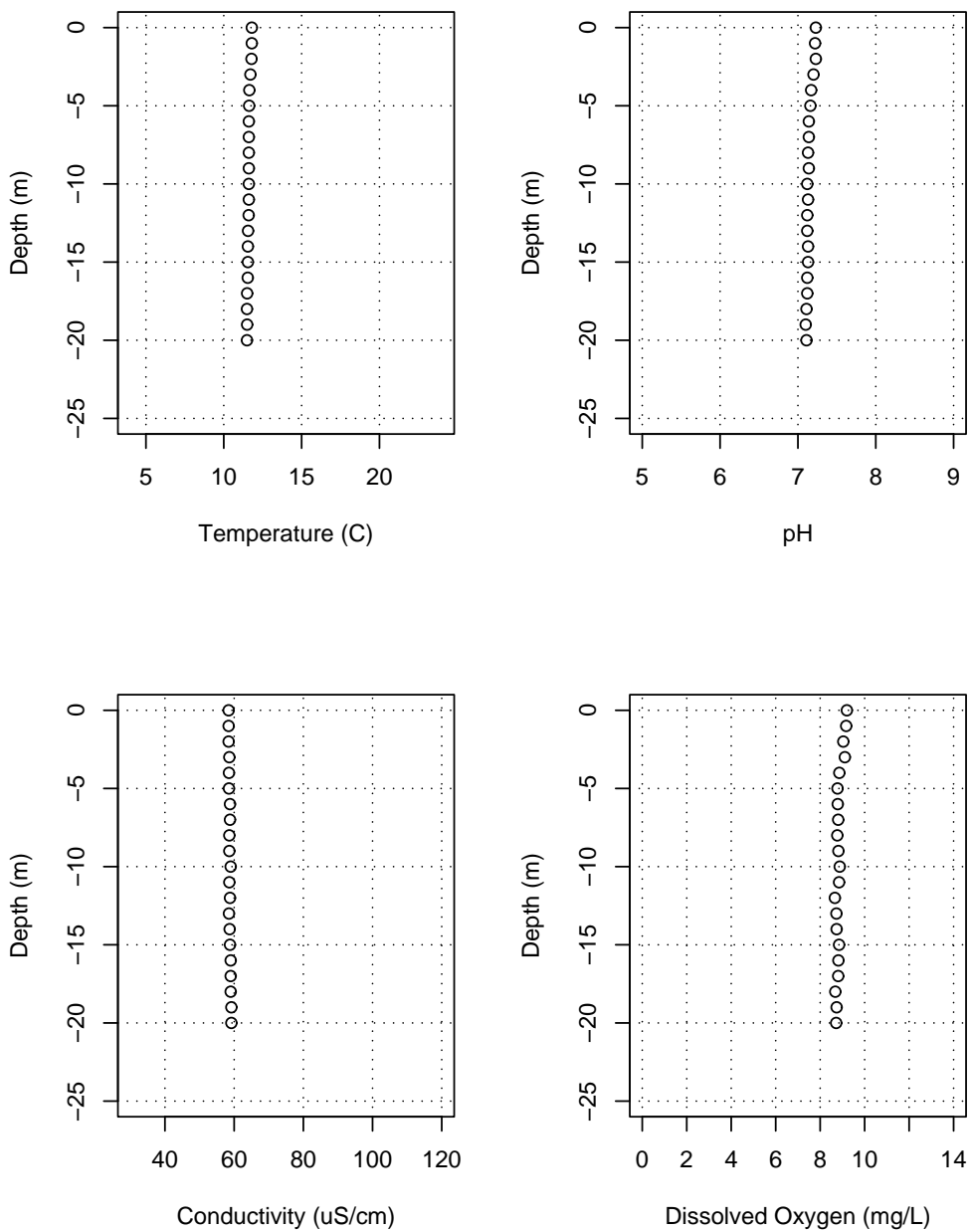


Figure B6: Lake Whatcom Hydrolab profile for Site 1, November 4, 2004.

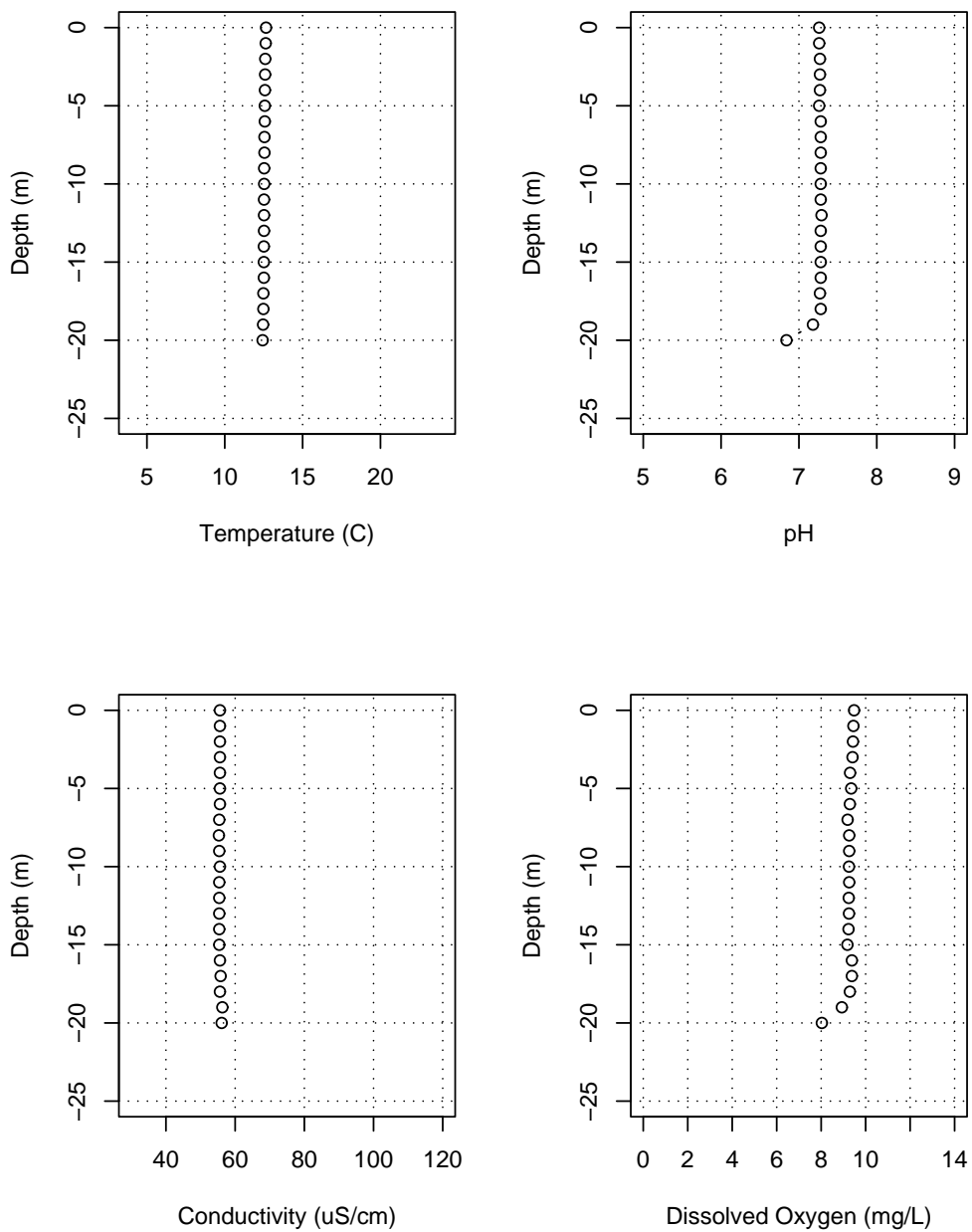


Figure B7: Lake Whatcom Hydrolab profile for Site 2, November 4, 2004.

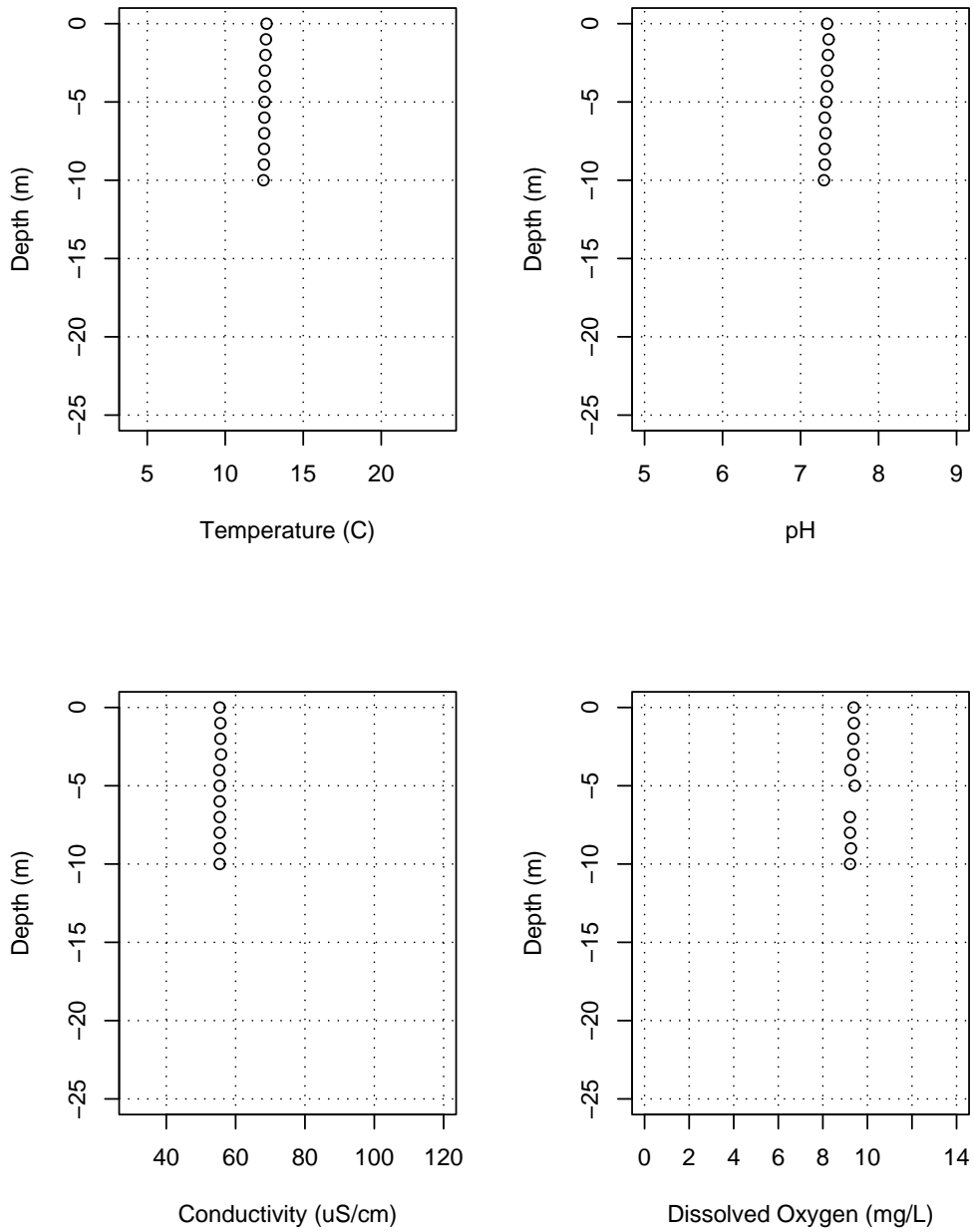


Figure B8: Lake Whatcom Hydrolab profile for the Intake, November 4, 2004.

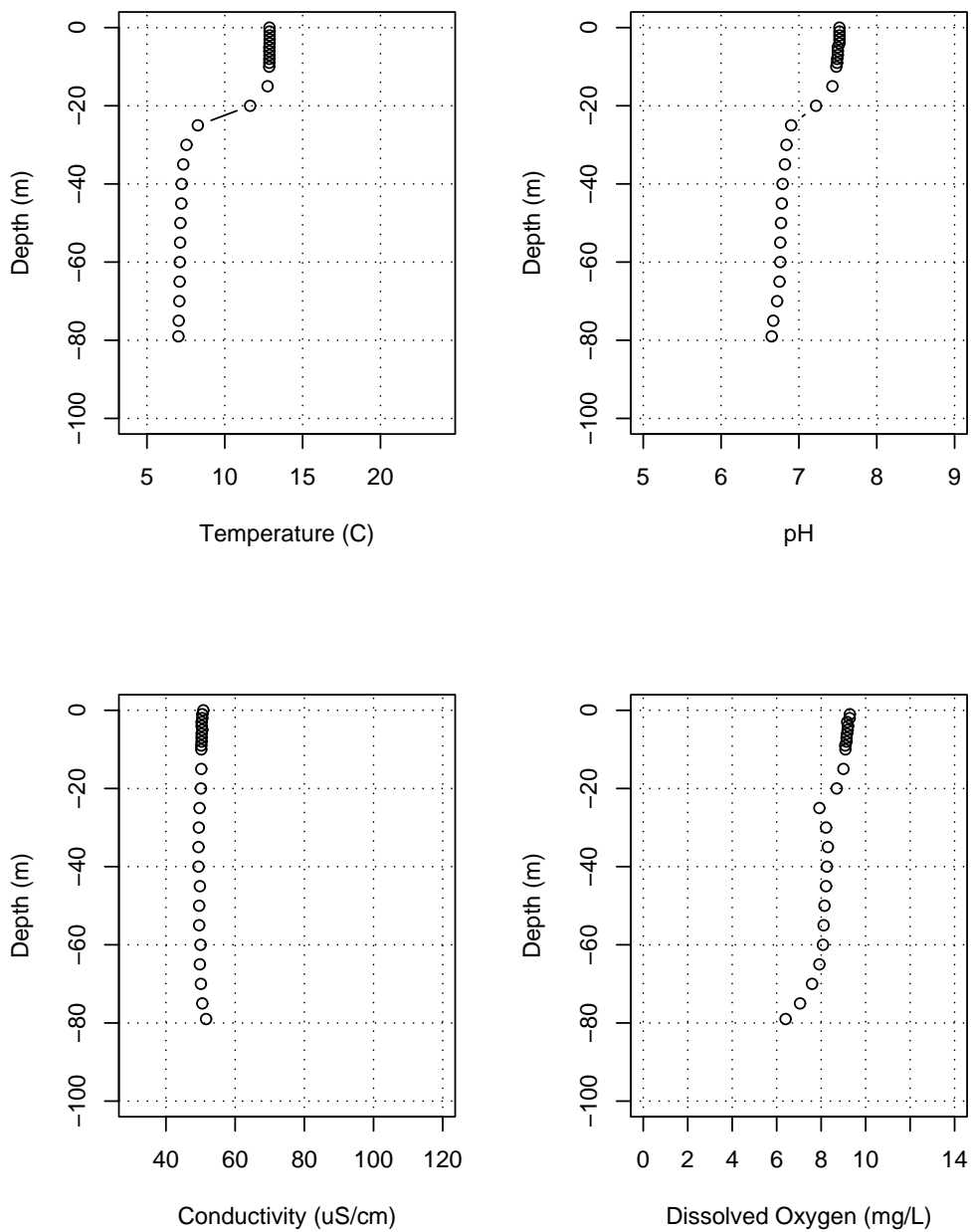


Figure B9: Lake Whatcom Hydrolab profile for Site 3, November 3, 2004.

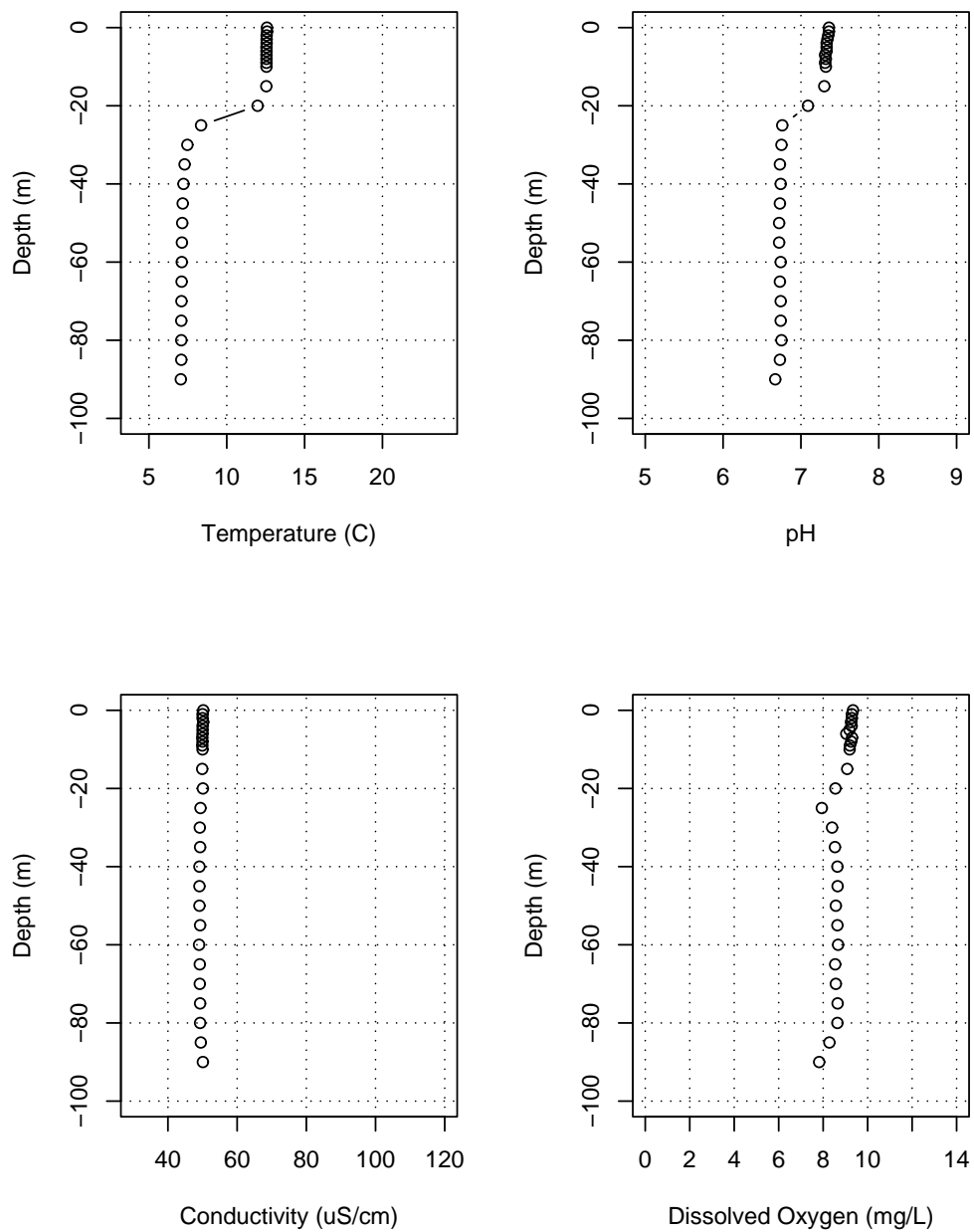


Figure B10: Lake Whatcom Hydrolab profile for Site 4, November 3, 2004.

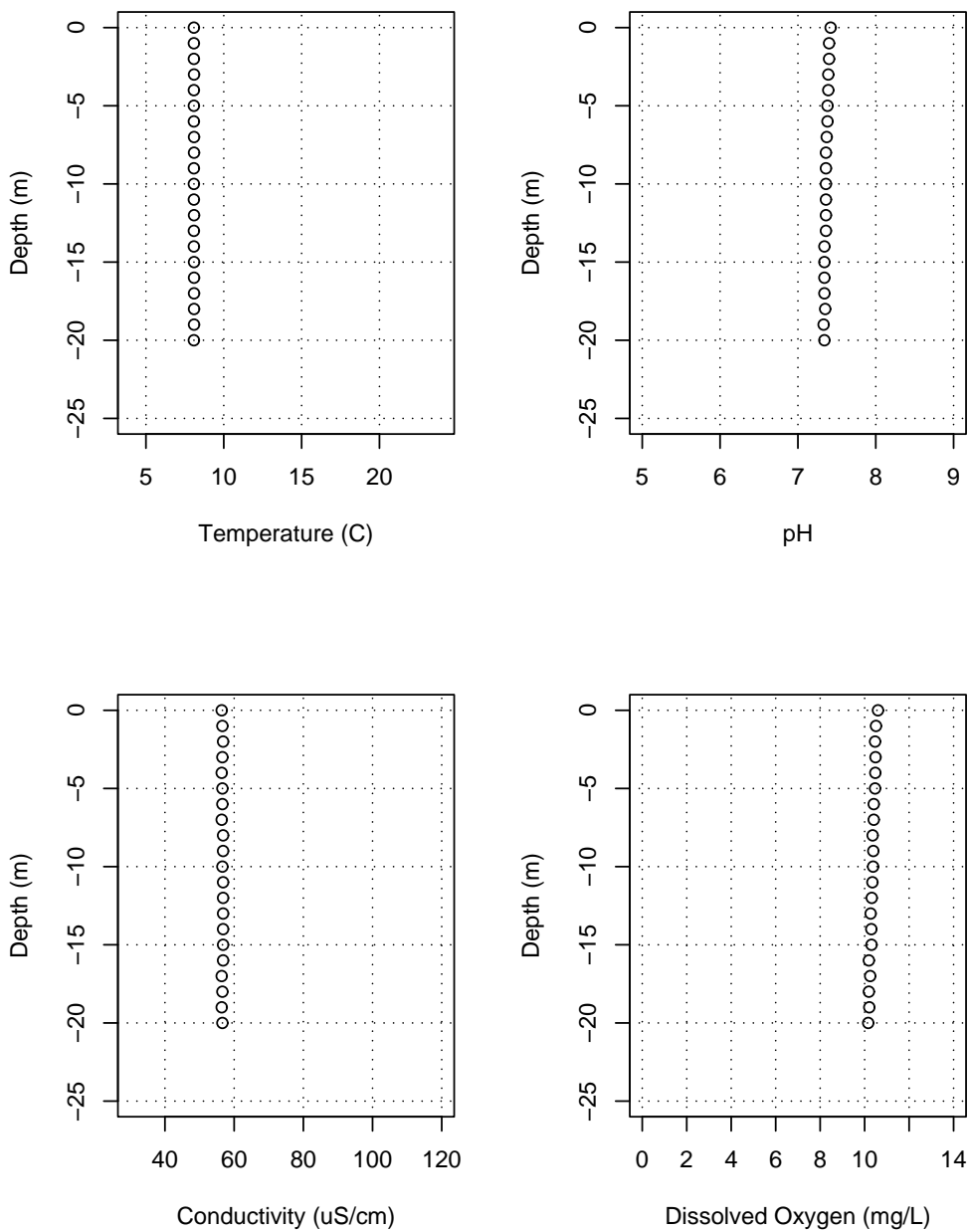


Figure B11: Lake Whatcom Hydrolab profile for Site 1, December 9, 2004.

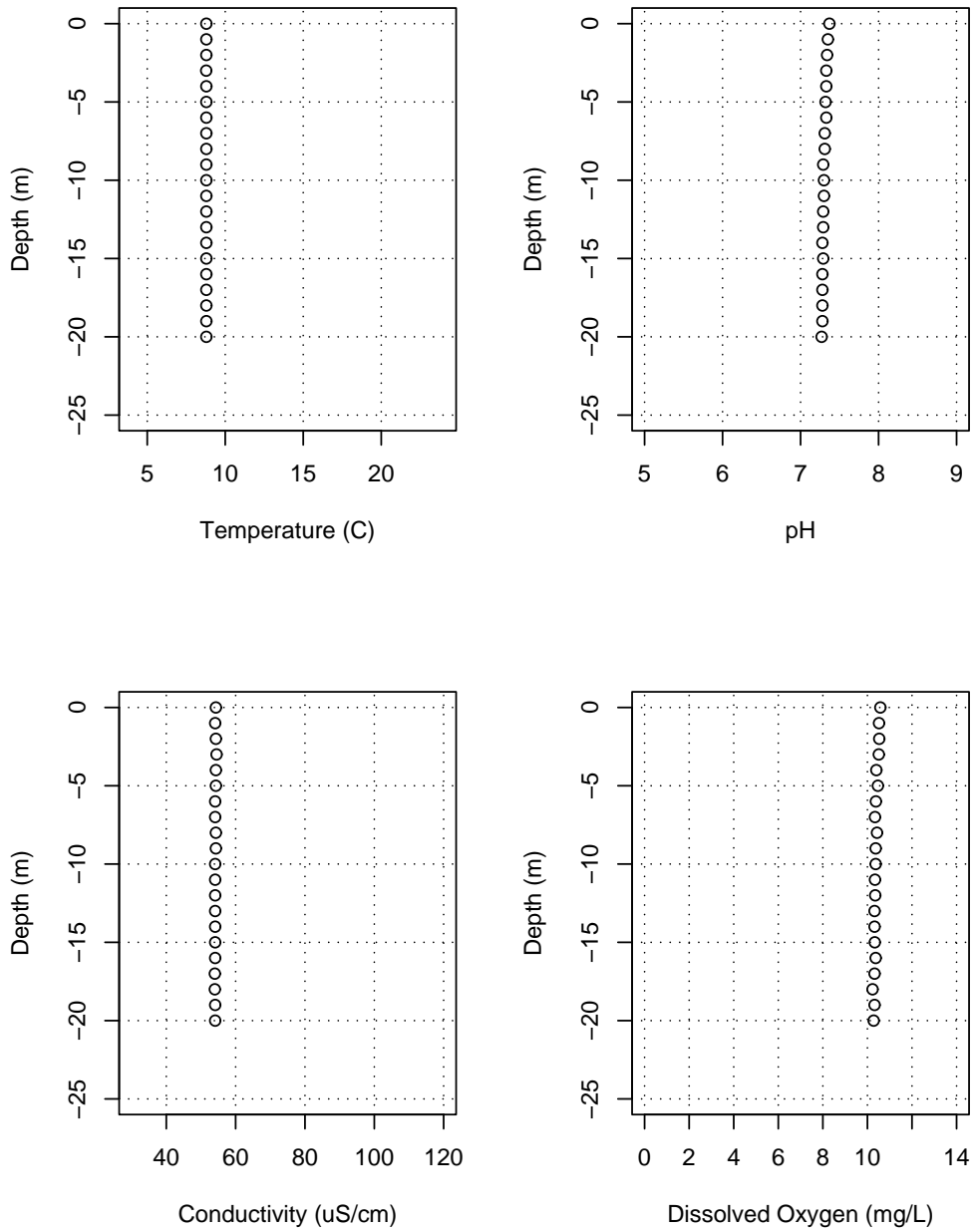


Figure B12: Lake Whatcom Hydrolab profile for Site 2, December 9, 2004.

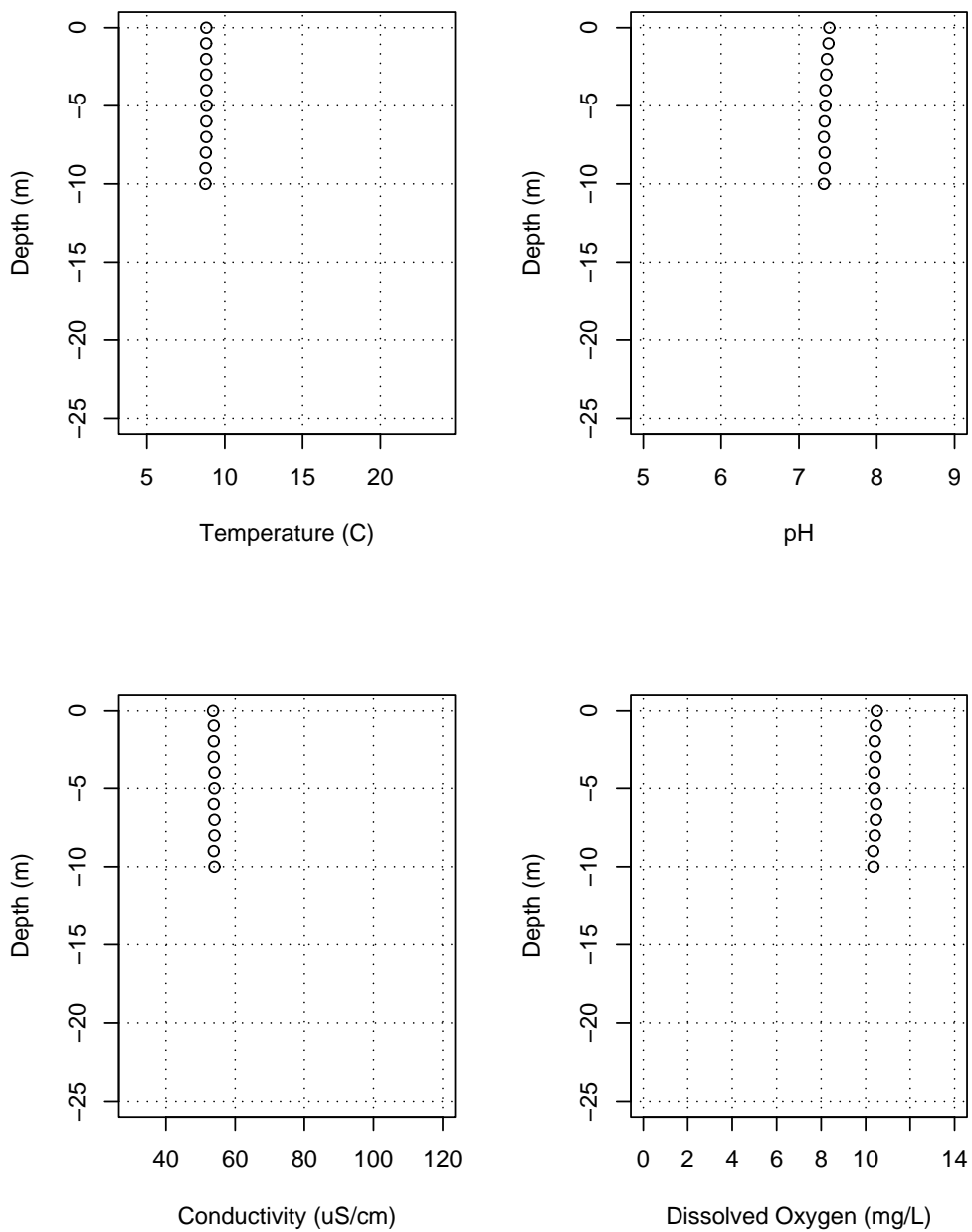


Figure B13: Lake Whatcom Hydrolab profile for the Intake, December 9, 2004.

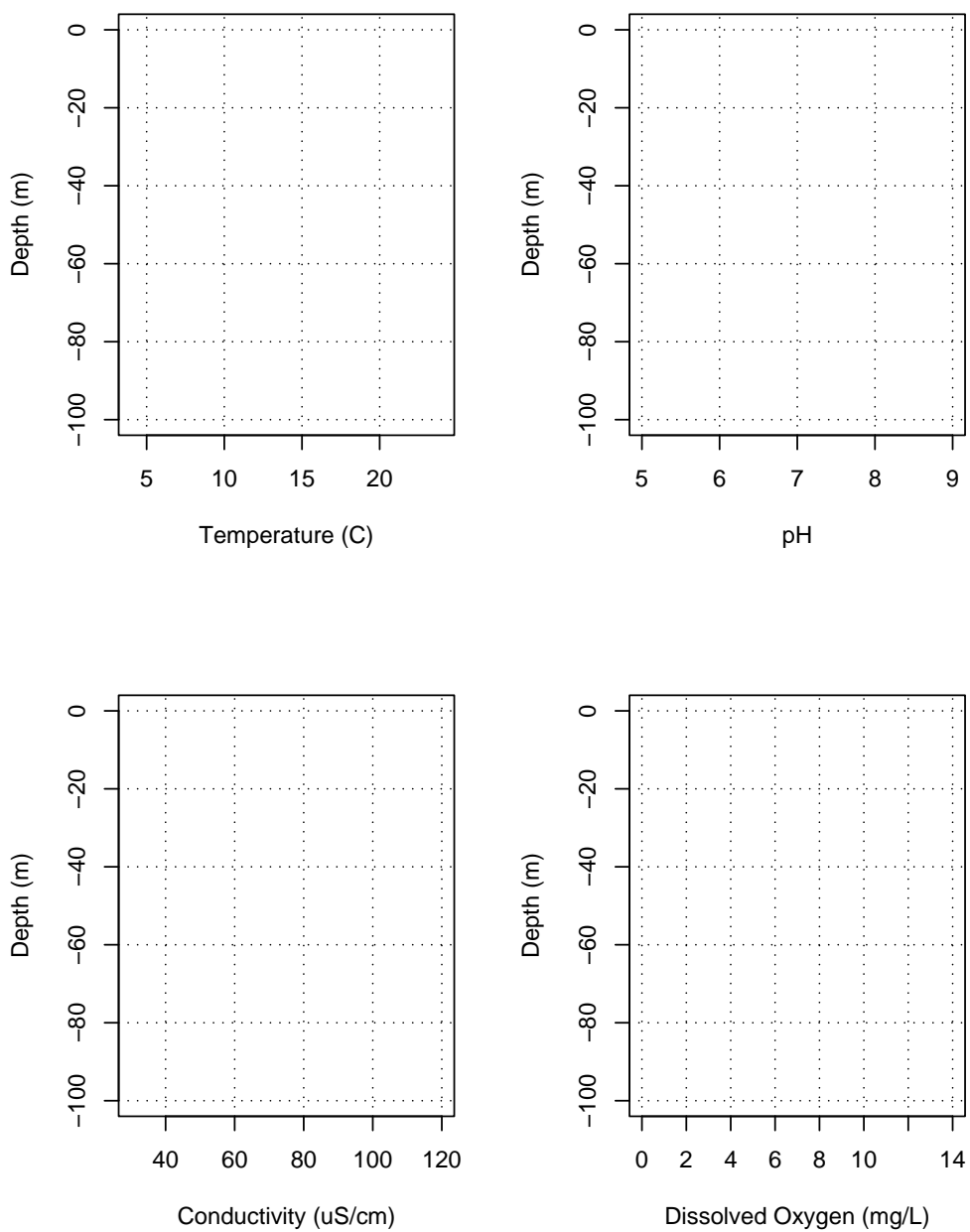


Figure B14: Lake Whatcom Hydrolab profile for Site 3, December 7, 2004. All data missing due to equipment malfunction.

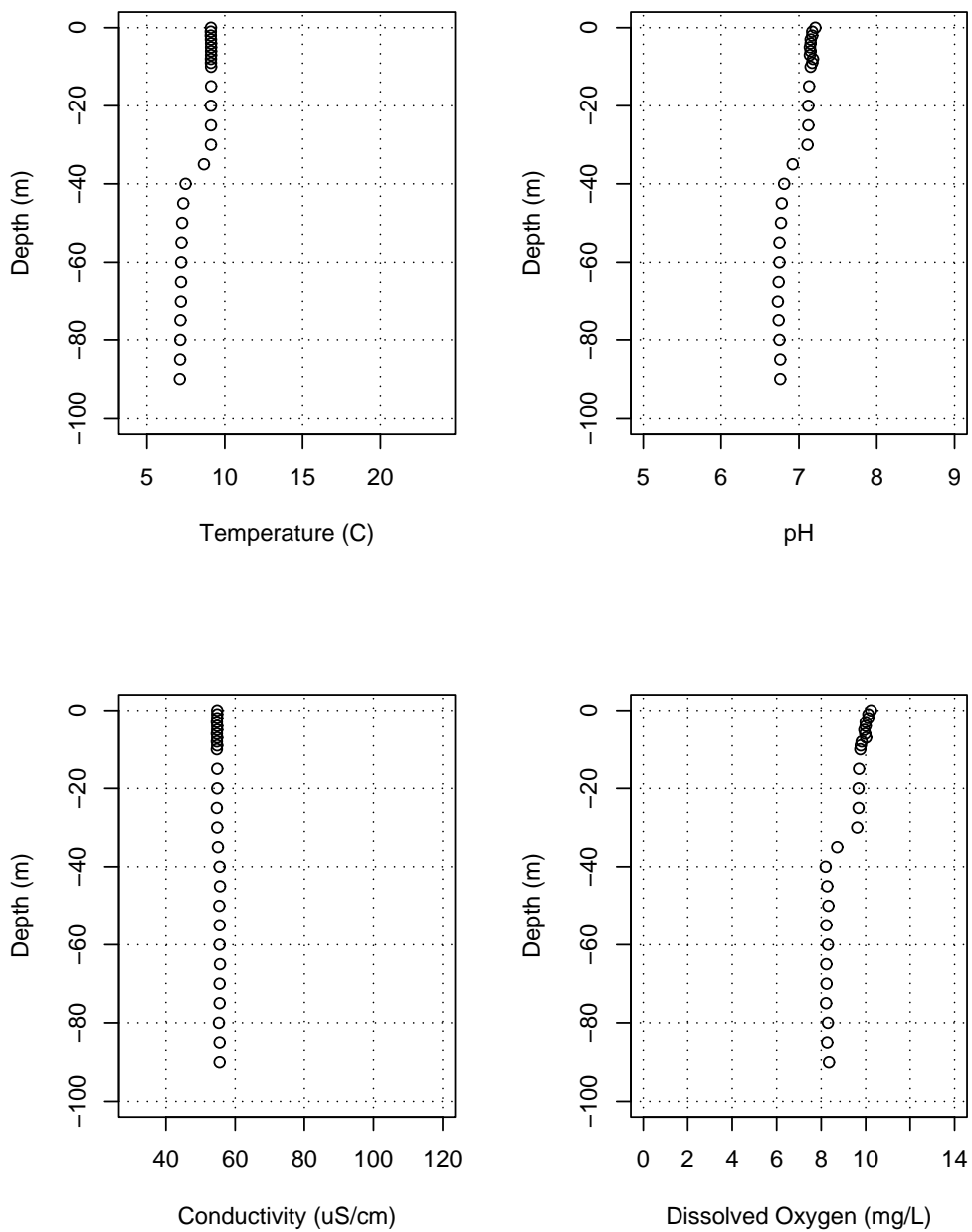


Figure B15: Lake Whatcom Hydrolab profile for Site 4, December 7, 2004.

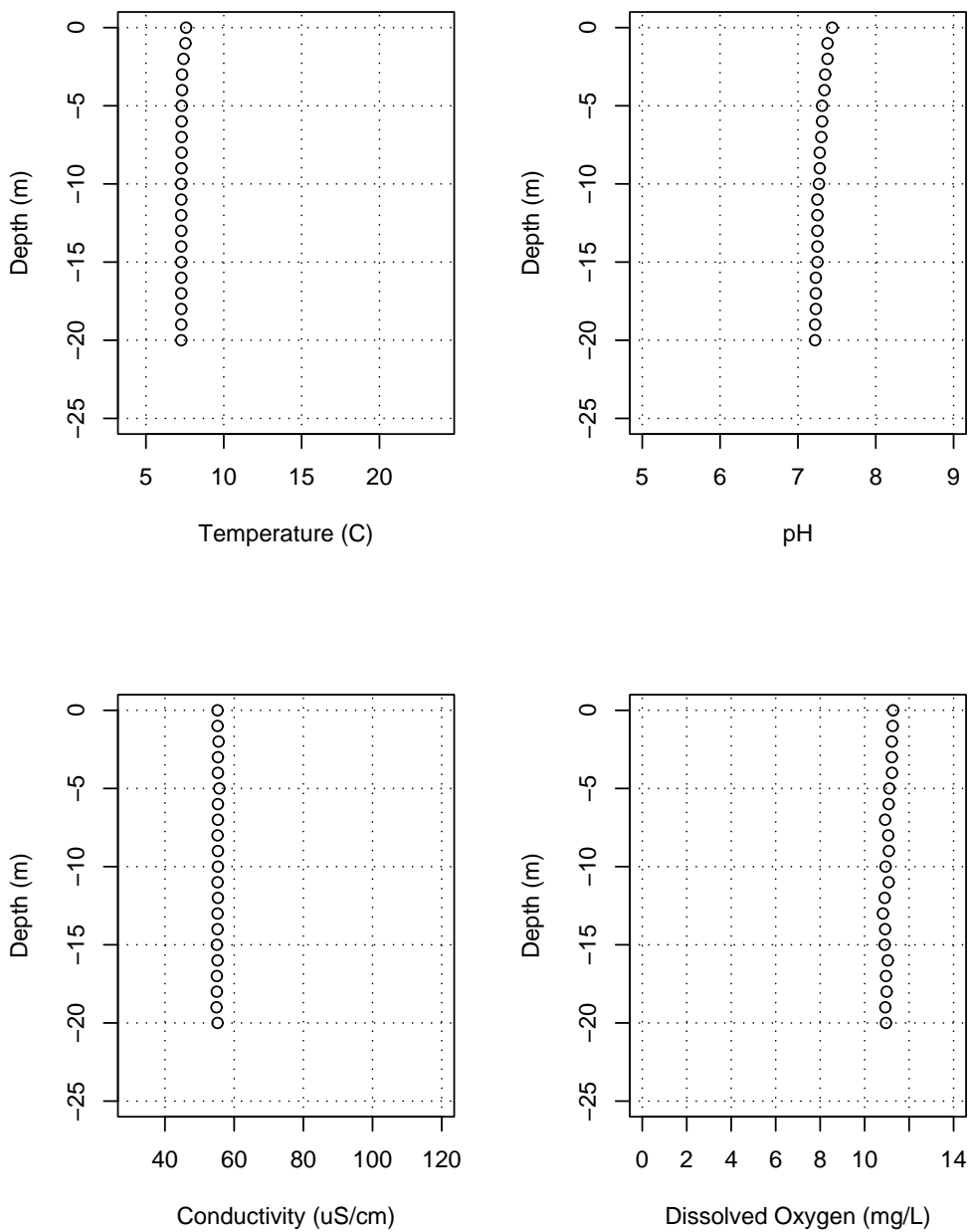


Figure B16: Lake Whatcom Hydrolab profile for Site 1, February 3, 2005.

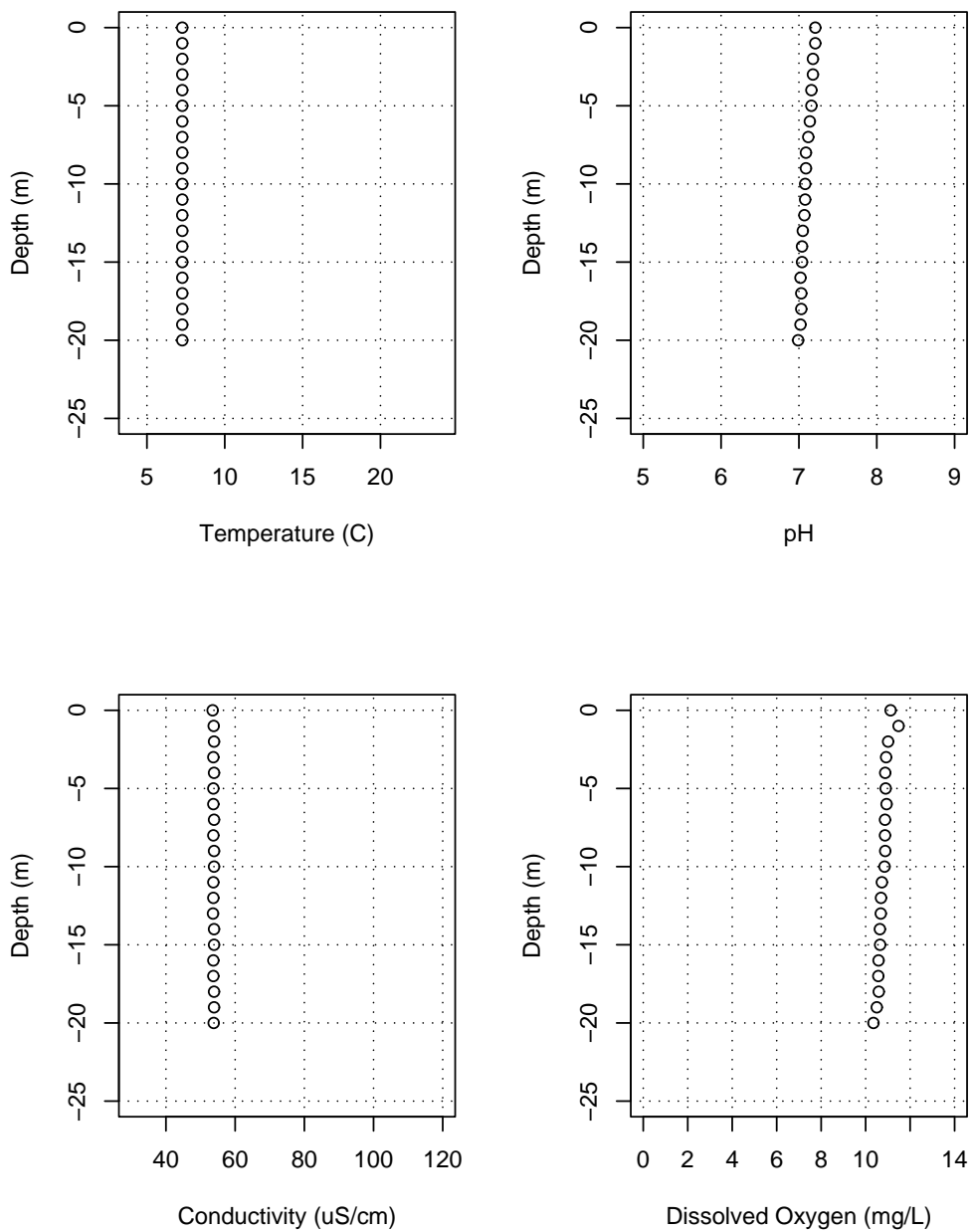


Figure B17: Lake Whatcom Hydrolab profile for Site 2, February 3, 2005.

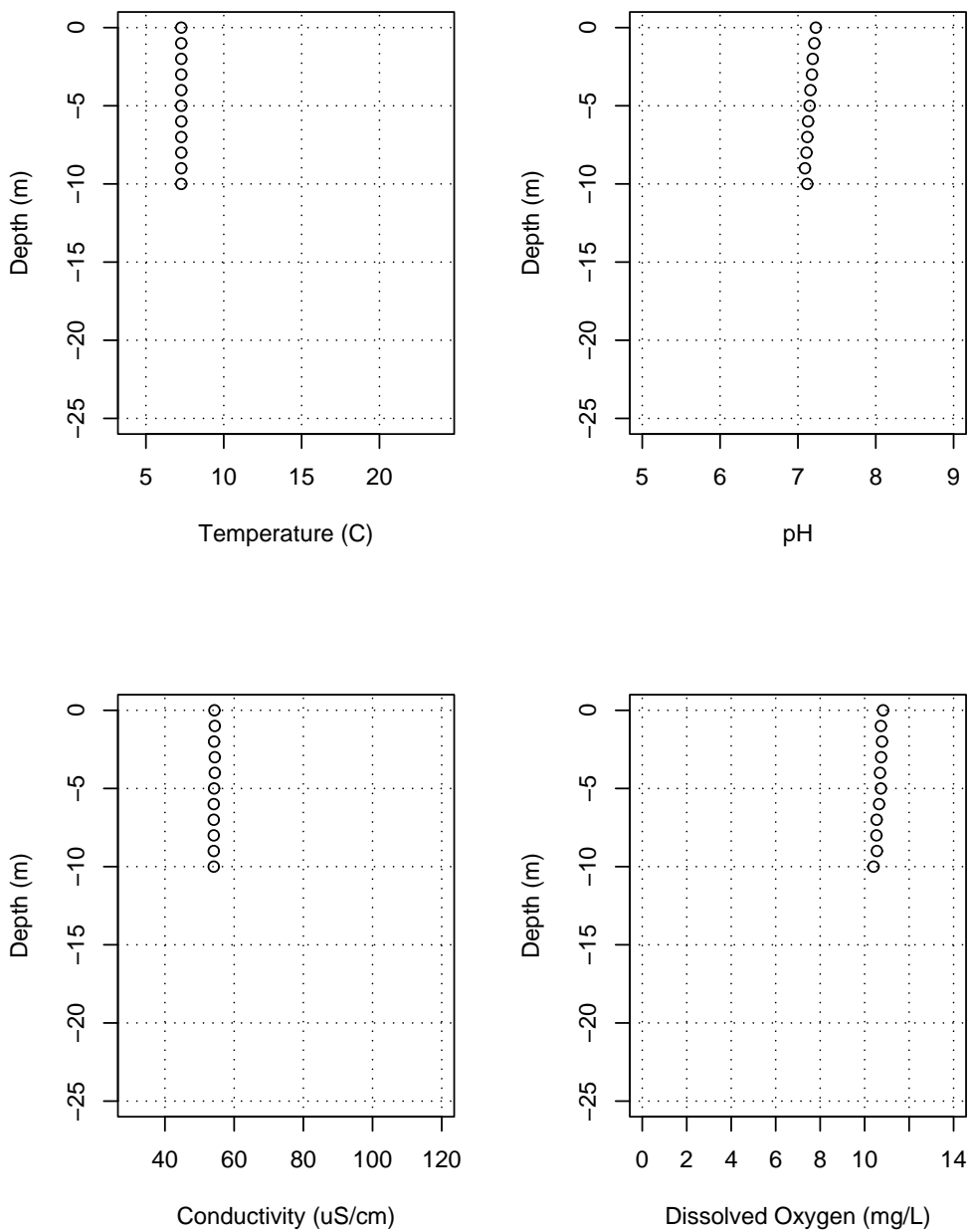


Figure B18: Lake Whatcom Hydrolab profile for the Intake, February 3, 2005.

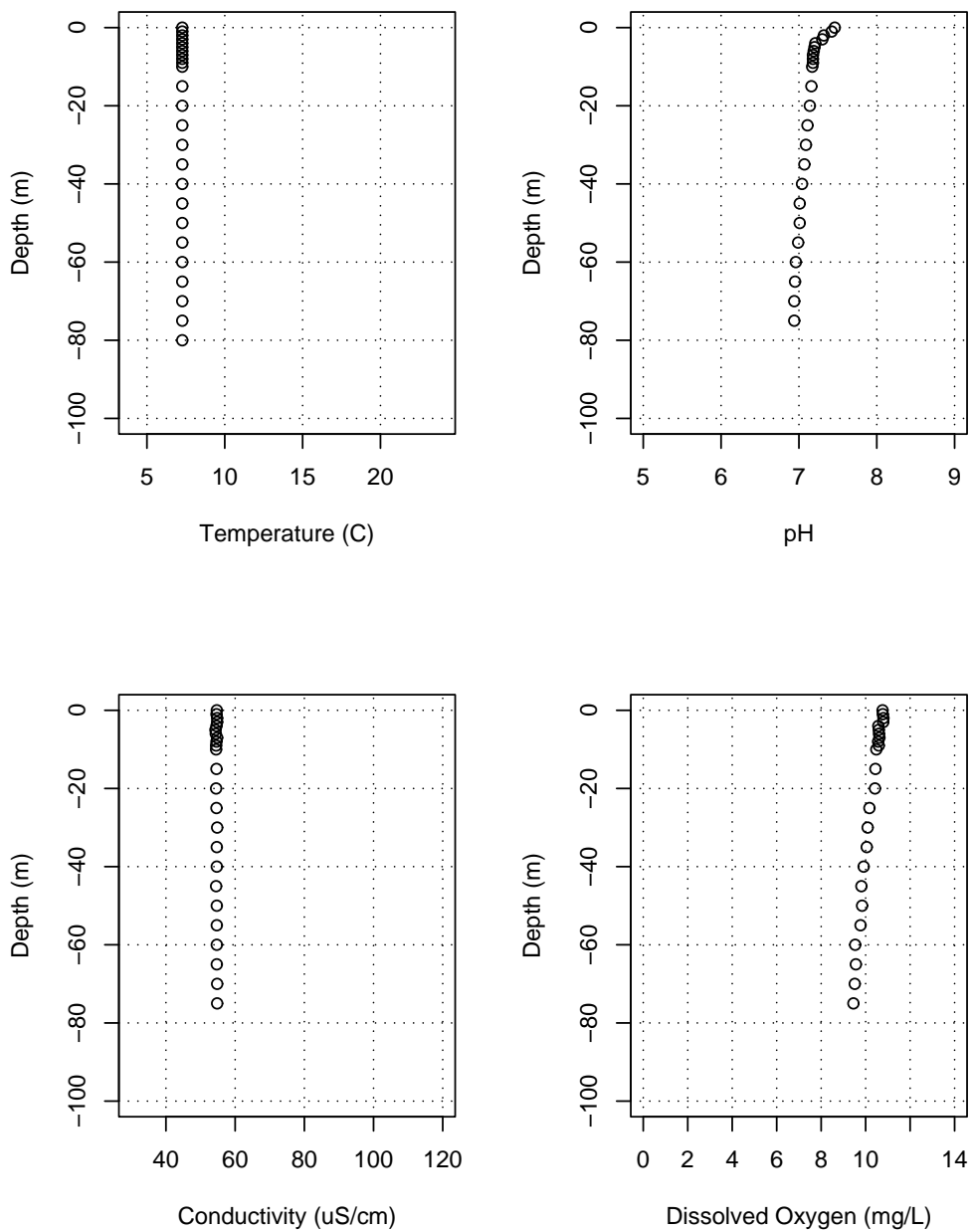


Figure B19: Lake Whatcom Hydrolab profile for Site 3, February 1, 2005.

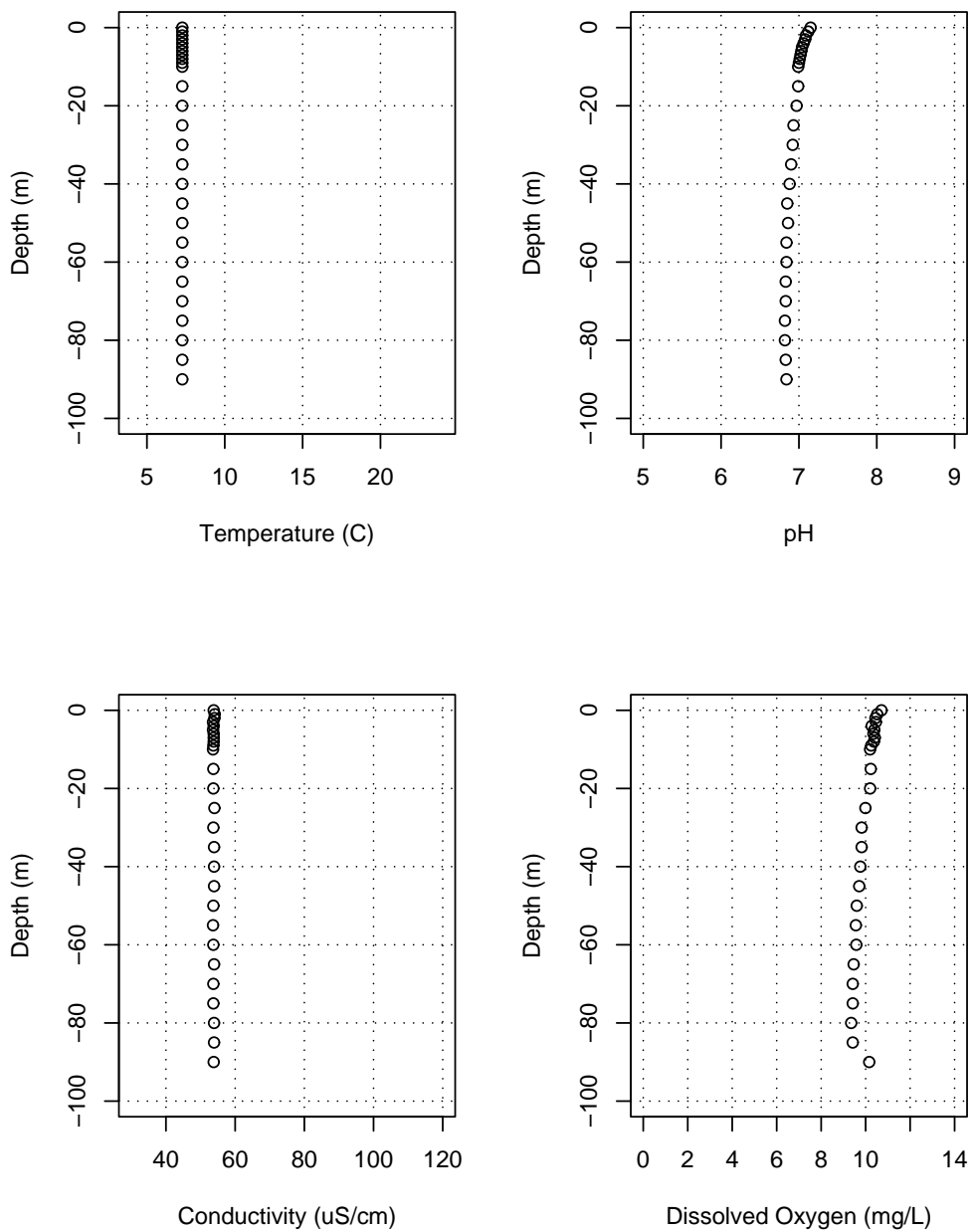


Figure B20: Lake Whatcom Hydrolab profile for Site 4, February 1, 2005.

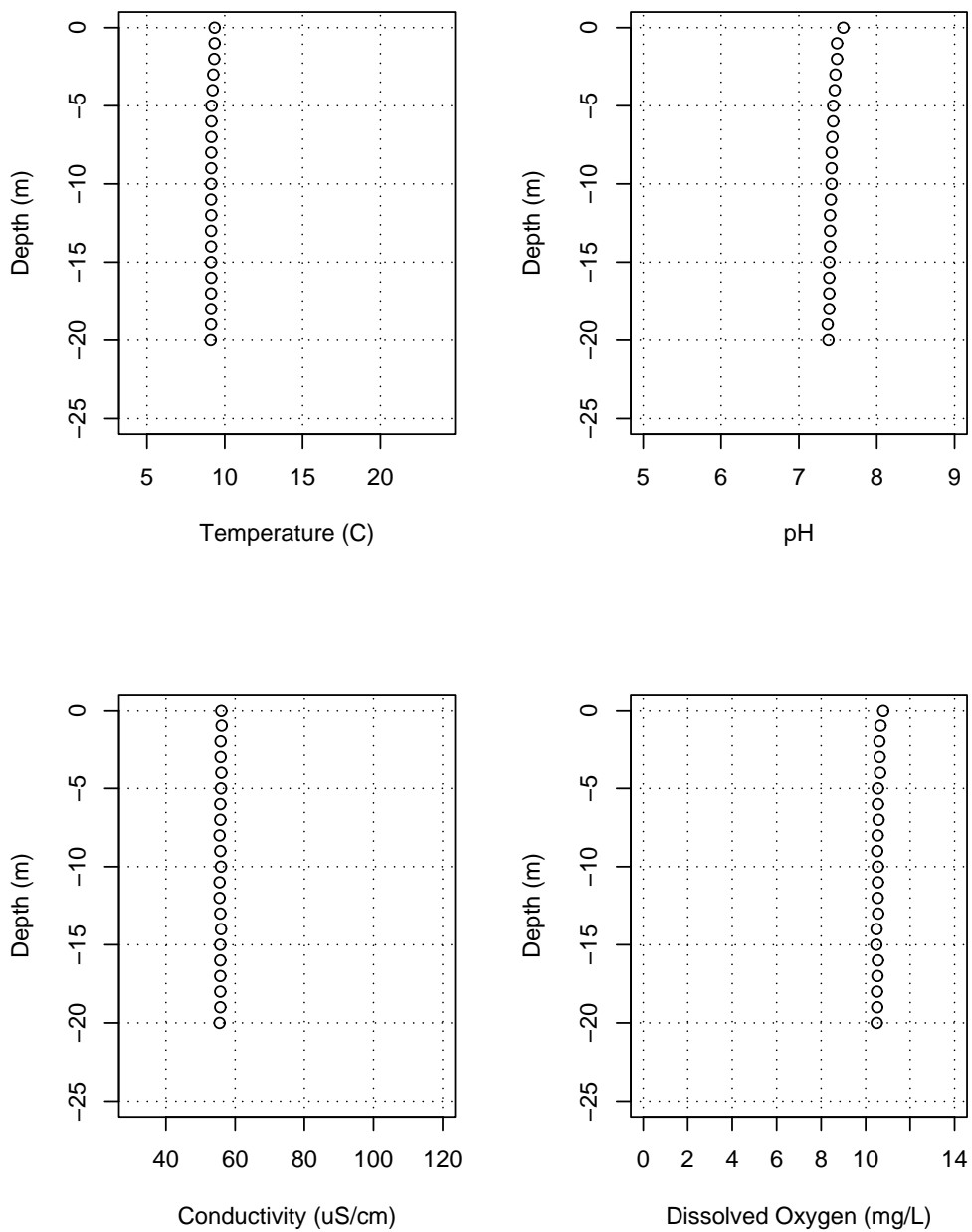


Figure B21: Lake Whatcom Hydrolab profile for Site 1, April 13, 2005.

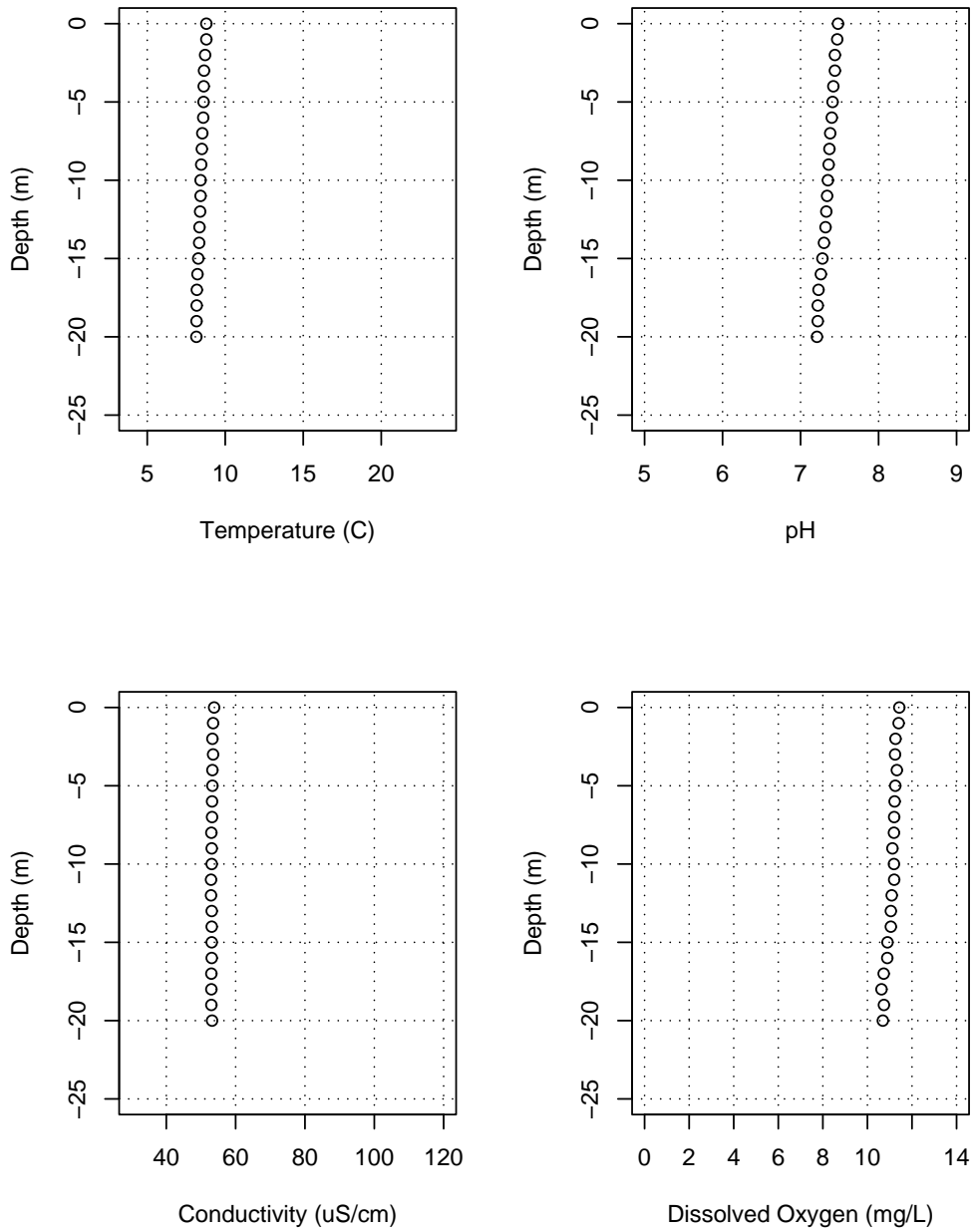


Figure B22: Lake Whatcom Hydrolab profile for Site 2, April 13, 2005.

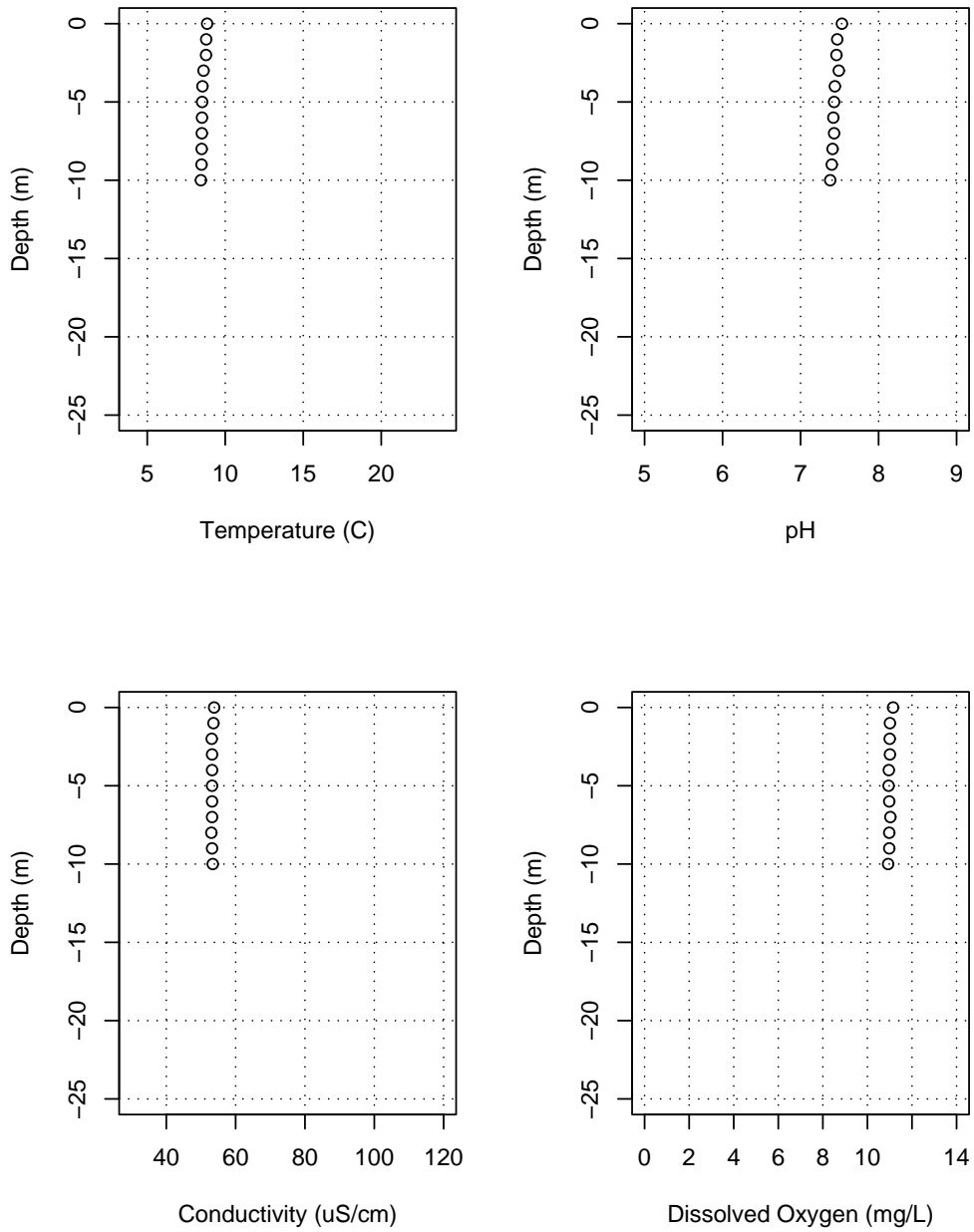


Figure B23: Lake Whatcom Hydrolab profile for the Intake, April 13, 2005.

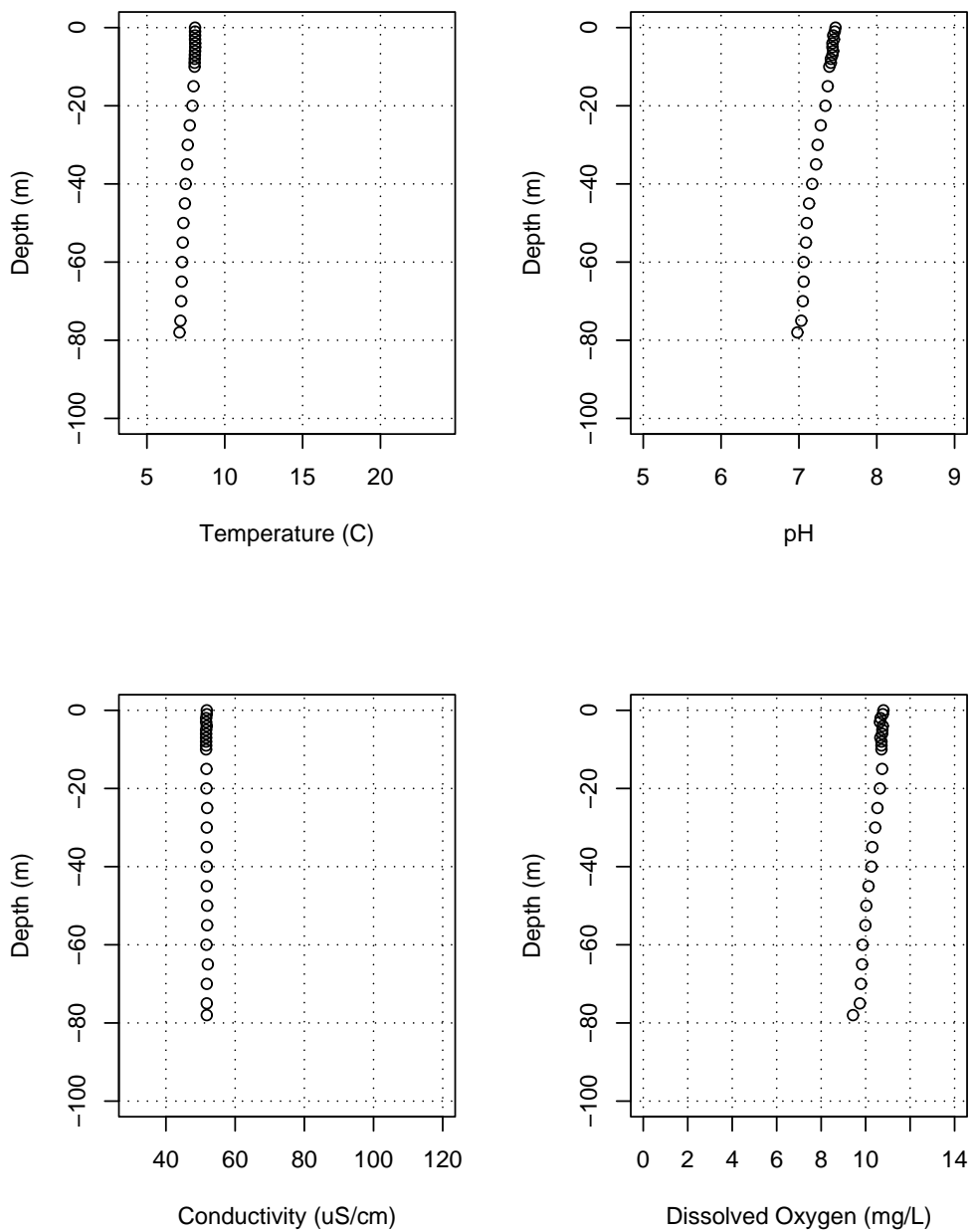


Figure B24: Lake Whatcom Hydrolab profile for Site 3, April 11, 2005.

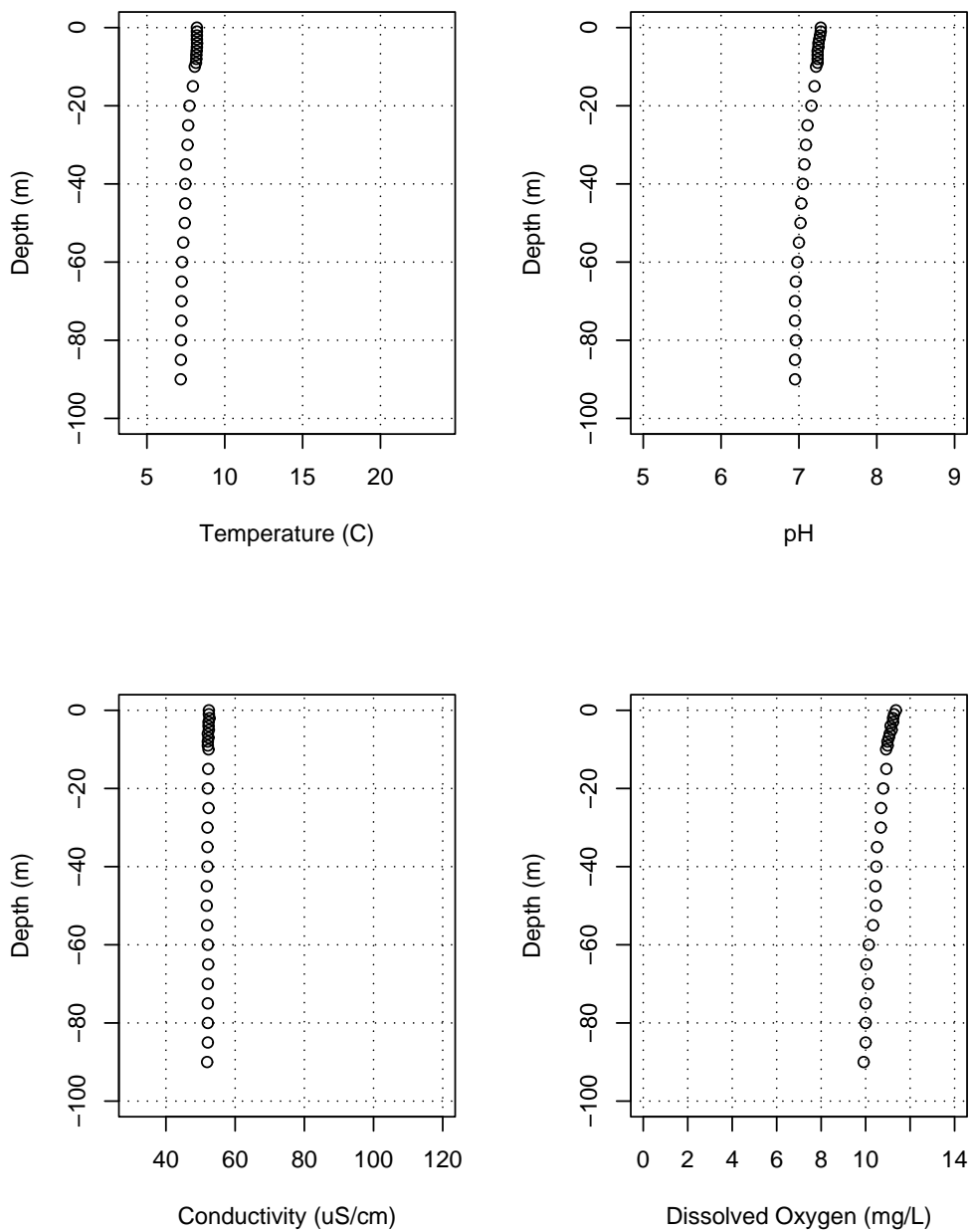


Figure B25: Lake Whatcom Hydrolab profile for Site 4, April 11, 2005.

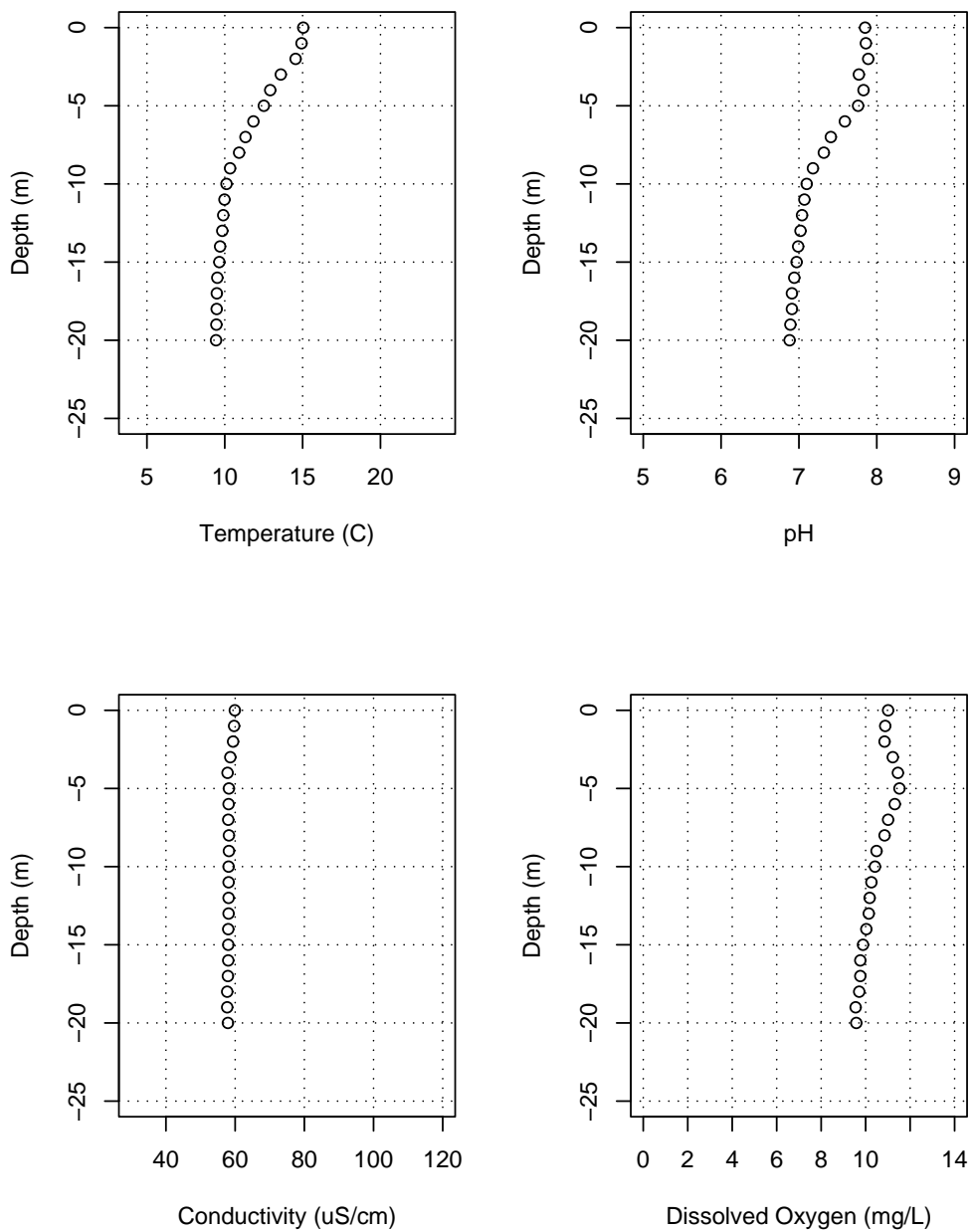


Figure B26: Lake Whatcom Hydrolab profile for Site 1, May 5, 2005.

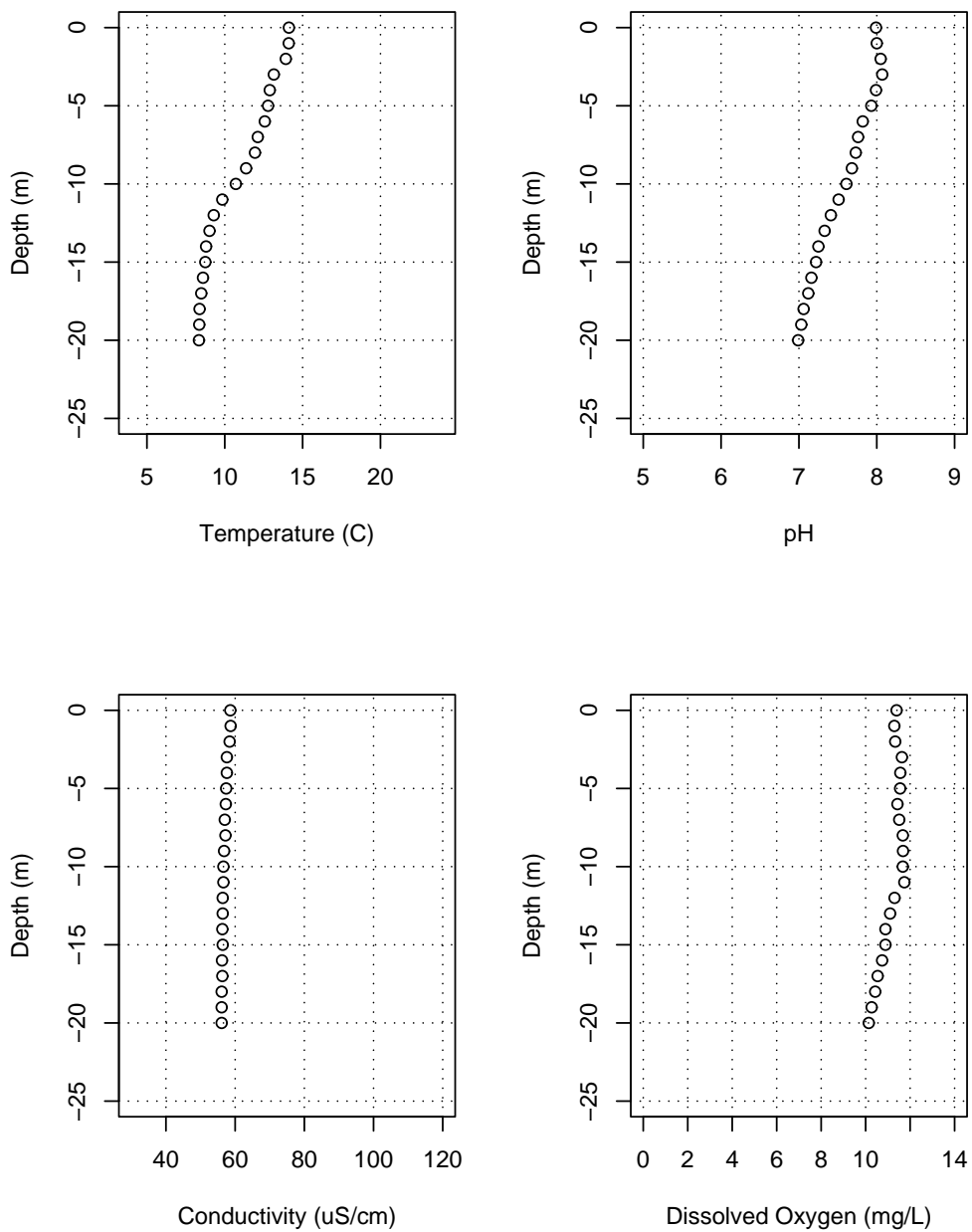


Figure B27: Lake Whatcom Hydrolab profile for Site 2, May 5, 2005.

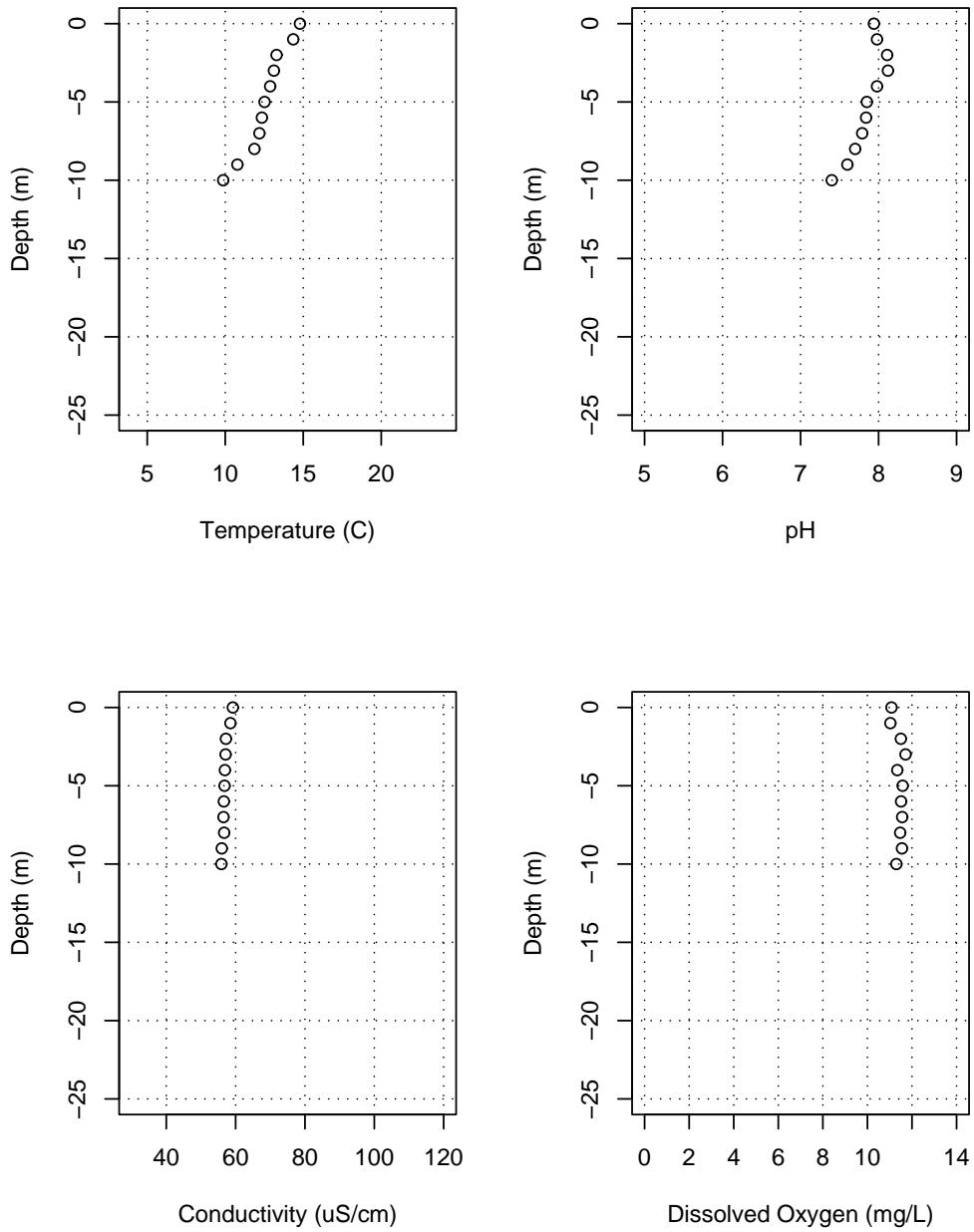


Figure B28: Lake Whatcom Hydrolab profile for the Intake, May 5, 2005.

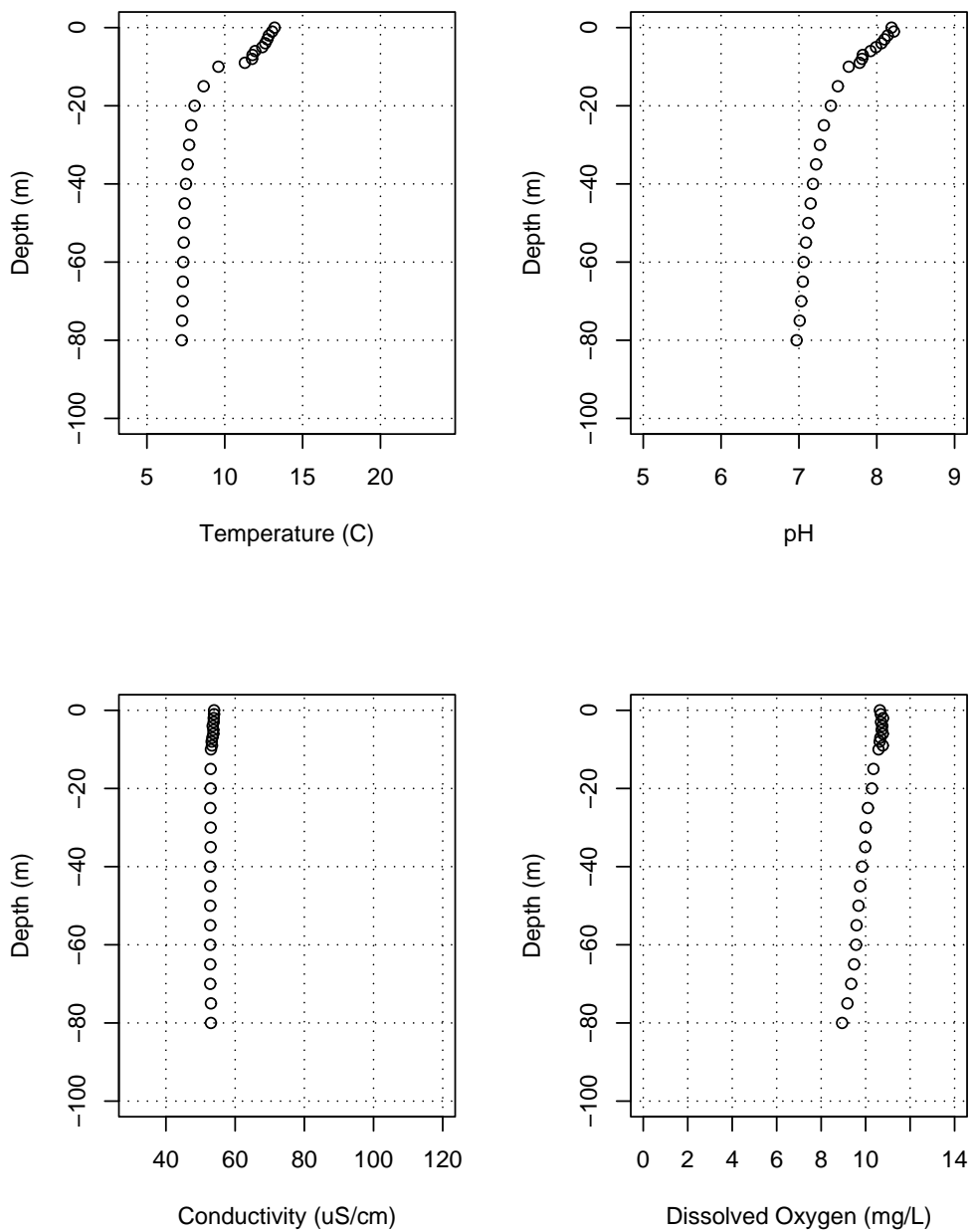


Figure B29: Lake Whatcom Hydrolab profile for Site 3, May 4, 2005.

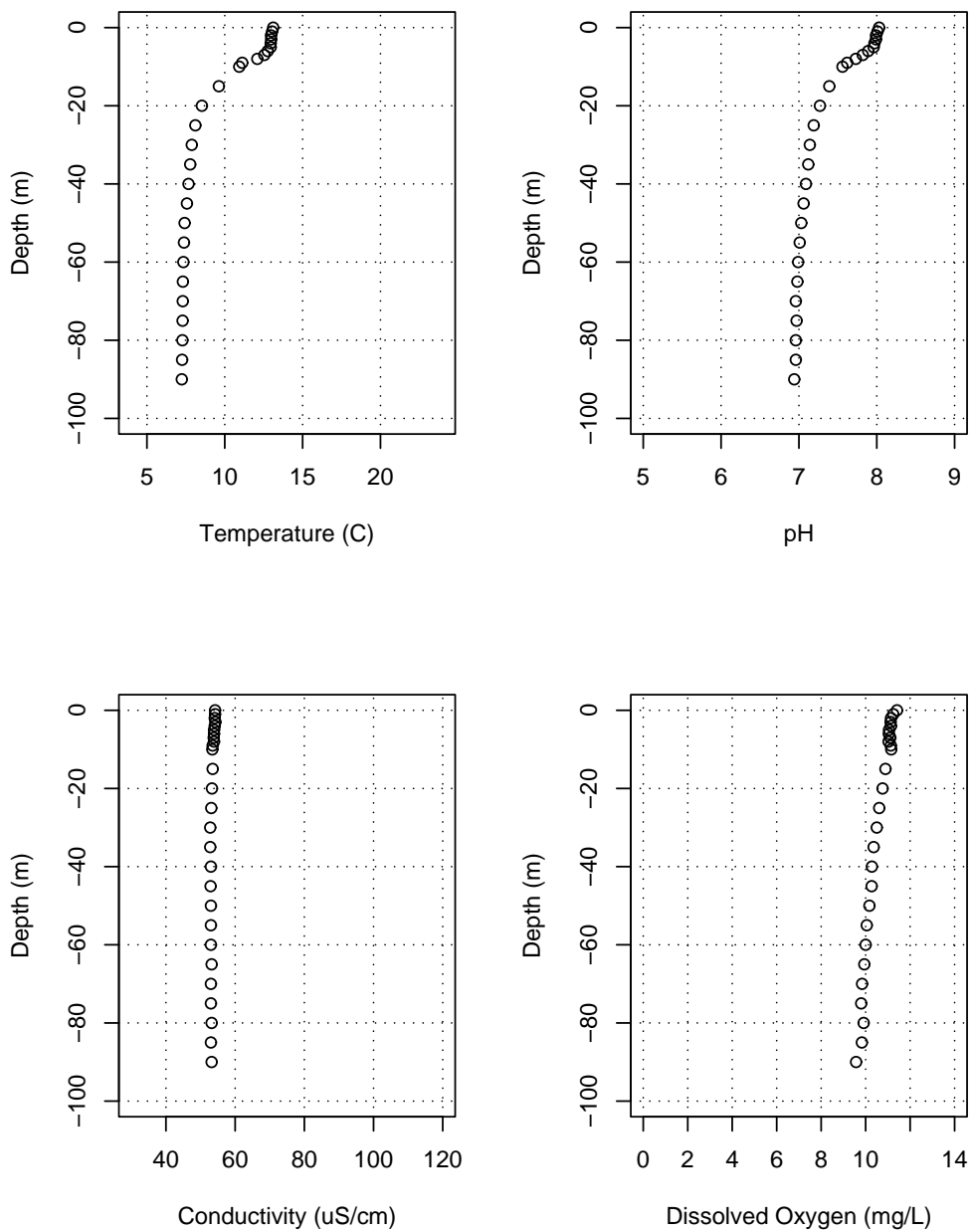


Figure B30: Lake Whatcom Hydrolab profile for Site 4, May 4, 2005.

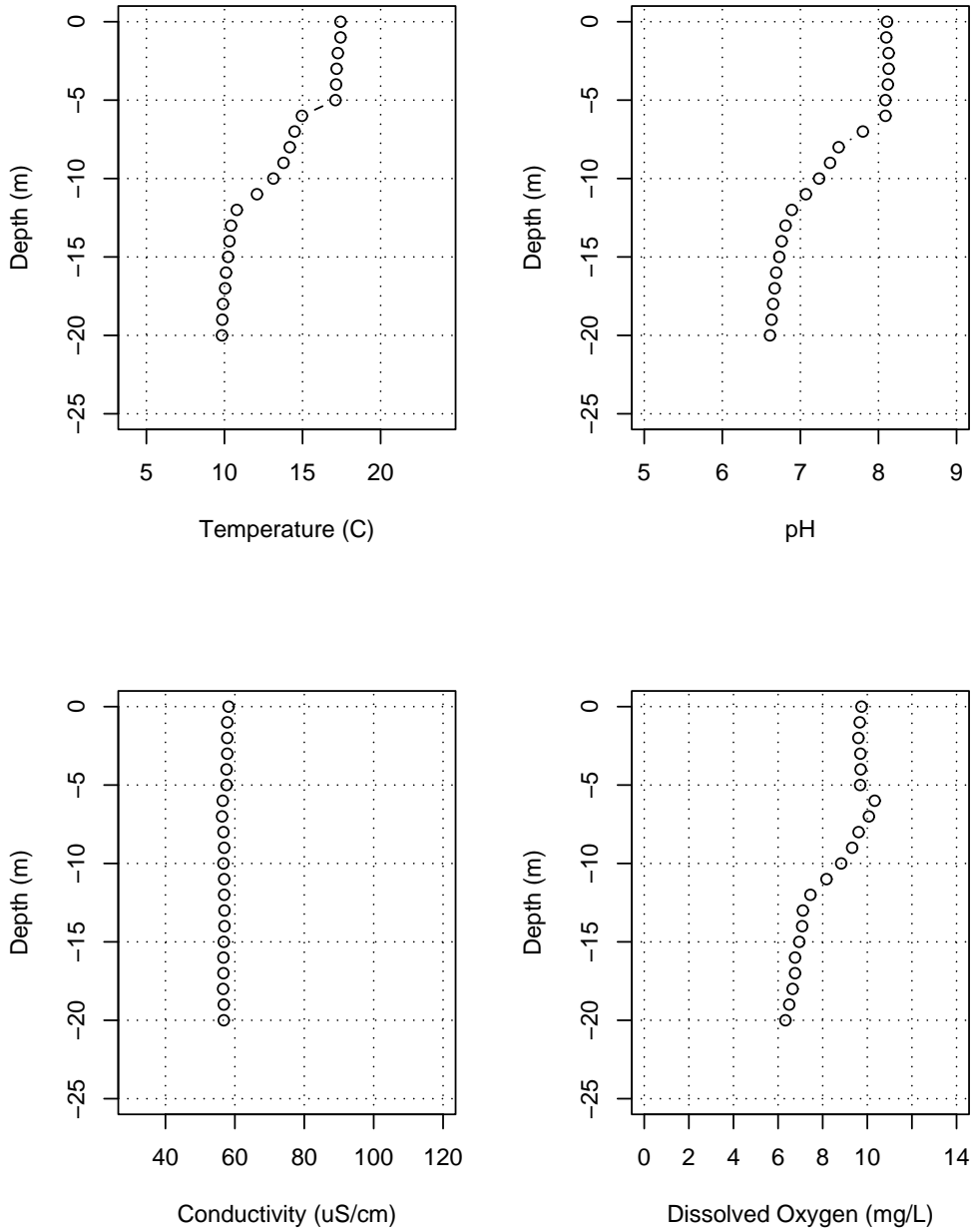


Figure B31: Lake Whatcom Hydrolab profile for Site 1, June 2, 2005.

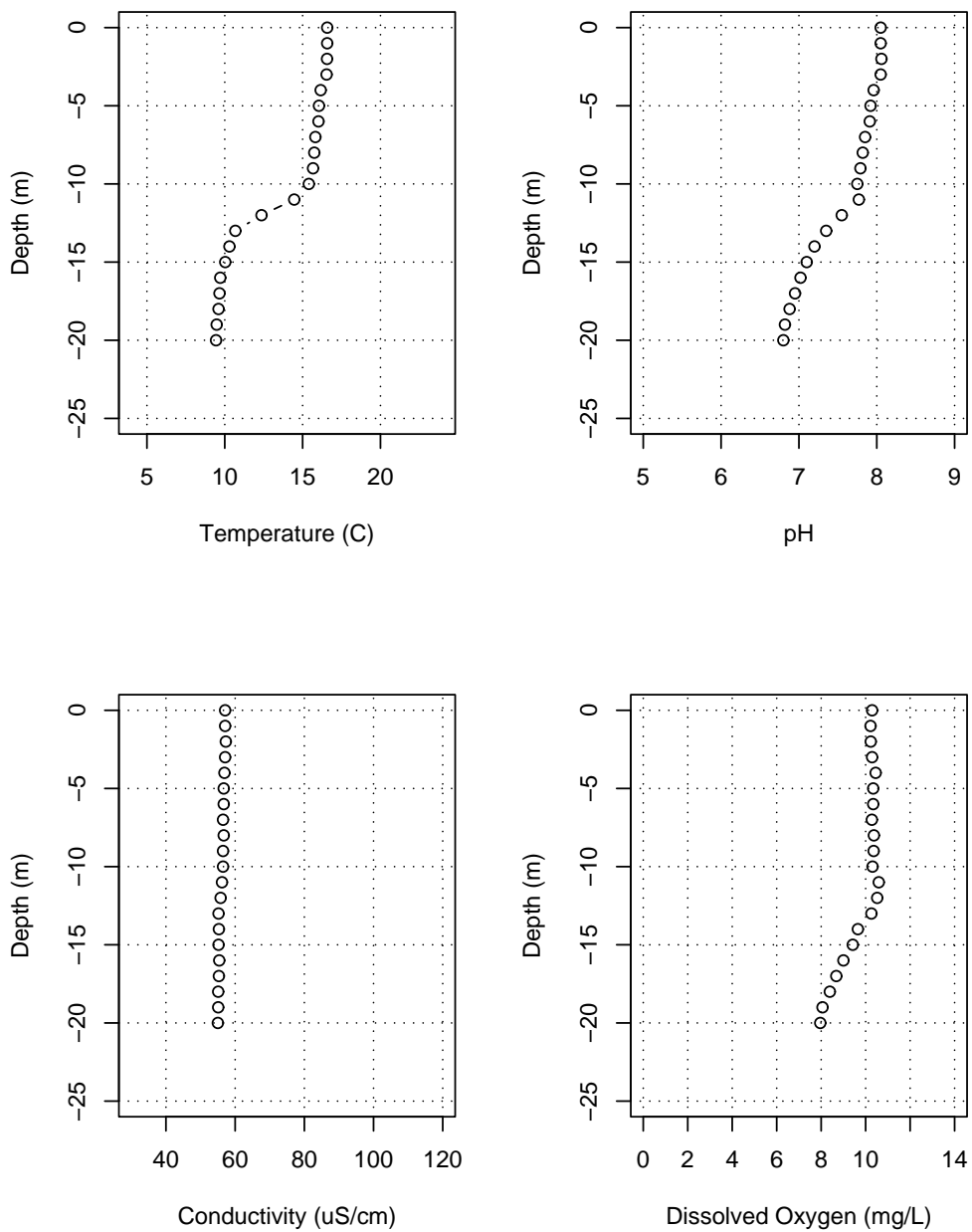


Figure B32: Lake Whatcom Hydrolab profile for Site 2, June 2, 2005.

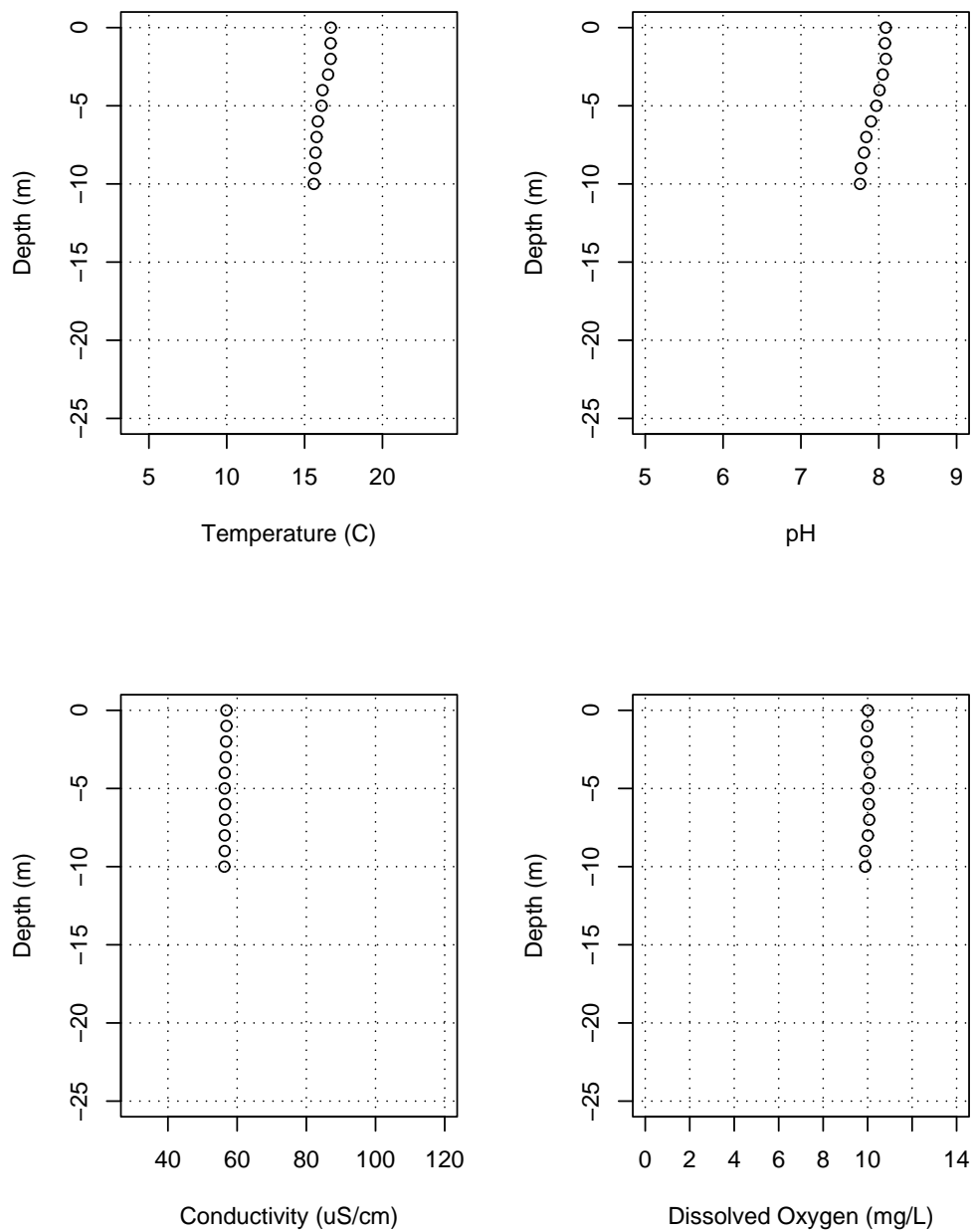


Figure B33: Lake Whatcom Hydrolab profile for the Intake, June 2, 2005.

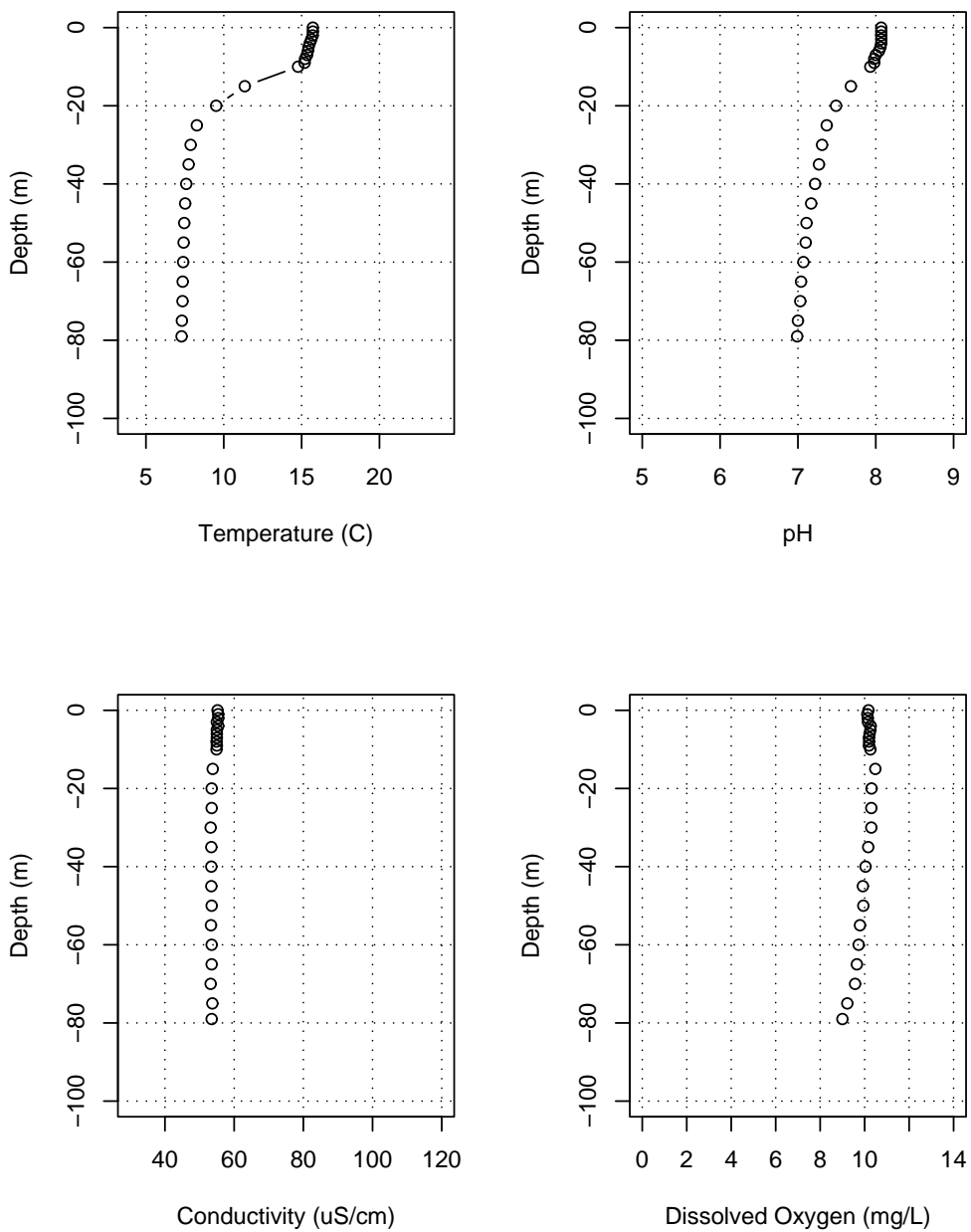


Figure B34: Lake Whatcom Hydrolab profile for Site 3, June 1, 2005.

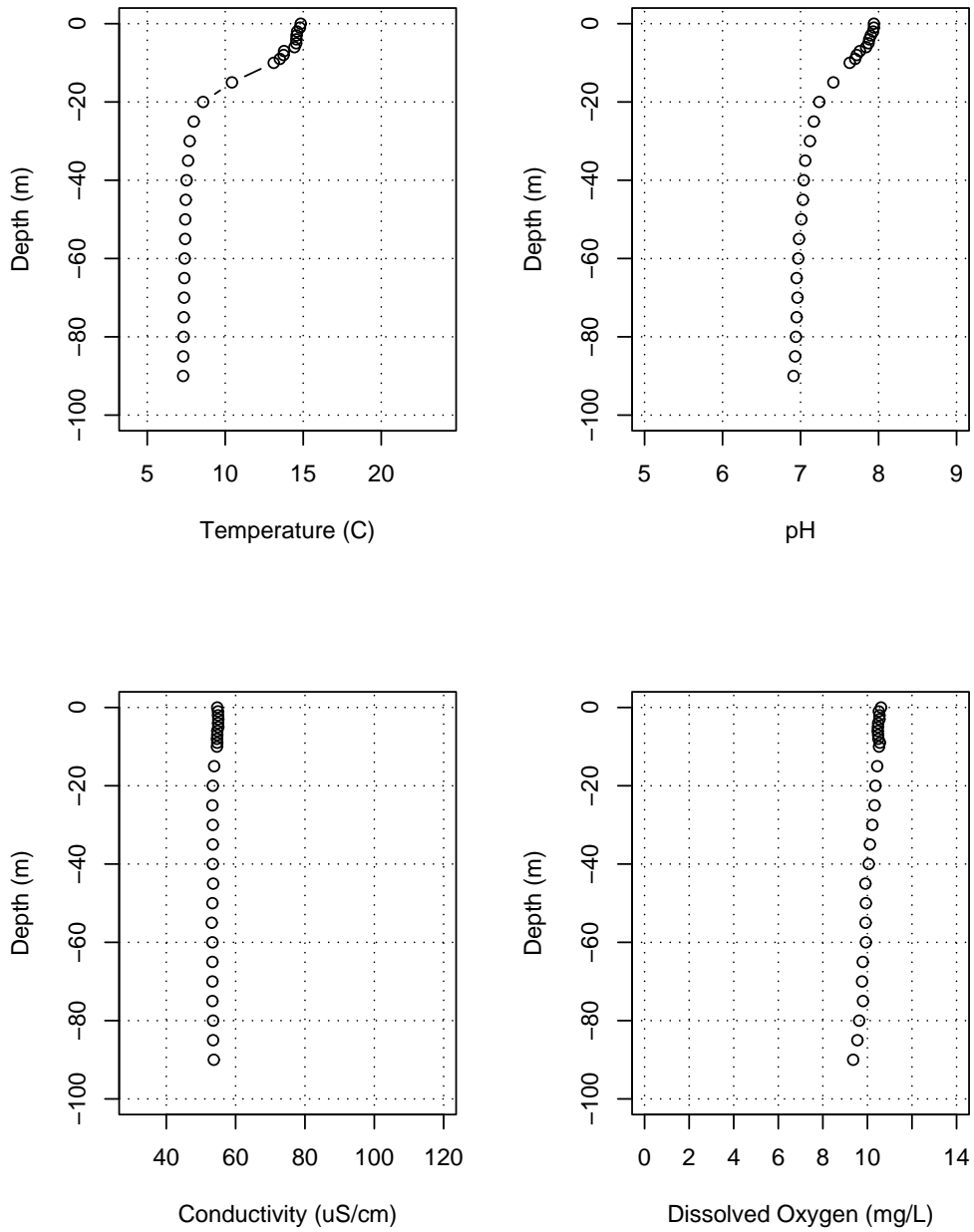


Figure B35: Lake Whatcom Hydrolab profile for Site 4, June 1, 2005.

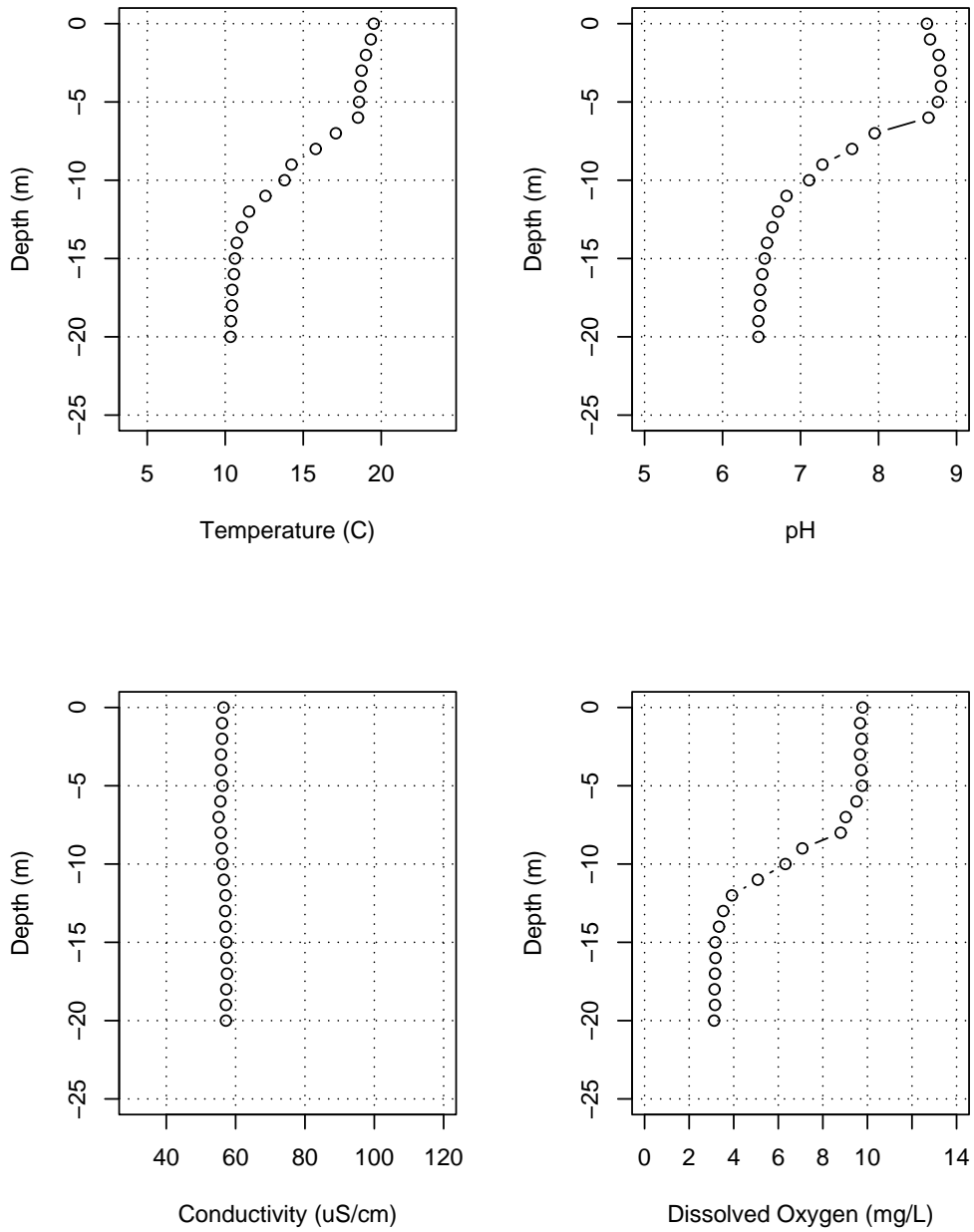


Figure B36: Lake Whatcom Hydrolab profile for Site 1, July 7, 2005.

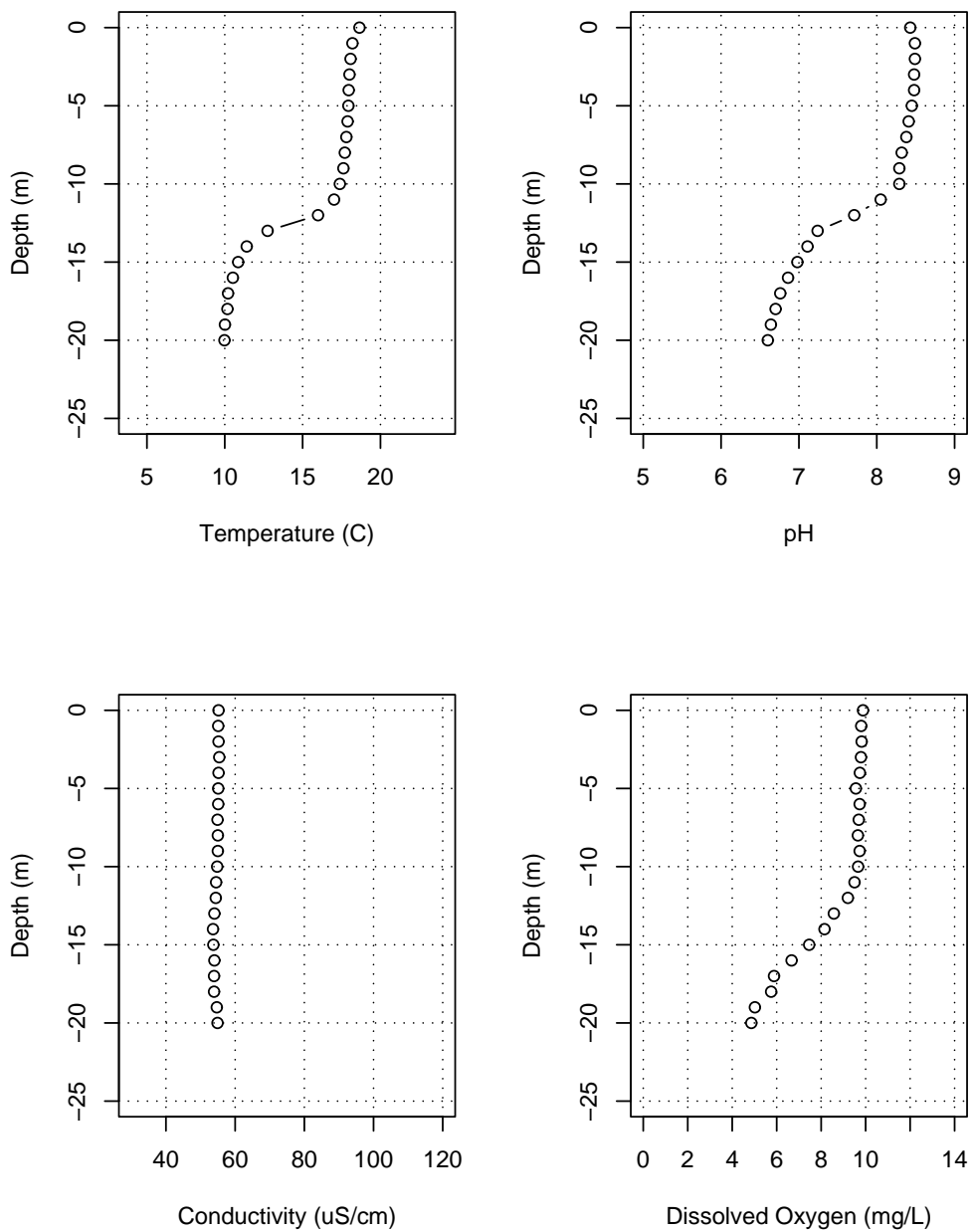


Figure B37: Lake Whatcom Hydrolab profile for Site 2, July 7, 2005.

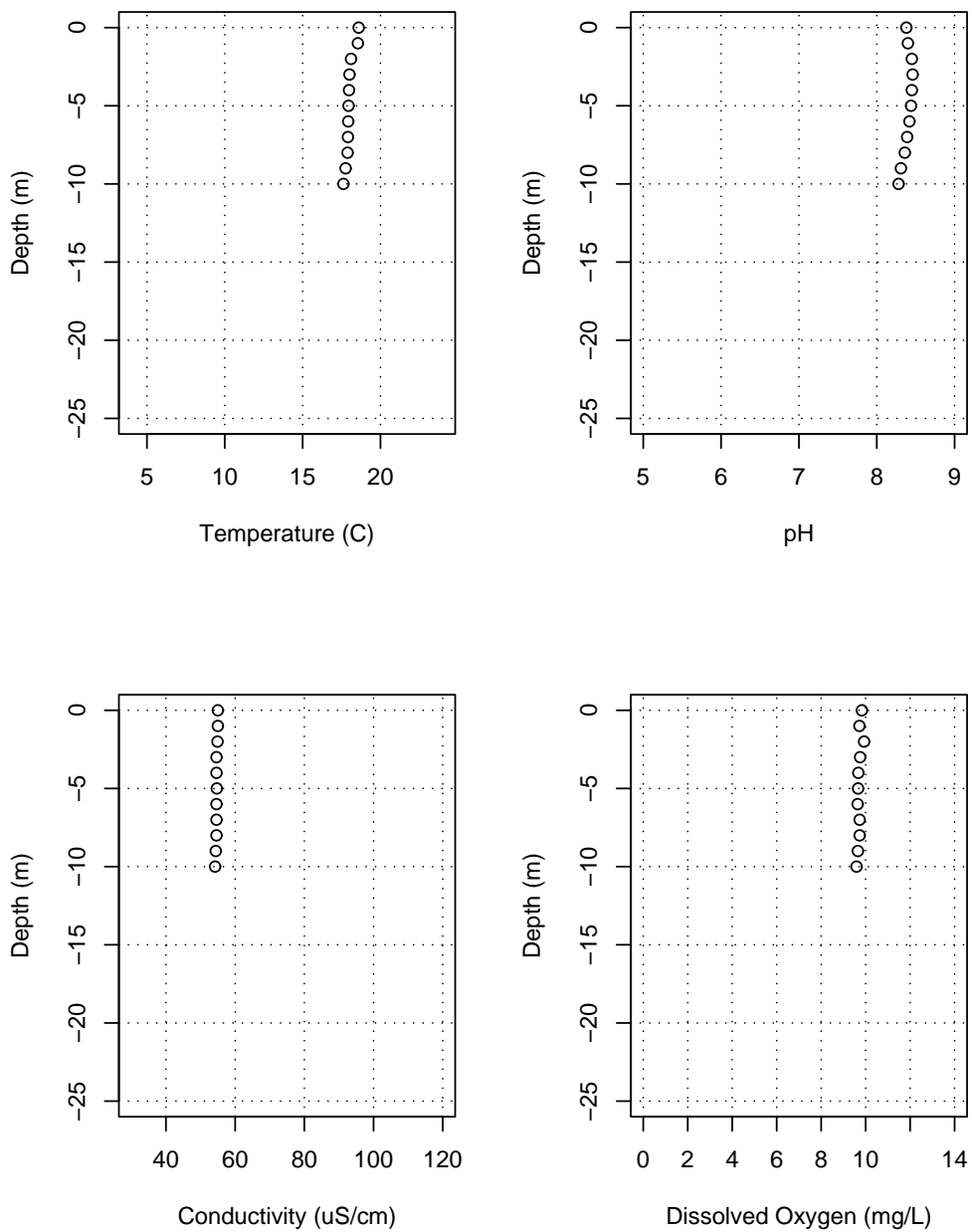


Figure B38: Lake Whatcom Hydrolab profile for the Intake, July 7, 2005.

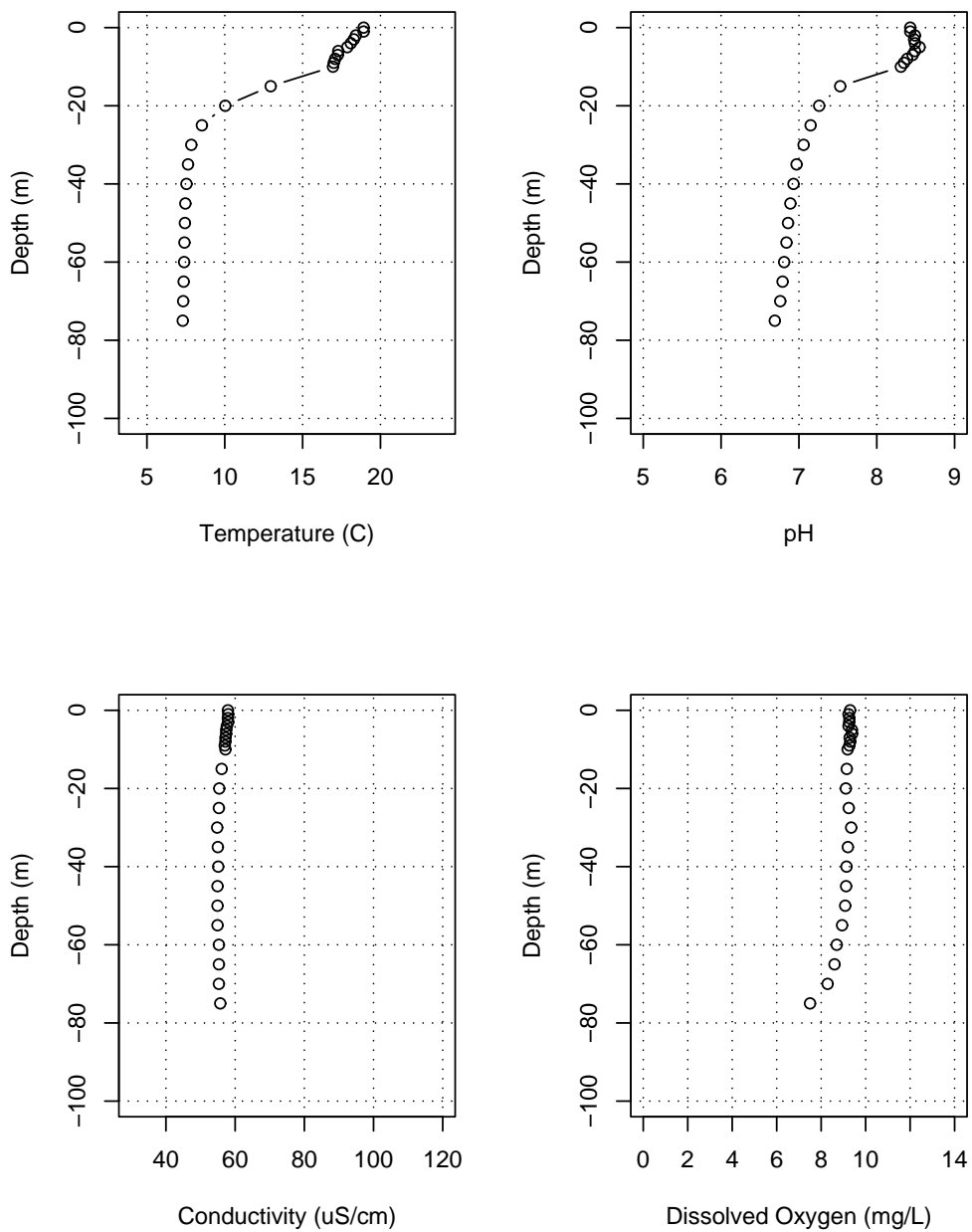


Figure B39: Lake Whatcom Hydrolab profile for Site 3, July 5, 2005.

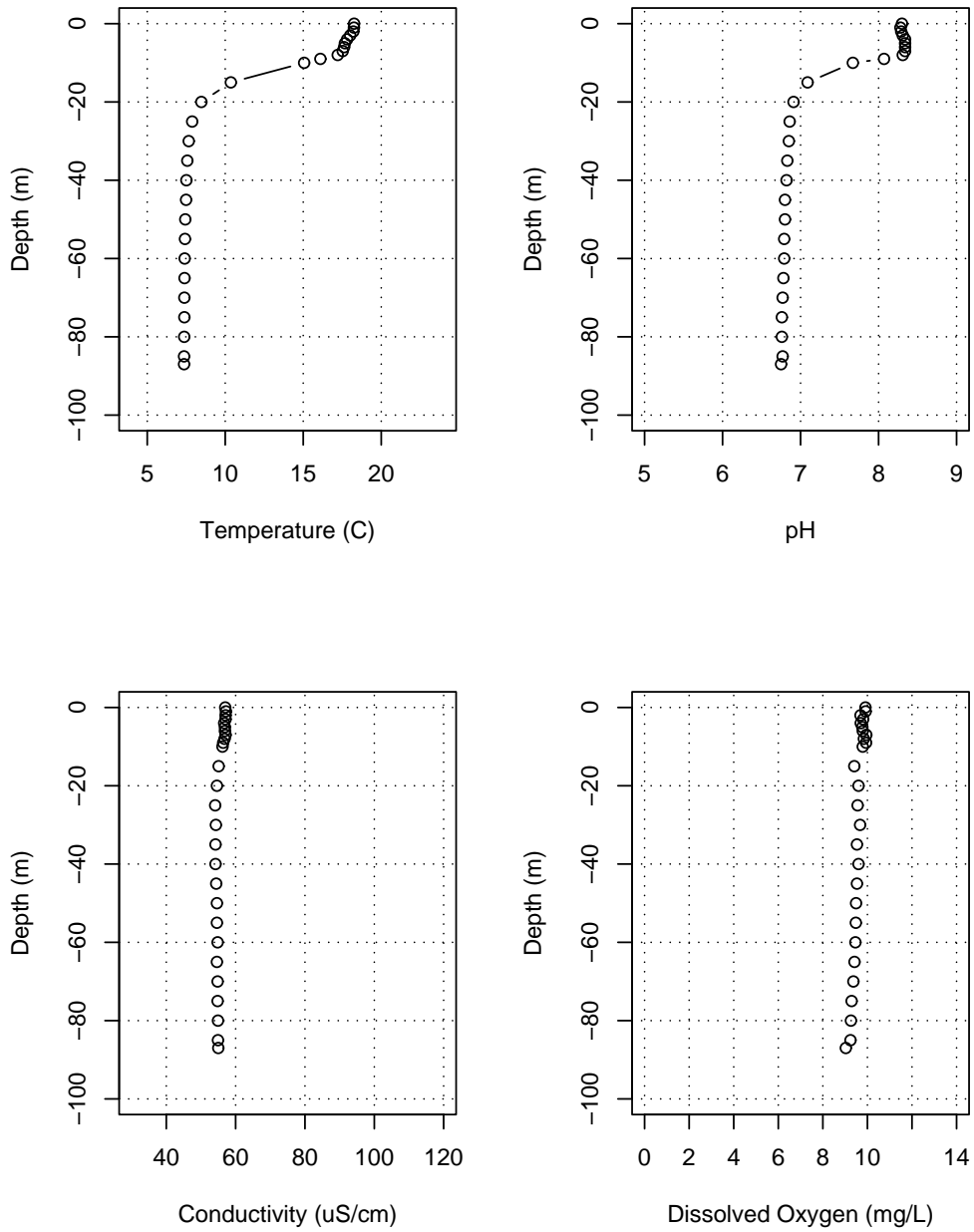


Figure B40: Lake Whatcom Hydrolab profile for Site 4, July 5, 2005.

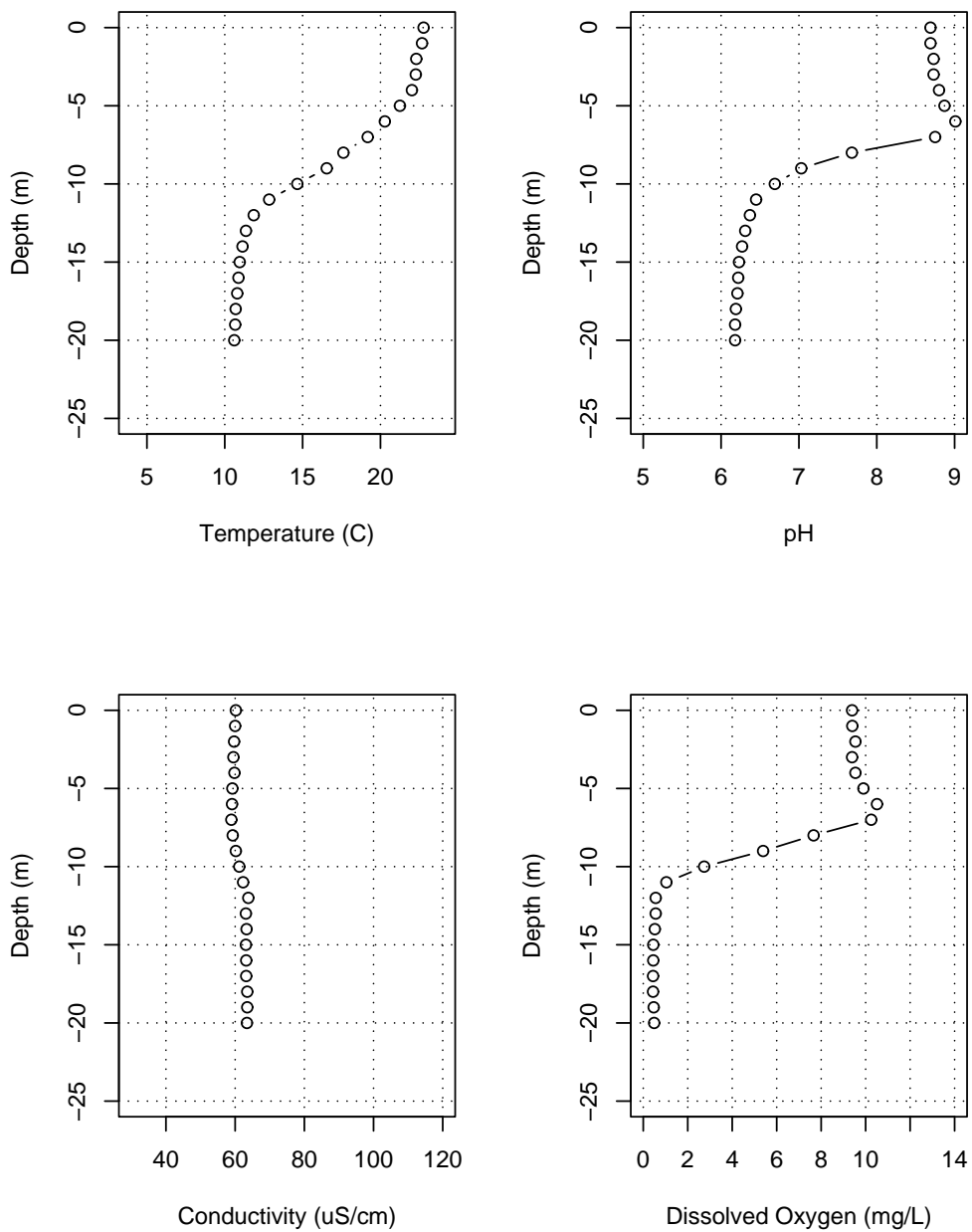


Figure B41: Lake Whatcom Hydrolab profile for Site 1, August 4, 2005.

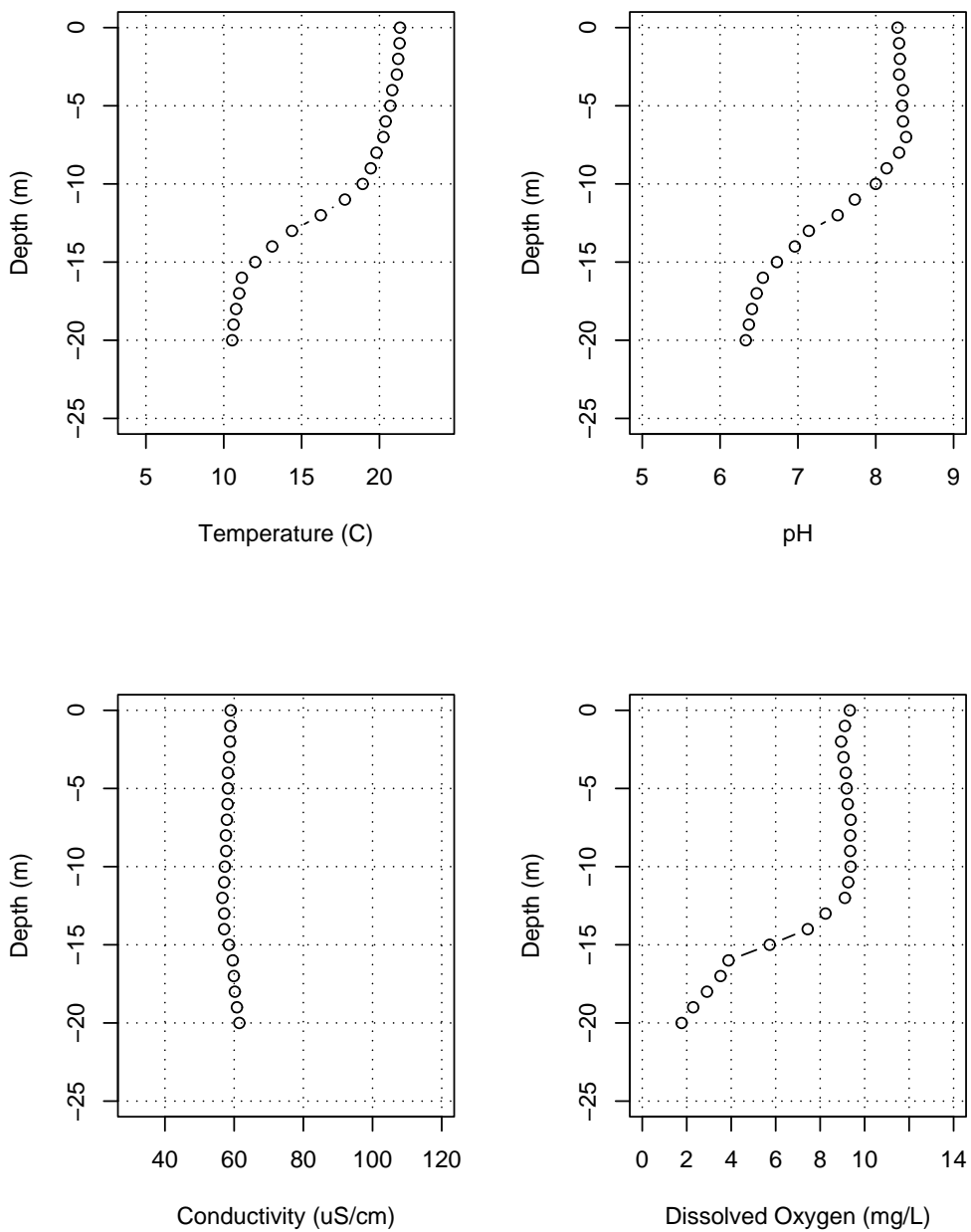


Figure B42: Lake Whatcom Hydrolab profile for Site 2, August 4, 2005.

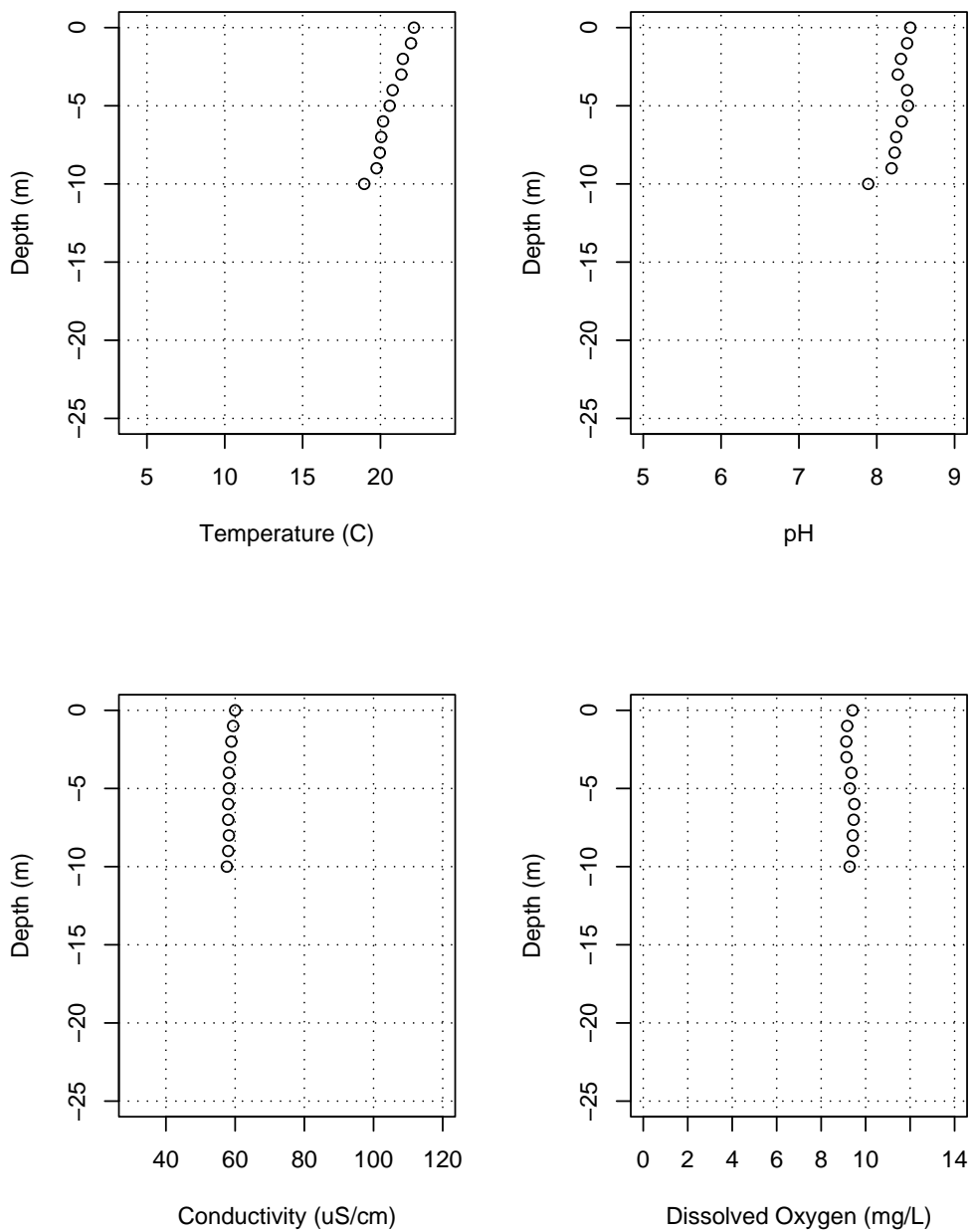


Figure B43: Lake Whatcom Hydrolab profile for the Intake, August 4, 2005.

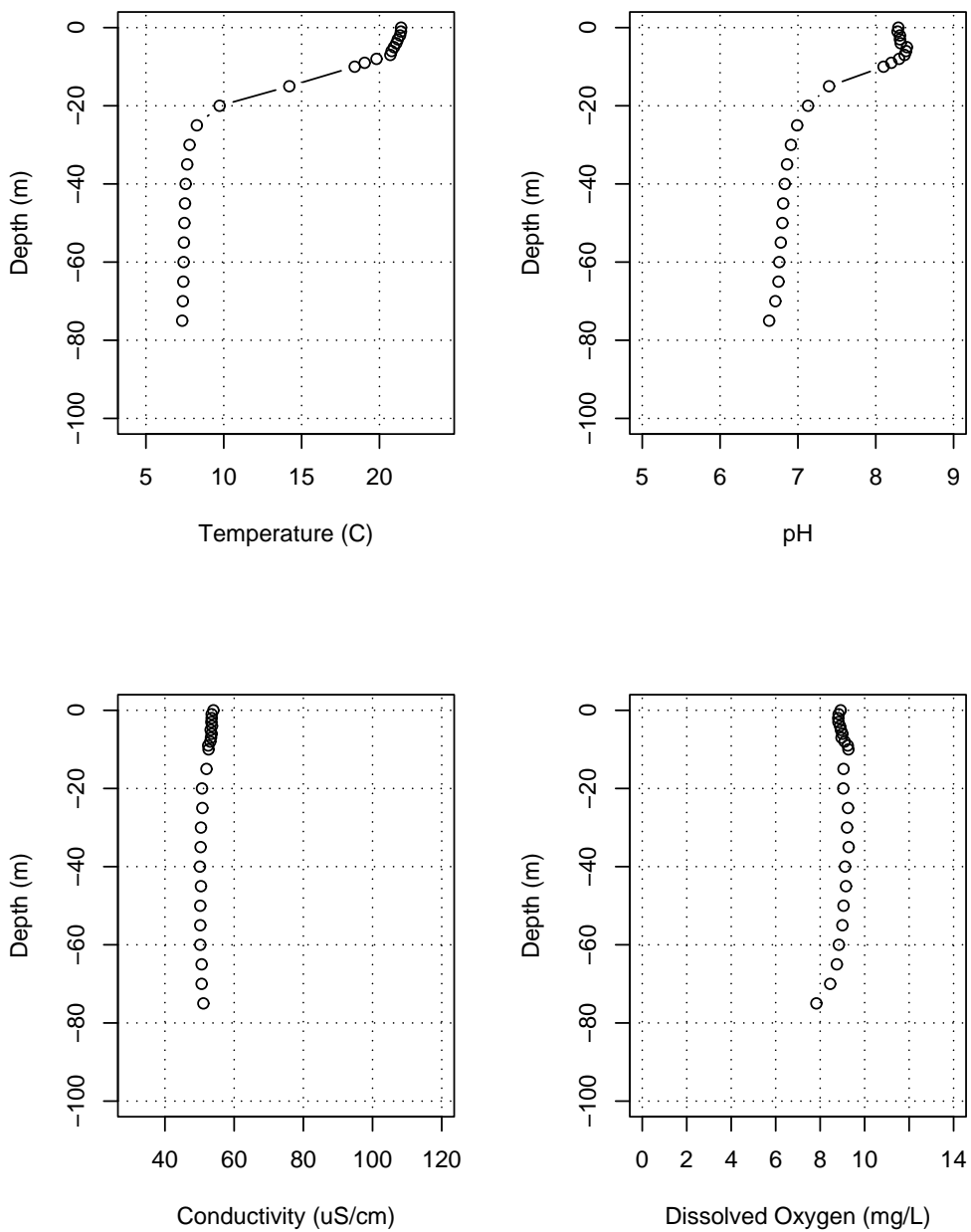


Figure B44: Lake Whatcom Hydrolab profile for Site 3, August 2, 2005.

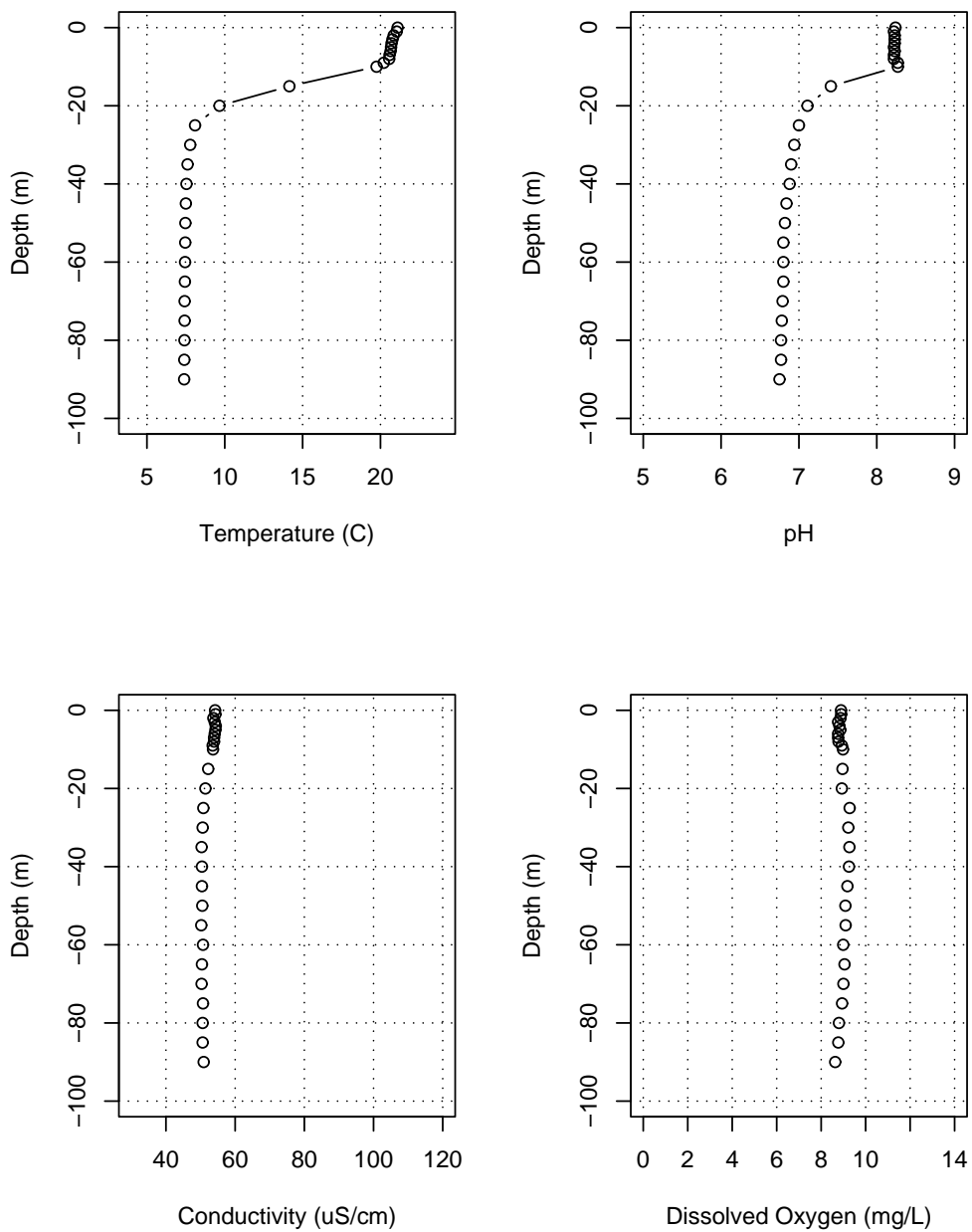


Figure B45: Lake Whatcom Hydrolab profile for Site 4, August 2, 2005.

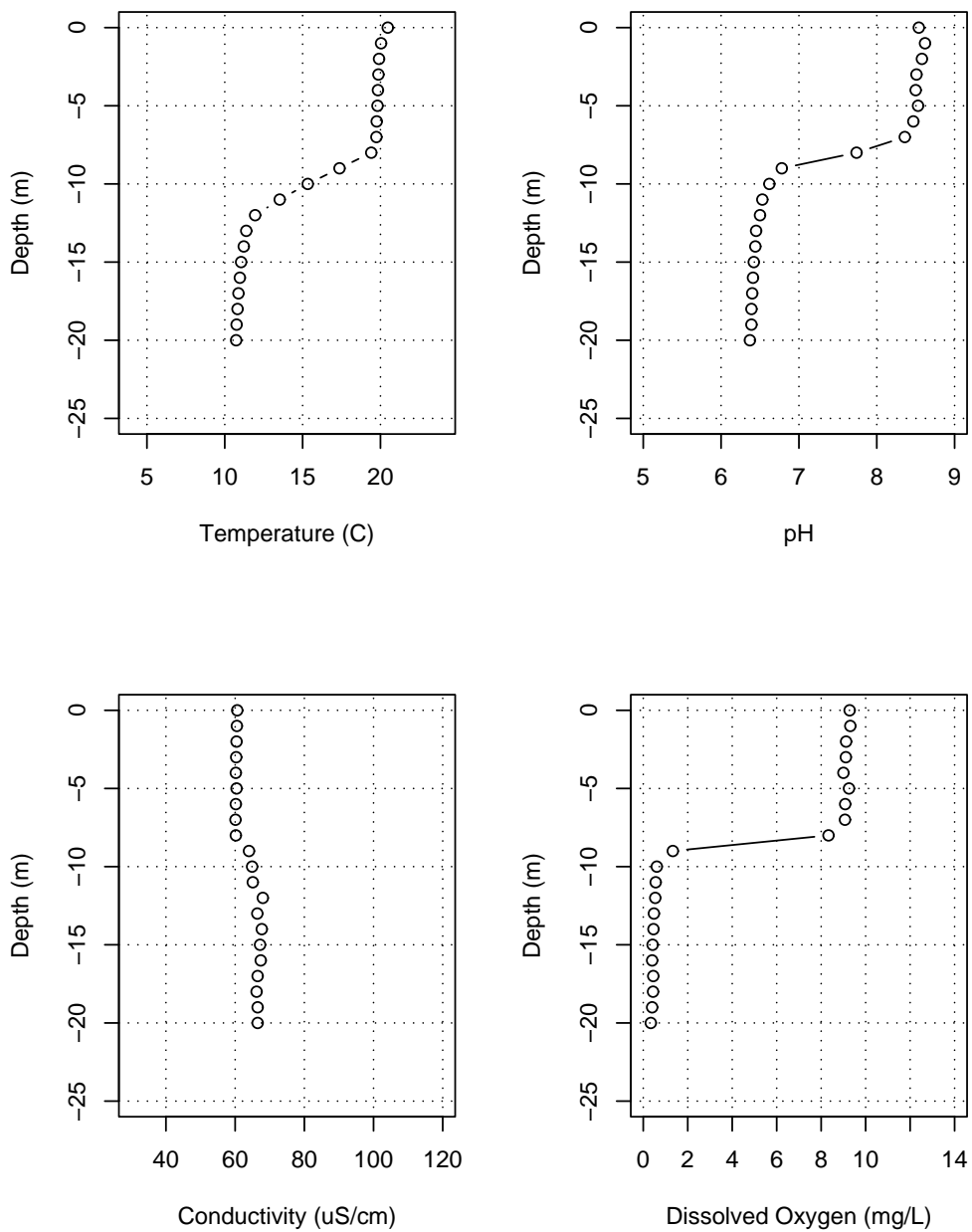


Figure B46: Lake Whatcom Hydrolab profile for Site 1, September 8, 2005.

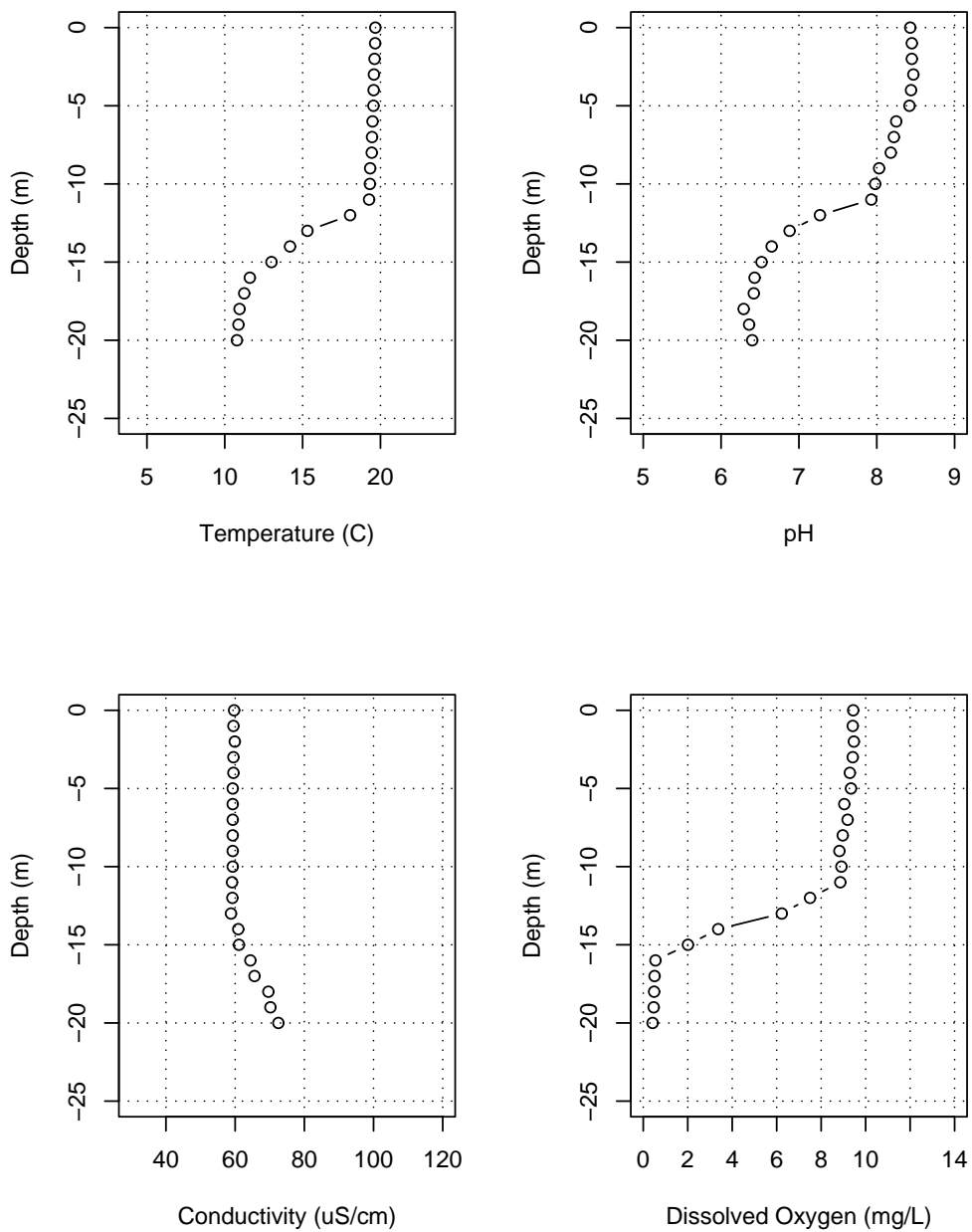


Figure B47: Lake Whatcom Hydrolab profile for Site 2, September 8, 2005.

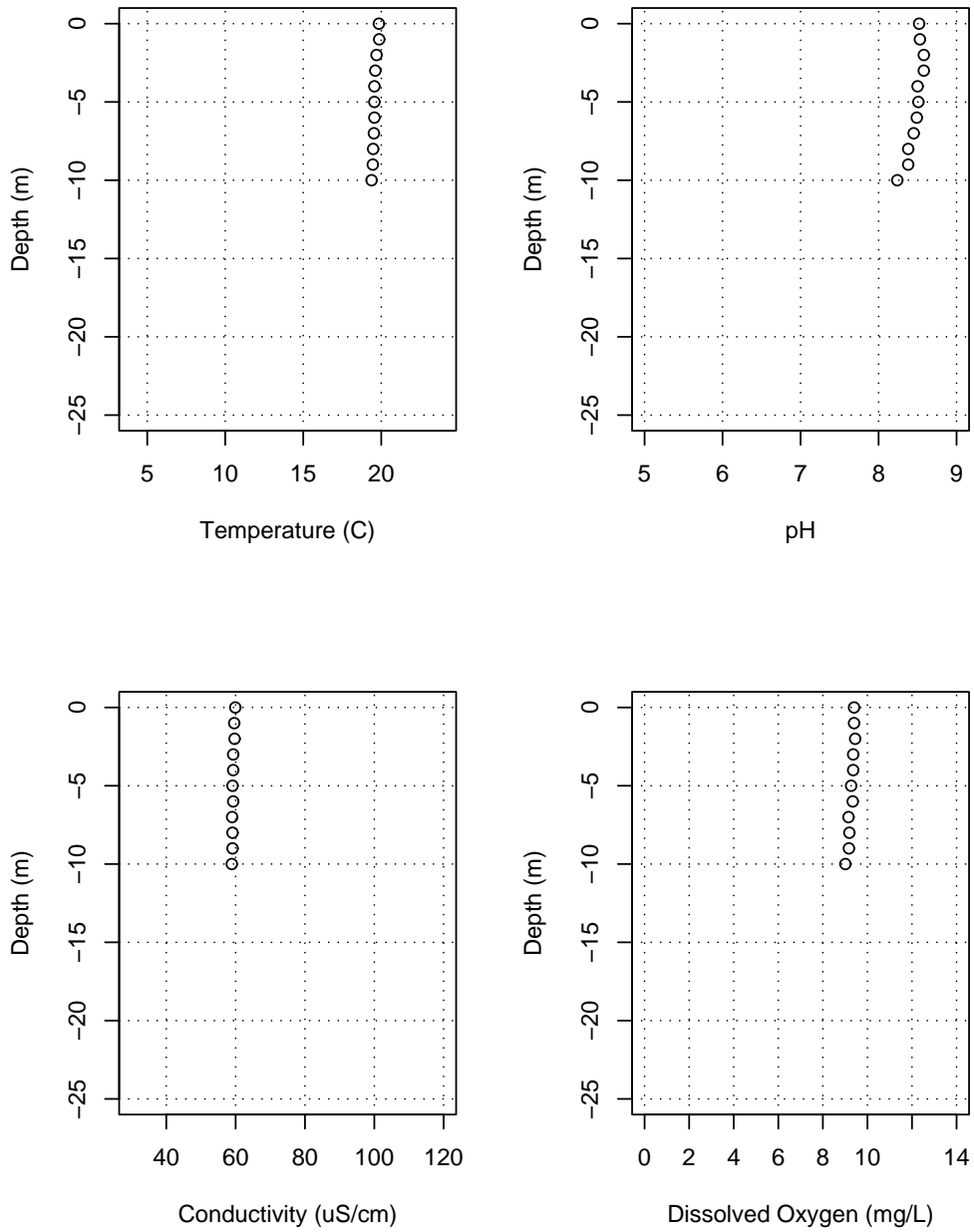


Figure B48: Lake Whatcom Hydrolab profile for the Intake, September 8, 2005.

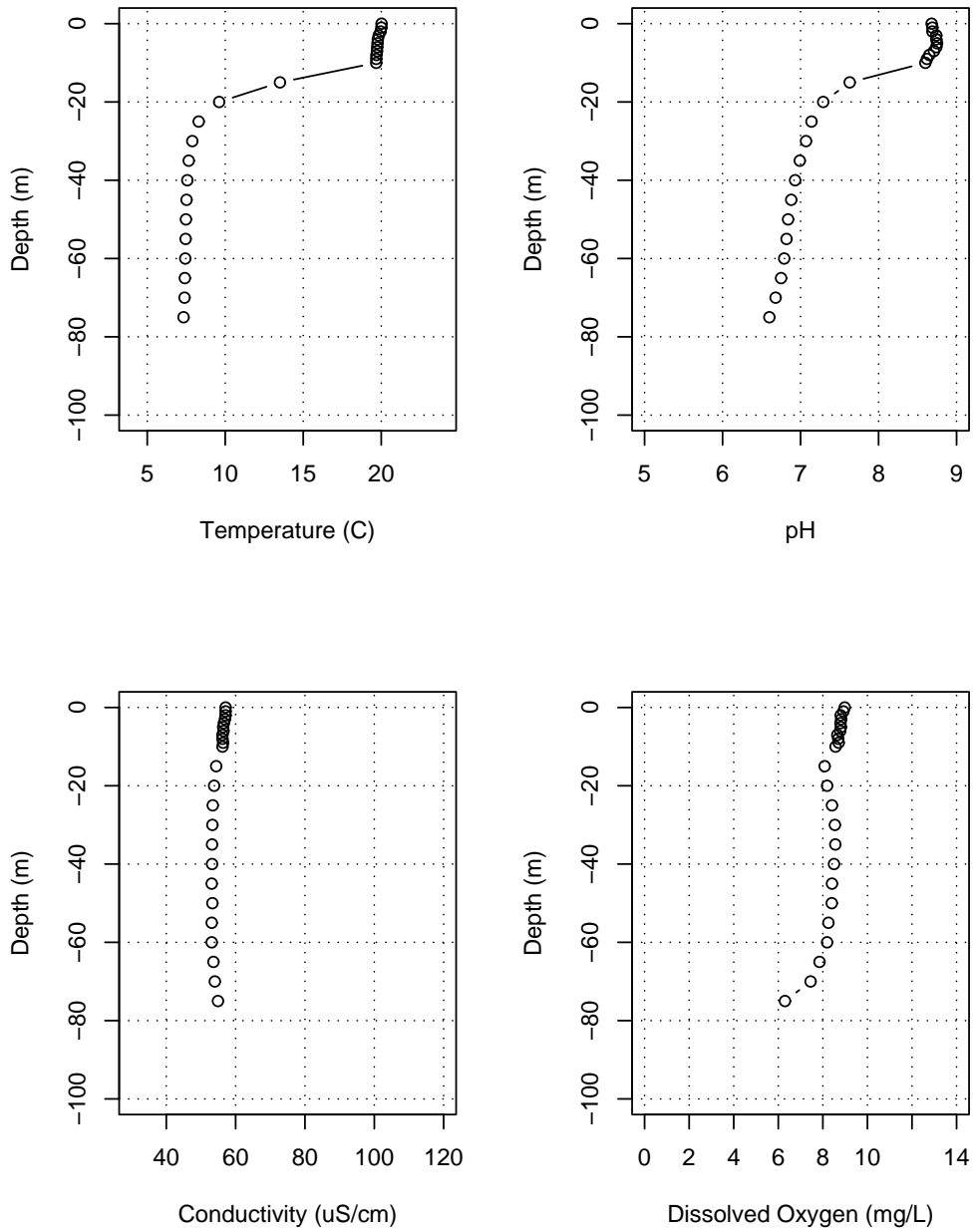


Figure B49: Lake Whatcom Hydrolab profile for Site 3, September 6, 2005.

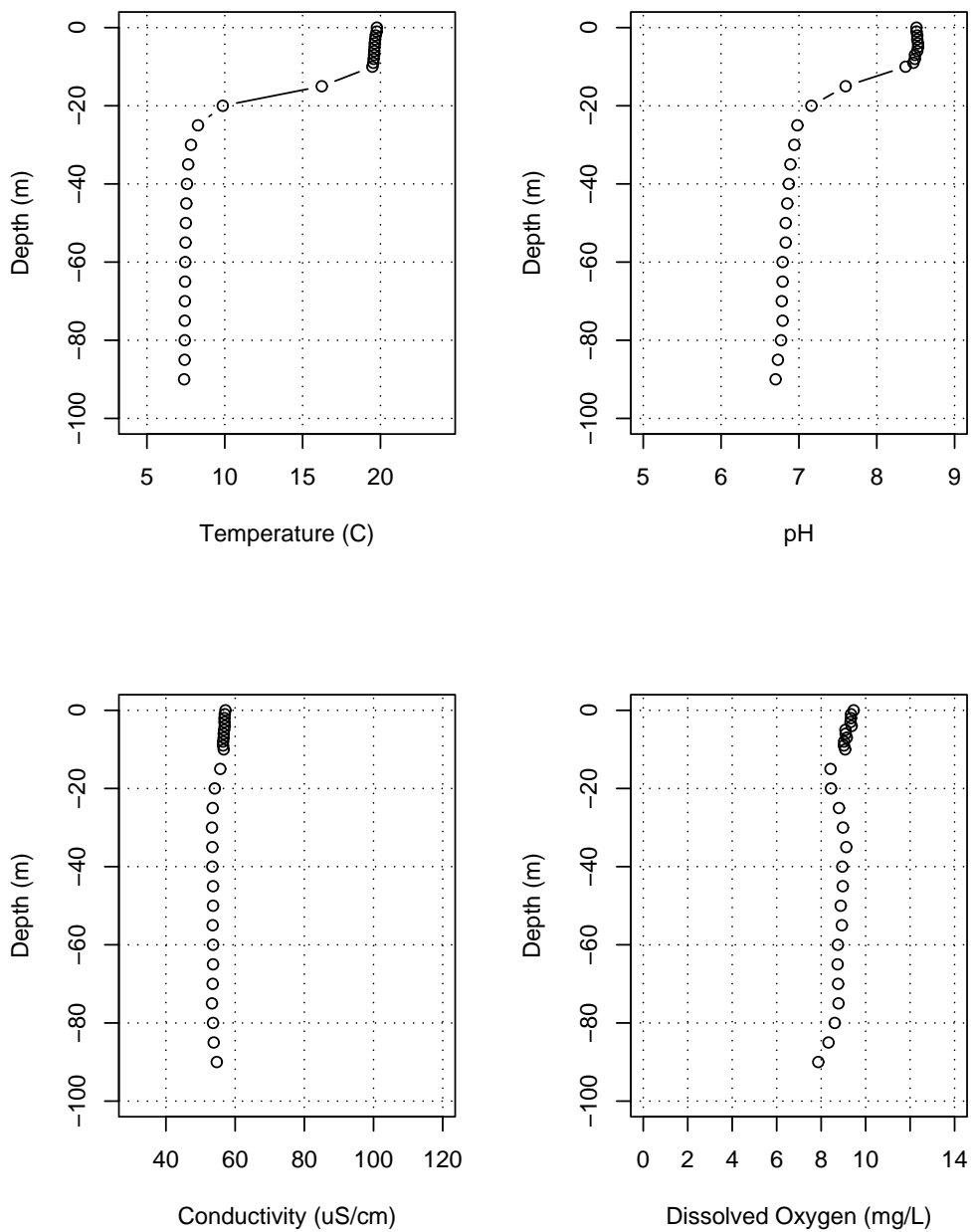


Figure B50: Lake Whatcom Hydrolab profile for Site 4, September 6, 2005.

B.2 Temperature, Dissolved Oxygen, pH, Conductivity

Lake Whatcom temperature data for Site 1, February 1988 through December 2005.

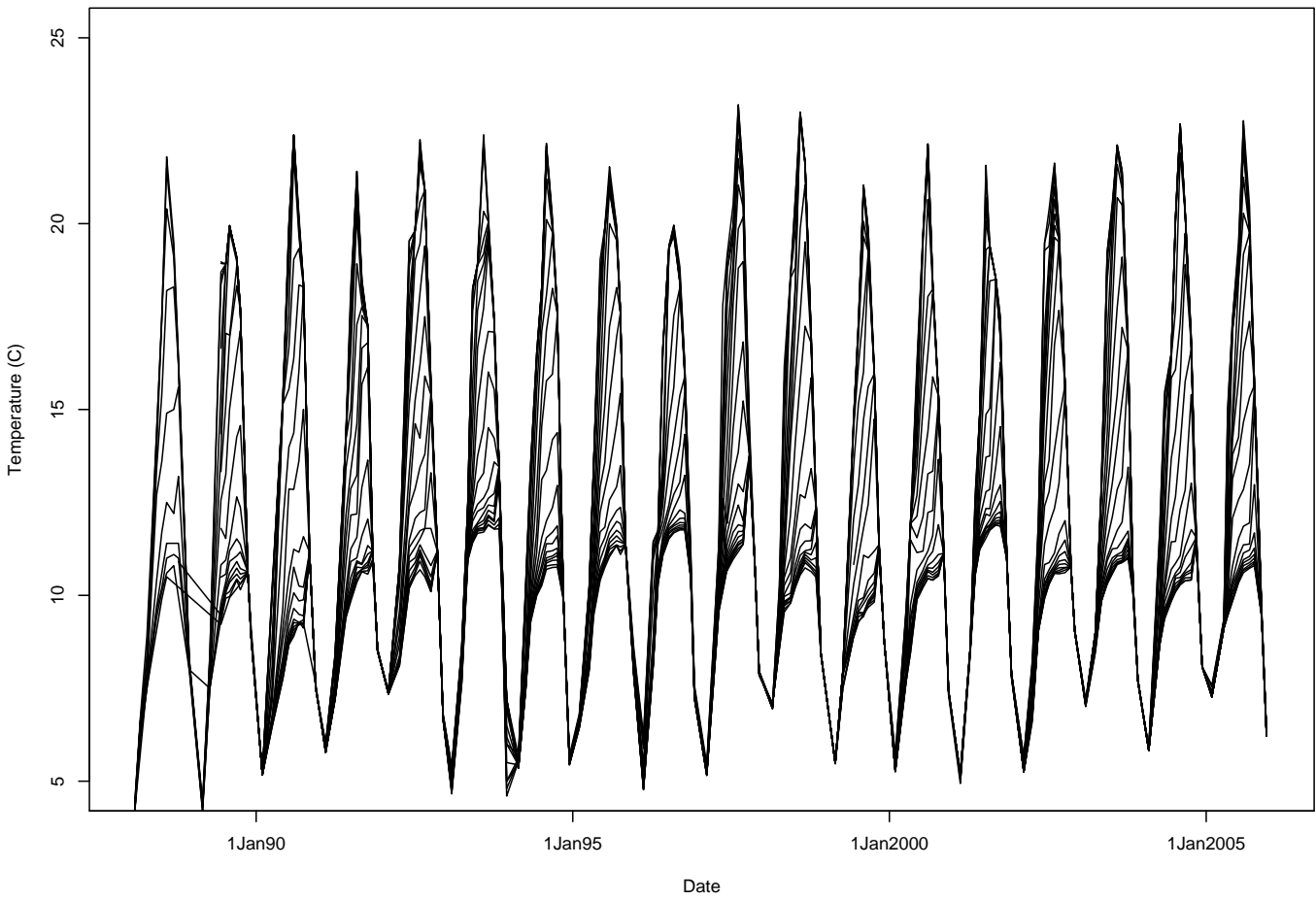


Figure B51: Lake Whatcom temperature data for Site 1 (1988-2005).

Lake Whatcom temperature data for Site 2, February 1988 through December 2005.

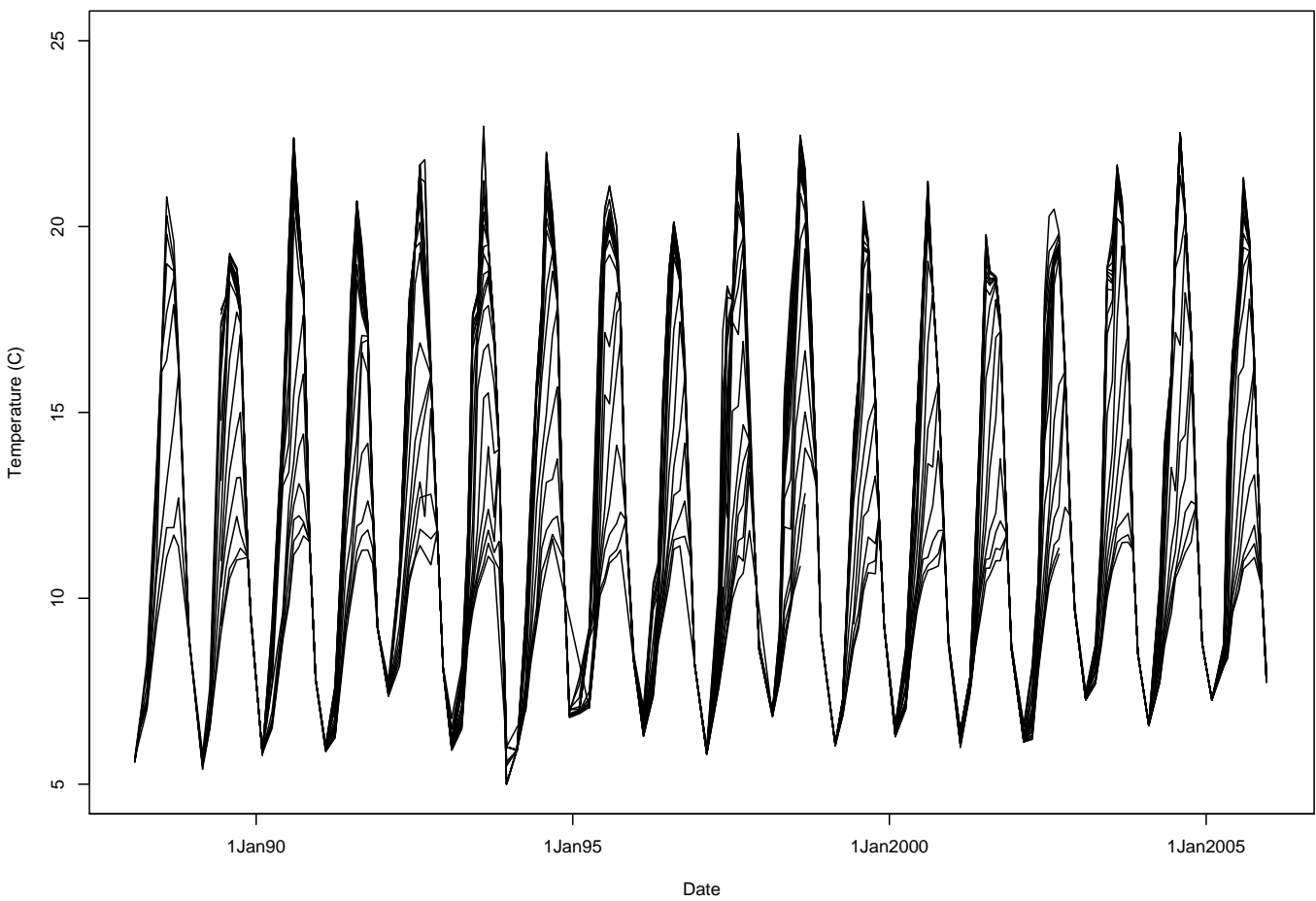


Figure B52: Lake Whatcom temperature data for Site 2 (1988-2005).

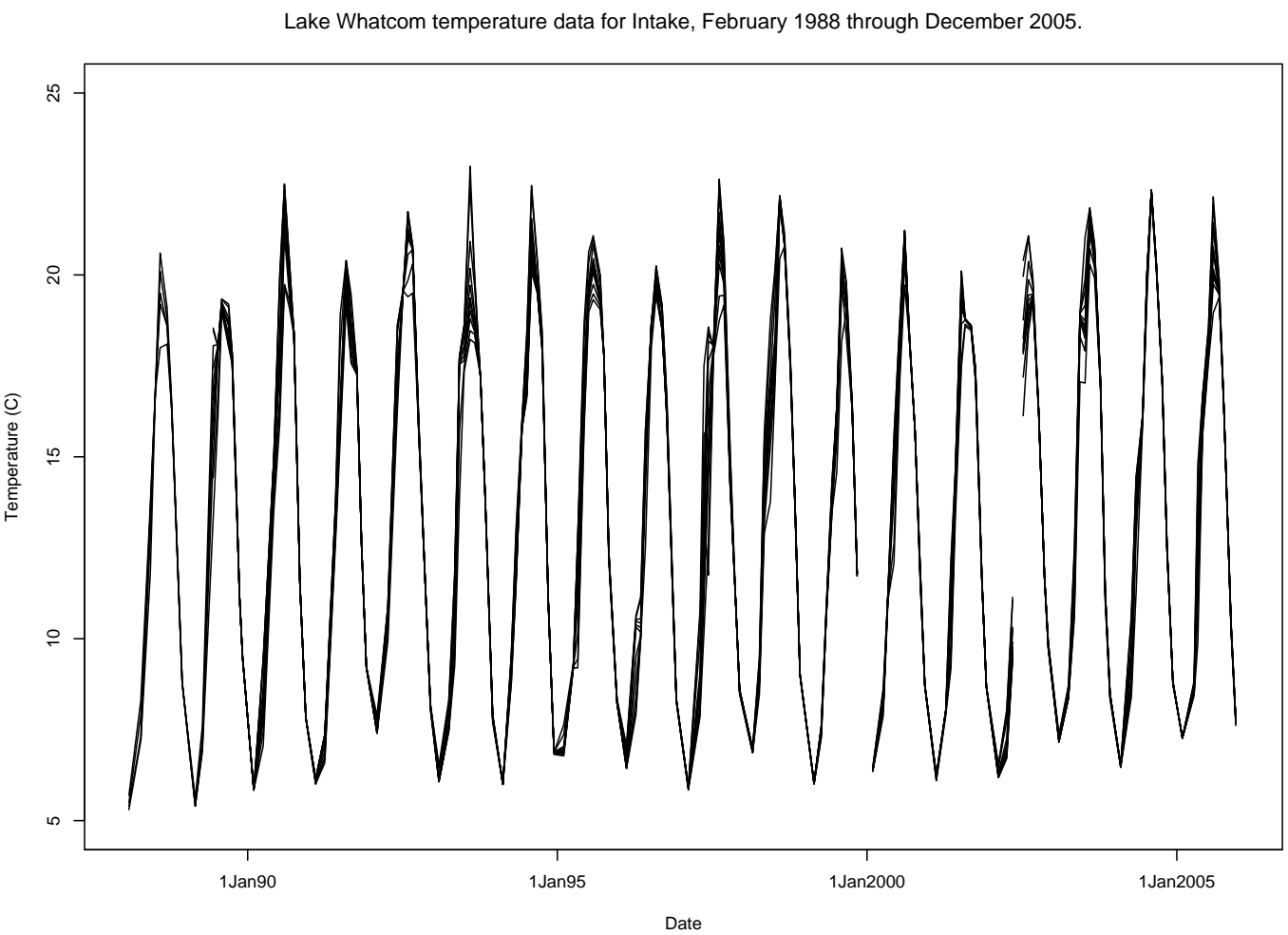


Figure B53: Lake Whatcom temperature data for the Intake (1988–2005).

Lake Whatcom temperature data for Site 3, February 1988 through December 2005.

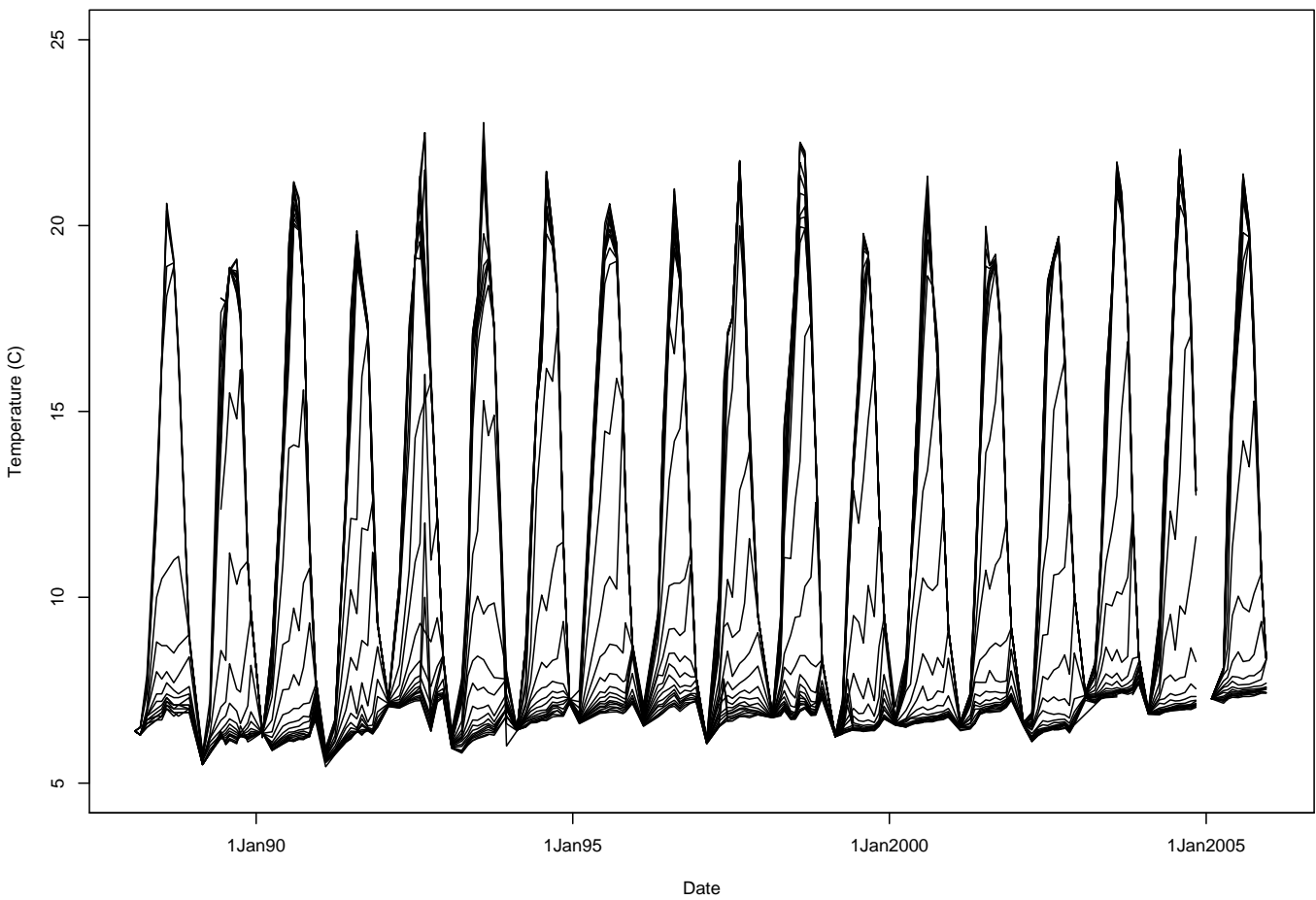


Figure B54: Lake Whatcom temperature data for Site 3 (1988-2005).

Lake Whatcom temperature data for Site 4, February 1988 through December 2005.

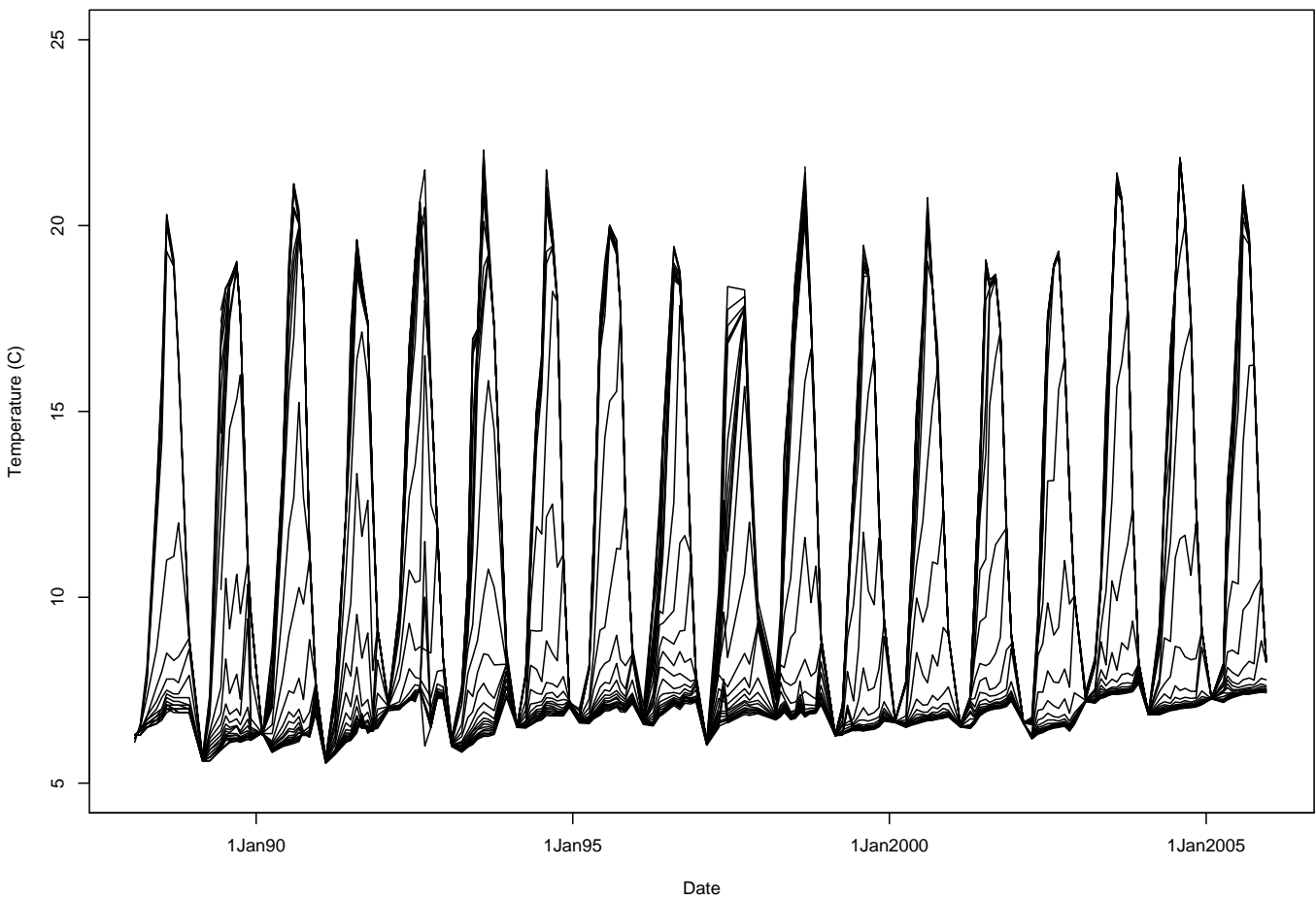


Figure B55: Lake Whatcom temperature data for Site 4 (1988-2005).

Lake Whatcom dissolved oxygen data for Site 1, February 1988 through December 2005.

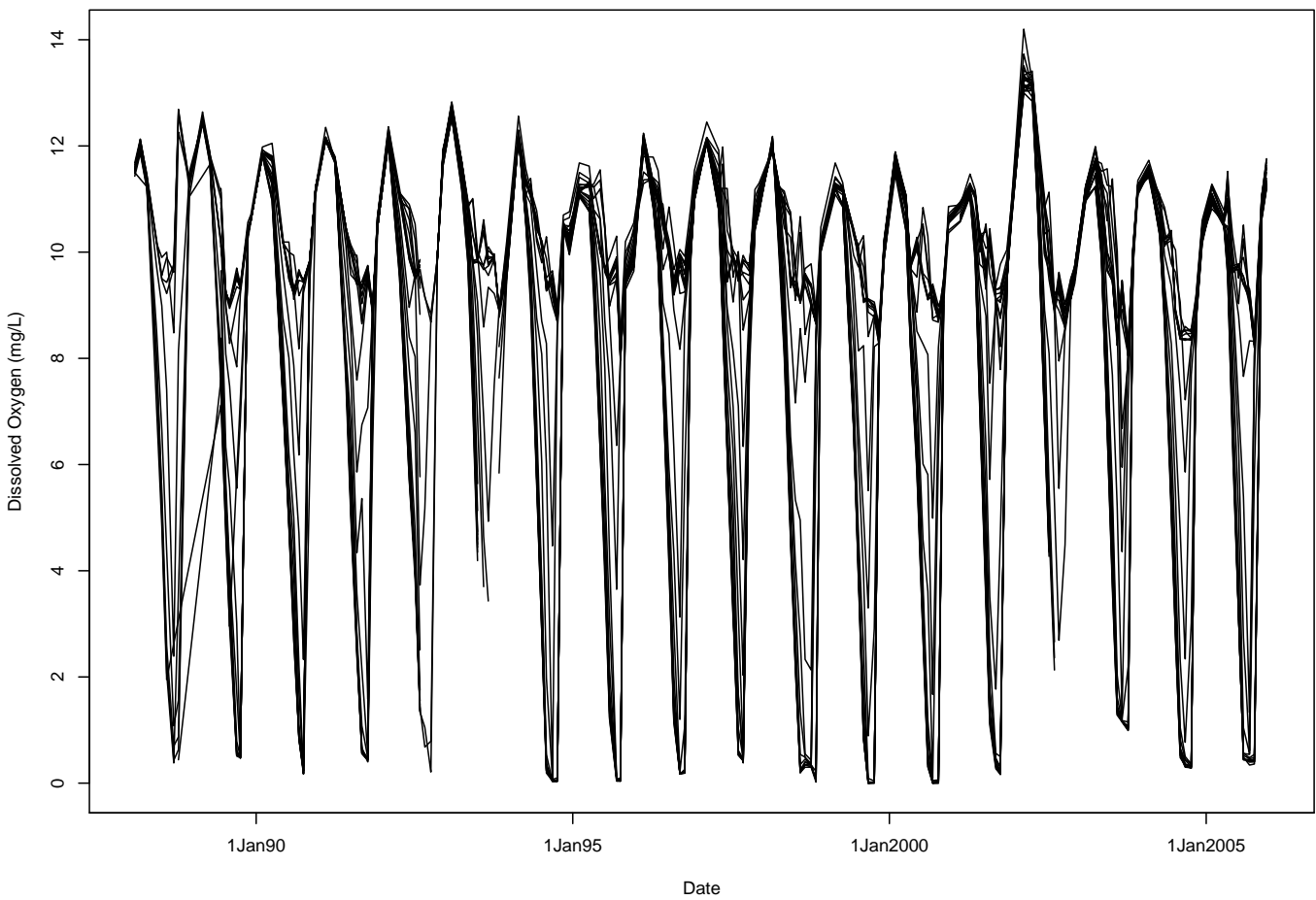


Figure B56: Lake Whatcom dissolved oxygen data for Site 1 (1988-2005).

Lake Whatcom dissolved oxygen data for Site 2, February 1988 through December 2005.

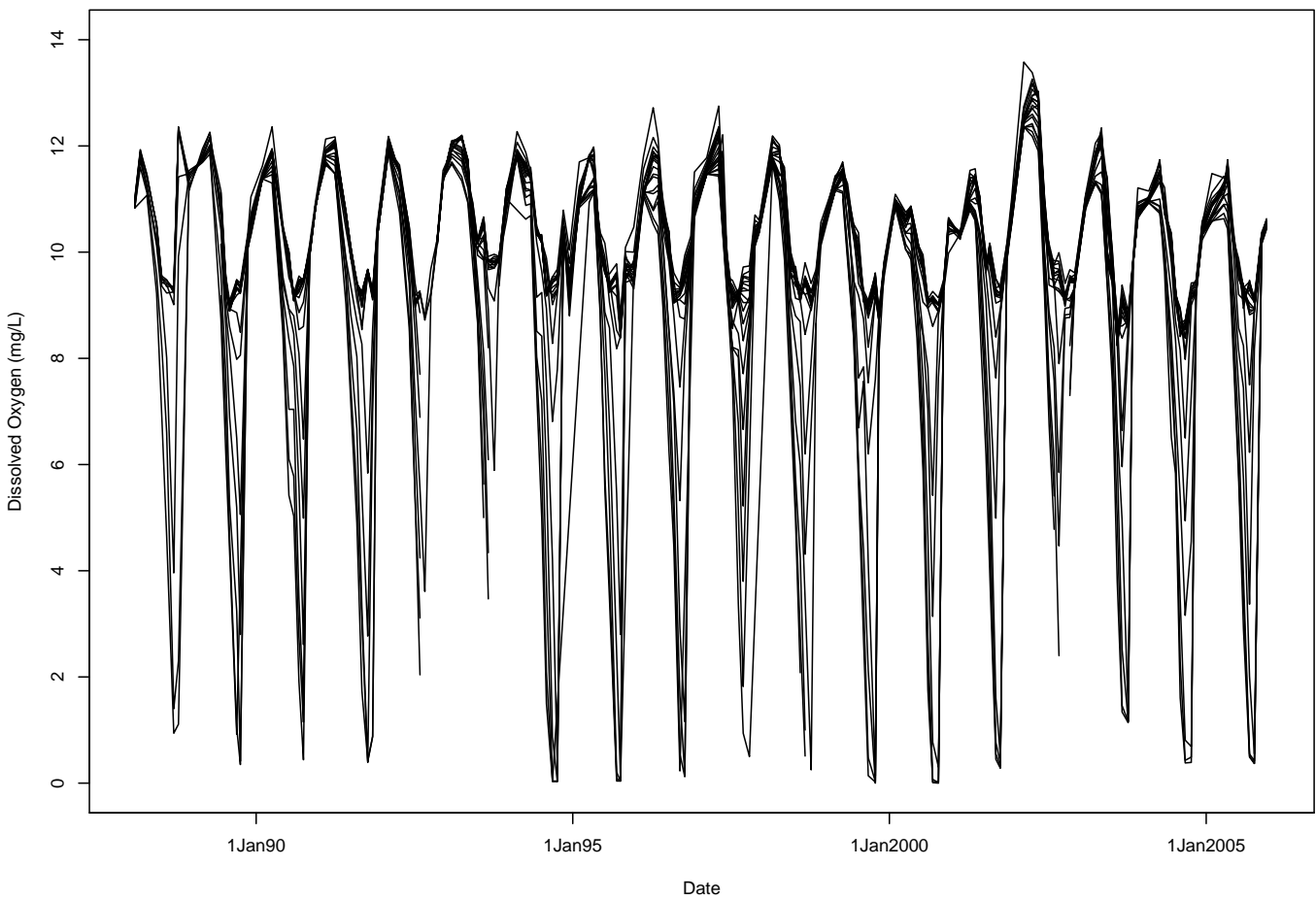


Figure B57: Lake Whatcom dissolved oxygen data for Site 2 (1988-2005).

Lake Whatcom dissolved oxygen data for Intake, February 1988 through December 2005.

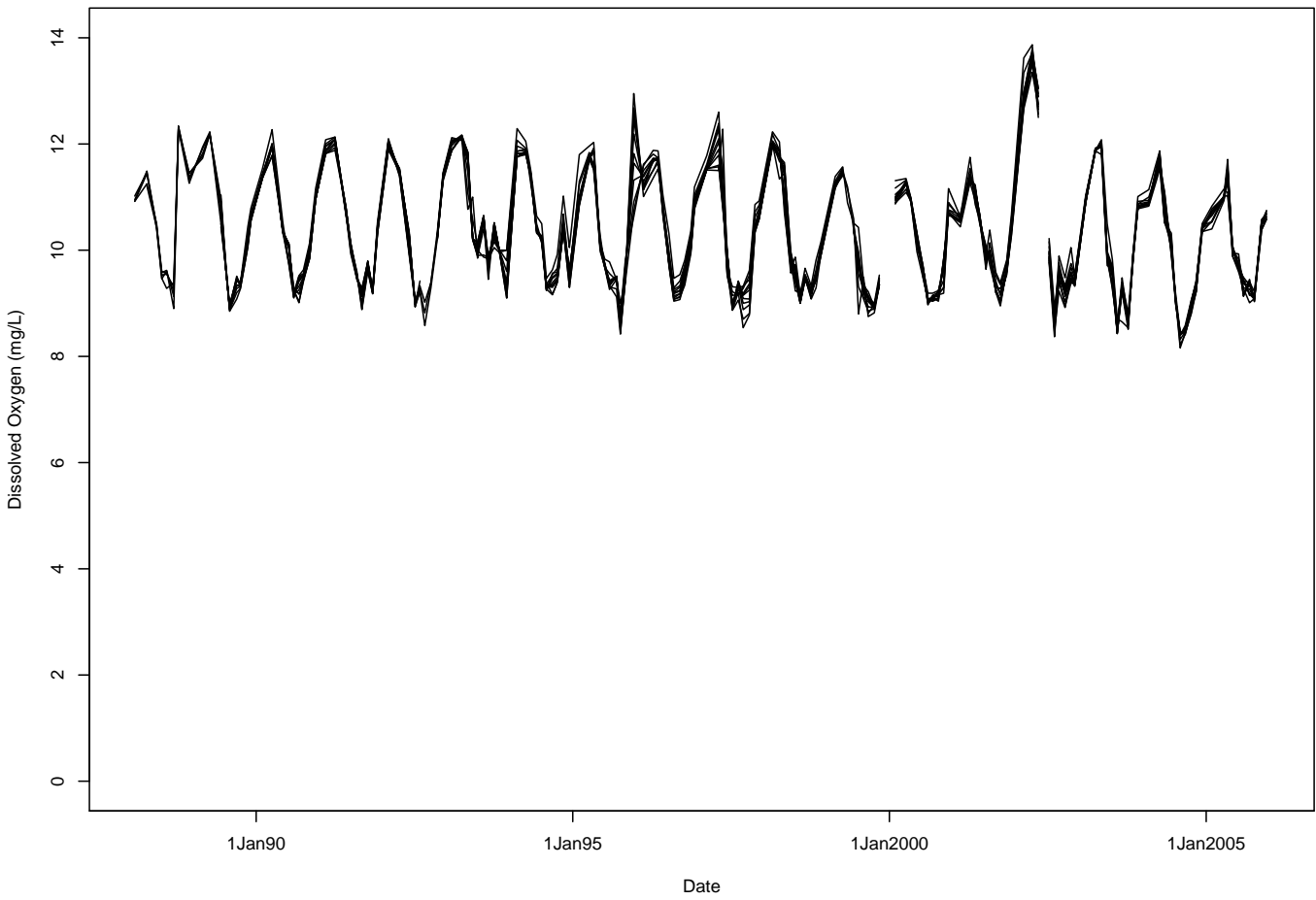


Figure B58: Lake Whatcom dissolved oxygen data for the Intake (1988–2005).

Lake Whatcom dissolved oxygen data for Site 3, February 1988 through December 2005.

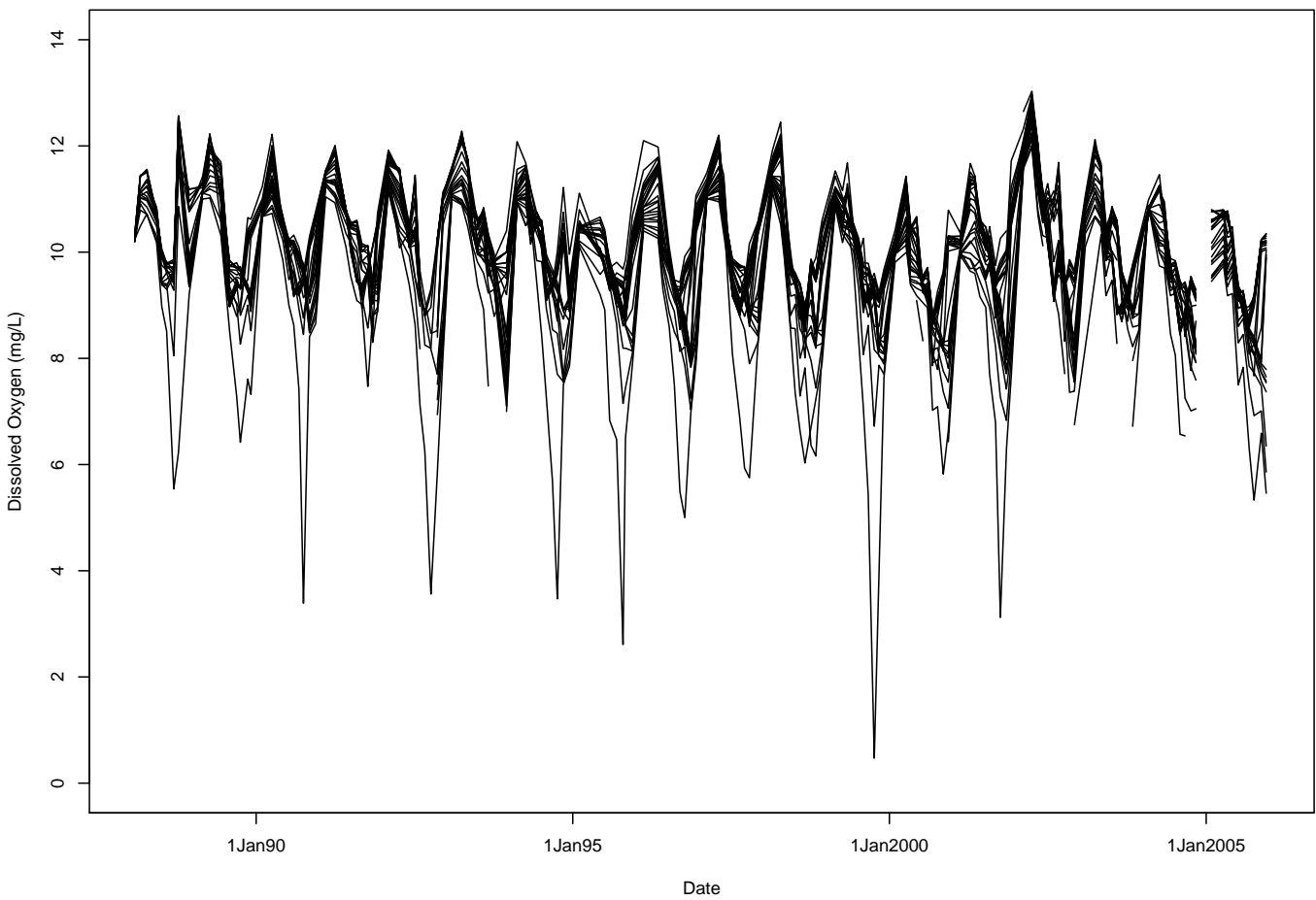


Figure B59: Lake Whatcom dissolved oxygen data for Site 3 (1988–2005).

Lake Whatcom dissolved oxygen data for Site 4, February 1988 through December 2005.

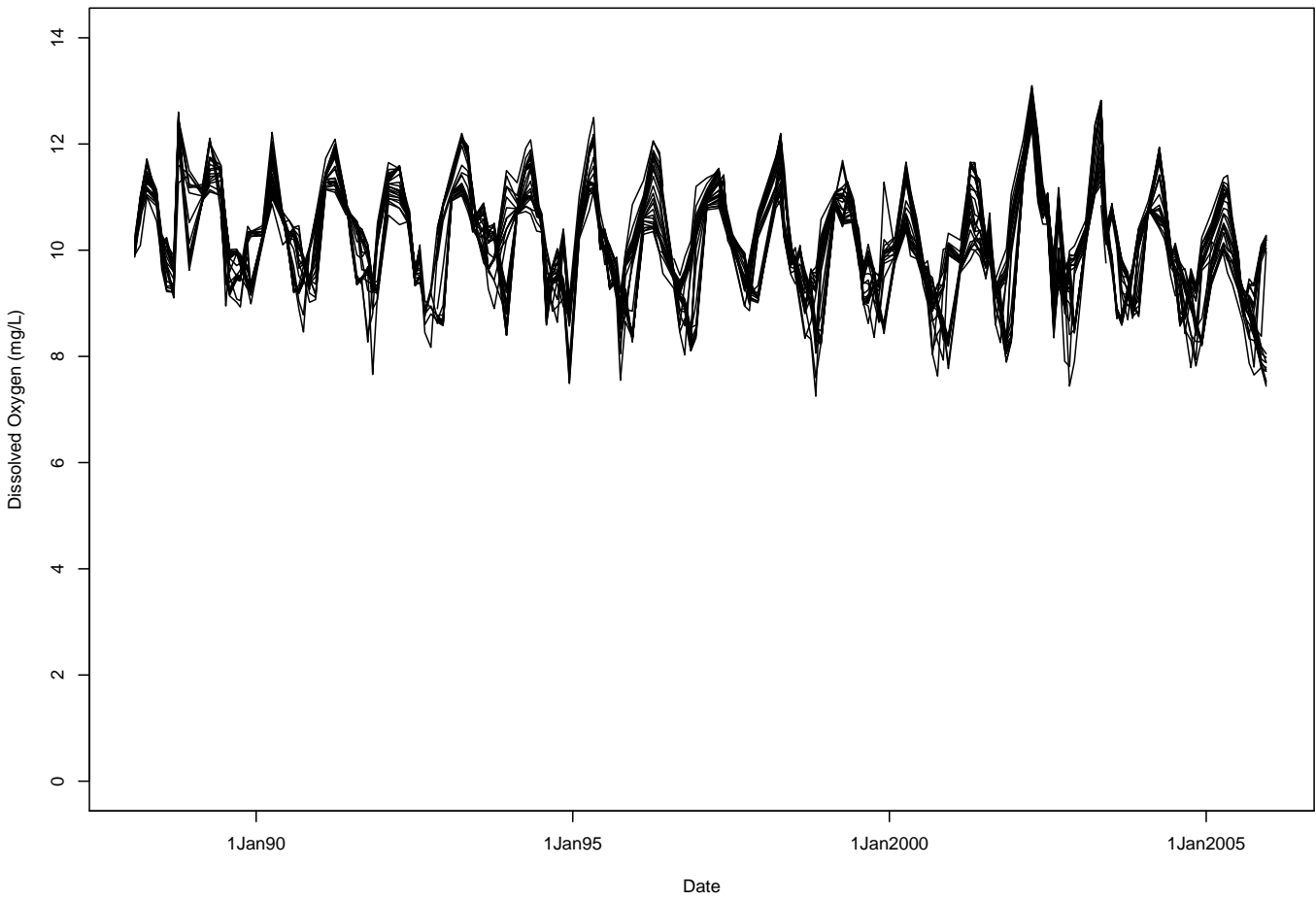


Figure B60: Lake Whatcom dissolved oxygen data for Site 4 (1988-2005).

Lake Whatcom pH data for Site 1, February 1988 through December 2005.

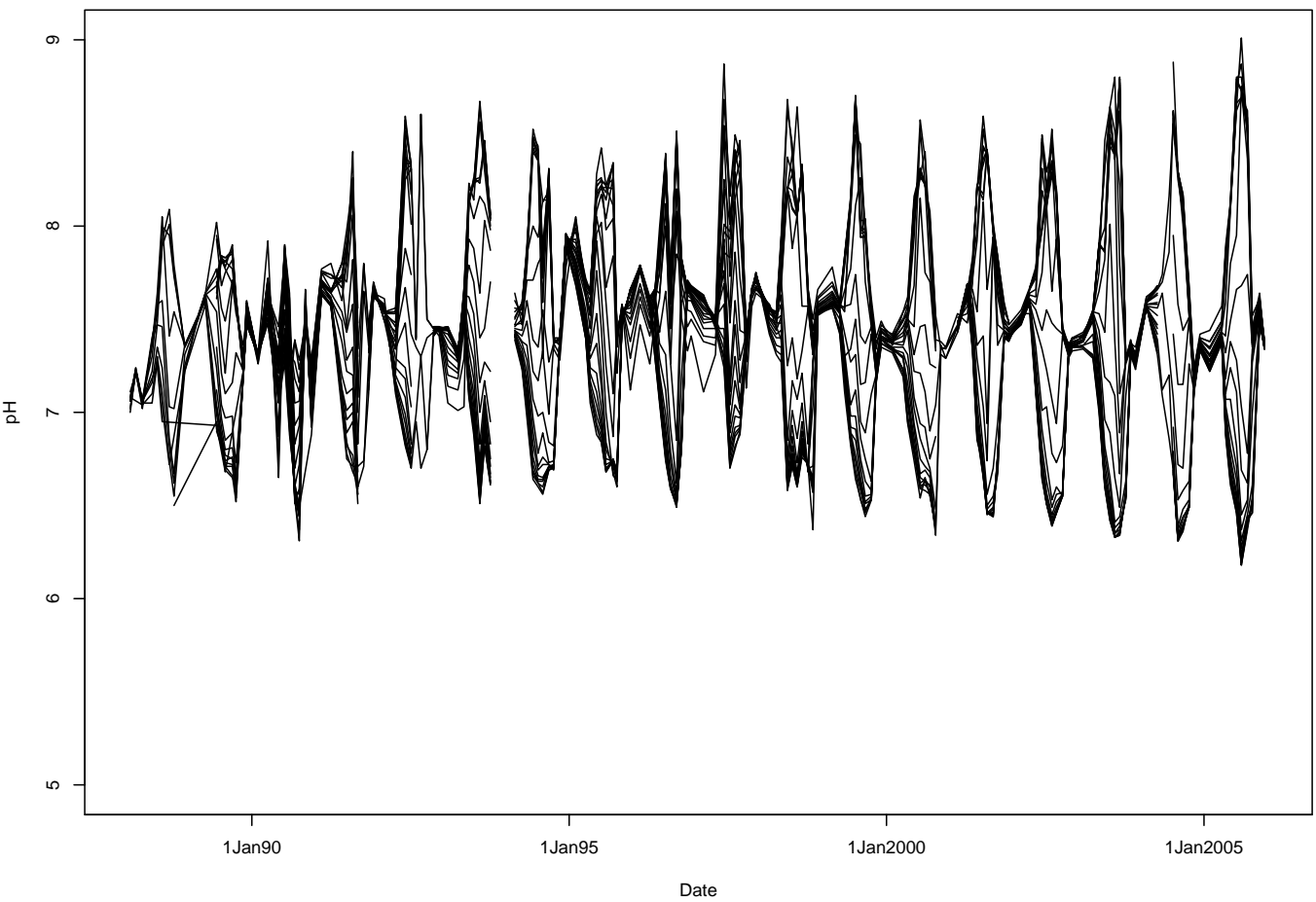


Figure B61: Lake Whatcom pH data for Site 1 (1988–2005).

Lake Whatcom pH data for Site 2, February 1988 through December 2005.

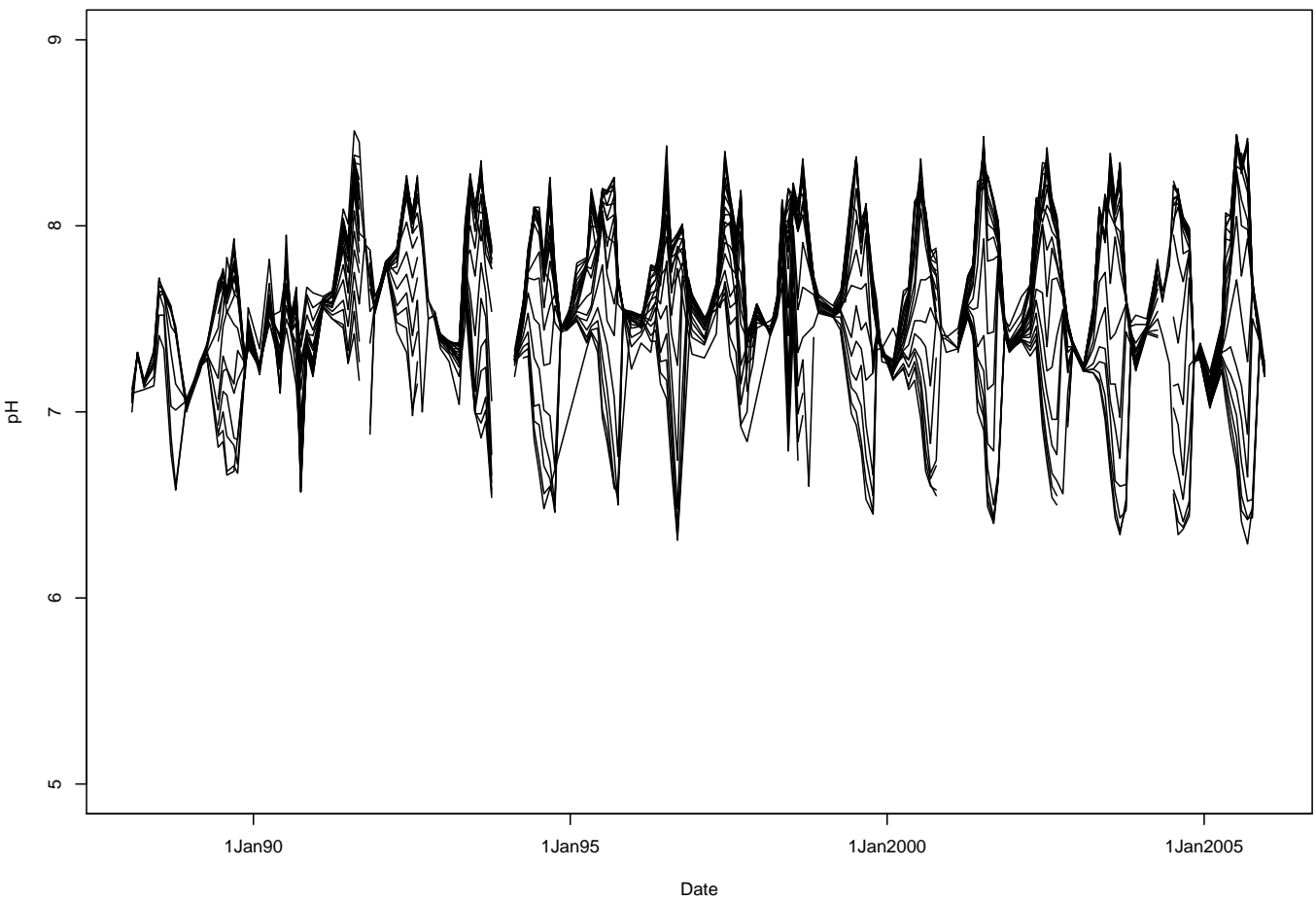


Figure B62: Lake Whatcom pH data for Site 2 (1988–2005).

Lake Whatcom pH data for Intake, February 1988 through December 2005.

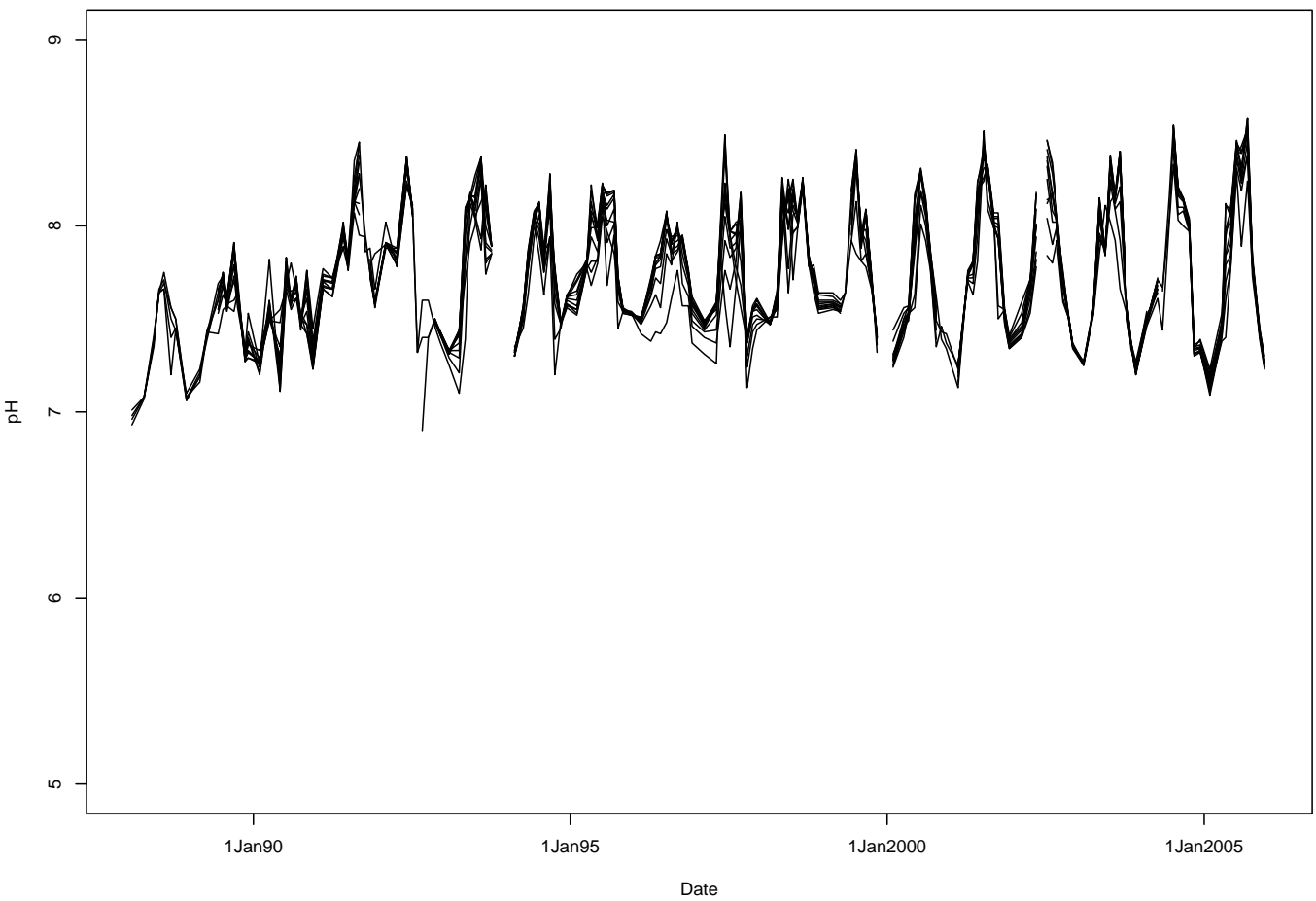


Figure B63: Lake Whatcom pH data for the Intake (1988-2005).

Lake Whatcom pH data for Site 3, February 1988 through December 2005.

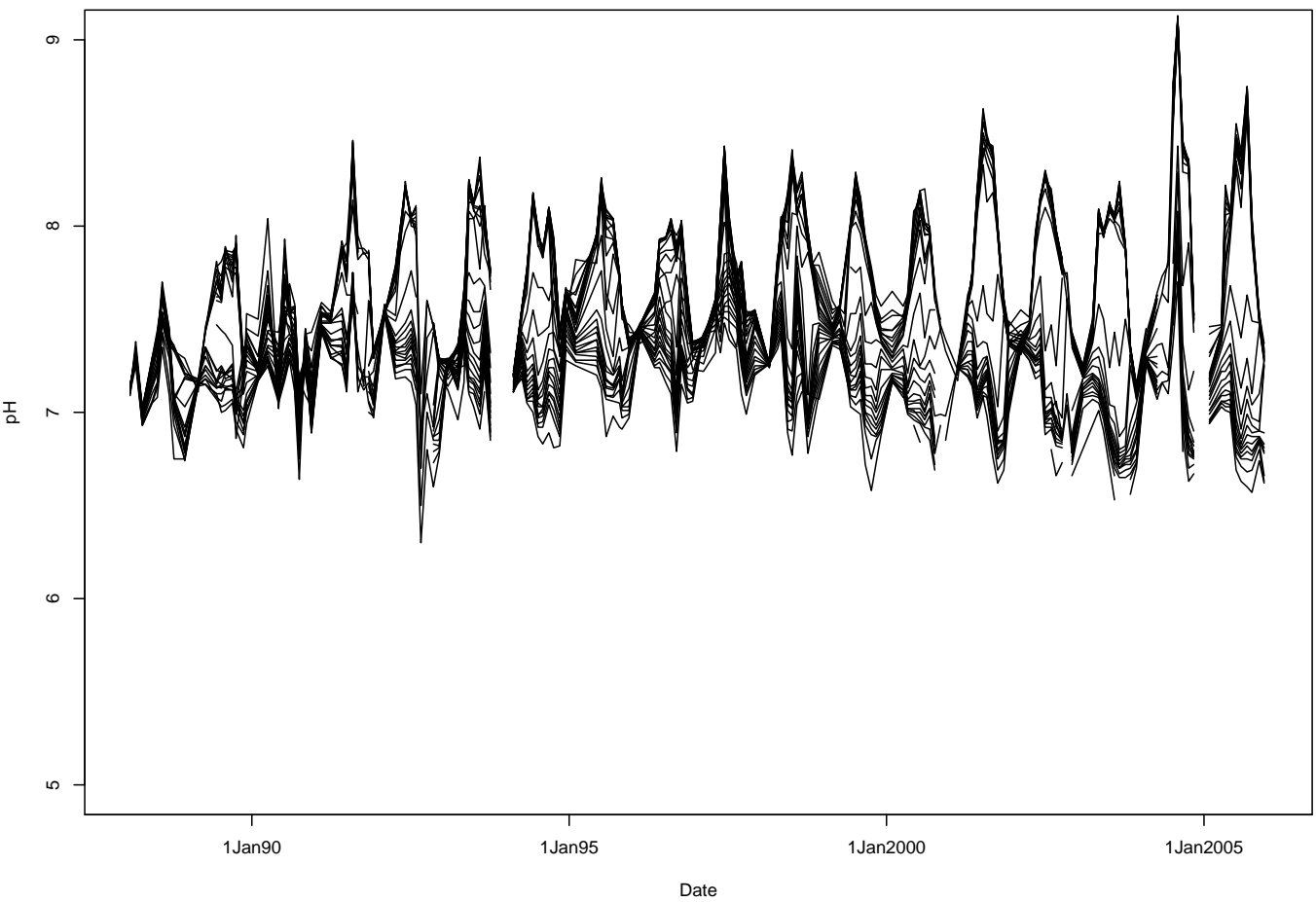


Figure B64: Lake Whatcom pH data for Site 3 (1988–2005).

Lake Whatcom pH data for Site 4, February 1988 through December 2005.

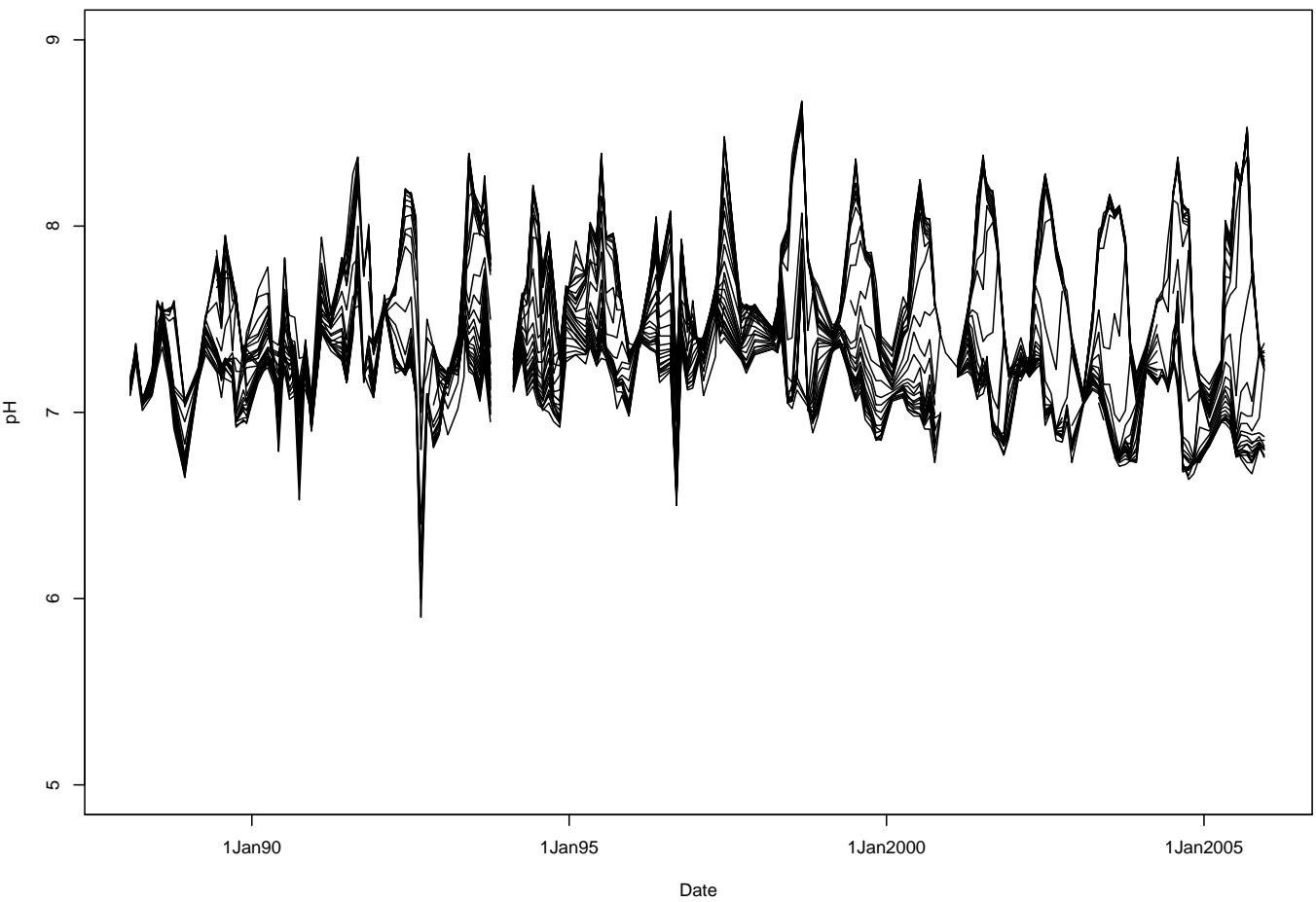


Figure B65: Lake Whatcom pH data for Site 4 (1988–2005).

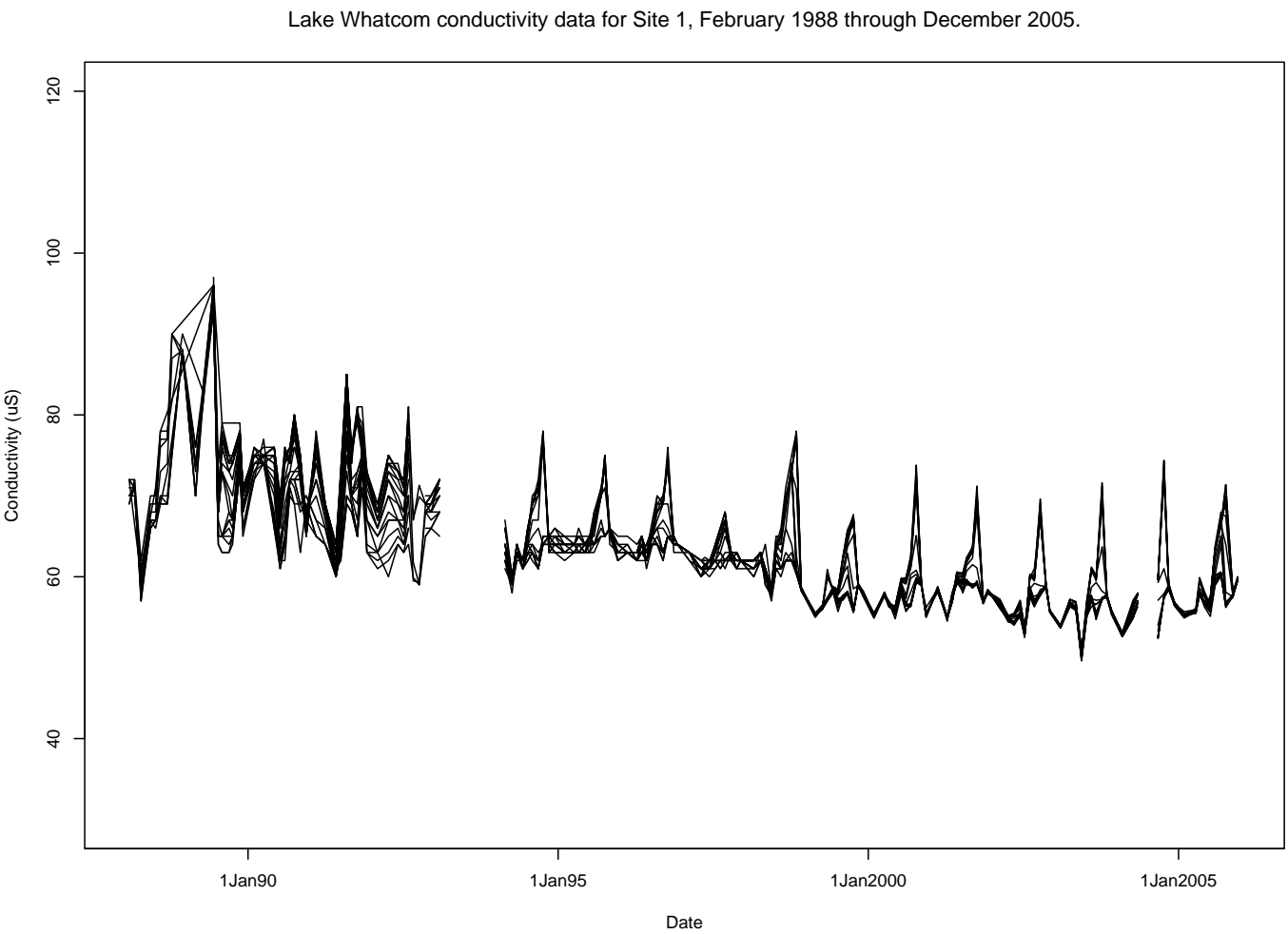


Figure B66: Lake Whatcom conductivity data for Site 1 (1988–2005). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

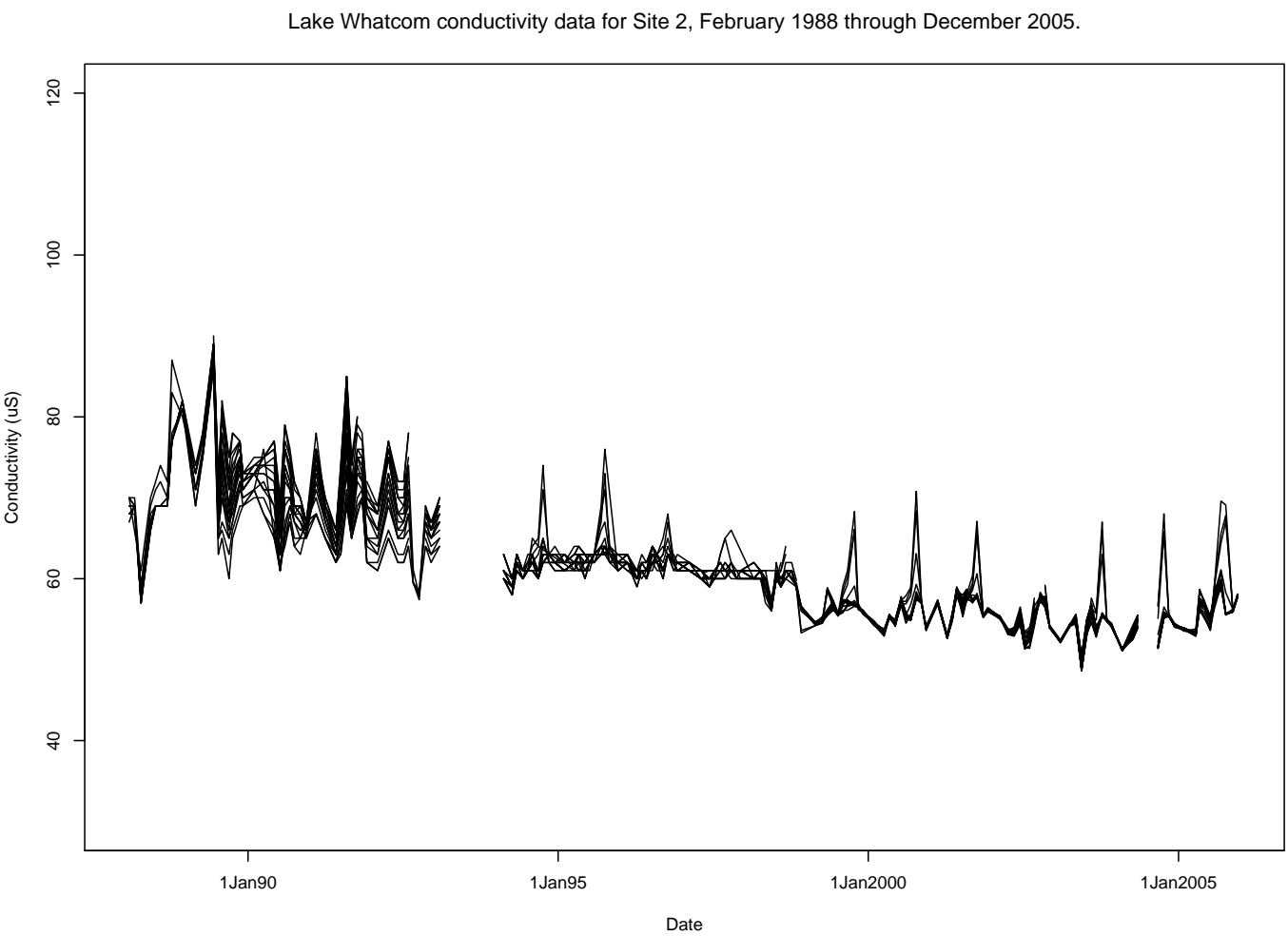


Figure B67: Lake Whatcom conductivity data for Site 2 (1988–2005). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

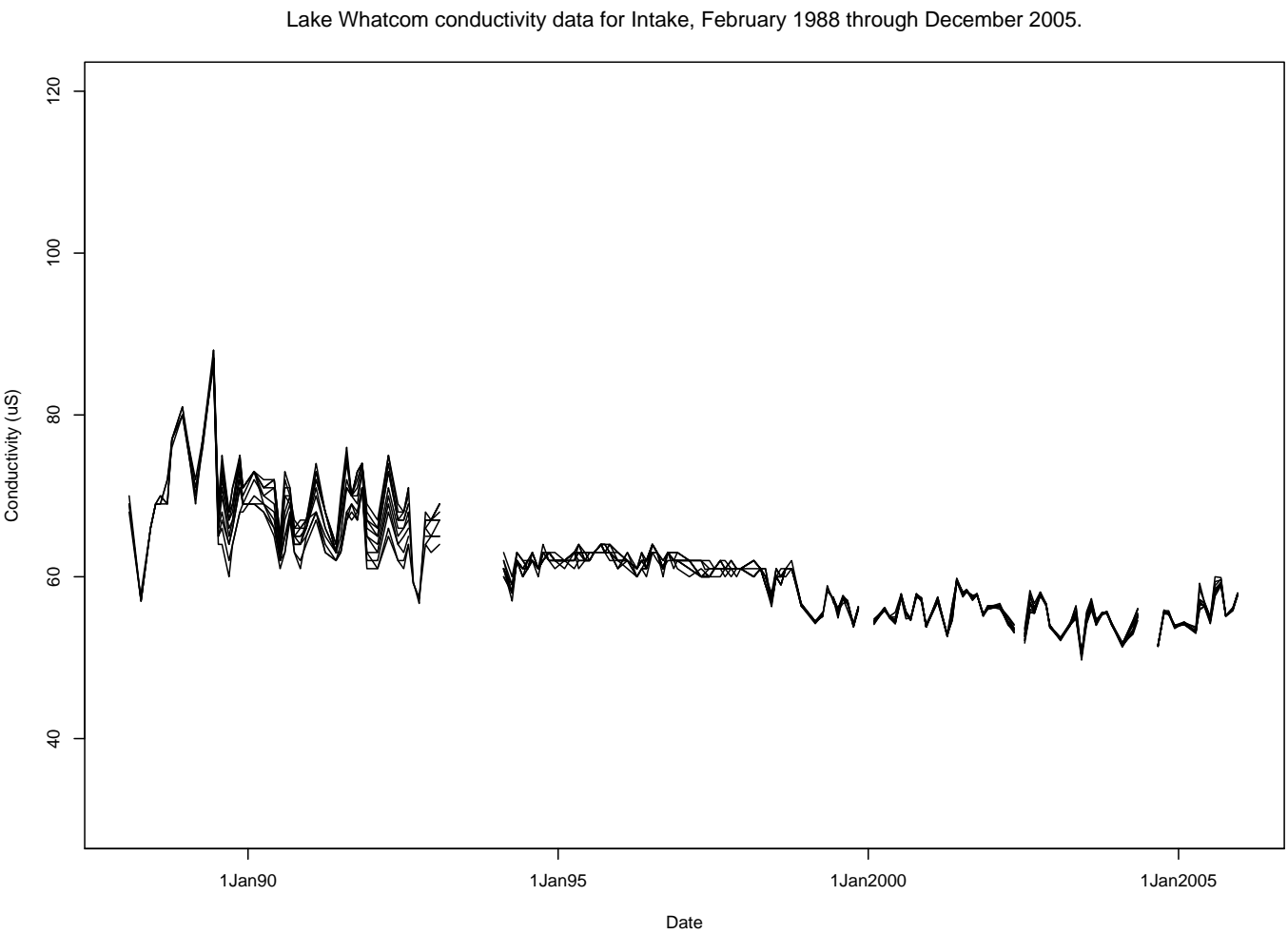


Figure B68: Lake Whatcom conductivity data for the Intake (1988–2005). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

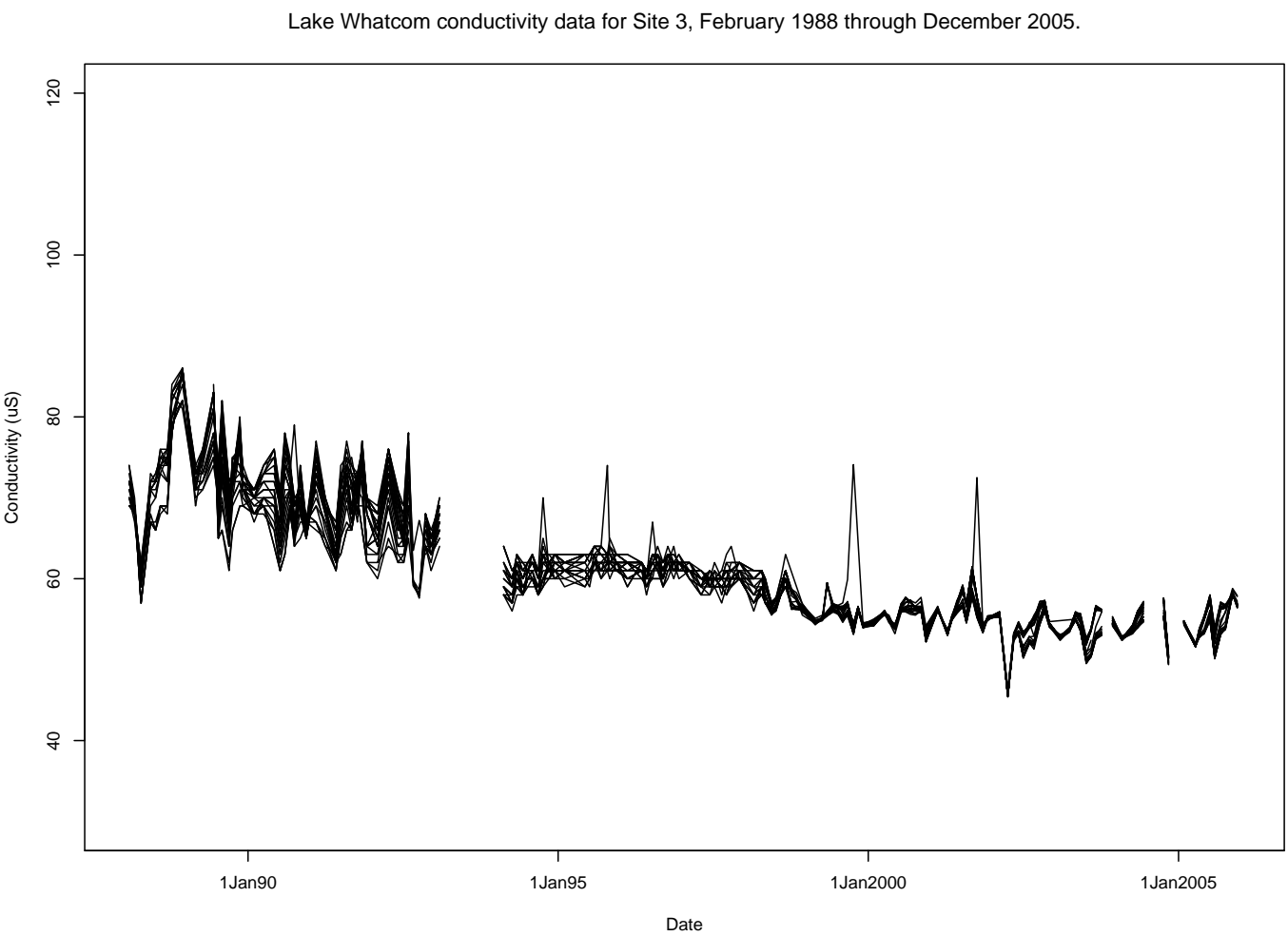


Figure B69: Lake Whatcom conductivity data for Site 3 (1988–2005). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

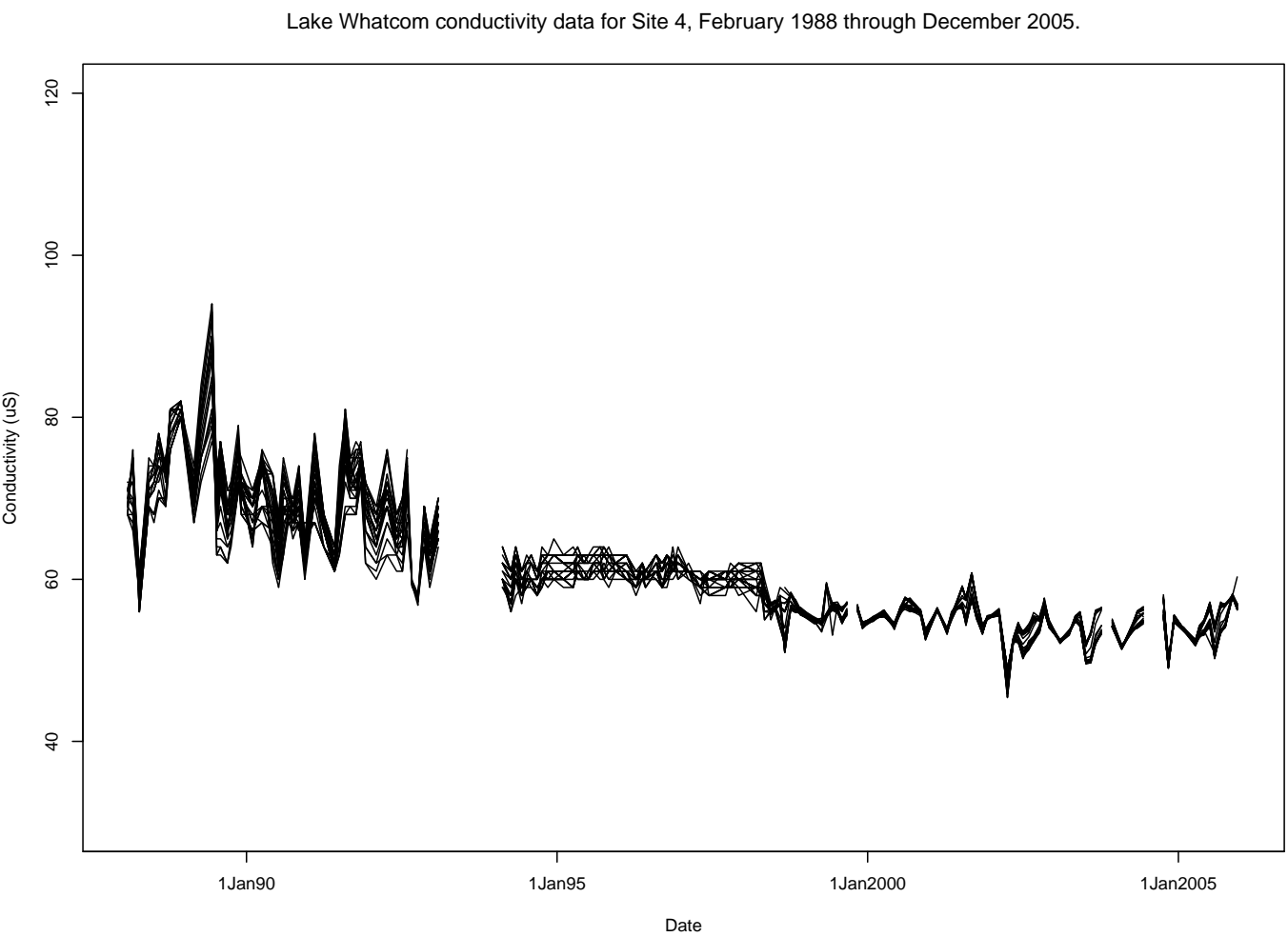


Figure B70: Lake Whatcom conductivity data for Site 4 (1988–2005). The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

B.3 Alkalinity and Turbidity

Lake Whatcom alkalinity data for Site 1, February 1988 through December 2005.

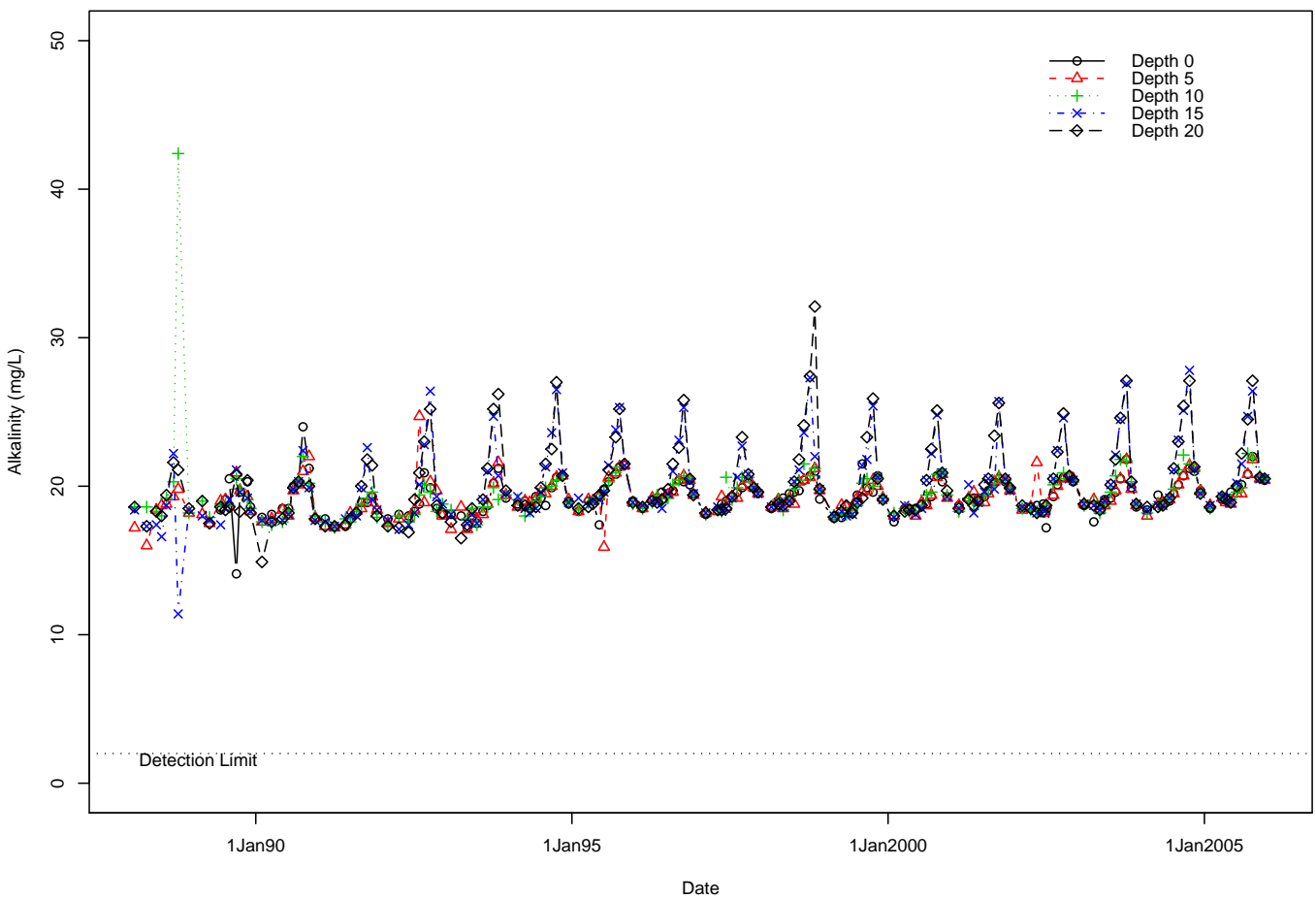


Figure B71: Lake Whatcom alkalinity data for Site 1 (1988-2005).

Lake Whatcom alkalinity data for Site 2, February 1988 through December 2005.

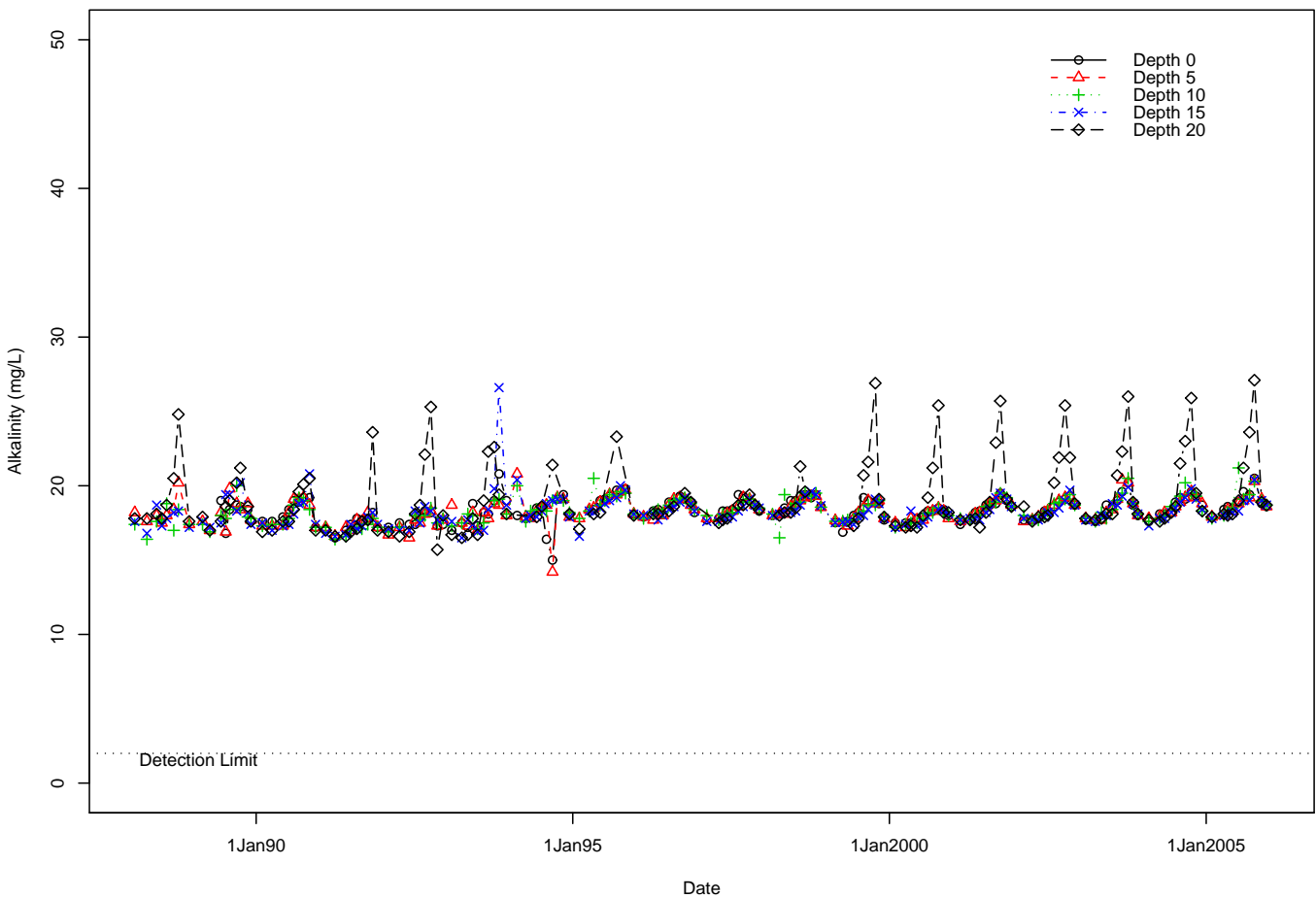


Figure B72: Lake Whatcom alkalinity data for Site 2 (1988-2005).

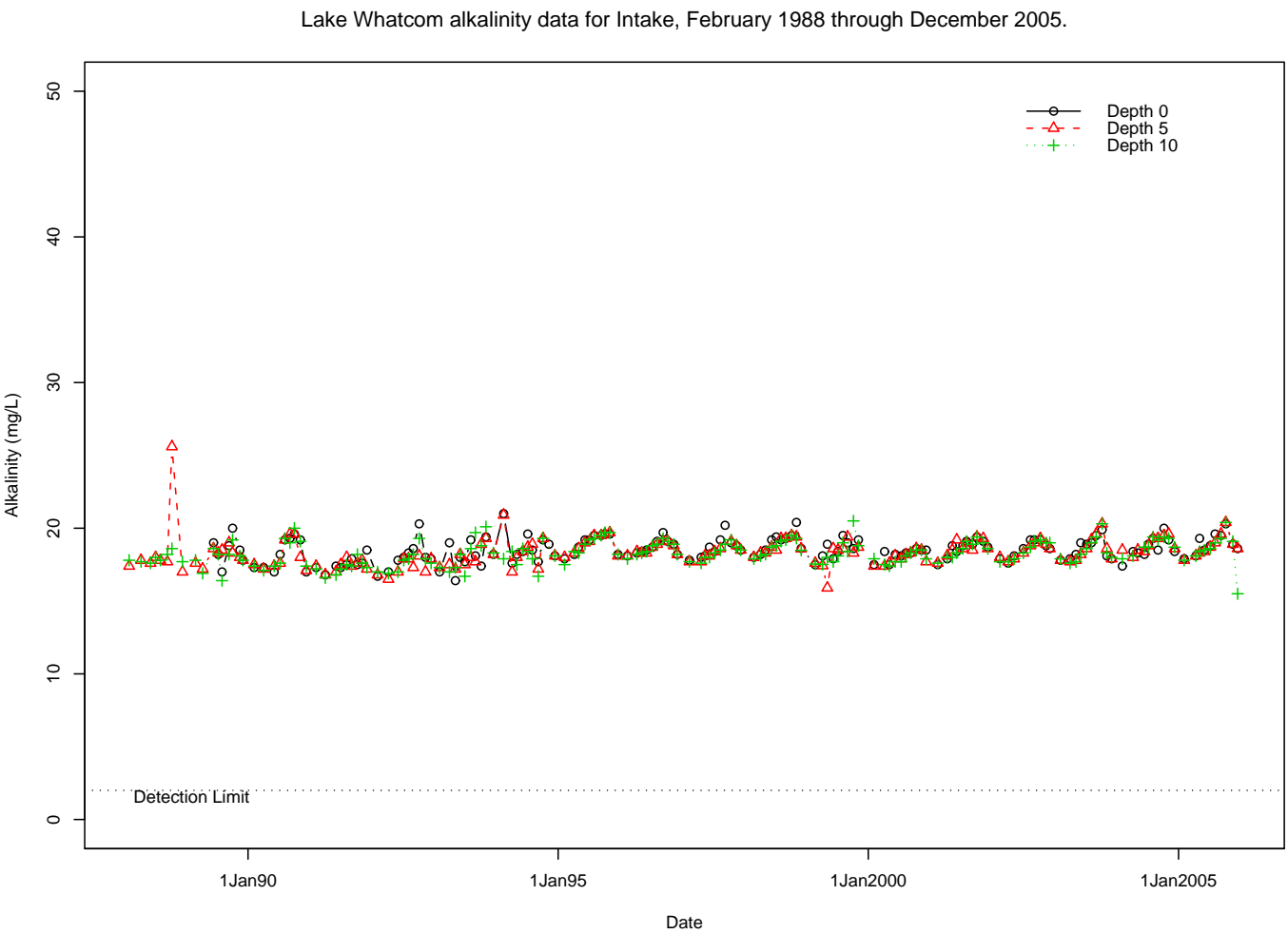


Figure B73: Lake Whatcom alkalinity data for the Intake (1988–2005).

Lake Whatcom alkalinity data for Site 3, February 1988 through December 2005.

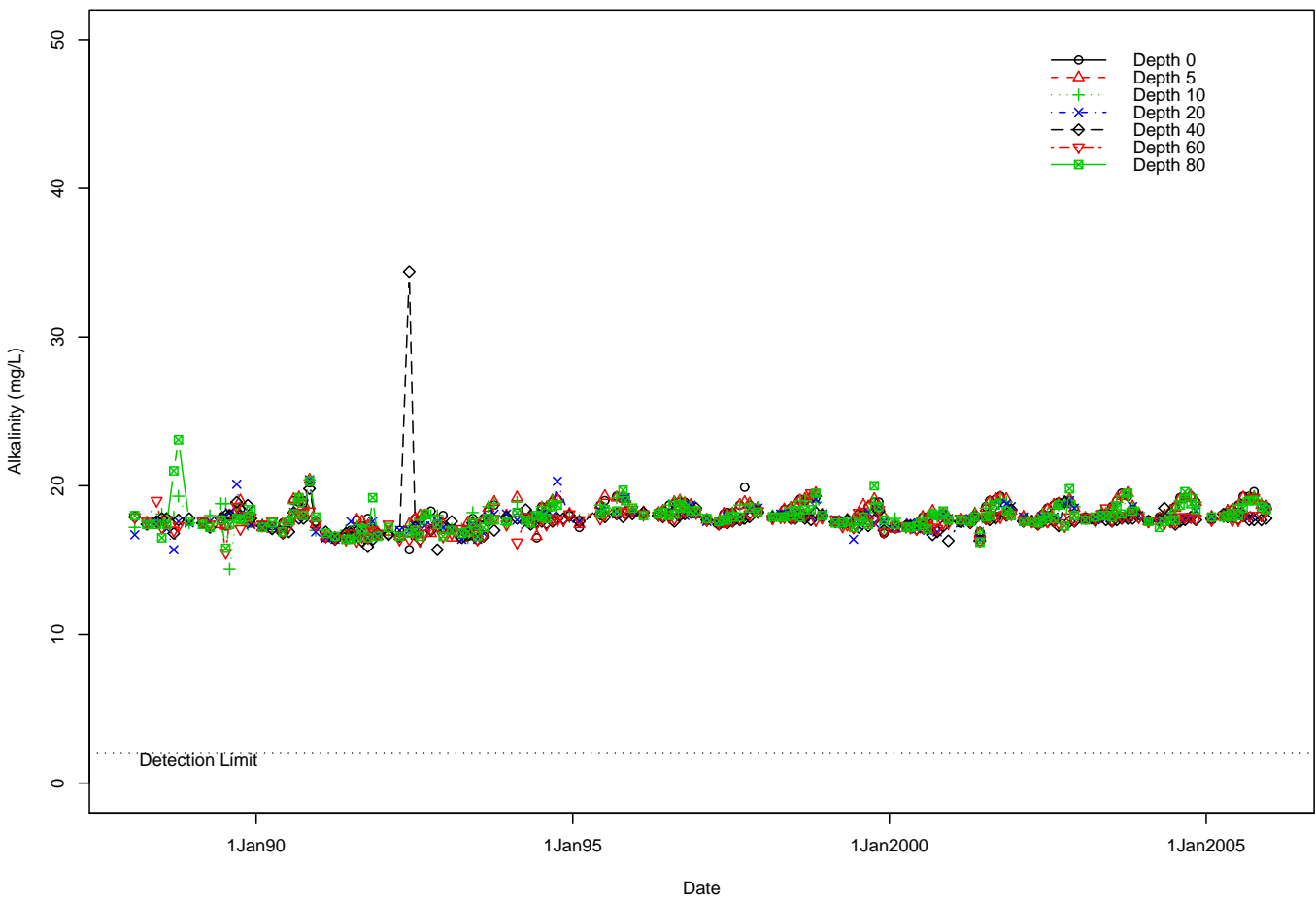


Figure B74: Lake Whatcom alkalinity data for Site 3 (1988-2005).

Lake Whatcom alkalinity data for Site 4, February 1988 through December 2005.

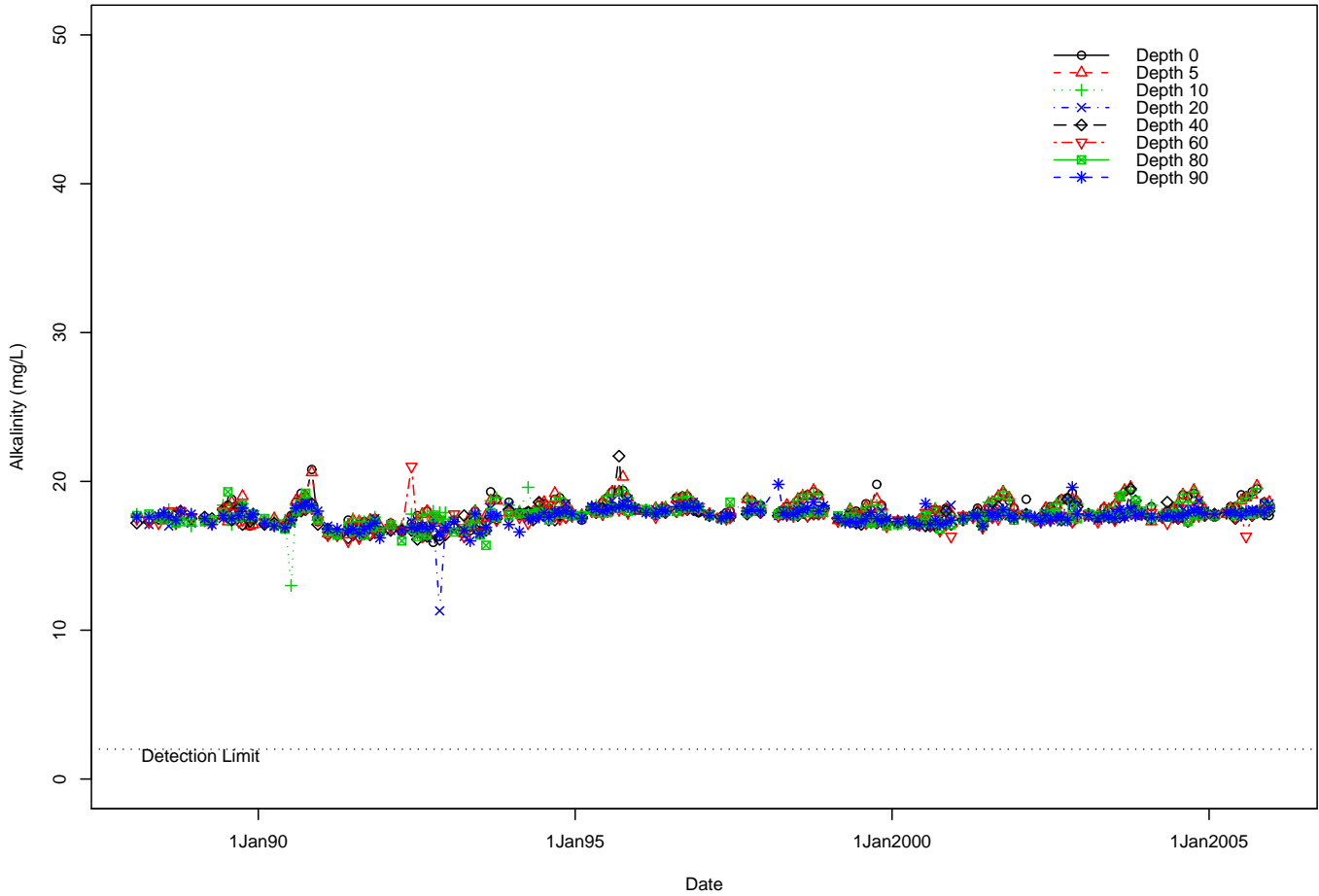


Figure B75: Lake Whatcom alkalinity data for Site 4 (1988-2005).

Lake Whatcom turbidity data for Site 1, February 1988 through December 2005.

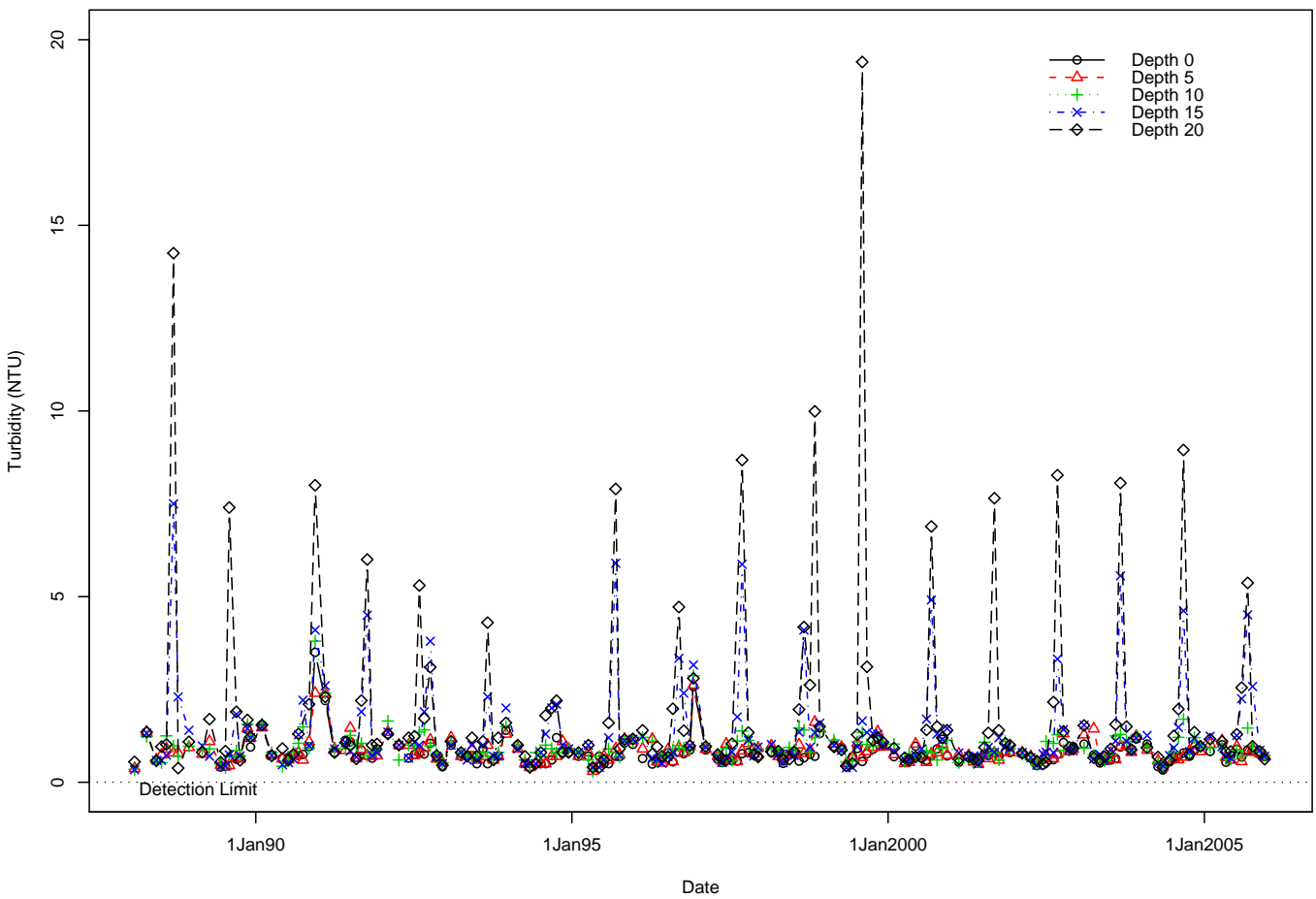


Figure B76: Lake Whatcom turbidity data for Site 1 (1988–2005).

Lake Whatcom turbidity data for Site 2, February 1988 through December 2005.

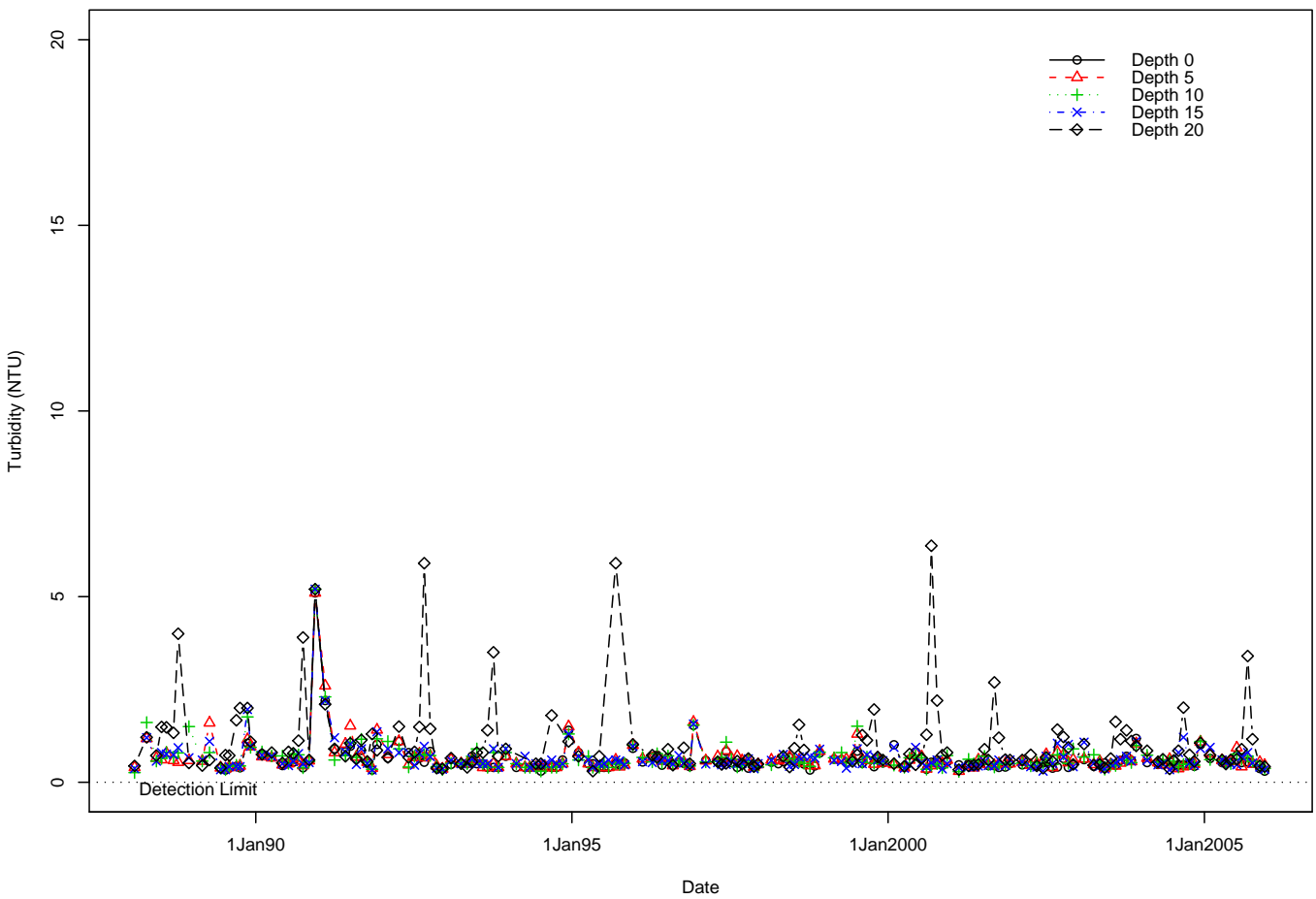


Figure B77: Lake Whatcom turbidity data for Site 2 (1988–2005).

Lake Whatcom turbidity data for Intake, February 1988 through December 2005.

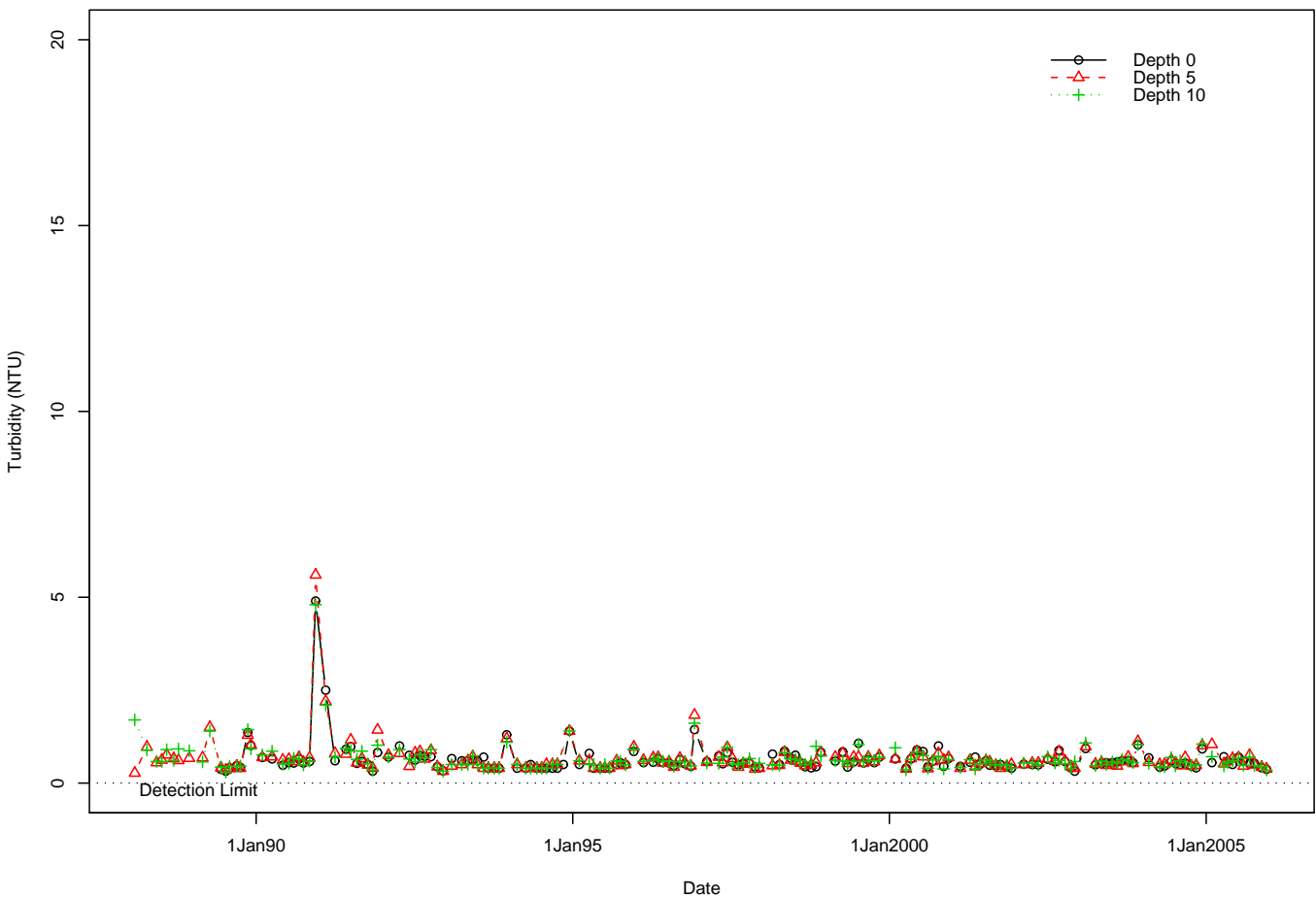


Figure B78: Lake Whatcom turbidity data for the Intake (1988–2005).

Lake Whatcom turbidity data for Site 3, February 1988 through December 2005.

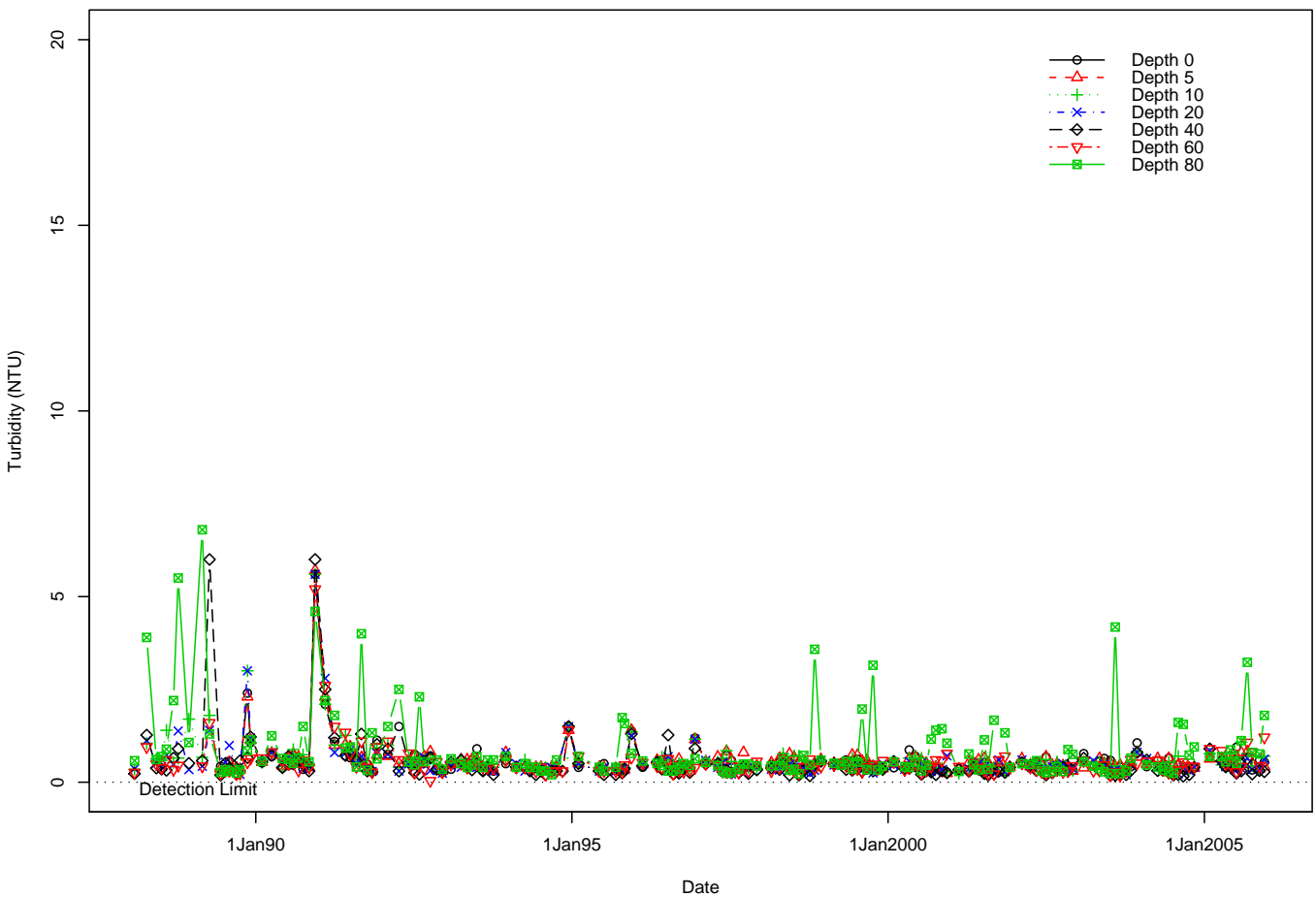


Figure B79: Lake Whatcom turbidity data for Site 3 (1988–2005).

Lake Whatcom turbidity data for Site 4, February 1988 through December 2005.

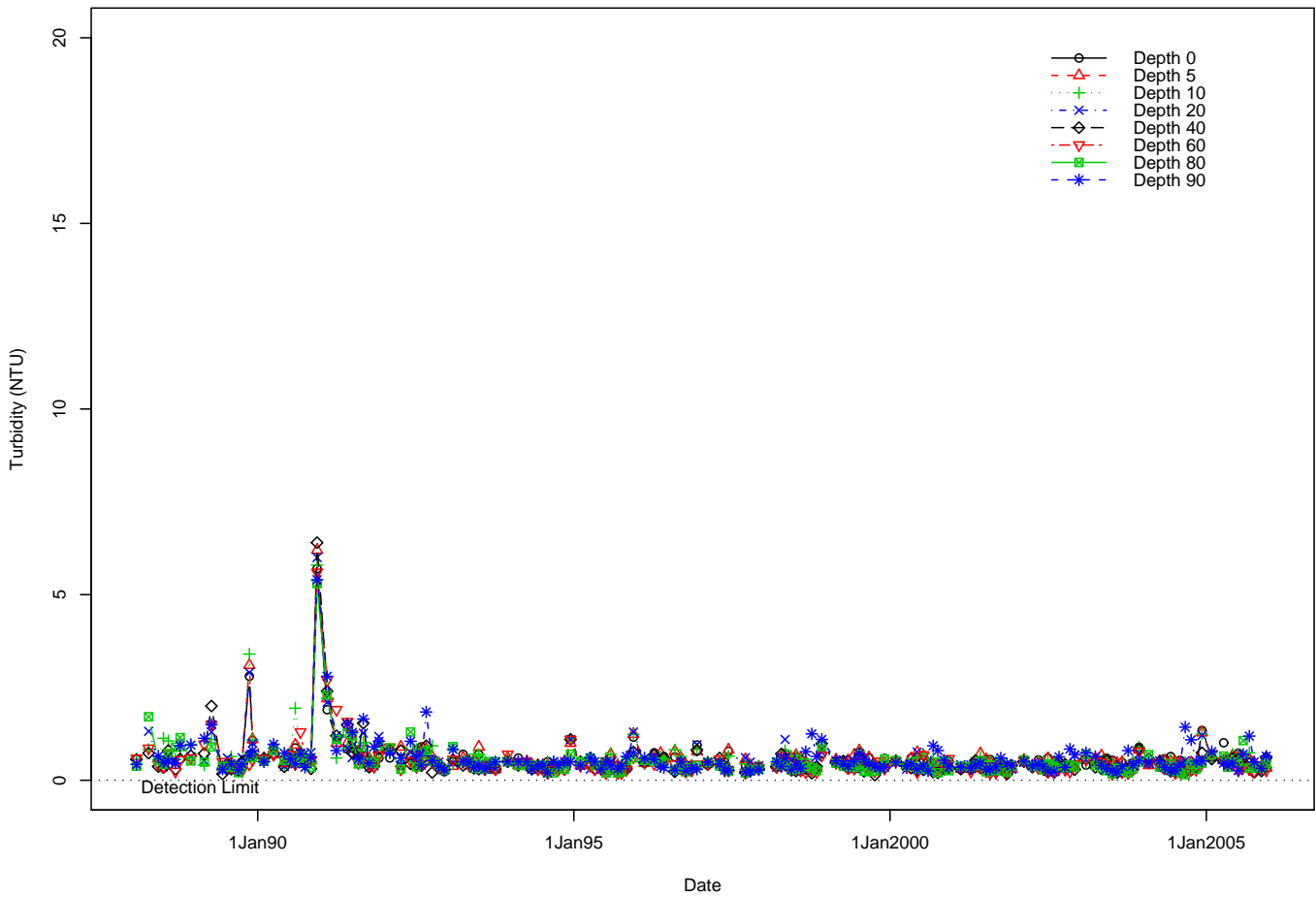


Figure B80: Lake Whatcom turbidity data for Site 4 (1988–2005).

B.4 Nitrogen and Phosphorus

Lake Whatcom ammonia data for Site 1, February 1988 through December 2005.

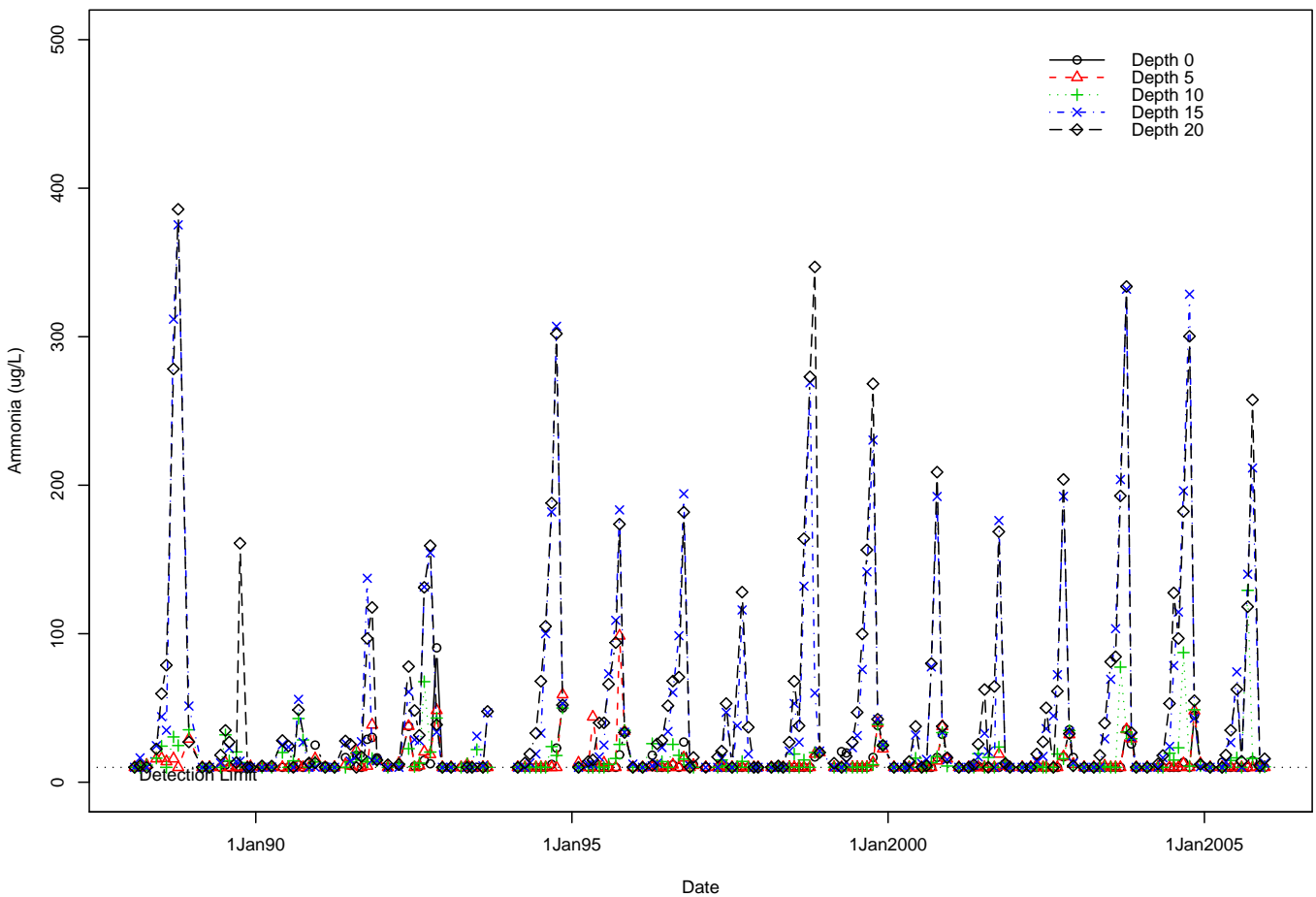


Figure B81: Lake Whatcom ammonia data for Site 1 (1988–2005).

Lake Whatcom ammonia data for Site 2, February 1988 through December 2005.

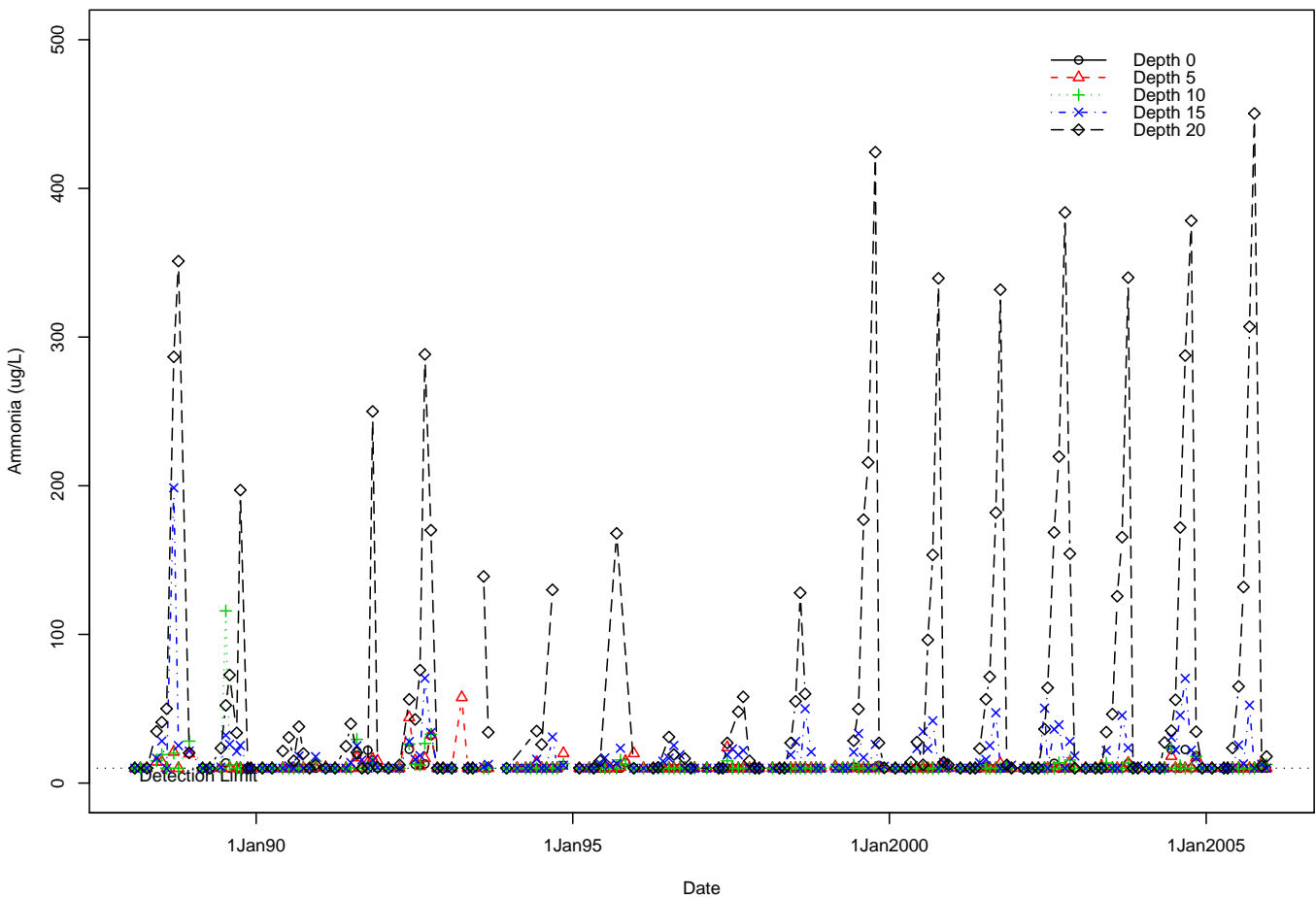


Figure B82: Lake Whatcom ammonia data for Site 2 (1988–2005).

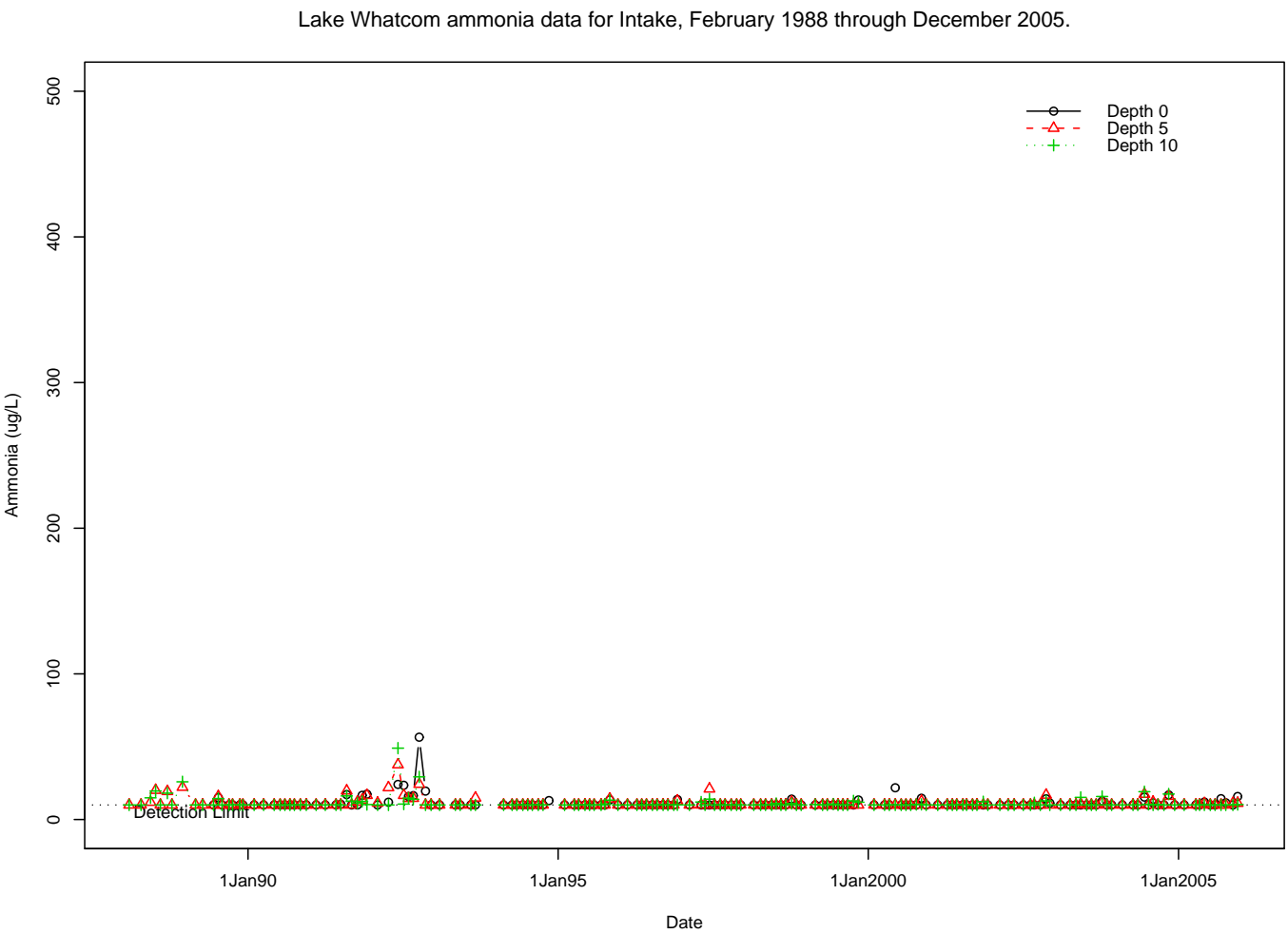


Figure B83: Lake Whatcom ammonia data for the Intake (1988–2005).

Lake Whatcom ammonia data for Site 3, February 1988 through December 2005.

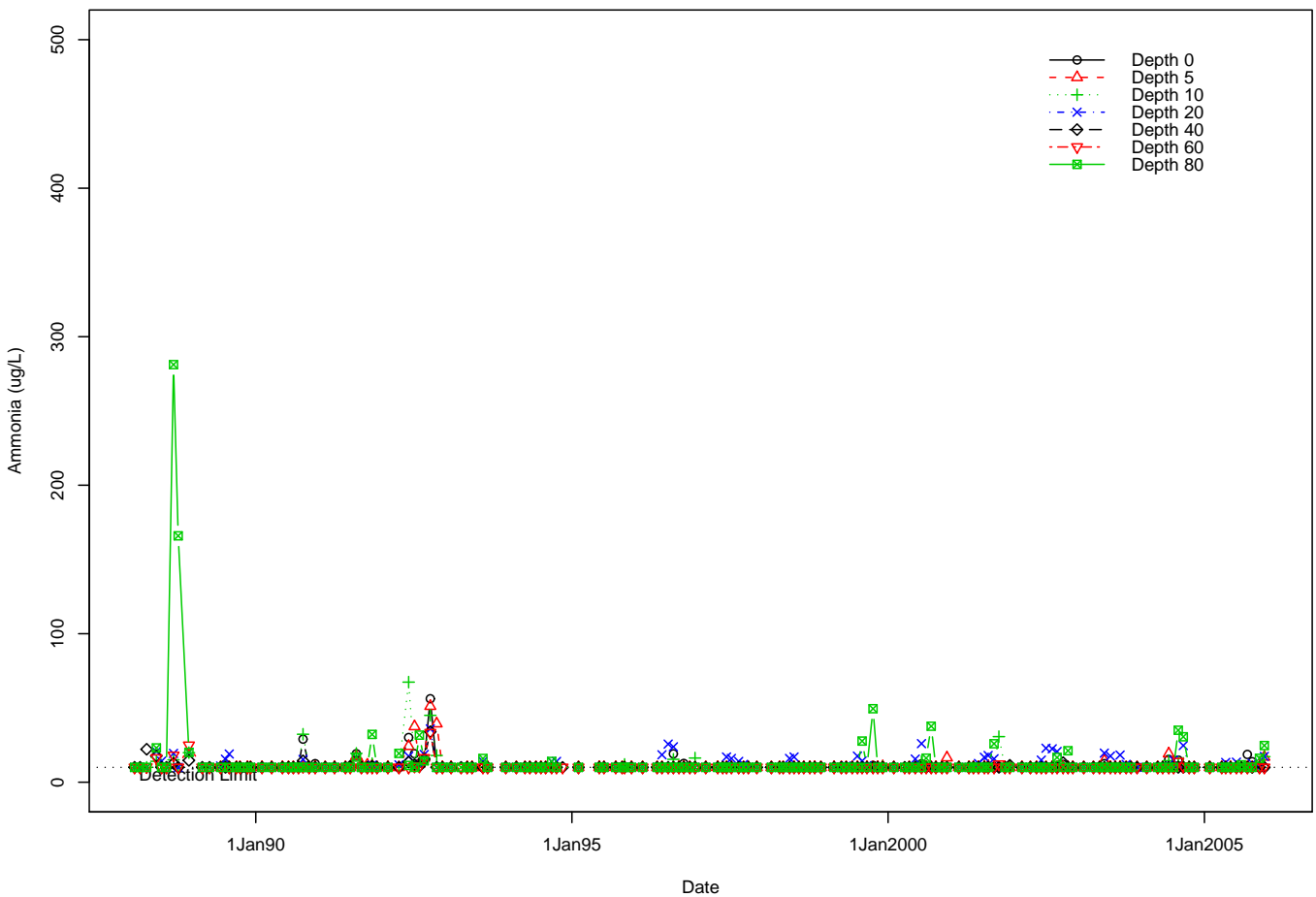


Figure B84: Lake Whatcom ammonia data for Site 3 (1988–2005).

Lake Whatcom ammonia data for Site 4, February 1988 through December 2005.

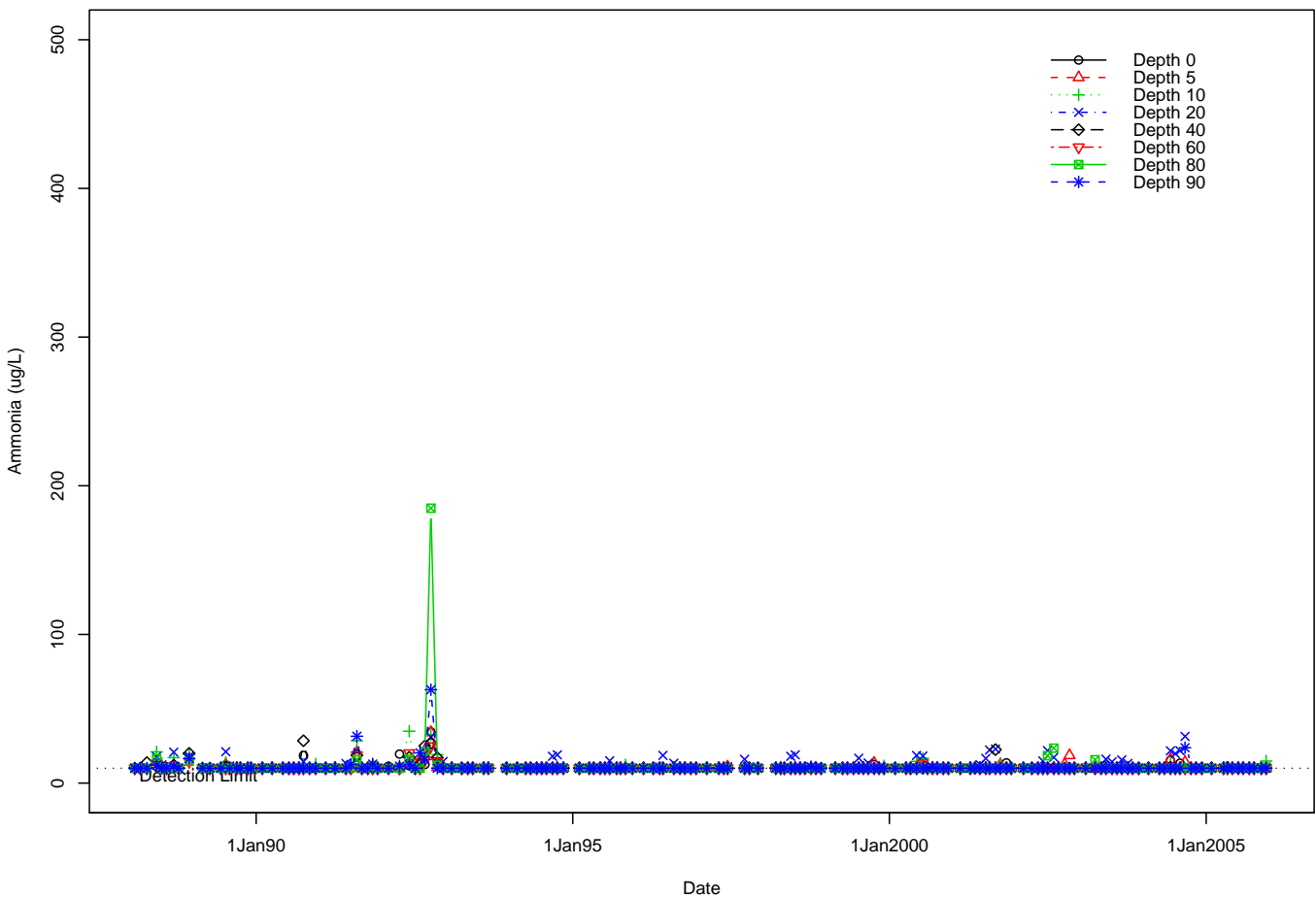


Figure B85: Lake Whatcom ammonia data for Site 4 (1988–2005).

Lake Whatcom nitrate/nitrite data for Site 1, February 1988 through December 2005.

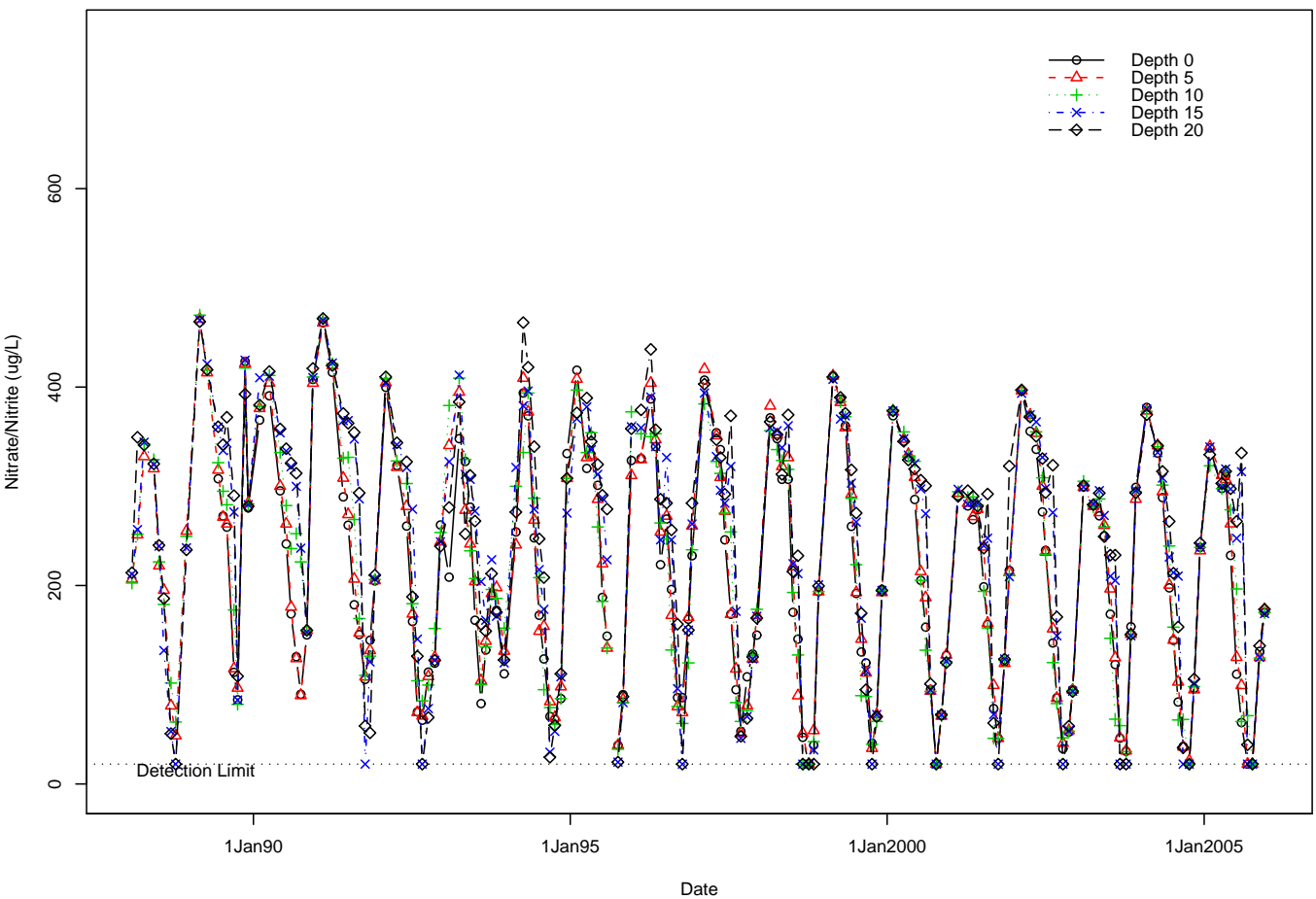


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1 (1988–2005).

Lake Whatcom nitrate/nitrite data for Site 2, February 1988 through December 2005.

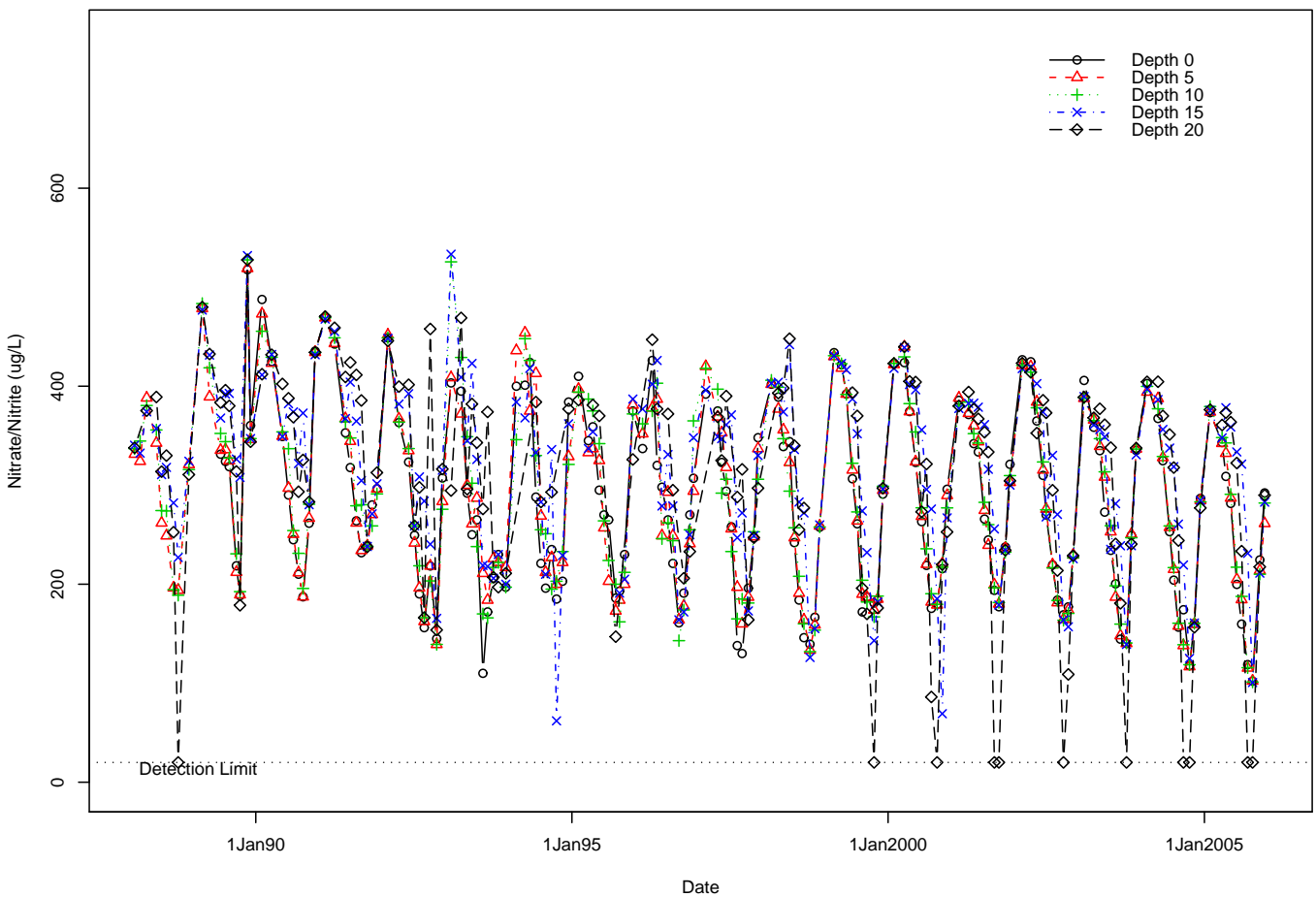


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2 (1988–2005).

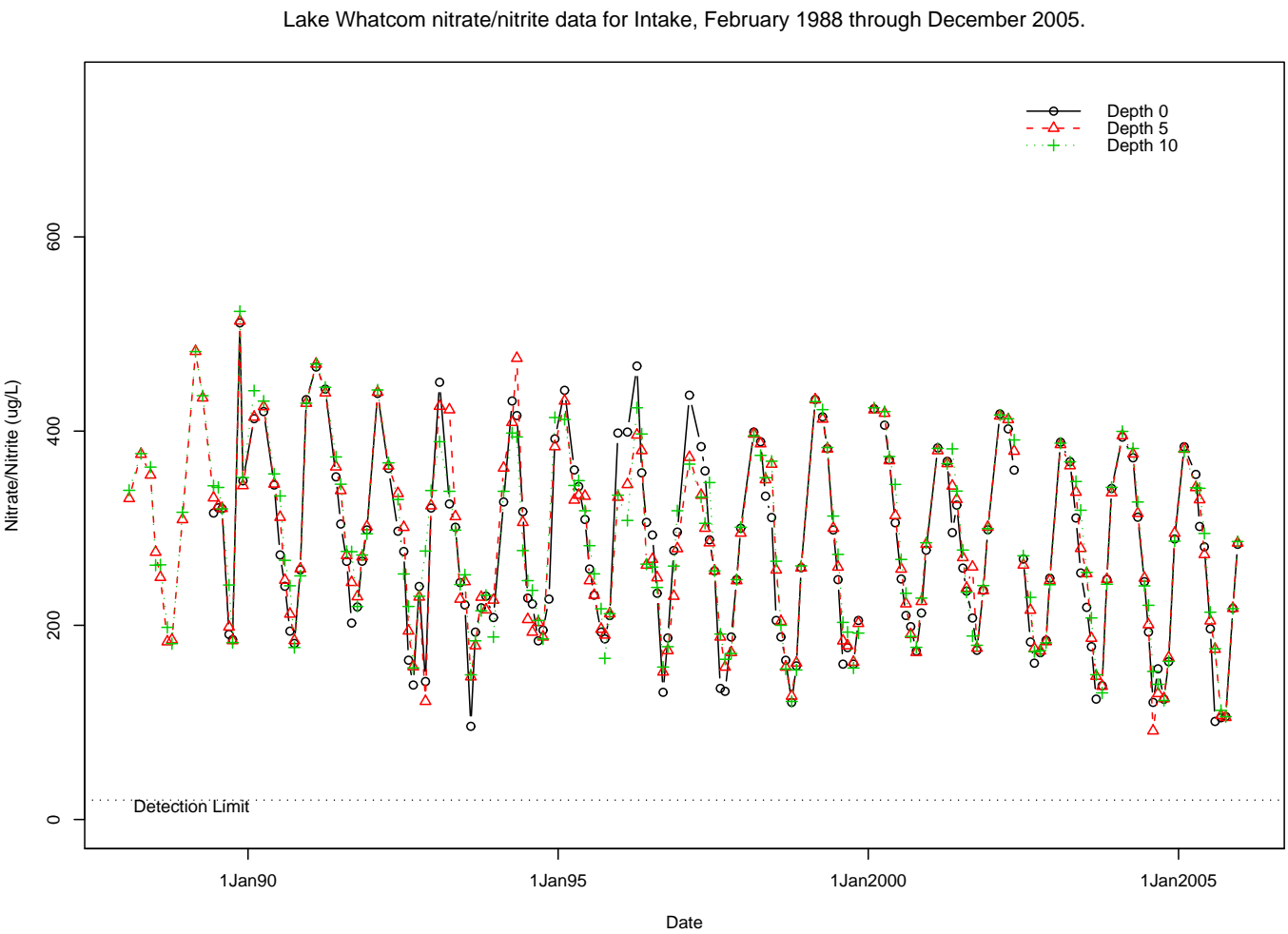


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake (1988-2005).

Lake Whatcom nitrate/nitrite data for Site 3, February 1988 through December 2005.

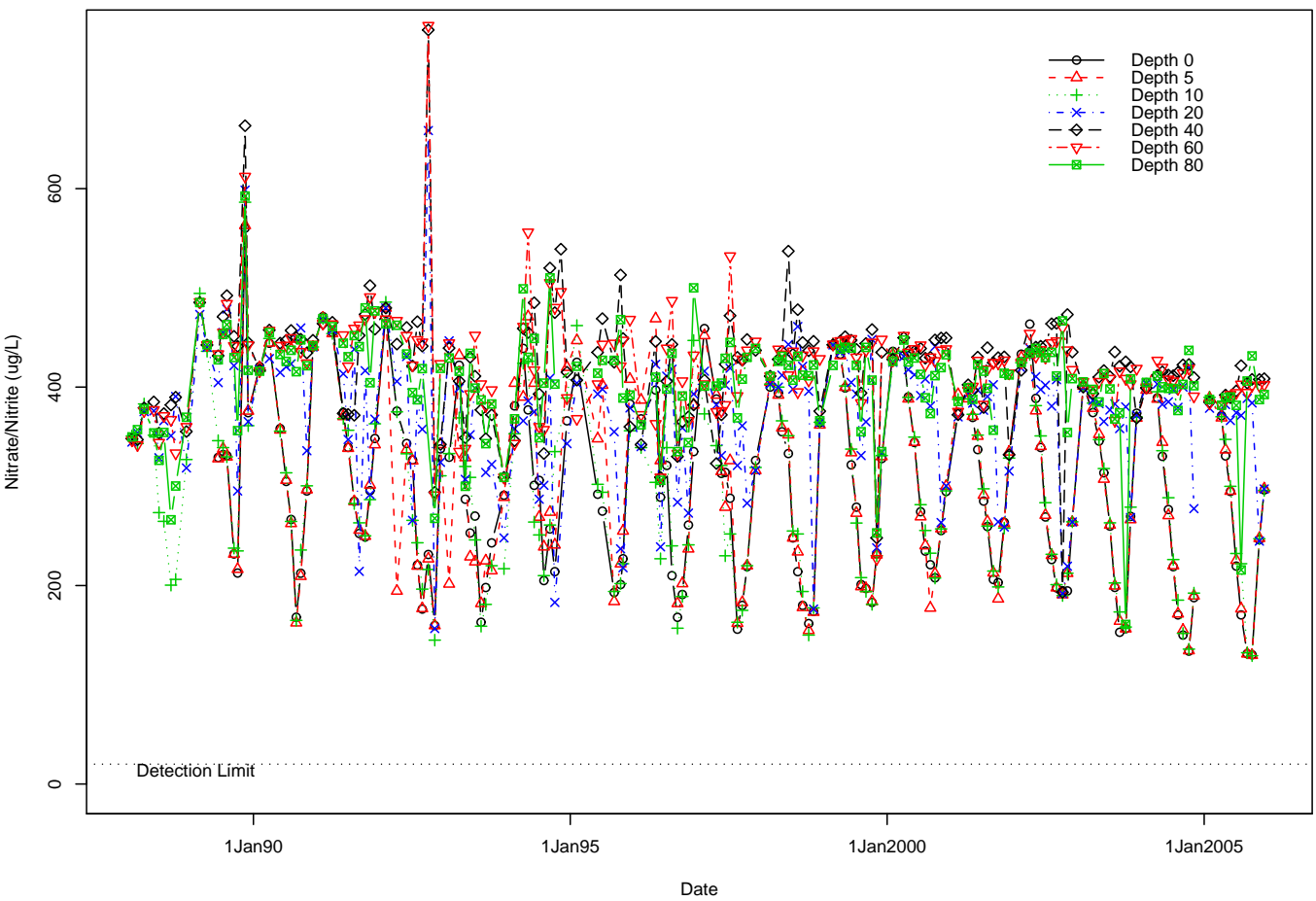


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3 (1988–2005).

Lake Whatcom nitrate/nitrite data for Site 4, February 1988 through December 2005.

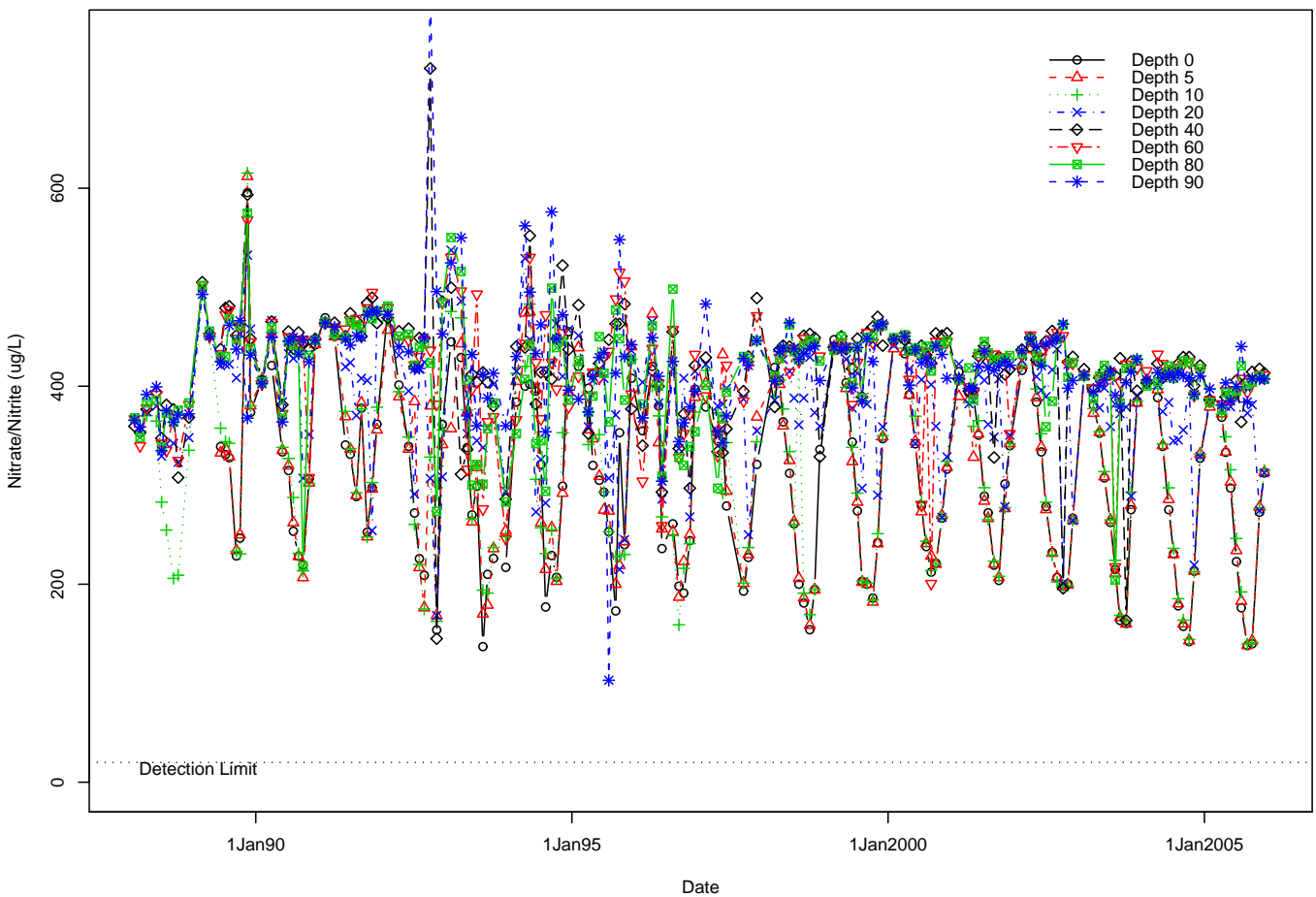


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4 (1988–2005).

Lake Whatcom total nitrogen data for Site 1, February 1988 through December 2005.

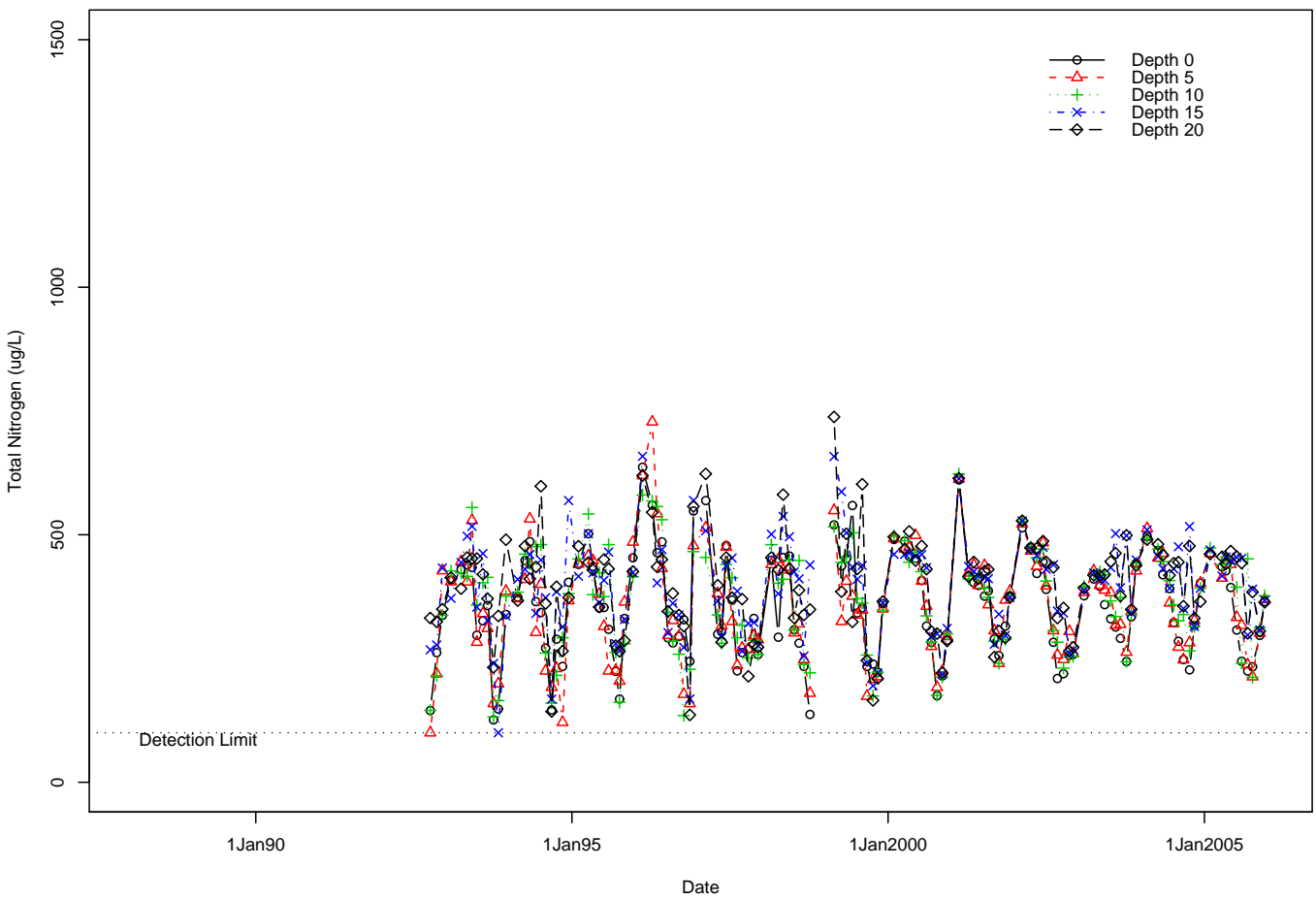


Figure B91: Lake Whatcom total nitrogen data for Site 1 (1988–2005).

Lake Whatcom total nitrogen data for Site 2, February 1988 through December 2005.

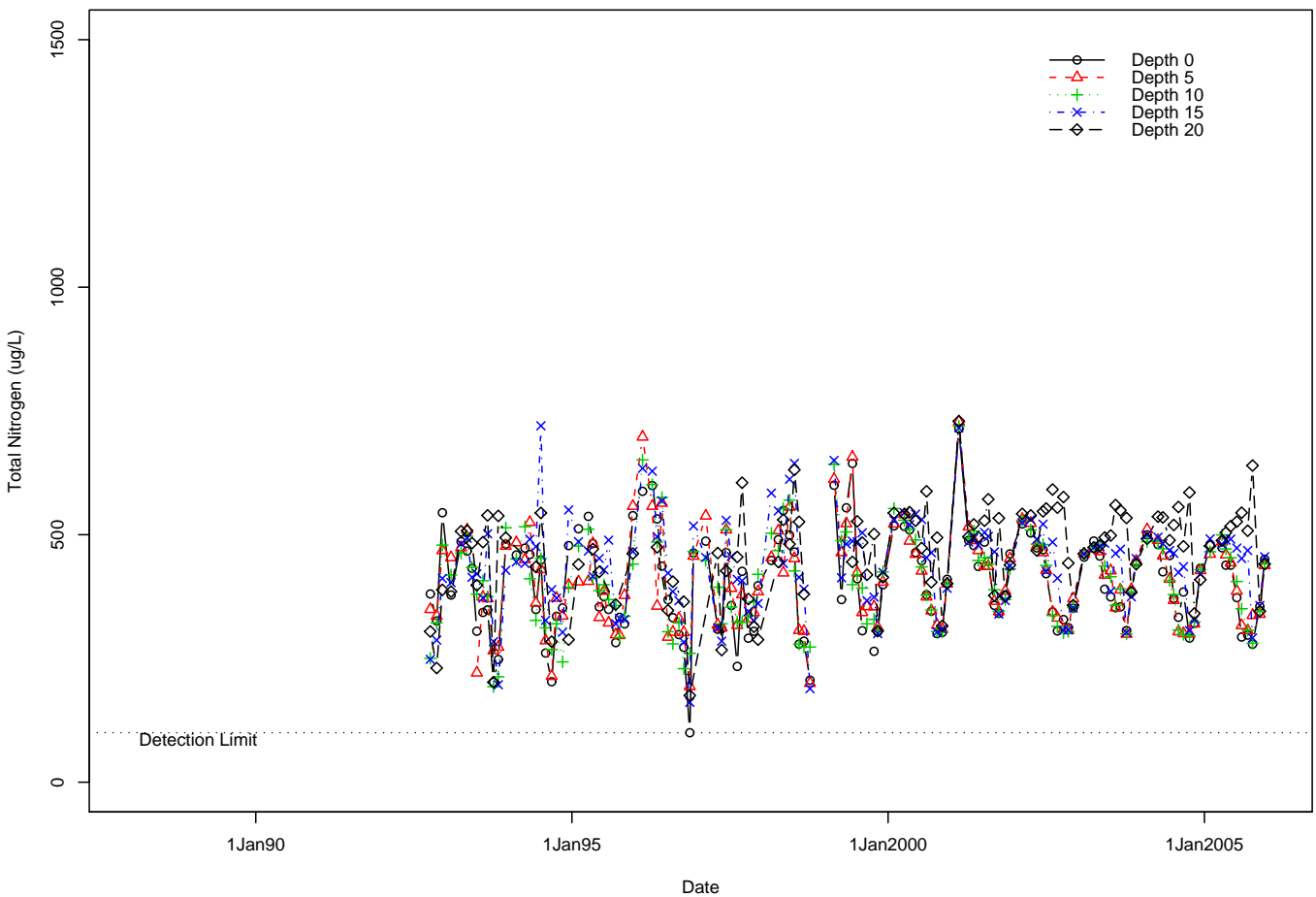


Figure B92: Lake Whatcom total nitrogen data for Site 2 (1988–2005).

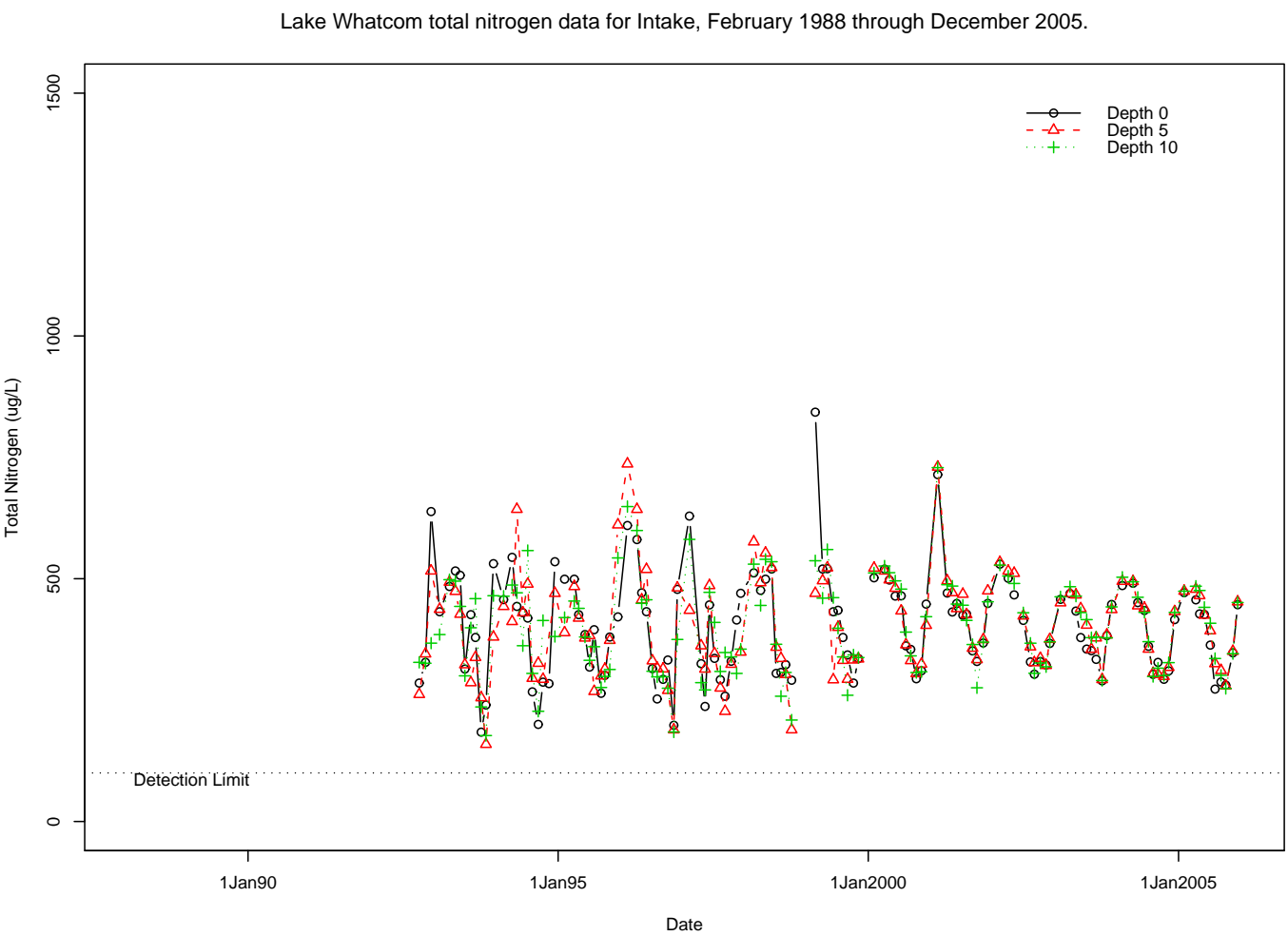


Figure B93: Lake Whatcom total nitrogen data for the Intake (1988–2005).

Lake Whatcom total nitrogen data for Site 3, February 1988 through December 2005.

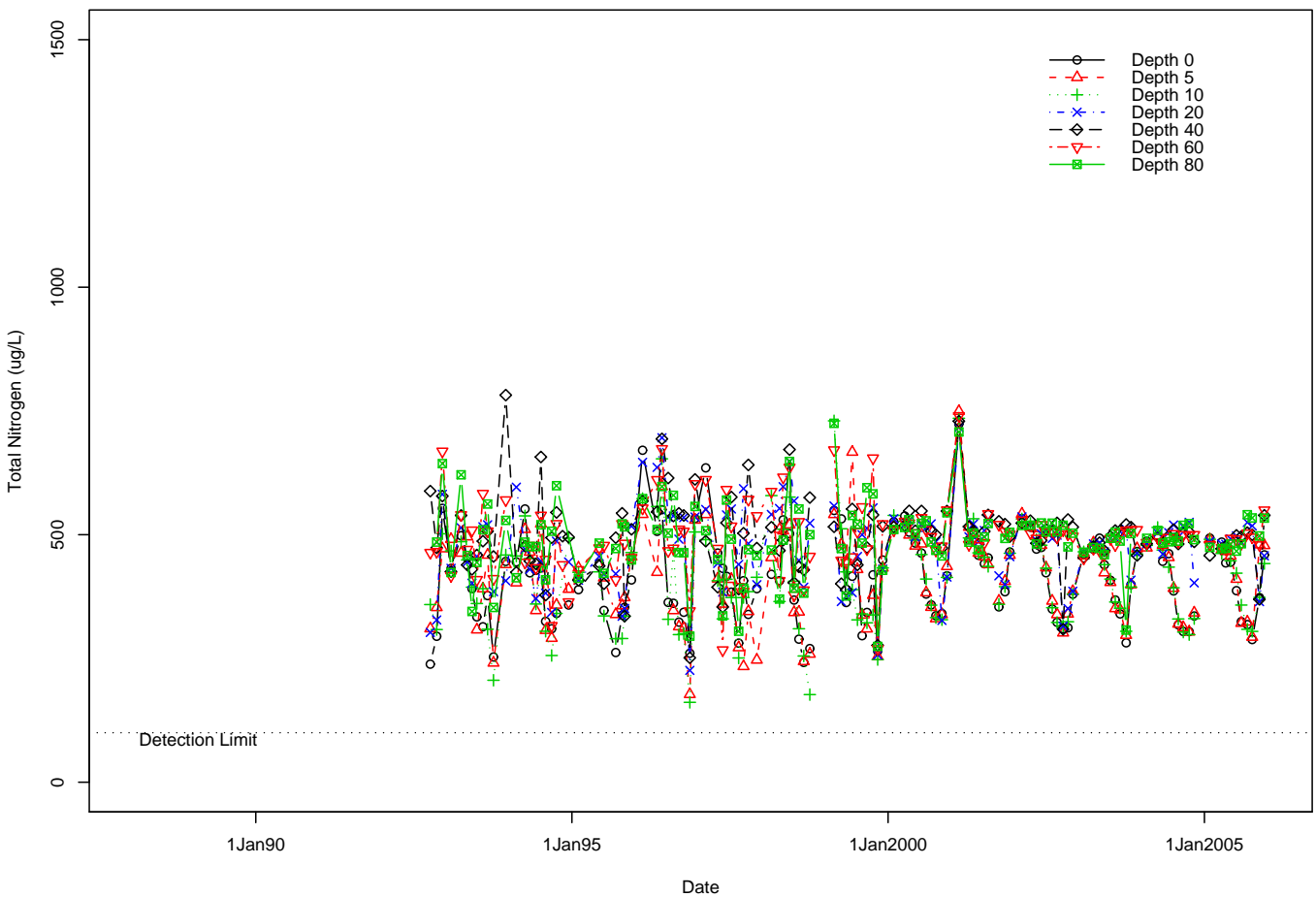


Figure B94: Lake Whatcom total nitrogen data for Site 3 (1988–2005).

Lake Whatcom total nitrogen data for Site 4, February 1988 through December 2005.

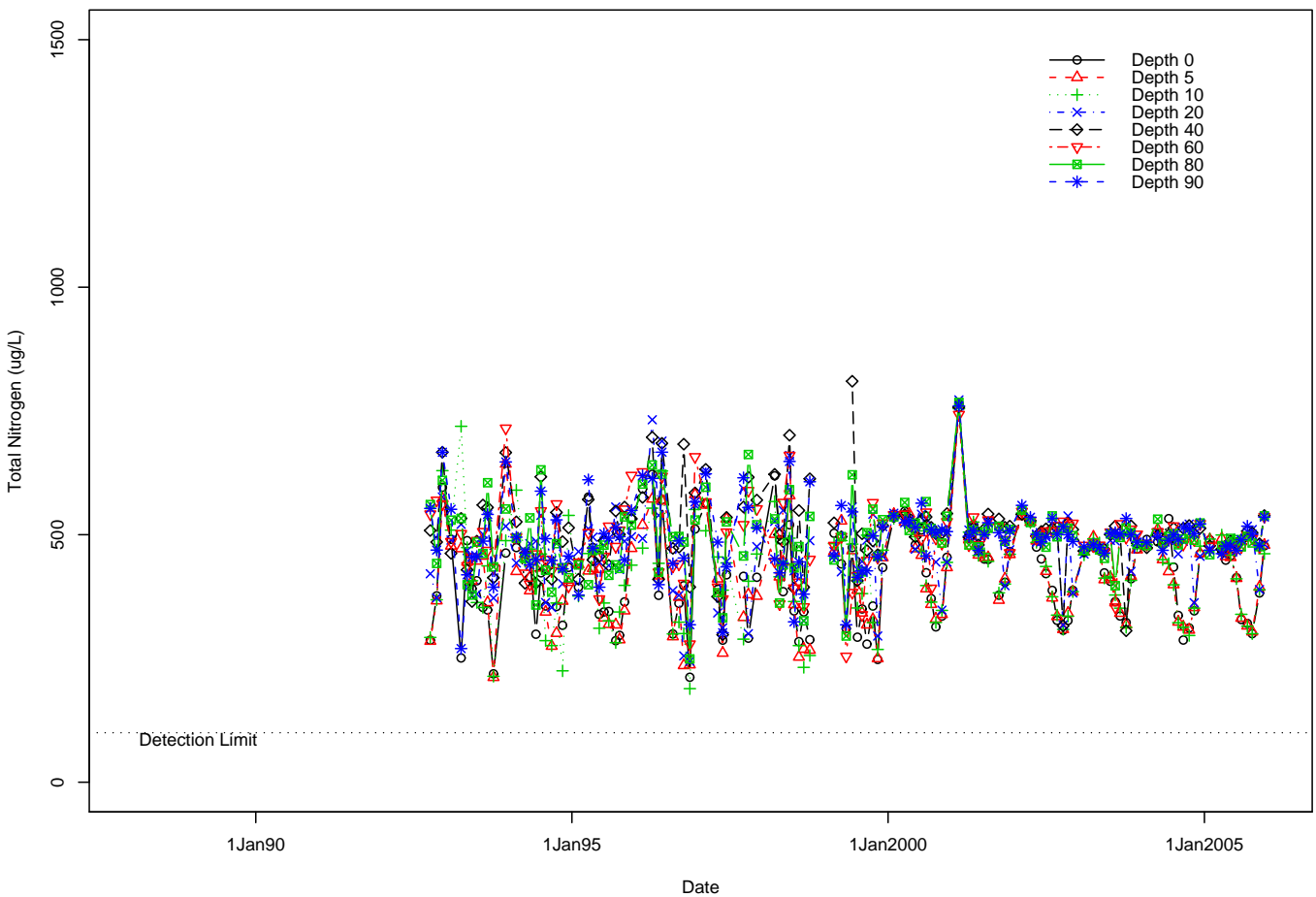


Figure B95: Lake Whatcom total nitrogen data for Site 4 (1988–2005).

Lake Whatcom soluble reactive phosphate data for Site 1, February 1988 through December 2005.

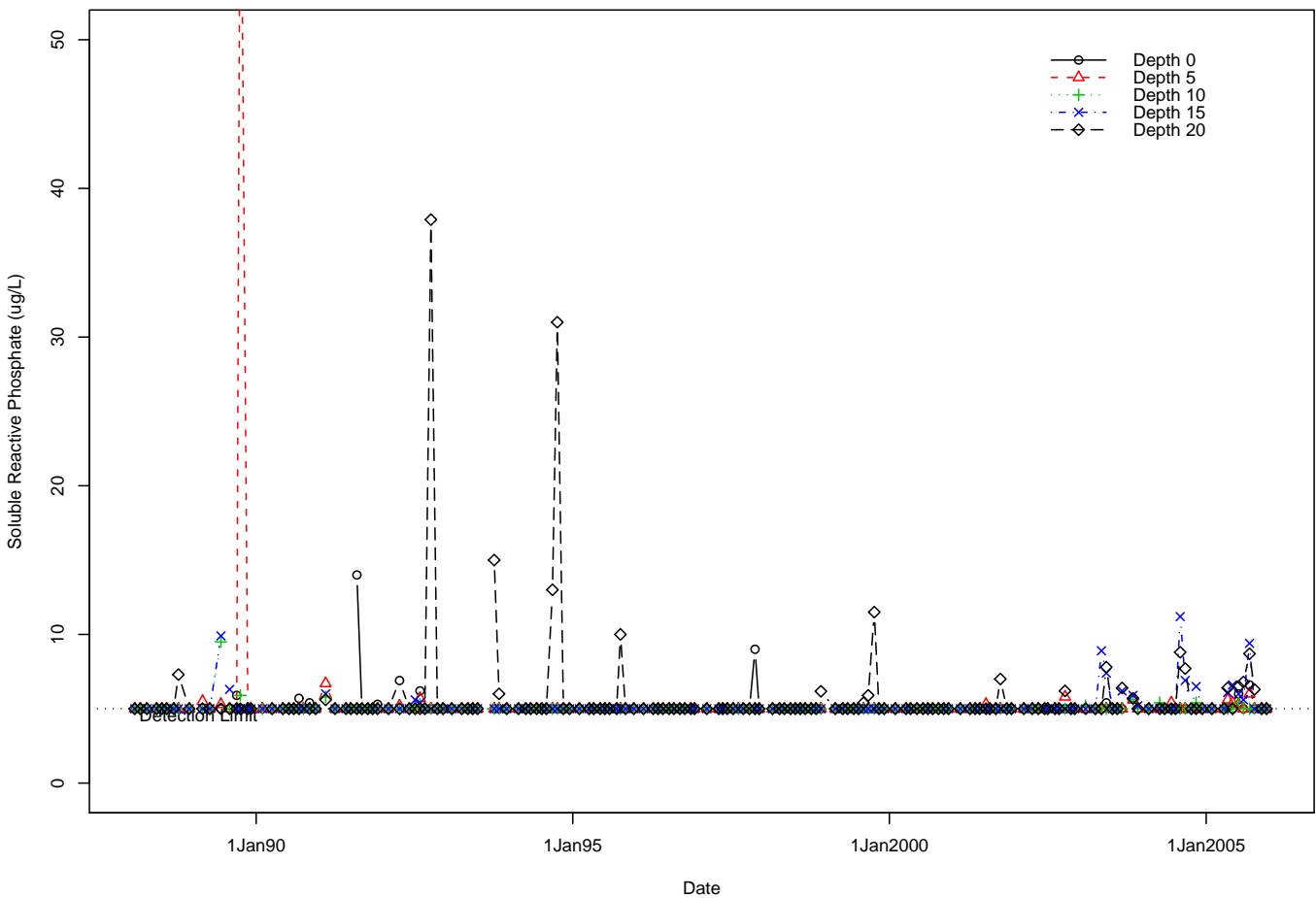


Figure B96: Lake Whatcom soluble phosphate data for Site 1 (1988–2005).

Lake Whatcom soluble reactive phosphate data for Site 2, February 1988 through December 2005.

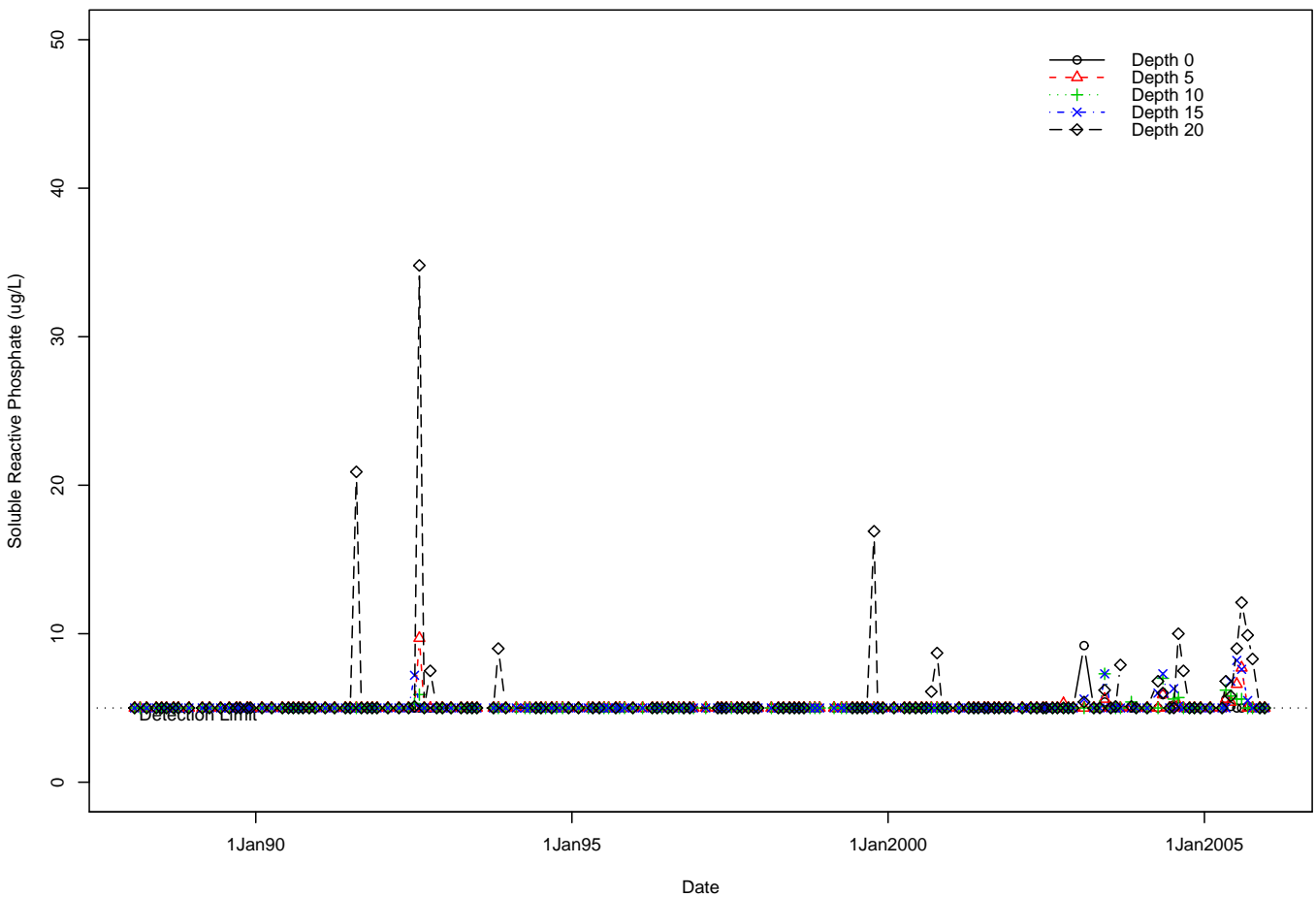


Figure B97: Lake Whatcom soluble phosphate data for Site 2 (1988–2005).

Lake Whatcom soluble reactive phosphate data for Intake, February 1988 through December 2005.

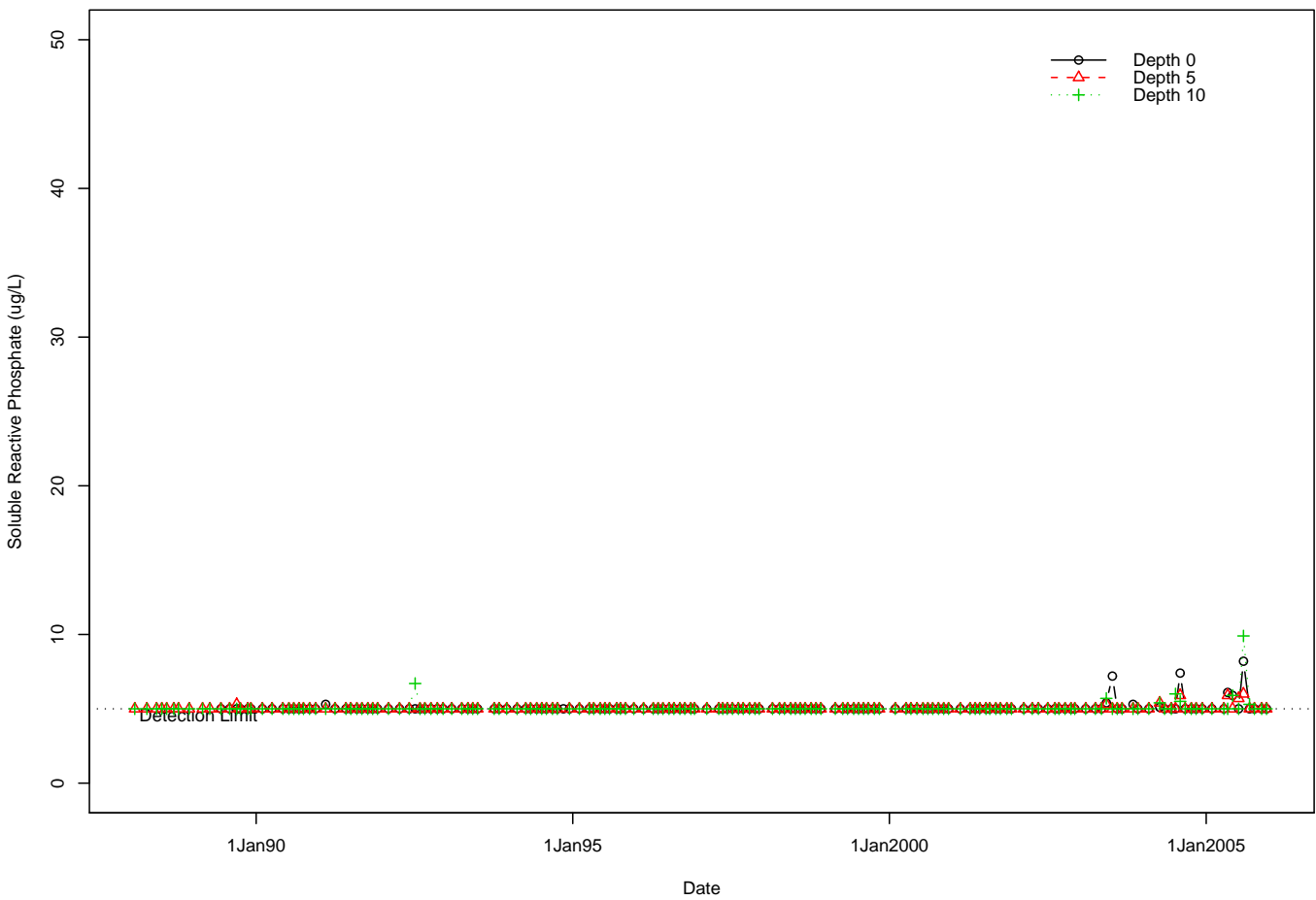


Figure B98: Lake Whatcom soluble phosphate data for the Intake (1988-2005).

Lake Whatcom soluble reactive phosphate data for Site 3, February 1988 through December 2005.

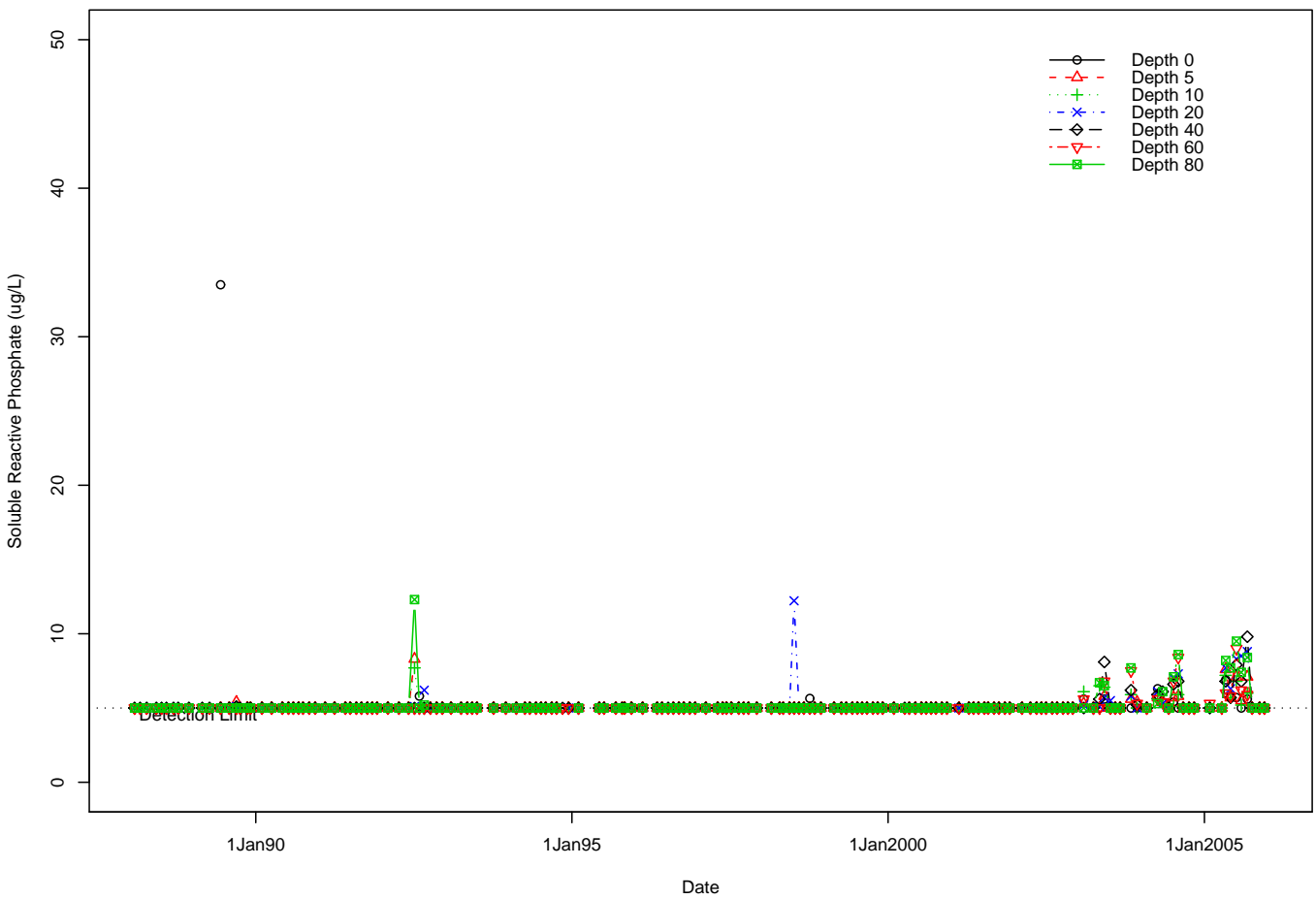


Figure B99: Lake Whatcom soluble phosphate data for Site 3 (1988–2005).

Lake Whatcom soluble reactive phosphate data for Site 4, February 1988 through December 2005.

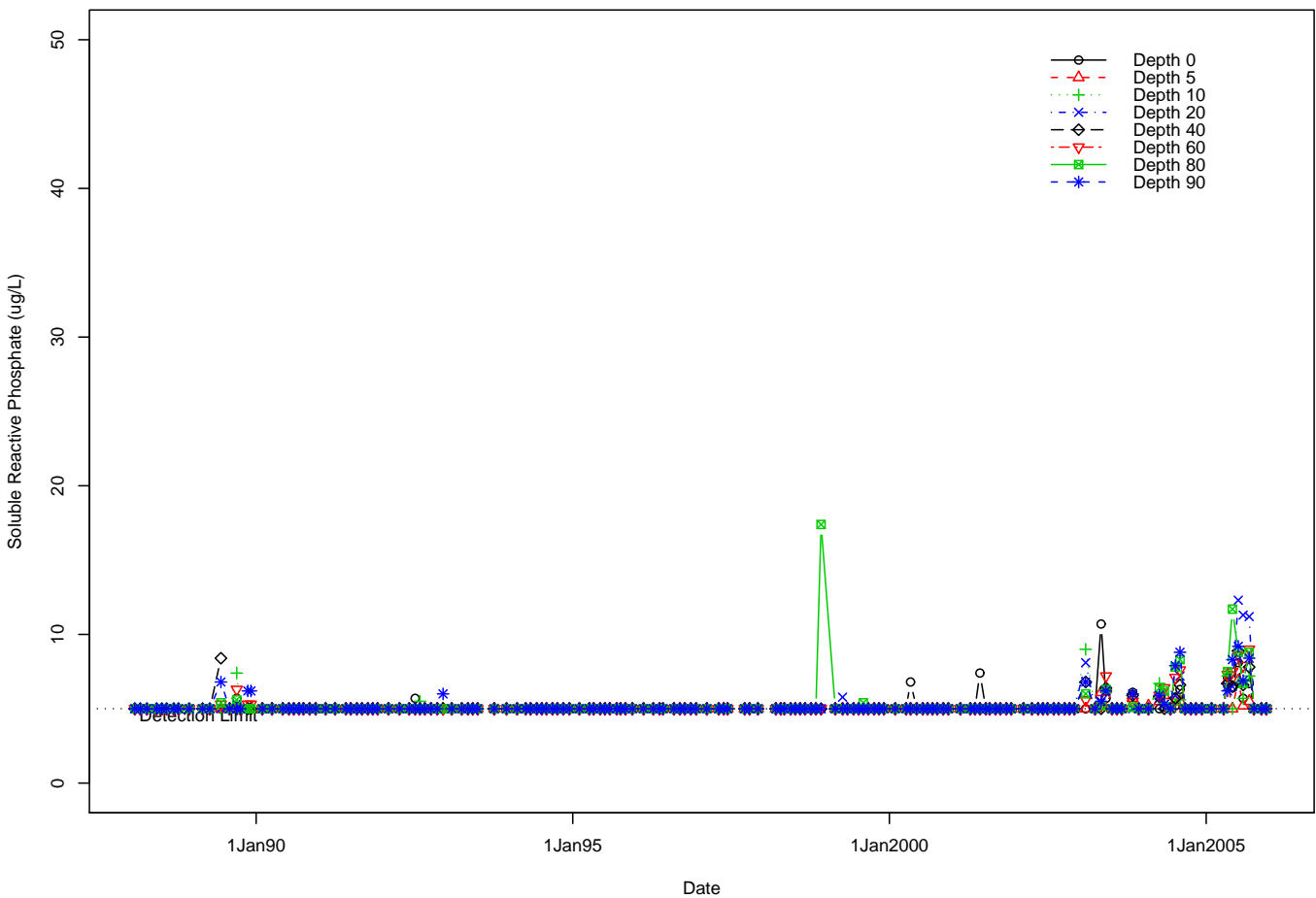


Figure B100: Lake Whatcom soluble phosphate data for Site 4 (1988–2005).

Lake Whatcom total phosphorus data for Site 1, February 1988 through December 2005.

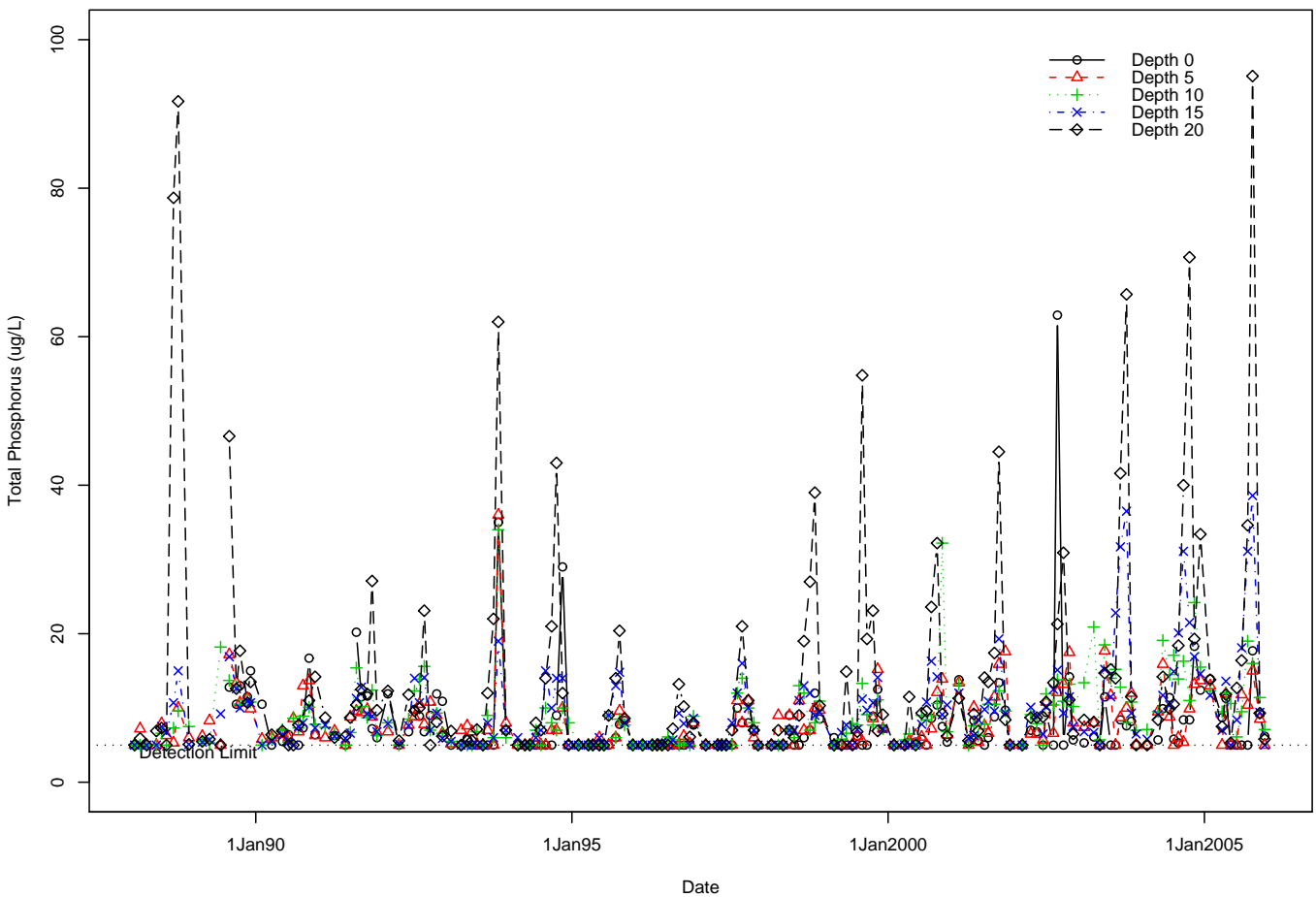


Figure B101: Lake Whatcom total phosphorus data for Site 1 (1988–2005).

Lake Whatcom total phosphorus data for Site 2, February 1988 through December 2005.

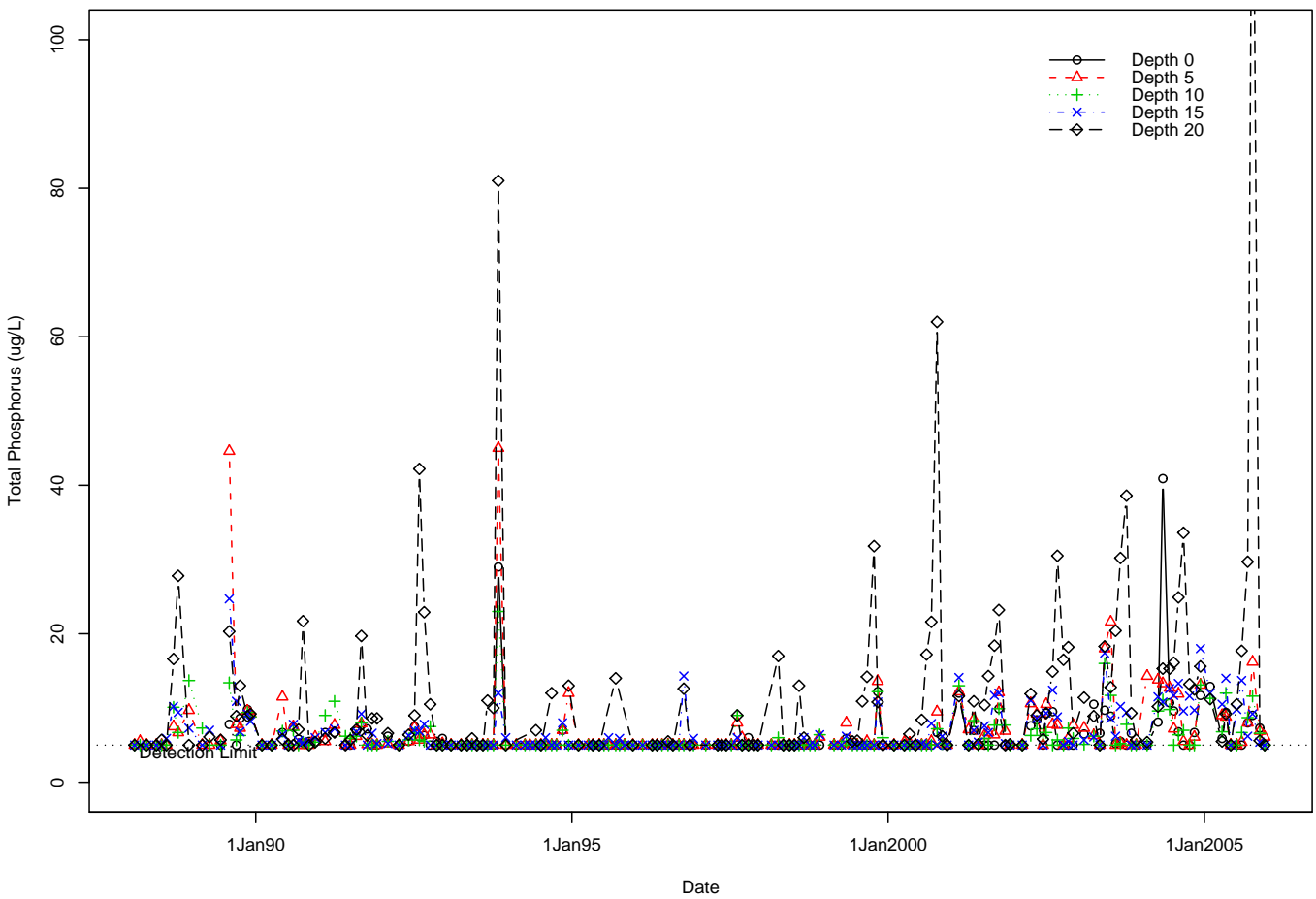


Figure B102: Lake Whatcom total phosphorus data for Site 2 (1988–2005).

Lake Whatcom total phosphorus data for Intake, February 1988 through December 2005.

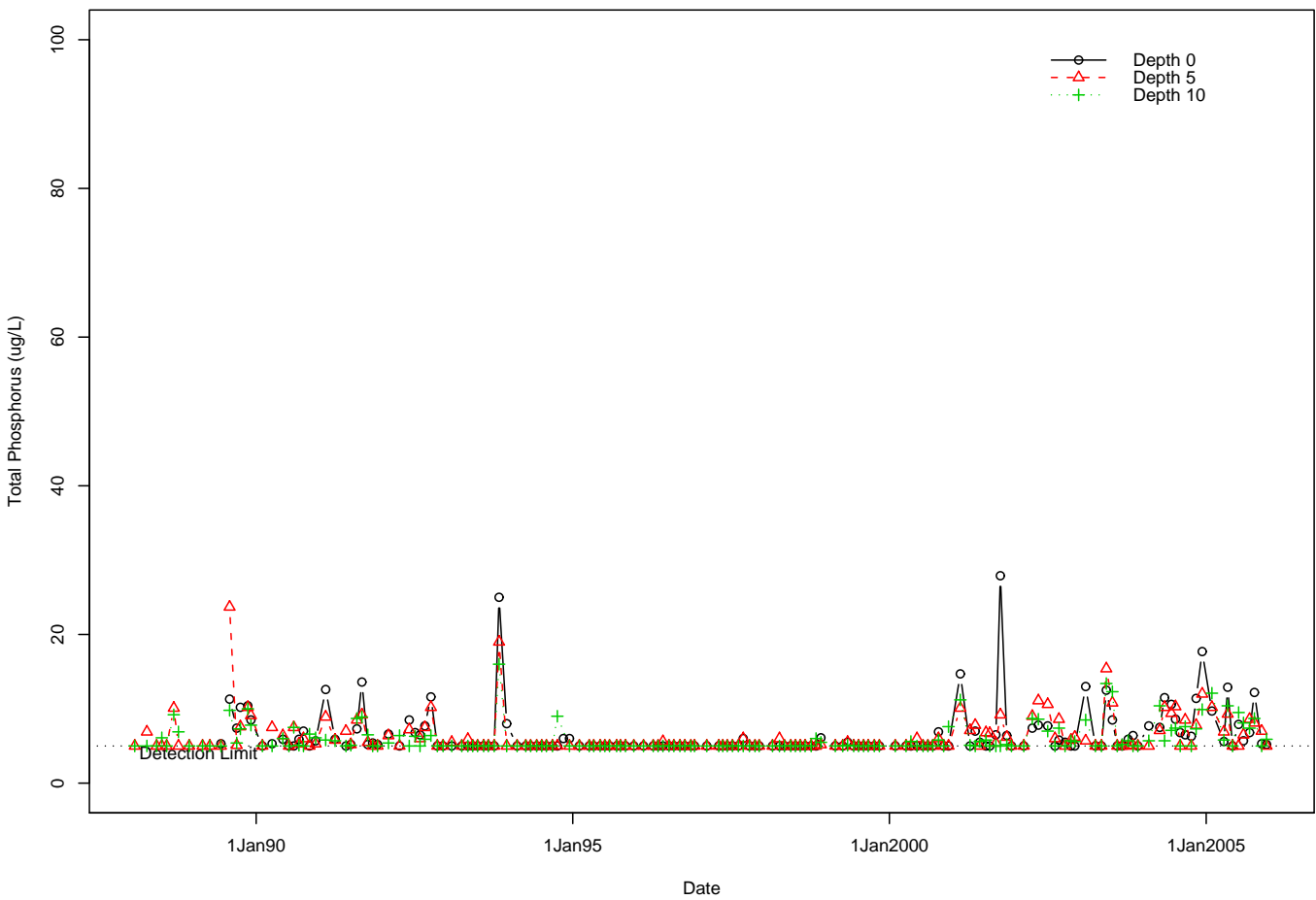


Figure B103: Lake Whatcom total phosphorus data for the Intake (1988-2005).

Lake Whatcom total phosphorus data for Site 3, February 1988 through December 2005.

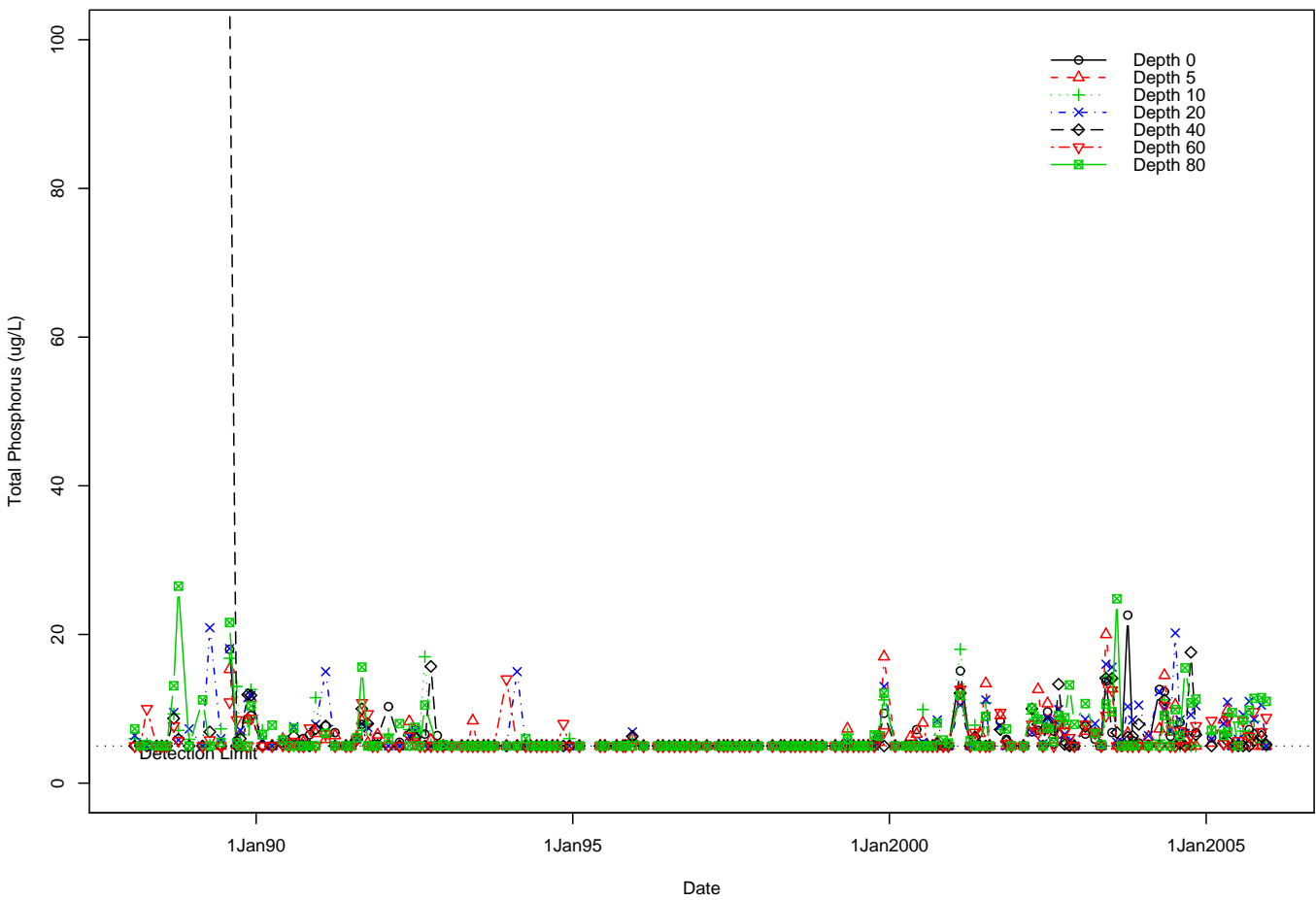


Figure B104: Lake Whatcom total phosphorus data for Site 3 (1988–2005).

Lake Whatcom total phosphorus data for Site 4, February 1988 through December 2005.

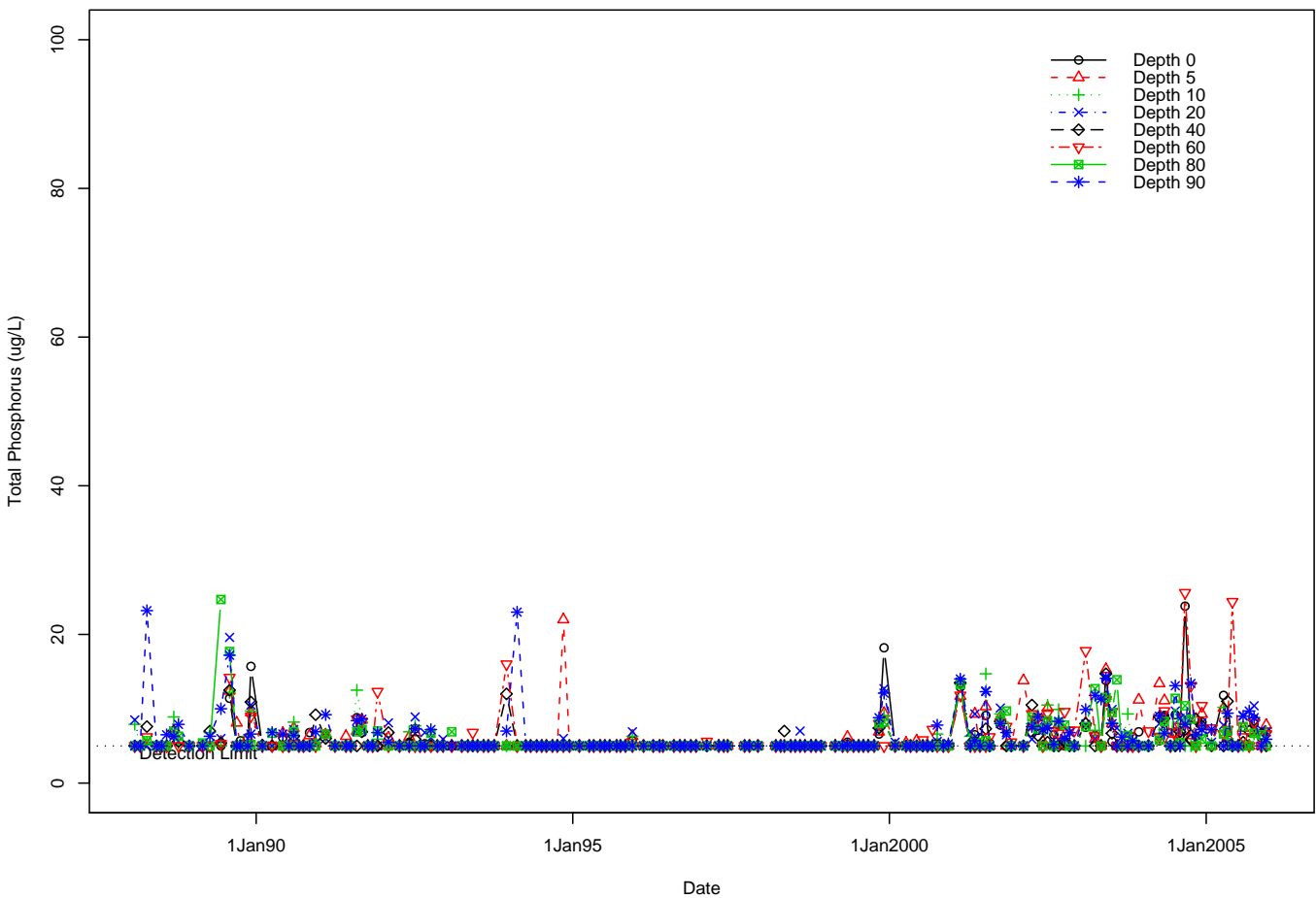


Figure B105: Lake Whatcom total phosphorus data for Site 4 (1988–2005).

B.5 Plankton, Chlorophyll, Secchi Depth

Lake Whatcom chlorophyll a data for Site 1, February 1988 through December 2005.

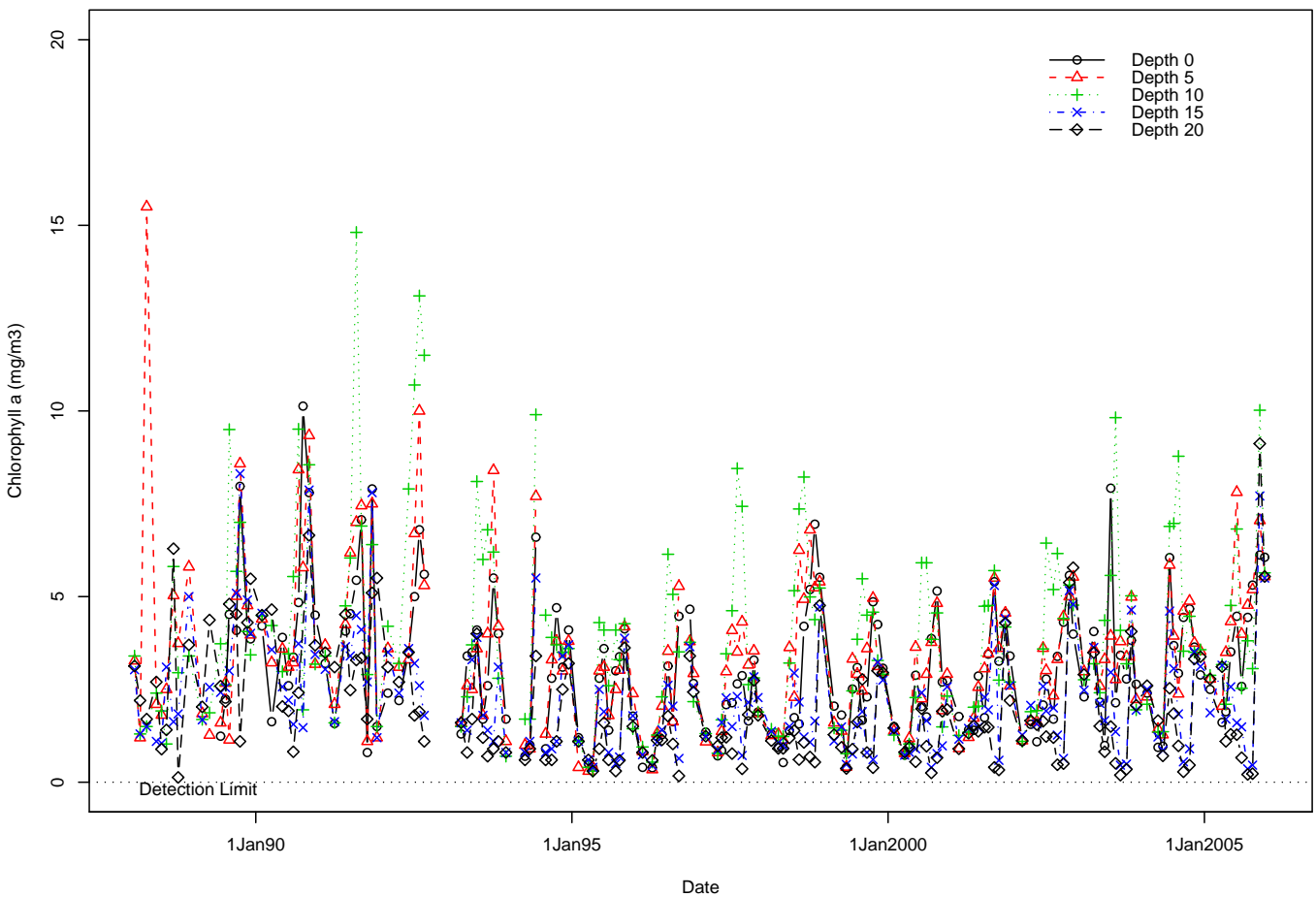


Figure B106: Lake Whatcom chlorophyll a data for Site 1 (1988–2005).

Lake Whatcom chlorophyll a data for Site 2, February 1988 through December 2005.

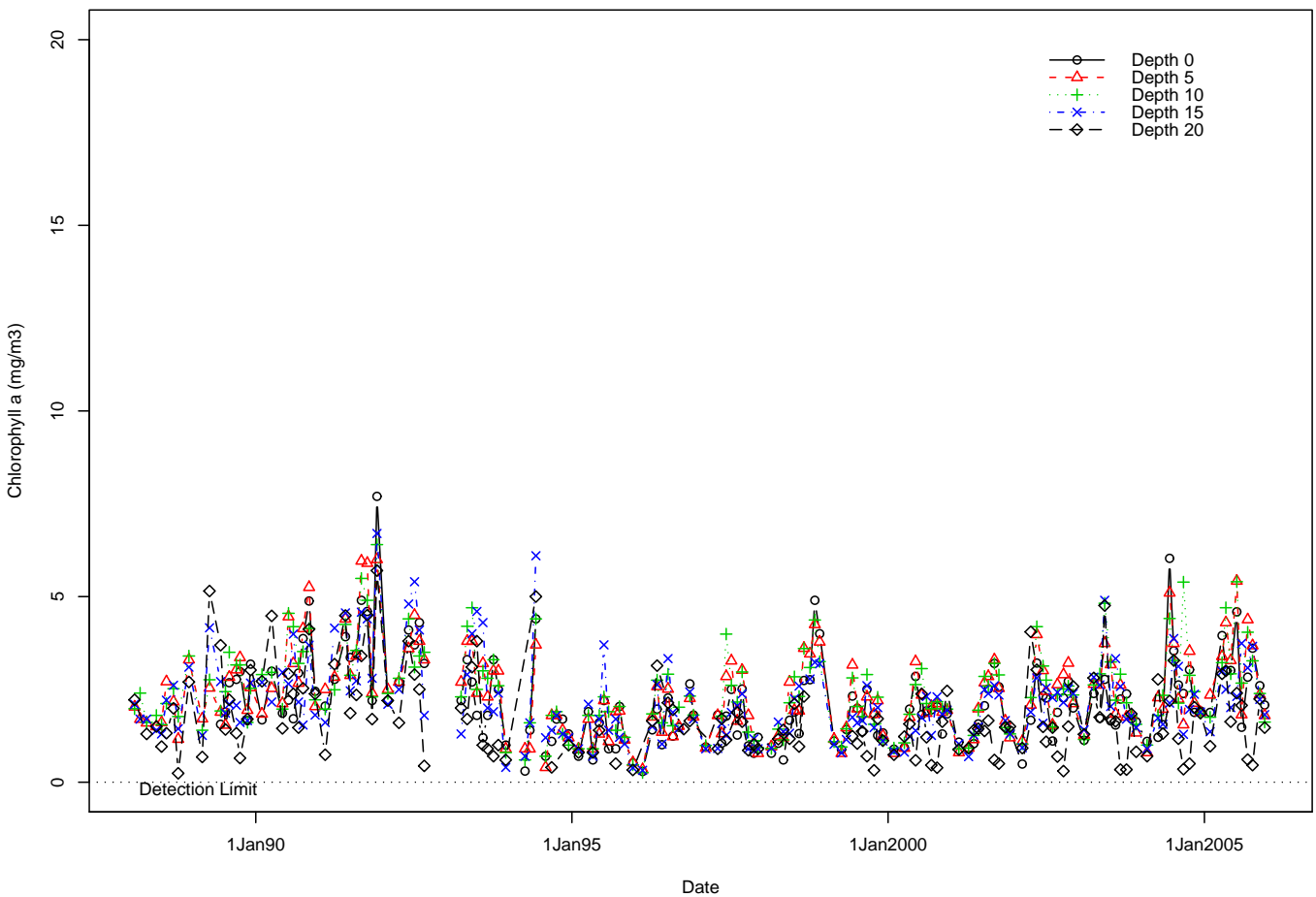


Figure B107: Lake Whatcom chlorophyll a data for Site 2 (1988–2005).

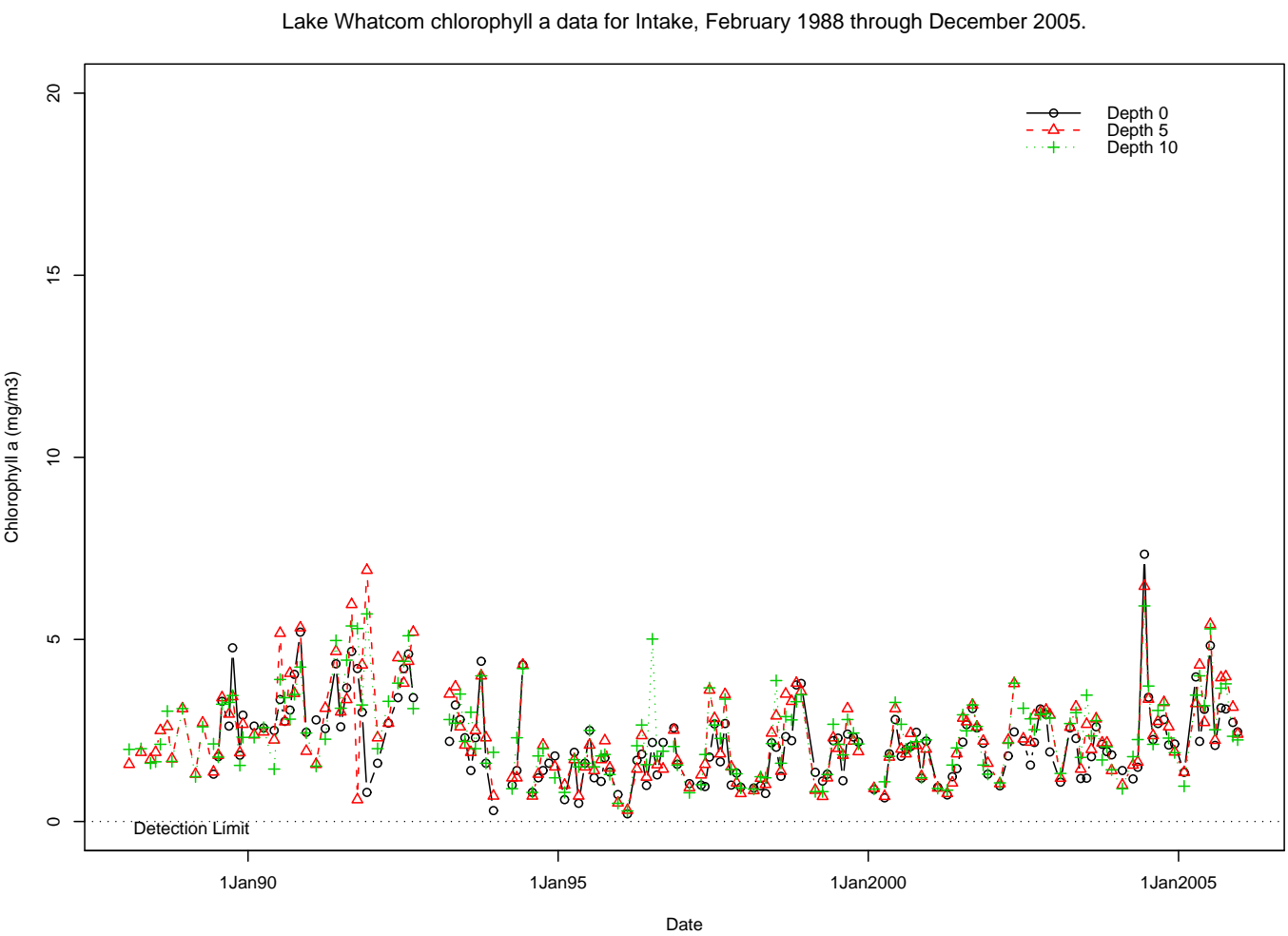


Figure B108: Lake Whatcom chlorophyll data for the Intake (1988-2005).

Lake Whatcom chlorophyll a data for Site 3, February 1988 through December 2005.

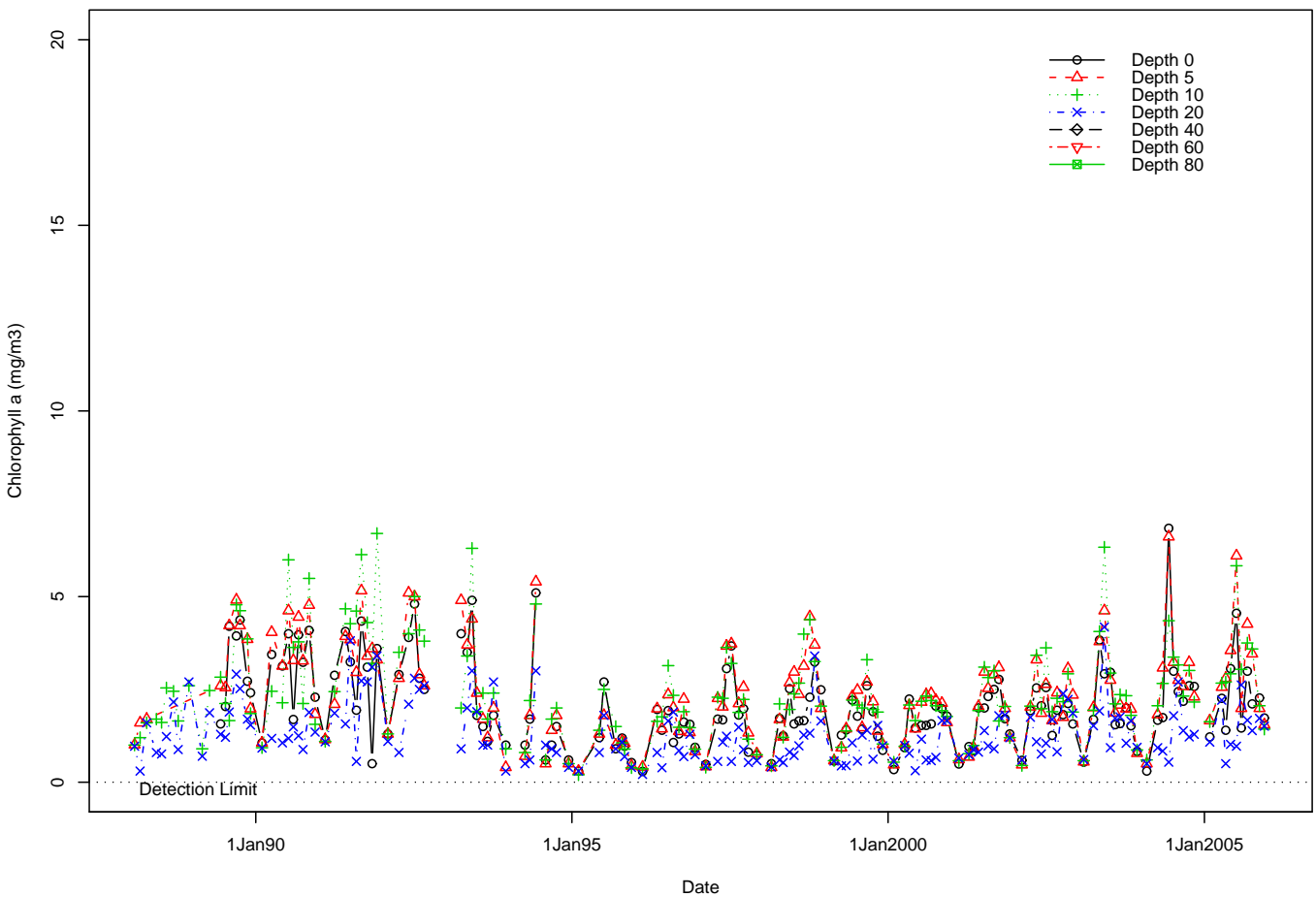


Figure B109: Lake Whatcom chlorophyll a data for Site 3 (1988–2005).

Lake Whatcom chlorophyll a data for Site 4, February 1988 through December 2005.

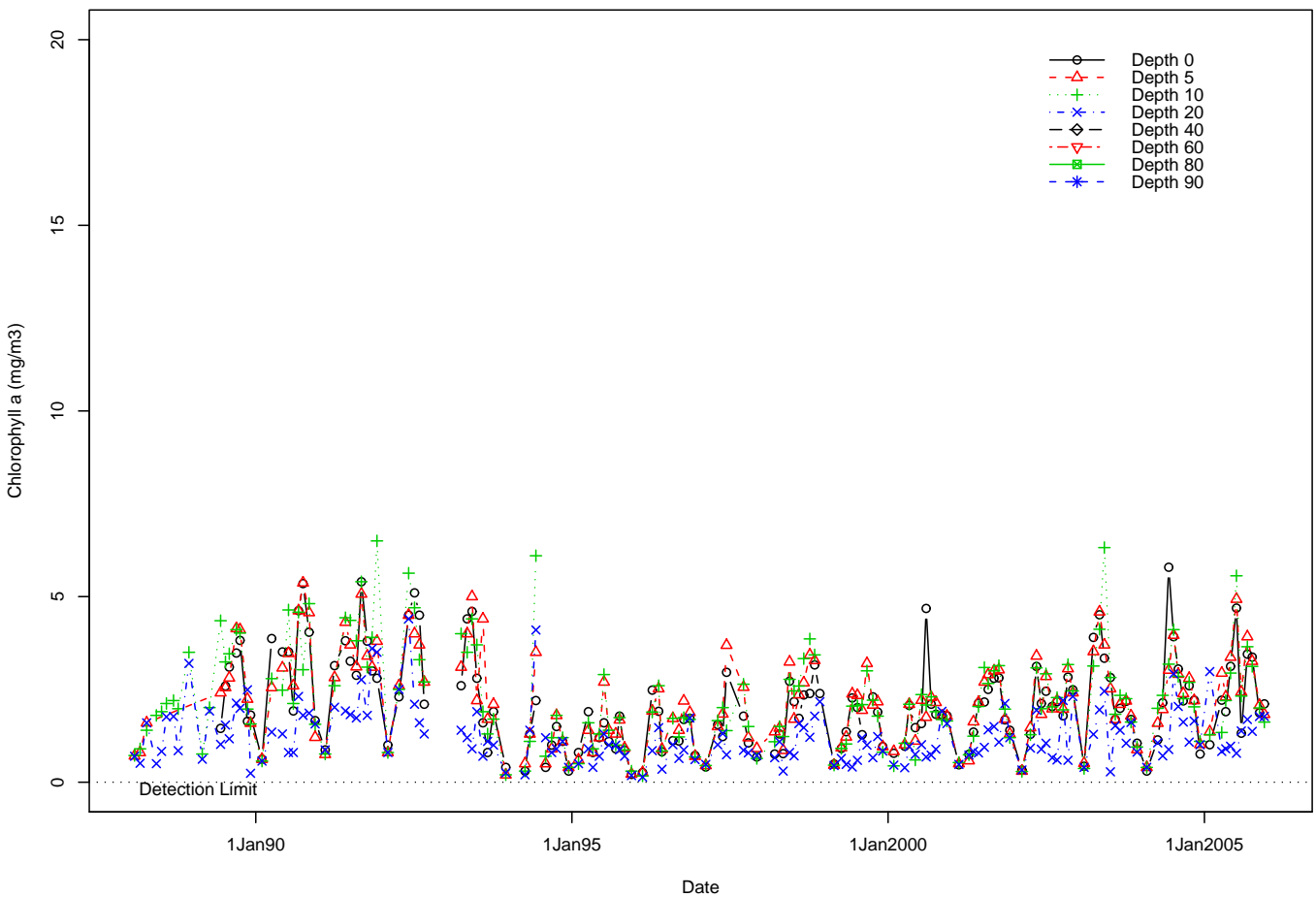


Figure B110: Lake Whatcom chlorophyll a data for Site 4 (1988–2005).

Lake Whatcom plankton data for Site 1, February 1988 through December 2005.

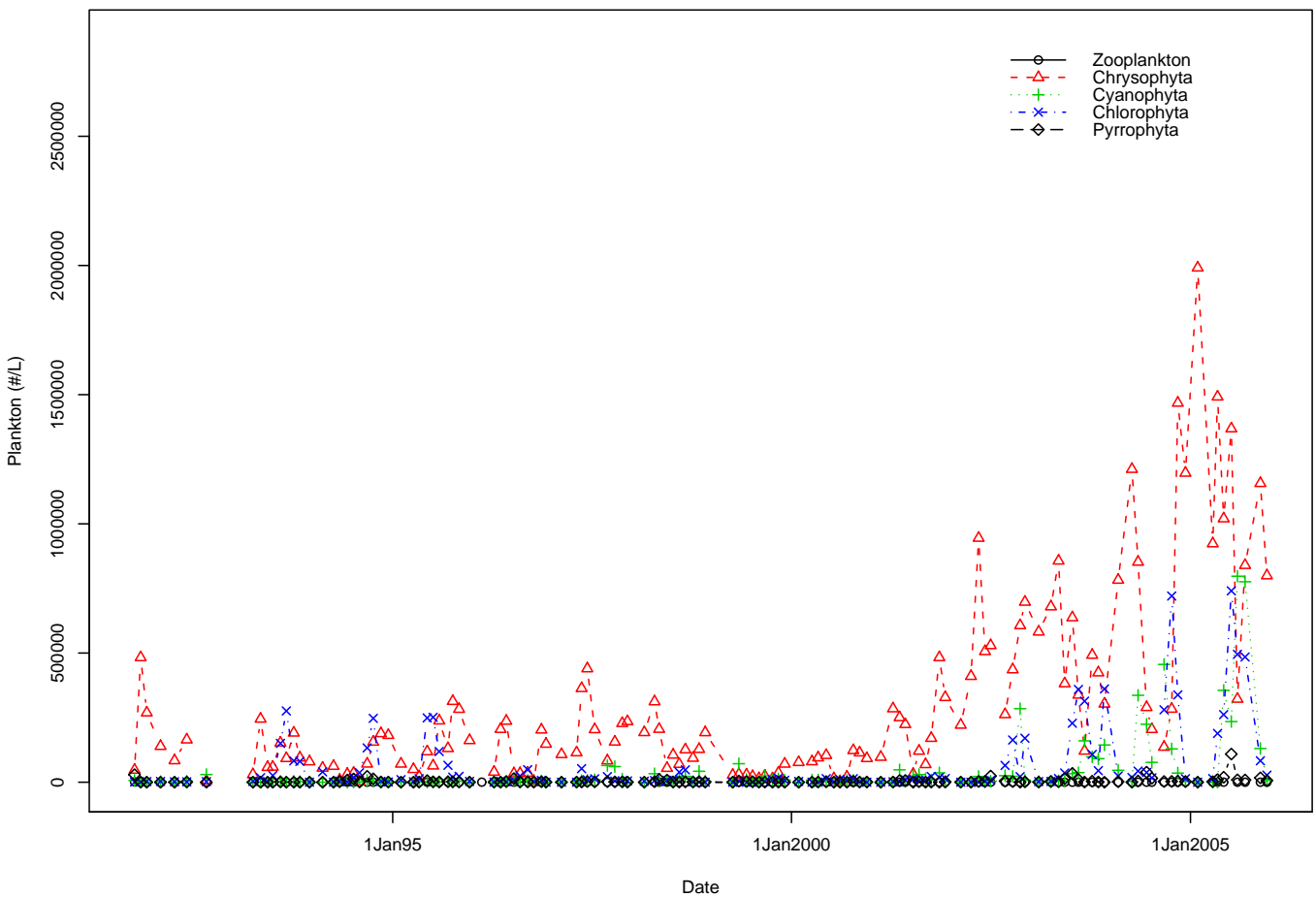


Figure B111: Lake Whatcom plankton data for Site 1 (1992–2005).

Lake Whatcom plankton data for Site 2, February 1988 through December 2005.

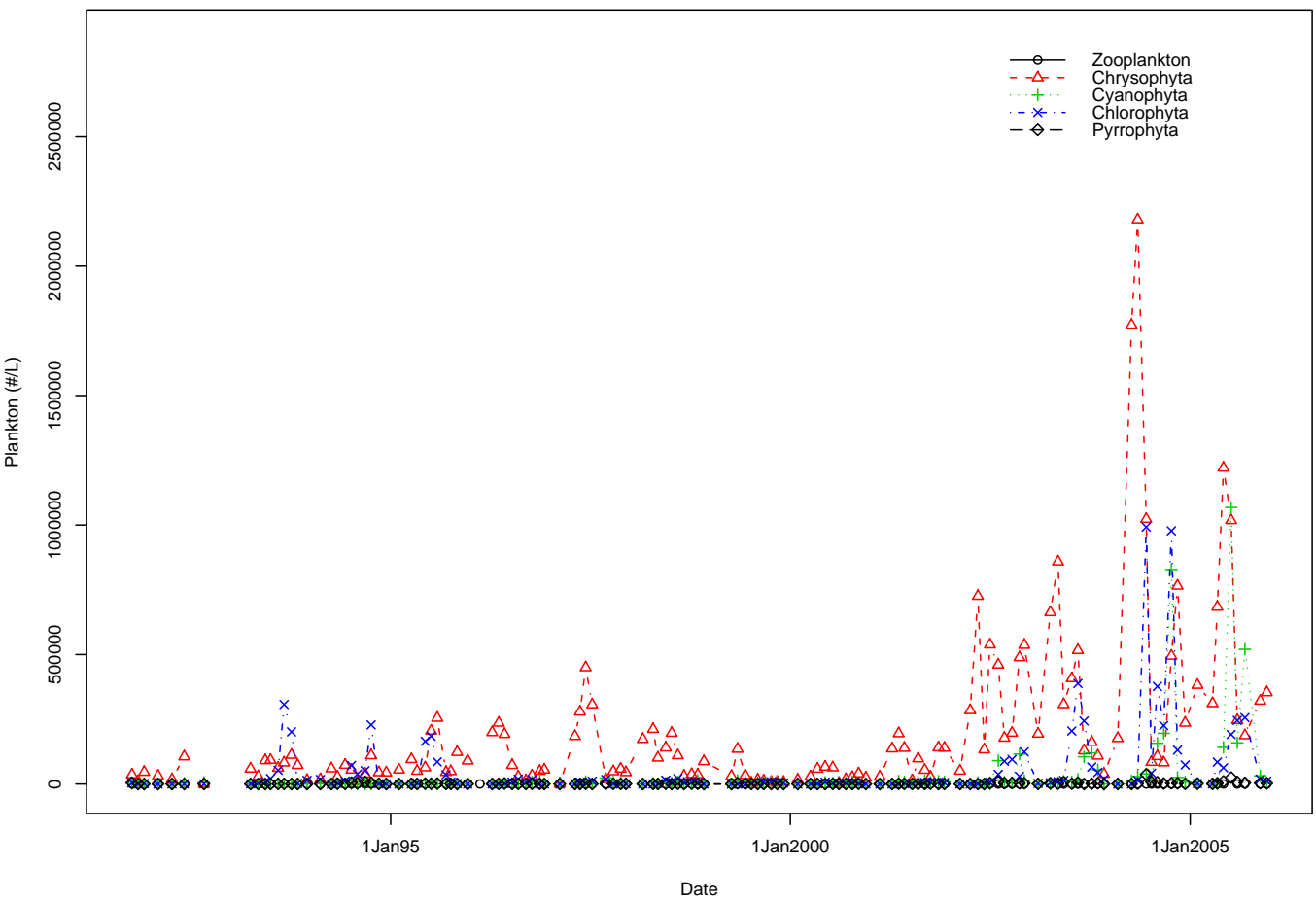


Figure B112: Lake Whatcom plankton data for Site 2 (1992–2005).

Lake Whatcom plankton data for Intake, February 1988 through December 2005.

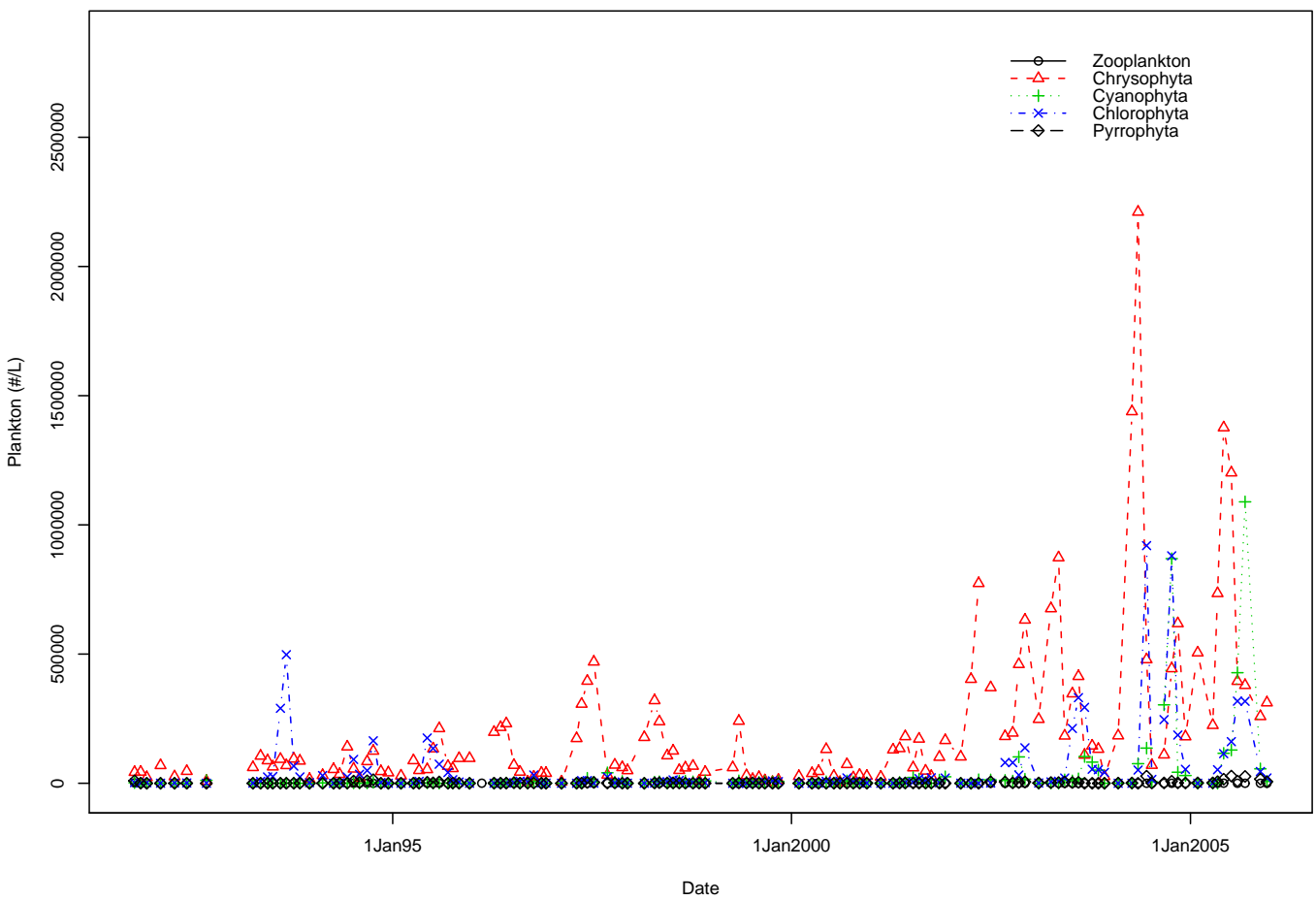


Figure B113: Lake Whatcom plankton data for the Intake (1992–2005).

Lake Whatcom plankton data for Site 3, February 1988 through December 2005.

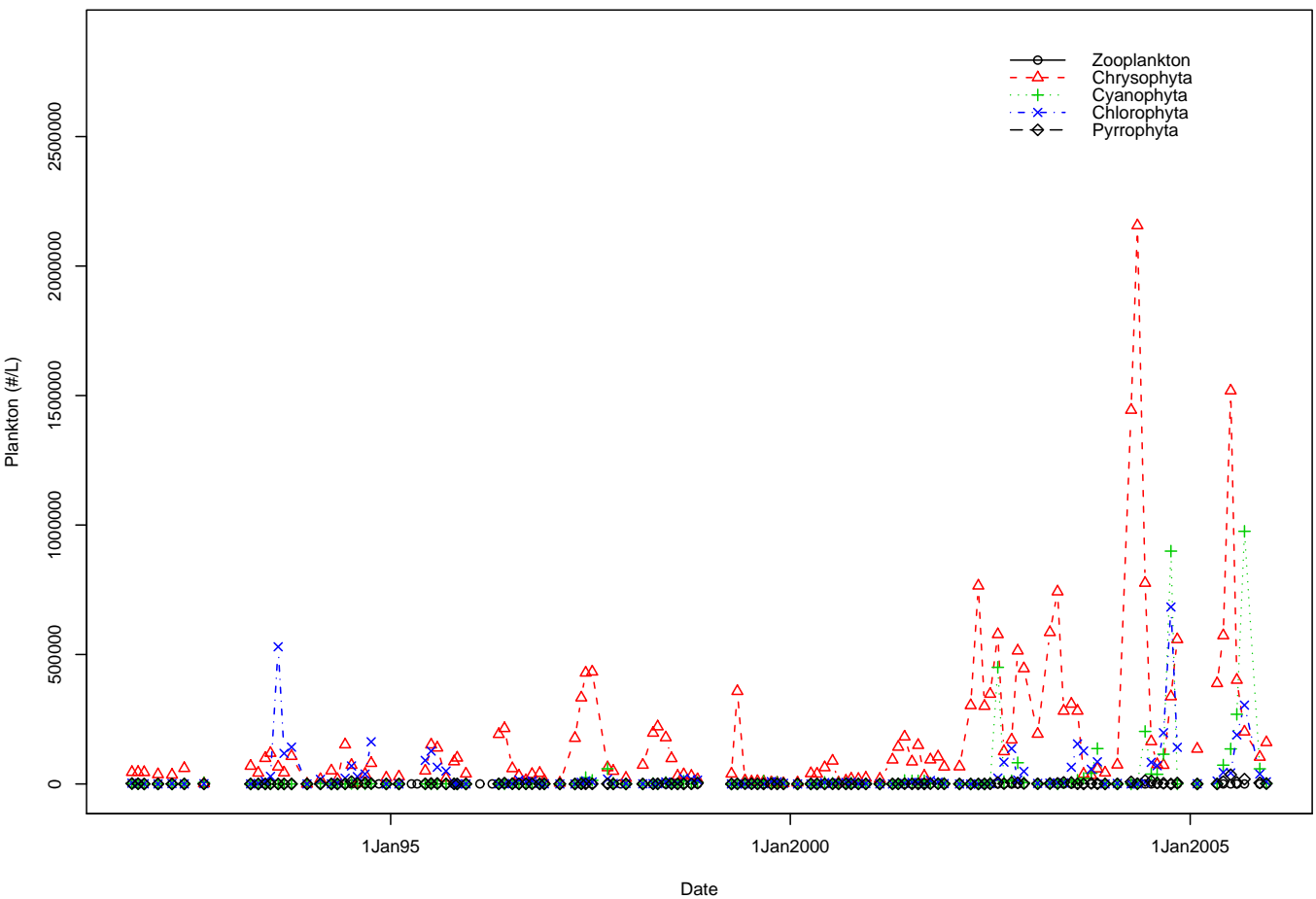


Figure B114: Lake Whatcom plankton data for Site 3 (1992–2005).

Lake Whatcom plankton data for Site 4, February 1988 through December 2005.

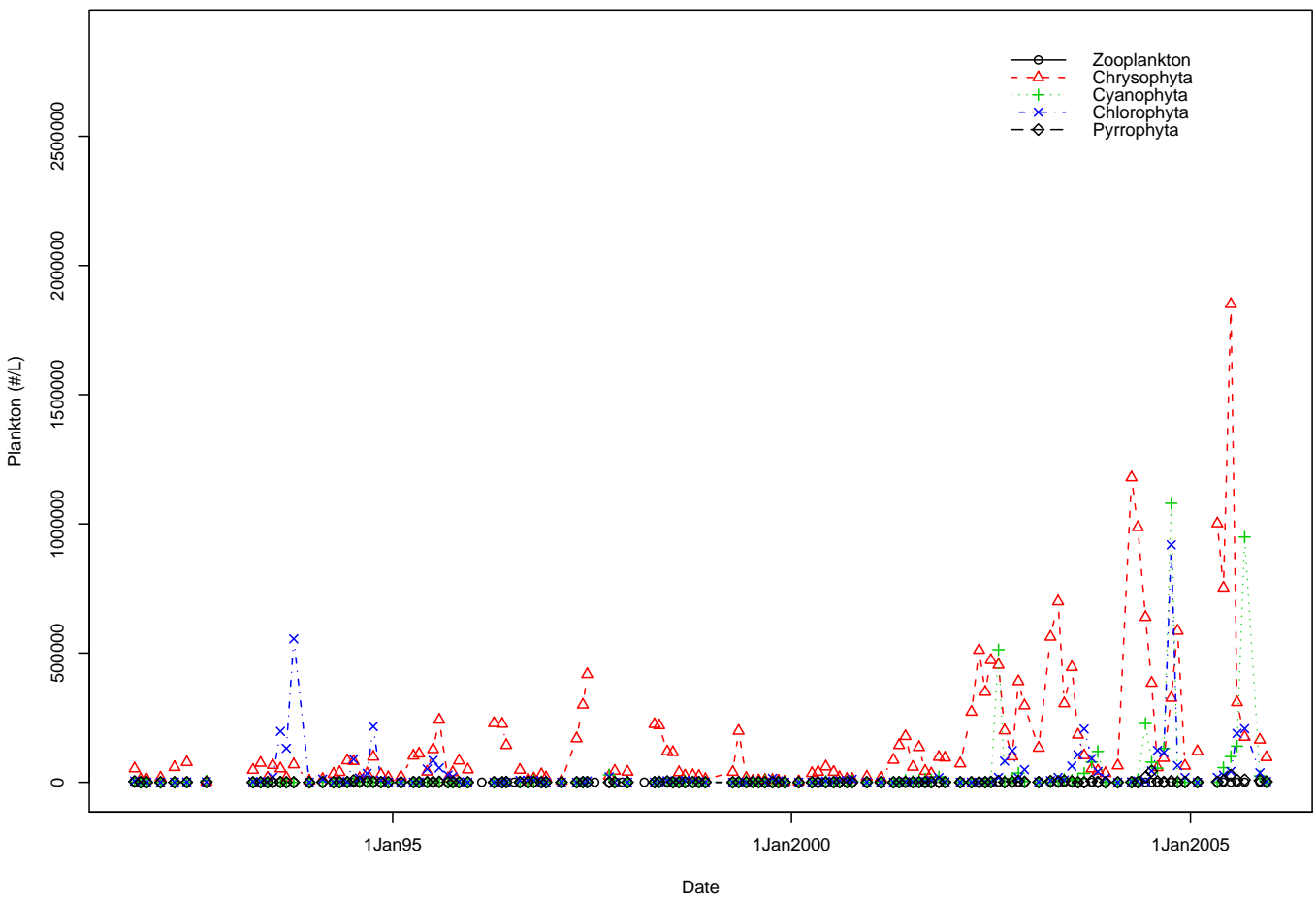


Figure B115: Lake Whatcom plankton data for Site 4 (1992–2005).

Lake Whatcom plankton data for Site 1, February 1988 through December 2005.

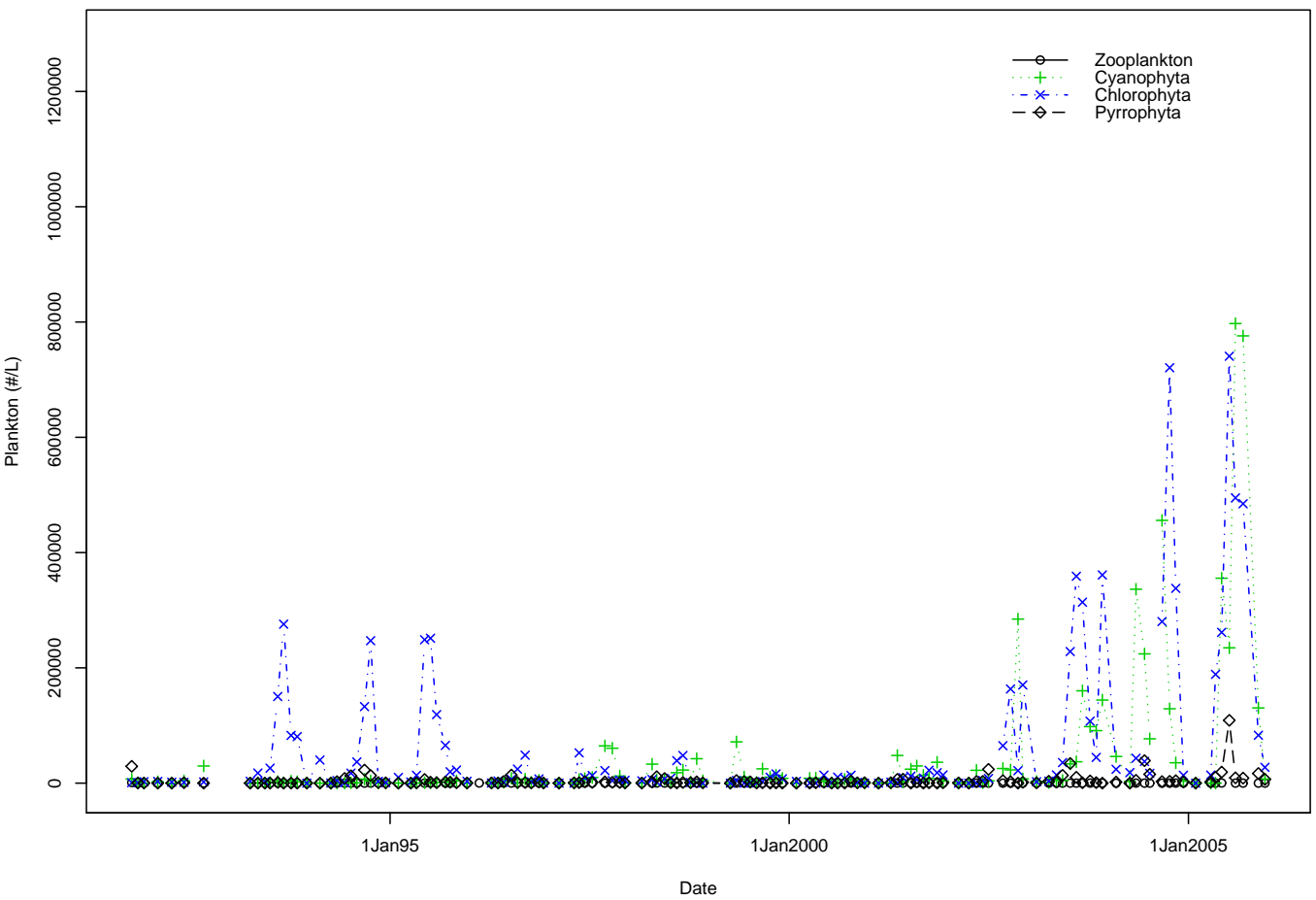


Figure B116: Lake Whatcom plankton data for Site 1, plotted to show Cyanophyta and Chlorophyta (1992–2005).

Lake Whatcom plankton data for Site 2, February 1988 through December 2005.

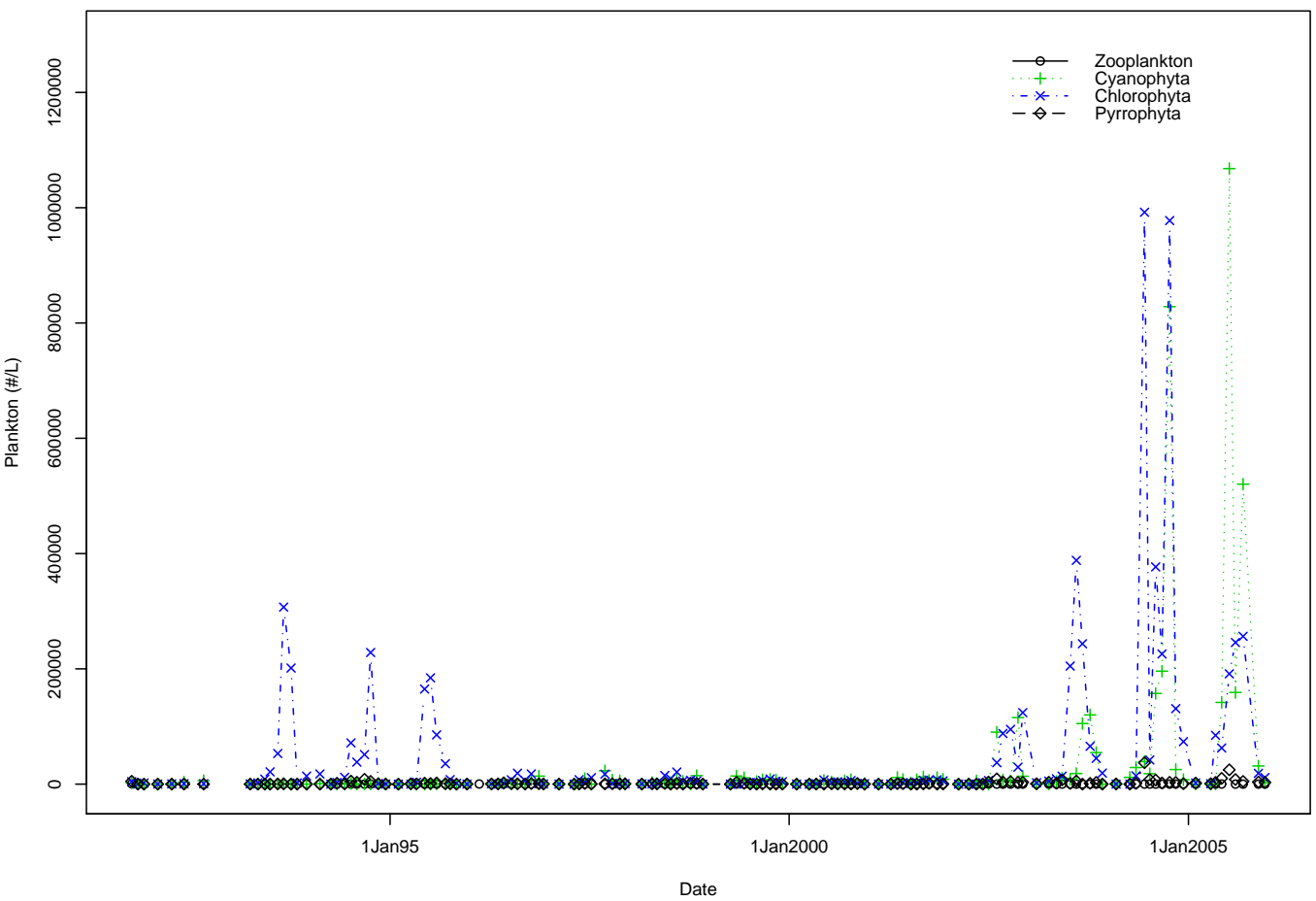


Figure B117: Lake Whatcom plankton data for Site 2, plotted to show Cyanophyta and Chlorophyta (1992–2005).

Lake Whatcom plankton data for Intake, February 1988 through December 2005.

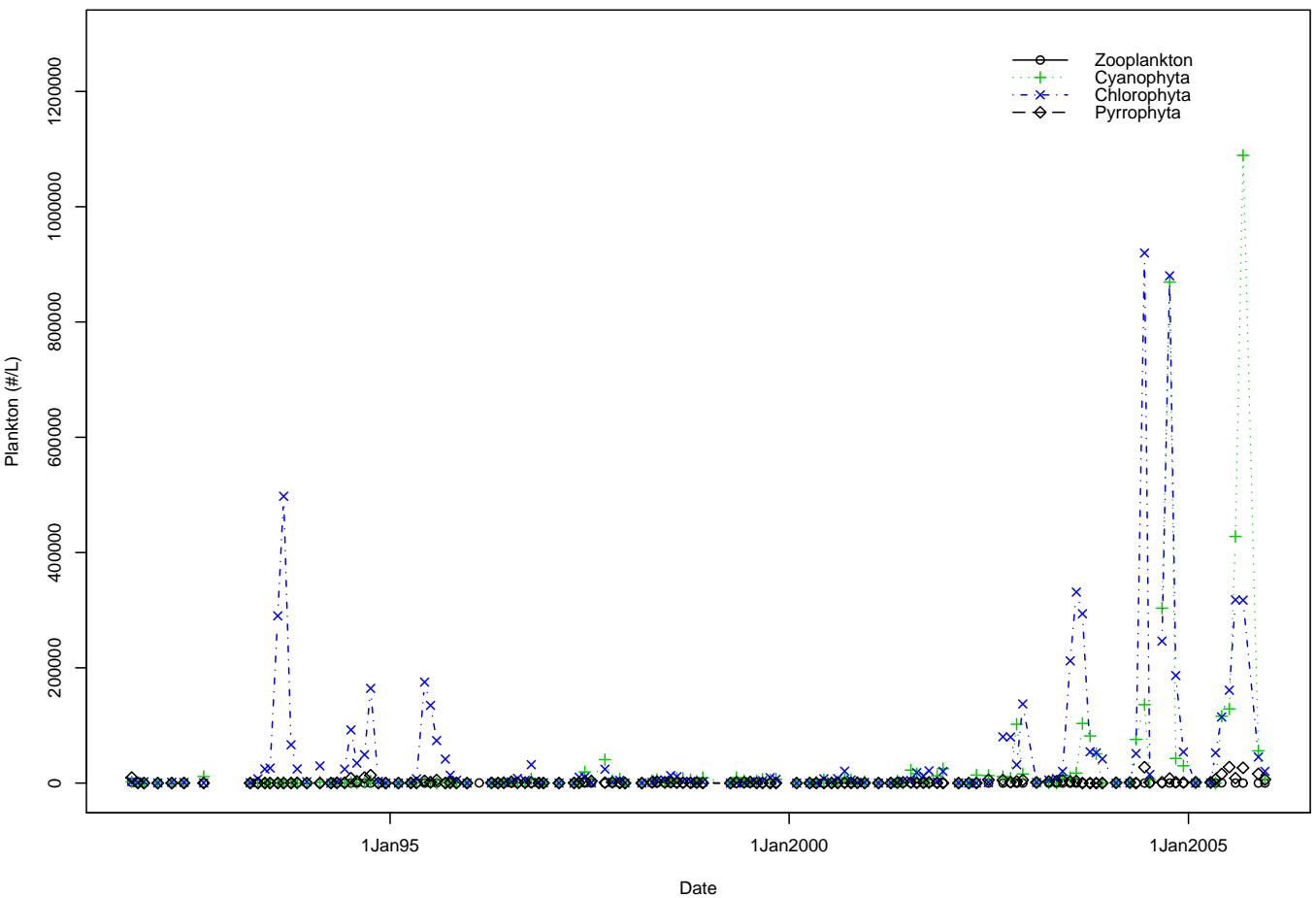


Figure B118: Lake Whatcom plankton data for the Intake, plotted to show Cyanophyta and Chlorophyta (1992–2005).

Lake Whatcom plankton data for Site 3, February 1988 through December 2005.

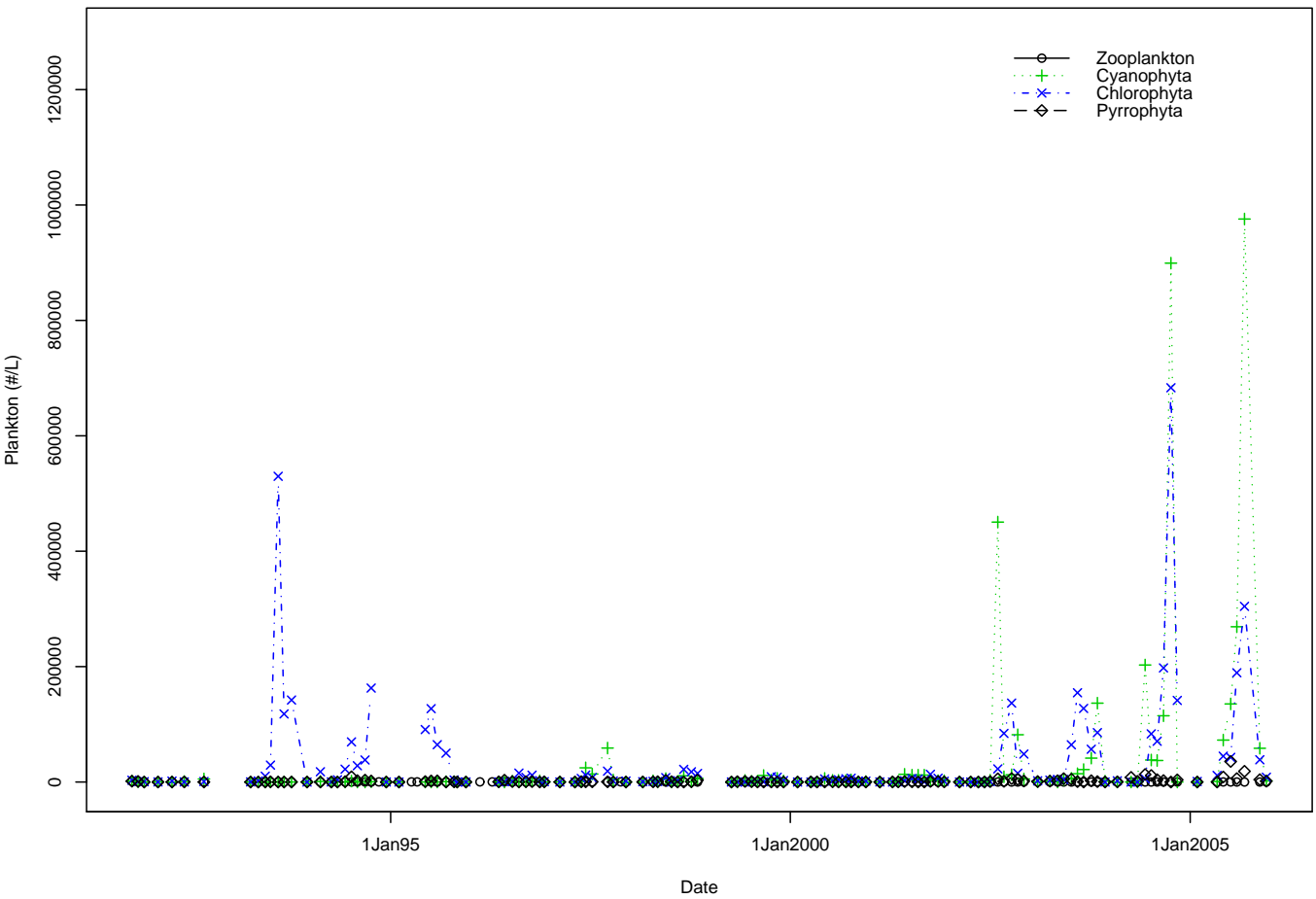


Figure B119: Lake Whatcom plankton data for Site 3, plotted to show Cyanophyta and Chlorophyta (1992–2005).

Lake Whatcom plankton data for Site 4, February 1988 through December 2005.

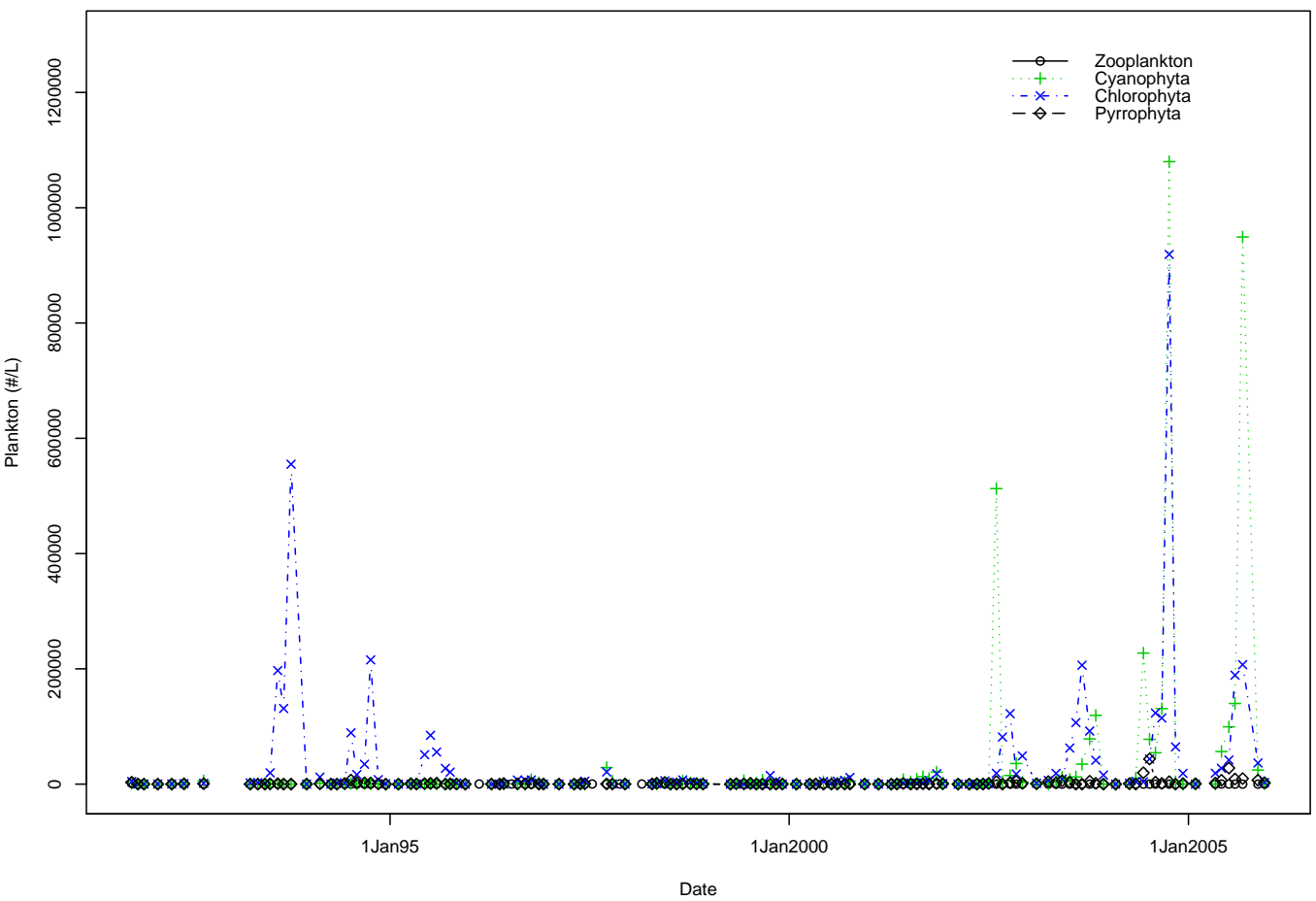


Figure B120: Lake Whatcom plankton data for Site 4, plotted to show Cyanophyta and Chlorophyta (1992–2005).

Lake Whatcom Secchi data for Site 1, February 1988 through December 2005.

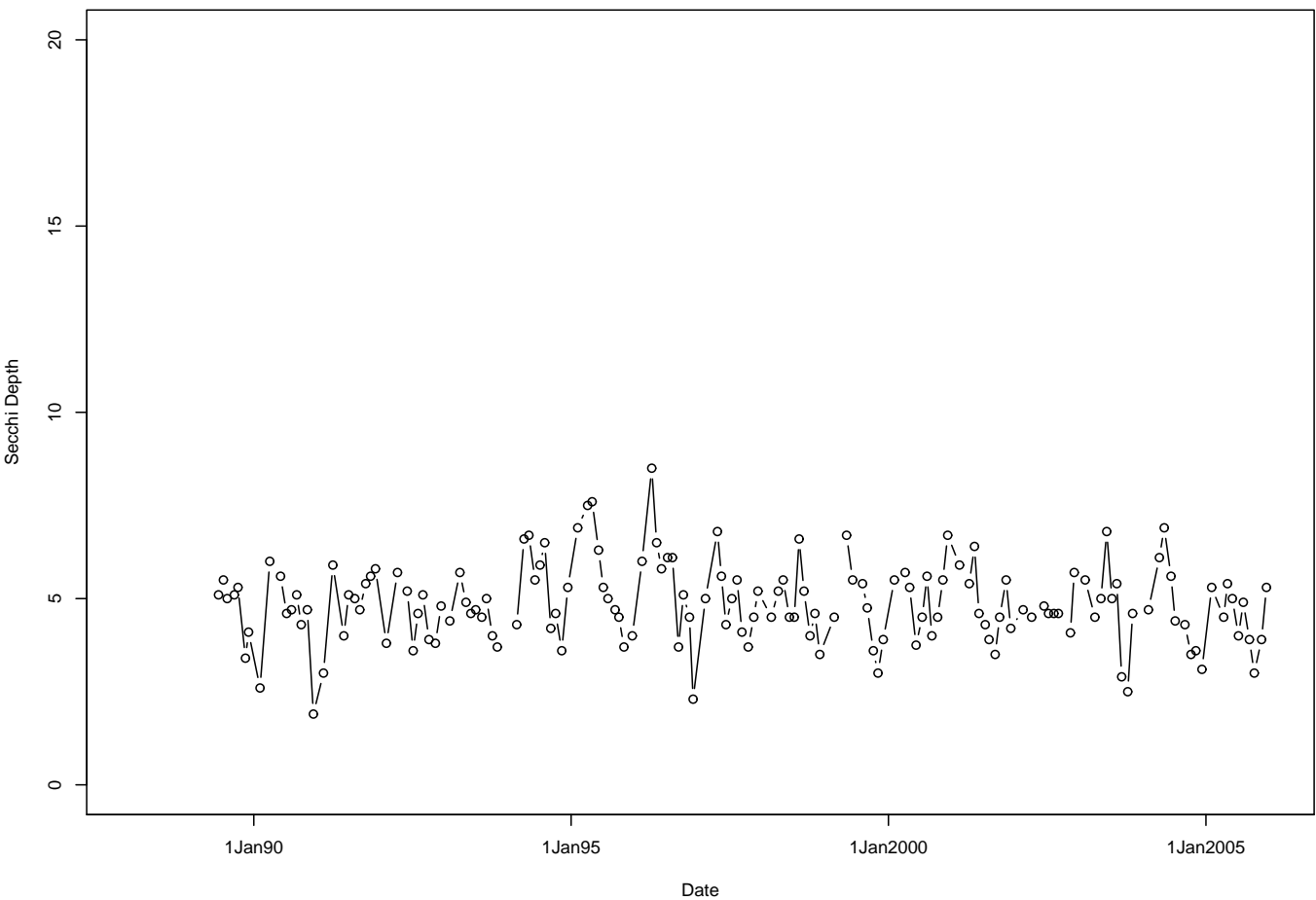


Figure B121: Lake Whatcom Secchi depths for Site 1.

Lake Whatcom Secchi data for Site 2, February 1988 through December 2005.

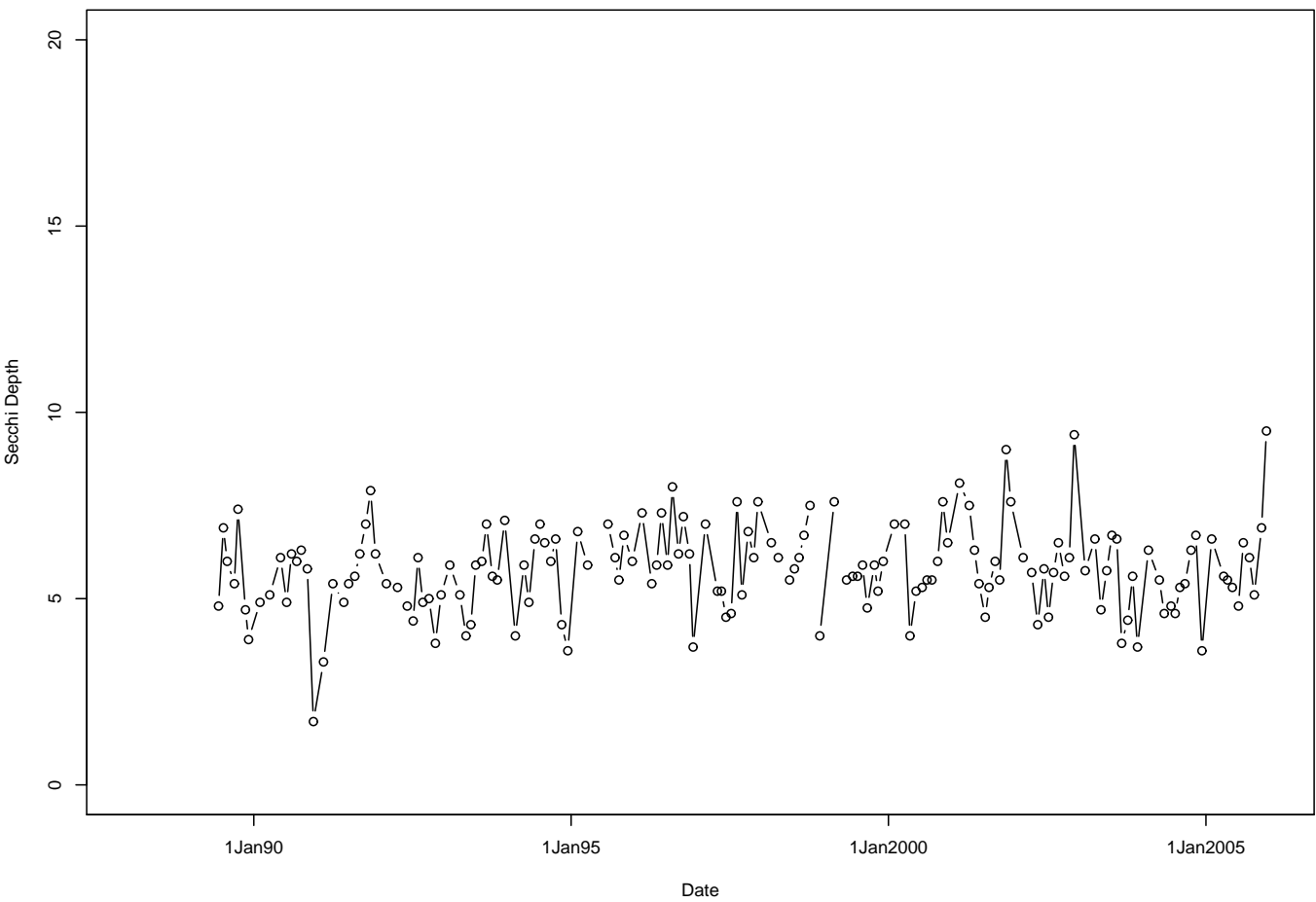


Figure B122: Lake Whatcom Secchi depths for Site 2.

Lake Whatcom Secchi data for Intake, February 1988 through December 2005.

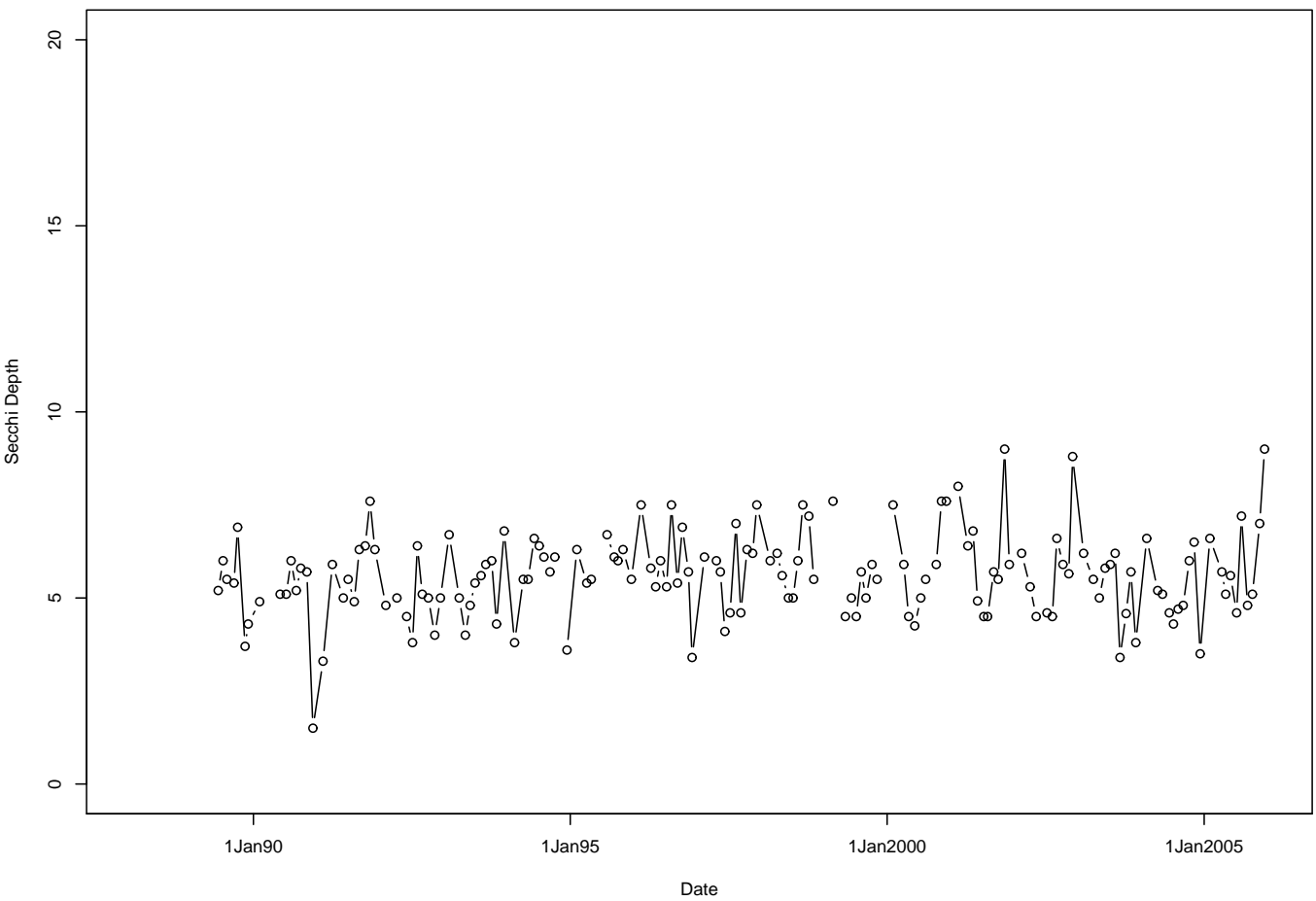


Figure B123: Lake Whatcom Secchi depths for the Intake.

Lake Whatcom Secchi data for Site 3, February 1988 through December 2005.

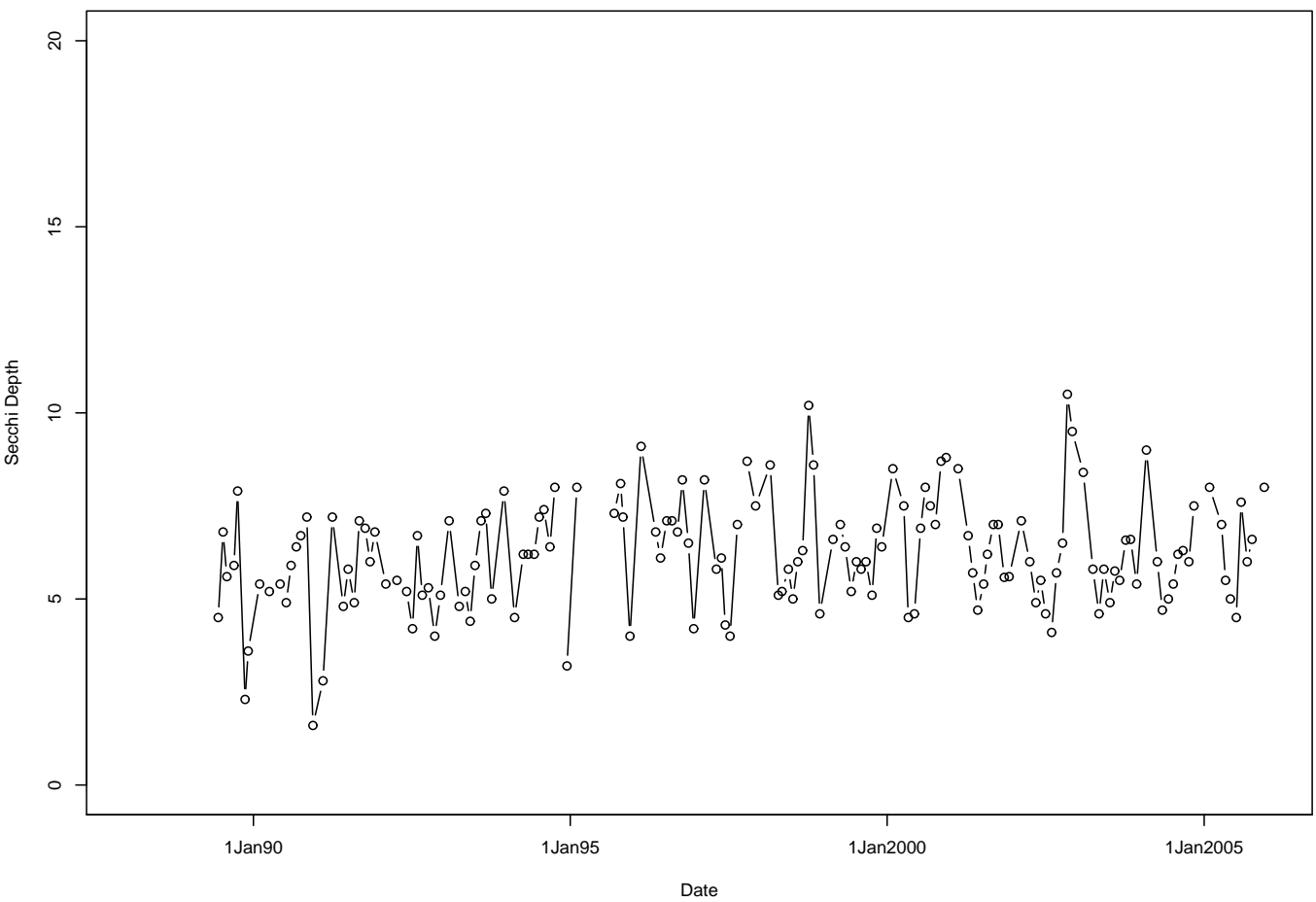


Figure B124: Lake Whatcom Secchi depths for Site 3.

Lake Whatcom Secchi data for Site 4, February 1988 through December 2005.

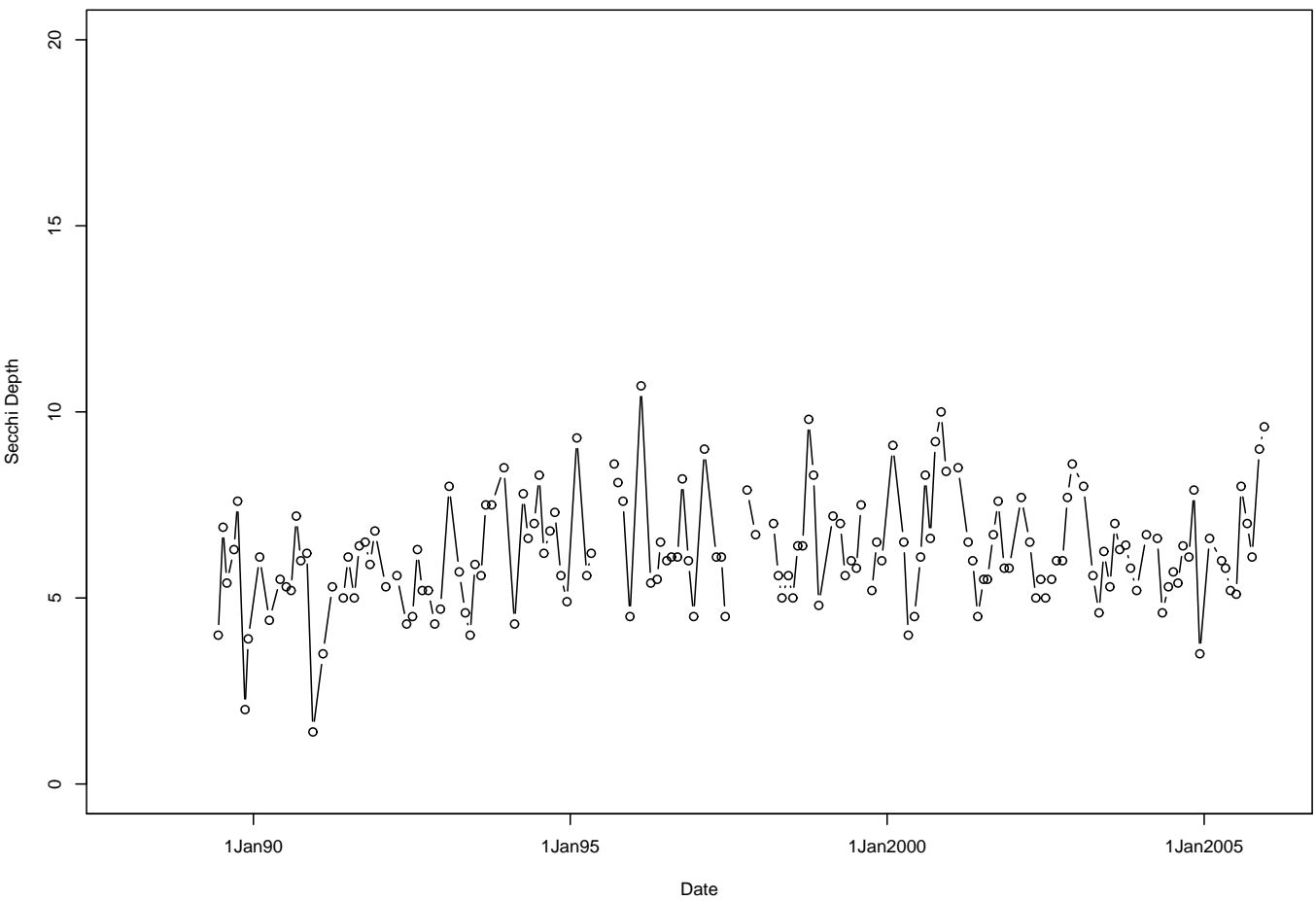


Figure B 125: Lake Whatcom Secchi depths for Site 4.

B.6 Coliform Bacteria

Lake Whatcom fecal coliform data for Site 1, February 1988 through December 2005.

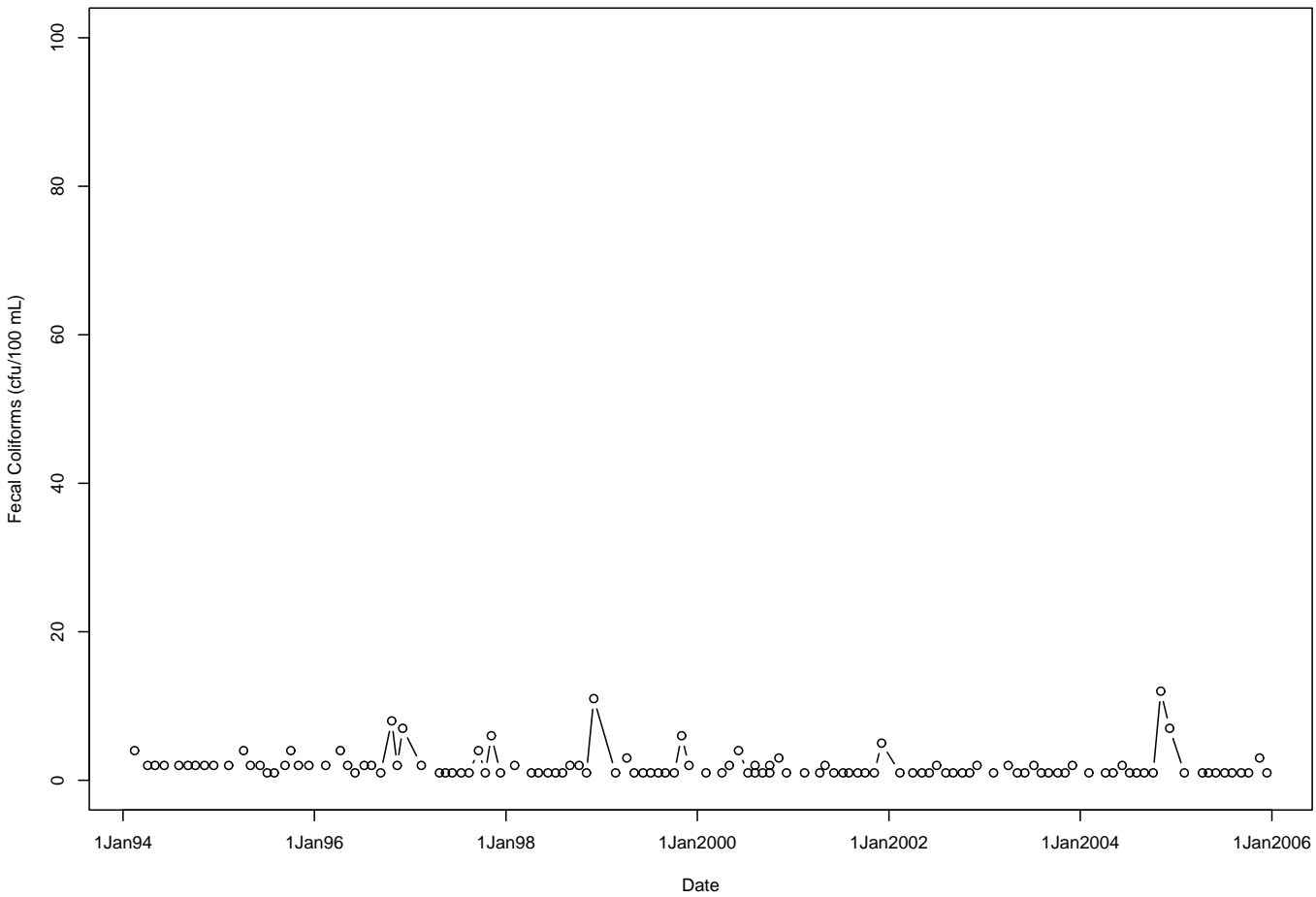


Figure B126: Lake Whatcom fecal coliform data for Site 1 (1994–2005).

Lake Whatcom fecal coliform data for Site 2, February 1988 through December 2005.

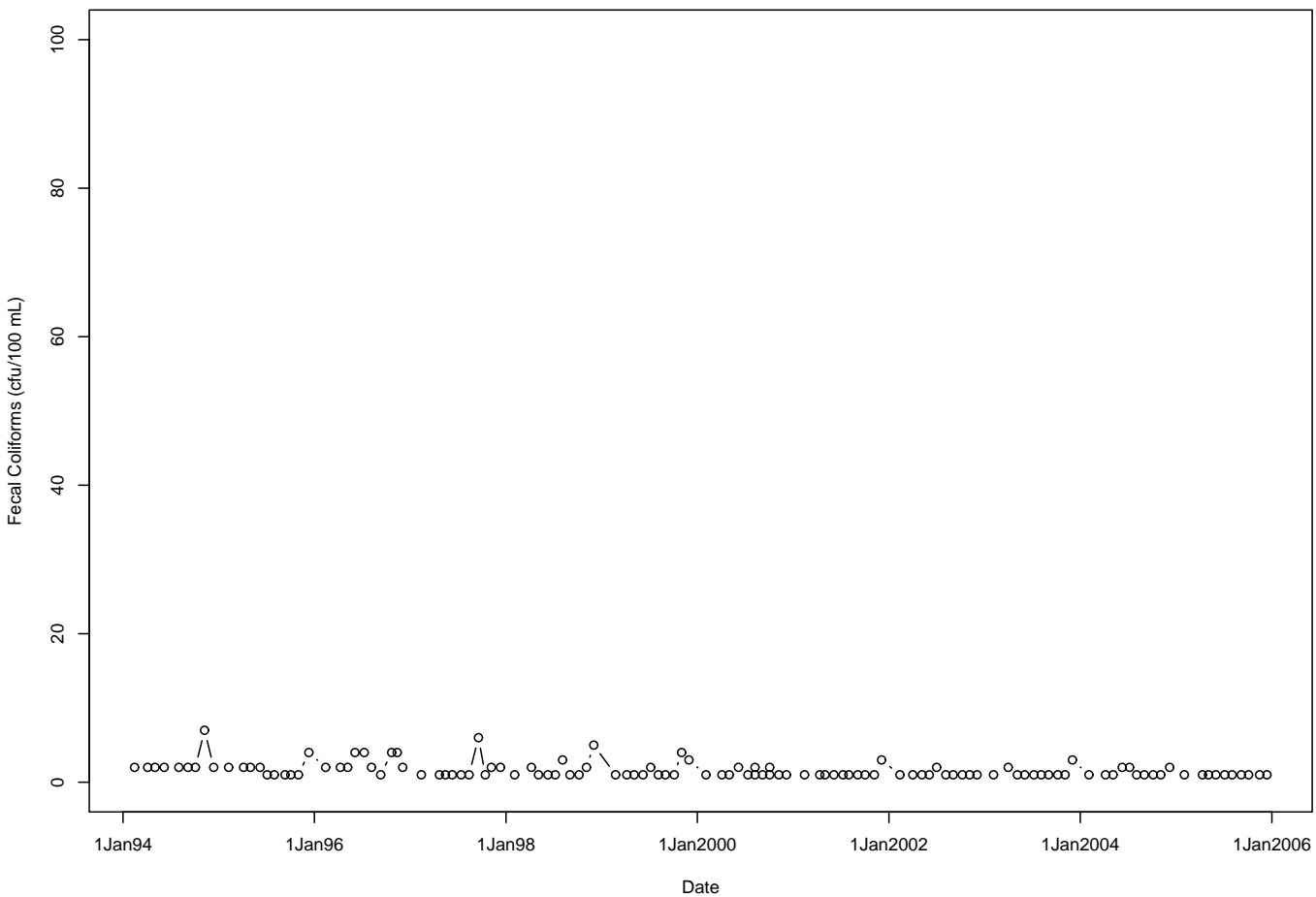


Figure B127: Lake Whatcom fecal coliform data for Site 2 (1994–2005).

Lake Whatcom fecal coliform data for Intake, February 1988 through December 2005.

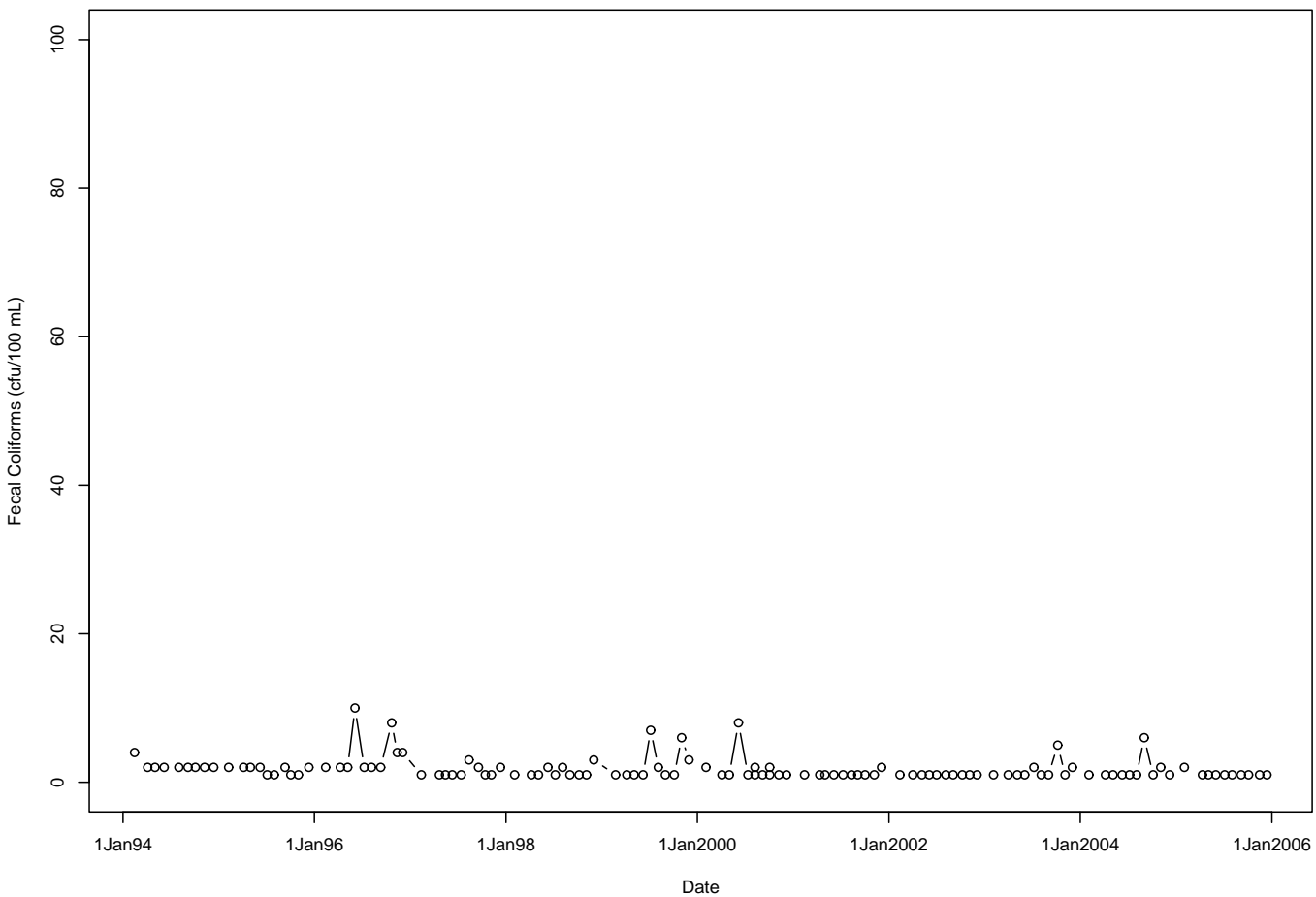


Figure B128: Lake Whatcom fecal coliform data for the Intake (1994-2005).

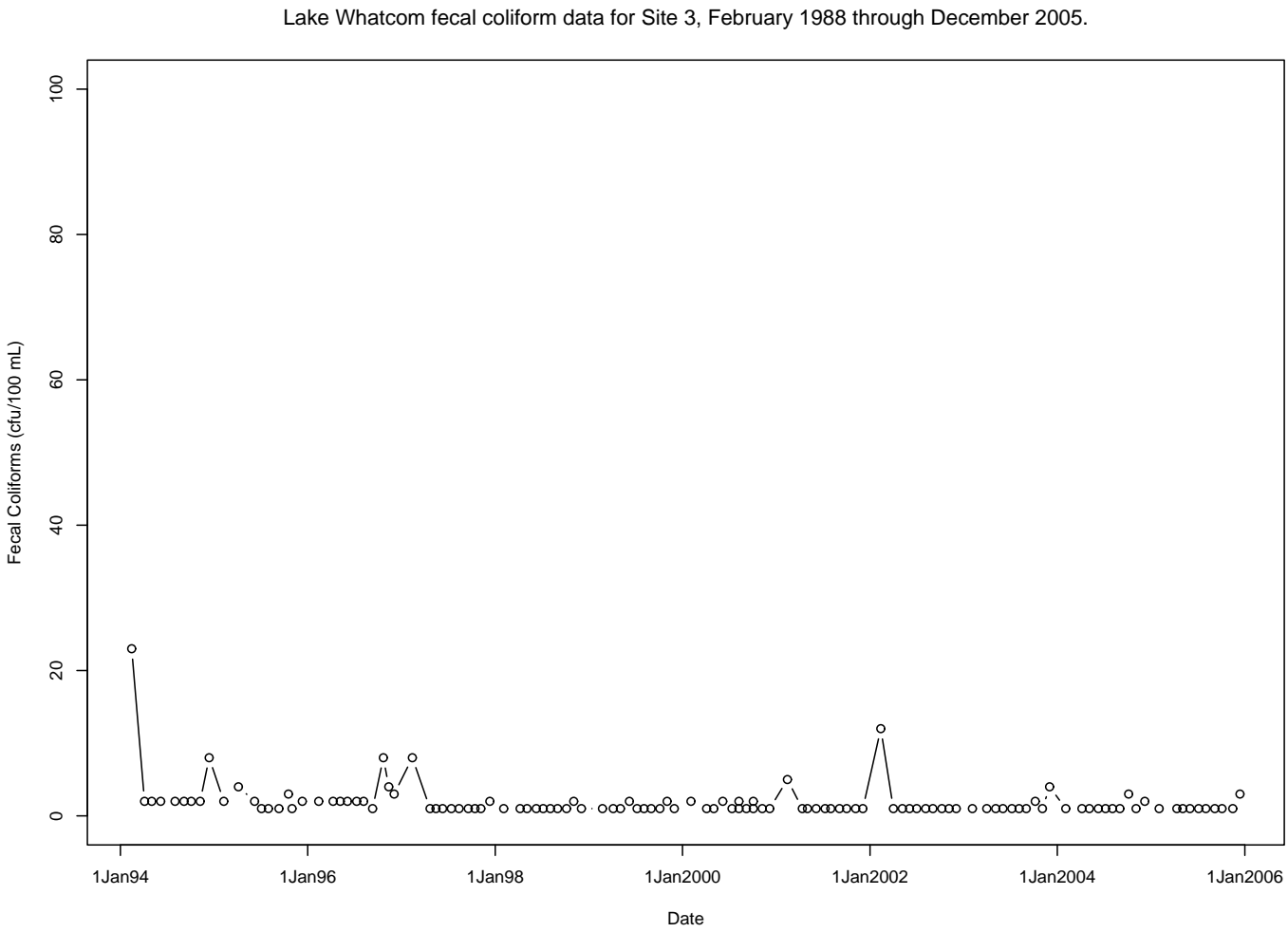


Figure B129: Lake Whatcom fecal coliform data for Site 3 (1994–2005).

Lake Whatcom fecal coliform data for Site 4, February 1988 through December 2005.

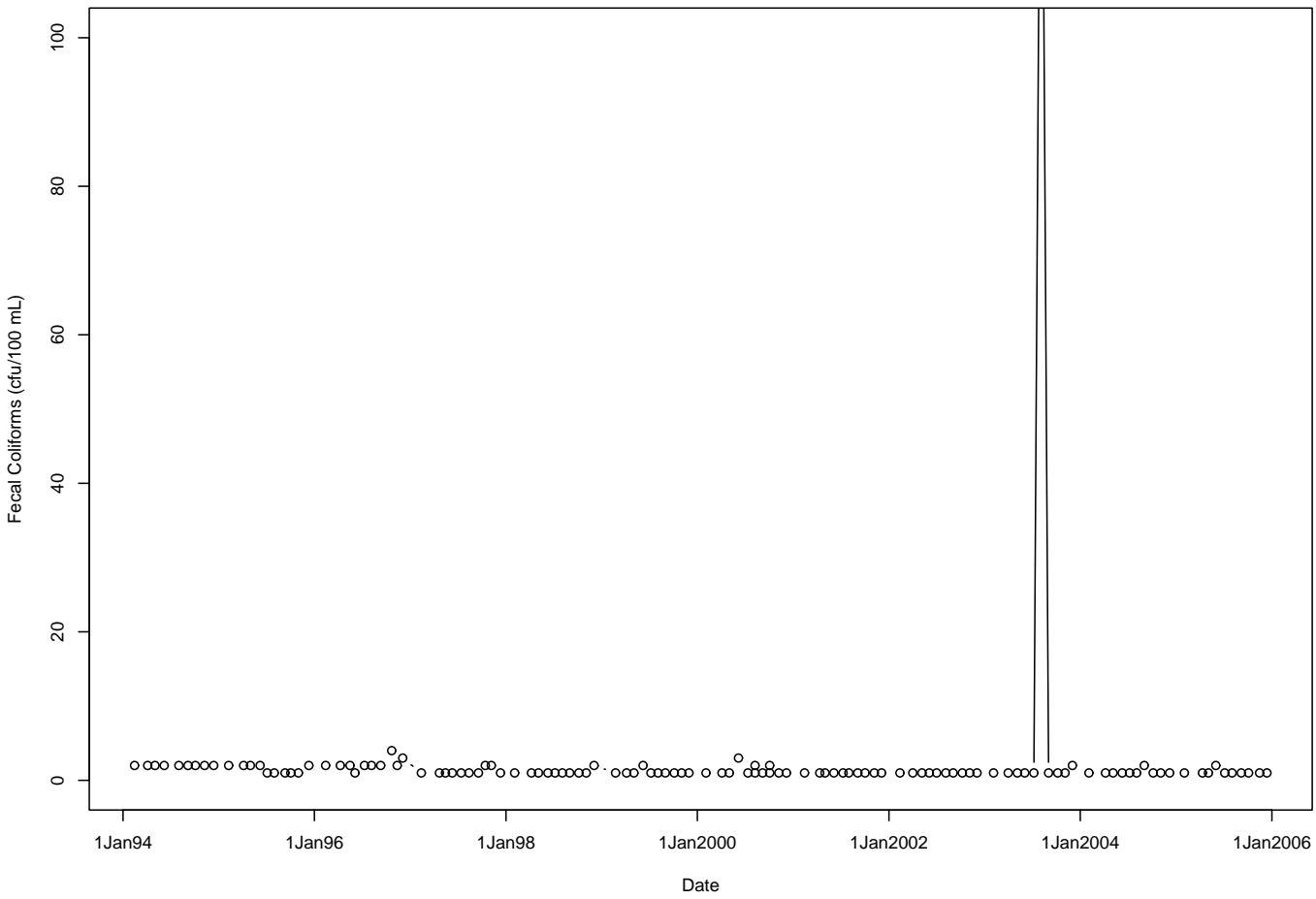


Figure B130: Lake Whatcom fecal coliform data for Site 4 (1994–2005).

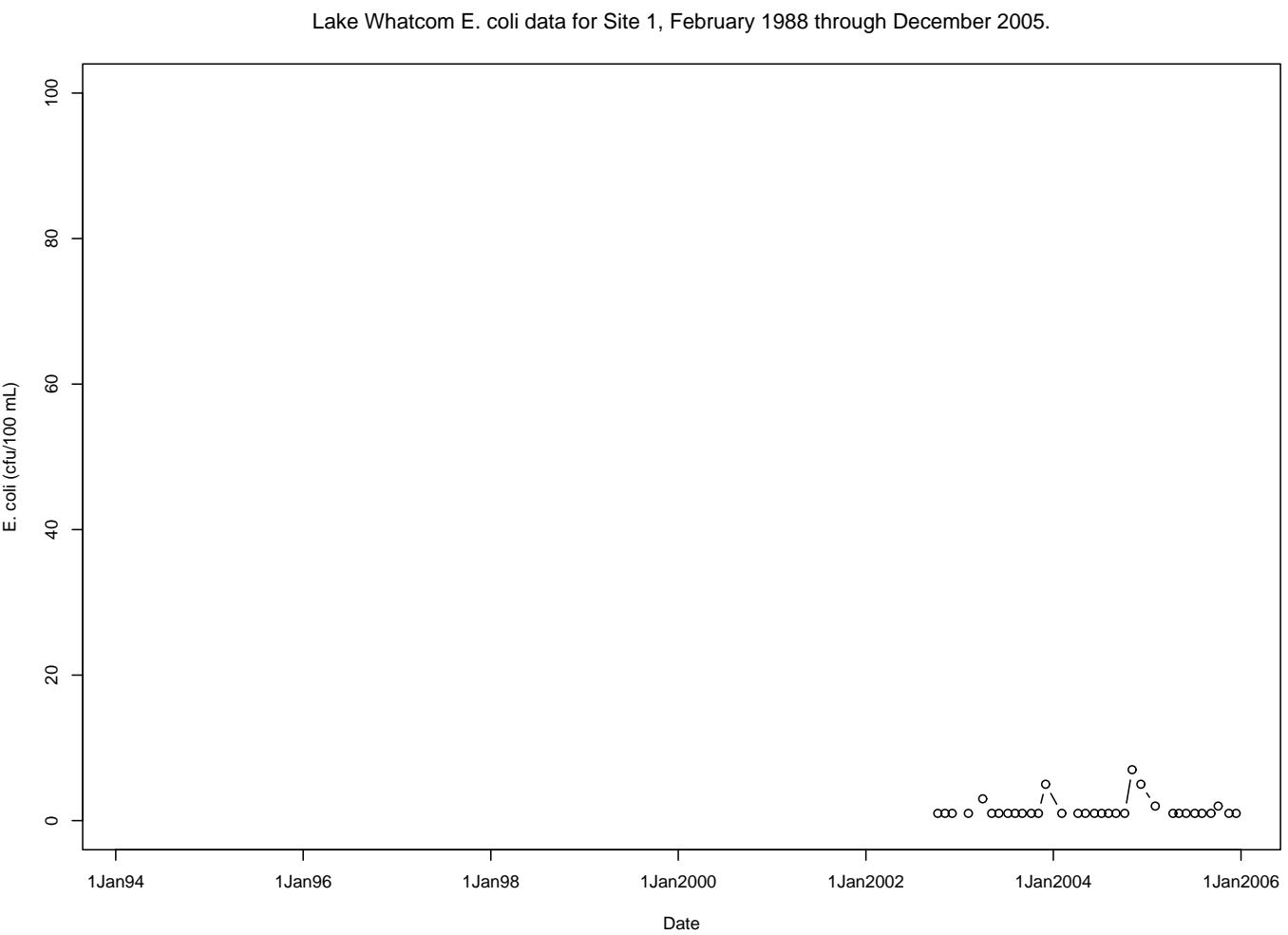


Figure B131: Lake Whatcom *E. coli* data for Site 1. Data collection started in October 2002.

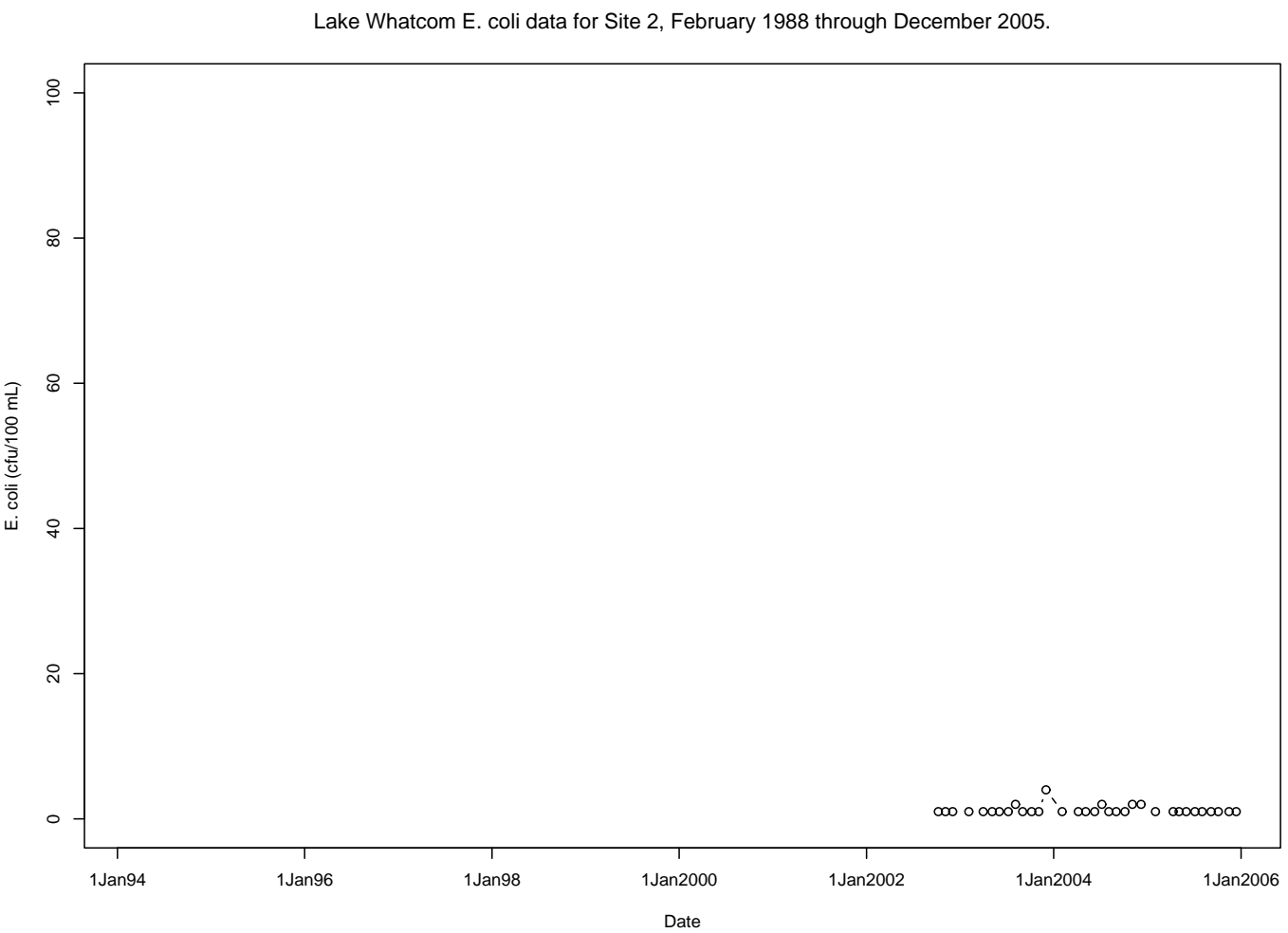


Figure B132: Lake Whatcom *E. coli* data for Site 2. Data collection started in October 2002.

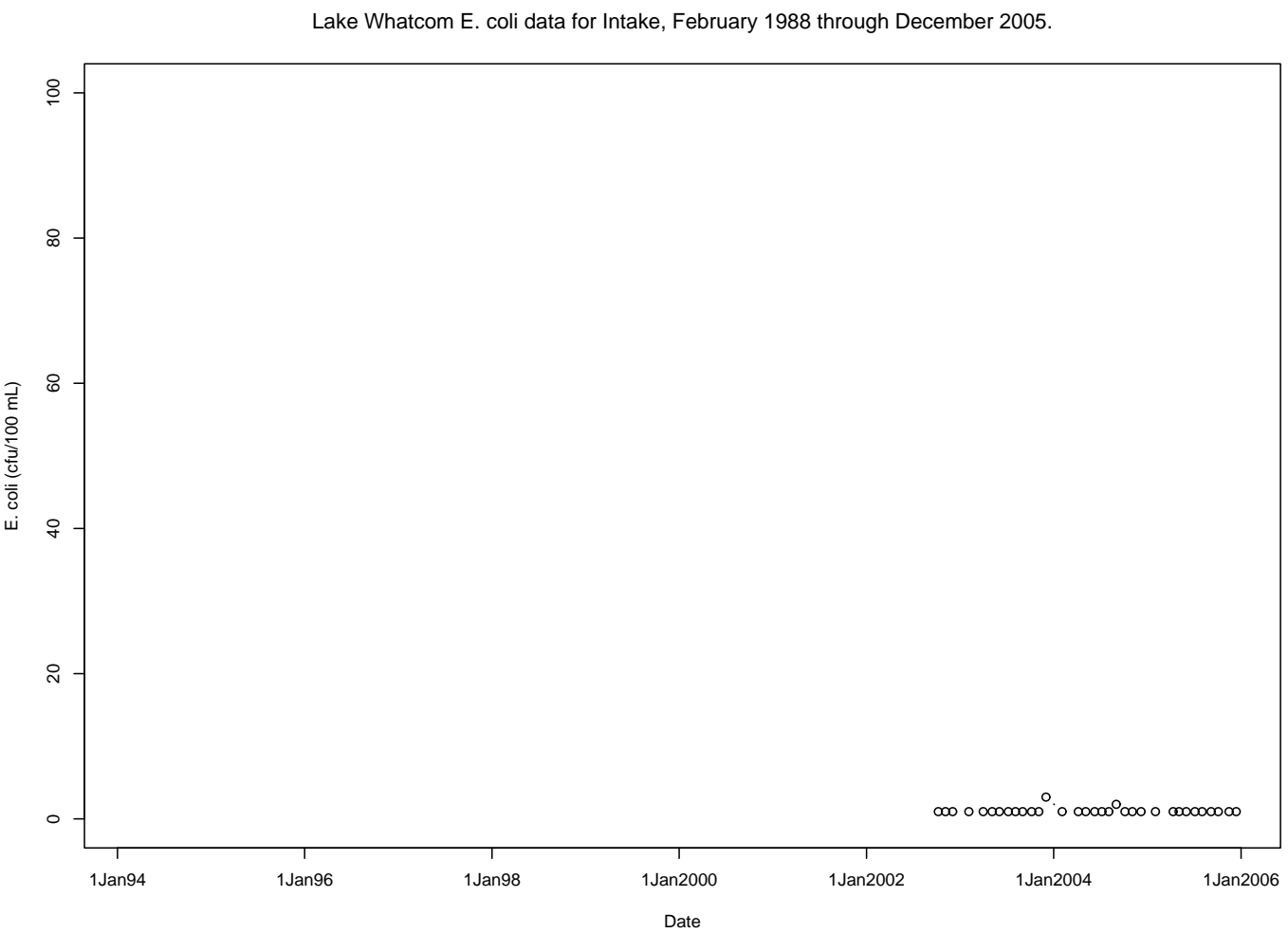


Figure B133: Lake Whatcom *E. coli* data for the Intake. Data collection started in October 2002.

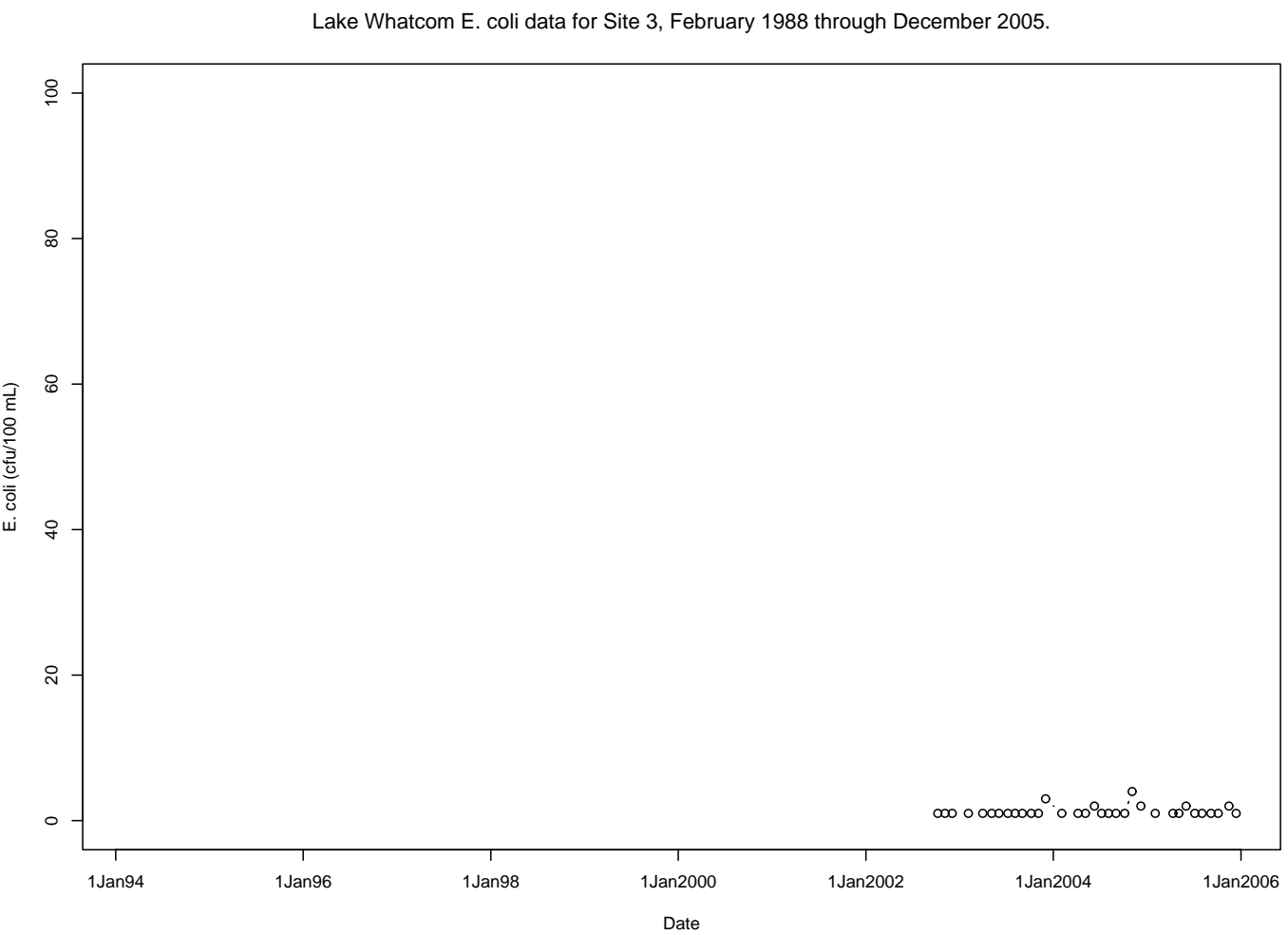


Figure B134: Lake Whatcom *E. coli* data for Site 3. Data collection started in October 2002.

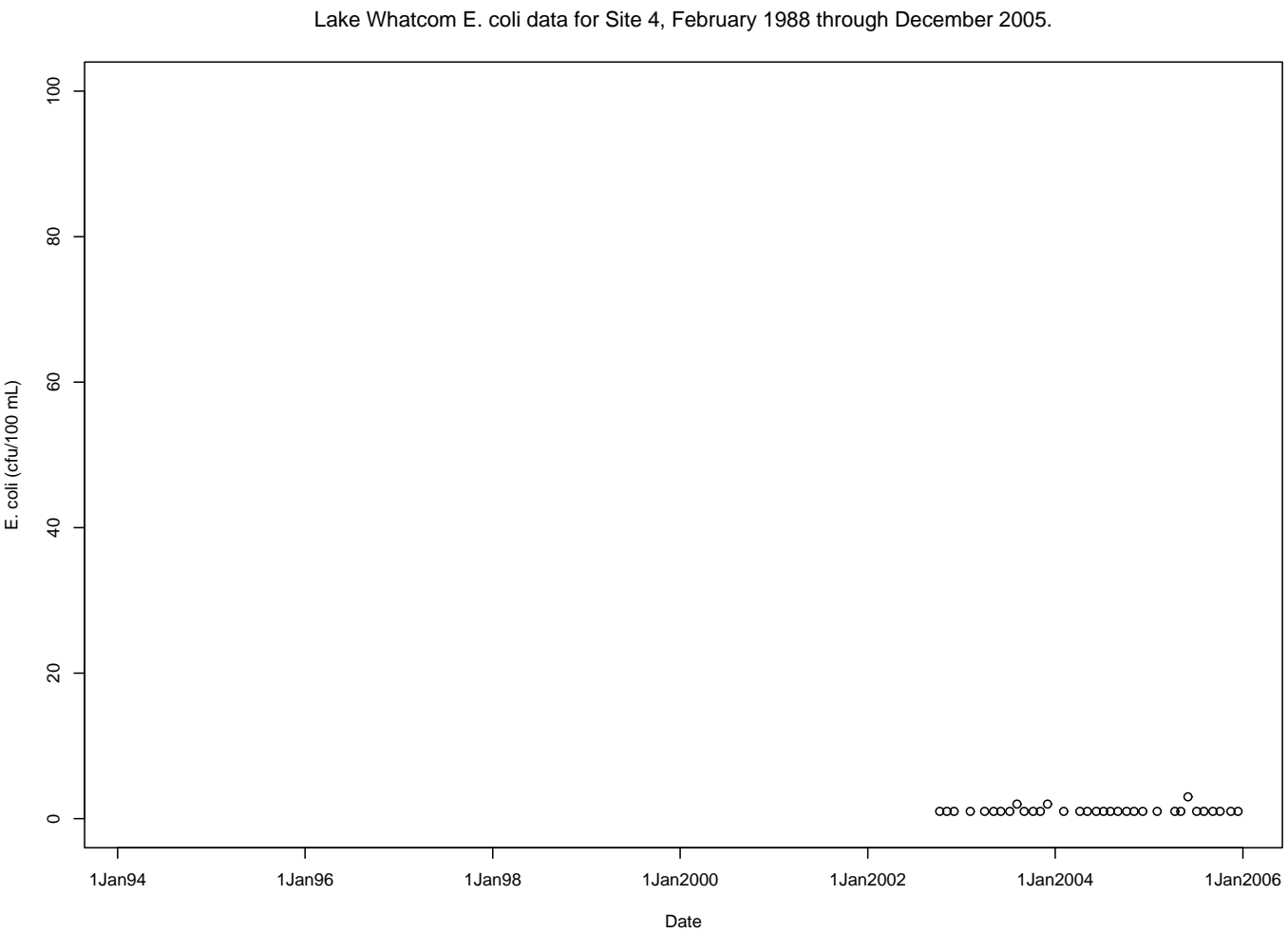


Figure B135: Lake Whatcom *E. coli* for Site 4. Data collection started in October 2002.

C Quality Control

In order to maintain a high degree of accuracy and confidence in the water quality data all personnel associated with this project were trained according to standard operating procedures for the methods listed in Table 2 (page 16). Single-blind quality control tests were conducted as part of the IWS laboratory certification process. The 2004/2005 results are presented in Table C1. All results from the single-blind tests were within acceptance limits.

	Reported Value [†]	True Value [†]	Acceptance Limits
Specific conductivity ($\mu\text{S}/\text{cm}$ at 25°C)	884	844	775–914
	570	569	528–611
Total alkalinity (mg/L as CaCO ₃)	38.9	38.9	33.9–44.6
	61.2	59.4	53.0–66.0
Ammonia nitrogen, autoanalysis (mg-N/L)	3.07	3.88	2.95–4.79
	16.9	17.5	13.6–21.2
Ammonia nitrogen, manual (mg-N/L)	3.81	3.88	2.95–4.79
	17.4	17.5	13.6–21.2
Nitrate nitrogen, autoanalysis (mg-N/L)	17.2	18.1	14.3–21.5
	21.1	21.3	16.9–25.3
Orthophosphate, autoanalysis (mg-P/L)	3.09	3.05	2.60–3.53
	0.829	0.840	0.702–0.984
Orthophosphate, manual (mg-P/L)	3.23	3.05	2.60–3.53
	0.879	0.840	0.702–0.984
Total phosphorus, autoanalysis (mg-P/L)	4.87	5.28	4.01–6.19
	4.47	4.30	3.27–5.05
Total phosphorus, manual (mg-P/L)	5.08	5.28	4.01–6.19
	4.42	4.30	3.27–5.05
pH	7.97	8.00	7.77–8.23
	9.82	9.80	9.49–10.1
Non-filterable residue (mg/L)	62.4	64.8	49.6–69.8
	82.0	88.1	68.4–95.2
Turbidity (NTU)	4.89	5.69	4.08–7.29
	7.56	7.41	5.11–9.70

[†]Performance Evaluation Reports WP-096 (10/15/2004) and WP-101 (04/05/2005)

Table C1: Summary of 2004/2005 single-blind quality control results.

C.1 Laboratory Duplicates

Ten percent of all samples analyzed in the laboratory were duplicated to measure analytical precision. Upper and lower acceptance limits (± 2 std. dev. from mean pair difference) and upper and lower warning limits (± 3 std. dev. from mean pair difference) were developed using data from September 2003 through September 2004 (upper examples in Figures C1–C8, pages 287–294), and used to evaluate laboratory duplicates from October 2004 through September 2005 (lower examples in Figures C1–C8).

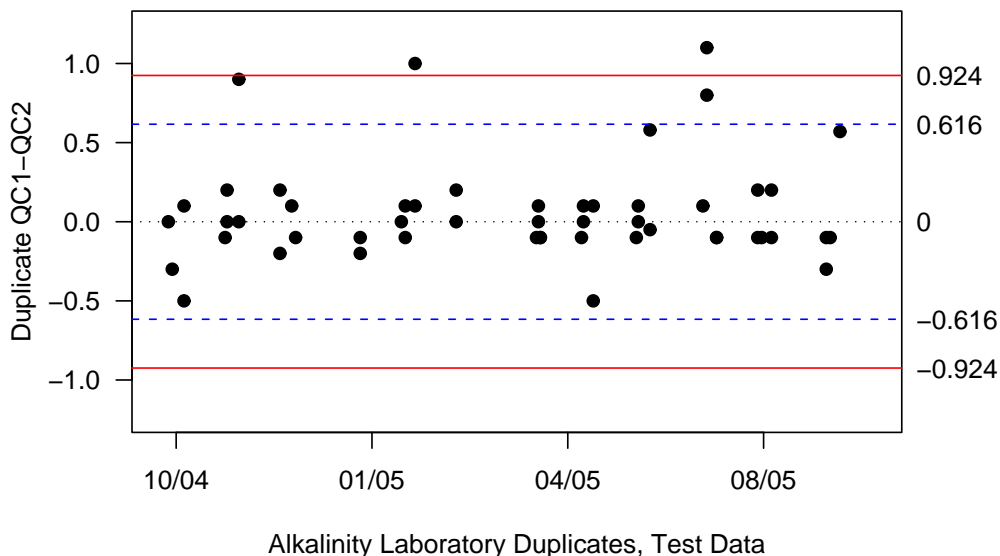
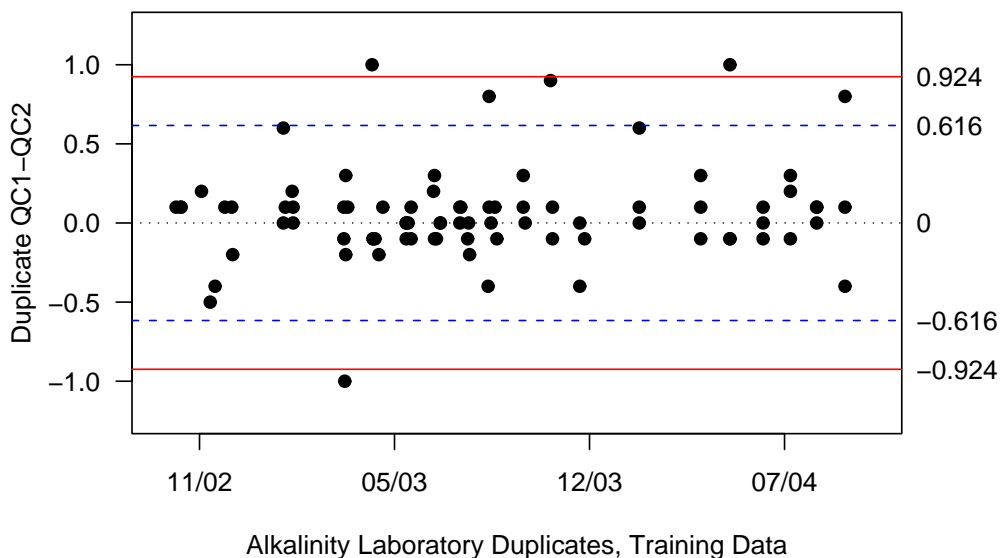


Figure C1: Alkalinity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

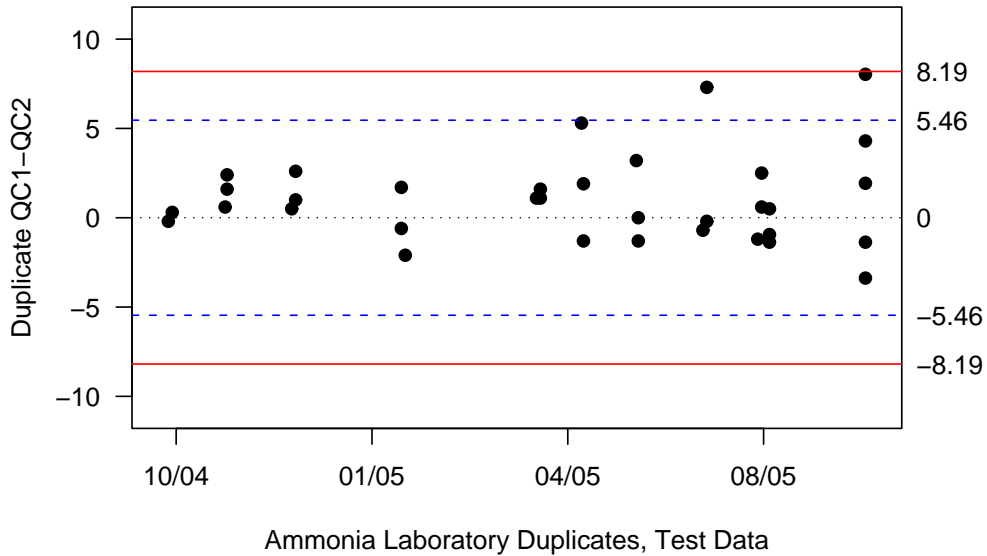
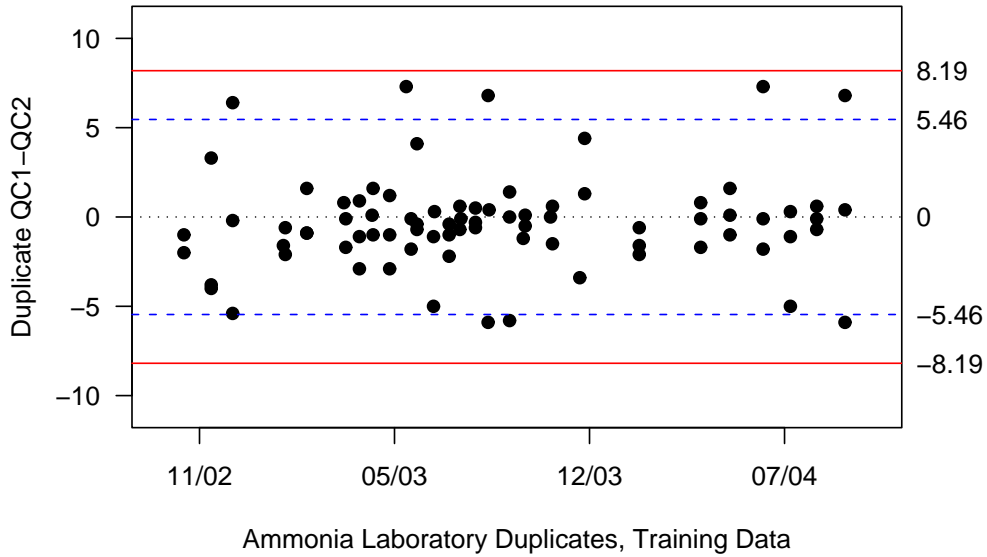


Figure C2: Ammonia laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

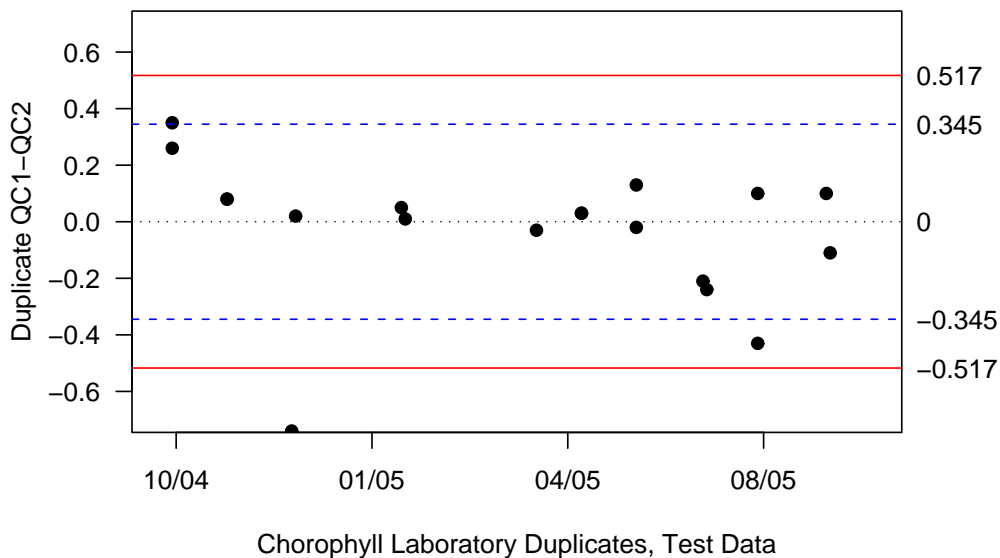
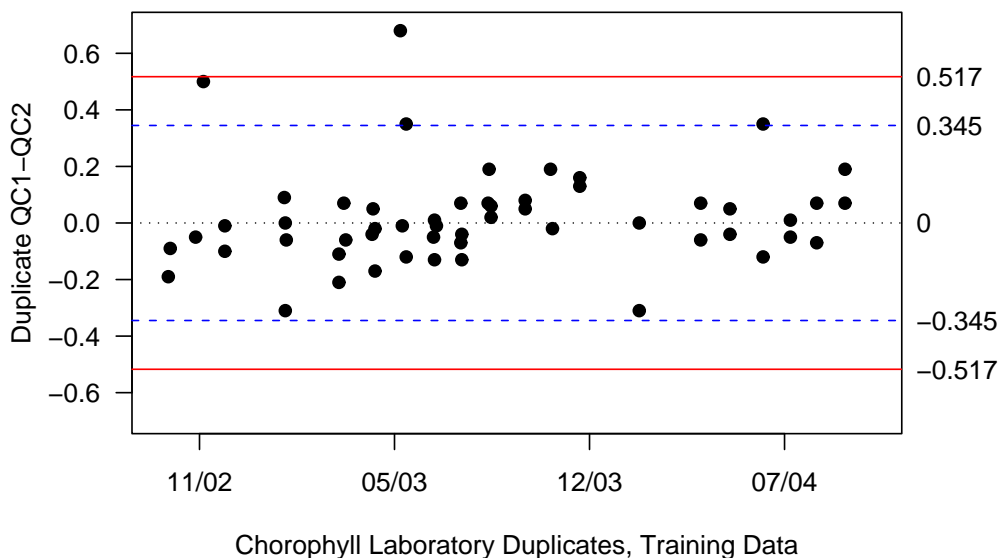


Figure C3: Chlorophyll laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate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

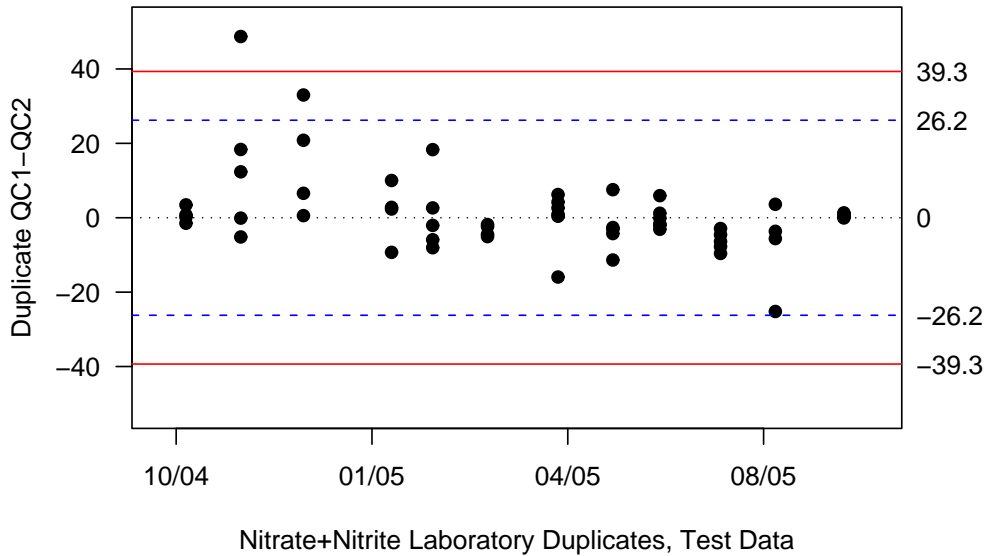
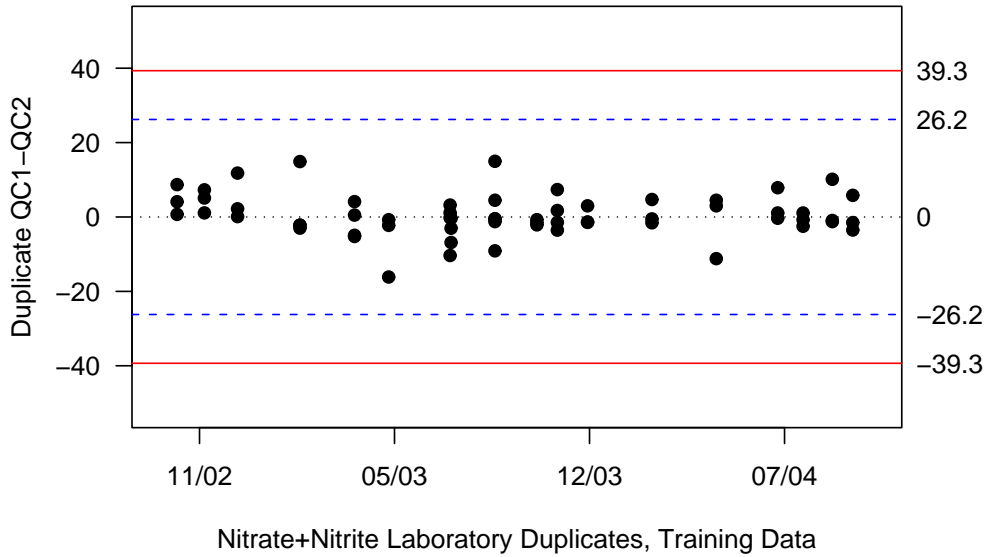


Figure C4: Nitrate/nitrite laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab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

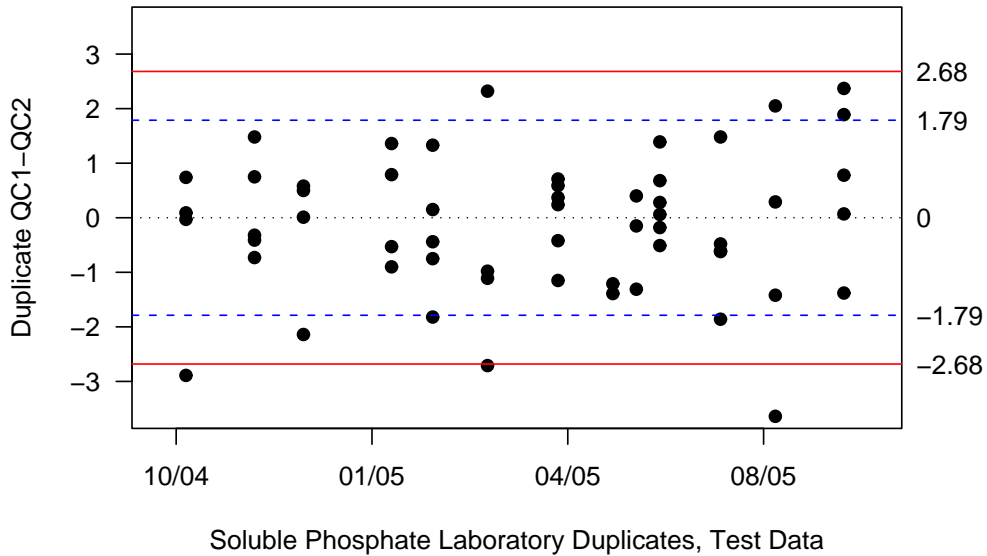
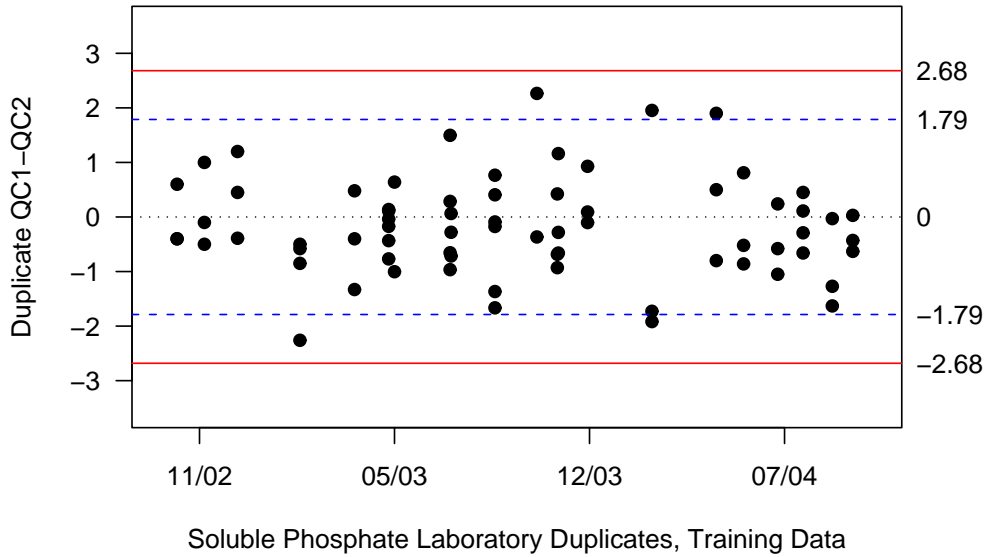


Figure C5: Soluble reactive phosphate laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two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

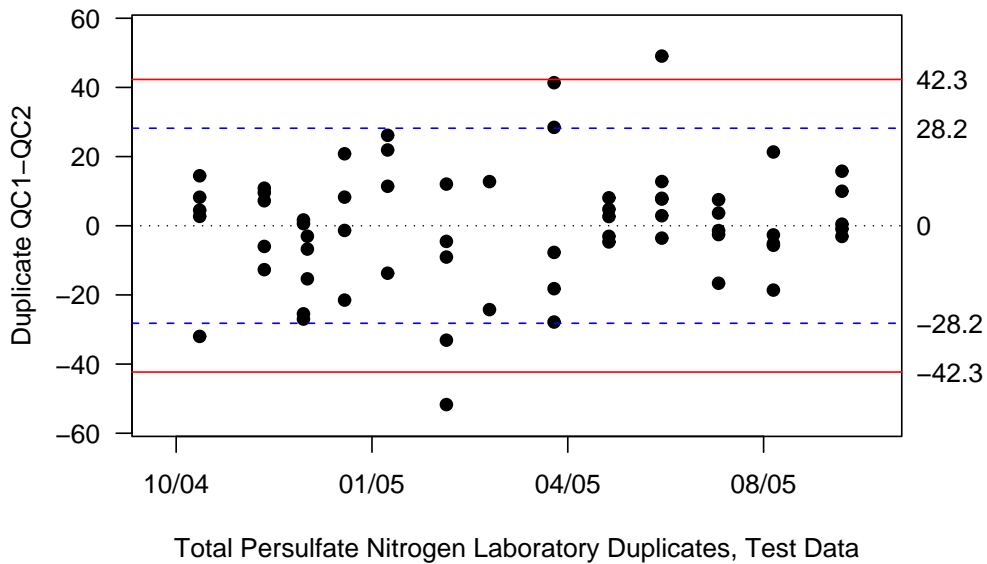
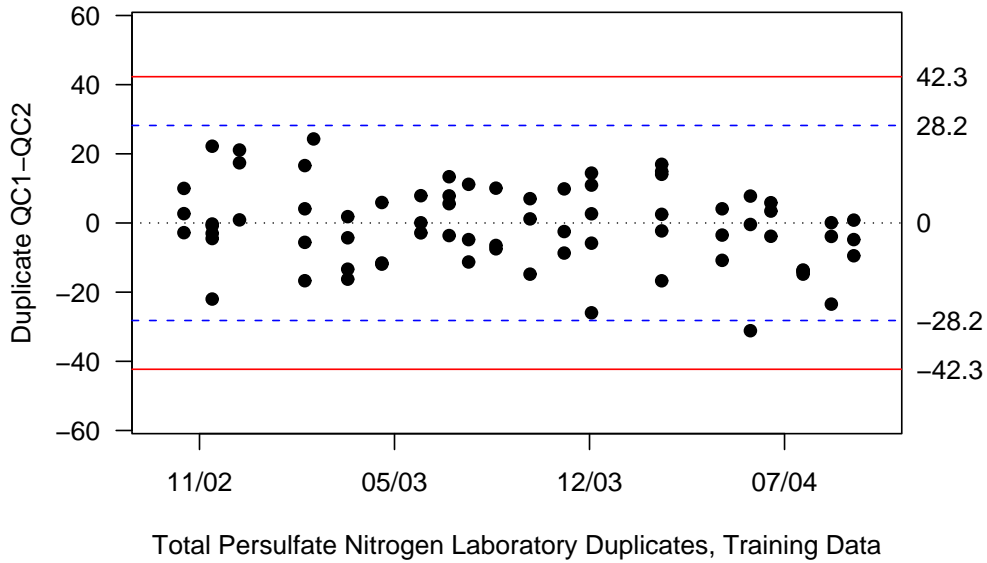


Figure C6: Total nitrogen laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab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

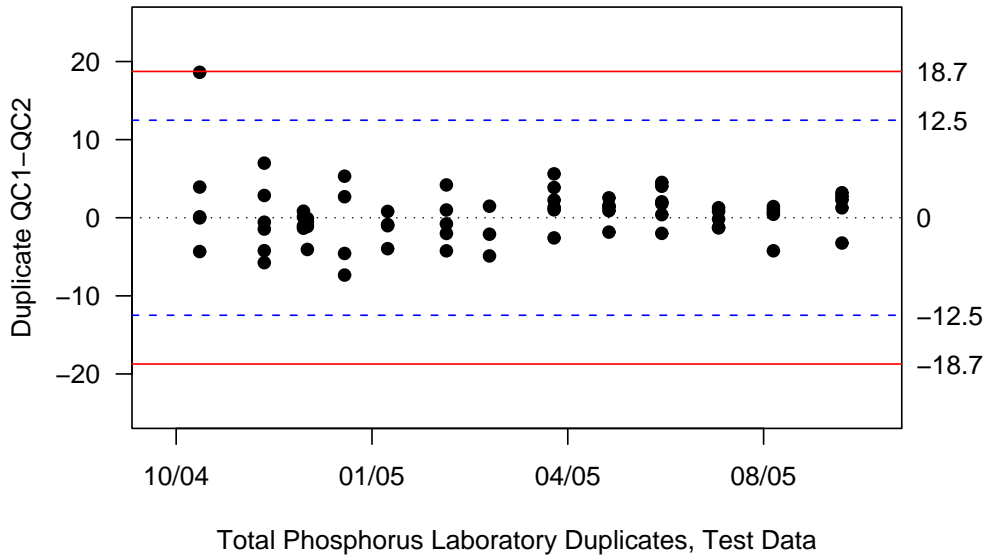
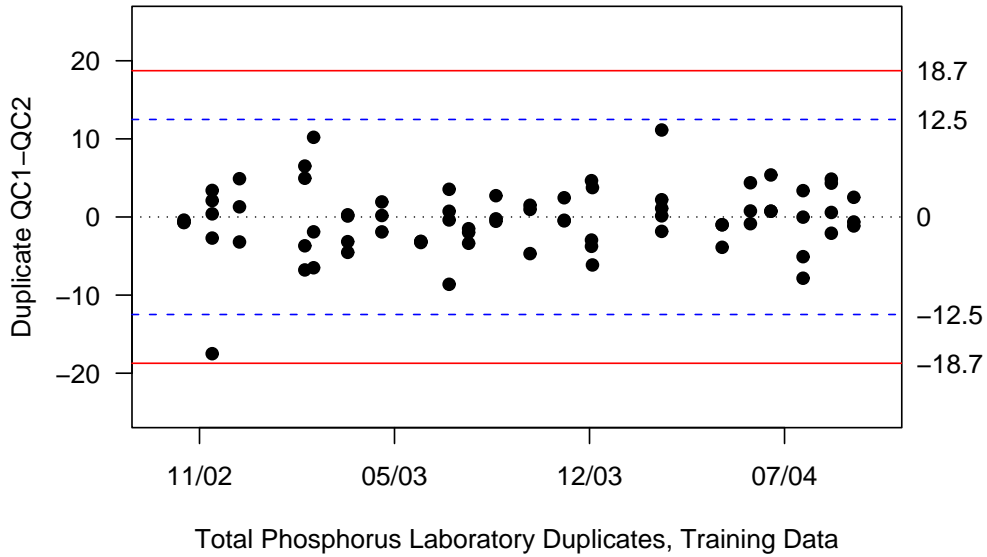


Figure C7: Total phosphorus laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

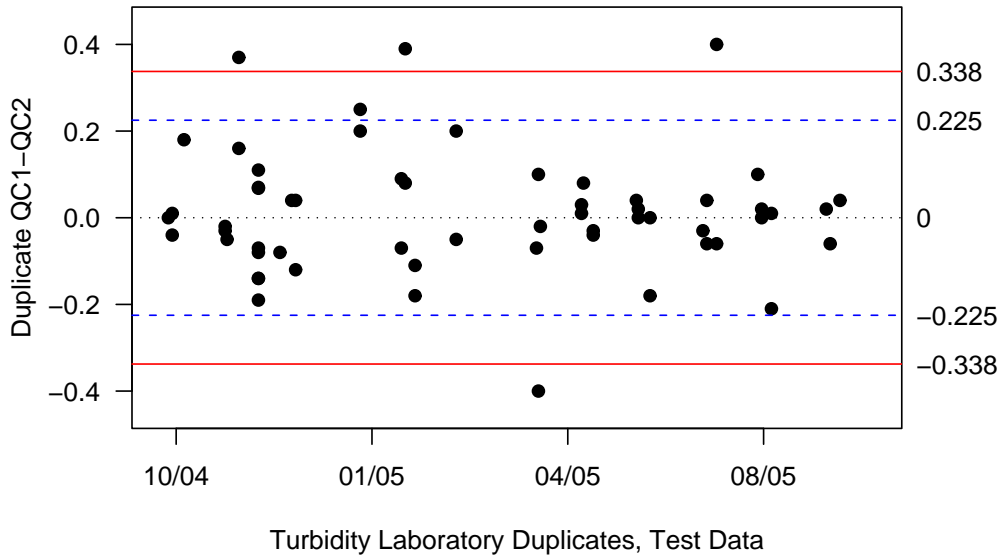
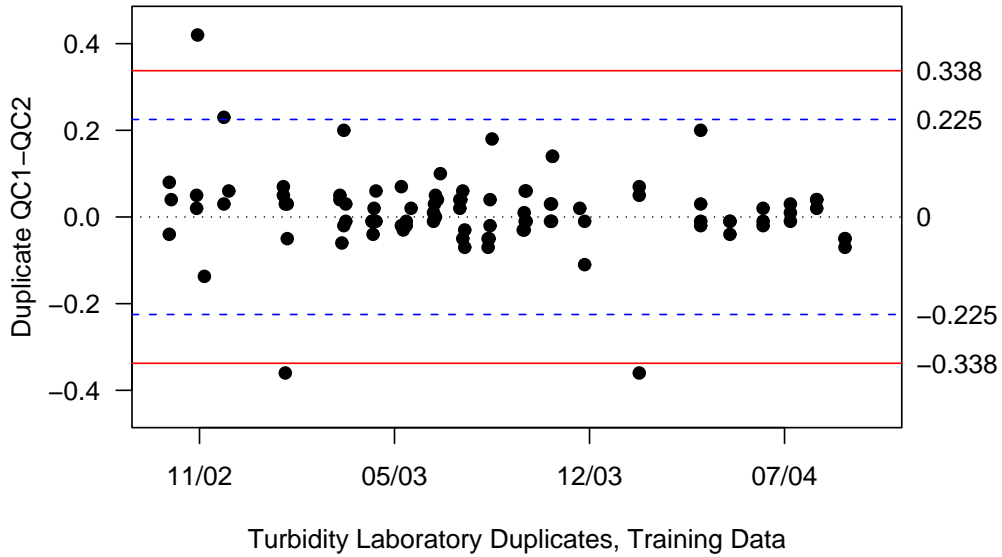


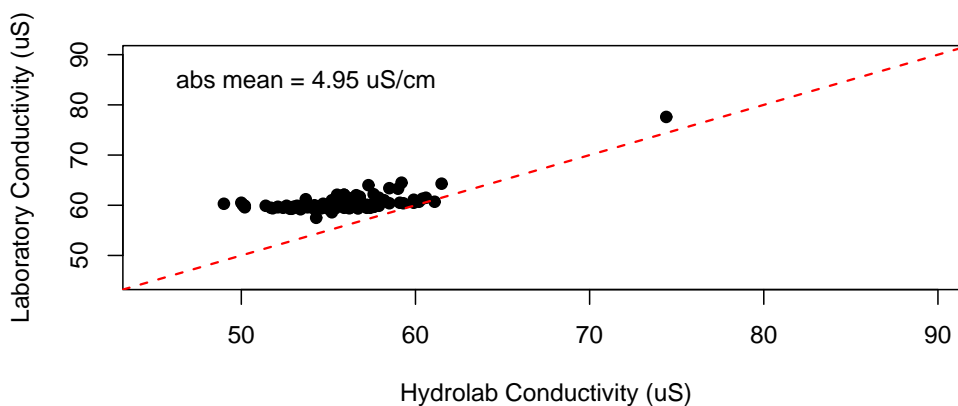
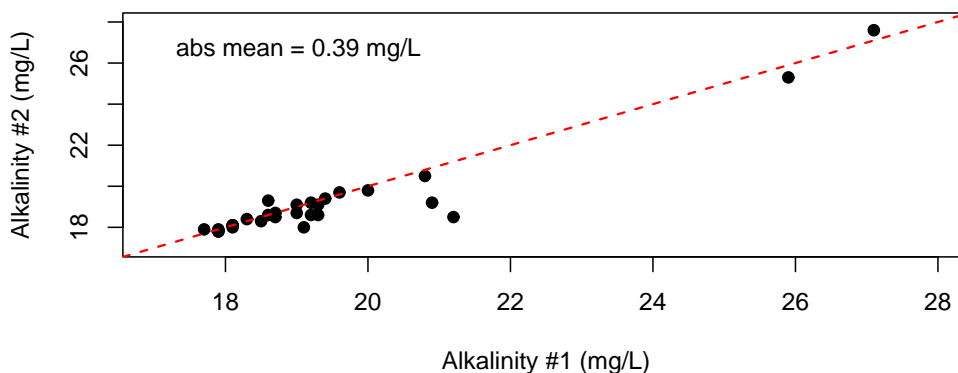
Figure C8: Turbidity laboratory duplicate control chart for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceding two years of lab duplicate data.

C.2 Field Duplicate Results

Separate field duplicates were collected and analyzed for a minimum of 10% of all of the water quality parameters except the Hydrolab data. To check the Hydrolab measurements, duplicate samples were analyzed for at least 10% of the Hydrolab measurements using water samples collected from the same depth as the Hydrolab measurement. The absolute mean difference* between field duplicates results indicated close agreement between duplicates, given that they came from different water samples (Figures C9–C13, pages 296–300).

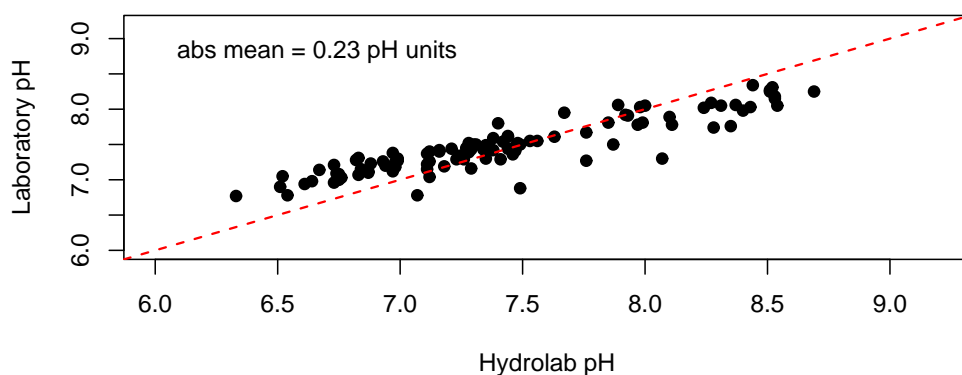
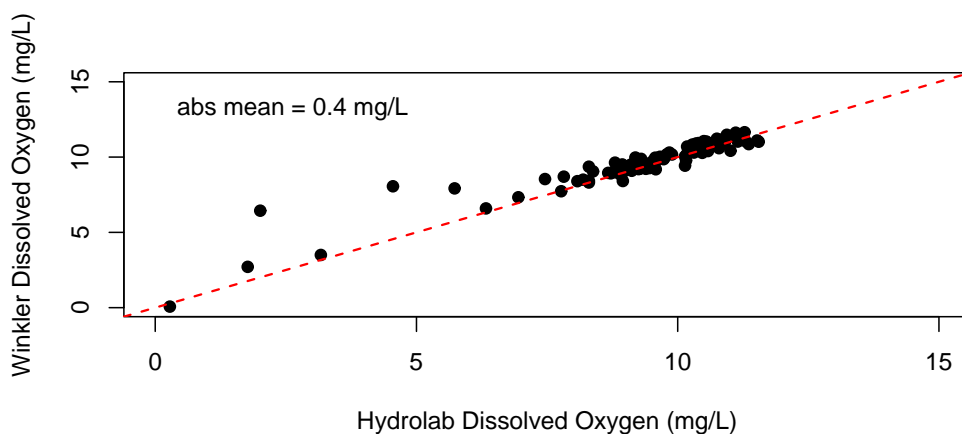
$$*\text{Absolute mean difference} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Although field duplicates are rarely as close as laboratory duplicates, there was good agreement between most of the field duplicate pairs. As in previous years, a systematic bias was observed in the conductivity results because the Hydrolab field meter is much more sensitive than our laboratory meter (Figure C9). Similarly, there was a small systematic bias in the pH data (Figure C10), with the Hydrolab results showing a more extreme range than the laboratory pH results. This is most likely due to slight changes in the amount of dissolved CO₂ and associated inorganic carbon ions (bicarbonate and carbonate) that occurred after the samples were collected. This type of pH shift is common in low alkalinity water samples. As in previous years, the only extreme differences between Hydrolab and Winkler dissolved oxygen samples occurred in late summer from near the thermocline in basins 1 or 2, where oxygen concentrations drop rapidly with increasing depth (Figure C10). This difference is caused by measuring true depth with the Hydrolab and “shallow-biased” depth with the marked line used to collect Winkler samples. Water currents and boat movement cause the marked line to drift at an angle from the boat, so the actual sampling depth is slightly shallower than what is indicated on the line. In the epilimnion and lower hypolimnion the depth differences have little effect on the field duplicate pairs because the dissolved oxygen concentrations are uniformly high or low. When the field duplicate pairs are collected along the abrupt oxygen gradient found in the thermocline, there can be a substantial difference in the paired samples.



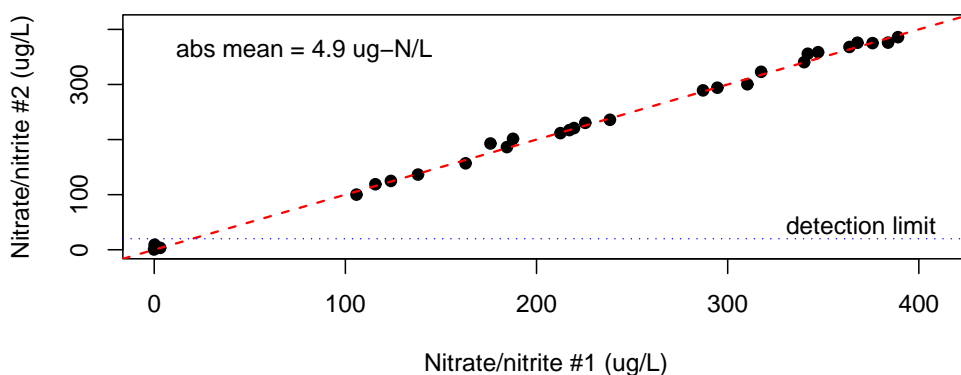
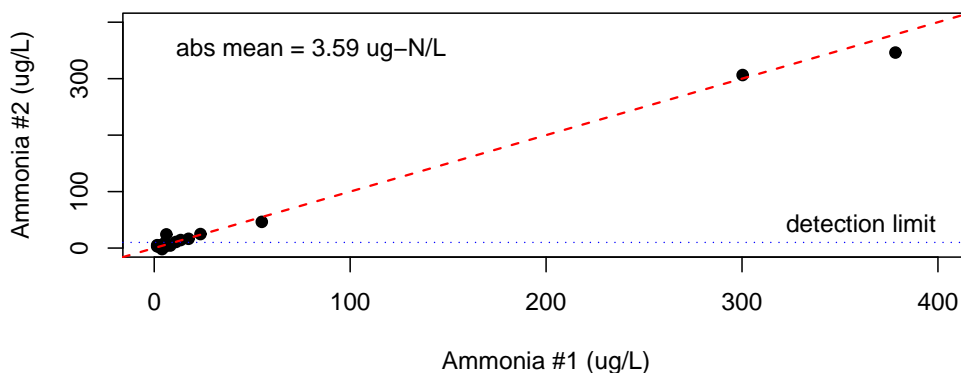
$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C9: Alkalinity and conductivity field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. Conductivity results show a systematic bias due to greater sensitivity of the Hydrolab field meter.



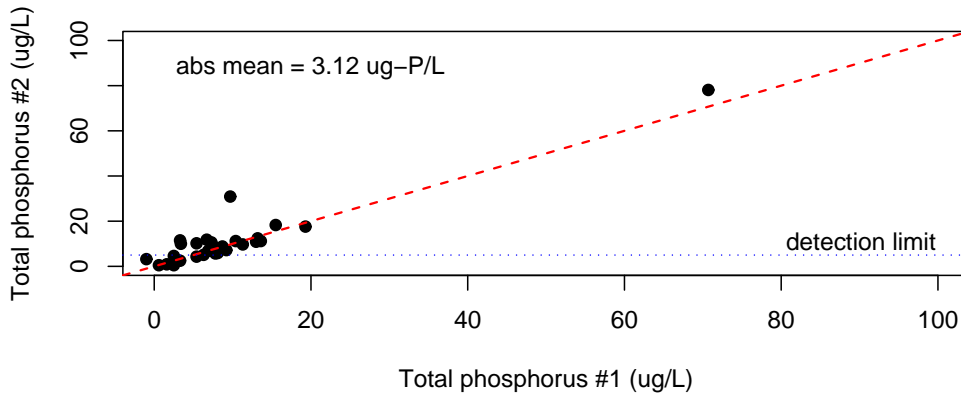
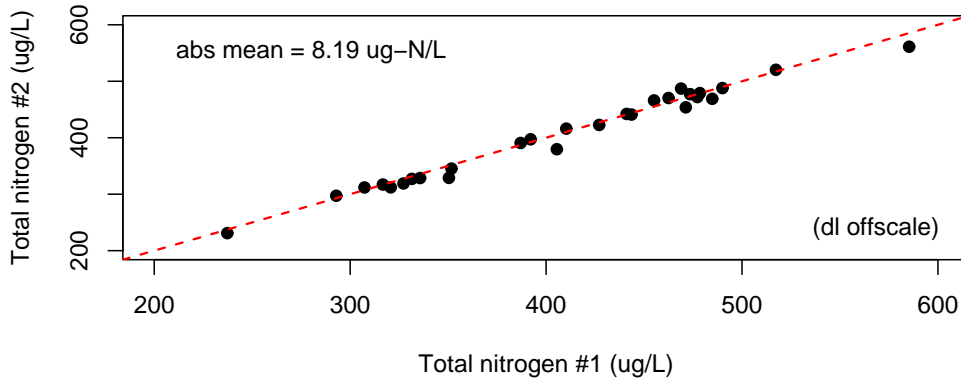
$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C10: Dissolved oxygen and pH field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship. The pH results show a slight systematic bias due to changes in dissolved CO₂ and associated inorganic carbon ions between field and laboratory samples.



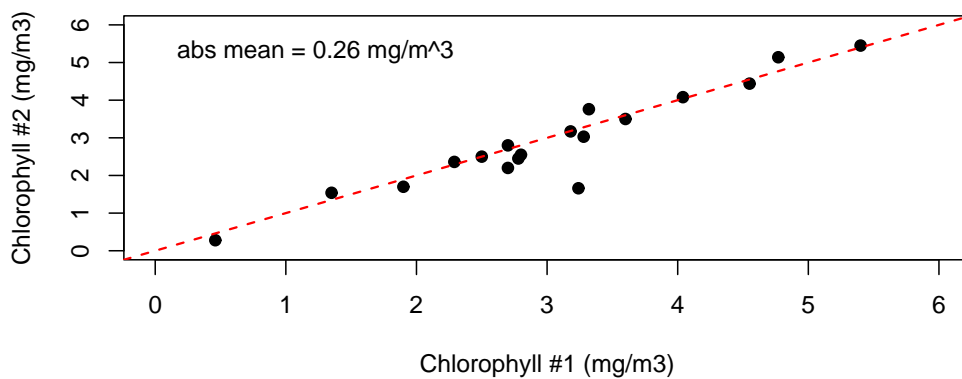
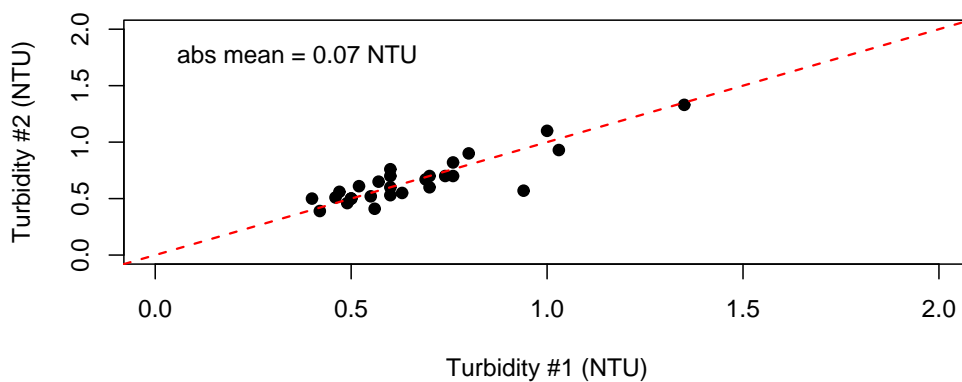
$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C11: Ammonia and nitrate/nitrite field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the historic detection limits.



$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C12: Total nitrogen and total phosphorus field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the historic detection limits. All total nitrogen samples were above the detection limit ($100 \mu\text{g-N/L}$).



$$\text{abs. mean} = \frac{|\text{Original Sample} - \text{Duplicate Sample}|}{2}$$

Figure C13: Turbidity and chlorophyll field duplicates for the 2004/2005 Lake Whatcom Monitoring Project. Diagonal reference line shows a 1:1 relationship.

D Lake Whatcom Data

The 2004/2005 Lake Whatcom water quality data are included on the following pages in the hardcopy version of this report. The historic detection limits and abbreviations for each parameter are listed in Table D1. Table D1 includes abbreviations and detection limits for all analytes measured during the current year's monitoring program, as well as any other analyses included in the verified historic data set included on the CD with this report.

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, for example, current detection limits in Table 2, page 16). 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 historic detection limits in order 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.

Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity (\pm)	Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity (\pm)
alk	Alkalinity	± 0.5 mg/L	As	arsenic, total	dl = 0.03/0.01/0.001 mg/L
ecoli	Bacteria, <i>E. coli</i>	dl = 2 cfu/100 mL	Cd	cadmium, total	dl = 0.002/0.0005 mg/L
ent	Bacteria, <i>Enterococcus</i>	dl = 2 cfu/100 mL	Cr	chromium, total	dl = 0.006/0.001 mg/L
fc	Bacteria, fecal coliforms	dl = 2 cfu/100 mL	Cu	copper, total	dl = 0.002/0.001 mg/L
tc	Bacteria, total coliforms	dl = 2 cfu/100 mL	Fe	iron, total	dl = 0.01/0.005 mg/L
toc	Carbon, total organic	dl = 1.0 mg/L	Pb	lead, total	dl = 0.001 mg/L
chl	Chlorophyll <i>a</i>	± 0.1 mg/m ³	Hg	mercury, total	dl = 0.01 mg/L
cond	Conductivity, Hydrolab	± 2 μ S/cm	Ni	nickel, total	dl = 0.01/0.005 mg/L
cond	Conductivity, lab	± 2 μ S/cm	Zn	zinc, total	dl = 0.002/0.001 mg/L
disch	Discharge	na			
nh3	Nitrogen, ammonia	dl = 10 μ g-N/L			
no3	Nitrogen, nitrate/nitrite	dl = 20 μ g-N/L			
tn	Nitrogen, total nitrogen	dl = 100 μ g-N/L			
do	Oxygen, Hydrolab	± 0.1 mg/L			
do	Oxygen, Winkler	± 0.1 mg/L			
pH	pH, Hydrolab	± 0.1 pH unit			
pH	pH, lab	± 0.1 pH unit			
srp	Phosphate, soluble reactive	dl = 5 μ g-P/L			
tp	Phosphorus, total	dl = 5 μ g-P/L			
secchi	Secchi depth	± 0.1 m			
temp	Temperature	± 0.1 ° C			
tss	Total suspended solids	dl = 2 mg/L			
ts	Total solids	dl = 2 mg/L			
turb	Turbidity	± 0.2 NTU			

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

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

Table 2 lists the current IWS detection limits for selected analyses; Appendix D.8 includes the the current AmTest reports and detection limits.

Table D1: Summary of analyses in the Lake Whatcom monitoring project.

D.1 Lake Whatcom Hydrolab Data

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

D.2 Lake Whatcom Water Quality Data

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

D.3 Lake Whatcom Tributary Data

Lake Whatcom monthly and 48-hr tributary data from the current sampling period are included in hardcopy format in the printed version of this report. Hardcopies of the Austin Creek and Beaver Creek intensive tributary monitoring were published in an earlier report. Electronic copies of all verified tributary data are available on the CD that accompanies the printed report or may be obtained by contacting the Institute for Watershed Studies, Western Washington University, Bellingham, WA, 98225.

D.4 Lake Whatcom Plankton Data

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

D.5 Storm Water Treatment Monitoring Data

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

D.6 City of Bellingham Coliform Data

Historic Lake Whatcom and tributary streams coliform data are included in hard-copy format in this report. Other coliform data from the current monitoring program (e.g., storm water treatment samples) were included in tables cited earlier in this report. Electronic copies of all coliform data may be obtained by contacting the City of Bellingham Public Works Department, Bellingham, WA, 98229.

D.7 Lake Whatcom Electronic Data

The annual Lake Whatcom reports include a CD containing historic Hydrolab and water quality data; Austin Creek, Anderson Creek, and Smith Creek hydrograph data; tributary data; plankton data; and storm water treatment system monitoring data. The files included on the CD are described in the file **readme.txt** included on the CD.

The electronic data files have **NOT** been censored to flag or otherwise identify below detection and above detection values. Refer to Tables 2 and D1 (pages 16 and 302) for applicable detection limits and abbreviations. It is essential that any statistical or analytical results that are generated using these data be reviewed by someone familiar with statistical uncertainty associated with uncensored data.

D.8 AmTest Metals and TOC (Lake, Creeks, Storm Water)

Copies of the AmTest analytical reports for metals and total organic carbon analyses are printed in the hardcopy version of this report (filed by collection date). Electronic copies of these data are not available.

Sample location	Date	Analyses
Lake Whatcom, surface and bottom	March 8, 2005	metals, total organic carbon
	October 21, 2005	metals, total organic carbon
Alabama Hill vault	November 20, 2004	metals, total organic carbon, hydrocarbons
	April 18, 2005	metals, total organic carbon, hydrocarbons
48-hr Creek composites	March 5, 2005	metals, total organic carbon (Anderson only)
	April 12, 2005	metals, total organic carbon
Park Place wet ponds	April 12, 2005	metals, total organic carbon
South Campus storm drain	March 5, 2005	metals, total organic carbon
	June 7, 2005	metals, total organic carbon

Sites Codes for the AmTest reports are as follows:

Lake Sites	Creek Sites	Storm Water Treatment Sites
11 O Site 1, surface (0.3 m)	AND Anderson Creek	ALA IN Alabama inlet
11 B Site 1, bottom (20 m)	AUS Lower Austin Creek	ALA OUT Alabama outlet
21 O Intake, surface (0.3 m)	SM1 Smith Creek	PP4 Park Place inlet
21 B Intake, bottom (10 m)		PP5 Park Place outlet
22 O Site 2, surface (0.3 m)		SCSD IN South Campus inlet
22 B Site 2, bottom (20 m)		SCSD E South Campus east outlet
31 O Site 3, surface (0.3 m)		SCSD W South Campus west outlet
31 B Site 3, bottom (80 m)		
32 O Site 4, surface (0.3 m)		
32 B Site 4, bottom (90 m)		