4-11-2007

Lake Whatcom Monitoring Project 2005/2006 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

Lake Whatcom Monitoring Project 2005/2006 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*

April 11, 2007

*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, Art Armstrong, Sahara Bailey, Ryan Bradley, Megan Diehl, Gerry Gabrisch, Jeremy Gilman, Rachael Gravon, Scott Groce, Tim Hannifin, Alexander Hansen, Lily Hickenbottom, Kara Hitchko, Kristofor Kannarr, Alexandra Karpoff, Mike LeMoine, Danielle Love, Jason Mahr, Deka Olson, Jordan Sly, Dan Whealdon-Haught, and Deborah Wilson 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 3

2.3.2 Dissolved oxygen 5

2.3.3 Conductivity and pH 6

2.3.4 Alkalinity and turbidity 6

2.3.5 Nitrogen and phosphorus 7

2.3.6 Chlorophyll, plankton, and Secchi depth 9

2.3.7 Coliform bacteria 10

2.3.8 Metals 11

2.3.9 Total organic carbon and disinfection by-products 12

3 Creek Monitoring **36**

3.1 Site Descriptions 36

3.2 Field Sampling and Analytical Methods 36

3.3 Results and Discussion 37

3.3.1 Monthly creek monitoring 37

3.3.2 48-hr sampling 39

3.3.3 Austin Creek and Beaver Creek intensive sampling 39

4 Lake Whatcom Hydrology **57**

4.1 Hydrograph Data 57

4.2 Watershed Modeling 57

4.3 Water Budget 58

4.4 Lake Whatcom Bathymetry Model 60

5 Storm Water Treatment Monitoring **79**

5.1 Sampling Procedures 79

5.2 Results and Discussion 80

6 References **94**

6.1 Lake Whatcom Reports 97

A Site Descriptions **100**

A.1 Lake Whatcom Monitoring Sites 100

A.2 Creek Monitoring Sites 100

A.3 Storm Water Monitoring Sites 102

B Long-Term Water Quality Figures **114**

B.1 Monthly Hydrolab Profiles 115

B.2 Temperature, Dissolved Oxygen, pH, Conductivity 166

B.3 Alkalinity and Turbidity 187

B.4 Nitrogen and Phosphorus 198

B.5 Chlorophyll, Plankton, and Secchi Depth 224

B.6 Coliform Bacteria 245

B.7 Lake Whatcom 2004–2006 Tributary Data 256

C Quality Control **294**

C.1 Performance Evaluation Reports 294

C.2 Laboratory Duplicates, Spikes, and Check Standards 296

C.3 Field Duplicate Results 318

D Lake Whatcom Data **332**

D.1 Lake Whatcom Hydrolab Data 334

D.2 Lake Whatcom Water Quality Data 350

D.3 Lake Whatcom Plankton Data 355

D.4 Lake Whatcom Tributary Data 357

D.5 Storm Water Treatment Monitoring Data 373

D.6 Lake Whatcom Electronic Data 376

D.7 AmTest Metals and TOC (Lake, Creeks, Storm Water) 377

List of Figures

1 Comparison of 2006 surface water temperatures to boxplots showing 1988–2005 surface temperature medians and ranges 23

2 Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 12 m 24

3 Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 14 m 25

4 Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 16 m 26

5 Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 18 m 27

6 Lake Whatcom summer near-surface total phosphorus concentrations, 1994–2006 28

7 Lake Whatcom total phosphorus concentrations compared to lake nutrient criteria for the Coast Range, Puget Lowlands, and Northern Rockies Ecoregions 29

8 Lake Whatcom summer near-surface chlorophyll concentrations, 1994–2006 30

9 Distribution of summer algal counts, 1994–2006 31

10 Distribution of summer Cyanobacteria counts at Sites 1–4, 1994–2006 32

11 Correlation between fecal coliforms and *E. coli* counts in surface water samples in the Lake Whatcom watershed, October 2004 – September 2006 33

12 Total organic carbon concentrations at the Intake and from the gatehouse 34

13 Total trihalomethanes and haloacetic acids concentrations in the Bellingham water distribution system, 1992–2006 35

14 Anderson Creek hydrograph, October 1, 2005–September 30, 2006 64

15 Austin Creek hydrograph, October 1, 2005–September 30, 2006 . 65

16 Smith Creek hydrograph, October 1, 2005–September 30, 2006 . . 66

17 Anderson Creek, Austin Creek, and Smith Creek rating curves . . 67

18 Lake Whatcom watershed precipitation groups and weighted areas 68

19 Lake Whatcom watershed direct hydrologic inputs, October 1, 2005–September 30, 2006 69

20 Lake Whatcom watershed hydrologic withdrawals, October 1, 2005–September 30, 2006 70

21 Summary of 7-day Whatcom Creek flows, water balance runoff estimates, and DHSVM runoff estimates, October 1, 2005–September 30, 2006 71

22 Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2005–September 30, 2006 72

23 Comparison of Lake Whatcom daily lake volumes for 2000–2006 73

24 Simulated creek flows for Euclid, Millwheel, Park Place, and Silver Beach Creeks, October 1, 2005–September 30, 2006 74

25 Simulated creek flows for Blue Canyon, Brannian, Carpenter, and Olsen Creeks, October 1, 2005–September 30, 2006 75

26 Simulated and gaged creek flows for Anderson and Smith Creeks, October 1, 2005–September 30, 2006 76

27 Simulated creek flows for Austin and Beaver Creeks, October 1, 2005–September 30, 2006 77

28 Updated Lake Whatcom bathymetry map 78

29 Percent reduction of total suspended solids concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites 91

30 Percent reduction of total phosphorus concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites 92

31 Total suspended solids and total phosphorus concentrations in inlet and outlet samples from the Alabama, Brentwood, and Park Place storm water treatment sites . . . 93

A1 Lake Whatcom 2005/2006 lake sampling sites . . . 104

A2 Lake Whatcom 2005/2006 creek sampling sites . . . 105

A3 Sampling sites in the Austin Creek and Beaver Creek watersheds, November 20, 2004 . . . 106

A4 Locations of the Park Place and Brentwood wet ponds and the Alabama Hill vault . . . 107

A5 Locations of the South Campus storm water treatment facility . . . 108

A6 Photograph of the Alabama Hill vault, May 2006 . . . 109

A7 Photograph of the Brentwood wet pond, July 2004 . . . 110

A8 Photograph of the original Park Place storm water treatment system prior to retrofit . . . 111

A9 Photograph of the Park Place storm water treatment system in May 2006, after an extensive retrofit . . . 112

A10 Photograph of the South Campus storm water treatment facility, January 2005 . . . 113

B1 Lake Whatcom Hydrolab profile for Site 1, October 6, 2005 . . . 116

B2 Lake Whatcom Hydrolab profile for Site 2, October 6, 2005 . . . 117

B3 Lake Whatcom Hydrolab profile for the Intake, October 6, 2005 . 118

B4 Lake Whatcom Hydrolab profile for Site 3, October 4, 2005 . . . 119

B5 Lake Whatcom Hydrolab profile for Site 4, October 4, 2005 . . . 120

B6 Lake Whatcom Hydrolab profile for Site 1, November 17, 2005 . . 121

B7 Lake Whatcom Hydrolab profile for Site 2, November 17, 2005 . . 122

B8 Lake Whatcom Hydrolab profile for the Intake, November 17, 2005 123

B9 Lake Whatcom Hydrolab profile for Site 3, November 15, 2005 . . 124

B10 Lake Whatcom Hydrolab profile for Site 4, November 15, 2005 . . 125
B11 Lake Whatcom Hydrolab profile for Site 1, December 15, 2005 . . 126
B12 Lake Whatcom Hydrolab profile for Site 2, December 15, 2005 . . 127
B13 Lake Whatcom Hydrolab profile for the Intake, December 15, 2005 128
B14 Lake Whatcom Hydrolab profile for Site 3, December 13, 2005 . . 129
B15 Lake Whatcom Hydrolab profile for Site 4, December 13, 2005 . . 130
B16 Lake Whatcom Hydrolab profile for Site 1, February 9, 2006 . . . 131
B17 Lake Whatcom Hydrolab profile for Site 2, February 9, 2006 . . . 132
B18 Lake Whatcom Hydrolab profile for the Intake, February 9, 2006 . 133
B19 Lake Whatcom Hydrolab profile for Site 3, February 7, 2006 . . . 134
B20 Lake Whatcom Hydrolab profile for Site 4, February 7, 2006 . . . 135
B21 Lake Whatcom Hydrolab profile for Site 1, April 6, 2006 136
B22 Lake Whatcom Hydrolab profile for Site 2, April 6, 2006 137
B23 Lake Whatcom Hydrolab profile for the Intake, April 6, 2006 . . . 138
B24 Lake Whatcom Hydrolab profile for Site 3, April 4, 2006 139
B25 Lake Whatcom Hydrolab profile for Site 4, April 4, 2006 140
B26 Lake Whatcom Hydrolab profile for Site 1, May 11, 2006 141
B27 Lake Whatcom Hydrolab profile for Site 2, May 11, 2006 142
B28 Lake Whatcom Hydrolab profile for the Intake, May 11, 2006 . . 143
B29 Lake Whatcom Hydrolab profile for Site 3, May 15, 2006 144
B30 Lake Whatcom Hydrolab profile for Site 4, May 9, 2006 145
B31 Lake Whatcom Hydrolab profile for Site 1, June 14, 2006 146
B32 Lake Whatcom Hydrolab profile for Site 2, June 14, 2006 147
B33 Lake Whatcom Hydrolab profile for the Intake, June 14, 2006 . . 148
B34 Lake Whatcom Hydrolab profile for Site 3, June 13, 2006 149

B35 Lake Whatcom Hydrolab profile for Site 4, June 13, 2006 150
B36 Lake Whatcom Hydrolab profile for Site 1, July 12, 2006 151
B37 Lake Whatcom Hydrolab profile for Site 2, July 12, 2006 152
B38 Lake Whatcom Hydrolab profile for the Intake, July 12, 2006 . . . 153
B39 Lake Whatcom Hydrolab profile for Site 3, July 11, 2006 154
B40 Lake Whatcom Hydrolab profile for Site 4, July 11, 2006 155
B41 Lake Whatcom Hydrolab profile for Site 1, August 8, 2006 156
B42 Lake Whatcom Hydrolab profile for Site 2, August 8, 2006 157
B43 Lake Whatcom Hydrolab profile for the Intake, August 8, 2006 . . 158
B44 Lake Whatcom Hydrolab profile for Site 3, August 9, 2006 159
B45 Lake Whatcom Hydrolab profile for Site 4, August 9, 2006 160
B46 Lake Whatcom Hydrolab profile for Site 1, September 13, 2006 . 161
B47 Lake Whatcom Hydrolab profile for Site 2, September 13, 2006 . 162
B48 Lake Whatcom Hydrolab profile for the Intake, September 13, 2006 163
B49 Lake Whatcom Hydrolab profile for Site 3, September 12, 2006 . 164
B50 Lake Whatcom Hydrolab profile for Site 4, September 12, 2006 . 165
B51 Lake Whatcom historic temperature data for Site 1 167
B52 Lake Whatcom historic temperature data for Site 2 168
B53 Lake Whatcom historic temperature data for the Intake 169
B54 Lake Whatcom historic temperature data for Site 3 170
B55 Lake Whatcom historic temperature data for Site 4 171
B56 Lake Whatcom historic dissolved oxygen data for Site 1 172
B57 Lake Whatcom historic dissolved oxygen data for Site 2 173
B58 Lake Whatcom historic dissolved oxygen data for the Intake . . . 174
B59 Lake Whatcom historic dissolved oxygen data for Site 3 175

B60 Lake Whatcom historic dissolved oxygen data for Site 4 176
B61 Lake Whatcom historic pH data for Site 1 177
B62 Lake Whatcom historic pH data for Site 2 178
B63 Lake Whatcom historic pH data for the Intake 179
B64 Lake Whatcom historic pH data for Site 3 180
B65 Lake Whatcom historic pH data for Site 4 181
B66 Lake Whatcom historic conductivity data for Site 1 182
B67 Lake Whatcom historic conductivity data for Site 2 183
B68 Lake Whatcom historic conductivity data for the Intake 184
B69 Lake Whatcom historic conductivity data for Site 3 185
B70 Lake Whatcom historic conductivity data for Site 4 186
B71 Lake Whatcom alkalinity data for Site 1 188
B72 Lake Whatcom alkalinity data for Site 2 189
B73 Lake Whatcom alkalinity data for the Intake site 190
B74 Lake Whatcom alkalinity data for Site 3 191
B75 Lake Whatcom alkalinity data for Site 4 192
B76 Lake Whatcom turbidity data for Site 1 193
B77 Lake Whatcom turbidity data for Site 2 194
B78 Lake Whatcom turbidity data for the Intake site 195
B79 Lake Whatcom turbidity data for Site 3 196
B80 Lake Whatcom turbidity data for Site 4 197
B81 Lake Whatcom ammonia data for Site 1 199
B82 Lake Whatcom ammonia data for Site 2 200
B83 Lake Whatcom ammonia data for the Intake site 201
B84 Lake Whatcom ammonia data for Site 3 202

B85 Lake Whatcom ammonia data for Site 4 203
B86 Lake Whatcom nitrate/nitrite data for Site 1 204
B87 Lake Whatcom nitrate/nitrite data for Site 2 205
B88 Lake Whatcom nitrate/nitrite data for the Intake site 206
B89 Lake Whatcom nitrate/nitrite data for Site 3 207
B90 Lake Whatcom nitrate/nitrite data for Site 4 208
B91 Lake Whatcom total nitrogen data for Site 1 209
B92 Lake Whatcom total nitrogen data for Site 2 210
B93 Lake Whatcom total nitrogen data for the Intake site 211
B94 Lake Whatcom total nitrogen data for Site 3 212
B95 Lake Whatcom total nitrogen data for Site 4 213
B96 Lake Whatcom soluble phosphate data for Site 1 214
B97 Lake Whatcom soluble phosphate data for Site 2 215
B98 Lake Whatcom soluble phosphate data for the Intake site 216
B99 Lake Whatcom soluble phosphate data for Site 3 217
B100 Lake Whatcom soluble phosphate data for Site 4 218
B101 Lake Whatcom total phosphorus data for Site 1 219
B102 Lake Whatcom total phosphorus data for Site 2 220
B103 Lake Whatcom total phosphorus data for the Intake site 221
B104 Lake Whatcom total phosphorus data for Site 3 222
B105 Lake Whatcom total phosphorus data for Site 4 223
B106 Lake Whatcom chlorophyll data for Site 1 225
B107 Lake Whatcom chlorophyll data for Site 2 226
B108 Lake Whatcom chlorophyll data for the Intake site 227
B109 Lake Whatcom chlorophyll data for Site 3 228

B110 Lake Whatcom chlorophyll data for Site 4 229
B111 Lake Whatcom plankton data for Site 1 230
B112 Lake Whatcom plankton data for Site 2 231
B113 Lake Whatcom plankton data for the Intake Site 232
B114 Lake Whatcom plankton data for Site 3 233
B115 Lake Whatcom plankton data for Site 4 234
B116 Lake Whatcom plankton data for Site 1, with Chrysophyta omitted 235
B117 Lake Whatcom plankton data for Site 2, with Chrysophyta omitted 236
B118 Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted 237
B119 Lake Whatcom plankton data for Site 3, with Chrysophyta omitted 238
B120 Lake Whatcom plankton data for Site 4, with Chrysophyta omitted 239
B121 Lake Whatcom Secchi depths for Site 1 240
B122 Lake Whatcom Secchi depths for Site 2 241
B123 Lake Whatcom Secchi depths for the Intake site 242
B124 Lake Whatcom Secchi depths for Site 3 243
B125 Lake Whatcom Secchi depths for Site 4 244
B126 Lake Whatcom fecal coliform data for Site 1 246
B127 Lake Whatcom fecal coliform data for Site 2 247
B128 Lake Whatcom fecal coliform data for the Intake site 248
B129 Lake Whatcom fecal coliform data for Site 3 249
B130 Lake Whatcom fecal coliform data for Site 4 250
B131 Lake Whatcom *E. coli* data for Site 1 251
B132 Lake Whatcom *E. coli* data for Site 2 252
B133 Lake Whatcom *E. coli* data for the Intake site 253

B134 Lake Whatcom *E. coli* data for Site 3 254
B135 Lake Whatcom *E. coli* for Site 4 255
B136 Monthly alkalinity data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 257
B137 Monthly alkalinity data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 258
B138 Monthly conductivity data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 259
B139 Monthly conductivity data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 260
B140 Monthly dissolved oxygen data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 261
B141 Monthly dissolved oxygen data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 262
B142 Monthly pH data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 263
B143 Monthly pH data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 264
B144 Monthly temperature data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 265
B145 Monthly temperature data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 266
B146 Monthly total nitrogen data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 267
B147 Monthly total nitrogen data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 268
B148 Monthly nitrate/nitrite data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 269

B149 Monthly nitrate/nitrite data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 270

B150 Monthly ammonia data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 271

B151 Monthly ammonia data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 272

B152 Monthly total phosphorus data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 273

B153 Monthly total phosphorus data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 274

B154 Monthly soluble reactive phosphate data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks . . 275

B155 Monthly soluble reactive phosphate data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 276

B156 Monthly total solids data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 277

B157 Monthly total solids data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 278

B158 Monthly total suspended solids data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks . . 279

B159 Monthly total suspended solids data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 280

B160 Monthly turbidity data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 281

B161 Monthly turbidity data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 282

B162 Monthly *E. coli* data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 283

B163 Monthly *E. coli* data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 284

B164 Monthly fecal coliform data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks 285

B165 Monthly fecal coliform data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks 286

B166 Monthly and 48-hr temperature and dissolved oxygen data from Lower Austin and Smith Creeks 287

B167 Monthly and 48-hr conductivity and pH data from Lower Austin and Smith Creeks 288

B168 Monthly and 48-hr alkalinity and turbidity data from Lower Austin and Smith Creeks 289

B169 Monthly and 48-hr ammonia and nitrate/nitrite data from Lower Austin and Smith Creeks 290

B170 Monthly and 48-hr soluble phosphate and coliform data from Lower Austin and Smith Creeks 291

B171 Monthly and 48-hr total nitrogen and total phosphorus data from Anderson, Lower Austin and Smith Creeks 292

B172 Monthly and 48-hr total suspended solids and total solids data from Anderson, Lower Austin and Smith Creeks 293

C1 Alkalinity laboratory duplicates for the Lake Whatcom monitoring program 297

C2 Alkalinity check standards for the Lake Whatcom monitoring program 298

C3 Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program 299

C4 Conductivity laboratory duplicates for the Lake Whatcom monitoring program 300

C5 Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program 301

C6 Ammonia laboratory duplicates for the Lake Whatcom monitoring program 302

C7 Ammonia check standards for the Lake Whatcom monitoring program . . . 303
C8 Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program . . . 304
C9 Nitrate/nitrite matrix spikes for the Lake Whatcom monitoring program . . . 305
C10 Nitrate/nitrite check standards for the Lake Whatcom monitoring program . . . 306
C11 Total nitrogen laboratory duplicates for the Lake Whatcom monitoring program . . . 307
C12 Total nitrogen matrix spikes for the Lake Whatcom monitoring program . . . 308
C13 Total nitrogen check standards for the Lake Whatcom monitoring program . . . 309
C14 Laboratory pH duplicates for the Lake Whatcom monitoring program . . . 310
C15 Soluble reactive phosphate laboratory duplicates for the Lake Whatcom monitoring program . . . 311
C16 Soluble reactive phosphate matrix spikes for the Lake Whatcom monitoring program . . . 312
C17 Soluble reactive phosphate check standards for the Lake Whatcom monitoring program . . . 313
C18 Total phosphorus laboratory duplicates for the Lake Whatcom monitoring program . . . 314
C19 Total phosphorus matrix spikes for the Lake Whatcom monitoring program . . . 315
C20 Total phosphorus check standards for the Lake Whatcom monitoring program . . . 316
C21 Turbidity laboratory duplicates for the Lake Whatcom monitoring program . . . 317

C22 Alkalinity field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 319

C23 Chlorophyll field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 320

C24 Conductivity field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 321

C25 Fecal coliform and E. coli field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 322

C26 Dissolved oxygen field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 323

C27 Ammonia field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 324

C28 Nitrate/nitrite field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 325

C29 Total nitrogen field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 326

C30 pH field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 327

C31 Soluble phosphate field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 328

C32 Total phosphorus field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 329

C33 Total suspended solids and total solids field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 330

C34 Turbidity field duplicates for the 2005/2006 Lake Whatcom Monitoring Project . . . 331

List of Tables

1 Summary of IWS and City of Bellingham analytical methods. . . 14

2 Summary of Site 1 ambient water quality data, Oct. 2005 – Sept. 2006. 15

3 Summary of Intake ambient water quality data, Oct. 2005 – Sept. 2006. 16

4 Summary of Site 2 ambient water quality data, Oct. 2005 – Sept. 2006. 17

5 Summary of Site 3 ambient water quality data, Oct. 2005 – Sept. 2006. 18

6 Summary of Site 4 ambient water quality data, Oct. 2005 – Sept. 2006. 19

7 Lake Whatcom 2005/2006 total metals data. 20

8 Lake Whatcom 2005/2006 total organic carbon data. 21

9 October hypolimnetic ammonia and hydrogen sulfide concentrations at Sites 1 and 2 22

10 Summary of Anderson Creek monthly water quality data, Oct. 2004 – Sept. 2006 41

11 Summary of upper Austin Creek monthly water quality data, Oct. 2004 – Sept. 2006 42

12 Summary of upper Beaver Creek monthly water quality data, Oct. 2004 – Sept. 2006 43

13 Summary of water quality data collected at the confluence of Austin Creek and Beaver Creek, Oct. 2004 – Sept. 2006 44

14 Summary of lower Austin Creek monthly water quality data, Oct. 2004 – Sept. 2006 45

15 Summary of Blue Canyon Creek monthly water quality data, Oct. 2004 – Sept. 2006 46

16 Summary of Brannian Creek monthly water quality data, Oct. 2004 – Sept. 2006 47

17 Summary of Carpenter Creek monthly water quality data, Oct. 2004 – Sept. 2006 48

18 Summary of Euclid Creek monthly water quality data, Oct. 2004 – Sept. 2006 49

19 Summary of Millwheel Creek monthly water quality data, Oct. 2004 – Sept. 2006 50

20 Summary of Olsen Creek monthly water quality data, Oct. 2004 – Sept. 2006 51

21 Summary of Park Place outlet monthly water quality data, Oct. 2004 – Sept. 2006 52

22 Summary of Silver Beach Creek monthly water quality data, Oct. 2004 – Sept. 2006 53

23 Summary of Smith Creek monthly water quality data, Oct. 2004 – Sept. 2006 54

24 Summary of Whatcom Creek monthly water quality data, Oct. 2004 – Sept. 2006 55

25 Comparison of October 2004–September 2006 fecal coliform data from Lake Whatcom tributaries to WAC 173–201A surface water standards. 56

26 Annual water balance quantities for the Lake Whatcom watershed, WY2002–WY2006. 61

27 Monthly input water balance quantities for the Lake Whatcom watershed, October 2005–September 2006. 62

28 Monthly output water balance quantities for the Lake Whatcom watershed, October 2005–September 2006. 63

29 Park Place wet pond and South Campus rock/plant filter composite samples and average percent reductions between inlet and outlet samples. 84

30 Alabama vault grab samples and average percent reductions between inlet and outlet samples 85

31 Park Place wet pond grab samples and average percent reductions between inlet and outlet samples. 86

32 South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples 87

33 Summary of total suspended solids and total phosphorus reductions at Alabama, Brentwood, Park Place, and South Campus storm water treatment sites 88

34 Comparison between 24-hr composite samples and multiple grab samples collected November 1–2, 2004 at the Alabama Hill vault. 89

35 Comparison between 48-hr composite samples and multiple grab samples collected February 27–March 1 and May 22–24, 2006 at the Park Place wet pond. 90

A1 Approximate GPS coordinates for the current Lake Whatcom Monitoring Project sampling sites. 103

C1 Summary of 2005/2006 single-blind quality control results. 295

D1 Summary of analyses in the Lake Whatcom monitoring project. . 333

Executive Summary

- This report describes the results from the 2005/2006 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 97.

- During the summer the lake stratified into a warm surface layer (the epilimnion) and a cool bottom layer (the hypolimnion). The surface water temperatures were slightly warmer than usual during February and November, but all months were within typical historic ranges. The lake was weakly stratified by the first week in May, with stable stratification present by mid-June.

- 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. Epilimnetic nitrate concentrations fell below 20 μg-N/L at Site 1, creating an environment favorable for cyanobacteria (bluegreen algae).

- Hypolimnetic nitrate concentrations dropped below 10 μg-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 consistent with anaerobic conditions.

- Summer near-surface levels of total phosphorus, chlorophyll, and plankton have increased significantly at all sites in the lake. All sites now appear to meet Ecology's total phosphorus criteria to be classified as mesotrophic.

- Despite increasing chlorophyll and algal levels, the addition of new water treatment chemicals resulted in a decrease in the concentration 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 all sites, but were within normal ranges for the lake. Other metals were occasionally detected, but the concentrations were near the limits of detection.

- Monthly creek sampling was conducted from October 2004 through September 2006. The final results from this two-year baseline monitoring project are described in this report.

- Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of total and dissolved solids, low alkalinities and conductivities, and low levels of nitrate and ammonia. Residential streams had higher concentrations of total and dissolved solids, higher alkalinities and conductivities, and higher nutrient concentrations.

- Many of the creeks failed to meet the surface water standards for coliforms (WAC 173–201A) because more than 10% of the samples exceeded 100 cfu/100 mL. Carpenter, Euclid, Millwheel, Park Place, and Silver Beach Creeks also failed because they had geometric mean concentrations exceeding 50 cfu/100 mL. Upper Austin and Beaver Creeks, Lower Austin Creek, Blue Canyon Creek, Smith Creek, and Whatcom Creek passed both criteria.

- 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 WY2006[1] included surface and subsurface runoff (71.1%), direct precipitation (17.9%), and water diverted from the Middle Fork of the Nooksack River (11.0%). Outputs included Whatcom Creek (74.8%), the City of Bellingham (10.9%), Georgia Pacific (2.5%), evaporation (7.8%), the Whatcom Falls Hatchery (3.3%), and the Lake Whatcom Water and Sewer District (0.6%).[2]

[1]Water Year 2005 covers the period from October 1, 2005 through September 30, 2006
[2]Formerly Water District #10

- The Distributed Hydrology-Soils-Vegetation Model (DHSVM) was applied to all of the creeks monitored during the 2-year baseline study. The simulated stream flow results are plotted for each site.

- An updated metric bathymetry model is being developed to provide new lake morphometry data for the lake as a whole and for each major basin based on the 1999 Bureau of Reclamation hydrographic survey of Lake Whatcom. A detailed report should be available by June 2007.

- Three storm water treatment systems were monitored in 2005/2006: 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.

- Of the three storm water treatment systems that were monitored in 2004/2005, only the South Campus system provided consistent phosphorus removal. The Park Place storm water treatment system was retrofitted with sand filters, and now appears to be removing a large amount of sediment (76–88%), but shows no evidence of phosphorus removal. Similarly, the Alabama Hill vault provided good sediment removal (43–69%) but no consistent phosphorus removal.

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 Lake Whatcom monitoring program over time. Many of the reports are available online at http://www.ac.wwu.edu/∼iws (follow links to the Lake Whatcom Watershed Project); 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 97.

Lake Whatcom is the primary drinking water source for the City of Bellingham and parts of Whatcom County, including Sudden Valley. Lake Whatcom also provides high quality water for the Georgia-Pacific Corporation mill[3], 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.

The major objectives of the 2005/2006 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.

[3]The 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 have been further reduced, and are currently ∼1–4 MGD.

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 2005/2006 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 333 (at the beginning of Appendix D) lists abbreviations and units used to describe water quality analyses in this document.

2 Lake Whatcom Monitoring

2.1 Site Descriptions

Water quality samples were collected at five long-term monitoring sites in Lake Whatcom (Figure A1, page 104, 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 on October 4 & 6, November 15 & 17 and December 13 & 15, 2005; and February 7 & 9, April 4 & 6, May 9 & 11, June 13 & 14, July 11 & 12, August 8 & 9, and September 12 & 13, 2006. Each sampling event is a multi-day task; all samples are collected during daylight hours, typically between 10:00 am and 3:00 pm.

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 1 on page 14. 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.

2.3 Results and Discussion

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

Tables 2–6 (pages 15–19) summarize the current field measurements, ambient water quality, and coliform data. The raw data are included in Appendix D and are available in electronic format on the CD that accompanies this report. The monthly Hydrolab profiles for temperature, dissolved oxygen, conductivity, and pH are plotted in Figures B1–B50 (pages 116–165).

The 2005/2006 lake data are plotted with historic lake data in Figures B51–B70 (pages 167–186) and Figures B71–B135 (pages 188–255). 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.

2.3.1 Water temperature

The mid-winter Hydrolab profiles (e.g., Figures B16–B20, pages 131–135) and the multi-year temperature profiles (Figures B51–B55, pages 167–171) 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.

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

The summer Hydrolab profiles (e.g., Figures B46–B50, pages 161–165) 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 June. The stability of stratification is determined in part by the temperature differences in the water column, but also by water circulation and local weather patterns. Once the water column temperature differs by at least 5° C, it is unlikely that the lake will destratify. Typically, this occurs in all three basins by early June.

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 13, 1997). 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 2006 surface water temperatures were warmer than usual during February and November, but all months were within typical historic ranges for the lake (Figure 1, page 23). The lake was weakly stratified by the first week in May (Δ T $< 5^\circ$ C), with stable stratification present at Sites 1–4 in mid-June (Figures B26–B35, pages 141–150).

2.3.2 Dissolved oxygen

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

As in previous years, Sites 1 and 2 developed severe hypolimnetic oxygen deficits by mid-summer (Figures B41–B42 and B56–B57, pages 156–157 and 172–173). 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 165 and 176). In contrast, Site 1 shows rapid depletion of the hypolimnetic oxygen concentrations following stratification (Figures B46 and B56, pages 161 and 172).

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 drops near zero.

To illustrate this trend we fitted the July and August data using an exponential function (see discussion by Matthews, et al., 2004). As indicated in Figures 2–5 (pages 24–27), there were significant negative correlations between dissolved oxygen and time for all samples collected from the hypolimnion during July and August.[6]

---

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

[6] Correlation analyses were used to examine the strength of relationships between two variables (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

A region of supersaturated oxygen was evident in the metalimnion at Site 1 in July (Figure B36, page 151). This was 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).

Sites 3–4 had small oxygen sags near the bottom during October, November, and December. The December oxygen sags were probably the result of late destratification. The December temperature profiles for Sites 3–4 showed a slight temperature difference between the surface and bottom, indicating that basin 3 had only recently started mixing. Both sites occasionally had small oxygen sags near the thermocline, which was probably caused by respiration of heterotrophic bacteria that accumulate along the density gradient between the epilimnion and hypolimnion (DeLuna, 2004).

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 177–186). 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. 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 (Matthews, et al., 2004).

2.3.4 Alkalinity and turbidity

Because Lake Whatcom is a soft water lake, the alkalinity values were fairly low at most sites and depths (Figures B71–B75, pages 188–192). 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.

---

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.

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 193–197). 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 199–223) 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]

Nitrate depletion was evident at all sites in the photosynthetic zone during the summer (Figures B86–B90, pages 204–208), particularly at Site 1, where the epilimnetic nitrate concentrations fell below 20 μg-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 Cyanobacteria (also known as bluegreen bacteria or bluegreen algae) in the plankton samples. Epilimnetic nitrate concentrations decrease at Sites 3–4, but rarely fall below 150 μg-N/L, making nitrogen co-limitation unlikely. The hypolimnetic nitrate concentrations dropped below 10 μg-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.

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, ammonia accumulates until the lake destratifies.

[7]Only Cyanobacteria and a few uncommon species of diatoms can use nitrogen gas.

High ammonia concentrations were measured just prior to overturn in the hypolimnion at Sites 1 and 2 (Figures B81 & B82, pages 199 & 200). 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. Currently, the ammonia and hydrogen sulfide concentrations are higher at Site 2 than at Site 1 (Table 9, page 22). Sites 3 and 4 often have slightly elevated ammonia concentrations at 20 m (metalimnion) or near the bottom at 80–90 m (Figures B84–B85, pages 202–203). This is caused by bacterial decomposition of organic matter, but the concentrations never approach the levels found in the hypolimnion at Sites 1–2.

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 μg-P/L) at all sites and depths except in the hypolimnion at Sites 1 and 2 just prior to overturn (Figures B96–B100, pages 214–218). Elevated total phosphorus levels were present in the hypolimnion at Sites 1 and 2 during stratification (Figures B101–B105, pages 219–223). 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 225–229). Peak chlorophyll concentrations were usually collected at 0–15 m, while samples from 20 m had relatively low chlorophyll concentrations. Twenty meters is near the lower limit of the photic zone, so the light levels are not optimal for algal growth at this depth.

The Lake Whatcom plankton counts were usually dominated by Chrysophyta, consisting primarily of diatoms, *Dinobryon*, and *Mallomonas* (Figures B111–B120, pages 230–239). Substantial blooms of bluegreen bacteria (Cyanobacteria) and green algae (Chlorophyta) were also measured at all sites during summer and late fall. Previous analyses of algal biovolume in Lake Whatcom indicated that although Chrysophyta dominate the numerical plankton counts, Cyanobacteria 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 240–244) showed no clear seasonal pattern because transparency in Lake Whatcom is affected by particulates from storm events and the Nooksack River diversion as well as algal blooms

Indications of eutrophication: 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 (see Wetzel,1983, for more about eutrophication).

Although Lake Whatcom phosphorus levels are still relatively low most of the year, the concentrations of total phosphorus appear to be increasing in samples collected during summer from near the lake's surface (Figures 6 and 7, pages 28 and 29). This means that phosphorus is becoming more plentiful at the times and depths when algal blooms are most likely to occur.

Figure 7 shows that Lake Whatcom phosphorus levels have risen from the oligotrophic range to the lower mesotrophic range, and occasionally exceed the action value of 20 μg-P/L defined by WAC 173–201A–230. The annual total phosphorus values in Figure 7 were calculated using protocols described by Ecology (2006). Each point on the figure (*i.e.*, each annual average) represents the average of the maximum, monthly, epilimnetic total phosphorus concentrations collected between June and October from 0–5 meters. At each site, two samples were collected on each sampling date (0 and 5 m), but the Ecology protocols specify using only the maximum value on each date. As a result, each site's annual average is based on five points, one per month, picking the maximum concentration measured at either 0 or 5 meters.[8]

Not surprisingly, summer near-surface chlorophyll concentrations and algal counts have also increased significantly ((Figures 8 and 9, pages 30 and 31). All four of the major algal taxonomic groups have increased in Lake Whatcom, but the most striking increase has occurred in the counts for Cyanobacteria, or bluegreen "algae" (Figure 10, page 32). [9]

Prior to 2003, Cyanobacteria were relatively uncommon in Lake Whatcom, usually appearing in predictable, but low density blooms in late summer or fall just prior to overturn. Since 2003, however, the Cyanobacteria densities have increased significantly at all sites, and are now common at all sites throughout the summer and fall. It should be noted that Cyanobacteria counts underestimate their actual biomass relative to most other algae (see discussion of Ashurst's work on phytoplankton biovolume in Matthews, et al., 2002b). Cyanobacteria cells are very tiny, so most species are counted as colonies rather than individual cells, while most other algae are counted as individuals.

2.3.7 Coliform bacteria

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

[8]In the absence of lake-specific studies, the Ecology guidelines specify using samples collected from June-September at 0–3 m, selecting only the maximum value on dates when more than one sample is collected at the same site. The guidelines also stipulate that additional times and depths should be included if lake-specific data indicate that high epilimnetic phosphorus concentrations may be present. In Lake Whatcom, samples collected in October and from 5 meters were included because the period of stratification runs from June–October, the epilimnion is more than 5 meters deep at all sites, and high phosphorus concentrations can occur at these additional times and depths. We also collect nutrient samples at 10 m depths, but this depth occasionally falls within the metalimnion or hypolimnion, so the 10 m samples were not included.

[9]Cyanobacteria are photosynthetic bacteria, not true algae.

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 11, page 33), so fecal coliform counts appear to be a reliable tool for determining compliance.

All of the mid-basin (Sites 1–4) and Intake values for fecal coliforms and *E. coli* counts were less than 10 cfu[10]/100 mL (Figures B126–B135, pages 246–255) 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).

Coliform samples collected near the dock offshore from the Bloedel-Donovan swimming area had slightly higher counts than at Site 1 (mid-basin). None of the Bloedel-Donovan counts exceeded 100 cfu/100 mL, and with geometric means of 3.3 and 3.4 cfu/100 mL for fecal coliforms and *E. coli*, respectively, the Bloedel-Donovan site 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 7 (page 20). This table includes only the regularly contracted metals (arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead, and zinc); Appendix D.7 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

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

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. Iron and zinc were detectable at all sites during February and September. The highest iron concentrations, 1.340 mg/L and 0.967 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 and copper were detected in many of the samples, but at levels close to detection limits.

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).

The 2005/2006 total organic carbon concentrations at the Intake were fairly low (Table 8, page 21). The long-term data, however, suggest that the concentrations may be increasing over time, particularly at the raw water gatehouse (Figure 12, page 34).[11]

As illustrated in Figure 13 (page 35), THMs have been increasing in Bellingham's treated drinking water, particularly during the fall (third quarter). To address this trend, the City started using a different chemical to help remove organic matter before the disinfection step in drinking water treatment process. Although the chemical increased annual treatment costs by $10,000-12,000 the resulting reduc-

[11]Gatehouse data were provided by the City of Bellingham Public Works Department.

tion in THMs is encouraging.[12] It is important to note that this approach has limits, and if algal densities continue to increase, we will likely see the THMs start to increase again.

Haloacetic acids (another important disinfection by-product) do not appear to be increasing with time (Figure 13) 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).

[12]Cost estimates provided by the City of Bellingham Public Works Department.

Parameter	Method	Historic DL†	2005/2006 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	–	–	± 0.07 pH unit
Temperature	Hydrolab (1997), field meter	–	–	± 0.1° C
Alkalinity	APHA (1998) #2320, low level, SOP-IWS-15	–	–	± 0.3 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	4.7 mg/L	± 5.8 mg/L
T. suspended solids	APHA (1998) #2540 D, gravimetric, SOP-LW-22	2 mg/L	0.7 mg/L	± 1.8 mg/L
Turbidity	APHA (1998) #2130, nephelometric, SOP-LW-11	–	–	± 0.2 NTUs
Ammonia (auto)	APHA (1998) #4500-NH_3 H., phenate, SOP-LW-19	10 μg-N/L	4.9 μg-N/L	± 7.2 μg-N/L
Nitrite/nitrate (auto)	APHA (1998) #4500-NO_3 I., Cd reduction, SOP-IWS-19	20 μg-N/L	4.8 μg-N/L	± 5.2 μg-N/L
T. nitrogen (auto)	APHA (1998) #4500-N C., persulfate digestion, SOP-IWS-19	100 μg-N/L	6.8 μg-N/L	± 16.0 μg-N/L
Sol. phosphate (auto)	APHA (1998) #4500-P G., ascorbic acid, SOP-IWS-19	5 μg-P/L	1.5 μg-P/L	± 2.8 μg-P/L
T. phosphorus (auto)	APHA (1998) #4500-P H., persulfate digestion, SOP-IWS-19	5 μg-P/L	3.1 μg-P/L	± 2.8 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 1: Summary of IWS and City of Bellingham analytical methods.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	18.3	20.4	20.6	27.1	2.0	50
Conductivity (μS/cm)	52.8	58.9	59.2	71.4	3.6	202
Dissolved oxygen (mg/L)	0.2	10.2	8.5	12.2	4.1	202
pH	6.3	7.4	7.4	8.8	0.6	202
Temperature (°C)	6.2	10.4	11.4	21.5	4.4	202
Turbidity (NTU)	0.6	0.8	0.9	2.6	0.4	50
Nitrogen - ammonia (μg-N/L)	$<$10	10.4	38.6	257.5	64.3	49
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	175.9	184.5	365.6	116.5	50
Nitrogen - total (μg-N/L)	211.9	390.0	401.5	540.5	92.3	49
Phosphorus - soluble (μg-P/L)	$<$5	$<$5	$<$5	7.8	2.3	50
Phosphorus - total (μg-P/L)	$<$5	9.8	13.2	95.1	14.2	49
Chlorophyll (mg/m^3)	0.2	3.1	3.6	10.8	2.5	48
Secchi depth (m)	3.0	4.0	4.1	5.3	0.6	9
Coliforms - fecal (cfu/100 mL)[‡]	$<$1	1	1	3	na	10
Coliforms - E. coli (cfu/100 mL)[‡]	$<$1	1	1	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., $<1 \Rightarrow 1$).

Table 2: Summary of Site 1 ambient water quality data, Oct. 2005 – Sept. 2006.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	15.5	18.9	19.0	20.4	1.0	30
Conductivity (μS/cm)	52.8	57.4	56.7	59.5	2.1	110
Dissolved oxygen (mg/L)	8.9	10.4	10.5	12.3	0.9	110
pH	7.2	7.8	7.9	8.5	0.4	110
Temperature (°C)	7.0	13.7	13.8	21	5.1	110
Turbidity (NTU)	0.4	0.5	0.5	0.8	0.1	30
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	15.8	3.2	30
Nitrogen - nitrate/nitrite (μg-N/L)	105.2	238.8	236.0	382.9	96.7	30
Nitrogen - total (μg-N/L)	274.0	418.7	406.5	532.0	88.2	30
Phosphorus - soluble (μg-P/L)	<5	<5	<5	6.5	1.8	30
Phosphorus - total (μg-P/L)	<5	6.3	8.1	37.9	606	30
Chlorophyll (mg/m^3)	0.8	2.8	3.0	5.4	1.1	30
Secchi depth (m)	4.0	5.1	5.5	9.0	1.5	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	1	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 3: Summary of Intake ambient water quality data, Oct. 2005 – Sept. 2006.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	18.0	18.8	19.2	27.1	1.5	49
Conductivity (μS/cm)	52.8	57.2	57.0	72.7	2.8	201
Dissolved oxygen (mg/L)	0.2	10.3	9.4	12.3	2.8	201
pH	6.3	7.4	7.5	8.5	0.5	201
Temperature (°C)	7.0	10.7	12.3	21.3	4.6	201
Turbidity (NTU)	0.3	0.5	0.7	7.8	1.0	50
Nitrogen - ammonia (μg-N/L)	<10	<10	27.2	450.4	71.0	50
Nitrogen - nitrate/nitrite (μg-N/L)	<20	271.4	252.0	390.4	105.1	50
Nitrogen - total (μg-N/L)	226.2	441.0	436.6	639.7	97.2	50
Phosphorus - soluble (μg-P/L)	<5	<5	<5	8.3	2.0	50
Phosphorus - total (μg-P/L)	<5	6.8	12.8	142.8	21.5	50
Chlorophyll (mg/m^3)	0.5	2.7	2.6	5.9	1.2	50
Secchi depth (m)	4.1	5.7	5.9	9.5	1.6	9
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	8	na	10
Coliforms - E. coli (cfu/100 mL)‡	<1	1	1	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., $<1 \Rightarrow 1$).

Table 4: Summary of Site 2 ambient water quality data, Oct. 2005 – Sept. 2006.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	16.7	18.3	18.4	19.9	0.6	68
Conductivity (μS/cm)	53.5	57.2	56.9	61.6	1.5	244
Dissolved oxygen (mg/L)	5.0	10.1	9.9	12.4	1.4	244
pH	6.4	7.2	7.4	8.5	0.5	244
Temperature (°C)	6.8	7.9	10.4	20.1	4.5	244
Turbidity (NTU)	0.2	0.4	0.5	1.8	0.3	69
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	24.7	6.0	69
Nitrogen - nitrate/nitrite (μg-N/L)	121.2	377.5	334.8	447.3	96.9	69
Nitrogen - total (μg-N/L)	287.0	503.4	473.4	559.9	79.0	69
Phosphorus - soluble (μg-P/L)	<5	<5	<5	6.7	1.7	69
Phosphorus - total (μg-P/L)	<5	6.6	7.3	33.4	4.0	69
Chlorophyll (mg/m^3)	0.3	2.4	2.5	6.1	1.3	50
Secchi depth (m)	3.9	6.6	6.3	8.0	1.5	9
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	3	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., $<1 \Rightarrow 1$).

Table 5: Summary of Site 3 ambient water quality data, Oct. 2005 – Sept. 2006.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	17.3	18.1	18.3	20.2	0.6	80
Conductivity (μS/cm)	53.0	57.1	56.8	60.3	1.5	269
Dissolved oxygen (mg/L)	7.4	10.0	9.9	12.2	1.1	269
pH	6.7	7.2	7.3	8.4	0.5	269
Temperature (°C)	6.7	7.6	10.0	20.0	4.3	269
Turbidity (NTU)	0.2	0.4	0.4	0.8	0.2	80
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	33.3	5.4	80
Nitrogen - nitrate/nitrite (μg-N/L)	129.0	398.0	353.2	448.2	91.6	80
Nitrogen - total (μg-N/L)	288.9	515.0	484.8	565.3	75.6	79
Phosphorus - soluble (μg-P/L)	<5	<5	<5	6.0	1.8	80
Phosphorus - total (μg-P/L)	<5	6.0	6.0	10.4	1.9	79
Chlorophyll (mg/m^3)	0.3	2.0	2.4	6.3	1.4	50
Secchi depth (m)	4.5	6.5	7.0	9.6	1.8	10
Coliforms - fecal (cfu/100 mL)‡	<1	1	1	1	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., $<1 \Rightarrow 1$).

Table 6: Summary of Site 4 ambient water quality data, Oct. 2005 – Sept. 2006.

	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 9, 2006	<0.01	<0.0005	<0.001	<0.001	0.039	<0.0002	<0.005	<0.001	0.003
Site 1	20	Feb 9, 2006	<0.01	<0.0005	0.002	<0.001	0.047	<0.0002	<0.005	<0.001	0.002
Intake	0	Feb 9, 2006	<0.01	<0.0005	0.002	<0.001	0.038	<0.0002	<0.005	<0.001	0.006
Intake	10	Feb 9, 2006	<0.01	<0.0005	<0.001	<0.001	0.034	<0.0002	<0.005	<0.001	0.004
Site 2	0	Feb 9, 2006	<0.01	<0.0005	<0.001	<0.001	0.026	<0.0002	<0.005	<0.001	0.002
Site 2	20	Feb 9, 2006	<0.01	<0.0005	<0.001	<0.001	0.031	<0.0002	<0.005	<0.001	0.014
Site 3	0	Feb 7, 2006	<0.01	<0.0005	0.002	<0.001	0.029	<0.0002	<0.005	<0.001	0.004
Site 3	80	Feb 7, 2006	<0.01	<0.0005	<0.001	<0.001	0.036	<0.0002	<0.005	<0.001	0.001
Site 4	0	Feb 7, 2006	<0.01	<0.0005	<0.001	<0.001	0.032	<0.0002	<0.005	<0.001	0.002
Site 4	90	Feb 7, 2006	<0.01	<0.0005	0.003	<0.001	0.037	<0.0002	<0.005	<0.001	0.003
Site 1	0	Sept 13, 2006	<0.01	<0.0005	0.001	0.002	0.039	<0.0002	<0.005	<0.001	0.003
Site 1	20	Sept 13, 2006	<0.01	<0.0005	<0.001	<0.001	1.340	<0.0002	<0.005	<0.001	0.006
Intake	0	Sept 13, 2006	<0.01	<0.0005	<0.001	<0.001	0.012	<0.0002	<0.005	<0.001	0.002
Intake	10	Sept 13, 2006	<0.01	<0.0005	<0.001	0.001	0.022	<0.0002	<0.005	<0.001	0.003
Site 2	0	Sept 13, 2006	<0.01	<0.0005	0.001	<0.001	0.013	<0.0002	<0.005	<0.001	0.004
Site 2	20	Sept 13, 2006	<0.01	<0.0005	<0.001	0.002	0.967	0.0005	<0.005	<0.001	0.010
Site 3	0	Sept 12, 2006	<0.01	<0.0005	0.002	<0.001	0.005	<0.0002	<0.005	<0.001	0.003
Site 3	80	Sept 12, 2006	<0.01	<0.0005	0.001	<0.001	0.038	<0.0002	<0.005	<0.001	0.007
Site 4	0	Sept 12, 2006	<0.01	<0.0005	<0.001	0.002	0.012	<0.0002	<0.005	<0.001	0.003
Site 4	90	Sept 12, 2006	<0.01	<0.0005	0.002	<0.001	0.068	<0.0002	<0.005	<0.001	0.005

Table 7: Lake Whatcom 2005/2006 total metals data. Only the metals specified in the monitoring plan are included in this table; the results for 24 additional metals are included in Appendix D.7.

Site	Date	Depth	TOC (mg/L)	Date	Depth	TOC (mg/L)
Site 1	Feb 9, 2006	0	3.8	Sept 13, 2006	0	5.9
	Feb 9, 2006	20	2.0	Sept 13, 2006	20	2.5
Intake	Feb 9, 2006	0	<1	Sept 13, 2006	0	<1
	Feb 9, 2006	10	2.8	Sept 13, 2006	10	<1
Site 2	Feb 9, 2006	0	<1	Sept 13, 2006	0	3.1
	Feb 9, 2006	20	2.2	Sept 13, 2006	15	1.0
Site 3	Feb 7, 2006	0	1.2	Sept 12, 2006	0	3.4
	Feb 7, 2006	80	2.8	Sept 12, 2006	80	4.4
Site 4	Feb 7, 2006	0	1.3	Sept 12, 2006	0	1.5
	Feb 7, 2006	90	1.1	Sept 12, 2006	90	3.5

Table 8: Lake Whatcom 2005/2006 total organic carbon data.

Date		H_2S (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)	0.13, 0.12*	257.5
	Site 2 (bottom)	0.25, 0.42*	450.4
October 2006	Site 1 (bottom)	0.20	334.1
	Site 2 (bottom)	0.42	354.1

*First concentration from HACH field kit; second concentration from duplicates analyzed by Edge Analytical.

Table 9: October hypolimnetic ammonia and hydrogen sulfide concentrations at Sites 1 and 2 (1999–2006). All samples were analyzed in the field using a HACH water quality test kit except in 2005, when duplicate samples were analyzed by Edge Analytical, Bellingham, WA.

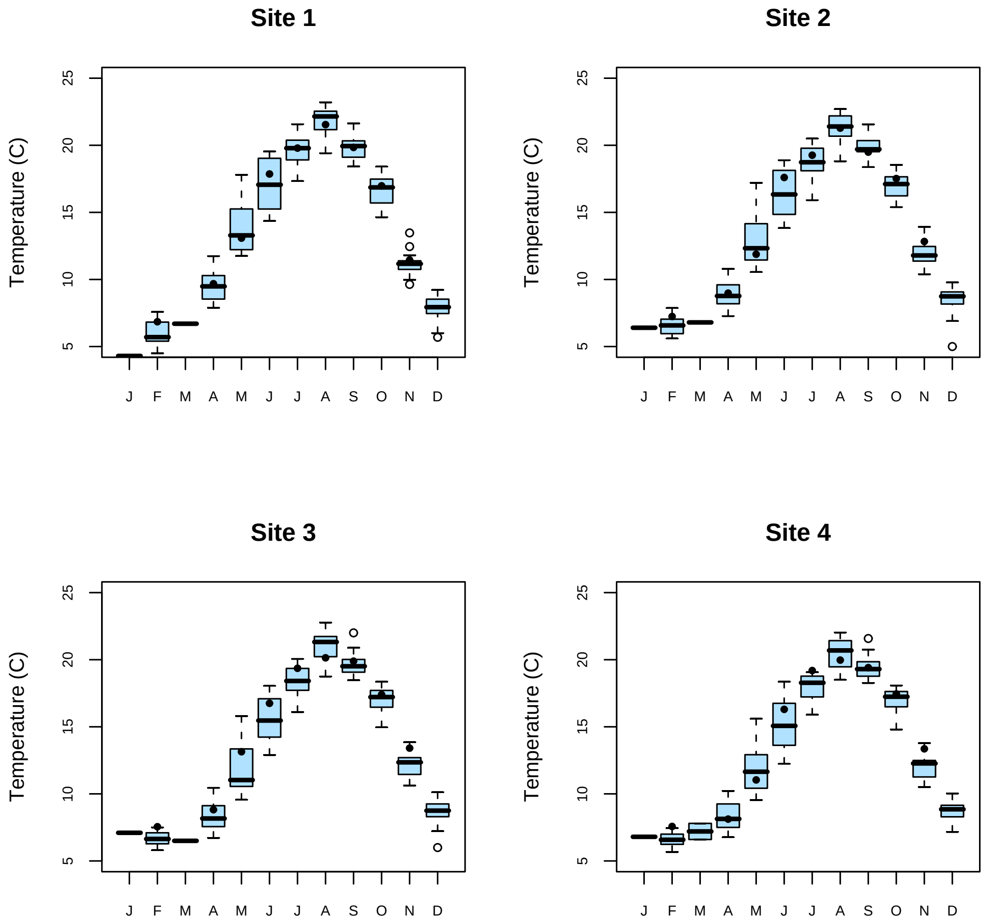


Figure 1: Comparison of 2006 surface water temperatures (●) to boxplots showing 1988–2005 surface temperature medians and ranges (depth <1 m for all sites and years). Boxplots show medians and upper/lower quartiles; whiskers extend 1.5 × interquartile range or to maximum/minimum values; outliers lie outside 1.5 × IQR.

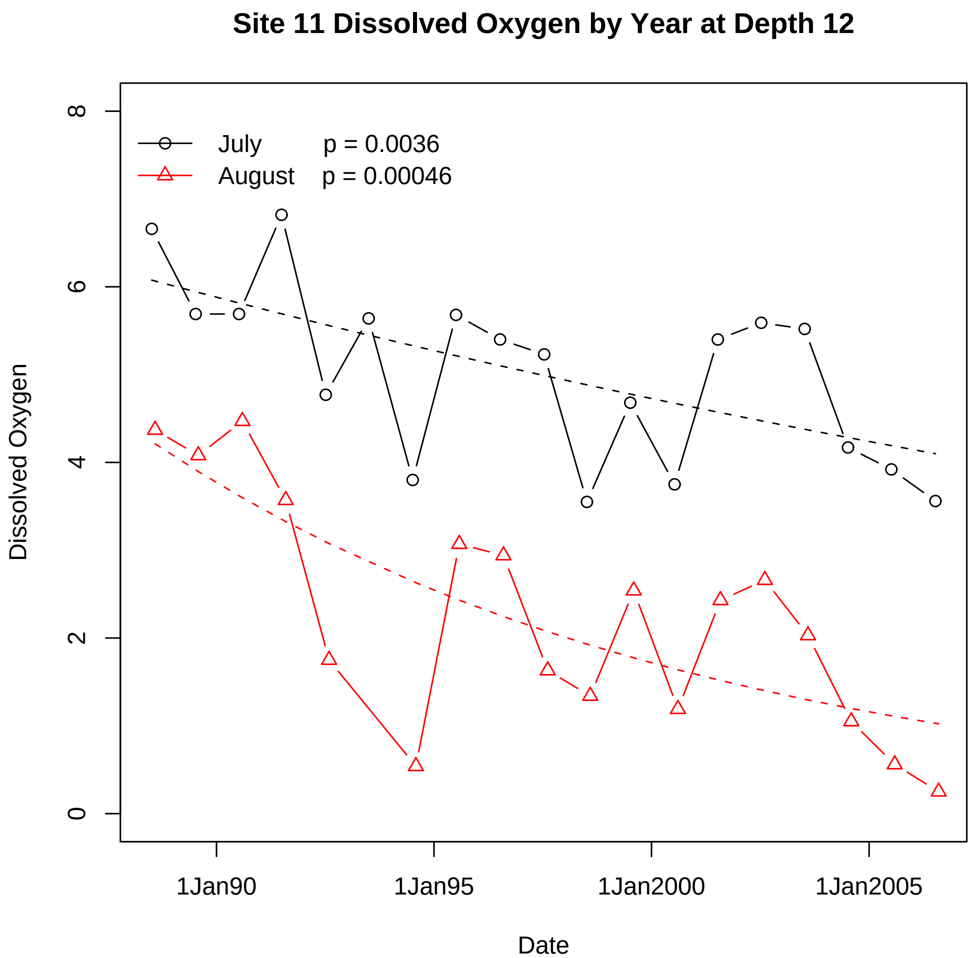


Figure 2: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 12 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

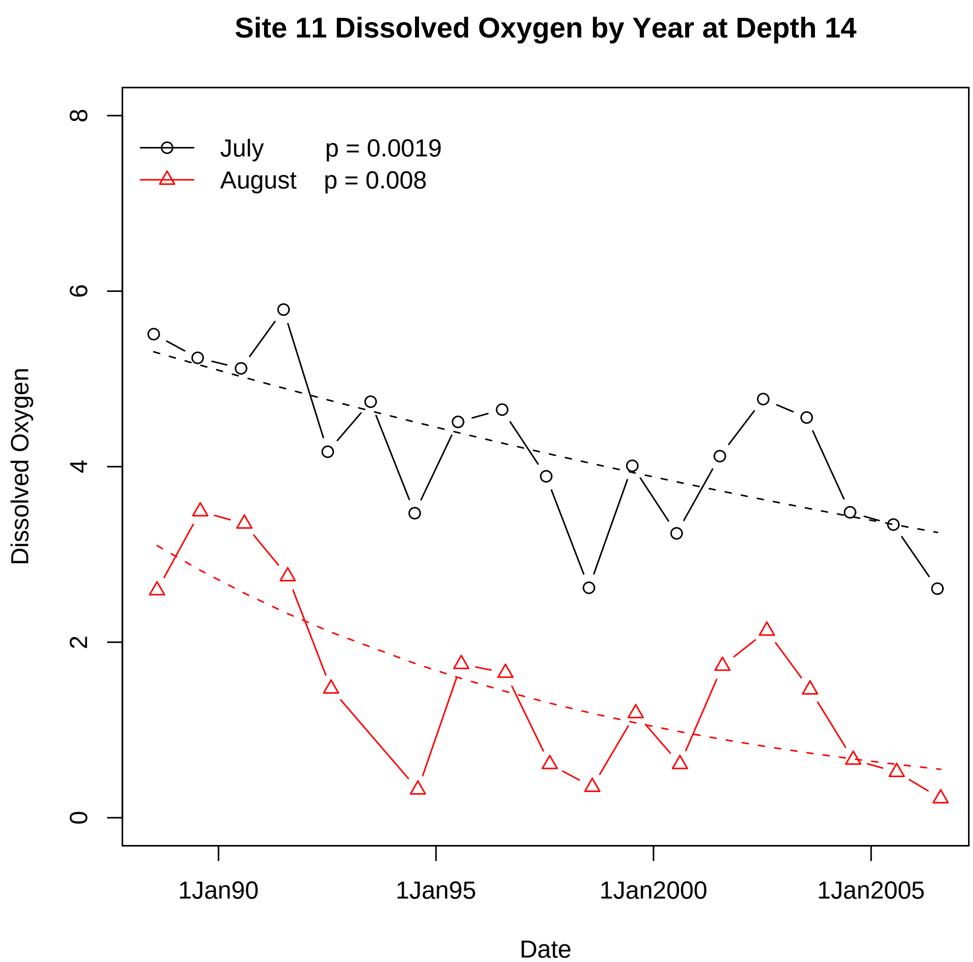


Figure 3: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 14 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

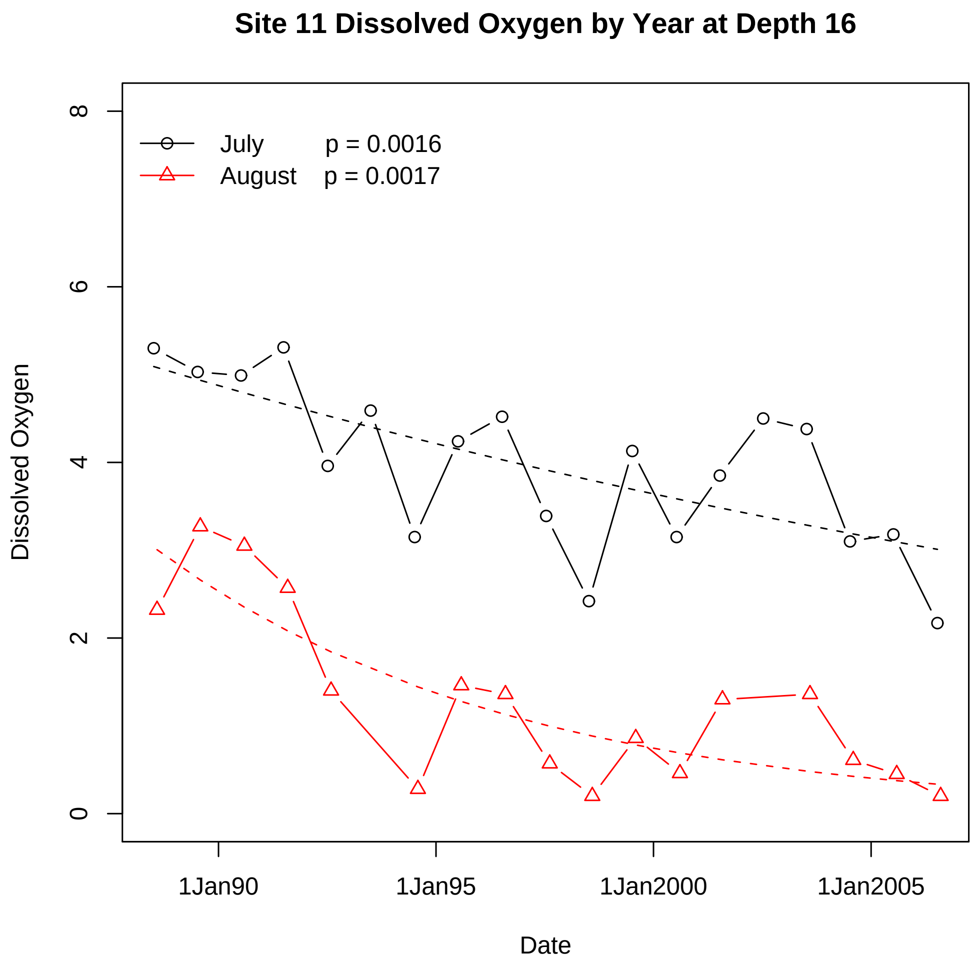


Figure 4: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 16 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

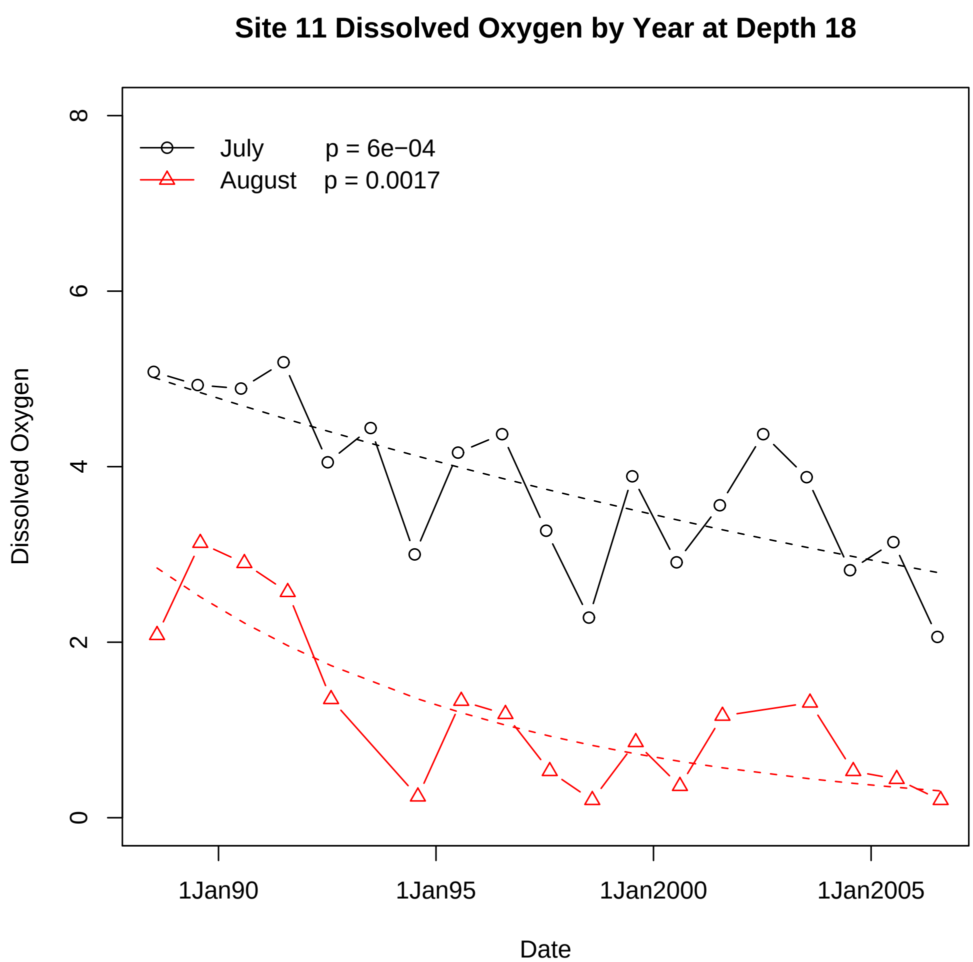


Figure 5: Nonlinear regression model showing relationship between dissolved oxygen and time at Site 1, 18 m. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

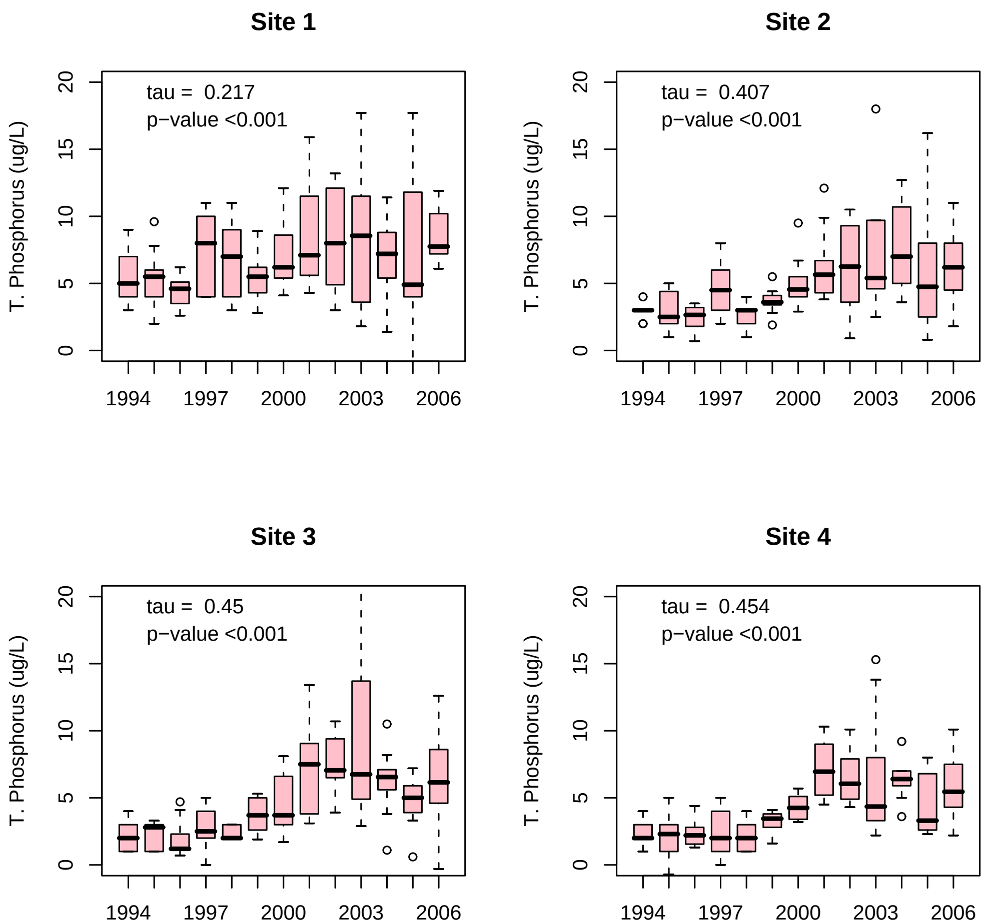


Figure 6: Lake Whatcom summer near-surface total phosphorus concentrations, 1994–2006. Data represent June through October concentrations at depths $\leq$5 m. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to maximum/minimum values; extreme outliers 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.

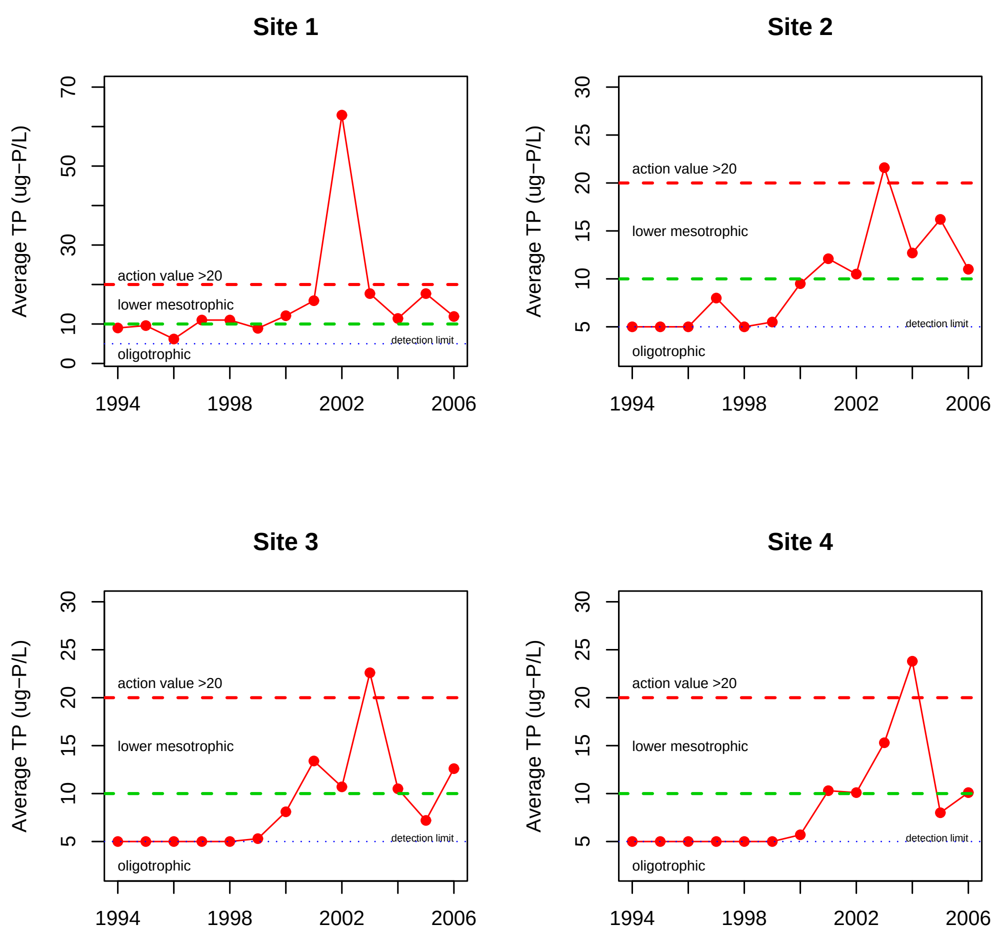


Figure 7: Lake Whatcom total phosphorus concentrations compared to lake nutrient criteria for the Coast Range, Puget Lowlands, and Northern Rockies Ecoregions (WAC 173–201A–230, Table 230.1). See Ecology(2006) and discussion on page 10 for description of methods. Note that the scale is different for Site 1 due to the high 2002 value.

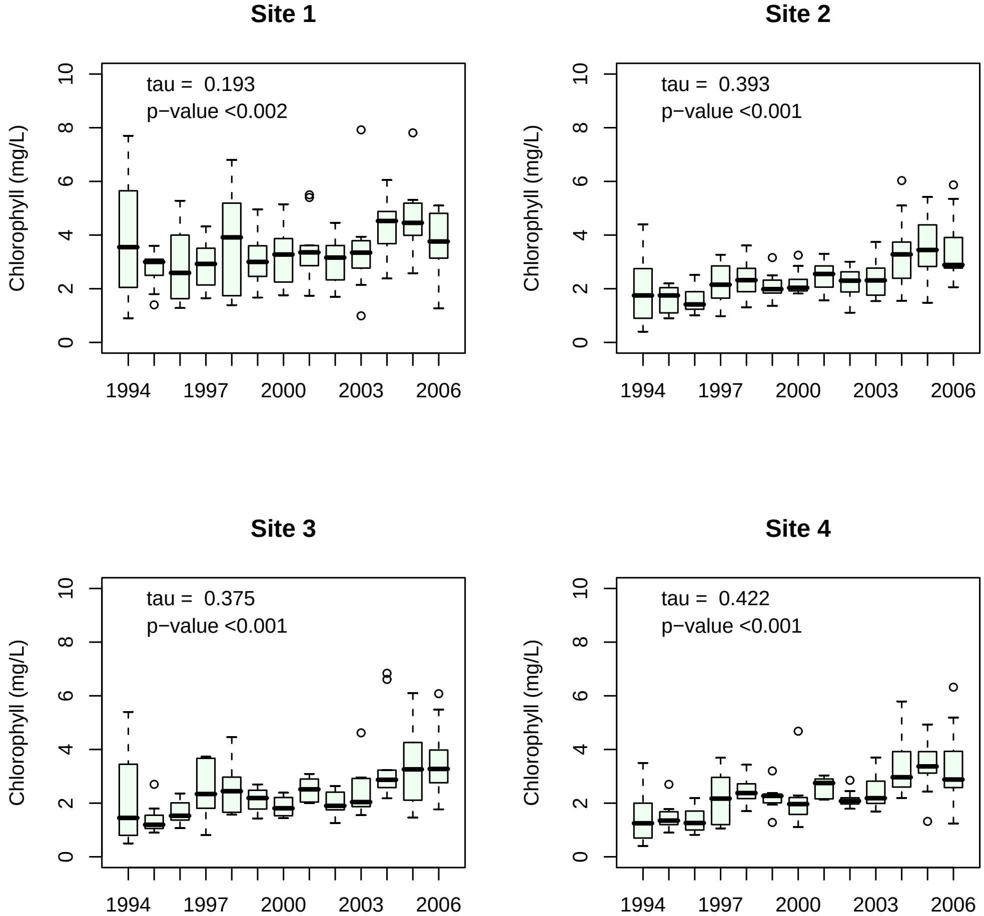


Figure 8: Lake Whatcom summer near-surface chlorophyll concentrations, 1994–2006. Data represent June through October concentrations at depths $\leq$5 m. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to maximum/minimum values. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

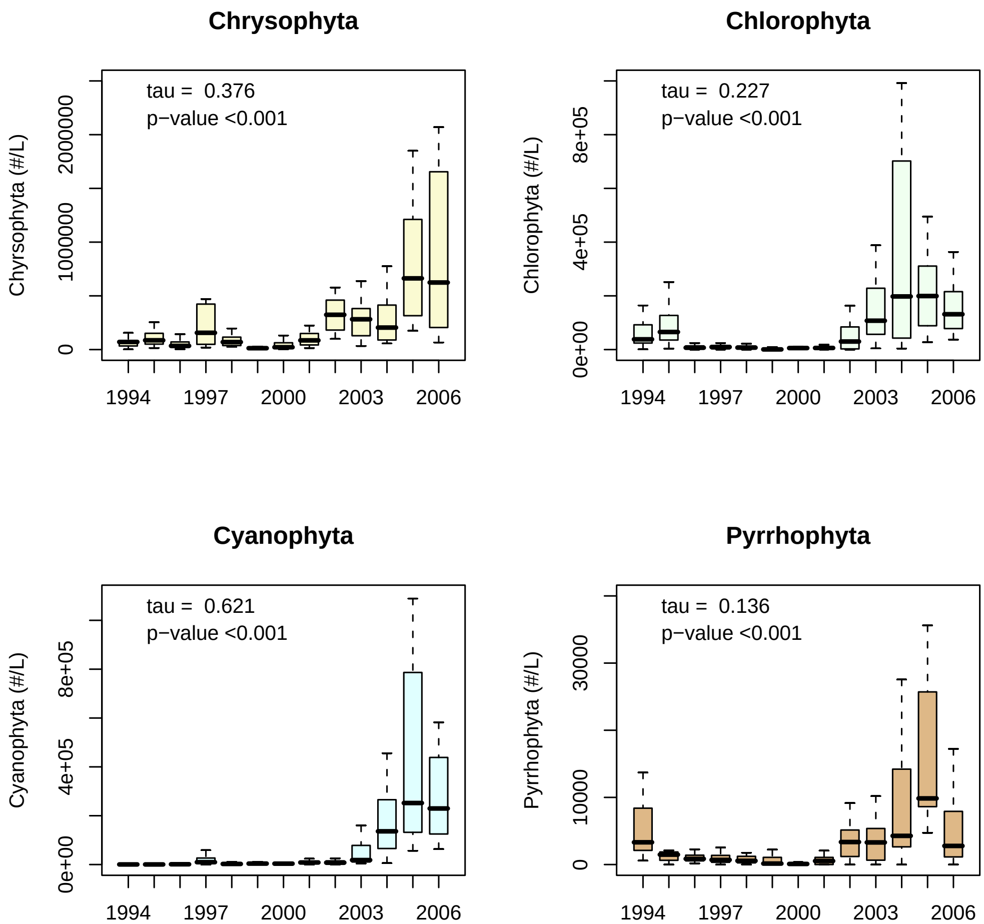


Figure 9: Distribution of summer algal counts, 1994–2006. Data represent June through October concentrations at all depths and sites. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to maximum/minimum values; extreme outliers were not plotted, but were 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.

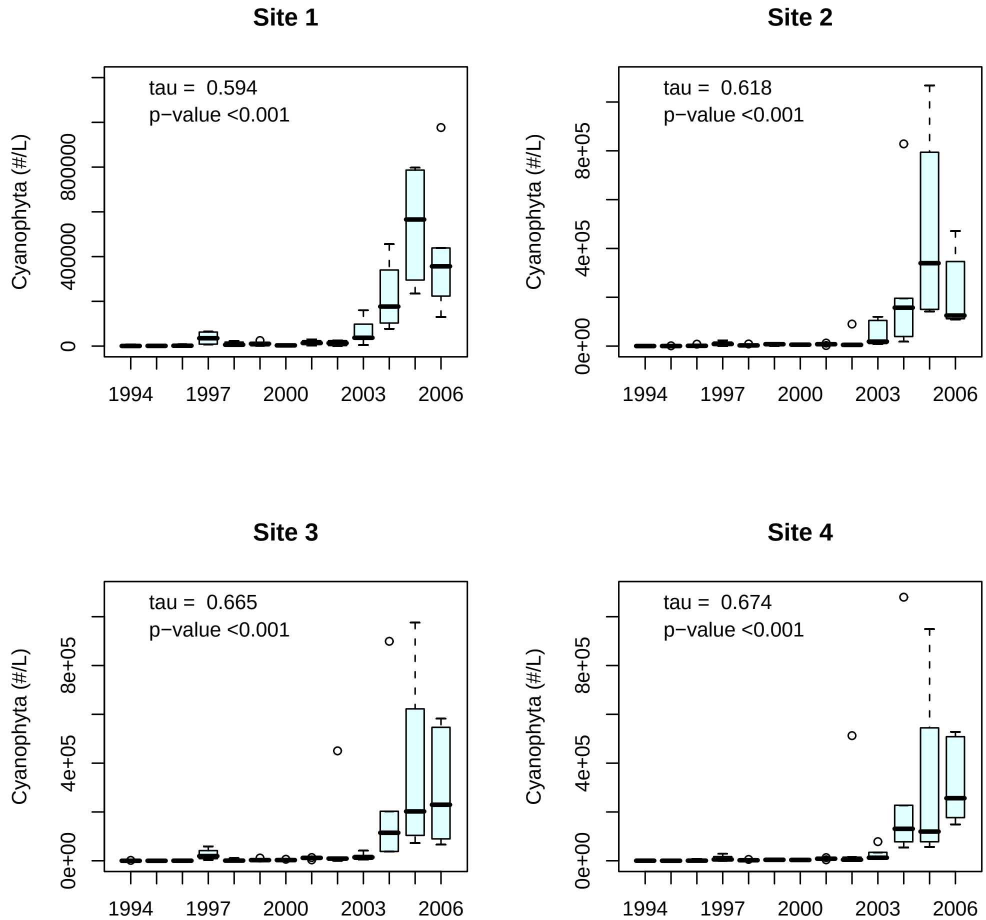


Figure 10: Distribution of summer Cyanobacteria counts at Sites 1–4, 1994–2006. Data represent June through October concentrations at all depths. Boxplots show median and upper/lower quartiles; whiskers extend 1.5 $\times$ interquartile range or to maximum/minimum values. Kendall's τ correlations were used because the data were not monotonic-linear; all correlations were statistically significant.

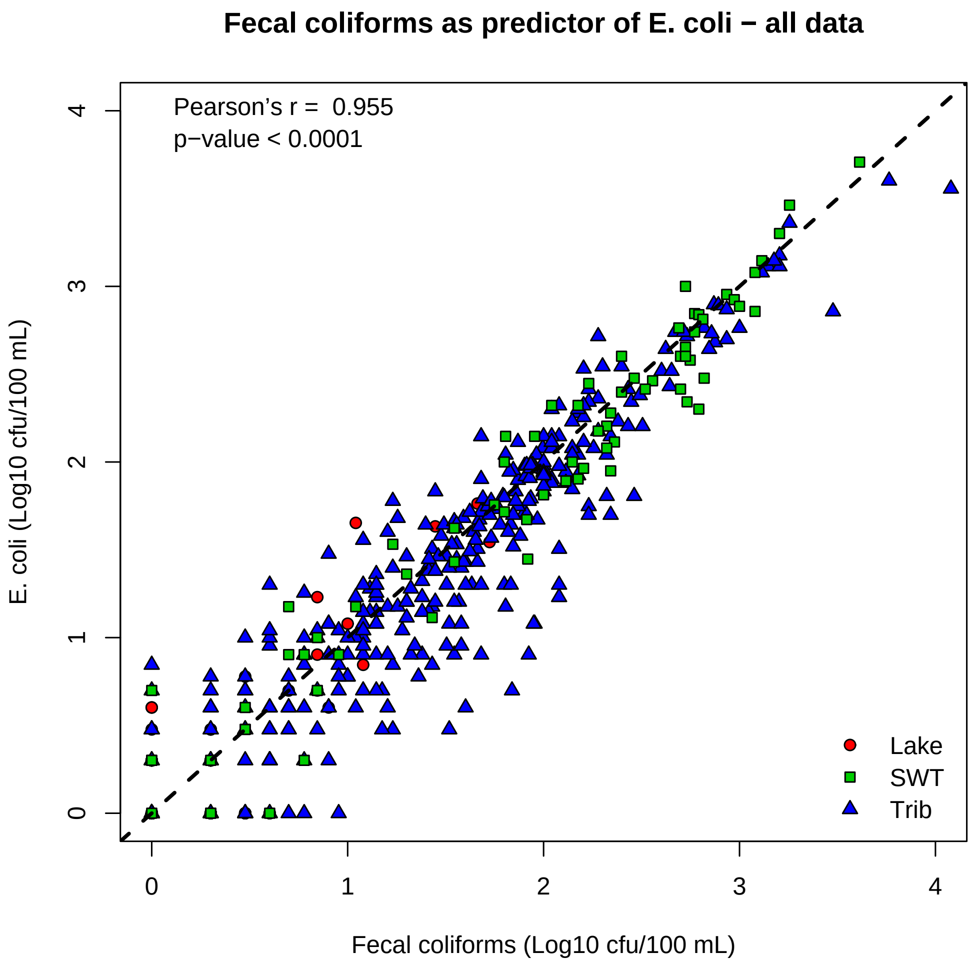


Figure 11: Correlation between fecal coliforms and *E. coli* counts in surface water samples (lake, stream, storm water treatment facility) in the Lake Whatcom watershed, October 2004 – September 2006. Pearson's r correlation was used because the log-transformed data were nearly monotonic-linear and the residuals were homogeneous. The diagonal line was added for reference to show a 1:1 relationship.

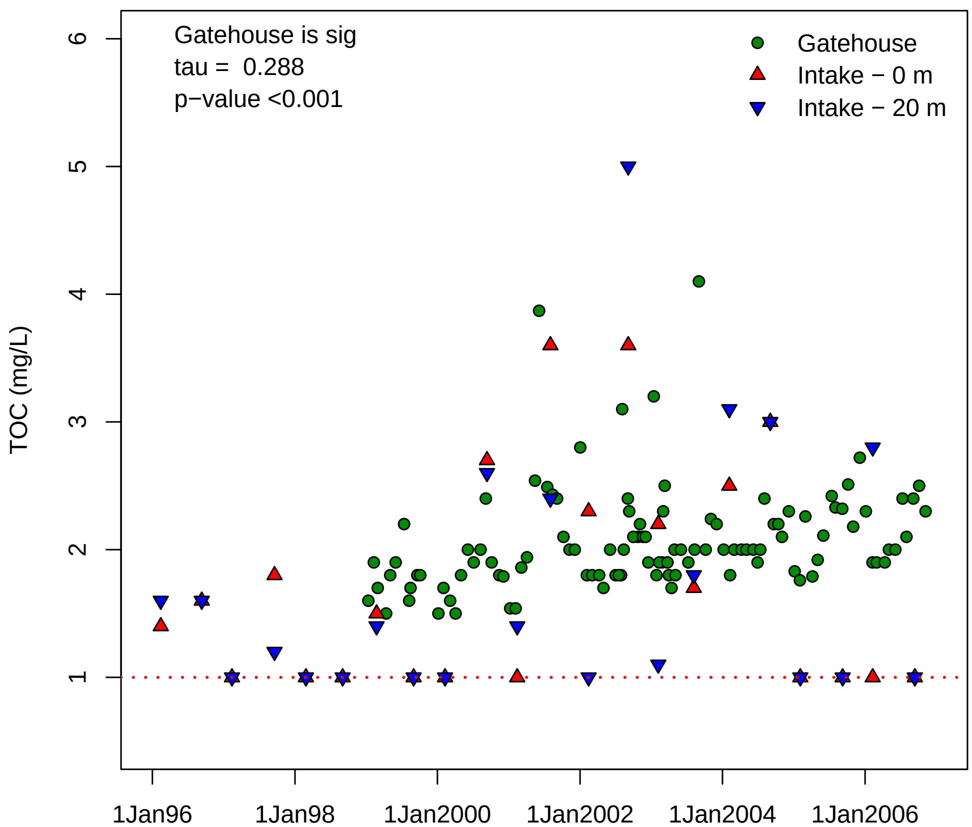


Figure 12: Total organic carbon concentrations at the Intake (off-shore, surface and bottom) and from the gatehouse. Gatehouse data were provided by the City of Bellingham Public Works Department. Note that multiple plotted points at the detection limit (red dotted line) may not be visible. Kendall's τ correlations were used because the data were not monotonic-linear; only the gatehouse correlation was statistically significant

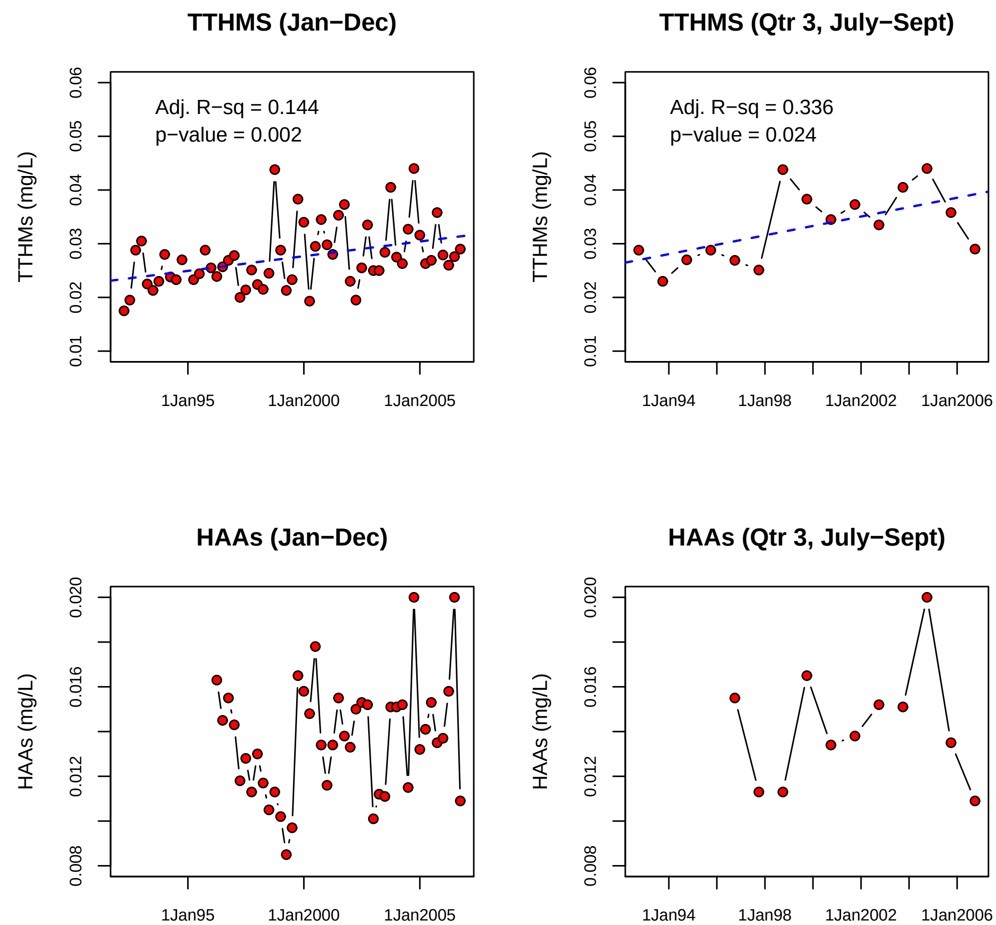


Figure 13: Total trihalomethanes (TTHMs) and haloacetic acids (HAAs) concentrations in the Bellingham water distribution system, 1992–2006. Regressions for Jan-Dec and Qtr 3 THMs vs. time were significant. Data were provided by the City of Bellingham Public Works Department.

3 Creek Monitoring

The major objective for the monthly creek monitoring was to provide baseline data for the major tributaries that flow into Lake Whatcom. Whatcom Creek was also sampled to provide baseline data for the lake's outlet.

3.1 Site Descriptions

Fifteen sites were sampled monthly from October 2004 through September 2006 to provide baseline tributary data in the Lake Whatcom watershed (Figure A2, page 105). Monthly samples were collected from Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, Euclid, Mill Wheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. The sampling locations for these sites are described in Appendix A.2.

In addition to monthly sampling, Anderson, Austin, and Smith Creeks were sampled twice during the 2004/2005 sampling year to collect 48-hr composite samples, and the Austin Creek and Beaver Creek watersheds were sampled intensively during a 1-day "creek walk." Although these results were summarized in last year's report (Matthews, et al., 2006), brief descriptions have been included in the 2005/2006 report to provide an overview of the two year creek monitoring effort. Beginning in October 2006, the frequency of creek monitoring was reduced to biannual sampling at the sites listed above.

3.2 Field Sampling and Analytical Methods

The analytical procedures for sampling the creeks are summarized in Table 1 (page 14). 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 1). 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 monthly at Blue Canyon Creek using the transect procedure described by USGS (Rantz, et al., 1982) and during 2004/2005 from ungauged sites in the Austin Creek and

Beaver Creek watersheds. All other sites have USGS or IWS gauges that provide discharge data to the City; all IWS discharge data are included in Appendix D.

3.3 Results and Discussion

3.3.1 Monthly creek monitoring

The monthly data are summarized in Tables 10–24 (pages 41–55). The raw data are included in Appendix D and are available in electronic format on the CD that accompanies this report. The raw data are also plotted against time to show the October 2004-September 2006 data for each creek (Figures B136–B165, pages 257–286). These figures include a dashed (blue) horizontal line that shows the median value for Smith Creek and a solid (red) horizontal line that shows the median value for each creek. Smith Creek was chosen as a reference because it is a major tributary to the lake and has a history of being relatively unpolluted.

Water temperatures and dissolved oxygen concentrations were relatively similar at all sites (Figures B140–B141 and B144–B145), with a few notable exceptions. Whatcom Creek had higher temperatures and lower oxygen concentrations than the other sites, reflecting the influence of Lake Whatcom (Figures B141 and B145). The Park Place wet pond outlet and Silver Beach Creek had slightly lower median dissolved oxygen concentrations and slightly higher median temperatures, which is typical for residential streams.

Most of the creeks in the Lake Whatcom watershed had relatively low concentrations of dissolved solids, indicated by low concentrations for alkalinity ($\leq$50 mg/L), conductivity ($\leq$100 μS), and total solids ($\leq$100 mg/L), with pH levels near 7.0 (Figures B136–B139, B142–B143, and B156–B157). Sites that did not match this description included the residential streams (e.g., Park Place outlet and Silver Beach Creek) and Blue Canyon Creek, which drains an area rich in soluble minerals. Most sites also had low total suspended solids concentrations ($\leq$10 mg/L) and low turbidities ($\leq$5 NTU) except for outliers that were usually related to precipitation events (Figures B158–B161). The influence of storm events on turbidity and suspended solids was clearly illustrated in the January 2006 data, which show distinct spikes at almost all sites except Whatcom Creek. Lake Whatcom serves as a sedimentation basin, and our monitoring site is located near the lake outlet, so sediment spikes from storm runoff were not present.

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 very similar, indicating that most of the nitrogen was inorganic (Figures B146– B149).[13] Most of the creeks had lower total nitrogen and nitrate/nitrate concentrations than Smith Creek. The exceptionally low concentrations in Whatcom Creek reflect algal uptake of nitrogen in the lake. Low inorganic nitrogen concentrations are not an indication of low pollution levels, and instead favor the growth of nuisance Cyanobacteria.

Ammonia concentrations were elevated in several residential streams (e.g., Park Place, Millwheel, and Euclid Creeks), as well as in Anderson and Whatcom Creeks (Figures B150–B151). 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 small "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 B152–B155). Total phosphorus and soluble phosphate concentrations were usually highest in the residential streams, and distinct peaks were present during storm events (e.g., January 2006).

High coliform counts are an indicator of residential pollution (Figures B162–B165), and many of the residential sites in the Lake Whatcom watershed failed to meet the coliform surface water standards set by WAC 173–201A:

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

[13] Total nitrogen concentrations do not include dissolved nitrogen gas, which is also present and abundant in streams, but is not readily available as a nutrient to most plants and algae.

Many of the creeks failed to meet the WAC coliform standard because more than 10% of their samples exceeded 100 cfu/100 mL; Carpenter Creek, Euclid Creek, Millwheel Creek, Park Place outlet, and Silver Beach Creek also failed to meet the criterion of a geometric mean lower than 50 cfu/100 mL (Table 25, page 56);

The forested sites in upper Austin and Beaver Creeks, Blue Canyon Creek, and Smith Creek passed the coliform standard, as did Lower Austin Creek, which is located downstream from Sudden Valley. Whatcom Creek also passes both criteria.

3.3.2 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. During January and March, 2005 monitoring period, multiple samples were collected during a 48-hr period to provide information about short-term variability in stream water quality. Composite samples were collected at 90 minute intervals for 48 hours from Anderson, Lower Austin, and Smith Creeks to measure total nitrogen, total phosphorus, total solids, and total suspended solids.[14] During this 48-hr period, 4 grab samples were collected from Lower Austin and Smith Creeks to measure temperature, dissolved oxygen, pH, conductivity, turbidity, alkalinity, ammonia, nitrate/nitrite, soluble phosphate, and fecal coliforms.

The results from the 48-hr monitoring project were reported in the 2004/2005 annual report (Matthews, et al., 2006), but an error was discovered after the report was published. The Smith Creek total nitrogen and total phosphorus data from March 2005 were transposed. The corrected data and updated figures are included in Appendix B, and the updated figures include the additional monthly monitoring data from 2005/2006 (Figures B166–B172).

3.3.3 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

[14]The composite samples were also analyzed for total metals; see Matthews, et al., 2006.

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 106). 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.wwu.edu/ iws.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	10.2	18.1	18.2	26.9	4.0	24
Conductivity (μS/cm)	39.4	61.1	60.0	73.4	9.3	24
Dissolved Oxygen (mg/L)	8.8	10.5	10.9	14.8	1.5	24
pH	6.7	7.0	7.0	7.6	0.2	24
Temperature (°C)	2.1	8.7	9.0	15.1	3.3	24
Turbidity (NTU)	0.4	2.5	10.1	107.0	21.9	24
Total solids (mg/L)	43.0	51.5	59.2	193.6	30.1	23
Total suspended solids (mg/L)	$<$2	3.4	12.6	168.8	34.0	24
Nitrogen - ammonia (μg-N/L)	$<$10	14.4	15.1	32.6	9.7	24
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	471.3	454.0	1131.9	297.5	24
Nitrogen - total (μg-N/L)	113.6	628.8	631.8	1862.2	401.8	24
Phosphorus - soluble (μg-P/L)	$<$5	7.8	8.1	14.6	3.2	24
Phosphorus - total (μg-P/L)	10.5	20.2	33.0	198.9	39.3	24
Coliforms - E. coli (cfu/100 mL)[‡]	2	17	21	180	NA	24
Coliforms - fecal (cfu/100 mL)[‡]	4	25	27	220	NA	24

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 10: Summary of Anderson Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	6.4	14.4	17.0	35.8	7.8	24
Conductivity (μS/cm)	35.0	52.4	66.7	181.6	36.0	24
Dissolved Oxygen (mg/L)	9.3	11.1	11.3	13.8	1.3	24
pH	7.1	7.4	7.4	7.7	0.2	24
Temperature (°C)	1.6	8.9	8.8	15.5	3.8	24
Turbidity (NTU)	0.2	0.5	1.6	18.8	3.8	24
Total solids (mg/L)	33.7	48.5	53.6	108.3	19.4	23
Total suspended solids (mg/L)	<2	<2	4.1	59.4	12.0	24
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	16.1	4.3	24
Nitrogen - nitrate/nitrite (μg-N/L)	255.2	475.5	521.7	1016.8	189.9	24
Nitrogen - total (μg-N/L)	306.8	560.6	608.4	1122.4	213.3	24
Phosphorus - soluble (μg-P/L)	<5	9.2	9.7	21.6	4.7	24
Phosphorus - total (μg-P/L)	<5	13.5	17.8	74.3	14.6	24
Coliforms - E. coli (cfu/100 mL)‡	<1	4	5	200	NA	24
Coliforms - fecal (cfu/100 mL)‡	<1	5	6	240	NA	24

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 11: Summary of upper Austin Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	8.3	14.5	16.7	33.6	6.3	23
Conductivity (μS/cm)	45.5	61.6	68.4	127.7	20.7	23
Dissolved Oxygen (mg/L)	8.5	10.7	10.7	13.5	1.3	23
pH	6.8	7.1	7.1	7.6	0.1	23
Temperature (°C)	1.3	9.0	8.9	14.5	3.6	23
Turbidity (NTU)	0.2	1.7	5.5	78.0	15.9	23
Total solids (mg/L)	40.2	54.2	61.7	179.0	28.1	22
Total suspended solids (mg/L)	<2	<2	8.5	144.7	29.9	23
Nitrogen - ammonia (μg-N/L)	<10	10.6	10.7	24.2	5.9	22
Nitrogen - nitrate/nitrite (μg-N/L)	212.5	702.8	710.0	1691.0	392.1	23
Nitrogen - total (μg-N/L)	370.6	742.8	868.3	1959.4	431.1	23
Phosphorus - soluble (μg-P/L)	<5	12.2	12.0	22.4	4.9	23
Phosphorus - total (μg-P/L)	6.3	23.6	31.3	128.8	25.0	23
Coliforms - E. coli (cfu/100 mL)[‡]	<1	6	8	210	NA	23
Coliforms - fecal (cfu/100 mL)[‡]	1	9	10	160	NA	23

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 12: Summary of upper Beaver Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	9.5	18.0	21.2	41.7	8.5	24
Conductivity (μS/cm)	45.3	71.1	80.7	163.5	30.5	24
Dissolved Oxygen (mg/L)	8.4	10.7	10.8	13.7	1.3	24
pH	6.8	7.3	7.3	7.7	0.2	24
Temperature (°C)	0.9	9.1	9.3	15.0	3.7	24
Turbidity (NTU)	0.4	1.6	7.5	120.0	24.2	24
Total solids (mg/L)	36.0	59.8	72.7	253.7	42.1	23
Total suspended solids (mg/L)	<2	<2	12.3	199.9	41.6	23
Nitrogen - ammonia (μg-N/L)	<10	<10	9.8	20.5	4.5	24
Nitrogen - nitrate/nitrite (μg-N/L)	227.9	539.4	601.9	1606.3	356.1	24
Nitrogen - total (μg-N/L)	318.3	623.8	746.6	1981.0	425.5	24
Phosphorus - soluble (μg-P/L)	<5	10.6	11.3	18.1	3.4	24
Phosphorus - total (μg-P/L)	10.9	20.5	26.7	142.8	25.7	24
Coliforms - E. coli (cfu/100 mL)[‡]	<1	16	15	350	NA	24
Coliforms - fecal (cfu/100 mL)[‡]	1	21	21	250	NA	24

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 13: Summary of water quality data collected at the confluence of Austin Creek and Beaver Creek, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	8.0	18.4	21.1	39.8	8.4	24
Conductivity (μS/cm)	49.1	68.0	77.1	137.5	24.9	23
Dissolved Oxygen (mg/L)	8.8	10.8	11.0	13.9	1.4	24
pH	7.0	7.4	7.4	7.7	0.2	23
Temperature (°C)	0.8	10.0	9.2	15.3	4.0	24
Turbidity (NTU)	0.2	1.3	5.6	89.2	18.0	24
Total solids (mg/L)	44.5	60.7	67.3	189.8	30.1	23
Total suspended solids (mg/L)	<2	<2	10.3	166.5	33.8	24
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	26.8	5.7	24
Nitrogen - nitrate/nitrite (μg-N/L)	202.6	554.7	582.1	1353.8	292.7	24
Nitrogen - total (μg-N/L)	303.4	634.6	714.1	1585.1	338.5	24
Phosphorus - soluble (μg-P/L)	<5	10.7	11.7	22.6	4.6	24
Phosphorus - total (μg-P/L)	5.0	20.5	23.3	113.3	20.2	24
Coliforms - E. coli (cfu/100 mL)[‡]	1	23	18	130	NA	24
Coliforms - fecal (cfu/100 mL)[‡]	3	34	24	170	NA	24

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 14: Summary of lower Austin Creek (downstream from confluence with Beaver Creek) monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	63.6	126.6	122.2	163.5	22.5	24
Conductivity (μS/cm)	165.2	270.5	265.0	289.0	27.9	24
Dissolved Oxygen (mg/L)	9.6	11.0	11.2	13.5	1.1	24
pH	7.9	8.3	8.3	8.4	0.1	24
Temperature (°C)	2.2	9.7	9.4	14.8	3.2	24
Turbidity (NTU)	0.8	2.1	3.7	35.5	6.9	24
Total solids (mg/L)	142.6	164.9	164.1	176.6	8.3	23
Total suspended solids (mg/L)	<2	3.5	6.7	63.6	12.5	24
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	11.2	3.5	24
Nitrogen - nitrate/nitrite (μg-N/L)	99.0	195.3	373.2	1602.2	398.1	24
Nitrogen - total (μg-N/L)	151.2	269.5	460.2	1898.7	463.1	24
Phosphorus - soluble (μg-P/L)	<5	8.2	8.9	17.2	3.3	24
Phosphorus - total (μg-P/L)	6.0	12.6	16.9	64.0	13.5	24
Coliforms - E. coli (cfu/100 mL)[‡]	<1	4	4	83	NA	24
Coliforms - fecal (cfu/100 mL)[‡]	<1	3	5	81	NA	24

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 15: Summary of Blue Canyon Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	4.8	9.7	10.9	21.2	4.1	22
Conductivity (μS/cm)	32.5	42.8	43.5	62.0	6.4	22
Dissolved Oxygen (mg/L)	5.9	10.4	10.2	13.1	1.9	22
pH	6.6	6.9	6.9	7.1	0.1	22
Temperature (°C)	2.4	8.4	8.7	14.2	3.2	22
Turbidity (NTU)	0.3	0.7	4.3	74.8	15.8	22
Total solids (mg/L)	30.1	36.7	43.8	168.6	29.1	21
Total suspended solids (mg/L)	<2	<2	7.9	138.2	29.3	22
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	15.9	3.9	22
Nitrogen - nitrate/nitrite (μg-N/L)	255.2	683.1	728.7	1770.3	400.7	22
Nitrogen - total (μg-N/L)	340.6	756.3	879.1	1986.5	457.2	22
Phosphorus - soluble (μg-P/L)	<5	5.3	5.6	10.6	2.5	22
Phosphorus - total (μg-P/L)	<5	12.8	19.8	172.3	34.2	22
Coliforms - E. coli (cfu/100 mL)[‡]	2	13	17	580	NA	22
Coliforms - fecal (cfu/100 mL)[‡]	1	13	18	750	NA	22

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 16: Summary of Brannian Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	10.6	22.7	26.1	45.3	10.6	22
Conductivity (μS/cm)	50.3	70.3	76.4	113.0	19.3	22
Dissolved Oxygen (mg/L)	4.8	10.8	10.5	14.6	2.2	22
pH	7.1	7.4	7.5	7.8	0.2	22
Temperature (°C)	0.0	8.7	9.1	16.2	4.2	22
Turbidity (NTU)	0.6	2.7	5.8	57.6	11.8	22
Total solids (mg/L)	52.6	69.7	74.6	144.7	20.7	21
Total suspended solids (mg/L)	<2	2.2	9.0	99.4	21.1	22
Nitrogen - ammonia (μg-N/L)	<10	<10	13.8	74.9	17.7	22
Nitrogen - nitrate/nitrite (μg-N/L)	292.3	580.9	684.6	1485.0	342.8	22
Nitrogen - total (μg-N/L)	511.7	782.3	938.6	2141.9	415.0	22
Phosphorus - soluble (μg-P/L)	<5	13.0	14.4	31.0	7.1	22
Phosphorus - total (μg-P/L)	15.3	24.4	31.2	104.4	19.7	22
Coliforms - E. coli (cfu/100 mL)[‡]	6	74	65	1500	NA	22
Coliforms - fecal (cfu/100 mL)[‡]	8	90	79	1600	NA	22

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 17: Summary of Carpenter Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	13.6	31.3	32.0	51.2	10.7	21
Conductivity (μS/cm)	57.8	96.2	96.0	132.7	21.3	21
Dissolved Oxygen (mg/L)	7.3	10.3	10.2	12.9	1.5	21
pH	6.9	7.3	7.3	7.5	0.1	21
Temperature (°C)	1.5	8.9	9.4	15.2	3.5	21
Turbidity (NTU)	1.3	2.1	4.7	48.1	10.0	21
Total solids (mg/L)	57.8	73.4	75.7	124.7	15.2	20
Total suspended solids (mg/L)	<2	2.1	6.6	77.6	16.5	21
Nitrogen - ammonia (μg-N/L)	<10	14.7	13.7	29.7	7.3	21
Nitrogen - nitrate/nitrite (μg-N/L)	101.6	522.4	527.2	1579.8	326.0	21
Nitrogen - total (μg-N/L)	298.6	661.0	723.1	1873.2	379.0	21
Phosphorus - soluble (μg-P/L)	6.6	15.1	15.0	20.7	3.7	21
Phosphorus - total (μg-P/L)	16.1	25.2	29.9	118.6	21.1	21
Coliforms - E. coli (cfu/100 mL)‡	8	56	58	540	NA	21
Coliforms - fecal (cfu/100 mL)‡	8	74	65	720	NA	21

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 18: Summary of Euclid Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	15.0	35.5	41.3	84.0	18.2	20
Conductivity (μS/cm)	61.5	101.4	107.5	179.6	32.0	20
Dissolved Oxygen (mg/L)	1.1	10.2	9.7	13.6	2.7	20
pH	7.1	7.3	7.5	9.2	0.4	20
Temperature (°C)	1.0	9.3	11.3	21.8	6.1	20
Turbidity (NTU)	3.7	6.8	9.5	43.0	8.8	19
Total solids (mg/L)	67.2	90.7	91.6	128.8	18.4	19
Total suspended solids (mg/L)	2.0	6.1	9.3	54.6	11.4	20
Nitrogen - ammonia (μg-N/L)	$<$10	19.9	50.2	569.4	124.0	20
Nitrogen - nitrate/nitrite (μg-N/L)	$<$20	529.7	558.1	2048.3	558.5	20
Nitrogen - total (μg-N/L)	417.3	941.3	1046.1	2436.1	580.1	20
Phosphorus - soluble (μg-P/L)	5.9	12.1	18.3	116.5	24.0	20
Phosphorus - total (μg-P/L)	26.9	43.3	60.5	198.0	47.4	20
Coliforms - E. coli (cfu/100 mL)‡	4	72	68	790	NA	20
Coliforms - fecal (cfu/100 mL)‡	16	100	97	740	NA	20

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 19: Summary of Millwheel Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	8.0	21.6	25.4	50.8	12.1	24
Conductivity (μS/cm)	51.9	71.1	79.8	136.3	25.2	24
Dissolved Oxygen (mg/L)	9.0	11.0	11.2	14.8	1.5	24
pH	7.2	7.5	7.5	7.8	0.2	24
Temperature (°C)	0.0	9.3	9.0	15.6	4.3	24
Turbidity (NTU)	0.3	1.2	5.2	86.9	17.5	24
Total solids (mg/L)	46.1	60.3	68.7	194.9	30.0	23
Total suspended solids (mg/L)	<2	<2	9.7	166.9	33.6	24
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	18.0	4.6	24
Nitrogen - nitrate/nitrite (μg-N/L)	271.6	799.2	840.7	2077.3	448.1	24
Nitrogen - total (μg-N/L)	409.8	885.3	971.1	2271.4	493.7	24
Phosphorus - soluble (μg-P/L)	<5	11.8	14.9	46.9	9.0	24
Phosphorus - total (μg-P/L)	10.7	19.6	23.8	119.7	21.5	24
Coliforms - E. coli (cfu/100 mL)[‡]	1	19	16	260	NA	24
Coliforms - fecal (cfu/100 mL)[‡]	1	41	22	270	NA	24

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 20: Summary of Olsen Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	36.0	86.8	91.9	132.5	24.4	23
Conductivity (μS/cm)	57.7	229.5	219.3	289.0	49.4	24
Dissolved Oxygen (mg/L)	6.6	9.3	9.3	11.9	1.6	24
pH	7.2	7.7	7.7	8.1	0.2	24
Temperature (°C)	4.5	12.6	12.3	19.9	4.7	24
Turbidity (NTU)	0.4	3.6	5.6	24.4	6.3	24
Total solids (mg/L)	108.4	144.8	143.8	185.8	22.3	23
Total suspended solids (mg/L)	<2	<2	4.6	39.2	8.1	24
Nitrogen - ammonia (μg-N/L)	19.3	28.5	35.5	82.2	17.0	24
Nitrogen - nitrate/nitrite (μg-N/L)	120.6	501.5	636.1	2648.4	556.8	24
Nitrogen - total (μg-N/L)	446.5	807.1	1012.6	3358.0	604.9	24
Phosphorus - soluble (μg-P/L)	13.9	23.6	24.8	55.8	9.7	24
Phosphorus - total (μg-P/L)	27.7	42.5	55.4	171.5	33.6	24
Coliforms - E. coli (cfu/100 mL)[‡]	4	68	77	1300	NA	23
Coliforms - fecal (cfu/100 mL)[‡]	6	86	111	18000	NA	23

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 21: Summary of Park Place outlet monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean[†]	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	31.5	72.8	79.2	137.8	31.7	23
Conductivity (μS/cm)	102.5	172.9	192.6	310.0	60.5	23
Dissolved Oxygen (mg/L)	8.0	10.2	10.4	14.4	1.7	24
pH	7.5	7.9	7.9	8.2	0.2	23
Temperature (°C)	0.0	10.9	10.3	16.6	4.5	24
Turbidity (NTU)	1.5	4.6	6.0	26.1	5.4	23
Total solids (mg/L)	97.3	122.8	133.4	192.8	29.1	22
Total suspended solids (mg/L)	$<$2	2.9	5.3	38.7	8.0	23
Nitrogen - ammonia (μg-N/L)	$<$10	12.3	10.9	19.3	5.7	23
Nitrogen - nitrate/nitrite (μg-N/L)	149.0	417.9	532.6	1403.1	333.1	23
Nitrogen - total (μg-N/L)	423.5	706.4	867.9	1981.0	386.0	23
Phosphorus - soluble (μg-P/L)	7.8	20.0	20.5	40.3	8.2	23
Phosphorus - total (μg-P/L)	25.1	40.5	43.3	98.1	16.5	23
Coliforms - E. coli (cfu/100 mL)[‡]	20	340	324	4000	NA	23
Coliforms - fecal (cfu/100 mL)[‡]	17	450	397	12000	NA	23

[†]Uncensored arithmetic means except as noted; not adjusted for repeated measures.
[‡]Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 22: Summary of Silver Beach Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	9.7	17.3	19.7	36.1	7.4	24
Conductivity (μS/cm)	48.5	57.9	65.0	106.9	15.5	24
Dissolved Oxygen (mg/L)	9.0	11.3	11.5	15.1	1.5	24
pH	7.2	7.5	7.5	7.7	0.2	24
Temperature (°C)	0.5	9.3	8.8	14.9	4.0	24
Turbidity (NTU)	0.2	0.9	2.5	34.8	6.9	24
Total solids (mg/L)	42.2	52.0	55.3	122.4	16.1	23
Total suspended solids (mg/L)	<2	<2	5.1	81.4	16.3	24
Nitrogen - ammonia (μg-N/L)	<10	<10	<10	11.6	3.5	24
Nitrogen - nitrate/nitrite (μg-N/L)	427.0	992.0	1016.9	2228.0	453.4	24
Nitrogen - total (μg-N/L)	519.6	1073.8	1138.4	2449.2	510.7	24
Phosphorus - soluble (μg-P/L)	<5	10.4	10.9	24.9	5.6	24
Phosphorus - total (μg-P/L)	8.0	12.7	15.5	65.7	11.5	24
Coliforms - E. coli (cfu/100 mL)‡	1	9	9	110	NA	24
Coliforms - fecal (cfu/100 mL)‡	<1	14	11	140	NA	24

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 23: Summary of Smith Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

Variable	Min.	Med.	Mean†	Max.	SD	N
Alkalinity (mg/L $CaCO_3$)	18.5	21.1	21.0	23.0	1.2	24
Conductivity (μS/cm)	60.8	63.2	67.3	163.1	20.4	24
Dissolved Oxygen (mg/L)	7.7	9.3	9.7	12.1	1.4	24
pH	7.3	7.5	7.5	8.2	0.2	24
Temperature (°C)	4.5	13.2	13.7	23.4	5.9	24
Turbidity (NTU)	0.5	1.0	1.0	1.6	0.2	24
Total solids (mg/L)	35.2	41.1	41.9	47.7	3.5	23
Total suspended solids (mg/L)	<2	<2	<2	3.4	1.0	24
Nitrogen - ammonia (μg-N/L)	<10	16.0	15.6	32.4	8.0	24
Nitrogen - nitrate/nitrite (μg-N/L)	<20	155.1	167.2	353.6	119.6	24
Nitrogen - total (μg-N/L)	226.6	364.4	368.0	526.4	95.4	24
Phosphorus - soluble (μg-P/L)	<5	<5	<5	6.2	1.7	24
Phosphorus - total (μg-P/L)	5.7	12.0	11.6	17.5	3.2	24
Coliforms - E. coli (cfu/100 mL)‡	<1	6	8	79	NA	24
Coliforms - fecal (cfu/100 mL)‡	2	9	9	74	NA	24

†Uncensored arithmetic means except as noted; not adjusted for repeated measures.
‡Geometric means; all censored values replaced with closest integer (i.e., $<1 \Rightarrow 1$).

Table 24: Summary of Whatcom Creek monthly water quality data, Oct. 2004 – Sept. 2006. Note that this summary includes data from two years of monthly sampling.

	Geom.Mean (GM) ≤50 cfu/100 mL		Max 10% >100 cfu/100 mL	
Anderson Creek	GM = 27	pass	17% >100	fail
Austin Creek, upper	GM = 6	pass	8% >100	pass
Beaver Creek, upper	GM = 10	pass	9% >100	pass
Austin/Beaver confluence	GM = 21	pass	17% >100	fail
Austin Creek, lower	GM = 24	pass	8% >100	pass
Blue Canyon Creek	GM = 5	pass	0% >100	pass
Brannian Creek	GM = 18	pass	14% >100	fail
Carpenter Creek	GM = 79	fail	45% >100	fail
Euclid Creek	GM = 65	fail	30% >100	fail
Millwheel Creek	GM = 97	fail	45% >100	fail
Olsen Creek	GM = 22	pass	17% >100	fail
Park Place outlet	GM = 111	fail	39% >100	fail
Silver Beach Creek	GM = 397	fail	83% >100	fail
Smith Creek	GM = 11	pass	8% >100	pass
Whatcom Creek	GM = 9	pass	0% >100	pass

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

Table 25: Comparison of October 2004–September 2006 fecal coliform data from Lake Whatcom tributaries to WAC 173–201A surface water standards.

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 14–16 (pages 64–66). The location of each hydrograph is described in Appendix A.2. 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 17 (page 67) 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 17. 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 Lake Whatcom watershed to simulate surface-water runoff into the lake and to predict stream flow magnitudes along stream segments where water quality measurements were collected. 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; Kelleher, 2006).

Watershed attributes in the DHSVM are defined by geographic information system 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). Precipitation data from the Geneva gate house and Brannian creek rain gauges were also used. All data were formatted into one-hour time steps.

The DHSVM model was used to estimate stream flow magnitudes at the creek monitoring sites (see Figures 24–27 on pages 74–77 for simulated hydrographs and Figure 28 on page 78 for a map of the monitoring locations). The simulated flow data for individual creeks were not included on the CD that accompanies this report, or in electronic format online, but interested individuals may request data from Dr. Robert Mitchell, Department of Geology, Western Washington University, Bellingham, WA.

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.[15] 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-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 18, page 68). The average direct-precipitation depth (inches) for a given day was converted to a volume in

[15] Formerly Water District #10

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 2005/2006 was 50.0 inches (6783 MG).

Daily lake evaporation was estimated using a model based on the Penman method (Dingman, 1994). The Penman method is 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 2005/2006 was 21.6 inches (2946 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 2005/2006 was 252,287 MG. Figure 23 (page 73) 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. Negative values of runoff are likely due to the change in storage estimates (Figures 21 and 22, pages 71 and 72).

Yearly water balance totals are listed in Table 26 (page 61) along with the yearly total values for the four previous water years. The total inputs and outputs were estimated to be 37,817 MG and 37,802 MG, respectively. The total volume of outputs correspond to 15.0% of the median total volume of the lake. Under the assumption that the lake is completely mixed and flow is steady state (inputs = outputs), this would correspond to a 6.7 year residence time, with residence times for the past 5 years ranging from 5.1–10.1 years.[16] Tables 27 and 28 (pages 62–63) show the 2005/2006 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 19–22, pages 69–72). All the inputs, except for runoff, are shown in Figure 19 and all the outputs, except for Whatcom Creek, are shown in Figure 20. The runoff estimated from the water budget and Whatcom Creek outflow are shown along with the runoff estimated using DHSVM in Figure 21. Figure 22 shows 7-day summed totals for inputs, outputs, and change in storage.

4.4 Lake Whatcom Bathymetry Model

In 1972, Lighthart et al. (1972) published the first comprehensive set of morphological data for Lake Whatcom. This model served as the primary source of lake morphometry information until 1999, when the U. S. Bureau of Reclamation (BOR) conducted a new hydrographic survey of Lake Whatcom (Ferrari and Nuanes (2001).

The 1999 hydrographic survey produced detailed bathymetric data for Lake Whatcom, and these data should be used to replace the older, less accurate 1972 morphometry values. However, the 1999 BOR soundings were measured in feet, and the derived bathymetric maps and volume capacities were calculated using English units (feet, acre-feet) rather than metric units. For scientific research, metric units are required. In addition, while the BOR study was extremely detailed, it focused on describing lake surface area and capacity (volume), and did not subdivide the lake by basins. As a result, many of the useful morphological measurements that were published by Lighthart, et al. have not yet been generated from the 1999 BOR data.

We are currently working with Mr. Gerry Gabrisch, who has created an updated, metric bathymetric model from the 1999 BOR depth soundings and shoreline contours (Figure 28, page 78). A detailed report should be available by June 2007 that describes the updated bathymetric model and provides morphometric data for the lake as a whole and for each major basin.

[16] Although 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.

	2005–2006	2004–2005	2003–2004	2002–2003	2001–2002
Inputs (MG)					
Direct Precipitation	6,783 (17.9%)	6,501 (16.2%)	7,612 (18.6%)	4,859 (19.5%)	7,078 (14.5%)
Diversion	4,155 (11.0%)	3,852 (9.6%)	5,095 (12.4%)	4,442 (17.8%)	4,693 (9.6%)
Runoff*	26,879 (71.1%)	29,673 (74.1%)	28,288 (69.0%)	15,589 (62.6%)	36,920(75.8%)
Total	37,817 (100%)	40,026 (100%)	40,955 (100%)	24,890 (100%)	48,691(100%)
Outputs (MG)					
Whatcom Creek	28,290 (74.8%)	30,899 (74.0%)	26,948 (71.2%)	13,361 (53.5%)	38,223 (77.5%)
Hatchery	1,253 (3.3%)	1,288 (3.1%)	1,278 (3.4%)	1,124 (4.5%)	901 (1.8%)
Georgia Pacific	960 (2.5%)	2,198 (5.3%)	2,053 (5.4%)	2,988 (12.0%)	3,046 (6.2%)
City of Bellingham	4,111 (10.9%)	4,111 (9.8%)	4,449 (11.8%)	4,342 (17.4%)	4,234 (8.6%)
LW Water/Sewer Distr.	242 (0.6%)	252 (0.6%)	204 (0.5%)	136 (0.6%)	126 (0.3%)
Evaporation	2,946 (7.8%)	2,990 (7.2%)	2,924 (7.7%)	3,016 (12.1%)	2,812 (5.7%)
Total	37,802 (100%)	41,738 (100%)	37,855 (100%)	24,971 (100%)	49,341 (100%)
Net change in storage	15	-1,692	3,139	-81	-651
Median lake volume (MG)	252,287	252,856	252,970	252,075	252,368
Outflow percent of volume	15.0%	16.5%	15.0%	9.9%	19.6%
Residence time (years)**	6.7	6.1	6.7	10.1	5.1

*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 26: Annual water balance quantities for the Lake Whatcom watershed, WY2002–WY2006.

Month	Input Percents Diver	Precip	Runoff*	Total
Oct	8.72	12.85	3.63	5.84
Nov	14.56	13.04	12.91	13.12
Dec	9.92	10.72	11.61	11.26
Jan	2.57	24.19	34.94	29.45
Feb	0.00	10.08	17.06	13.93
Mar	0.00	4.02	5.94	4.95
Apr	9.88	7.79	7.25	7.63
May	22.58	6.37	3.38	6.03
Jun	26.36	3.73	3.37	5.96
Jul	5.43	1.54	0.63	1.32
Aug	0.00	2.35	-0.33	0.19
Sep	0.00	3.33	-0.39	0.32
	Input Volume (MG)			
Total	4,155	6,783	26,879	37,817

*Runoff = surface runoff + groundwater

Table 27: Monthly input water balance quantities for the Lake Whatcom watershed, October 2005–September 2006.

Month	Output Percents						Total
	WC	Hatch	GP	COB	WSD	Evap	
Oct	10.39	7.71	11.54	7.50	6.95	4.52	9.54
Nov	16.13	6.77	11.12	7.11	7.25	1.47	13.51
Dec	8.73	8.12	12.73	6.86	7.95	1.02	8.01
Jan	33.53	8.73	12.30	6.92	8.80	2.15	26.67
Feb	21.94	7.72	9.51	6.21	7.11	3.28	17.89
Mar	2.32	8.68	5.14	6.93	7.64	6.27	3.44
Apr	1.66	7.71	7.54	6.80	7.22	13.25	3.51
May	0.65	7.42	3.20	8.16	8.23	11.27	2.63
Jun	3.18	7.46	2.68	9.03	8.48	13.70	4.80
Jul	0.57	9.79	7.40	13.33	11.28	17.96	3.86
Aug	0.57	10.36	7.74	12.44	10.64	15.38	3.58
Sep	0.33	9.53	9.09	8.71	8.46	9.72	2.55
	Output Volume (MG)						
Total	28,290	1,253	960	4,111	242	2,946	37,802

Table 28: Monthly output water balance quantities for the Lake Whatcom watershed, October 2005–September 2006.

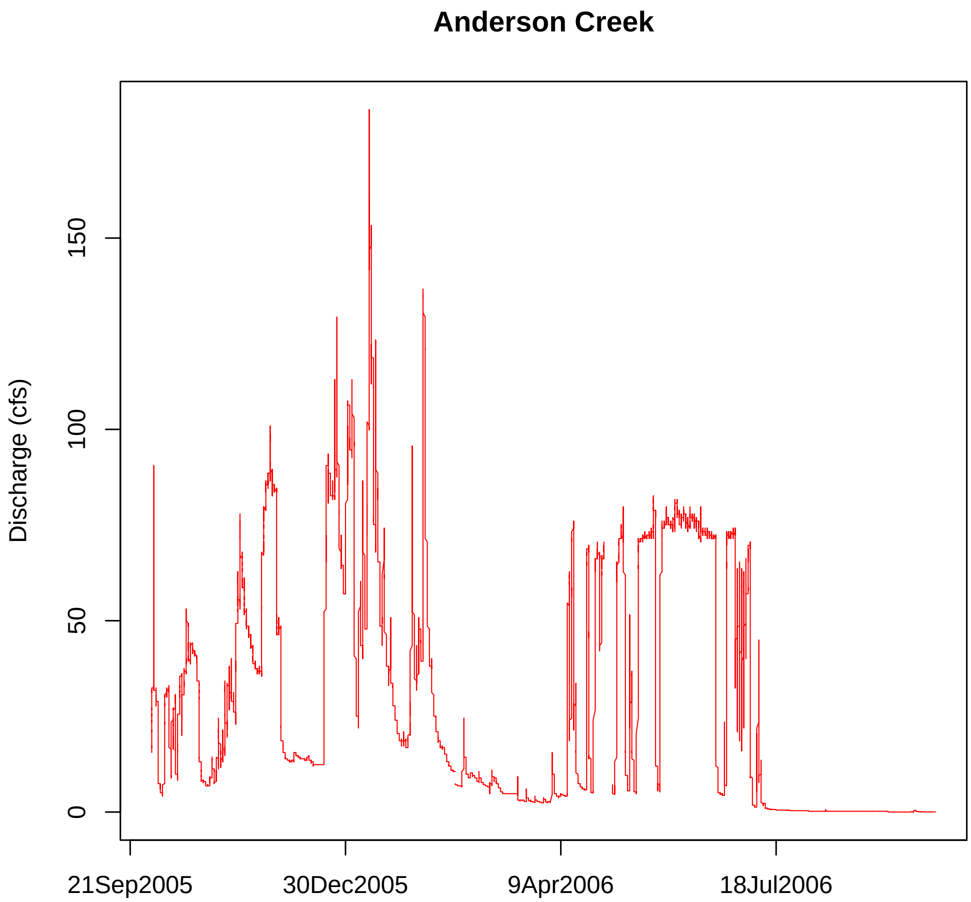


Figure 14: Anderson Creek hydrograph, October 1, 2005–September 30, 2006. Data were recorded at 15 minute intervals.

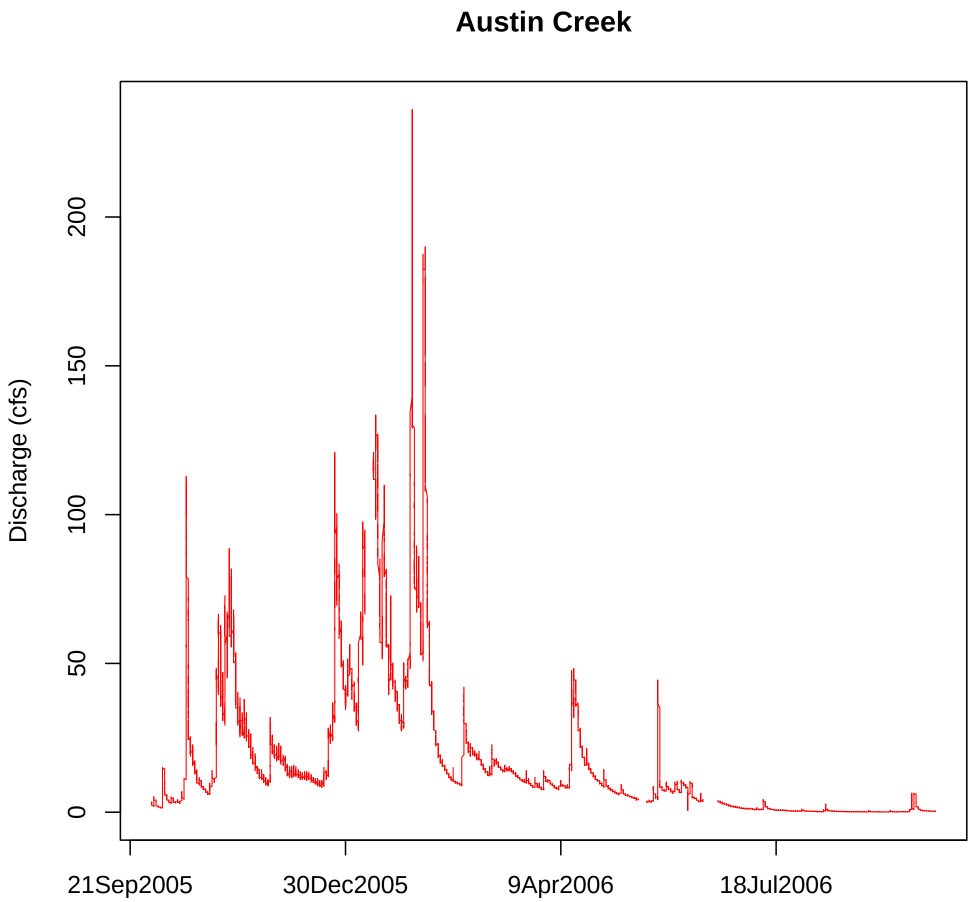


Figure 15: Austin Creek hydrograph, October 1, 2005–September 30, 2006. Data were recorded at 15 minute intervals.

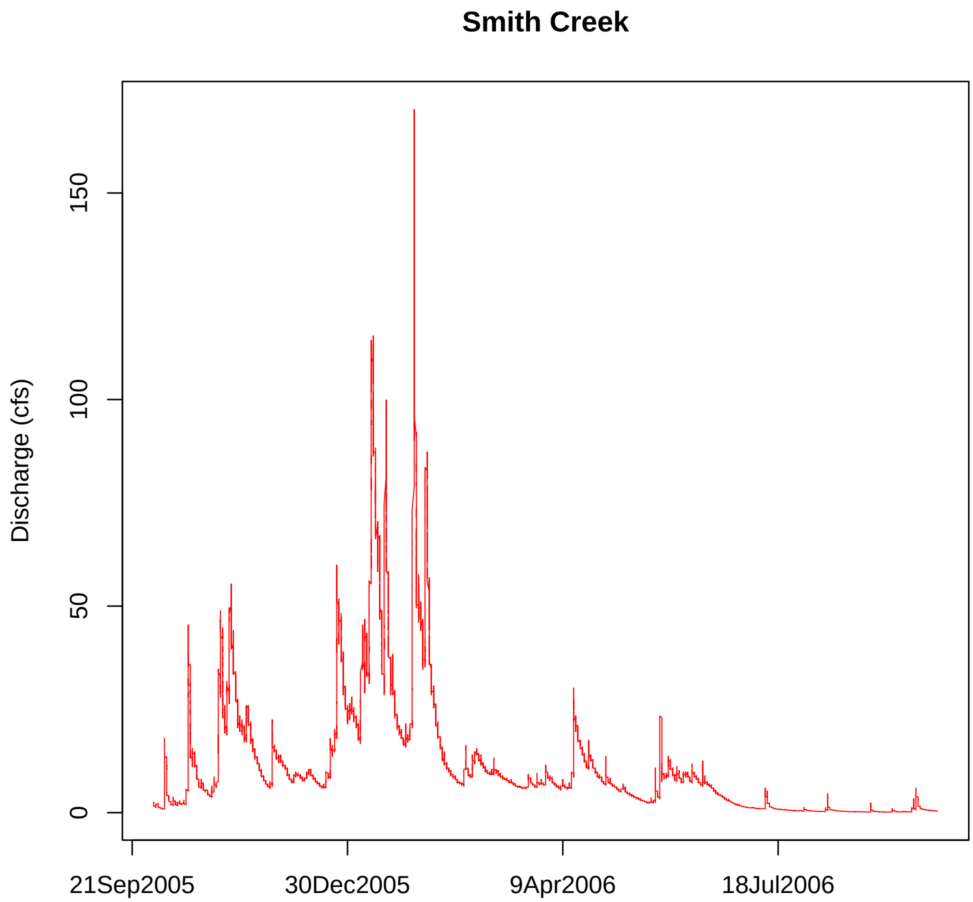


Figure 16: Smith Creek hydrograph, October 1, 2005–September 30, 2006. Data were recorded at 15 minute intervals.

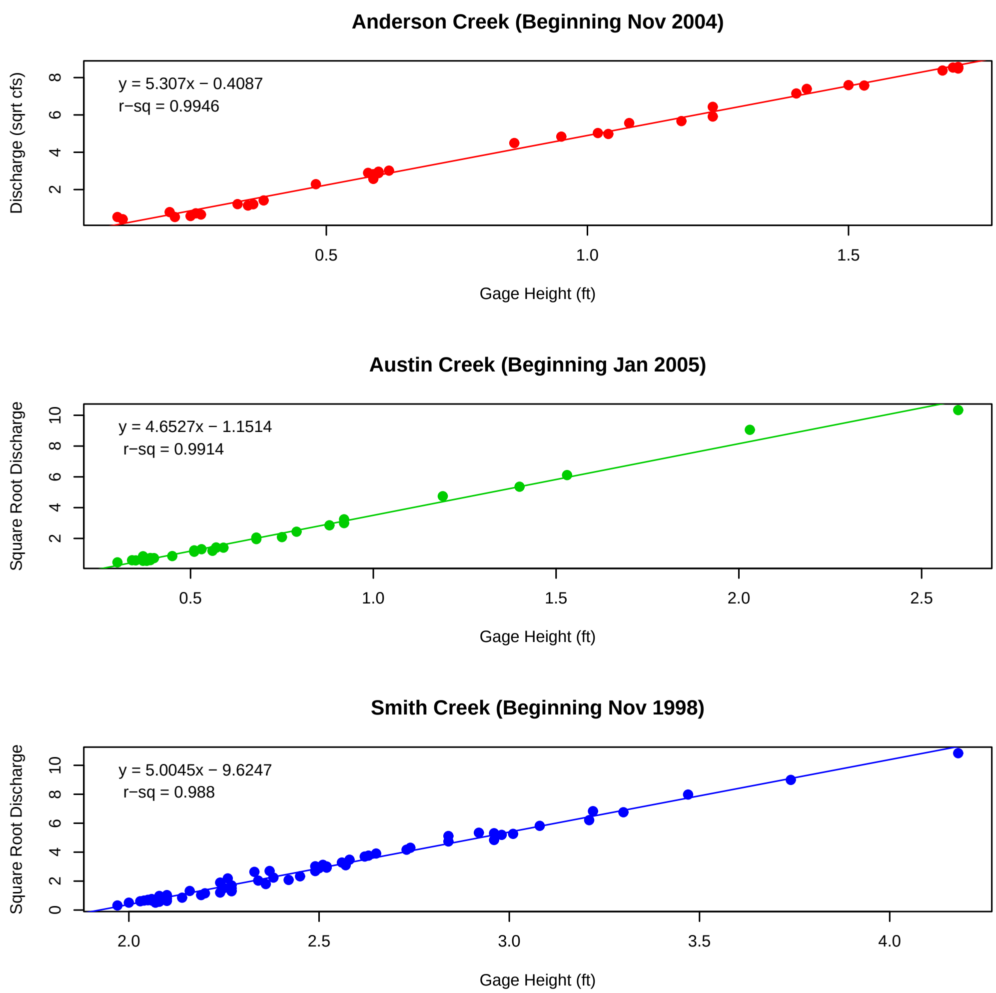


Figure 17: Anderson Creek, Austin Creek, and Smith Creek rating curves. Regressions show the relationship between gauge height (x) and square root transformed discharge (y), beginning from the date listed on each figure. For earlier rating curves, contact the Institute for Watershed Studies.

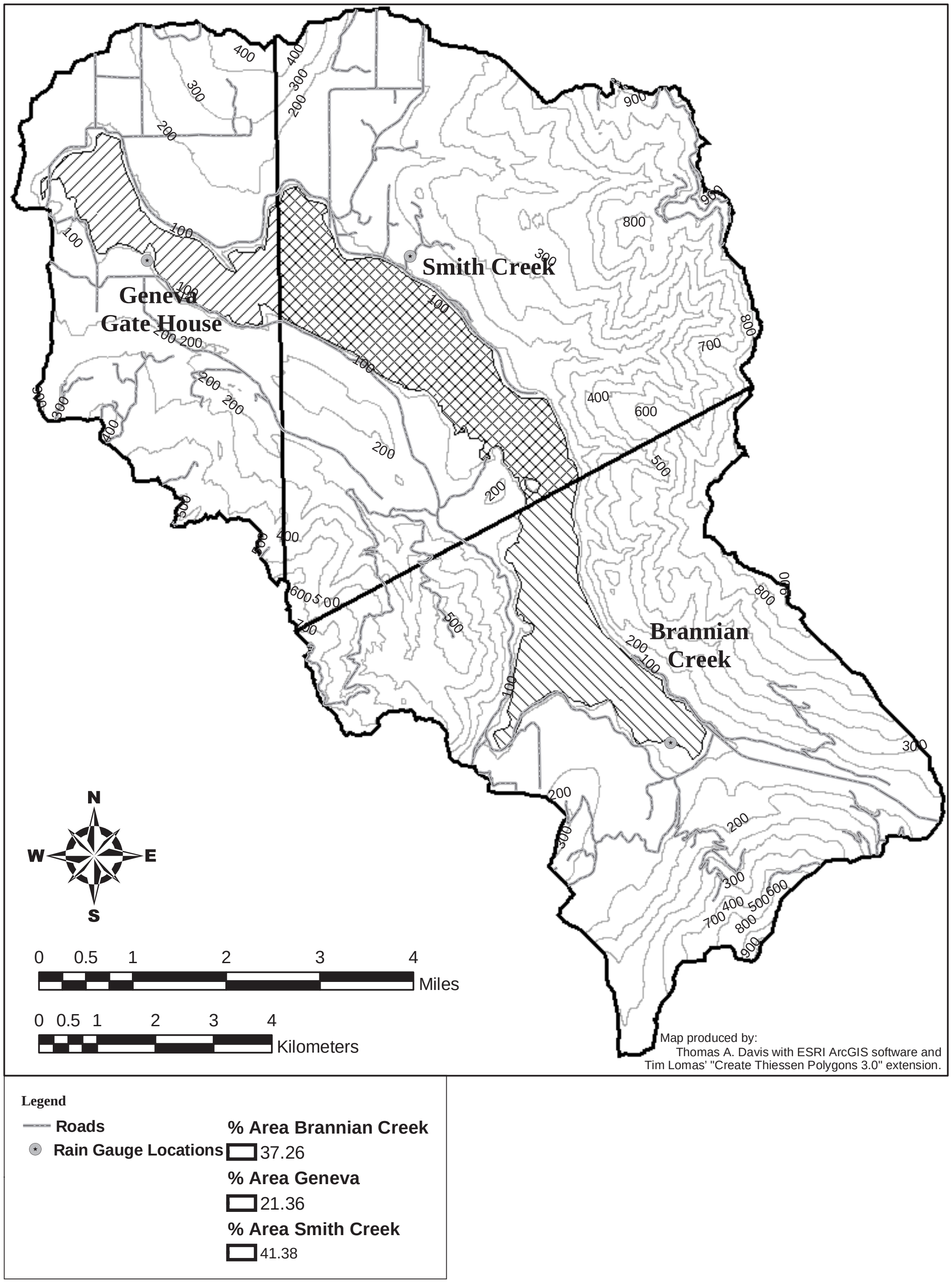


Figure 18: Lake Whatcom watershed precipitation groups and weighted areas.

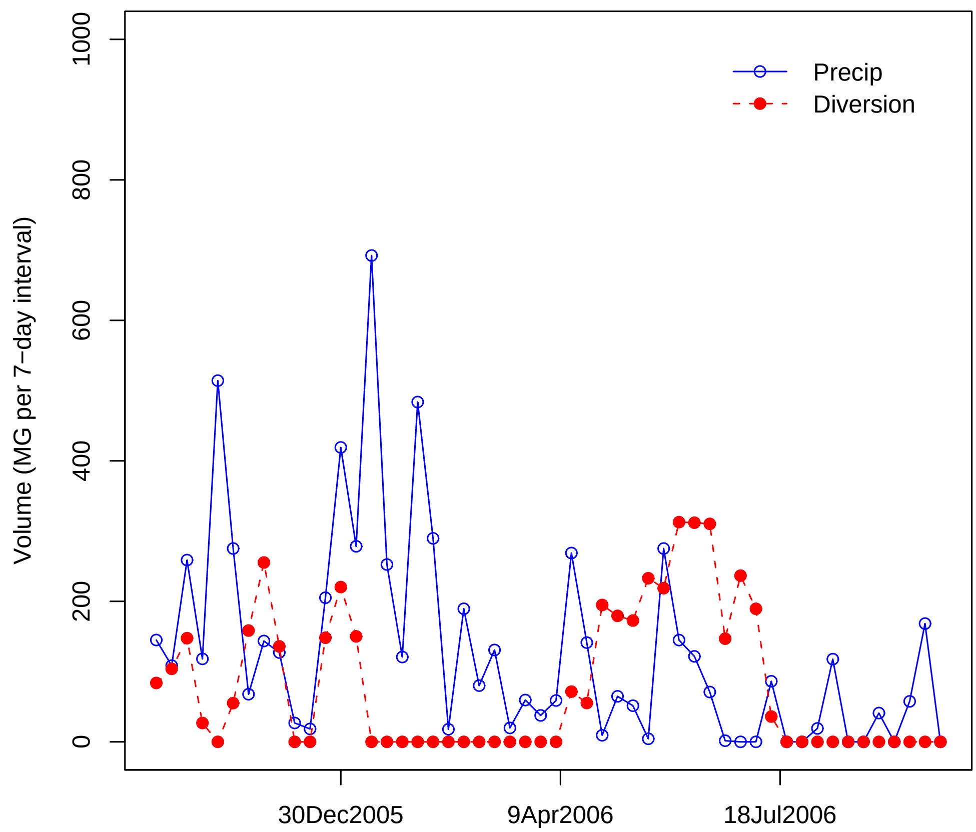


Figure 19: Lake Whatcom watershed direct hydrologic inputs, October 1, 2005–September 30, 2006.

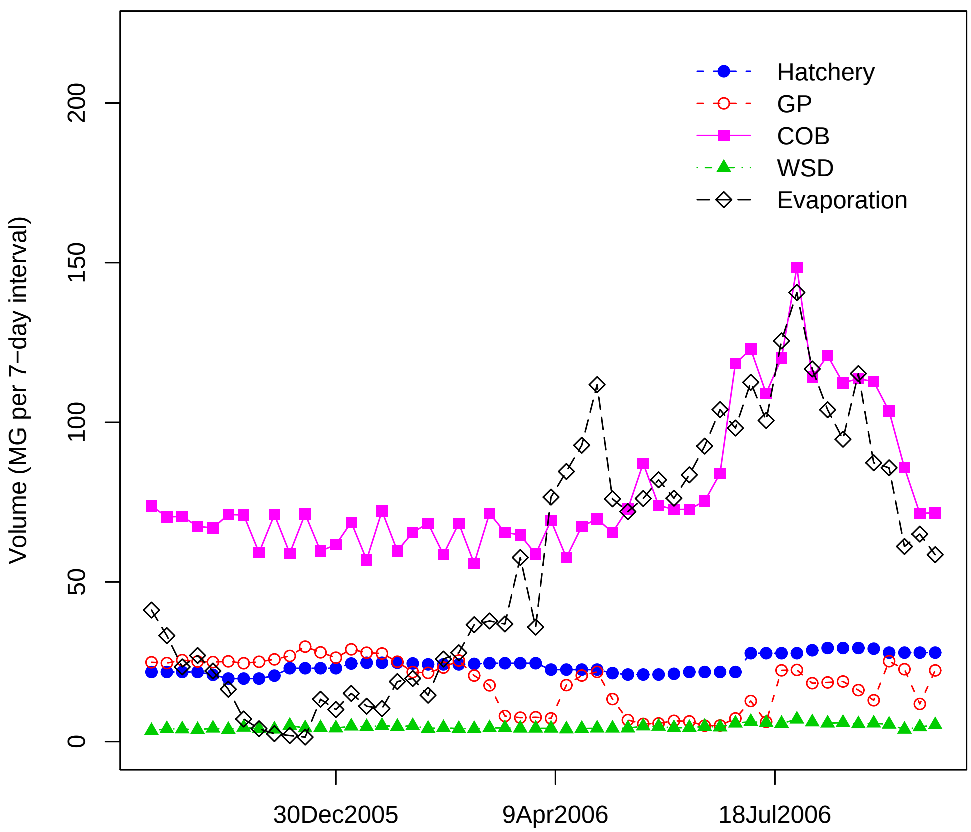


Figure 20: Lake Whatcom watershed hydrologic withdrawals, October 1, 2005–September 30, 2006.

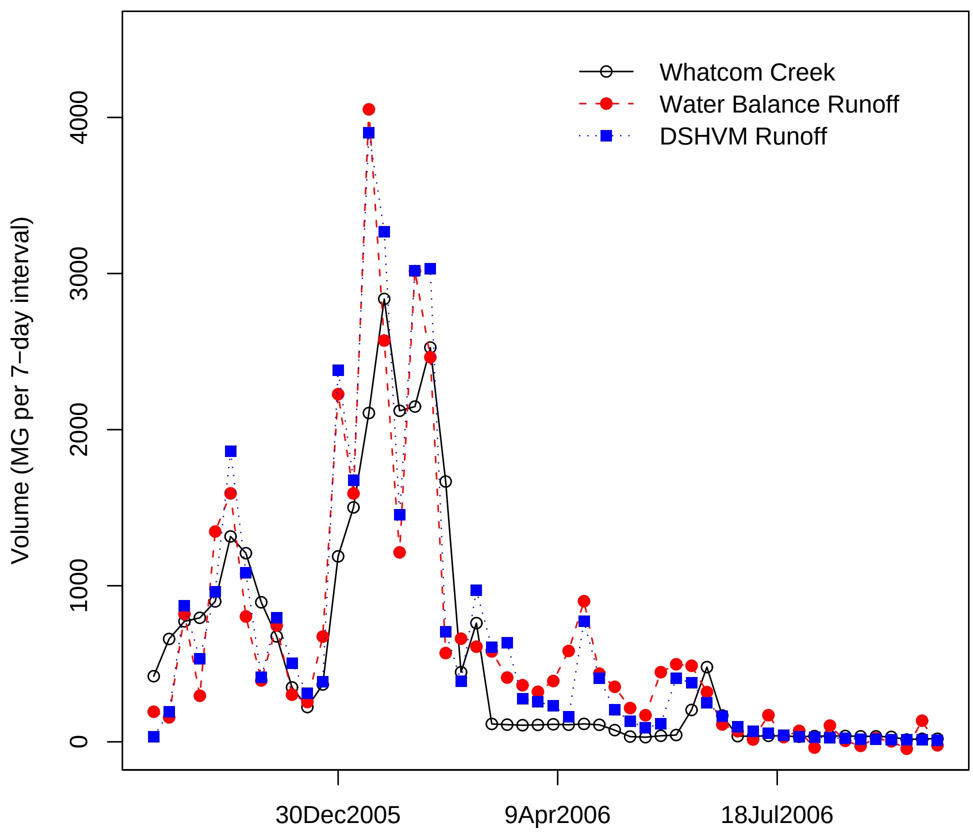


Figure 21: Summary of 7-day Whatcom Creek flows, water balance runoff estimates, and DHSVM runoff estimates, October 1, 2005–September 30, 2006.

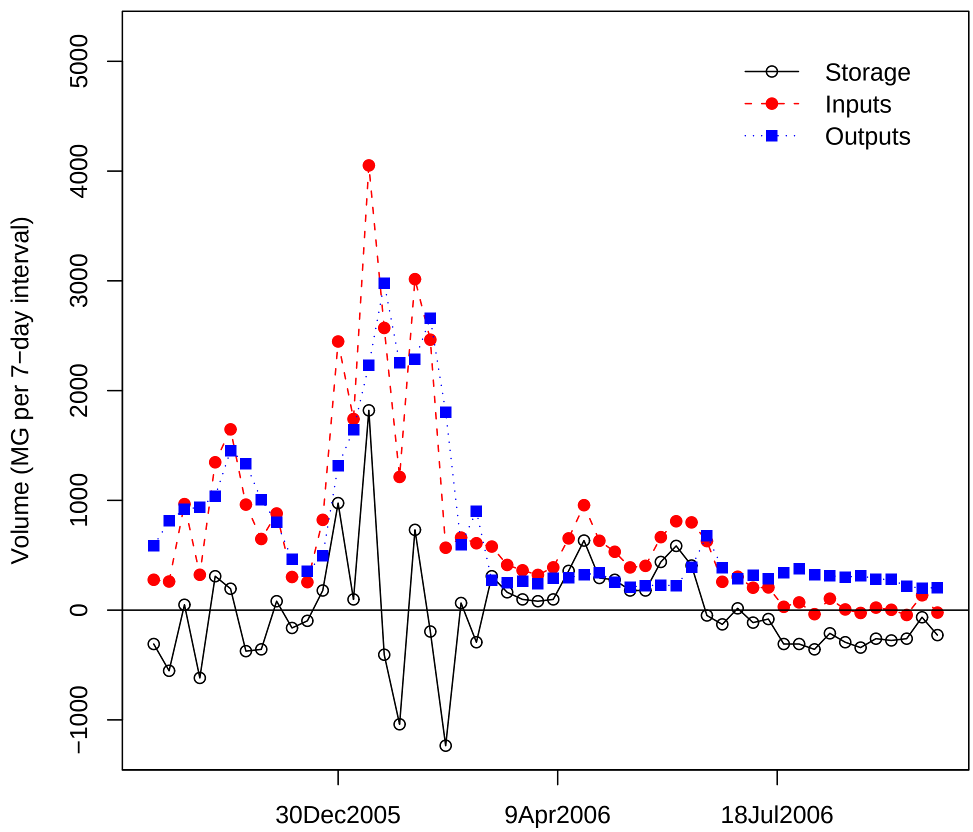


Figure 22: Summary of 7-day inputs, outputs, and changes in Lake Whatcom storage, October 1, 2005–September 30, 2006.

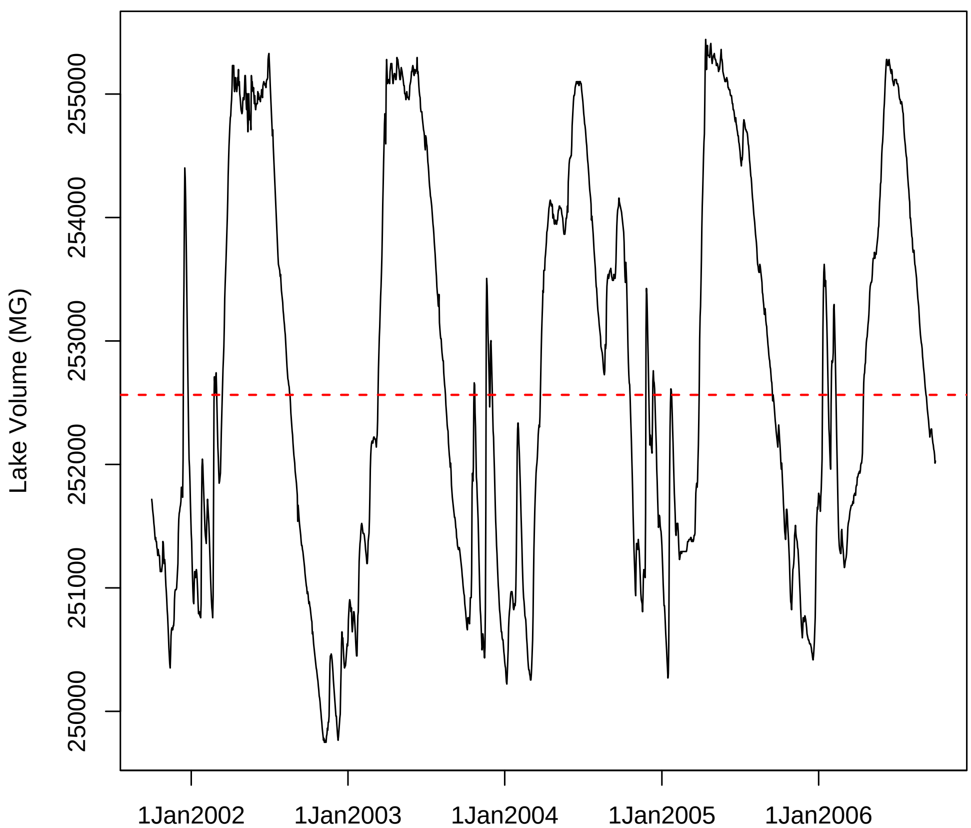


Figure 23: Comparison of Lake Whatcom daily lake volumes for 2000–2006. Horizontal line represents median lake volume for the period plotted.

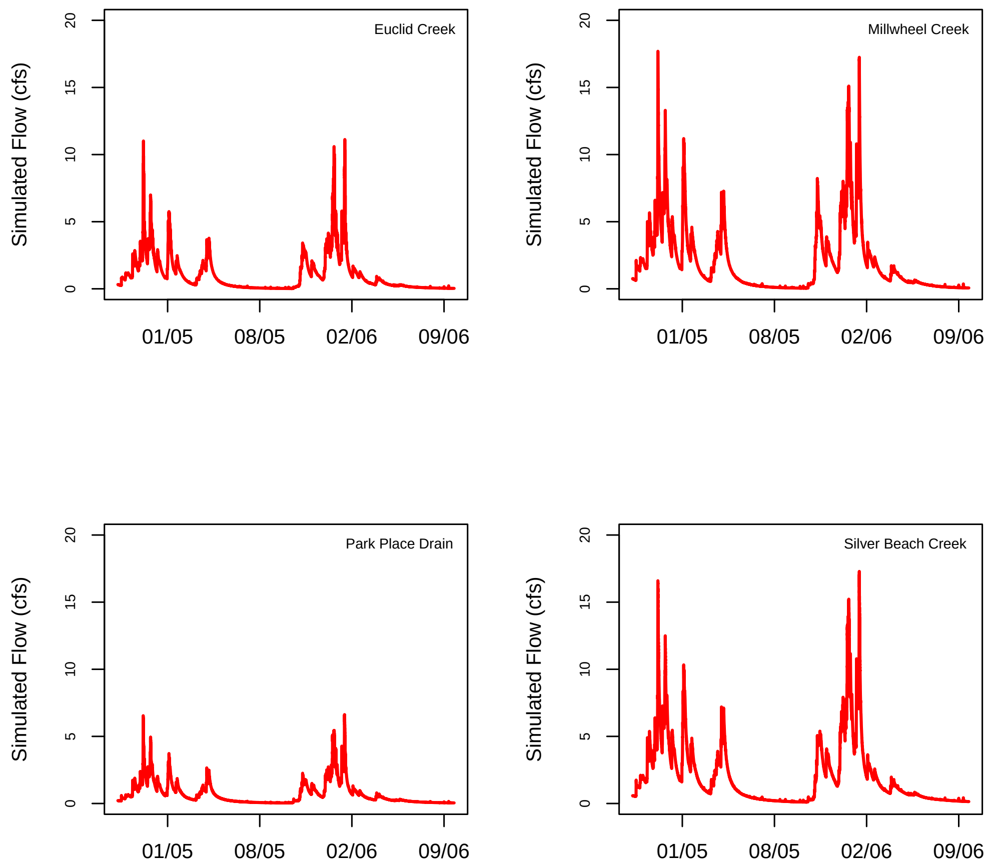


Figure 24: Simulated creek flows for Euclid, Millwheel, Park Place, and Silver Beach Creeks, October 1, 2005–September 30, 2006. These small Lake Whatcom tributaries have simulated discharge rates of $<$20 cfs.

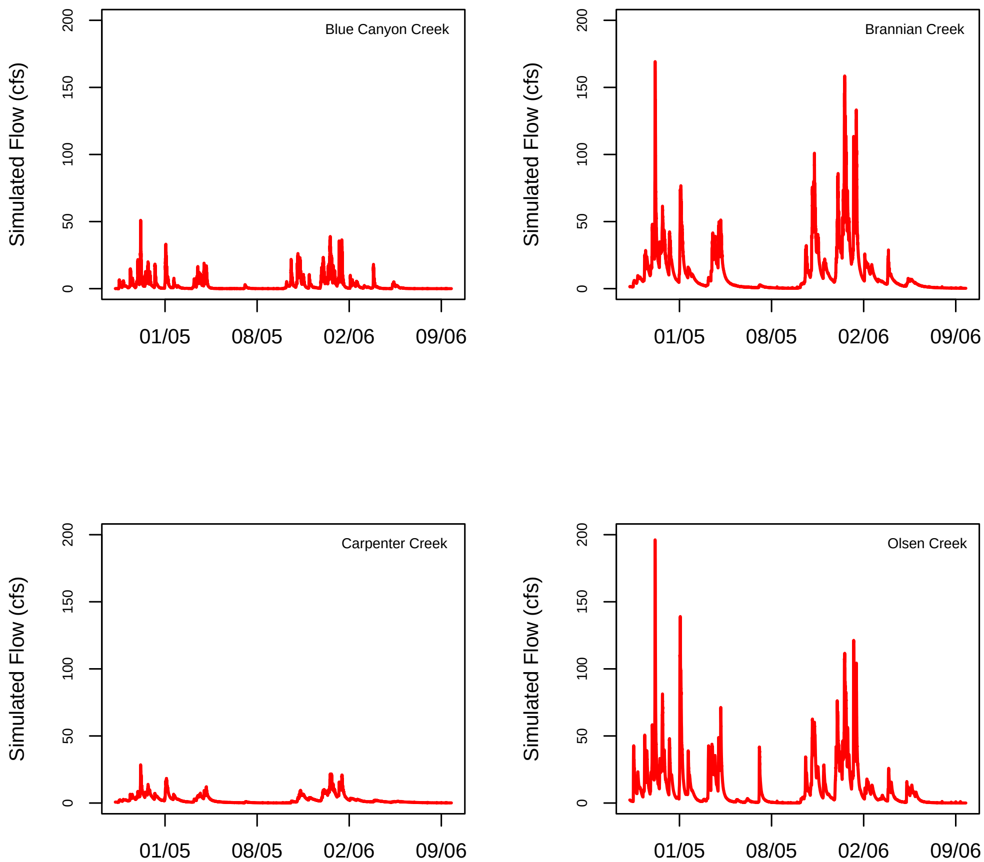


Figure 25: Simulated creek flows for Blue Canyon, Brannian, Carpenter, and Olsen Creeks, October 1, 2005–September 30, 2006. These mid-sized Lake Whatcom tributaries have simulated discharge rates of <200 cfs.

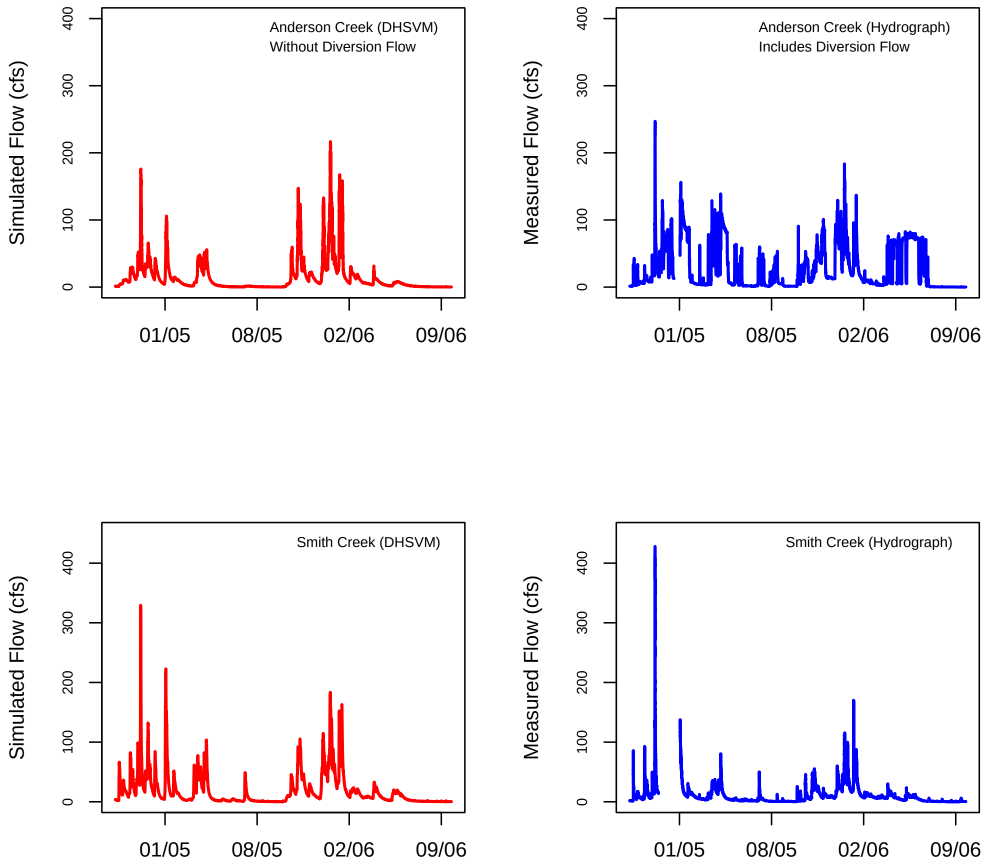


Figure 26: Simulated and gaged creek flows for Anderson and Smith Creeks, October 1, 2005–September 30, 2006. These large Lake Whatcom tributaries have flows that can exceed 200 cfs and have recording gages that collect flow data at 15 min. intervals. The simulated Anderson Creek flows (upper left) do not include diversion flow; the figure showing gaged flows (upper right) illustrates the influence of the diversion.

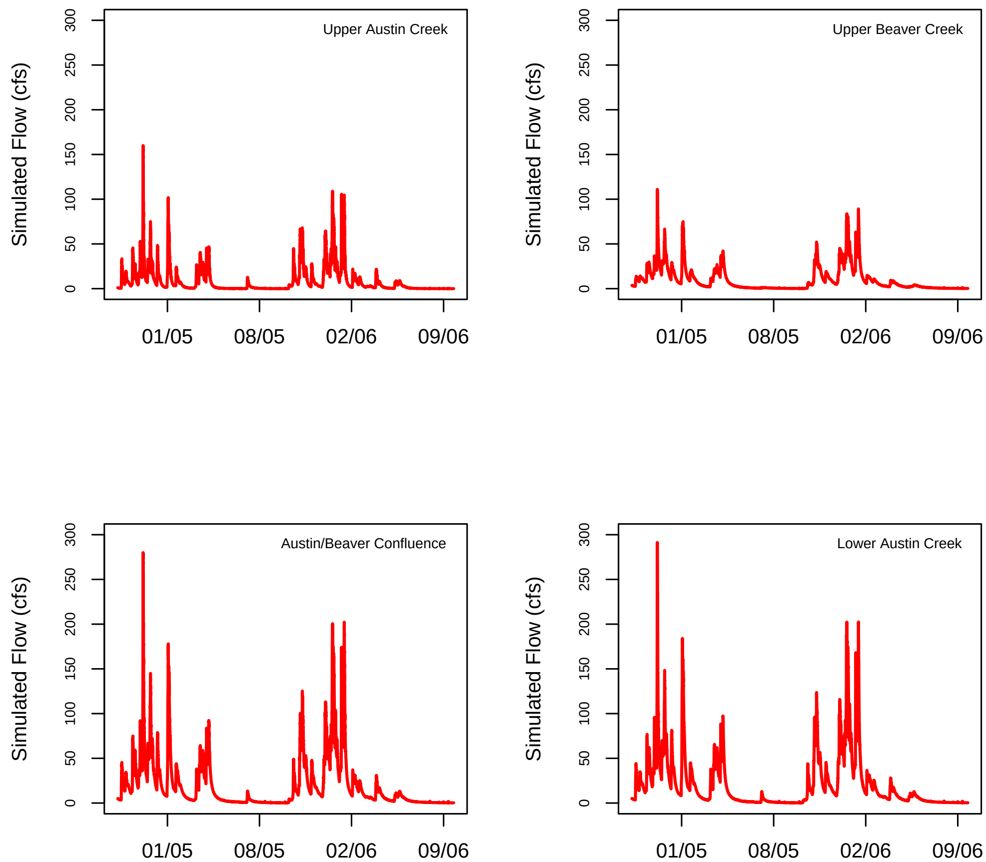


Figure 27: Simulated creek flows for Austin and Beaver Creeks, October 1, 2005–September 30, 2006. Lower Austin Creek represents the combined flows from upper Austin Creek and all of Beaver Creek.

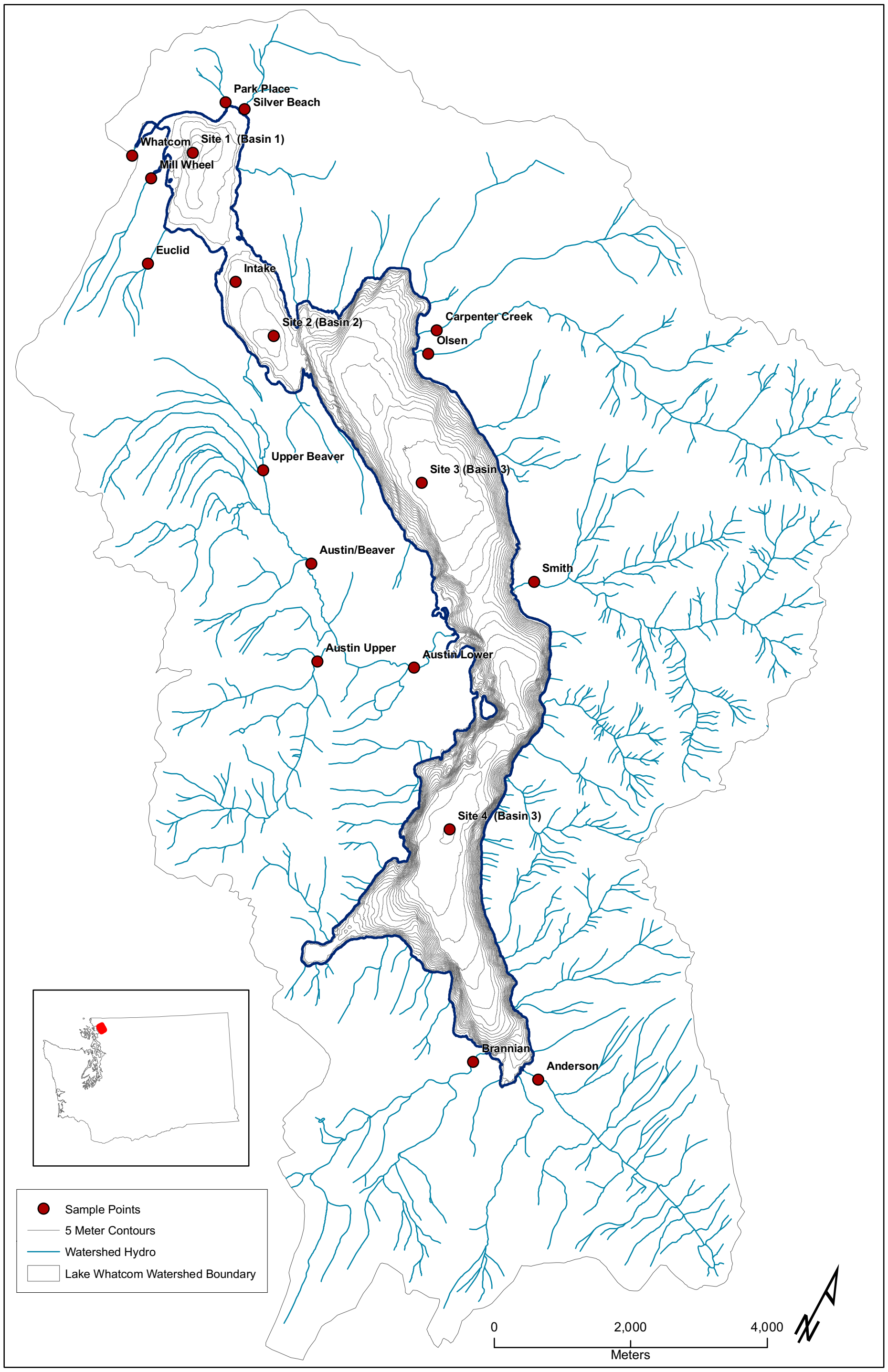


Figure 28: Updated Lake Whatcom bathymetry map created by G. Gabrisch from data collected by the U. S. Bureau of Reclamation and made available by the City of Bellingham.

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 2005/2006 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.[17] The locations of all current and previous monitoring sites are described in Appendix A, beginning on page 100, and illustrated in Figures A4 and A5 (pages 107 and 108). Photographs of the monitoring sites are included in Figures A6–A10 (pages 109–113).

5.1 Sampling Procedures

Due to construction activities, weather conditions, and low flows, Park Place and South Campus were only sampled twice, while the Alabama Hill vault was sampled three times. Park Place was sampled on February 27–March 1[18] and May 22–24, 2006. The South Campus storm water treatment facility was sampled on November 9–10, 2005 and April 17–19, 2006. The Alabama vault was sampled on February 28, April 29, and November 1–2, 2006.

Where possible, composite samples were collected at inflow and outflow points using ISCO samplers (provided by the City of Bellingham) that collect water samples 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 carbon, total nitrogen, and total phosphorus. Multiple grab samples were collected during the sampling period at the inflow(s) and outflow(s) at each site to measure bacteria (fecal coliforms and *E. coli*), conductivity, dissolved oxygen, pH, and temperature, which are parameters that can't be measured from composite samples. Bacteria samples were analyzed by the City of Bellingham; conductivity, dissolved oxygen, pH, and temperature were measured in the field using the Hydrolab.

[17] The 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.

[18] Composite sampling started during the afternoon of February 27; grab sampling started the following morning on February 28.

Due to flow and design constraints, 48-hr composite sampling is rarely possible in the Alabama Hill vault. In order to obtain data from this site, multiple grab samples were collected over 24–48 hrs to measure total solids, total suspended solids, total nitrogen, and total phosphorus in addition to the parameters normally collected from grab samples. Although composite sampling is preferred, previous data from this site and the Park Place wet ponds suggest that grab samples may provide reasonably similar results compared to composite samples (see discussion on page 81).

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).

Tables 29–32 (pages 84–87) show the raw data and percent analyte reduction from the storm water treatment systems that were monitored in 2005/2006. Percent reduction was calculated as follows, based on the approach described by Winer (2000) for *Event Mean Concentration Efficiency*:

$$\begin{aligned}
\text{Reduction}(\%) &= \frac{\overline{x}_{\text{inlet}} - \overline{x}_{\text{outlet}}}{\overline{x}_{\text{inlet}}} \times 100 \\
\text{where :} & \\
\overline{x}_{\text{inlet}} &= \text{inlet avg. conc.} \\
\overline{x}_{\text{outlet}} &= \text{outlet avg. conc.}
\end{aligned}$$

Although we use percent reduction to describe changes that occur as water passes through the storm water treatment sites, it is important to note that changes in measurements such as temperature, pH, dissolved oxygen, and conductivity, are not necessarily indicative of pollutant removal. Temperature, for example, decreased at the Park Place outlet during the February sampling event and increased during May. This reflects the slower movement of water through the wet pond and sand filters, which allowed time for runoff to warm or cool, depending on air temperature. At the same site, the dissolved oxygen was lower at the outlet, most likely due to microbial oxygen consumption coupled with slower flow rates and less water turbulence, which limited reoxygenation of the runoff.

Two of the most important storm water measurements, relative to lake eutrophication, are total suspended solids and total phosphorus reductions. As discussed on page 8, phosphorus is likely to limit algal growth in Lake Whatcom, and phosphorus often enters lakes physically or chemically bound to the surface of particles. From Tables 29–31 we see that all three sites removed suspended solids, with percent reductions ranging from 43.1% (Alabama vault, November 1–2, 2006) to 91.6% (South Campus, April 17–19, 2006). Only the South Campus site had significant reductions for total phosphorus (61.5–68.2%). The other sites either exported phosphorus, with higher concentrations at the outlet compared to the inlet, or showed minimal reductions that would not be statistically different from zero (the Alabama vault had an 8.7% phosphorus reduction on April 29, 2006).

The 2005/2006 results for total suspended solids and total phosphorus reductions were consistent with historic patterns at each site (Figures 29–30, pages 91–92), with the possible exception of Park Place (see discussion on page 82). Statistical analysis of the historic data revealed that none of the sites within the watershed provided significant phosphorus reductions, and only the Alabama Hill vault provided significant total suspended solids reductions (Table 33).[19]

Since phosphorus is known to move with particulates, it might seem contradictory to have solids reduction but not phosphorus reduction. However, not all suspended solids are equally attractive to phosphorus. Phosphorus tends to bind to small, charged particles (e.g., clay), which are slow to settle. Larger particles settle quickly, and are thus easily removed by a variety of storm water treatment systems, but may not carry much of the total phosphorus load in storm runoff.[20] This phosphorus transport feature might explain the weak relationship between total suspended solids and total phosphorus concentrations that is present in storm runoff samples from the watershed (Figure 31, page 93).

[19]Statistical significance was based on a one sample t-test to determine whether the mean percent reduction was significantly different than zero ($H_o : \overline{x} = 0$).

[20]Western Washington University graduate student Scott Groce is currently working on a research project to assess the relationship between soil characteristics and phosphorus in the Lake Whatcom watershed.

Alabama Hill vault: The Alabama Hill vault is an underground canister system that can be filled with special materials designed to remove specific pollutants from surface runoff (Figure A6, page 109). Due to flow and design constraints, composite sampling is only feasible when there has been a sustained period of heavy precipitation that does not also result in back-flow contamination of the outflow by untreated surface runoff. Because of these sampling concerns, we were only able to collect multiple grab samples during 2005/2006.

In November 2004, heavy precipitation created the right conditions for collecting a 24-hr composite sample.[21] During the same time period we collected multiple grab samples to assess the similarities and differences between the composite and grab sample results for removal to total suspended solids and total phosphorus. We were not able to collect composite samples from the vault in 2005/2006, so we collected concurrent grab and composite samples from the Park Place wet pond.

In the Alabama Hill vault, the total phosphorus reductions were virtually identical for the composite and grab samples (Table 34, page 89). The total suspended solids reductions were not as close, but both indicated that there was minimal, if any, removal of suspended solids. The paired composite and grab sample reductions from Park Place were also very close (Table 35, page 90). Both types of samples confirmed large reductions in total suspended solids (75.8–88.0%) but no removal of total phosphorus (TP *export* of 5.5–22.1%). These results suggests that the multiple grab samples, although not ideal, may provide a good approximation of solids and phosphorus removal when composite sampling is not possible.

Park Place retrofit: Both of our 2006 sampling dates followed an extensive redesign of the Park Place system that involved filling two of the three wet ponds with sand (Figures A8 and A9 show photographs from before and after the retrofit. Previously, storm runoff entered the system and flowed sequentially through three wet ponds before being discharged at the outlet. Due to severe constraints on available land, the ponds were small relative to the amount of water flowing into the system. As a result, storm water often received minimal treatment prior to discharge. Following the retrofit, water now flows into the first pond, then is split and directed into two sand-filled cells before discharging.

[21] Flow through the vault was not sufficient to collect a 48-hr composite sample.

After only two sampling events, it is too early to determine the effectiveness of the retrofit, but the preliminary results for total suspended solids are encouraging. Prior to the retrofit, there was no consistent reduction of suspended solids, (Figure 29), and the mean percent removal was not significantly different from zero (Table 33). After the retrofit, the composite samples showed consistent total suspended solids removals of >80% (Table 29). In addition to the 48-hr composite samples, we collected multiple grab samples during both the February and May sampling event. These also showed excellent total suspended solids removal of 75.8–88.0% (Table 35

Unfortunately, the retrofit did not appear to improve total phosphorus reductions, and the 2006 results were similar to those from before the retrofit (Figure 30 and Table 35).

Site	Date	TSS (mg/L)	TS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
Park Place inlet	Feb 27–Mar 1, 2006	6.5	115.0	4.7	0.910	0.057
Park Place outlet	Feb 27–Mar 1, 2006	1.2	112.1	4.2	0.837	0.062
	Percent reduction:	80.9	2.5	10.6	8.0	-8.8
Park Place inlet	May 22–24, 2006	14.6	NA	6.7	0.702	0.086
Park Place outlet	May 22–24, 2006	2.8	NA	6.4	0.650	0.105
	Percent reduction:	81.0	NA	4.5	7.4	-22.1
S. Campus inlet	Nov 9–11, 2005	32.7	236.1	8.3	1.247	0.078
S. Campus outletE	Nov 9–11, 2005	9.5	197.7	8.1	0.956	0.035
S. Campus outletW	Nov 9–11, 2005	2.2	190.1	9.6	0.649	0.025
	Percent reduction:	82.1	17.9	-6.6	35.6	61.5
S. Campus inlet	Apr 17–19, 2006	6.6	237.6	3.6	1.053	0.055
S. Campus outletE	Apr 17–19, 2006	1.0	230.6	2.3	0.683	0.020
S. Campus outletW	Apr 17–19, 2006	0.1	201.7	NA	0.411	0.015
	Percent reduction:	91.6	9.0	36.1	48.1	68.2

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)
Park Place inlet	Feb 27–Mar 1, 2006	<0.01	<0.0005	0.007	0.005	0.508	<0.0002	<0.005	0.001	0.013
Park Place outlet	Feb 27–Mar 1, 2006	<0.01	<0.0005	0.001*	0.009	0.209	<0.0002	<0.005	0.001*	0.008
	Percent reduction:	NA	NA	85.7	-80.0	58.9	NA	NA	0.0	38.5
Park Place inlet	May 22–24, 2006	<0.01	<0.0005	0.006	0.014	1.100	0.0002	<0.005	0.002	0.019
Park Place outlet	May 22–24, 2006	<0.01	<0.0005	0.004	0.014	0.273	0.0002*	<0.005	0.002	0.035
	Percent reduction:	NA	NA	33.3	0.0	75.2	0.0	NA	0.0	-84.2
S. Campus inlet	Nov 9–11, 2005	<0.01	<0.0005	0.001*	0.007	2.200	<0.0002	<0.005	<0.001	0.024
S. Campus outletE	Nov 9–11, 2005	<0.01	<0.0005	0.005	0.008	0.550	<0.0002	<0.005	<0.001	0.016
S. Campus outletW	Nov 9–11, 2005	<0.01	<0.0005	0.004	0.007	0.140	<0.0002	<0.005	<0.001	0.012
	Percent reduction:	NA	NA	-350.0	-7.1	84.3	NA	NA	NA	41.7
S. Campus inlet	Apr 17–19, 2006	<0.01	<0.0005	0.001*	0.008	1.900	<0.0002	<0.005	<0.001	0.010
S. Campus outletE	Apr 17–19, 2006	<0.01	<0.0005	0.006	0.005	0.140	<0.0002	<0.005	0.001	0.010
S. Campus outletW	Apr 17–19, 2006	<0.01	<0.0005	0.004	0.003	0.032	<0.0002	<0.005	<0.001	0.008
	Percent reduction:	NA	NA	-400.0	50.0	95.5	NA	NA	NA	10.0

*Value replaced with detection limit to calculate percent reduction.

Table 29: Park Place wet pond and South Campus rock/plant filter composite samples and average percent reductions between inlet and outlet samples. Negative values represent an increase in concentration at the outlet.

Site	Date (Time)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	FC (cfu/100 mL)	E. coli (cfu/100 mL)
Inlet	Feb 28, 2006 (A)	6.0	7.65	11.40	158.1	100	65
Outlet	Feb 28, 2006 (A)	6.2	7.30	10.55	146.4	35	42
	Percent reduction:	-3.3	4.6	7.5	7.4	65.0	35.4
Inlet	Apr 29, 2006 (A)	12.0	7.36	9.44	48.0	NA	NA
Inlet	Apr 29, 2006 (B)	12.0	7.39	9.18	68.3	NA	NA
Inlet	Apr 29, 2006 (C)	12.1	7.49	9.26	99.4	NA	NA
Outlet	Apr 29, 2006 (A)	12.0	7.45	8.68	49.4	NA	NA
Outlet	Apr 29, 2006 (B)	12.0	7.40	8.29	67.8	NA	NA
Outlet	Apr 29, 2006 (C)	12.0	7.46	7.80	85.1	NA	NA
	Percent reduction:	0.3	-0.3	11.2	6.2	NA	NA
Inlet	Nov 1–2, 2006 (A)	11.0	7.24	NA	134.0	1200	720
Inlet	Nov 1–2, 2006 (B)	11.6	7.29	9.64	204.0	1000	720
Inlet	Nov 1–2, 2006 (C)	11.5	7.49	9.28	254.0	530	400
Outlet	Nov 1–2, 2006 (A)	10.9	7.40	NA	135.0	620	960
Outlet	Nov 1–2, 2006 (B)	11.5	7.41	9.62	203.0	530	1000
Outlet	Nov 1–2, 2006 (C)	11.5	7.51	8.53	261.0	110	210
	Percent reduction:	0.6	-1.4	4.1	-1.2	53.8	-17.9

Site	Date	TSS (mg/L)	TS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
inlet	Feb 28, 2006 (A)†	6.4	NA	5.4	1.386	0.097
outlet	Feb 28, 2006 (A)†	2.0	NA	4.4	1.522	0.107
	Percent reduction:	68.7	NA	18.5	-9.8	-10.3
inlet	Apr 29, 2006 (A)	40.3	NA	NA	1.289	0.242
inlet	Apr 29, 2006 (B)	24.6	NA	NA	1.532	0.243
inlet	Apr 29, 2006 (C)	18.9	NA	NA	1.887	0.278
outlet	Apr 29, 2006 (A)	21.9	NA	NA	1.172	0.201
outlet	Apr 29, 2006 (B)	8.6	NA	NA	1.427	0.202
outlet	Apr 29, 2006 (C)	5.3	NA	NA	1.569	0.294
	Percent reduction:	57.2	NA	NA	9.1	8.7
Inlet	Nov 1–2, 2006 (A)	10.2	101.8	NA	2.409	0.147
Inlet	Nov 1–2, 2006 (B)	4.2	148.1	NA	4.503	0.147
Inlet	Nov 1–2, 2006 (C)	2.6	175.6	NA	4.486	0.109
Outlet	Nov 1–2, 2006 (A)	6.4	100.4	NA	2.355	0.178
Outlet	Nov 1–2, 2006 (B)	3.1	144.3	NA	4.381	0.176
Outlet	Nov 1–2, 2006 (C)	0.2	176.8	NA	4.382	0.204
	Percent reduction:	43.1	0.9	NA	2.5	-38.5

†Only one grab sample could be collected due to flow conditions.

Table 30: Alabama vault grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential, beginning with A, and include A–D if there was sufficient flow through the system to collect four samples. 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	Feb 28–Mar 1, 2006	6.0	7.22	11.67	146.8	540	220
Inlet	Feb 28–Mar 1, 2006	6.7	7.34	11.47	155.0	190	150
Inlet	Feb 28–Mar 1, 2006	7.0	7.55	9.67	158.2	150	210
Inlet	Feb 28–Mar 1, 2006	7.3	7.71	10.52	158.7	160	92
Outlet	Feb 28–Mar 1, 2006	5.8	6.97	6.90	167.8	7	5
Outlet	Feb 28–Mar 1, 2006	6.0	6.94	7.13	167.6	6	2
Outlet	Feb 28–Mar 1, 2006	6.2	7.20	5.82	168.5	2	4
Outlet	Feb 28–Mar 1, 2006	6.6	7.08	7.89	157.0	82	47
	Percent reduction:	8.9	5.5	36.0	-6.8	90.7	91.4
Inlet	May 22–23, 2006	13.7	7.47	9.44	107.0	14000	16000
Inlet	May 22–23, 2006	13.3	7.58	10.39	154.0	4100	5100
Inlet	May 22–23, 2006	14.0	7.58	10.00	154.0	1800	2900
Inlet	May 22–23, 2006	13.6	7.48	10.28	152.0	860	900
Outlet	May 22–23, 2006	15.3	6.78	6.06	127.0	1600	2000
Outlet	May 22–23, 2006	14.6	6.85	3.55	149.0	63	52
Outlet	May 22–23, 2006	14.3	6.87	4.47	144.0	90	140
Outlet	May 22–23, 2006	14.3	6.86	3.37	153.0	6	8
	Percent reduction:	-7.1	9.1	56.5	-1.1	91.5	91.2

Site	Date	TSS (mg/L)	TS (mg/L)	TOC (mg/L)	TN (mg-N/L)	TP (mg-P/L)
Inlet	Feb 28–Mar 1, 2006	5.7	105.9	NA	0.812	0.052
Inlet	Feb 28–Mar 1, 2006	2.5	110.7	NA	0.768	0.040
Inlet	Feb 28–Mar 1, 2006	12.5	123.4	2.5	0.777	0.090
Inlet	Feb 28–Mar 1, 2006	3.5	116.3	NA	0.714	0.045
Outlet	Feb 28–Mar 1, 2006	2.4	113.6	NA	0.819	0.057
Outlet	Feb 28–Mar 1, 2006	0.8	112.1	NA	0.813	0.057
Outlet	Feb 28–Mar 1, 2006	1.1	109.8	2.7	0.789	0.057
Outlet	Feb 28–Mar 1, 2006	1.6	109.4	NA	0.818	0.114
	Percent reduction:	75.8	2.5	-8.0	-5.5	-25.6
Inlet	May 22–23, 2006	55.1	NA	NA	1.226	0.192
Inlet	May 22–23, 2006	8.4	NA	NA	0.614	0.089
Inlet	May 22–23, 2006	11.0	NA	NA	0.856	0.089
Inlet	May 22–23, 2006	9.6	NA	NA	0.586	0.083
Outlet	May 22–23, 2006	5.0	NA	NA	0.869	0.172
Outlet	May 22–23, 2006	1.6	NA	NA	0.574	0.102
Outlet	May 22–23, 2006	2.5	NA	NA	0.640	0.105
Outlet	May 22–23, 2006	1.0	NA	NA	0.529	0.099
	Percent reduction:	88.0	NA	NA	20.4	-5.5

Table 31: Park Place wet pond grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential; 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	Nov 9–10, 2005	12.9	7.48	8.97	391.0	10	7
Inlet	Nov 9–10, 2005	12.9	7.53	8.47	393.0	8	5
Inlet	Nov 9–10, 2005	13.0	7.46	8.42	411.0	NA	2
Inlet	Nov 9–10, 2005	11.8	7.62	9.81	195.0	580	490
OutletE	Nov 9–10, 2005	11.3	7.48	6.86	374.0	34	17
OutletE	Nov 9–10, 2005	11.7	7.49	6.41	385.0	27	35
OutletE	Nov 9–10, 2005	11.7	7.45	6.16	402.0	NA	15
OutletE	Nov 9–10, 2005	12.2	7.46	7.78	321.0	300	290
OutletW	Nov 9–10, 2005	10.0	7.44	5.02	335.0	3	3
OutletW	Nov 9–10, 2005	10.0	7.44	4.80	339.0	2	1
OutletW	Nov 9–10, 2005	10.1	7.40	4.92	402.0	NA	4
OutletW	Nov 9–10, 2005	10.3	7.51	7.06	366.0	180	220
	Percent reduction:	13.7	0.8	31.3	-5.2	54.3	42.0
Inlet	April 17–19, 2006	10.8	7.63	NA	366.0	15	11
Inlet	April 17–19, 2006	11.0	7.61	NA	392.0	3	3
Inlet	April 17–19, 2006	11.2	7.59	8.87	383.0	5	1
Inlet	April 17–19, 2006	11.0	7.56	8.56	401.0	1	4
OutletE	April 17–19, 2006	9.7	7.65	NA	357.0	15	5
OutletE	April 17–19, 2006	10.4	7.65	NA	383.0	NA	NA
OutletE	April 17–19, 2006	11.0	7.66	7.02	386.0	8	9
OutletE	April 17–19, 2006	10.0	7.64	6.87	396.0	2	1
OutletW	April 17–19, 2006	9.1	7.64	NA	306.0	2	2
OutletW	April 17–19, 2006	9.4	7.60	NA	340.0	NA	NA
OutletW	April 17–19, 2006	9.1	7.62	5.96	346.0	1	2
OutletW	April 17–19, 2006	9.2	7.61	5.70	370.0	1	1
	Percent reduction:	11.5	-0.5	26.7	6.5	19.4	29.8

Table 32: South Campus rock/plant filter grab samples and average percent reductions between inlet and outlet samples. Sample collection times were sequential; negative values indicate an increase in concentration at the outlet.

	Total Suspended Solids		
Site	Mean	95% CI	Sig
Alabama (n=6)	31.6	0.7 – 62.5	0.05
Brentwood (n=15)	-51.0	-102.1 – 0.007	0.05
Park Place (n=32)	14.5	-7.7 – 36.8	ns
South Campus (n=15)	80.0	72.7 – 91.4	$<$0.0001

	Total Phosphorus		
Site	Mean	95% CI	Sig
Alabama (n=6)	-7.2	-28.2 – 13.8	ns
Brentwood (n=16)	-11.1	-69.1 – 46.8	ns
Park Place (n=34)	-5.1	-17.3 – 7.1	ns
South Campus (n=16)	50.3	41.3 – 59.3	$<$0.0001

Table 33: Summary of total suspended solids and total phosphorus reductions at Alabama, Brentwood, Park Place, and South Campus storm water treatment sites. Statistical significance was tested using a one sample t-test to determine whether the mean percent reduction was significantly different than zero ($H_o\ \overline{x} = 0$). Brentwood was not monitored in 2005/2006, but is scheduled to be monitored in 2006/2007.

Sample Type	Source	TSS	TP
24 hr composite	inlet	13.97	0.21
(90 min. intervals)	outlet	11.37	0.20
	Percent reduction:	18.6	3.3
Grab samples	inlet avg.	12.78	0.16
(n=4 in 24 hr)	outlet avg.	13.64	0.16
	Percent reduction:	-6.7	2.9†
Individual grab sample results:			
Grab #1	inlet	10.43	0.13
Grab #2	inlet	31.27	0.17
Grab #3	inlet	6.35	0.20
Grab #4	inlet	3.07	0.15
Grab #1	outlet	21.97	0.15
Grab #2	outlet	26.30	0.15
Grab #3	outlet	4.00	0.18
Grab #4	outlet	2.28	0.14

†Not zero because inlet/outlet averages were rounded after calculation of percent reduction

Table 34: Comparison between 24-hr composite samples and multiple grab samples (n=4 during 24 hr) collected November 1–2, 2004 at the Alabama Hill vault.

		Feb/Mar		May	
Sample Type	Source	TSS	TP	TSS	TP
48 hr composite	inlet	6.50	0.06	14.57	0.09
(90 min. intervals)	outlet	1.24	0.06	2.77	0.11
	Percent reduction:	80.9	-8.8†	81.0	-22.1
Grab samples	inlet avg.	6.04	0.06	21.03	0.11
(n=4 in 48 hr)	outlet avg.	1.47	0.07	2.52	0.12
	Percent reduction:	75.8	-25.6	88.0	-5.5
Individual grab sample results:					
Grab #1	inlet	5.67	0.05	55.10	0.19
Grab #2	inlet	2.50	0.04	8.40	0.09
Grab #3	inlet	3.50	0.09	11.00	0.09
Grab #4	inlet	2.37	0.05	9.63	0.08
Grab #1	outlet	2.37	0.06	5.00	0.17
Grab #2	outlet	0.81	0.06	1.59	0.10
Grab #3	outlet	1.07	0.06	2.48	0.11
Grab #4	outlet	1.61	0.11	1.01	0.10

†Not zero because inlet/outlet averages were rounded after calculation of percent reduction

Table 35: Comparison between 48-hr composite samples and multiple grab samples (n=4 during 48 hr) collected February 27–March 1 and May 22–24, 2006 at the Park Place wet pond.

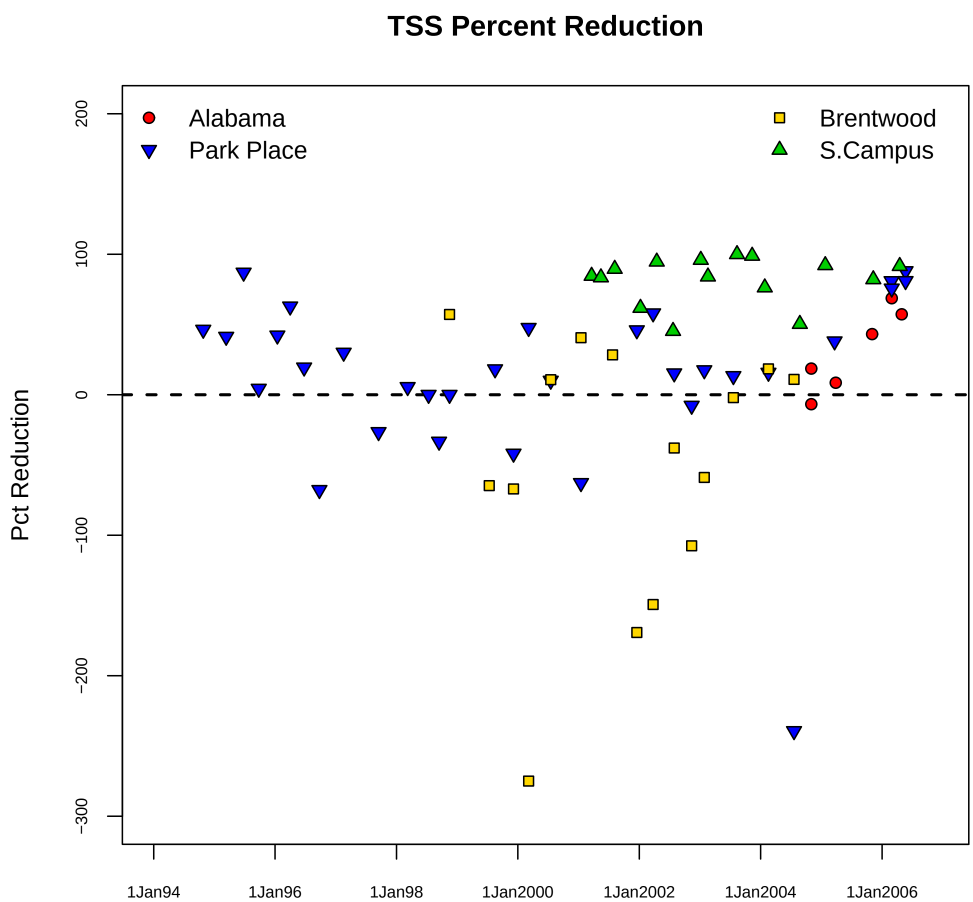


Figure 29: Percent reduction of total suspended solids concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites. Negative values indicate higher concentrations at the outlet compared to the inlet. Two sites, Alabama and South Campus, had significant solids reductions (One sample t-test; p-value $\leq$0.05); the Brentwood site had significant solids export (p-value $\leq$0.05). Brentwood was not monitored in 2005/2006, but is scheduled to be monitored in 2006/2007.

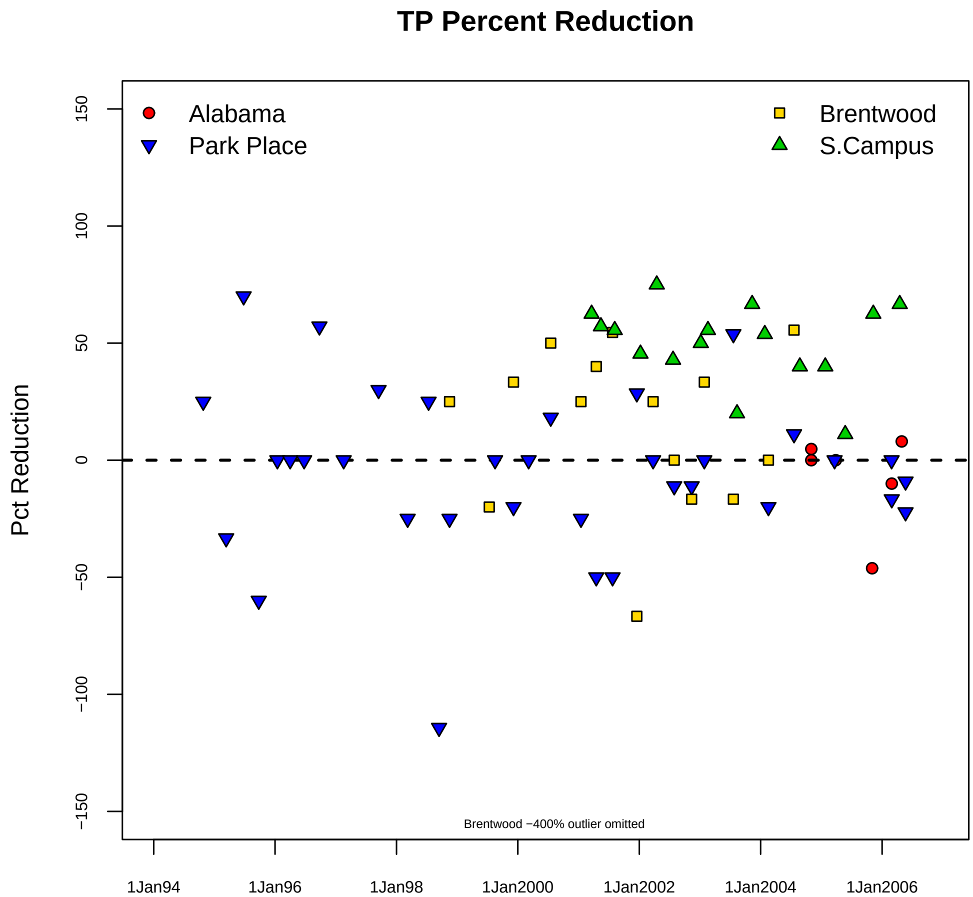


Figure 30: Percent reduction of total phosphorus concentrations at the Alabama, Brentwood, Park Place and South Campus storm water treatment sites. Negative values indicate higher concentrations at the outlet compared to the inlet. Only South Campus had significant phosphorus reduction (One sample t-test; p-value $\leq$0.05). Brentwood was not monitored in 2005/2006, but is scheduled to be monitored in 2006/2007.

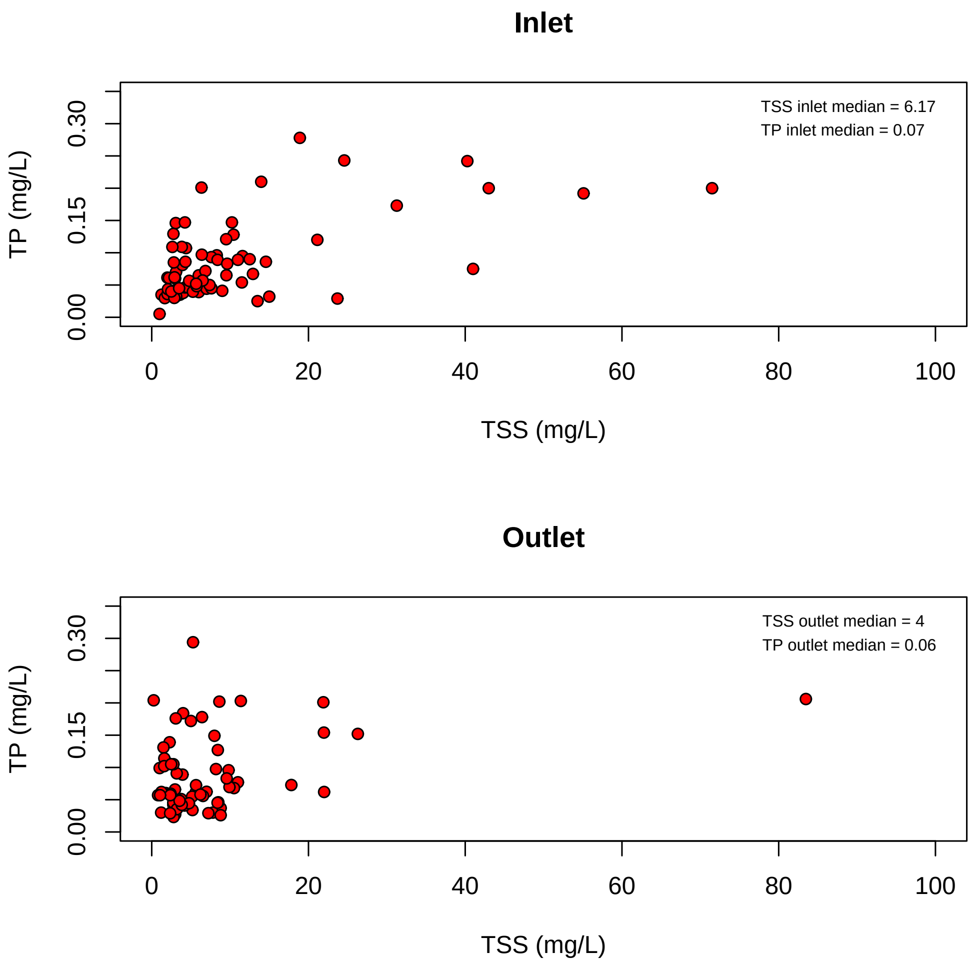


Figure 31: Total suspended solids and total phosphorus concentrations in inlet and outlet samples from the Alabama, Brentwood, and Park Place storm water treatment sites. Each point represents the TSS and TP concentrations measured in individual composite or grab samples. Figure shows that TSS concentrations were generally lower at the outlet but TP concentrations were about the same.

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.

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.

Ecology. 2006. Assessment of Water Quality for the Clean Water Act Sections 303(d) and 305(b) Integrated Report. Washington State Department of Ecology, WQP Policy 1–11, dated September 6, 2006.

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.

Hydrolab. 1997. Data Sonde 4 Water Quality Multiprobes User Manual, Revision D., August 1997. Hydrolab Corporation, Austin, TX.

Kelleher, K. D. 2006. Streamflow calibration of two sub-basins in the Lake Whatcom watershed, Washington using a distributed hydrology model. M. S. thesis, Huxley College of Environmental Studies, Western Washington University, Bellingham, WA.

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. 2006. Lake Whatcom Monitoring Project 2003–2004 Final Report. Final Report prepared for the City of Bellingham Public Works Department, March, 2006, Bellingham, WA.

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

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

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

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

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.

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.wwu.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 104–108) show the locations of the current monitoring sites and Table A1 (page 103) 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 IWS for detailed information about the site location.

Brannian Creek samples are collected approximately 40 m downstream from South Bay Rd. near the USGS hydrograph gauge. This site was added in October 2004 as part of the monthly 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 storm drain that empties into Lake Whatcom at Park Place Ln. Samples from this site include outlet flow from the Park Place storm water treatment facility.

Silver Beach Creek samples are collected approximately 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 the 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 flows directly into Lake Whatcom.

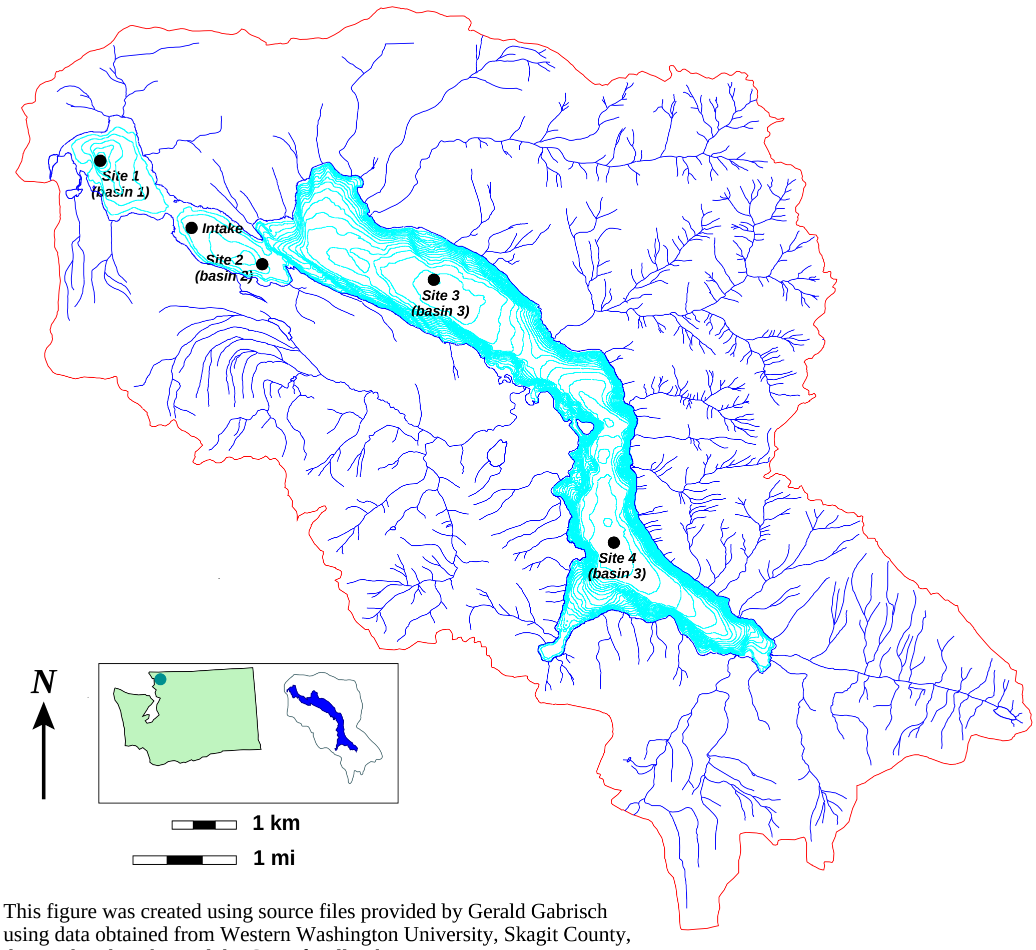
The **South Campus storm water treatment facility** is located south of the intersection between Bill McDonald Pky. and South College Dr, and treats runoff from the southern portion of Western Washington University. The runoff flows into a large underground concrete settling vault located on the northwest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

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

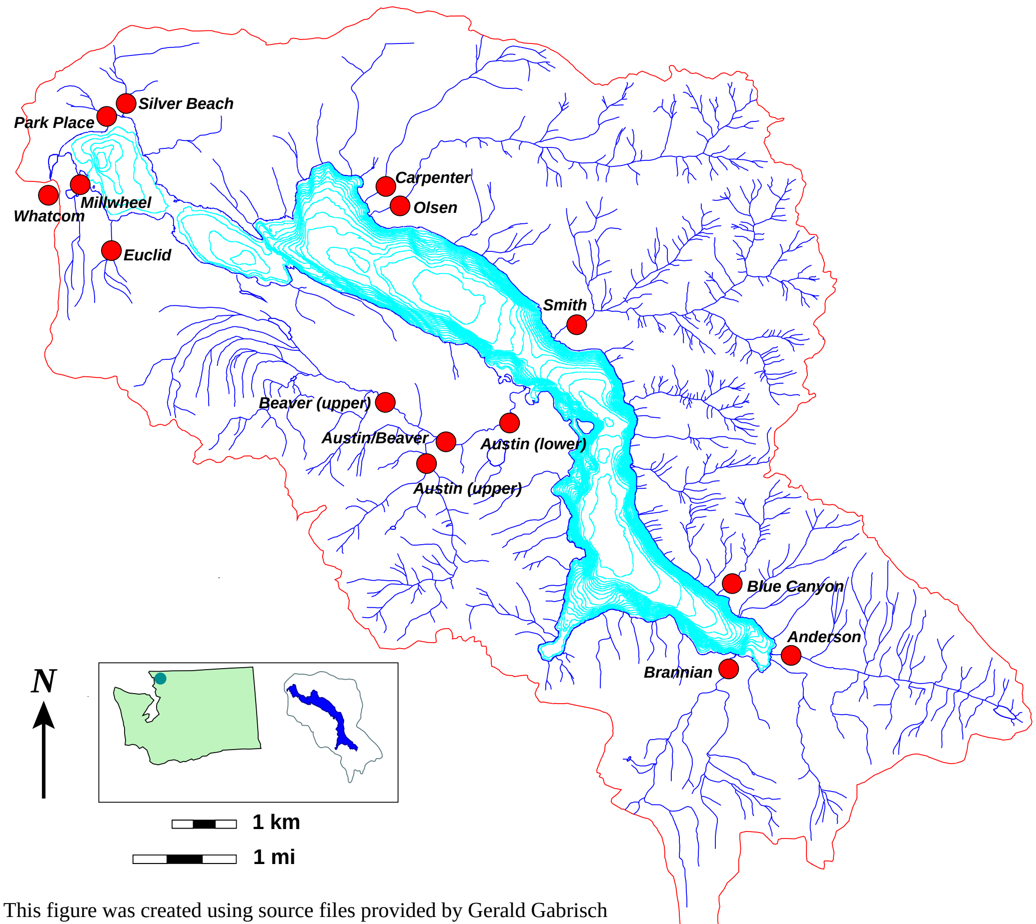
Storm Water Sites	Latitude	Longitude
Alabama Hill	no GPS data available	
Brentwood	no GPS data available	
Park Place	48.4608	122.2433
South Campus	no GPS data available	

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



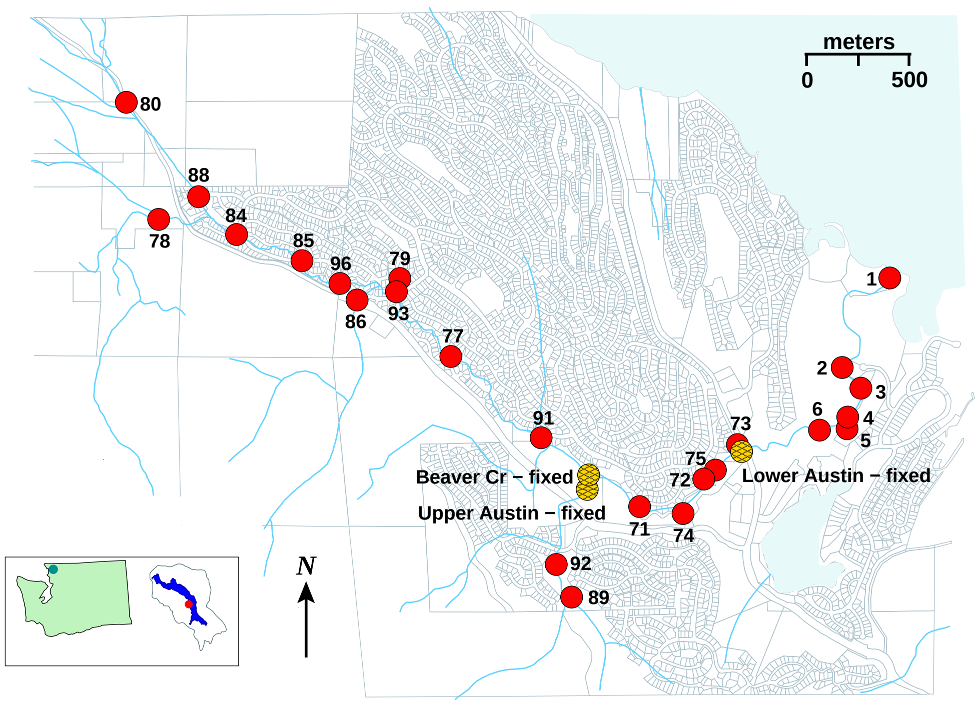
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A1: Lake Whatcom 2005/2006 lake sampling sites.



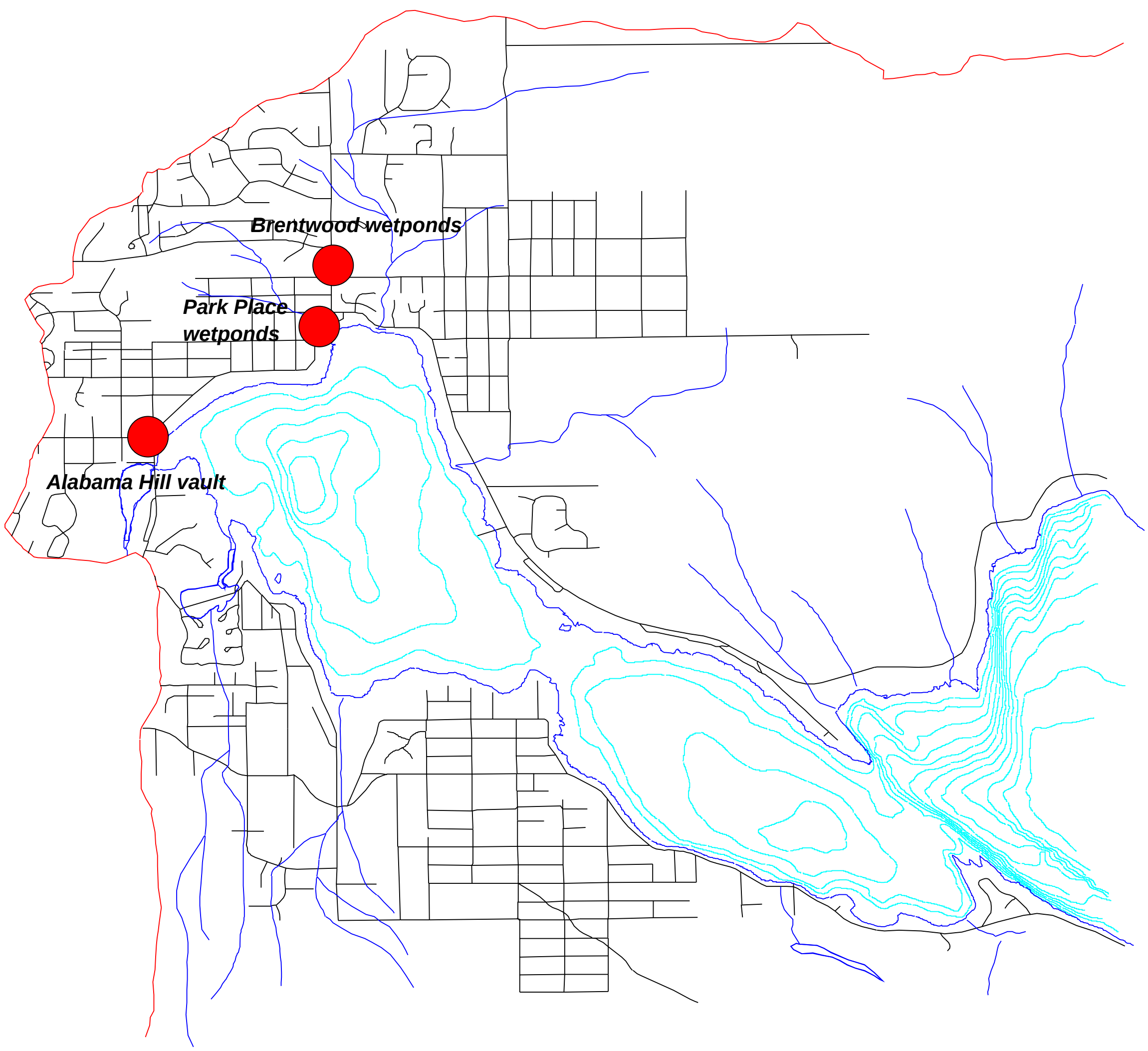
This figure was created using source files provided by Gerald Gabrisch using data obtained from Western Washington University, Skagit County, the Nooksack Tribe, and the City of Bellingham.

Figure A2: Lake Whatcom 2005/2006 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 and the Alabama Hill vault.

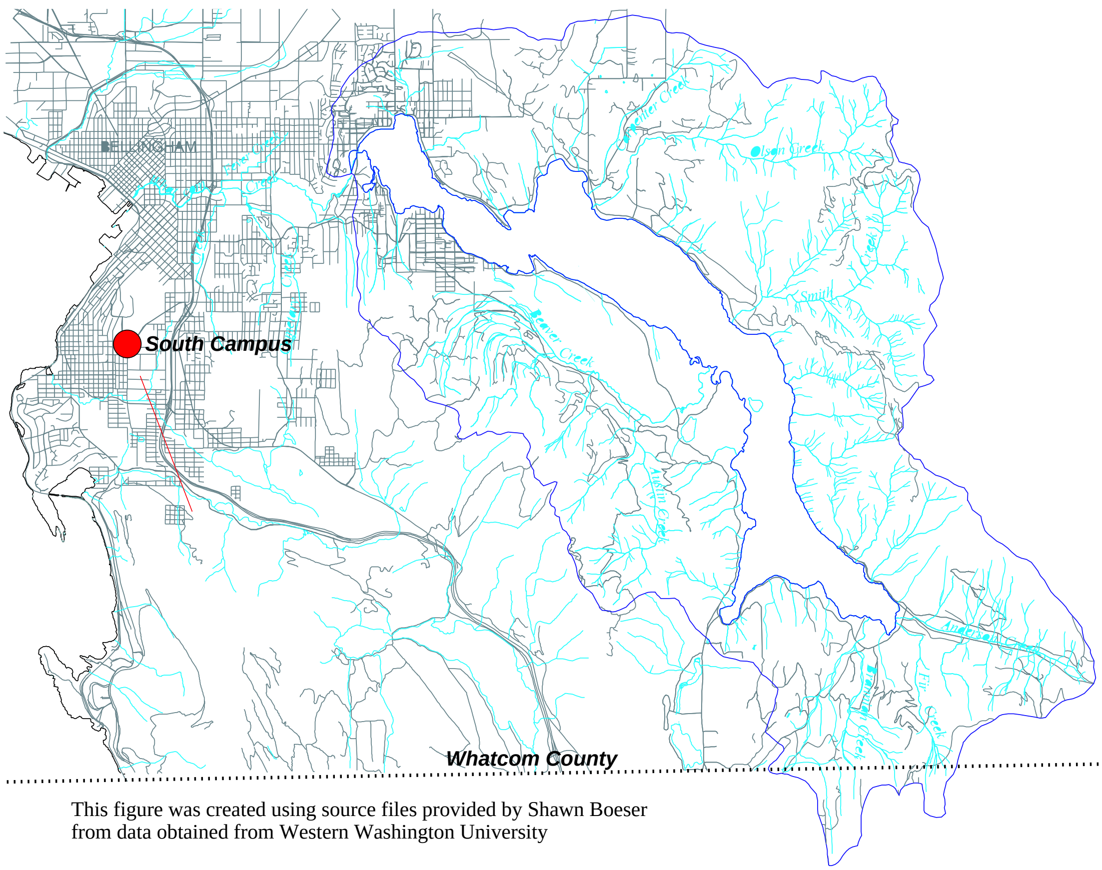


Figure A5: Locations of the South Campus storm water treatment facility.

Figure A6: Photograph of the Alabama Hill vault, May 2006.

Figure A7: Photograph of the Brentwood wet pond, July 2004. This site was not sampled in 2005 or 2006, but is scheduled for sampling in 2007.

Figure A8: Photograph of the original Park Place storm water treatment system prior to retrofit (March 2005).

Figure A9: Photograph of the Park Place storm water treatment system in May 2006, after an extensive retrofit where two of the sites wet cells were filled with sand.

Figure A10: Photograph of the South Campus storm water treatment facility, January 2005.

B Long-Term Water Quality Figures

The current and historic Lake Whatcom water quality data are plotted on the following pages. Detection limits and abbreviations for each parameter are listed in Table 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 1, page 14). 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 182–186, 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

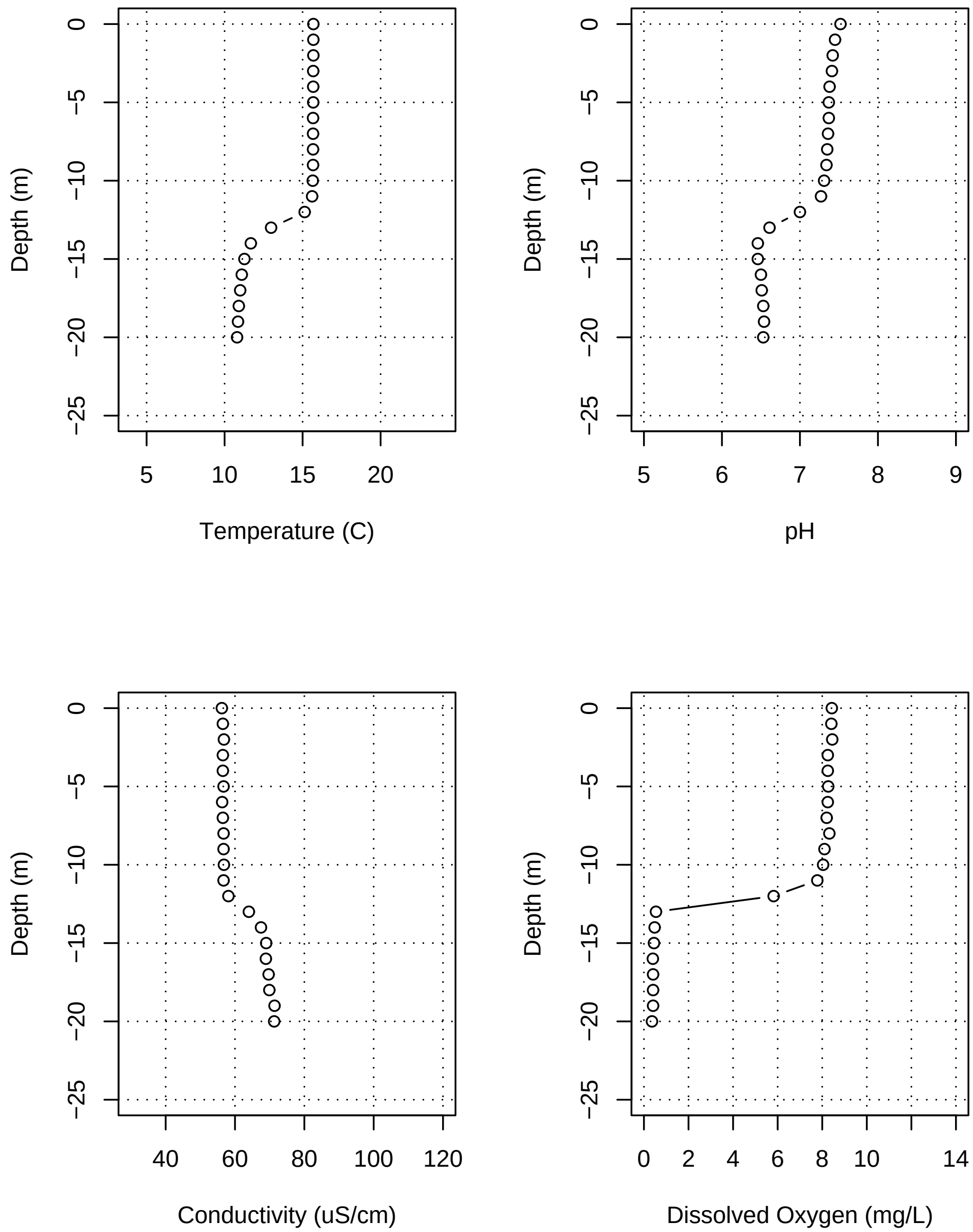


Figure B1: Lake Whatcom Hydrolab profile for Site 1, October 6, 2005.

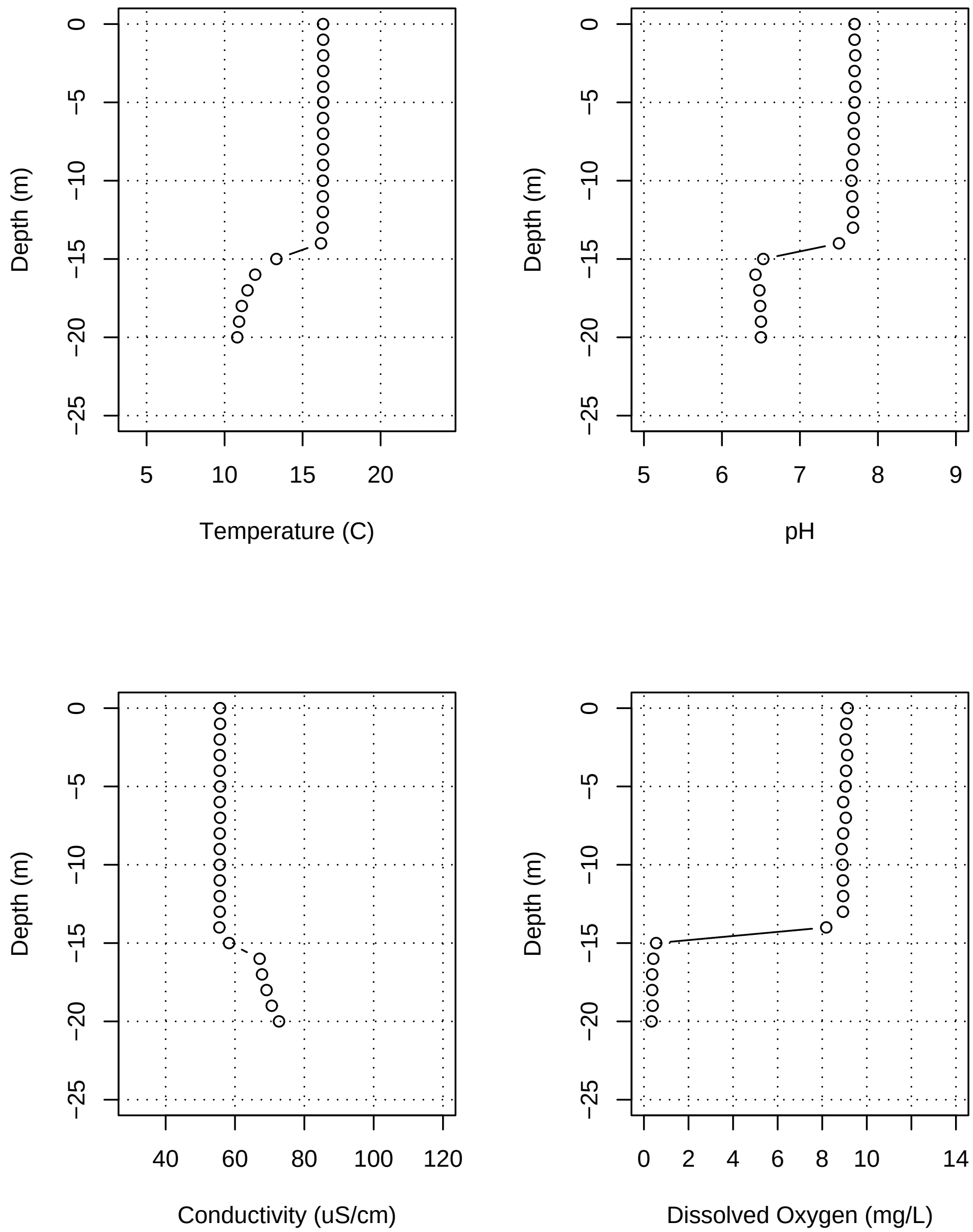


Figure B2: Lake Whatcom Hydrolab profile for Site 2, October 6, 2005.

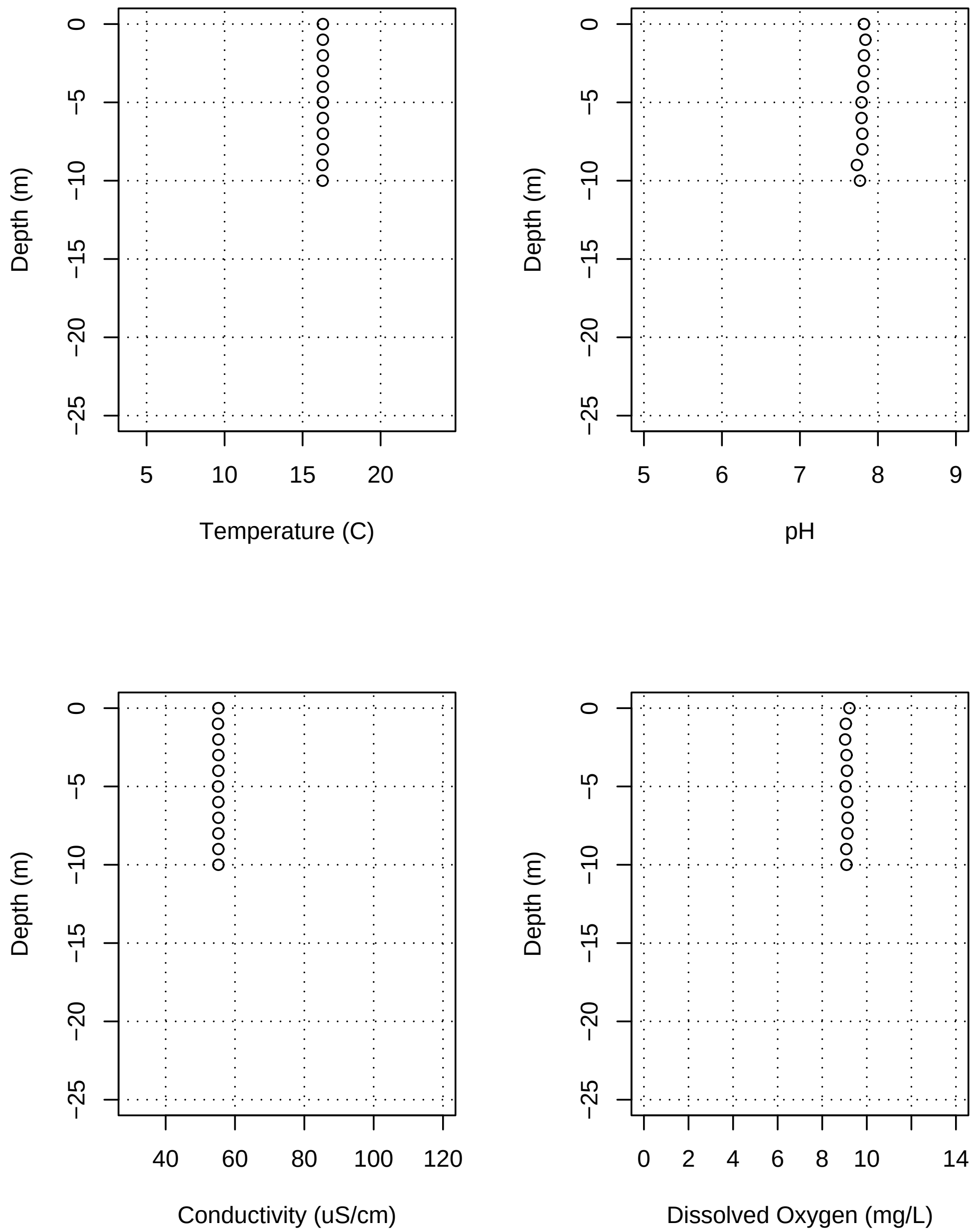


Figure B3: Lake Whatcom Hydrolab profile for the Intake, October 6, 2005.

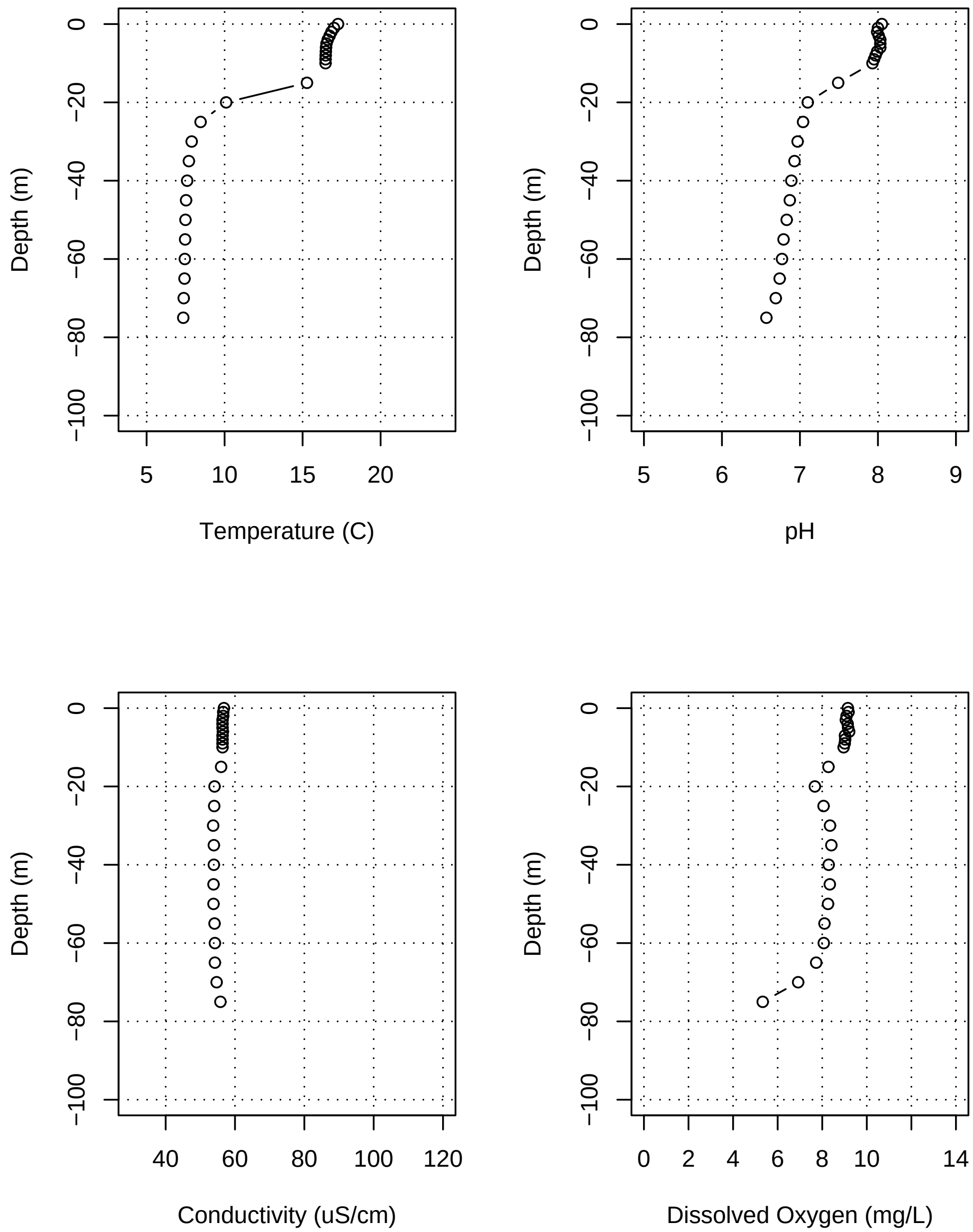


Figure B4: Lake Whatcom Hydrolab profile for Site 3, October 4, 2005.

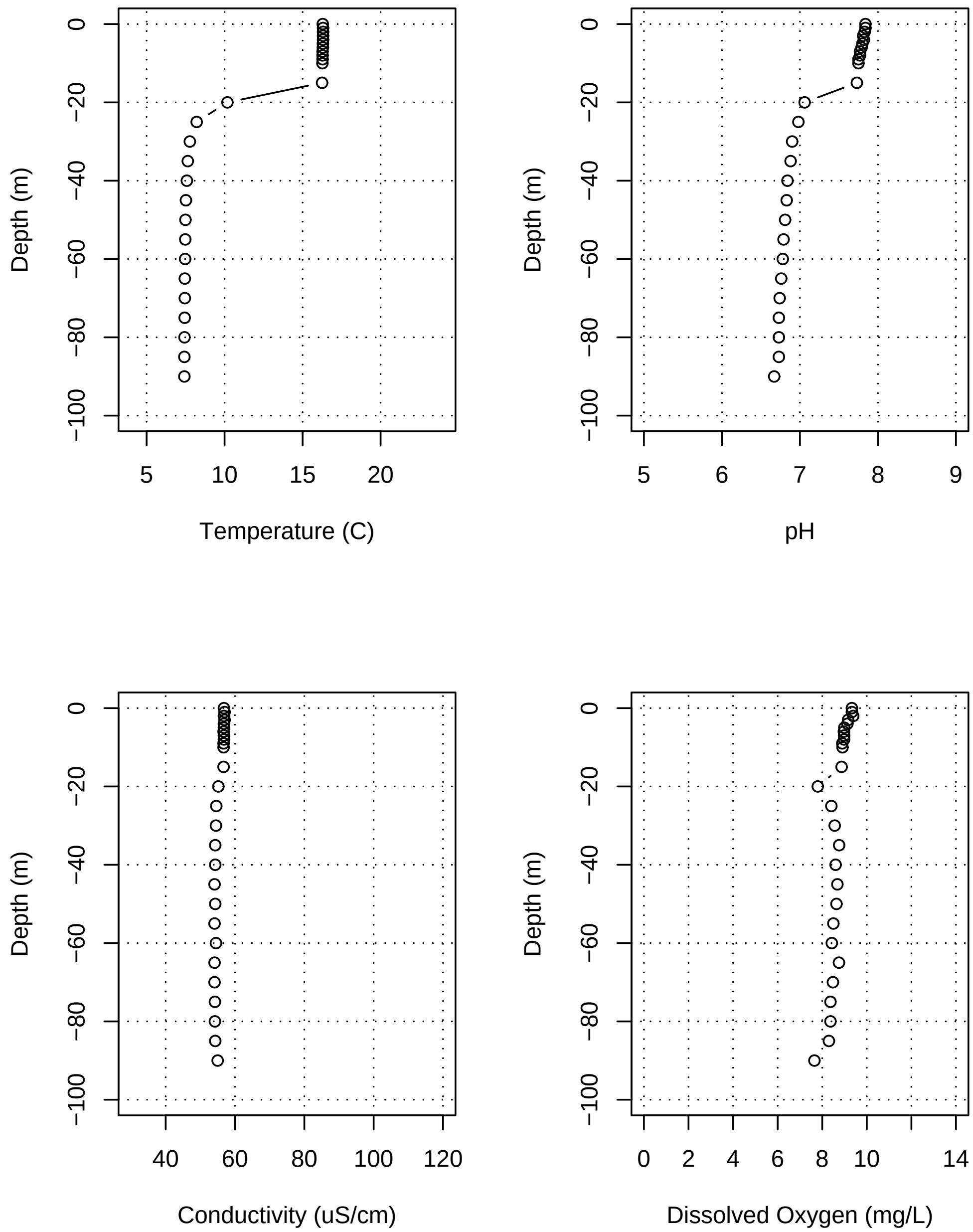


Figure B5: Lake Whatcom Hydrolab profile for Site 4, October 4, 2005.

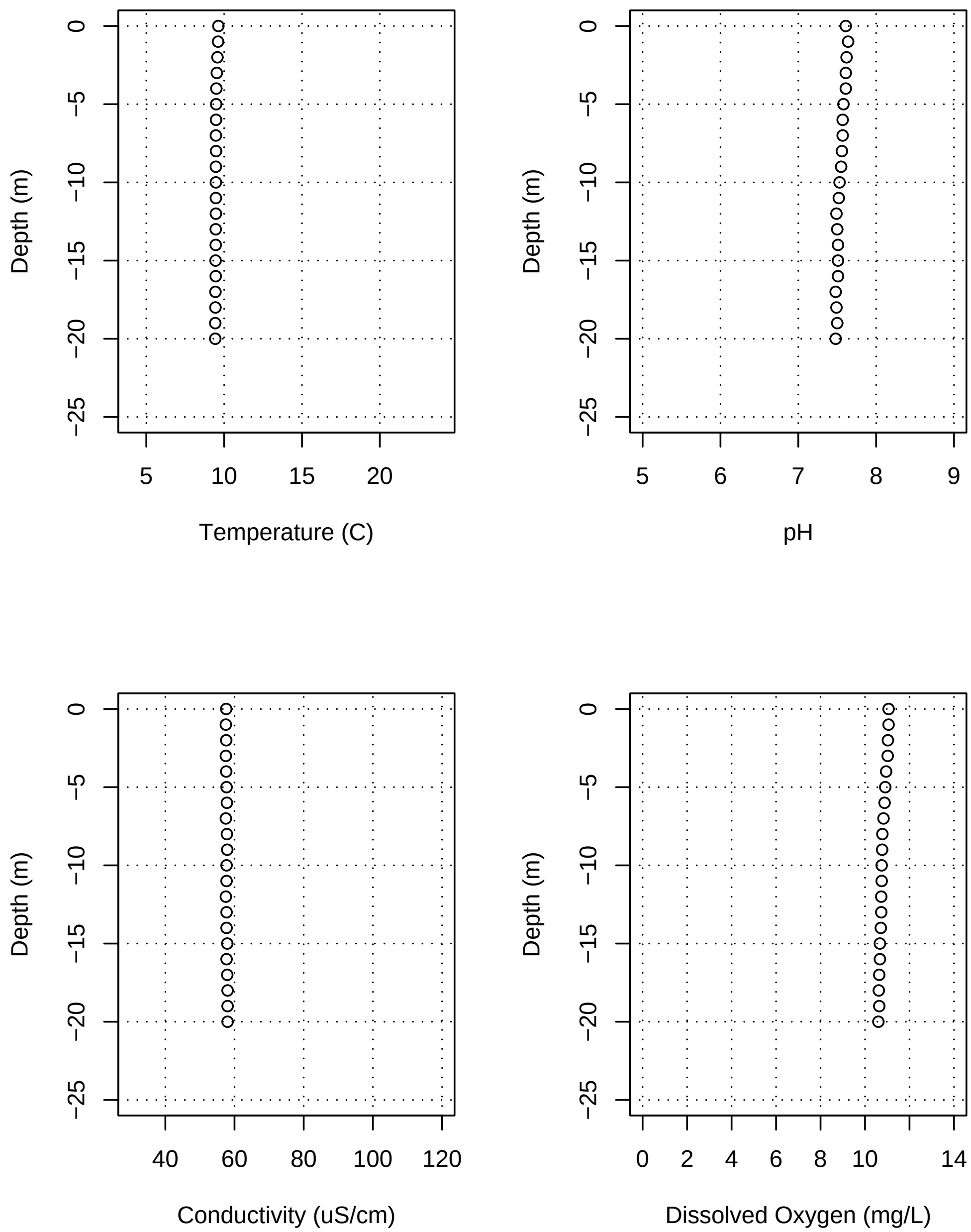


Figure B6: Lake Whatcom Hydrolab profile for Site 1, November 17, 2005.

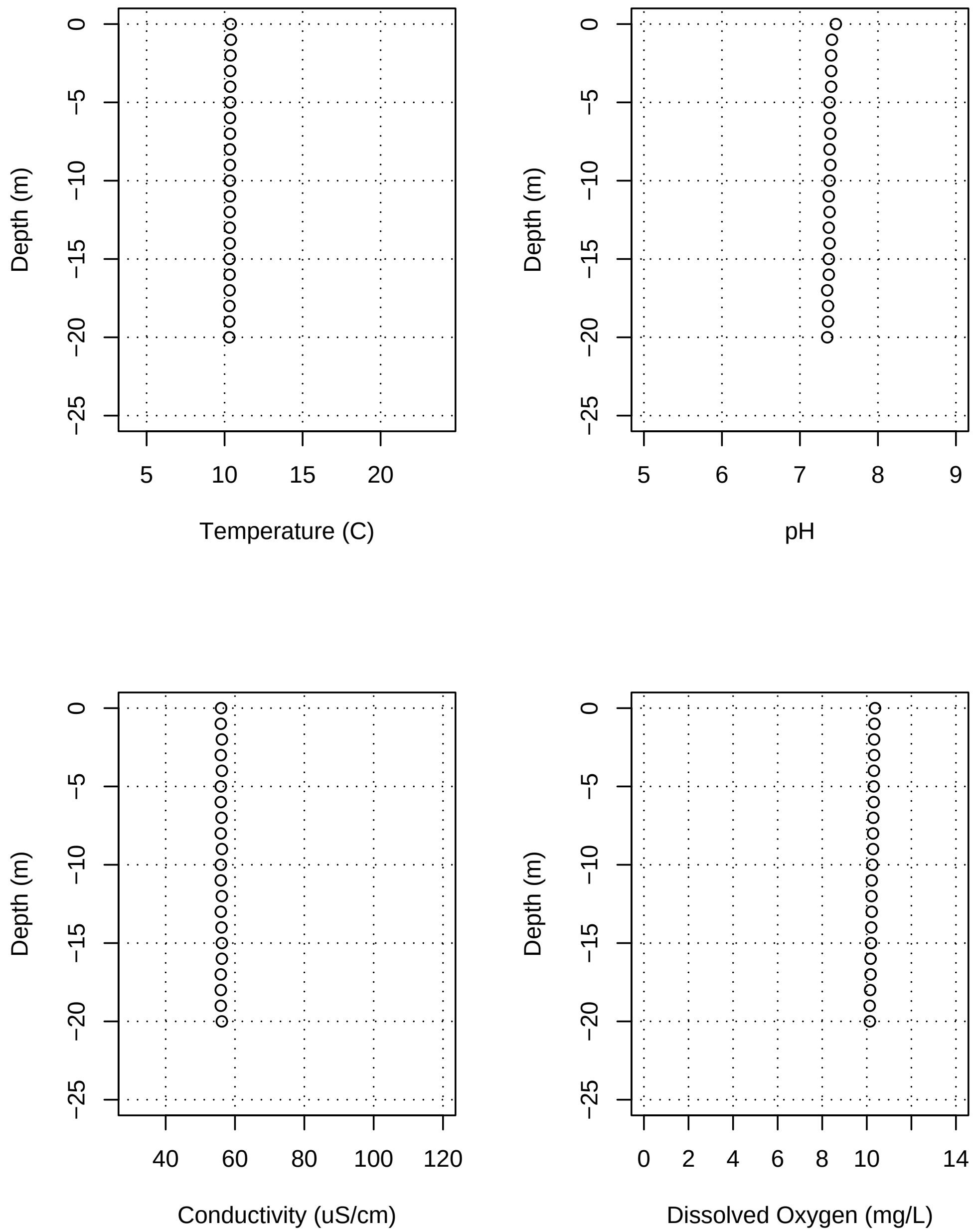


Figure B7: Lake Whatcom Hydrolab profile for Site 2, November 17, 2005.

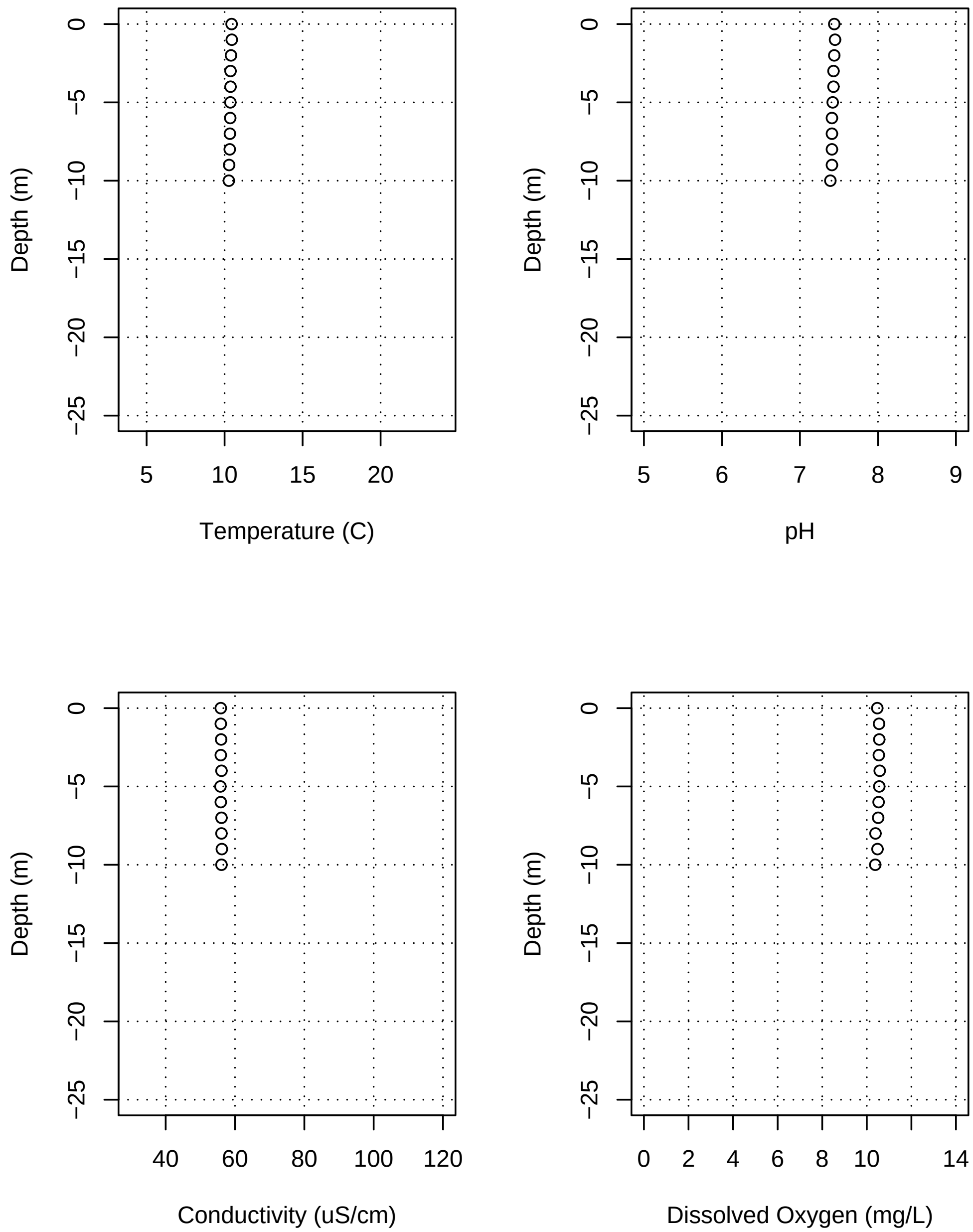


Figure B8: Lake Whatcom Hydrolab profile for the Intake, November 17, 2005.

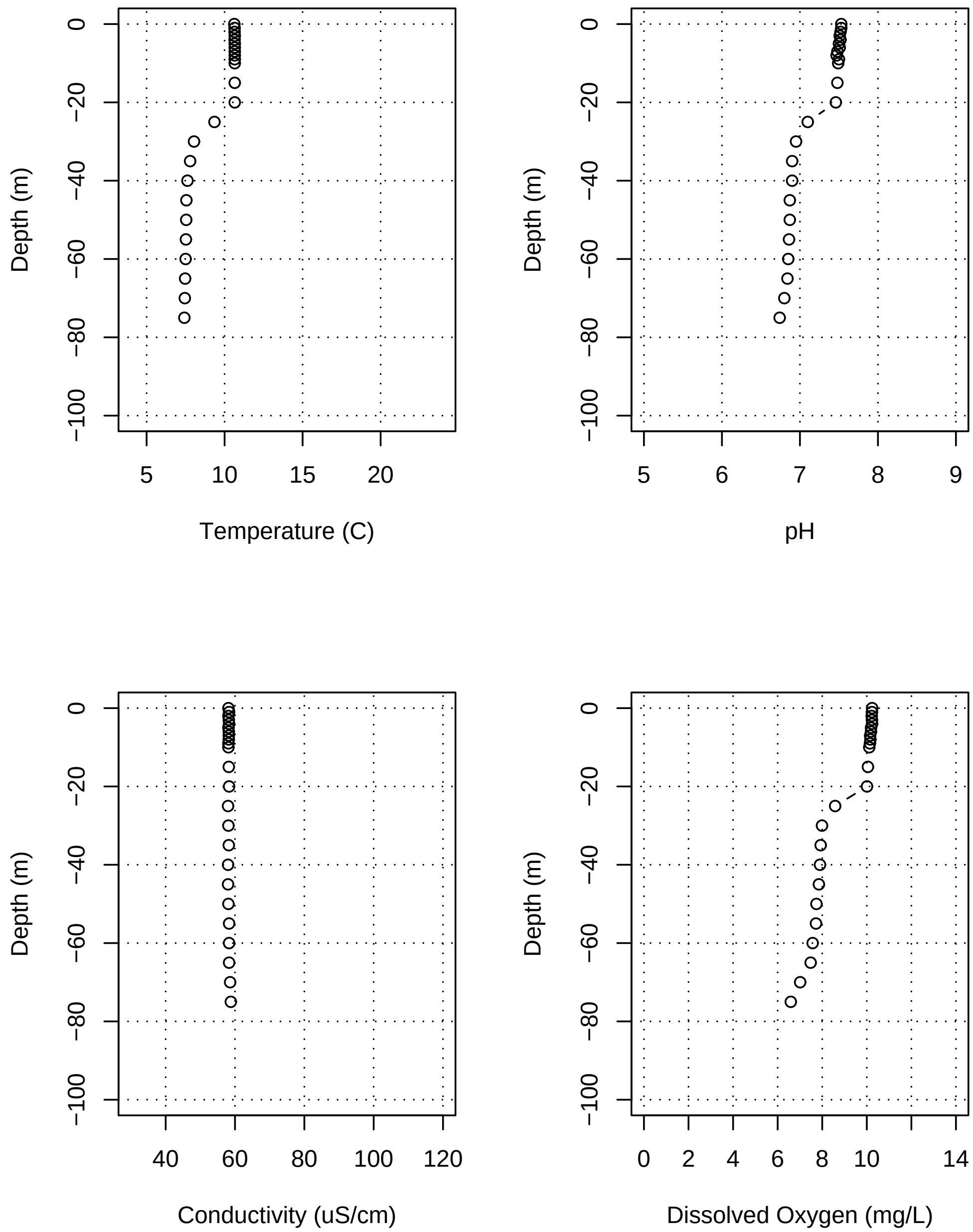


Figure B9: Lake Whatcom Hydrolab profile for Site 3, November 15, 2005.

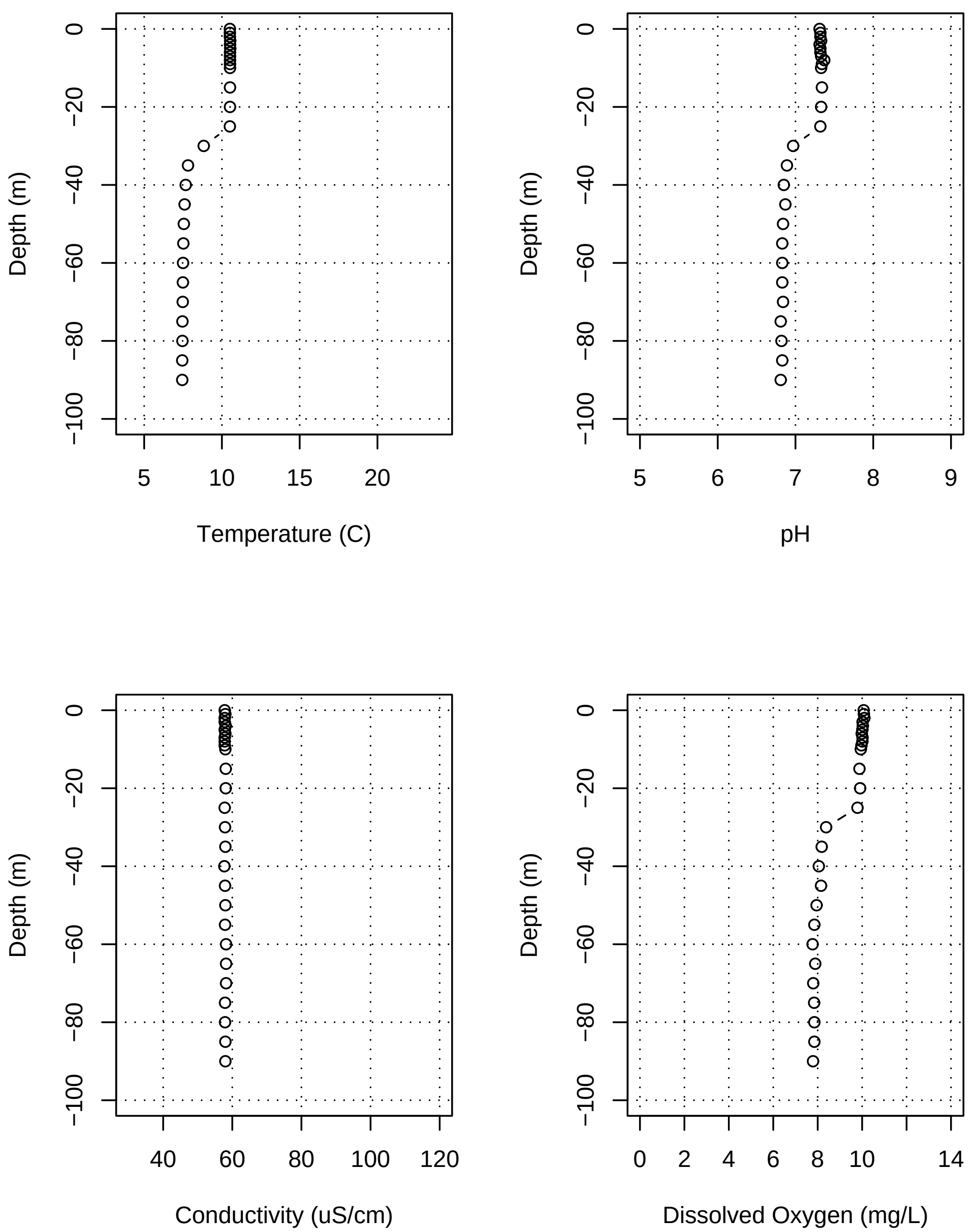


Figure B10: Lake Whatcom Hydrolab profile for Site 4, November 15, 2005.

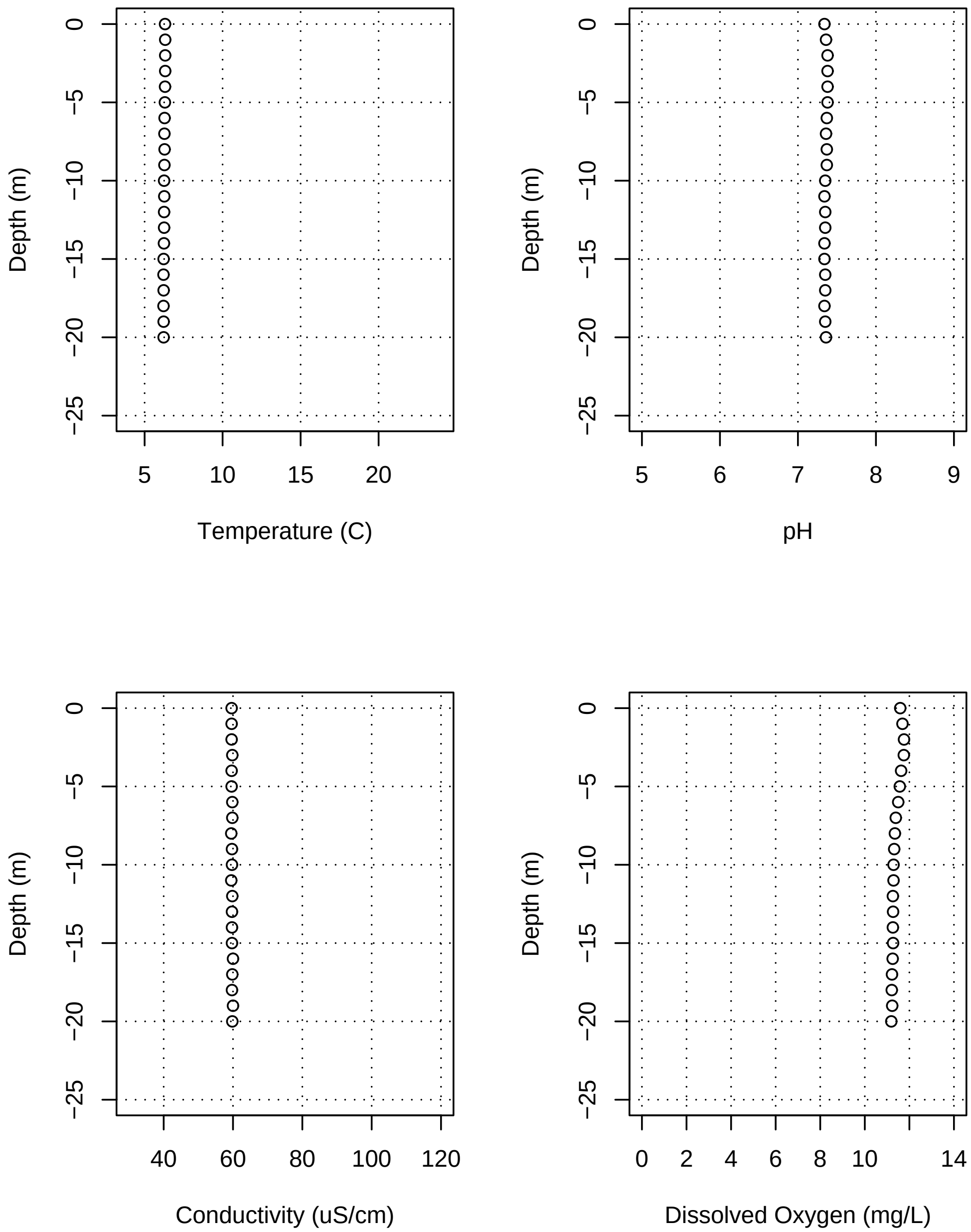


Figure B11: Lake Whatcom Hydrolab profile for Site 1, December 15, 2005.

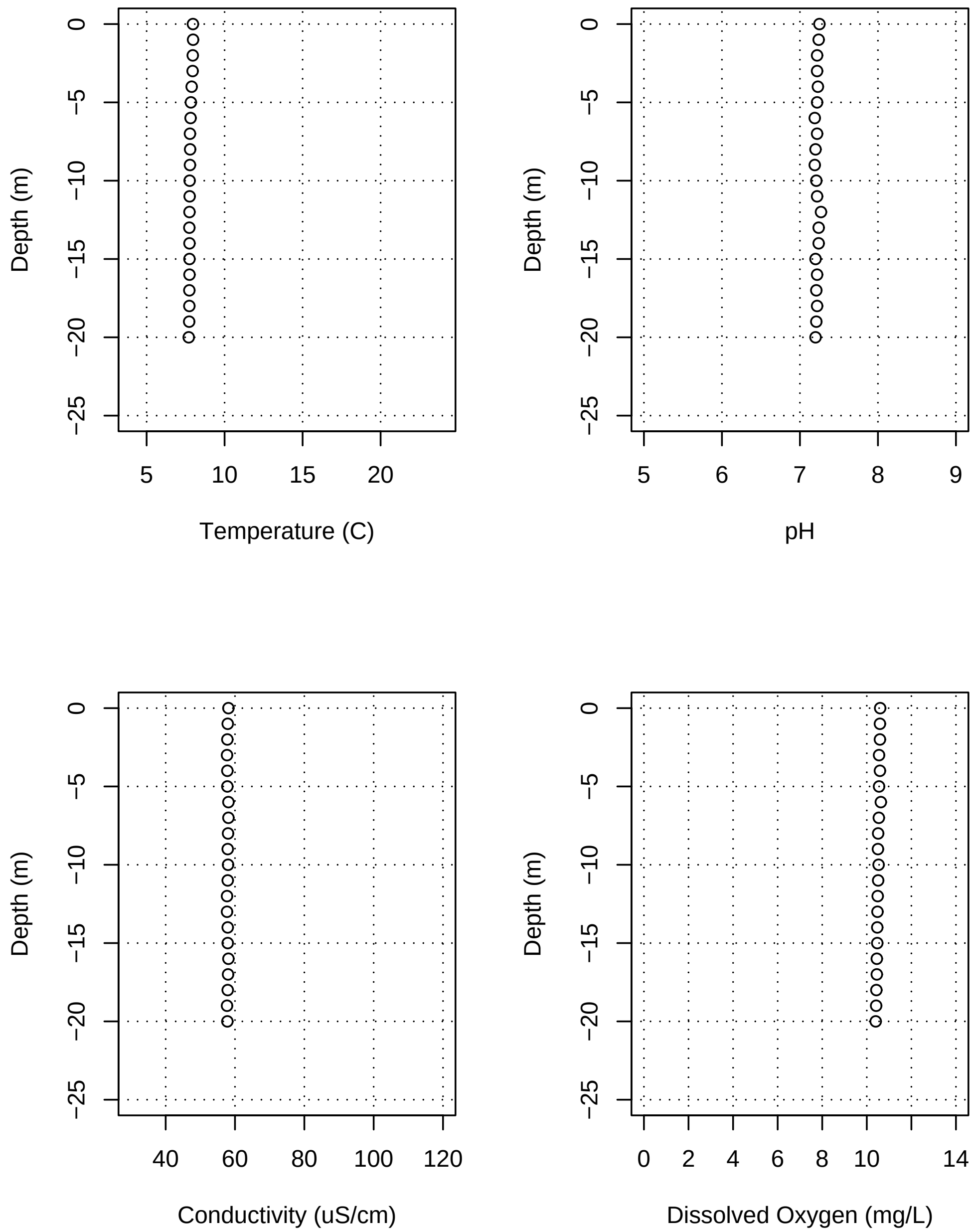


Figure B12: Lake Whatcom Hydrolab profile for Site 2, December 15, 2005.

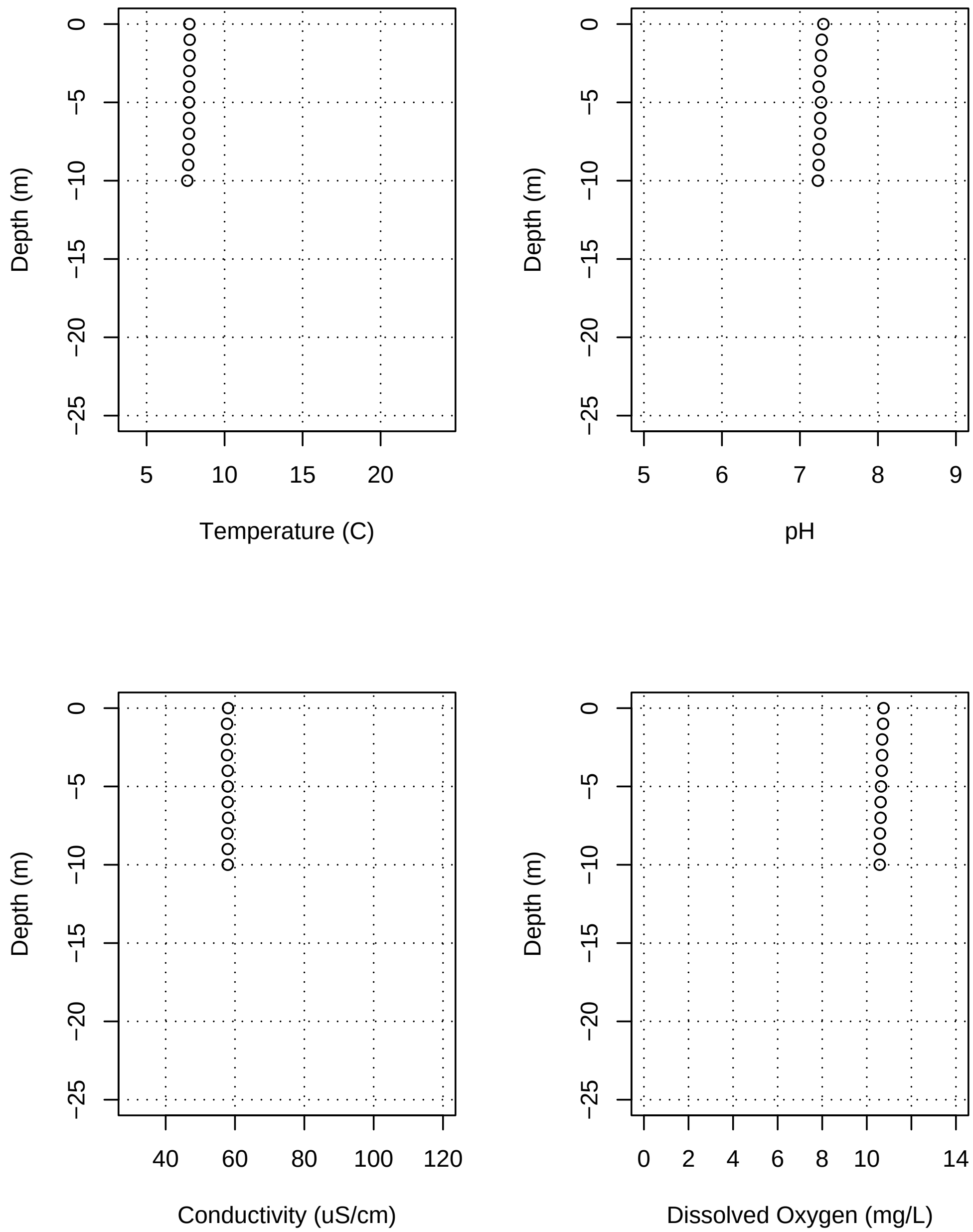


Figure B13: Lake Whatcom Hydrolab profile for the Intake, December 15, 2005.

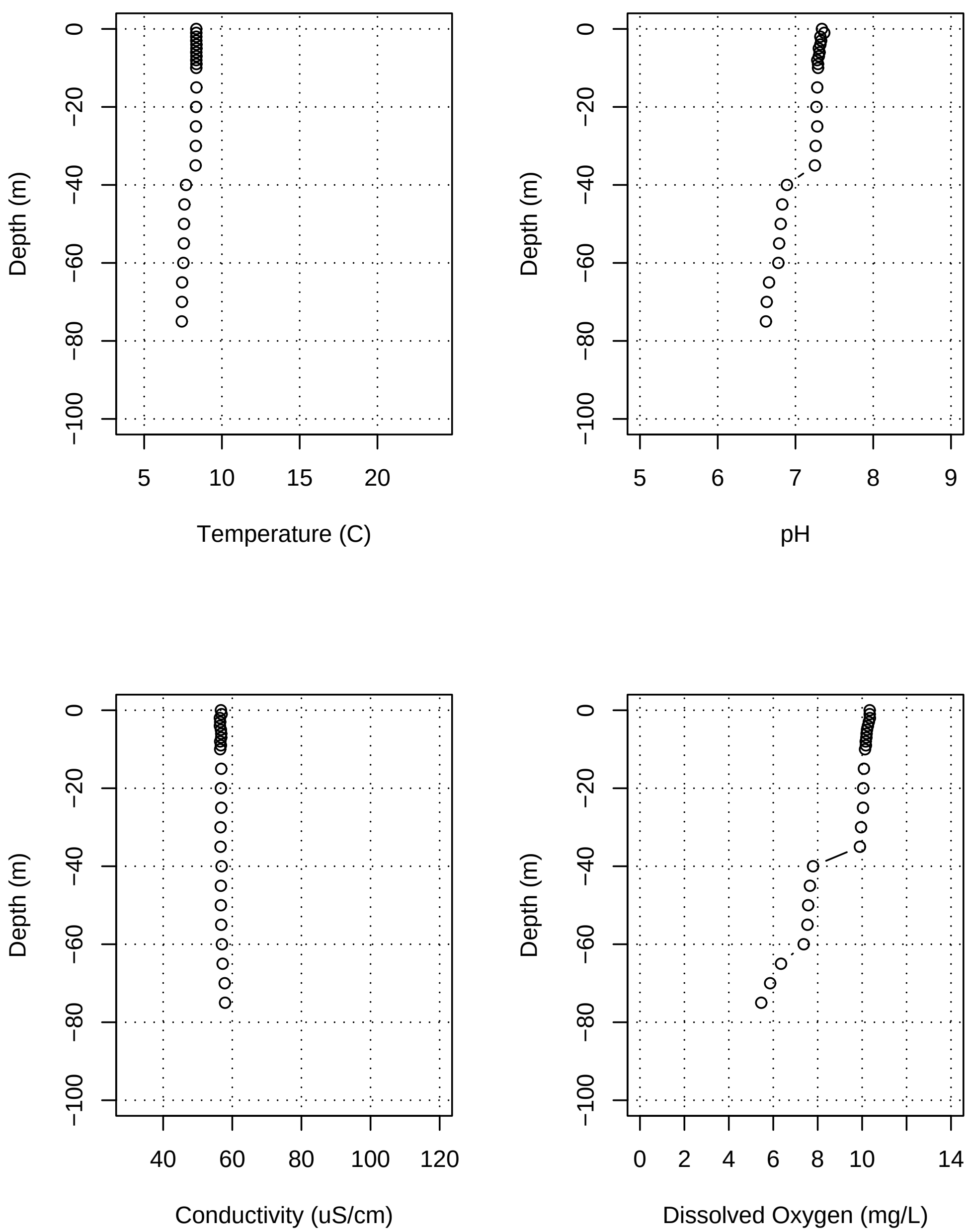


Figure B14: Lake Whatcom Hydrolab profile for Site 3, December 13, 2005.

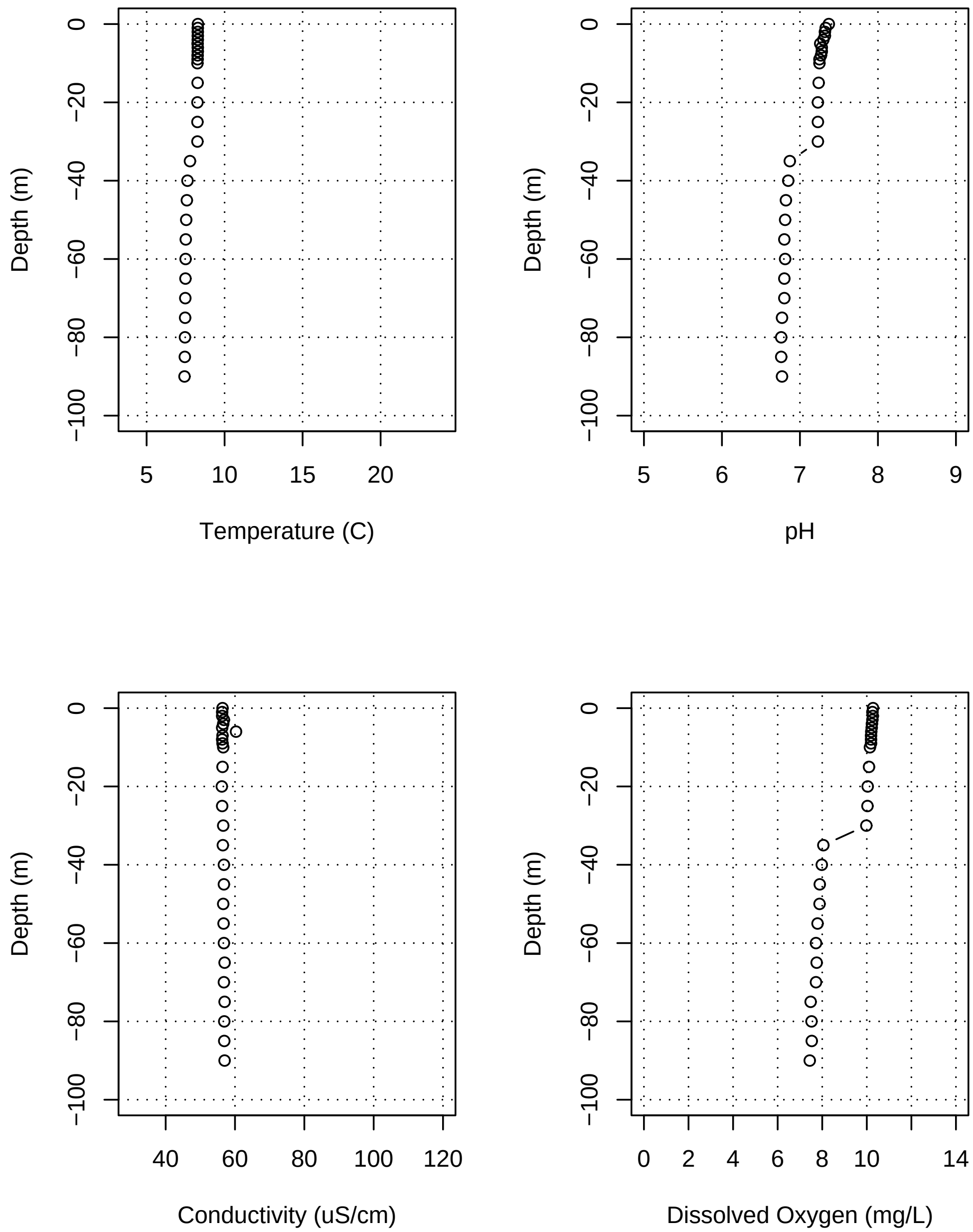


Figure B15: Lake Whatcom Hydrolab profile for Site 4, December 13, 2005.

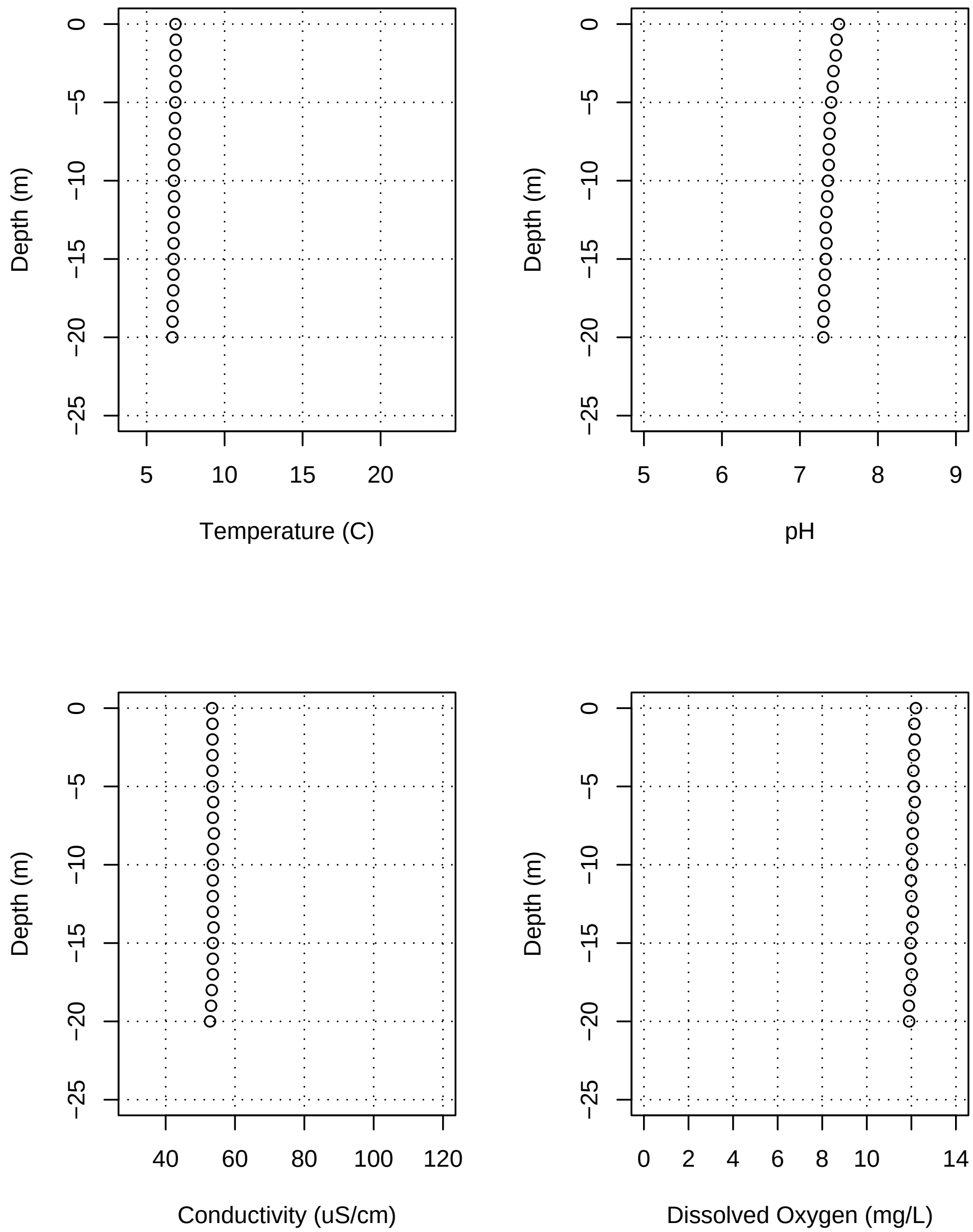


Figure B16: Lake Whatcom Hydrolab profile for Site 1, February 9, 2006.

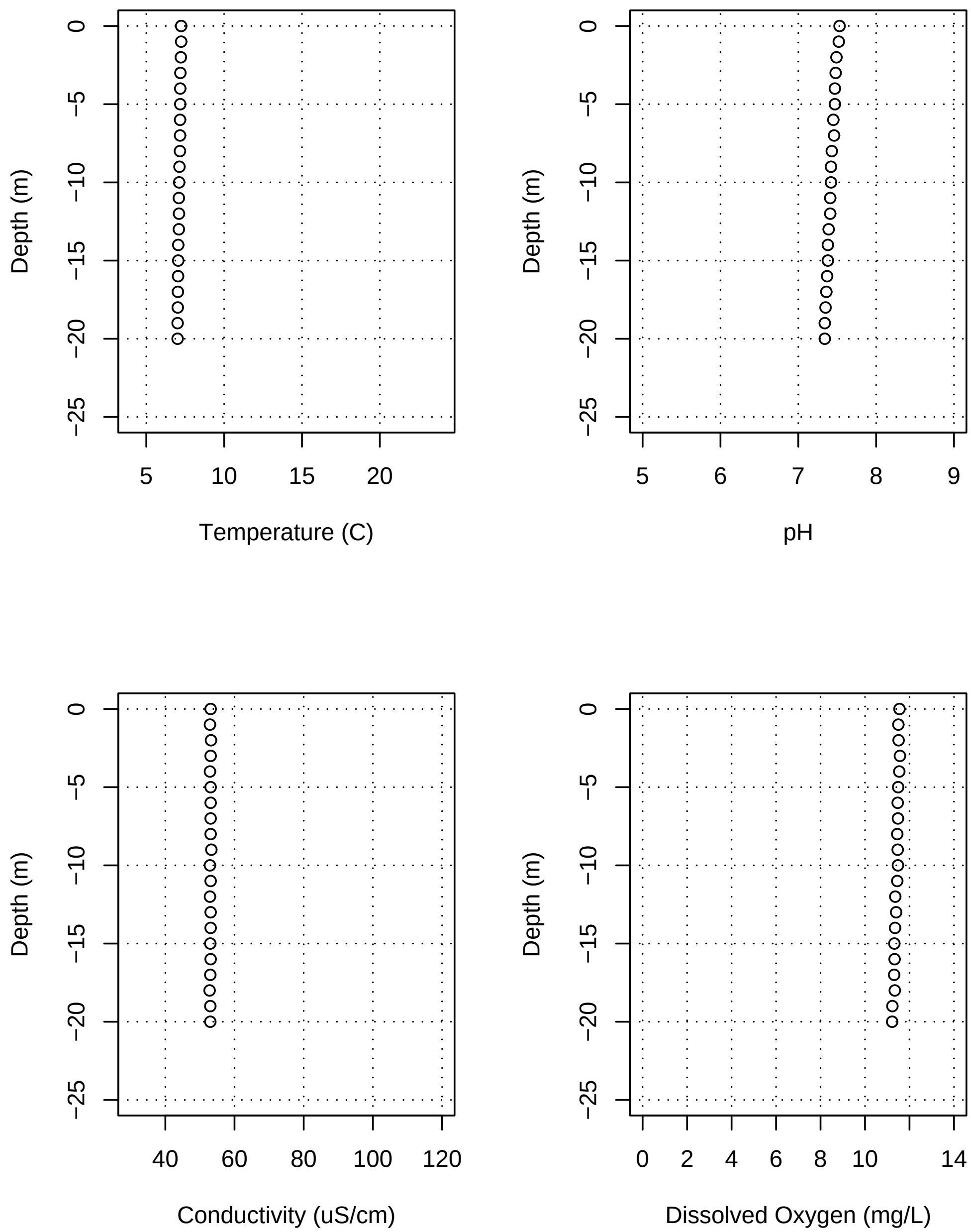


Figure B17: Lake Whatcom Hydrolab profile for Site 2, February 9, 2006.

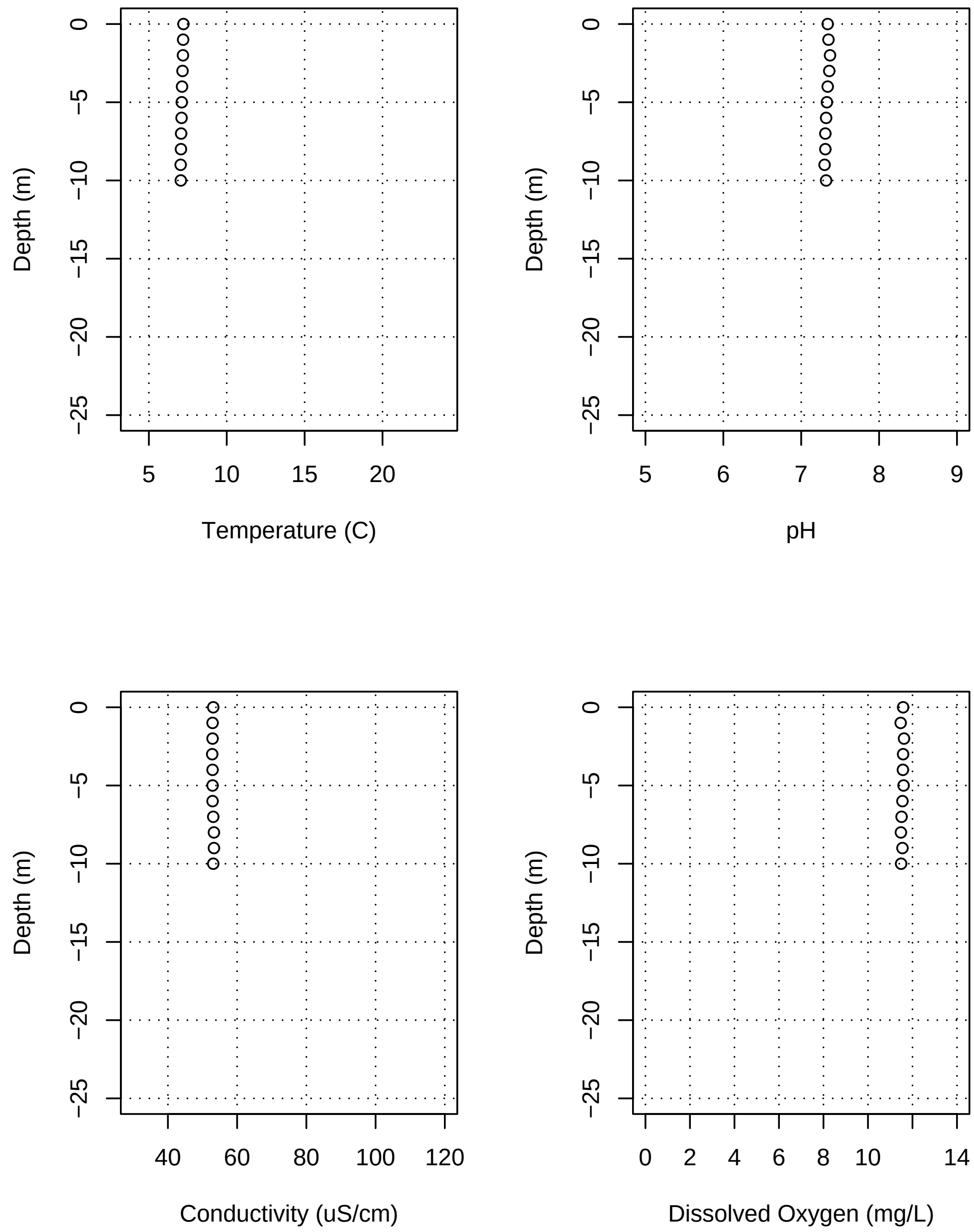


Figure B18: Lake Whatcom Hydrolab profile for the Intake, February 9, 2006.

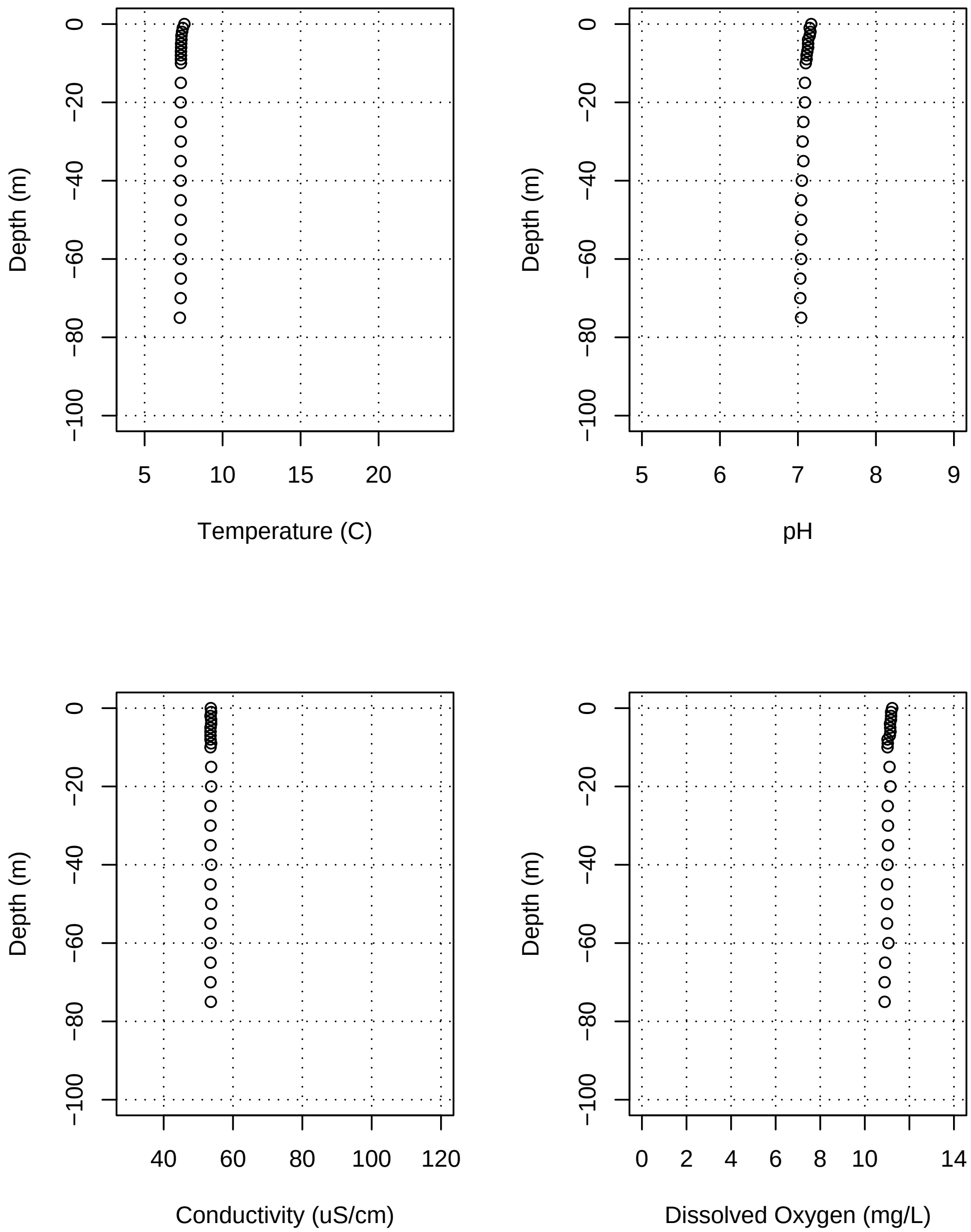


Figure B19: Lake Whatcom Hydrolab profile for Site 3, February 7, 2006.

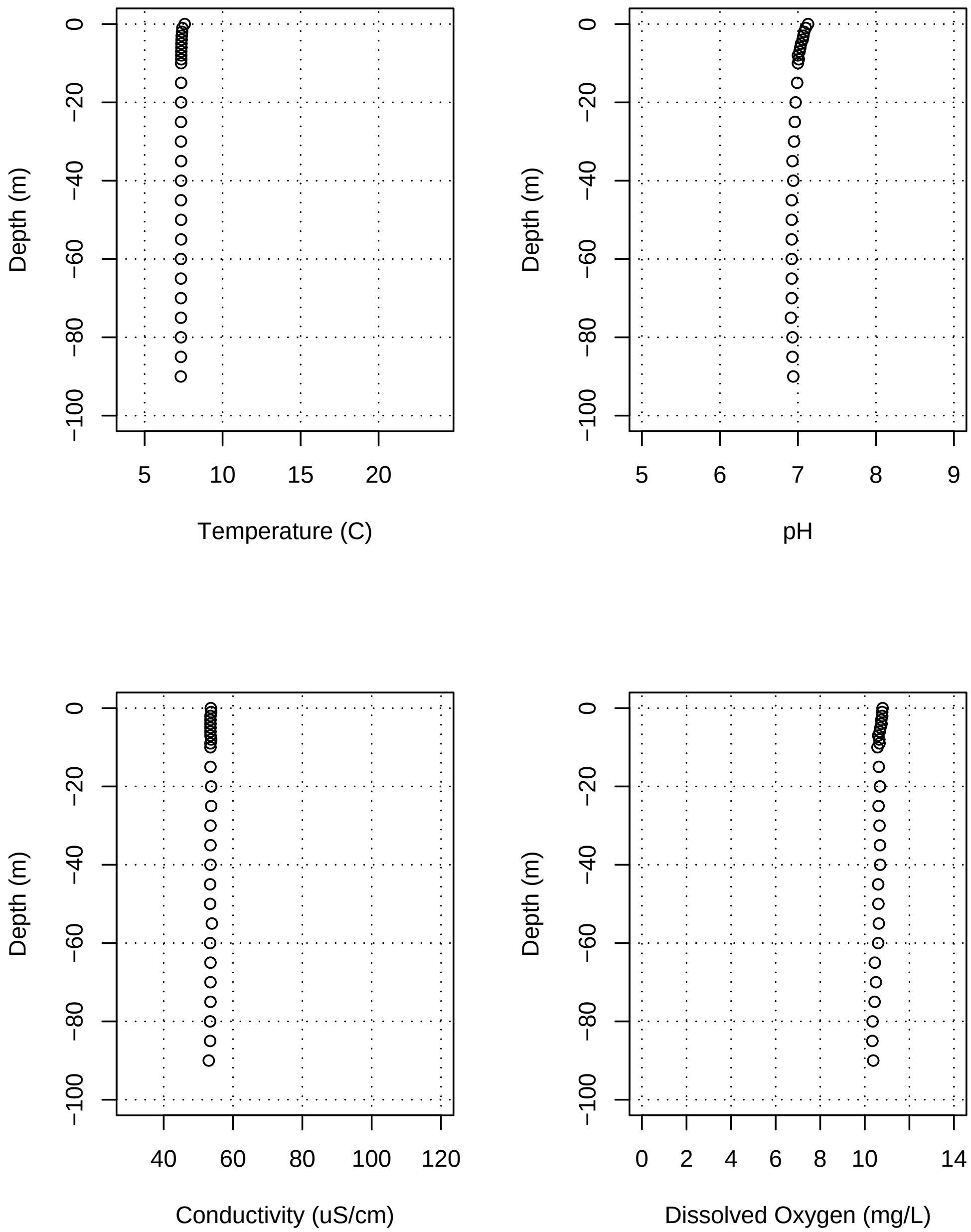


Figure B20: Lake Whatcom Hydrolab profile for Site 4, February 7, 2006.

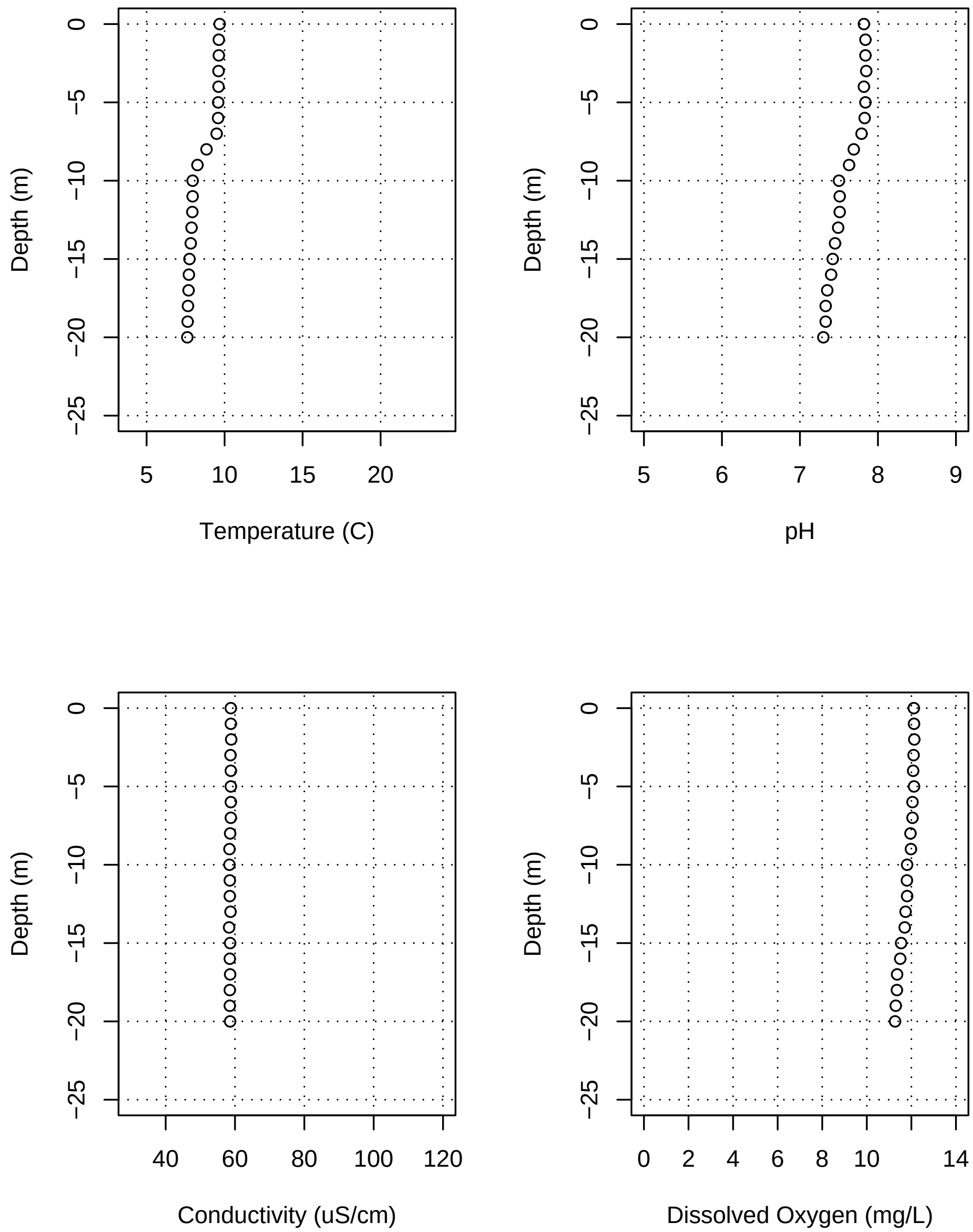


Figure B21: Lake Whatcom Hydrolab profile for Site 1, April 6, 2006.

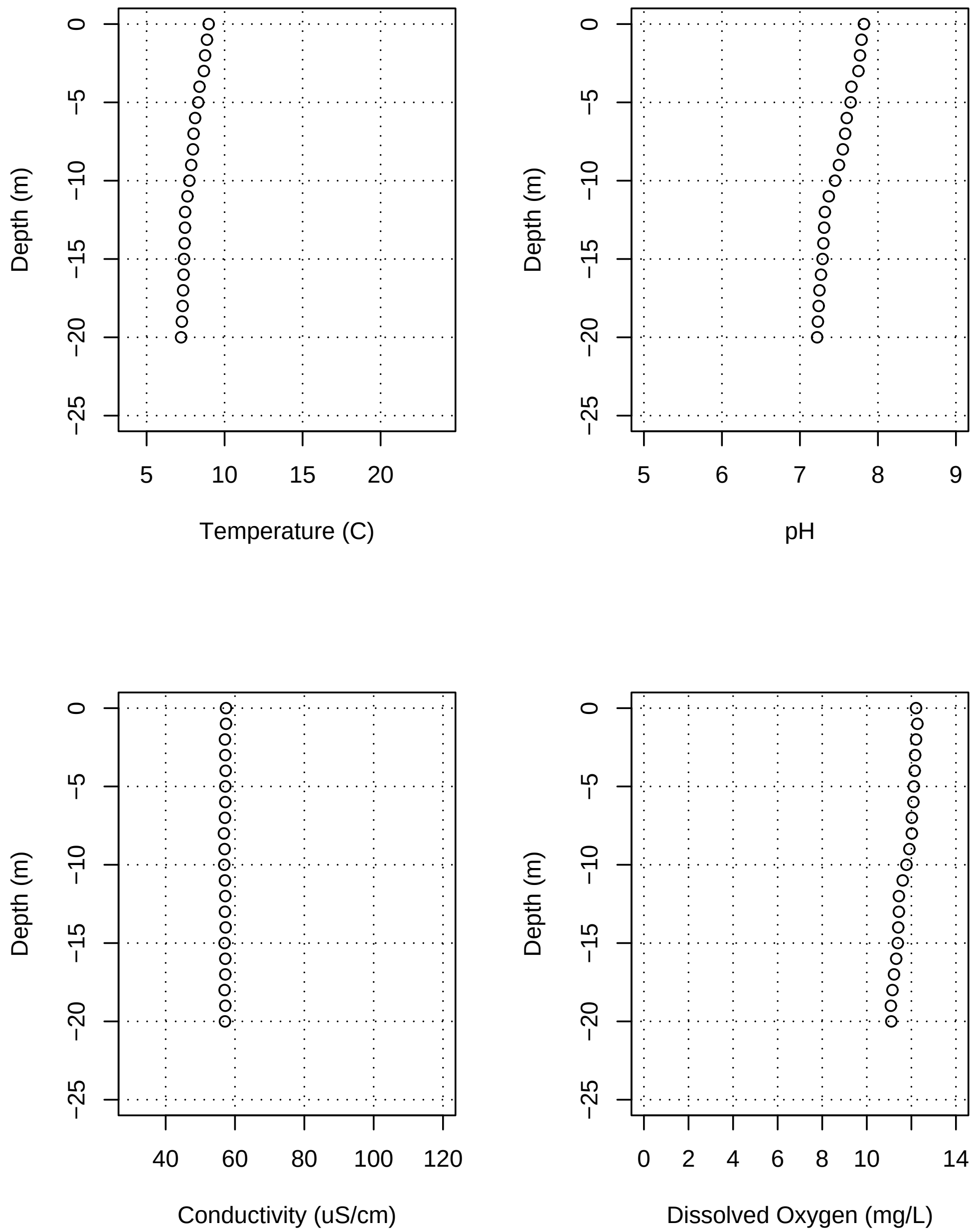


Figure B22: Lake Whatcom Hydrolab profile for Site 2, April 6, 2006.

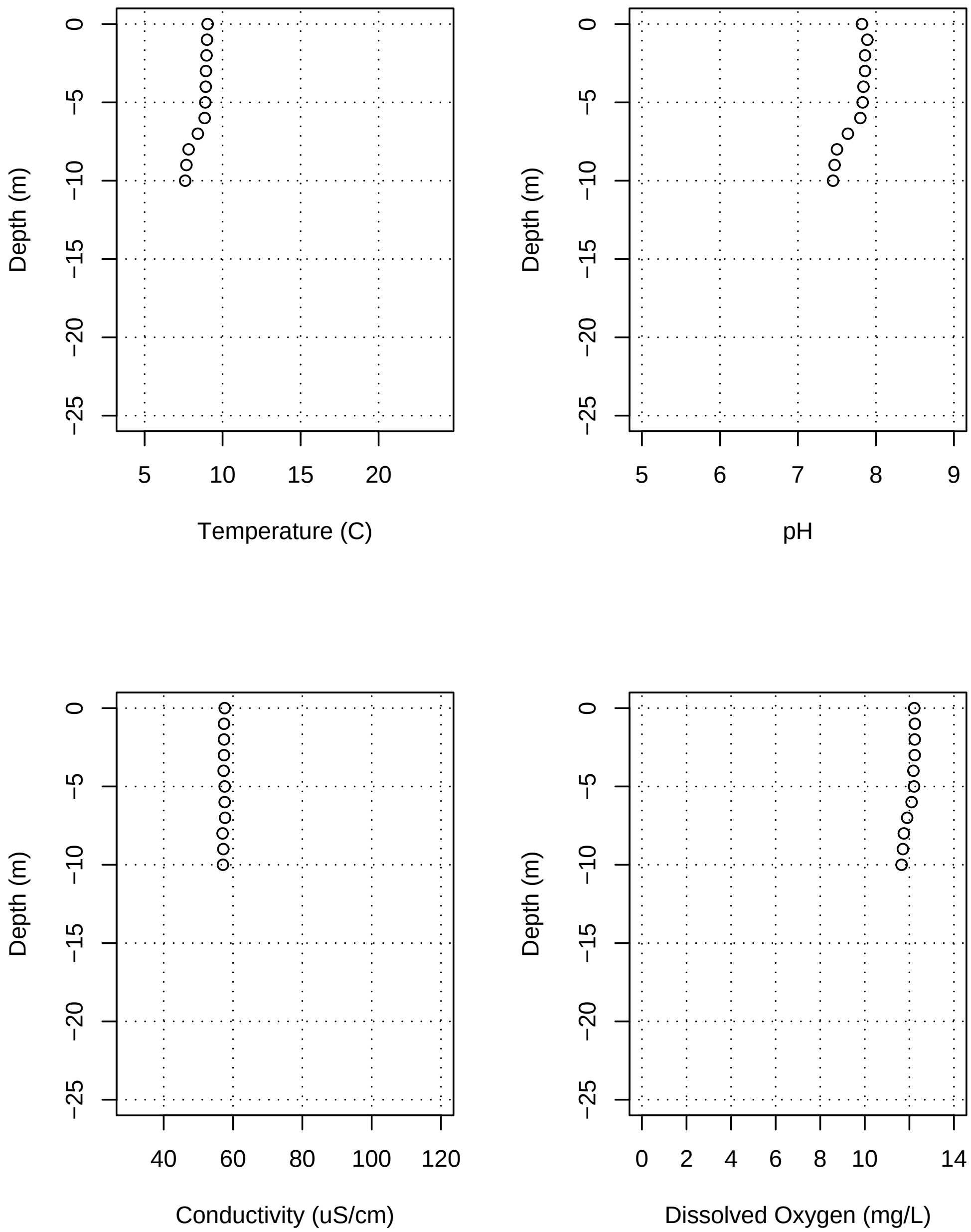


Figure B23: Lake Whatcom Hydrolab profile for the Intake, April 6, 2006.

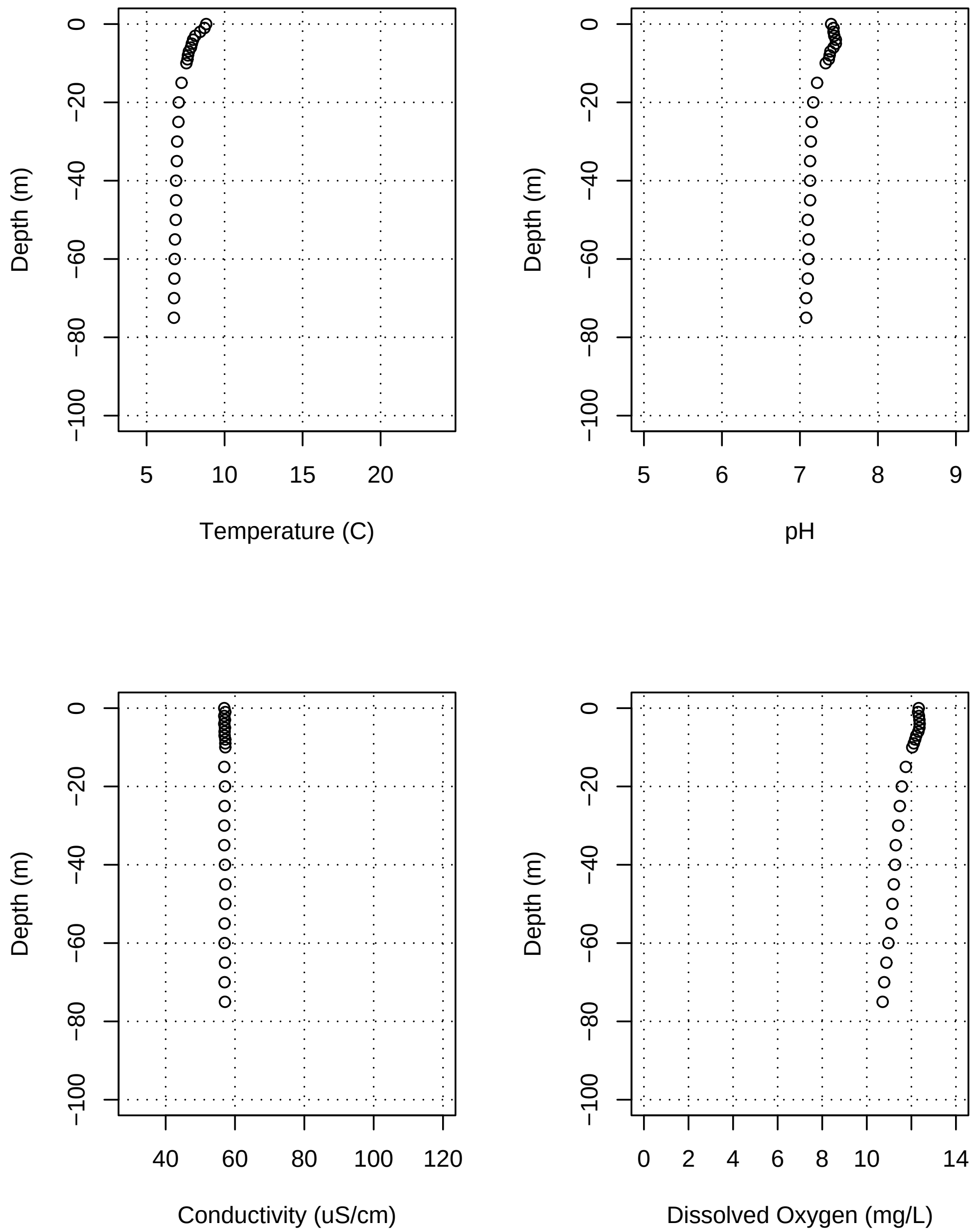


Figure B24: Lake Whatcom Hydrolab profile for Site 3, April 4, 2006.

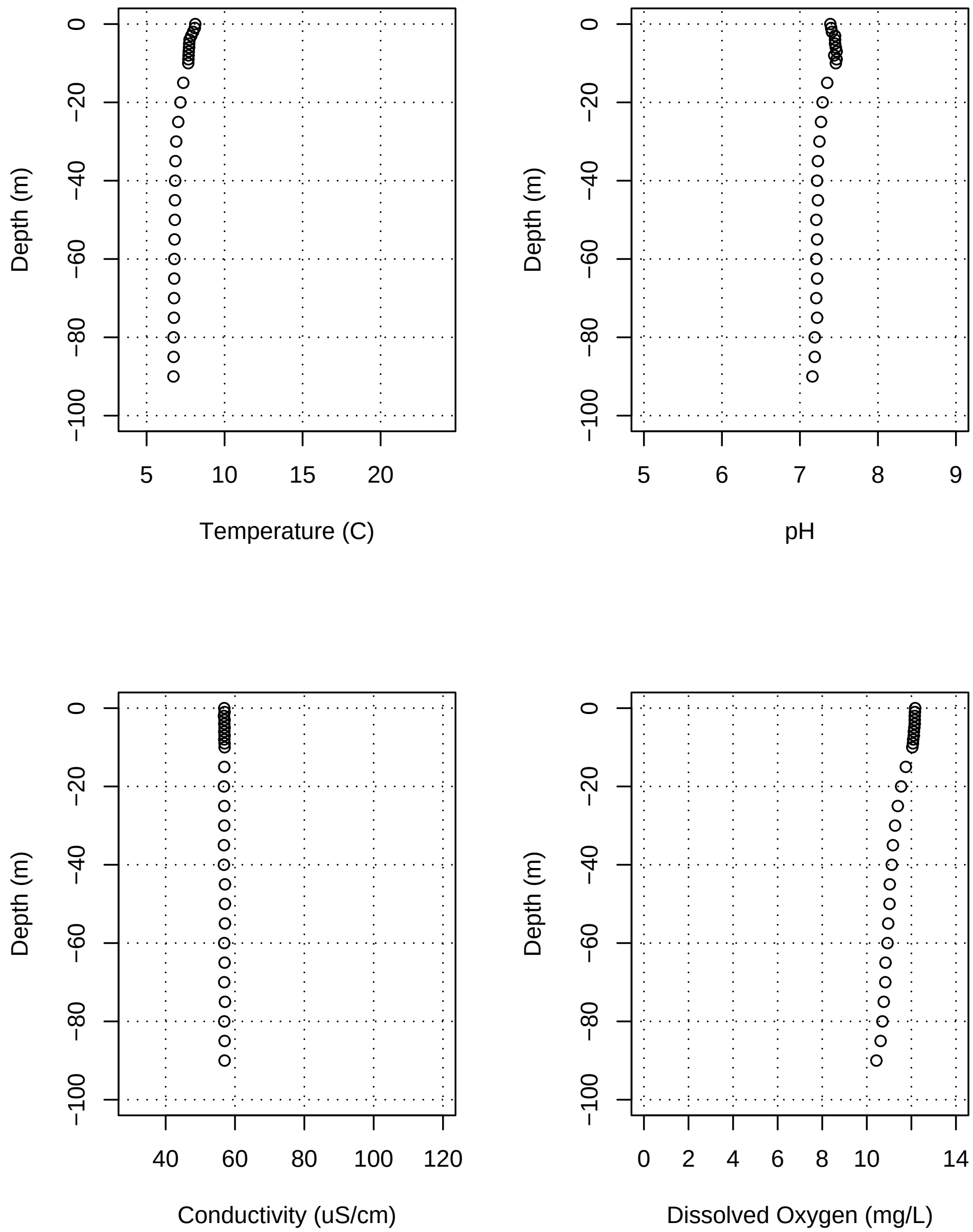


Figure B25: Lake Whatcom Hydrolab profile for Site 4, April 4, 2006.

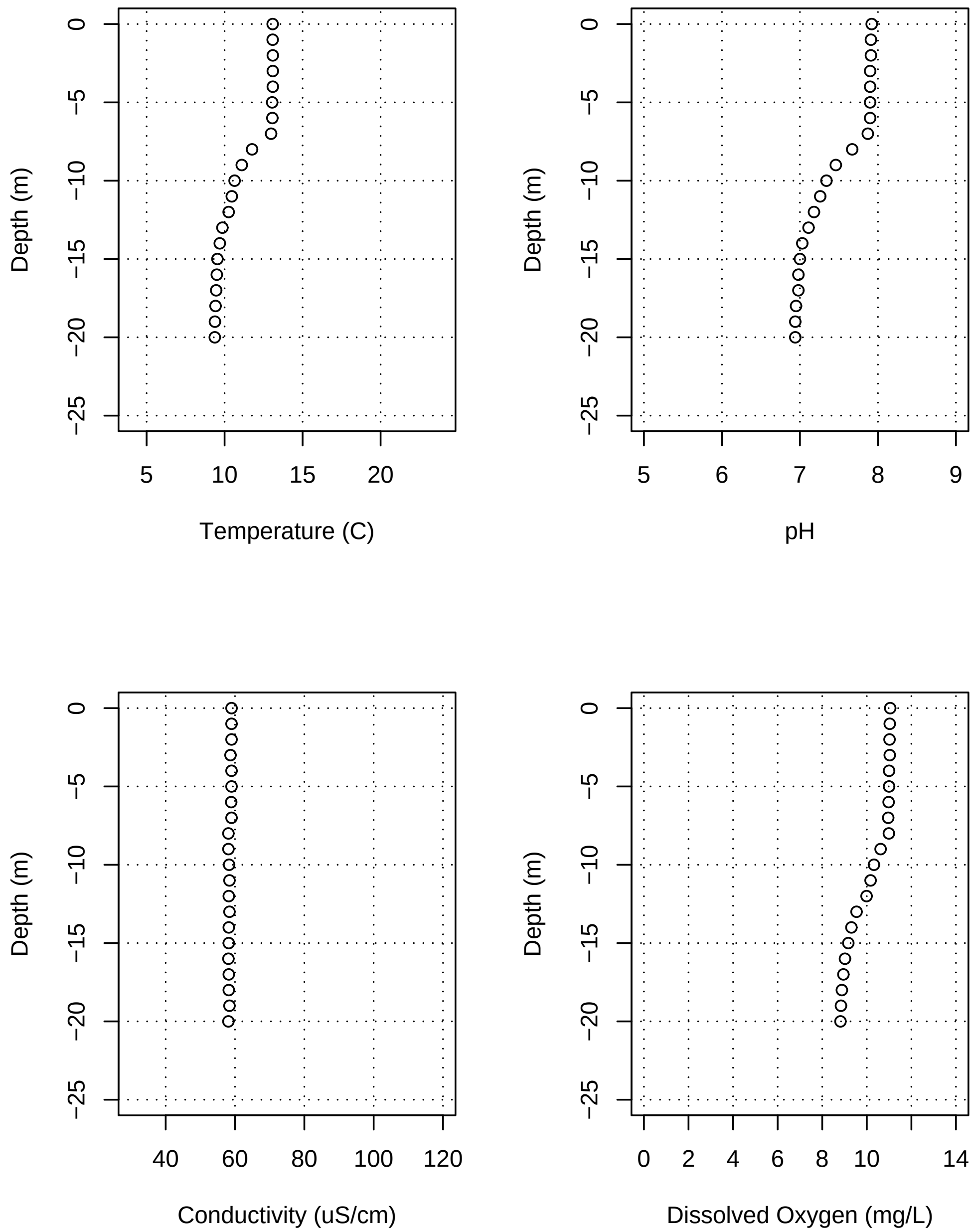


Figure B26: Lake Whatcom Hydrolab profile for Site 1, May 11, 2006.

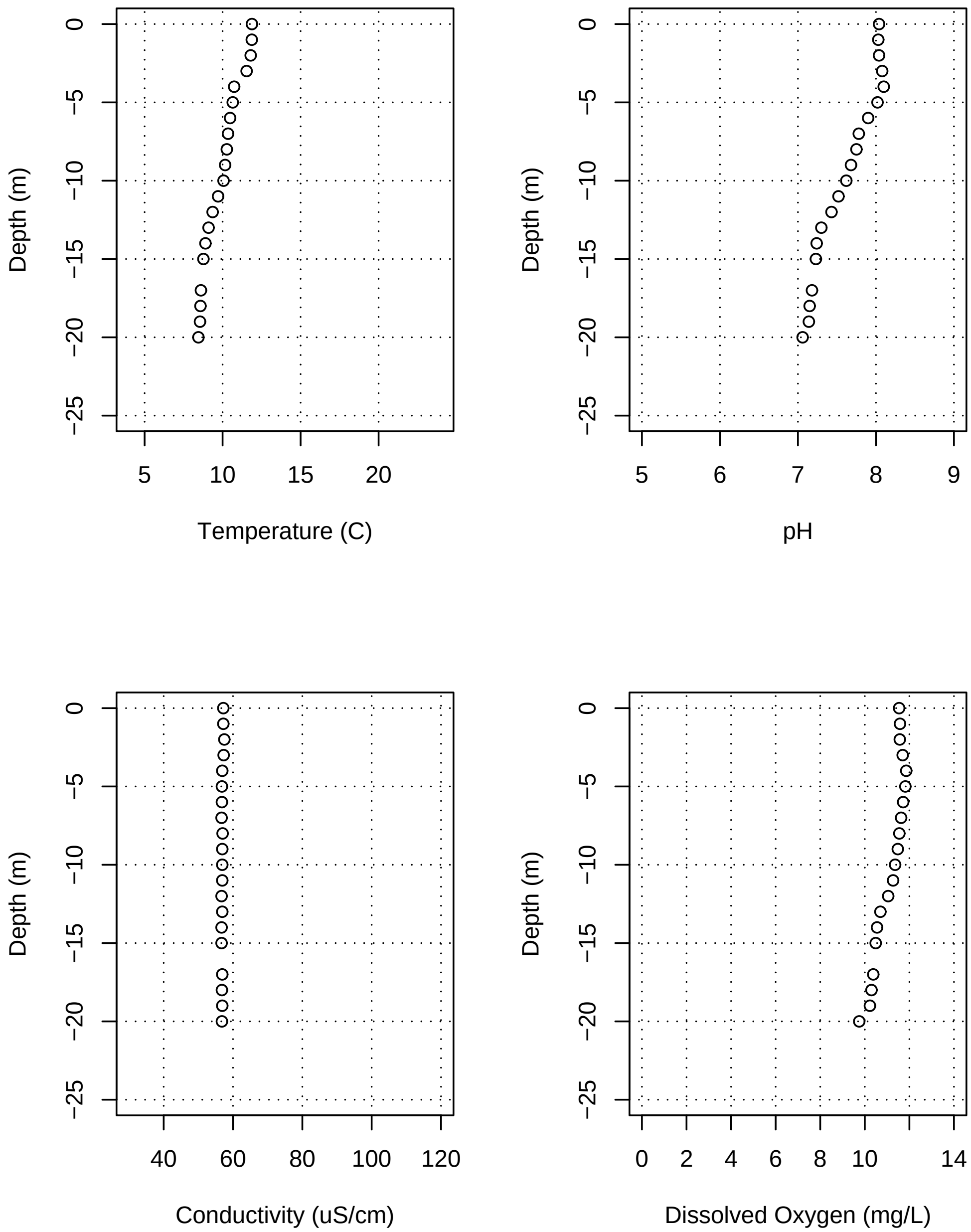


Figure B27: Lake Whatcom Hydrolab profile for Site 2, May 11, 2006.

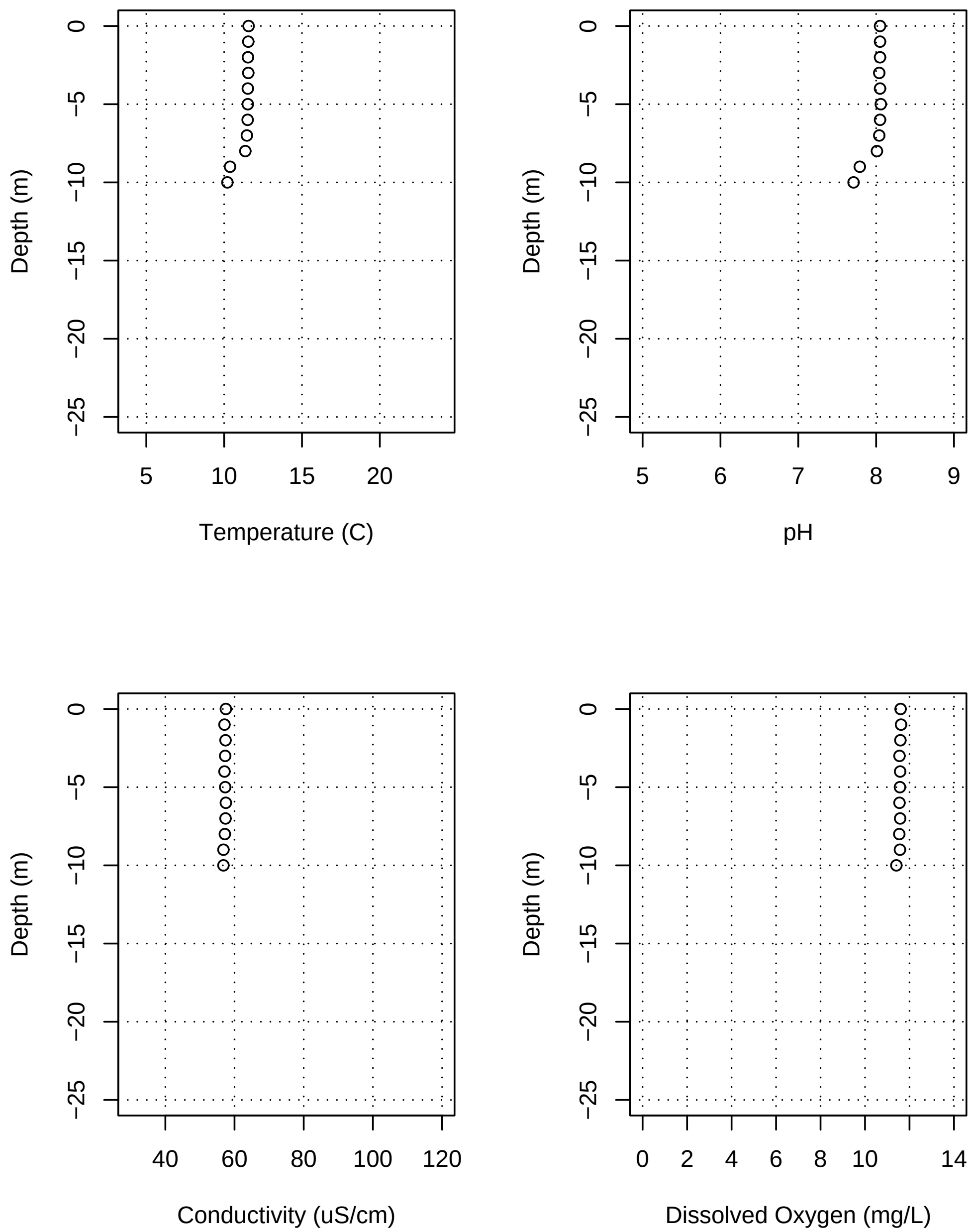


Figure B28: Lake Whatcom Hydrolab profile for the Intake, May 11, 2006.

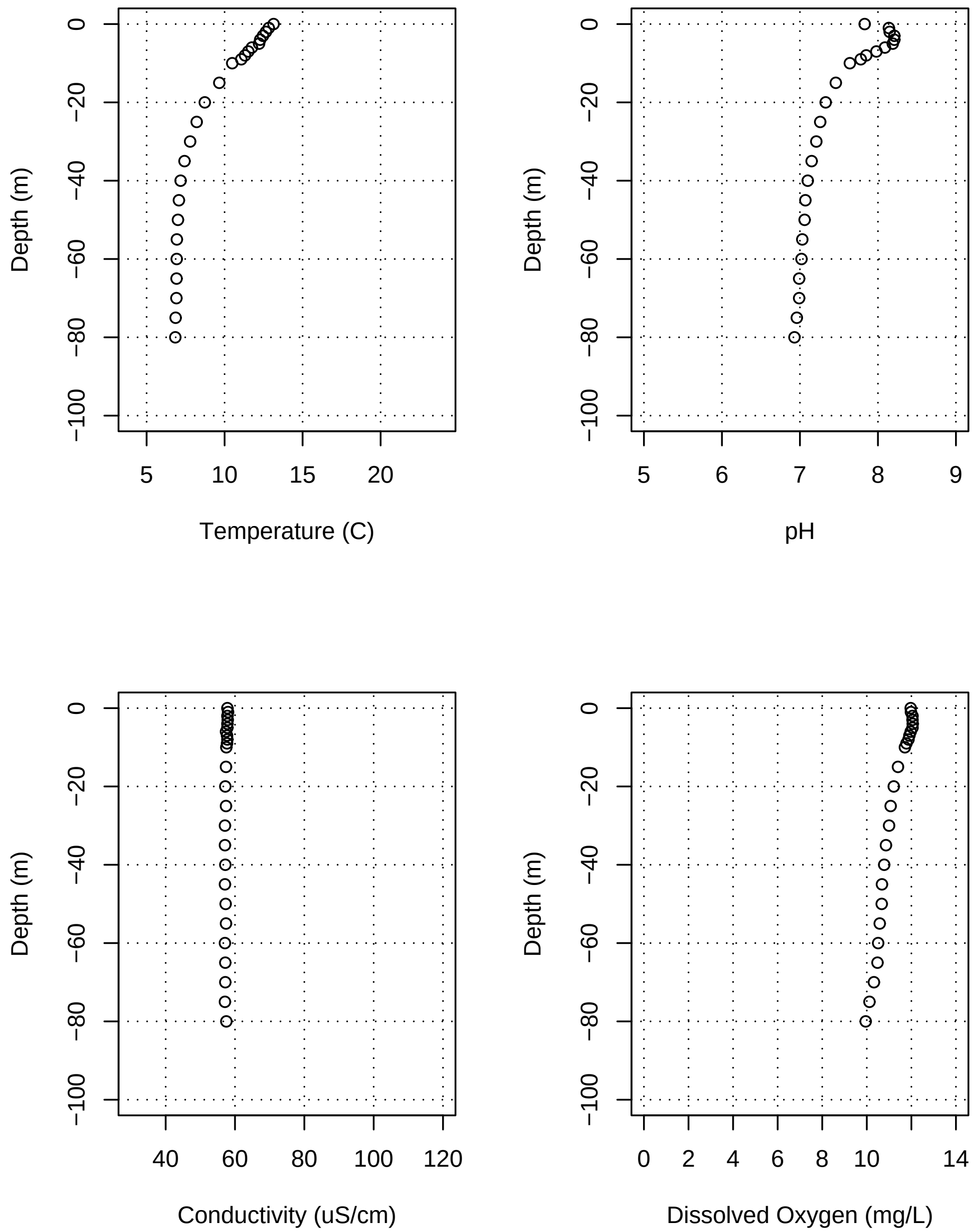


Figure B29: Lake Whatcom Hydrolab profile for Site 3, May 15, 2006.

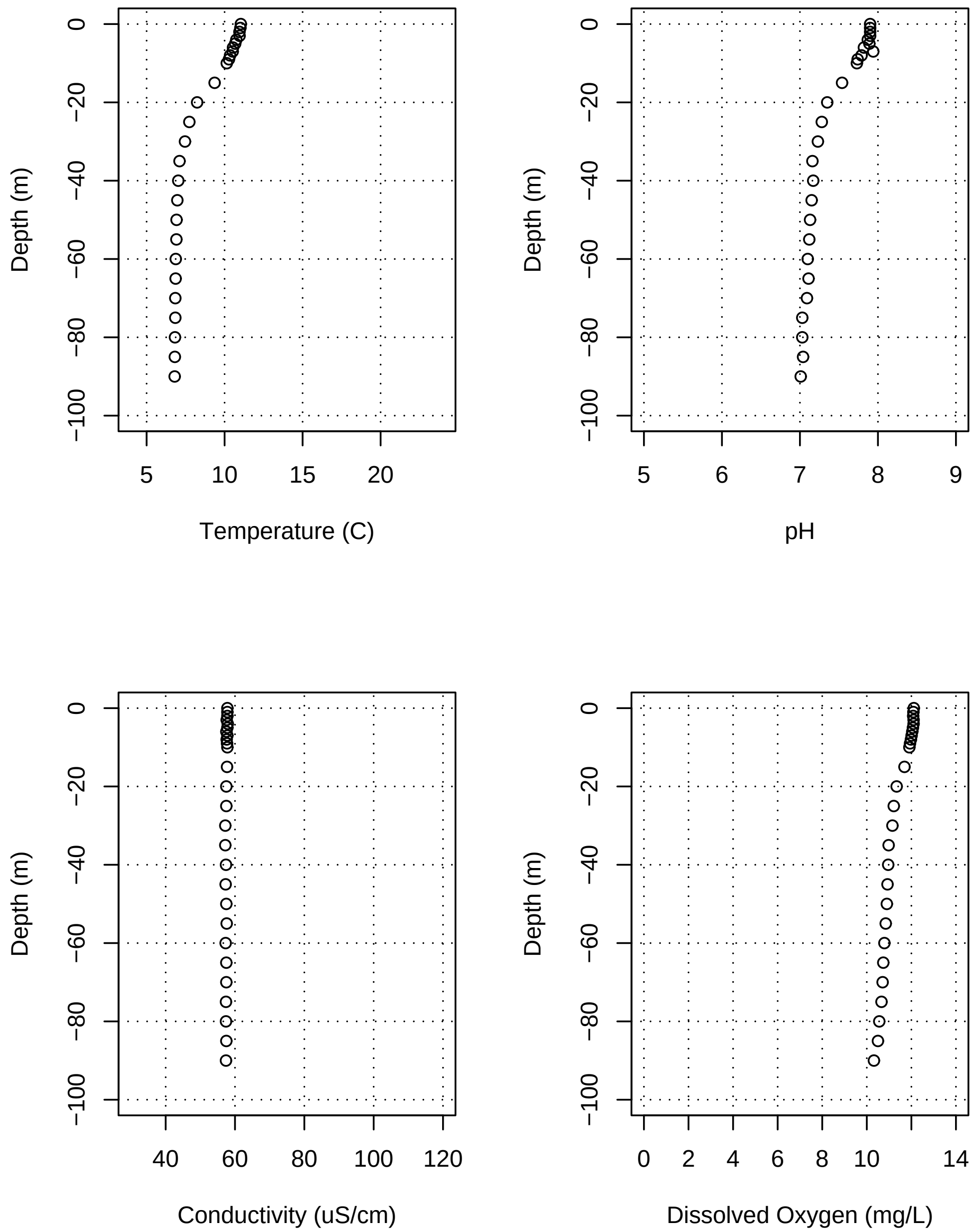


Figure B30: Lake Whatcom Hydrolab profile for Site 4, May 9, 2006.

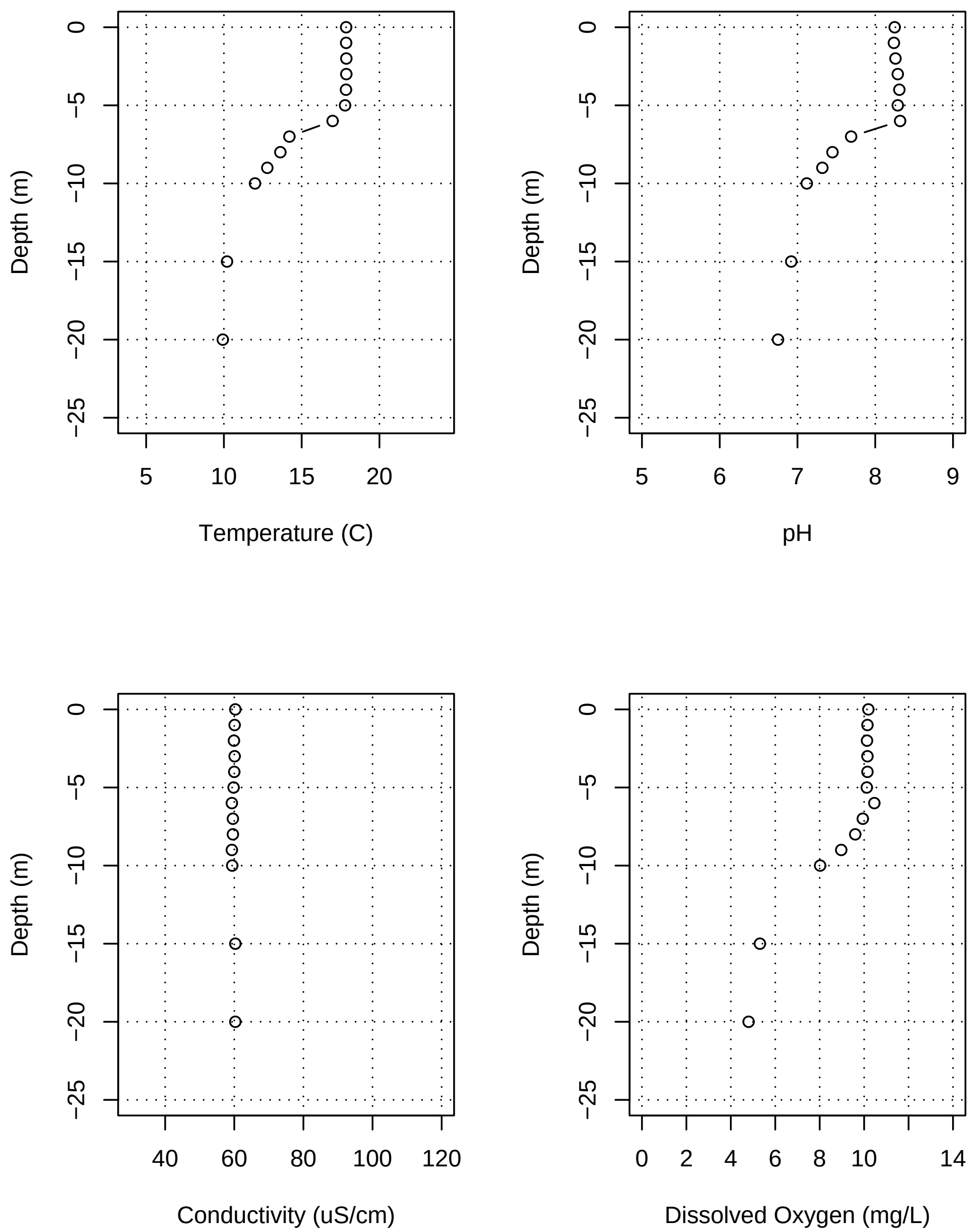


Figure B31: Lake Whatcom Hydrolab profile for Site 1, June 14, 2006. Points below 10 m missing due to equipment malfunction.

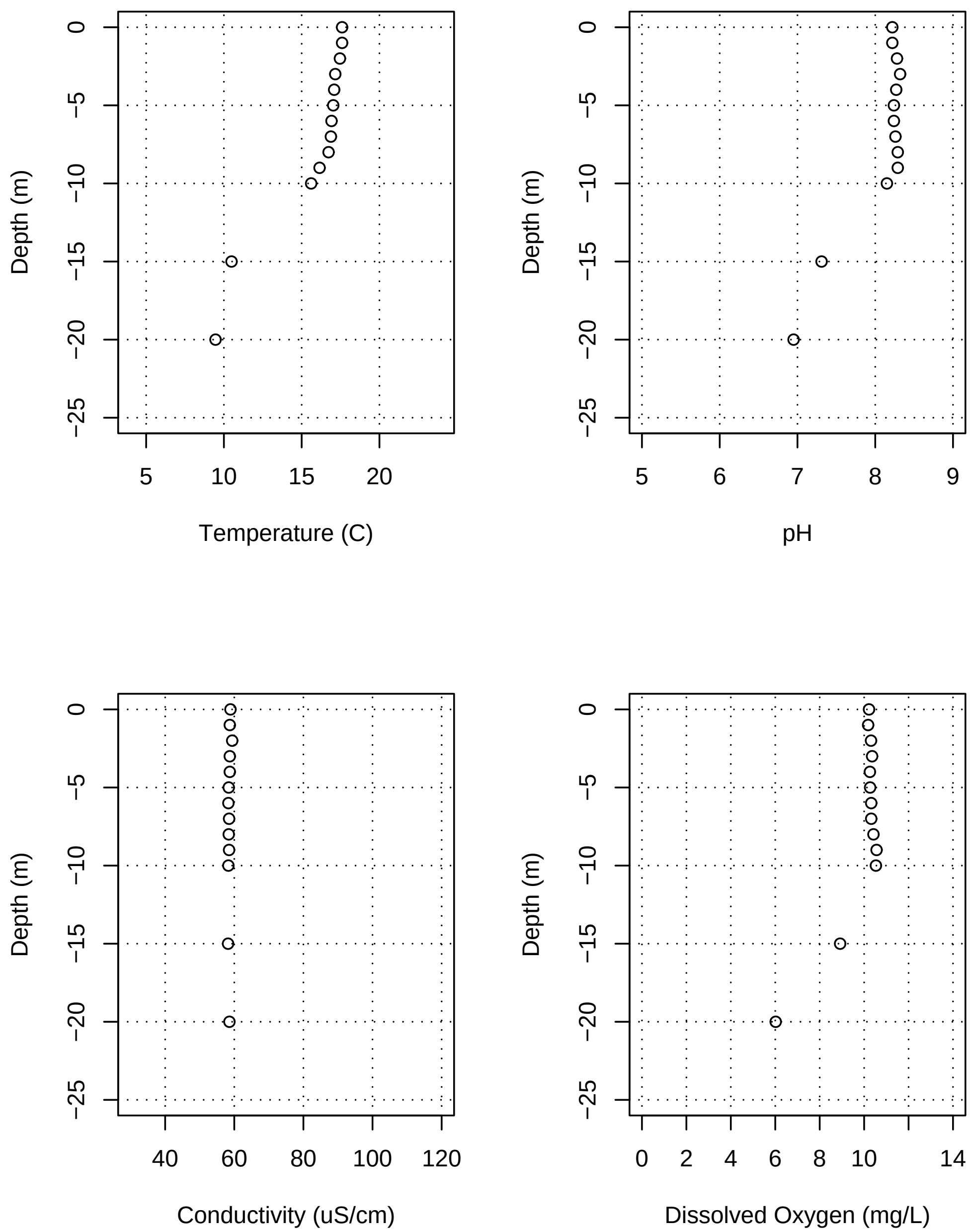


Figure B32: Lake Whatcom Hydrolab profile for Site 2, June 14, 2006. Points below 10 m missing due to equipment malfunction.

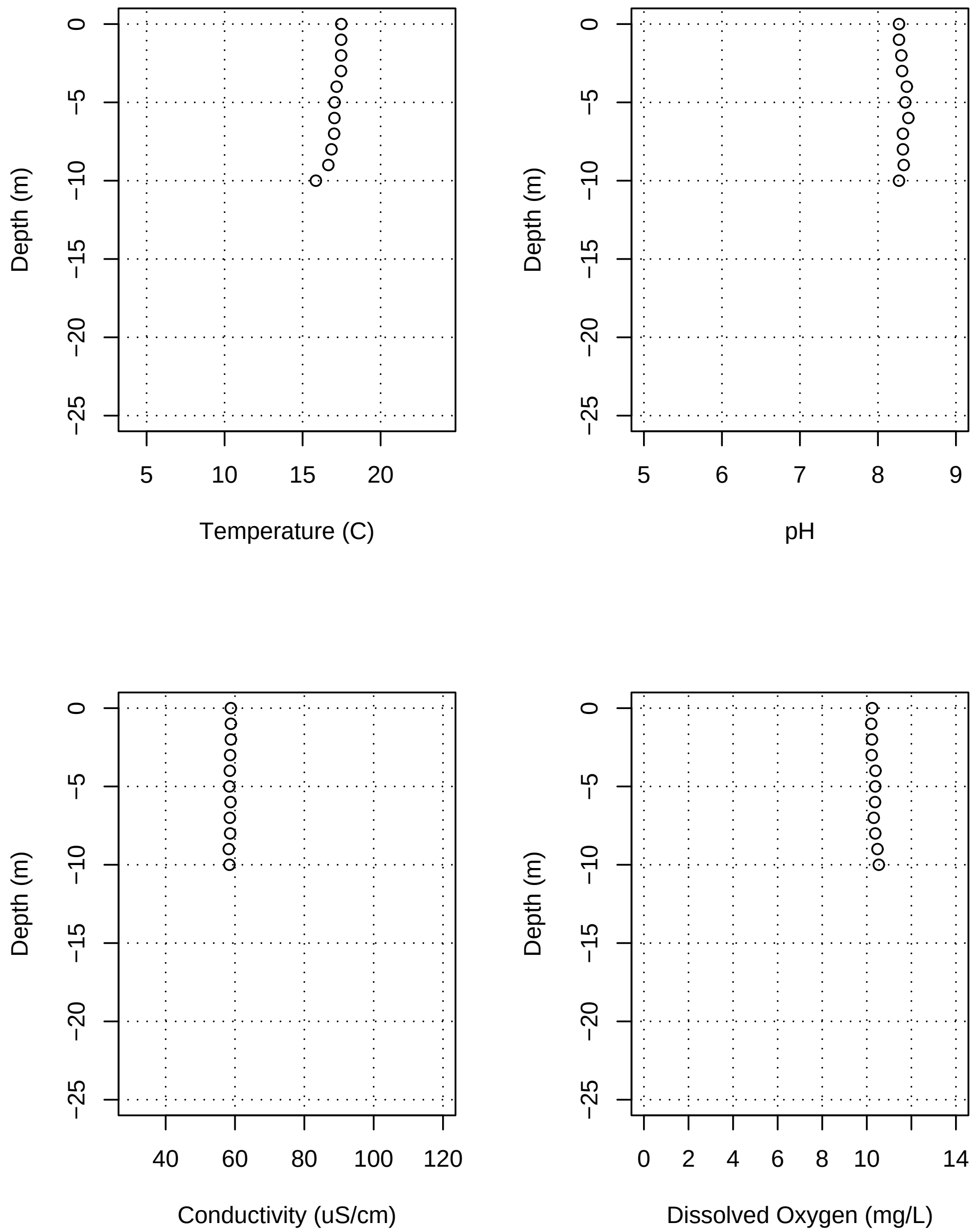


Figure B33: Lake Whatcom Hydrolab profile for the Intake, June 14, 2006.

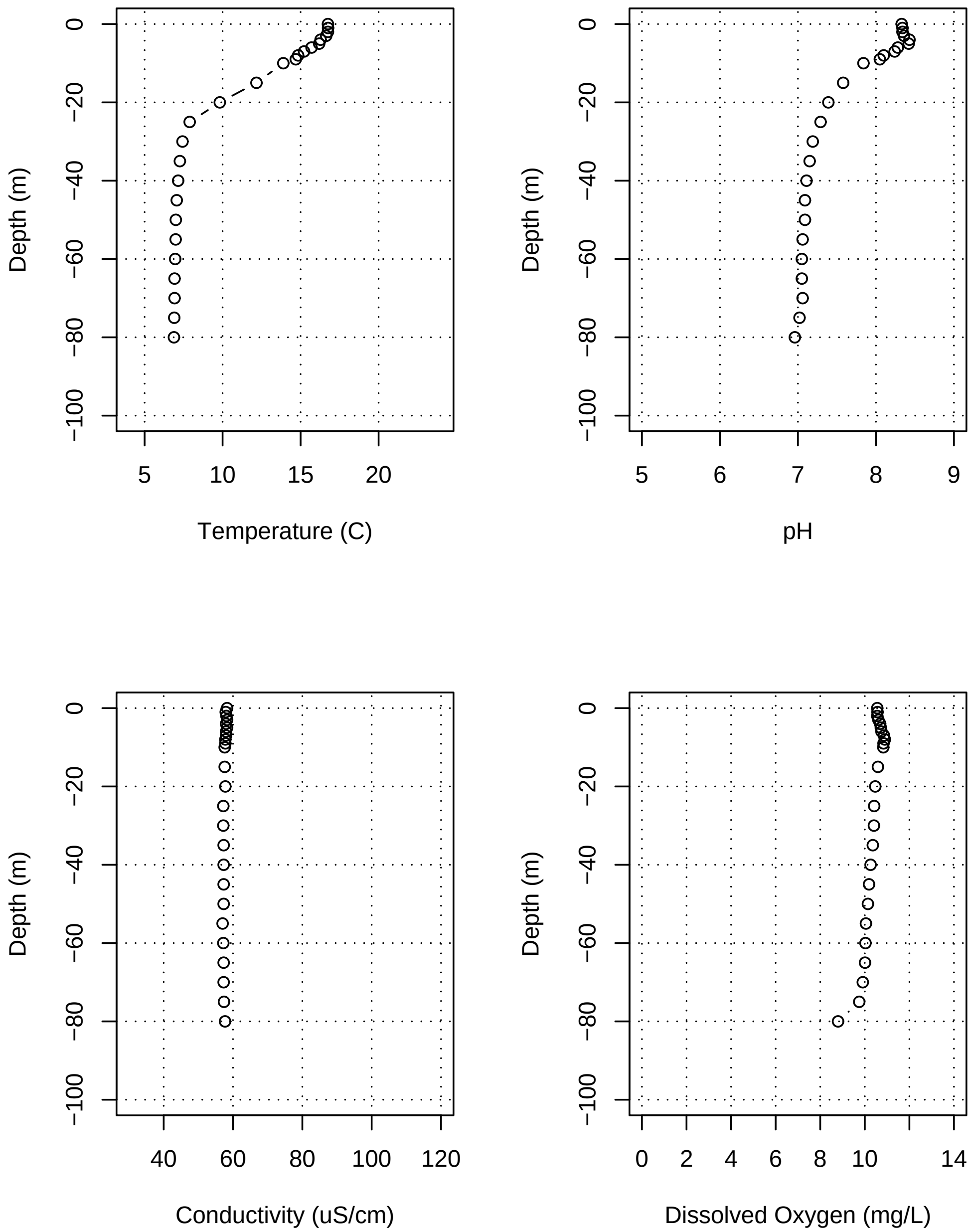


Figure B34: Lake Whatcom Hydrolab profile for Site 3, June 13, 2006.

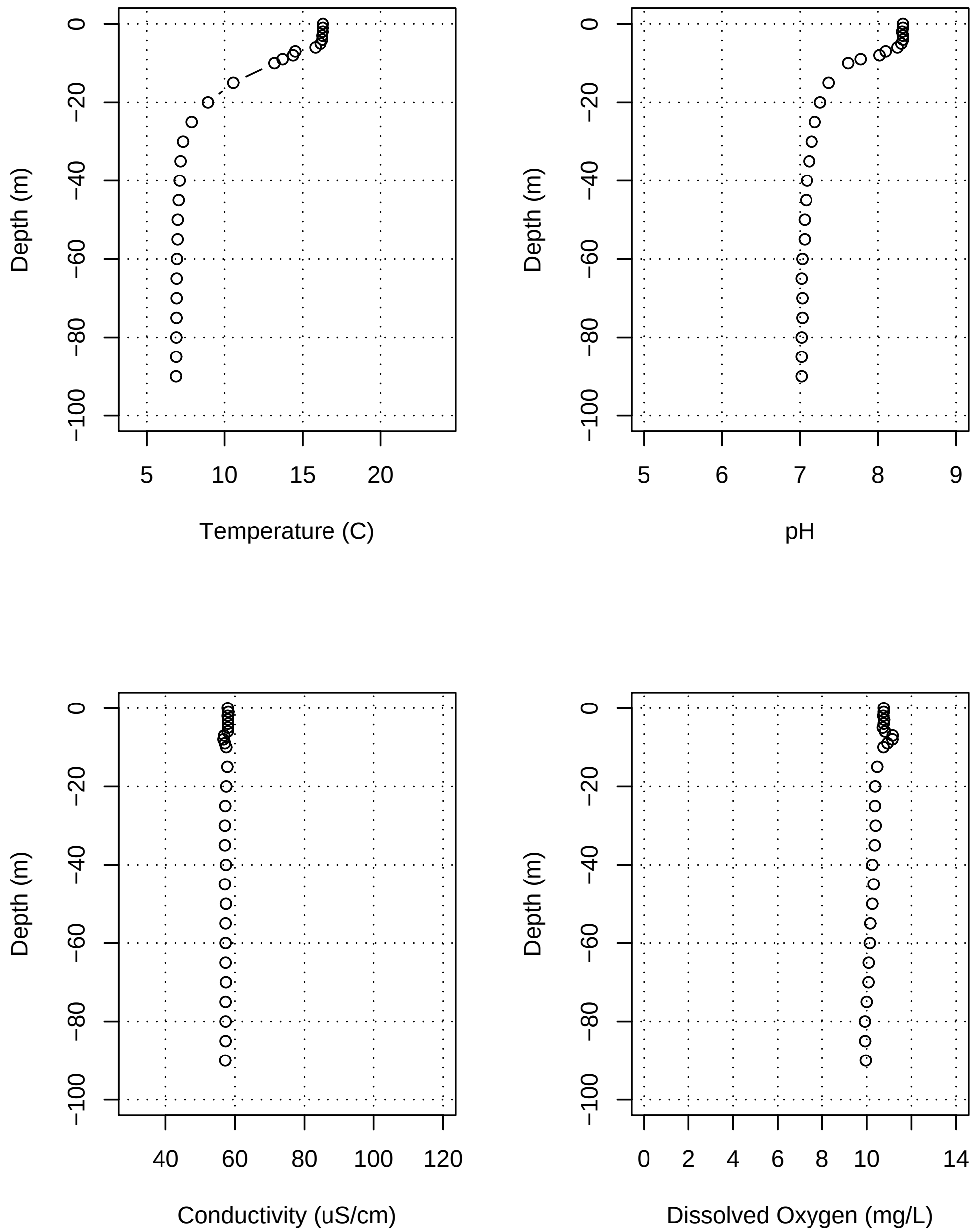


Figure B35: Lake Whatcom Hydrolab profile for Site 4, June 13, 2006.

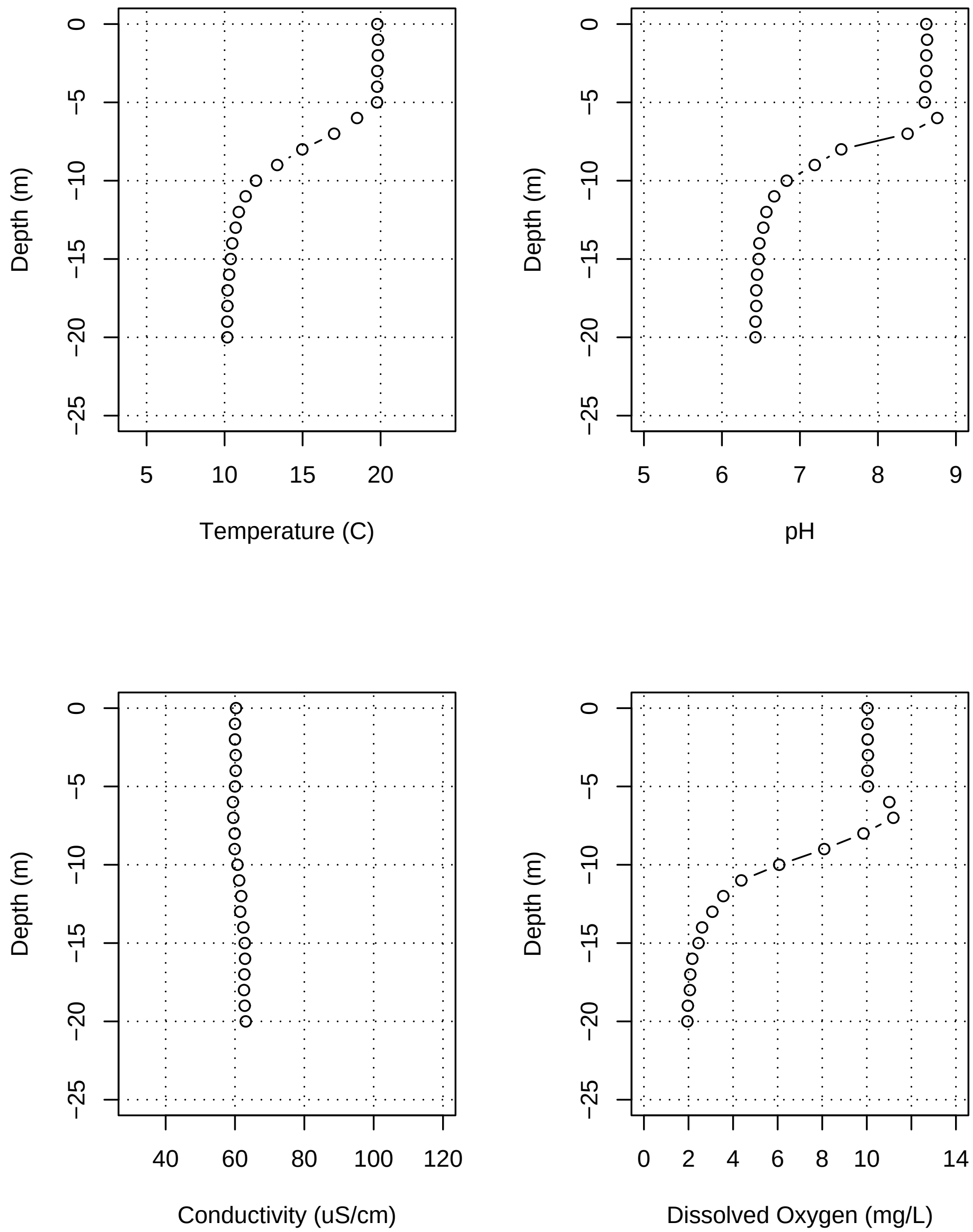


Figure B36: Lake Whatcom Hydrolab profile for Site 1, July 12, 2006.

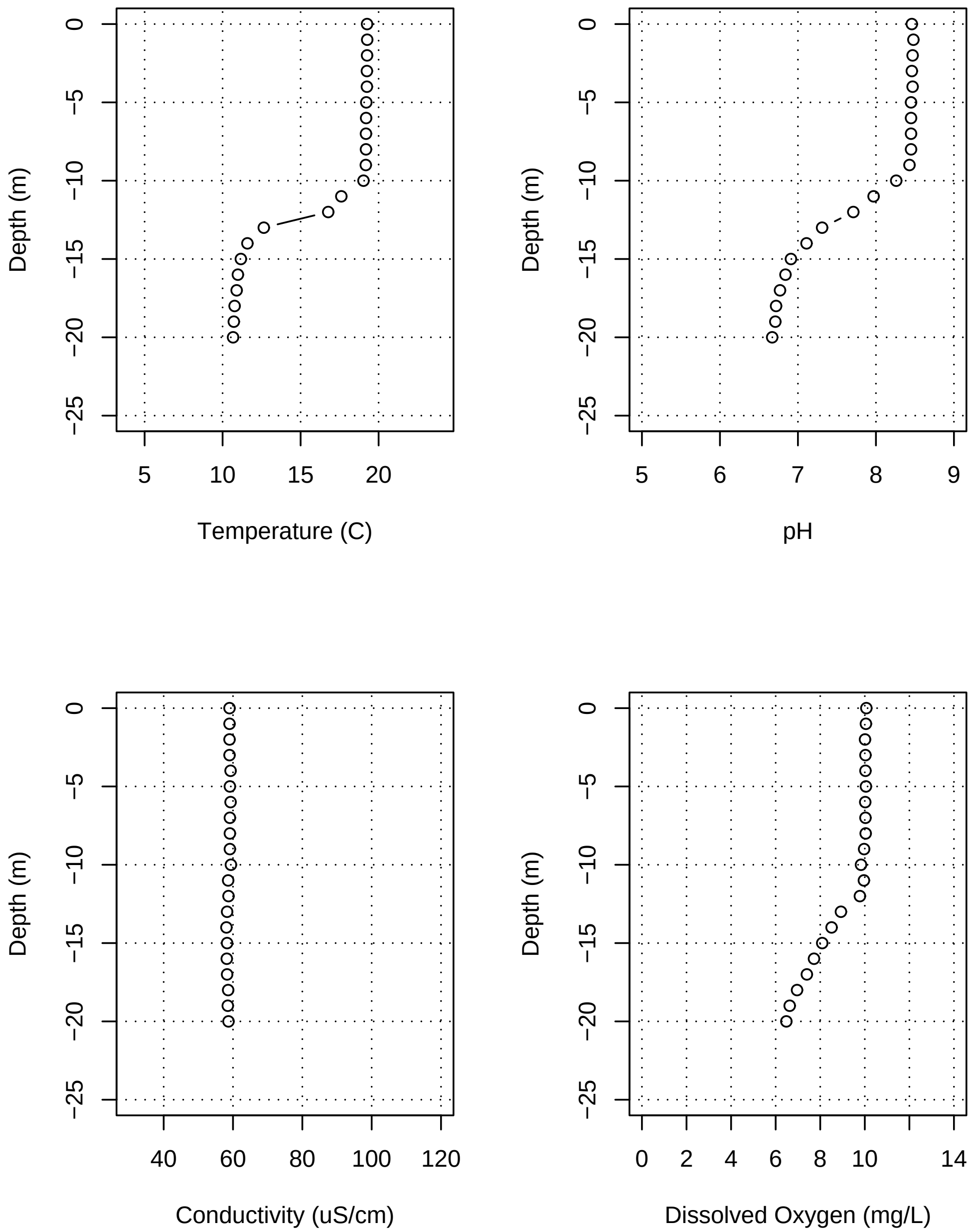


Figure B37: Lake Whatcom Hydrolab profile for Site 2, July 12, 2006.

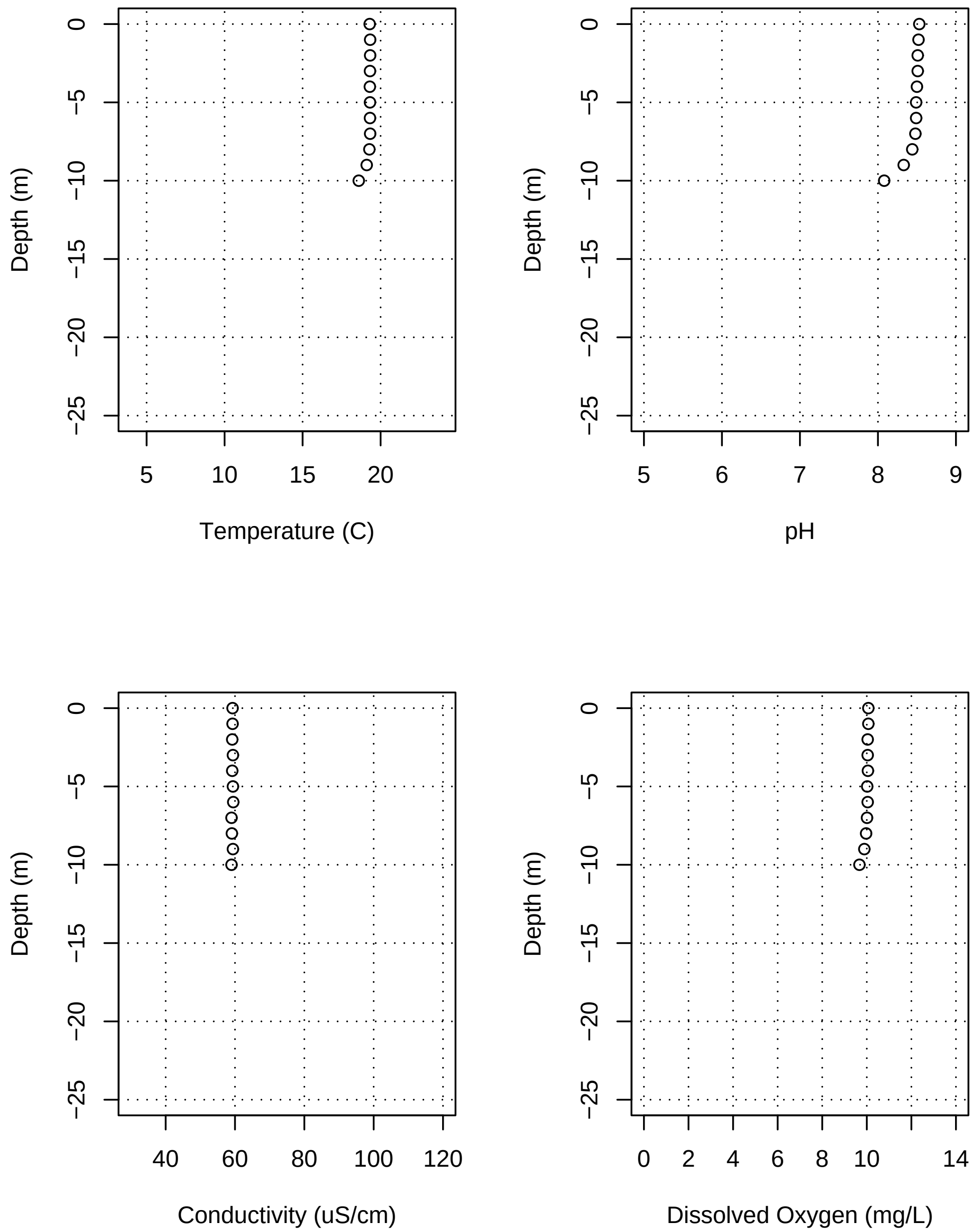


Figure B38: Lake Whatcom Hydrolab profile for the Intake, July 12, 2006.

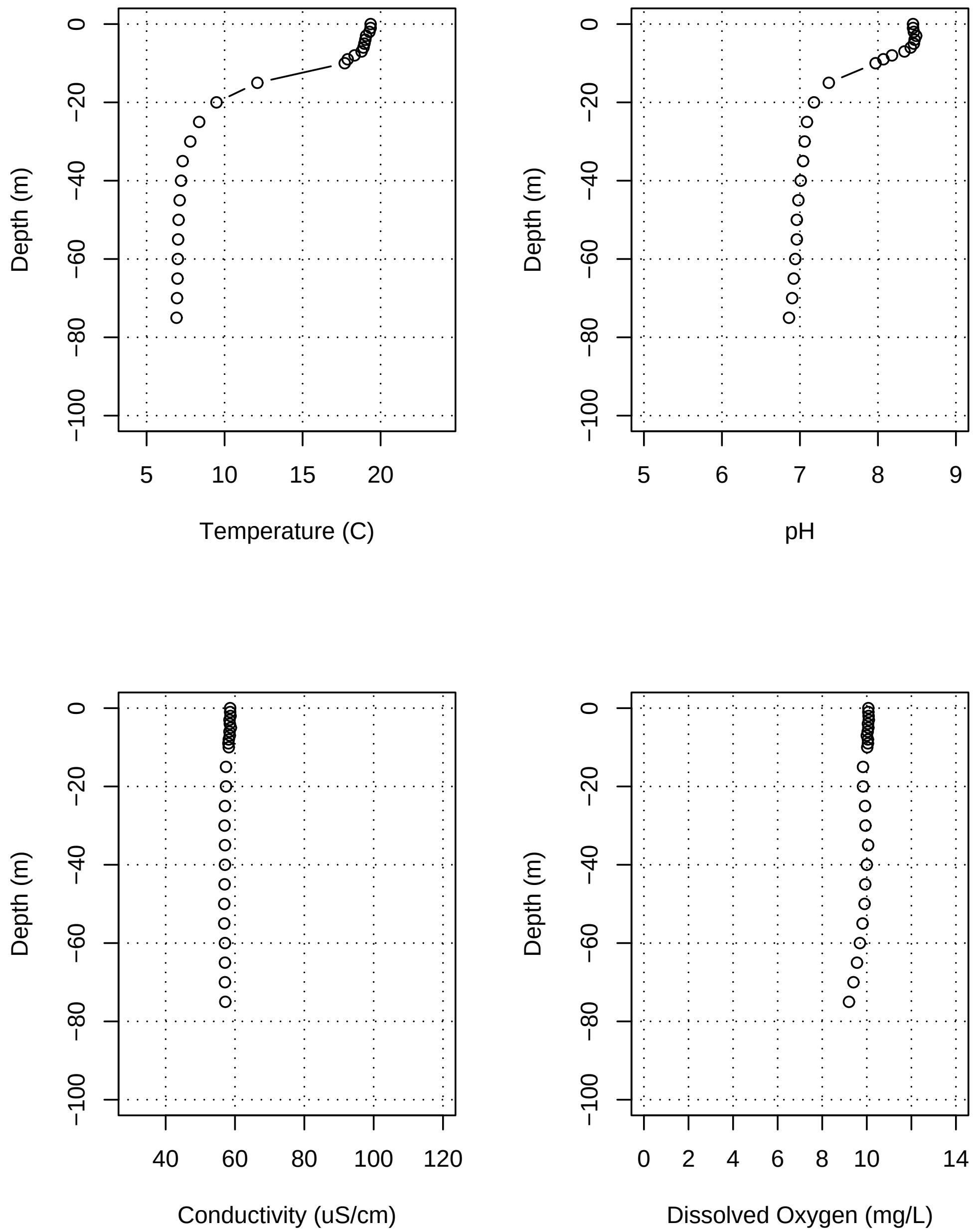


Figure B39: Lake Whatcom Hydrolab profile for Site 3, July 11, 2006.

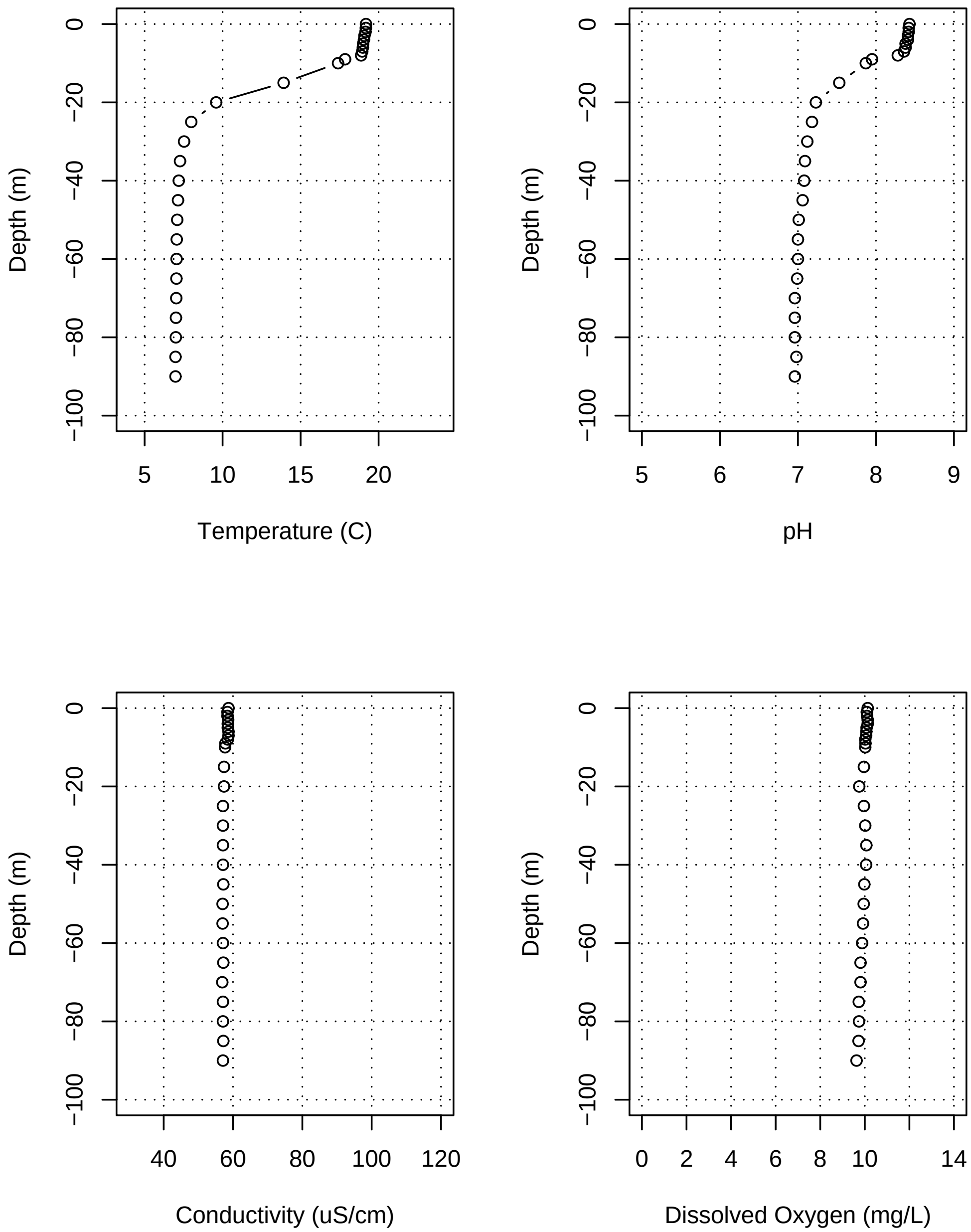


Figure B40: Lake Whatcom Hydrolab profile for Site 4, July 11, 2006.

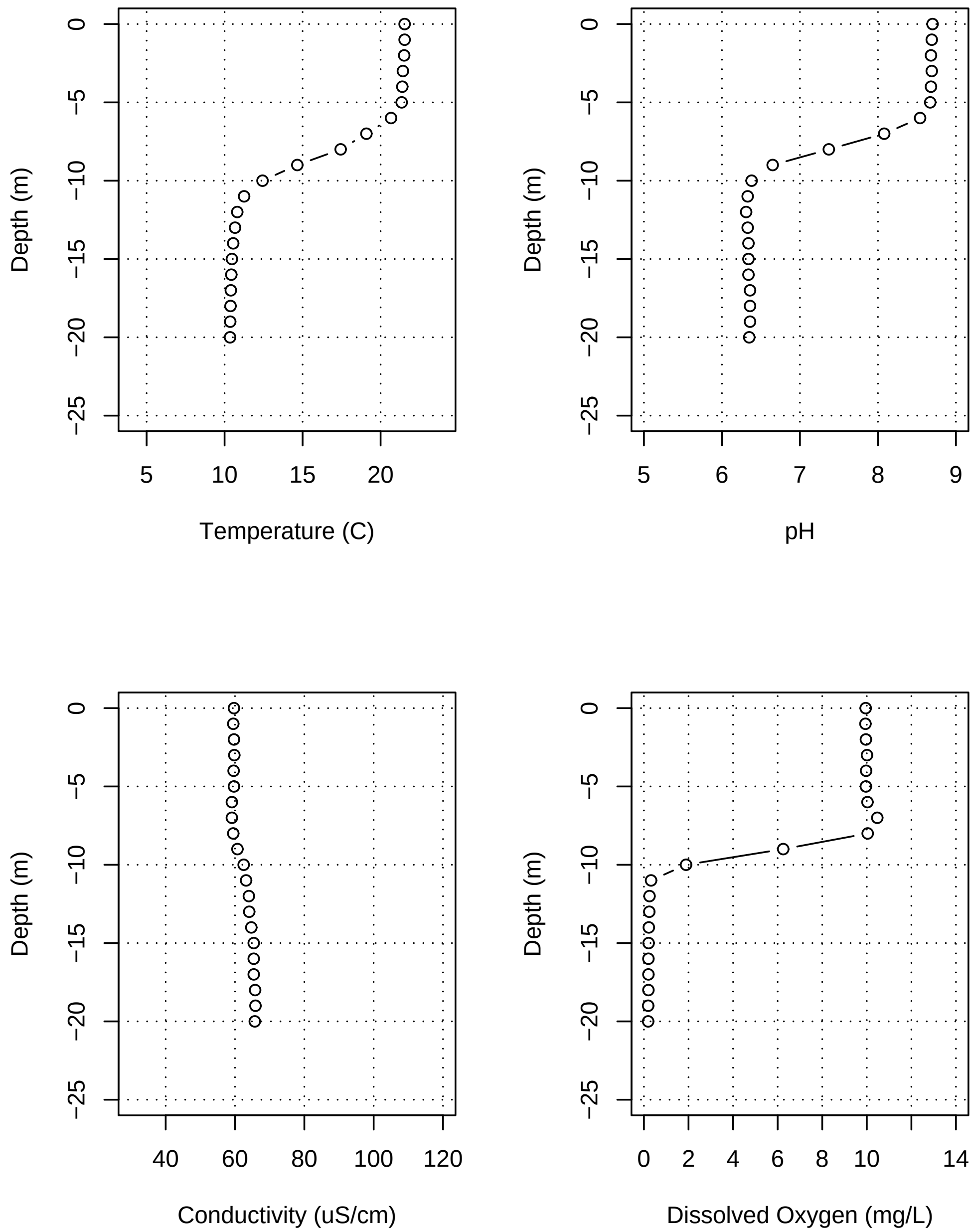


Figure B41: Lake Whatcom Hydrolab profile for Site 1, August 8, 2006.

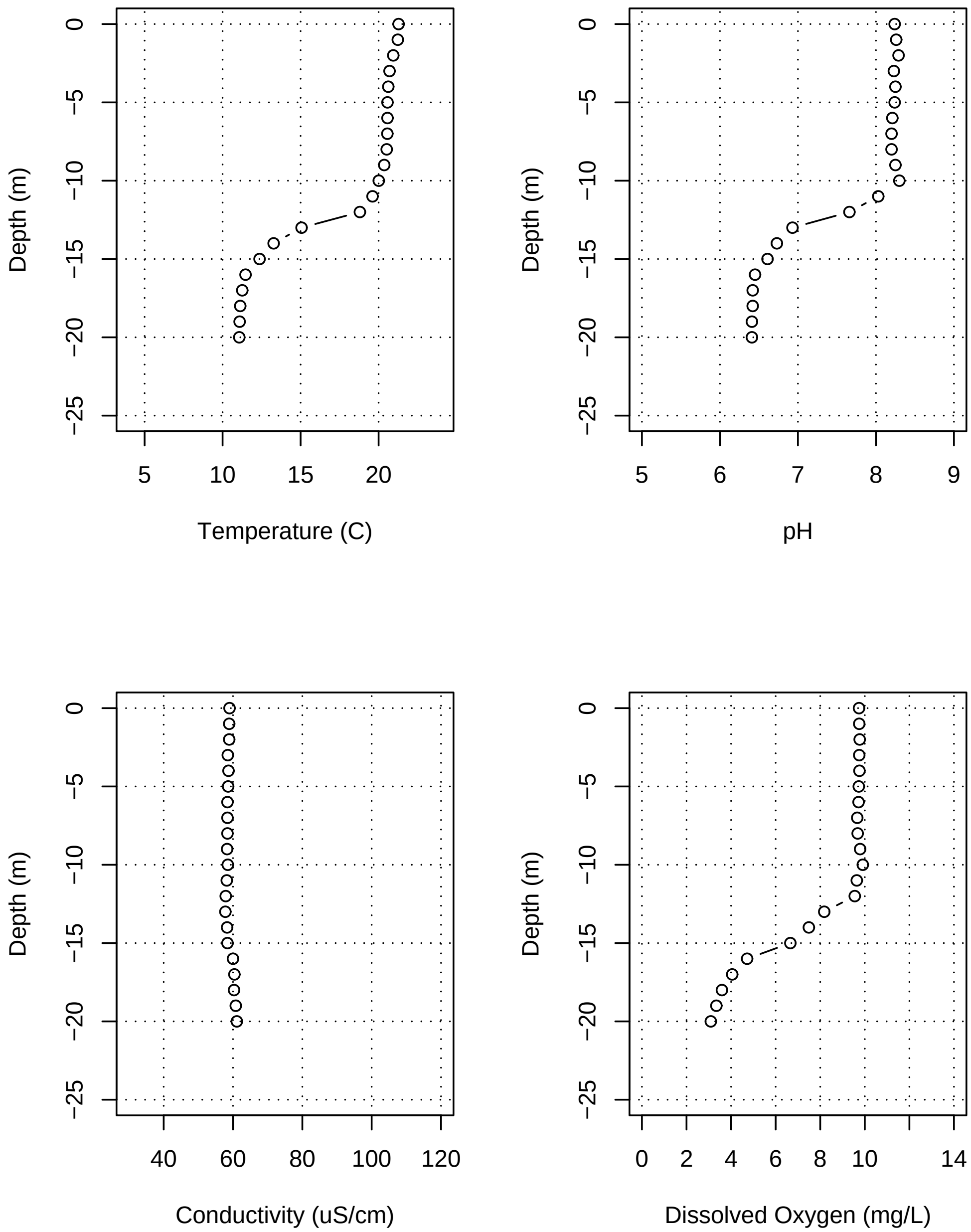


Figure B42: Lake Whatcom Hydrolab profile for Site 2, August 8, 2006.

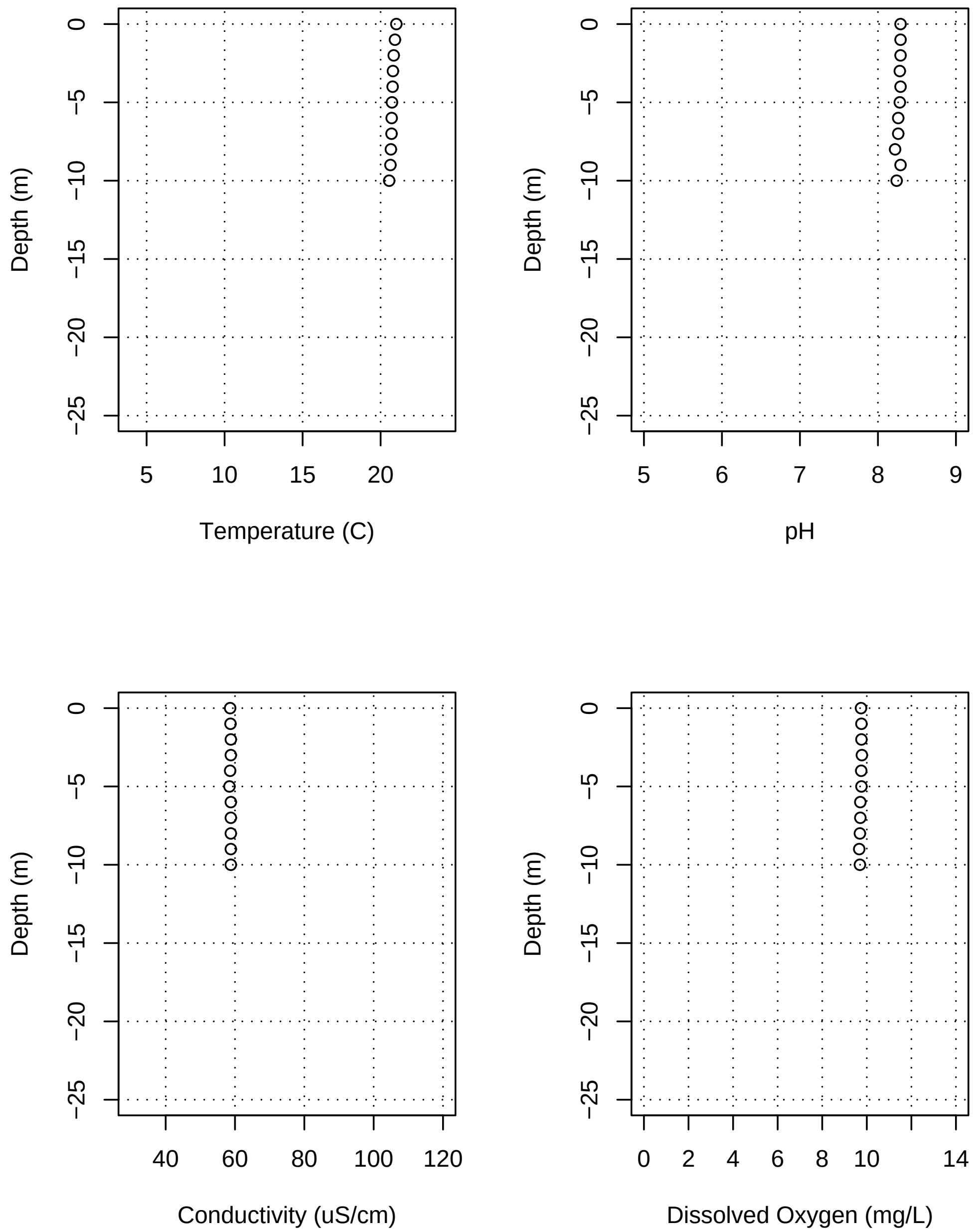


Figure B43: Lake Whatcom Hydrolab profile for the Intake, August 8, 2006.

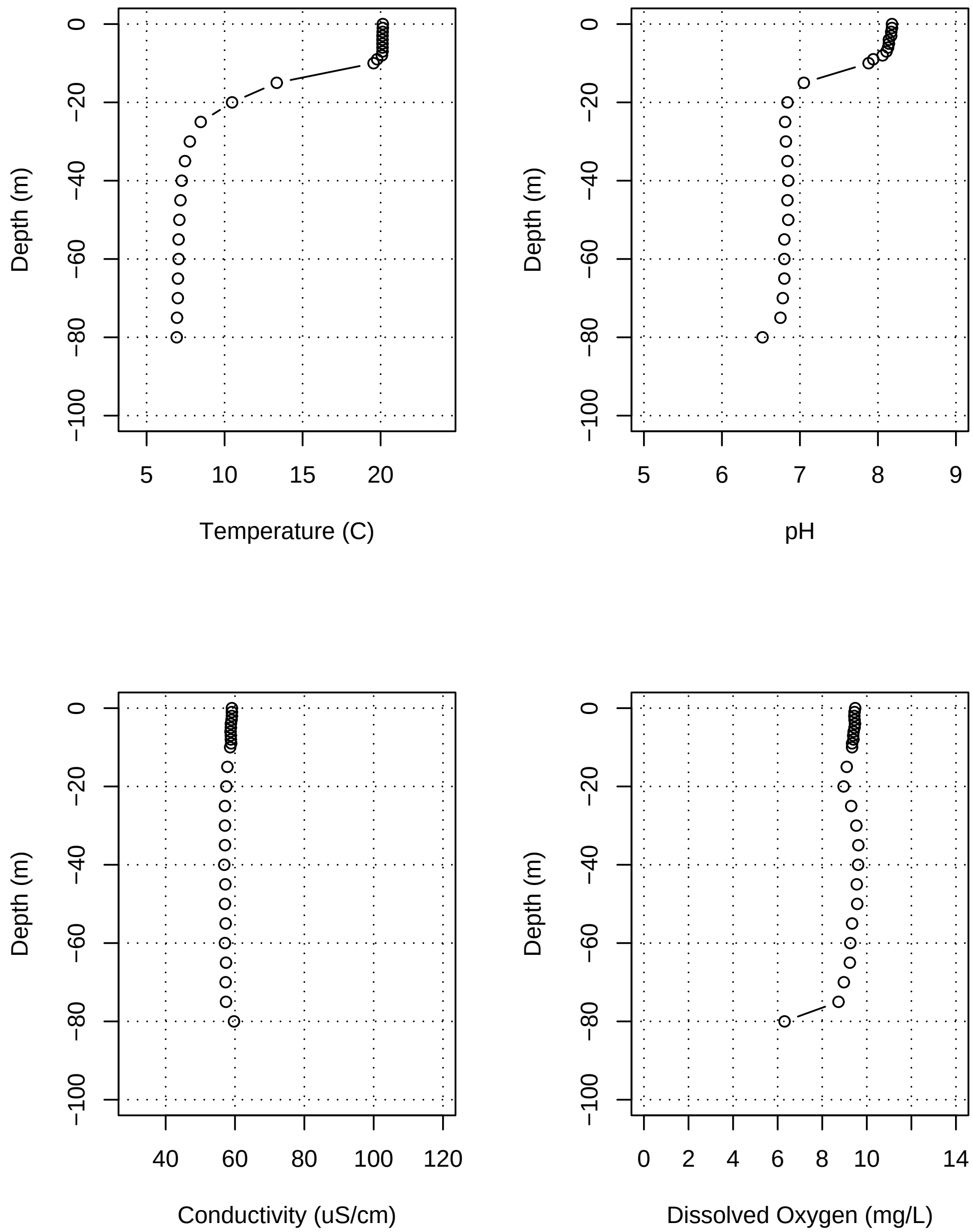


Figure B44: Lake Whatcom Hydrolab profile for Site 3, August 9, 2006.

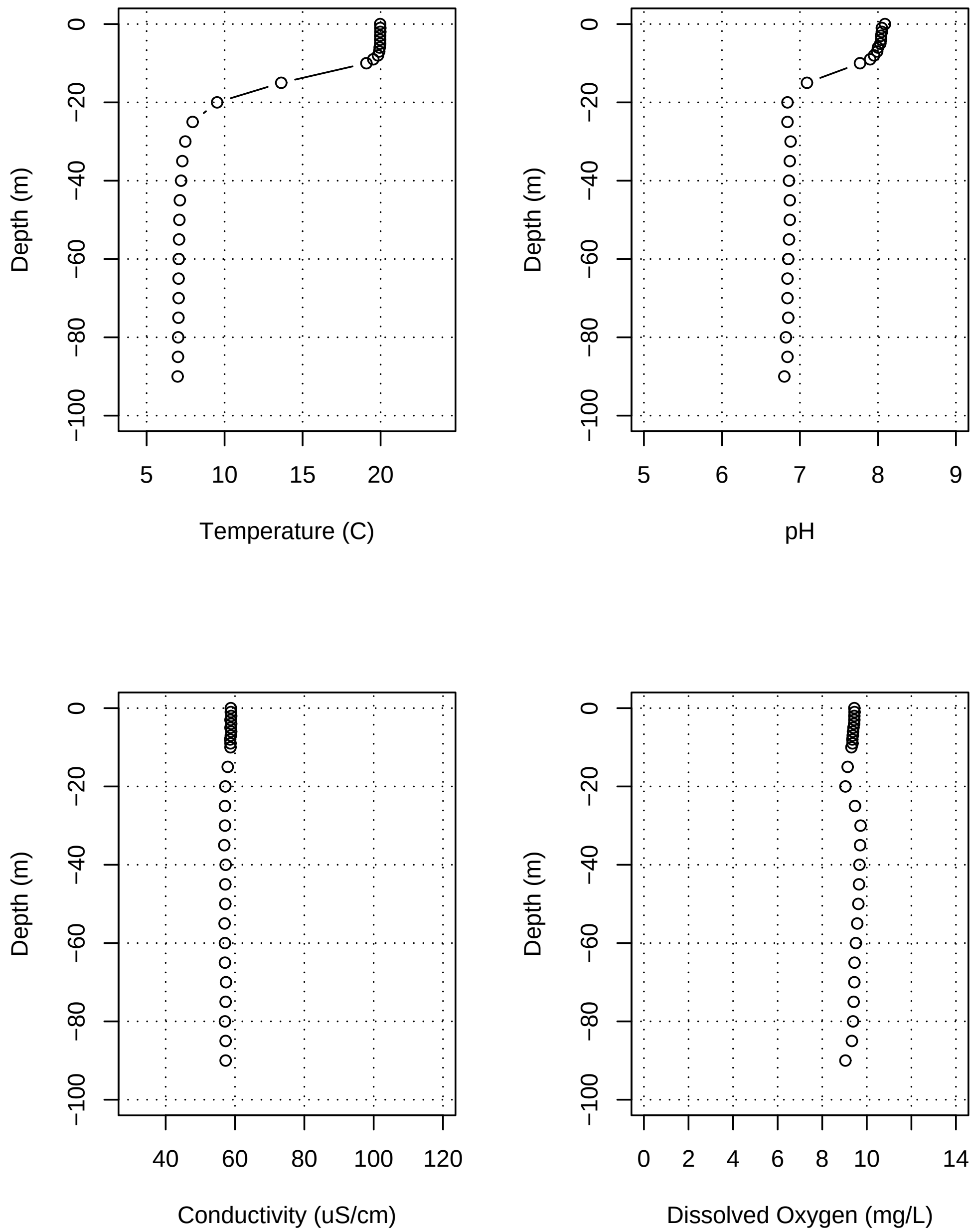


Figure B45: Lake Whatcom Hydrolab profile for Site 4, August 9, 2006.

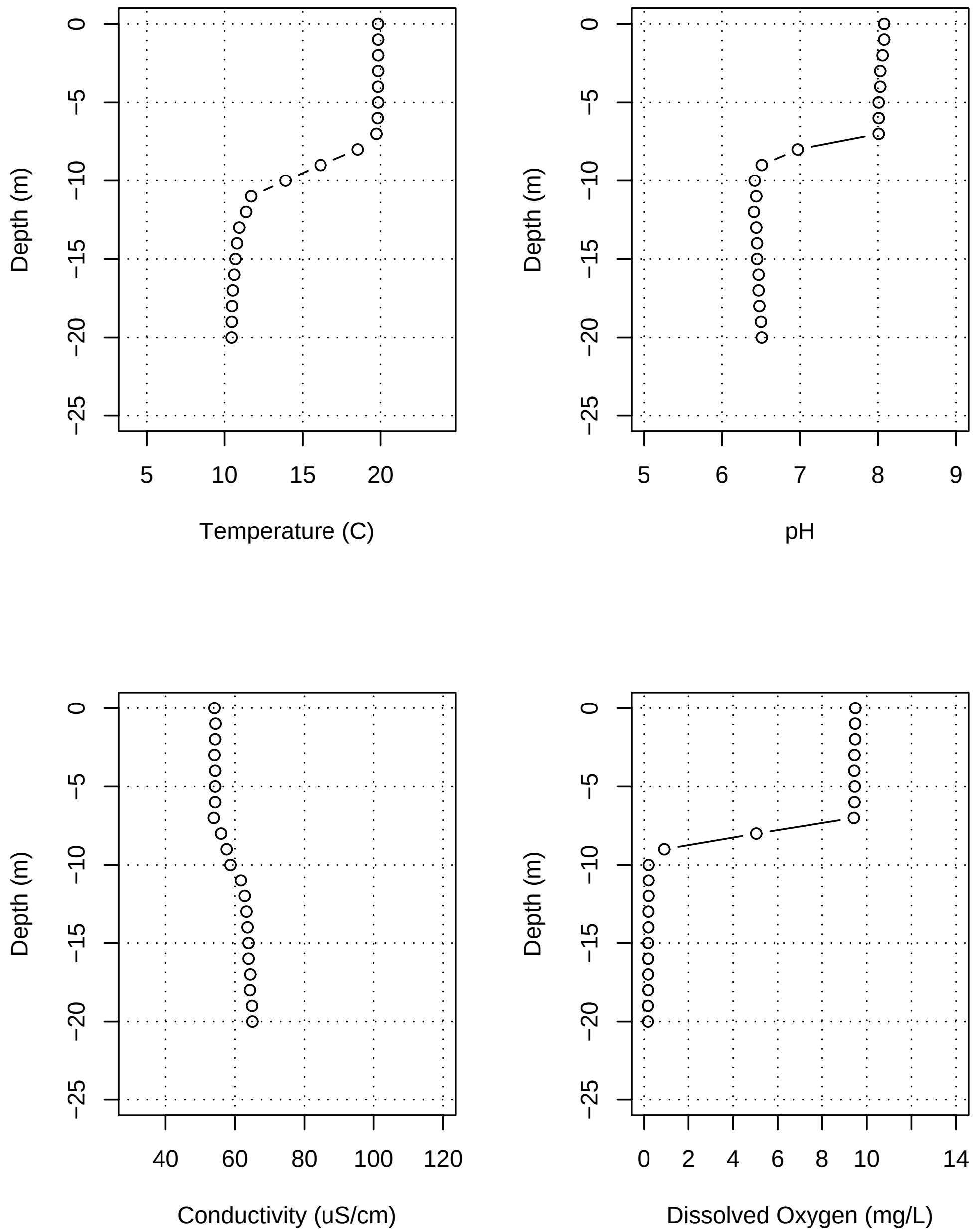


Figure B46: Lake Whatcom Hydrolab profile for Site 1, September 13, 2006.

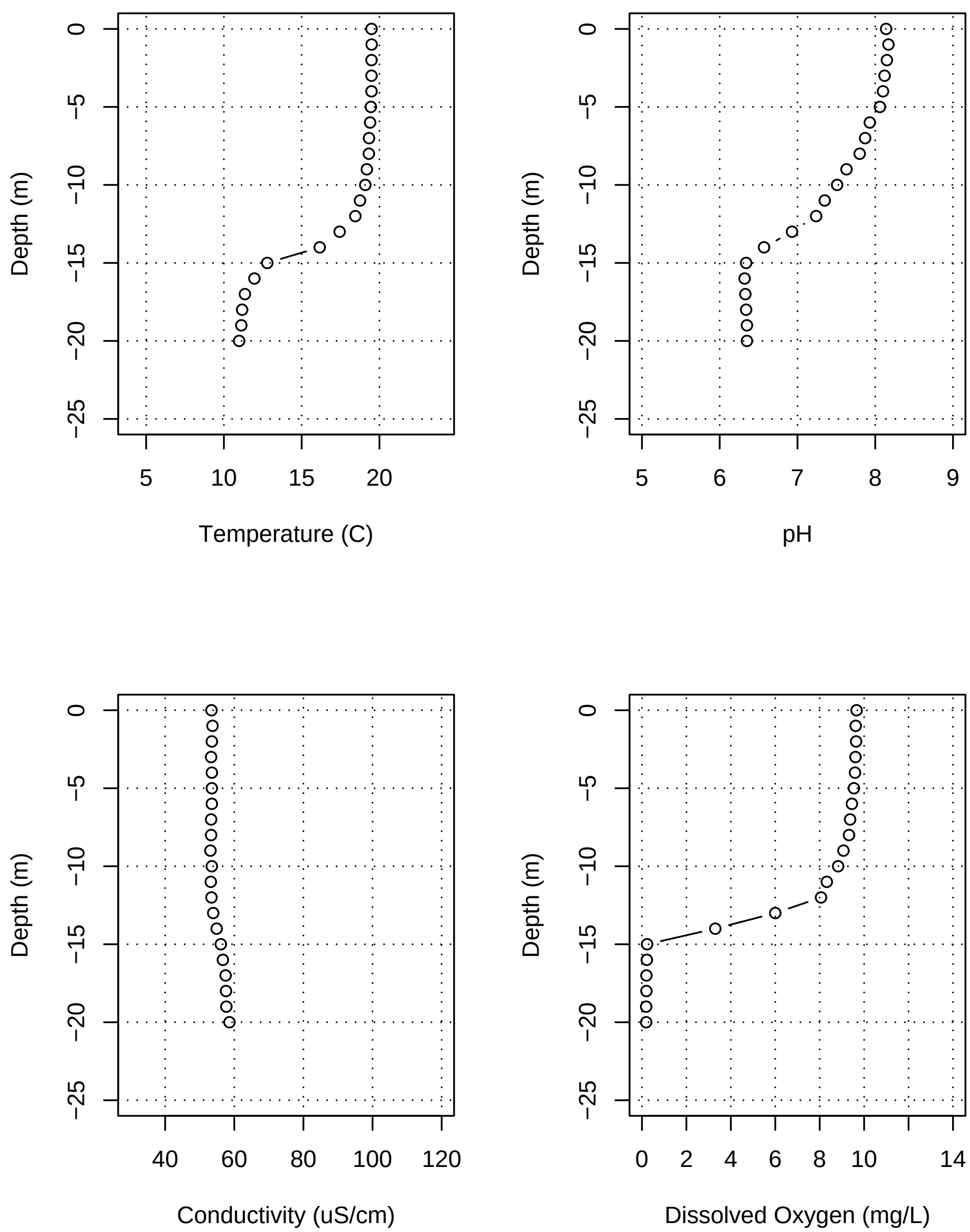


Figure B47: Lake Whatcom Hydrolab profile for Site 2, September 13, 2006.

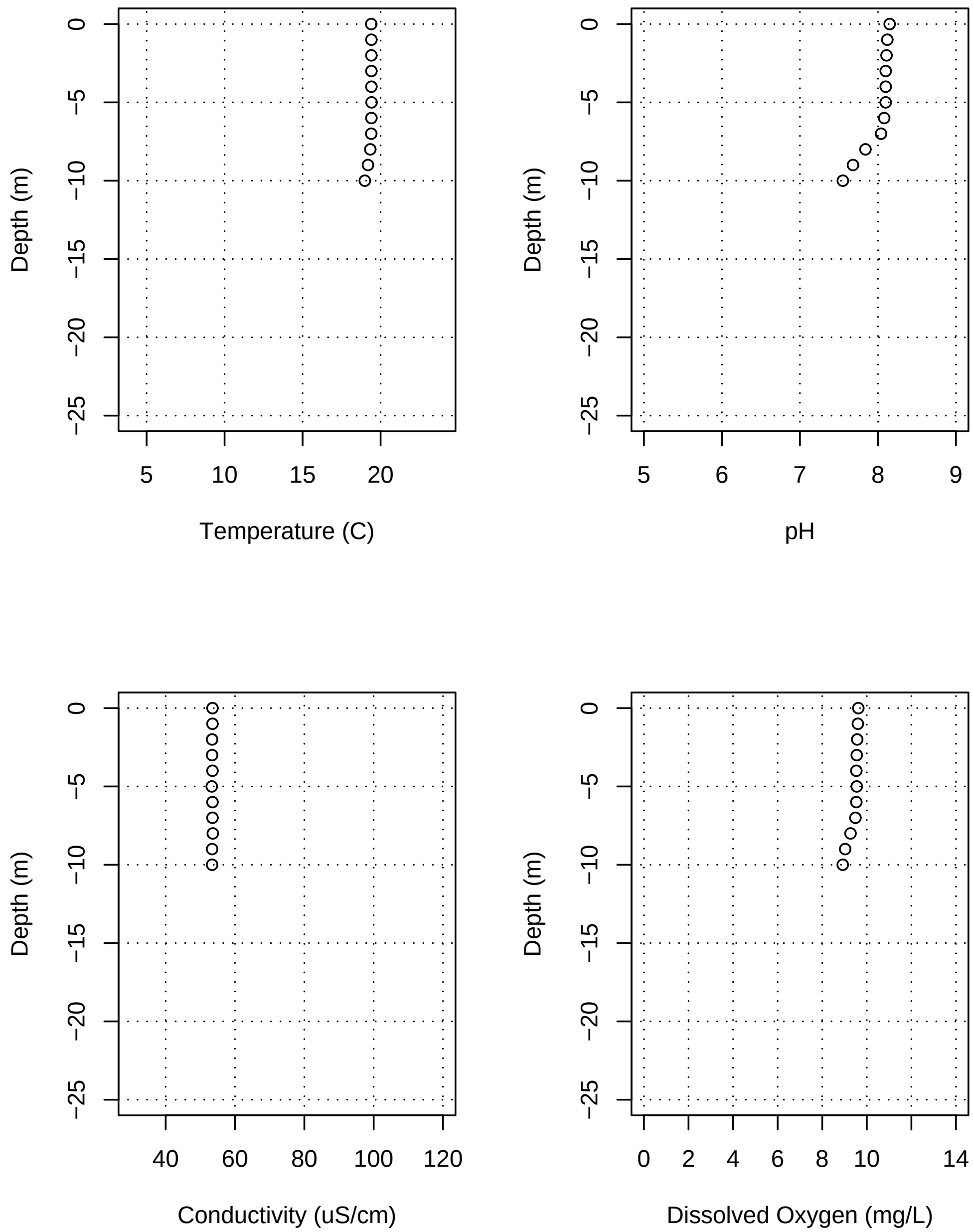


Figure B48: Lake Whatcom Hydrolab profile for the Intake, September 13, 2006.

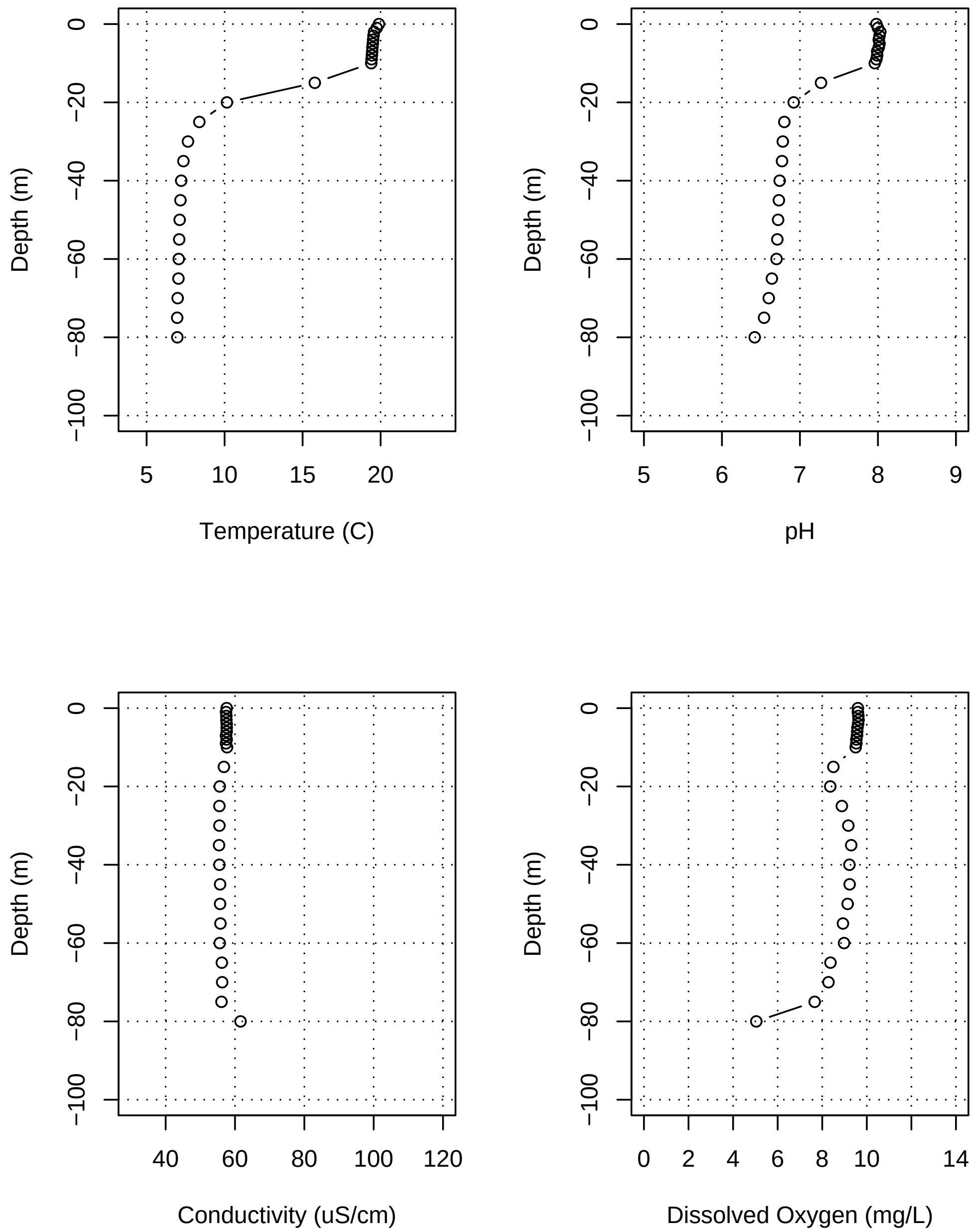


Figure B49: Lake Whatcom Hydrolab profile for Site 3, September 12, 2006.

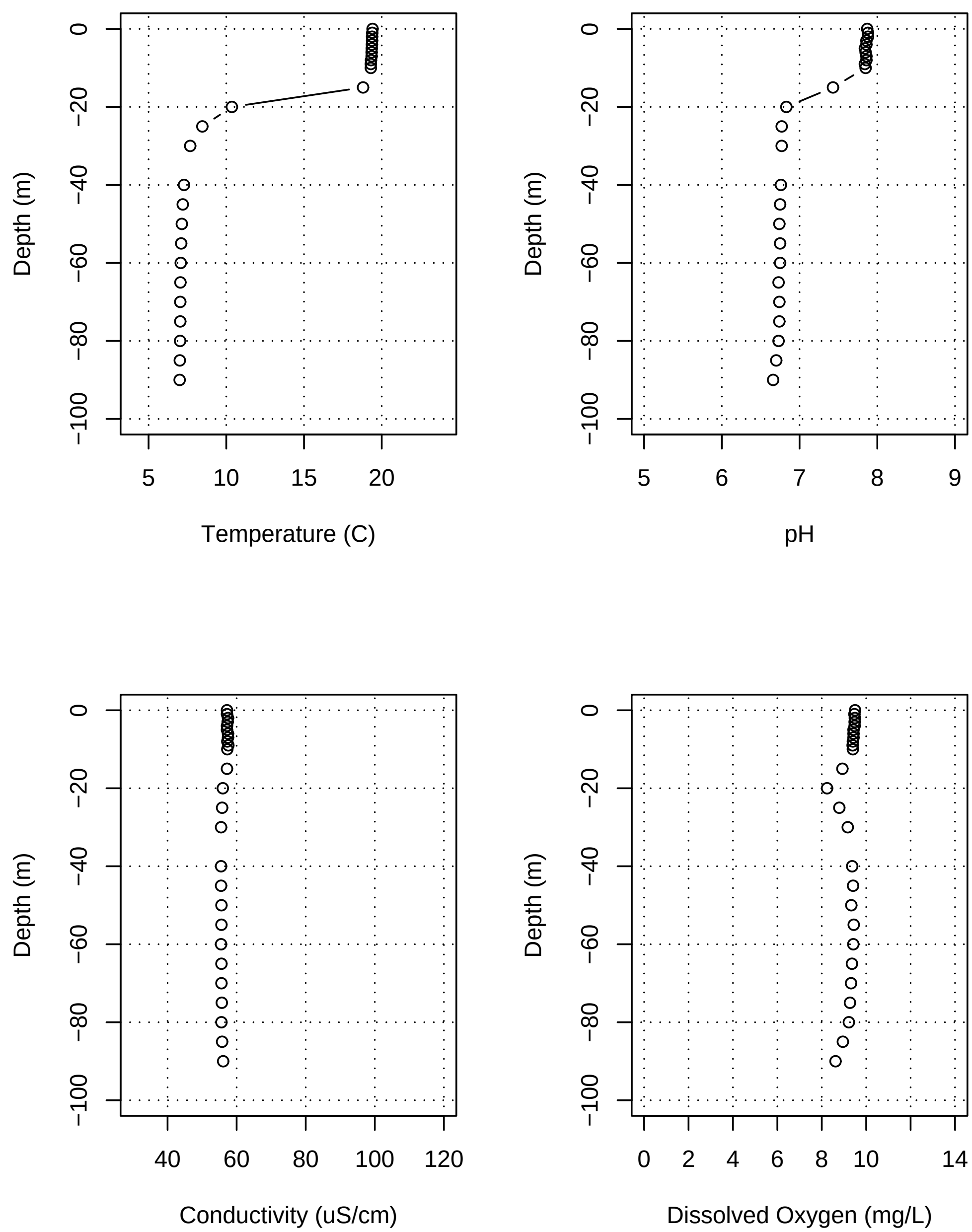


Figure B50: Lake Whatcom Hydrolab profile for Site 4, September 12, 2006.

B.2 Temperature, Dissolved Oxygen, pH, Conductivity

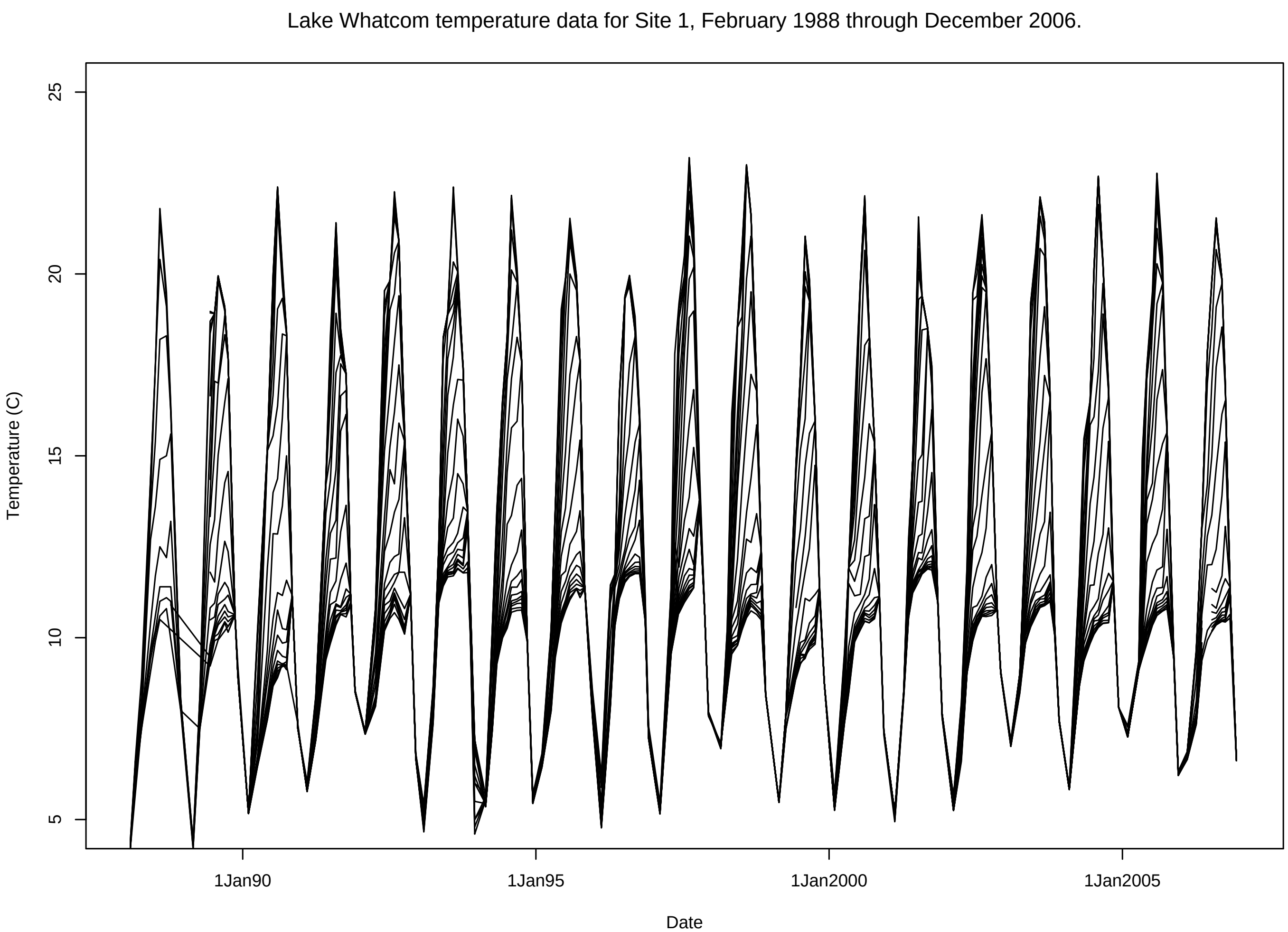


Figure B51: Lake Whatcom historic temperature data for Site 1.

Lake Whatcom temperature data for Site 2, February 1988 through December 2006.

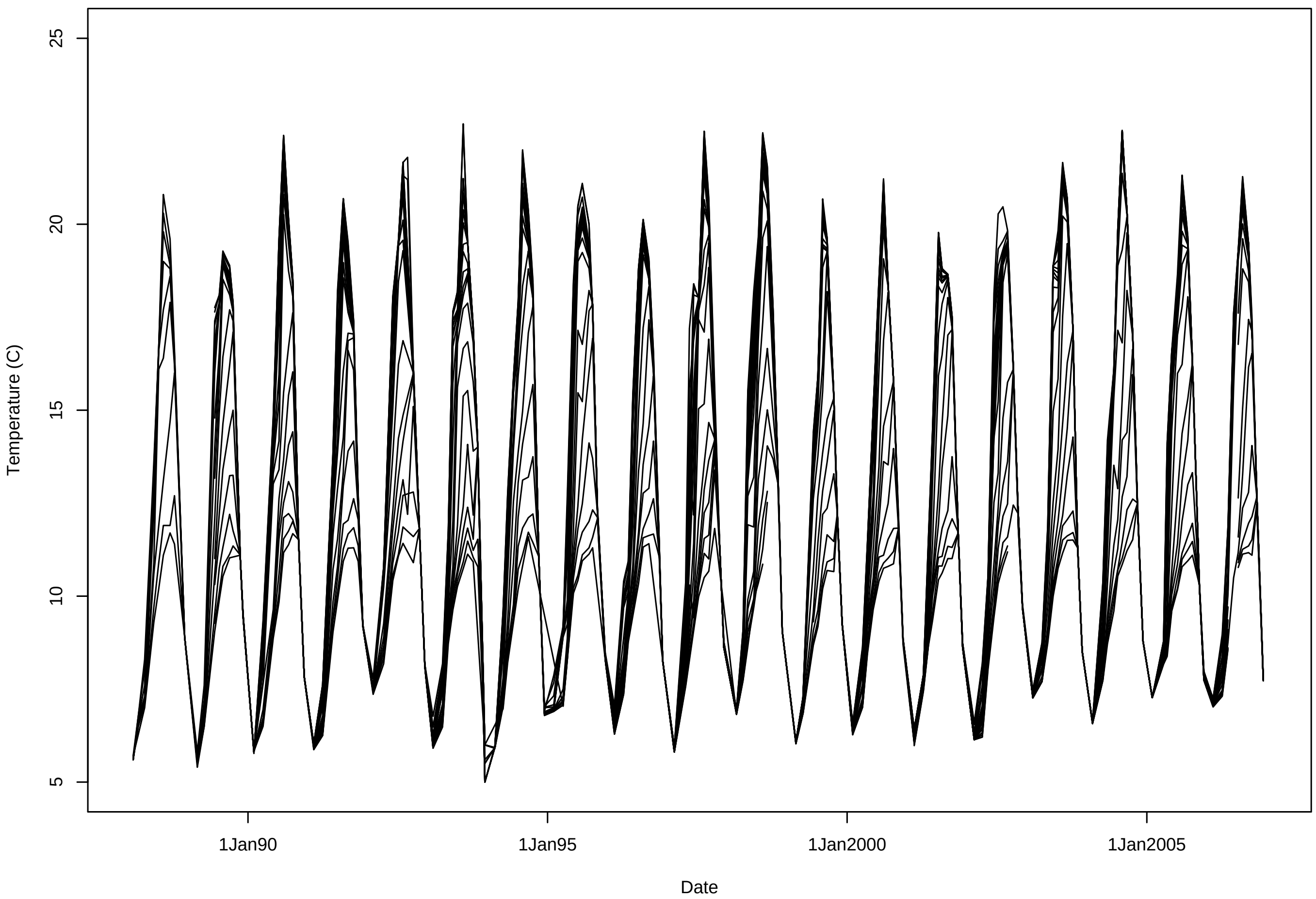


Figure B52: Lake Whatcom historic temperature data for Site 2.

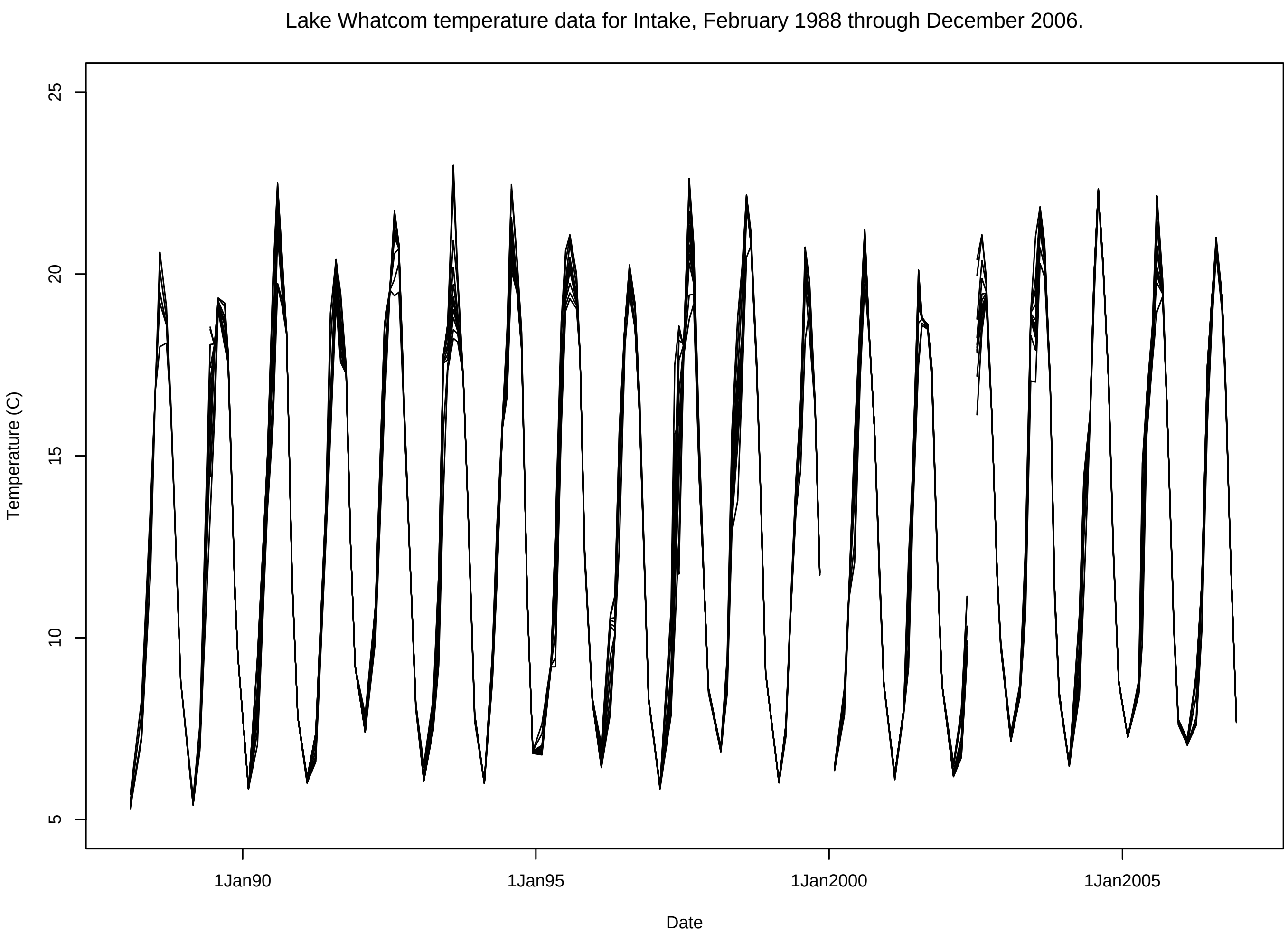


Figure B53: Lake Whatcom historic temperature data for the Intake.

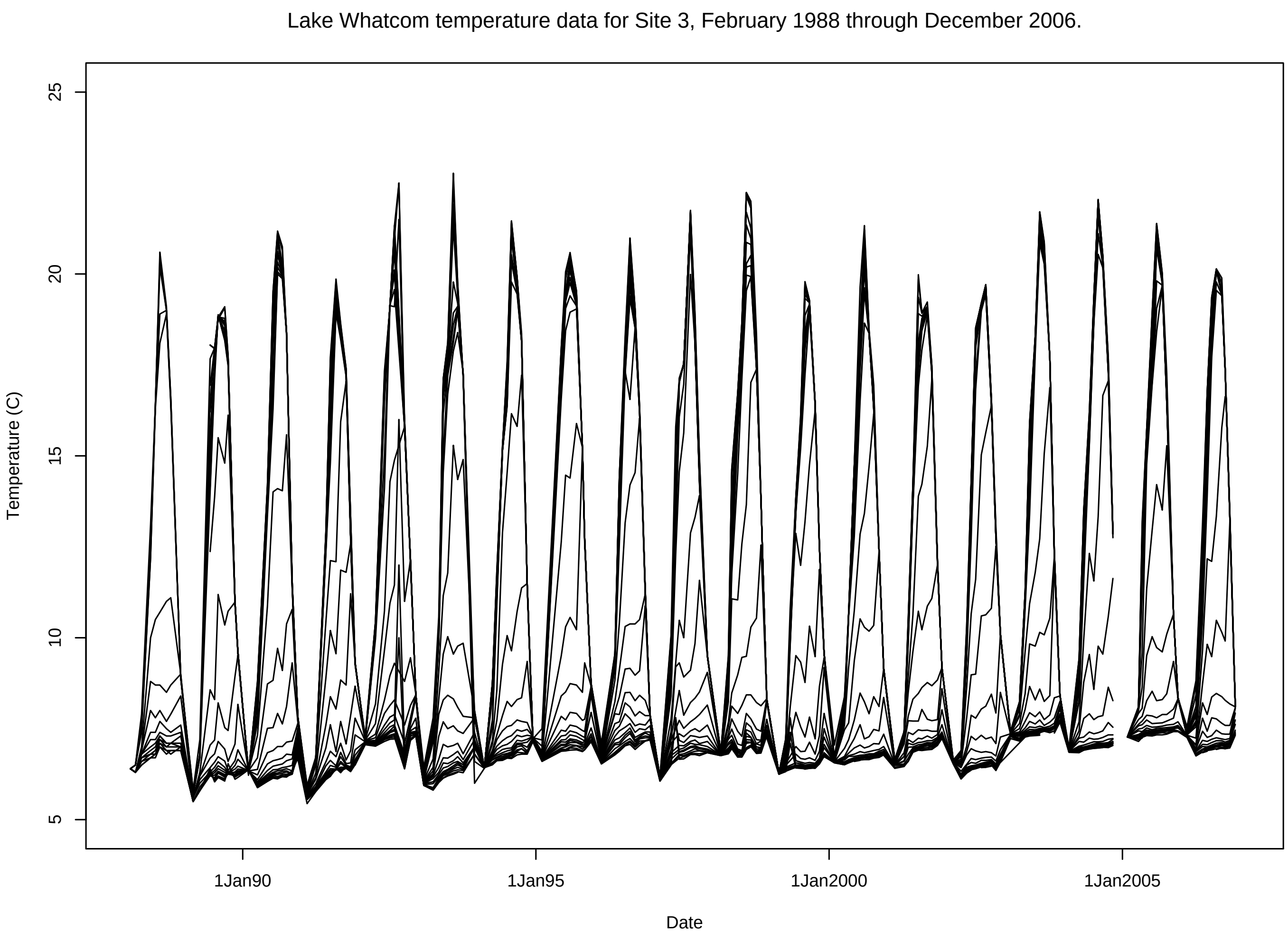


Figure B54: Lake Whatcom historic temperature data for Site 3.

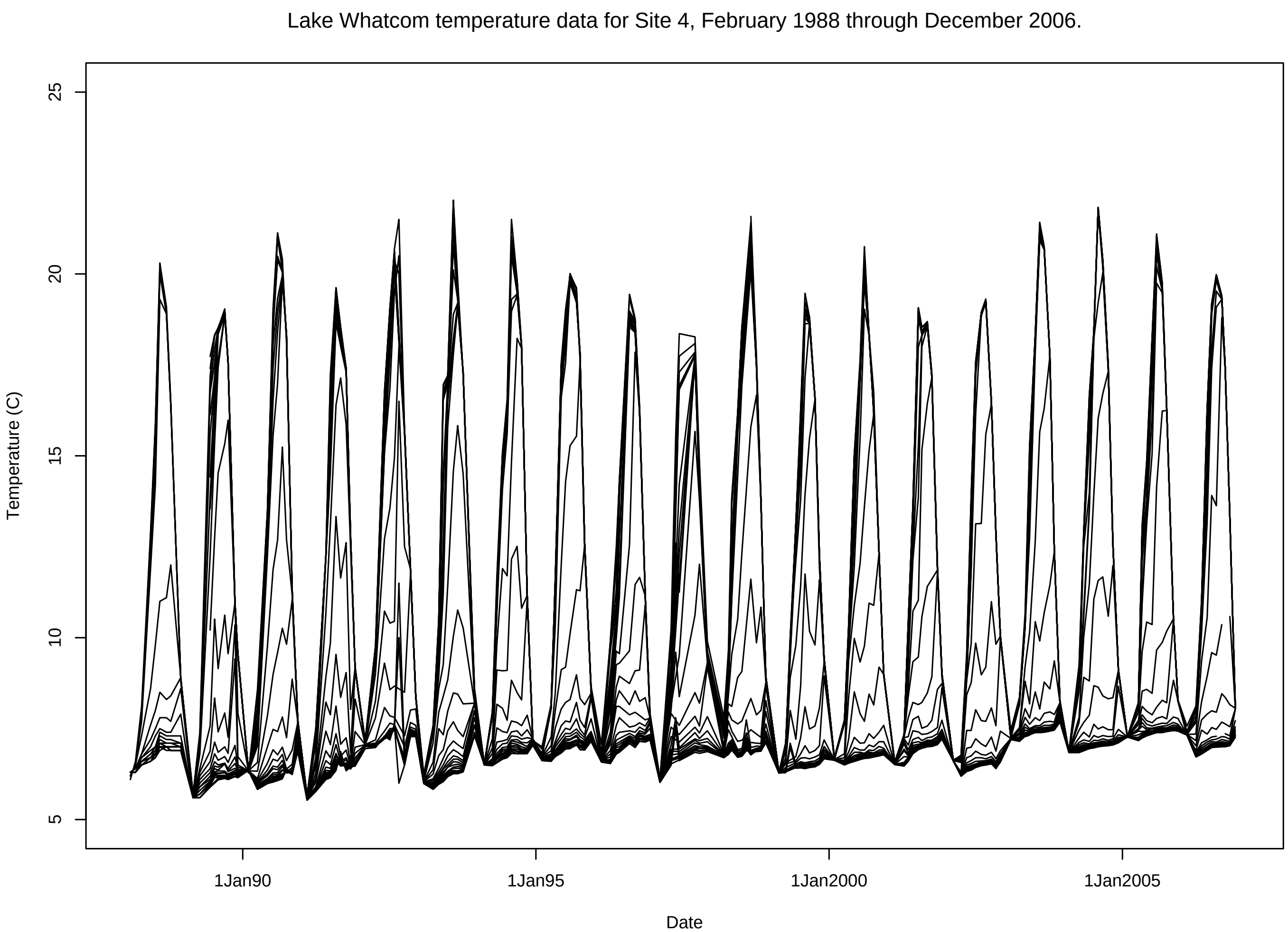


Figure B55: Lake Whatcom historic temperature data for Site 4.

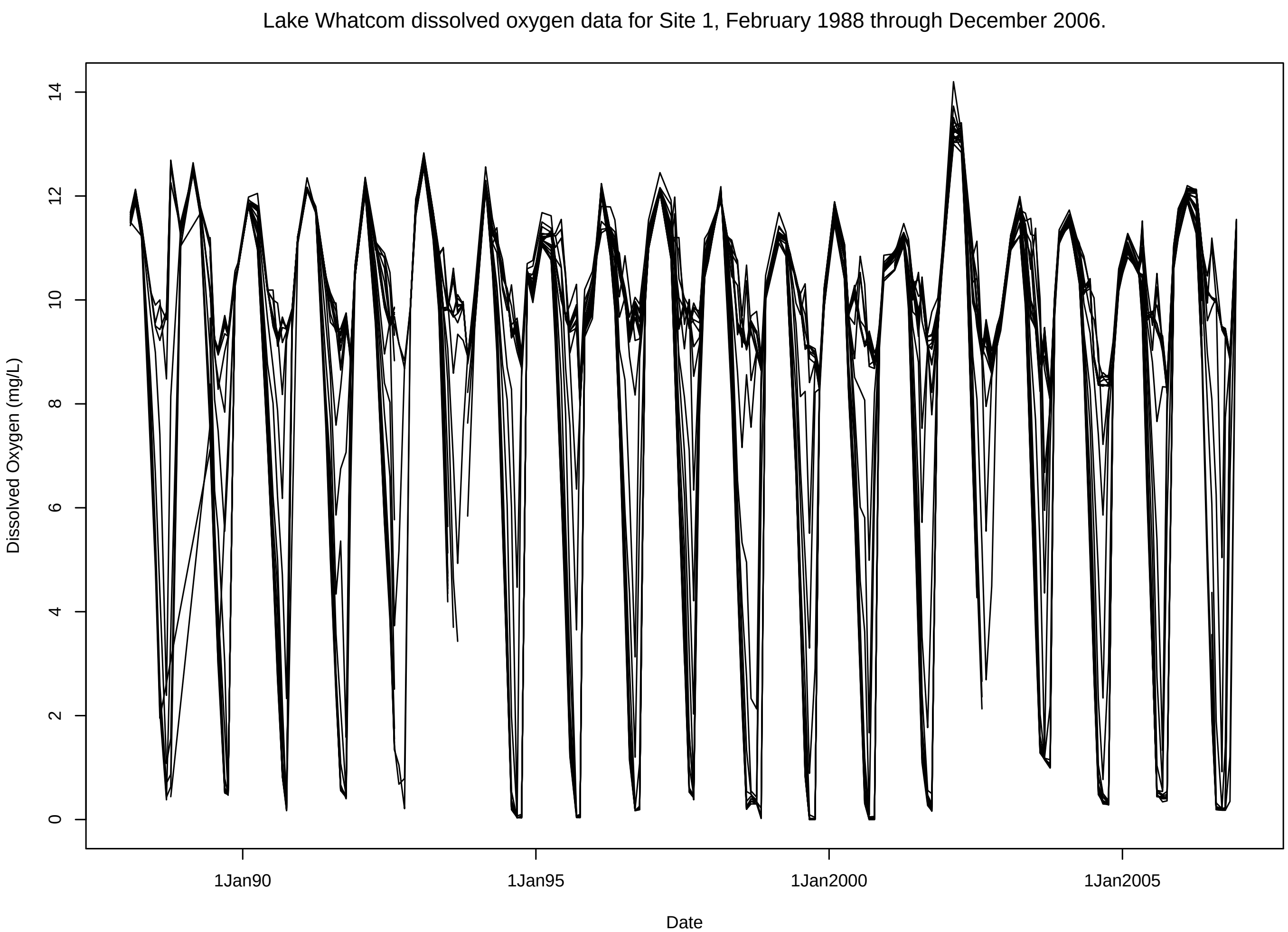


Figure B56: Lake Whatcom historic dissolved oxygen data for Site 1.

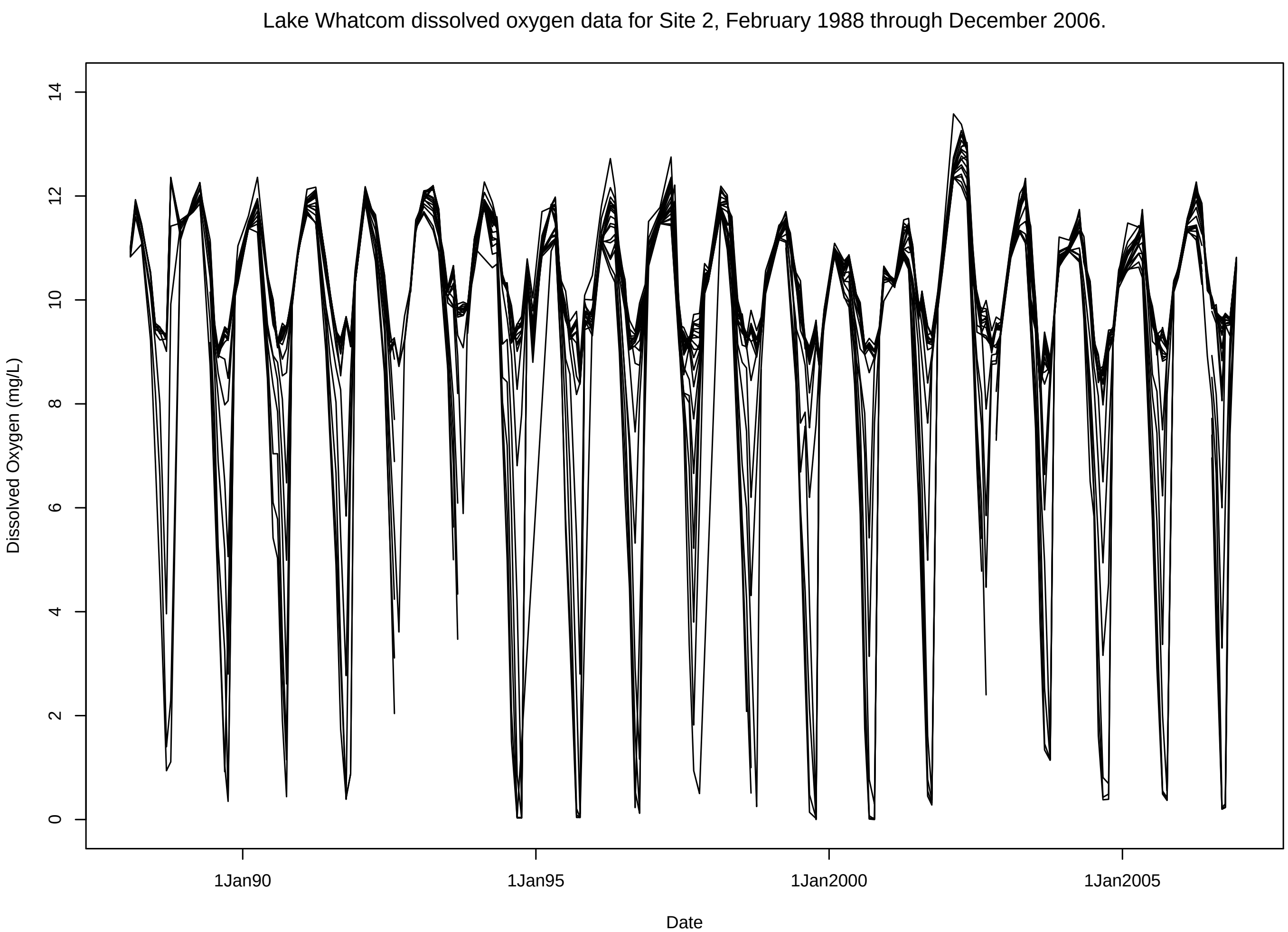


Figure B57: Lake Whatcom historic dissolved oxygen data for Site 2.

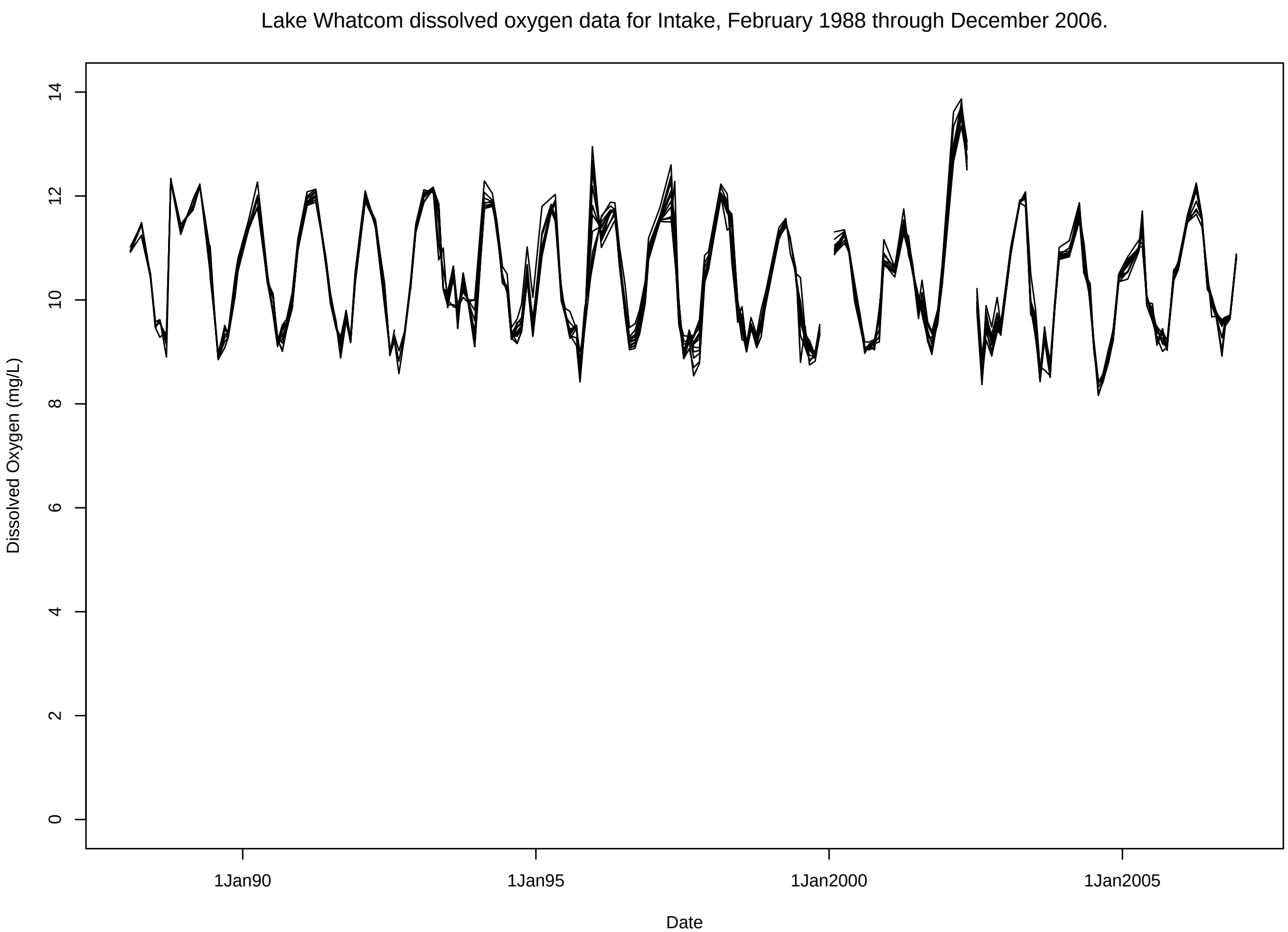


Figure B58: Lake Whatcom historic dissolved oxygen data for the Intake.

Lake Whatcom dissolved oxygen data for Site 3, February 1988 through December 2006.

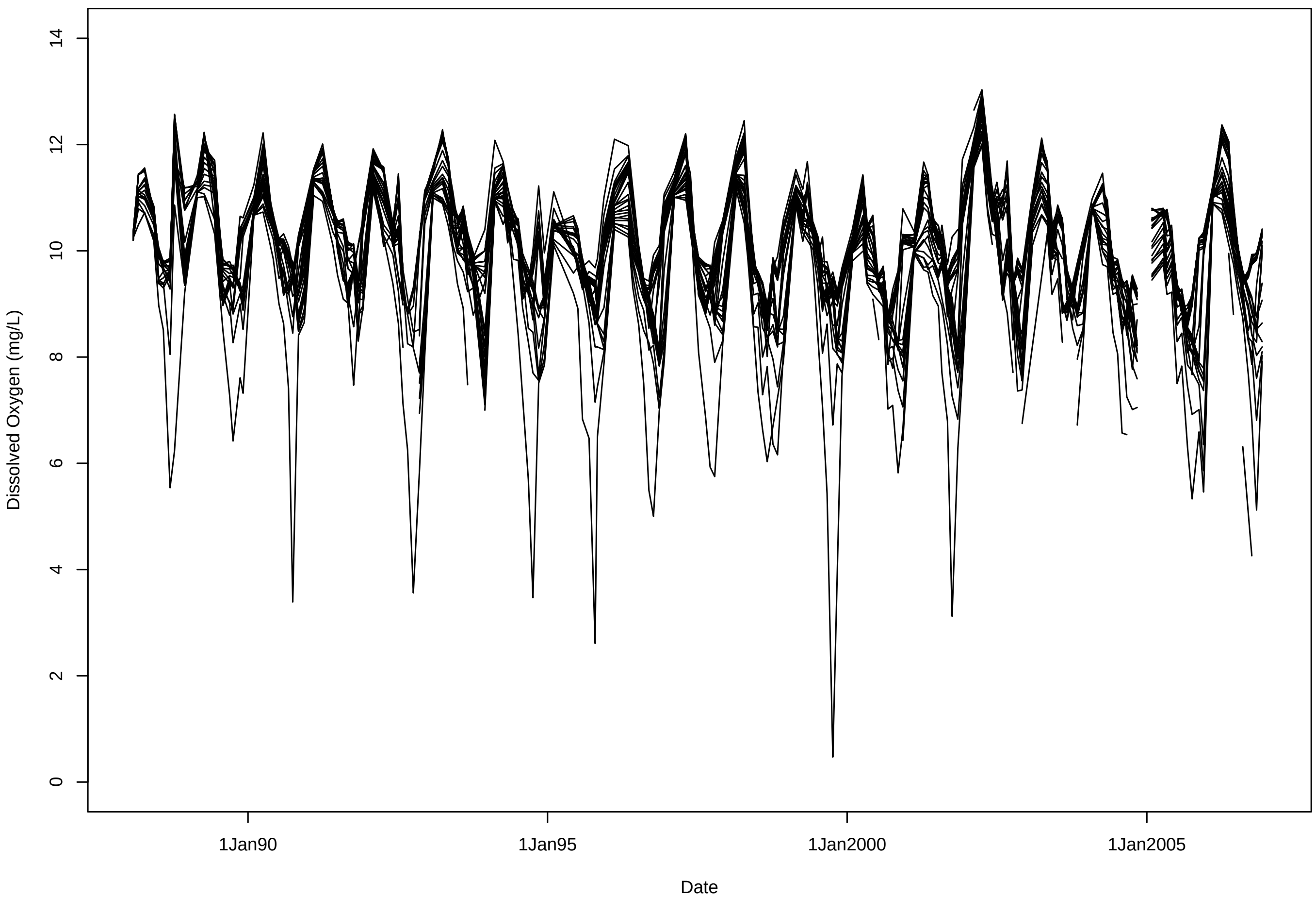


Figure B59: Lake Whatcom historic dissolved oxygen data for Site 3.

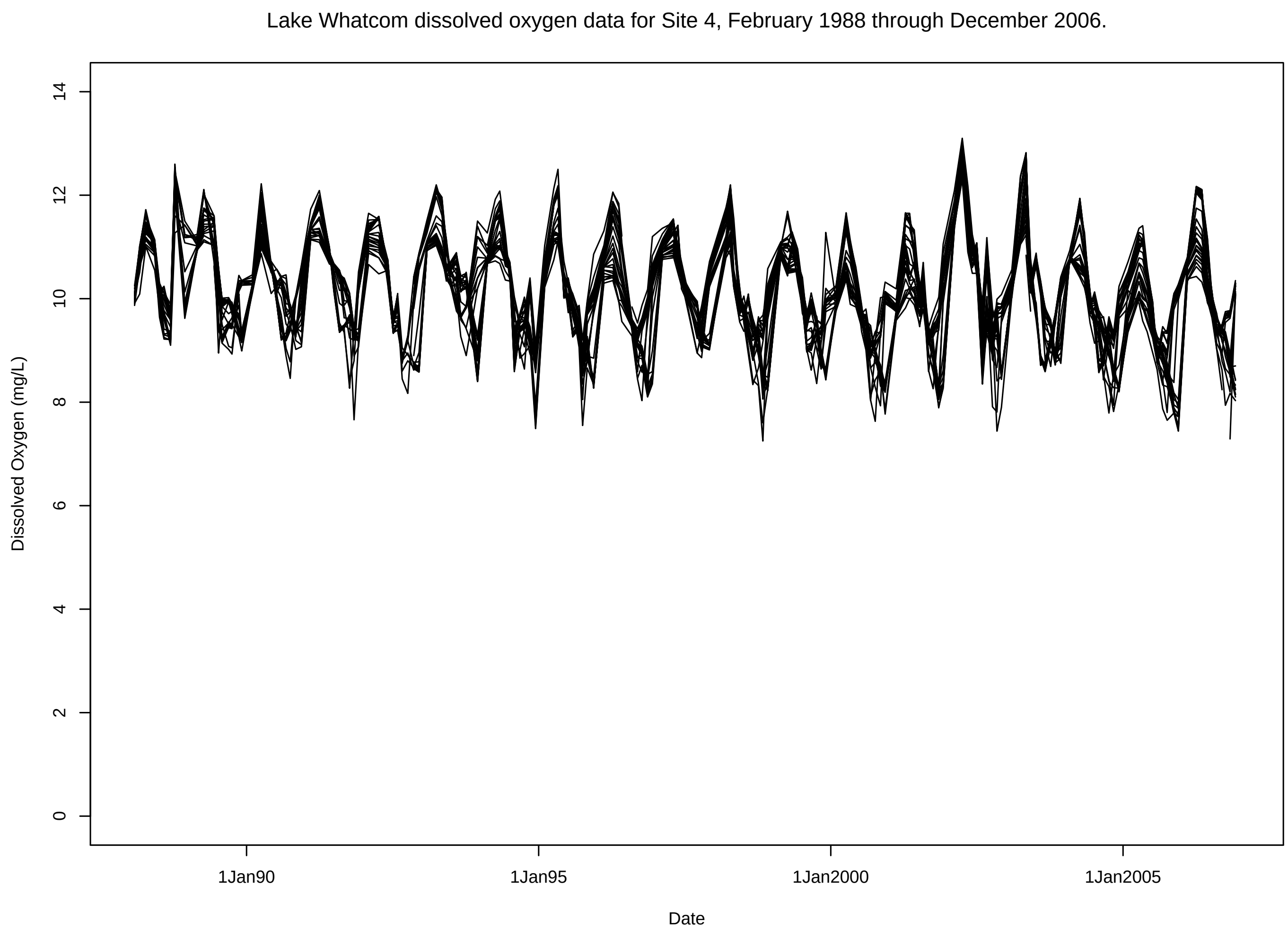


Figure B60: Lake Whatcom historic dissolved oxygen data for Site 4.

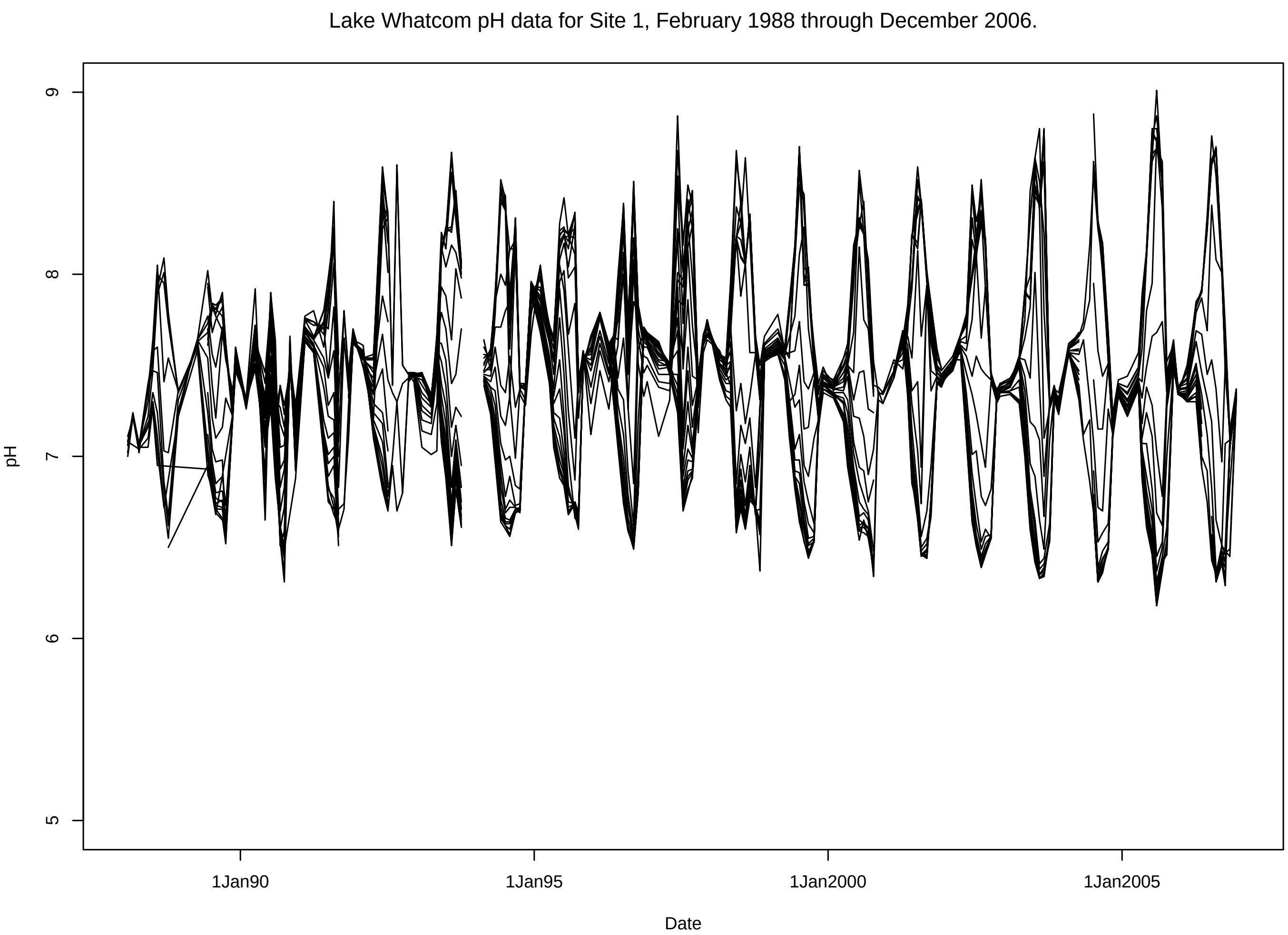


Figure B61: Lake Whatcom historic pH data for Site 1.

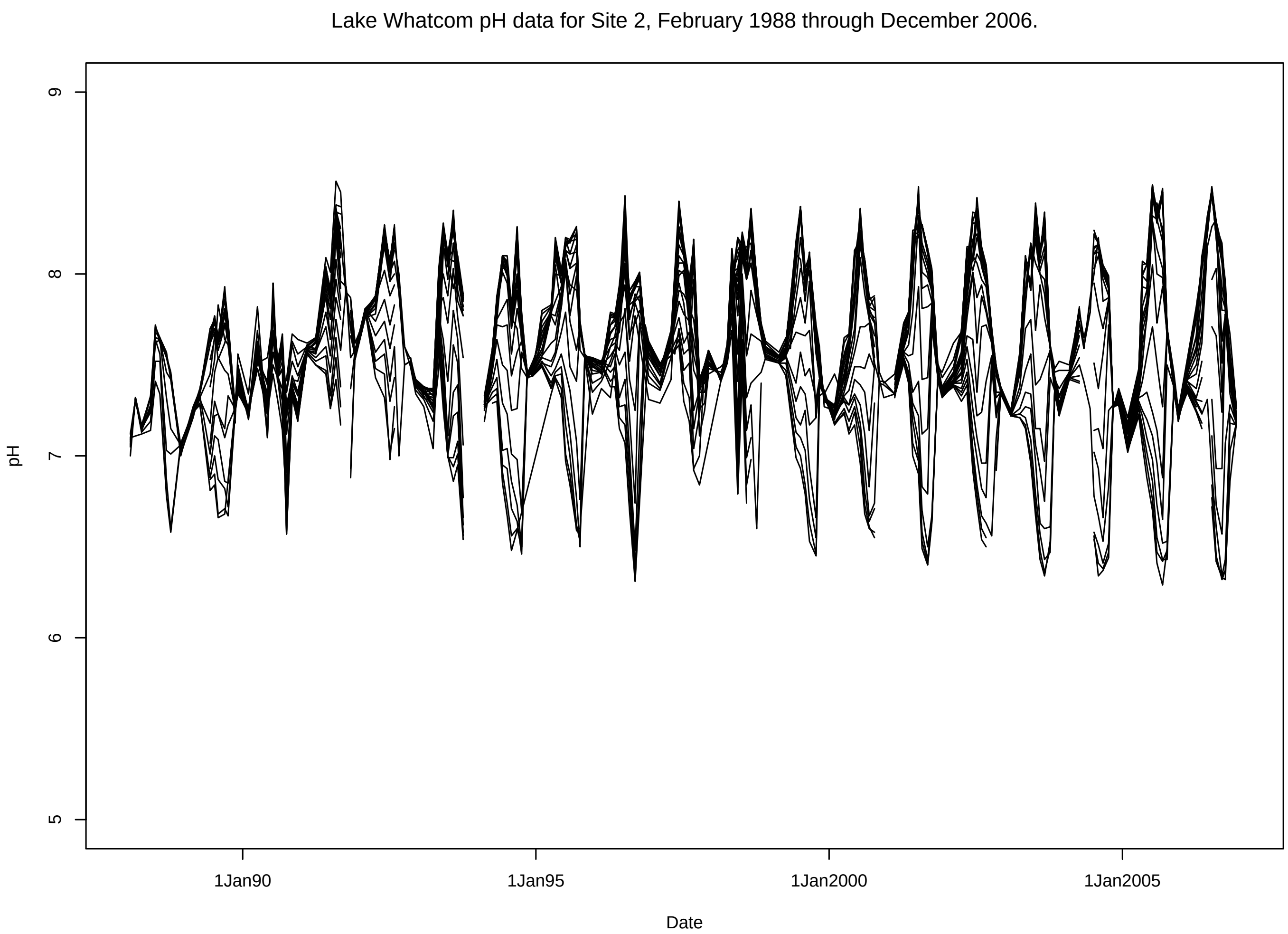


Figure B62: Lake Whatcom historic pH data for Site 2.

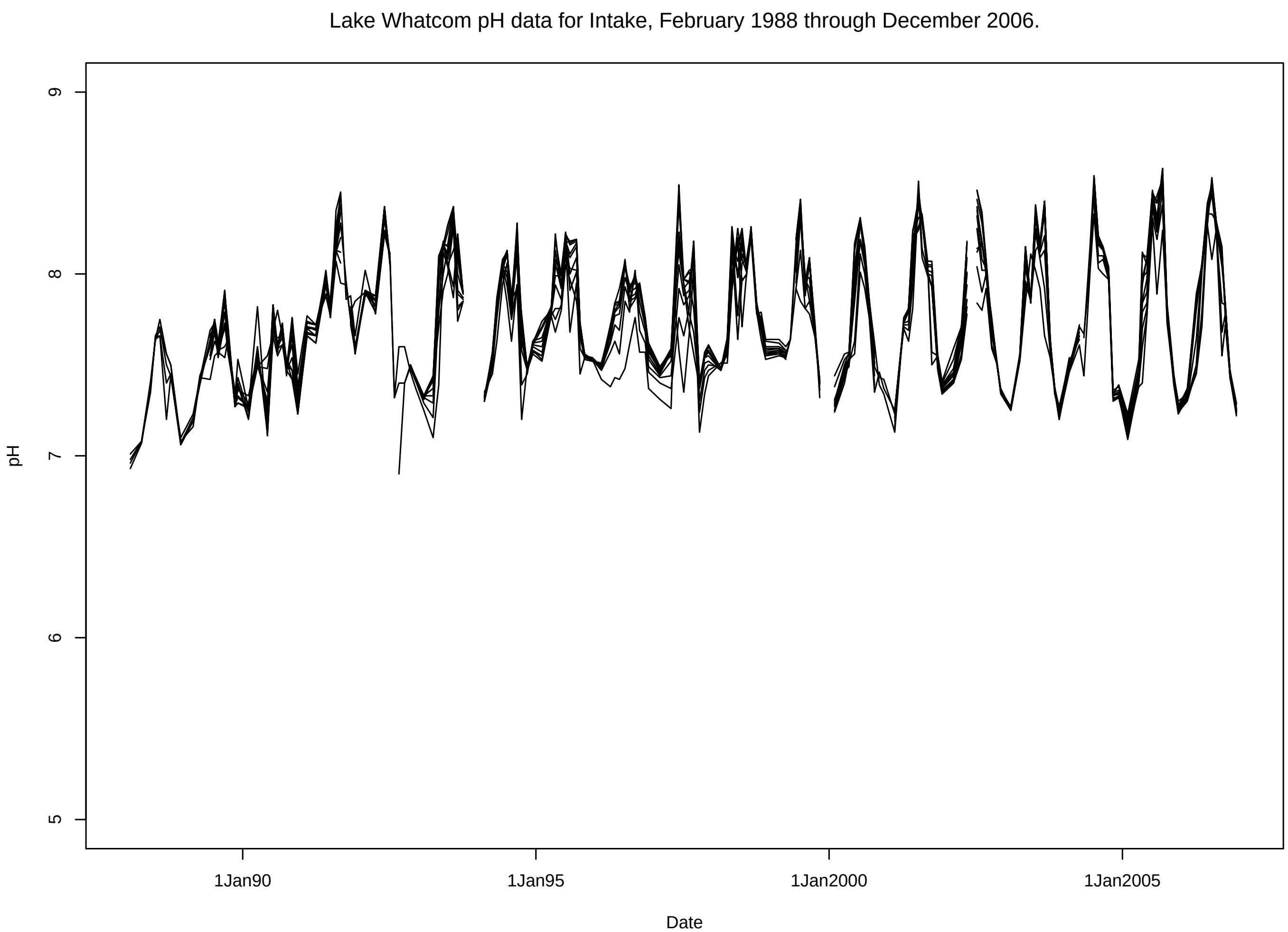


Figure B63: Lake Whatcom historic pH data for the Intake.

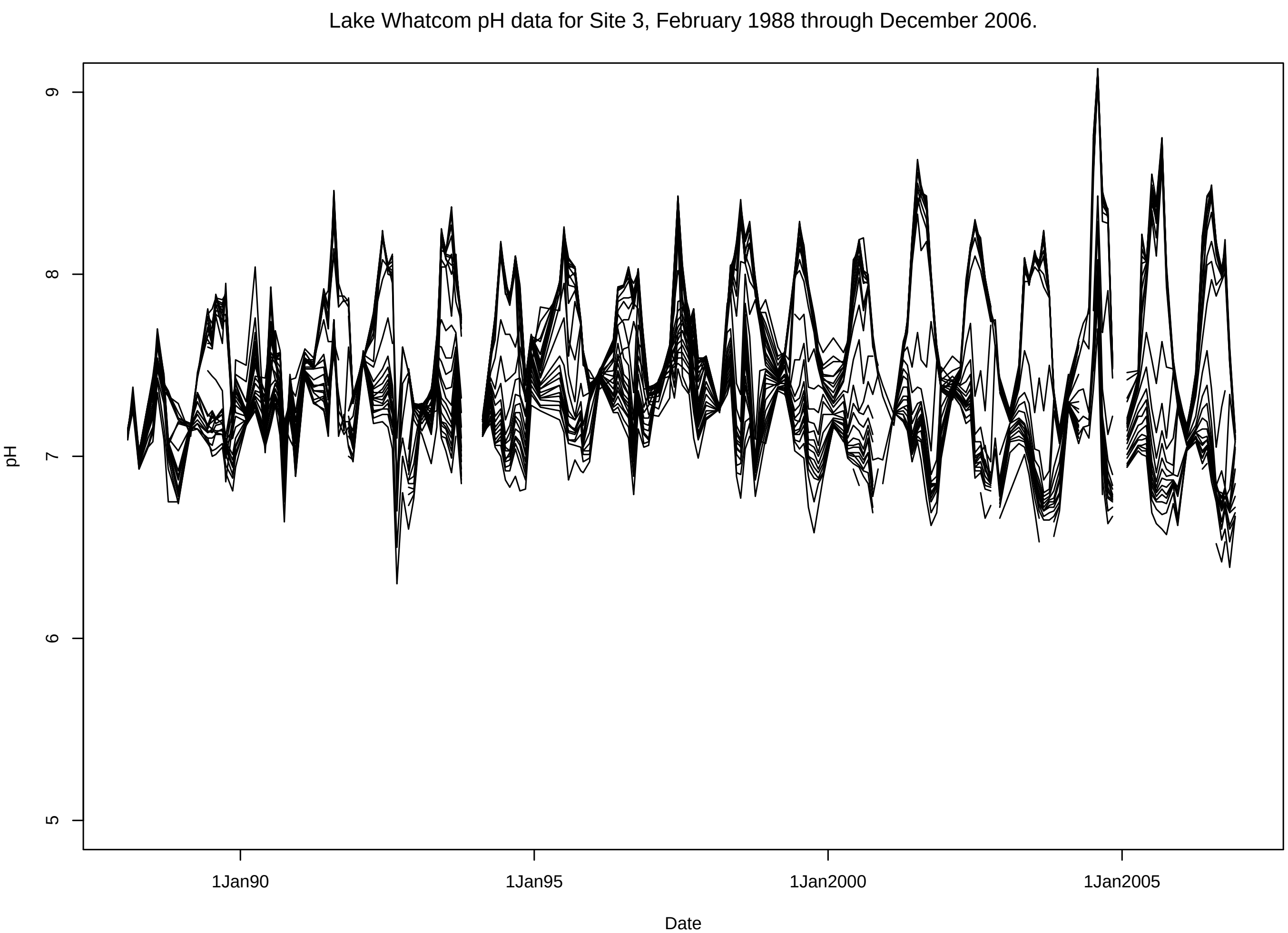


Figure B64: Lake Whatcom historic pH data for Site 3.

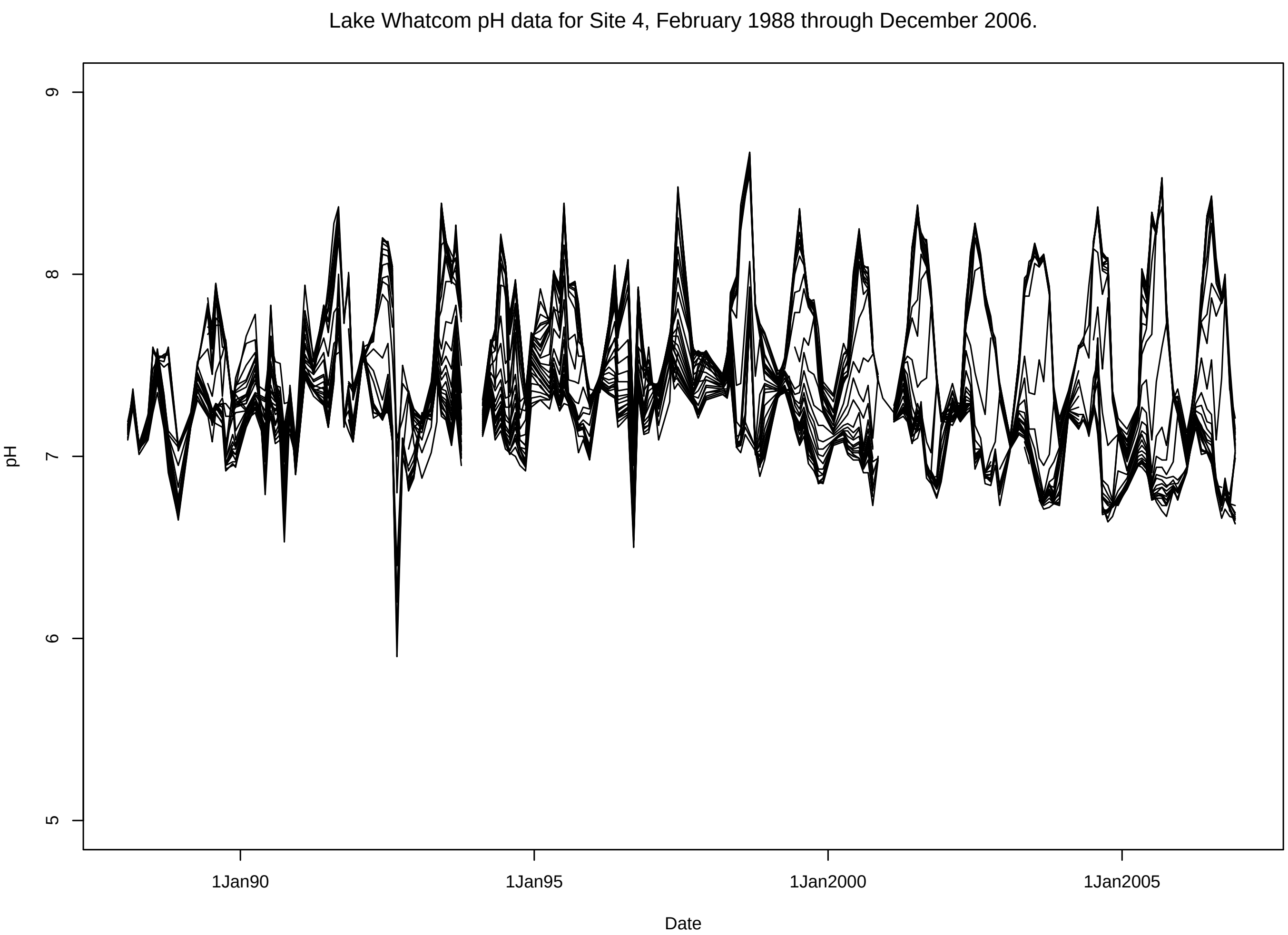


Figure B65: Lake Whatcom historic pH data for Site 4.

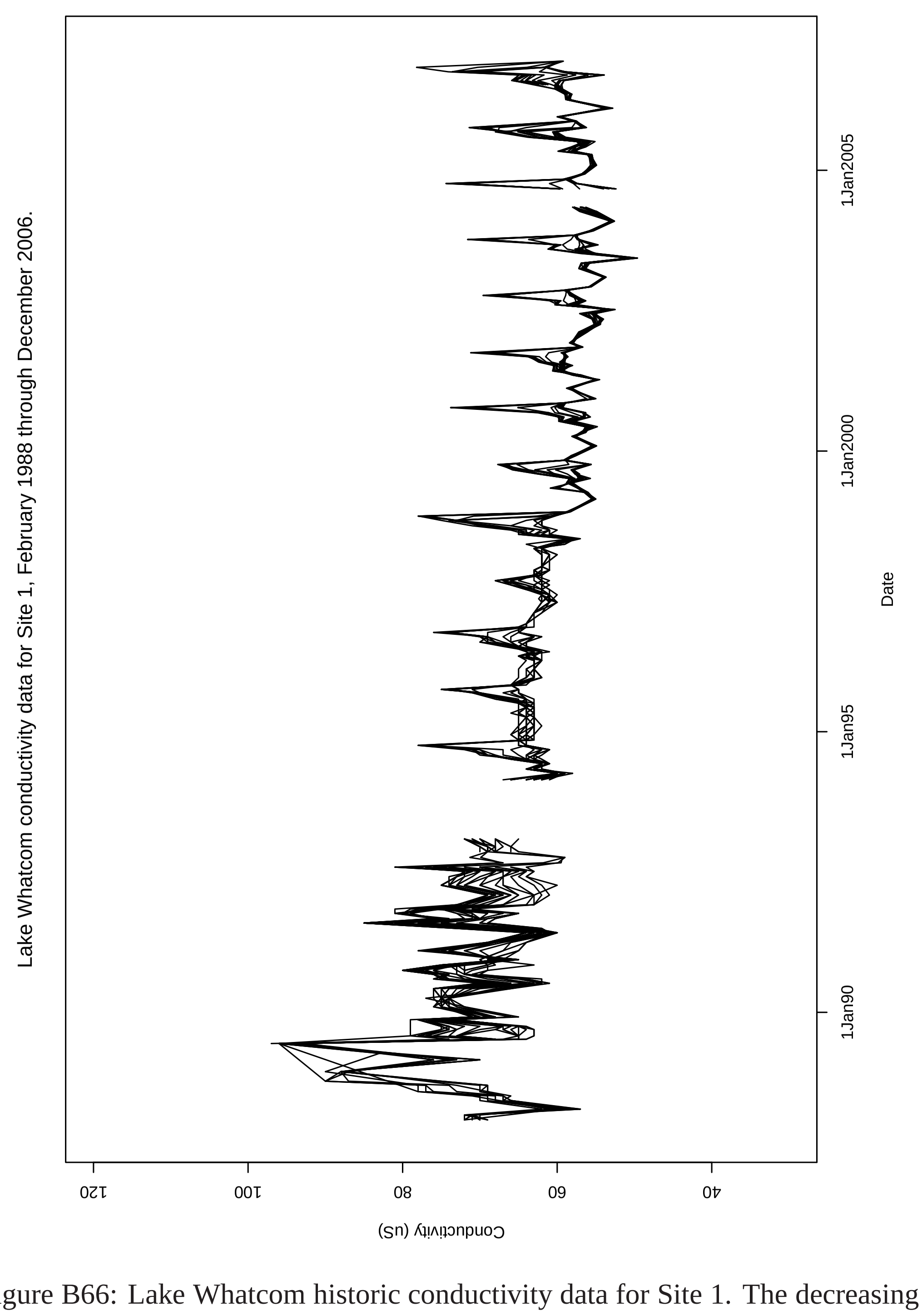


Figure B66: Lake Whatcom historic conductivity data for Site 1. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

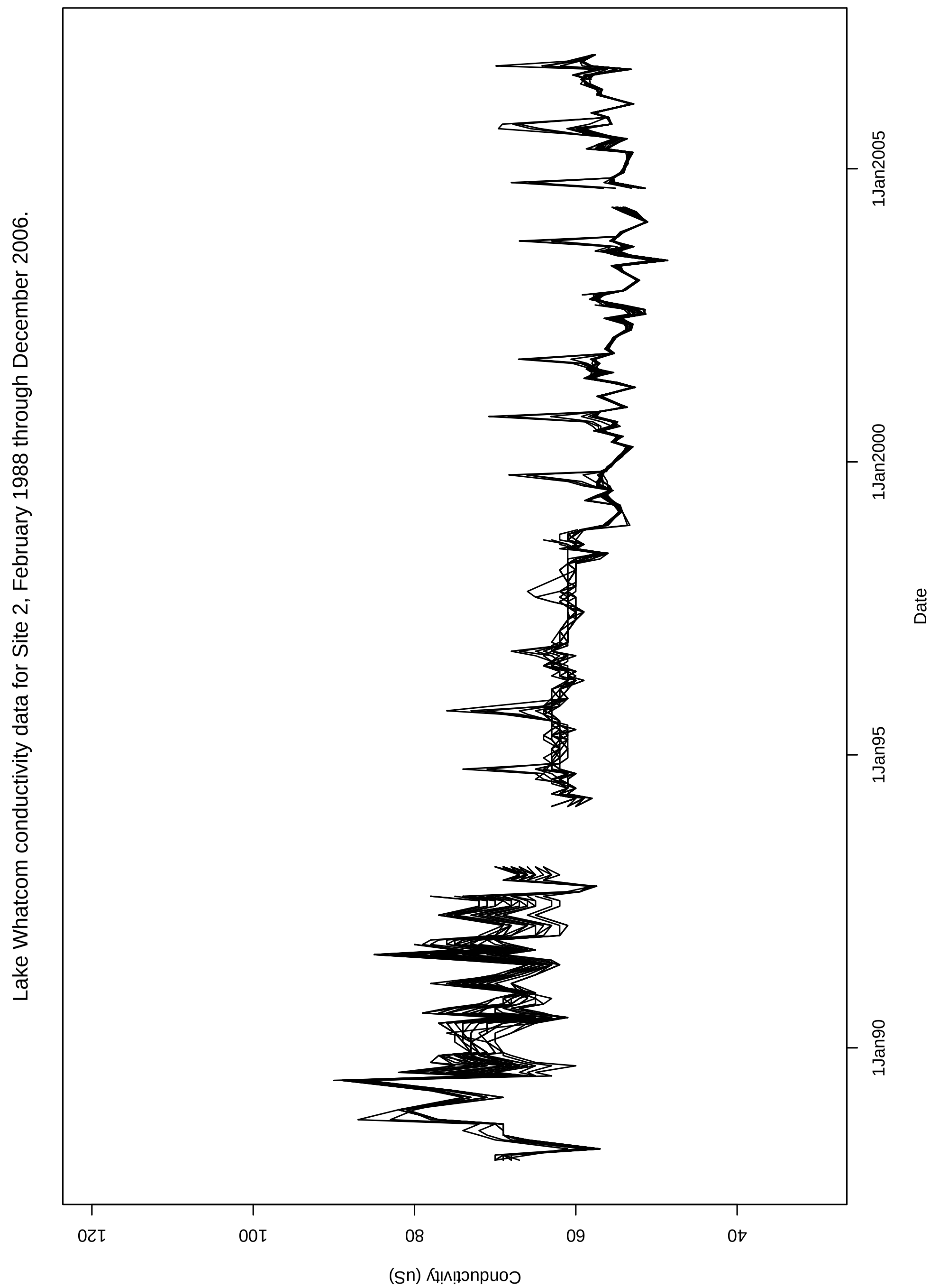


Figure B67: Lake Whatcom historic conductivity data for Site 2. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

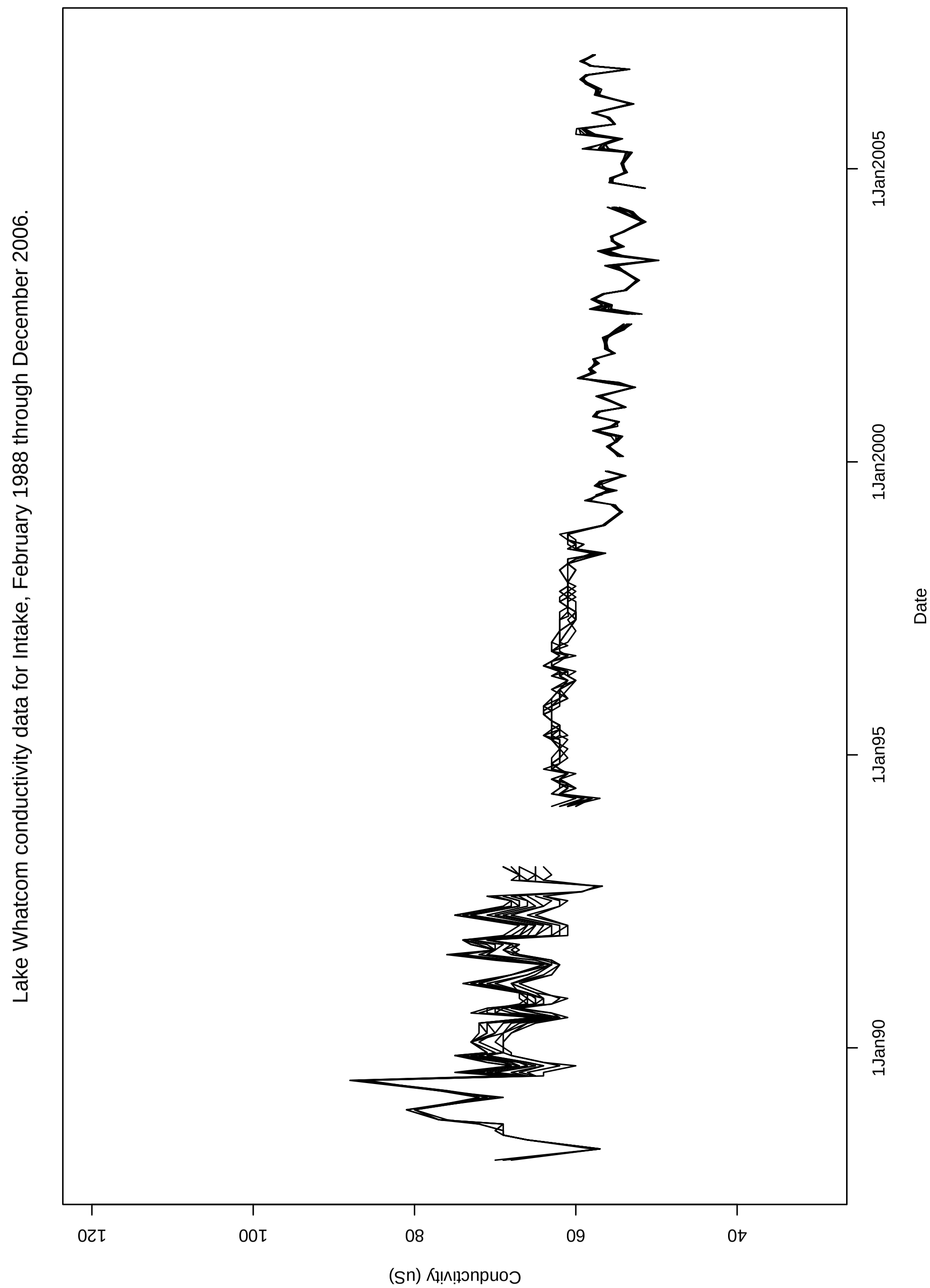


Figure B68: Lake Whatcom historic conductivity data for the Intake. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

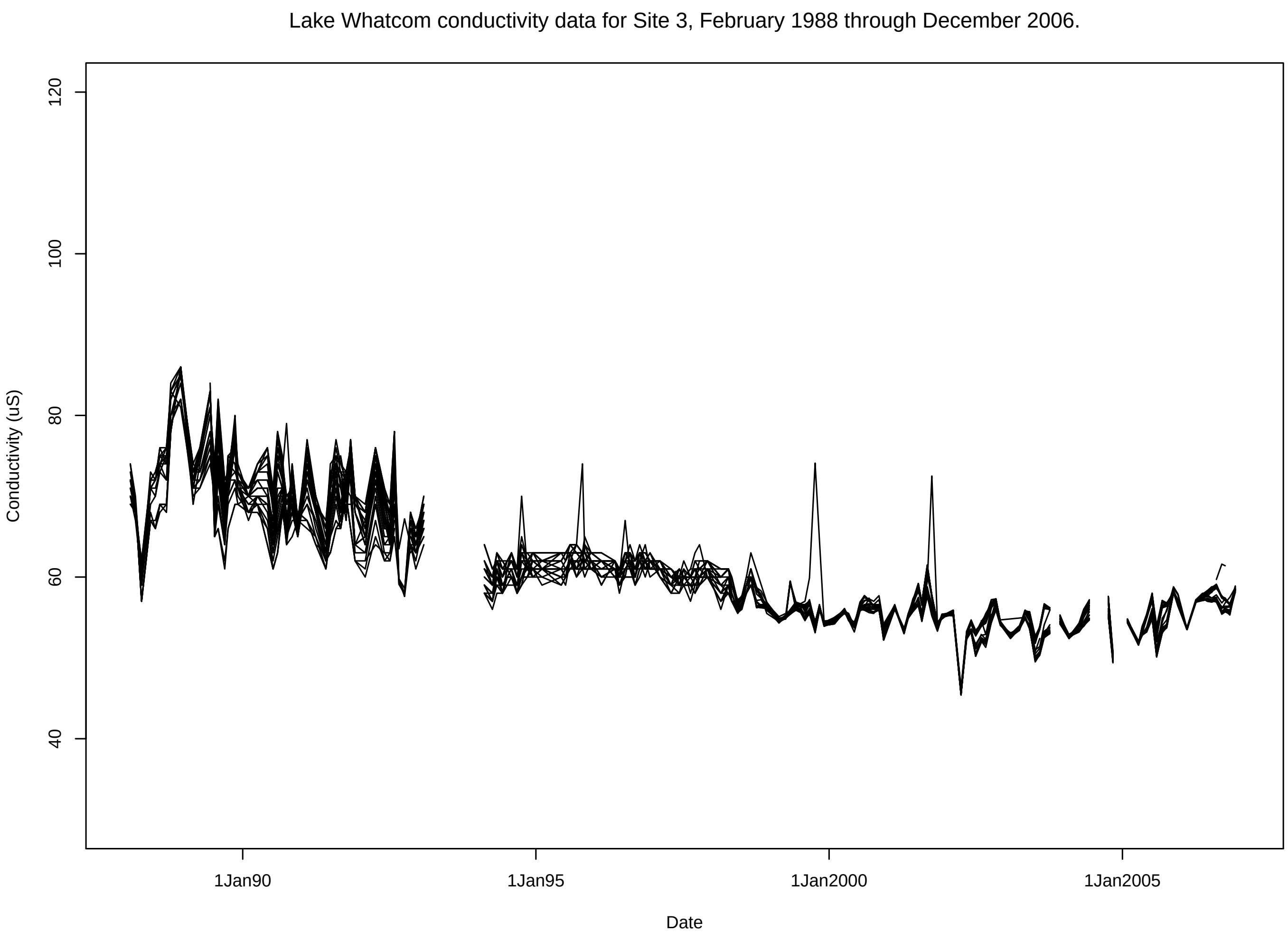


Figure B69: Lake Whatcom historic conductivity data for Site 3. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

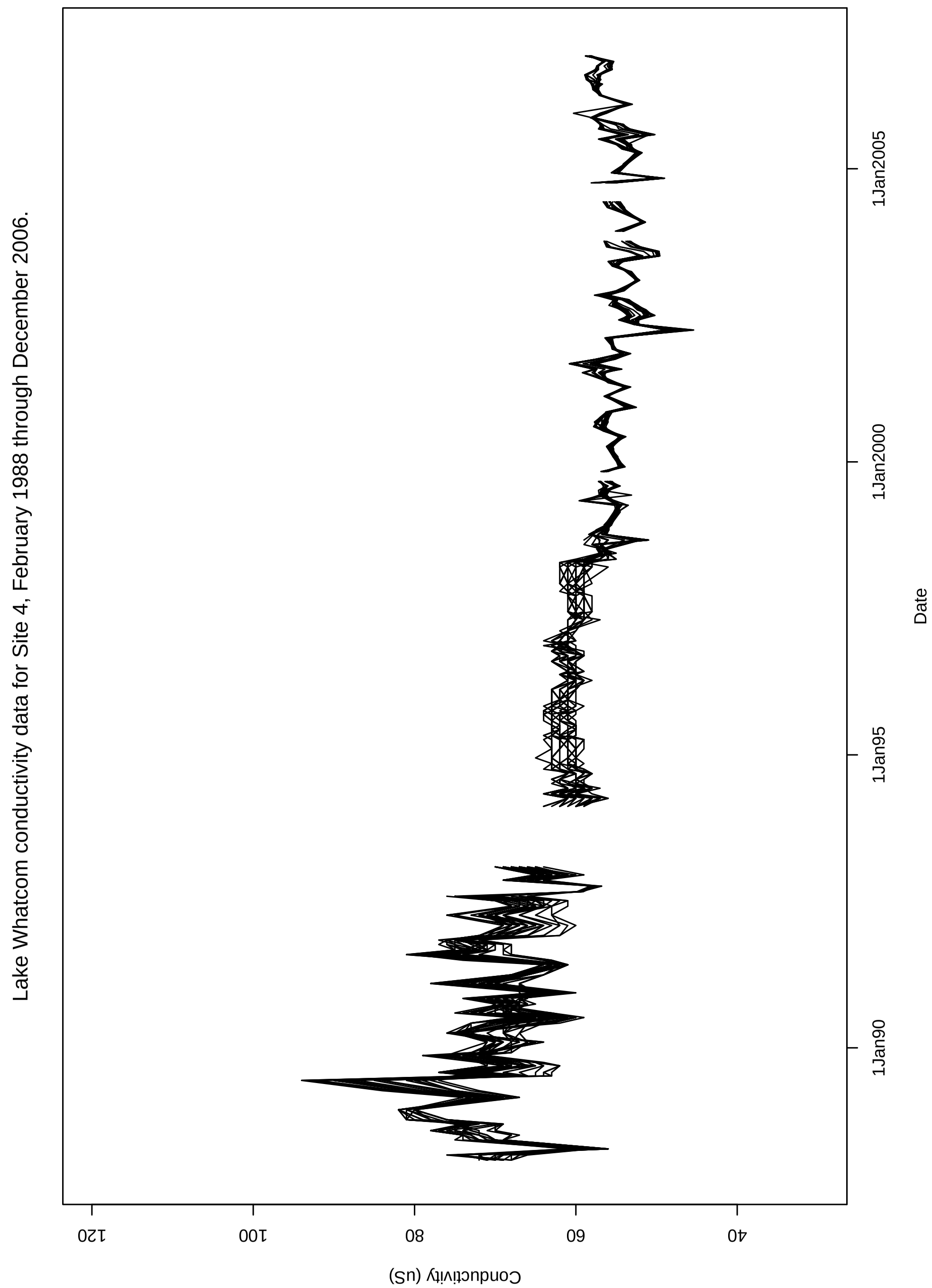


Figure B70: Lake Whatcom historic conductivity data for Site 4. The decreasing conductivity trend is the result of changing to increasingly sensitive equipment during the past two decades.

B.3 Alkalinity and Turbidity

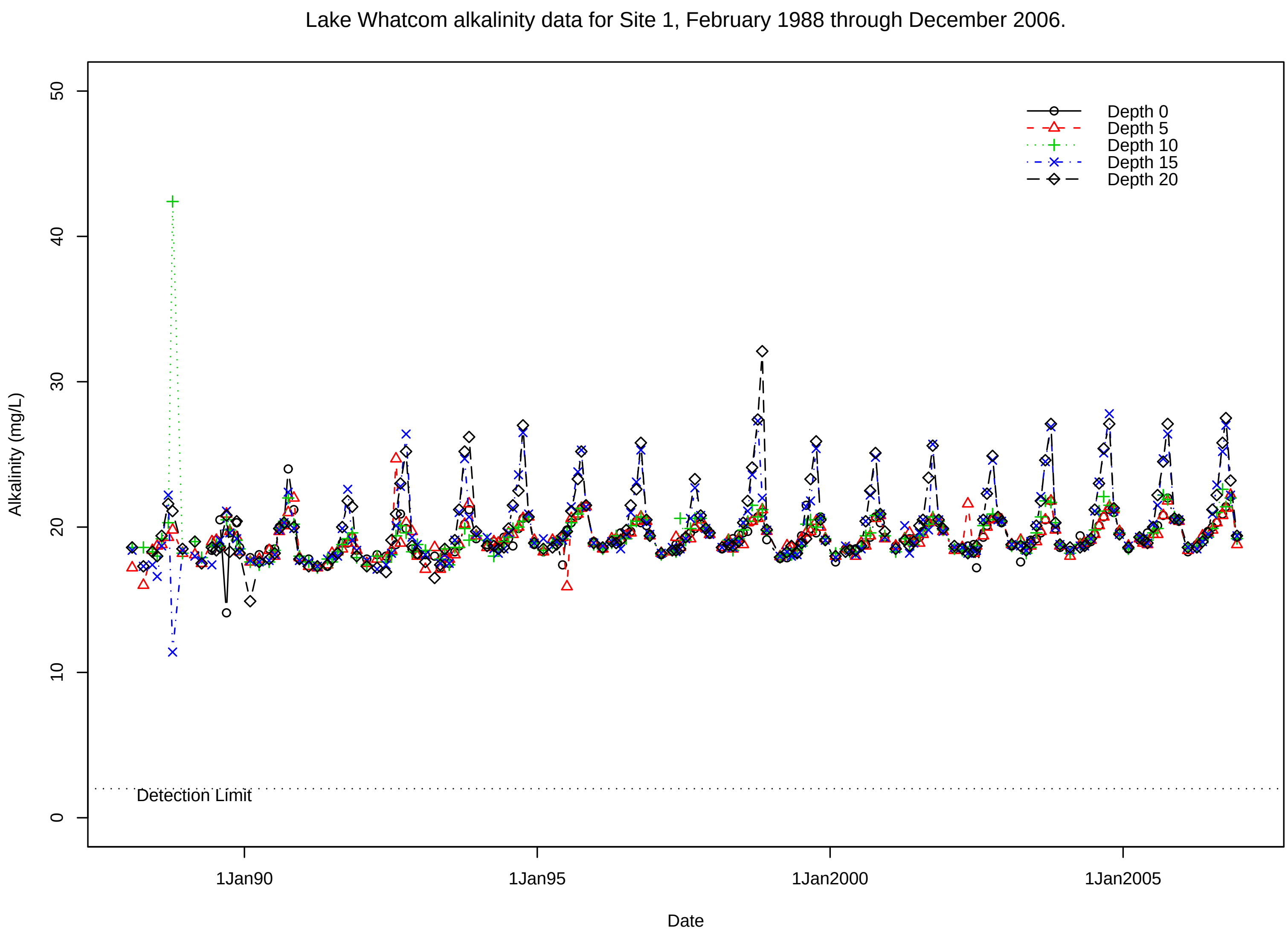


Figure B71: Lake Whatcom alkalinity data for Site 1.

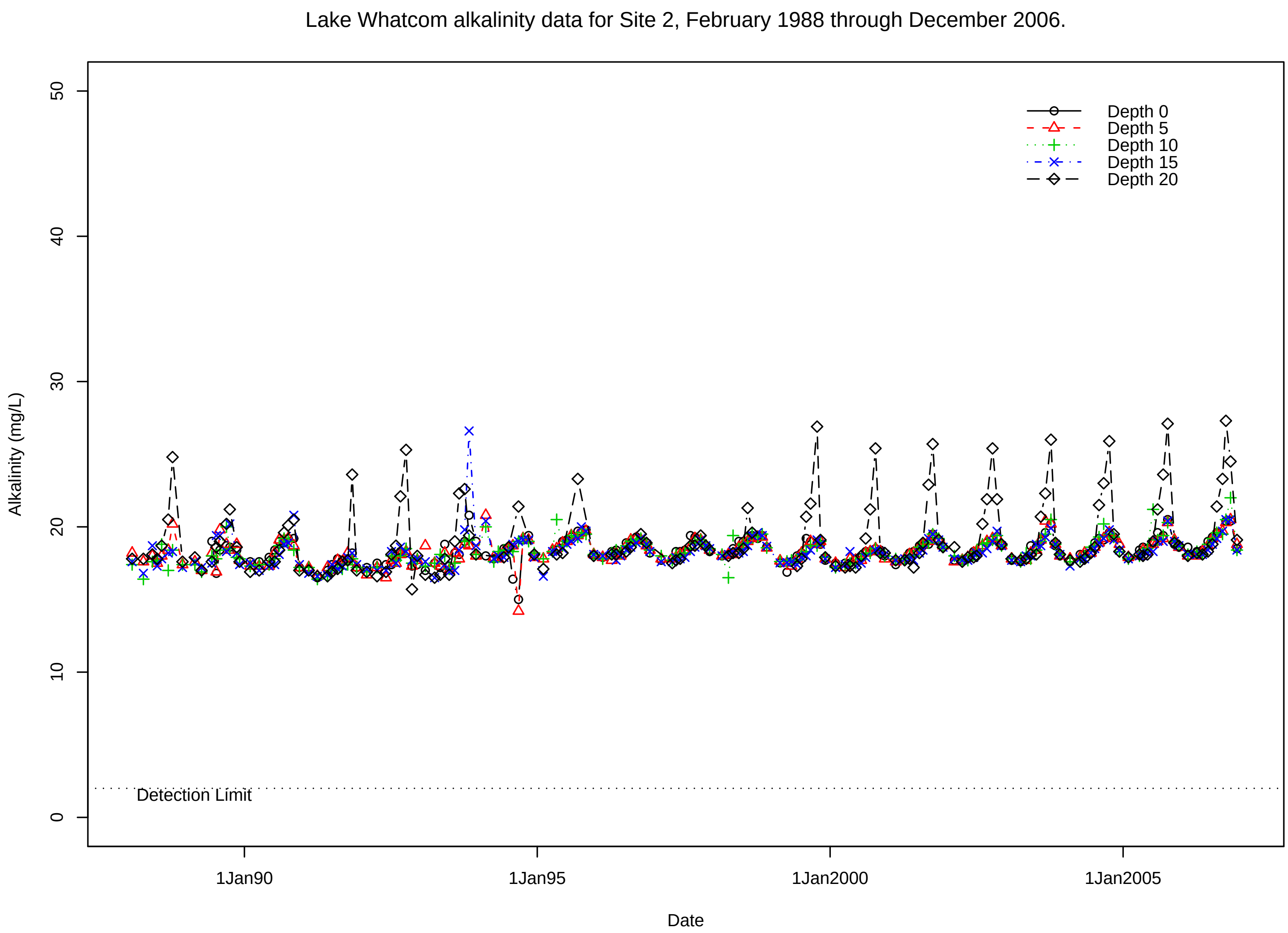


Figure B72: Lake Whatcom alkalinity data for Site 2.

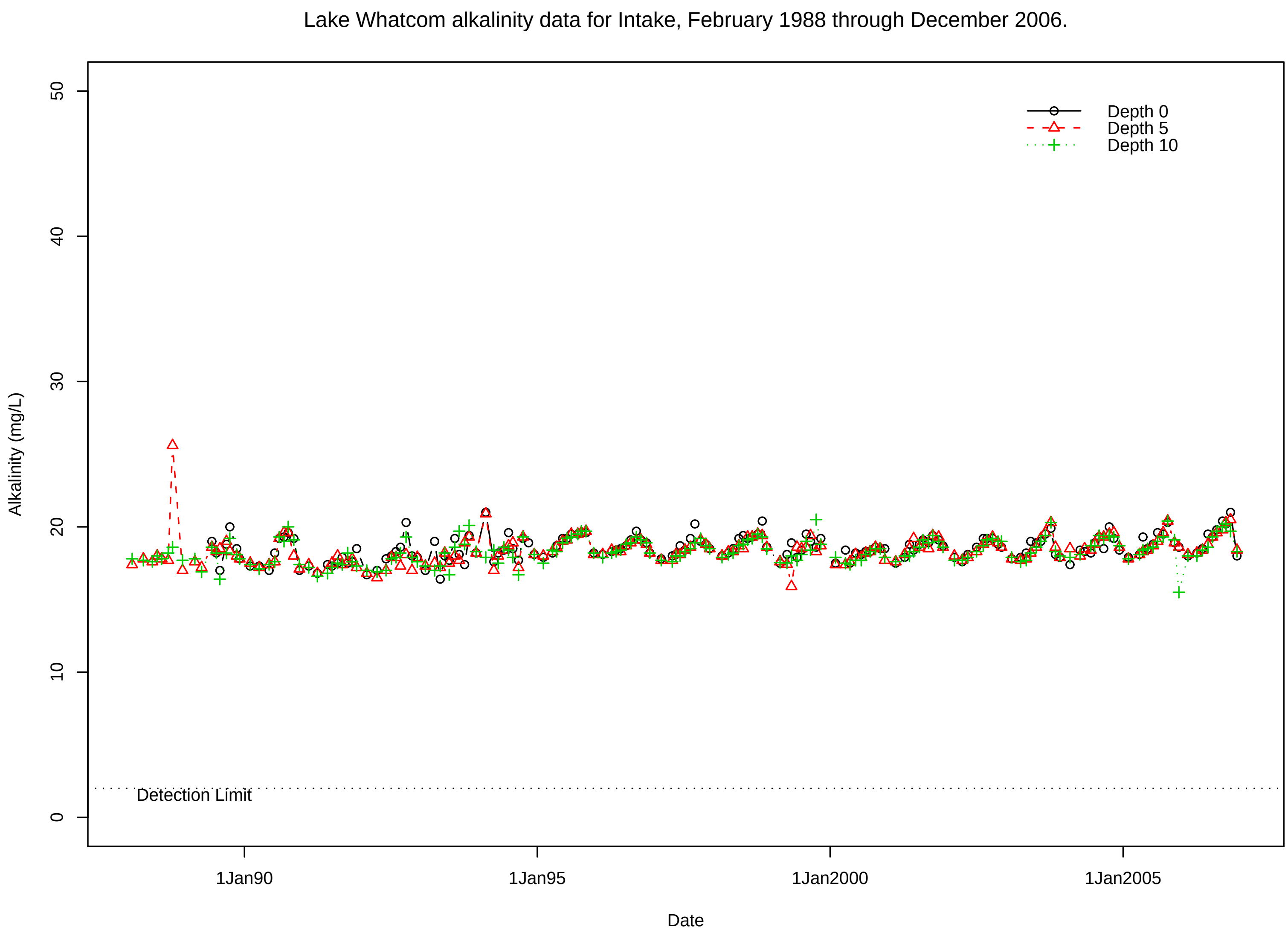


Figure B73: Lake Whatcom alkalinity data for the Intake site.

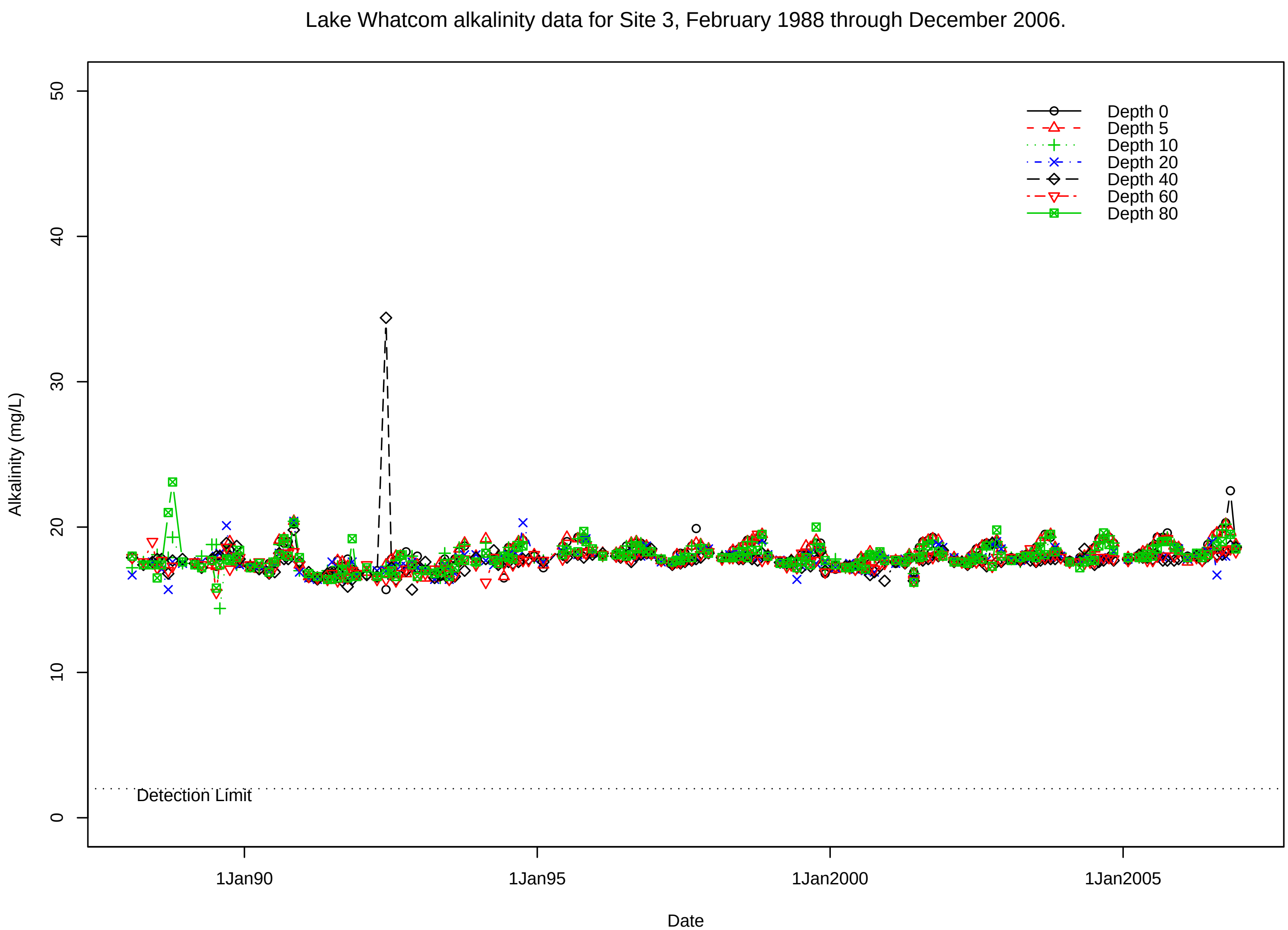


Figure B74: Lake Whatcom alkalinity data for Site 3.

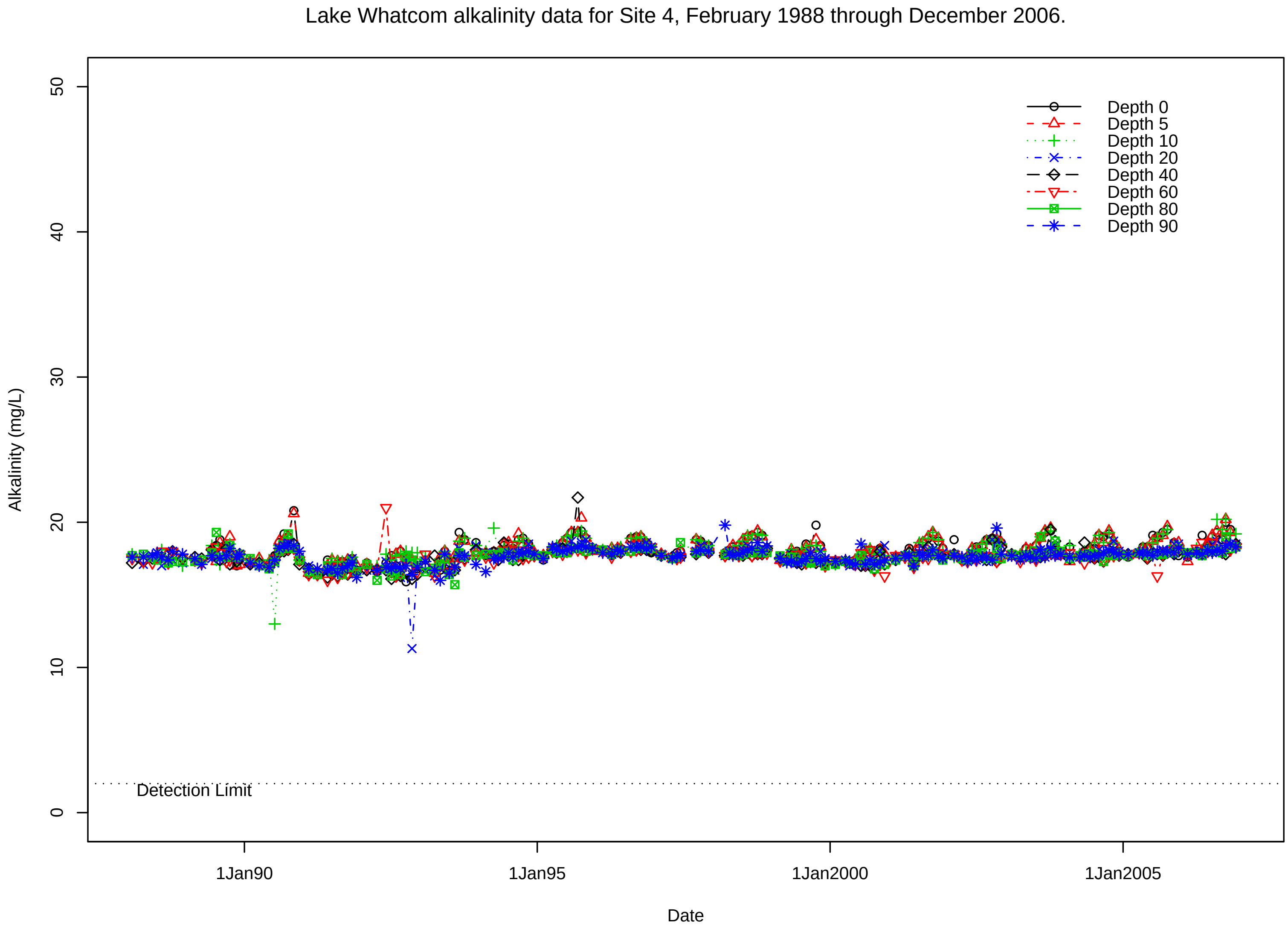


Figure B75: Lake Whatcom alkalinity data for Site 4.

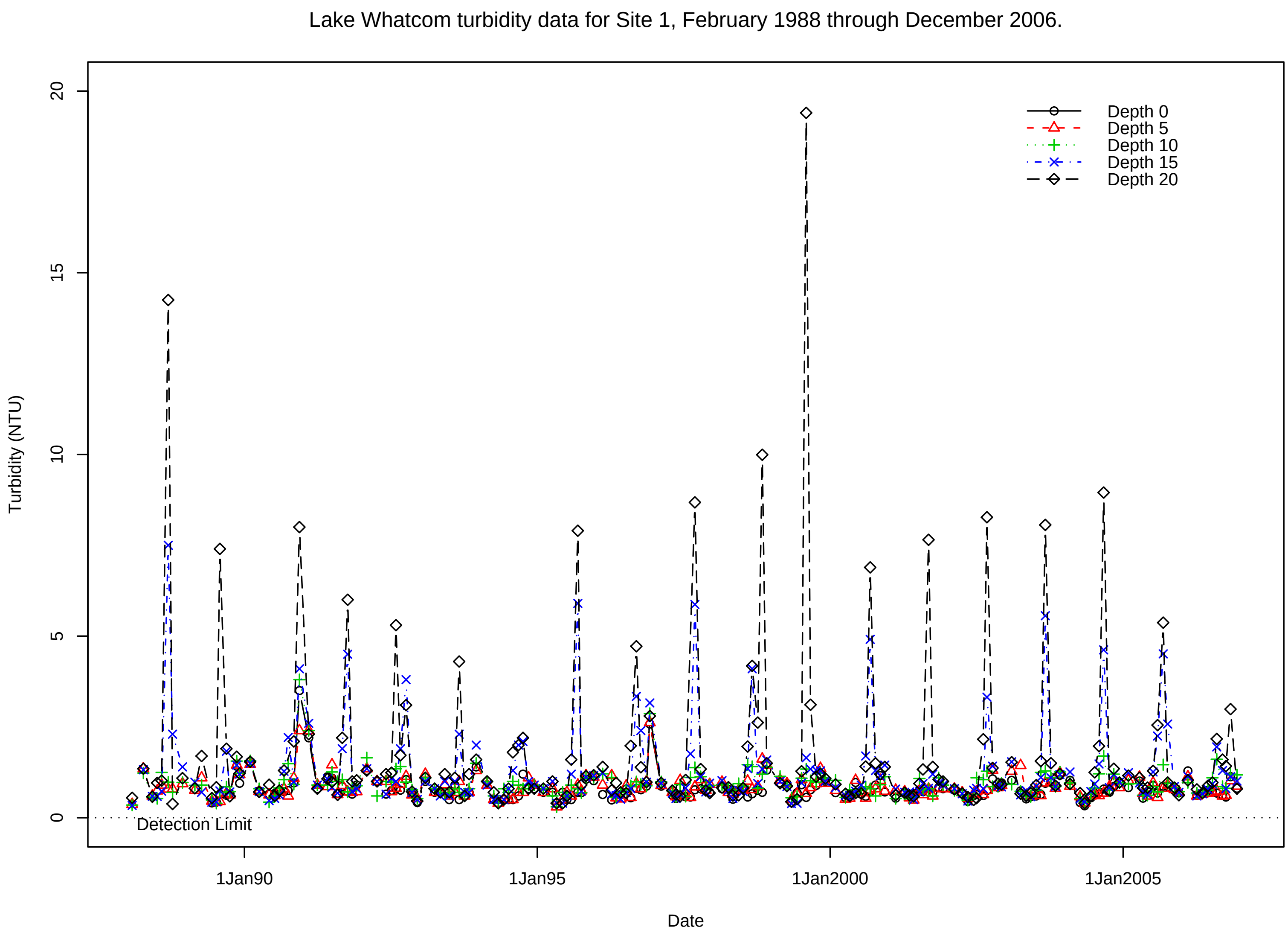


Figure B76: Lake Whatcom turbidity data for Site 1.

Lake Whatcom turbidity data for Site 2, February 1988 through December 2006.

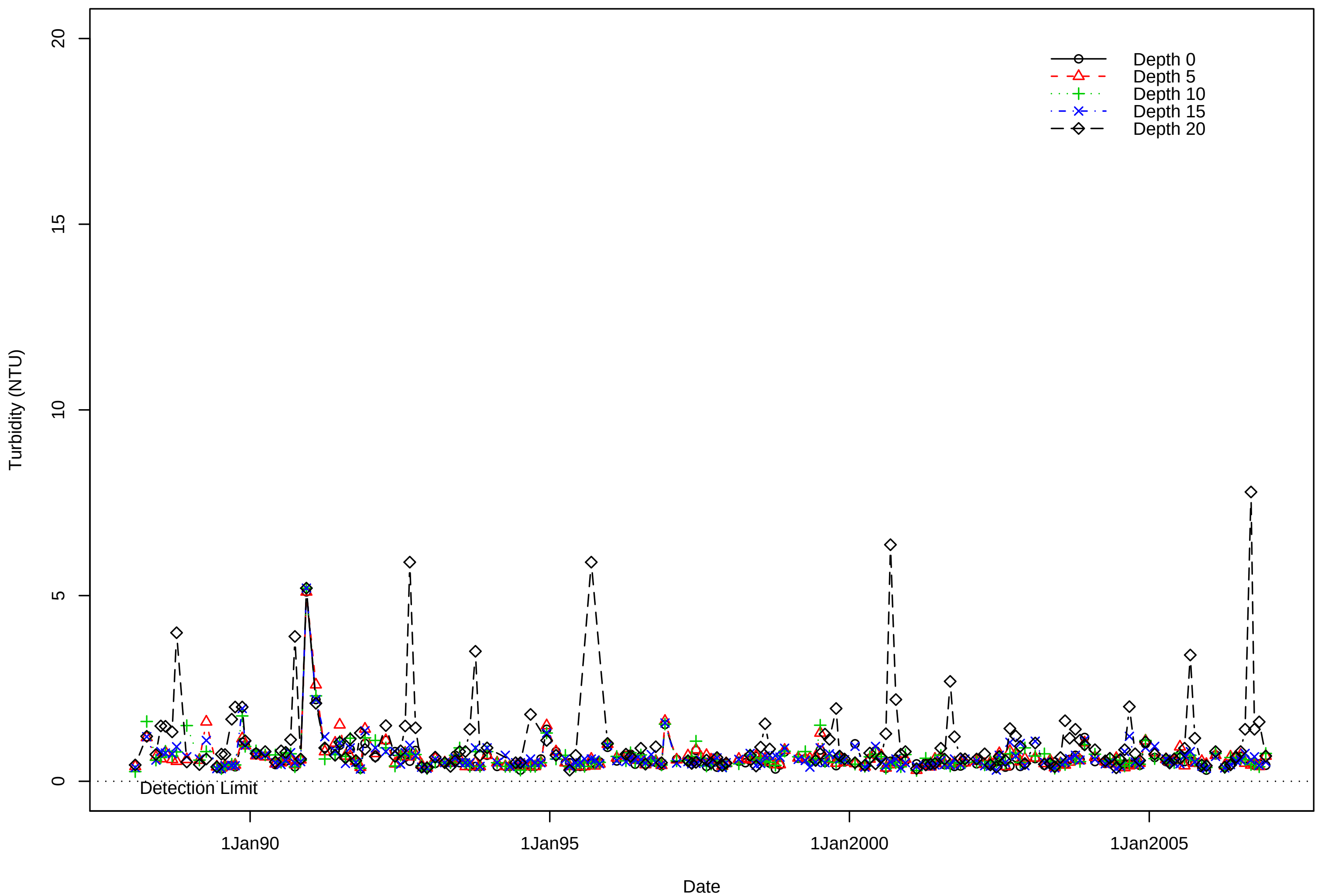


Figure B77: Lake Whatcom turbidity data for Site 2.

Lake Whatcom turbidity data for Intake, February 1988 through December 2006.

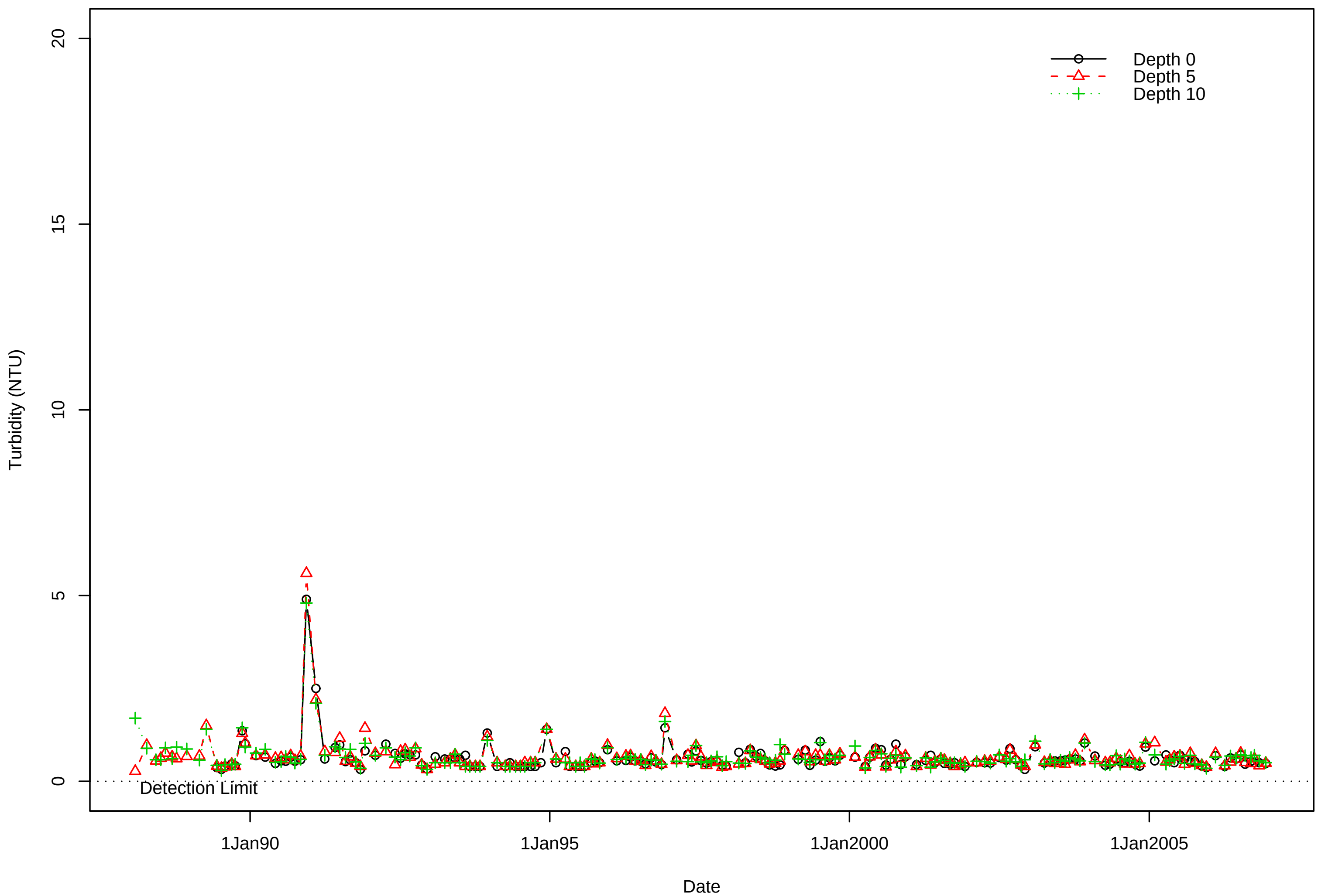


Figure B78: Lake Whatcom turbidity data for the Intake site.

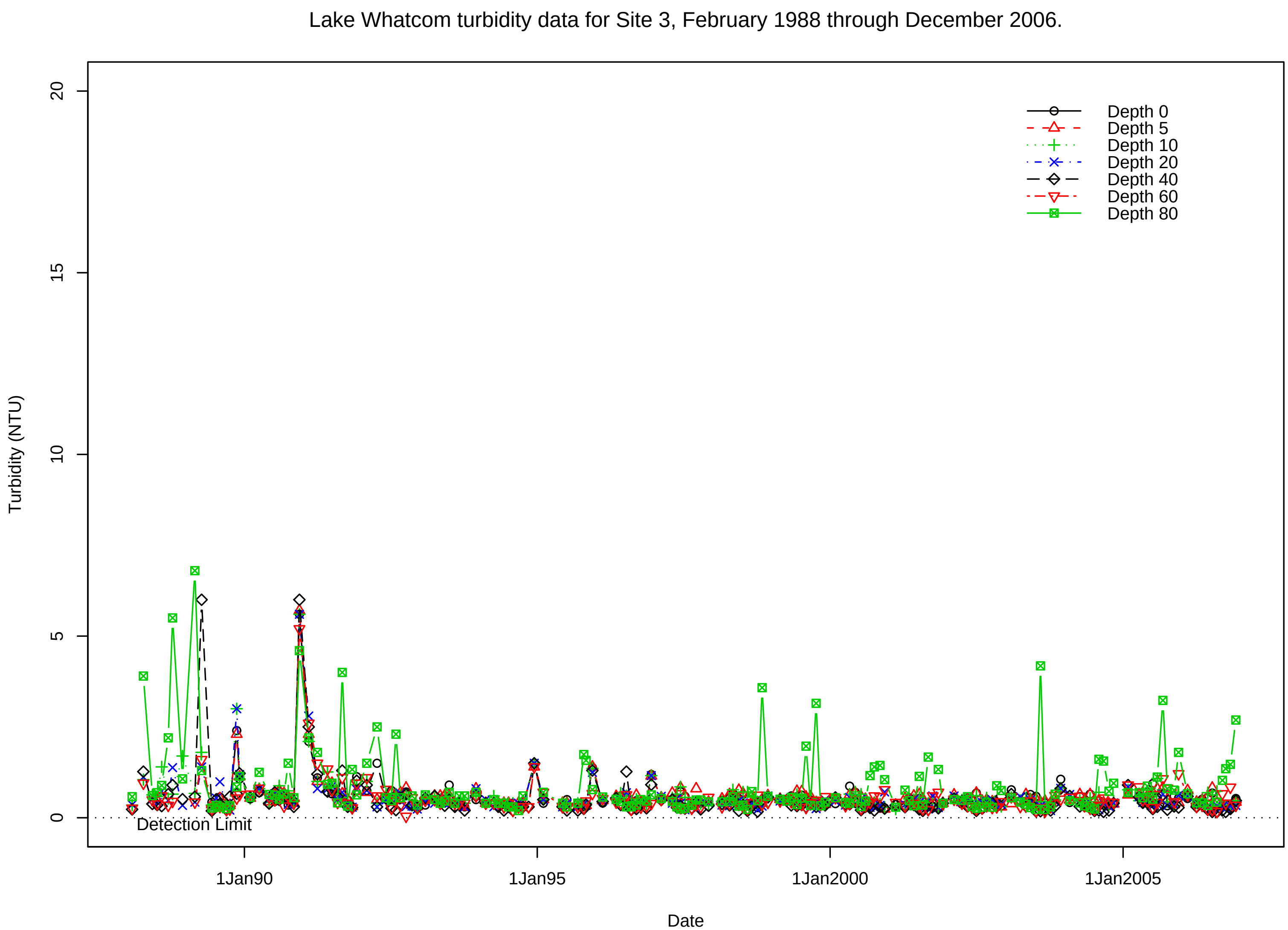


Figure B79: Lake Whatcom turbidity data for Site 3.

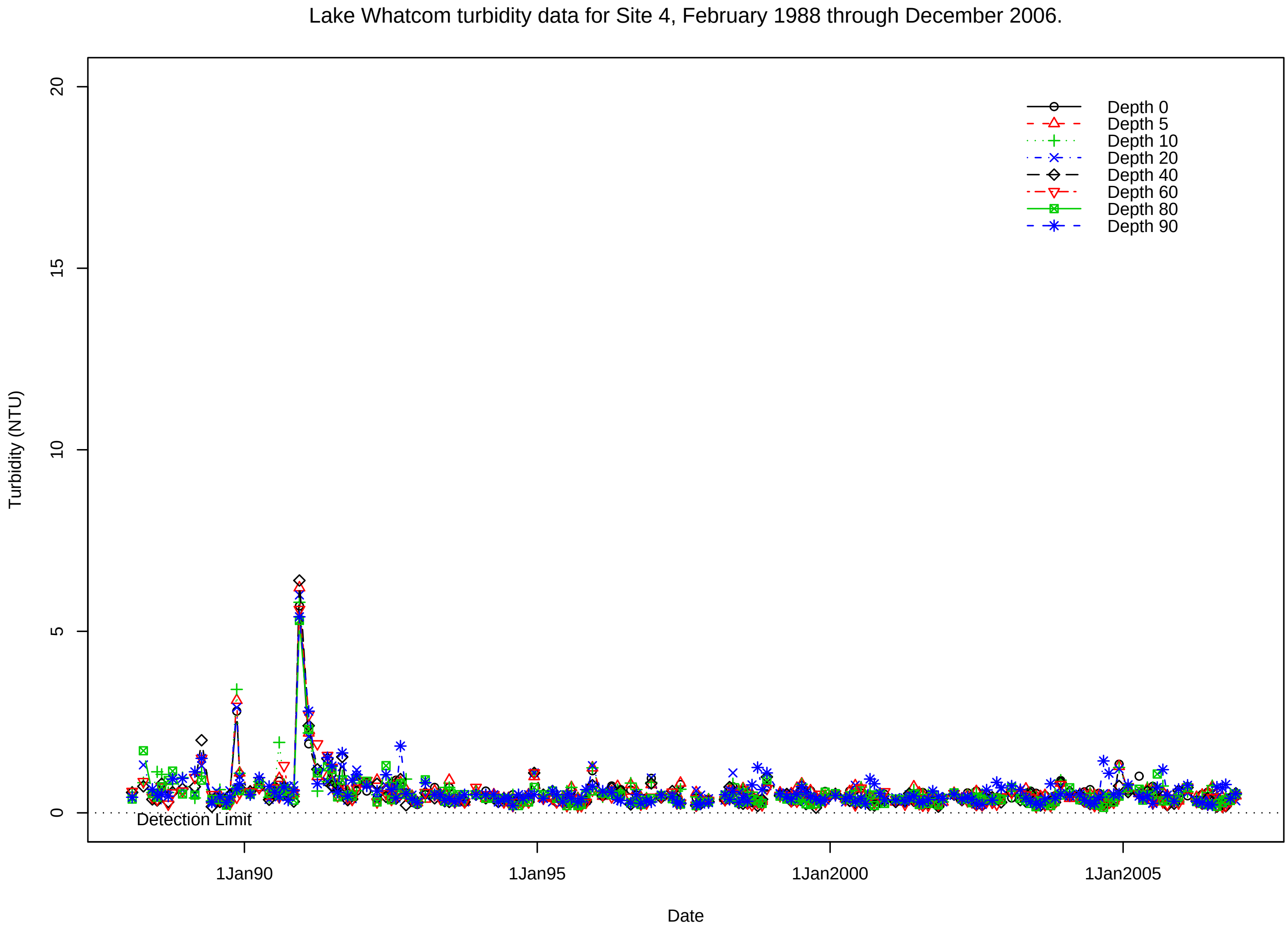


Figure B80: Lake Whatcom turbidity data for Site 4.

B.4 Nitrogen and Phosphorus

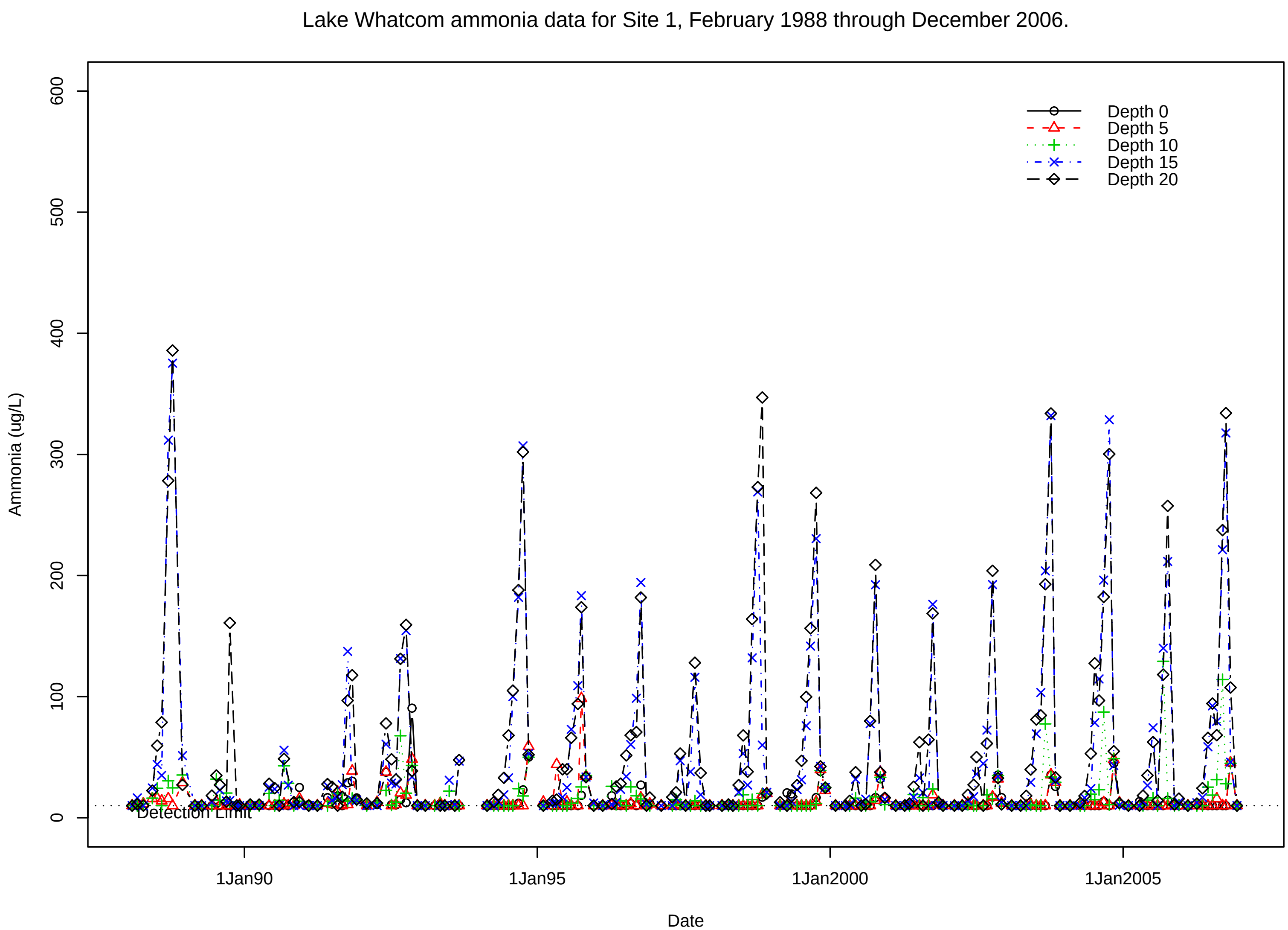


Figure B81: Lake Whatcom ammonia data for Site 1.

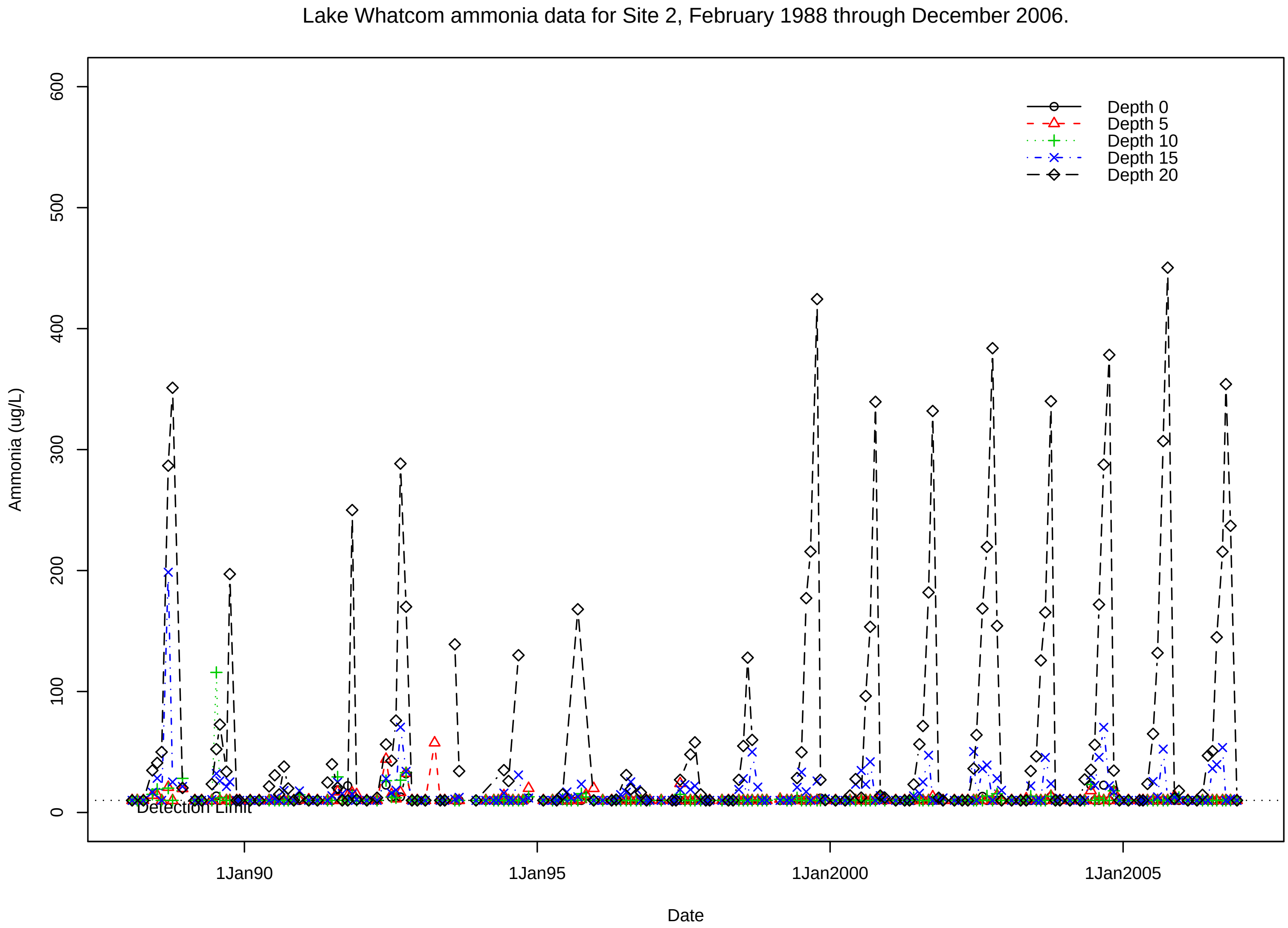


Figure B82: Lake Whatcom ammonia data for Site 2.

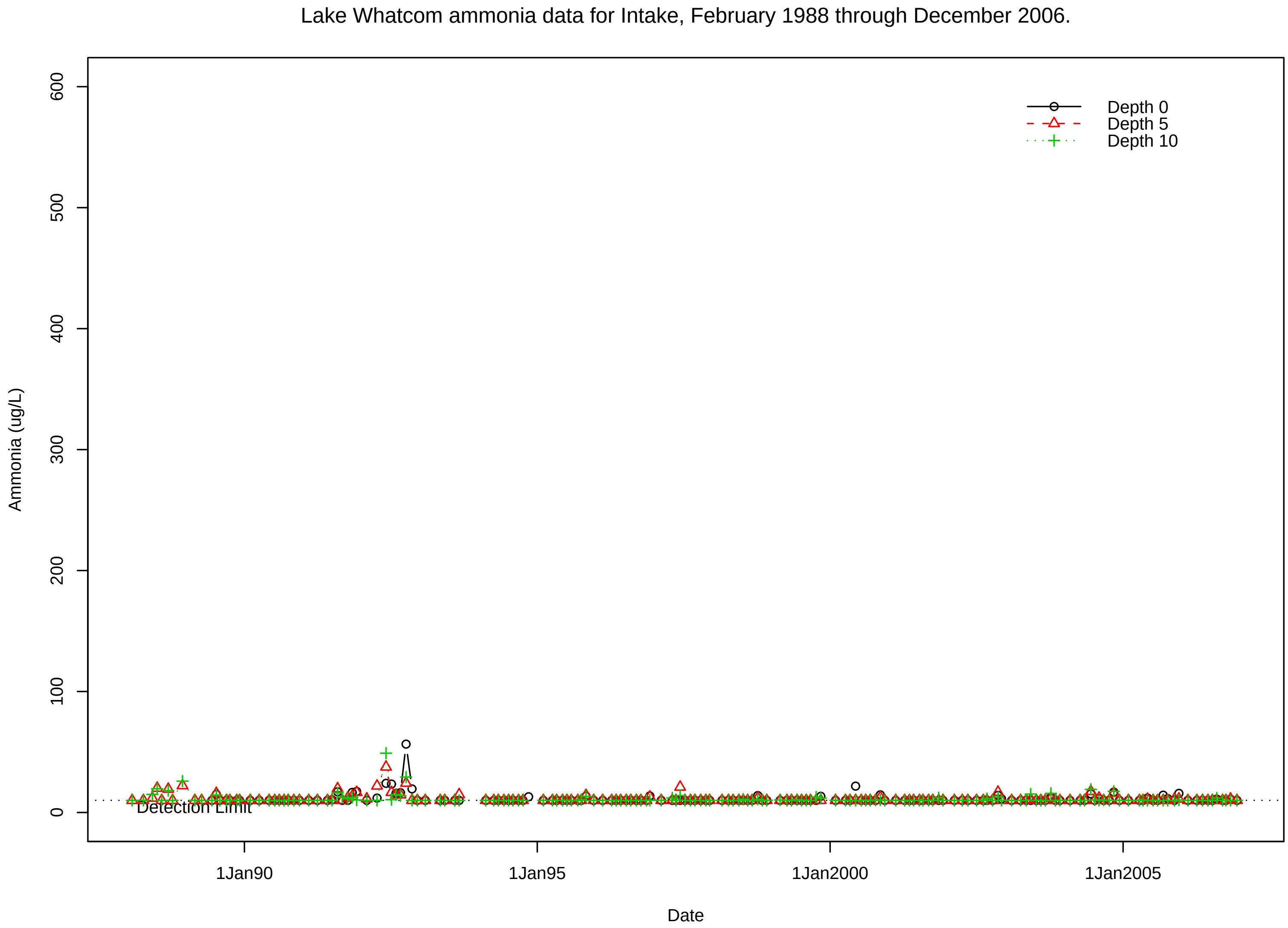
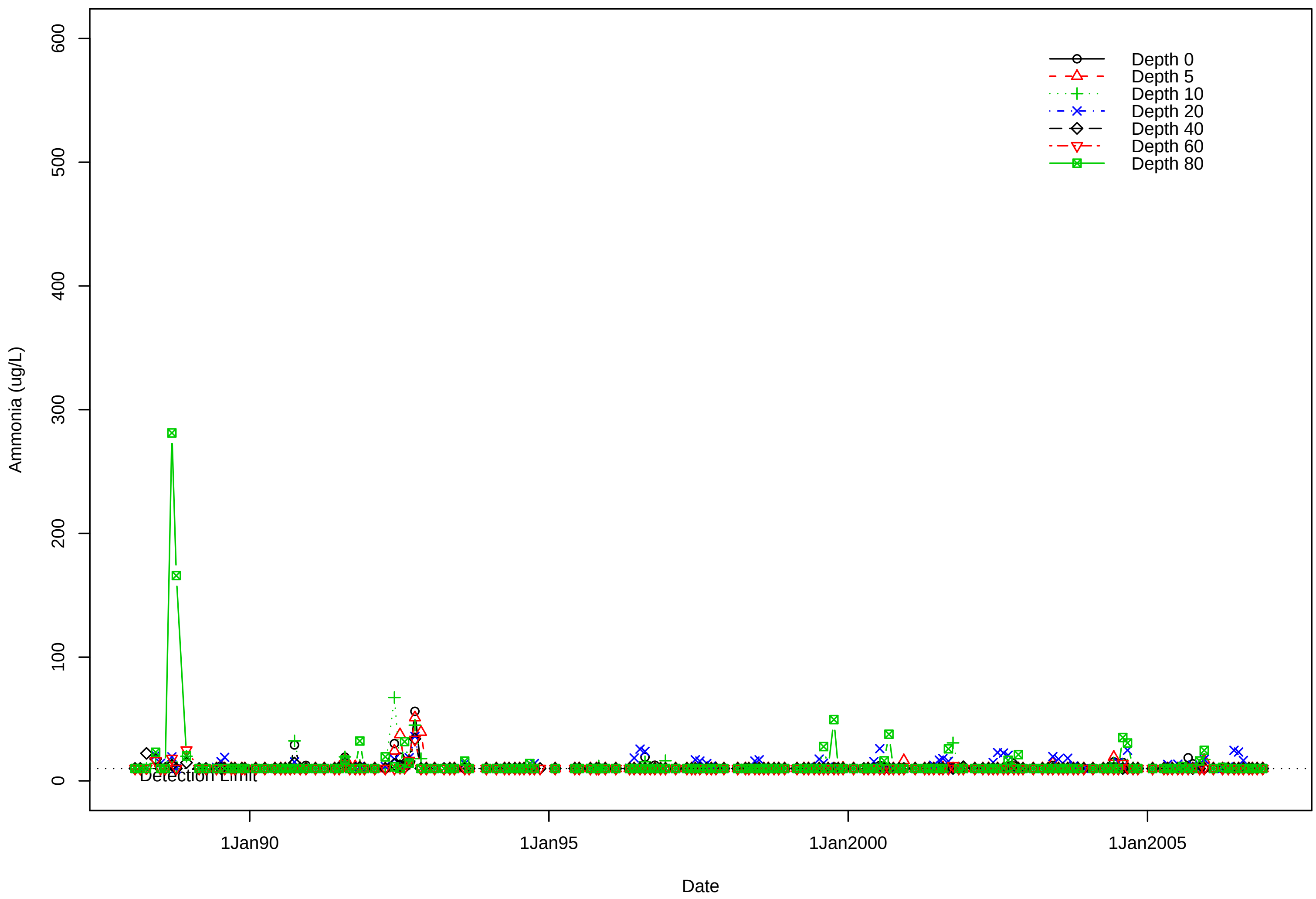


Figure B83: Lake Whatcom ammonia data for the Intake site.

Figure B84: Lake Whatcom ammonia data for Site 3.

Lake Whatcom ammonia data for Site 3, February 1988 through December 2006.



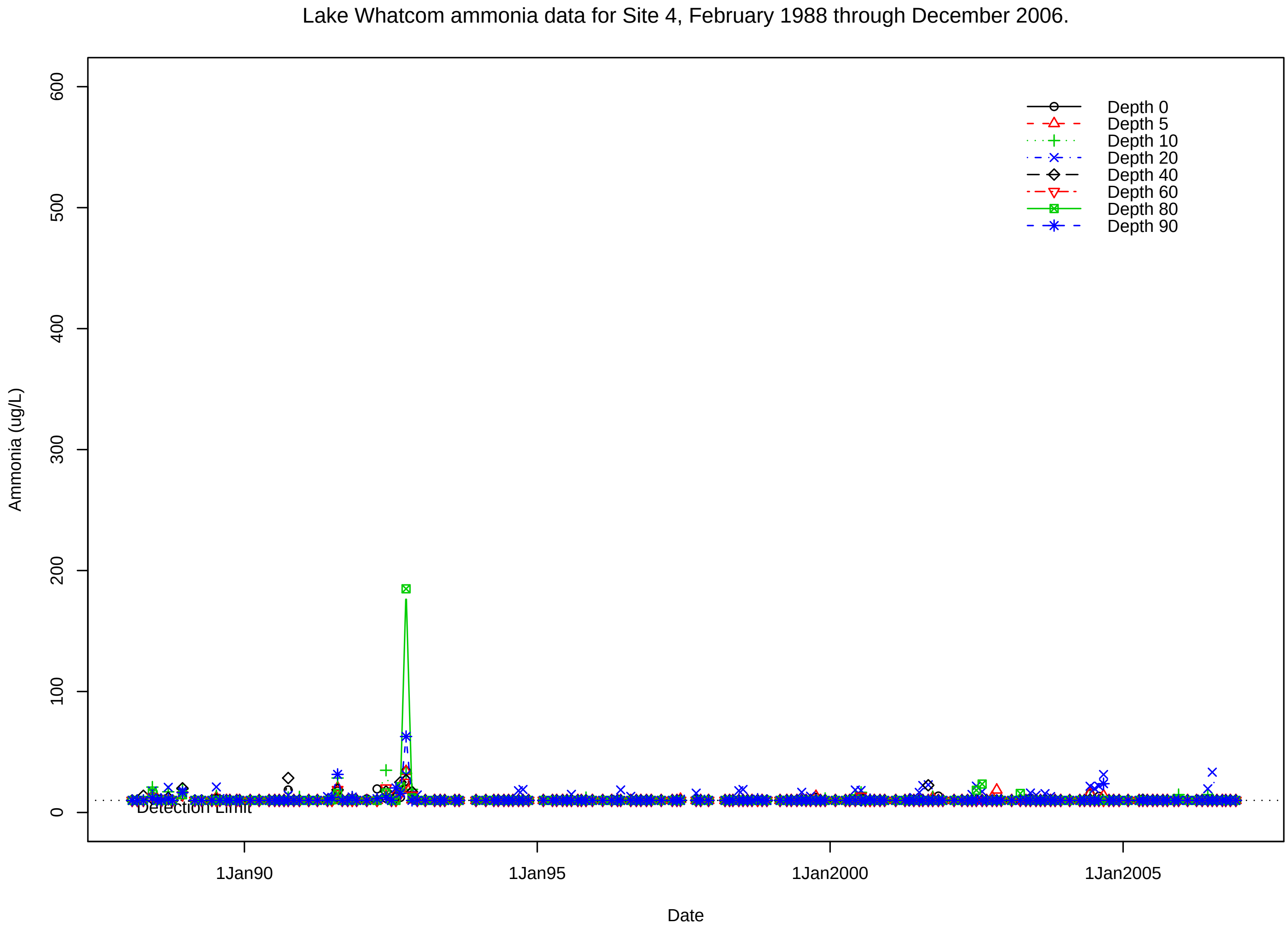


Figure B85: Lake Whatcom ammonia data for Site 4.

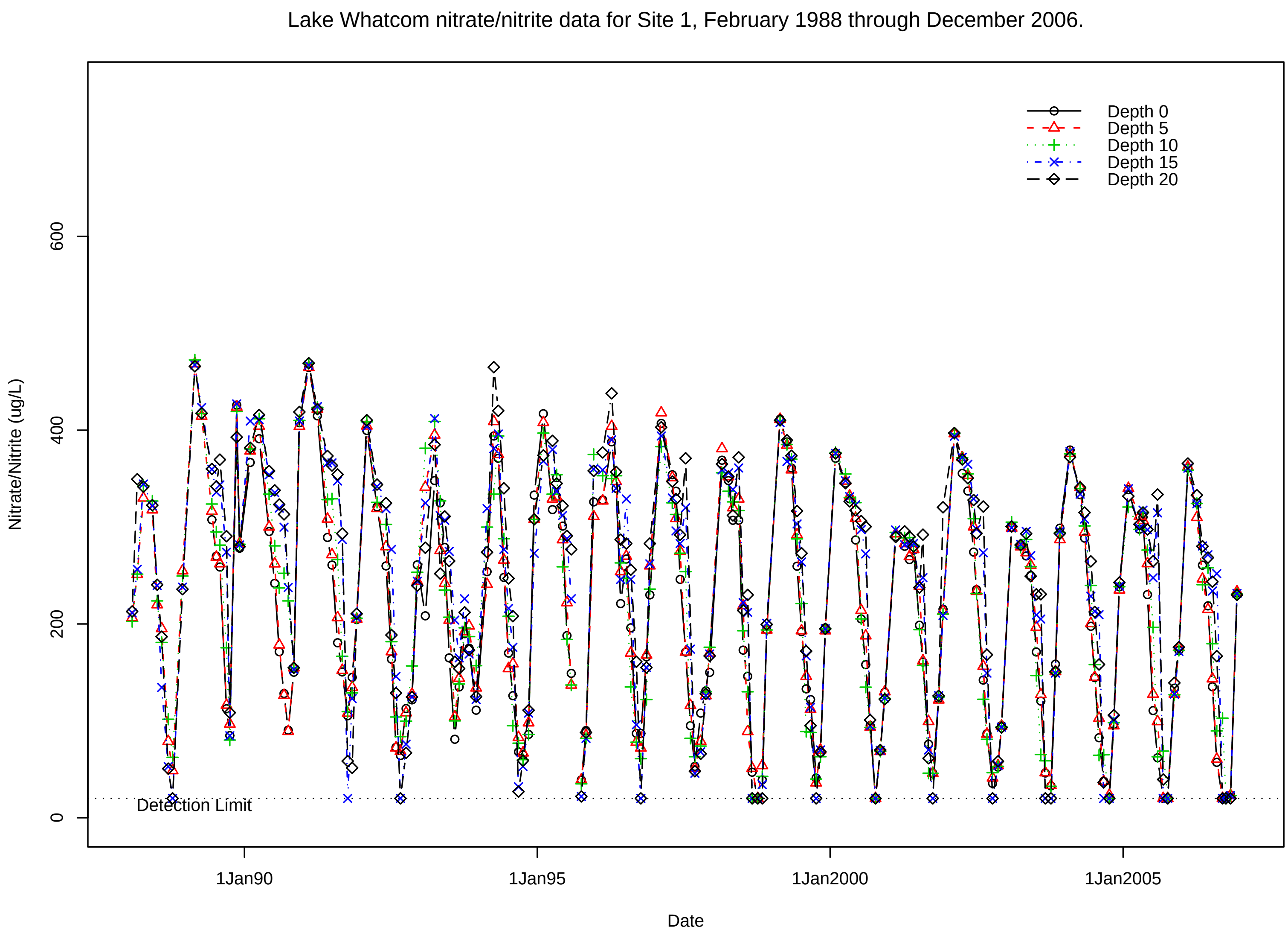


Figure B86: Lake Whatcom nitrate/nitrite data for Site 1.

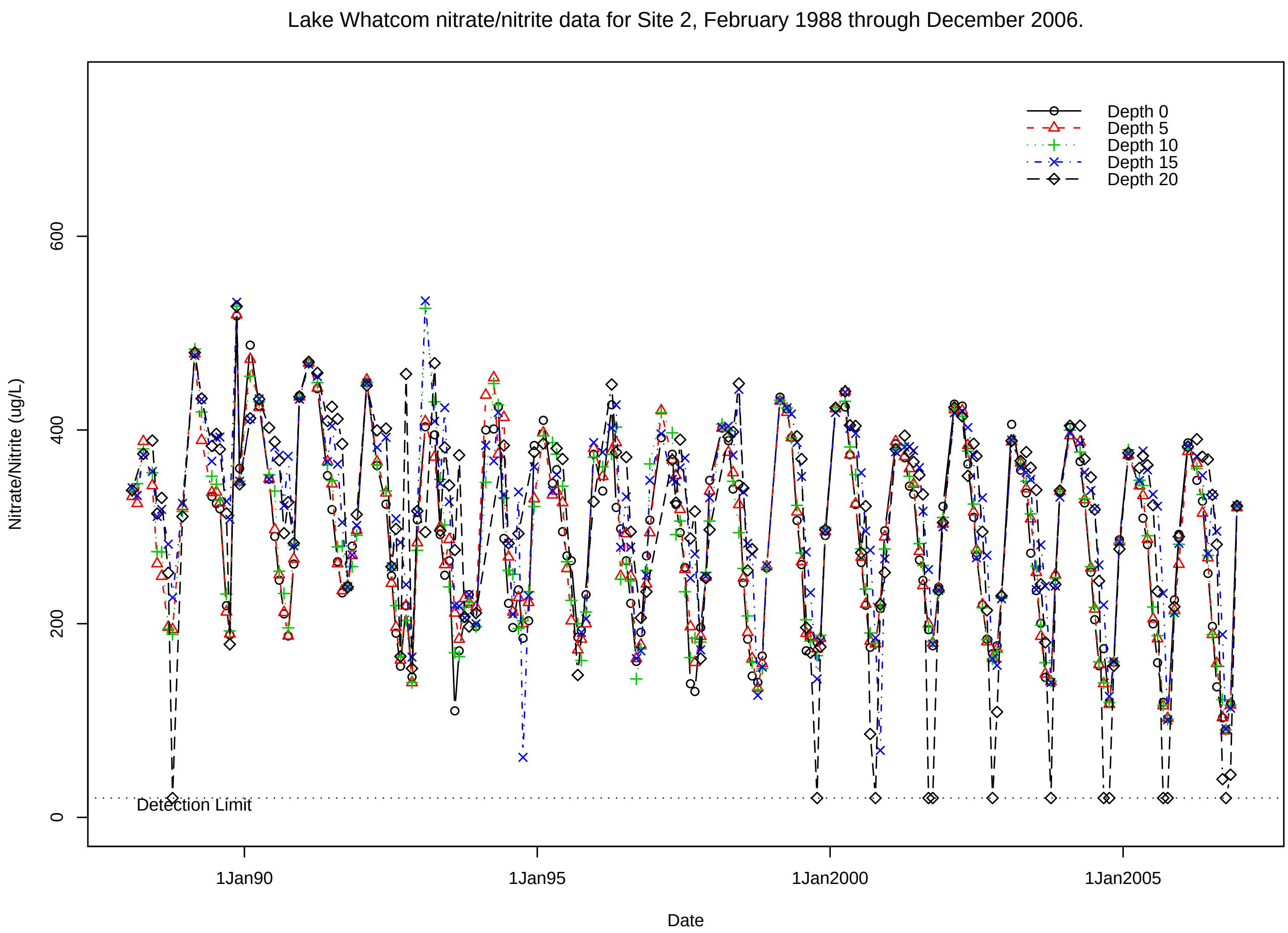


Figure B87: Lake Whatcom nitrate/nitrite data for Site 2.

Lake Whatcom nitrate/nitrite data for Intake, February 1988 through December 2006.

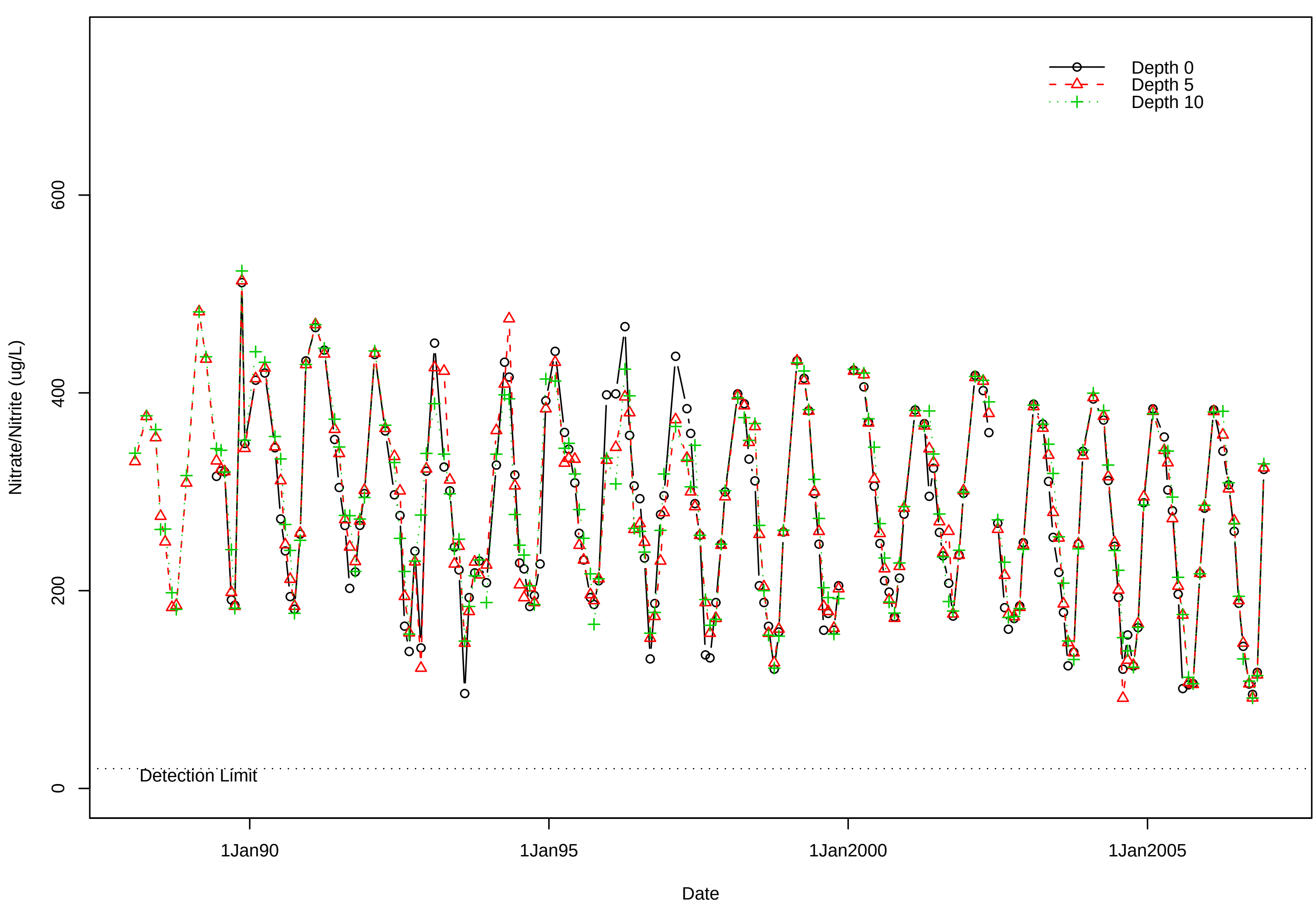


Figure B88: Lake Whatcom nitrate/nitrite data for the Intake site.

Lake Whatcom nitrate/nitrite data for Site 3, February 1988 through December 2006.

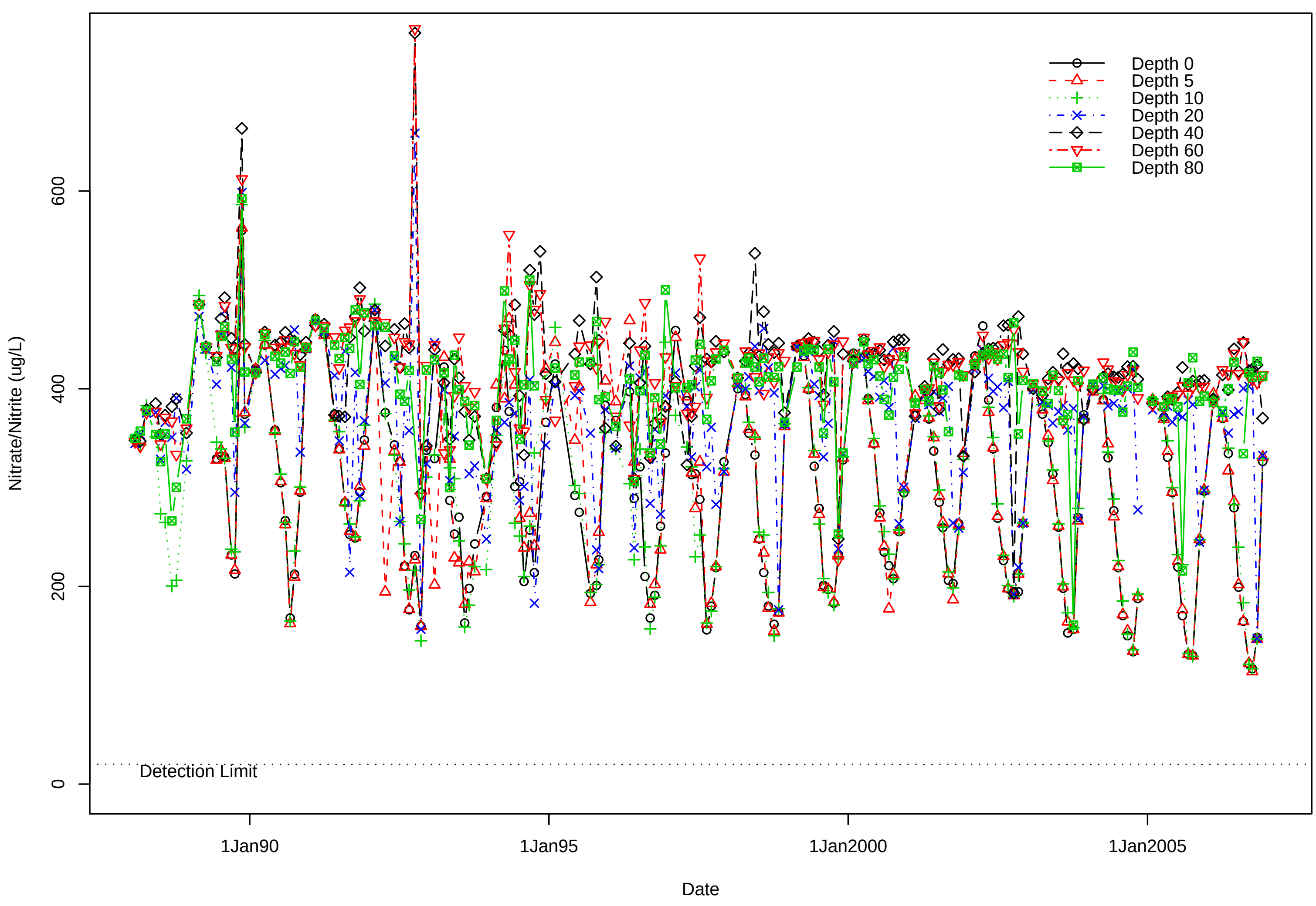


Figure B89: Lake Whatcom nitrate/nitrite data for Site 3.

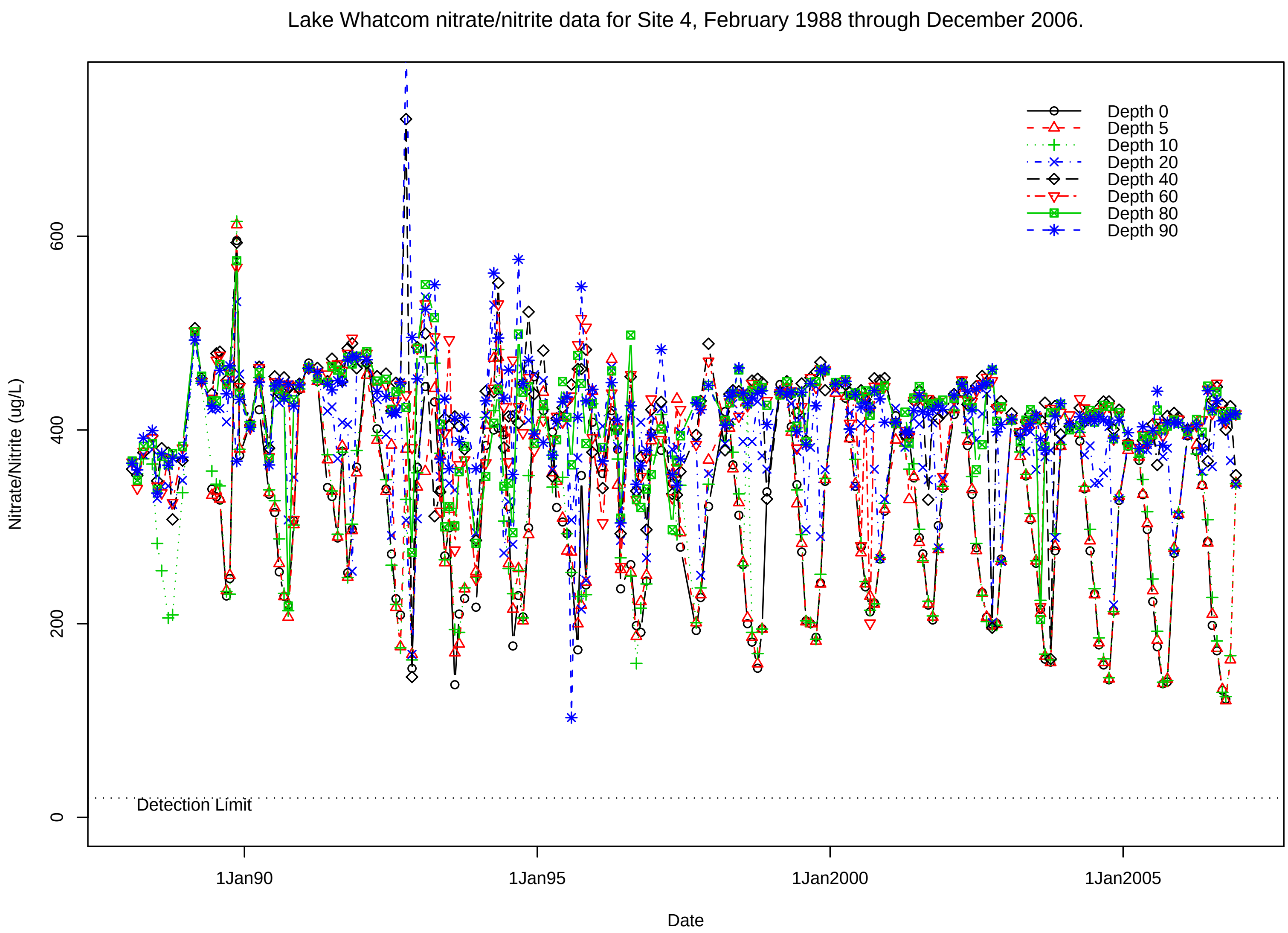


Figure B90: Lake Whatcom nitrate/nitrite data for Site 4.

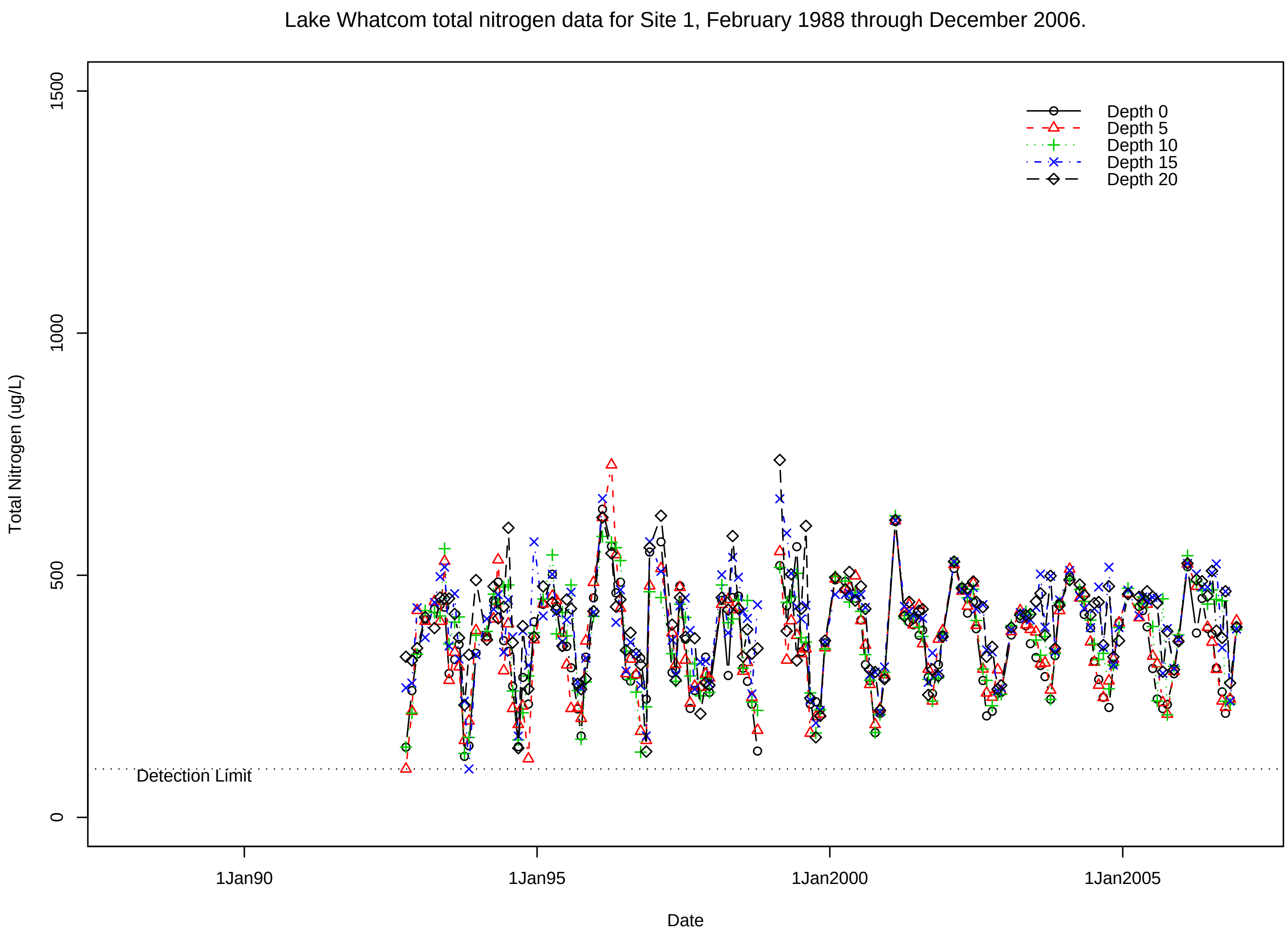


Figure B91: Lake Whatcom total nitrogen data for Site 1.

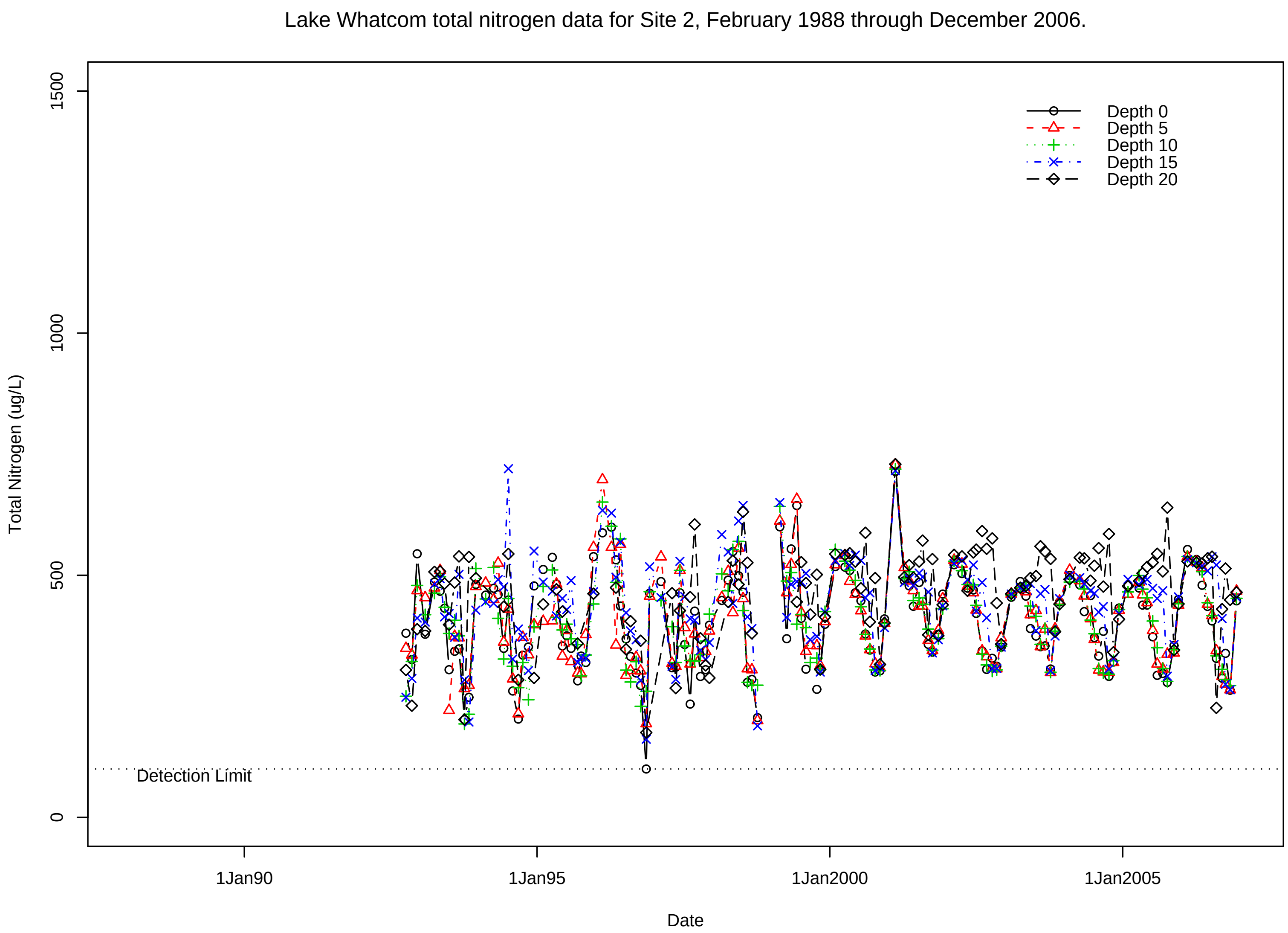


Figure B92: Lake Whatcom total nitrogen data for Site 2.

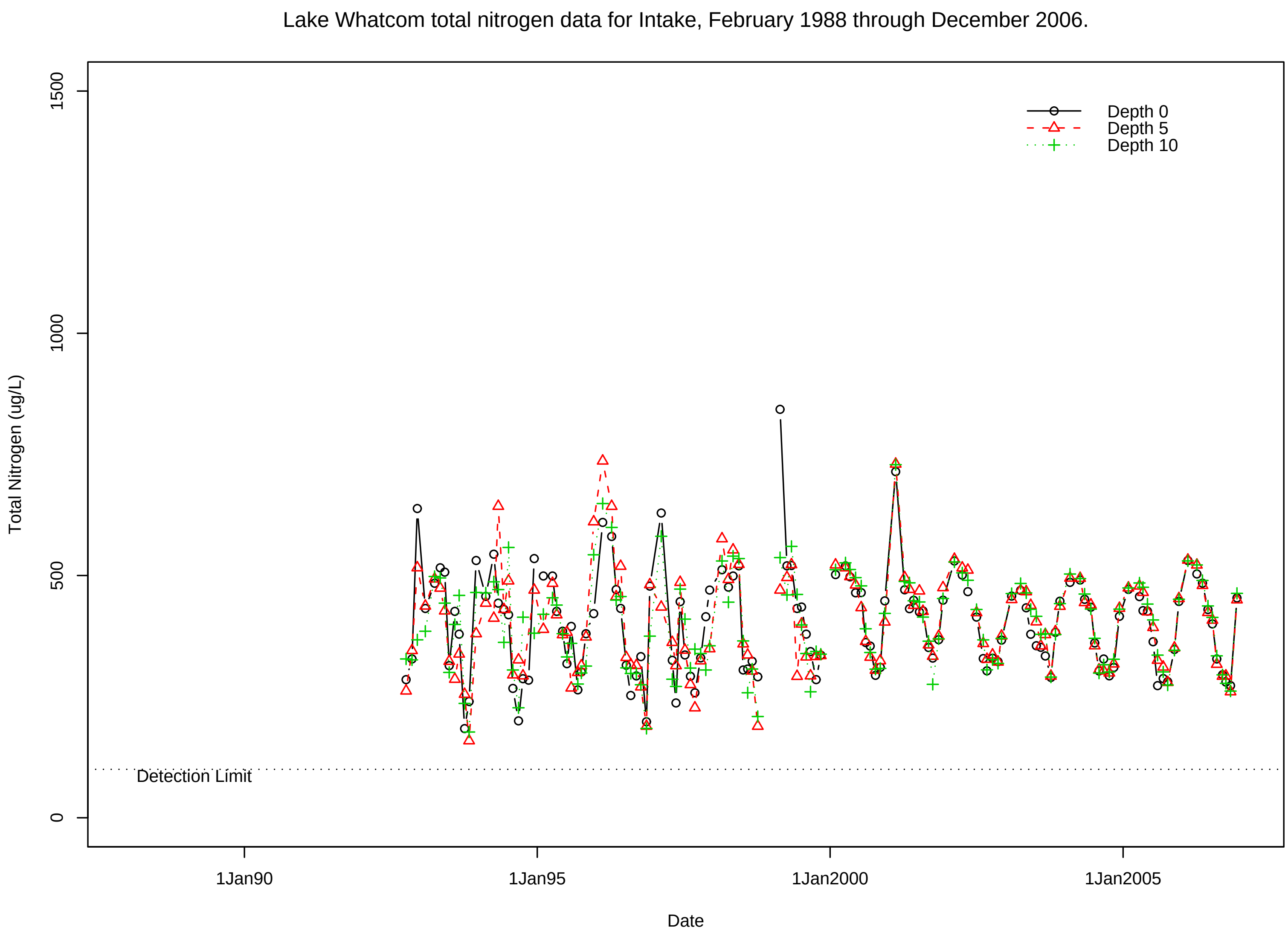


Figure B93: Lake Whatcom total nitrogen data for the Intake site.

Lake Whatcom total nitrogen data for Site 3, February 1988 through December 2006.

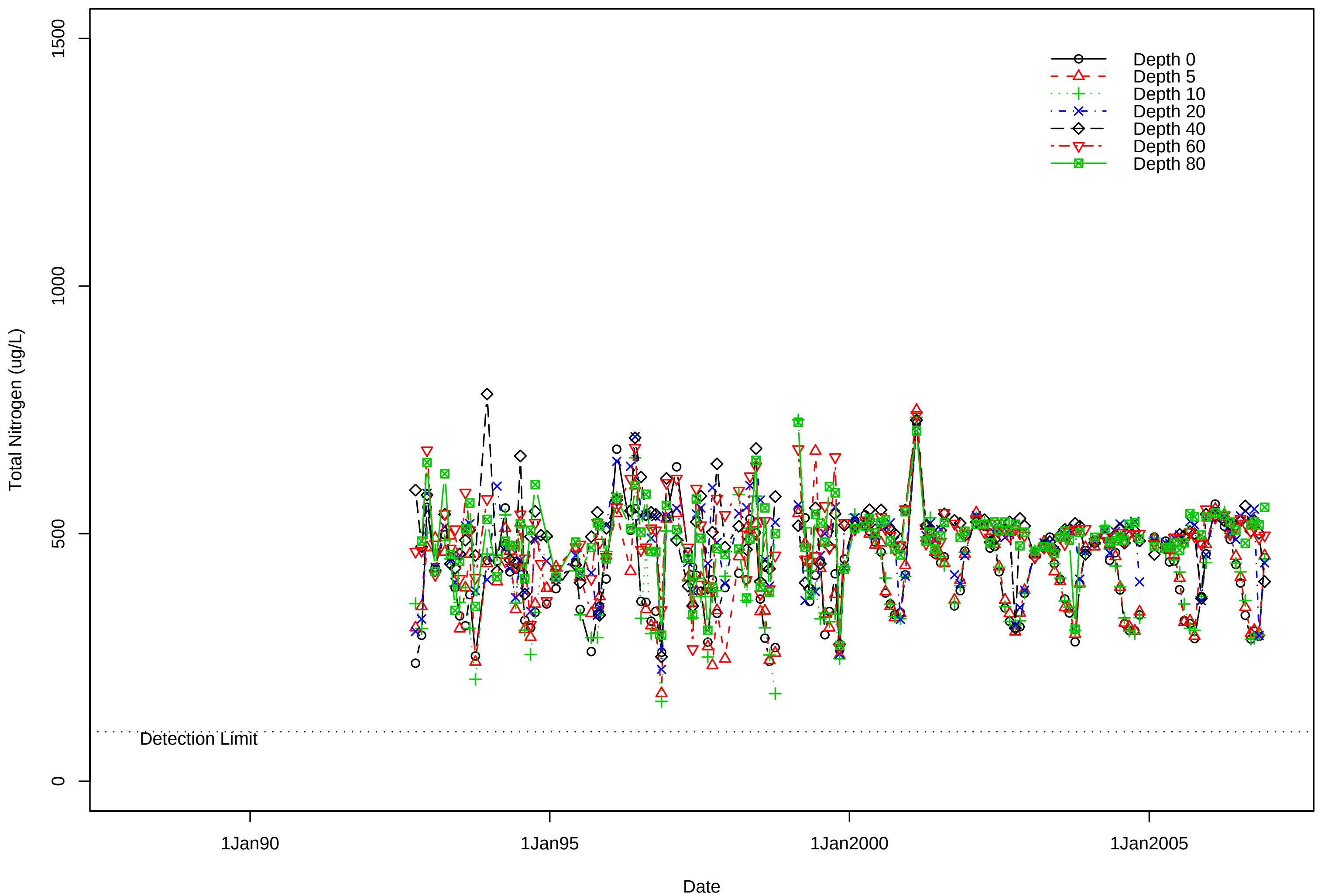


Figure B94: Lake Whatcom total nitrogen data for Site 3.

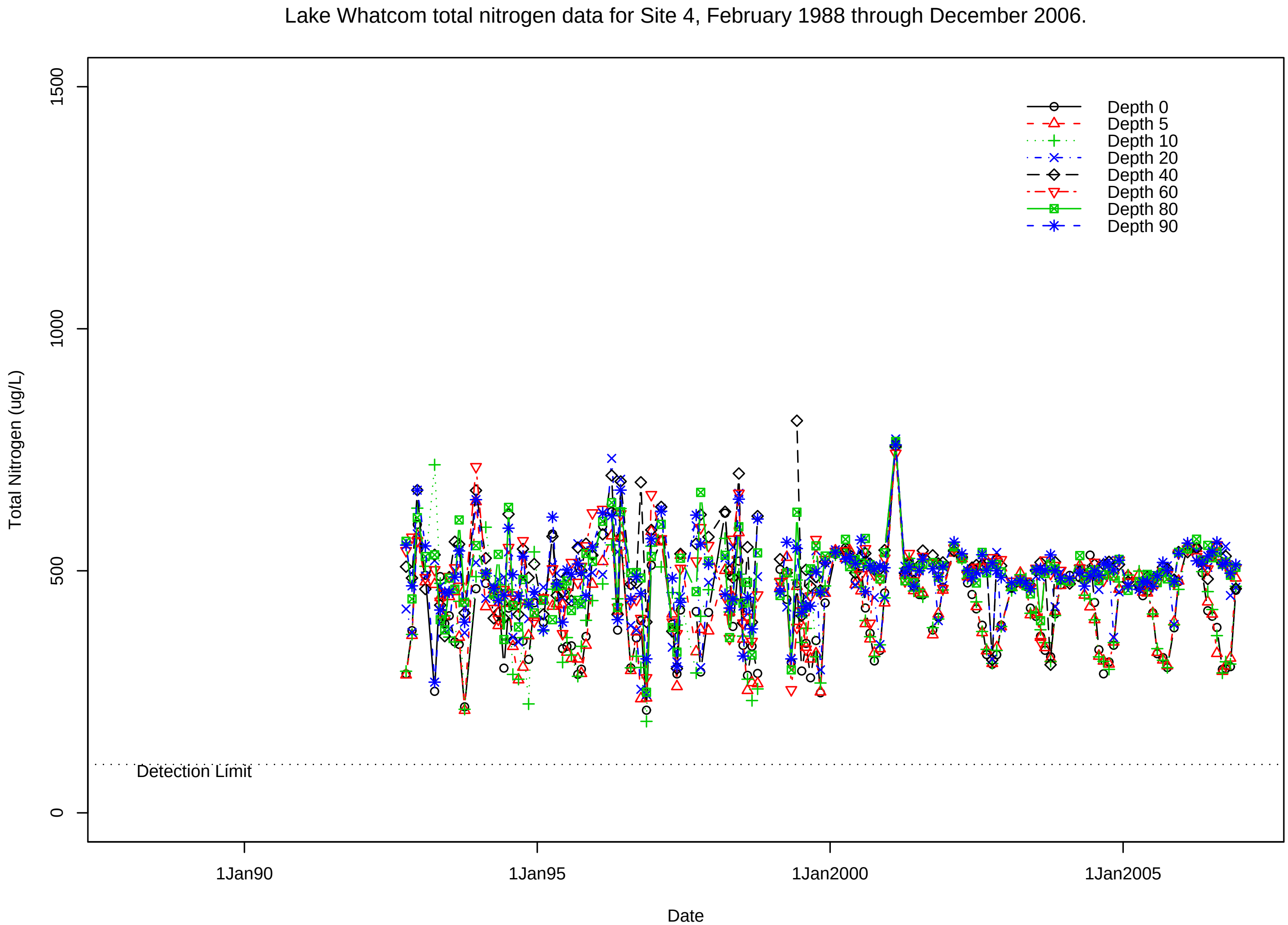


Figure B95: Lake Whatcom total nitrogen data for Site 4.

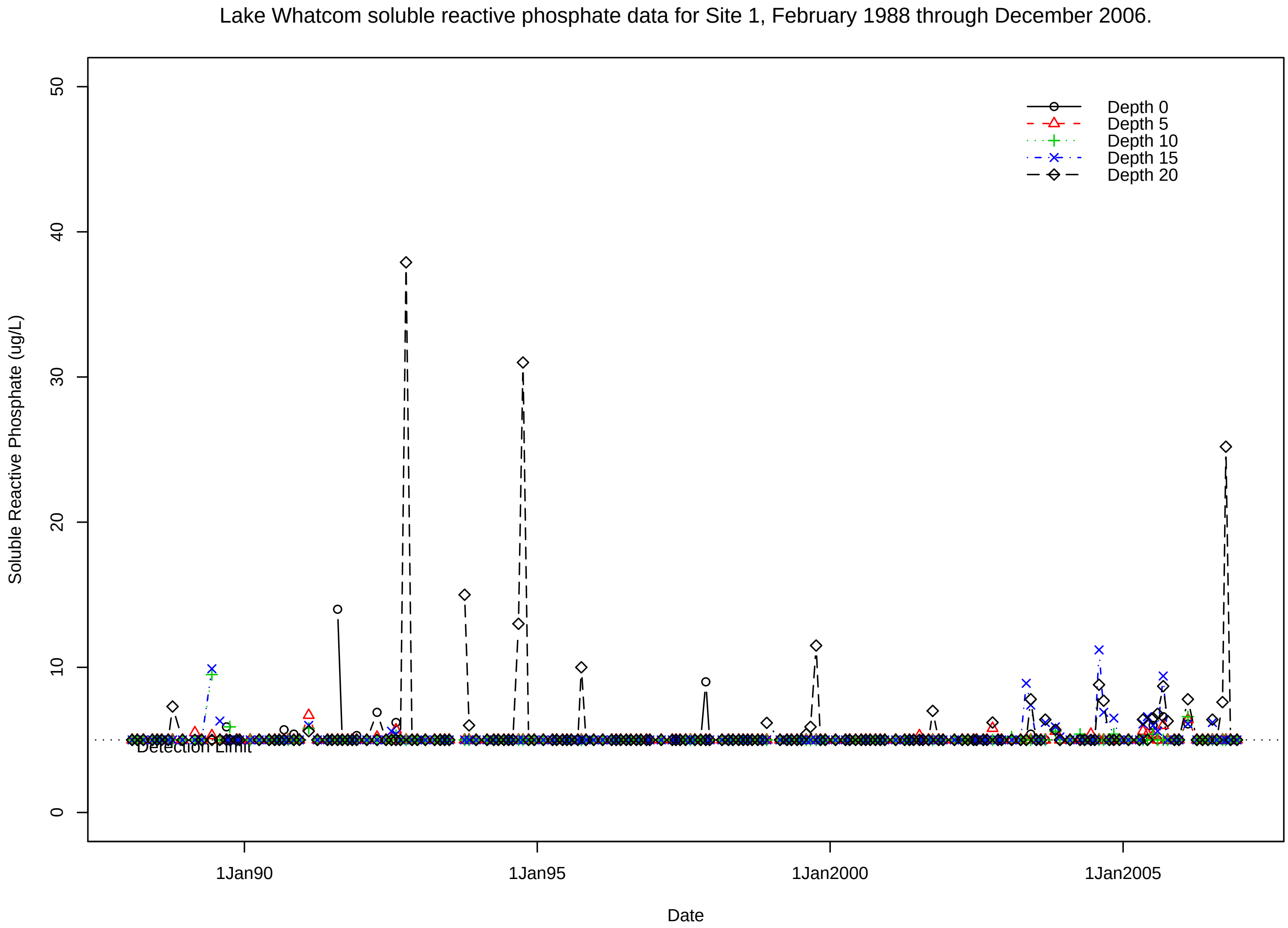


Figure B96: Lake Whatcom soluble phosphate data for Site 1.

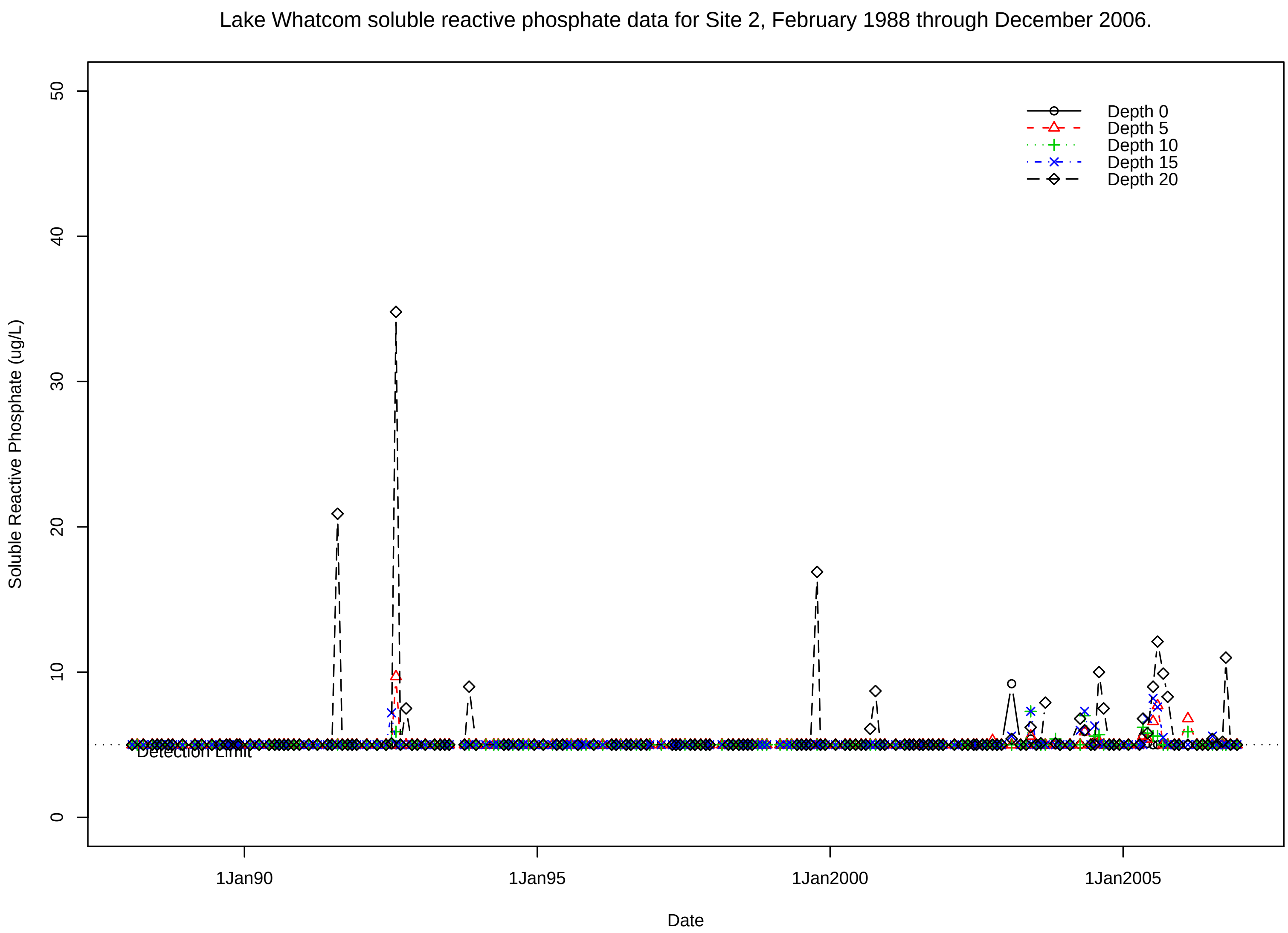


Figure B97: Lake Whatcom soluble phosphate data for Site 2.

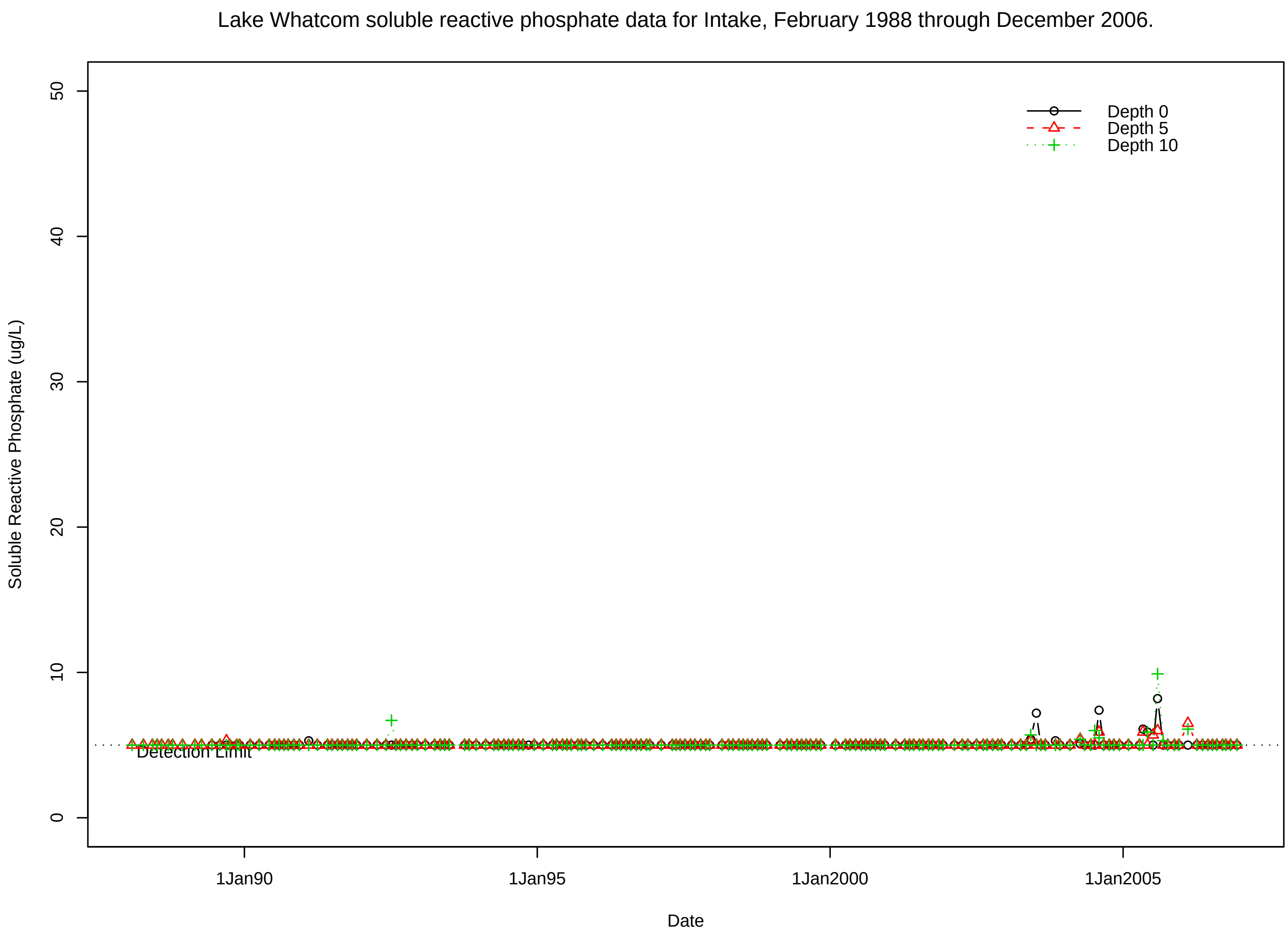


Figure B98: Lake Whatcom soluble phosphate data for the Intake site.

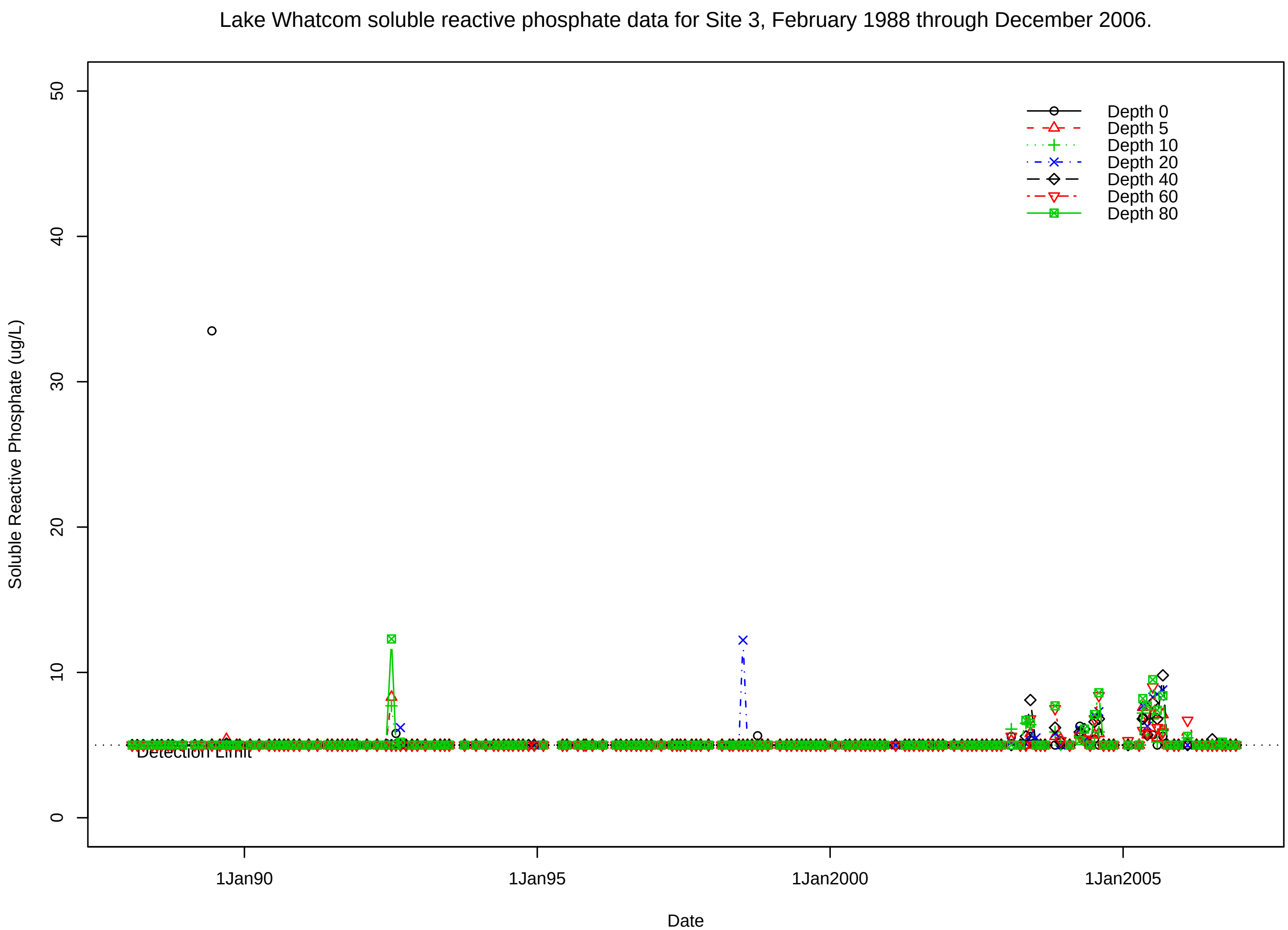


Figure B99: Lake Whatcom soluble phosphate data for Site 3.

Lake Whatcom soluble reactive phosphate data for Site 4, February 1988 through December 2006.

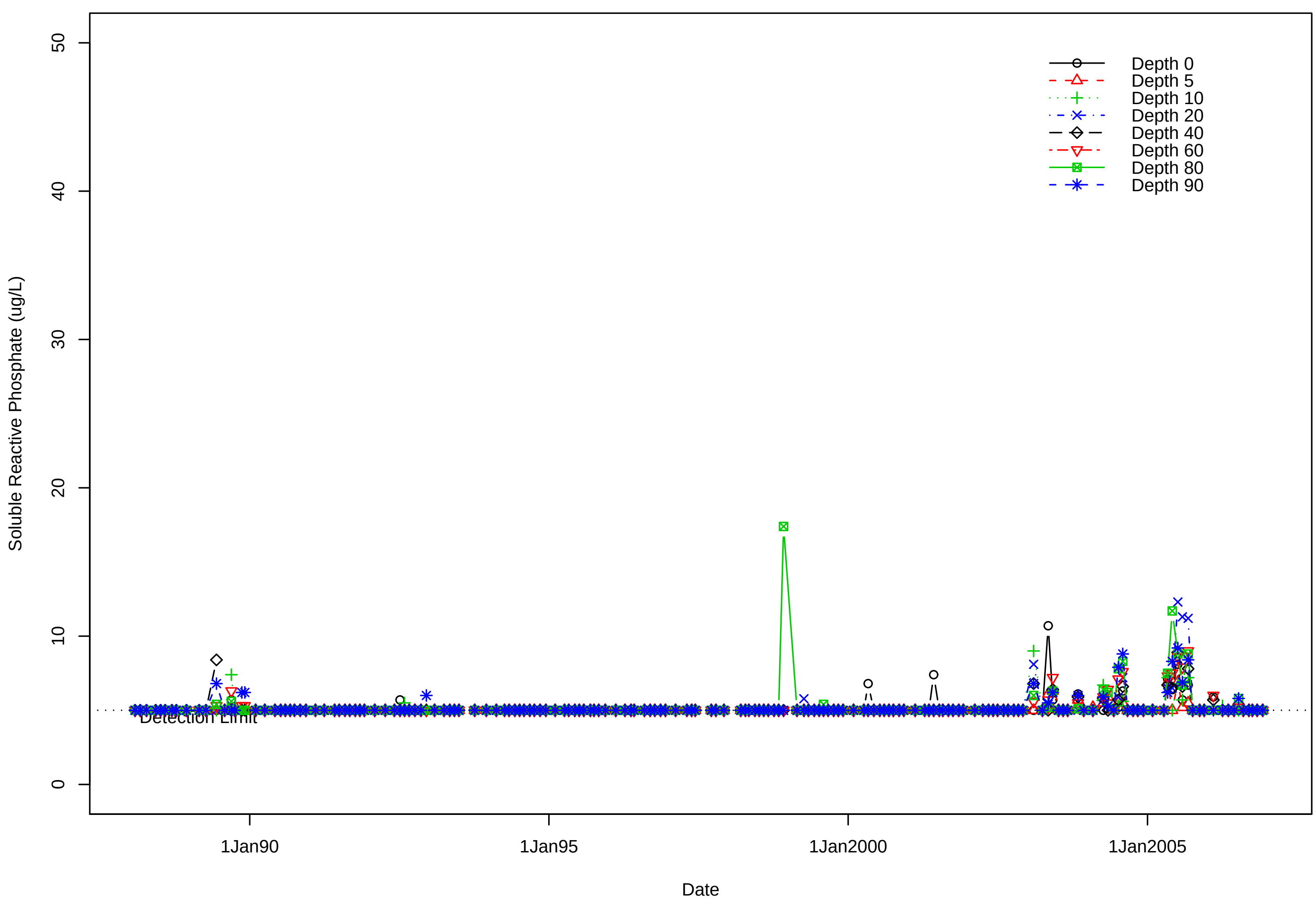


Figure B100: Lake Whatcom soluble phosphate data for Site 4.

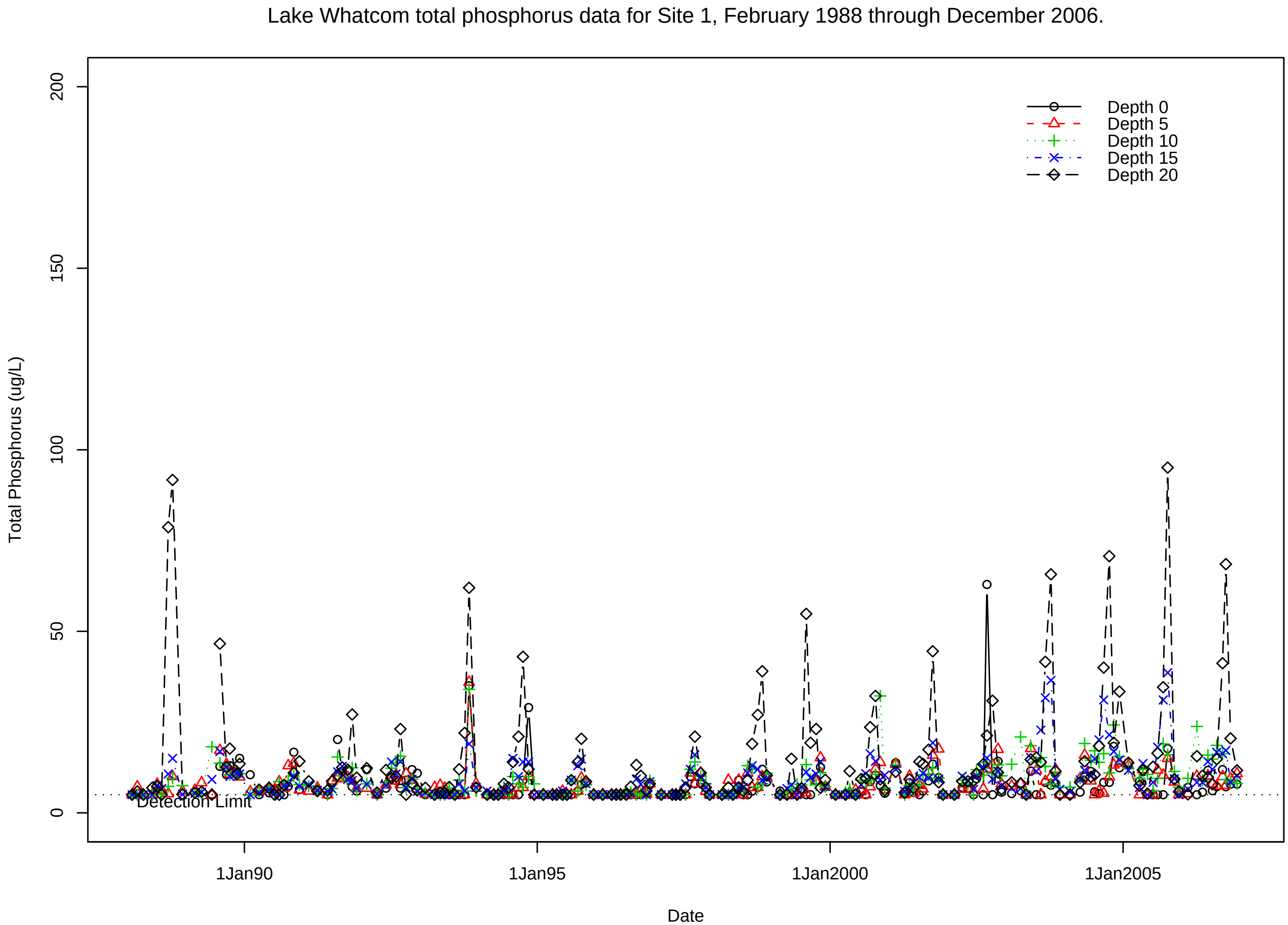


Figure B101: Lake Whatcom total phosphorus data for Site 1.

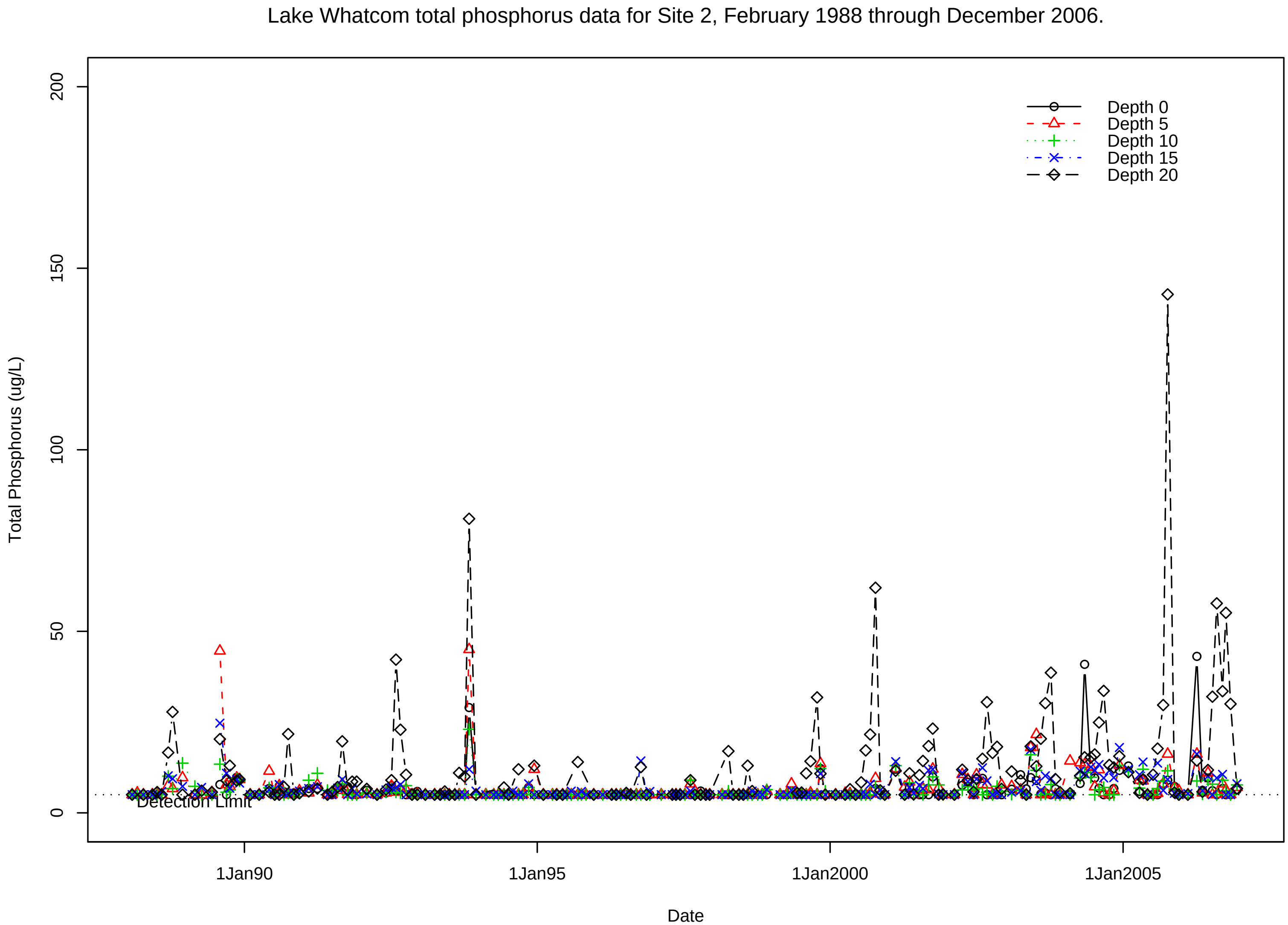


Figure B102: Lake Whatcom total phosphorus data for Site 2.

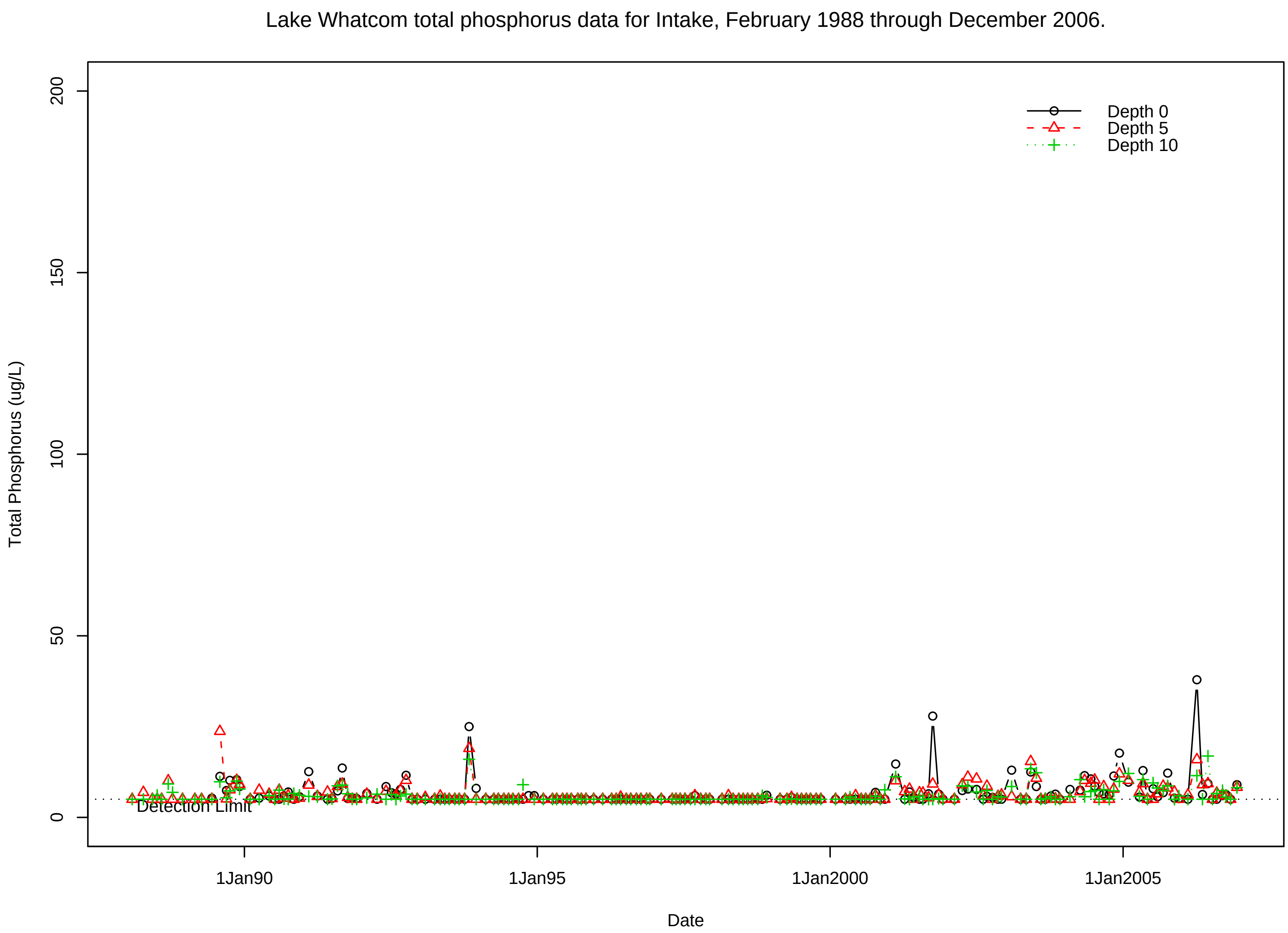


Figure B103: Lake Whatcom total phosphorus data for the Intake site.

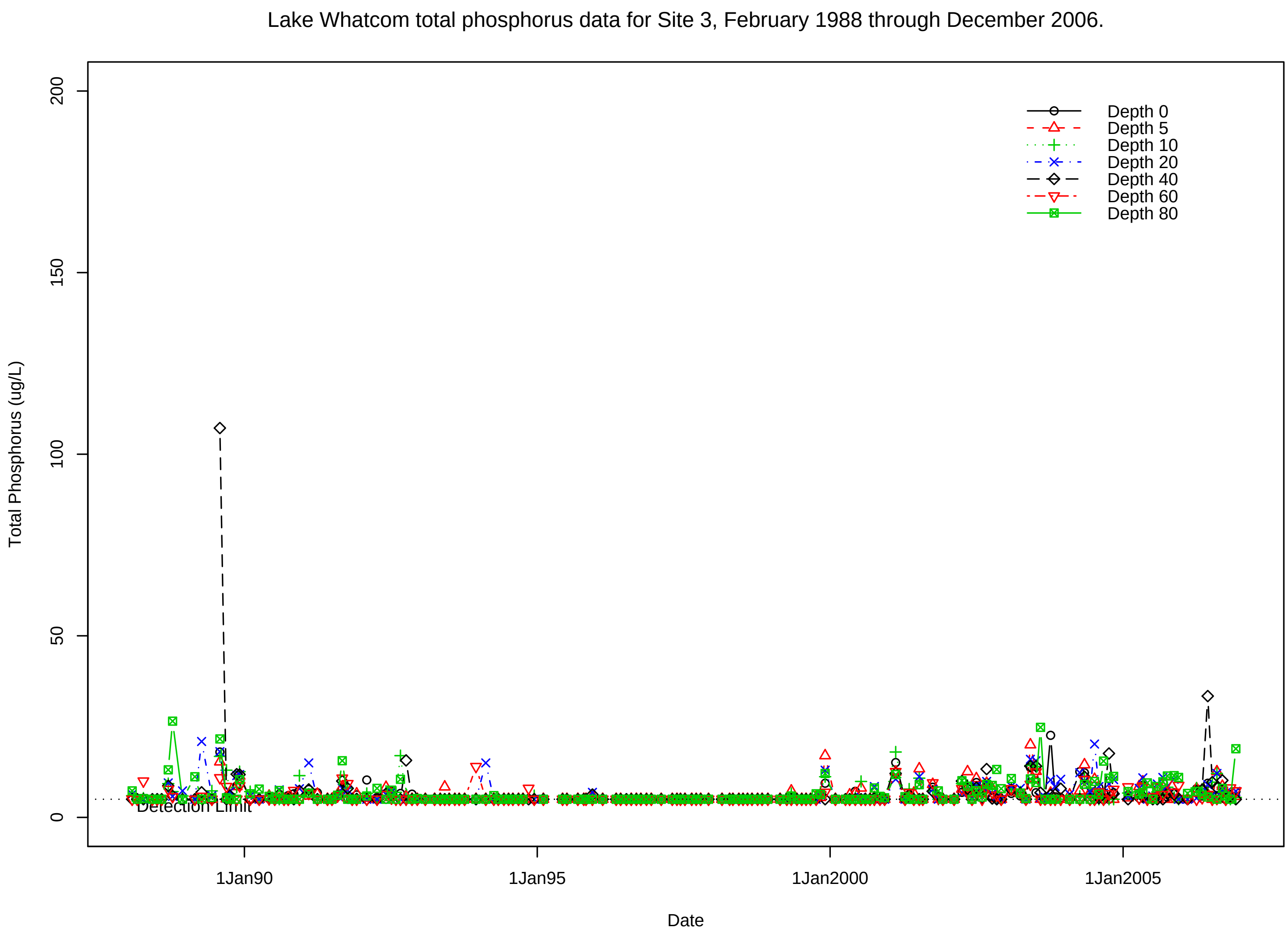


Figure B104: Lake Whatcom total phosphorus data for Site 3.

Lake Whatcom total phosphorus data for Site 4, February 1988 through December 2006.

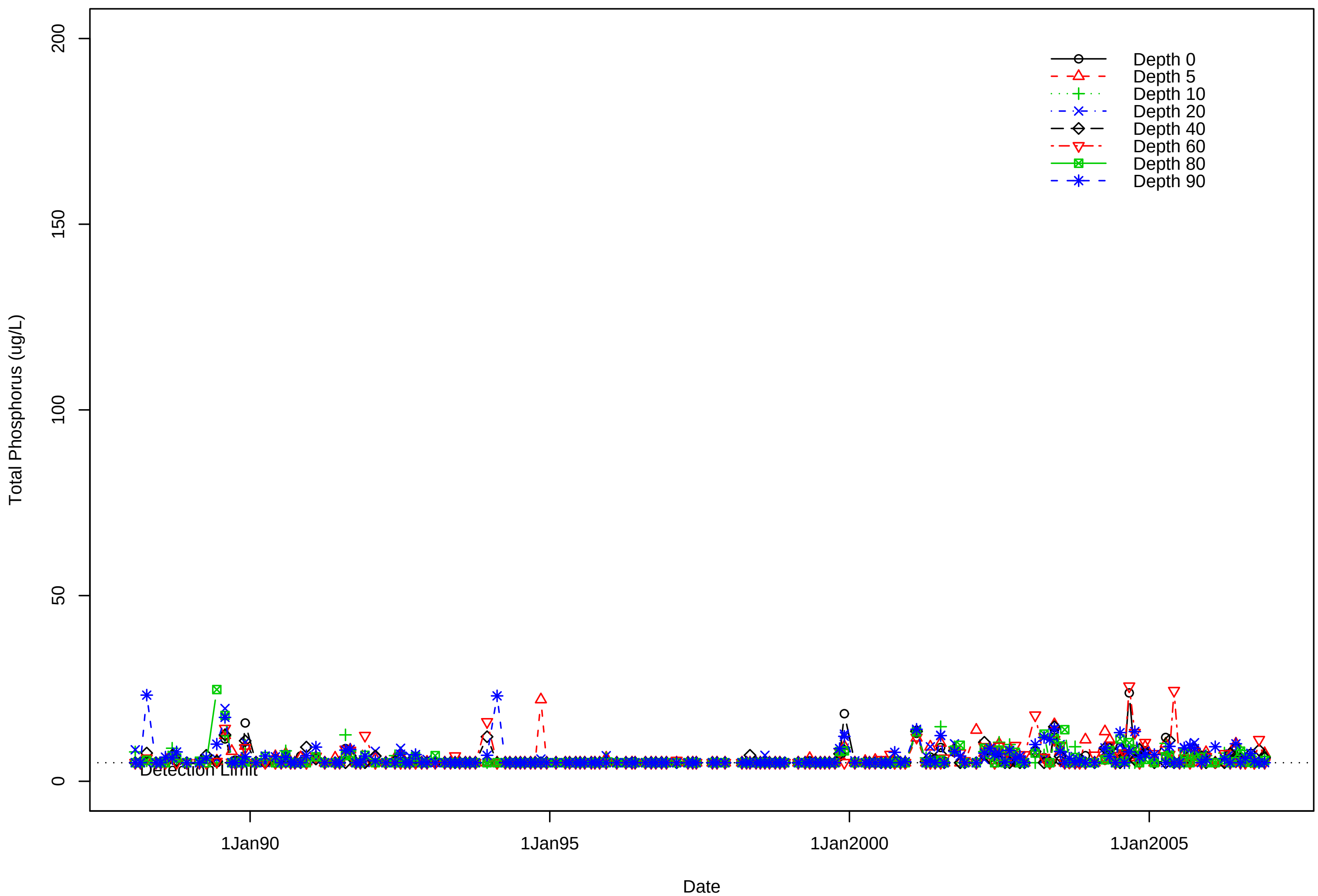


Figure B105: Lake Whatcom total phosphorus data for Site 4.

B.5 Chlorophyll, Plankton, and Secchi Depth

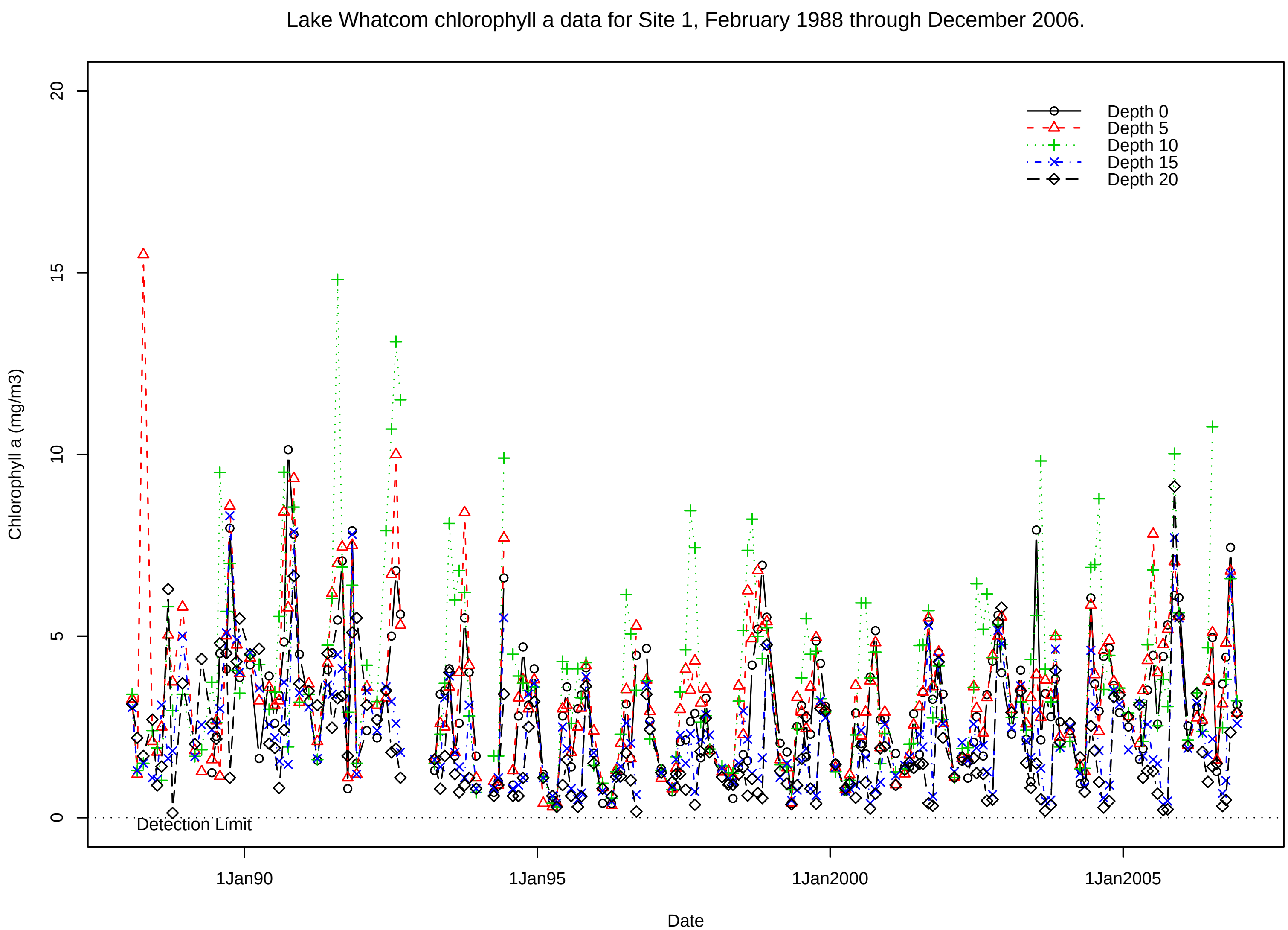


Figure B106: Lake Whatcom chlorophyll data for Site 1.

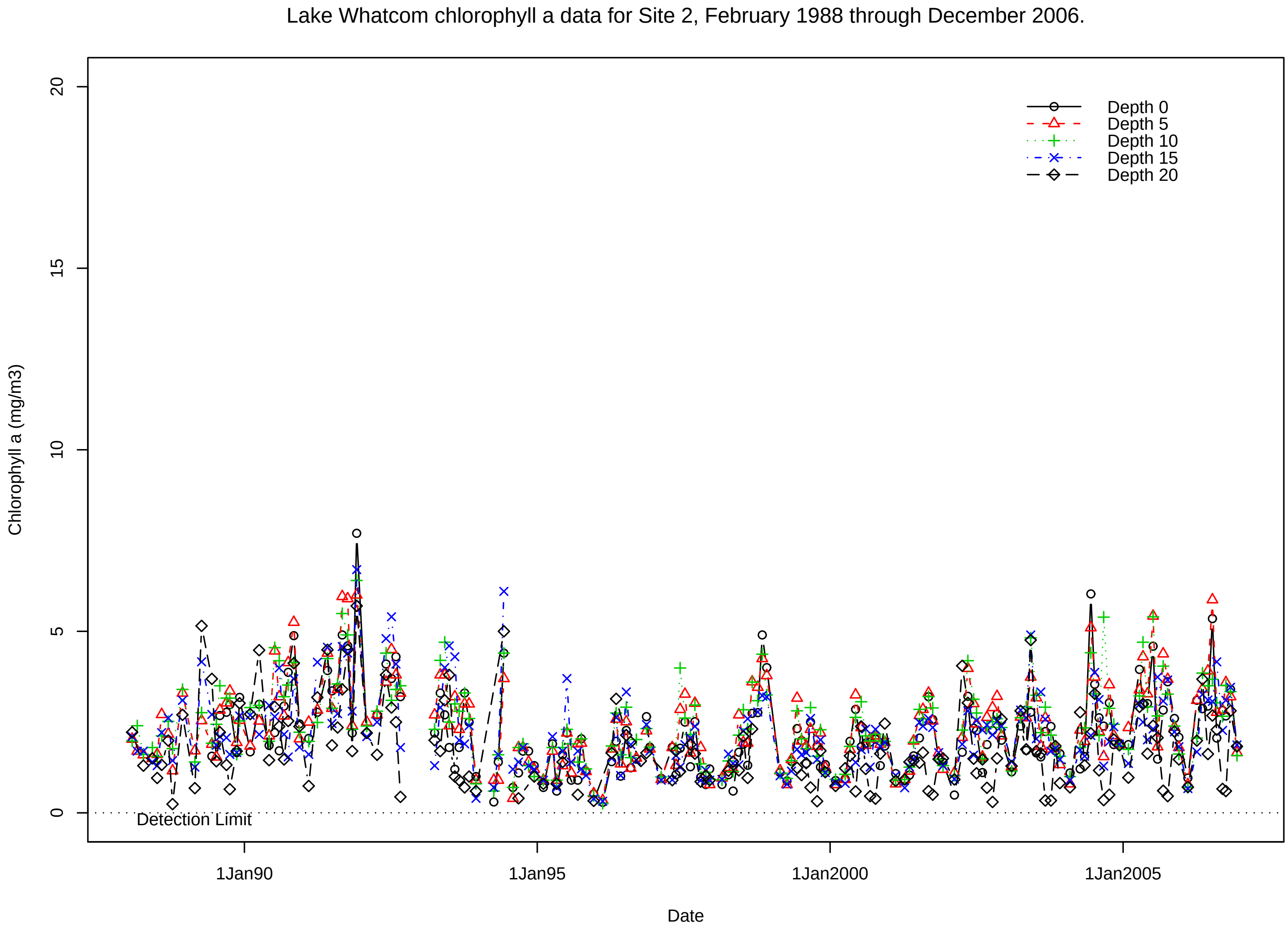


Figure B107: Lake Whatcom chlorophyll data for Site 2.

Lake Whatcom chlorophyll a data for Intake, February 1988 through December 2006.

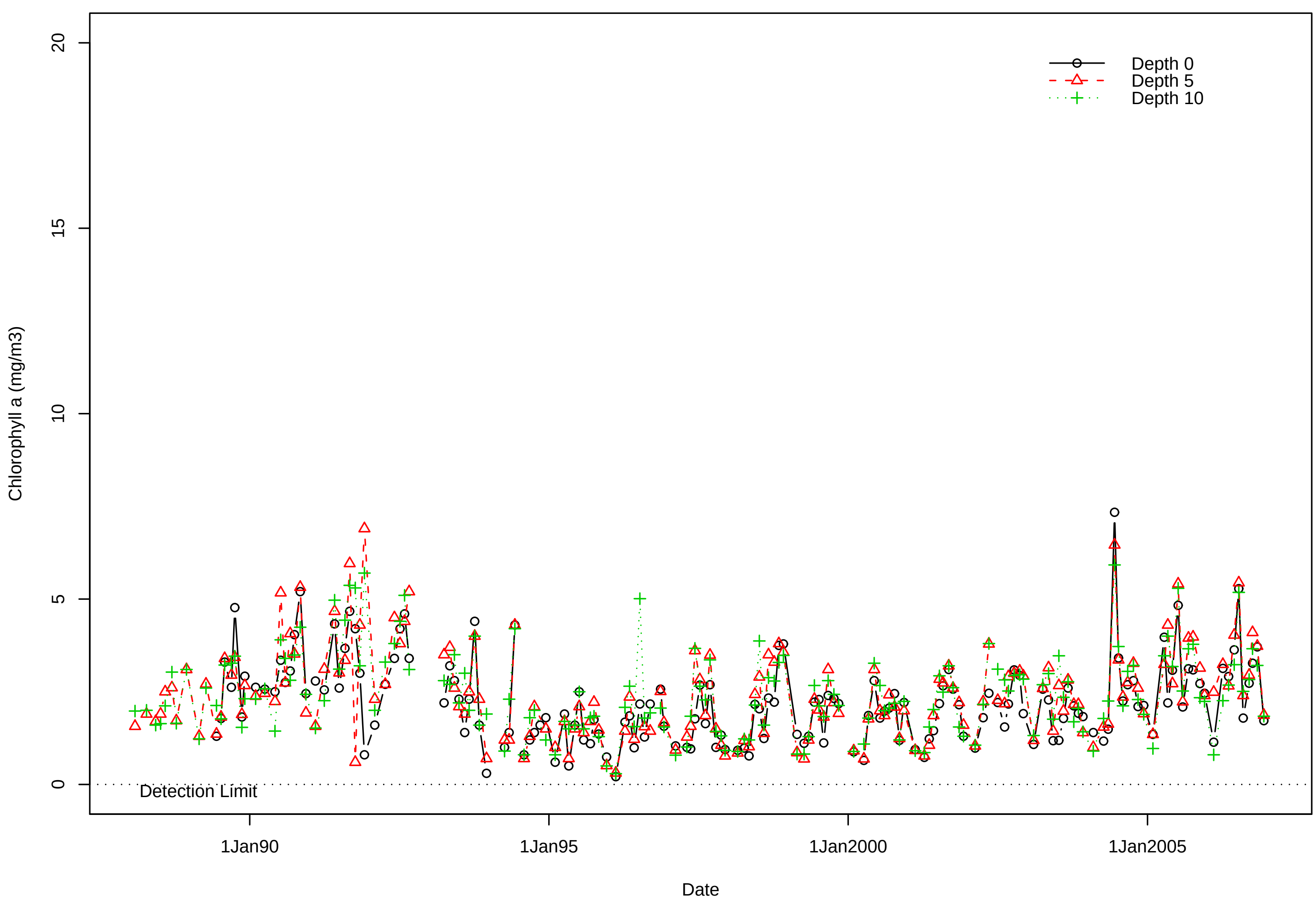


Figure B108: Lake Whatcom chlorophyll data for the Intake site.

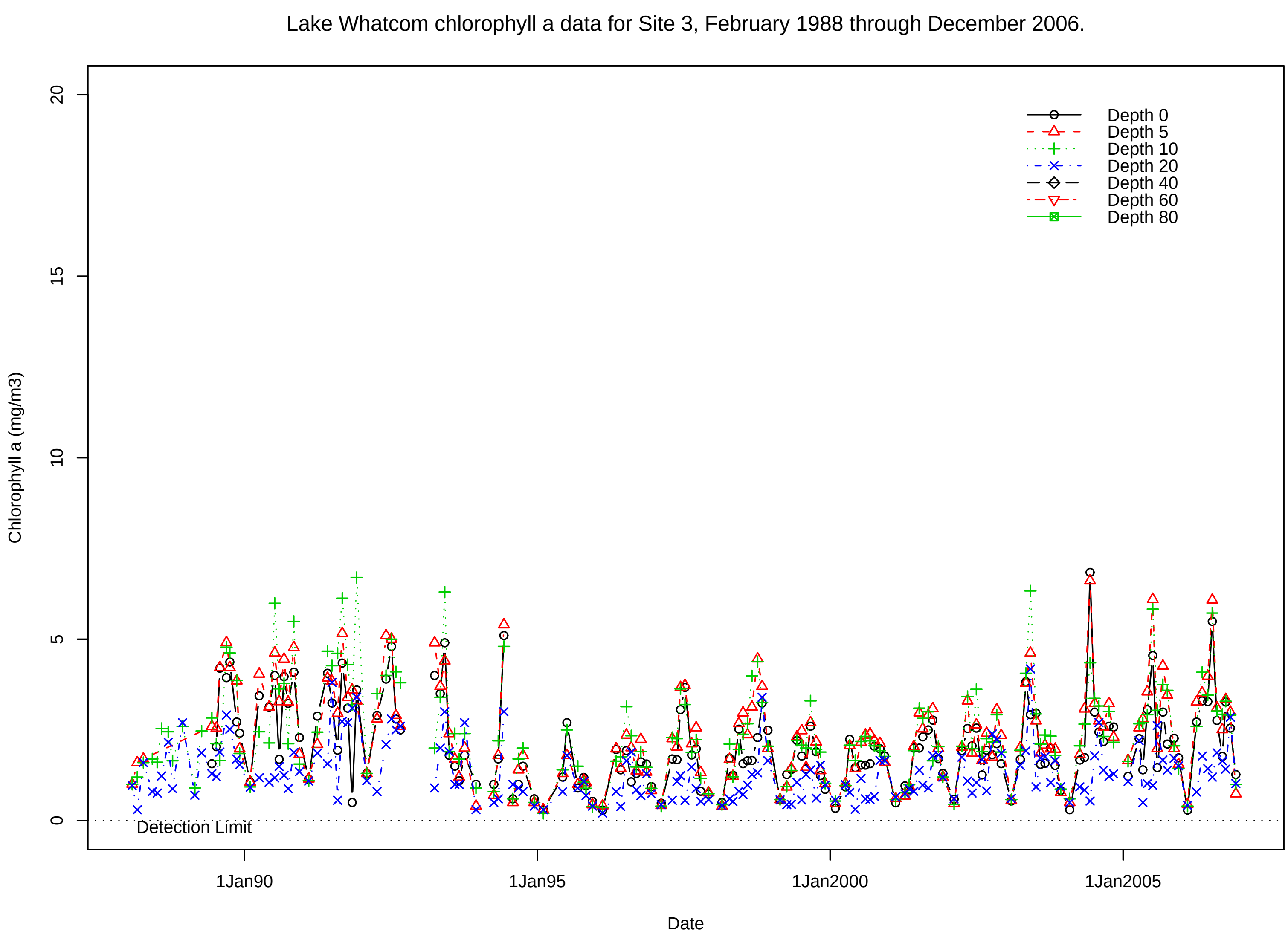


Figure B109: Lake Whatcom chlorophyll data for Site 3.

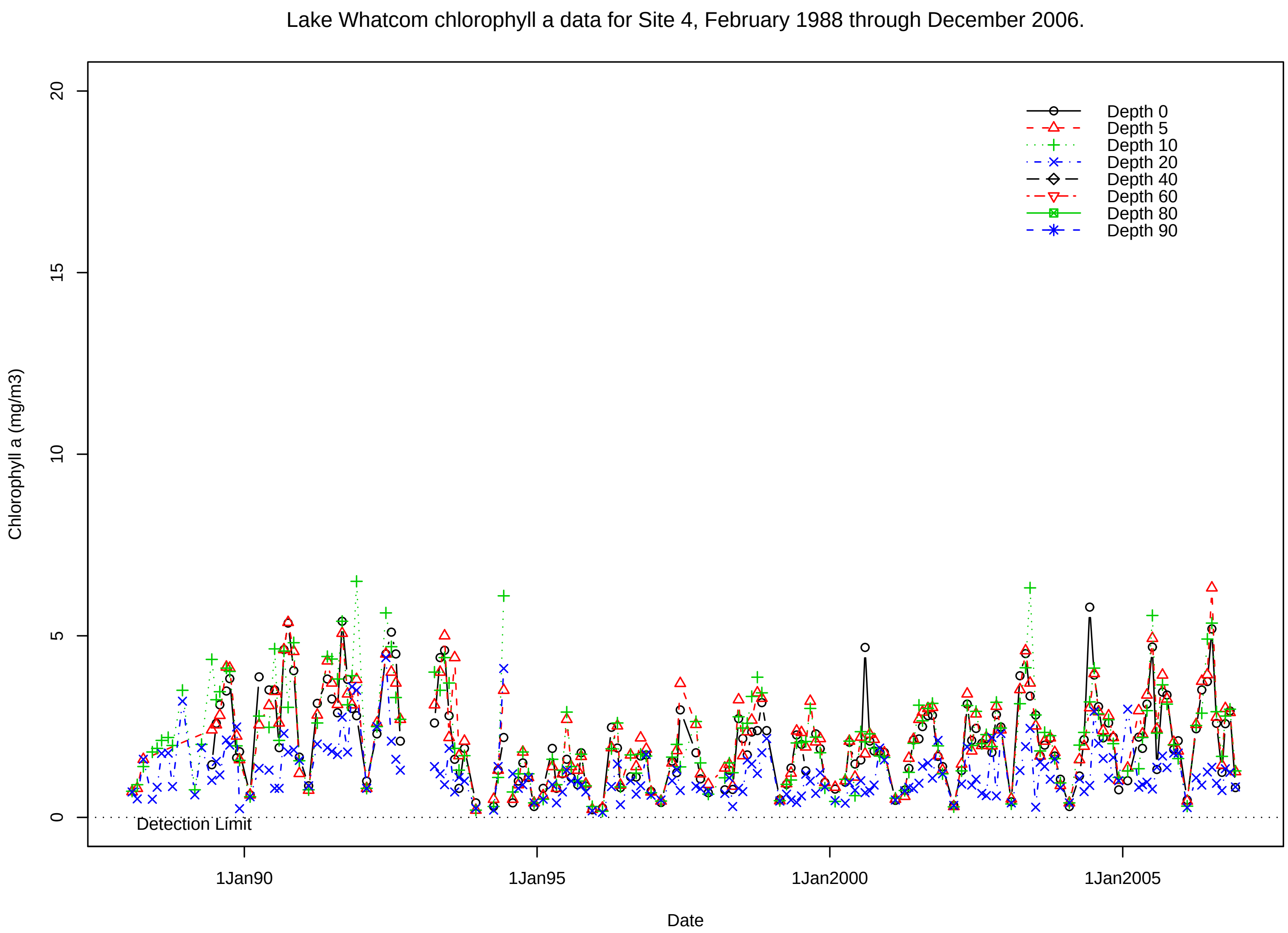


Figure B110: Lake Whatcom chlorophyll data for Site 4.

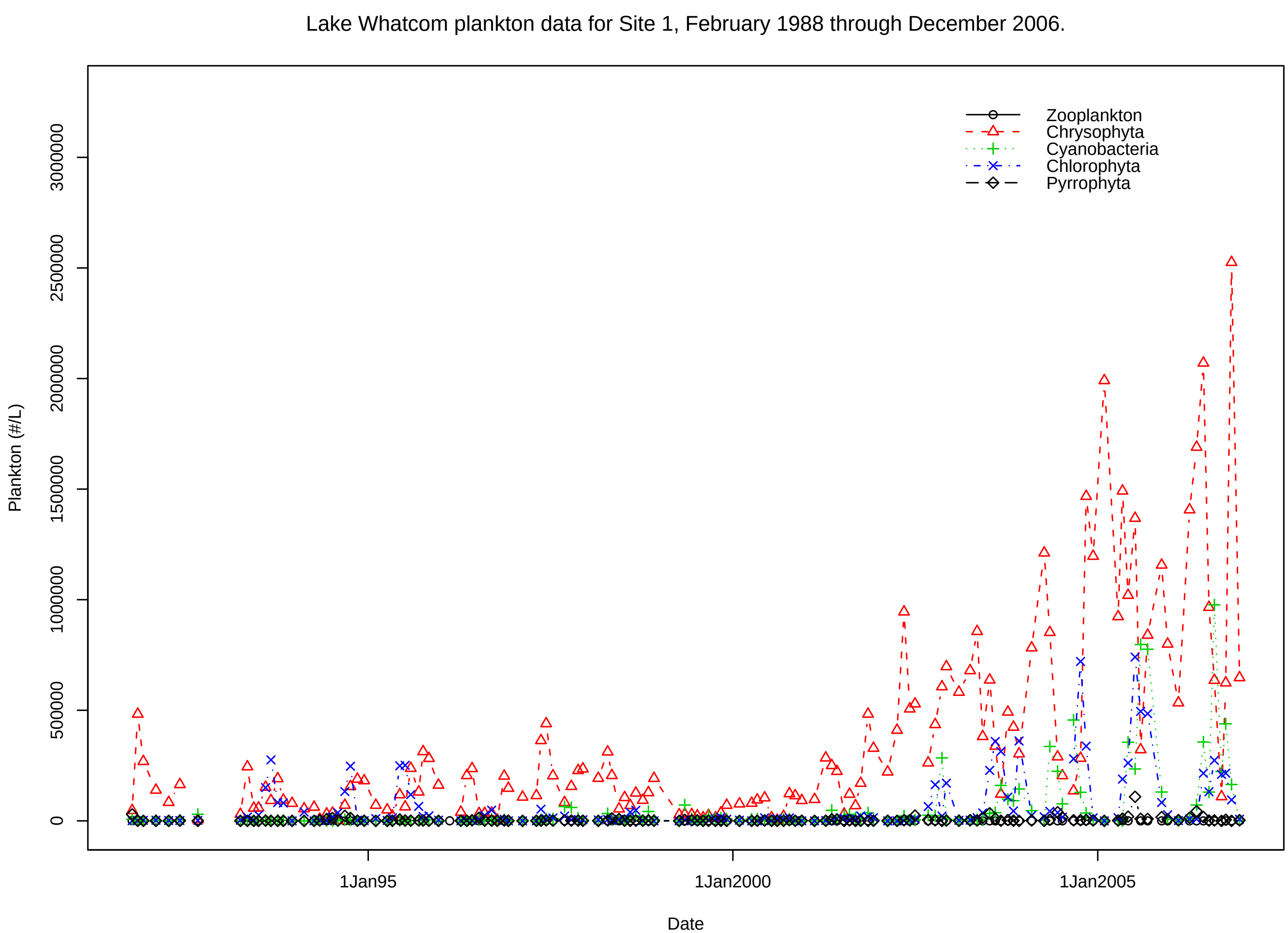


Figure B111: Lake Whatcom plankton data for Site 1.

Lake Whatcom plankton data for Site 2, February 1988 through December 2006.

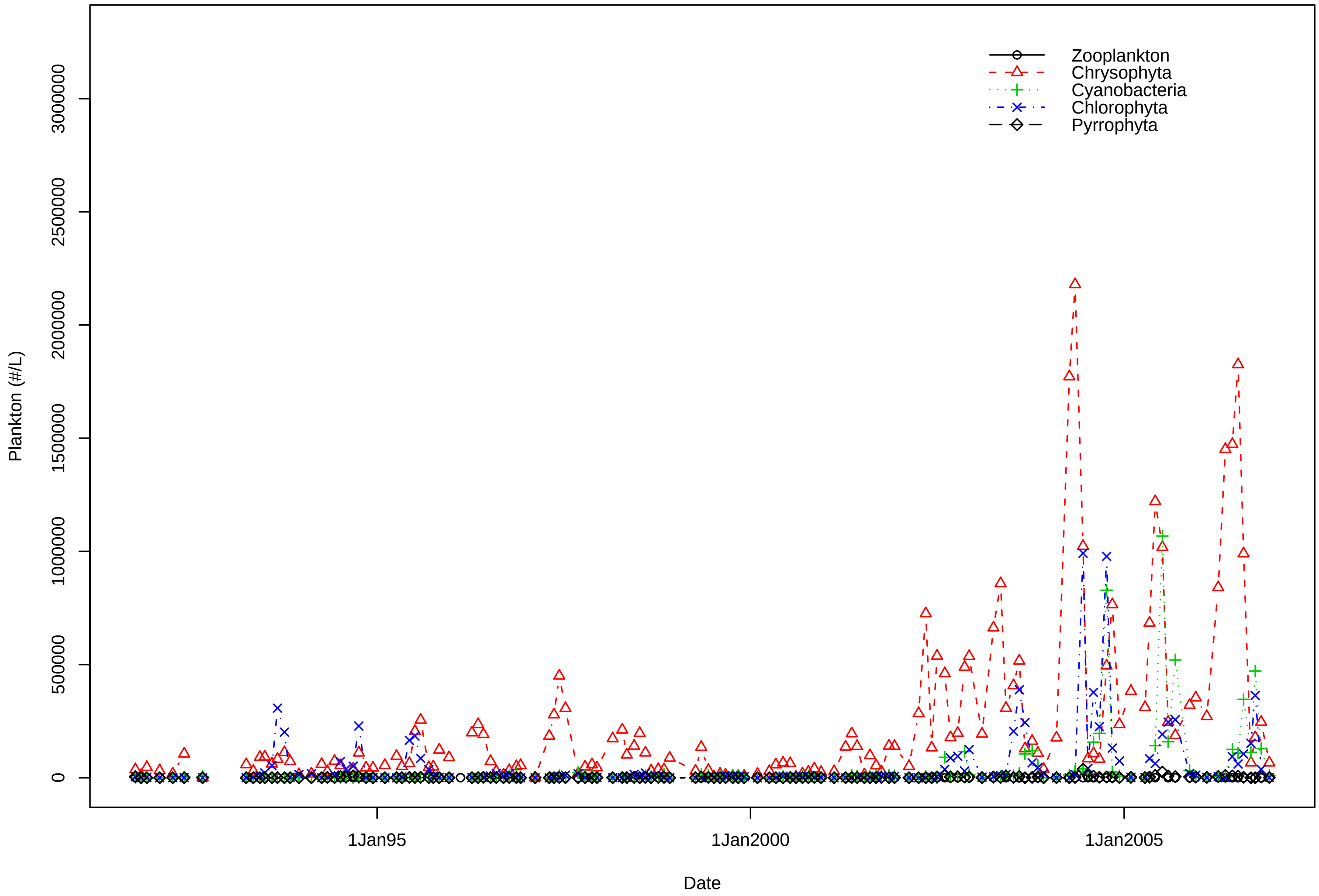


Figure B112: Lake Whatcom plankton data for Site 2.

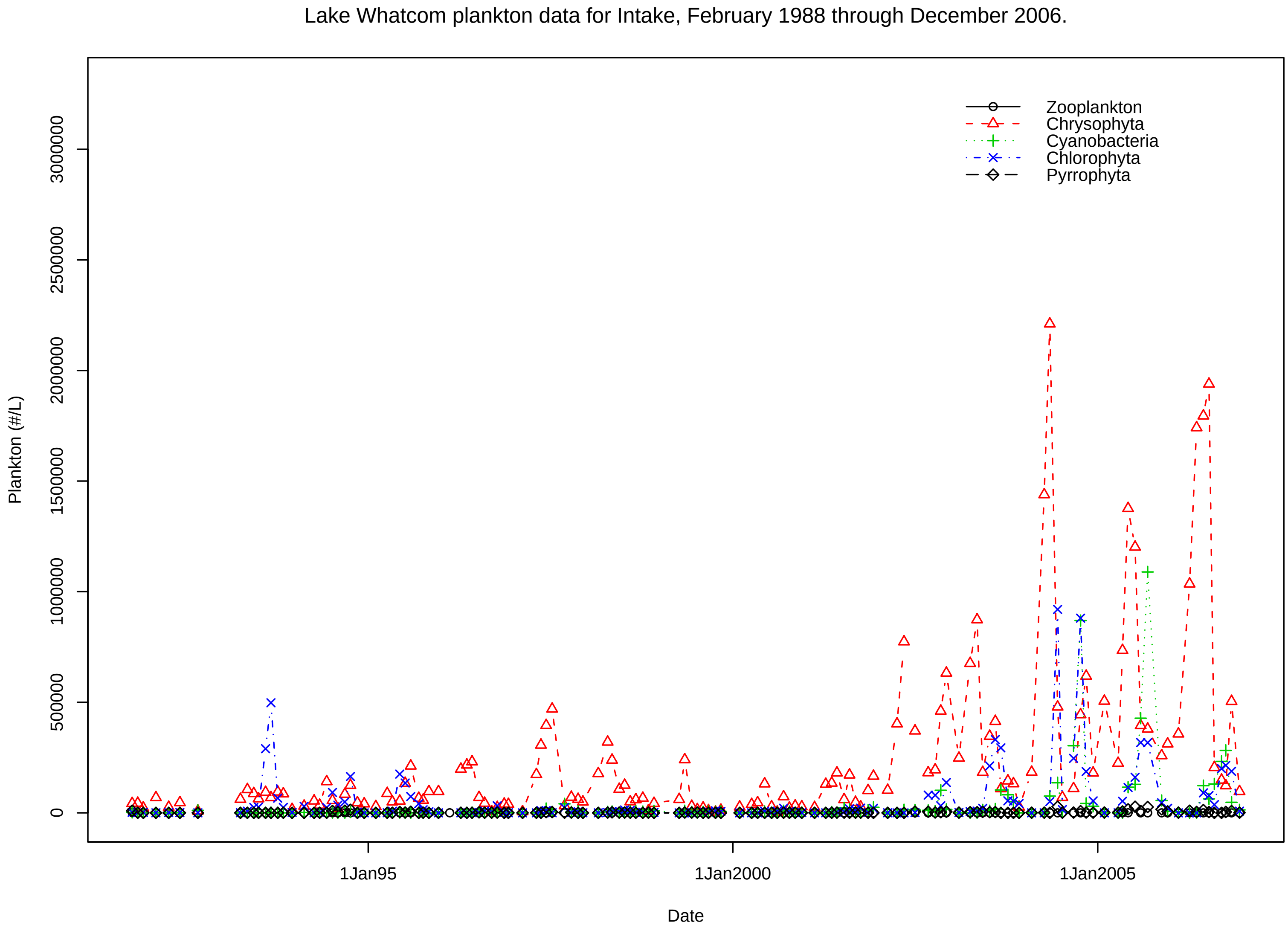


Figure B113: Lake Whatcom plankton data for the Intake Site.

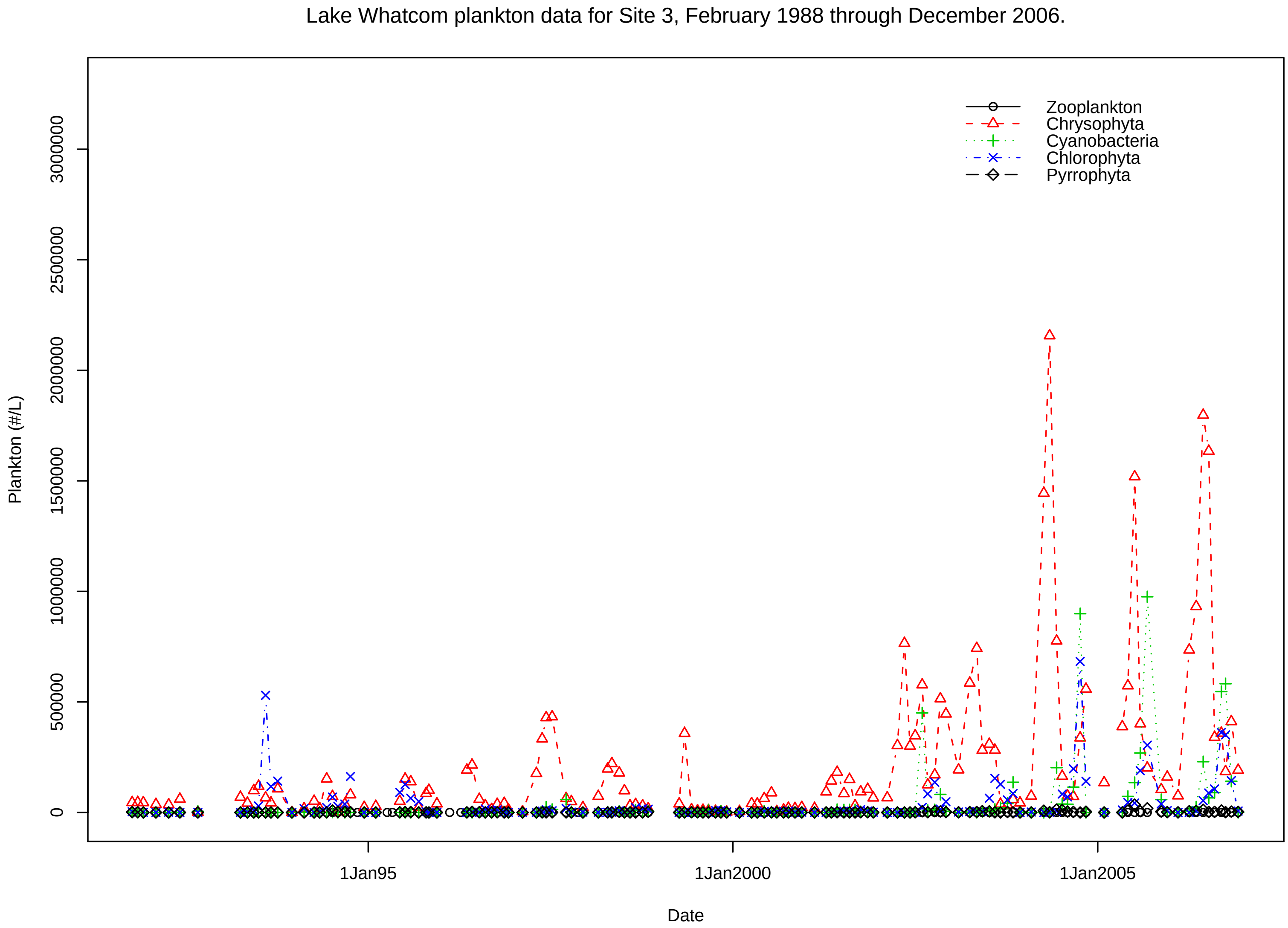


Figure B114: Lake Whatcom plankton data for Site 3.

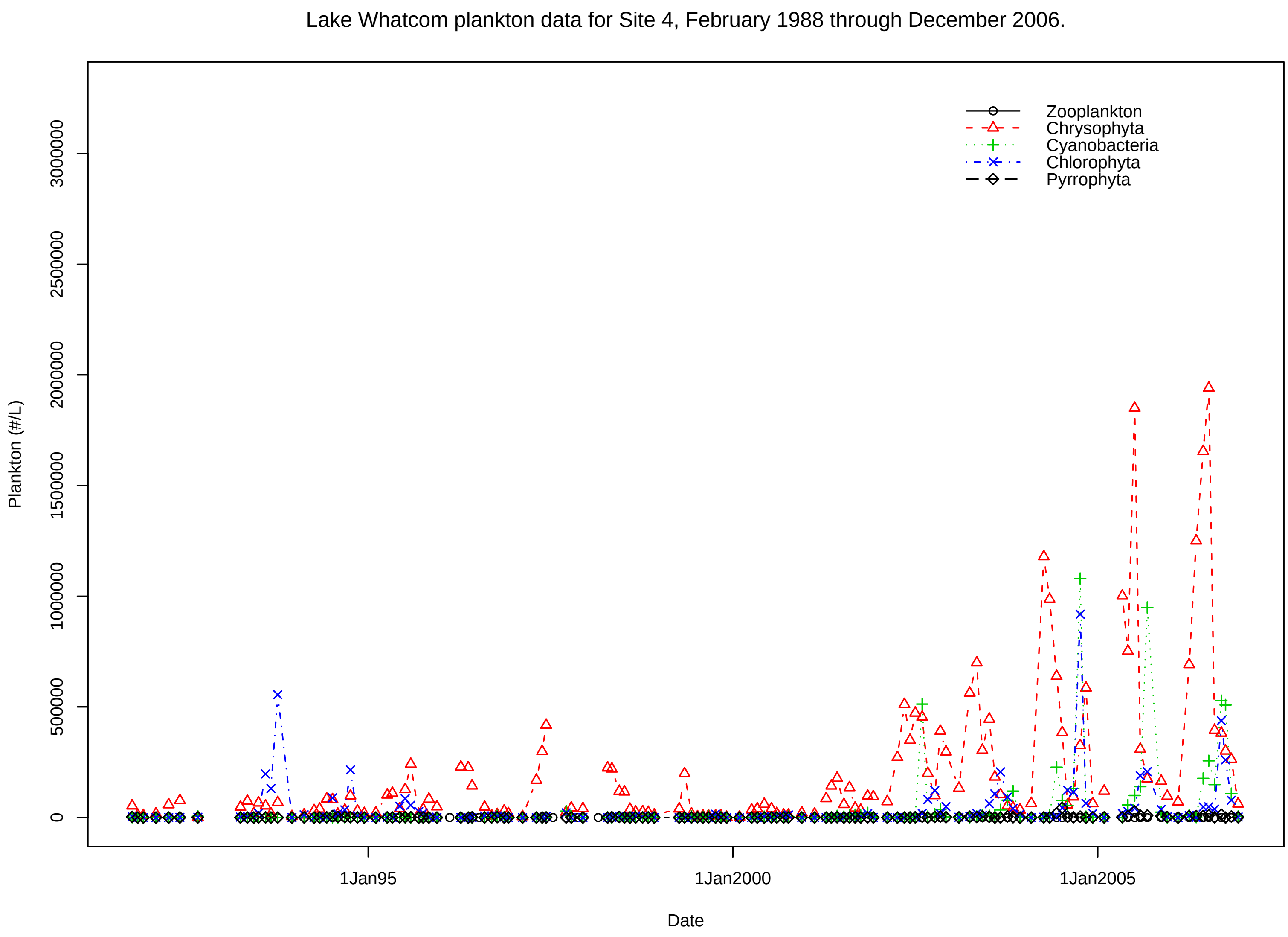


Figure B115: Lake Whatcom plankton data for Site 4.

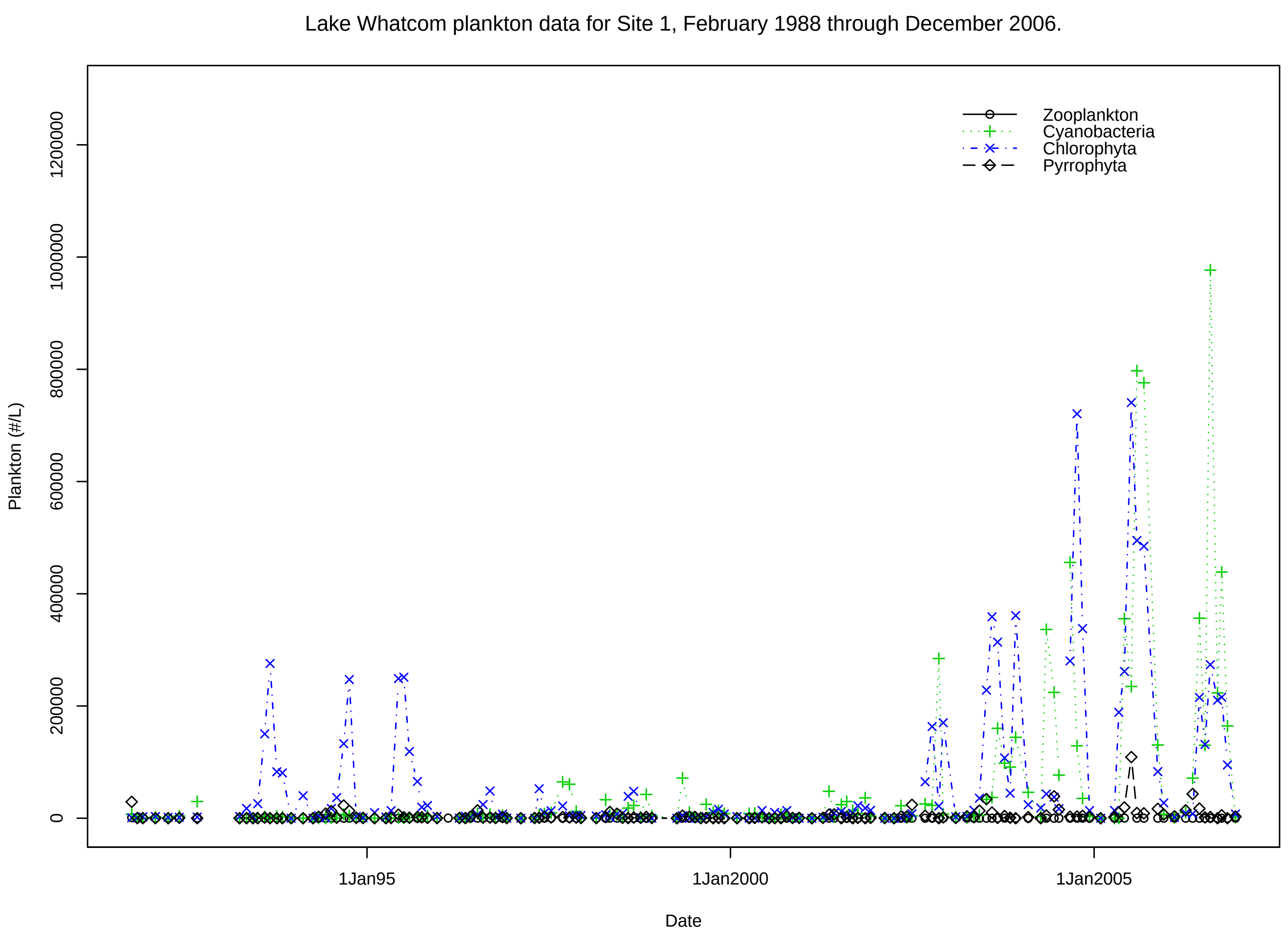


Figure B116: Lake Whatcom plankton data for Site 1, with Chrysophyta omitted to show remaining plankton groups.

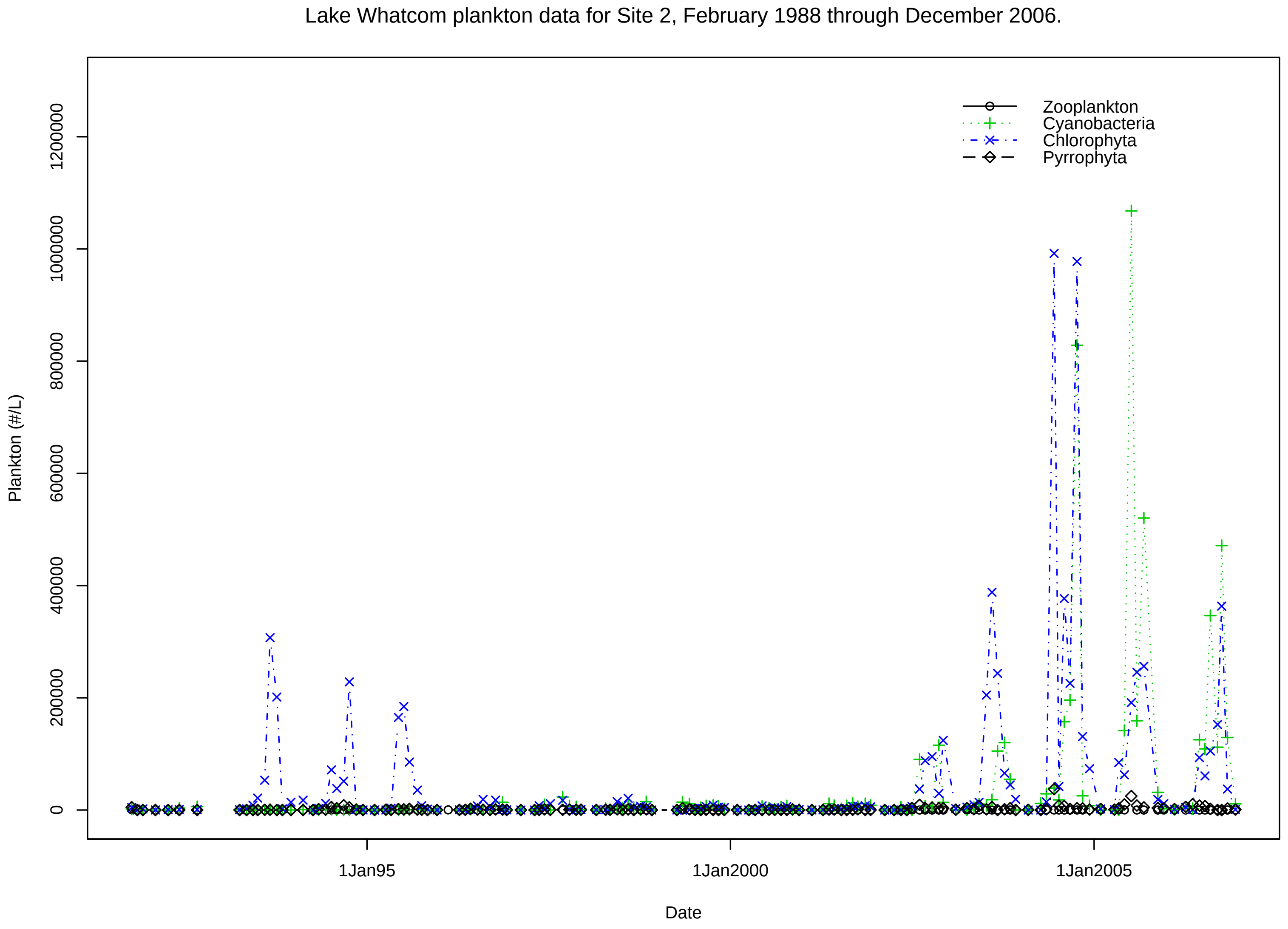


Figure B117: Lake Whatcom plankton data for Site 2, with Chrysophyta omitted to show remaining plankton groups.

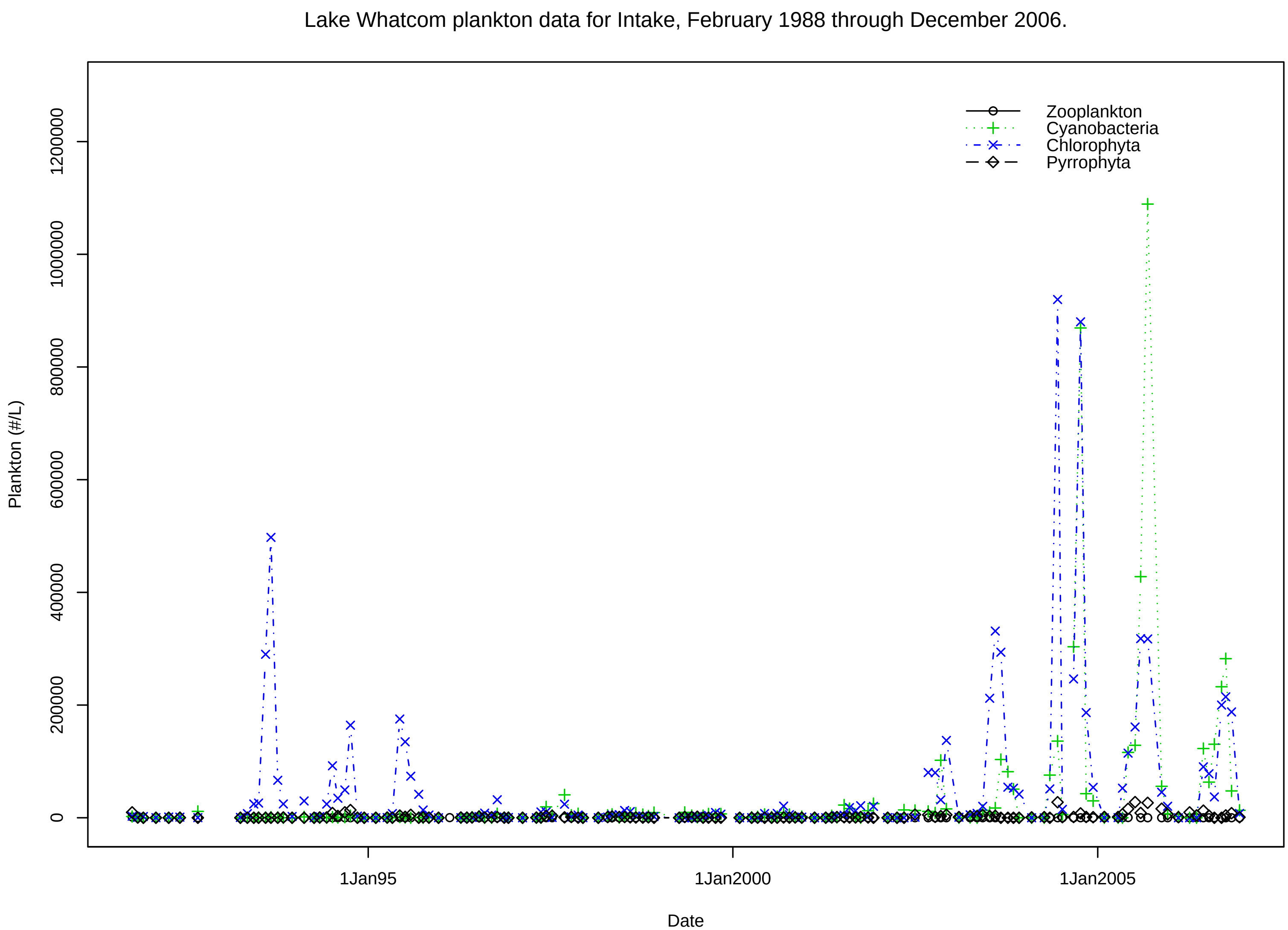


Figure B118: Lake Whatcom plankton data for the Intake Site, with Chrysophyta omitted to show remaining plankton groups.

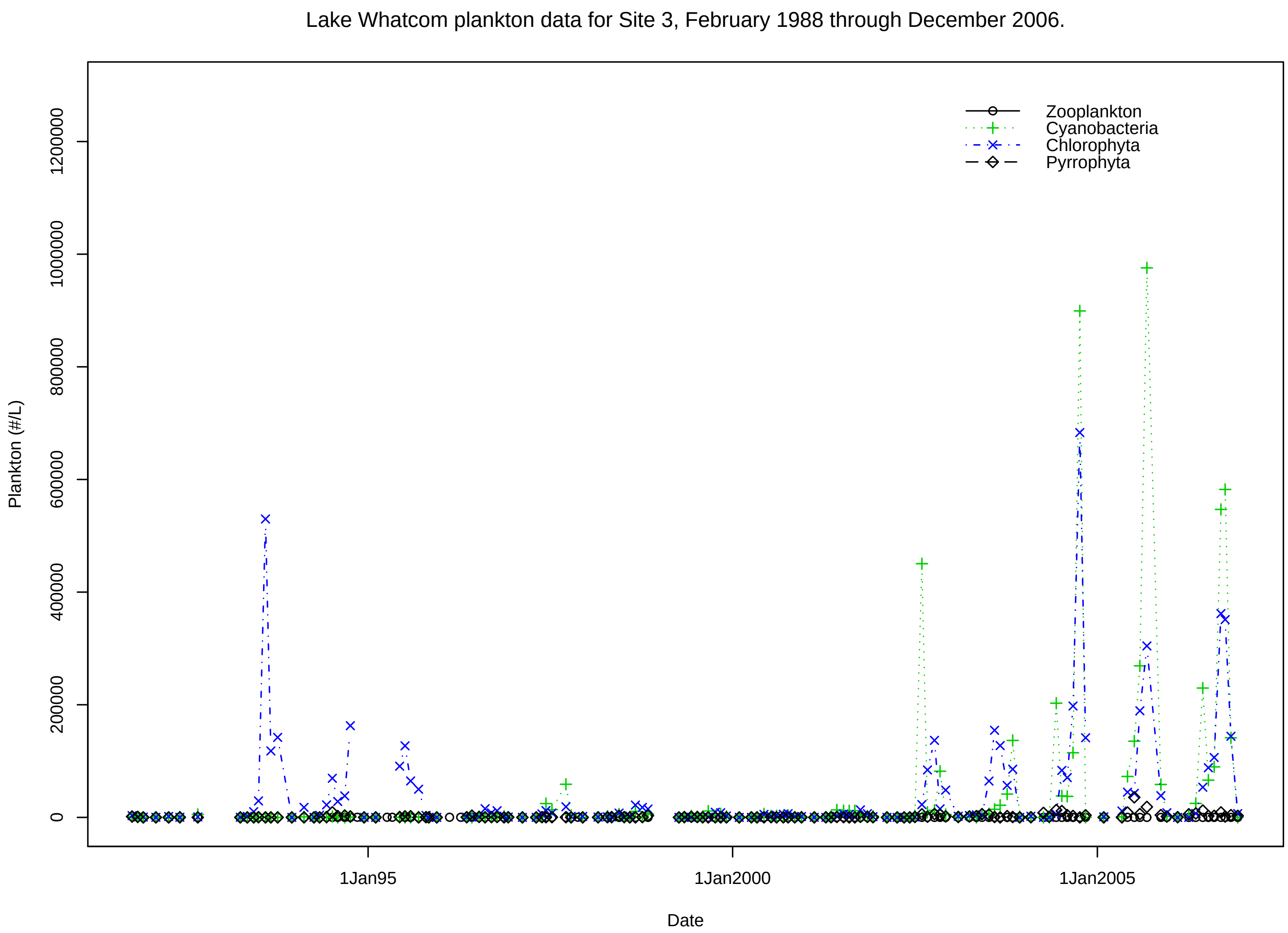


Figure B119: Lake Whatcom plankton data for Site 3, with Chrysophyta omitted to show remaining plankton groups.

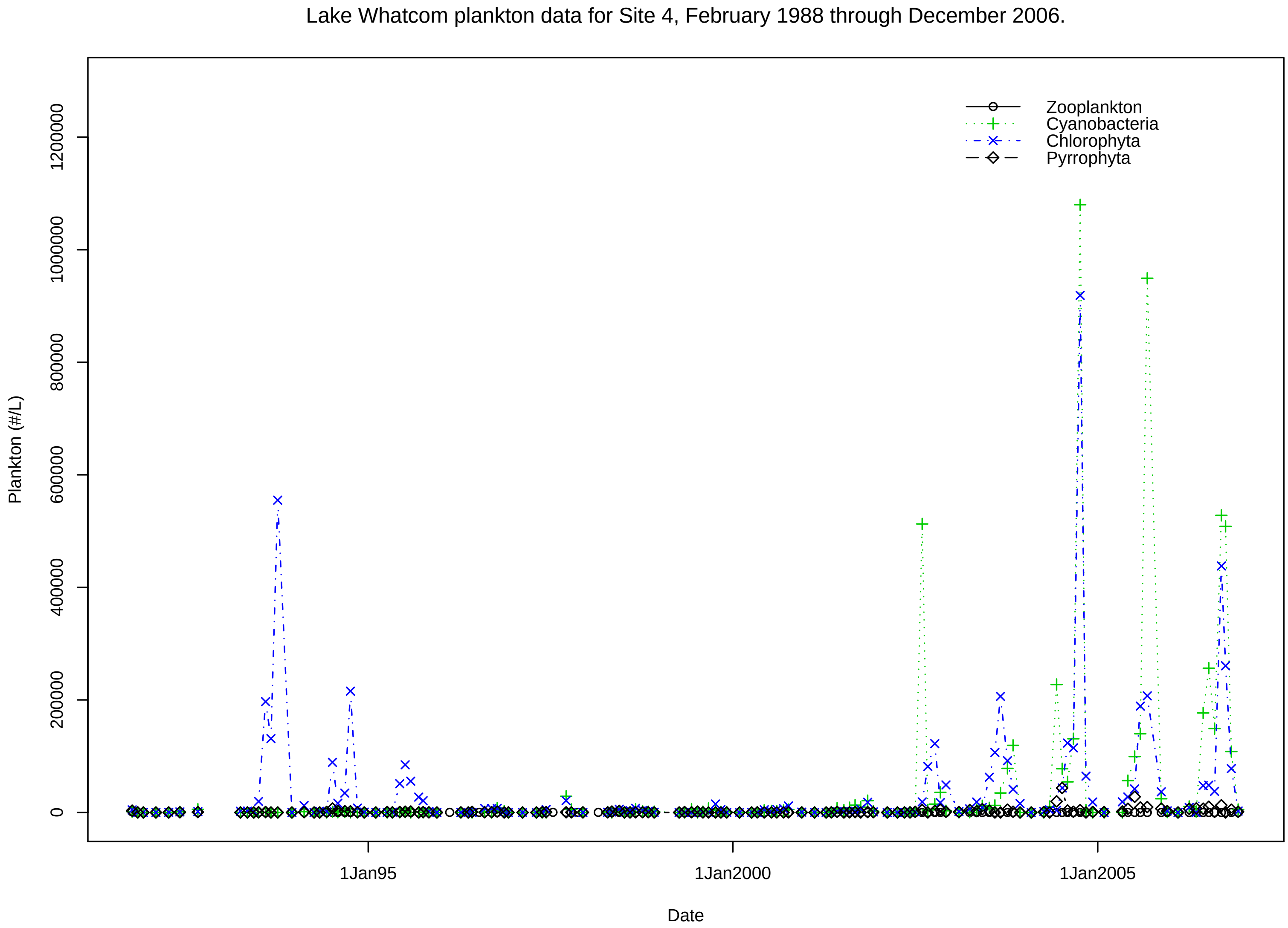


Figure B120: Lake Whatcom plankton data for Site 4, with Chrysophyta omitted to show remaining plankton groups.

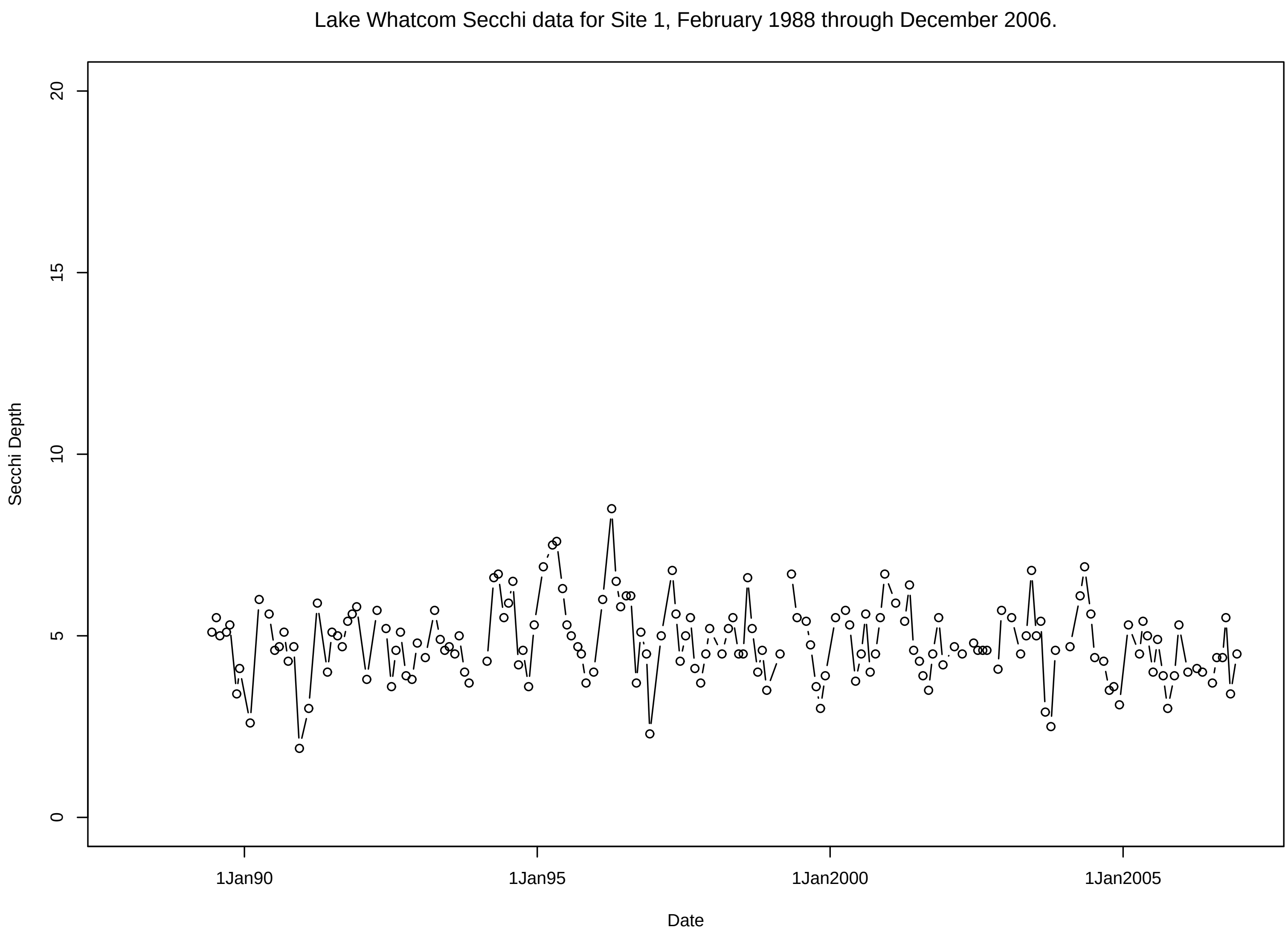


Figure B121: Lake Whatcom Secchi depths for Site 1.

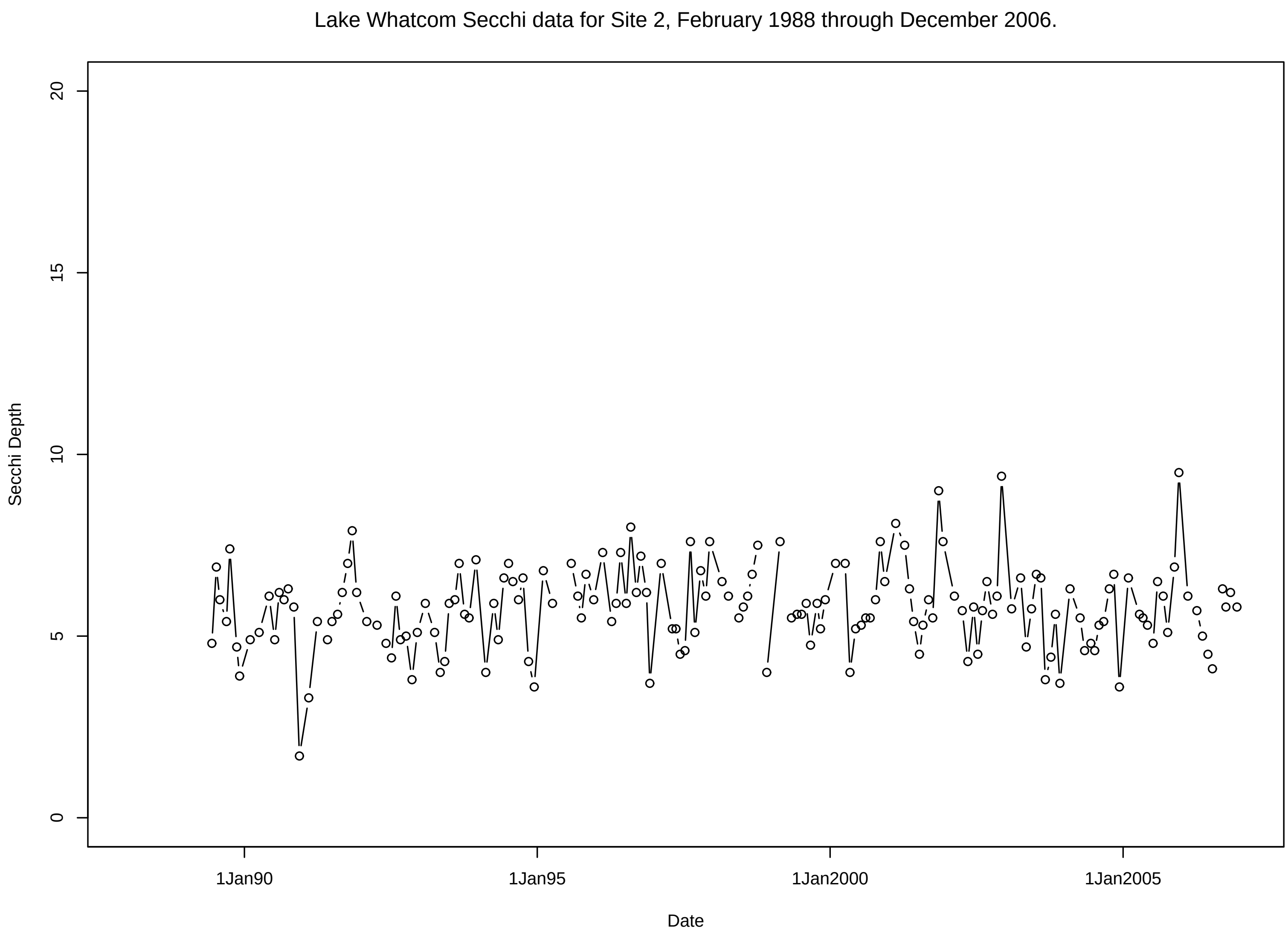


Figure B122: Lake Whatcom Secchi depths for Site 2.

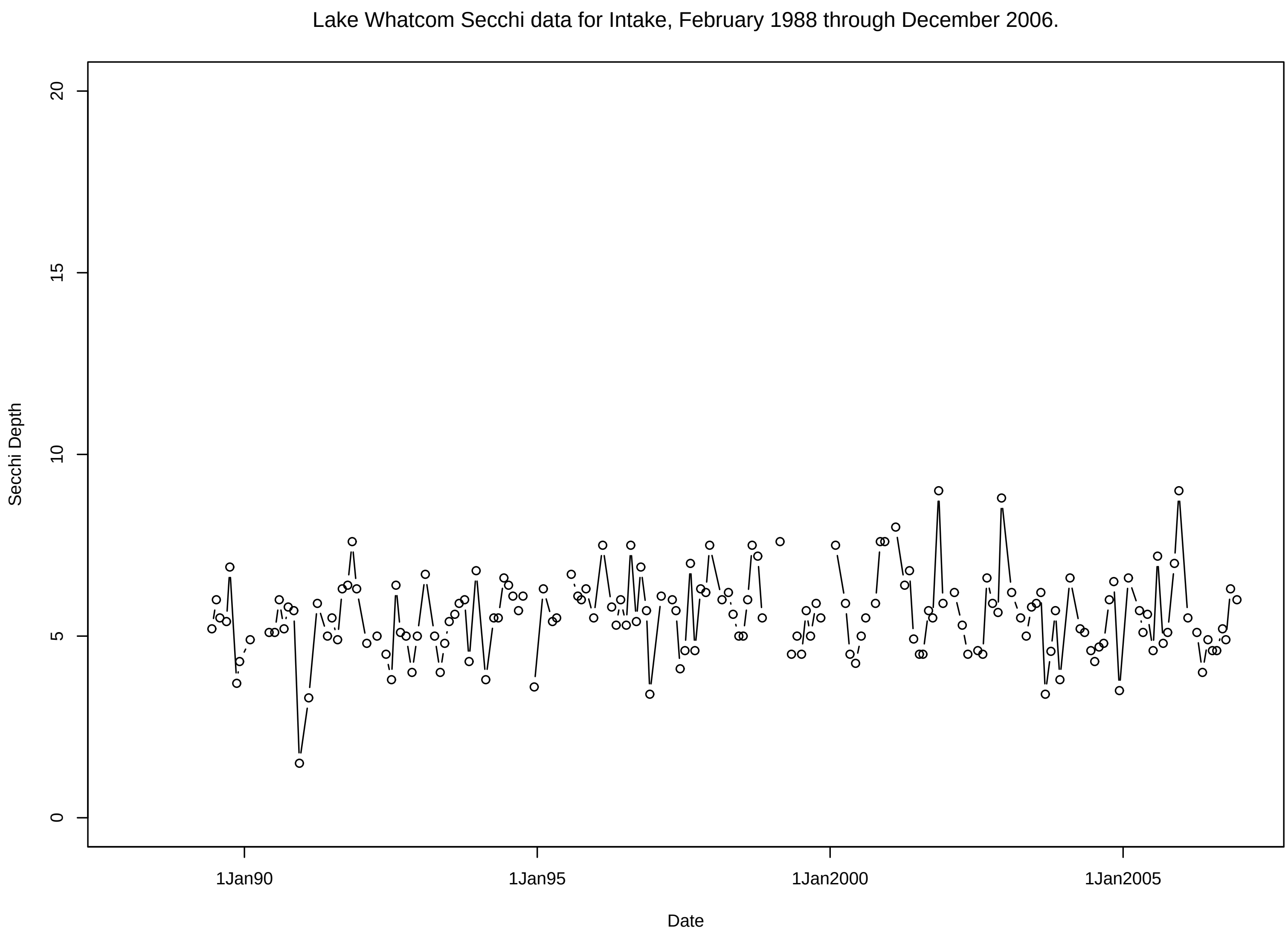


Figure B123: Lake Whatcom Secchi depths for the Intake site.

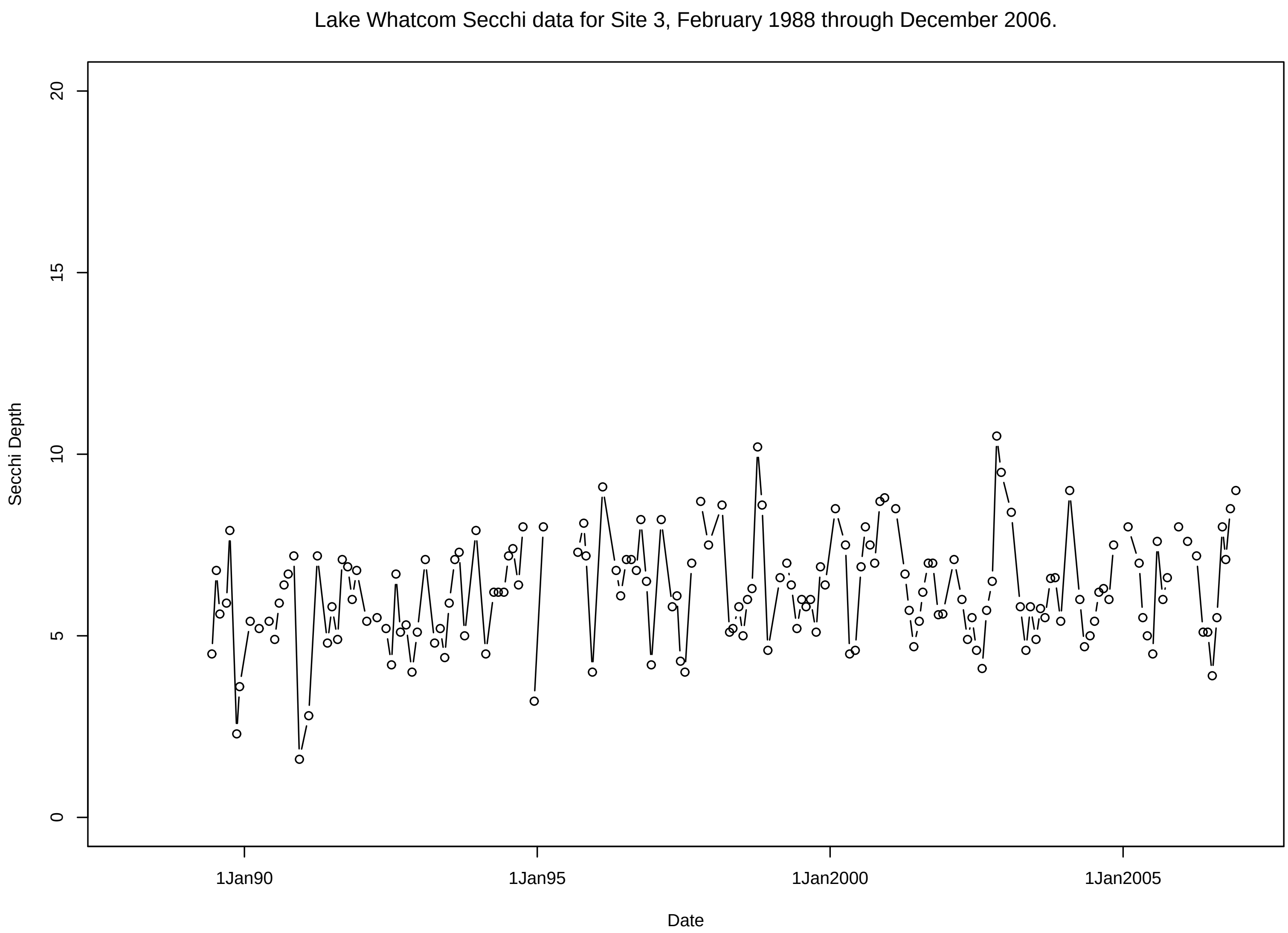


Figure B124: Lake Whatcom Secchi depths for Site 3.

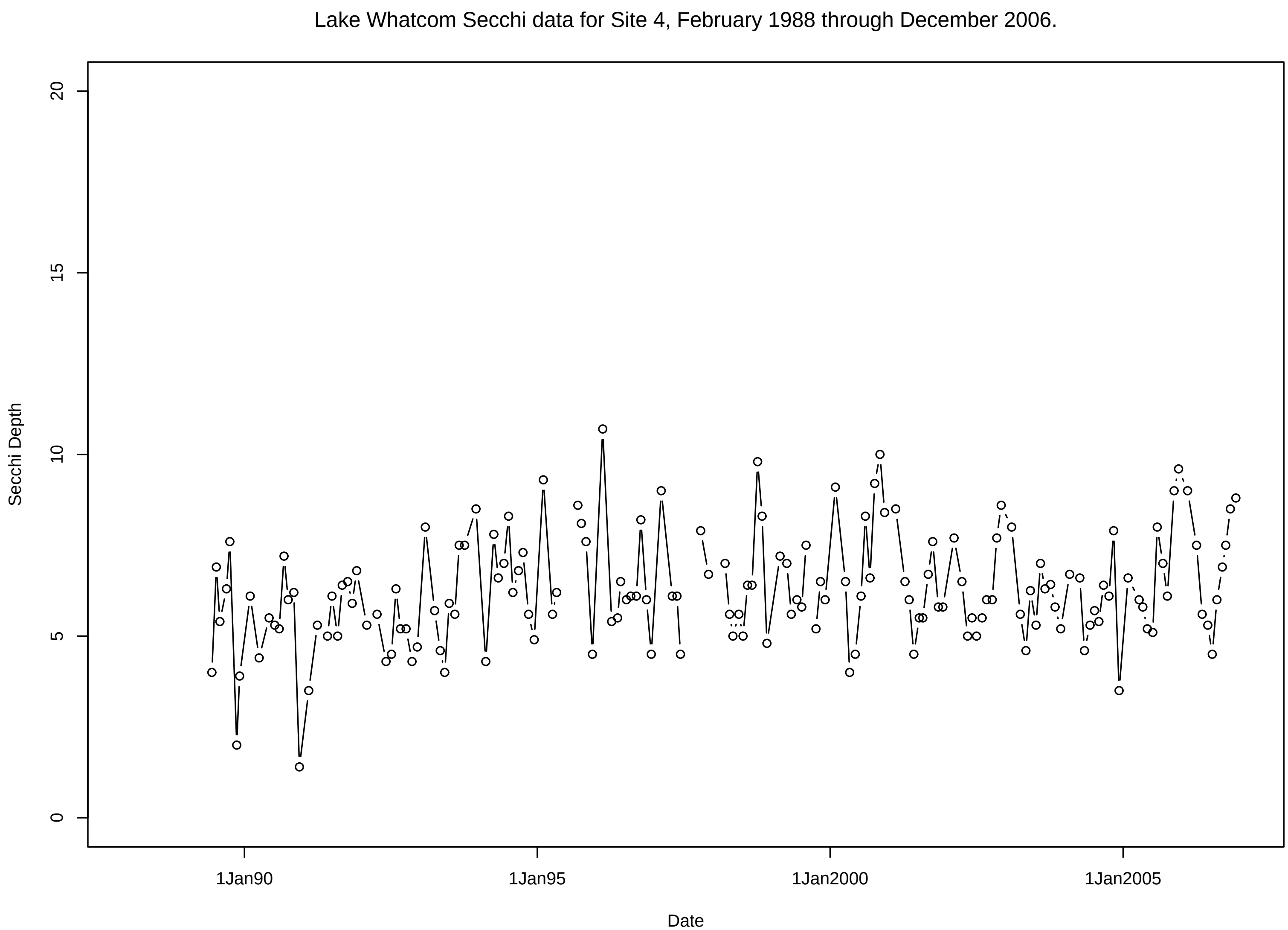


Figure B125: Lake Whatcom Secchi depths for Site 4.

B.6 Coliform Bacteria

Lake Whatcom fecal coliform data for Site 1, February 1988 through December 2006.

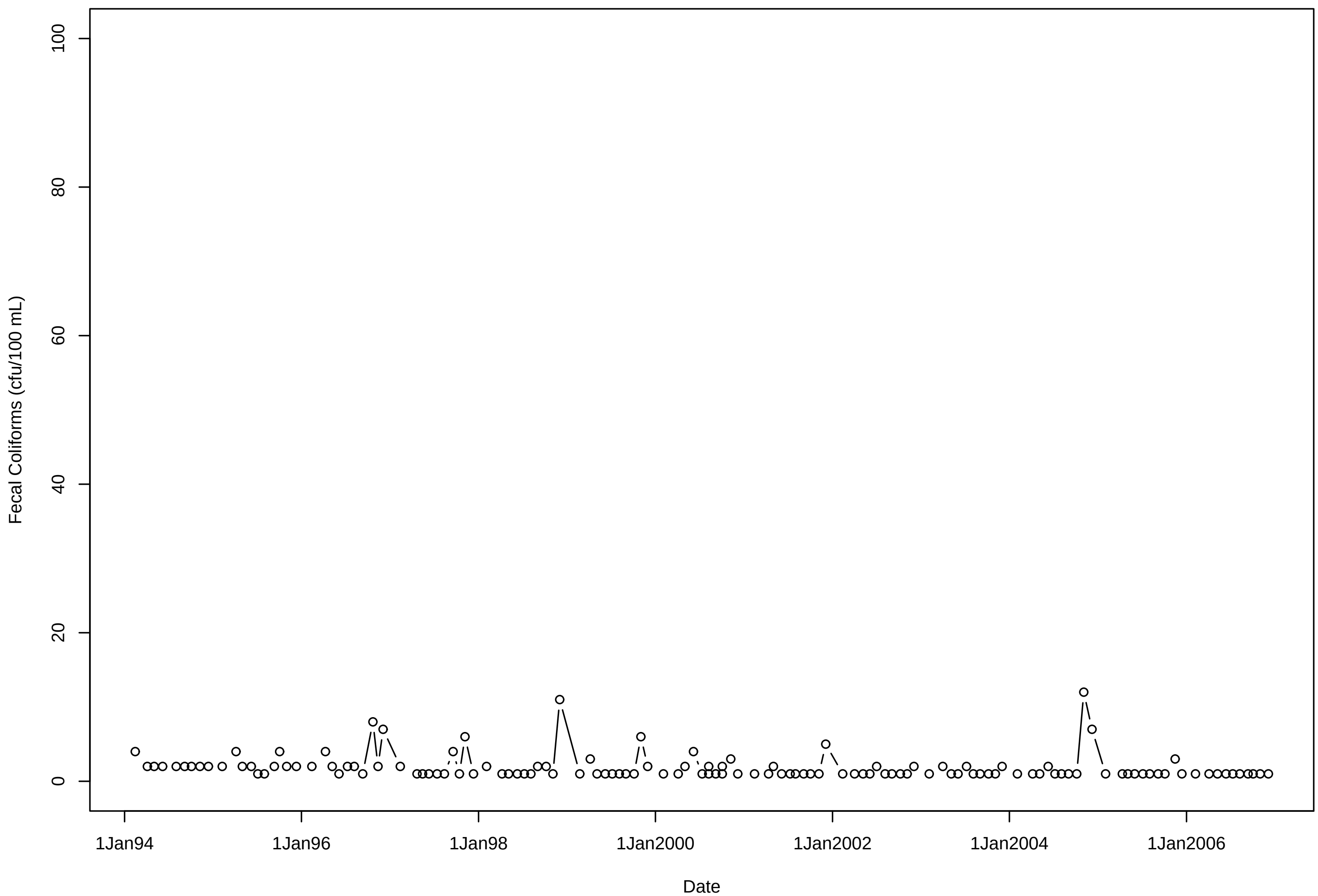


Figure B126: Lake Whatcom fecal coliform data for Site 1.

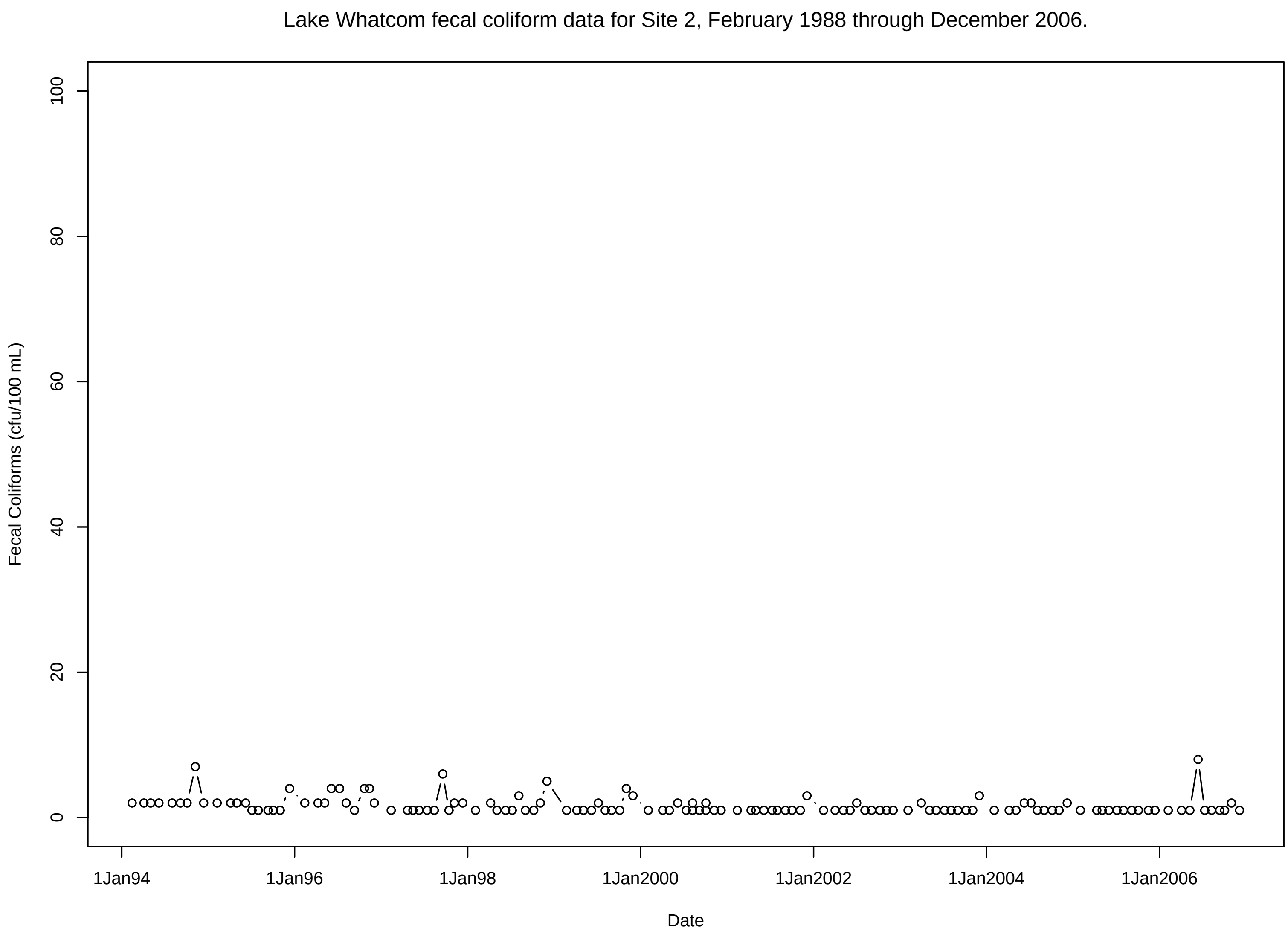


Figure B127: Lake Whatcom fecal coliform data for Site 2.

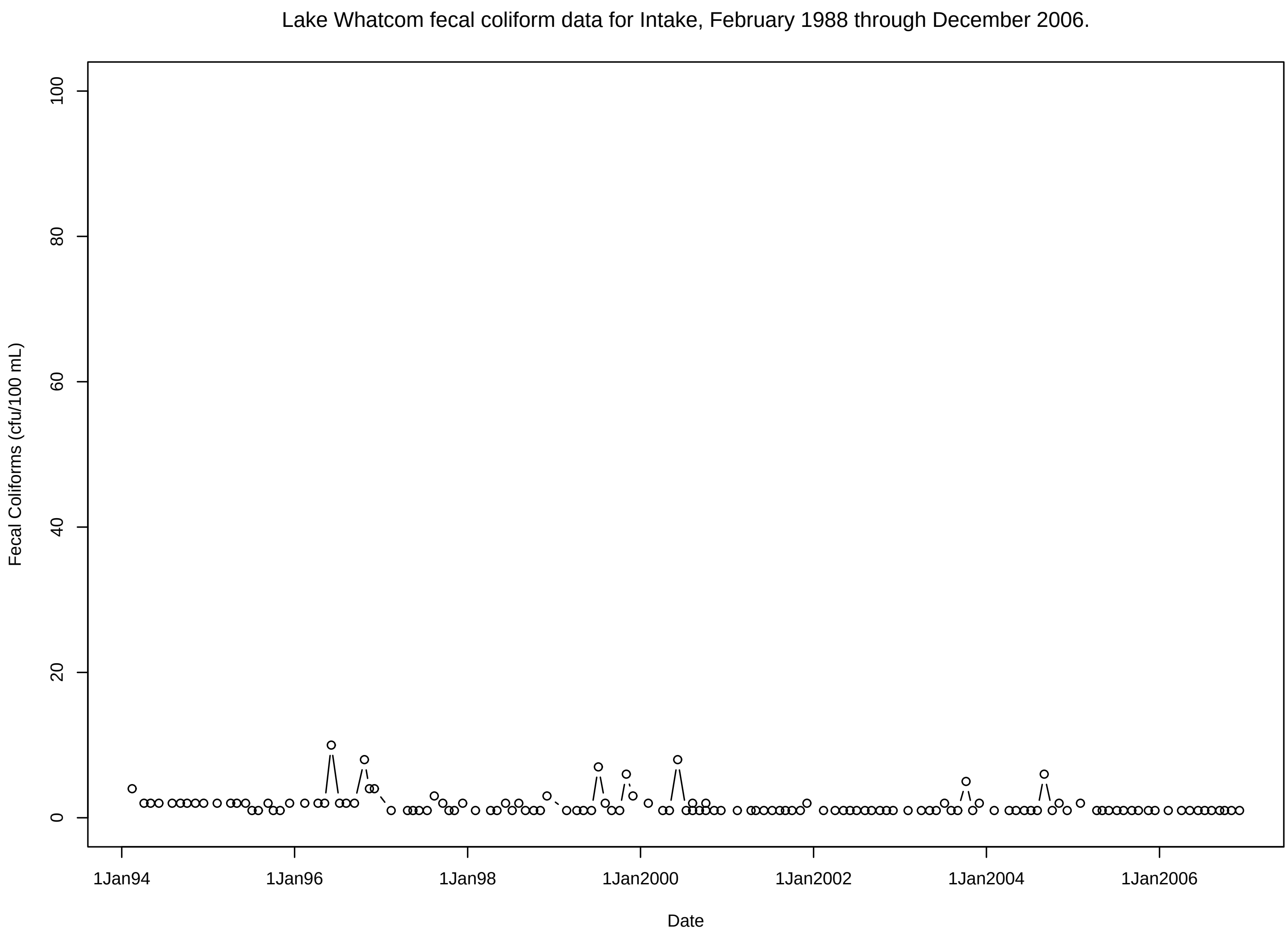


Figure B128: Lake Whatcom fecal coliform data for the Intake site.

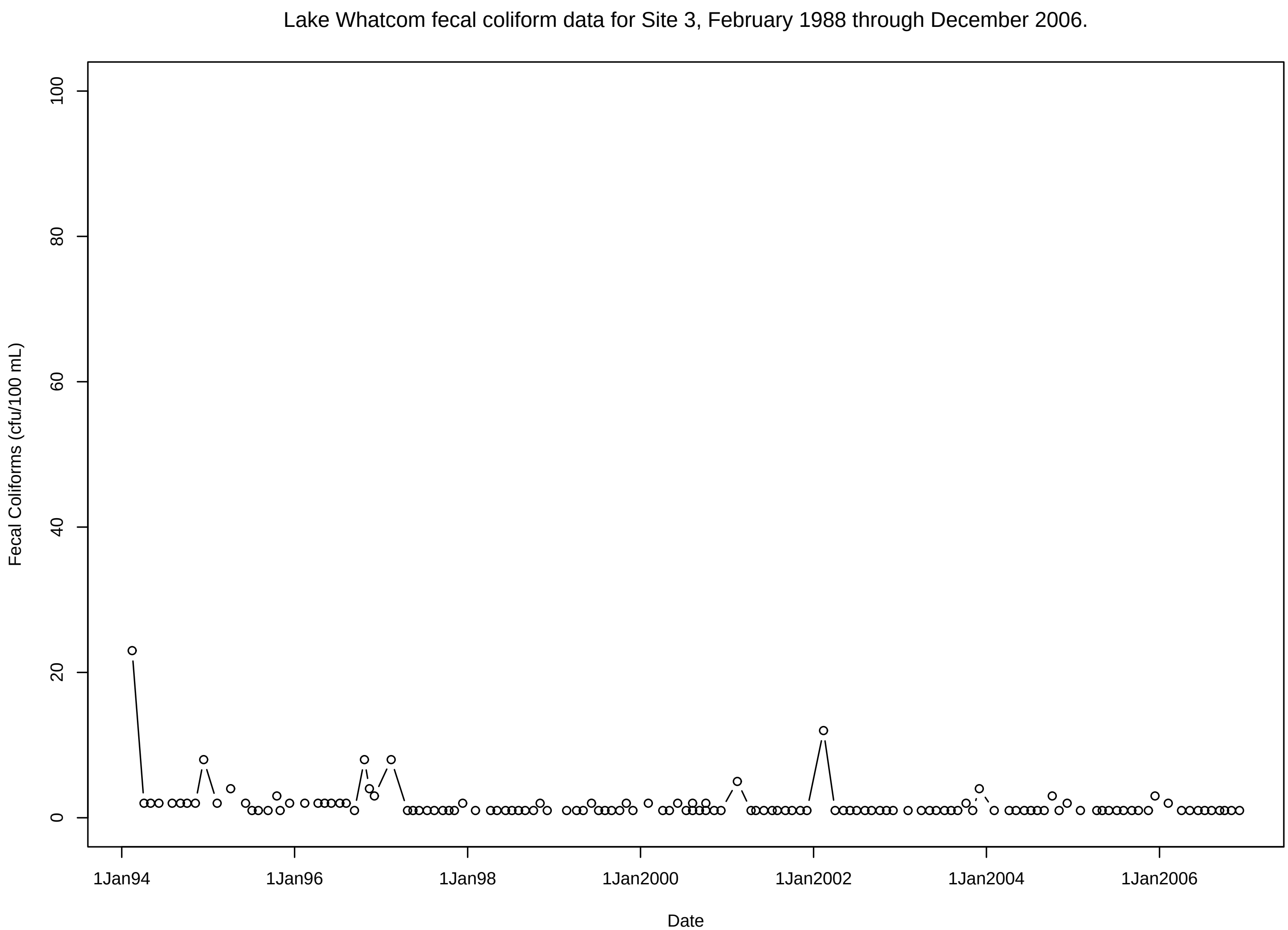


Figure B129: Lake Whatcom fecal coliform data for Site 3.

Lake Whatcom fecal coliform data for Site 4, February 1988 through December 2006.

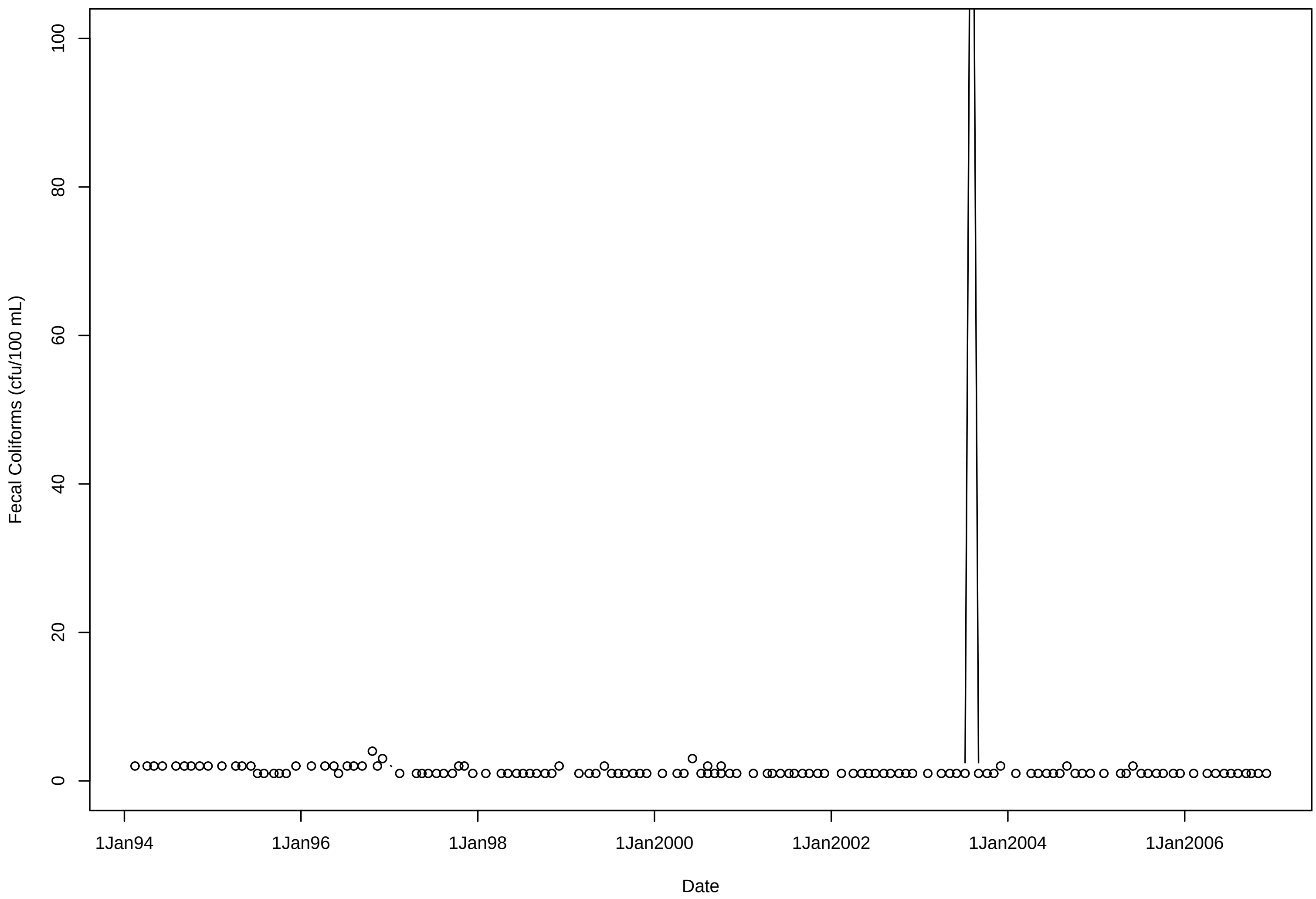


Figure B130: Lake Whatcom fecal coliform data for Site 4.

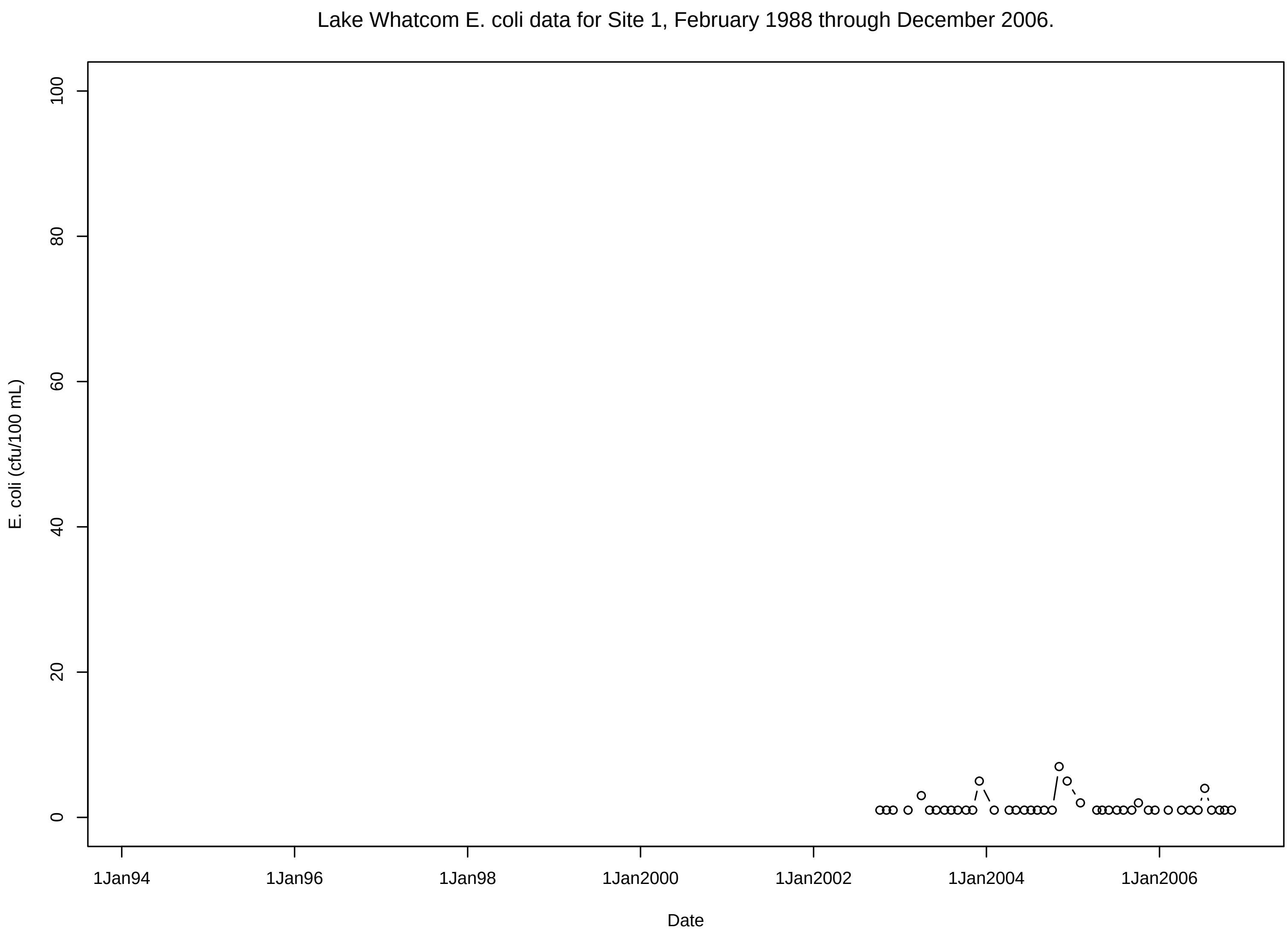


Figure B131: Lake Whatcom *E. coli* data for Site 1.

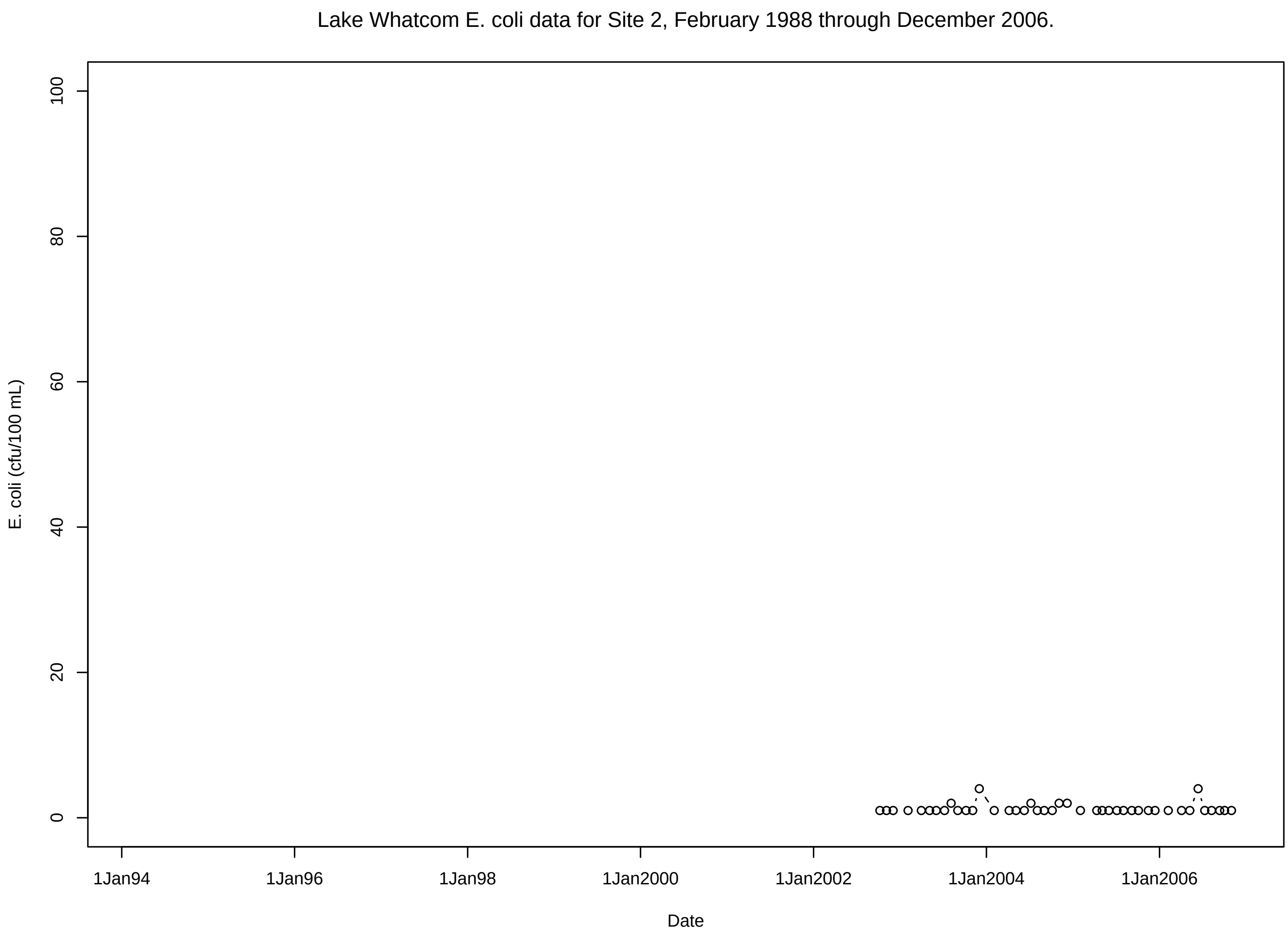


Figure B132: Lake Whatcom *E. coli* data for Site 2.

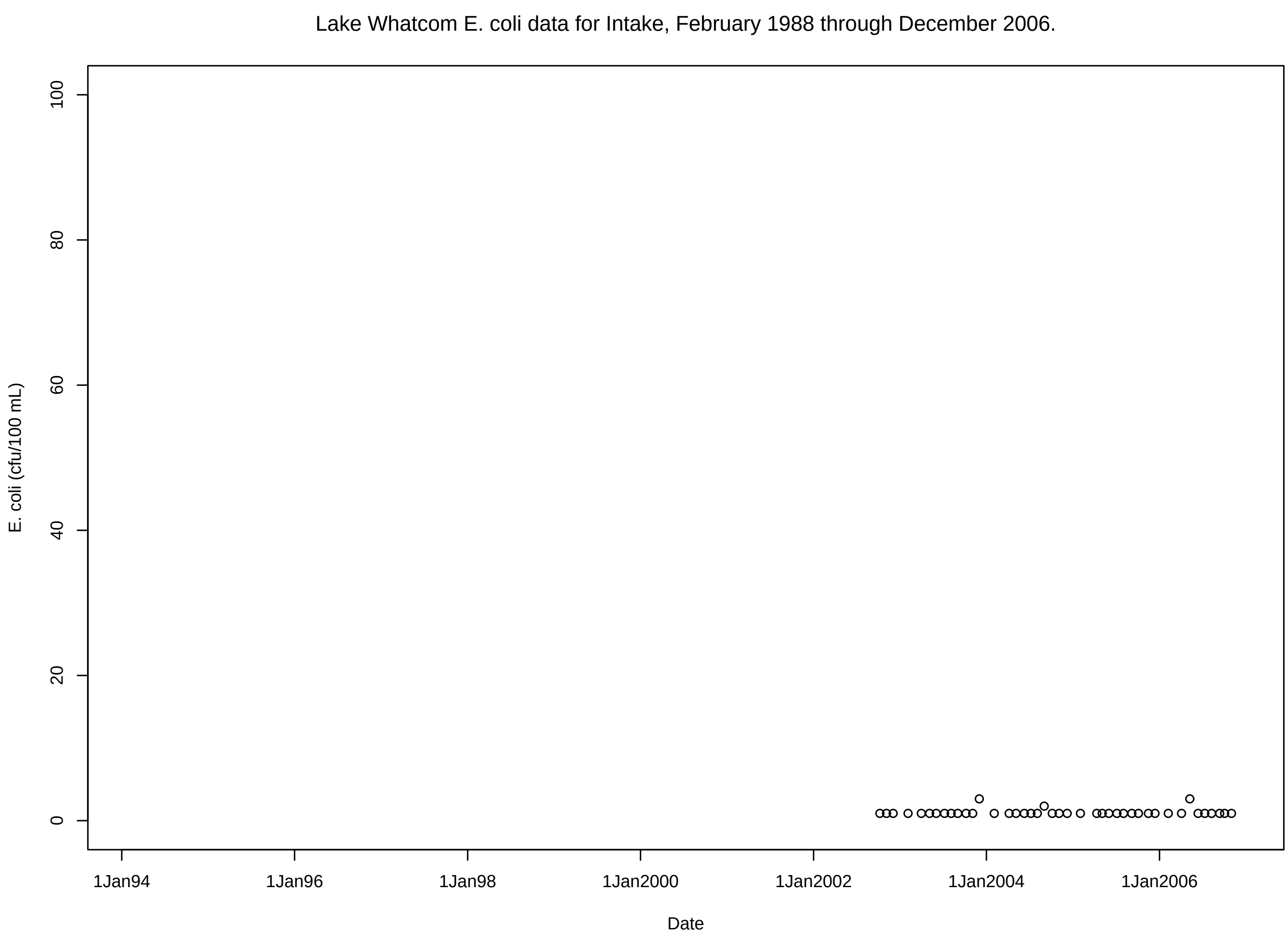


Figure B133: Lake Whatcom *E. coli* data for the Intake site.

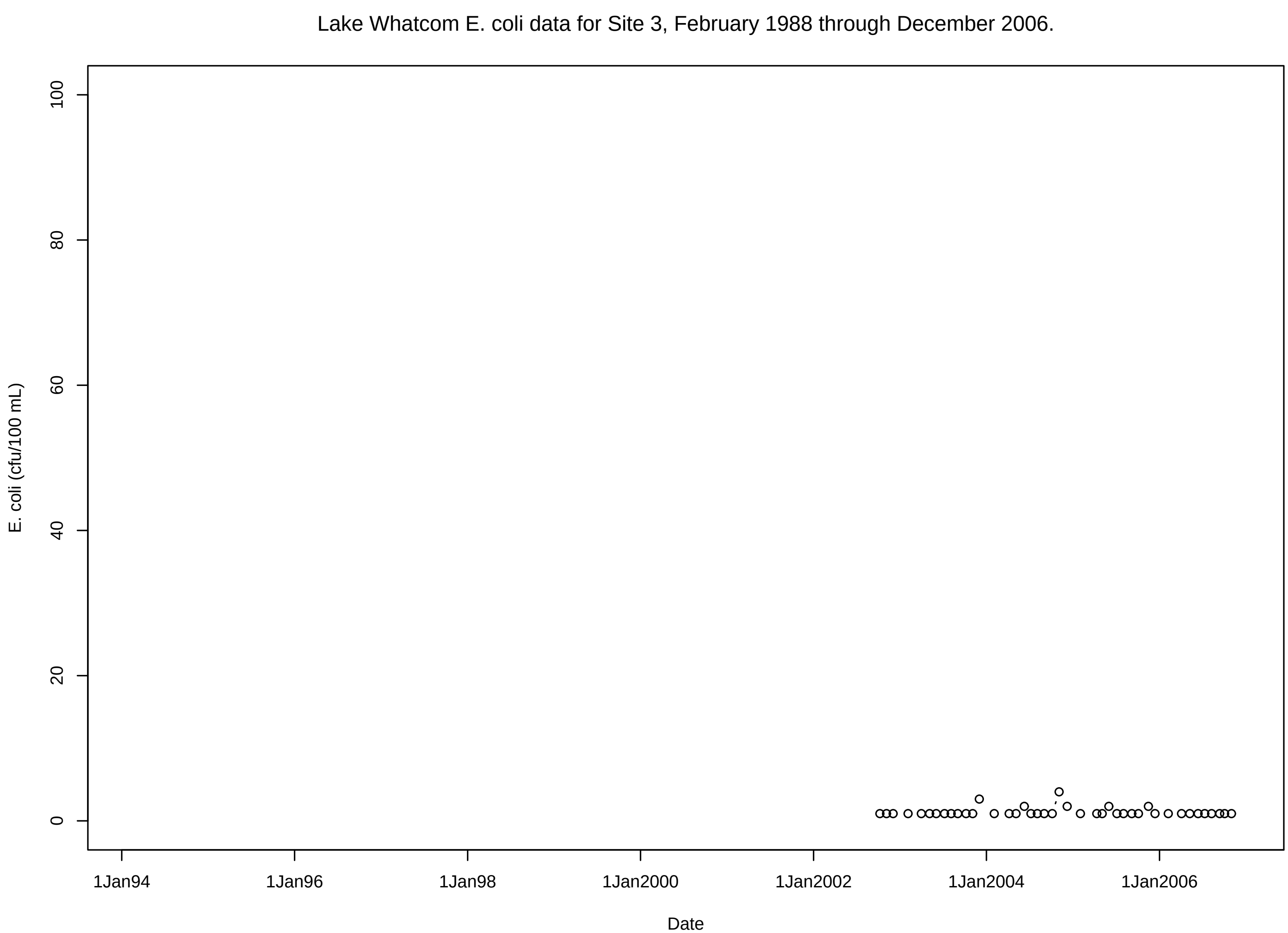


Figure B134: Lake Whatcom *E. coli* data for Site 3.

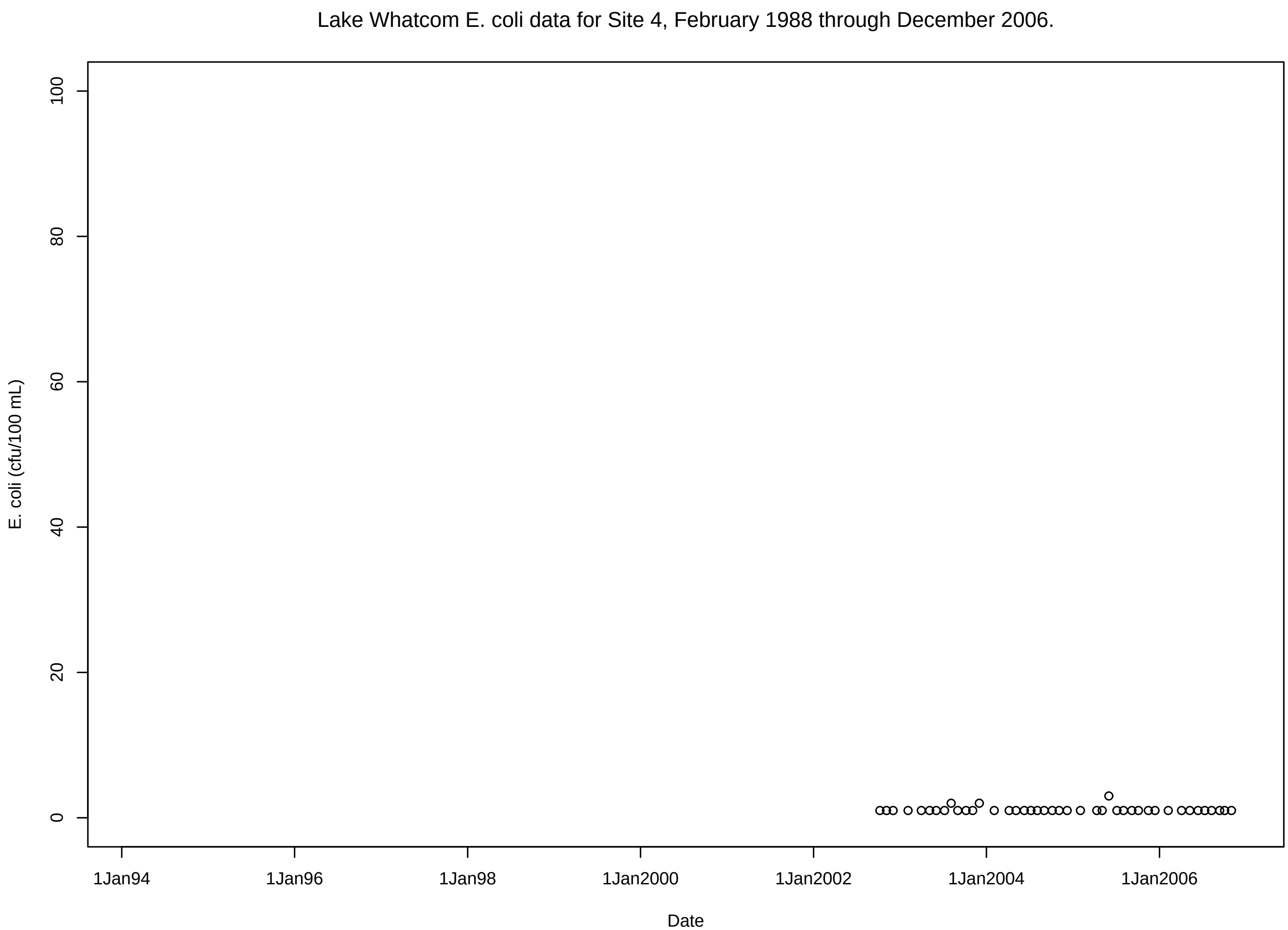


Figure B135: Lake Whatcom *E. coli* for Site 4.

B.7 Lake Whatcom 2004–2006 Tributary Data

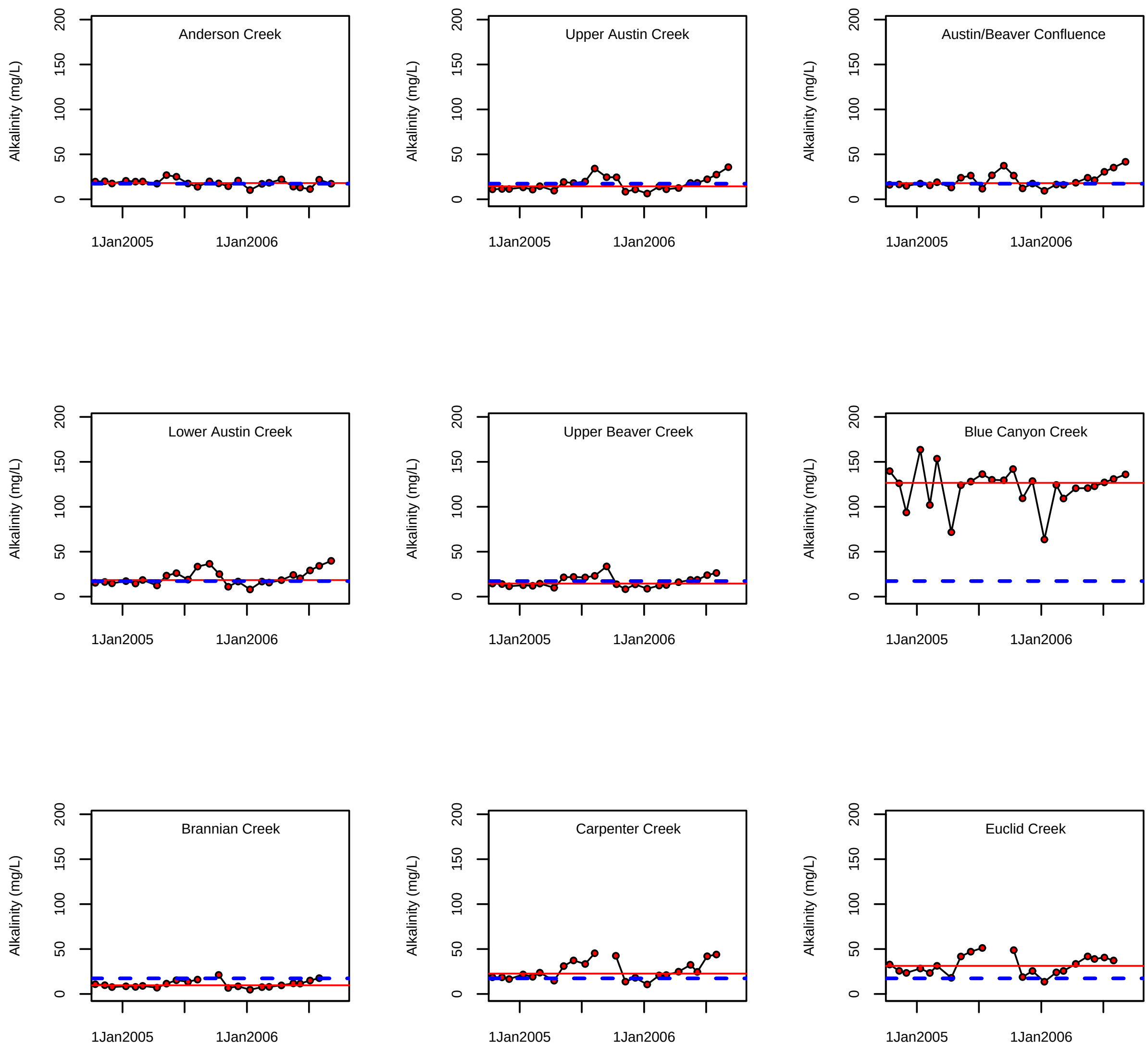


Figure B136: Monthly alkalinity data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

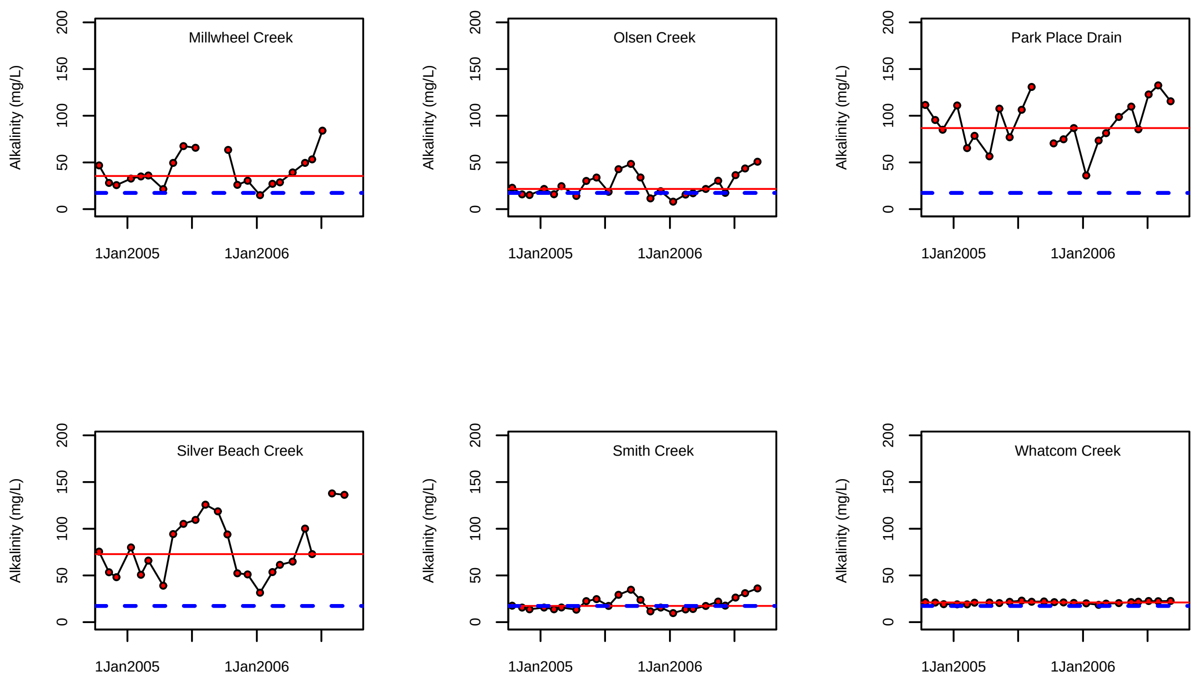


Figure B137: Monthly alkalinity data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

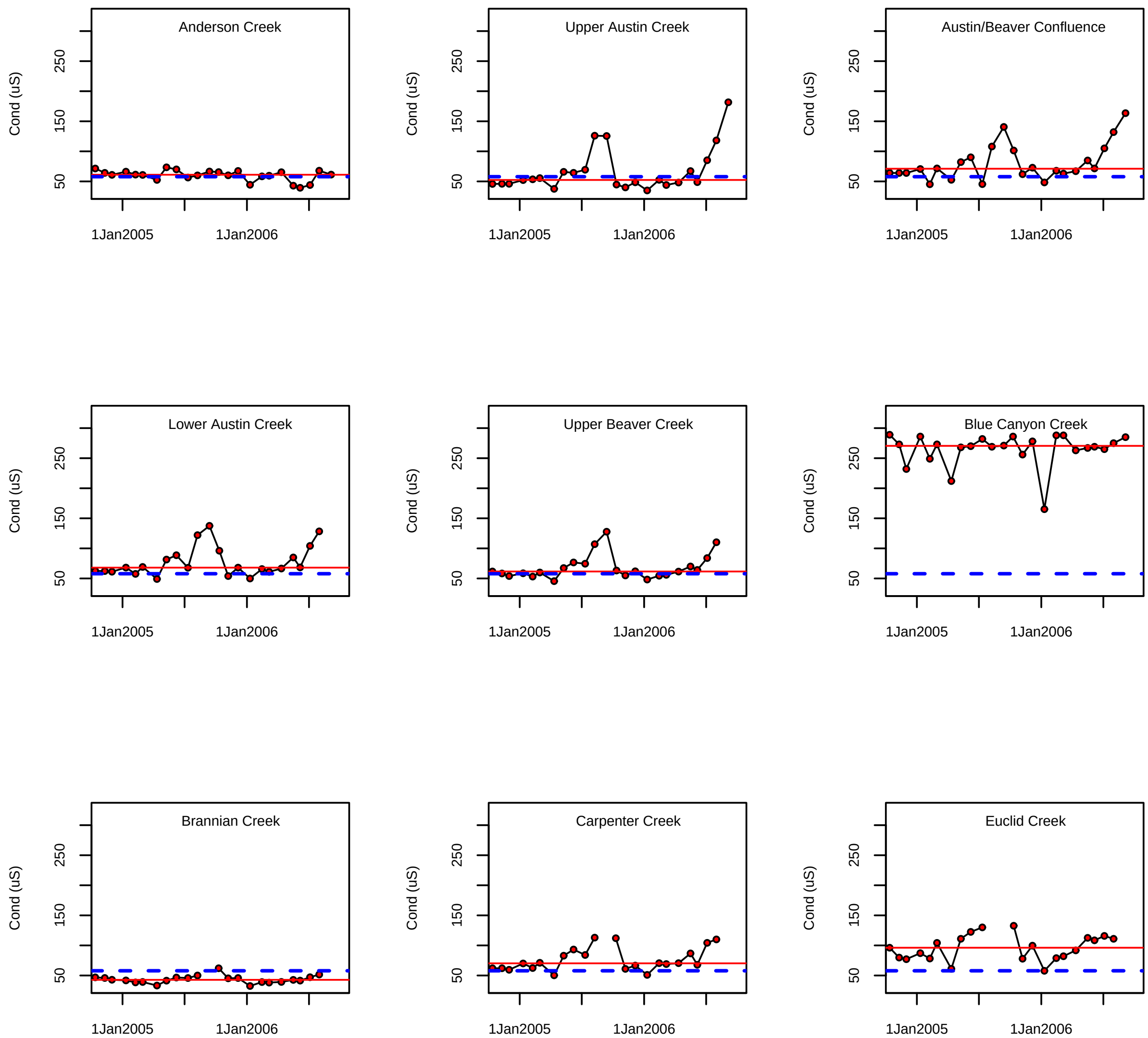


Figure B138: Monthly conductivity data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

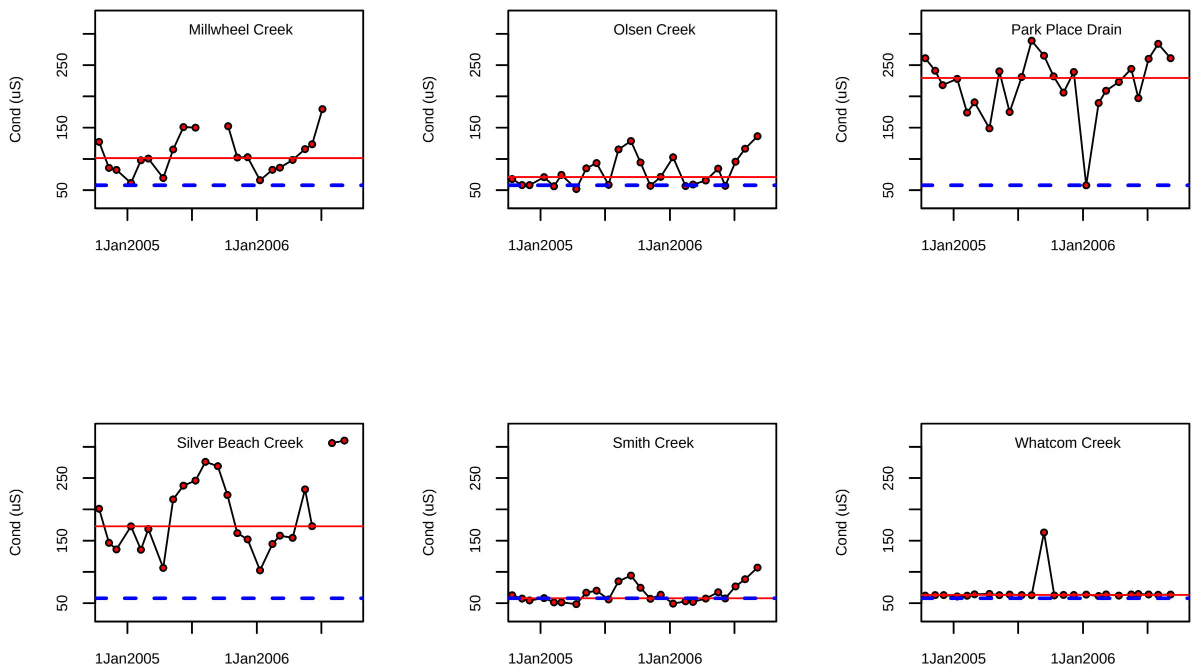


Figure B139: Monthly conductivity data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

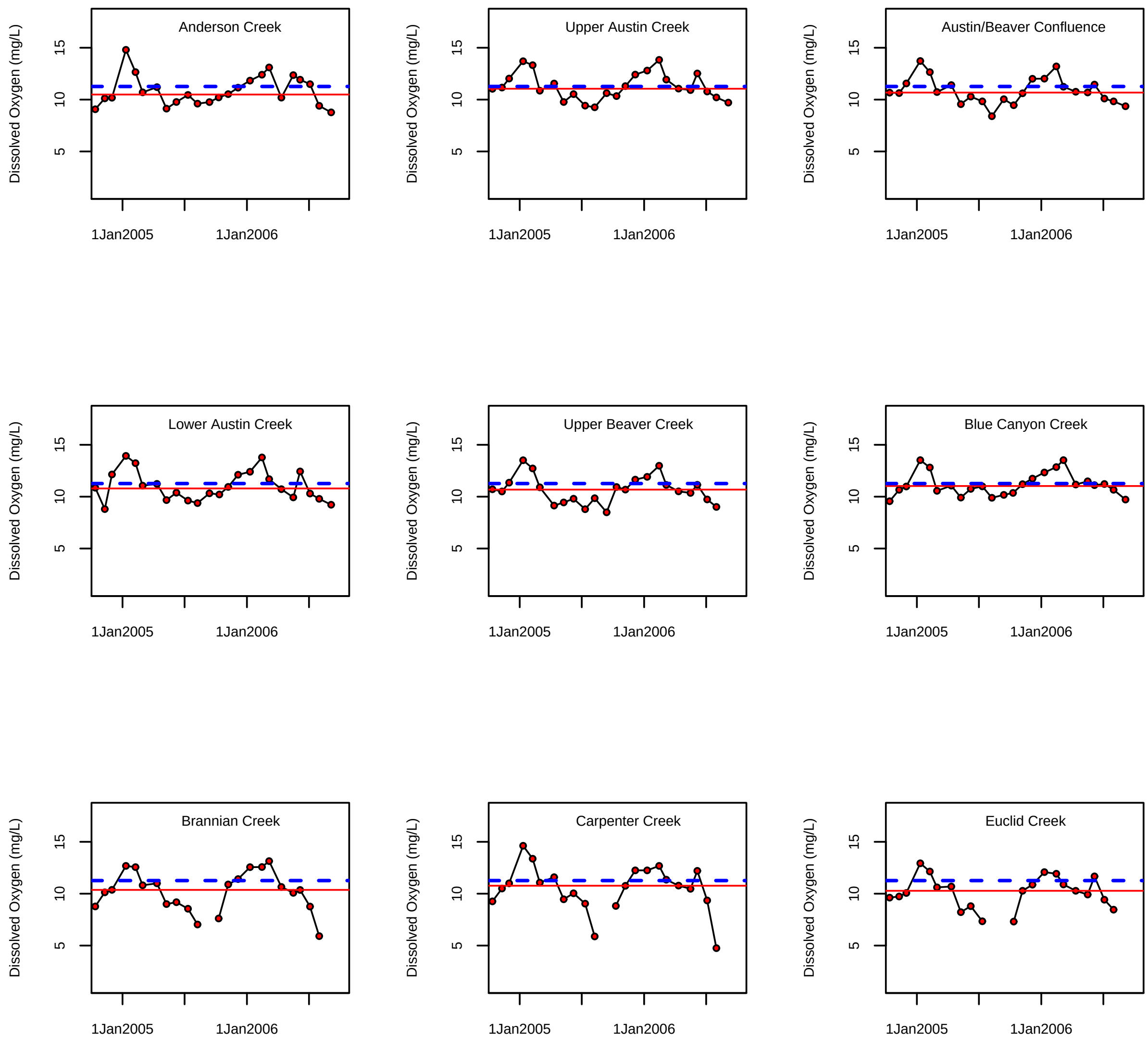


Figure B140: Monthly dissolved oxygen data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

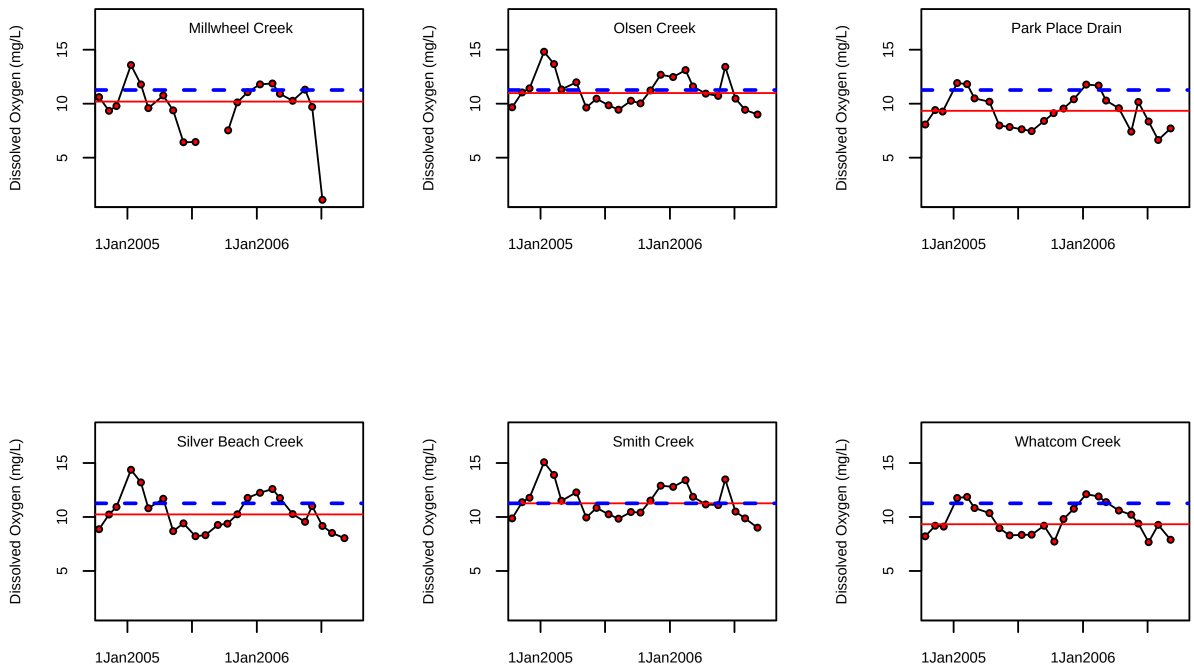


Figure B141: Monthly dissolved oxygen data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

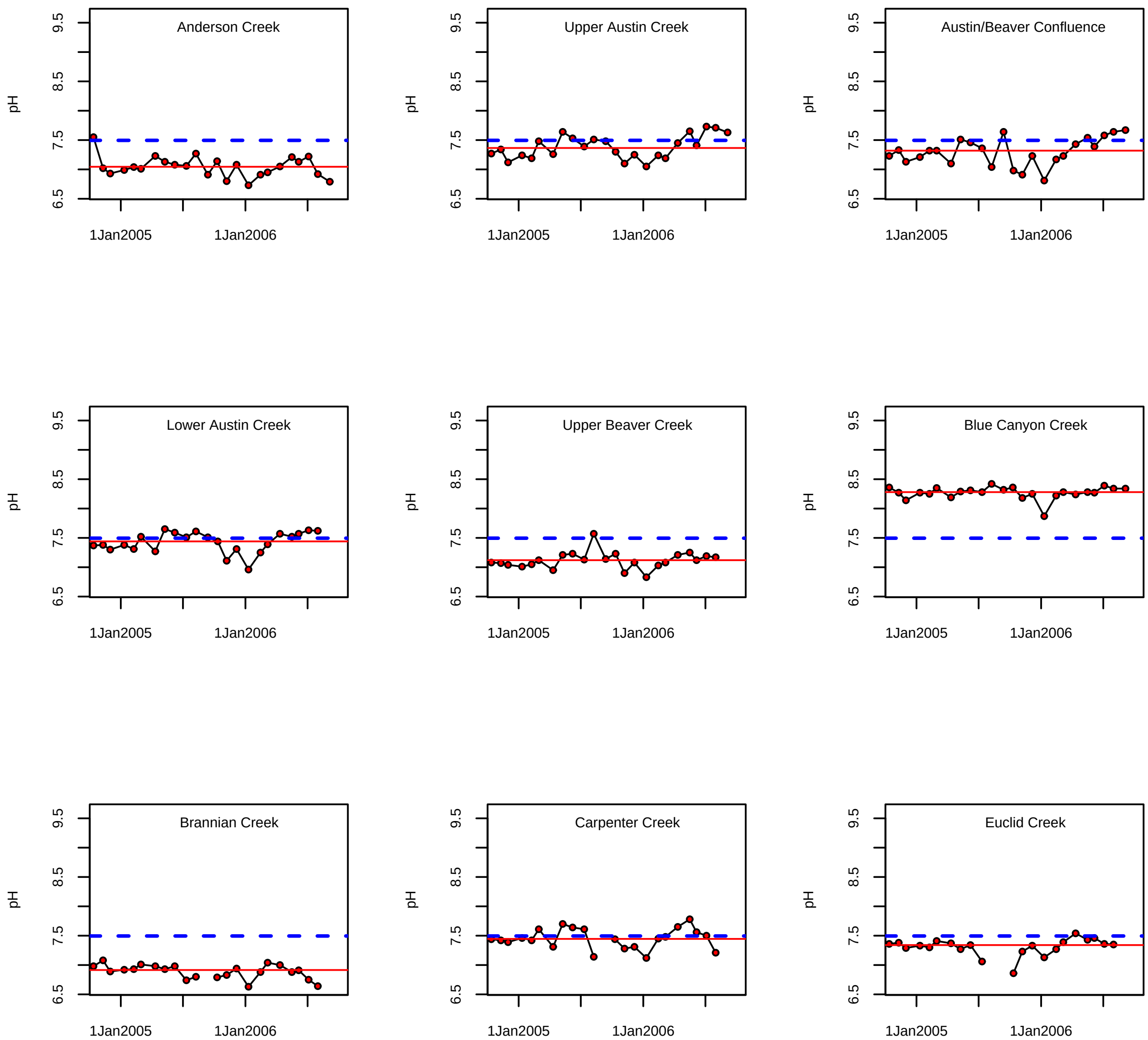


Figure B142: Monthly pH data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

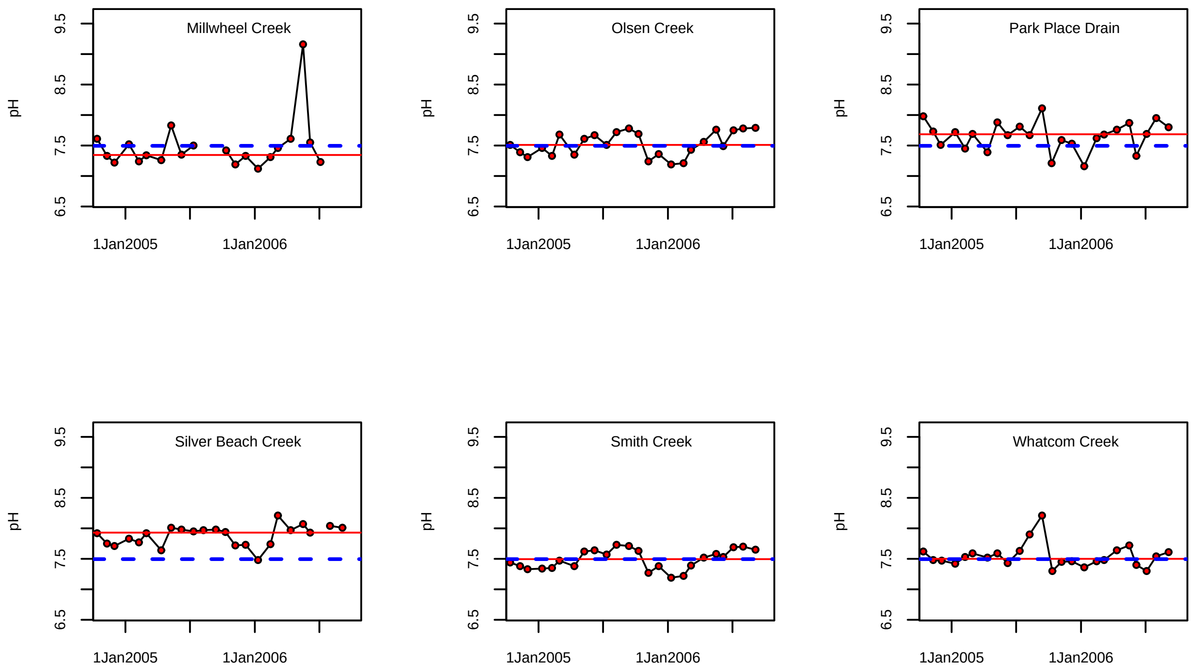


Figure B143: Monthly pH data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

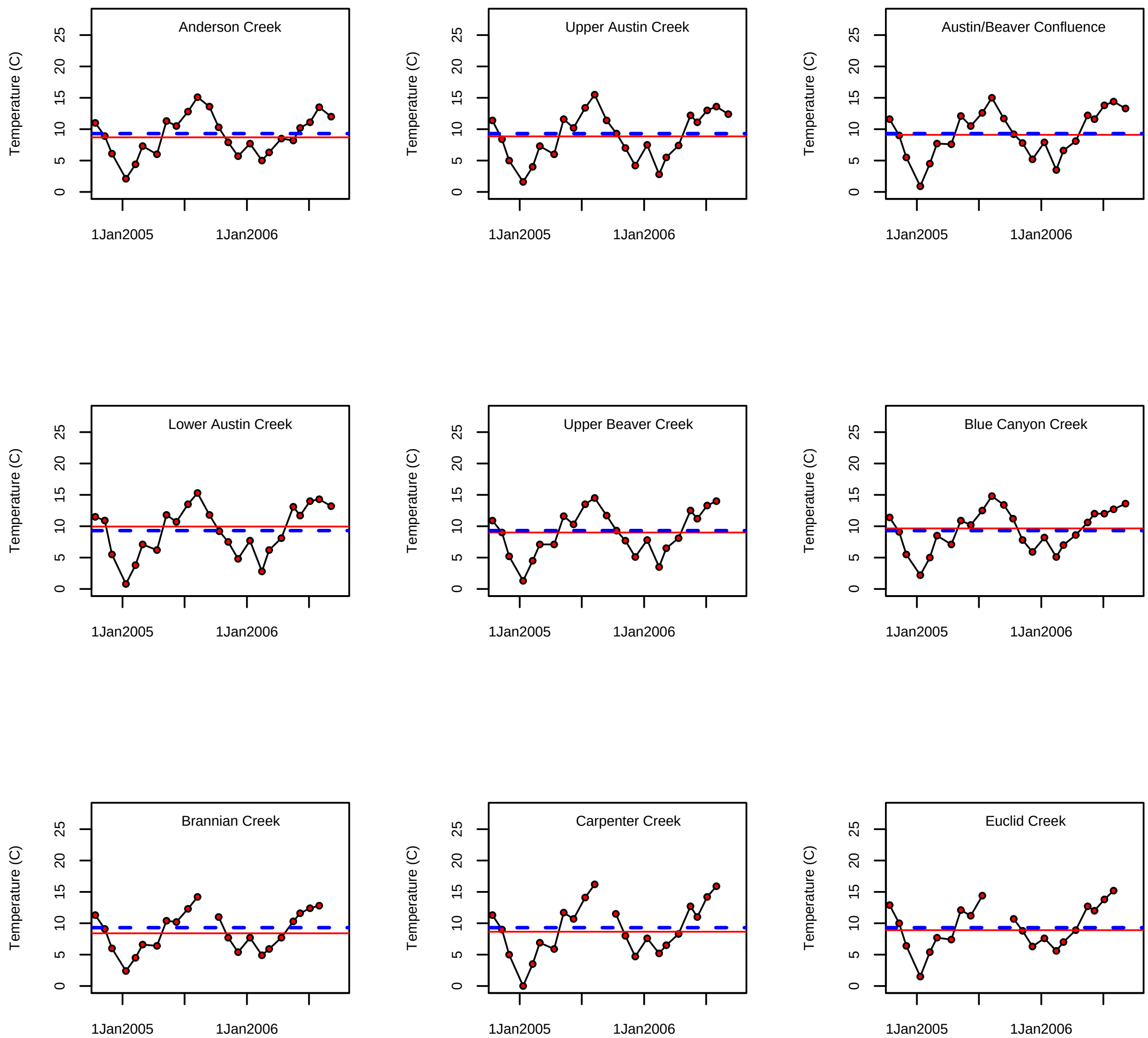


Figure B144: Monthly temperature data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

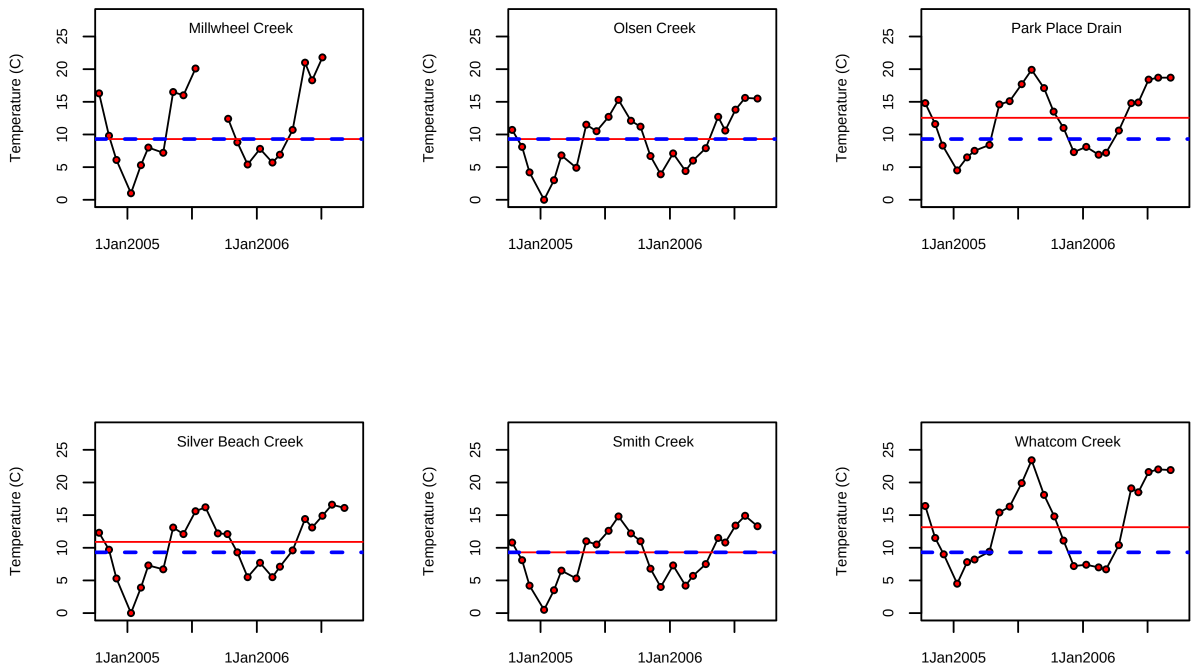


Figure B145: Monthly temperature data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

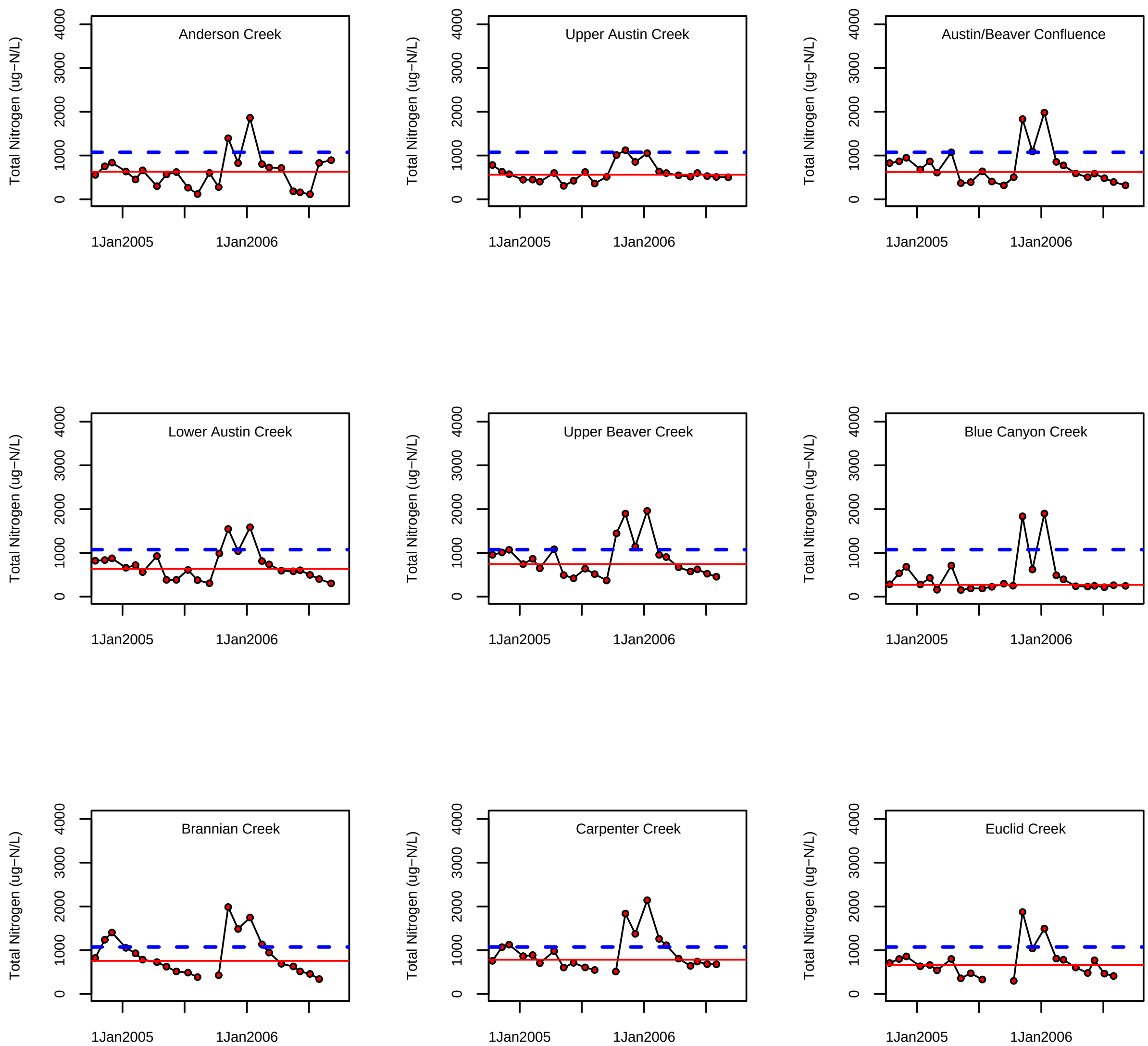


Figure B146: Monthly total nitrogen data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

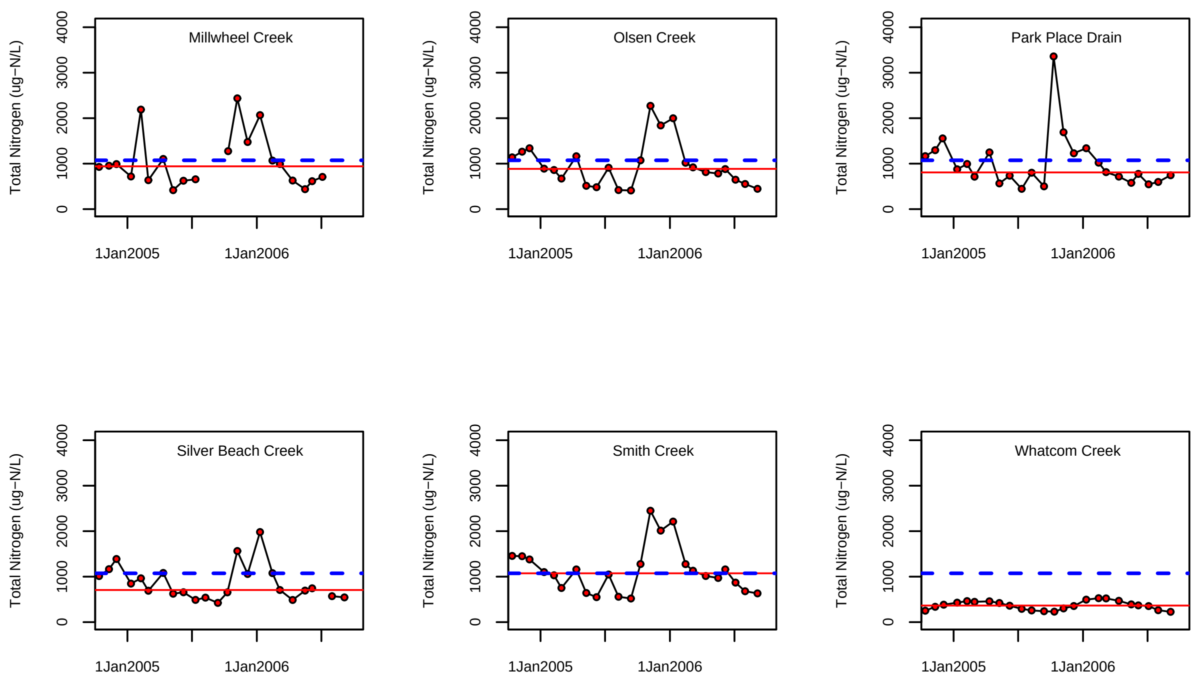


Figure B147: Monthly total nitrogen data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

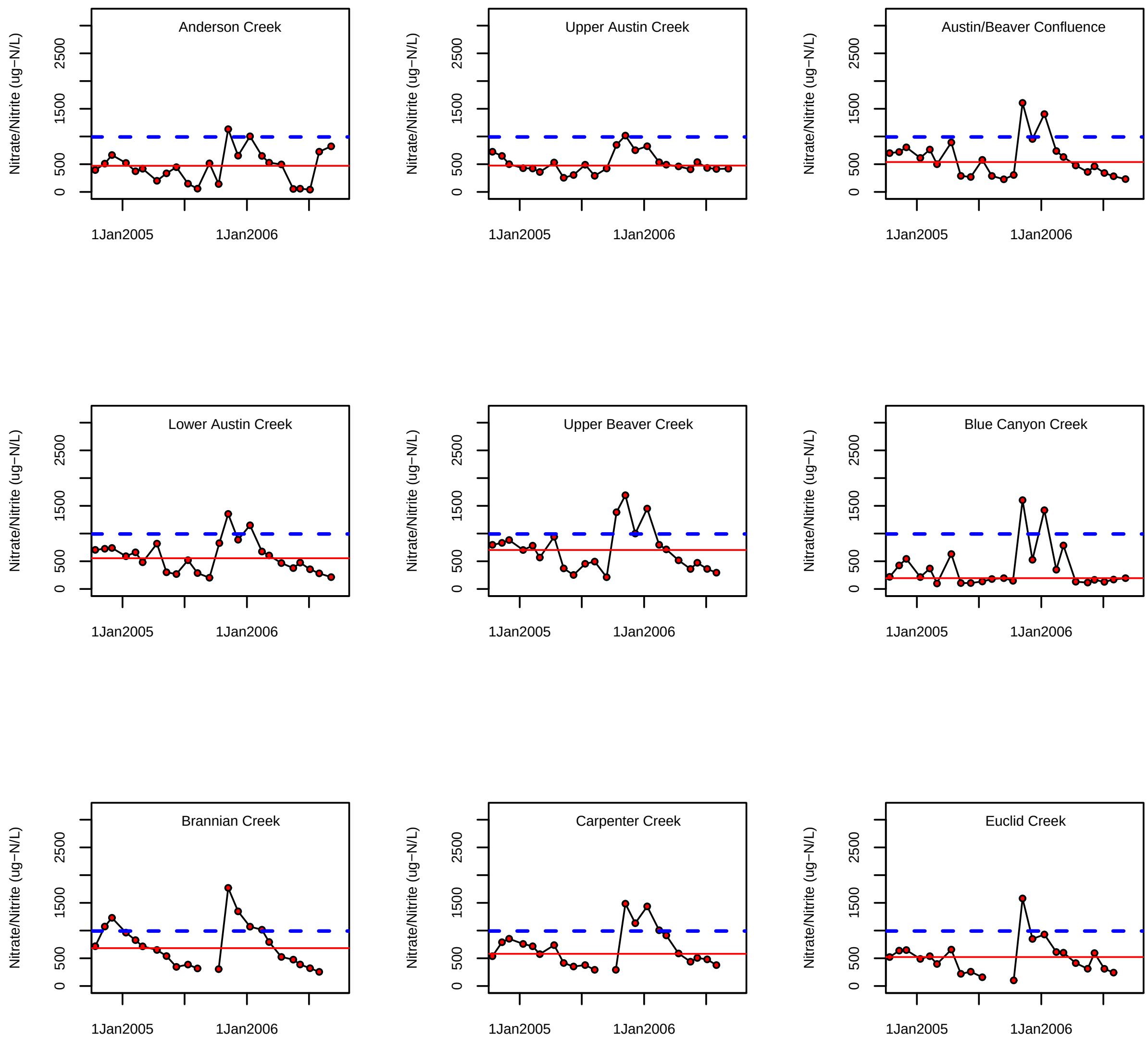


Figure B148: Monthly nitrate/nitrite data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

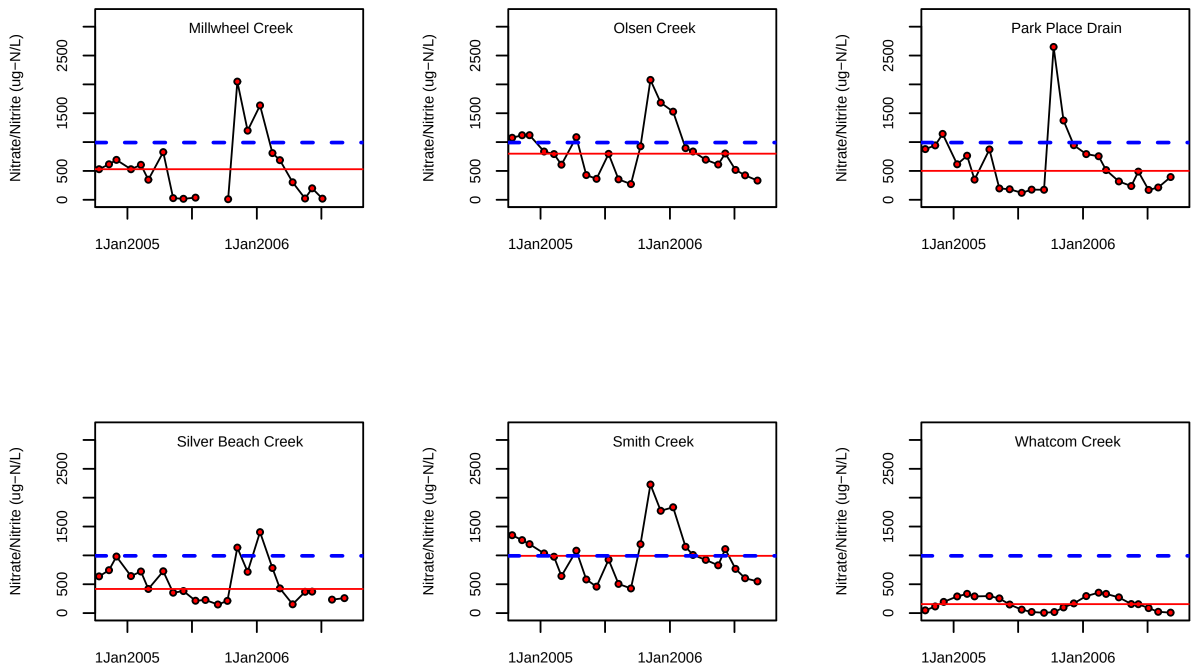


Figure B149: Monthly nitrate/nitrite data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

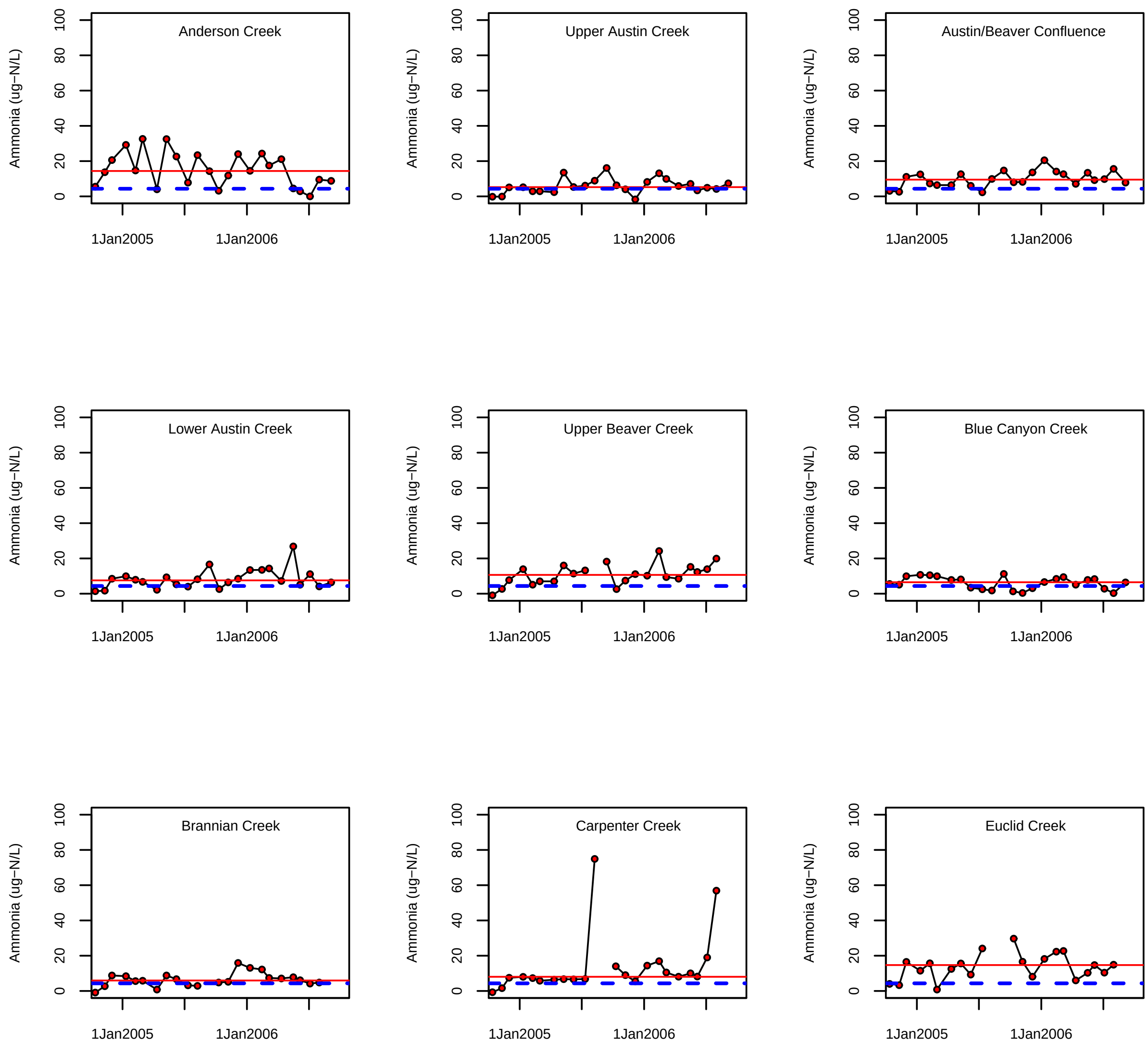


Figure B150: Monthly ammonia data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

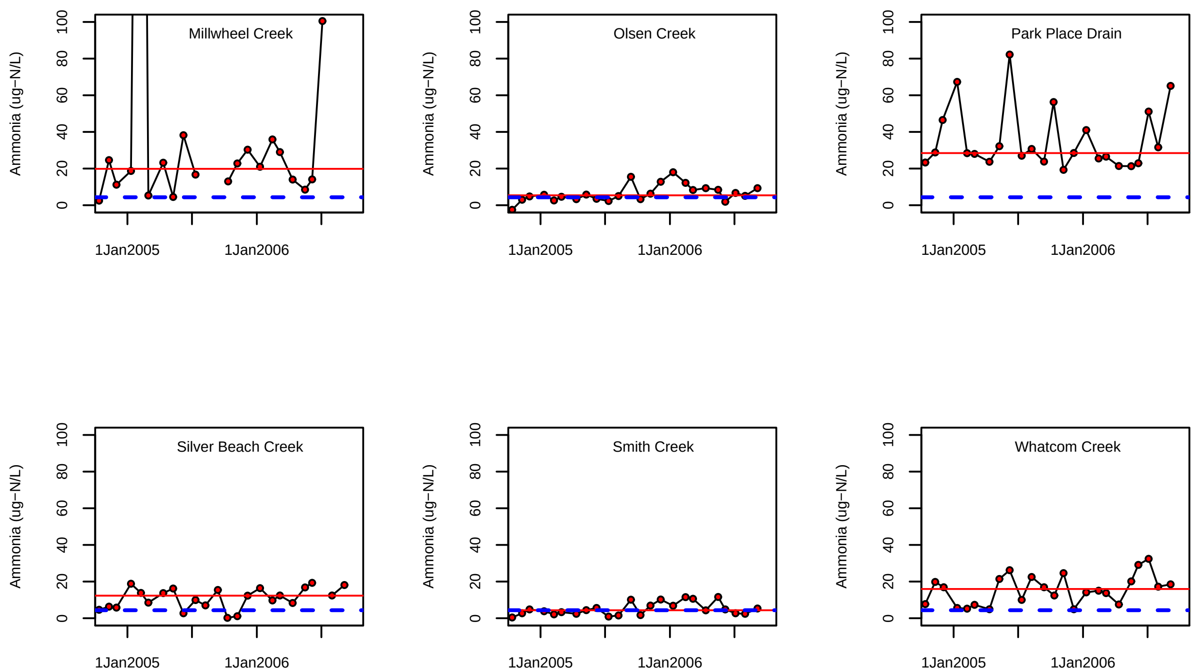


Figure B151: Monthly ammonia data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek. One outlier from Millwheel Creek is off scale (569 μg-H/L, Feb 8, 2005).

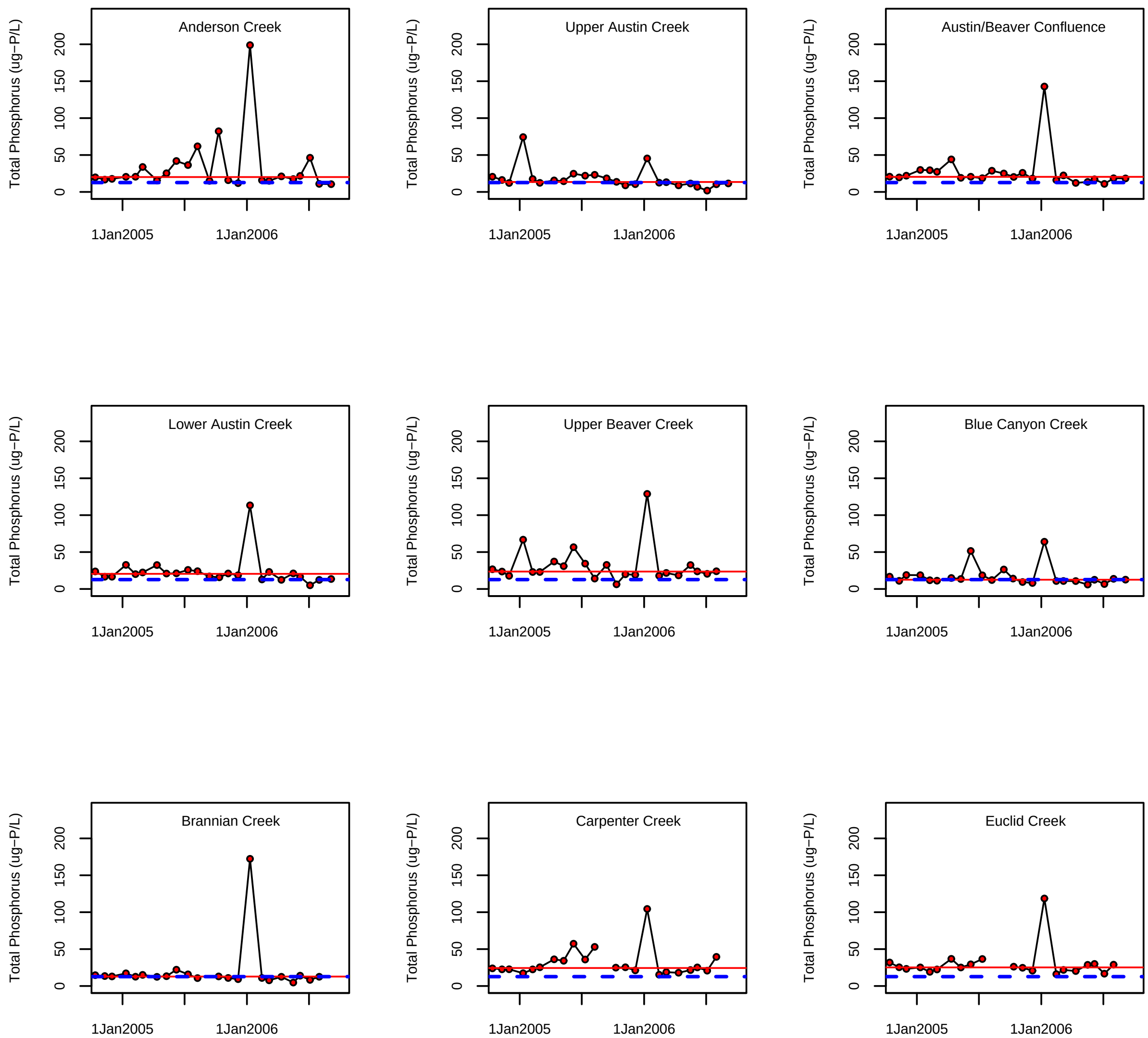


Figure B152: Monthly total phosphorus data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

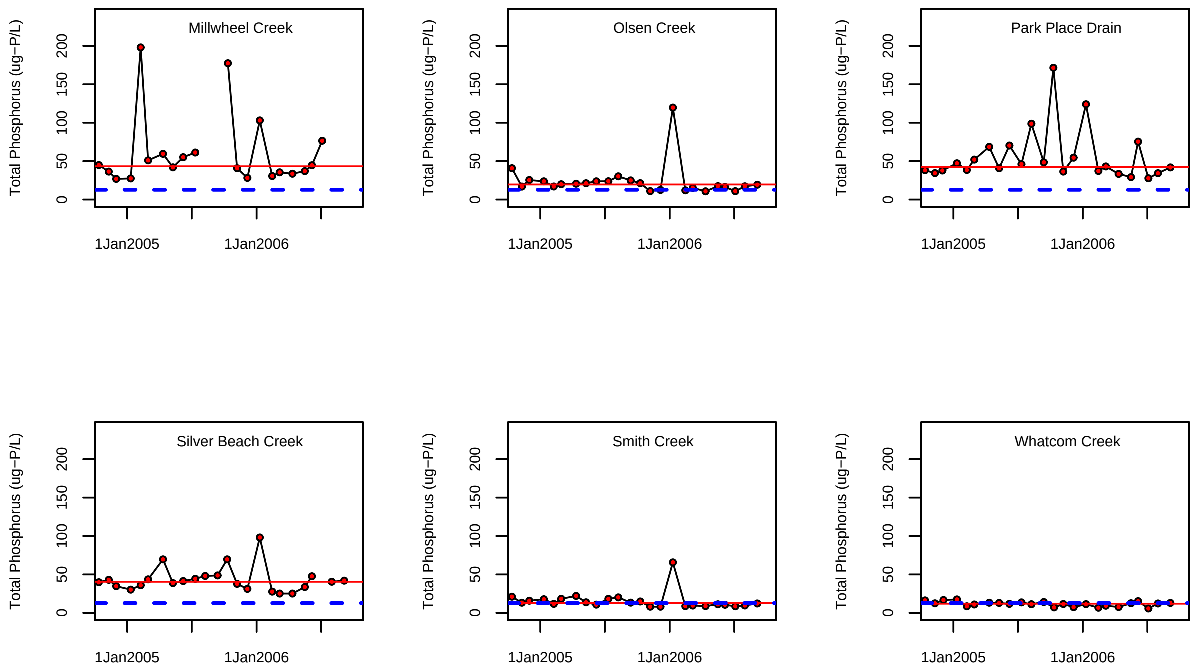


Figure B153: Monthly total phosphorus data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

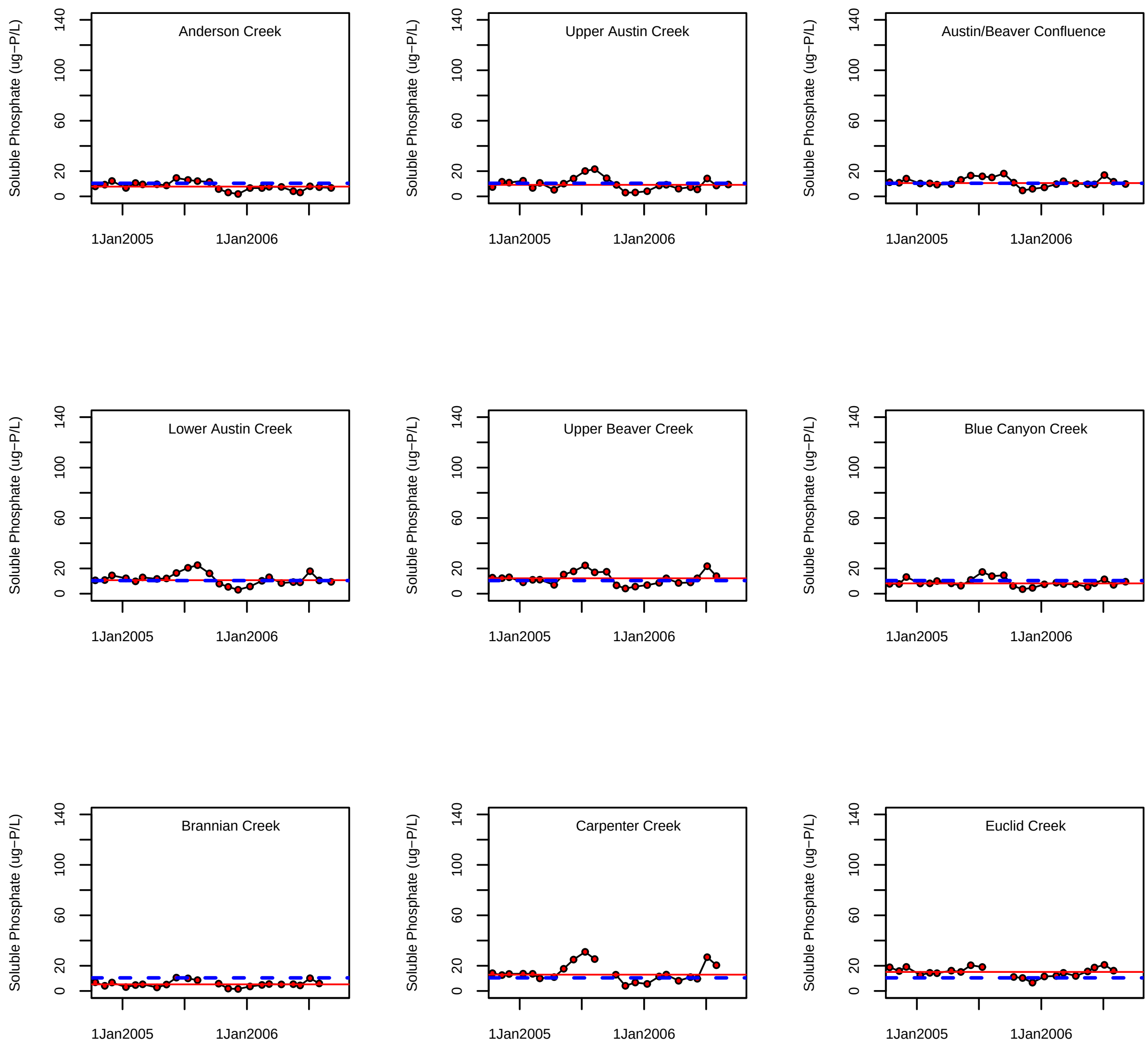


Figure B154: Monthly soluble reactive phosphate data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

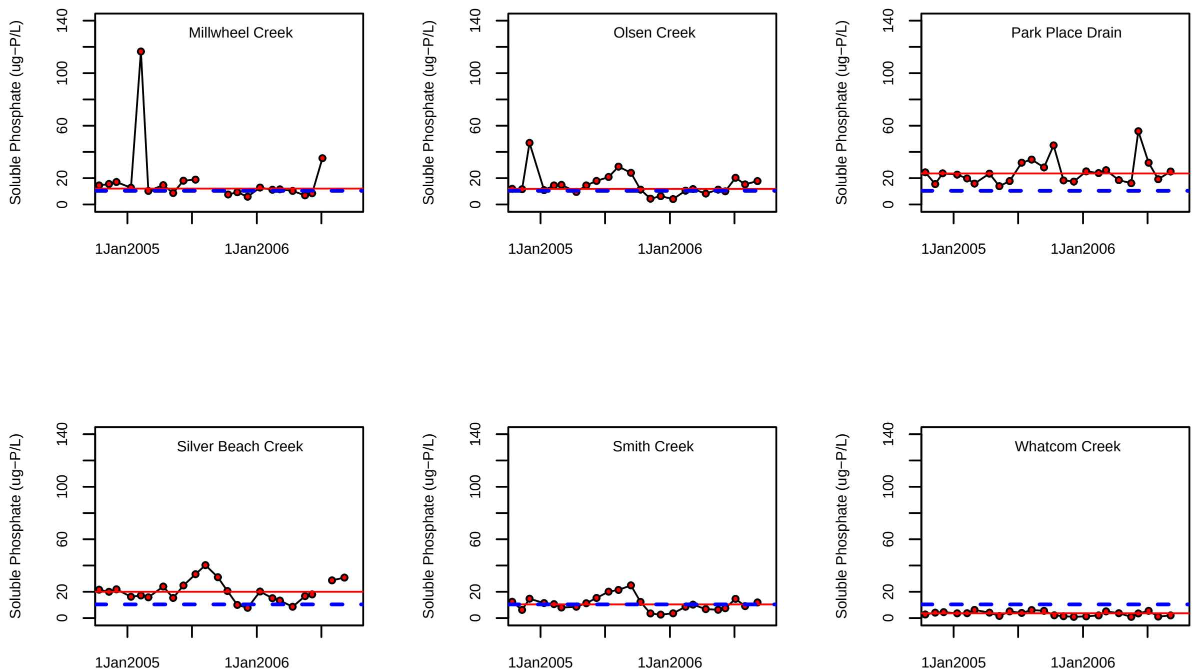


Figure B155: Monthly soluble reactive phosphate data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

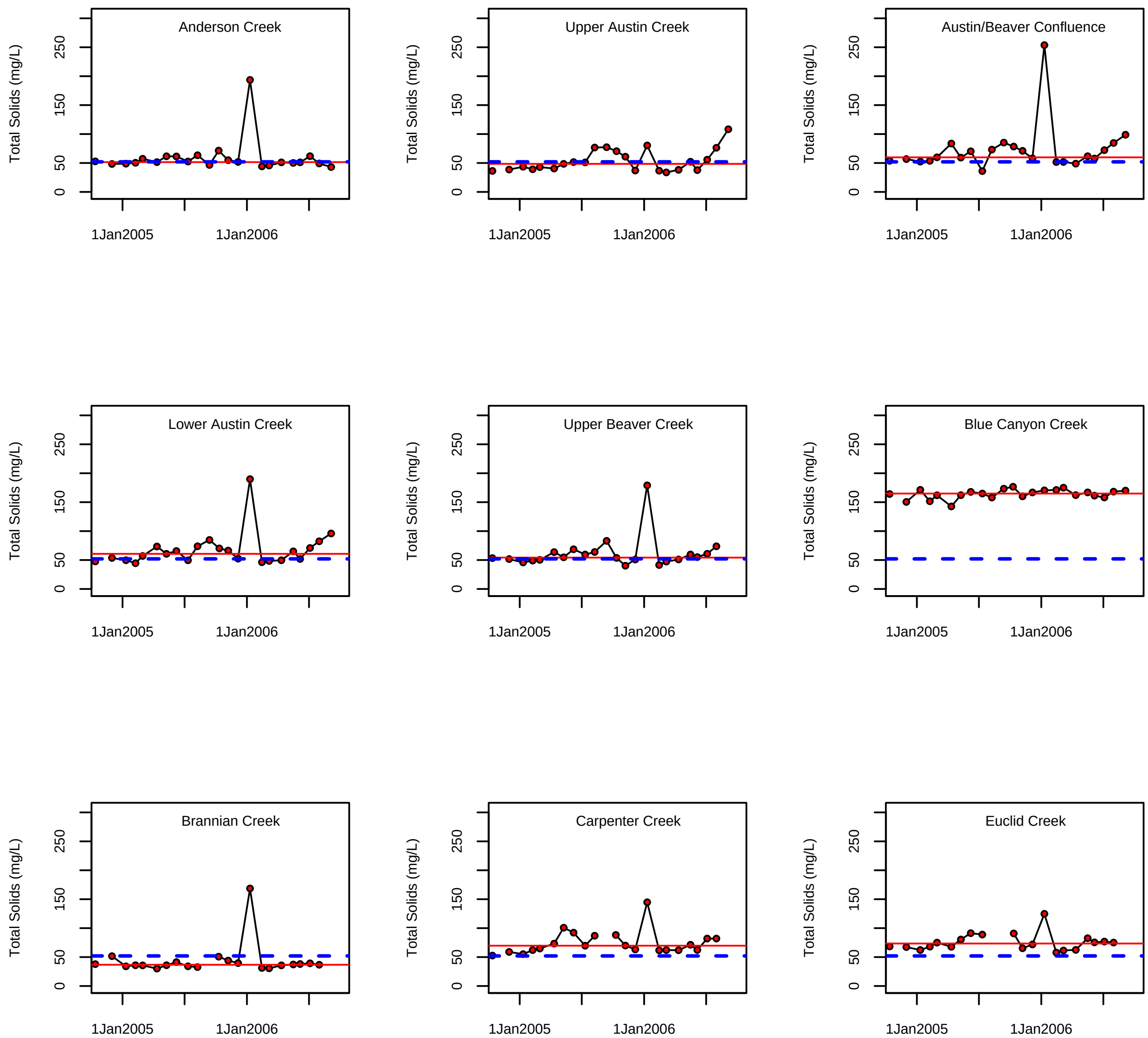


Figure B156: Monthly total solids data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

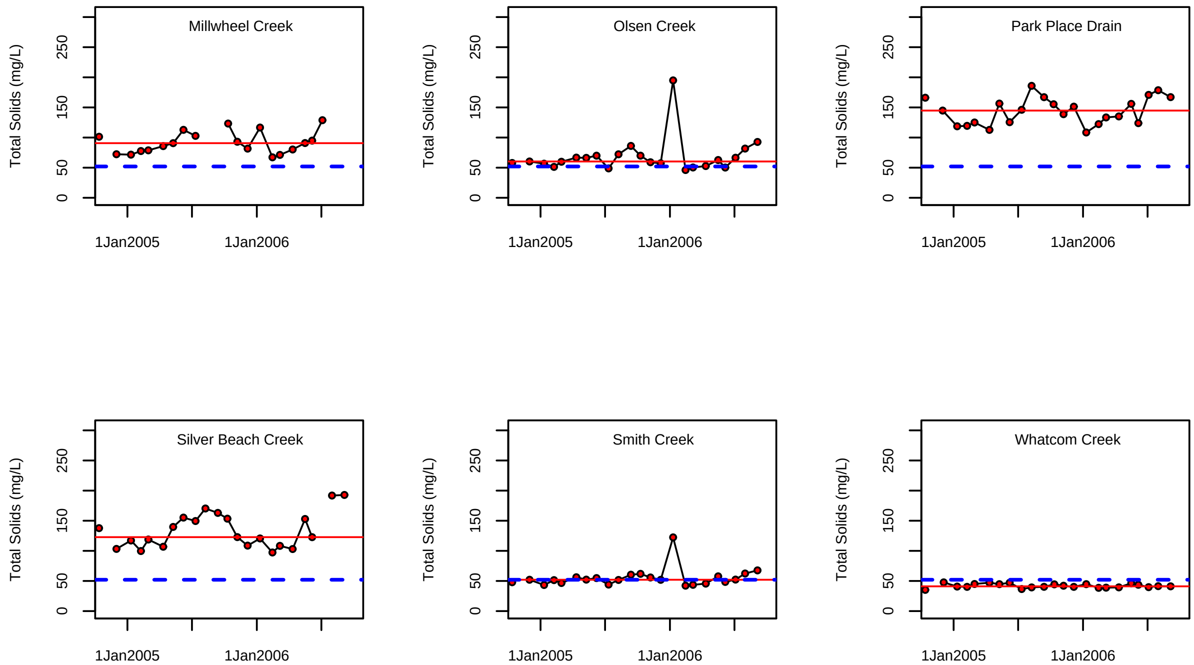


Figure B157: Monthly total solids data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

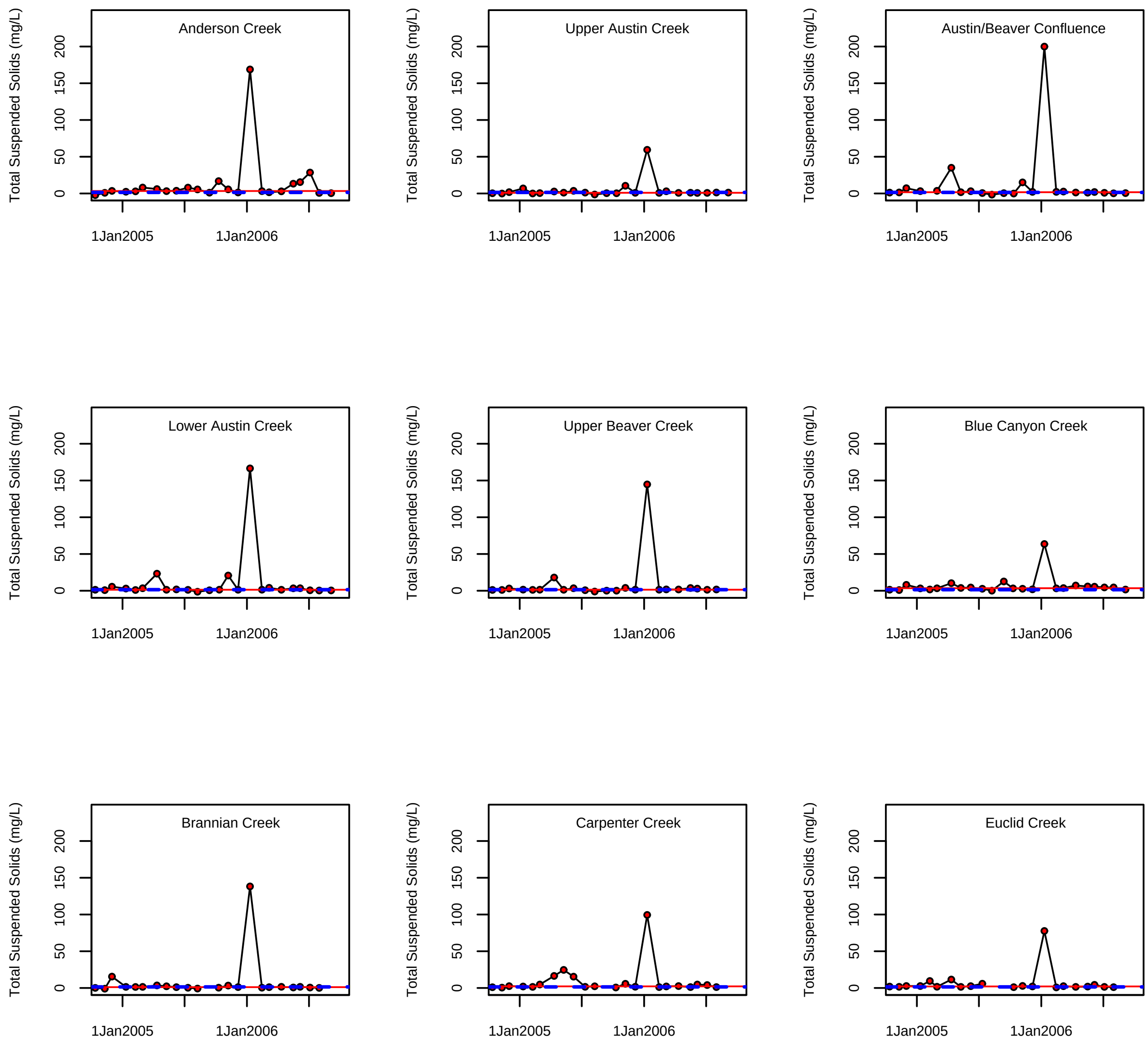


Figure B158: Monthly total suspended solids data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

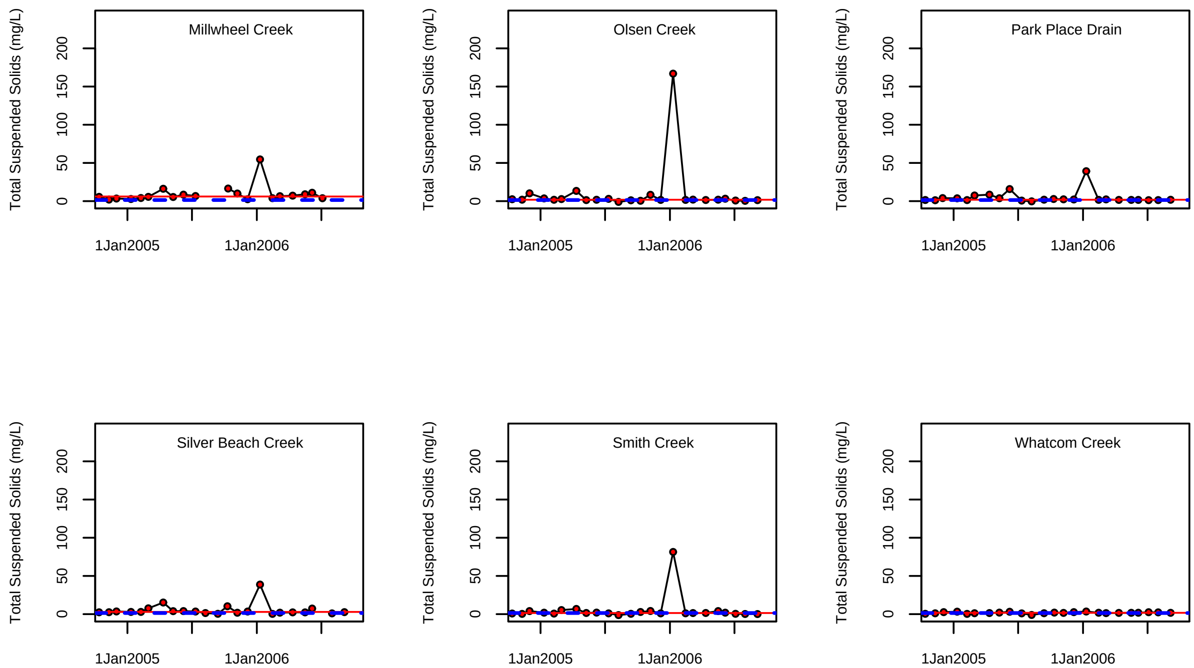


Figure B159: Monthly total suspended solids data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

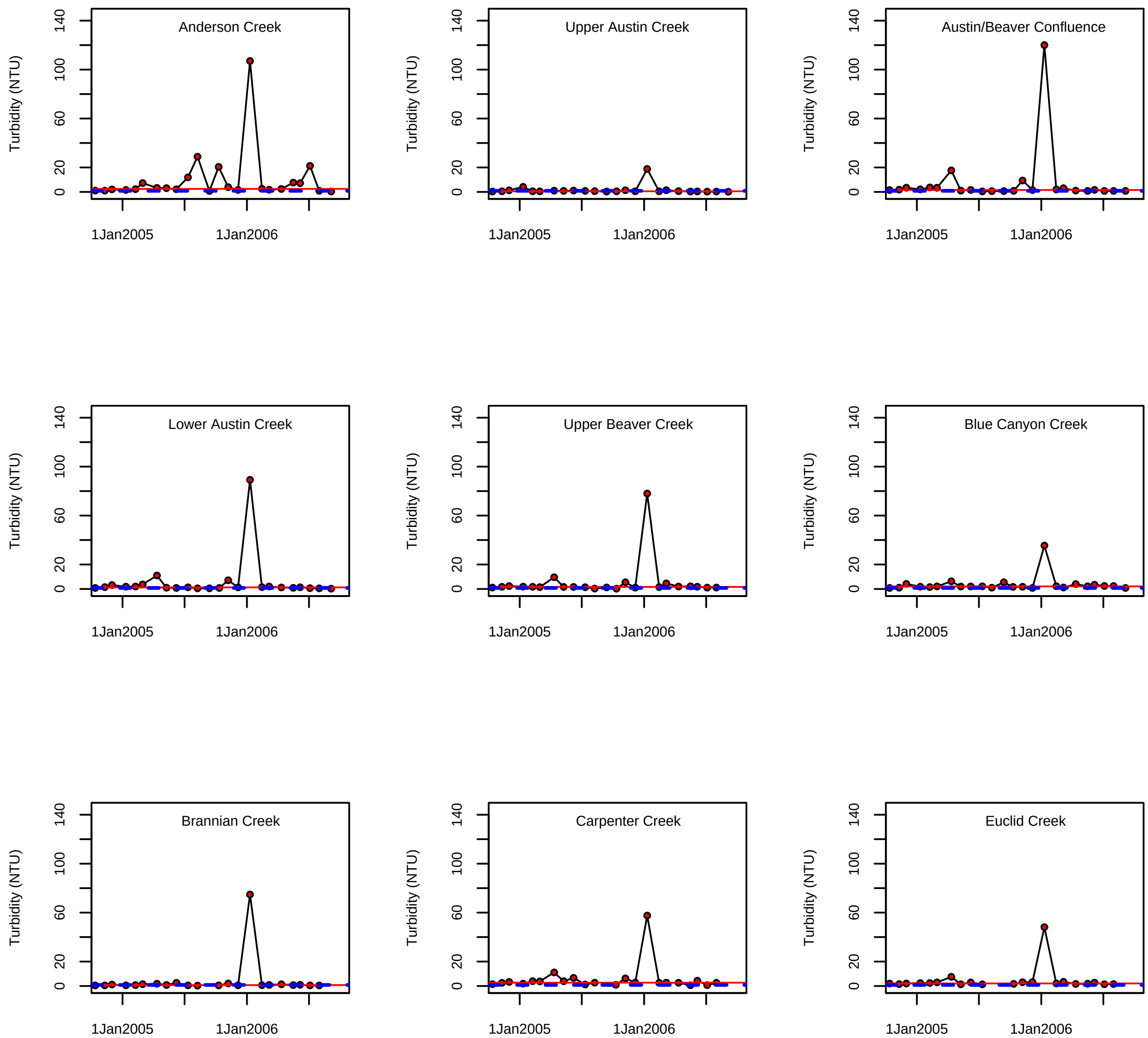


Figure B160: Monthly turbidity data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

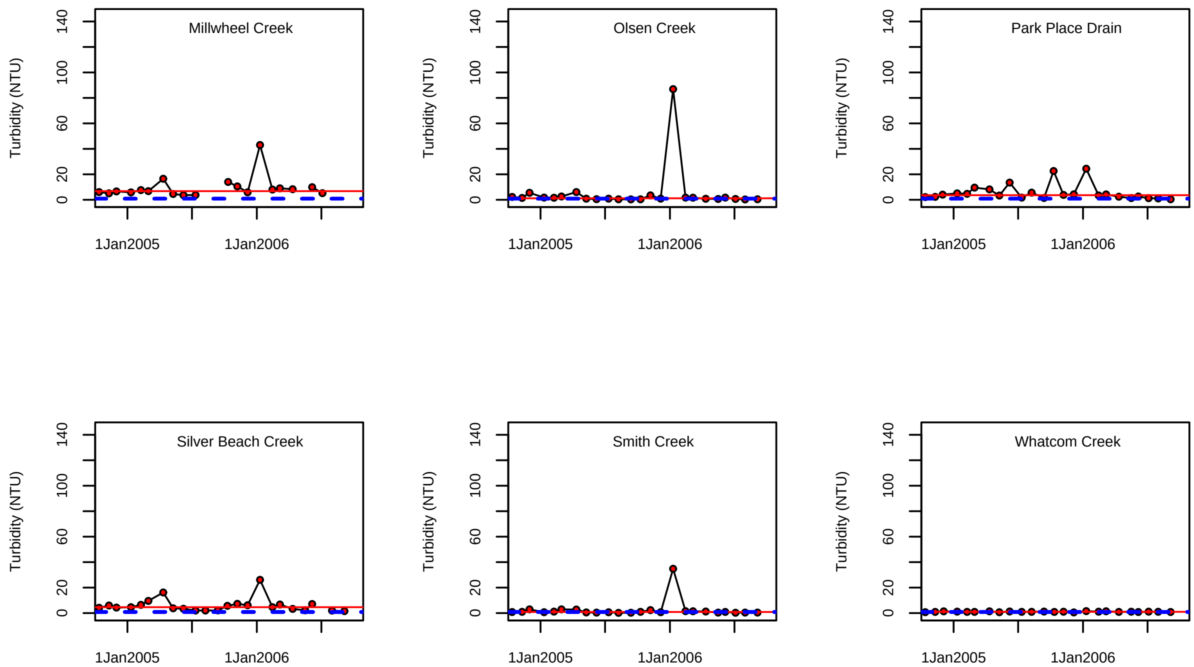


Figure B161: Monthly turbidity data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

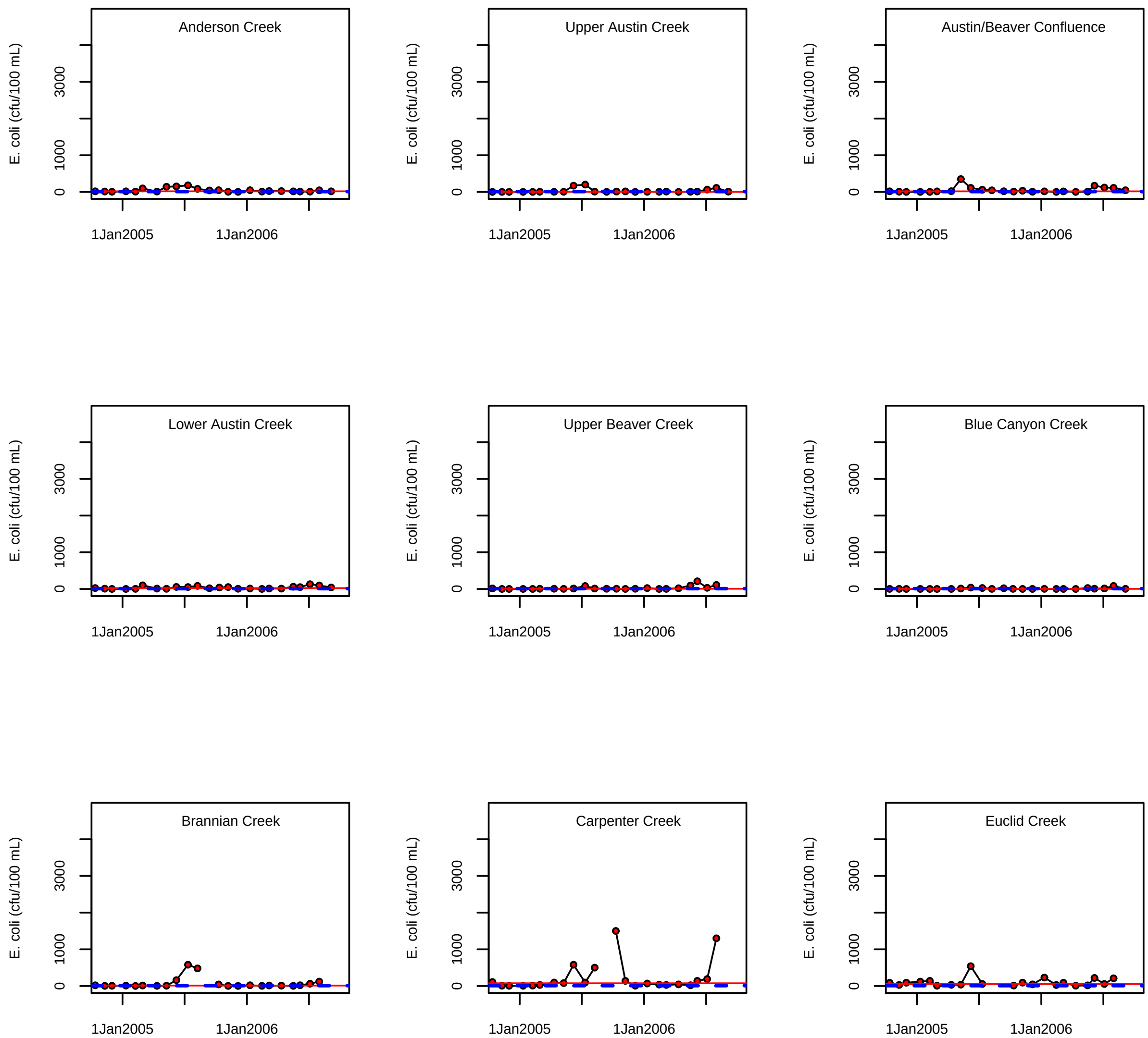


Figure B162: Monthly *E. coli* data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

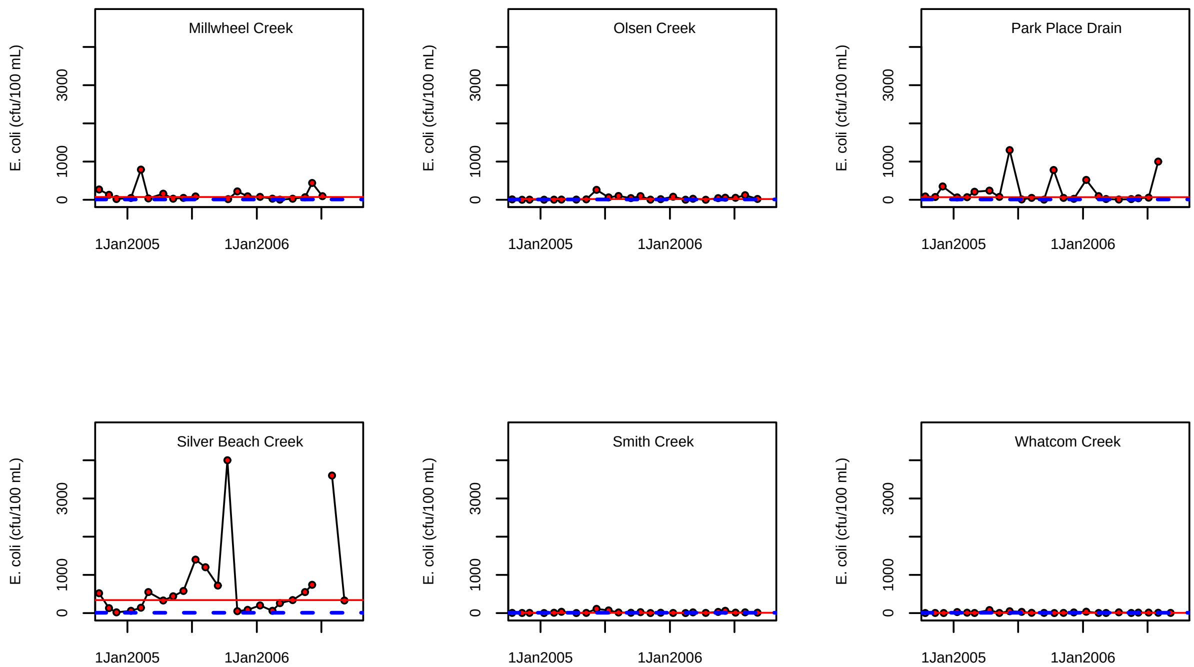


Figure B163: Monthly *E. coli* data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

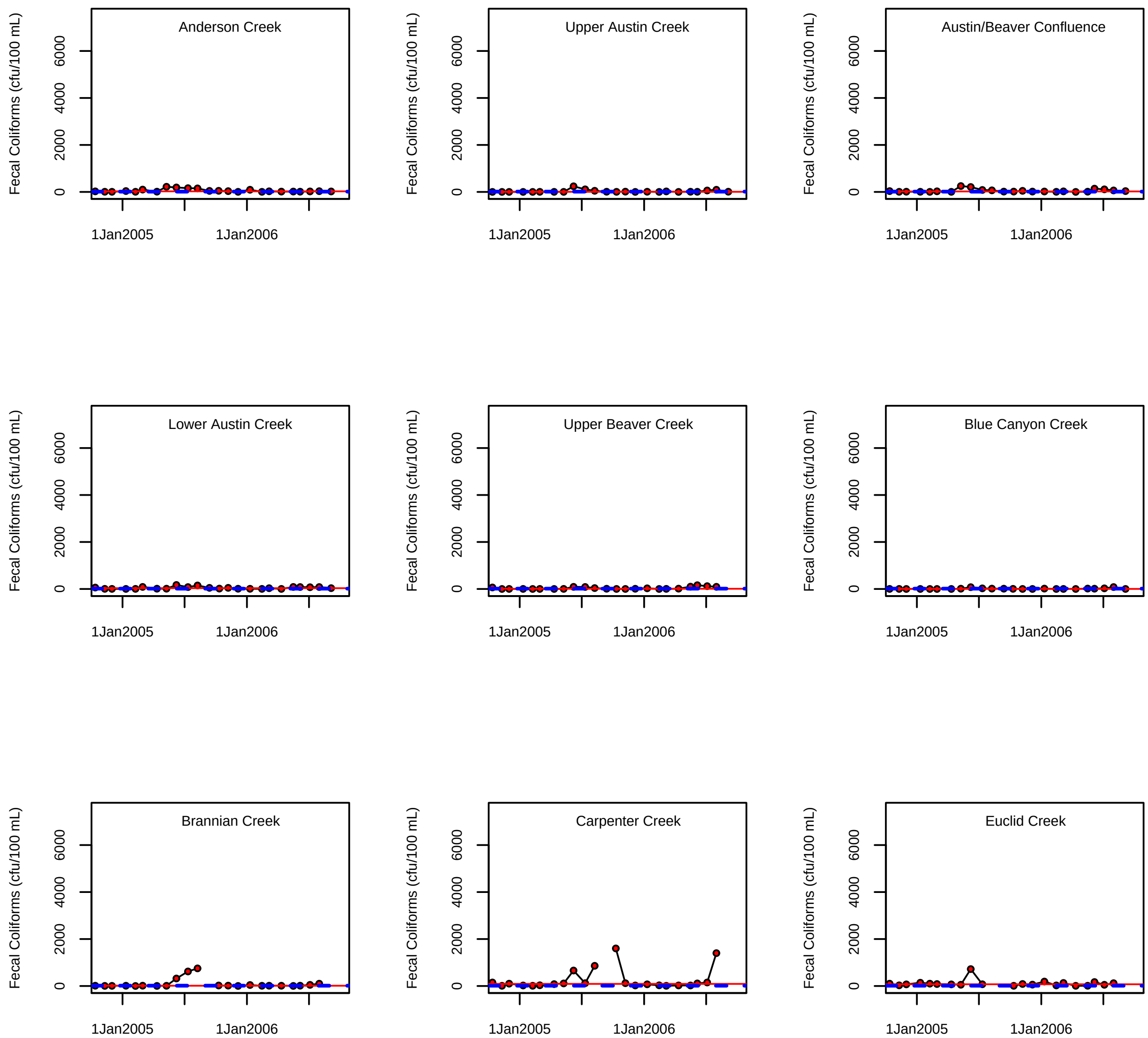


Figure B164: Monthly fecal coliform data for Anderson, Austin, Beaver, Blue Canyon, Brannian, Carpenter, and Euclid Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek.

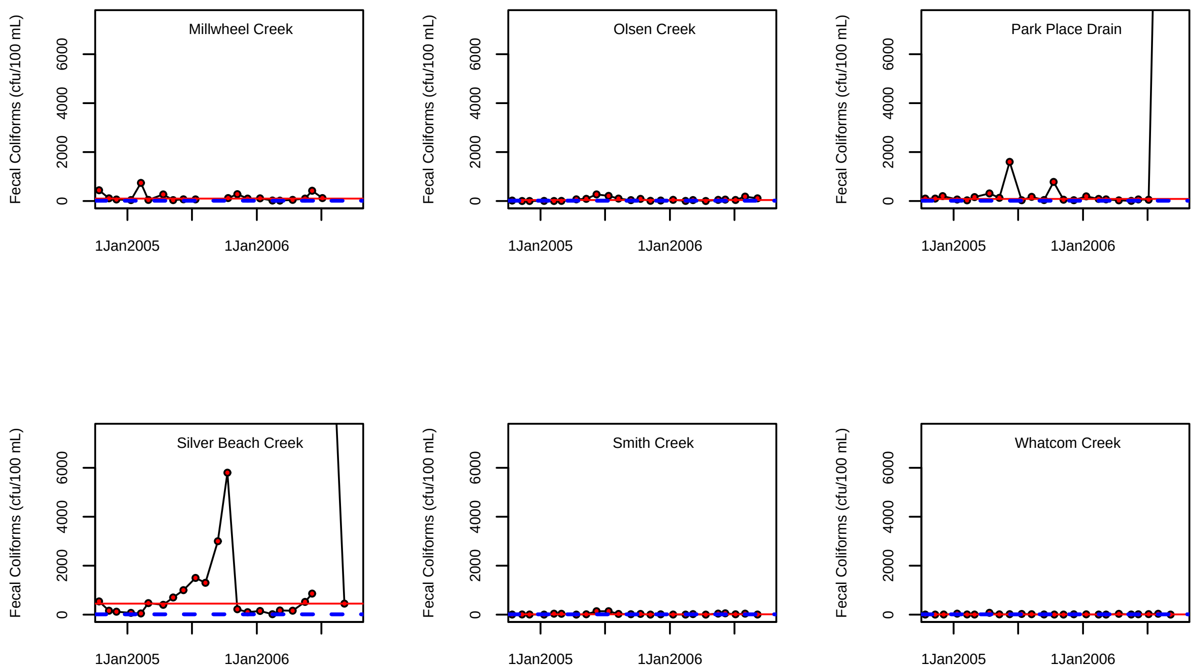


Figure B165: Monthly fecal coliform data for Millwheel, Olsen, Park Place, Silver Beach, Smith, and Whatcom Creeks. Dashed (blue) horizontal reference line shows the median value for Smith Creek; solid (red) horizontal reference line shows the median value for each creek. Several outliers (>7500 cfu/100 mL) were off scale.

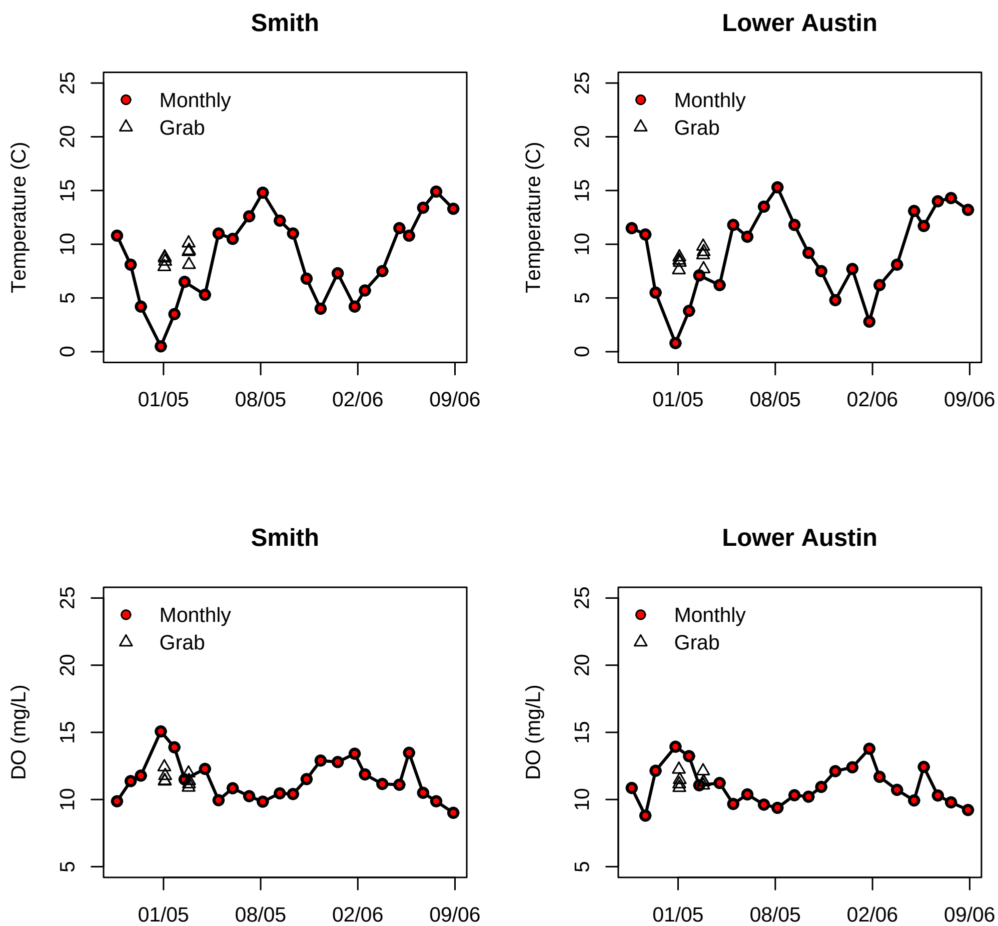


Figure B166: Monthly and 48-hr temperature and dissolved oxygen data from Lower Austin and Smith Creeks (grab samples only).

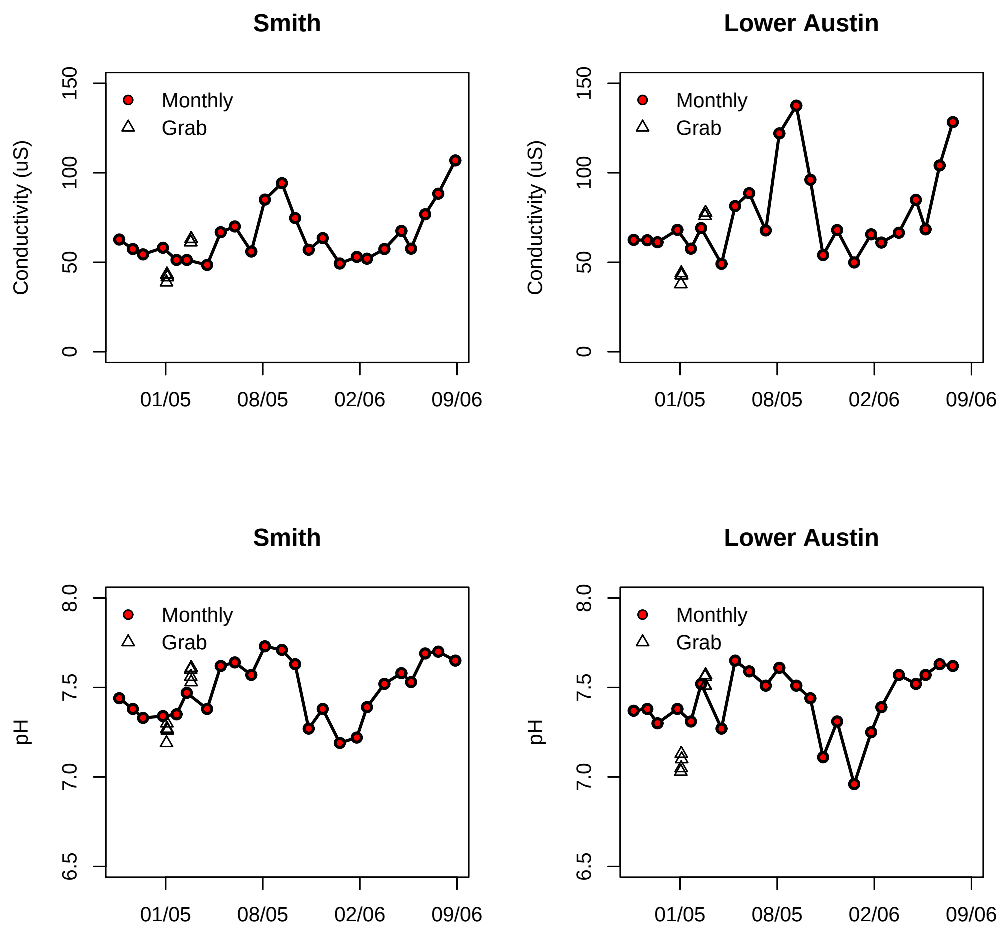


Figure B167: Monthly and 48-hr conductivity and pH data from Lower Austin and Smith Creeks (grab samples only)

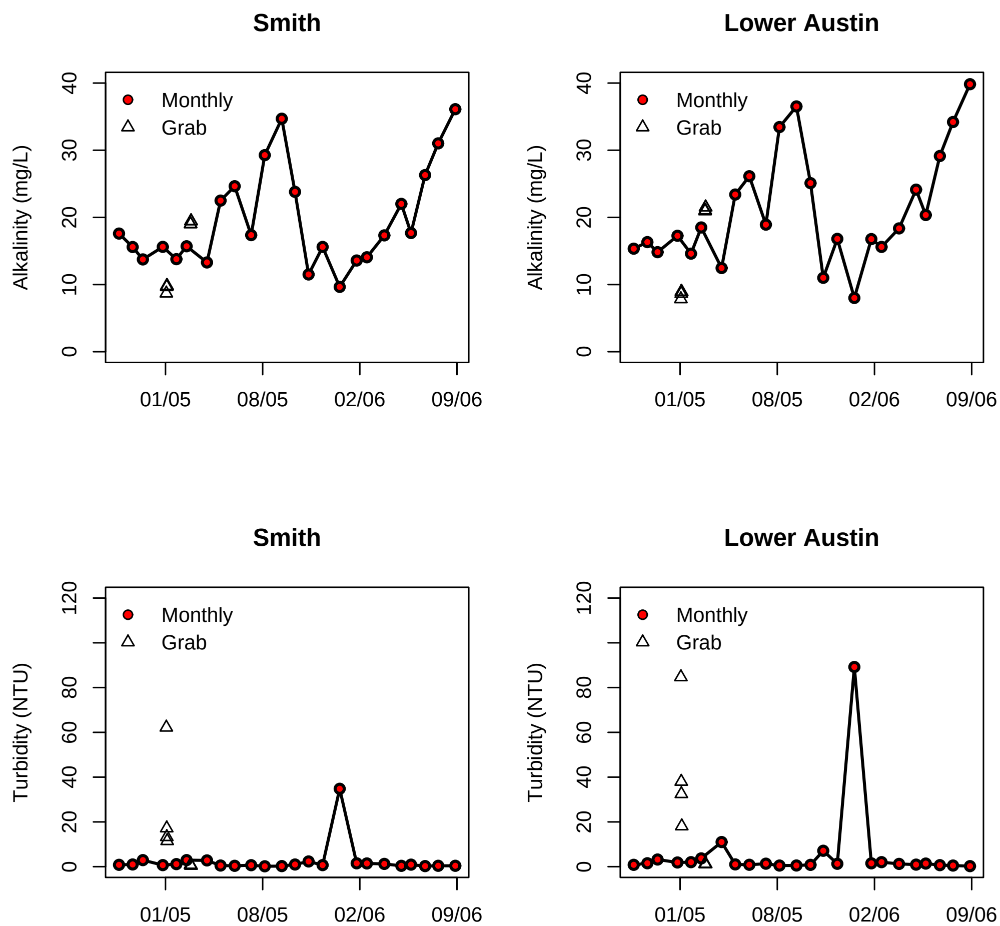


Figure B168: Monthly and 48-hr alkalinity and turbidity data from Lower Austin and Smith Creeks (grab samples only).

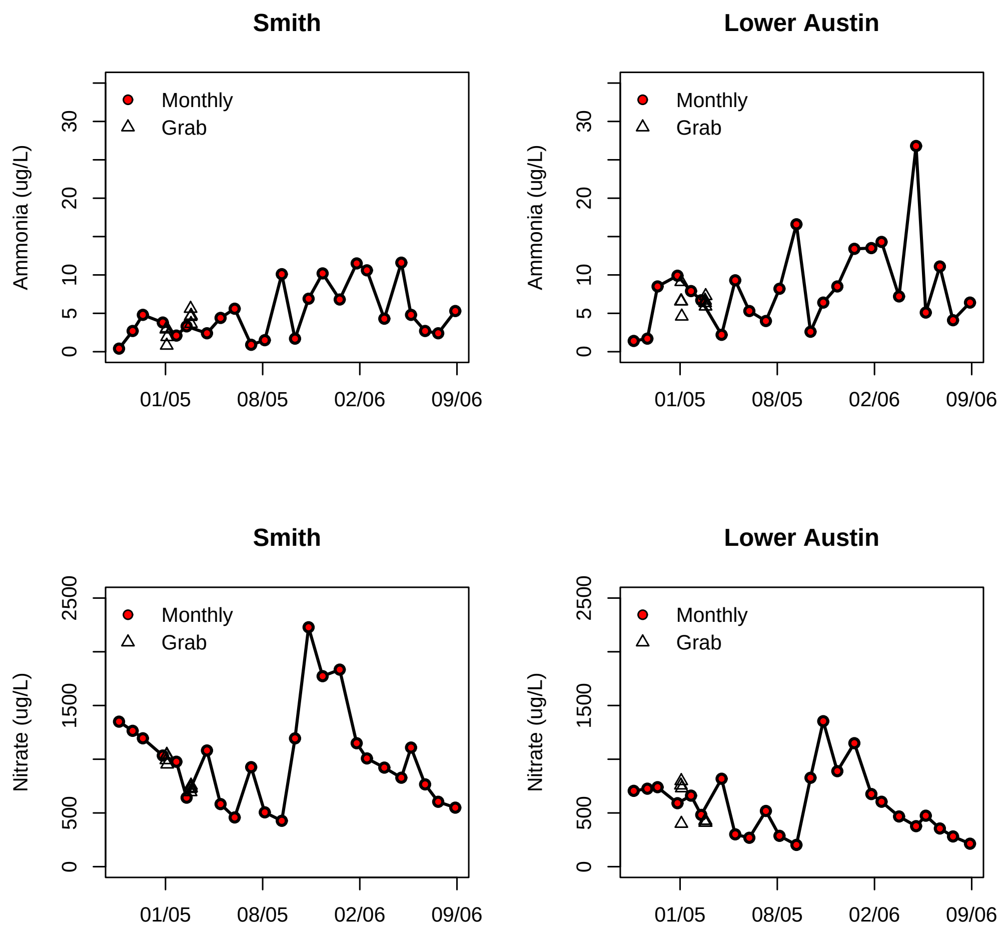


Figure B169: Monthly and 48-hr ammonia and nitrate/nitrite data from Lower Austin and Smith Creeks (grab samples only).

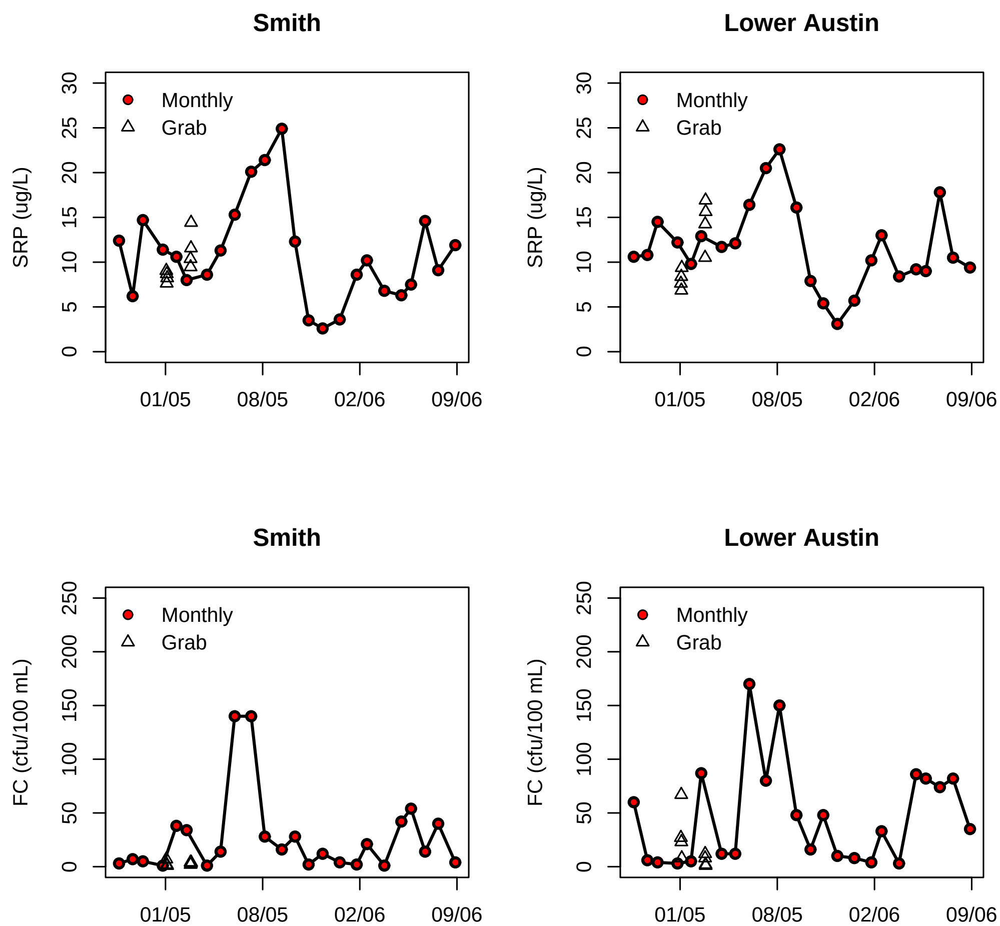


Figure B170: Monthly and 48-hr soluble phosphate and coliform data from Lower Austin and Smith Creeks (grab samples only).

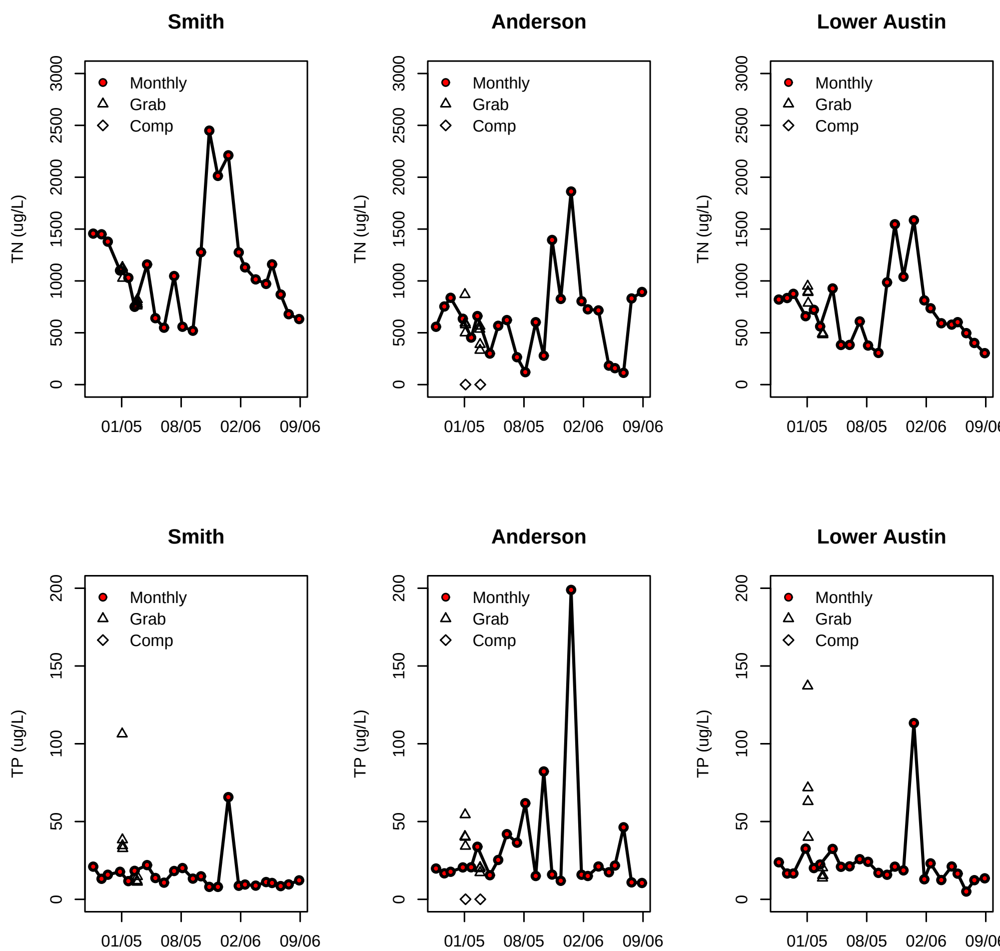


Figure B171: Monthly and 48-hr total nitrogen and total phosphorus data from Anderson, Lower Austin and Smith Creeks. This figure contains revised data as described in the text on page 39.

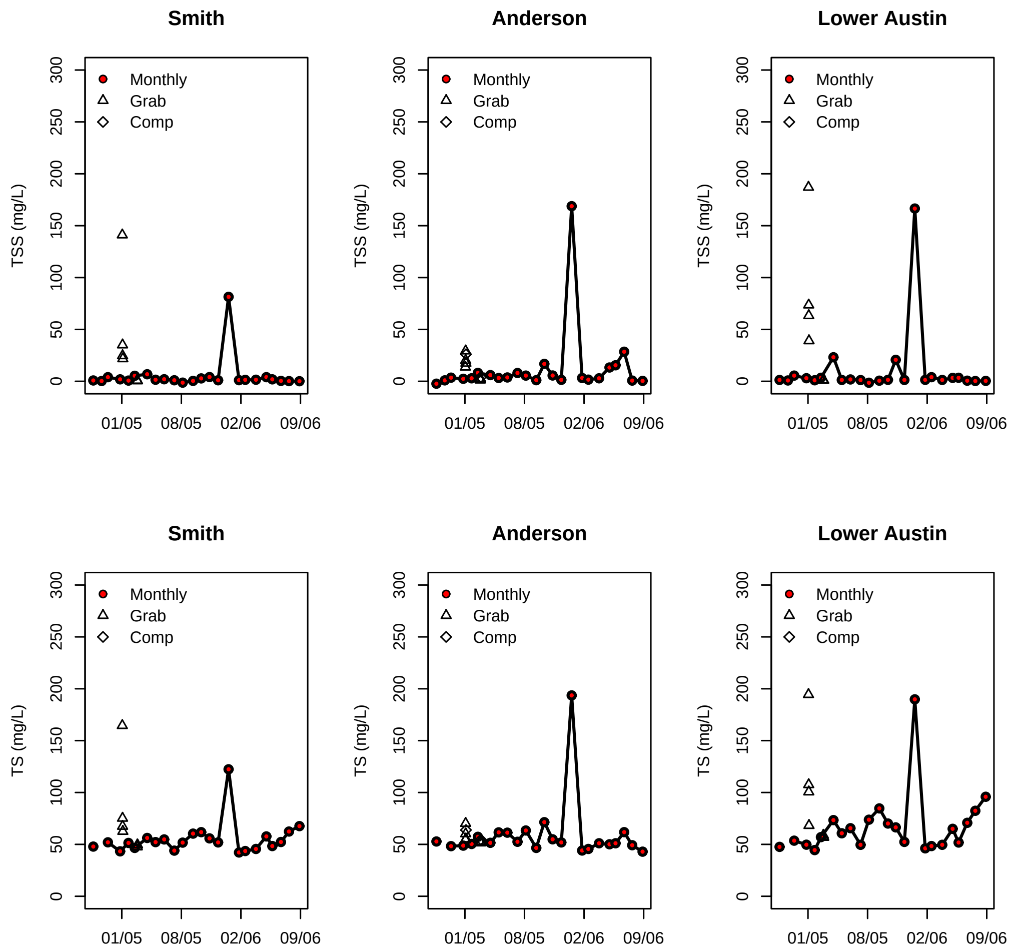


Figure B172: Monthly and 48-hr total suspended solids and total solids data from Anderson, Lower Austin and Smith Creeks.

C Quality Control

C.1 Performance Evaluation Reports

In order to maintain a high degree of accuracy and confidence in the water quality data all personnel associated with this project were trained according to standard operating procedures for the methods listed in Table 1 (page 14). Single-blind quality control tests were conducted as part of the IWS laboratory certification process (Table C1). All results from the single-blind tests were within acceptance limits.

	Reported Value†	True Value†	Acceptance Limits	Test Result
Specific conductivity (μS/cm at 25°C)				
WP–105 (10/17/2005)	841.0	812	731–893	pass
WP–111 (04/14/2006)	587.0	589	530–648	pass
Total alkalinity (mg/L as $CaCO_3$)				
WP–105 (10/17/2005)	75.8	75.4	66.4–83.6	pass
WP–111 (04/14/2006)	72.2	71.2	62.5–79.2	pass
Ammonia nitrogen, manual (mg-N/L)				
WP–105 (10/17/2005)	14.0	13.6	10.1–16.9	pass
WP–111 (04/14/2006)	14.1	13.8	10.3–17.1	pass
Ammonia nitrogen, autoanalysis (mg-N/L)				
WP–105 (10/17/2005)	14.6	13.6	10.1–16.9	pass
WP–111 (04/14/2006)	13.4	13.8	10.3–17.1	pass
Nitrate nitrogen, autoanalysis (mg-N/L)				
WP–105 (10/17/2005)	39.8	38.6	30.1–46.5	pass
WP–111 (04/14/2006)	21.1	20.5	16.0–24.7	pass
Orthophosphate, manual (mg-P/L)				
WP–105 (10/17/2005)	3.01	3.01	2.46–3.59	pass
WP–111 (04/14/2006)	0.97	0.960	0.733–1.20	pass
Orthophosphate, autoanalysis (mg-P/L)				
WP–105 (10/17/2005)	2.97	3.01	2.46–3.59	pass
WP–111 (04/14/2006)	0.922	0.960	0.733–1.20	pass
Total phosphorus, manual (mg-P/L)				
WP–105 (10/17/2005)	4.31	4.34	3.55–5.18	pass
WP–111 (04/14/2006)	9.02	9.26	7.66–10.9	pass
Total phosphorus, autoanalysis (mg-P/L)				
WP–105 (10/17/2005)	4.41	4.34	3.55–5.18	pass
WP–111 (04/14/2006)	9.47	9.26	7.66–10.9	pass
pH				
WP–105 (10/17/2005)	5.29	5.30	5.10–5.50	pass
WP–111 (04/14/2006)	7.18	7.20	7.00–7.40	pass
Non-filterable residue (mg/L)				
WP–105 (10/17/2005)	79.7	84.9	69.6–94.3	pass
WP–111 (04/14/2006)	32.8	35.4	25.9–41.7	pass
Turbidity (NTU)				
WP–105 (10/17/2005)	14.2	15.0	12.8–16.8	pass
WP–111 (04/14/2006)	6.46	6.10	5.07–7.03	pass

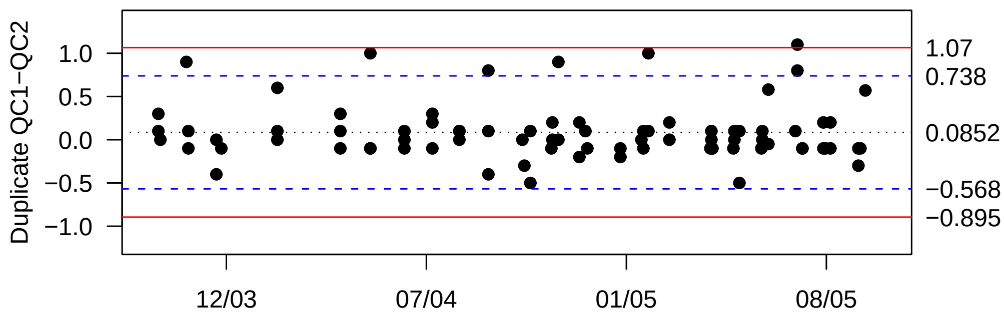
Table C1: Summary of 2005/2006 single-blind quality control results.

C.2 Laboratory Duplicates, Spikes, and Check Standards

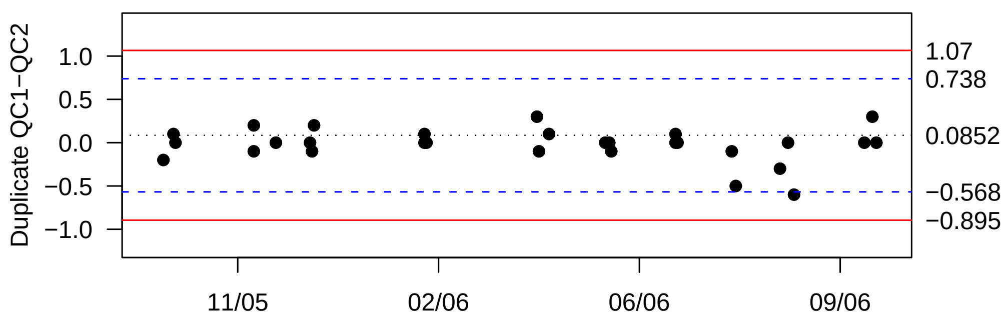
Ten percent of all samples analyzed in the laboratory were duplicated to measure analytical precision. Sample matrix spikes were analyzed during each analytical run to evaluate analyte recovery for the nutrient analyses (ammonia, nitrate/nitrite, total nitrogen, soluble reactive phosphate, and total phosphorus). External check standards were analyzed during each analytical run to evaluate measurement precision and accuracy.[22]

The quality control results for laboratory duplicates, matrix spikes, and check standards are plotted in control charge. 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 2005 (upper examples in Figures C1–C21, pages 297–317), and used to evaluate data from October 2005 through September 2006 (lower examples in Figures C1–C21).

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

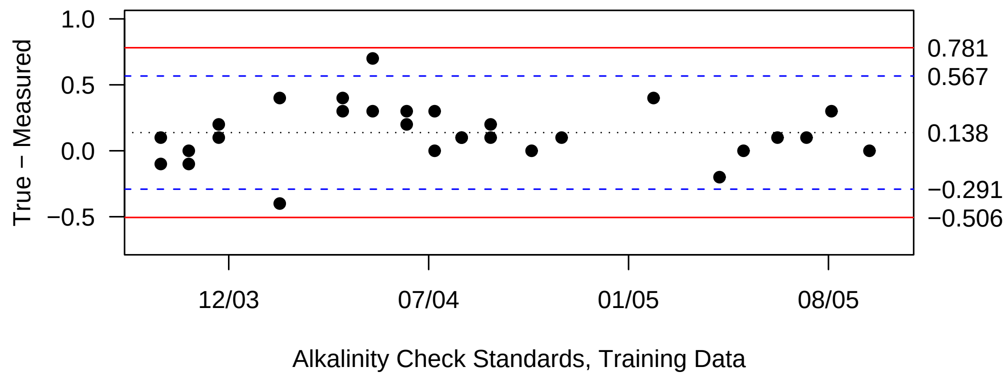


Alkalinity Laboratory Duplicates, Training Data



Alkalinity Laboratory Duplicates, Test Data

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



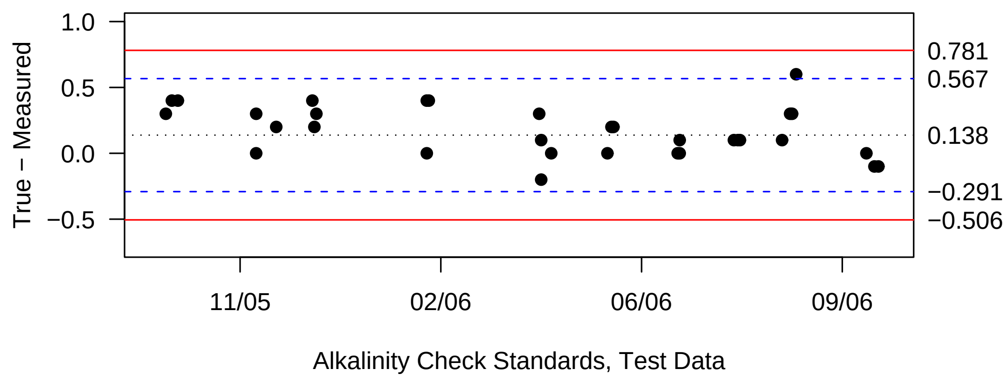
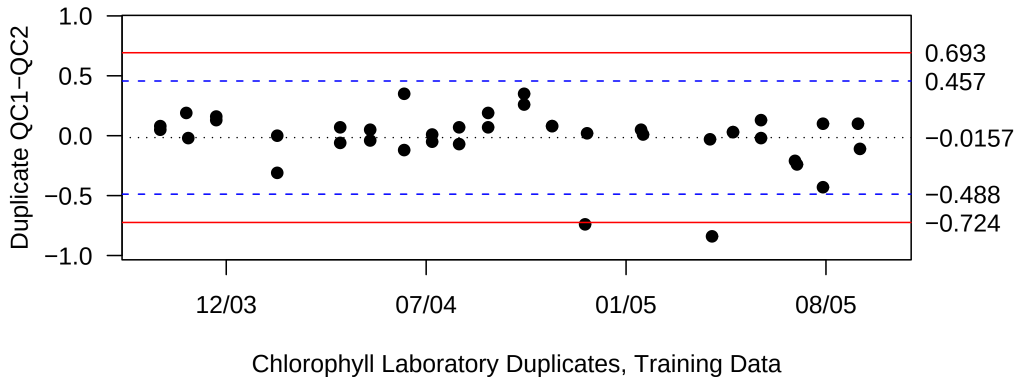


Figure C2: Alkalinity check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



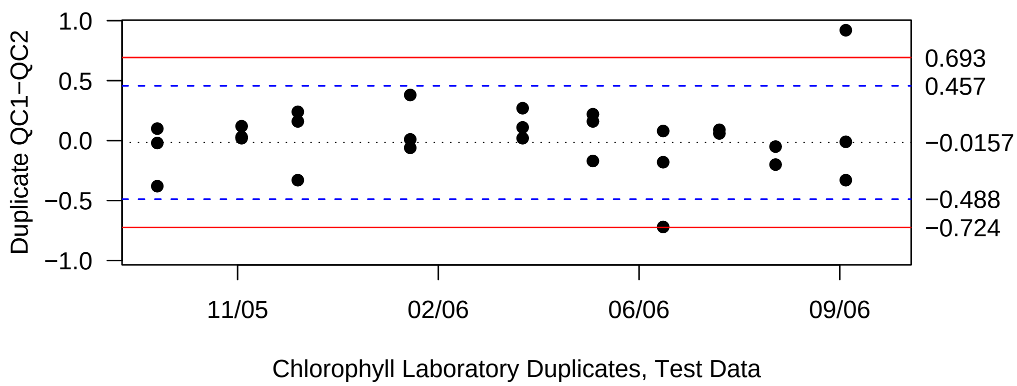
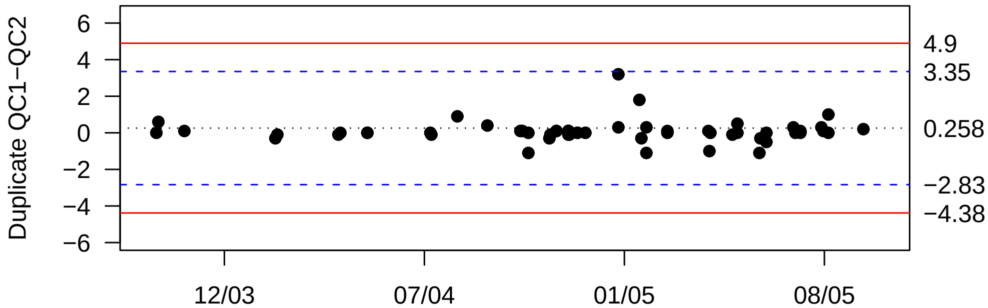
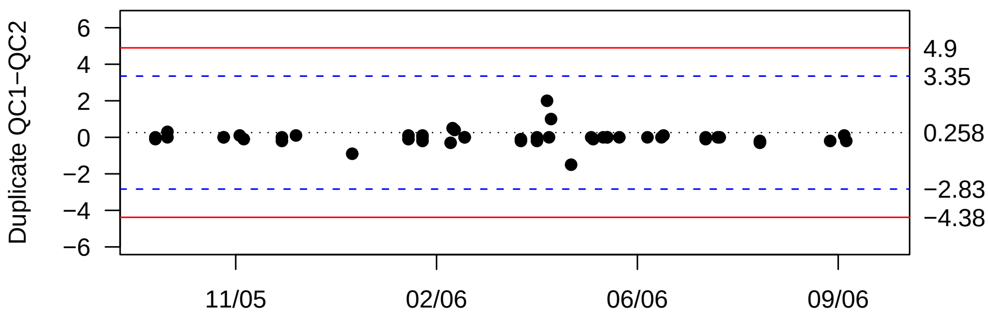


Figure C3: Chlorophyll laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

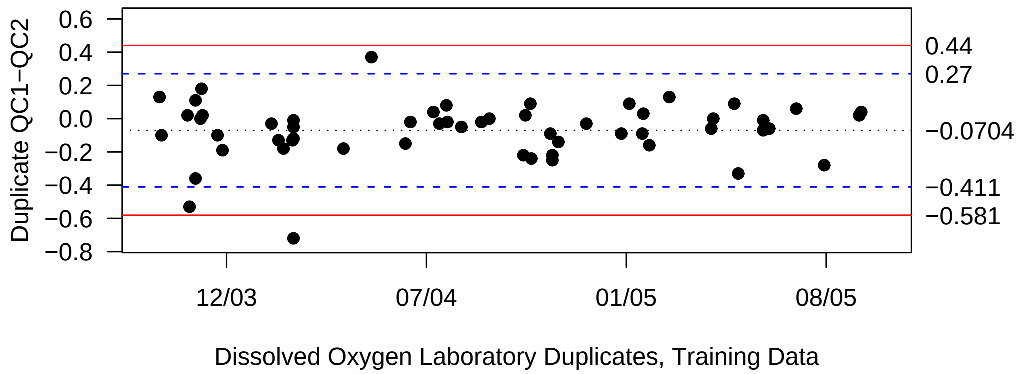


Conductivity Laboratory Duplicates, Training Data



Conductivity Laboratory Duplicates, Test Data

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



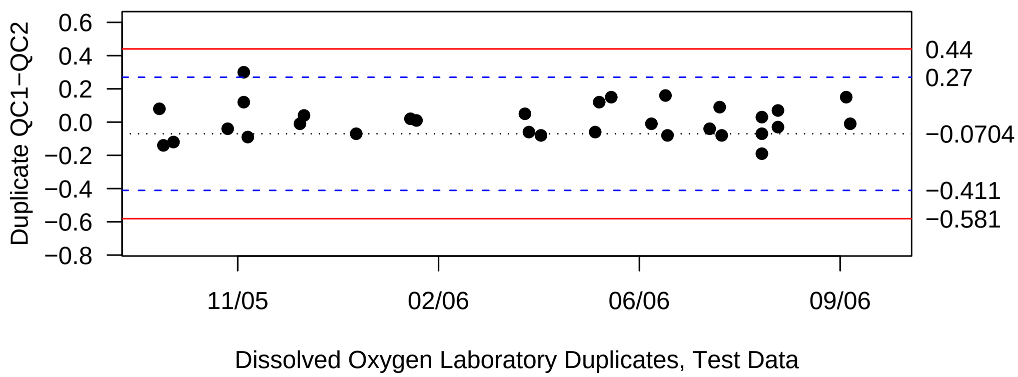
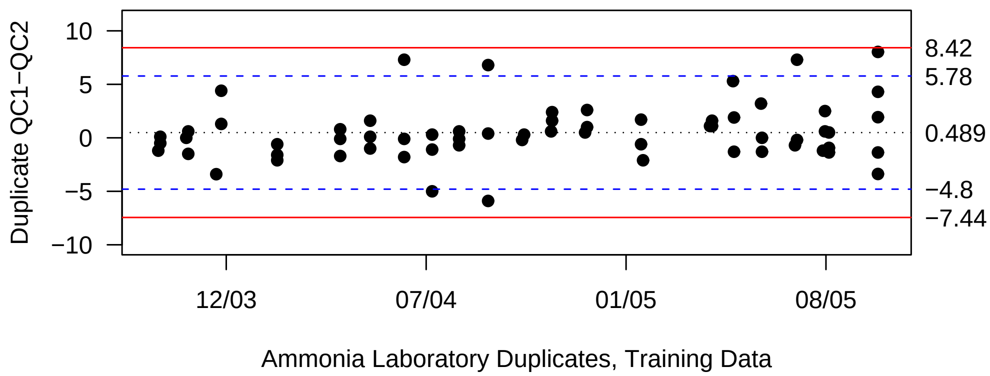


Figure C5: Dissolved oxygen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



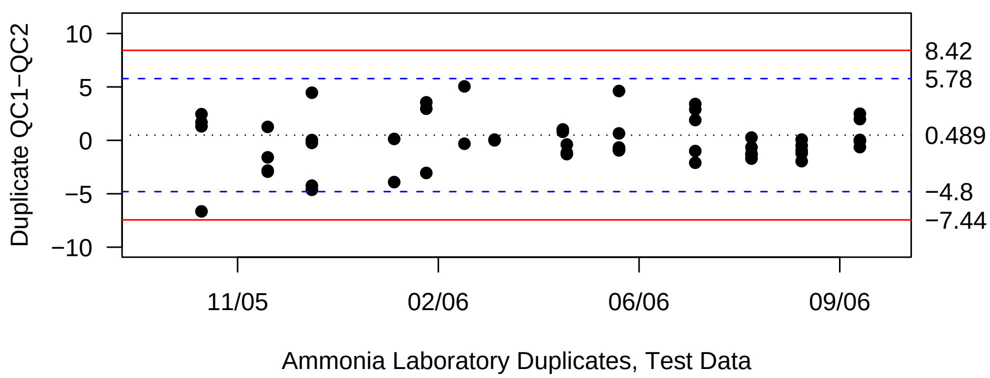
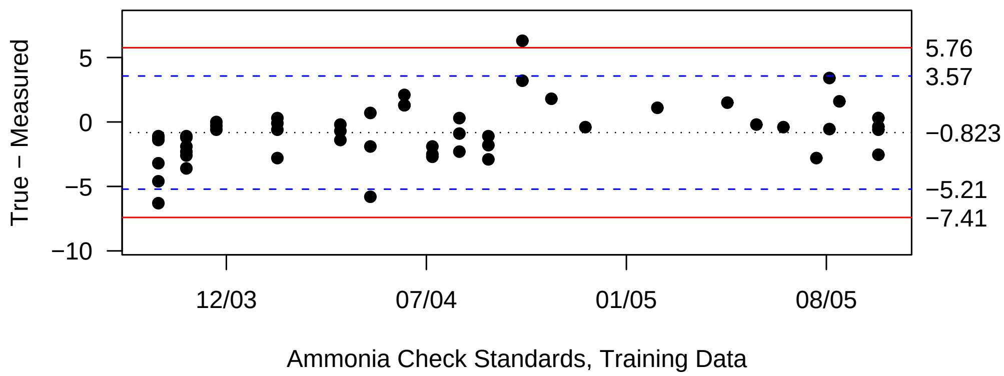


Figure C6: Ammonia laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



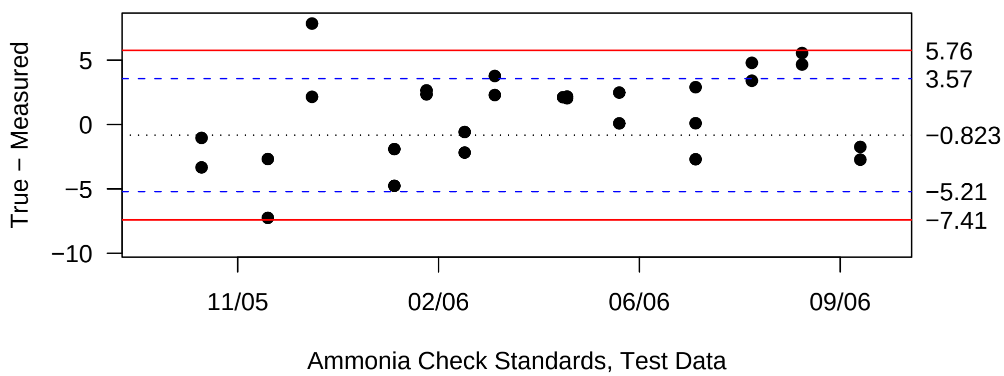
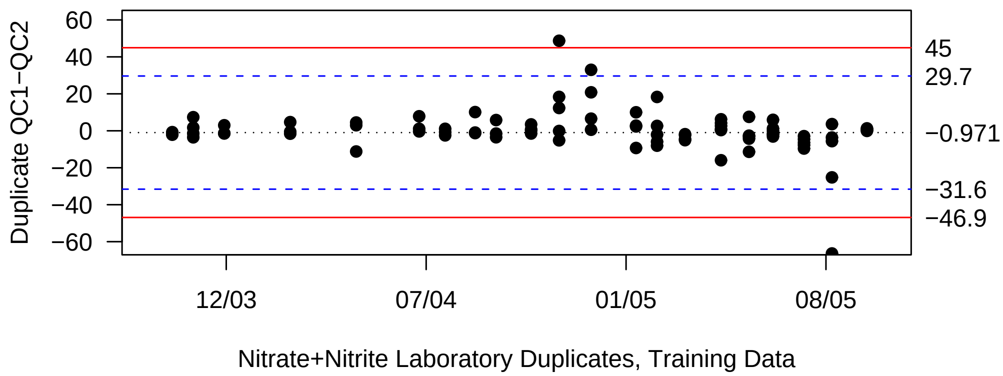


Figure C7: Ammonia check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



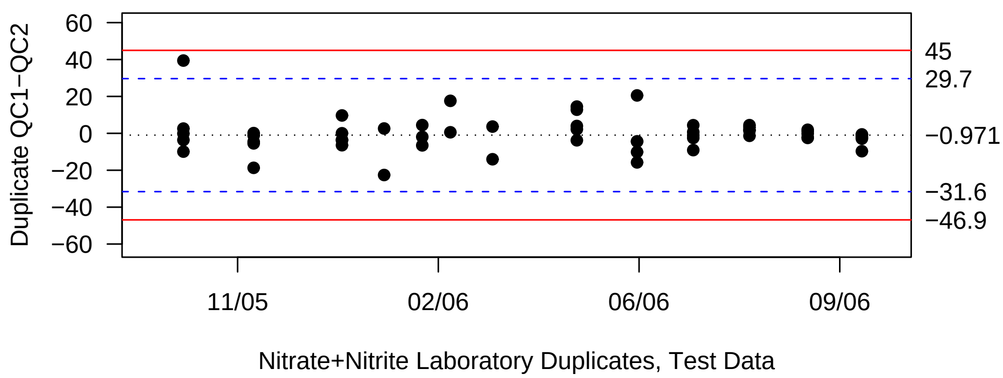
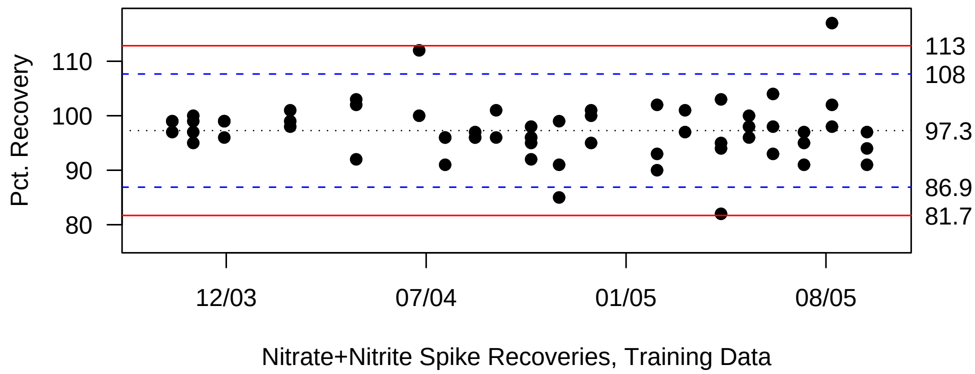


Figure C8: Nitrate/nitrite laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate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



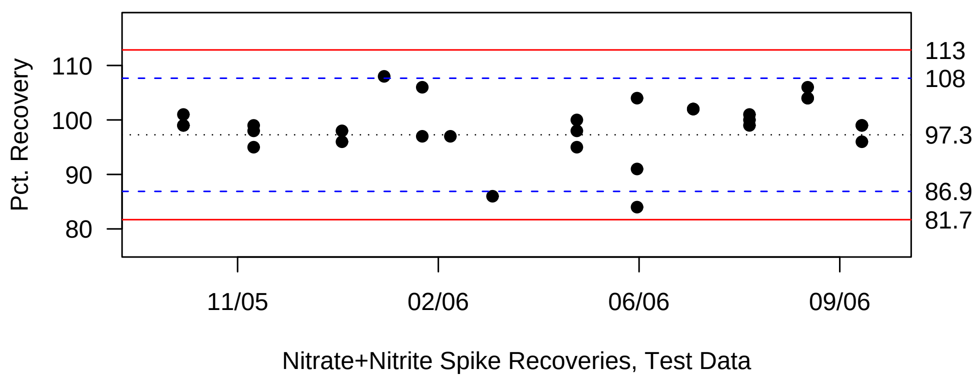


Figure C9: Nitrate/nitrite matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

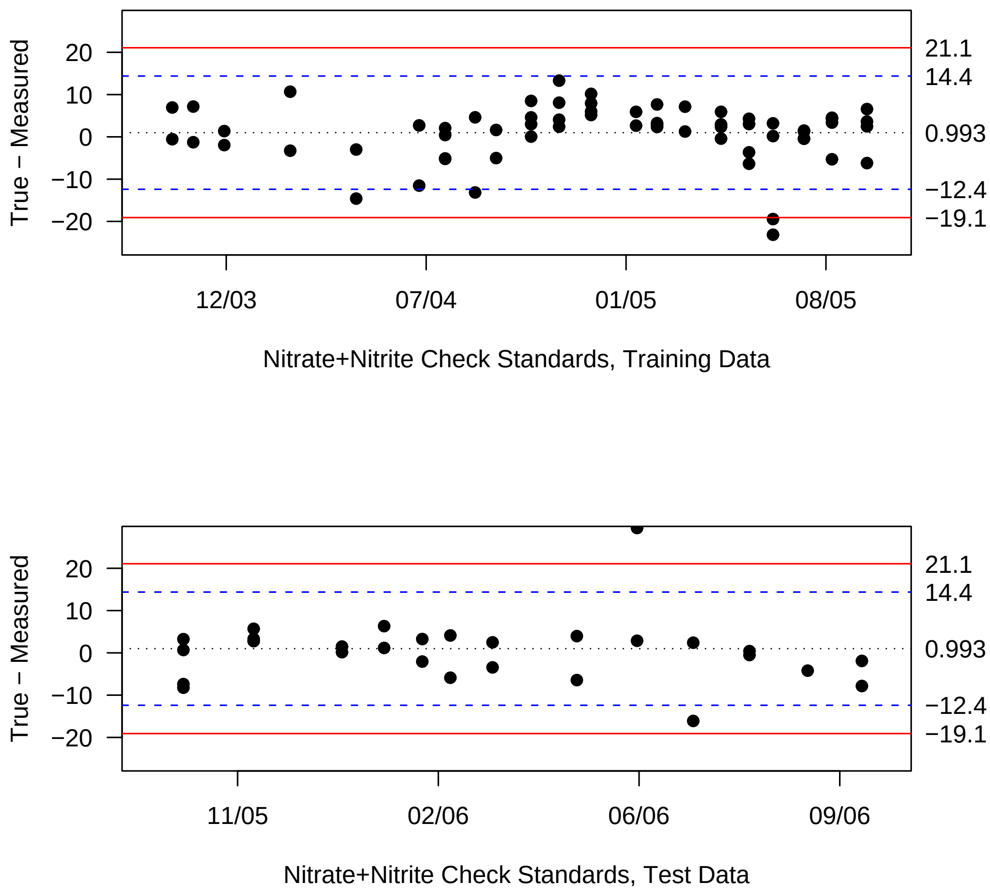
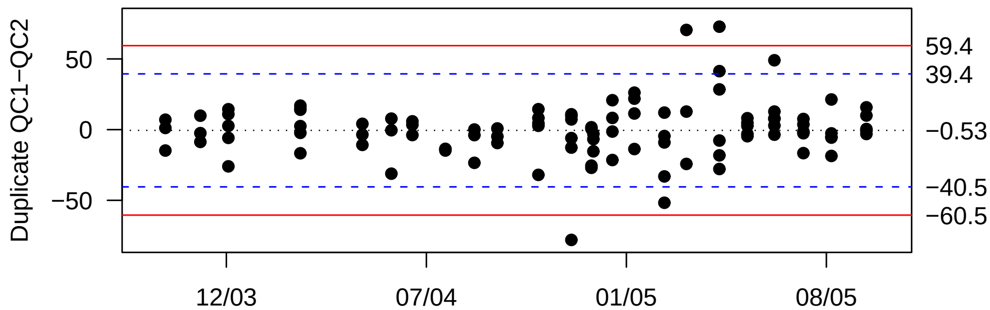
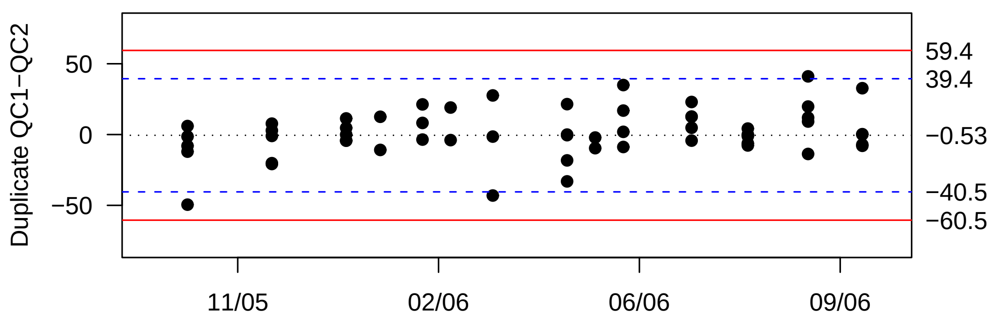


Figure C10: Nitrate/nitrite check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

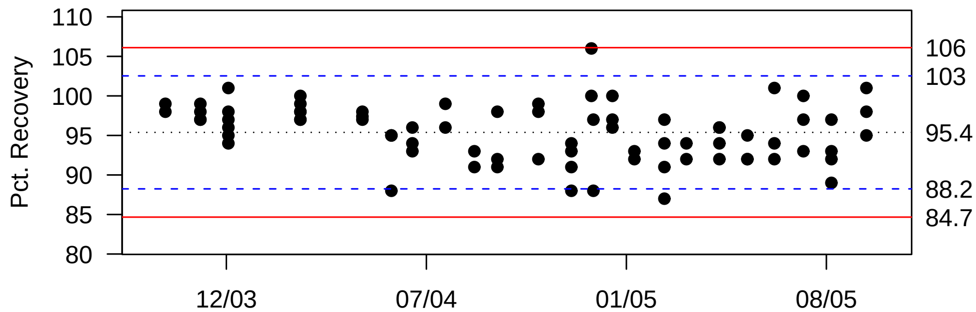


Total Persulfate Nitrogen Laboratory Duplicates, Training Data

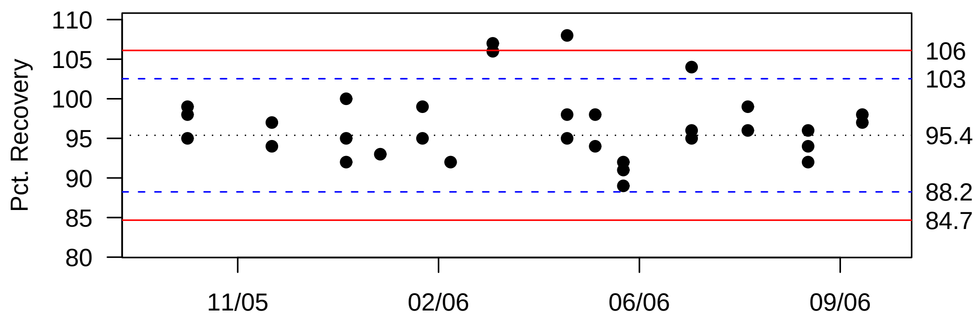


Total Persulfate Nitrogen Laboratory Duplicates, Test Data

Figure C11: Total nitrogen laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

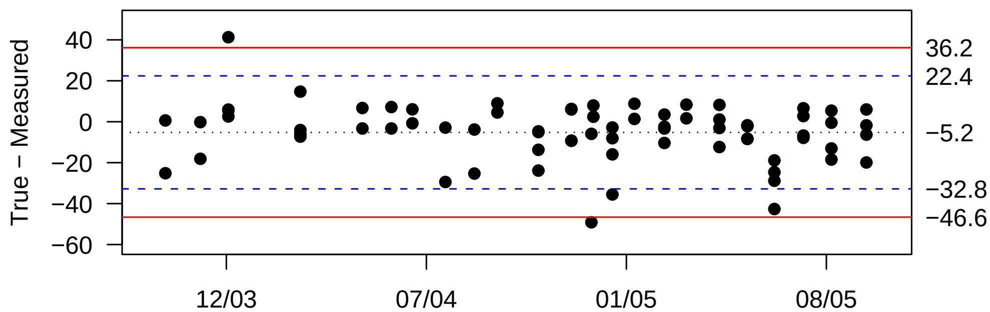


Total Persulfate Nitrogen Spike Recoveries, Training Data

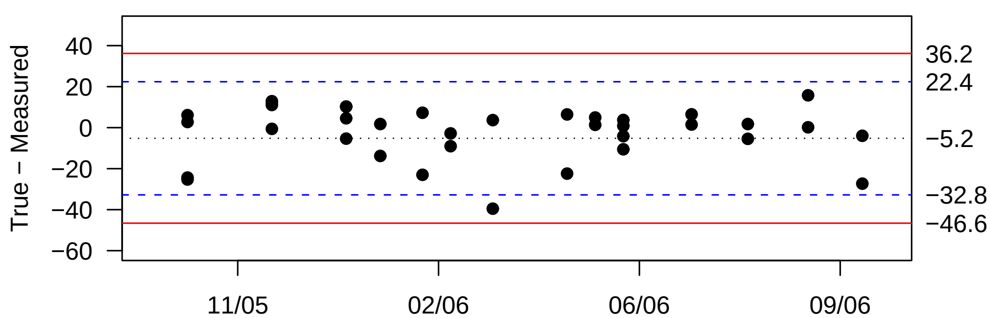


Total Persulfate Nitrogen Spike Recoveries, Test Data

Figure C12: Total nitrogen matrix spikes 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 preceeding two years of lab duplicate data.

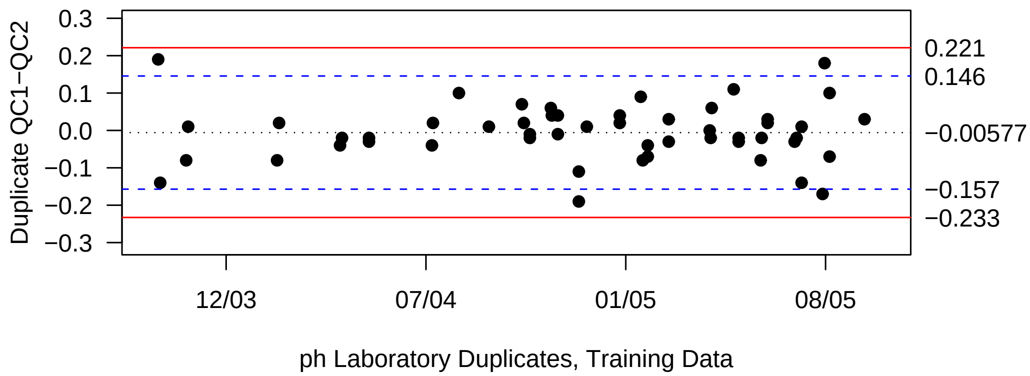


Total Persulfate Nitrogen Check Standards, Training Data



Total Persulfate Nitrogen Check Standards, Test Data

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



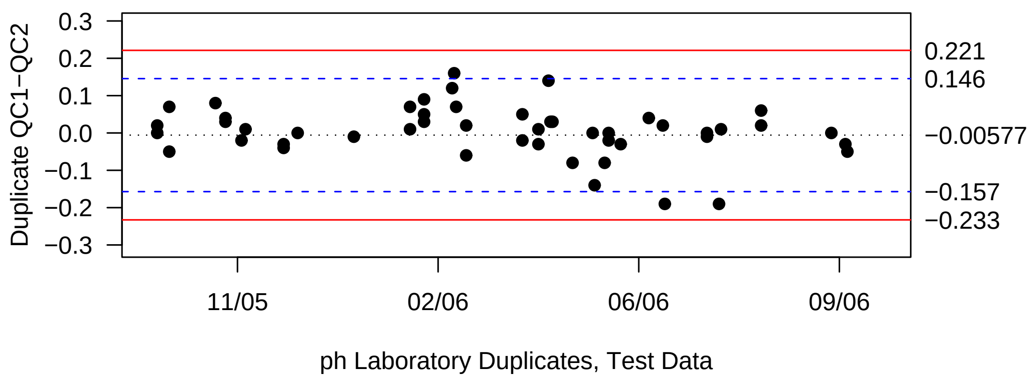
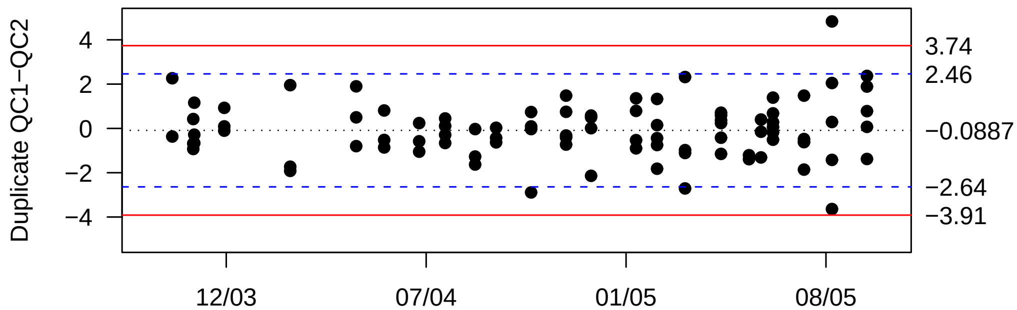
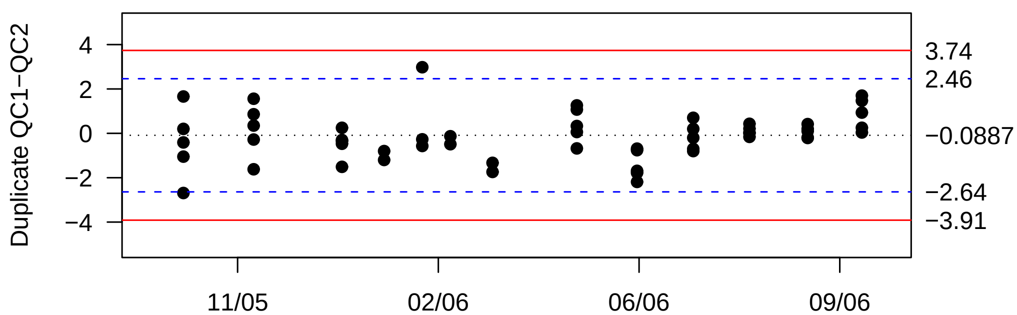


Figure C14: Laboratory pH duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

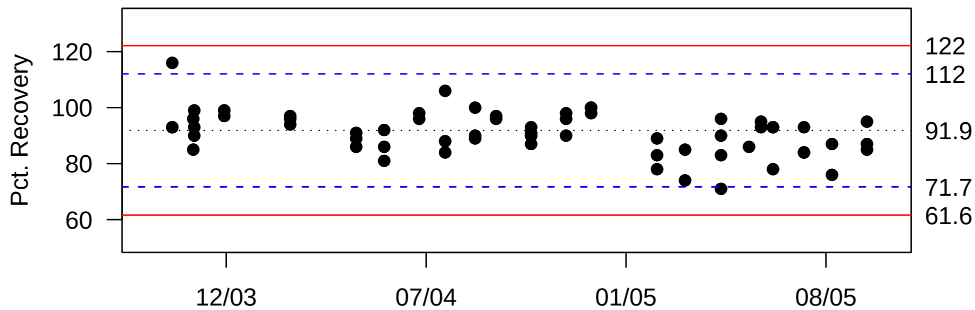


Soluble Phosphate Laboratory Duplicates, Training Data

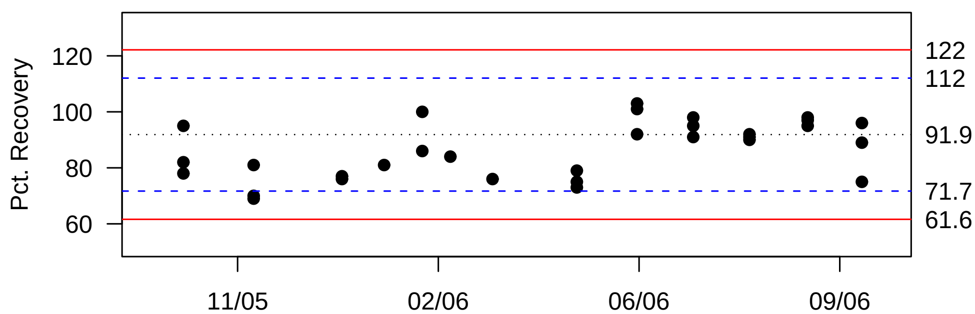


Soluble Phosphate Laboratory Duplicates, Test Data

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

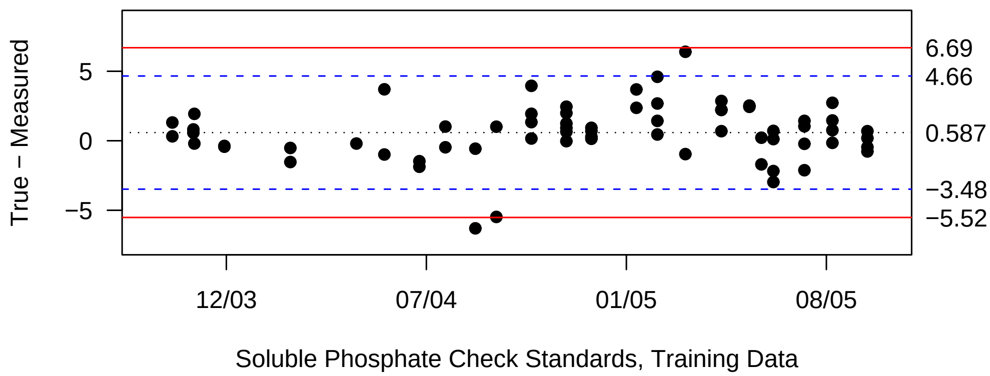


Soluble Phosphate Spike Recoveries, Training Data



Soluble Phosphate Spike Recoveries, Test Data

Figure C16: Soluble reactive phosphate matrix spikes 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 preceeding two years of lab duplicate data.



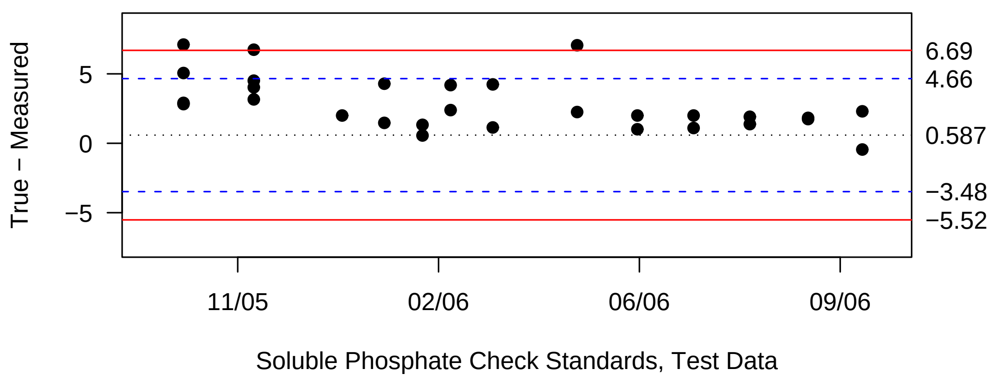
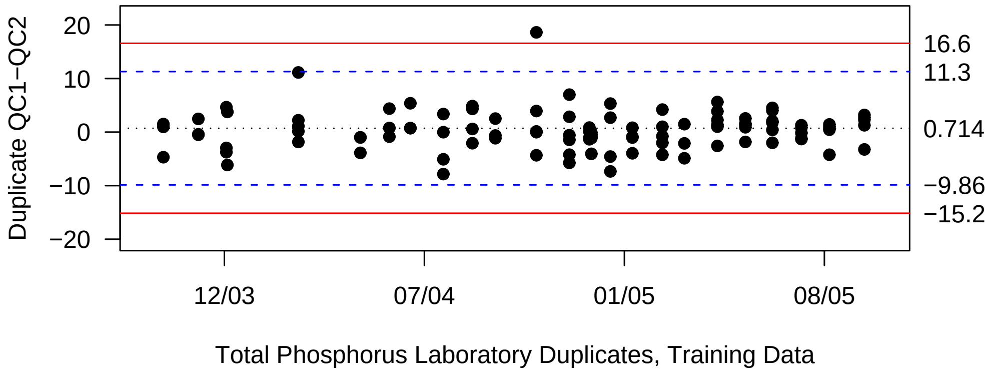


Figure C17: Soluble reactive phosphate check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



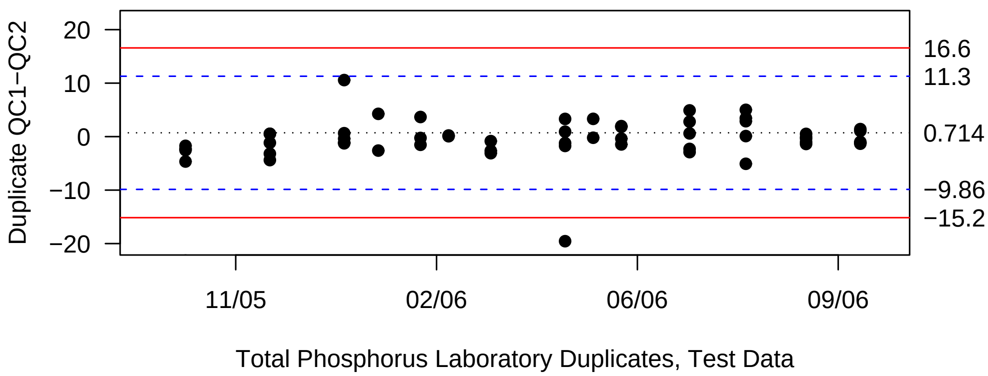
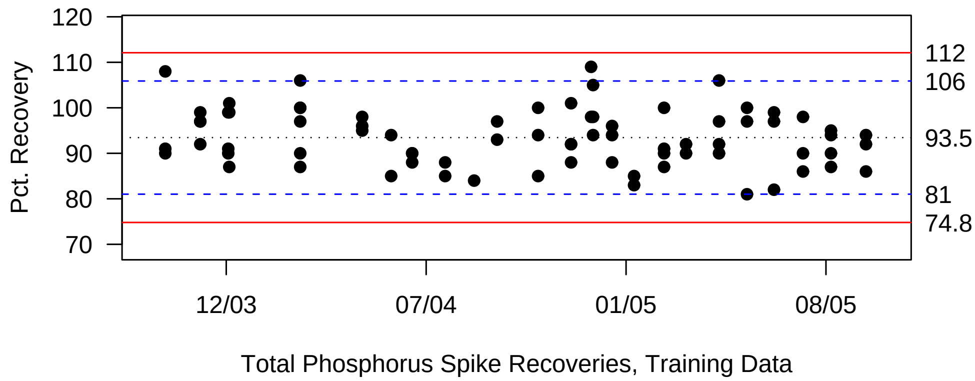


Figure C18: Total phosphorus laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



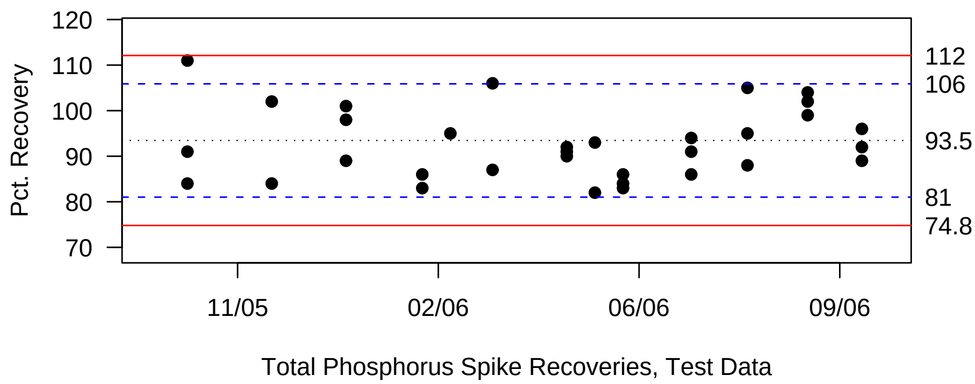


Figure C19: Total phosphorus matrix spikes for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

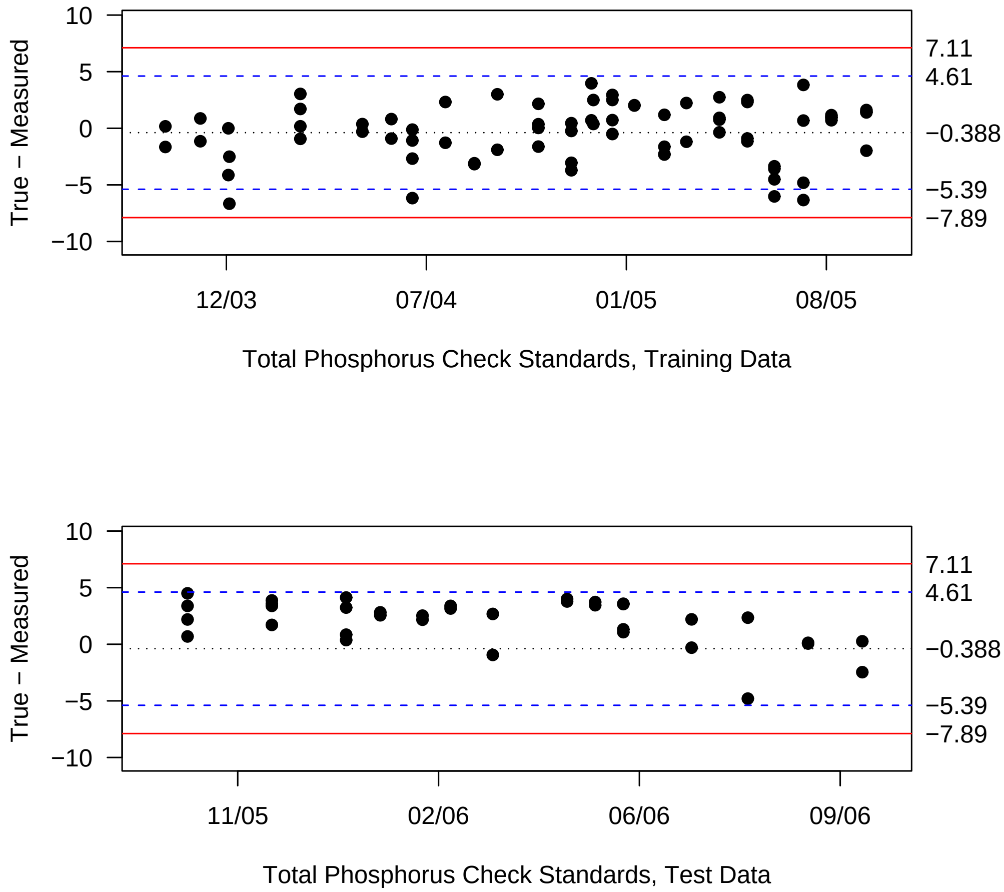
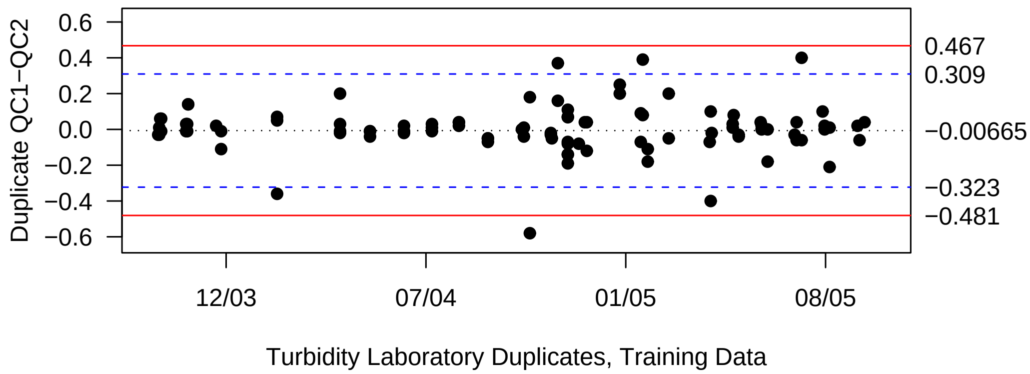


Figure C20: Total phosphorus check standards for the Lake Whatcom monitoring program. Upper/lower acceptance limits (± 2 std. dev. from mean pair difference) and upper/lower warning limits (± 3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.



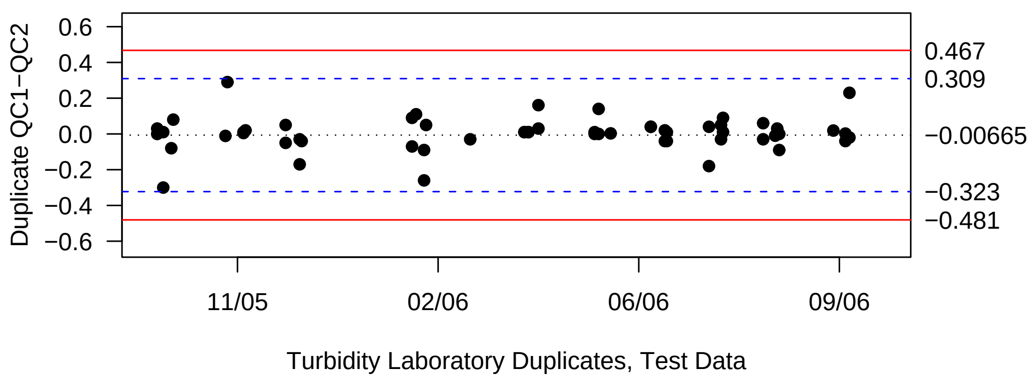


Figure C21: Turbidity laboratory duplicates for the Lake Whatcom monitoring program. Upper/lower acceptance limits (±2 std. dev. from mean pair difference) and upper/lower warning limits (±3 std. dev. from mean pair difference) were calculated based on the preceeding two years of lab duplicate data.

C.3 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 (Figures C22–C34, pages 319–331). 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* was calculated for the 2005/2006 lake data and 2004/2006 tributary data[23] using the following equation:

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

[23]This report summarized the two year monthly tributary monitoring project; monthly tributary monitoring was discontinued in October 2006.

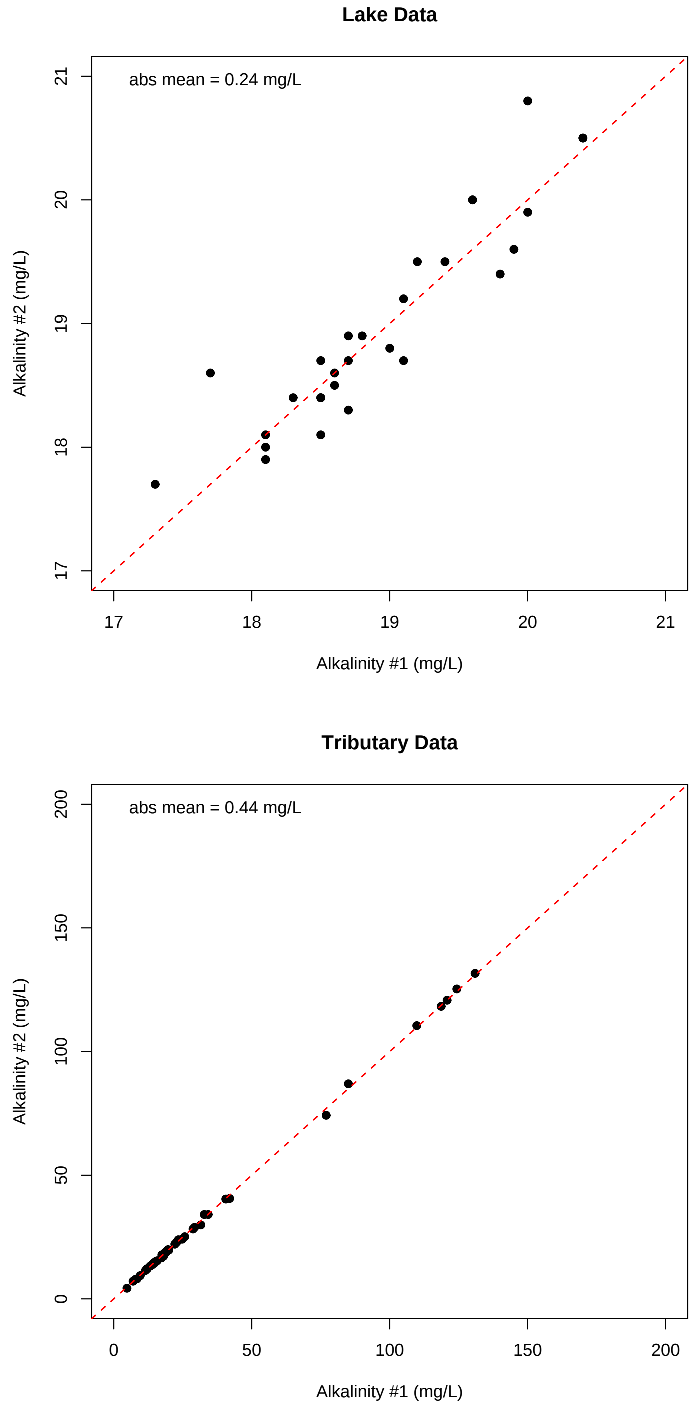


Figure C22: Alkalinity field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship. Higher degree of scatter in the lake replicates is due to the low concentrations in the lake samples; the absolute mean difference is lower for lake samples.

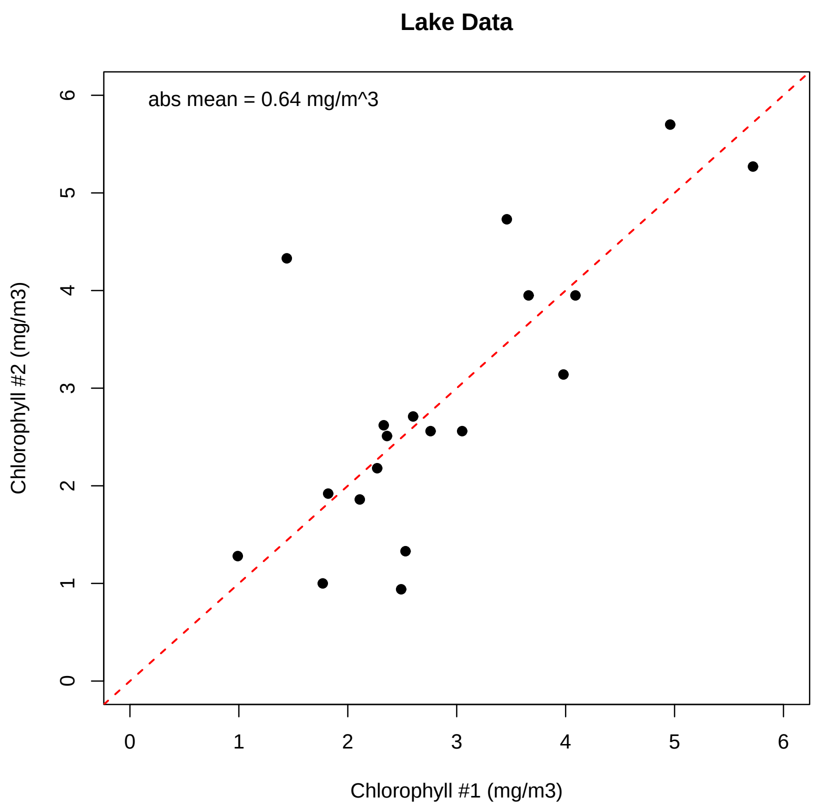


Figure C23: Chlorophyll field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake data only). Diagonal reference line shows a 1:1 relationship.

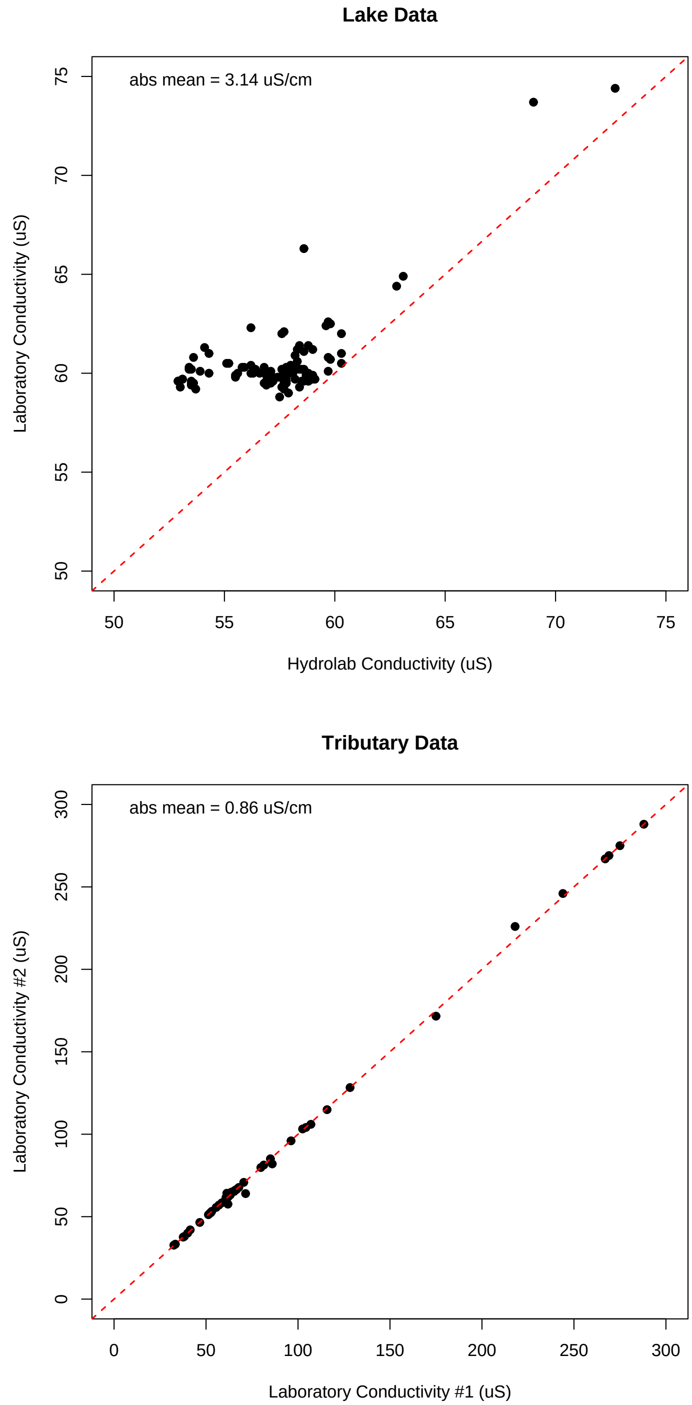
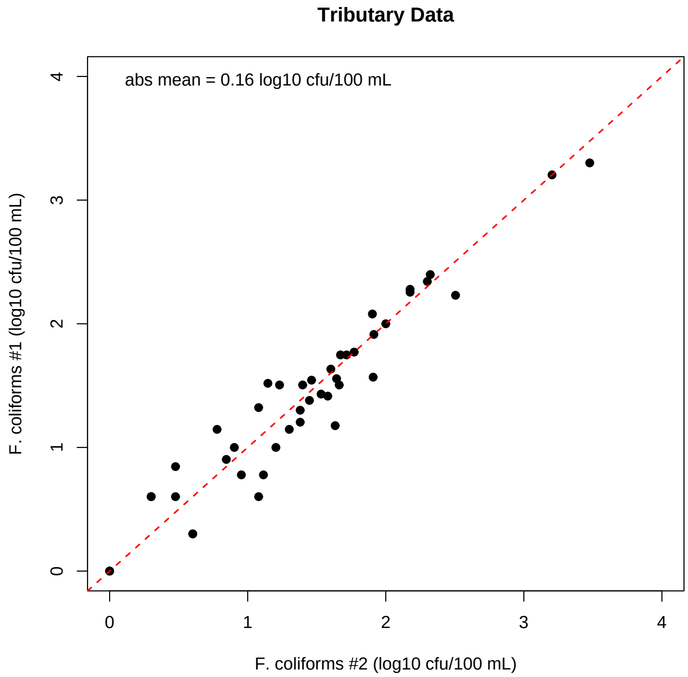


Figure C24: Conductivity field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship. Lake duplicates show a systematic bias due to greater sensitivity of the Hydrolab field meter.



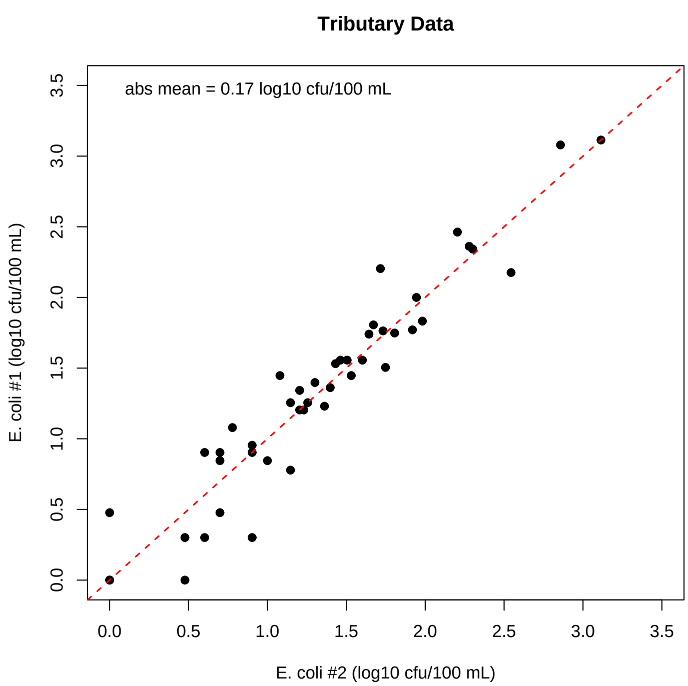
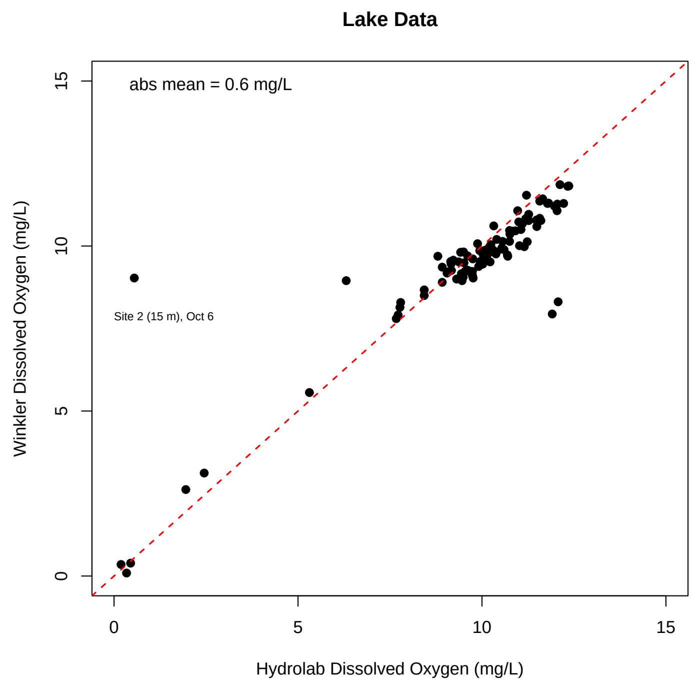


Figure C25: Fecal coliform and E. coli field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (tributary data only). Diagonal reference line shows a 1:1 relationship.



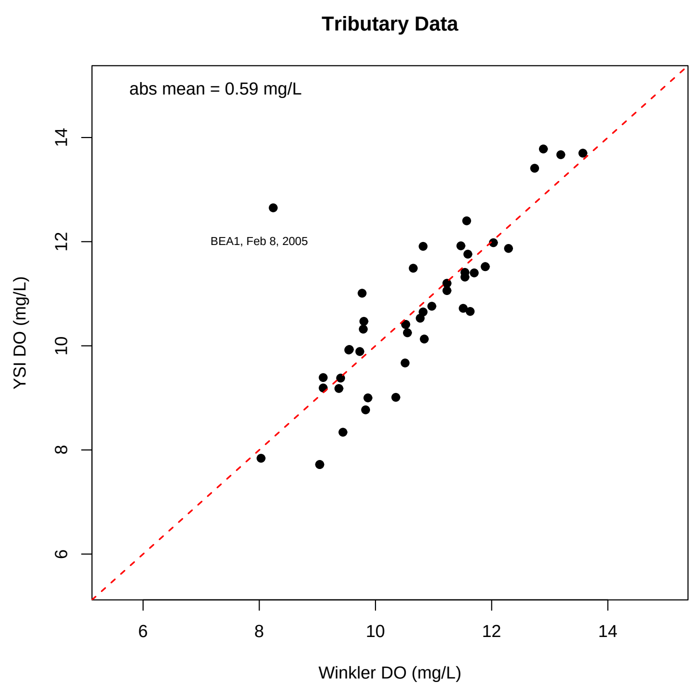


Figure C26: Dissolved oxygen field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship. The lake outlier duplicates were collected when an extreme oxygen gradient was present. The tributary outlier duplicates may represent Winkler titration error.

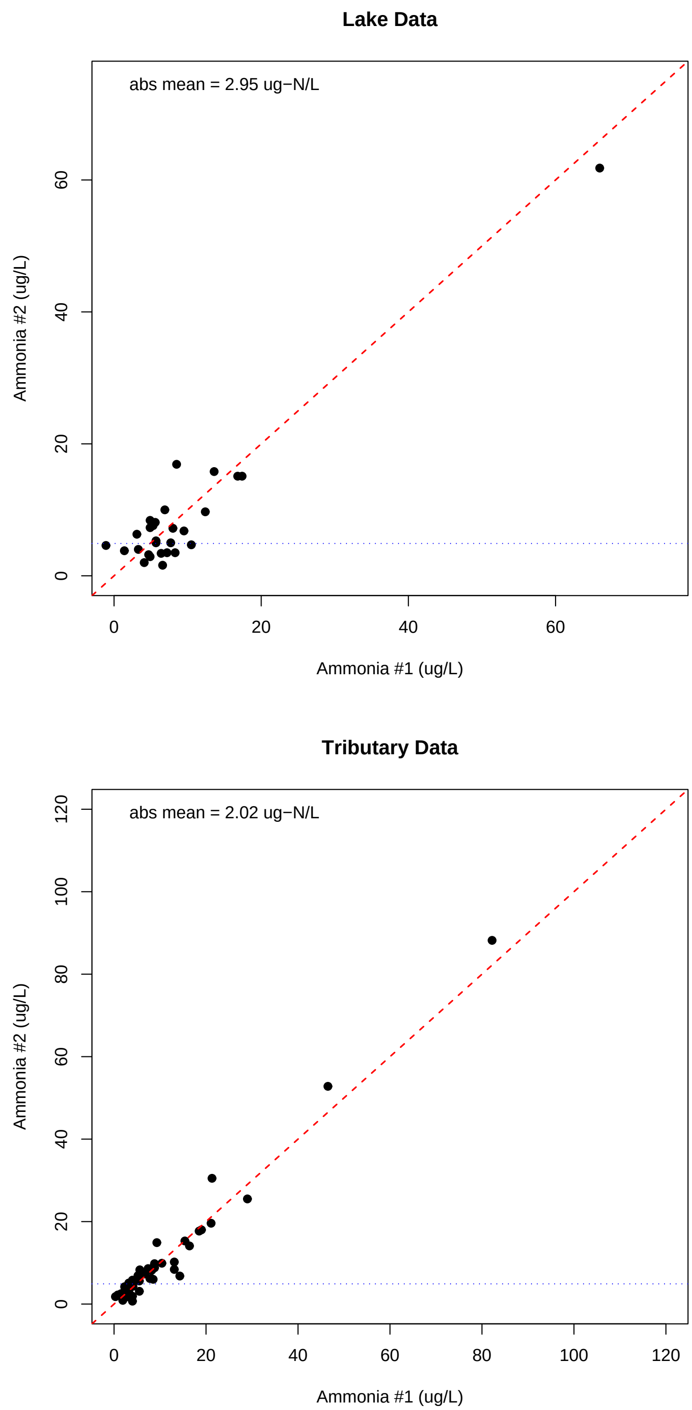
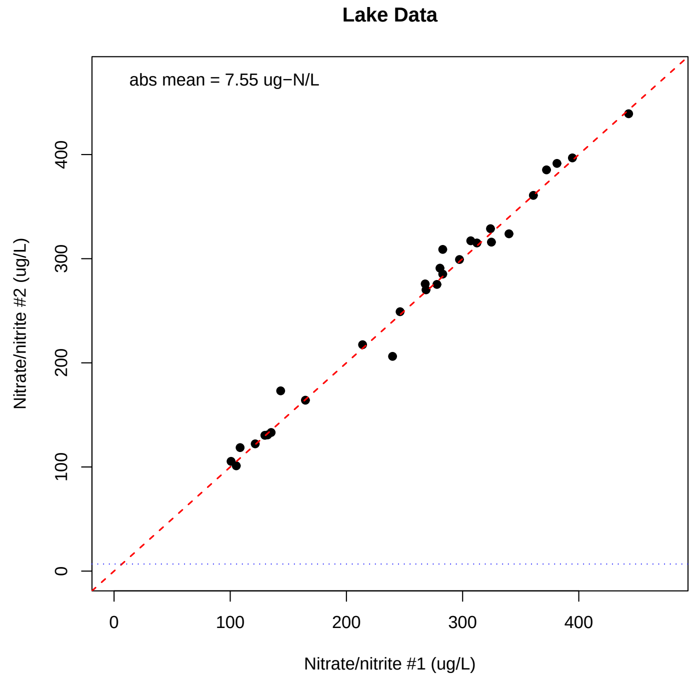


Figure C27: Ammonia field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.



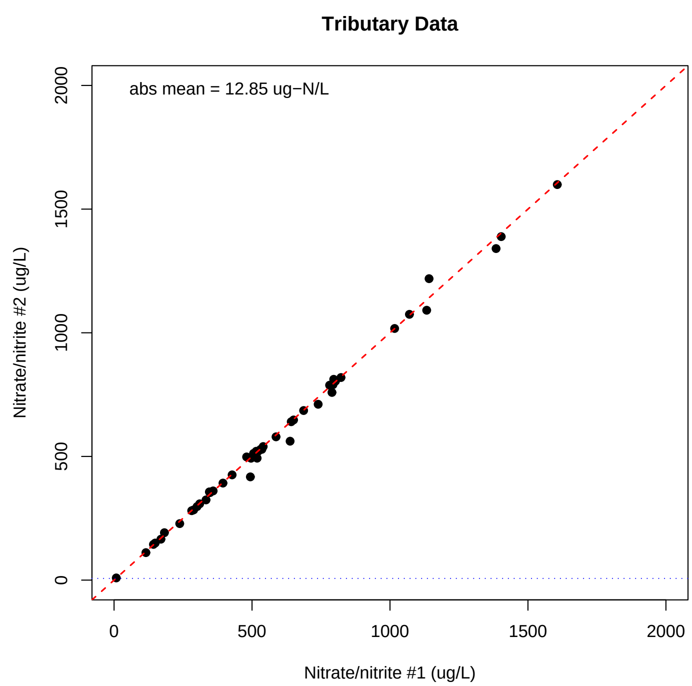


Figure C28: Nitrate/nitrite field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits.

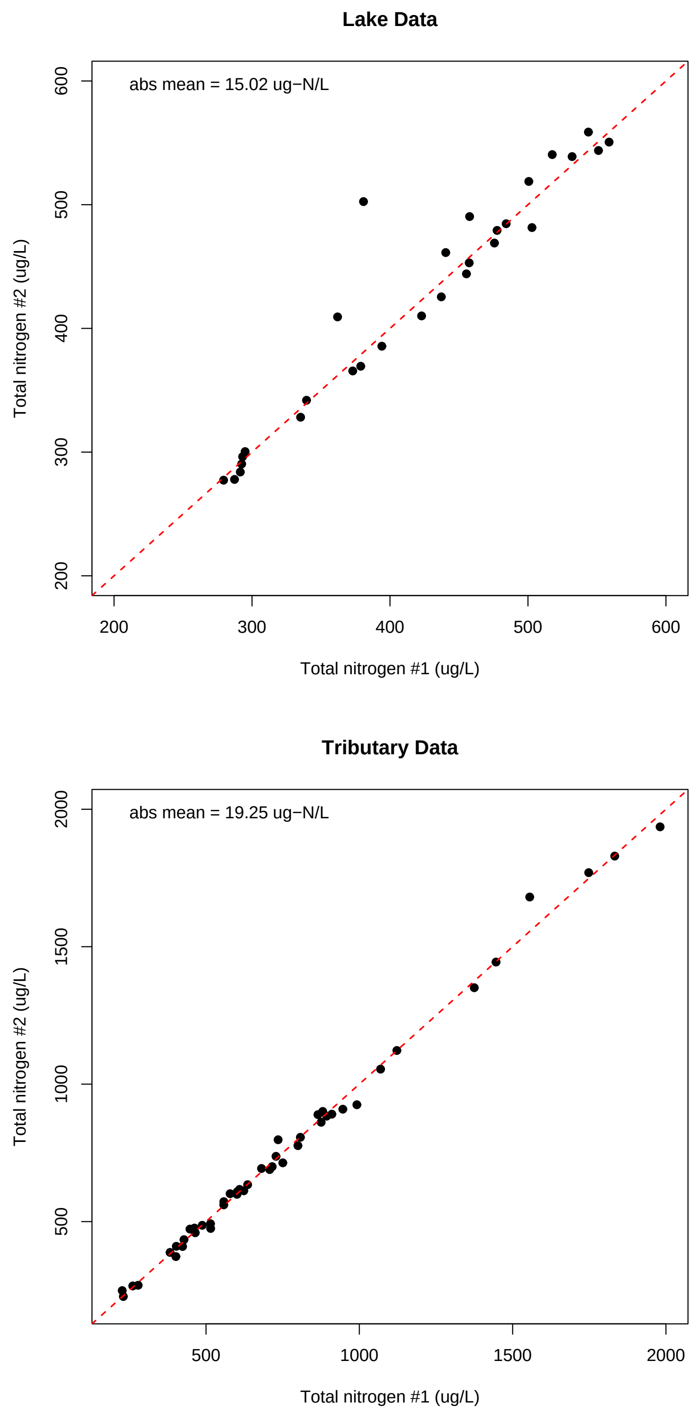
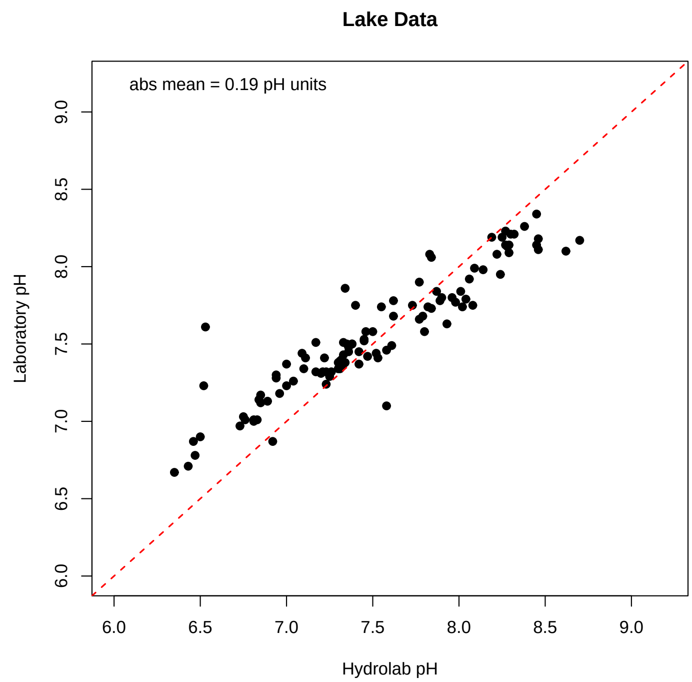


Figure C29: Total nitrogen field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship. All total nitrogen samples were above the detection limit.



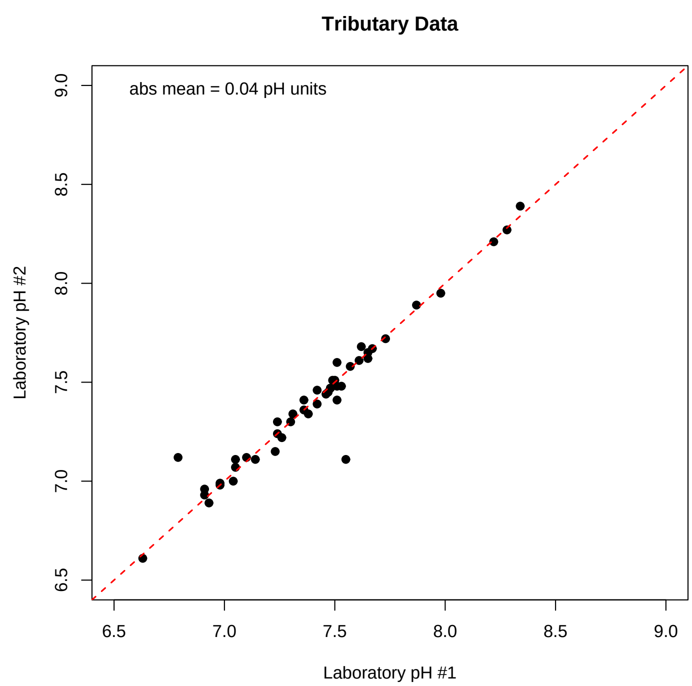


Figure C30: pH field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship. The lake results show a slight systematic bias due to changes in dissolved CO_2 and associated inorganic carbon ions between field and laboratory samples.

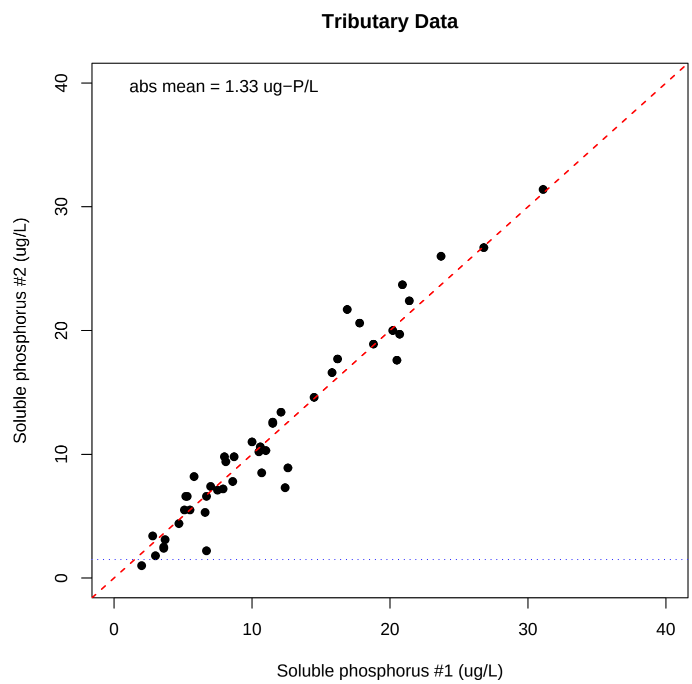
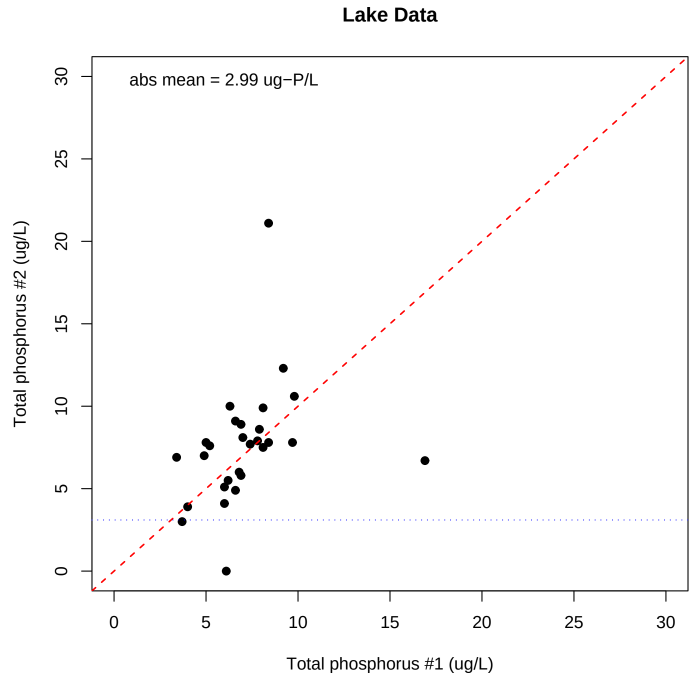


Figure C31: Soluble phosphate field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (tributary data only). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. Field duplicates are not plotted for lake data because most are near the analytical detection limit.



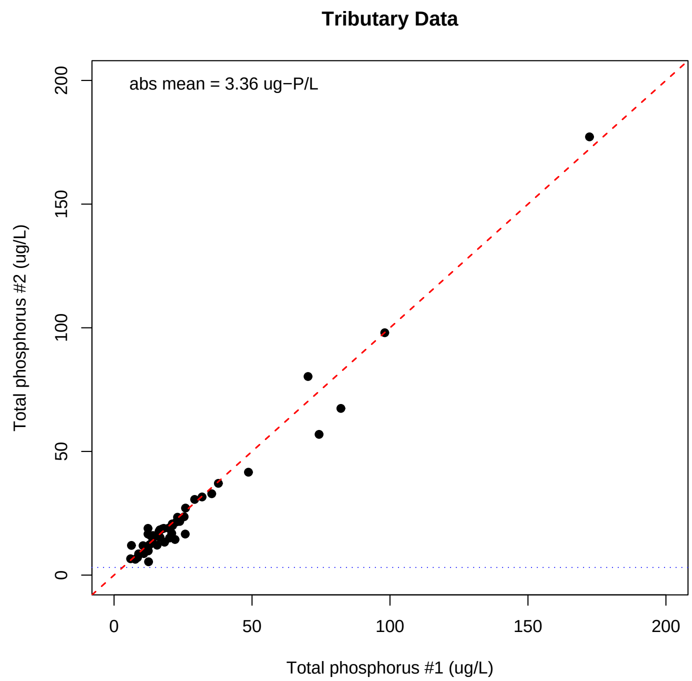


Figure C32: Total phosphorus field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship; horizontal reference line shows the current detection limits. Higher degree of scatter in the lake duplicates is due to the low concentrations in the samples; the absolute mean difference is lower for lake samples.

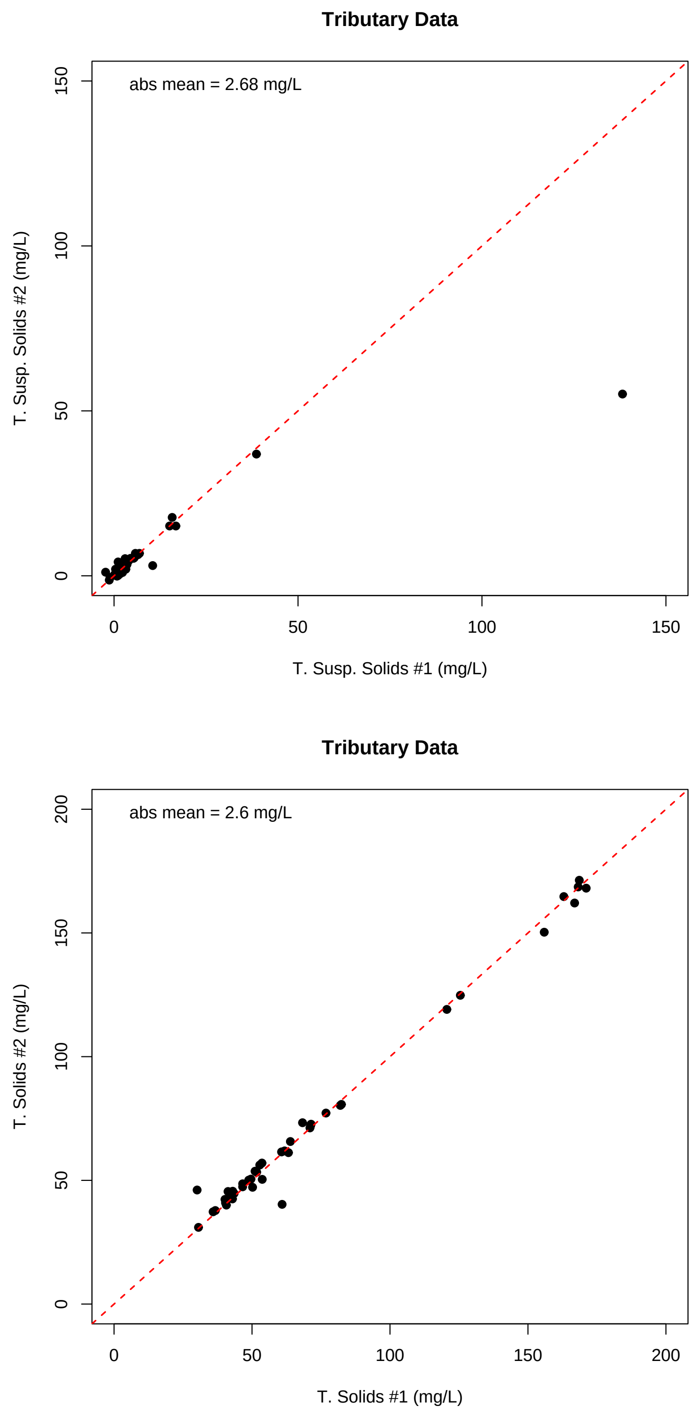


Figure C33: Total suspended solids and total solids field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (tributary data only). Diagonal reference line shows a 1:1 relationship. The tributary outlier samples were collected during high flow and may represent variation in sediment transport.

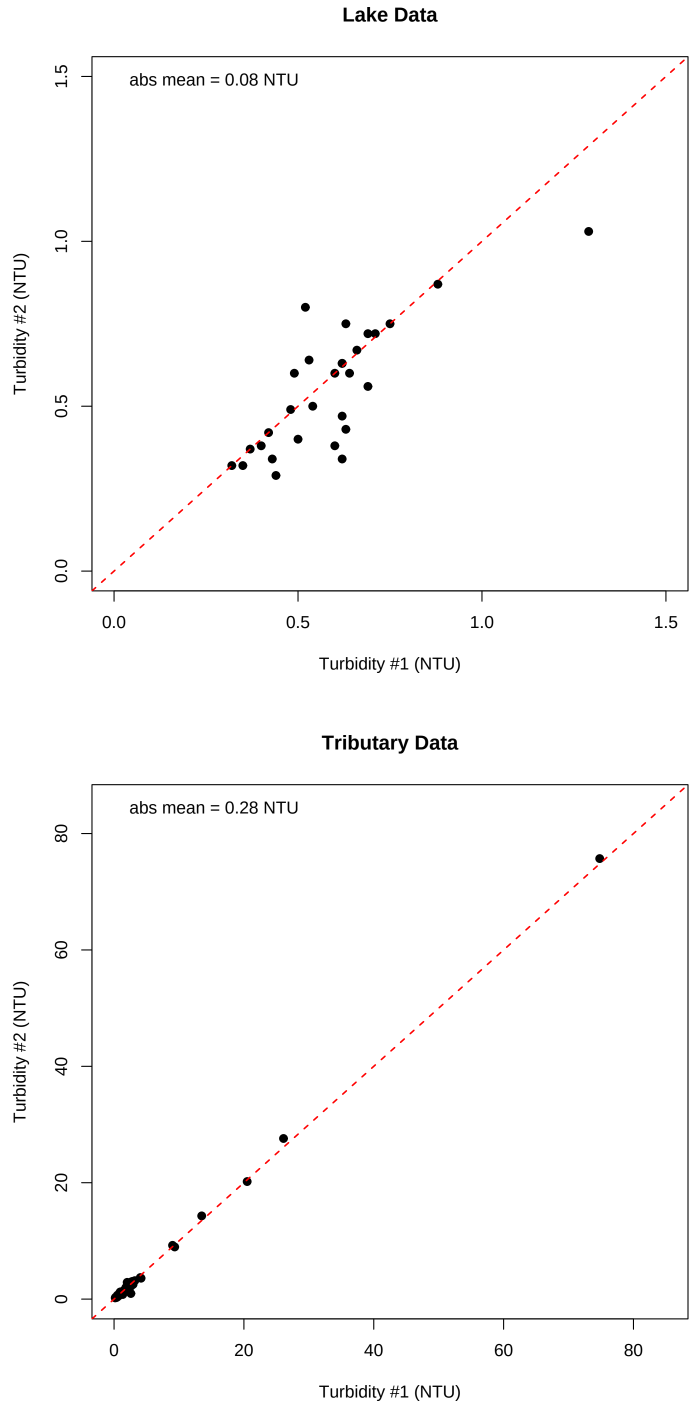


Figure C34: Turbidity field duplicates for the 2005/2006 Lake Whatcom Monitoring Project (lake and tributary data). Diagonal reference line shows a 1:1 relationship. Higher degree of scatter in the lake duplicates is due to the low concentrations in the samples; the absolute mean difference is lower for lake samples.

D Lake Whatcom Data

The Lake Whatcom raw data are available in hardcopy format in printed versions of the annual reports, with the exception of the coliform data, which are available from the City of Bellingham Public Works Department. Online reports do not include printed copies of the raw data, but electronic copies of most current and historic data are posted on the Institute's website (http://www/ac/wwu/edu/∼iws).

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

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

Unless otherwise indicated, the electronic data files have NOT been censored to flag or otherwise identify below detection and above detection values. As a result, the ascii files may contain negative values due to linear extrapolation of the standards regression curve for below detection data. It is essential that any statistical or analytical results that are generated using these data be reviewed by someone familiar with statistical uncertainty associated with uncensored data.

Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity (±)	Abbrev.	Analysis	Historic Det. Limits (dl) or Sensitivity (±)
alk	Alkalinity	± 0.5 mg/L	As	arsenic, total	dl = 0.03/0.01/0.001 mg/L‡
ecoli†	Bacteria, *E. coli*	dl = 2 cfu/100 mL	Cd	cadmium, total	dl = 0.002/0.0005 mg/L‡
ent†	Bacteria, *Enterococcus*	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 *a*	± 0.1 mg/m^3	Hg	mercury, total	dl = 0.01 mg/L‡
cond	Conductivity, Hydrolab	± 2 μS/cm	Ni	nickel, total	dl = 0.01/0.005 mg/L‡
cond	Conductivity, lab	± 2 μS/cm	Zn	zinc, total	dl = 0.002/0.001 mg/L‡
disch	Discharge	na			
nh3	Nitrogen, ammonia	dl = 10 μg-N/L			
no3	Nitrogen, nitrate/nitrite	dl = 20 μg-N/L			
tn	Nitrogen, total nitrogen	dl = 100 μg-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 μg-P/L			
tp	Phosphorus, total	dl = 5 μg-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			

†Coliform data are available from the City of Bellingham Public Works Dept.
‡AmTest detection limits decreased in 1999 and 2002.

Table D1: Summary of analyses in the Lake Whatcom monitoring project. The historic detection limits listed in this table are conservative estimates designed to permit comparisons with historic data. Table 1 on page 14 lists the current IWS detection limits for selected analyses and Appendix D.7 lists the current AmTest detection limits.

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. Bacteria data have not been included in this appendix, but are available from the City of Bellingham Public Works Department. 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 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.4 Lake Whatcom Tributary Data

Lake Whatcom monthly creek data and the revised 48-hr tributary data 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. Bacteria data have not been included in this appendix, but are available from the City of Bellingham Public Works Department. 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.5 Storm Water Treatment Monitoring Data

The storm water treatment data from the current sampling period are included in hardcopy format in the printed version of this report. Bacteria data have not been included in this appendix, but are available from the City of Bellingham Public Works Department. 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 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. Bacteria data have not been included in this appendix, but are available from the City of Bellingham Public Works Department.

Unless otherwise indicated, the electronic data files have **NOT** been censored to flag or otherwise identify below detection and above detection values. Refer to Tables 1 and D1 (pages 14 and 333) 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.7 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	February 9, 2006	metals, total organic carbon
	September 12, 2006	metals, total organic carbon
Alabama Hill vault	March 1, 1006	metals,total organic carbon, hydrocarbons
Park Place wet ponds	March 1, 2006	metals, total organic carbon
	May 24, 2006	
South Campus storm drain	November 10, 2005	metals, total organic carbon
	April 19, 2006	metals, total organic carbon

Sites Codes for the AmTest reports are as follows:

Lake Sites		Storm Water Treatment Sites	
11 O	Site 1, surface (0.3 m)	ALA IN	Alabama inlet
11 B	Site 1, bottom (20 m)	ALA OUT	Alabama outlet
21 O	Intake, surface (0.3 m)	PPCOMP IN	Park Place inlet
21 B	Intake, bottom (10 m)	PPCOMP OUT	Park Place outlet
22 O	Site 2, surface (0.3 m)	SC IN	South Campus inlet
22 B	Site 2, bottom (20 m)	SC OUT E	South Campus east outlet
31 O	Site 3, surface (0.3 m)	SC OUT 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)		